Peering into the Formation of New Worlds with the Next Generation Very Large Array

Credit:NAOJ

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ngvla

NRAO

The Highest Angular Resolution Frontier, AAS 247, Phoenix AZ
January 7, 2026

CSUN MATADORS

Protoplanetary Disks: the Cradles of Planets

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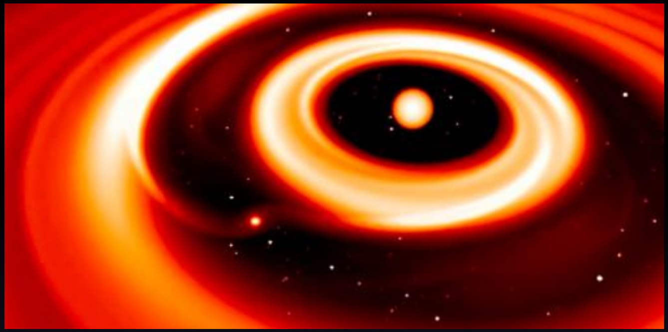

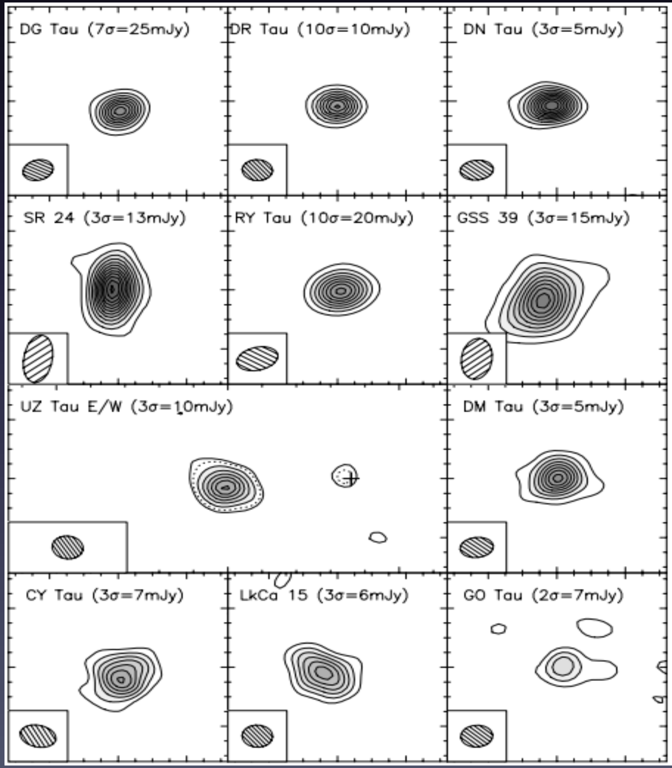

