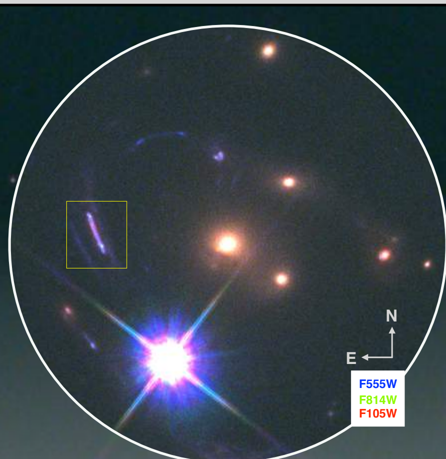
Spatially Resolved Outflows In a Seyfert Galaxy at z = 2.39

Travis Fischer[1], Jane Rigby[1], Guillaume Mahler[2], Michael Gladders[3], Keren Sharon[2], Michael Florian[1], Steve Kraemer[4], Matt Bayliss[5], Håkon Dahle[6], L. Felipe Barrientos[7], Eva Wuyts[8], Traci L. Johnson[3]

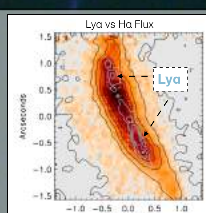
[1]665, NASA's Goddard Space Flight Center, Greenbelt, MD, United States [2]University of Michigan [3]University of Chicago [4]Catholic University of America [5]MIT [6]University of Oslo [7]Pontifical Catholic University of Chile [8]Max Planck Institute for Extraterrestrial Physics

We present spatially resolved analysis of rest-frame optical and UV imaging and spectroscopy for a lensed galaxy at z = 2.39 that hosts an active galactic nucleus. Proximity to a natural guide star has enabled high signal-to-noise VLT SINFONI + adaptive optics observations of rest-frame optical diagnostic emission lines, which exhibit an underlying broad component with FWHM ~700 km/s in both the Balmer and forbidden lines. Measured line ratios place the outflow robustly in the region of the ionization diagnostic diagrams associated with AGN. We compare the spatial extent and morphology of the Lyα, UV and dust-corrected Hα emission, and disentangle the effects of star formation and AGN ionization on each tracer. This unique opportunity — combining gravitational lensing, AO guiding, redshift, and AGN activity — allow a complete and magnified view of three main tracers of the physical conditions and structure of the interstellar medium in a star-forming galaxy hosting a weak AGN at cosmic noon.

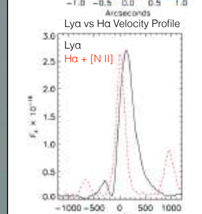


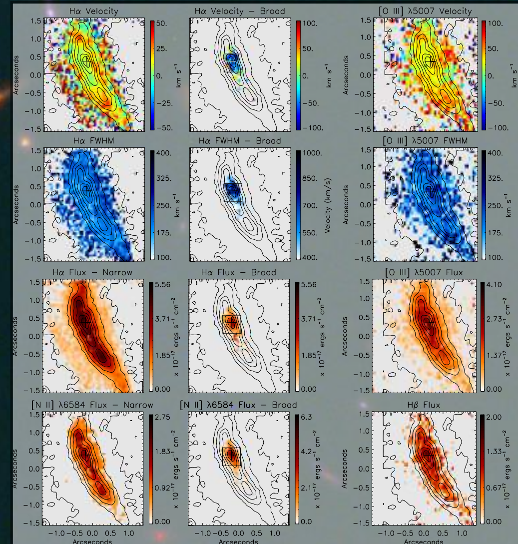
Bottom circle: *HST* WFC3 F555W/F814W/F105W composite image of the lensed Sloan Giant Arcs Survey (SGAS) galaxy, SGAS2-0033. SINFONI observations of the target lensed arc are shown approximately by the green box. The bright source to the southeast is a star, which was used as the natural guide star for SINFONI adaptive optics. The bright source to the southwest is a star, which was used as the natural guide star for SINFONI adaptive optics.

We find that the Lyα-emitting gas is most prominent between, not cospatial with, the brightest knots of Hα that reside over the AGN and likely star-forming regions. This discrepancy between the morphology of Lyα and Hα is similar to what has been reported in local starburst galaxies (Ostlin et al. 2009; Hayes et al. 2013)

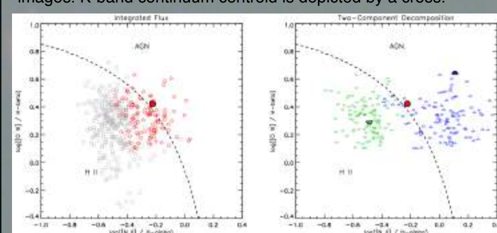


We also compare the spectral signatures of Lyα and Hα, with Lyα emission obtained from longslit MagE observations as detailed in Rigby+ 2018. The observed velocity structure of Lyα in comparison to Balmer emission is typical in studies of green pea galaxies (Yang et al. 2017; Orlitova et al. 2018).





