Gas Kinematics with JWST: Outflows and Disk Rotation

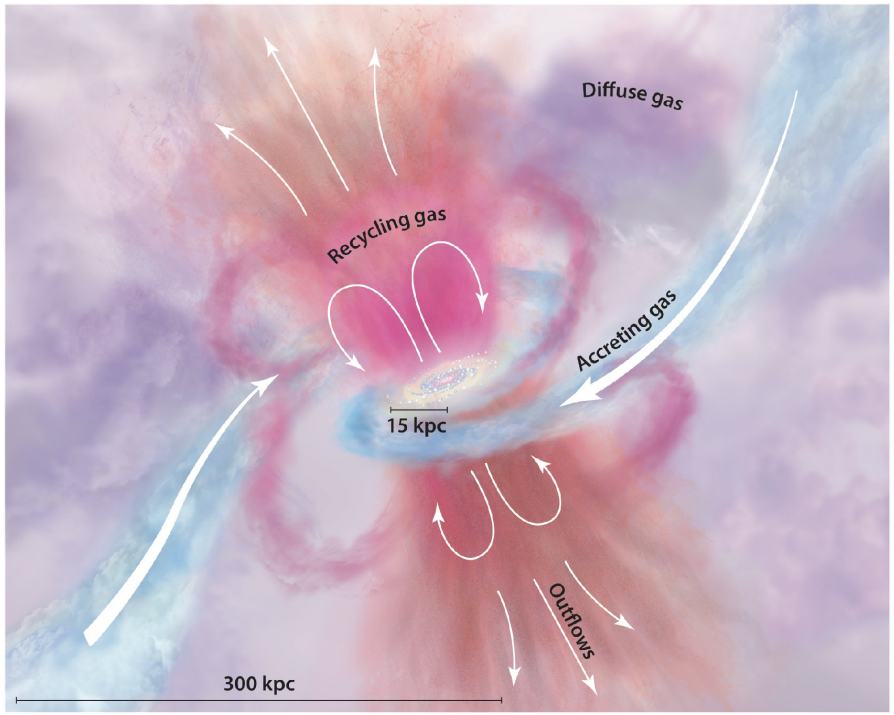
Yi Xu

Based on

Xu et al. 2023 arXiv:2310.06614

Xu et al. 2024 arXiv:2404.16963

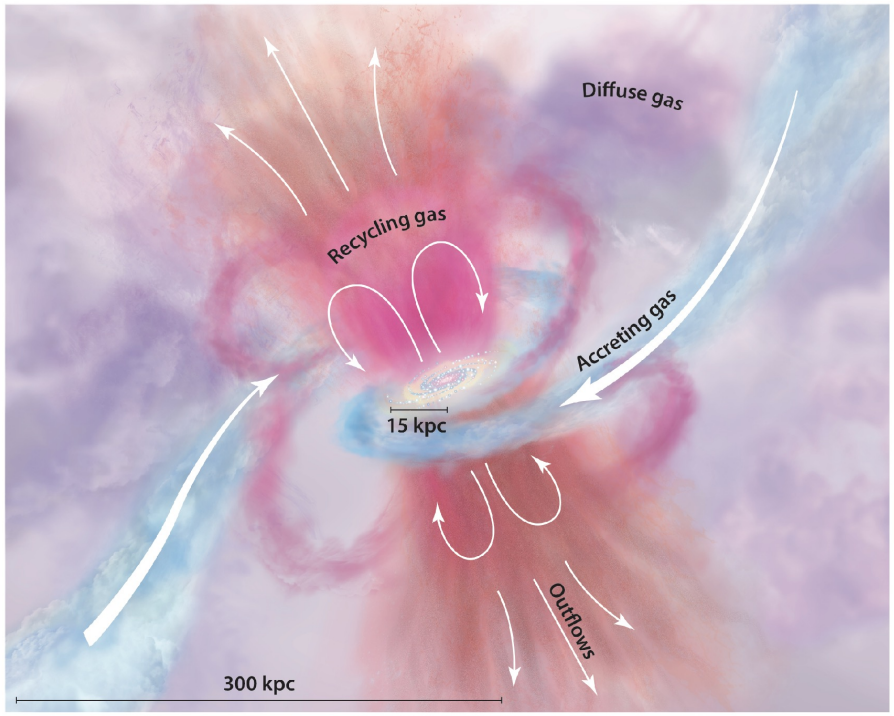
Introduction



Tumlinson+2017

What I **like** about gas kinematics

- Gas is fuel of star formation
- Gas motion probes mass distribution
- Gas outflow/turbulence indicates feedback strength



Tumlinson+2017

What I **like** about gas kinematics

- Gas is fuel of star formation
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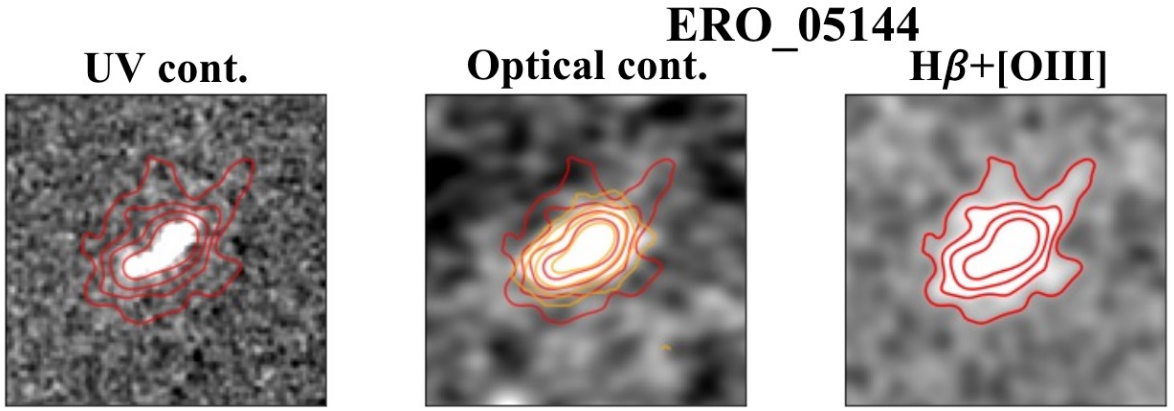
What I **don't like** about **studying** gas kinematics

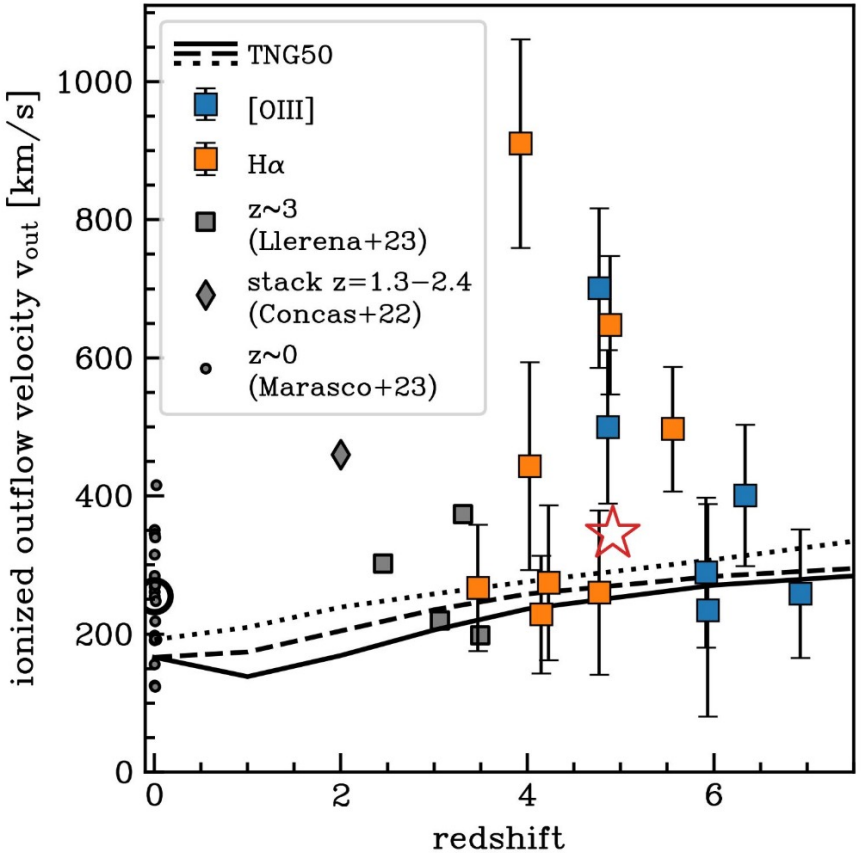
- Only line-of-sight velocity
- Requires high resolution data (spatial and spectral)
- Many alternative interpretations

