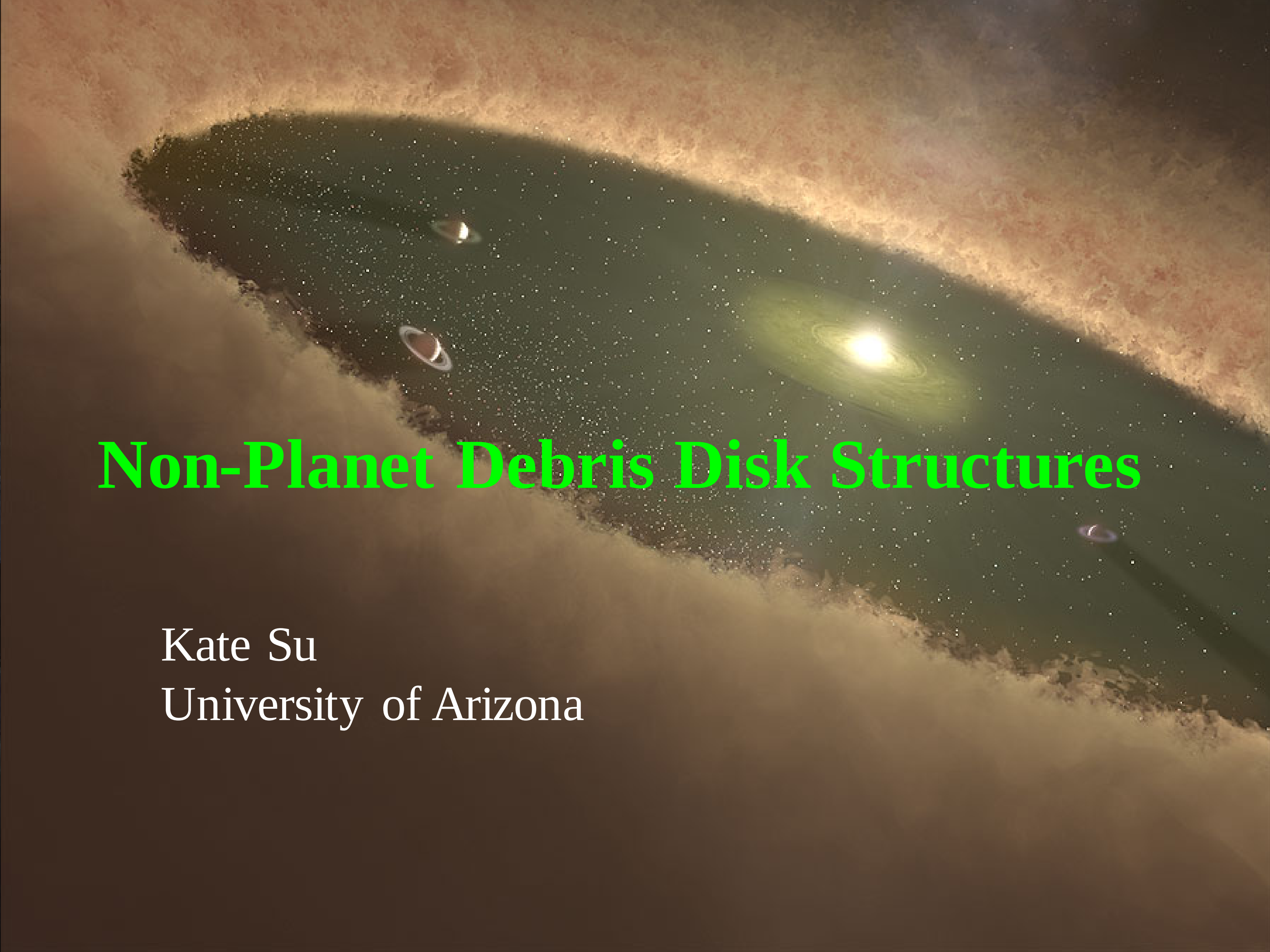


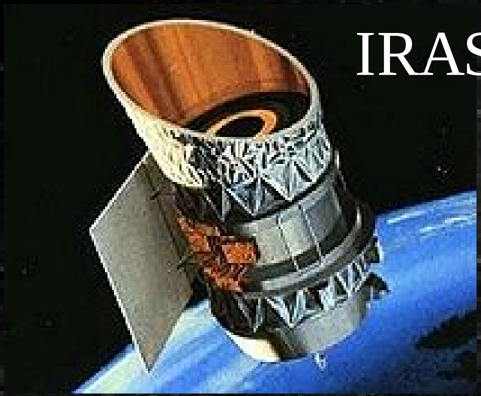
Non-Planet Debris Disk Structures

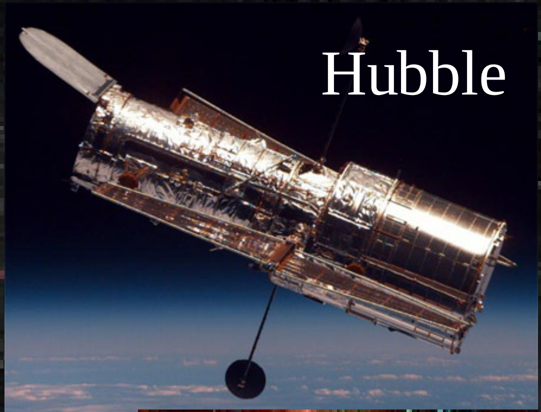
Kate Su
University of Arizona

Outline

- Challenges of Interpreting Observations
- Physics in play (collisions, radiation pressure, PR drag, stellar wind, stellar wind drag… etc.)
- Internal Effects
  - Gas drag (if there is remaining gas…)
  - Collisions + Non-gravitational Forces
  - Sublimation
- External Effects
  - ISM interaction
  - Stellar Encounter/Flyby
- Future Prospect

Great Facilities to Study Debris Disks


IRAS


Hubble


Spitzer


ARKARI


Herschel


WISE

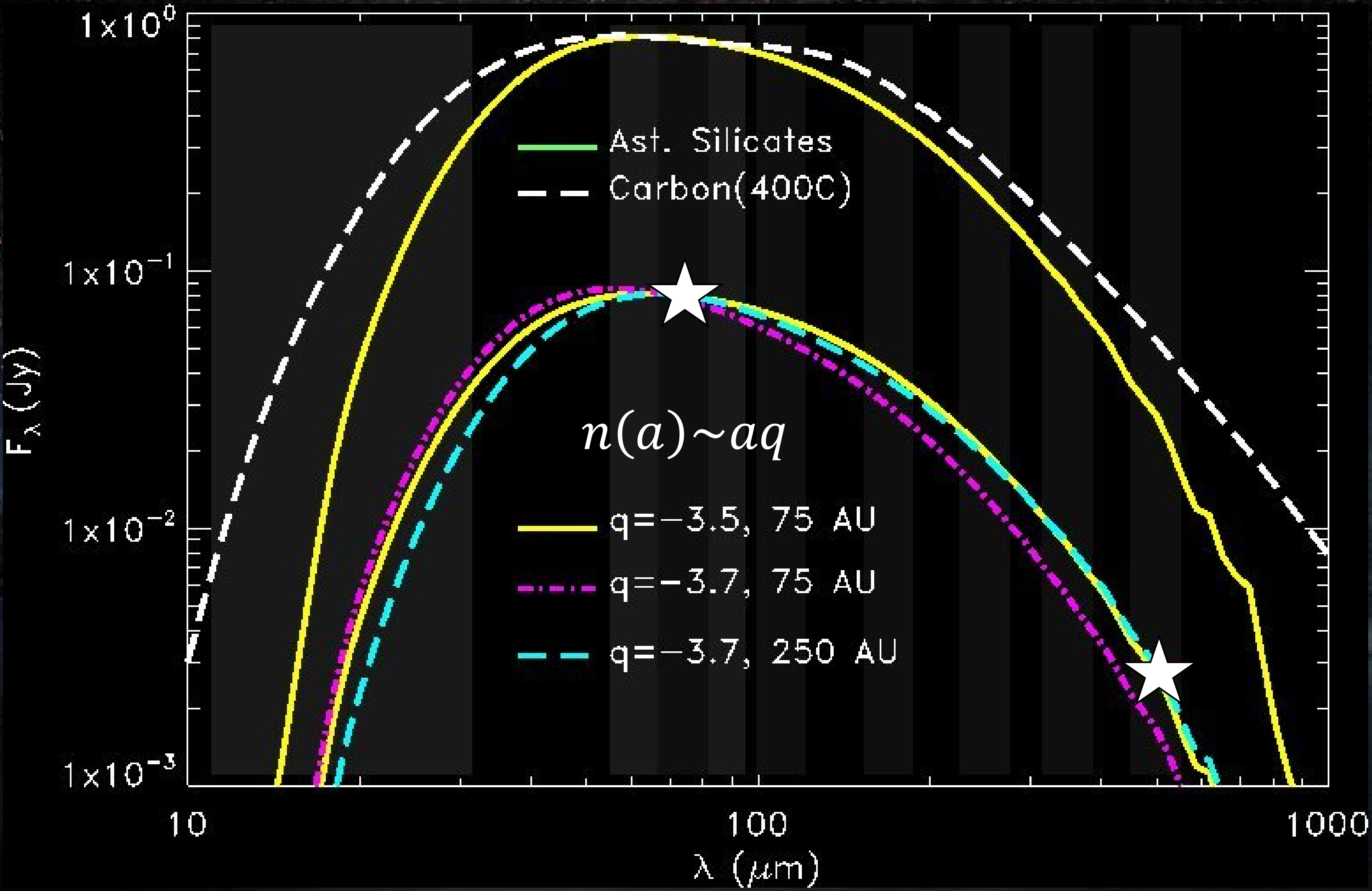
More than ~400 debris disks known

Small (μm-size) particles dominate the disk opacity and large (>>100 μm-size) particles dominate the mass

- Connection between small and large particles?
- Can we use observations (dust particles) to trace planetesimals (km-size bodies)?

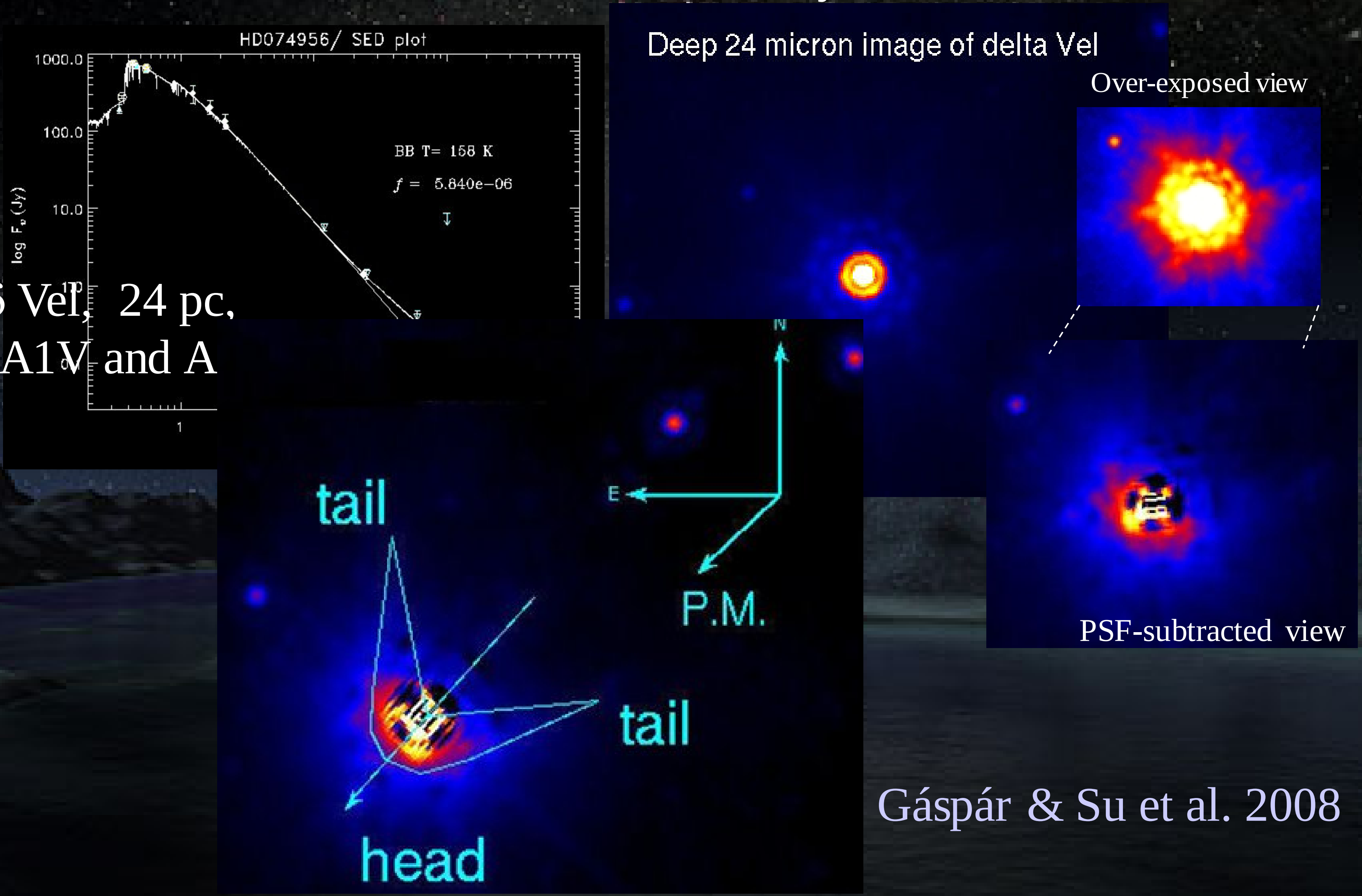
Challenges of Interpreting Observations

- Unresolved sources: degeneracy of broad-band SEDs



Challenges of Interpreting Observations

- Resolved sources: are all IR excess systems debris disks?