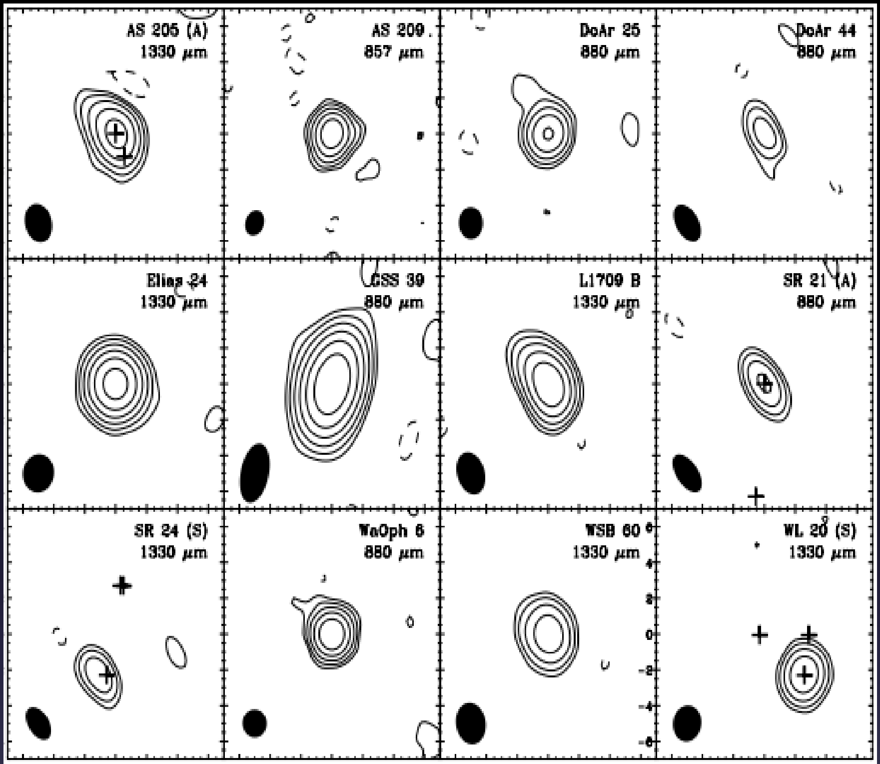

Pre-ALMA res ~ 0.2 – 0.3”:
disk substructures very rare

Isella+ 09, Andrews+ 09

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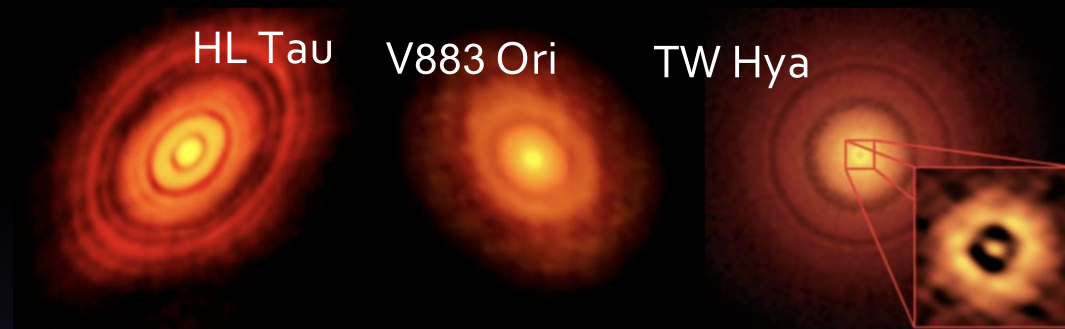
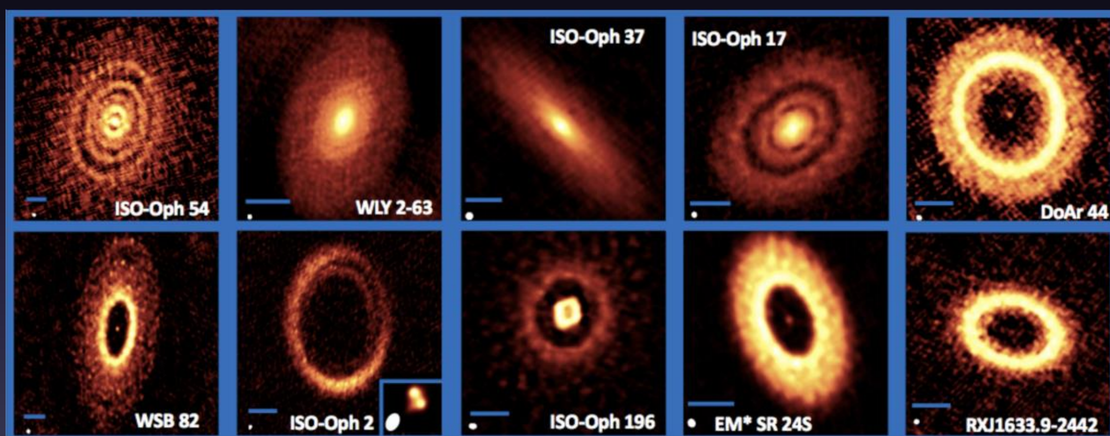
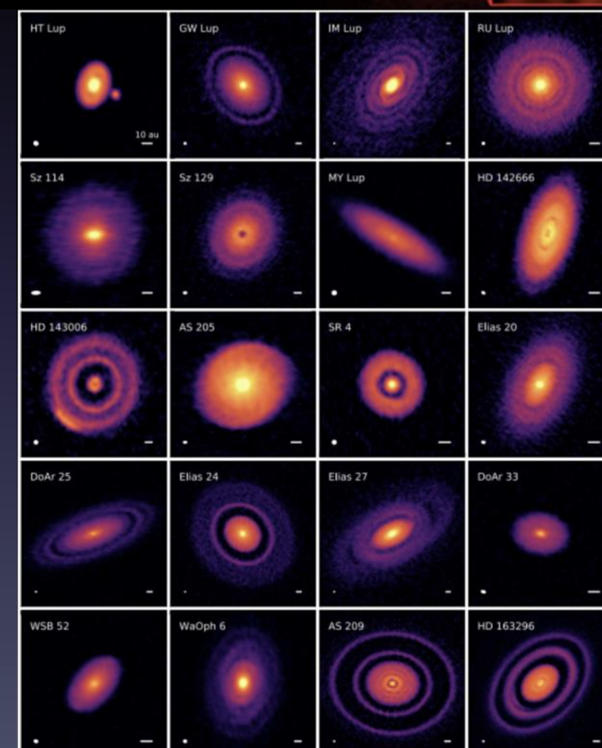




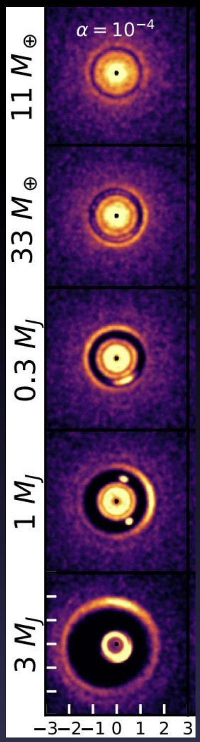


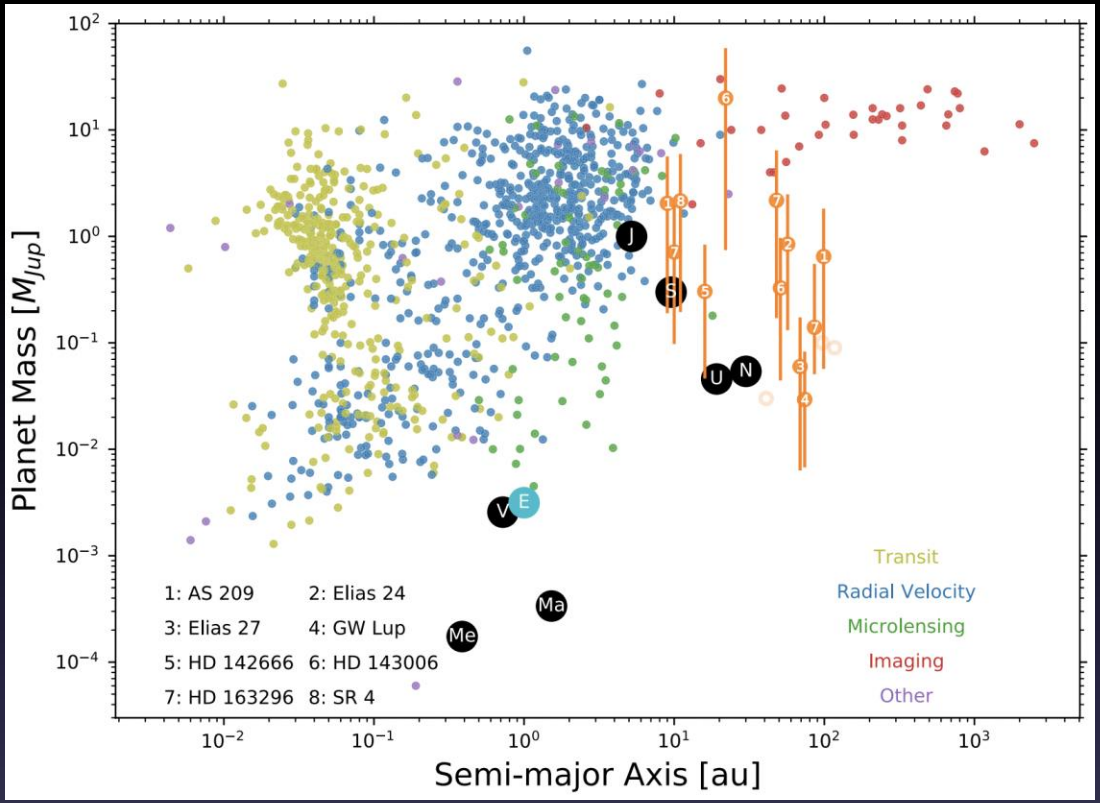
ALMA res ~ 20 – 30 mas:
substructures in most bright disks

