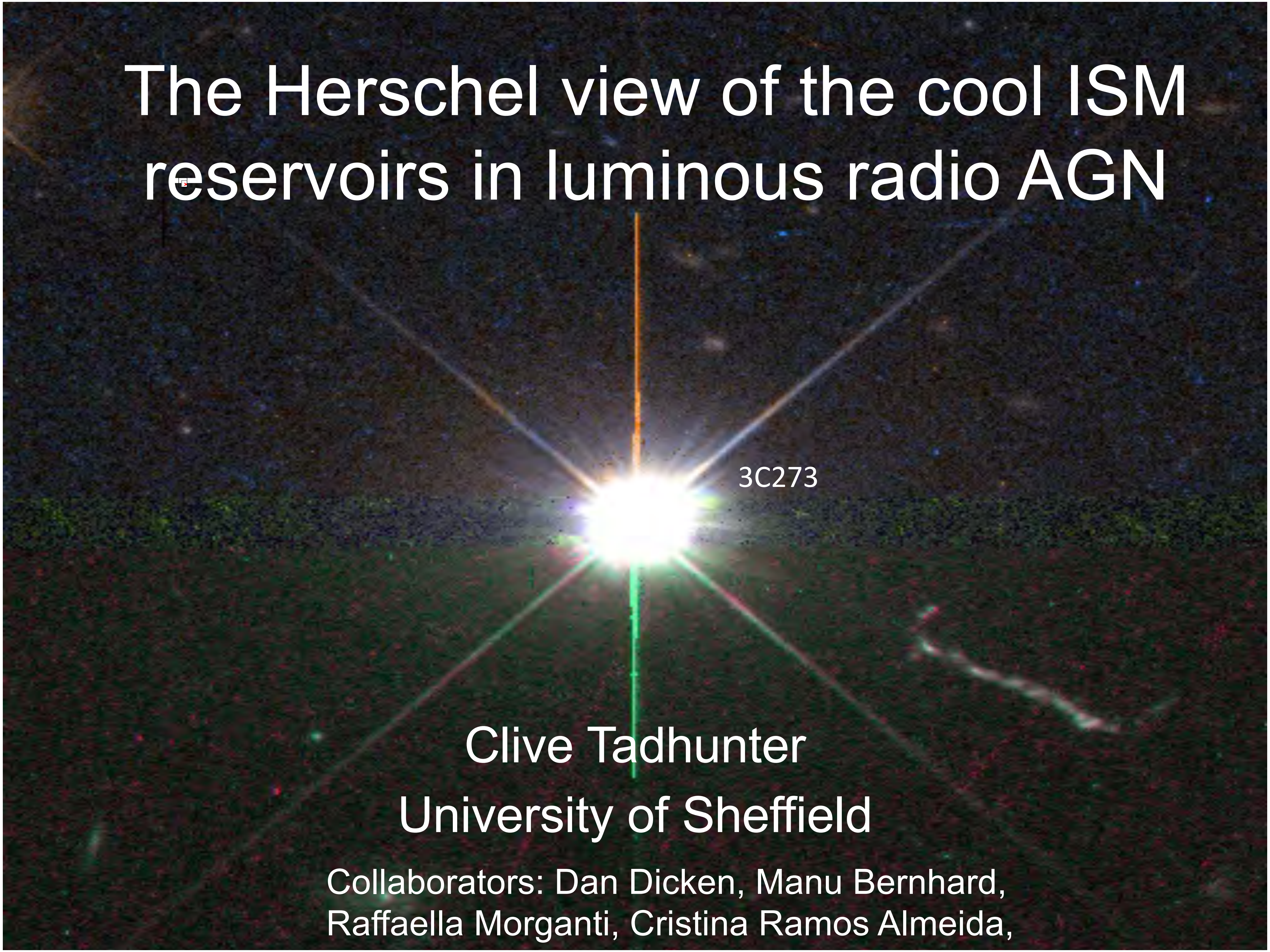
The Herschel view of the cool ISM reservoirs in luminous radio AGN

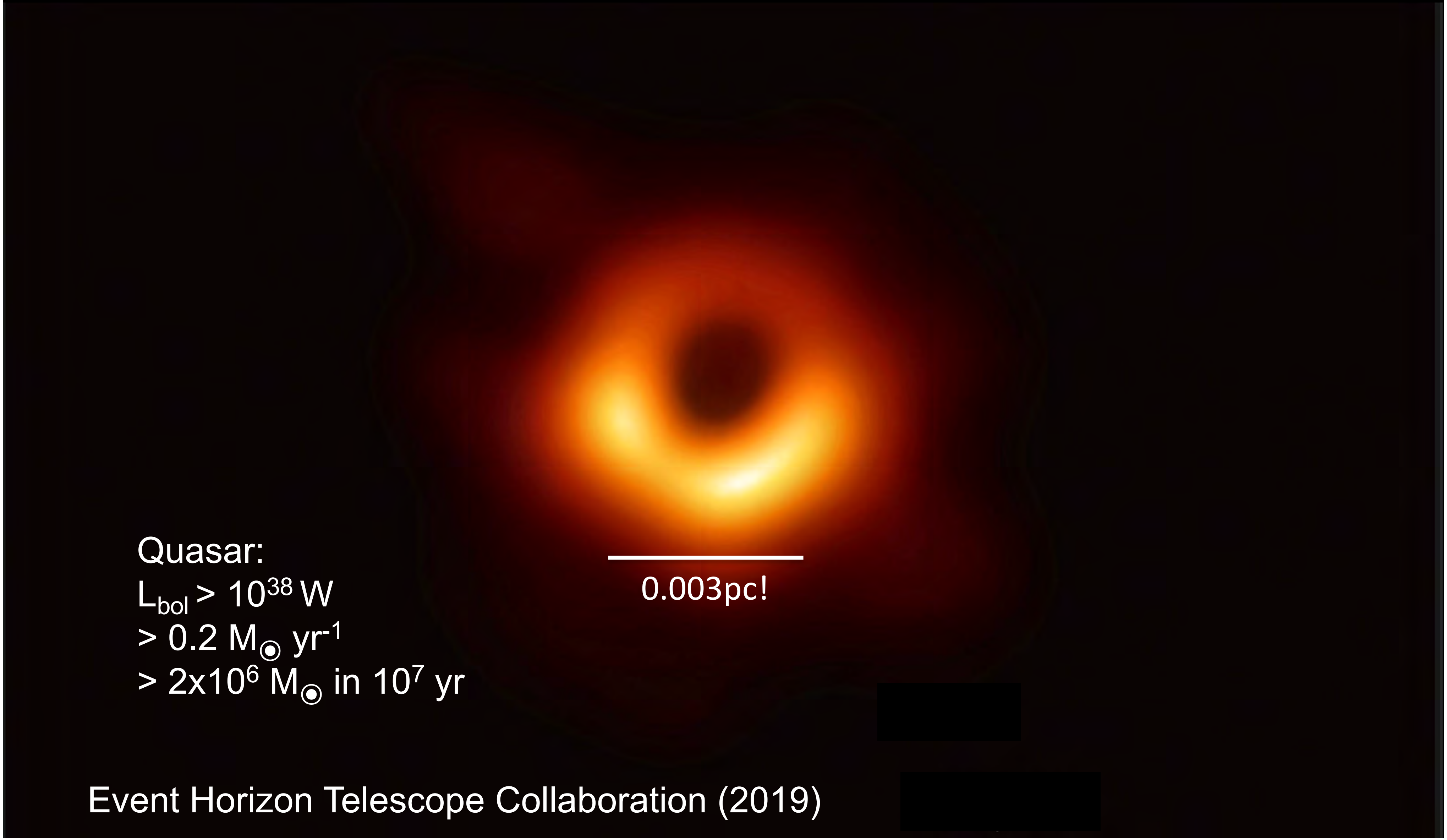


Clive Tadhunter

University of Sheffield

Collaborators: Dan Dicken, Manu Bernhard, Raffaella Morganti, Cristina Ramos Almeida,

