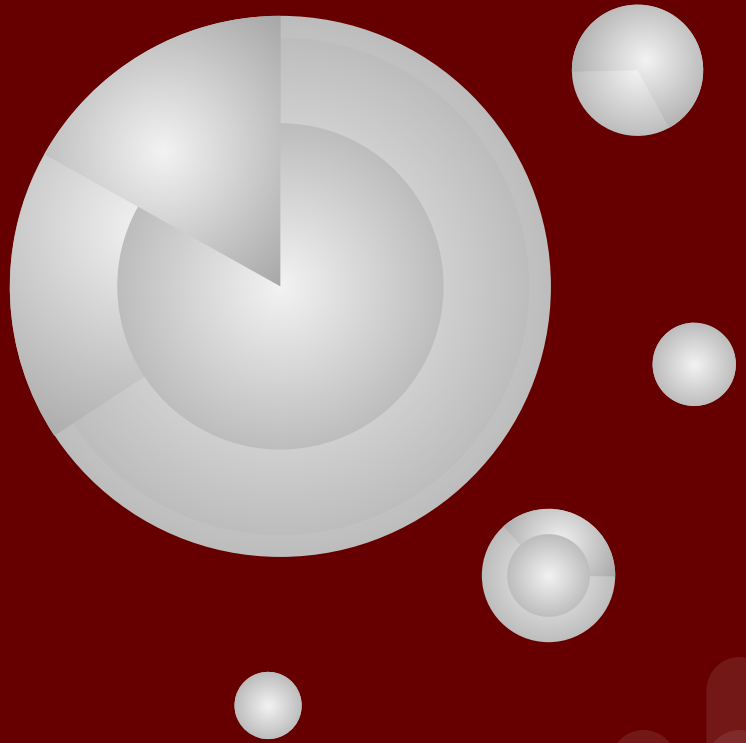
Star-forming clumps and their molecular gas content



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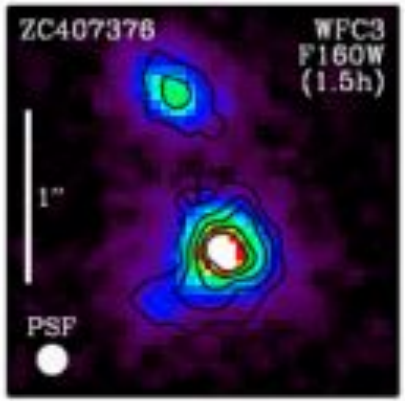
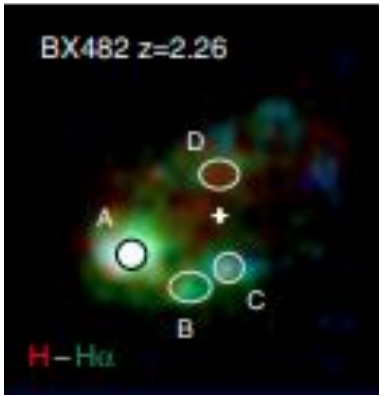
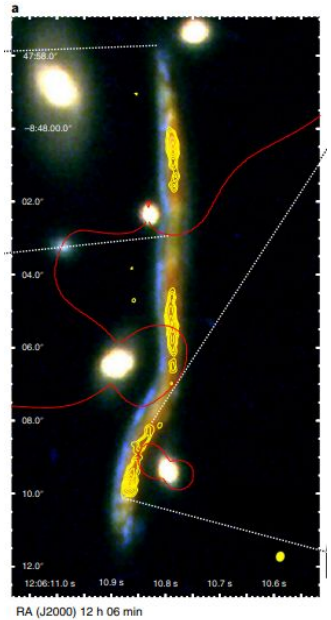
What are star forming clumps

- Galaxies at the epoch of star formation are dominated by irregular star-forming clumps.
- These clumps are strongly visible in star formation tracers
- Thought to be produced via ‘Gravitational Instability’ or ‘Mergers’.