ALMA Partnership+15,Andrews,...Ricci+ 16,18, Cieza+16,20

Young Planets from Disk-Planet Interaction

Models

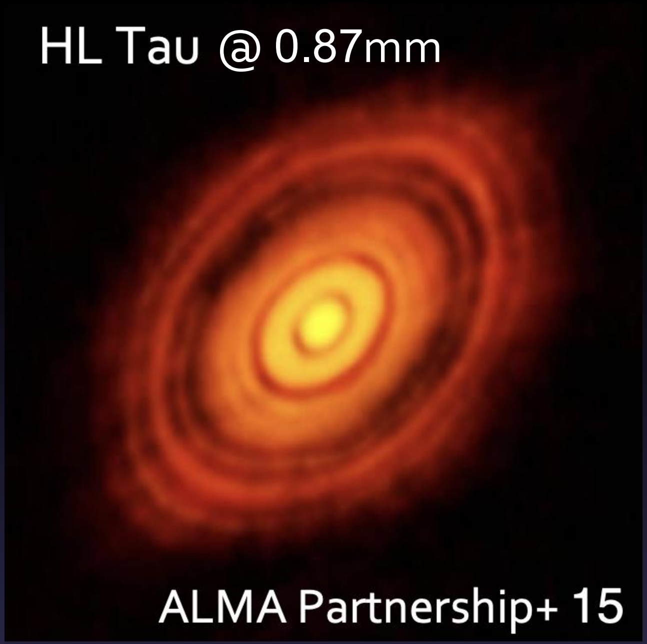




Zhang,Ricci+19 (see also Lodato+20)

ALMA sees disk substructures due to giant planets at $r > 10$ au

Young Planets from Disk-Planet Interaction



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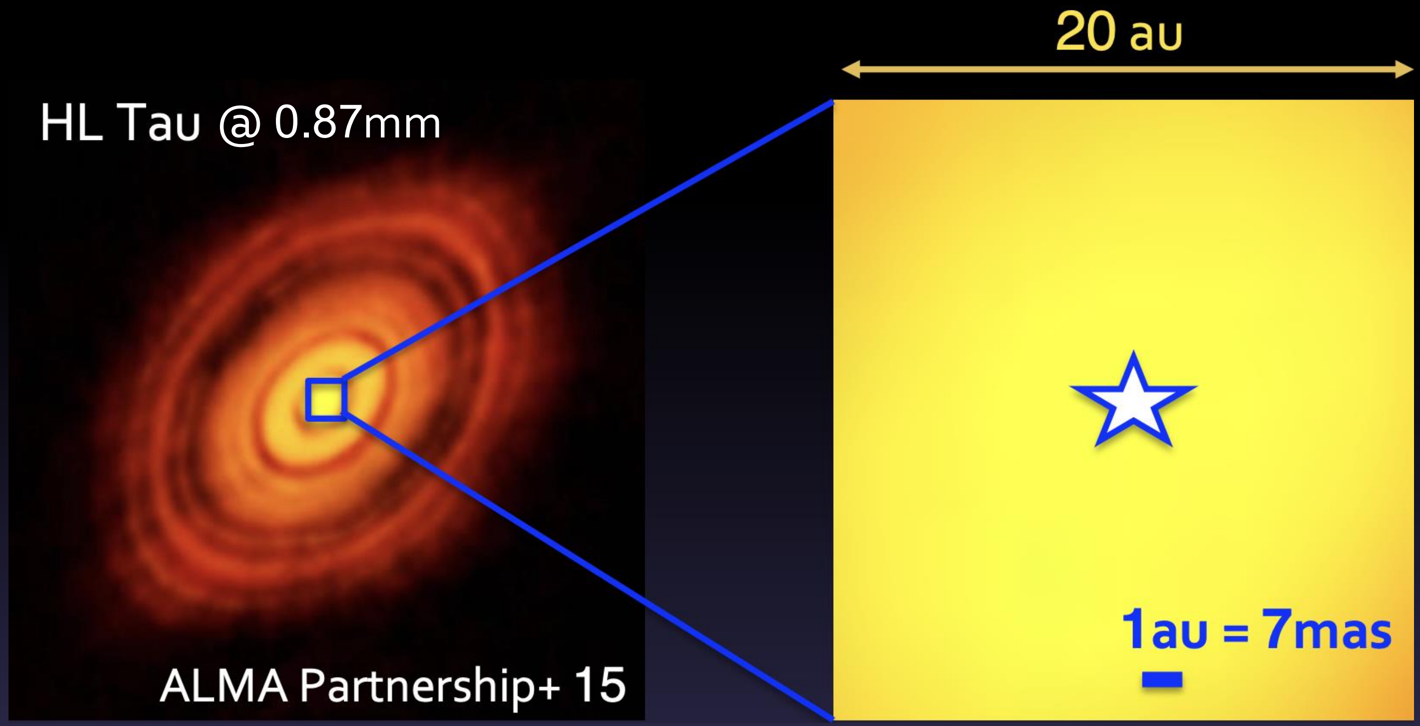

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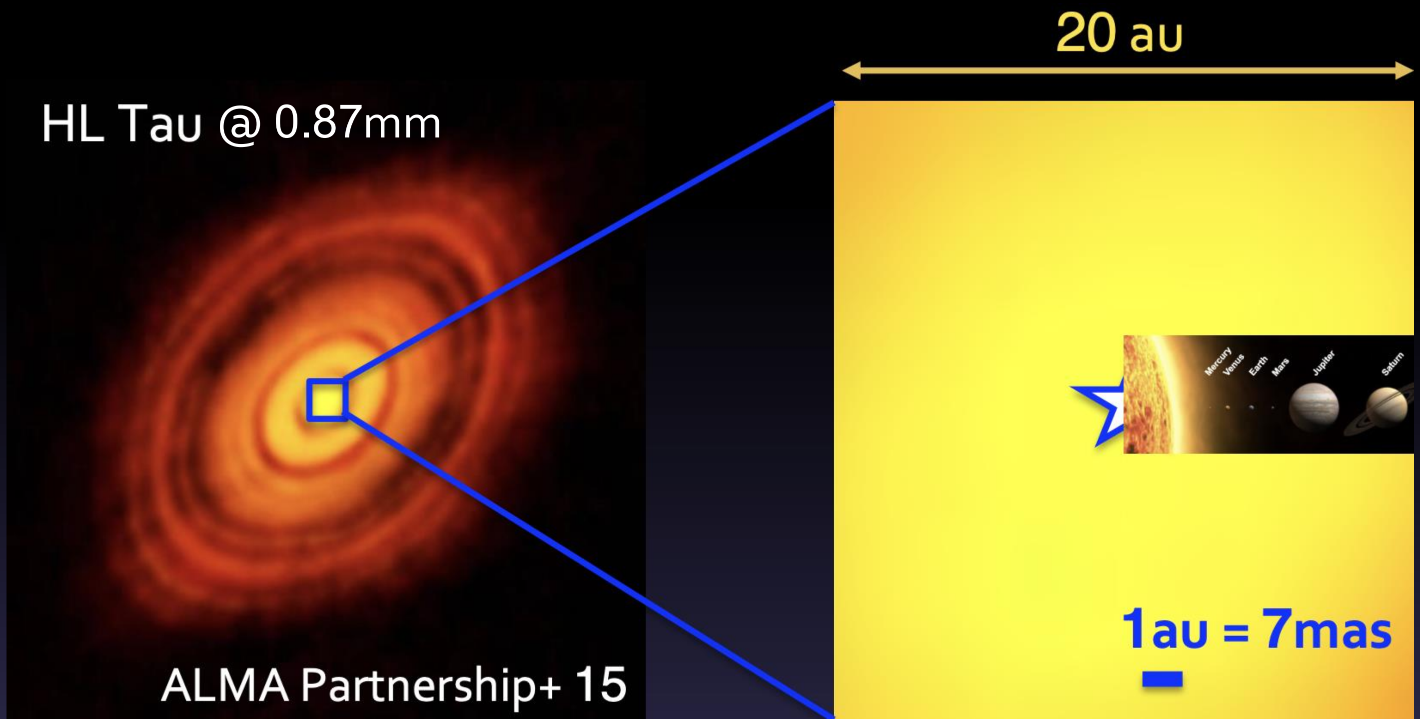


