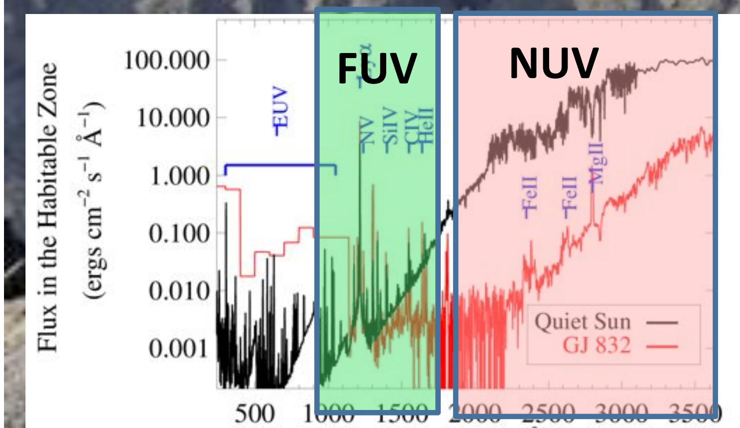
Earth-mass Planets around M and K dwarfs: The Production of (and eventual detection of) "Biomarker" Gases

- Shape and amplitude of stellar UV spectrum may drive abiotic production of "biomarker" gases like ozone on rocky planets in the habitable zone

Tian et al. 2014 Domagal-Goldman et al. 2014

- X-ray→ UV→ visible survey of M and K exoplanet host stars within 15 pc to understand the initial conditions for atmospheric chemistry: MUSCLES Survey with *HST*, *Chandra*, *XMM*, ground-based telescopes

PI - France



France+ 2012, 2013

M dwarf: FUV/NUV ~ 1
Sun: FUV/NUV ~ 10 $^{-3}$

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(w/ Linsky, Roberge, Kaltenegger, Llama et al.)

SIG2 UVOIR Workshop, June 2015

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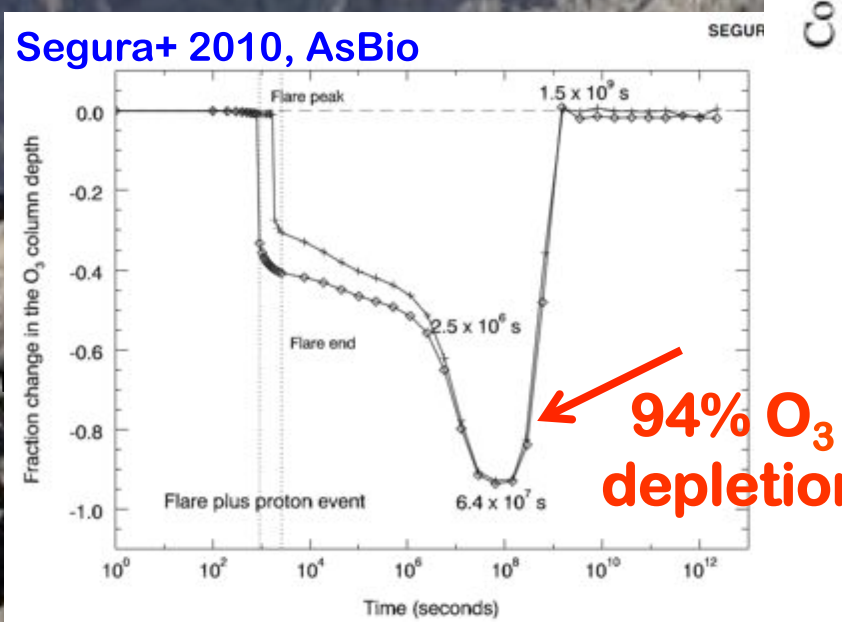
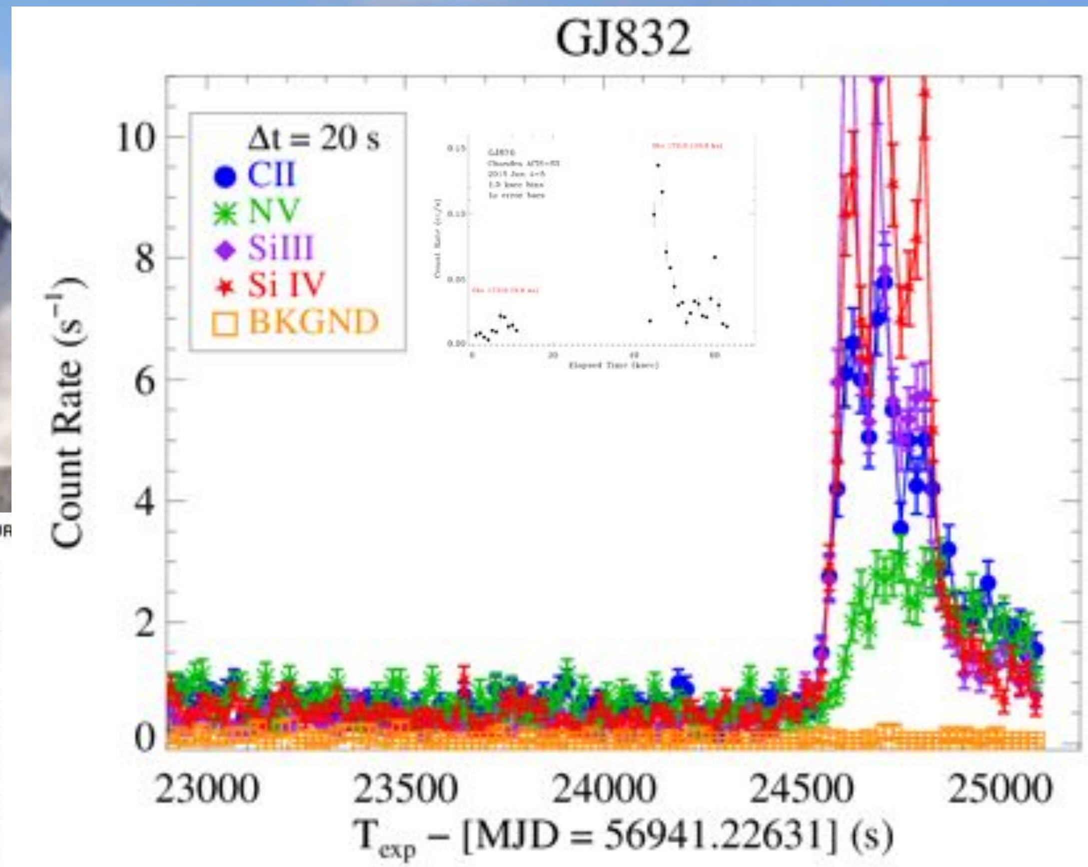
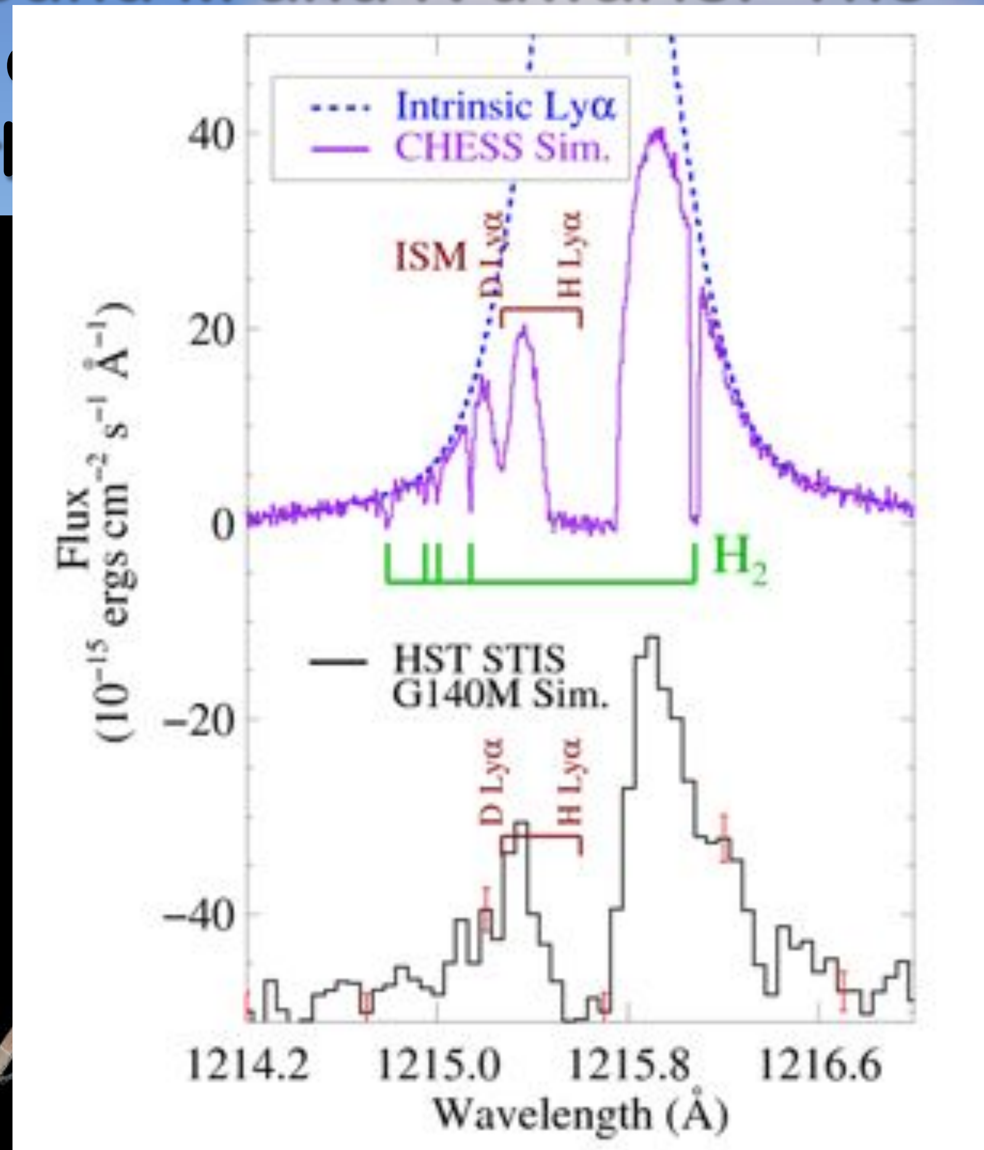




Factor of 10 UV/X-ray flux changes on "inactive" stars

Earth-mass Planets around M and K dwarfs: The Production of (and … “Biomar…

Artist's View of Extrasolar Planet HD 209458b
NASA, ESA, and G. Bacon (STScI) • STScI-PRC10-21



- Hot Jupiter transits: FUV transmission spectroscopy the best technique for observations of atmospheric mass-loss outside the solar system. Currently limited by data quality.

