Warm Molecular Gas and Dust in AGN Hosts

Andreea Petric

Institute for Astronomy, University of Hawaii

Resident Astronomer at the Canada France Hawaii Telescope

Ahu kupanaha iā Hawai'i 'imi loa!

~ The Hawaiian value of pursuing new knowledge brings bountiful rewards!

Motivation: Supermassive Black Holes and the Galaxies that Host them

Motivation: Correlations and/or Co-evolution?

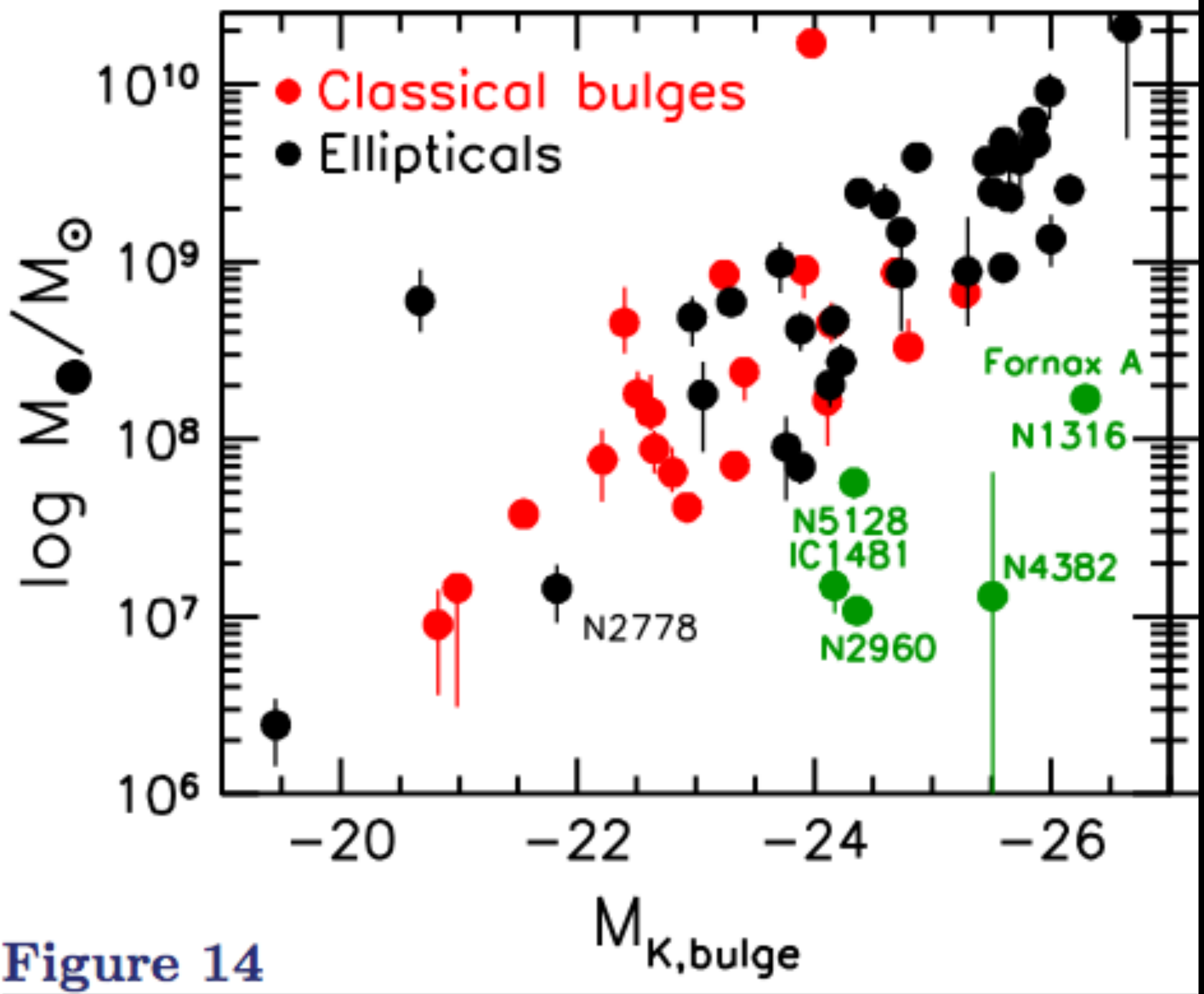
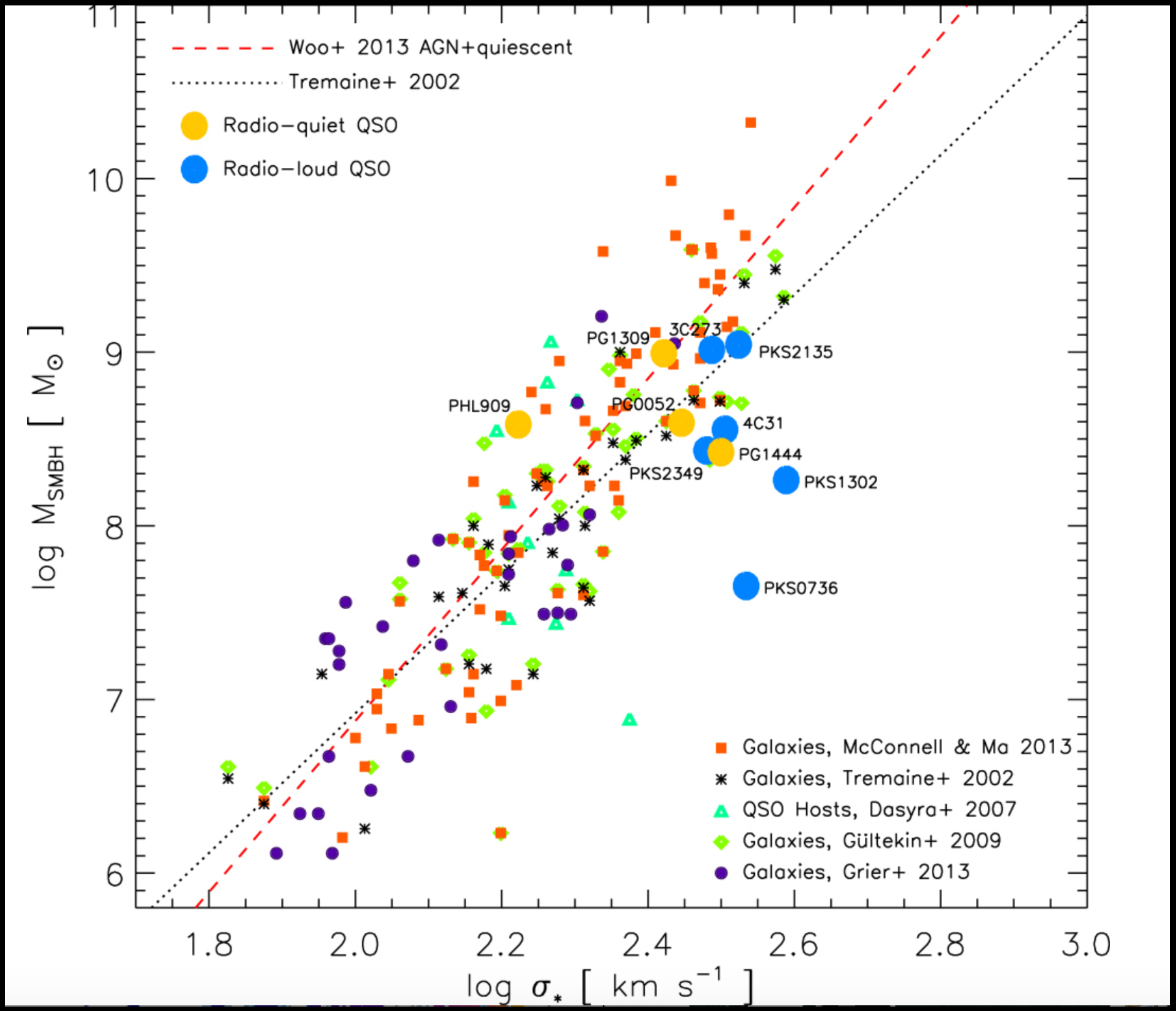


Figure 14



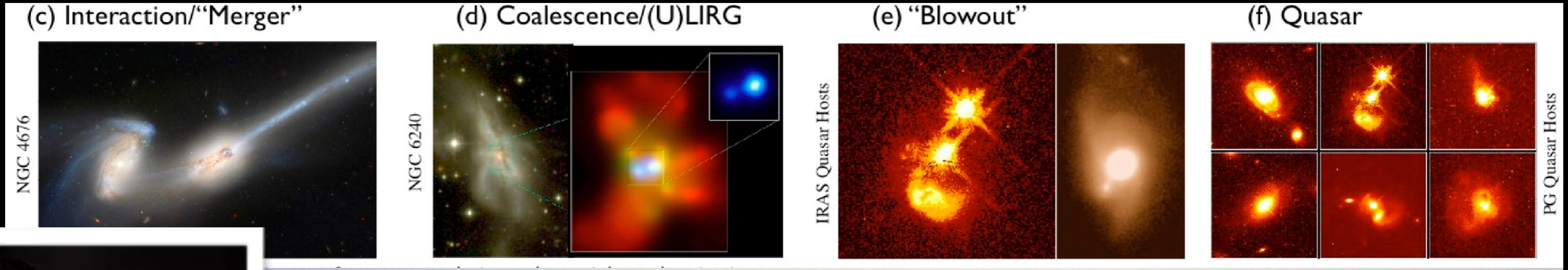
Kormendy & Ho (2013)

Sheinis & López-Sánchez (2017)

- A central issue in the study of the formation and evolution of galaxies is the **connection between the central supermassive black hole (SMBH) and the surrounding bulge stars.**

QSO triggering through Gas Rich Mergers

Do AGN impact the ISM of their hosts?



Eduardo Vitral
Ecole
Polytechnique

Jordan Raffard
Observatoire de
Paris

Barbara Mazzilli
Universite de
Starsbourg

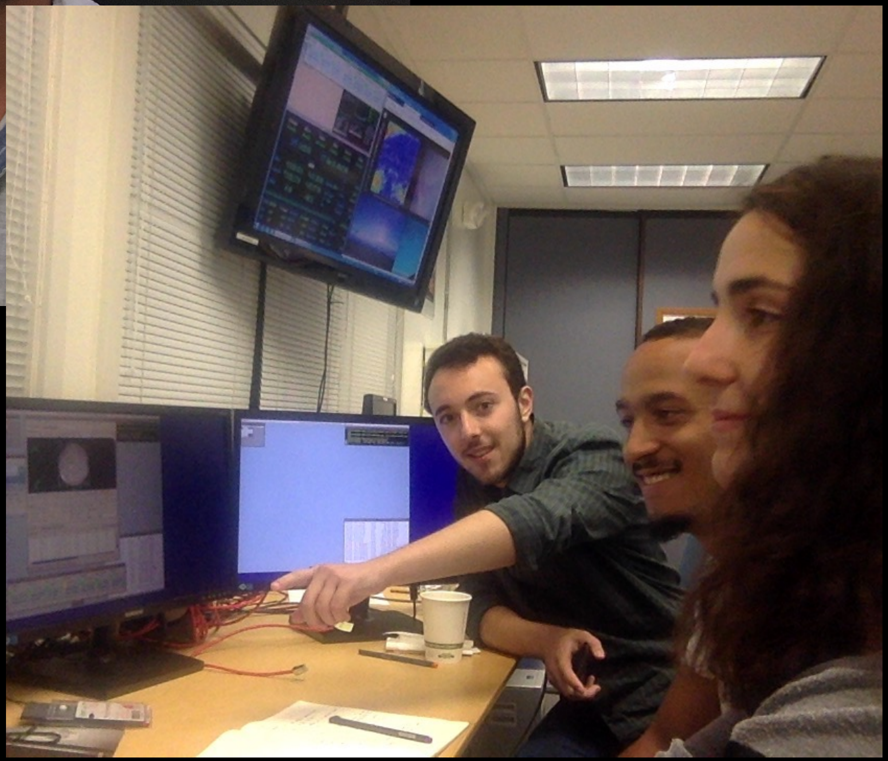
Erini
Lambrides
John Hopkins
& Gemini

Gabriella Sanchez
University of Hawaii,
Manoa

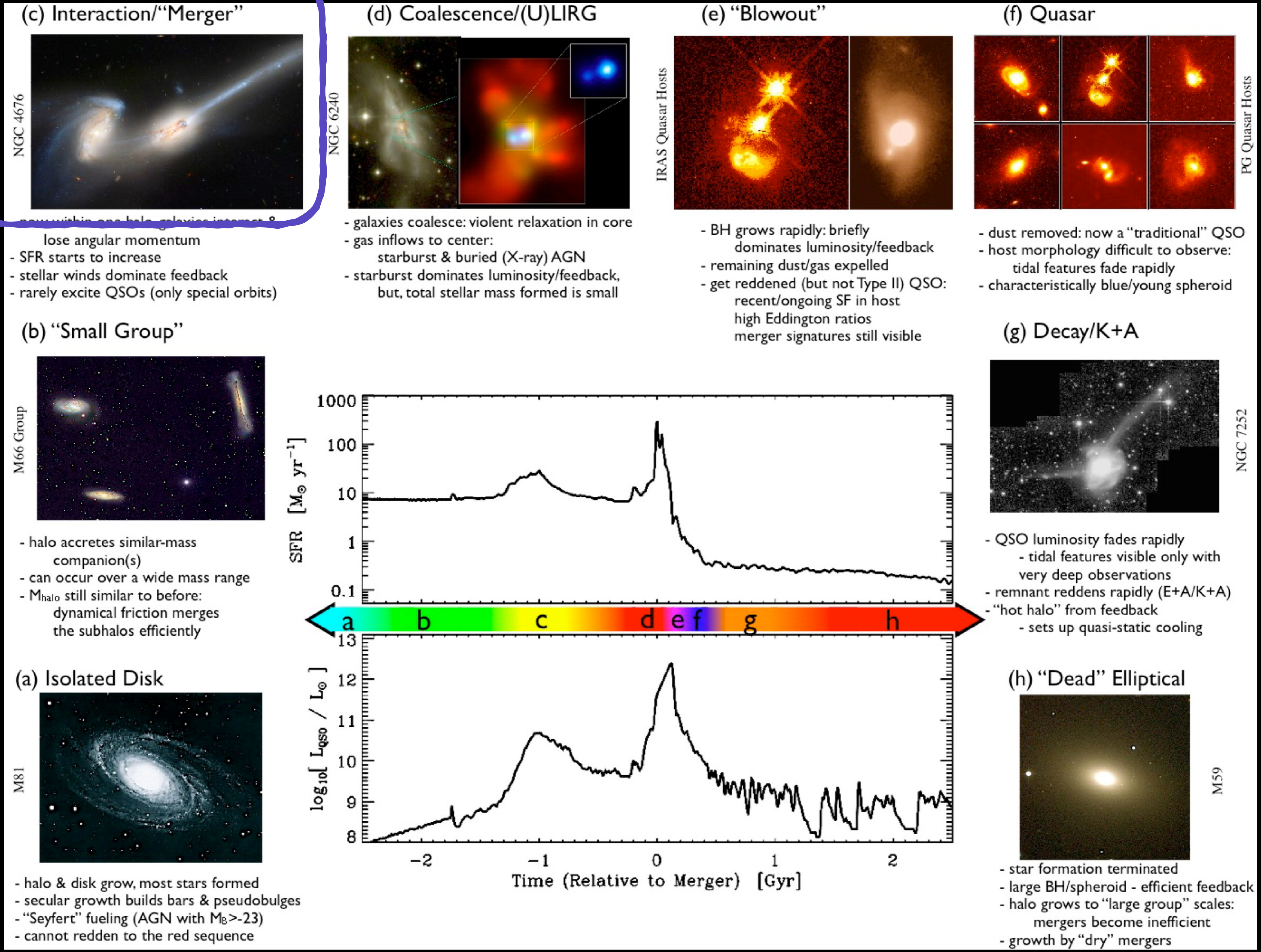
Jameeka
Marshall
University of
Hawaii, Hilo