Higher ang res (< 5 mas) needed to resolve region of terrestrial planet formation;

λ > 1 mm to minimize optical depth of the dust emission

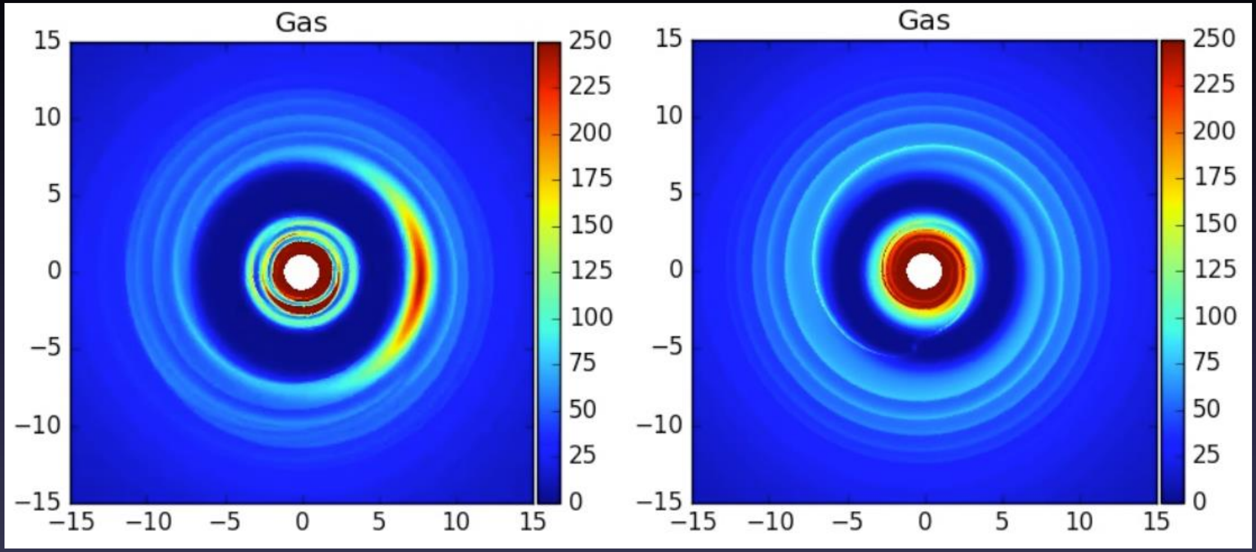
→ ngVLA!

Hydrodynamic Sims of Disks + Planet

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

Gas evolves viscously, gravitational interaction with planet

Jupiter @ 5 au



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

Ricci+ 18

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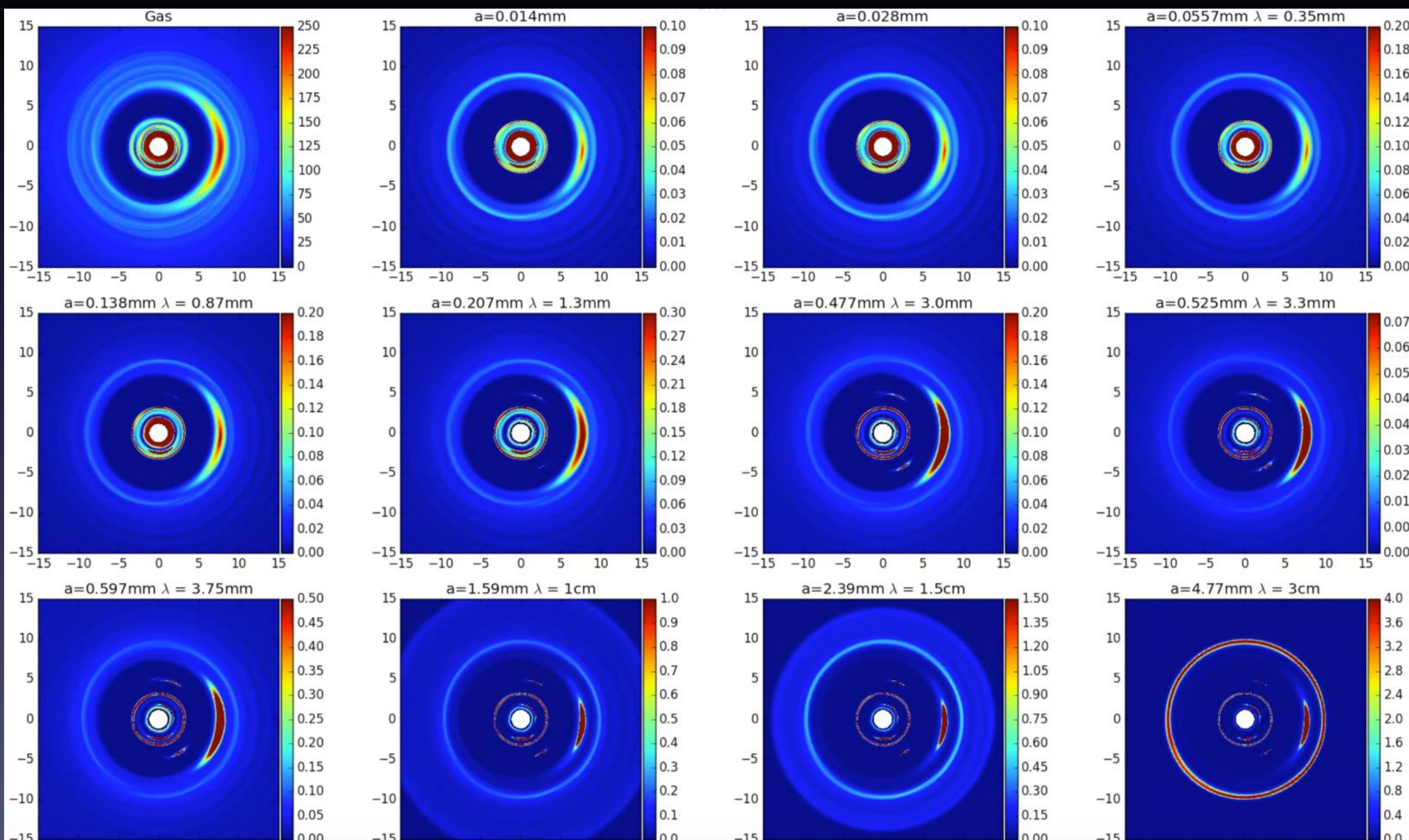
Dust and gas coupled aerodynamically, gas drag depends on grain size