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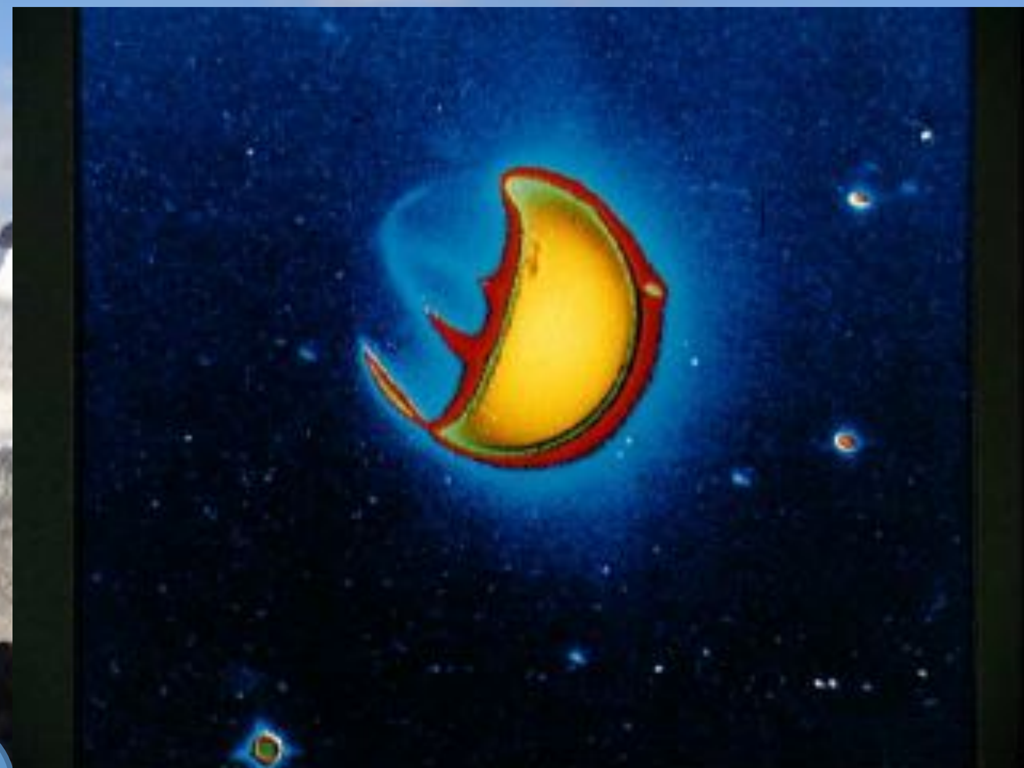

- Exo-Earth transits: they have extended atomic atmospheres too…

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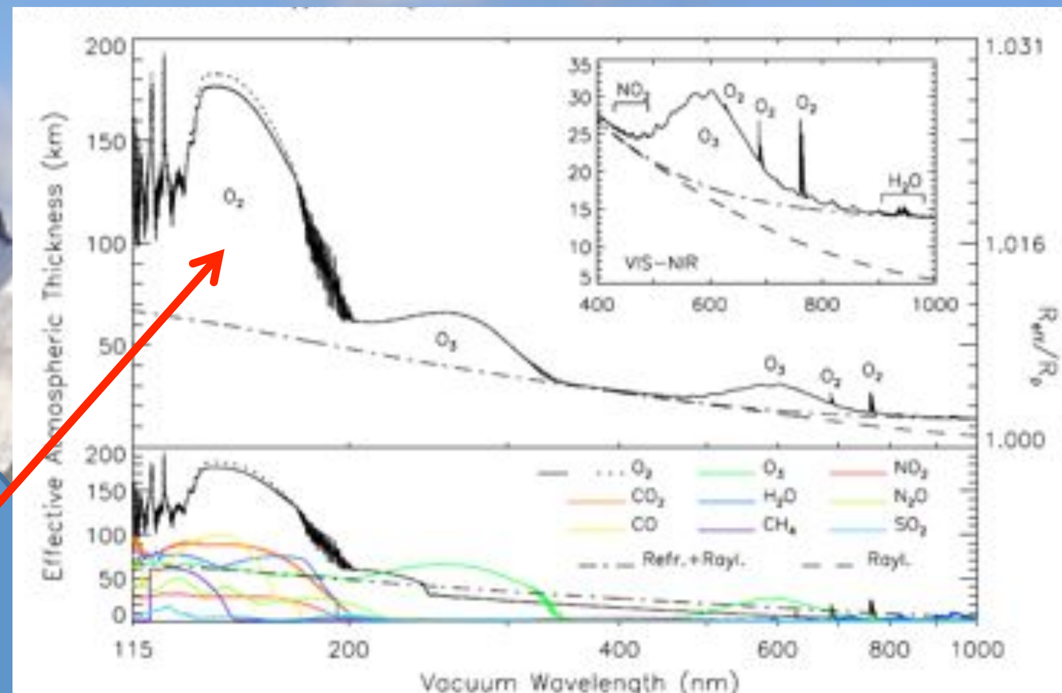
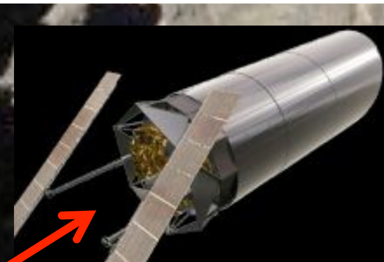


Bétrémieux & Kaltenegger 2013

- (R_{planet}/R_*) for O_2, O_3, CO, CO_2, H_2, and H all peak in the UV, 100 - 400 nm.
- O_3 peak at 250 nm, O_2 peak at 160nm: habitable planets around F and A stars. (start discovery now)
- NEED: 8+ m primary, facility-class UV spectrograph, large photon-counting UV detectors



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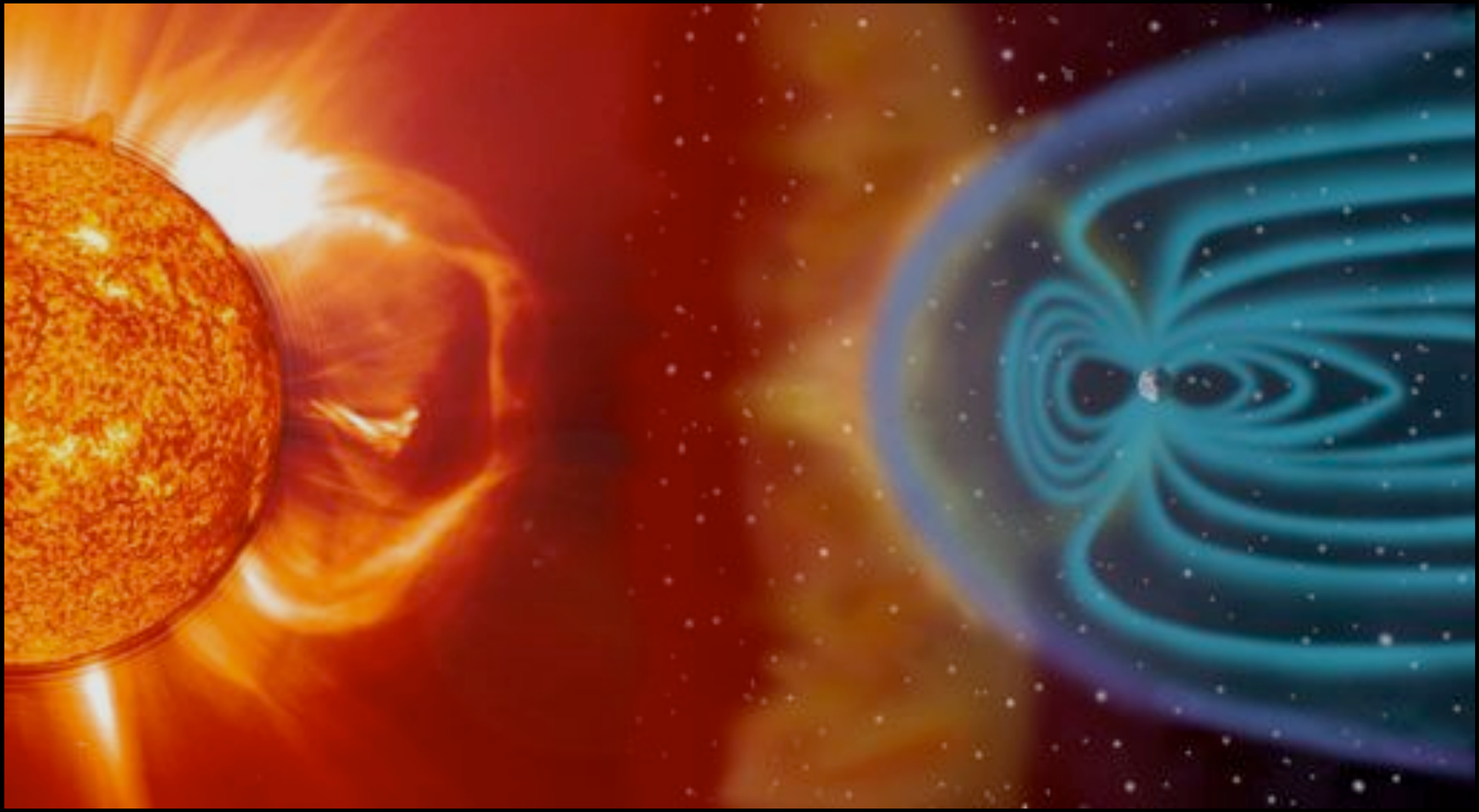
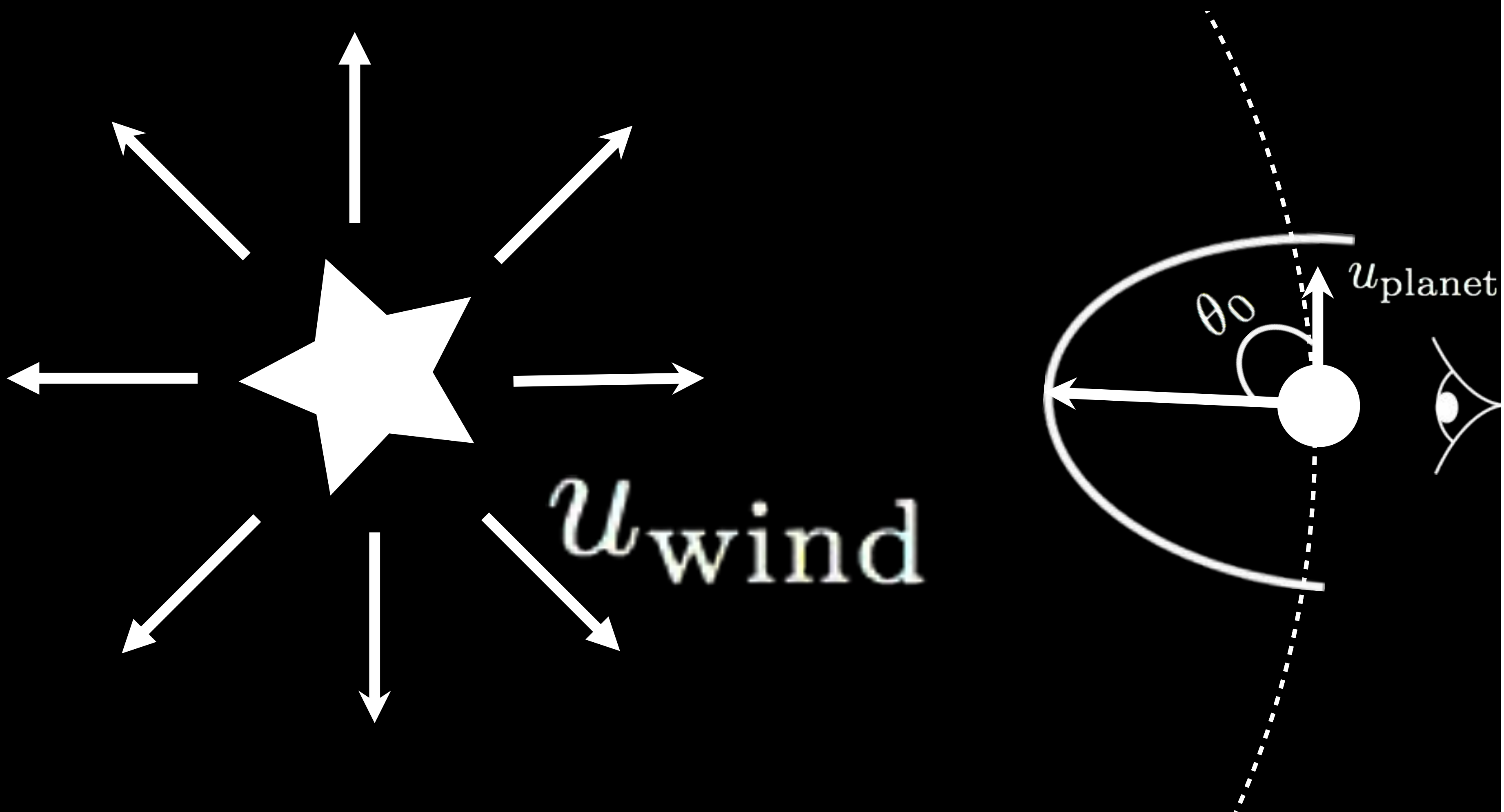
Slides from Joe Llama – Lowell Obs

