IFU Observations of high-z ULIRGs: Gas Morphologies and Kinematics

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1. Background and Motivation

Submm Galaxies (SMGs: high-z ULIRGs, $L_{FIR}>10^{12}L_{\odot}$) have some of the highest star formation rates (SFRs) in the Universe (~$1000M_{\odot}$/yr). However, it is unclear what triggers the huge star formation and ultraluminous activity in these high-z galaxies. Local ULIRGs appear to be often triggered by mergers and interactions (Sanders et al. 1996) but is this the same at high-z?

There has been a large simulation effort to better understand the physical processes which trigger and terminate the ULIRG bursts in these galaxies. Narayanan et al. (2009) use hydrodynamical simulations with dust radiative transfer models to simulate major mergers. At various points throughout the mergers there are times when the predicted luminosities match the brightest observed z=2 SMGs. If the ULIRG burst occurs in the early stage of the merger the gas morphology would be rotation dominated, if it occurs at the pre-coalesced stage the morphology would be disturbed and if it occurs at the late-stage one would observe the compact morphology of a coalesced system. Dave et al. (2010) identify SMGs at z=2 in their hydrodynamical simulations finding that the high SFRs are often generated by massive galaxies (>$10^{11}M_{\odot}$), which are sitting at the centre of large potential wells, accreting smaller galaxy fragments (gas rich satellites with <10:1 mass ratios). This results in complex gas morphologies and kinematics within the SMGs at z=2.

Morphological and kinematic studies can thus provide a huge amount of information about the formation and evolution of these galaxies. The ionized gas can be mapped using integral field spectroscopy, tracing emission lines (e.g. Hα) within the galaxies. There is only a small sample of high-z ULIRGs which have been studied in this way (Swinbank et al. 2005, 2006 and Menendez-Delmestre et al. in prep), the majority of which exhibit characteristics of complex merging systems. Merger signatures are also found when tracing the molecular gas distribution using CO line observations; Engel et al. (2010) find most of their sample of 12 SMGs appear to be major mergers either exhibiting distinct components or showing either compact or disturbed morphologies; indicative of late stage or pre-coalesced mergers respectively.

We aim to test if most SMGs are mergers, or if other processes also contribute to the ultralumious activity, by mapping the Hα emission line within 5 high-z ULIRGs, observed using NIFS, an IFU on Gemini. The sensitivity of the Hα observations to star formation allows for the identification of mergers where CO line observations may only detect a single component.

3. Comparison to SINS galaxies

We compare the sample of high-z ULIRGs, and their components, to a sample of UV/optically selected star forming galaxies, at 1.3<z<2.6, observed as part of the SINS survey (Forster-Schreiber et al. 2009), as shown in Figure 2.

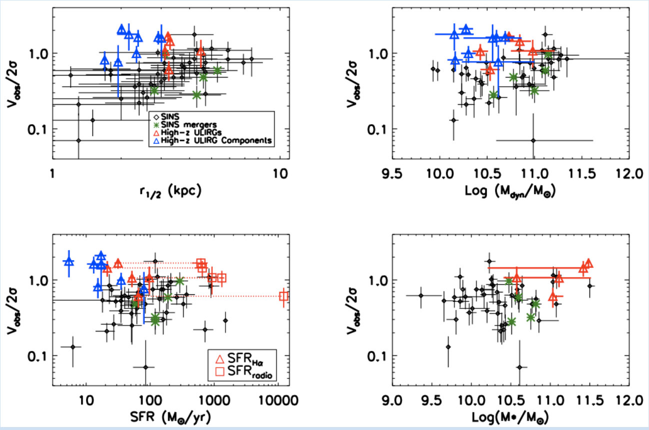

Figure 2: *Properties of the high-z ULIRG sample compared to the sample of SINS galaxies. $V_{obs}/2\sigma$ is a measure of the extent to which a system is rotation or dispersion dominated.*

The high-z ULIRGs form a different population to the SINS galaxies. The majority of the SINS sample are non-mergers so this difference indicates that the high-z ULIRGs are more likely to be a sample of mergers. Indeed the SINS mergers form the population with properties most similar to the high-z ULIRGs, confirming the conclusions from studying the kinematic maps alone.

The high values of $V_{obs}/2\sigma$ in the high-z ULIRG sample are due to large velocity gradients within the systems. Recent simulations of SMGs predict there are two populations of merger-driven SMGs; some are the coalescence stage of a merger and some are two disks, overlayed in the same beam at the infall stage of a merger (Hayward et al 2011). It is therefore possible that the minimum and maximum velocities we observe lie within different merging components or two different objects appearing as one system, explaining the high velocity differences.

The half-light radii, $r_{1/2}$, of the complete high-z ULIRG systems lie towards the upper region of the SINS sizes implying that they are not compact systems, supporting the findings that high-z ULIRGs are not scaled up versions of the compact ULIRGs found locally (which are formed in mergers) and thus other forms of ULIRG burst triggers should also be considered at high-z. The low $SFR_{H\alpha}$ values compared to the SFR_{radio} values are due to the underestimation of the extinction in these dusty galaxies and indicates that the star formation in these sources could be even more extended.

