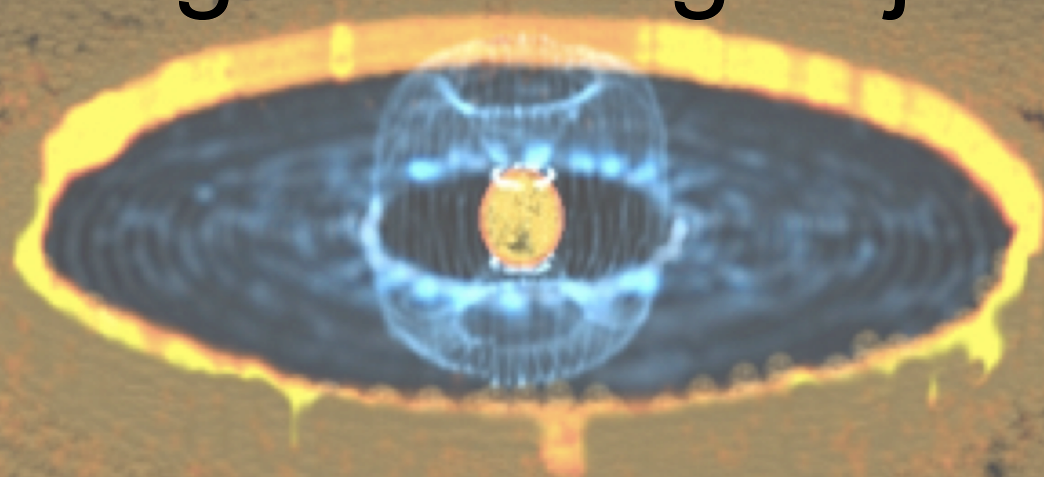
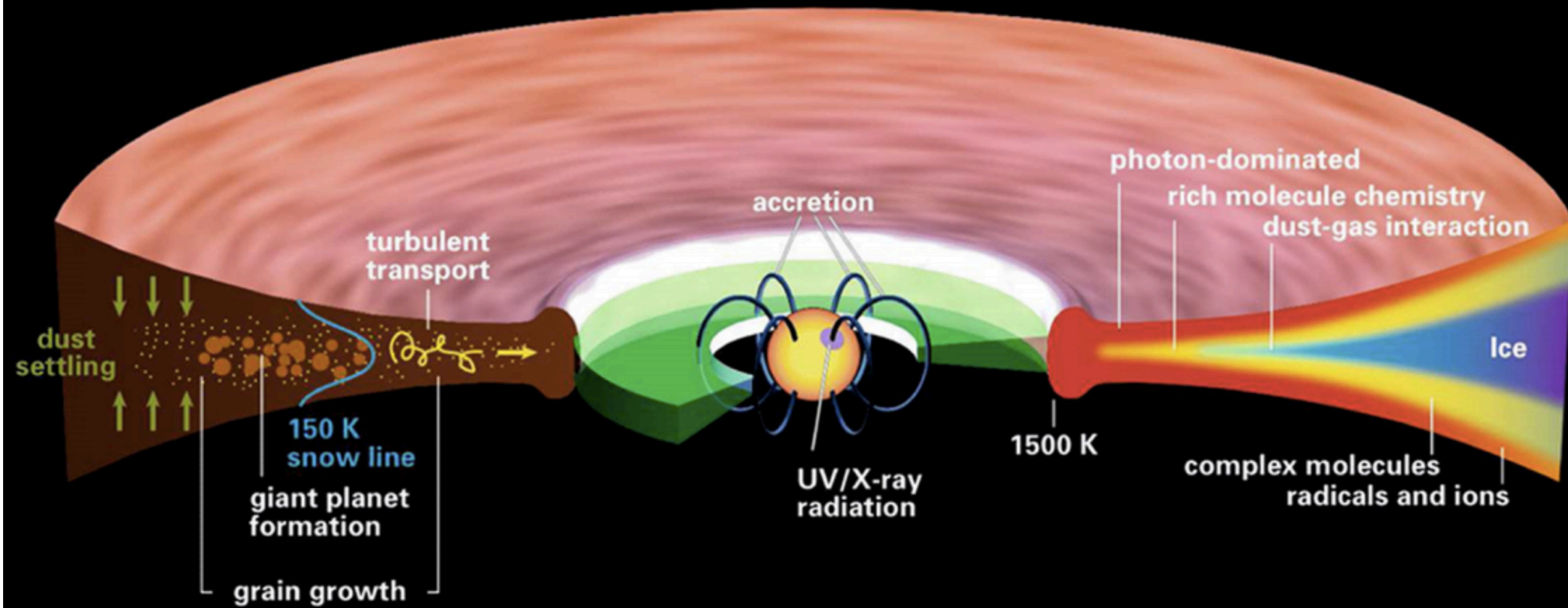
Footprints of the magnetosphere: The star-disk connection in young accreting objects



Catherine Espaillat

Boston University

Our current sketch of a protoplanetary disk



Henning & Semenov 2014

The star-disk connection in accreting stars

How do we measure accretion in young stars?

What can we learn about the star-disk connection via accretion along the stellar magnetic field?

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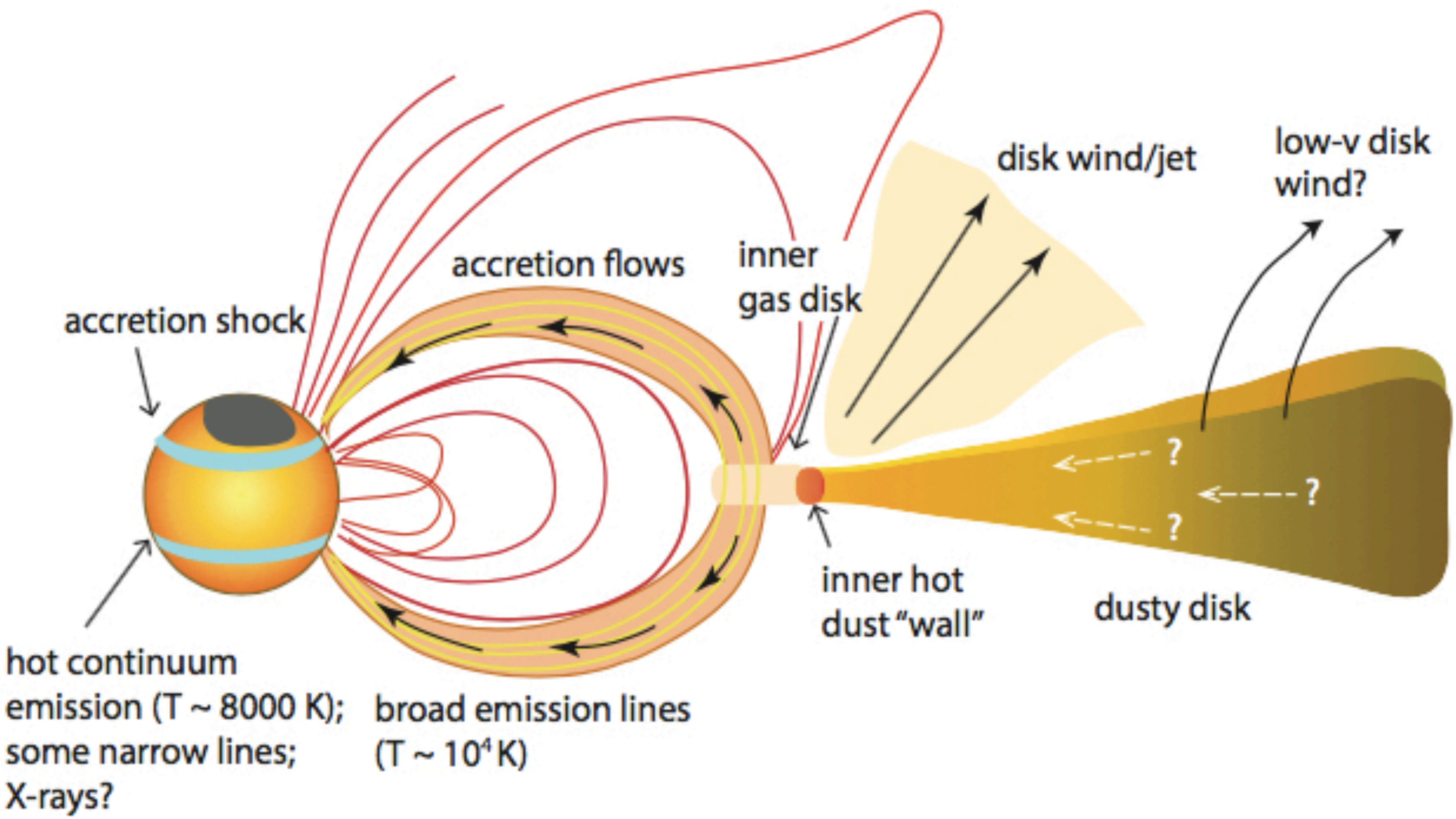
Where do we go from here?

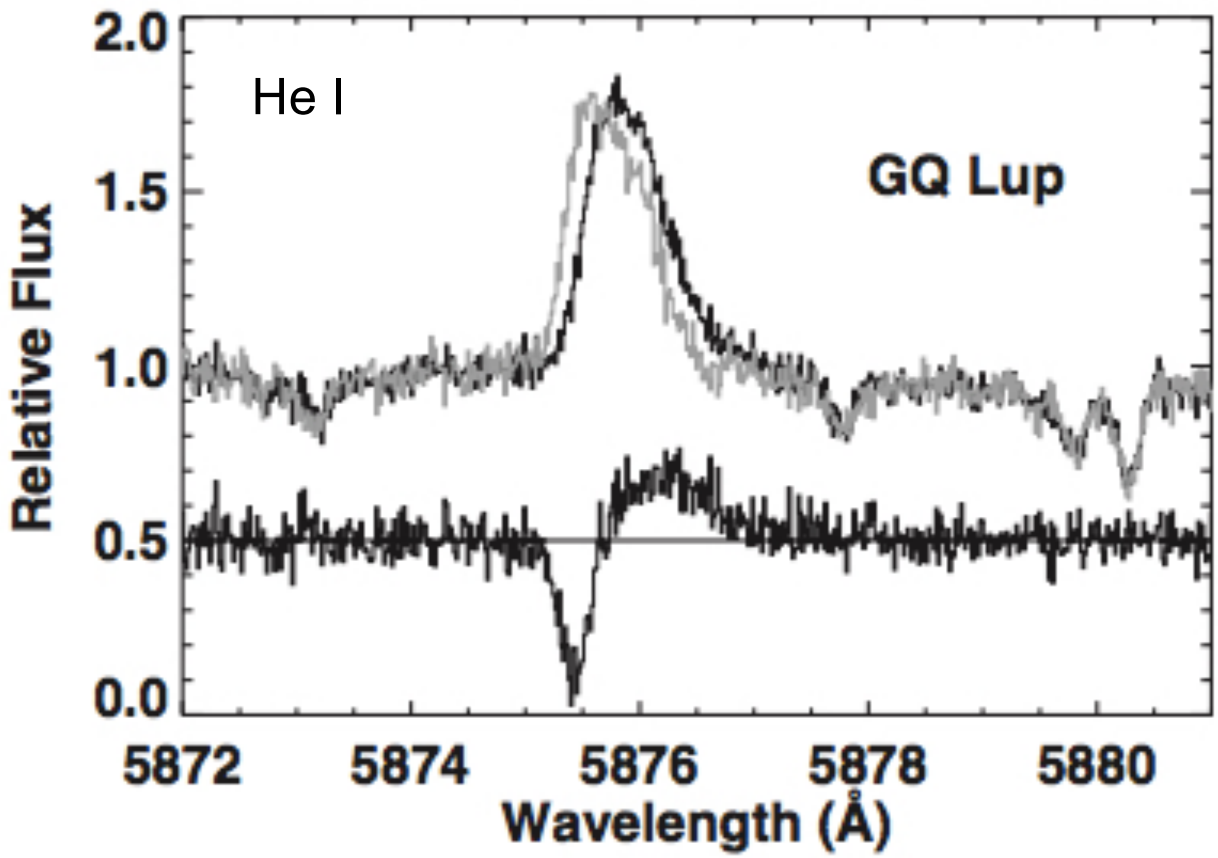
Accretion onto low-mass pre-main sequence stars thought to occur via magnetic field lines



Hartmann, Herczeg, & Calvet 2016

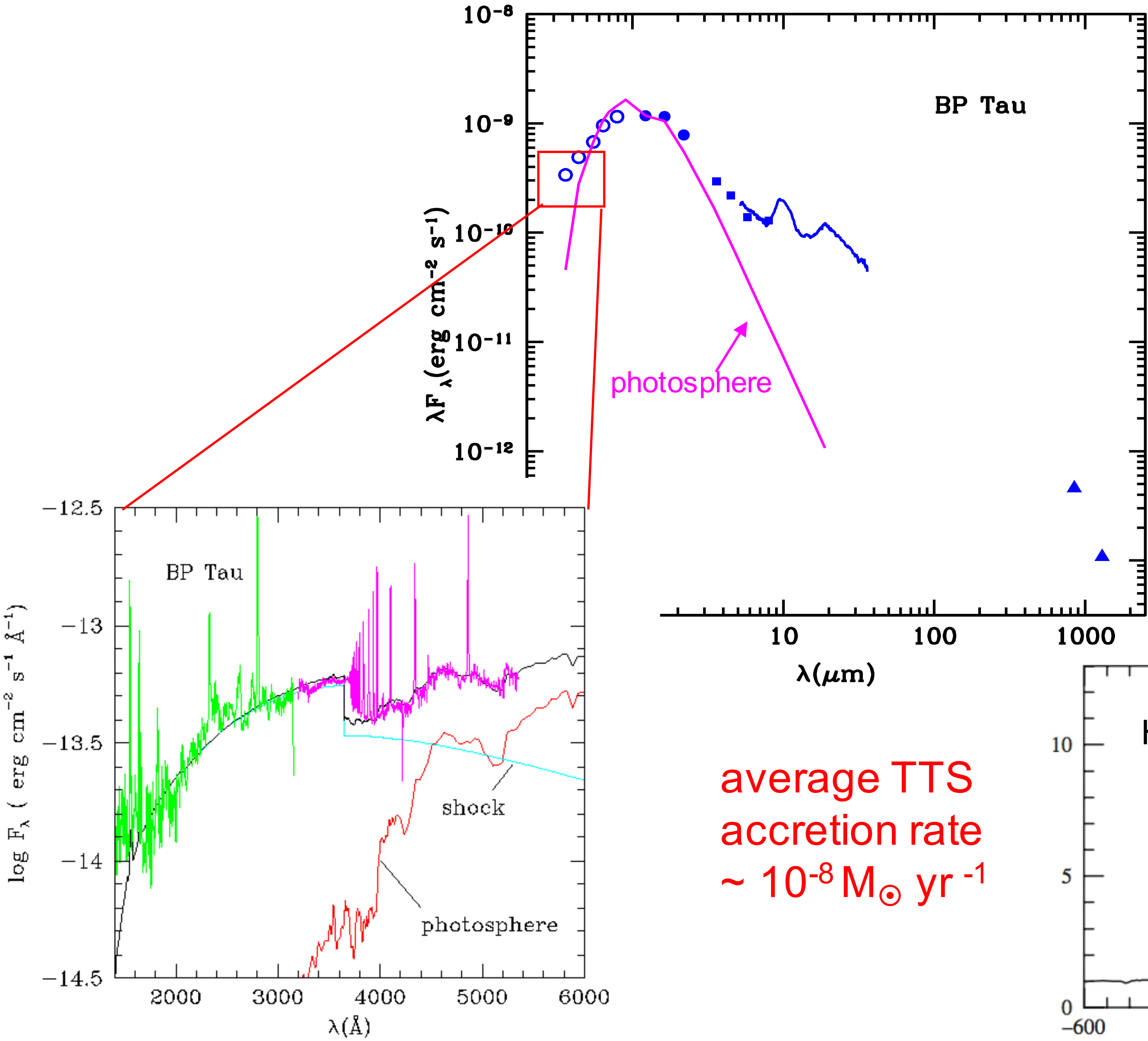
Magnetic field strengths of young pre-main sequence stars are typically ~1-2 kG

