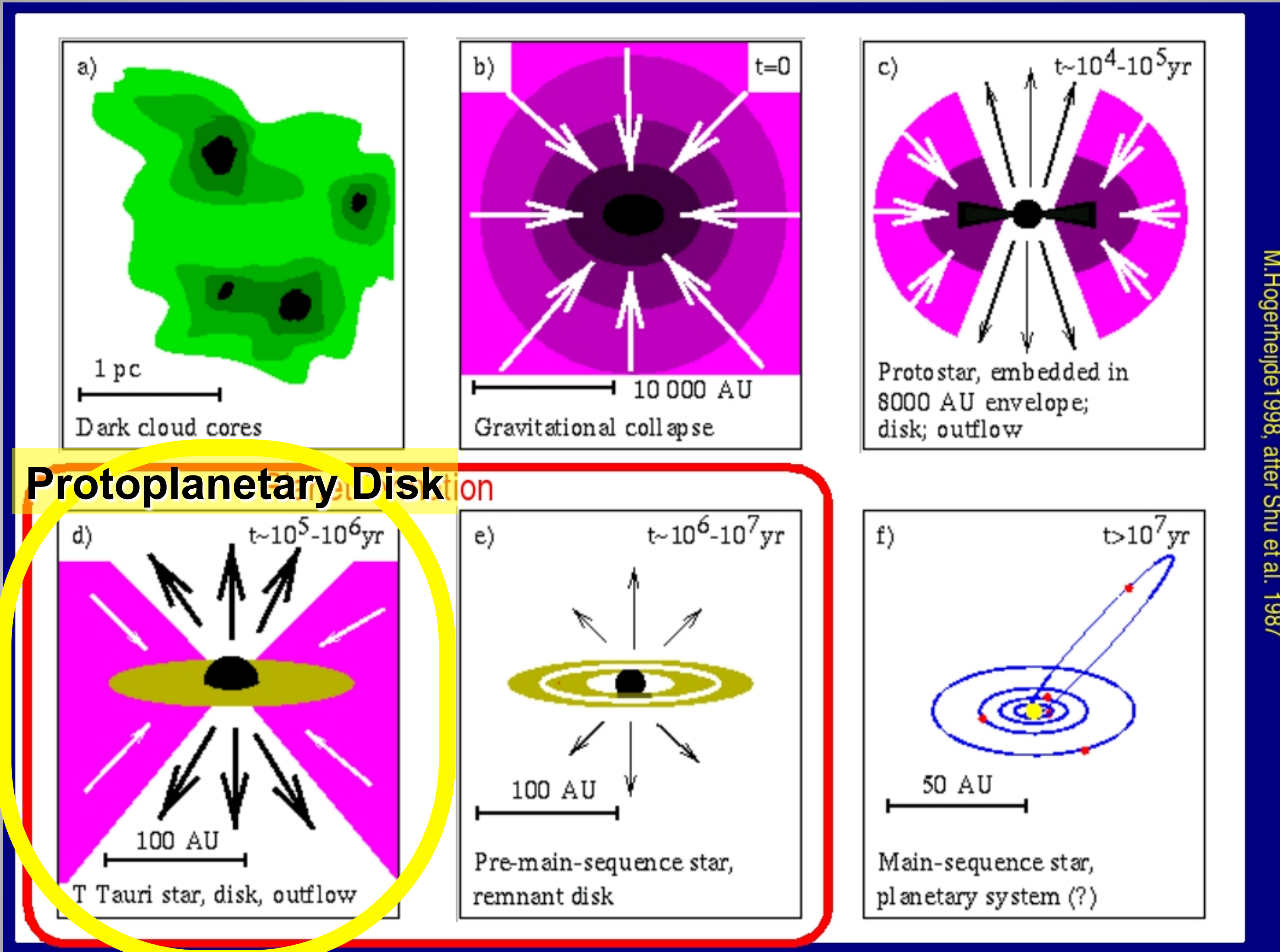
Signatures of Planets in Protoplanetary Disks

Hannah Jang-Condell

University of Wyoming

Neal Turner (JPL)
Alan Boss (CIW-DTM)
Marc Kuchner (NASA-GSFC)
John Debes (STScI)
Alycia Weinberger (CIW-DTM)
Aki Roberge (NASA-GSFC)
Glenn Schneider (Steward)


a)
1 pc
Dark cloud cores
b)
t=0
10 000 AU
Gravitational collapse
c)
t~10^4-10^5 yr
Protostar, embedded in 8000 AU envelope; disk; outflow
Protoplanetary Disk
d)
t~10^5-10^6 yr
100 AU
T Tauri star, disk, outflow
e)
t~10^6-10^7 yr
100 AU
Pre-main-sequence star, remnant disk
f)
t>10^7 yr
50 AU
Main-sequence star, planetary system (?)
M.Hogerheijde1998, after Shu et al. 1987

Young Circumstellar Disks

Protoplanetary Disks

- Optically thick
- Gas-rich
  - 100:1 gas:dust
- Young ~1-10 Myr
- Typically distant
  - ~140 pc
- Age of Giant Planet formation

Debris Disks

- Optically thin
- Gas-poor
  - 1:100 gas:dust
- Not-so-young ~1 Gyr
- May be nearby
  - ~few pc
- Age of Terrestrial Planet Formation

Modeling Disks

Protoplanetary Disks

- Gas dynamics
- Optically thick radiative transfer

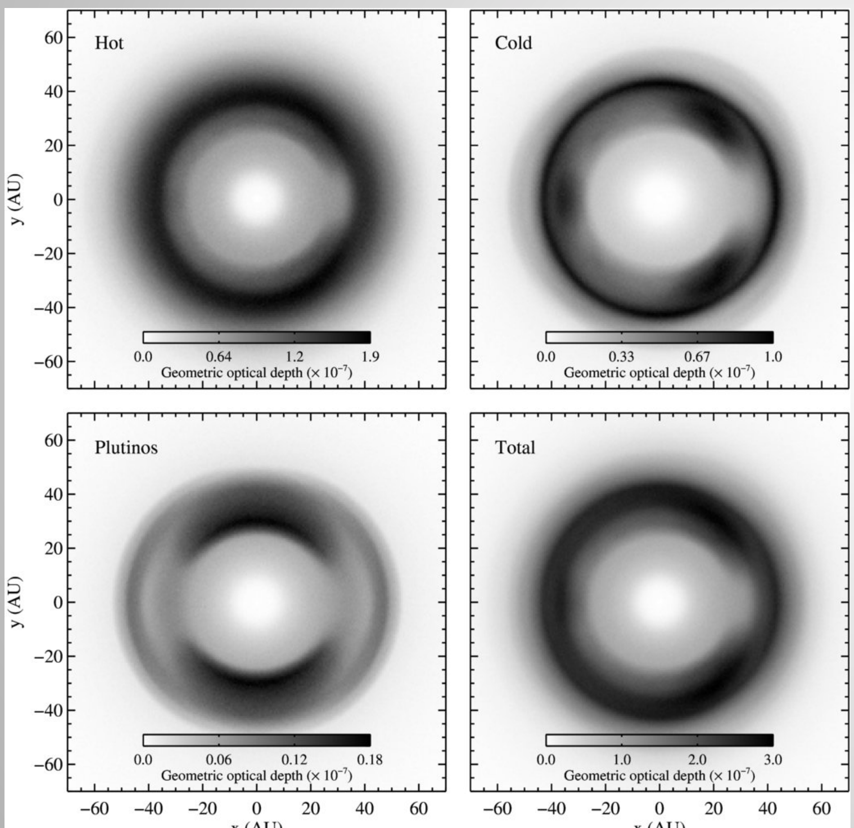
Debris Disks

- N-body dynamics
- Radiation pressure
- Optically thin radiative transfer

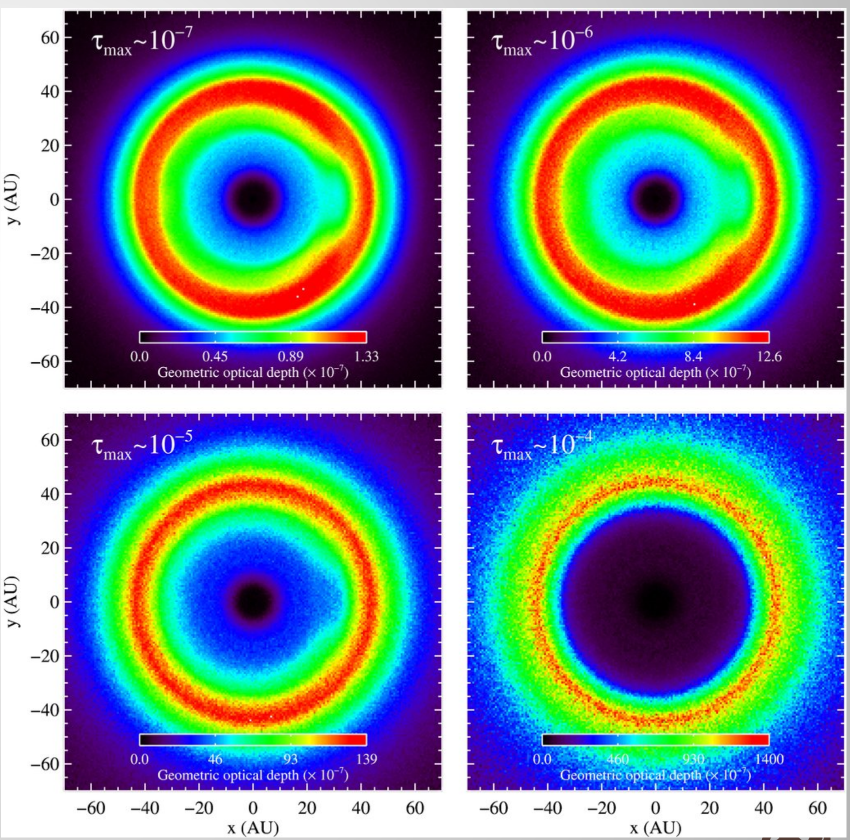
Kuiper Belt Simulations

Kuchner & Stark, 2010

Collisionless



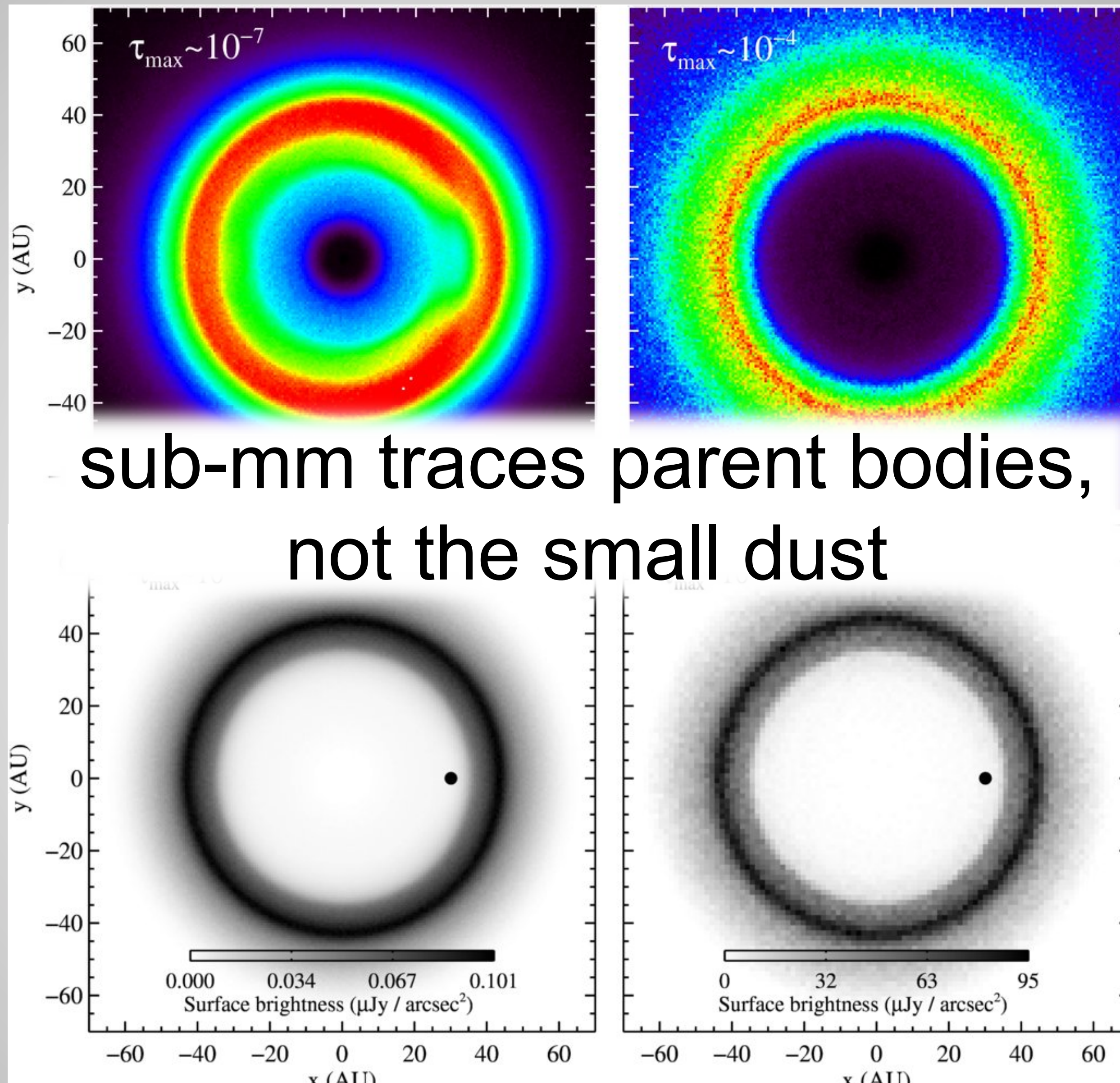
With Collisions



Kuchner & Stark, 2010

optical depth:

0.8 mm emission:



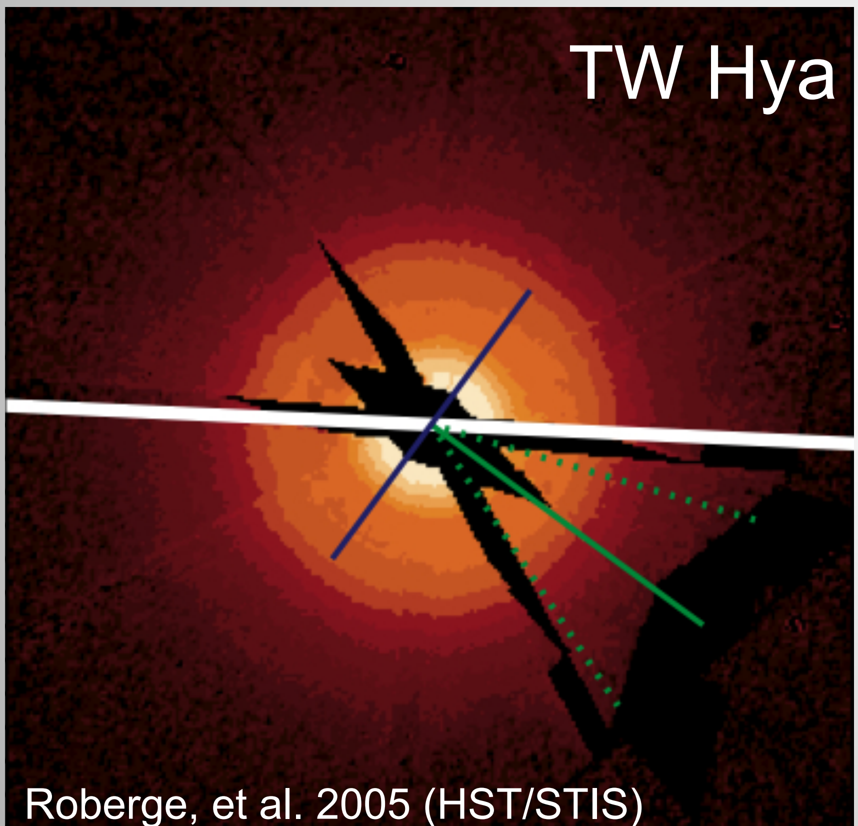
sub-mm traces parent bodies, not the small dust

