Molecular Gas in Optically Bright QSOs

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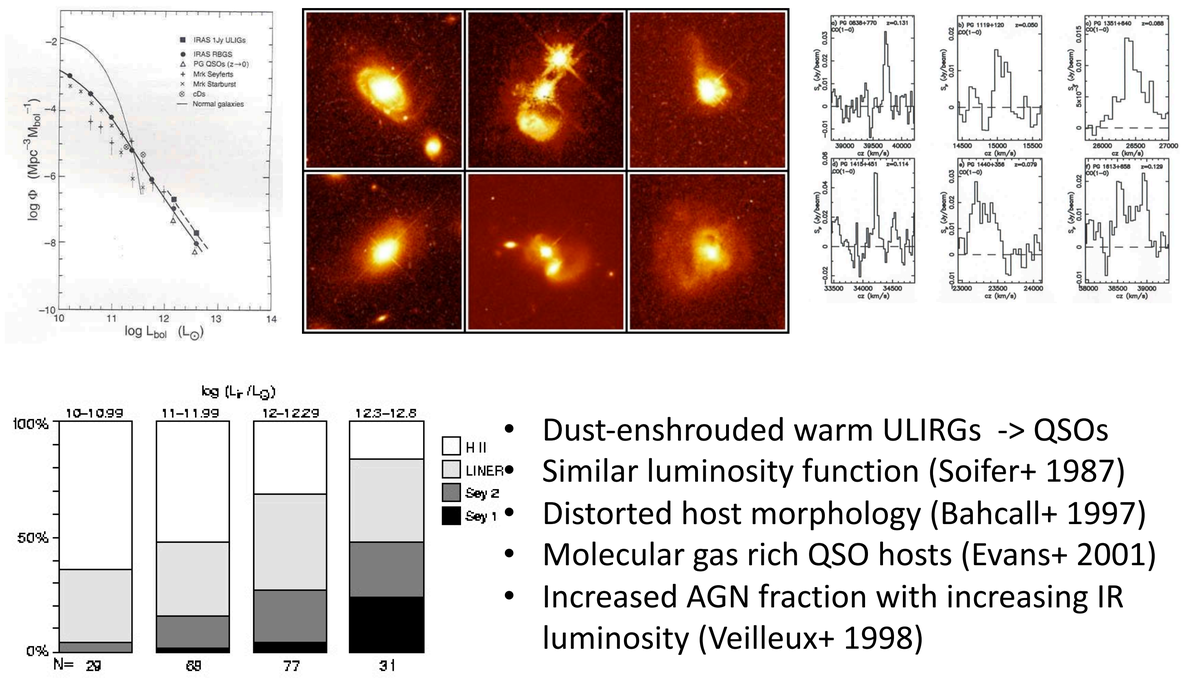
Summary:

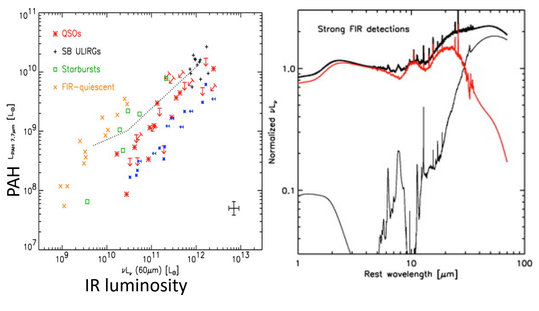
Testing the evolutionary connection between ULIRGs and QSO hosts has been a key component in the study of both galaxy types and suggests that optically bright QSOs might still reside in molecular gas-rich environments with ongoing star formation. We present here a study of the molecular gas properties of a sample of z < 0.3 luminous Palomar-Green (PG) QSO hosts. This study consists of two components: The first is the IRAM 30m Telescope survey of CO emission from the PG QSO hosts, which shows that a significant fraction (30%) of PG QSO hosts are indeed molecular gas-rich. The second is the pilot ALMA observational study of CO(3-2) emission from 4 PG QSO hosts with 200-500 pc spatial and 10 km/s velocity resolution. Our high-resolution ALMA observations reveal a diverse morphology and kinematics of the molecular gas in these hosts and show that the properties of the star formation rate in the high-density region in the vicinity of AGN are similar to that of ULIRGs. However, the current high-resolution ALMA observation misses large scale diffuse faint emission and indicates that lower angular resolution observations are required to have a complete picture of the molecular gas in the QSO hosts.

