5th workshop on mm Astronomy – Bologna, 12-14/06/2023

3D modelling of the molecular gas kinematics in optically-selected jellyfish galaxies

Cecilia Bacchini
INAF – Astronomical Observatory of Padova

Based on Bacchini et al. 2023 ApJ

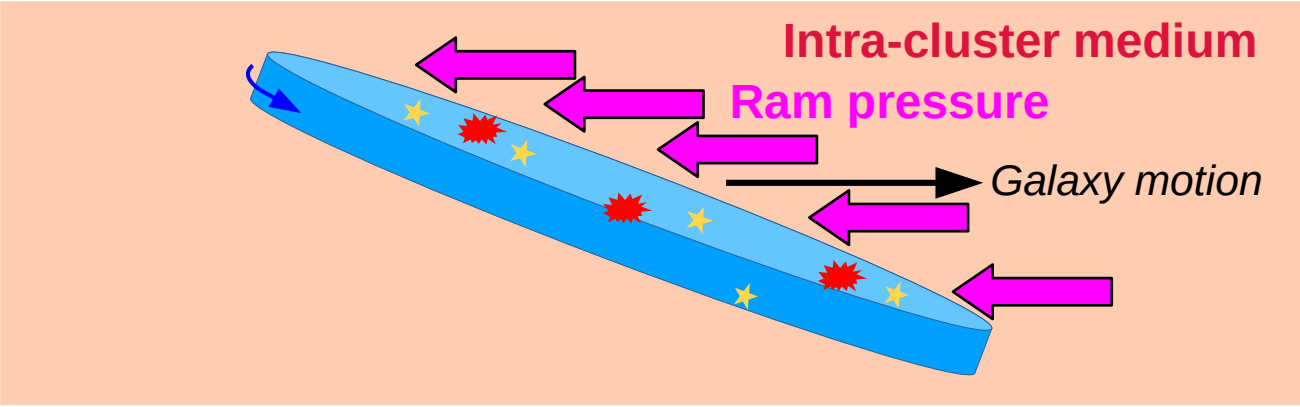
Jellyfish galaxies

NASA/Hubble & NASA, M. Gullieuszik and the GASP team

NASA, ESA, Ming Sun (UAH), and Serge Meunier

Jellyfish galaxies

Ram pressure (RP) due to the hydro interaction with the ICM.



$$P_{\rm ram} = \rho_{\rm ICM} V_{\rm gal}^2$$

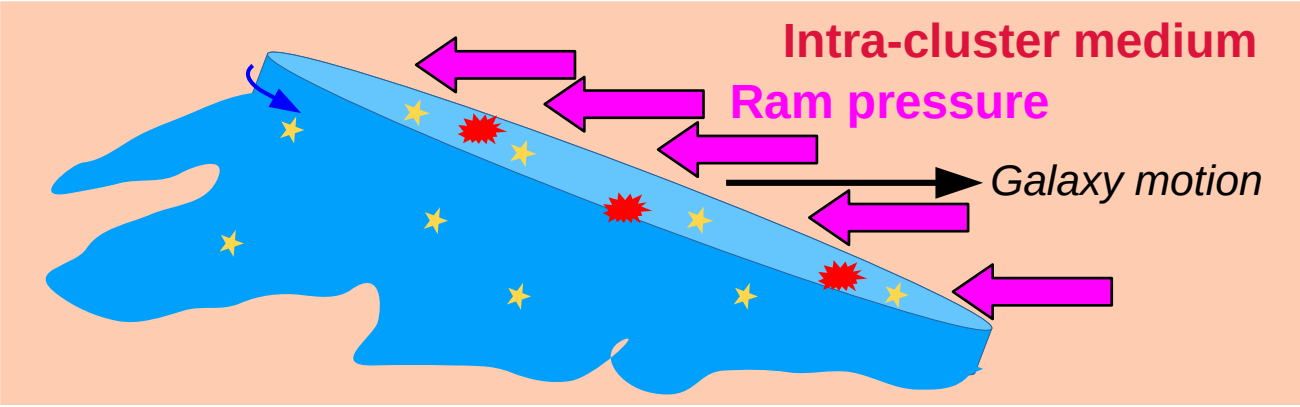
Gunn & Gott 1972

Jellyfish galaxies

Ram pressure (RP) due to the hydro interaction with the ICM.

↓

Gas disturbed or removed (*ram pressure stripping*, RPS), while **stars unperturbed**.

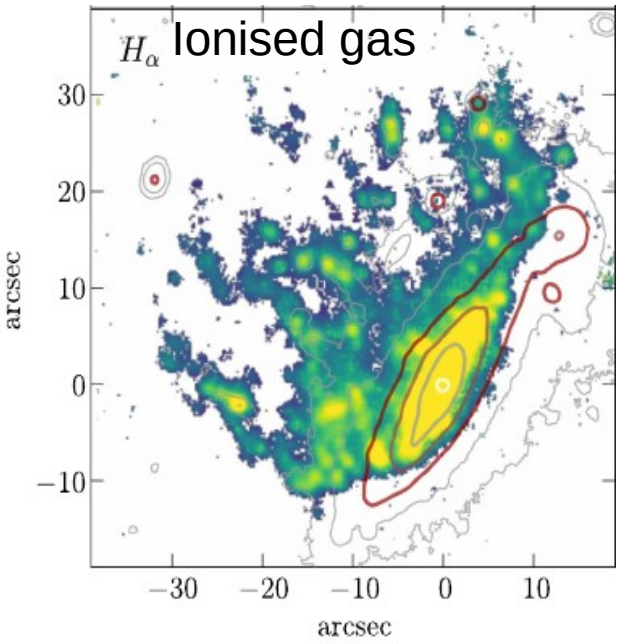


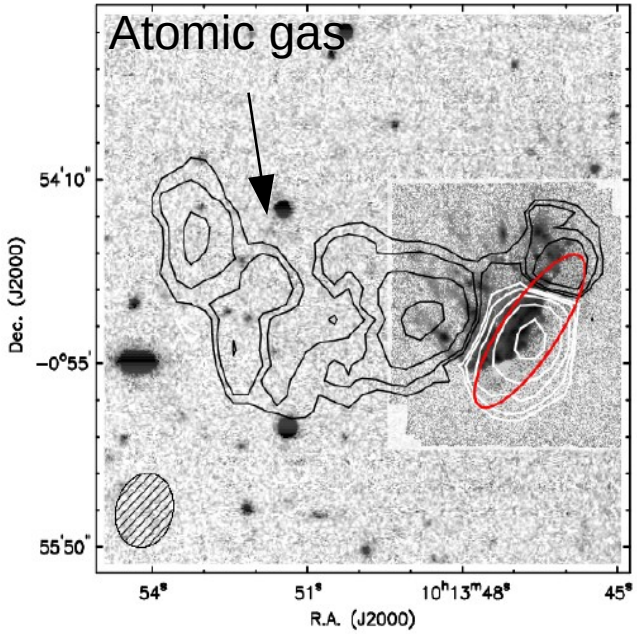
$$P_{\rm ram} = \rho_{\rm ICM} V_{\rm gal}^2 > \frac{\partial \Phi}{\partial z} \Sigma_{\rm ISM}$$

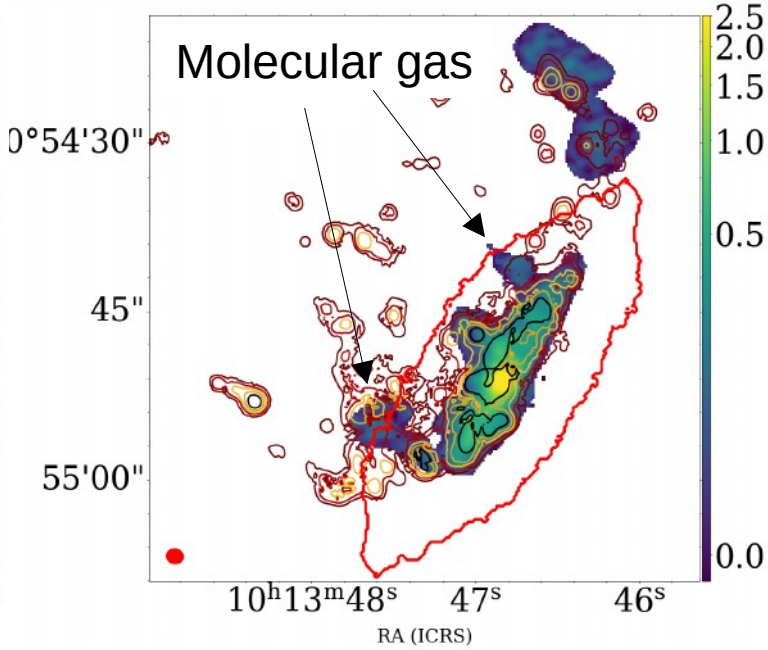
Gunn & Gott 1972

RP effect on multi-phase ISM

Different impact on different gas phases (stripping, depletion, truncation)







Gullieuszik+2017; Deb+2020; Moretti+2020ab

GASP

"GAs Stripping Phenomena

in galaxies with MUSE"

MUSE@VLT large program

IFU data for 114 cluster & field galaxies

+

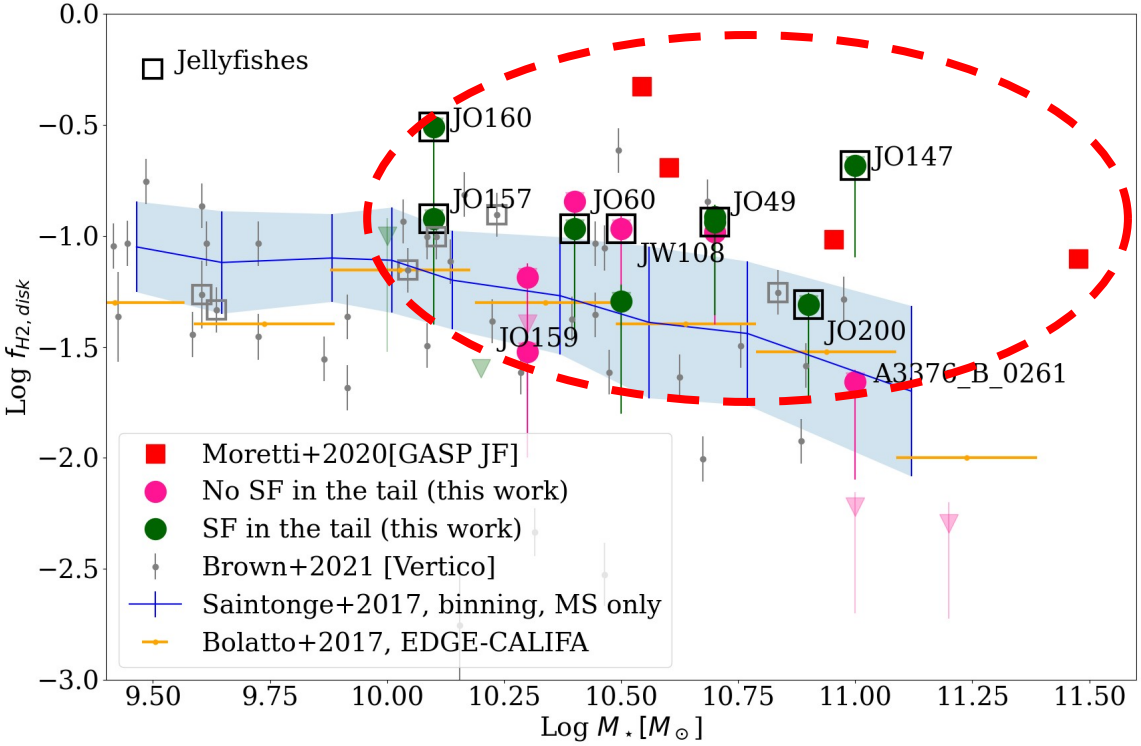
Follow-up programs for a **multi-wavelength** view

(e.g. radio, sub-mm, UV, X)

