Searching for the turbulence/shock dominated galaxies with WFIRST’s Grism at $1.8 < z < 2.0$

Phil Appleton

Project Scientist and Team Lead
NASA Herschel Science Center
Caltech

Main Collaborators Katey Alatalo (Caltech), Sabrina Cales (Yale), Jeff Rich (Carnegie), Mark Lacy (NRAO), Ute Lisenfeld (Granada), Kristina Nyland (NM Tech), Lisa Kewley (ANU), Patrick Ogle (NED/Caltech) Lauranne Lanz (Caltech)

Special thanks to Dario Fadda (Caltech) for help with SDSS spectra
Basic Assumption

WFIRST’s Grism will cover sufficient range of wavelength to span key rest-frame emission line diagnostics at $1.8 < z < 1.95$ and the $\text{H}\alpha/[\text{O}I]6300$ complexes $1.1 < z < 1.9$

Science Exploitation Example

We are studying a set of very rare galaxies at low-z that seem to be shock-dominated and may be galaxies in transition or experiencing negative feedback

WFIRST may allow us to investigate large numbers of these rare objects at $z= 1.8-1.9$ where galaxy cold accretion, galaxy disk building and Proto-cluster formation is occurring
WFIRST GRISM
Low-R but huge surveys possible

WFIRST GRISM Projected throughput
(Jeffrey Kruk, private communication)
Shocks and Turbulence in dense environments in the Local Universe

Stephan’s Quintet Contain $>10^9 \, M_{\odot}$

warm molecular gas group-wide which is shock-heated by dissipation of energy from collision:

mid-IR rotational $H_2$ and C+ very powerful


Shocked/turbulent gas in Radio Galaxies

Powerful warm $H_2$ and C+ in 3C326

Guillard et al. 2014

Spitzer and Herschel studies of more compact groups are revealing evidence of shocked diffuse gas

Shock systems have distinct IR colors suggesting a transitional population

Cluver+2013

Shock $H_2$ gas in the anomalous arms of NGC 4258

Ogle, Lanz & Appleton, 2014
Stephan’s Quintet: the archetypal collisionally induced shocked system, but AGN outflows can also shock large quantities of the ISM in galaxies.

From Konstantopoulos, Appleton et al. (2013)

NGC1266

Buried AGN shocking surroundings

Alatalo+11,+12,+14

Bipolar outflow

Strongly Suppressed SF, Huge molecular content in core

Optical Shock Signature:

High [OI]6300/H\textalpha ratio

Very broad lines often asymmetric
SPOGS
Post-starburst galaxies with evidence of large scale-shocked gas

Katie Alatalo initiated the SPOGS project to define SPOGS in the VO/BPT diagnostic ratios

Models suggest shocks have distinctive line ratios in various emission-line diagnostic diagrams

Models From Jeff Rich

Shocked ISM has well-determined spectral diagnostics based on both observation and theory
WISE/OPTICAL COLORS OF GALAXIES SHOW MAJOR BIFURCATION

SPOGS may represent a rapidly transitioning population perhaps dominated by shocks? *(Alatalo+14)*

Shocked post-starbursts and LINERS seem to dominate the zone between Blue and red galaxies—Perhaps shocks may play a role in transitioning galaxies.

SPOGS and other LINERS occupy an interesting region in galaxy evolutionary phase space—they are worth investigating further.
Can we find more shocked systems?
Here I present an initial sampling of spectra from SPOGS+LINER sample
derived from the Oh+2011 sample (OSSY) designed to find potentially shocked systems.

Scaled up versions of these may exist at high-z.

These objects represent < 0.5% of the SDSS galaxies
IN THE LOCAL UNIVERSE THEY ARE RARE!

DO SIMILAR OBJECTS EXIST AT HIGH Z—

BIG SURVEYS WOULD BE REQUIRED
Rogues spectral-gallery of potentially shock-excited galaxies $[\text{OIII}]/\text{H}\beta < 0.1$, $-0.7 < [\text{OI}]/\text{H}\alpha < 0$

We seem to have found a sample of objects with similar spectral characteristic to Stephan's Quintet and NGC 1266.
Effects of lower resolution on line ratios? \((\text{WFIRST-AFTA GRISM } 690 < R < 900)\)

- We examined 140 (mainly SF dominated) spectra of galaxies from our SDSS sample and convolved to the resolution to WFIRST/GRISM.
- Extracted line fluxes of principal lines.
- Compared results.
- The preliminary study does not take into account detailed aspects of the planned GRISM but just explores the degradation of resolution—More work will be needed.
Isolated strong lines have no obvious issues in this limited study.

In particular at WFIRST-AFTA GRISM resolution, we can recover the Hβ narrow lines quite well despite the presence of Hβ absorption in many cases.

Note—this is NOT a proper simulation with WFIRST/GRISM Spectral sampling and effects of Confusion from nearby sources.

More work is needed.

Assumed resolution from Interim Report  R= 690-900
How do the key diagnostic ratios do with the low-R spectra?

EFFECT OF RESOLUTION ONLY

[NIII]/Hα ratio

Tendency to slightly underestimate Hβ increasing ratio

[OIII]/Hβ

[OI]6300/Hα

[OI]6300 feature is often overestimated in the smoothed spectra when compared with Hα
Scaling up from Stephan’s Quintet the Spiderweb Radio Galaxy $z = 2.16$?

PKS 1138-26 Ogle et al. (2012)

$3.7 \times 10^{10} L_\odot$ in 0-0 $S(3)$ line alone!

Mid-IR signal from molecular hydrogen shows likely huge quantities of shocked molecular hydrogen— a super-stephans quintet?

If ionized gas scales with amount of warm $H_2$ then shocked systems may be detectable with WFIRST at $z = 1.8$
Summary

• Assuming approximately 2000-3000 galaxies/sq degree for WFIRST detectable $> 10^{-16}$ ergs/s/cm$^2$, and for the larger surveys planned 2000-3000 sq degrees/yr, even if only 0.5% of galaxies are dominated by shocks—we should find thousands of shocked galaxies

• Emission-line diagnostics will be doable for the brighter galaxies at $z=1.8-1.9$ (covering H$\beta$ to H$\alpha$) with the current GRISM bandwidth, and could be larger if extended to longer wavelengths $>1.95 \mu$m. The resolution is only $\sim$3x poorer than SDSS, and at this $z$ would cover a huge volume. With $R=625-900$ basic diagnostic line measurements are possible.

• Scaled-up versions of local shocked systems may be detectable. If these galaxies are associated with quenching of star formation, it would provide a window into the universe at a time when disks are being built and cold-flows are potentially important. Follow-up with JWST 0-0S(3-5) line H$_2$?

• Radio galaxies and dense proto-clusters may be worth targeting with deep observations exploiting targets from micro-Jy all-sky radio surveys (SKA and precursors, and eVLA). Dense environments may contain more shocked gas (e. g. as in the Hickson Compact groups—Cluver et al. 2013)
Extras
GEMINI Visible SPECTRA of Stephan’s Quintet show high degree of turbulence!

SHOW BROAD FAINT EMISSION WITH LOOPS AND BUBBLES OF GAS Extending over 500-1000 km/s range EXCITATION IS THAT OF SHOCK excitation (Xu et al. 2003—Shocks e.g. Rich et al. 2012).