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RADMC-3D ray tracing for dust continuum (Dullemond 12)

➡ $I^{model}(x,y)$ @ 0.87, 1.3mm (ALMA), 3, 7mm, 1cm (ngVLA)

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

➡ $I^{obs}(x,y)$

Ricci+ 18

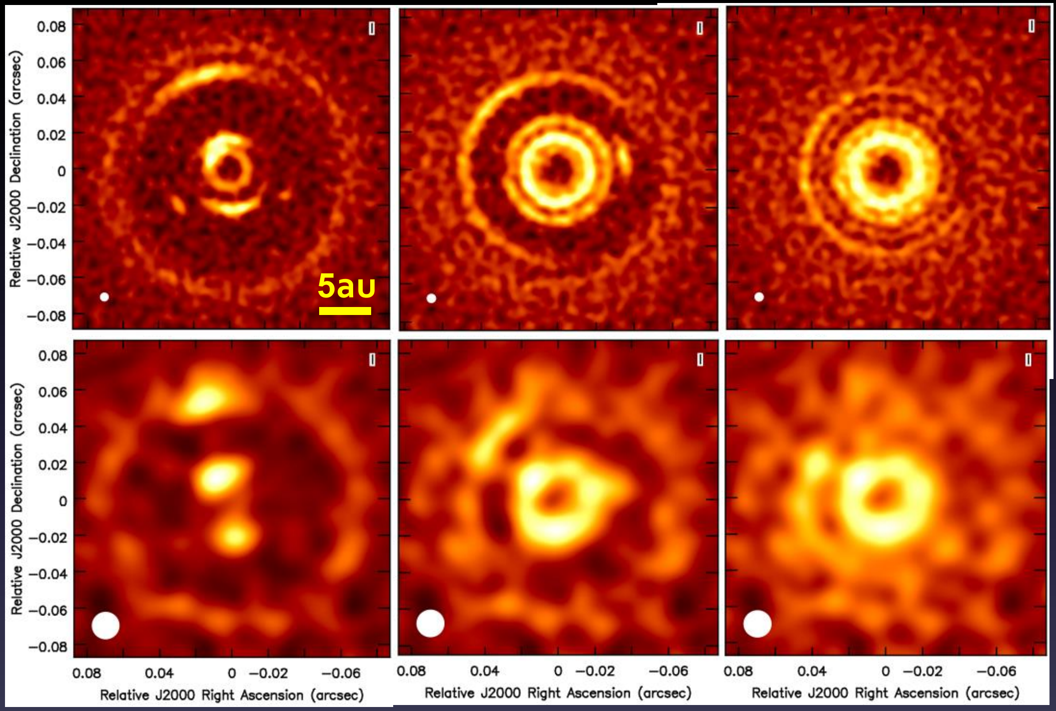
Giant Planets @ 5 au - $\alpha_{visc} = 10^{-5}$

M_{disk} = 0.006 M_{Sun}
d= 140 pc

ngVLA @ 3mm
(beam = 5mas
~ 0.7 au
rms = 5e-7 Jy/b)

ngVLA @ 1cm
(beam = 16mas
~ 2 au
rms = 15e-8 Jy/b)

Jupiter Saturn Neptune



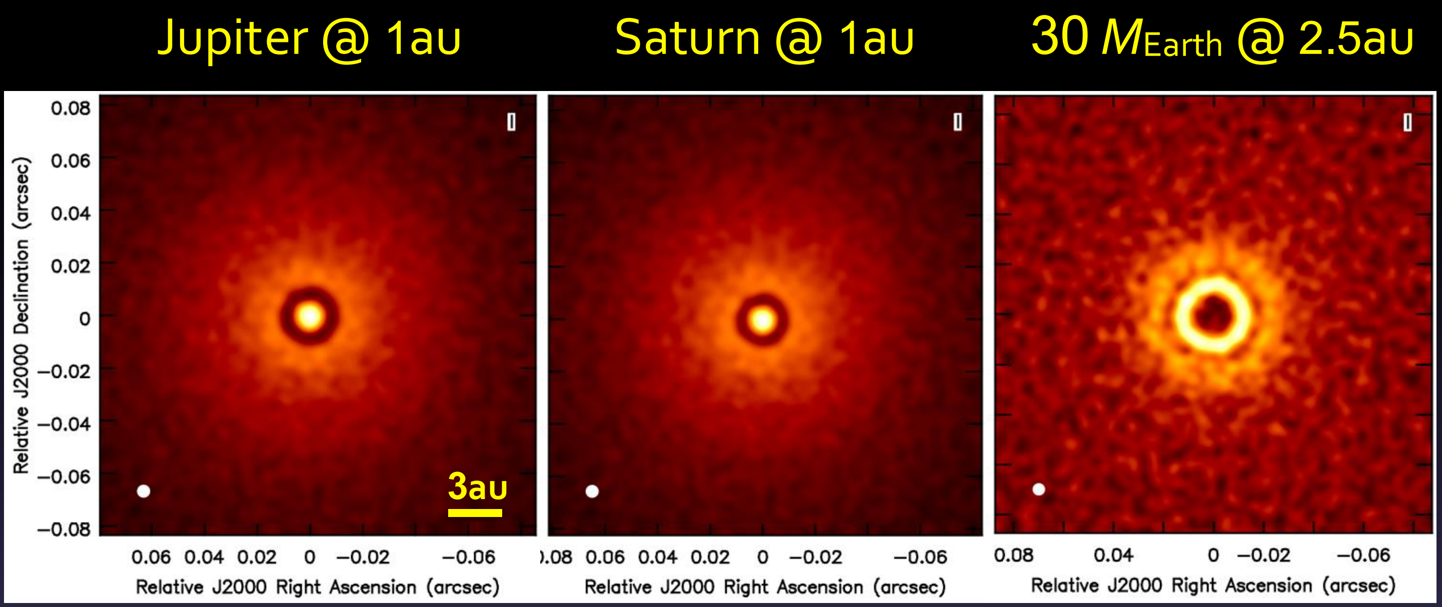
Ricci+ 18

Giant Planets @ < 5 au, $\alpha_{visc} = 10^{-3}$

$M_{disk} = 0.006\ M_{Sun}$
d= 140 pc

ngVLA @ 3mm

(beam = 5mas
~ 0.7 au
rms = 5e-7 Jy/b)



