Planet Gaps in the Dust Layer of 3D Protoplanetary Disks: Observability with ALMA

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Motivation

- Protoplanetary disks : science driver for ALMA

- First investigations *Wolf et al. (2002), Wolf & D'Angelo (2005)*
  - Hydrodynamical simulations of 2D gas-only disks
  - Synthetic images: 3D structure (gaussian in z), uniform dust
  - ALMA at its limits (shortest λ, longest baselines)
  - Constant 30° phase noise

- Subsequent improvements
  - Simulations of 3D gas+dust disks, self-consistant dynamics
    Barrière-Fouchet et al. (2005), Fouchet et al. (2007)
  - Synthetic images based on resulting 3D dust distribution
    Pinte et al. (2007)
  - More realistic phase noise (GILDAS, CASA)

Hydrodynamical Simulations

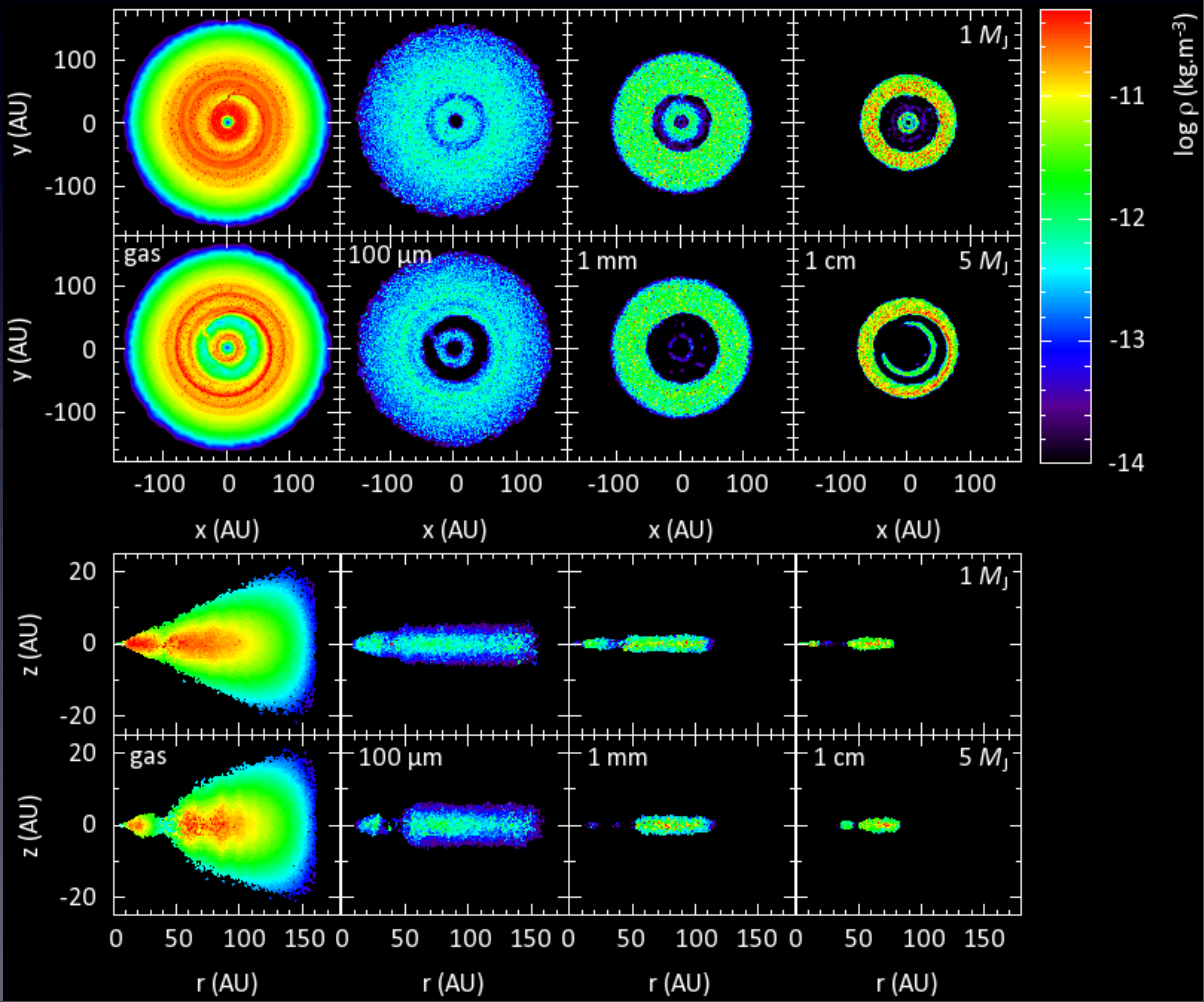
- SPH 3D two-phase (gas+dust) code

- CTTS disk
  - $M_\star = 1\ M_\odot$
  - $M_{disk} = 0.02\ M_\odot$

- Initial dust/gas ratio
  - 10^{-2}

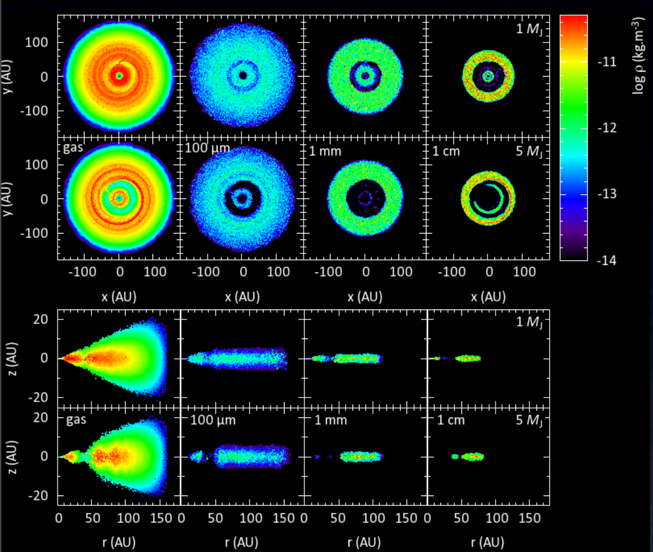
- Grain sizes
  - 100 μm, 1 mm, 1 cm

- Planet
  - $M_P = 1$ and $5\ M_J$
  - $a = 40$ UA

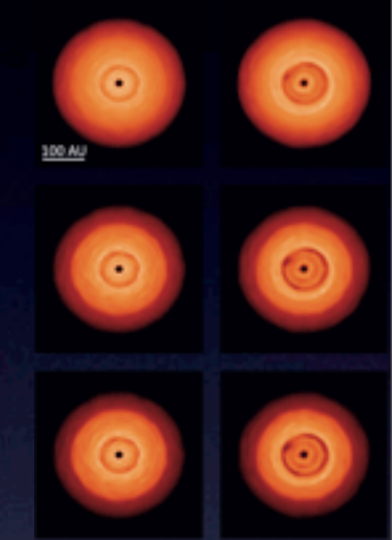


Fouchet et al. (2010)

