Detecting the signposts of planet formation with the ngVLA

Credit:NAOJ

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NRAO

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RICE

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- ngVLA to detect disks *substructures* (rings/gaps, asymmetries) due to planets in terrestrial planet forming region
- Complementarity with ALMA

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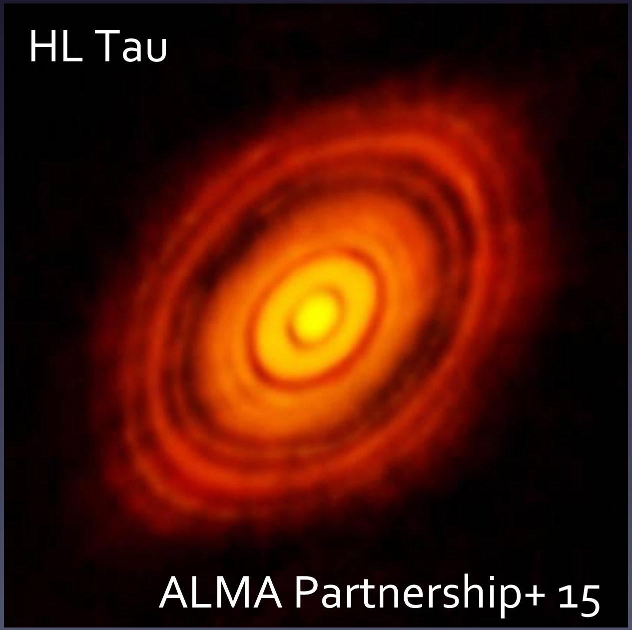

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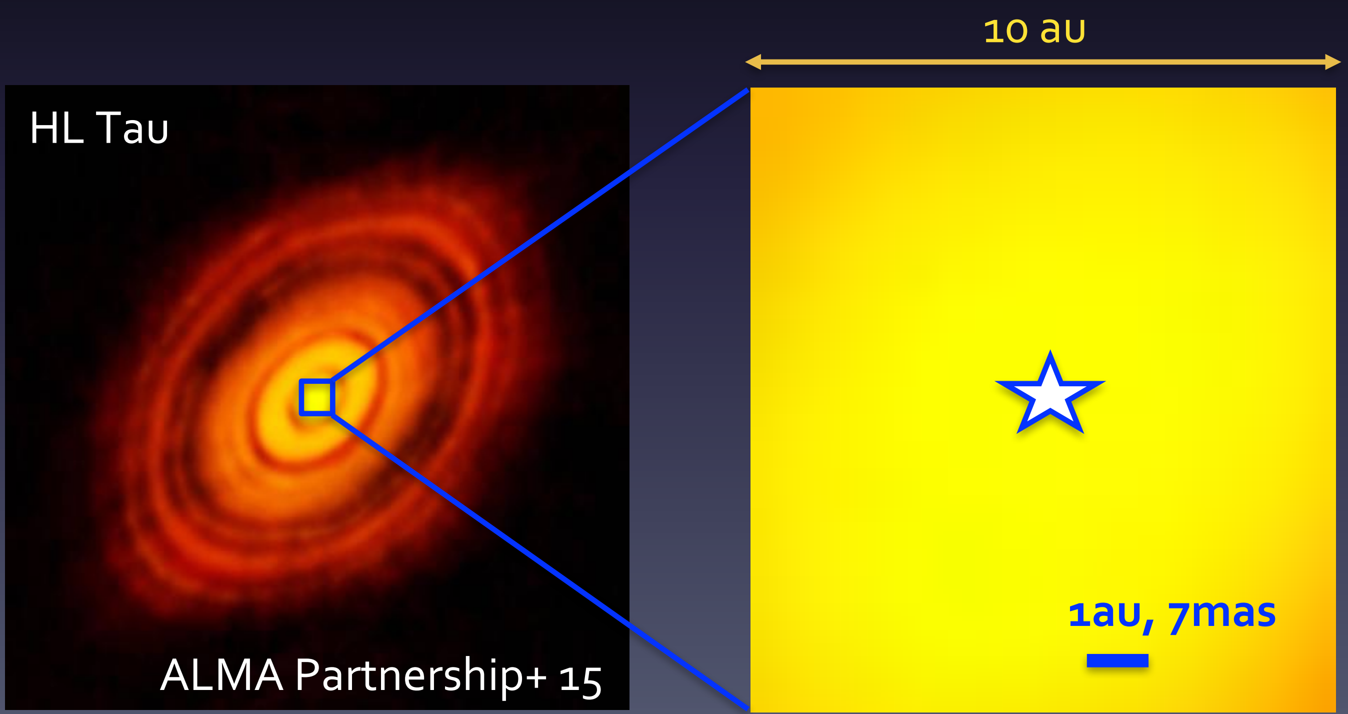
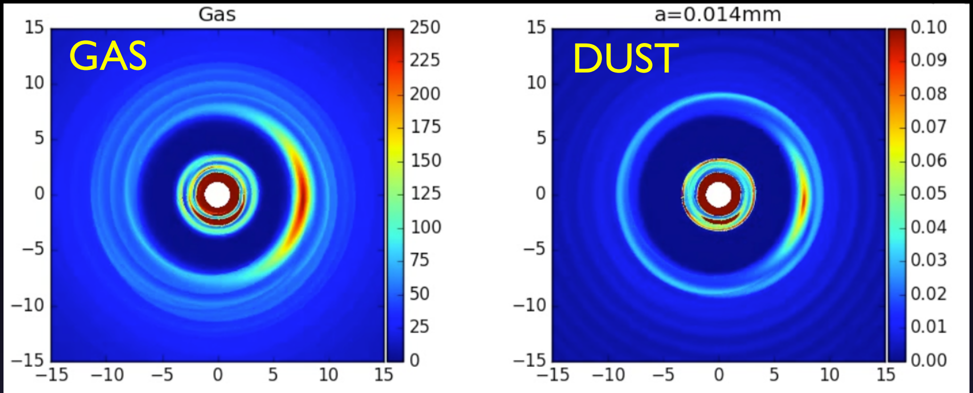


What planet-driven substructures can we see?

