# Dusty Quasars in a Teenage Universe

*How will MSE help us understand them?*

**Andreea Petric** ( IfA/CFHT/MSE)
Mark Lacy (NRAO)
Yjan Gordon (U. of Manitoba)
Chris O'Dea (U. of Manitoba)
Sara Ellison (U. of Victoria)
Xiaohui Fan (Steward Observatory, U. of Arizona)
Claudia Lagos Urbina (U. of Western Australia)
Yue Shen (U. of Illinois at Urbana-Champaign)
Andy Sheinis (CFHT)

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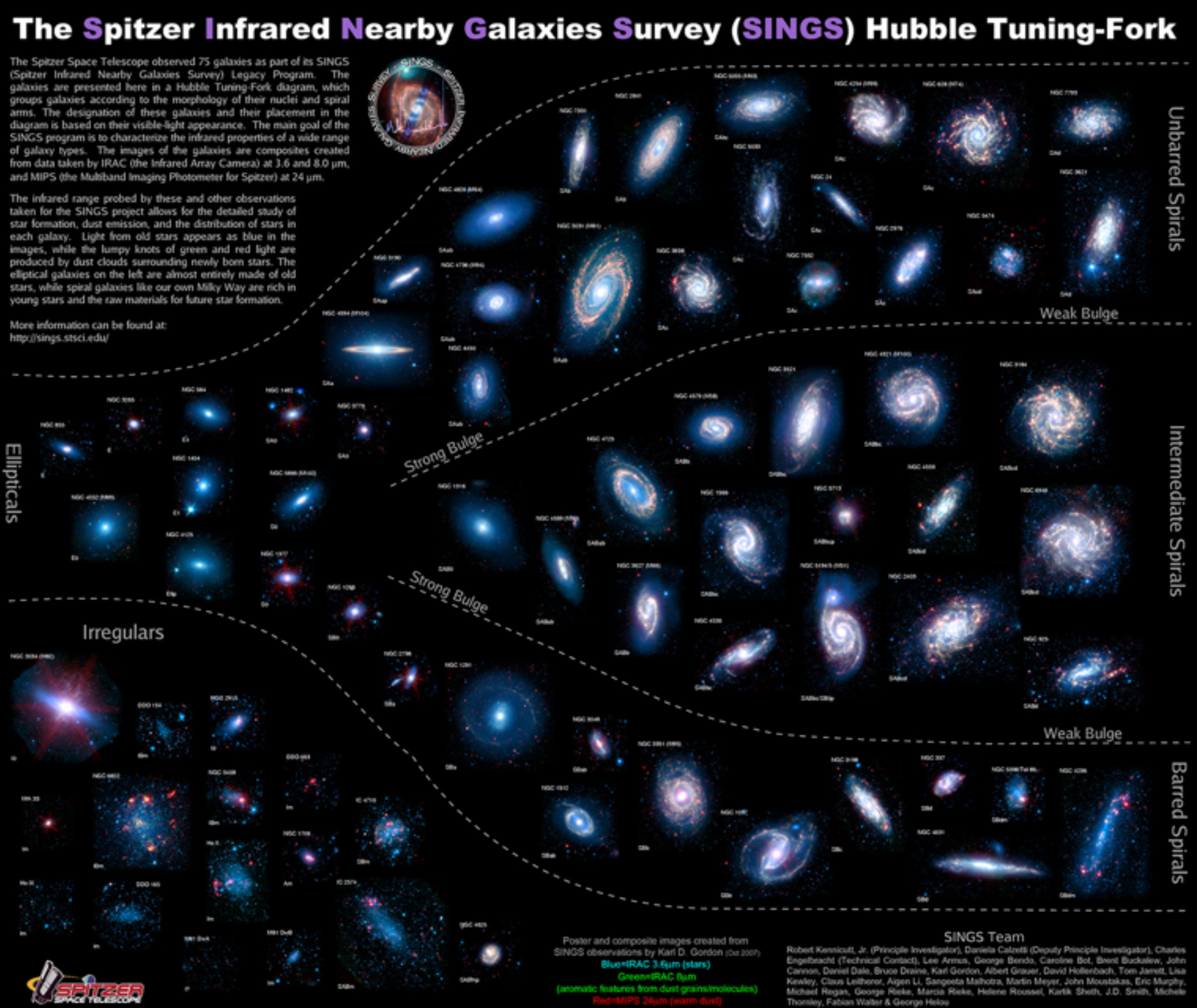
~ Pursuing new Knowledge brings bountiful rewards