Genzel +11, Forster Schreiber+14, Dessauges-Zavadsky +19,

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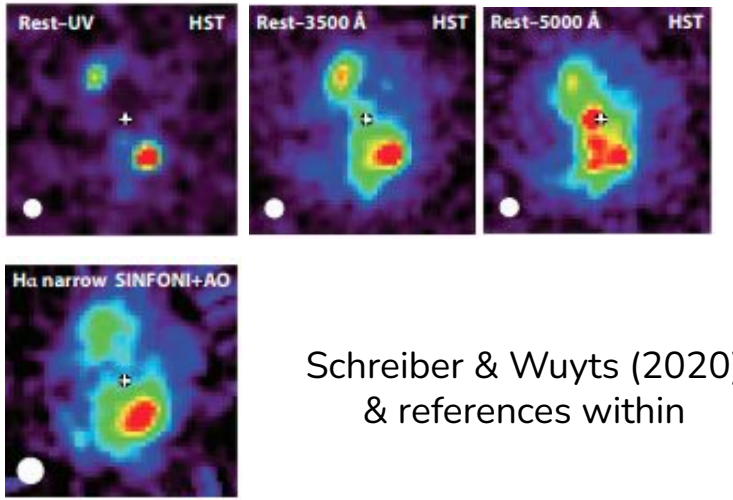
BX610

- BX610 has excellent ancillary data (HST, SINFONI)
- Thought to be a typical clumpy galaxy at redshift 2.21
- SFR estimates of 60-300 M⊙ /yr
- Dominated by 2 clumps in UV
- **Uncertainty if purely rotating disk (Rizzo + 23)**



Schreiber & Wuyts (2020)
& references within

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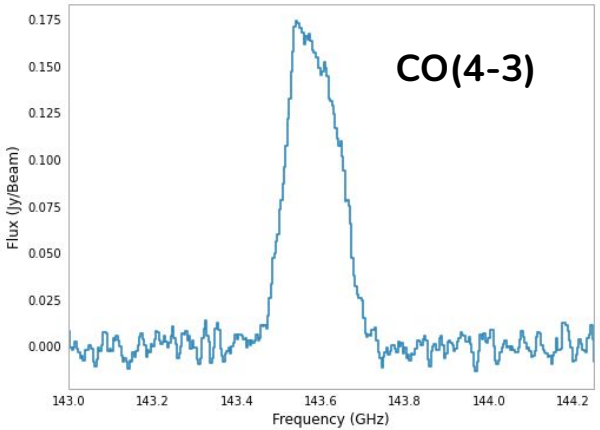
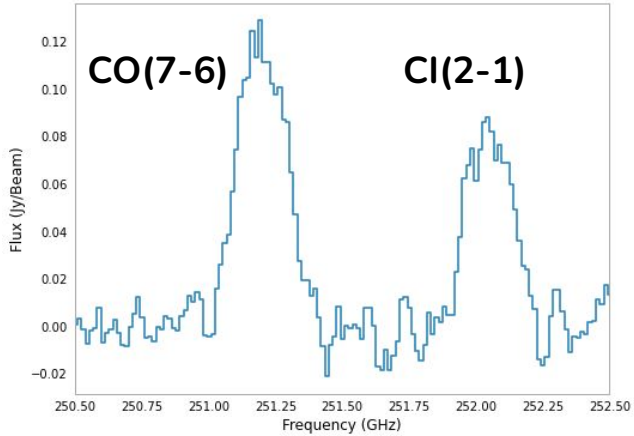
Observations used in this project

- Targeting CO(4-3), CO(7-6) and 400GHz continuum at ~0.15'', 0.06'' & 0.08'' resolutions.
- We use **archival** observations of integration times 13.8hr, 4hr & 1hr
- Correspond also to 600μm, 400μm and 200μm rest-frame continuum.





