18th Potsdam Thinkshop: The Role of Feedback in Galaxy Formation:
from small-scale winds to large-scale outflows

New Constraints on Molecular Gas Outflows in Massive SFGs

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& the PHIBSS collaboration

AIP, 14.07.2025

Outflows

Infrared

Radio

X-ray

Star formation-driven

Credit: X-ray: NASA/CXC/JHU/D.Strickland; Optical: NASA/ESA/STScI/AURA/The Hubble Heritage Team; IR: NASA/JPL-Caltech/Univ. of AZ/C. Engelbracht

AGN-driven

NASA, CXC, SAO, Astrophotography by Rolf Olsen, NASA-JPL, Caltech, NRAO, AUI, NSF, UOH, M. J. Hardcastle

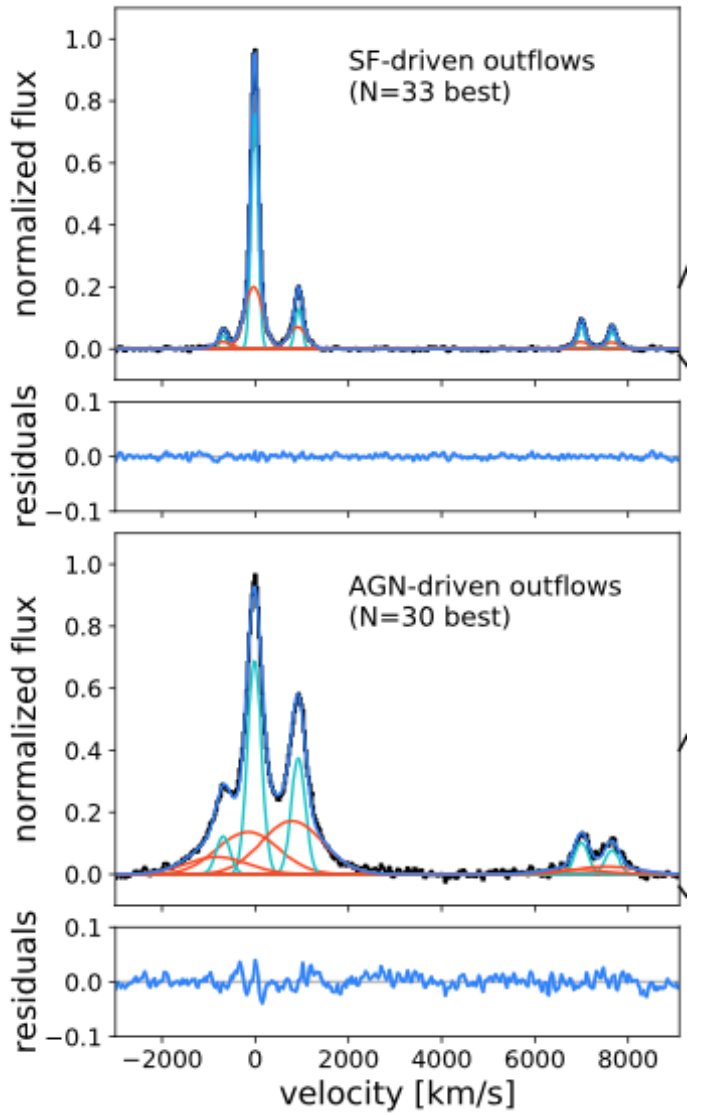
Outflows at Cosmic Noon

- Harder to investigate small physical scales and various gas tracers!
- One possibility: looking for (often) blue-shifted wings in the profile of optical emission lines.

Observations:

- **SF-driven outfows:** ~10^2 km/s velocities, incidence correlates with SFR
- **AGN-driven:** ~ 10^3 km/s velocities, incidence correlates with galaxy stellar mass

Ionised gas outflows do not carry enough mass to have the impact on galaxies we believe they have!



Foerster Schreiber et al. 2019

Eg: Veilleux et al. 2005, Newman et al. 2012, Genzel et al. 2014, Foerster Schreiber et al. 2019, Concas et al. 2022

Molecular Gas Outflows at Cosmic Noon

Is the bulk of outflows in the molecular gas phase?

Difficulties:

- Molecular gas is a lot harder to detect with **sufficient SNR** to identify outflows
- Molecular gas outflows seem to have **lower velocities** than their ionized gas counterparts
- Detections are (almost) only in **bright AGNs or quasars**