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



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

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

*Kormendy & Ho (2013)*

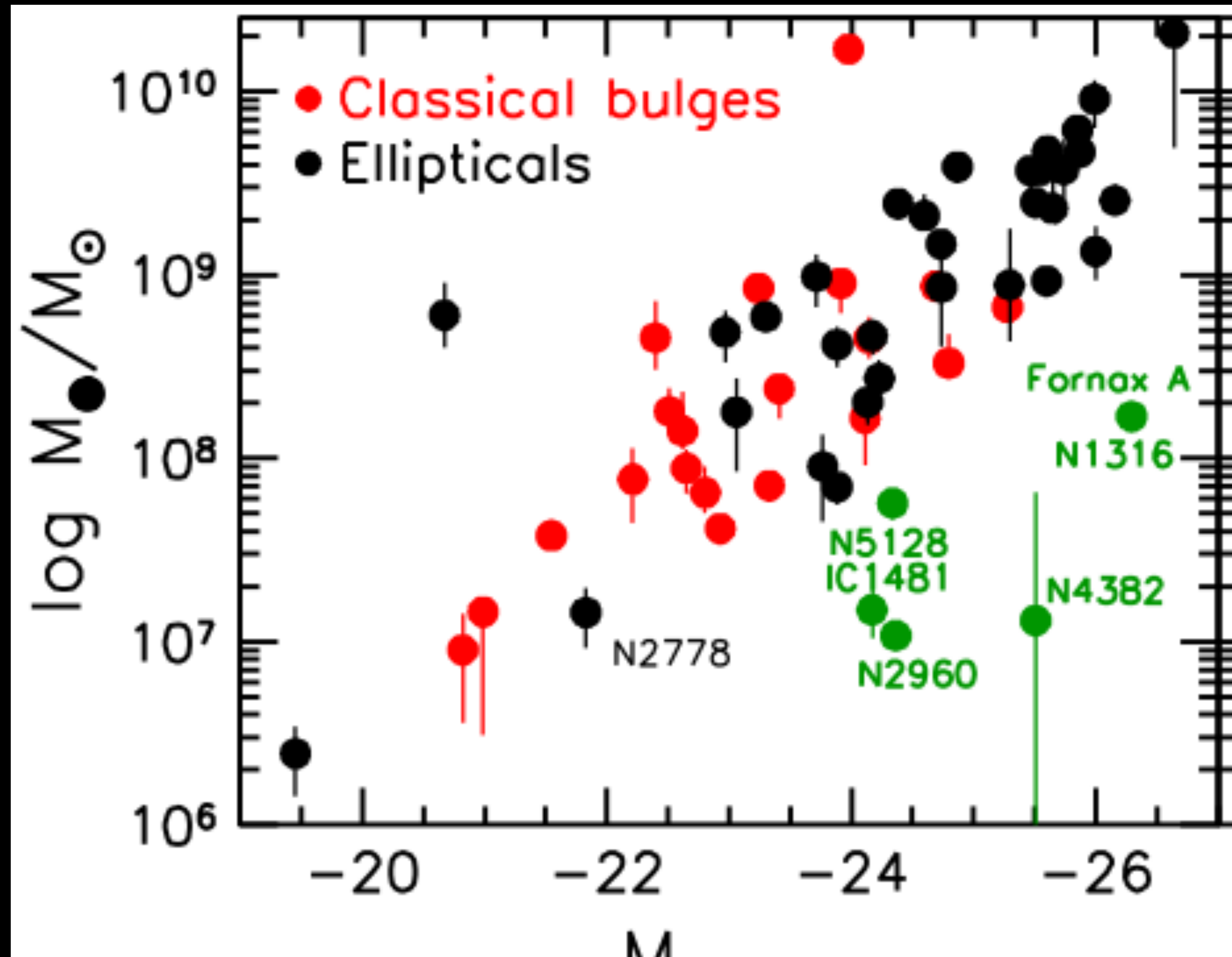
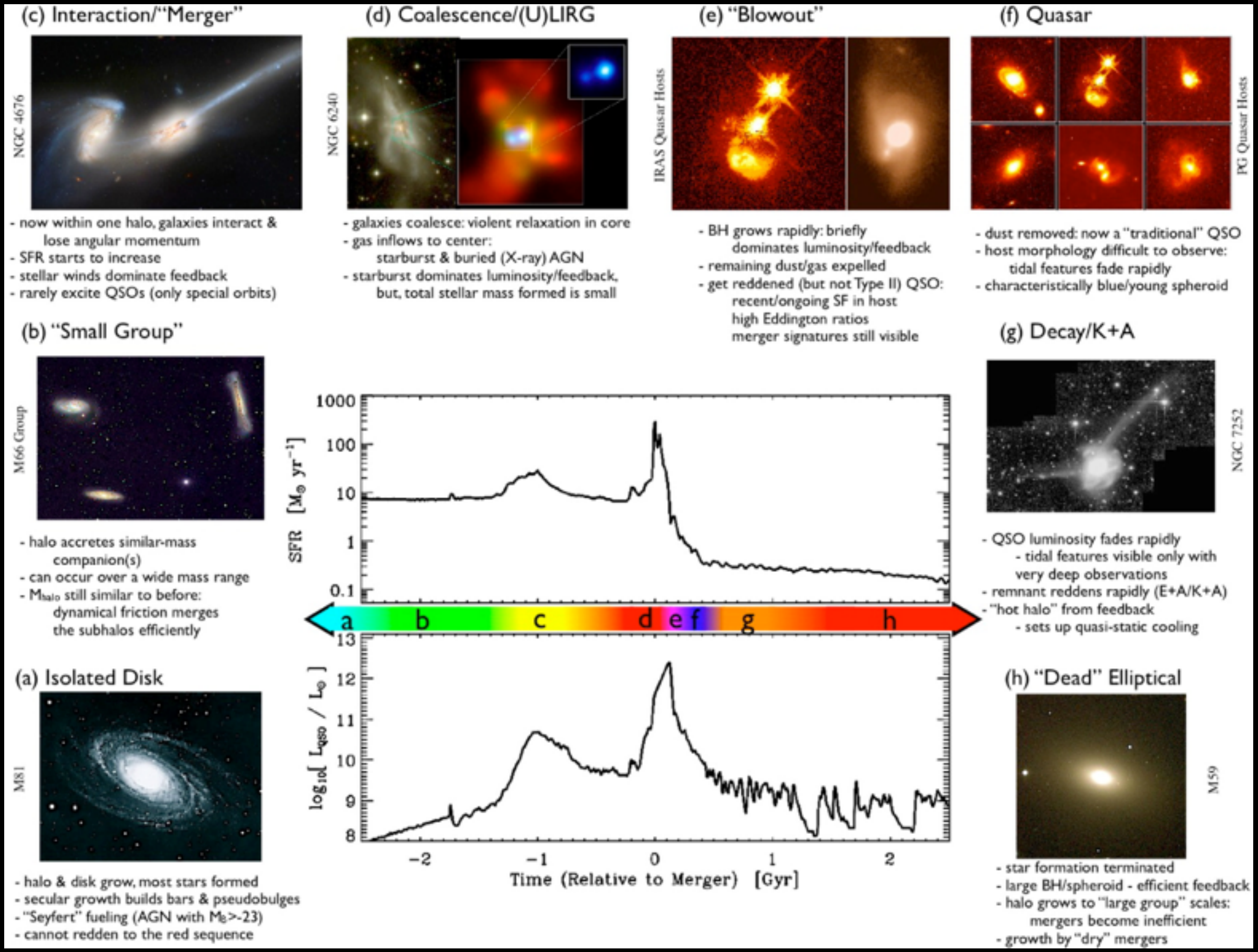



**Figure 14**

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.