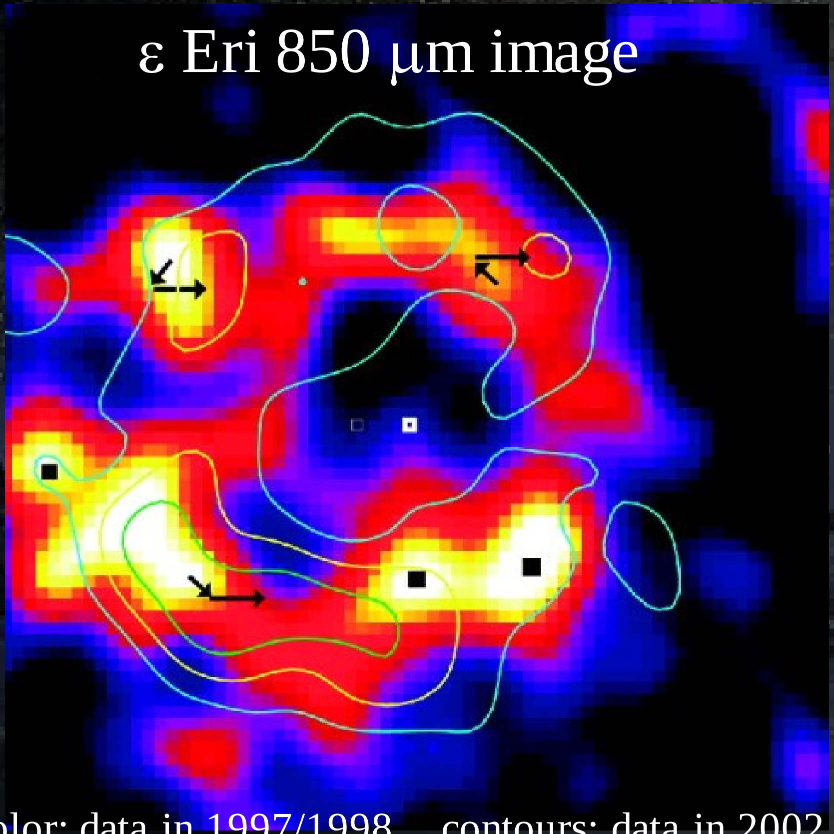
δ Vel, 24 pc,
(A1V and A

Gáspár & Su et al. 2008

Challenges of Interpreting Observations

- Resolved sources: are all structures debris-disk related?

IR cirrus and background galaxies contribute false detection!



ε Eri 850 μm image

color: data in 1997/1998 contours: data in 2002

Greaves et al. 2005

SPIRE image of NGC 4725

Courtesy of KINGFISH team

Physics in Play (besides the gravity of a “planet”)

- Gas drag
- Collisions

$$\tau_{\rm coll} = 2\times 10^3 {\rm yr}\,\gamma \left(\frac{r}{50{\rm AU}}\right)^{3/2-\alpha} \left(\frac{a}{\mu{\rm m}}\right) \left(\frac{\rho_g}{{\rm g~cm}^{-3}}\right) \left(\frac{\pi a^2}{S_z}\right) \left(\frac{M_*}{M_\odot}\right)^{-1/2} \left(\frac{M_d}{10^{-3} M_\oplus}\right)^{-1}$$

- Radiation Pressure

$$\tau_{blow} = \frac{1}{2}\left(\frac{(R/AU)^3}{M_*/M_\odot}\right)^{1/2}$$

$$\beta = \frac{F_{rad}}{F_{grav}} = 0.575\ \frac{g\ cm^{-3}}{\rho} \frac{\mu m}{a} \frac{L_*}{L_\odot} \frac{M_\odot}{M_*}$$

- Poynting-Robertson drag

$$\tau_{PR} = 2\times 10^6 {\rm ~yr} \left(\frac{r}{50{\rm AU}}\right)^2 \left(\frac{a}{\mu{\rm m}}\right) \left(\frac{\rho_g}{{\rm g~cm}^{-3}}\right) \left(\frac{1}{Q_{rad}}\right) \left(\frac{L_*}{L_\odot}\right)^{-1}$$

- Stellar Wind

$$\frac{\tau_{SW}}{\tau_{PR}} = 3\frac{Q_{rad}}{Q_{SW}} \frac{L_*}{L_\odot} \frac{\dot{M}_\odot}{\dot{M}_*}$$

- Stellar Wind drag

$$\tau_{SW} = 6\times 10^6 {\rm ~yr} \left(\frac{r}{50{\rm AU}}\right)^2 \left(\frac{a}{\mu{\rm m}}\right) \left(\frac{\rho_g}{{\rm g~cm}^{-3}}\right) \left(\frac{1}{Q_{sw}}\right) \left(\frac{\dot{M}_*}{\dot{M}_\odot}\right)^{-1}$$

- Sublimation
- Other secondary effects (Yarkovsky effect, Lorentz force..)

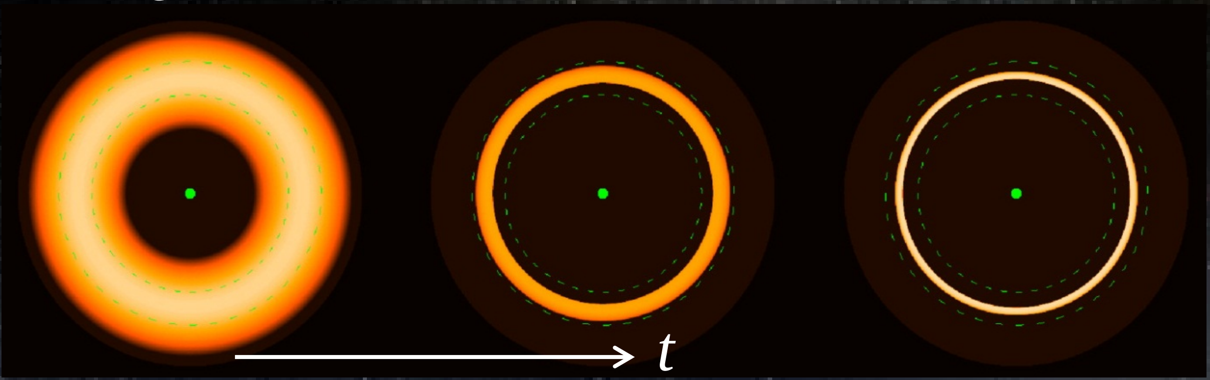
Ref: Burns et al. 1979; Gustafson 1994

Internal – Remaining Gas?

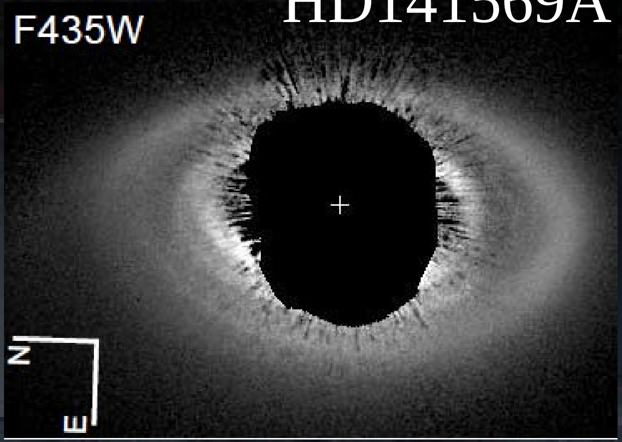
A narrow ring due to dust migration in a gas disk

M_g~10 $M_\oplus$: Takeuchi & Artymowicz 2001; Klahr & Lin 2005

M_g~0.1 $M_\oplus$: Besla & Wu 2007



HD141569A



Clampin et al. 2003

- Primordial gas is mostly depleted by 10 Myr (≤ a few $M_\oplus$, Pascucci et al. 2006; Fedele et al. 2010) with some exceptions (49 Cet: Hughes et al. 2008; HD 21997: Moor et al. 2011)
- Small amount of second generation gas around very young systems (β Pic, HD32297)

HR4796A

Schneider et al. 1999

Internal – Collisions + Radiation Pressure

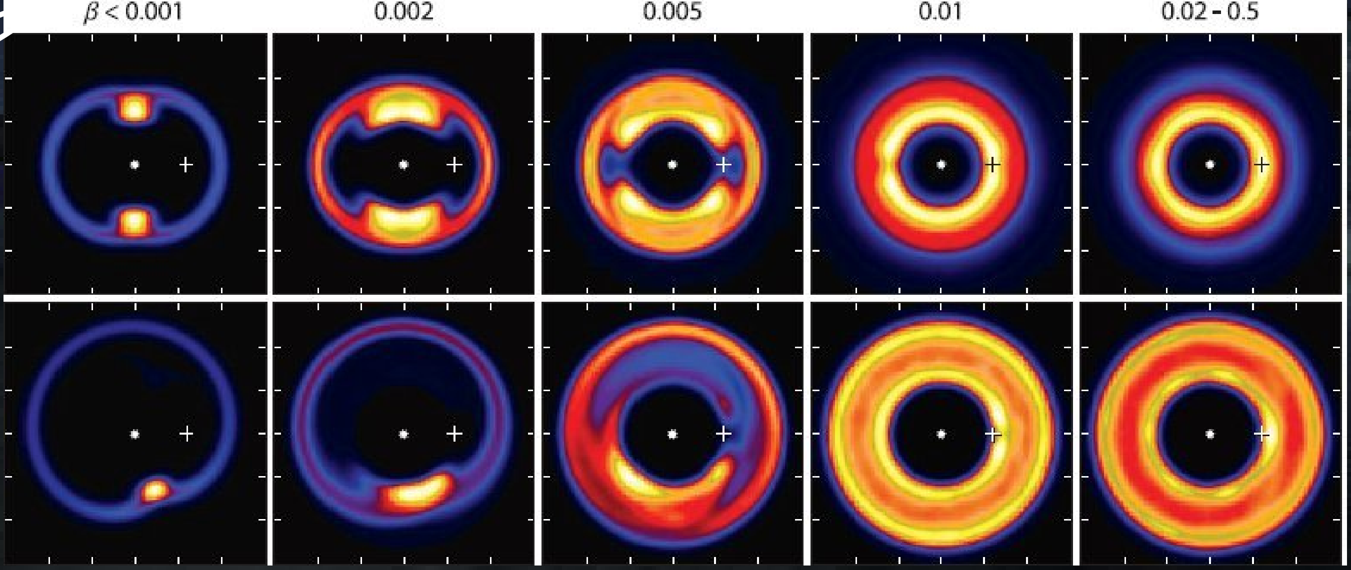
- Collision Cascades/Grinding

grains released from parent bodies on circular obits

$$e_{birth} = \frac{\beta}{(1-\beta)}$$

$$\beta = \frac{F_{rad}}{F_{grav}} = 0.575 \frac{g\ cm^{-3}}{\rho} \frac{\mu m}{a} \frac{L_*}{L_\odot} \frac{M_\odot}{M_*}$$

Face-on view of the surface density of different grain sizes (Wyatt 2006)

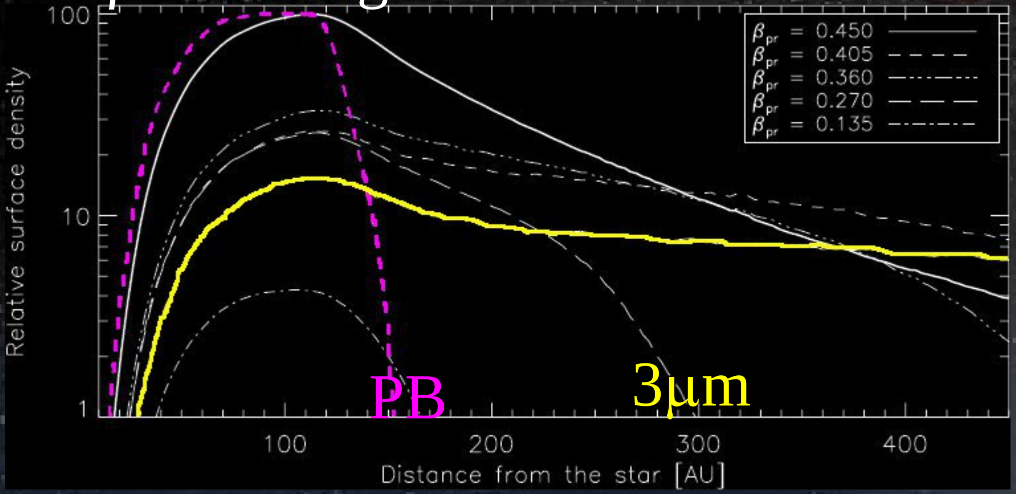


planetesimals trapped in resonances with a 30 $M_\oplus$ planet

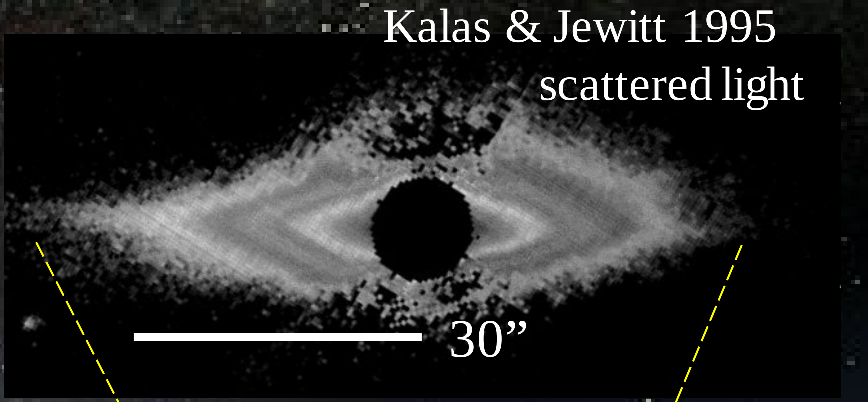
Internal – Collisions + Radiation Pressure

