The host galaxy properties of powerful radio sources across cosmic time

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z2p5 & *SHzRGS* teams

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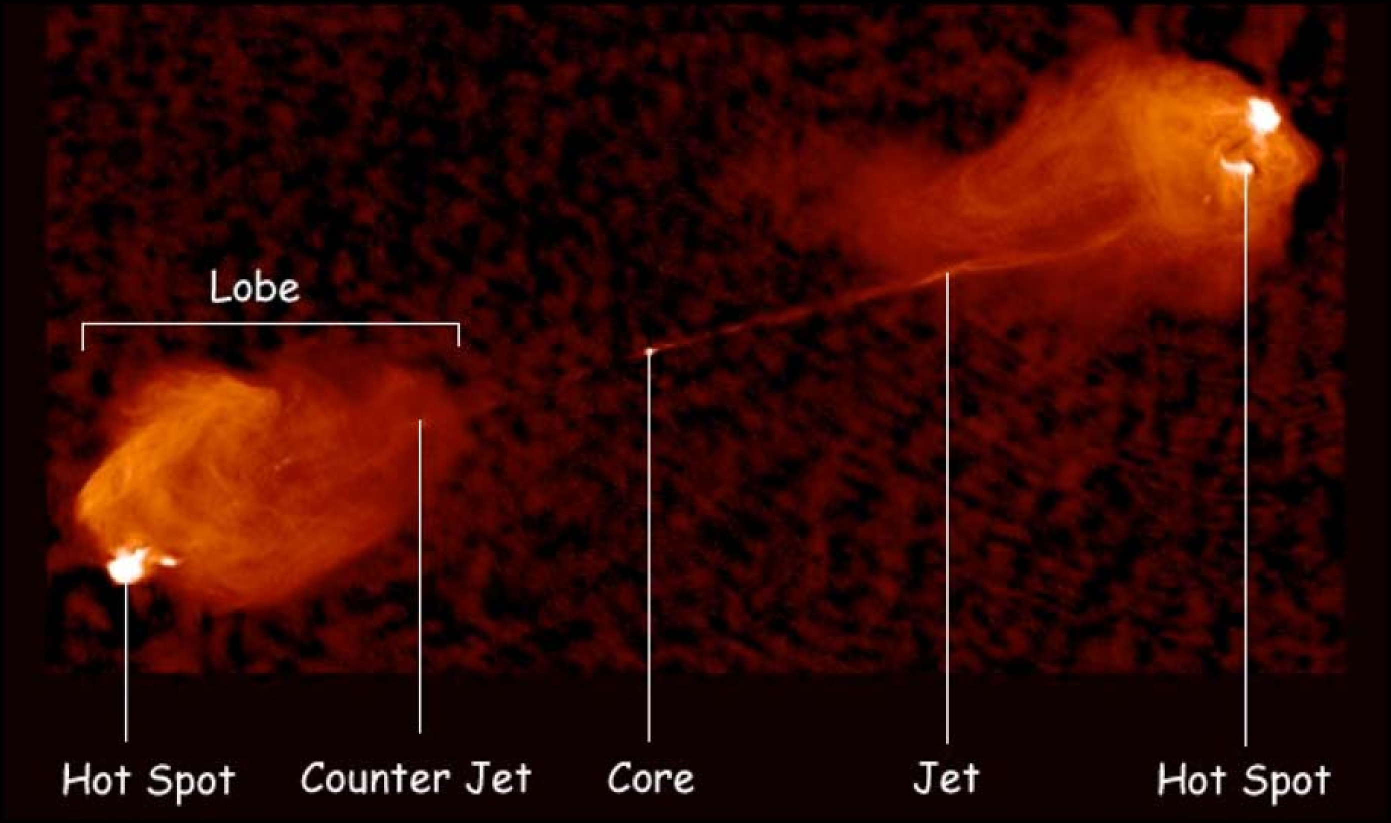
What are they?

- First extragalactic radio sources identified with optical counterparts in 1949
- Centaurus A and Virgo A soon followed by Cygnus A in 1951
- *Bright* radio -> *faint* optical hard to accept.
- Followed by the discovery/identification of the quasars in the early ‘60s