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

Ricci+ 18, see also Wu+ 24

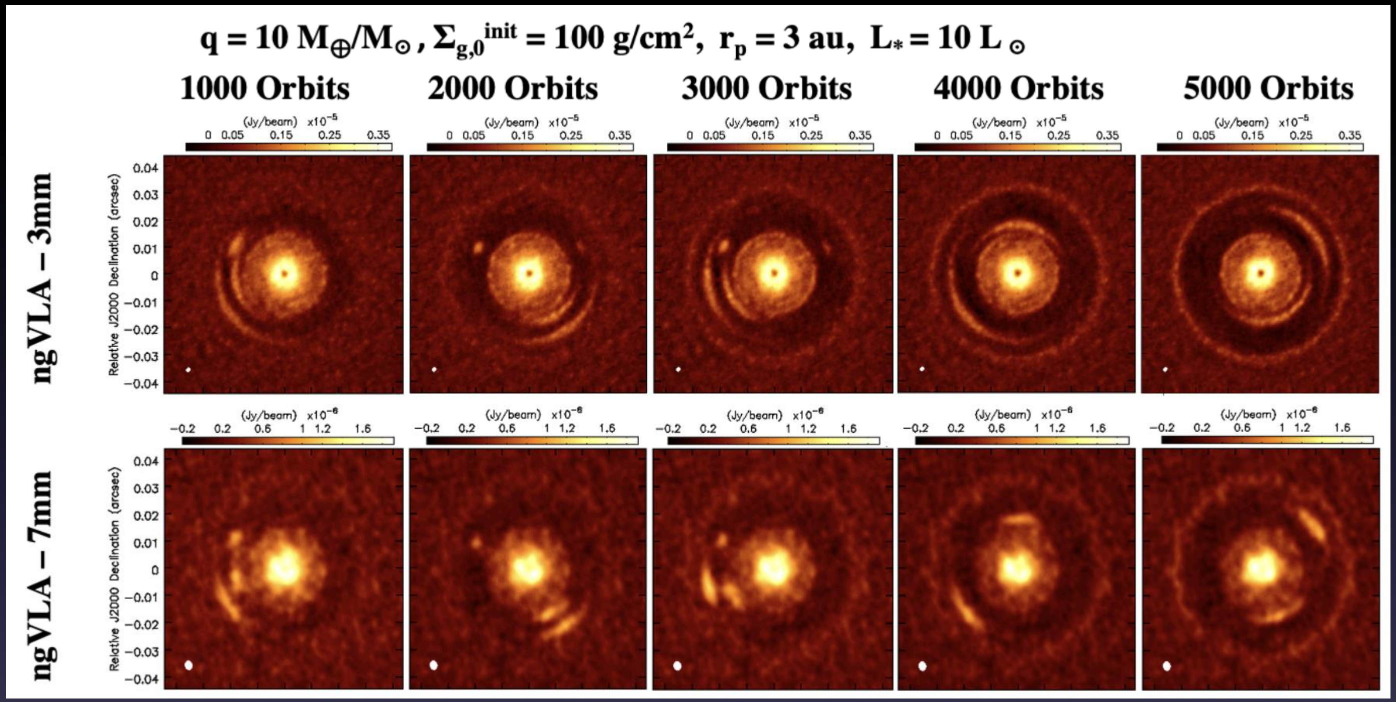
Super-Earths @ 3 au - $\alpha_{visc} = 10^{-5}$

Disk-planet sims with Dusty FARGO (Masset 2000, Baruteau & Zhu 16):

d= 140 pc

ngVLA @ 3mm
(beam = 1.5mas
~ 0.2 au
rms = 1e-7 Jy/b)

ngVLA @ 7mm
(beam = 3mas
~ 0.4 au
rms = 5e-8 Jy/b)



ngVLA detects substructures due to Super-Earth planets around Solar-mass stars, close to Earth around low mass stars; only way to investigate them? (Sanchis+20, Alarcon+24)

Harter, Ricci+ 20

Monitoring Orbital Motions

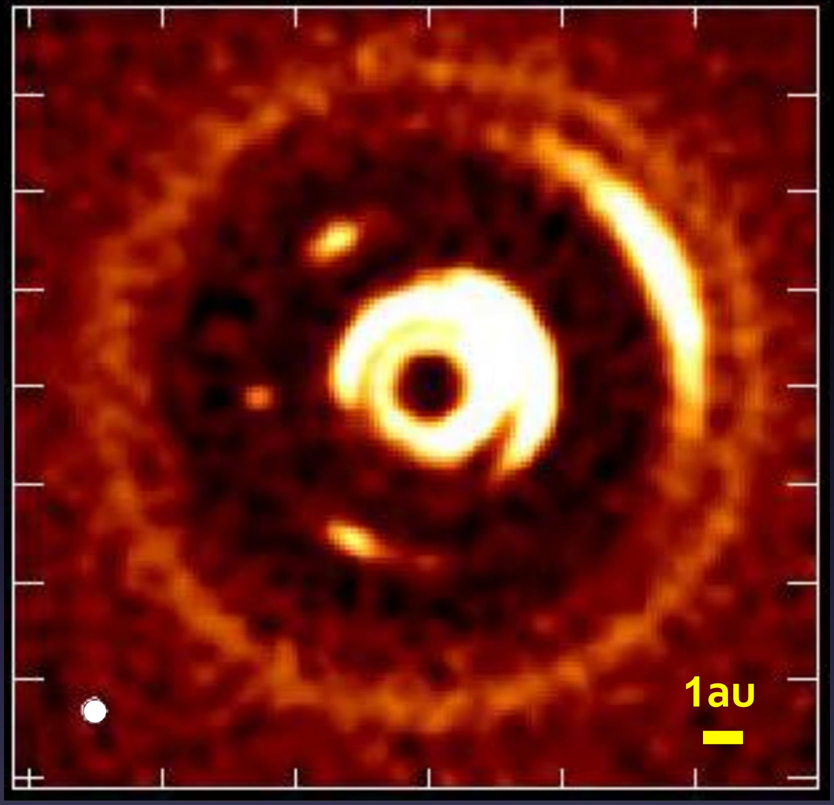
ngVLA @ 3mm

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

Circumplanetary disk:

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

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



1 frame per month

1 orbit in 12 years

Test models of triggered planet/planetesimals formation

Zhu+ 18 for ngVLA potential to detect circumplanetary disks

Ricci+ ngVLA Memo #101 for kinematic signatures in CO

Disk Substructures due to Disk Instabilities

Disk substructures can reveal (M)HD instabilities:

- Disk physics (angular momentum transport)

- Planet(esimal) formation (solid growth/trapping)

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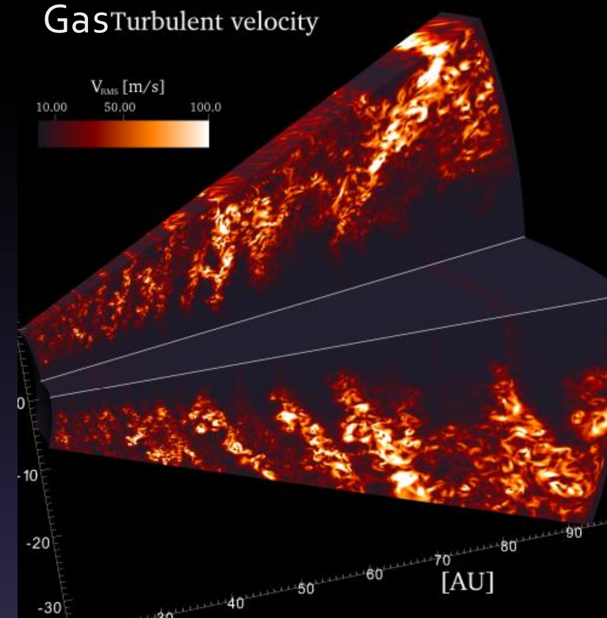
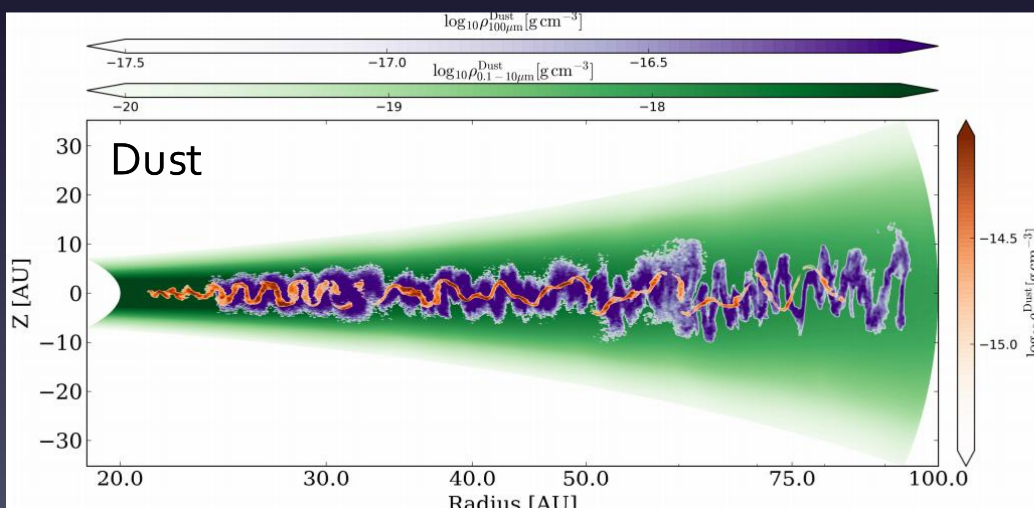
Flock+ 17

Gas



Ex: Vertical Shear Instabilities in

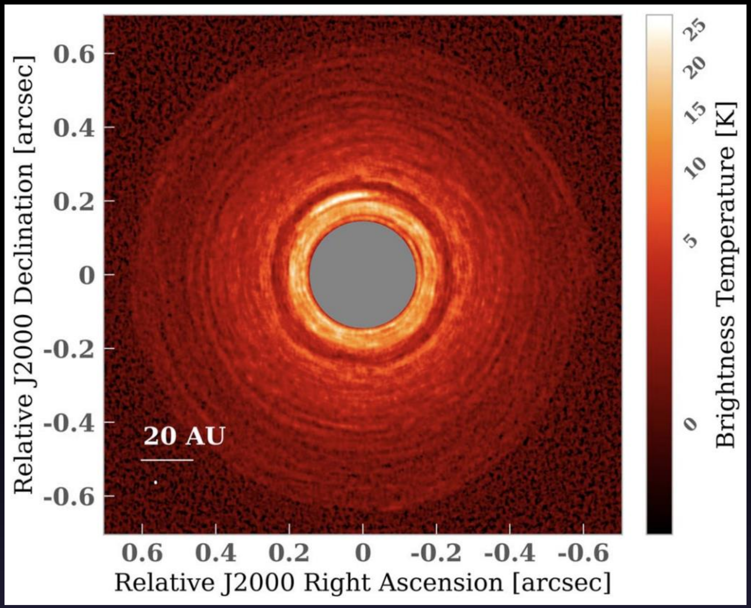
3D Radiative hydrodynamic sims



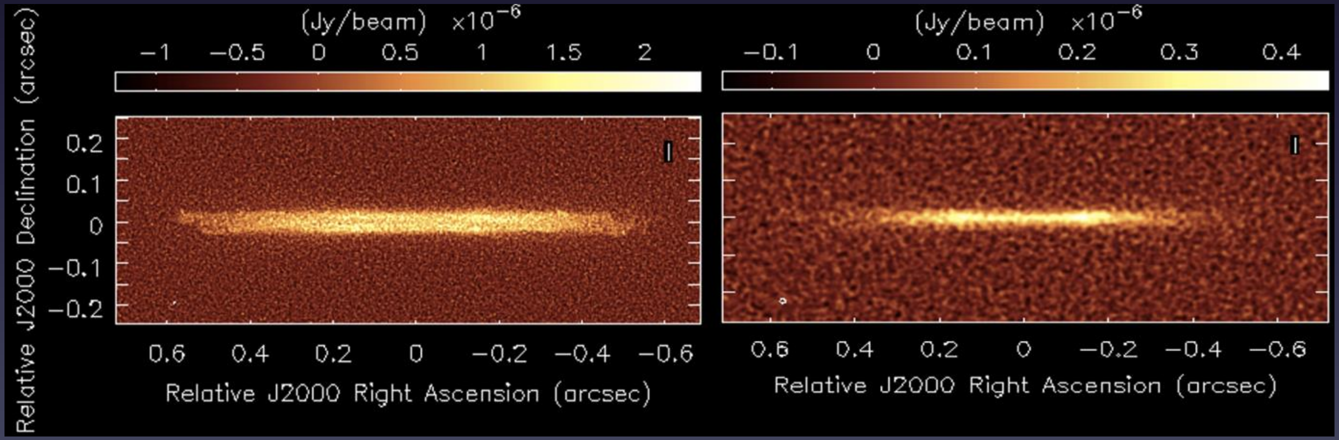
Disk Substructures due to VSI

ngVLA @ 3mm

(beam = 6mas
rms = 1e-7 Jy/b)