Raw synthetic images



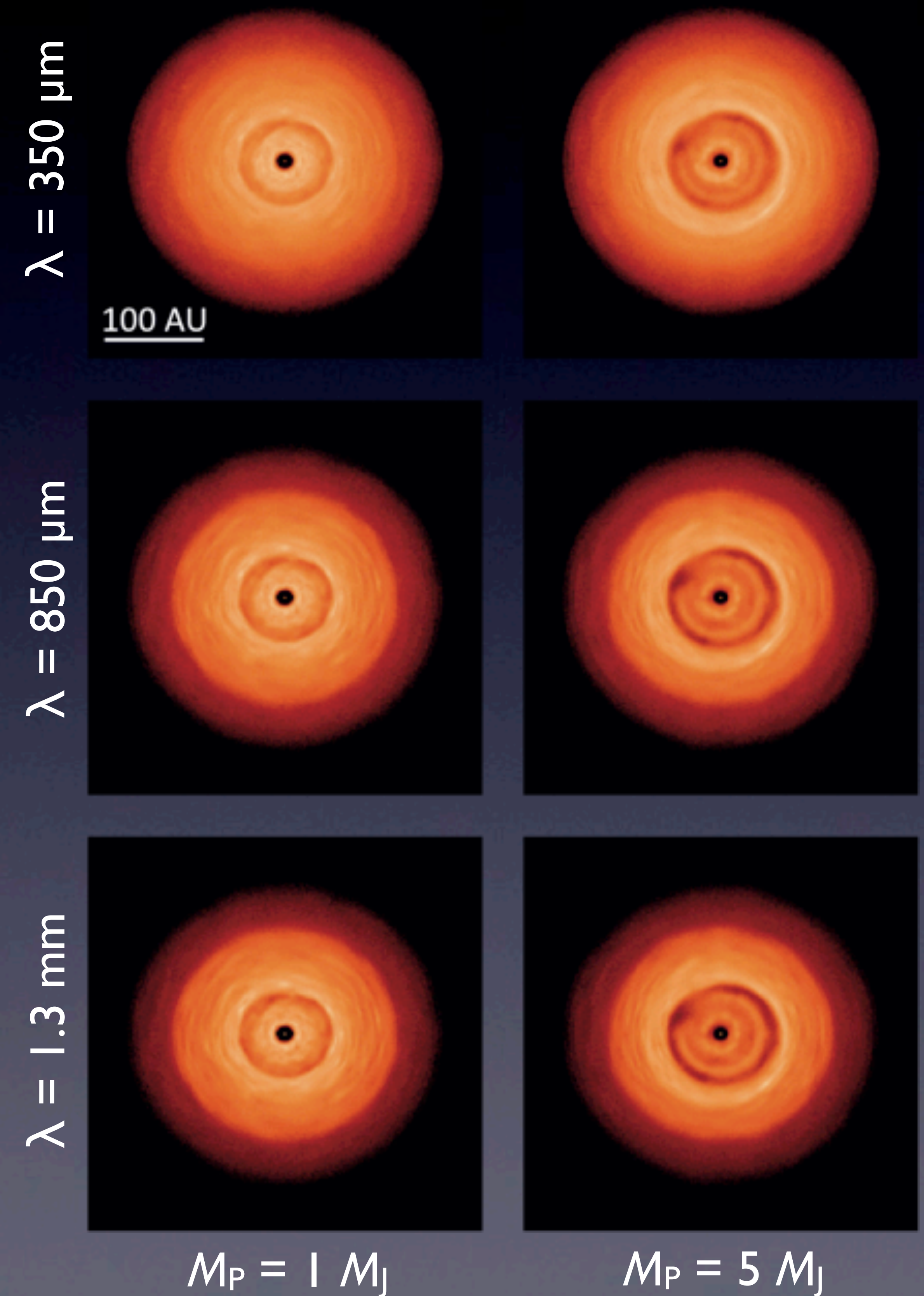
MCFOST
Pinte et al. (2006)



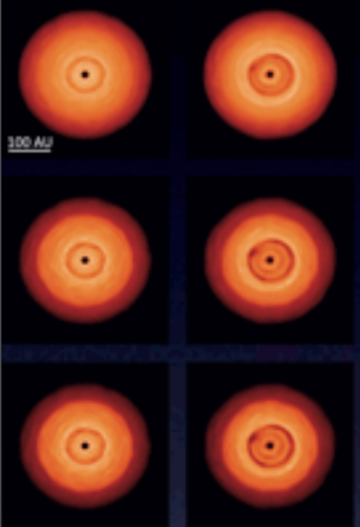
- 3D SPH particle distribution ⇒ 3D density structure on MCFOST grid
- Interpolation as a function of grain size: $dn(a) \propto a^{-3.5}\, da$
- 3D radiative transfer: Monte Carlo + ray tracing

