Gas Accretion Across a Pre-Transition Disk Cavity:

New Observations of LkCa 15

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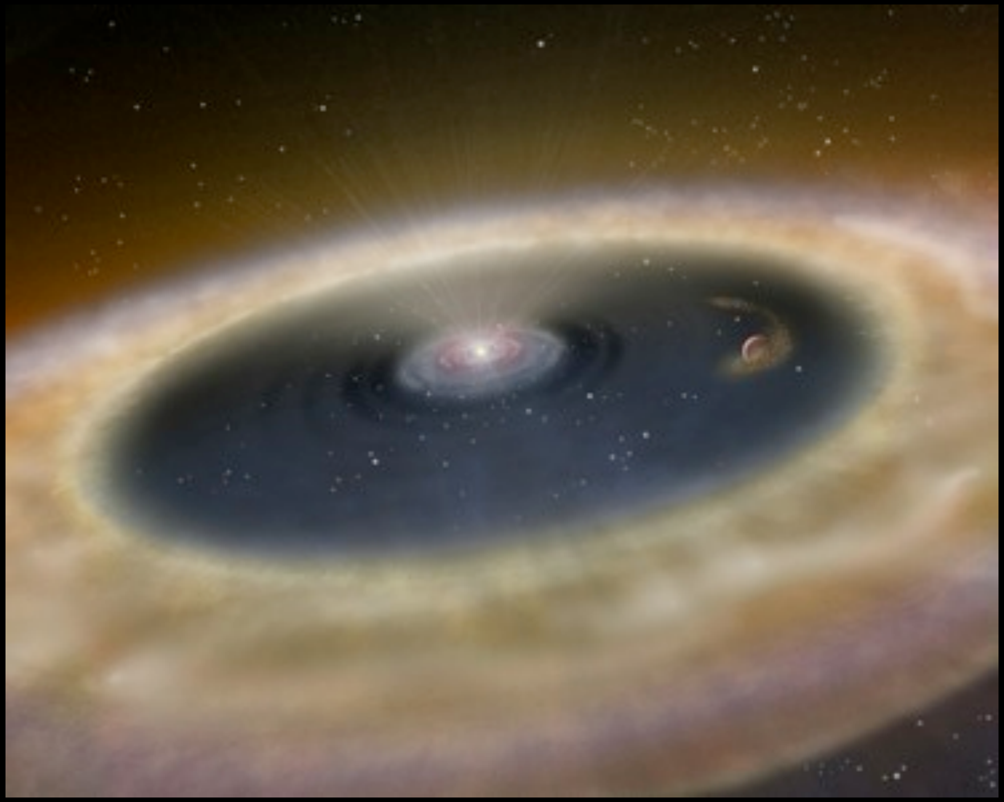


ARTIST'S IMPRESSION OF LKCA 15 (KAREN TERAMURA, UH IFA)

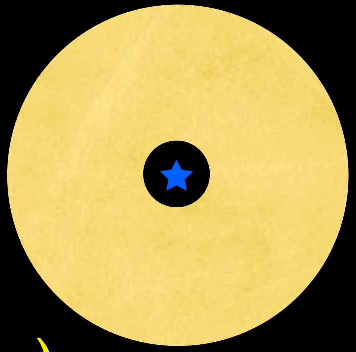
Definitions

* Classical T Tauri Stars (CTTS):

newborn stars surrounded by an accretion disk

inner edge of disk at a few stellar radii from star (magnetospheric truncation)

accretion rate onto star of order 10^8 $M_\odot$/yr

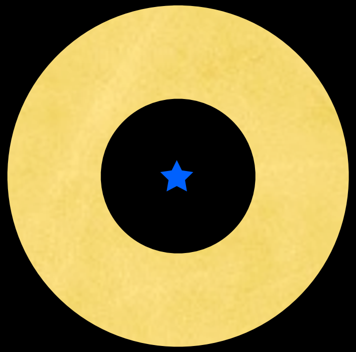


* Transition Disks:

large inner cavity in disk (of order ~AU to 10s of AU)

accretion rate onto star usually significantly lower

cavity may be carved out by planets or photoevaporation (?)

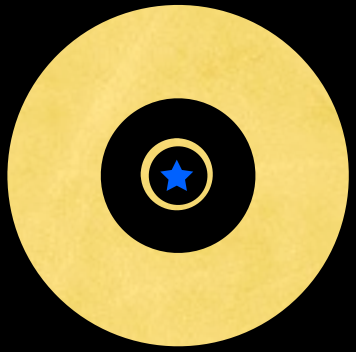


* Pre-Transition Disks:

both an inner disk and outer disk, separated by a large gap

accretion rate onto star comparable to that in CTTS

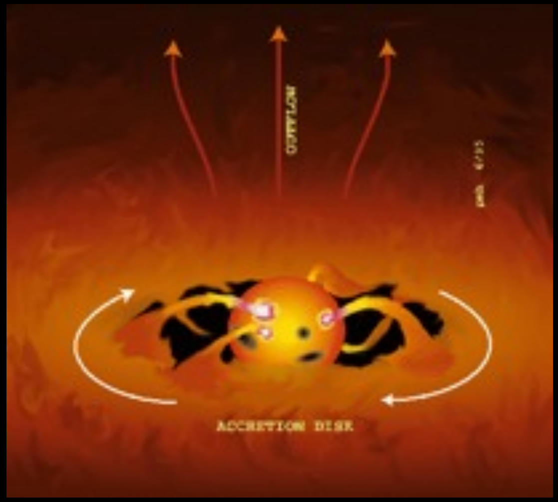
cavity carved out by planets ?