GQ Lup has highest measured magnetic field strength at ~ 6 kG

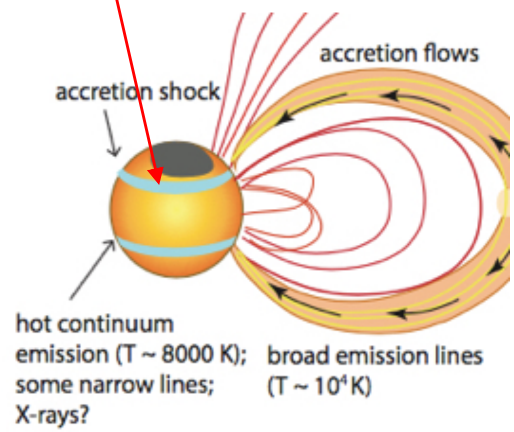


Johns-Krull et al. 2013

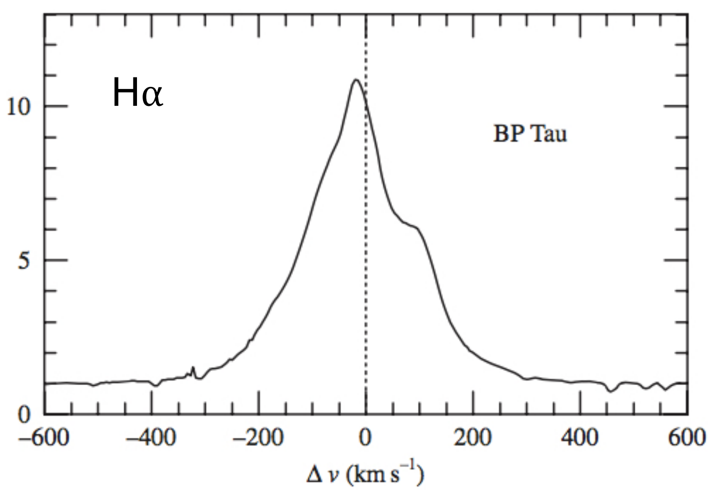
Accretion signatures in young stars



UV excess originates from accretion shock on stellar surface

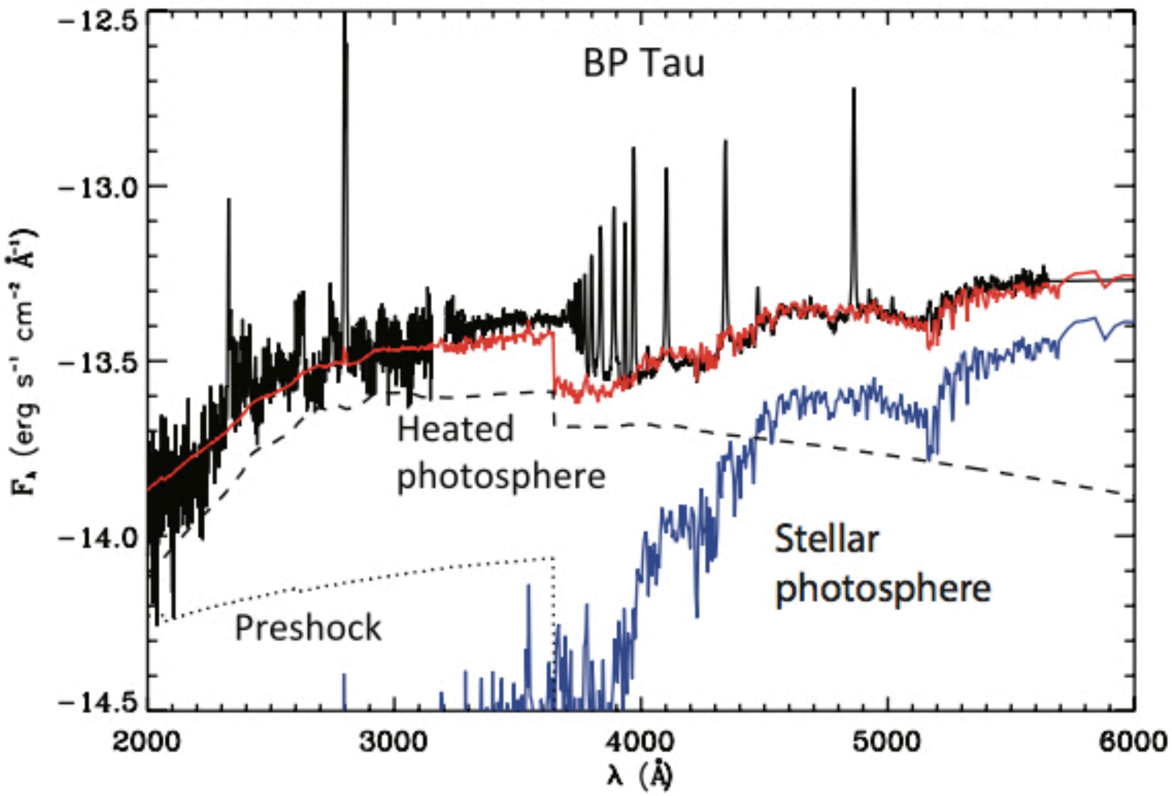


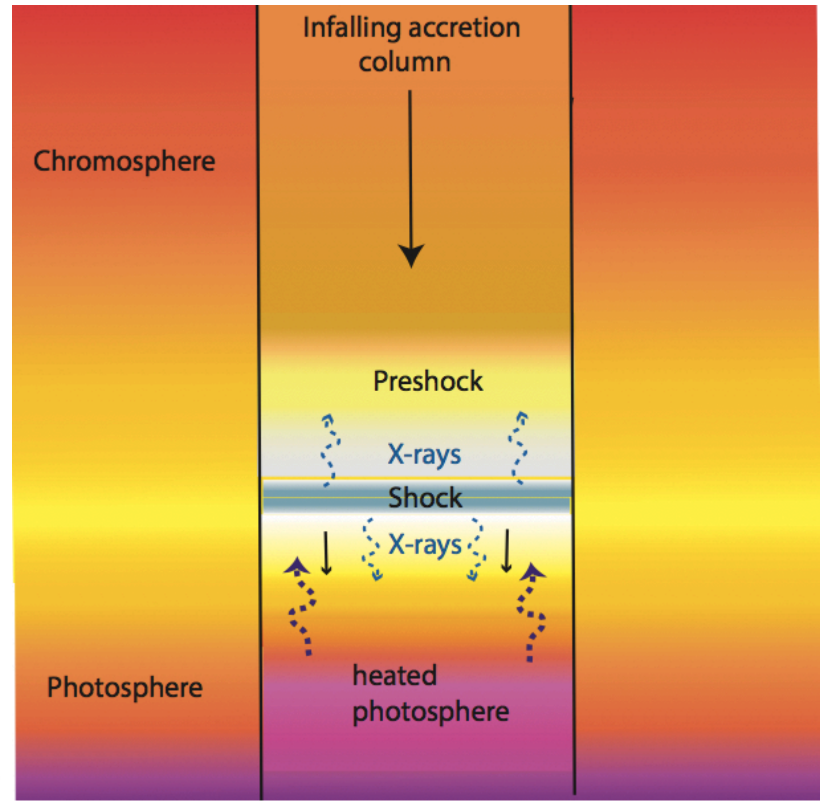
average TTS accretion rate ~ $10^{-8} M_{\odot}$ yr $^{-1}$



Calvet & Gullbring 1998

Measuring accretion rates from NUV excess emission





Hartmann, Herczeg, & Calvet 2016; Calvet & Gullbring 1998

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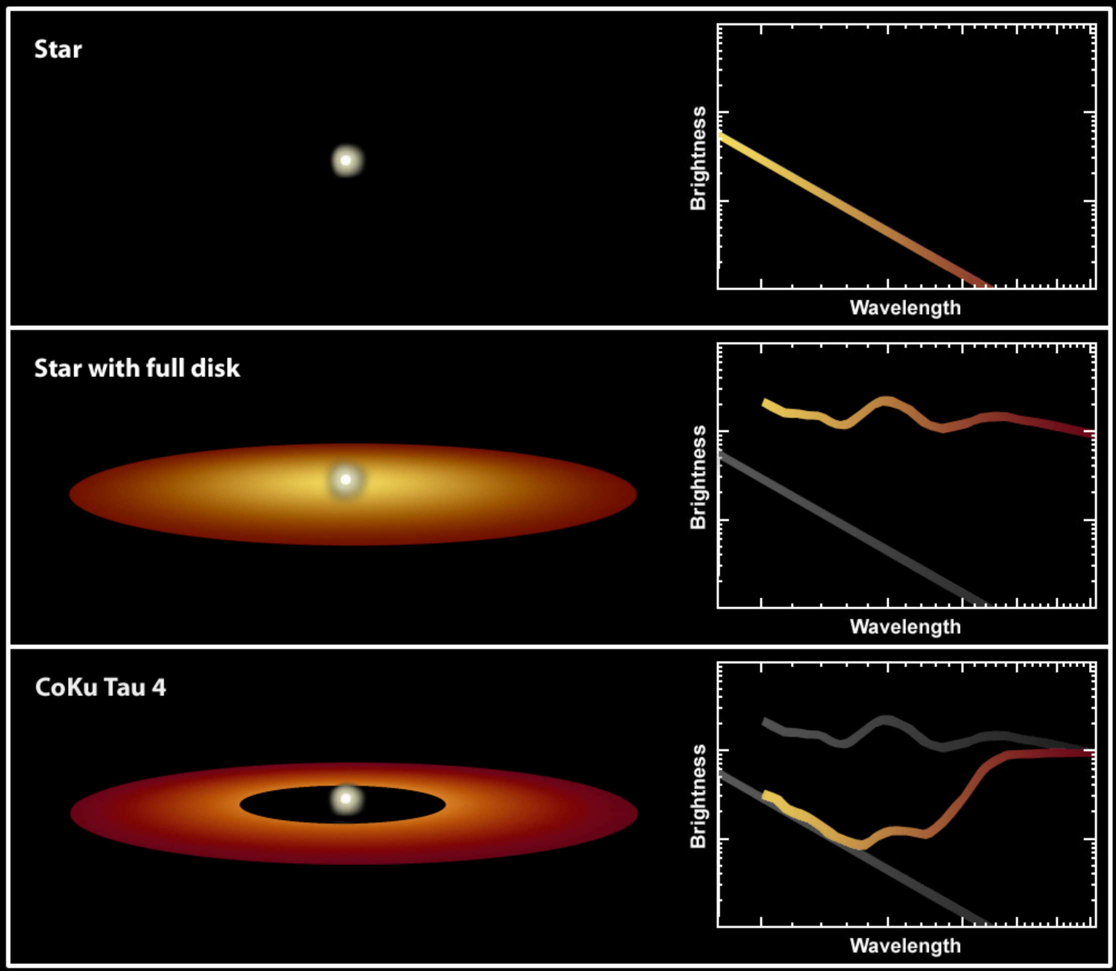
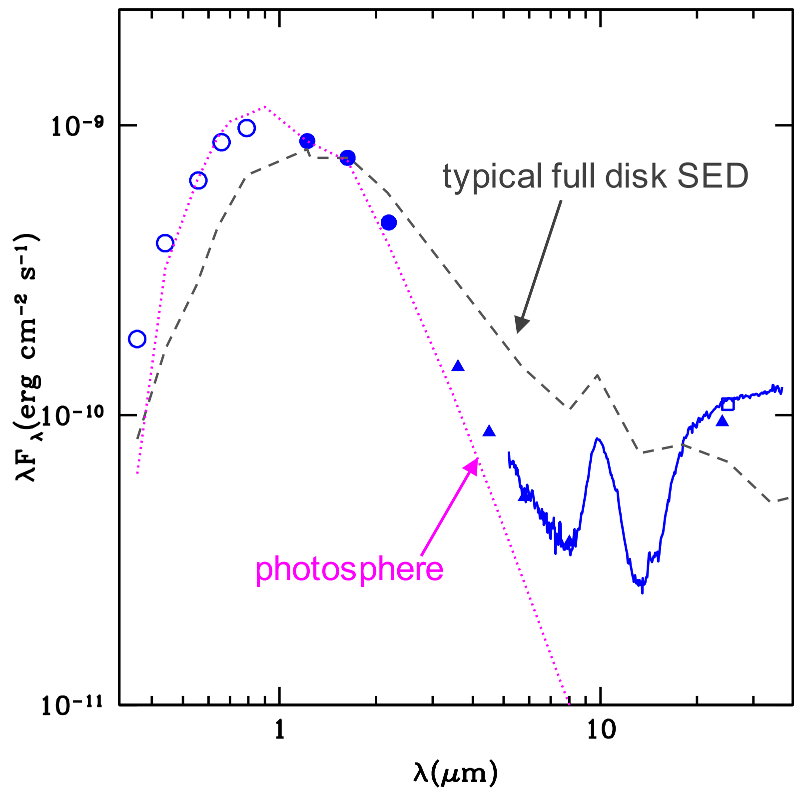
Where do we go from here?

