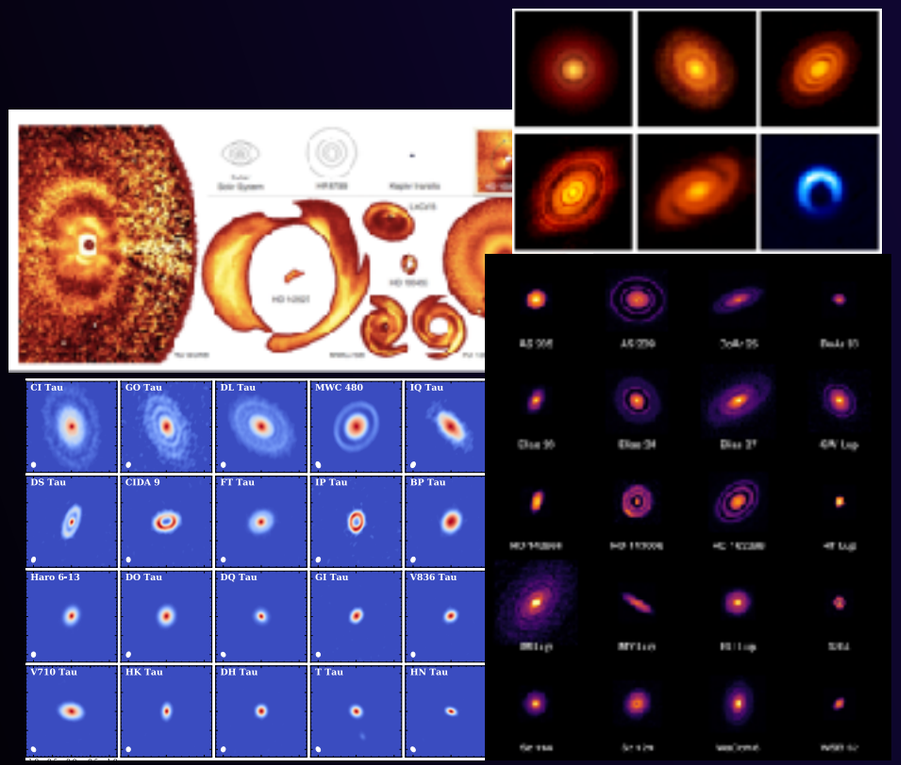
HOW MASSIVE ARE **PROTOPLANETARY/ PLANET HOSTING/PLANET FORMING** DISCS?



CAN ALL THESE STRUCTURES TELL US SOMETHING ABOUT THE (GAS) DISC MASS?

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DANIEL PRICE (MONASH-MOCA)

