LUVOIR 5th Face-to-Face STDT Meeting

Caltech, Pasadena CA
July 31 – Aug 2, 2017
Talk slides available at http://asd.gsfc.nasa.gov/luvoir/events/

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High-Level Meeting Summary

Day 1 (Monday July 31, afternoon)

We kicked off with welcomes from Jeff Booth (JPL) and the STDT chairs. Matt Bolcar gave an update from the engineering team on LUVOIR Architecture A (15-m diameter telescope). Further information appears below in the "Detailed Minutes" section. The bulk of the design work for Architecture A is complete. The telescope and three of the four instruments (Coronagraph A, LUMOS A, and HDI) have been through the GSFC Instrument Design Lab process. The spacecraft and sunshield were designed during the Mission Design Lab (MDL) run, which caps a complete mission design study. The fourth instrument (POLLUX) is being designed in Europe; progress is being made and the final design will be delivered in time for the Final Report. A few remaining black boxes will be filled in the coming months. To facilitate this, specifications for the fiber-fed spectrographs within the coronagraph need to be set by the Exoplanets Working Group soon. We then heard a brief update on the POLLUX spectropolarimeter from Co-PI Jean-Claude Bouret of Laboratoire d'Astrophysique de Marseille.

We then proceeded with updates on the Interim Report. Aki Roberge presented estimated page counts (see Table 1). The total (~ 180 pages) is more than we'd planned at the April STDT meeting (~ 150 pages). Suggestions for keeping the report length under control included 1) putting high-level motivations in the Introduction, 2) trying to streamline each section, 3) moving many details into the "Further LUVOIR Science Cases" appendix, and 4) utilizing outside reports (e.g. the ExoPAG SAG 15 report) and published papers. There was a discussion on the overall philosophy for the report and its intended audience. We expect that the hardware chapters will expand in the Final Report, while hopefully the science chapters will be largely complete after the Interim Report. For review of the science

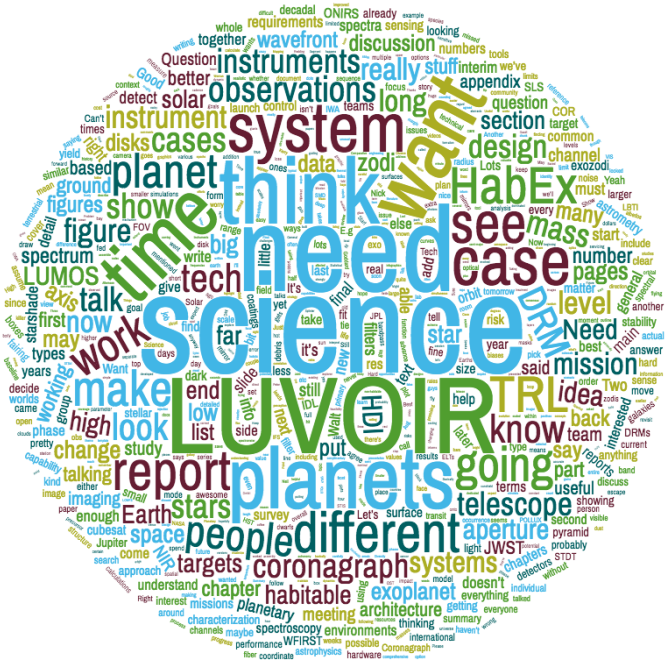

Figure 1: Word cloud for 5th LUVOIR STDT meeting.

content in both reports, we will rely on the LUVOIR Senior Advisors Group. NASA HQ will only review "implementation" and provide feedback after the Interim Report.

Table 1: Estimated and preliminary page counts for Interim Report

Chapter	Title	Pages
1	Exec. Summary	2
2	Introduction	10
3	Is there life elsewhere?	20
4	Are we unusual?	20
5	Cosmology, large scale structure, and dark matter	15
6	Galaxies and galaxy evolution	15
7	Stars, stellar evolution, and the local universe	15
8	How does the universe work?	5
9	The LUVOIR observatory architecture	15
10	The LUVOIR telescope and instruments	25
11	POLLUX	20
12	LUVOIR technology development	15
13	LUVOIR Cycle 1	3
	TOTAL	**180**
Appx. A	Further LUVOIR science cases	
Appx. B	Science simulation details and DRMs	
Appx. C	Detailed technical results	
Appx. D	Additional LUVOIR instrument concepts	

We then heard updates from John O'Meara on the Cosmic Origins chapters (5, 6, & 7), Mark Marley on the Exoplanet & Solar System chapters (3 & 4), and Matt Bolcar on the design and technology chapters (9, 10, & 11). The goal is to have the bulk of the text in hand to the leads by around Aug 15. At that point, we will need to move the report draft from Google Docs (or whatever file sharing system) to a Word file. Then only a limited number of people will interact with the document.

Next came a lengthy communications and graphics discussion. We have a number of resources for generating high-quality science and technical graphics. Please start making sketches and sending them to Shawn D-G. Furthermore, since this is the 21st century, the reports can be "multi-media" documents with embedded videographics (or links to videos).

Plans for the Jan 2018 AAS meeting were discussed. Current idea is two splinter meetings during the main meeting: one with talks and one with hands-on work with simulation tools. We did a tools splinter at the last winter AAS, but this time, we want to get more out of it (capture people's work). Jason Tumlinson demonstrated the current versions of the online simulation tools, which can now save and restore the settings and results of a calculation. We would also like to develop a web form to capture text on people's science cases (for use in "Further Science Cases" appendix).

Shawn showed the current version of the new, mobile-friendly LUVOIR public website. The plan is to finalize it by Sept. 1. We then wrapped up the meeting for the day and went out for some really good Mexican food (thanks to Leonidas Moustakis for arranging that).

Day 2 (Tuesday Aug 1)

The second day kicked off with discussion about international interest in additional LUVOIR instrument studies (expressed by JAXA and the Swiss Space Office). All agree that more interest is great. Aki presented a suggested scenario to capture additional instrument ideas while dealing with a few complications/concerns (see presentation slides). In sum, we'll add another appendix for "Additional LUVOIR Instrument Concepts" for new ideas at whatever level of maturity (from a few paragraphs to actual studies). The engineering team can provide telescope parameters and mass, power, & volume allocations to any group that wants them. The POLLUX instrument study will stay in the main report. No international instruments will be costed by Aerospace as part of this study. There was general agreement that this was a good solution.

Then we moved on to a presentation from Aki about Design Reference Missions (DRMs). These are "meant to provide quantitative rack up of total science case that can be achieved with planned hardware under realistic conditions". DRMs are one of the few things that we are required to deliver to NASA HQ with the Final Report. In principle, they are straightforward. In practice, DRMs vary a lot in comprehensiveness and level of detail. A few examples were shown (TPF-C, HORUS, Exo-S). For the purposes of the LUVOIR study, we have adopted a prime mission duration of 5 years (with 10 years of consumables). Accurate observation overheads are always difficult to determine at such and early stage; we'll likely adopt reasonable percentages on the exposure times. Finally, it's not feasible for us to do complete DRMs for every science case. Ideally, we'll have DRMs for every major science case (the signature science questions) and then leave some percentage of the 5 years unassigned ("open time" for additional science investigations).

Debra Fischer then led an interesting discussion of LUVOIR technology development with cubesats (and other small missions). There was general agreement that while not every LUVOIR technology challenge can be addressed this way, some certainly can. A particularly promising area seems to be UV coatings. We then went into two splinter sessions (COR & PCOS, EXO & SS) to start defining the calculations we'll need to do. After lunch, we went into splinter sessions on Interim Report writing (EXO & SS, COR & PCOS, Design & Tech).

We ended the day with a presentation by Matt Bolcar on initial decisions for LUVOIR Architecture B (design run to begin in the fall). The originally planned instrument complement on Architecture B (Coronagraph B, LUMOS B, ONIRS) didn't include a camera that could be used for guiding. We'll need to incorporate that capability into one of the instruments, thereby also recapturing some of the HDI science. Which instrument is TBD. There was a philosophical discussion about whether Architecture B should be a scaled-down version of Architecture A or a distinctly different facility. There was a general consensus for the latter option. Finally, the decision was made to study a Ritchey-Chretien (RC) telescope for Architecture B (the Architecture A telescope is a TMA).

Day 3 (Wednesday Aug 2, joint with HabEx STDT)

The joint meeting day with the HabEx STDT kicked off with welcomes and individual introductions. We then heard status reports on LUVOIR science (Debra Fischer) and design (Aki

Roberge), followed by similar presentations on HabEx (Scott Gaudi and Keith Warfield). One highlight from the LUVOIR design presentation that wasn't mentioned in the previous two days … during the Mission Design Lab run, a preliminary analysis of whether we can tip LUVOIR towards the Sun was done. It appears possible, and may allow the facility to view Venus.

Next Rhonda Morgan and Matt Bolcar led a presentation session on Common Technologies. We heard separate presentations on common detector technologies and low-order wavefront sensing (part of WFIRST tech development). Matt Bolcar then spoke on LUVOIR telescope segment phasing. He then presented thoughts on what we should be doing about our common technologies. Basically, despite common science goals, the technological solutions chosen differ between the two missions. He suggested that we should identify the shared performance parameters, establish common definitions, and understand divergences in requirements. We then broke for lunch.

After lunch, we went into three splinter sessions (EXO, Astro & Solar System, Tech), followed by splinter session reports. Detailed notes on the EXO session are available below. There was agreement on the Eta_Earth values to use for DRM calculations (best guess 25%, conservative value 10%). For other planets, the ExoPAG SAG13 definitions and occurrence rates will be adopted. The HabEx team has just begun developing their Solar System science case, but from the discussion, it appears there are a number of promising areas. Finally, we ended the meeting with a brief wrap-up including next steps.

Detailed Minutes

Courtesy of Giada Arney

Day 1 (Monday July 31, afternoon)

Jeff Booth: Introductory remarks. Welcome to Pasadena again. "I think LUVOIR is certainly revolutionary and maybe two steps away from implementation." "On behalf of JPL and campus we're really happy you're here."

(everyone introduces themselves around the room)

(sound feedback is causing issues)

John O'Meara: LUVOIR brought to you by Skrillex.

Debra Fischer: Intro remarks. Welcomes everyone.

Brad Peterson: This is the meeting where it really starts to happen. What we do now and next meeting will really form basic skeleton of whitepaper.

John: Thanks to Doctor Bolcar for returning from his honeymoon recently (applause)

Update on Architecture A Design Process

Matt Bolcar

At this point since Architecture A more or less finished, I will go through entire thing from beginning to end but also show stuff we've done since basically the beginning. I want to thank the people who've been doing work on this at Goddard. (shows slide of names of GSFC people who have worked on the engineering).

- Three mirror anistigmat design with fine steering mirror
- Instantaneous FOV 15x8 arcmin
- Nominal field of regard anti-sun hemisphere
- Al+LiF + thin protective coating. Al + LiF high TRL and well-understood.
- 270 K operating temperature with passively cooled focal planes ~70 K

Marc Postman: TRL of gimble?

Matt: about TRL 6. Engineering effort of design. Nothing about it that is scary or new.

- HDI:
- modified back of HDI pick off mirror location in telescope FOV
- HDI 2 channel imaging instrument: UV/Vis (200 nm – about 1 um). Diffraction limited performance at 500 nm.
- NIR imager (1 – 2.5 um)
- Switch channels with channel select mechanism

Leonidas Moustikas: How do you switch between different channels?

Matt: Wheel in middle is channel select mechanism. One lets light to NIR mechanism. One reflects light to VIS channel. Other are diarchic beam splitters but not at full throughput or bandpass for either. So can do 100% for either, or less than 100% for both at once.

- 52 UVIS filters

Marc: Solar system colleagues happy with filters?

Britney Schmidt: Yes those pretty good!

Aki Roberge: The specific filters can change later. We wanted to make sure there were enough filter slots, added filter wheels just for SS.

Britney: Super cool.

Aki: Yeah we ordered up on filters.

Walt: Yes!

Marc: What is filter size?

Matt: Individual filters 130 mm.

Matt: Now onto coronagraph. I think IDL team still having nightmares about it…!

- Coronagraph:
- UV (200 – 400 nm) imaging only
- VIS (200 - 850 nm) imaging and spectroscopy
- NIR (850 – 2.5 um) imaging and spectroscopy
- Each has 15% bandpass filters. Also 2% bands for wavefront control.
- Each channel has 2 deformable mirrors
- Spectrometers not designed in detail; still black boxes; not difficult to design; not difficult to fit into the volume
- While observing in two channels, use third channel as wave front sensing
- "Coronagraph is extraordinary dense instrument"
- to fit all mechanisms, had to increase angle of incidence on some mirrors
- UV has 8 masks (overlapping IWAS and OWAs to give full coverage over full band). VIS has 9 masks. NIR has 11 masks.
- Filters: 29 in UV, 29 in VIS, 37 in NIR. (!) All have matching 2% wavefront bands.
- For primary dark hole digging big matrix inversion. 10x Virtex-5 FPGAs for this.

Jason Tumlinson: This computer inside coronagraph?

Matt: It is a box inside the coronagraph?

Jason: Does it need to be doing this wavefront sensing control all the time?

Matt: When not doing wavefront sensing still managing primary mirror, taking data from HDI, generating point commands.

Jason: Moving data even inside can be hard.

Matt: Electrical architecture…we don't anticipate any kind of…All it's sending to CSP….We didn't think about that (sorry this is garbled I didn't get all of it)

- Lumos:
- Didn't change anything since last presentation on it
- Multi-object spectrograph uses micro shutter array
- TRL 4 trending up

- 1800 kg !!
- Spacecraft:
- Petal sunshield

Shawn Domagal-Goldman: Tip to tip how big is sunshield?

Matt: 70-something meters. Smaller petals 3 meters each. It's big!

Karl Stapelfeldt: Question about reaction wheels/gyros

Matt: Gyros spin at constant speed. Spin with torque. Noise spectrum better than expected from (missed this)

Jason: JWST learned a lot of lessons about propellant…

Matt: We don't use propellant tanks for slewing. We have propellant for momentum offloading, etc.

Aki: Spacecraft vibrationally isolated from telescope.

Matt: Right now our primary disturbances is CMGs(?) but we should look at the slosh.

(technical difficulties. Adobe connect crashed for him. People online cannot hear)

Dave Redding: Station keeping?

Matt: Yes.

Missed who asked this question: How long does it take to get there?

Matt: Baseline 90 days.

- Notional day in the life (general astro)
- Plan for parallel observations

Marc: Data for downlink?

Matt: 1 Terra bit in data for downlink.

Jason: Don't skimp on data volume anywhere. You will always end up with more than you think.

Matt: Right. For most part we've been pretty conservative in right direction for that. One think to look at is cables across payload to spacecraft. Space fibers across gimble need to be studied.

Jason: JWST went wrong by assuming they knew exactly what science program will look like. We shouldn't do that.

Matt: Right.

- Basic idea of observations very similar to HST.
- Some things will require fixed time (exoplanets)

John: Order of magnitude size of treasury?

Matt: We didn't spend a lot of time trying to decide. We just wanted to have guest observer and dedicated.

Aki: We wanted to make sure to design a spacecraft that can execute an observing plan. This day in the life is just for engineers.

Matt: Yes completely cartoons to show things can happen simultaneously.

Jason: When looking at how long you can spend on a patch of sky all that folds into field of regard, what angles you have in play, will fold in and be related to how often you have to revisit. Having a concrete program with limited cases like a 1000 hour deep field will be useful exercise.

Matt: Reasonably detailed con-ops something we should do.

Karl: Beta angle 60 degrees?

Matt: Don't know what that is.

Karl: Boresight from sun(?)

Matt: Depends on things like where moon is. Can tip further but might get more stray light. Or we can make sunshield bigger.

- Volume is good. Observatory fits into SLS envelope. A little heavy "LUVOIR needs to go on a bit of a diet" when you add 30% margin. Working on now. In last several days we've already shed several 1000 kg. (laughter) I'm not concerned about mass as this point.
- 44.3 mt!

Aki: I was a little surprised that we came up against mass margin of SLS.

Julie Crooke: Why we didn't worry about mass during IDL.

Matt: Lots of places we can optimize for mass now. Cleaning up "little" errors can help revise our mass down.

Brad: Block 2 fairing?

Matt: Yes. 8.4 m.

Brad: I picked up in literature 10 m fairing?

Matt: Block 1B with 8.4 m fairing. Short and long version. Also 10 m fairing. We tried to fit into 8.4 m long to be conservative.

Jason: This mission is regarded by many people in the world as the technically biggest stretch. Bigger than HabEx. Out of everything you went through, what's the one thing you'd put at top of list…?

Matt: Hold that thought! (Brings up technology gap list slide) Ta da!

- Ultra stable opto-mechanical systems is TRL 2
- Showing all works at picometer level is biggest challenge
- Segment phase and control TRL 3
- Segmented aperture coronagraph architecture TRL 3
- High reflectivity broadband FUV-NIR mirror coatings TRL 3

Dave: Mirror segments at TRL 5 are deliverable …that's true for glass. But as subsystem I thought lower number?

Matt: For glass, true for mirrors. For Si carbide mirrors that's true. In actual deliverable I can share with you. Finer detail on individual pieces. Distinction between glass and si carbide.

Shouleh Nikzad: High range dynamic range. We have other options… (I missed most of her question)

Matt: Delta doping other piece of that. I do call that out.

Debra: Now to answer Jason's question do we know how this compares to other studies?

Matt: I don't have with me. Question is how does this TRL stack up to other missions?

Aki: I don't know answer for Webb but a pause and learn I interpreted takeway that for 3 of 4 missions (Lynx, HabEx, LUVOIR) all techs varied but all racked up about same. One big thing TRL 2 and a bunch of 3-4s. OST different. No TRL 2s but larger number of TRL 3s and 4s.