Poggianti+2016, 2017b

Gas content & SFR

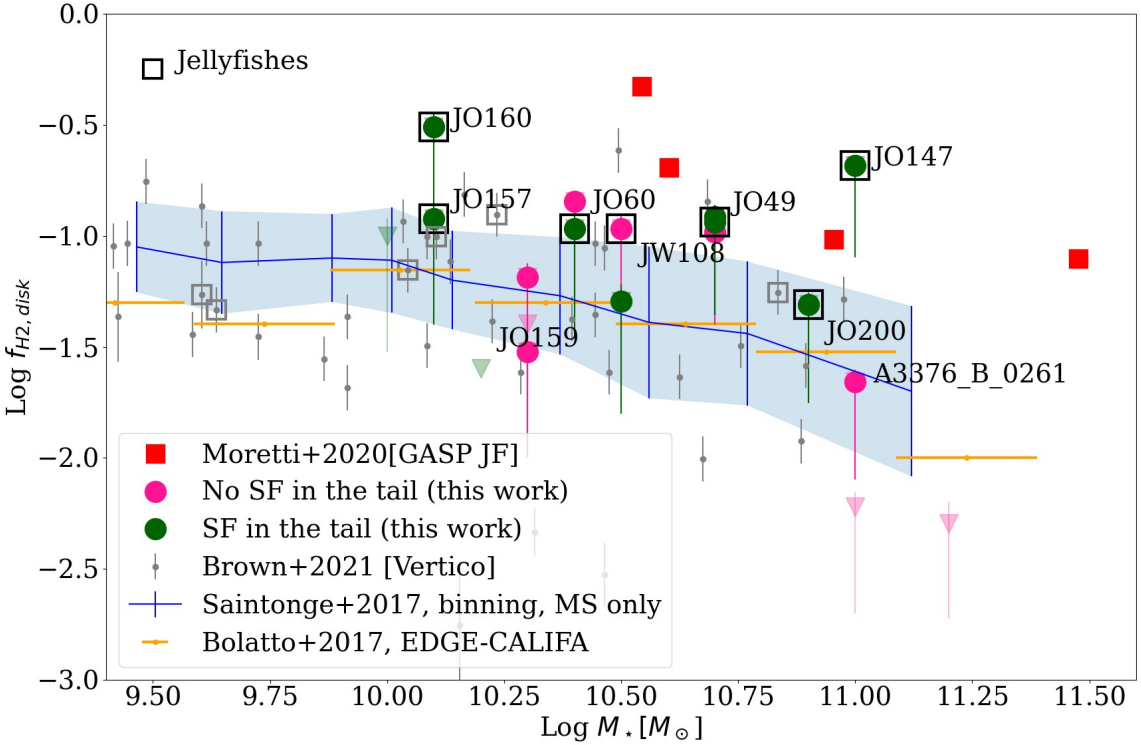
Phase of **H_2 abundance**



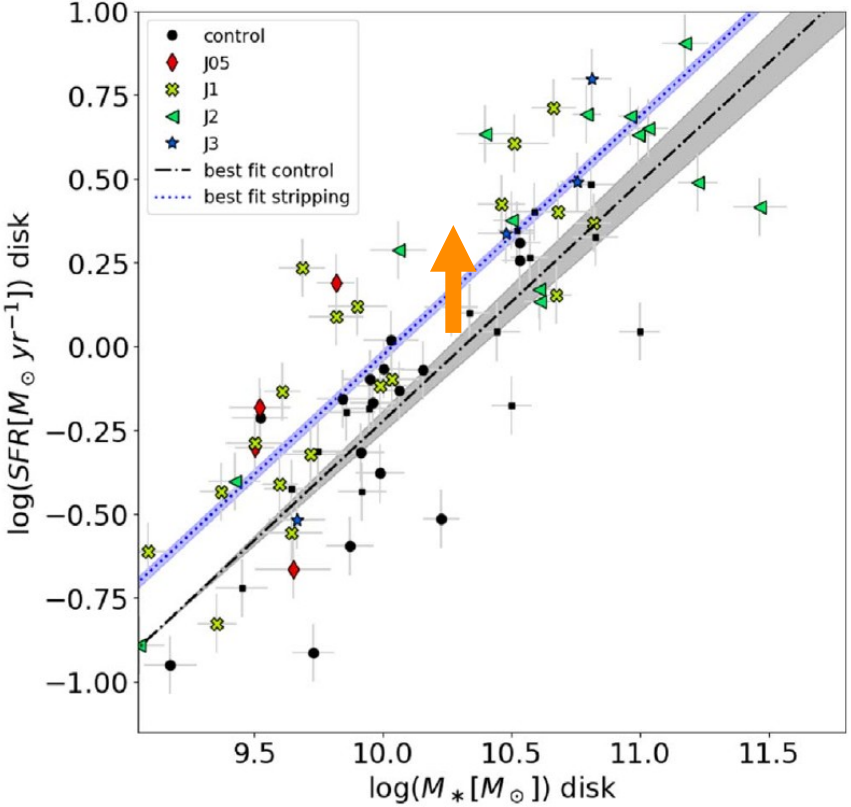
Zabel+2022; Moretti+ to be submitted

Gas content & SFR

Phase of **H_2 abundance**



Enhanced SFR w.r.t. field galaxies



Zabel+2022; Moretti+ to be submitted

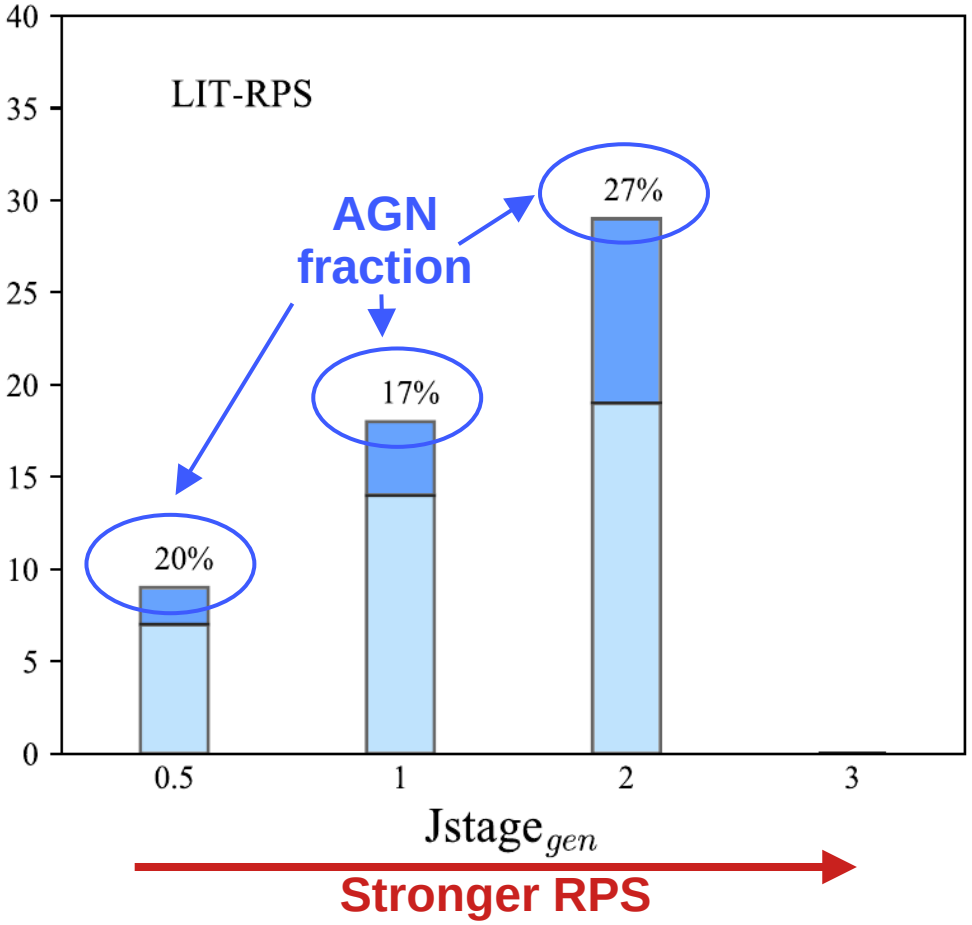
Vulcani+2018

RP & AGN activity

Debate: more AGNs in RPS galaxies?

↓

RP can push gas inward and feed the BH?



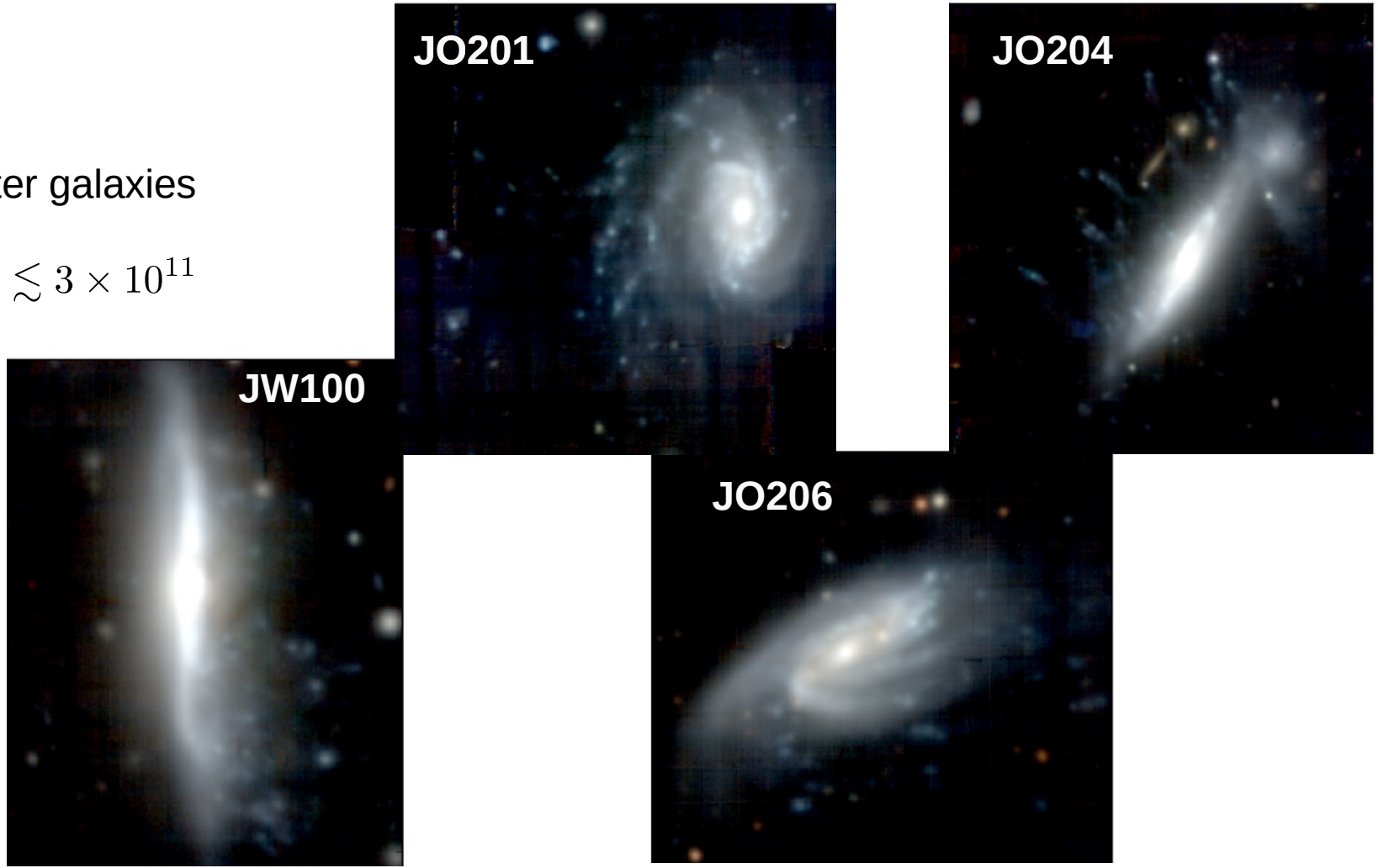
Poggianti+2017a; Peluso+2022; Akerman+2023

Sample

Sample:

