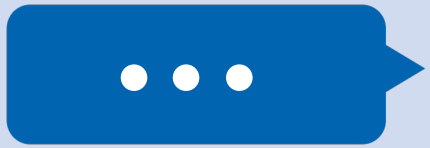
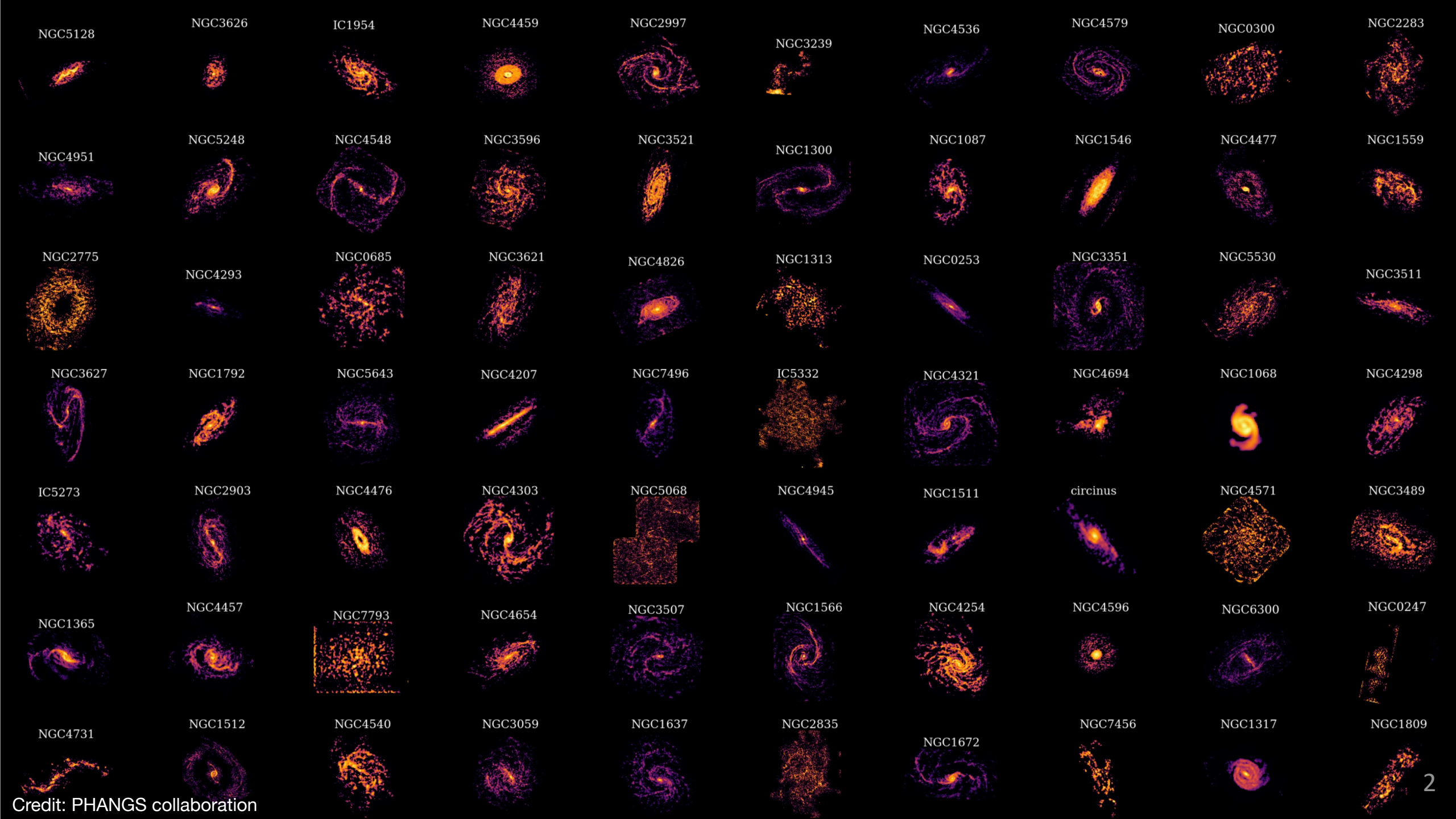
On the Tremaine-Weinberg method:

Olga Borodina
Thomas Williams
Eva Schinnerer
Mattia Sormani
Sharon Meidt

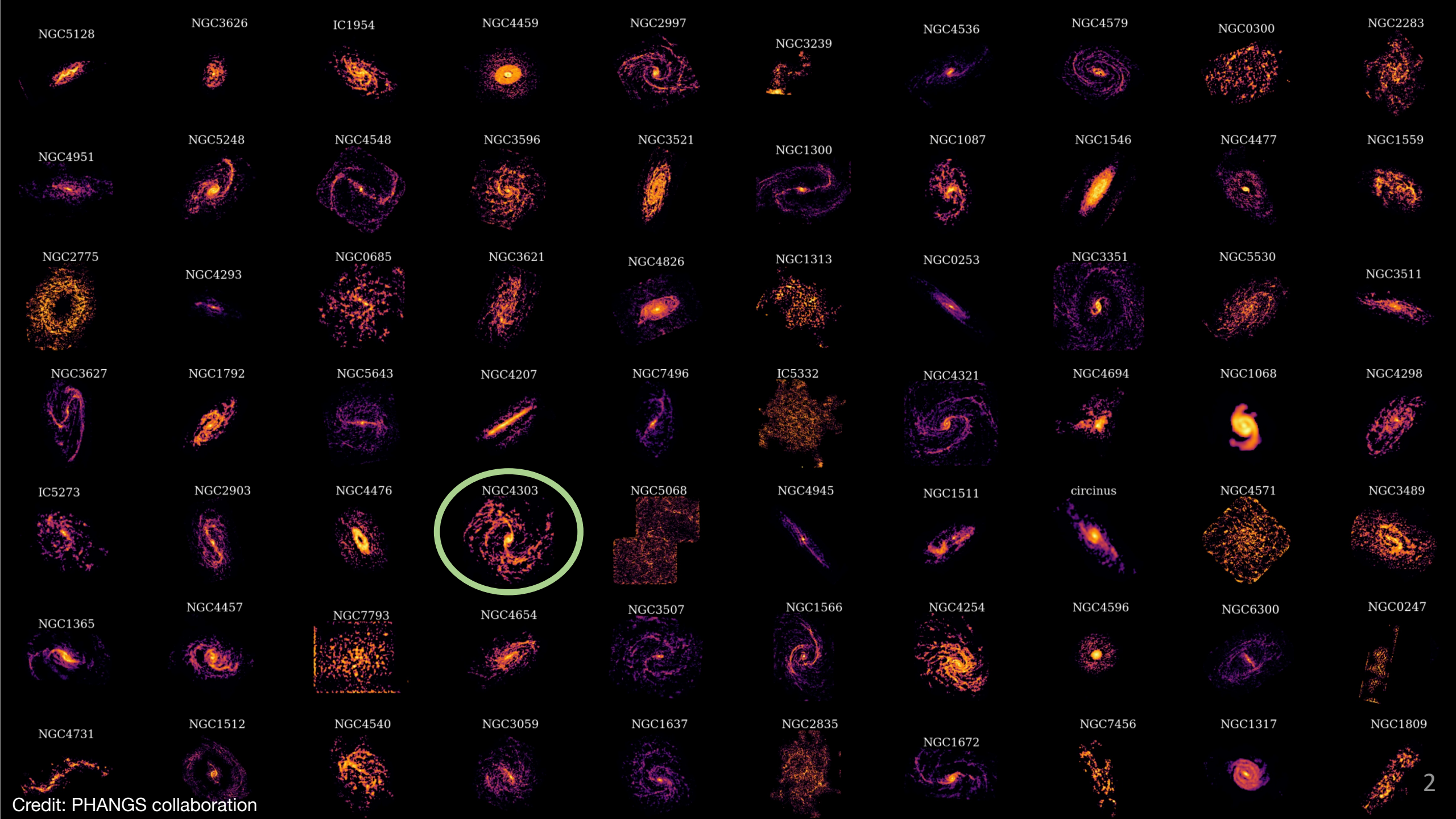
can we trust gas tracers to measure pattern speeds?