Stefan
Kimura
Willamette
College

Simon
Petrus
Universite
Grenoble



The Cycle of AGNs and Host Galaxies



(c) Interaction/"Merger"

- now within one halo, galaxies interact &
  lose angular momentum
- SFR starts to increase
- stellar winds dominate feedback
- rarely excite QSOs (only special orbits)

(d) Coalescence/(U)LIRG

- galaxies coalesce: violent relaxation in core
- gas inflows to center:
  starburst & buried (X-ray) AGN
- starburst dominates luminosity/feedback,
  but, total stellar mass formed is small

(e) "Blowout"

- BH grows rapidly: briefly
  dominates luminosity/feedback
- remaining dust/gas expelled
- get reddened (but not Type II) QSO:
  recent/ongoing SF in host
  high Eddington ratios
  merger signatures still visible

(f) Quasar

- dust removed: now a "traditional" QSO
- host morphology difficult to observe:
  tidal features fade rapidly
- characteristically blue/young spheroid

(b) "Small Group"

- halo accretes similar-mass
  companion(s)
- can occur over a wide mass range
- M_{halo} still similar to before:
  dynamical friction merges
  the subhalos efficiently

(g) Decay/K+A

- QSO luminosity fades rapidly
  - tidal features visible only with
    very deep observations
- remnant reddens rapidly (E+A/K+A)
- "hot halo" from feedback
  - sets up quasi-static cooling

(a) Isolated Disk

- halo & disk grow, most stars formed
- secular growth builds bars & pseudobulges
- "Seyfert" fueling (AGN with $M_B>-23$)
- cannot redden to the red sequence

(h) "Dead" Elliptical

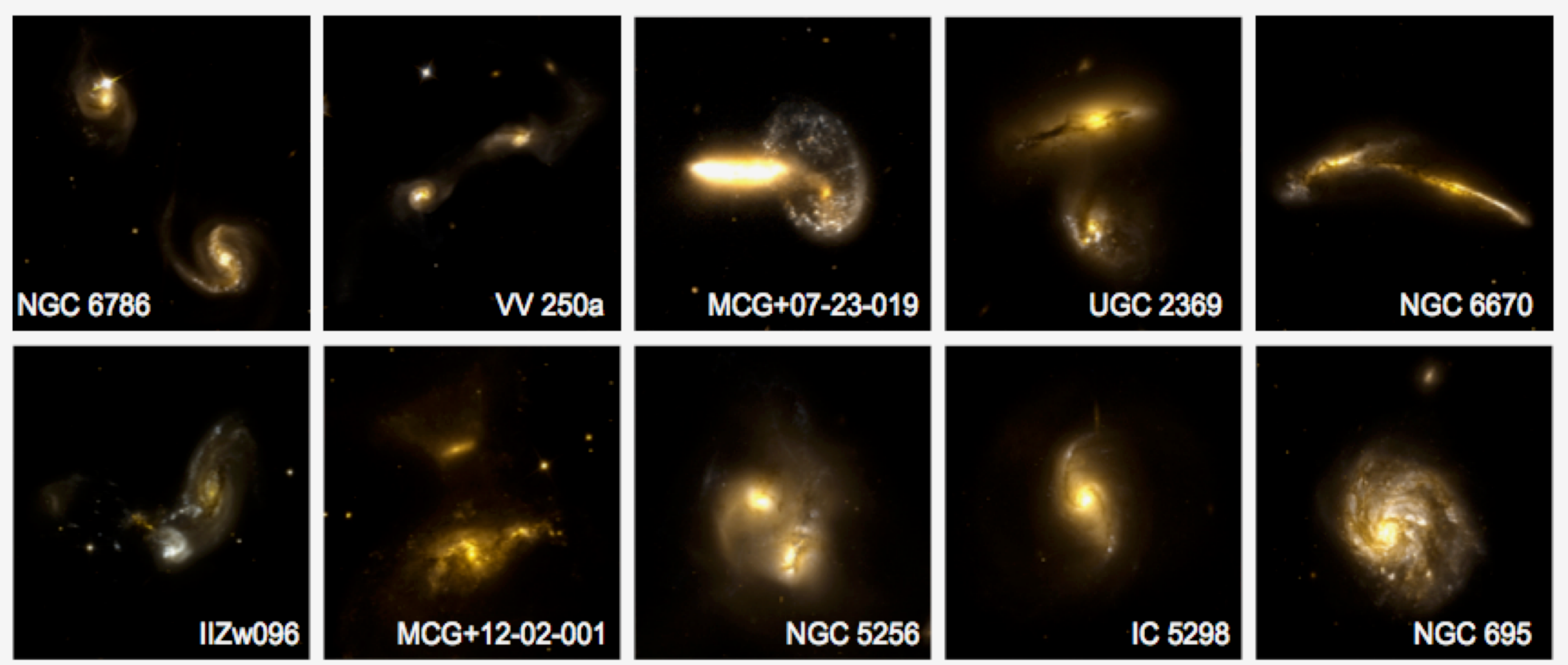
- star formation terminated
- large BH/spheroid - efficient feedback
- halo grows to "large group" scales:
  mergers become inefficient
- growth by "dry" mergers

Hopkins group, Caltech

Local LIRGs

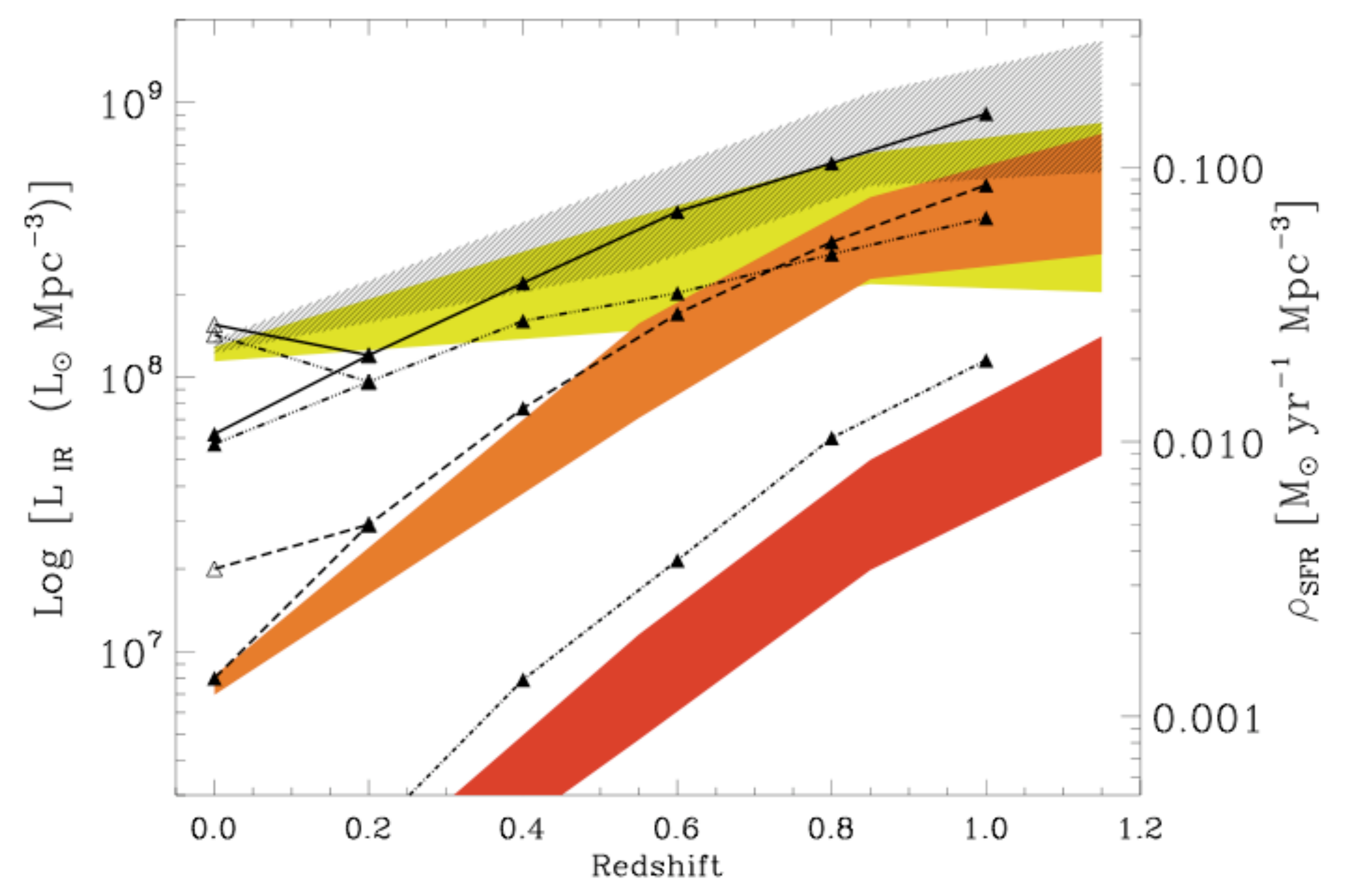
GOALS (Spitzer Legacy Program)

202 LIRGs (248 nuclei) in the local Universe ($z<0.088$)
selected from the IRAS Revised Bright Galaxy Sample (Armus et al 2009)



~50% are mergers, ~10% are AGN, SFR 2->~100 $M_\odot$/yr

Importance of LIRGs



Normal galaxies

LIRGs $L_{IR} > 10^{11}L_\odot$

ULIRGs $L_{IR} > 10^{12}L_\odot$

Magnelli et al. (2009)
Le Floch 2005

- The co-moving number density of LIRGs has increased by a factor of ≈100 between $0<z<1$
- By $z≈1.0$ LIRGs produce half of the total co-moving infrared luminosity density.

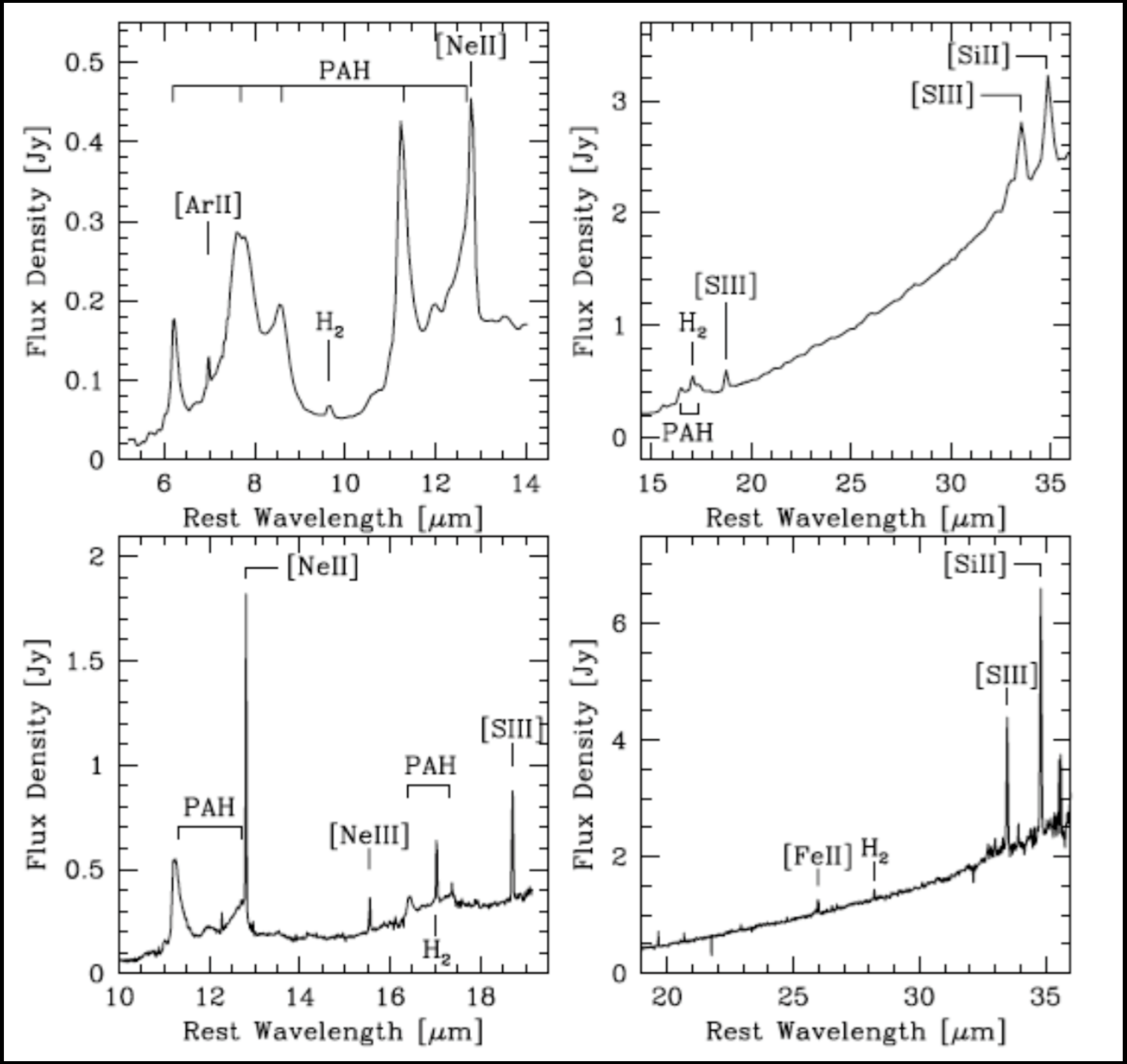
What can MIR Spectroscopy tell us?