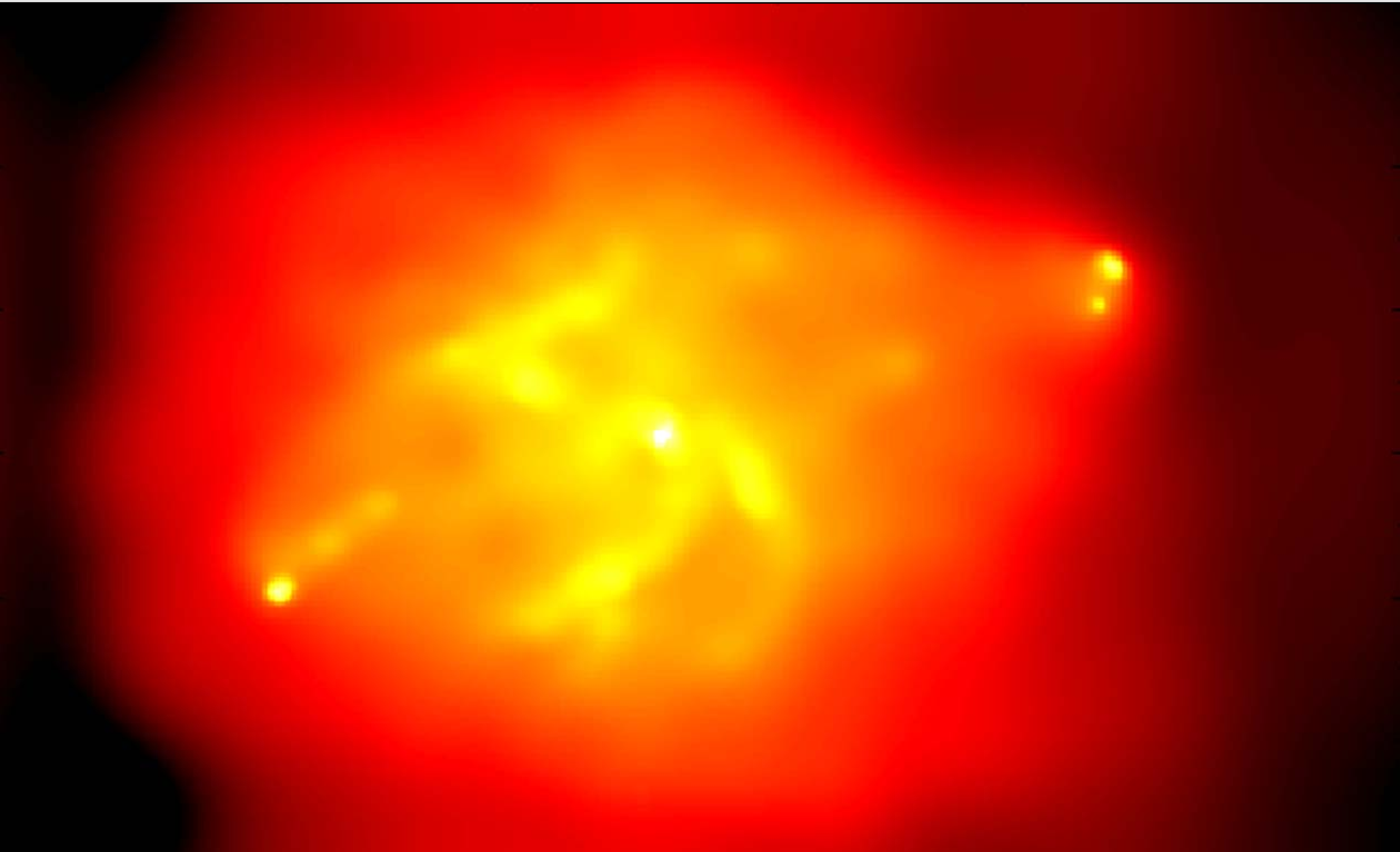
Cygnus A

VLA
Chandra
HST/Keck



Cygnus A

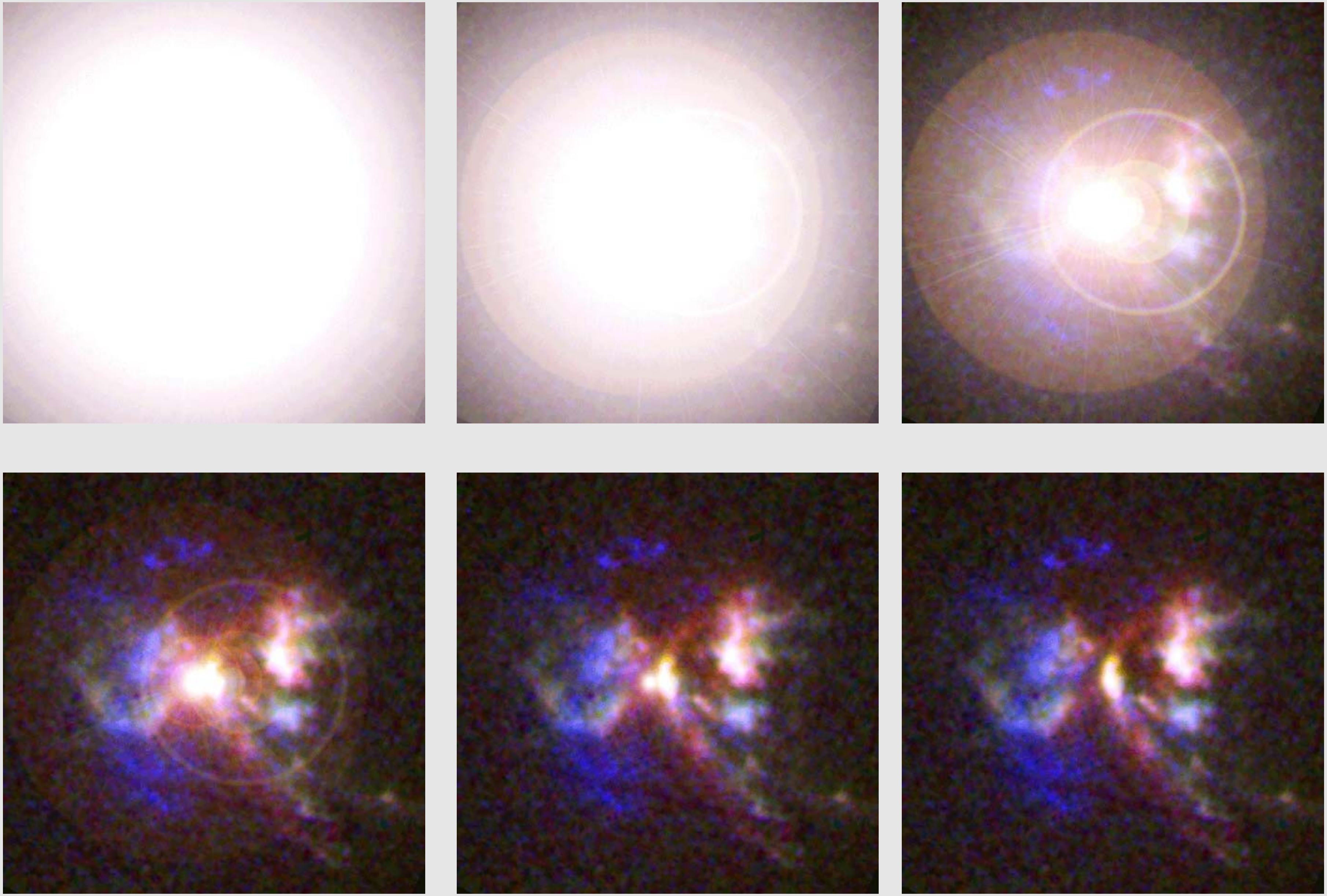
VLA
Chandra
HST/Keck



Cygnus A

VLA
Chandra
HST/Keck

- Massive ‘elliptical’ galaxies containing a currently active nucleus powered by accretion onto a (spinning) supermassive black hole
- Desire to study host galaxies leads to study or *radio galaxies* rather than *quasars*
- Orientation-based unification allows exploitation of ‘natural coronograph’



Stills from animation in presentation

Cosmic context

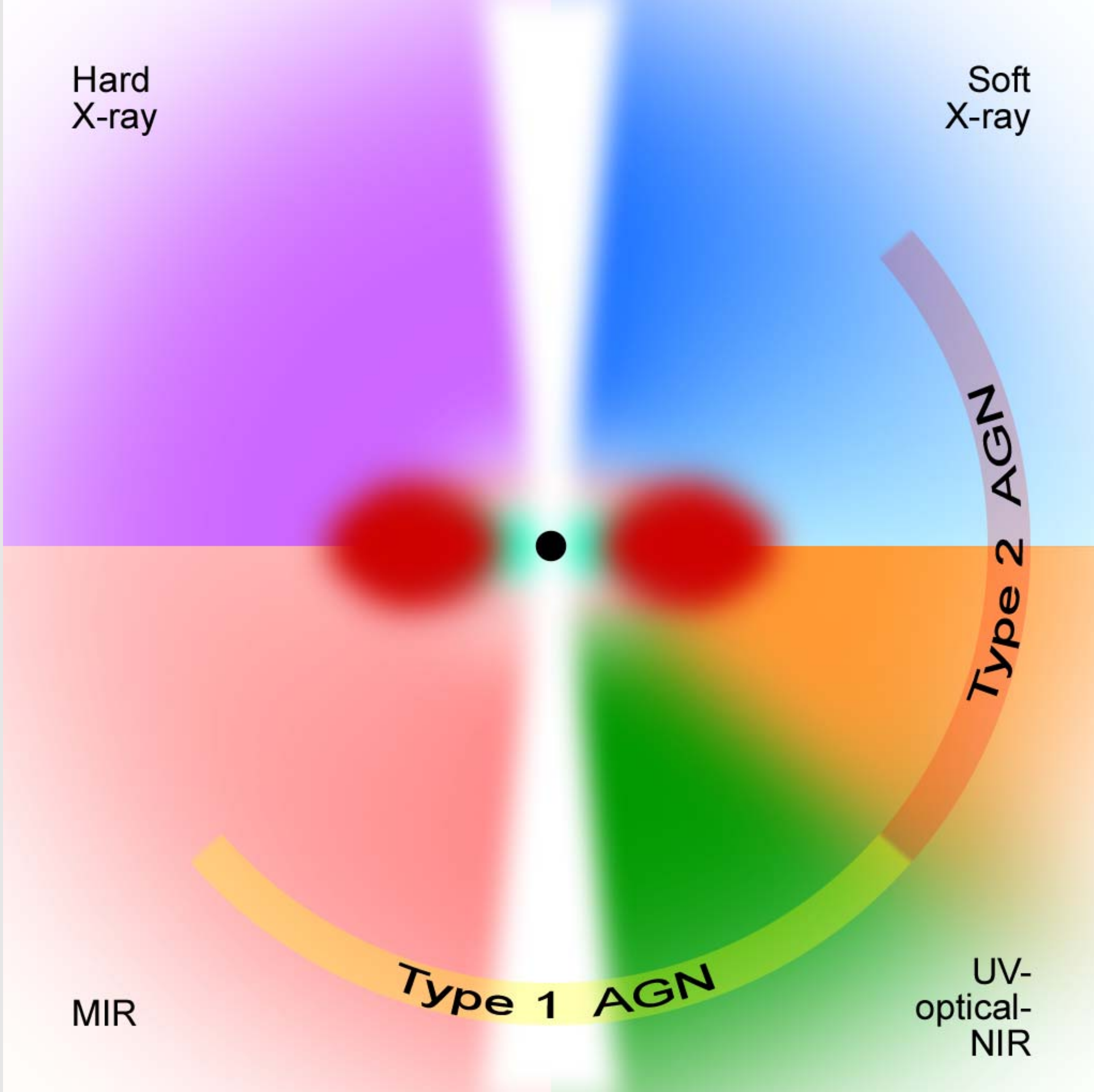
- The RG were the first galaxies to be found above redshifts of 1, 2, 3 and 4 – enabling a leap to the high z universe
- They mark the most massive galaxies at each epoch
  - probability of being a powerful radio source a strong function of stellar (and black-hole) mass – but still only a few % of them are radio loud
    at any one time
- They mark the positions of the first protoclusters (Venemans et al. 2007)

- The juxtaposition of powerful sources of radiation from nucleosynthesis (stars) and from gravitational collapse (AGN)
- The sites of feedback* in action…