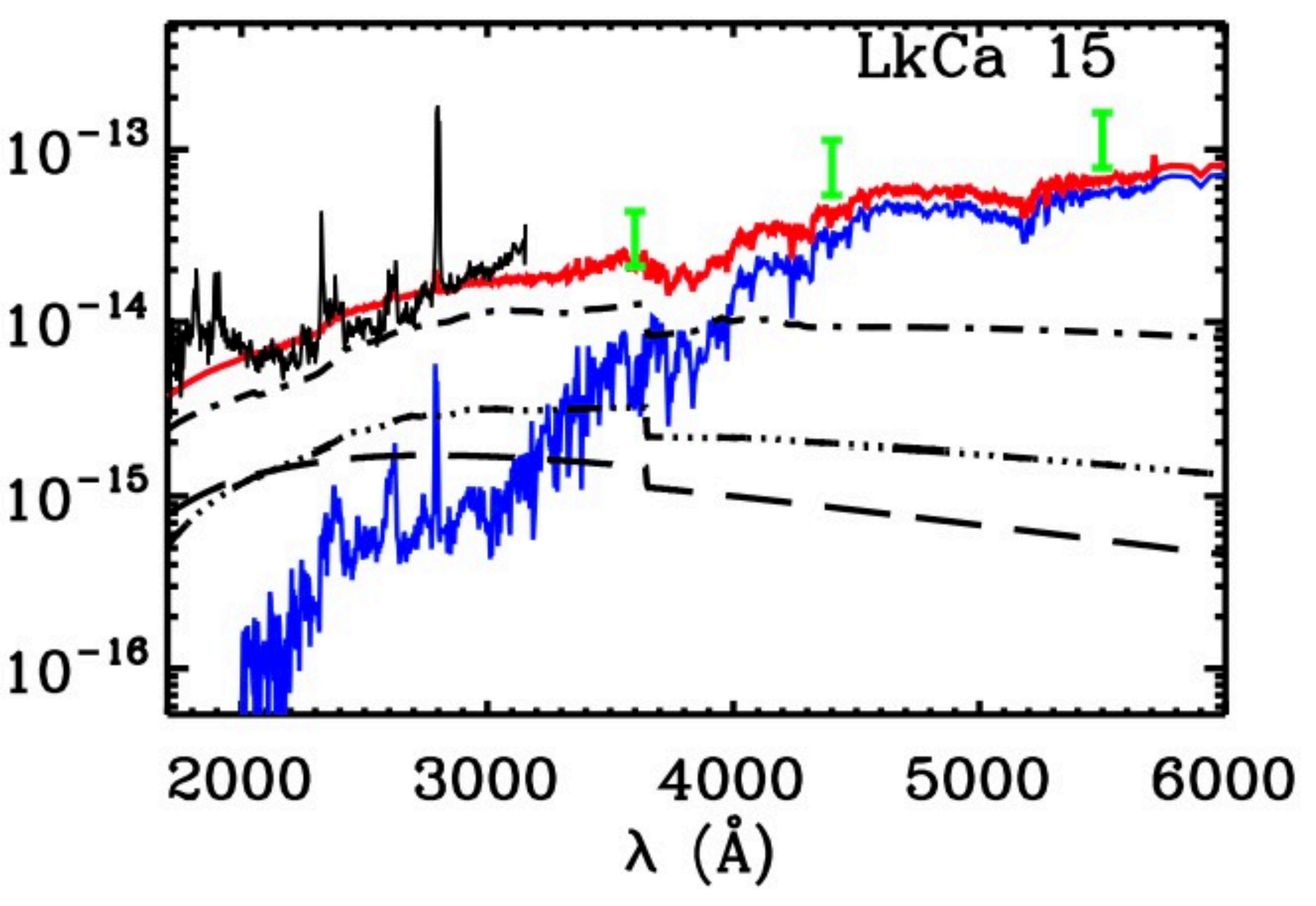


The Pre-Transition System LkCa 15

Taurus SFR
Age ~ 1-2 Myr
SpT: K3 (~4730 K)
M_{*} ~1 $M_{\odot}$

Accretion from UV-Excess



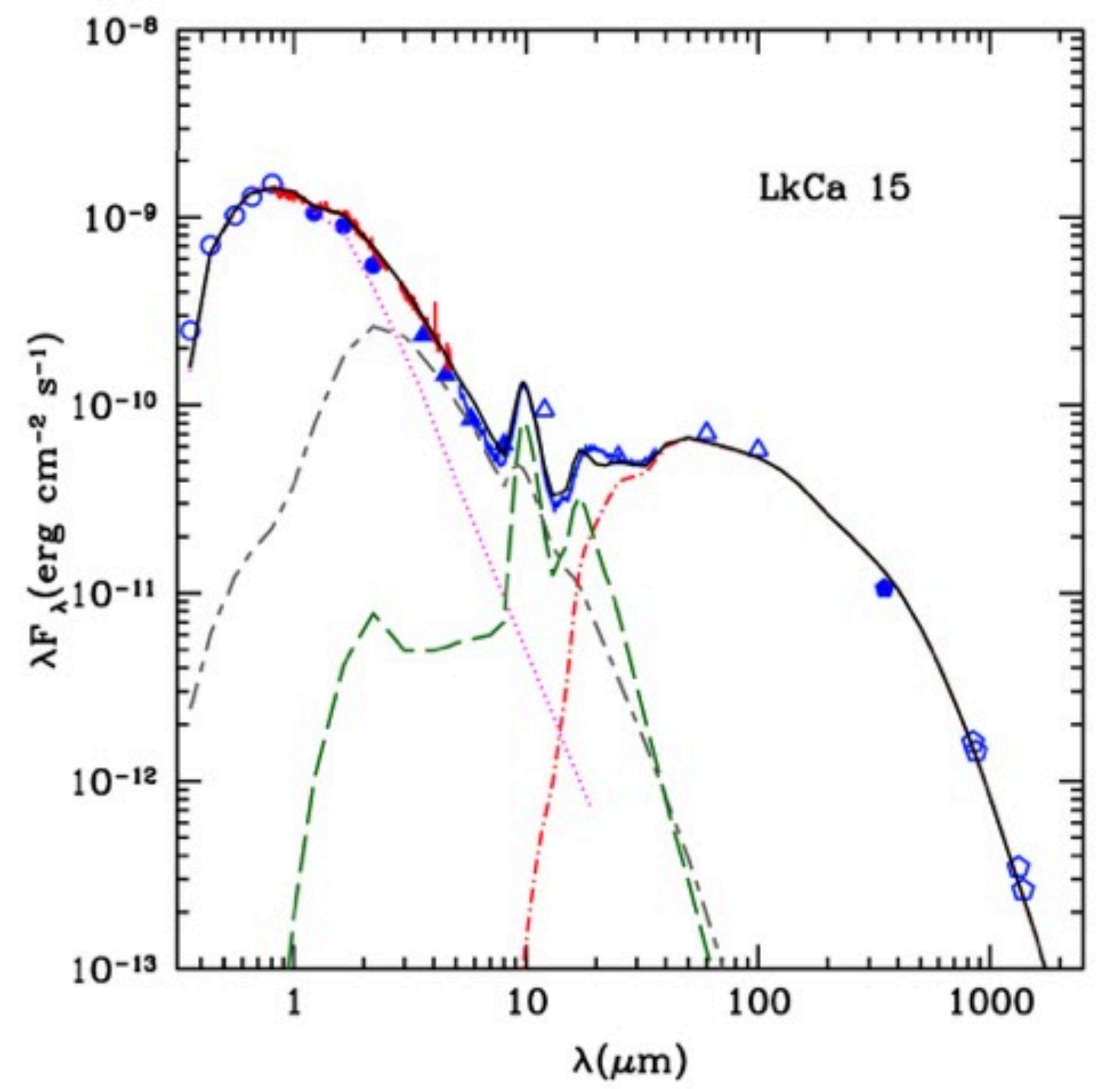


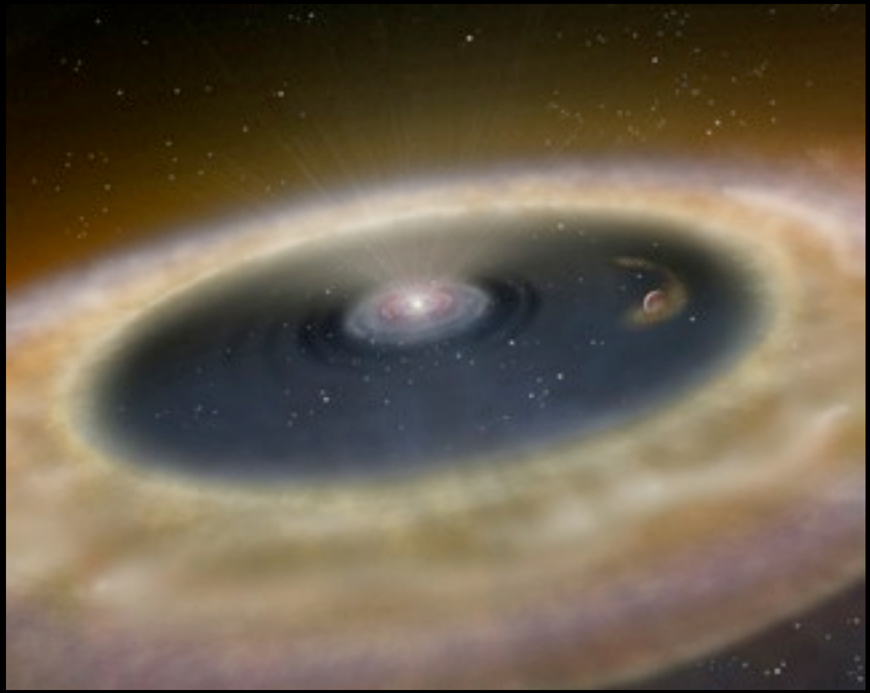
$\dot{M} \sim 3\mathrm{x}10^{-9}\ M_\odot/\mathrm{yr}$

