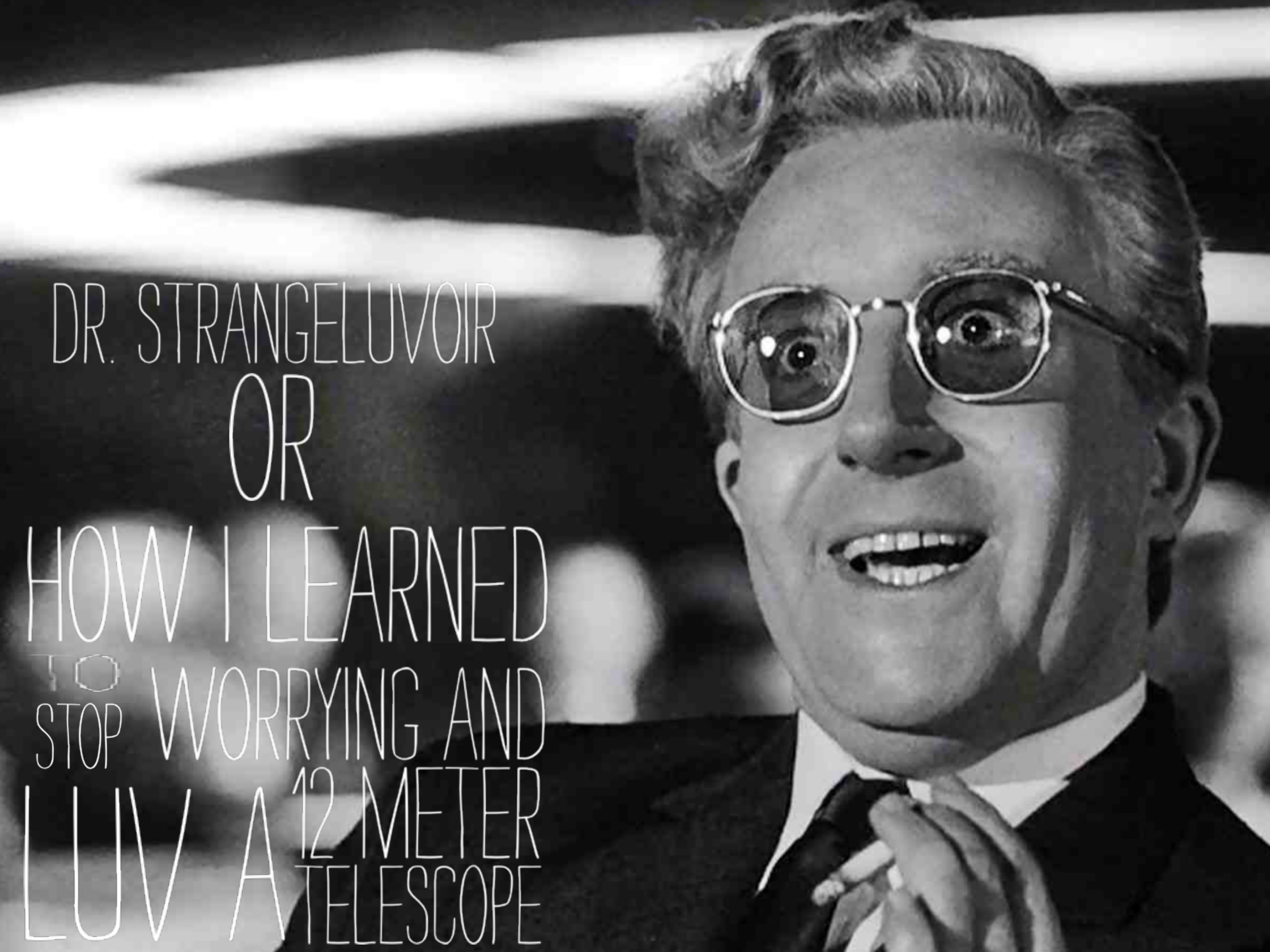
Twenty years from now you will be more disappointed by the things that you didn't do than by the ones you did do. So throw off the bowlines. Sail away from the safe harbor. Catch the trade wind in your sails. Explore. Dream. Discover.

-H. JACKSON BROWN

LUVOIR F2F, AUGUST 18 2016

COSMIC ORIGINS SCIENCE WITH LUVOIR


DR. STRANGELUVOIR
OR
HOW I LEARNED
TO STOP WORRYING AND
LUV A 12 METER TELESCOPE

THANKS GO OUT TO

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- STDT members who submitted quicksheets or more

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- SWG sub-group community members who answered the call

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- SWG sub-group community members who answered the call
- International contributions

HISTORICAL POINT #1

NO MATTER WHAT YOU COME UP WITH, LYMAN SPITZER ALREADY THOUGHT OF IT

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III. Astronomical Research with a Large Reflecting Telescope

The ultimate objective in the instrumentation of an astronomical satellite would be the provision of a large reflecting telescope, equipped with the various measuring devices necessary for different phases of astronomical research. Telescopes on earth have already reached the limit imposed by the irregular fluctuations in atmospheric refraction, giving rise to "bad seeing". It is doubtful whether a telescope larger than 200 inches would offer any appreciable advantage over the 200 inch instrument. Moreover, problems of flexure become very serious in mounting so large an instrument. Both of these limitations disappear in a satellite observatory, and the only limitations on size seem to be the practical ones associated with sending the equipment aloft.

While a large reflecting satellite telescope (possibly 200 to 600 inches in diameter) is some years in the future, it is of interest to explore the possibilities of such an instrument. It would in the first place always have the same resolving power, undisturbed by the terrestrial atmosphere. If the figuring of the mirror could be sufficiently accurate, its resolving power would be enormous, and would make it possible to separate two objects only .01" of arc apart (for a mirror 450 inches in diameter); an object on Mars a mile in radius could be clearly recorded at closest opposition while on the moon an object 50 feet across could be detected with visible radiation. This is at least ten times better than the typical performance of the best terrestrial telescopes. Moreover, in ultra-violet light the theoretical resolving power would of course be considerably greater; ideally an object 10 feet across could be distinguished on the moon

Spitzer, 1946

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Spitzer, 1946

COSMIC ORIGINS

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NASA 2013 Roadmap

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NASA 2013 Roadmap

COR WITH LUVOIR: FROM THE BIG BANG TO BIOSIGNATURES

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COR SWG Subgroup	Science Driver	STDT or Community (*) Lead	INSTRUMENTATION NEEDS					
			UV IM	UV Spec	O IM	O Spec	IR Im	IR Spec
Cosmology, Large Scale Structure, and Dark Matter	DM Distributions from stellar motions	Tumlinson via HDST report			✓		✓	
	DM: Strong lensing	???, Oguri*	✓		✓		✓	
	DM: Dwarf Galaxy Cores	Tumlinson (via HDST report)			✓		✓	
	Galaxy LF evolution	Finkelstein*, Shiminovich	✓	✓	✓	✓	✓	✓
	Lyman Continuum escape	Calzetti (for dwarfs), Finkelstein*, Teplitz	✓	✓	✓	✓		
	Distance ladder foundations	Scowcroft*			✓	✓	✓	✓
	The FUV and EUV background	O'Meara, McCandliss*, Shiminovich	✓	✓				
	Supernovae	Graham*	✓	✓	✓	✓	✓	✓
	IGM: tomography, power spectrum	O'Meara		✓		✓		
	IGM: thermal and ionization eq. of state	O'Meara, McCandliss*		✓		✓		
	IGM/CGM imaging the cosmic web	Schiminovich	✓	✓	✓	✓		
	Near field cosmology: phase space of LG stars	Tumlinson			✓	✓	✓	
	Reionization: mapping sources	Ouichi* (for galaxies), Finkelstein*			✓	✓	✓	✓
	Testing gravity	???	✓	✓	✓	✓	✓	✓
	Sandage Test	O'Meara, Schiminovich		✓		✓		
	Helium reionization	O'Meara		✓				

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	CGM: gas inflow and outflow, baryon cycle	O'Meara, Gallagher, Tumlinson*, Matsuoka*	✓	✓	✓	✓	✓	✓
	Galaxy structure evolution	Postman, Teplitz	✓	☐	✓	☐	✓	☐
	Galaxy SF evolution	Teplitz, Shiminovich	✓	✓	✓	✓	☐	☐
	AGN outflows	Tremonti	☐	✓	☐	✓	☐	☐
	SMBH demographics & evolution	Peterson	☐	☐	☐	☐	☐	☐
	AGN accretion disks	Peterson?	✓	✓	✓	✓	☐	☐
	Nearby galaxy masses: proper motions	Tumlinson (consult with van der Marel)	☐	☐	✓	☐	✓	☐
	Galaxy masses: dynamics/ kinematics	???	☐	☐	✓	✓	☐	☐
	Star forming regions at z>=1 & Galaxy ISM evolution	Rigby, Teplitz	✓	✓	✓	✓	☐	☐
	High redshift galaxies	Finkelstein*	☐	☐	✓	✓	✓	✓
	AGN-stars interactions	McCandliss*	✓	✓	✓	✓	☐	☐

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Stars, Stellar Evolution, and the Local Universe	IMF: Microlensing	Tumlinson (via HDST report)	☐	☐	✓	☐	✓	
	IMF: Origin	Calzetti, Gallagher, others*	☐	☐	☐	☐	☐	
	SF histories of nearby galaxies	???	☐	☐	✓	☐	☐	
	Massive stars in the MW and nearby galaxies	Evans*, Garcia*, Barstow, Nota	✓	✓	✓	✓	☐	
	Environments of planet assembly	France, Pascucci, Fleming*, Padgett, Gomez de Castro	✓	✓	✓	✓	✓	
	Protostellar outflows & jets	Schneider*, Herczeg*, Padgett, Gomez de Castro	✓	✓	✓	✓	✓	
	Origin of elements heavier than Fe	Roderer*	☐	✓	☐	✓	☐	
	Nearby Stellar Populations	Larsen*, Barstow, Padgett, Nota	☐	☐	✓	✓	☐	
	Bulk composition of exoplanets via WD obs	Gaensicke*, Barstow	✓	✓	✓	✓	☐	
	WD mass-radius relation	Barstow	✓	✓	✓	✓	☐	
	Neutron star eq. of state	???	✓	✓	✓	✓	☐	
	Population III	Roderer* (for metals), ???	☐	☐	✓	✓	✓	
	Transient stellar progenitors	Tumlinson via HDST report	✓	✓	✓	✓	✓	
	Proto-planetary, circumstellar disks	France, Pascucci, Fleming*, Padgett, Gomez de Castro	✓	✓	✓	✓	✓	
	Feedback & star formation	Tremonti	✓	✓	✓	✓	✓	