DUST BUSTERS

MoCA
Monash Centre for Astrophysics

OUR INGREDIENTS

Anna Miotello's talk
Inga Kamp's talk

Disc mass composition:
Gas 99% + dust 1% + hosting/forming planets

Small dust,
coupled with gas

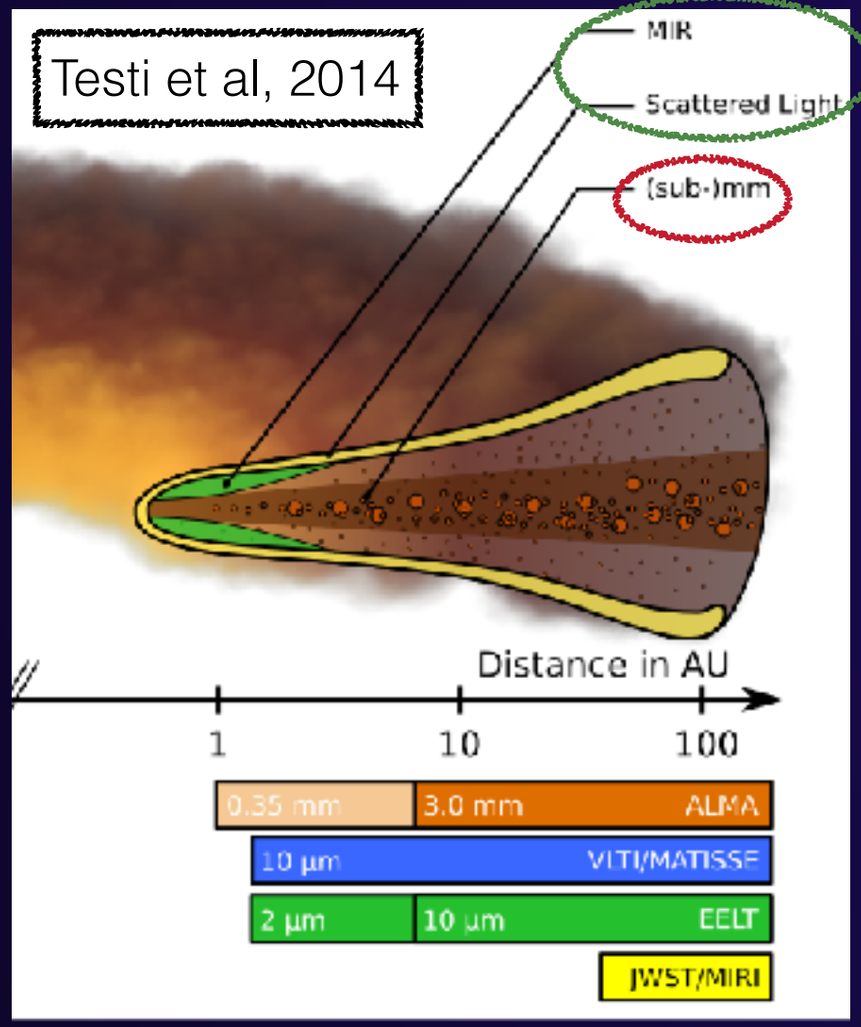
Large dust,
Decoupled by the gas

Gas: H_2 is the most abundant species, but:

- Symmetry of H_2 : rotational lines emission too weak!
- We need tracers: CO-isotopologues in the molecular layer

Dust:

- Disc opacity: dust is probed by continuum (sub-)mm observations
- Grain growth: first stage of planet formation
- Chemistry Ilse Cleeves' talk



HOW MUCH MASS IS THERE IN PROTOPLANETARY DISCS?

Optically thin mm flux (e.g. from ALMA)

Distance to disk (e.g. from Gaia)

$$M_{\rm dust} = \frac{F_\nu d^2}{\kappa_\nu B_\nu(T_{\rm dust})}$$

Single grain **opacity** (large uncertainty)

Dust temperature (e.g. **isothermal** 20 K

Dust mass primarily in (sub)mm grains

$$M_{\rm disk} \approx 100 \times M_{\rm dust}$$

ISM gas-to-dust ratio (gas is 99% of disk mass)

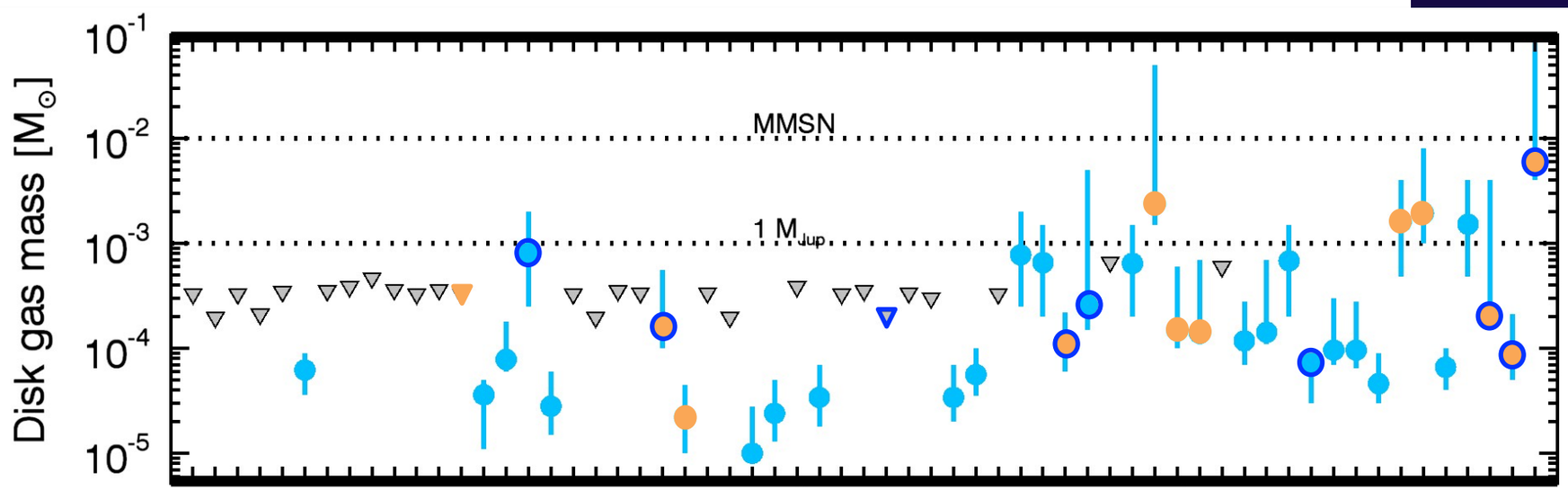
From the disc-ussion

lower limit estimate: low CO-based gas masses and gas-to-dust ratios

Also, are we sure about the dust mass?

Why do protoplanetary disks appear not massive enough to form the known exoplanet population?