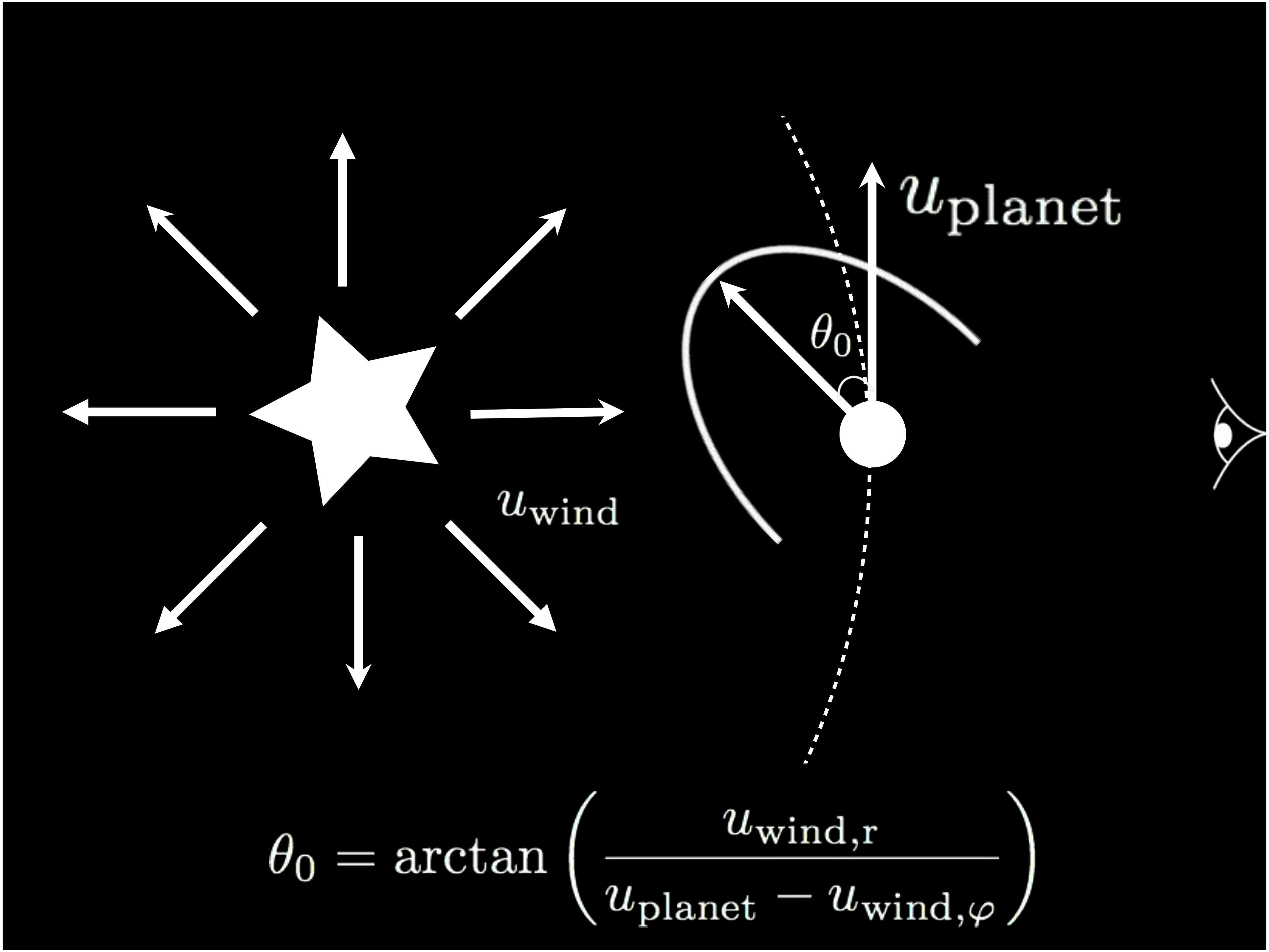


Stellar wind

Vidotto et al. 2010: Interaction between stellar wind and planetary magnetic field causes compression.



$$\theta_0 = \arctan\left(\frac{u_{\mathrm{wind,r}}}{u_{\mathrm{planet}} - u_{\mathrm{wind},\varphi}}\right)$$