Matt: They listed a lot of enhancing techs. Not enabling. I call ours enabling.

Aki: Lynx, HabEx, LUVOIR all similar numbers in the end

Matt: We have a complete architecture A! Everything fits! Lots of analysis to do though. (applause) Lots to do to achieve stability. Goddard engineering team and IDL done a fantastic job. Goal to finalize A be end of August. Because then we transit to Architecture B OTE in September.

Aki: Date on slide is wrong! (Shows Aug 2018)

Matt: Yes or else I'm taking an extended vacation (laughter)

Jason: What is right time to look at nominal plan for test sequence?

Matt: For INT? We went into that in MDL. We did survey of facilities. Look at what point you start getting too big. Industry partners going to look at IMT plan for instruments and observatory.

Jason: Happen over next year?

Question on calibration of science instruments from an industry partner.

Matt: We notionally put radiometrical calibration system do to corrections. LUMOS has calibration with shutters. Not yet for coronagraph. Can do traditional stellar calibration.

John: What do you need from us?

Aki: There's stuff tomorrow.

Matt: Tomorrow we need to start talking about Architecture B.

Aki: Next Jean Claude going to give POLLUX update.

POLLUX update

Jean-Claude Bouret (LAM)

- Top level science requirements
  - R = 120,000 (200,000)
  - 98-290 nm; 6 nm min order length
  - SNR = 10 for flux 1e-17 erg/s/cm2
- FUV: 90nm, 123 nm
- MUV 119 nm, 220 nm
- NUV 210 nm, 390 nm
- "Calibration is going to be a big issue"

- Have estimates of throughput. “IT’s really low. Especially with polarimetric mode.” 2% with that. 6% without polarimetric.

Kevin France: that’s better than STIS!

Marc: I gathered from aperture size and high res the main seience cases are stellar sources?

Jean-Claude: Mostly stellar and exoplanets but also very good cases for cosmology. Also interstellar medium and CGM. Polarimetry mostly for stellar physics, exoplanets.

Marc: Polarimeter can be removed?

Jean-Claude: Yes

Aki: We didn’t really talk about polarimetry science cases. Walt you have some in solar system? We just didn’t cover. Talk to Jean Claude please.

Walt Harris: Yeah I will.

Jean-Claude: We have a good document summarizing our science cases so far based on high res and polarimetry.

Aki: Coffee break now! Reconvene 2:45.

---coffee break----

Overview of interim report

Aki Roberge

Aki: From last face to face we decided to shoot for 150 pages for interim report. For reference the Exo-S interim report was 77 pages and final report was 150 pages. We have more to cover so going longer is ok. We are at 180 pages. Are these limits feasible.

Debra: Life elsewhere 20 pages seems like a lot to cover.

Aki: Lots of stuff to cover in there. Solar system too.

Britney: This is a proposal phase and we’re talking about motivating measurements I think we can afford to be brief and reference well because then delivering more of a punch. In mission proposal we have 12 pages for solar system for entire science. We have to do everything in 12 pages.

Aki: That’s a lot shorter than typical astrophysics.

Britney: True but these are the scales at which we have to define concept. Especially if having example cases as appendices. Also we don't want it to look out of balance. If going with 15 per section still pretty long . That's a review paper for each chapter. Want people to read whole thing. Pulling out 5 pages from here there everywhere might help.

Julie: Just going off from typical proposals you submit, I'm looking at science, that's 85-90 pages of science between chapters 3-8 and knowing that telescope and instruments and architectures is significantly smaller, I think that's unbalanced.

Aki: This is for interim report. For final I'm expecting hardware chapters to expand. Most definitely they have to cover Architecture B. As far as out of balance on science, it seems different impressions on what they should be like. Astrophysics ones are like this. TPF-C is like this but twice length.

Debra: Audience?

Aki: NASA HQ?

Debra: Will these be public?

Aki: Yes

Julie: Philosophical question: LUVOIR's biggest problem is perception of feasibility. If we put 2-3x as much on science, LUVOIR has an awesome science case and everyone will acknowledge. Do we need to add more to "Is this feasible?"

Aki: For final report yes. Tech will obviously expand. I was kind of hoping we would be pretty done with most of the science material before it. Polishing for final report. Given we can write it right now, we should.

John: Completely different angle is that this isn't a document for HQ. This is what we bring in January and slap down in front of whole astro community. We have a good science case but I don't think people believe that. Over-performing now and then cutting should be goal If we have gold in these sections, if we take that community, hard for community to respond that "you didn't think about XYZ." Hit community hard in January. That's our big party moment. Having as strong and as big science case we can to show that science per dollar is fantastic. That's perception we're fighting. I agree we should reference well. In terms of my charge to the room I would rather we have embarrassment of riches of having 30 pages and have to cut to 15.

Aki: Only guidance from HQ is that Exo-S and Exo-C is a model and they weren't 40 pages. They were like this.

Britney: I get that. We should not get into weeds. Somebody needs to edit this for areas of science covered but don't want to prescribe all of the science but also don't want to get into the weeds.

Aki: I guess we can come back to this after a while. Table this and think about for later. In interest of not getting into weeds and not going OVER 180 pages. Highlight motivations in intro and not repeat in chapters. Should try to streamline sections. Bekki and I did that to planet formation-y section. Move details into appendix. Weeds to in appendix.

Mooni(?): As far as interim report at HQ, we're not reviewing science. We are interested in tech roadmap architecture, and somewhere what your risks are.

Aki: As much as we KNOW them but it is an interim report. We will have a lot on A but less on B.

Mooni: Cost info is useful. If you have.

Aki: Maybe.

Dave: What can we expect back from HQ in terms of response to report? Clarification? Guidance on A vs B?

Aki: ANY feedback?

Mario Perez: LUVOIR team will have review of science team based on senior advisory group. HabEx have same. OST putting together group like that. I expect Lynx will have. Will be interesting for us to see compliance. Is story clear? Implementation issues? People going to review also the other reports as well. Leadership of each mission.

Aki: Who we?

Mario: Yeah in management plan have people from centers

Aki: I don't remember this part. Talk about later?

Mario: Comment not on science. On implementation.

Aki: Feedback on science case we rely on senior advisors. Alan [Dressler] is one of them over there. I guess for more design hardware stuff?

Mario: We send to expert

Aki: I don't remember this from pause and learn

Julie: Go back to allocation pages please? I assume risks section in either 9 or 10 or 12?

Aki: Matt's plan mostly in 12…?

Julie: I'll just say one last time. If you want to keep all pages for science, but my general feeling is, well, is Matt fine with that?

Matt: I'm not dismayed by this. 55 pages for architecture and instrument and tech is fine. I don't see that being too small a number. It may switch but as an overall allocation it's fine. If I think we won't meet those limits when further along I'll talk. But right now seems fine.

Brad: These are self-imposed limits. Not page limits. Guidelines. Targets.

Aki: Self-imposed Yes.

Marc: As reference WFIRST SDT report was 320 pages.

Aki: That's too long!

Marc: That may be too long. Intro was 30 pages. Science was 60 pages. They spent a lot of time discussing science on an approved mission. 180 not crazy.

Matt: I agree with Aki. Final report will have much longer design and tech section because covering two architectures in detail and more thorough tech plan by then. Final report either equal balance or outweighed in other direction. For now fine.

Aki: I was going to flip through where we are on current outline. Lots of people looked at it. I want to make sure we have holistic view. Already out of date because this morning did things with Pollux chapter.

(shows Is there Life Elsewhere chapter?)

Debra: We don't want to lose people in a sea of info?

Aki: We're already tight I think. I think this is pretty lean and mean.

Debra: I'm glad balanced re. pages between exoplanets and cosmic origins.

Aki: That was on purpose.

Debra: Yes.

Aki: Given page limits can't spent long on state of field and synergies sections. Karl can you do it like a report if we need a section? ExoPAG or PASP?

Shawn: At least for exoplanet science cases are multiple SAG reports out in next couple years or out that will go through a lot of this science in detail.

Aki: Daniel Apai SAG report comprehensive. Must be short in main report. If more needs to be said, do in other venue.

(shows Cosmic Origins chapters)

Aki: I don't think these have changed since we last looked at it. We added physics of cosmos chapter. We want to show we have a little something for everybody. We had GSFC LISA meeting last week. I think we need to help them interestingly enough to understand the astronomy value of discovering the targets they're going to discover. A lot of them aren't astronomers. They're physicists. The topic of varying fundamental constants going to be in POLLUX chapter anyway but going to move.

(shows telescope and instruments chapters)

Aki: Here's telescope and all instruments. Courtney, ONIRS section can be plans. Can be short. POLLUX chapter…pending approval by science team, can structure with 3 signature science cases as well: stellar magnetic fields, planetary systems, and extragalactic and cosmology. We may need to add another appendix. I will discuss tomorrow.

Julie: Numbers on right?

Aki: Page numbers in current outline. Meaningless. Questions, comments? Great.

Cosmic Origins report update

John O'Meara

John: I have no idea how this will look. So what?

(slides look crappy because of technical issues)

John: This will ruin all the jokes

(switching laptops)

John:

- Certain things only possible with LUVOIR
- Incremental science is not what we want
- We felt strongly that lots of good PCOS science will happen with LUVOIR.
- Joint meeting with LISA folks at Goddard. We talked about similarities of technical requirements and how we can work together for transient observations.

- Chapter titles (placeholders):
    - Chapter 5: How does cosmic structures arise?
    - The Microphysics of Cosmology
    - Stellar Mass Limits at the Extreme Low End ("lovely thing only LUVOIR can do")
    - The galaxy luminosity function at the extreme end
- "The low mass end demands aperture!"
- He's excited about a plot showing how long it takes to see down to 34th magnitude
    - "I'll say that again. 34th magnitude!"
- Chapter 6: How does galaxies assemble?
    - "Dave Schiminovich if you're watching I really need you to update this figure!" (figure of 10 m telescope)
- Chapter 7: Stars, stellar evolution, and the local universe
    - How do stars form?
    - How and in what environments do planets assemble?
- "I weep openly every time I see the Andromeda PHAT image…when I think about we can do this out there."
- John has a slide of Darth Vadar "I'm here to put put back on schedule. Darth Vadar: Sith Project Manger."
- "I want killer figures for every signature science case and code used to generate" "I really love the figures that take all the architectures and science cases and comparing those. Statement of what telescopes can do."
- "If you didn't write a quicksheet, write one."
- Callout boxes will pepper entire document
- Need things by August 15th

Jason: I have a statement. If you need something in the ETCs that isn't there tell me. It's easy to add.

Brad: All filters?

Jason: No. Not yet.

Marc: Code will allow HDI. He limited number of knobs.

Brad: I want to clarify these are done with real estimates of throughputs. LUMOS up to date with results of IDL run. For HDI we still need to put in zero points. Still working to get ONIRS ETC.

Giada Arney: Please look at coronagraph and provide comments. Dropdown for 9 and 15 m with presets for those two, including settings that came out of IDL.

Brad: Inscribed circles included?

Giada: Yes.

Aki: Mostly complete drafts by Aug 15 would be great.

Exoplanets and Solar System report update

Mark Marley

- (more technical issues…)
- "We're not as far along as we should be."
- Currently we have 7 pages in Chapter 3 "This is signature science. We really want to shine. Most pages from Chris Stark."
- Chapter 4: 16 pages
- Some things moved to appendix? Ocean and icy worlds to appendix?

Aki: I don't want to move ocean/icy worlds to appendix? Signature solar system case. If anything might be alternative habitable environments bit.

- Need to be robust to discovery pipeline
- Having a nice figure will go a long ways towards explaining search/characterization strategy
- Clouds in chapter 4 can be moved to appendix?
- Need high quality figures, not just text
- "Spend time making the killer figures"
- regular telecons needed to spur progress?
- August = time to get text developed

Olivier Guyon: Infographics that explain process…it's not just infographics. We don't have the STORY well developed. More than just graphics.

Aki: I think we have sense in our heads but not written down. Inverted pyramid of easy observations to hard ones. Best targets filter down to next hardest thing. Filter down best planets.

Olivier: Complicated story. Tools overlap. Explaining overlap is hard.

Mark: Qualitatively we understand. How to do? We don't have IFS. What about if 3-4 dots in system? How do we know we have same planet if moves? Lots devils in detail.

Aki: How we know if same planet or not problem for IFS or fibers.

Olivier: How do we fold in non-LUVOIR measurements? RV, astrometry. Weaker science case than if we take a more comprehensive look.

Marc: High precision astrometry mode LUVOIR-only capability. Make sure you have that.

Aki: We will talk about value of mass measurement for atmosphere modeling. I don't think we were planning to use astrometry for discovery. Not more efficient that just straight shot with coronagraph imager. Probably isn't.

Olivier: I think we're interested in this chapter talking about planets we'll get spectra for. Not interested in planets for which we can't do that. We can assume we'll do all detections with coronagraph. Don't need to consider planet discovered by other techniques LUVOIR can't see.

Dave: Curious to know how much overlap between scientific discussion and instrument discussion? As we go through logistics of writing how we're going to split that up?

Mark: Question as we write these, we're writing to a capability, but not observing case. Where do we cut the level?

Aki: We have to go further. One of only things HQ requires is design reference missions. I will talk about tomorrow.

Mark: Going that far in chapters?

Aki: Yields and results from DRMs should appear in main chapters. E.g. how many planets, how many spectra?

David: DRMs grounded in hardware specifics.

Aki: In theory DRMs straightforward. In practice everyone does differently.

Olivier: Need to avoid writing things we can't do!

Aki: Quantitative assessments needed. We will have to say in main chapters how much we get with our hardware and reasonable mission operations assumptions. DRM is connection between science and hardware.

Dave: Myriad of details. These are things that have gone through design lab process. In context of this that you guys can make claims of what you can see. Grounded in hardware part of story. Must be comprehensive.

Aki: That's the ideal gas goal of what we're doing. Science sections should refer to DRMs. Appendix will have all details of calculations. Results need to be in main chapter.

Mark Marley: For for instance characterizing ocean worlds in solar system. What's killer figure? Aperture versus what?

Aki: Excellent topic for splinter. What calculations will we do to show what this hardware can do?

Marc: DRMs appear in special boxes?

Aki: Results, yes.

Marc: Gives separate flavor.

Aki: Hard part is figuring out actual calculations. Chris yield stuff is DRM. Good DRM. Don't have that for any other science case. Need to figure out what we need to calculate. Splinter tomorrow will get serious about that.

Vikki Meadows (online): I assume we need structure from goals to objectives to measurement requirements. DRM comes back on measurement requirements and says we can do that.

Aki: DRM puts in actual times. Works it all together with whole rest of mission. Says if this is observation you need to do, you figure out how long it takes and how long it takes.

Shawn: DRM starts from opposite side. We demonstrate how many and what quality observations we can make to meet science goals.

Aki: Chris yield calculations good example of DRM.

Vikki: We can synthesize requirements from science end. E.g. to detect oxygen you need this integration time and this resolution.

Mark: Use simulation tools and start making figures.

Vikki: We didn't go quite to DRM for Exo-C.

Aki: We did some of that for Exo-S

Vikki: We did a year in the life. We go that far as well? Actual observing sequence?

Aki: We need to talk about this tomorrow. Huge variety in possible approaches. Ones I've been involved with all completely different.

Shawn: Vikki to be clear we should discuss logic you laid out. Need to explain how we went from goals to requirements.

Vikki: Thanks everyone

Design and Technology report update

Matt Bolcar

Matt: As far as chapters on design and tech, we will see lots of progress soon because I'm submitting SPIE papers soon! Need text on HDI and ONIRS.

Aki: Courtney, this is our plans, not designs.

Matt: I will fold two SPIE papers into their chapters and write OTE part. Tech is separate SPIE paper I will write up. SPIE papers I write up this and next week.

Dave: Are we getting status updates on developments in coronagraph design and task area?

Matt: You mean SCDA?

Dave: SCDA one. There's whatever Olivier may have going on. Whatever Neil's done. I hope we could get a status.

Aki: How about in your technology splinter.

Dave: You all are invited!

Matt: Coronagraph instrument chapter is coronagraph. Tech chapter will reference all tech.

Dave: Folks I mentioned please go to splinter. If you have materials to show, please show.

Aki: Now we do communication discussion.

---short break---

Communications discussion

Debra Fischer / Shawn D-G

John: Shawn is that the Make Adobe Connect Again? (technical issues…)

Marc: (missed beginning of this) LUVOIR doing systematic exploration of every star system within 50 pc of sun. Puts LUVOIR on map as habitable world discovery mission. (comment about what LUVOIR is vs what HabEx is)

Debra: Is issue it gets tricky when we talk about what LUVOIR is, but when we start to define what HabEx is…

Shawn: Before HDST and LUVOIR and ATLAST, nobody thinking about extra kind of quality observations that larger aperture can enable. Time resolved spectroscopy. Not in TPF

Aki: There's stuff in TPF I didn't realize. More In there than I thought. They hit a lot we're thinking of. Not in as much detail.

Shawn: We'll be much better than before. We as LUVOIR not properly emphasizing what we can do. Best cases where HabEx can get spectra, we get high cadence high res spectra.

Olivier: DRM doesn't highlight data quality. Spectral signatures that are weak we can see. Wavelength coverage: Larger aperture farther in IR. DRM hides quality, we need quality of obs not just numbers.

Bertrand Mennesson: To answer Marc's point, fact that LUVOIR is presenting itself as able to do statistics implicitly says to can characterize individual planets. So you can insist on that as well. Make that point clear. Obvious. Other thins that we're starting to look into what kind of data we can get. Chris starting to simulate days in the life of HabEx.

Aki: Idea Bekki had for key graphic in planet formations section is to make up a planet system and identify all the things that we measure in it. We should do that too from exoplanet side. Point to point source that pops up to spectrum.

