Obscured AGN at the Cosmic Noon

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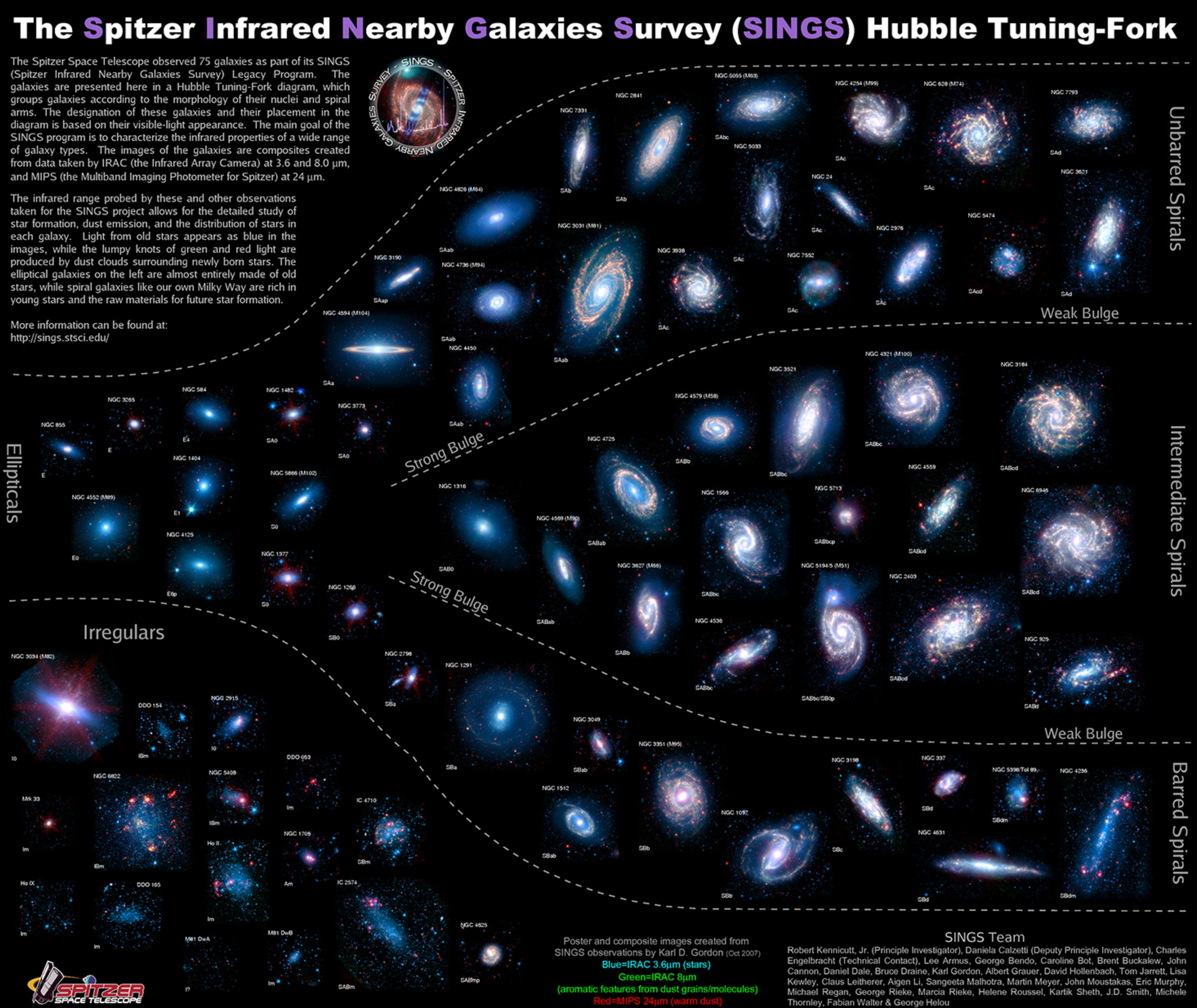
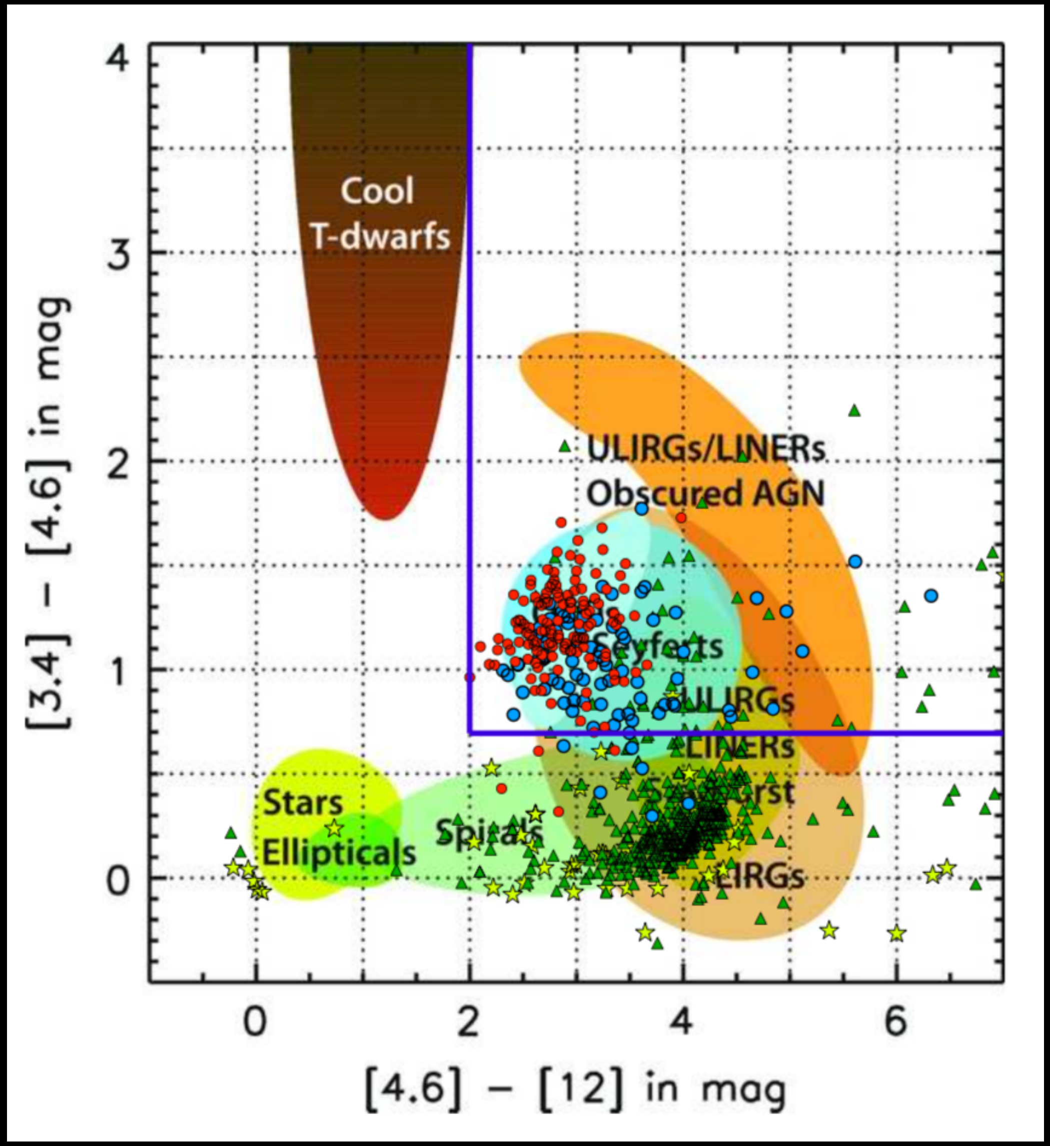
AP+ MSE AGN working group 2019: https://arxiv.org/pdf/1905.10489.pdf

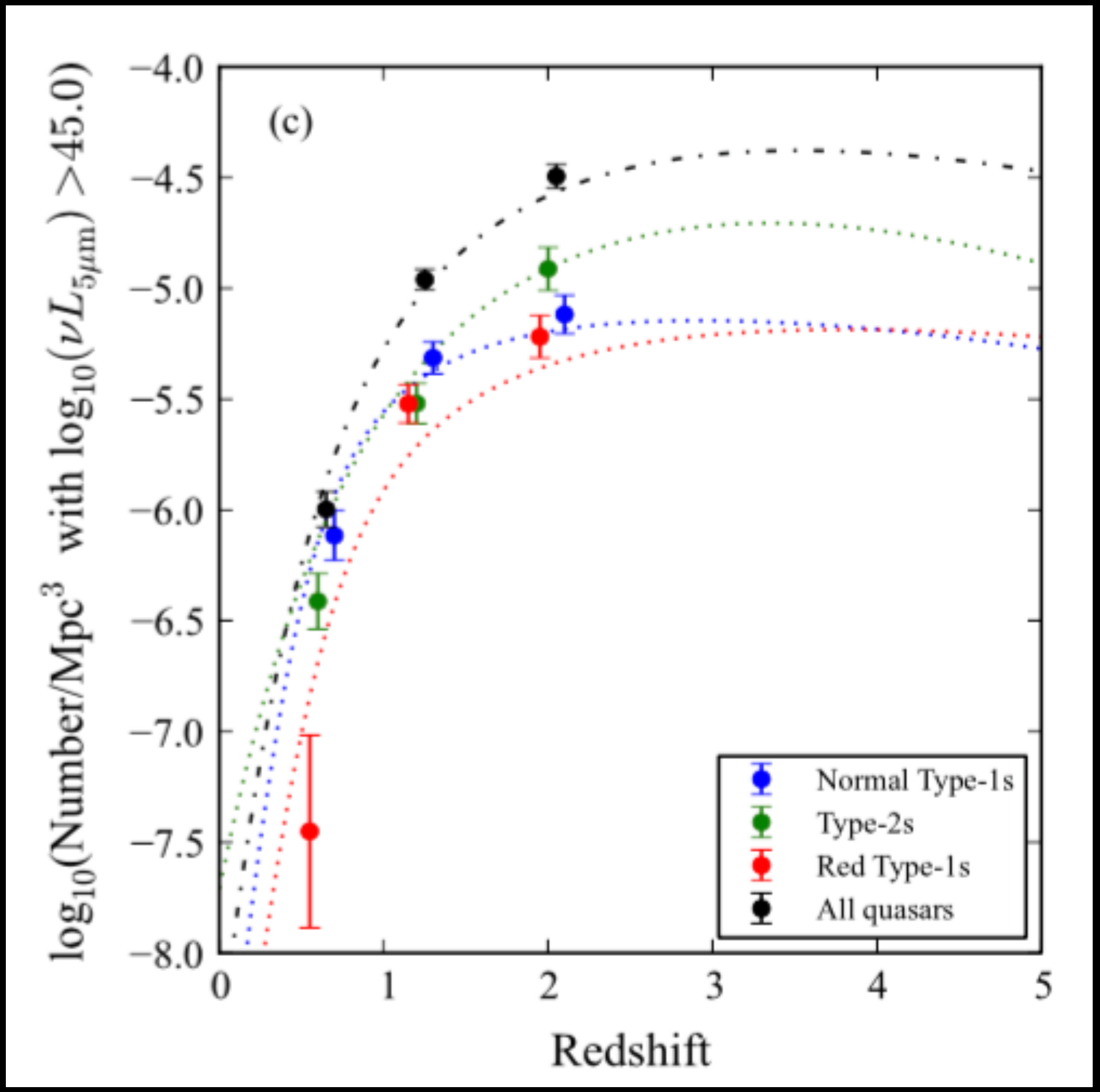
Galaxies have different Shapes, Sizes, Luminosities, and Types of Bulges



Where, when, and how were all these black-holes formed?

How important are those dusty QSOs for the general population of AGN?





Lacy et al (2004,2005), Wright et al. (2010), Glikman et al. (2007,2015)

red Type 1 Av~1, broad lines

red Type 2 Av~5, narrow lines

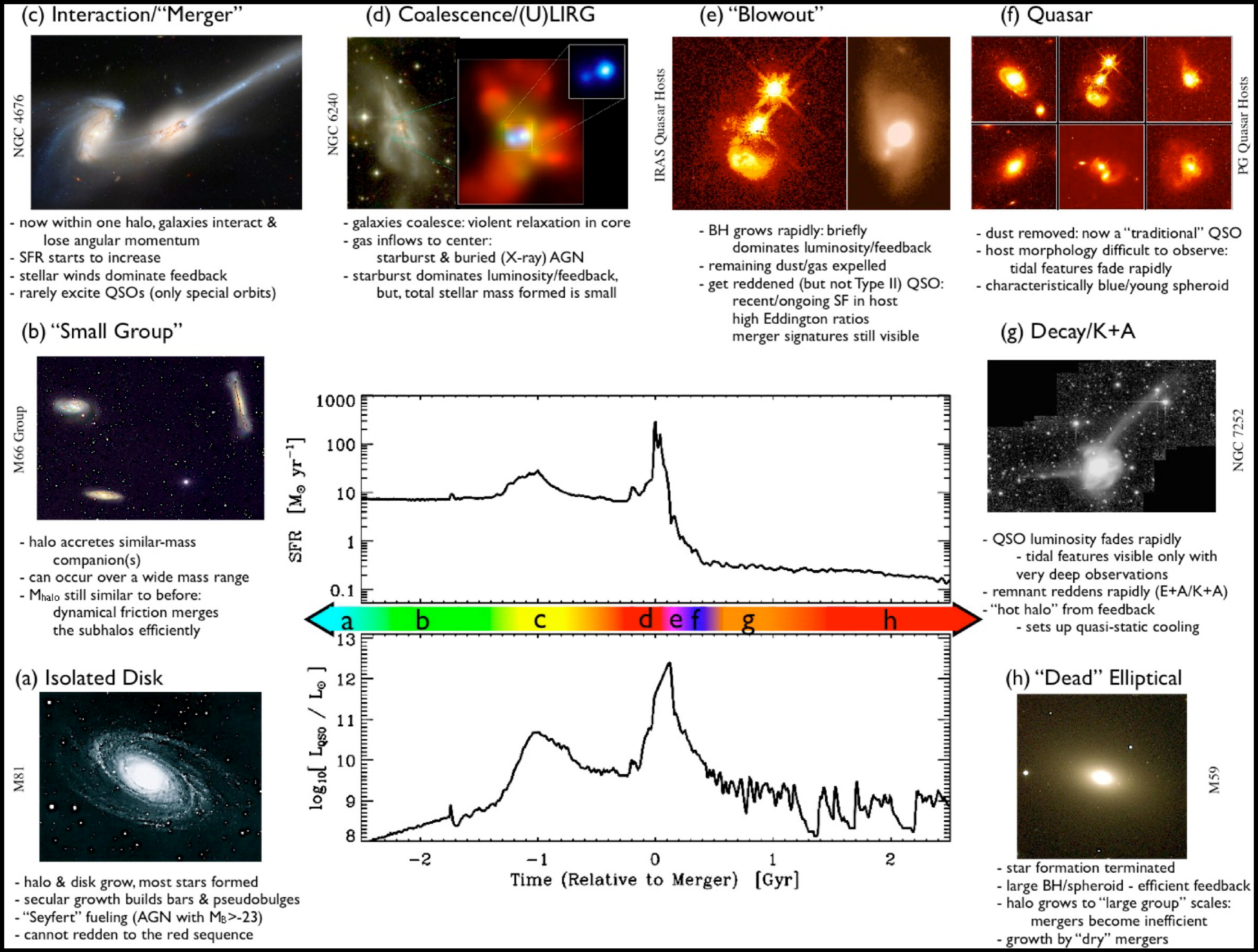
Lacy et al (2015)

Mid-IR color-color diagrams as a tool to find obscured AGN.