C. F. Manara[1,*], A. Morbidelli[2], and T. Guillot[2]



THE SCALE: DUST & GAS INTERACTION

Stokes number

$$\mathrm{St} = t_{fric}\Omega_k = \frac{\rho_p a}{\Sigma_{gas}}\frac{\pi}{2}$$

at midplane

$\mathrm{St} < 1$ Dust and gas are COUPLED

Palm Cove with sandy water (and crocos)

THE SCALE: DUST & GAS INTERACTION

Stokes number

$$\mathrm{St} = t_{\mathrm{fric}}\Omega_{\mathrm{k}} = \frac{\rho_{\mathrm{p}} a}{\Sigma_{\mathrm{gas}}}\frac{\pi}{2}$$

at midplane

$\mathrm{St} < 1$ — Dust and gas are COUPLED

$\mathrm{St} \gg 1$ — Dust and gas are DECOUPLED

Somewhere else
with clear water
(without crocos)

THE SCALE: DUST & GAS INTERACTION

Stokes number

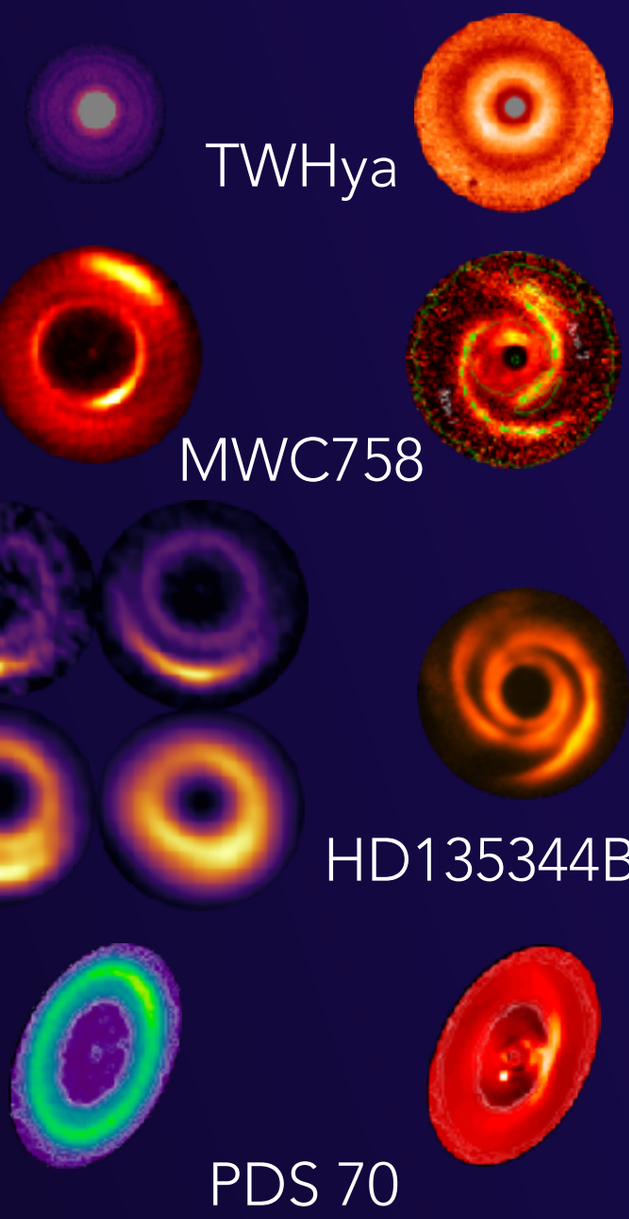
$$\mathrm{St} = t_{fric}\Omega_k = \frac{\rho_p a}{\Sigma_{gas}}\frac{\pi}{2}$$

at midplane

- $\mathrm{St} < 1$ — Dust and gas are COUPLED
- $\mathrm{St} \gg 1$ — Dust and gas are DECOUPLED

If the dust grain size is known, depending on the sub-structures we see (spirals, rings...) both in the gas and in the dust, we can infer information on **degree of coupling between dust and gas** → gas disc mass

ALMA SPHERE



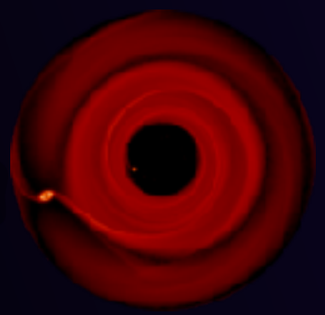
....and many others

WORKFLOW

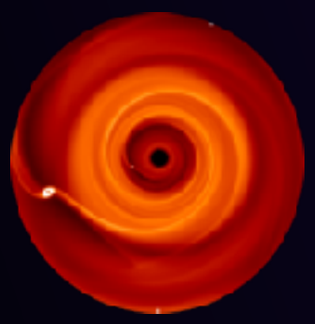
Hydrodynamical and radiative transfer simulations of protoplanetary discs with different Stokes number values (i.e. different disc mass values).