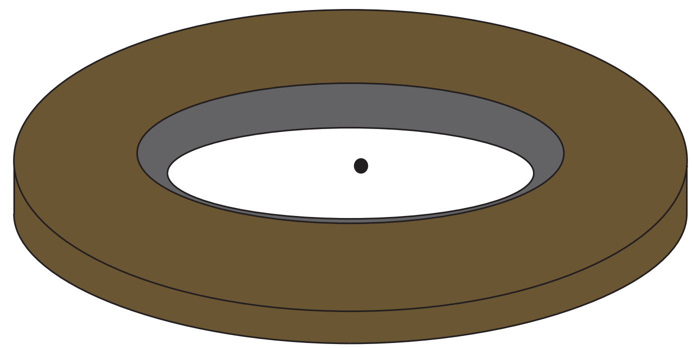
Transitional disks have IR dips in SED, indicating an inner disk hole



Some inner holes contain small, hot dust

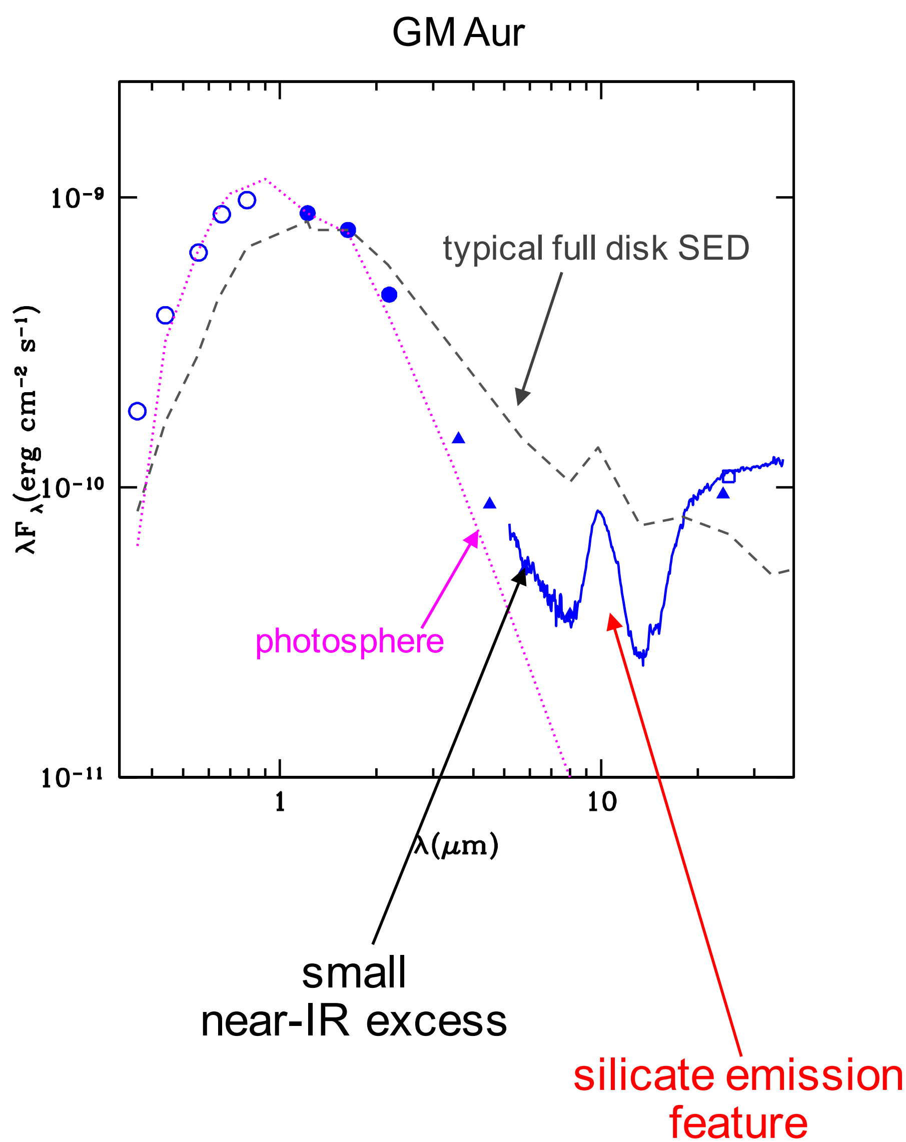
GM Aur

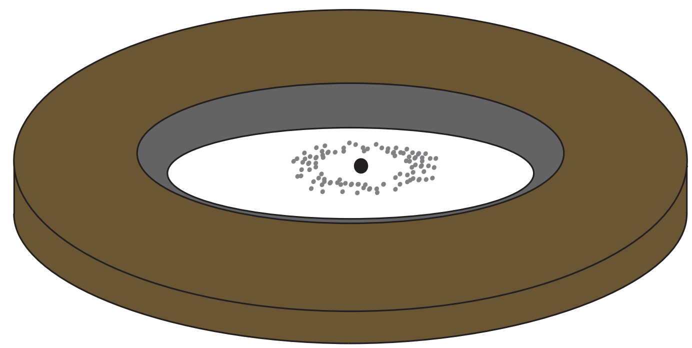




Espaillat et al. 2011

Some inner holes contain small, hot dust





Espaillat et al. 2011

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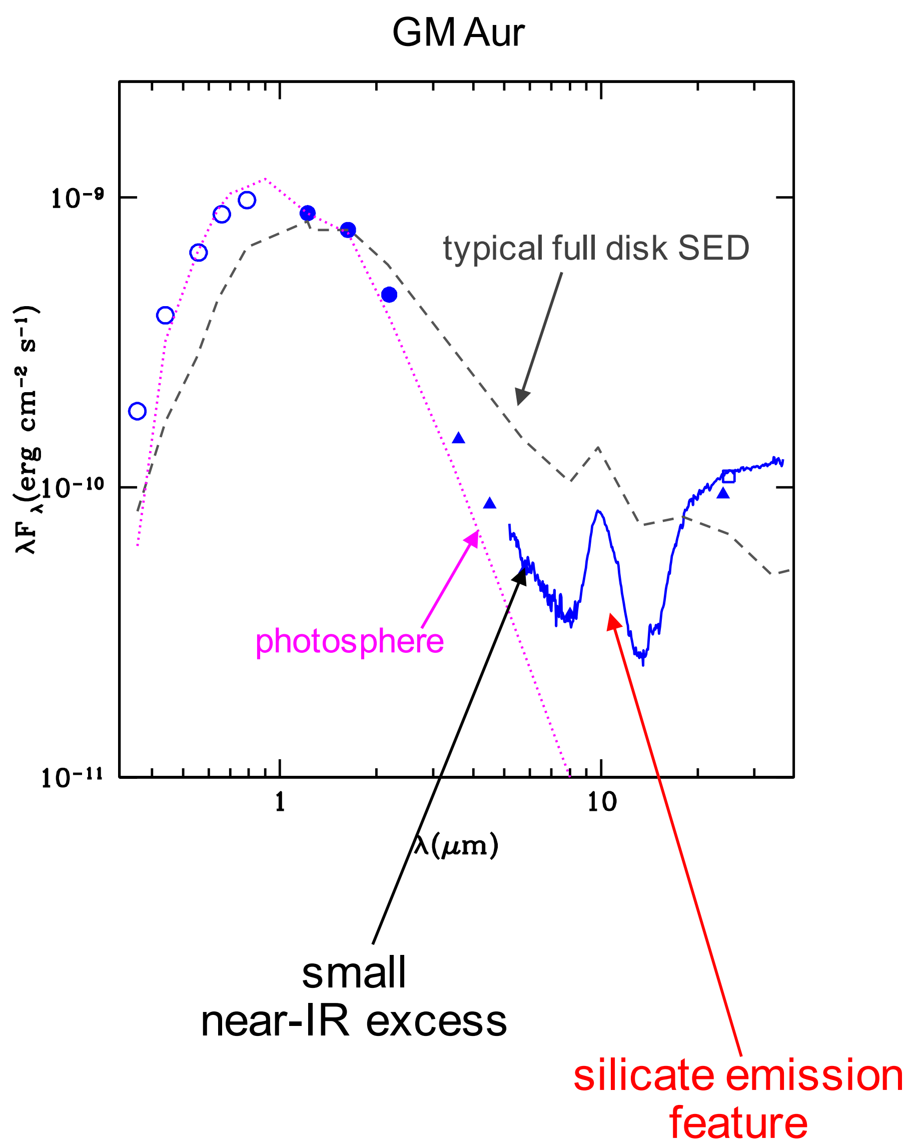
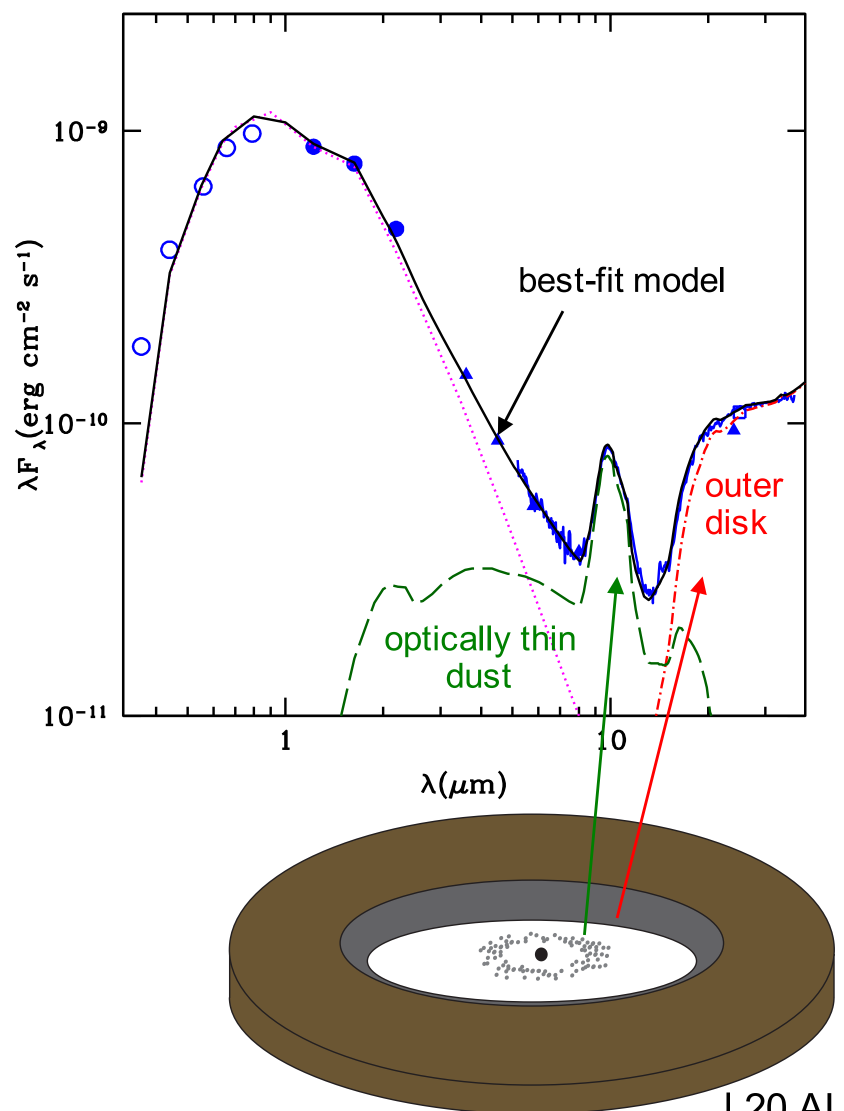
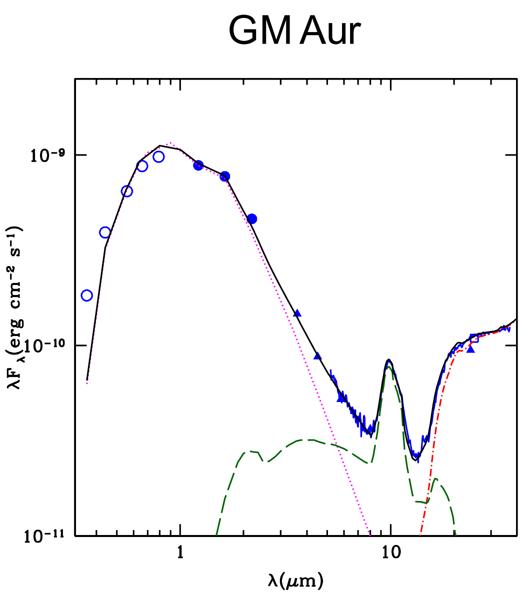
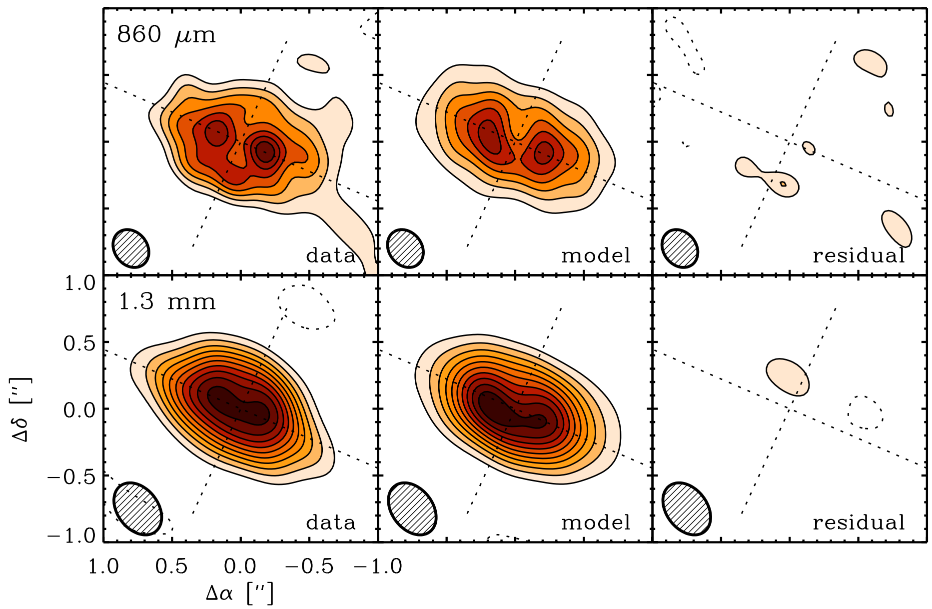