COSMOLOGY, LARGE SCALE STRUCTURE, AND DARK MATTER

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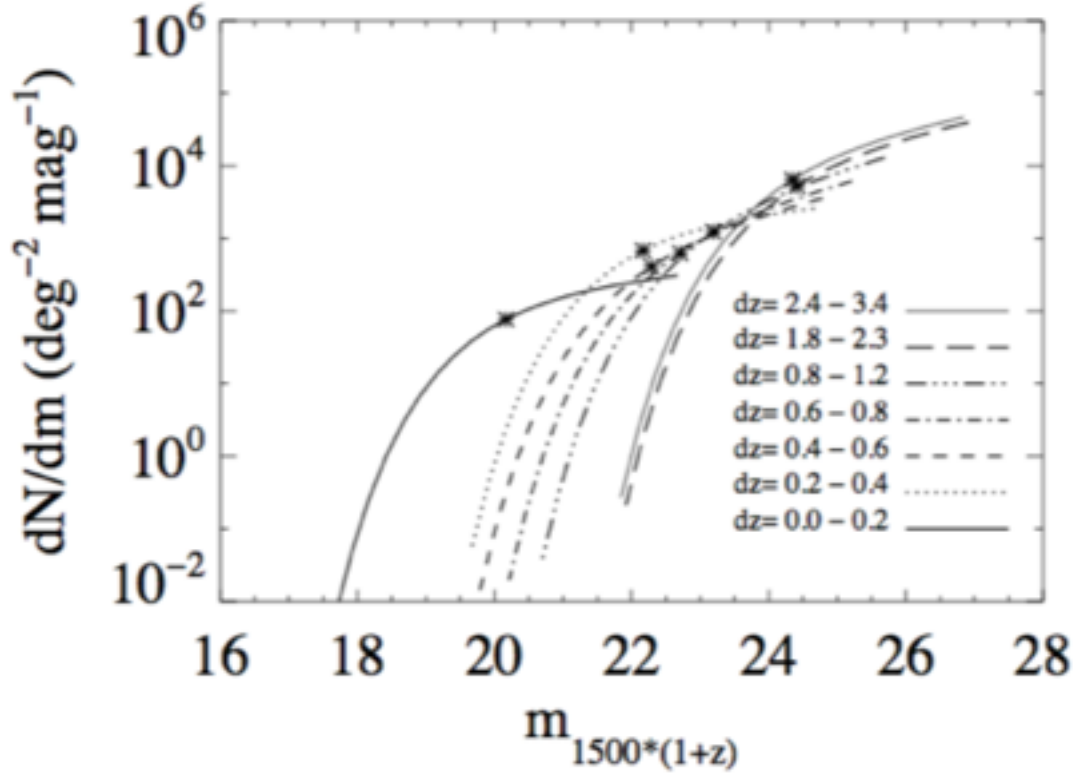
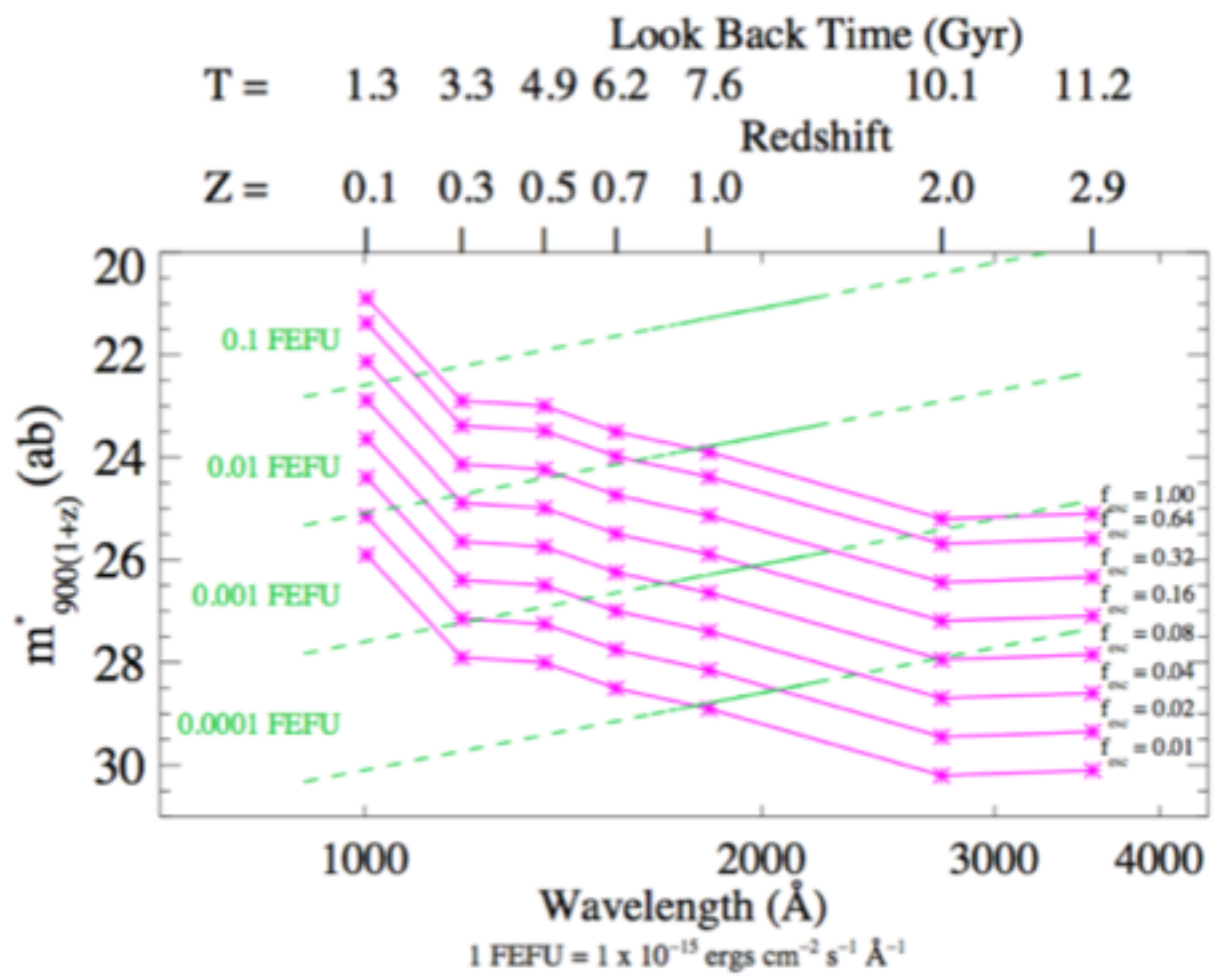
- The evolution of the escape of ionizing radiation over cosmic time (McCandliss)

KEEP THE LUV IN LUVOIR!





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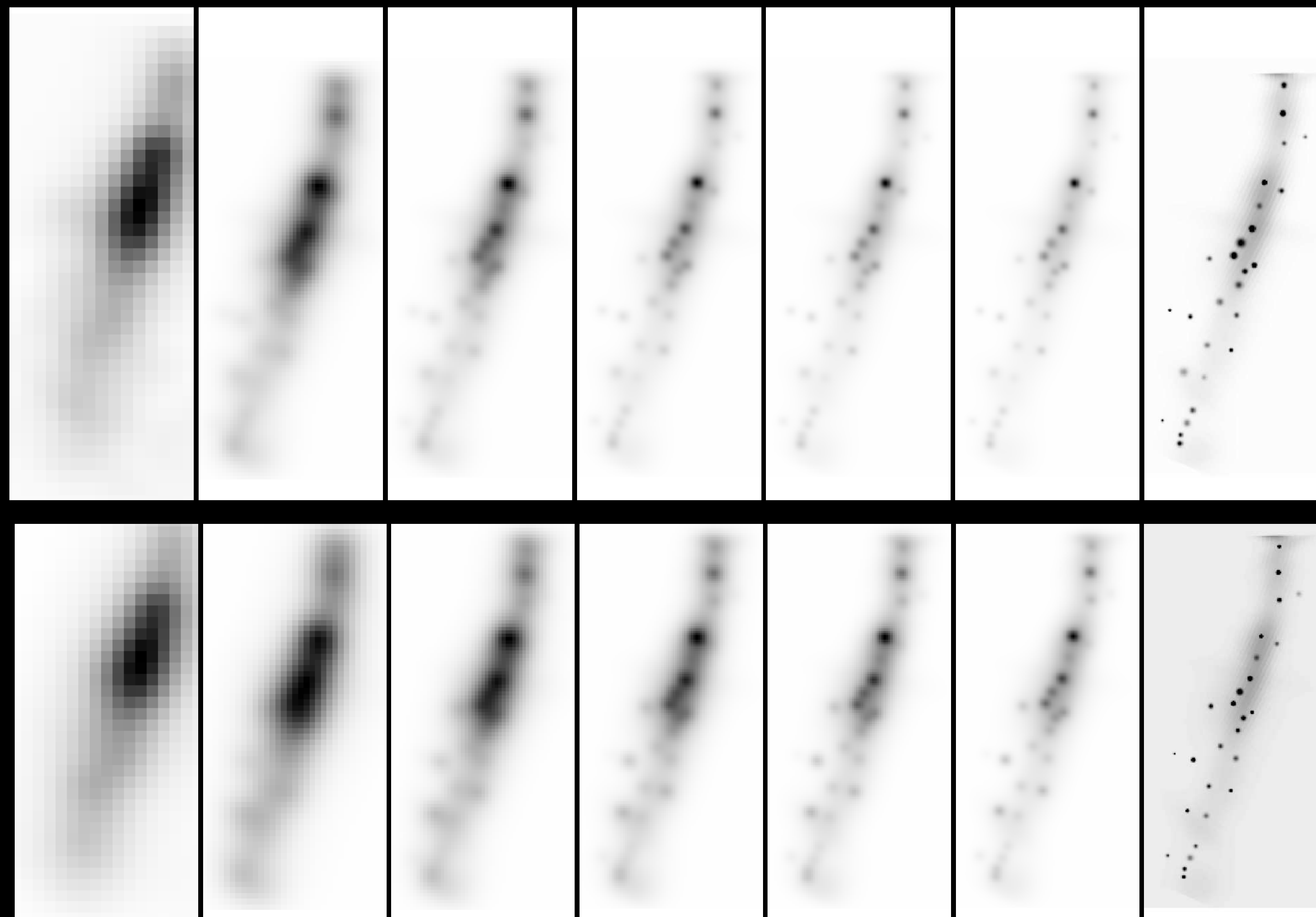
- Observing structures down to 0.0003L* (Postman)

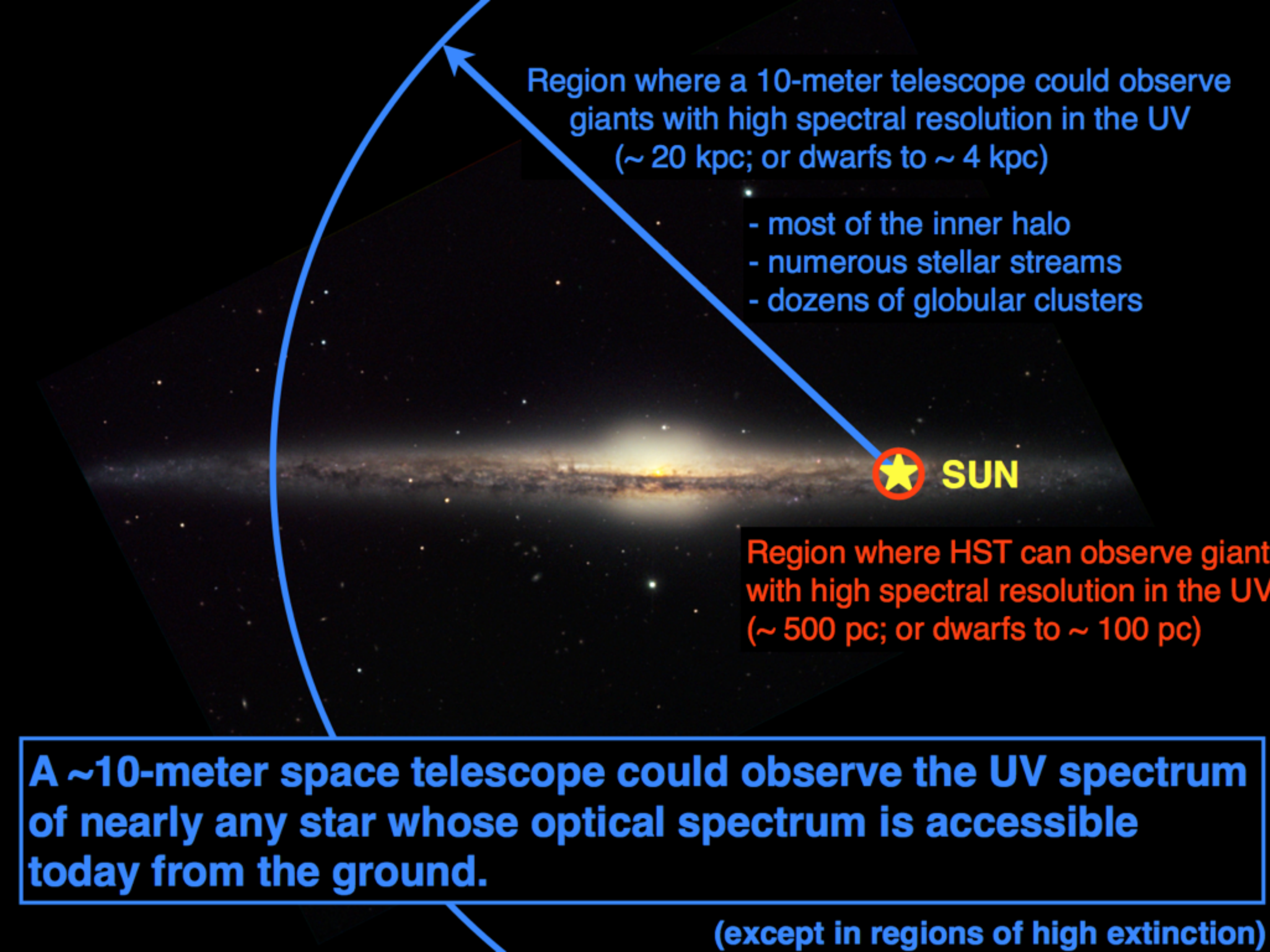
STAR FORMING REGIONS DOWN TO 100PC AT Z>1



J. Rigby

STARS, STELLAR EVOLUTION, AND THE LOCAL UNIVERSE

- Characterize the first stars, supernovae, and metals in the universe via UV spectra of the most metal poor stars (Roderer)


Region where a 10-meter telescope could observe
giants with high spectral resolution in the UV
(~ 20 kpc; or dwarfs to ~ 4 kpc)
- most of the inner halo
- numerous stellar streams
- dozens of globular clusters
SUN
Region where HST can observe giant
with high spectral resolution in the UV
(~ 500 pc; or dwarfs to ~ 100 pc)
A ~10-meter space telescope could observe the UV spectrum
of nearly any star whose optical spectrum is accessible
today from the ground.
(except in regions of high extinction)

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- The extinction law from UV to IR in the Galaxy (Gómez de Castro)

HISTORICAL POINT 2

YODA WAS RIGHT

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YODA WAS RIGHT

"you want the impossible"

“you want the impossible”

“you want the impossible”

“that…is why you fail”

WHAT DOES IT MEAN TO "DO THE IMPOSSIBLE"

