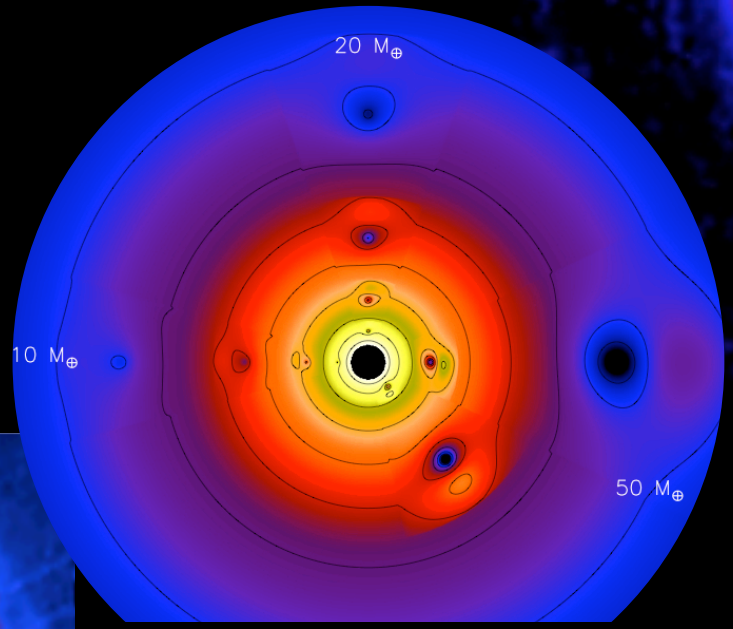
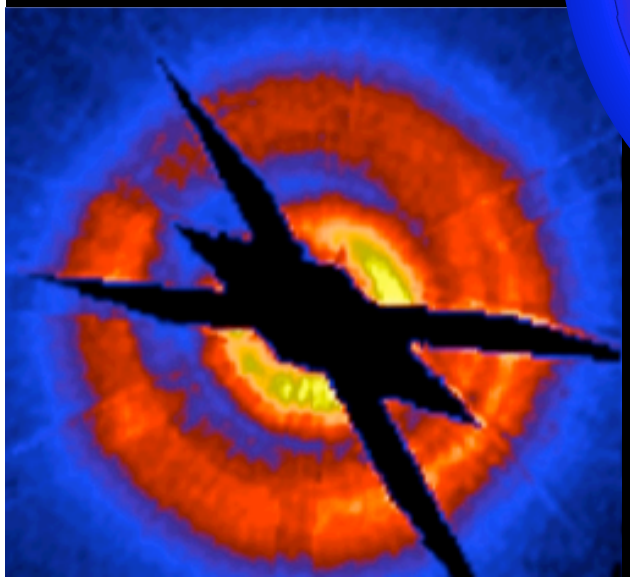
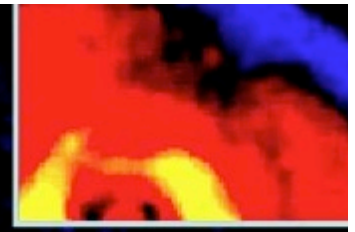
Detecting Planets in Protoplanetary Disks







Dr. Hannah Jang-Condell

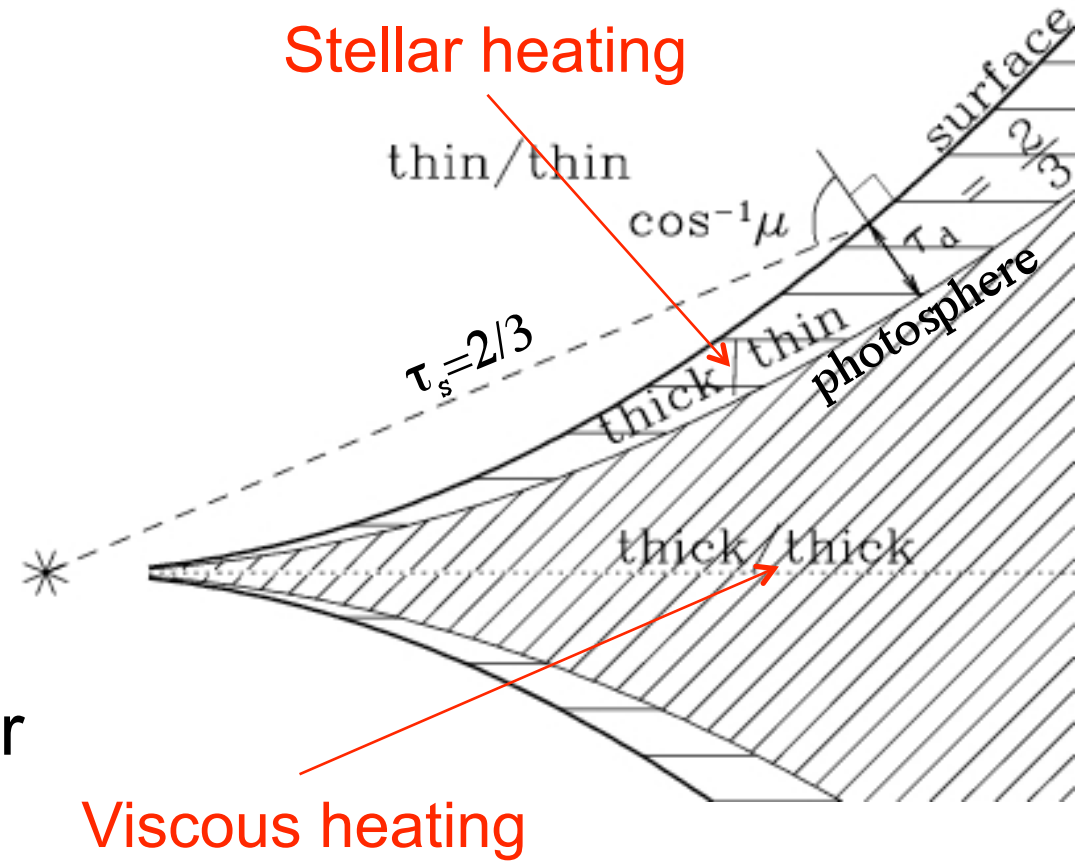
Michelson Postdoctoral Fellow

University of Maryland

NASA's Goddard Space Flight Center

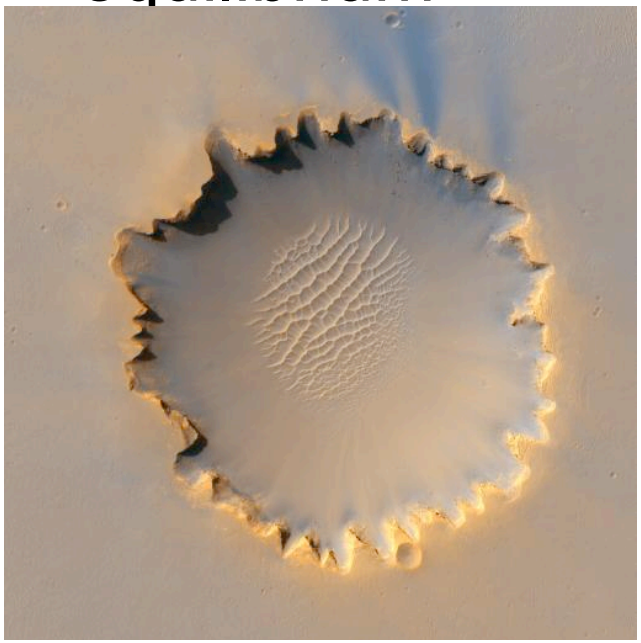
Disk Model

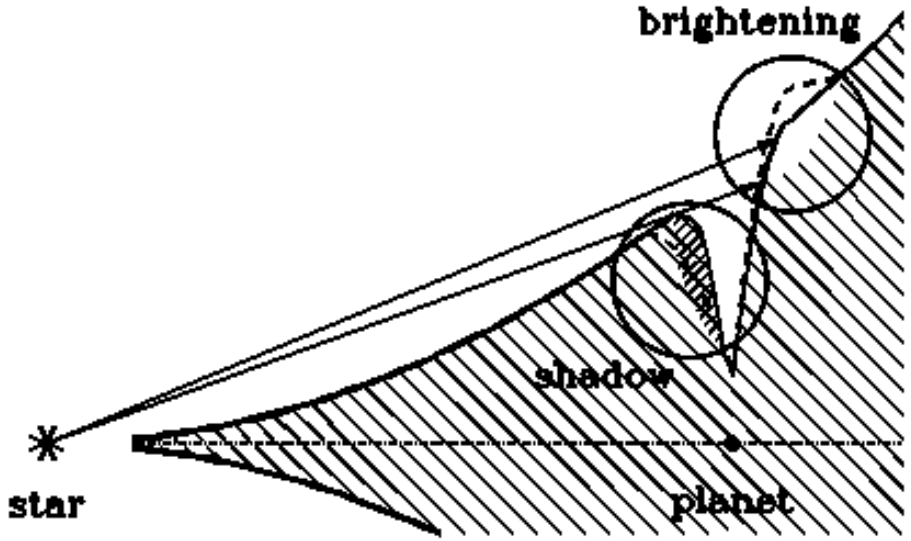
- Protoplanetary/ Primordial disk
- Start with α-disk model (viscous accretion)
- Add heating from stellar irradiation: Radiative Transfer Modeling



Embedded Planets

- Steady state
- Hydrostatic equilibrium

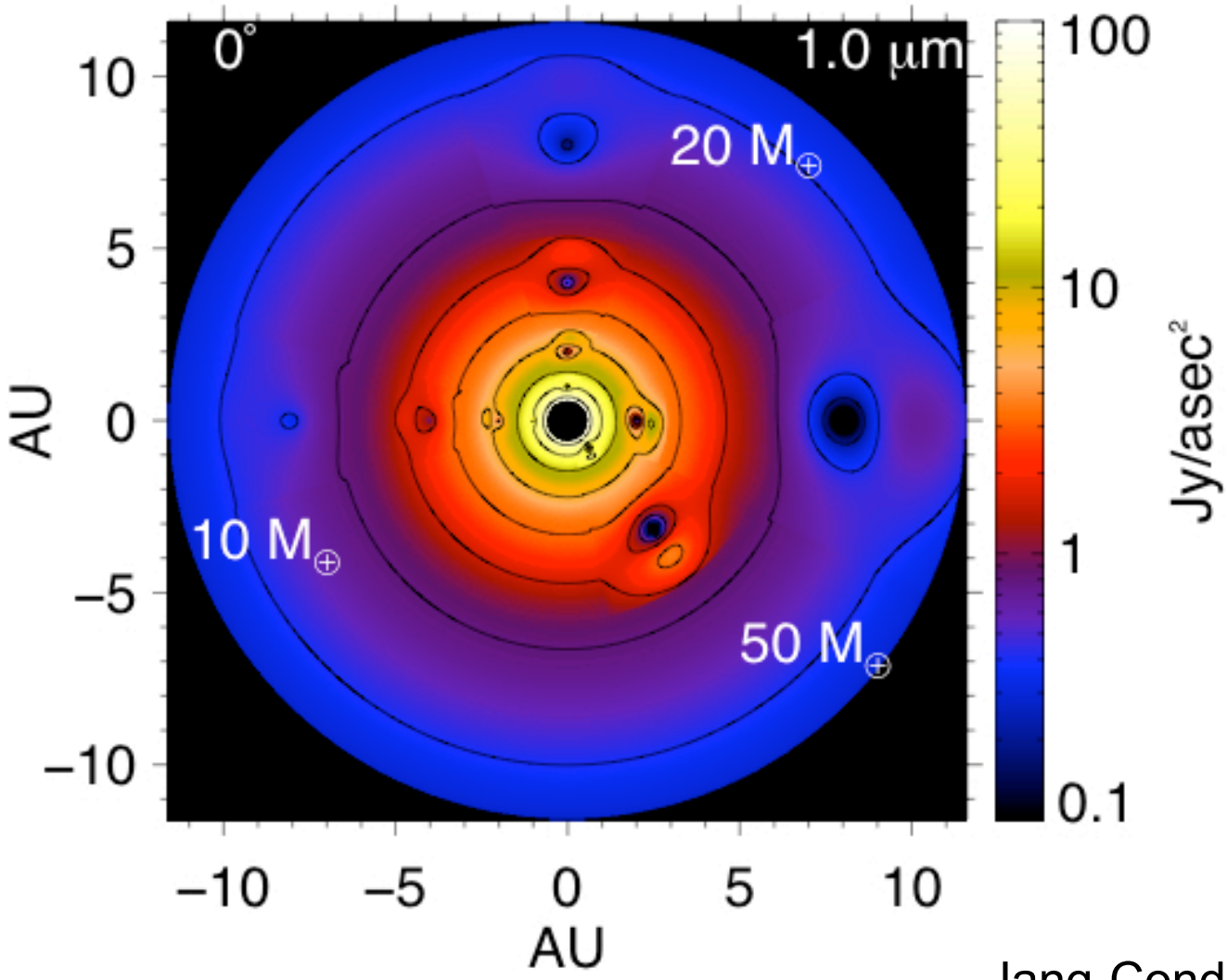




(Jang-Condell & Sasselov 2003, 2004; Jang-Condell 2008)