PHANTOMSPH

Density maps



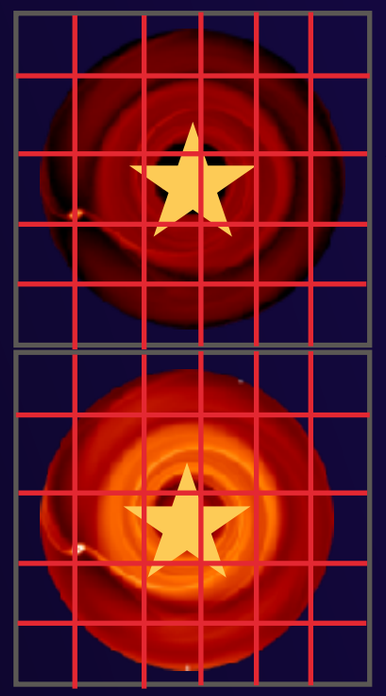
μm dust



mm dust

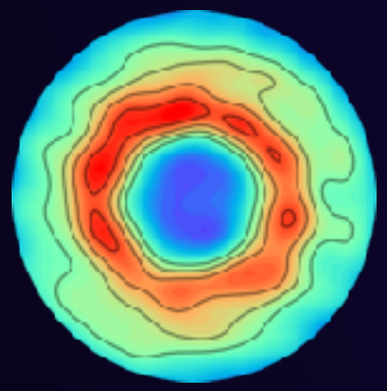
PHANTOM (Price et al 2018)

$$n(a) \propto a^{-q}$$
$$a = [0.1 - 10]\,\mu\text{m}$$
$$a = [0.01 - 1]\,\text{cm}$$



RADMC-3D (Dullemond et al 2012)