➡ Thermal emission maps

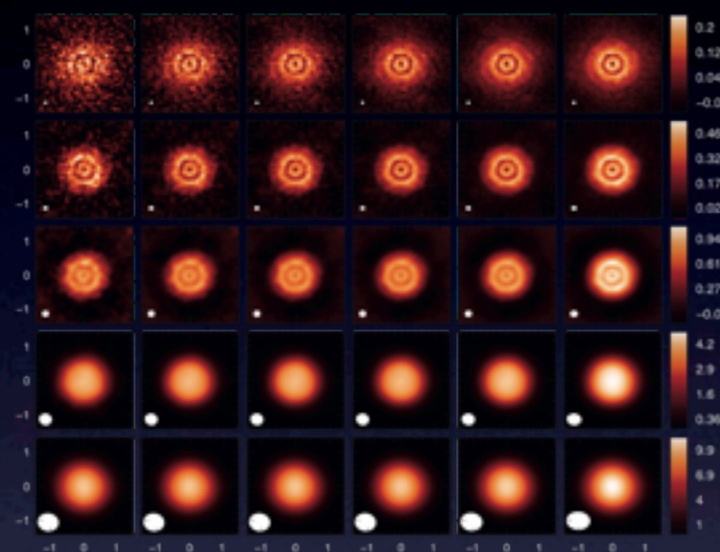
Raw synthetic images



ALMA simulated images



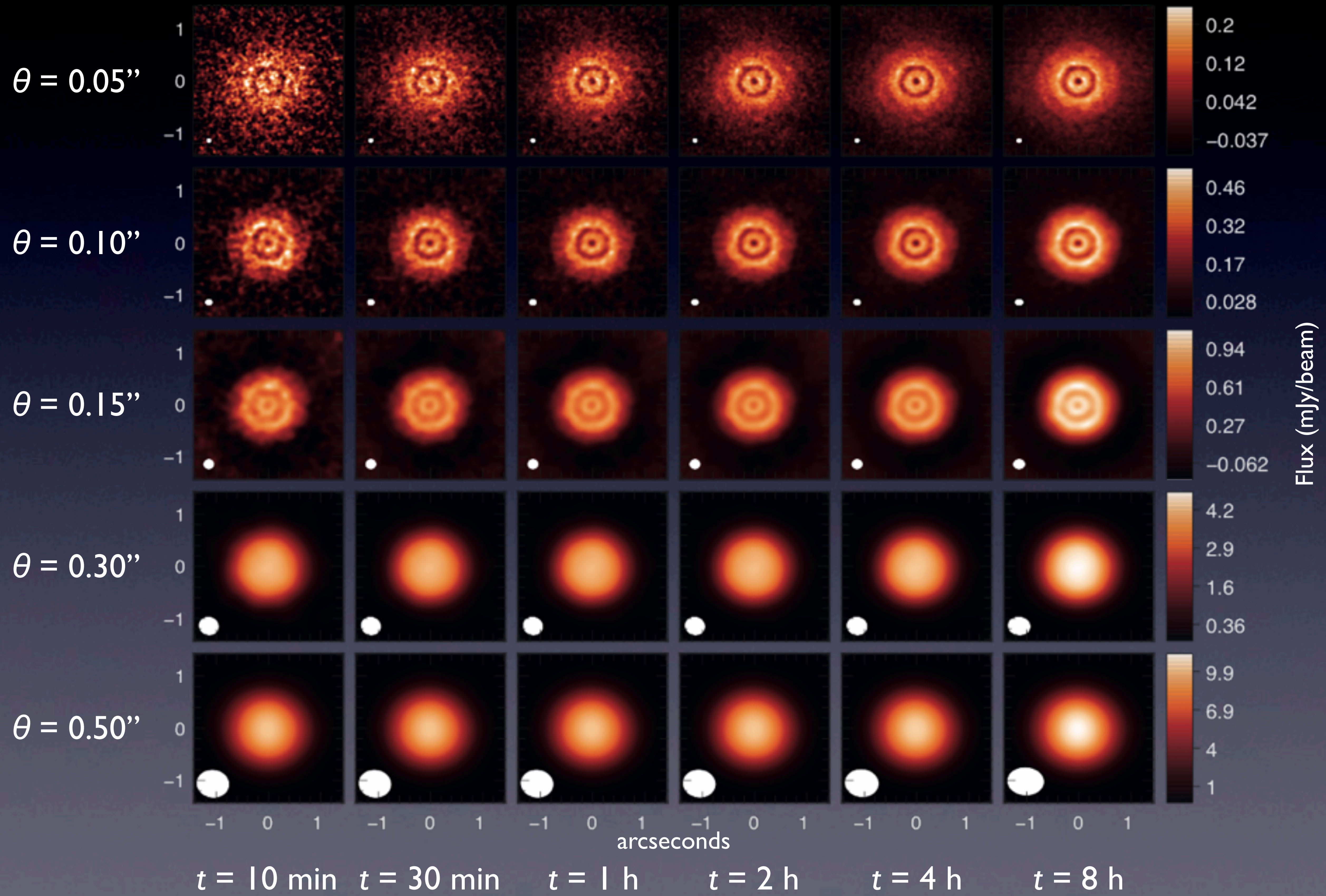
CASA
Common Astronomy Software Applications



- Instrument simulator for ALMA: synthetic visibilities + thermal noise + phase noise
- Various integration times, λ, angular resolutions, distances...
- Reference disk
    - i = 18.2°, d = 140 pc, δ = -23°
    - median sky quality (pwv = 1.08 mm), no phase noise