  - ** negative and/or positive??*


Their component parts

And anisotropies

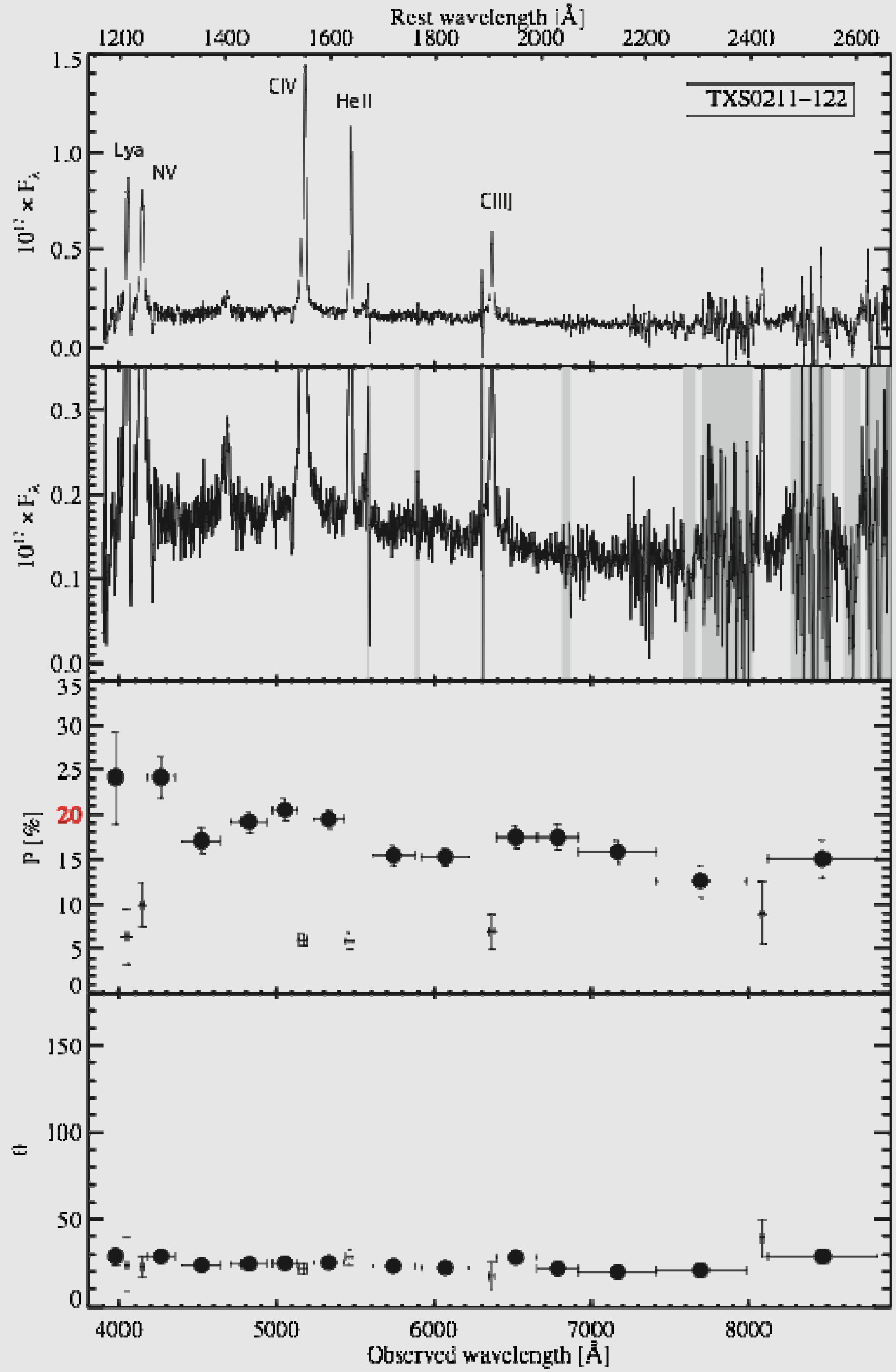


The Host + AGN catalogue of parts

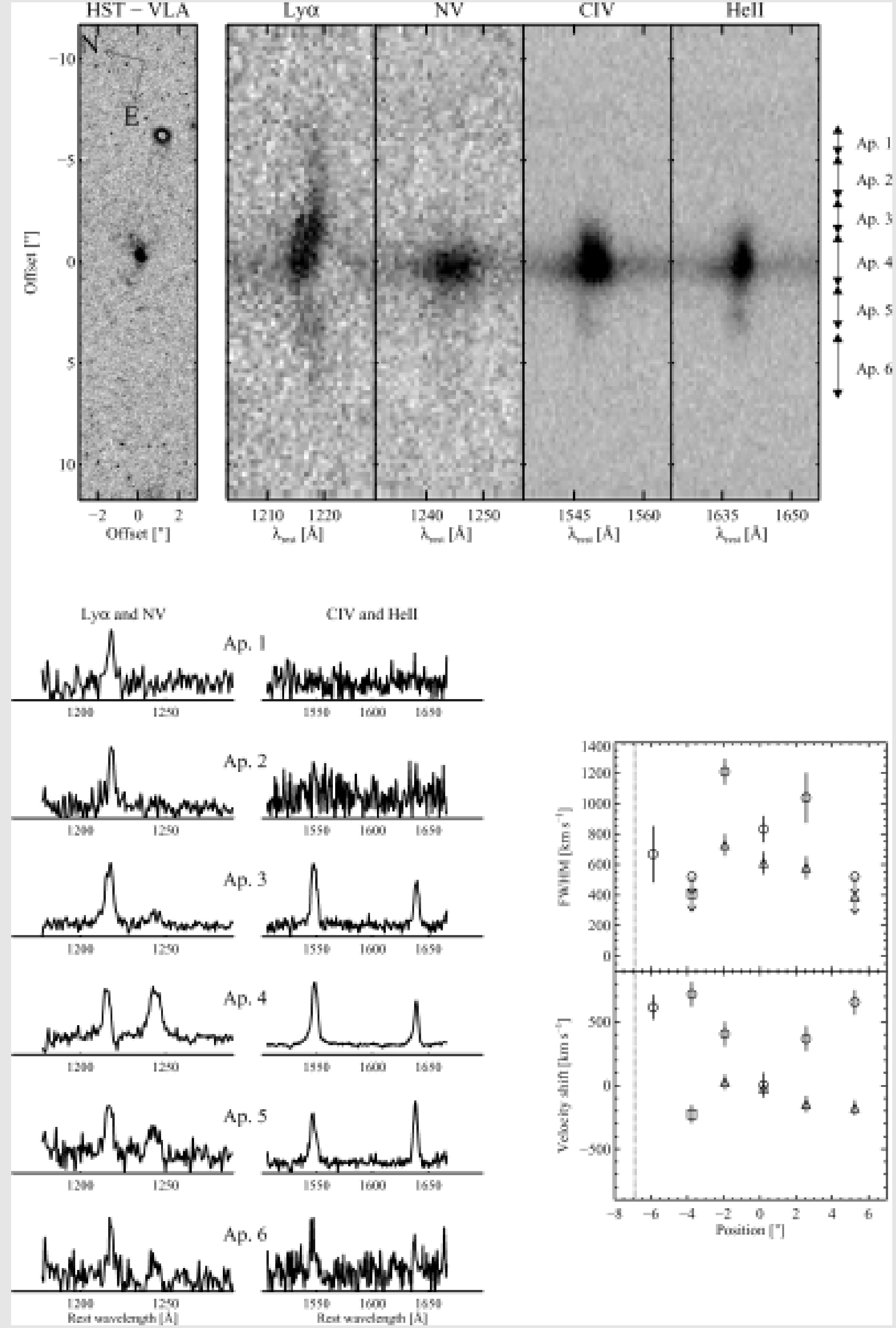
- Two programmes:
  - The *z2p5* spectroscopic/polarimetric study of z ~ 2.5 radio galaxies
    - High quality spectra from Lya to [S II] and restframe UV polarimetry
  - The *SHzRGS* Spitzer survey of 69 radio galaxies 1 < z < 5.2
    - Separate the stellar and AGN contributions to the SED
    - Construct the restframe H-band Hubble diagram and determine stellar masses
    - Examine the RG environment with multi-band data
    - *Both programmes founded upon extensive archival HST data for optical/NIR photometry and morphology*

- Keck LRISp observations of 9 RG
  - high radio power sources from USS survey (Röttgering 1995) 2.2 < z < 3.6
  - long slit spectopolarimetry 3900–9000Å with R~600
  - typical exposure 20ks
  - slit along radio axis
- VLT ISAAC observations of 9 RG
  - from USS survey 2.2 < z < 2.6
  - 3 in common with above
  - long slit spectroscopy in J, H and K with R ~ 500
  - typical exposure 3–10ks in each band
  - slit along radio axis (congruent for sources in common)

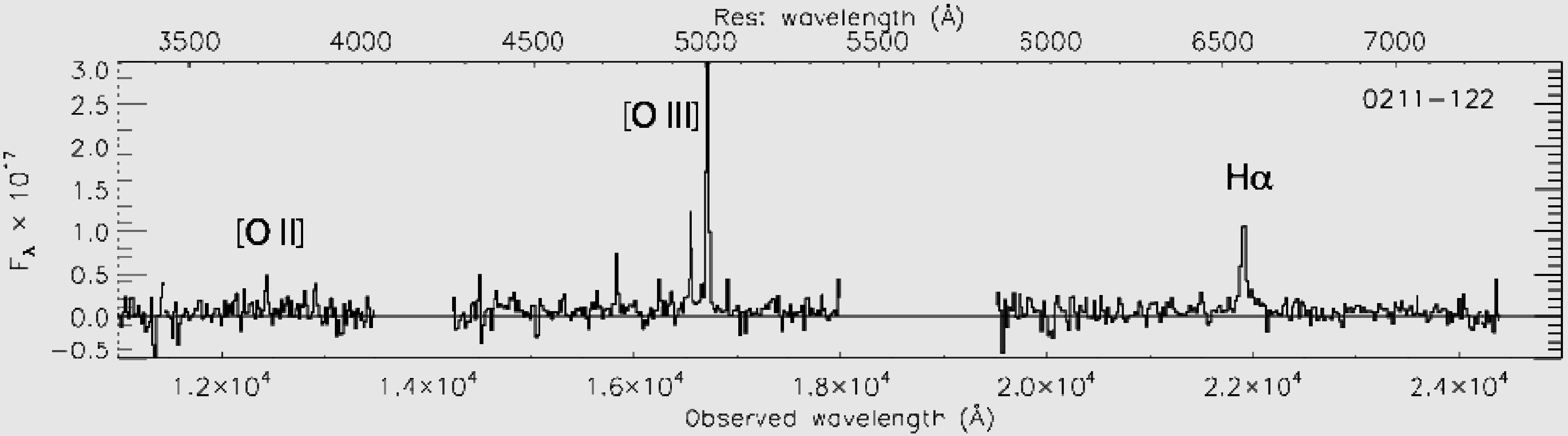
- Keck LRISp spectropolarimetry
  - Vernet et al. (2001)
- Flux
- P(%)
- Position angle