Warm H_2 emission lines
measured in MIR (rotational)

PAH lines
=> SFR v AGN

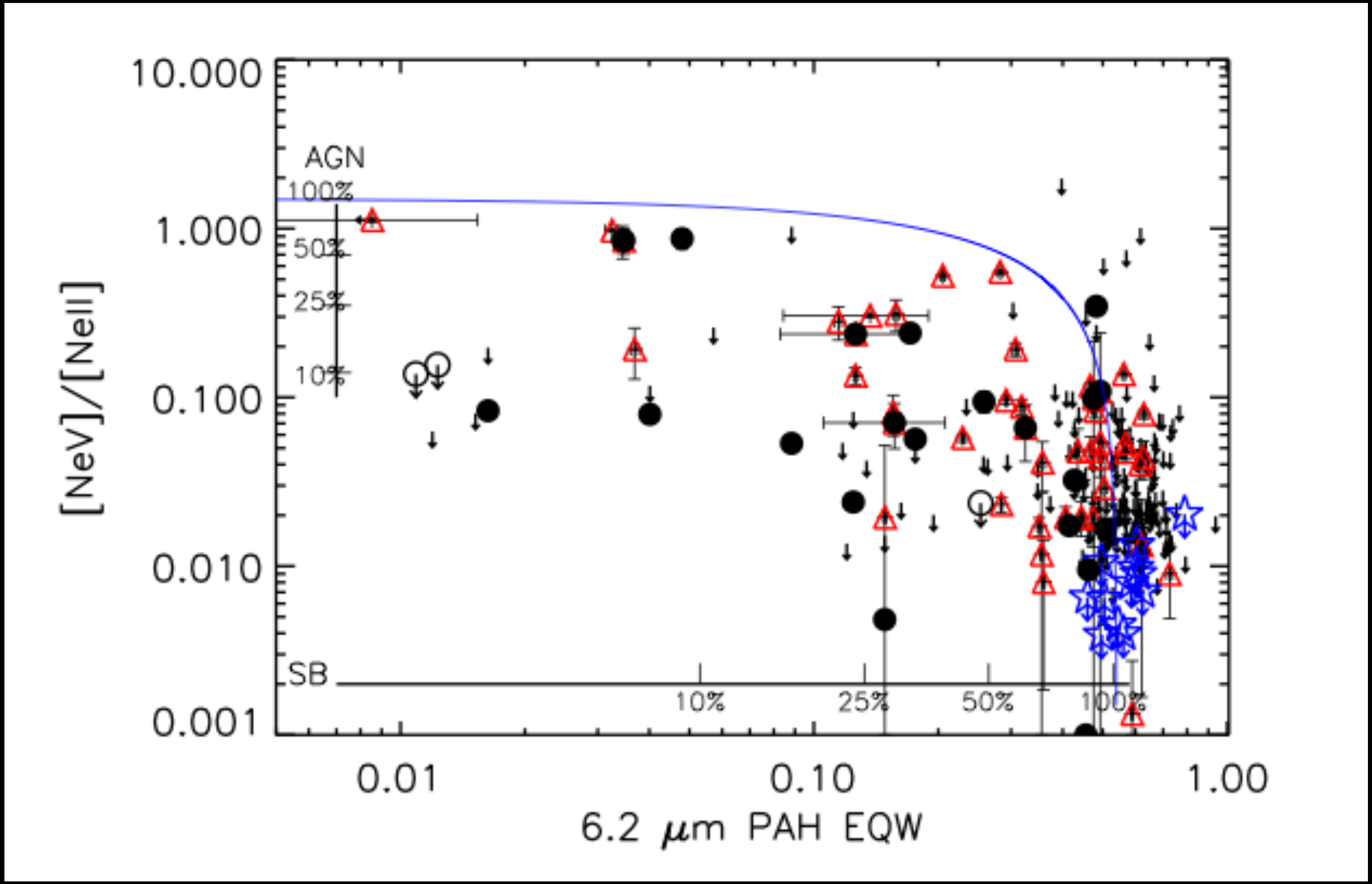
High & Low Ionization lines
=> SFR v AGN

Continuum slope
=> SFR v AGN



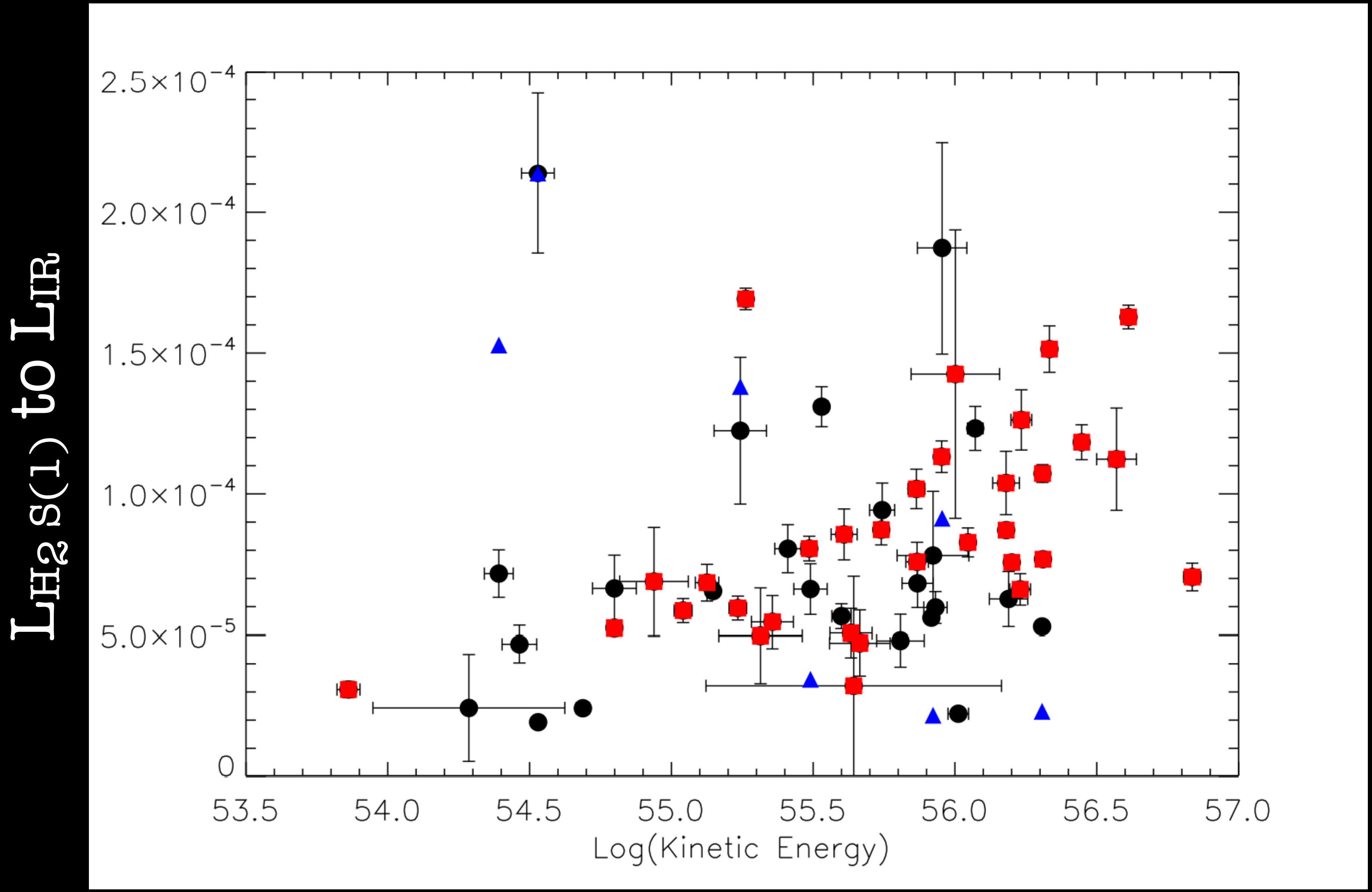
Spitzer/IRS

MIR diagnostics: the contributions of SB & AGN to L_{IR}



Statistically MIR diagnostics give similar answers => ~10% of LIRGs are AGN dominated

Warm Molecular Gas in LIRGs



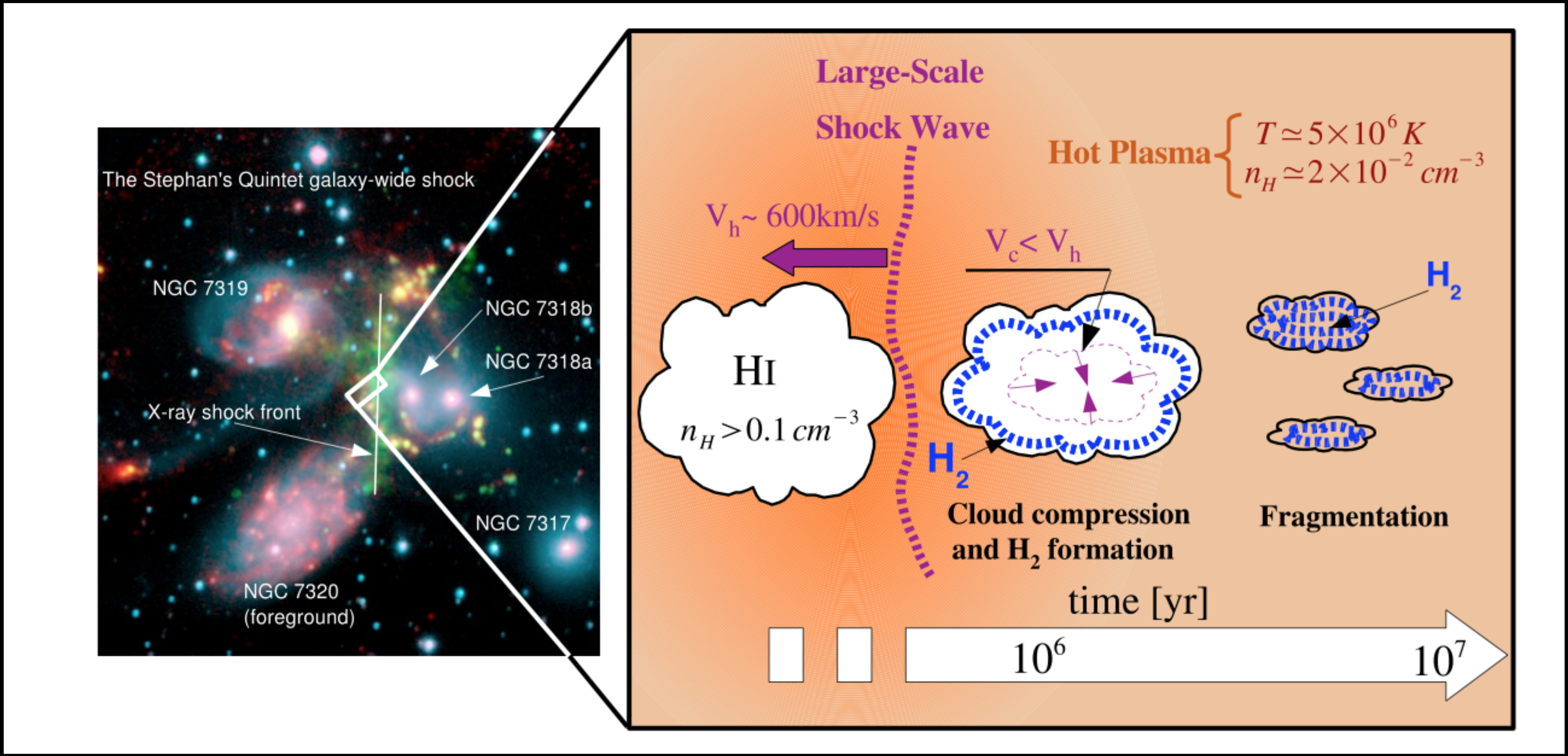
Black: non-mergers
Blue: early mergers
Red: advanced mergers

(AP+ 2018)

20% of LIRGs have more H2 than we would expect from PDRs (Stierwalt,+, AP+ 2018)

Estimated kinetic energies comparable to what is needed for the gas to escape the system.