4 late-type cluster galaxies

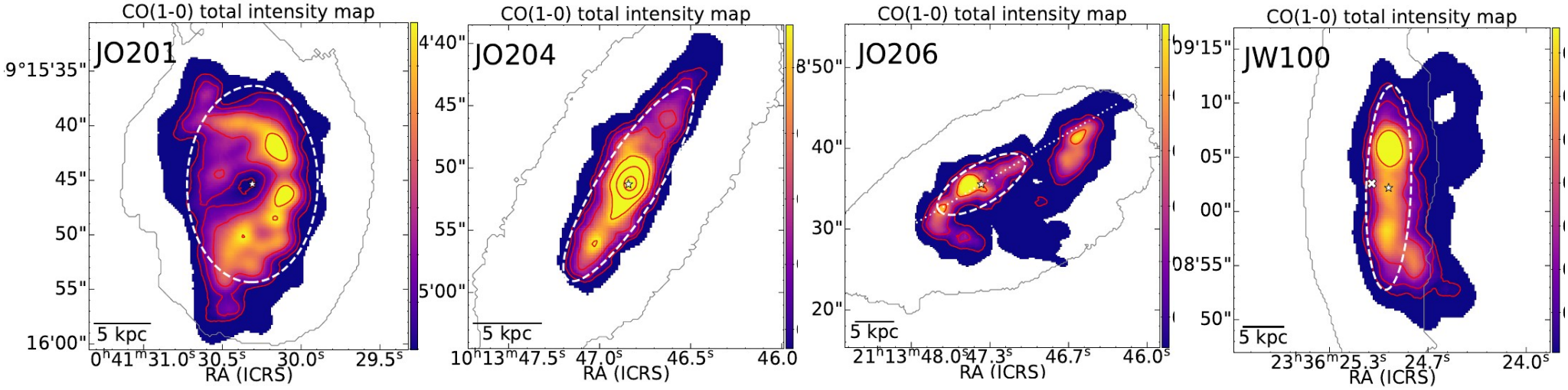
$$4 \times 10^{10} \lesssim \frac{M_\star}{M_\odot} \lesssim 3 \times 10^{11}$$



VRI images
Radovich+2019

ALMA data

CO(2-1) and **CO(1-0)**
Spatial resolution ~ 1”-2”
Channel width Δv=10 km/s



Information on distribution and kinematics of molecular gas

ALMA data

CO(2-1) and **CO(1-0)**
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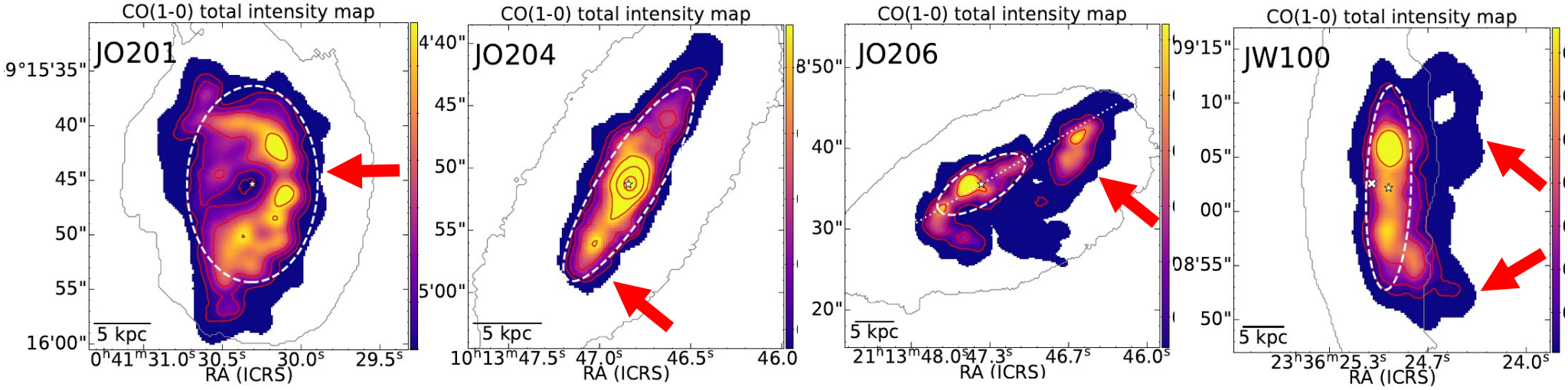


Information on distribution and kinematics of molecular gas

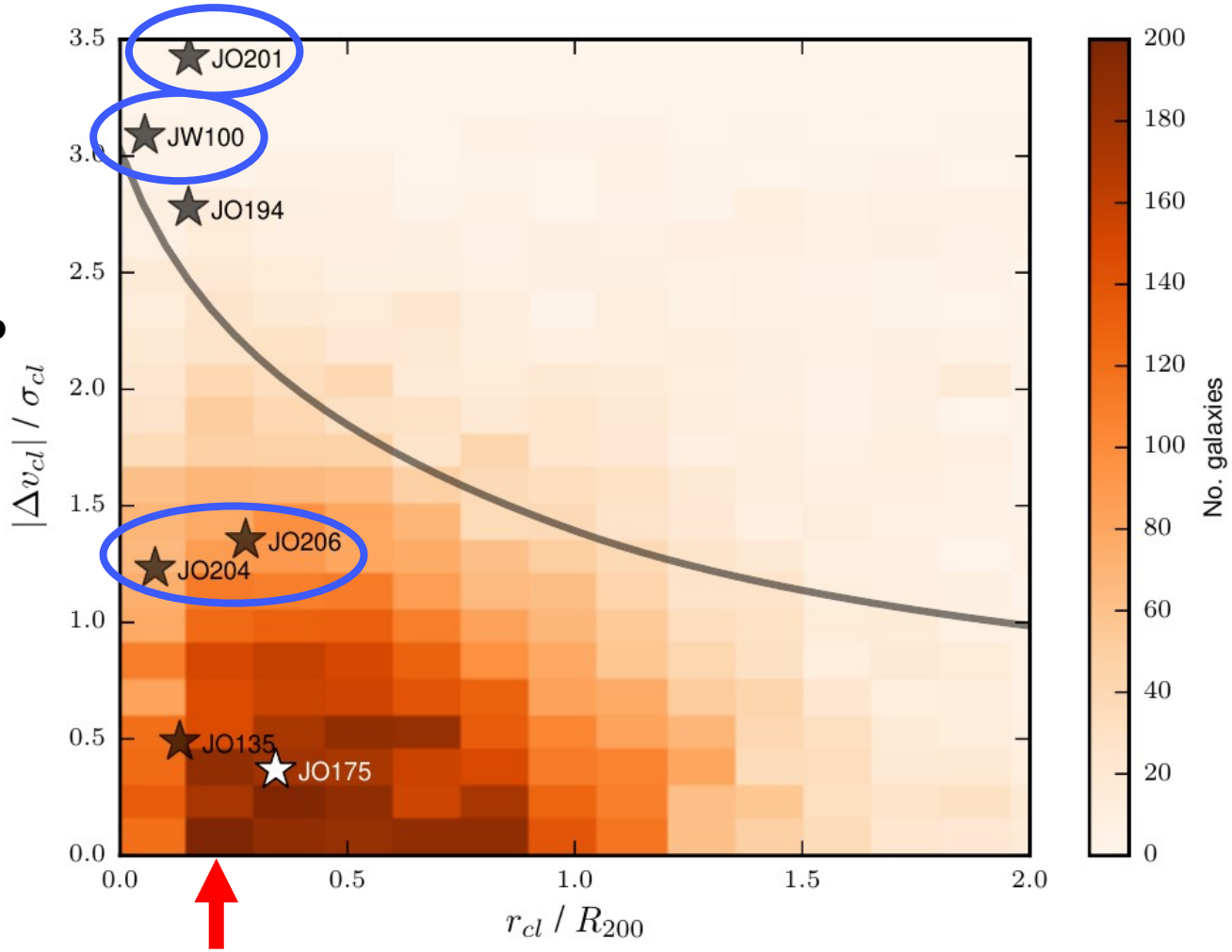
What we know

Sample:

JO201, JO204, JO206, JW100

Info:

- **Favourable conditions for RP**



Poggianti+2017

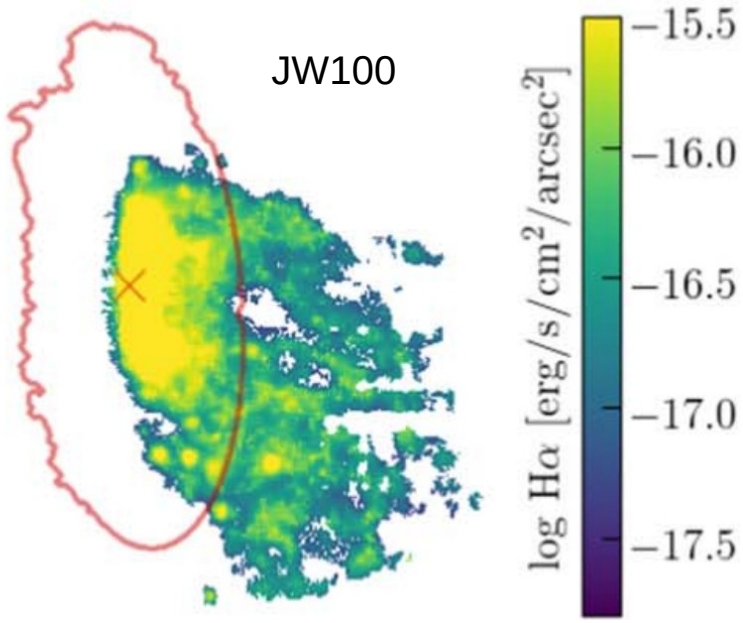
What we know

Sample:

JO201, JO204, JO206, JW100

Info:

- Favourable conditions for RP
- **Tails of ionized gas**



Gullieuszik+2020

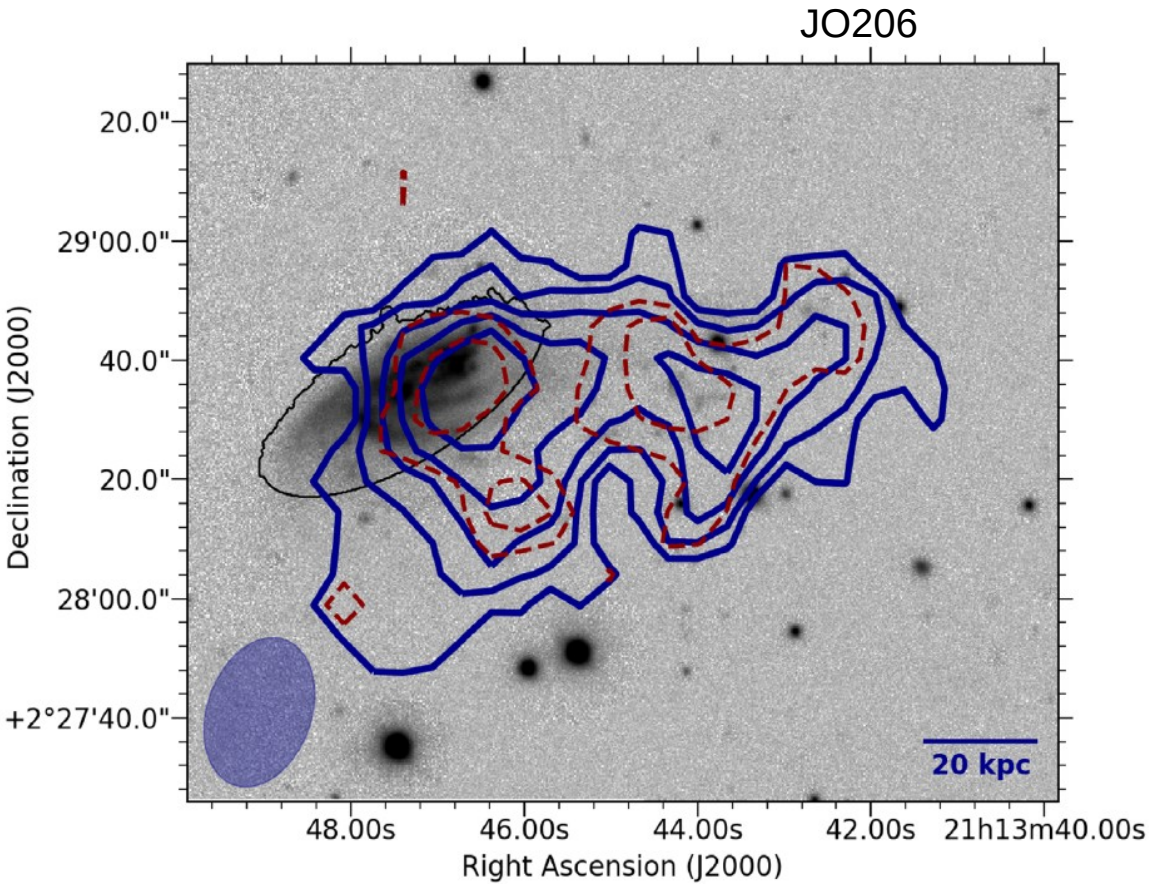
What we know

Sample:

JO201, JO204, JO206, JW100

Info:

- Favourable conditions for RP
- Tails of ionized gas
- **HI: deficient and asymmetric**



Ramatsoku+2019

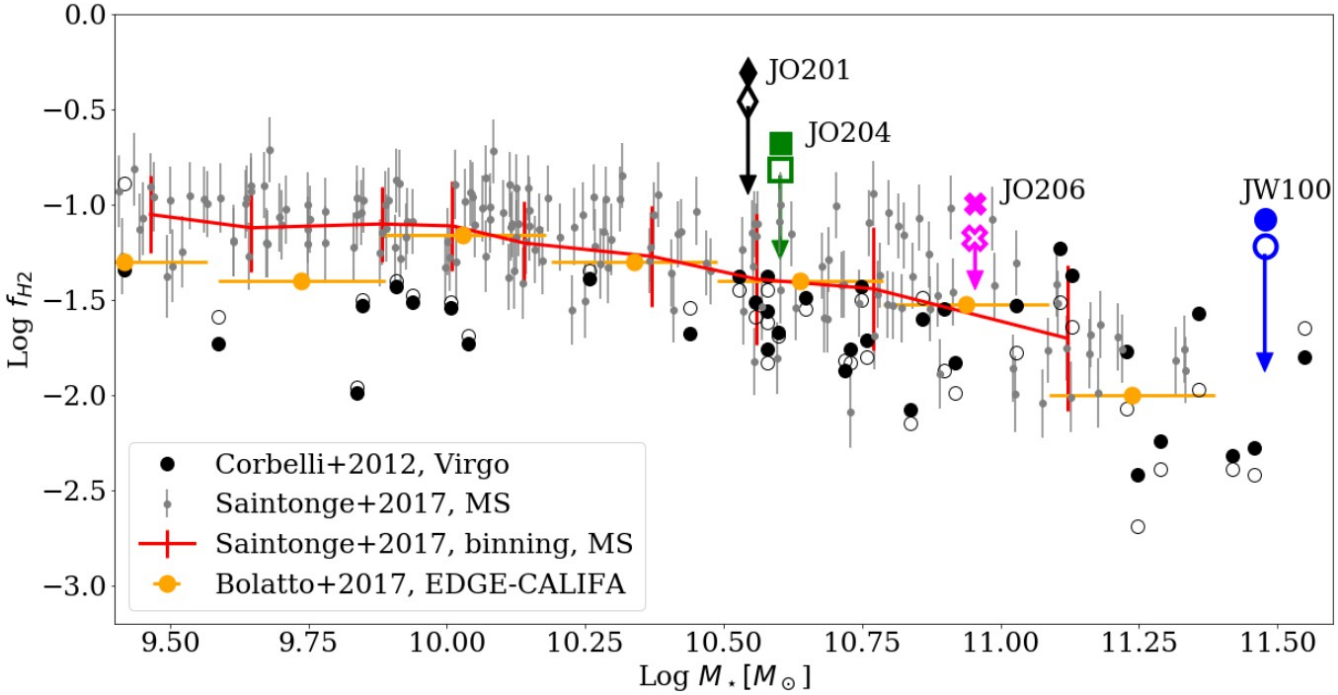
What we know

Sample:

JO201, JO204, JO206, JW100

Info:

- Favourable conditions for RP
- Tails of ionized gas
- HI: deficient and asymmetric
- **H_2 very abundant**



Moretti+2020

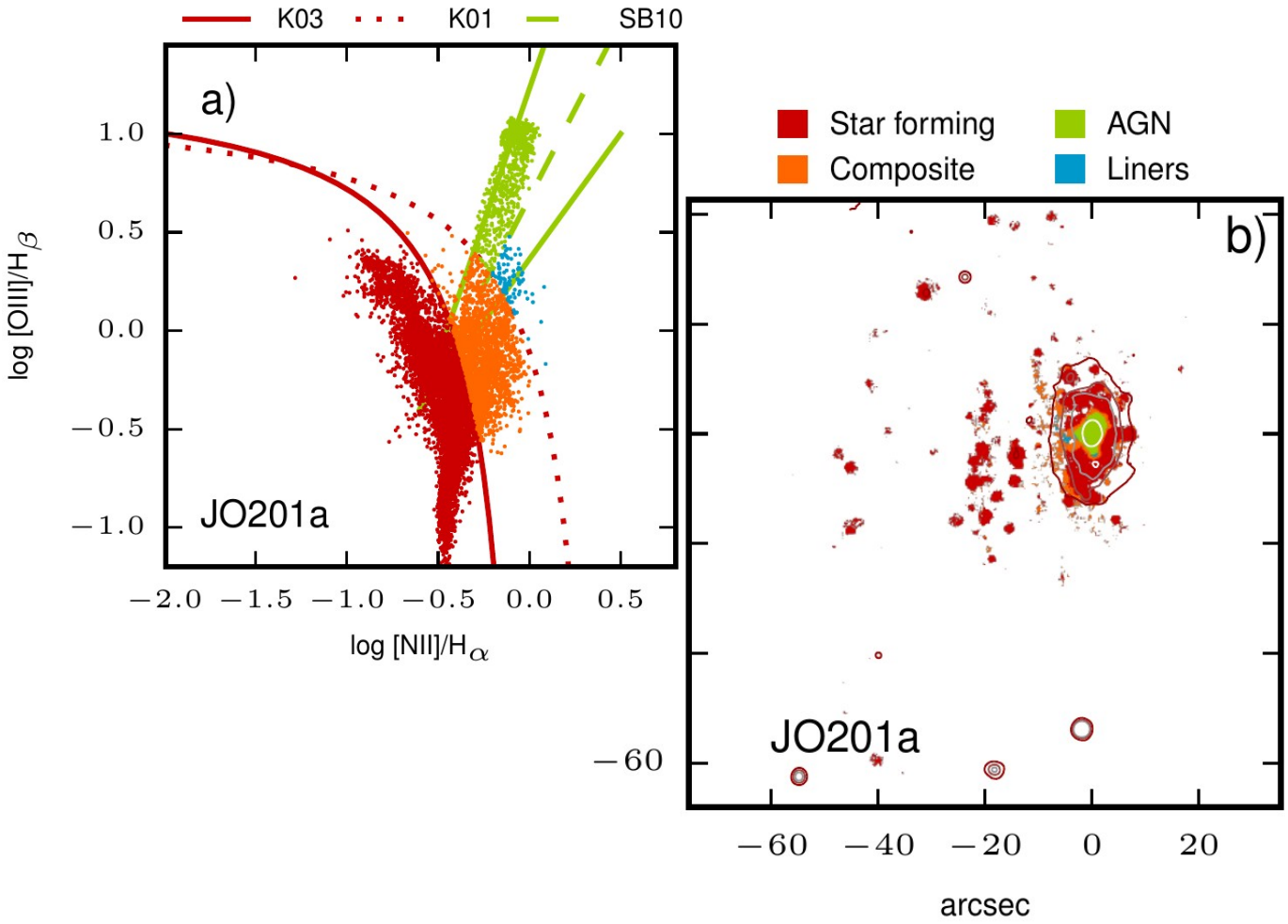
What we know

Sample:

JO201, JO204, JO206, JW100

Info:

- Favourable conditions for RP
- Tails of ionized gas
- HI: deficient and asymmetric
- H_2 very abundant
- **Host AGN → ionised gas outflows**



Poggianti+2017

Motivation

GOAL: analyse molecular gas distribution and kinematics.

1) **Impact of RP** on the molecular gas distribution and kinematics?
   Some gas **still rotating?**

2) **Outflows** of molecular gas driven by the RP and/or the AGN?

3) **Inflows** of molecular gas driven by the RP towards the AGN?

Motivation

GOAL: analyse molecular gas distribution and kinematics.

1) **Impact o**
Some ga

2) **Outflow**

3) **Inflows**

Method

Molecular gas kinematics (perturbed)

vs

Stellar kinematics (unperturbed)

↓

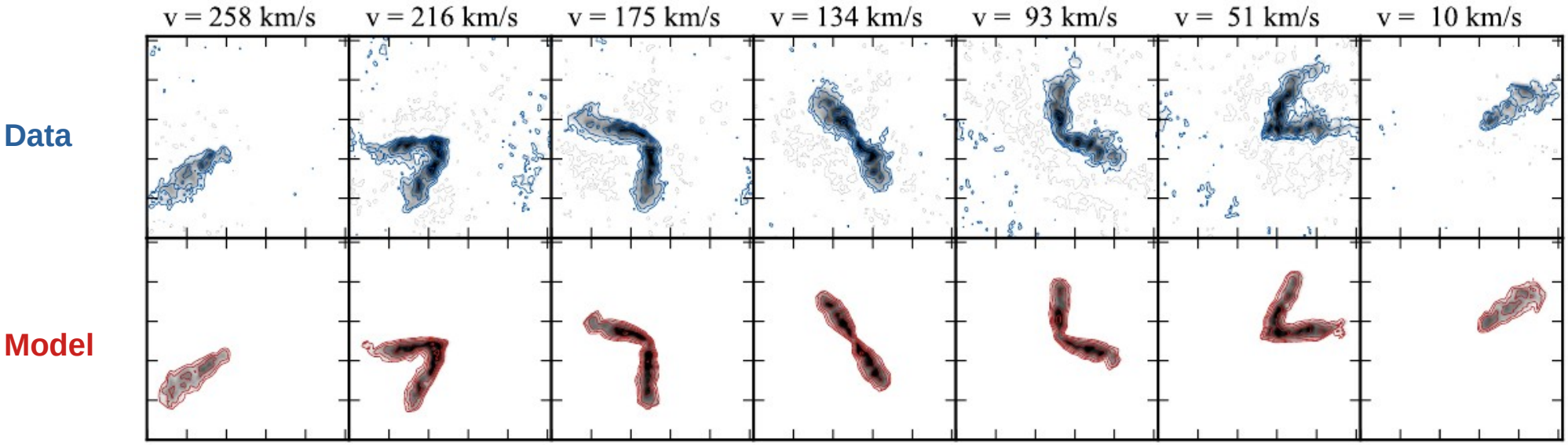
Effect of RP

Modeling of CO datacubes

3D Based Analysis of Rotating Objects via Line Observations

Di Teodoro & Fraternali 2015

$$V_{los}(x,y) = V_{sys} + V_{rot}(R)\cos\theta\sin i + V_{rad}(R)\sin\theta\sin i$$



