“Particle traps” at planet gap edges in disks: effect of grain growth and fragmentation

Jean-François Gonzalez
Centre de Recherche Astrophysique de Lyon, France

Guillaume Laibe
University of St Andrews, Scotland, UK

Sarah Maddison
Swinburne University of Technology, Melbourne, Australia

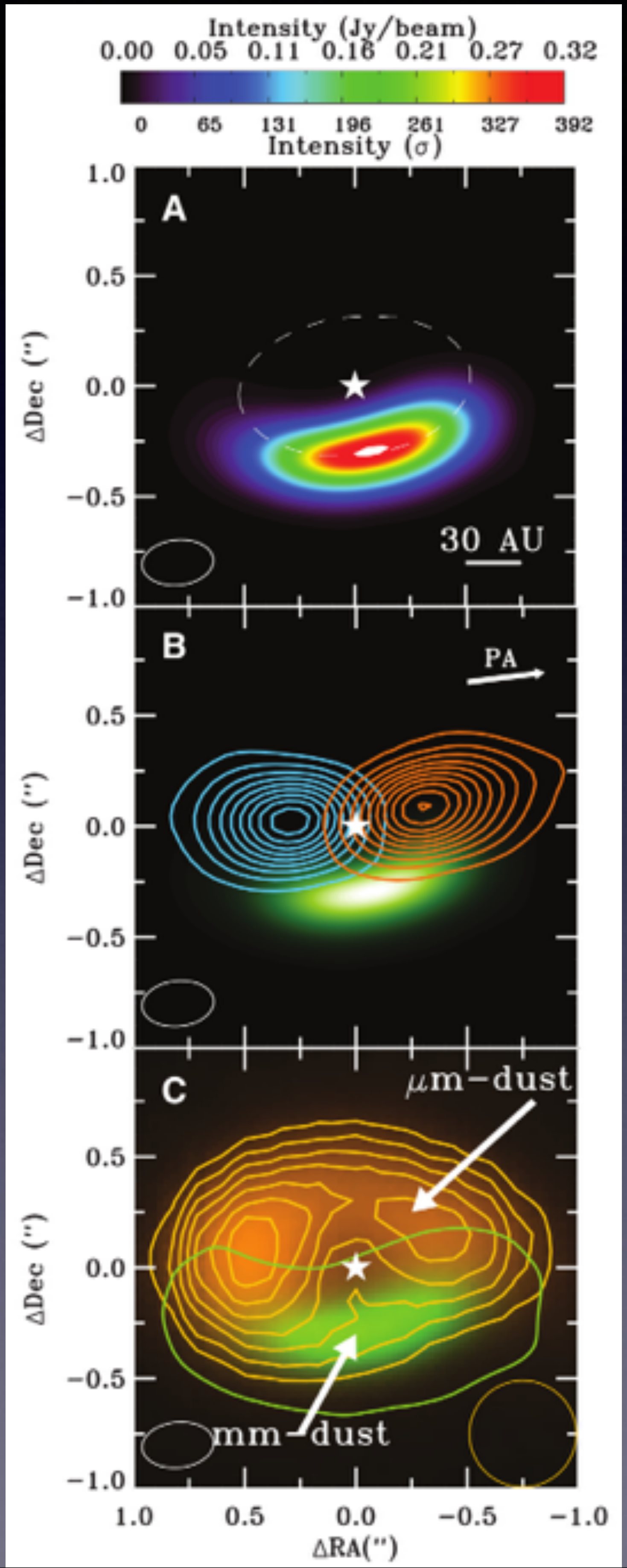
Christophe Pinte
Institut de Planétologie et d’Astrophysique de Grenoble
& Laboratoire Franco-Chilien d’Astronomie

Particle traps

- The barriers of planet formation
  - Radial drift
    Weidenschilling (1977), Nakagawa et al. (1986), Youdin & Shu (2002), Laibe et al. (2012,2013)
  - Fragmentation
    Dullemond & Dominik (2005), Blum & Wurm (2008)
  - Bouncing
    Zsom et al. (2010), Windmark et al. (2012)

    ⇒ can be overcome with stochastic motion
    Garaud et al. (2013)
- Particle traps: possible solutions
  - Vortices
    Barge & Sommeria (1995), Regály et al. (2012), Méheut et al. (2013)
  - Snow line, dead zone inner edge
    Kretke & Lin (2007), Dzyurkevich et al. (2010)
  - Planet gap edges
    de Val-Borro et al. (2007), Fouchet et al. (2007,2010), Gonzalez et al. (2012)
  - “Bumpy” gas surface density
    Pinilla et al. (2012)