Mergers Complicate Picture of Feedback

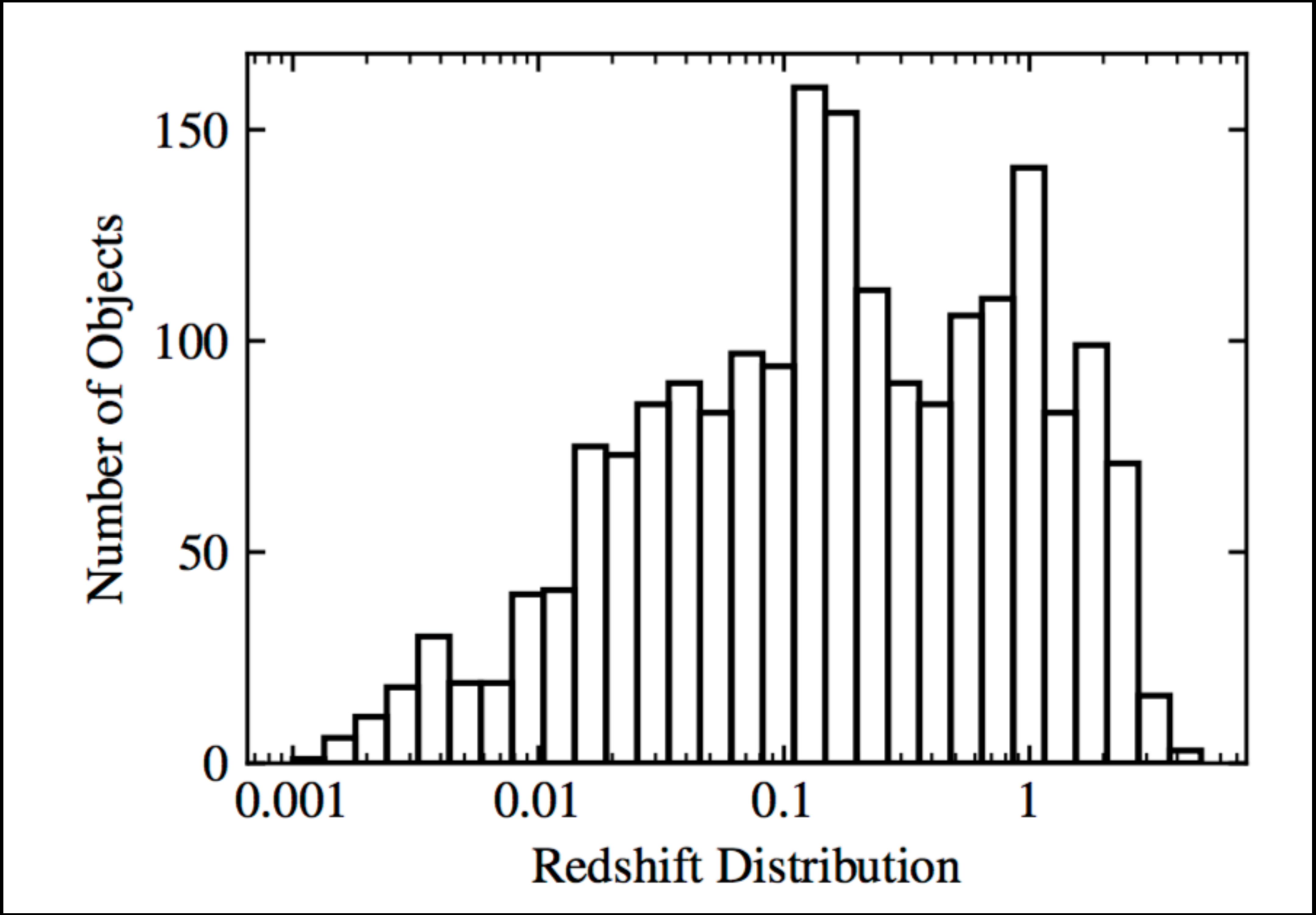


Guillard et al. 2009

Molecular gas emission also enhanced by gravitational interactions

Warm Molecular Gas as a function of the AGN contribution to the IR luminosity

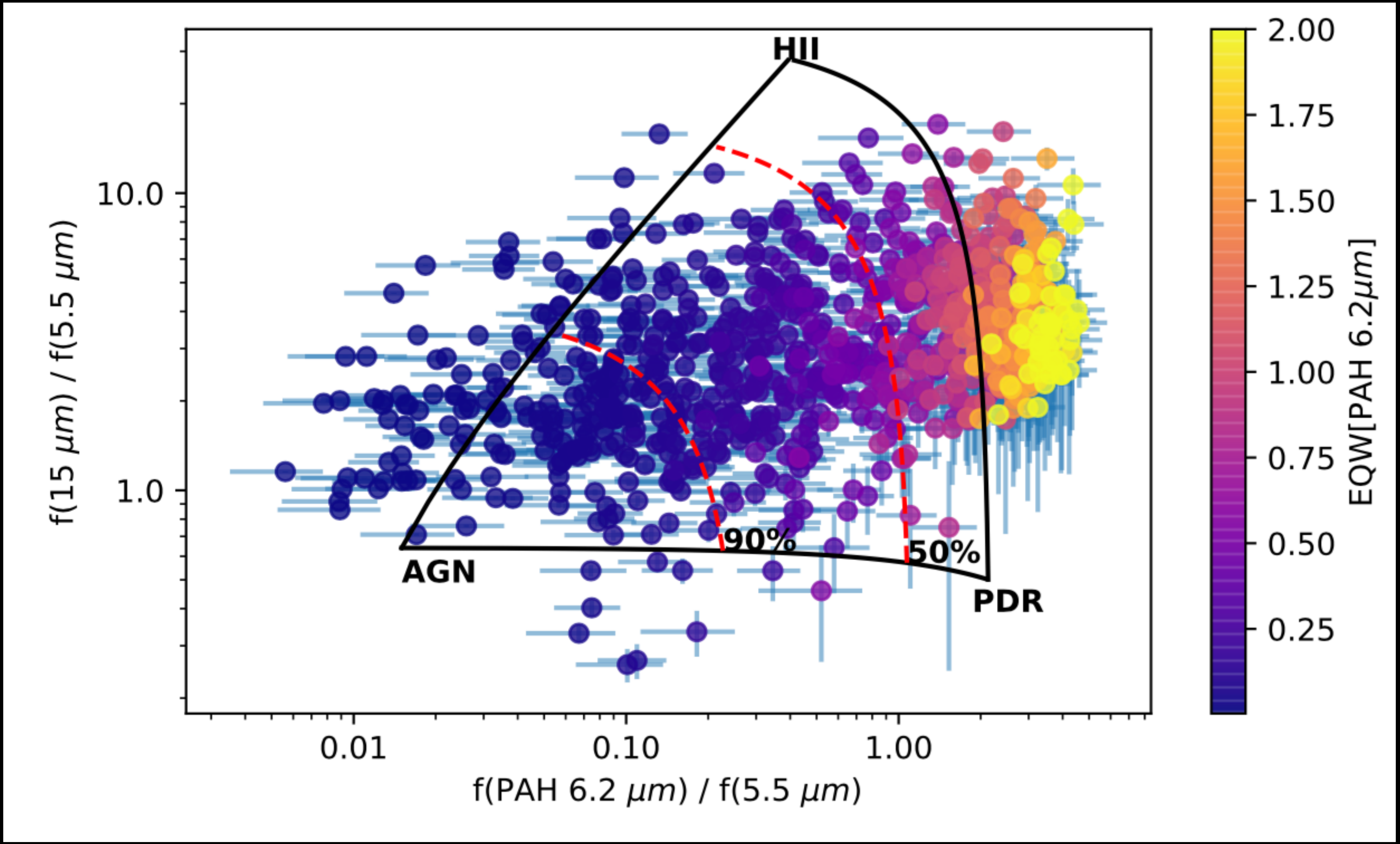
Following the gas in **all** the AGN (Spitzer/IRS)



(Lambrides, AP, +. 2018 submitted)

~2000 sources from the Spitzer IRS low resolution spectra

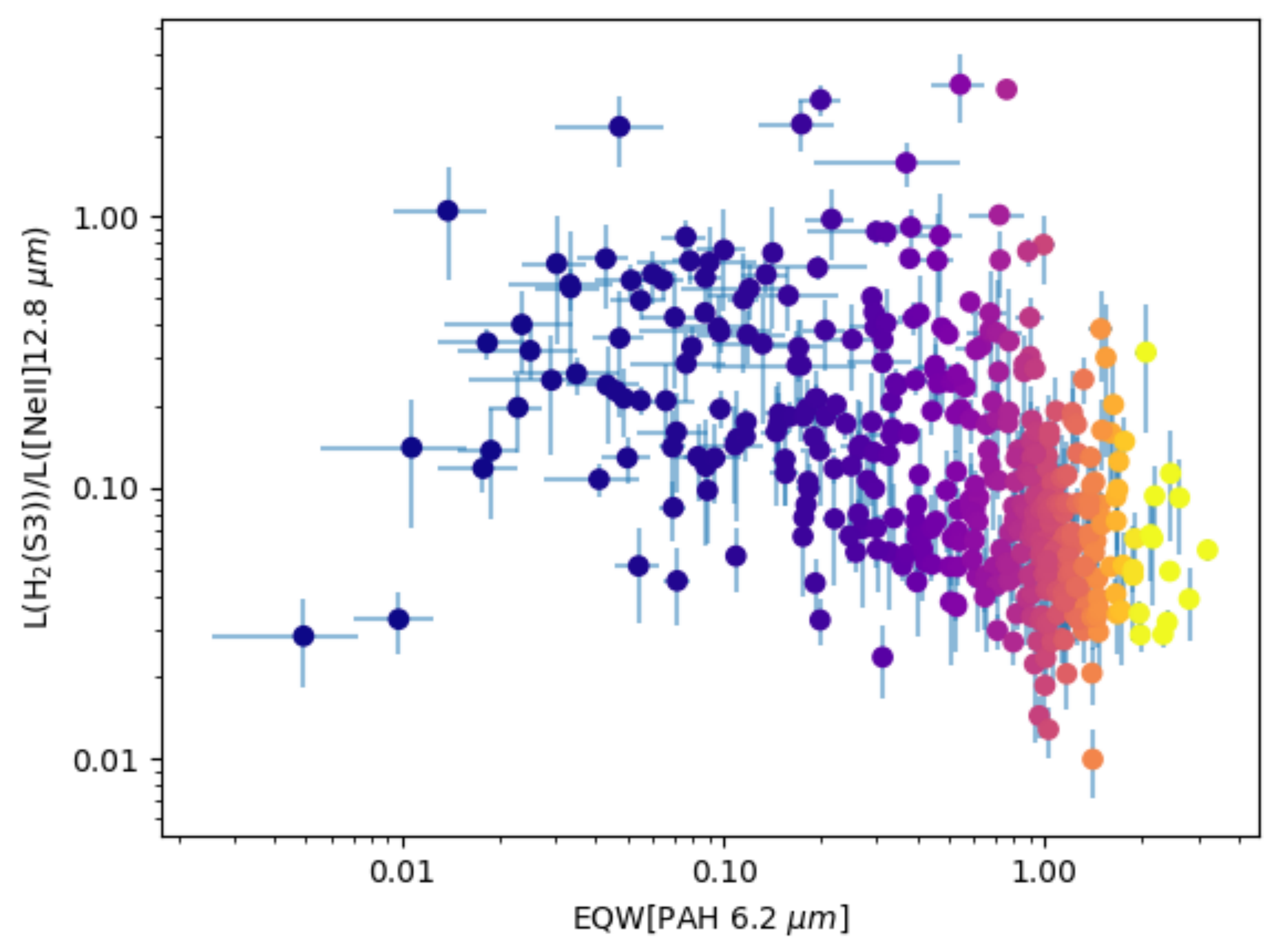
Following the gas in **all** the AGN (Spitzer/IRS)



(Lambrides, AP, +. 2018 submitted)

Multiple diagnostics to infer which are AGN
50% of the sample

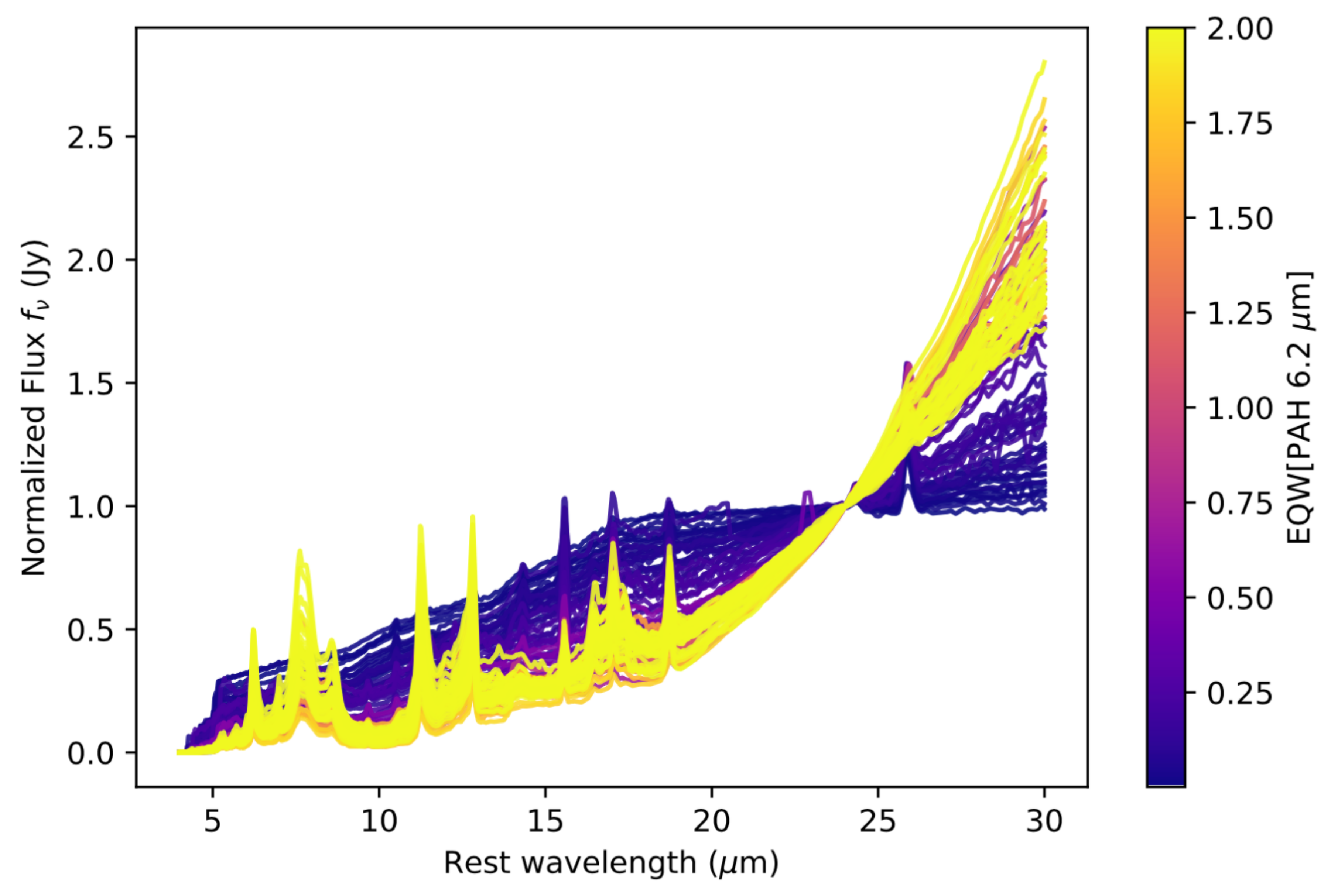
AGN hosts may have more H2 cooling



(Lambrides, AP, +. 2018 submitted)

The relative fraction of warm H_2 to IR/PAHs/[NeII] is higher in galaxies harboring an AGN.