Jason: No reason we can't do 100 planets.

Aki: Key graphic that tries to capture quality of observations on template system.

Olivier: Life finding not easy. Will require lots of high quality data.

Marc: Since this is communications topic, but you just said it's report. It's 2017, we're in 21st century. Can our report be an electronic report that has videographics? E.g. some video that demonstrates 100 planets? Most people don't print out things these days.

Debra: PDFs can have videos and animations.

Mario: Sure we can. We can explore that.

Aki: That's fun. I like idea.

Shawn: To follow on what Olivier says, we should embrace our inner HabEx. What are observations we can make on 5 or 10 best targets. How far in detail can we go?

Debra: We need to talk about videos. Goddard or STScI will help. Other thing: I'm curious whether NASA interested in having some kind of parameter space diagram that shows what OST will detect, what astrometry can detect, what microlensing can detect as way of communicating decadal survey. To that end, I wonder if there is work we need to do risk

mitigation. Not technical, but are there science that needs to be done and we need to think about comissioning/carrying out that work.

Aki: Supplemental/precursor science?

Debra: for astrometry case, do we need to revisit at nanoarcsec precision scale how stellar noise contributes floor?

Aki: I don't think we need nanoarcsec for our purposes.

Debra: For Earths we do. Earth at 10 parsecs is .3 microarcsec. Precision must be factor of 10 better. Something to think about in terms of supporting case. '

Olivier: For astrophysical noise floor, beaten to death. On solid ground. No big red flag. Don't see need to revisit. Problem on instrumentation side. How do we demonstrate sub-micro arcsecond on large aperture? Quite new.

Aki: We should liberally reference previous work.

Debra: Lagrange paper and others.

Shawn: Other thing for science/research in advance of reports is we've talked about what RV and astrometry can do. I also think we should think about what kind of science we get just from continuing business as normal by extending cadence of RV. May not detect Earths but get info on systems and that can inform LUVOIR. Gray area between nothing and everything requires investigation.

Aki: Time to start talking about plans for AAS?

Debra: Good idea. Two more quick things. Shawn and Mark and John, do we have system in place for editing reports? Feels awkward to me to go in and edit the google docs.

Shawn: So far letting leads for chapters to pick whatever sharing method they want. Maybe we can use as common platform Slack for team communications. (Shawn demonstrates Slack)

Aki: Doesn't solve problem Debra is talking about.

Shawn: Not cross-team simultaneous editor. That solution so far worked out independently by chapter leads.

John: Only half the people use github. I much rather instead we embrace pencils down date for edits until we get to point of single editor. Why I put out Aug 15th COR. After that only I will be editing.

Need mythbusters slide on what ground can and can't do. We need a bullet point on why ground can't do X.

Debra: On awesome vs aperture plots, we need to also think about videos. Two minute videos?

John: At maximum. Don't want too long.

John: I have grand visions for LUVOIR summary videos. Short things 40 seconds to a minute max. Want something you can quickly show people on your hone. 10-30 seconds.

Debra: Want to talk about exoplanet movies?

Shawn: Mark first want to talk about co-editing exoplanet chapters?

Mark: We have a small universe of people. Google docs is fine.

Aki: Figures are annoying in google docs. Please drop in figures in folder.

Shawn: Google docs good for drafting, not for final.

Aki: Will have to switch later.

Julie: We will have a proposal specialist to do final thing in In Design and proposal graphics artist. You can draw it on a napkin and fax or scan it or email it to him.

Mark: That needs to be clear. What's protocol?

Shawn: There's four resources at GSFC. Two things Julie mentioned: people doing document editing, second is infographics people, third is science visualization studio. They work with data. If we want a visualization of Chris DRM or bullseye target of galaxies, we can do those in 3D space. Last is called CI Labs. They are our Lucas Arts studio. They do conceptual animations. For instance, if you have science you want to conceptually animation, they do that. Good workflow is if chapter leads tell us what they want associated with report. Bring it up to Aki, Debra, Brad, me, Julie.

Aki: What we need is concrete ideas, sketches for graphics.

Shawn: Even if not finalized.

Aki: Hack together and send it to us.

John: For every signature science case, do a sketch.

Shawn: Things we have already from CI Labs side is LUVOIR deployment video, "beauty passes" at L2. LUVOIR in a lightbox. These replace standard instrument slides. Last thing we ordered is exoplanet case animation and idea there is the challenge of characterize planets based on single pixel of observation. Basically animate observation of exoplanet. Quality and resolution improve over time. Cartoon of planet will show what we know or don't know over time. Might start off as blob, then sphere, then sphere has clouds, water, ocean, oxygen, etc. We will cartoon-ify this. Good if we had something like that from COR and at least one for solar system. For those working on those parts of report, figure out best science cases to visualize.

Brad: STScI has resources to use.

Kevin: One thing that is a unique LUVOIR capability is animating day in life of photon going through LUMOS. Something never been done. Imagine a bunch of background quasars going through galaxy, going through array. We did for SMEX concept a while ago. When becomes spectrum at end is very nice. Cool thing for COR.

Aki: Do you have a template?

Kevin: I can show old version. We can update and improve it. Idea to go from star field to spectrum.

Shawn: Send to us and I will schedule meeting you can call into.

Aki: One we absolutely need for infographics is one on observational strategy from point sources to biosignatures. The filter. The pyramid-like filter. Coarse on lots of things. Most promising get next level. Shawn you have in your head, turn into infographic.

Shawn: We need to show we can do deep dives AND gets lots of data.

Mark: Also a tension between that and also survey. Do we behave differently if we have advanced info vs if we don't (e.g. masses)

Debra: In addition to awesome vs aperture, I like idea of astronomy before vs after LUVOIR.

Jason:
(demos LUVOIR tools)
I thought it would be nice to have pretty versions of tools. Now I have presentation mode versions. Black background and pretty fonts. These online alongside everything else. Also if you want any other styling changes that's possible. I use this embedded in keynote.

John: Online tools how we go from 20 science cases in handbook to 200.

Jason: If someone gives calculation, we save their parameters. If we change one thing or one filter, we don't have to recompute. We just change telescope.

Shawn: Does that help answer AAS question?

Aki: For splinter. Notion about two splinters: talks and hands on tools like last time. This time we want more out of it. Would be great to get more out of it. This is awesome Jason. Thank you. In addition we need a web form for people can enter their science case text in web form too and save it.

Jason: We should have spent a little time to conceptualize what it will look like. Lots of areas of science, different instruments. We can use our structure to ingest things.

Aki: Web form could capture text.

(Shawn demos new website)

Debra: Date when it goes live?

Shawn: When happy with it!

John: Can we say pencils down Sept 1?

Aki: I think so!

Debra: Let's close meeting. Thanks!

Day 2 (Tuesday Aug 1)

International interest in additional LUVOIR instruments

Aki Roberge

Kevin: do they have to contribute something concrete? People contribute a lot of things. They could talk about them, write statement of interest?

Aki: Handle in a way to maximize flexibility. Don't mess with current planned instruments. We make it clear that flights instruments will be chosen after decadal and mention second generation instruments.

I always have aerosospace sitting over here scaring me. They won't consider any international instruments as baseline and won't cost them. This will give us maximum flexibility and capture benefit of international interest without screwing anything up.

Jason: Brad and I recently in Leiden which was attended by many international people. Tremendous interest on part of agency officials for joining this mission. I think we should be as welcoming as possible for alternative instrument concepts. Should we arrange whether it's officially under LUVOIR auspices or at arm's length to have meeting or series of telecons to coordinate?

Aki: We have to tell them it's a possibility to start with. International reps first for sure.

Jason: I can imagine extra half day tacked onto face to face. Having opportunity good idea. I would add that we should be able to support additional instrument concepts with a tool if they want it. Institute paying for that.

Aki: If there's person power to do it.

Jason: Yes.

Dave: Second generation instruments: Is that real?

Aki: We are not designing or costing them, but we are planning for serviceability.

Dave: If we identify second generation instruments as focus for other countries, we need to make it more concrete.

Marc: Our four instruments are strawman. Nobody should believe that they are the first generation instruments that for sure will fly.

Dave: Credibility of claim of second generation instruments?

Brad: I have to work with a group called future assembly and servicing of satellites team (FASST). We presented to NAC science committee and human exploration committee. STMD also interested. Three directorates pulling in same direction.

Dave: One to go

Brad: Working on concept that do need serviceability. Taking it seriously. Yes do need multiple generations of instruments. We might decide to fly simpler instrument to make mass margin. Very flexible.

Aki: General theme of flexibility should be emphasized up front in report

Julie: Dave, I would add that the STDT selected these four instruments to study first but I can imagine dozen or more possible. Not up to us to decide what those will be. Will be open competition for instruments later. I have no idea but not for us to decide. Also selected these because most stressing cases on observatory as whole.

Dave: Way for international partner part of complement even if Aerospace won't cost it? This offers hope for potential collaborators. But is it real? Does this prevent them from being considered?

Aki: No Aerospace costing is just part of this study.

Dave: So real hope for international partners to provide instrument?

Aki: Absolutely.

John: Big interest at Leiden meeting. Need to do loudly to get as big a capture radius as we can. Do it very loud and embracing as we can. Tell them what our report is and what it isn't.

Aki: On to do list email to international reps explaining this. But POLLUX is still special because you guys (i.e. CNES) stepped up early.

Shawn: I have a question. Is there a meeting that reps of these countries will be at in next year or so?

Mario: COSPAR.

Shawn: Too aggressive to have general assembly?

Mario: In this meeting, most of the countries included e.g. Spain, Isreal, Great Britain willing to yield to US on leadership. JAXA gave stronger statement that they regret not being part of HST or JWST.

Brad: They said not ready for HST but JWST was a mistake.

Aki: So there's that. What is the thing called? IAU?

(some chatter I can't hear)

Mario: Last thing they said is there will be white paper for everyone to read. One thing was conclusion will be in white paper that anything under 12 m for any space agency they are not interested.

Aki: That is interesting. Another thing is Kevin Heng volunteered to host us in Bern. Can we afford it? We'll discuss later, Julie.

Kevin: International space science institute in Bern.

Brad: When they solicit proposals? May have missed that boat.

Leonidas: Usually it's a two-year commitment. If proposal is successful you commit to many meetings.

Aki: Ok a little more complicated but not necessarily unfeasible. Giada, are you writing stuff down? (yes! ☺) Ok, onto DRMS.

Assessing the science return: DRM Discussion

Aki Roberge

DRMs:

- DRMs meant to provide quantitative rack up of total science case that can be achieved with planned hardware under realistic conditions
- TPF-C published in journal articles and separate technical reports. Referenced briefly in main STDT report.

Marc: Question is what is the real objective of including this?

Aki: HQ is requiring us to deliver this. I view it as actual proof that we can do the science we claim with hardware we design. Proof of concept. HORUS did HST-like reports but didn't use them. Want to avoid. Exo-S did calculations, described in report, gave result.

A few principles: baseline lifetime 5 years with 10 years of consumables. One thing we always struggle with DRMs at this stage is overheads. We probably just need to calculate science exposures and slap reasonable percentages on for overheads. Also in our case doing DRM calculations for every science case including appendix is unfeasible. Deal with it by leaving open time in five years into which we can do the other stuff.

Chris work on exoplanet yields (including discovery and partial spectroscopy) is in very good shape. But a lot more stuff here. Goal for splinter session is to sit down and decide what it is you want to calculate. Keep expectations feasible. Need something comprehensive but we can still get it done. While we have Chris' stuff, lots more exoplanet characterization stuff we want to do. Listing them and guessing how much of each thing we end up doing will be good start. Ditto for general astrophysics. Rack up listing in each cases: what are the characteristic types of observations and about how many do you need to do to actually achieve science goal? And then SSAT volunteering to get exposure calculations done. To actual churn the ETCs to associate times with observations.

Marc: How do we deal with GO?

Aki: That's a big chunk of open time.

Marc: Should be very big chunk. WFIRST having problem that all time but a bit allocated. We are selling as general observatory.

Aki: I think we should say that all of this is GO time. These are just representative science cases that someone might propose.

John: These are HST treasury programs.

Aki: Yes. We prove you can do them. We are not saying these will be done like this. By that time I might be watching this launch from a deck chair in Florida anyway. Does this make sense?

Technology development and sub-orbital payloads

Debra Fischer

Debra: Probably biggest risk we face are TRL levels. Great if we can come up with how to retire some of the risk. I am very excited by some of the precision astrometry. Yesterday Mike Shao and I talking about doing Cubesat to do precision astrometry. Today Jason and Marc talking about Kevin's proposal about doing Cubesat to retire risk on UV coatings. Place international partners can contribute substantially? Cubesat program under APRA program and my understanding there there probably be a little extra money in Cubesat program next year. Makes it kind of exciting. Mitigation of risk really compelling.

Aki: I would be interested to hear from Matt and tech working group which lowish TRL items suitable for being partially retired with cubesats.

Dave: UV issues can be tackled directly and efficiently. We can space qualify components and processes. Proposals for instances for on-orbit bare Al coatings. Push down into 60 nm range.

Debra: In particular way to double up?

Matt: I agree with Dave. Cubesat great demonstration platform for individual components. Lowest one ultra-stable systems. Probably won't make a lot of progress with cubesats. Requires big systems. Deformable mirrors, microshutters, yes.

Kevin: To come back to what Debra was asking about doubling up, at least from UV side we can do coatings, detectors, maybe one or two other things in cubesat.

Matt: Microshutters?

Kevin: Maybe. Done on sounding rockets actually. Smaller things you can do on cubesats. Cubesat Launch Initiative asked about going to L2.

Debra: With a cubesat??

Kevin: Yeah. They talked about possibility of doing with early SLS. Not available today. But we aren't in position to do until early 2021 anyway. Doing in situ could come up in future.

Walt: Great idea. Another thing is a lot of interest in developing lunar L2 shuttles using ASPA rings. We could put a bunch of tech together into a micro-scale observatory and attach it to space station. And then bring it back.

Woman sitting behind me: Can Mario comment on what it means for TRL advancement flying in a cubesat? Count more or less than sounding rockets?

Mario: As long as you fly instruments in same environment. TRL related to relevant environment. If you're doing deep space and flying cubesat in low orbit won't work as well.

Debra: I get that for detectors. But not from precision astrometry demo? You don't care about environment.

Mario: But that's technique, not TRL level.

Debra: Comment on Walt's idea? Why we can't send something to ISS?

Mario: We receive call from astrophysics to come up with ideas. We just launched on to space station NICER and ICECREAM launched in next few weeks. Second payload launching. Other ones European collabs. These are US missions. Funding up to 40 maybe 50 million dollars.

Dave: We carried OpTIIX through PDR. It died. When SMD could not provide 2-3 million dollars that would have leveraged 30 or whatever million dollars from rest of NASA. Puzzled as to how to engage SMD to break out of strict rule that everything spend money on must be completed.

Mario: My advice is try again based on success of other missions. Two already flying.

Brad: New sheriff in town.

Dave: Formal opportunity for us?

Mario: SMEX and MIDX.

Kevin: There are a couple things that I don't want to lose sight of. If talking about explorer must be TRL 6 before flying. Mission opportunity 4 by PDR. This is a tech development program we're talking about here. We need to distinguish big things that must be on space station or sounding rockets from small things that can be done on cubesat. For things like coatings, detectors. We're interested in long term degradation properties. Dirty place like space station not ideal. If interested in all things LUVOIR wants to do. Cubesats alone well suited for some things. Don't think an explorer mission relevant for our tech side.

Aki: I wasn't deeply involved in OpTIIX thing. Looking at it from periphery of GSFC. Reason fell apart at end was that it didn't do any science. SMD won't put down money on things that don't do science. SMD still hasn't figured out how to support tech development.

Olivier: Extension of suborbital, we should consider ground-based. Not always applicable but still useful for some things. Divide between ground and space harder to cross.

Woman behind me: I want to poke at whole TRL advancement using platforms. If long term durability that can be done in lab. If it's about getting to space can do with cubesat. Are we going to poke at it saying it's not same type of system. Flying on cubesat not flying on LUVOIR. TRL about system, not components.

Aki: But low TRLs are not.

Woman: Every time you get different people in room they interpret it differently. Need some kind of confirmation from HQ when we put effort to advance TRL with cubesat, by end when we're done, we know where we are.

Julie: I want to comment that when Mario offered up mission of opportunity, people brought up that mission opportunities must be at TRL 6 and TRL 5 when submit. Not an option for us. We start at TRL 3 or 4. Just wanted to emphasize that this is something HQ could grapple about.

Mario: Issue is what Aki said. SMD normally selects anything based on science drivers and outcomes. NASA bad in sending tech demonstration. Even STMD wants some science. I think we are not afraid as we were before of doing tech demonstrations. I think if TRL can be improved in lab, you don't have to fly. If some can be done from ground, we're open. Coronagraph tested on ground.

Brad: TRL 6 says it must be in relevant environment ground or space.

Mario: Lab, ground, orbital program. Microshutters had never flown for JWST except on rocket. Only TRL proof they had. First time they flew they failed. I think orbital program provides testbed. Cubesat mission of opportunity later. Path lab, ground, suborbital, cubesat. Approaching goal of relevant environment.

Jason: I want to point out that not within mandate of STDT to push these tech development projects through NASA. STDT should focus on how set of needs maps to feasible set of demonstrations.

Aki: For sure, Jason. But lots of people here involved in tech development and can push things forward. But we have to write a PLAN for tech development. Discussions like this valuable part of that plan.

Allen Dressler: I don't see tall poles in TRL. Calling attention to them not productive? There really are programs that there's key tech that if you can't do, you have no mission.

Matt: Look at list of our tech gaps. Only one we can do is coatings. Valuable for cubesat to do UV demo of cubesat and detectors. But won't remove our risks.

