Detection of dust settling with ALMA

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Summary

I) Predicted settling

II) Dust grain emissivity

III) Disks modeling and results

IV) Conclusion

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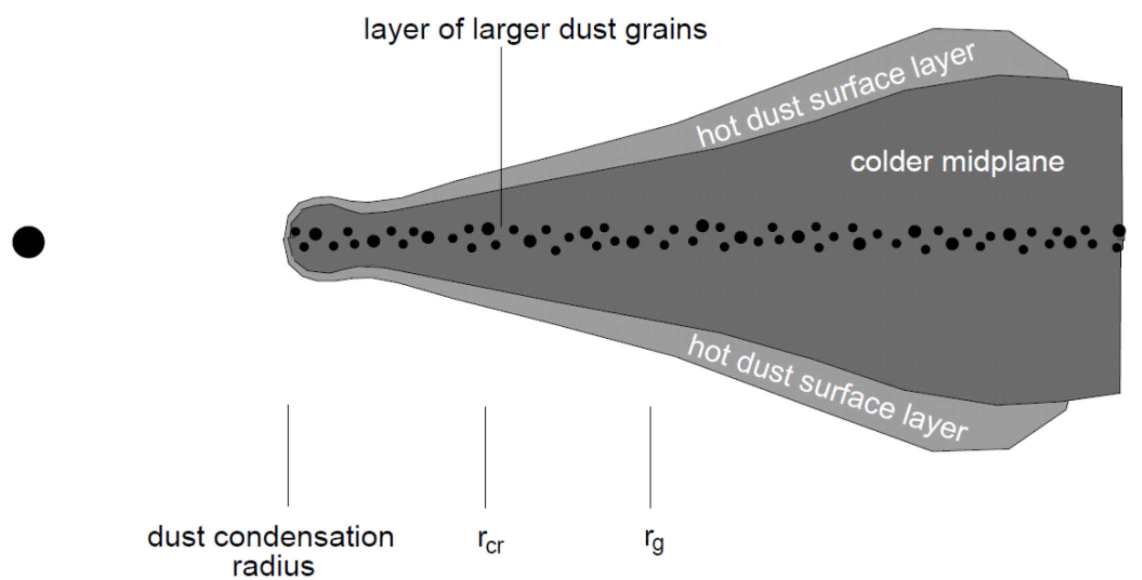
Predicted settling

Settling:

- in favour : star gravity
- against : coupling with gas (pressure, turbulence)

⟶ vertical segregation in function of the grain size



Dullemond et al., 2007

What we need to know:

- the vertical distribution
- the emissivity

In function of the grain size

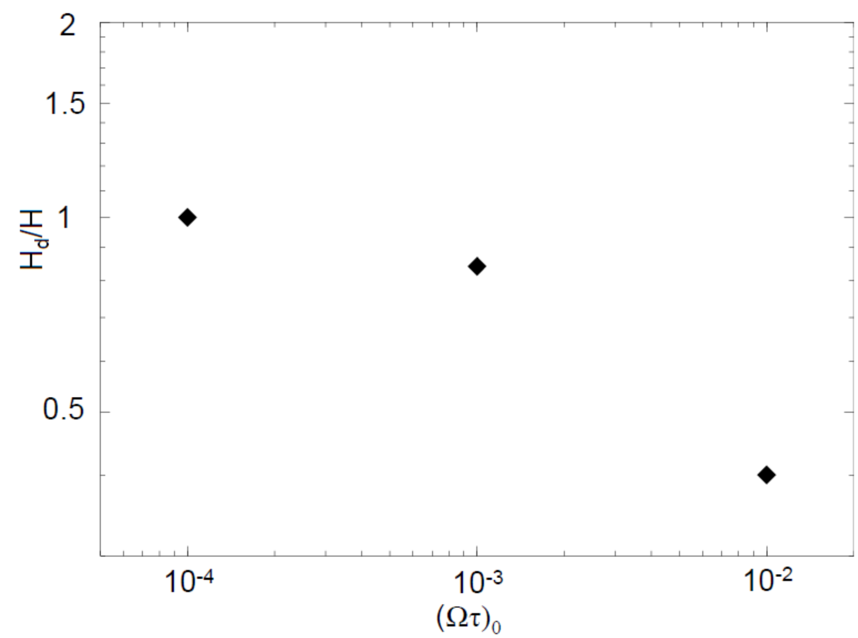
Predicted settling

Parametrised law to represent the dust scale height:

$$\frac{H_d}{H} \propto ((\Omega\tau)_0)^{-\alpha}$$

With Ω the velocity speed and τ (= $(\rho_s a)/(\rho_g c_s)$) the dust stopping time.