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

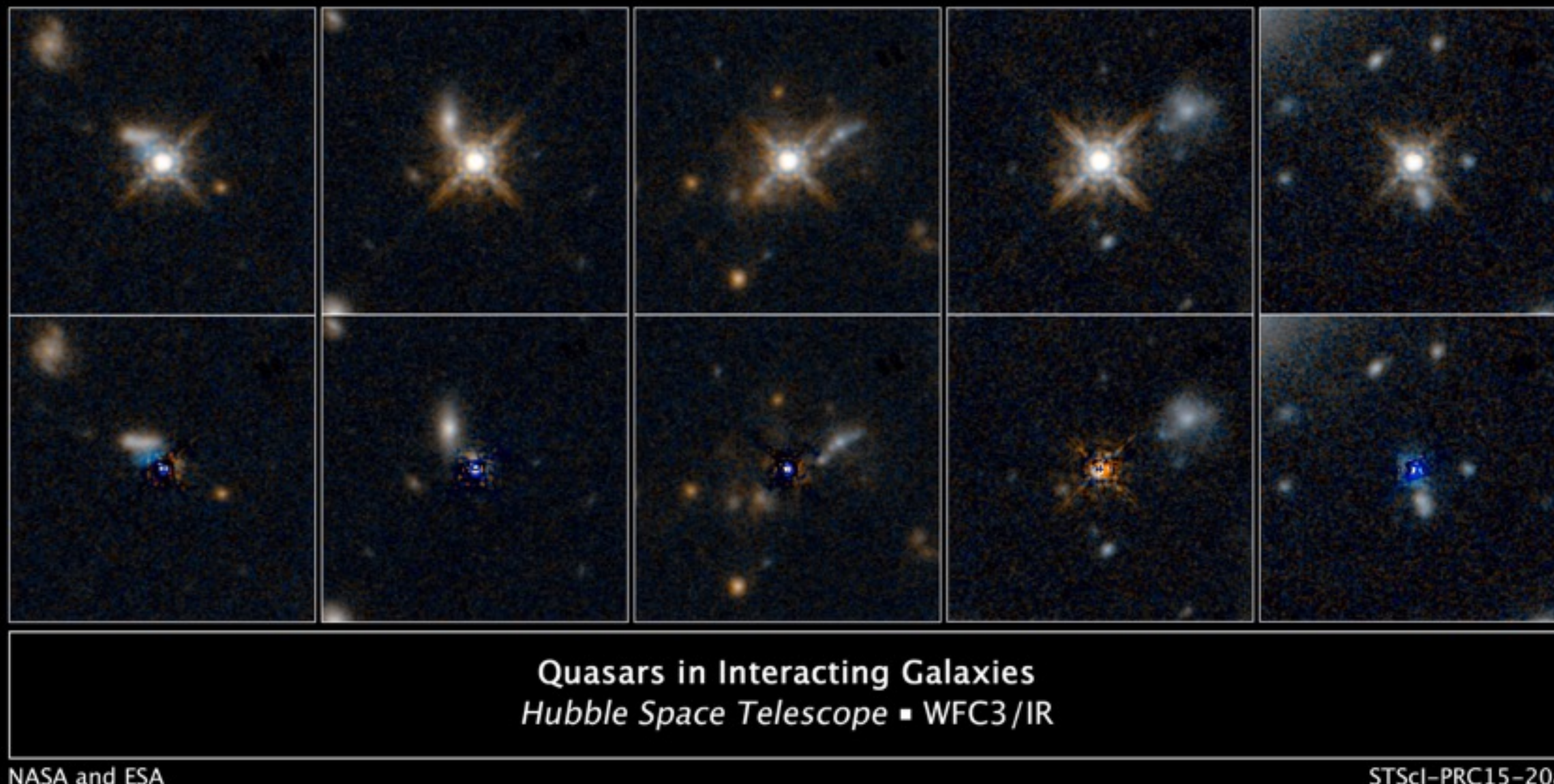



*Hopkins group, Caltech*

# Dusty Quasars

QSO + host

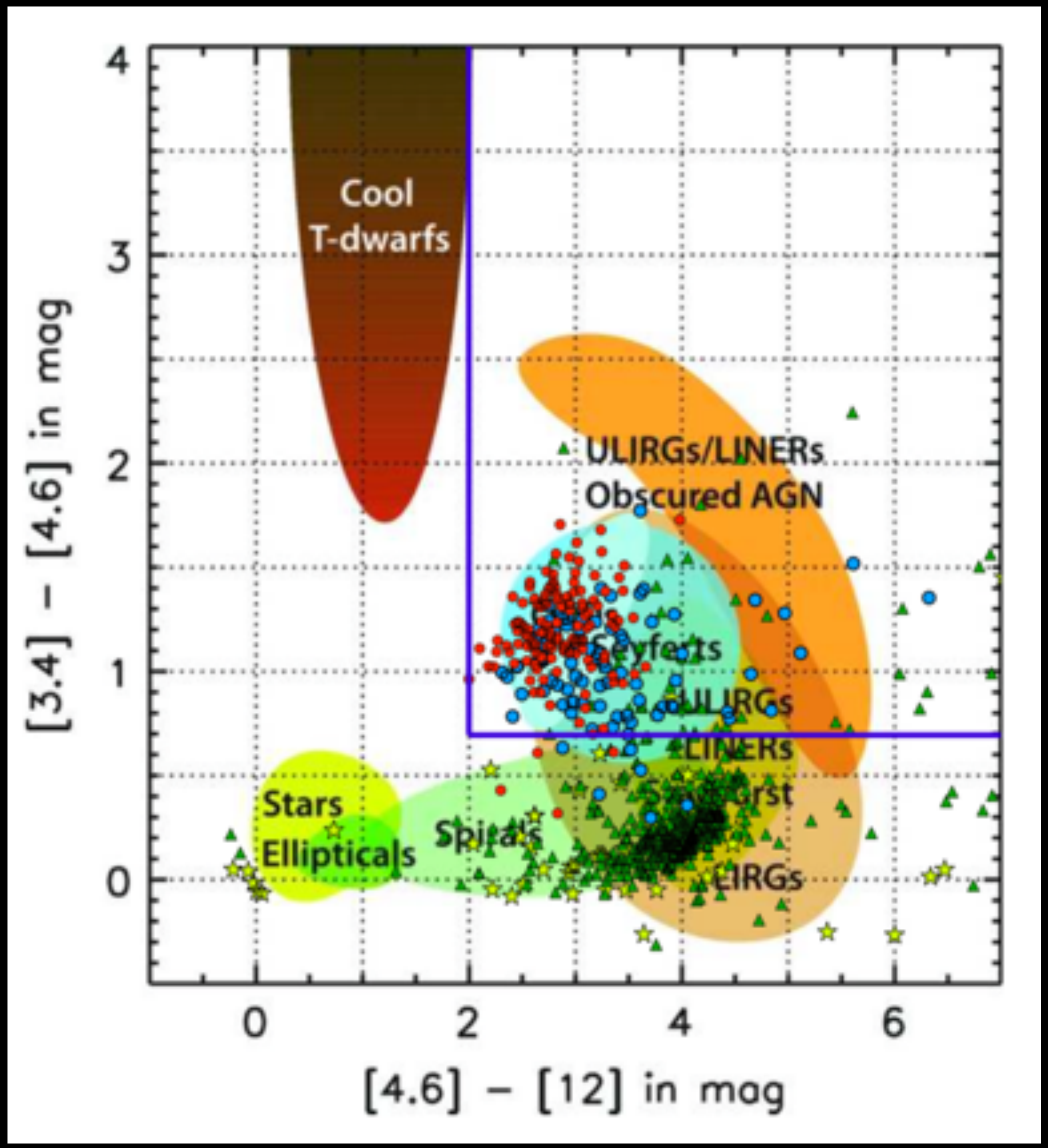
host



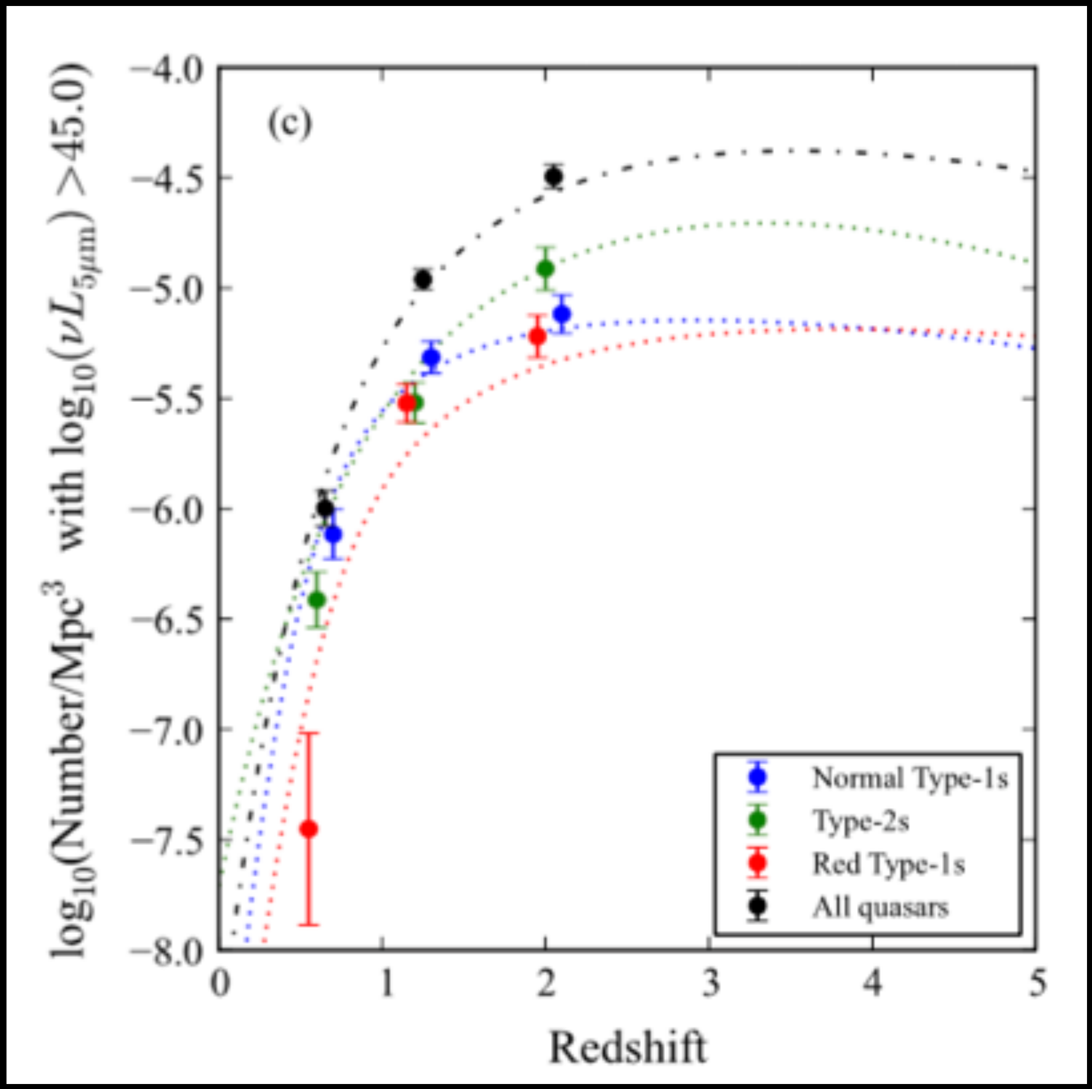

NASA, ESA, and E. Glikman (Middlebury College, Vermont)

Dust-reddened quasars make-up 25-60% of the total population and at $z > 0.7$ most are mergers *(Glikman et al. 2007, 2012, Lacy et al. 2018)*.