Debris Disk Talks

- β Pictoris – Dent
- AU Mic – MacGregor
- Fomalhaut – Kalas
- Theory – Pan

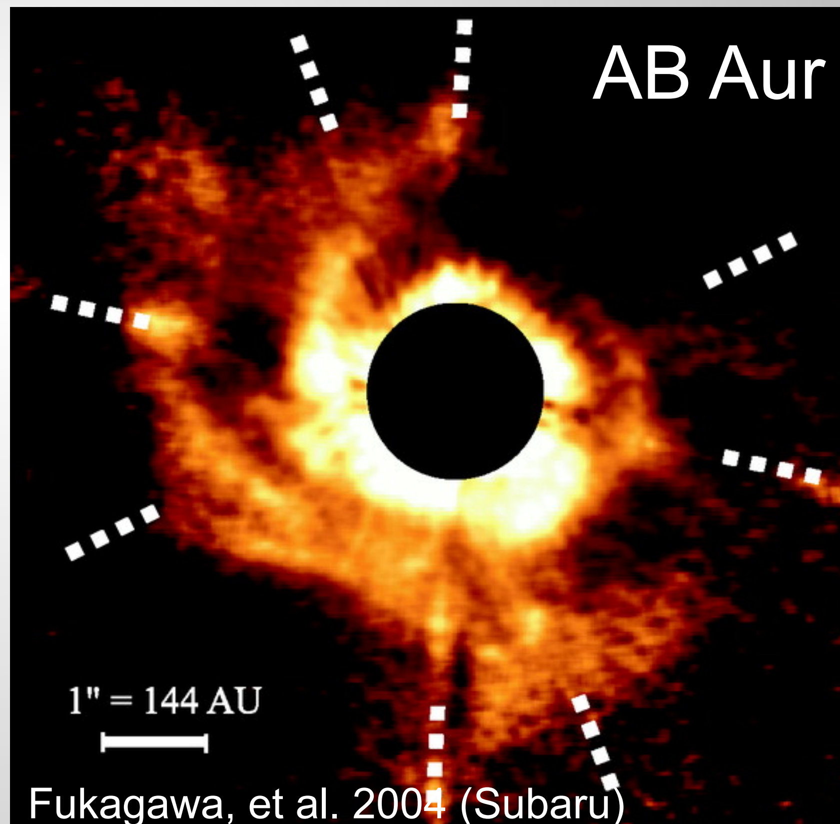
Protoplanetary Disks

T Tauri (F,G,K stars)



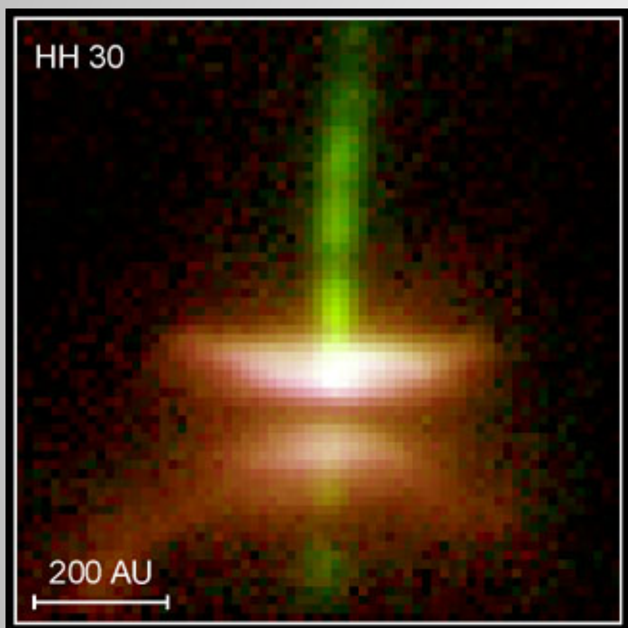
Roberge, et al. 2005 (HST/STIS)

Herbig Ae/Be (A,B stars)



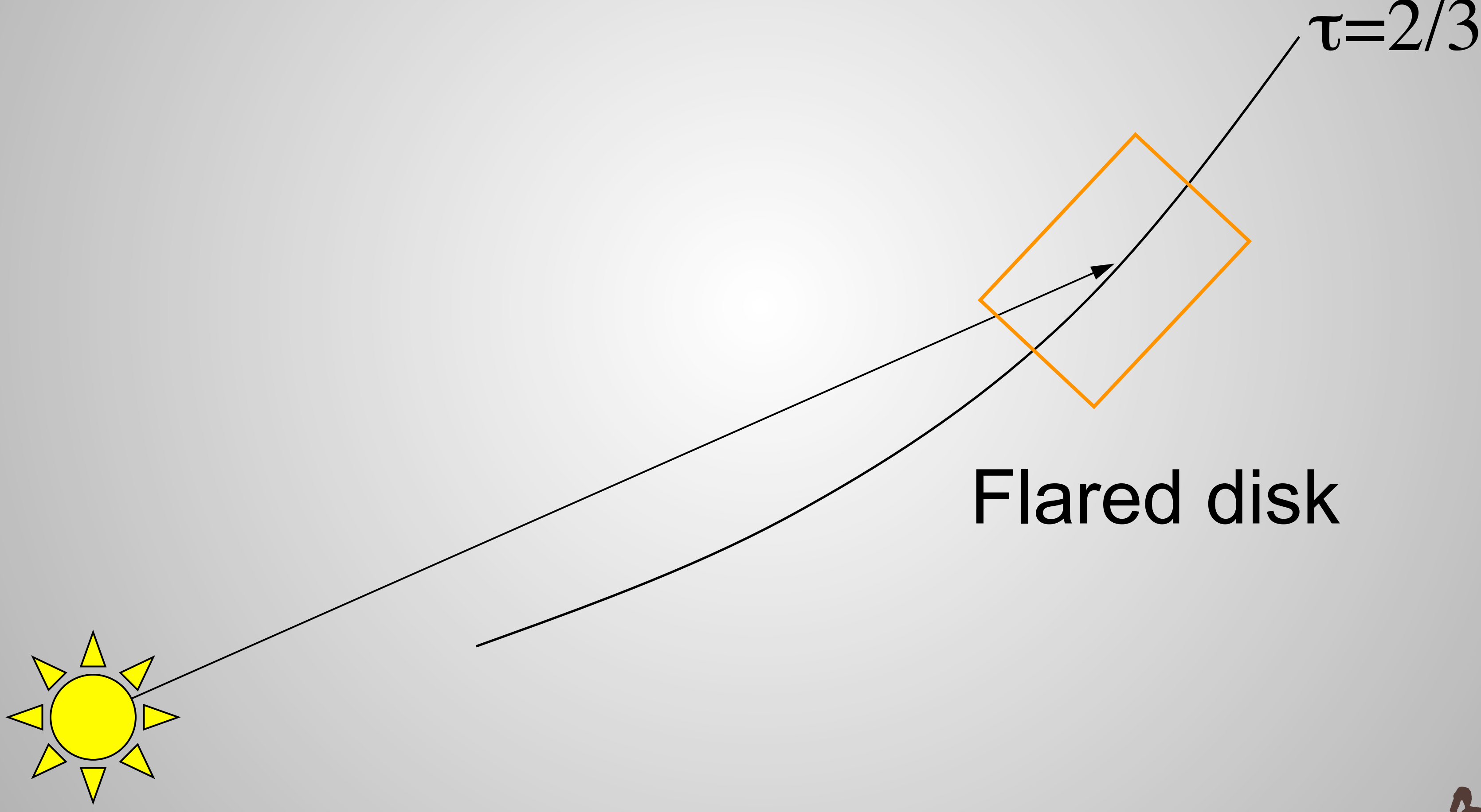
Fukagawa, et al. 2004 (Subaru)