14:02

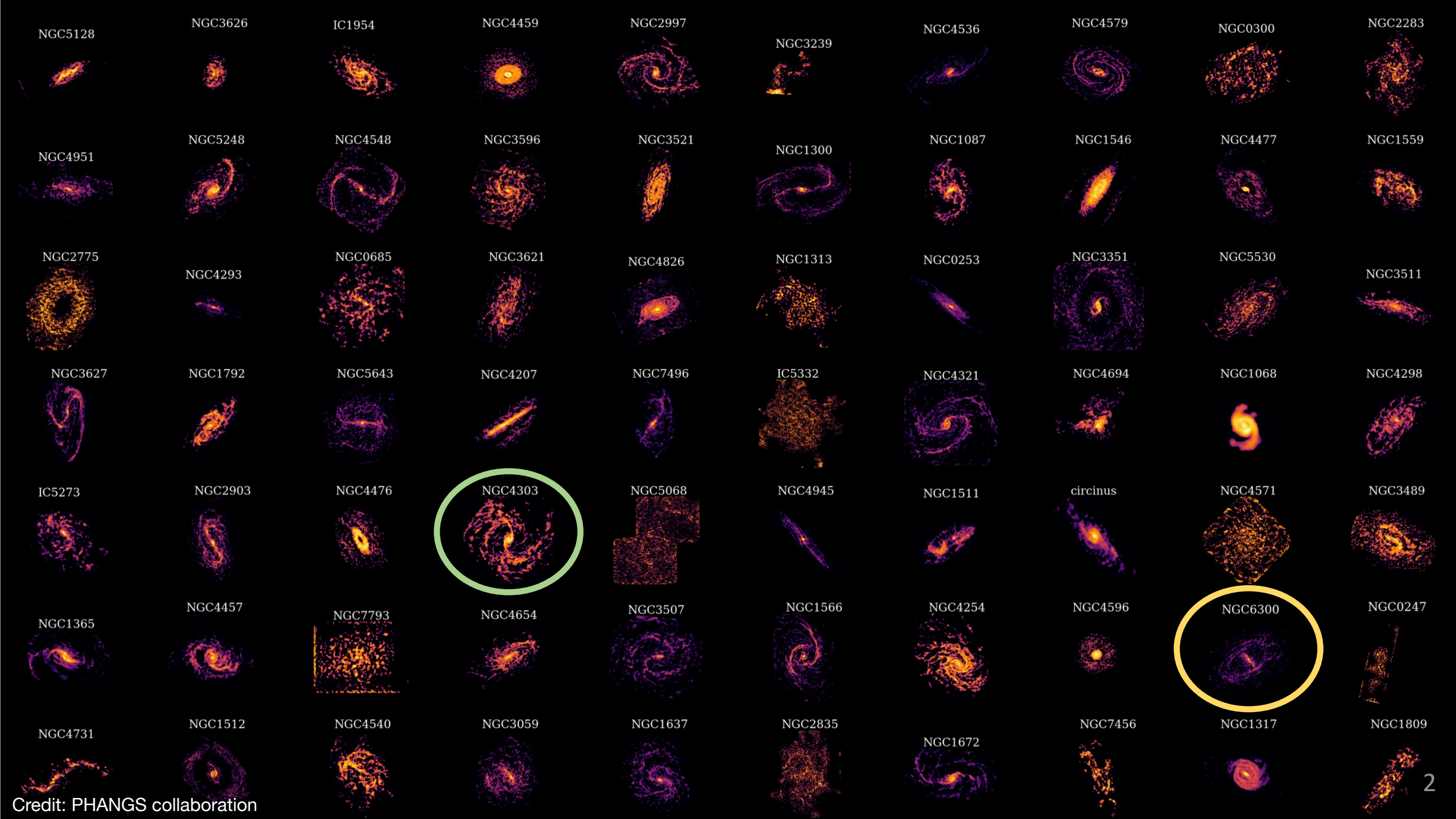




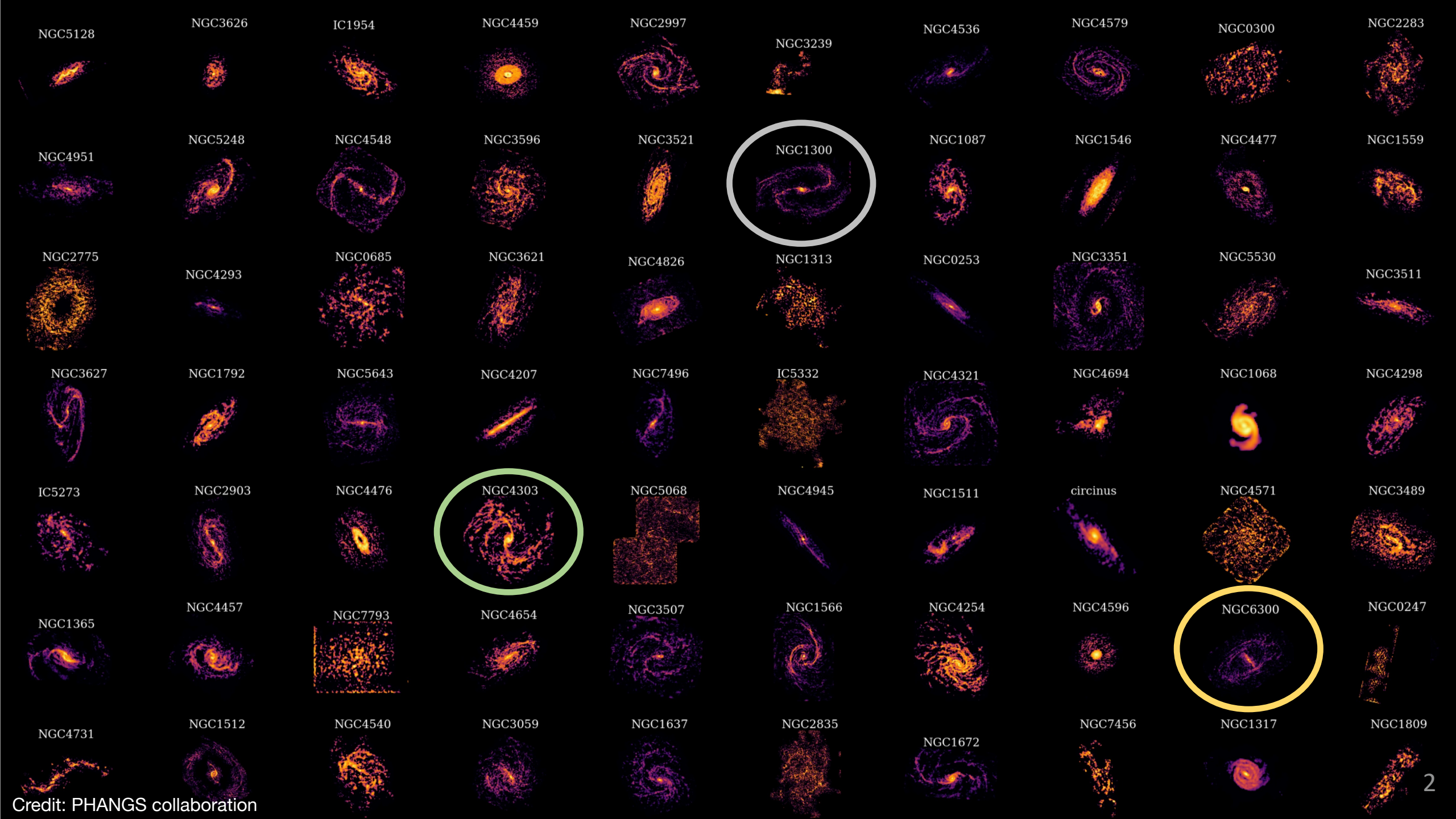
Credit: PHANGS collaboration



Credit: PHANGS collaboration



Credit: PHANGS collaboration

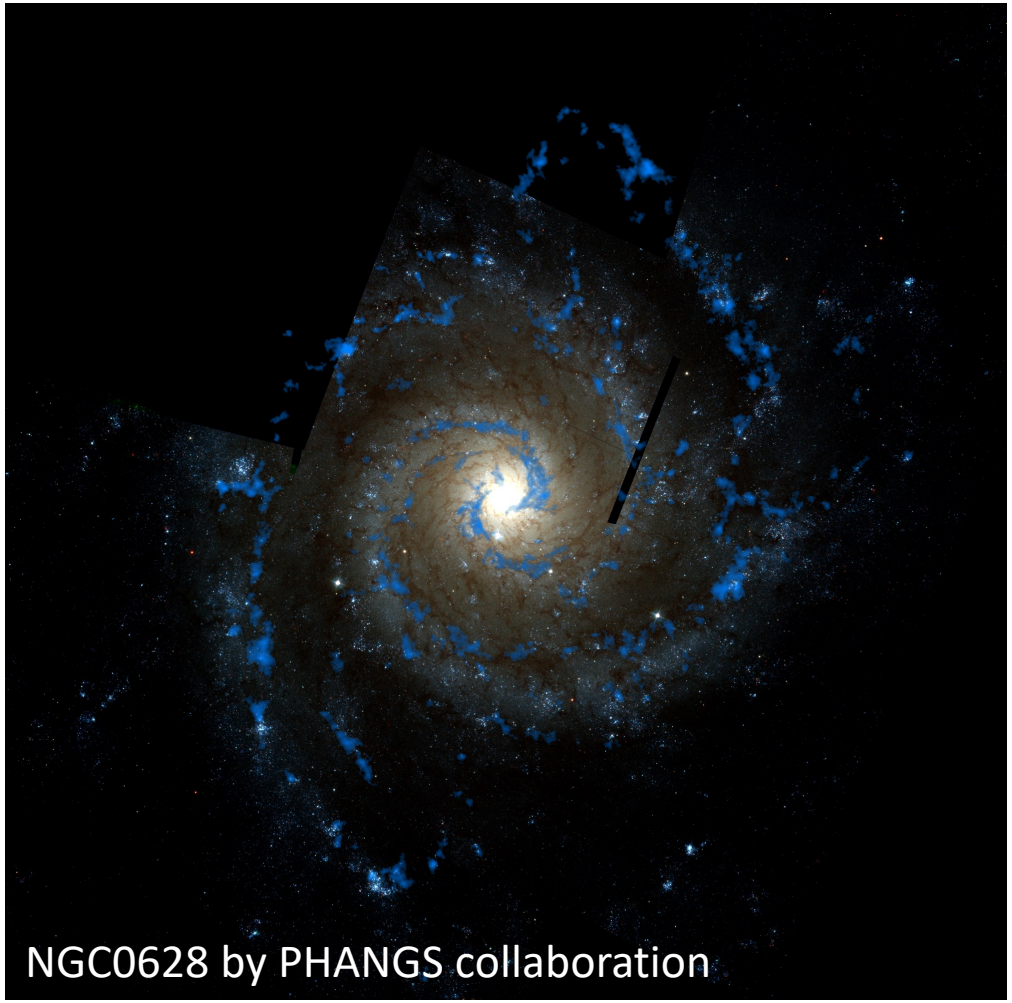


Credit: PHANGS collaboration

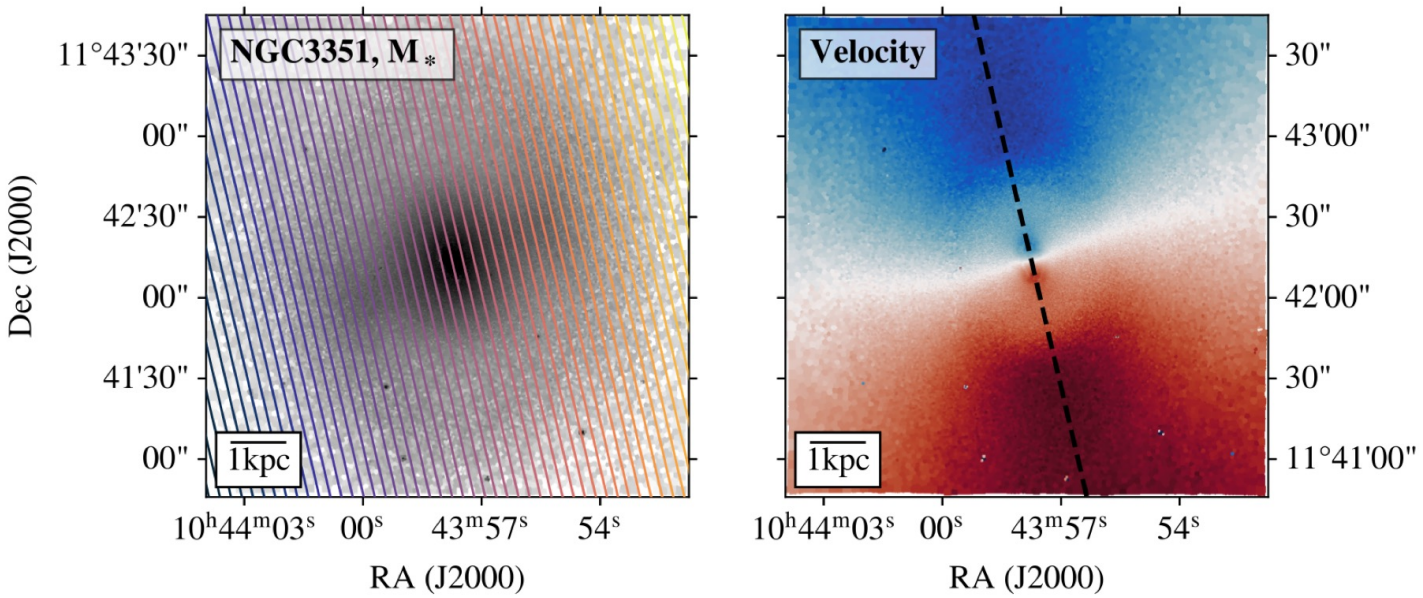
Tremaine-Weinberg Method (1984)

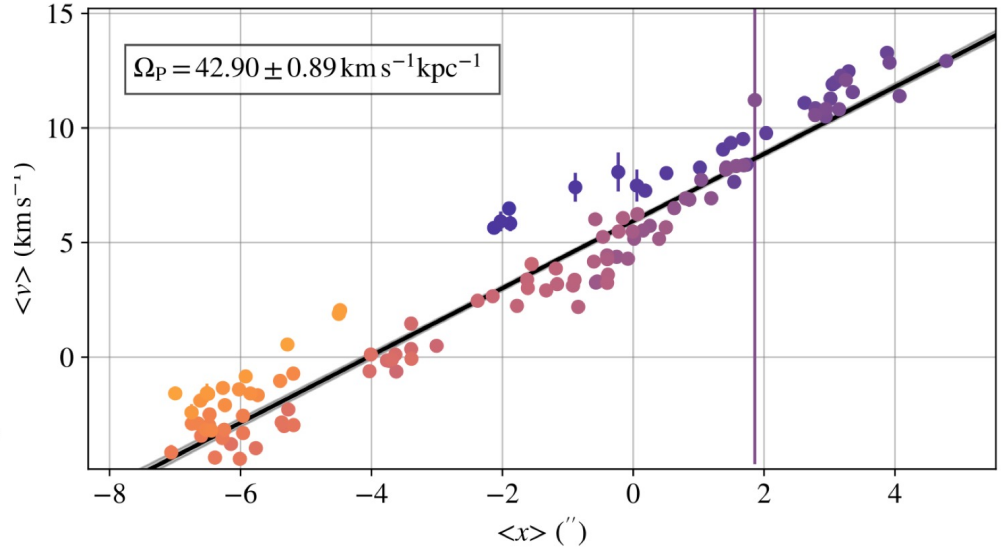
Three conditions:

- The galaxy disk is flat;
- The disk contains a constant, well-defined pattern speed;
- The tracer obeys the continuity equation.


NGC0628 by PHANGS collaboration

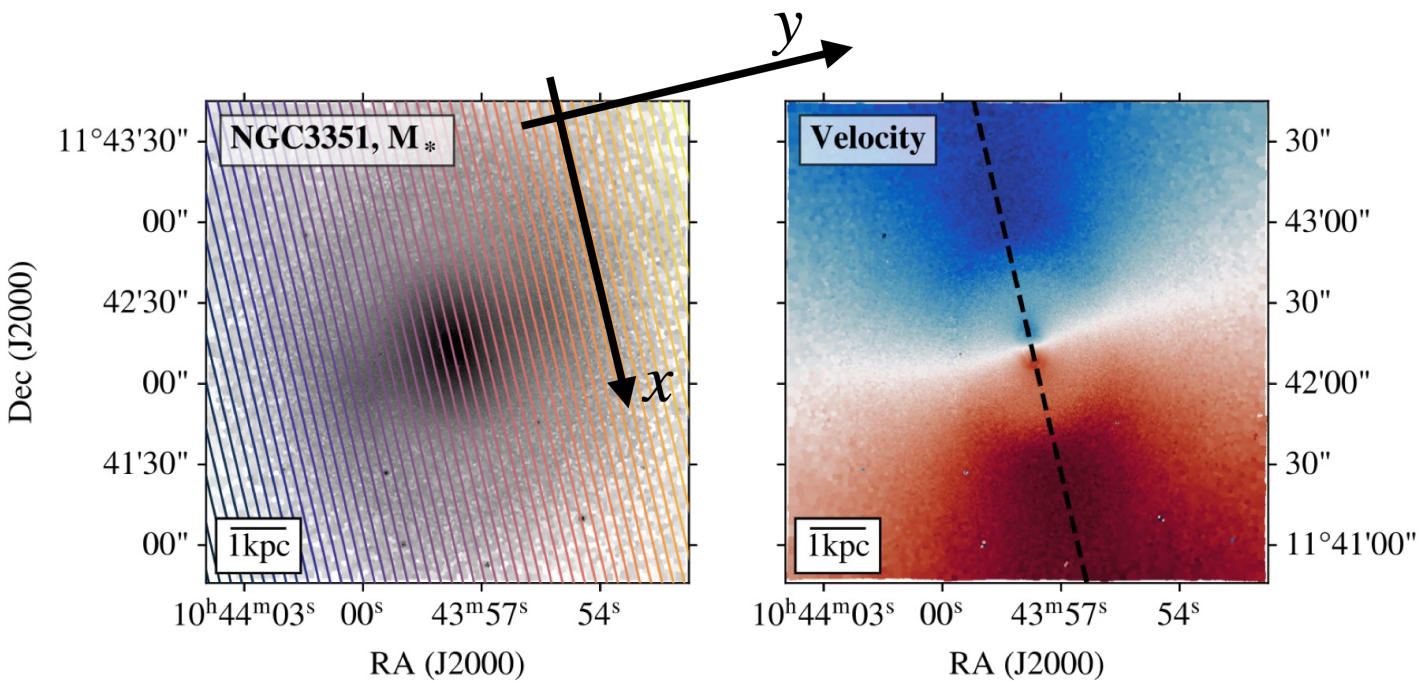
Tremaine-Weinberg Method (1984)

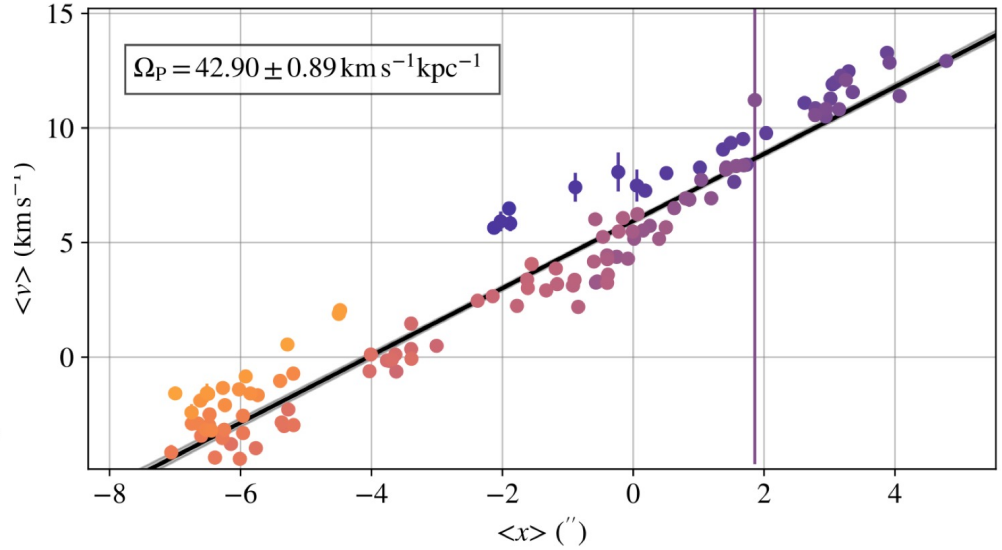




T. Williams et al. (2021)

Tremaine-Weinberg Method (1984)