(Ingleby et al. 2013)

Bouvier et al. 2013 (PPVI)

Disk Structure from SED





Optically thick inner disk:

few stellar radii -- 0.2 AU ($\lesssim 2x10^{-4}\ M_{\odot}$)

Optically thin inner disk:

0.2 -- 4 AU ($\sim 2x10^{-11}\ M_{\odot}$ in dust)

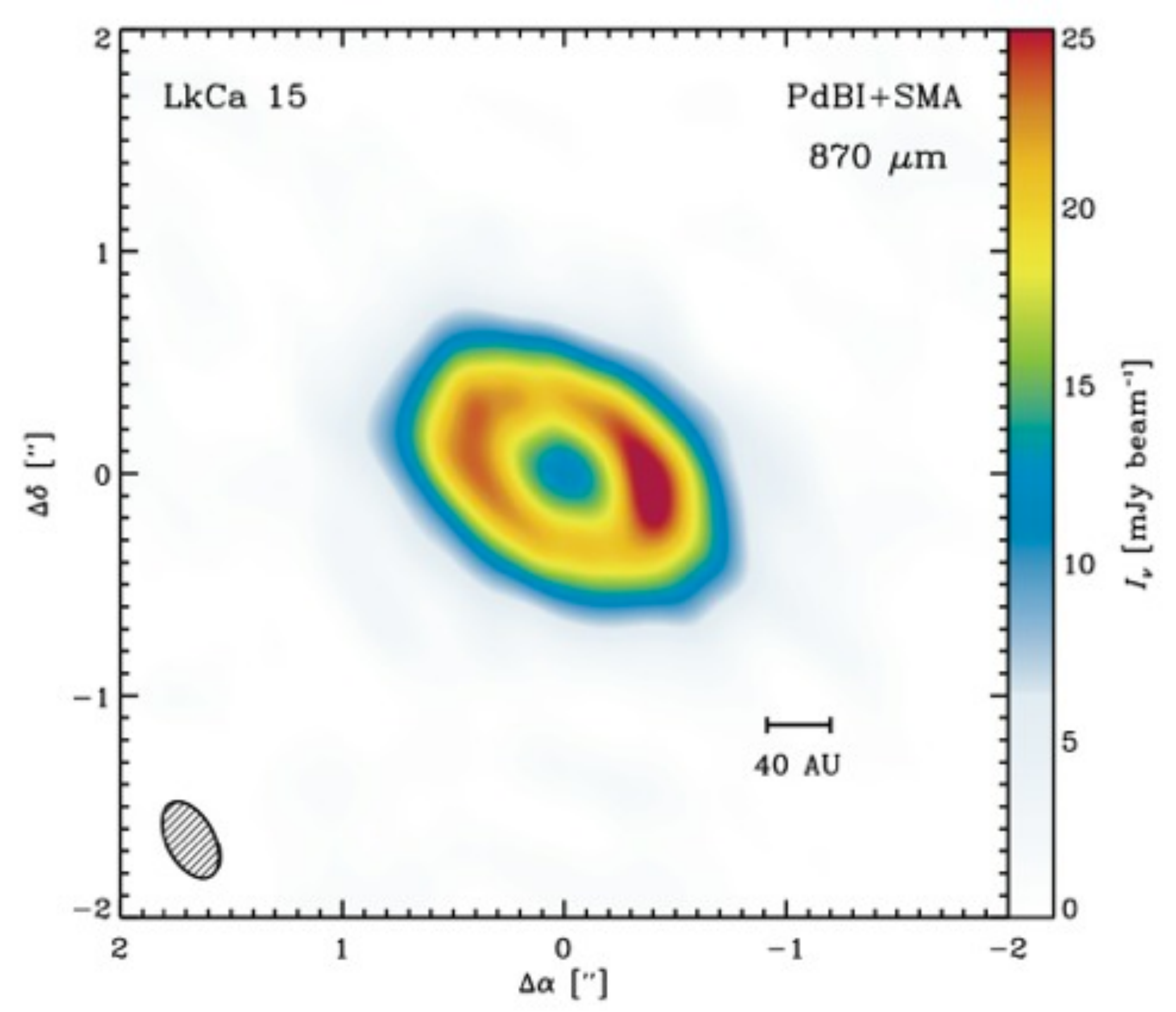
Optically thick outer disk:

Inner Radius ~ 50 AU

(Espaillat et al. 2010)

Irwin & Bouvier 2009

Sub-mm Resolved Imaging

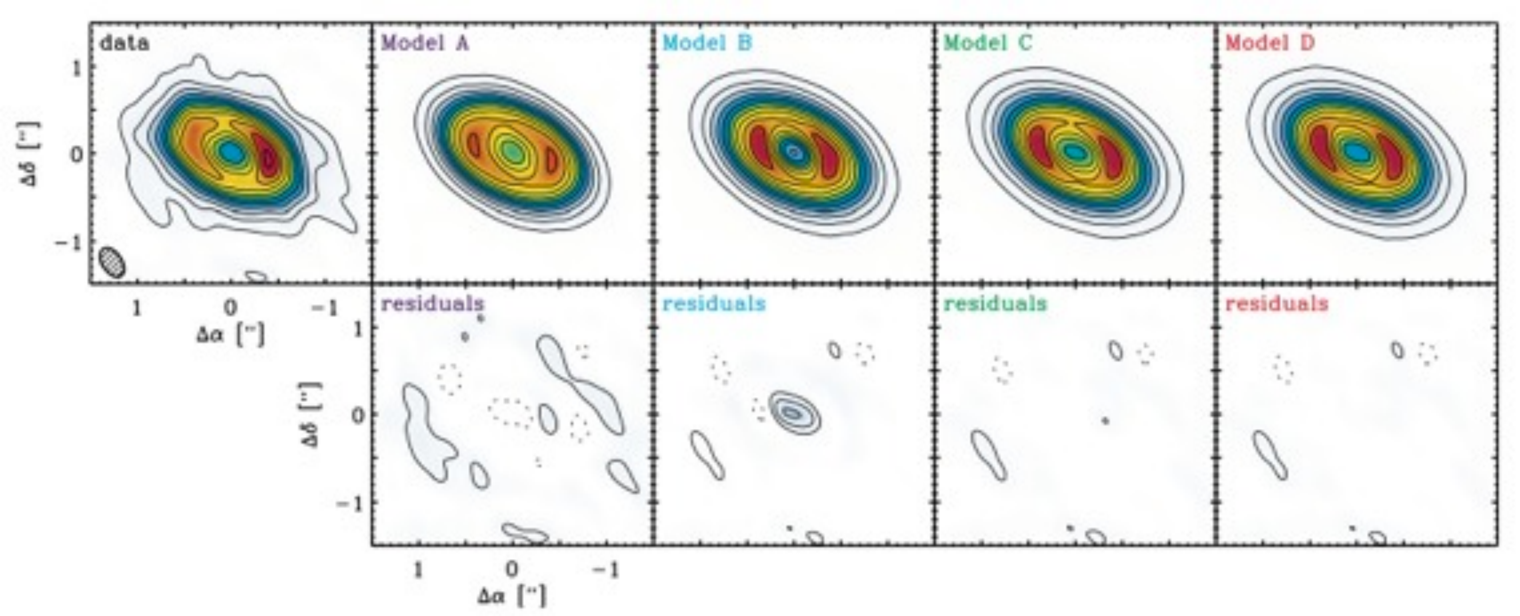


Optically thick outer disk:

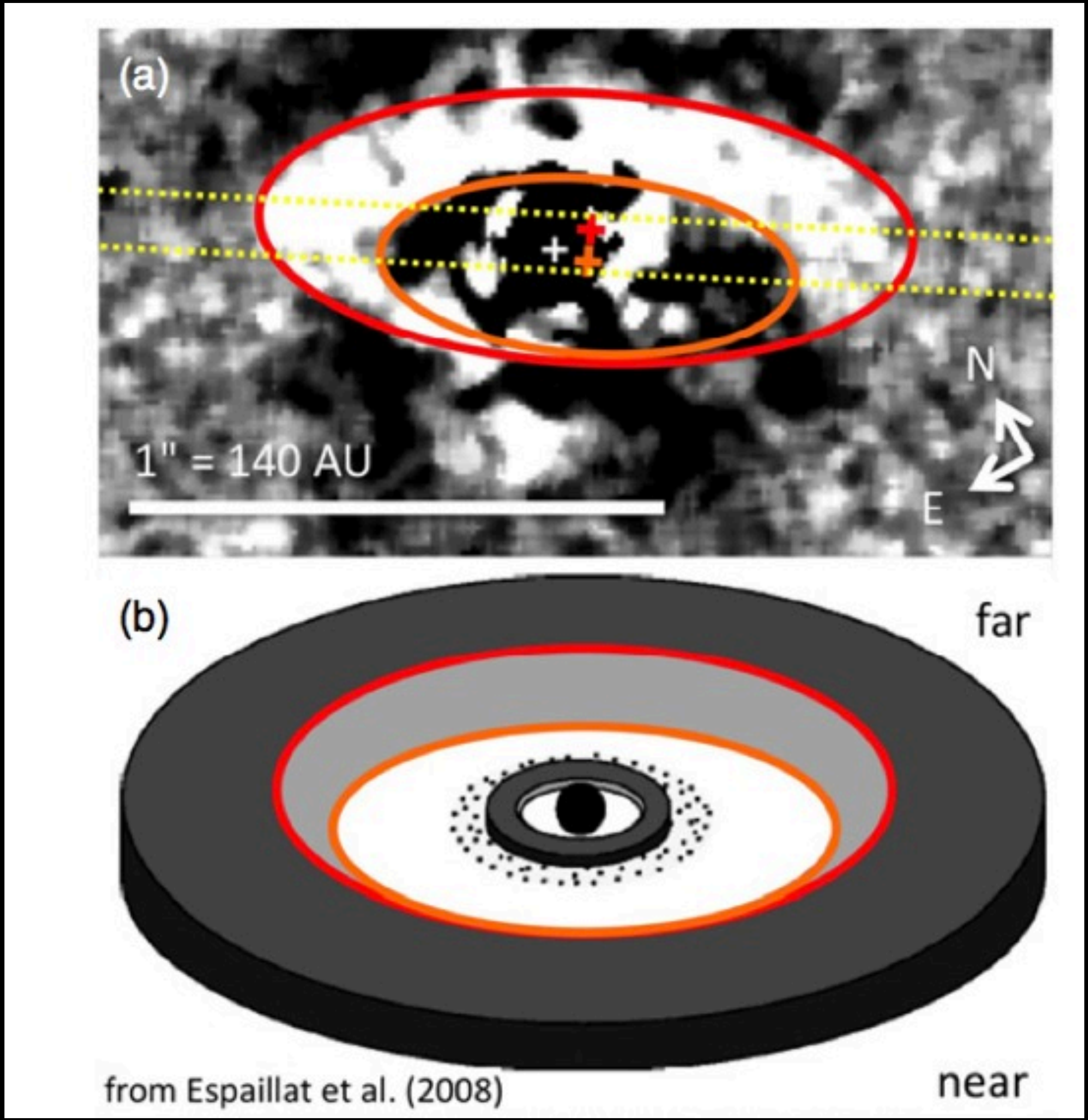
~ 50 -- 85 AU (i.e., ~ ring)

(Andrews et al. 2011)

NOTE: gas may extend out much further to few 100 AU
(eg, Pietu et al. 2007: ~ 300--600 AU)