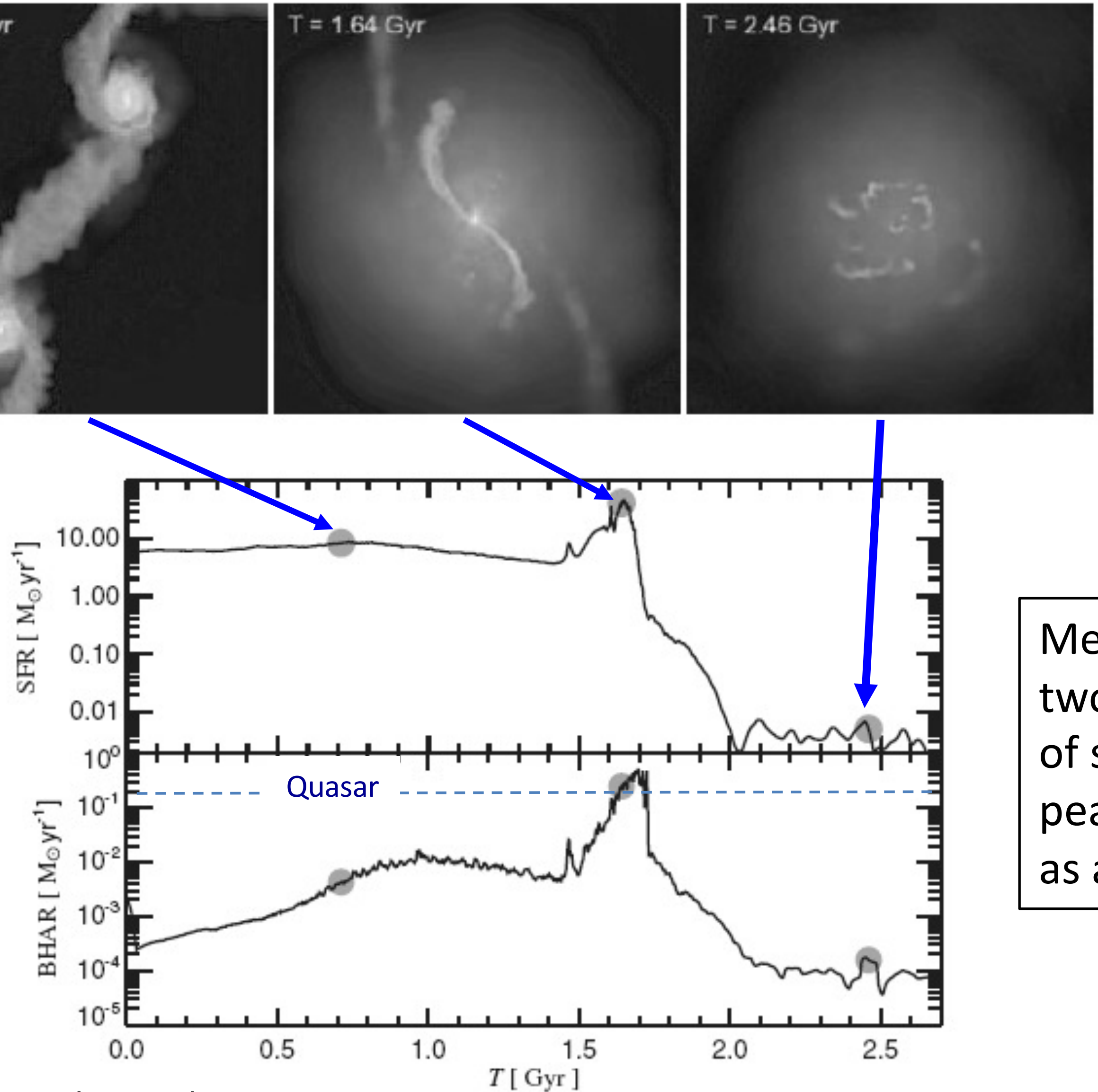
Supermassive black holes: the energy source for active galactic nuclei



Quasar:
$L_{bol} > 10^{38}$ W
$> 0.2\ M_\odot\ yr^{-1}$
$> 2x10^{6}\ M_\odot$ in 10^{7} yr

Event Horizon Telescope Collaboration (2019)

Quasars triggered at the peaks of major, gas-rich mergers (e.g. Sanders et al. 1988)

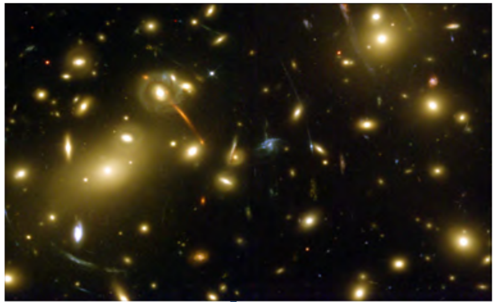


Merger between two spiral galaxies of similar mass – at peak would appear as a ULIRG

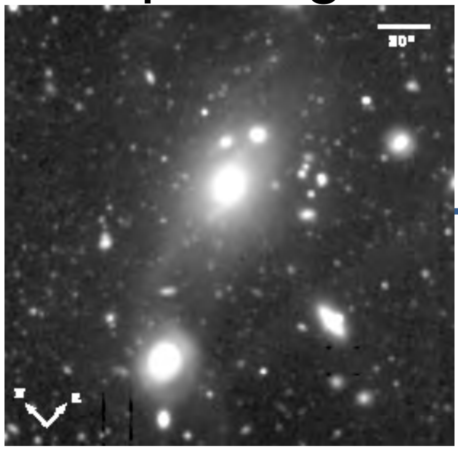
Springel et al. (2005)