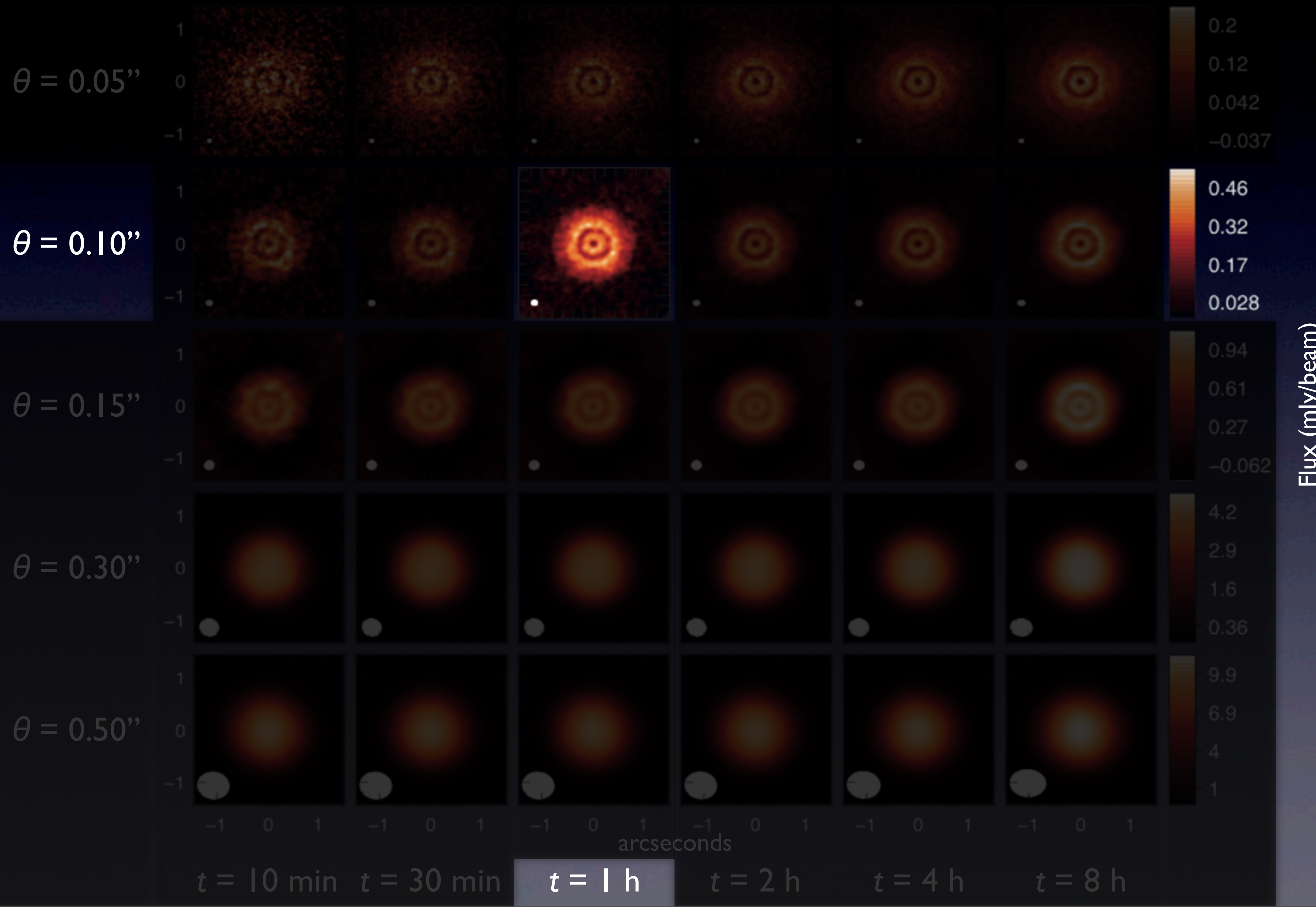
ALMA simulated images

M_P = 1 M_J λ = 850 μm



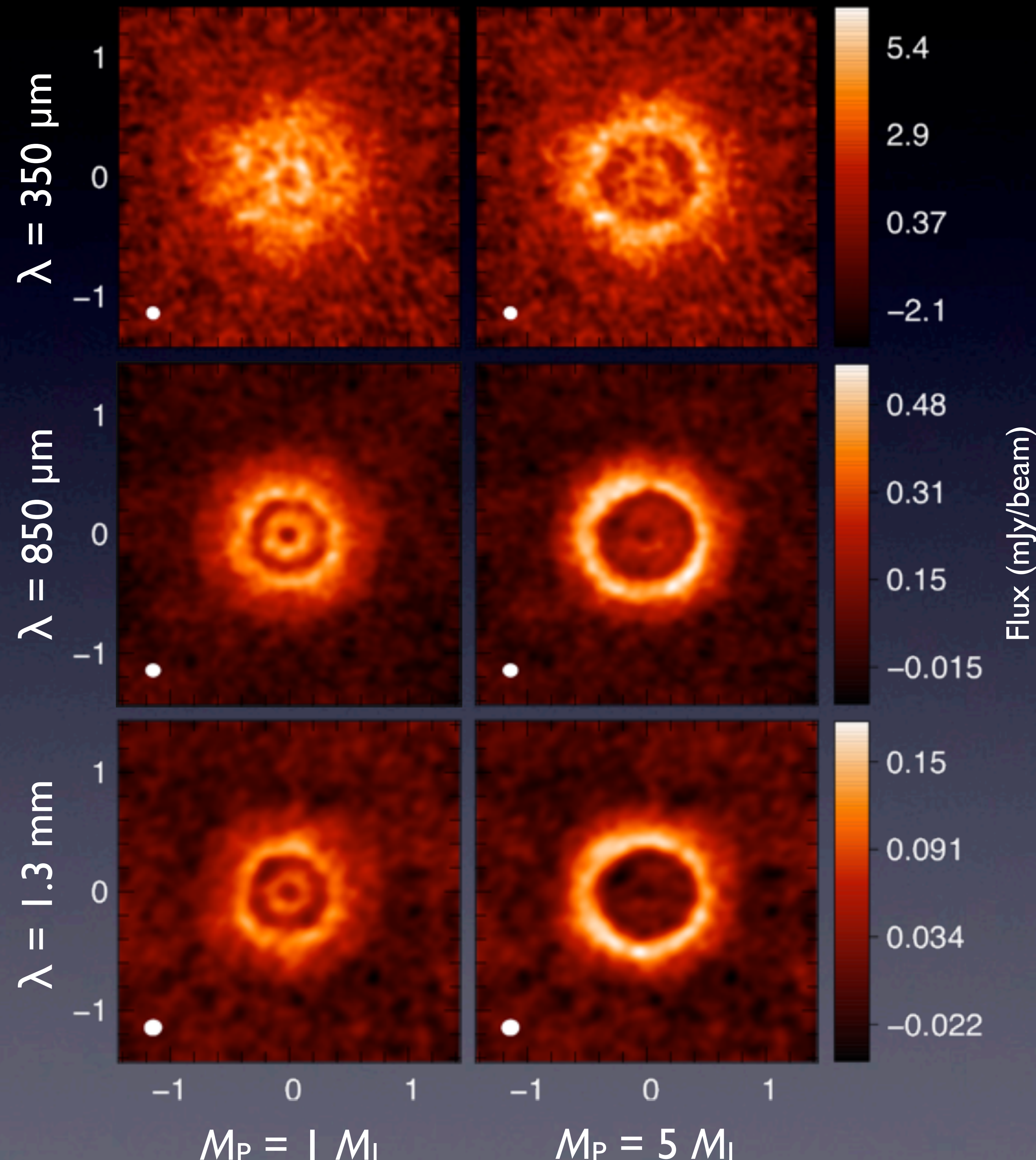
ALMA simulated images

$M_P = 1\ M_J \quad \lambda = 850\ \mu m$



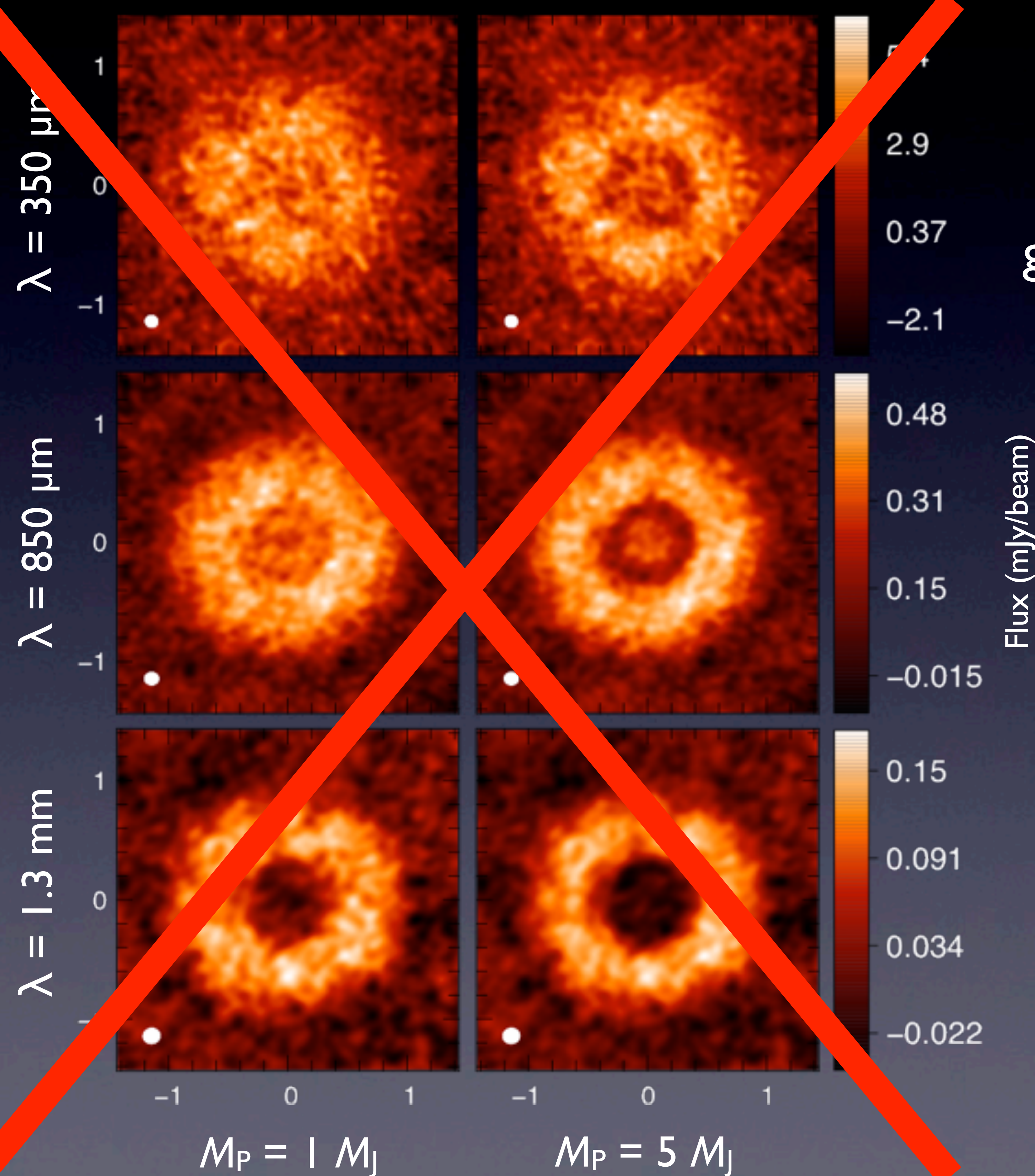