1) Assumptions on initial disk structure, star and planet properties

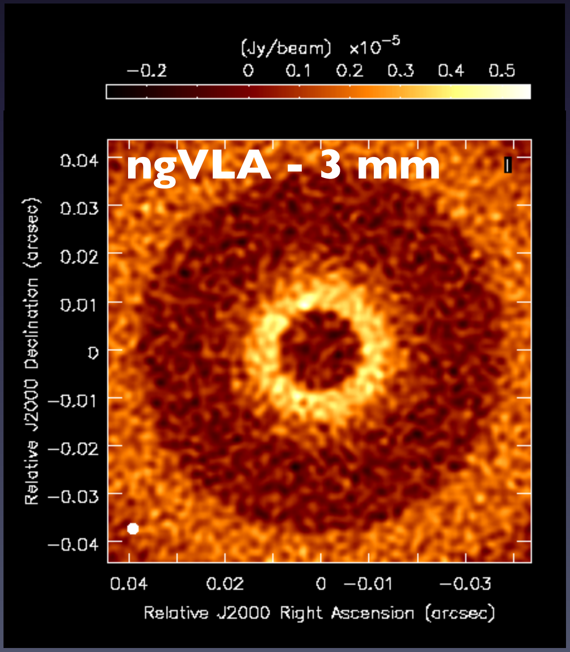
2) Hydrodynamical simulations, Ray tracing

➡ $I^{model}(x,y)$



3) ngVLA & ALMA simulations

➡ $I^{obs}(x,y)$



1) Assumptions on disk, star, planet

Star) $M_\star = 1\ M_{Sun}$, age ~ 1 Myr

Initial disk structure) Gas: "self-similar" surface density

0.8

$$\Sigma_{gas}(r, t=0) = \Sigma_c \left(\frac{r}{r_c}\right)^{-\gamma} \exp\left[-\left(\frac{r}{r_c}\right)^{2-\gamma}\right]$$

20 au

M_{disk} = 0.006, 0.06 M_{Sun}

Dust: initial dust-to-gas mass ratio = 0.01, $n(a) \sim a^{-3.5}$

$$T(r) = 37\ \mathrm{K} \times \left(\frac{\mathrm{r}}{10\ \mathrm{au}}\right)^{-1/2}$$

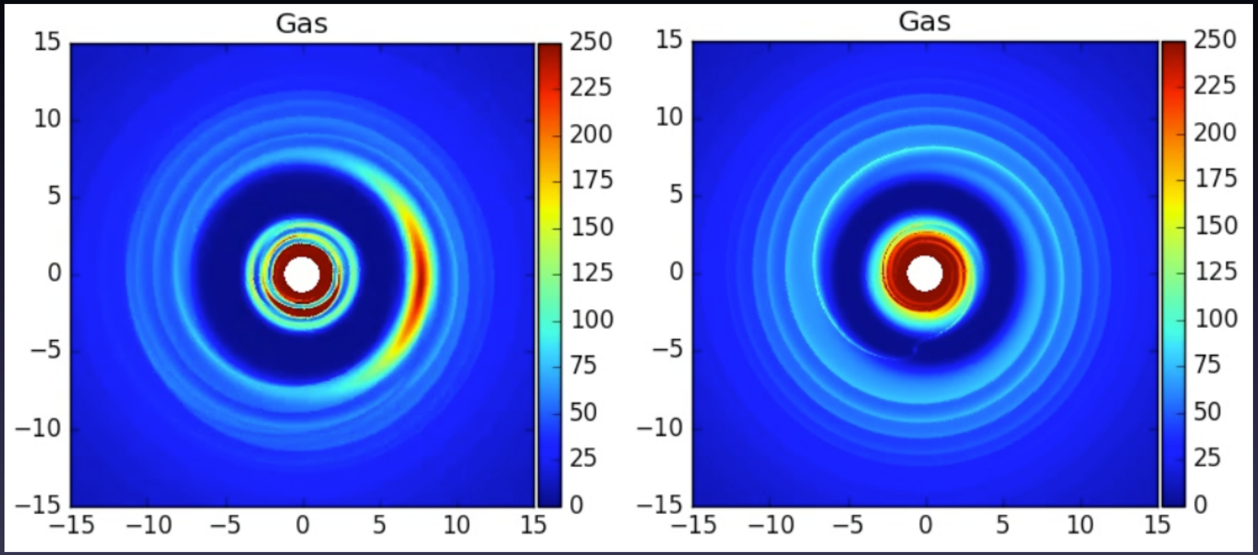
Planet) M_{pl} = 5, 10, 17, 30, 50, 100, 300 M_{Earth} @ r_{pl} = 1, 2.5, 5 au

2) Hydrodynamical sims and Ray tracing

LA-COMPASS bi-fluid (gas+dust) hydro code (Li+05, 09):