Investigating triggering mechanisms

Large-scale environments

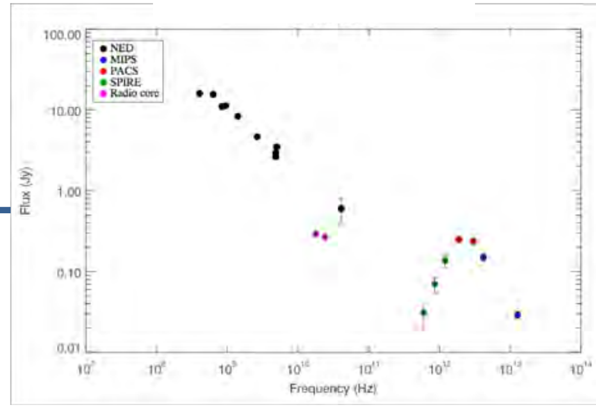


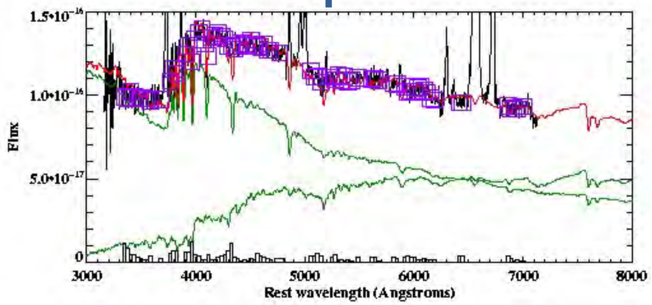
Galaxy morphologies



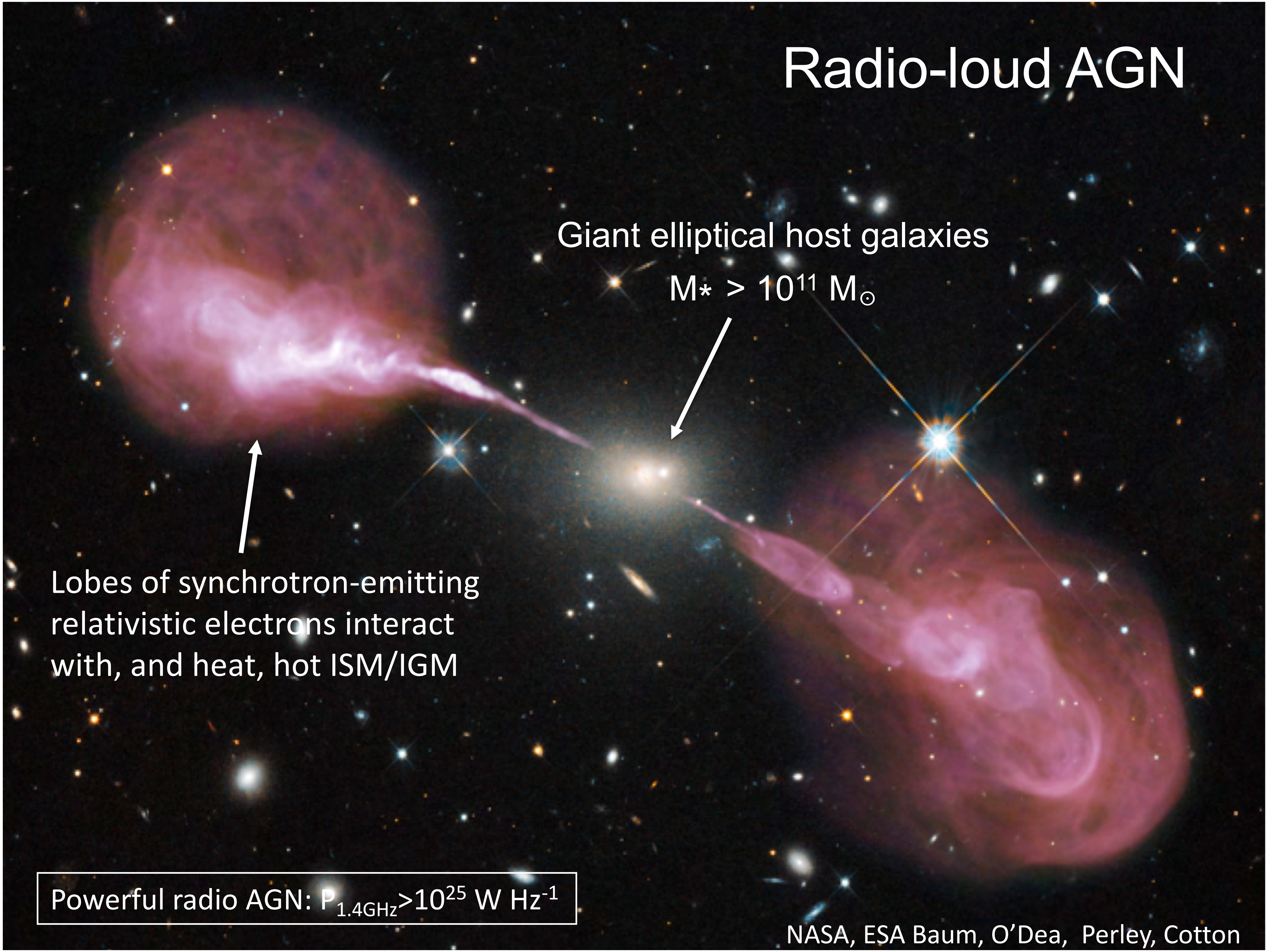
Triggering mechanism?

Cool ISM contents





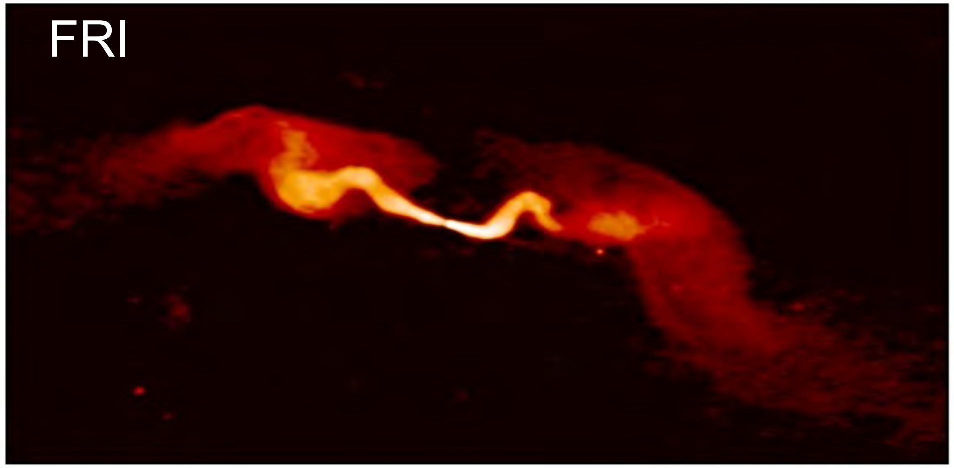
Star formation

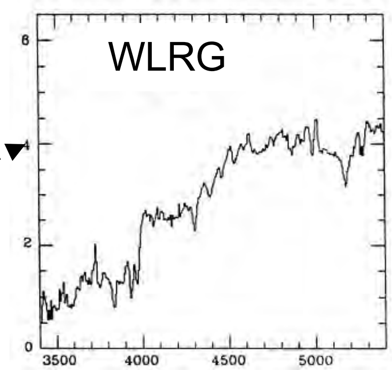

Radio-loud AGN
Giant elliptical host galaxies
$M_* > 10^{11}\ M_\odot$
Lobes of synchrotron-emitting relativistic electrons interact with, and heat, hot ISM/IGM
Powerful radio AGN: $P_{1.4GHz} > 10^{25}\ W\ Hz^{-1}$
NASA, ESA Baum, O'Dea, Perley, Cotton