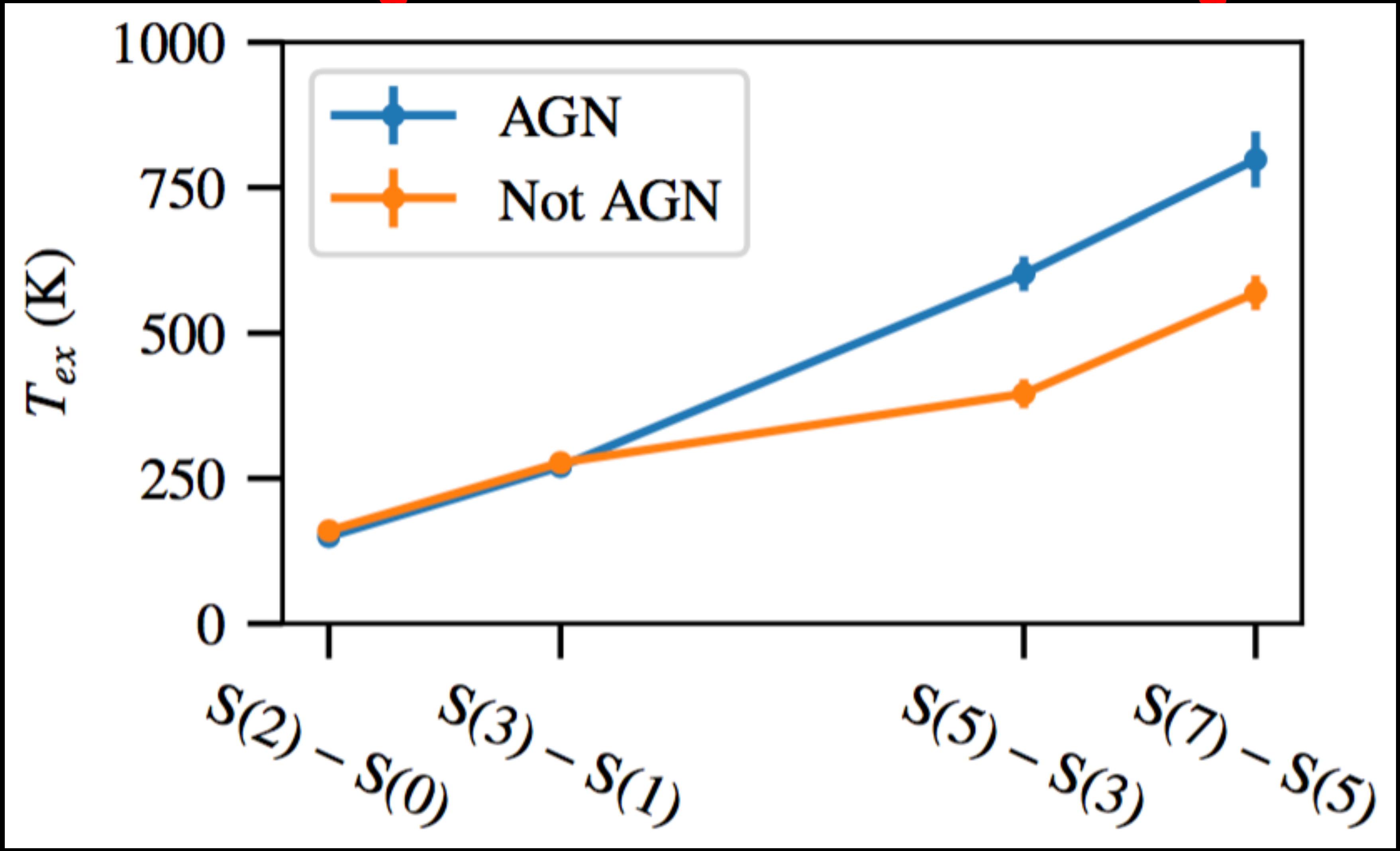
Mid-IR Templates

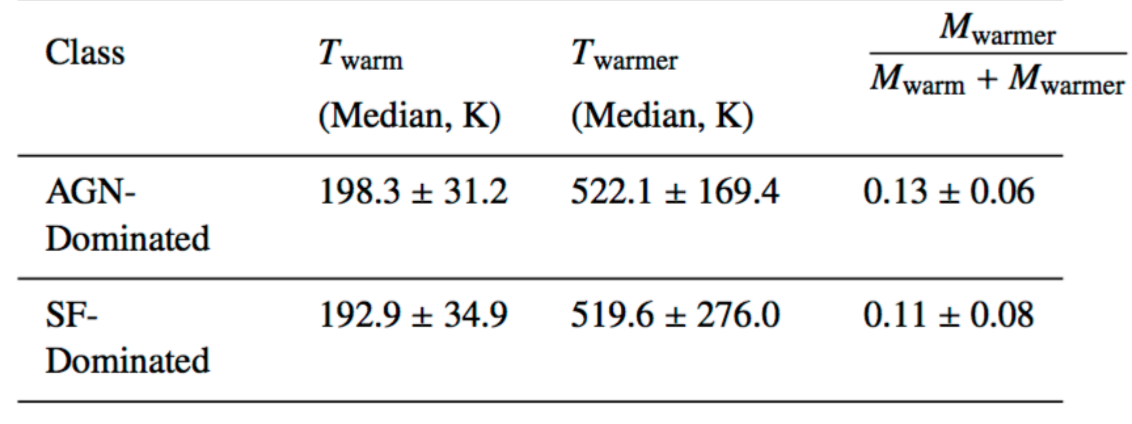


(Lambrides, AP, +. 2018 submitted)

Create templates to look at H2 cooling as a function of AGN contribution to the IR.

Follow the gas in **all** the AGN observed with Spitzer's Infrared Spectrograph





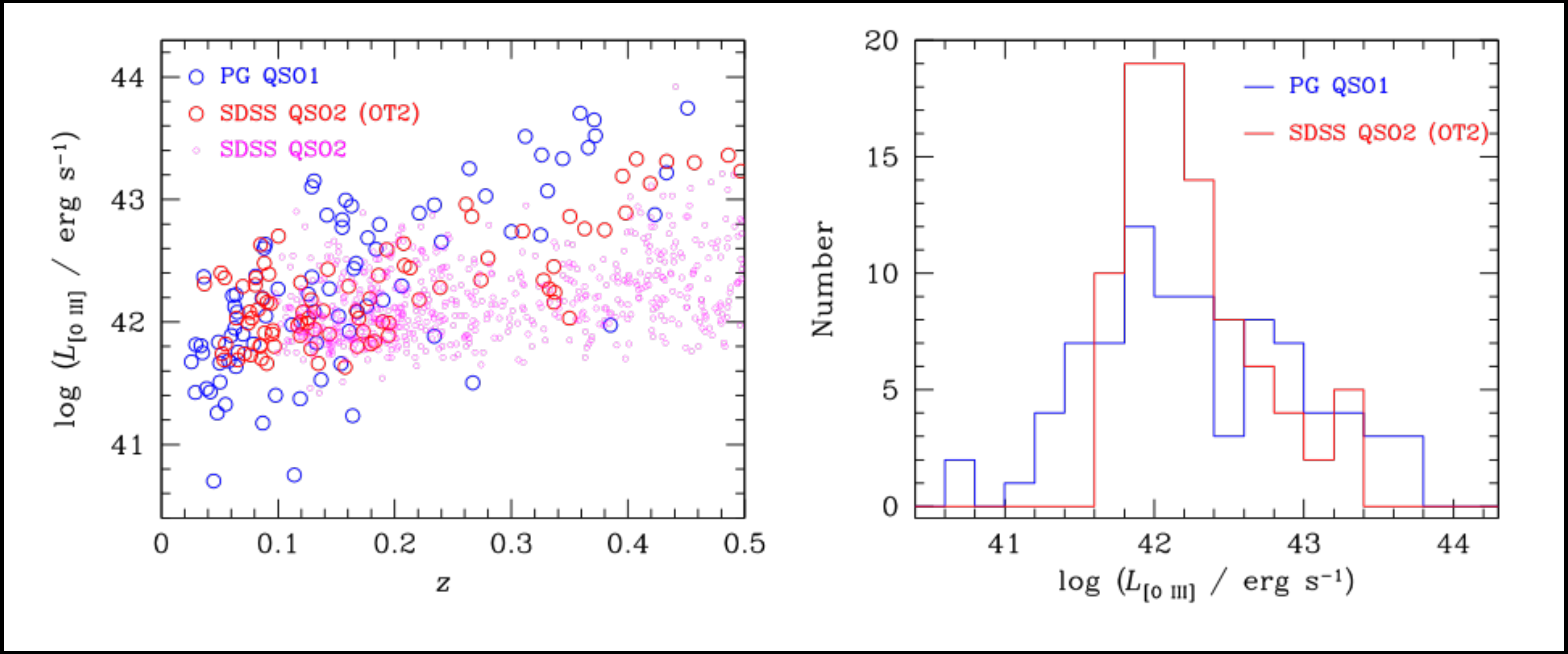
Class	$T_{\rm warm}$ (Median, K)	$T_{\rm warmer}$ (Median, K)	$\frac{M_{\rm warmer}}{M_{\rm warm}+M_{\rm warmer}}$
AGN-Dominated	198.3 ± 31.2	522.1 ± 169.4	0.13 ± 0.06
SF-Dominated	192.9 ± 34.9	519.6 ± 276.0	0.11 ± 0.08

(Lambrides, AP, +. 2018 submitted)

AGN hosts have warmer warm H_2

Does the cold molecular gas in QSO hosts care about the presence and type of QSO?

Cold dust in optically luminous, nearby QSOs

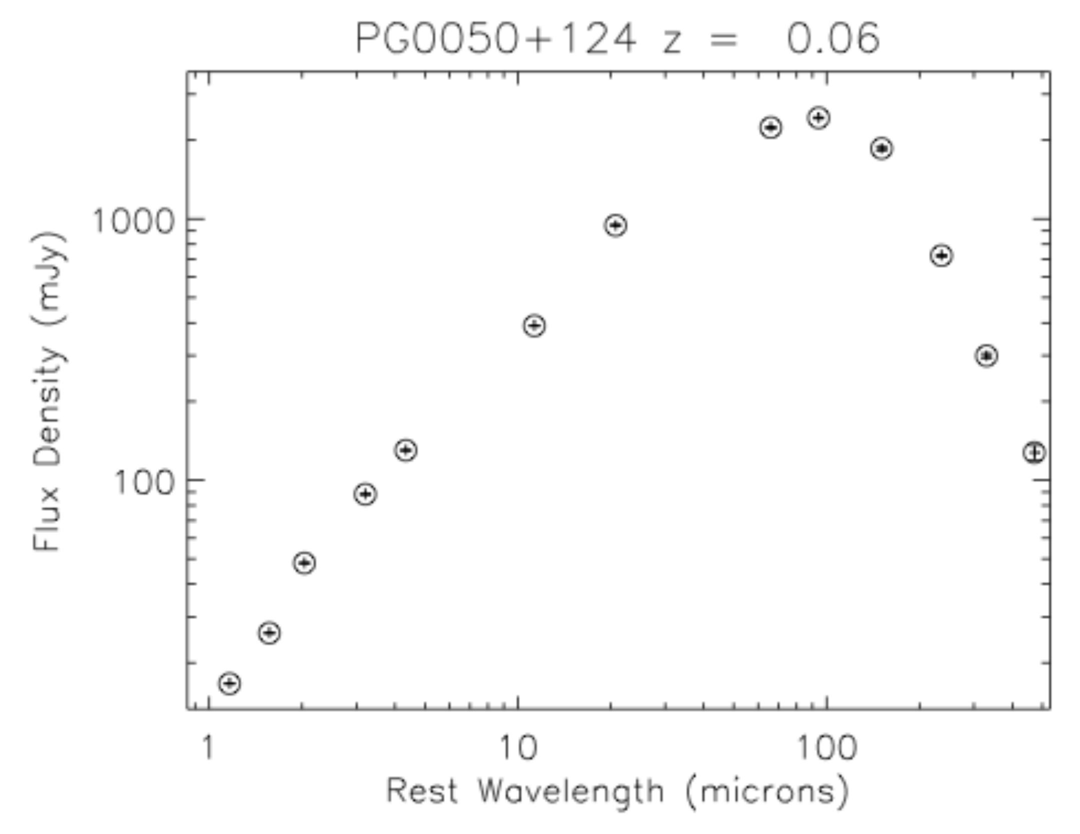


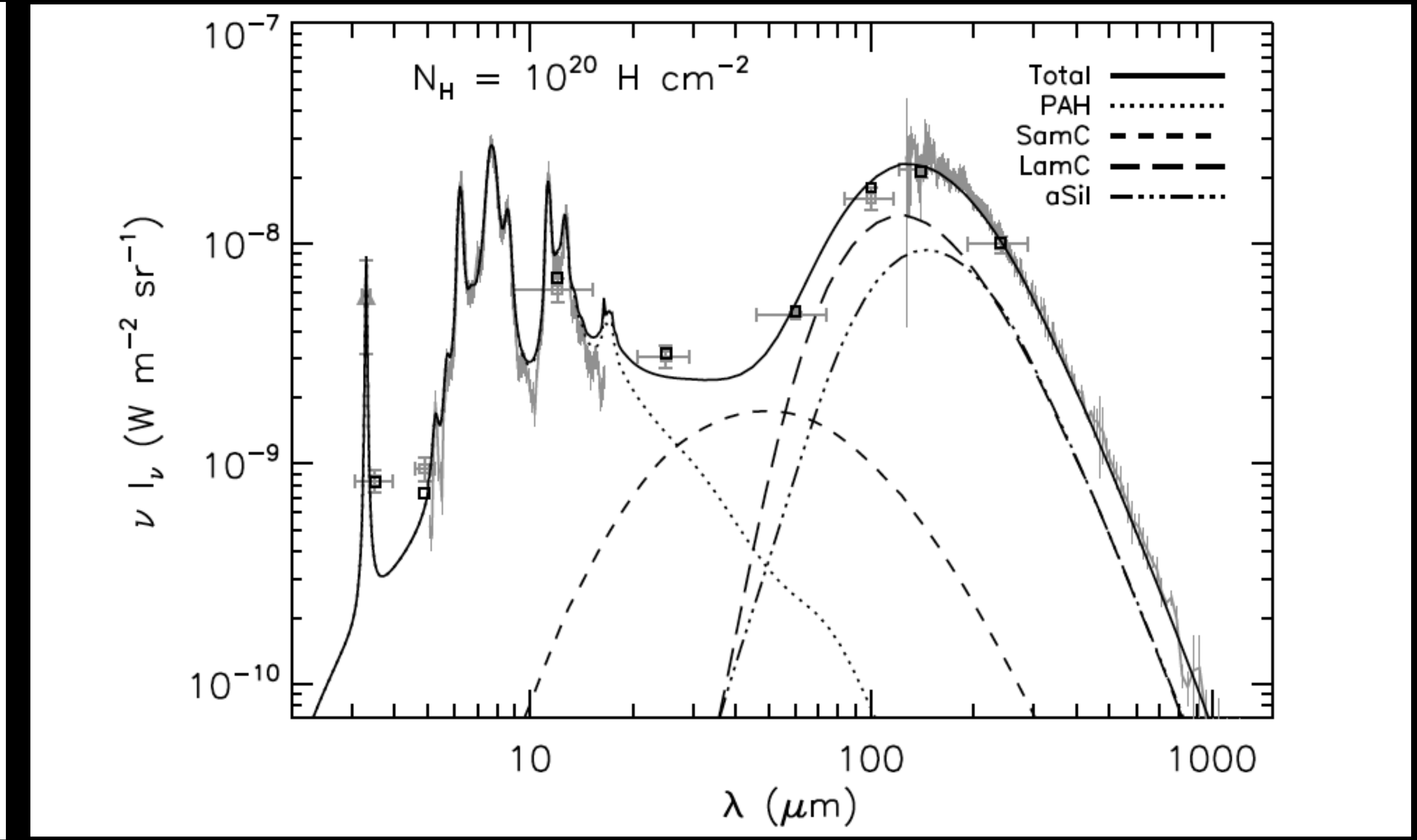
85 QSO1s and 87 QSO2s
matched in **redshift** and $L_{\mathbf{[OIII]}}$ to
85 QSO1s (z<0.5) (Reyes et al. 2008, AP+ 2015)

If merger picture dominates then we expect QSO2s to have **higher SFR** and **more cold ISM**.