Probing the Epoch of Formation

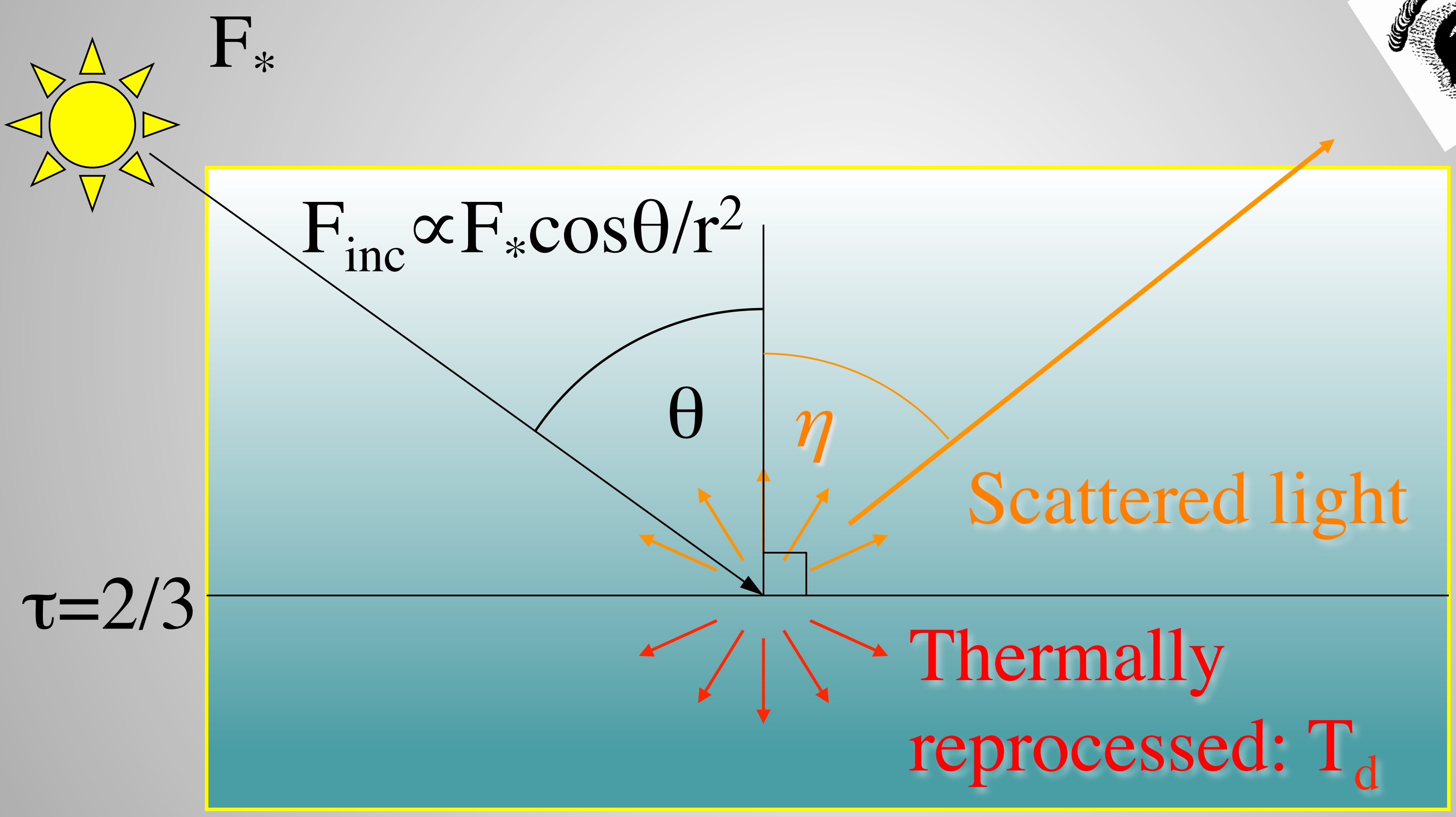


Protoplanetary disk

Radiative Transfer

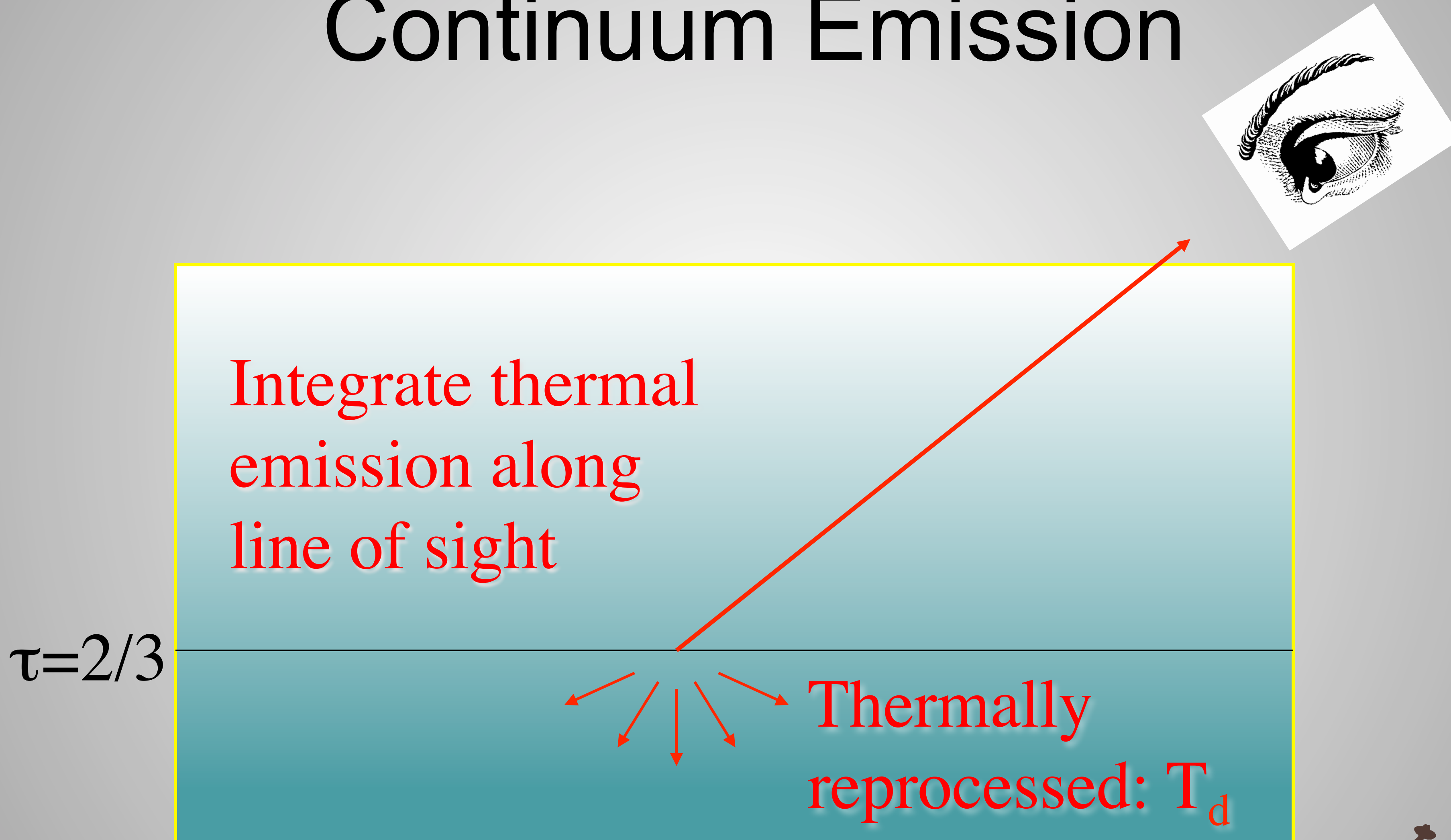


Scattered light



Jang-Condell 2009

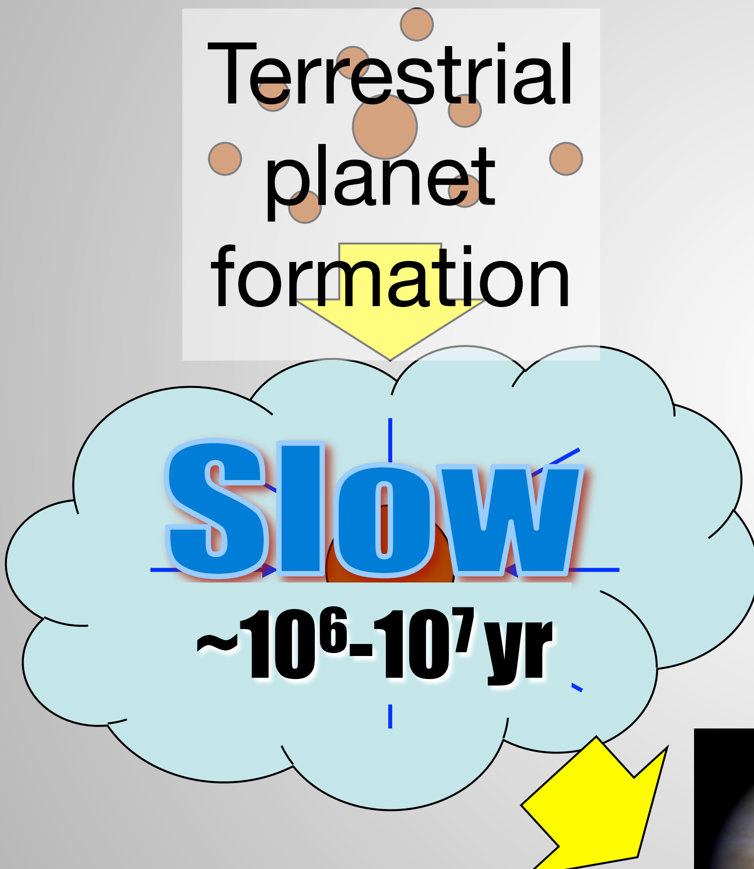
Continuum Emission



Jang-Condell 2009

Giant Planet Formation

Core Accretion



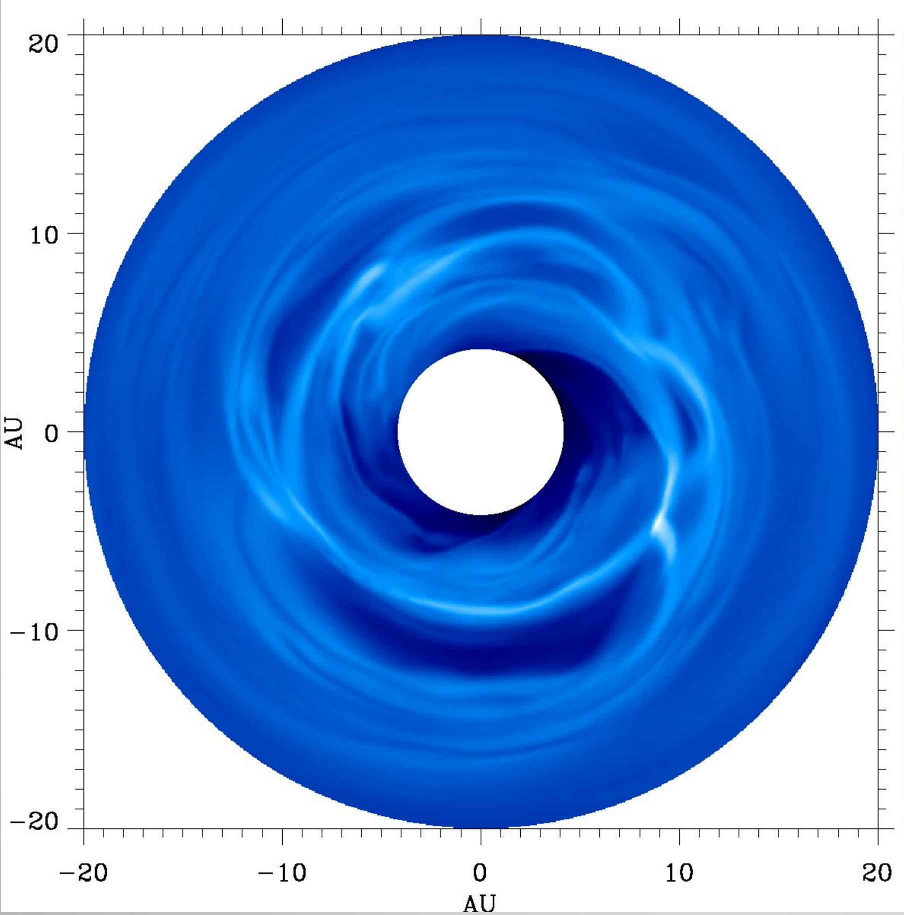
Disk Instability

Metallicity
mismatch

DISK INSTABILITY

Disk Instability

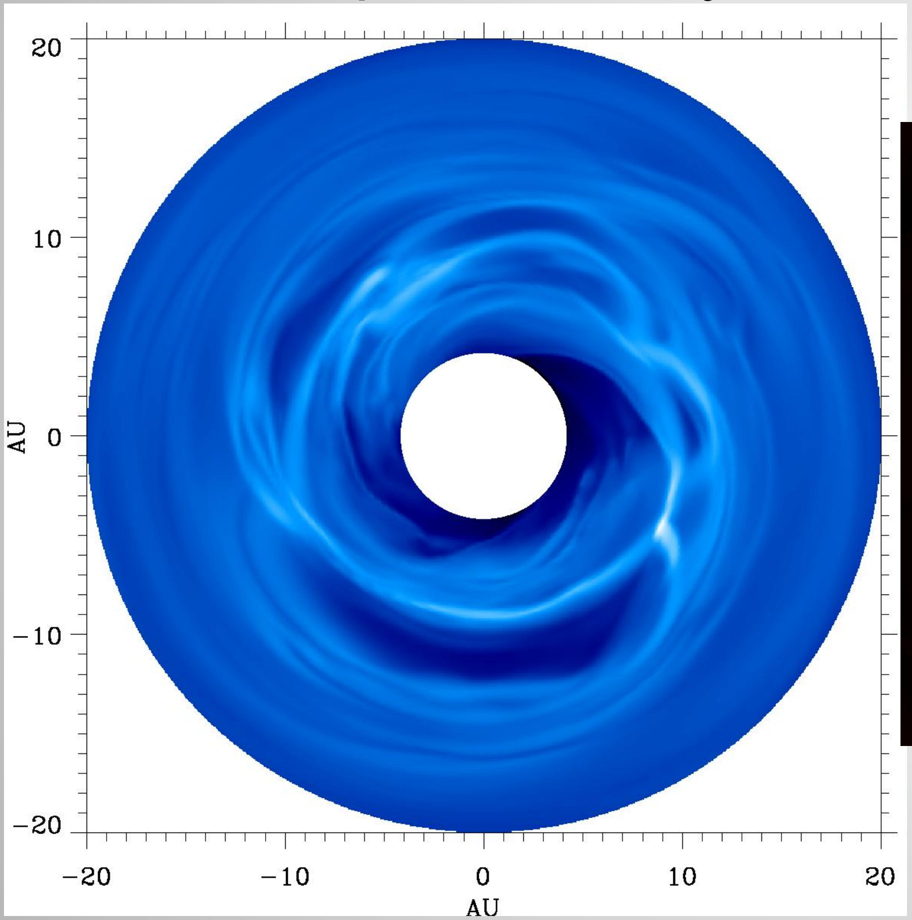
Midplane density



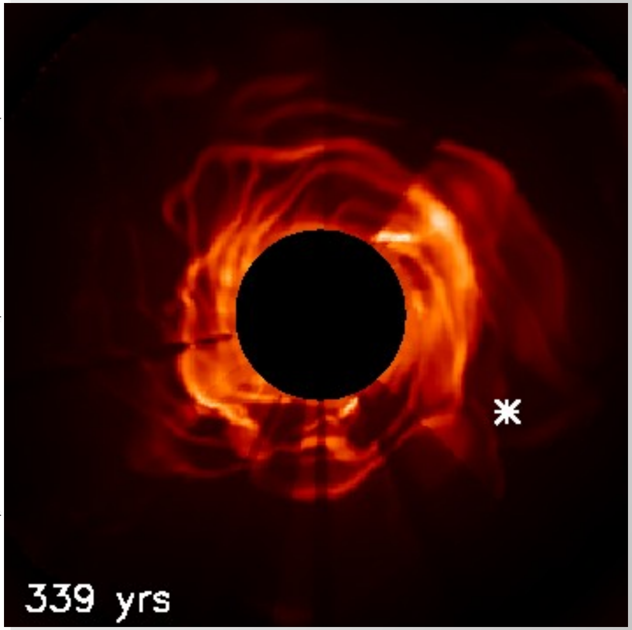
- Boss 2001
- 3D hydrodynamic simulations of disk instability
- Self-gravitating clump formed

Disk Instability

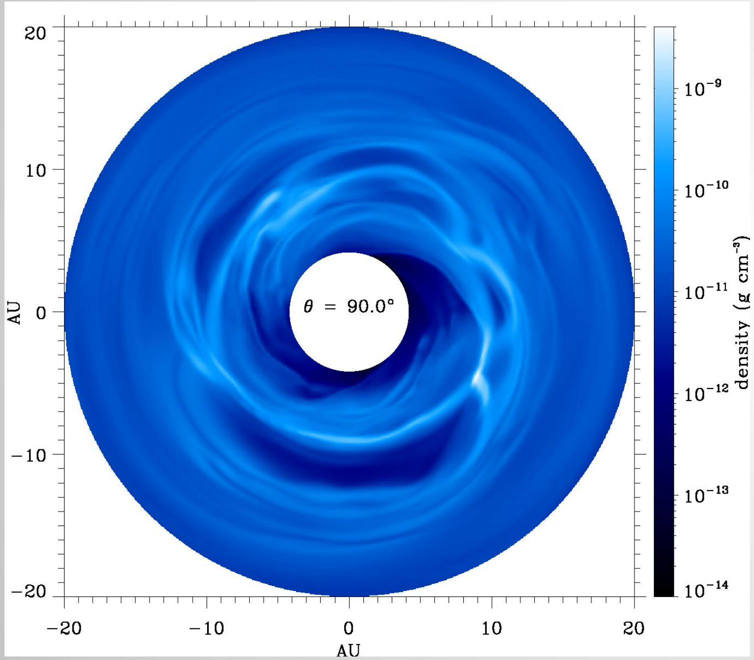
Midplane density

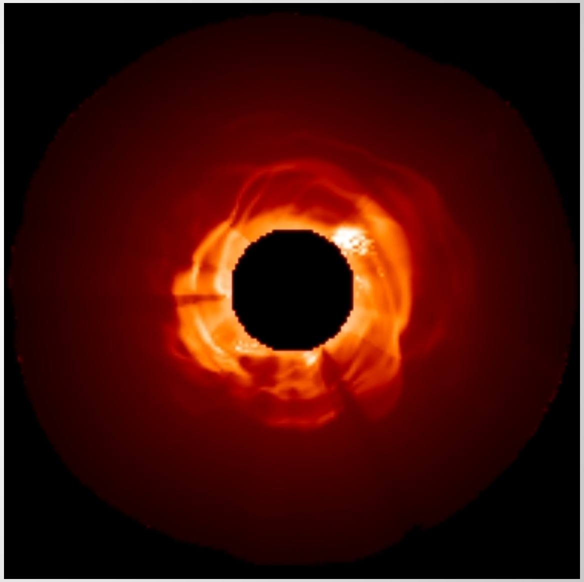


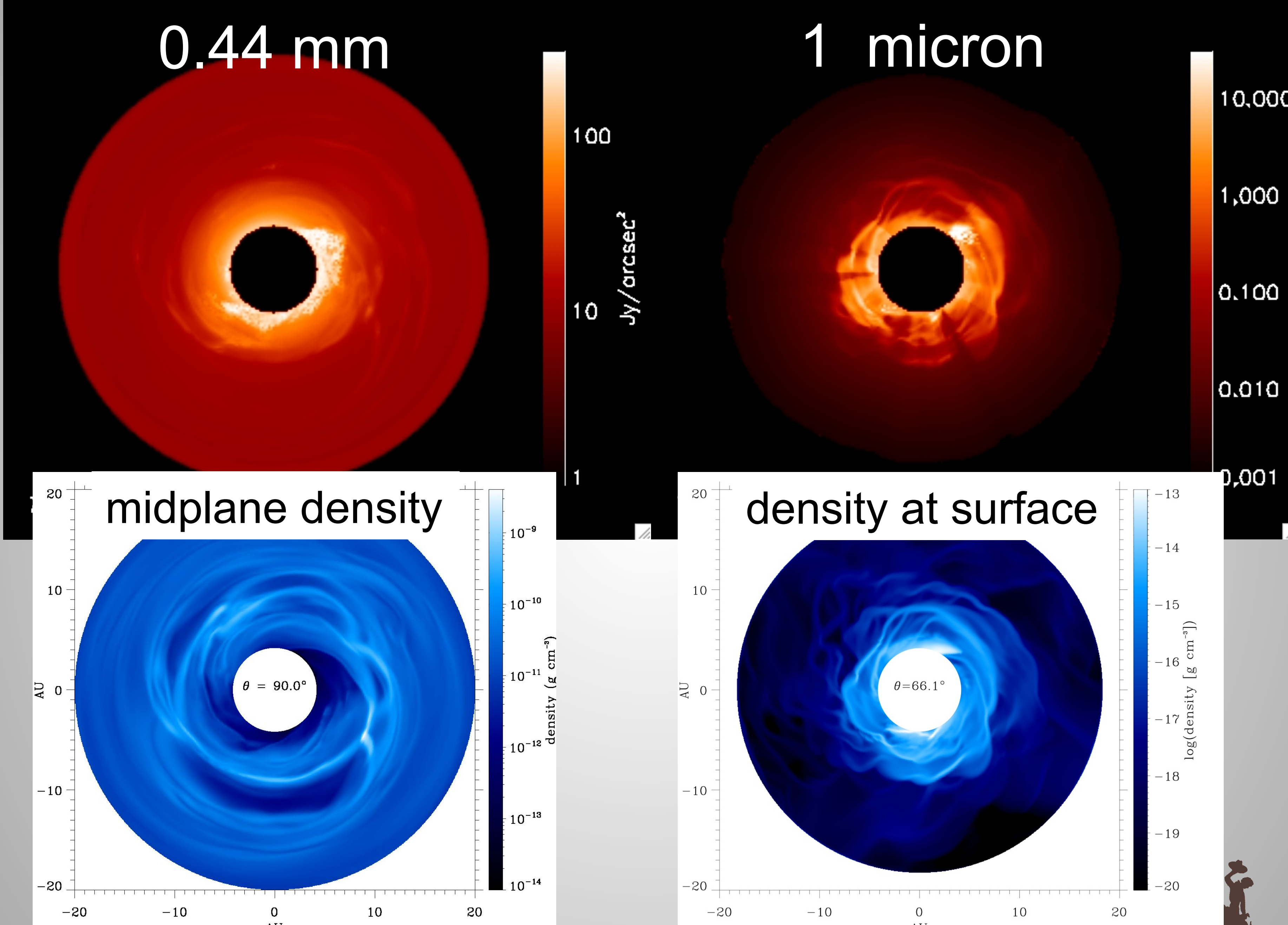
1 micron image



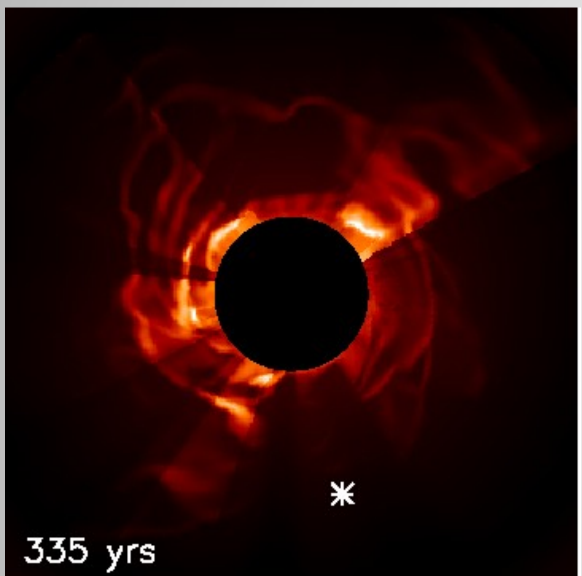
Jang-Condell & Boss (2007)