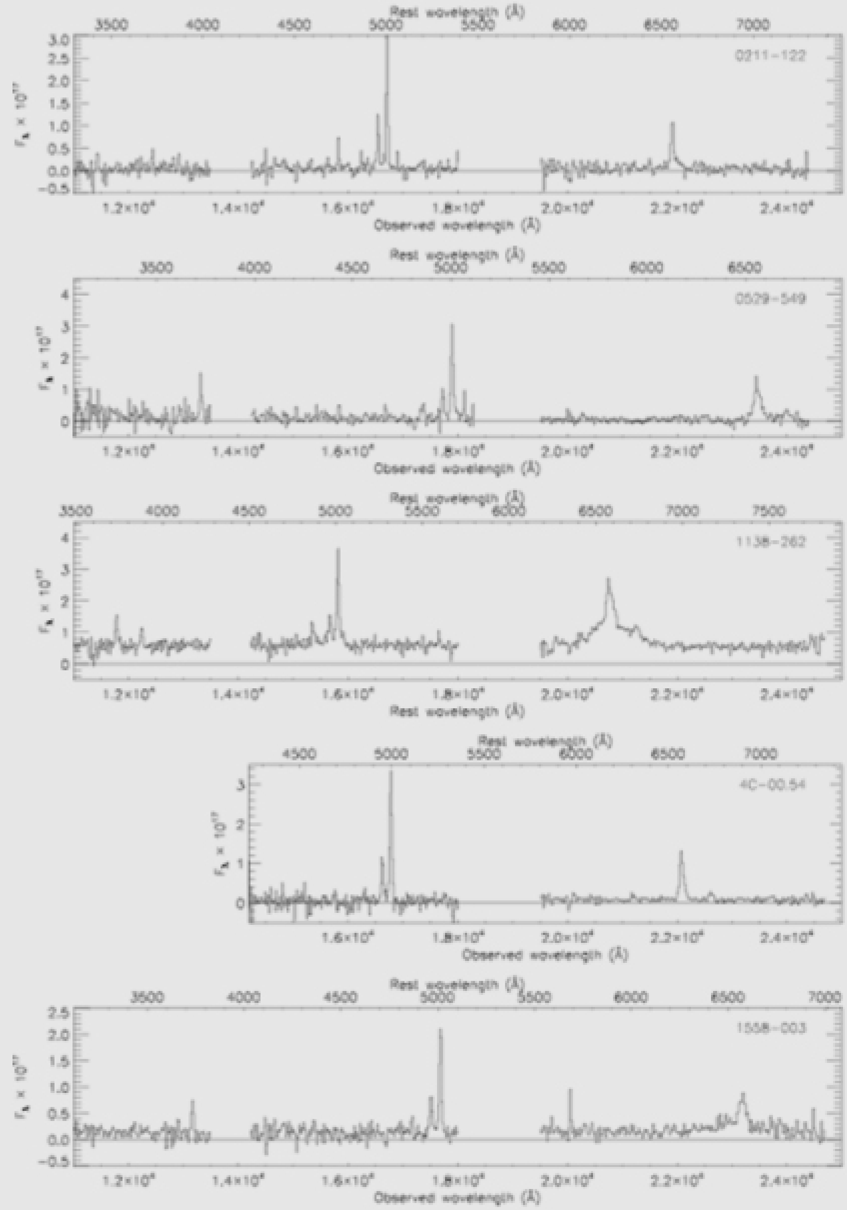


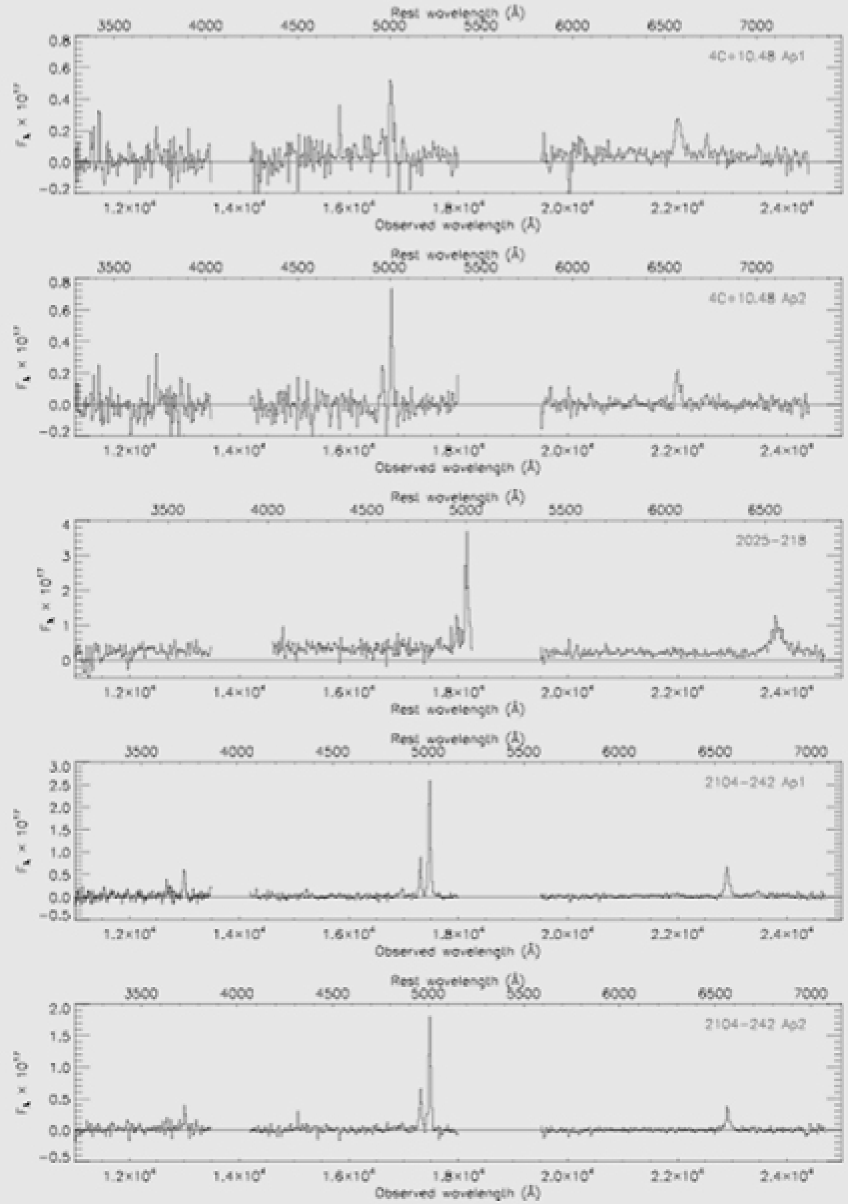
- TXS 0211-122
  - 2D spectra
  - HST/VLA map

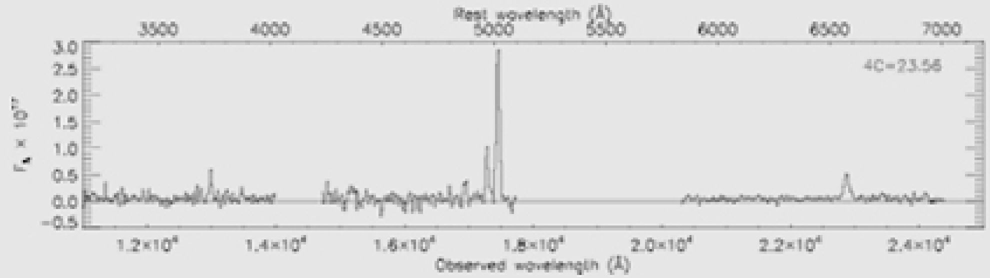


- ISAAC spectroscopy in J, H and K
  - Humphrey et al. (2007)



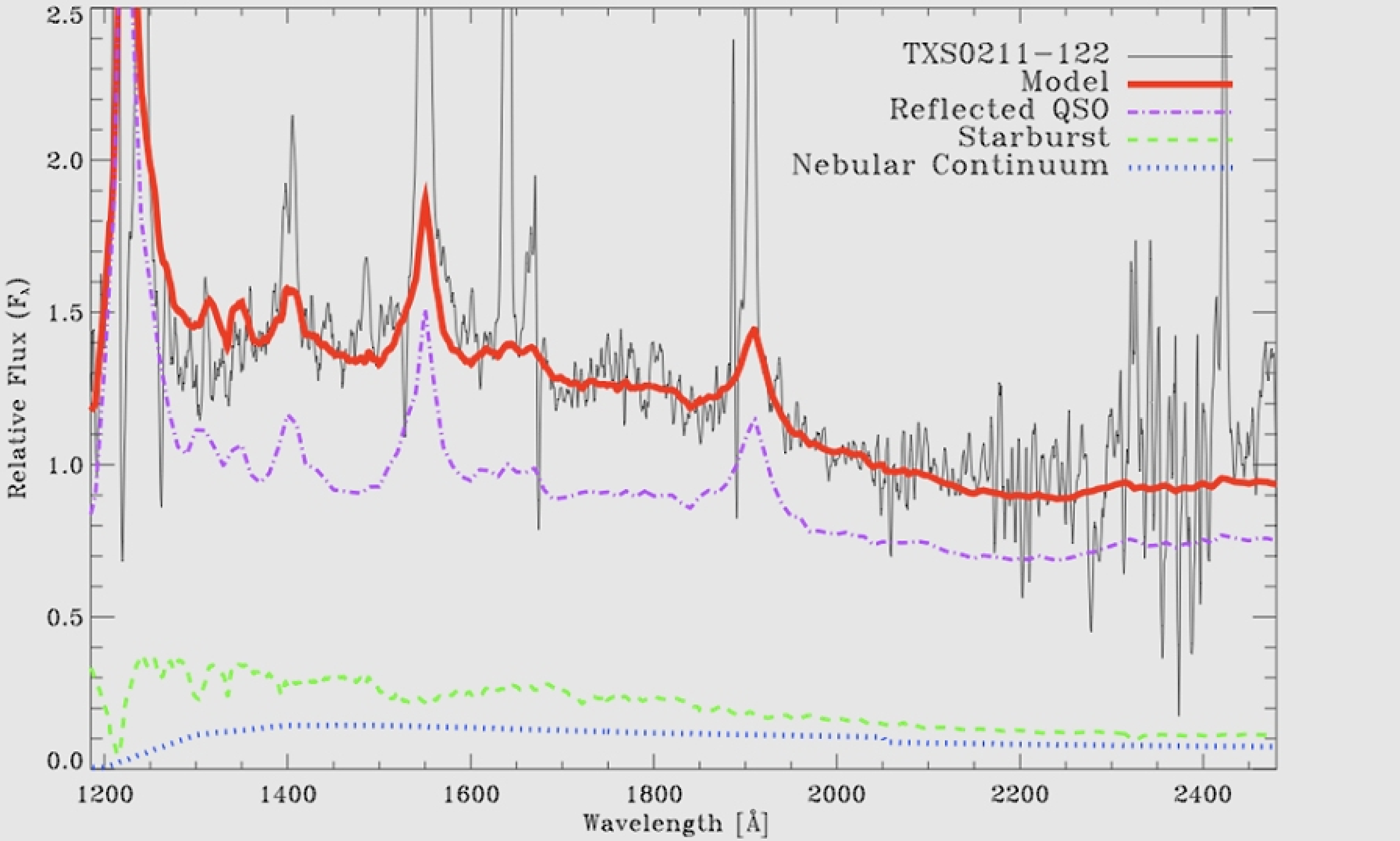

Rest wavelength (Å)
0211-122
Observed wavelength (Å)
Rest wavelength (Å)
0529-549
Observed wavelength (Å)
Rest wavelength (Å)
1138-262
Rest wavelength (Å)
Rest wavelength (Å)
4C-00.54
Observed wavelength (Å)
Rest wavelength (Å)
1558-003
Observed wavelength (Å)