Correlations between optical and radio classifications

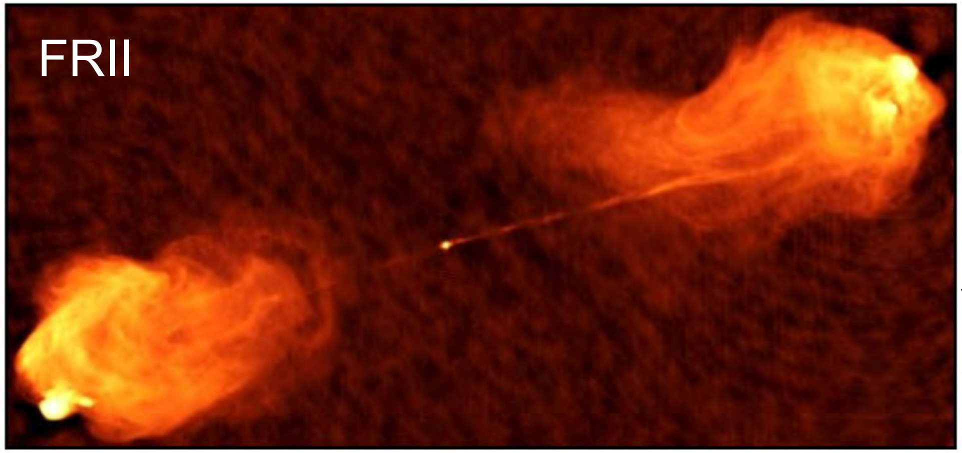
Radio morphology

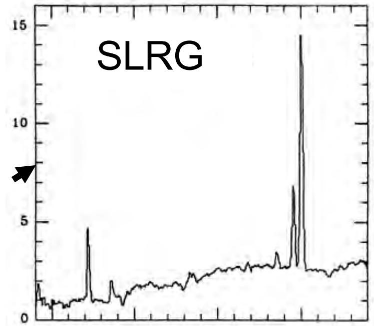
Optical spectra



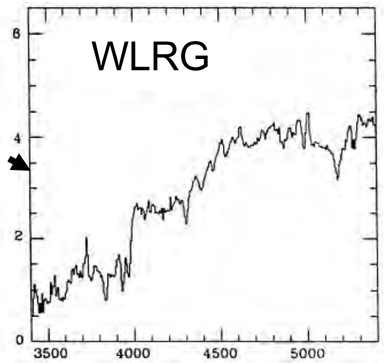


FRI almost invariably WLRG





SLRG almost invariably FRII



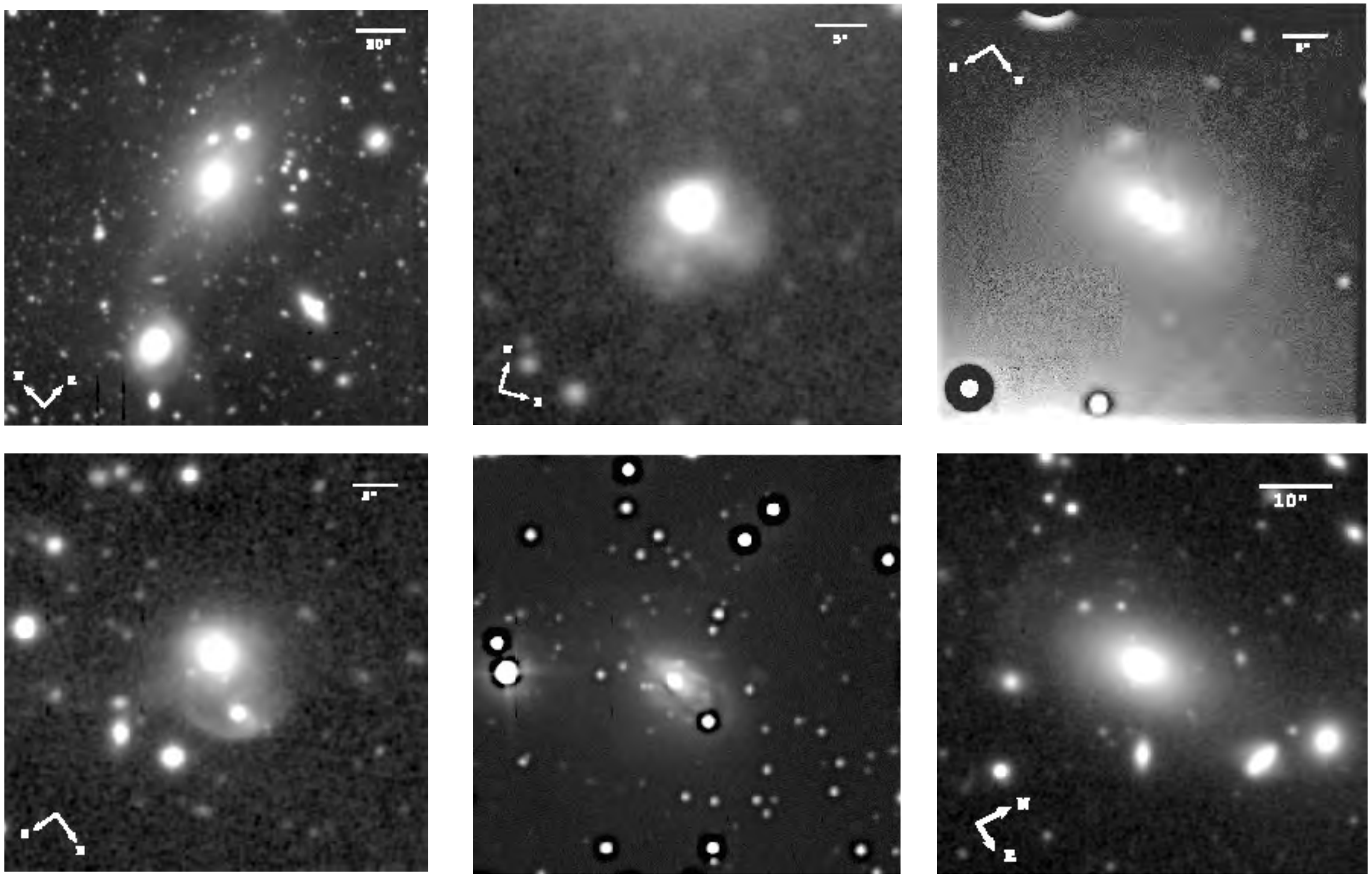
Some FRII (~10-20%) are WLRG

Multi-wavelength observations of the 2Jy sample

- Complete sample of 46 southern ($\delta < +10^{o}$) radio sources with $S_{2.7GHz} > 2$ Jy, intermediate redshifts ($0.05 < z < 0.7$), steep radio spectra ($\alpha > 0.5$), high radio powers ($10^{25} < P_{1.4GHz} < 10^{28}$ W Hz^{-1})
- *Most sources are have nuclei of quasar-like luminosity, but covers a range of AGN luminosities*

- Best observed of all radio AGN samples in terms of the depth and completeness of its multi-wavelength data

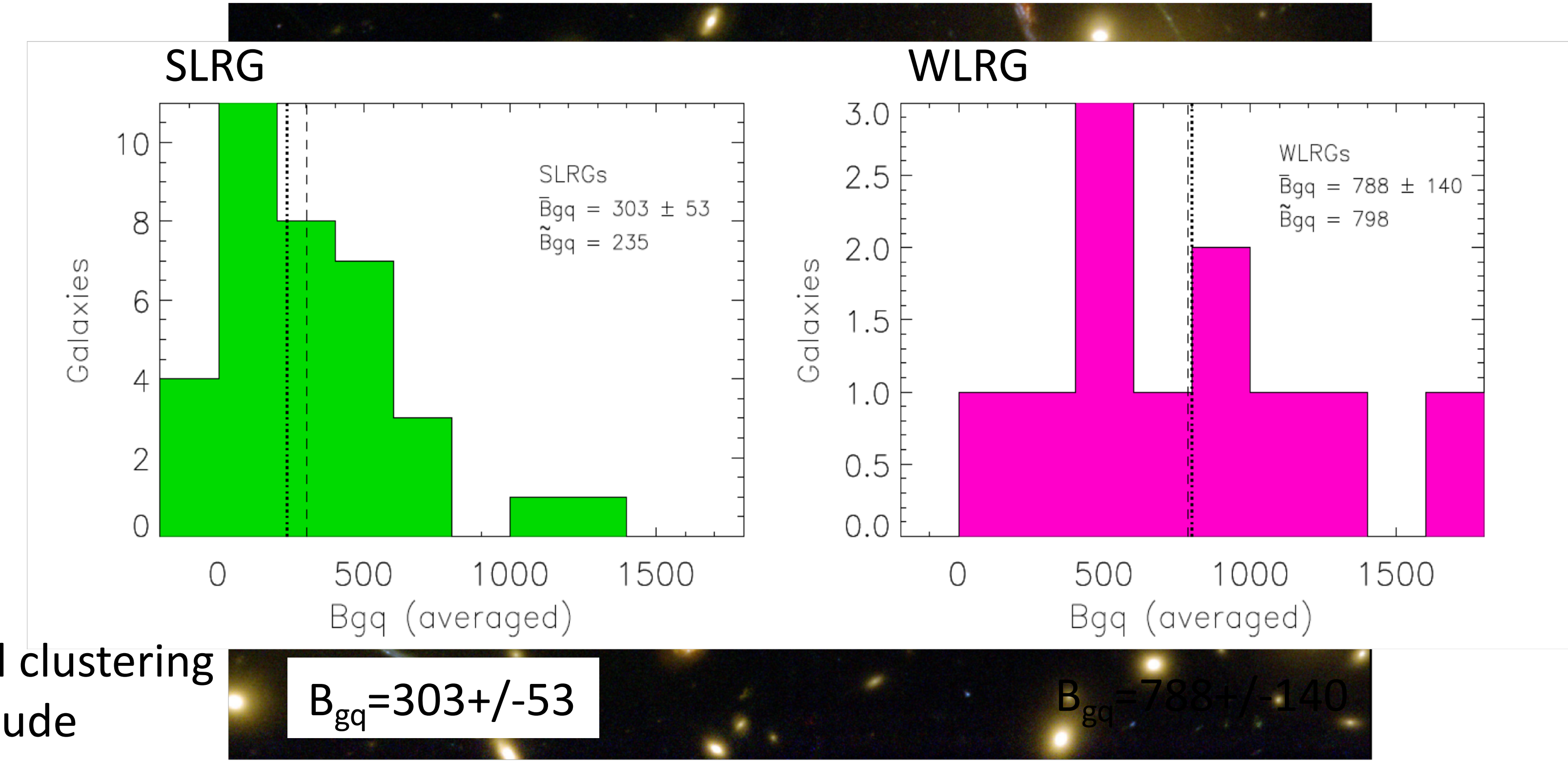
Deep Gemini imaging of the 2Jy sample



95% of quasar-like SLRG show evidence for tidal features at high surface brightness levels, but only 27% of WLRG.