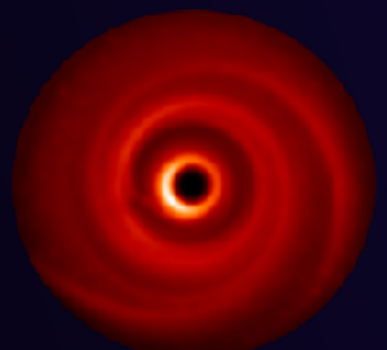
ALMA



CASA Common Astronomy Software Applications

SYNTHETIC IMAGE

SPHERE

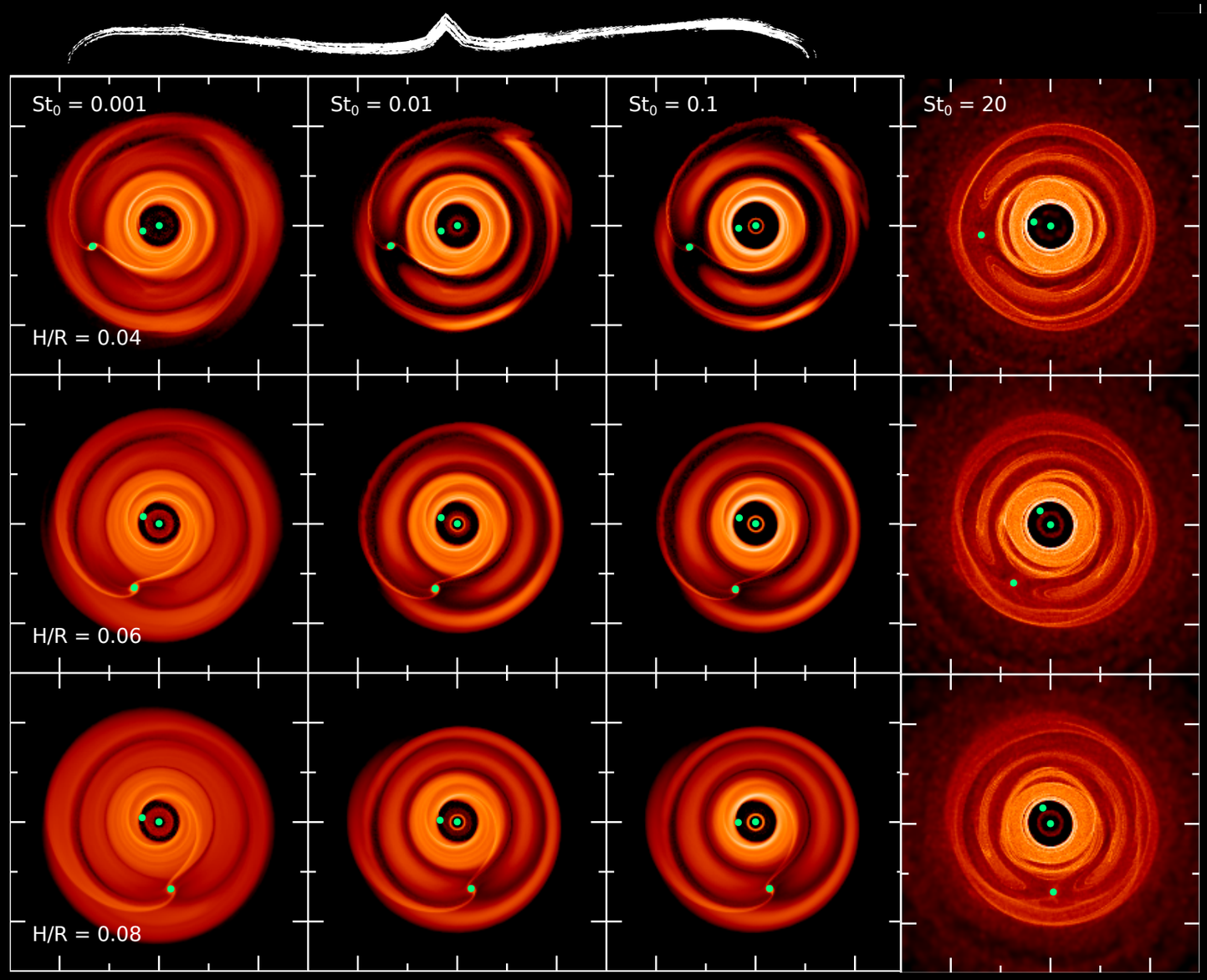


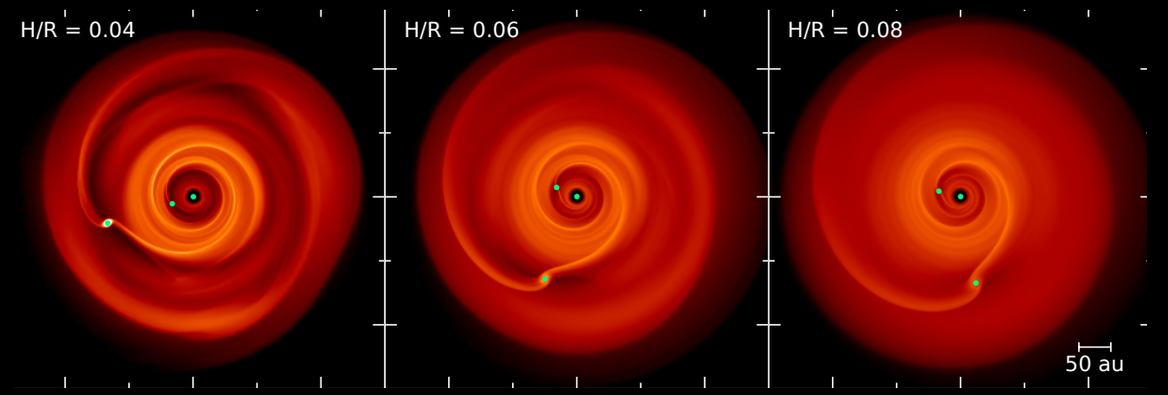
SPH SIMULATIONS

- One and two fluids simulations: different degree of coupling

DUST: ONE-FLUID

(Price & Laibe 2015; Ballabio et al. 2018)





GAS

2 embedded PLANETS:

-sink particles

- migration

- accretion

DUST: TWO-FLUID

(Laibe & Price 2012a,b)

