Potentially Quiescent Molecular Gas in a Recent Merger Remnant

Elliptical Galaxy NGC 1316
Early-type galaxies often have kinematically decoupled substructures.

- Stars and gas rotate at different speeds or directions.
  - Wish to know how these structures evolve and form.
  - Theories point to a merger origin for these substructures.
NGC1316 (Fornax A)

- Lenticular galaxy, 19.0 ± 0.9 Mpc away
  - Jensen, et al. 2003
- Strong radio emitter
  - F. Schweizer 1980
- A recent (~3.0 Gyr) merger remnant
  - Goudfrooij, et al. 2001
- CO maps show it has misaligned molecular gas

Optical (blue) and radio (red) images of the galaxy Fornax A, or NGC 1316.
Observations

- VIMOS IFU on the VLT
- Galaxy-centered and CO peak images taken in 2008
- Visible wavelength (4000 – 6000 Å)
- Each image made of four quadrants
- ~1600 spectra on each exposure

Small sample of the raw science frame
IFU Spectroscopy

- Integral Field Unit
- Transforms a 2-D view into multiple spectra (one for each spatial resolution element)
  - VIMOS IFU takes in light on microlenses and fibers which are distributed over pseudoslits to get spectra
- Powerful tool for studying internal dynamical structure in galaxies
Data Reduction

- ESO has a pipeline for VIMOS data – Gasgano
- Takes in calibration data and raw science frames to produce RSS images
- Before this, science frames must be cleaned of cosmic rays -IRAF
- Cleaned raw science frames are wavelength-calibrated and corrected for differences in fiber transmission through Gasgano
- Finally, the quadrants are combined into one image and the exposures are averaged after weighting them for different sky conditions
Data Reduction - GASGANO

Calibration Frames

Trace spectra location
Flat fielding
Transmission Correction
Wavelength Calibration
Sky Removal

Combine four quadrants
Combine all exposures

End product: Datacube for analysis
First, must rebin the spectra to a “constant” S/N

- Ensures reliable and unbiased extraction of kinematics
- Our target S/N was 60

Voronoi Rebinning (Cappellari, 2003)

- Adaptive bin generator for 2-D data

An example output image of the rebinned spectra. Top shows the bins, with the centroid marked by a white cross. Bottom is a spread of the bins to the target S/N denoted by the straight line.
Analysis: pPXF and GANDALF  
(Cappellari and Emsellem 2004; Sarzi 2006)

- Match each spectrum to a library of stellar templates

- Penalized Pixel Fitting procedure
  - Returns the stellar velocity and dispersion
  - Marks emission lines to be fit later

- Gas AND Absorption Line Fitting
  - Returned the [OIII] velocity and dispersion
  - Flux for [OII], Hβ, and NI
  - Gas kinematics were tied to the [OIII] line, as it is less sensitive to template mismatch
  - Only emission above a certain A/N was accepted to avoid recording noise

Example GANDALF fit

Emission Line only output
A clear gradient, with the galaxy rotating (red away and blue toward us). Suggests a weak stellar disk.

Gas velocity seems to be misaligned with the stellar velocity. Kinematically decoupled from stars.
The high values of the gas velocity dispersion and the \([\text{OIII}]/\text{H}\beta\) ratio indicate that NGC1316 is not robustly forming stars.

Maps of star-forming galaxies from Sarzi, et al. (2005)
Note the low [OIII]/H\beta ratio and low gas velocity dispersion
Galaxy Maps (Galaxy-Centered)

Equivalent width tells the relative strength of emission compared to surrounding flux. The [OIII] map may reveal some structure. Hβ has a peak in the middle. The ratio of the fluxes seems to be too high for star formation. This means there must be another cause for gas ionization in NGC1316.
Conclusions

- The stellar velocity map shows clear galaxy rotation, but not an obvious galactic disk
- The gas velocity is misaligned with the galactic velocity
  - Denotes kinematically decoupled substructure
- Star formation in NGC1316 is not strong as evidenced by the high gas velocity dispersion and [OIII]/Hβ ratio
  - Another cause for gas ionization – not star formation
Future Work

- Analyze the CO Peak exposures of NGC1316
- Reduce and analyze NGC7252
- Extract absorption linestrengths in order to determine the age and metallicity of the stellar population
- Determine the processes ionizing the gas
Acknowledgements

- Thank you very much to Alison Crocker for all her help at every step
- Thank you to the Five College Astronomy Department for giving me the opportunity to learn and research here

Questions?