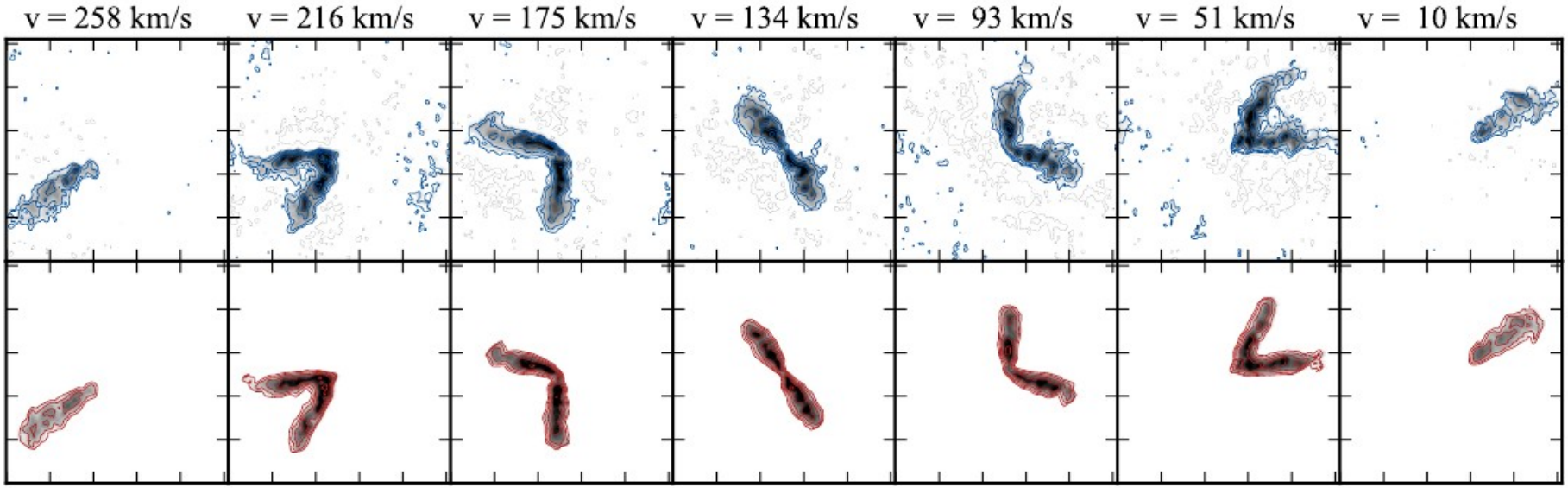
Modeling of CO datacubes

3D Based Analysis of Rotating Objects via Line Observations

Di Teodoro & Fraternali 2015

Rotation velocity **Radial velocity** **σ Velocity dispersion**

$$V_{los}(x,y) = V_{sys} + V_{rot}(R)\cos\theta\sin i + V_{rad}(R)\sin\theta\sin i$$



Data

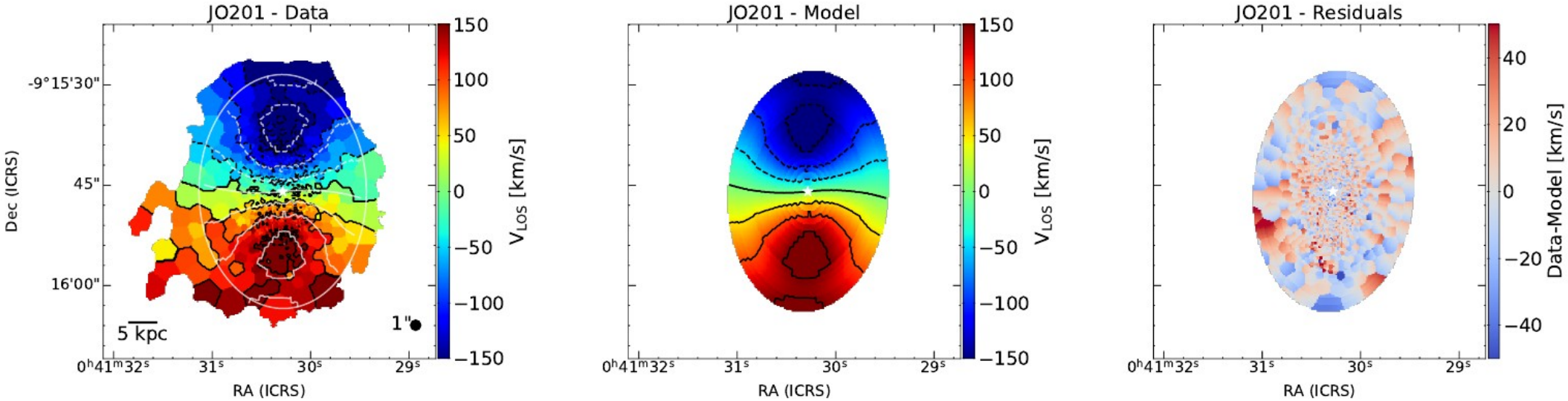
Model

Modeling of stellar velocity field

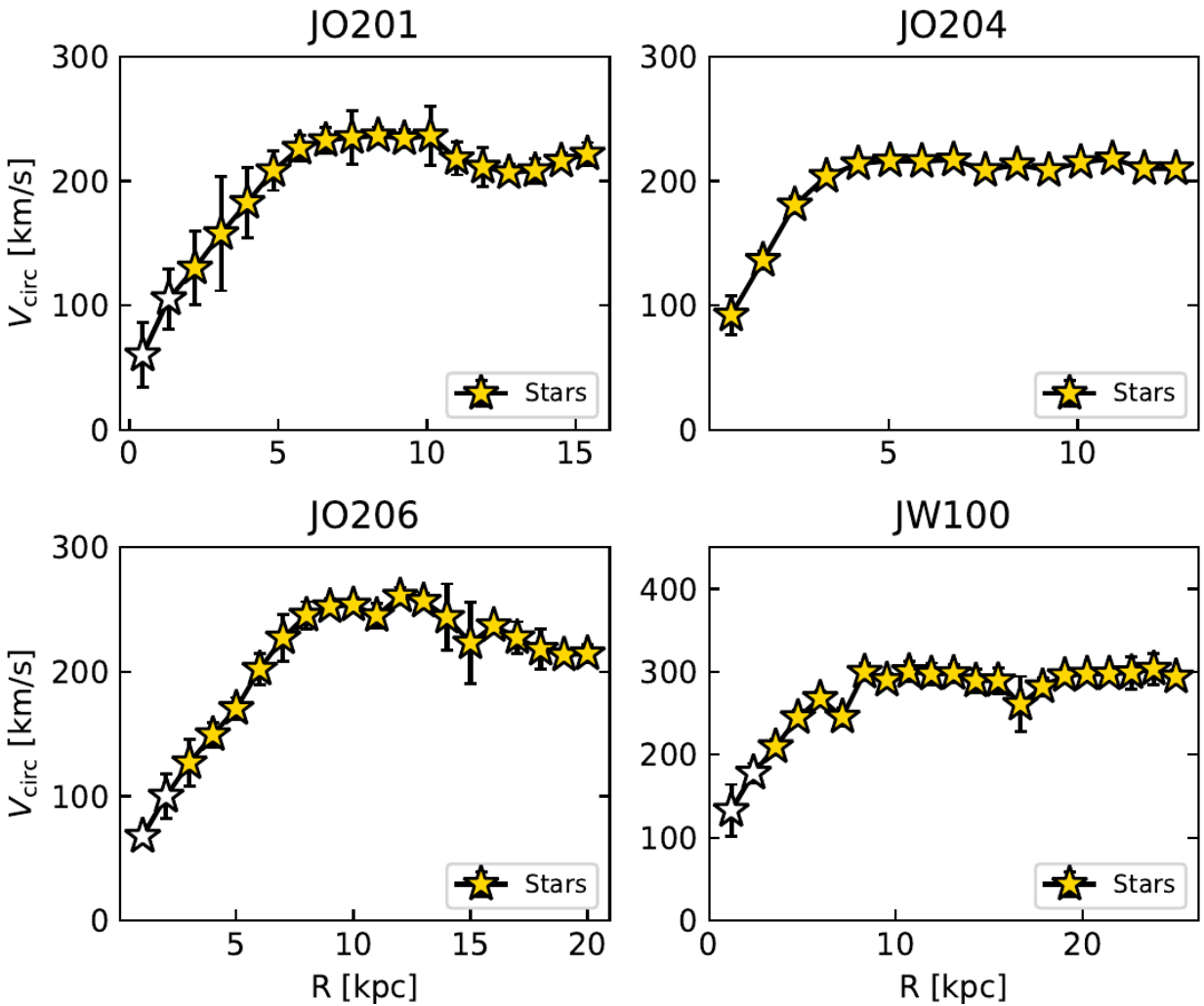
3D Based Analysis of Rotating Objects via Line Observations