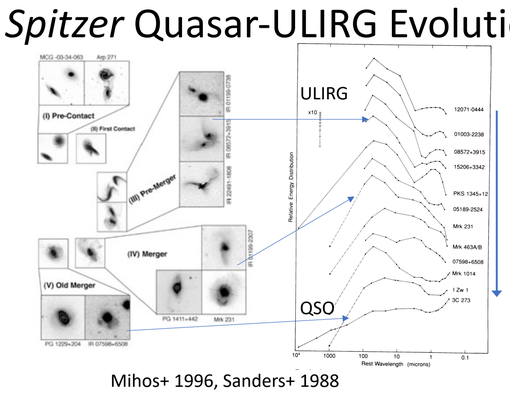
ULIRG-QSO connection – Emerging Paradigm (Sanders+1988)



- Dust-enshrouded warm ULIRGs -> QSOs
- Similar luminosity function (Soifer+ 1987)
- Distorted host morphology (Bahcall+ 1997)
- Molecular gas rich QSO hosts (Evans+ 2001)
- Increased AGN fraction with increasing IR luminosity (Veilleux+ 1998)

Recent Observational Support: *Spitzer* Quasar-ULIRG Evolution Study (QUEST)



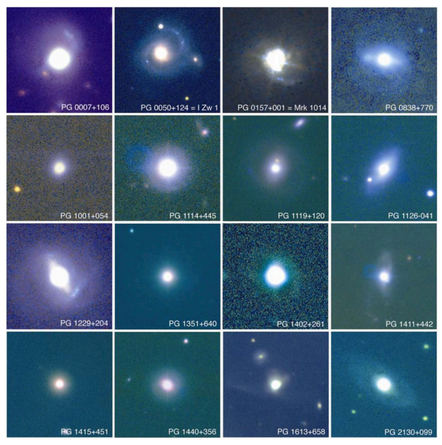


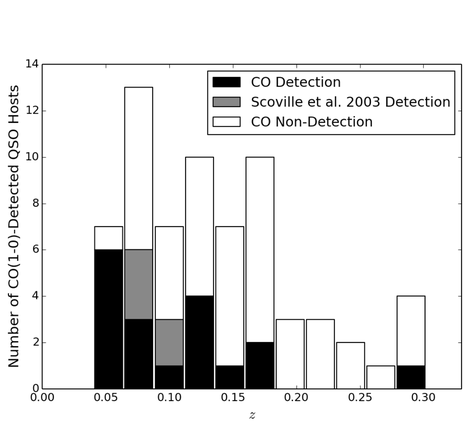
Mihos+ 1996, Sanders+ 1988

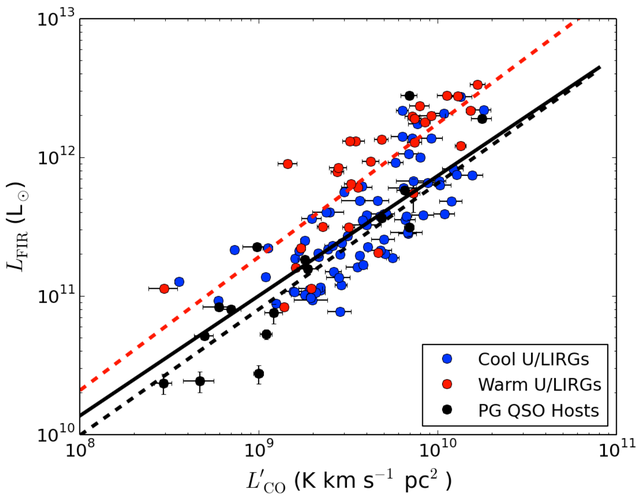
- Motivation: Comparison between ULIRGs and QSOs
- Sample : 118 ULIRGs (from 1 Jy IRAS sample z<0.3) and ~40 “UV-selected” PG QSOs matching the redshift of the ULIRG sample with full range of L,IR excess, radio loudness
- Bulk of far-IR emission from QSO is due to star formation (Schweitzer+. 2006)
- Mid-IR SED of PG QSO after subtracting the star formation SED are very similar to the AGN (Netzer+ 2007)
- FIR faint AGN host seems to be more advanced (elliptical) merger (Veilleux+ 2009)