Allen: If you try to jump ahead of that run risk that other groups will start tech war. I don't think these will sink us in decadal survey.

Aki: Personally I have been terrified of TRL 2s. Worried aerospace will slap us with big risk that translates into dollars. They also said they look at holistic sum of TRL items. Aerospace said knocking off 3s will help. But Decadal isn't aerospace. Decadal can interpret differently if they want.

Julie: Aerospace said that the Decadal and community know detectors will improve, UV coating improve. Those won't sink ship. Hardest one is ultra-stable opto-mechanical. Throw resources at it?

Shawn: When we talk to aerospace, suggest that our internal investments be made in highest risk item vs spreading out between multiple items. When we gave them two options of advancing low TRL significantly or sort of low ones a bit, they said first was best. That's what we're doing with team level resources internally. If people outside team find opportunities that can do other part of it that's incredibly useful. Not as useful as ultra-stable opto mechanical systems, but still useful. Fair Matt?

Matt: Right on.

Marc: What are we doing for that thing?

Matt: It's not team resources. SATs, IRADs, work at JPL, CAN work. Money going to individual efforts to build up components. We have industry teams participating. Point being there is a lot of work going on. Need to happen sooner than later is systems level demonstration. Need to show that as a whole we can get to picometer stability. We need to get to that. Getting there but not yet.

Shawn: I want to say one other thing. In addition to advancing in advance of decadal survey, we have responsibility to have tech demonstration in report that goes from decadal survey to mission and show how we will advance TRLs up to launch. So if you have ideas for later, make sure Dave and Matt know about it.

Dave: Two things to say, WFIRST coronagraph. Other is come to our tech splinter. Will focus on studies to do to fill in story. I don't know if we can do it but I'd be thrilled if we can get that one red TRL 2 up to TRL 3 to decadal.

Matt: Heading in that direction. We can do it.

Shawn: That number 2 came from a group that was independent from us.

Matt: But we were in agreement with that.

Shawn: And that assessment says if we do modeling Matt talking about we'll be at a 3.

Aki: And there's a 3 on there we can deal with cubesat. Let's do it.

Laurent Pueyo: We'll launch (something). We have model showing how wavefront acts with time. Nm level not picometer level. Data soon.

Mario: Will address Q. on what is being funded. (discusses projects people are doing). Final report must include these efforts.

Debra: Coffee break now.

---coffee break---

Exoplanets & Solar System DRM splinter session

Notes by Giada Arney

Solar system
Planetary system architecture

- Comets, asteroids, KBOs
- Comparative atmospheres, diversity and composition
- Planetary surfaces
- Ocean worlds

Britney thinks spectroscopy targets biggest unknown at this point
Lots already done on surfaces, aurorae, atmospheres
Need ONIRS tool done
We need to ask people what they want that we don't have yet

Courtney wants to be able to upload your own spectrum to tools

Vikki: Can we justify spectroscopy with LUVOIR vs what we do from ground with EELTs? Science case for being above atmosphere?

Britney: Question especially since not going far into NIR. Question about temperature and focal planet. In UV there's still a case. Lot to be done.

Vikki: Spectral mapping killer app because can't get spatial res from ground.

Britney: Exactly.

Mark: Depends on how good adaptive optics are.

Shawn: AO works better in IR?

Vikki: Yes.

Shawn: Visible might be complimentary to AO on ground.

Olivier: Hard in optical with VLTs. Challenge depends on guide star. Jupiter fairly big. Can use satellites as guide star. Definitely hard in optical. In IR will work but maybe not at 100%.

Mark: Anything else to consider on solar system? Ok move onto exoplanet DRM. Talking to Aki we really need consideration beyond what Chris already done? Two categories: non-habitable, transit science, what else?

Olivier: Extension beyond transit is folding in other measurements.

Mark: Ground based count as part of DRMs as long as we don't need it.

Olivier: How do we interpret data we get with LUVOIR folding in additional measurements? Mass may not come from LUVOIR but critical for interpreting spectra we get with LUVOIR. Don't want depend too strongly on things that may or may not pan out. At this point we don't know enough to allocate times for making astrometry. We can write requirements of what we need.

Laurent: How much time to spend tracking down false positive astrophysically? E.g. spend 10% of time chasing down background stars?

Olivier: Example where can use ground based telescopes ahead of time. Identify false positives ahead of time.

Courtney: Chapter or appendix where we talk about ground based? And talk about other observations we can get in advance or simultaneously?

Shawn: Other thing that is too detailed for report but also should talk about what ground based obs give us for prior info between now and LUVOIR. Talk about ways to get down to rocky HZ worlds with precursor obs. We will be able to account for those much better by 2035.

Mark: Point of view of DRM for hours we have to add up to is:

1) For mass > whatever (5 earth masses) no search just exposure.
2) Want characterize UV -> near IR

Courtney Dressing and Debra: re. first point still really hard! Depends on semi-major axis!

Courtney: We can specify as semi-amplitude.

Karl: Grab something representative.

Shawn: Mass limit of RV?

Debra: Depends on velocity amplitude. K=2 m/s current state of art with roughly 1 m/s error bars.

Courtney: Also sample of stars not all same. Probably worth thinking about this a little more carefully.

Karl: Paper done for Exo-S and Exo-C. Nice to repeat for LUVOIR targets.

Mark: Question is for comparative planetary science, do we do dedicated search or do what falls out of HZ search.

Karl: you're asking how many RV planets in HZ search that Chris already created. We need to know answer and ask question of group is that enough for other planet science we want to do?

Shawn: Thinking for future teams is trade we've been talking about on IFU. We should talk about how science with planet diversity question is impacted by whether we have IFU or camera. Documenting is important.

Mark: Certainly in no IFU case we have to search. And how much time does it take?

Karl: Can we agree that standard observing mode in parallel for vis and NIR observations so we get better IWA?

Dave: Yes that can be done. Three coronagraph fields.

Laurent: Two in parallel doing science and one for wavefront sensing stability.

Shawn: Detailed simulations of planet diversity we have UV, Vis, NIR channel. We get to pick which one is wavefront stability. Other two can either do camera image or high re spectrum. We can flip between those two and flip between coronagraph masks to look at different IWAs, wavelength within band, spectroscopy or imaging.

Laurent: For baseline coronagraph which is shaped pupils Neil is designing, the way we put the masks in filter wheels, we will hit HZ regardless. This why so many filters.

Dave: Question I have is we talked a lot about IWA. OWA also influence architecture. DM density or whatever.

Karl: If you want 10^{10} contrast, you want to get out to where giant planet has 10^{10} contrast to use out to useful field of view. Out to 10 AU.

Shawn: Roughly 10x IWA.

Karl: No a range of distances. 1 arcsec is realistic OWA. Thing I want to ask is can we do wavefront control in coronagraph using UV and do observations in NIR.

Laurent: Doing wavefront to dig dark hole in visible, once get dark hole use UV to get wavefront sensing.

Olivier: Most targets UV doesn't have a lot of photons.

Dave: We've done numbers. Will have quick summary.

Karl: Important to know we can do optical and NIR at same time.

Laurent: Absolutely.

Karl: UV may not be useful for wavefront control?

Laurent: For all targets, true.

Shawn: Can extend UV channel far enough into VIS to get enough photons. Also tech demo also laser guide star.

Dave: Also indirect methods. Wavefront sensing won't do high bandwidth stuff. Other stuff for that. Accuracy vs loop closure times. We think with 1mK thermal control, a laser metrology system will be able to maintain 10 picometer stability. Will drift but will relax bandwidth required for wavefront sensing. Still juggling exercise for different methods to achieve overall system goal. We have tools. Will play tools out in different combinations.

Shawn: For sake of DRM assume for now we can use any of the three channels as out of band wavefront control band. If we're concerned about that let's not table it but address separately. If ends up not possible we may have to re-address DRM.

Karl: Let's ask for it yeah.

Shawn: But only one small chunk of channel at given time because of filters.

Olivier: Can't use all 3 channels at same time for science?

Laurent: Yes

Mark: For this DRM we're getting other classes of planets. If we see fat juicy HZ planet, integrations on Jupiters are free. In some cases no HZ target and that counts against us for observing Jupiter. For DRM need flowdown for dedicated time to do this. I don't have a feeling for how to approach.

Debra: List of target stars?

Shawn: Yes Chris has list. He populates with planets and does simulated observations. He presented at last STDT. He ends up showing field image of what you see with coronagraph.

Laurent: We are giving him real coronagraphs.

Mark: Tell Chris keep running list of other types of planets you characterize.

Giada: Chris tools give how much of spectrum you get for planets? Given OWA/IWA?

Dave: Yes

Shawn: I think we need to go through detailed logical chain of which bands at which res in which order. Need one case of system with known targets. We need a brain melding session.

Mark: Let's touch on few more cases. Transiting planet science.

Dave: IR.

Mark: UV for escape.

(some discussion about transits. Missed notes for a min)

Shawn: What we discussed in SSAT is that when we talk about main science case in main part of report that main strengths in spectroscopy case is UV science but we also for these corner cases for both kinds of info write up in appendices as another example application.

Dave: Those will be cases for broadest potential for spectral characterization.

Eric Lopez: Transformative things we can do and truly unique that LUVOIR can do is comparative planetology of exospheres across range of parameter space for different classes of planets for rocky ones all the way up to giants. We currently have sample size of 4.5 planets for which we have detection of any species. Whereas when you have 8+ m space telescope you can get many important species. You can do potentially for HZ transiting plants, can do for TRAPPIST, can get time resolved observations. Calculation we need to do is take some sort of

simulated transit catalogs, simulate real stars, magnitudes, radii, guesses at masses. Calculation I imagine is you get of order 30 planets, what can you see?

Shawn: By time we launch we will have covered JWST wavelengths. UV transits is complimentary to JWST.

Vikki: Can I add extra point? Building off what Eric said and Giada mentioned earlier, our deliverable should be molecules detected. That is important for transit science. That should be our ultimate measurement for direct imaging size. Chris isn't going that far. Also want to say if we don't have realistic spectra we can't get realistic phase dependence. Importance for yield.

Mark: Detection vs abundance needs to be discussed.

Dave: for active stars we've been through debate but don't forget capability. Especially for depletion of atmospheres.

Olivier: Also need to discuss astrometry of planet to star. How do we resolve orbit of planet around star?

Karl: 3-4 followup visits. Eric Nielson done analysis for HabEx and we can share.

Olivier: We have not yet discussed polarimetry. What do we need to make? What precision?

Mark: Depth of characterization once we have good target is a good question.

Shawn: We get polarization info for free, right? We have to do polarization as part of wavefront control.

Laurent: That's a discussion with WFIRST.

Mark: Problem with spectropolarimetry is that in bands where planet darkest fewest photons.

Laurent: maybe for imaging. Maybe for disks.

Mark: I'm a polarimetry skeptic for planets.

Olivier: Can get polarization maintaining fibers. If we need it we can implement.

Laurent: Is there a science case for it?

Mark: Cassini looked at Jupiter at half phase where should be super polarized but not.

Karl: Add planetary phase curves. Since I'm afraid you'll erase disks again, we need to do same thing as RV planets. From Chris target list look and see how many known disks are in there. See if satisfactory science case or not.

Shawn: Even for systems with known disks current observable we can see closer to star into HZ.

Karl: For things not disk selected targets?

Shawn: What is science we get out of extending observations of disks closer to star? Coronagraph enabling

Karl: For some disks that's desirable. Can come up with disk-selected target list. Start to develop case. See colors, different epochs, projected speed.

Laurent: Wanna go back to first point. Chris has disks. Exozodi. We need to include that exozodi problem. Throw away targets where HZ we can't do anything. Then we move forward to something else?

Karl: First visit on target where just has lots of dust. Probably don't do revisit for HZ. Might do revisit for other planets.

Mark: Still part of signature science case?

Shawn: Some not in full DRM but for appendix probably. Mini DRM if you will.

Karl: I want to make sure some good debris science case.

Bekki Dawson: We have young debris disk case. There is a young debris disk science case. Also case for older systems in case where exozodi is nuisance but also a good thing because can tell you structure that can give constraints on planet mass. Part of science case. What we haven't done is say what number of targts or other capabilities it dicates.

Debra: Precision on measuring dust? Can measure one zodi? First characterization?

Mark: WFIRST will be first.

Bertrand: WFIRST at 10-100 zodi level. Hope that you guys will do much better.

Karl: I think it can do better. We can talk.

Mark: What are we missing? Follow up of HZ good targets. Comparative planetary science. Transit science. Disks. What else?

Aki: I came over with message from other side. As high level view of how we're gonna do this DRM, Mario said HQ is ok with this. Way they're doing DRMs is 100 hour treasuries. One for each COR science case. Fine if exo is different. It's going to be. Notion is approximately speaking fill up a year of COR, fill up a year of exo, some for solar system. Those are treasuries. Rest of 5 years is open. In open time is time to do some of all of the other stuff we're talking about in report. Mario said HQ ok with not planning out every minute for 5 years.

Mark: I hear do a really good job on exo HZ search. Can leave other stuff…

Aki: Other stuff can be more open

Courtney: Nice to have time in appendix for time to do certain things.

Shawn: Table?

Aki: Couple examples of short programs too to show a bit of the range. COR spending a lot of time thinking about what parallels they get when doing exoplanet obs. Serendipitous parallels during long exoplanet observations. Characteristic long exoplanet exposure time would be good for them. They have programs that don't care where they point in sky.

Mark: Need to pick and scope out in some detail legacy programs.

Courtney: I think we're missing UV characterization of host stars.

Aki: Any info I carry back to COR?

Courtney: Debris disks!

Aki: They're here. Debris disks are EXO. Protoplanetary disks COR. They're done with that DRM.

Bertrand: Thing we have in both mission studies. Debris disks, exozodis. I think people getting **confused** between these. To me exozodis are just faint end of debris disks.

Aki: I always view protoplanetary disks as primordial. Debris disks are young planetary systems. We've talked about this many years ago.

Debra: Zodi considered noise source. Exposure time for debris disk in ETCs? I want that.

Aki: Young debris disks a lot brighter. Really short observations.

Debra: What about 1-2 zodi?

Aki: Get for free when doing exoplanet obs.

Bertrand: That's your paper Aki. For 4 m telescope looking at solar system at 10 pc flux of 1 zodi equivalent is 4x Earth. Larger telescope is zodi less of hindrance.

Aki: I kind of don't care. If I want to study debris disks, I will want to look at younger brighter systems.

Debra: We might care in terms of which stars best to drill down for Earths.

Aki: LBTI host survey hopefully delivering mean exozodi level.

Bertrand: Individual stars need to wait for mission.

Aki: Mission planning software will adapt. Chris software will de-prioritize. Chris DRM codes, this is one of his new innovations of a smart planner that accounts if you hit a bad one, it will move on.

Karl: In LUVOIR with bigger aperture exozodi fainter. Want to see structure to get constraints on mass. Want to know how long to image zodi with LUVOIR.

Aki: Day we can make 1-1 comparison with exozodi observations and planet mass is day I will worry about this in detail. We aren't there yet.

Mark: Characterize every target in UV or just ones with planets?

Courtney: Vikki you think we want UV from star for all planets, not just ones HZ?

Vikki: Absolutely, do it for all planets. Highly evolved things subjected to a lot of UV for a long time. And important for false positives.

Mark: For all planets?

Vikki: Yes. For stellar evolution as well if possible for evolved targets.

Eric: I wanted to add that for some targets we're often not just interested in UV today but UV history. If evolved targets we need to know what UV like when 100 Myr old. Some work done before LUVOIR, but characterizing young active stars and history. Want UV activity in detail. High SNR time series information is new opportunity in FUV, NUV, in many different species all at once.

Vikki: Totally agree. We need to know spectrum and activity at time we observe to understand photochemistry as we see it now and determine if any disequilibrium. Knowing history key to understanding evolution and bulk composition we see now.

Mark: If great targets, ground based will follow up.

Vikki: Can't do UV from ground.

Eric: Time series UV on timescales of 10s of minutes to hours. Relevant timescale of flares. Worthwhile to see what sort of major progress can be made that can't be doable now.

Dave: We get this for free on all with rejected light.

Shawn: If LUMOS does simultaneous observations game changer

Dave: Not see same object.

Courtney: That would be game changer.

Mark: We need to do follow up for orbits, phase curves, full spectrum at low res, high spectral res, what are exposure times? Chris taking into account exposure times for spectral yield?

Shawn: I think he's aware of this but isn't doing it yet. Coronagraph bandpass will be important. Chris worried about this when he talks to us. Makes me think he incorporates. For folks in room thinking about LUVOIR vs HabEx. HabEx has legit advantage as it will use starshade for spectral characterization. Bandpassses for starshade broader.

Courtney: Important to add what we can do on LUVOIR with starshade? In appendix?

Mark: We'd have to stop down.

Shawn: Good to include.

Courtney: Nice for people reviewing proposal to know don't have to give up starshade for LUVOIR.

Karl: Really really big starshade.

Mark: For HZ DRM need to make sure Chris has enough ofr HZ case. For comparative planetary science I'm hearing we don't need full DRM and exposure time estimates. Eric to make nominal list for transit planet science case. Disks Karl you do?

Karl: Aki already done.

Bekki: I don't have target list.

Karl: I can help.

Mark: Solar system we discussed already.

Shawn: Matt confirmed that LUMOS can't do simultaneous observations of host star. Can monitor with out of band channel.

Kevin: LUMOS observations very fast.

Mark: Can we get Chris list of objects?

Shawn: Chris going to be here for HabEx meeting?

STScI people: No. On vacation.

Jason: The exo Earth yield tool has these. You want list of stars?

Mark: We want a copy.