Outflows at high z with JWST



spatially extended emission line

Y. Zhang, …, YX, et al. 2023, arXiv:2306.07940

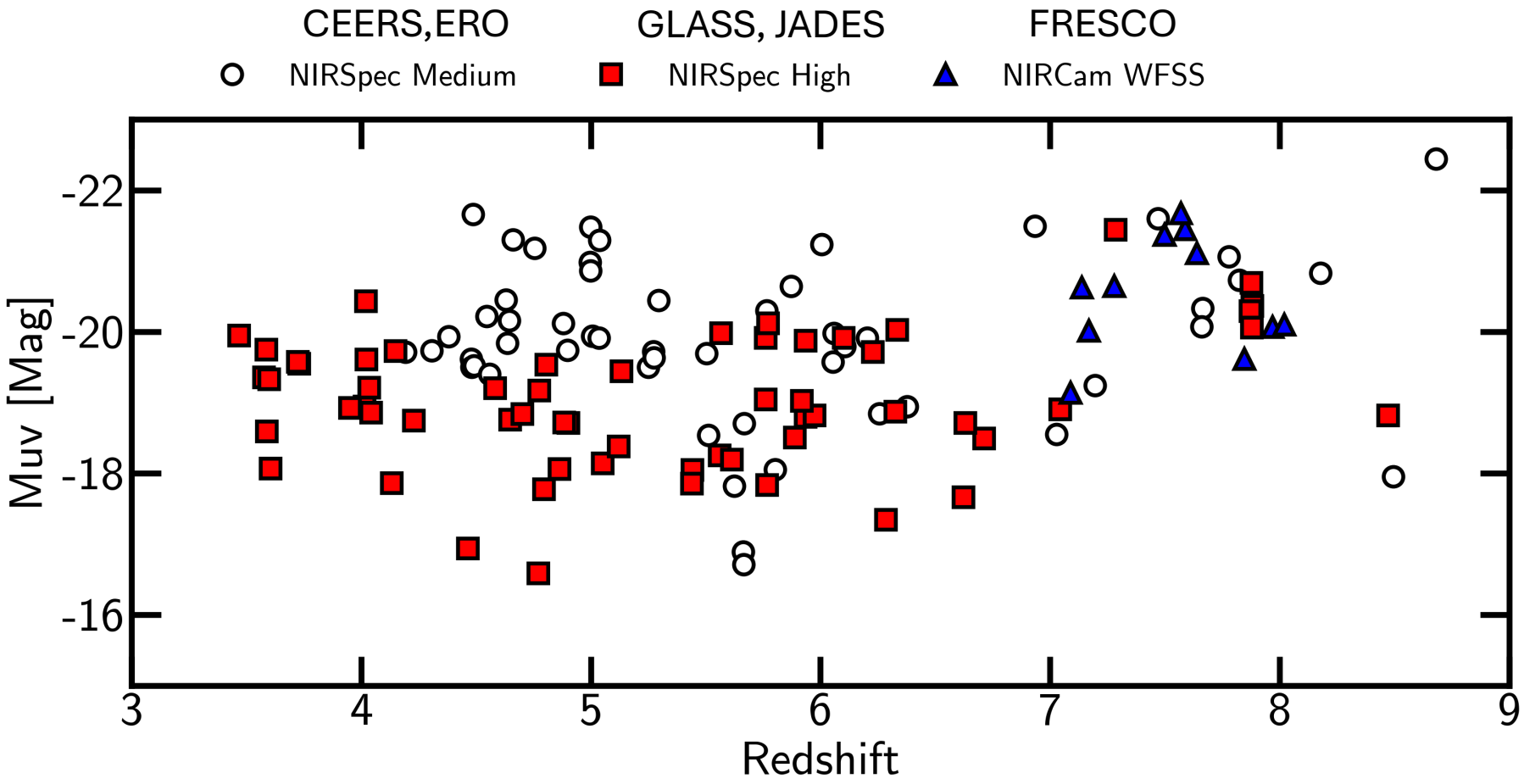


Carniani et al. 2024

Dataset #1

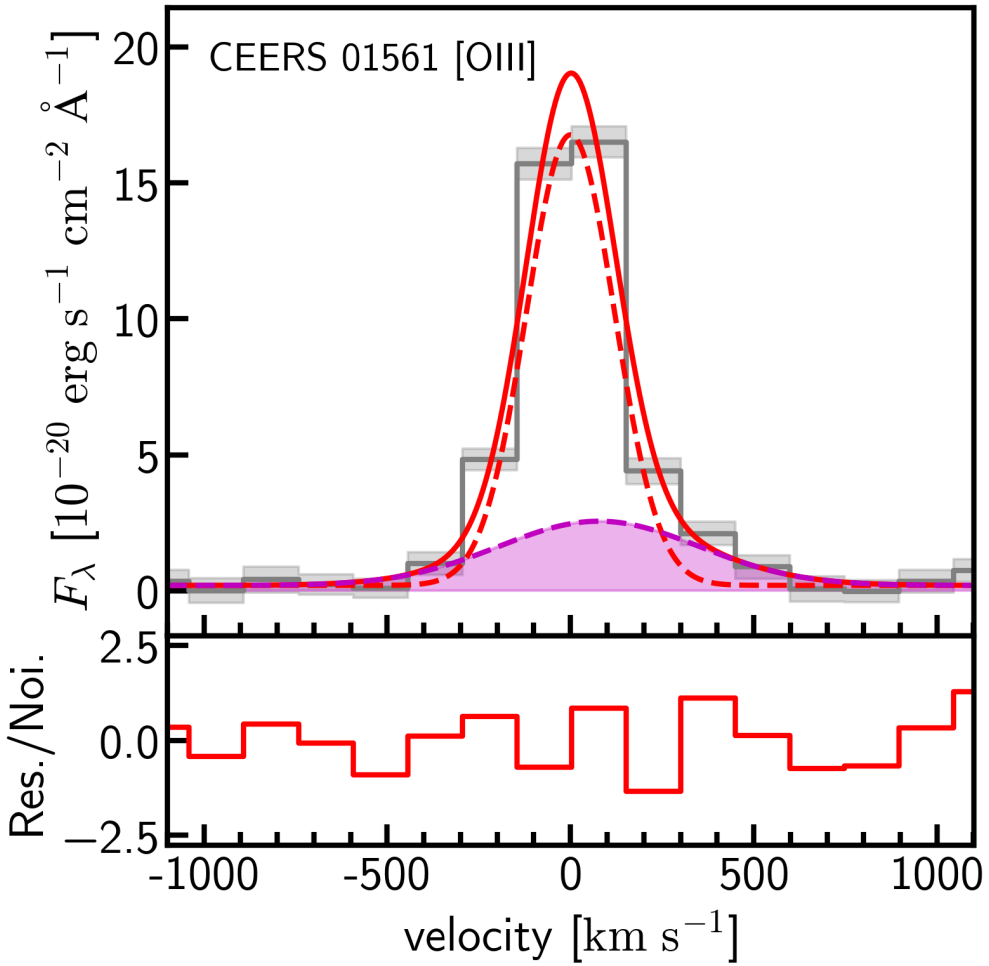
130 galaxies at z~3-9 with Hα or [OIII]λ5007 detections