PG QSOs: HI survey by Ho, Darling & Greene (2008)
CO survey by e.g. Evans et al. (2006)

Follow the gas with FIR emission

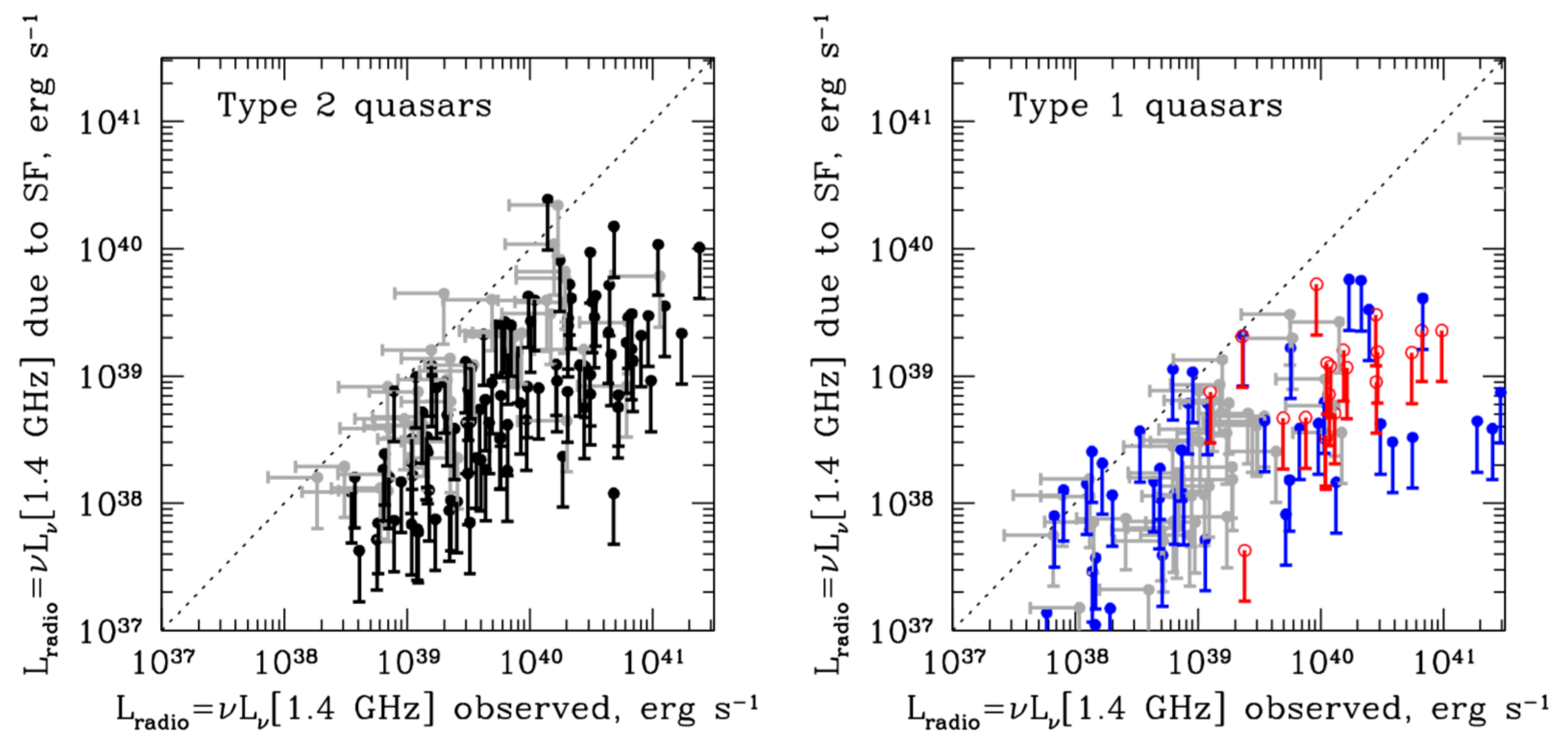




Compiegne et al. 2011

- Assuming that FIR traces emission from dust grains heated by UV from young stars
- Model IR SED with graybodies and dust models
- Amount of dust correlates with molecular gas
- Use this to estimate the amount of cold ISM.
- Herschel 70 to 500 µm photometry, WISE, 2MASS (AP+ 2015)

Star Formation Rates in QSO Hosts



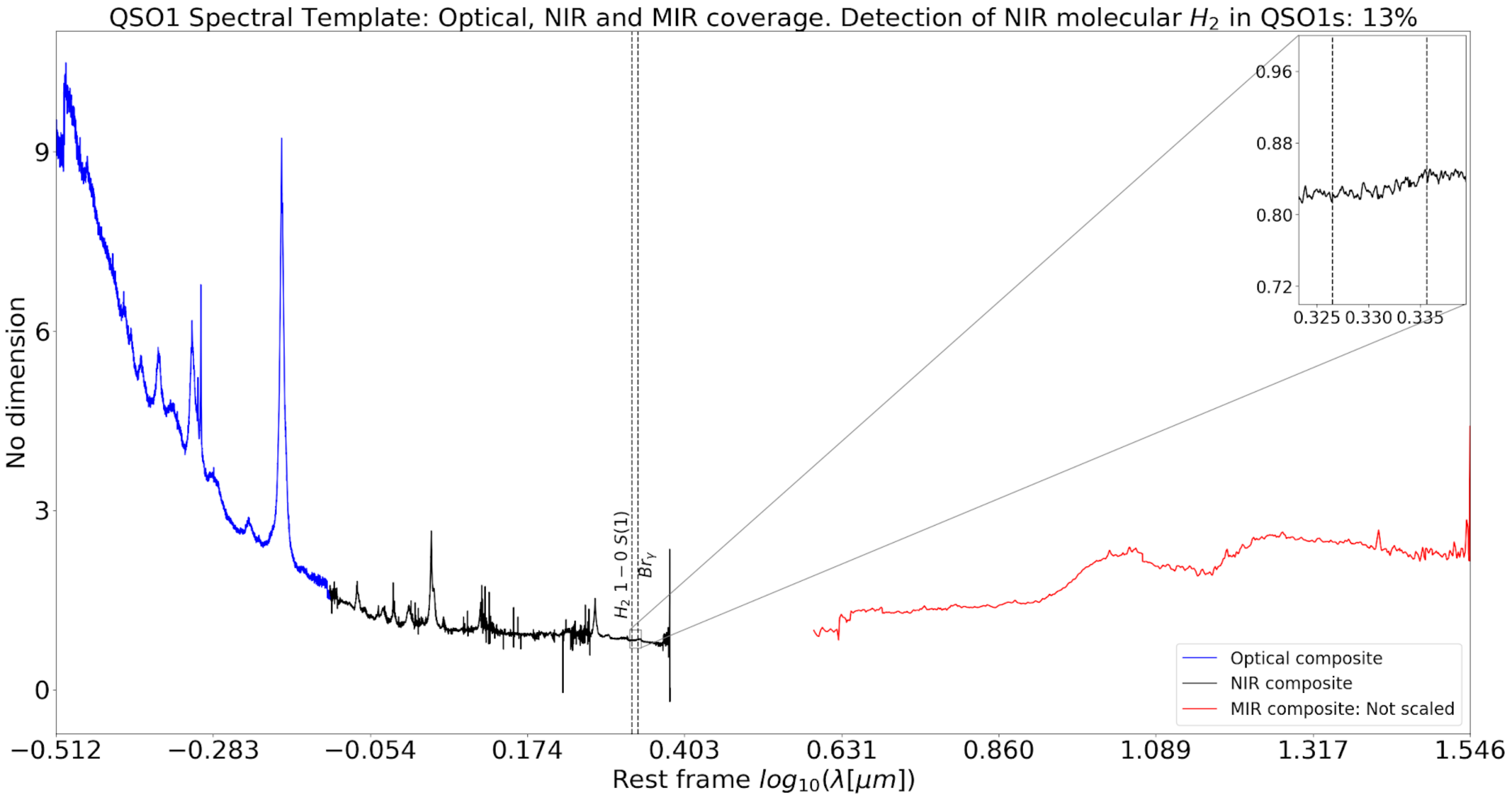
Zakamska, Lampayan, AP,+ (2016)

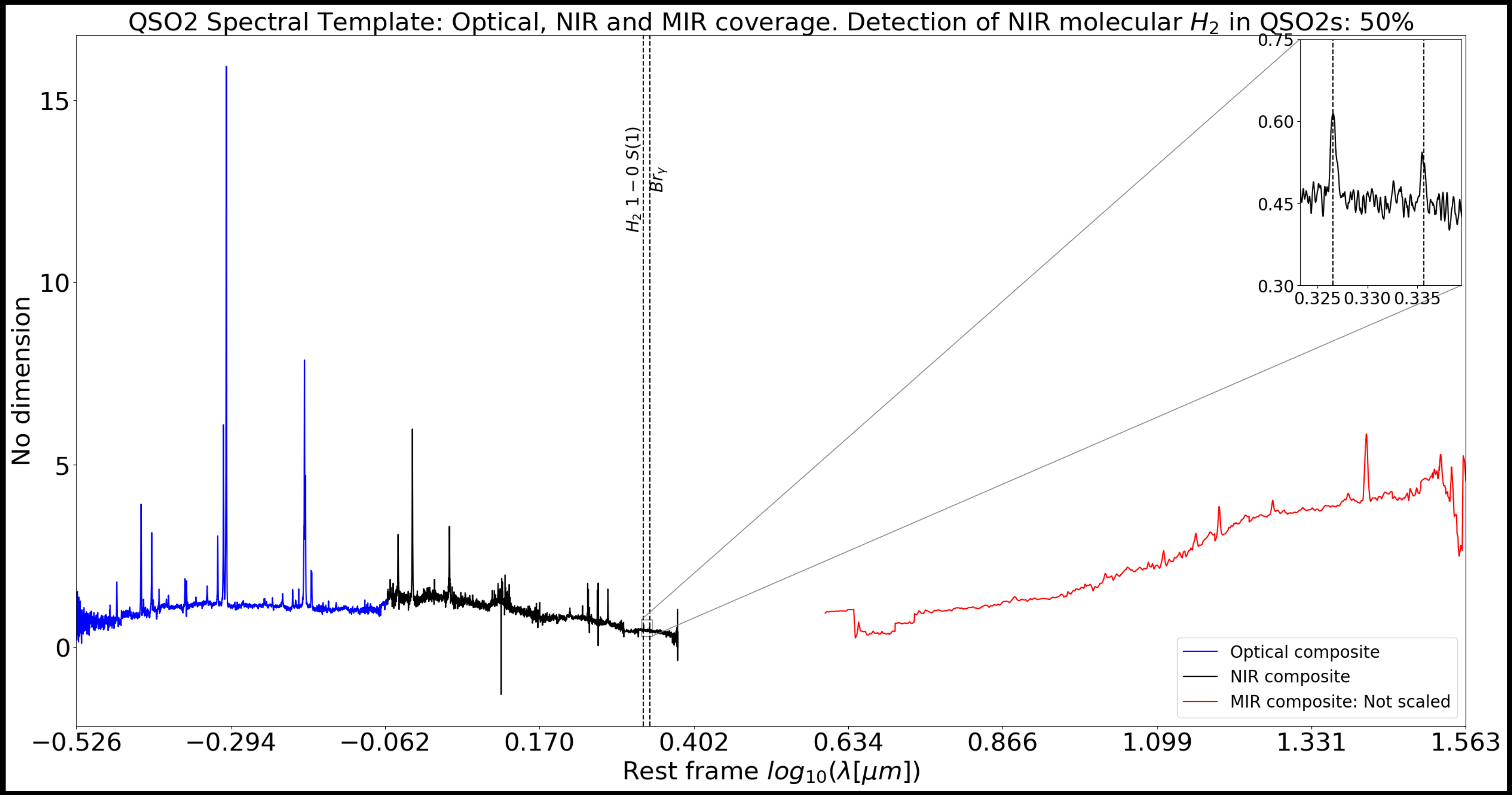
FIR data confirm that QSO2s have higher star-formation rates than QSO1s

consistent with the gas-rich merger progenitors scenario.

Near Future Prospects: Hot, Warm, and Cold Molecular Gas Estimates as a Function of AGN power.

NIR spectroscopy of 40 QSO1s + QSO2s


QSO1 Spectral Template: Optical, NIR and MIR coverage. Detection of NIR molecular H_2 in QSO1s: 13%


QSO2 Spectral Template: Optical, NIR and MIR coverage. Detection of NIR molecular H_2 in QSO2s: 50%

More hot H2 in QSO2.

(Vitral, AP+ in prep.)

Prospects in the Next Decade:

Next step: The Maunakea Spectroscopic Explorer

Conceptual Design Review completed Jan. 2018
Preliminary Design starting Jan. 2019

http://mse.cfht.hawaii.edu
(new website coming soon!)

Detailed Science Case (200+ pages):
https://arxiv.org/abs/1606.00043

Concise Overview of MSE (10 pages):
https://arxiv.org/abs/1606.00060

Project Book available soon!

Key Specifications

Simultaneously:

- Low res: 3249 fibres, *m*~24, λ ~ 0.36-1.8 µm
- High res: 1083 fibres, *m*~20, λ/Δλ ~ 40,000

Accessible sky	30000 square degrees (airmass < 1.55)						
Aperture (M1 in m)	11.25						
Field of view (square degrees)	1.52						
Etendue = FoV x π $(M1/2)^2$	151						
Modes	**Low**		**Moderate**	**High**			**IFU**
Wavelength range	0.35-1.3 µm, 1.5-1.8 µm		0.36-0.95 µm	0.36-0.90 µm #			IFU capable; anticipated second generation capability
	0.36-0.95 µm	J, H bands		0.36-0.45 µm	0.45-0.60 µm	0.60-0.90 µm	
Spectral resolution, R = $\lambda_c/d\lambda$	2500 *(3000)*	3000 *(5000)*	6000	40000	40000	20000	
Multiplexing	3249		3249	1083			
Spectral windows	Full		= Half	$\lambda_c/30$	$\lambda_c/30$	$\lambda_c/15$	
Sensitivity ★	m =24.0 ⁕		m = 23.5 ⁕	m=20.0 ✧			
Velocity precision ★	20 km/s ▽		9 km/s ▽	<100m/s ★			
Spectrophotometric accuracy	<3% relative		<3% relative	N/A			