Ramos Almeida et al. (2011,2012)

The large-scale environments of radio AGN

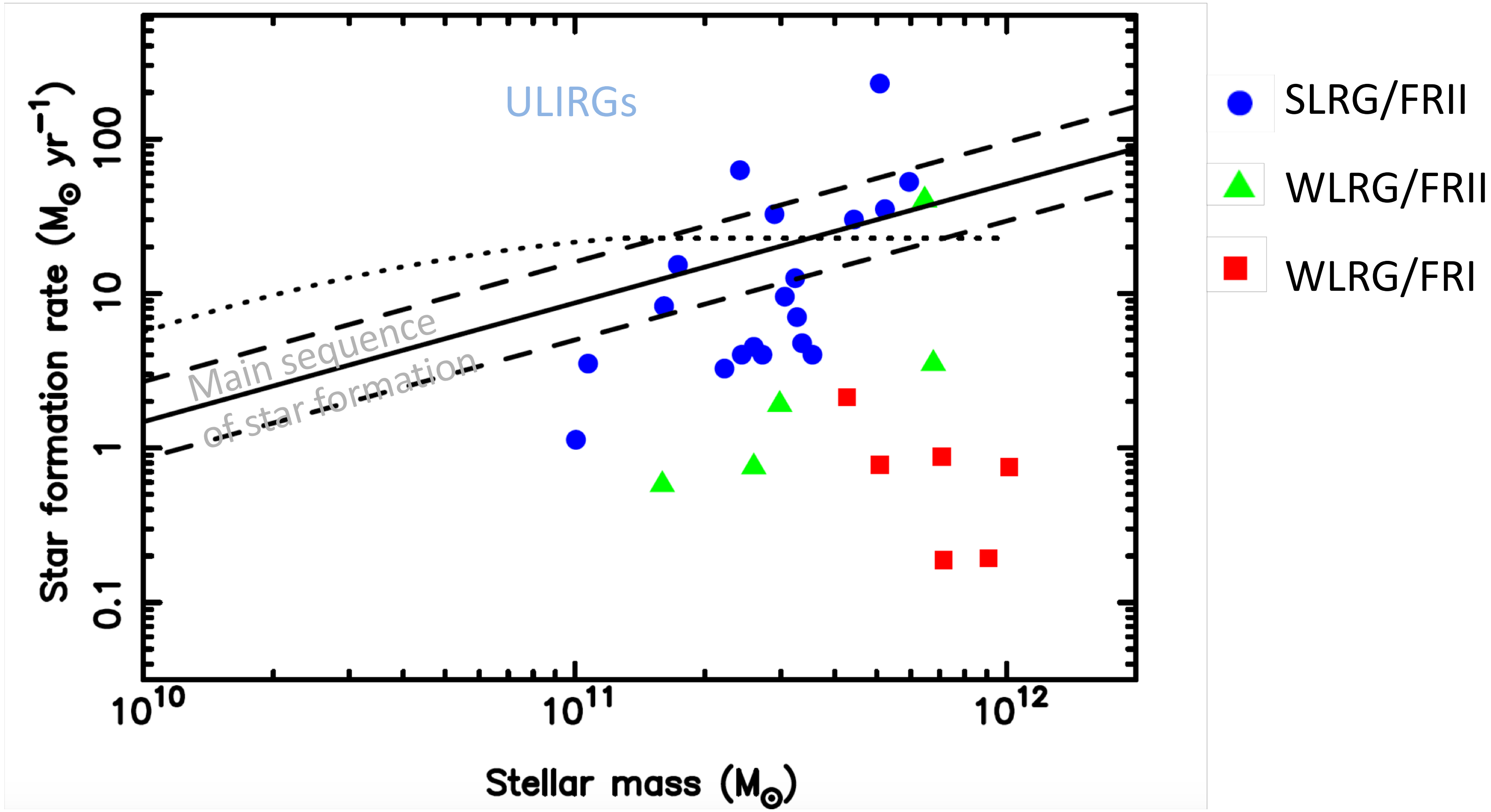


Spatial clustering amplitude

Ramos Almeida et al. (2013)

Whereas quasar-like SLRG typically in galaxy groups, WLRG are in moderate to rich cluster environments.

Far-IR (70μm) derived star formation rates for 2Jy radio galaxies

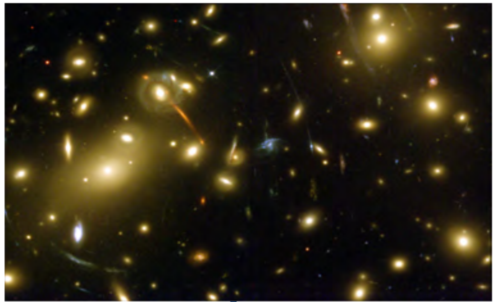


- Star formation rates in radio galaxies typically low (0.1 – 30 $M_\odot$ yr^{-1})
- Evidence that WLRG have lower SFR than SLRG

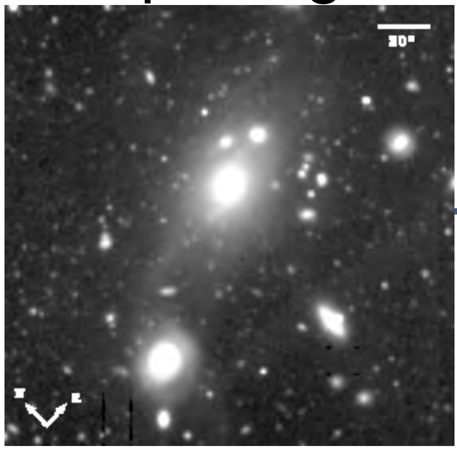
➔ Unlikely that the majority of powerful radio galaxies triggered at the peaks of *major, gas-rich* mergers

Investigating triggering mechanisms

Large-scale environments

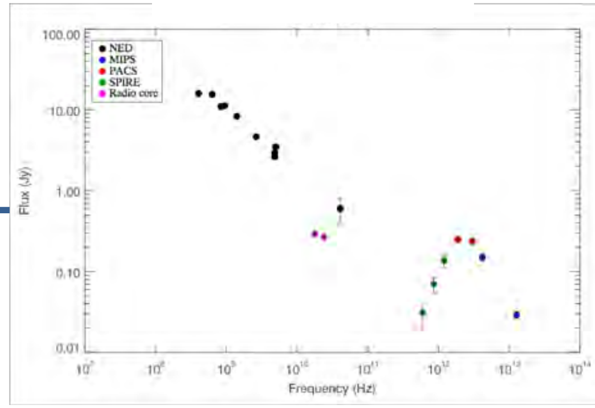


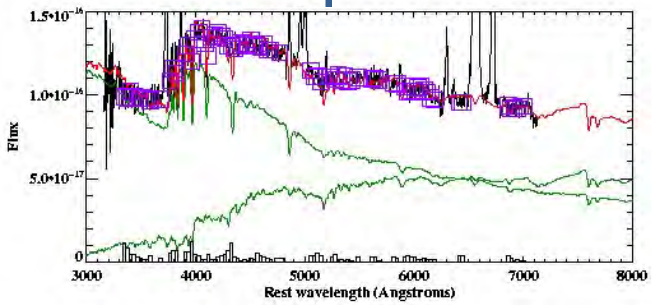
Galaxy morphologies



Triggering mechanism?