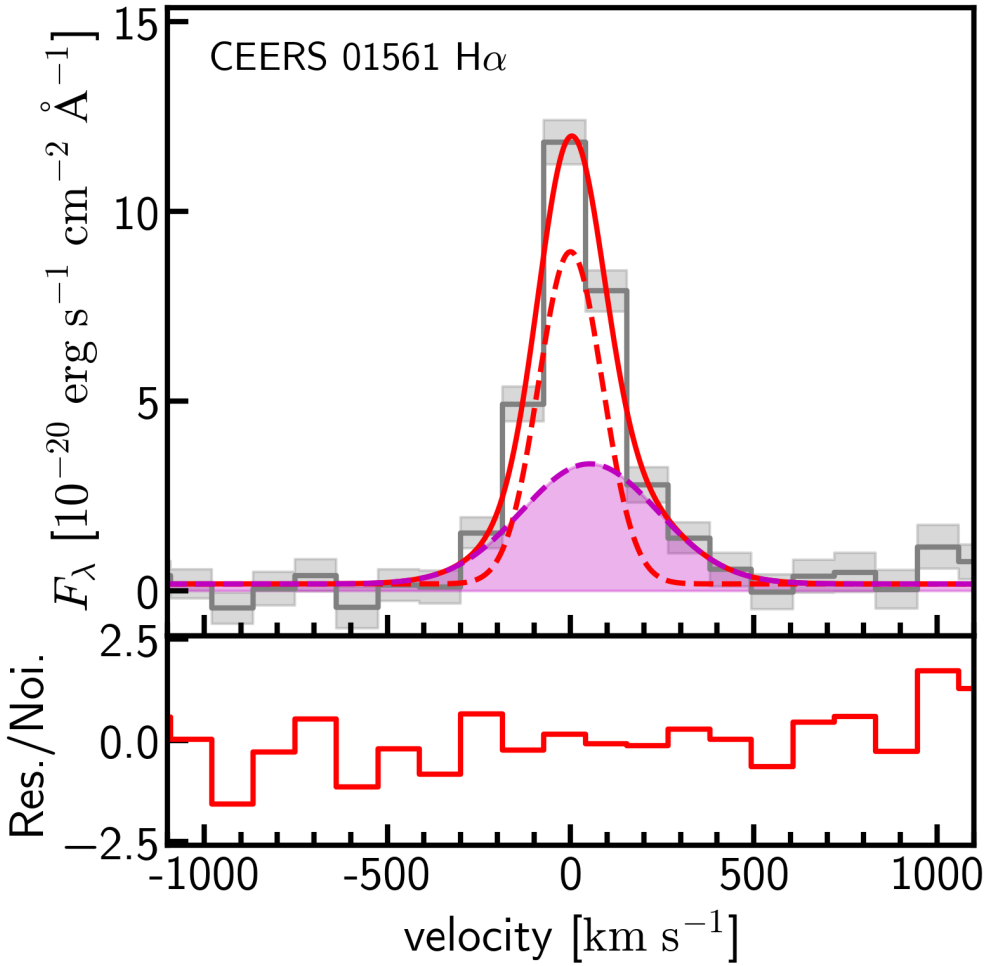
and more to be included



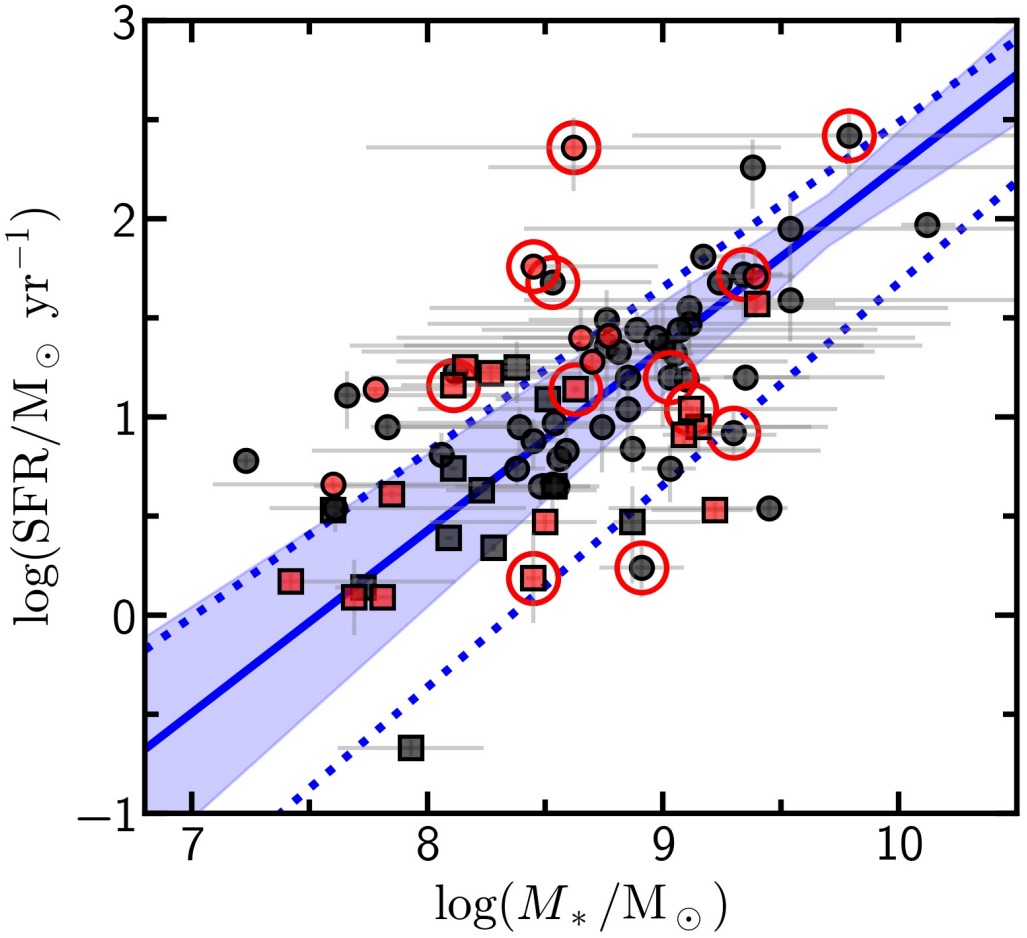
Detecting outflows

Broad wings in [OIII] and/or Hα tracing hot ionized outflows



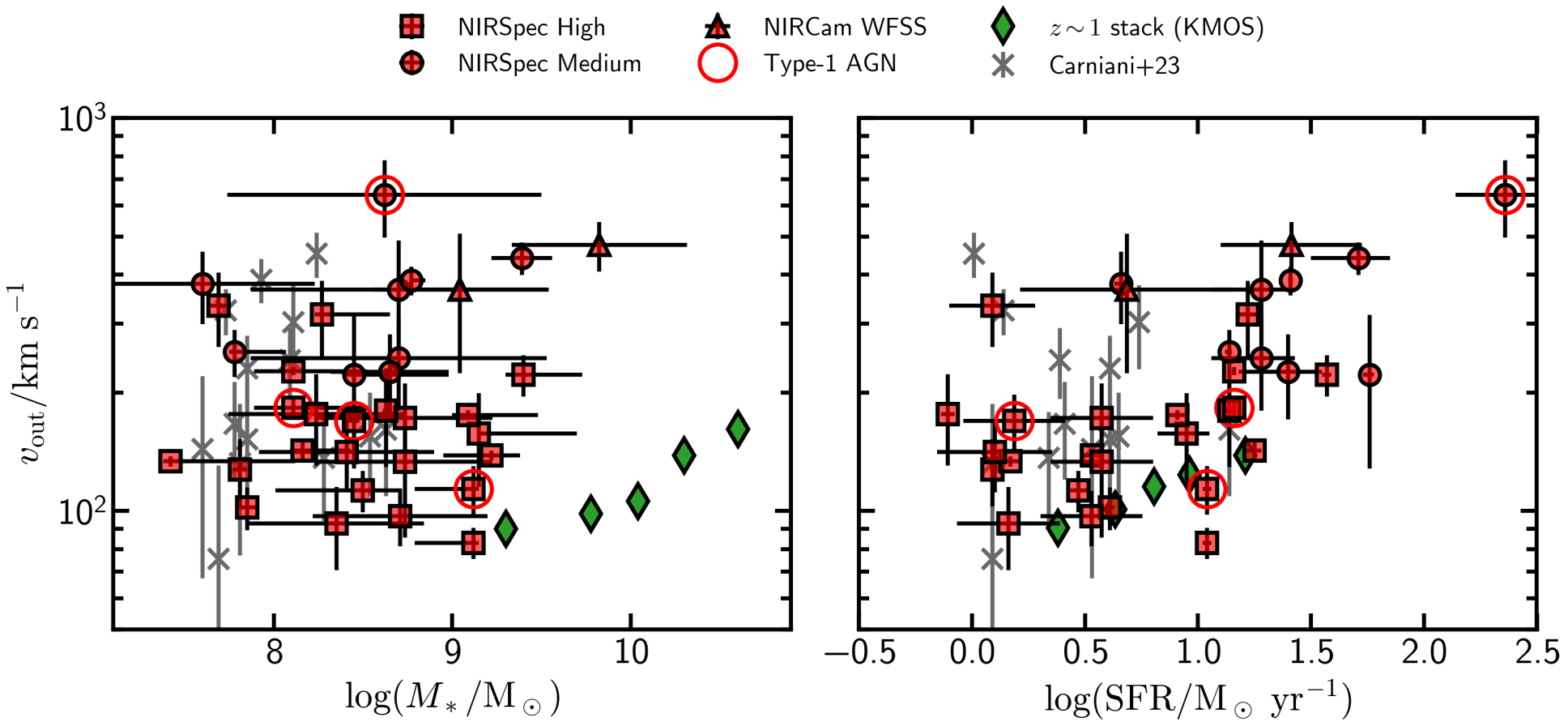


Detecting outflows



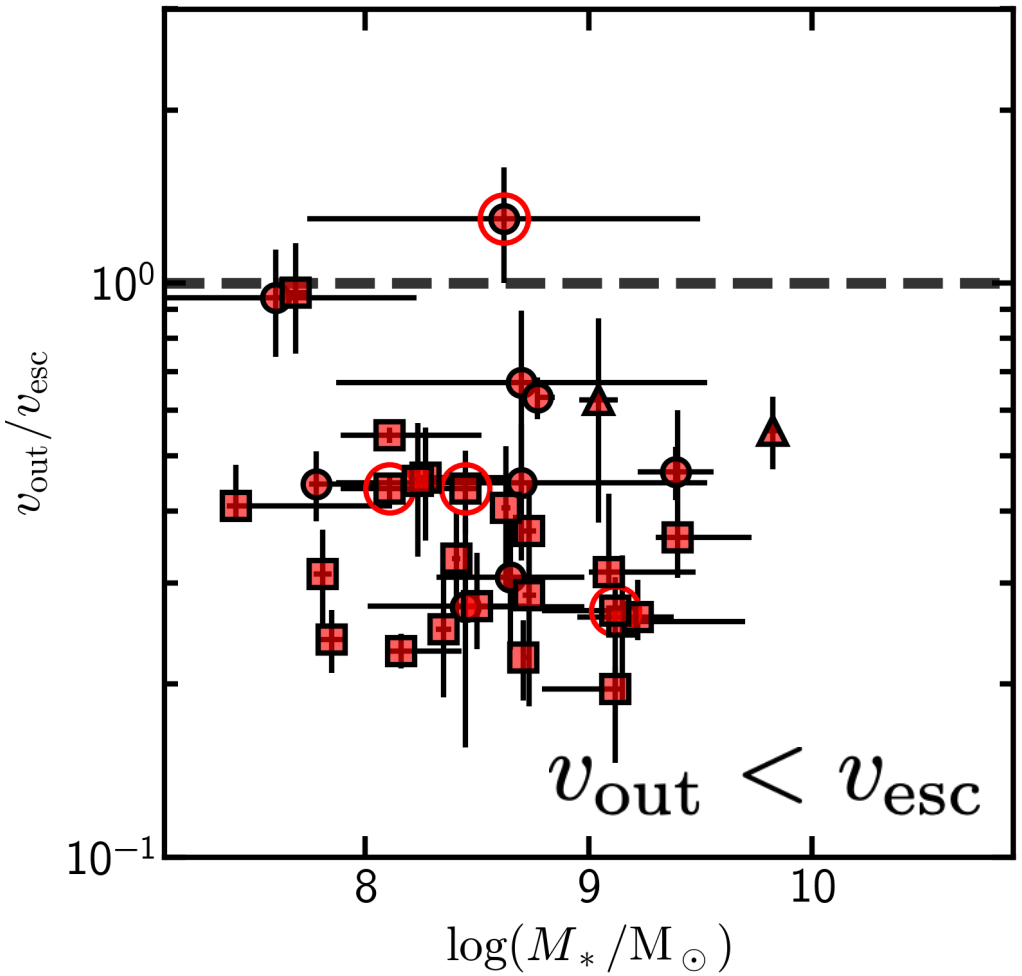
- 30 galaxies host outflows
- 12 Type-1 AGN => 6 w/ outflows
- Evenly scattered around the SFMS
- Ubiquitous outflow with no clear dependence on SFR or stellar mass