Dust scale height in function of $(\Omega\tau)_0$



Adapted from
S. Fromang & R. P Nelson, 2009

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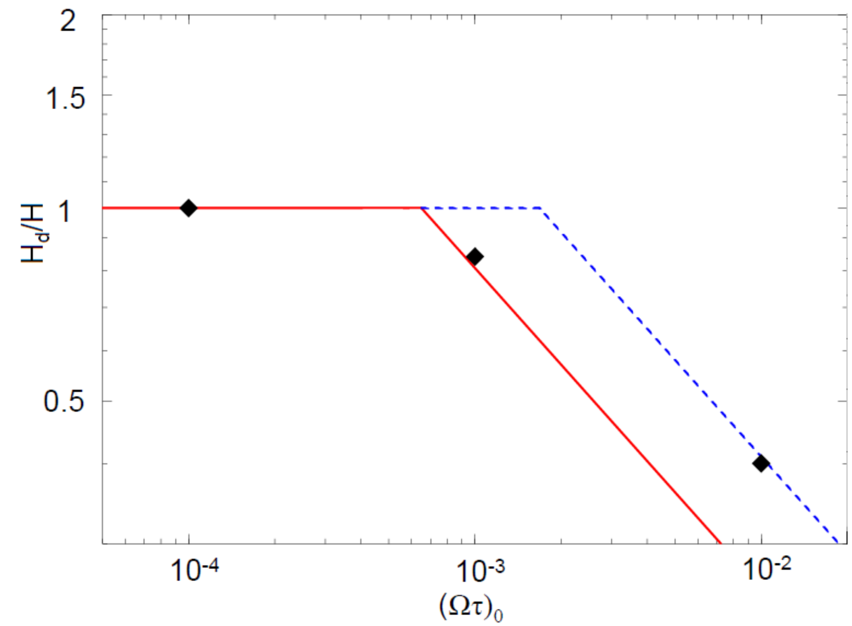

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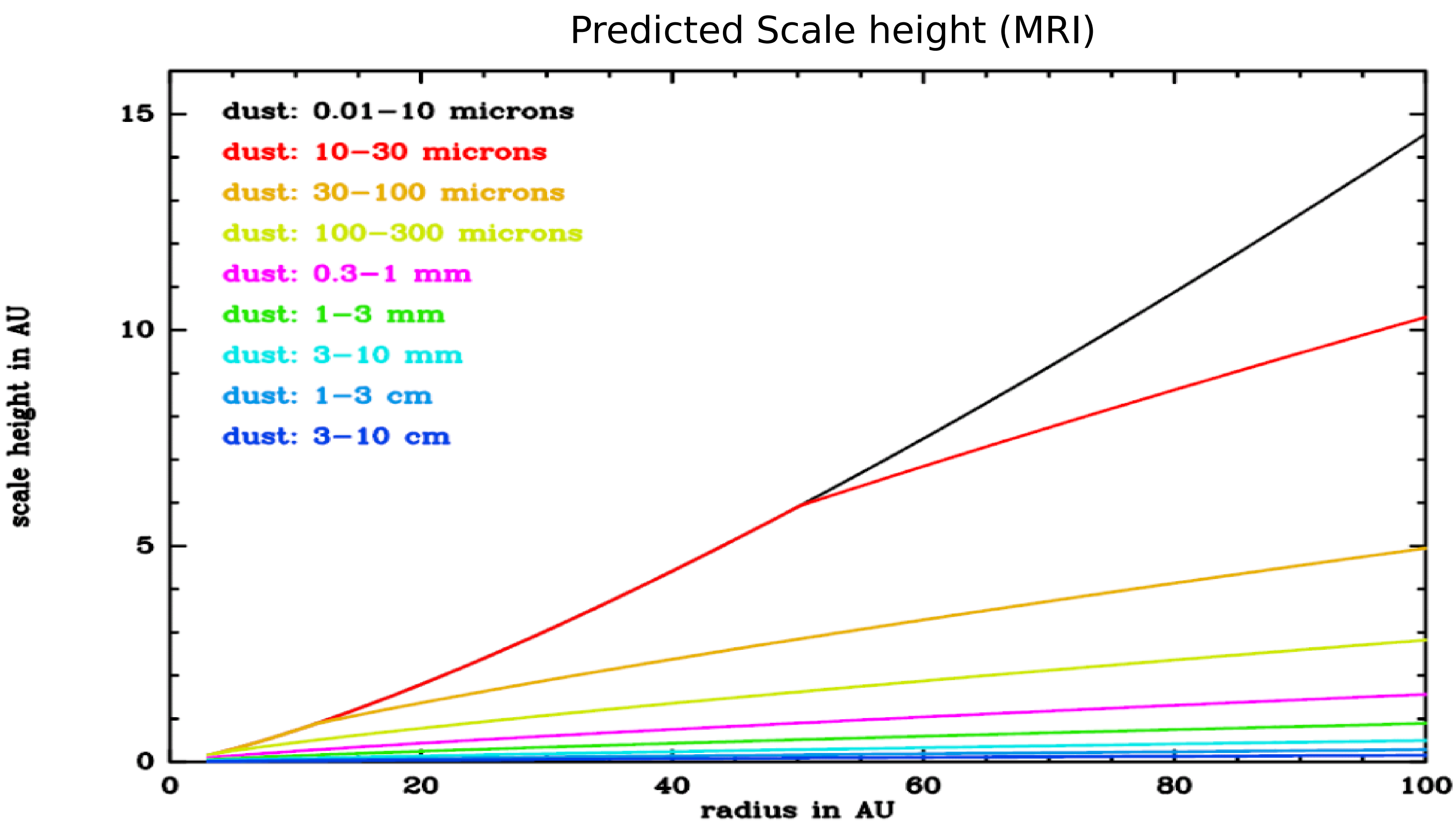
Théorie, simulations et observations:

- small grains: $\alpha = 0.05$ (Pinte et al,2008, IR obs,)
  or even 0, discussion Fromang.
- big grains: $\alpha = 0.5$ (Dubrulle et al, 1995) (Carballido et al, 2006)

Predicted settling

Vertical gaussian distributions

- several types of grains:
- bigger are the grains, smaller are their scale height



Boehler et al, 2012

Predicted settling

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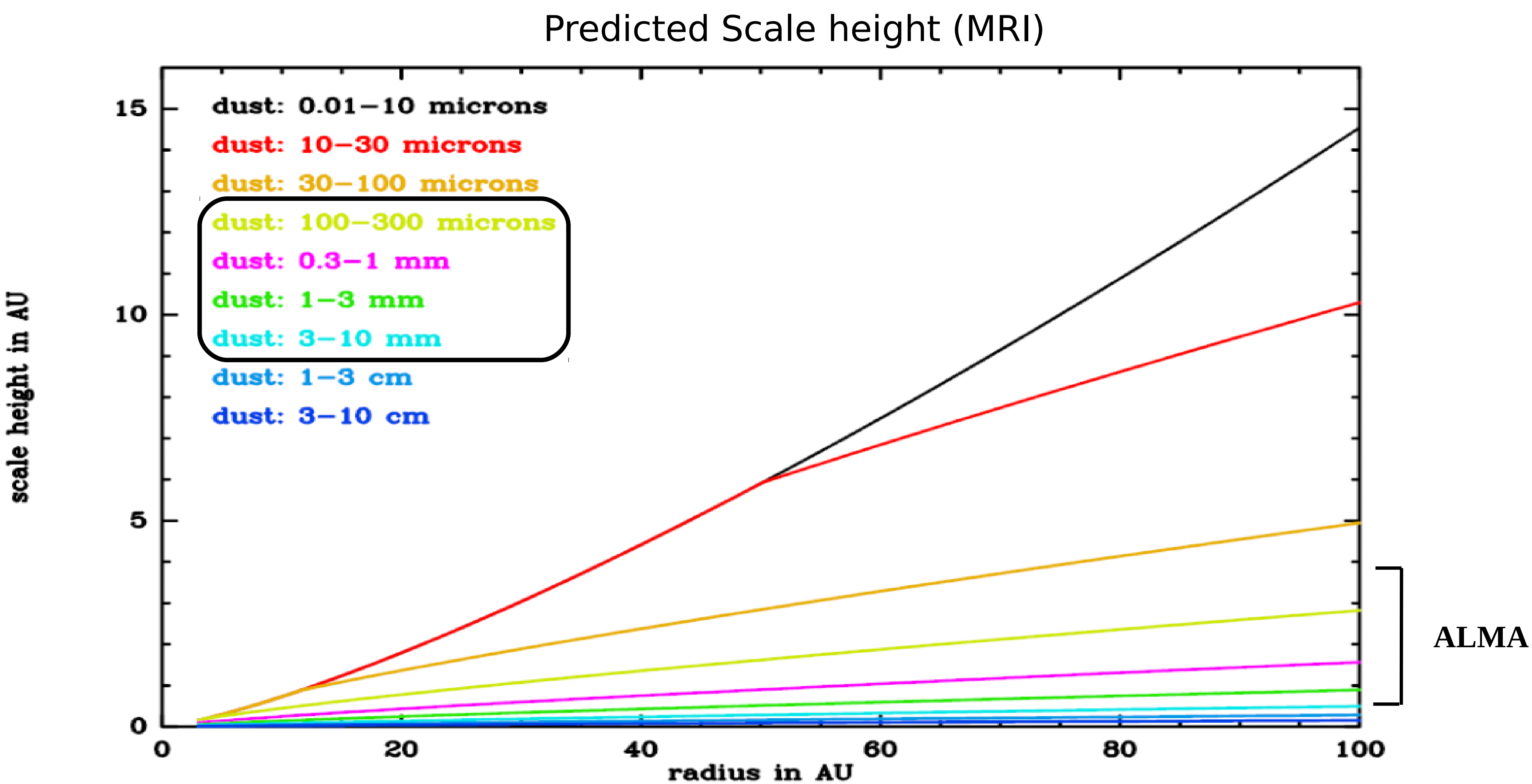

