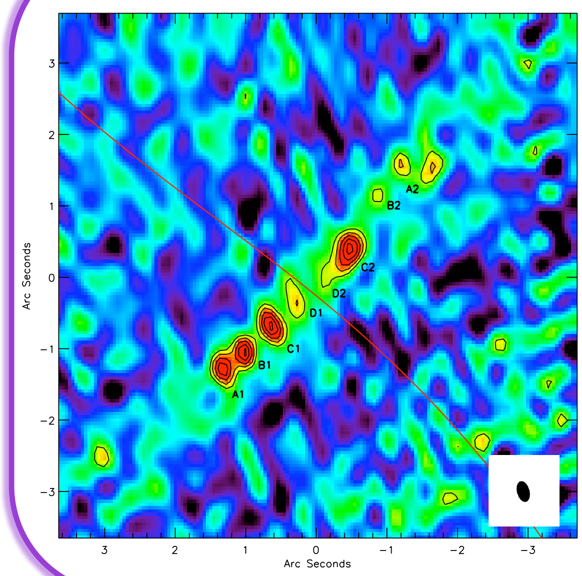
The ISM of a z=2.3 star-forming galaxy

Alice Danielson et al. 2011, MNRAS,410,1687; Mark Swinbank et al. 2011 (ApJ submitted)
Rob Ivison et al. 2010, A&A 517, 35

An essential element of our understanding of distant galaxies comes from observations of emission from molecular and atomic interstellar gas, particularly cooling through ^{12}CO, [CII] and [CI]. A majority of the detections of this emission from high-redshift galaxies has been from powerful quasars and it has been very difficult to probe the physical properties of high-redshift starburst galaxies. However, recently, gravitational lensing provided us with such an opportunity.

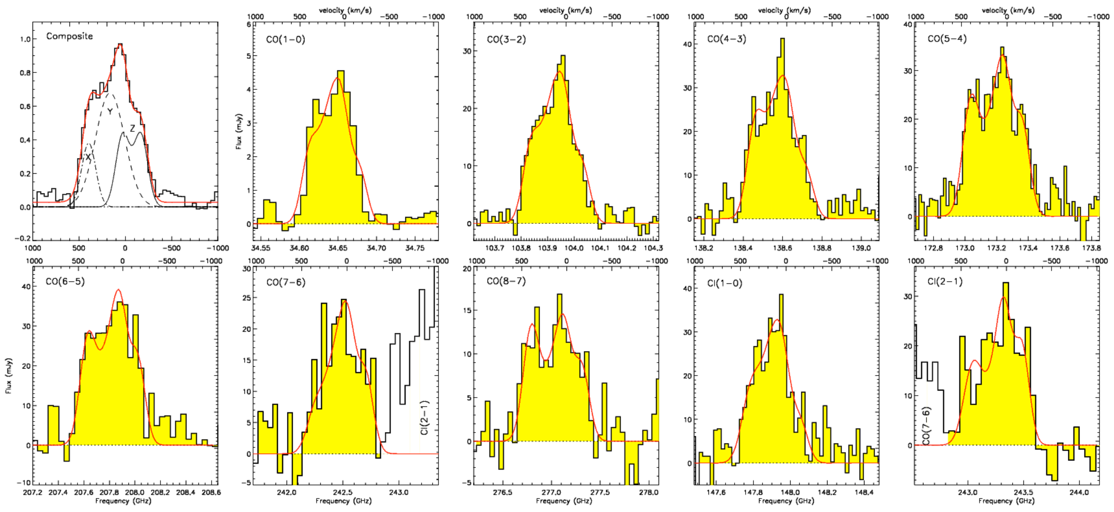
SMMJ2135-0102 is a star-forming (~400±20$M_{\odot}yr^{-1}$) galaxy at z=2.3259 which was discovered in 2010 and has since been studied extensively. It is magnified 32x by a foreground galaxy cluster, boosting both the size and flux, thus providing a unique opportunity to probe the conditions and processes occurring within a high-redshift star-forming galaxy.

SMA 870μm map (Swinbank et al. 2010)



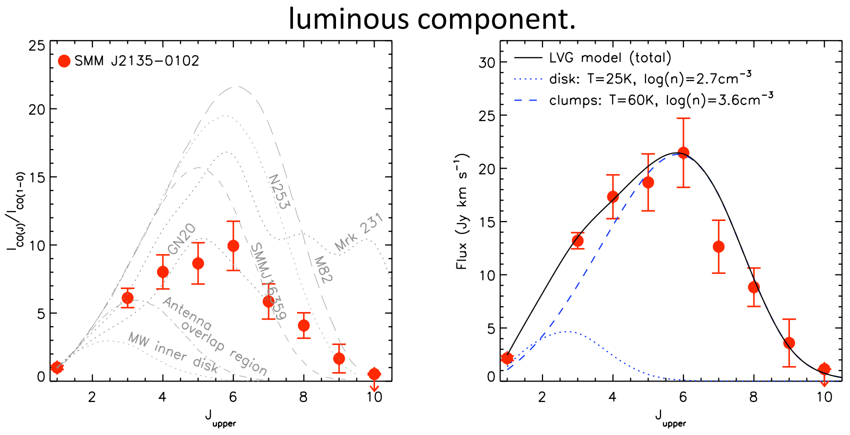
Rest-frame 260μm continuum map of SMMJ2135, showing the sub-mm morpholgy. The galaxy comprises **4 separate emission regions** mirrored about the lensing critical curve (red line). The star-formation density of the clumps is >100x higher than in typical local GMCs.