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- Perform a measurement or make a discovery that has never been made
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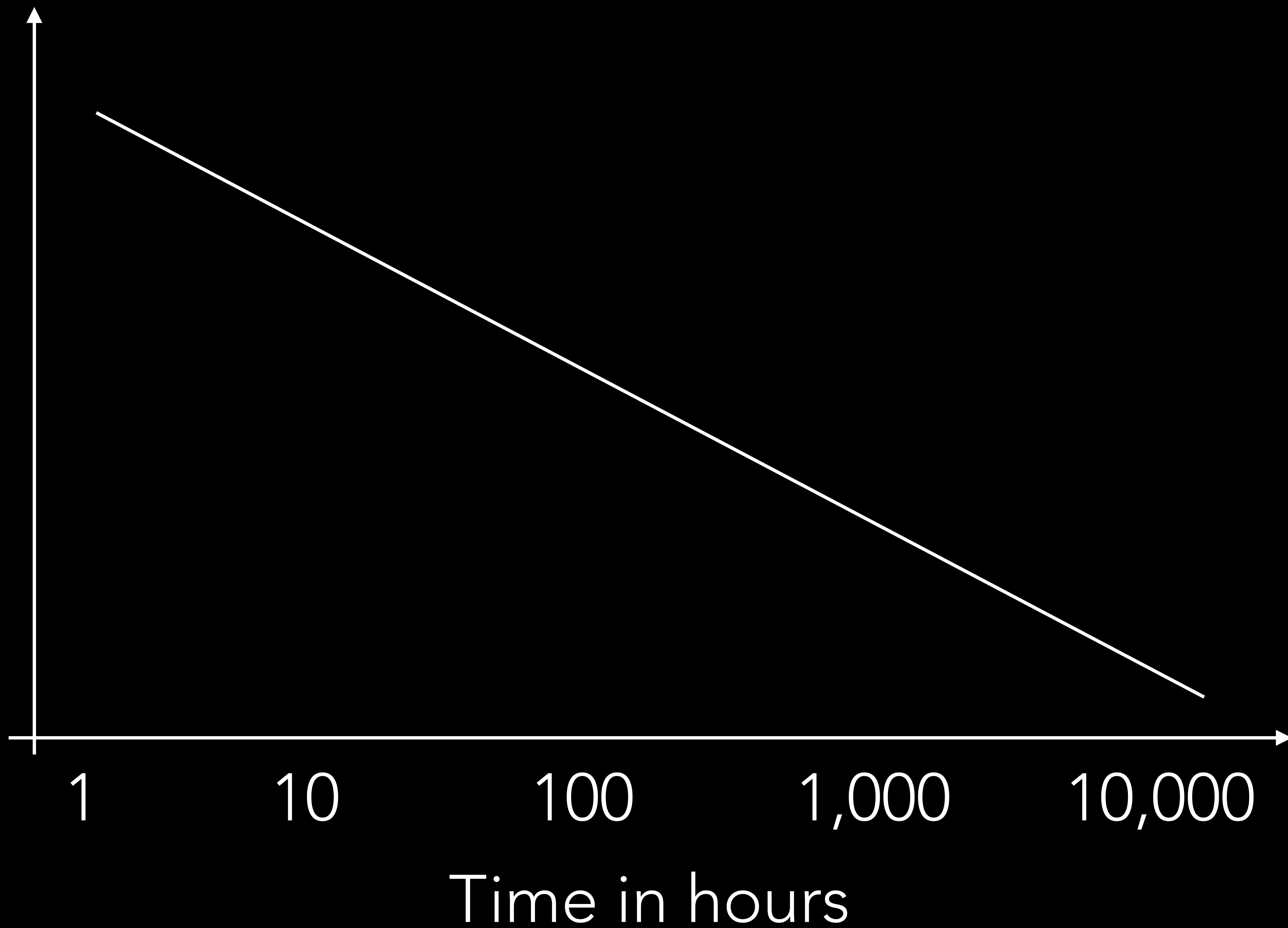
- A different, *operational* definition: turn a program that requires > 1000 hours into a routine one

WHAT DOES IT MEAN TO "DO THE IMPOSSIBLE"?



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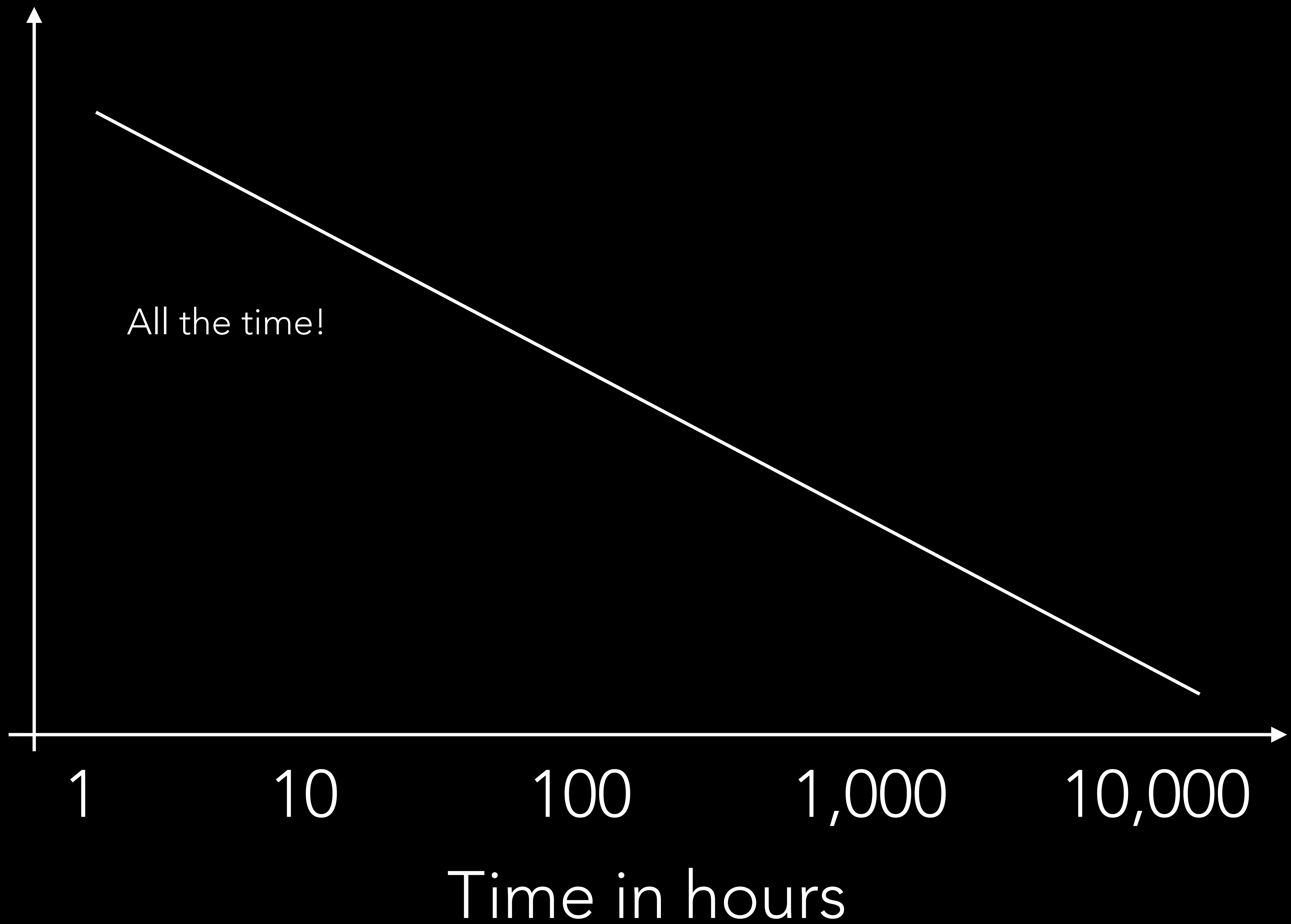

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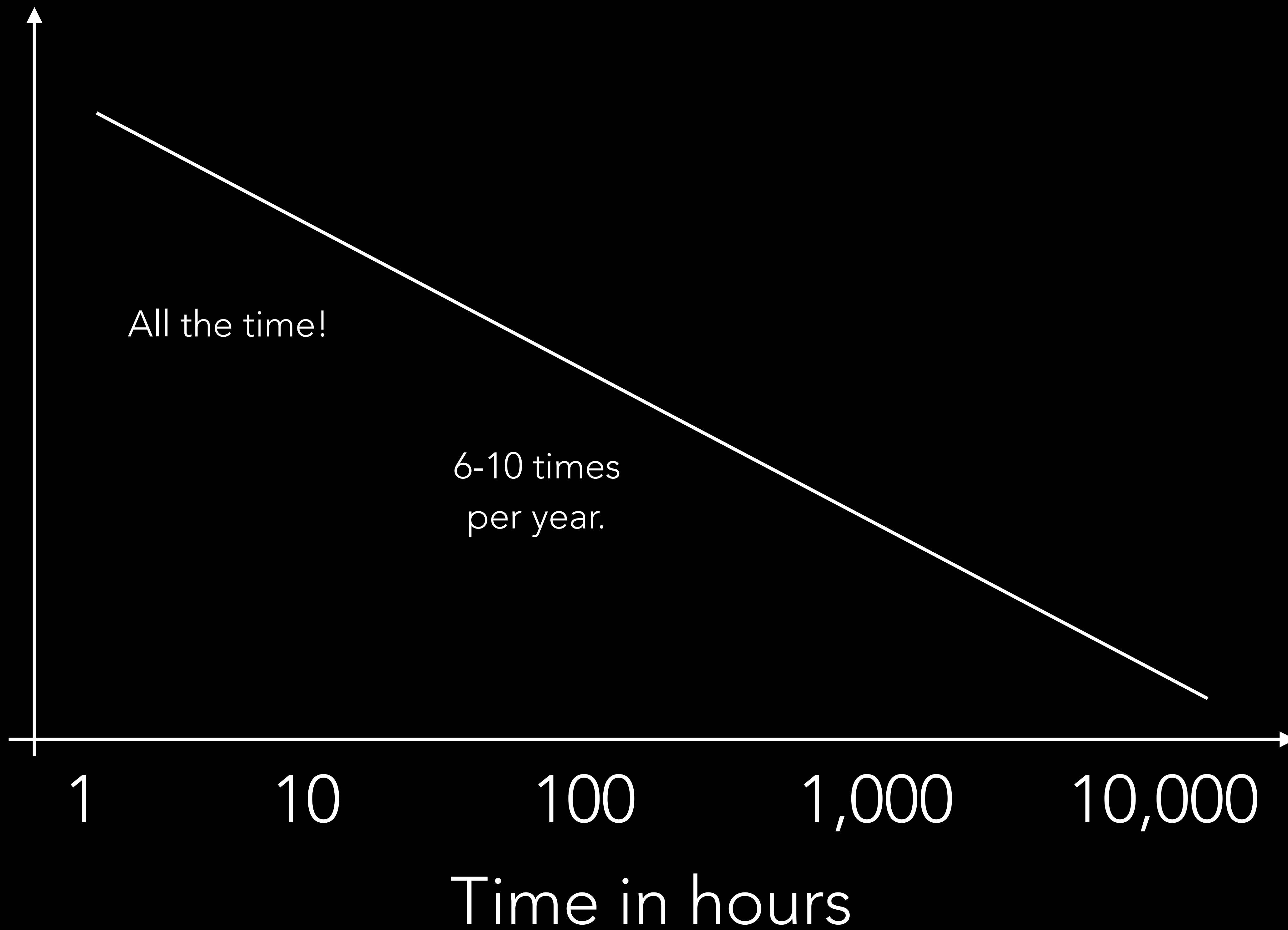

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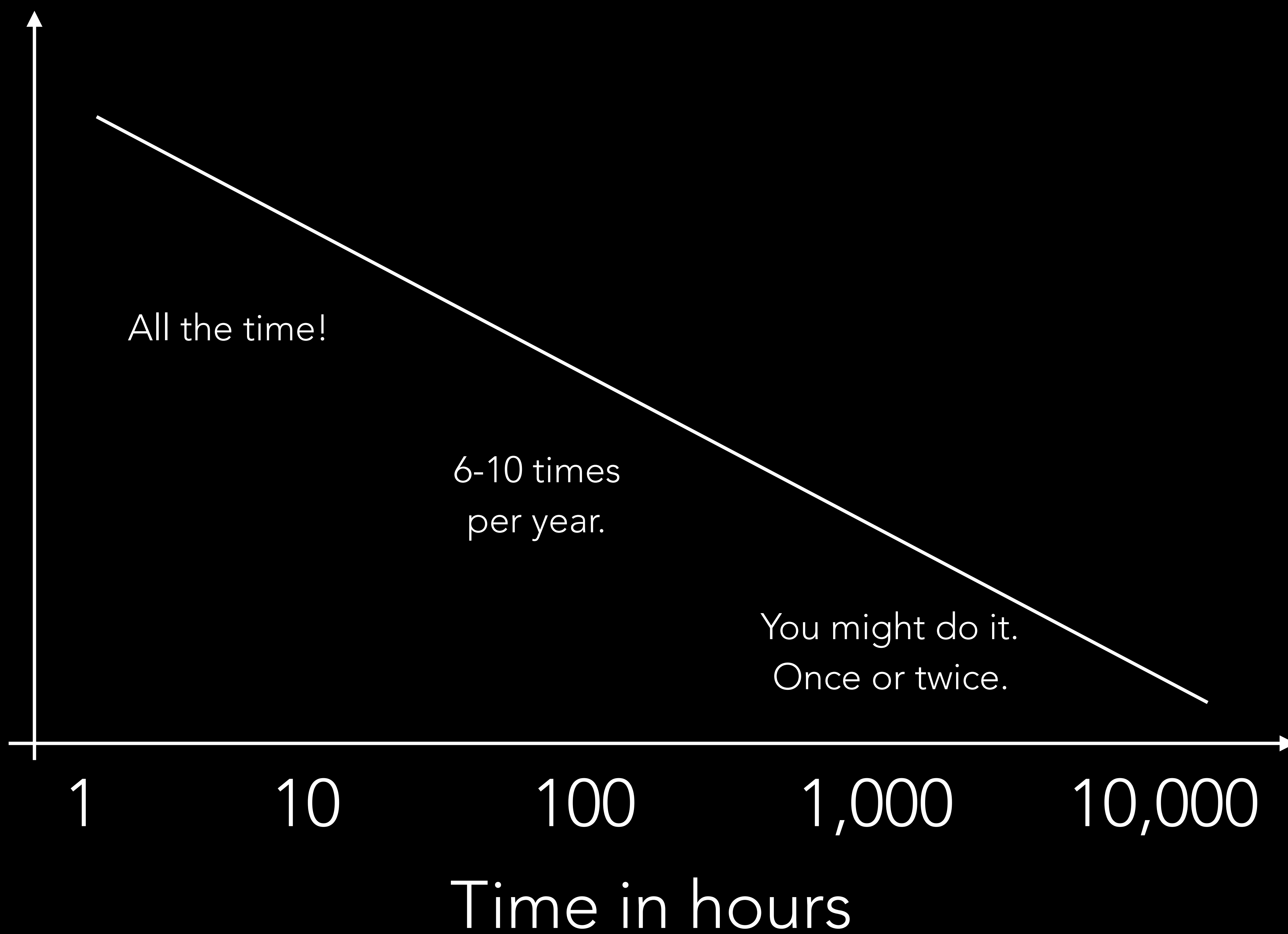