Outflow velocity $v_{\rm out} = |v_{\rm cent,out} - v_{\rm cent,narrow}| + {\rm FWHM_{out}}/2$



- faster or comparable with low-z results
- large scatter

Discussions on outflows

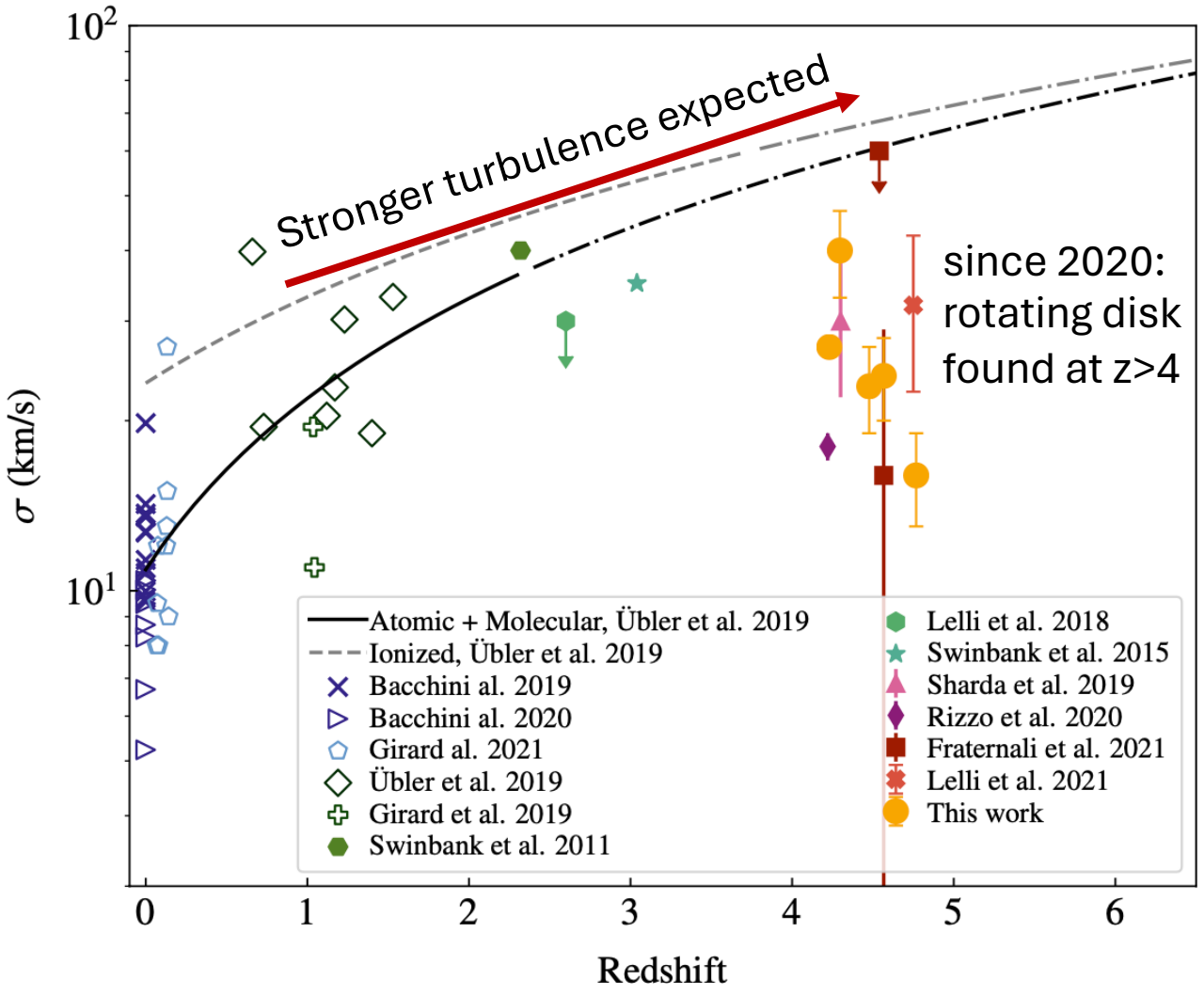


Outflows are not fast enough to escape

Or… in general:

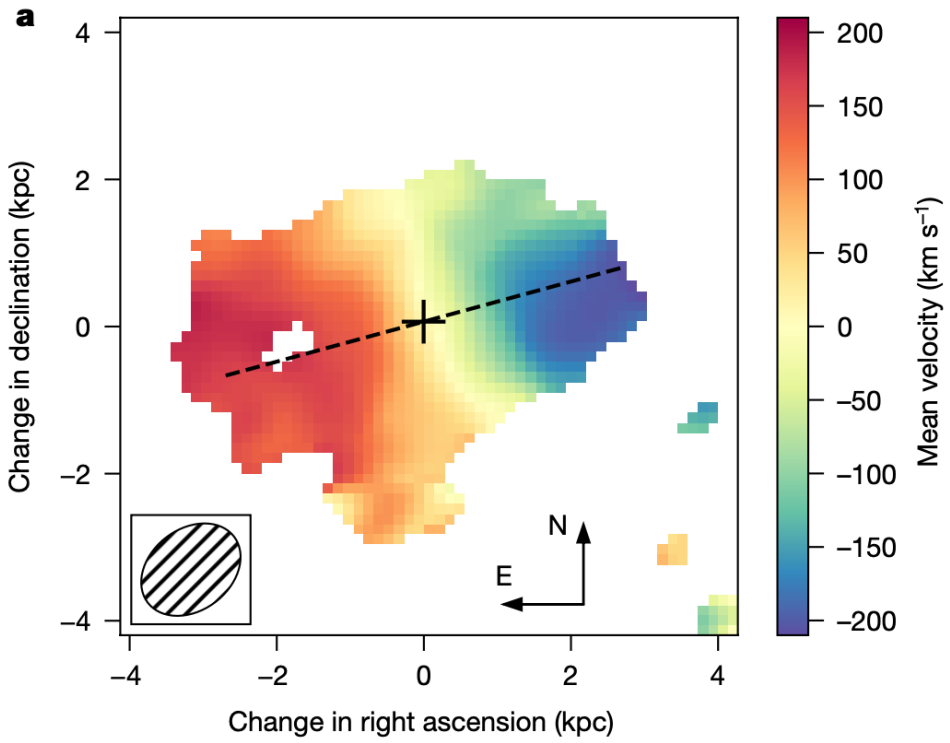
High-z galaxies **do not** power strong outflows

Disk formation



Rizzo et al. 2021

"Wolfe Disk" z=4.26 (*Neeleman et al. 2020)*



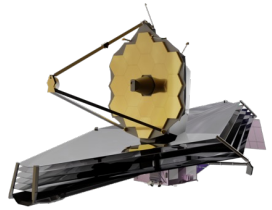
Open question:

How early may rotating disk form?