20
10
0
−10
−20
AU
−20
−10
0
10
20
AU
θ = 90.0°
10−9
10−10
10−11
10−12
10−13
10−14
density (g cm−3)

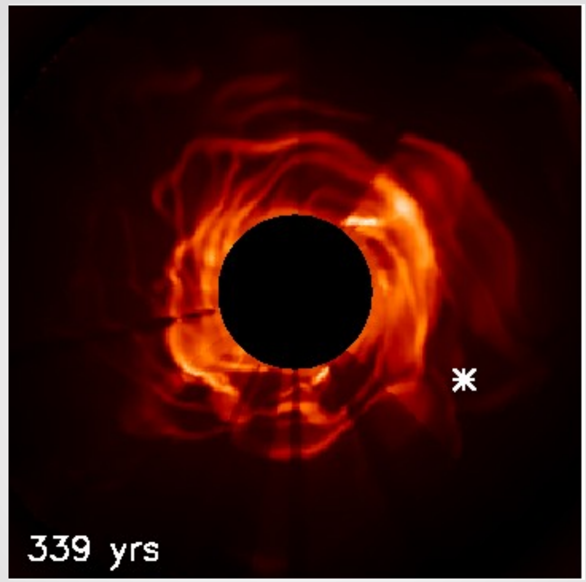



0.44 mm
1 micron
100
10
1
Jy/arcsec^2
10,000
1,000
0.100
0.010
0.001
midplane density
density at surface
θ = 90.0°
θ=66.1°
density (g cm^{-3})
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
log(density [g cm^{-3}])
−13
−14
−15
−16
−17
−18
−19
−20
AU
20
10
0
−10
−20

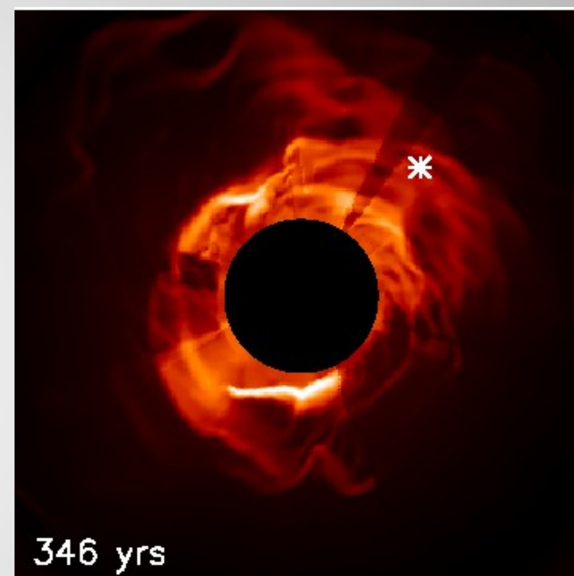
Variability



335 yr

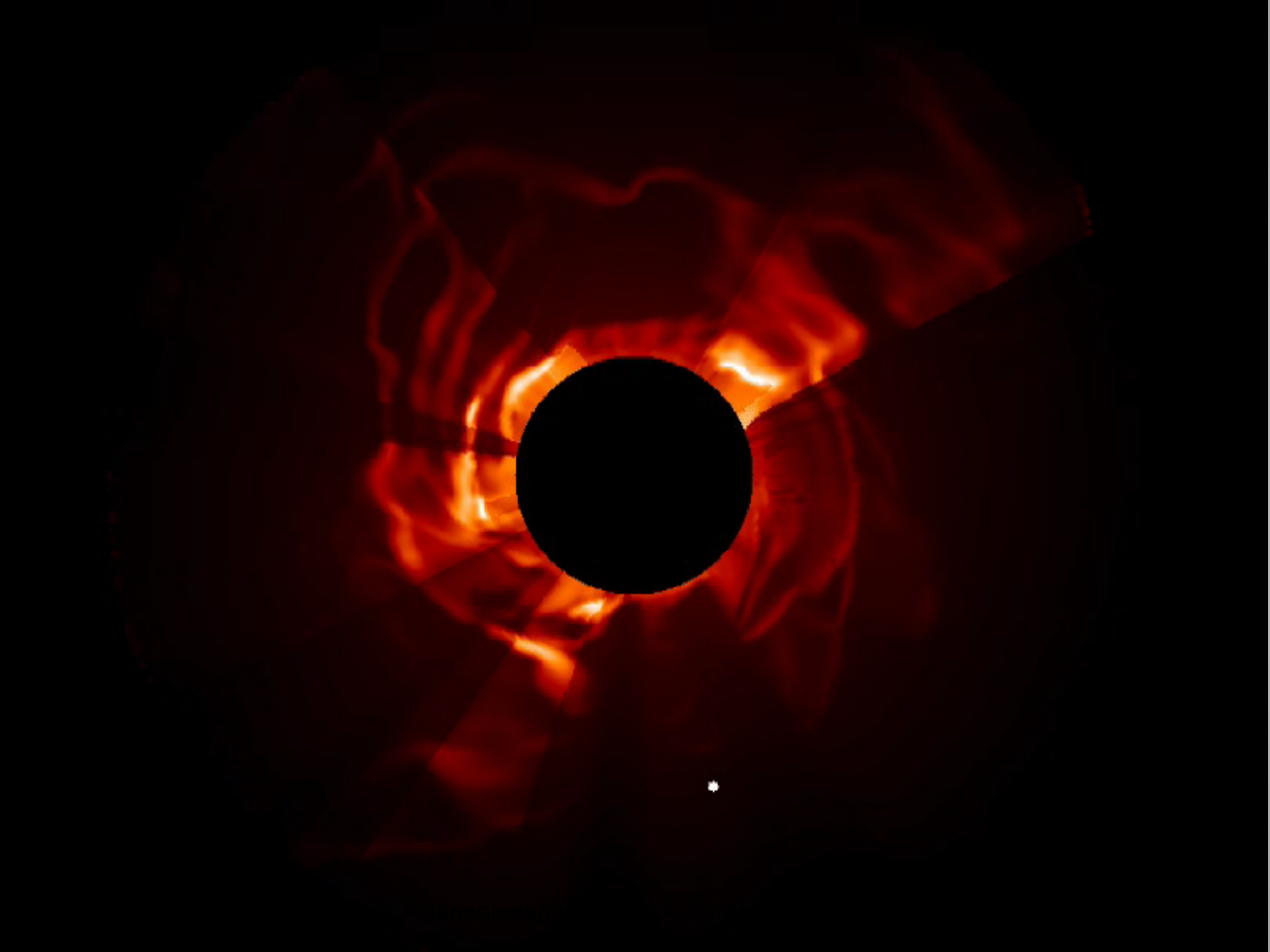


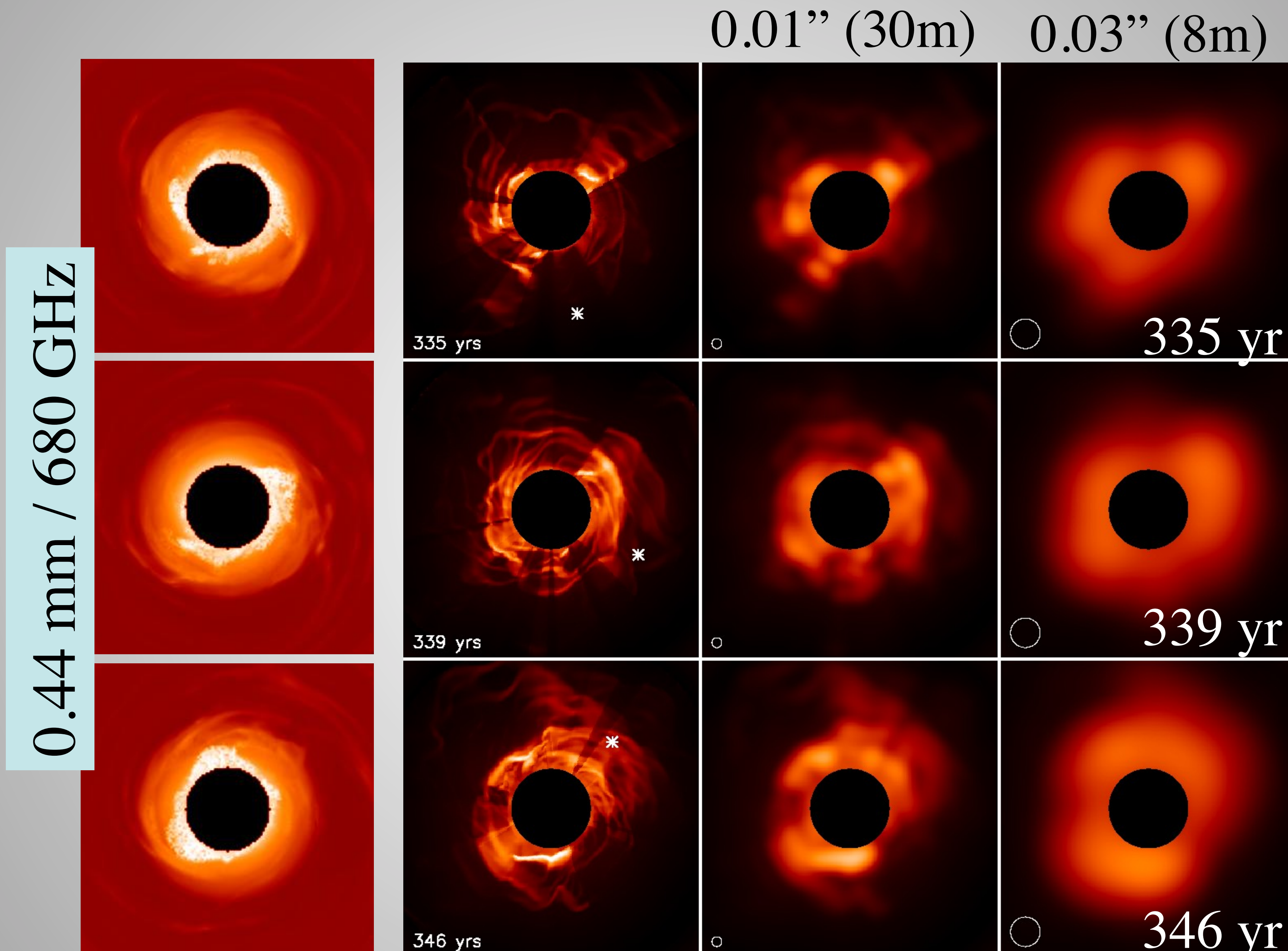
339 yr



346 yr

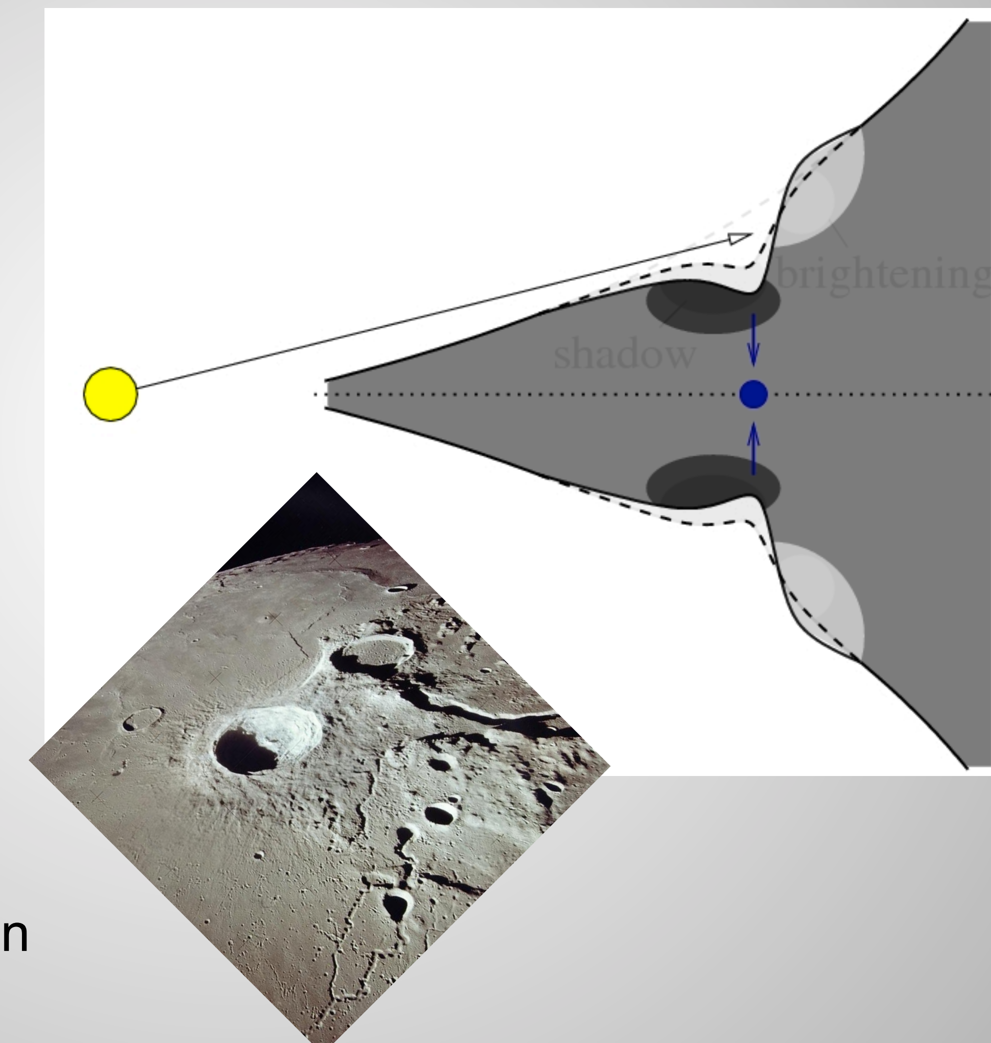
Jang-Condell & Boss (2007)

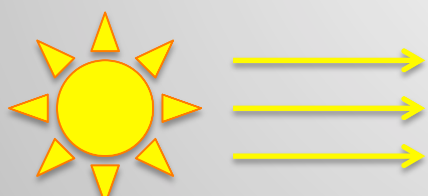



0.01" (30m)
0.03" (8m)
0.44 mm / 680 GHz
335 yrs
339 yrs
346 yrs
335 yr
339 yr
346 yr