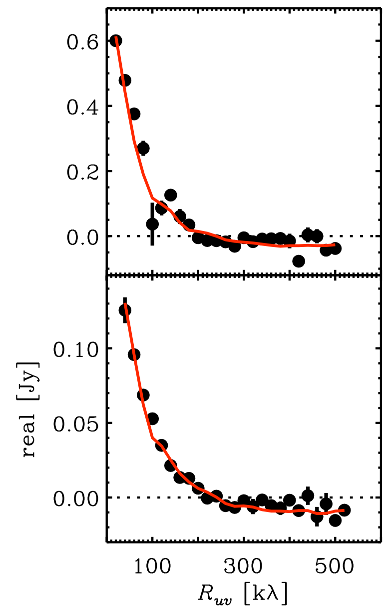


Espaillat et al. 2011

Combining submm imaging and SED modeling to confirm disk cavity of GM Aur



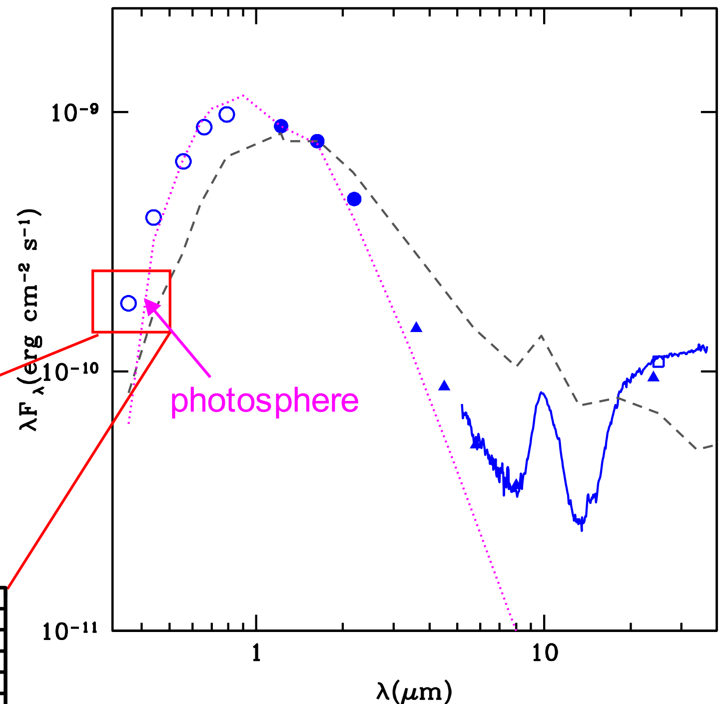


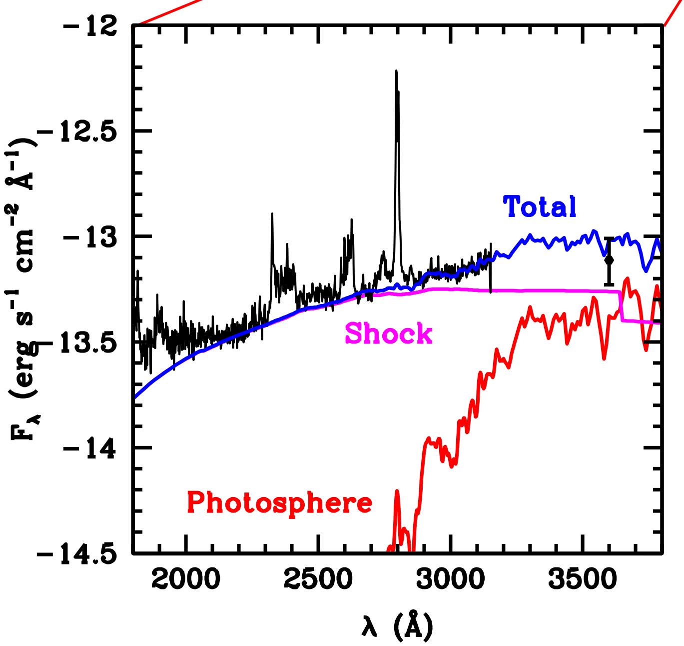


best-fit model to observed SED → simulated images & simulated visibilities

Hughes et al. 2009

Gas can continue to accrete across cavity in dust disk





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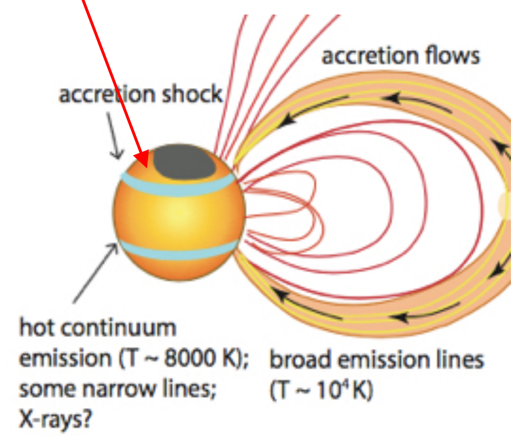


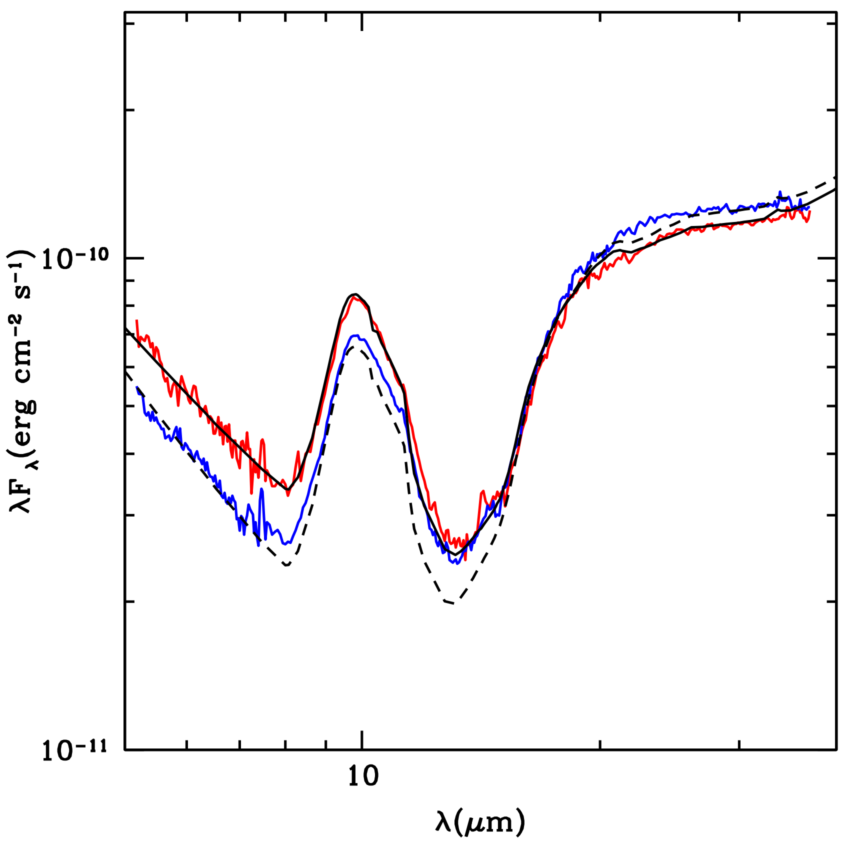
GM Aur $\dot{M}$ ~ 10^{-8} $M_\odot$ yr^{-1}

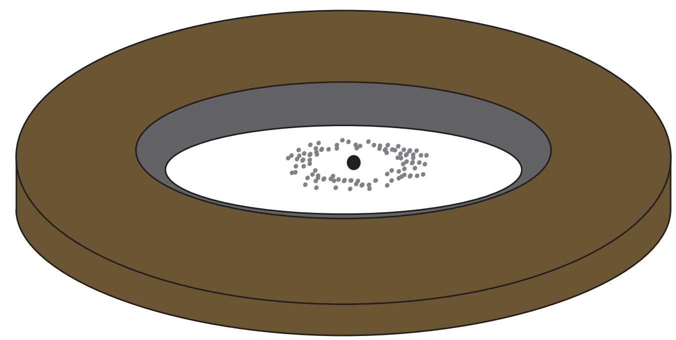
T Tauri star average $\dot{M}$ ~ 10^{-8} $M_\odot$ yr^{-1}

Ingleby et al. 2013

MIR variability in transitional disks

GM Aur

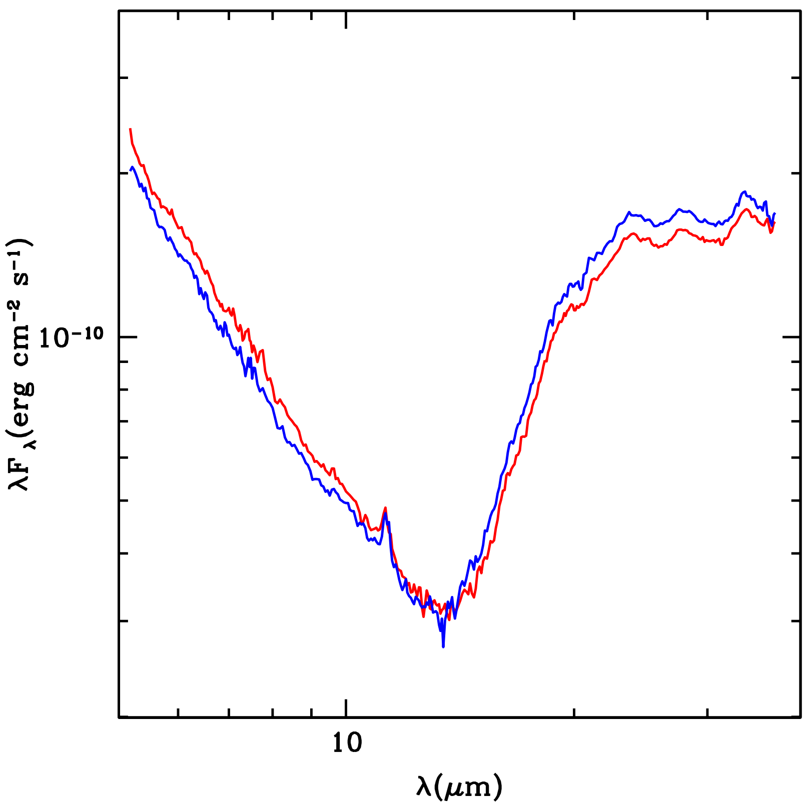




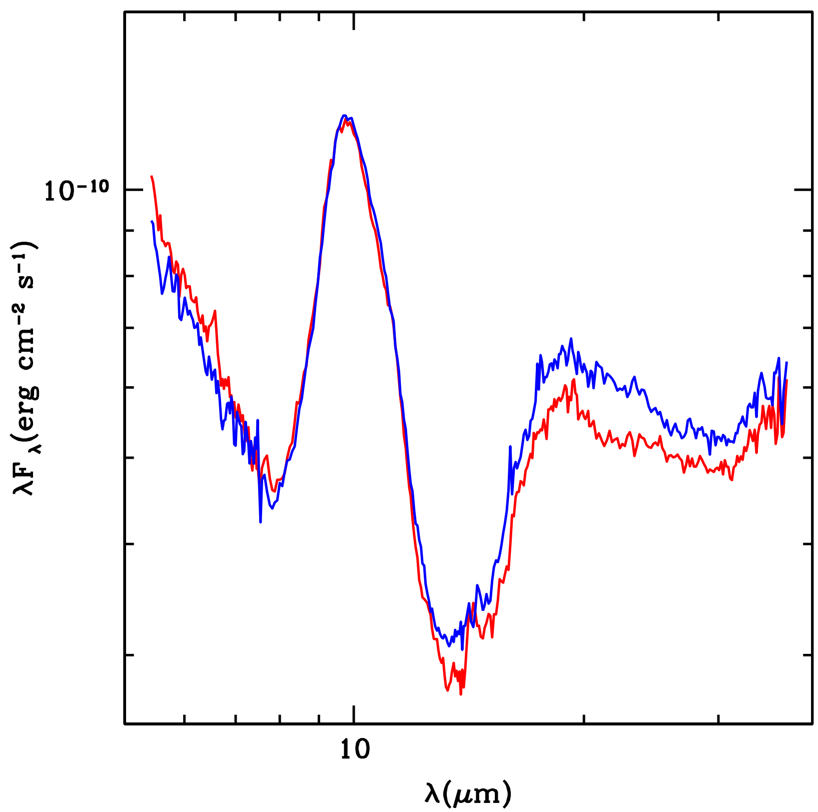
Espaillat et al. 2011

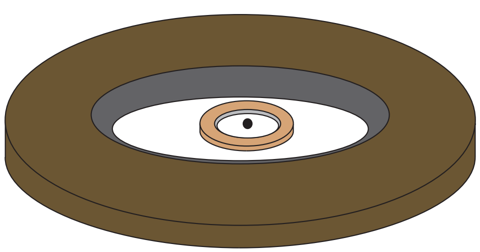
Pre-transitional disks have variable "see-saw" IR emission