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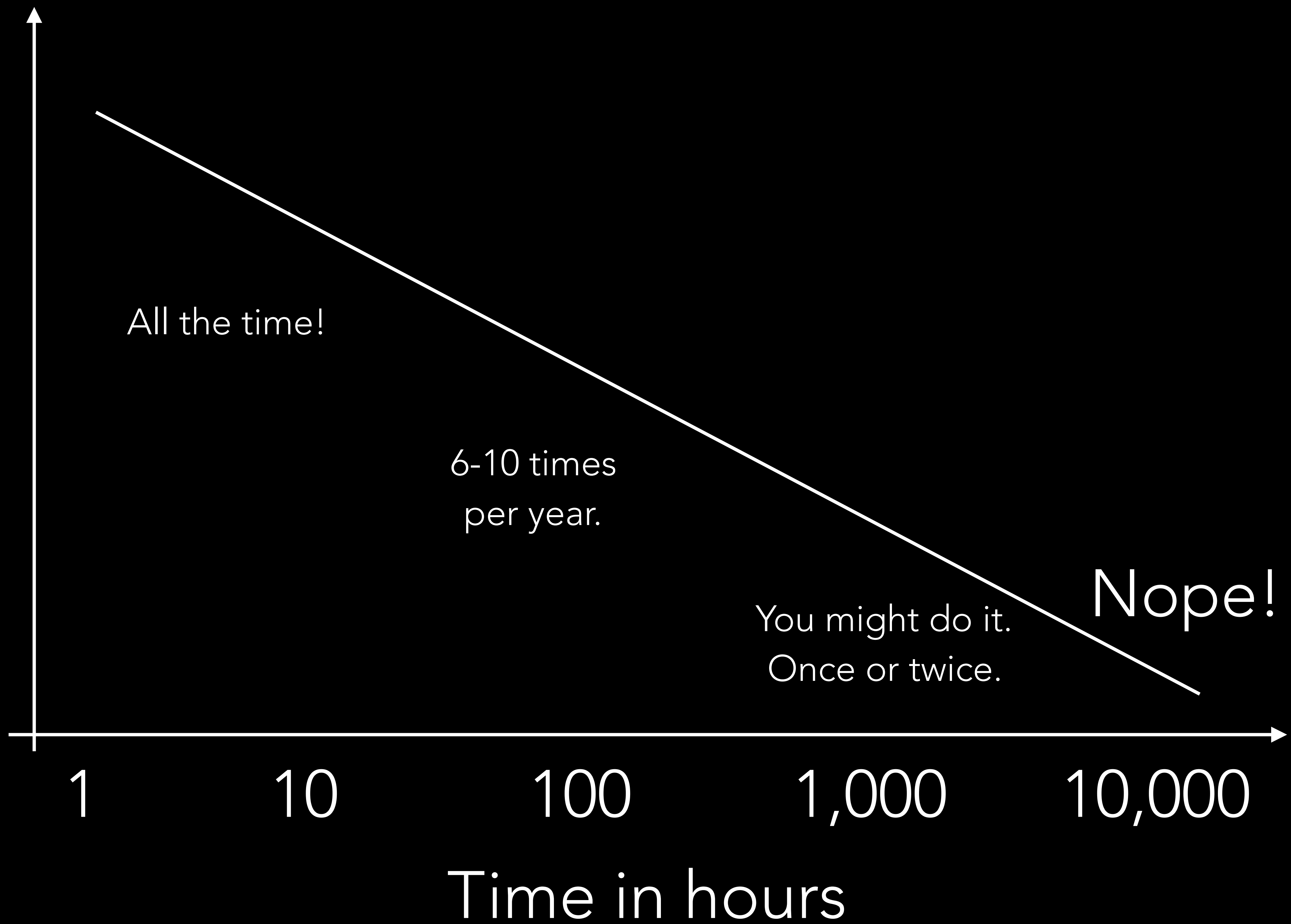
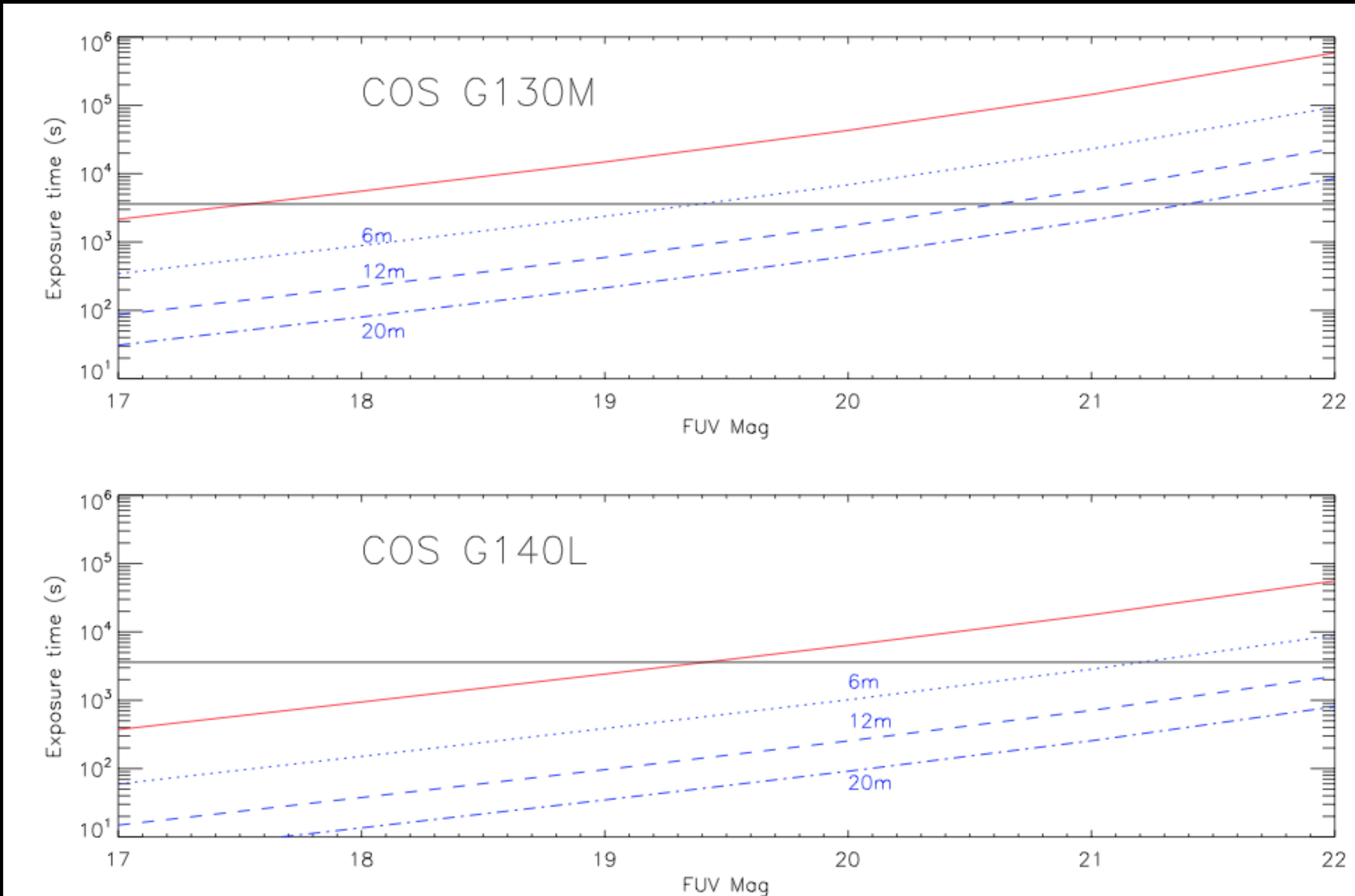


POINT SOURCE UV SPECTROSCOPY



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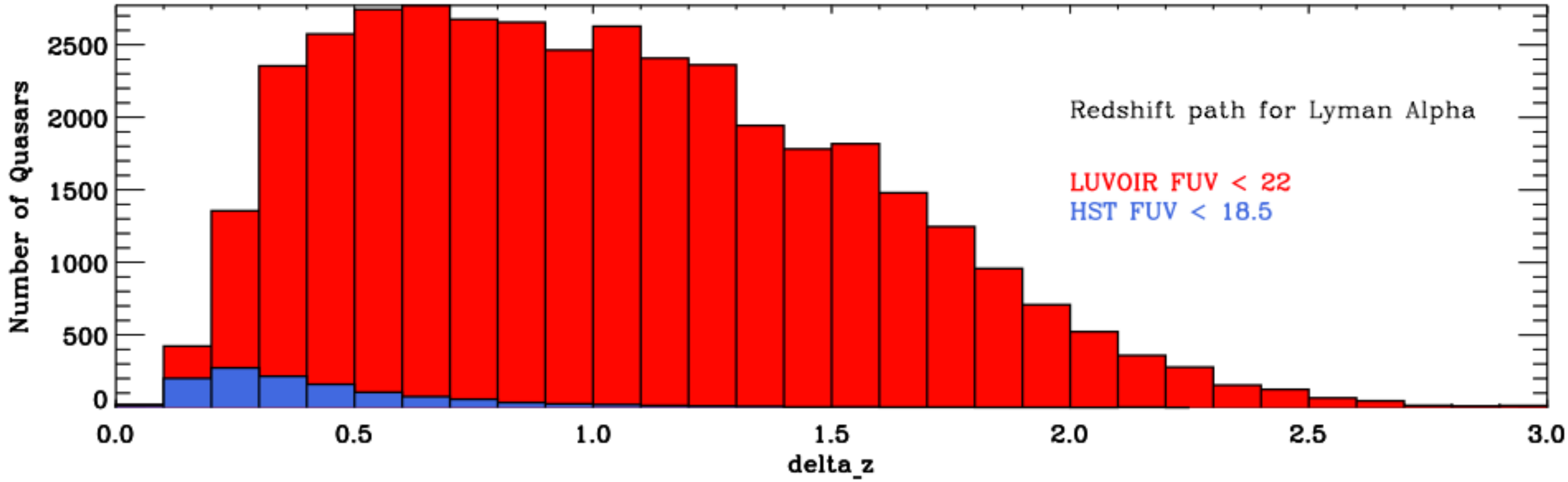

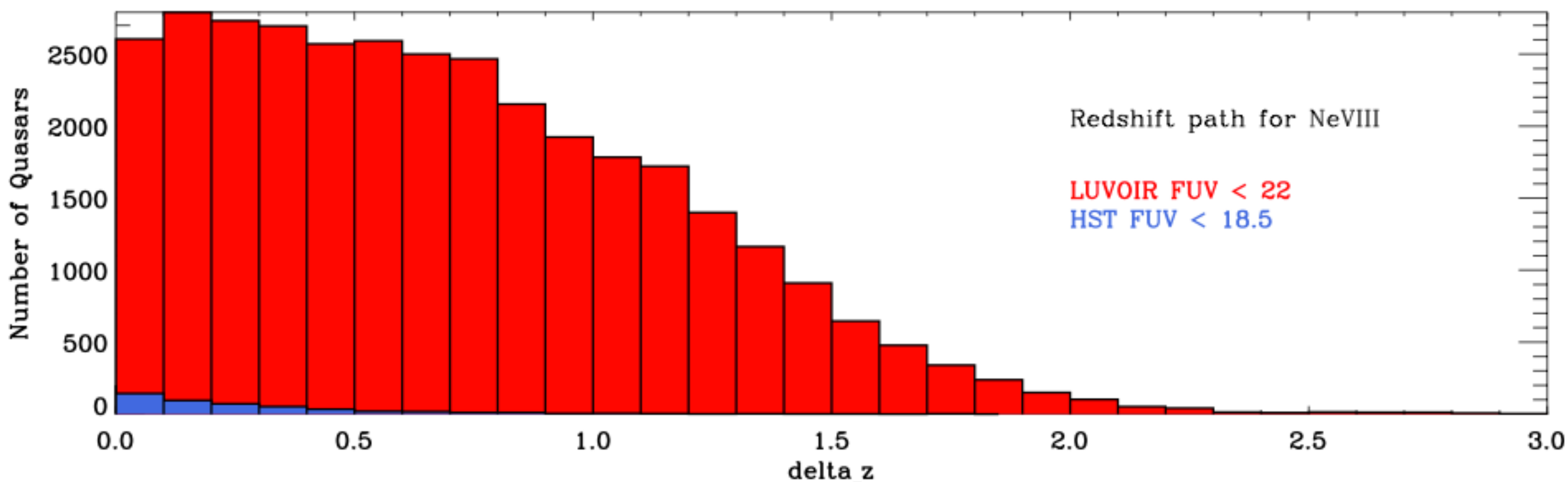

IMPLICATIONS FOR APERTURE

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- Smaller apertures take longer times, reducing the number of large investments you can make, *shrinking the total discovery space*