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




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

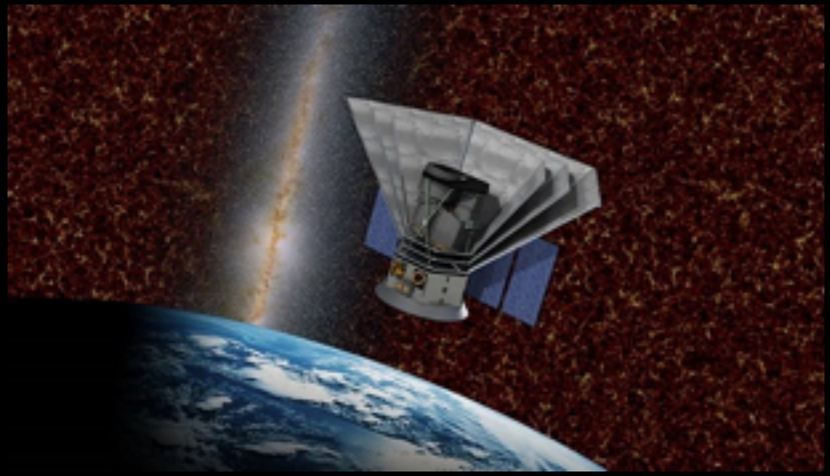
SDSS optical selection also yielded thousands of QSO2s.
*Zakamska et al. (2003); Reyes et al. (2008).*

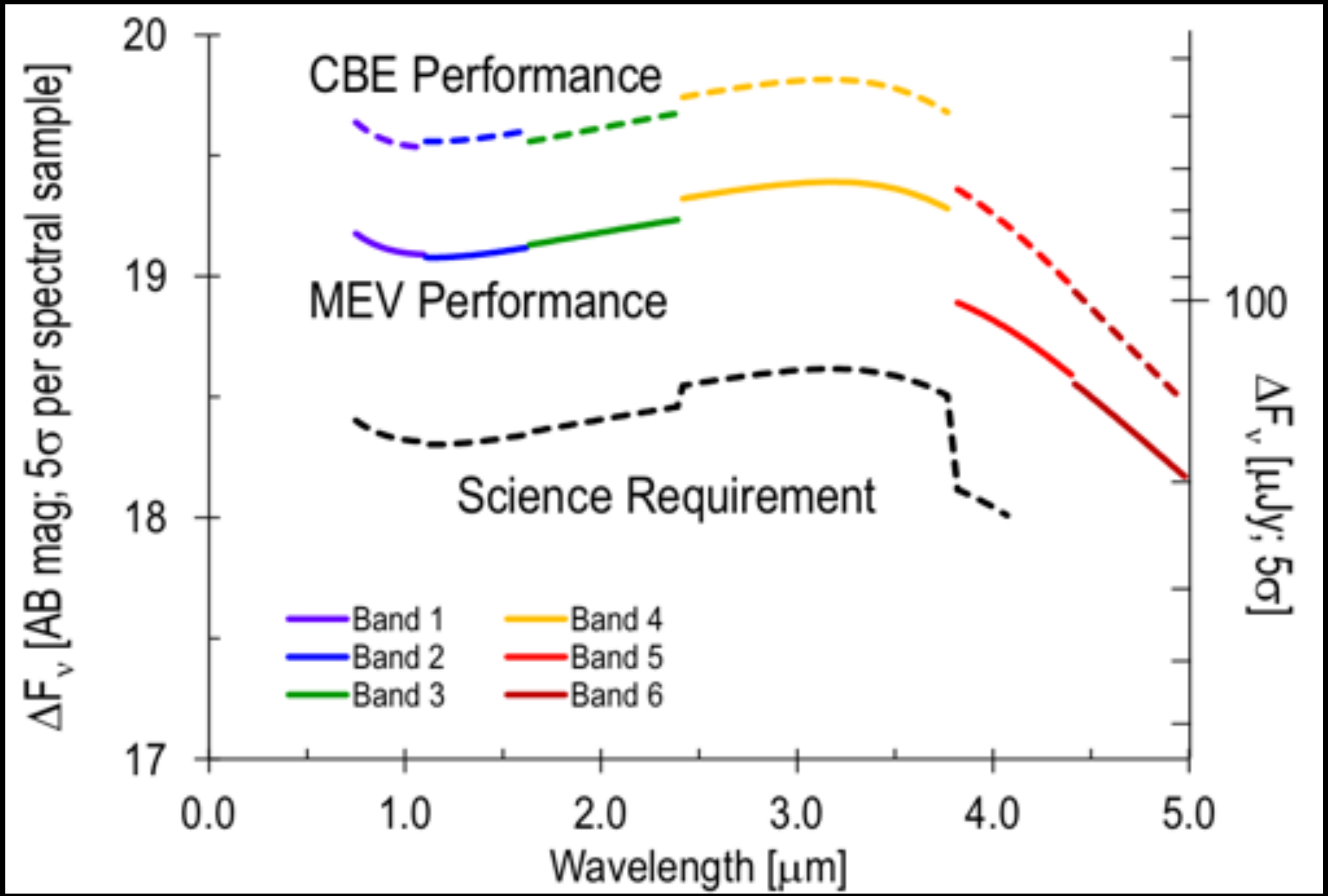
Evolution with redshift of obscured sources differs from that of un-obscured AGN.