Dataset #2

- JWST NIRSpec IFU
  - Integral field spectroscopy
  - Pixel scale 0”.1/pix
    - 0”.06/pix with dithering
  - FoV: 3”x3”
  - R=1000 G235M used in this study

- Public Data of GN-z11 (z=10.6)
  - DDT 4426 (PI: Roberto Maiolino)
  - 10.6 hours integration
  - Bright and extended C III] emission
    - Trace hot ionized gas
  - **Kinematics not studied**



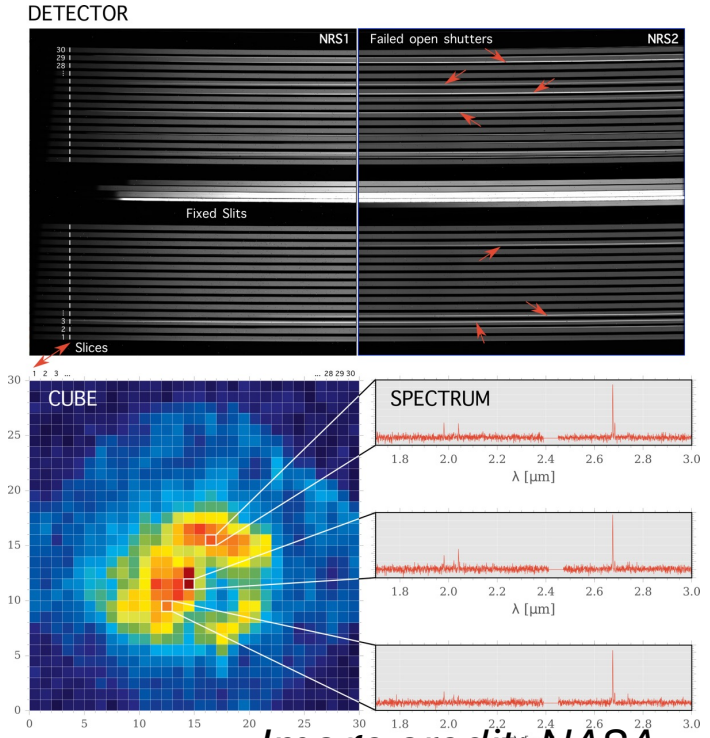
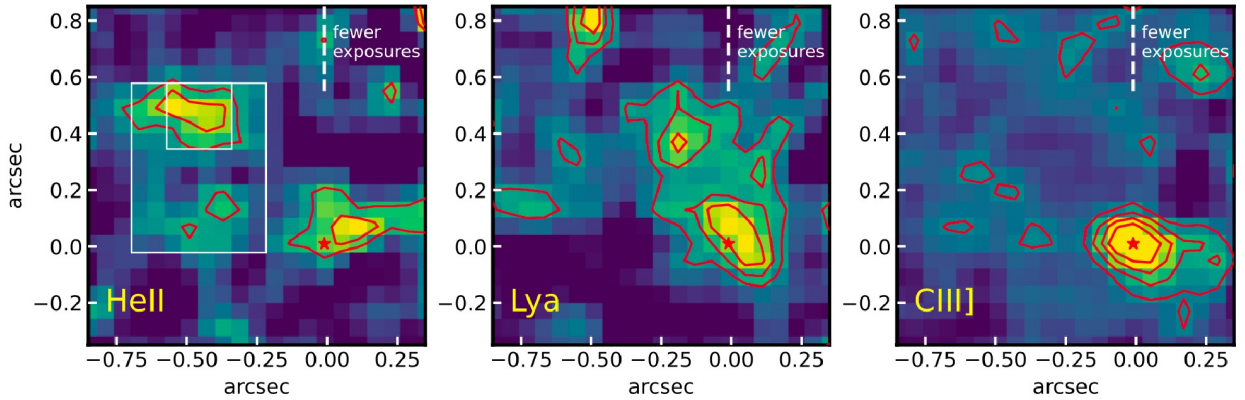


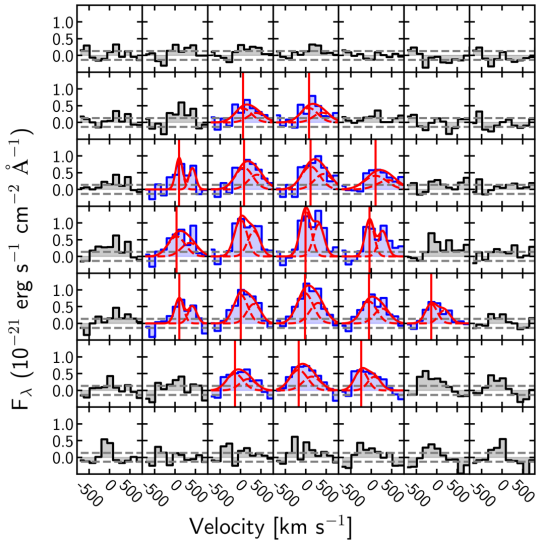
Image credit: NASA

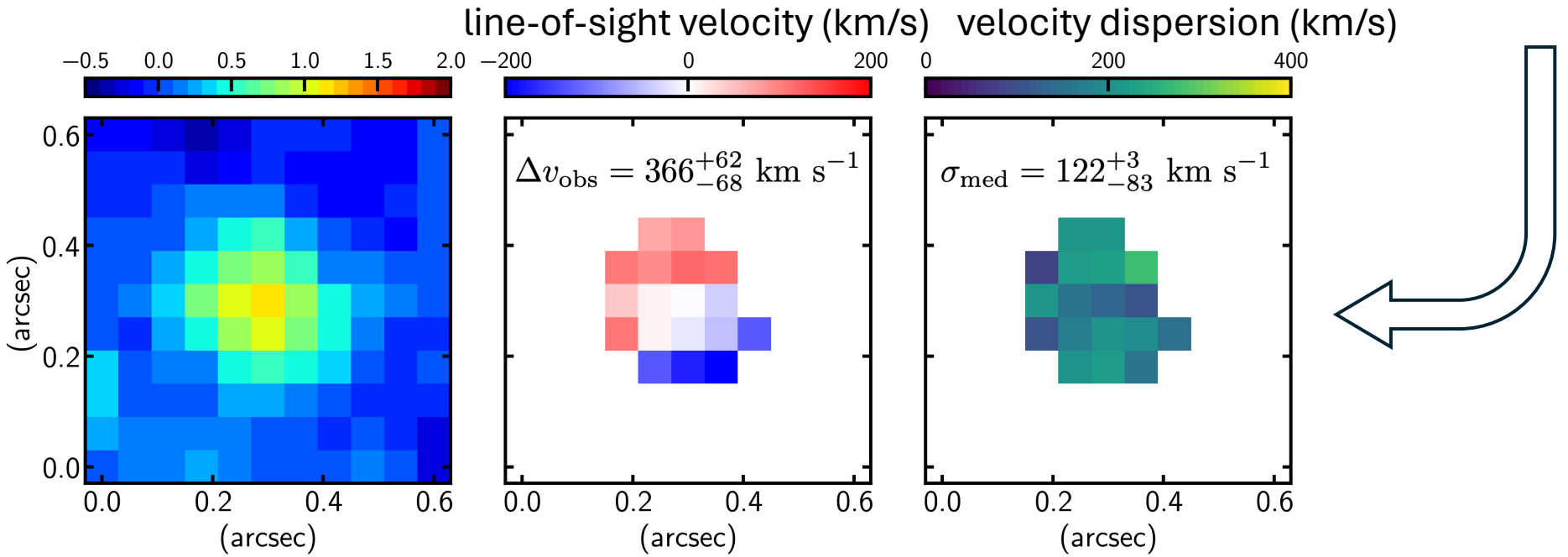


Maiolino et al. 2023

C III] kinematics

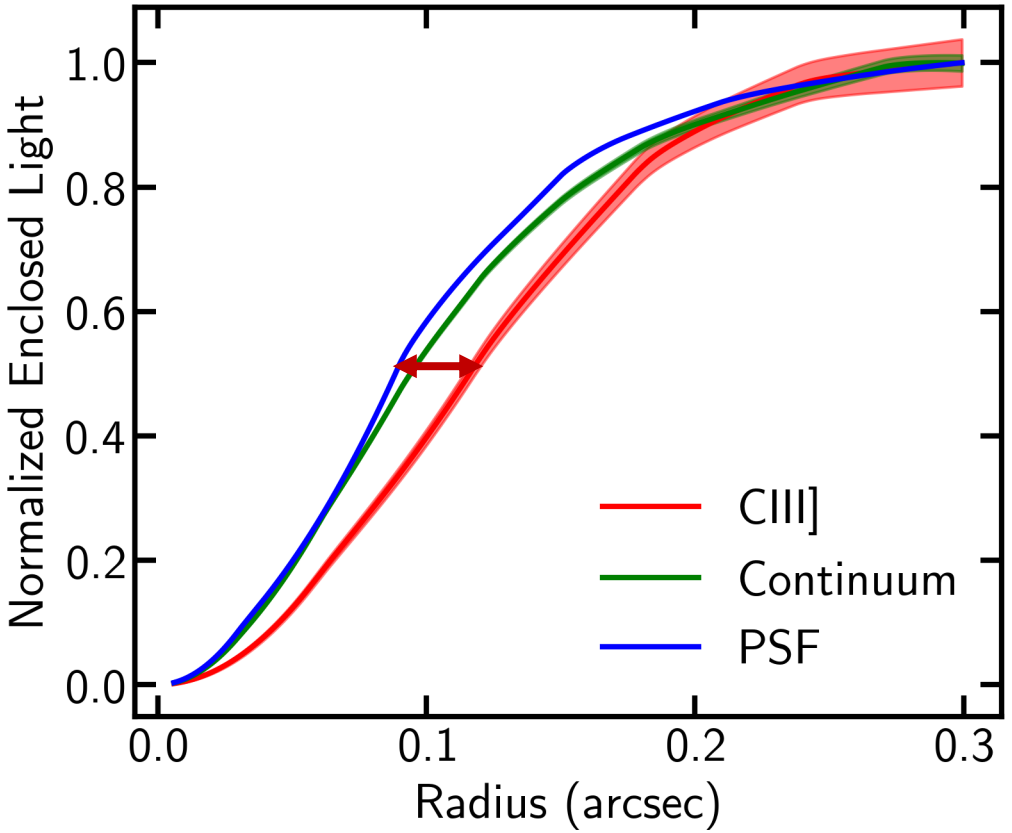
- C III] => most prominent emission lines
- Spectral fitting in each spatial pixel with S/N>6
- Result
  - Clear velocity gradient $\Delta v_{\rm obs}/2\sigma_{\rm med} = 1.50^{+1.05}_{-0.28}$
  - **Rotating disk at z=10.6?**