SDSS optical selection also yielded thousands of QSO2s.
Zakamska et al. (2003); Reyes et al. (2008).

Evolution with redshift of obscured sources differs from that of un-obscured AGN.

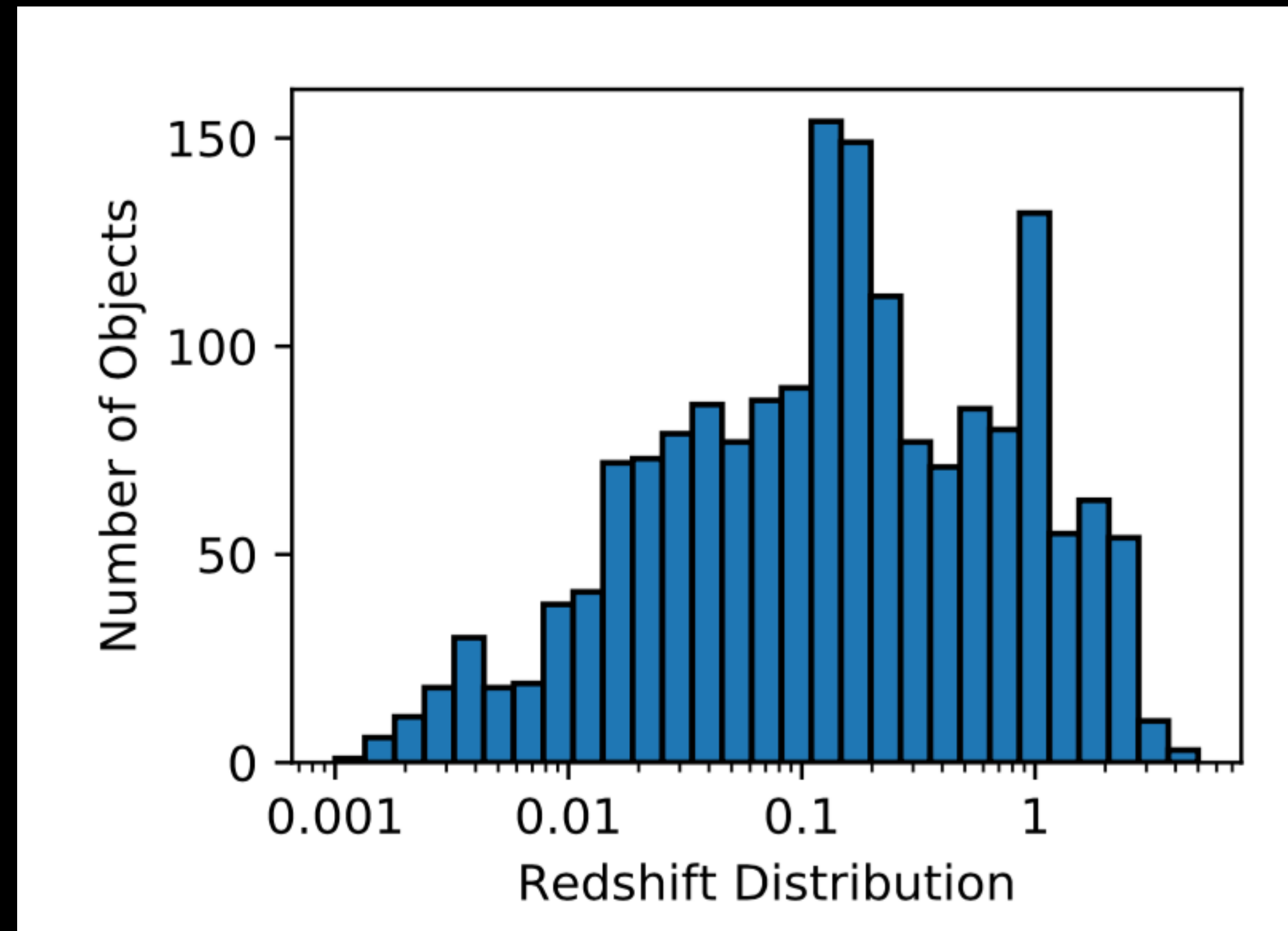
One path to correlation:
Gas Rich Mergers — Luminous QSOs in Dead Ellipticals



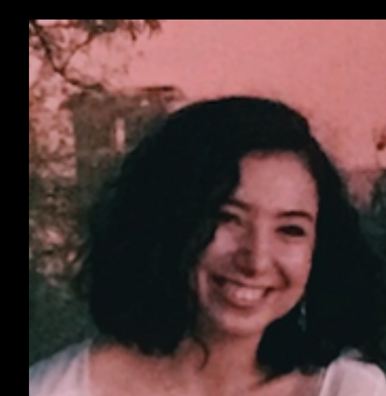
Hopkins group, Caltech

Warm molecular gas and dust in **all** the AGN observed with Spitzer's IR Spectrograph

Erini Lambrides, JHU



(Lambrides, AP+ . 2019, Minsley, AP+ 2020)

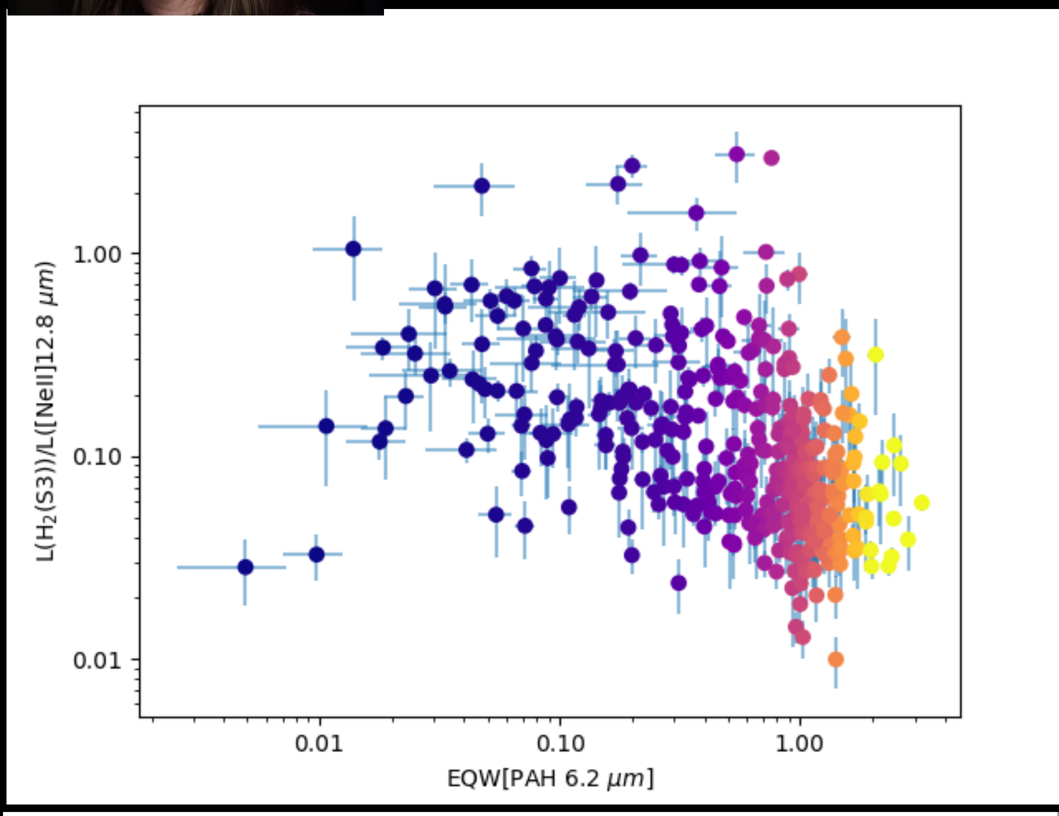


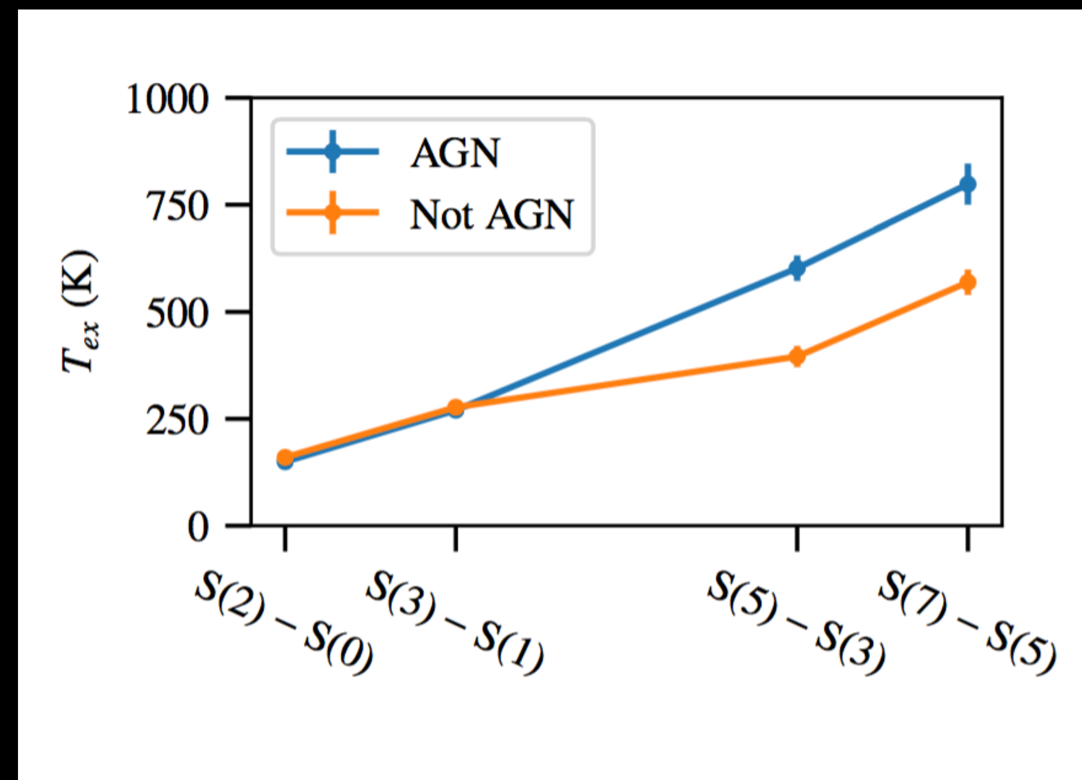
Gathered all spectra for proposals that mention AGN/QSO/Radio Galaxy/Seyfert in their abstract

2200 objects! morphologies of z<0.1 galaxies from PanSTARRS, coming next morphologies for z>0.1 from CFIS

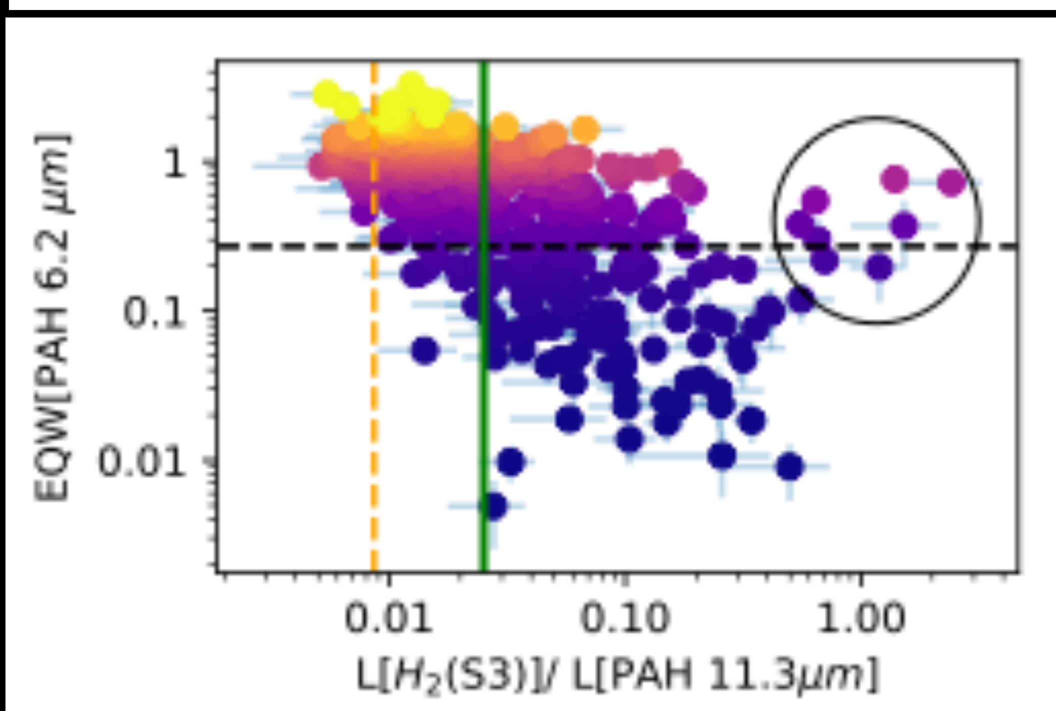
Rebecca Minsle
Bates College

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





Allison Dries-Padilla
University of Hawaii, Hilo



- The relative fraction of warm H2 to IR/PAHs/[NeII] is higher in galaxies harboring an AGN.
- Not a merger effect!
- Dust features span a wider set of properties in AGN hosts.
- H_2 excess <=> [OI],[OIII] outflows (Riffell, Zakamska, Riffell 2020)