COR & PCOS DRM splinter session

Notes by Julie Crooke

Efficiency = photon counting time relative to wall clock time

Individual Instrument efficiency = photon counting time relative to wall clock time for an individual instrument

Parallel instrument observatory efficiency: photon counting (including all instruments) time relative to wall clock time when zero instruments are collecting photons

To Do List:

1. Adopt an efficiency ~60% (Can sub in another number later)
2. We need to name all of the science observations that we can then assign ROM integration times for each science case
3. Is moving mechanisms detrimental to other science instruments (other than the coronagraph)
4. Each instrument should show their "100 hour highlight"
    a. Flux level
    b. Signal to noise (S/N)
    c. FOV
    d. How long does it take to accomplish a single field?
    e. How many fields does the science case need?
    f. Example: In ~1 hour, LUMOS will reach S/N = 10 per resolution element (R = 40,000) over a 3'x1.6' field to F(sub lambda) = F(100 Angstroms) = 2 x 10^(-16)
5. Are there "precursor" observations needed?
6. Can we create a "Template DRM Sheet"?

7. Make a list of each “100 Hour Topic”
8. GSFC’s SSAT offers the analysis tool to
9. For any given science case, does it need to seek a specific target on the sky vs. can the science case look at any random pointing?
10. Everyone think about how far into the 5 years do we want to plan vs. a GO program?
11. These are all “GO Treasury Programs”
12. Exercise all science instrument modes
13. Make sure you state, for each science case, the “Instrument Name” “Mode Name” and time if you know it, otherwise give that to GSFC SSAT and they can help figure out the time needed for a given science case
14. Matt Bolcar is meeting with Mike Shao to discuss efficiency of switching to different instrument modes
15. Alan Dressler: It would be helpful for LUVOIR to state, “How much time will be used for surveys vs. time used for searching many different targets to generate a composite from a number of pointings?
16. Also, while there is a primary instrument operating at one time and that instrument has a certain observing efficiency, it may be great to point out that there could be parallel observations which would increase the overall “observatory efficiency”.
17. Aerospace will ensure our science story and hardware implementation are self-consistent and needs to be accomplished within the first five-year program
18. What goes in the DRM:
    a. List instrument(s) and the modes (detectors, gratings, resolutions, filters/bands, etc.) your science case needs (might be multiple instruments)
    b. List number of pointings
    c. Number of targets and their location on the sky?
    d. Justification for exposure time (S/N @ flux level) (Exposure Time Calculator (ETCs)
    e. Total exposure time
    f. Can this be done with parallels? ((1) either when you are prime can you tolerate other instruments operating and (2) or if another instrument/mode is prime, can you perform your necessary science being a secondary?)
    g. Is it compatible with other instrument modes?
    h. Cadence: (need to observe this target every (frequency) for a given duration)
    i. Target of Opportunity
    j. Other constraints?

---lunch break---

Exoplanets & Solar System interim report splinter session

Notes by Giada Arney

Need “LUVOIR will do this” for science questions to tie back to facility

What does LUVOIR do best?

Vikki wants a “selling filter.” Not just the science case.

Vikki: I really hate “conventional habitable environments.” Implies we know what that means. I changed to terrestrial exoplanet habitable environments. Don’t need to spent huge amount of time on alternative habitable environments.

Mark: Move to appendix?

Vikki: At moment we have things like H dominated worlds. Can we even do that? We need eyes and focus on detectability. Courtney, they put M dwarf habitable planets in alternative habitable environments.

Courtney: What?? That should be in main science case.

Vikki: Agree to move up into subclass of terrestrial habitable environments?

Courtney: Yes!

Vikki: We can talk about G dwarf classic and then talk about M dwarfs. I don’t think alternative habitable environments. Largest real estate in galaxy. We can get some in direct.

Courtney: Ones we will get with LUVOIR will be will characterized by time we launch.

Vikki: Can make lovely case for transiting observations and what direct imaging can provide for deep lower atmosphere.

Courtney: We’re starting this as a science paper. Should we instead write it as a news article. Lead with headlines?

Karl: “LUVOIR will do this.”

VikkI: Our entire selling case should be right at the top. We really need to sell people. Proposal won and lost in first 30 seconds.

Debra: Astronomy before and after LUVOIR. Some figure that kicks off and hooks people.

Vikki: I don’t like starting with “What does habitable mean?” I think we should start off with the diversity of habitable environments. Exo and solar system.

Mark: Inhabited Earth through time is example of template spectrum changing through time.

Vikki: I see Earth through time as alternative biosignatures. False negative potential.

Giada: Proterozoic oxygen is there. Oxygen is the best case we can get. We should be honest about the opportunities and challenges of anoxic phases though. Talk about oxygen, Proterozoic, and anoxic phase.

Vikki: I like sequence you just said.

Eric: We need to emphasize that physics that produce abiotic oxygen uniquely detectable with LUVOIR.

Vikki: Agree. False positives section.

Giada: Where does early Earth stuff go? Environments vs biosignatures?

Vikki: First part is environments, second is biosignatures.

Giada: Tricky to disentangle for some phases of history. E.g. methane.

Vikki: Introduce anoxic environments in the first section.

Eric: What are the observations? We will image? We will see atmospheres?

Aki: That section based on Shawn's published work about putting planet in holistic astrophysical context. Summary of recent work on how to get oxygen without life.

Eric: I'm asking about earlier section.

Mark: First we find planet we like (habitable 3.2) then we look for life (second section 3.3). 3.3 is digging down into high res spectra.

Aki: 3.4 is where it ties the whole soup to nuts connected to DRM sequence. Start with these observations, if this then that. If other go this direction.

Mark: It's weird because we've got two signature science cases.

Aki: This is one long story: which worlds are habitable, which are inhabited. A while back we laid it out that in 3.4, Shawn takes pieces from 3.2, 3.3 and makes a sequence of observations progressing to describe the filter. Triangular filter of how you progress from coarse observation on a bunch of things to following up more deeply on more promising targets.

Vikki: In science cases can do desired characteristics, measurements requirements for those, and in DRM tie together.

Aki: I think you can tie them all together in 3.4 to actual observations.

Mark: With the additional sections for transiting case, for solar system.

Aki: Yes that gets a little tricky. Well it doesn't have to be…it's possible DRM for ocean/icy worlds is best stayed in 3.2.3. That is ok too.

Eråic: I was wondering for section 3.2 and 3.3, should there be a specific summary of what is the core treasury observation. For 3.2 we will characterize if already detected or we find X number of planets likely rocky in HZ.

Mark: Move Chris's section to 3.4?

Courtney: Intersperse figures to tie all together?

Aki: 3.2.6 is what you write for 3.2.7.

Courtney: 3.2.6 is how you do this, 3.2.7 is why you want to do this with LUVOIR.

Aki: Why LUVOIR is how to do this is done above. Basically Chris 3.2.6 IS DRM. In general I don't see why spinning out another sub-sub section for how LUVOIR does this best when It should be general theme.

Courtney: Should be callout boxes.

Aki: Callout boxes. Yes.

Mark: This is awesome vs aperture.

Aki: Should be body of text. Resist urge to spin out zillions of subsections.

Courtney: Plus if callout box what someone will see if just skimming document

Mark: We just need to get text in here to see what makes most sense.

Courtney: Worthwhile to think about figures we need?

Mark and **Aki**: Yes.

Eric: Should have cartoon planet showing what you get from surface to exosphere.

Aki: And sources and sinks. So people see that a biosignature is a source out of balance with sinks.

Vikki: and add star at top. Other planets in system. Holistic package of whole system.

Aki: I wouldn't try to pack too much into one figure. If architecture/dynamics thing, I think Bekki has idea for how to deal with that.

Bekki: Maybe it goes in next chapter.

Aki: But it will be referenced. This is good idea for figure but focus on atmospheres.

Eric: I have thoughts on specifics on how to do for non-habitable planets for chapter 4. If someone has good thoughts on how to do for chapter 3, we can coordinate with Goddard graphics people. Giada we coordinate?

Giada: Yes

Aki: Yeah

Vikki: Britney any way to work in solar system aspect as well to diagrammatically show different habitable environments? Theme going that what we learn from SS and exo informs each other.

Aki: That could use some thought.

Vikki: Having graphic could be helpful.

Britney: I don't think it will look like one of these plots. I suppose you could stick Jupiter on there or something like that. Sure there's a way to represent it.

Vikki: I think this is saying we need to develop science theme.

Debra: Sticking with data, what we're doing now is here's what a habitable world will look like. Instead think about data we actually get from telescope and have that point to science interpretations. Right now we start with interpretation of data and search for that thing. LUVOIR does statistical surveys. I know this mixes up 3 and 4.

Aki: Laurent showed me video this morning of a different version of Kepler orrery. Hard to describe in worlds. Summarizes if dots are planets out of DRM and zooms in a bit. Start out as black dots. Then become colored because photometry. Then orbits. Then spectrum pops up. They go from black dots to spectra. Infographic like what Mark sketched is good illustration for why we are setting up our experiment in the way we set it up.

Giada: Sounds similar to the video Shawn wants to do.

Aki: Yes.

Mark: In terms of figures for awesome vs aperture…

Aki: Shawn had an idea for a graphic like a year ago. We have to decide if this is too politically sensitive or not. (sketches)

Olivier: This doesn't capture diversity with aperture. Maybe we draw population on two axes, or mass on one axis. As telescope size increases, larger number of those that we grab.

Aki: Do people like this executive summary figure?

Debra: Yes.

Eric: Equivalency for galaxies?

Debra: we need to avoid doing a HabEx comparison.

Aki: Yes. The top we do EELTs.

Debra: Now we go into parameter space and show characterization we can do. Have that drive organization rather than just starting out with habitable planets.

Mark: Chris has all of this. Just to visualize it.

Aki: We make axis habitable zone proxy.

Debra: some probability we will detect those planets with those instruments. Hard to decide with ELTs what will be seen.

Aki: Olivier correct me if wrong, nobody thinks ELTs will reach contrast levels.

Olivier: Sweet spot for ELTs is NIR. M and possibly K. One nice way of representing is you can draw range of spectrum ELTs will detect will be complimentary for what LUVOIR will do. Ground based do NIR of Proxima Cen. HabEx will do visible part. I think it depends. Sunlike stars with terrestrial planets very hard for ELTs. They won't do it

Vikki: What about 10 um observations?

Olivier: I should have mentioned 10 micron. ELTs will do planets around sunlike stars at 10 um. Spectroscopy. First light instrument will do that. Number of targets not huge. About 10 stars. We will get their spectra from 6-7 to maybe 13 microns. If you have visible light and you have thermal emission at 10 um on those planets you actually can measure radius.

Aki: Which stars?

Olivier: Procyon, Sirius, Alpha Cen A and B.

Betrand: Spatial resolution an issue.

Aki: Those are A types… eeeesh

Mark: We haven't talked about our second chapter yet. Moving on to chapter 4... I hate the word planetology. We have 3 science cases. Architectures, atmospheres, surfaces.

Vikki: Executive summary at top again?

Mark: Yeah. What's the elevator pitch for architectures?

Bekki: Right now it's three aspects. Planet formation, one is being able to use architecture to better understand planet you're interested in. Other is identifying diversity of planetary systems.

Mark: Important to capture more. Beyond counting. It's types, compositions, disks, ice giants, whole context.

Bekki: Yeah. Not much discussion of occurrence rates right now.

Mark: What about figures?

Courtney: Cool to see a cool system. Show how much more we learn about system as a whole.

Debra: Definitely show how astronomy is transformed.

Vikki: And tie in back to how it informs habitable planets as well.

Bekki: I have a draft figure in folder. Some figures in figures folder.

Courtney: I like that

Bekki: With that one, idea is to show example system and tie back to how it informs us on potentially habitable planet in system. Cartoon that Aki and I also talking about there could be a mock image instead of just cartoon. In this case planet of interest is in blue circle. Caption talks about how different pieces of system all inform us on habitable planet.

Mark: It's the context of the system. What if every habitable planet has a Jupiter?

Eric: Bekki, could you add series of blow out boxes? Box from Earth with potential spectrum. From disk showing you can detect down to such and such fraction of zodi. For Jupiter we detect other companions down to such and such limits. Bits on how amazing you can do on different components.

Bekki: Good idea.

Mark: Good.

Bekki: Where we could have more awesome vs aperture more for young exoplanet section which includes young debris disks. Can talk about how you really need this aperture telescope to be sensitive to terrestrial forming region.

Mark: Number of systems.

Bekki: Easier for young exoplanet systems. Other figures we could have could show how as a function of age you see region of terrestrial planet formation changing and images showing feature that terrestrial planets sculpt in disks. Not sure if we have room or not. Don't illustrate necessity of huge telescope.

Eric: For something like that, could you do something like take one of the LUVOIR Hl tau image and then show fantastic feature you can see now out at 20-50 AU, and then zoom in to region unresolved with current tech. Show synthetic image that looks like ALMA for inner disk.

Bekki: Good idea.

Mark: But not HL Tau.

Eric: Right. Tons of synthetic ALMA images for what they can do in exteriors or disks. In terms of figures for science case 2, I was imagining the exoplanet atmosphere summary figure for this case. A similar figure to what Mark drew up there. Instead of solid surface, you have 1 bar atmosphere and show cloud deck, show whatever, zoom out with spectrum in optical photosphere, other blowouts with information on the exosphere, wind, star, maybe connecting atmospheric escape probed by near and far UV and these instruments,

Courtney: Also good case to tie in solar system connection as well

Eric: In one figure you can show compositions, hazes, clouds, atmospheric dynamics

Walt: Certainly for solar system UV unobtainable

Mark: Some things go into appendix. E.g. clouds. Atmospheric dynamics? Does that go into appendix? Surfaces belongs here. Can we see spectral features on barren planets.

Walt: Chondritic spectra. Not as small as mercury but core of evaporated object.

Mark: Signature case? Or "oh by the way" case?

Eric: I notice planetary surfaces of temperate terrestrial atmospheres here. Habitability section?

Britney: Geo case you can do basalts, magma ocean. Spectrally not sure all that different.

Vikki: Ices?

Britney: Almost any ice band swamped except 3 um band. But we can't get it. Not sure would work for terrestrial planets. Band ratios people use. Ice is out.

Eric: Could you distinguish between Mars like and moon like surface?

Britney: Band ratios gives color. We have some filters on there that might work for that. Standard photometry on those would work.

Eric: Delete "temperate" from the surface part in 4.4.3

Courtney: Why is this in 4.4 and not elsewhere? Fits into "are we unusual?"

Britney: For solar system it's useful

Mark: Are we unusual just catch all phrase.

Eric: Comparing exoplanets and solar system falls into comparative planetary science. Direct imaging can do surfaces. This our first chance to do survey of different surface types.

Britney: I never liked are we unusual.

Karl: Me neither.

Vikki: Bigger picture of putting our solar system in context.

Debra: This title is for congress.

Britney: It doesn't describe the science well.

Walt: Can we even do it? Our system is not a typical system we'll find. We'll have biases that won't focus on a system with no large planets closer than Jupiter.

Britney: This is how do planets work.

Walt: Requires eliminates biases in sample. Given likelihood of finding system like ours

Eric: We don't necessarily eliminate biases. We need biases we can understand. Probing parameter space not probed before. If you look at Kepler population see a population that doesn't look like solar system.

Walt: With all of our planets in half an AU, probability of finding transiting planets is X. If we see Jupiter transit in sunlike system, you can start to place constraints on probability.

Eric: Systems with hot, short period transiting planets.

Walt: Already finding Jupiters, Saturns, starting to find terrestrials. Putting our system into context is how system is organized. Is anything about how LUVOIR will do what it does going to give us answer to that. Putting us in context is if we see systems organized like ours or do we see systems organized like Earth?

Britney: I think we should find a different word than Diverse (re. a suggestion typed "The Diversity of Planetary Systems"). One thing to list off possibilities. Weeds vs system science. We can list off 9000 possibilities of things we can do. Doesn't help us understand. Connections are between this is the context. I think that would be helpful. Don't know what the word is.

Mark: What are planetary processes that we can understand systematically?

Britney: We need continuum of objects

Mark: Idea is if we study solar system we study ourselves

Britney: Mapping 30 Mercuries in detail not useful. Useful to know they're there.

Mark: Mapping the phase space of planets. Diverse points to that.

Vikki: Comparative planetary system science?

Mark: She wants a question.

Britney: Diverse doesn't have a point.

Mark: What are systematics?

Vikki: Processes rather than characteristics.

Britney: Architectures, how system built, atmosphere, chemistry. These processes.

Shawn: How do planets work?

Britney: What I said before. Is that too simplistic?

Courtney: How do planetary systems form and evolve?

Mark: Form too COR?

Bekki: We have that in here.

Britney: All arbitrary. They're always forming. You could use evolve if you want. That captures I think both.

Shawn: For, operate, evolve

Britney: How do planetary systems operate?

Vikki: Other part of exploration is to know diversity of systems out there. Speaks to formation processes.

Britney: Show collecting. Not telling you anything.

Vikki: You can minimize it to that but that's not intent. We want to find systems different to ours and understand why.

Britney: Coming from asteroid community I suggest that not be the strategy.

Mark: Let's table this. We're out of time. Main thing we need is not a title but text and figures. Start shooting figure concepts to GSFC figure folks.

Vikki: I can take lead on getting chapter 3 done. August 15 deadline going around? Do we work to that?

Mark: Let's be in seriously good shape by Aug 30. Goes out to review among advisors Oct 1st-ish. We talked about figures. What else?

Courtney: Dynamics would be great movie. Like one Kevin Stevenson put together. Mapping surface features, time dependent mapping.

Vikki: Not something we can uniquely do though.

Eric: I have idea for aperture vs awesome for escape. X axis aperture. Y axis stellar type. For escape observations, have to probe particular distance. Show what species, what escape rates you can probe as function of stellar type and aperture.

Mark: Sketch that up. Other thoughts?