u_{planet}
θ_0
u_{wind}
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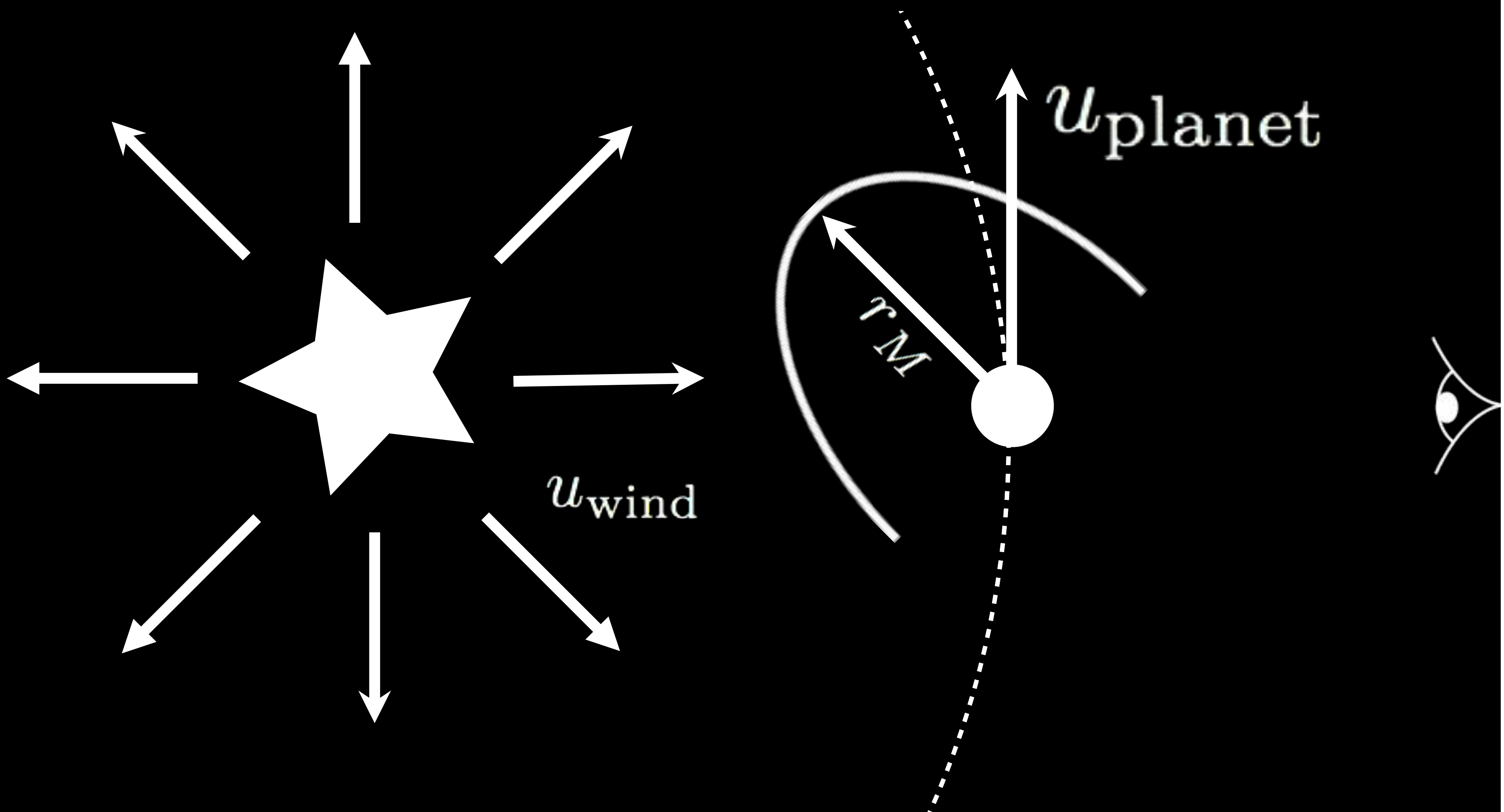
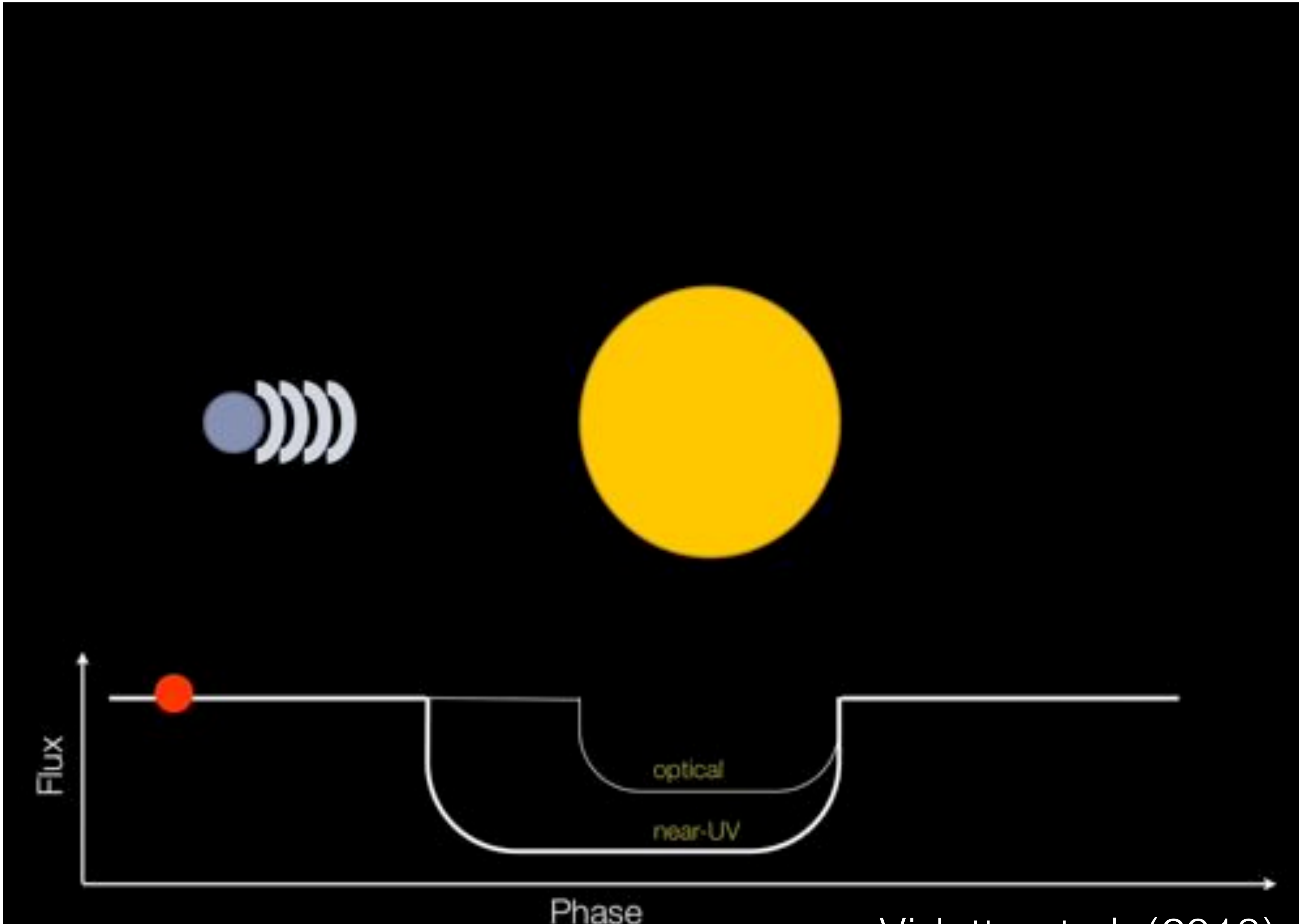
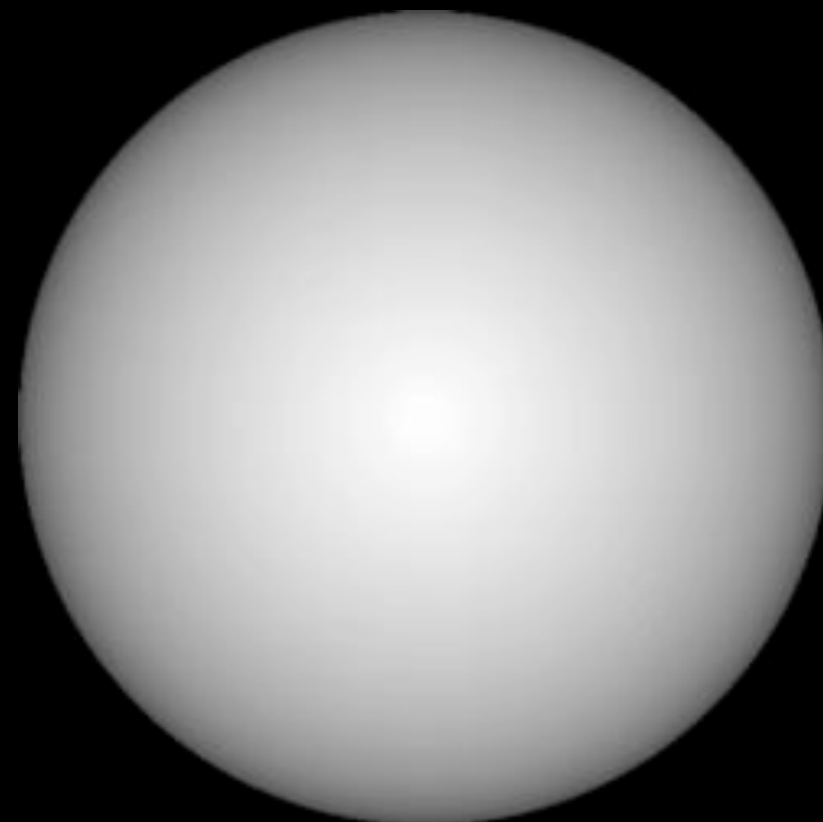


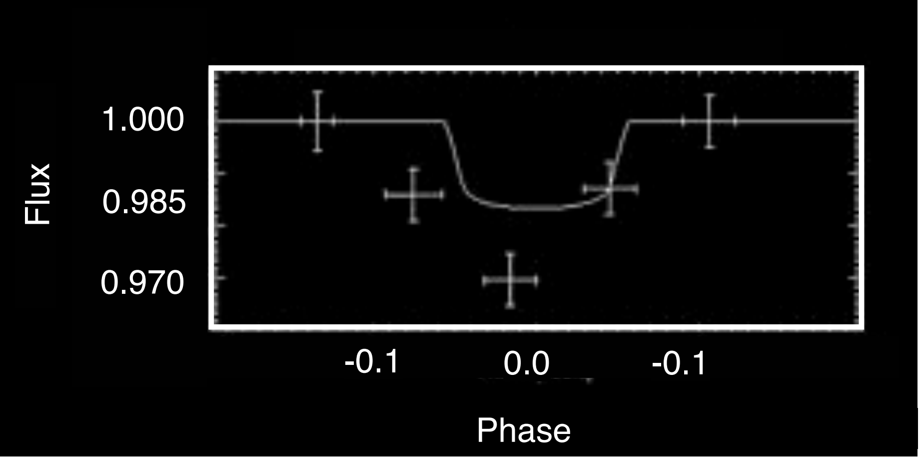
$$B_{\mathrm{planet}}(r_M) = \frac{B_*}{2}\left(\frac{R_{\mathrm{planet}}}{r_M}\right)^3$$



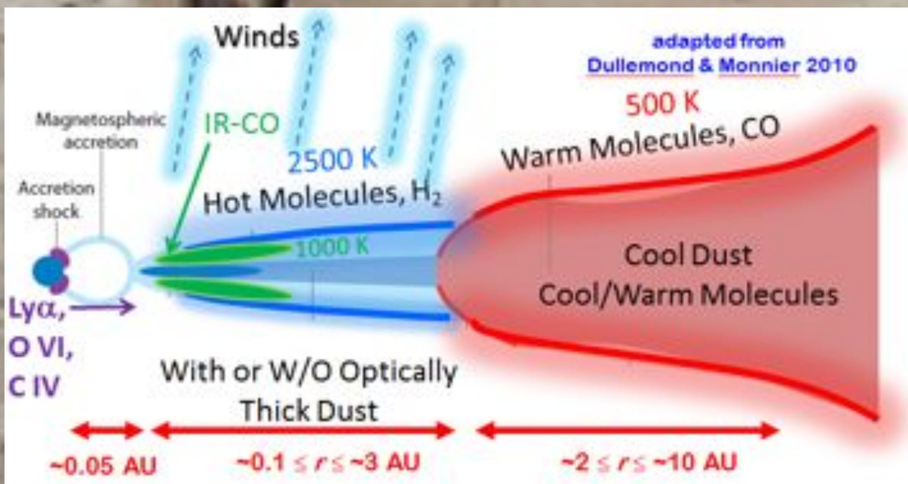
Vidotto et al. (2010)

- **Llama et al. (2011):**
  - Potential detection of a magnetic field around WASP-12b.
  - Magnetosphere protects the atmosphere to ~5 Rp.
  - Bp ~ 24 Gauss.
  - ArXiv: 1106.2935



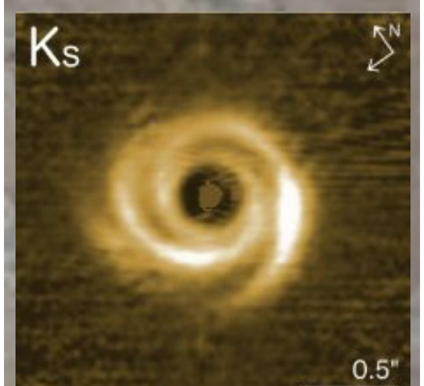


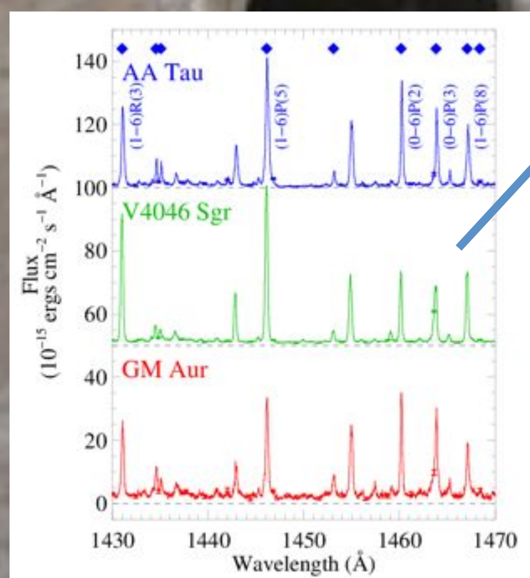
Composition, Distribution, and Lifetime of Molecular Gas at *r* < 10 AU in Protoplanetary Disks



- The far-UV and Lyman-UV have the strongest dipole-allowed transitions systems of H_2 and CO. Resolved spectral line profiles contain information about the 3-D distribution of gas inside 10 AU in disks with ages ≤ 30 Myr

- Survey of ~40 protoplanetary systems with *HST*-COS, characterizing the H_2 disks and discovering fluorescent CO in these environments (*France+ 2011, 2012; Hoadley+ 2015*)





Garufi+ (2013) ; France+ (2012)

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(w/ Herczeg, Brown, Alexander, et al.)

