GALAXIES AT CROSSROADS:

New Constraints on Molecular Gas Outflows in Massive SFGs

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& the PHIBSS collaboration

MPE - Garching

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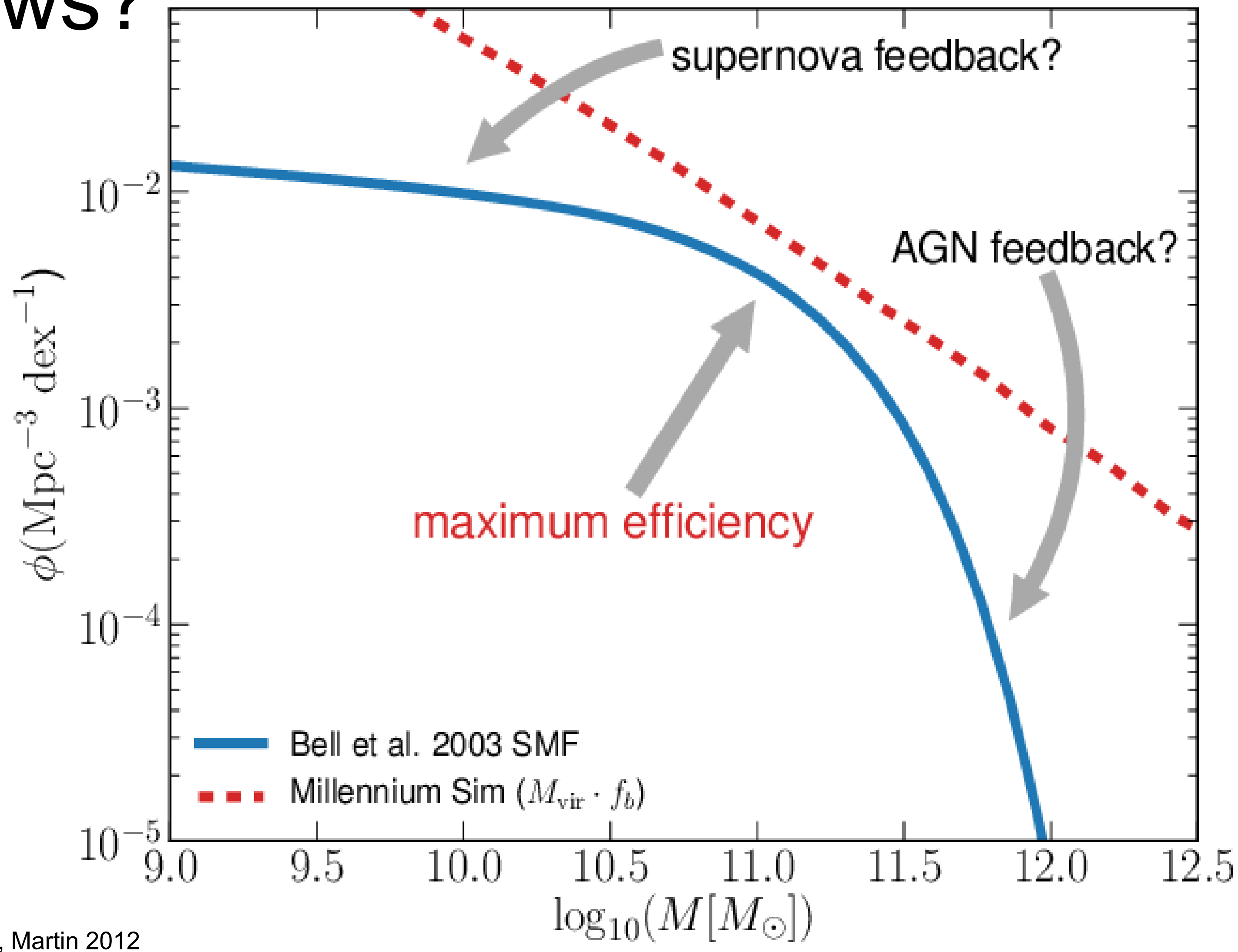
Why do we need outflows?

- Mass loading factor: $\boldsymbol{\eta = \frac{\dot{M}_{out}}{SFR}}$
- To ease tensions, **need a mass loading factor of 1 or above.**

Mutch et al. 2013



Eg: Dekel & Silk 1986, Murray et al. 2005, Fabian et al. 2012, Cicone et al. 2013, Martin 2012