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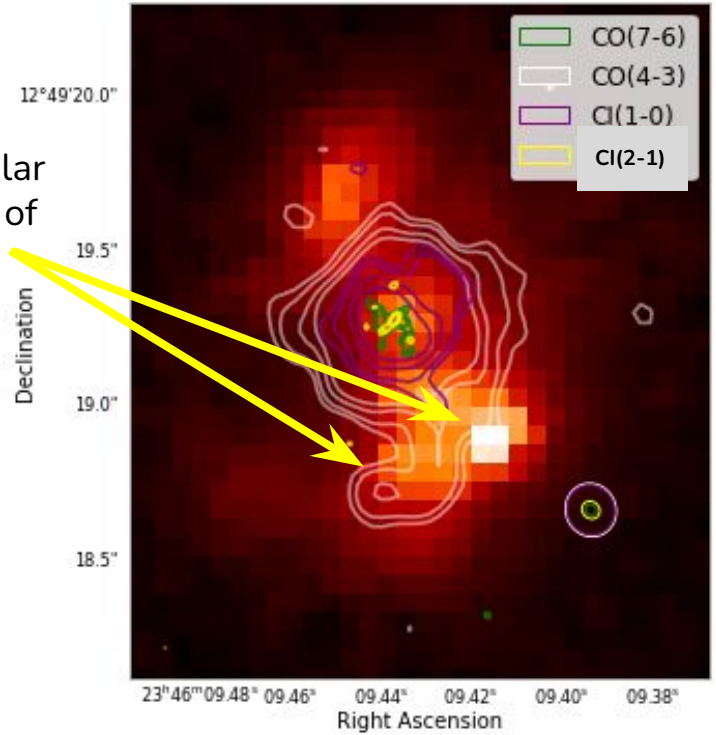
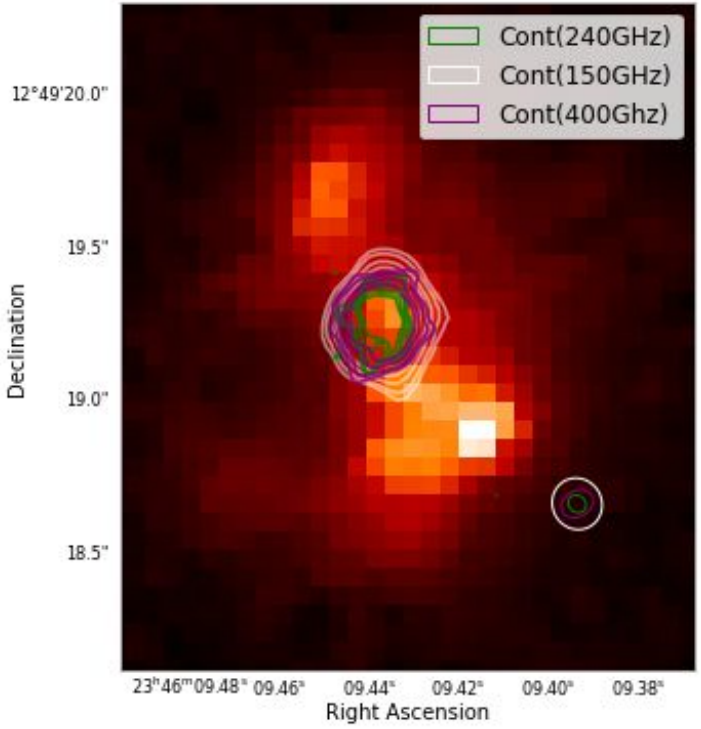
Molecular Gas Morphology & Dust

2 irregular regions of CO





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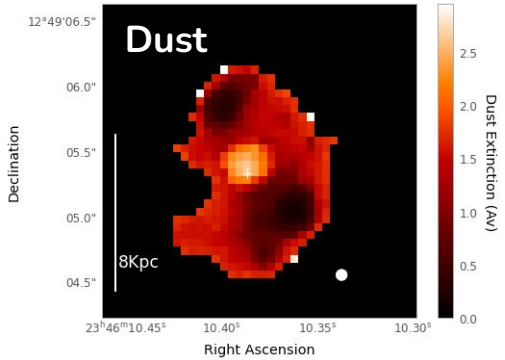
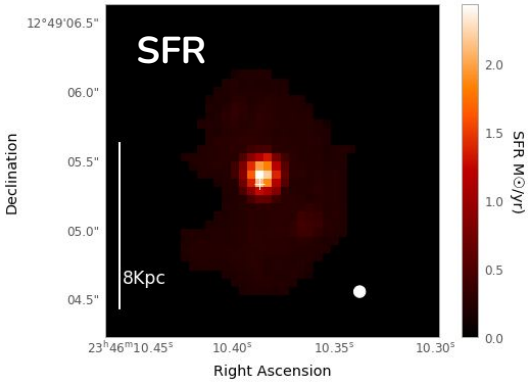
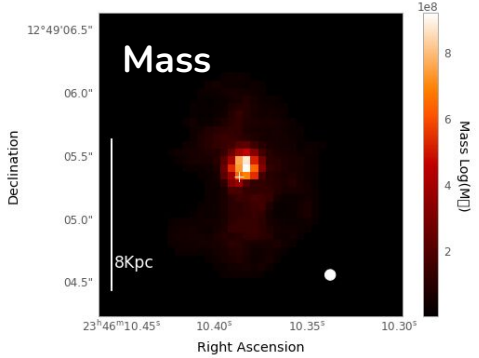
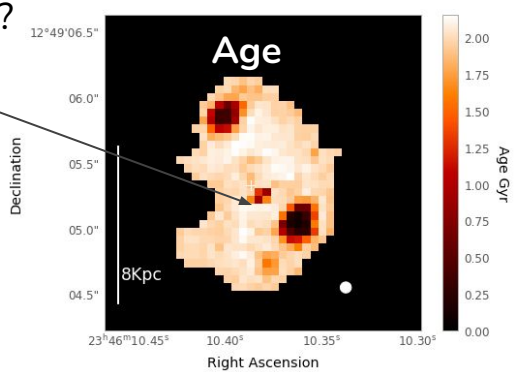
SED fitting - Using new continuum data