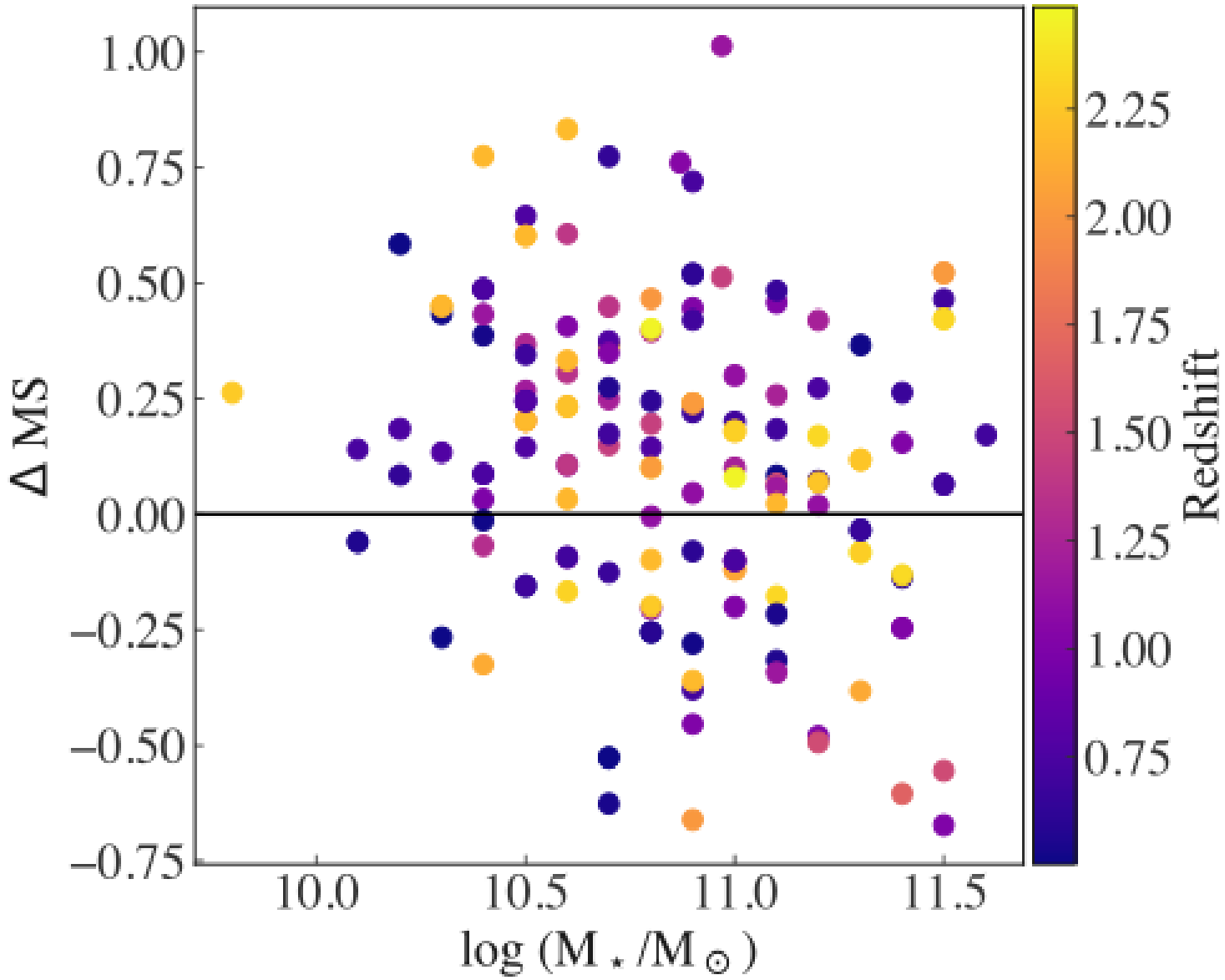
Eg: Cicone et al. 2018, Herrera-Camus et al. 2019, 2021, Veilleux et al. 2020, Butler et al. 2021

The PHIBSS Survey

- PdBI/NOEMA CO survey

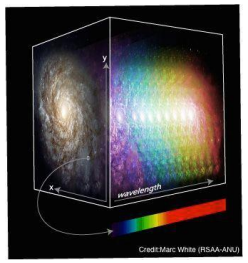
- Main sequence galaxies at $0.5 < z < 2.6$
  - 154 detections
  - Known $M_\star$, SFR and R_e from anscillary data

Barfety et al. 2025 in press.



Tacconi+13,18, Freundlich+19

Methods



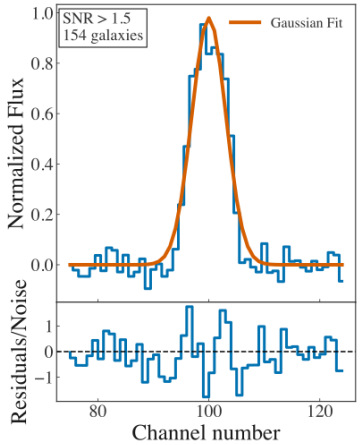
Data cube → • Fit spectrum • Collapse around line → • Run SExtractor (Bertin & Arnouts 1996) • Mask detected area → Extract spectrum → Integrated spectrum

Iterate

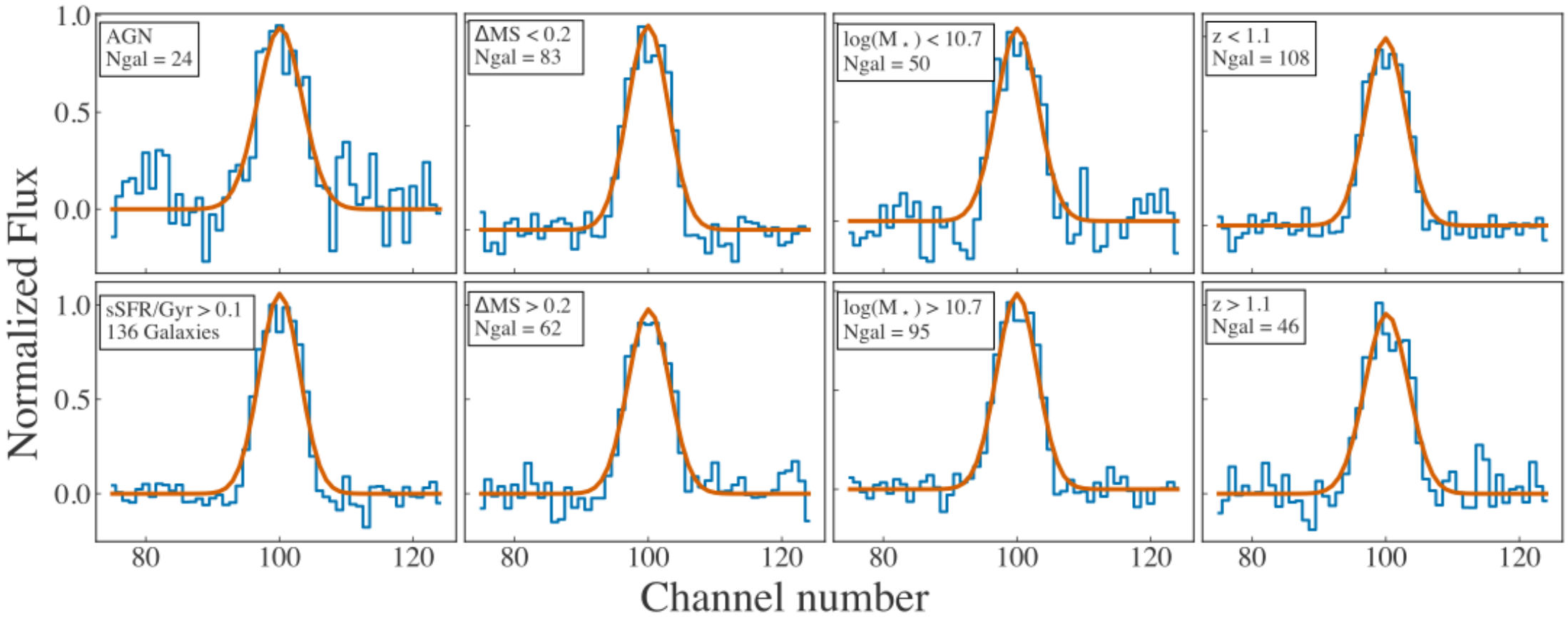
160+ Integrated spectra → • SNR cut • **Rebinning** • Normalization → Stacking → • Single Gaussian fit • Double Gaussian fit → Modeled emission line