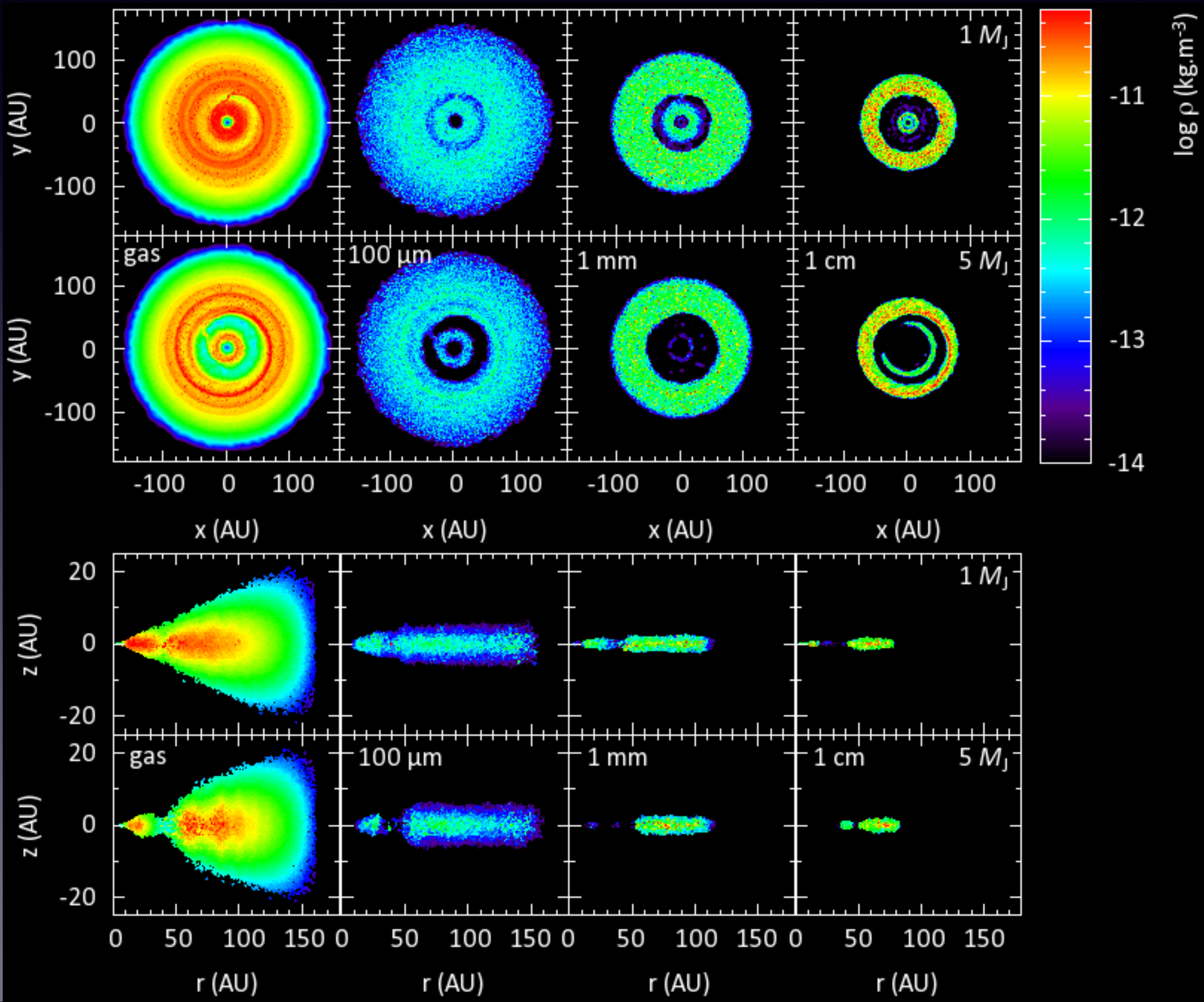
ALMA observations of Oph IRS 48



van der Marel et al. (2013)

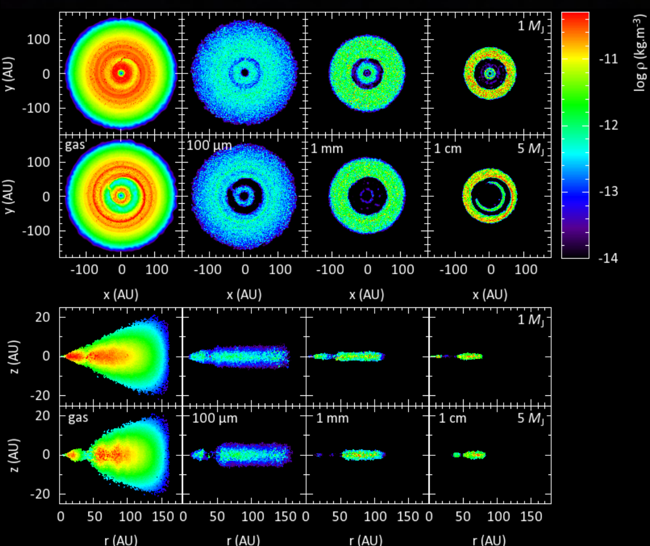
Grains of constant size

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



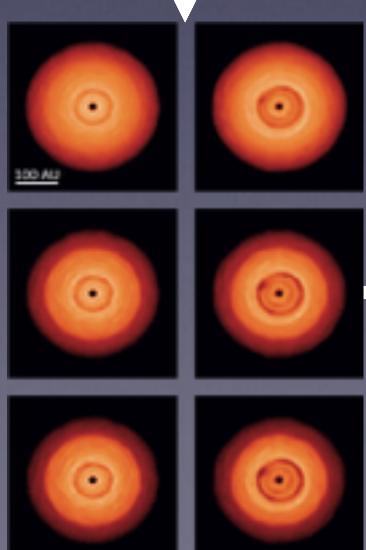
Fouchet et al. (2010)