Boehler et al, 2012

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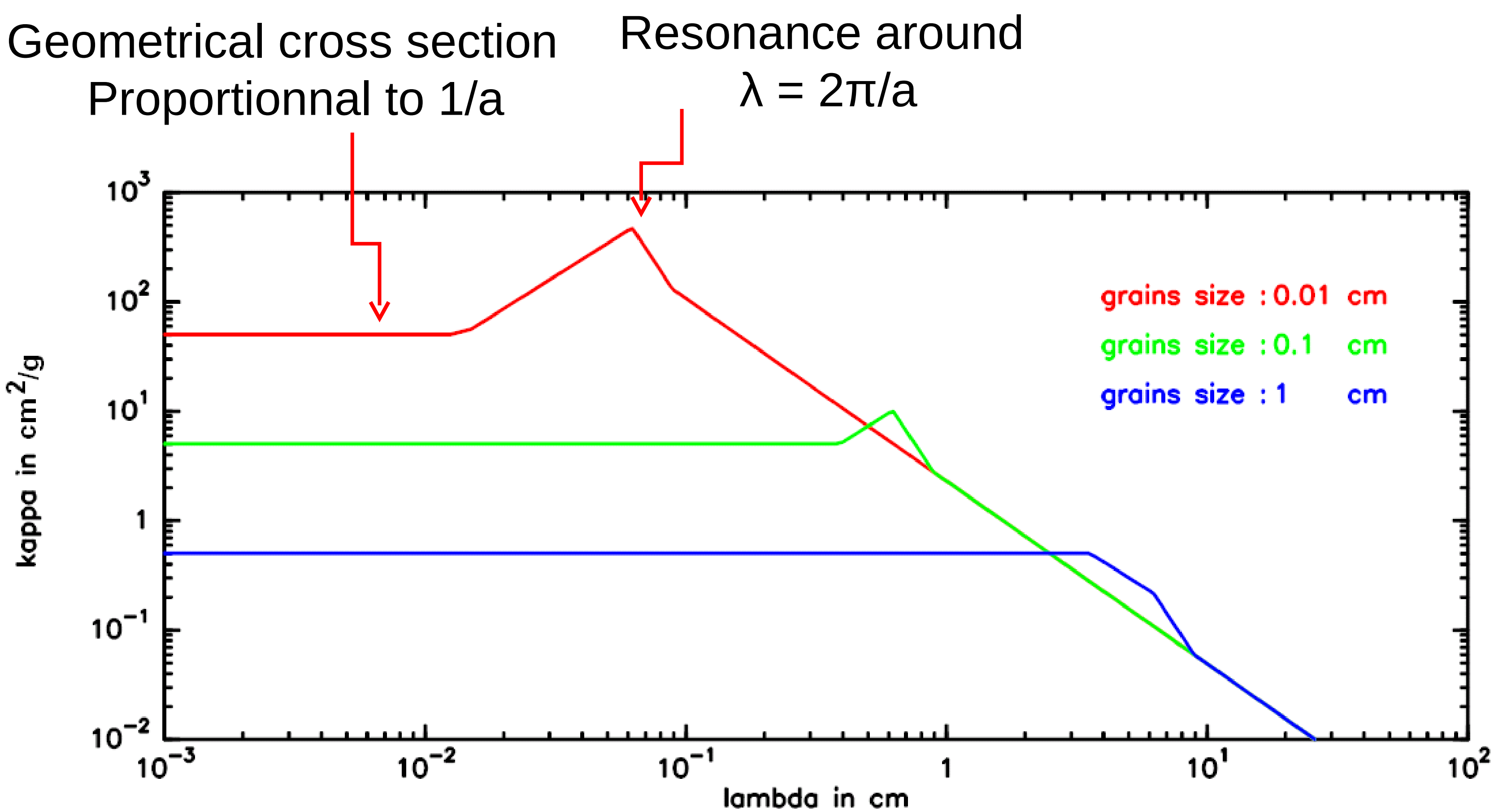
Dust grain emission

Method:

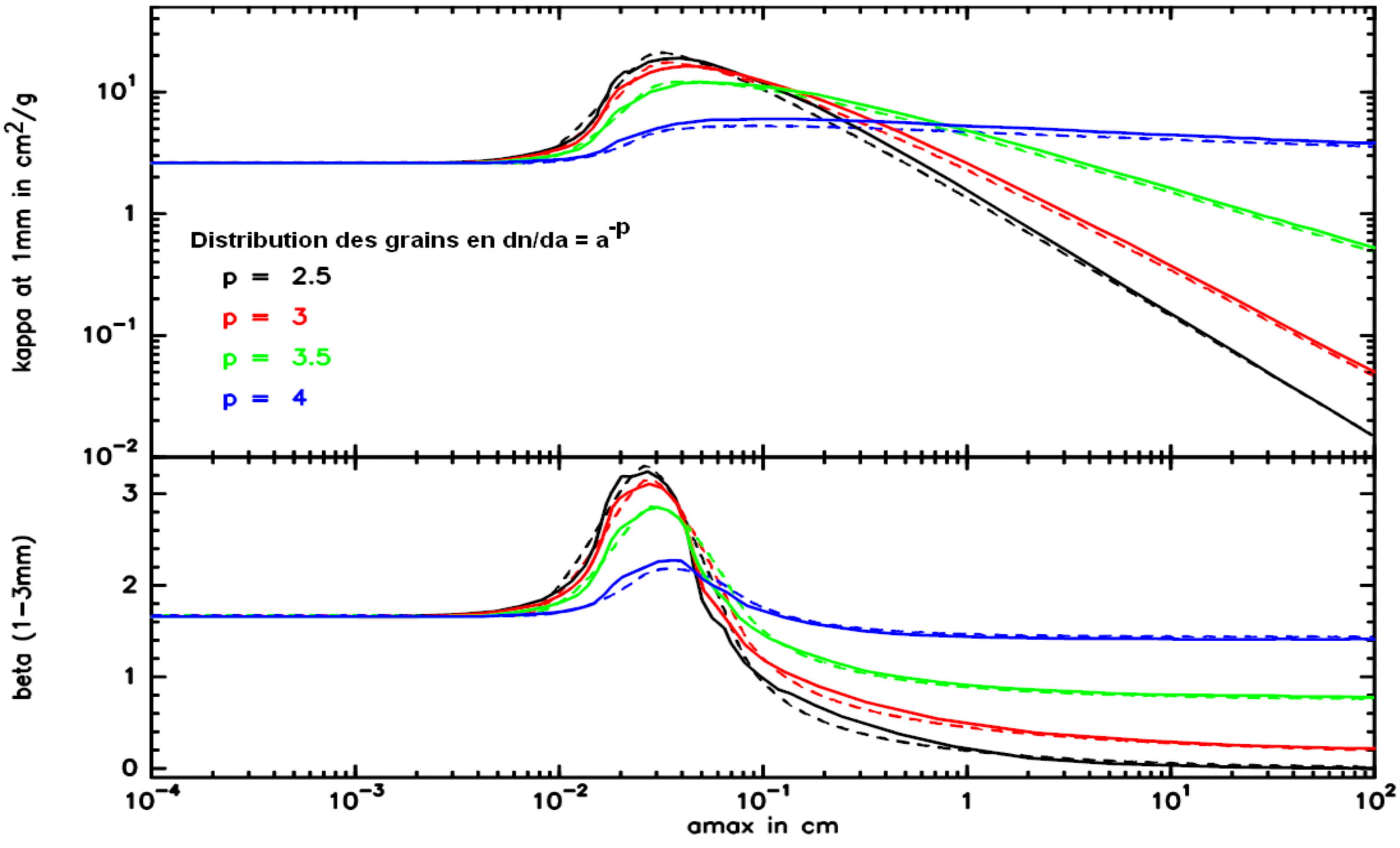
Parametrised law allowing to determine the emission coefficients in function of λ and of the grain radius



Boehler et al, 2012

Calibration of the emissivity curves

Data coming from Ricci et al, 2010:
- obtained by the Mie theorie
- With for composition: 10 % astronomical silicates, 20 % of carbonaceous
material, 30 % of water ice and 40% of vacuum



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Pseudo-observations created

Physical characteristics	Adopted values
type of grains	Moderate ($\leq$ 3 mm) or big ($\leq$ 10 cm)
gas scale height	in hydrostatic equilibrium (Eq. 5)
Temperature	$T_k(r) = 30\left(\frac{r}{R_0}\right)^{-0.4}$ Kelvin
Density	$\Sigma_g(r) = 3.4\left(\frac{r}{R_0}\right)^{-1}$ g.cm^{-2}
Reference radius	$R_0 = 100$ AU
Disk edges	$R_{int} = 3$ AU and $R_{out} = 100$ AU
Inclinations	70, 80, 85 and 90°

Conditions of observation :

- Maximum baselines of 2.5 km
- 4 wavelenghts: 0.5mm (0.45''), 0.9 mm (0.89''), 1.3 mm (0.13'') and 3mm (0.30'')
- 30 minutes of integration time per frequency and a thermal noise of 111, 30, 20 and 13 µJy (respectively).