LiMe-STACKER

Jolly et al. 2020

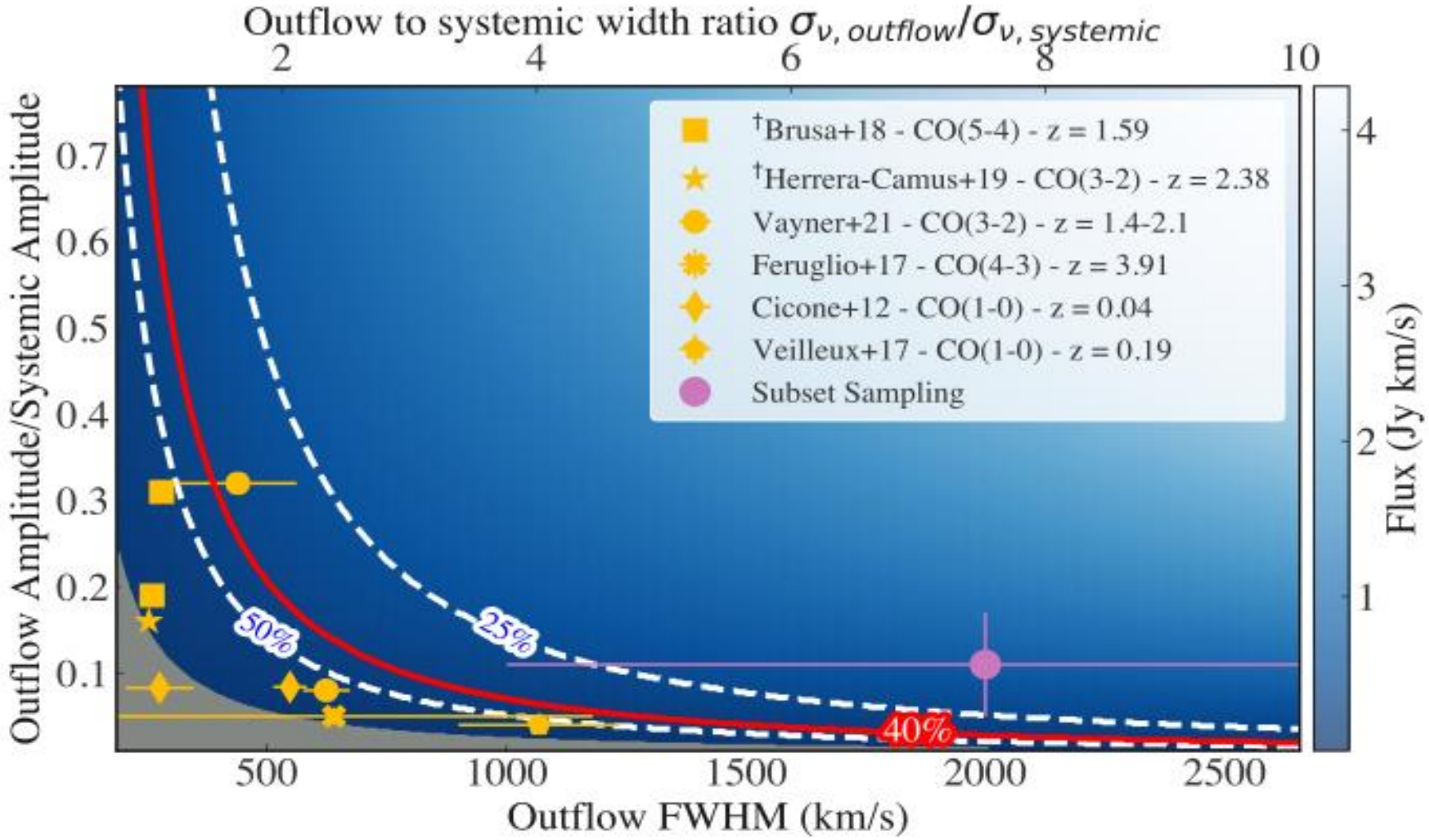


No outflow signature – in any physical subsample!