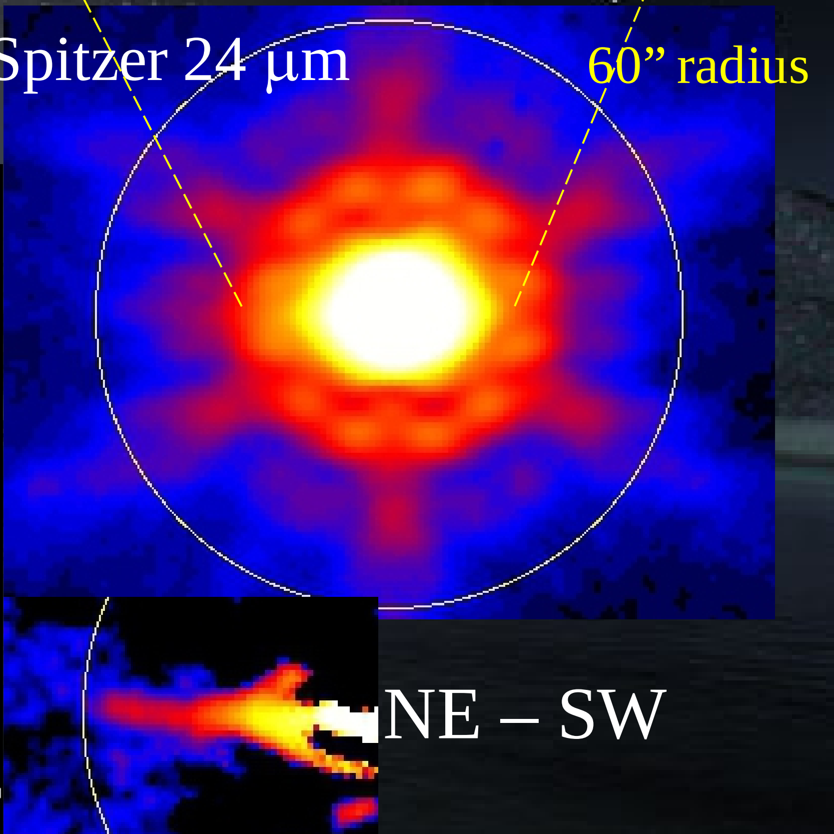
- Collision Cascades/Grinding + Radiation Pressure

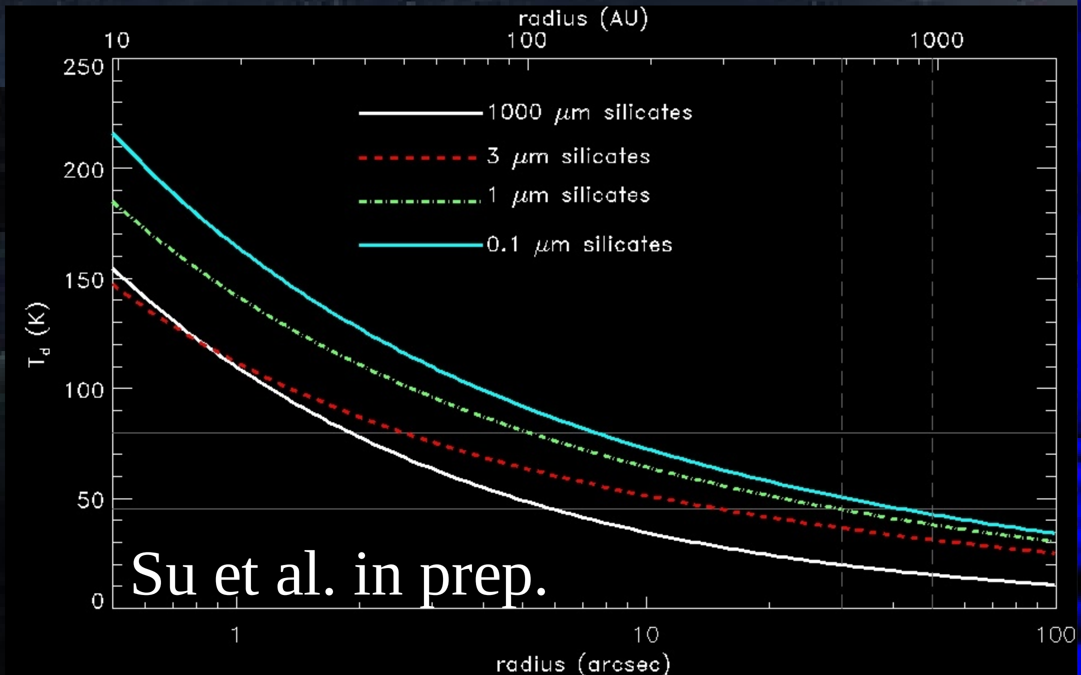
β Pic: Augereau et al. 2001



Kalas & Jewitt 1995 scattered light







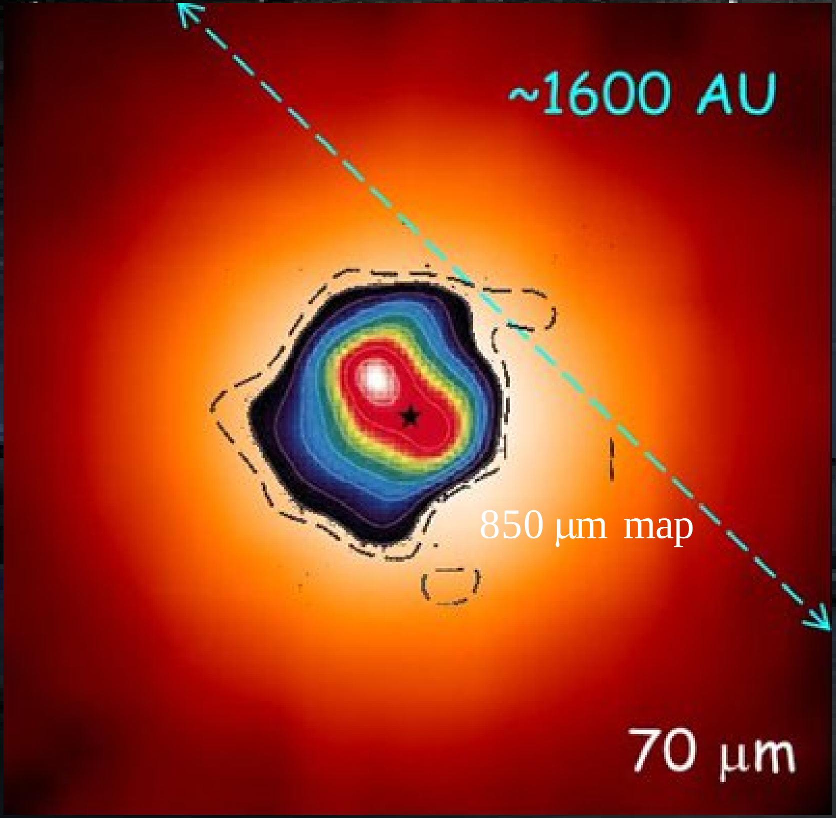
Su et al. in prep.

Internal – Collisions + Radiation Pressure

- Collisions + Radiation Pressure

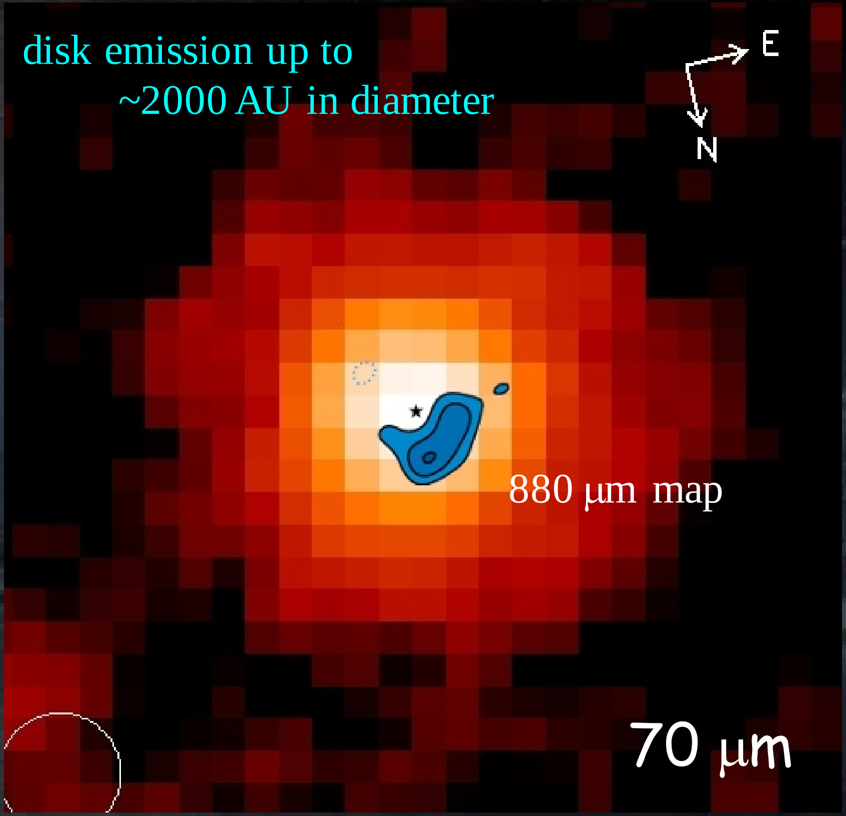
Extended halo around early-type stars: Vega and HR 8799

Vega Disk A0V, 7.6 pc



MIPS 70 µm: Su et al. 2005
SCUBA 850 µm: Holland et al. 1998

HR 8799 Disk A5V, 40 pc


disk emission up to ~2000 AU in diameter

MIPS 70 µm: Su et al. 2009
SMA 880 µm: Hughes et al. 2011

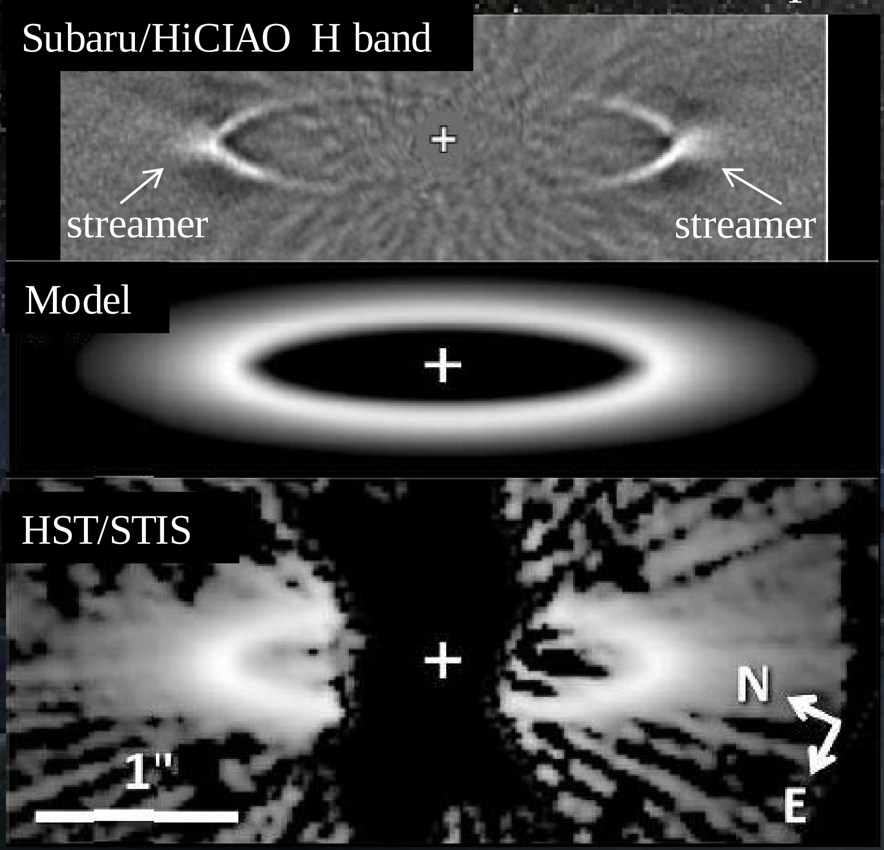
Internal – Collisions + Radiation Pressure