Rest wavelength (Å)
Observed wavelength (Å)
$f_\lambda \times 10^{17}$
4C+10.48 Ap1
4C+10.48 Ap2
2025-218
2104-242 Ap1
2104-242 Ap2



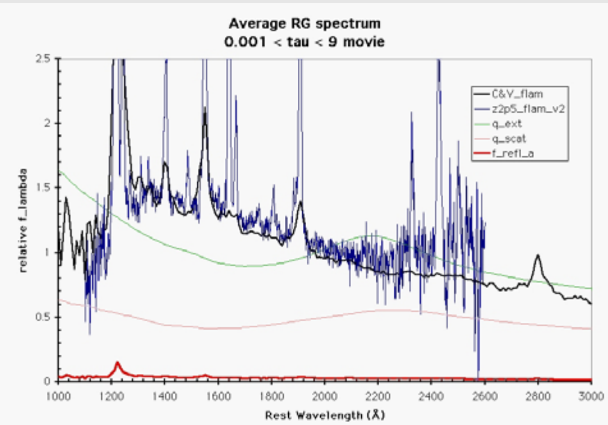
Rest wavelength (Å)
3500
4000
4500
5000
5500
6000
6500
7000
4C+23.56
3.0
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
1.2×10⁴
1.4×10⁴
1.6×10⁴
1.8×10⁴
2.0×10⁴
2.2×10⁴
2.4×10⁴
Observed wavelength (Å)

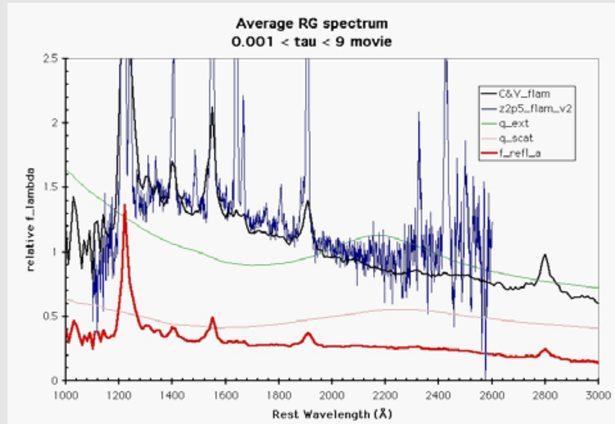
- Continuum fitting using 'clumpy-scattering' model

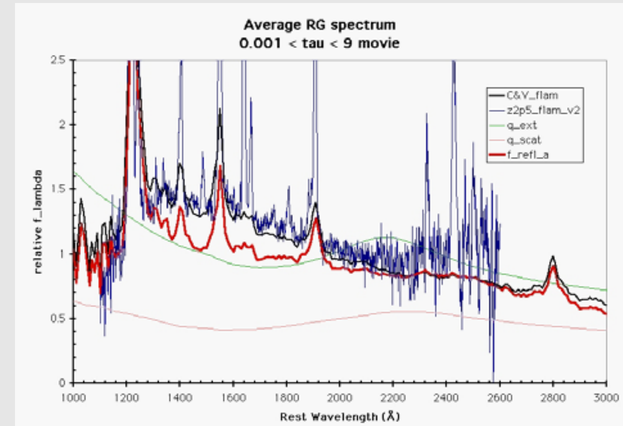


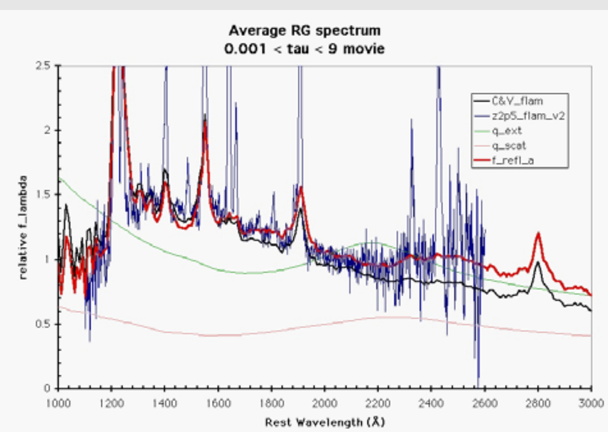
•Clumpy-scattering in action – no free parameters except intensity

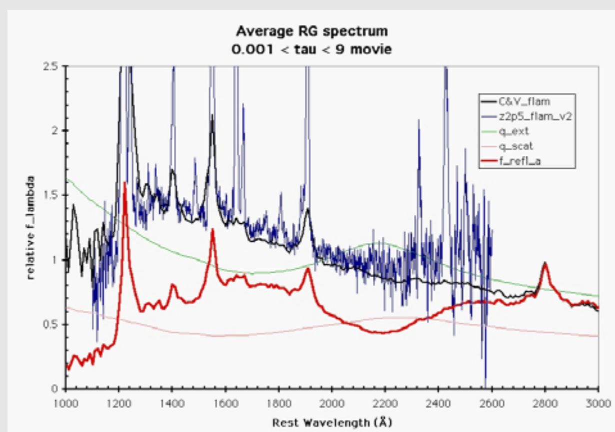
Stills from animation in presentation (left to right, top to bottom)