Barfety et al. 2025

Molecular gas outflow properties

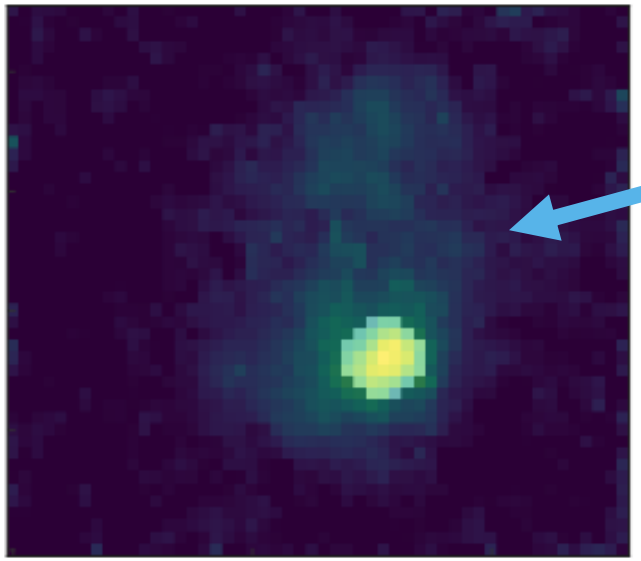


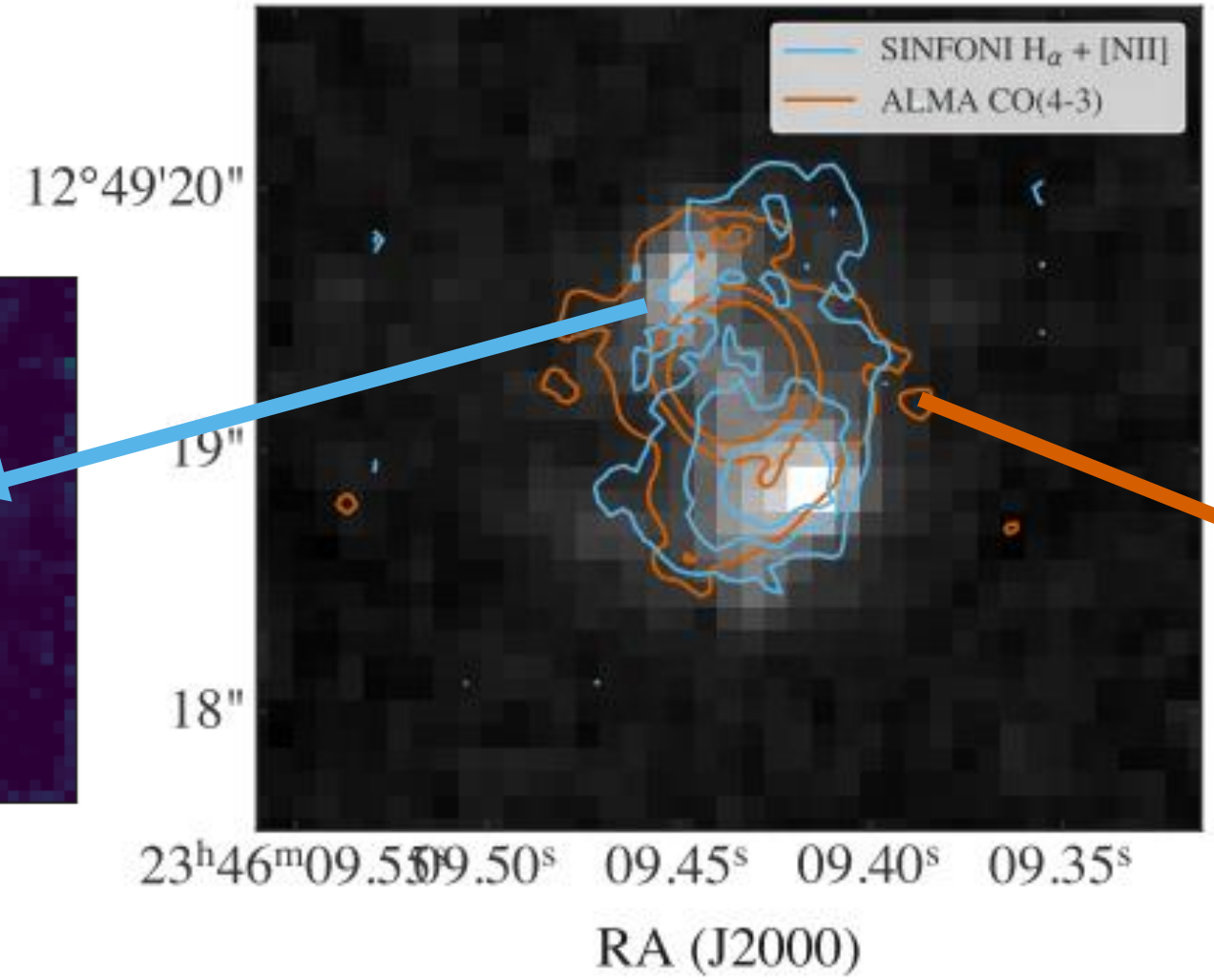
Barfety et al. 2025

BX610 – Spatially Resolved Case at z = 2.19

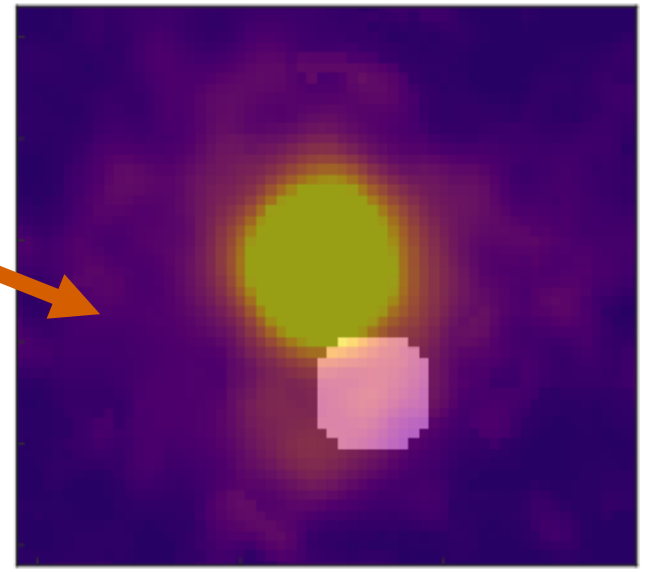
PRELIMINARY

8.5h – PSF: 0.28”