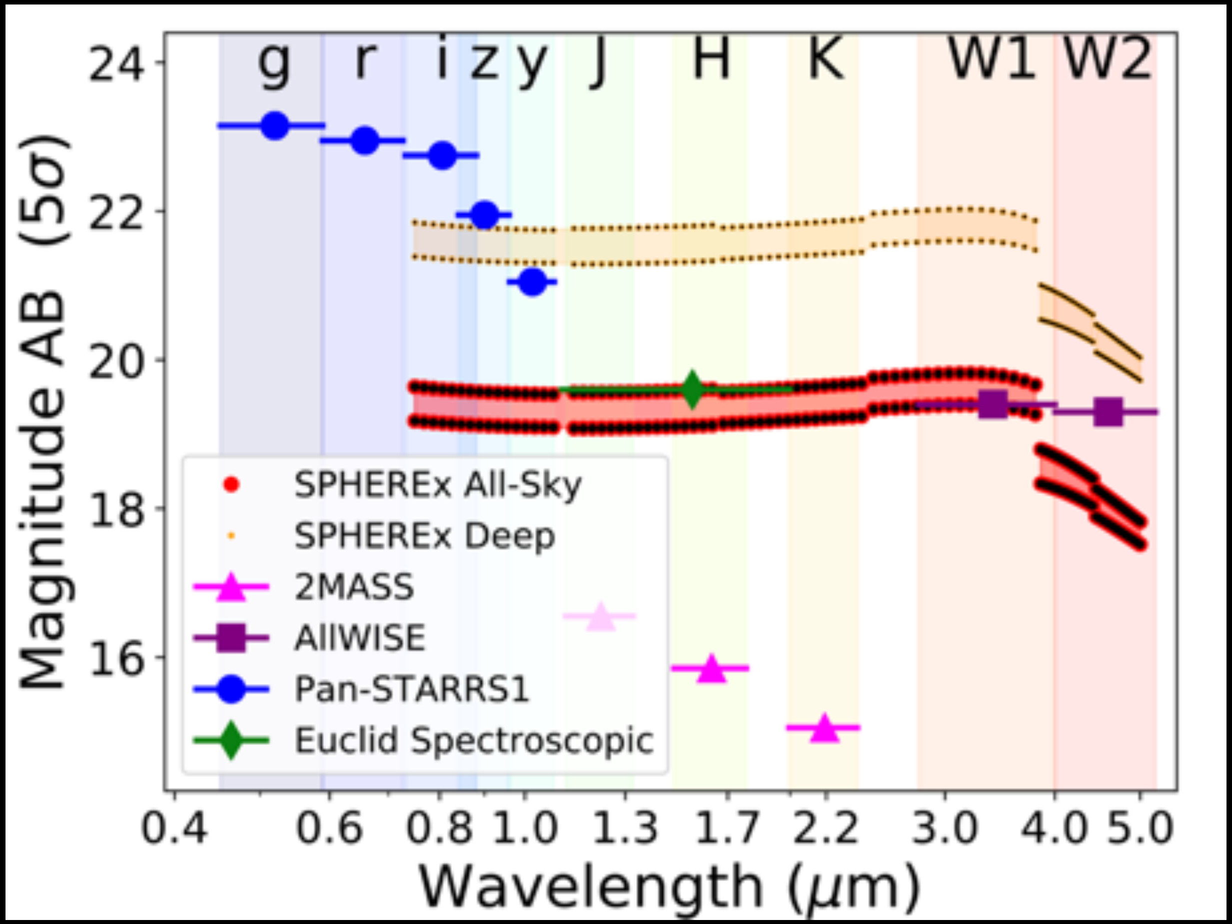
New generation of IR, X-rays, and radio surveys to peer through the dust.