Census of Molecular Gas in QSO hosts: IRAM 30m CO survey of PG QSO (Evans et al. 2020)

- CO provides a direct tracer of star-forming molecular gas
- Previously, targeted for mostly IR excess QSOs
- “UV-selected” QSOs (All 61 PG QSOs in 0.045<z<0.3) surveyed with CO(1-0) and/or CO(2-1)
- CO(1-0) detected for 30% of the sample
- Range of gas mass: 3-170x10^8 M$_{sun}$
- Qualitatively similar IR-CO correlation between QSOs and (cool) ULIRGs
- UV-bright QSO hosts (not IR biased) are molecular gas rich







Zoomed-in View of Molecular Gas in QSO hosts: High-resolution ALMA Study of 4 PG QSO (Yoon et al. in preparation)

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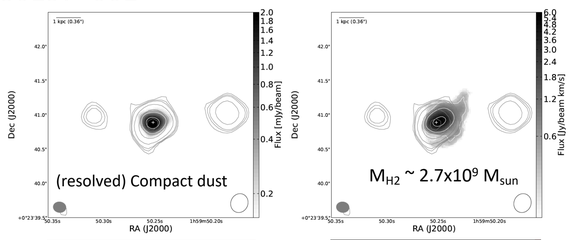
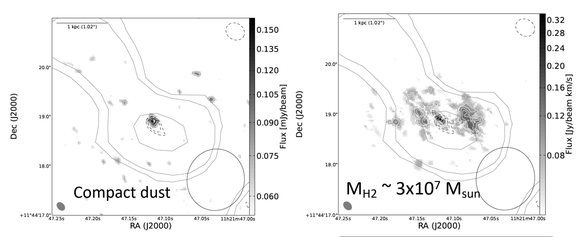
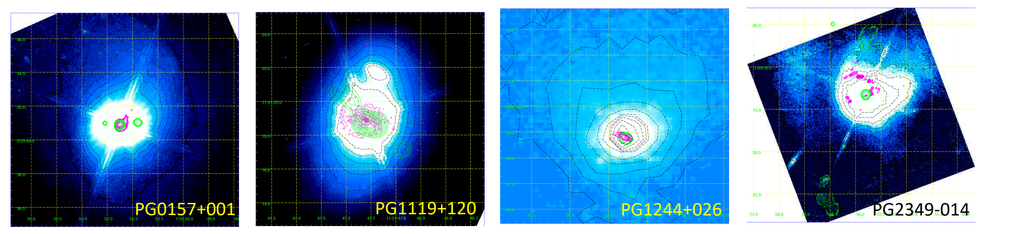
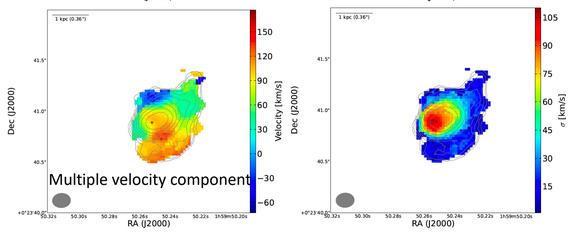


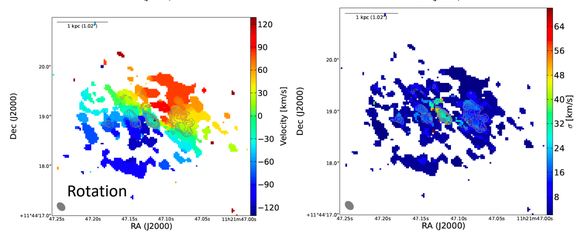
PG1119+120





HST/NICMOS images of PG QSO sample. Green contours and purple contours show radio continuum and integrated CO(3-2) emission