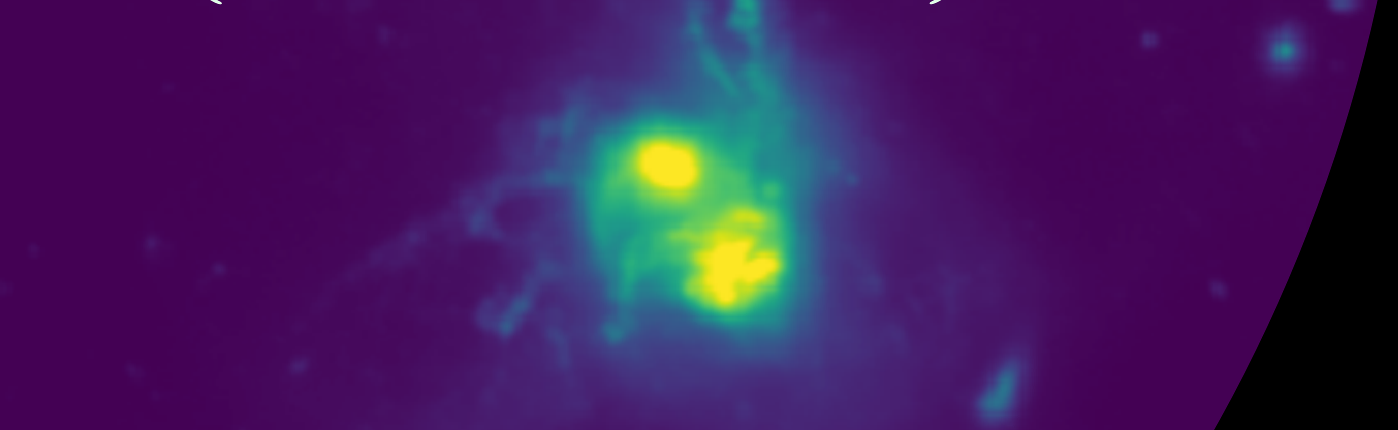
(Lambrides, AP+. 2019, Minsley , AP+ 2020, Dries-Padilla in.prep)

What about feedback ?

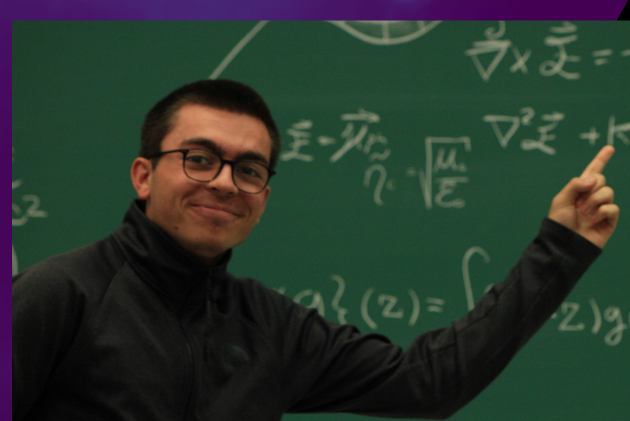
Spatially Resolved optical spectroscopy of multiple AGN hosts

1. [OIII] 5007, 4959 ->multiple components
2. Shocked gas, narrow recombination lines
3. If those sources were at z~2 kinematic features similar to some extremely red QSOs (Perrotta et al. 2019)

1. What are the Ionized gas kinematics and how do they compare with the kinematics of high redshift sources?
2. What are the SFR
3. Do we see circumgalactic medium enrichment?

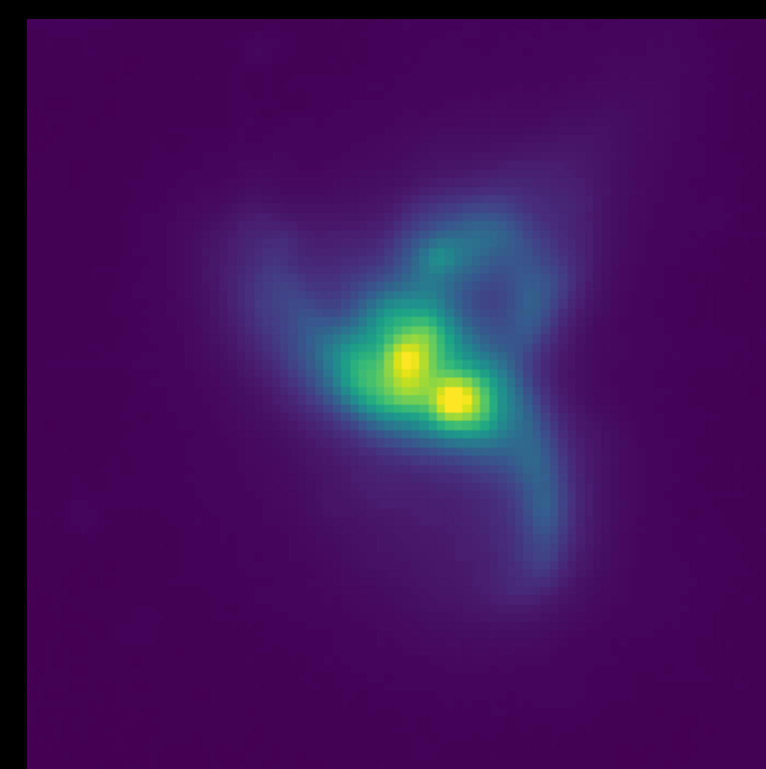


Maya Merhi
Lycoming College IfA REU



Damien Beaulieu
Universite de Laval

Karina Barboza
UCLA IfA/REU



Spatially Resolved optical spectroscopy of multiple AGN hosts

1. Roman's superb spatial resolution, high sensitivity, combined with its low-resolution spectroscopy will produce dual-agn candidates with kpc scale separations.
2. Ground highly multiplex system with higher velocity resolution be used to study the gas kinematics.

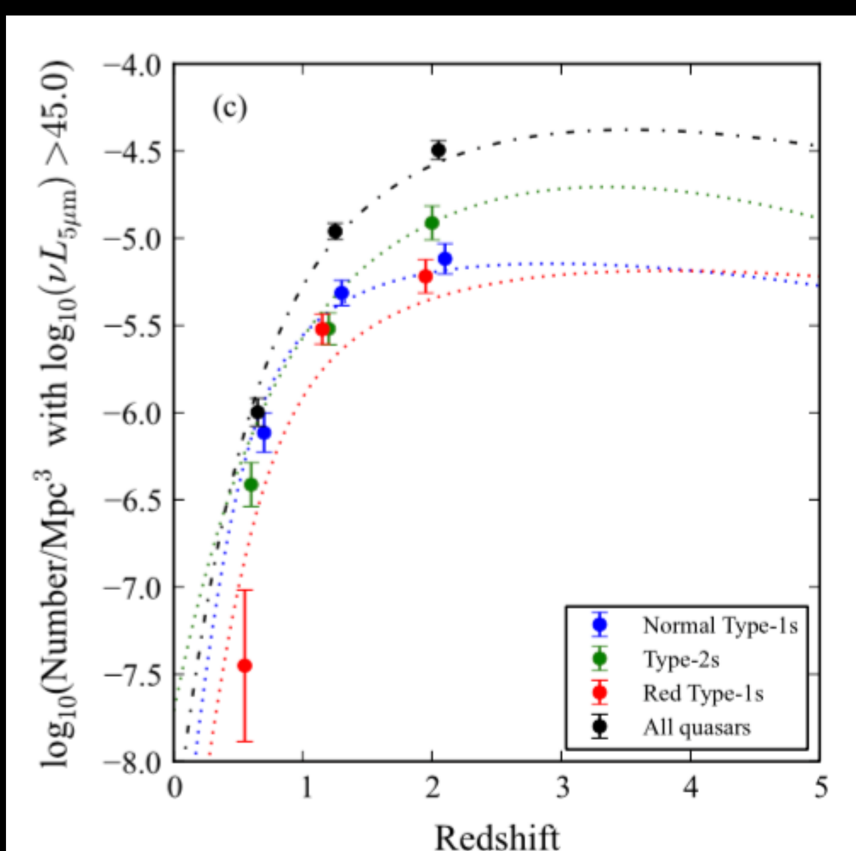
New generation of IR, X-rays, and radio surveys to peer through the dust.

The Nancy Grace Roman Telescope

Roman Space Telescope Imaging Capabilities							
Telescope Aperture (2.4 meter)			Field of View (45′x23′; 0.28 sq deg)		Pixel Scale (0.11 arcsec)	Wavelength Range (0.5-2.0 μm)	
Filters	**R062**	**Z087**	**Y106**	**J129**	**H158**	**F184**	**W146**
Wavelength (μm)	0.48-0.76	0.76-0.98	0.93-1.19	1.13-1.45	1.38-1.77	1.68-2.00	0.93-2.0
Sensitivity (5σ AB mag in 1 hr)	28.5	28.2	28.1	28.0	28.0	27.5	28.3

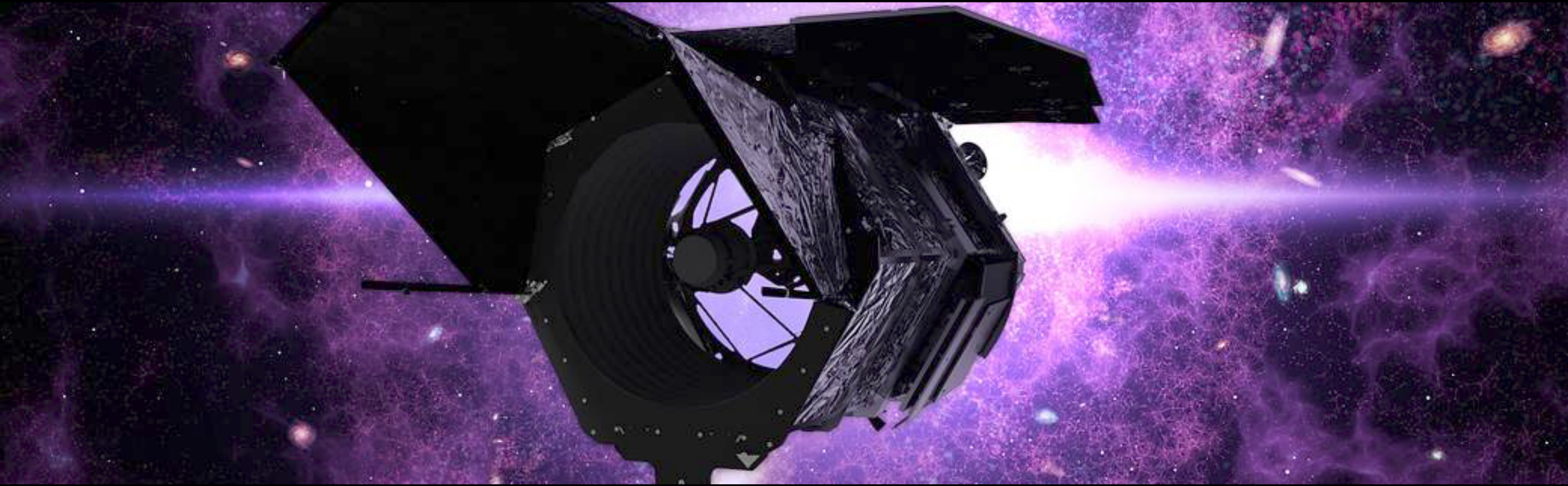
Roman Space Telescope Spectroscopic Capabilities				
	Field of View (sq deg)	**Wavelength (μm)**	**Resolution**	**Sensitivity (AB mag) (10σ per pixel in 1hr)**
Grism	0.28 sq deg	1.00-1.93	435-865	20.5 at 1.5 μm
Prism	0.28 sq deg	0.75-1.8	70-170	23.5 at 1.5 μm