Optimal parameters

t = 1 h θ = 0.10"



Well-mixed approximation

t = 1 h θ = 0.10"

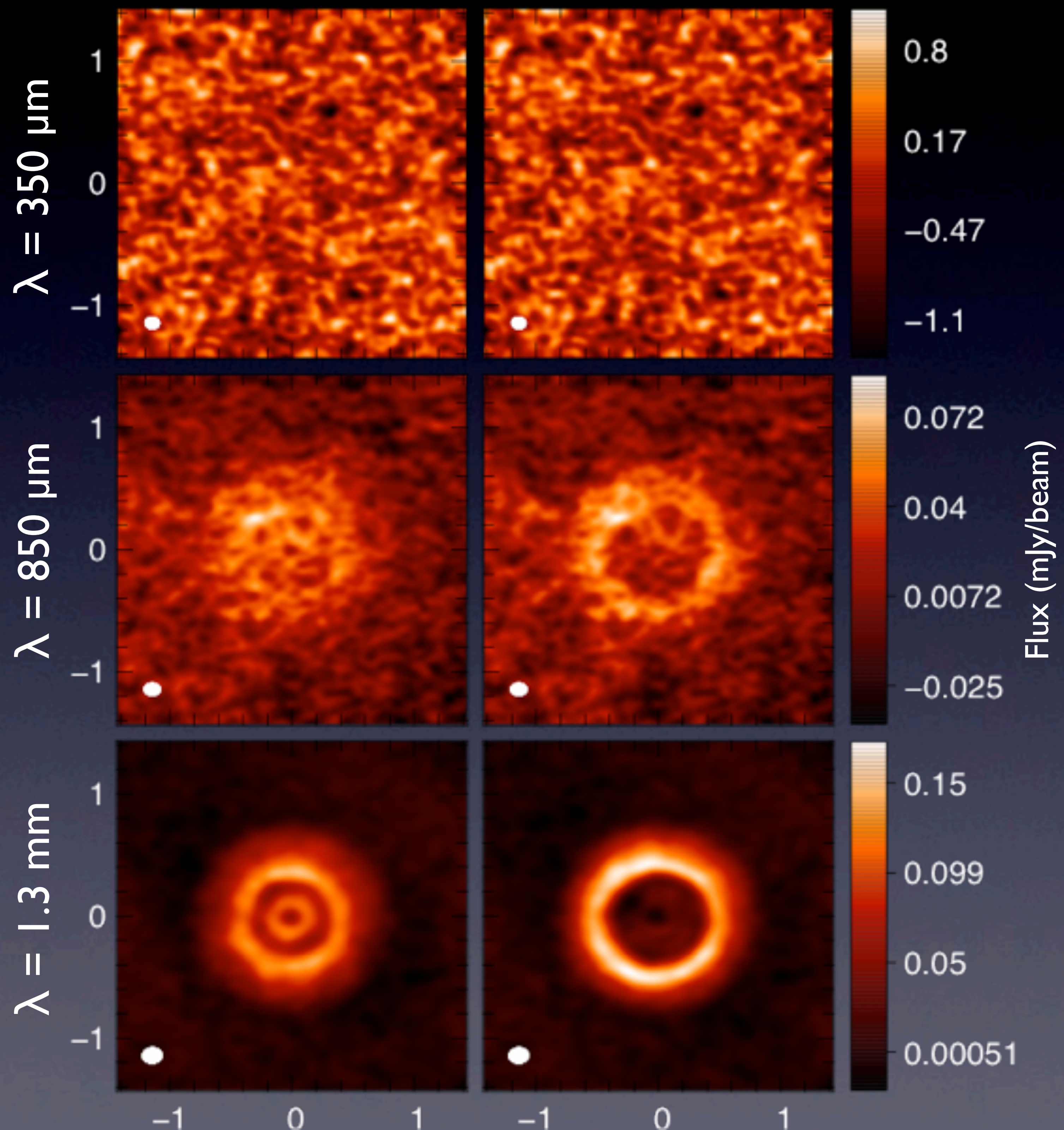


Dust assumed to follow the gas distribution

Effect of phase noise

t = 1 h θ = 0.10"