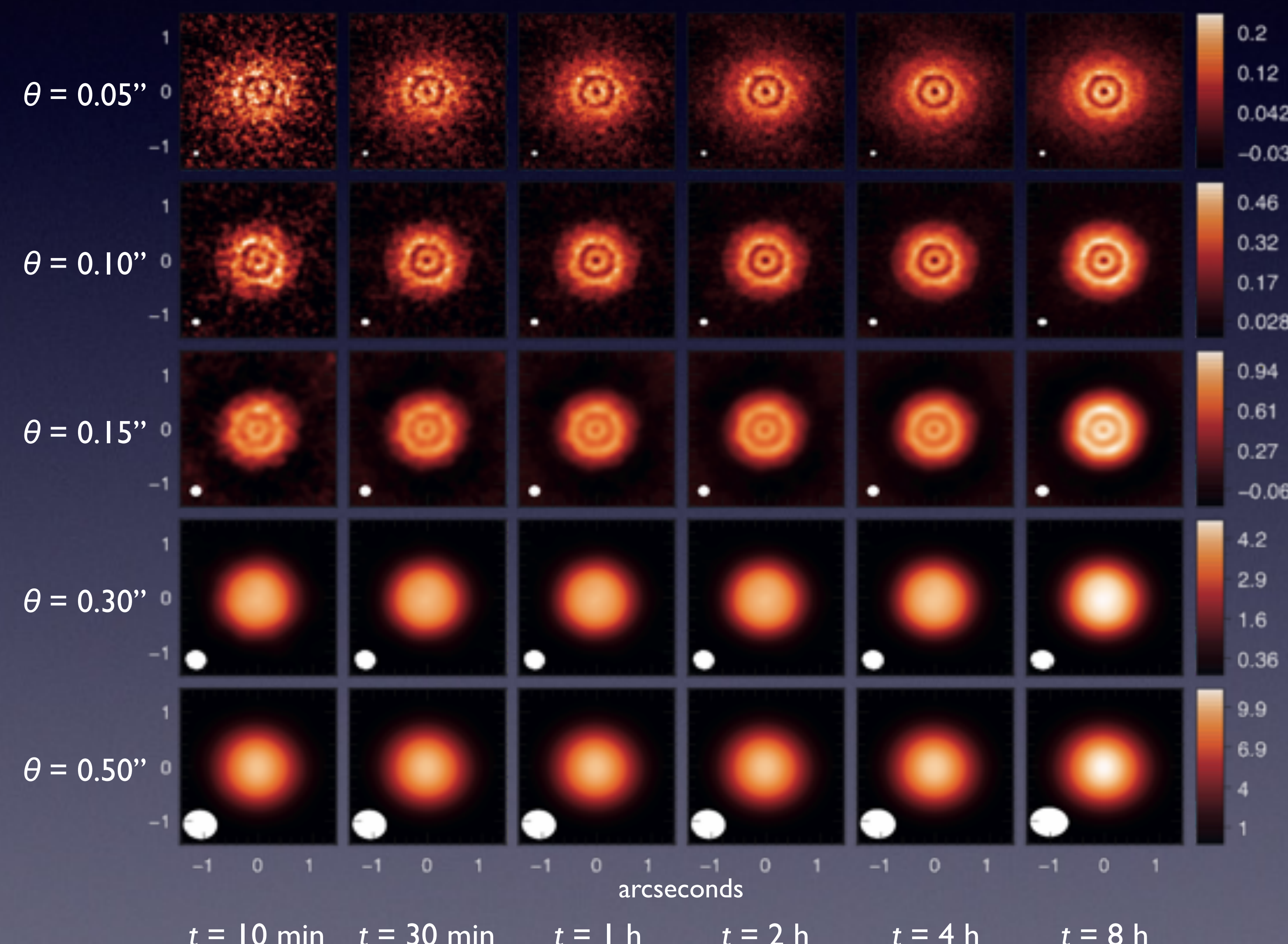
Synthetic images



MCFOST

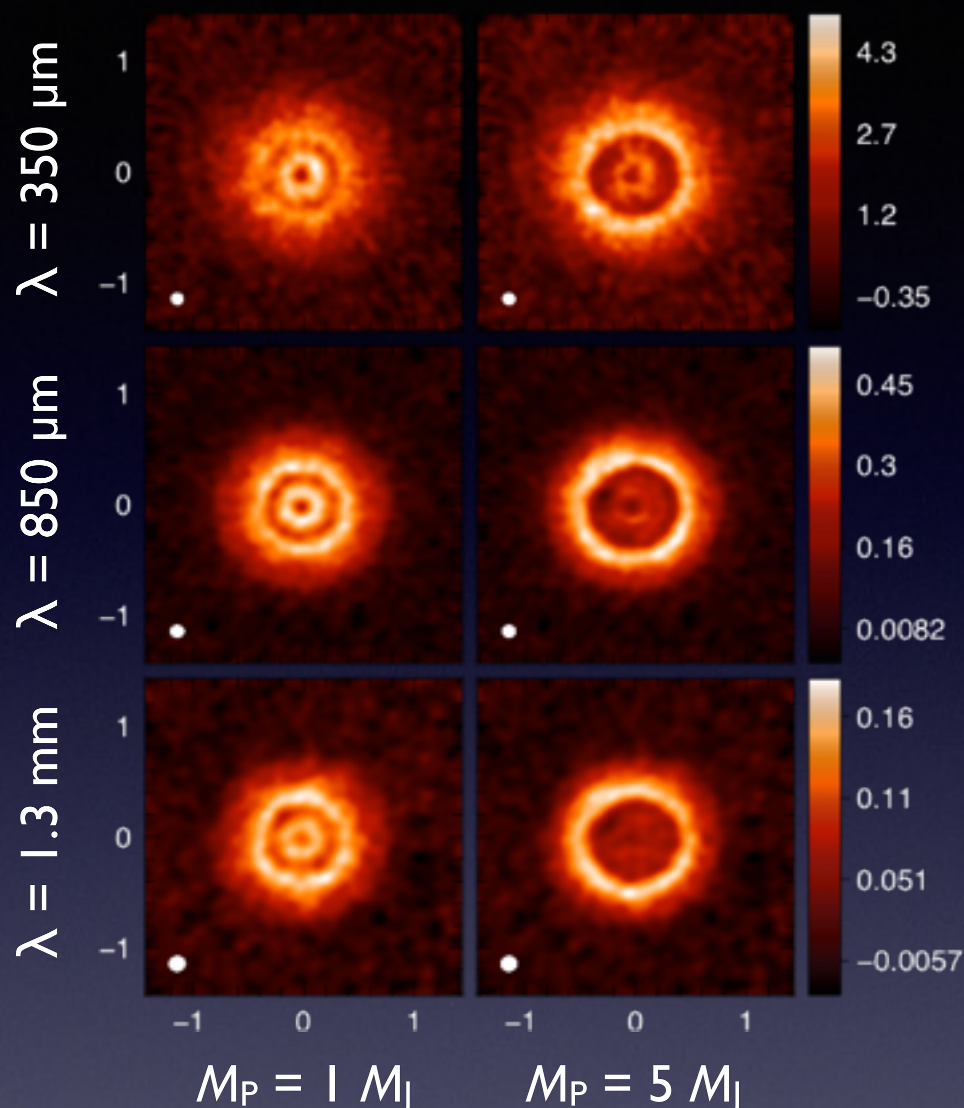
Pinte et al. (2006)