SIG2 UVOIR Workshop, June 2015

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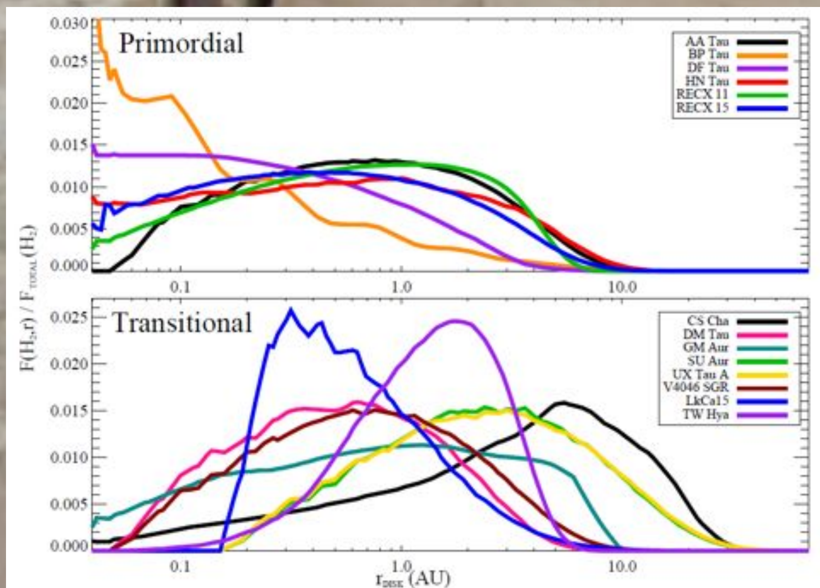
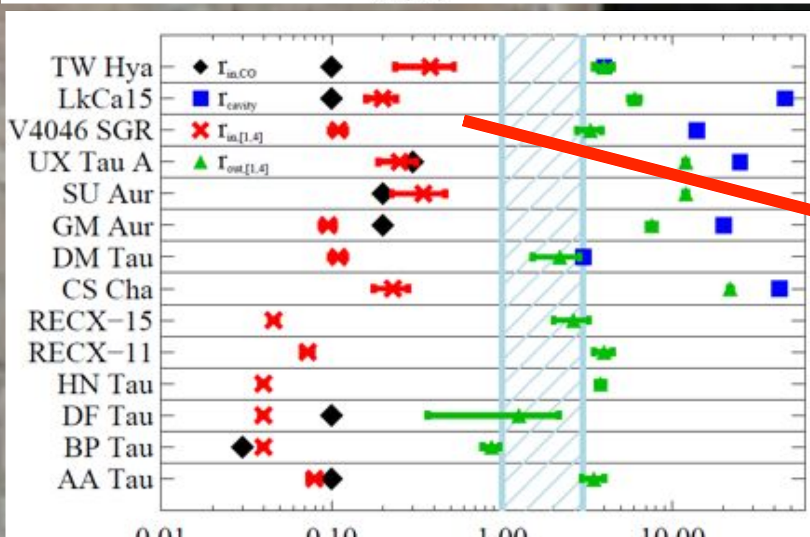
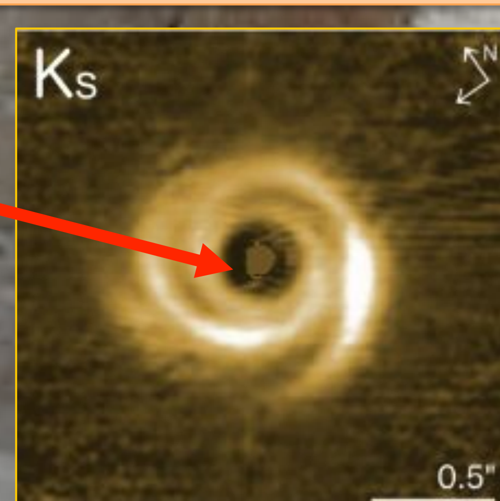




Hoadley+ (2015)

- UV and IR data finds molecular gas inside gust gaps to be ubiquitous. Possible signature of forming protoplanetary systems.
- UV lines of H_2 & CO - Sensitive to extremely small amounts of gas, period of transition to debris disks: primordial gas disk lifetime.
- MOS with R = 3000-5000 could survey hundreds/thousands of disks



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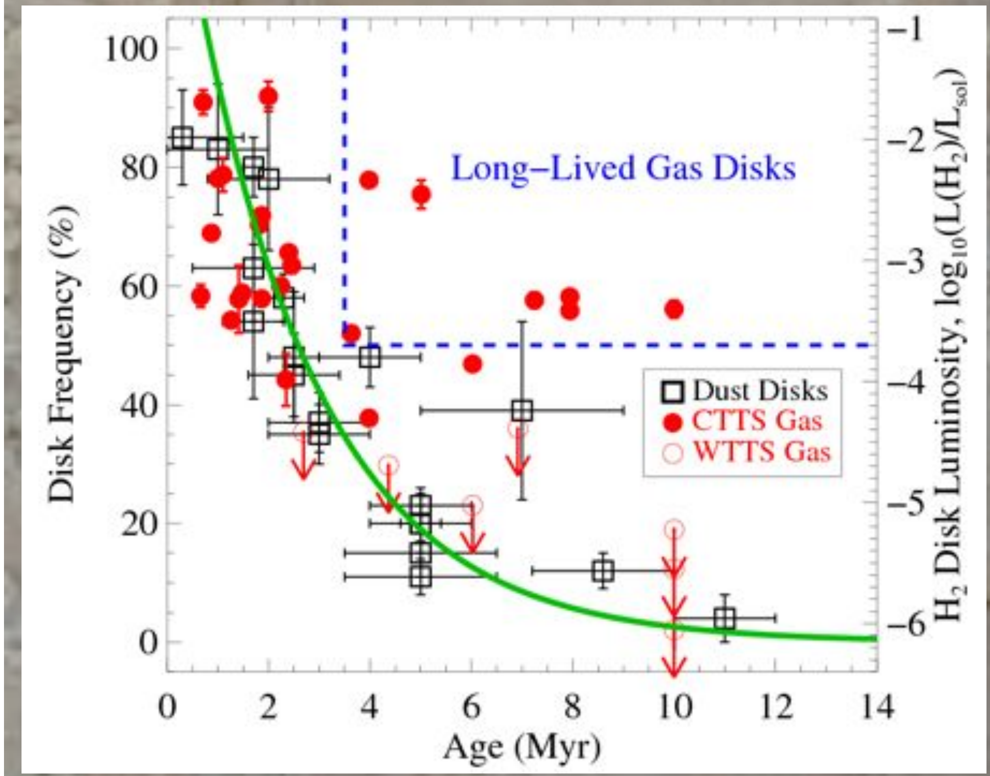

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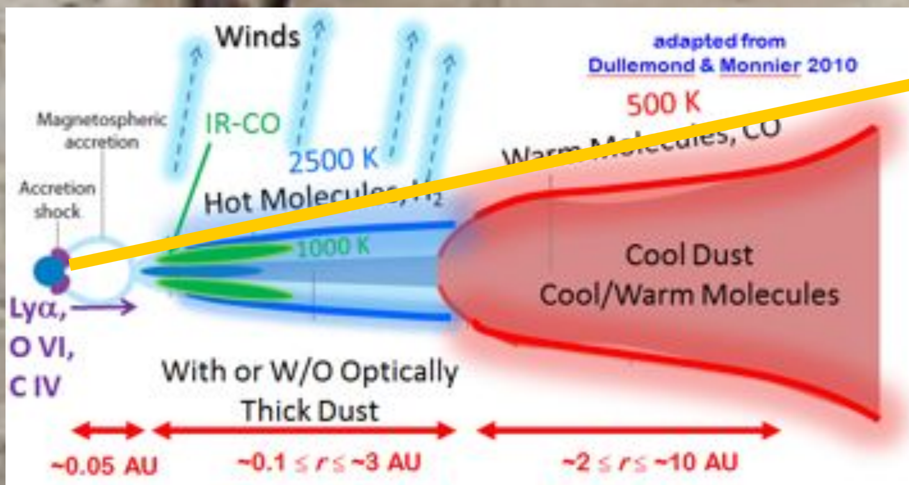
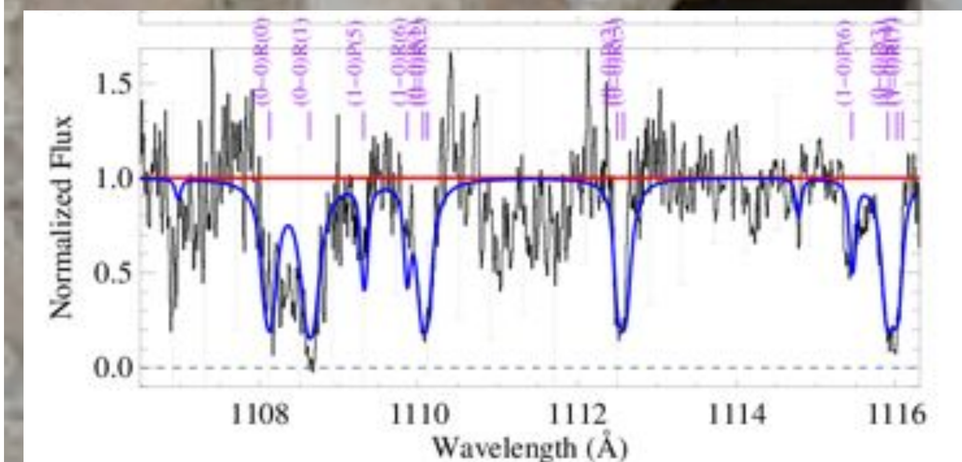
Composition, Distribution, and Lifetime of Molecular Gas at $r < 10$ AU in P…ary Disks





First cool H_2 absorption detection towards a low-mass protoplanetary disk, France+ (2014b).
$F_{cont} \sim 2 \times 10^{-15}$ erg cm^{-2} s^{-1} Å^{-1}

- Larger samples in a range of star-forming environments are necessary to provide a complete picture of the composition, structure, and lifetime of gas disks.
- Higher sensitivity + high-resolution far-UV absorption line spectroscopy of CO, H_2, and H_2O enable quantitative compositional analysis
- NEED: 8+ m primary, facility-class UV echelle spectrograph, advanced UV coatings for 100 - 120 nm region