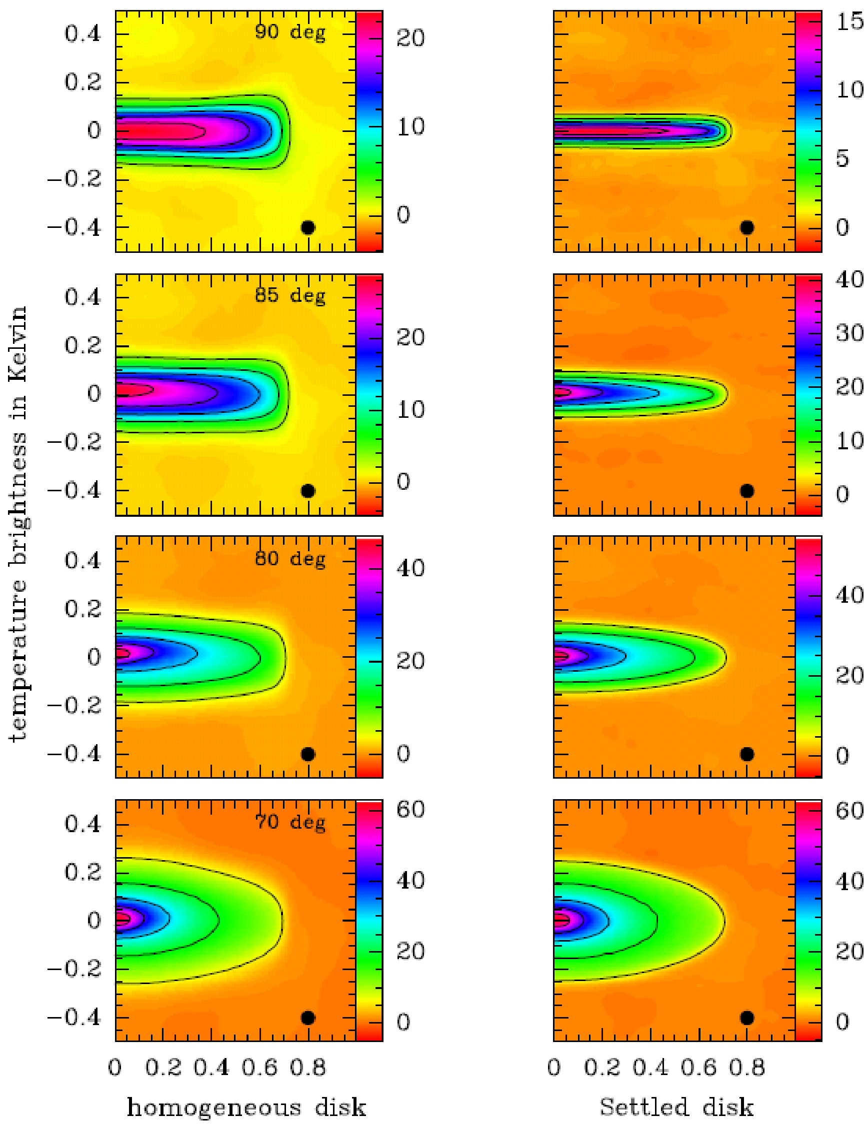
Comparison of settled disks and non-settled disks having the same gas distribution

90°

85°

80°

70°

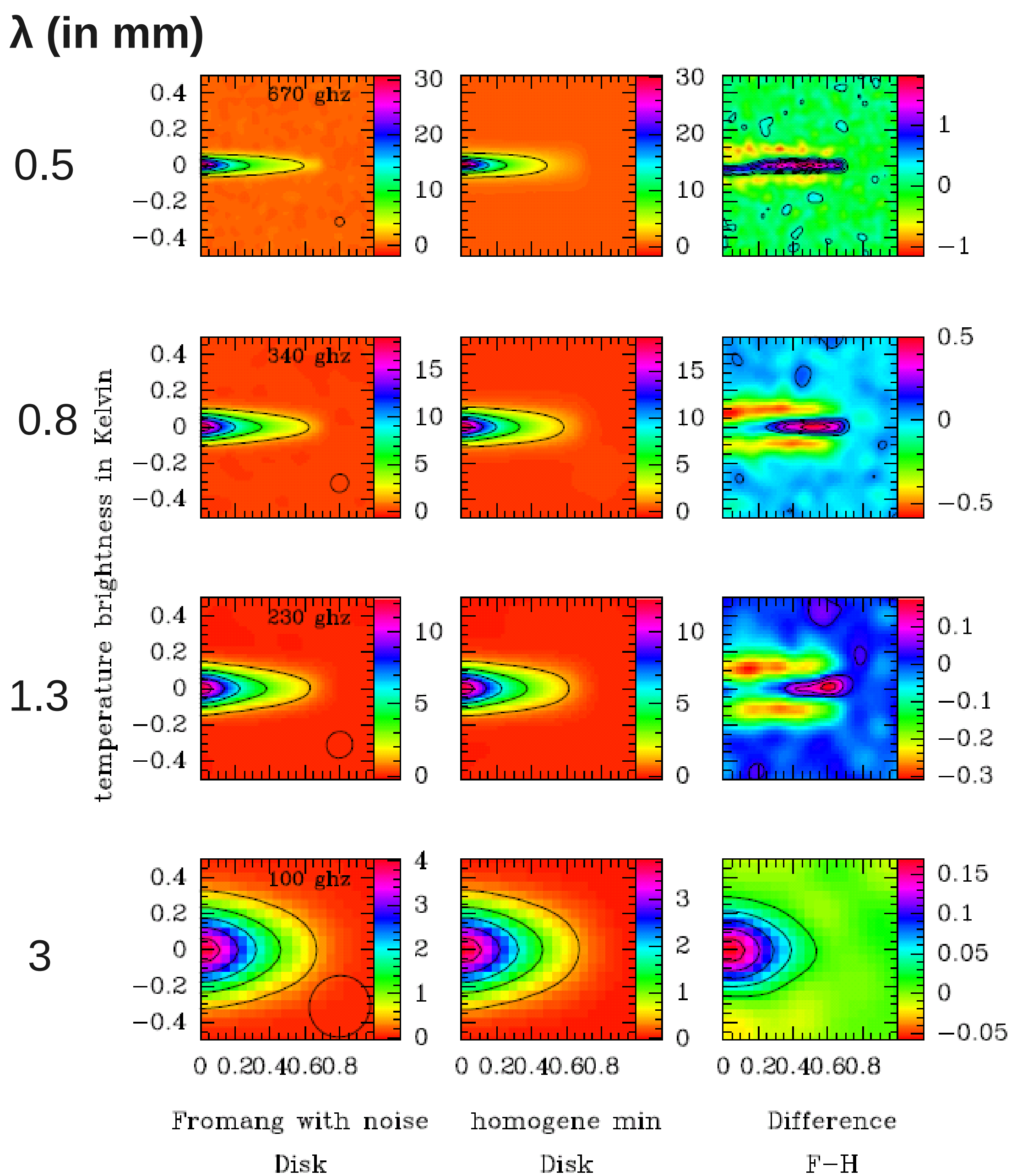


Boehler et al, 2012

Pseudo-Images of disks viewed:
- at 0.5mm (0.045 ")
- with ALMA in a configuration with Bmax = 2.5 km