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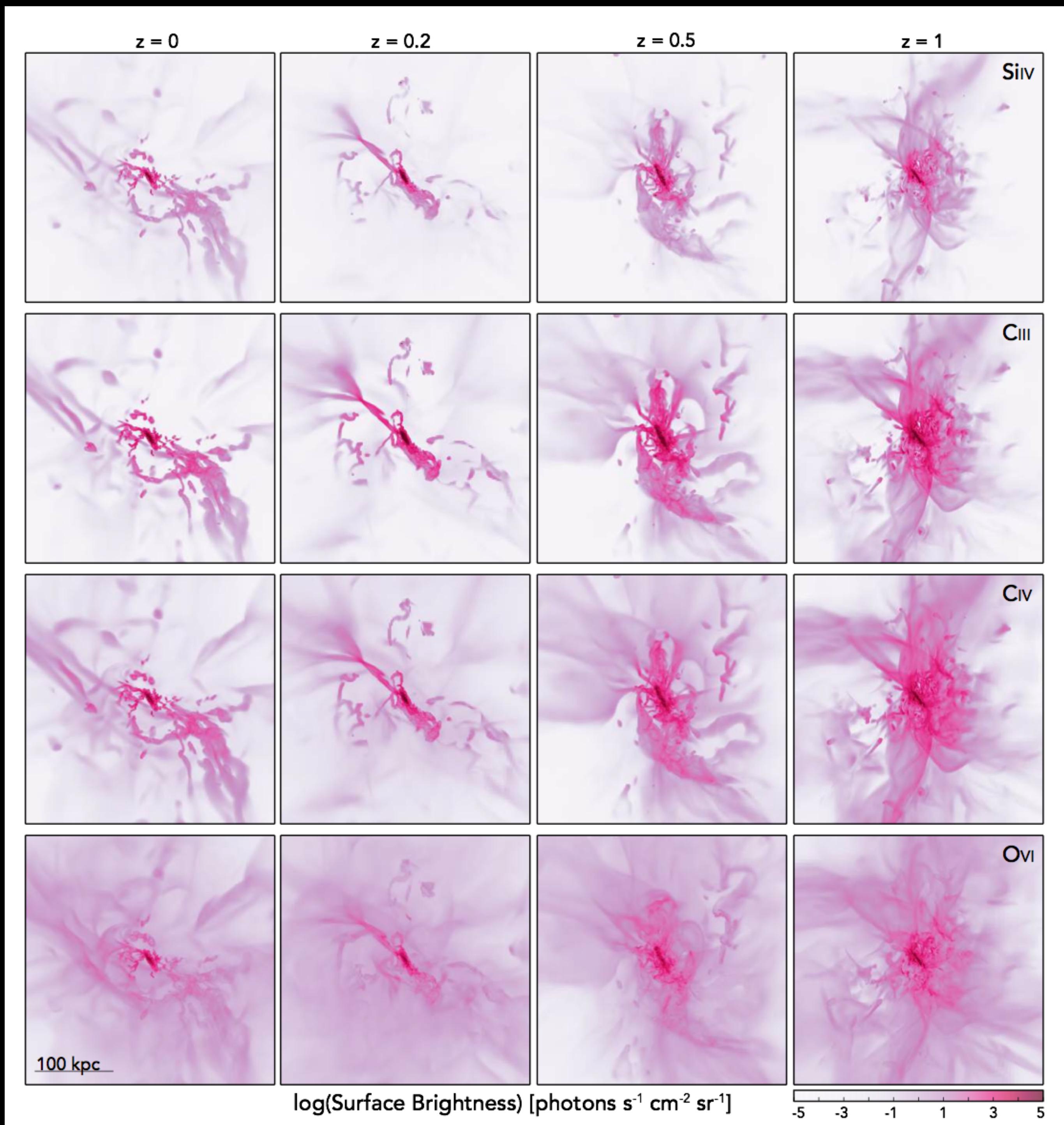
- We should not be comparing raw capacity when we compare apertures
- We should compare total science programs, considered holistically, bound by the ultimate limited resource: mission lifetime

DOING THE IMPOSSIBLE WITH LUVOIR

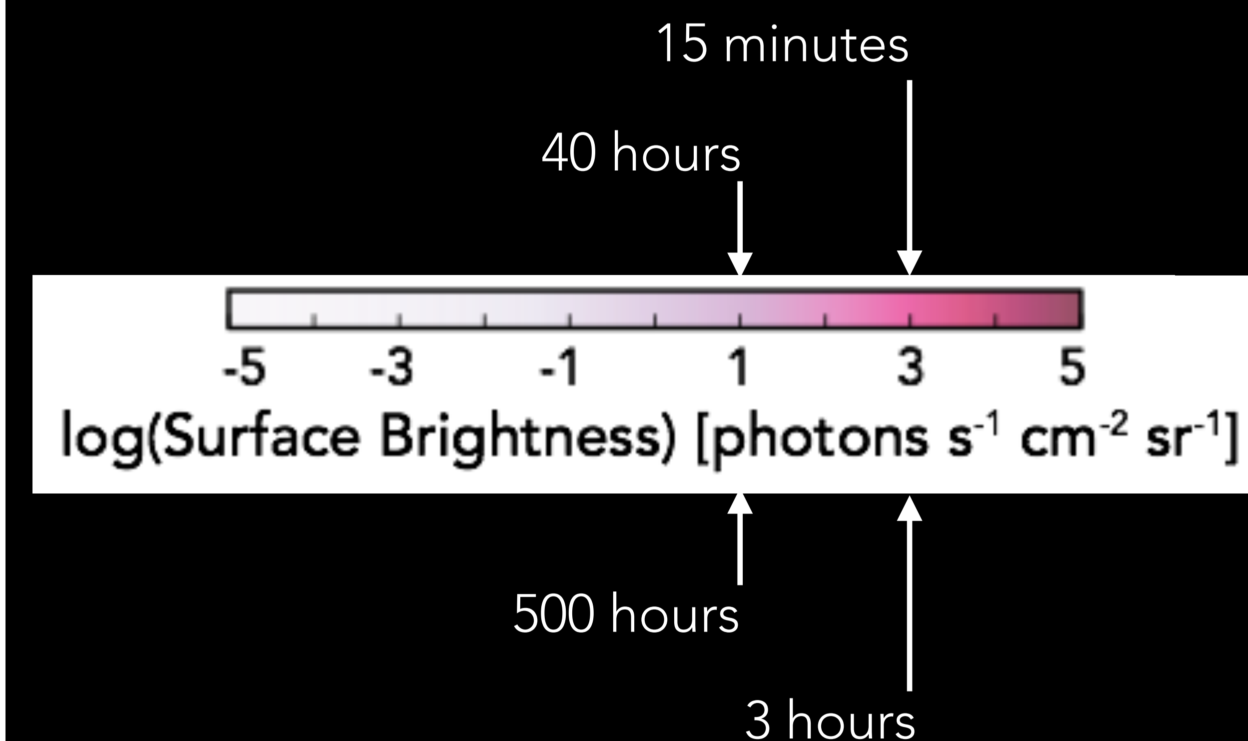
MISSION IMPOSSIBLE #1

- imaging the CGM at z<2 to unravel galaxy fueling and feedback



Corlies & Schiminovich (2016)