Bekki: Figure I want to have is what you get for rest of system if you succeed in imaging Earth in terms of zodiacal dust, other planets in system

Eric: Is this mass, semi major axis figure?

Ravi: Angular resolution contrast for different plants.

Debra: Borrow heavily from existing reports for HDST and ATLAST.

Mark: Let's pause there. Everyone focus on getting text and figures in.

---coffee break-----

COR & PCOS interim report splinter session

Notes not available.

Design & Technology interim report splinter session

Notes not available.

Preparing for Architecture B

Matt Bolcar

- 3 IDL runs for coronagraph, LUMOS, ONIRS, empty fourth bay?

Kevin: Other than ONIRS how decided which of the two needed to be studied again? We might want to really ask ourselves which need another.

Julie: Honestly you will never fly a LUVOIR without HDI.

Matt: Pause for a moment. I have slides, then we have an hour for discussion. What are exactly instruments we want to study?

Laurent: Going through architecture A, which are easier to scale? Which studied in more detail?

Matt: Absolutely coronagraph. Must maximize science. "A" is Lamborghini.

Leonidis: Can we call it a Tesla so it's American?

Matt: Sure. B is Chevy Volt (laughter; slide says "Volkswagen")

Bertrand: I don't want to hear what HabEx is on that scale (laughter)

Dave: Smaller, less complex, friendlier LUMOS?

Kevin: It's extremely friendly!

Aki: I'm misremembering about the relative ranking. Gaps between instruments in vote I may be misremembering. Question I would ask to HDI and LUMOS leads is which instrument has to change the most to be on a 9 m?

Kevin: I don't expect LUMOS to change a lot. What will change is how much bay shrinks. My guess is LUMOS returns won't change much at all. Optics will change figures. Hoping we don't have to pick up extra bounces.

Shawn: Other way to look at it is there a way to study simpler or different approach. Coronagraph as to be self-consistent with telescope. Trades on table for coronagraph. Scales matter but are there alternative options we need to explore? Simpler HDI?

Kevin: Not LUMOS

Marc: Simpler HDI. Could go to critical not Nyquist sampling. Got two channels Maybe you say get rid of NIR. I recall main reason HDI is big and heavy is in 15 m that's a big beam and we had do all of those bounces to get it down into 6 inch filters. I think HDI scales straightforwardly.

Matt: Speaking personally we could pick either HDI or LUMOS and argue they scale down to 9m. Which we study comes down to which we think has most changes.

Aki: I feel weird with B with no UV capability.

Kevin: Based on LUMOS from A, if you change Bay side, this is something I can tell you how much will change in 2-3 days without taking everyone's time for another IDL. That's my hunch.

Brad: We can't do B without UV. COR will feel that's a stab in back.

Matt: Imagine a single instrument that does UV spectroscopy and have imaging channel for visible?

Brad: Is this another instrument?

Matt: Third instrument could be a mashup of LUMOS and HDI.

Aki: That might be most interesting thing to do. Feasible?

Matt: We have to be careful. Can't do 90 nm – 2.5 um in single channel.

Walt: If merge HDI with another instrument should go with optical NIR. Do it with ONIRS? Means sacrificing filters and FOV.

Aki: Imaging channel in ONIRS?

Matt: I anticipated this anyway. We need a guide camera anyway.

Shawn: Oh!

Jason: You guys didn't think of that?

Shawn: The atmospheric modeler didn't! Matt did!

Aki: If we didn't have an instrument with UV we'd use different coatings.

Kevin: no no we need IDL again.

Brad: first paragraph description for B, we can say you can count on another instrument not studied.

Aki: Have to choose coatings for that possibility.

Brad: This is not science driven decision.

Matt: All instruments for A equally applicable to B. Just need to be scaled.

Marc: Can I clarify: when we do science discussion for B, are we allowed to do things like stellar populations or high redshift galaxies, or 100 pc everywhere if we don't have HDI in B?

Aki: We just have to be clear about this. This was always an issue. Must be clear about tagging science cases with instruments.

John: All signature science cases will have curves for each architecture.

Dave: Why don't we study completely different instruments?

Aki: I don't want to completely throw out our plans over last year.

Brad: Scaling will provide insight. Only one truly different is coronagraph.

Marc: We came up with core science cases on exoplanets and COR side and elements are UV astrophysics, exoplanet characterization, high angular resolution things. Instruments all basically in this subset. Completely different instruments means a completely difference science case. I don't think you want that.

Dave: Ok

Shawn: safe to say we have to do scaling work on one not included in this (LUMOS, HDI)?

Matt: Yes first order optical design to say "does it fit in the box?"

Shawn: If that's the case, if time allowed and we did that sooner, that might help understand better how much the scaled down versions change

Aki: Going back again, we need a guider camera, I like idea of merging imaging channel into ONIRS. That seems like the easiest best of both worlds situations. Then we keep a LUMOS in there. Have imaging.

Shawn: May end up looking like coronagraph.

Matt: Third iteration is we do LUMOS and HDI and then a coronagraph. Because ONIRS is fiber fed spectrometer it may look very similar to one in coronagraph.

Courtney: If we can cover science cases

Matt: We put fiber fed spectrometer on coronagraph as well.

Courtney: Must preserve ultra high res capability. Fullfill HDI science goals that way.

Matt: I will write down for now include wide field capability in one of the instruments. I think something we should think about what makes most sense to put that in?

John: How does it impact guiding?

Matt: I think it will be fine. Must make sure FOV of imager big enough to see a bright enough star for guiding.

- Launch vehicle details: lift capacity is 10,000 kg
- Fairing dynamic envelope 4.5 x 10.6 m
- Observatory can weigh 6650 kg (~JWST!)
    - Instruments combined can weigh as much as HDI does RIGHT NOW!
    - 1330 kg
    - ATLAST 9.2 m telescope with no instruments was 7300 kg. ATLAST was not designed for mass

Shawn: Any obvious places you're aware of on telescope side of things to get us lighter?

Dave: Lighter optics!

Julie: Getting rid of BSF

Matt: BSF is the big thing. That thing is heavier than needs to be. Must survive launch loads and also allow for servicing. Those two things make it difficult. If you can get rid of structure after launch it, that helps. Make instruments structural.

Debra: When thought about A and B we wanted to make telescopes as big as can be to fit in fairings. We thought 9m telescope costs would scale down.

Matt: If SLS comes along we can certainly fit a 9m in that.

Brad: Another option we have is on orbit assembly

Courtney: Isn't this the safe architecture?

Marc: No. Wasn't 9 m telescope insurance against SLS not existing?

Dave: Let's not dismiss this. We don't launch a robot with a bunch of sticks. Could mean we have major sub-assemblies that have a simple interface that can be applied by vehicles that take them up there. Ways to think about this that can truly save money.

Aki: How does this make it less risky than A? Makes it more.

Brad: I wouldn't presuppose that.

Dave: We have prejudices that haven't been explored.

Brad: Need to make sure astronomers don't make engineering decisions. We need to get the science. Then we think about best way to get it on orbit.

Julie: Good point Brad. If this is prioritized by decadal, our job is to show it's scalable. We must show feasibility.

Brad: A possible outcome is that decadal could say not worth building a telescope < 12 m. Doesn't make dramatic change. We have to then figure out how.

Shawn: I think we should have a way to discuss this as a way to deal with future uncertainties. Try as hard as we can to fit B into single 5m fairing. If we get to point of fitting with thinner margins, this is way to discuss launch vehicle risk: two options. Trade up to larger rock, trade to two rockets.

Brad: Even if 9.2 fits in 5m fairing, doesn't give much science capability. Not to justify expenses.

Aki: Simples thing is to deliver telescope with empty bays

Kevin: Matt do you have sense of how mission impossible these masses are?

Matt: Keep in mind we're talking about instrument masses still 50% larger than NIRCAM. NIRCAM is pretty capable. We're a factor of 30% more mass than we need to be. Not crazy. We can find that. Not insane. But difficult. Approach for A is we gave them a blank check for mass. This time we go in saying we must save mass wherever we can.

Kevin: Slide in instruments like HST

Matt: Don't throw baby out with bathwater.

Jason: I picked brain of John Arenberg. Talking about how to approach LUVOIR from "let's minimize cost" perspective. He advised thinking about it as how much of JWST can we reuse? Close as you can get to evolving JWST just a little bit along at same dry mass. Instruments must be same mass. Think about it that way?

Aki: We did think about it that way for A even. Reusing JWST heritage a much as possible.

Jason: Good advice generally. More clear here for B. Case where you could draw really concrete connections.

John: The one thing I like from strategic stand-point is we strategically chose A and B based off fairing. I want to see similar to discussion on international partners is place in final report showing we did our homework. Cursory analysis of on-orbit to show decadal we've been mindful of these things. If we do homework to show ways around problems, useful for final report. Get input for people in industries.

Aki: In architecture overview chapters, had sections on design alternatives. Goes there.

Marc: Looking at old ATLAST 9.2 m. That 7200 kg number was just for the OTA not including spacecraft.

Matt: Don't think that's correct. That's an older study you're looking at.

Marc: Ok so you shaved 4 metric tons in four years. We're fine!

Shawn: Keep that diet going.

John: One hell of a nutrisystem

Matt: ATLAST studied in 2009 that included an instrument compliment. That was around 11000 kg total. What we did since but before LUVOIR dropped it. Not end of world, but we must be careful.

- 2 approaches for B: scaled down version of A. Easier to do.
- OR
- Treat B as brand new design. Purposely make different decisions to more thoroughly explore parameter space. (lots of nodding heads)

Marc: Include off axis?

Aki: Maybe?

Matt: OST doing 9m off axis. Can't fit into 5 m fairing.

Julie: Can't fit into fairing. Going to SLS.

Dave: I advocate for 2nd approach. Will allow us to use higher TRL elements. We don't have concept for edge sensor system to meet requirements. More mature and capable alternatives. Don't do same thing over.

Jason: Advice I was passing on from Arenberg was closer to second one. Evolution of JWST.

Matt: Enough distinct differences between JWST and us. Not quite same. Scaling form but not function of JWST.

Dave: You won't face challenges of B if just do scaling down.

Matt: Anyone here opposed to this approach?

(silence)

Aki: We should also poll STDT members not here as well.

- A was a 3 m anastigmat to provide big FOV but came at cost at large secondary obscuration and reduced UV throughput
- Recommends B be an RC design.

Julie: I was talking to Paul earlier. He has magnificent idea of allowing RC for just UV channel and corrective optics that allows everything else to be wide FOV

Matt: 2009 ATLAST was TMA telescope with on axis Cassegrain. Problem is in order to get good performance cassegrain focus FOV tiny. 10". Fine for coronagraph not LUMOS.

Kevin: On B, I think we will find that all of the things except HDI will be shrunk. Shrinking overall good FOV probably ok. 9m

Dave: We will discuss tomorrow with Mike Rogers.

Aki: I want to reiterate that this is going to be hard but don't panic. We probably can do it.

Matt: What's on the cover of Hitchhiker's guide? Don't panic?

Marc: Driver for TMA on A?

Matt: FOV

Aki: I guess I want to understand … is there really any chance we will have 4th empty instrument bay?

Matt: Potentially chance for 4th empty bay. We might have volume for 4 instruments maybe not mass

Olivier: Estimate doesn't include second generation instruments. Later you can increase mass. Empty bays not stupid.

Matt: Yes

Aki: We need to think at this point. Not decide. When you want us to decide on LUMOS vs HDI? What needs to be decided first and when?

Courtney: Coronagraph first?

Matt: Yes

John: Then we decide at Oct F2F the details

Aki: Telescope design?

Matt: I heard no opposition to RC.

Aki: RC it is!

Courtney: Also coronagraph most important instrument in some sense. Useful to have time later to figure out what may go wrong.

Shawn: Julie, what happened to IDL runs that were missed the last time there was a govt shutdown?

Julie: We're screwed. But it'd only be instrument #1

Matt: If push comes to shove then I'm ok canning May one and doing that internal. We shift everything down.

Aki: Neil, or any coronagraph people here, is that ok? Can we do first?

Neil Zimmerman: Still a lot of work to do on A…

Matt: We need to know bandpass, need to know – given everything on A – what is bandpass you want? What OWA, IWA? Explore IFS option. What res does it need to be?

Julie: Prioritize all. Prioritize channels.

Aki: Most of these are science decisions for exo working group.

Shawn: Two channels at least?

Matt: Yes

Mark: Two channels and IFS?

Bertrand: Chance we hear about fiber fed spectrograph approach tomorrow? I'm interested in hearing tomorrow.

Matt: Not a lot from design perspective. Technique mostly technique Dimitri Mawet came up with. We baseline in our design his scheme for aligning fibers. I can talk about.

Bertrand: Bandwidth?

Matt: Science is 15%.

Bertrand: At given time fiber fed accepts 15% bandwidth?

Matt: At one time. But may be able to be broader. I will make list of things we need in advance of coronagraph study.

Kevin: Other challenge is after telescope done both HDI and LUMOS must both internally figure out

Aki: Hardest decision to make quickly is fiber coupling

Courtney: I think we want to if we want to look for molecules in planet atmosphere using Snellen technique.

Matt: I still keep ONIRS separate in study. And then we discuss combining in text.

Aki: everything else to be decided can be decided except this.

Discussion on cutting off UV and everything > 2 microns for B coronagraph

Shawn: Dedicated telecon on this? With exo working group and coronagraph team

Aki: Yes. And soon

Shawn: In STDT telecon timeslot.

Aki: Second question I have: ready to go with telescope B? When do we have to tell you what coronagraph looks like?

Matt: Let me get back to you.

Aki: Makes architecture A easy in some ways. Easy for us. Hard on engineers. Now not so much.

Day 3 (Wednesday Aug 2, joint with HabEx STDT)

Jeff Booth: Welcomes both teams.

Brad: Please introduce yourselves again.

(people introduce themselves)

Joint meeting intro

Scott Gaudi

Want to give brief into to goals of meeting.

- Share tech assumptions and developments
- Agree on common assumptions for output for meaningful comparisons
- Identify common themes, sections, plots, text, etc
- Identify rep for each common section that will be responsible for continuity
- Strategize plans for reading and commenting on each other's reports
- Continue good-faith efforts to provide continuum of optinos, not competition

Suggestions for content:

- Difference between HabEx and LUVOIR
- State of field in 2030s
- Science
- Tech

- Common figures, themes useful.
- Not all general astrophysics scale smoothly with aperture. Breakpoints. Some things LUVOIR can do that HabEx can't. But many applications that scale nicely and we should highlight them. Continuum of options.
- Develop case for managing tech and bringing them to TRL 5 and to highest TRL we need by time mission ready to launch.
- He likes one of Ty's figure. Architecture independent. Shows SNR = 10 at 0.55 um for 12 m LUVOIR for a target at 12 pc, 5m HabEx 30 hours at 7 pc, etc
- Encourages people to show slide on difference between LUVOIR and HabEx. HabEx exploratory mission and LUVOIR a survey mission

Aki: Please don't call it a survey mission

Debra: We're also explorer

Aki: Surveying more stars not same as survey mission

Scott: Fair enough

- "Stop light we never finally converged upon"

- Vague cost slide "because we don't actually know the answer to this question. Not really our job to figure this out. It's the CATE's job to figure this out."

Shawn: Go back to tech slide? I have idea for something. Is this a slide we're presenting now?

Scott: No set aside until agreement

Shawn: In lieu of doing in near term might want to just say process two teams are going through to evaluate TRLs and working with independent groups to evaluate TRL levels missions are at and fed to various tech funding programs. Some language like that we can probably use

Scott: Not a bad suggestion

Kevin: I object to spirit of TRL stoplight plot. I see everything on HabEx slide enhancing and LUVOIR requires all enabling. I think we need more consensus

Scott: This is old version of slide. A new version is appropriate.

(some more discussion on this slide)

Scott: I want this to get our story straight.

Aki: Every time we look at this thing that's what happens. I think time to let this one go.

Scott: Whenever I show this slide people not involved love it. Maybe we need different version of it.

Aki: I hope you're not showing THIS slide with LUVOIR stuff we haven't agreed to

Scott: We agreed at one time

Matt: We agreed at one point but then diverged

Aki: On Ty's plot, nice to do but not quite right but doesn't take into account IWA/OWA. Not accurate yet.

Scott: I'm sure can be improved. But I like idea of it

Aki: I just checked with our own tool but it's not accurate. Need to work on that one.

Scott: I like because does indicate tradeoffs

Aki: Some colored bands to indicate bandpasses would be nice

Alan: Figure worthwhile if you make clear that it's approximate and move on with similar figure that has things you want

LUVOIR status: Science

Debra Fischer

"I want to highlight nice things that happened over past couple days"

- Cubesats to retire risks
- Architecture A done
- Accreted new international observers/interest/partners. Two want to contribute instrument concept study for appendix
- "Good time to look for friction points between what we're saying for LUVOIR vs HabEx"
- "killer app as we HabEx is how we can image Earth 2.0"
- discusses molecules we can detect
- She is uncomfortable with ExoEarth yield as a function of aperture plot. Wondering if LUVOIR should be showing plots that compare to HabEx and vice versa

Aki: (discussing the plot of the last bullet point) This is assuming a coronagraph for every single one. This is a 4m coronagraph comparison, not HabEx comparison (re ExoEarth candidates plot). This is for old eta-Earth. With new eta-Earth all numbers will creep up

Bertrand: Just detection or spectroscopy?

Aki: Partial spectroscopy. Just hitting enough spectra to tell if detected water

Shawn: This follows on earlier with spectrum. We have tools we've developed and these simulate LUVOIR. Adaptable for HabEx. Most easily for coronagraph case. Now Chris including starshade for yield

Bertrand: For HabEx we do broadband detection with coronagraph. Better IWA. 1 um spectroscopy we do starshade with same IWA at 1 um.

Shawn: Do we have something on agenda about simulations?