Cool ISM contents

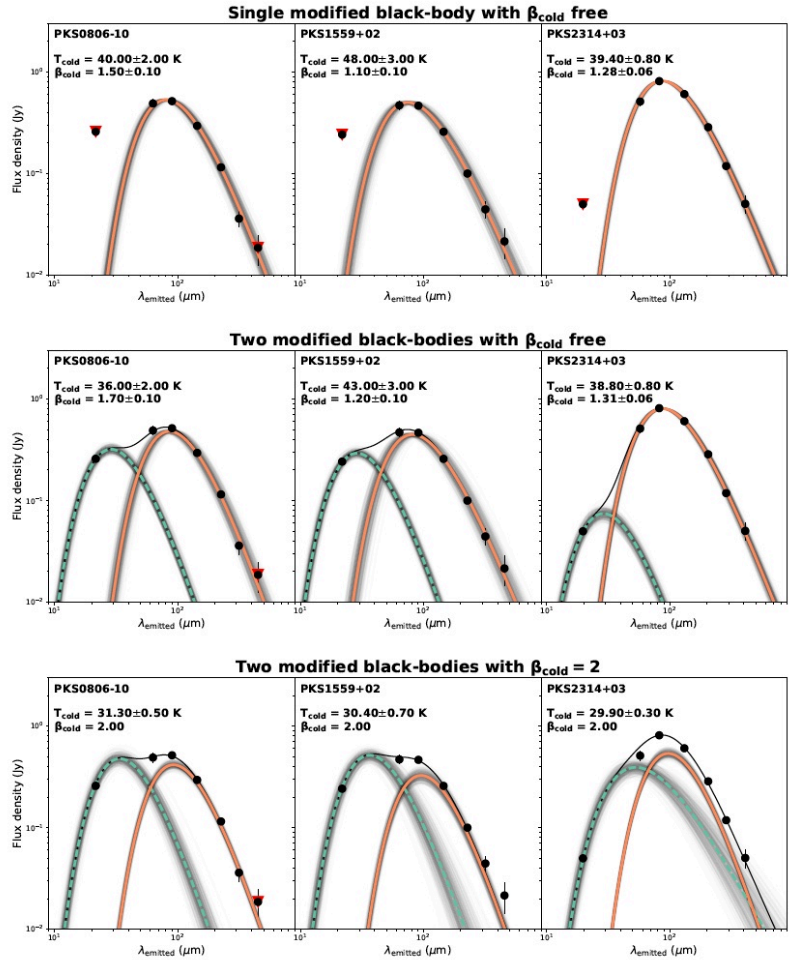




Star formation

Herschel “must do” observations of the 2Jy sample: measuring the cool ISM reservoirs

- Deep PACs 100, 160μm observations of all 46 objects (100% detection at 100μm, 90% detection at 160μm)
- Deep SPIRE observations of 19 far-IR bright objects
- Use SED fitting to SPIRE-observed objects to test assumptions of modelling approach
- Dust masses precise to factor ~2 just using just 100 and 160μm data



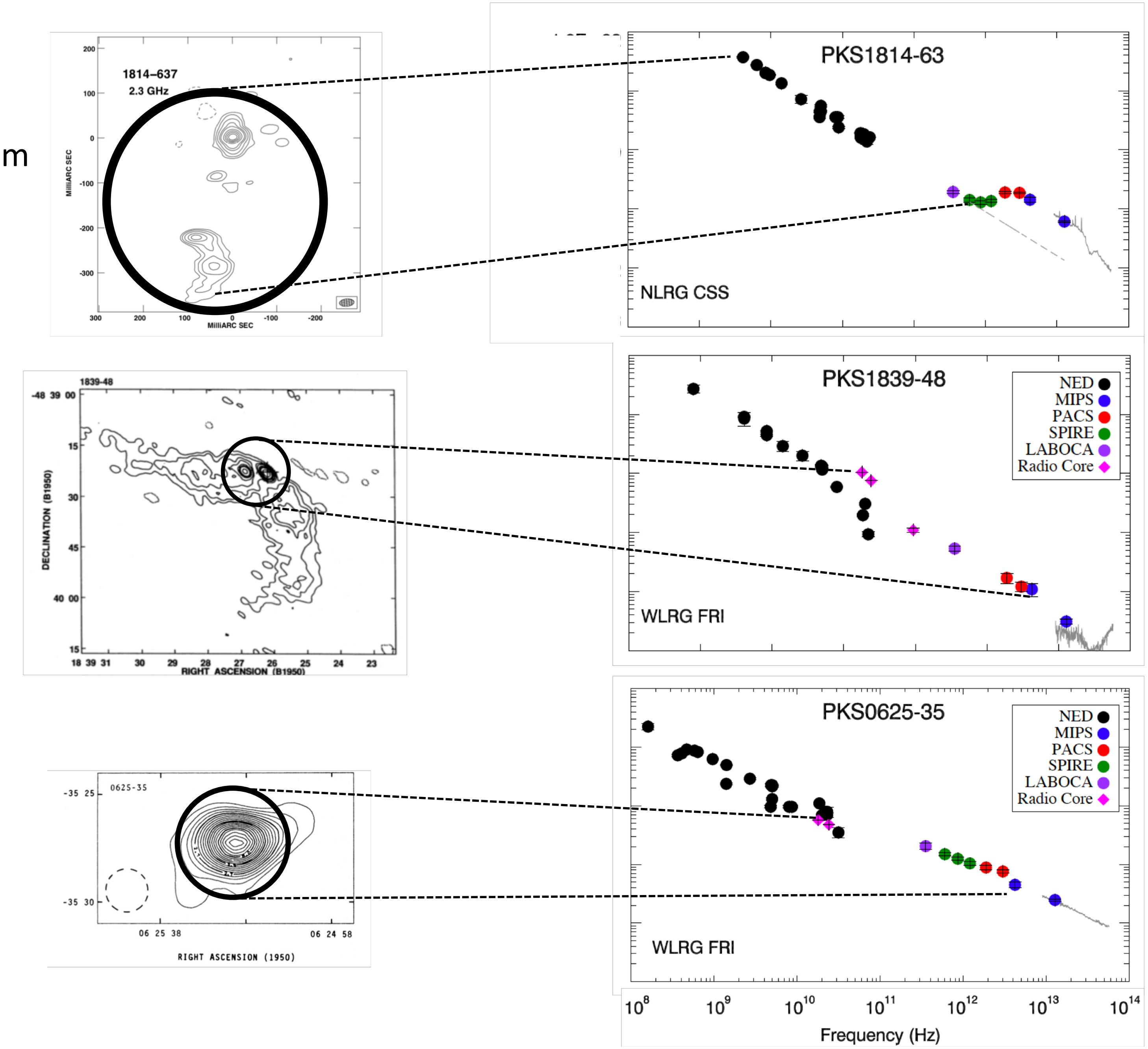
Tadhunter et al. (2014)
Dicken et al. (2019)

Potential non-thermal contamination

Contamination by steep spectrum lobe emission in Herschel beam

Contamination by flat spectrum core emission in Herschel beam

Extreme contamination by flat spectrum core emission in Herschel beam



How massive is the gas/dust reservoir?

- Define quasar to have $L_{bol}>10^{38}$ W ($M_B < -23$)
- Black hole must accrete > 0.2 $M_{\odot}\ yr^{-1}$ to maintain activity
- Typical quasar lifetimes: ~10^6 - 10^8 yr

➔Mass accreted by SMBH over lifetime: ~$2x10^5$ - $2x10^7$ $M_{\odot}$

- But, on the basis of the black hole mass/host galaxy correlations, for every 1 $M_{\odot}$ accreted by the black hole, ~1000 $M_{\odot}$ stars must be formed in the bulge of the host galaxy...