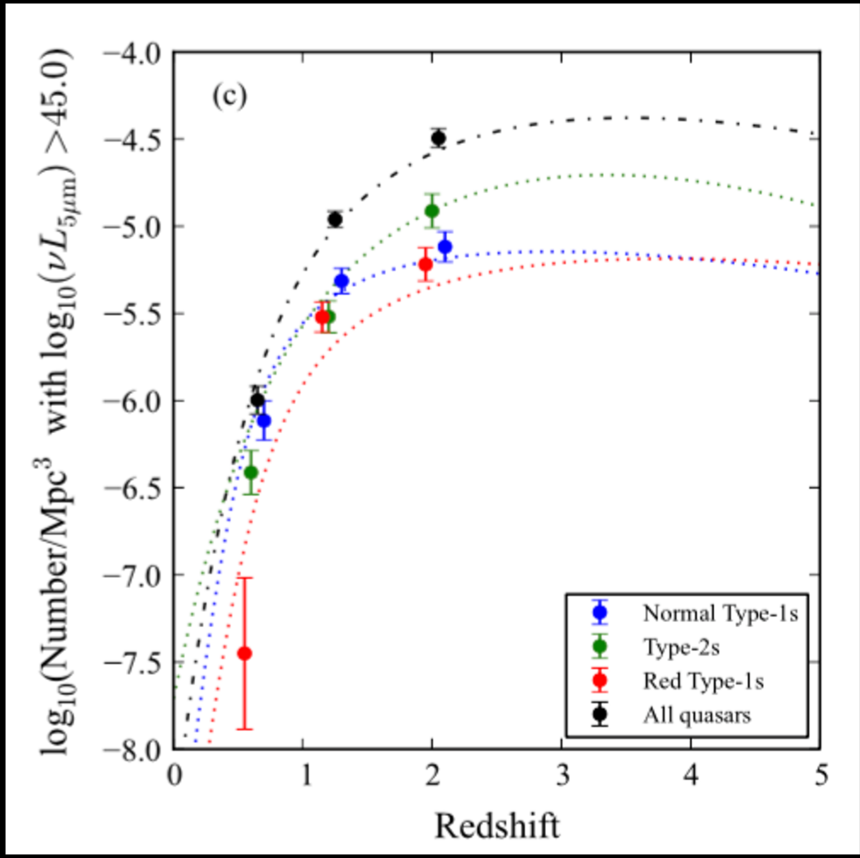
Roman Space Telescope Coronagraphic Capabilities					
	Wavelength (μm)	**Inner Working Angle (arcsec)**	**Outer Working Angle (arcsec)**	**Detection Limit***	**Spectral Resolution**
Imaging & Spectroscopy	0.5-0.8	0.15 (exoplanets) 0.48 (disks)	0.66 (exoplanets) 1.46 (disks)	10^{-9} contrast (after post-processing)	~50



Lacy et al (2015)

The Nancy Grace Roman Telescope





Lacy et al (2015)

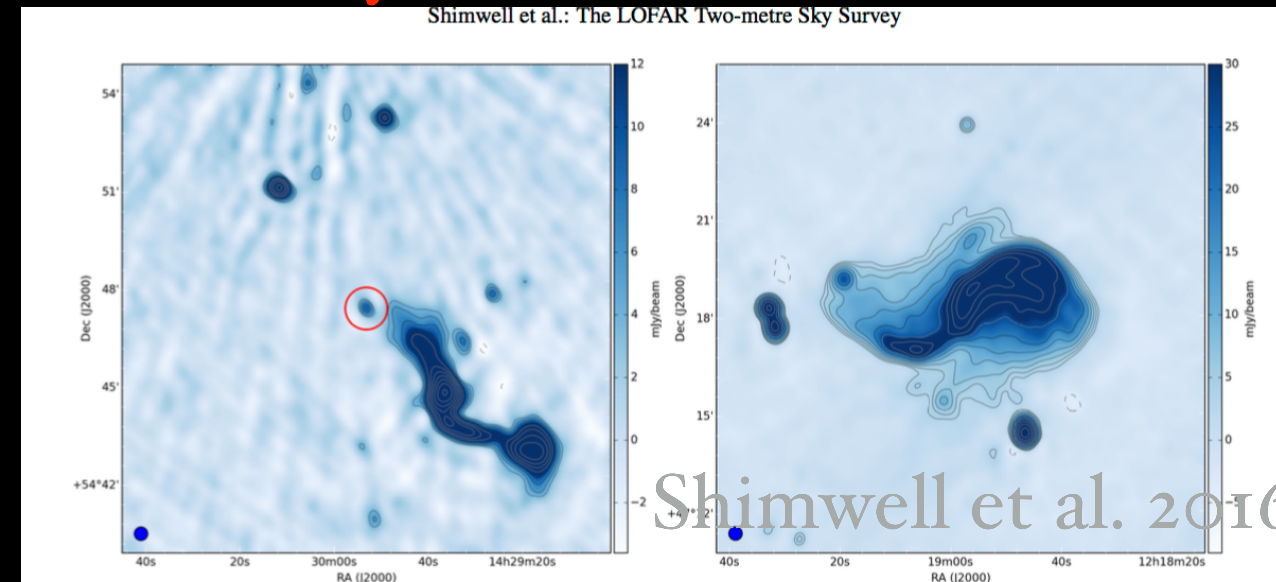
H band multiplexing: in Roman Deep fields =>~ 2E4, 6E4, 1E5, 2E5 at H band magAB=21, 22, 23, and 24 respectively.

Roman-> morphologies, redshifts

MSSE-> star-formation, kinematics, H-band required for SFH at z > 1

Radio missions around the world, X-ray eROSITA

- The ASTRON LOFAR all Northern Sky 120-168 MHz Survey
- 5” resolution
- 100 microJy/beam sensitivity
- 25% of the Northern sky done
- 10% of data available to the public



Shimwell et al. 2016

- The Australian SKA Pathfinder’s Evolutionary Map of the Universe EMU Survey of all of the Southern Sky and up to +30Deg North at ~1.3 GHz
- 10” resolution
- 10 microJy/beam sensitivity
- challenge for EMU => spectroscopic redshifts! (Norris et al. 2011)

- South Africa’s precursor to SKA: MeerKAT
- International GHz Tiered Extragalactic Exploration project (MIGHTEE)
- As of Jan 2019: “early observation of several MIGHTEE pointings have been completed”.

Jarvis et al. 2017, Taylor et al. 2017

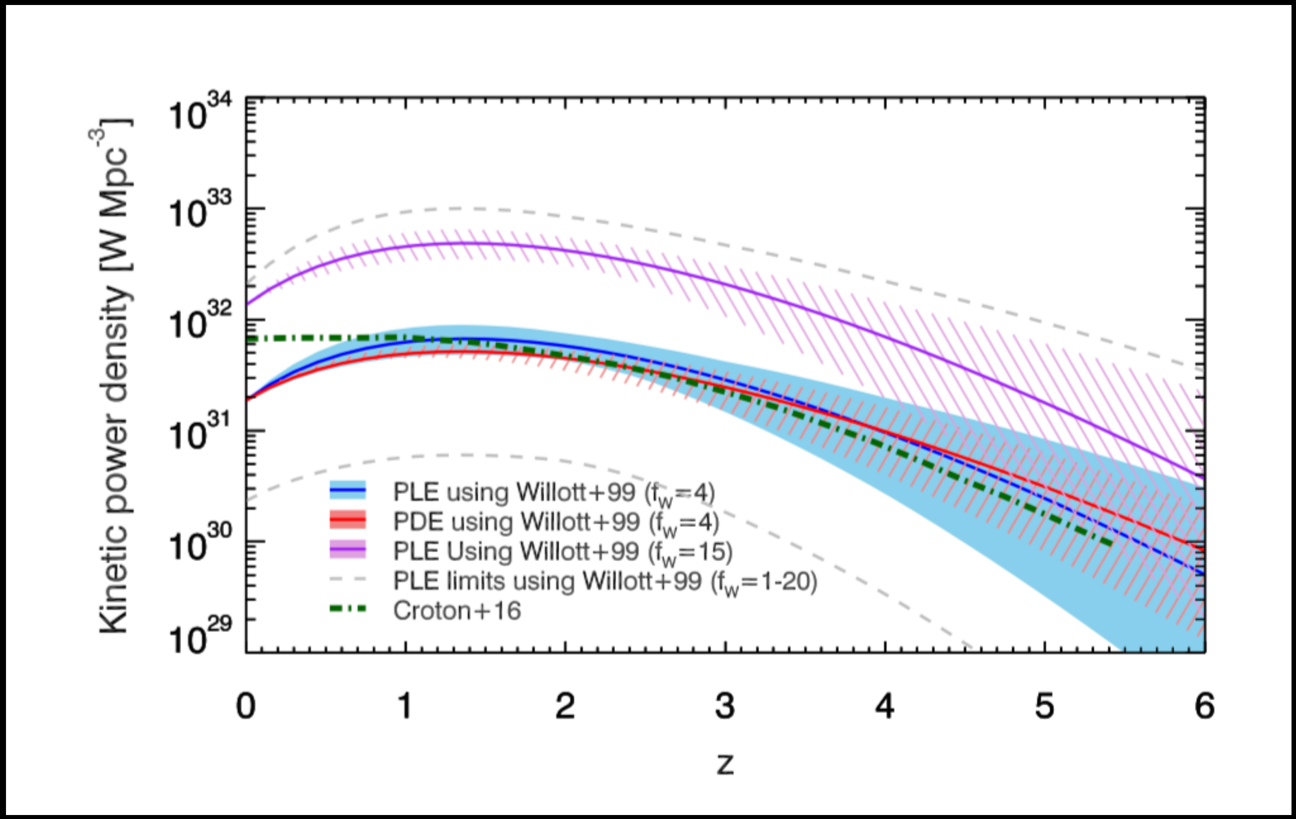
Tier	Frequency (GHz)	Sensitivity (rms)	Resolution (arcsec)	Area (degree^2)	Time (hours)
Tier 1	1.4	5.0μJy	8.5	1000	2400
Tier 2	1.4	1.0μJy	8.5/3.5	35	1950
Tier 3	1.4	0.1μJy	3.5	1.0	1700
Tier 4	12	1.0μJy	3.2/0.4	0.25	700
Tier 5	12	0.2μJy	0.4	0.01	440

How do distinguish between high- and low-excitation accretion modes via analysis of emission line ratios

Why are low-redshift massive galaxies are less luminous than cosmological simulations predict:

(1) quasar mode feedback at high accretion rates and

(2) radio mode feedback at lower accretion rates when AGN drive jets and cocoons that heat the circum-galactic and halo gas which shut down cooling in massive haloes and bring the bright end of the luminosity function into agreement with observations.

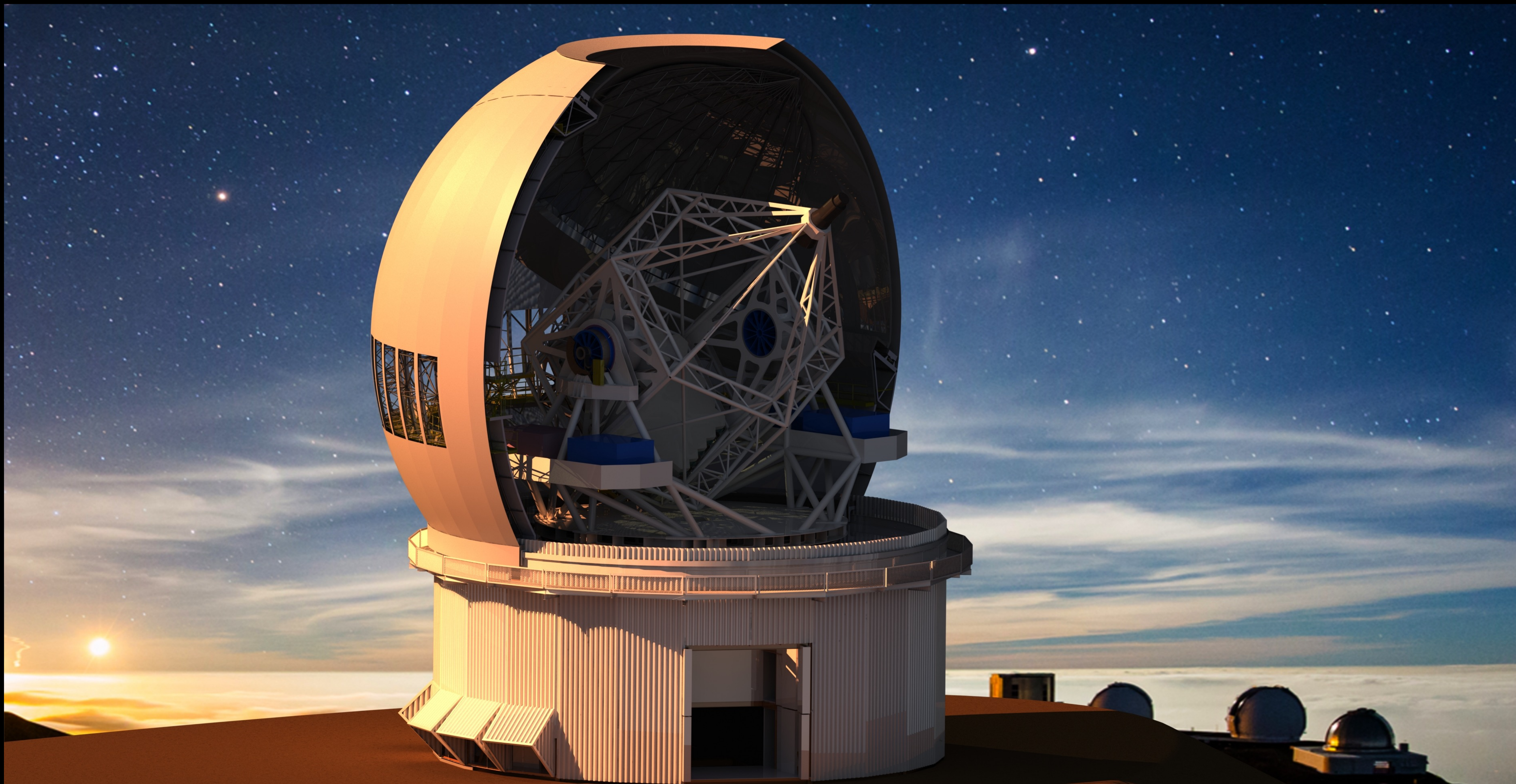


Radio surveys of AGN suggest that the kinetic luminosity from radio AGN may be sufficient to balance the radiative cooling of the hot gas at each cosmic epoch since redshift 5. However fewer than 20 objects at *z*~5 were used. (Smolcic et al. 2017)

Roman can trace morphologies and redshifts, spatially separate host and AGN.

MSE can leverage current and future radio survey to find thousands at this redshift.