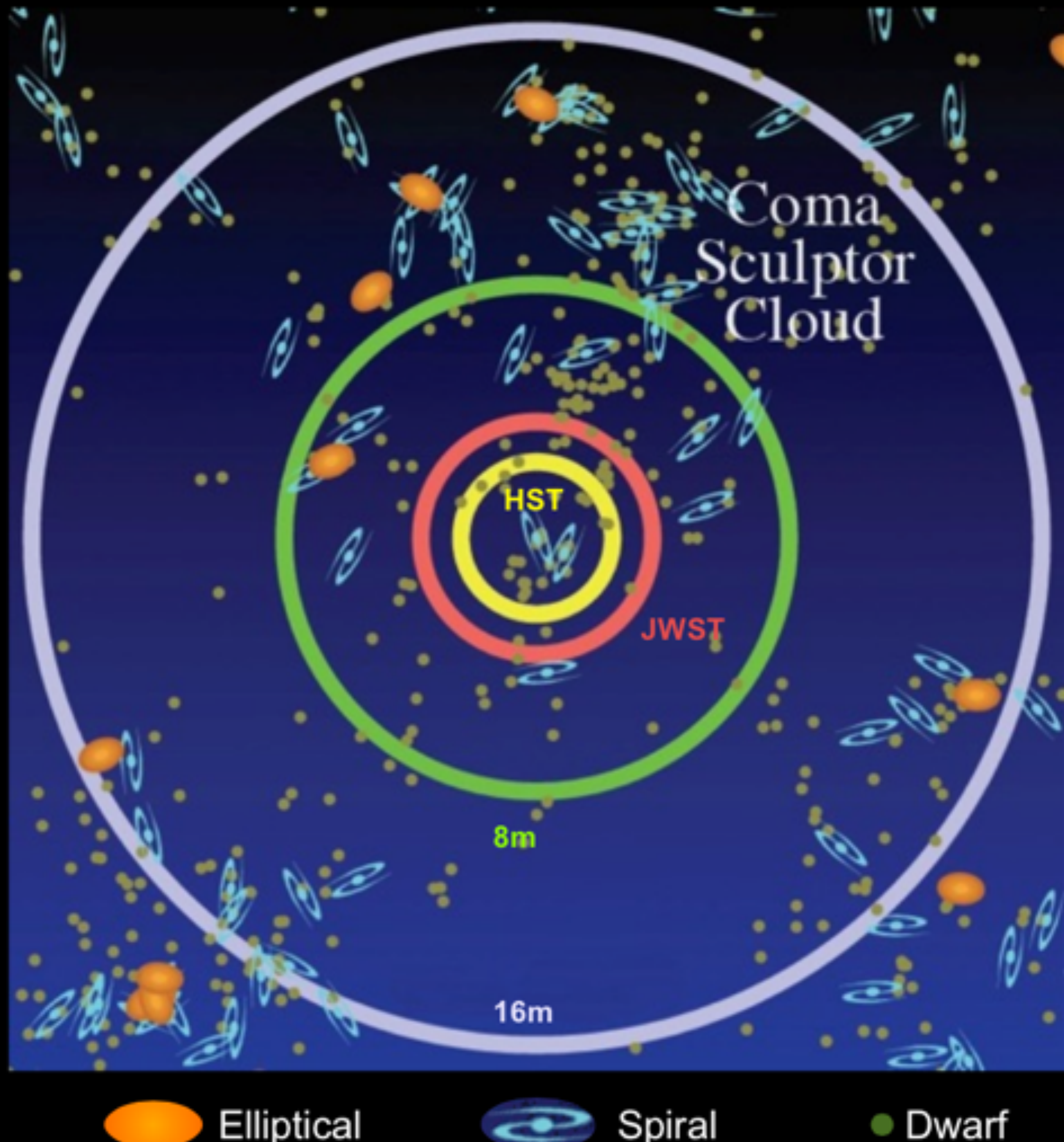
10 meter telescope

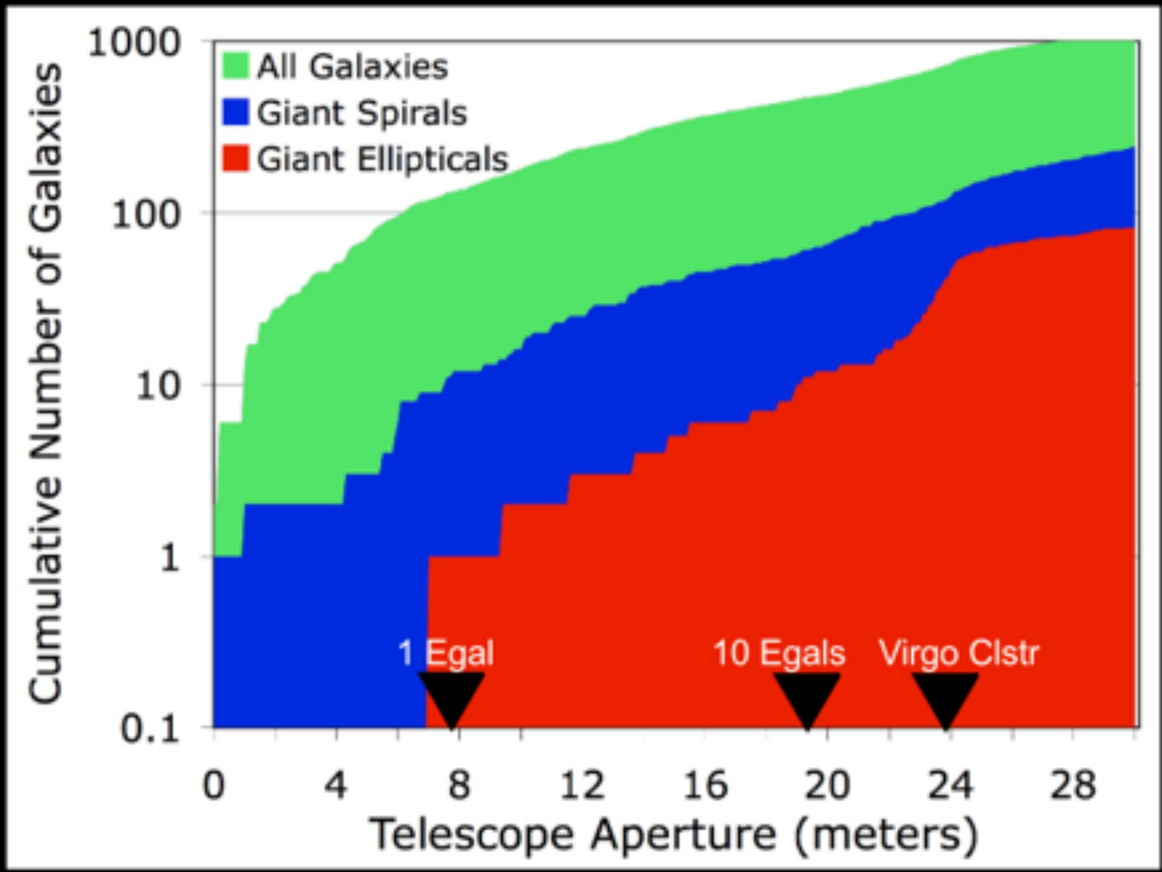


4 meter telescope

MISSION IMPOSSIBLE #2

- Star formation histories and the IMF

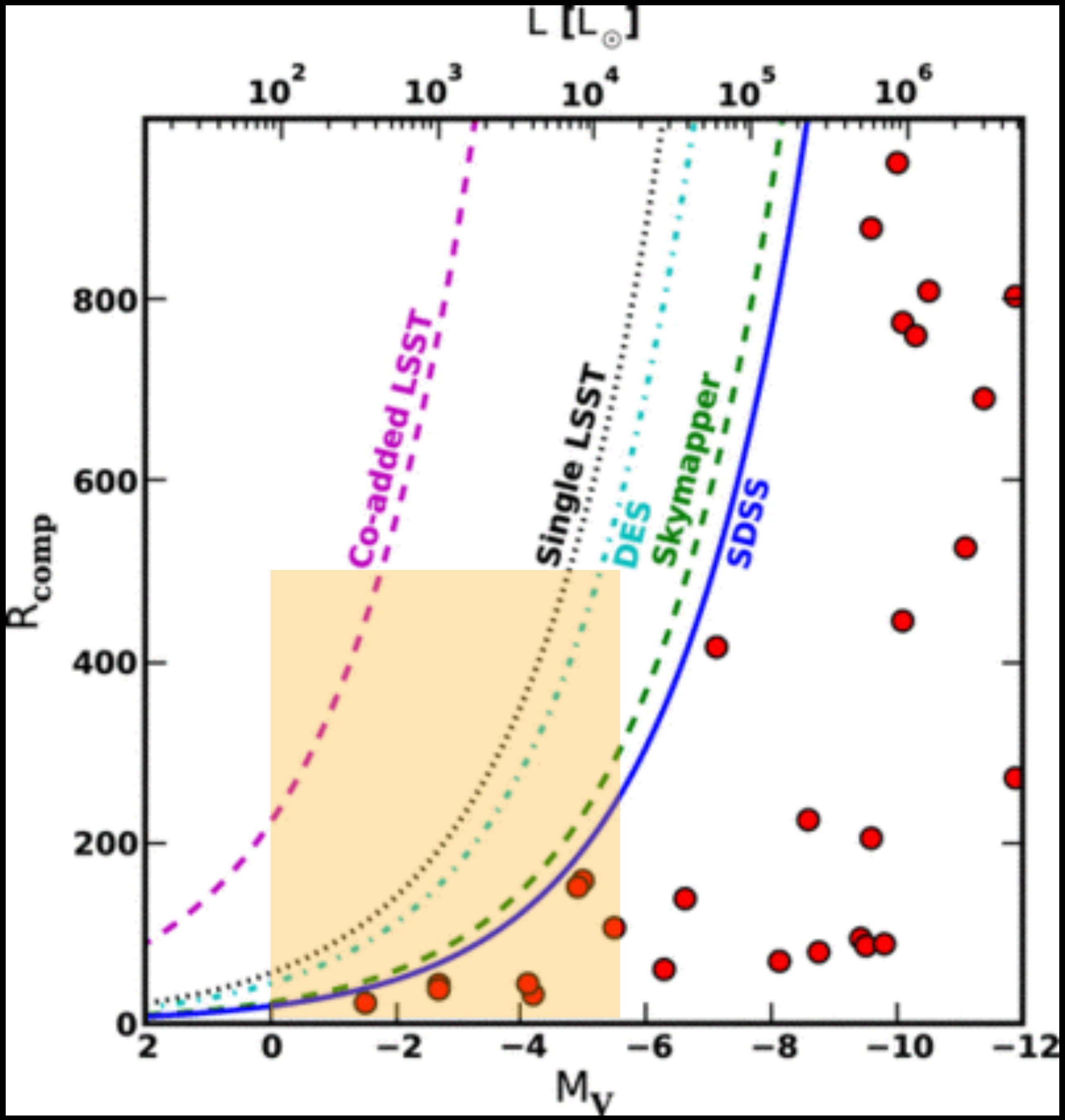




8-12 meter aperture reaches 1-3 giant ellipticals

MISSION IMPOSSIBLE #3

Probe star formation and dark matter in the darkest halos - hundreds of faint MW satellites to be discovered by LSST.



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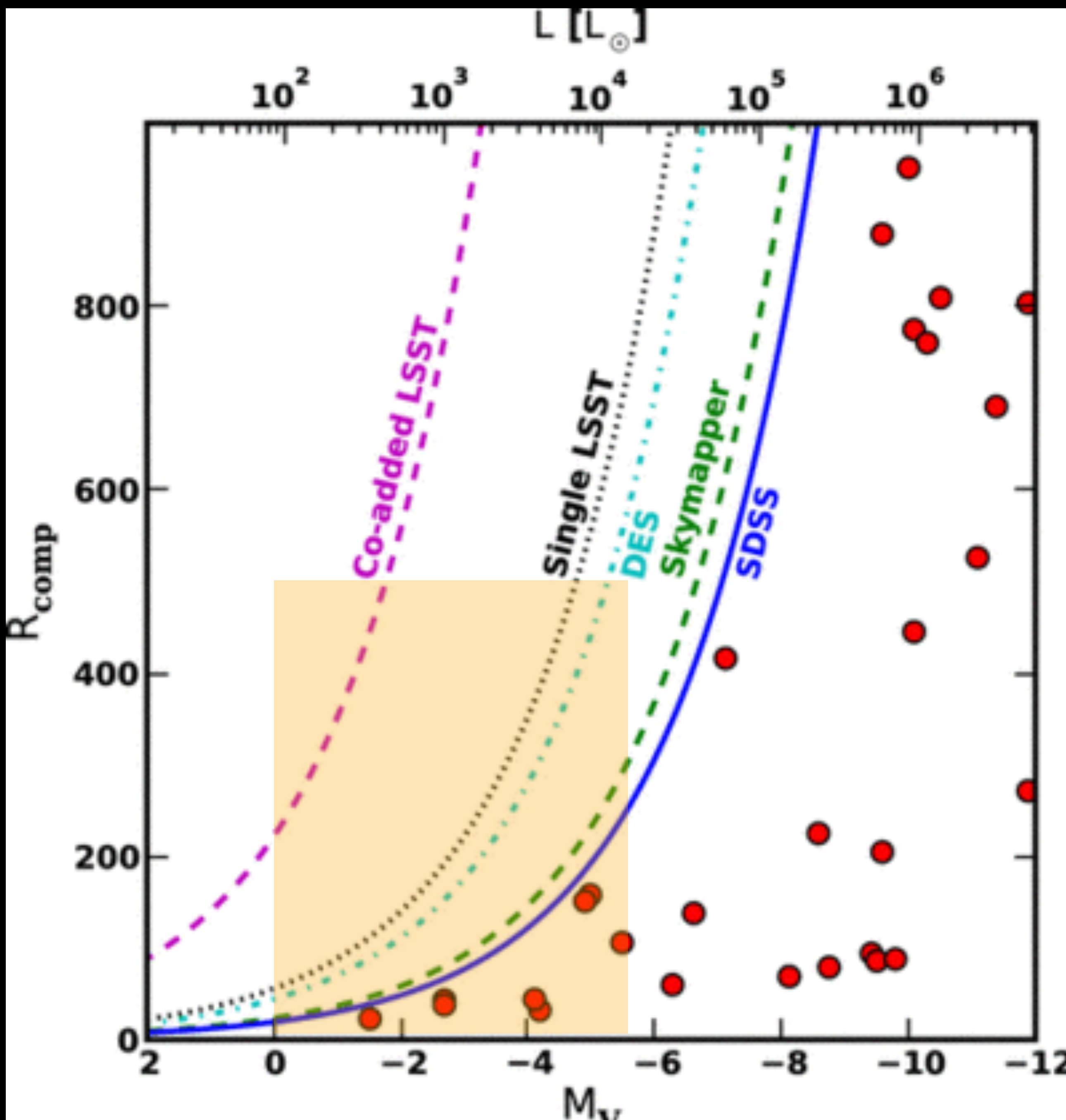

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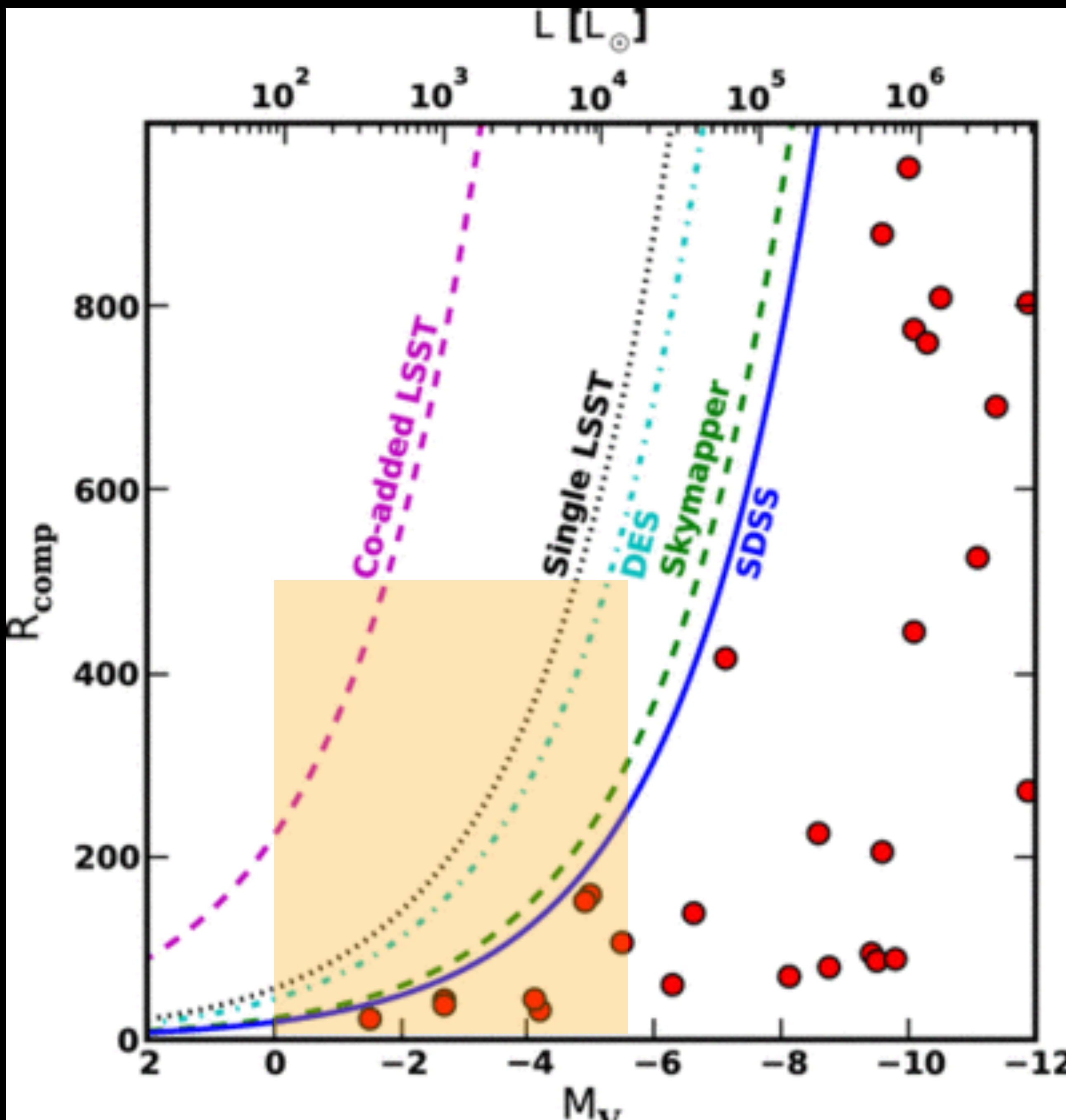