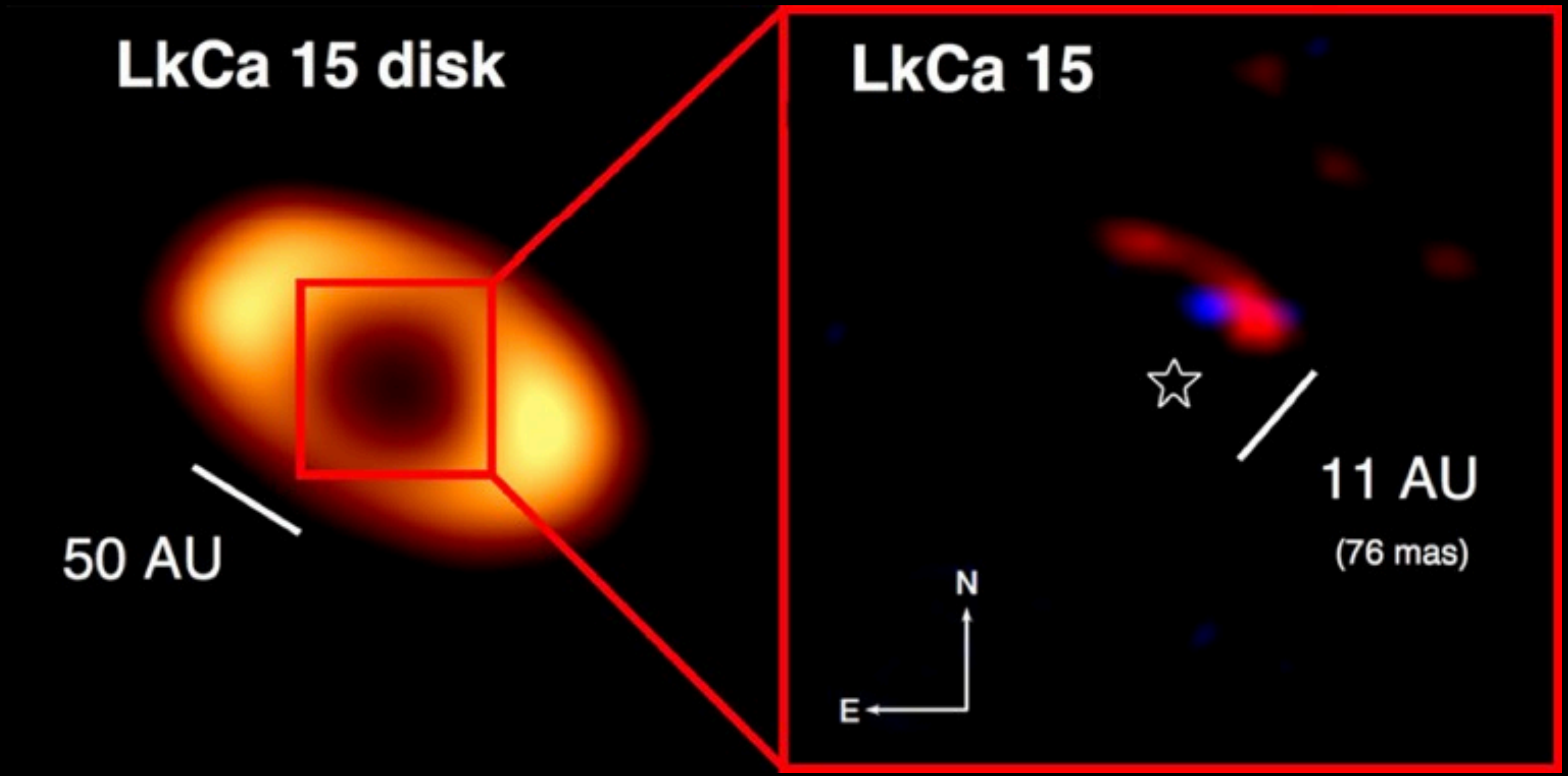
NIR Scattered Light Imaging



from Espaillat et al. (2008)

(Thalmann et al. 2010)

Possible Planet Detection

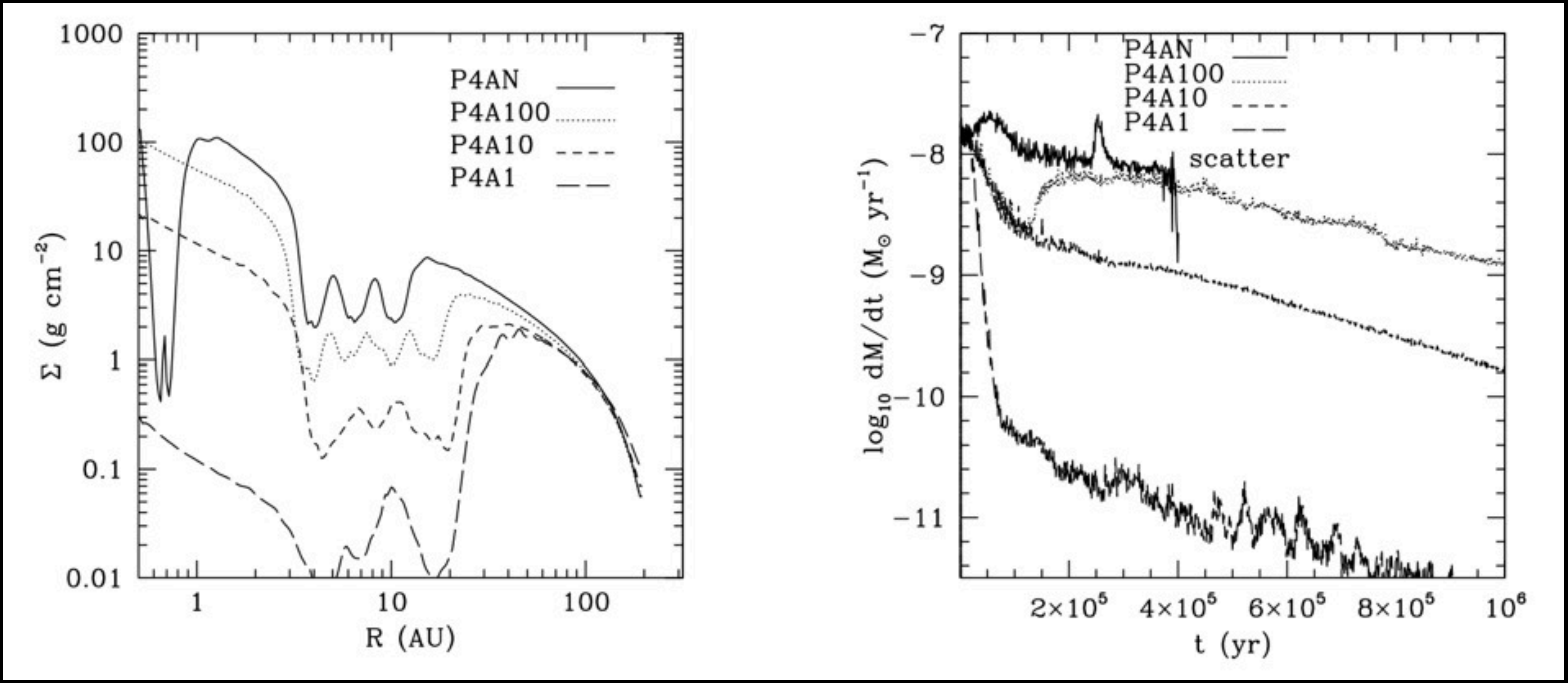


But this one planet alone cannot explain the gap from ~few -- 50 AU

(Kraus & Ireland et al. 2012)

Hypothesis: Multiple Planets

(Zhu et al. 2011, 2012)



PROBLEM: Assuming standard ISM dust-to-gas ratio, reducing the surface density of dust in the gap to the observed value also reduces the accretion rate onto the star to values much lower than observed.

PROPOSED RESOLUTION 1: dust-to-gas ratio in the gap is much lower than standard ISM. (filtration at inner edge? settling within gap?)

PROPOSED RESOLUTION 2: most of the dust hidden within narrow optically thick ‘streamers ‘ of accreting material across gap