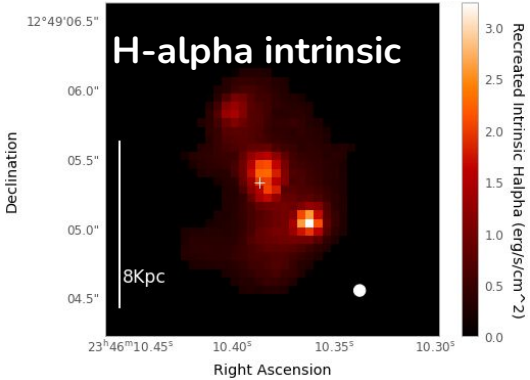


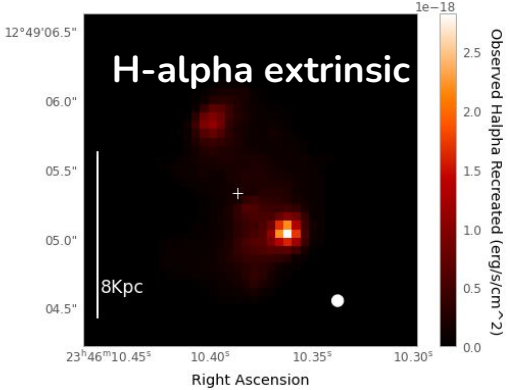




Whats this?







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Results of SED fitting/Molecular gas

CO mass **clump**: $\mathrm{Log}_{10}(M\odot) = 9.76 +/- 0.9$

CO mass **central region**: $\mathrm{Log}_{10}(M\odot) = 10.82 +/- 0.3$

So clump is 1/14th size of central region

Stellar Mass: $\mathrm{Log}_{10}(M\odot) = 11.05$

SFR = 122 +/-10 M⊙/yr

CAVEAT...

$$L'_{\mathrm{CO}} = 3.25 \times 10^7 S_{\mathrm{CO}} \Delta v \nu_{\mathrm{obs}}^{-2} D_{\mathrm{L}}^2 (1+z)^{-3}.$$

$$M(\mathrm{H_2}) = \alpha L'_{\mathrm{CO}}$$

4.36 but could be up to 8.2!
According to Brisbin +19

Bolato +15, Brisbin +19

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Line flux - BX610

Underestimated compared to low resolution.

[CI] ratios don't change

Line	Flux JyKm/s	Error JyKm/s	Gaussian Maj Arcsec	Gaussian Min Arcsec	Previous work JyKm/s	Error previous work JyKm/S
CO(4-3)	0.55	0.03	NA	NA	1.82 (Brisbin et al)	0.26
CO(4-3) clump	0.04	0.01	NA	NA	NA	NA
CO(7-6)	0.445	0.073	0.253	0.202	1.88 (Brisbin et al)	0.28
CI(1-0)	0.157	0.015	0.392	0.355	0.8 (Brisbin et al)	0.15
CI(2-1)	0.274	0.054	0.221	0.203	1.34 (Brisbin et al)	0.24
Continuum	Flux (Aperture) mJy	Error mJy	Gaussian Maj Arcsec	Gaussian Min Arcsec	Flux (Previous work) mJy	Error (previous work) mJy
S150	0.179	0.022	0.260	0.218	0.41 (Brisbin et al)	0.09
S250	1.054	0.078	0.121	0.31	2.39 (Brisbin et al)	0.31
S400	6.00	0.077	0.222	0.203	NA	NA