- Collisions + Radiation Pressure

Extended halo around early-type stars: HR 4796 A and Fomalhaut

HR 4796 A Disk

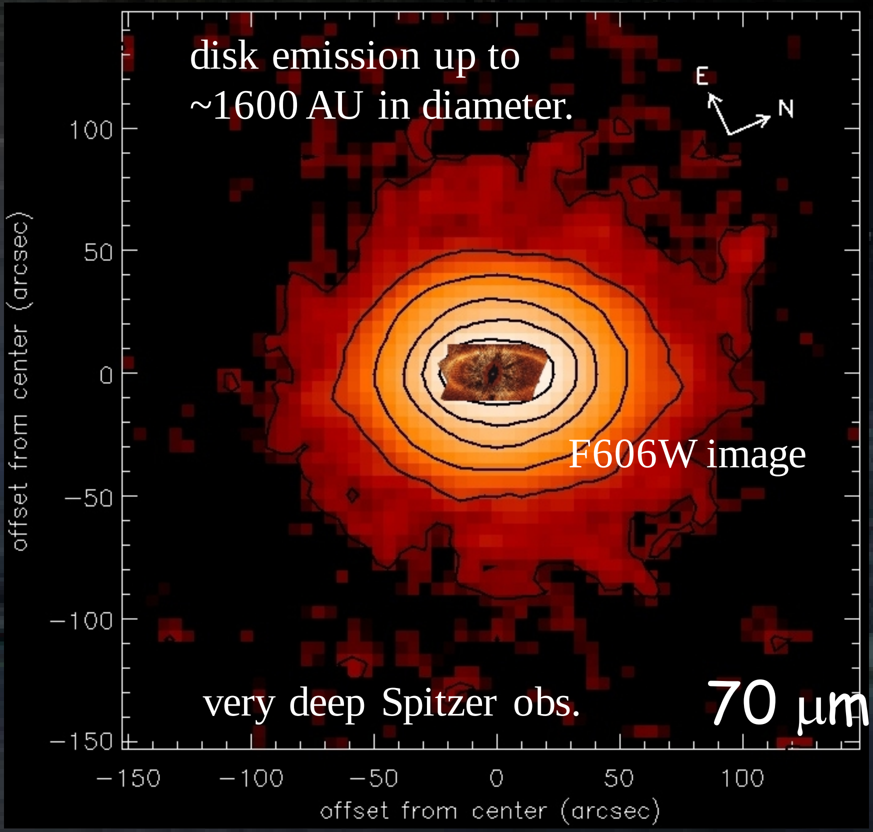
A0V, 72.8 pc



Subaru/HiCIAO: Thalmann et al. 2011
HST/STIS: Schneider et al. 2009

Fomalhaut Disk

A3V, 7.7 pc


disk emission up to ~1600 AU in diameter.

F606W image

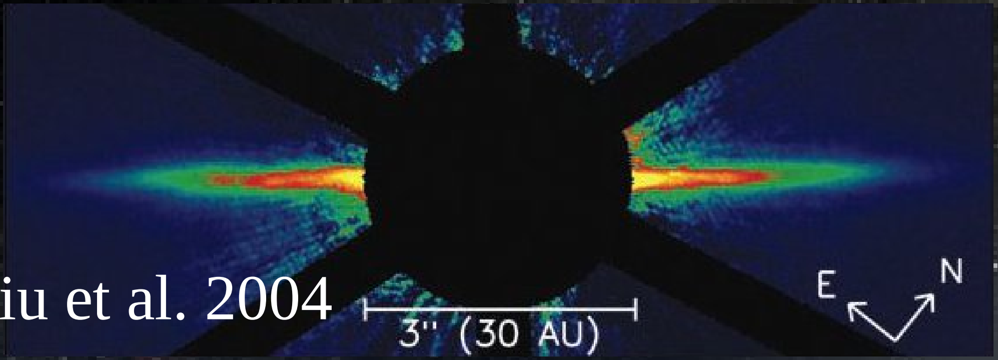
very deep Spitzer obs.

MIPS 70 μm: Espinoza, Su et al. in prep.
HST scattered light: Kalas et al. 2005

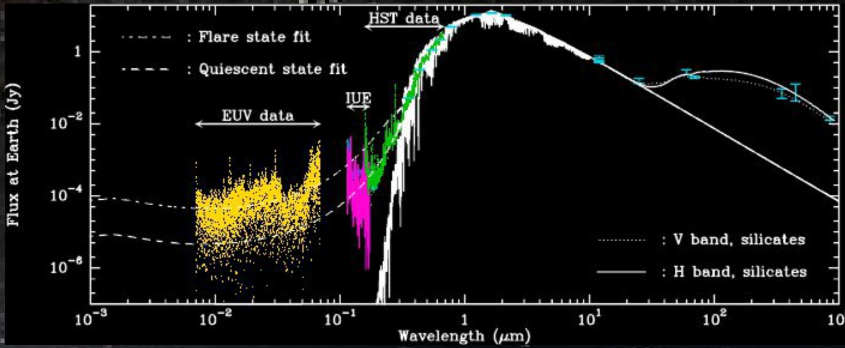
Internal – Collisions + Stellar Wind/Drag

- Collisions + Stellar Wind + Stellar Wind drag

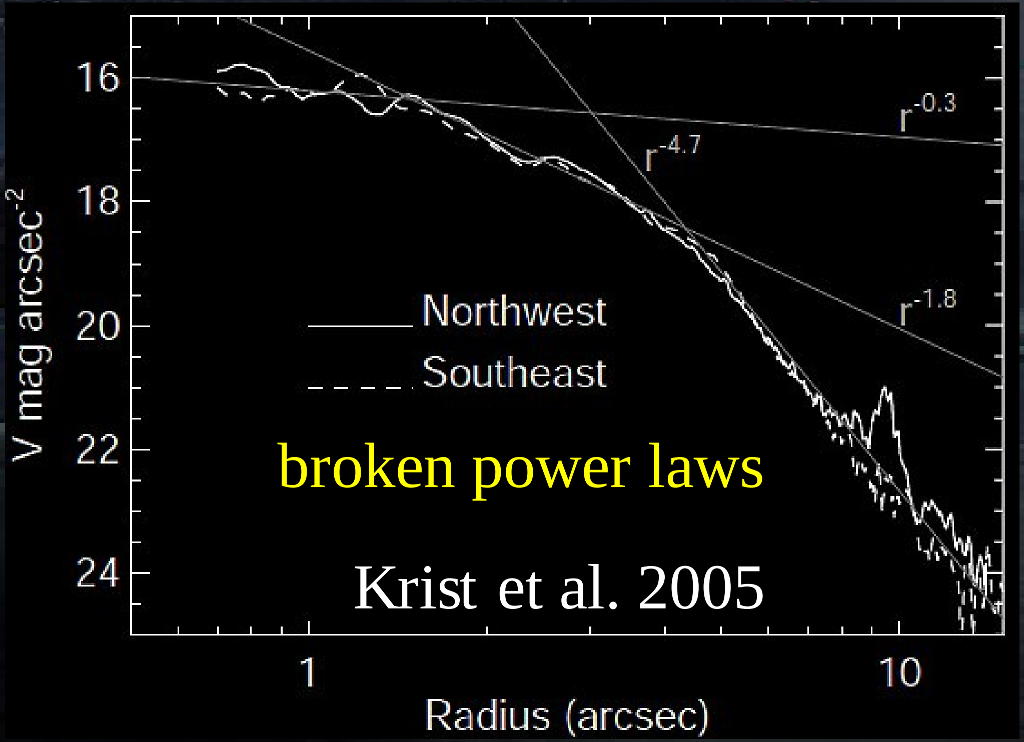
M-type disk: AU Mic



Liu et al. 2004

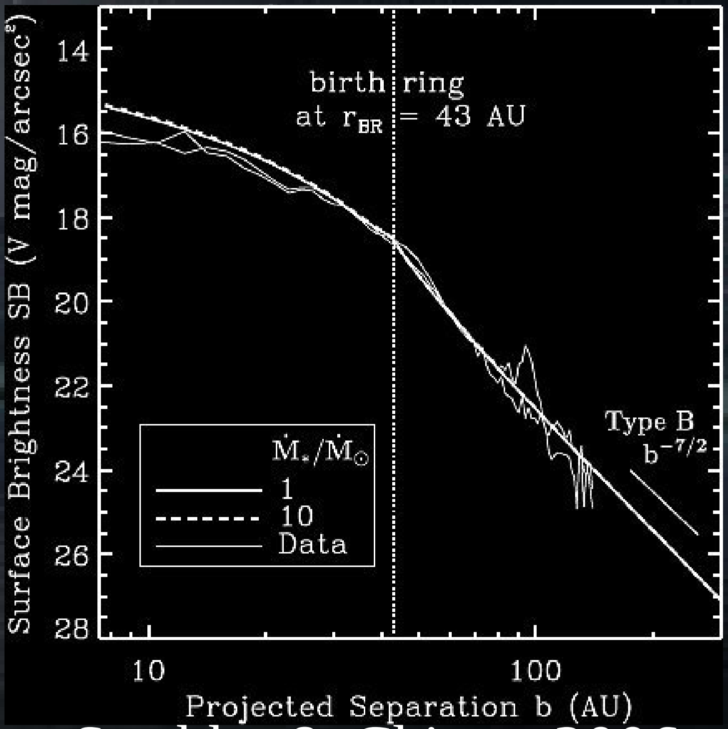


Augereau et al. 2006



broken power laws

Krist et al. 2005

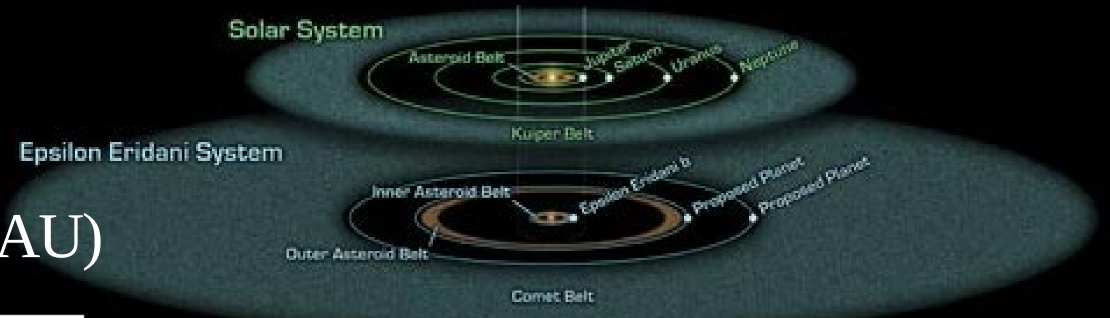


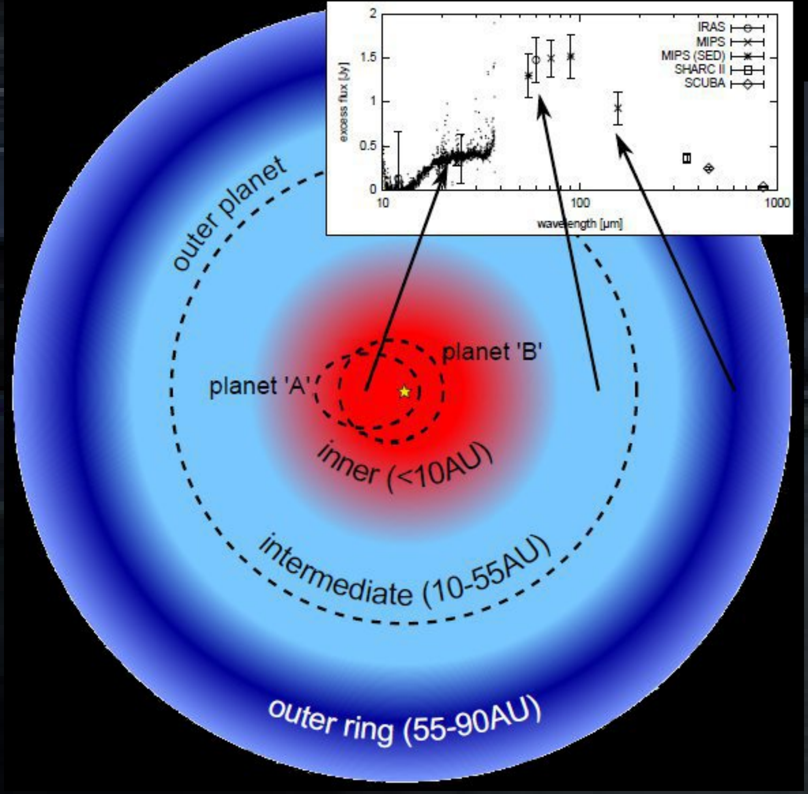
Strubbe & Chiang 2006

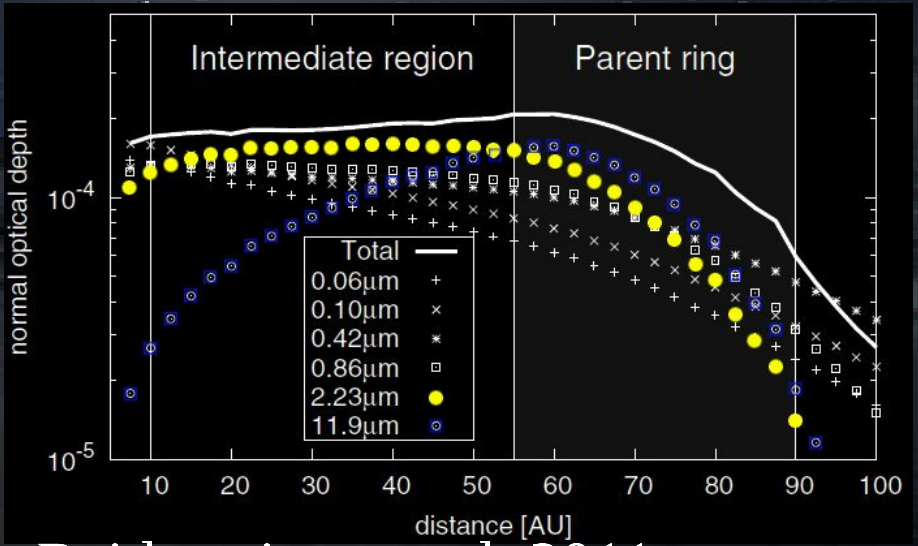
Internal – Collisions + Drag Forces

- Collision Grinding + PR drag + Stellar wind drag: ε Eri

Backman et al. 2009:
cold disk (35-90 AU)
warm rings (~3 and ~20 AU)