Debra: Really good one

Aki: Chris best apples-to-apples comparison. These not yields of real missions.

Scott: These not DRMs either

Shawn: This was not

Scott: I'm not uncomfortable with you showing this plot. Although yields a little bit low we aren't detecting dozens of planets with HabEx and that's just a fact

Aki: In a relative sense these numbers probably accurate

Debra: Discussion of precursor science, mass measurements, simulations all valuable.

Dave: What are doing to at least look at scalability of general astrophysics between missions? Should LUVOIR stuff inform capabilities of HabEx?

Scott: There are members of the HabEx STDT on working groups of LUVOIR and they've had several telecons discussing common science themes and identified a few common science themes. In breakout we will settle on 3-4 science themes scalable between different architectures.

LUVOIR status: Architecture

Aki Roberge

- Design of architecture A basically complete
- Not have mass margin for 4 instruments on B. Empty 4th slot. Planning for it to be serviceable
- "shout out to incredibly valuable tech development that has happened via WFIRST coronagraph. We should all be waving the flag for that more"

- LUMOS goes into FUSE bandpass “major upgrade of HST STIS but not really do it justice”

Kevin: I object that when people hear STIS they think low throughput

Aki: I’ll add a thing that it’s STIS but high throughput

- HDI Nyquist sampled at 400 nm
- ONIRS not yet through IDL and will probably change somewhat or quite a bit based on discussion yesterday. Maybe imaging mode in here. Res may come down but include imaging channel. Consider including high precision RV
- POLLUX study is concept that could serve as a support for future ESA contribution
- Can get good angle on the sun. Can observe Venus!!

Vikki: (re. observing Venus) Oh my god!

Matt: “Towards the sun not at the sun”

HabEx status: Science

Scott Gaudi

- Alina Kiessling is now deputy study scientist
- Characterizing a “handful” of exoplanet Earths
- Optimal means maximizing science yield while maintaining feasibility. “This is one of the ways we depart from LUVOIR”
- Adopting a conservative approach.
- “happy to characterize a handful of potentially habitable worlds.”
- Still want to enable a range of general astrophysics
- UV is difficult because dark and because UV coatings and detectors. Nominal cutoff around 250 nm.

Nick Siegler: is methane not recognizable?

Shawn: No

Giada: Not for modern day Earth. Earlier Earths it is.

Shawn: Cross correlation technique gives hope

- Two general astrophysics instruments. One to be given to foreign contribution.
- 250 – 1.8 um for high contrast mode
- stretch 90nm – 2 um

Rhonda: UV detectors may be at TRL 5

Scott: No TRL 2 technologies. Six enabling TRL 3 technologies need to be improved. Expect only two TRL 3 techs by final report

Kevin: On yield you showed different curves for starshade vs coronagraph. Same planets for both? Or different planets?

Scott: I think similar

Debra: have you gone through IDL?

Scott: Yeah we call that Team-X

Keith: Fairly analogous and came back again for second starshade look.

HabEx status: Architecture

Keith Warfield

- vector vortex 6 and lyot combination
- 4m on axis design

Nick: Assume SLS for baseline 4 m?

Keith: Baseline 4m went to SLS. Monolith telescope favors coronagraphy. Pushed us to 20 tons for telescope-spacecraft. Exceeds Falcon Heavy.

Nick: Other option hedge against SLS?

Keith: Even if we could make mass work off axis design doesn't fit 5m fairing. Need on axis and creativity to make it work

- starshade 80 m and 72 m designs "pretty much done"
- telescope design complete
- "last thing we want to tie down is getting our sensing story together"
- "we got ongoing questions about SLS. People ask is it really going to happen?"
    - "It's moving along."
    - They have built tanks, engines, tests in Utah, billions of dollars sunk in at this point
    - "From all appearances it is moving forward"
- considering 3 telescope options but most promising is off axis segmented design that Marshall put together, high heritage JWST design. "I would think of it ideally as only starshade application. Fast and on axis." Want additional work for Dave Redding for another design based on work going on at JPL.

Alan: Mission lifetime? Thruster reaction wheels?

Keith: baseline lifetime is 5 years with consumables for 10. But when we went to TeamX they said the thrusters used over 10 years. Something we'll have to consider. Will plan on servicing thrusters. Low level of propellant needed

Unknown person: Question about vibration isolation

Keith: Vibration isolation expert here later today. We'll do some comparative assessment in interim report. Contrast end to end performance product for final report. Interim report will show sufficient for the job.

Aki: Going along Alan's question. Are you guys planning to have second generation instruments or talk about at all?

Keith: The instrument bays are over here in this coffin-shaped thing on side. Coronagraph, starshade camera, workhorse camera, UV spectrograph under primary. All intended to be serviceable down line. Would like to complete primary mission science without servicing

Aki: Fixed or replaced? Can swap in a new instrument?

Keith: Yes but haven't worked out the details

Shawn: Another coffin?

Keith: Another coffin on side

Scott: There are constraints. Can't just do any instrument. Because of way M1, M2, M3 are.

Shawn: That's more clear when you see ray trace.

Scott: We had to make choices for packaging to get capabilities and still maintain volume constraints. Only can do certain beam to certain instrument.

Aki: ok

Nick: Comment that you built in flexibility where you can go with or without SLS. If want to reduce risk level can jettison starshade and work with coronagraph

Keith: OR another possibility is you work with coronagraph and bring starshade later

Nick: Part of reason why hybrid architecture was chosen because more easily de-scopeable. Can't take off coronagraph

Common technologies

Rhonda Morgan / Matt Bolcar

Rhonda: Matt and I have a session to talk about common technologies. I will offer two presentations on low order wavefront sensing and milestones and progress achieved by WFIRST. Also a talk about detectors and what the state of the art is.

HabEx-LUVOIR common detector briefing and update

Shouleh Nikzad

- Summary of detector baseline for LUVOIR
- Stefan done summary for HabEx
- Mentioned ultra low lose IR. “Need to unify terminology on what this means.” LUVOIR consensus HXRGs low enough. For HabEx talking about APDs
- EQ for single layer coatings achieve > 50% EQ
- Delta doped silicon arrays for high EQ, low noise, and stable response. Agnostic to architecture of detector
- Skipper CCD invented decades ago. Issues with readout time but working on it. Options for low noise UV and vis and up to 1 um
- New tech is quantum image sensor.
- NUV LUMOS for costing 8k x 8k CMOS
- Integrating visible rejection filters into SI array after it gets vacuum elimination treatment. Optimize in-band and also out-of-band rejection. Same level of rejection as with photocathodes
- EMCCD maturation: maturation via a couple of programs. WFIRST sprearheading a lot of this. Working with E2V for QE improvement. Testing on a balloon. Flight with Kevin France on CHESS (DD p-channel CCD → high radiation tolerance). With Walt, has funded rocket for EMCCD plan in 2019
- IR detector technologies:
    - Linear mode avalanche photodiodes
    - MgCdTe most promising
    - High gain and avalanche extremely important to have stability

Nick: When working with Bernie Raucher, he talks about not knowing limits of current detectors. Feels if you keep pushing on how noise can be reduced on various elements might be reasonable solution

Shouleh: Bernie did present that work. There is a possibility of it improving. Can get into more detail later. Had a limit. Why also looked at APDs. Always a chance that Teledyne will update ROIC design. Ultra low noise capability is need.

Bertrand: Comment on IR detectors. (someone) Mentioned that improved results by factor of 10 and publish soon

Shouleh: I've been in contact with Ian Baker. More results to come. Very optimistic about pushing gain higher while keeping dark low.

Bertrand: Balancing act. Want high gain but as gain goes up dark goes up

Low-order wavefront sensing

Fang Shi

- Zernike wavefront sensing. Put small modulation at focus of PSF. Interference between light being delayed vs not interferes and converts the phase aberrations at pupil into intensity variations on detector
- Have testbed that mimics flight design
- Line of sight error injected. 14 mas rms drift + CBE line of sight jitter at 600 rpm, 72 harmonic tones
- For low order wavefront drifts, move stage back and forth
- With disturbances on contrasts degraded to 10^-7, with closed loop have 10^-8. OF course for real one need better.
- Shaped pupil 4e-9
- Hybrid lyot 1.6e-9
- "bottom line is this thing works"
- LOWFS sensor demonstrated to level of 0.2 mas and low order mode to level of 12 pm rms

Bertrand: No Q but a statement. Fantastic work. All will benefit from this. Another step to put in report is to see how this performance translates to our systems. Many requirements might go up.

Fang: Know caveat for each system requirement for LOWFS different. Bottom line much tighter

LUVOIR and HabEx common tech

Matt Bolcar

- Fiber fed IFS
- 4 high level tech. Two in support of exo missions. TRL numbers being shown are our assessment numbers but in agreement of independent assessment
- Segment phasing and control. Implemented closed loop control between primary mirror segments and segment actuators. Closing loop at the segment helps maintain stability of primary mirror
    - "intent is to create virtual monolith"
    - 622 edge sensors for 120 segments
    - measure distance between edges, measure shear height, measure angle
    - "not trivial"

Bertrand: what is approach for controlling phase of individual segments?

Matt: LUVOIR architecture A is rigidi body controlled segments. Not warping mirrors. Segment surface figure is controlled by stability. Making sure they are stiff and thermally stable. Those spatial frequencies taken out by DMs inside

Dave: This afternoon tech splinter we go into different approaches and more on ones seen here on that

Matt: Yes Dave has a lot of talks lined up

- Fiber fed spectrometer described to Dmitri Malway
- Adopted WFIRST approach to being able to put in APLC, VV or any other type for coronagraph
- Beam splitter sends light into both detector and fiber

Dmitri: Basic lab demonstration of guiding. Used for interoferemetry for 20 years now. Instrument at Keck implementing this concept.

Bertrand: Any issue with beacon source reflecting into science fiber?

Dmitri: Need to run continuously for pointing stability.

- Little agreement on common tech so far
- Despite large overlap on science case very different approaches means v different tech solutions. Yet there may (or should) be common requirements on performance
- Example: LUVOIR and HabEx baselining EMCCDs in the coronagraph. Do we have same noise performance? Claiming same TRL? Leverage same architecture/design/packaging? If differences, why?
- Also both using coronagraph. Agreed that coronagraphs require stable wavefront. Diverge on magnitude of stability? Spatial and temporal frequencies of interest? Why diverging?
- “Not saying we should answer these today”
- identify performance requirements each mission shares

Aki: I think you hit nail on head. Exactly what we should be doing instead of arguing about details on stoplight chart. We need to talk about consistency and understanding on what we are trying to get tech to do. Crucial info must be consistent in reports and we need to understand it for our own sakes.

Nick: A point when you will be confident whether you need surface actuation on all segments? Big change

Matt: Gets to question of end-to-end modeling together and understand whether or not degrees of freedom not to correct the surface deformations. At GSFC doing stop modeling to see dynamic disturbance, thermal disturbance, find contrast. Decide if need more degrees of freedom. Question isn't whether we need this to achieve contrast. If we do that does it makes things easier in terms of INT and fabrication? Can adopt approach with less control but have to make things better or more control but be more relaxed.

Nick: What timeframe?

Matt: In next year probably. Probably the clog in the pipe to get Dave info he needs.

Kerri Cahoy: Is there a study available how the contrast performance is affected by targets, their magnitudes, and map of stars available next to them?

Matt: Aren't you working on that?

Kerri: Yes but anyone else looking?

Dave: Looking not just LOWFS but because we need higher spatial freq than what's spatially filtered by occulting spot also looking at out of band wavefront sensing. Tracking performance vs intensity. If you want give us a bright source in right spot…

Kerri: Want to motivate being able to do that

Dave: We can help with that

Bertrand: Difficulty is coronagraphs don't have same sensitivity to aberrations. That said some spatial frequencies should be consistent requirements. How to make sure enough communication between teams

Matt: Challenge is getting info in one place. Seen extreme stability requirements. I don't have solution of how. I haven't said how. We need to be better on communicating. Need to explain our methods. Folks like Neil and Laurent doing coronagraph designs. Things Dave doing.

Bertrand: Splinter sessions after lunch. Solar System and Gen. Astro merged

---lunch break---

Exoplanet splinter session

Notes by Giada Arney

Shawn: Let's talk about top level differences in approaches and science advantages conveyed so everyone understands were missions differ. Maybe talk a little about ways to coordinate

between interim and final reports broadly in general sense on science themes and if time talk about discussing specific assumptions you want to make.

Bertrand: Be conservative? Best current estimates?

Debra: I can't believe data we have now is really the answer which is that exozodi levels so high in these other solar systems would expect SS 1-3 zodis. Really 10-20?

Mark: assume lognormal distribution

Bertrand: LBTI results must be handled carefully. Likelihood curve. For 19 stars at moment we get zodi with measurement uncertainties.

Debra: Chosen for larger levels of zodi to make detection?

Bertrand: 29 observed so far with previously known far IR excesses. Concentrating on 19 stars with no previously known excess of any kind. Probably not time for details of how distributions derived but lot of layers of data processing. We have sets of data and showed underlying distribution of zodi brightness is log-normal. That's two parameters and you do a maximize likelihood profile estimate of 1 or 2 params. Mu sigma. Median is exponential of mu. Extra step is if you want posterior of median look at other parameters. In process of reconciling. Most likely median is 0 is what I get.

Shawn: when you analyze data you get difference?

Bertrand: Slightly discrepant results at moment. One might be right one wrong. Don't over-interpret LBTI curves so far. More coming up. Nothing I've seen so far tells zodis at 10 zodi level. At 95% confidence median zodi is smaller than 25.

Shawn: Same place with exododi as with eta-Earth with common dataset and different interpretation?

Bertrand: No. Statistical treatment. Get there in next few weeks. For analysis of current data.

Giada: Stars in zodi survey similar to types of stars that LUVOIR or HabEx would be looking at?

Bertrand: Yes. Actually what kinds of spectral types LUVOIR concentrating on? For HabEx two major objectives.

Debra: I have Chris star list on laptop.

Bertrand: We want to do solar type but also ALL of nearby main sequence stars. E.g. nearby A star unless has far NIR excess

Shawn: Similar for us. We don't set up explicit biases but we do have observational biases. Mode is in K's.

Exozodi JPL person whose name I didn't catch: If there are things you need to know that I can tell you, let me know and I'll find out if I can get it.

Bertrand: You asked me a few days ago if it'd make sense if LUVOIR HabEx make sense to get in touch with LBTI to help prioritize targets. Day or half day of discussion? Subset of LUVOIR team?

(nodding and agreement)

Shawn: common team members probably sufficient for this.

Bertrand: Should open to anyone interested. Probably in September.

Shawn: In few weeks estimates come together? Is that going to appear someplace? On arxiv? Website?

Bertrand: Steve would like to put numbers in table. We can circulate.

JPL person: We will be able to circulate

Bertrand: Steve wanted to include statement from LUVOIR and HabEx teams on why these measurements important. With larger aperture LUVOIR less sensitive to exozodi

Shawn: I propose we use that number if coming out in a few weeks for both teams on exozodi. We assume 3 exozodi

Bertrand: Chris shows even if you assume distribution of zodi science yield not too strongly affected. Case with all stars same and case with log-normal give about same results. 3 was a guesstimate.

Shawn: Should we use that number out of LBTI paper? For interim report?

Bertrand: Yes and by time we reach final report should have better estimate

JPL person: We will reach goal of 35 stars sometime after December

Leslie Rogers: what metric Chris DRM results insensitive to? Yield of detected plants? Characterizeability?

Bertrand: Some characterizeability in terms of time for spectra. Distance estimates only accounts for additional shot noise for exozodi. Not takes into account clumps and increased

confusion. We need to know at 10-20 zodi level if median zodi level that light. Clumps about as bright as earth

Bekki: How many targets has time series been done for?

JPL person: 13? 14?

Bertrand: Question is how many observed enough times to reliably estimate zodi level. Much less than that.

Shawn: Leslie, Bekki does this sound like a good way to go forward? Use this or interim report and update for final?

Leslie: Yes

Bertrand: Independent analysis of data would also be good

Shawn: Maybe presentation like we just had from Chris? Bekki work for you?

Bekki: Yes. Helpful to say something quantitative about disk structure. But this will help.

Shawn: Have section to talk about implications of uncertainty

Bertrand: won't tell us for sure what happens in visible where observing. We get IR. Depends on grain properties. Need WFIRST coronagraph for this ahead of these missions

Eric: Do you need to pick a nominal value that's reasonable but also consider same worst case scenario? 10 zodis?

Bertrand: how many values do we adopt? Which one? Most likely? 95% confidence?

Shawn: need text to discuss

Debra: Tech note on zodis to share between teams

Shawn: Chris presentations useful. Something like that would be great

Mark: Ideally you have him do it multiple times for mean and plus/minus a sigma.

Bertrand: Confusion bigger issue than zodi level. Clumps challenge

Shawn: Explain that challenge in report. How we word the issues

Debra: LBTI best way to keep mitigating this risk? Suborbital?

Bertrand: experiments limited by background issues. Detector behavior. Can't solve

Debra: We'll learn it on sky then?

Bertrand: LBTI gets 35 stars. Even if double get factor of two on uncertainty.

Doug Hudgins: Does it matter if answer is 12 zodis vs 6 zodis? Makes difference in telescope design?

Bertrand: HabEx most affected. If upper limit on median zodi is smaller than 10 we're good. Two things can come out of survey. Statistical info on median. Second is per individual target what's happening

Debra: Or as function of spectral type, age

Bertrand: one thing that happened with Keck Nuller, still we were able to identify useful trends. Strong correlation between lot of dust far away and level of exozodi in center. If can confirm that trend with LBTI useful. Can predict what a particular star will have. Value in following up individual targets. Making sure we didn't miss perpendicular disks.