\# Dichroic positions are approximate

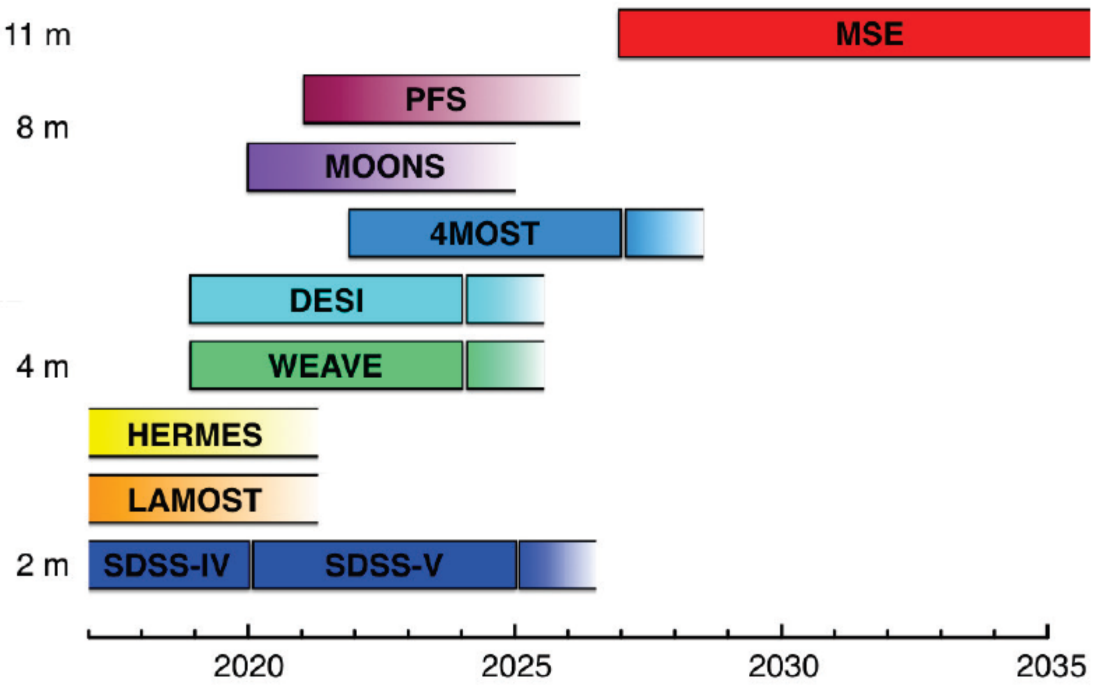
⁕ SNR / resolution element = 2

✧ SNR / resolution element = 2

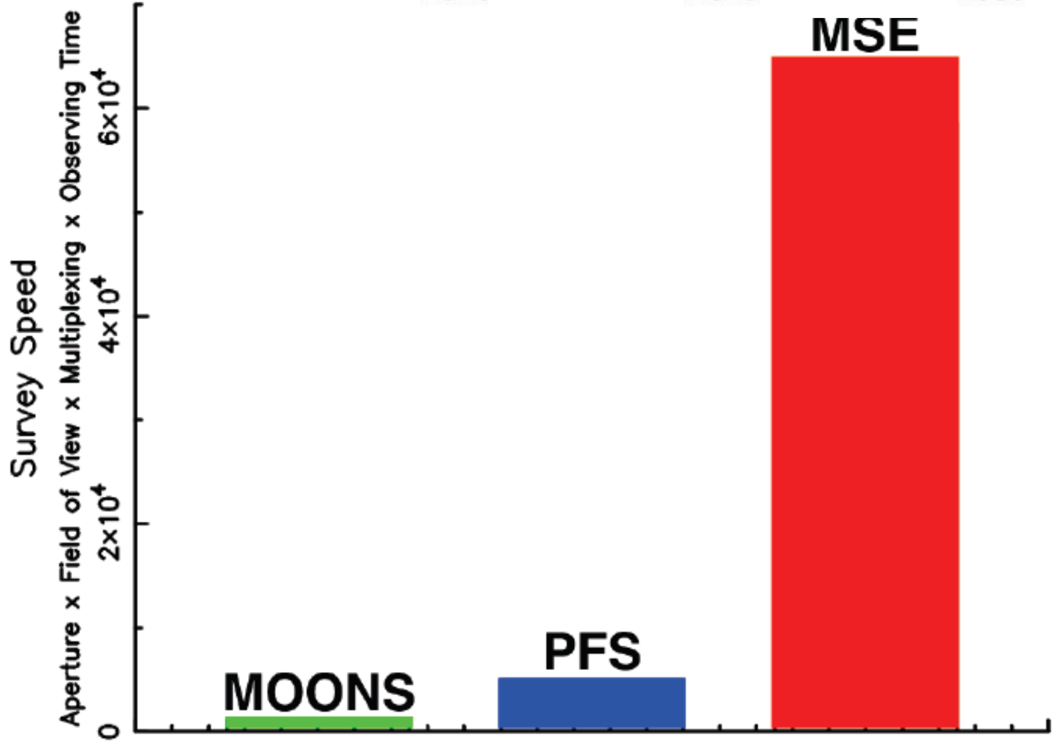
▽ SNR / resolution element = 5

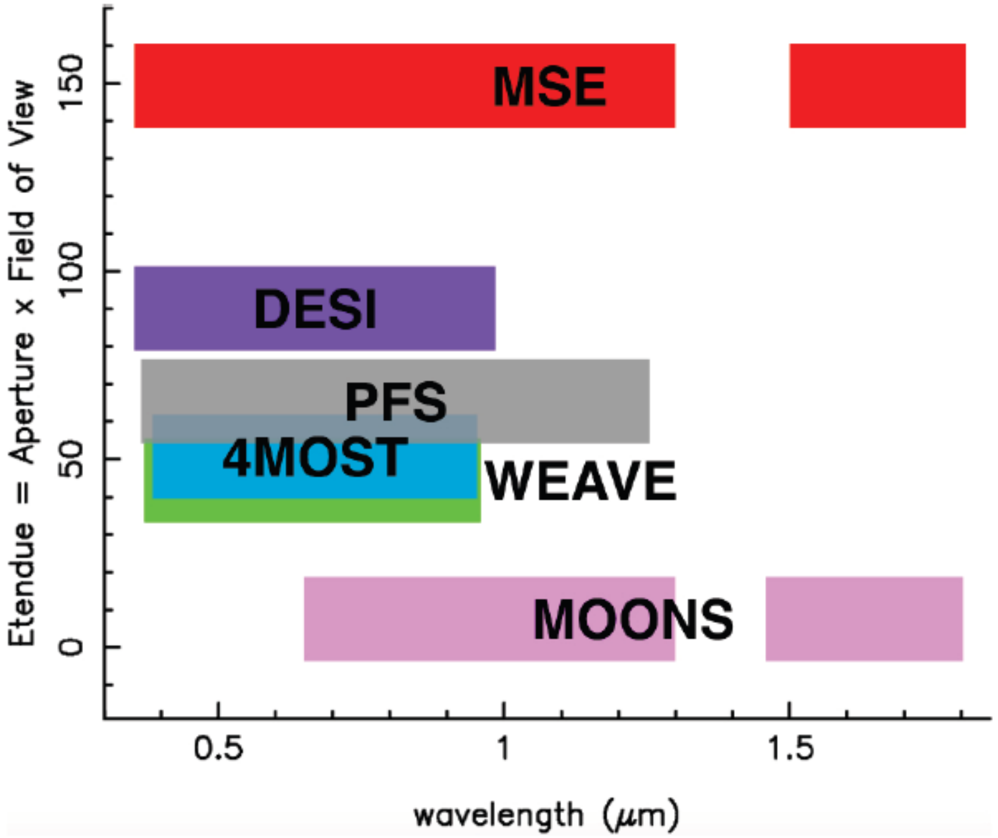
★ SNR / resolution element = 30

MSE and other MOS facilities



Dedicated facility
Large aperture
Large field of view
High multiplexing
Exquisite image quality





Conclusions

- Warm molecular gas in AGN hosts is warmer than that in star-forming galaxies across a wide range of AGN luminosities.

- Highest rotational transitions S(5), S(7) are found in mergers in subsamples of LIRGs, all sources with resolved H_2 lines with $\sigma > 350$ km/sec are mergers.

- QSO2 higher SFR than QSO1s based on their FIR/radio ratios, and higher NIR detection rates

- Difficult to separate the effects of the merger on the ISM from that of the AGN.