2. Kinematic Maps

We trace the Hα emission line within each (binned) pixel of 5 high-z ULIRGs (2.1<z<2.7) gaining maps of Hα intensity, velocity and velocity dispersion. 3 examples are shown in Figure 1. We identify the major kinematic axis, or choose the axis which covers the multiple intensity peaks, and place a 'slit' along the axis to search for evidence of disk-like rotating structures within the sources.

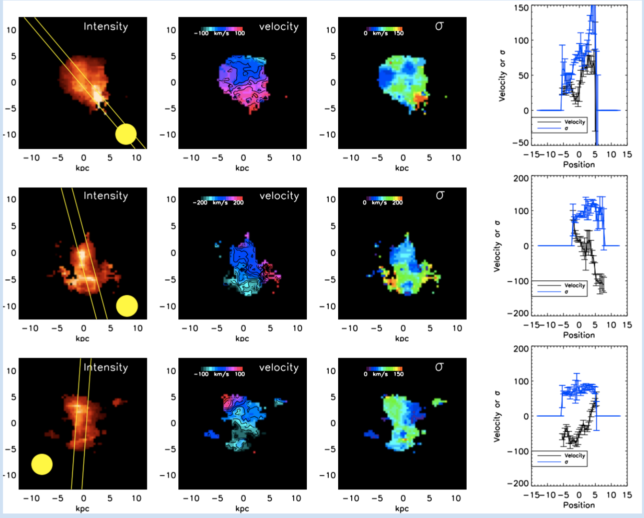

Figure 1: Hα intensity, velocity and velocity dispersion maps for 3 of the sources created by fitting a Gaussian profile to the Hα emission line within each (binned) pixel and using the resulting properties of the lines. Velocity and dispersions along the chosen kinematic axis, marked by area between the yellow lines, are also plotted in black and blue respectively.

None of the sources show disk-like characteristics or signatures of rotation curves. All sources exhibit multiple components or intensity peaks providing evidence that all are systems in the process of merging. We therefore split up the sources into their constituent components based on either distinct spatial separation or the minimum in S/N contours.

4. High σ and relation to Σ_{SFR}

Despite the higher values of $V_{obs}/2\sigma$ in the high-z ULIRG sample compared to the SINS galaxies these are significantly lower than those observed in local disks. The values are low due to the high velocity dispersions rather than low velocity ranges. The high σs may be caused by the merging process (Narayanan et al. 2009), or from gas accretion (Genzel et al. 2006) or the harassment of massive galaxies by smaller satellites (Dave et al. 2010) causing turbulence, or due to feedback from star formation via supernovae winds (Efstathiou et al. 2000). It is not clearly only the act of merging which may drive the high σs within the sources and it may be connected to the star formation itself.

The relation between the SFR density and σ per pixel is shown in Figure 3, we follow the same analysis as Lehnert et al. (2009), overplotting the same basic models. The models produce relationships which generally follow the observations however the fits are poor since the models are too simplistic to fully describe the relation between the gas dynamics and star formation. The σ α $(\Sigma_{SFR})^{1/2}$ models fit the data best, especially if we take into account the SFRs are not extinction corrected and thus all points likely lie further to the right of the plot, indicating that the gas is, to some extent, driven by the star formation energy output.

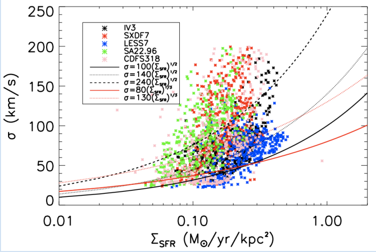

Figure 3: Velocity dispersion - SFR density relation per pixel for the high-z ULIRGs. Black lines: 3 efficiencies of a model assuming σ is proportional to the square root of the input energy rate (proportional to the SFR); the case if the energy from the star formation is powering the gas motion. Red lines: 2 efficiencies of a model assuming the turbulent motions dominate the σs and all the energy from star formation is dissipated as turbulence.

5. Conclusions

Engel et al. (2010) suggest that most SMGs are formed in major mergers. Our Gemini-NIFS observations of Hα in 5 high-z ULIRGs support this with all exhibiting multiple components, disturbed morphologies and turbulent dynamics.

We find that the high-z ULIRGs are morphologically and kinematically distinct to a sample of UV/optically selected star forming galaxies at the same redshift (studied in the SINS survey) and display the characteristics of systems undergoing mergers. We observe higher values of $V_{obs}/2\sigma$ in the high-z ULIRG sample compared to the SINS galaxies however the values are still lower than in local disk galaxies. We find the high σs, lowing the value of $V_{obs}/2\sigma$, may be driven by the star formation itself.

Analyzing the outputs of simulations with different ULIRG burst triggers, in the same way as these observations, will enable us to determine which scenario produces SMGs with properties which best match those observed in the real Universe and thus identify the most likely ULIRG burst trigger.

References:

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