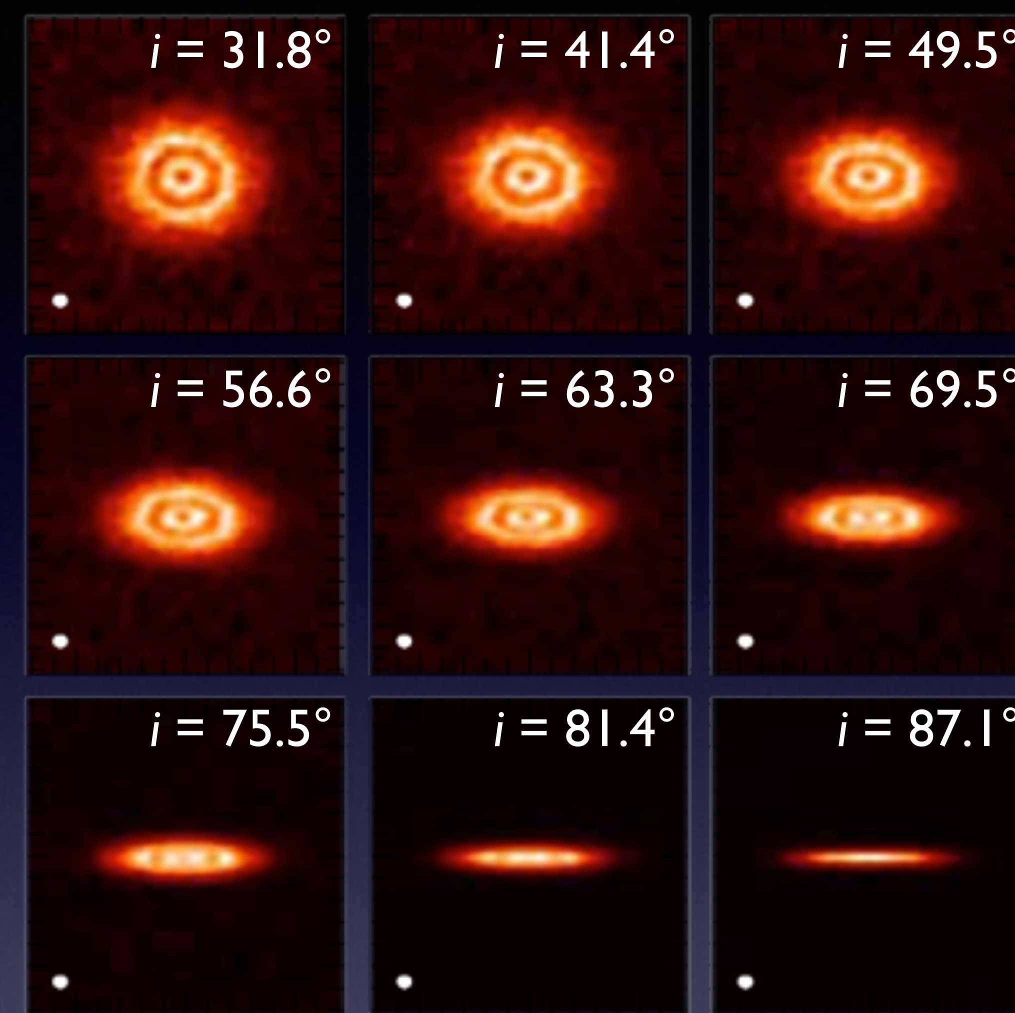




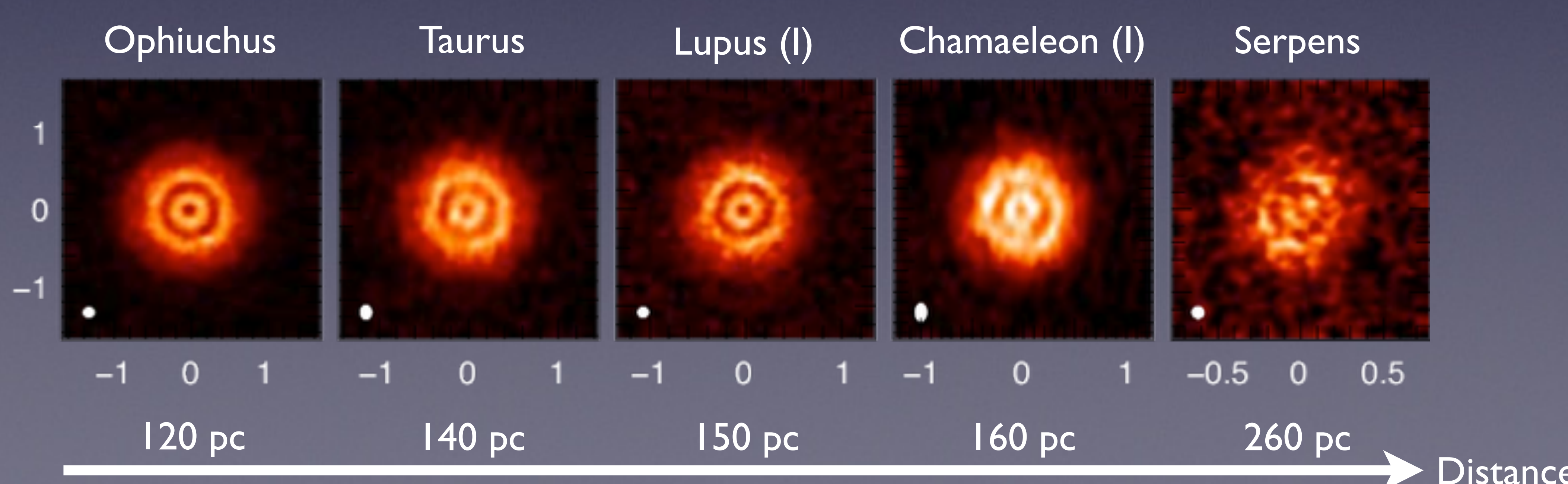
Gonzalez et al. (2012)