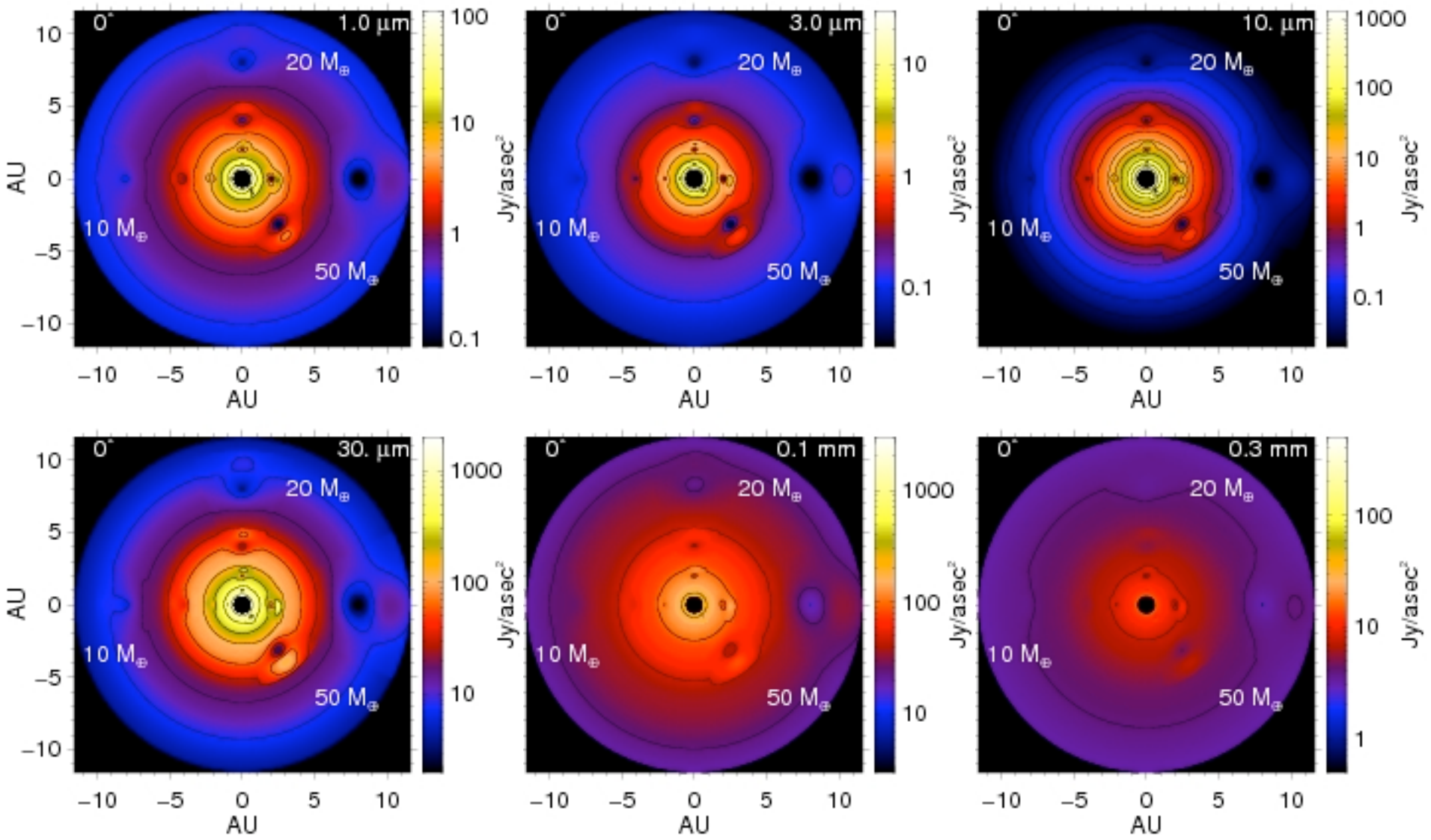
Victoria Crater, Mars. Image Credit: NASA/JPL-Caltech/University of Arizona/Cornell/Ohio State University