- Gas evolves viscously, gravitational interaction with planet

Jupiter @ 5 au



$\alpha_{visc} = 10^{-5}$ $\alpha_{visc} = 10^{-3}$

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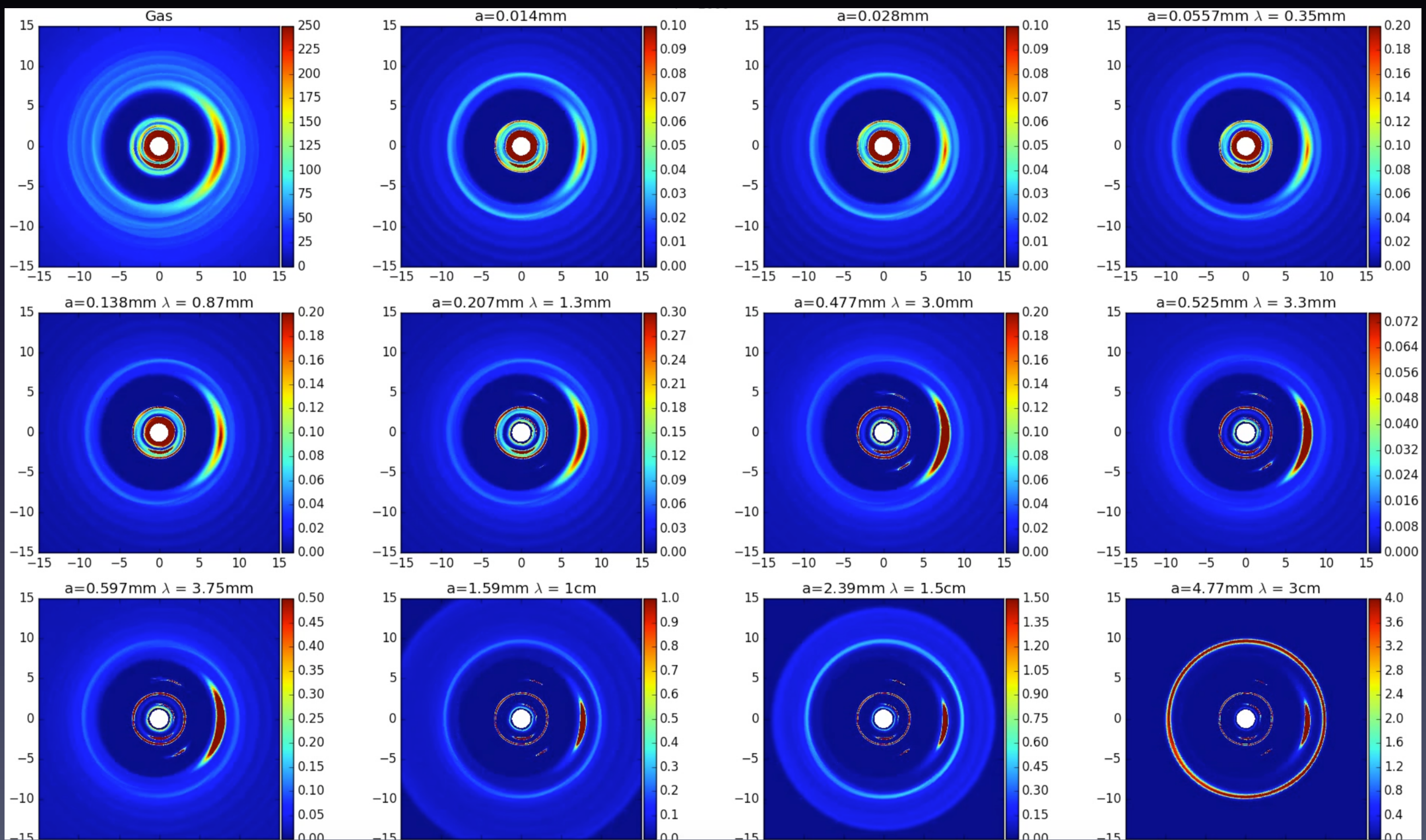

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- Gas evolves viscously, gravitational interaction with planet
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RADMC ray tracing for dust continuum at t =1500 orbits

➡ $I^{model}(x,y)$ @ 0.35, 0.87, 1.3mm (ALMA), 3mm, 1cm (ngVLA)

3) ngVLA & ALMA simulations

$I^{model}(x,y)$ skymodel for CASA *simobserve* & *clean*

Simobserve) 8-hour synthesis centered at transit

For ngVLA, *setnoise* to set thermal noise per visibility

Clean) Multiscale, r = -1 (ngVLA), -2 (ALMA), inner/outer uv-taper

300 antennas, 3 array configurations

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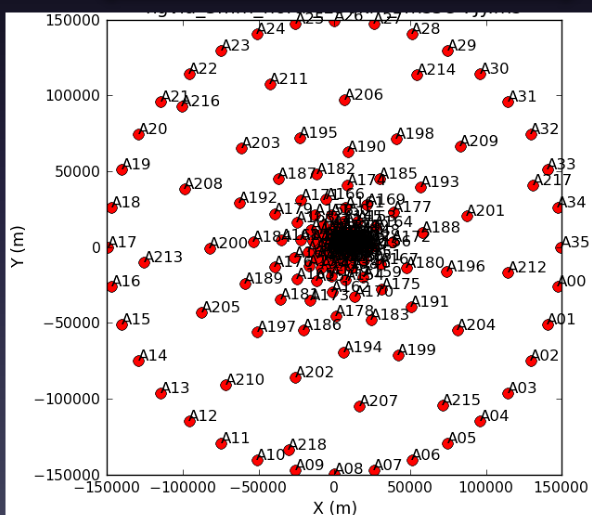
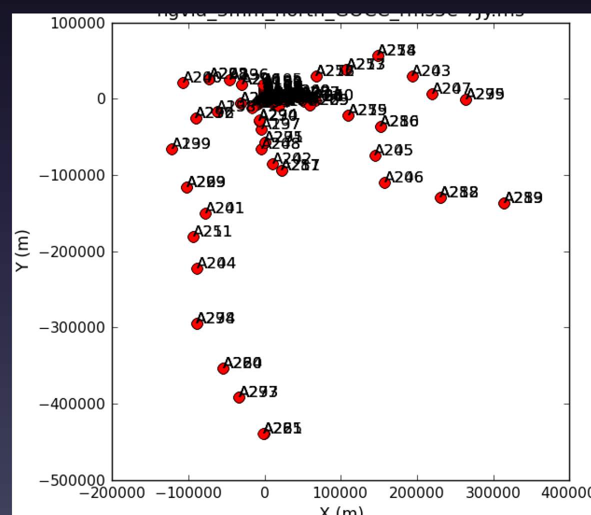
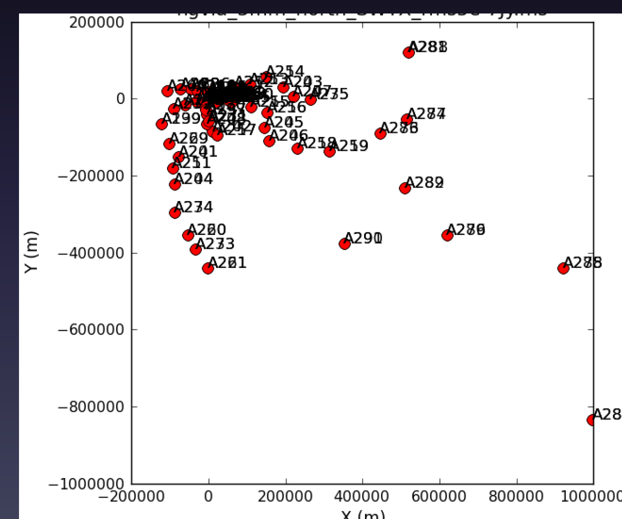
300 km