Di Teodoro & Fraternali 2015

$$V_{los}(x,y) = V_{sys} + V_{rot}(R)\cos\theta\sin i$$

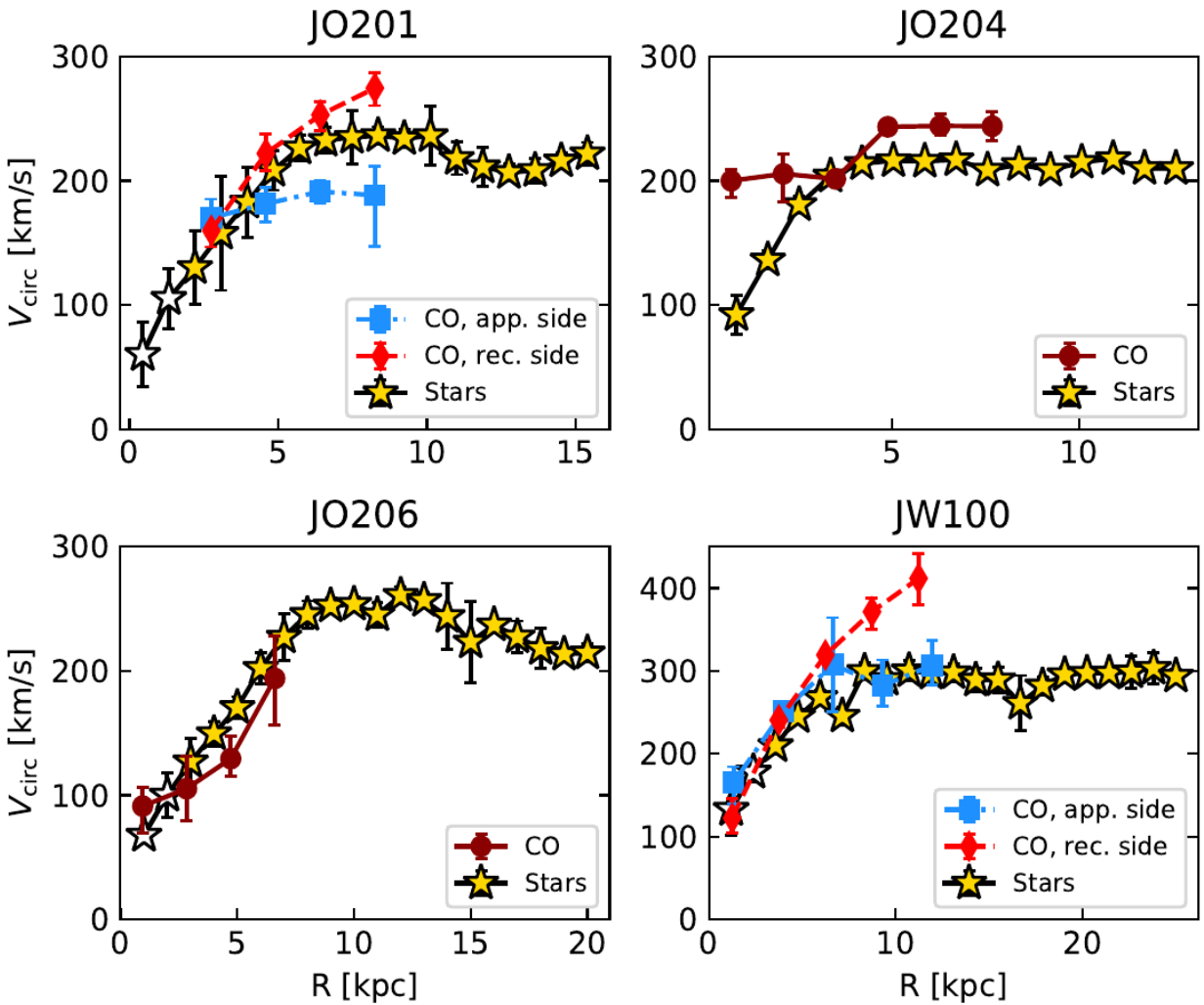


Stellar circular velocity



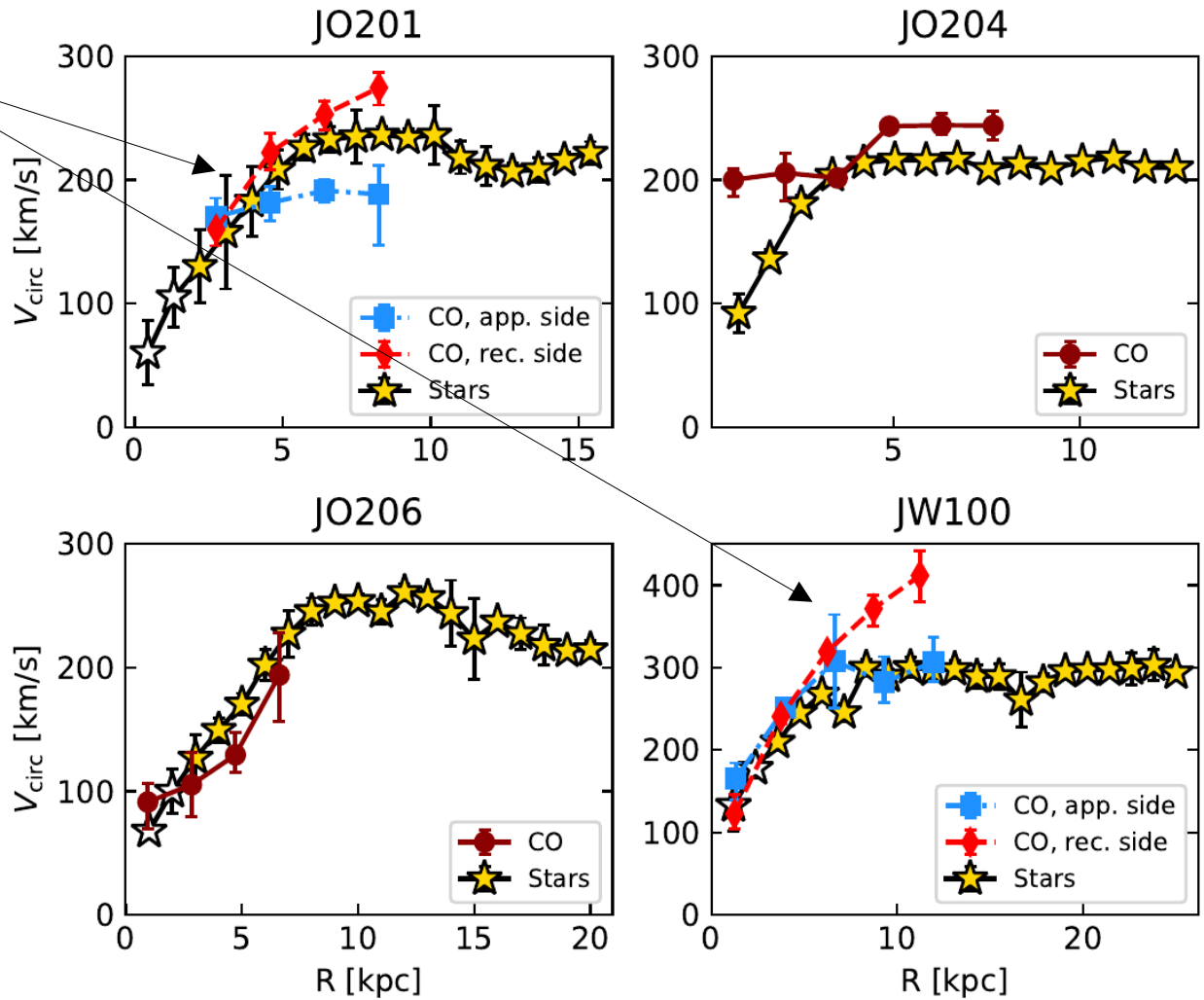
Stellar Vrot
correted for
pressure-support

Stellar vs CO circular velocity



Stellar vs CO circular velocity

Kinematic lopsidedness



Stellar vs CO circular velocity

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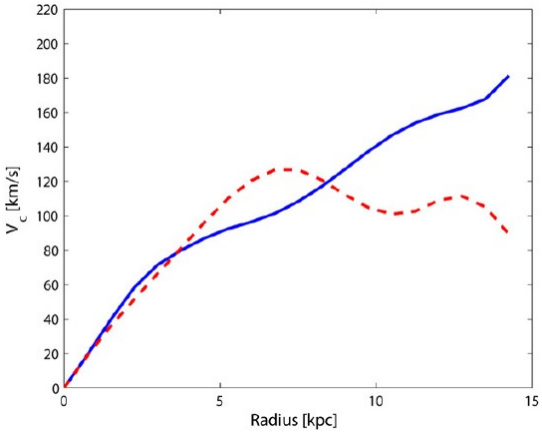
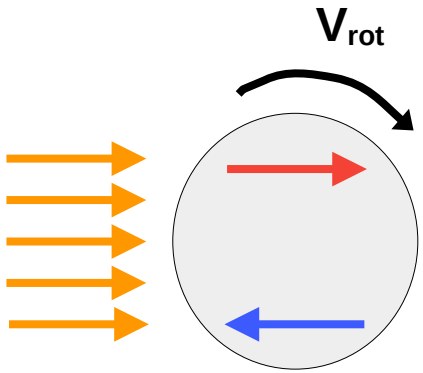
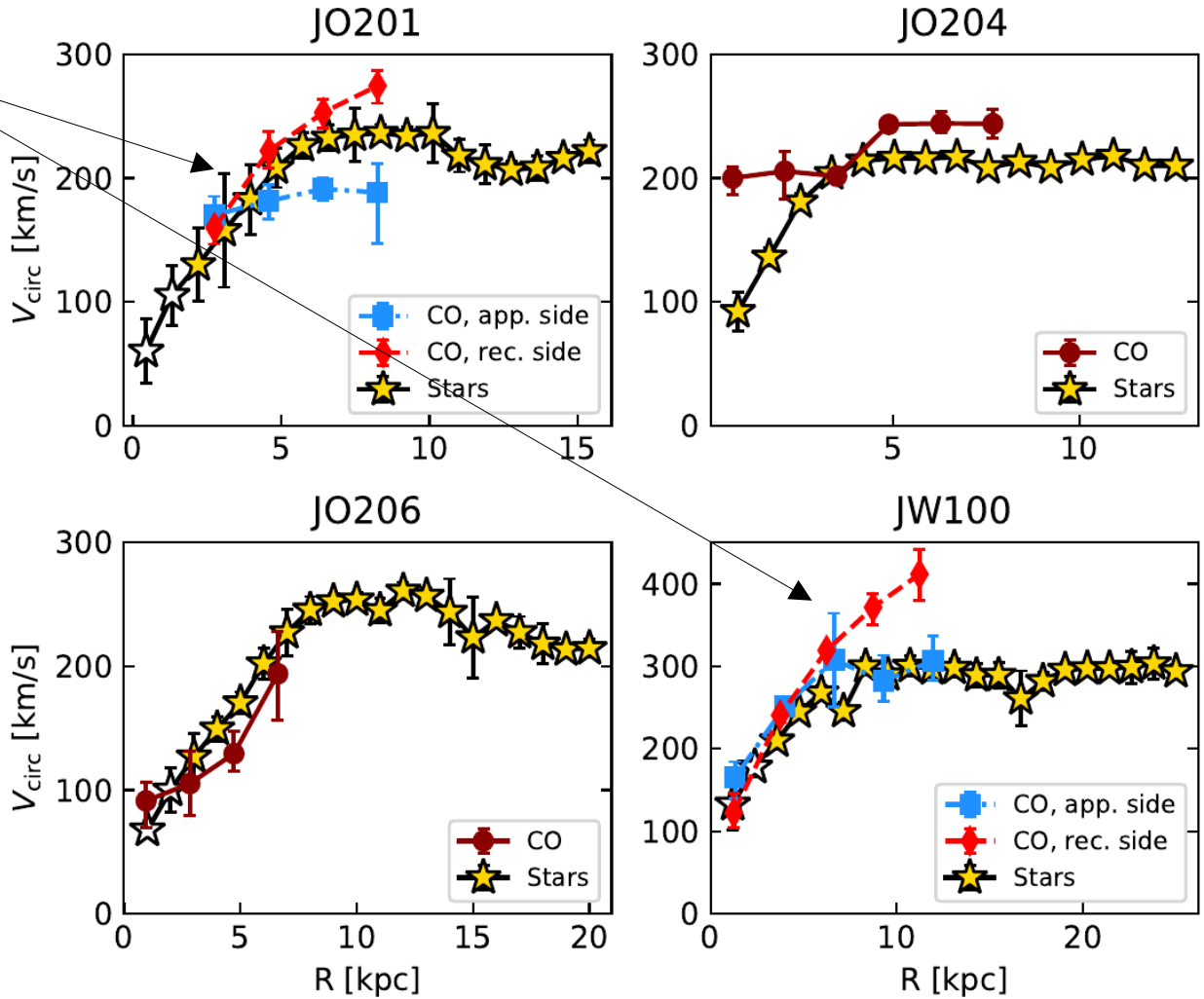
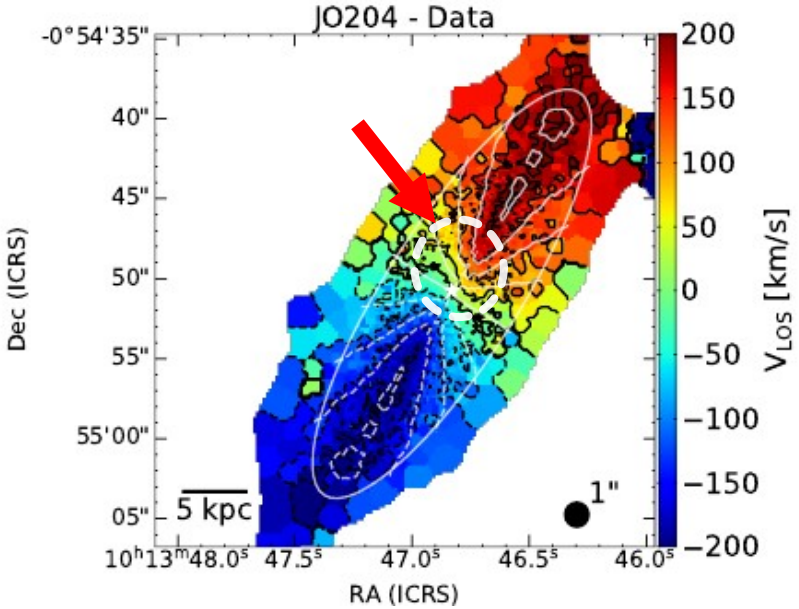