CO(7-6) more highly distributed In disk

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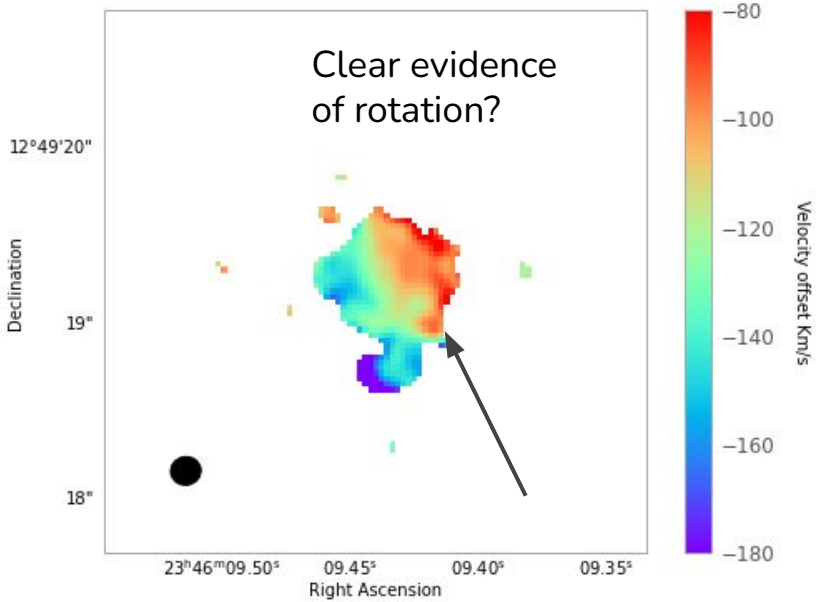
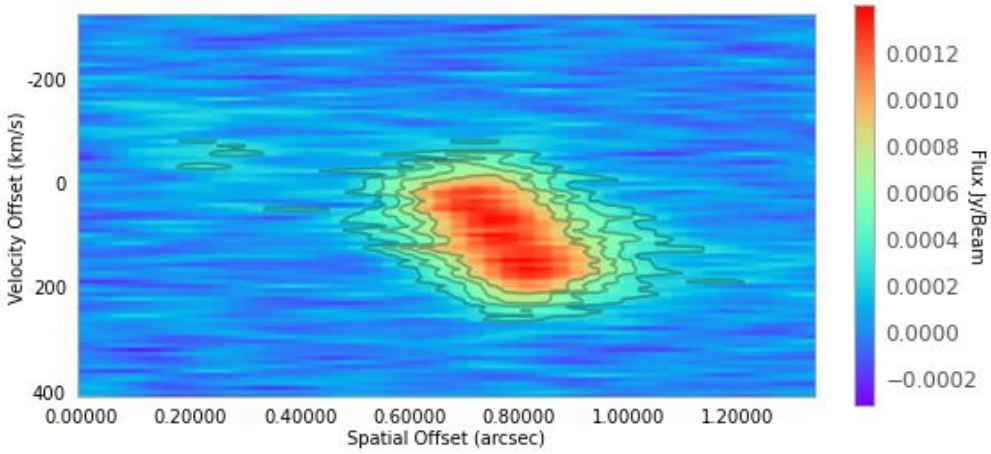
Velocity distribution



Moment 1



PV diagram (North-South)

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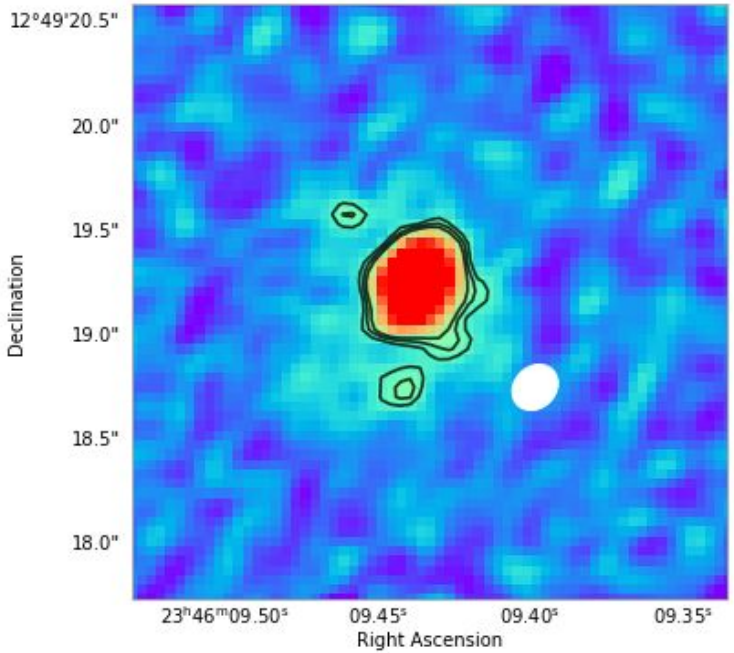
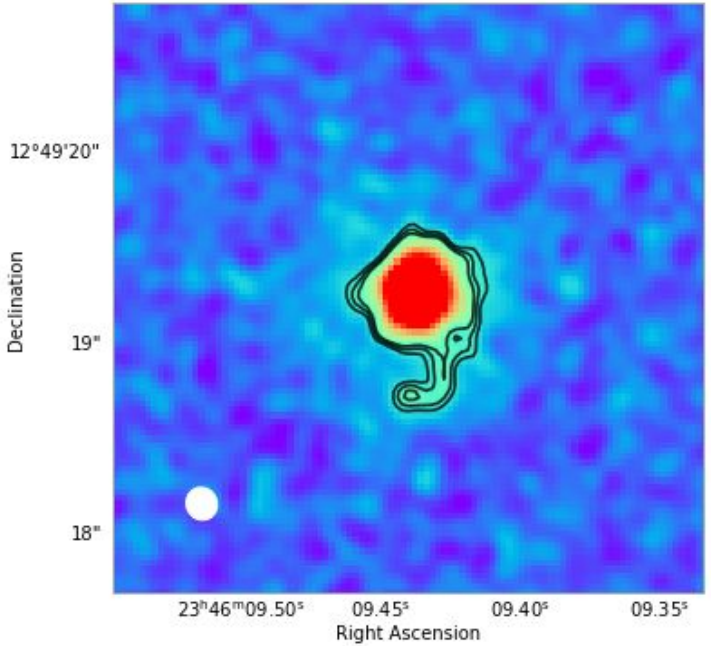
Merger or outflow?