# 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

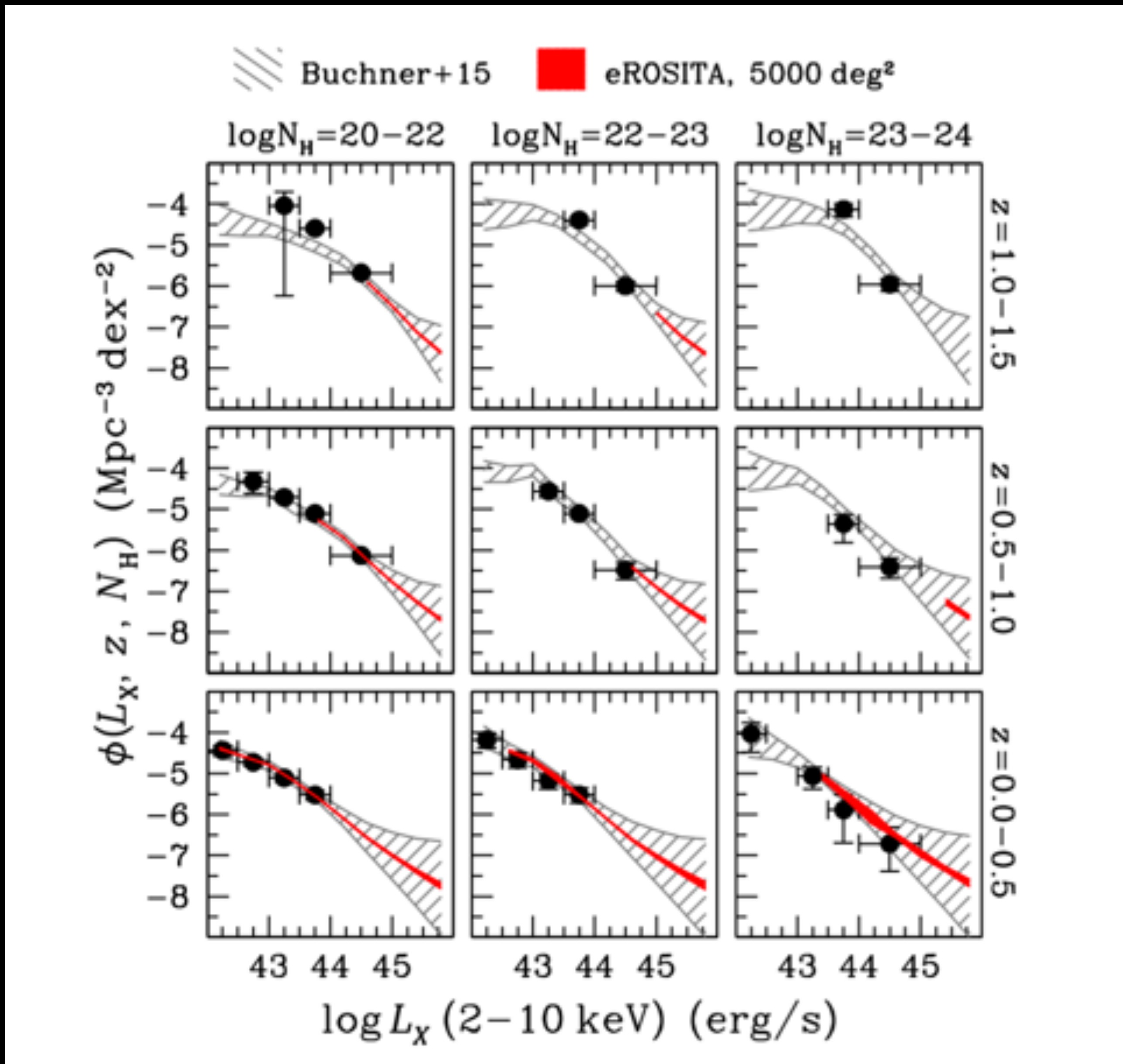


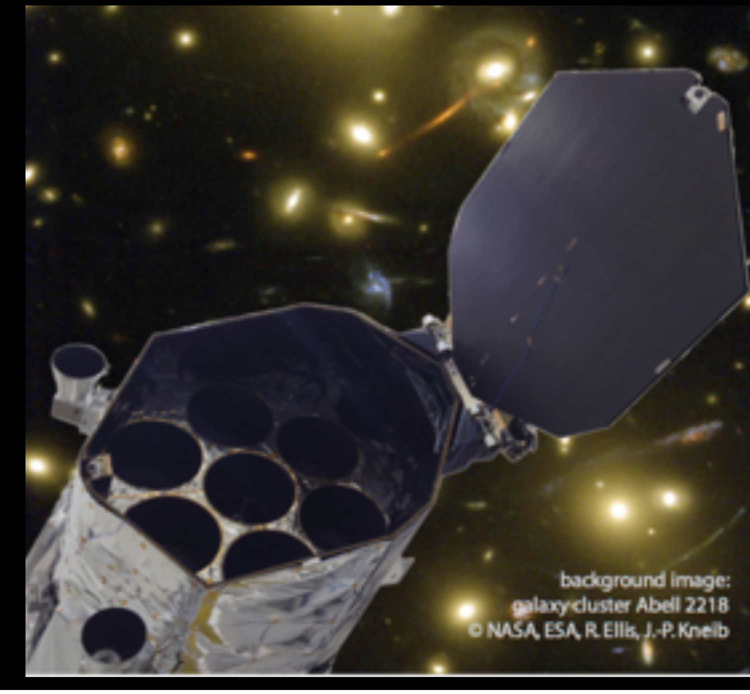


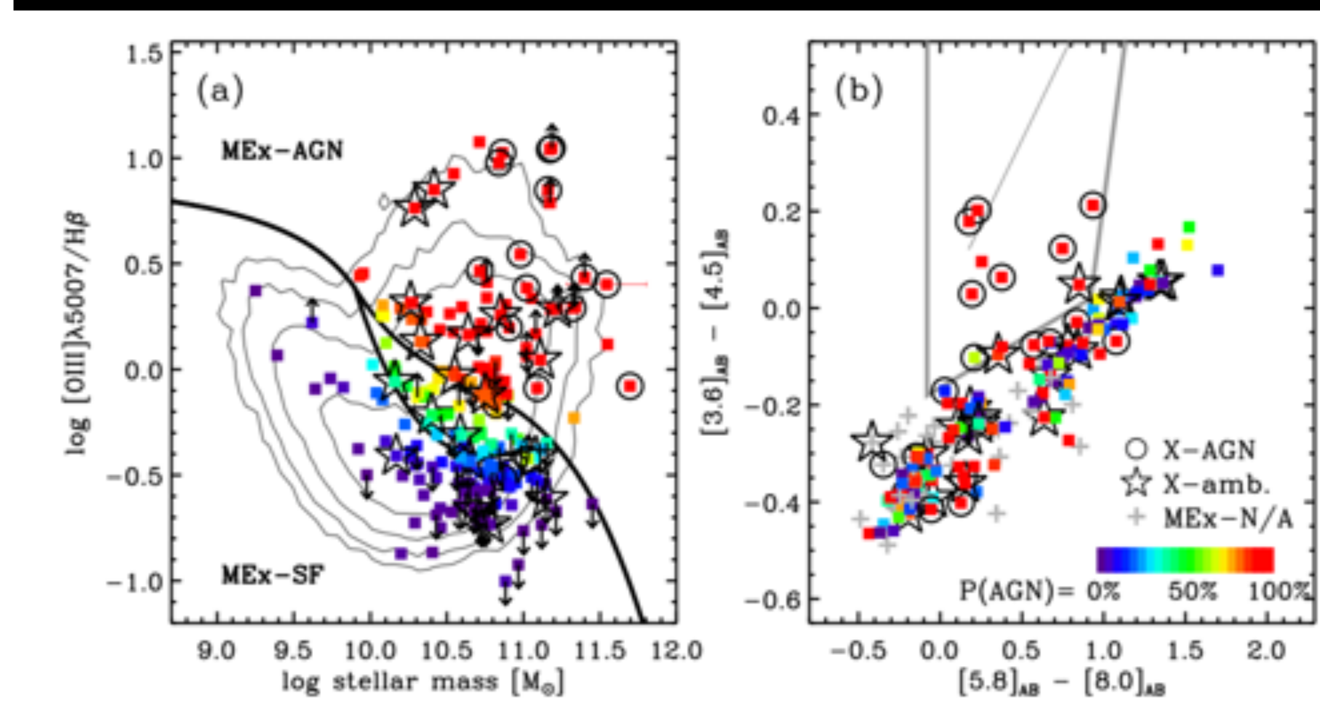




- SPHEREx can isolate the AGN using MIR colors (~3000 QSO2s at z>0.8)
- IR and optical reverberation mapping of bright AGN (i <18mag)
- Star-formation activity in bright AGN using PAH 3.3 microns