ALMA simulated images



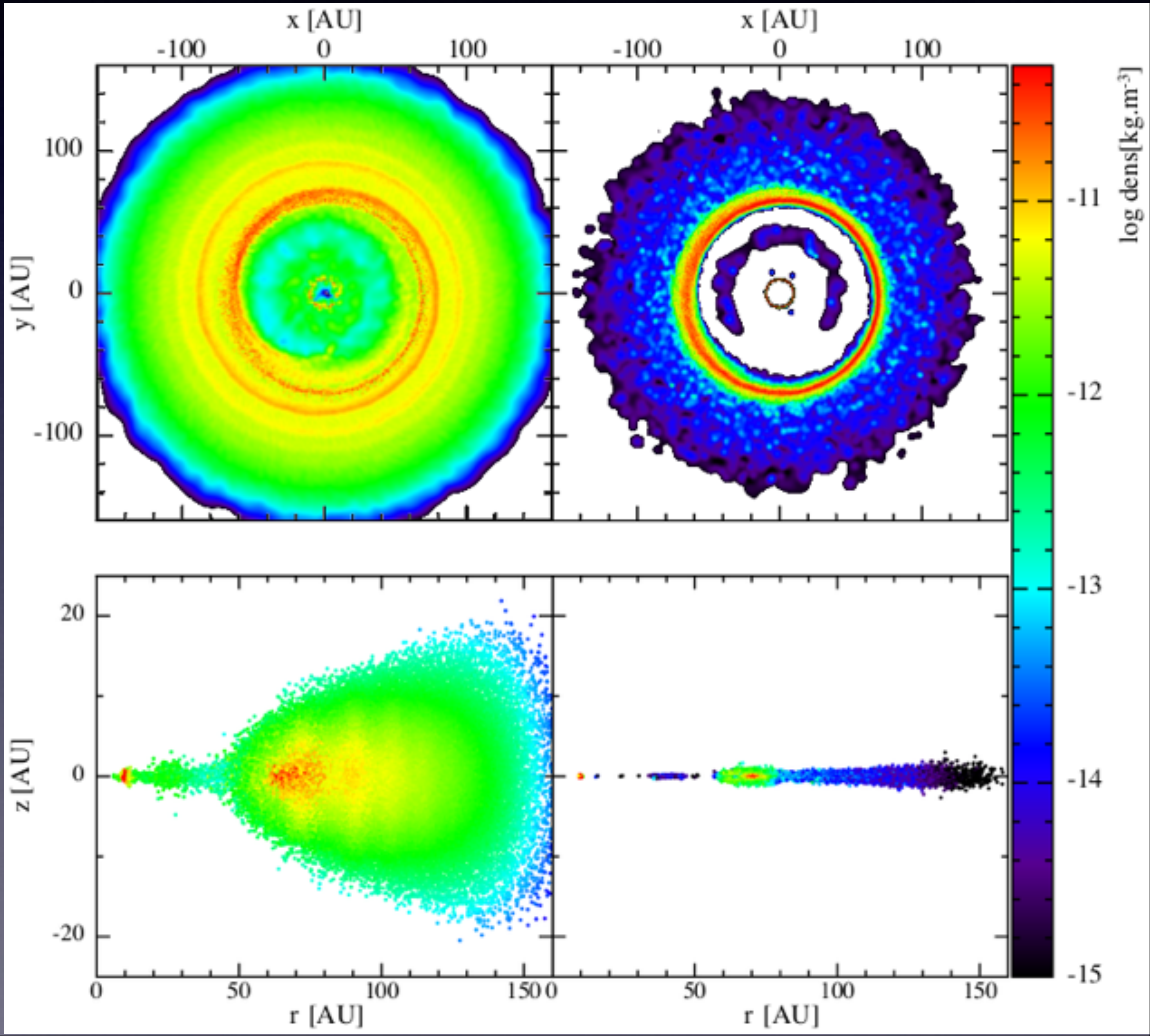


Gonzalez et al. (2012)