Debra: I didn't even know boundary where zodi doesn't matter

Bertrand: Chris simulated 4 m telescope in 2012 looking at solar system analog with Earth with different levels of exozodi. In each case trying to extract point source of Earth and see if can see it. At 20 zodi brightest thing you extract is clump, not Earth. How we came up with rough number.

Giada: Need to think about distinguishing planets from dust clumps? We've been thinking about stars vs planets with colors

Bertrand: Yes good idea. Spectrum should be smooth

Debra: Cold black body.

Bekki: Multiple epochs you can see not moving at Keplarian velocity. If you see something you can blame it on can see if in right position. Case where planet captured into resonances and clumps outside? In some cases multi epochs help

Shawn: Bertrand and Bekki communicate common text between reports on this?

Bekki: Sure

Debra: Such an interesting publication too

Shawn: Move on to occurrence rates, eta Earth, habitable zones and other zones. Someone should summarize what Chris presented to two teams. Not Chris he's on vacation.

Debra: He took 25% eta Earth value from literature

Eric: I worry about doing that. Dodgy methods in literature

Shawn: For HZ Chris has used conservative HZ on x axis and 1.6 on y axis upper end for size. On lower end used the cosmic shoreline. Scales with distance to star.

Eric: Chris calculates eta Earth himself?

Shawn: Using SAG 13 occurrence rates. Second derivative of occurrence rate with regard to semi major axis and size.

Leslie: Completeness and recovery tests not recovered

Shawn: SAG 13 numbers extremely defensible

Mark: A construct we use. Doesn't matter

Eric: There's physically right and then process right. Those SAG 13 power laws worry me. Assumes radius and period separable power laws. Foulton et al not what you see. If fit power laws to whole population you could wildly overestimate. Factor of 2-3.

Debra: Better way to do it?

Eric: Best I can imagine now is something like Burke et al 2015 but limited to only things smaller than 1.6 radii and if you go beyond 100 days you don't need to worry about planets being stripped sub-Neptunes.

Debra: So 100-200 days fine?

Eric: Yeah and my impression from Kepler meeting is with new DR 25 candidates they will have large error bars but have meaningful constraint for actual Earth analogs for G and K.

Debra: Timeline?

Eric: I got from Jesse Christianson. Next year…

Debra: But for interim report wouldn't be crazy for us to use existing values.

Eric: But we must consider worst case scenario as well. E.g. 10%. Show how robust we are against that

Shawn: 10% relatively easy because we've been doing that. Is everyone ok with that? Simulations with .1 and a second set with 0.25?

(general agreement)

Bertrand: Scott and Sara not here. Maybe different opinions. But I think they might agree with this idea.

Eric: Joint radius period distribution worries me

Leslie: I think given Burke analysis in 2015, they've done most careful job of characterizing systematics. Still assuming broken power law distribution and multiple periods. Even with updated DR 25 looking at planets at edge of sensitivity. Will be very sensitive to the model assumptions made. Any type of power law assumption and characterization of completeness

Shawn: Speaks to number in HZ?

Leslie: Speaks to overall fitting of distribution dLog Period/d Log Radius

Eric: (showing Figure 8 of Fulton et al)
Issue of completeness at Earth end
For hot things see occurrence rate going down in size
No real earth analogs in sample? Maybe hot stripped Neptunes?

Leslie: So far one of lowest estimate of eta-Earth from Dan Forman Macky. Gaussian processes. Reason why lowest is when you try to extrapolate eta-Earth beyond where data provides constraints. Someone should do with updated DR 25. Should give lower limit. It really is using opposite extreme in terms of how flexible model is and how much you allow planets outside categories of interest.

Mark: What did Dan get?

Bekki: 2%

Shawn: .02 plus or minus an order of magnitude or something

Bertrand: Why flexibility drops estimate?

Eric: radius and size distribution not independent of each other. His model implicitly allows for that

Bekki: At least one person is redoing this

Shawn: we just had discussion of how different treatment can be as low as 2%. Is that too low? Does using 10% cover those concerns. There's a science question and also a perception question. If we go with 2, 10, 25%, people will assume 10% is the reasonable one

Bekki: We could do 100% as well.

Shawn: We could take Wes Traub number of 1.05

Bertrand: Let LUVOIR look at 2% case. I'm not gonna do that (laughs)

Eric: my impression from Kepler meeting is number of new DR 25 targets will change significantly

Bertrand: when you say will change significantly do you mean error bars or mean estimate?

Shawn: Error bars will get smaller

Eric: Based on the number of new planets I saw I imagine upper limit is not going to change but lower limit might be in 5-10% range.

Debra: There's a lot to do before interim report. 10-25% is defensible. We can have words that it will be revised in next year.

Shawn: We need really good justification for anything else but those numbers. If we have good justification, we should make sure SAG 13 incorporates this method.

Bertrand: 10% for all spectral types?

Eric: Not for M dwarfs

Shawn: FGKs

Bekki: M dwarf numbers more secure

Shawn: I suggest one eta-Earth for FGK and one for M dwarfs. Dressing et al is good for M dwarfs. 30-ish percent. Now overall occurrence rates.

Debra: Neptune-like, Jupiter-like etc?

Shawn: What are categories going to be? Two teams don't have to agree?

Debra: Why not?

Shawn: Once we define those types how do we estimate how often they occur. Let's talk about the boxes just like HZ boundaries and how we estimate how often things fall in those boxes.

Bertrand: Diversity of planets not just radius, distance.

Shawn: Place Chris started off proposes boxes. Like HZ based on size and distance from host star. Doesn't include things like composition. We try to figure out some way to divvy up phase space to predict significant differences in future spectra. Best thing we came up with is rockys, gas giants, tweeners. Separation from host star is condensation of different cloud layers. When you form new cloud deck you trap that gas so remove its affects on spectrum. Think something like breakpoints. We took very simple climate model Parmentier model and Eric Hebrard calculated separation distances where clouds condense as you move farther out.

Eric: You don't need to worry about gravity effects?

Shawn: I think that's included. This is impacted by composition like C/O. We did couple simulations. That doesn't have huge impact on the boundaries. This is like HZ. It's a series of theories bound to be wrong in one if not many ways. But we can draw box to count inside of.

Eric: correlation between mass and radius that's a small enough effect that you can draw equilibrium temperature line

Shawn: We simulated planets differently for each size bins but not multiple sizes within bin.

Leslie: In mass radius space, if you interpolated between earth and Jupiter, 1/r^2 = constant (?). Pressure defined by transit depth doesn't change as much as might expect.

Shawn: You all in favor of cloud condensation as physical process used to divide between planet types?

Leslie: I'm in favor

Bertrand: Should also be consistent with albedos

Leslie: Albedos depend on host star

Bertrand: Good point. Not changing right now.

Shawn: Chris using model from Kerry to calculate albedos. Leslie you say we should make sure include spectral type.

Leslie: Taking into account defining HZ around M dwarfs. Kerry should be able to generate. (albedos for different star types)

Eric: Aomawa Shields done work

Giada: Not quite same work we're talking about here

Vikki: Diversity of planet types tricky. Simplistically higher albedos depending on which aerosols form. Depends so much on actual bulk composition of planet, physics. Interior and exterior higher albedos. Venus aerosols and outside you get icy surfaces and water clouds.

Eric: Worried about stripped planets

Giada: Not many likely to be stripped planets in our sample due to IWA

Shawn: Planets in our sample not likely stripped as we don't do a lot of M's

Debra: Stars within 10 pc a few 100 stars put in random populations. Show what we detect? Can include info about zodi.

Shawn: For final report? Not interim?

Bertram: Chris done some?

Shawn: Spectral libraries of spectra, based on planet population statistics

Now there is a discussion of "goodness of spectrum" which is where you lose ability to detect different molecules at different distances, IWAs. Also integration times. I was participating in discussion so no detailed notes here. Basically Vikki and I were saying that your main deliverable is "how well do I understand this planet" is different from "do I detect this planet?" And the information you are able to get from any individual planet varies with both planetary semi major axis and also distance of that planetary system. The types of filters you will have access to for characterizing planets depends on these parameters. Some percentage of planets you have access to you will never be able to characterize well with LUVOIR or HabEx. Interesting to think more carefully about the cases where you can say a lot more about the planets.

Discussion of pyramid filter. How many stars can you search for planets (just detectability); Rayleigh scattering; etc.

Eric: I wouldn't want see doing that comparison but explicitly separating impact on difference science cases. LUVOIR will have advantage for non-habitable cases. But for habitability case may be closer.

Bertrand: Have to show a pyramid for each planet type

Shawn: I was going to suggest we have follow up discussion to draw layers of pyramid but maybe we have follow up meeting of exoplanet parts of teams in next few weeks. Start to crystallize as we start to do writing. From HabEx side very little written. I know this because I haven't written anything.

Bertrand: I have viewgraph that talks to this pyramid…

Leslie: Some of this might get into actual operational program for each observatory. Time required for each follow up will be architecture dependent. Ordering of pyramid in terms of how impacts operations may be different.

Shawn: Pyramid might be done in parallel. Broadband images of X systems and can search for planets in same number of systems. Nested in that is what Leslie thinking about. She thinking about auxiliary information. I think her group thinking more than either of teams.

Leslie: People comprising team includes Shawn and I, Kerry, her postdoc Owen, Eric Nielson, Karl S, Peter P, Scott G. Peter working on doing a DRM type simulation similar to Chris but for potential ground-based RV leading up to HabEx. Some simulated radial velocity constraints on various categories. Optimistic and less optimistic scenario. One aspect his working group doing. Eric Nielson along with Owen and Kerry for grid of types of planets doing some simulations to see for various assumptions how many observations we need to get certain level of precision on orbital semi-major axis, eccentricity, orbit average incident flux on planet. Evan working on that as well from a forward modeling aspect and how to account for info in terms of planning revisits. Karl writing section on impact of precursor imaging: identifying confusing background sources.

Shawn: Revisits for orbit determination we (LUVOIR) haven't been talking about much. We're hoping to do with astrometry

Leslie: Eccentricity one of the things Eric working on

Shawn: Debra you think someone from HabEx working group should present this to LUVOIR?

Debra: Yes that'd be great

Bertrand: Chris simulated orbit determination roughly. E.g. How many planets can be observed six times with accumulated completeness above 4.

Leslie: 4 motivated by Eric Nielson orbital retrieval. With 4 astrometric detections you can retrieve orbital semi-major axis and eccentricity

Debra: How does timing of observations matter in terms of phase coverage?

Leslie: We've discussed at qualitative level. Eric hasn't fully simulated. Taking random phases or fixed cadence. Evan's work will hopefully address.

Evan Morris: I'm working on observing a monte carlo of planets and following around orbit at different cadences to see not just what gets completeness but also constrain inclination and semimajor axis. See what decrease in error is

Debra: if have planets with different periods, we sample long period one poorly. Can't retrieve it. What am I missing?

Leslie: As long as you cover a third of an orbit you can do ok. Things improve when you cover an entire orbit and have extra constraint on period as well. Based on Eric's initial simulations we set generous long period cut on no more than 3x mission duration. We may want to shorten a bit.

Debra: Always single planet systems?

Leslie: Yes. Chris also thinking about planet confusion.

Bertrand: Requirement to detect all planets with minimum mass.

Debra: I love idea of making game out of this. Assign random properties and then you say pick you stars and see what you can recover

Shawn: First thing you mentioned Leslie is universe of planets we know of

Leslie: Chris and Peter working together on that. Part of goal to eventually tie that into Eric's orbit retrieval work. We will have more detailed answer to how much you can decrease number of revisits to constrain orbit.

Shawn: Good to incorporate into both reports. Who doing that section of LUVOIR report?

Bertrand: (shows example of pyramid) Goes from detection to number of Earth twins for which you determine orbit, earth twins do characterization in visible only, then you can extend to UV, then you can extend to NIR

Discussion on "can I detect it?" is not main science goal. Characterization is main science goal. But we have to figure out fiducial points. Oxygen? Water? What else? In report should discuss though not go into detail the top level things we would do on the most interesting targets (e.g. look for glint, phase and seasonal variations.

Statistical estimates done for just 6-7 detection

Summary: 2 values for Eta Earth. Tech note on zodis. Different types of planets.

Shawn: SAG 13 numbers for planets beyond HZ? (general agreement)

General astrophysics splinter session summary

Scott Gaudi

- Hubble constant
  - Only a dozen or so galaxies for which we have Cepheid distances and Type 1a SNs. If can go out with larger aperture and get individual Cepheids into Hubble flow then get more galaxies with Type 1a supernova and that link stronger. LUVOIR larger aperture so can get out further. Cepheids are hot stars so going to blue useful (why this is better than JWST)
- Dark matter properties in dense environments
  - idea to probe dark matter power spectrum to small scales. Dark matter not cold at small scales? Central structure of dwarf galaxies dark matter dominated should be very cuspy but often appear to have a core. Can you do with baryon physics? Maybe you can do with dark matter being something else. Find low surface brightness, dark matter dominated galaxies in local group. Find stars in them, measure RVs. Might tell something about properties of dark matter. Also can go fainter and smaller mass and further with larger aperture.
- Lifecycle of baryons
  - quasars or AGN as backlights to foreground galaxies and probe circumgalactic medium. Missing baryon problem in local universe where roughly half of baryons missing compared to overall cosmic accounting. Thought to be warm or hot IGM. Not a lot of probes of this gas. If you can go to fainter and higher res you can probe more halos and look for gas using various species. Further in uv can get more and more absorption lines. One argument/reason for going to UV. We both have instruments that can do that. Faintness of QSO you can use depends on aperture.
- For each of these, common assumptions and calculation methodologies are needed for consistent predictions

Solar System splinter session summary

Scott Gaudi

- Exospheres of planets
  - atmospheric escape long standing problem poorly understood
  - Mars particularly strong case
- D/H ratio in comets “where did Earth get its water?”
- Searches for small KBOs. “They do move so you can’t just expose forever”
- Plumes/jets from icy moons
- Aurora
  - Giant planets
  - Satellites

- Small body volatility versus heliocentric distance
- High spatial res of small bodies
    - Satellites, impact craters, etc.

Debra: Also considering 30-m telescopes from ground?

Britney: These are ones 30-m's can't do

Karl: Question on Europa plumes. Europa clipper coming up. Want to know what our science is in addition to that

Britney: Clipper does a flyby every two weeks. Not always able to view Europa. Geysers not always on. Whether clipper is there or not can do obs from ground not from spacecraft. Continuing on following missions going to happen. Surface change and other dynamics can't be looked for without this capability. 2022 launch. 2026-2029 arrival at Jupiter. Two years later prime mission of two years plus. Maybe contemporaneous. Large LUVOIR you get 10 km or better res on surface. You can look for surface change to figure out where to put a lander. Gets 42 flybys in prime mission.

Scott: Flybys to not spend too much time in Jupiter magnetosphere

Britney: Yeah but also return more data since not in Europa eclipse at that time

Aki: How are you going to handle these in your report, Scott? Solar System chapter? Boxes?

Scott: Subsection of solar system. Common topics either exact text in reports or boxes we call out or pretty figures that scale with aperture or maybe both.

Walt: One other thing is the pre-science you get by having bore sighted focal planes for exoplanet systems for very long times. Can do deep fields far deeper than anything we've done before for every target.

Exoplanet splinter session summary

Giada Arney

- Lots of discussion on eta-Earth but people generally settled on using SAG-13 and 10% as two values for FGKs for "median" and "conservative" cases, plus Courtney's work for M dwarfs for that population
- Scott was concerned about changing eta-Earth values between interim and final report. General consensus seems to be to wait for the new estimates to come out and then decide what to do.
- Lively discussion on the "pyramid filters." Scott Gaudi seems to be suggesting a very simple pyramid for detection and characterization (two tier pyramid). LUVOIR scheme may be more complex. Possibly need a flowchart in addition to a pyramid. Scott

concerned about going down rabbit holes. But at least discussing the challenges is the most honest approach since planets are complicated
- Lots of interest in exozodi and when we'll get better values. Aki not concerned about clumps since they have different colors/spectra compared to planets.

Tech splinter session summary

Dave Redding

- VV coro design
- Other coronagraphs
- Small secondary 9m LUVOIR
- Thruster RCS
- MET
- Edge sensors
- Concurrent WFSC

Wrap-up discussion

Karl: Question for co-chairs of studies. Lots of things we want to coordinate. Nice if list of those to remind us all. Interested in also coordinating discussion of precursor observations.

Shawn: At risk of giving us more work because chairs and study scientists busy what if cross team members assemble that list? Me, you, Olivier, and Chris is de facto.

Scott: Lee a little busier at moment. Lots of decisions to coordinate need to actually coordinate. I think starting off with list is helpful. Can you start assembling list tonight? Other thing I recommend is find a point person of whoever is writing that section of report and coordinate with whoever is writing that for the other team.

Aki: To make easier, let's swap outlines. Our outline has name assignments on who is doing what.

Scott: Give outlines to Karl and Shawn. We have to actually fill outline first. LUVOIR folks you're done we're just getting started.

Aki: By some definitions of done.

Scott: Well you're done with your meeting. For leads of working groups also onus on them to make sure communication happens as well. Between those three ways of making sure these coordinations happen hopefully have bases covered. Other suggestions about coordination? Karl you mentioned topic we missed is precursor obs.

Aki: Let's read document first and then joint telecon in a few weeks.

Scott: Leslie mentioned LUVOIR team not yet thought about auxiliary information. Auxiliary info has biweekly telecons. If someone from LUVOIR wants to join let us know.

Karl: I'm on that already.

Scott: Other comments?

Aki: Drinks?

Scott: Useful we settled upon value on eta Earth. Kind of amazing. Other good decisions about coordination made. Thank you.

Debra: Thank you everyone

Aki: Thank you JPL and Jeff Booth for lovely hosting as usual. We don't get Brie at GSFC.