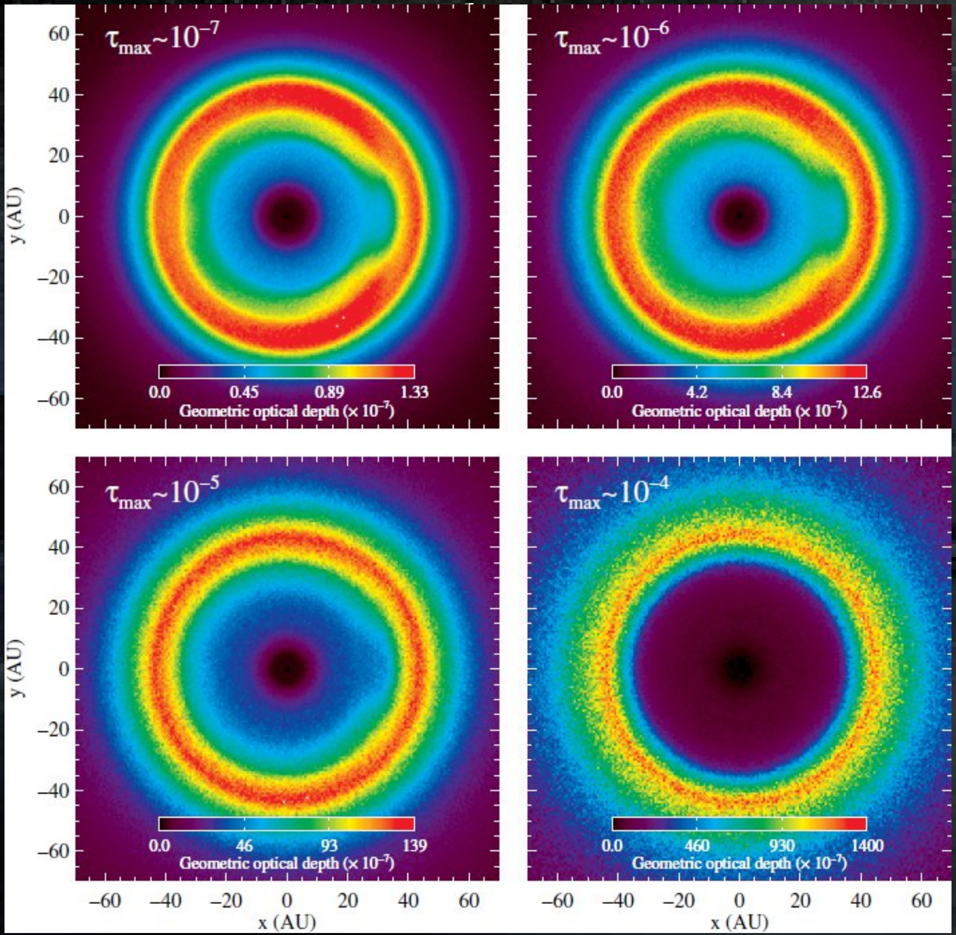
Reidemeister et al. 2011

Internal – Collisions

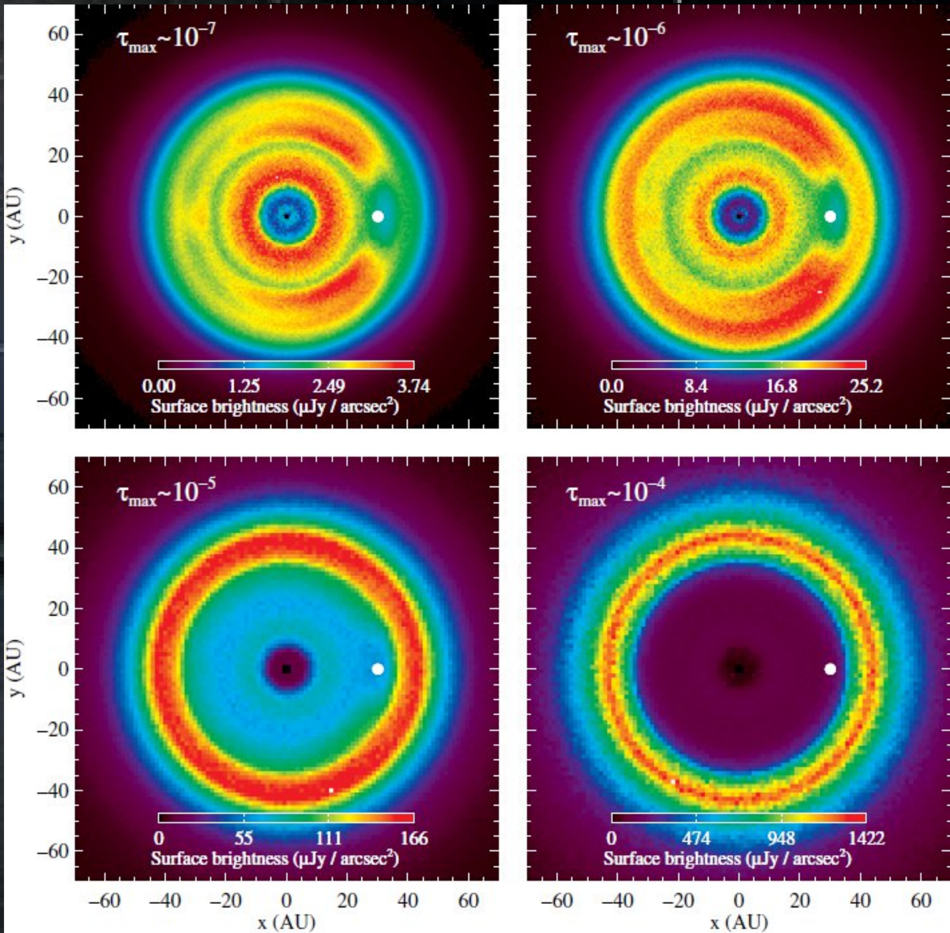
- Collision Cascades/Grinding + Drag Forces

Kuchner & Stark 2010 show that morphology of the disk depends on optical depth as well (transported disk vs. collision dominated disk)

Density



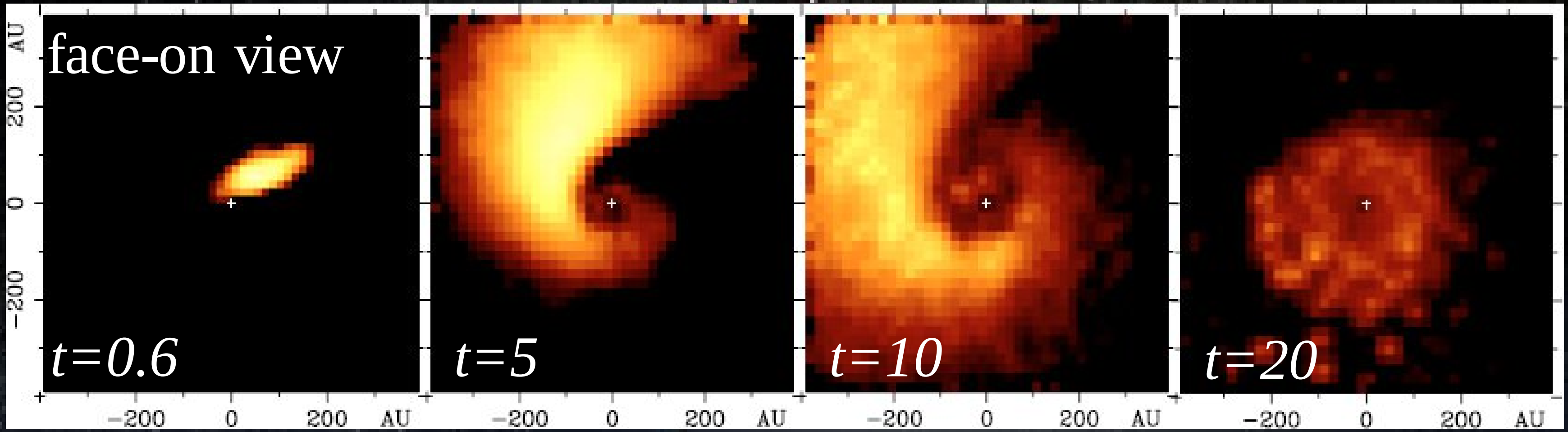
Surface Brightness ($\lambda\sim60$ μm)