Next step: The Maunakea Spectroscopic Explorer



http://mse.cfht.hawaii.edu
Detailed Science Case (200 pages + Appendices): https://arxiv.org/abs/1606.00043
Concise Overview of MSE (10 pages): https://arxiv.org/abs/1606.00060
AP+ MSE AGN working group 2019: https://arxiv.org/pdf/1905.10489.pdf

Next step: The Maunakea Spectroscopic Explorer

Table 4: MSE in comparison to other planned MOS instruments on 8-m class telescop

	8 - 12 m class facilities						
	VLT / MOONS		Subaru / PFS		MSE		
Dedicated facility	No		No		Yes		
Aperture (M1 in m)	8.2		8.2		11.25		
Field of View (sq. deg)	0.14		1.25		1.52		
Etendue	7.4		66		151		
Multiplexing	1000		2394		4329		
Etendue x Multiplexing	7400 *(= 0.01)*		158004 *(= 0.24)*		653679 *(= 1.00)*		
Observing fraction	< 1 ?		0.2 (first 5 years) 0.2 - 0.5 afterwards ?		1		
Spectral resolution (approx)	4000	18000	3000	5000	3000	6500	40000
Wavelength coverage (um)	0.65 - 1.80	windows	0.38 - 1.26	0.71 - 0.89	0.36 - 1.8	0.36 - 0.95 50%	windows
IFU	No		No		Second generation		

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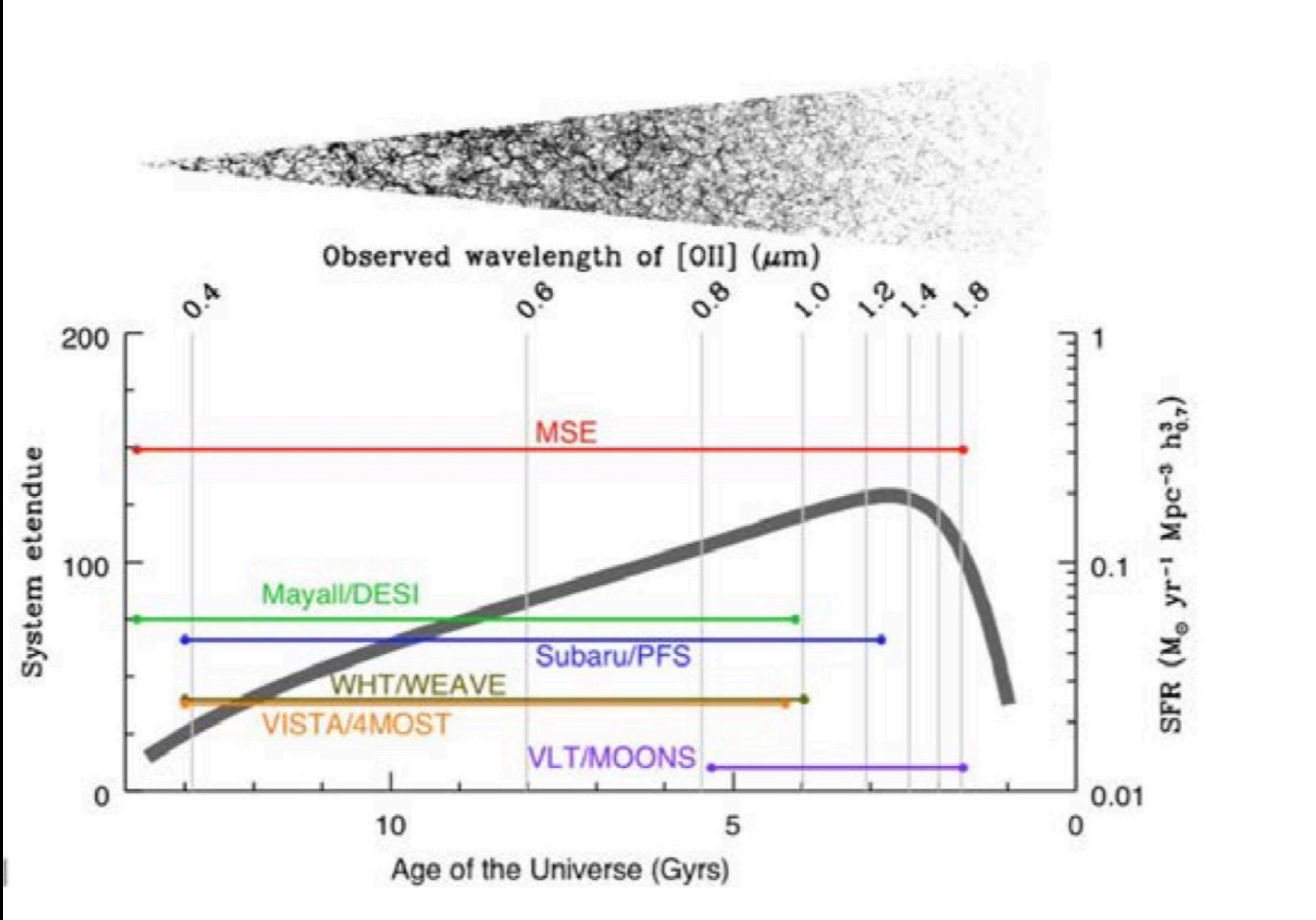
Conclusions

- Obscured and un-obscured populations of AGN evolve differently.

- To understand why this is and how it affects our models of black hole growth and star-formation more targets are needed at redshifts > 1.6

- IR, X-ray, and radio missions are poised to find such populations but need MSE for rest-frame UV-optical spectra to redshifts, the amount of reddening, and star-formation histories.

Next step: The Maunakea Spectroscopic Explorer



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Where, when, and how were all these black-holes formed?

- A multi-epoch reverberation mapping campaign with MSE will yield 2000 – 3000 robust time lags
  → an order of magnitude more than the expected yields from current campaigns,
- Accurate SMBH mass measurements for the largest sample of quasars to date and unprecedented mapping of the central regions

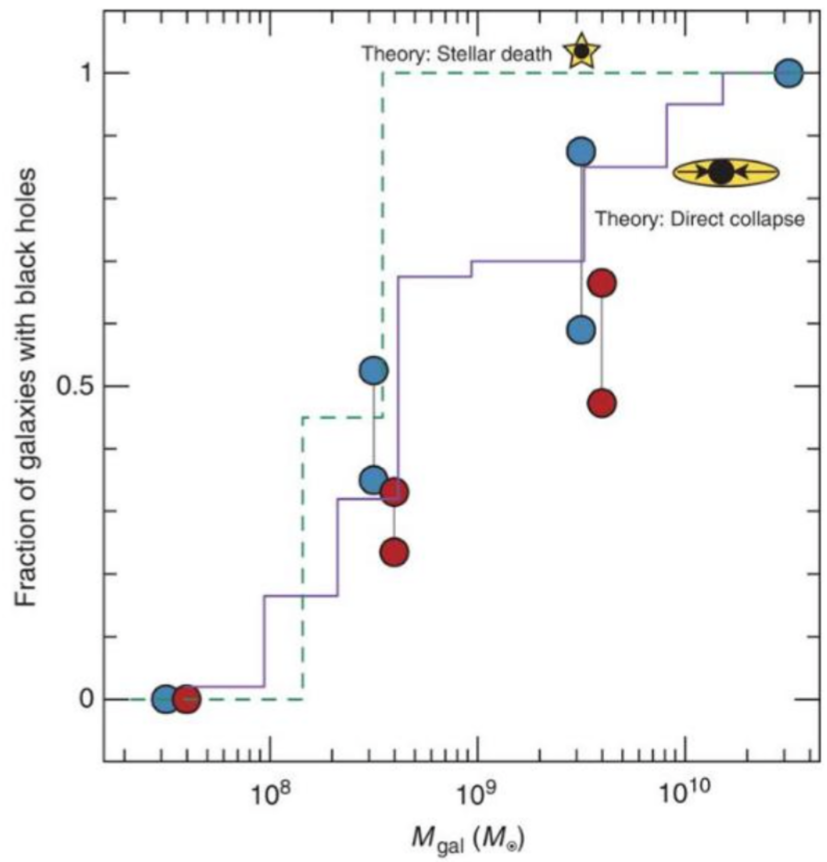
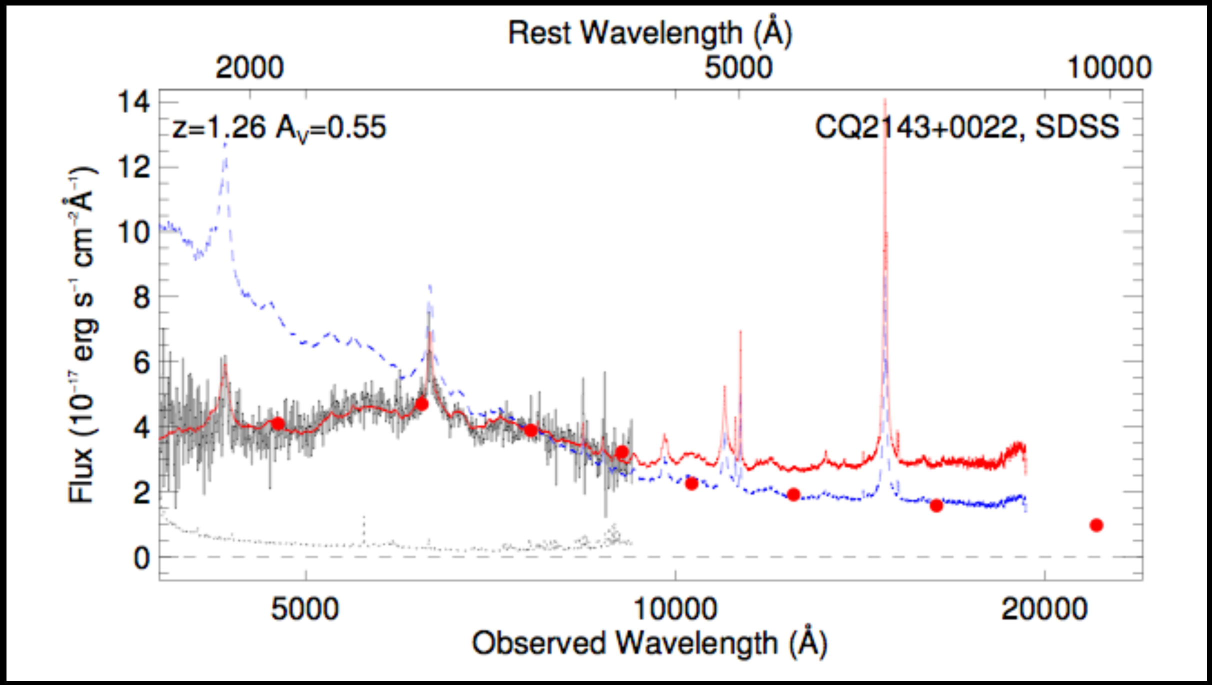


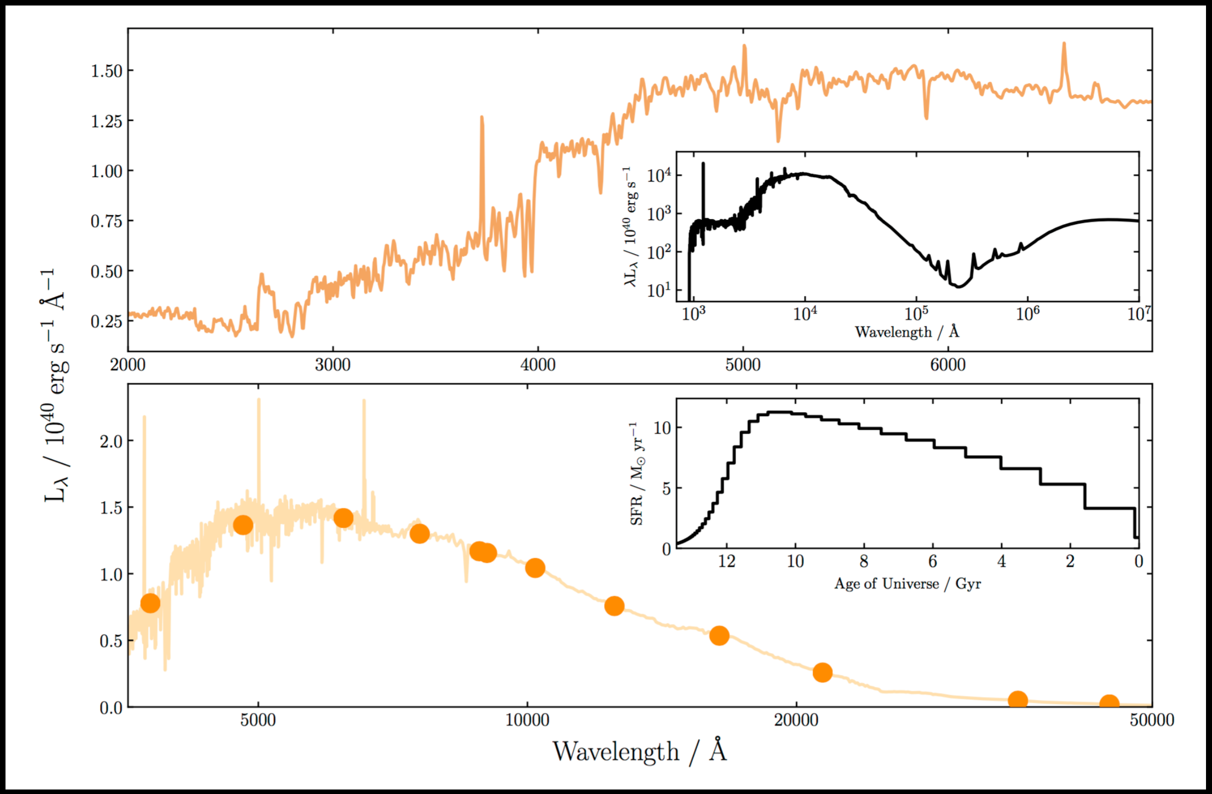
Figure 90: Expected fraction of galaxies with $M_{gal} < 10^{10}$ $M_\odot$ that contain black holes with $M_{BH} > 3 \times 10^5$ $M_\odot$, for high efficiency massive seed formation (solid purple line), as well as stellar deaths (green dashed line). Figure from Greene et al. (2012).