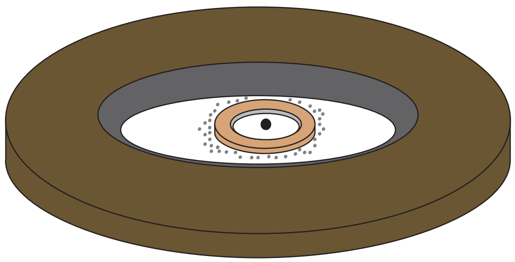
UX Tau A



LkCa 15

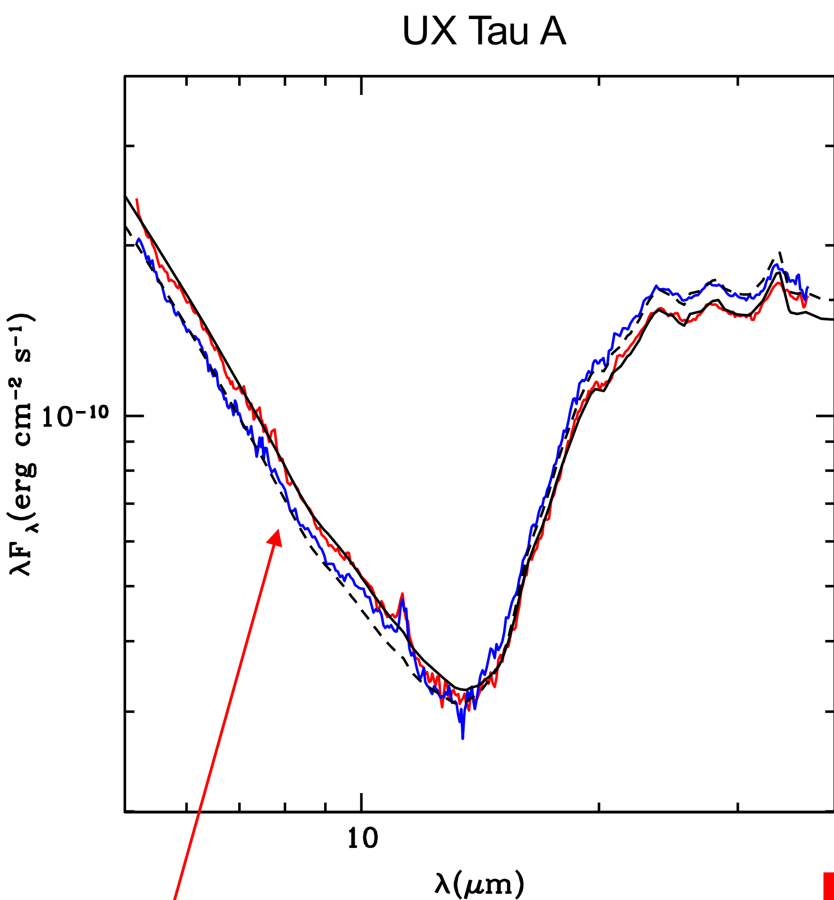


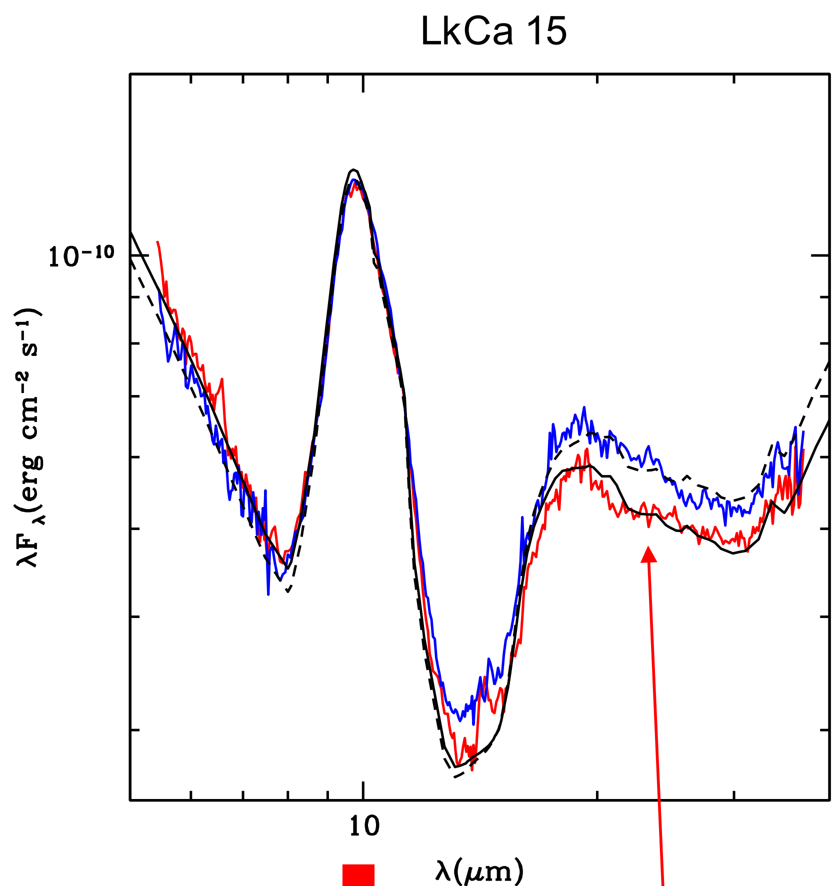




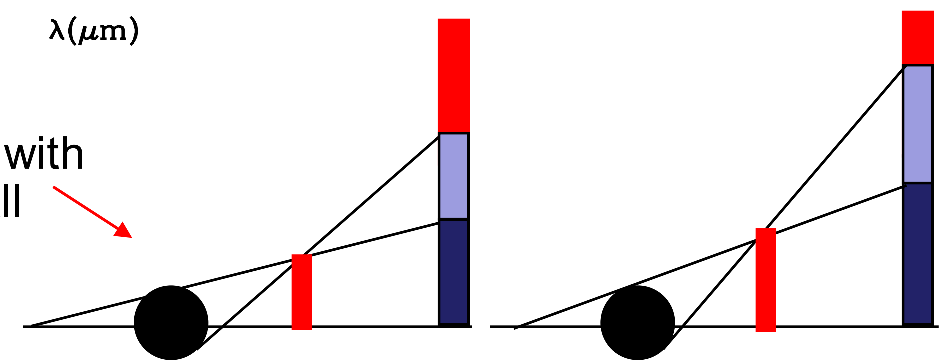
Espaillat et al. 2011; also Muzerolle et al. 2010, Flaherty et al. 2012

Can fit each SED by changing the height of the inner wall





broken line: model with shorter inner wall



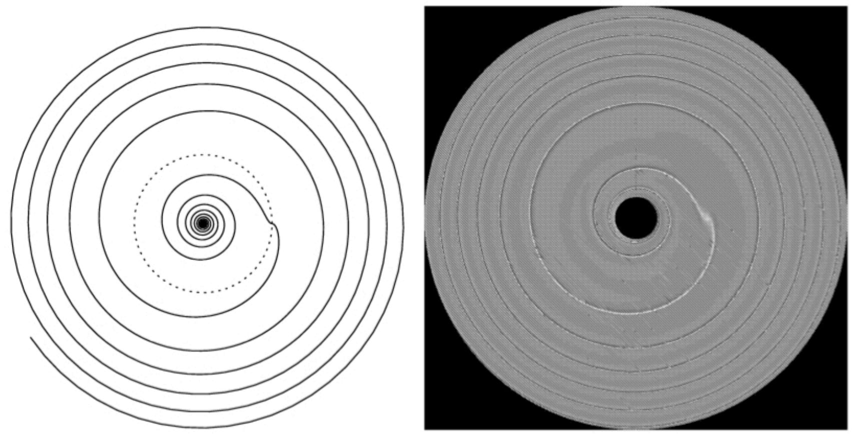
solid line: model with taller inner wall

Espaillat et al. 2011

Potential causes of MIR variability in pre-transitional disks

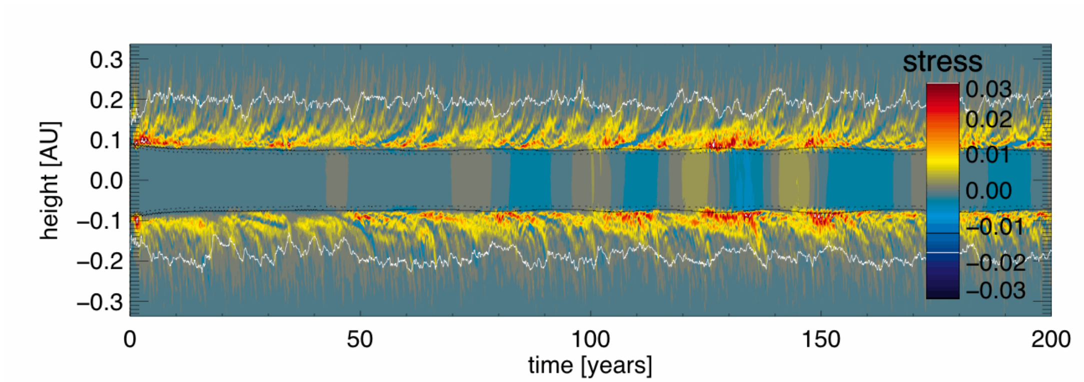
Planet-disk interaction

Flaherty et al. 2011



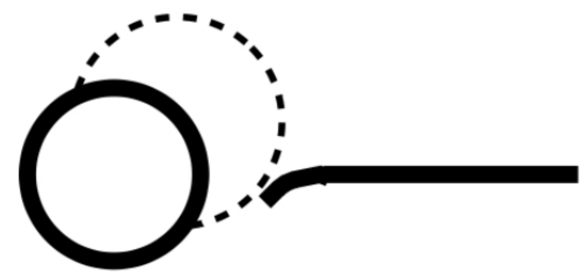
Ogilvie & Lubow 2002

Turbulence from MRI



Hirose & Turner 2011

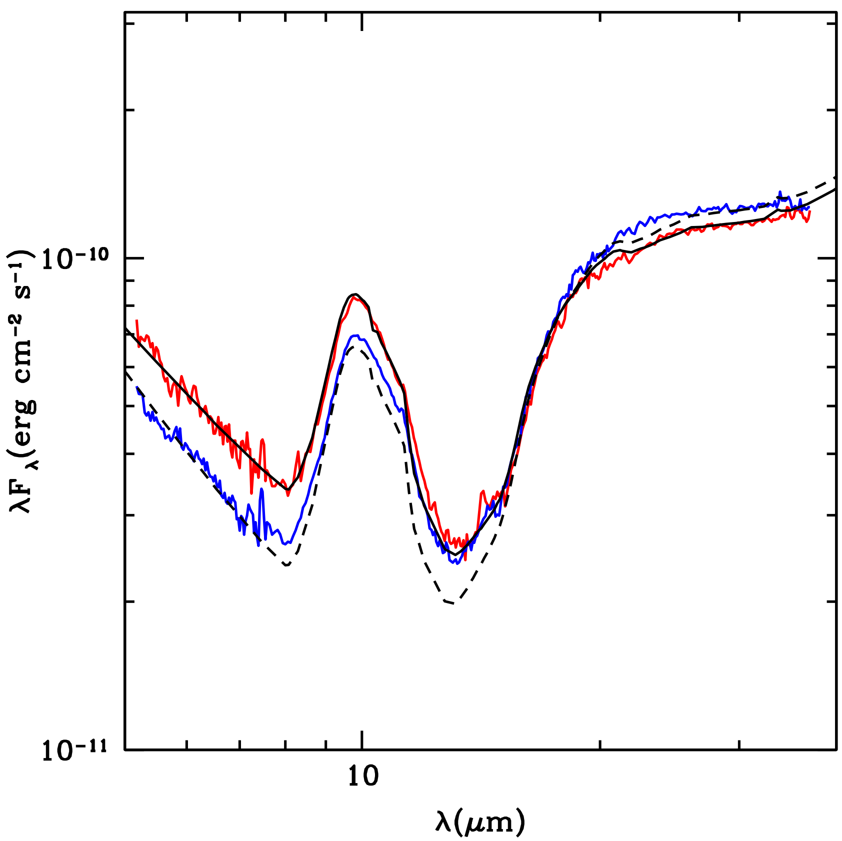
Warped inner disk

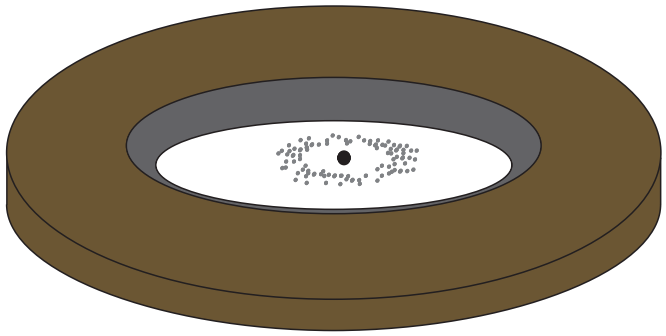


Flaherty et al. 2011

What causes MIR variability in transitional disks?