Planet Shadows at 1um



Jang-Condell 2009

Planet Shadows

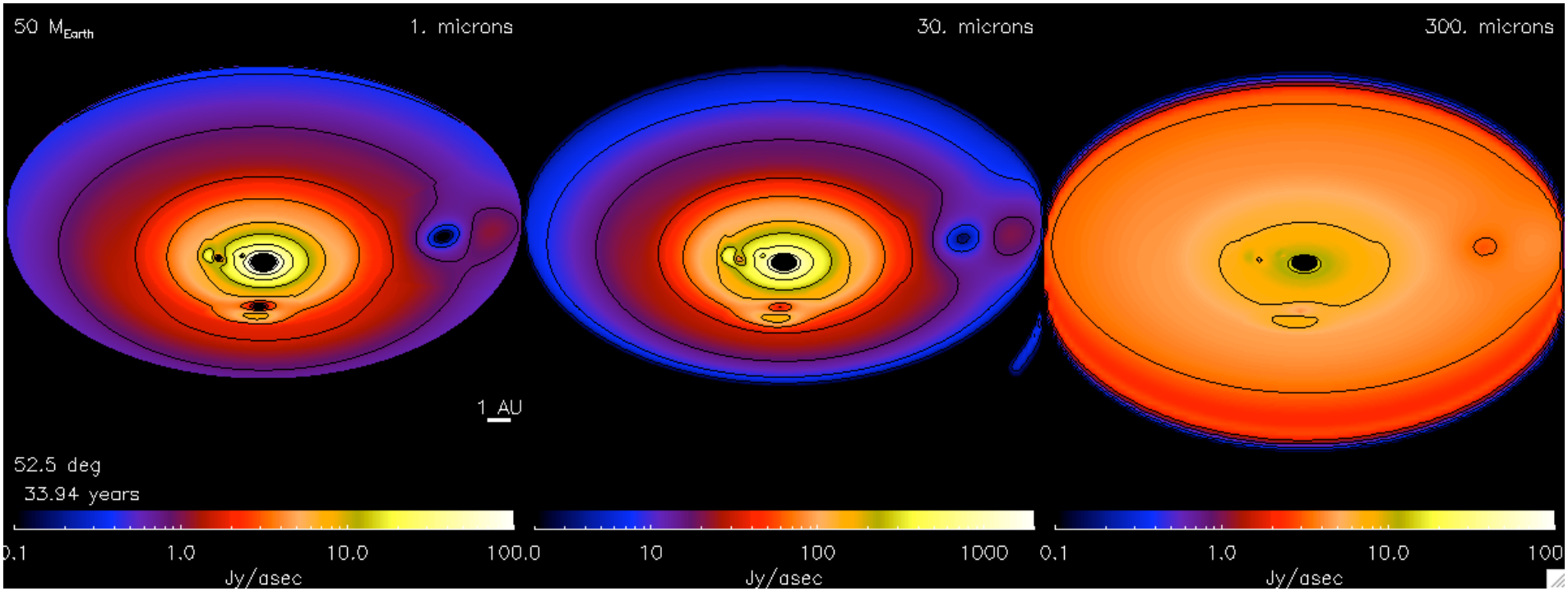


13 Nov 2009

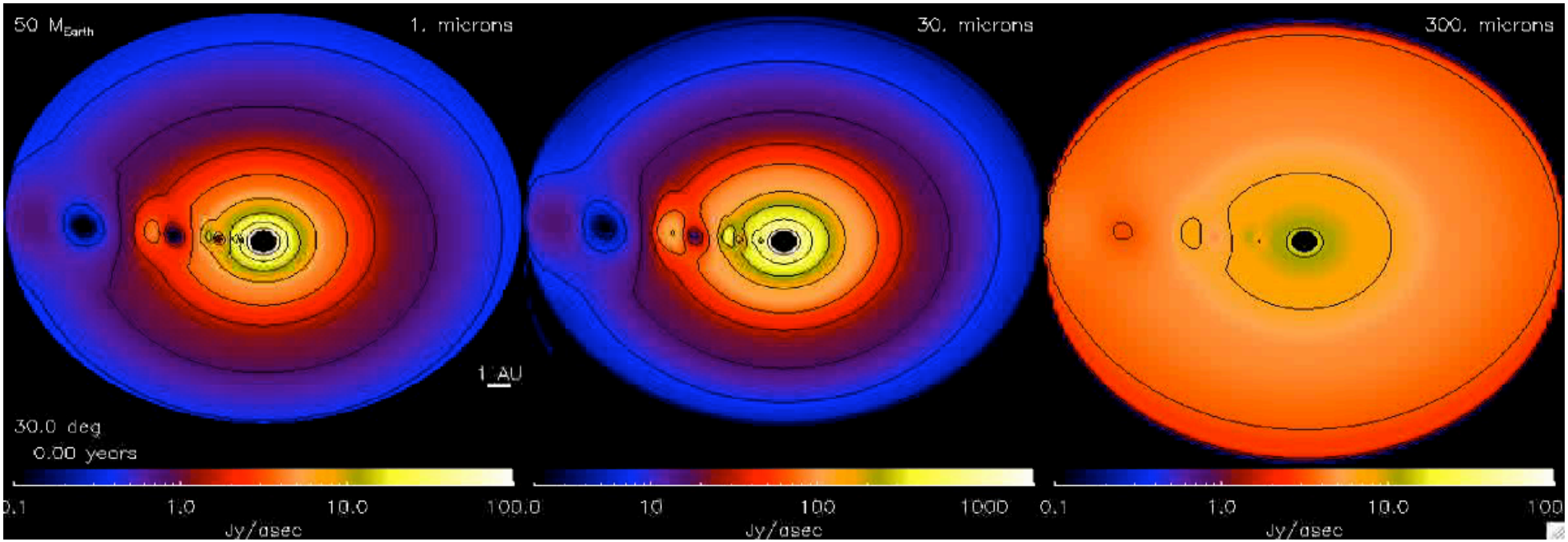
Sagan Symposium -- Jang-Condell

Jang-Condell 2009

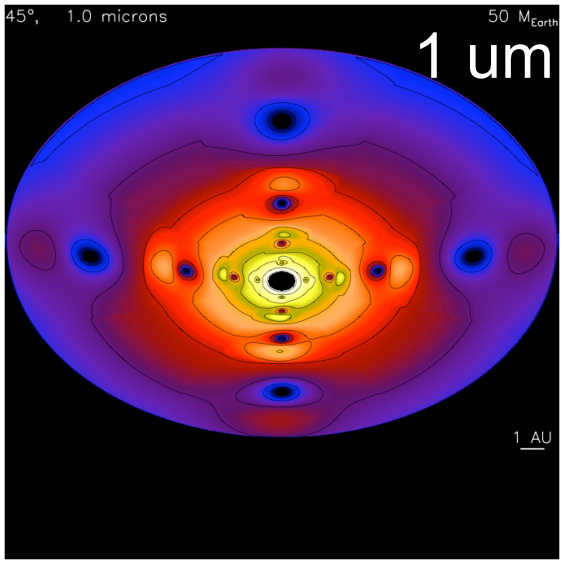
Inclination

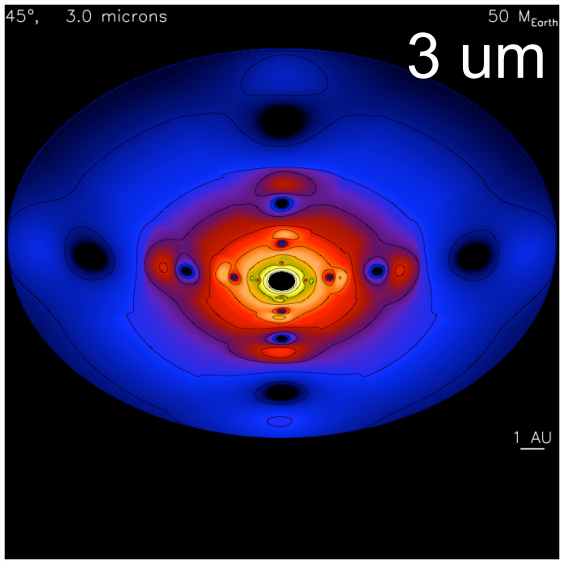


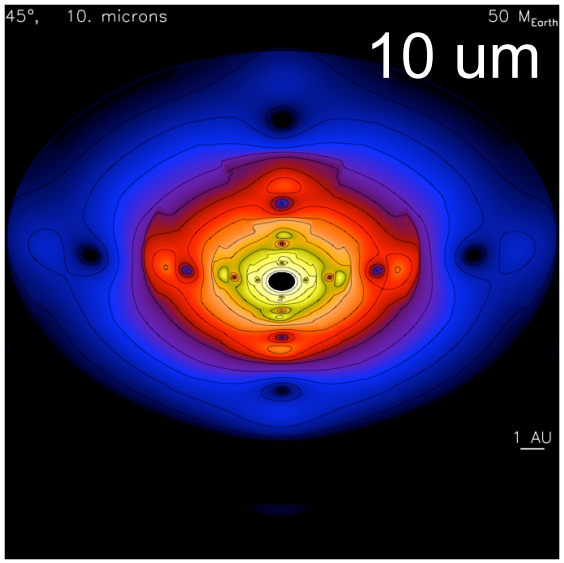
Inclination

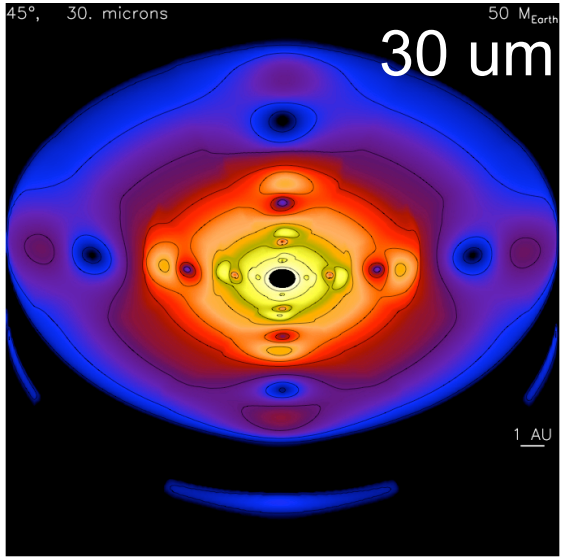


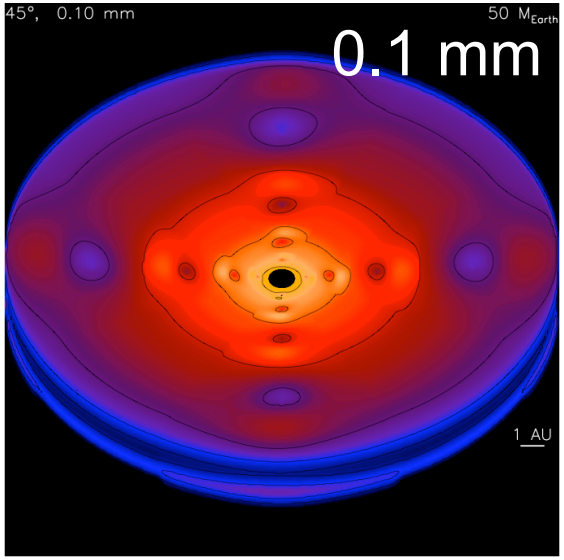
Jang-Condell 2009

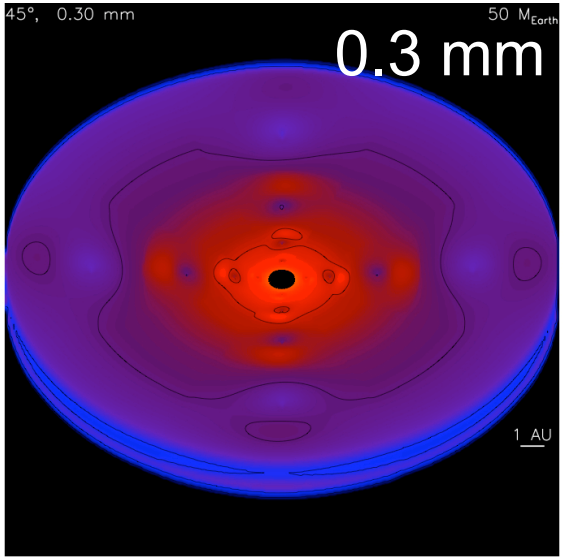


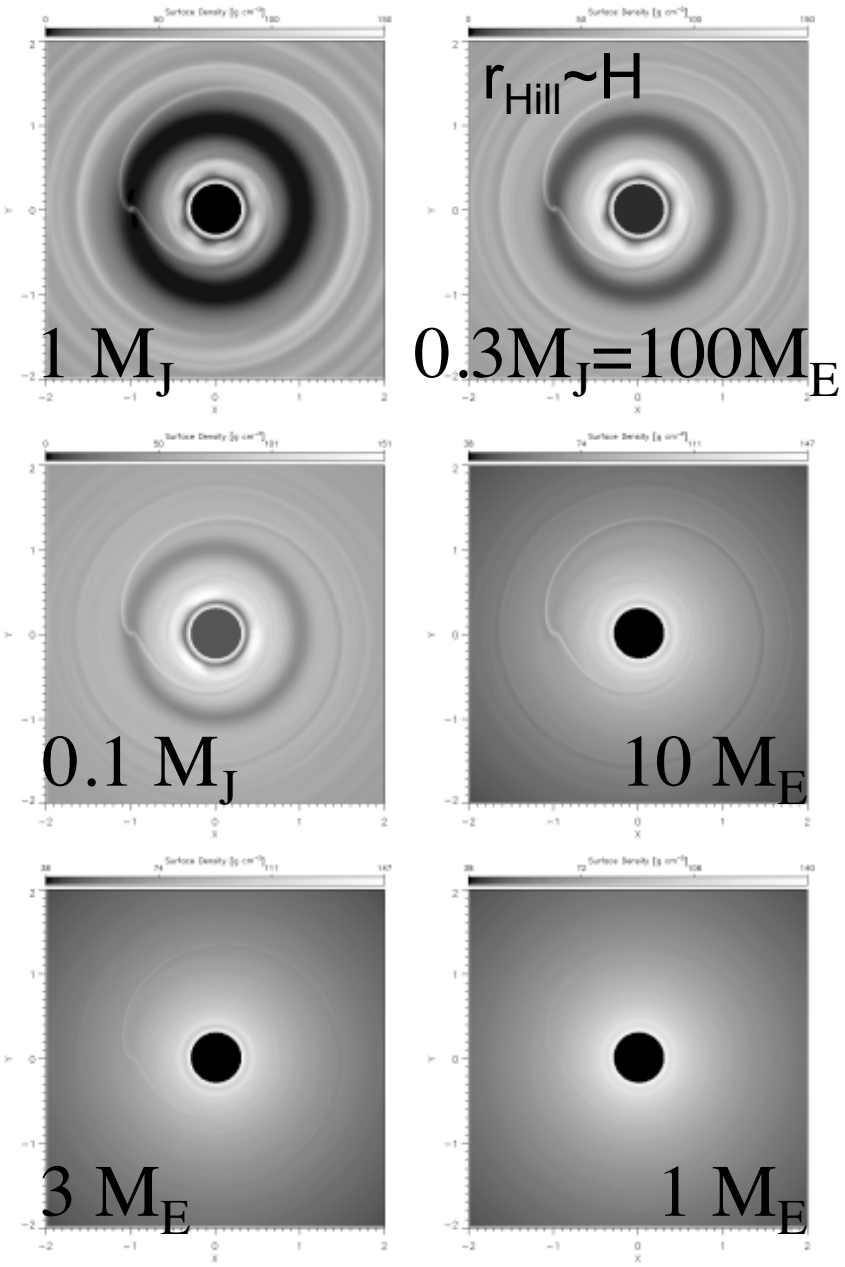








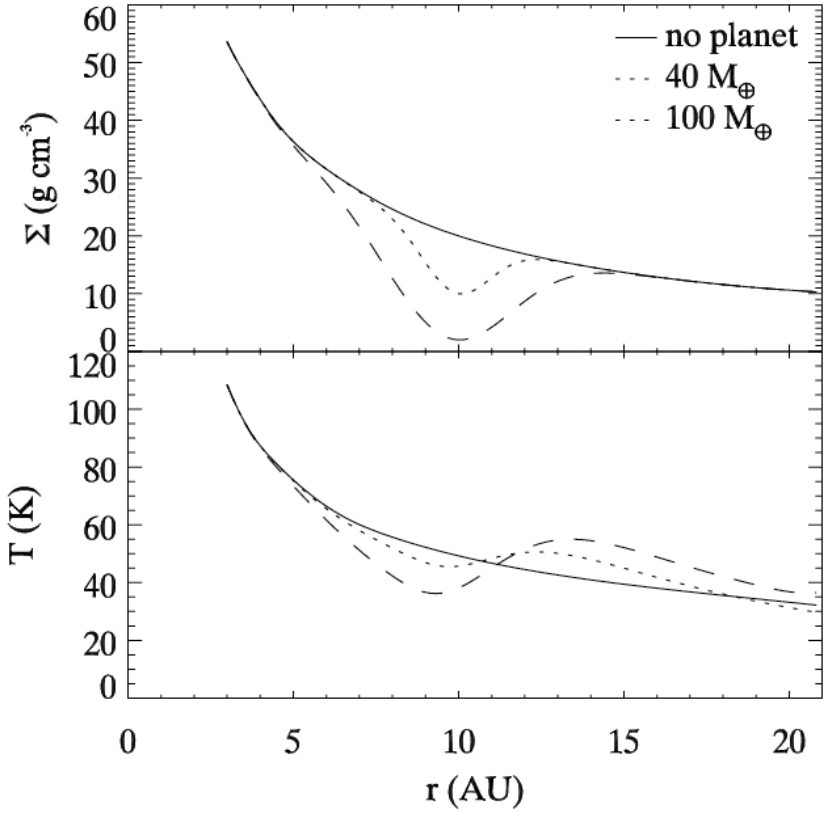




Partial Gaps

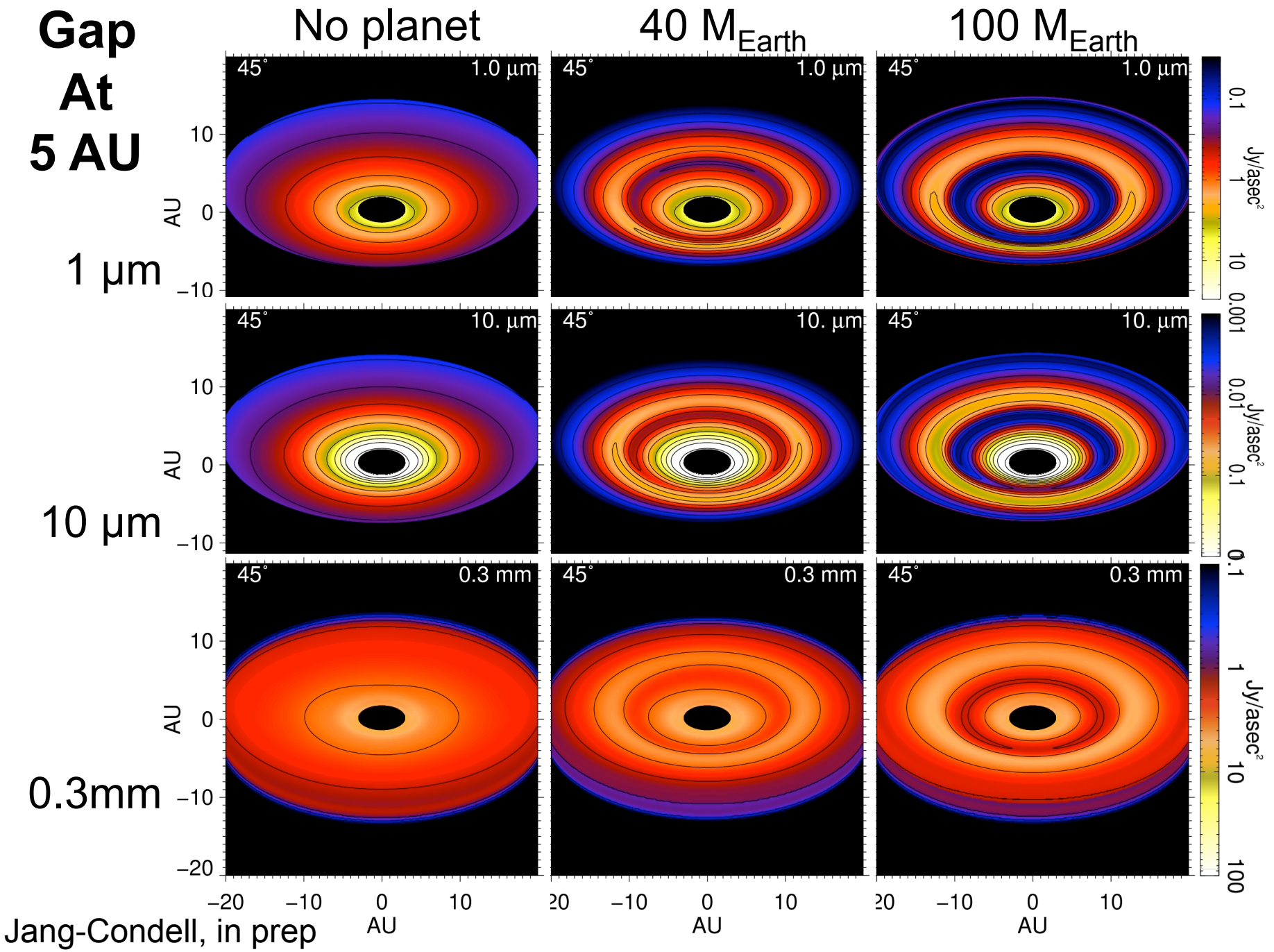
- Hydrodynamic simulations of planets at 4 AU
- Gap-opening threshold:
  - $r_{Hill} = (M_p/3M_*)^{1/3}a = H$

Bate, et al. 2003

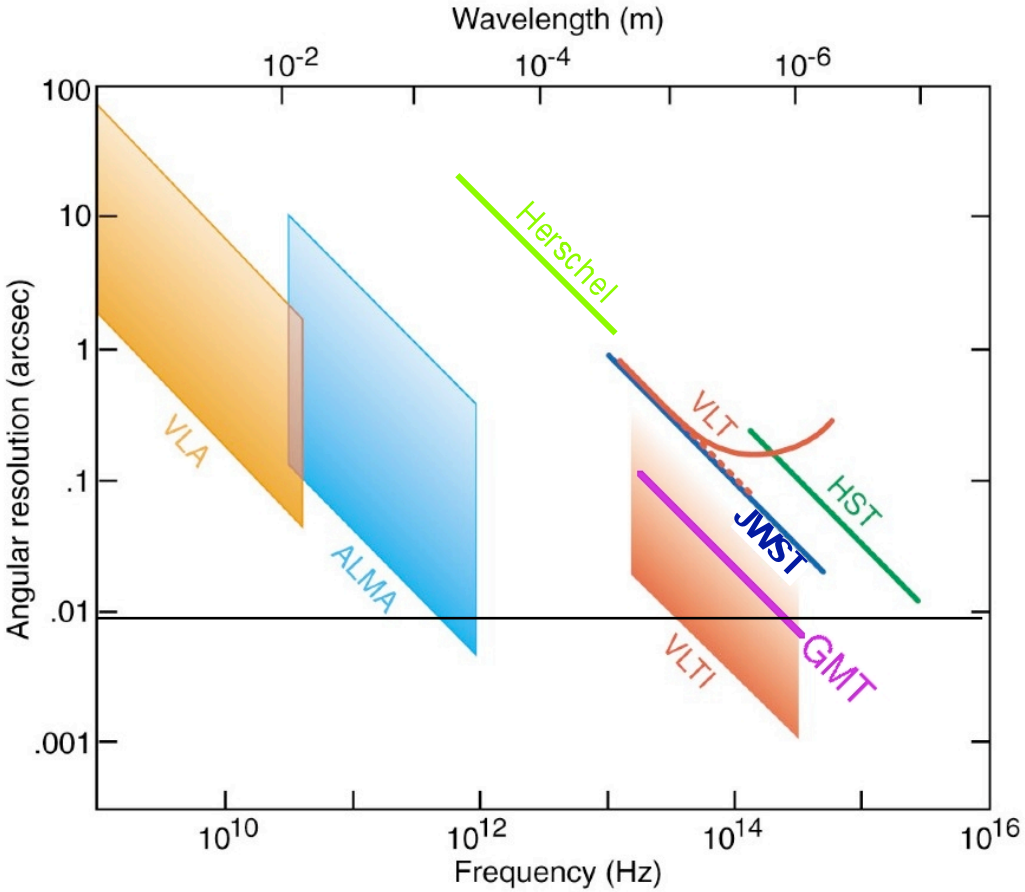


Partial Gaps

- Critical gap-opening threshold:
  - r_{Hill}=H
  - 90% clearing
- Sub-critical:
  - 1/3 critical mass
  - 50% clearing


Gap
At
5 AU
No planet
40 M_Earth
100 M_Earth
1 μm
10 μm
0.3mm
45°
1.0 μm
10. μm
0.3 mm
AU
Jy/asec²
Jang-Condell, in prep

Observational Challenges



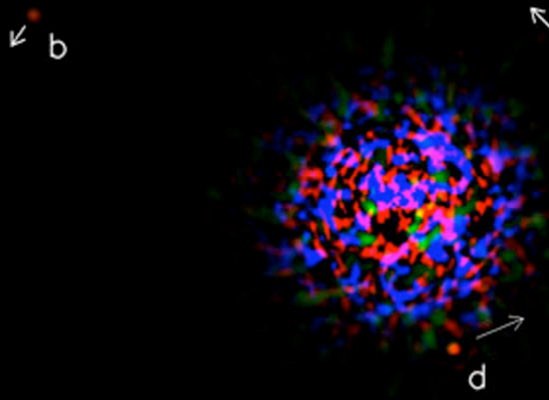
- Angular resolution
- High sensitivity
- High contrast
- Small inner working angle
- BUT there's still hope!

http://www.alma.nrao.edu/

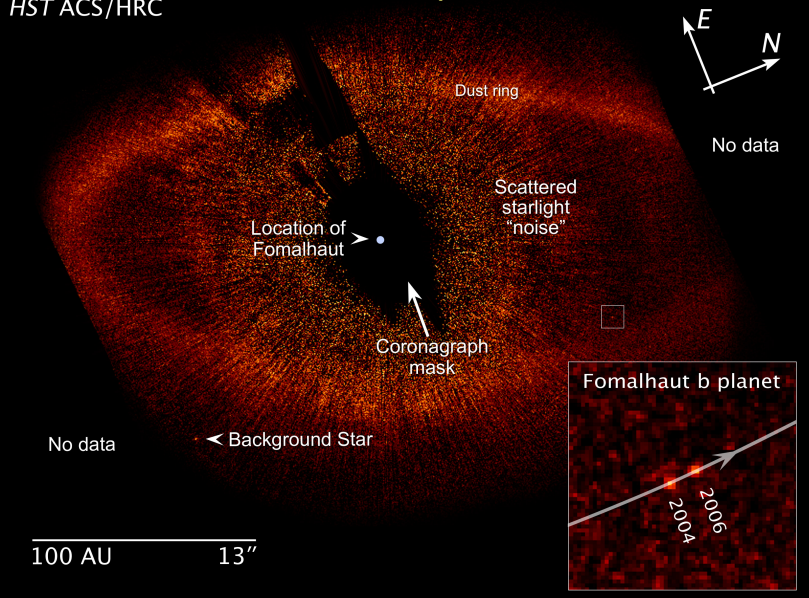
Distant Planets

2M1207 (Chauvin, et al. 2004)

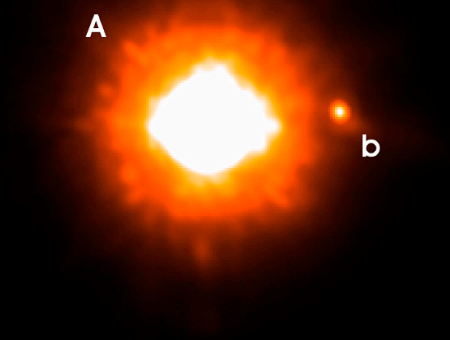
HR 8799 (Marois, et al. 2008)