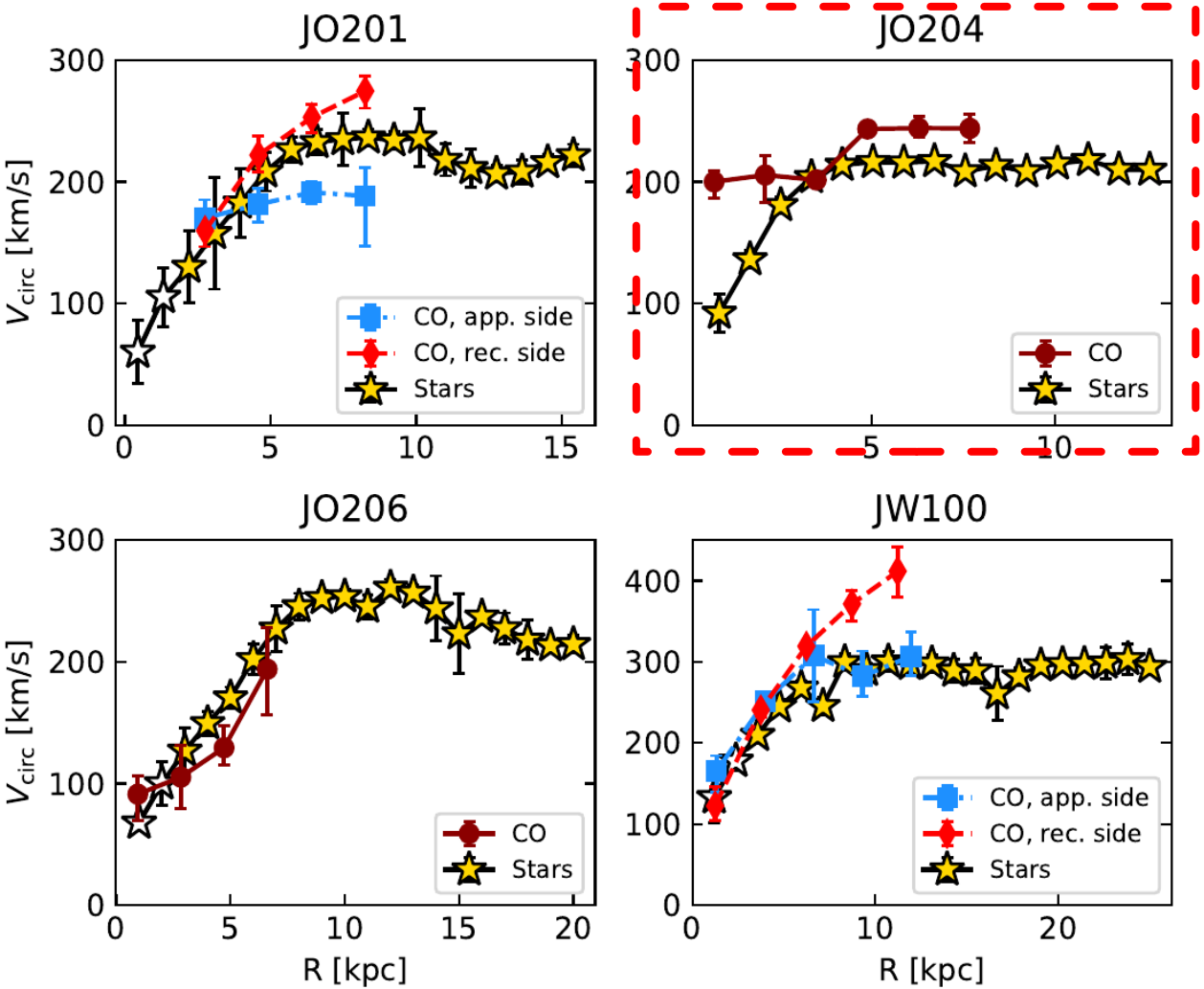
Kronberger+2008



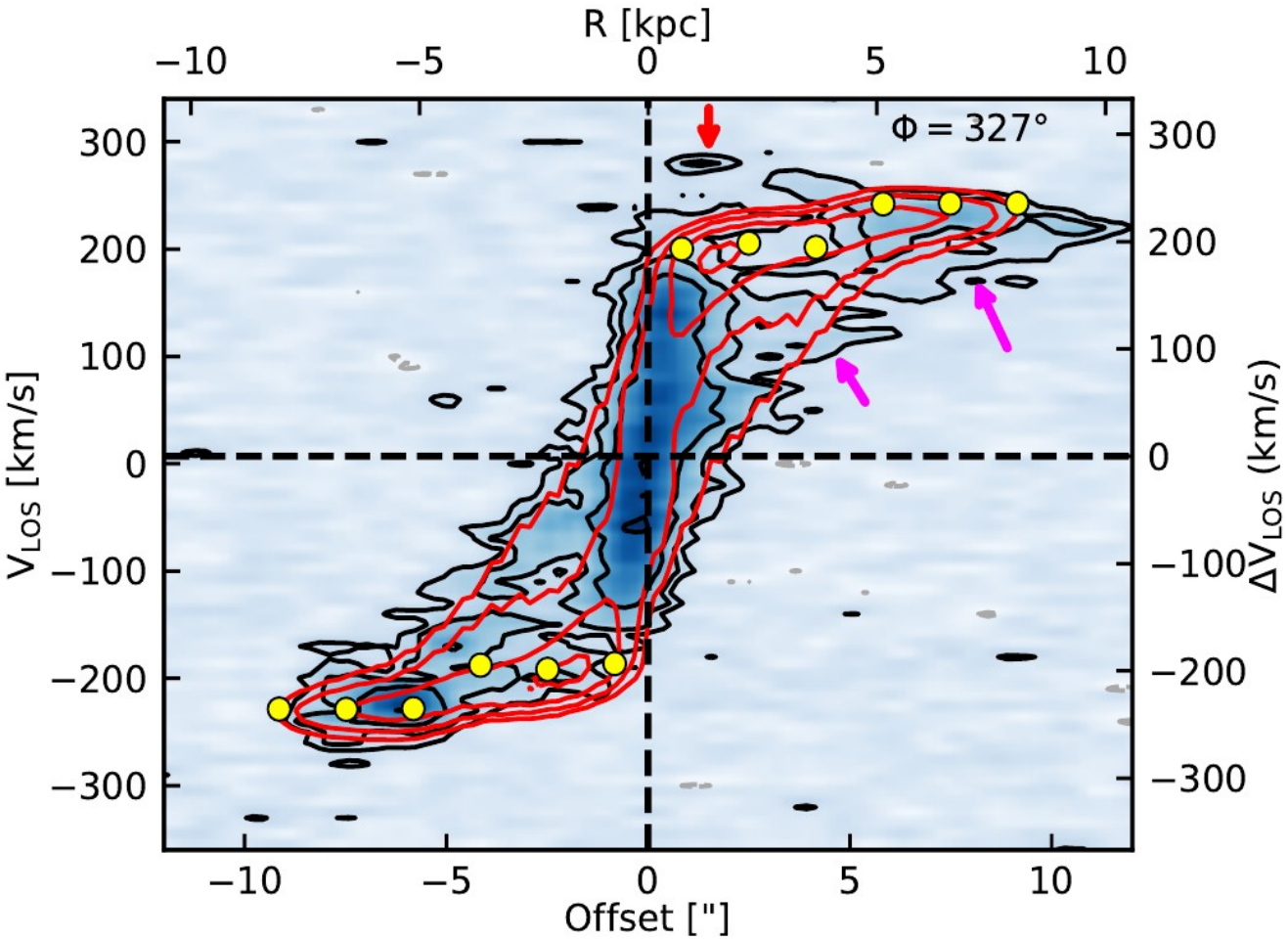


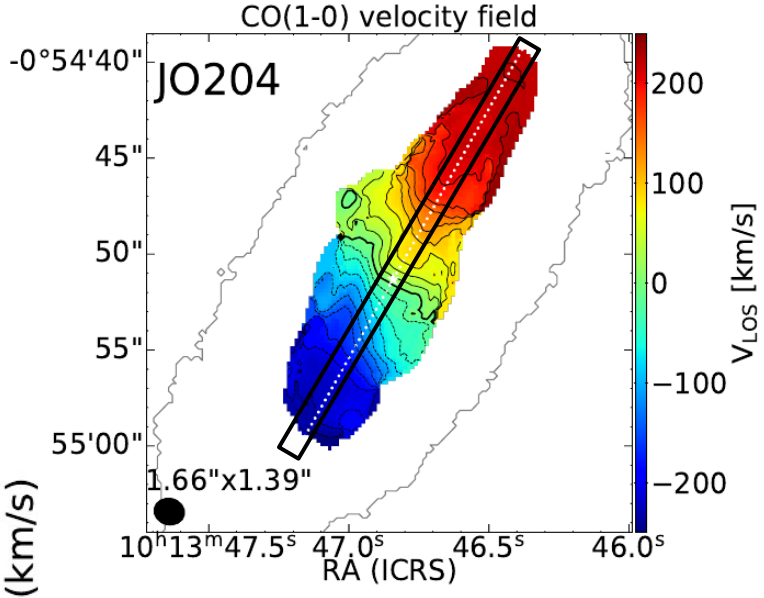
Stellar vs CO circular velocity





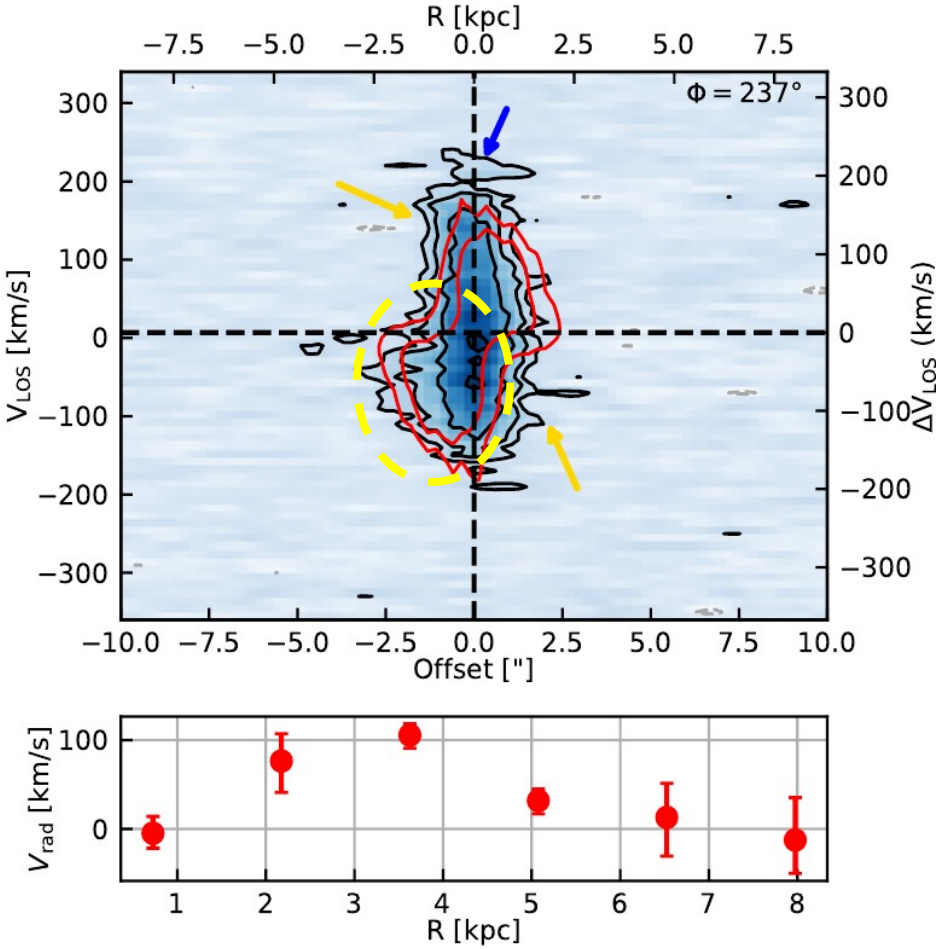
JO204

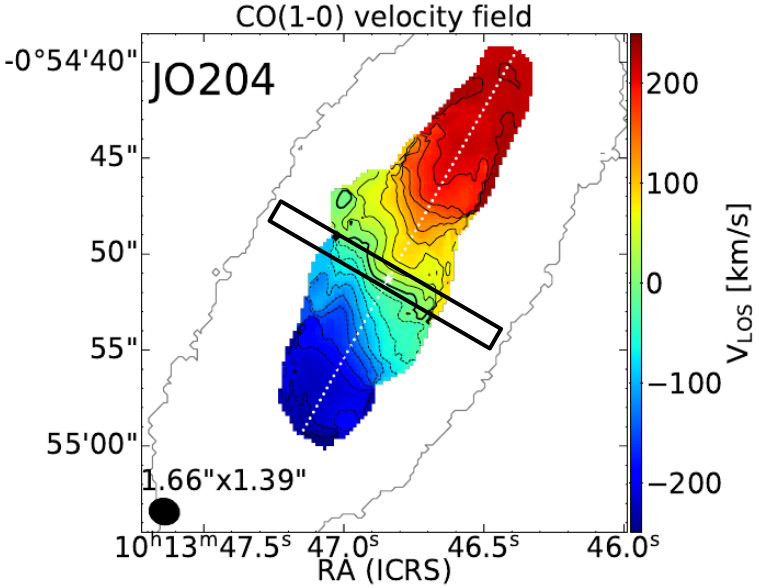




- **Rotation-dominated**
- **Low-velocity gas:** decelerated by RP
- **High-velocity gas:**
  - x_2 orbits due to bar?
  - Outflow?