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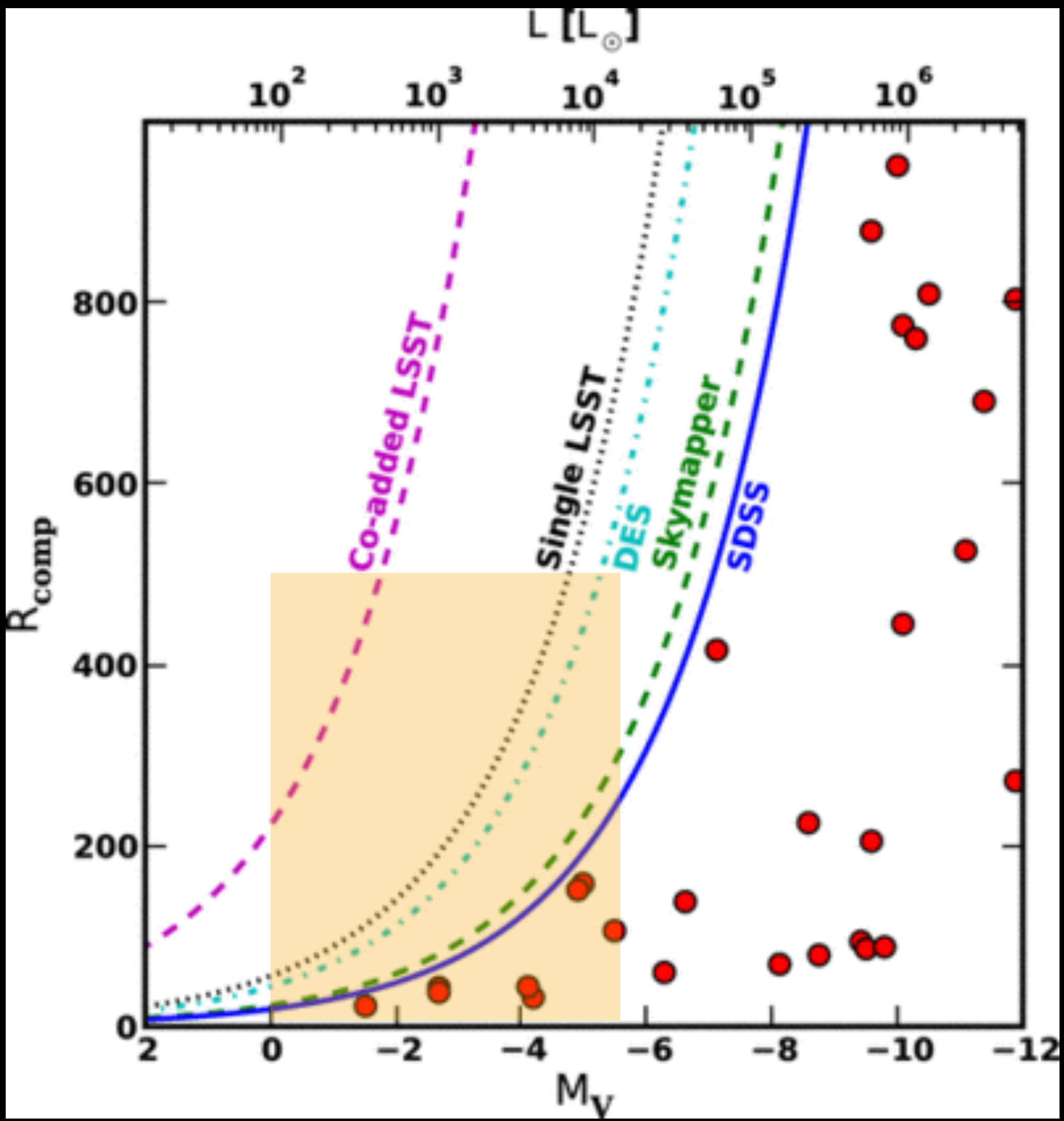

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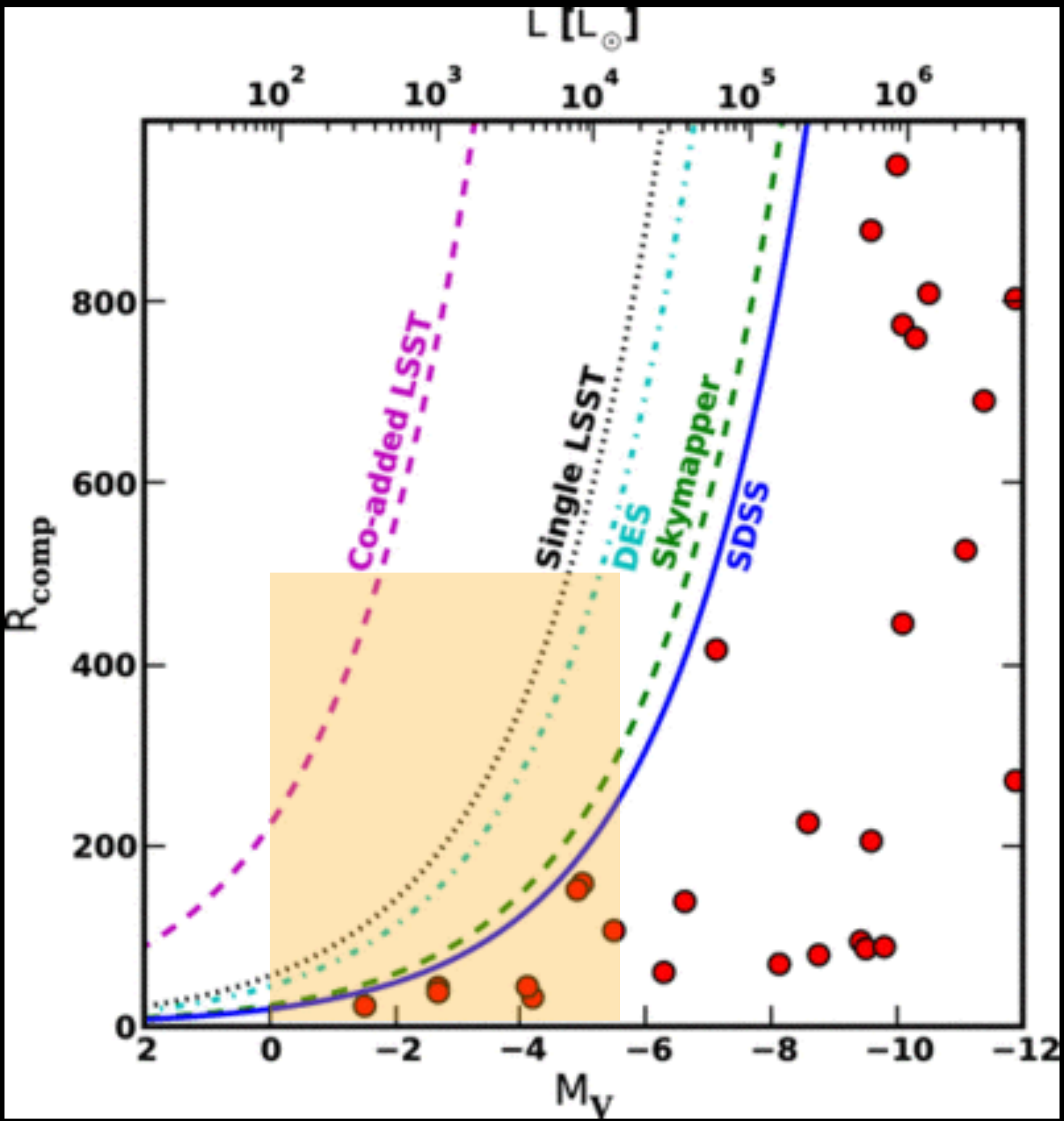

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- 4 m reaches ~200 kpc, but this is 50x less volume and still inside R_{vir}.

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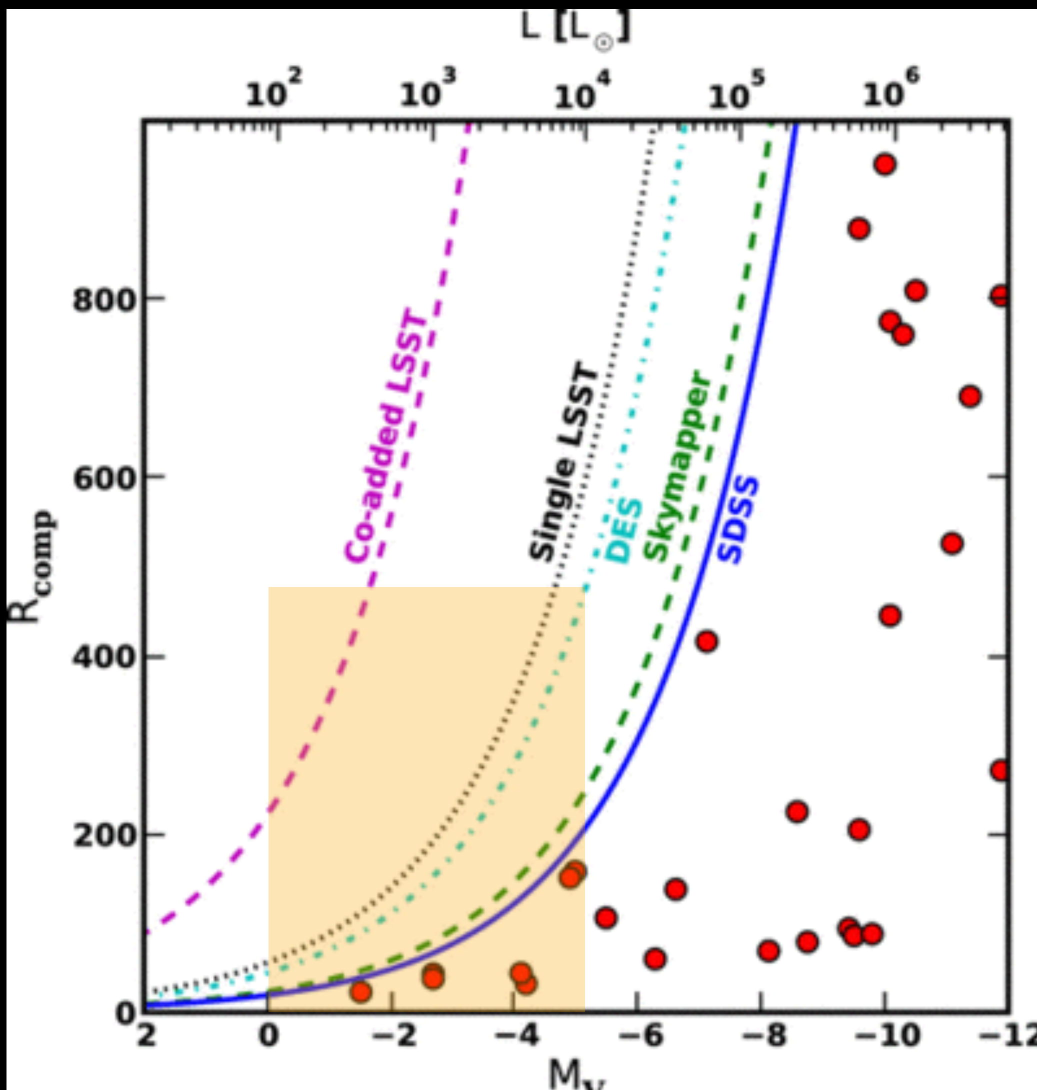
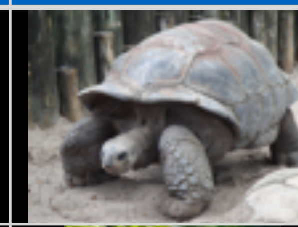
Probe dark matter in the darkest halos - hundreds of faint MW satellites to be discovered by LSST.