The dust settling is visible for an inclination > 70°

Differences between a settled pseudo-observation and the closest non-settled model



Boehler et al, 2012

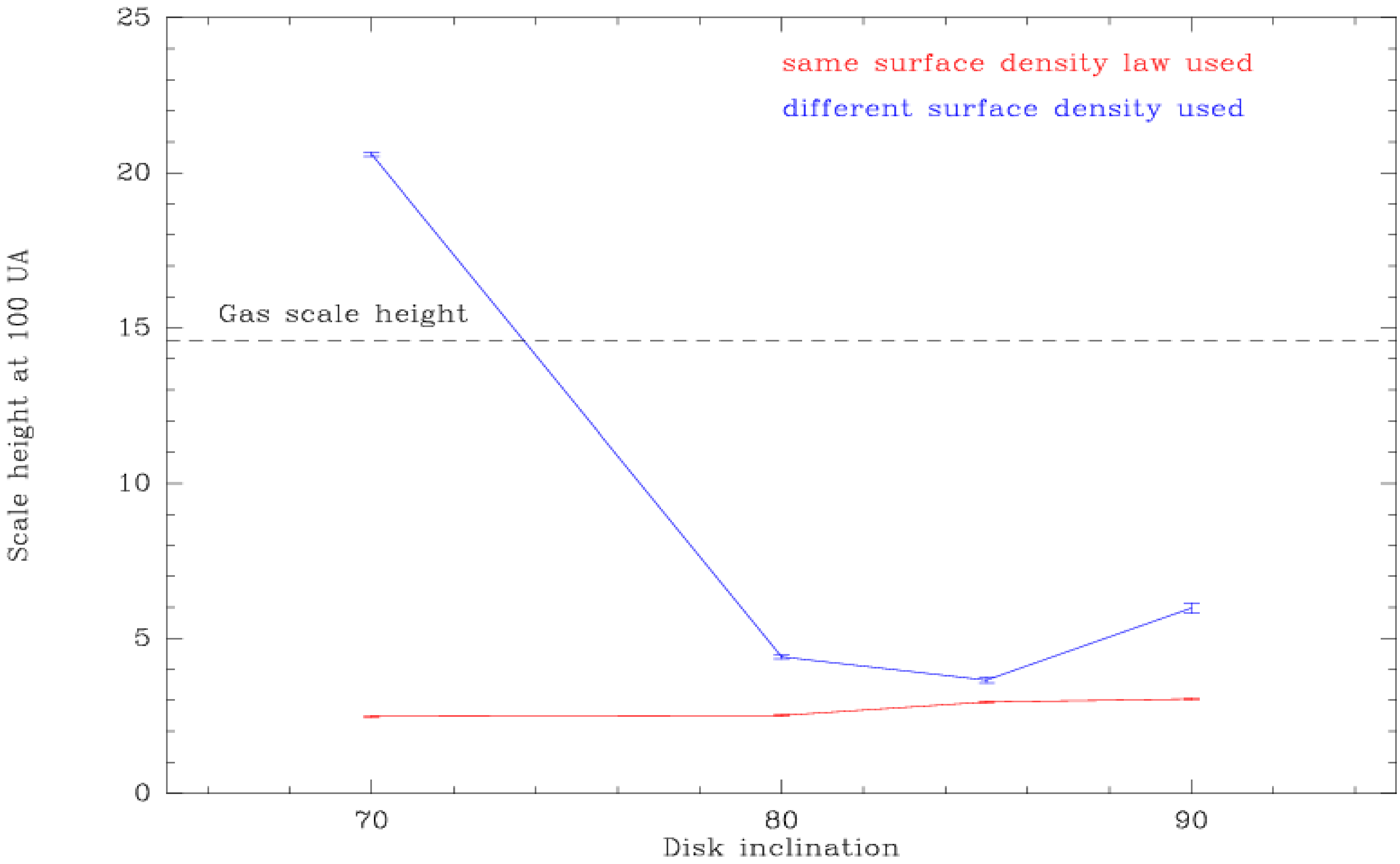
Left column :
pseudo – observation of settled disks)

Middle column:
Non settled disks obtained after minimization

Right column:
difference in emission of both disks

- resolution too weak at 3 mm
- The non-settled model has too much emission at high altitude but not enough on the mid-plane