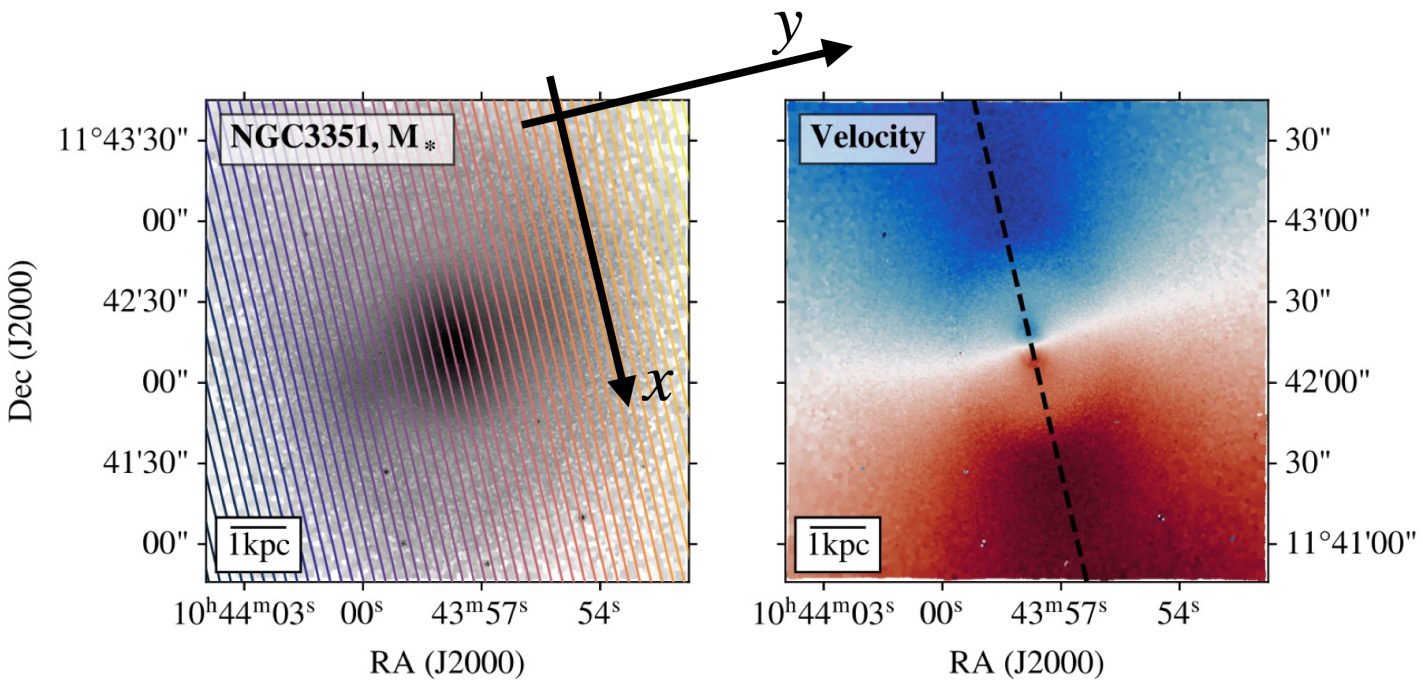


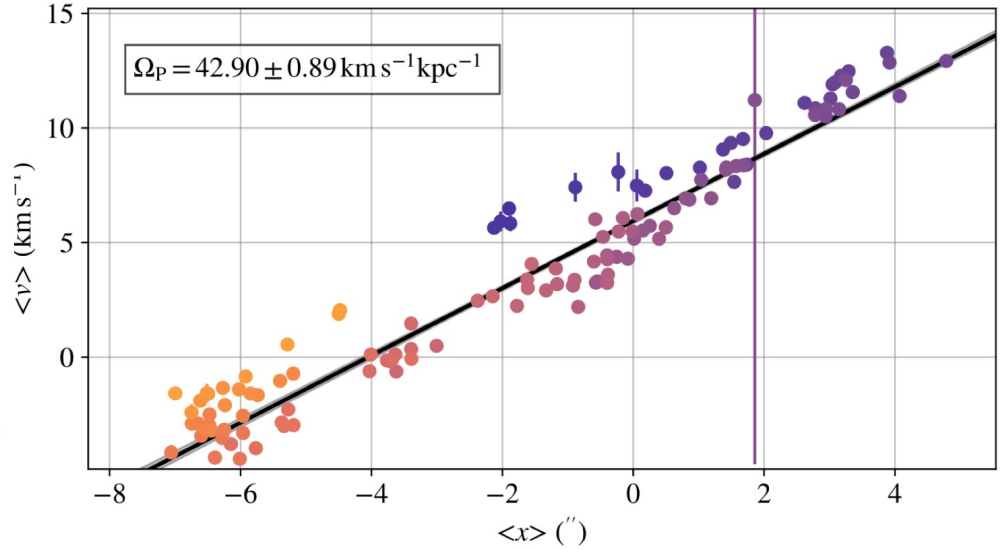


T. Williams et al. (2021)

$$\Omega_{\rm P}\sin(i) = \frac{\int_{-\infty}^{\infty} h(y) \int_{-\infty}^{\infty} v_{\rm LOS}(x,y)\,\Sigma(x,y)\,{\rm d}x{\rm d}y}{\int_{-\infty}^{\infty} h(y) \int_{-\infty}^{\infty} x\,\Sigma(x,y)\,{\rm d}x{\rm d}y} = \frac{\langle v\rangle}{\langle x\rangle}$$

Tremaine-Weinberg Method (1984)



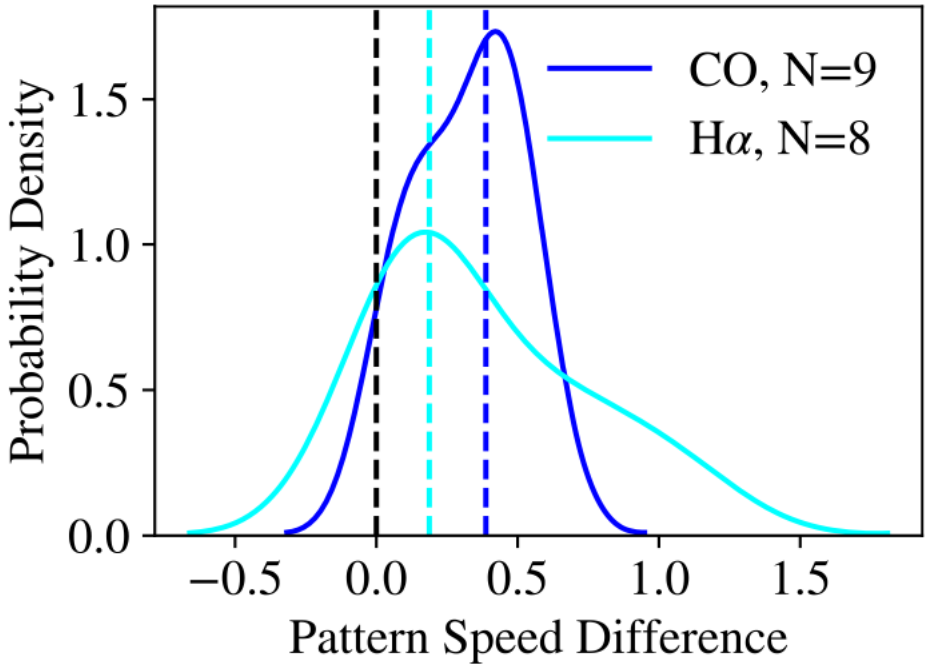


T. Williams et al. (2021)

$$\Omega_{\mathrm{P}} \sin(i) = \frac{\text{sum of weighted velocities}}{\text{sum of weighted x-coordinates}} = \frac{\langle v \rangle}{\langle x \rangle}$$