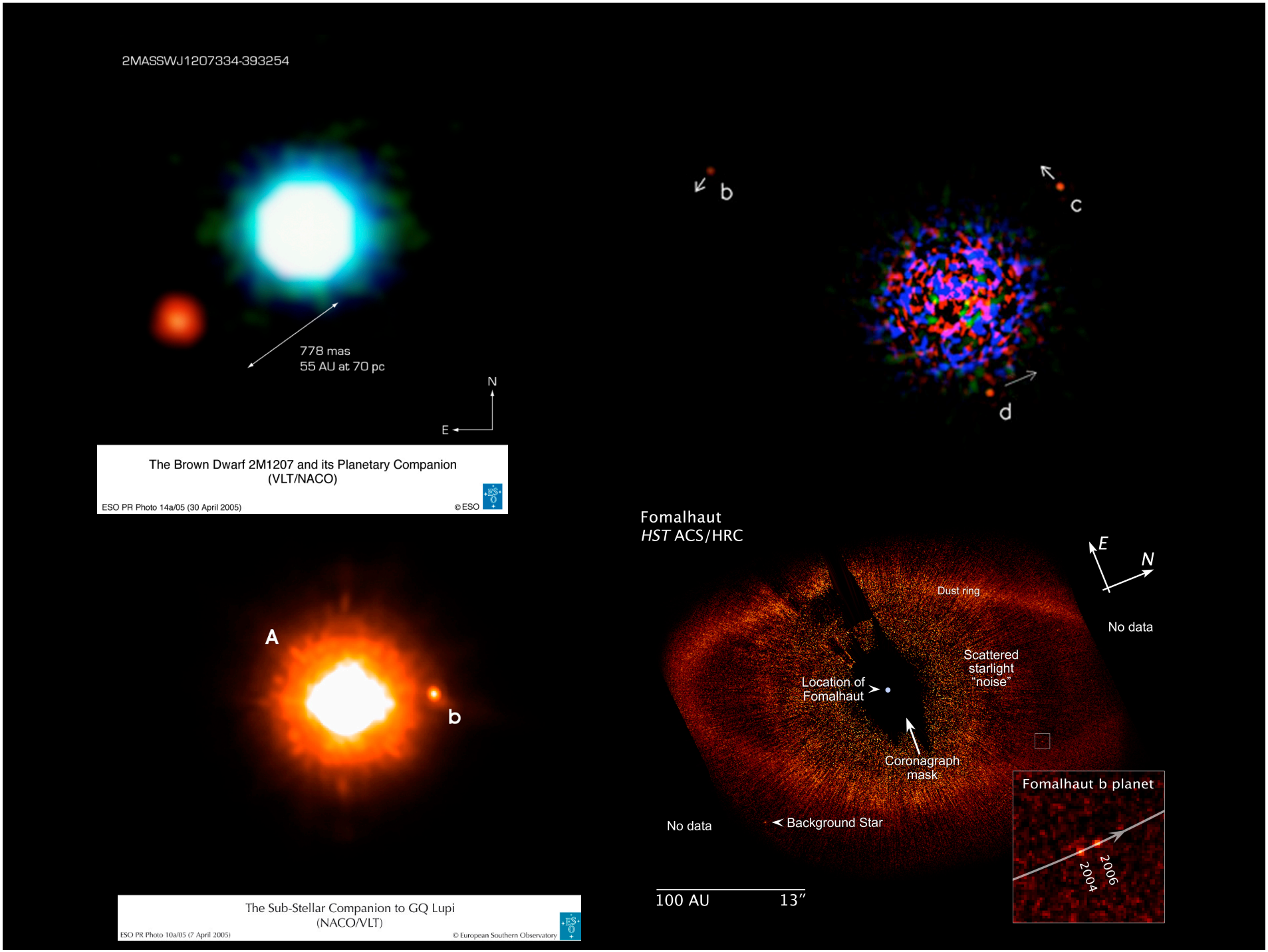


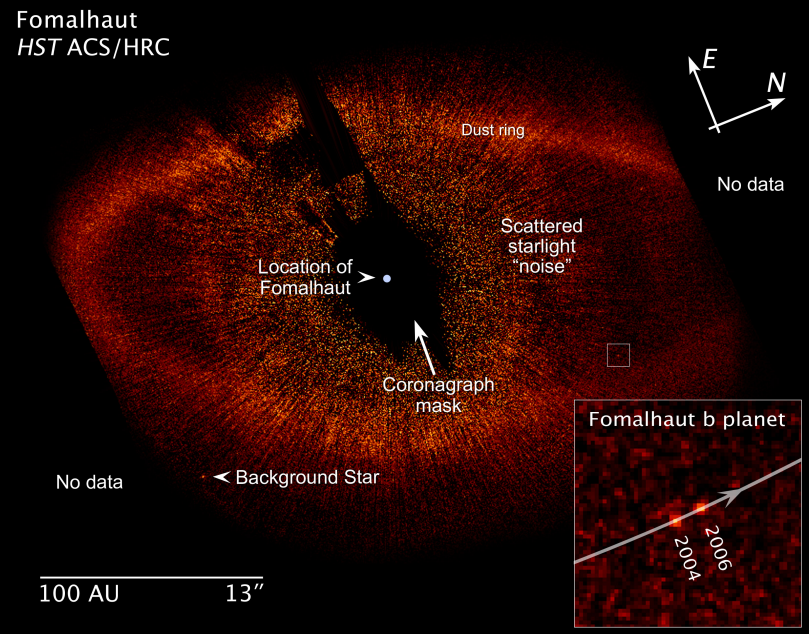
Fomalhaut (Kalas, et al. 2008)



GQ Lupi (Neuhäuser, et al. 2005)




2MASSWJ1207334-393254
778 mas
55 AU at 70 pc
N
E
The Brown Dwarf 2M1207 and its Planetary Companion
(VLT/NACO)
ESO PR Photo 14a/05 (30 April 2005)
© ESO
b
c
d
A
b
The Sub-Stellar Companion to GQ Lupi
(NACO/VLT)
ESO PR Photo 10a/05 (7 April 2005)
© European Southern Observatory
Fomalhaut
HST ACS/HRC
E
N
Dust ring
No data
Scattered
starlight
"noise"
Location of
Fomalhaut
Coronagraph
mask
Fomalhaut b planet
2006
2004
No data
Background Star
100 AU
13″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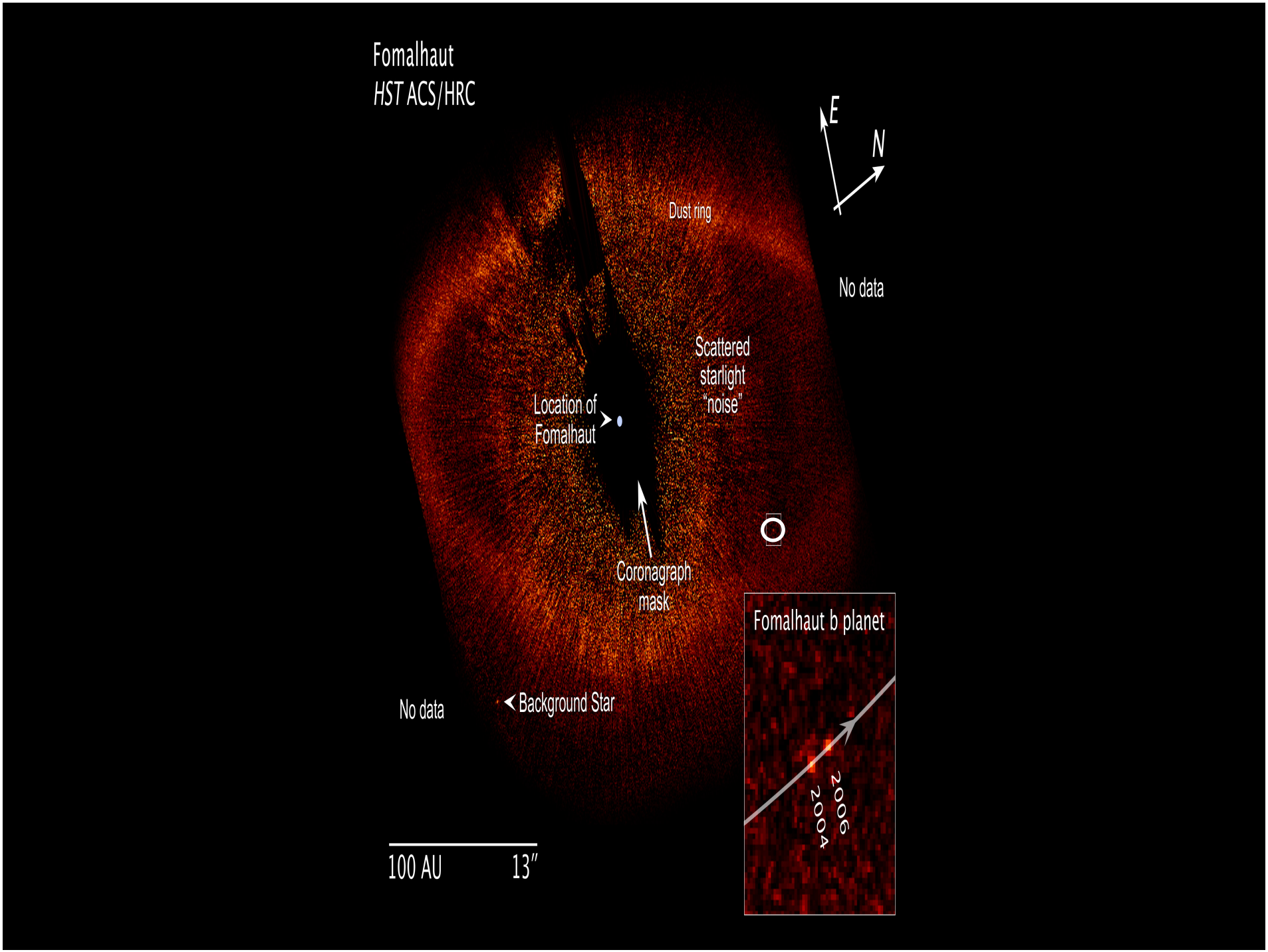
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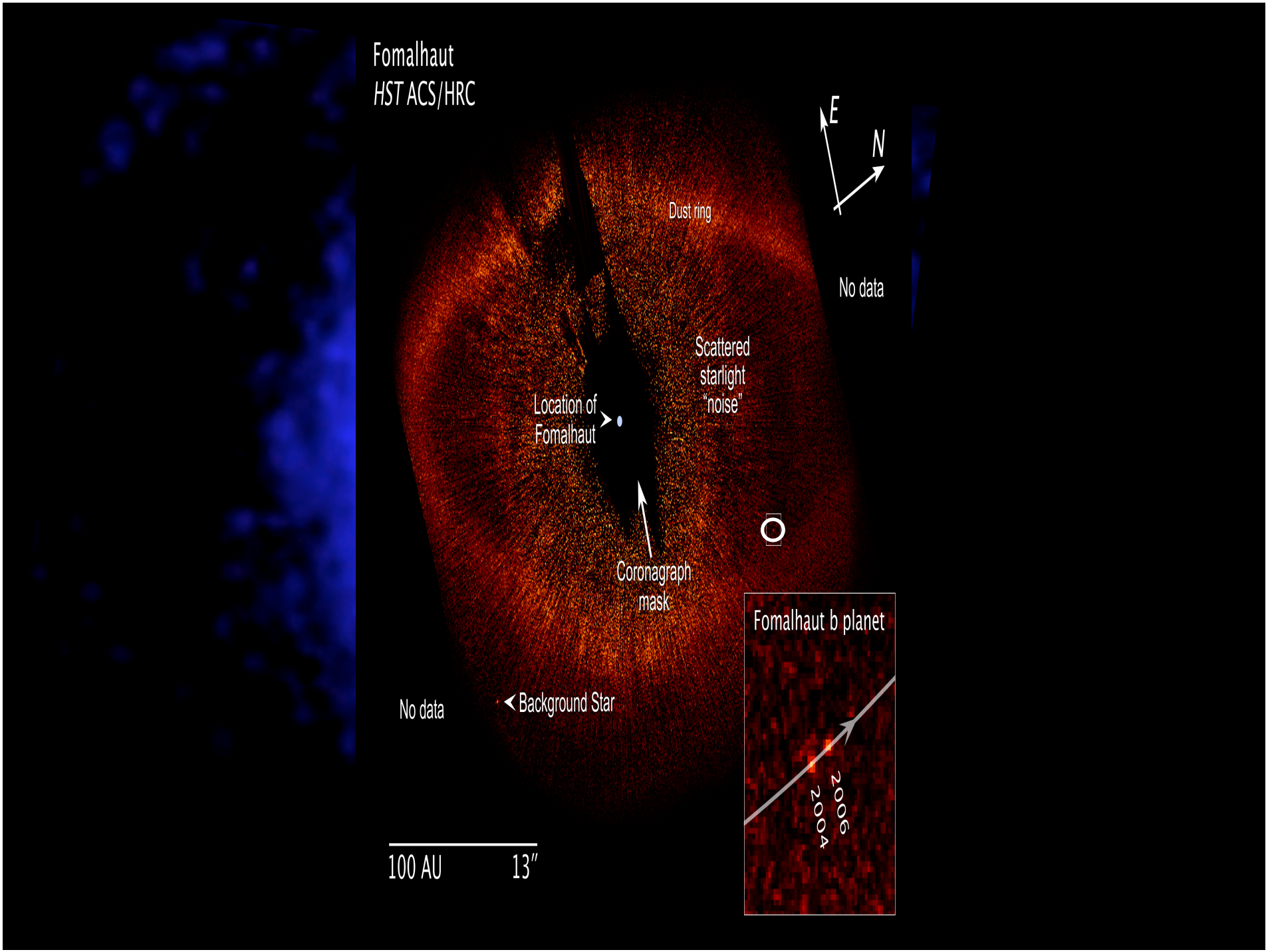
Fomalhaut
HST ACS/HRC
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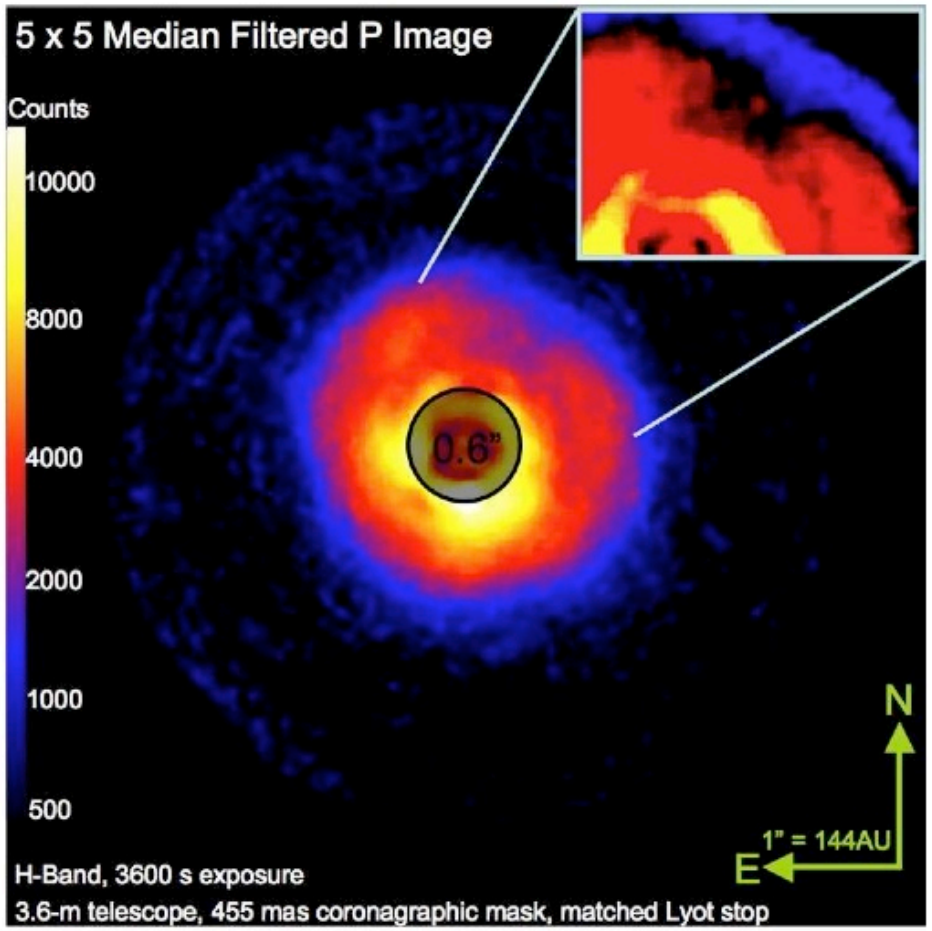
Dust ring
No data
Scattered
starlight
"noise"
Location of
Fomalhaut
Coronagraph
mask
Fomalhaut b planet
2006
2004
No data
Background Star
100 AU
13″