Gas in Cavity: HCO$^+$

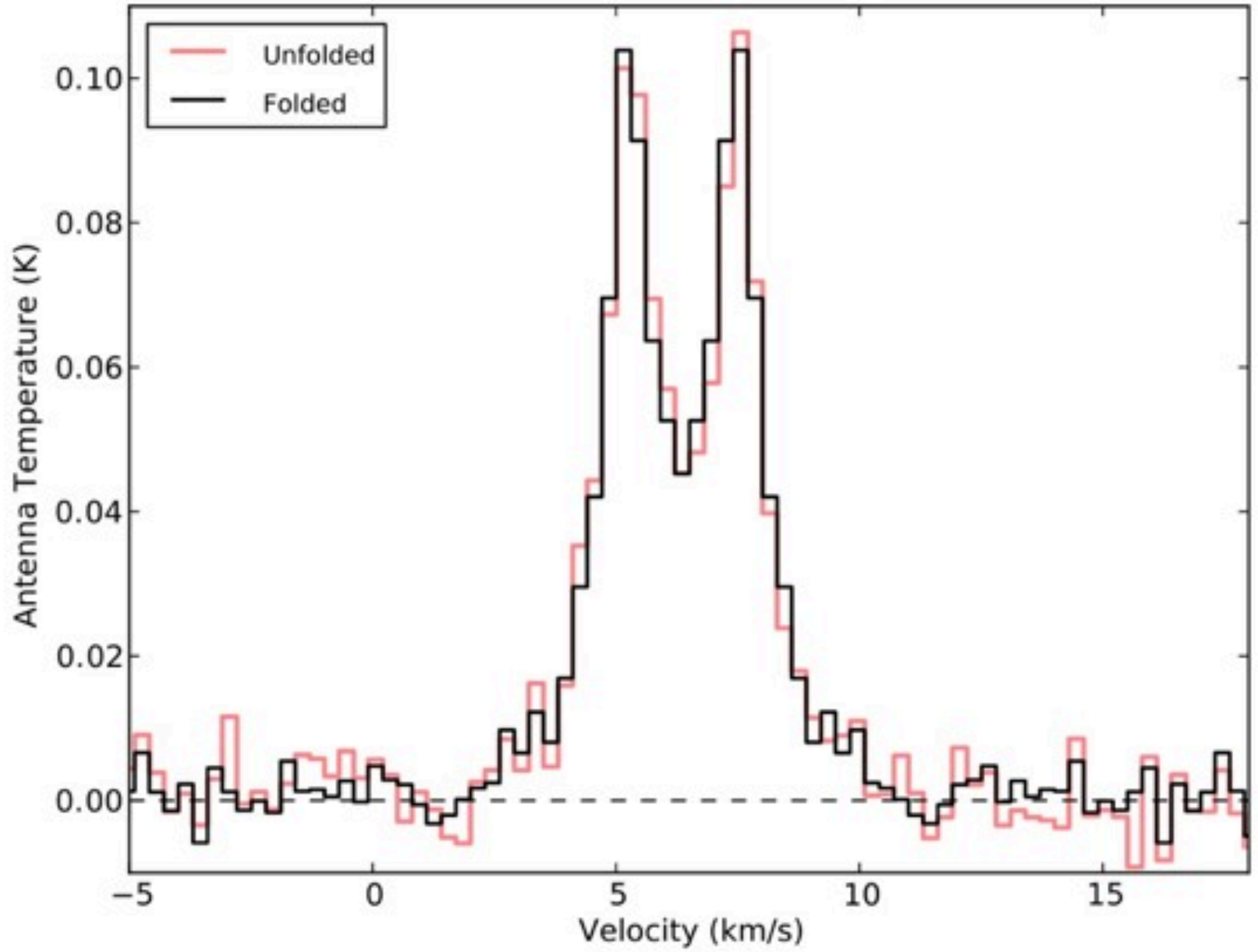


Figure 1. HCO$^+$ $J = 4 \rightarrow 3$ spectrum initial reduction binned to 0.3 km $s^{-}1$ velocity channels (red) and the spectrum folded symmetrically about the line centre at 6.4 km s^{-1} (black). The unfolded spectrum had a 1σ RMS of 0.005 K and the folded spectrum at a 1σ RMS of 0.003 K.

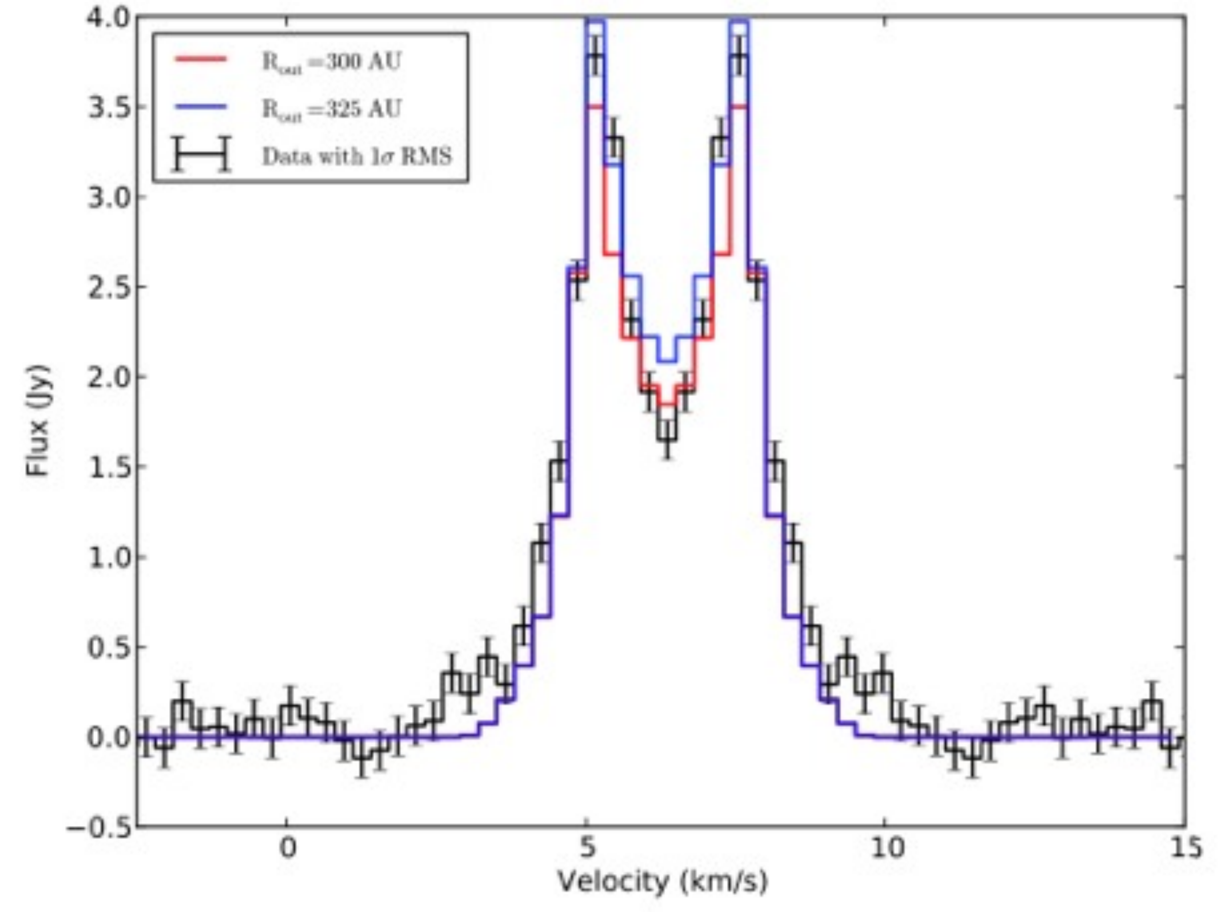
(Drabek-Maunder et al. 2014)

$$\Sigma = \Sigma_{\rm c}\left(\frac{r}{R_c}\right)^{-\lambda}\exp\left[-\left(\frac{r}{R_c}\right)^{2-\lambda}\right]$$

$$\begin{aligned} M_d &= \int_{R_{in}}^{R_{out}} 2\pi\ r\ \Sigma\ \mathrm{d}r \\ &= \frac{2\pi\Sigma_{\rm c}R_c^2}{2-\lambda}\left(\exp\left[\frac{-R_{in}}{R_c}\right]^{2-\lambda} - \exp\left[\frac{-R_{out}}{R_c}\right]^{2-\lambda}\right) \end{aligned}$$