Reddening, star-formation histories, excitation

- use hydrogen recombination lines
- optical through NIR, fits of the extinction properties across the disk
- gas excitation conditions



Fynbo et al. 2013



Carnal et al. (2017)

However several questions remain:

(1) accuracy of models used to estimate the kinetic luminosities of radio-loud AGN,

(2) estimates of the accretion rates,

(3) stellar population/star formation characterization of radio galaxies.

axies with a young stellar population and active star formation.

Next step: The Maunakea Spectroscopic Explorer

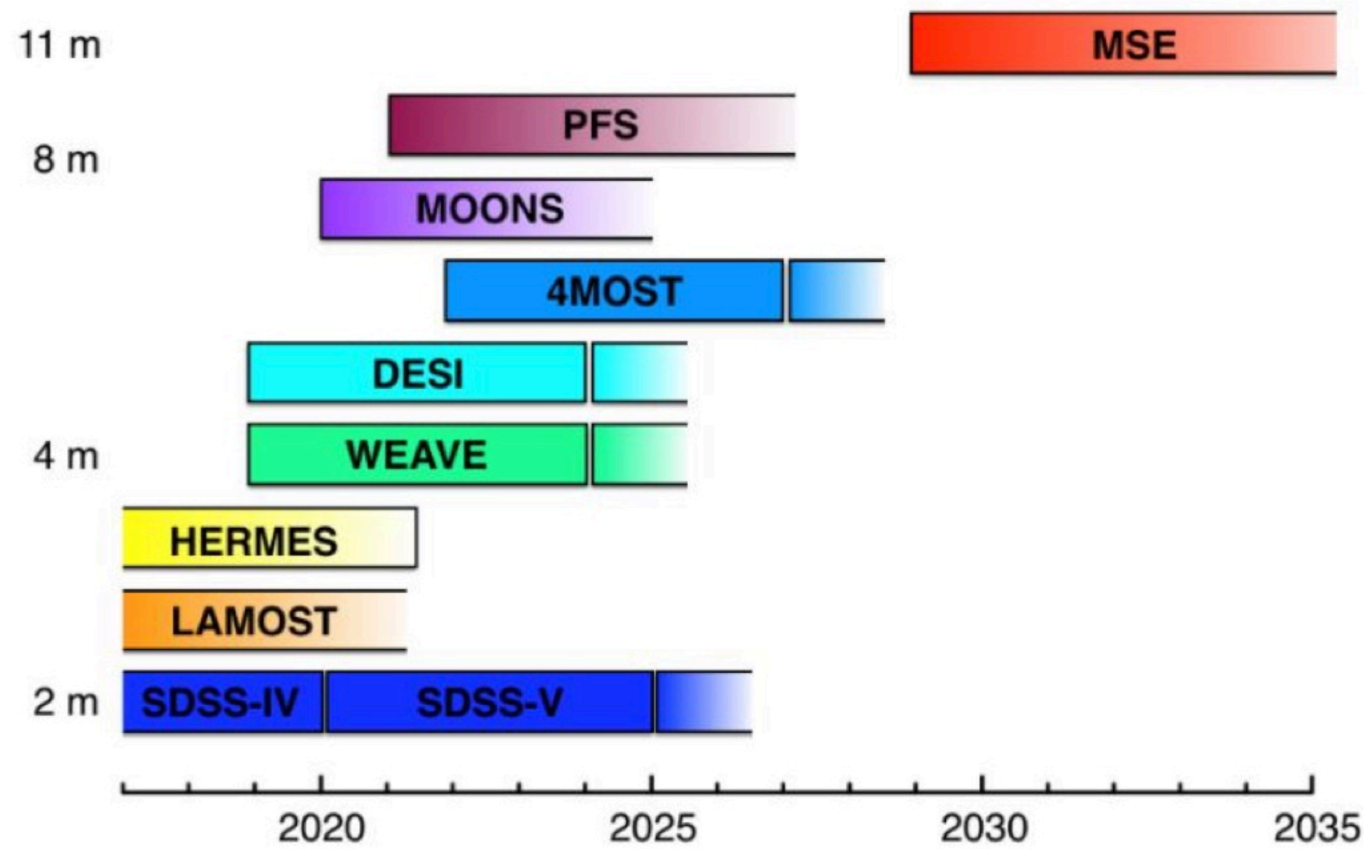


Figure 1: Current anticipated timelines (horizontal axis) for existing and planned massively multiplexed spectroscopic surveys according to telescope aperture (vertical axis). Bounded boxes indicate the duration or lifetime of the survey or facility; absence of a vertical solid line indicates the facility has no clear end date.

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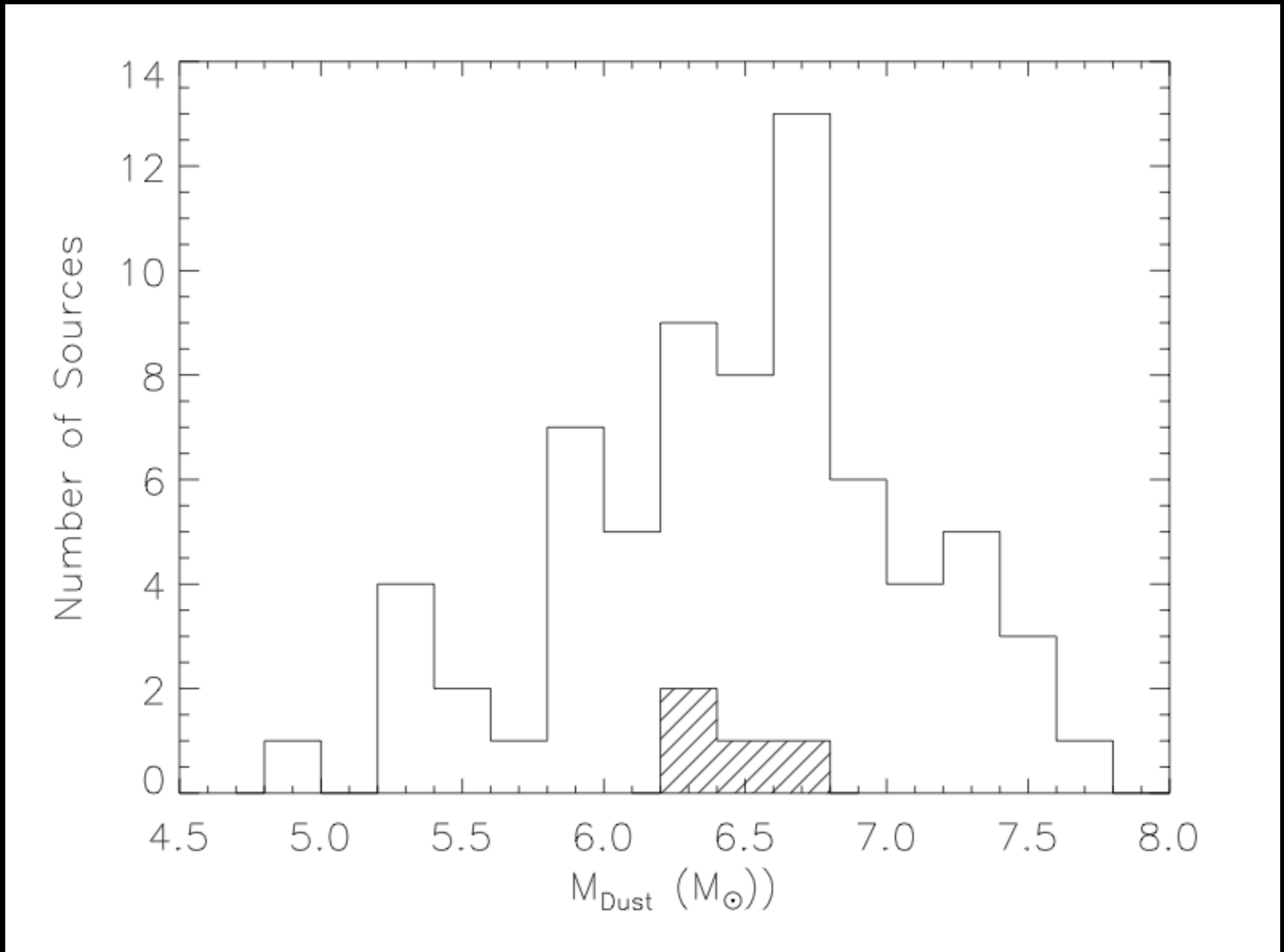
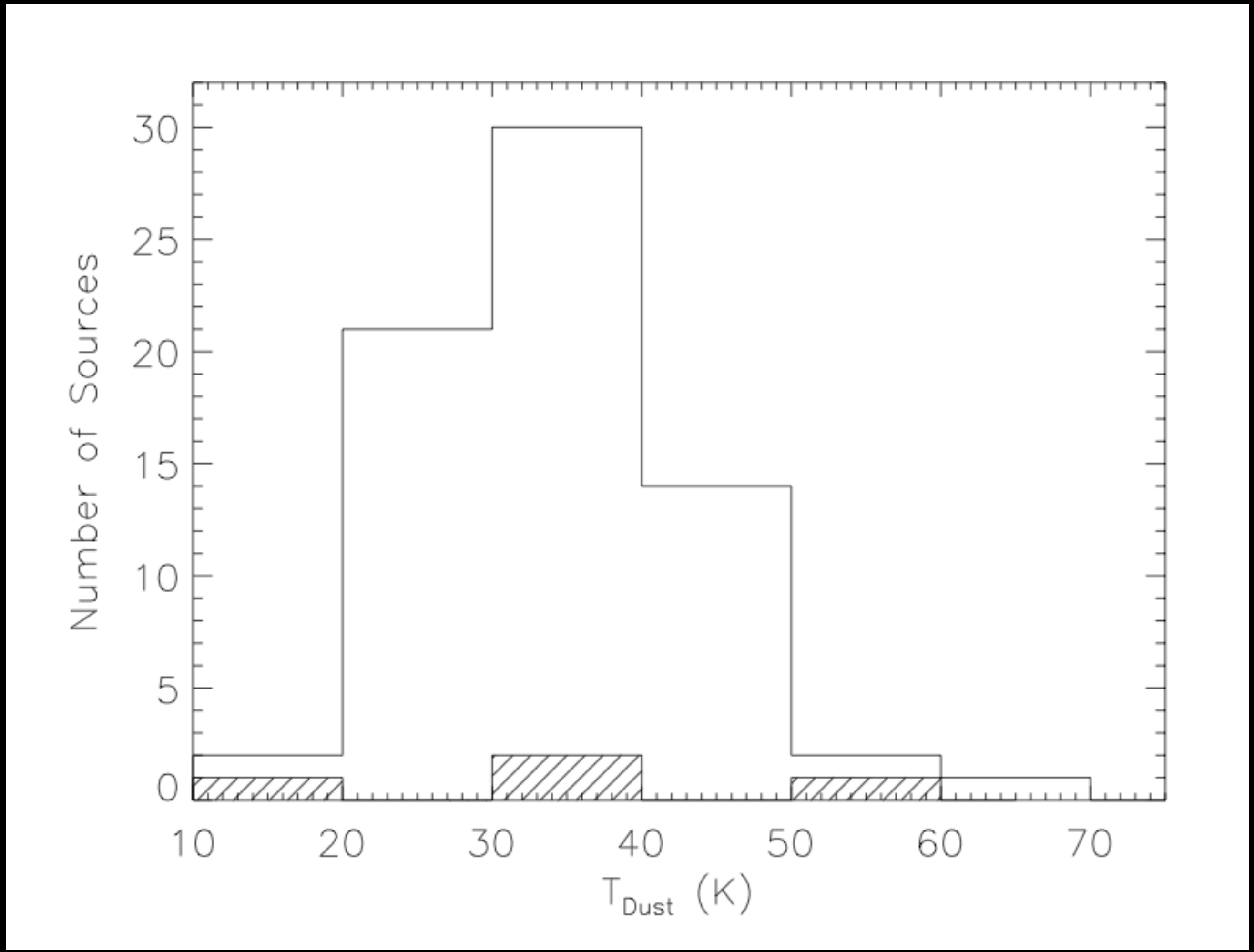
Dust Masses and Temperatures



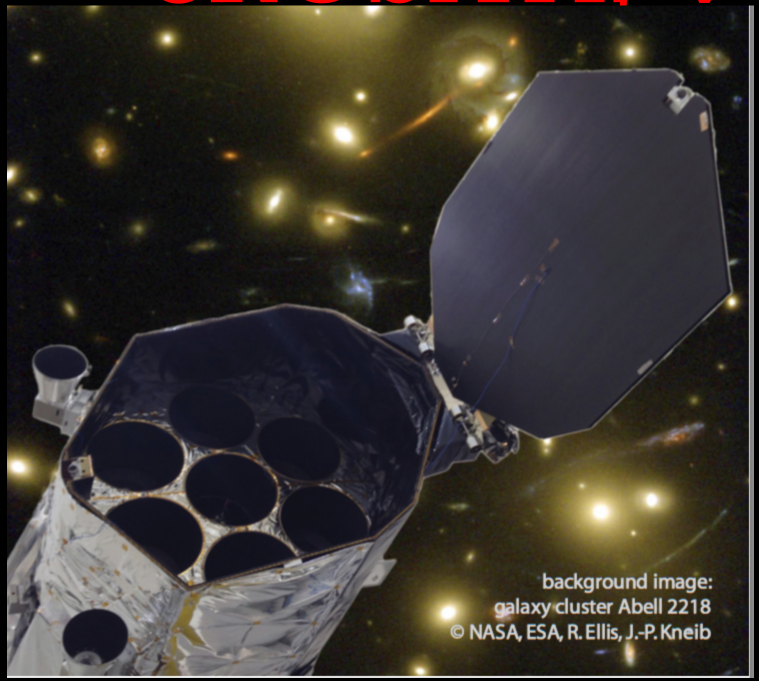


Petric et al. 2015

Statistical analysis suggests that dust masses in the hosts of QSOs are similar to those of nearby ellipticals (from Smith et al. 2012) but lower than those of nearby star-forming galaxies (from Skibba et al. 2011)