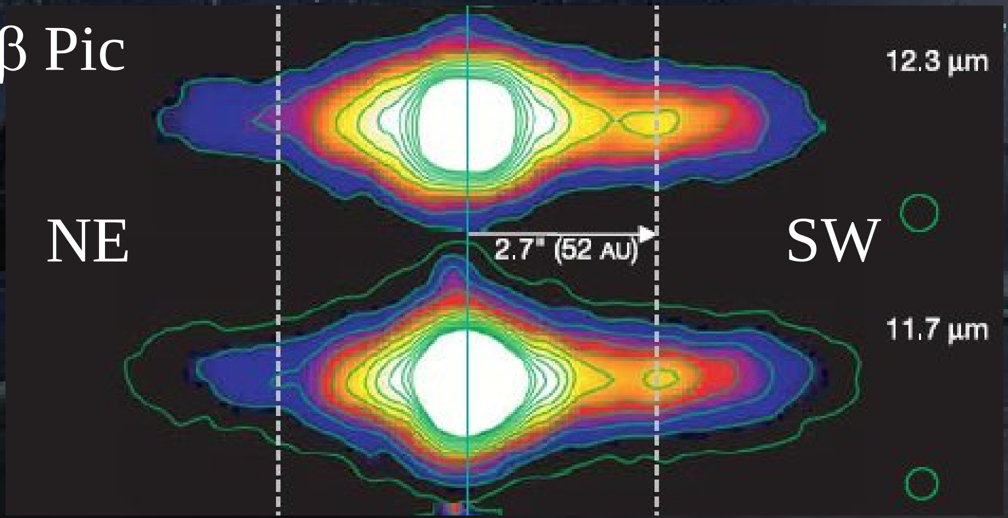
Internal – Collisions

- Dust Avalanche

Grigorieva et al. 2007

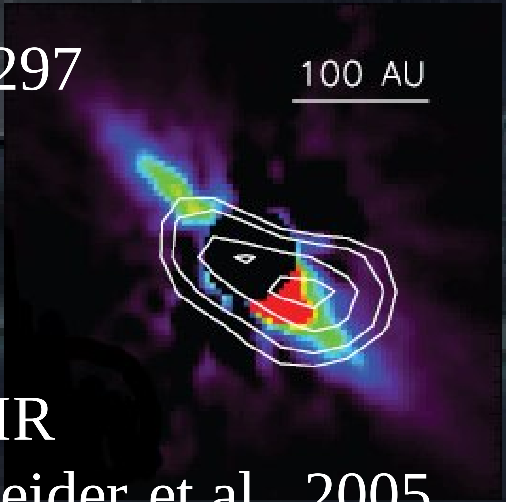


β Pic



Gemini/T-ReCS; Telesco et al. 2005

HD 32297



color: NIR

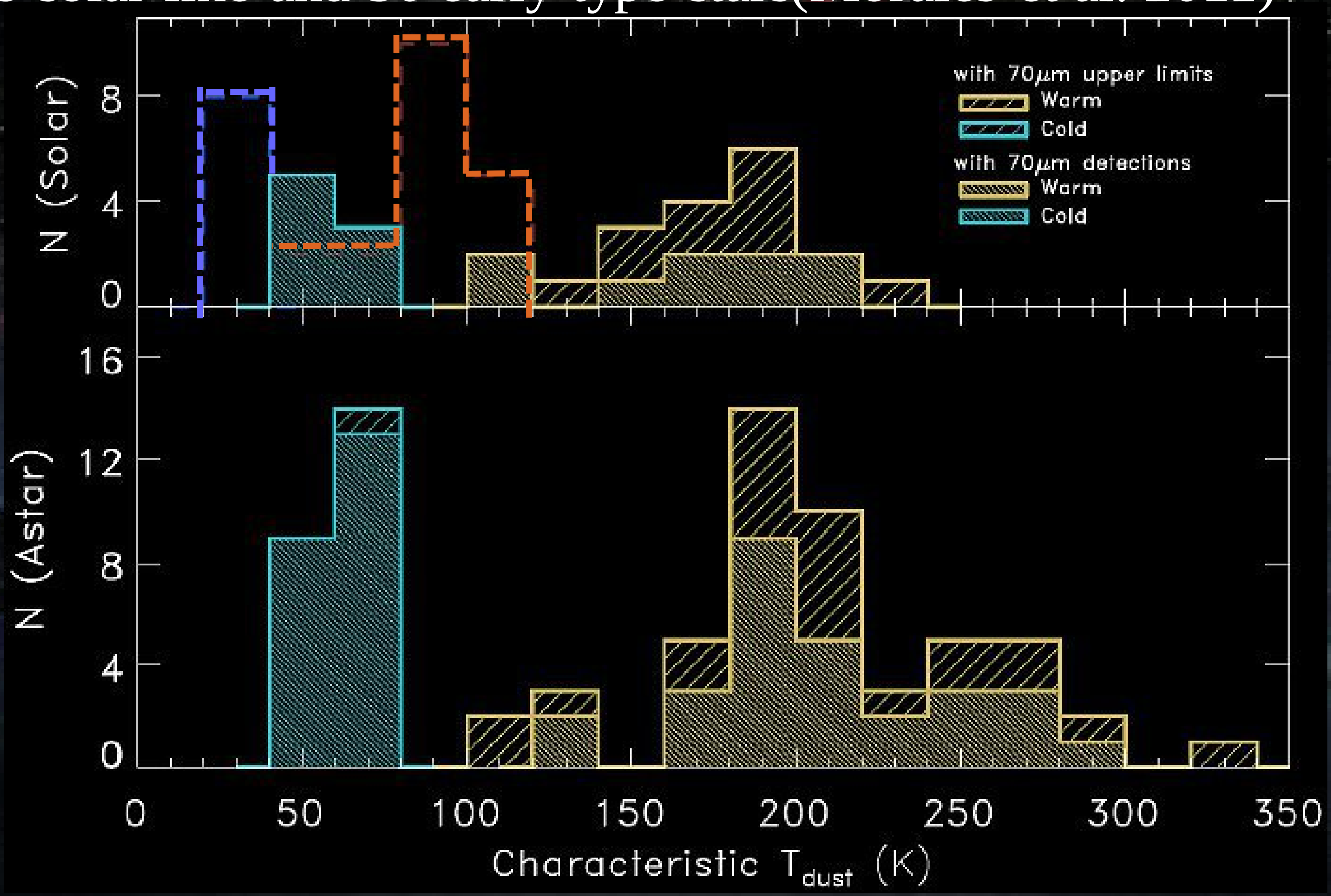
Schneider et al. 2005

contours: 1.3 mm

Maness et al. 2008

Internal – Ice Sublimation?

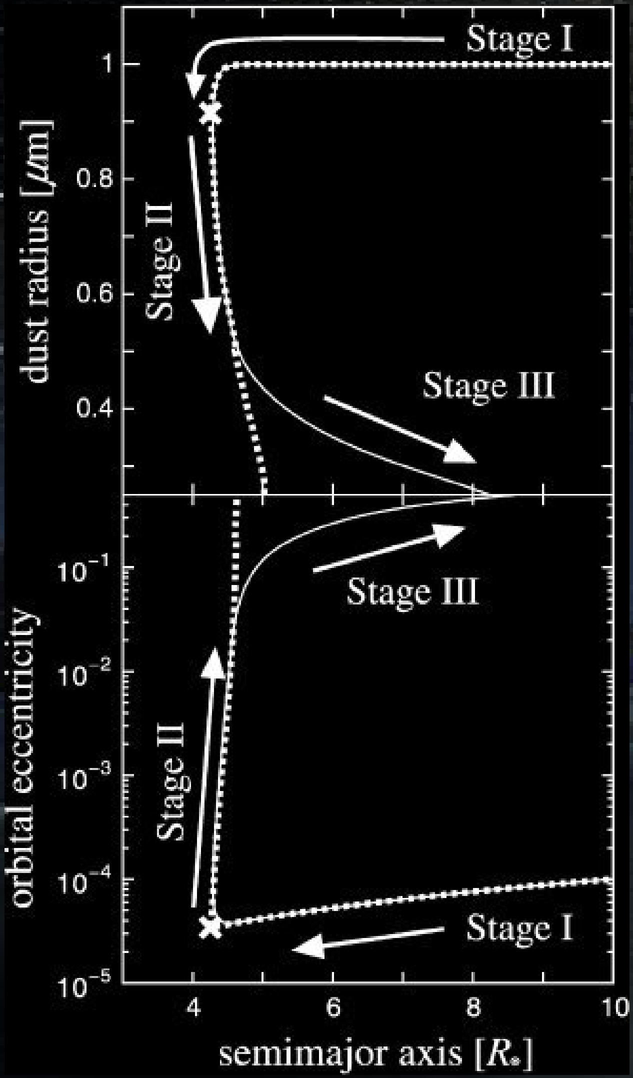
Stars selected based on 24 μm excesses with ages <1 Gyr :
19 solar-like and 50 early-type stars(Morales et al. 2011)

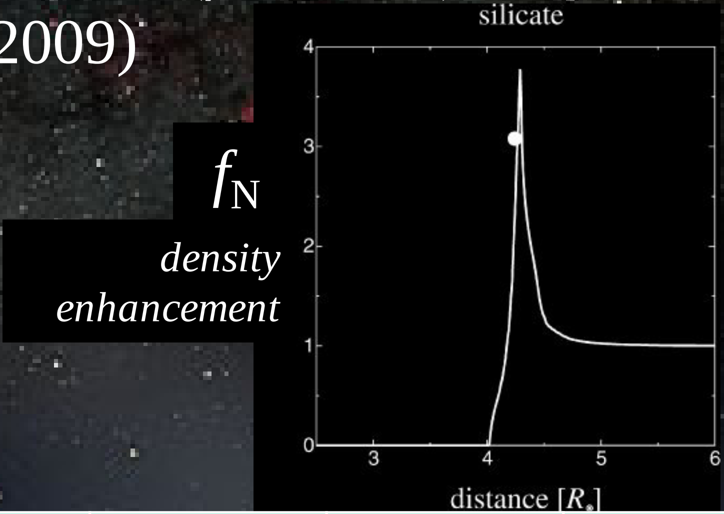


Similar T_d distributions between solar-like and early-type stars!!

Internal – Sublimation

- sublimation in drag-dominated ($f < 1x10^{-5}$) disk (Kobayashi et al. 2008, 2009)





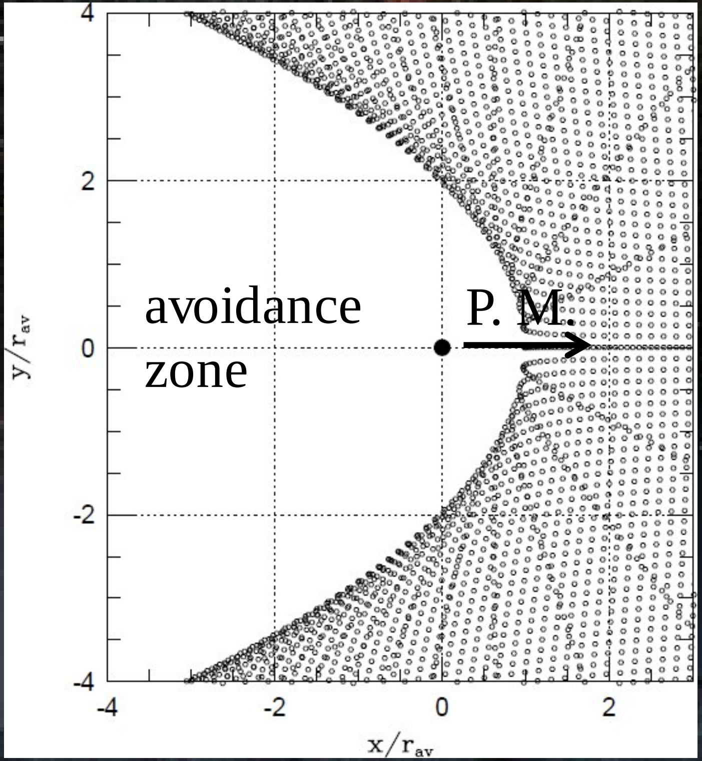
		Icy	**Silicate**	**Carbon**
	T_{sub}	~100 K	~1200 K	~2100 K
Sun	r_{sub}	22 AU	0.023 AU	0.018 AU
	f_N	2.7	3.3	9.2
β Pic	r_{sub}	31 AU	0.13 AU	0.05 AU
	f_N	2.2	6.5	27

K-band hot excesses:
Vega (Absil et al. 2006), Fomalhaut (Absil et al. 2009), τ Ceti (Di Folco et al. 2007), ζ Aql (Absil et al. 2008).

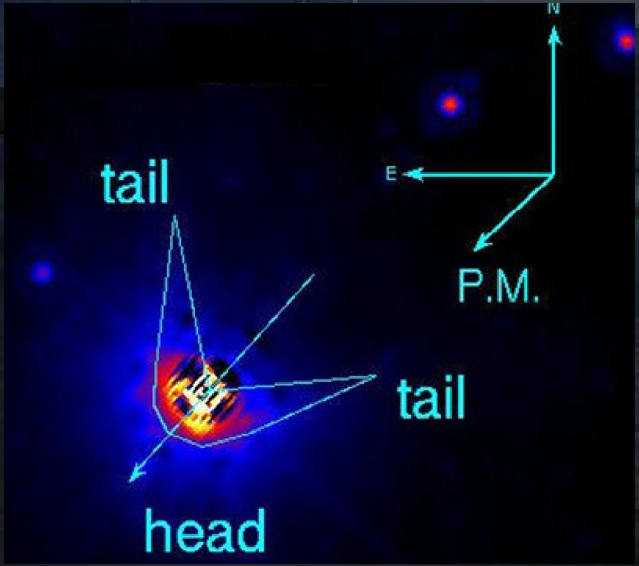
External – ISM interaction

- ISM Sandblasting Effect

Artymowicz & Clampin 1997 show that this effect has minor importance for the structure and evolution of early-type debris disks, except in their outskirts (>400 AU). Under favorable conditions, it may cause asymmetries in observed brightness and color.



δ Vel, 24 pc,
(A1V and A5V)