Observed spectra of molecular and atomic emission lines of ^{12}CO and [CI] fine structure lines from SMMJ2135 (Danielson et al. 2011)



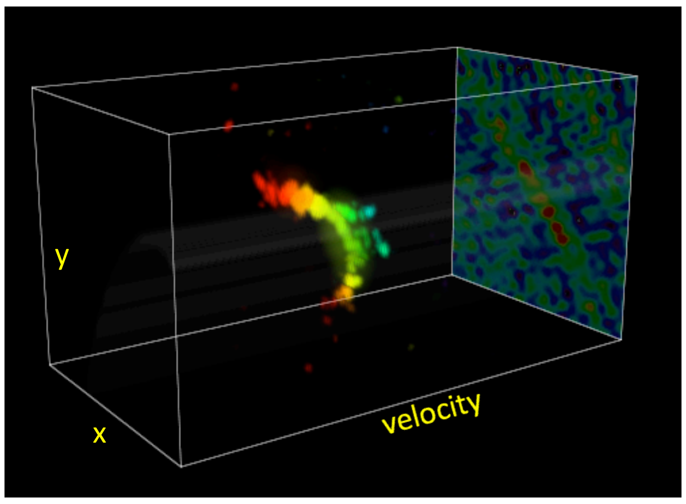
The emission line profiles all show **multiple velocity components with varying intensity between transitions**. We find that a 3-component parametric model describes the kinematic structure well.

The **^{12}CO spectral line energy distribution** (SLED) for SMMJ2135 shows a peak at around J_{upper}=6 (resembling local starbursts). The ^{12}CO SLED has **two phases of the ISM**, with a 25K extended, low excitation, massive component and a 60K dense, luminous component.



Our LVG analysis implies a gas mass of **~4x10^{10}$M_{\odot}$** and thus α~2.0; significantly higher than the mass of (1.4±0.1)x10^{10}$M_{\odot}$ derived from the standard ULIRG conversion factor of α=0.8 to convert between $L'_{^{12}CO(1-0)}$ and M_{H_2}.

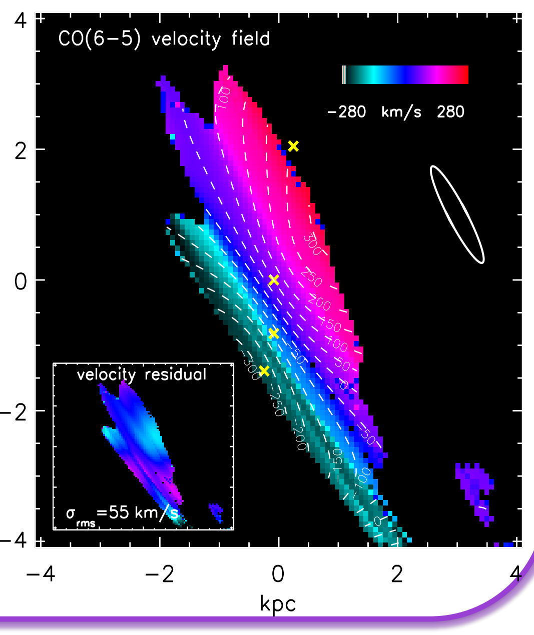
Volume rendered visualisation of the **CO(6-5) emission line cube** (x, y, velocity) from high resolution (0.2") observations with PdBI. This image plane cube is colour coded by velocity and rendered by intensity.



The "U" shape shows the fold in the velocity field about the critical curve, and the velocity field shows a peak-to-peak gradient of ~550km/s. **The clumps seen in the CO emission are well aligned with the clumpy morphology seen in the rest-frame 260μm continuum emission** (back face of the cube).

Swinbank et al. 2011

Two-dimensional velocity field of the molecular gas from the CO(6-5) after correcting for lensing amplification. The velocity field shows a velocity gradient of **~500kms^{-1} across ~3kpc in projection**, indicating a **dynamical mass of (6.0±0.5)x10^{10}M**. The contours represent the best-fit disk model and the crosses mark the positions of the star-forming regions from the SMA 870μm map.



Larson's relations- clump properties

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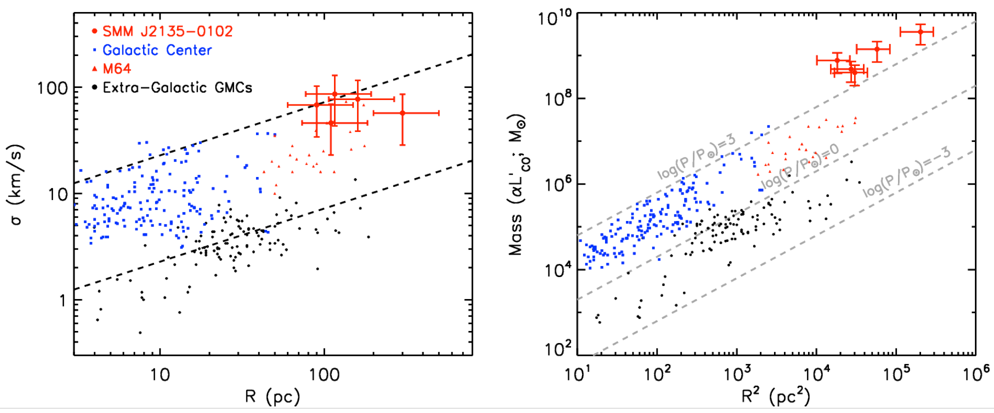

The velocity dispersion versus cloud radius (left) and gas mass versus size (right) for the resolved star-forming regions in SMMJ2135, as compared with molecular clouds within galaxies in the local Universe. The star-forming regions do not follow the local relation for GMCs in quiescent environments but rather suggest that the ISM is under a pressure 100x that of the Milky-Way. Consequently, the molecular gas is expected to be **~100x denser on all scales, with a velocity dispersion ~10x higher, than the gaseous ISM in the Milky Way, which would dramatically elevate the star formation efficiency.**

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