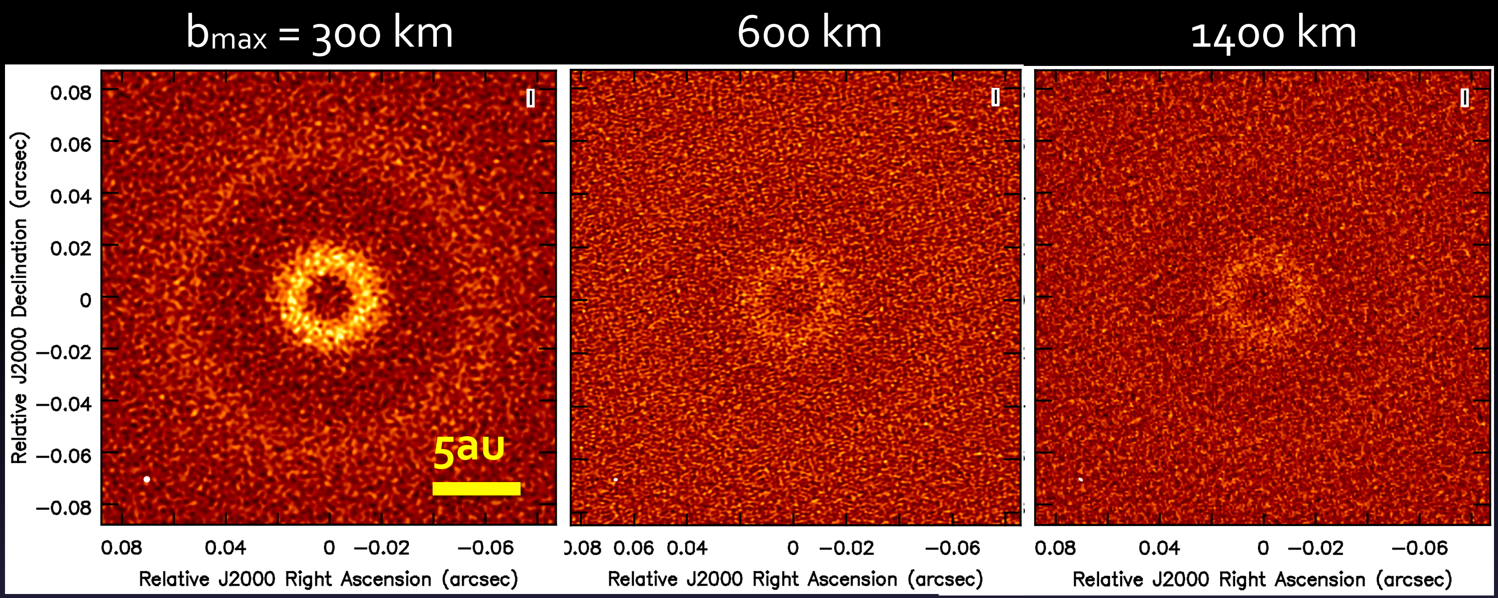
b_{max} = 300 km	600 km	1400 km
ang res: 2.5mas@3mm, 8mas@1cm	1.2mas@3mm, 4mas@1cm	0.5mas@3mm, 1.7mas@1cm