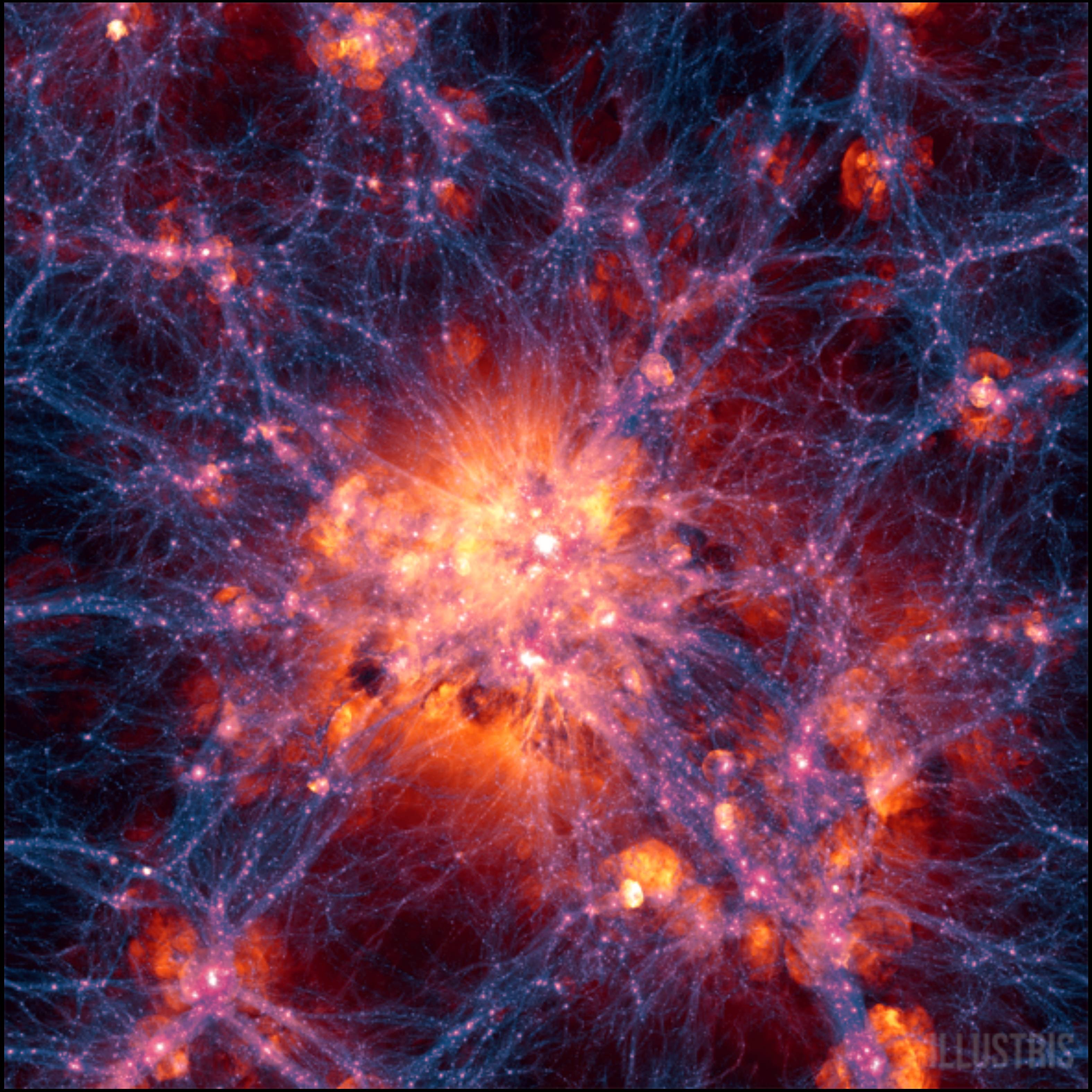


Velocity dispersions are 1-5 km/s. Measure DM potential in most DM-dominated and isolated galaxies.

What is the DM?

Distance	Speed	Example	Goal
10 pc (nearest stars)	10 cm s^{-1} 0.2 mph		planets
100 pc (nearest SF regions)	100 cm s^{-1} 2.2 mph		planets in disks
10 kpc (entire MW disk)	0.1 km s^{-1} 223 mph		dissipation of star clusters
100 kpc (MW halo)	1 km s^{-1} 2200 mph		DM dynamics in dwarf sats.
1 Mpc (Local Group)	100 km s^{-1}		3D motions of all LG galaxies
10 Mpc (Galactic Neighborhood)	100 km s^{-1}		cluster dynamics

THESE WILL ONLY GET BETTER. LUVOIR CAN ECLIPSE THEM, AND DEMAND THEIR SUCCESSORS



HISTORICAL POINT 3

THE LUVOIR STDT MAY NOT KNOW WHAT THE MOST IMPORTANT SCIENCE OF 2035 IS

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Scientific Uses
of the
Large
Space Telescope

AD HOC COMMITTEE ON THE LARGE SPACE TELESCOPE
SPACE SCIENCE BOARD
NATIONAL ACADEMY OF SCIENCES–NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY OF SCIENCES
WASHINGTON, D.C.
1969

TWO THOUGHTS

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- 1) We don’t know the future

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- 1) We don’t know the future
- 2) We can’t read minds

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  We should only consider a LUVOIR that can also do as of yet unknown science. Be flexible and powerful.

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- 1) We don't know the future

We should only consider a LUVOIR that can also do as of yet unknown science. Be flexible <u>and</u> powerful.

- 2) We can't read minds

We must make a serious effort to reach out and listen to the full community, and give them the tools to think big.

HISTORICAL POINT 4

WE HAVE ALWAYS HAD LARGER TELESCOPES ON THE GROUND. THAT'S OK

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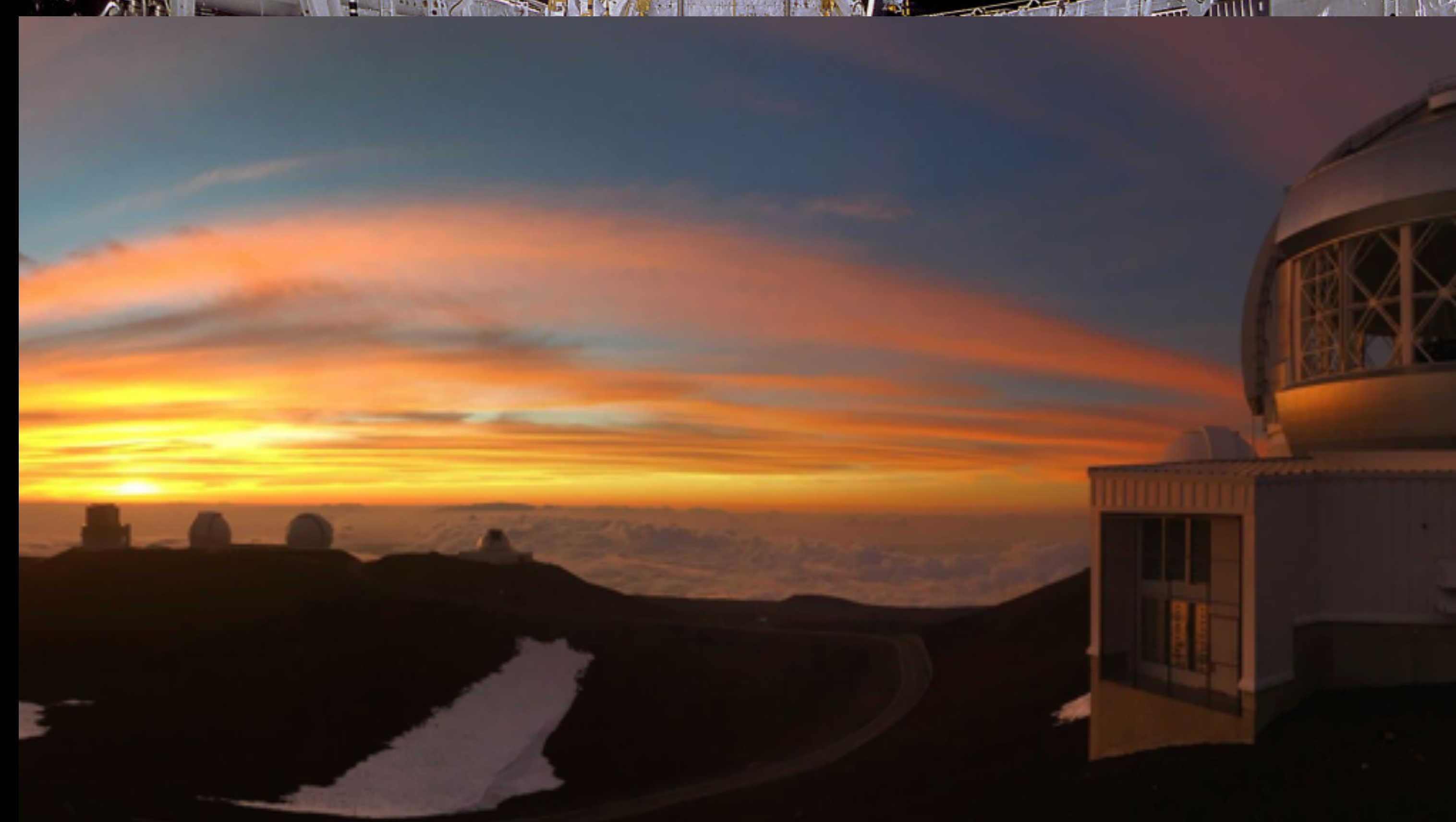


THERE IS UNPRECEDENTED JOINT DISCOVERY SPACE

- LSST
- TMT/EELT/GMT
- SKA
- ALMA
- Many others

Let's use both, each at what it is best for

At 1.5 μm (H), a diffraction-limited 30m will reach the same spatial resolution as a space-based 10m at 0.5 μm.

Sky backgrounds prevent ground-based ELTs from applying their spatial resolution at the faintest desirable limits.

<u>ELTs excel at:</u>

-high res imaging on bright sources

-IR spectroscopy in atmospheric transmission windows

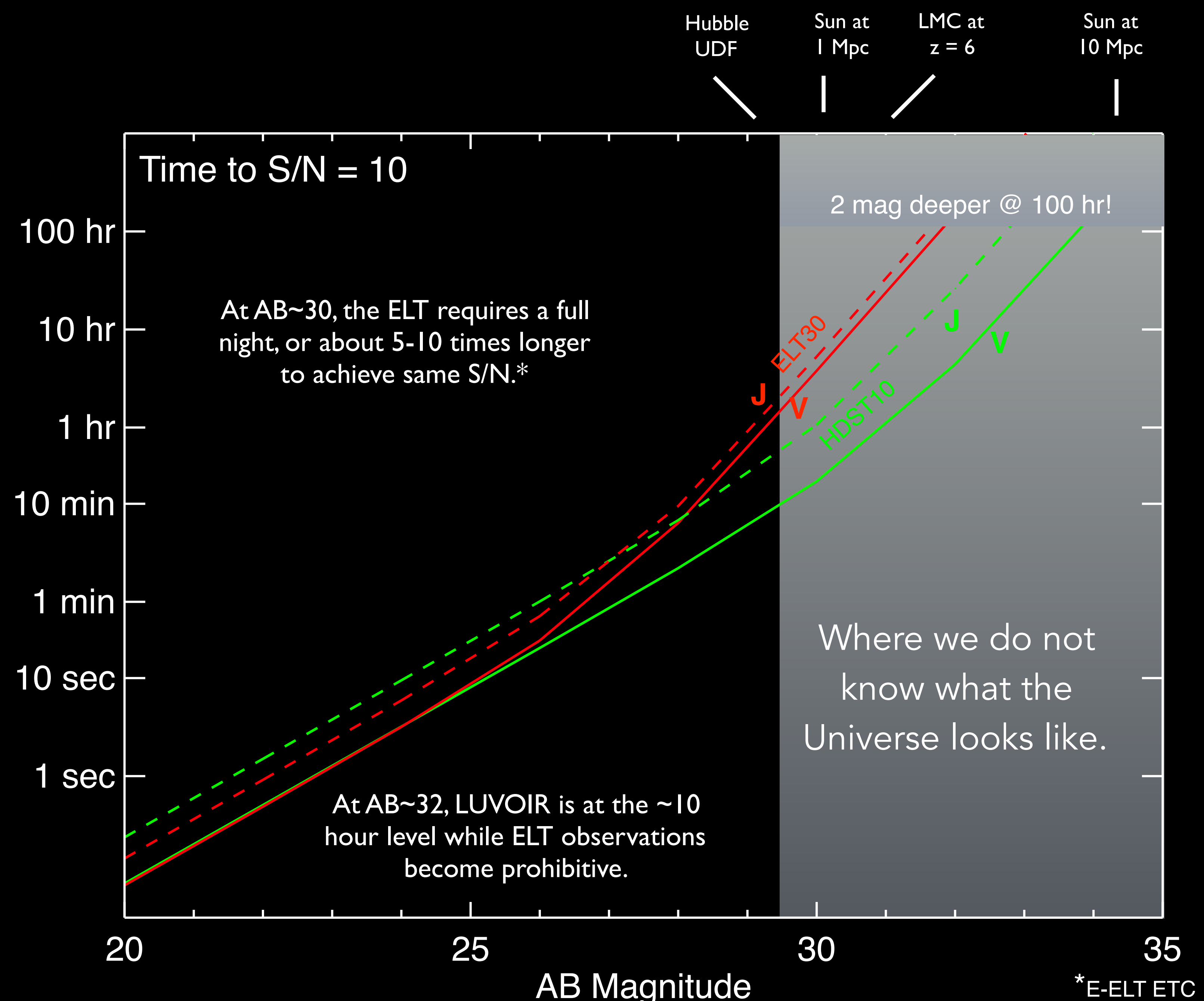
- high resolution optical spectroscopy

<u>LUVOIR excels at:</u>

- deep/wide imaging at all wavelengths
- low-res/2D spectra at all wavelengths
- astrometry, high contrast (stable PSF)
- anything requiring the UV

<u>They complement each other for:</u>

- LUVOIR detection in imaging, ELT spectroscopy for stars and galaxies
- multiphase gas diagnostics at all z



EMERGING INSTRUMENT THEMES

- UVOIR imaging with as wide a FOV as possible
- Low (R~100) to moderate (R~5,000) UVOIR MOS or IFU
- High (R>25,000) point source UVO spectrograph
- FUV spectroscopic capability (Lyman edge)

ALSO WORTH CONSIDERING

- Polarimetry
- Fast timing
- Ultra-precise astrometry
- Laser comb
- Energy resolving detectors

WHAT COULD WE DO IF WE HAD?

- μ-arcsecond astrometry
- S/N 10,000 at R=100,000
- Photon counting at extremely high rates
- R=1,000,000 spectroscopy

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- We have a huge parameter space in COR science with LUVOIR, some of it not yet known
- Much of it is revolutionary, and requires a revolution
- We have a lot of work to do, and we should not go it alone
- It's time to build the tools, make the plots, and write the story

“It’s kind of fun to do the impossible”

–WALT DISNEY