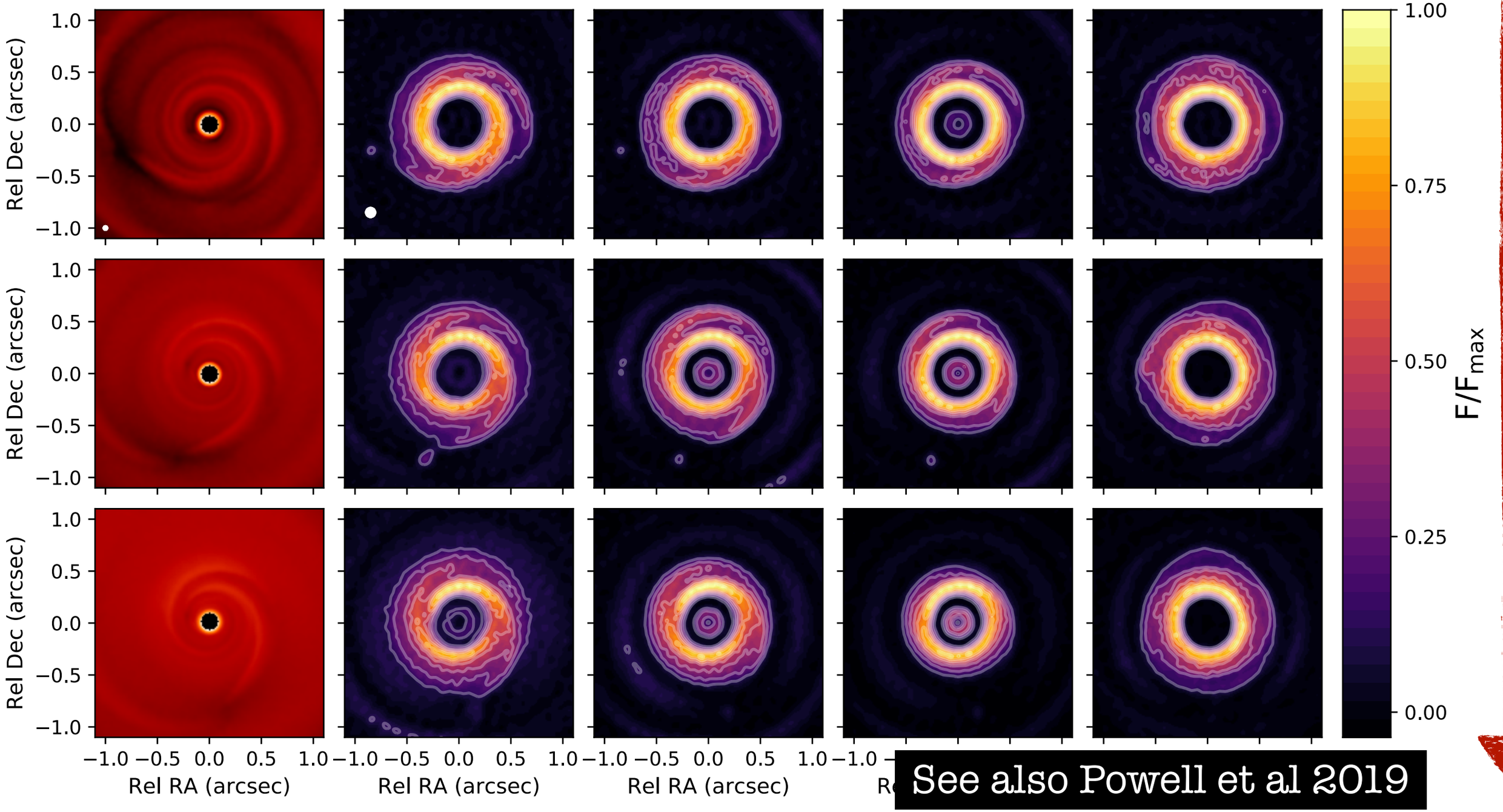
SYNTHETIC IMAGES: SPHERE & ALMA

Veronesi et al submitted

ALMA, cycle 6, 230 GHz, band 6

SPHERE

$St \simeq 10^{-3}$ $St \simeq 10^{-2}$ $St \simeq 10^{-1}$ $St \simeq 20$