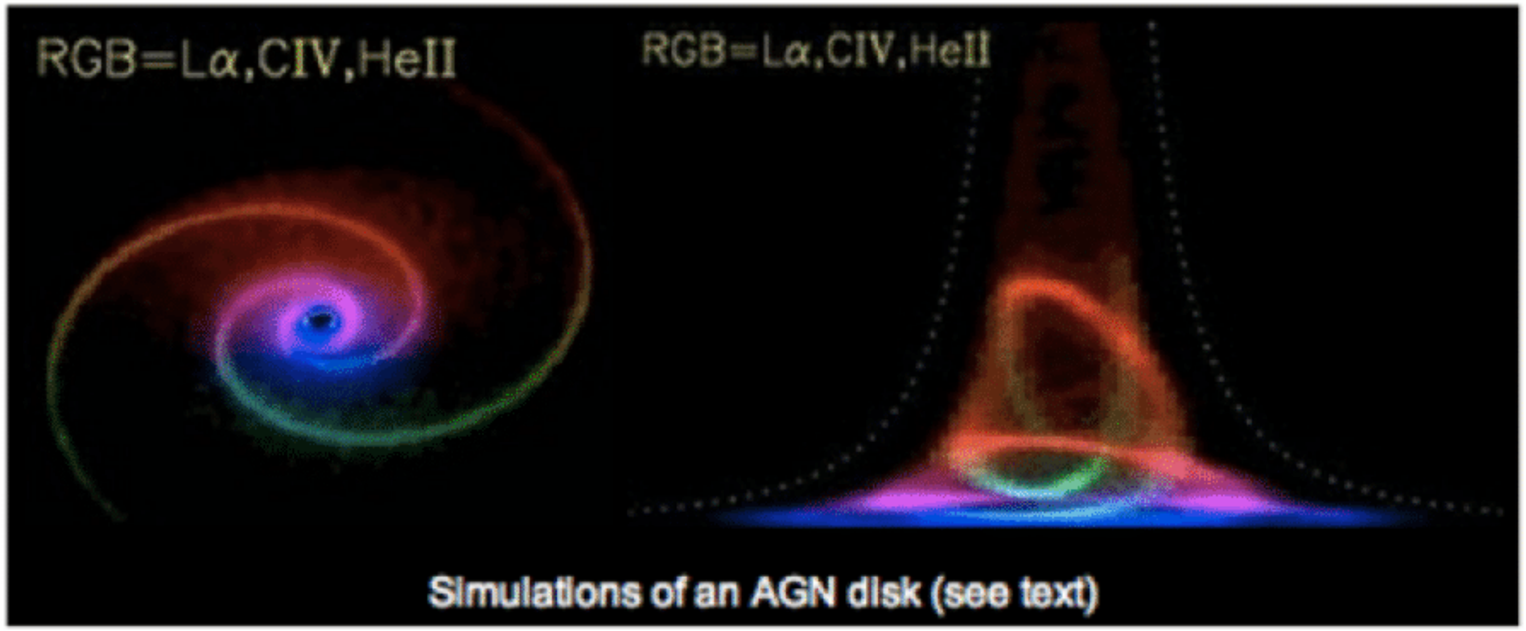
Extra slides

Mapping the Inner Parsec of Quasars

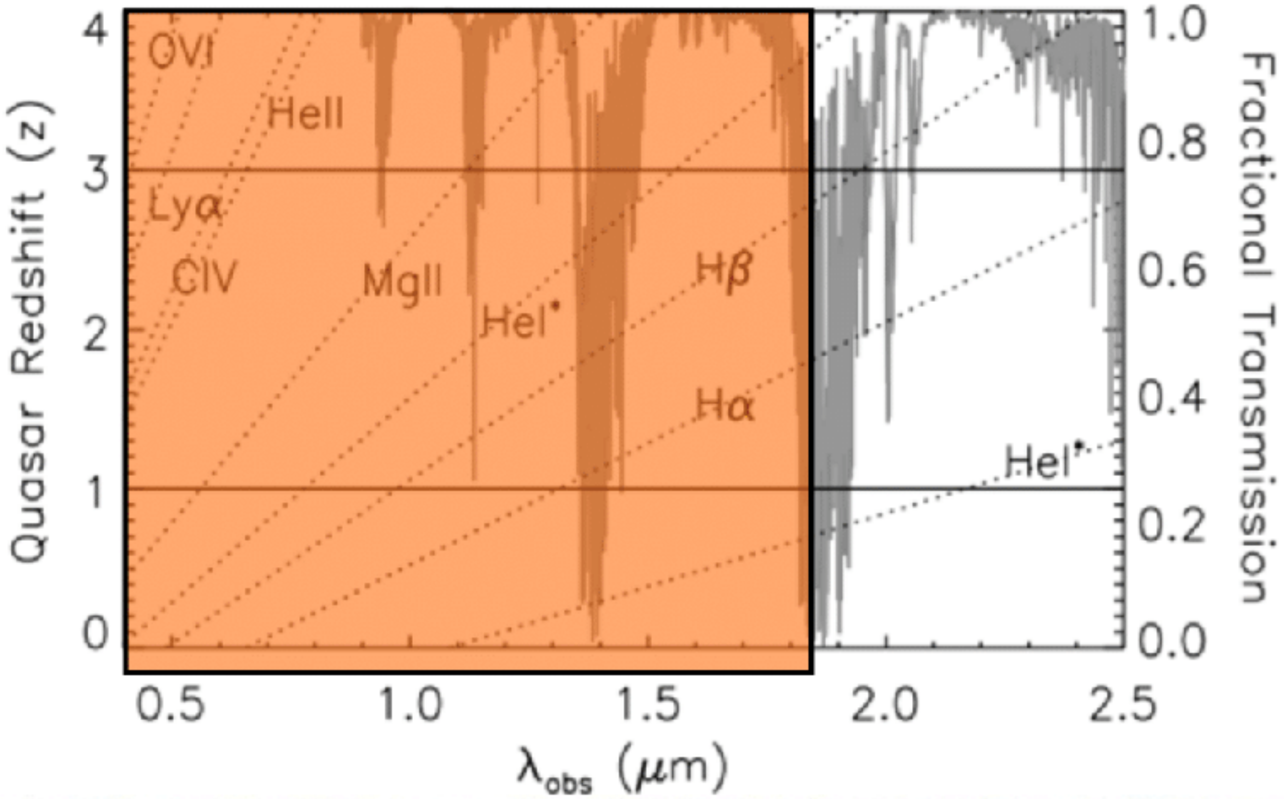
Time domain astrophysics

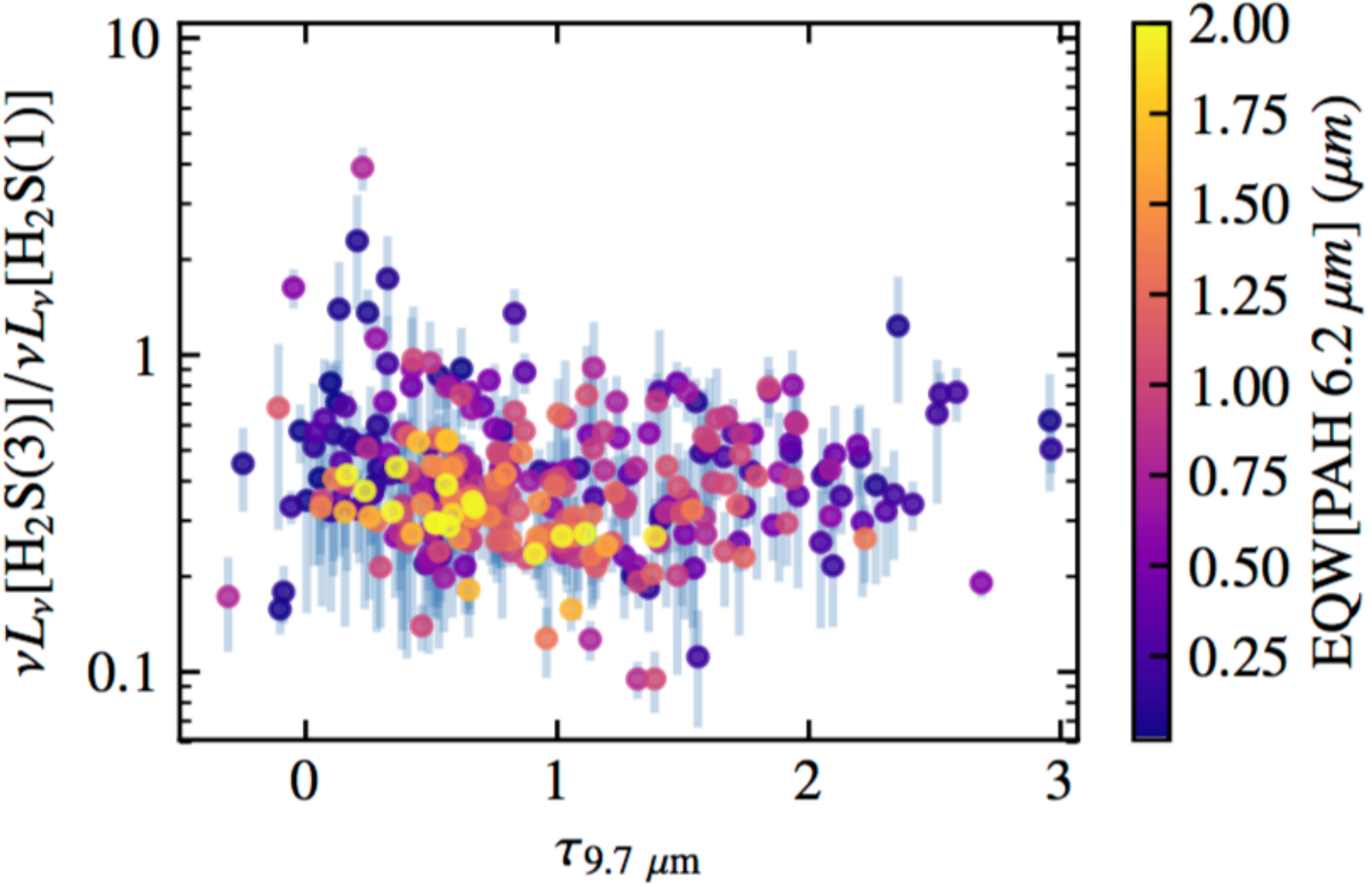
~100 observations of 5000 quasars spread over years to map the structure and kinematics of the inner parsec of supermassive black holes actively accreting during the peak quasar era

(Compare with ~50 nearby, wimpy AGN that currently have high quality measurements)

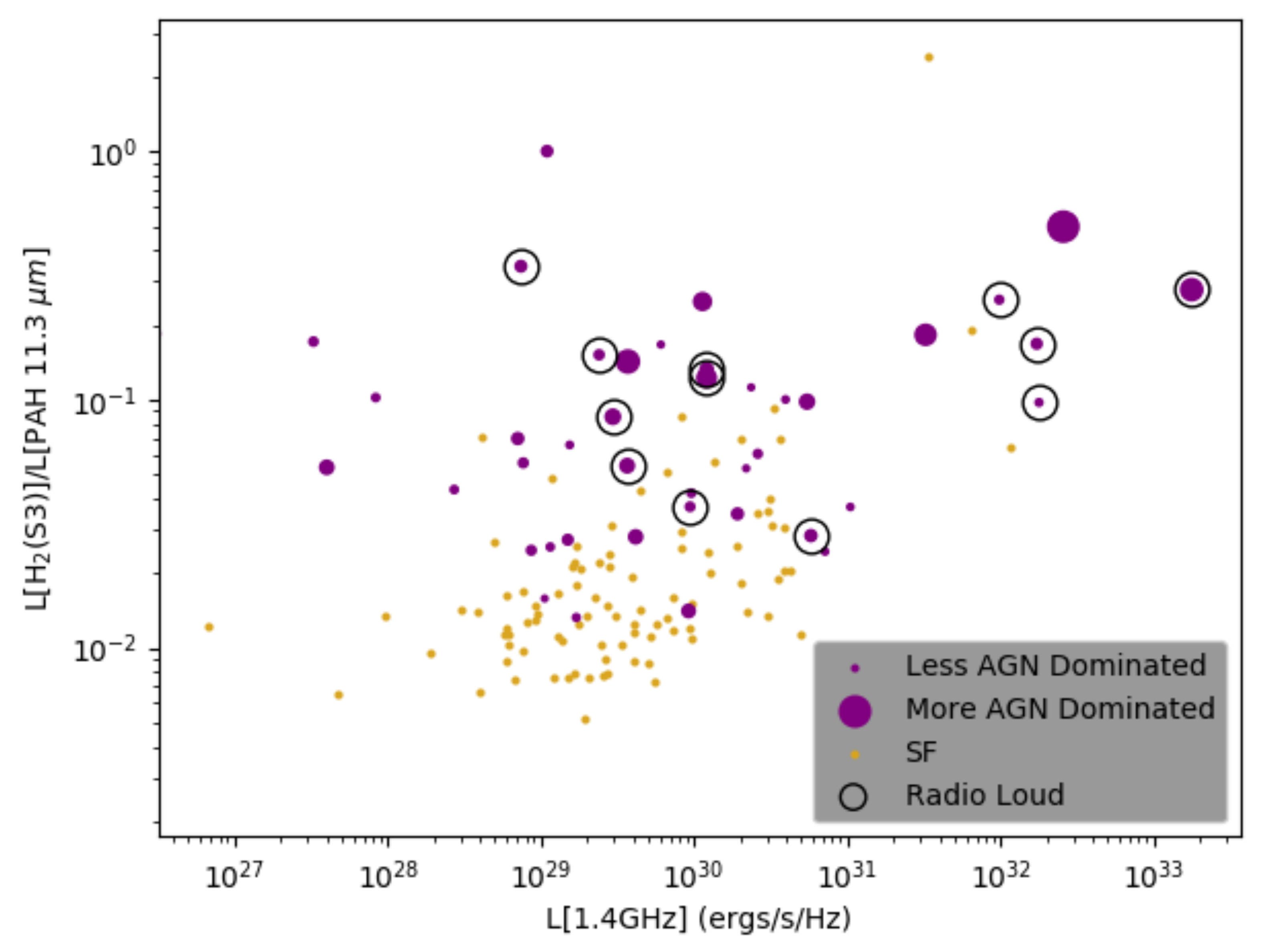


Simulations of an AGN disk (see text)




$\nu L_\nu[\mathrm{H_2S(3)}]/\nu L_\nu[\mathrm{H_2S(1)}]$
10
1
0.1
0
1
2
3
$\tau_{9.7\ \mu m}$
EQW[PAH 6.2 μm] (μm)
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25

Follow the gas in **all** the AGN observed with Spitzer's Infrared Spectrograph



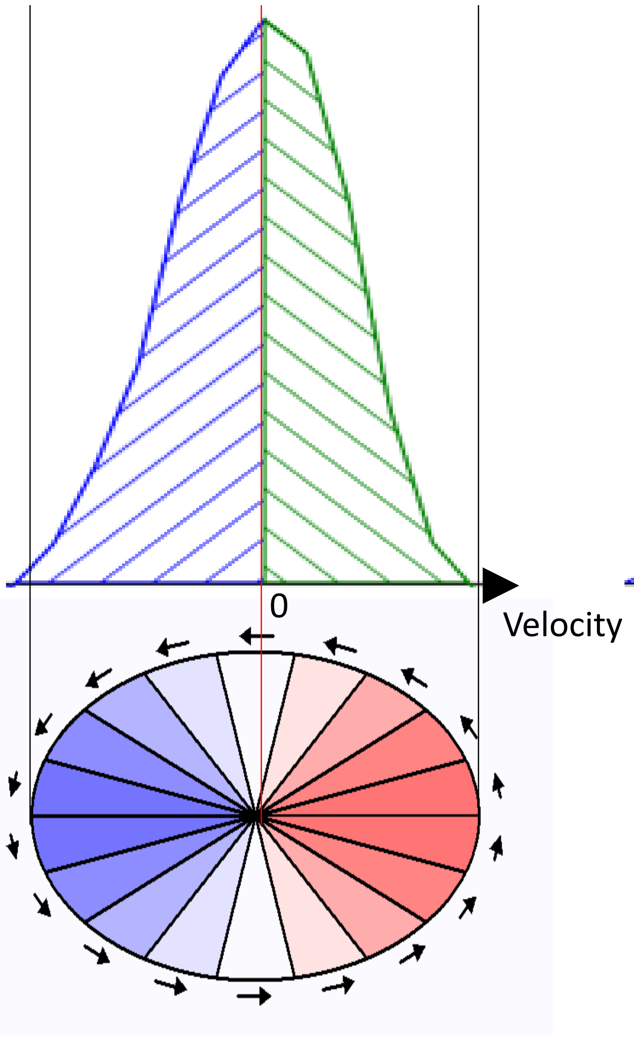
Highest H2 to IR/PAH ratios are seen in Radio - loud AGN

(Lambrides, AP+ Ogle et al. 2010)

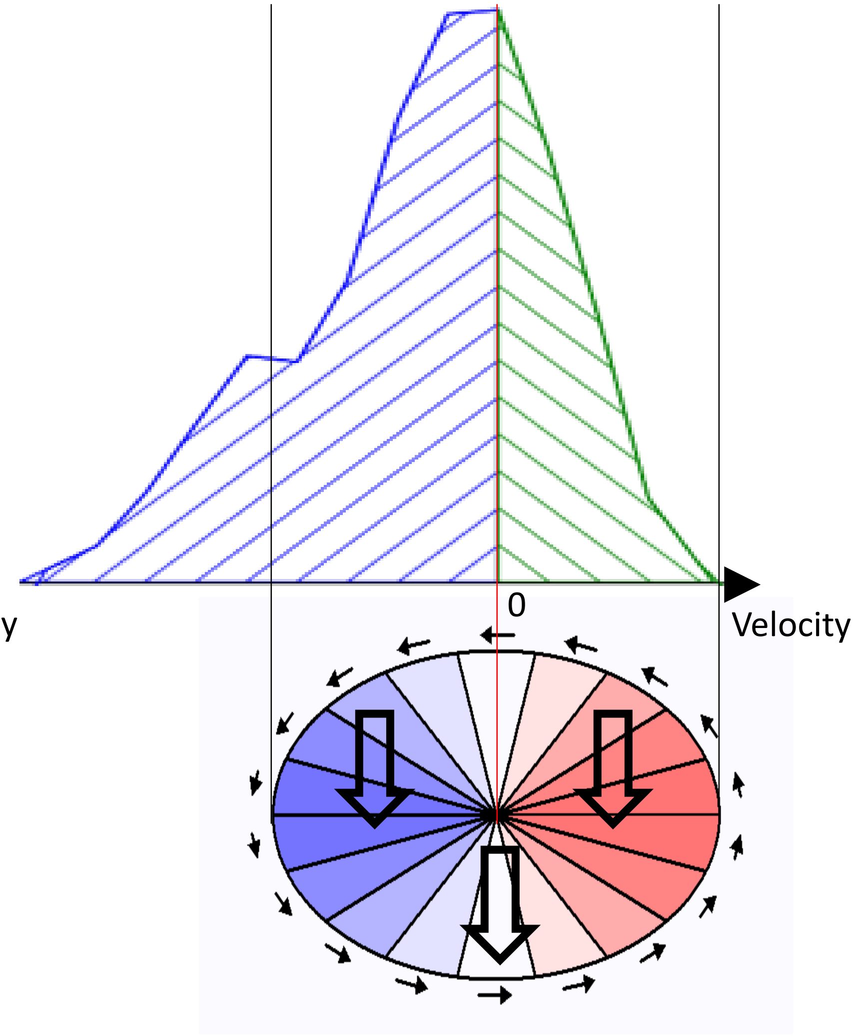
Warm Molecular Gas
through ro-vibrational lines

Asymmetry

__Possible reasons : flows__



__Doppler effect__
Galaxy's rotation



__Doppler effect__
Galaxy's rotation + Flows

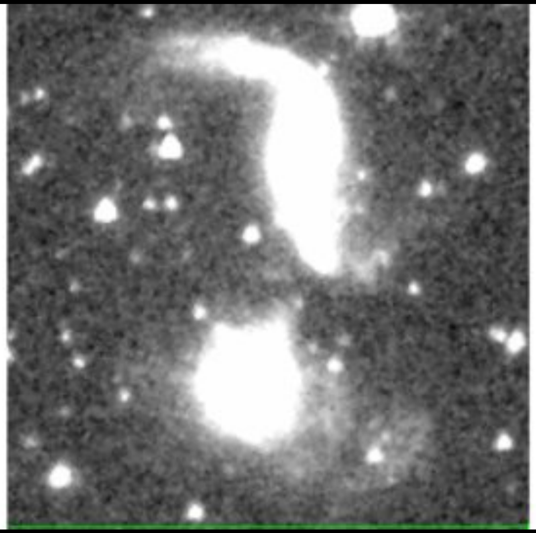
Need to characterise this flow
- Composition
- Direction
- Velocity

Not in this survey

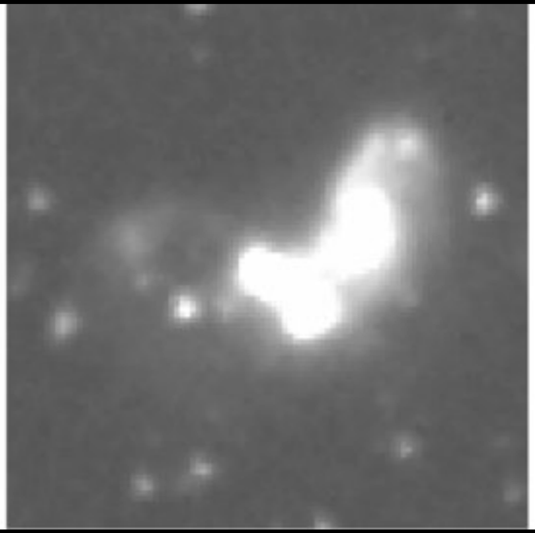
Sources with broad MIR profiles appear to have asymmetric NIR H_2 lines (Petrus, AP + in prep)

stage 0

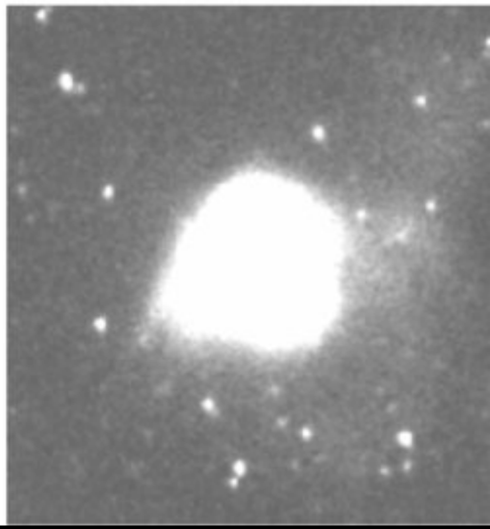
stage 1



stage 2



stage 3



stage 4