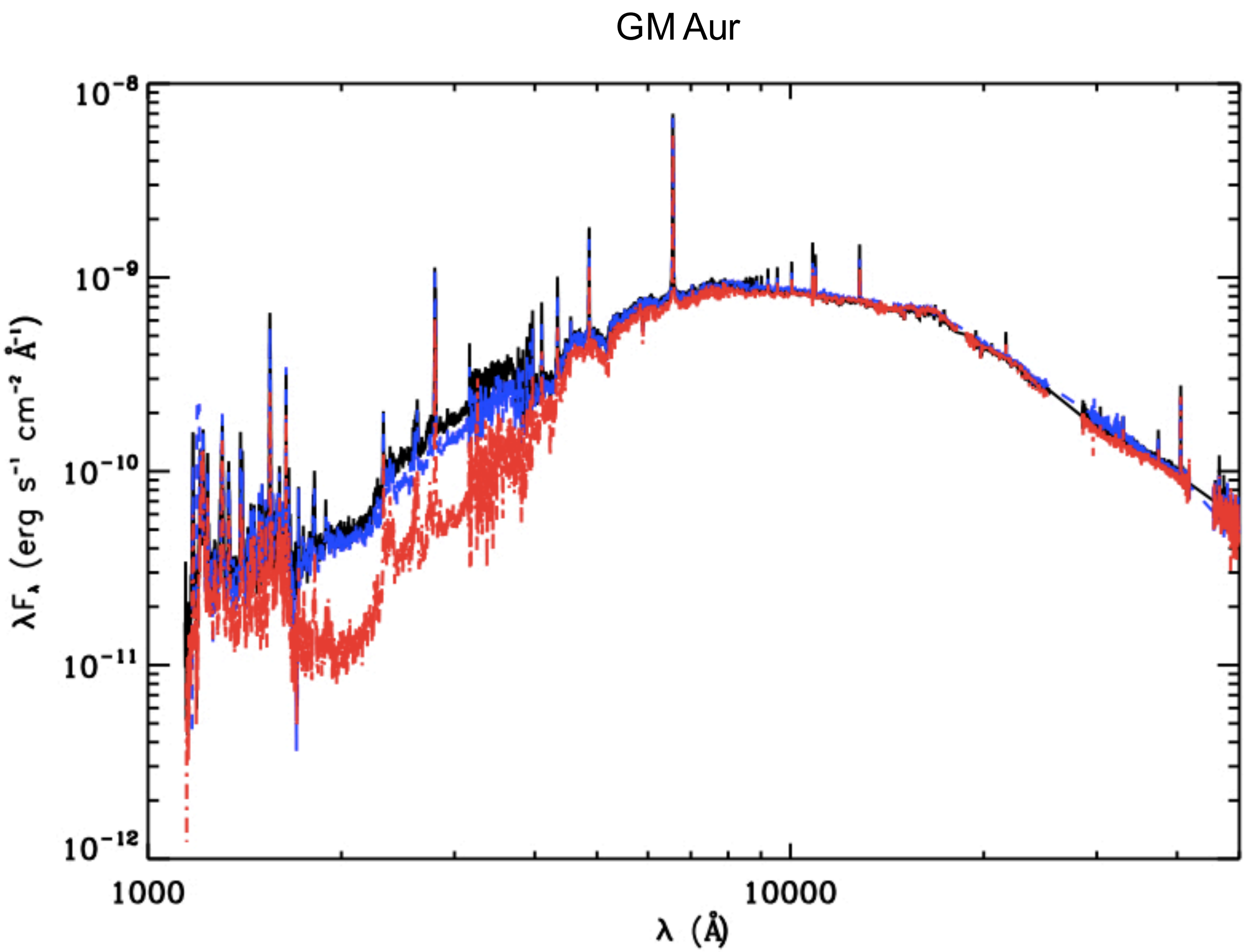
GM Aur





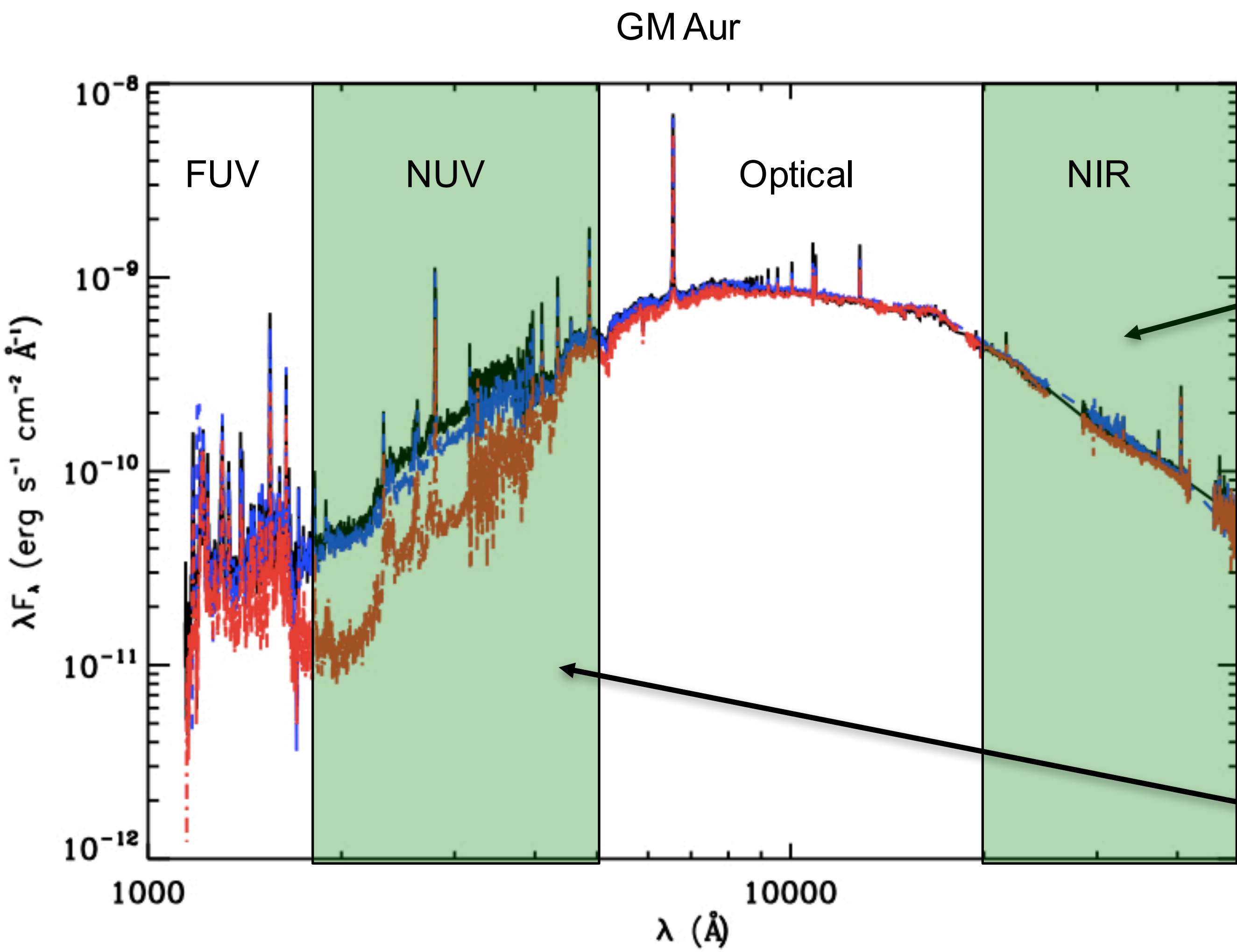
Espaillat et al. 2011

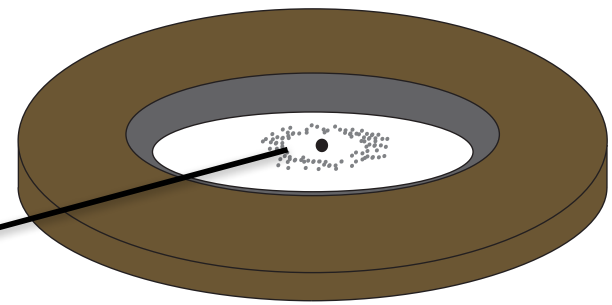
FUV-NIR variability in GM Aur

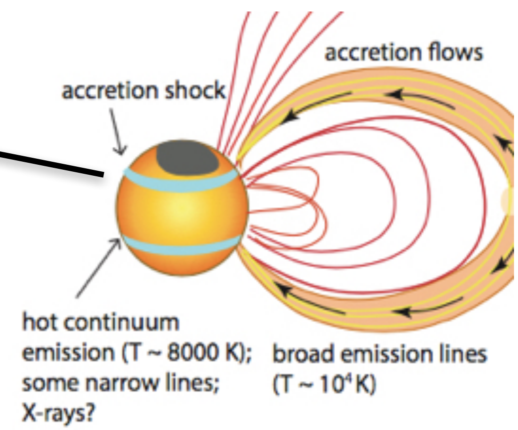


Ingleby, Espaillat et al. 2015

FUV-NIR variability in GM Aur



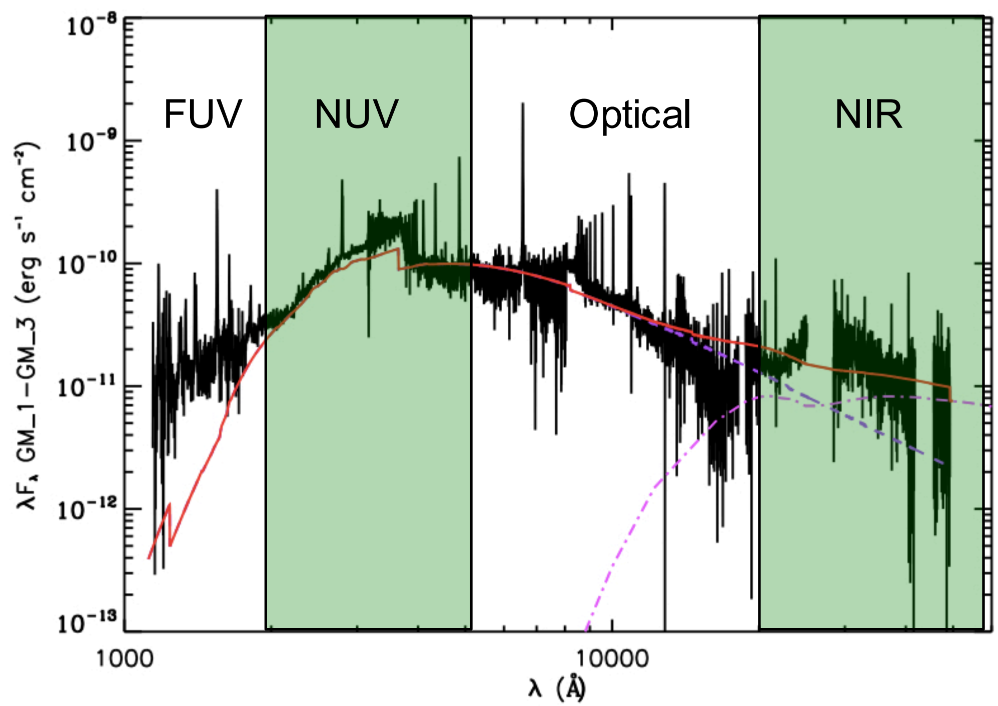




Ingleby, Espaillat et al. 2015

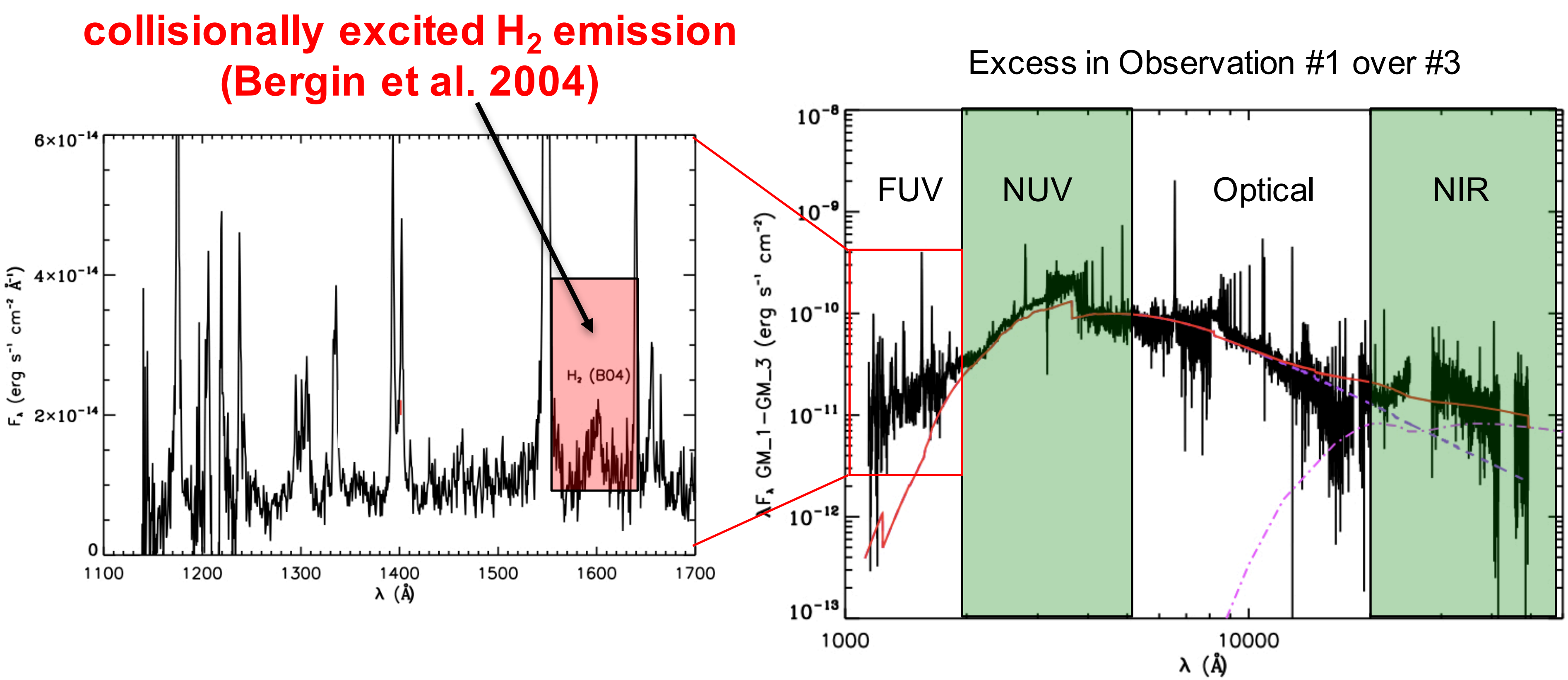
Decrease in FUV-NIR emission of GM Aur

Excess in Observation #1 over #3



Ingleby, Espaillat et al. 2015

Decrease in FUV-NIR emission of GM Aur

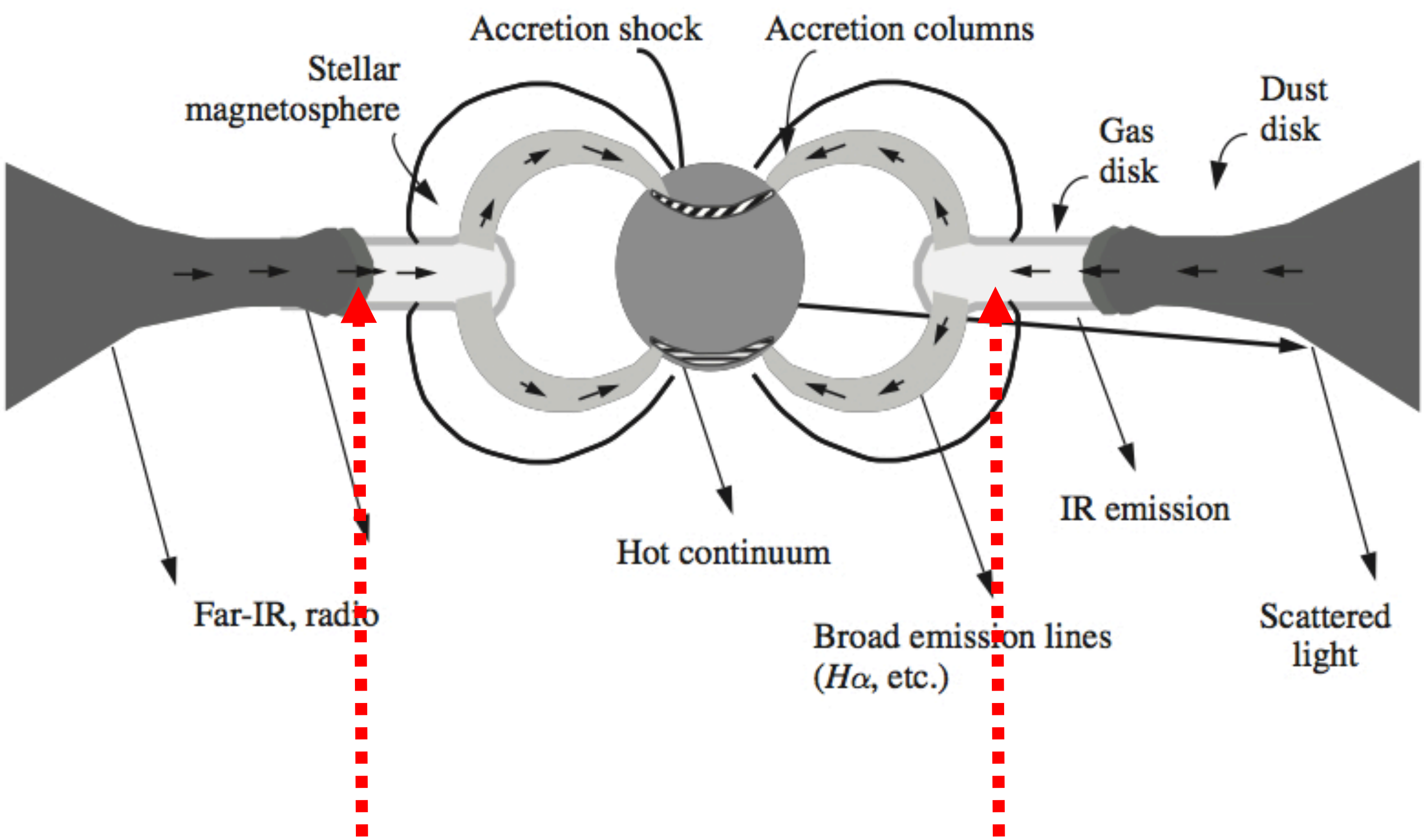


1. accretion column
2. dust disk
3. gas disk

→ all decrease in density on 3 month timescale → tracing same area in disk very close to star