See also Powell et al 2019

CAN WE SAY SOMETHING MORE?
RESIDUALS

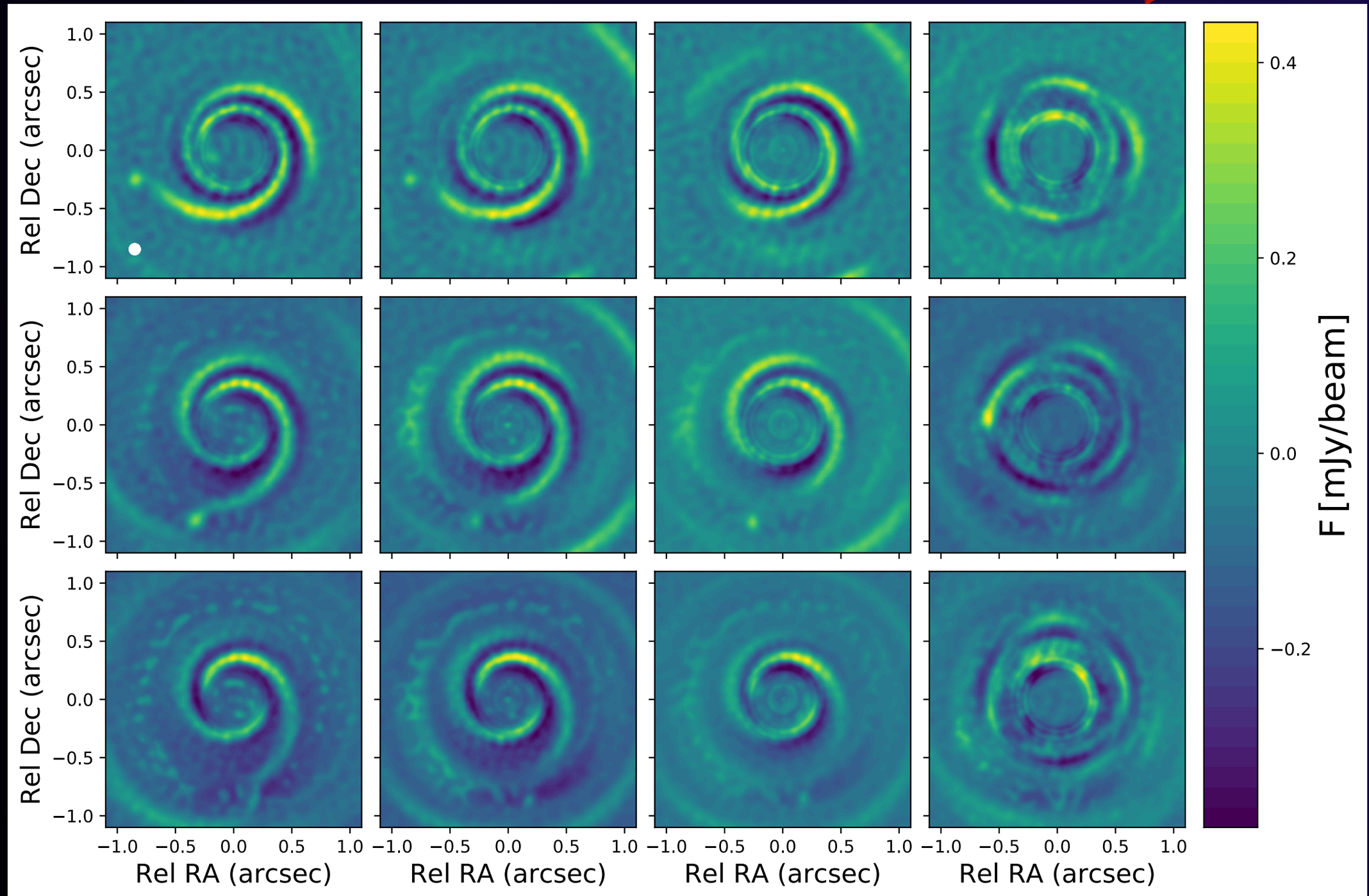
Veronesi et al submitted

$\mathrm{St} \simeq 10^{-3}$ $\mathrm{St} \simeq 10^{-2}$ $\mathrm{St} \simeq 10^{-1}$ $\mathrm{St} \simeq 20$