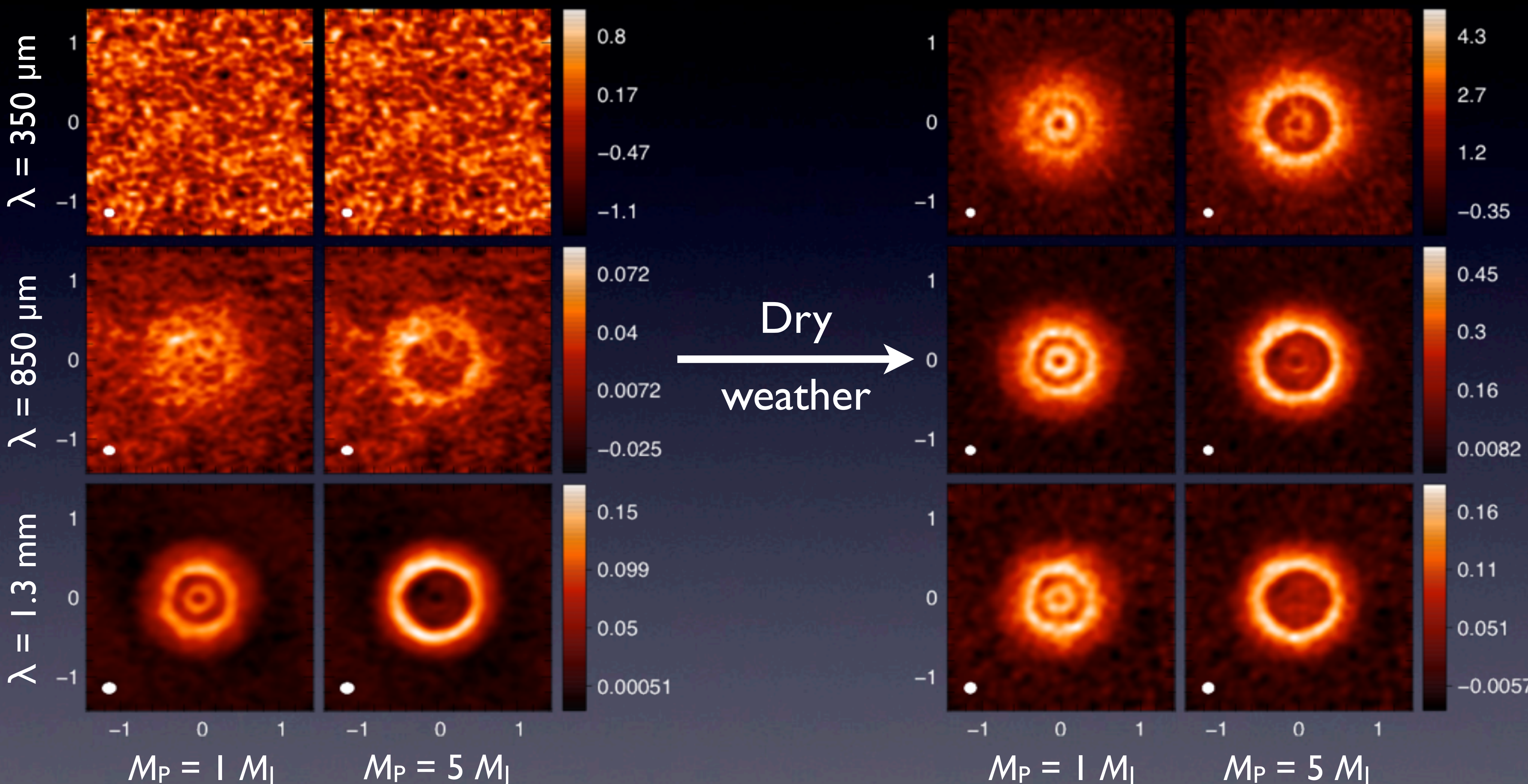
Median sky quality
pwv = 1.08 mm



M_P = 1 M_J M_P = 5 M_J

Effect of phase noise

t = 1 h θ = 0.10"