SIGNATURES OF CORE FORMATION

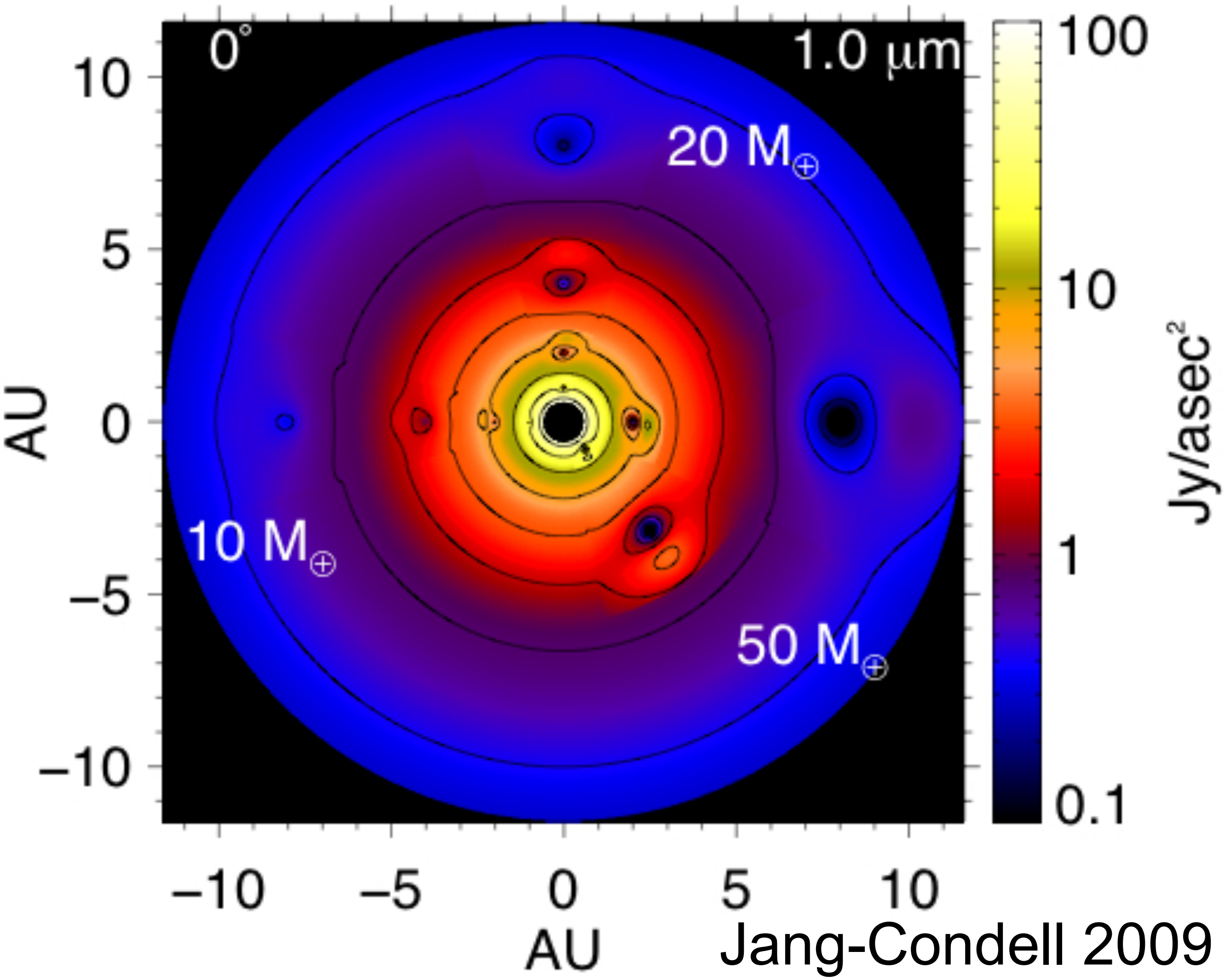
Planet Shadows





Aristarchus crater, the Moon
Credit: NASA (Apollo 15)

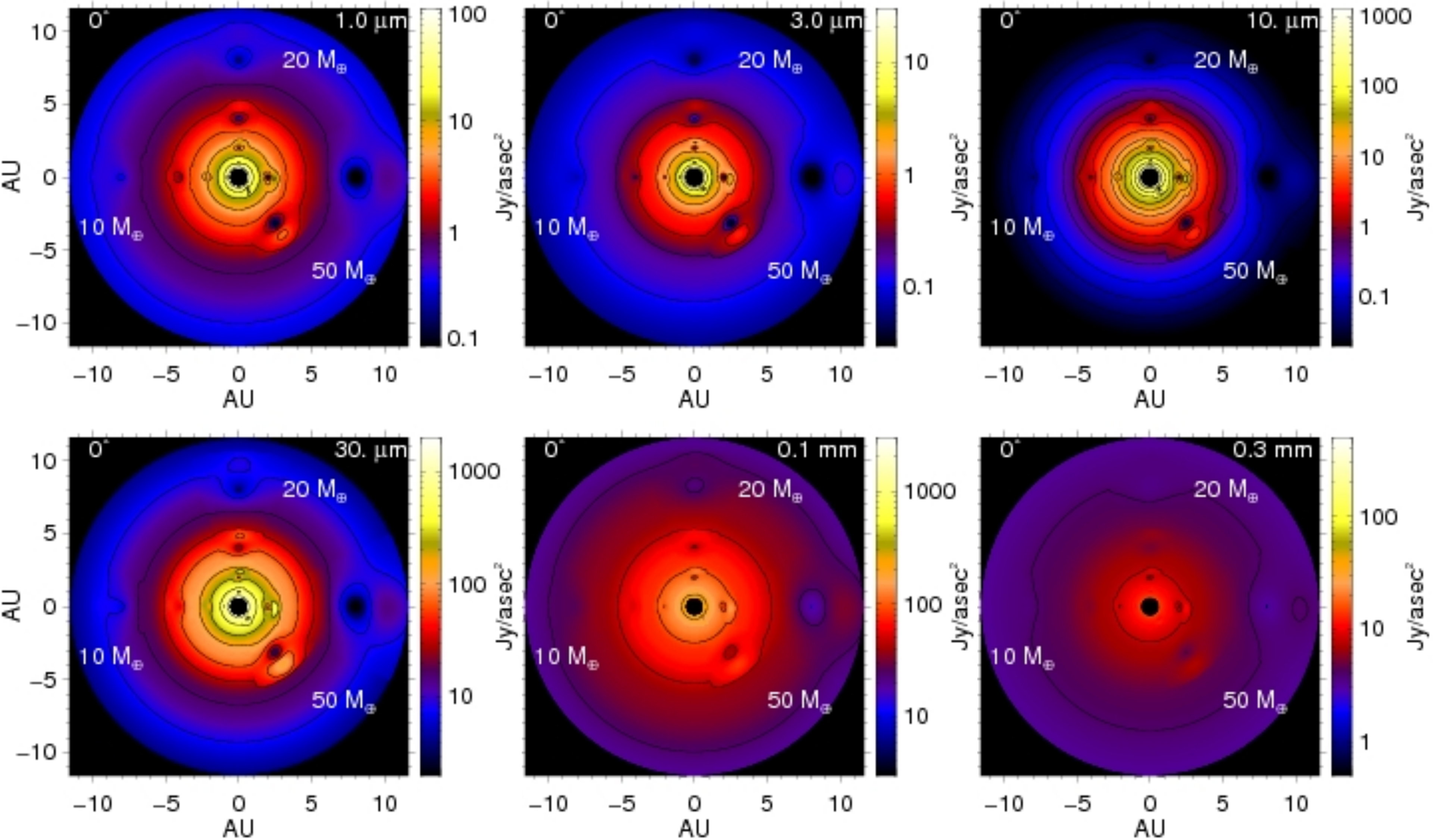
Planet Shadows at 1um



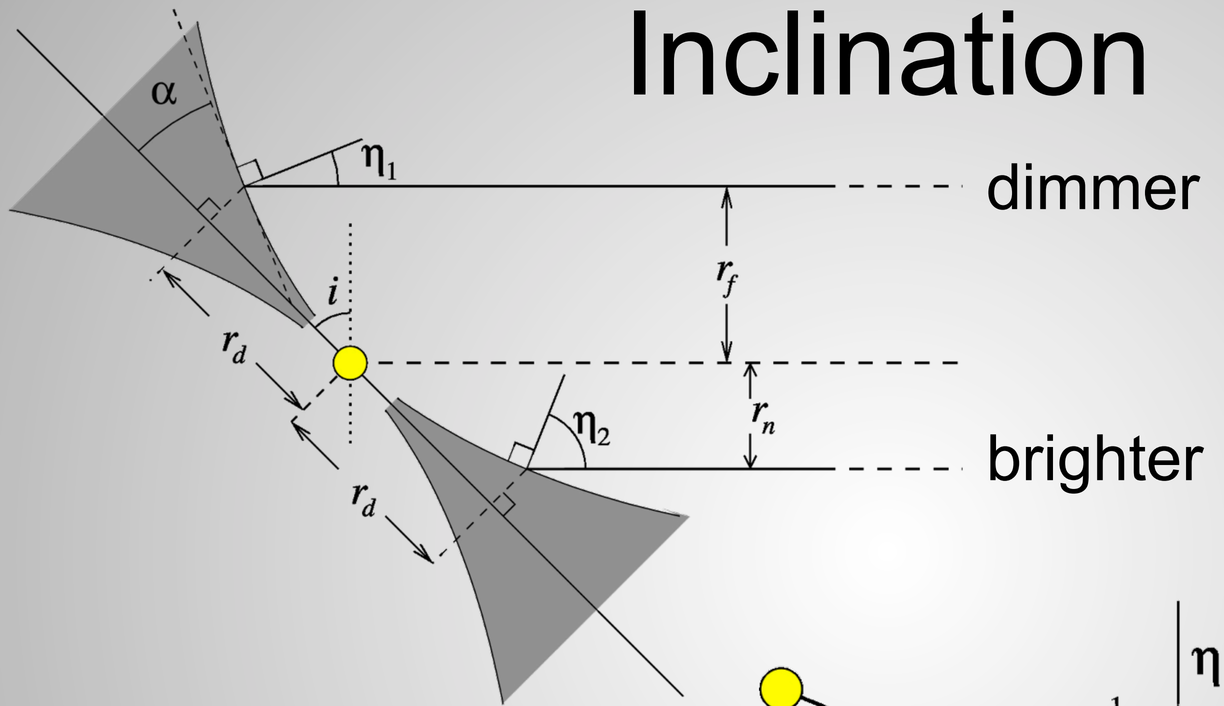
Jang-Condell 2009

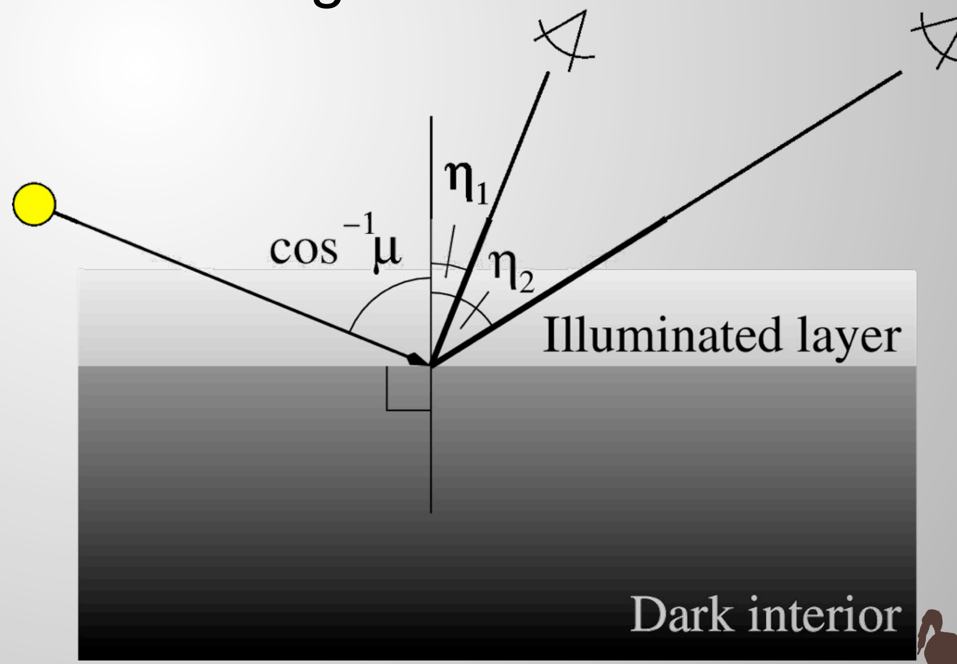
Planet Shadows

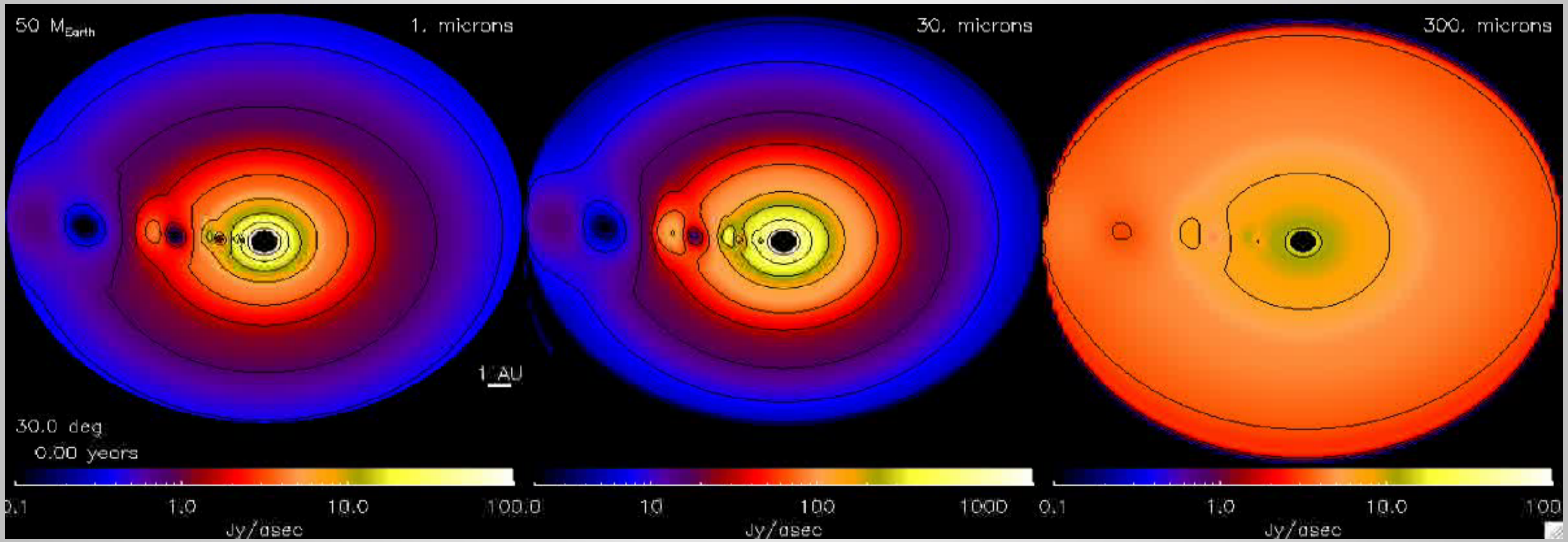
Jang-Condell 2009



Inclination







50 M Earth
1. microns
30. microns
300. microns
1 AU
30.0 deg
0.00 years
0.1
1.0
10.0
100.0
Jy/asec
10
100
1000
Jy/asec
0.1
1.0
10.0
100
Jy/asec