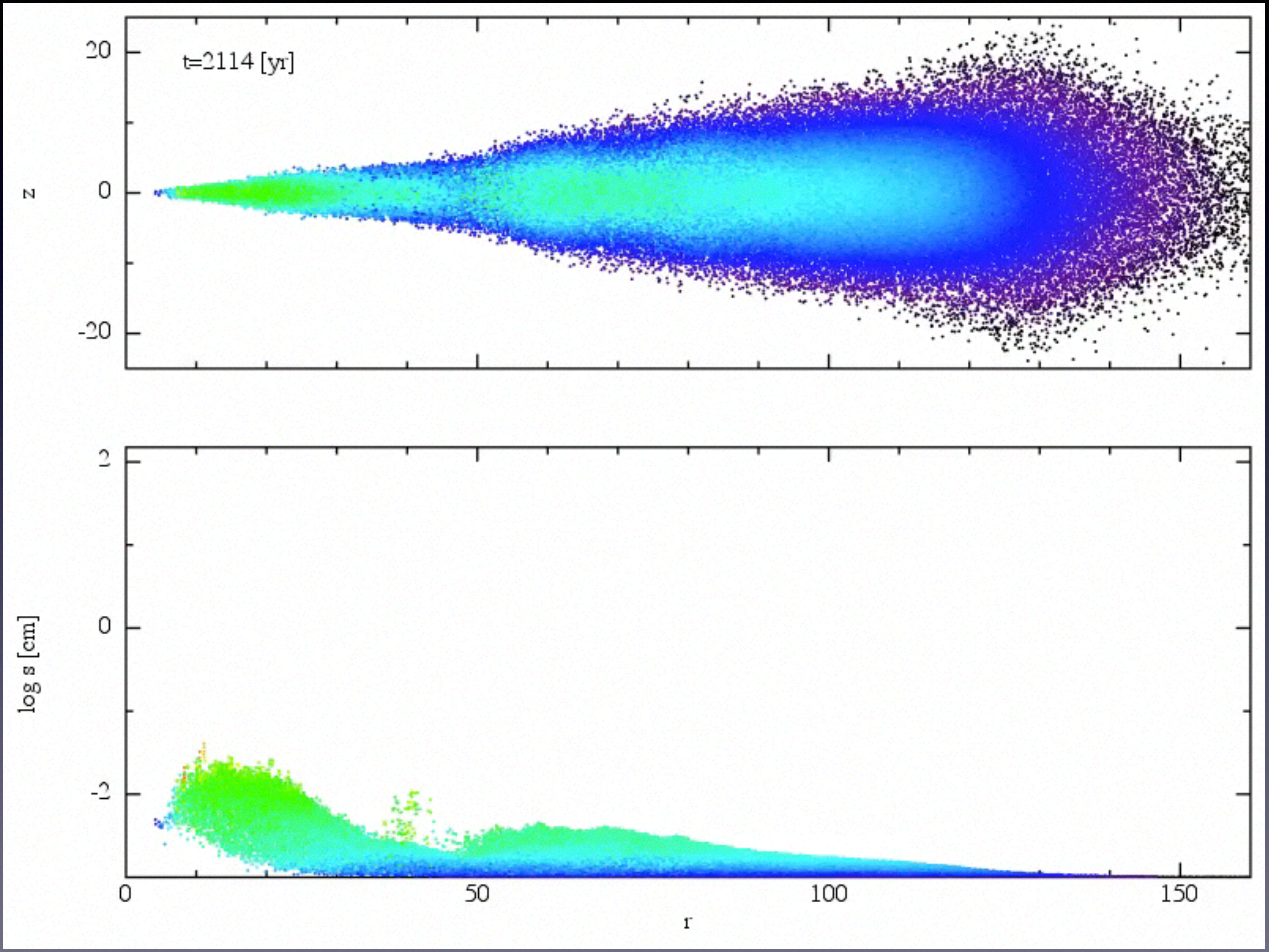


Growth and fragmentation

- Growth model of Stepinski & Valageas (1997)
  - Solid particles
  - Perfect sticking
- Fragmentation threshold
  - $V_{rel}<V_{frag}$: growth
  - $V_{rel}>V_{frag}$: shattering
- Initial grain size
  - 10 μm, uniform
- Same setup
  - CTTS disk
  - 5 M_J planet