Results: ngVLA angular resolution

Jupiter @ 5au, $M_{\rm disk}$ = 0.006 $M_{\rm Sun}$, d= 140 pc

ngVLA @ 3mm

rms = 5e-7 Jy/b



Disk surface brightness is too low for these $b_{\rm max}$

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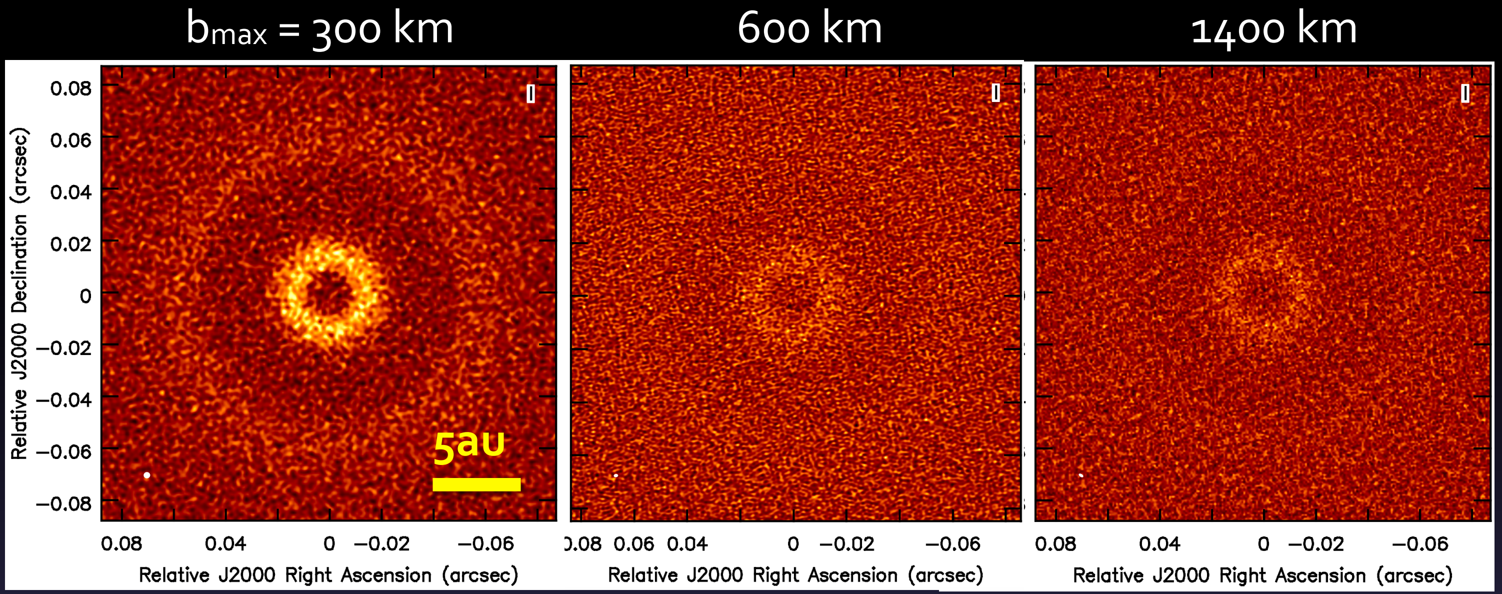
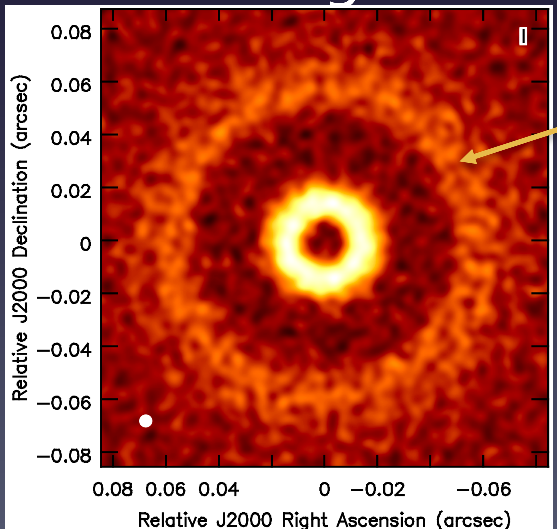


Disk surface brightness is too low for these b_{max}

Outer-taper = 5mas



SNR ~ 7

b_{max} ~ 150 - 200 km

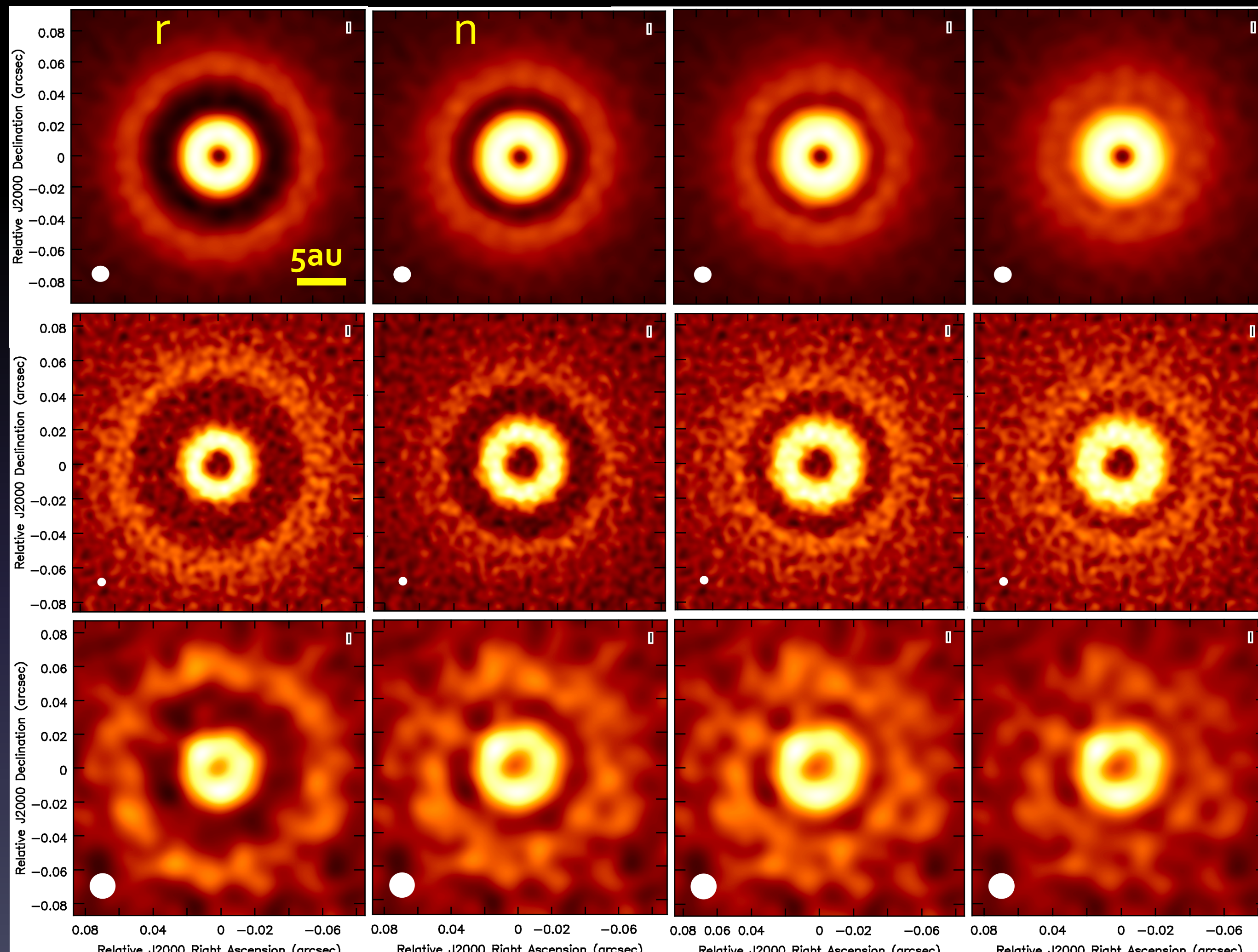
Results: planets @ 5 au - $\alpha_{visc} = 10^{-3}$