➔The *total* gas reservoir for a particular quasar triggering event is ~$2x10^8$ – $2x10^{10}$ $M_{\odot}$

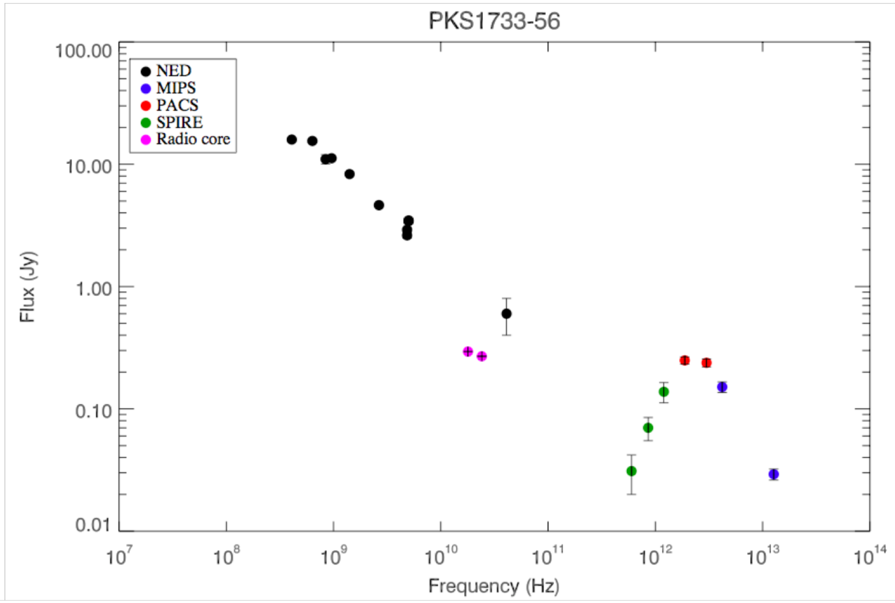
➔For typical quasar lifetime of ~10^7yr predict dust mass ~$2x10^7$ $M_{\odot}$ for M_{gas}/M_{dust}=100

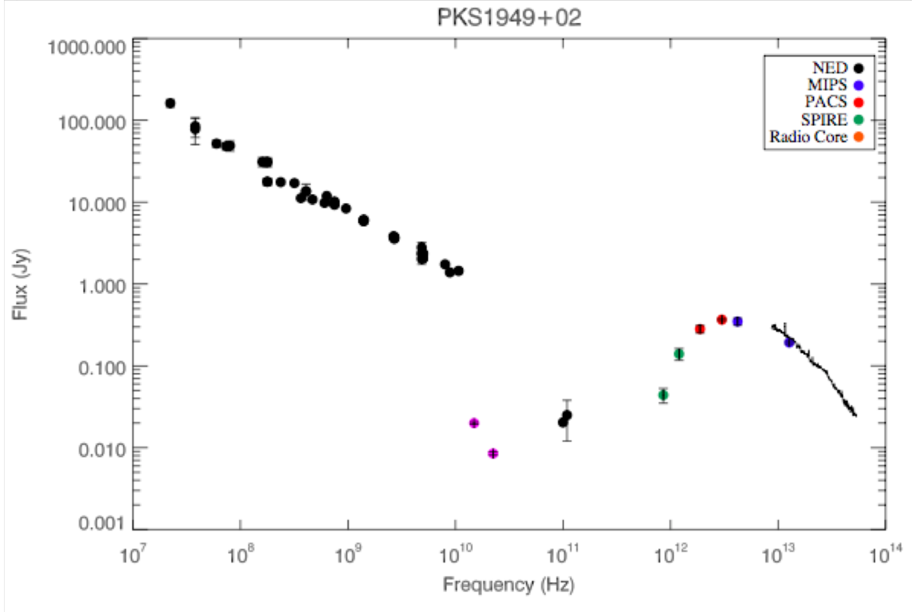
Determining dust masses using Herschel data for the 2Jy sample

- Assume a *single* temperature modified BB fit
- Fits to SEDs and colour-colour plots (objects with SPIRE data) ➔ $\beta \sim 1.2$
- Determine dust temperatures (T_d) from F_{160}/F_{100} ratio and $\beta=1.2$
- Dust masses follow from:

$$M_d = \frac{S_\nu D^2}{\kappa_\nu^m B(\nu, T_d)}$$

- Dust mass determination precision: ~factor 2 (for given κ_{160})