Pure growth

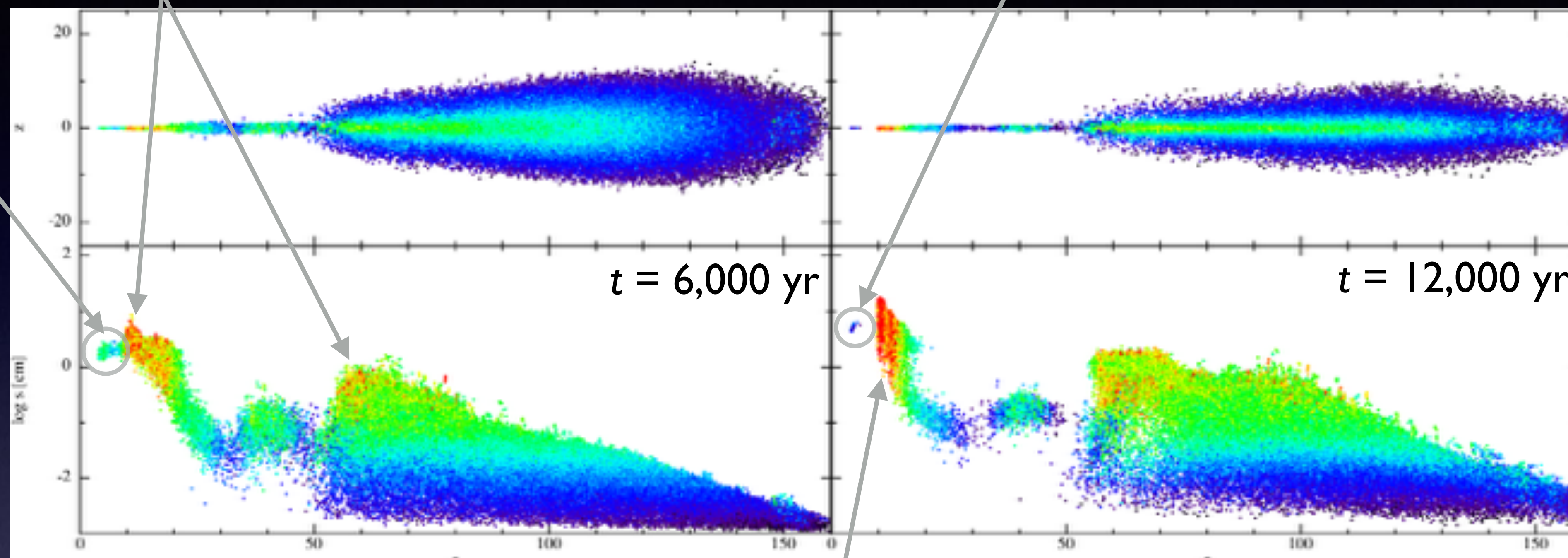


Pure growth

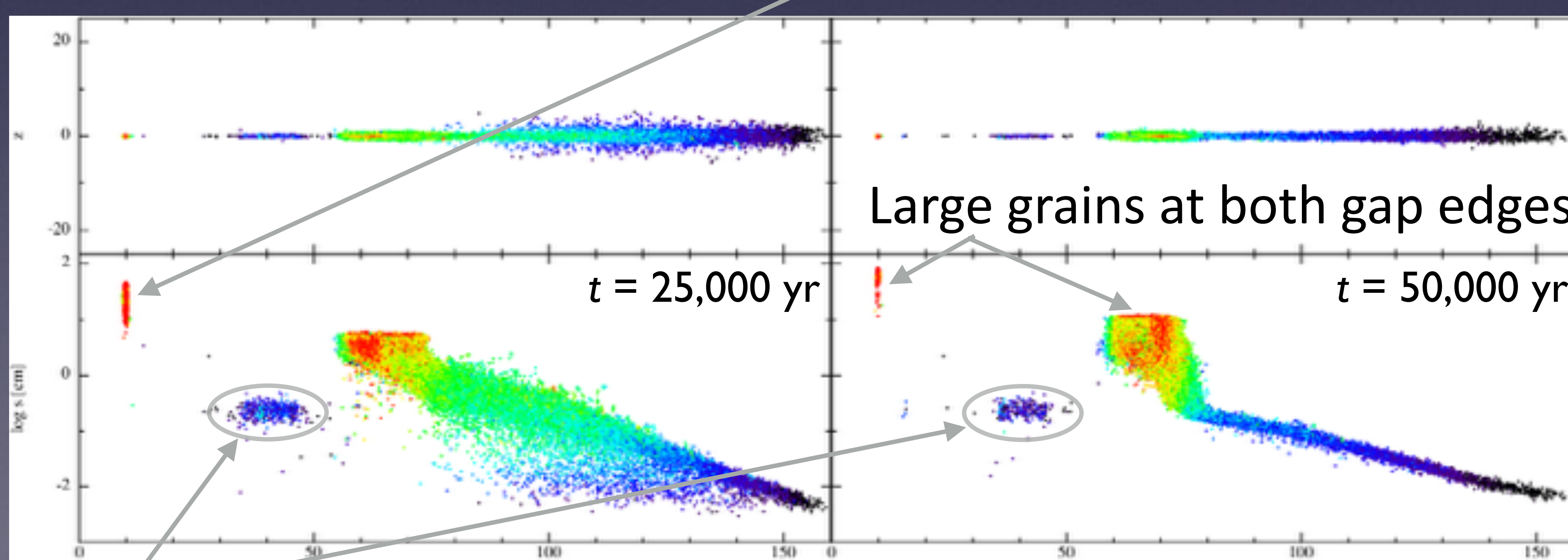
Grains having reached St=1 migrate rapidly towards the star