Emission line measurements from SINFONI H- and K-band IFU observations. First, second, and third rows display centroid velocity, FWHM, and integrated flux maps of Hα and [O III] λ5007. Fourth row displays integrated flux maps of [N II] λ6584 and Hβ. Black contours represent continuum-subtracted Hα flux images. K-band continuum centroid is depicted by a cross.



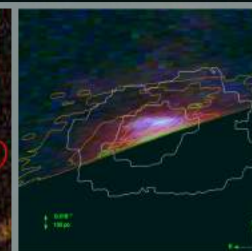
Above left: BPT diagram of individual spaniel measurements using the high-redshift classification from Kewley+ (2013). Grey points are single component fits, red points are two-component Hα + [N II] fits. Above right: Separating the two-component fits into narrow (green) and broad (blue) components shows that the broad component is AGN ionized. Larger points represent spectrum from 0.5" x 0.5" binned region over the location of the broad component gas.

Below: Gaussian fits to the 0.5" x 0.5" binned spectrum and resultant fluxes in both the observed image plane and the reconstructed source plane.

Table 1
Binned AGN Flux Measurements

Line	Narrow FWHM (km s^{-1})	Image Plane (erg s^{-1} cm^{-2})	Source Plane (erg s^{-1} cm^{-2})	Dered. Source (erg s^{-1} cm^{-2})	Broad FWHM (km s^{-1})	Image Plane (erg s^{-1} cm^{-2})	Source Plane (erg s^{-1} cm^{-2})	Dered. Source (erg s^{-1} cm^{-2})
Hβ	100	4.77×10^{-18}	2.40×10^{-18}	6.94×10^{-18}	705	3.34×10^{-18} a	8.80×10^{-20} a	2.20×10^{-18} a
[O III]λ5007	100	1.70×10^{-17}	5.56×10^{-19}	1.34×10^{-17}	705	1.16×10^{-17}	3.87×10^{-19}	9.22×10^{-19}
[O I]λ6300	100	1.32×10^{-18}	4.52×10^{-19}	8.69×10^{-18}	725	4.89×10^{-18}	1.18×10^{-19}	2.50×10^{-18}
Hα	100	3.49×10^{-18}	1.07×10^{-17}	1.98×10^{-17}	725	1.33×10^{-17}	3.40×10^{-19}	6.20×10^{-18}
[N II]λ6584	100	1.16×10^{-18}	3.46×10^{-19}	6.39×10^{-18}	725	1.72×10^{-17}	4.61×10^{-19}	8.50×10^{-18}
[S II]λ6716	100	2.98×10^{-18}	8.43×10^{-19}	1.51×10^{-18}	725	2.76×10^{-18} b	8.84×10^{-20} b	1.61×10^{-18} b
[S II]λ6731	100	2.48×10^{-18}	7.65×10^{-19}	1.30×10^{-18}	725	6.40×10^{-18}	1.72×10^{-19}	3.13×10^{-18}

a Estimated assuming $H\alpha_{narrow} / H\beta_{narrow} = H\alpha_{broad} / H\beta_{broad}$
b 3σ detection flux limit



Left: From our strong lensing model, we find the lensing critical line, which separates regions of different image multiplicities, lies directly over the center of the arc of SGAS 0033, such that the north and south ends of the arc are reflections of one another and sample roughly half of the fully imaged galaxy.

Right: Source plane reconstruction of the arc shows SGAS 0033 as it would have been seen without a lens. White contours represent rest-frame optical continuum emission. We measuring a radial extent of the outflowing gas in the source plane of r ~100 pc.

Using this extent, an outflow velocity of 725 km s^{-1}, and a measured NLR gas mass of 7.4 x 10^4 M$_\odot$, we calculate a mass outflow rate of $\dot{M}$ = 0.55 M$_\odot$ yr^{-1} .

Star formation rate (SFR)

Hα luminosity measured from the non-AGN ionized gas is converted to a SFR using the Kennicutt (1998) relation and adjusted to the initial mass function from Charbrier (2003). Measuring the source plane Hα luminosities north and south of the lensing critical line , we find SFRs of 22.8 M$_\odot$ yr^{-1} and 70.7 M$_\odot$ yr^{-1}, respectively. Measuring the individual, extended Hα emission knots offset from the continuum peak, we measure a SFR of 2 - 5 M$_\odot$ yr^{-1}.

We have analyzed spatially-resolved, rest-frame UV / optical imaging and spectroscopy of a Seyfert AGN at z~2 for the first time. Our major findings are as follows:

1) Observed AGN-ionized outflows have a maximum extent of ~100 pc. We calculate a mass outflow rate over this distances of $\dot{M}$ = 0.55 M$_\odot$ yr^{-1}. The corresponding ratio of outflow power to bolometric luminosity is exceedingly low, log($\dot{E}/L_{bol}$) = -3.76, suggesting that the AGN provides little impact on the host galaxy.

2) SGAS 0033 is also exhibits a SFR on the order of 10s of solar masses per year, which greatly exceeds the AGN mass outflow rate. As such, the current state of the AGN in SGAS 0033 would be unlikely to quench star-formation within the galaxy.

3) AGN outflows have little effect on Lyα structure compared to similar galaxies not hosting AGN.

4) Faint emission-line signatures of AGN combined with strong star formation makes detecting AGN at z~2 extremely difficult without gravitational lensing.