AB Aur in scattered polarized light

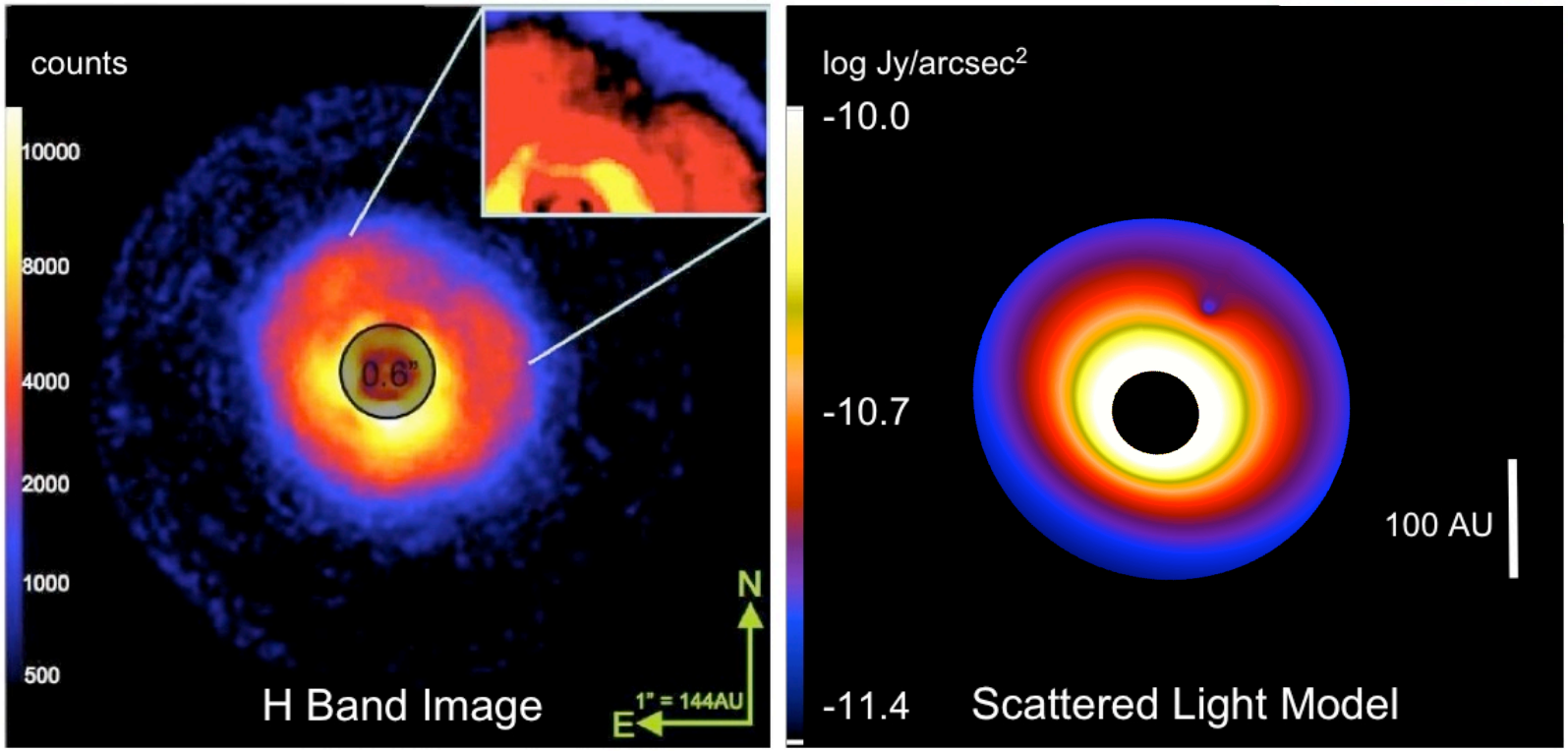


Oppenheimer, et al., 2008

AB Aur

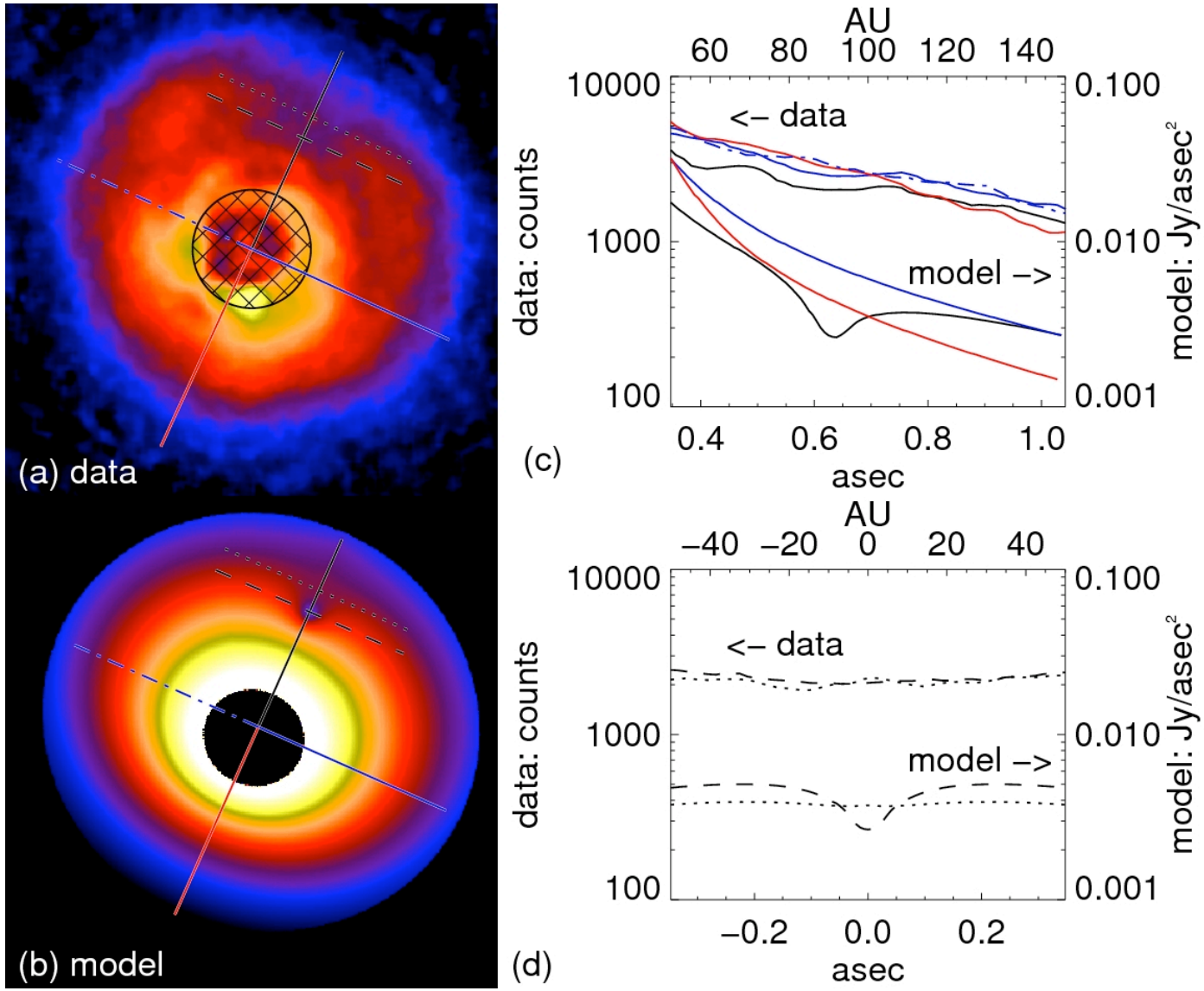
Oppenheimer, et al. 2008

Jang-Condell & Kuchner, submitted

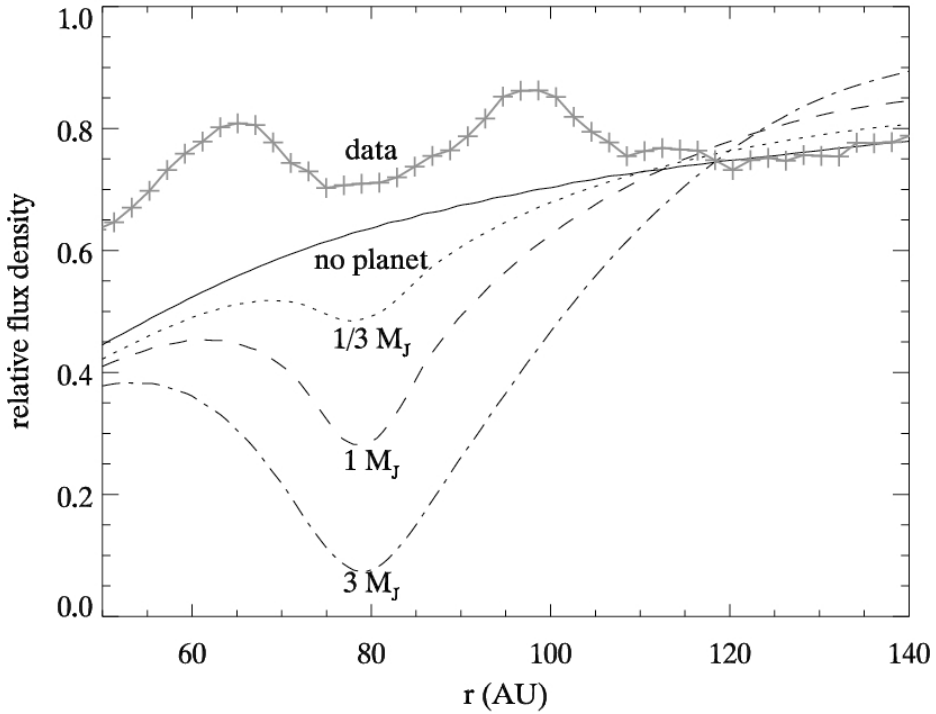


1 M_J @ 100 AU, 20° inclination

Jang-Condell & Kuchner, submitted



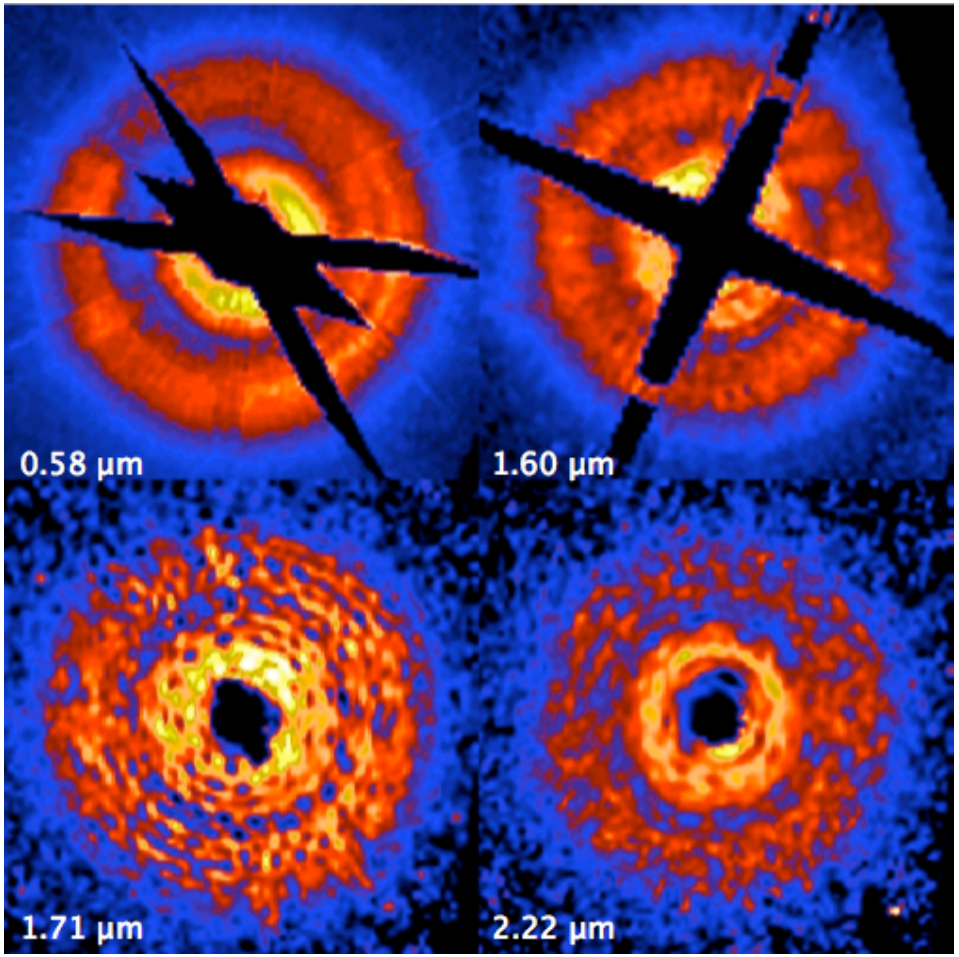
Planet or No Planet?