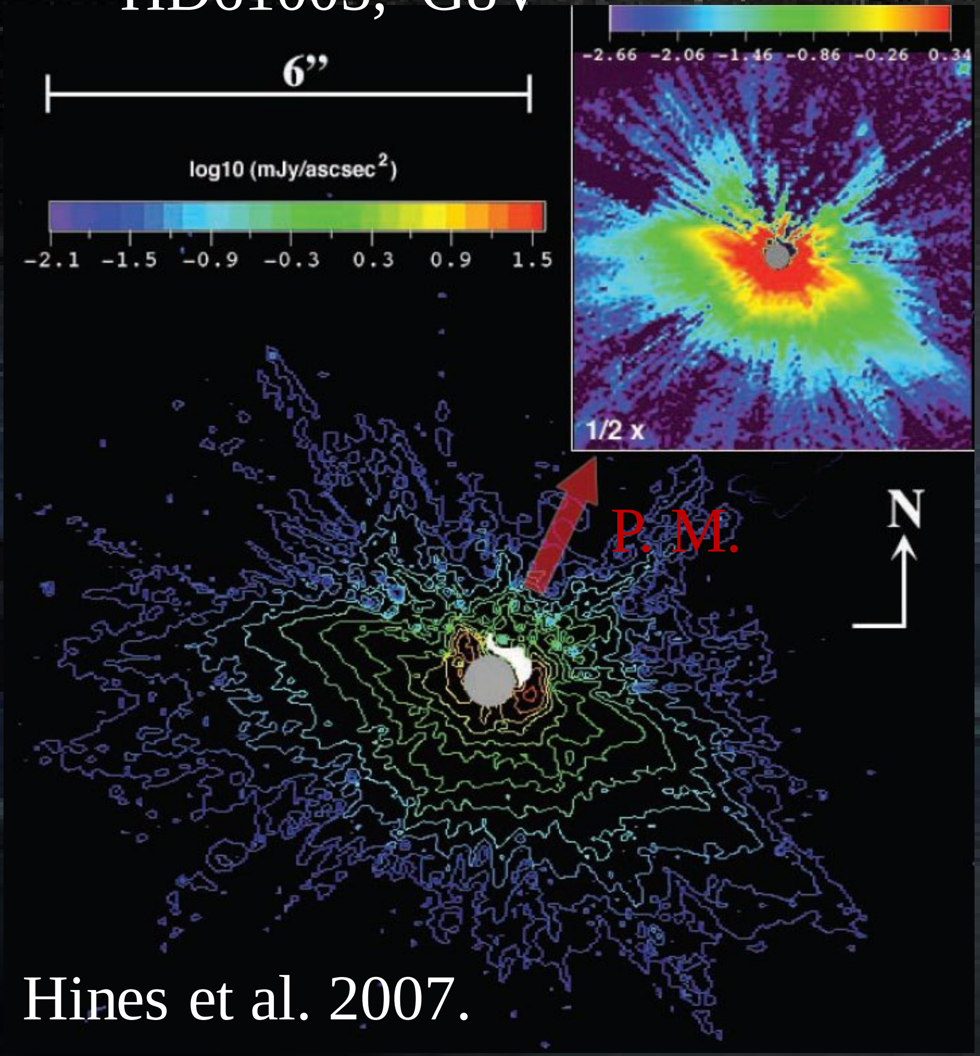


Gáspár & Su et al. 2008

External – ISM interaction

- ISM Sandblasting Effect

HD61005, G8V

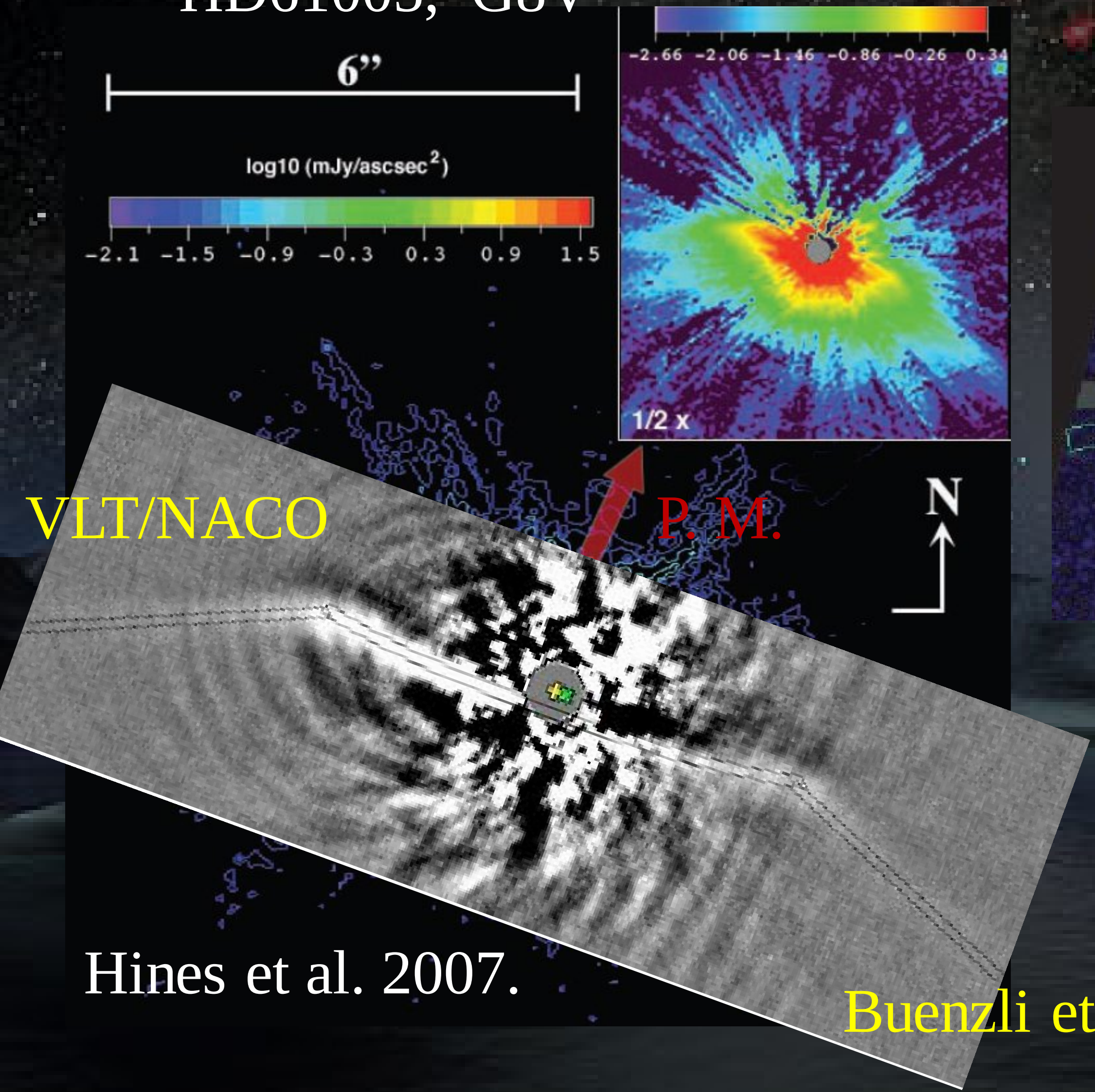


Hines et al. 2007.

External – ISM interaction

- ISM Sandblasting Effect

HD61005, G8V



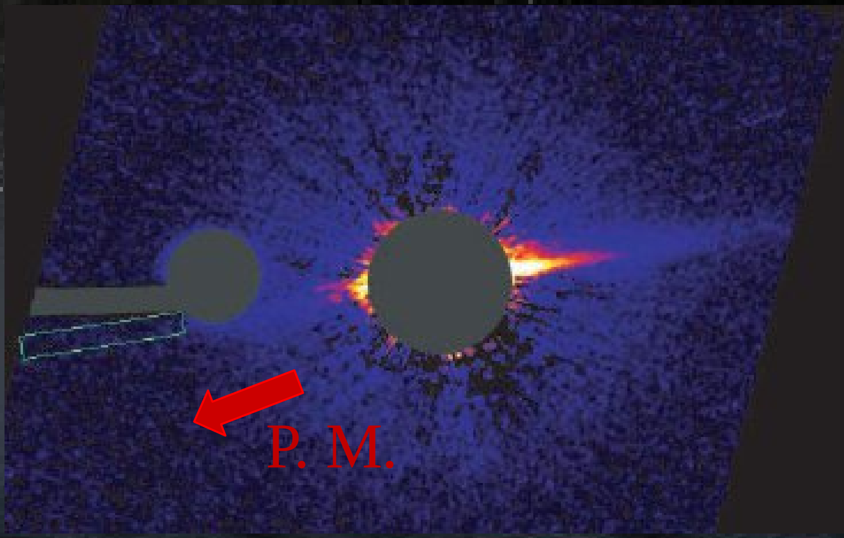
VLT/NACO

P. M.

Hines et al. 2007.

Buenzli et al. 2010

HD 15115, F2V



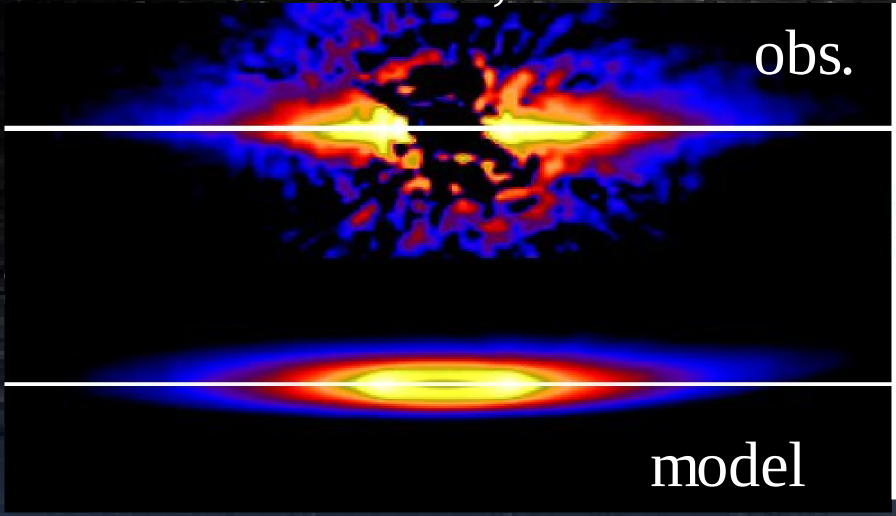
P. M.

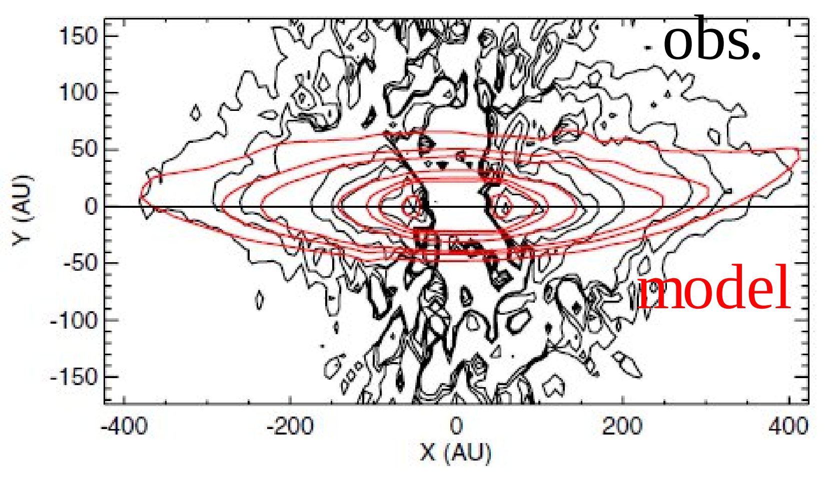
Kalas et al. 2007

External – ISM interaction

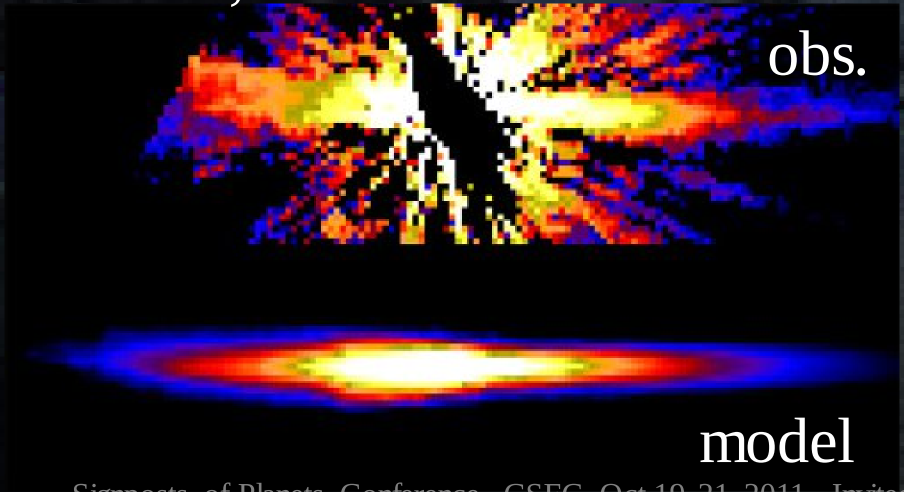
- ISM Sandblasting Effect Debes et al. 2009.

HD 32297, A5V

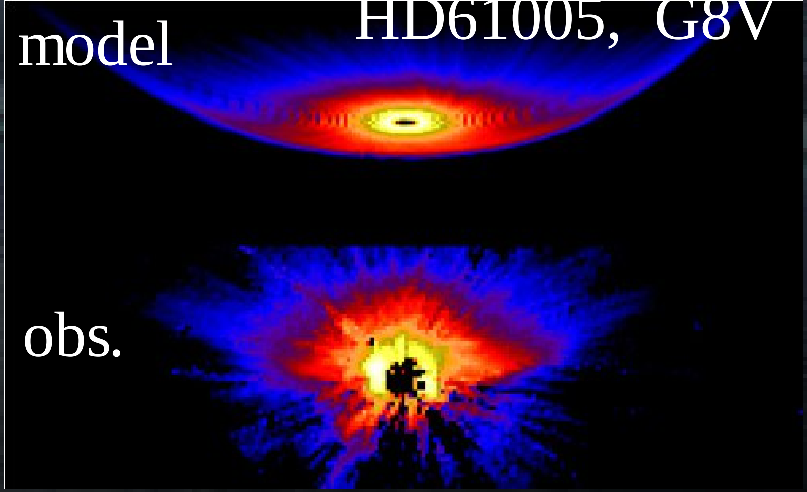




HD 15115, F2V

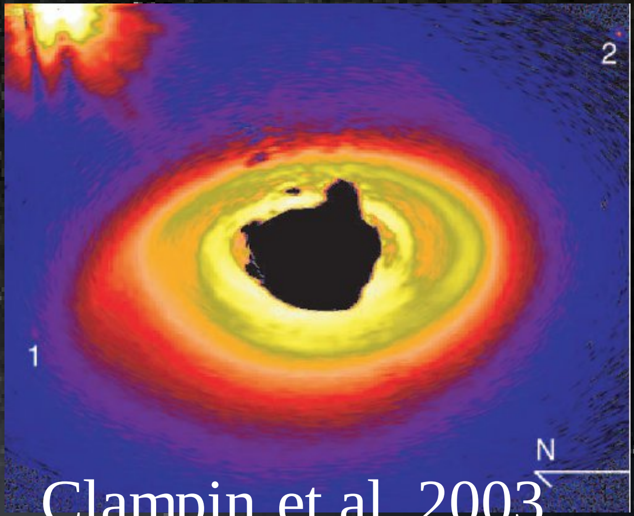


HD61005, G8V

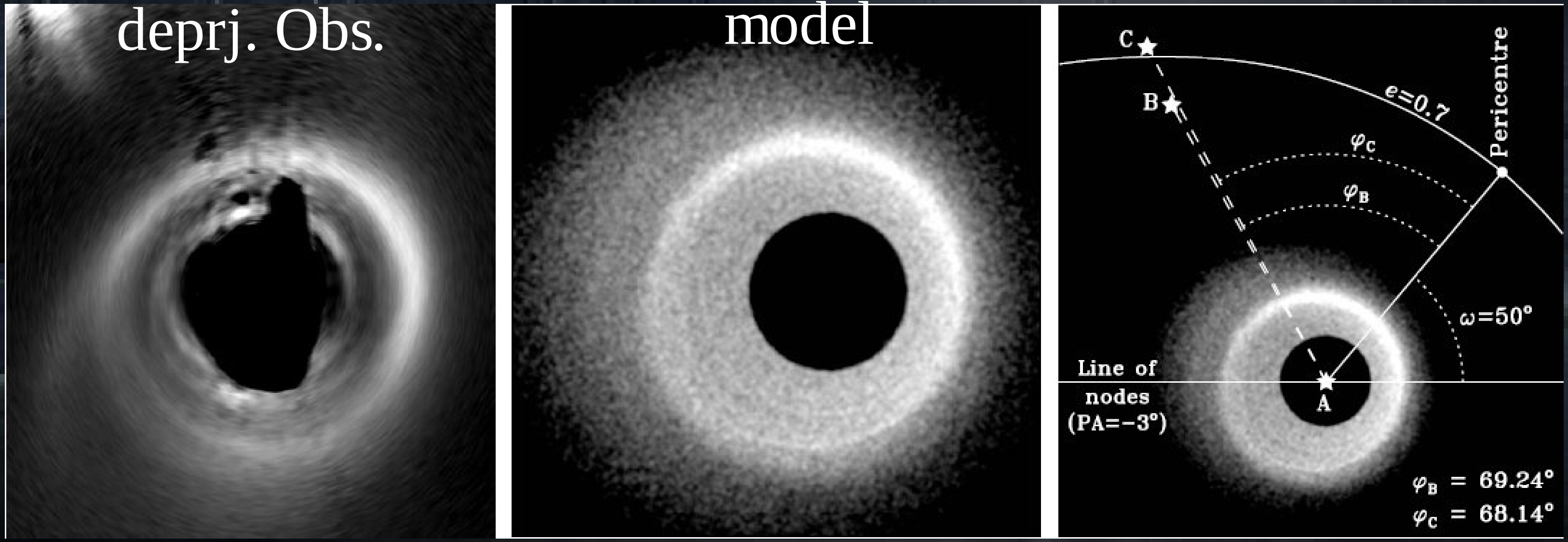


External – Distant Companion/Stellar Flyby

- Tidal interaction with companion or stellar flyby can caused spiral structure in HD141569A