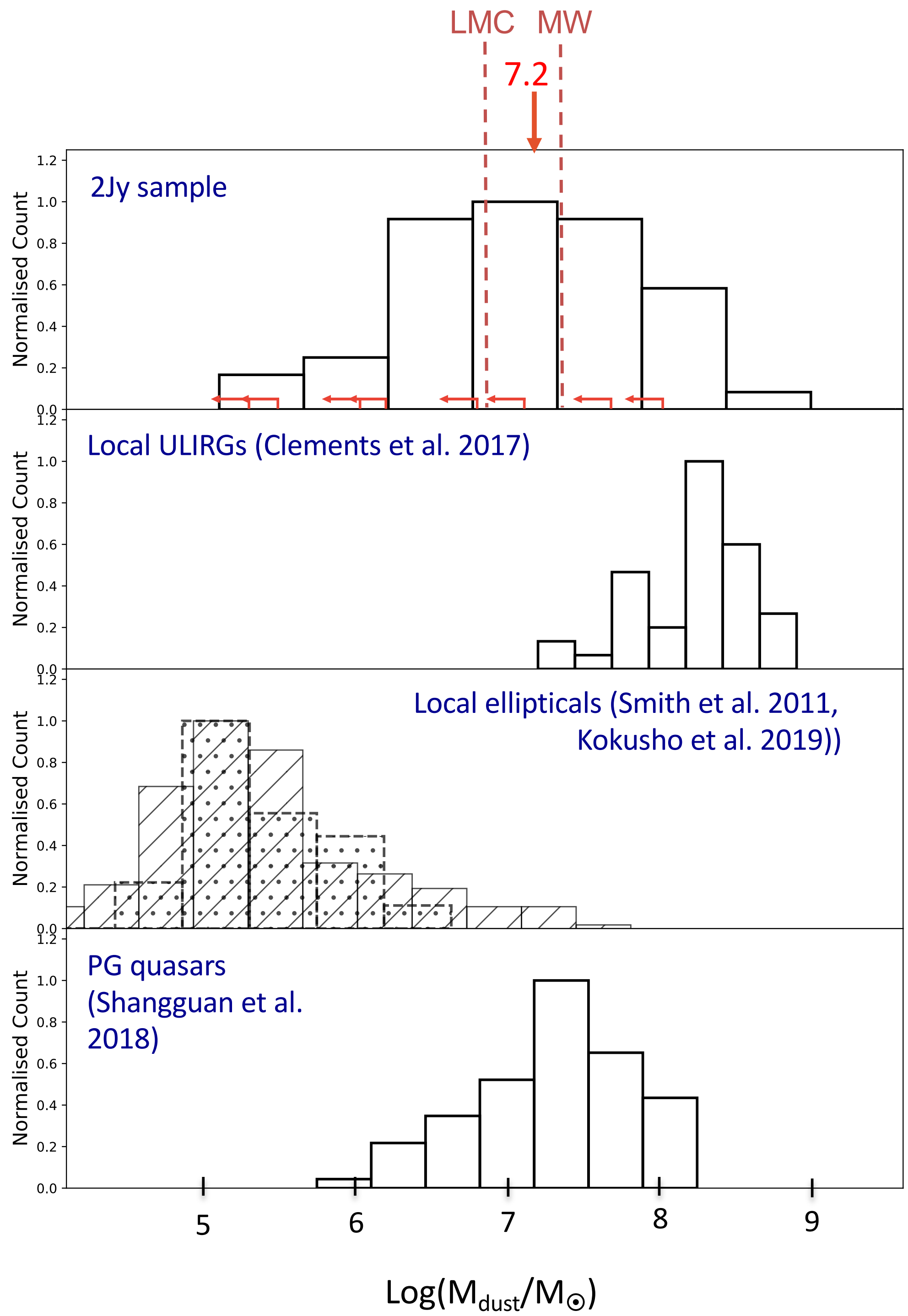




Dust mass results

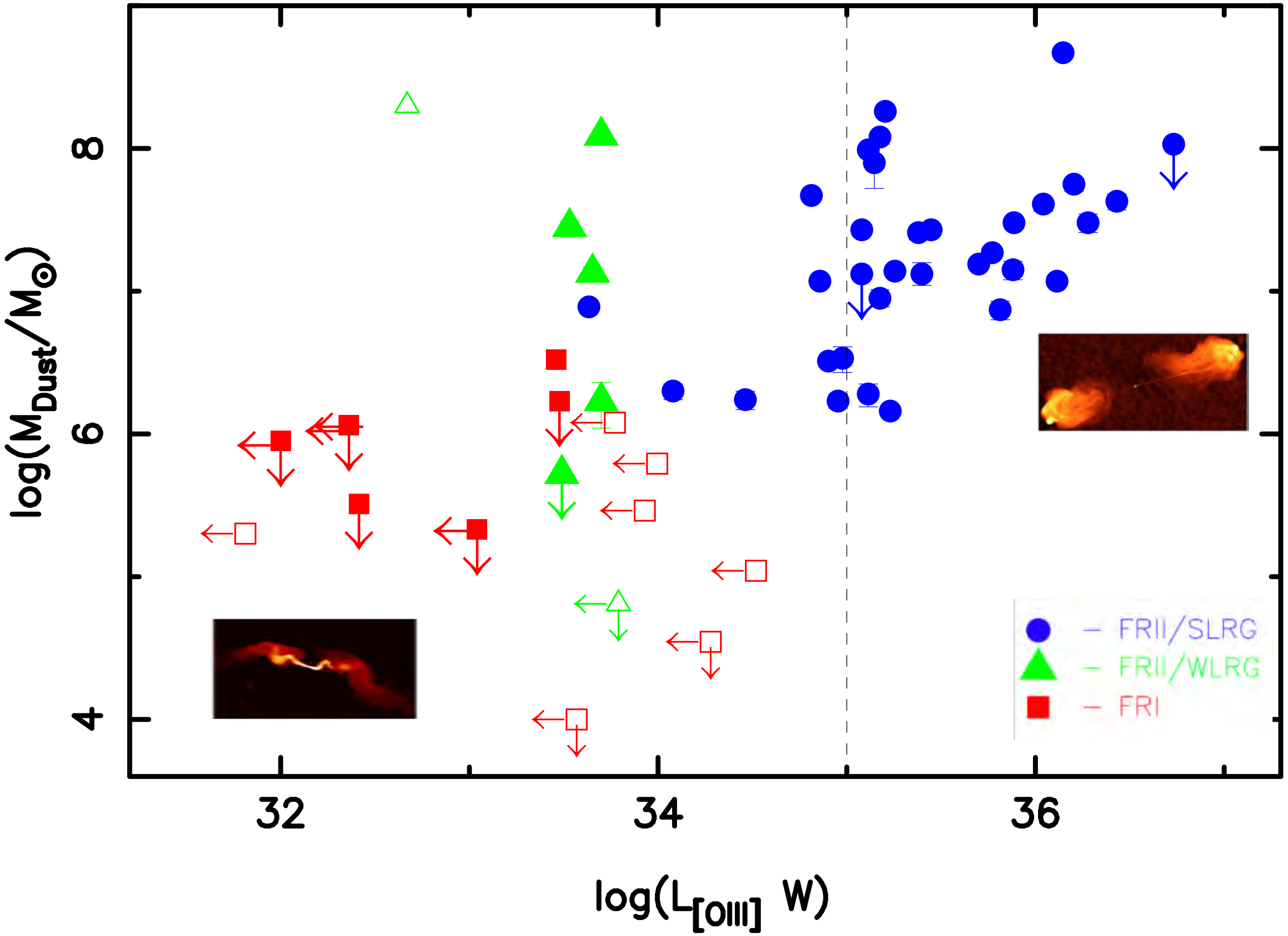
- Typical radio AGN dust masses ~10x lower than ULIRGs, but >10x higher than elliptical galaxies
- <15% of elliptical galaxies have $M_{dust} > 10^6 M_\odot$
- Only requires ~2xLMC cool ISM to trigger quasar

→ In most cases triggering mergers are relatively minor (although ~10-20% of SLRG consistent with more major mergers)



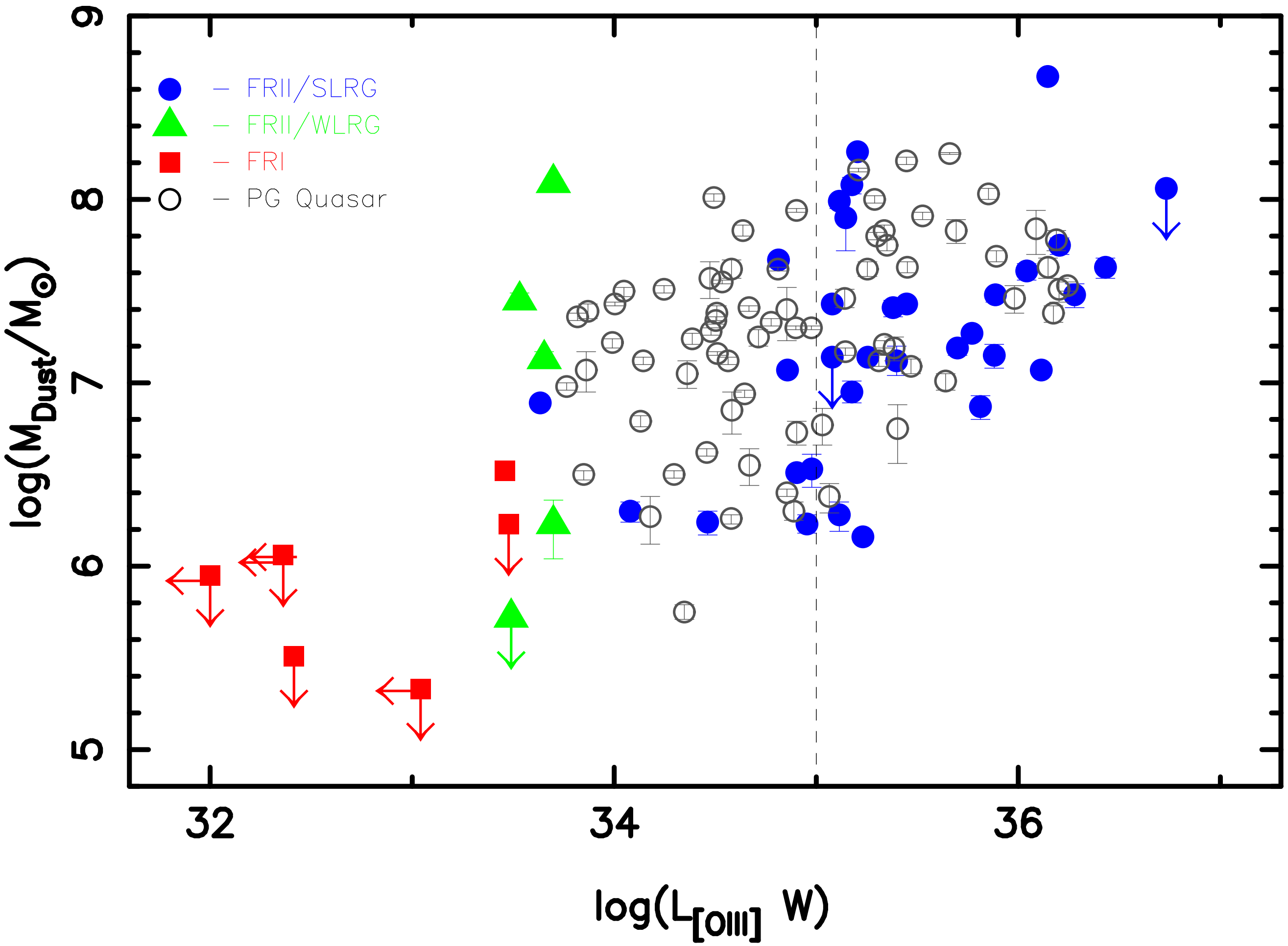
Tadhunter et al. (2014)
Dicken et al. (2019)

Dust masses and radio AGN sub-classes



Evidence that WLRG/FRI have lower dust masses on average than SLRG/FRII, consistent with different triggering mechanisms

2Jy and PG quasar sample comparison



PG quasar sample (z < 0.5) – representative of local, luminous, radio-quiet AGN – shows a similar range of dust masses to 2Jy radio AGN

Conclusions

- Dust masses of 2Jy radio AGN are intermediate between those of quiescent elliptical galaxies and ULIRGs
- Combined with information on detailed morphologies, environments and star formation properties, consistent with SLRG radio AGN in local universe being triggered in relatively modest mergers
- Radio-quiet PG quasars have similar cool ISM reservoirs to 2Jy radio AGN, consistent with similar triggering mechanism
- Lower dust masses of WLRG/FRI compared with SLRG/FRII, suggest different triggering mechanisms