Ingleby, Espaillat et al. 2015

Comparing timescales and spatial scales



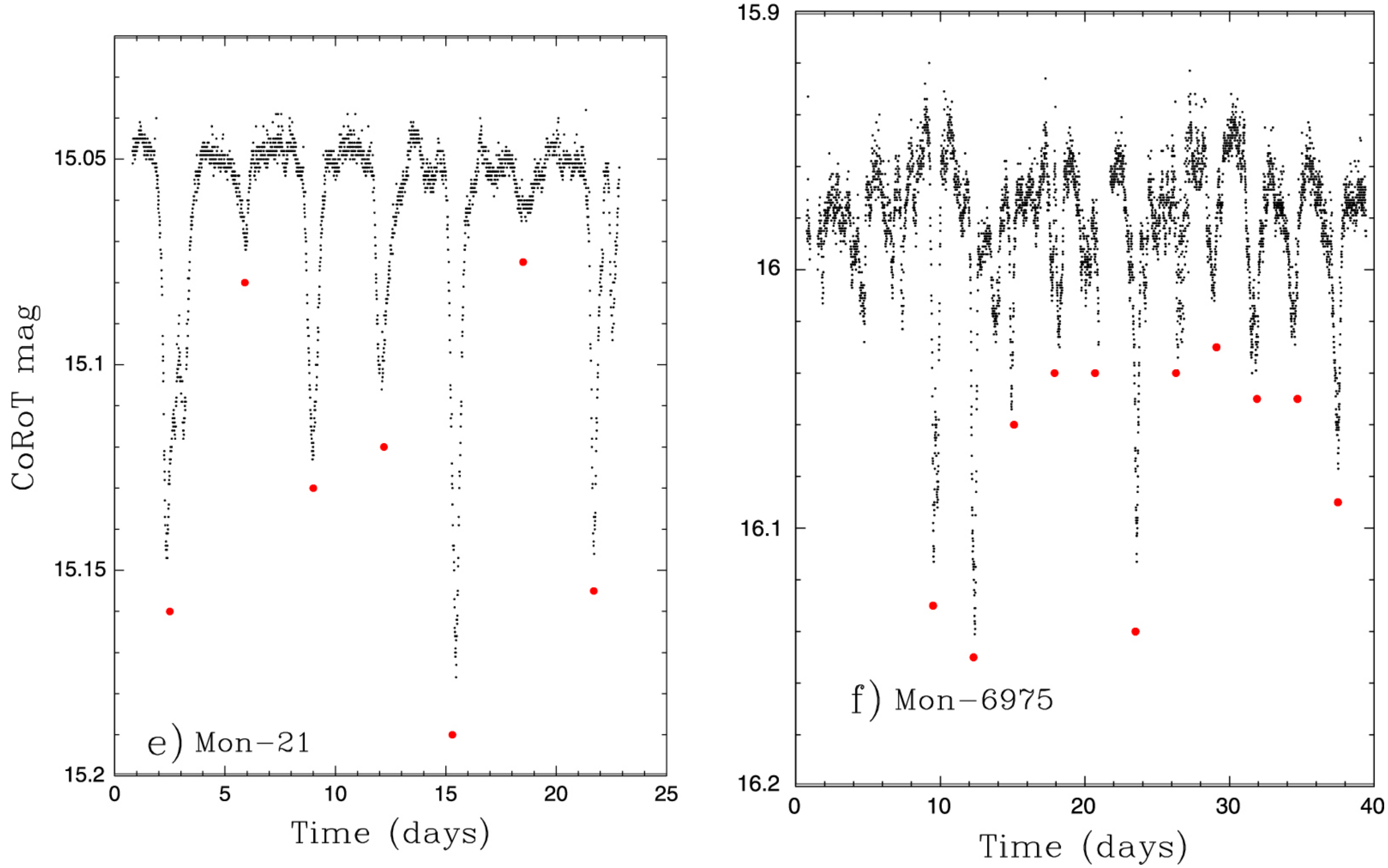
dust destruction radius
R_{dust} ~ 10 R_{star} (0.08 AU)

magnetospheric truncation radius
R_{mag} ~ 5 R_{star} (0.04 AU)

corotation radius
R_{cor} ~ 8.5 R_{star} (0.07 AU)

Hartmann 2008

Other studies find evidence that there is dust near the co-rotation radius



Stauffer et al. 2015

Short timescale accretion related variability seen in many objects

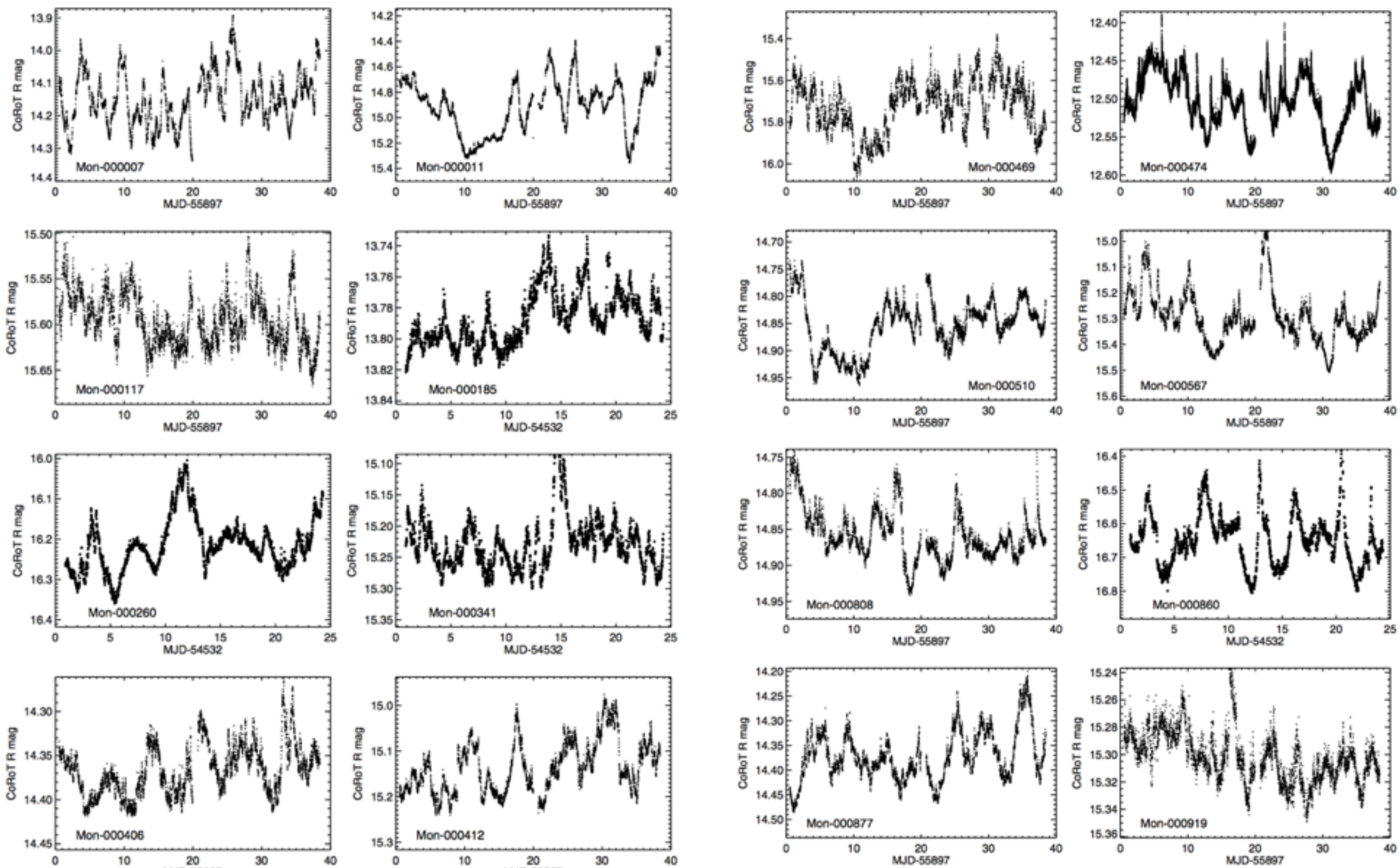
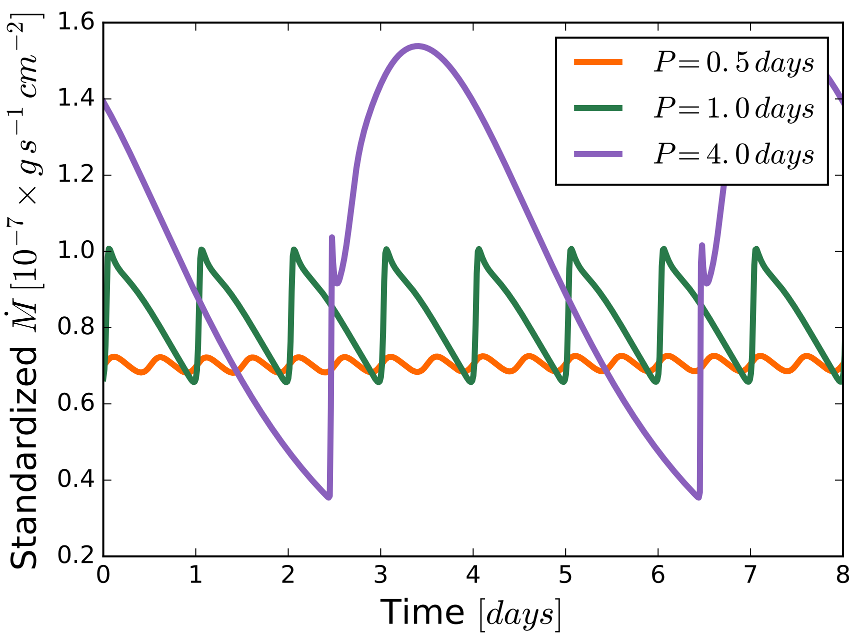
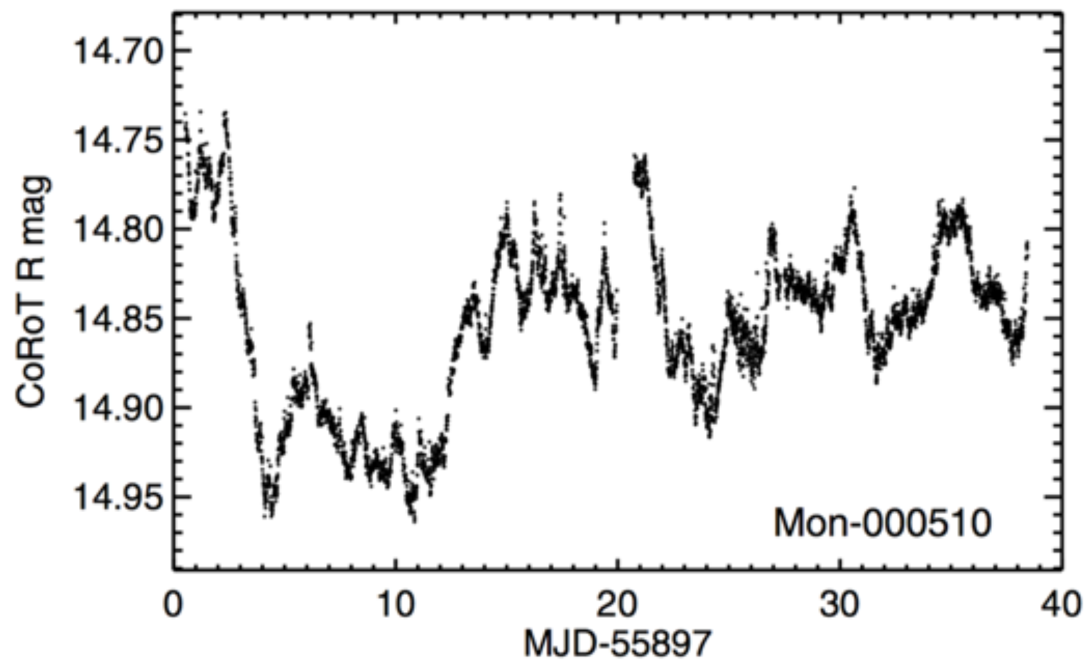


Figure 21. (Continued)

Stauffer et al. 2014

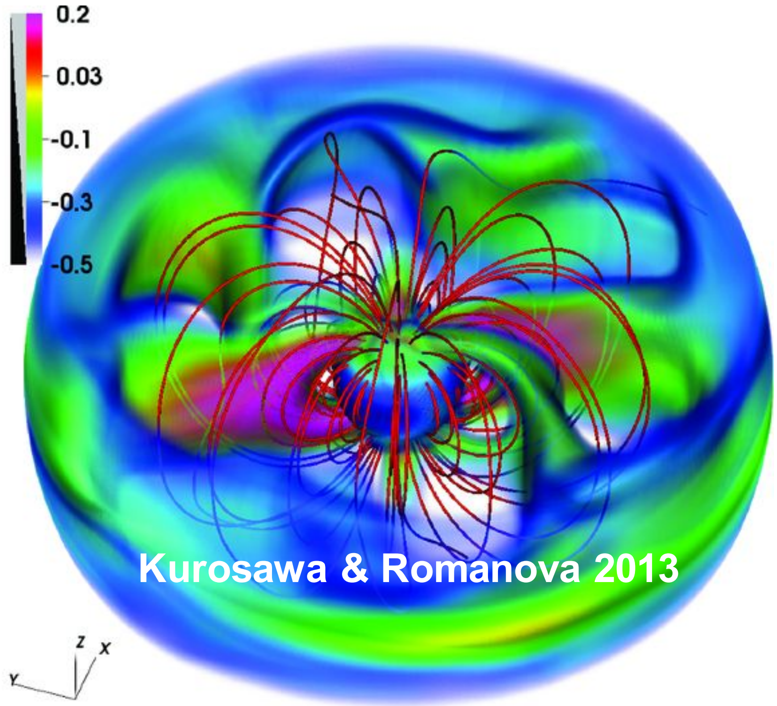
Drive variability by changing density to represent instabilities at the disk