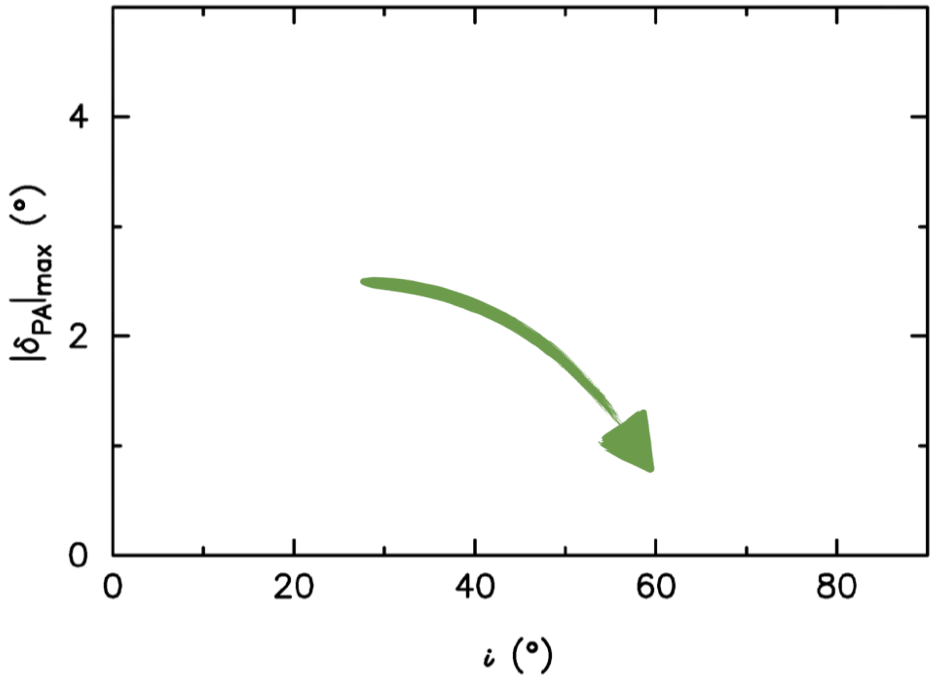
Previous studies

Observations



T. Williams et al. (2021)

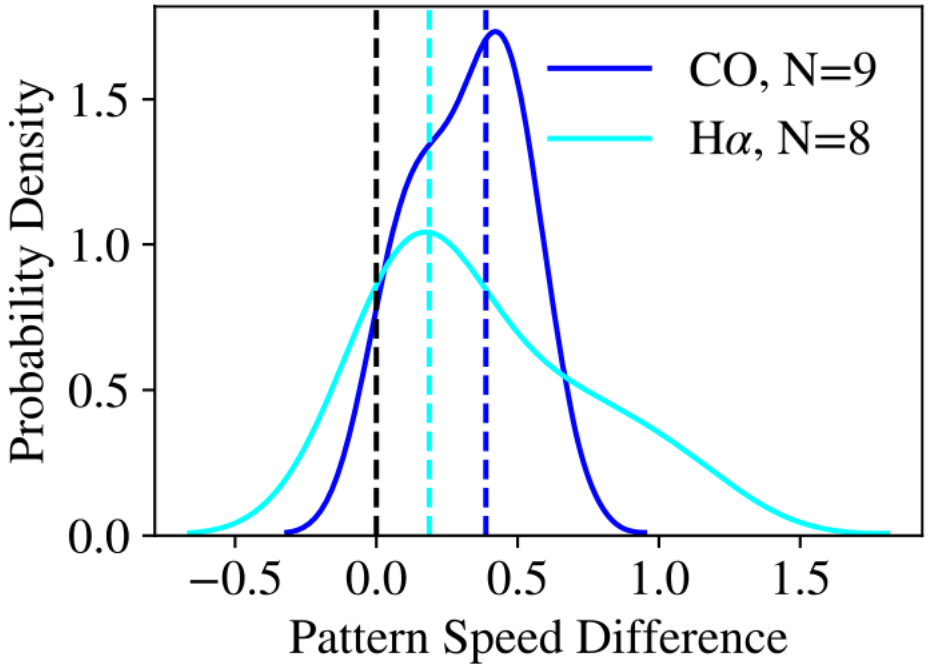
Simulations



V. Debattista (2003)

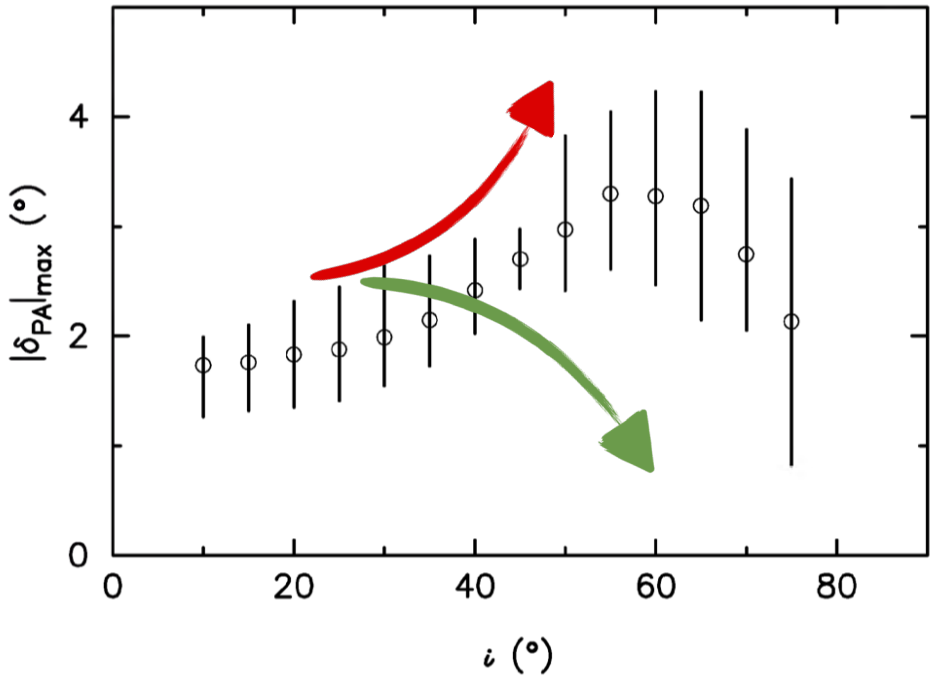
Previous studies

Observations



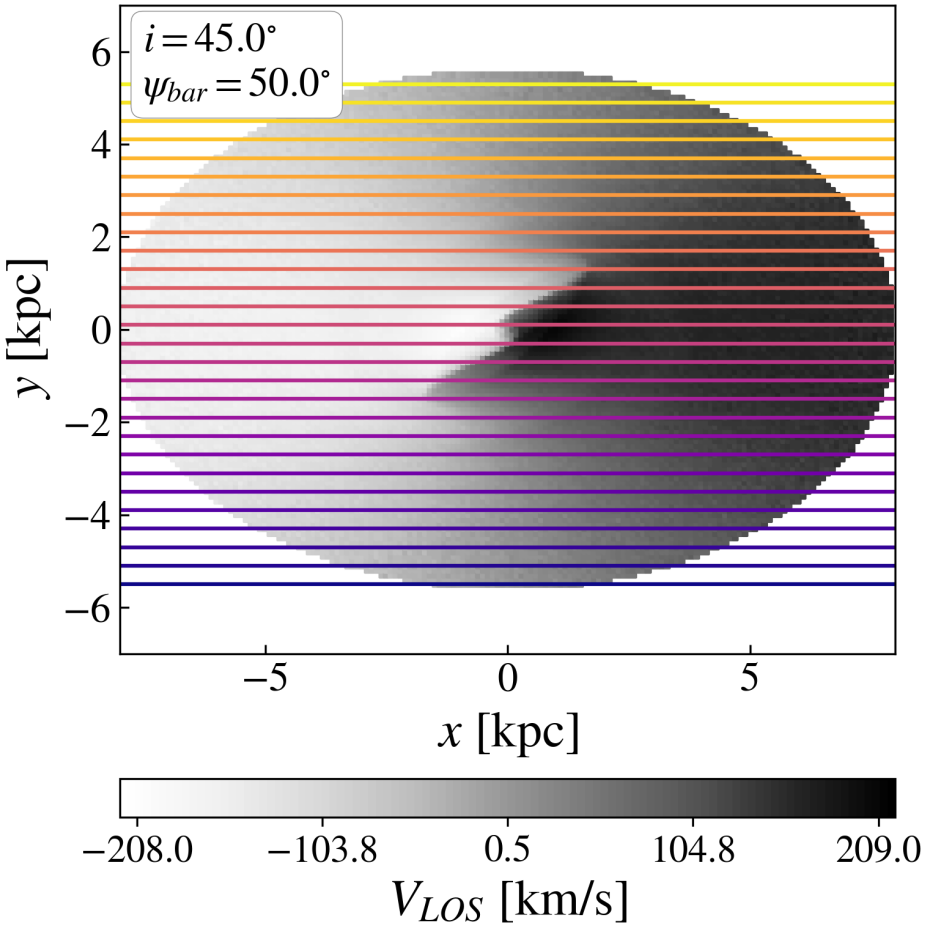
T. Williams et al. (2021)

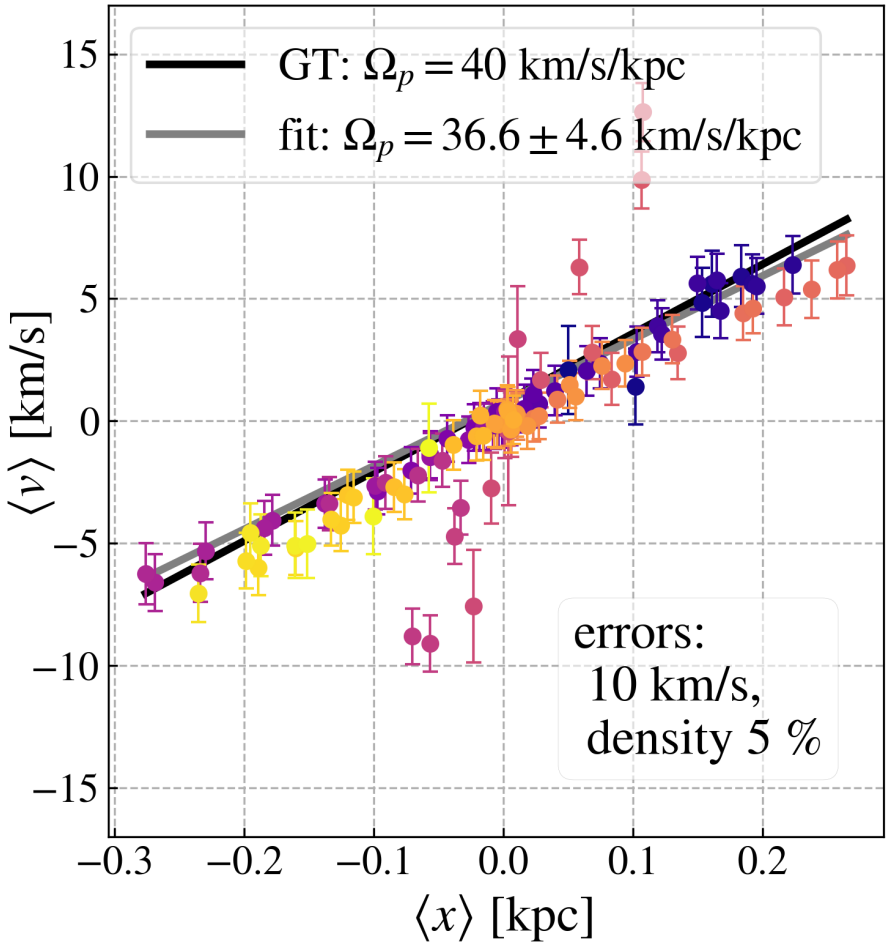
Simulations



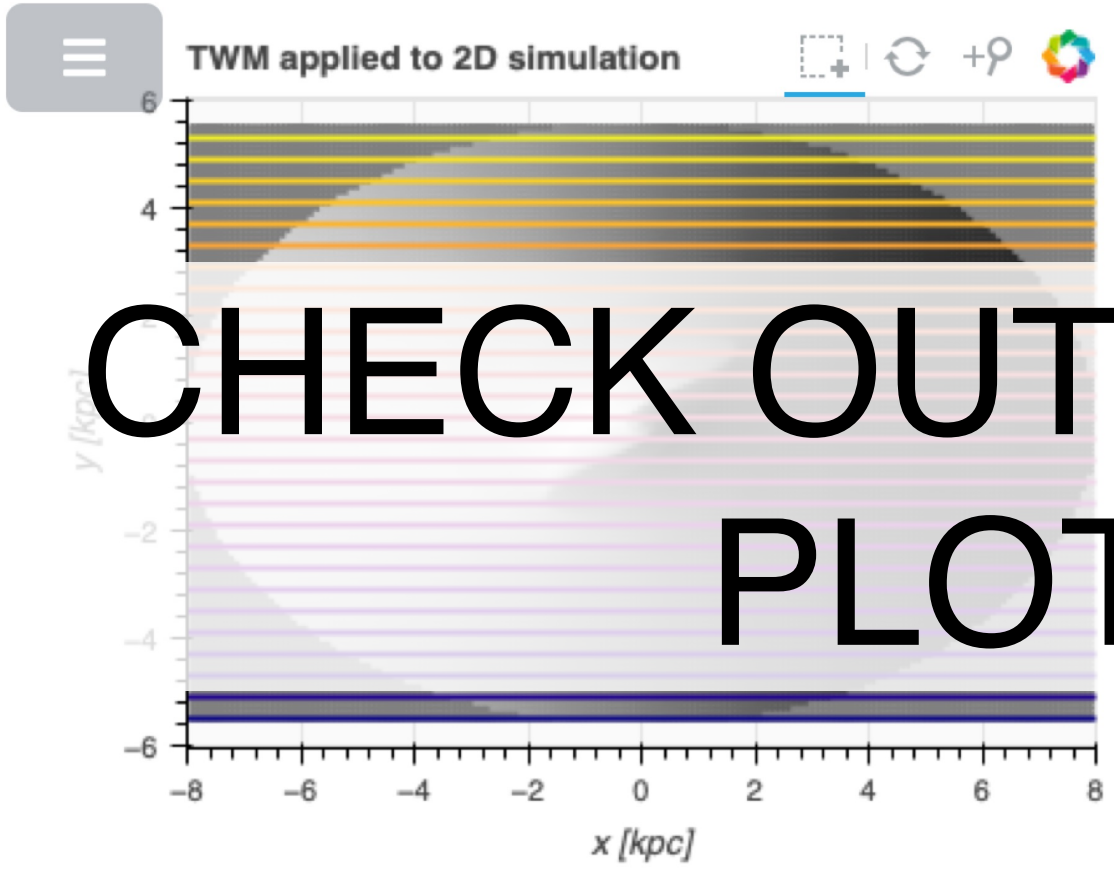
V. Debattista (2003): the higher inclination, the bigger errors in PA we can tolerate