0.3'' + 0.15'' CO(4-3)



0.15'' CO(4-3)



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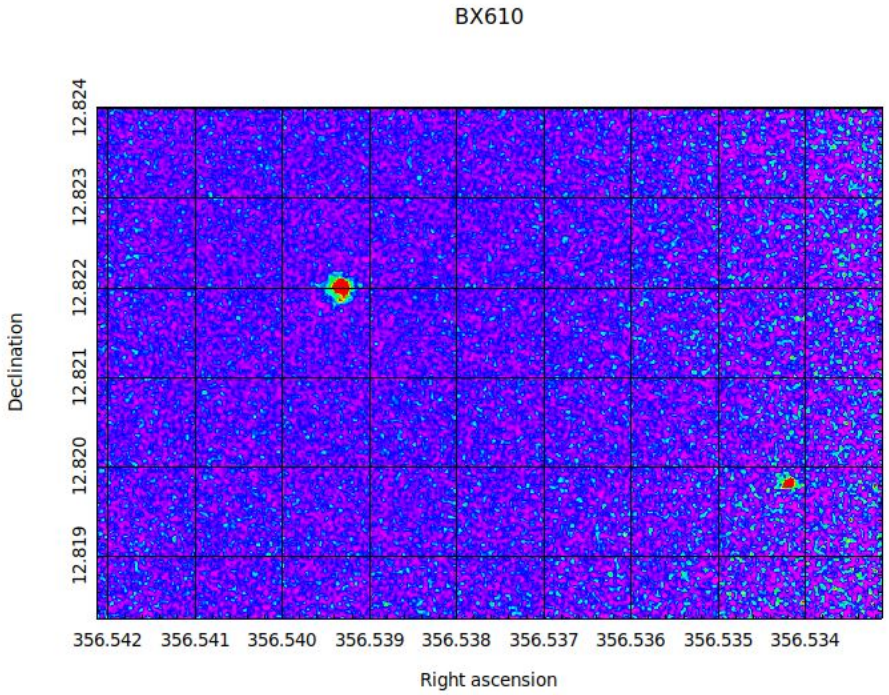
Merger Scenario

-Galaxy at same redshift with just over 1/4 CO flux of BX610

- Located at distance of 155 Kpc.