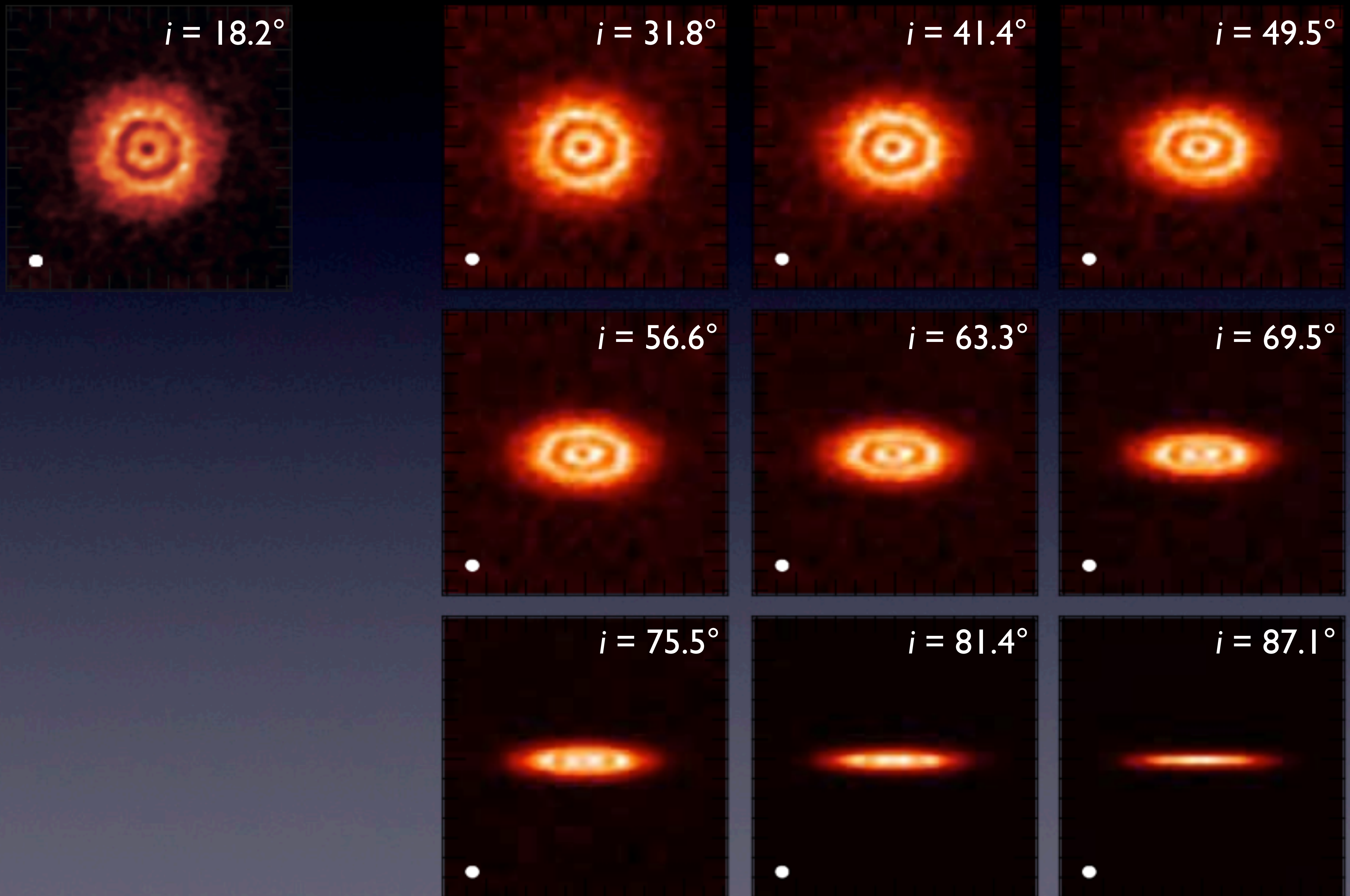


Median sky quality
pwv = 1.08 mm

Best 10% of sky quality
pwv = 0.3 mm

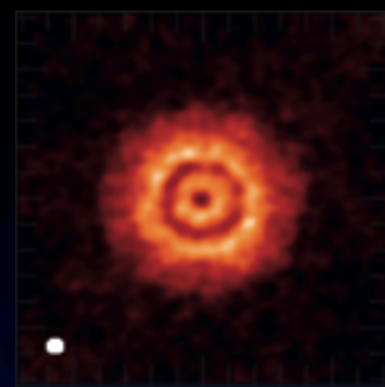
Varying disk inclination

$M_P = 1\ M_J$ $\lambda = 850\ \mu m$ $t = 1\ h$ $\theta = 0.10''$



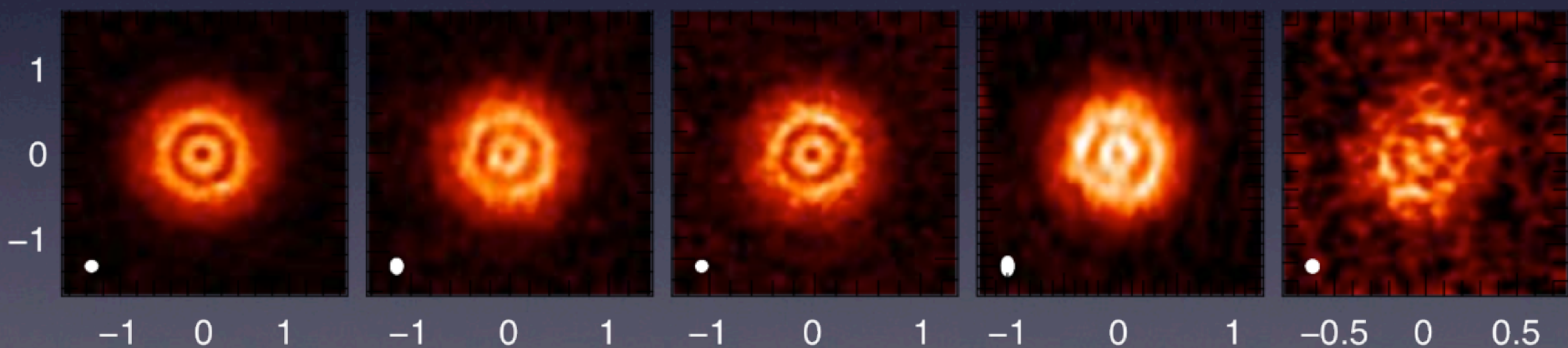
Varying distance and declination

$M_P = 1\ M_J$ $\lambda = 850\ \mu m$ $t = 1\ h$



Reference disk @ 140 pc
$\delta = -23°$
$\theta = 0.10''$

Ophiuchus	Taurus	Lupus (I)	Chamaeleon (I)	Serpens
$\delta = -24°$	$\delta = +25°$	$\delta = -34°$	$\delta = -77°$	$\delta = +01°$
$\theta = 0.12''$	$\theta = 0.10''$	$\theta = 0.09''$	$\theta = 0.09''$	$\theta = 0.05''$