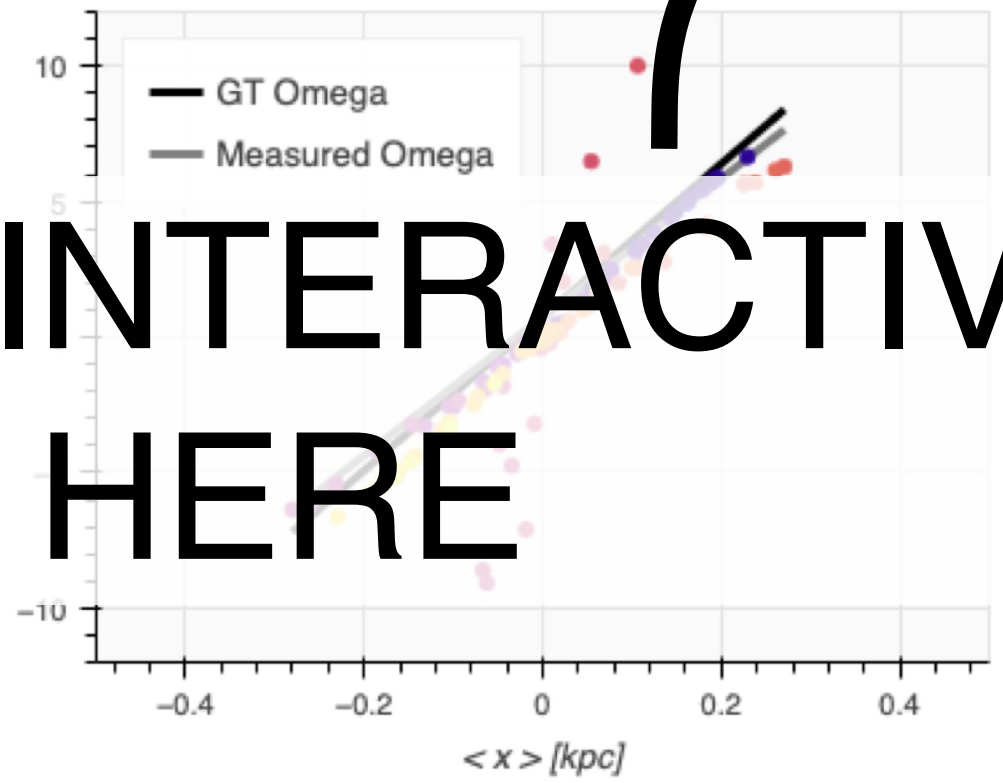
2D simulations: everything works, but…



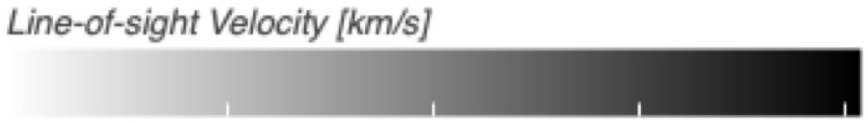


… some slits show wrong result

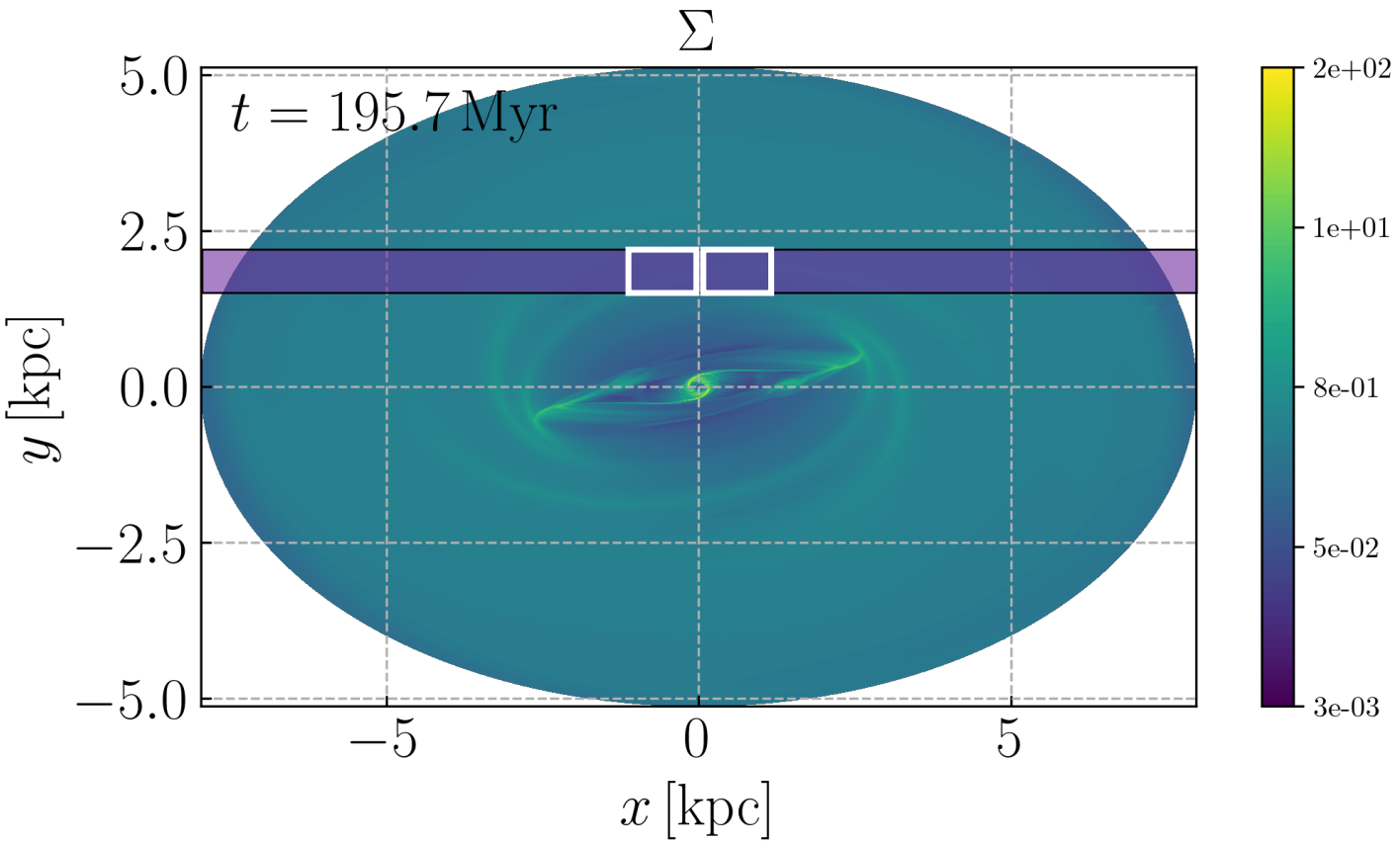




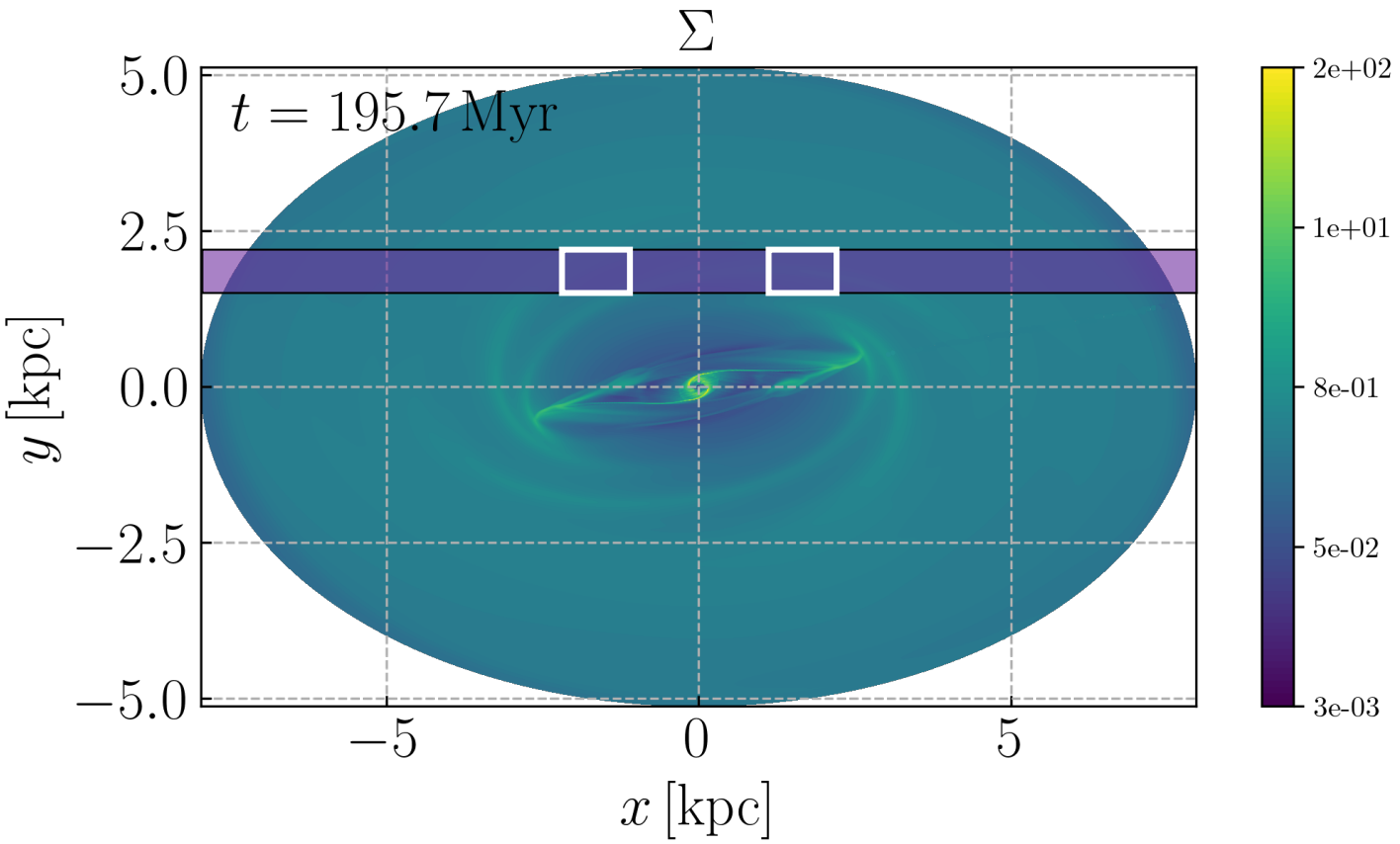
CHECK OUT INTERACTIVE PLOT HERE



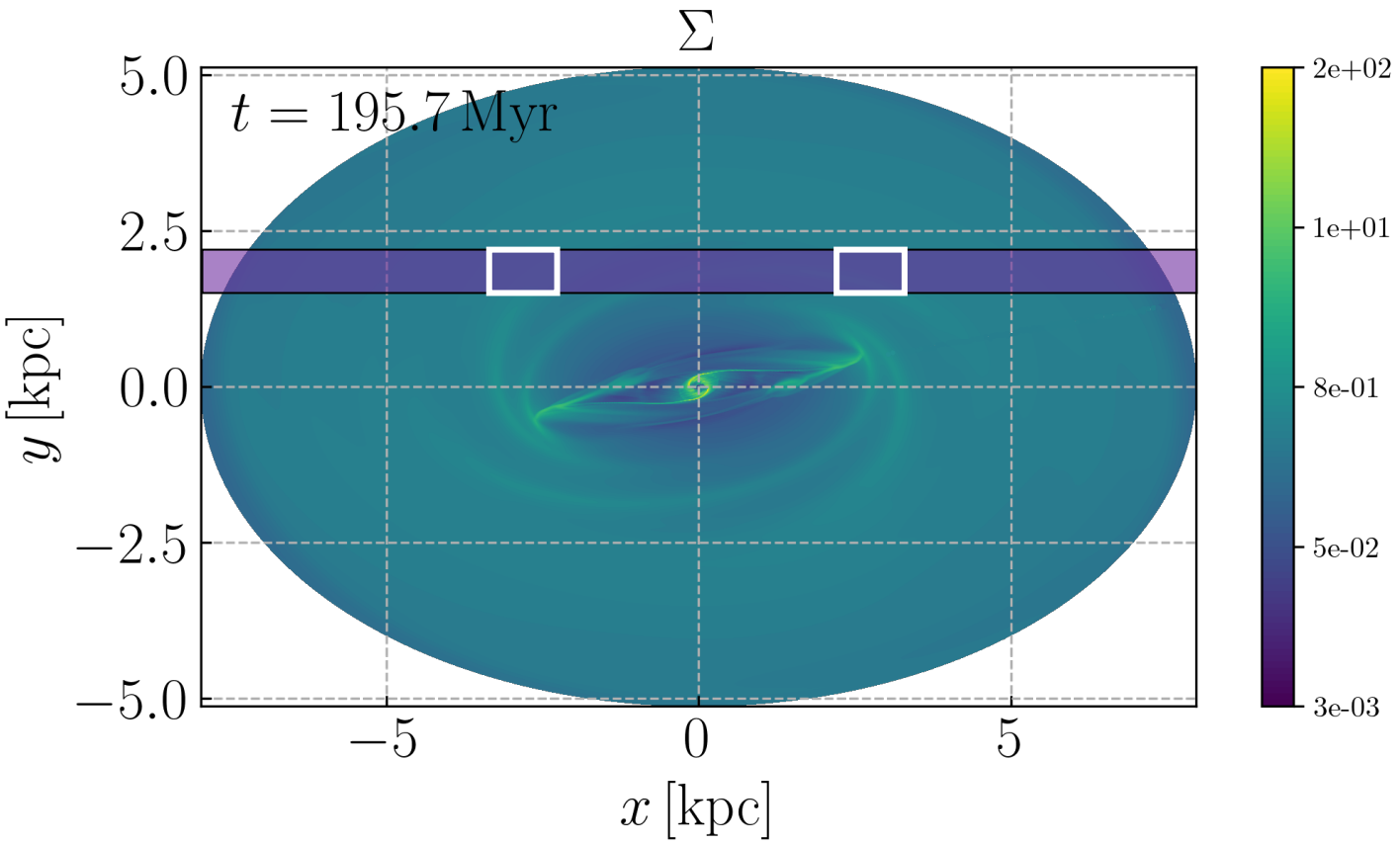
Possible explanation



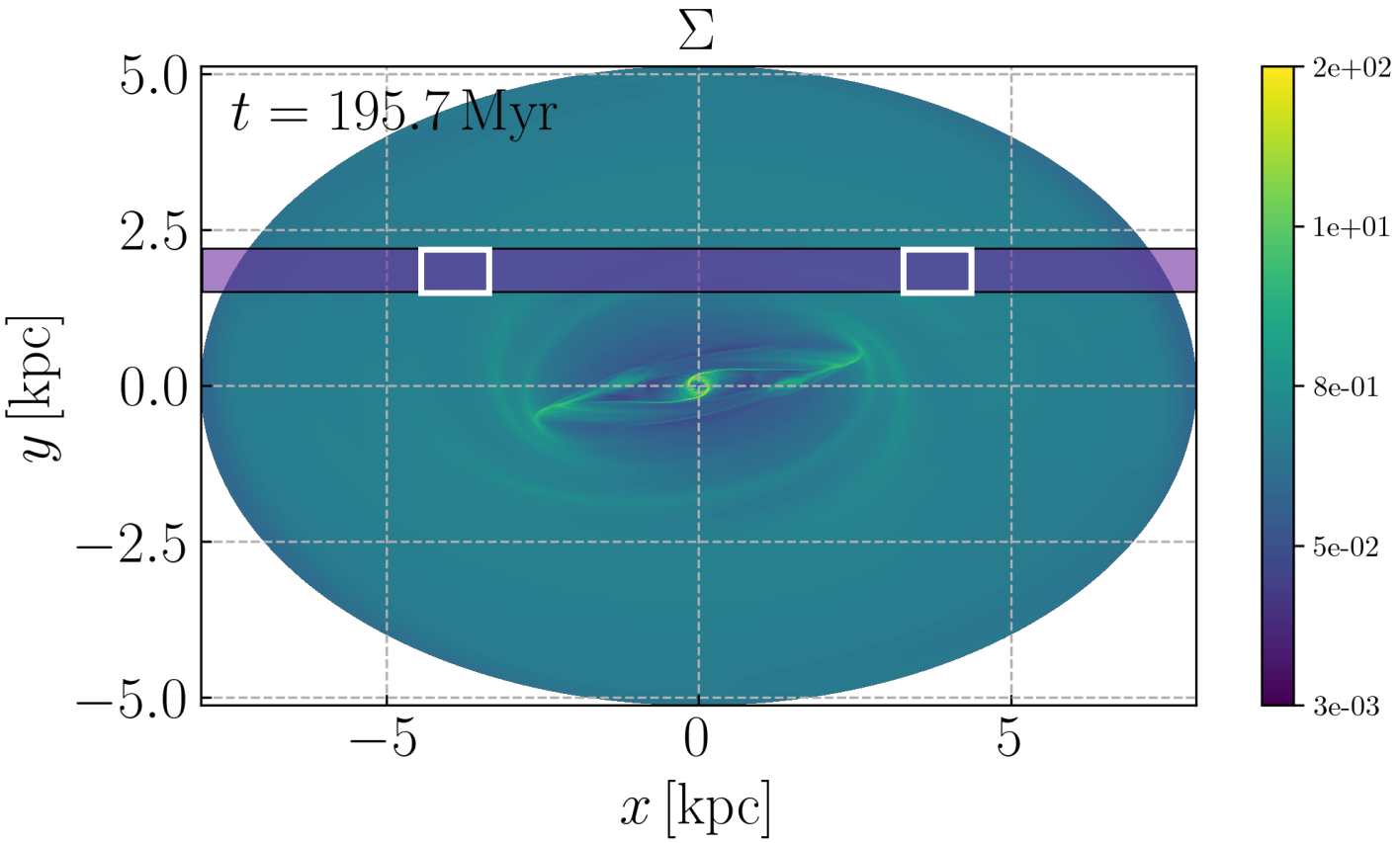
Possible explanation



Possible explanation

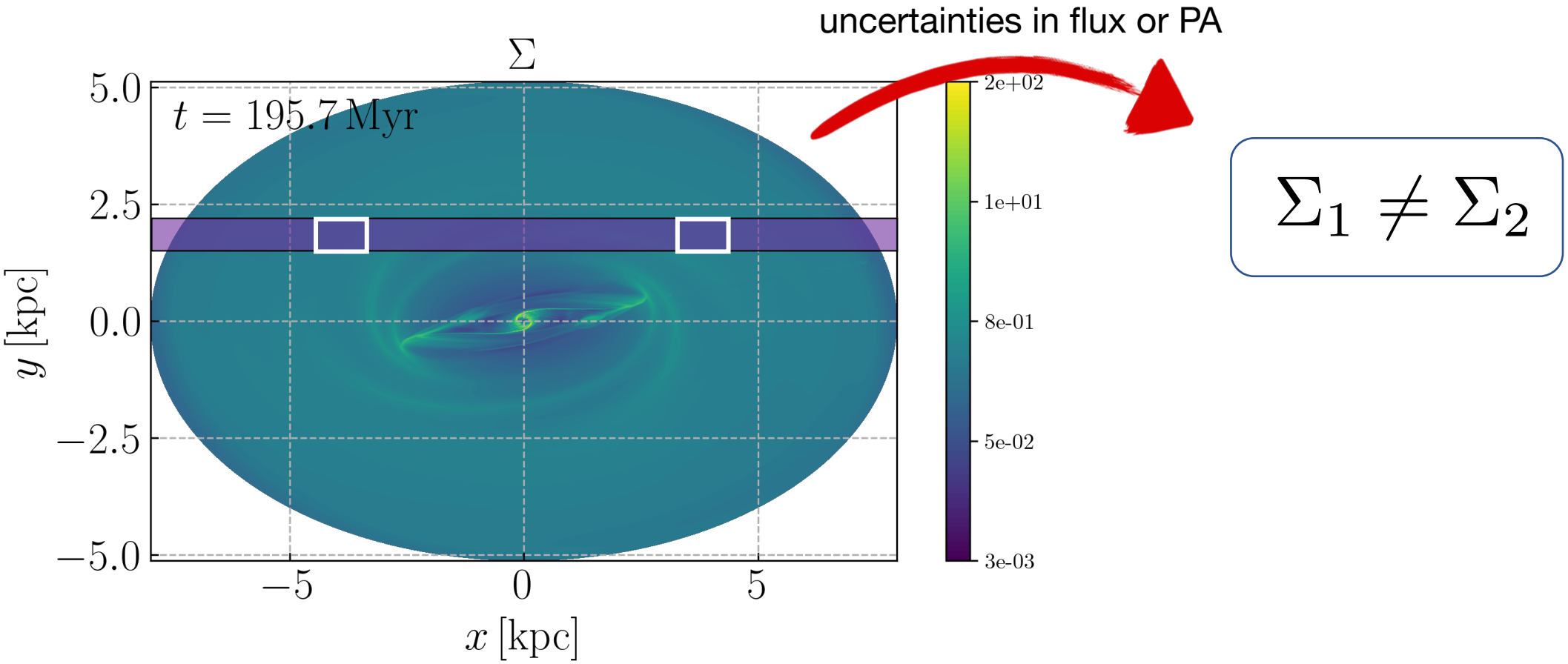


Possible explanation

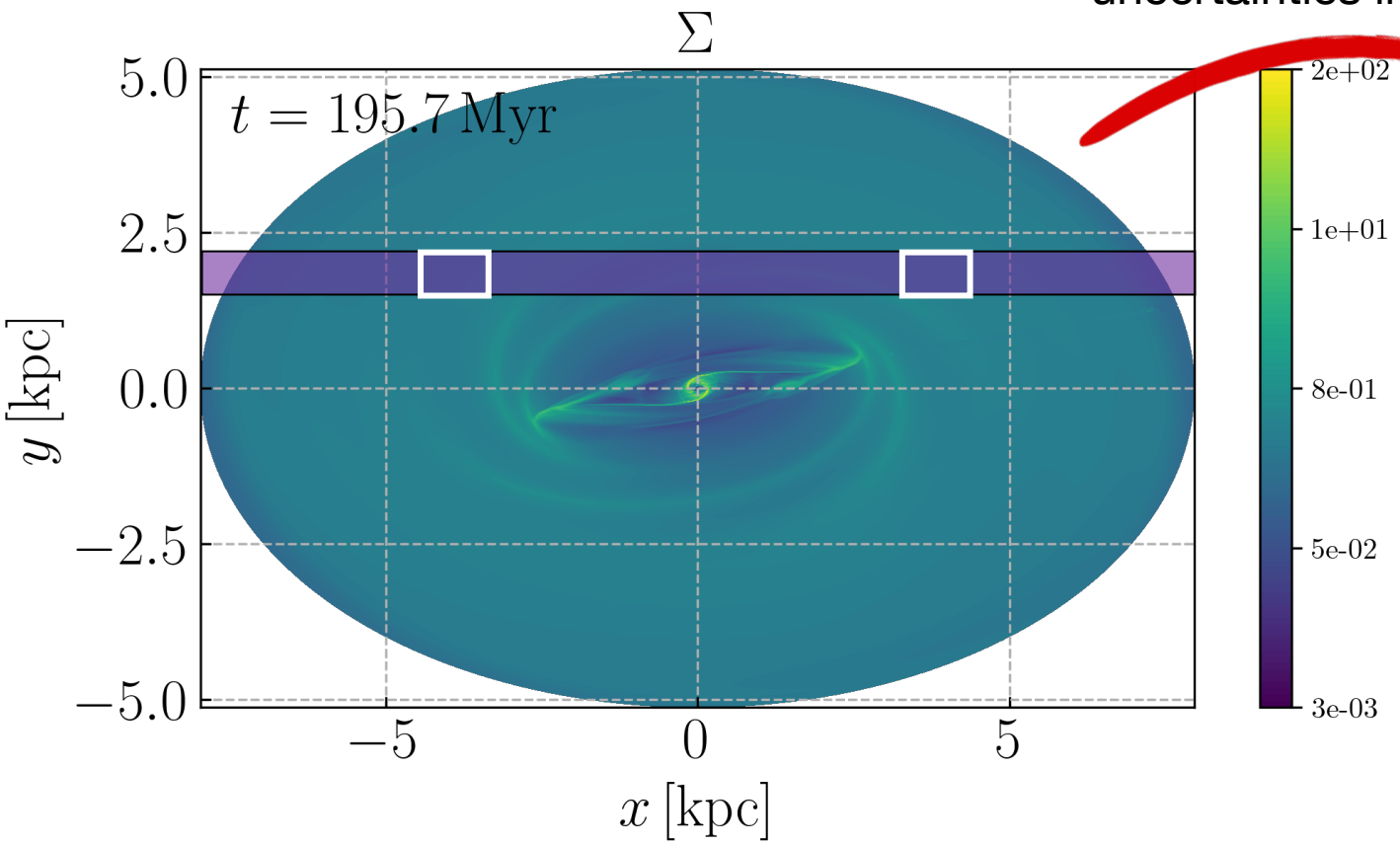