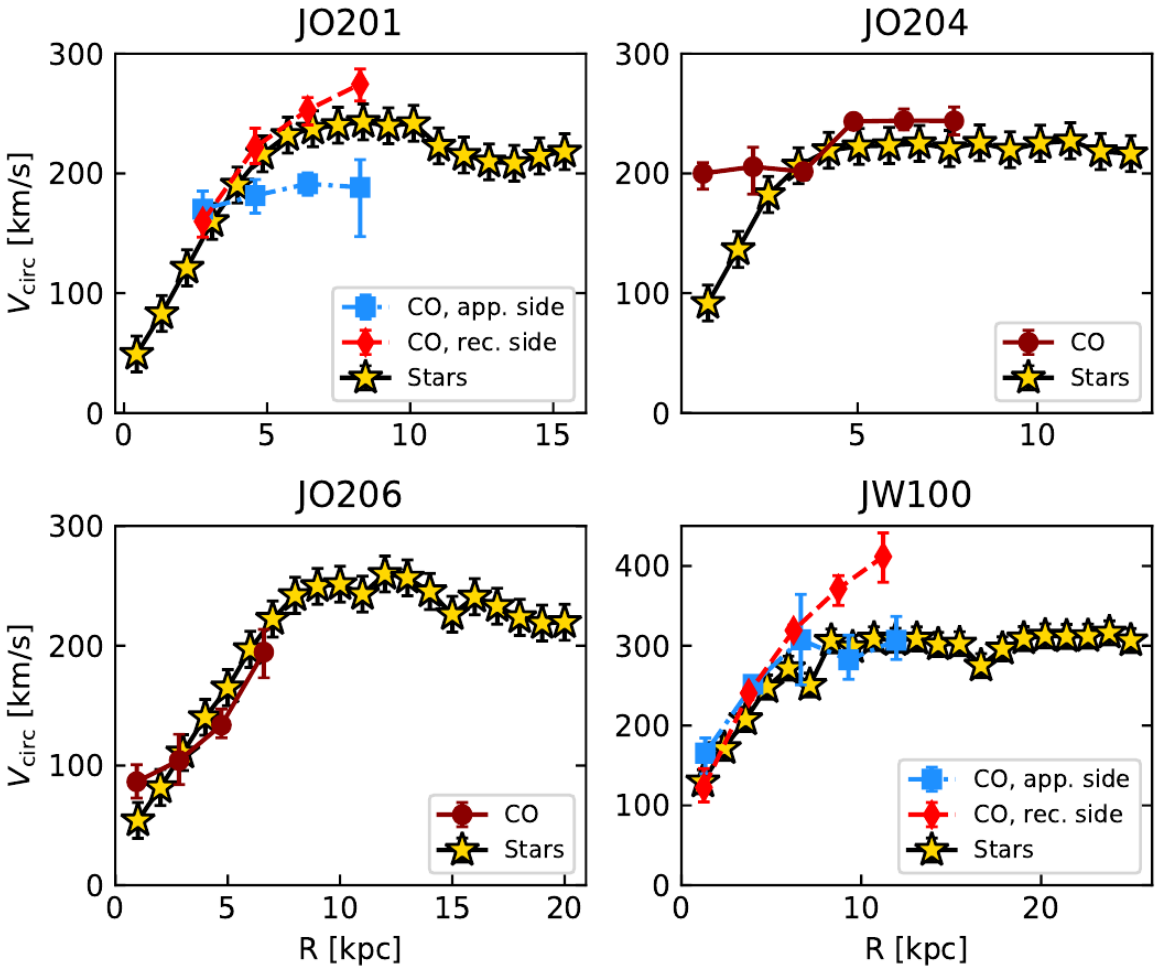
JO204





Strong radial motions → bar

Stellar vs CO kinematics

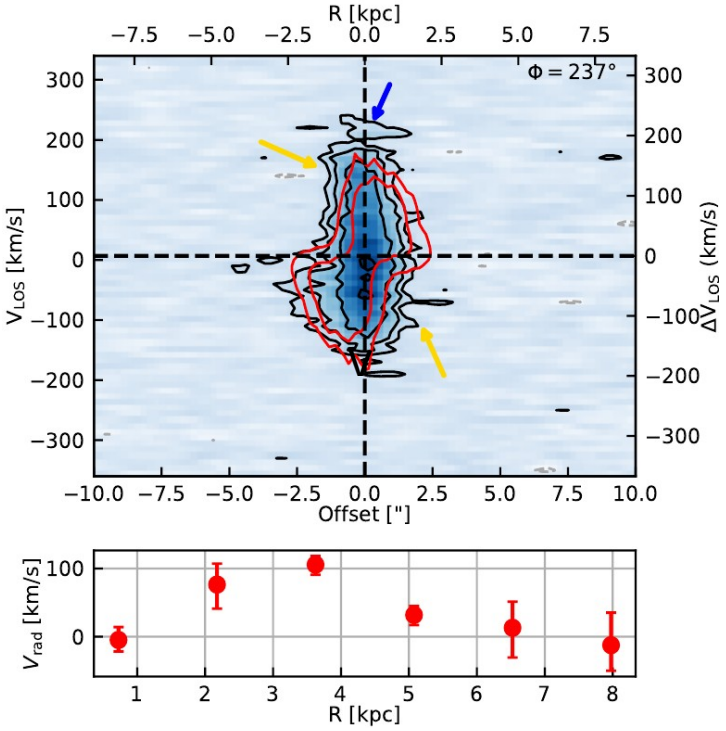


3/4 barred, maybe also JW100.

<u>Bar region</u>: **bar or rotation**.
<u>Outside</u>: **RP** in 3/4 (secondary in JO204).

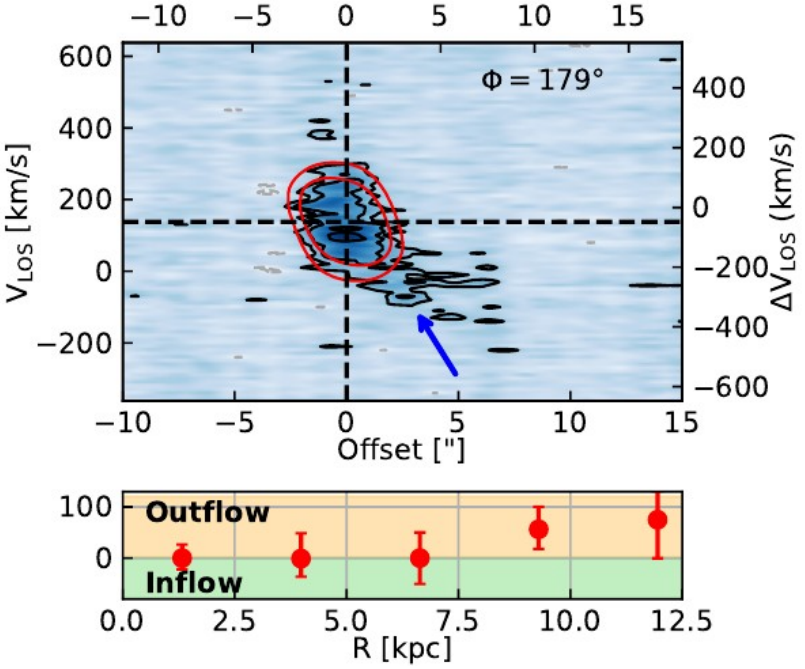
Radial motions

JO204

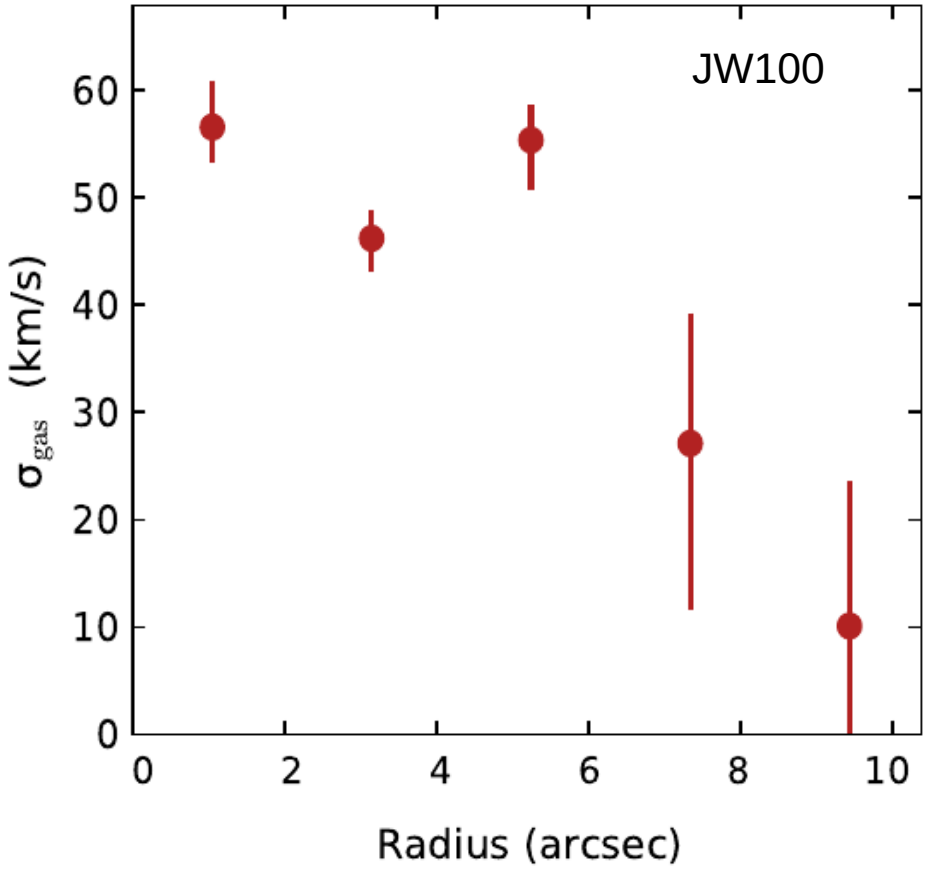


Radial flows:
Bar-driven inflow (JO206?, JO204).
RP-driven outflow (JO201?, JW100).

JW100

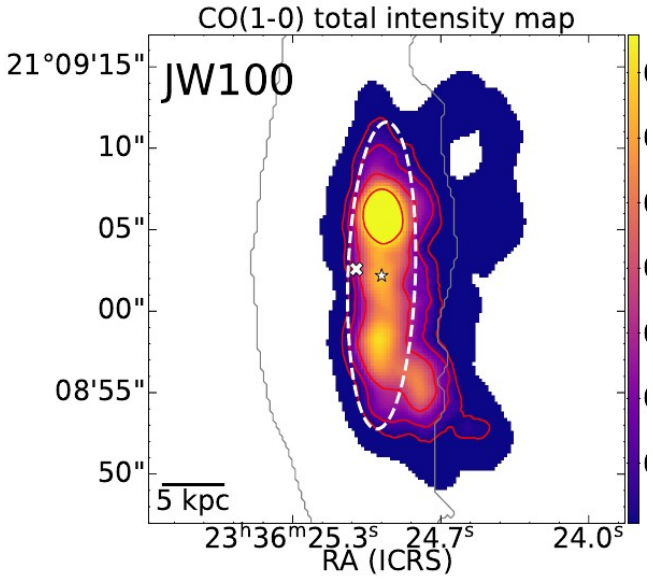


CO velocity dispersion



CO turbulence enhanced (x2-3) by:

- bar (inner regions)
- RP, either directly or not (SNe)



Conclusions

Q1: **RP impact** on the molecular gas distribution & kinematics? Some still **rotating**?
A1: Accelerate/decelerate gas **depending on RP direction & strength.**
Some gas **rotating**.

Q2: **Outflows** of molecular gas driven by the RP and/or the AGN?
A2: **No** clear **AGN-driven** outflows (not always multi-phase).
Possibly **RP**-driven radial outflow.

Q3: **Inflows** of molecular gas driven by the RP towards the AGN?
A3: Inflows **present**, but also bars. Bar-RP interplay in feeding AGN?

Take-home message

1. **Molecular gas more resilient to RP** than other gas phases.

2. **Gas turbulence enhanced by RP**, either directly or through SNe.