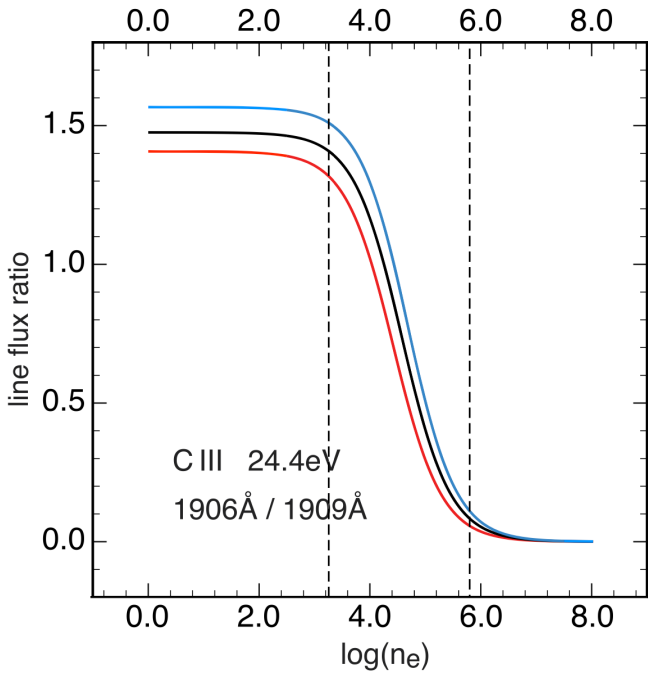


Is the velocity gradient spatially resolved?

C III] is spatially extended over point-spread function (PSF) and the compact UV continuum



Is the velocity gradient mimicked by C III] line ratio?



Kewley et al. 2019

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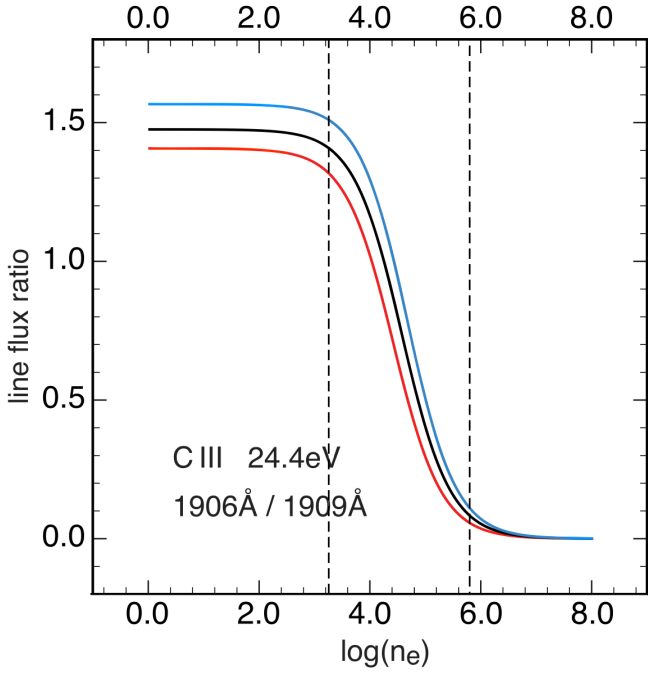

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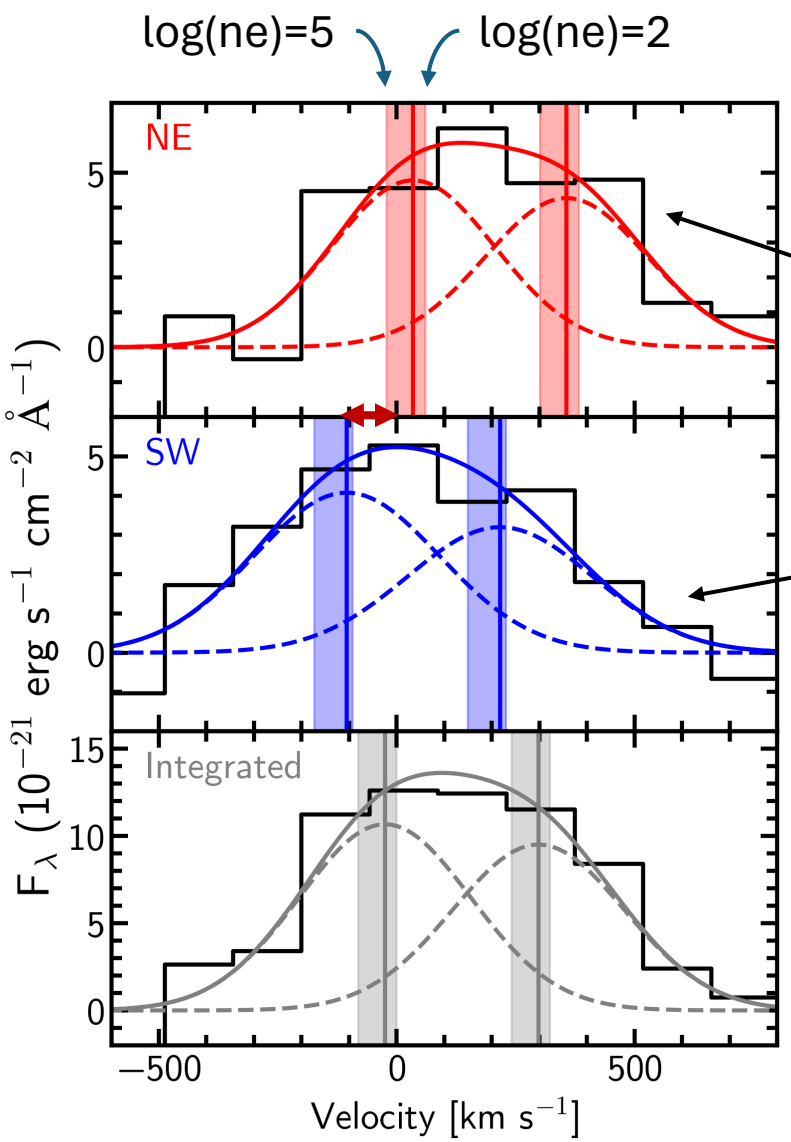
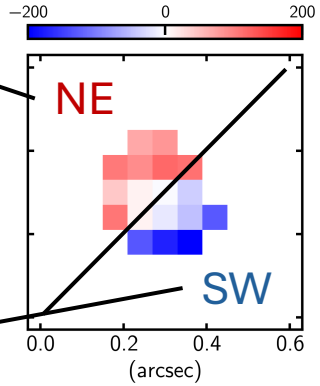
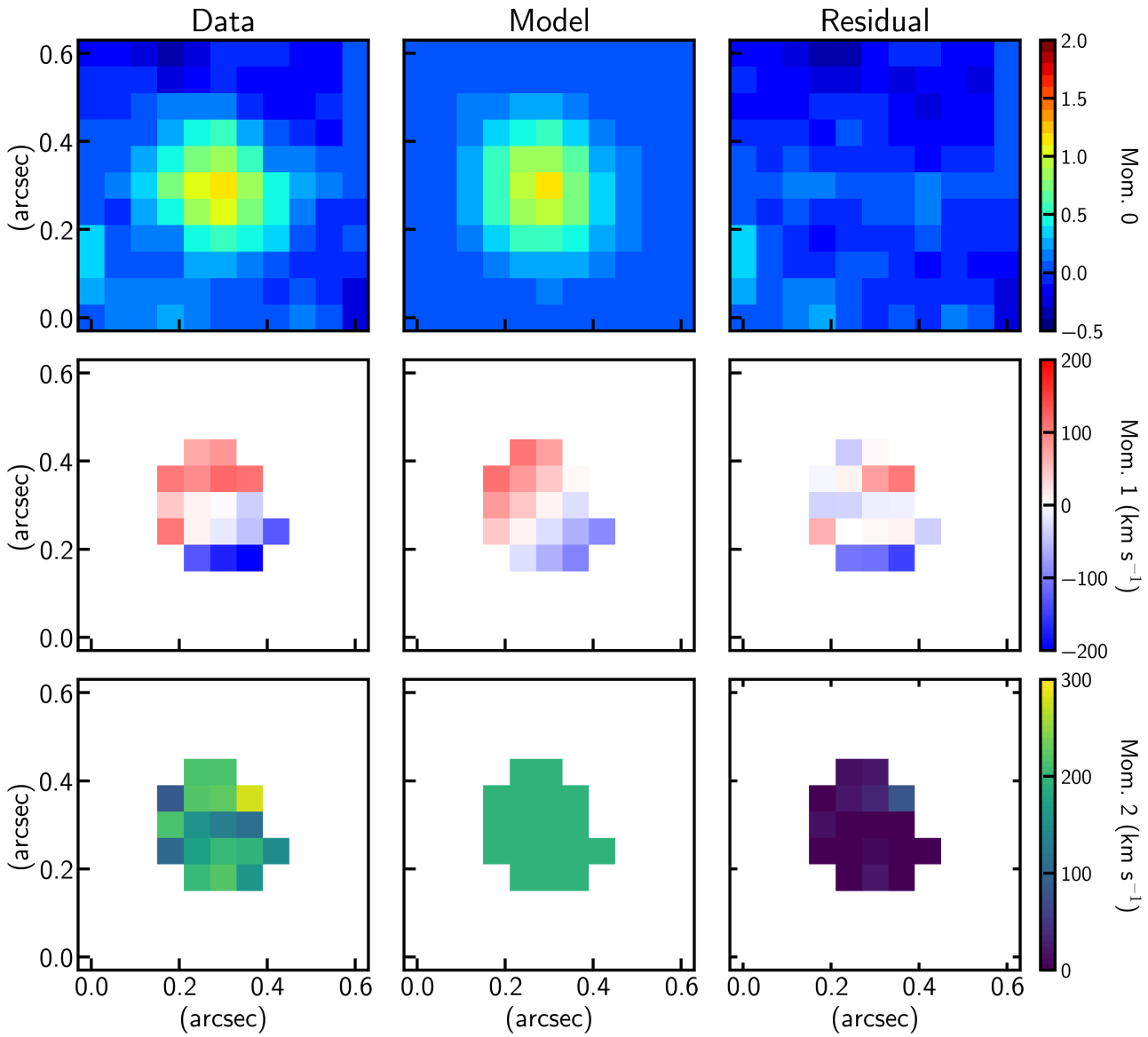