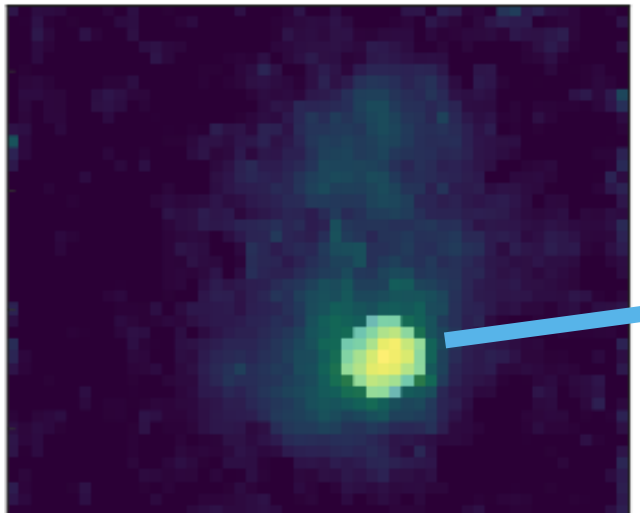


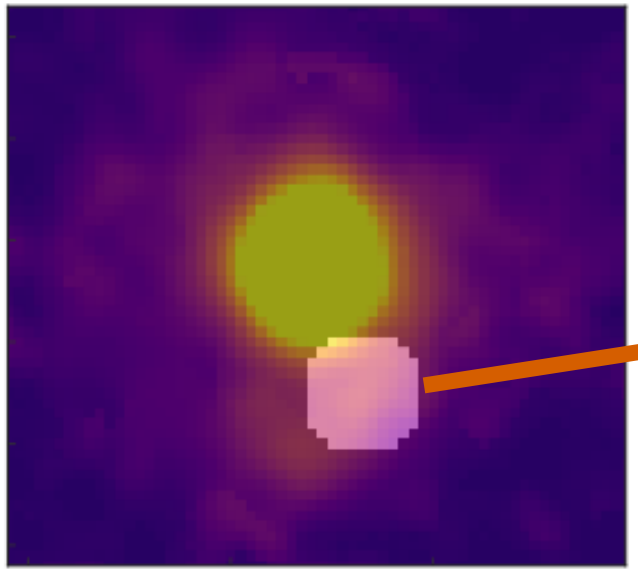
24h – Beam: 0.2”



Barfety et al 2025 in prep.