$$\langle v \rangle = 0$$
$$\langle x \rangle = 0$$

Possible explanation



Possible explanation



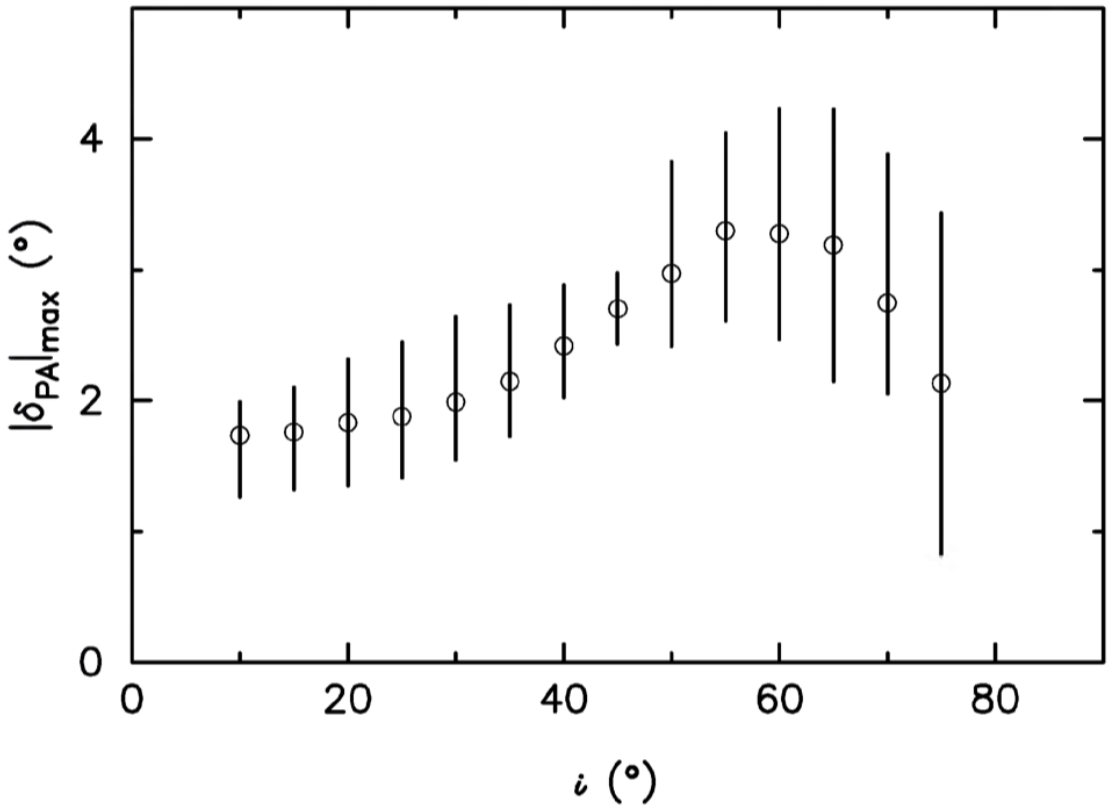
uncertainties in flux or PA

$$\Sigma_1 \neq \Sigma_2$$

$$\Omega$$

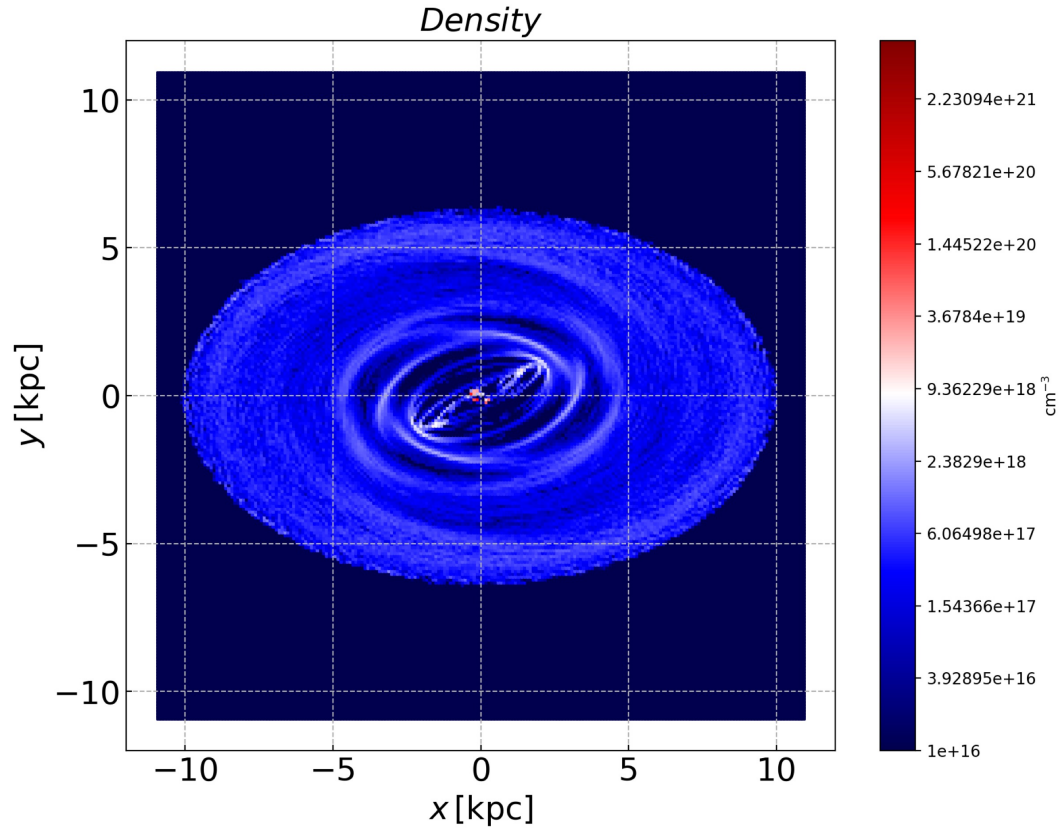
Possible explanation

We pick up weighted velocity field and **not** the actual pattern speed



3D simulations: different gas tracers

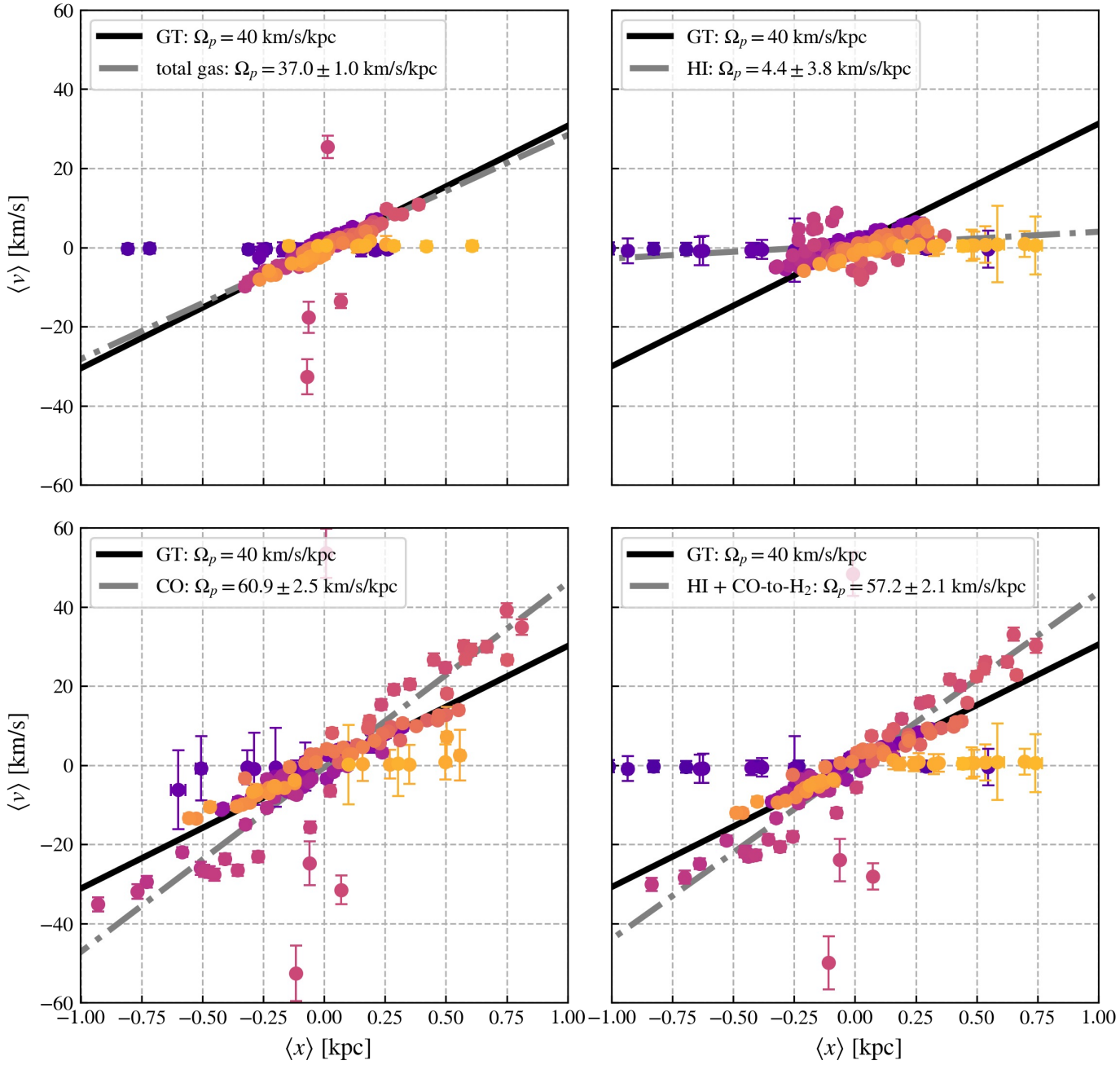
- different chemical components
- separately they don't obey continuity equation
- clumpiness!