Velocity gradient cannot be explained by the line ratio difference

Rotation velocity from forward modelling



GalPak^{3D} model

- exponential disk
- arctan rotation curve
- convolved with line-spread function and PSF

Results:
Explained by an edge-on (i~70°) rotating disk!

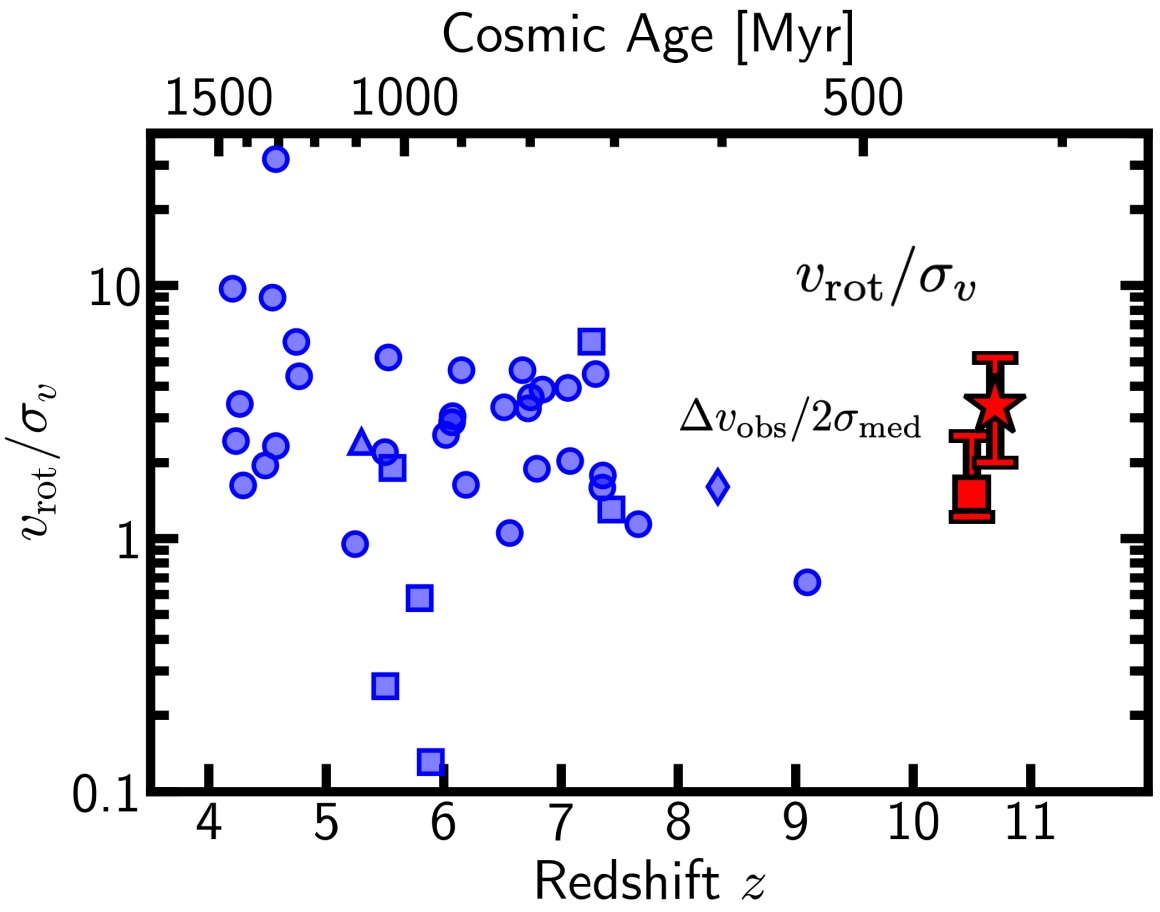
$$v_{\rm rot} = 376^{+110}_{-151}\ {\rm km\ s^{-1}}$$

$$\sigma_v = 113^{+24}_{-48}\ {\rm km\ s^{-1}}$$

$$v_{\rm rot}/\sigma_v = 3.33^{+1.72}_{-1.50}$$

Possible rotating disk

Rotation-dominated disks may form in the **first 500 Myr** of the universe!

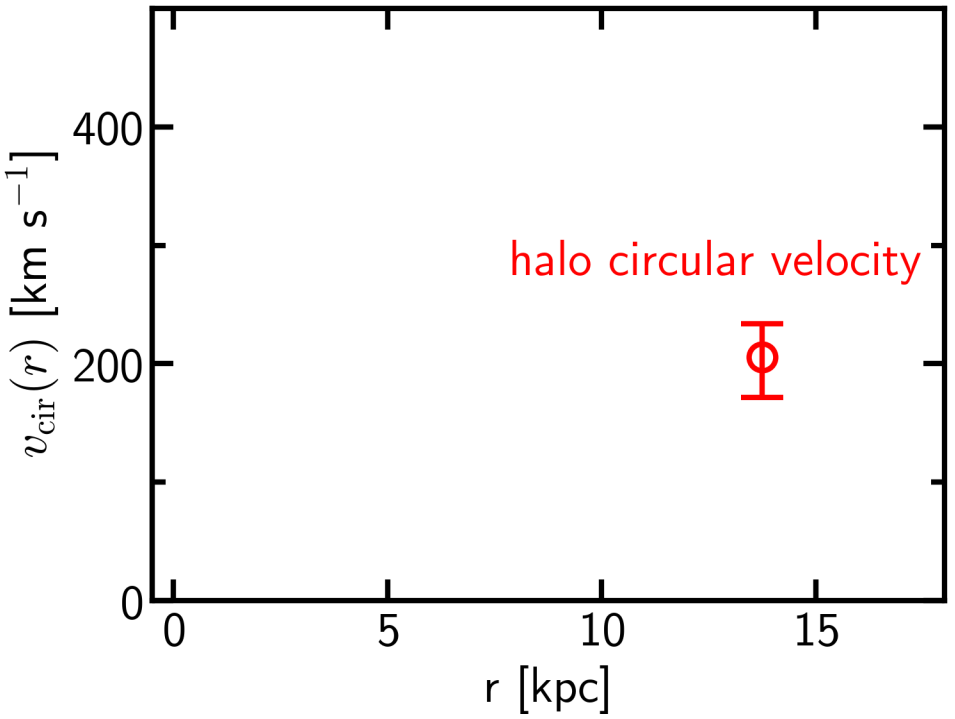


Is this surprising?