Dust masses and temperatures of QSO1s and QSO2s are similar but L160um higher for QSO2s.

eROSITA, Very Large Array Sky Survey,



VLASS Summary	
Frequency	2-4GHz
Resolution	2.5 arcsec
Sky coverage	All Sky North of Dec. -40 deg. (33885 deg^2)
Sensitivity per epoch	120 μJy RMS
Combined (3 epoch) sensitivity	69 μJy RMS
Polarization	I,Q,U
Cadence	3 epochs separated by 32 months
Start Date	September 15 2017
Expected number of sources	~5,000,000

Juneau et al. (2013) => z=0.3-1 both X-ray and MIR miss a large fraction of AGN

eROSITA all Sky Survey on board of the Spectrum-Roentgen-Gamma satellite (Merloni et al. 2012) will detect about 3 million AGN to z≃ 6

~10^5 obscured AGN, spatial resolution 26” in survey mode, faintest eRosita~21

Very Large Array Sky Survey VLASS

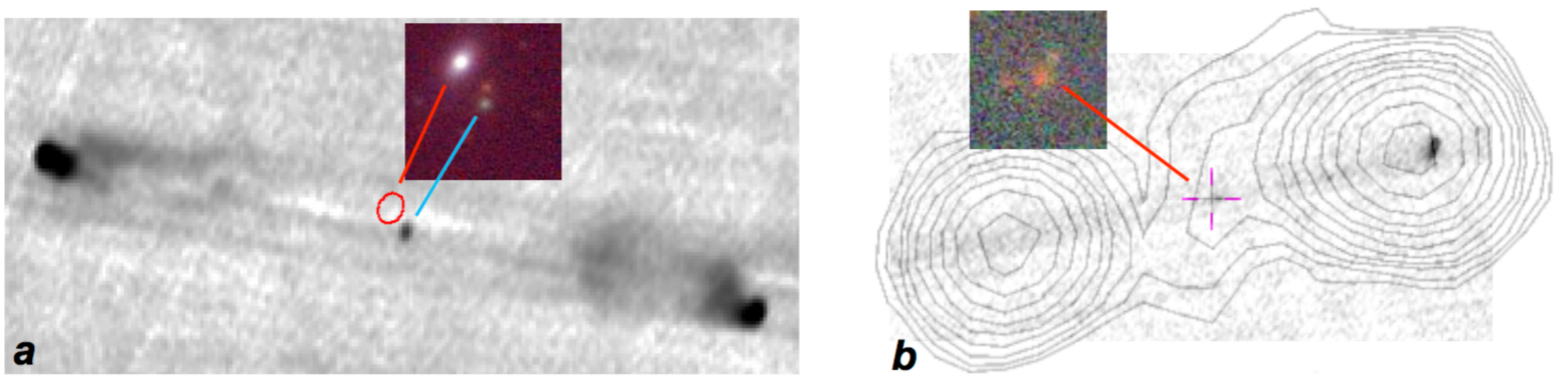


Figure 1. VLASS images of (a) J1452–1311 and (b) J0452+0247, with Pan-STARRS insets of 25" and 15"

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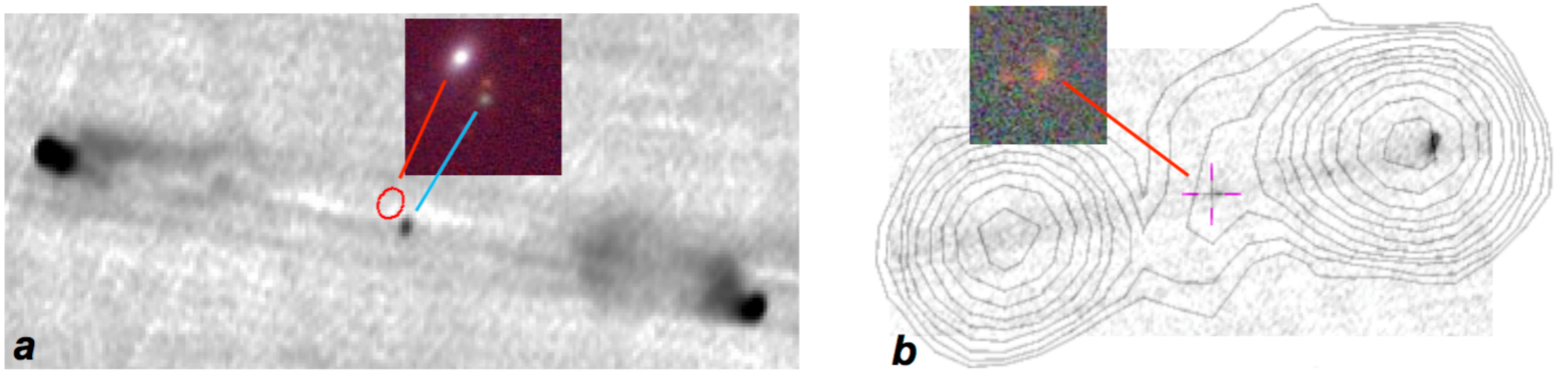
- Provides a reference radio sky at high angular resolution for multi-wavelength studies
- In conjunction with WISE, photo-zs from these surveys, will be able to determine accurate demographics of radio- loud/intermediate population, important for constraining AGN feedback theories.
- VLASS will provide a baseline for follow-up of AGN flares.

Very Large Array Sky Survey VLASS



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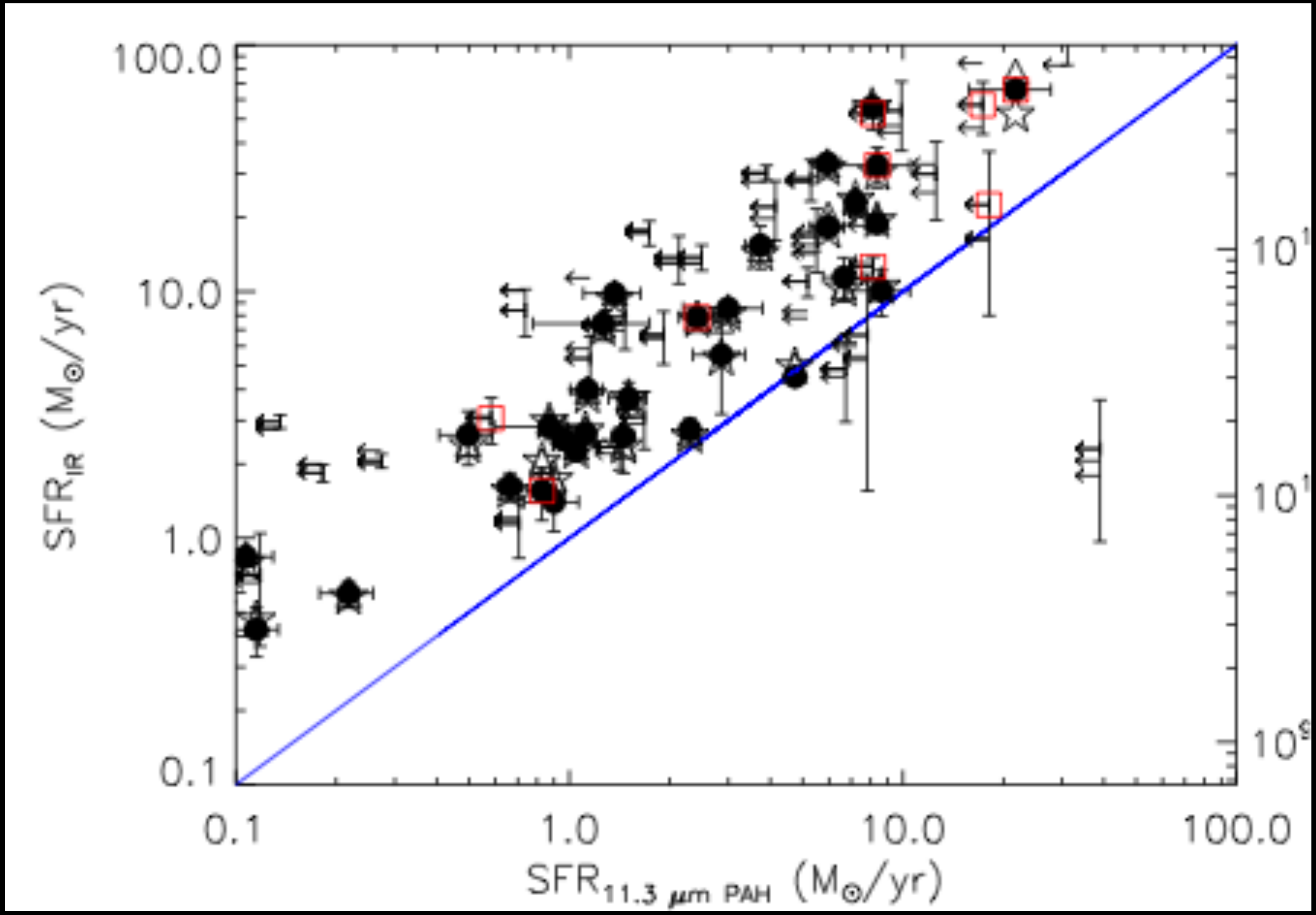
Star-Formation Indicators



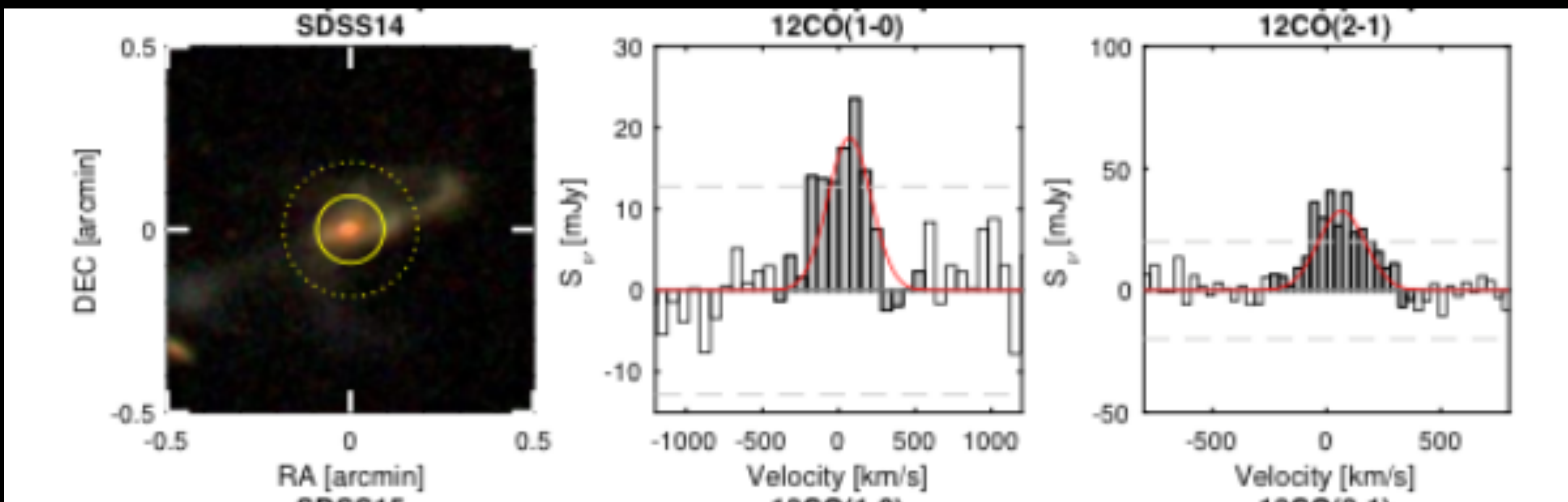
Petric et al. 2015

Estimates of star-formation based on the **FIR continuum emission** correlate to those based on the **11.3 microns PAH feature**.

However, star-formation rates estimated from the FIR luminosities are **higher** than those estimated from the 11.3 microns PAH emission.

Cold gas in QSO Hosts

Jameeka Marshall
University of Hawaii, Hilo,
Gemini Observatories



QSO1 and QSO2s have CO detection rates at similar M*.

QSO1 and QSO2s have similar FIR/CO ratios.