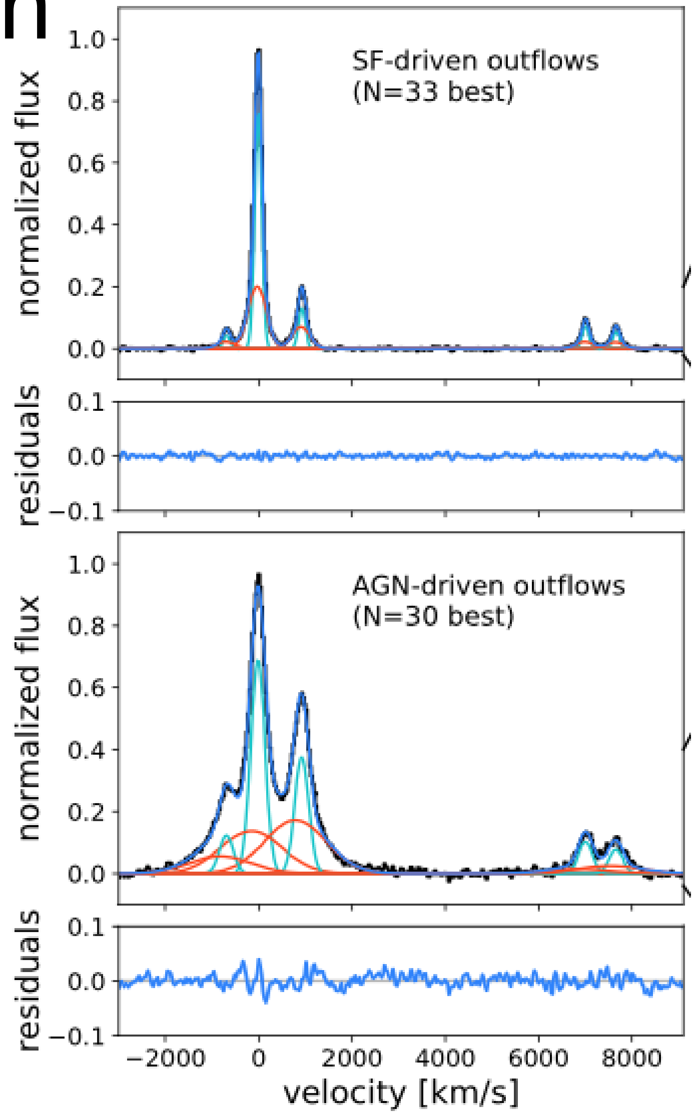
Ionised Gas Outflows at Cosmic Noon

AGN- & SF-driven outflows have different properties:

- **AGN-driven:** ~ 10^3 km/s velocities, correlating with the mass of the galaxy

- **SF-driven:** ~10^2 km/s velocities, correlating with SFR

Mass loading factor: η<1



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 outlows in the molecular gas phase?

Difficulties:

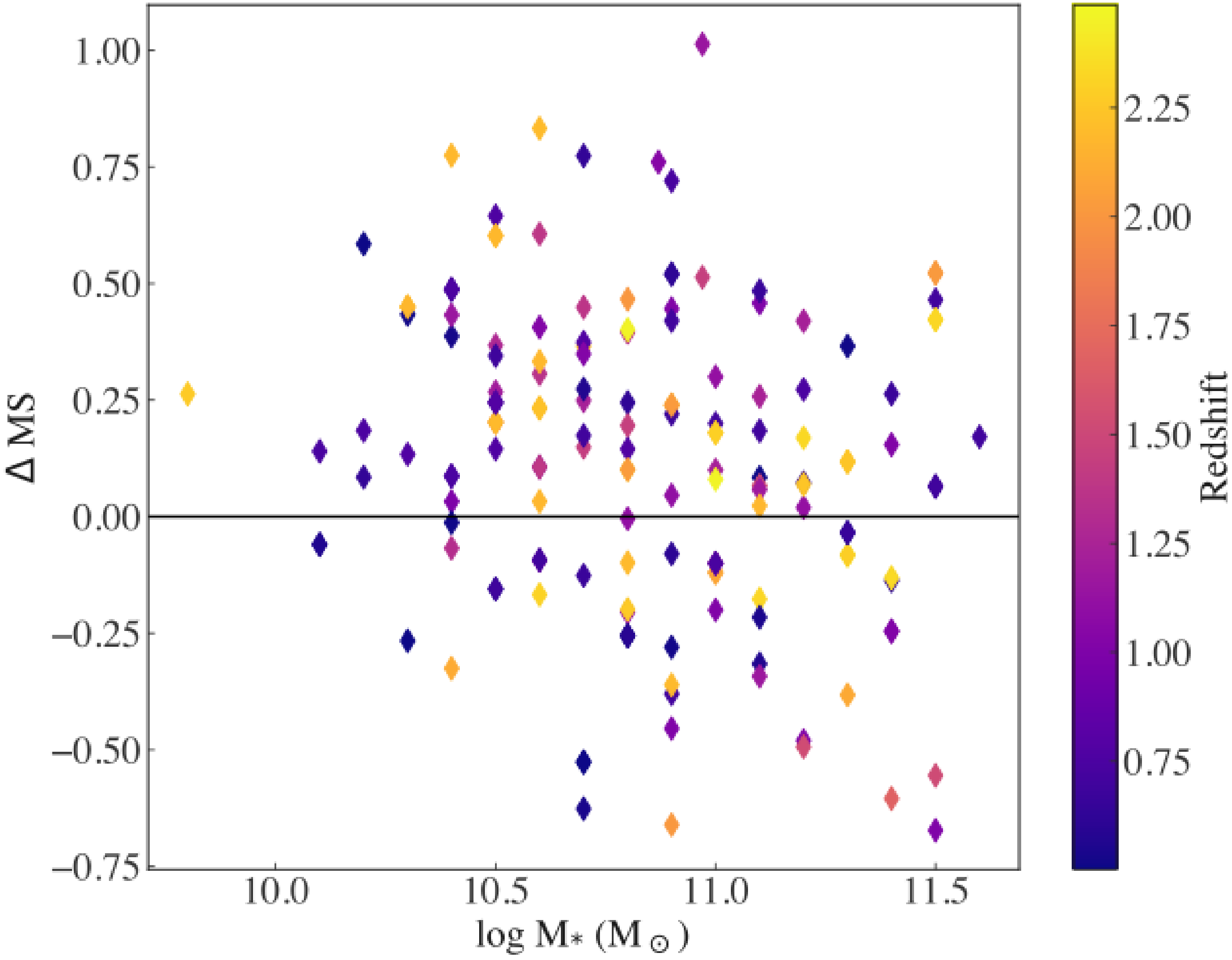
- Molecular gas is a lot harder to detect with **sufficient SNR** to identify outflows
- Molecular gas outflows seem to have **lower velocities** than their ionized gas counterparts
- Detections are (almost) only in **bright AGNs or quasars**