Robinson, Owen, Espaillat, & Adams, submitted

Probing where material is loaded onto star



Inhomogeneities in the inner disk → less mass loading onto star

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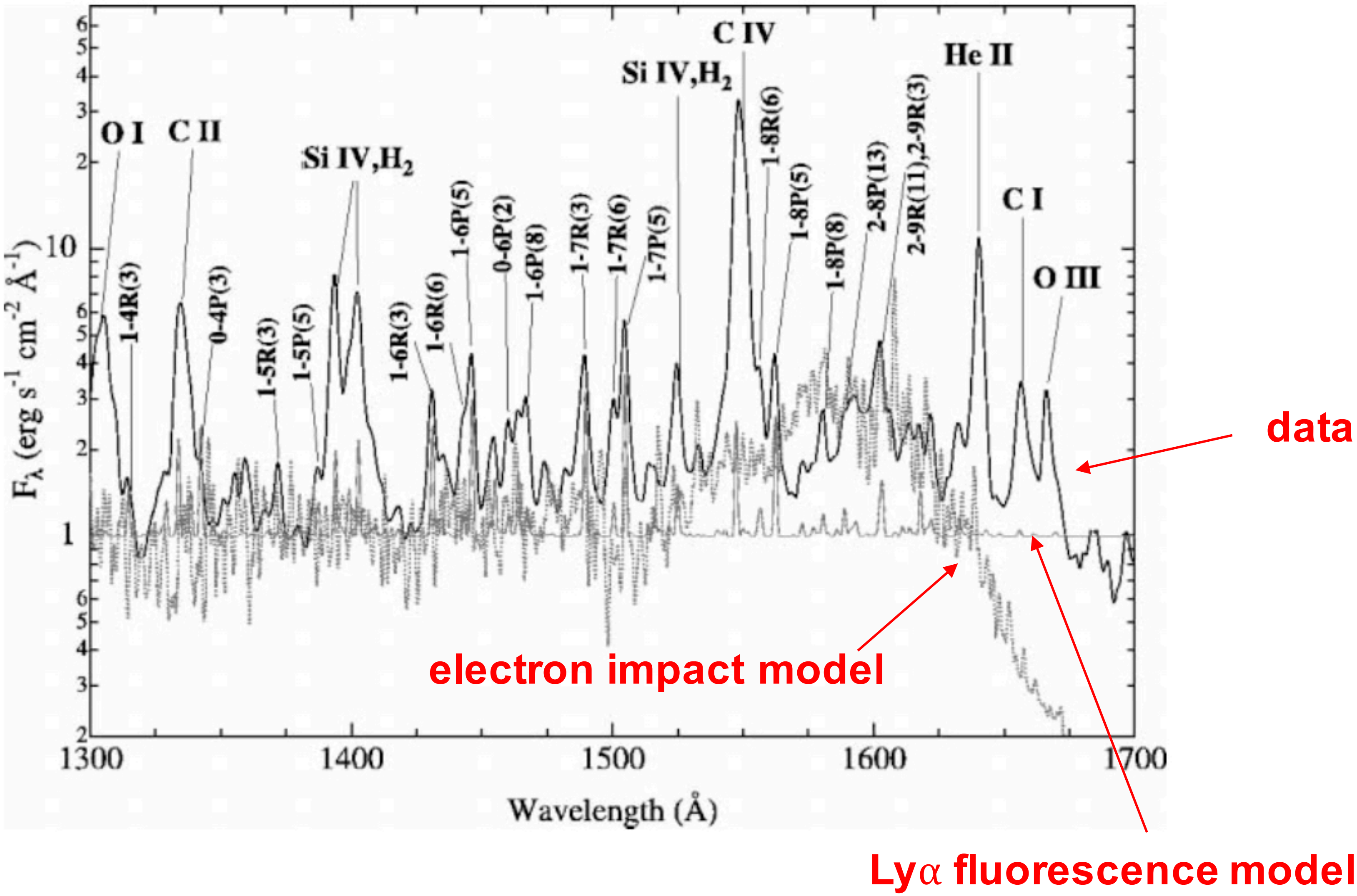
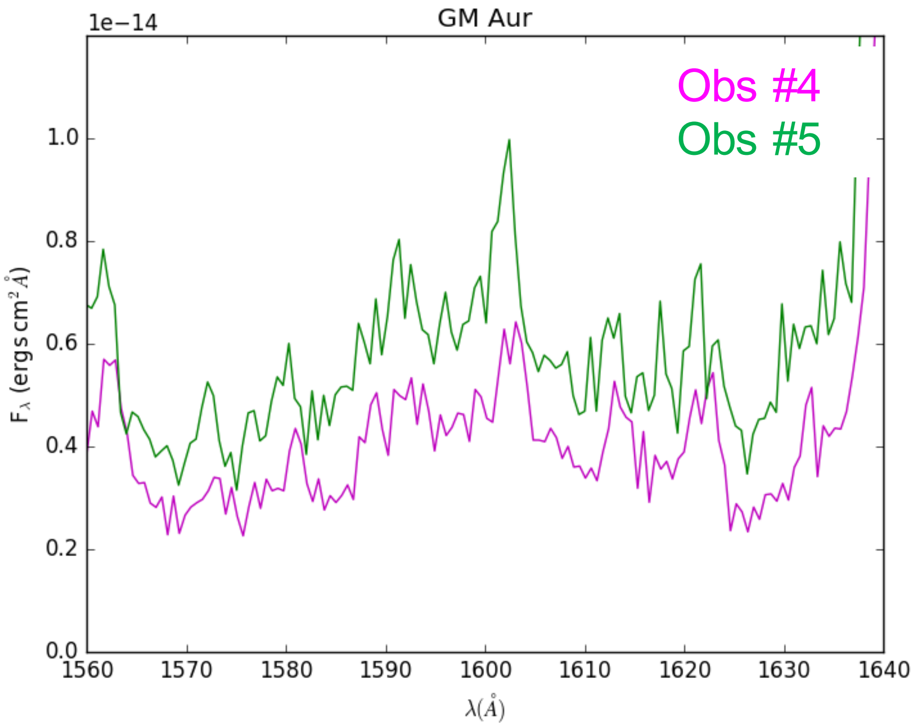
Where do we go from here?

X-ray excitation induces H_2 emission



Bergin et al. 2004

Linking H_2 emission and X-ray emission



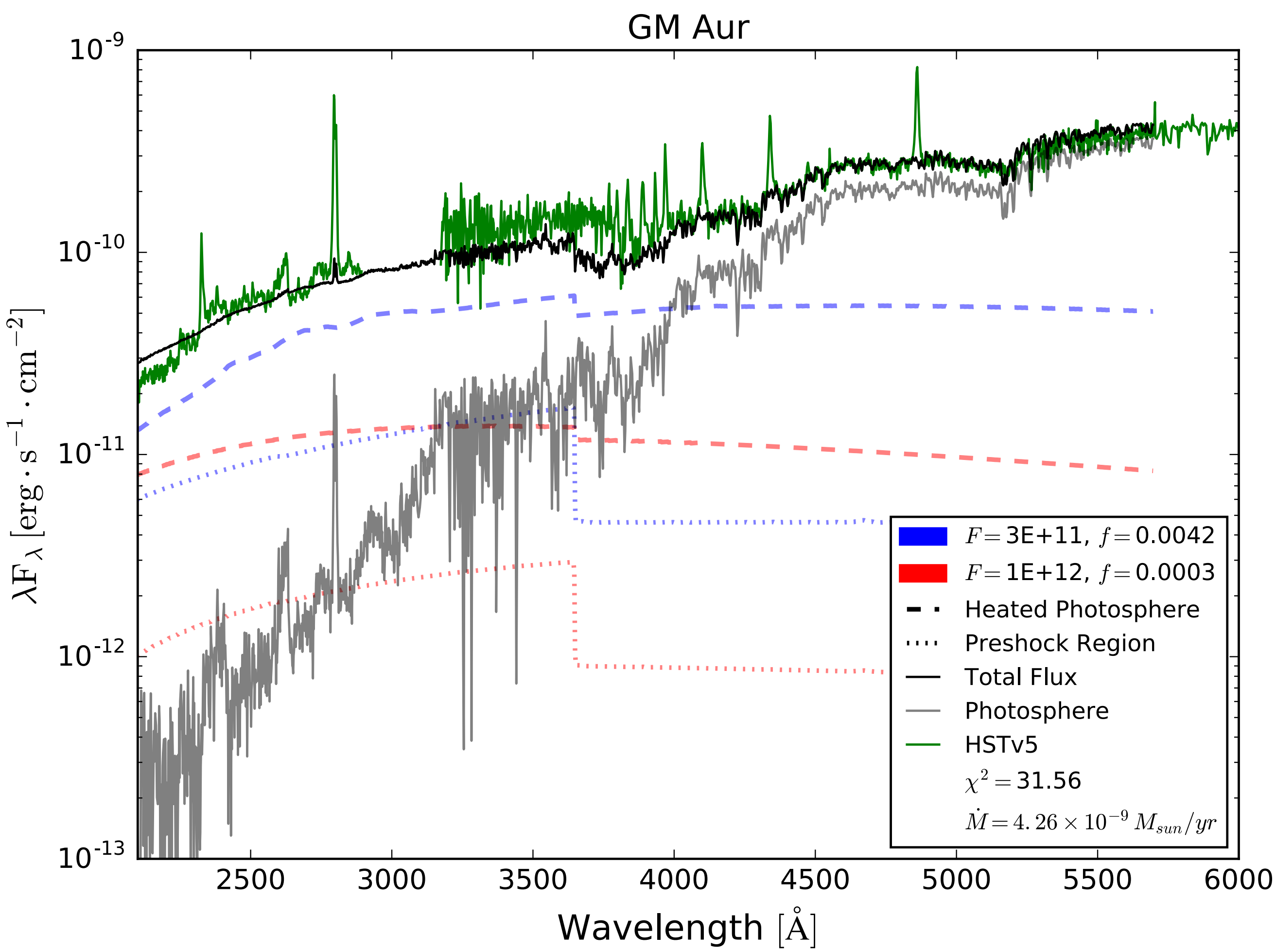
	Accretion Rate (Msun/yr)	X-ray flux (erg/cm2/s)
Obs #4	1.1e-9	3.6e-13
Obs #5	6.3e-10	3.1e-12

H_2 Obs #5 > H_2 Obs #4

($\dot{M}$ Obs #5) x (F_X Obs #5) > ($\dot{M}$ Obs #4) x (F_X Obs #4)

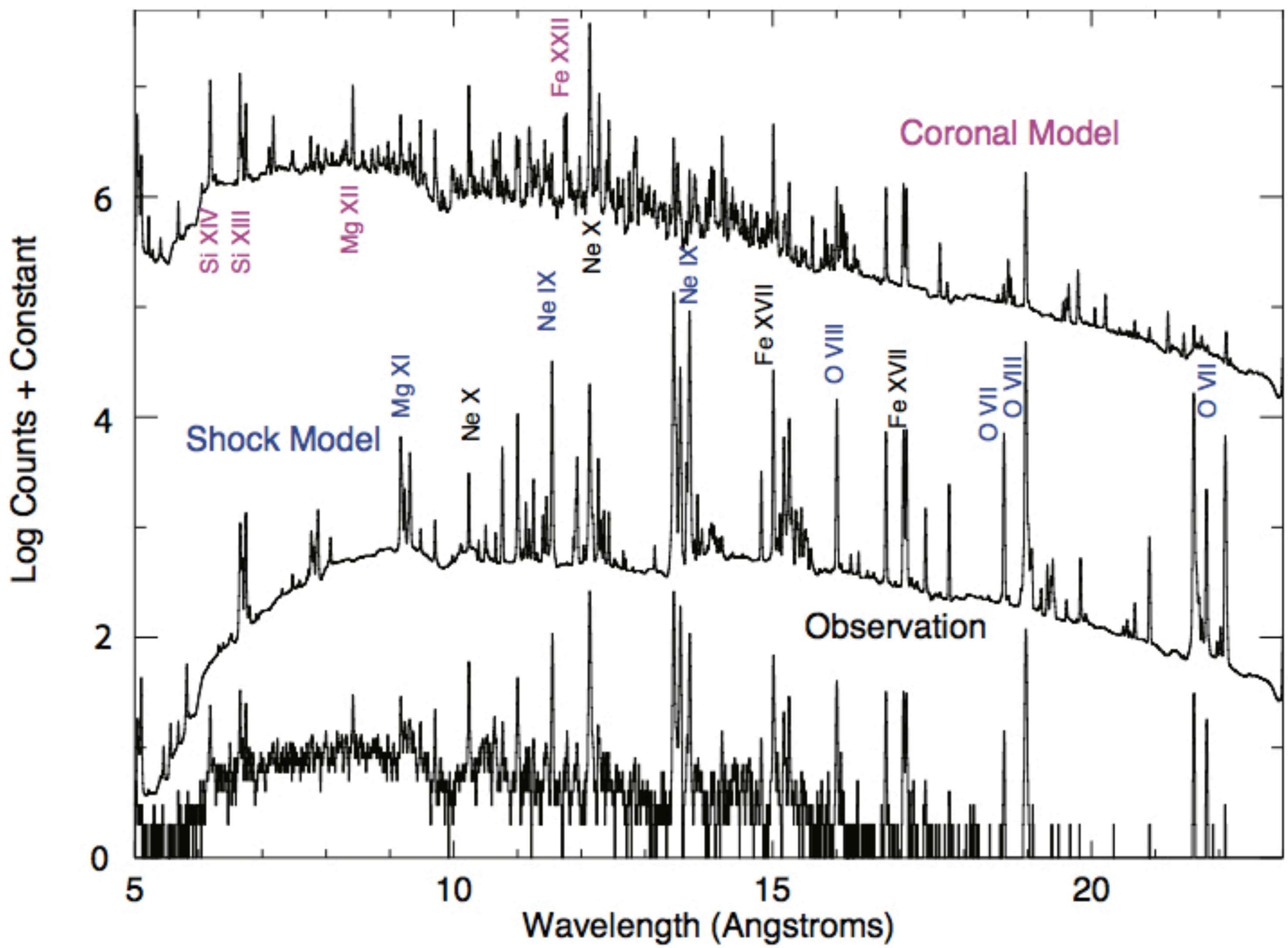
Espaillat et al., in preparation

Higher energy accretion column when X-ray emission is high



Espaillat et al., in preparation

Coronal emission dominates the X-ray spectrum of TW Hya



Hartmann, Herczeg, & Calvet 2016

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- Inhomogeneities in the inner disk can lead to less mass loading onto the star

What can we learn about the star-disk connection via interaction of the stellar radiation field and gas close to the star?

- X-ray excitation induces H_2 emission

Where do we go from here?

- Ideal to have simultaneous X-ray, STIS, and NIR spectra to further test the above