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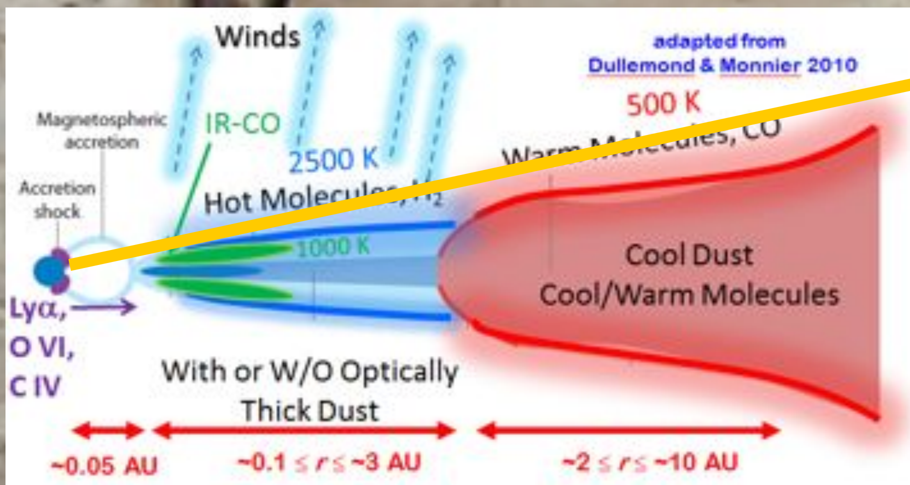
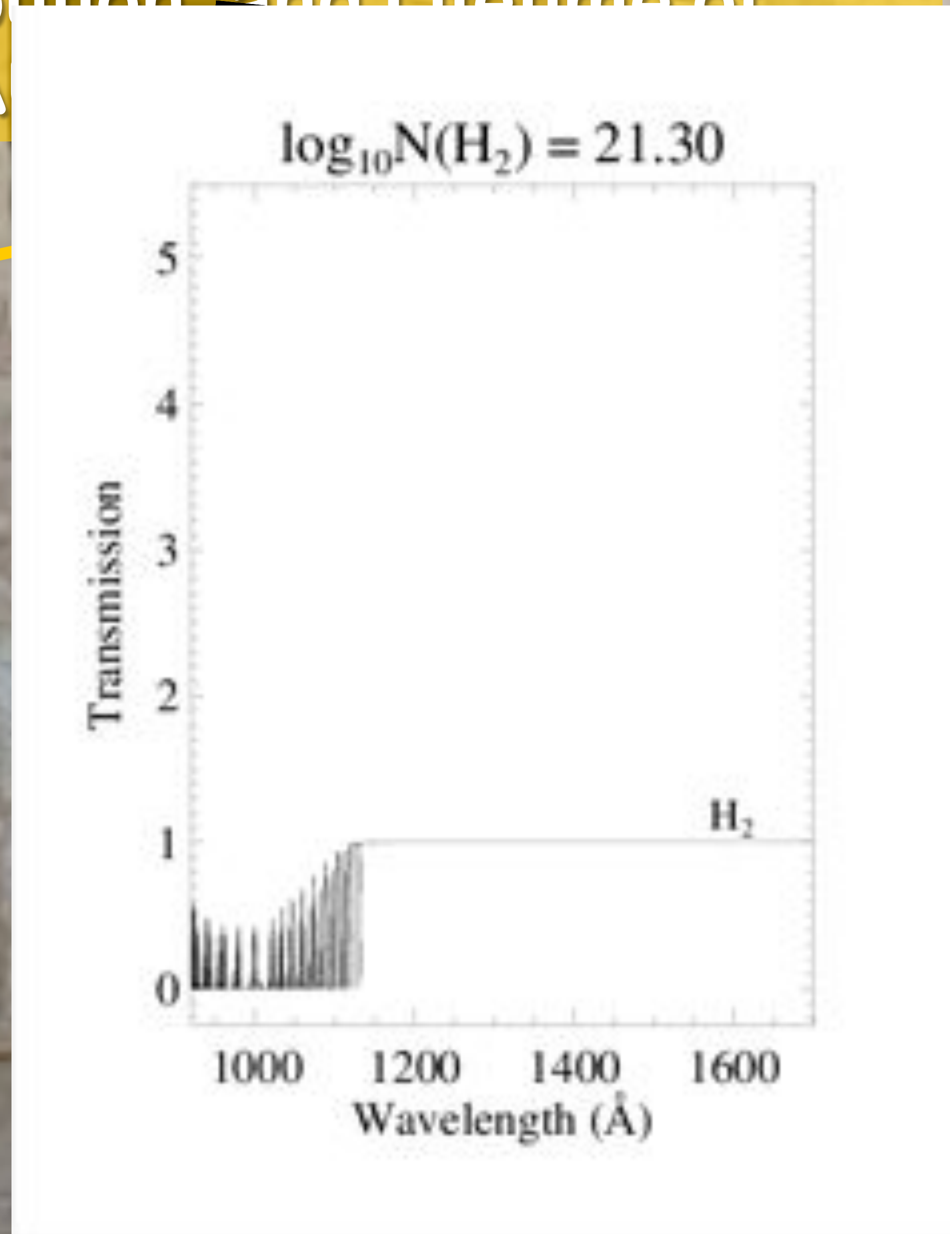
Composition, Distribution, and Lifetime of Molecular Gas at *r* < 10 A





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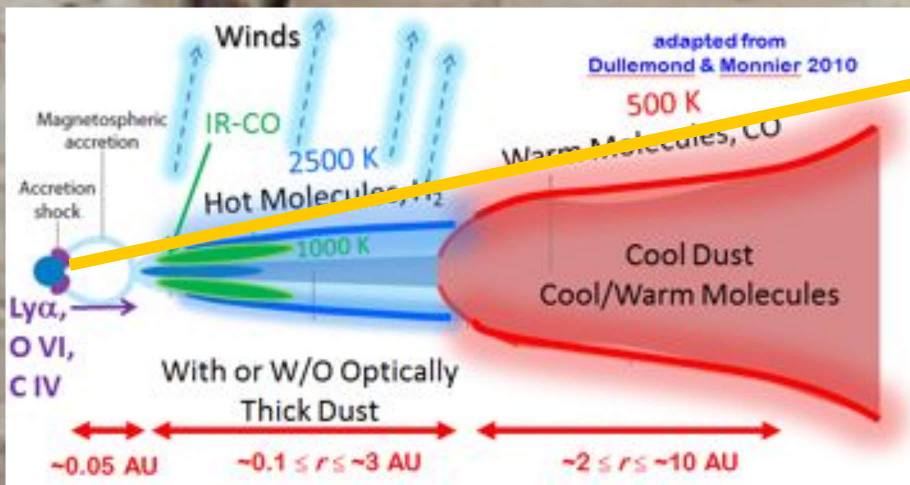

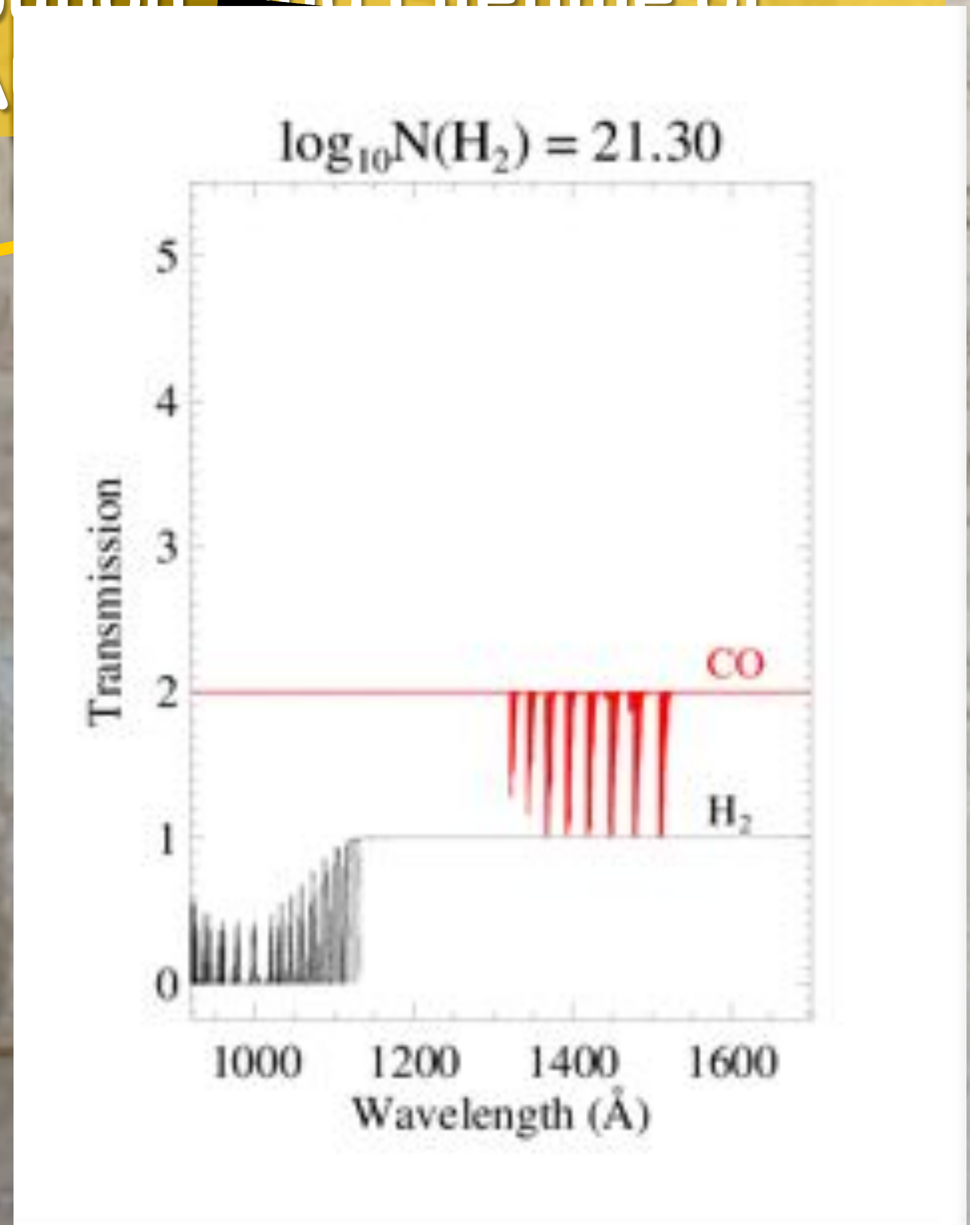

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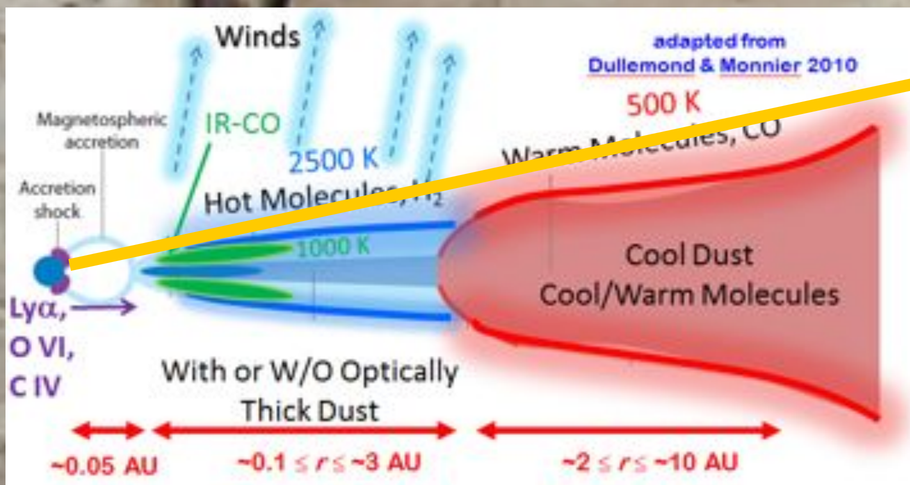