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

PHIBSS Survey

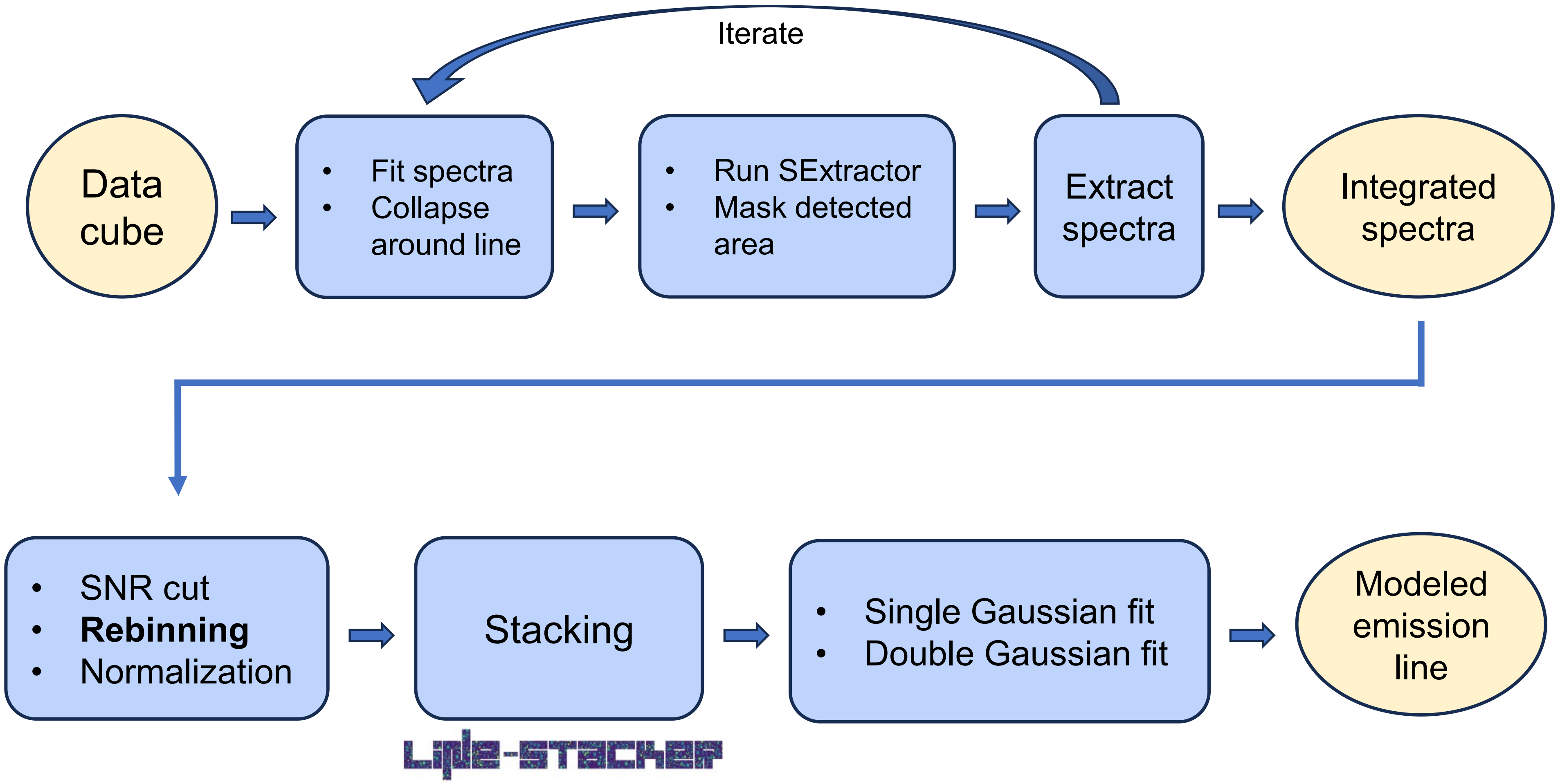
- PdBI/NOEMA CO survey
- **154** main sequence galaxies