Jupiter | Saturn | 50 M_{Earth} | 30 M_{Earth}

ALMA @ 0.87mm

ngVLA @ 3mm
(beam = 5mas
rms = 5e-7 Jy/b)

ngVLA @ 1cm
(beam = 16mas
rms = 15e-8 Jy/b)



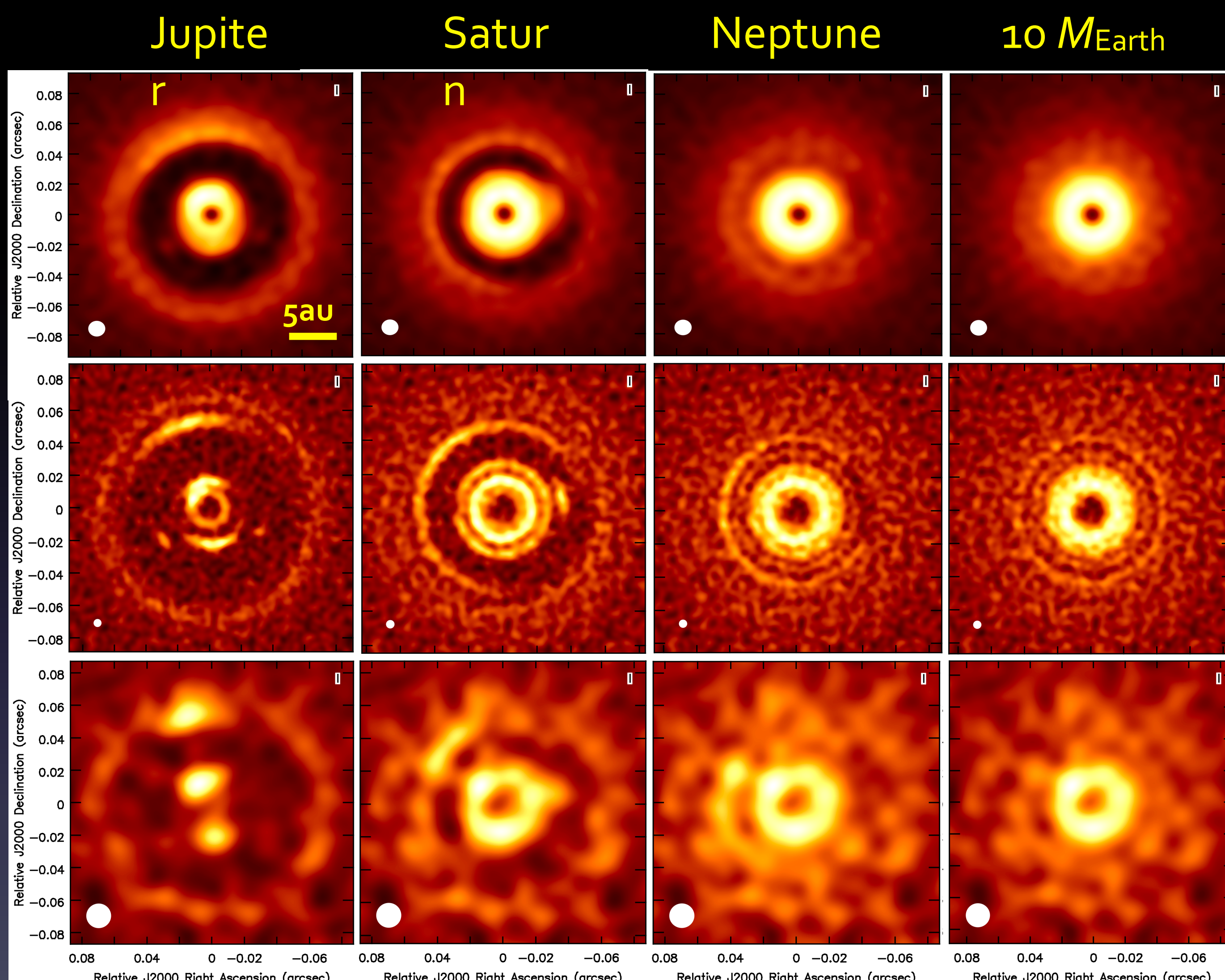
ngVLA @ 3mm resolves radially gaps down to ~ 30 M_{Earth}