# How do we find them?




*Georgakakis et al. 2017*

*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

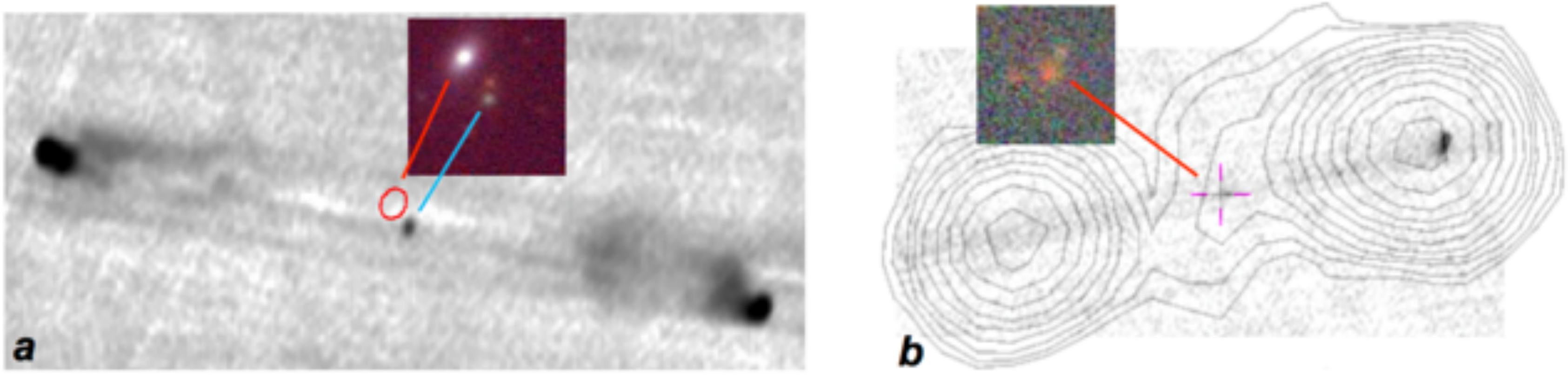


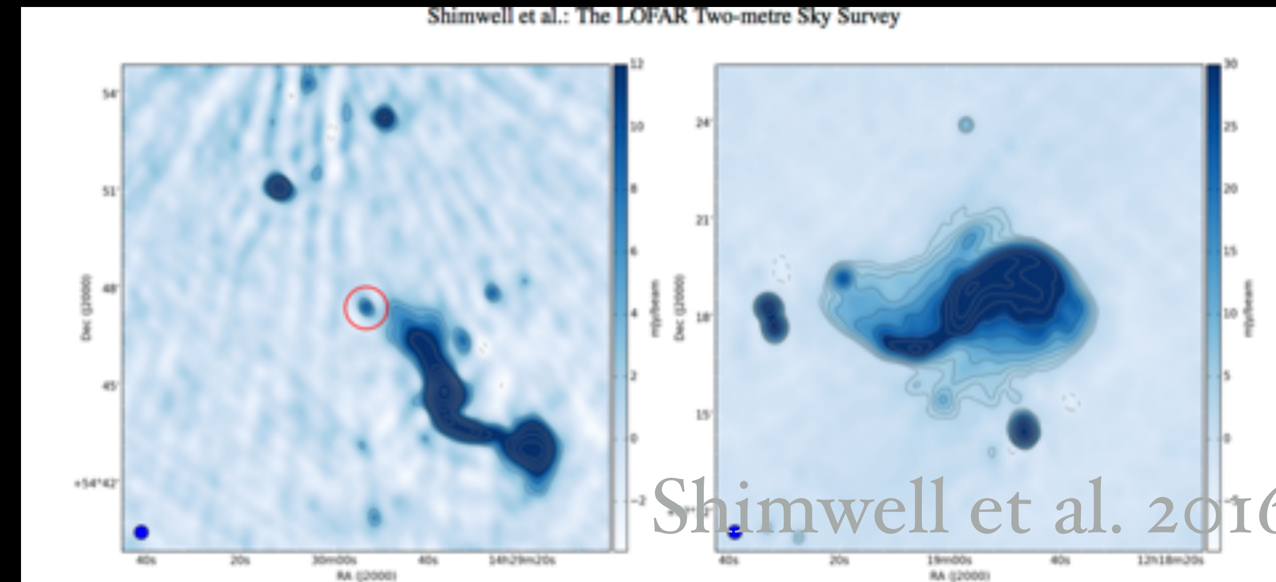

*Figure 1. VLASS images of (a) J1452−1311 and (b) J0452+0247, with Pan-STARRS insets of 25" and 15"*

| 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 |

- 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.

# Radio missions around the world

- 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

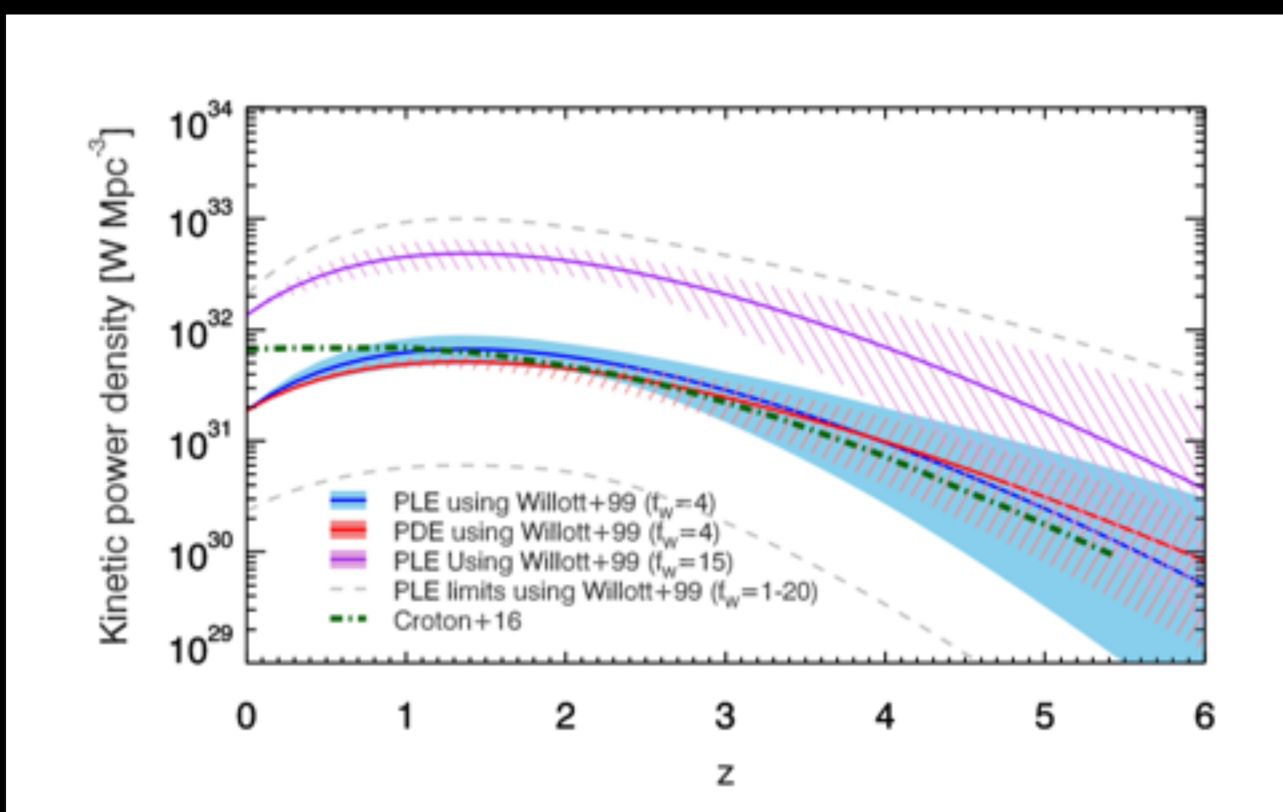
| Tier | Frequency (GHz) | Sensitivity (rms) | Resolution (arcsec) | Area (degree$^2$) | Time (hours) |
|---|---|---|---|---|---|
| Tier 1 | 1.4 | 5.0$\mu$Jy | 8.5 | 1000 | 2400 |
| Tier 2 | 1.4 | 1.0$\mu$Jy | 8.5/3.5 | 35 | 1950 |
| Tier 3 | 1.4 | 0.1$\mu$Jy | 3.5 | 1.0 | 1700 |
| Tier 4 | 12 | 1.0$\mu$Jy | 3.2/0.4 | 0.25 | 700 |
| Tier 5 | 12 | 0.2$\mu$Jy | 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 th circum-galactic and halo gas which shut down cooling in massive haloes and bring the bright 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)