Core Accretion

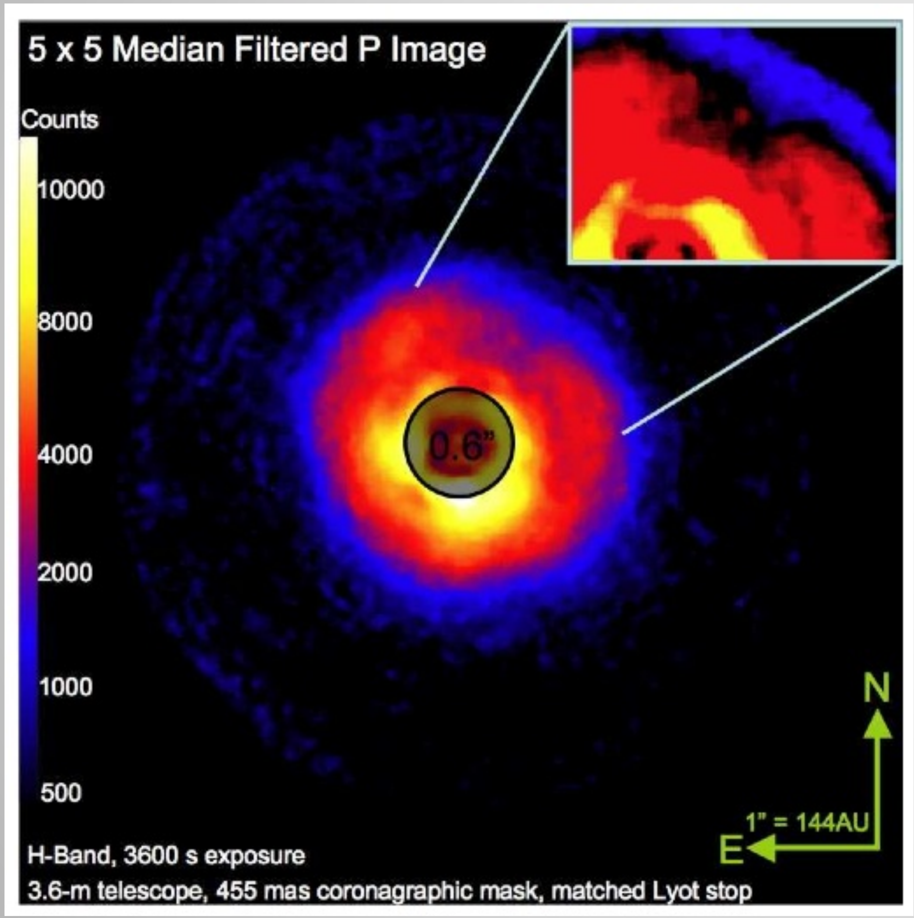
- Older YSO (Class II-III)
  - Passive disk
- Quiescent structure
- Perturbation follows planet
- Planet signature detected in visible, IR

Disk Instability

- Younger YSO (Class I-II)
  - Actively accreting
- Highly perturbed
- High variability (few years)
- Planet signature possibly detected in sub-mm

Multi-wavelength observations are vital

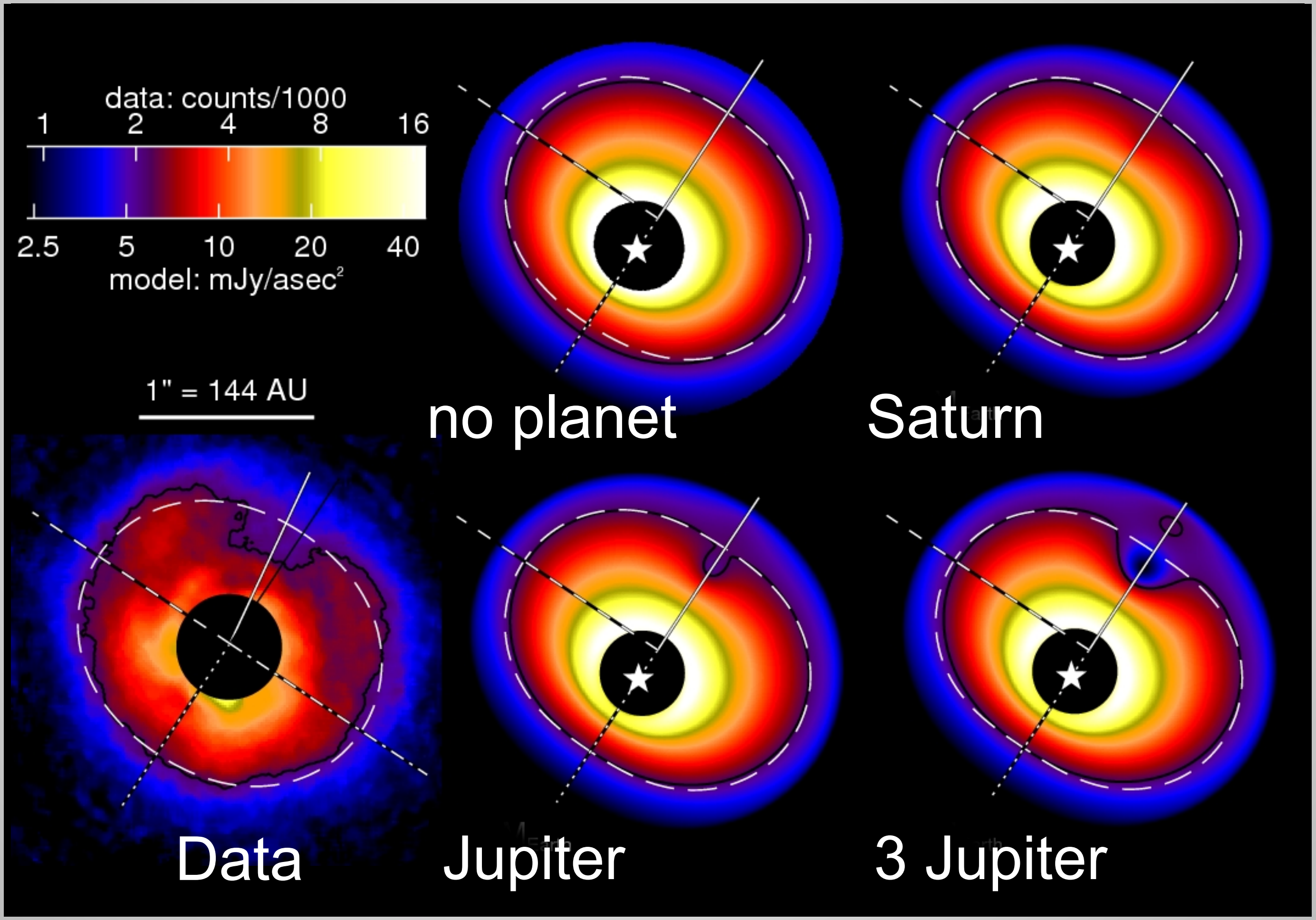
AB Aur



- Oppenheimer, et al., 2008
- Scattered polarized light
- "Spot"
  - 2.8σ
  - 5-37 M_{Jup}

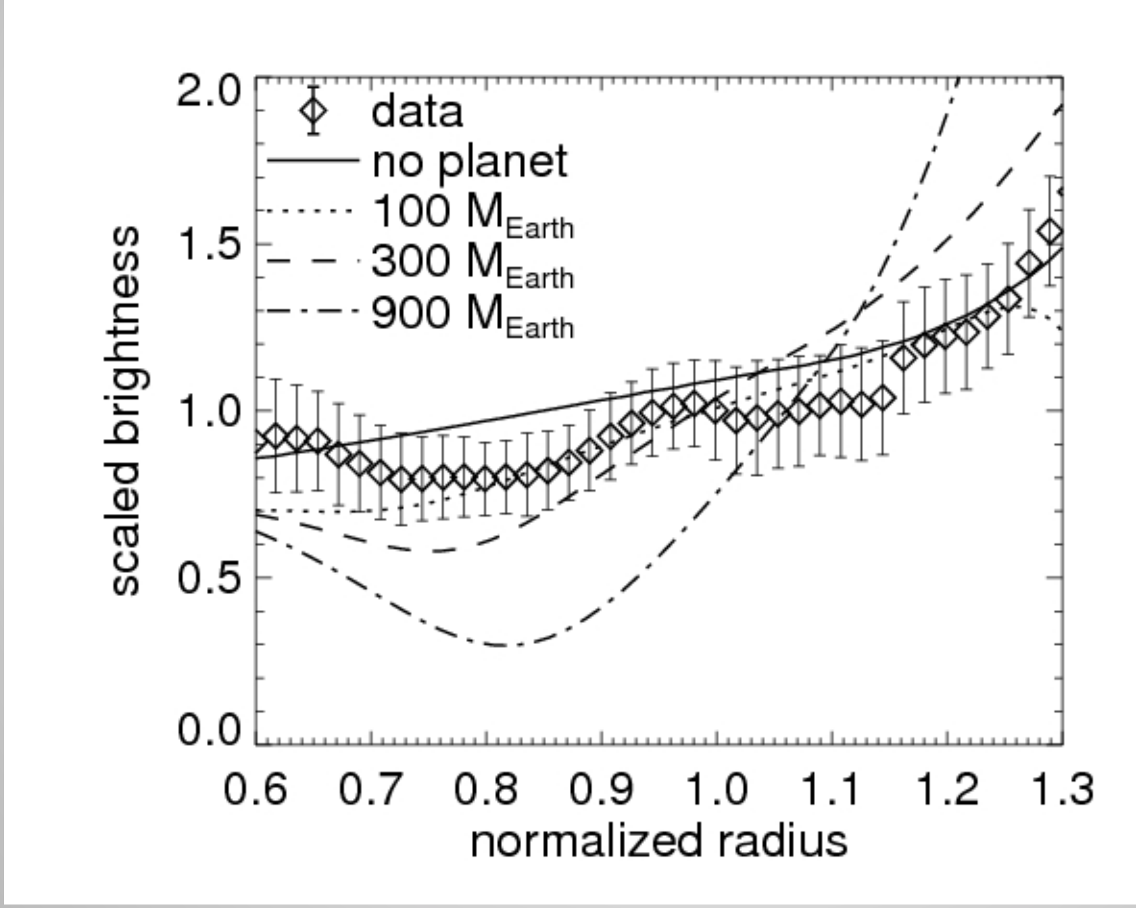
A planet in AB Aur?

Jang-Condell & Kuchner, 2010



< 1 M_{Jup} in AB Aur

Jang-Condell & Kuchner 2010



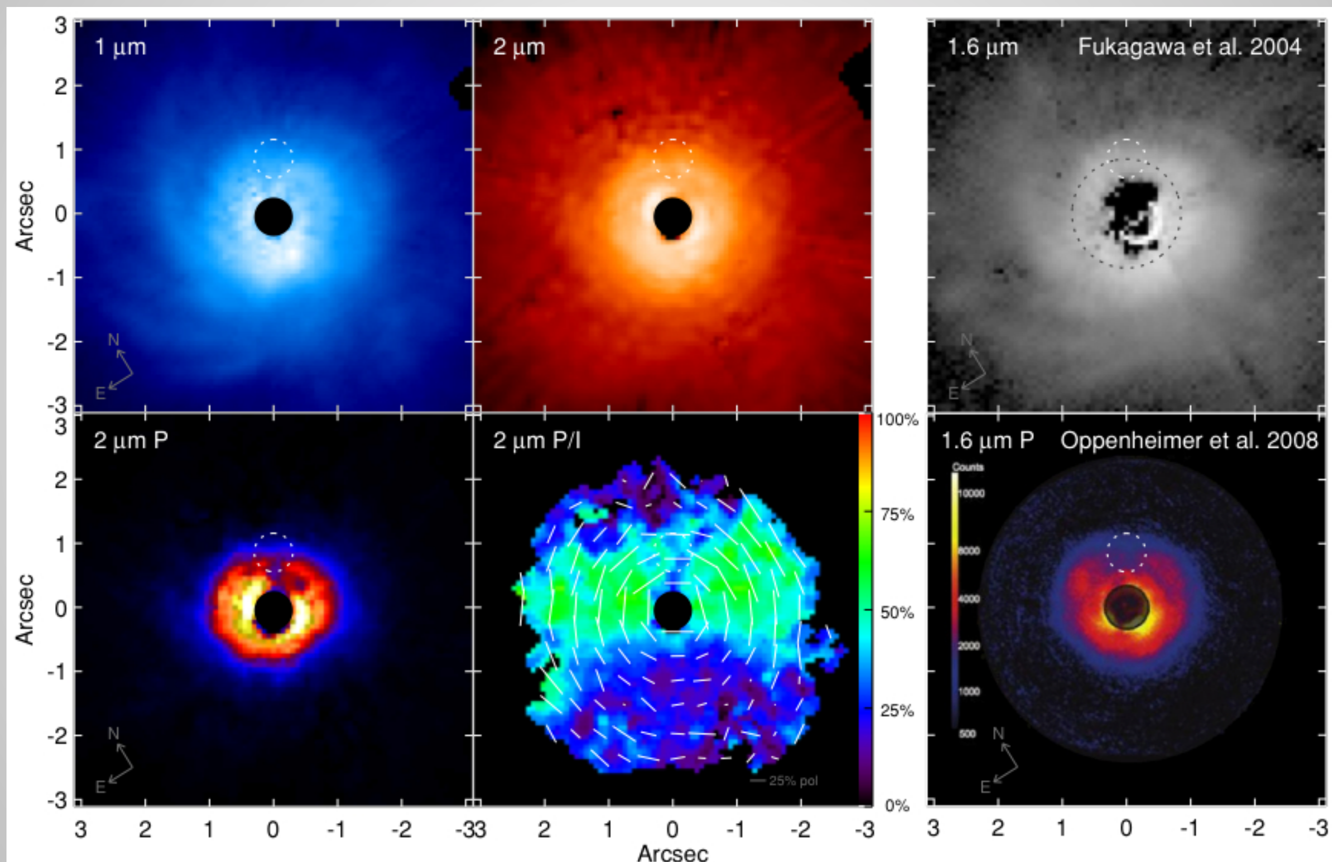
	χ_ν^2
No planet	0.8
Saturn	0.4
Jupiter	2.2
3 Jupiter	17

No 5-37 M_{jup} Planet!

Polarization "dimple"

Perrin, et al. 2009

NICMOS

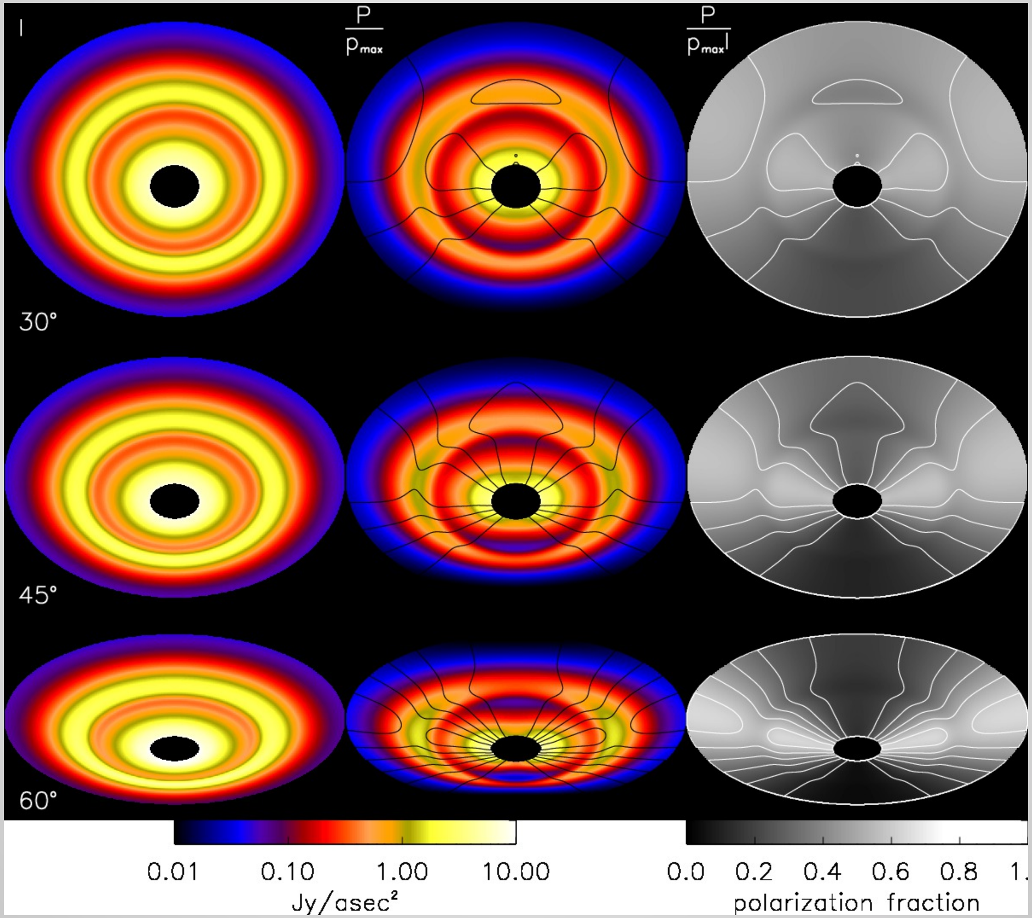


Subaru

Lyot Project

Be careful when interpreting P images!