- GN-z11 is **massive** for z=10.6 => growing fast and possibly undergo weak feedback
- GN-z11 is **compact** => mass is concentrated in the center

Discussions on early rotating disk

Mass distribution probed by circular velocity : $v_{\rm cir}(r) = \sqrt{\frac{GM(<r)}{r}}$



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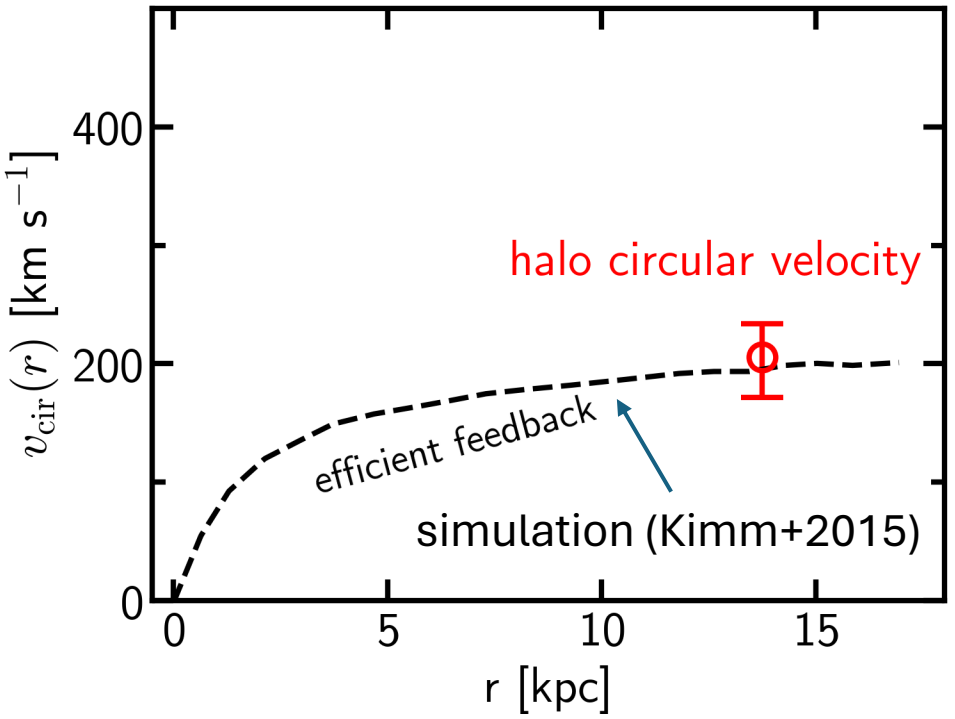

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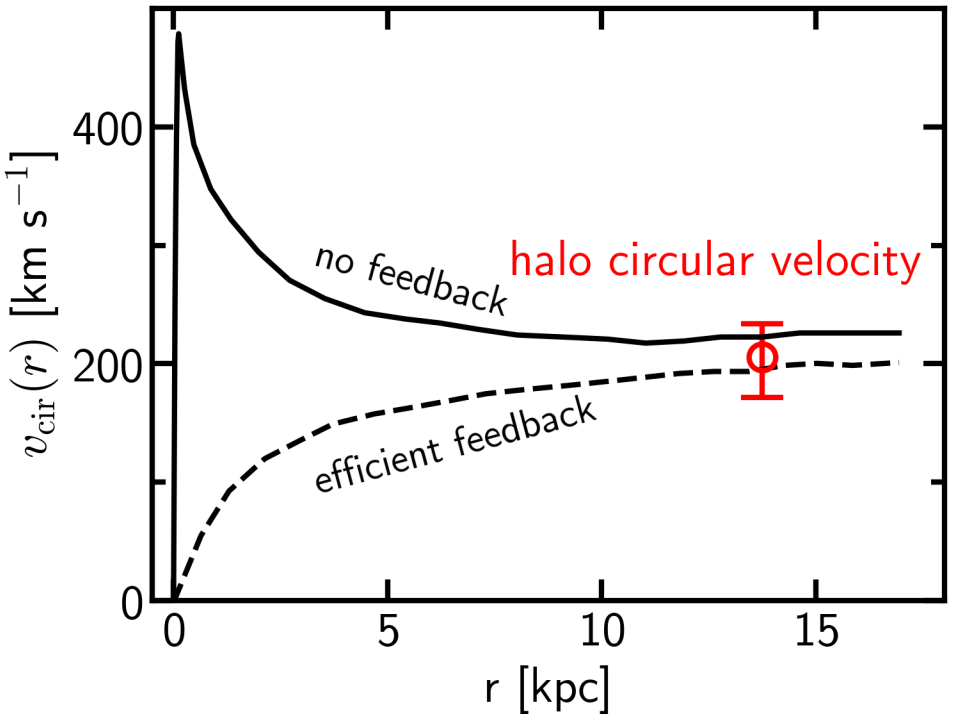

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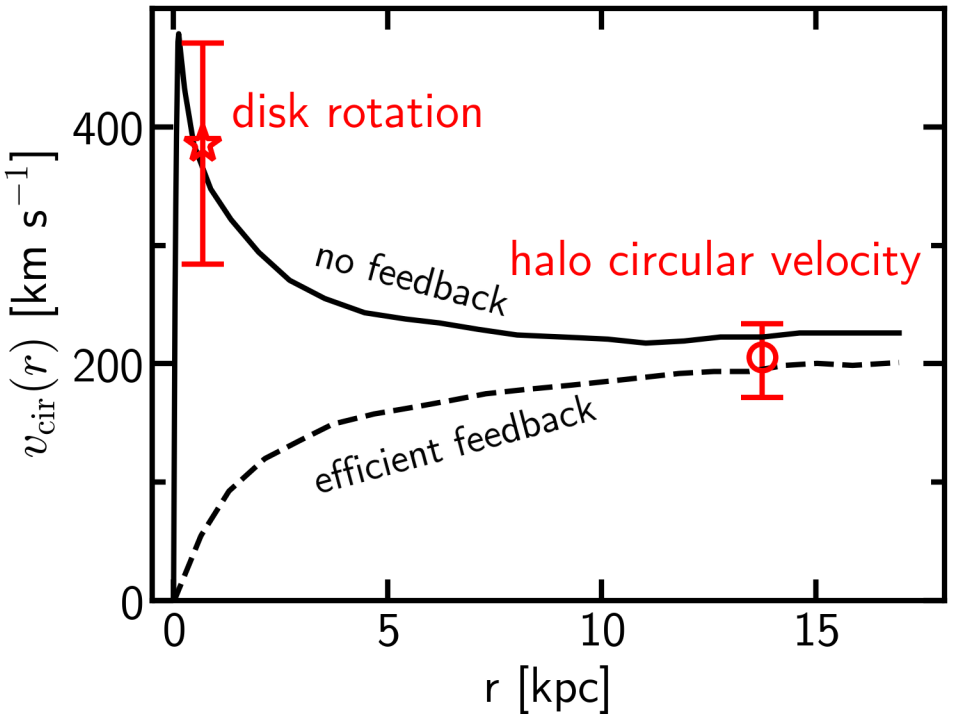
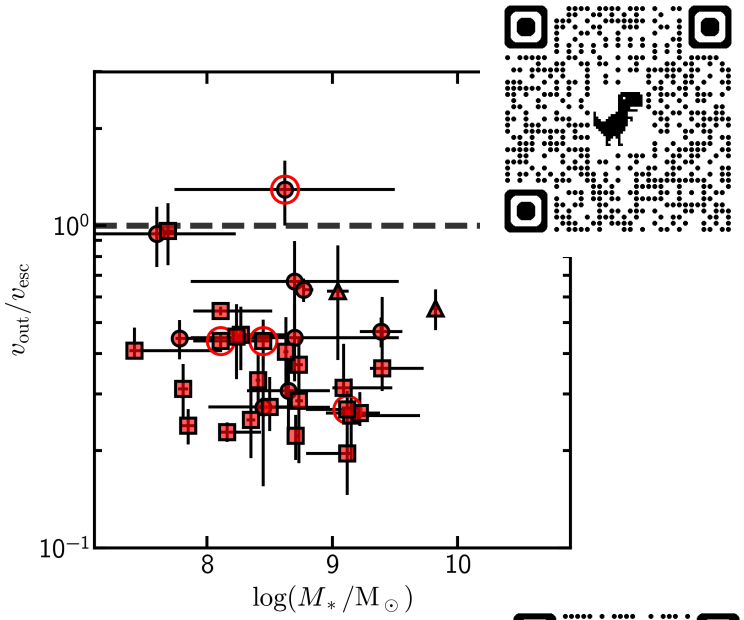
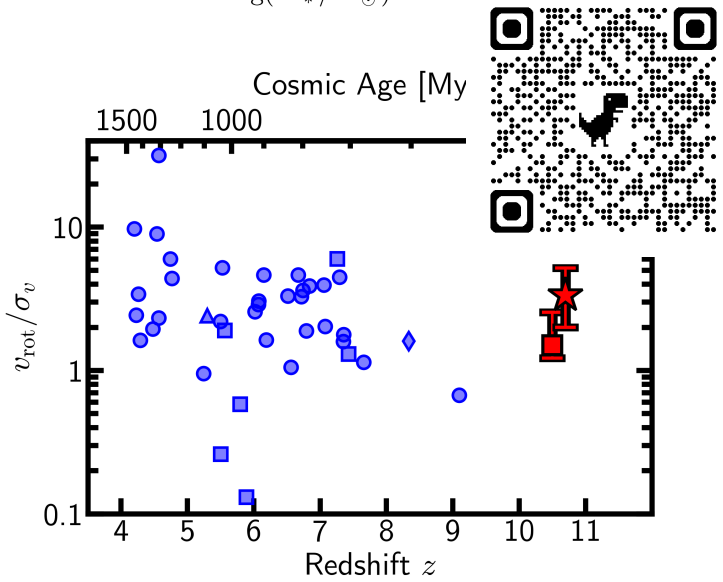


Rotating disk may form in the early universe under weak feedback!?

Summary



- 30 galaxies detected with outflows out of 130 high-z galaxies
- Outflows are likely not strong at high z



- Disk rotation in GN-z11 at 10.6 revealed by JWST NIRSpec IFU
- Forward modelling suggests rotation-dominated disk with $v_{\rm rot}/\sigma_v = 3.33^{+1.72}_{-1.50}$
- Fast $v_{\rm rot}$ may suggest disk formation under weak feedback