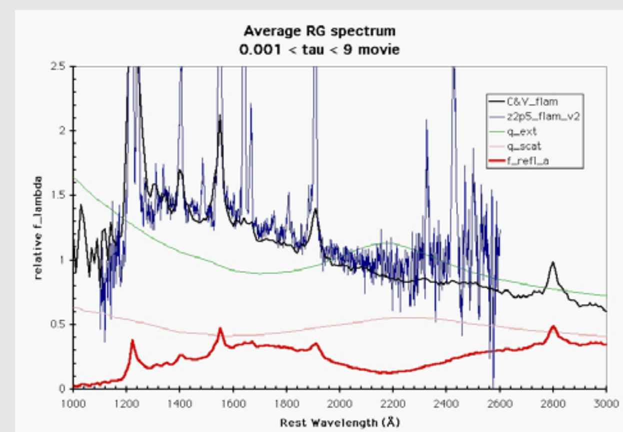




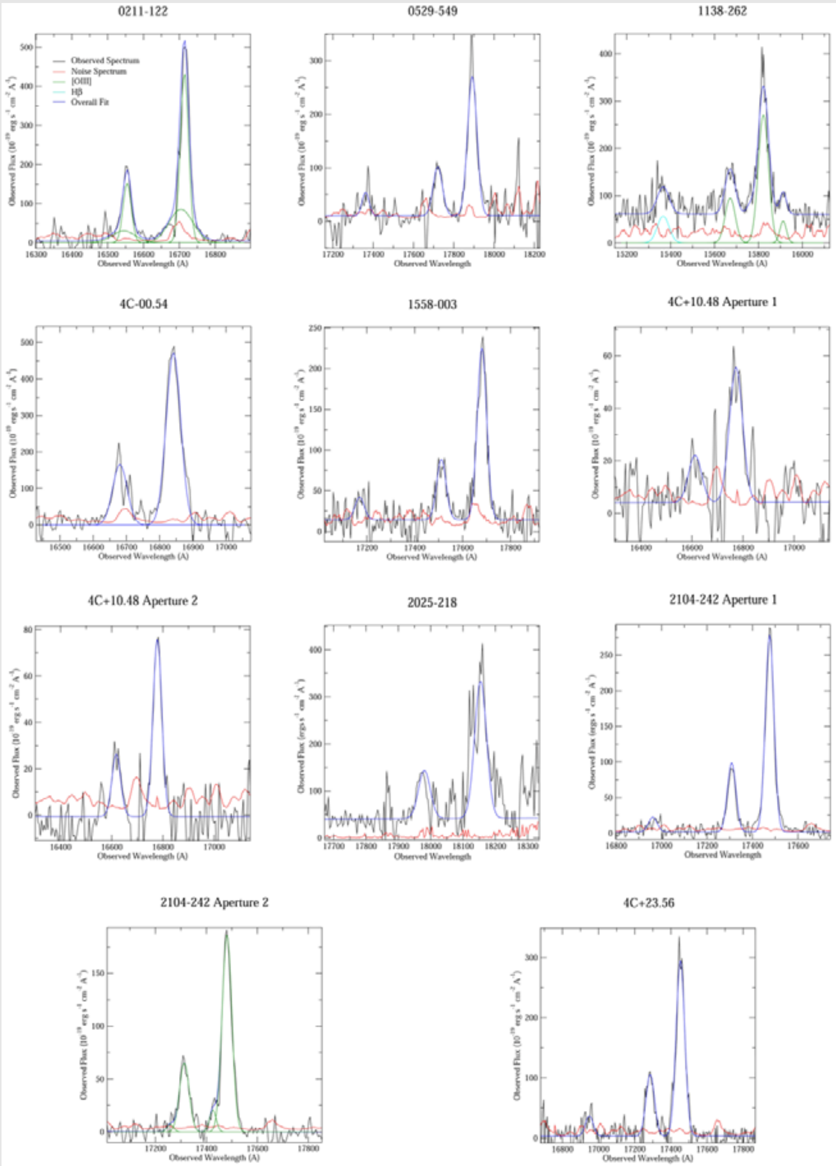


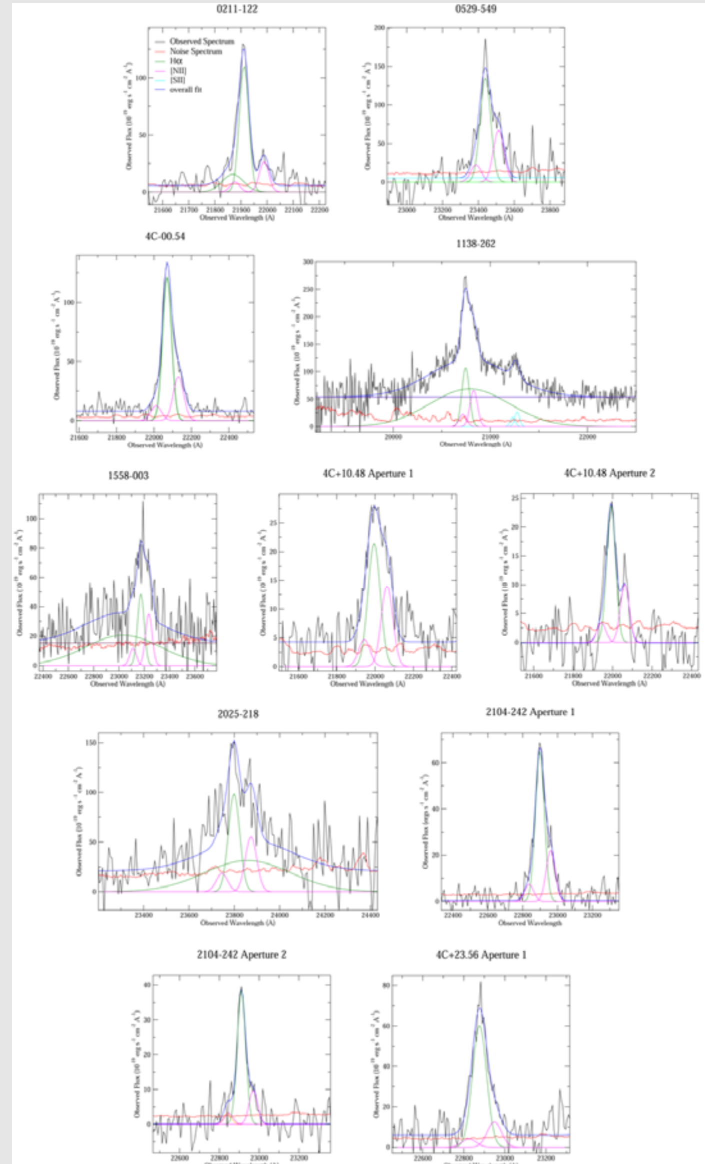






Emission line fitting, [O III] and H-alpha



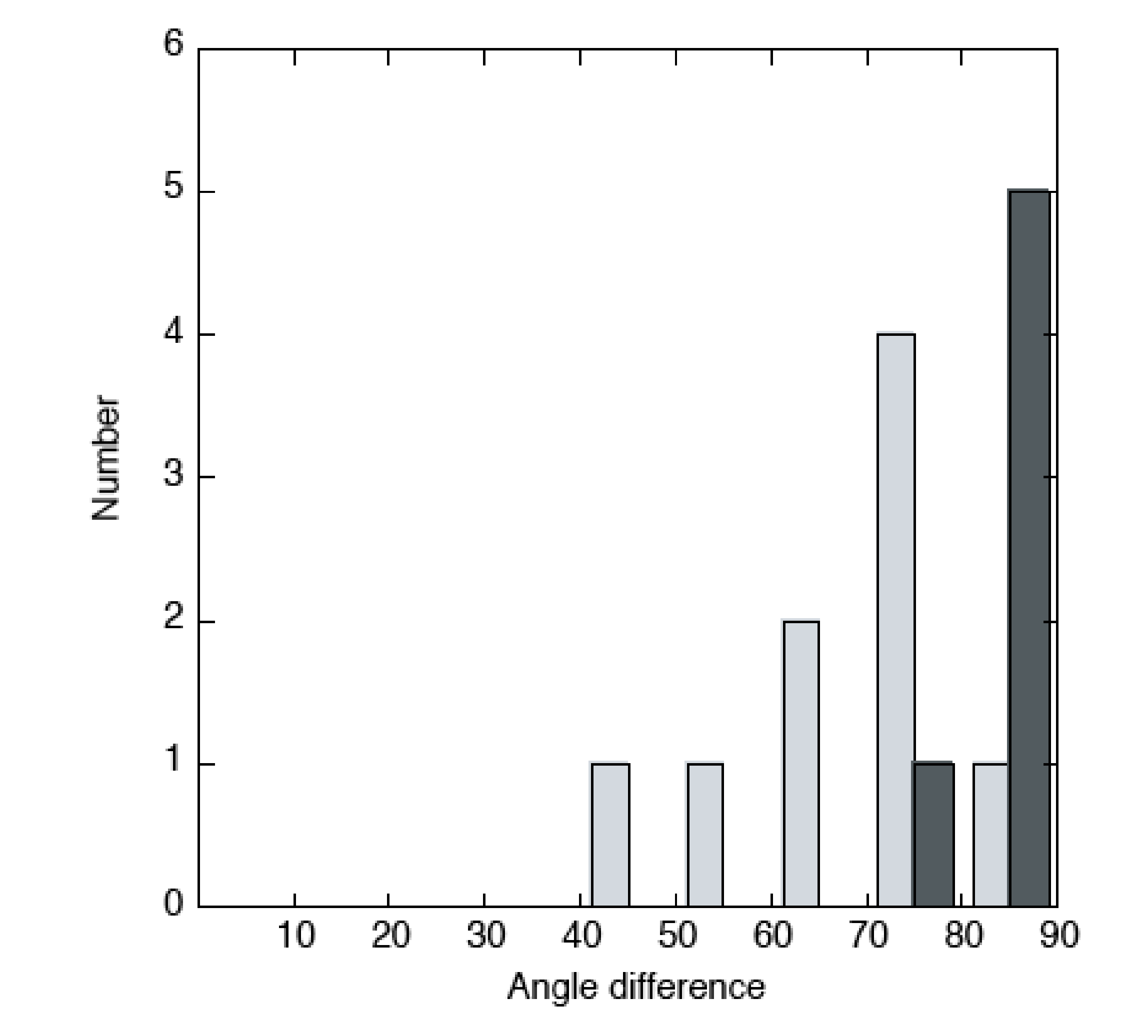


Principal results

- Continuum
  - The restframe UV continuum in these powerful sources is generally dominated by ‘grey’ dust scattering of the obscured AGN from a clumpy medium
  - The fractional linear polarization P_{ctm} (1250–1400Å) ranges from a few to 20%
    - but note that the narrow emission lines are unpolarized and some objects show a scattered BLR
  - E-vector more closely perp. to UV elongation than to radio axis
  - P_{ctm} correlates with NV/CIV and anti-correlates with Lya/CIV
  - Sources with high emission line A_V show high polarization