-Could have undergone a recent pass through the galaxy

-Led to large scale disruption



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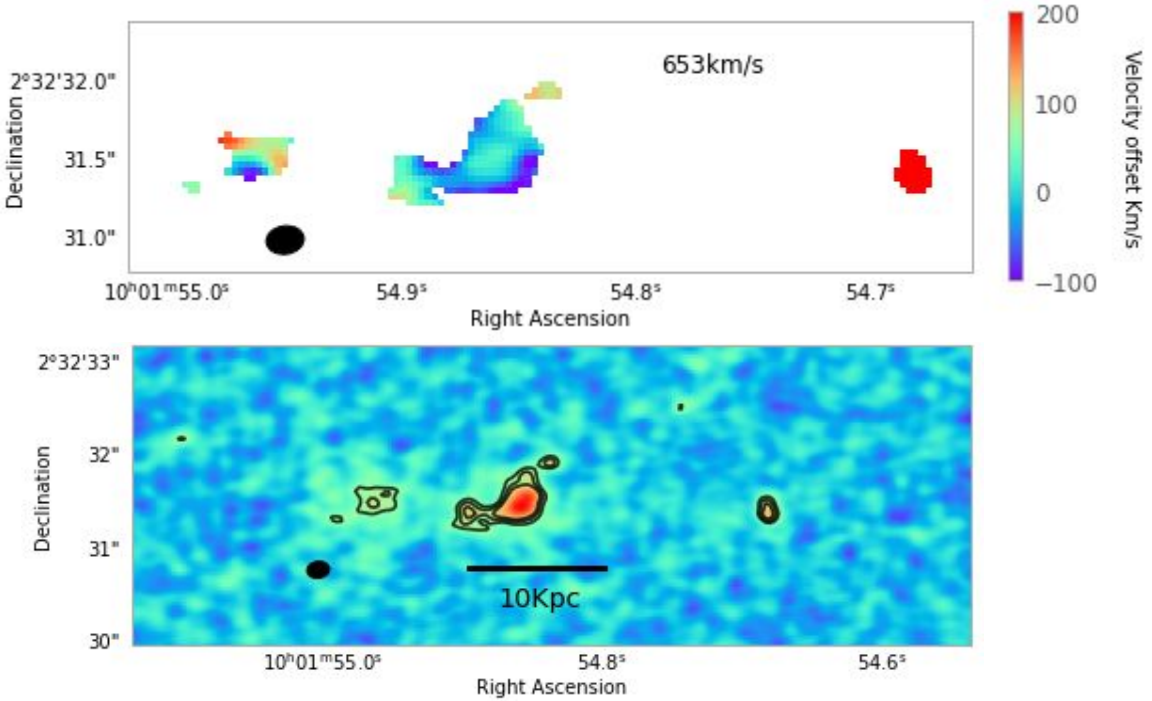
Example of z = 4.5 merging galaxy in [CII]

- At higher redshifts mergers are thought to be far more common
- In a separate project we have high resolution observations of molecular gas in [CII]
- Clumps show very similar characteristics to that seen in BX610

Devereaux et al (in prep)



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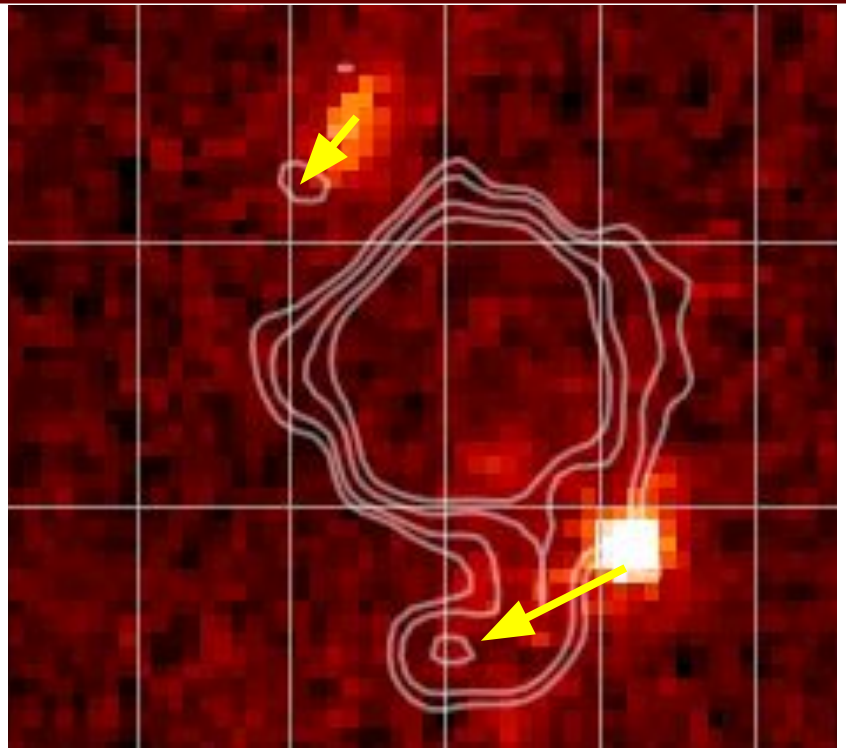
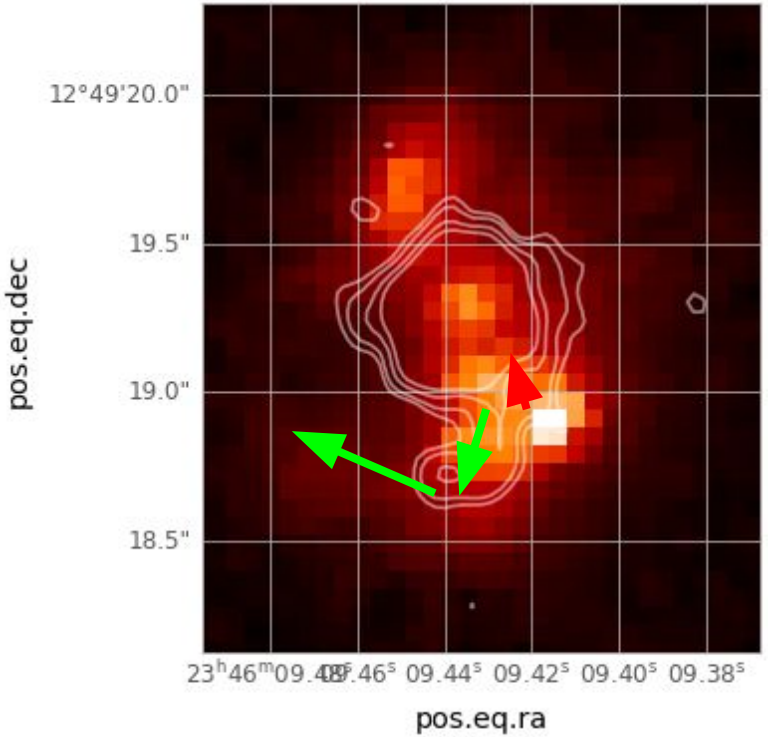
Outflow/Inflow scenario