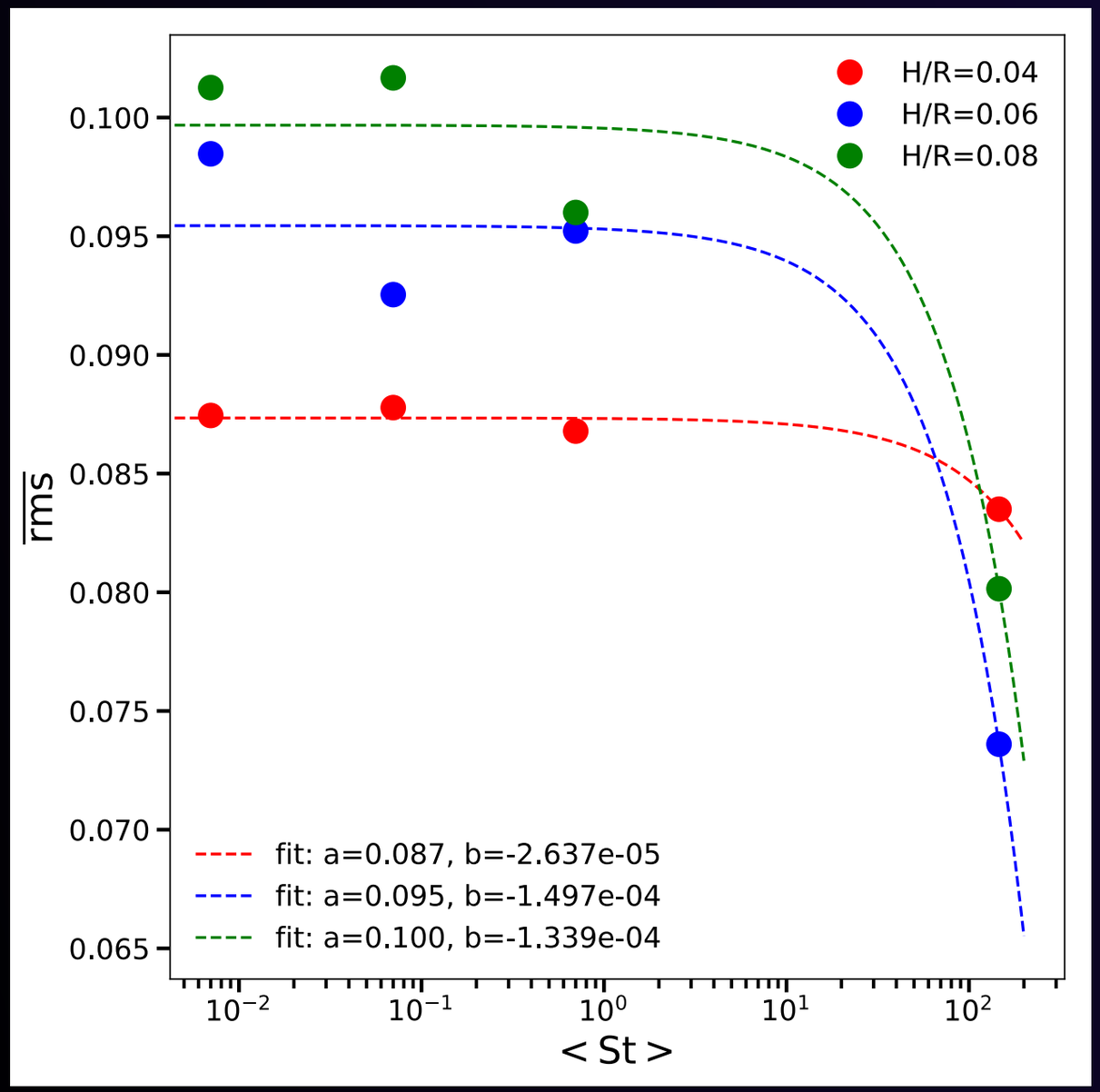
H/R=0.04

H/R=0.06

H/R=0.08



CAN WE SAY SOMETHING MORE?



By increasing the Stokes number, the weighted average of the standard deviation decrease ... the system becomes more axi-symmetric

TAKE HOME MESSAGES

- Importance of investigating the dust and gas interaction in order to understand what is the origin of the substructures we are observing

- **Stokes number**: if grain size is known ⟶ information on the amount of gas mass by looking at the degree of coupling between dust and gas

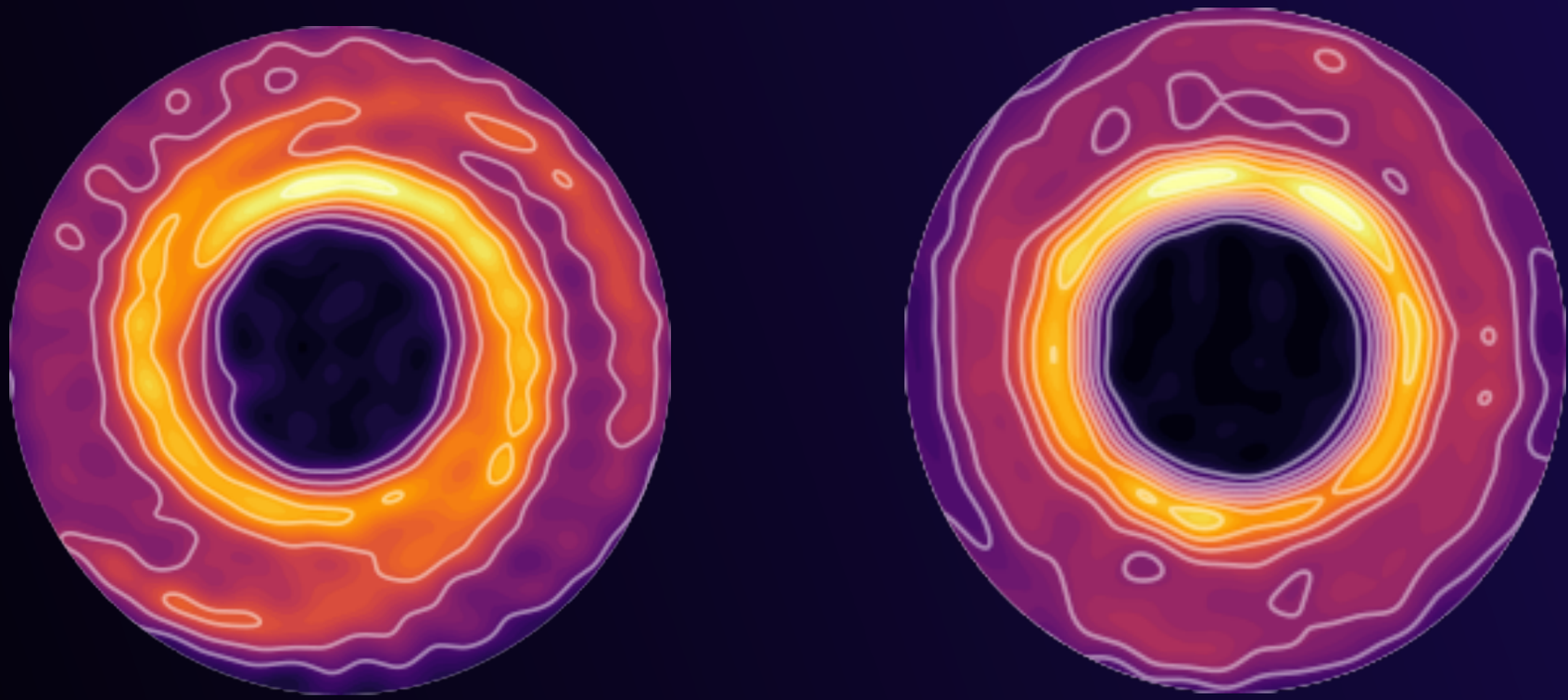
- ALMA synthetic images: from low St (high mass) to high St (low mass) ⟶ spirals become axi-symmetric structures

- But…we need more **multi-wavelengths observations** for the same source

DUST BUSTERS

THANKS FOR THE ATTENTION!

That's all discs!



QUESTIONS?