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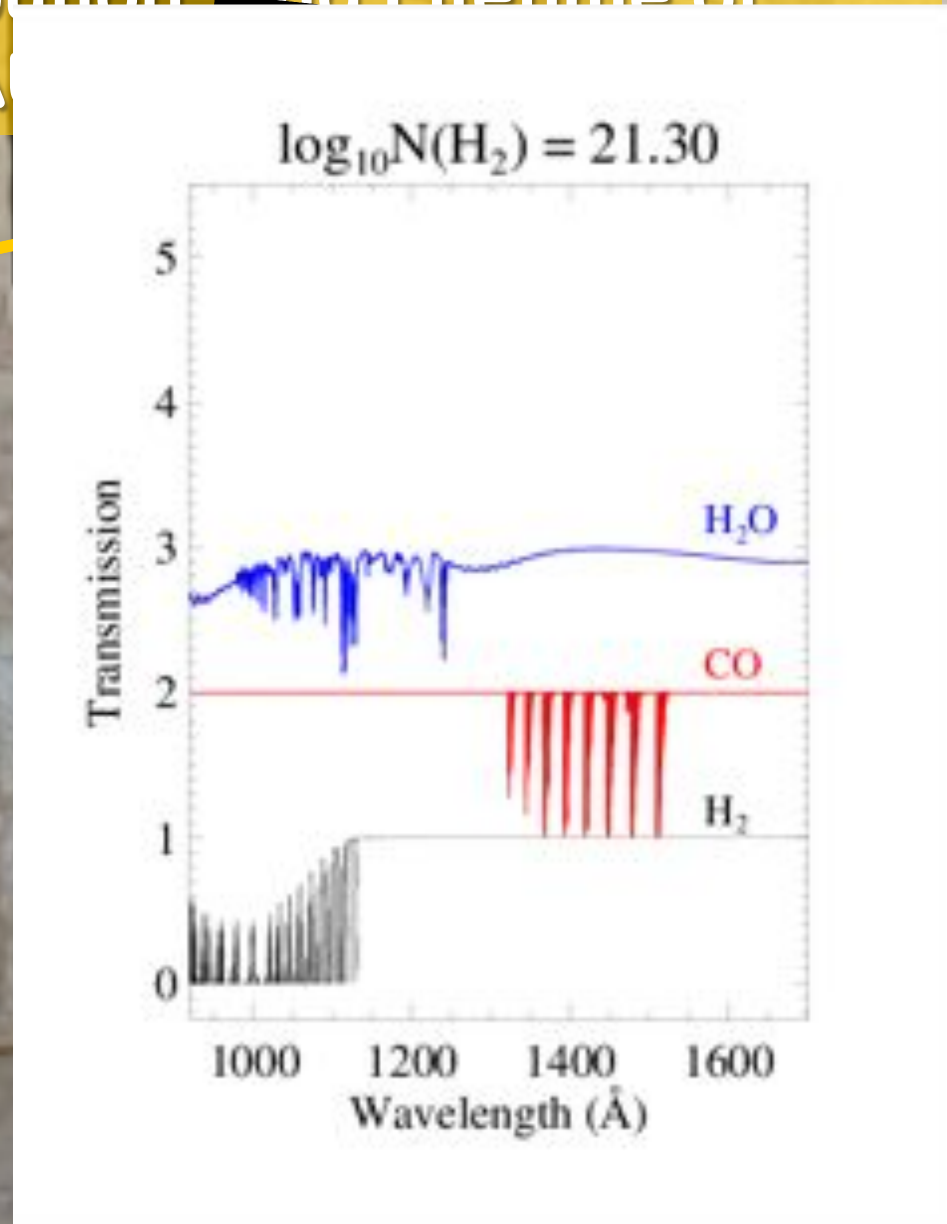

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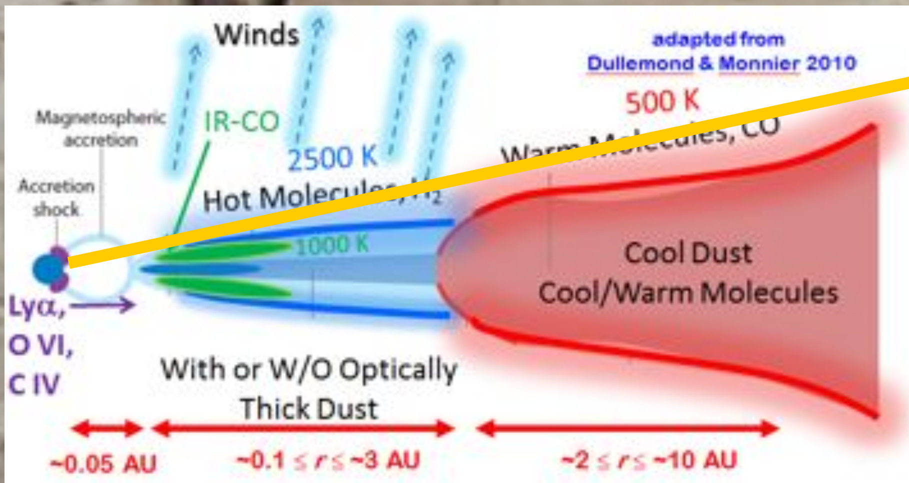

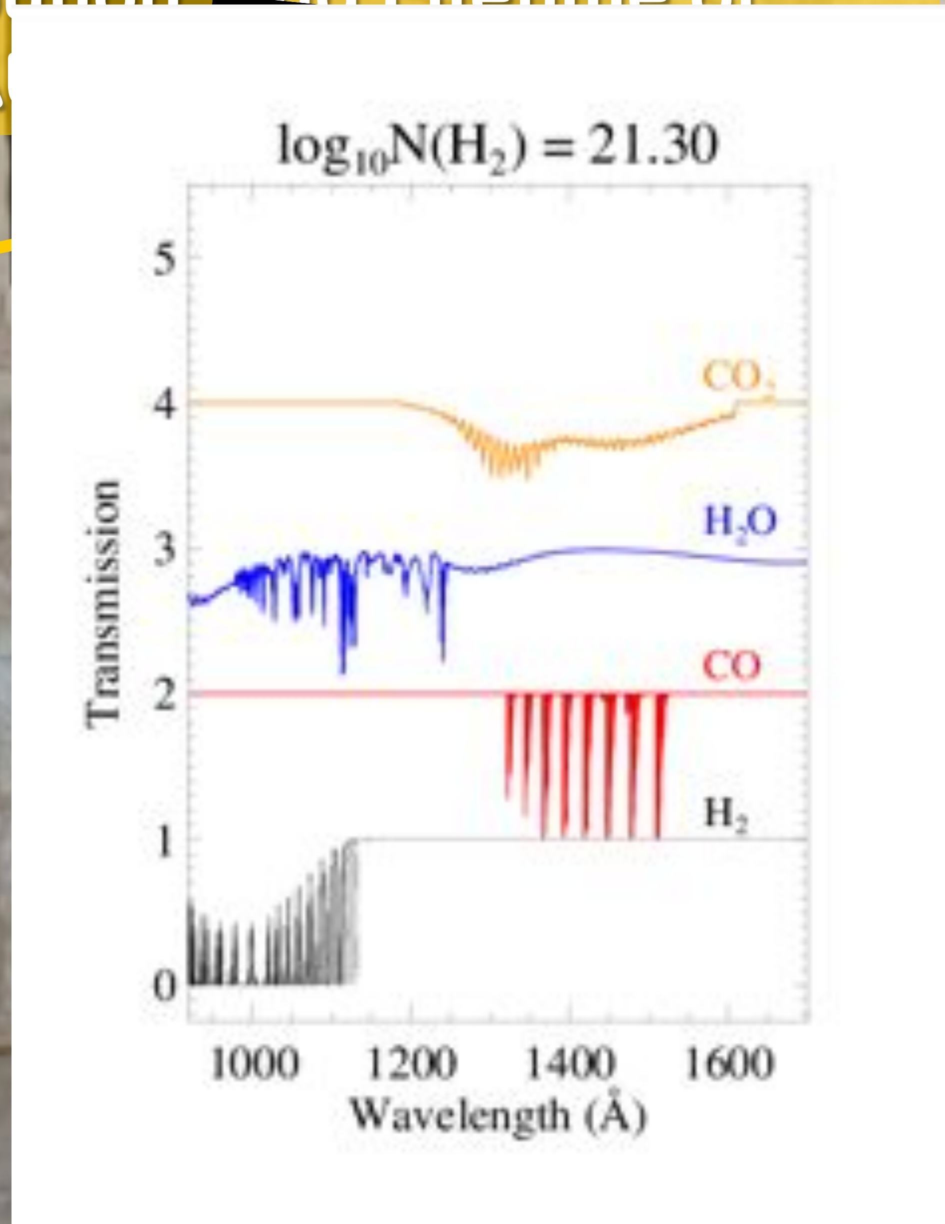

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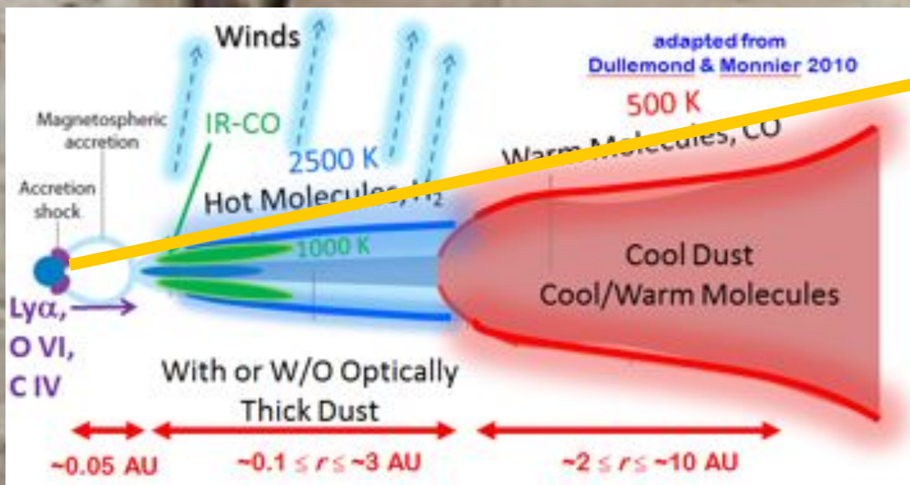