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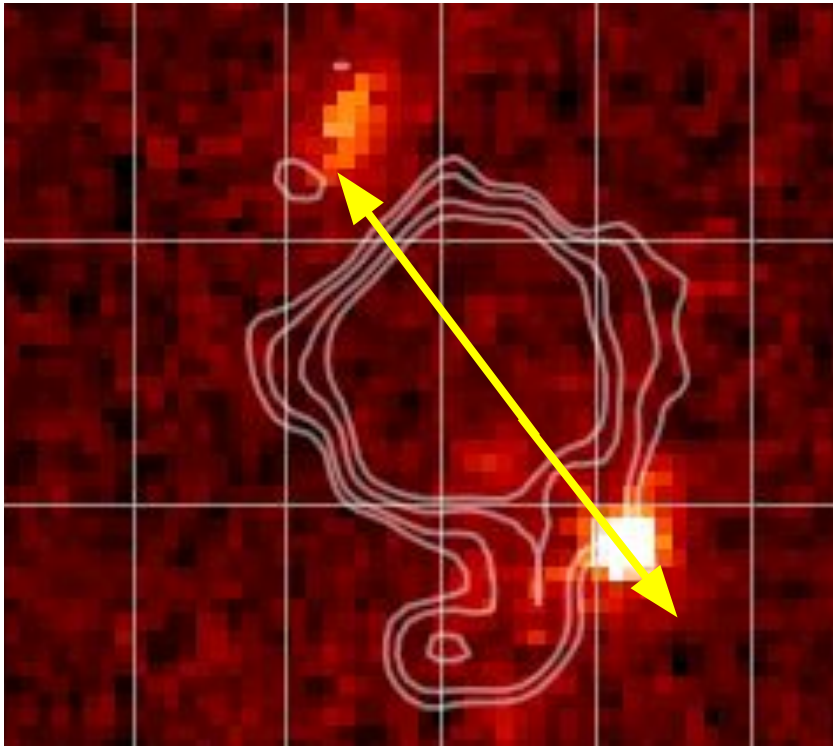
AGN induced clump scenario

- Clumps are located 180 degrees from one another.
- Strong evidence of a ‘weak’ AGN in this galaxy from H-alpha/[NII] ratios. Forster Schreiber+18,
- AGN outflows could be inducing star formation



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Summary/The future

- Our work indicates mergers still important even at z~2
- CO might be observable in this galaxy due to a recent merger
- Is this typical galaxy instead untypical?
- Have we given **more questions than answers?**
- Increased high depth ALMA observations of molecular gas tracers will uncover clumps in other star forming galaxies.