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

However several questions remain:

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

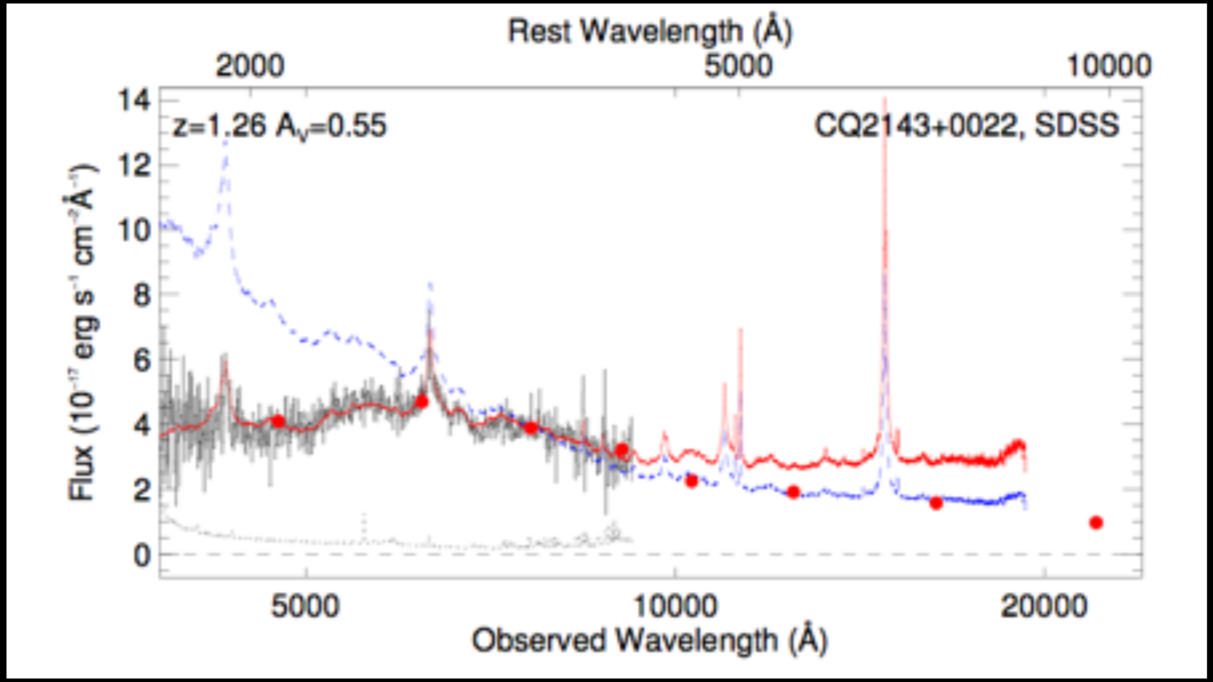
(2) estimates of the accretion rates,

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

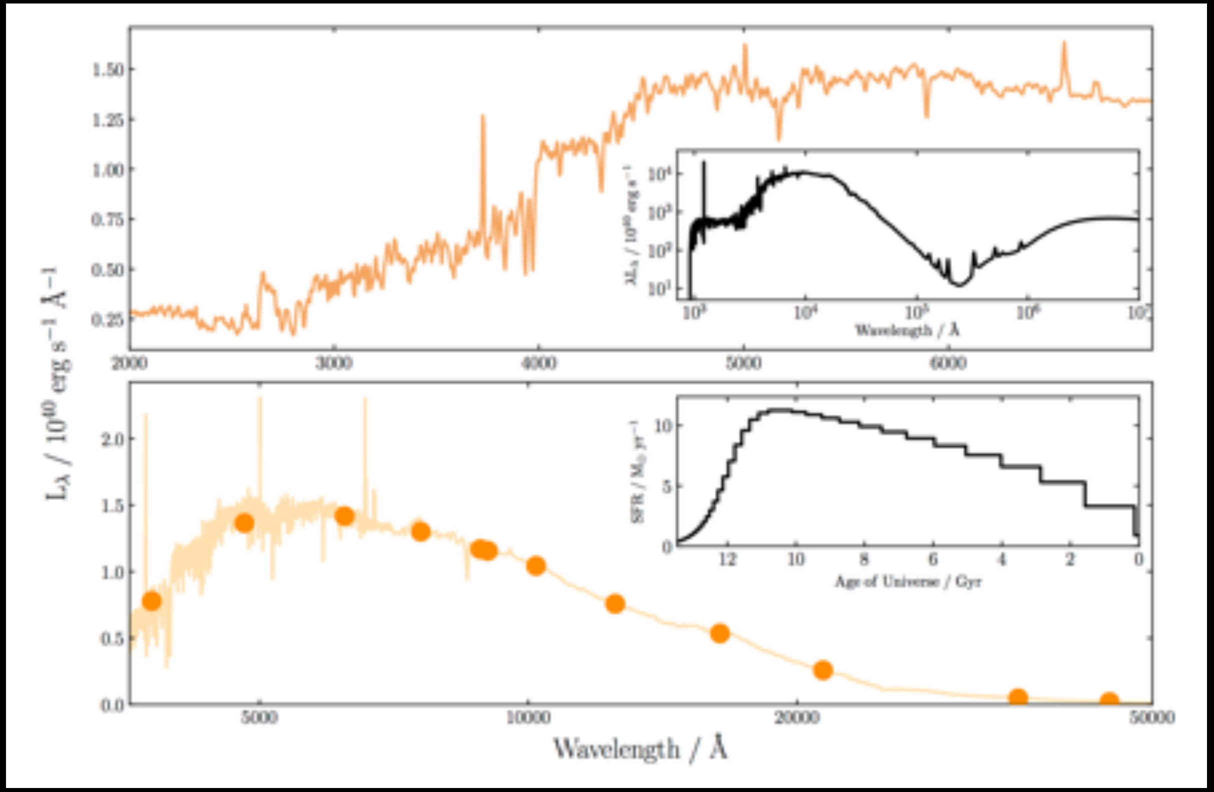
axies with a young stellar population and active star formation.

# 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)*

# 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

# 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.

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