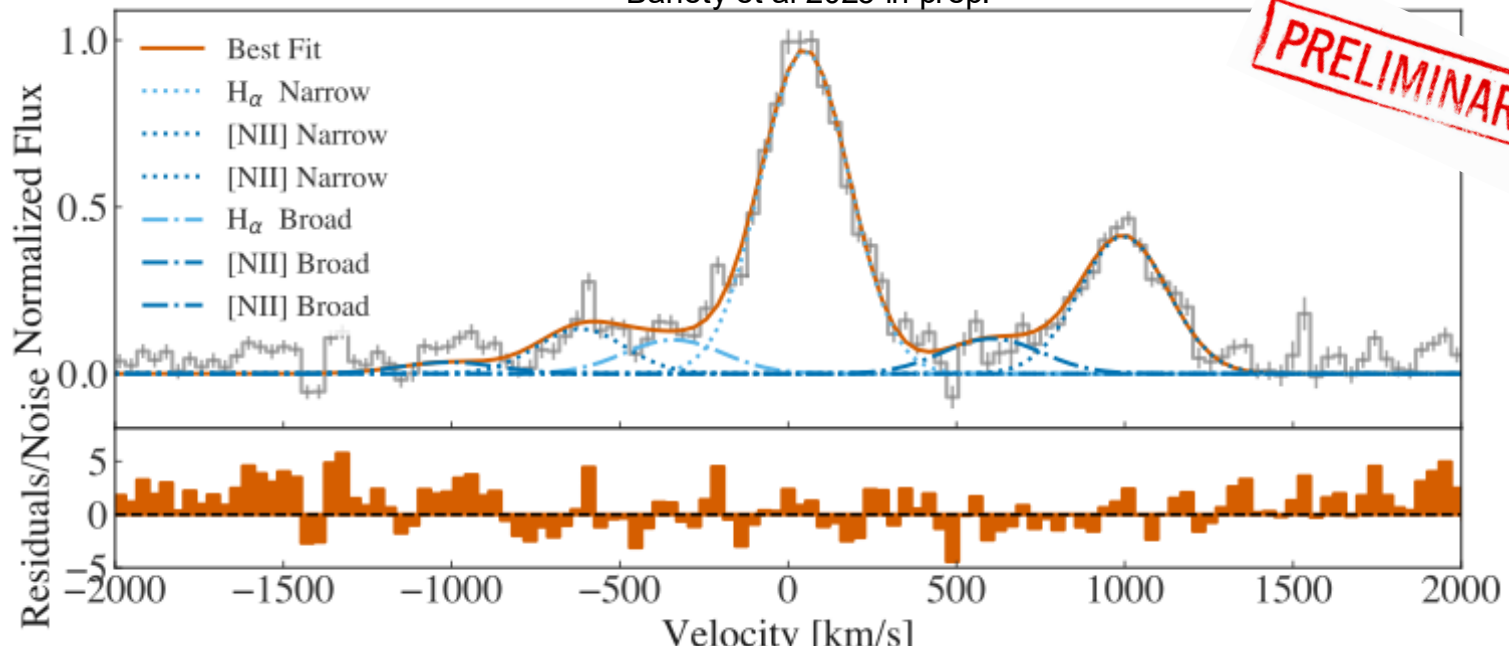
BX610

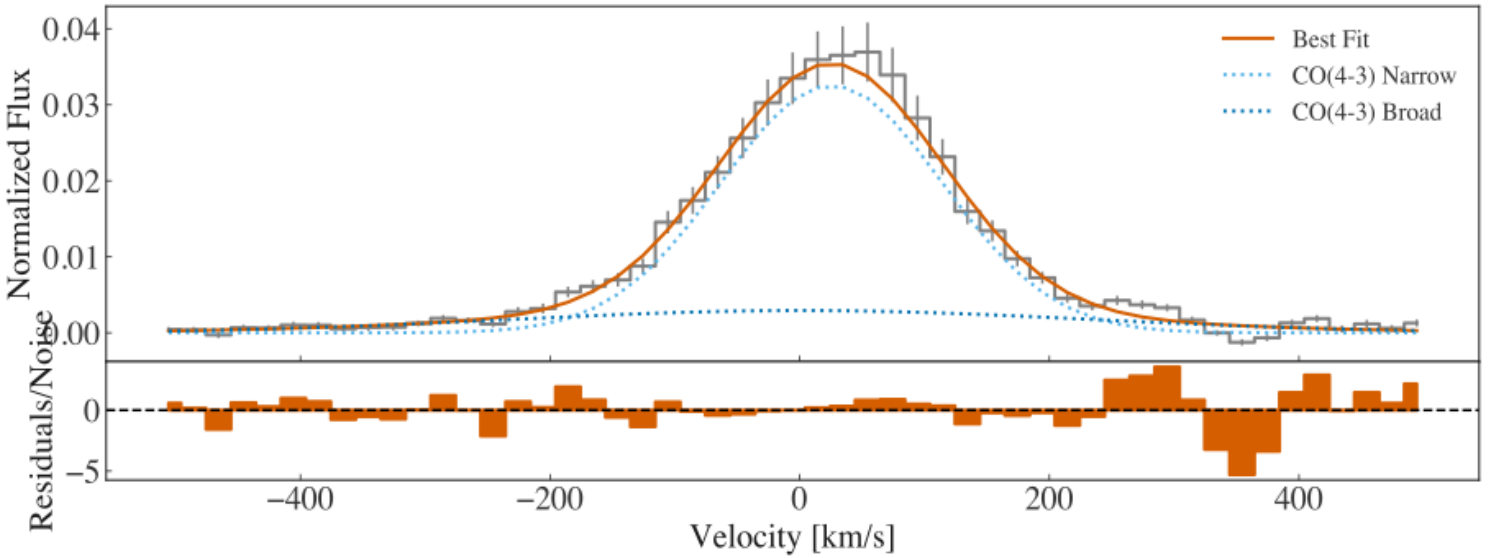




Barfety et al 2025 in prep.

PRELIMINARY





Main Takeaways

- Molecular gas outflows in cosmic noon MS galaxies are **weaker than expected.**

- Either:
  - Molecular gas outflows in “normal” galaxies require **deeper observations** with **high spatial and spectral resolution,**

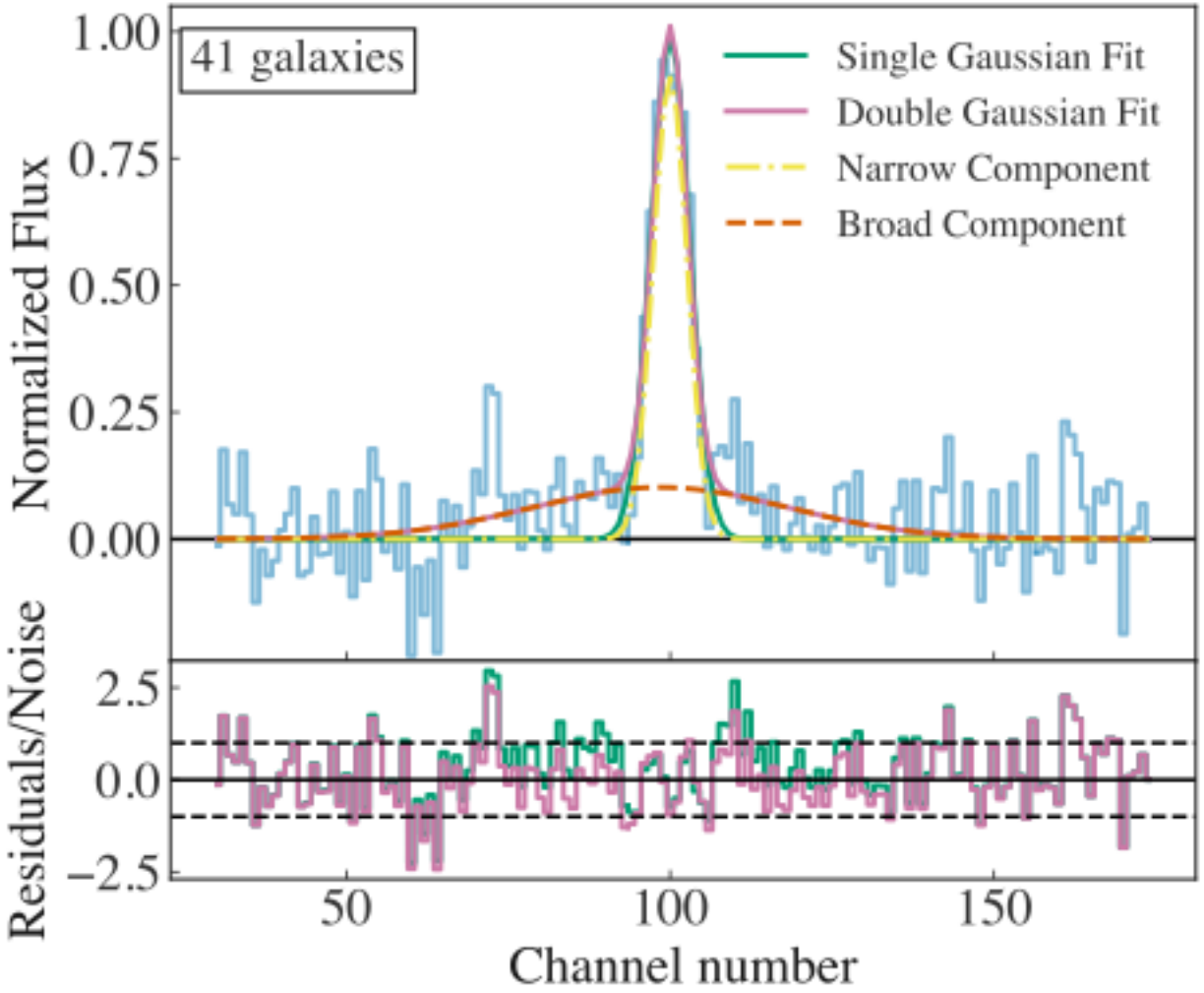
  - Or molecular gas outflows in those galaxies are **less prevalent** than thought.