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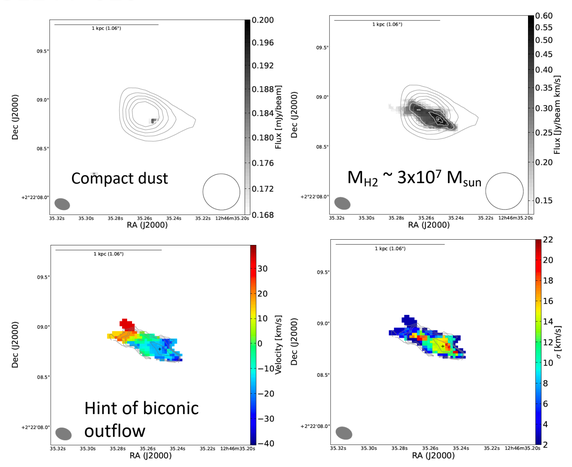

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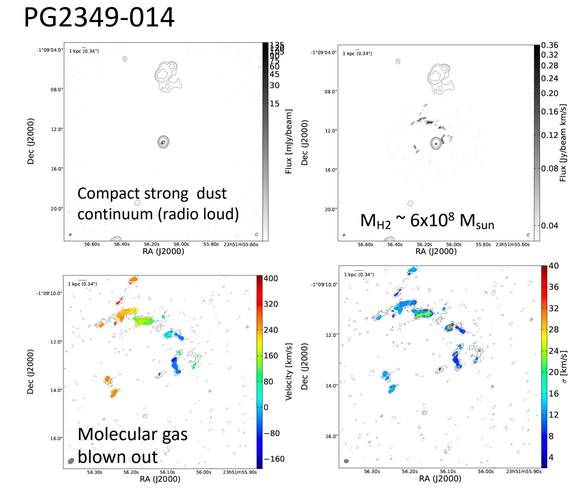
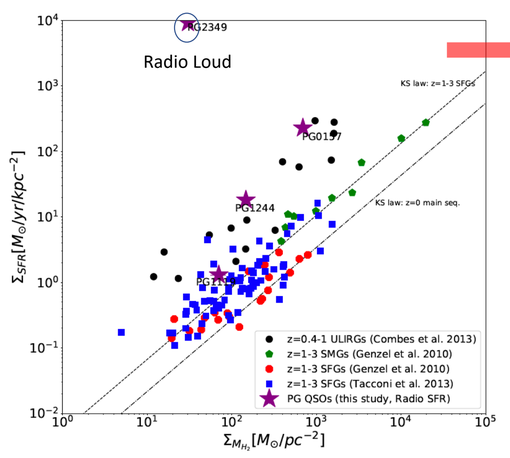


Dust continuum (top left), Moment 0 (top right), Moment 1 (bottom left) and Moment 2 (bottom right) map for each PG QSO. Gray contours in the dust continuum and moment 0 maps are radio continuum image (4.8 or 8.4 GHz)

- Resolved gas kinematics and morphology to understand the properties of star formation in the vicinity of AGN
- ALMA CO(3-2) observation of 4 selected PG QSOs to trace dense, warm molecular gas associated with high mass star forming region
- High resolution (comparable to ALMA) radio continuum image from VLA archive is used to estimate the independent SFR
- Diverse gas morphology and kinematics are discovered
- Similar Kennicutt-Schmidt law with the ULIRGs and SF galaxies
- However, IF observation resolves out the most of CO emission



NB: Figure will be updated with the result from the beam matched analysis

Reference:
Bahcall et al. 1997, APJ, 479, 642
Netzer et al. 2007, ApJ, 666, 806
Evans et al. 2001, AJ, 121, 4
Evans et al. in preparation
Sanders et al. 1988
Schweitzer et al. 2006
Veilleux et al. 2009
Yoon et al. in preparation