Clampin et al. 2003

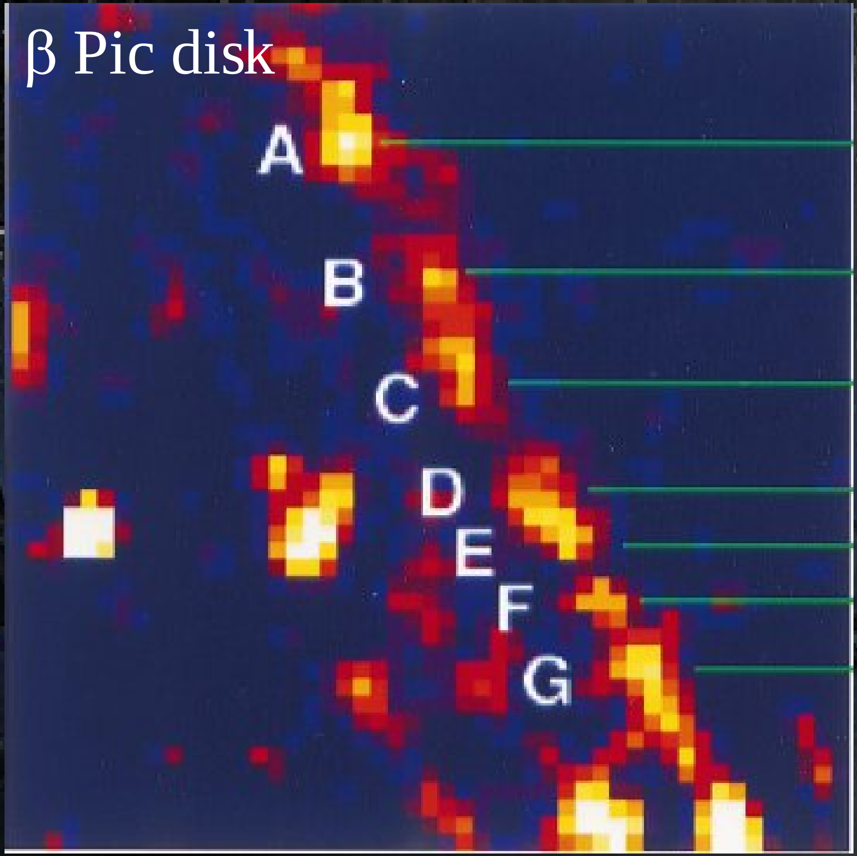

deprj. Obs.

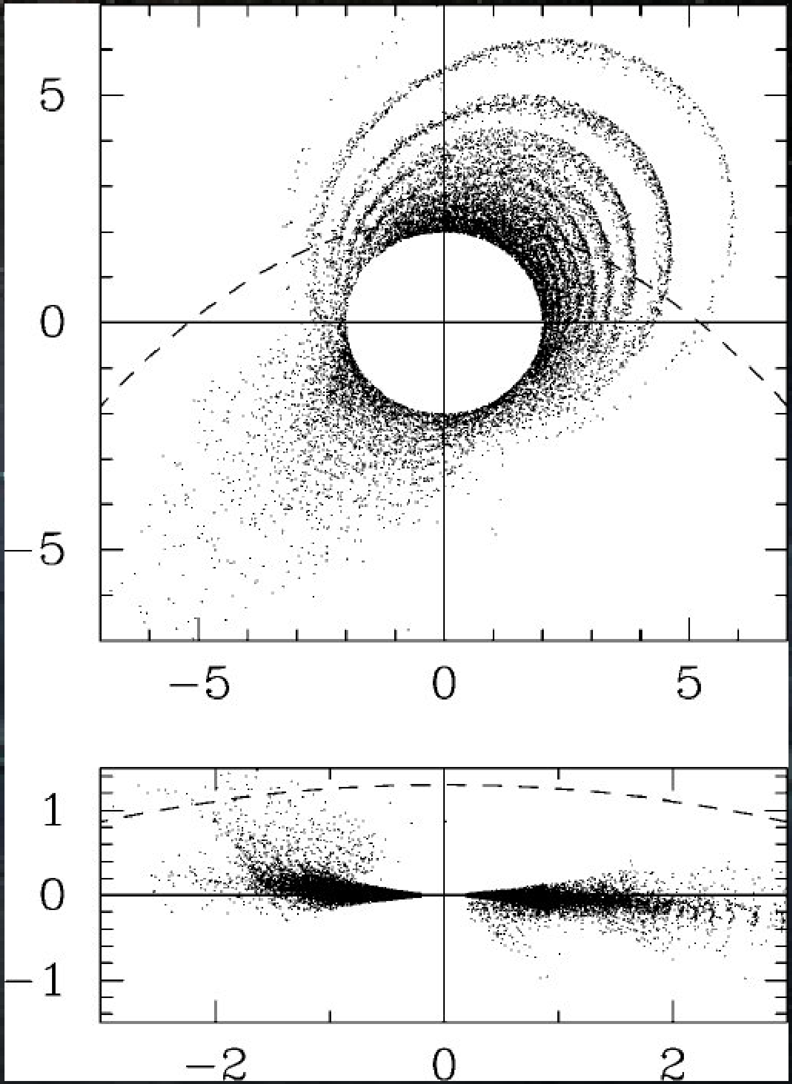
model

Augereau & Papaloizou 2004

External – Distant Companion/Stellar Flyby

- Stellar flyby causes clumpy structures in the outer β Pic disk



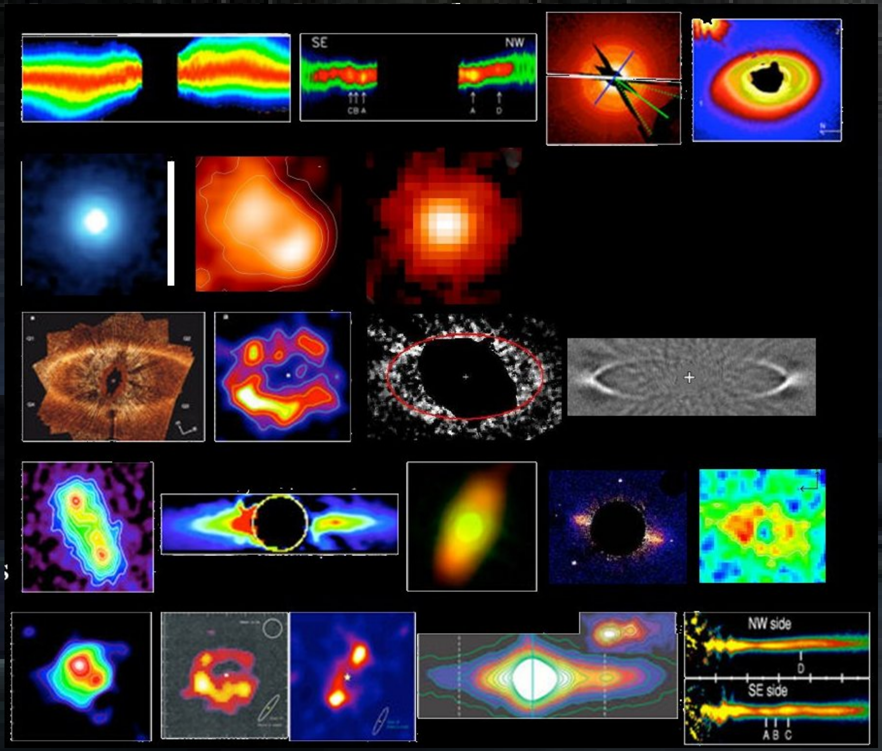


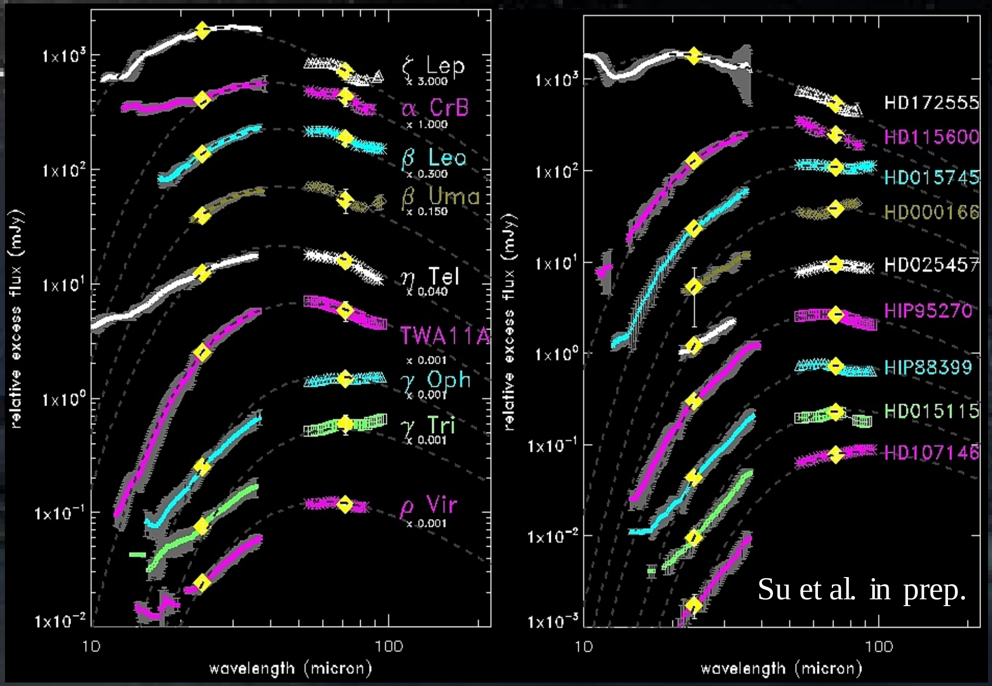
Kalas et al. 2000

Diversity of Disk Structures

Snapshots of Planetary Systems Evolution

Resolved disks at multiple wavelengths + Detailed disk SEDs



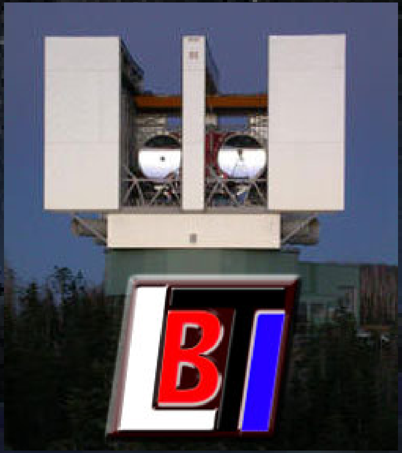


Su et al. in prep.

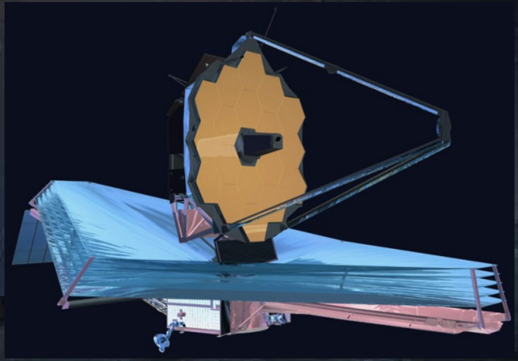
Combination of modeling and observing disk and SED behavior can reveal a broad range of processes affecting exoplanetary systems.

Future Prospect

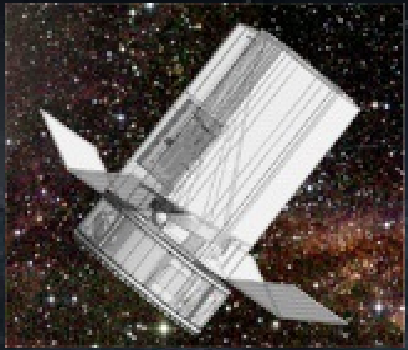
- Need more resolved disks at multiple wavelengths!
- Great opportunities with upcoming ground- and space-based facilities



ALMA



JWST



EXCEDE

and many more…..