The bulk of outflows might be **in other phases** (eg. warm molecular, neutral atomic phases)

Thank you!

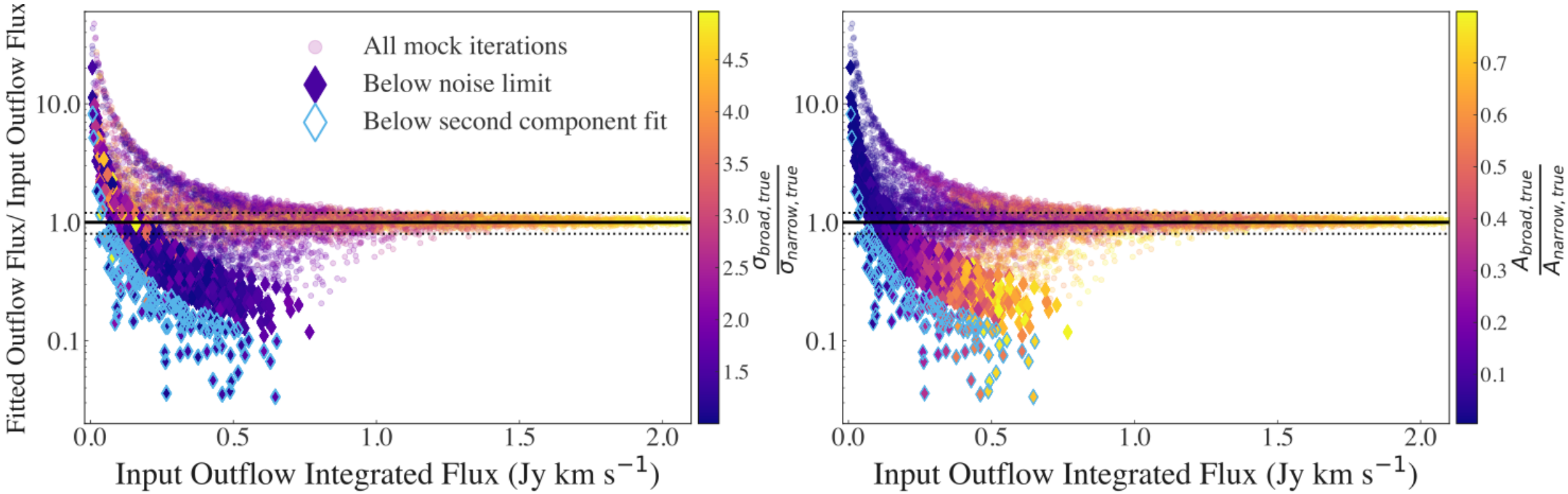
Click here for the paper!

Tentative detection in “bootstrapped” sample



Barfety et al. subm.

Mock Outflows



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Upper limits on outflow properties

Sample	$\langle z \rangle$	$\langle \log(M_\star/M_\odot) \rangle$	$\langle R_e \rangle$ kpc	$\langle \nu_{obs} \rangle$ GHz	$\langle$ SFR $\rangle$ $M_\odot$/yr	v_{out} km/s	$\dot{M}_{out,mol}$ $M_\odot$/yr	η_{UL}
All	1.05	10.8	4.35	136.9	50.1	$450 - 2300^\dagger$	$135 - 1567$	$2.7 - 31.3$
AGN	1.09	11.0	3.25	140.6	112.9	$1360^\dagger$	1619	14.3
$M_\star < 10^{10.7}\,M_\odot$	1.01	10.5	4.30	134.2	31.6	$\mathbf{380}^\dagger$	**78**	**2.5**
$M_\star > 10^{10.7}\,M_\odot$	1.01	11.0	4.45	140.7	63.1	$\mathbf{420 - 1360}^\dagger$	$\mathbf{237 - 1383}$	$\mathbf{3.8 - 21.9}$
ΔMS > 0.2	1.13	10.7	3.60	137.7	79.4	$390 - 1500^\dagger$	$373 - 2814$	$4.7 - 35.4$
ΔMS < 0.2	1.02	10.9	5.00	137.1	31.6	$450 - 1520^\dagger$	$85 - 525$	$2.7 - 16.6$
z > 1.7	2.21	10.8	3.50	158.5	108.1	$460 - 1000^\dagger$	$345 - 1105$	$2.2 - 6.9$
z < 1.7	0.76	10.8	5.25	144.0	31.6	$460 - 1990^\dagger$	$106 - 956$	$3.4 - 30.2$
Subset Sample	1.01	11.0	5.30	140.7	50.1	1857 ± 905	1528 ± 793	30 ± 16