M. Sormani et al. (2018)

Total gas

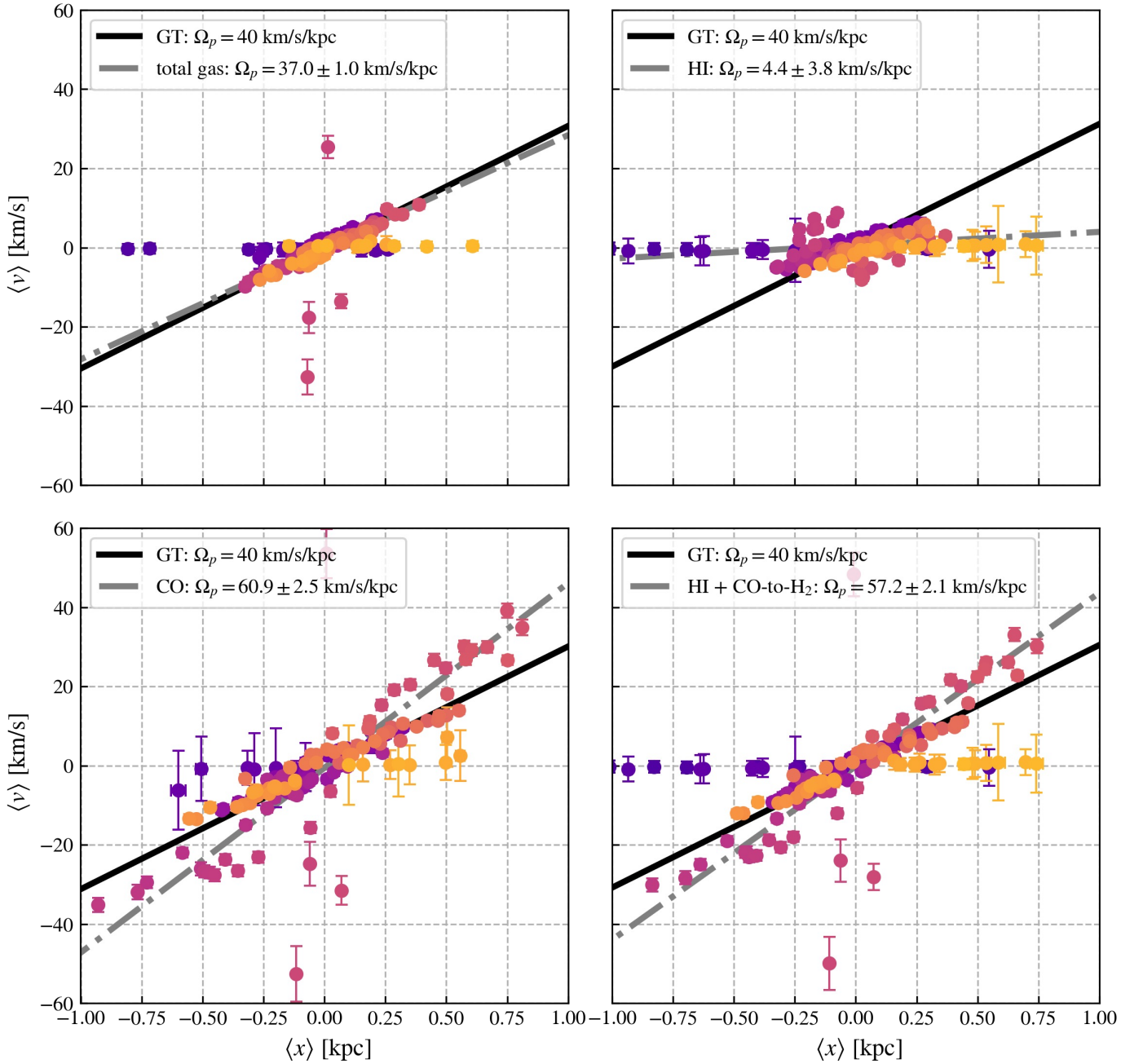
HI



CO

mocked total H

Total gas



HI

M. Bureau et al. (1999)
A. Banerjee et al. (2013)

CO

mocked total H

On the Tremaine-Weinberg method:

Olga Borodina
Thomas Williams
Eva Schinnerer
Mattia Sormani
Sharon Meidt

can we trust gas tracers to measure pattern speeds?

14:02

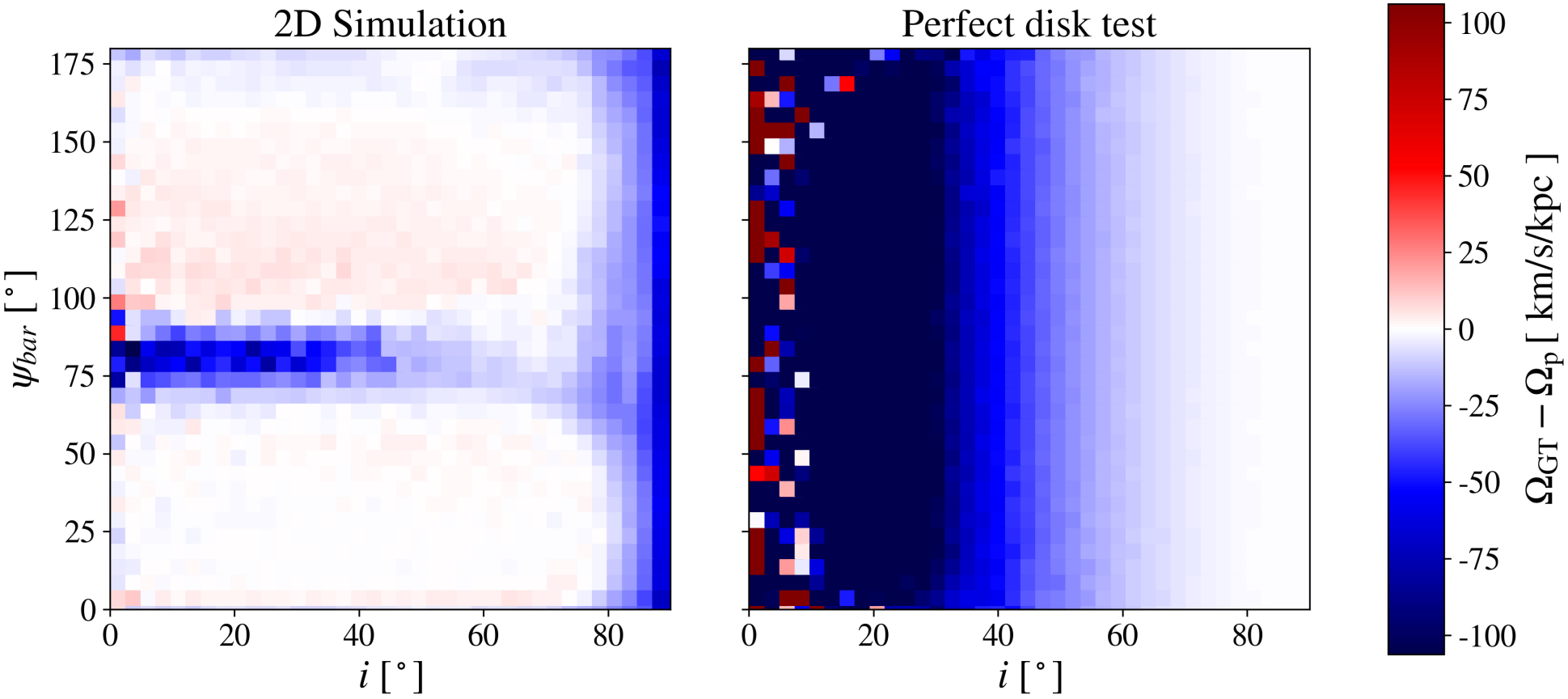
not really

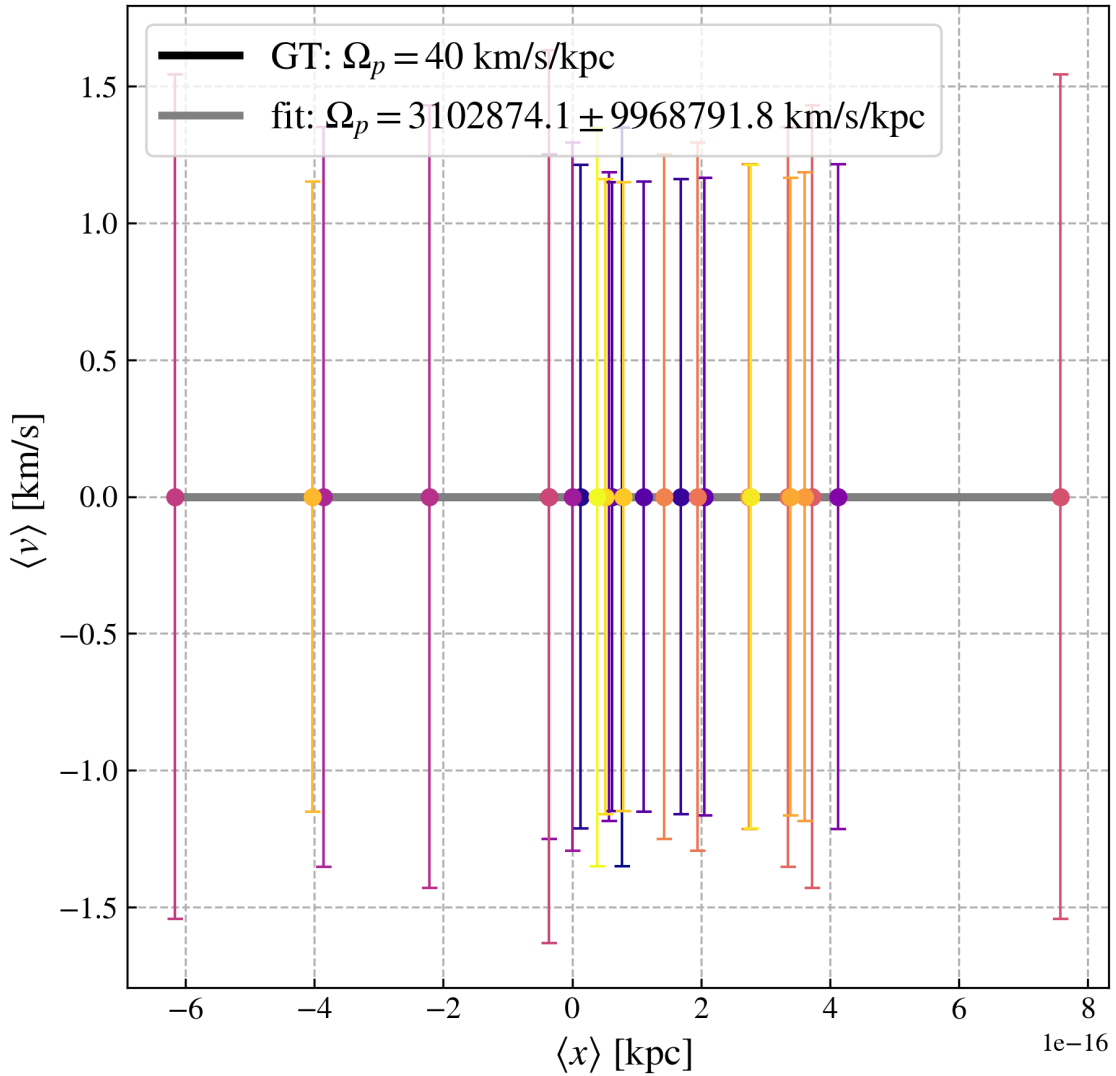
15:19 ✓✓

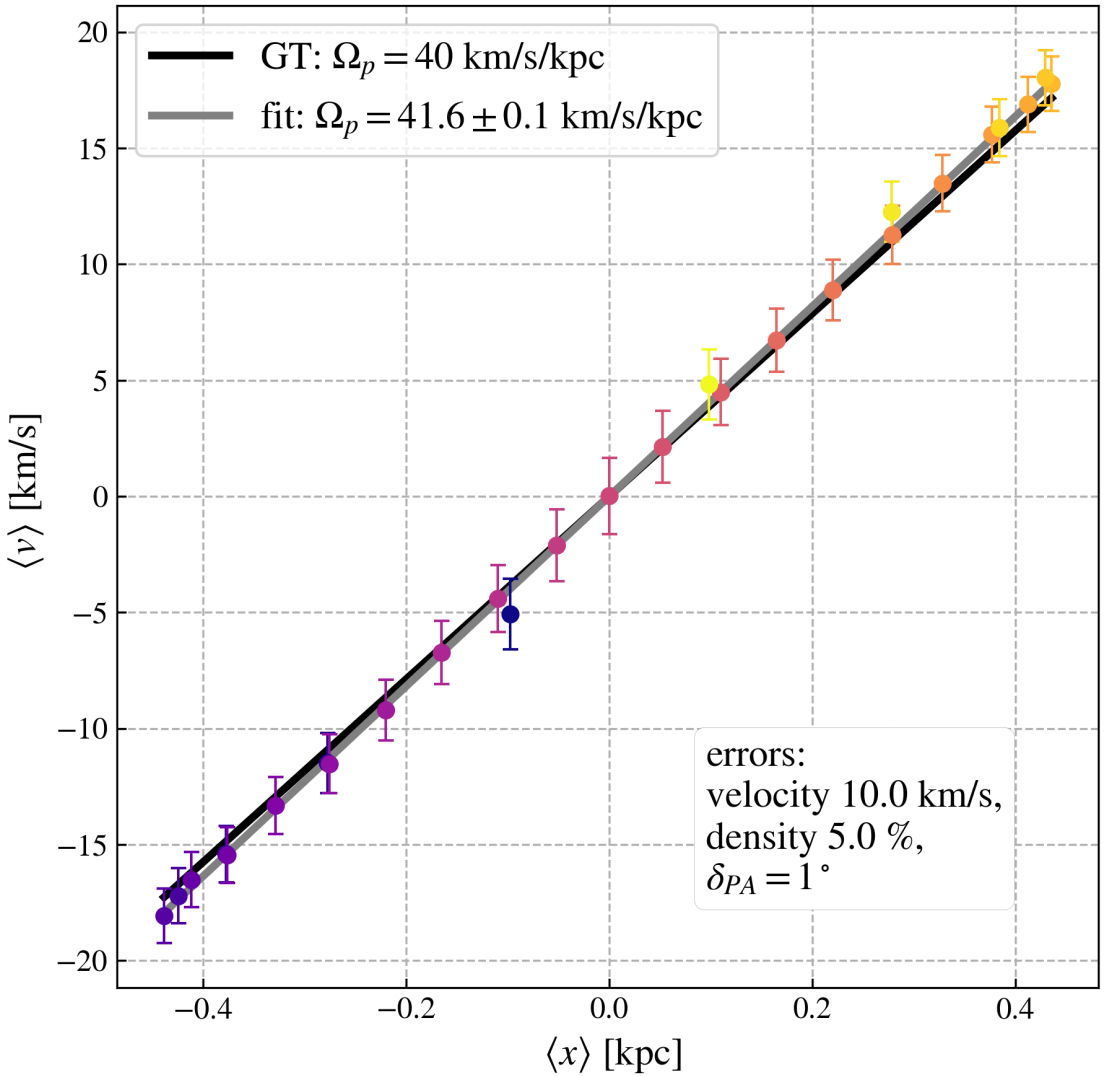
PHANGS

Max-Planck-Institut für Astronomie Heidelberg
Max Planck Institute for Astronomy Heidelberg