TBD: 26.3 hrs SOFIA program to compare 158 micron [CII]

Next step: The Maunakea Spectroscopic Explorer

Survey	Area (sq. deg)	Depth (Selection band)	Depth (equivalent i)	Sample size
S1-W	3200	$i < 23$	$i < 23$	6M
S1-D	100	$i < 24.5$	$i < 24.5$	800k
SDSS-Legacy	8032	$r < 17.8$	$i < 16.8 - 17.8$	928k
6dF	17046	$K < 12.75$	$i < 15.6$	150k
GAMA	300	$r < 19.8$	$i < 18.8 - 19.8$	238k
DESI	14000	$r < 19.5$	$i < 18.5 - 19.5$	9.8M
WAVES-Wide	1500	$i < 21$	$i < 21$	1.0M

Table 7: The baseline MSE extragalactic surveys discussed in this chapter, S1-W and S1-D, are compared with other relevant spectroscopic surveys in terms of their area, depth and sample size. To compare r−band selected surveys with the proposed i−band selection, we assume a colour range of $(r - i) = 0 - 1$, typically of galaxies at $0 < z < 0.2$. This is appropriate to determine the faintest i-band magnitude for which a r-selected sample would be complete.

http://mse.cfht.hawaii.edu
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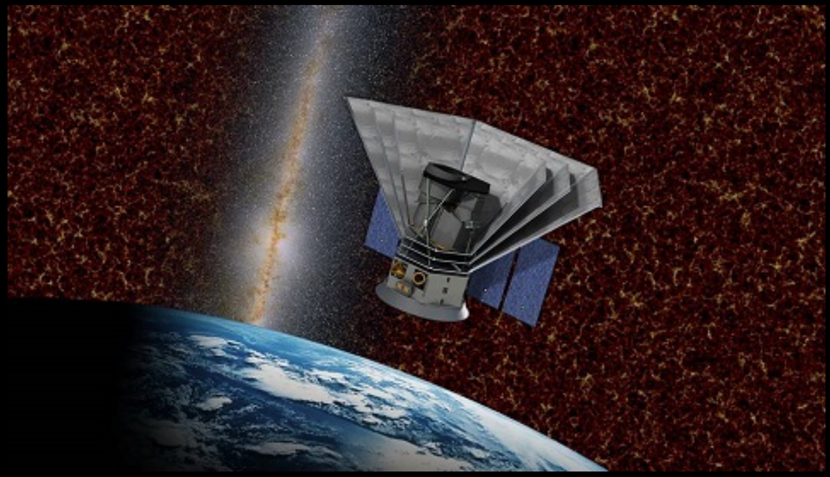
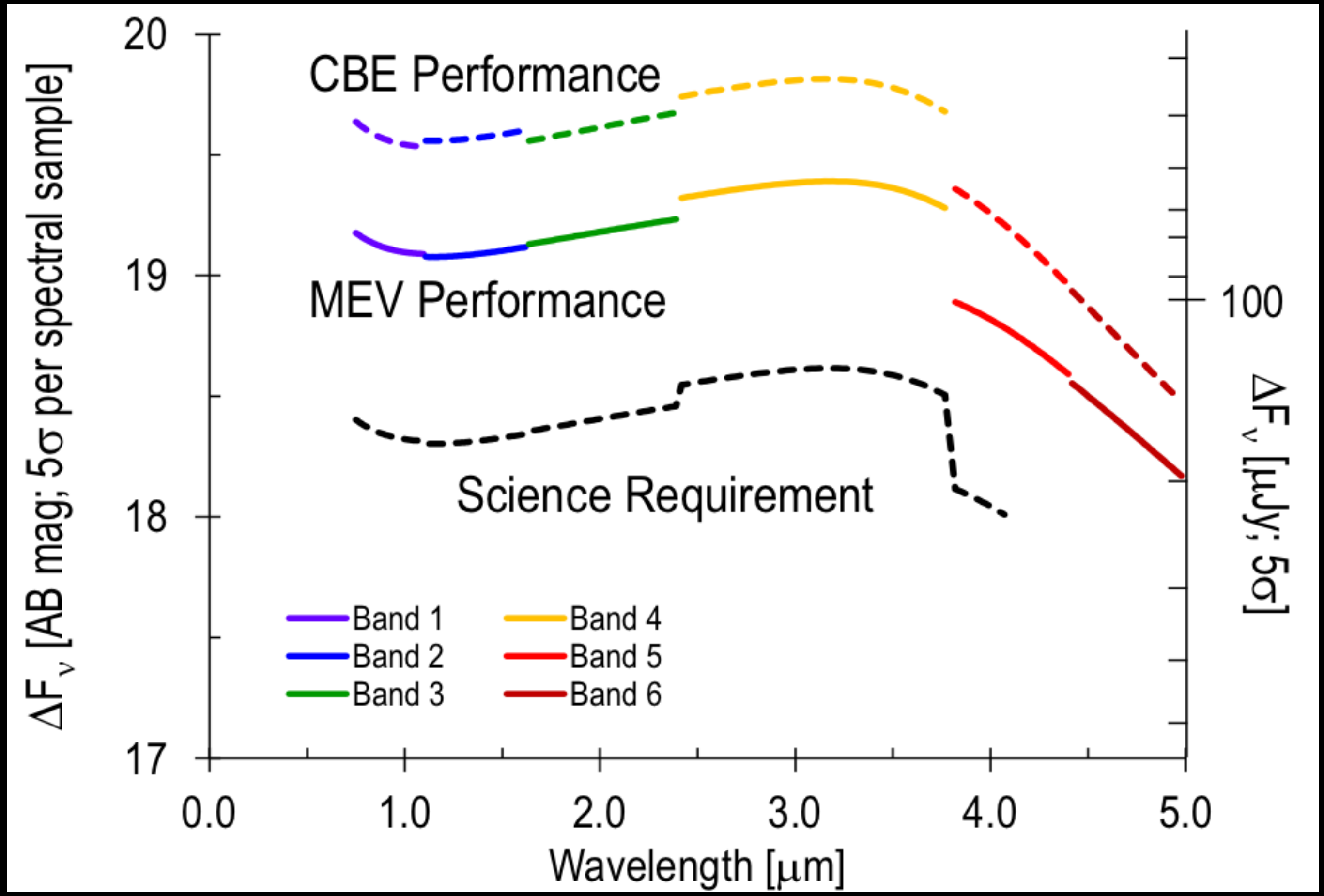
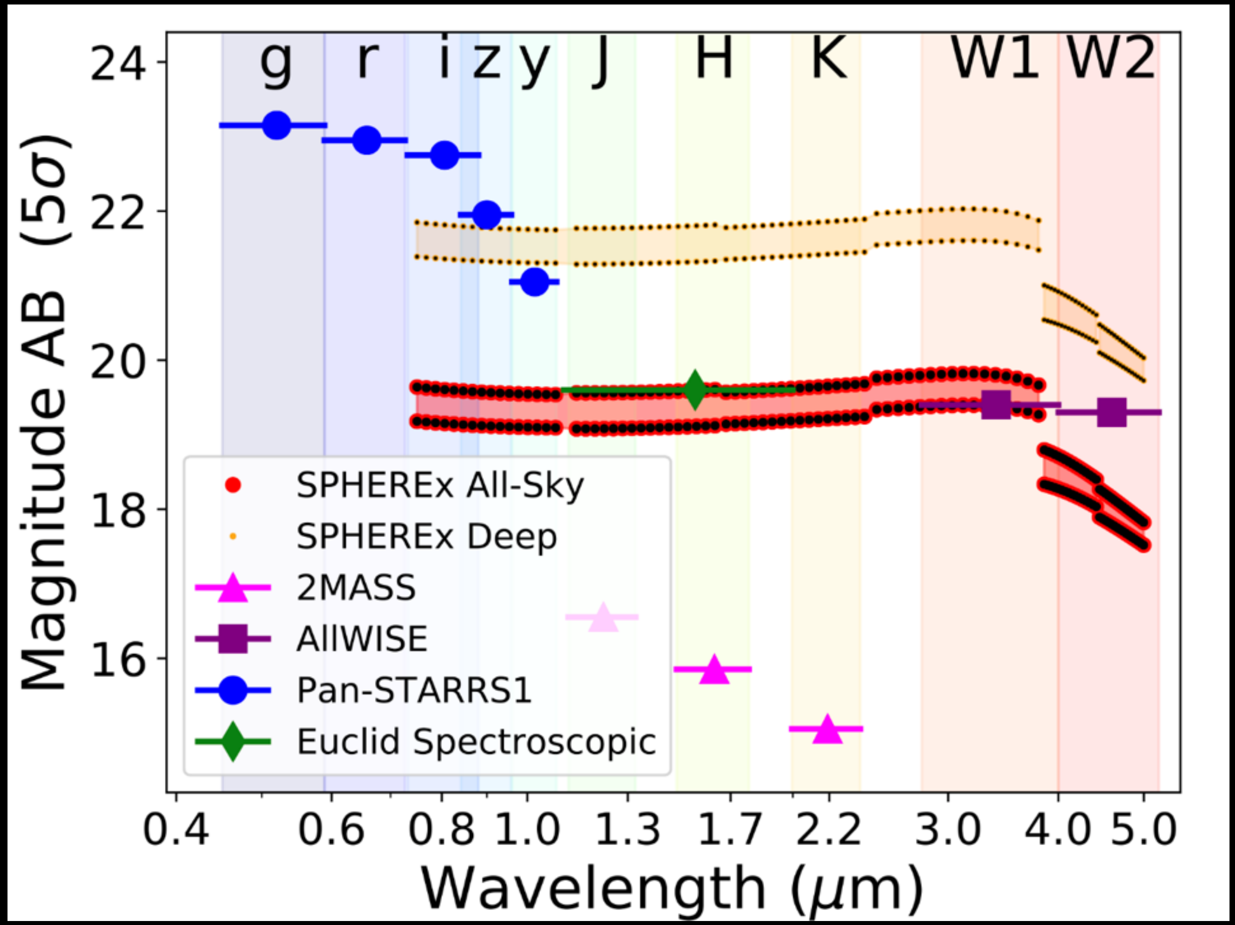
SphereX — the Spectro-Photometer for the History of the Universe, epoch of reionization and Ices Explorer

- All-sky spectral survey
- 6.2” resolution,
- 0.75-5.0 microns
- R~41.4-135 spectral resolution







- SPHEREx can isolate the AGN using MIR colors (~3000 QSO2s at z>0.8)
- IR and optical reverberation mapping of bright AGN (i <18mag)
- Star-formation activity in bright AGN using PAH 3.3 microns

MSE - requirements

- Wavelength coverage for spectroscopic redshifts, star-formation histories, and BH mass estimates
  - [OII] 3727, 3729A, [OIII] 5007, Hbeta, [SII]6716+6731, Halpha, [NII] 6548,6583
  - Ly alpha 1216 Å for z>2.2
  - 4000 A break for z<3.5 i.e. [3850-3950A] and [4000 4100] ->traces the old stellar population, W([OII]) current star-formation activity, W(Hdelta) indicates the presence of A-type stars and is sensitive to star formation that took place up to 1 Gyr ago
  - use redshift bins to increase the wavelength coverage
- Resolution requirements
  - R~ 3000 for sky subtraction and line width estimates
- Sensitivity requirements
  - mAB ~ 24 in 1 hr in H-band
- Other
  - sub-arcscond positoning to help alleviate confusion of radio/IR observations
  - # of targets => ?10^4 to 10^5 from SphereX, and radio surveys

Correlation, co-evolution, or just a bit of influence

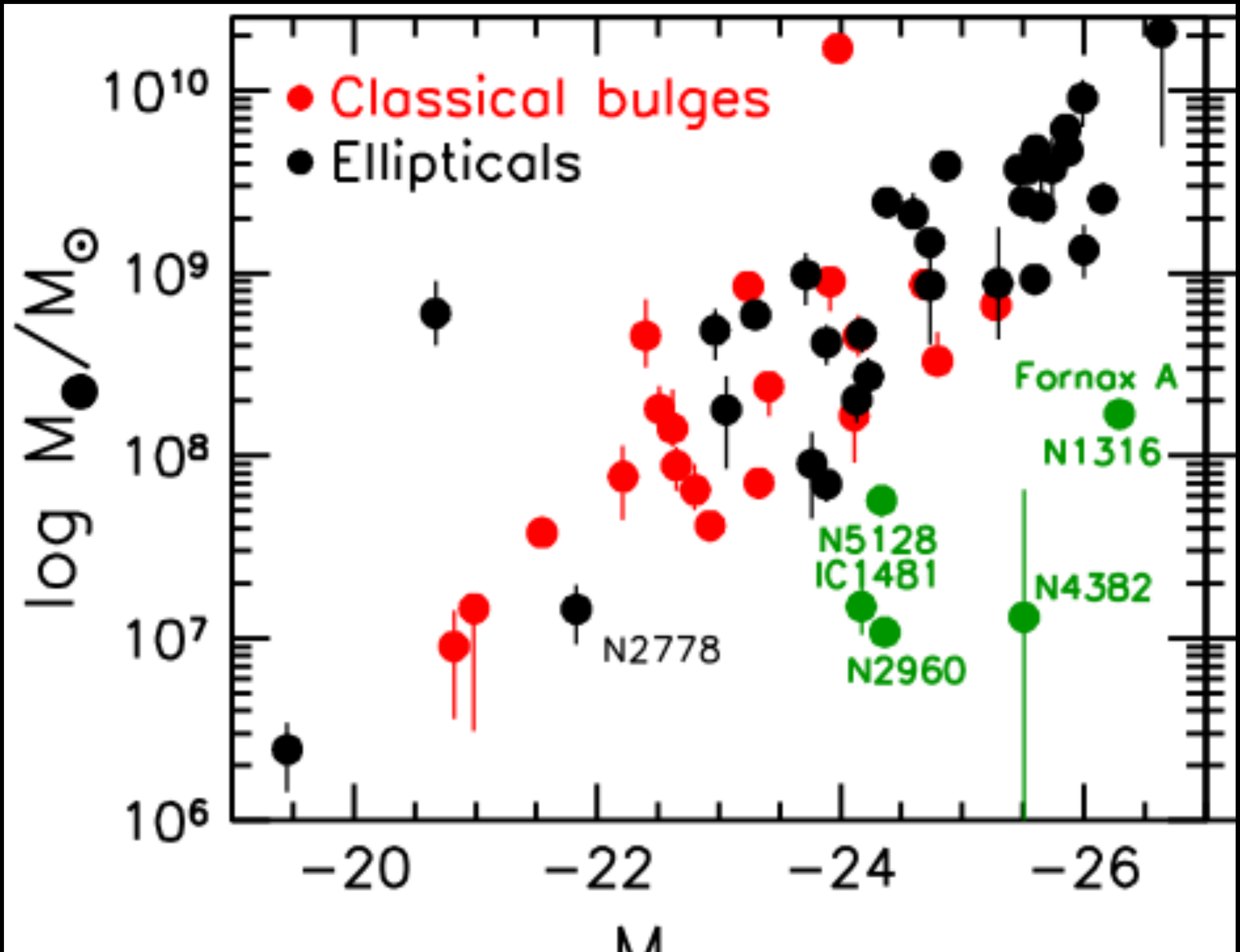


Figure 14

Kormendy & Ho (2013)

Galaxy mergers (Jahnke & Maccio 2018) are able to produce galaxies whose central masses correlate with their bulge masses.

The scatter in the correlation => need for other mechanisms (e.g. feedback) at play, processes that can explain the scatter and also reconcile predicted and observed galaxy functions.