Barfety et al. in prep



Tacconi+13,18, Freundlich+19

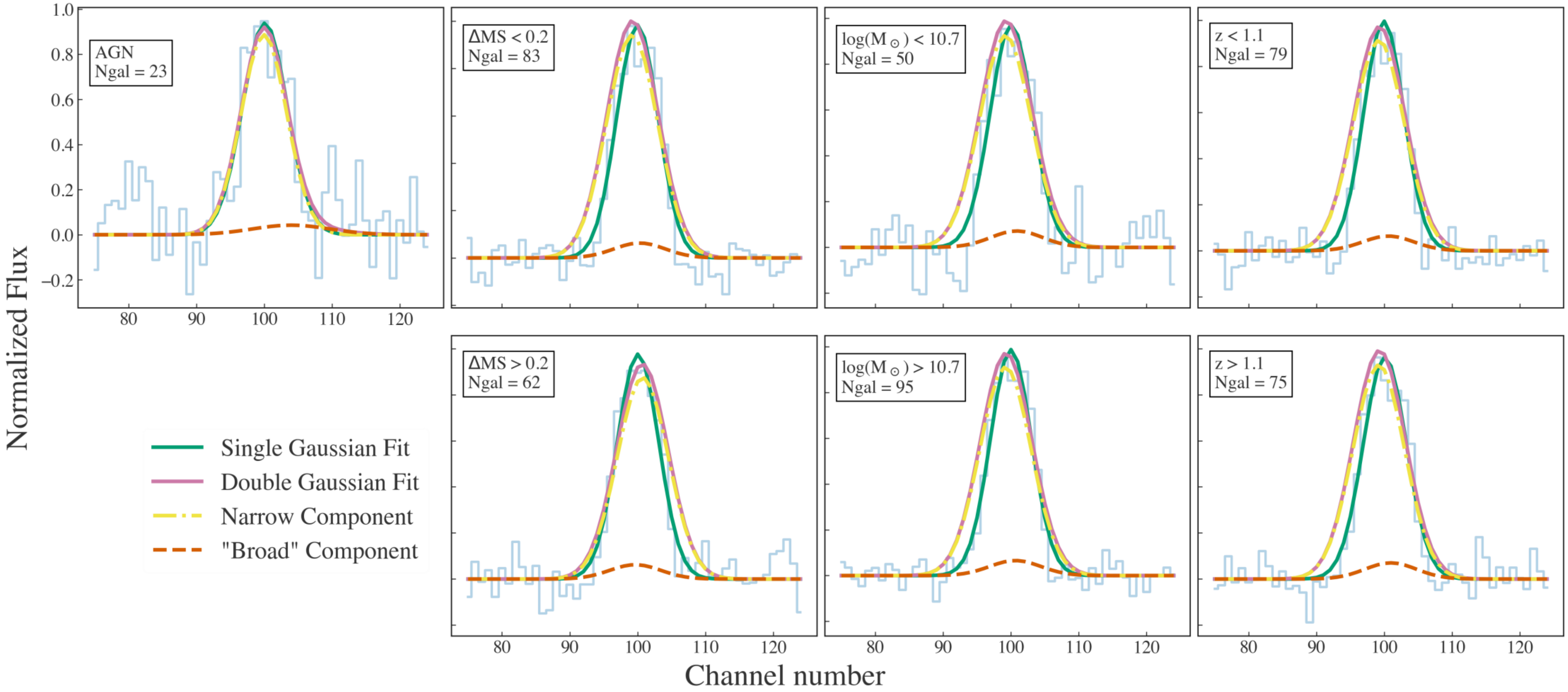
Methods



Jolly et al. 2020

Stacking Analysis: Results

No outflow signature – in any subsample!