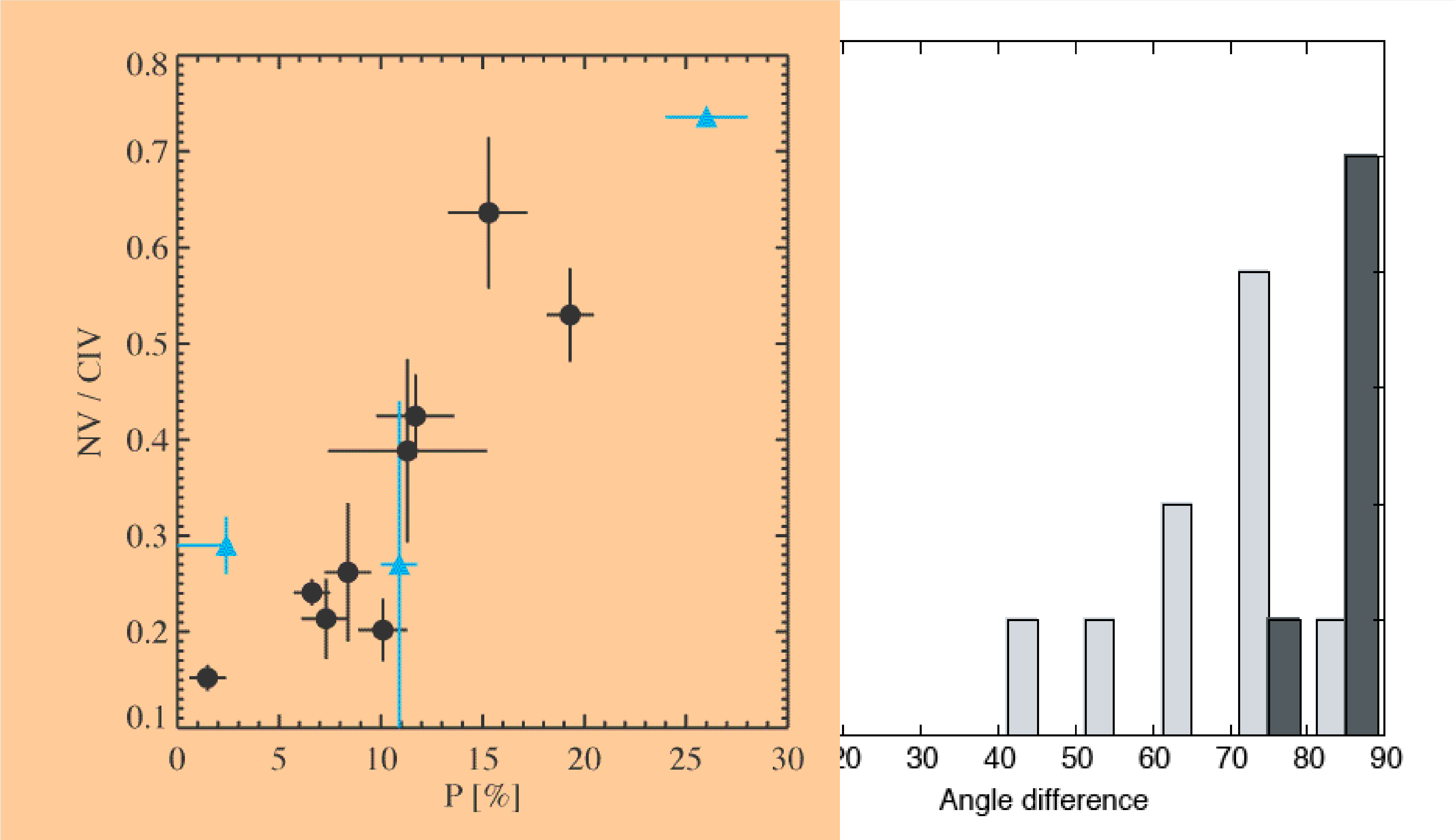
Principal results

- Continuum
  - The restfr
    powerful s
    by ‘grey’
    AGN from a
  - The fracti
    P_{ctm} (1250-
    - but note
      unpolari
      scattere
  - E-vector m
    elongation
  - P_{ctm} correl
    correlates
  - Sources wi
    high polarization



Principal results

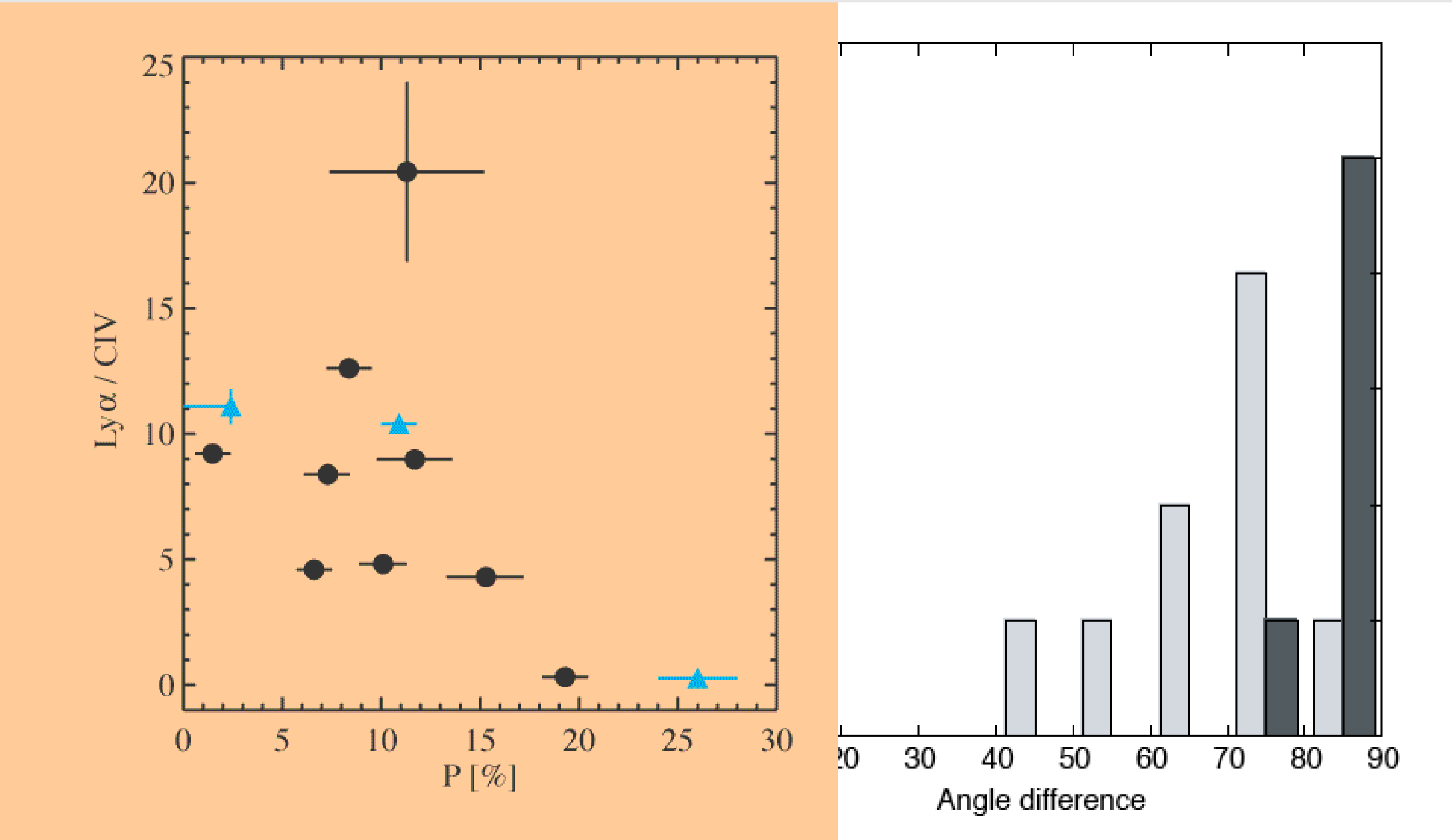
- Continuum



high polarization

Principal results

- Continuum



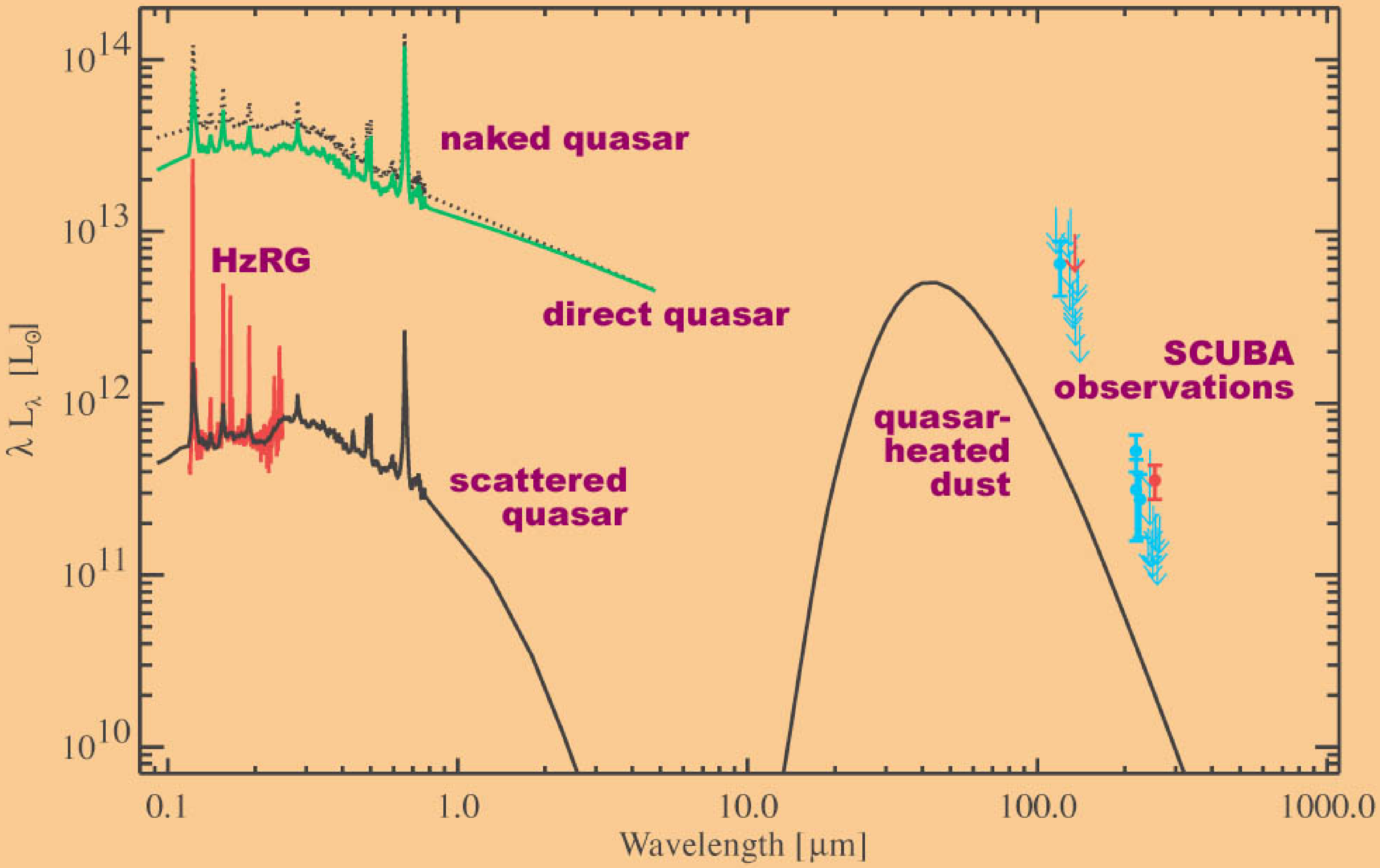
high polarization

- Emission lines
  - Lines from wide range of ionization
  - Predominantly AGN photoionized with a range in ionization parameter U but some evidence for shock contributions
  - New, sensitive, measures of T_e from UV/optical line ratios – particularly [O III] 1660/5007 – giving an average of 14,000K
  - Kinematics divide into perturbed (>1000km/s) regions – associated with the radio jets – and quiescent (<250km/s) halos
  - Large Lya halos (>100kpc, L_{La} ~ 10^{43-44} erg/s) seen in other lines, eg. CIV, HeII, [O III], Ha => they are ionized and not neutral scatterers