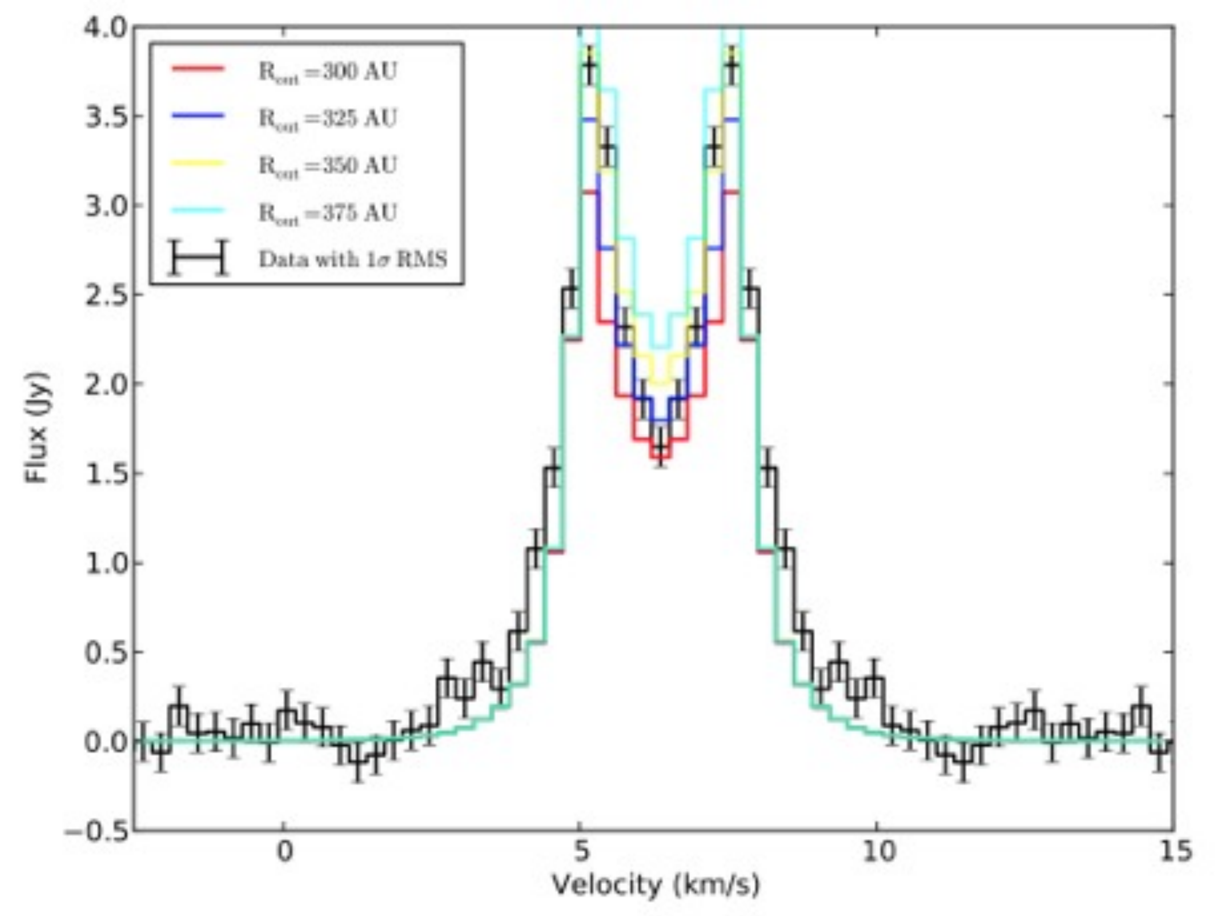
$$H(r) = \frac{c_s(r)}{\Omega(r)}$$

$$H_d^2 = H_g^2 \times \min\left[1.0, (a/a_{settle})^{-\delta}\right]$$



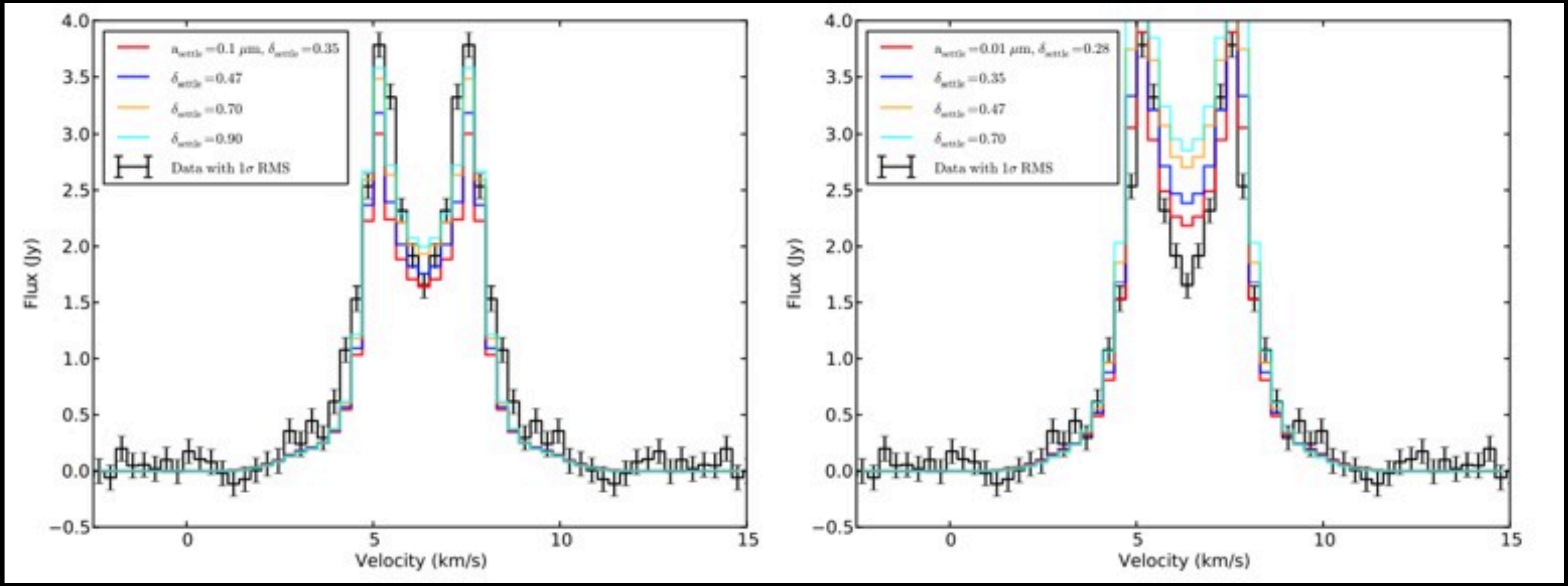
Empty Cavity

(models using ProDiMo)
(Woitke et al. 2009)