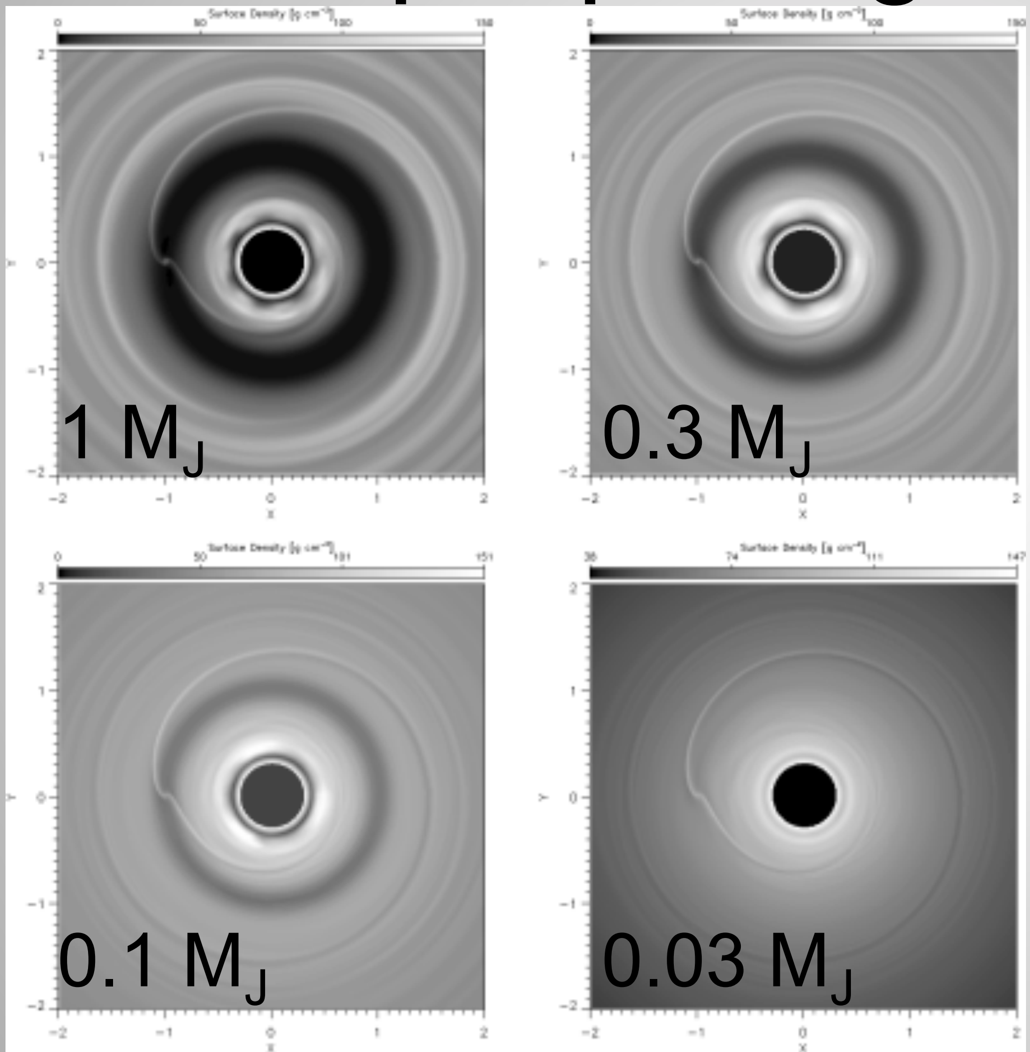
Use Caution with Polarized Light Images



Jang-Condell, in prep

GAP OPENING BY PLANETS

Gap Opening by Planets

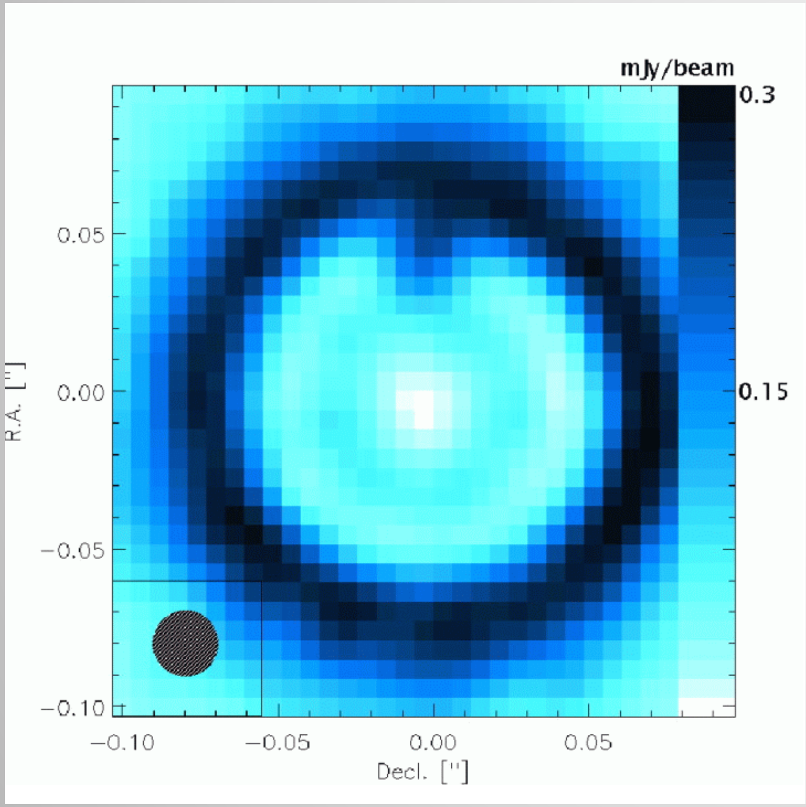


- Bate et al., 2003
- Gap-opening threshold (Crida, et al ‘06)