Efficient growth at the gap edges

Last grains lost to the star



After outgrowing St=1, grains are decoupled and grow without migrating



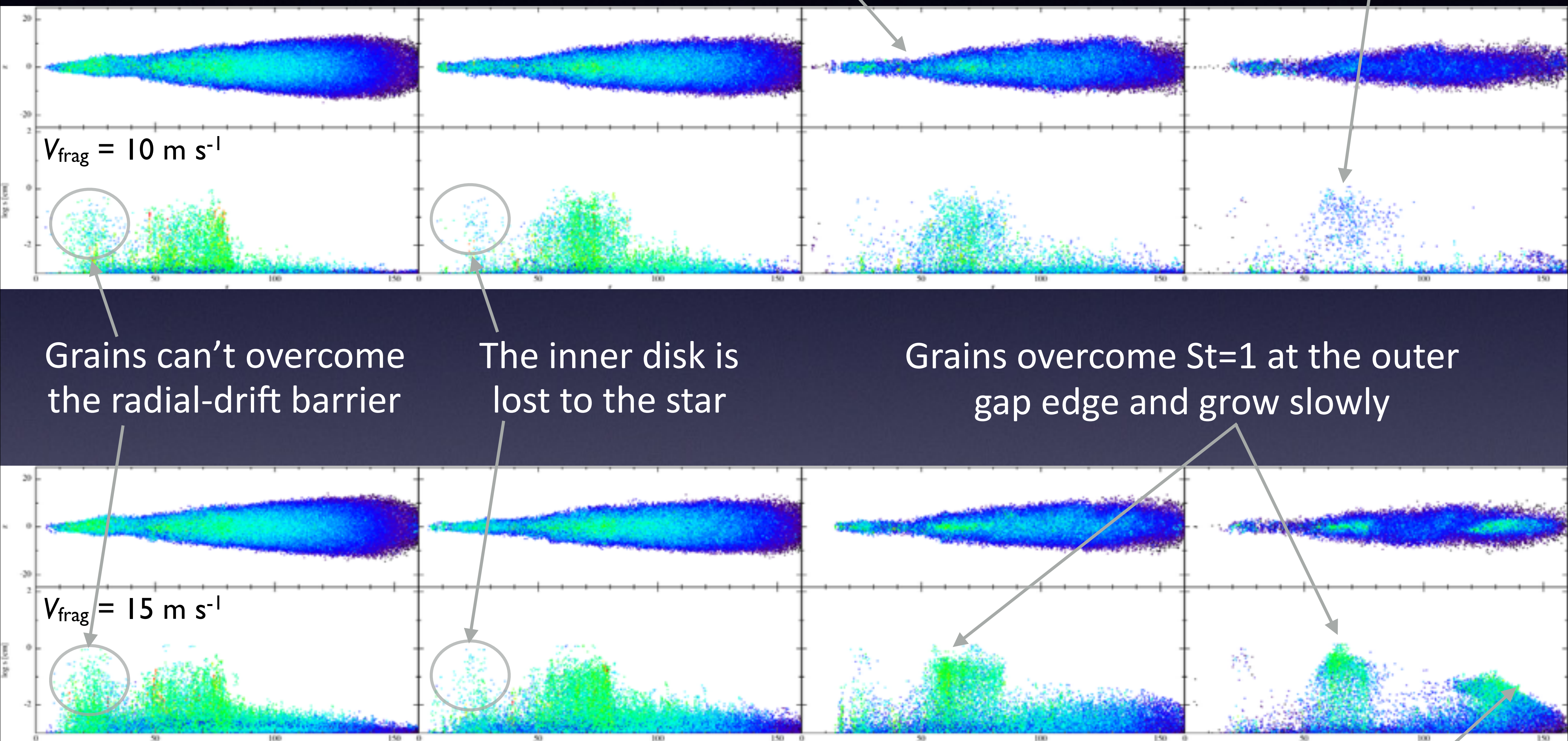
Large grains at both gap edges

Grains in corotation with the planet, on horseshoe orbits

Growth and fragmentation

Grains never decouple and follow the gas through the gap

The dust disk slowly drains out

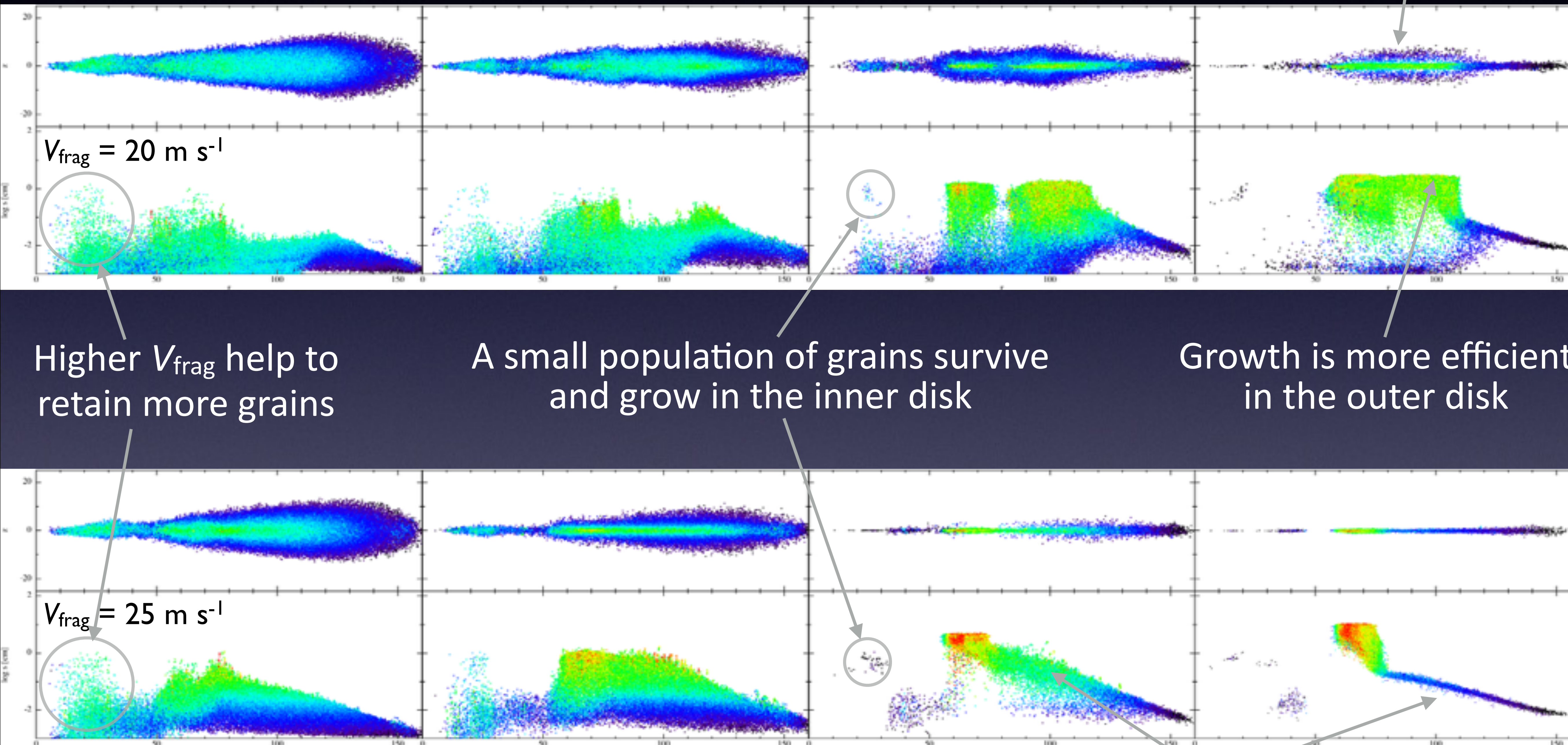


Lower V_{rel} lead to slow growth

t = 6,000 yr | t = 12,000 yr | t = 25,000 yr | t = 50,000 yr

Growth and fragmentation

Larger grains are more settled



Higher V_{frag} help to retain more grains

A small population of grains survive and grow in the inner disk

Growth is more efficient in the outer disk

The outer disk is almost not affected by fragmentation

t = 6,000 yr *t* = 12,000 yr *t* = 25,000 yr *t* = 50,000 yr

Conclusion

- Pure growth
  - Very efficient growth at both gap edges
  - Sizes > 10 cm
  - Gap edges: potential sites for the formation of additional planets

- Growth and fragmentation
  - Different growth behavior depending on radial location
  - Easier growth for larger $V_{\rm frag}$
  - Low $V_{\rm frag}$ (considered in most studies)

    ⇒ no significant growth past the radial-drift barrier

- Can grains really grow at $V_{\rm rel}$ above 20 m s^{-1}?

  ⇒ Yes!

  - Porous material — *Meru et al. (2013)*
  - Mass transfer in high-mass-ratio collisions — *Teiser & Wurm (2009)*