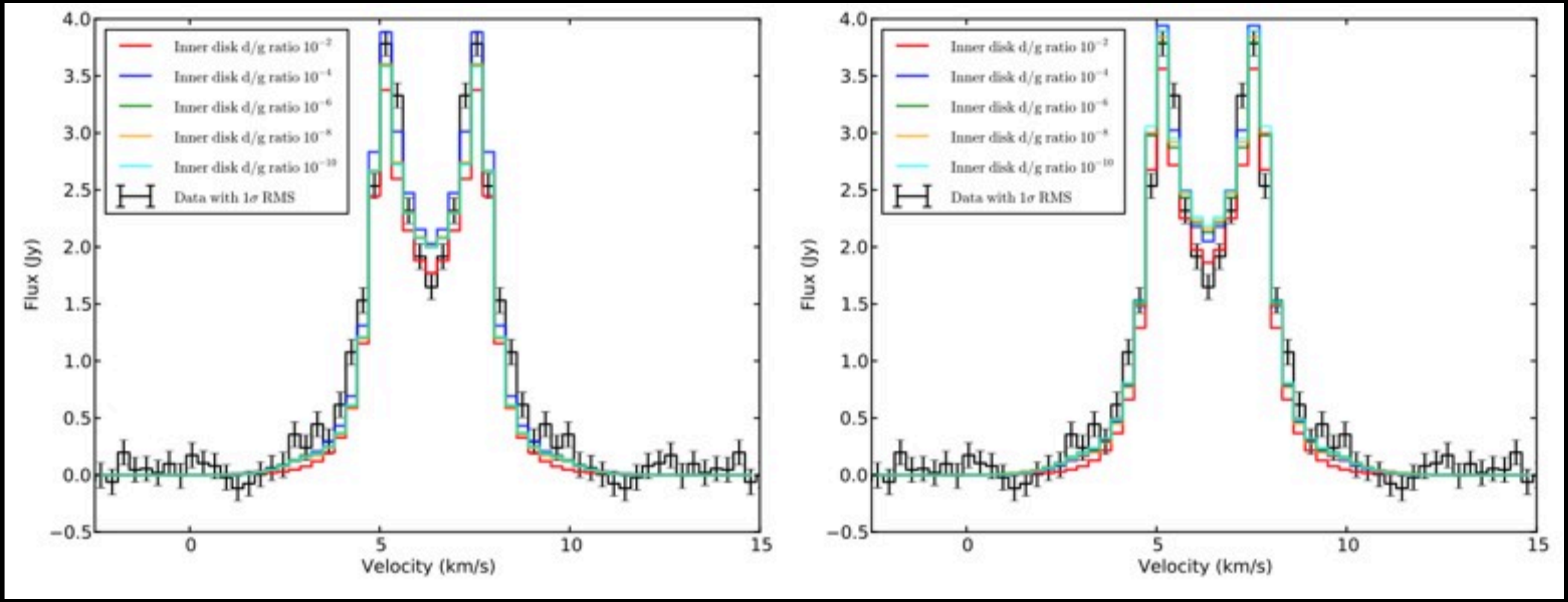


Cavity with:
standard surface density
standard (ISM) d:g ratio

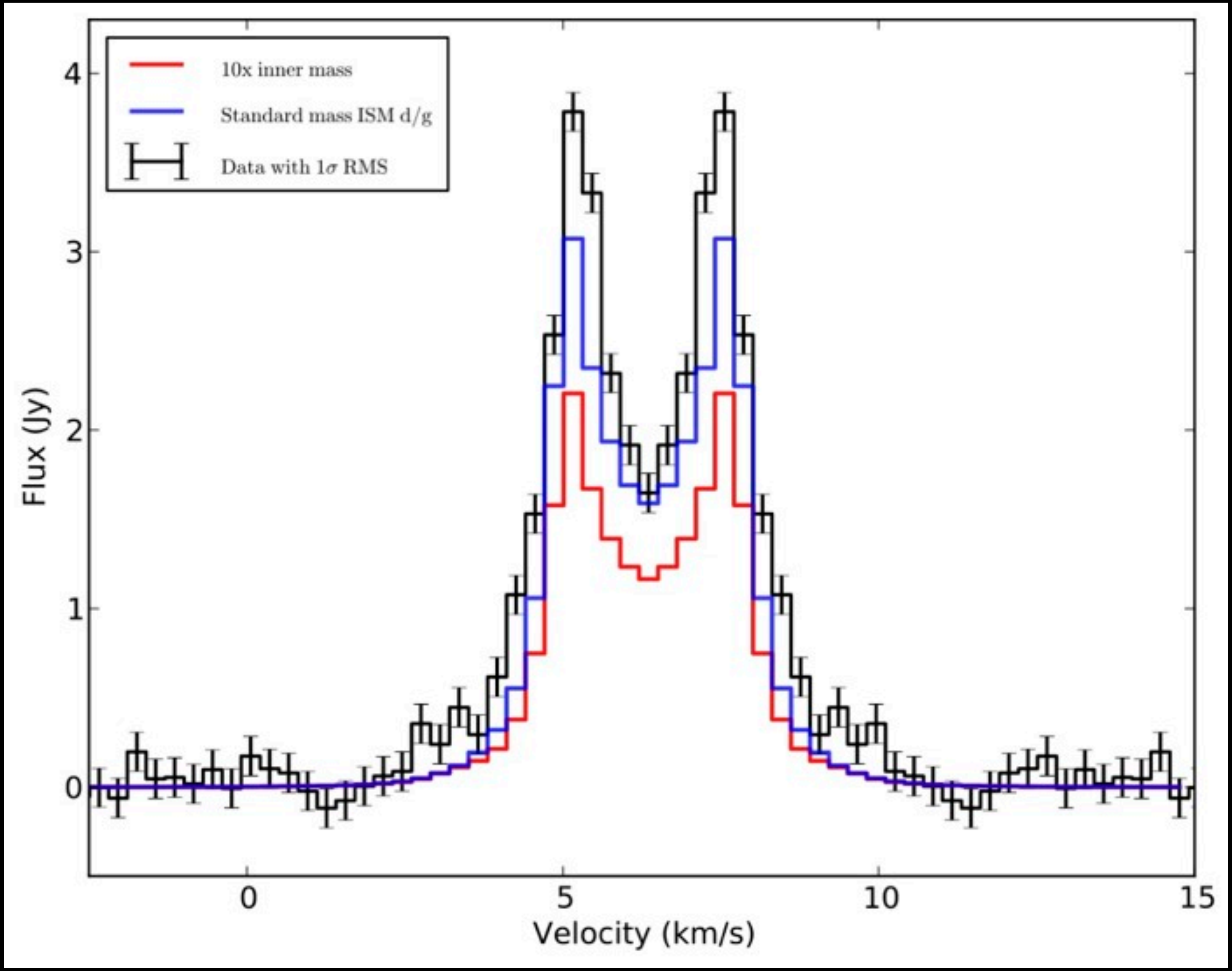
Cavity with d:g = 10^{-10} , increased settling



Cavity with varying d:g , fixed (increased) settling



Cavity with standard ISM d:g, 10x standard surface density



Conclusions

- Gas detected in HCO+ in the LkCa 15 disk

- Line wings imply gas exists within the large dust cavity (consistent with the obs. high accretion rate)

- Standard ISM well-mixed dust-to-gas ratio within the cavity cannot explain the line-wing data: the dust cools the gas too much in this case. The gas must be depleted in well-mixed dust. This is independent of the gas geometry (homogeneous or streamers) in the cavity.

- The dust depletion may be due to lower dust-to-gas ratio, or increased settling, or both (consistent with the thoery of dust filtration at the gap outer boundary)

- The gass mass within the cavity is consistent with the standard amount expect in the absence of a cavity (~0.09 Msun). Thus, while any planets creating the gap may influence the gas geometry (e.g., creating streamers), they do not significantly affect the gas mass in the cavity, at least in LkCa 15.