ngVLA @3mm



ngVLA @1cm

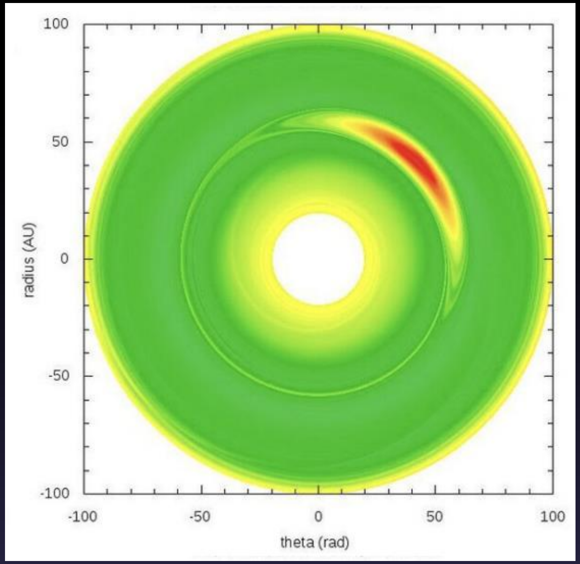
beam = 5mas
rms = 3e-7 Jy/b

beam = 12mas
rms = 4e-8 Jy/b

Blanco,Ricci,Flock+21

Disk Substructures due to RWI

Rossby Wave Instability produces large vortices which trap solids



Barge,Ricci+18
Carilli,Ricci+ ngVLA Memo #11

Disk Substructures due to RWI

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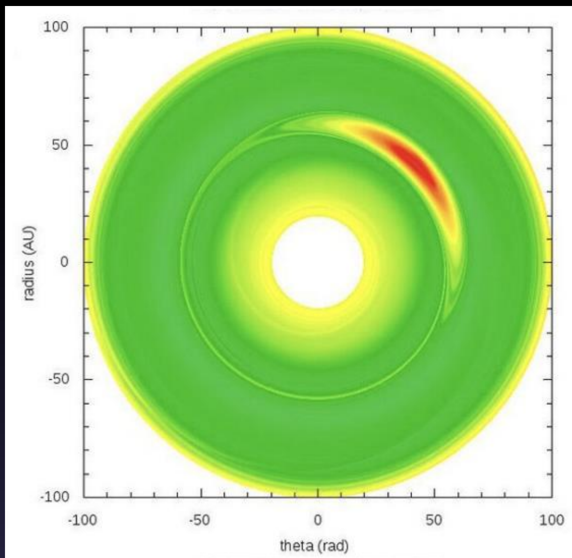
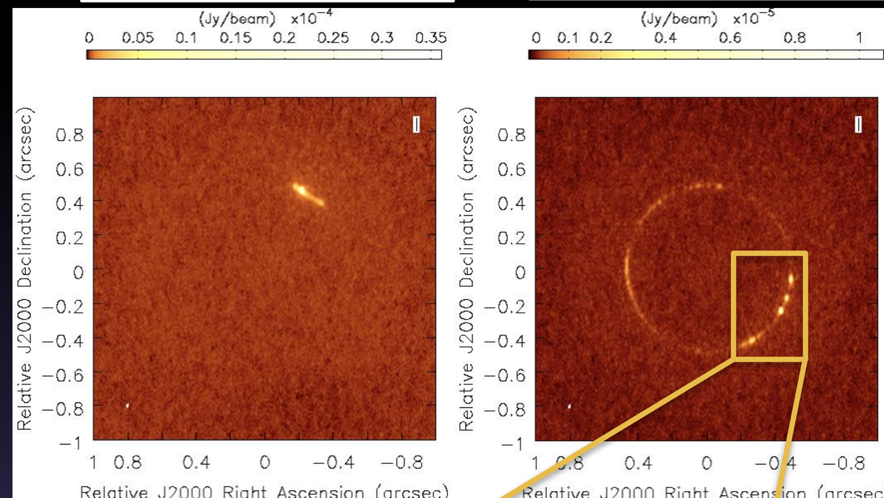
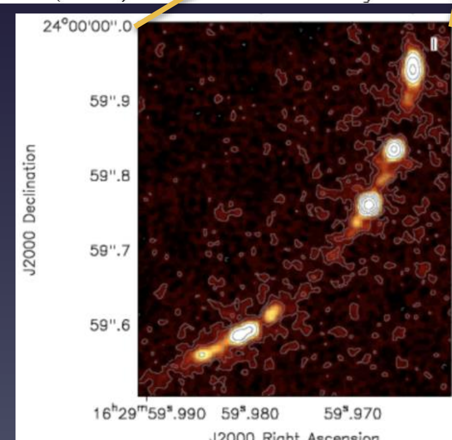


ngVLA @ 3mm

ngVLA @ 1cm





Solids concentrate in dense clumps, potential seeds of planetesimals

Barge, Ricci+18

Carilli, Ricci+ ngVLA Memo #11

Take away messages

ngVLA key for investigating young planets in disk regions of terrestrial planet formation, down to Super Earths at ~ 1 au

Disks up to ~ 1 kpc, statistical comparison with exoplanets

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Disks up to ~ 1 kpc, statistical comparison with exoplanets

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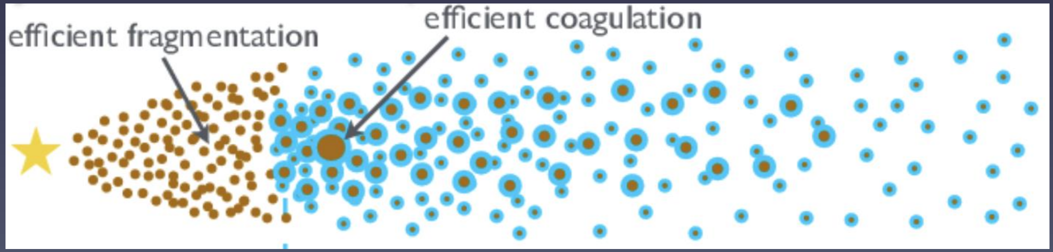
ngVLA can resolve free-free emission expected for disk winds and distinguish between MHD & Photoevaporative winds (Ricci, Harter, Ercolano+ 21), as well as map dust growth across the water snowline



Banzatti, Ricci+15