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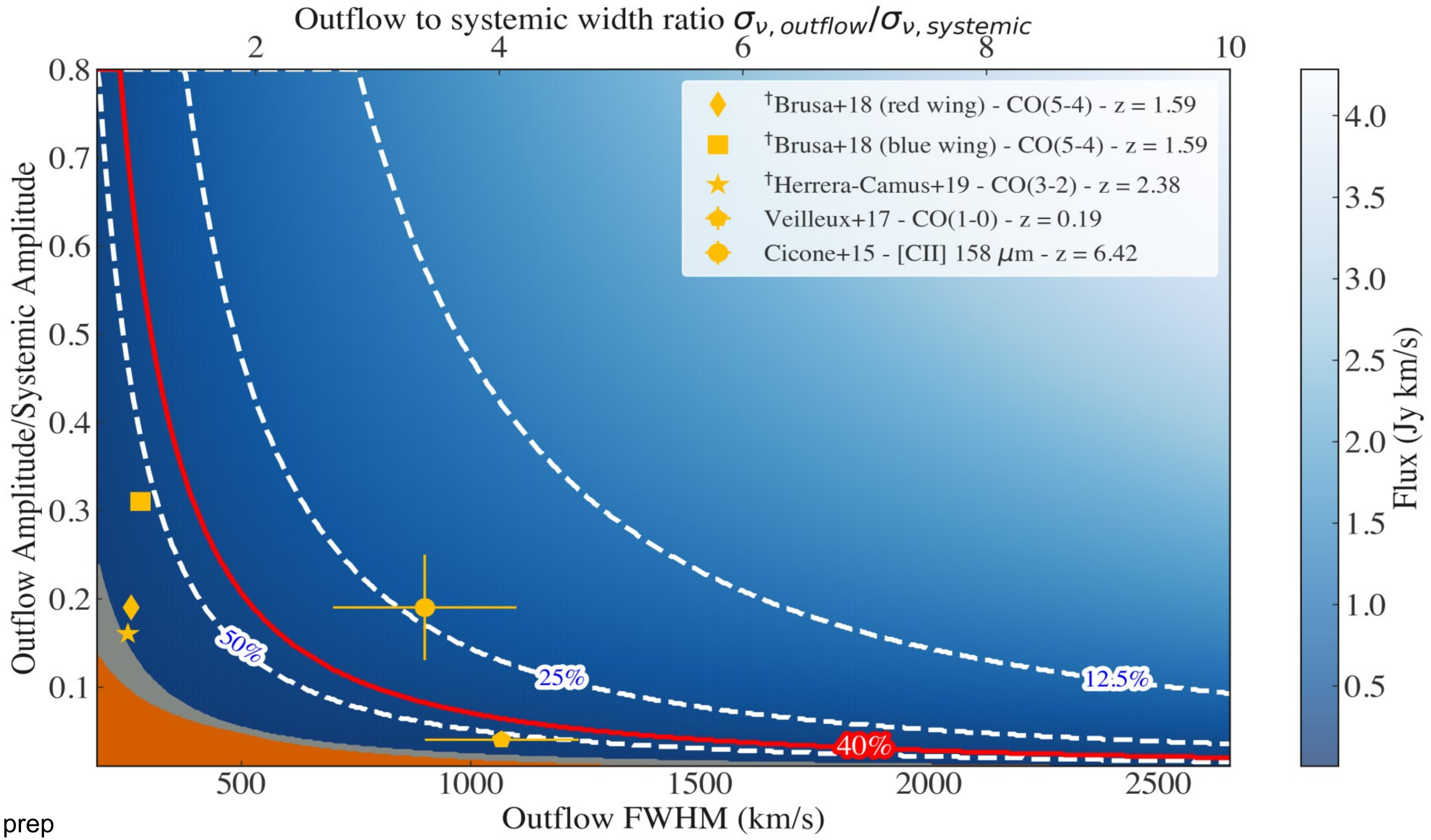
Molecular Gas Outflow Properties



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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.
- Molecular outflows might be **dissociated into other phases** (eg. warm molecular, ionised, neutral atomic phases)

The role of molecular gas outflows in regulating star formation remains challenging to pin down observationally


Thank you!

Upper Limit Computation

- Upper limit on outflow rate:

$$\dot{M}_{out} = 21\ M_{\odot}.yr^{-1}$$

- Upper limit on mass loading factor:

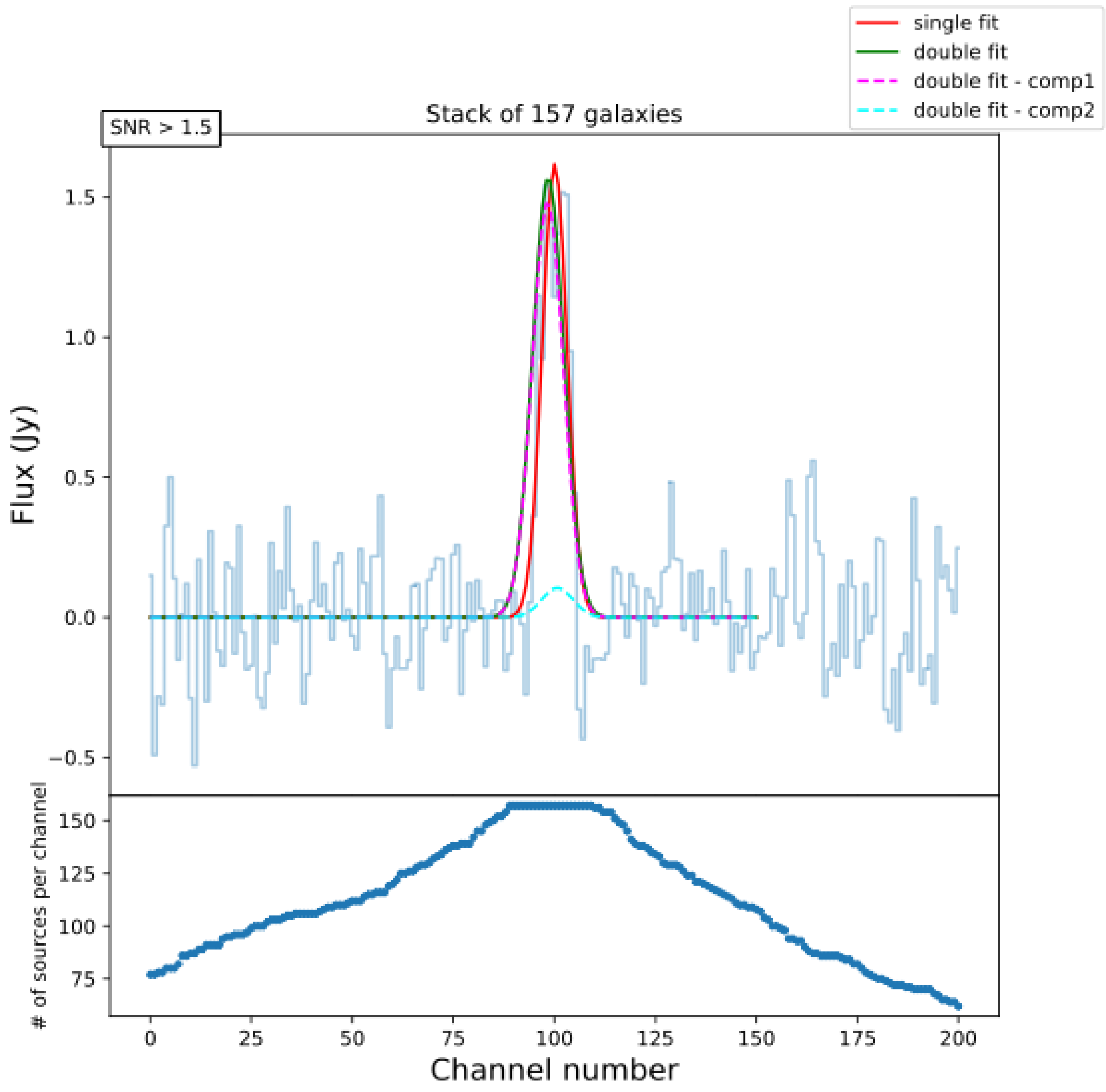
$$\eta = 0.43$$

Highly dependent α_{CO}, the CO-H_2 conversion factor (here $\alpha_{CO} = 0.8$).