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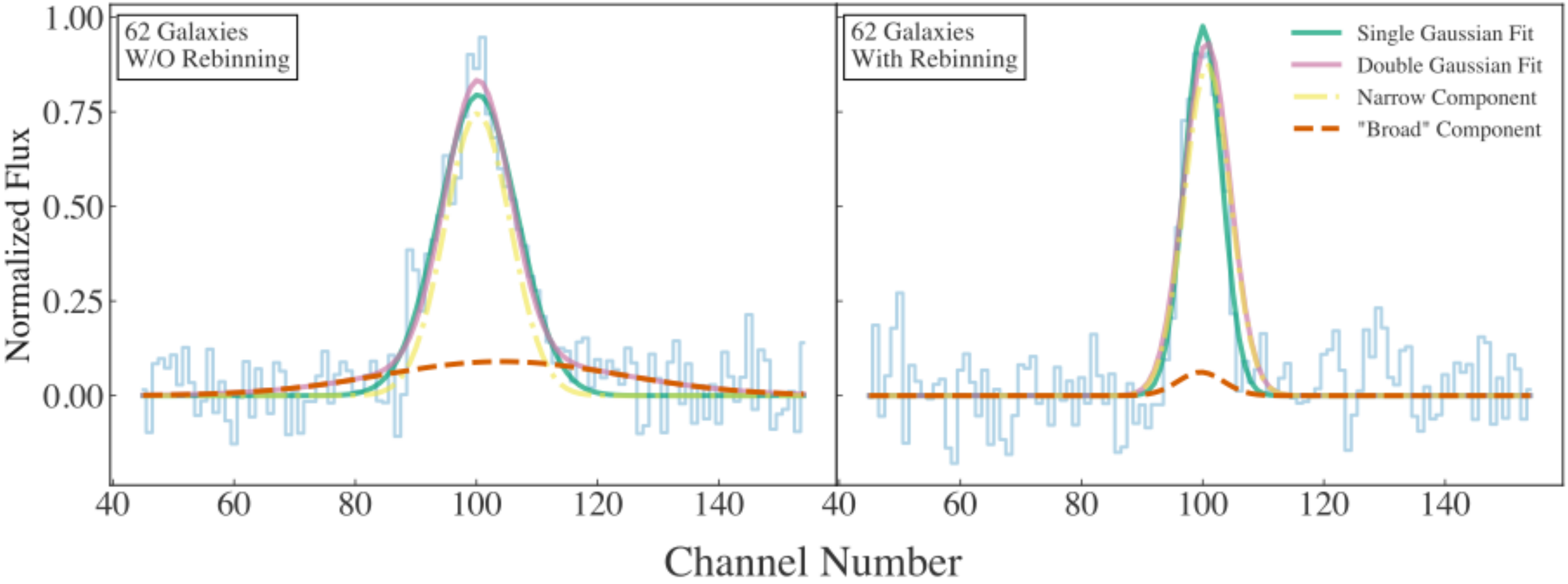
Why re-binning?



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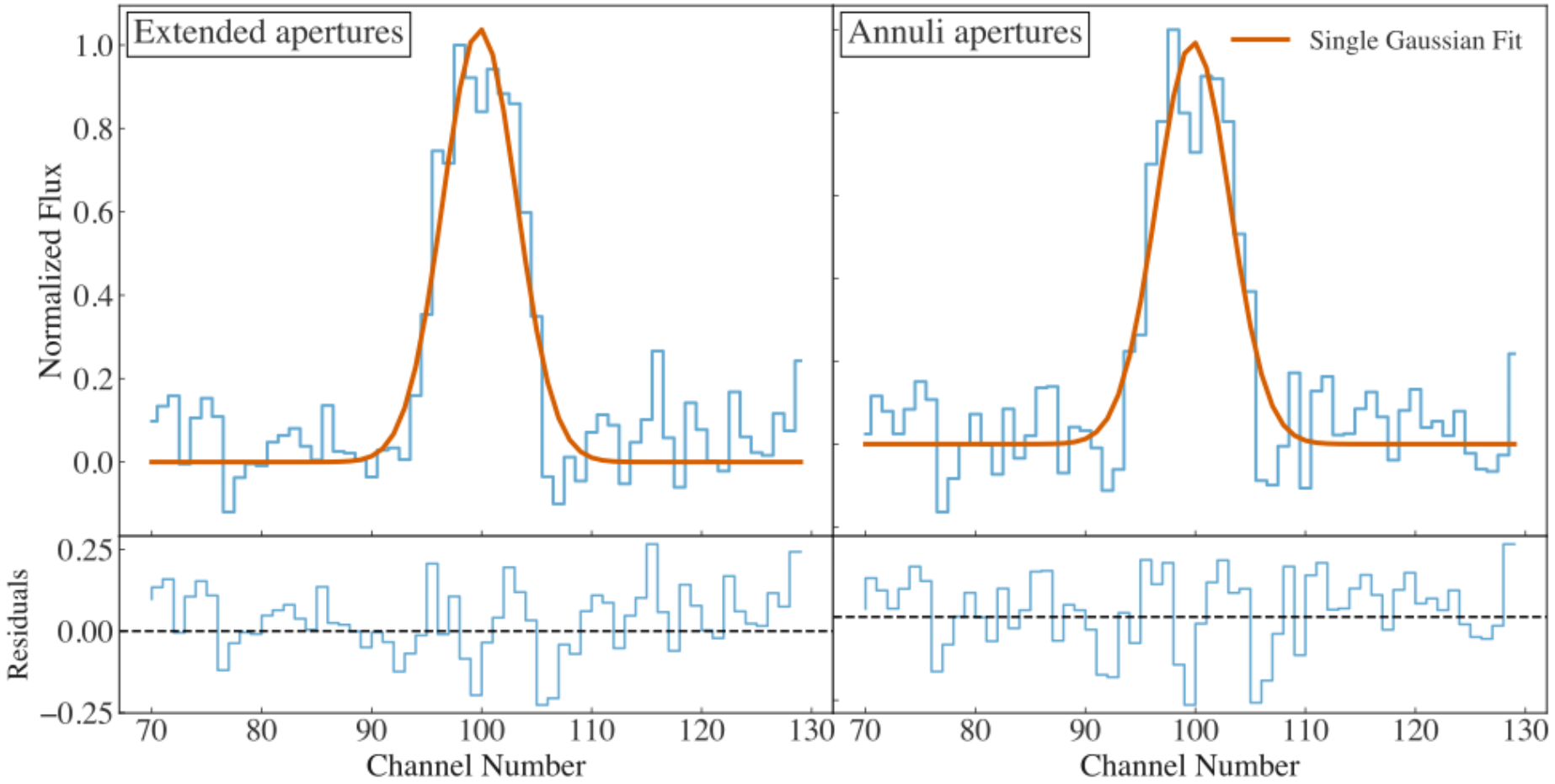
Extended Aperture

- Extend the aperture around the detection area
- Follow the same procedure as above
- **Extended emission detected, but no outflow signatures**



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