- Normalize brightness profile to that of major axis
- Planet no more massive than Saturn

A Gap in TW Hya

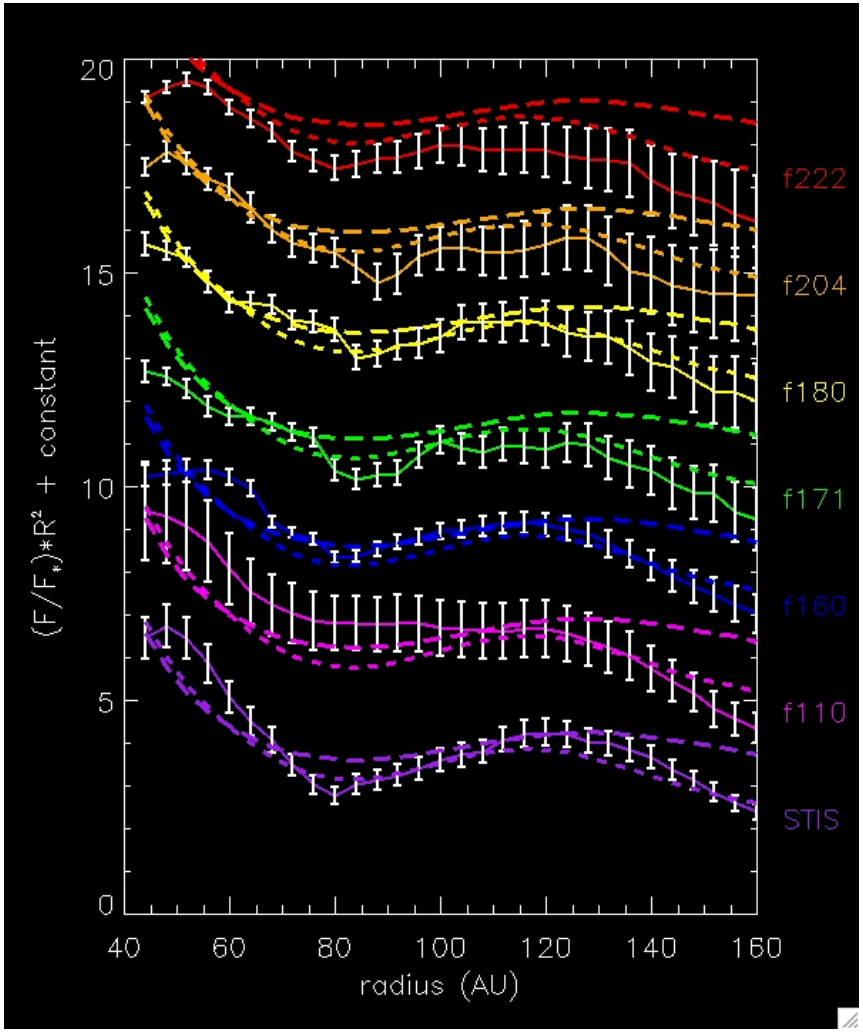
- Hubble observations
  - STIS
  - NICMOS
  - 7 wavelengths
- Debes, Jang-Condell, et al. (in prep)

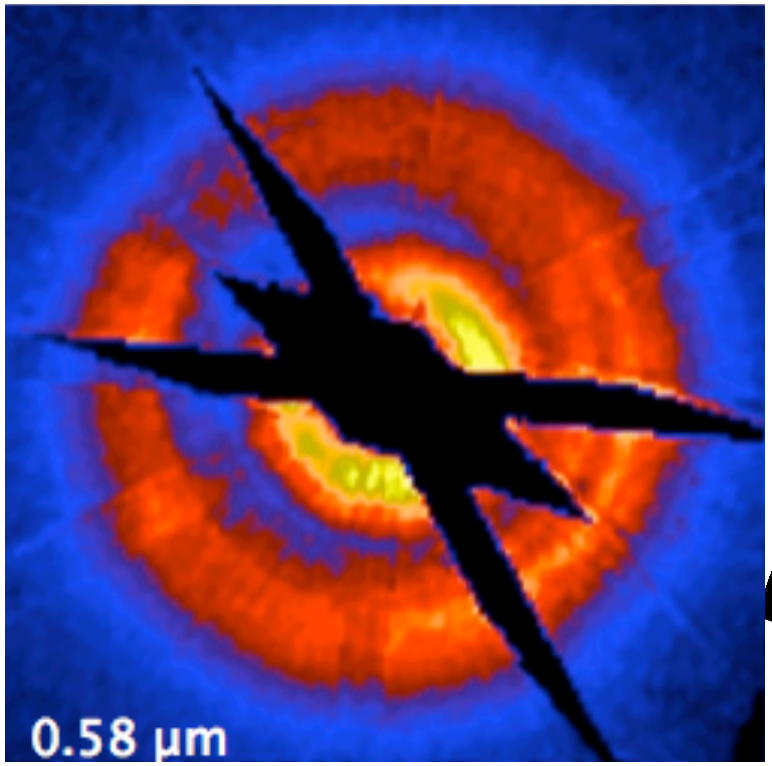


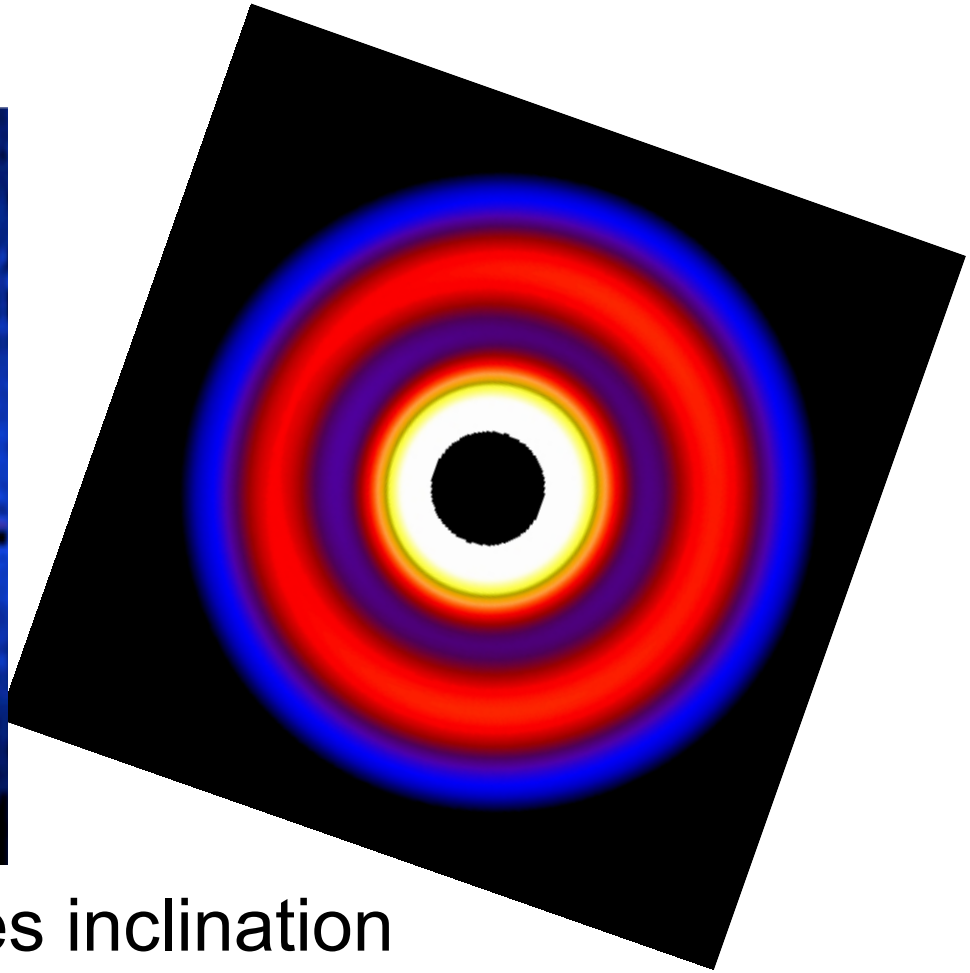
Multiwavelength Fit

- Best fit gap depth = 30%
- For TW Hya, at 80 AU: M_{crit}=0.9 M_{Jup}
- 30% gap:

~0.3 M_{Jup} = Saturn mass







7 degrees inclination

Isotropic scattering

Summary

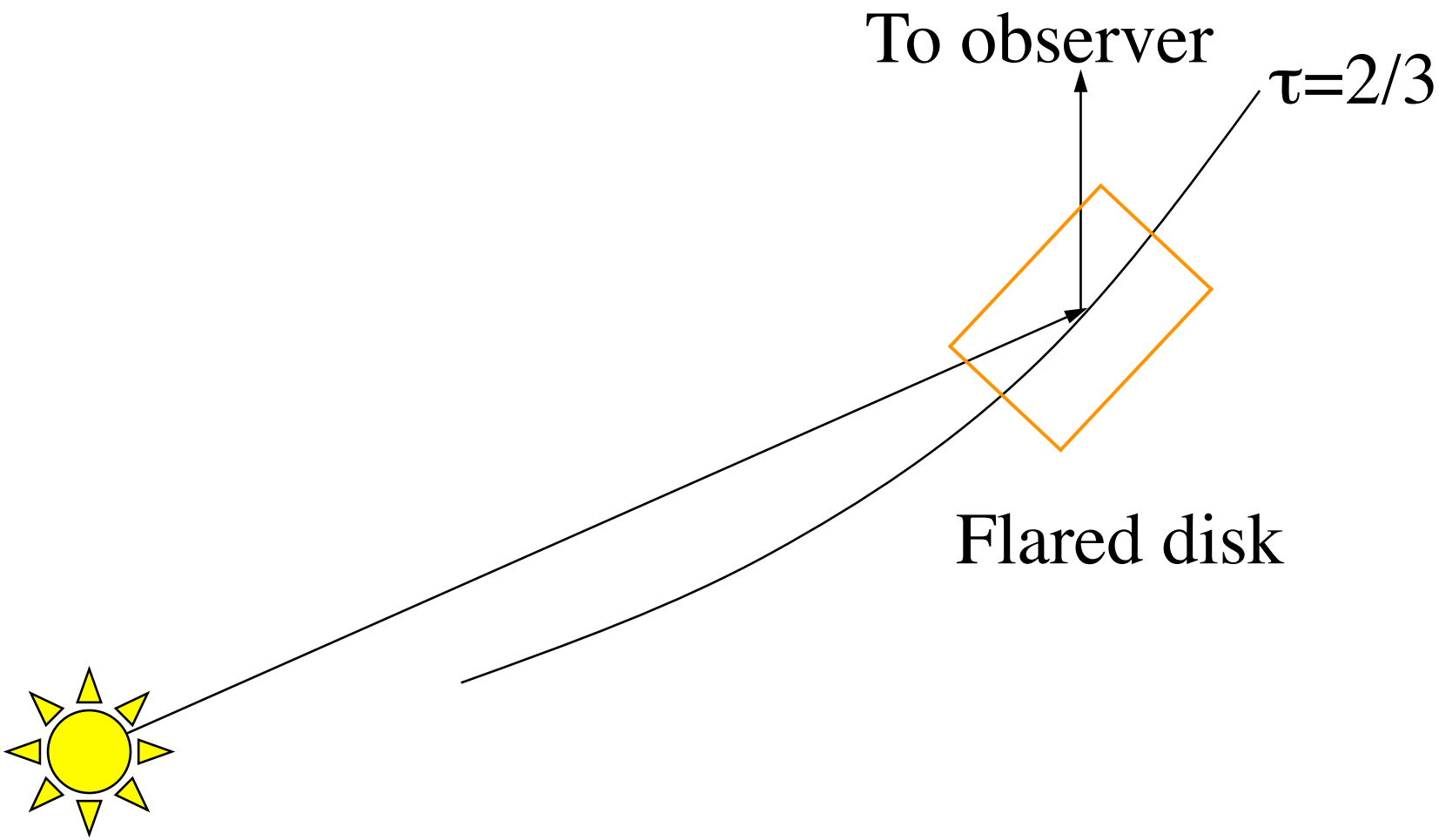
- Protoplanets create shadows in disks much larger than themselves (dimples, gaps)
- Observing planets in disks will constrain timescales and locations of formation
- Best shadow contrast in optical and IR, but star is bright
- Low shadow contrast in radio, but ALMA might still be sensitive enough

Collaborators

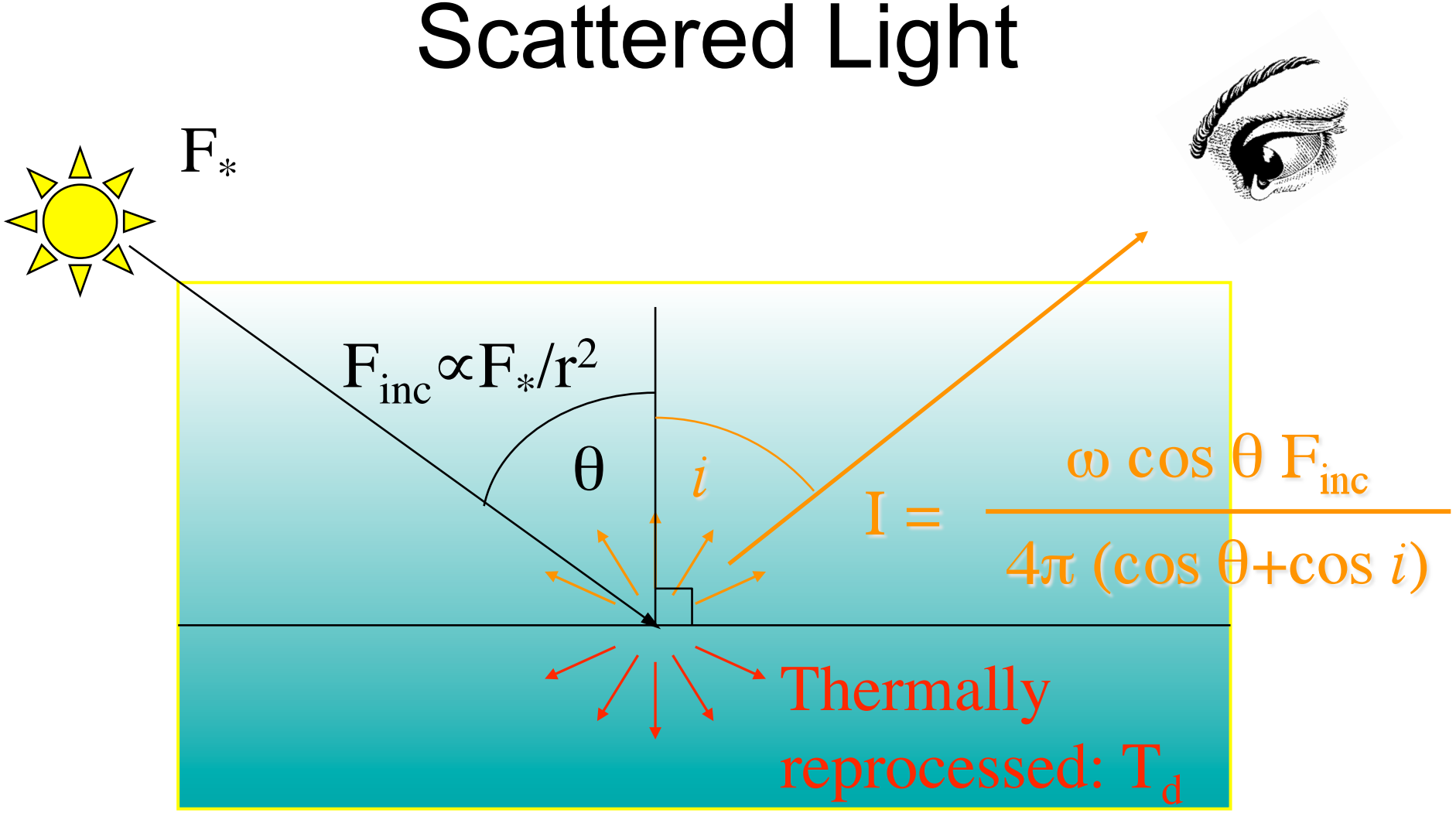
- Marc Kuchner (GSFC)
- Lee Mundy (UMd-CARMA)
- John Debes (GSFC)
- Dimitar Sasselov (Harvard)

Extra Slides

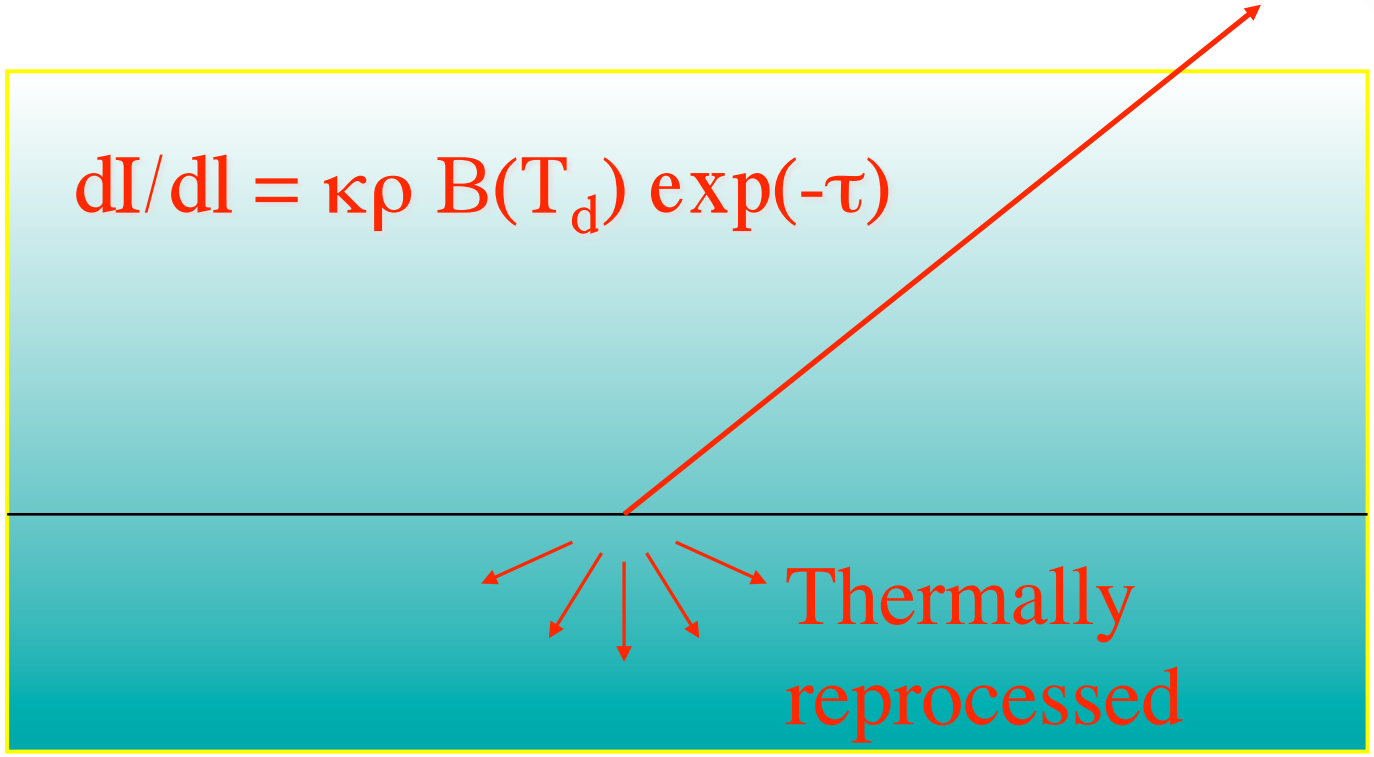
Calculating Observables



Scattered Light



Thermal Emission



Simulated Images

Shorter wavelengths,
higher opacities,
probe surface layers

Longer wavelengths,
lower opacities,
probe deeper