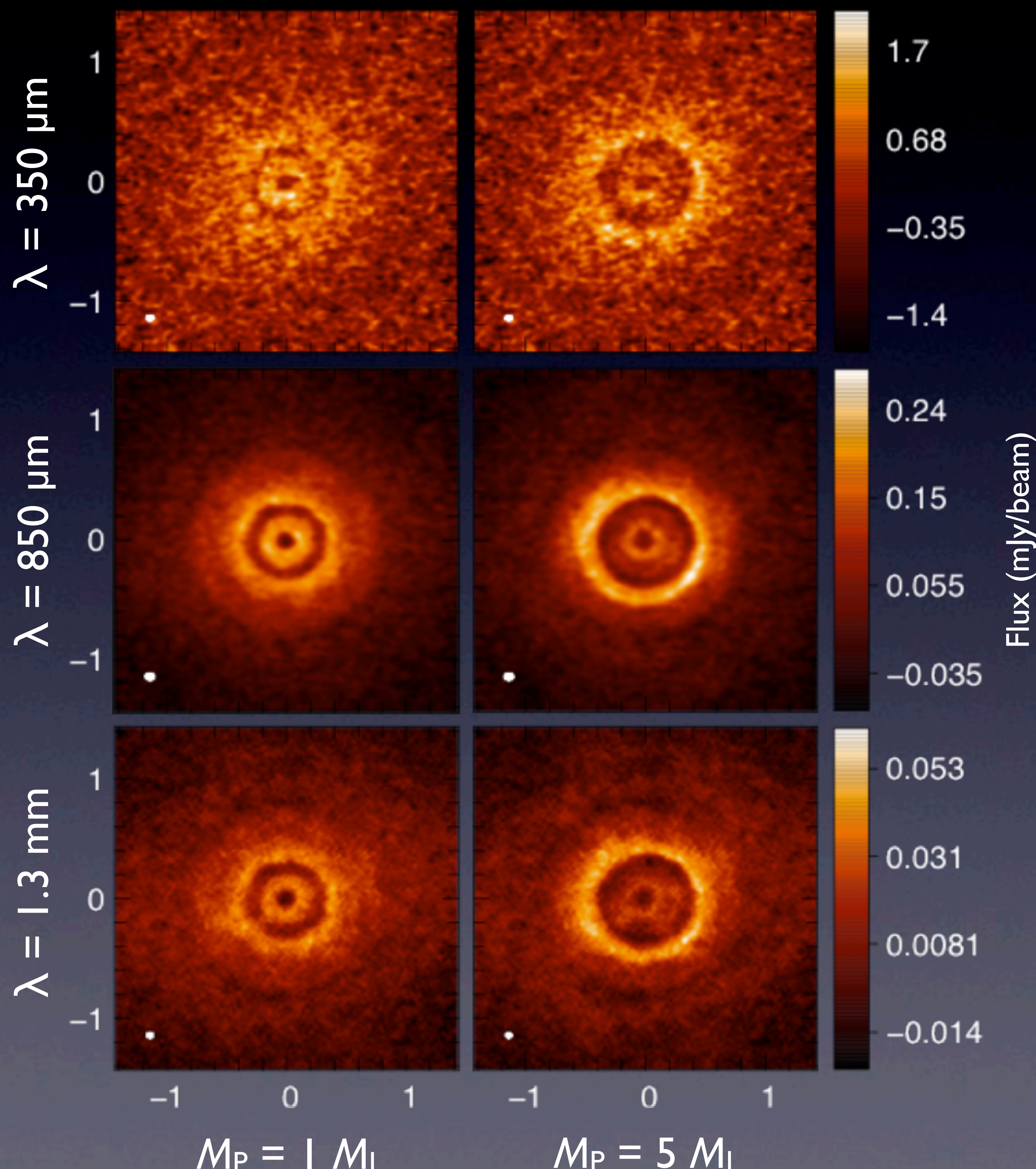
120 pc	140 pc	150 pc	160 pc	260 pc

Distance

Pushing ALMA further

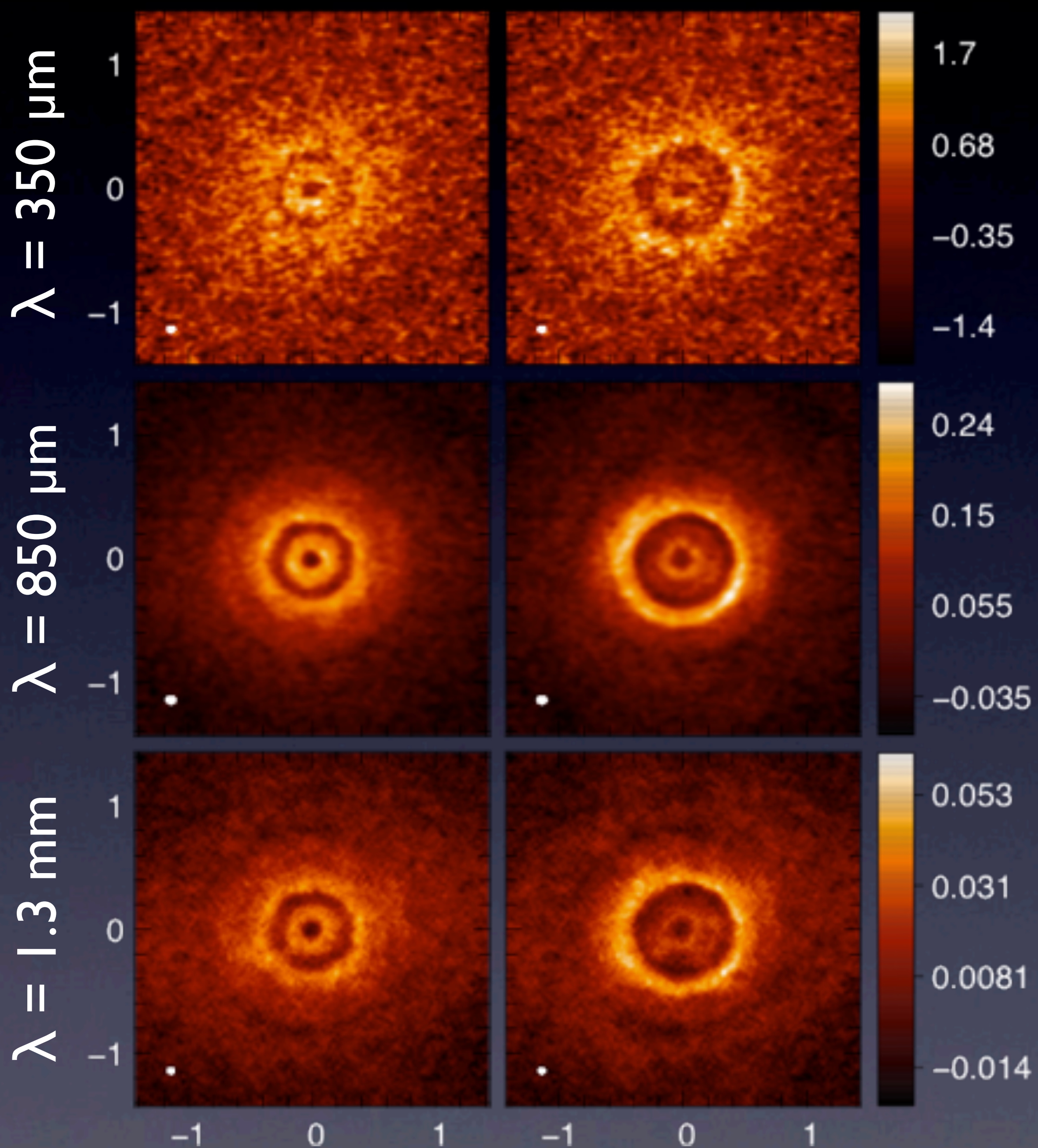
t = 8 h θ = 0.05”

Median sky quality
pwv = 1.08 mm

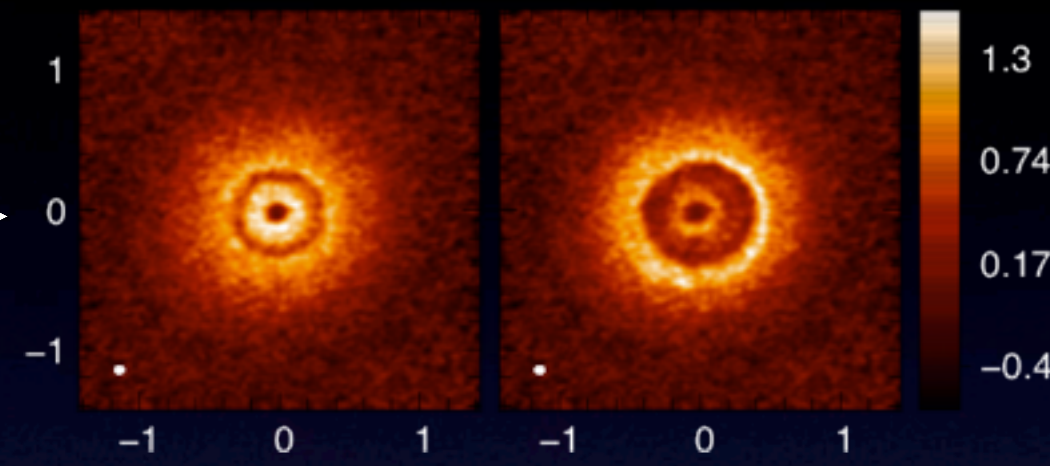


Pushing ALMA further

t = 8 h θ = 0.05"



Dry → weather



M_P = 1 M_J M_P = 5 M_J

M_P = 1 M_J M_P = 5 M_J

Median sky quality
pwv = 1.08 mm

Best 10% of sky quality
pwv = 0.3 mm

Conclusion

- Pipeline for a systematic study of disks as observed by ALMA
  - 2-phase 3D SPH → radiative transfer → ALMA simulator
- Self-consistent dust dynamics essential for realistic maps
- Gap detection
  - single 1-hour exposure at well chosen λ sufficient
- Characterization
  - multi-λ, longer t, smaller θ...
  - distinction from transition disk requires short λ
- Detectability is robust wrt disk inclination or declination

➡ ALMA should routinely observe planet signatures in nearby star-forming regions

More information:

Gonzalez et al. 2012, A&A, in press (arXiv:1208.5436)