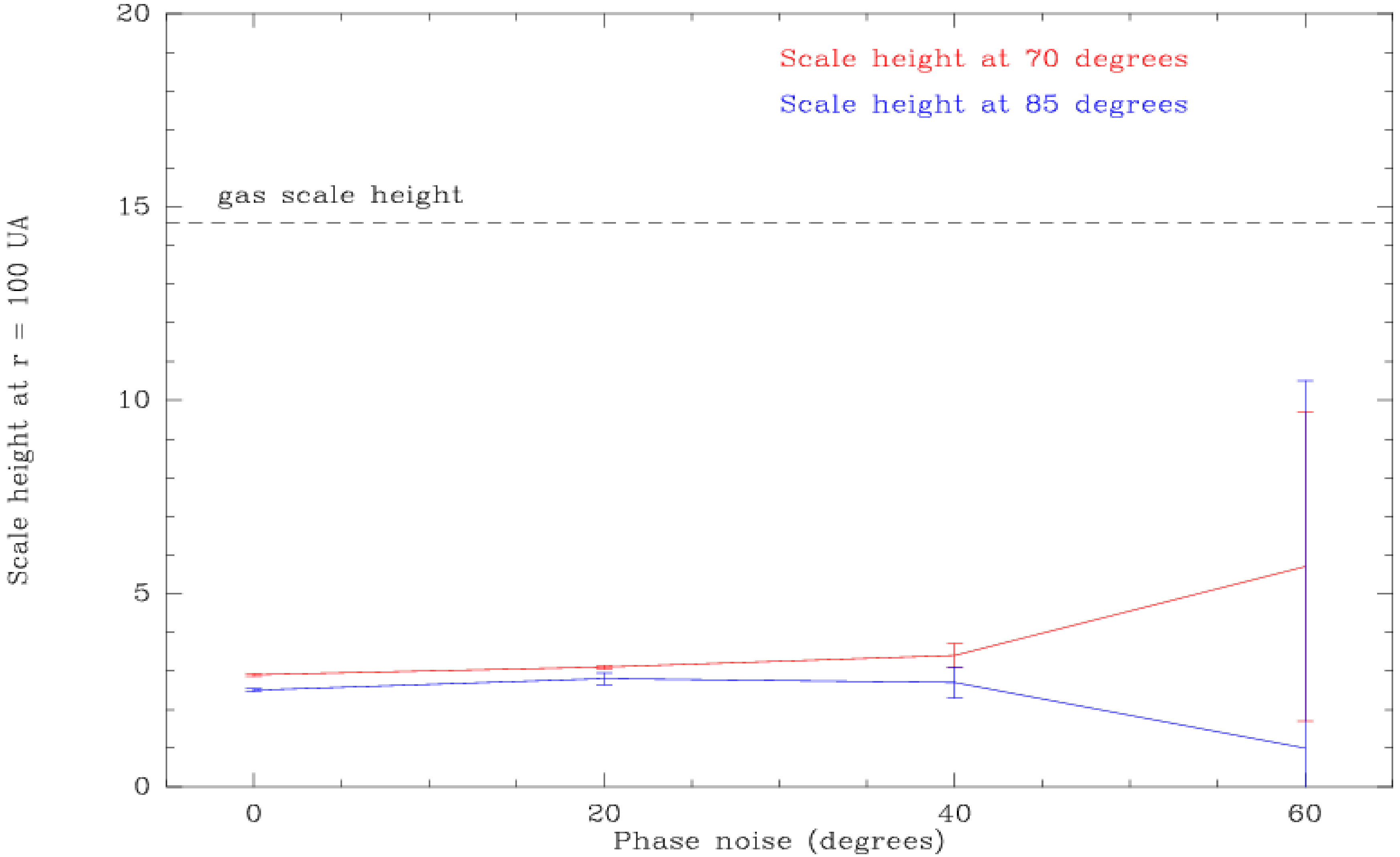
Scale height of a settled disk



Boehler et al, 2012

Dust scale height < gas scale height in hydrostatic equilibrium

Influence of the phase noise



A phase noise < 40 °:

- does not prevent to observe settling

Boehler et al, 2012

Conclusion

Dust settling observable with ALMA:

- With baselines up to 2.5 km:

    from 0.5 to 1.3 mm and an integration time of 30 mn

    an disk inclination > 75-80°

- Longest baselines are necessary to observe at 3 mm

Observational strategy:

First step :

Use moderates baselines to observe settling

Second step :

Use two different wavelengths, by keeping the same angular resolution, to evaluate the dust scale height for two different sizes of grains.

Disks with inclinations

- OPH-E_MM3: 90°, at 140pc, diameter of 210 AU, dans le nuage d'ophiucus
- Rem: les notations OPH-(A,B,C,D,E) se réfèrent à des cœurs de formations d'étoiles dans le nuage,
- Beta pic: 90°, à 19.3 pc, et un diamètre de 501 AU.
- CB 26: 88°, à 140 AU et un diamètre de 770 AU.
- HH 30: 83°, à 140 AU et un diamètre de 420 AU.
- DN Tau: 77°, à 140 AU et un diamètre de 70 AU.
- DG Tau B: 75°, à 140 pc et un diamètre de 550 AU.
- AA tau: 75°, à 140 pc et un diamètre de 187 AU.