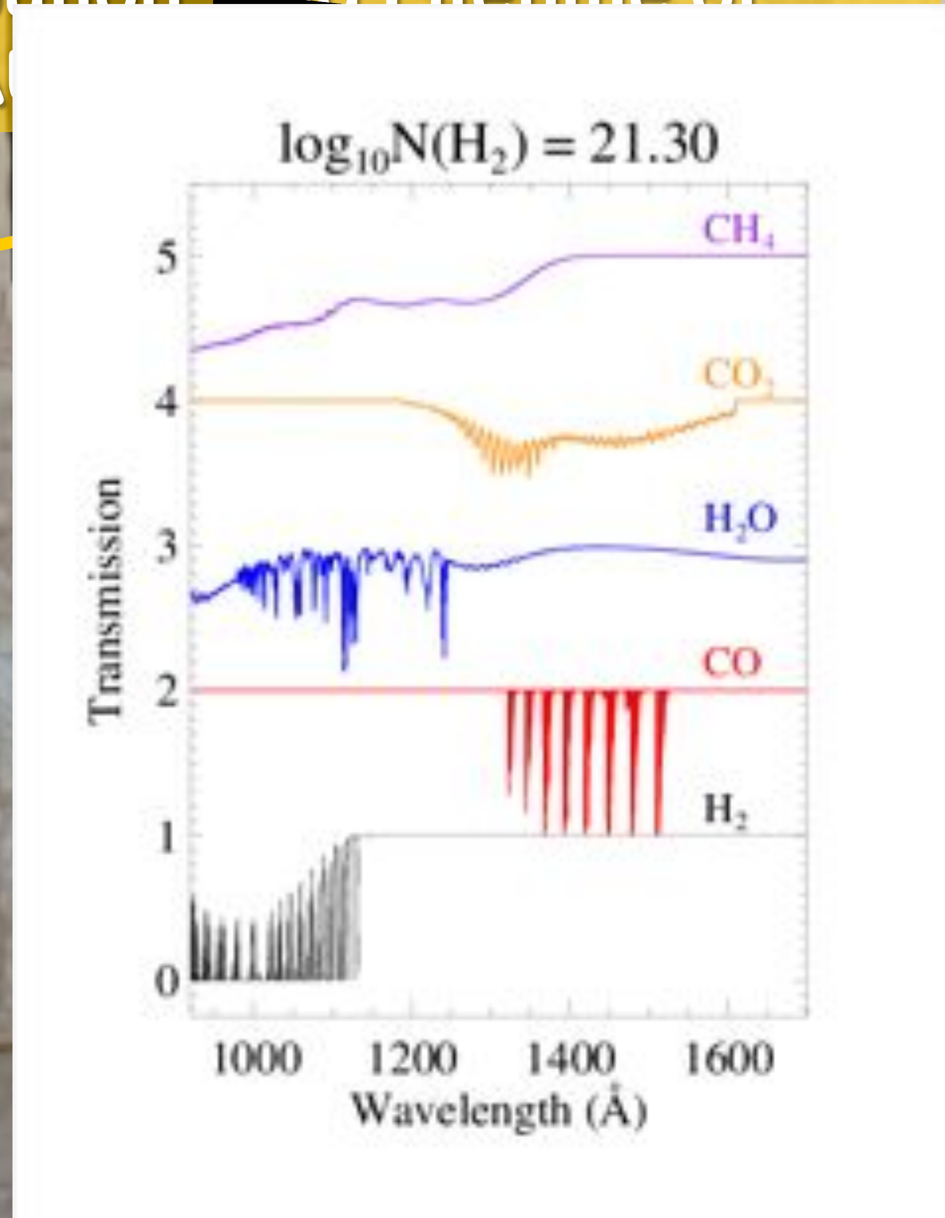

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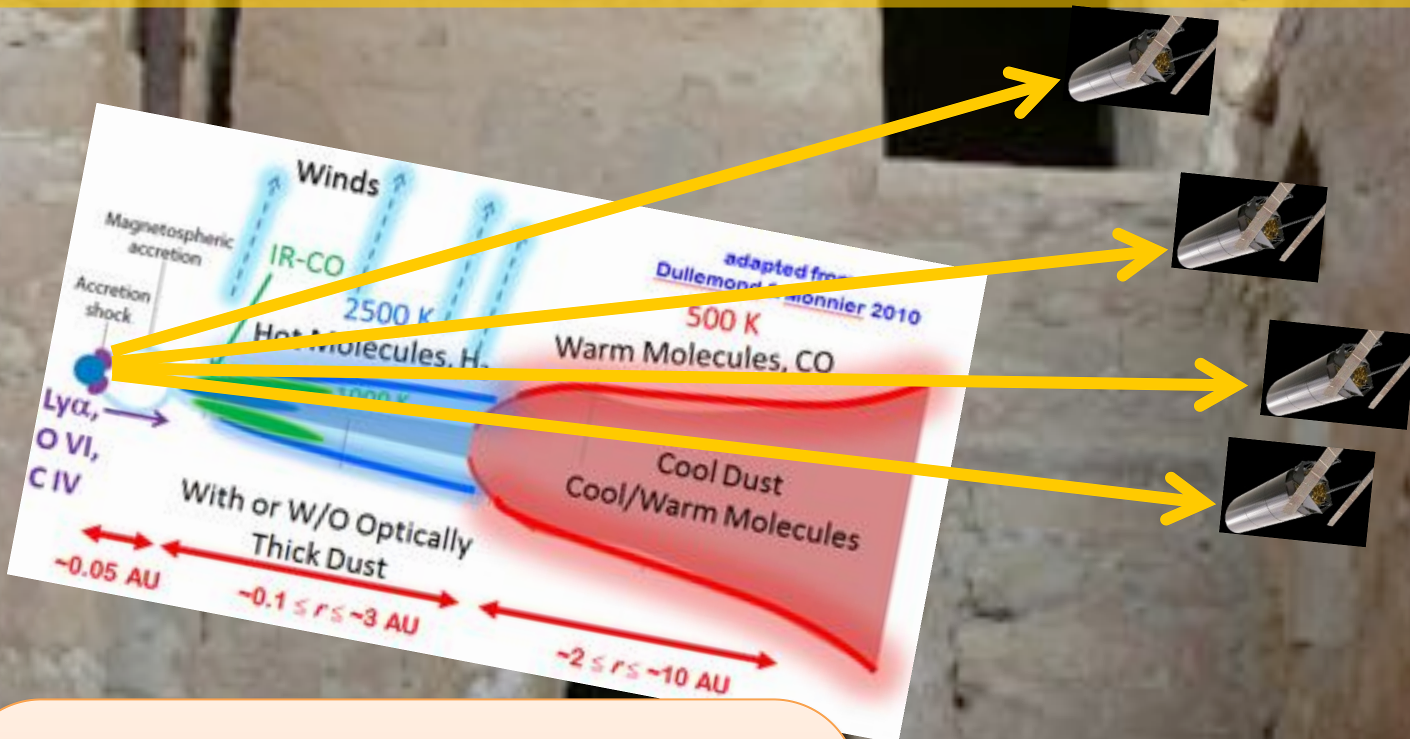

- Inclination of a large number of disks can be known from SMA and ALMA
- ***Distribution of inclination angle and ages allows 4-D mapping of disks [r,h,t,λ]***
- Telescope aperture determines how close to the disk midplane you can probe (current record for UV spectroscopy: $A_V = 7.6$)

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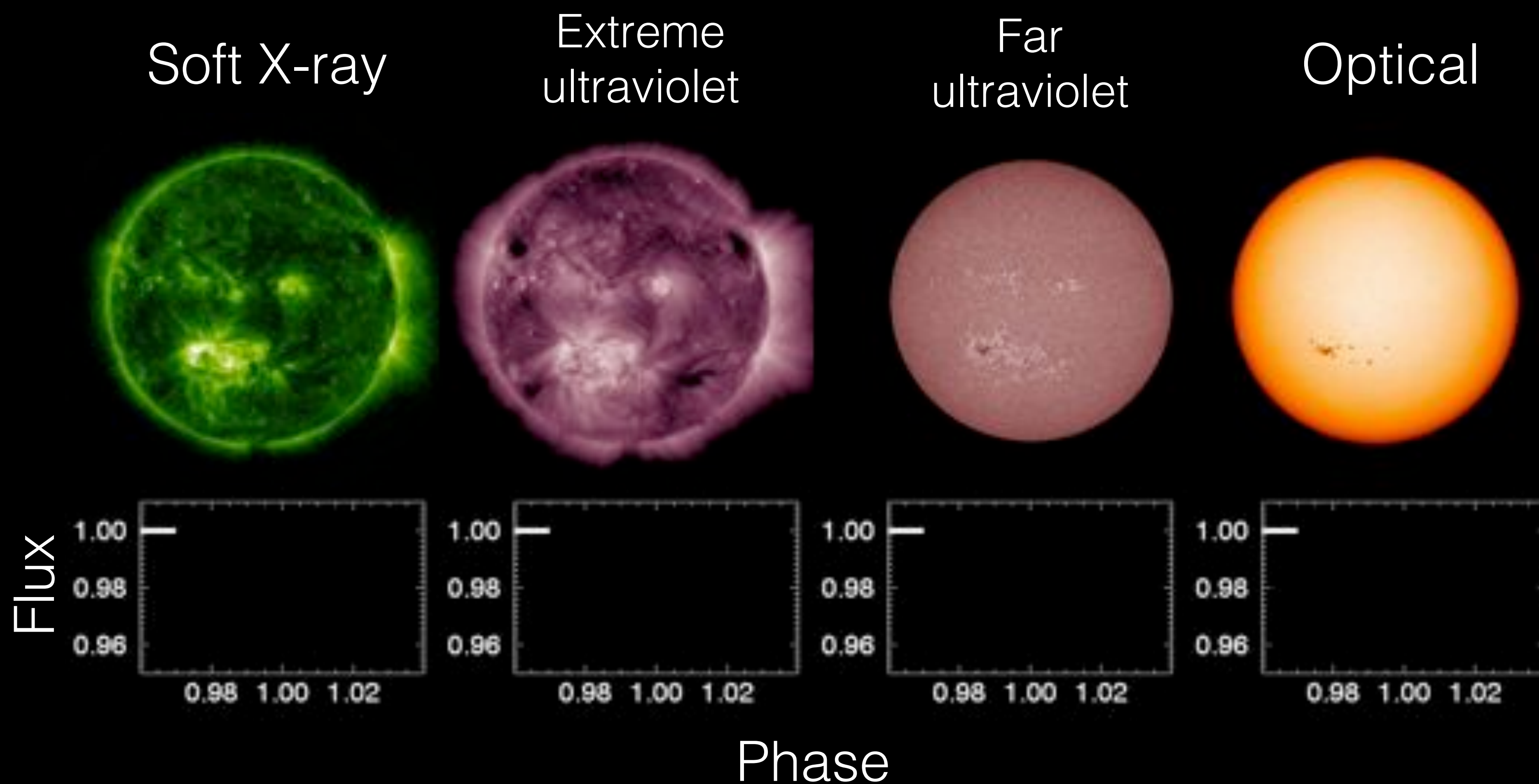
End.

Slides from Joe Llama – Lowell Obs



Llama & Shkolnik (submitted)