Foerster Schreiber et al. 2019

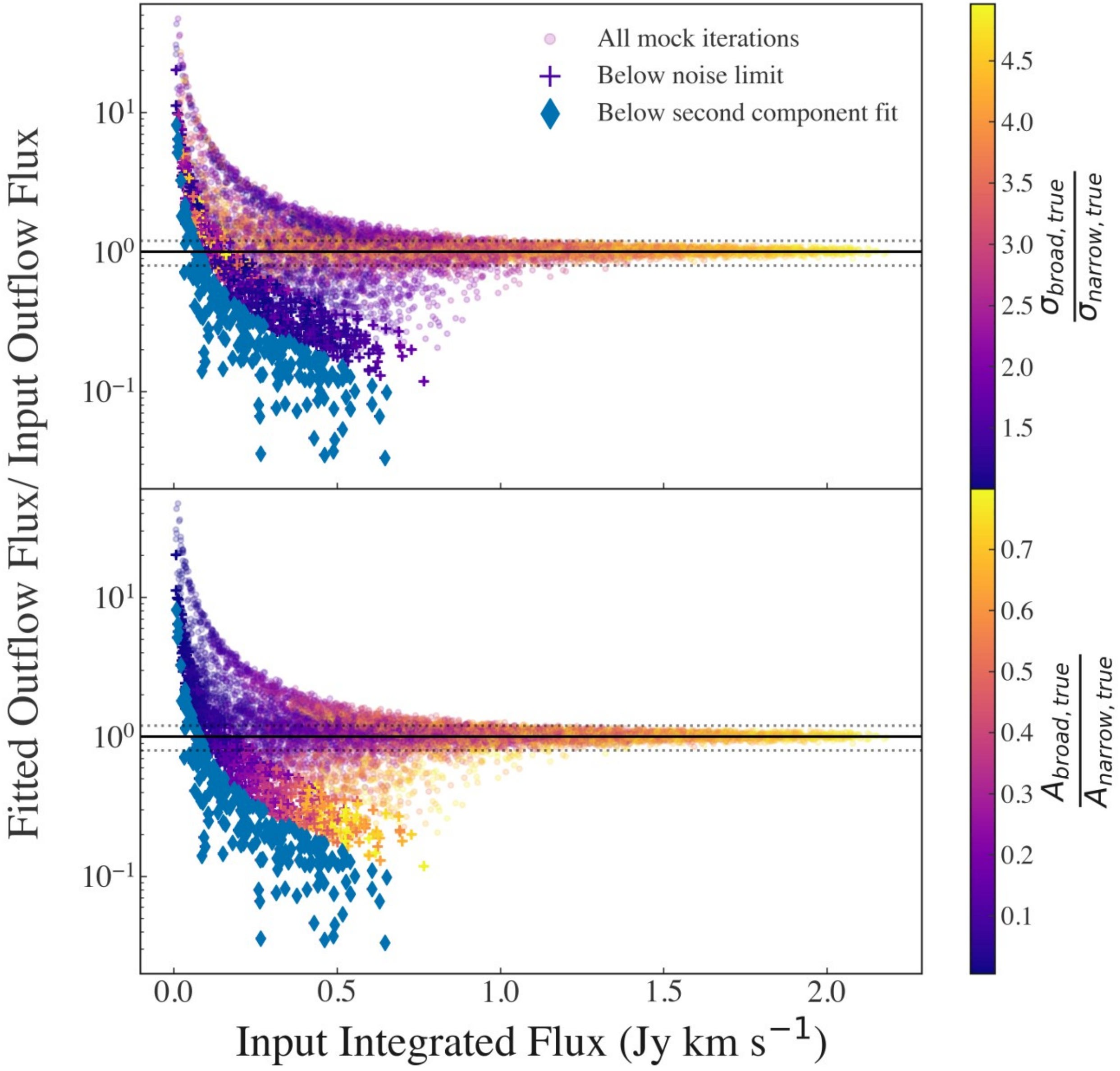
Extended Aperture

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

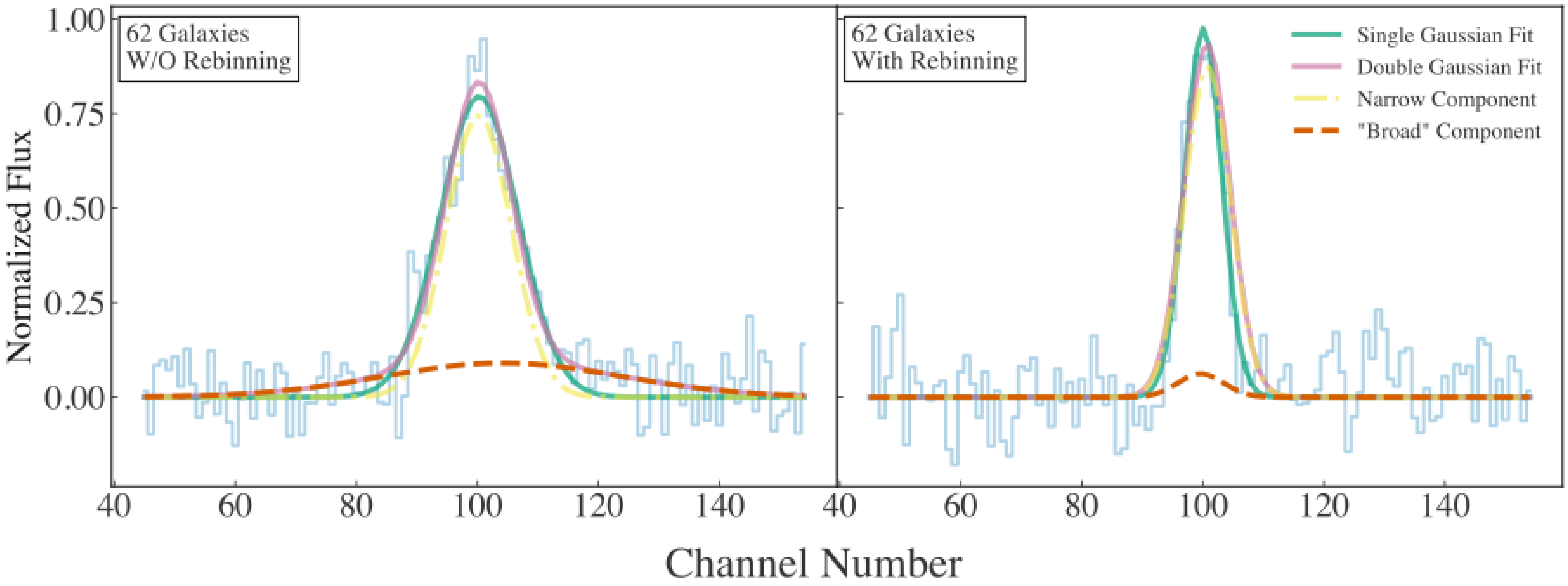


Mock Outflows

- 10,000 iterations
- Input Gaussian component

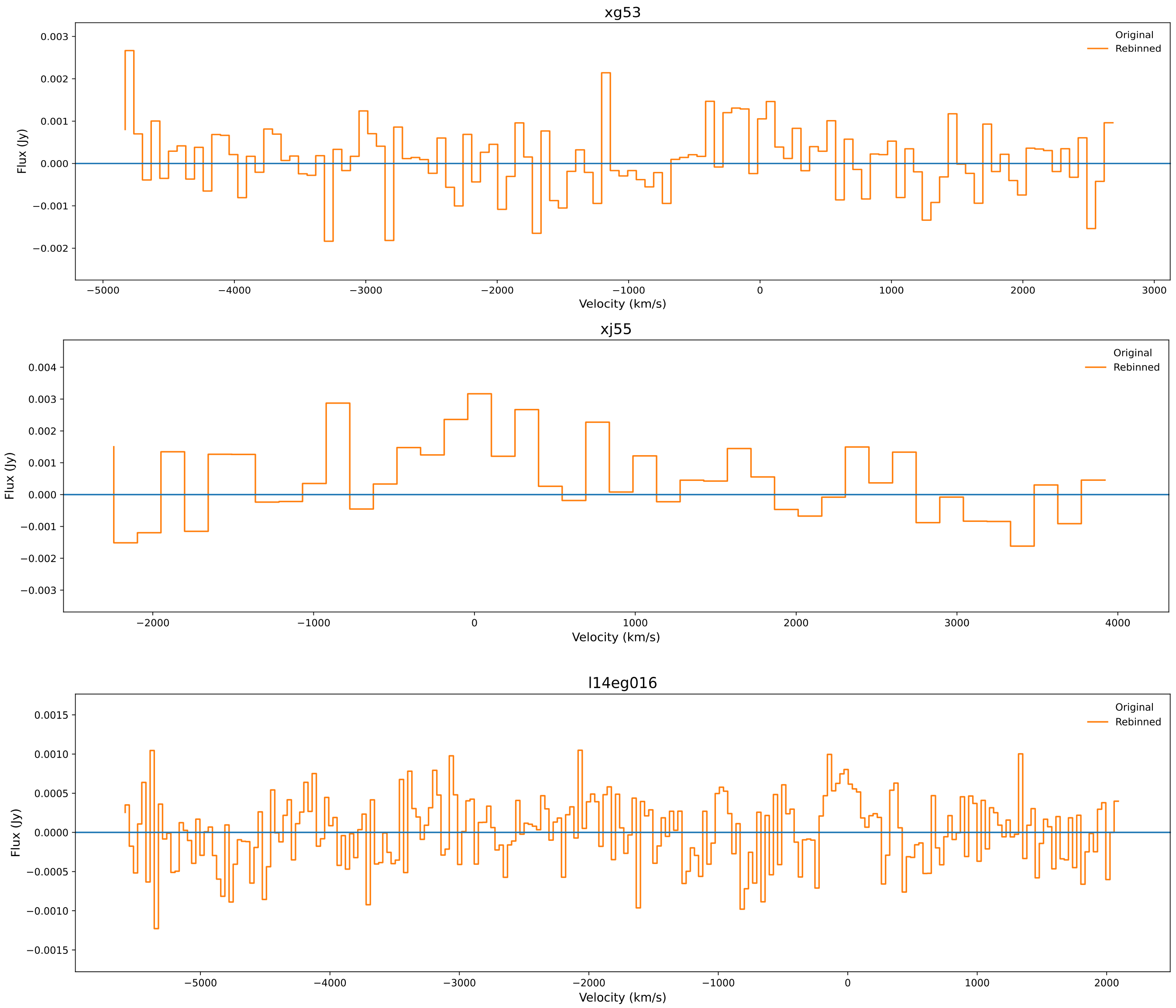


Why re-binning?



Spectral Stacking

- Increases SNR as $\sqrt{N}$
- Spectra are:
  - Normalized to line amplitude
  - Rebinned
  - Aligned to the systemic velocity



Single Spectra Analysis

- 42% CO(2-1)
- 54% CO(3-2)
- 4% CO(6-5)

Barfety et al. in prep

Foerster Schreiber et al. 2019