Results: planets @ 5 au - $\alpha_{visc} = 10^{-5}$

ALMA @ 0.87mm

ngVLA @ 3mm
(beam = 5mas
rms = 5e-7 Jy/b)

ngVLA @ 1cm
(beam = 16mas
rms = 15e-8 Jy/b)



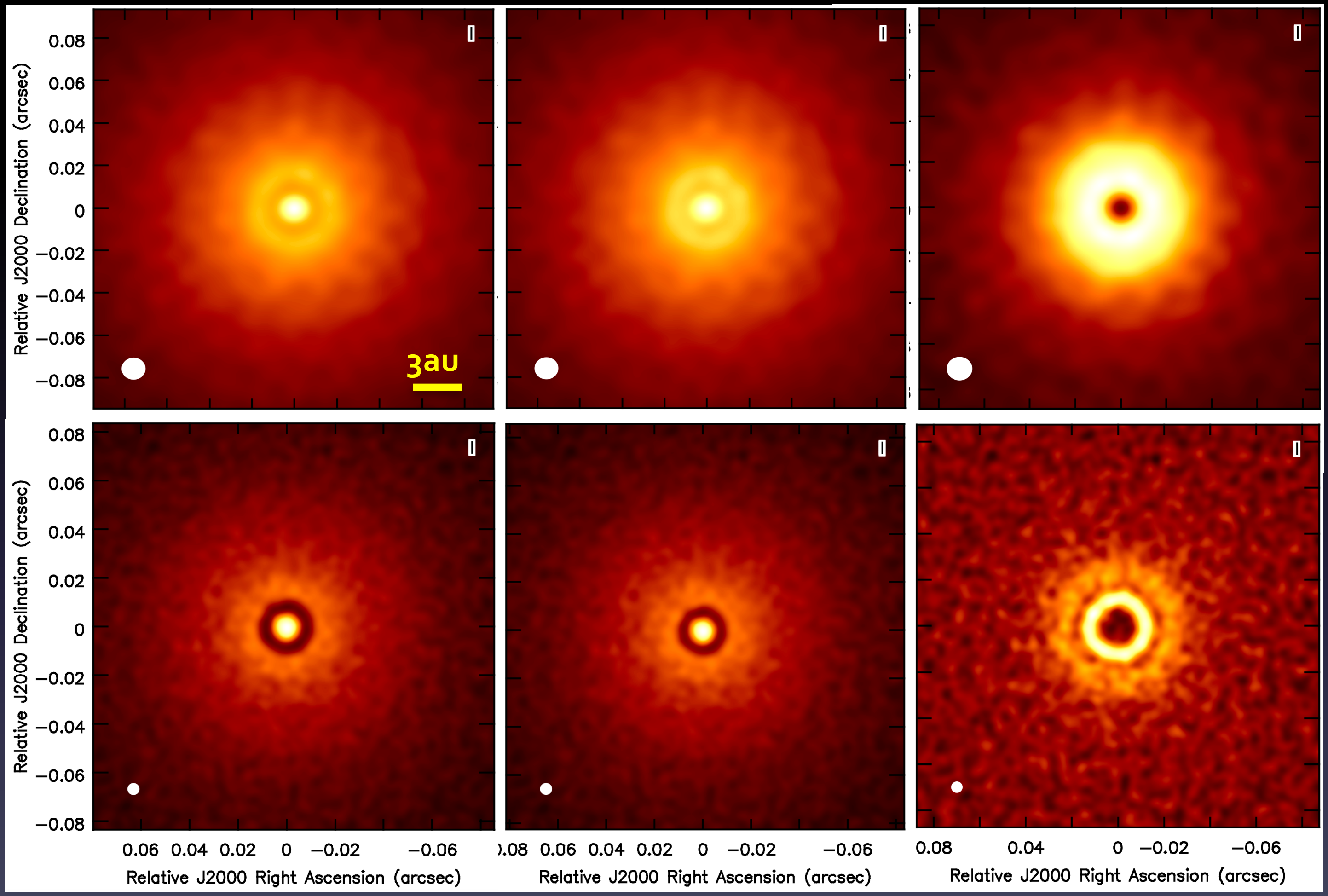
ngVLA @ 3mm identifies gaps/substructures down to ~ 10 M_{Earth}

Results: planets @ < 5 au, α_{visc}=10^{-3}

Jupiter @ 1au | Saturn @ 1au | 30 M_{Earth} @ 2.5au

ALMA @ 0.87mm

ngVLA @ 3mm
(beam = 5mas
rms = 5e-7 Jy/b)



