Investigating quasar host galaxies with strong gravitational lensing

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John McKean, Simona Vegetti et al.
Formation of a massive elliptical galaxy

Stellar light (optical)

Gas density (FIR—sub-mm)
Probing below the confusion limit in the FIR

- 70% of sample are detected
- ~10% of quasars have FIR properties similar to Herschel DSFGs with SFRs > 1000 M$_\odot$ yr$^{-1}$
- Generally consistent with quasar evolution scenarios, but extreme SFRs in tension with
Dust temperatures comparable to DSFGs

- median lensing-corrected SFR of $120^{+160}_{-80} \, M_\odot \, \text{yr}^{-1}$ (assuming typical magnification of 10)
- Dust temperatures $38^{+12}_{-5} \, K$, consistent with star formation in most cases
- Some AGN contribution?

66% of lensed quasars have high levels of dust-obscured SF in host galaxy
Radio-infrared correlation

Radio excess

Optically-selected, with radio excess = low power radio jets?

Heating from AGN?

Stacey et al. 2018
Radio-infrared correlation - LoTSS/HETDEX

Stacey et al. submitted
VLBI follow-up of optically-selected quasars

- We have begun follow-up of targets with FIRST radio detections - only two observed so far.
- $2\sigma$ above radio-infrared correlation and *not detected on VLBI-scales*.
- Suggests ~50% of FIRST radio emission is not in a compact component… or does it?
Disentangling AGN and SF in the Cloverleaf

- Cloverleaf has significant radio excess (x10), resolved radio jet (e-MERLIN), but is **not** detected with EVN.

- Non-detection on VLBI-scales doesn’t mean radio emission is not AGN.

- How else to understand AGN contributions?

Even with VLBI, disentangling AGN contribution may be difficult
Resolving dust and gas on scales 80—300 pc

- Lensing magnification x10 increases effective resolution by similar factors, to resolve structure, kinematics at high-z
- Can test extreme SFRs we derive in FIR by comparison to dust and molecular gas content

- Magnification is not a number — need sophisticated source reconstruction techniques

Paraficz et al. 2018

CO(2—1) Bulk of cool gas

CO(9—8) Star-forming gas

CO(11—10) AGN-excited gas

Stacey & McKean 2018
MGJ0414+0534 (z=2.64)

- ALMA 340 GHz continuum, resolution 0.1”—0.3”
- Composite AGN (synchrotron) and SF (dust)
- Resolving scales 100—400 pc at z=2.6

Stacey & McKean (2018)
MGJ0414+0534 - CO (11—10) line

- CO (11—10) high-excitation molecular gas, FWHM ~ 1200 km/s
- Flux ratio anomaly revealed on small spatial scales

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Stacey & McKean (2018)
MGJ0414+0534 - preliminary reconstruction of gas and dust

• Reconstructed dust emission
  • Compact size ~ 1 kpc (magnified x18) similar to DSFGs
  • Implied SFR $880 \, M_{\odot} \, \text{yr}^{-1}$

• Reconstructed CO (11—10)
  • Compact size of ~ 400 pc
  • Enclosed dynamical mass $\sim 10^{10} \, M_{\odot}$
  • Toomre parameter, $Q_g \sim 0.7$ not a stable disk?

Gravitational lensing helps resolve compact dust and gas in host galaxy
Summary

• At least 66% of lensed quasars have high levels of dust-obscured SF in host galaxy, measured with Herschel/SPIRE (Stacey et al. 2018, arXiv: 1705.10530)

• Lensed RQQs seem consistent with radio—infrared correlation (Stacey et al. submitted). But even with VLBI, disentangling SF from AGN may be difficult: need very sensitive, high-resolution data in radio and FIR/sub-mm.

• Resolving dust and molecular gas on small scales with help of gravitational lensing (Stacey & McKean 2018, arXiv:1808.05571) could help test extreme SFRs derived from FIR/sub-mm and constrain energy injection into host galaxy from AGN

This presentation/publication has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 730562 [RadioNet]