Bootstrapping

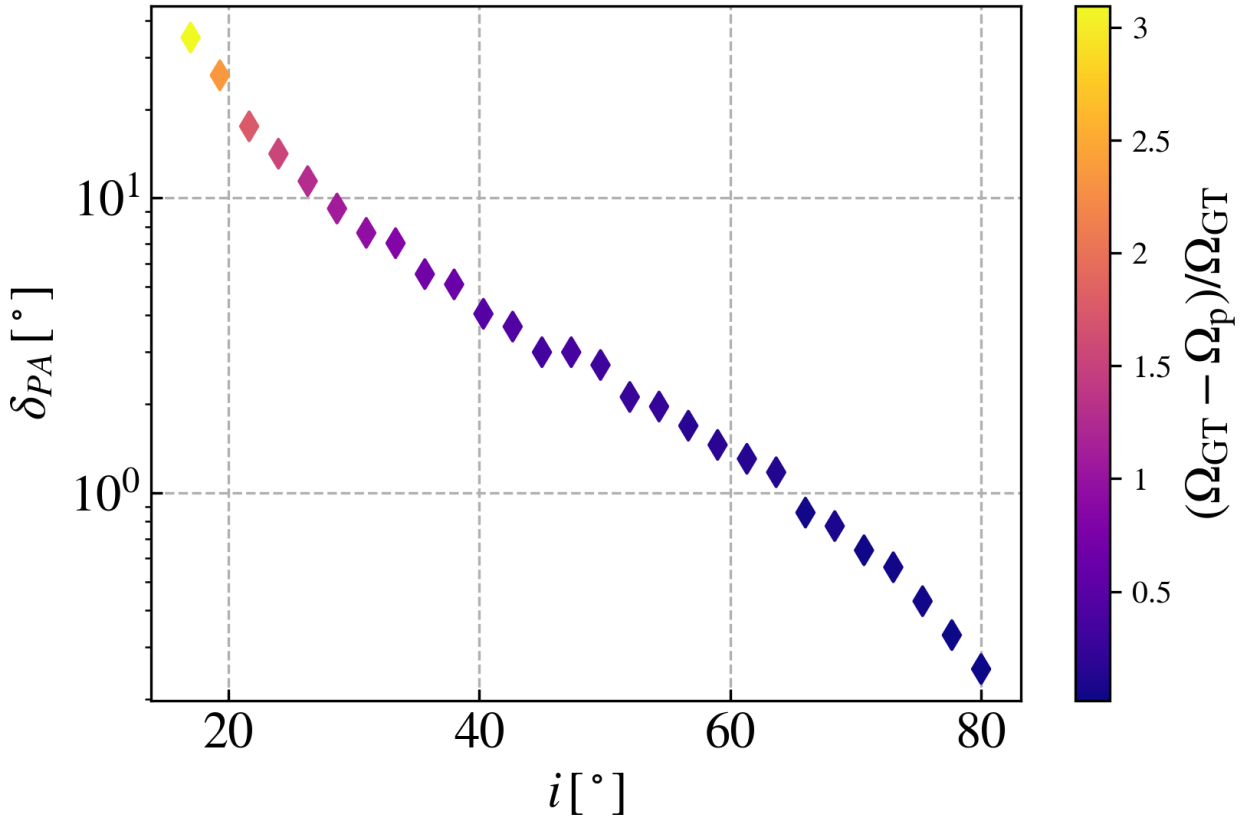



GT: $\Omega_p = 40$ km/s/kpc
fit: $\Omega_p = 3102874.1 \pm 9968791.8$ km/s/kpc
$\langle v \rangle$ [km/s]
$\langle x \rangle$ [kpc]
1e−16

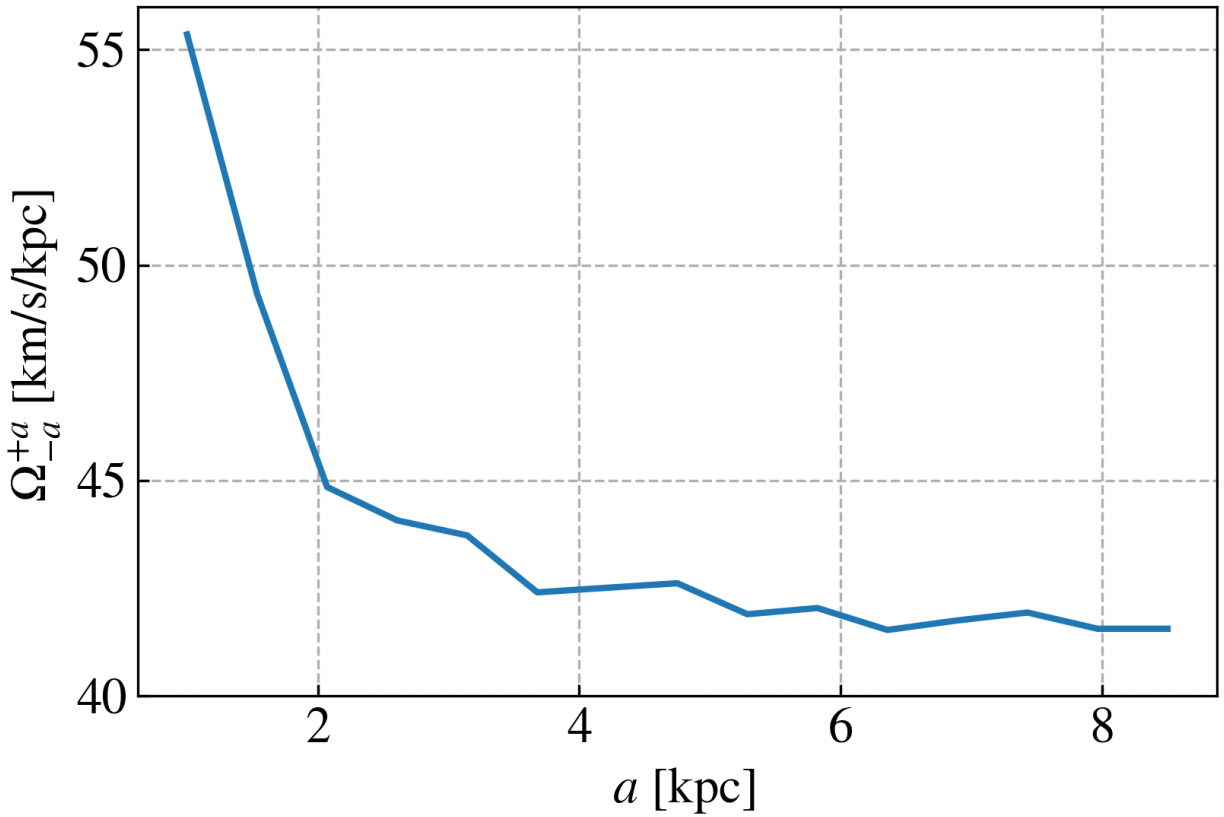

GT: $\Omega_p = 40$ km/s/kpc
fit: $\Omega_p = 41.6 \pm 0.1$ km/s/kpc
errors:
velocity 10.0 km/s,
density 5.0 %,
$\delta_{PA} = 1^\circ$
$\langle v \rangle$ [km/s]
$\langle x \rangle$ [kpc]

Perfect disk

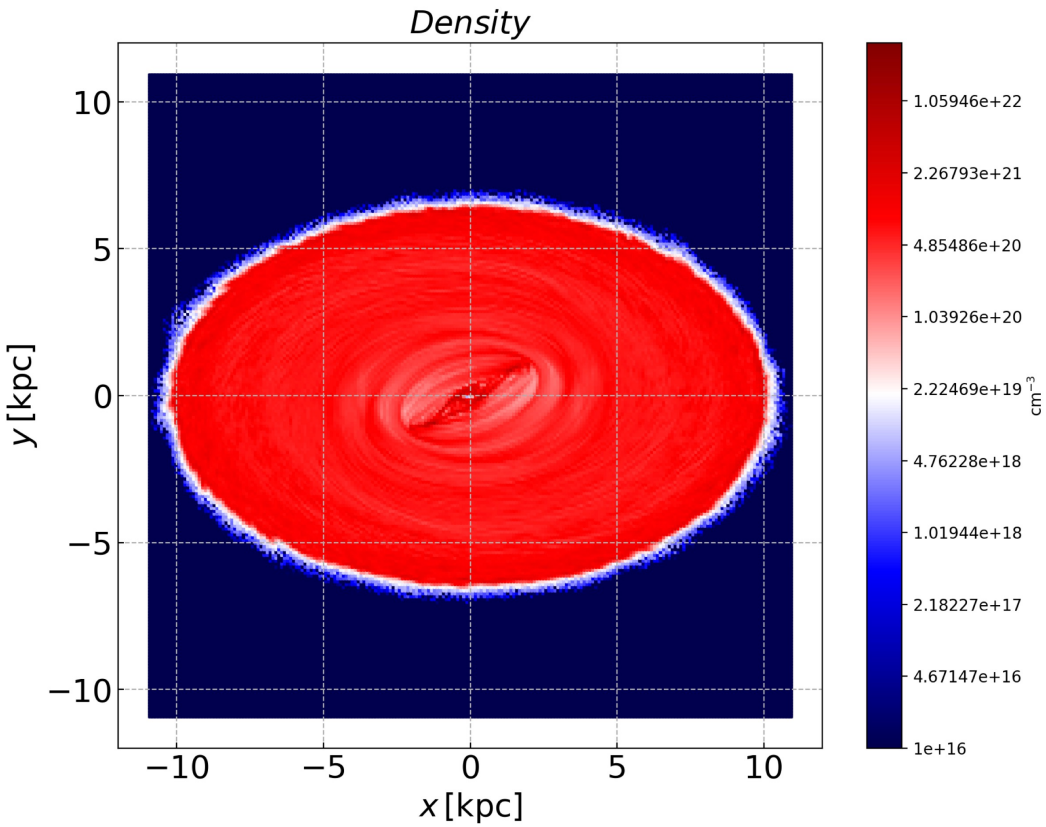
- Exponential density profile
- Solid body rotation



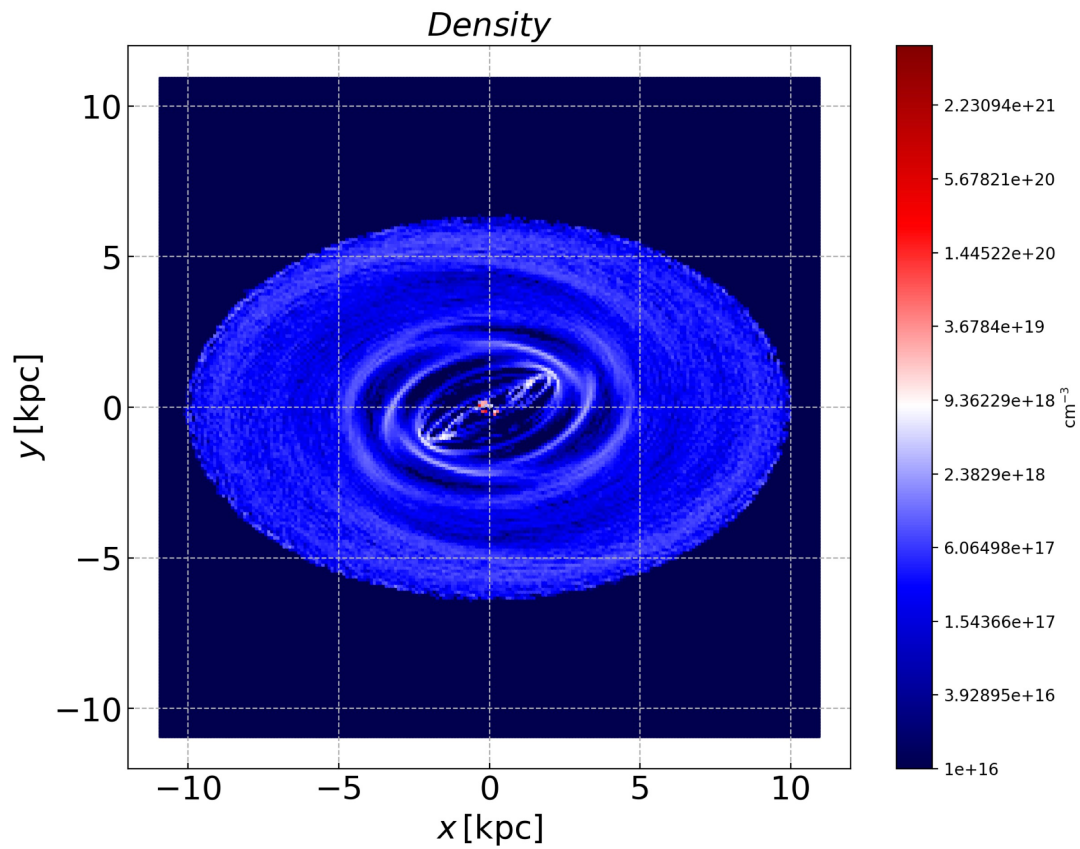
Average velocity field for perfect disk



HI


Density
10
5
0
−5
−10
y [kpc]
−10
−5
0
5
10
x [kpc]
1.05946e+22
2.26793e+21
4.85486e+20
1.03926e+20
2.22469e+19
4.76228e+18
1.01944e+18
2.18227e+17
4.67147e+16
1e+16
cm^{-3}

CO


Density
10
5
0
−5
−10
y [kpc]
−10
−5
0
5
10
x [kpc]
2.23094e+21
5.67821e+20
1.44522e+20
3.6784e+19
9.36229e+18
2.3829e+18
6.06498e+17
1.54366e+17
3.92895e+16
1e+16
cm^{-3}