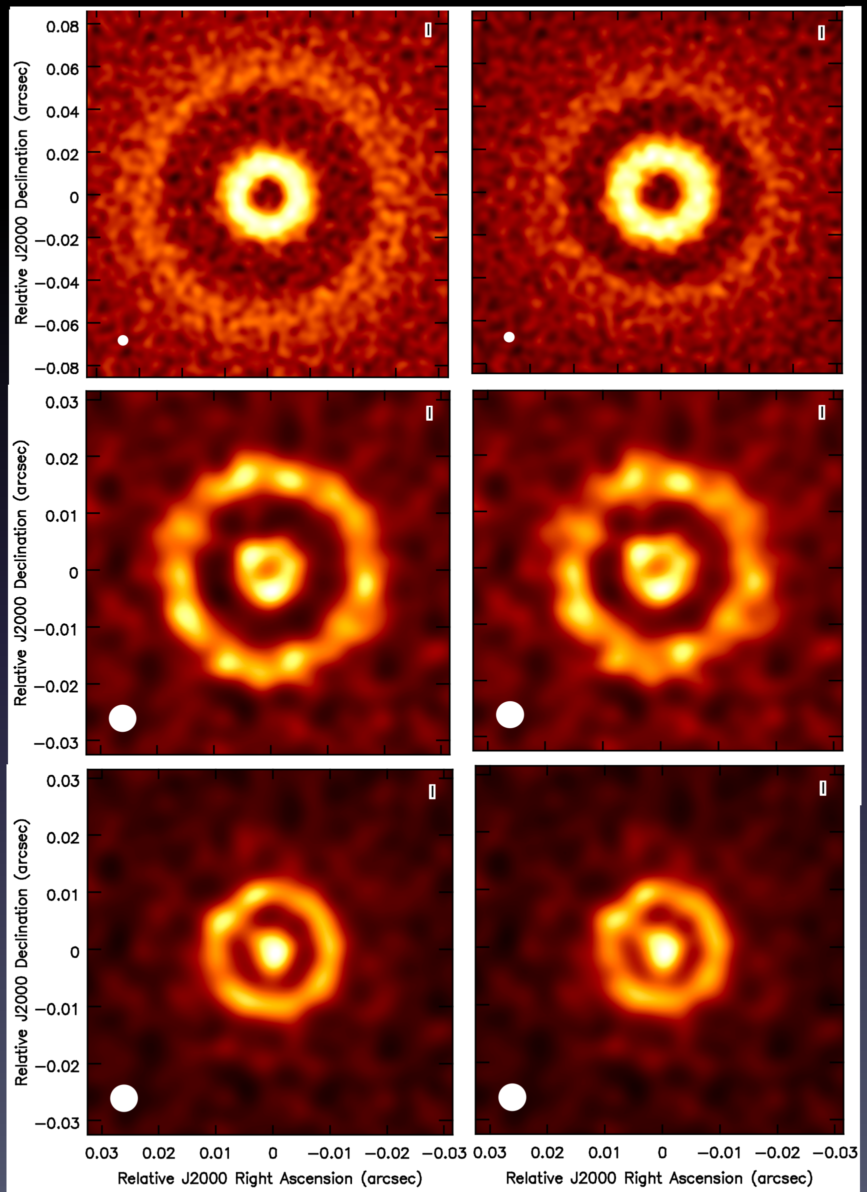
ngVLA @ 3mm radially resolves gaps of giant planets down to ~1a

Results: distance/regions

ngVLA @ 3mm

Jupiter @ 5au   Saturn @ 5au

Regions, #($F > F^{model}$)



140 pc
(beam = 5mas
rms = 5e-7 Jy/b)

Taurus (~ 70)
Ophiuchus (> 70?)

400 pc
(beam = 5mas
rms = 5e-7 Jy/b)

Orion (> 50 in ONC)

700 pc
(beam = 5mas
rms = 3e-7 Jy/b)

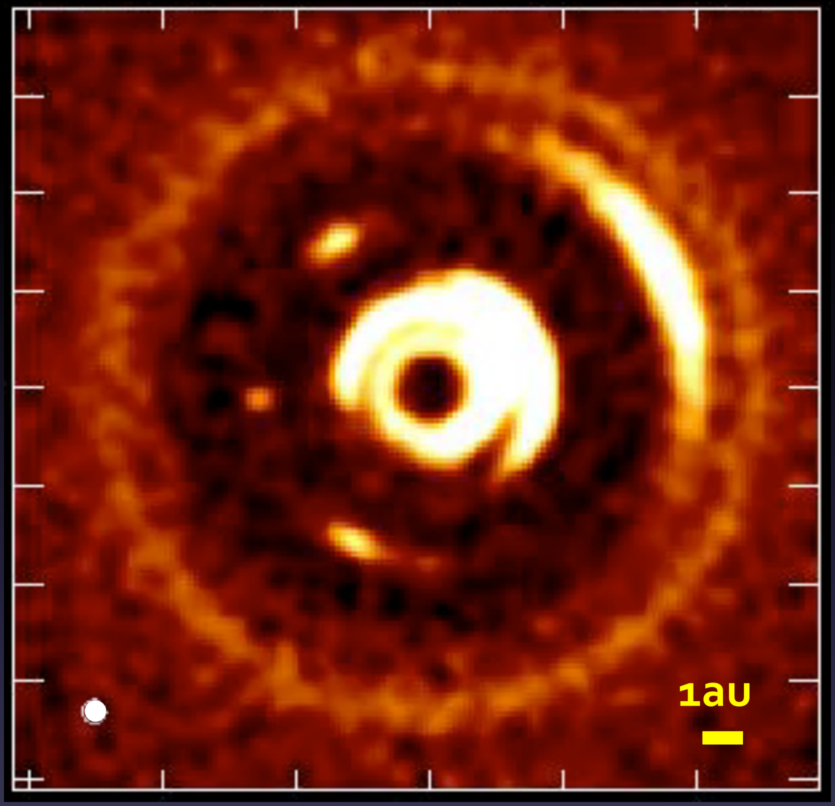
Cep OB2, OB3, OB4

Results: time variability

ngVLA @ 3mm

(beam = 5mas
rms = 2e-7 Jy/b)

Jupiter @ 5au, $\alpha_{visc}=10^{-5}$



1 frame per month

1 orbit in 12 years

Circumplanetary disk:

$M_{disk} = 10^{-4} M_{pl}$
$r_{disk} = 0.5\, r_{Hill}$
$M_{acc} = 10^{-7} M_{pl}\, yr^{-1}$

Tests to models of triggered planet/planetesimals formation

Take away messages

3mm key for studies of protoplanetary disks with the ngVLA

Ang res = 5mas good tradeoff between ang res and sensitivity; at 3mm: b_{max} ~ 150 km

Noise < 5e-7 Jy/beam at 3mm to resolve gaps and substructures from planets down to ~ 10 - 30 M_{Earth}

Disks within ~ 700pc, statistical comparison with more mature planetary systems from exoplanet studies

Paper in prep, all models and images will be made available onlin