$$\frac{3H}{4r_{Hill}} + \frac{50}{q\mathrm{Re}} = 1$$

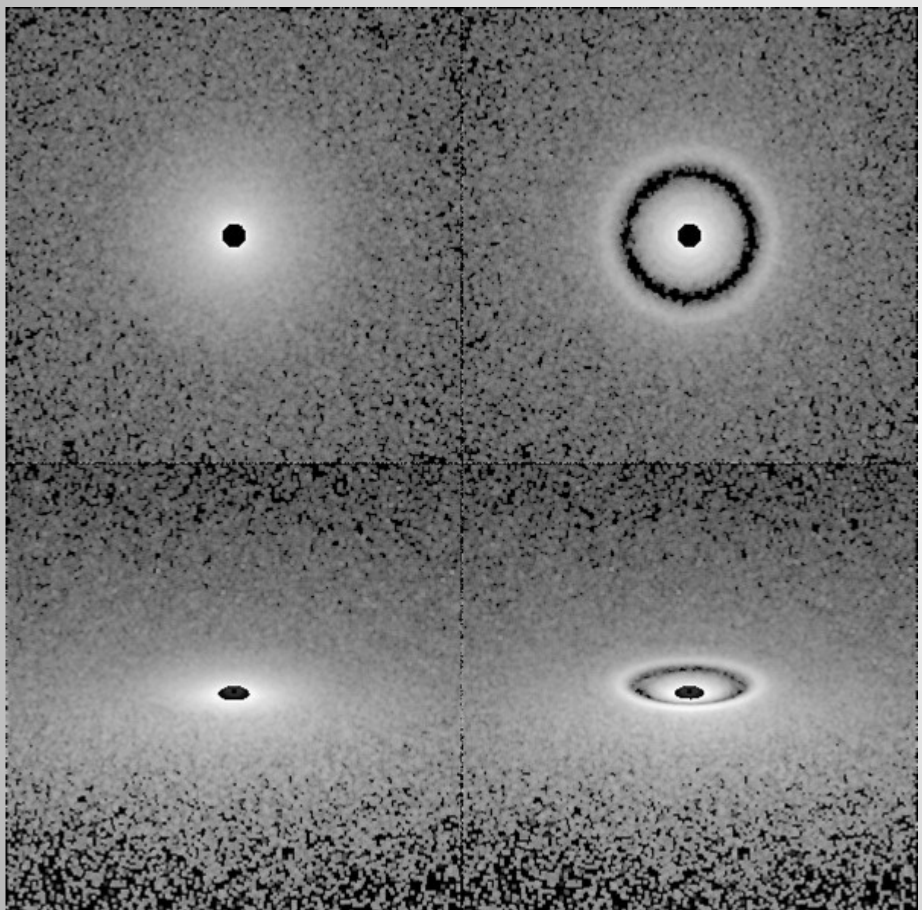
$M_{crit} = 1\ M_J$

Giant Planet Opening a Gap



- 1 M_{Jup}
- 0.5 M_{sun}
- 5 AU
- 100 pc
- Wolf & D'Angelo 2005

Gaps in Scattered Light

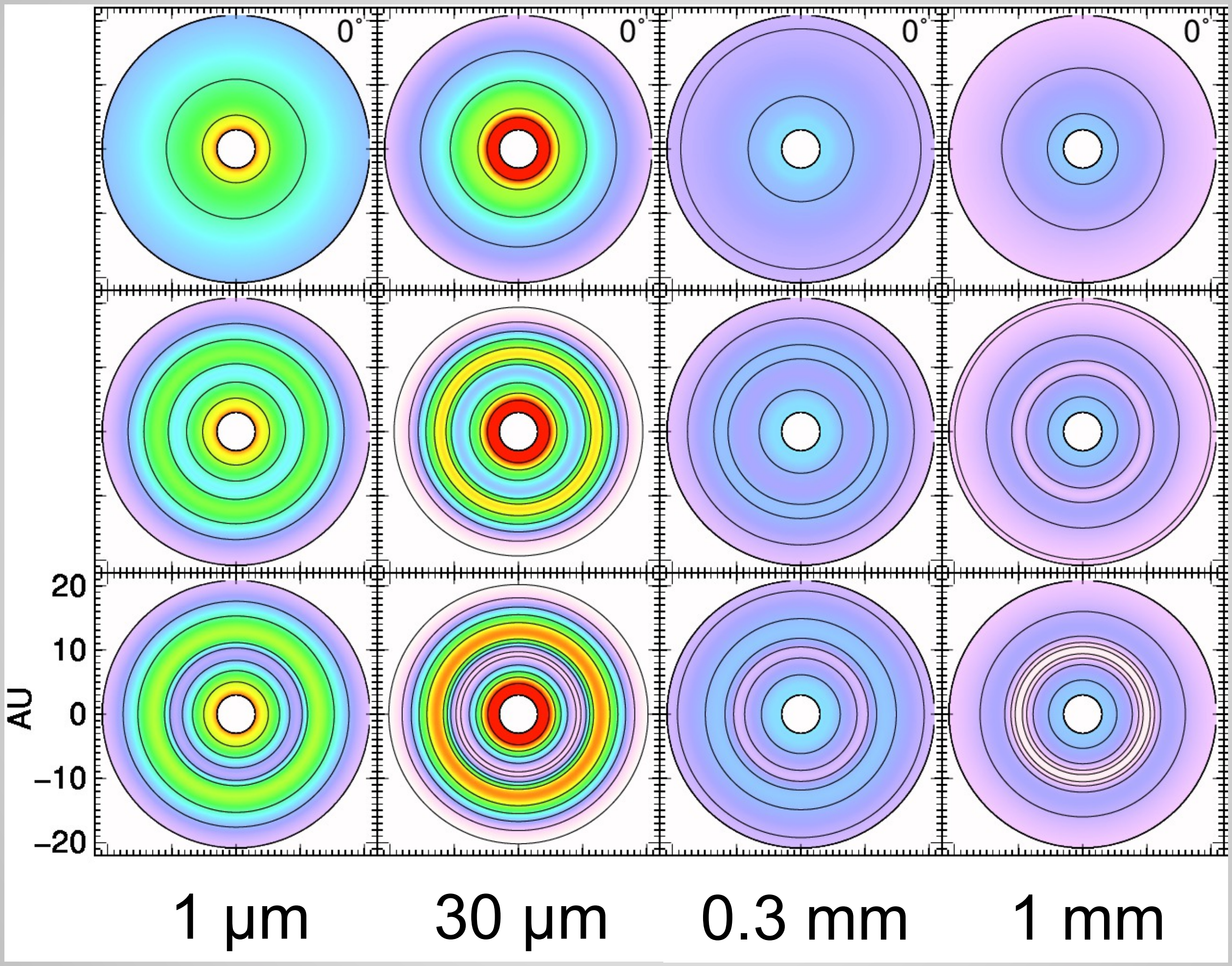


- 2 M_J at 1 AU
- Includes puffing of outer wall of gap
- Varnière, et al. 2006

Jang-Condell & Turner 2012

1 M_{sun}

Planet at 10 AU

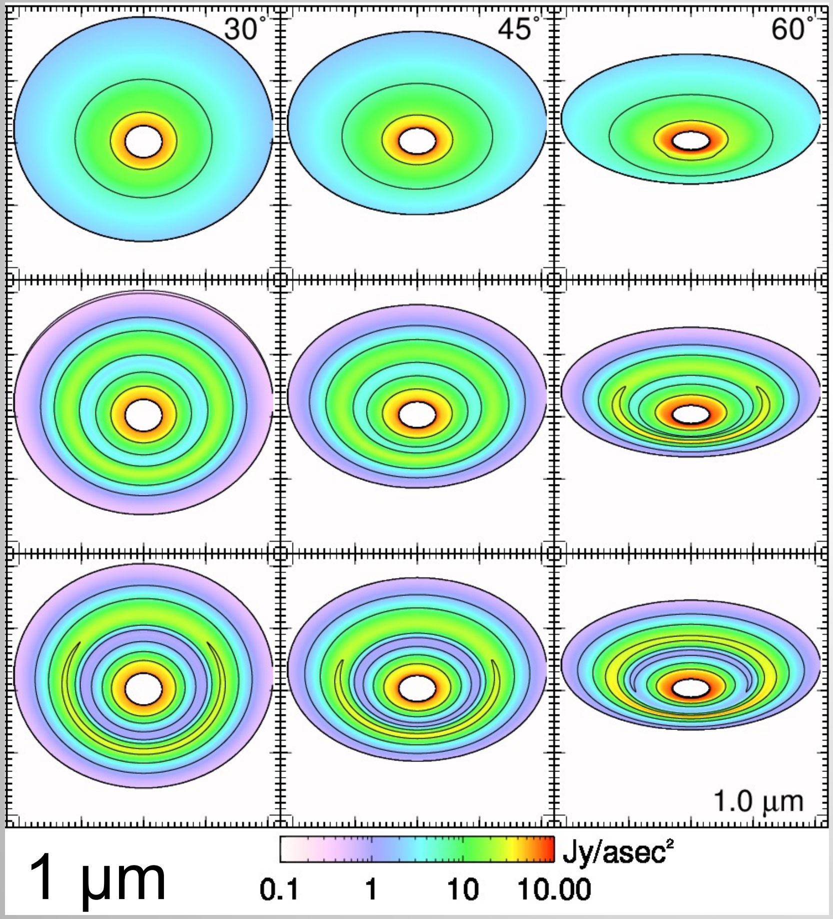


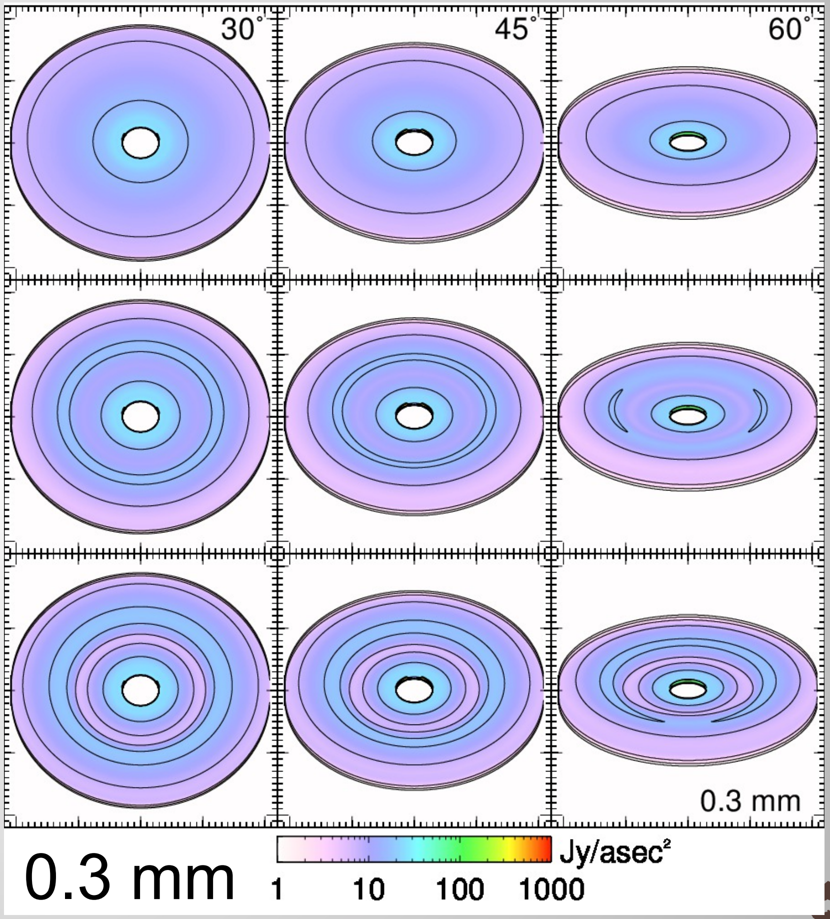
70 M_{Earth}

200 M_{Earth}

Inclined Disks

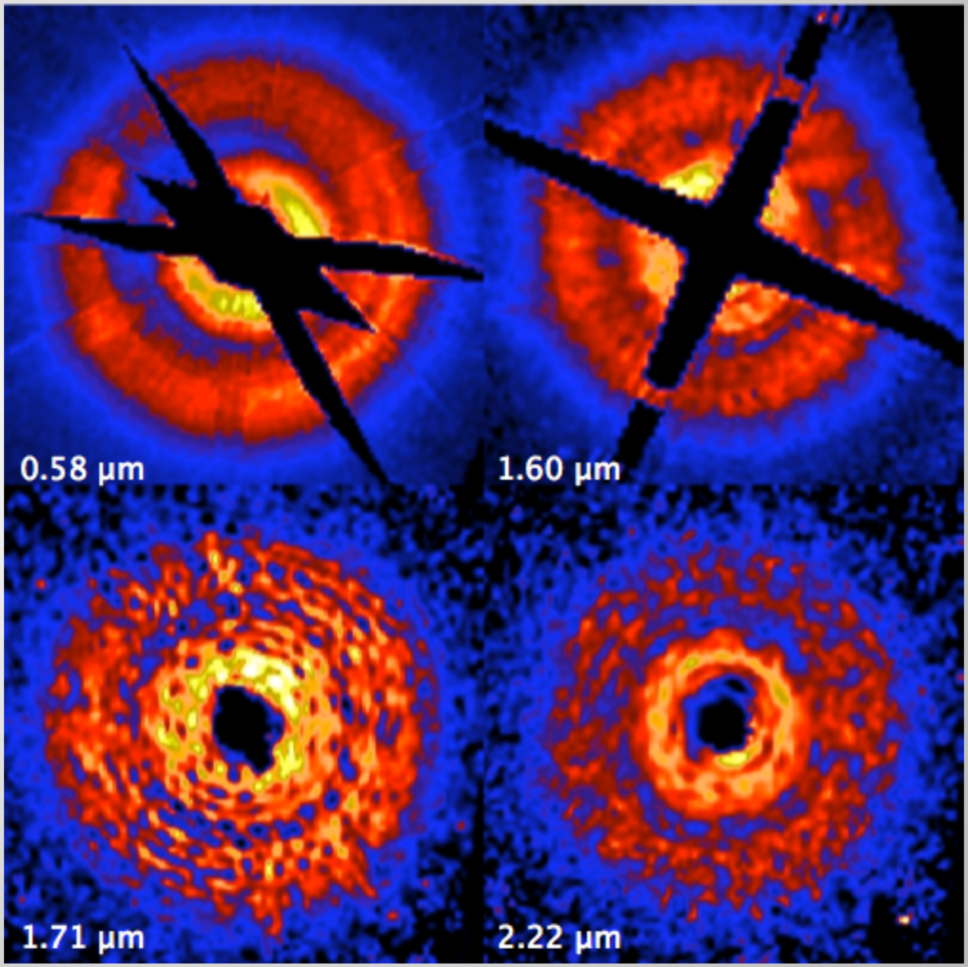
Jang-Condell & Turner, submitted





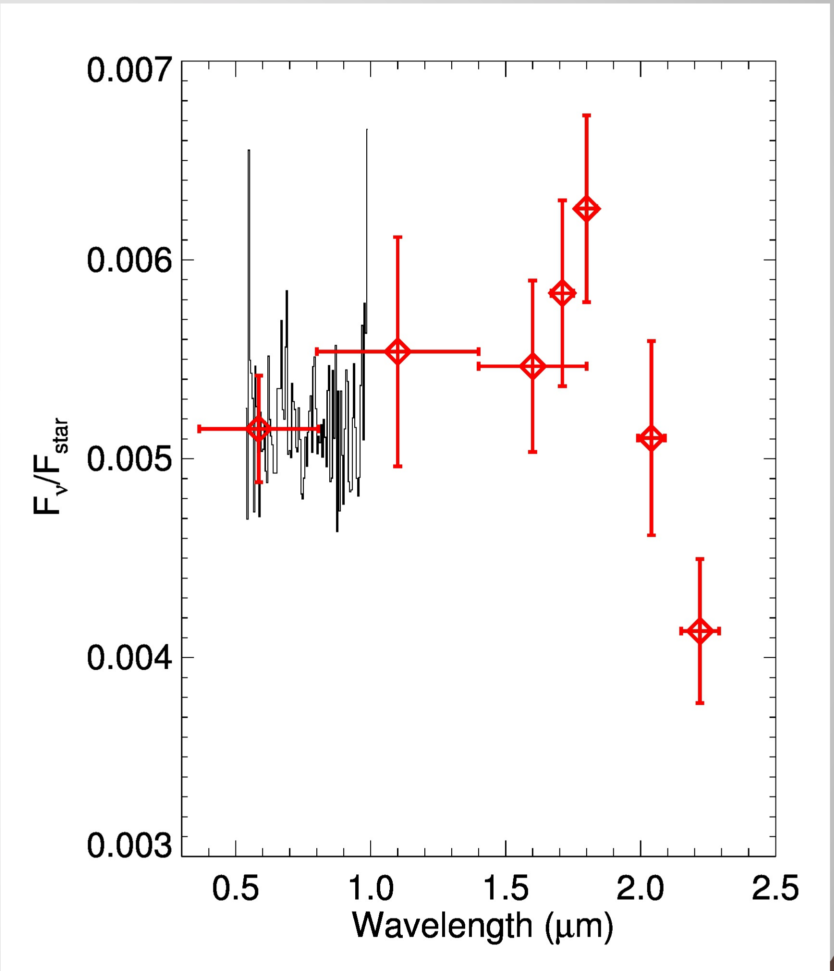
TW Hya

- 56 parsecs
- Hubble observations
  - STIS
  - NICMOS
  - 7 wavelengths
- Debes, Jang-Condell, et al. (submitted)



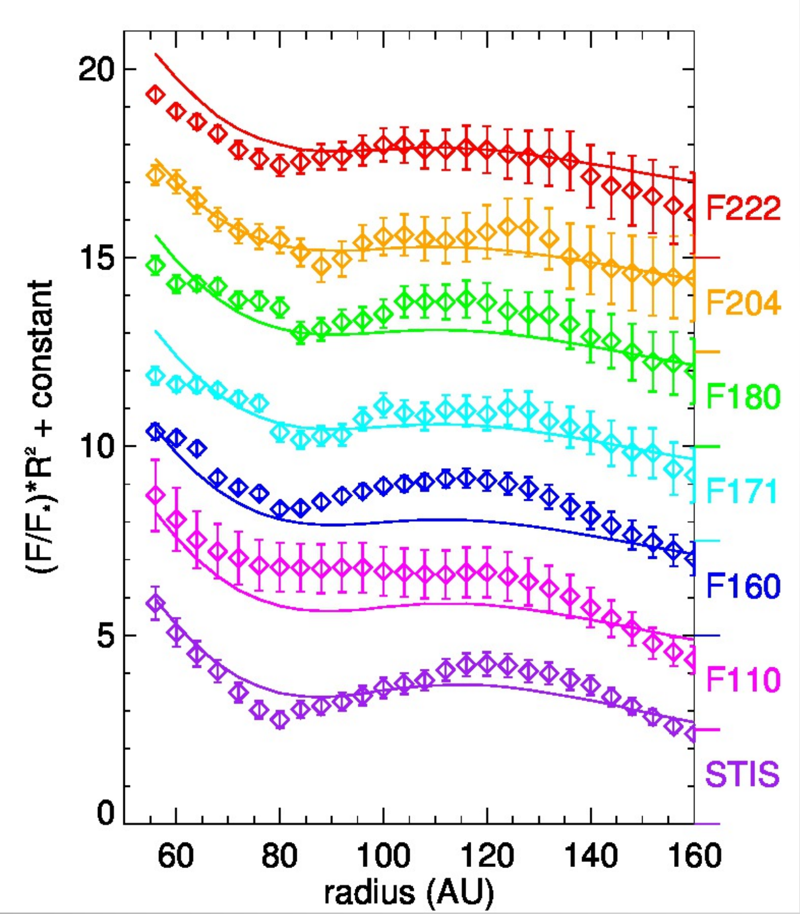
TW Hya

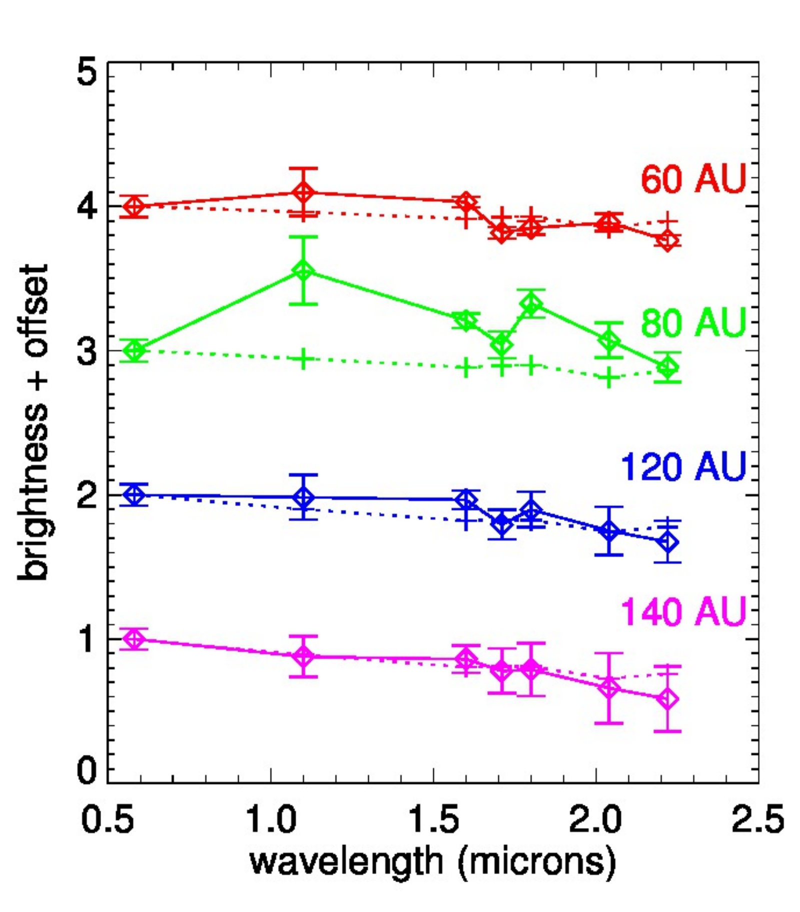
- Match spectral and spatial data
- Dust opacities
  - Size distribution
  - Composition
- Fit parameters:
  - Gap depth
  - Gap width
  - Grain size
  - Disk truncation



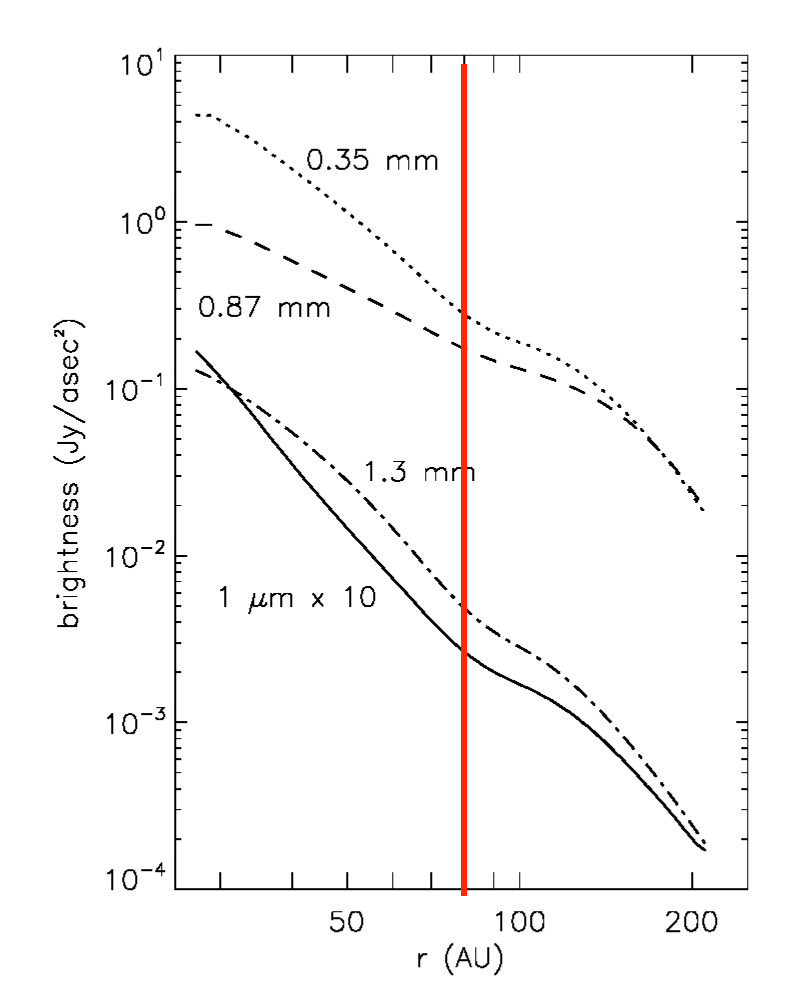
TW Hya best fit: 30% Gap

6-20 M_{earth} planet





TW Hya in sub-mm & mm



- Best fit model: truncated at 100 AU
- Sub-mm/mm observations: disk truncated at 30-50 AU (Andrews+ 2012, Gorti+ 2011, Isella+ 2009)
- Dust settling? Grain growth? Grain drift? (Maddison talk)

Summary

- Multiwavelength observations are vital for finding planets in disks
- Multiwavelength observations provide a complicated picture of disks

Mahalo!