- Emission lines (ctd)
  - Photoionization modelling shows that the metallicity Z (and N/H) are close to Solar with variations of < x2
  - This is similar to the result at low redshift by Robinson et al. (1987)

- Light from a young stellar population?
  - Hard to detect unambiguously, though we believe it dilutes the linear polarization below the ‘pure’ scattering values
  - UV from massive stars may produce the large Lya/CIV ratios (LAE objects) seen predominantly in HzRG with z > 3
    - *Villar-Martin et al. (2007)*
  - The cool dust emission (sub-mm) from HzRG is more likely to arise from stellar than AGN - heated dust

- The dust scattering model (Vernet et al. 2001)



SHzRGS

A comprehensive Spitzer survey of HzRGs: the most massive galaxies at every epoch

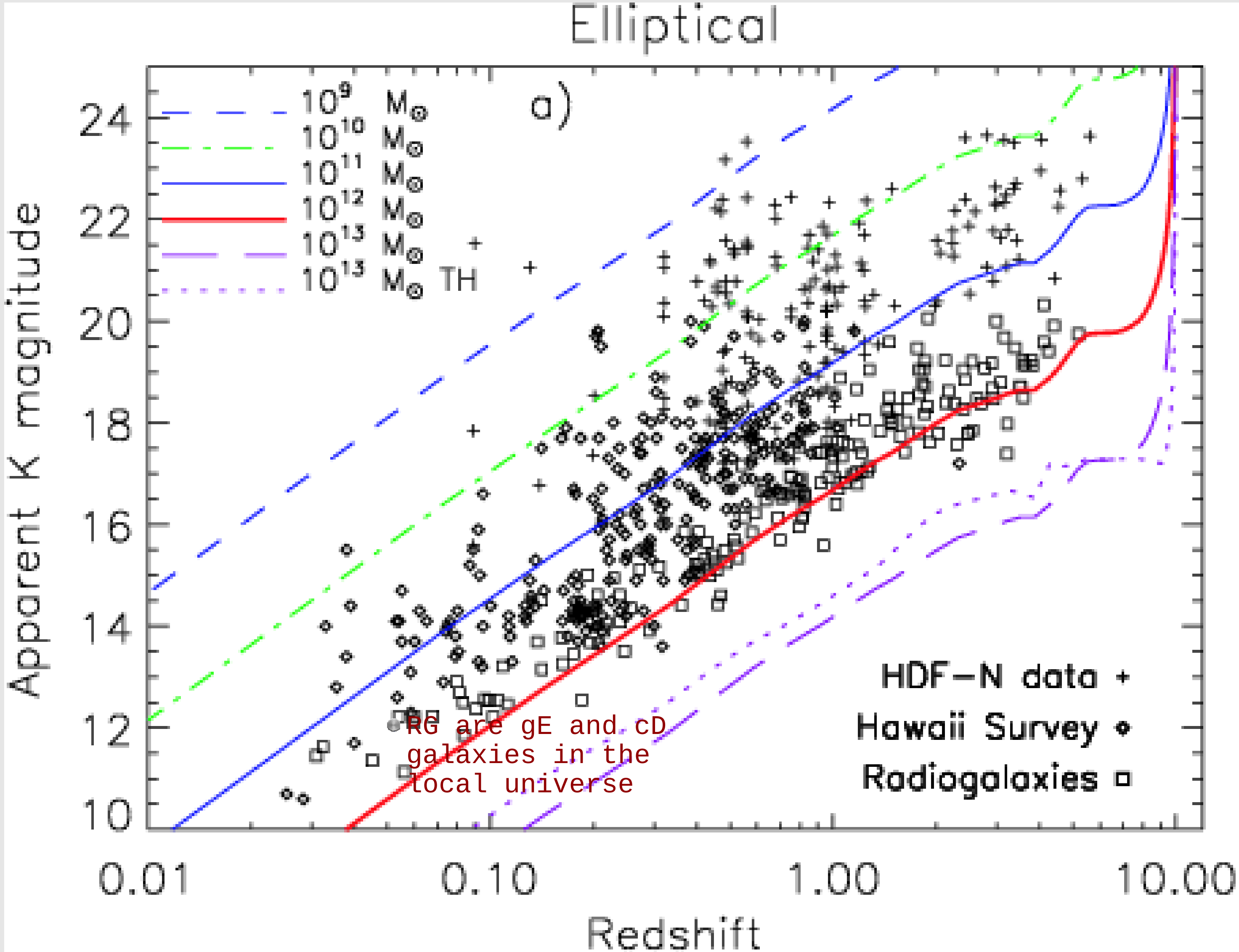
- 28.3 hr of Spitzer Cycle 1 GO observations
- 69 HzRGs at $1<z<5.2$ ($L_{3GHz} > 10^{26}$ W Hz^{-1})
- 3 camera imaging to measure the SEDs of stellar populations and the dust properties
- Supporting data in other bands (including HST archival data) to characterise the AGN contributions
- Observations between Nov 2004 and Nov 2006
- And hopefully more data from a GTO Cycle 4 proposal!

  - To appear in ApJS (astro-ph/0703224)

SHzRGS

Motivation

- RG are gE and cD galaxies in the local universe
- $r^{1/4}$ light profiles in distant sources (NICMOS)
- HzRG reside in (proto-)cluster environments
- Large, luminous Lya halos
- sub-mm detections => high star formation rates
- NIR Hubble diagram (K-z; Rocca-Volmerange et al. 2004)
- Correlation of stellar bulge and BH masses



RG are gE and cD galaxies in the local universe

Motivation

- Decompose SED into AGN and stellar parts using X-ray - radio observations
- Characterise environments using optical, NIR and MIR imaging

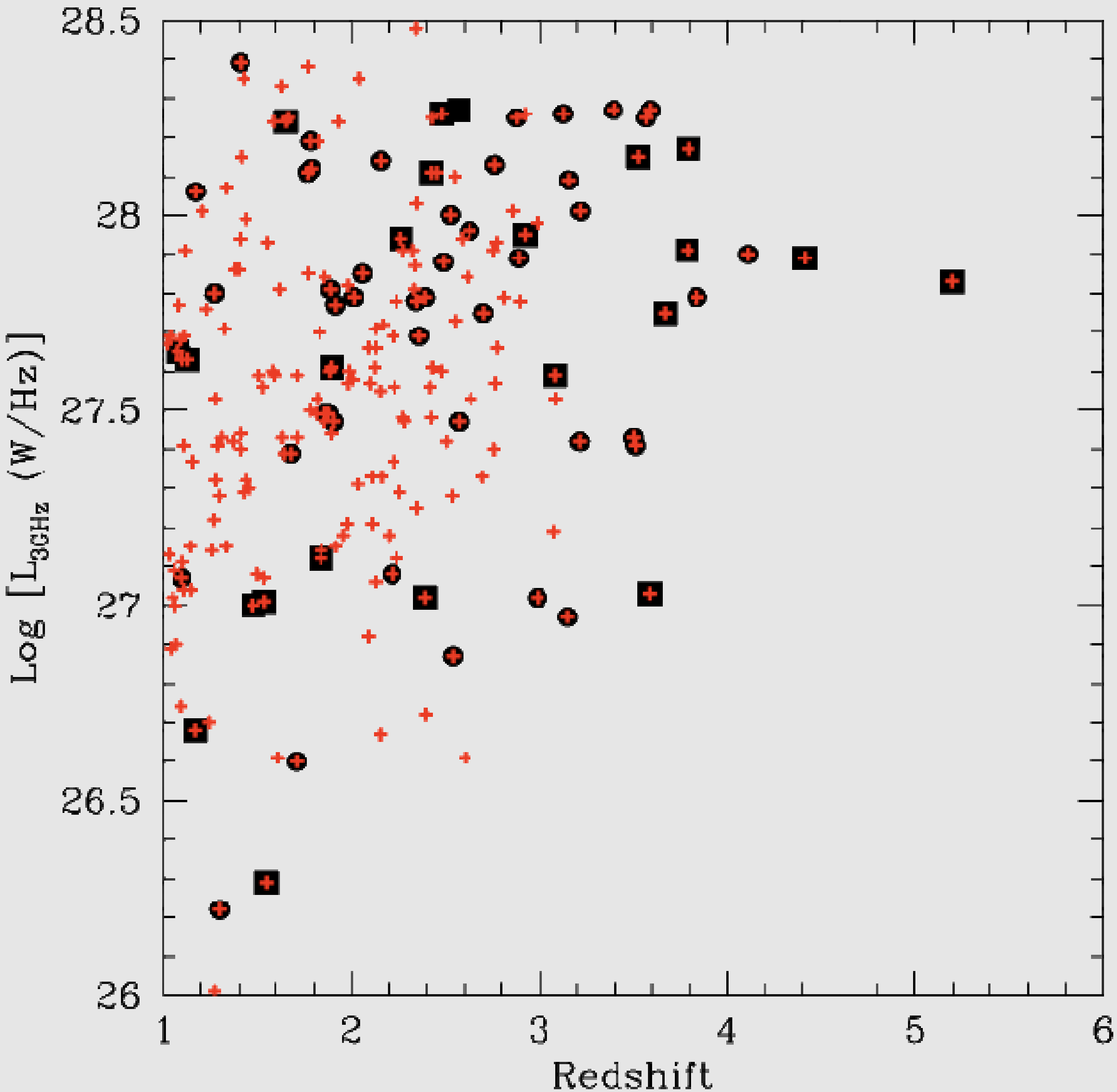
SHzRGS

•The sample

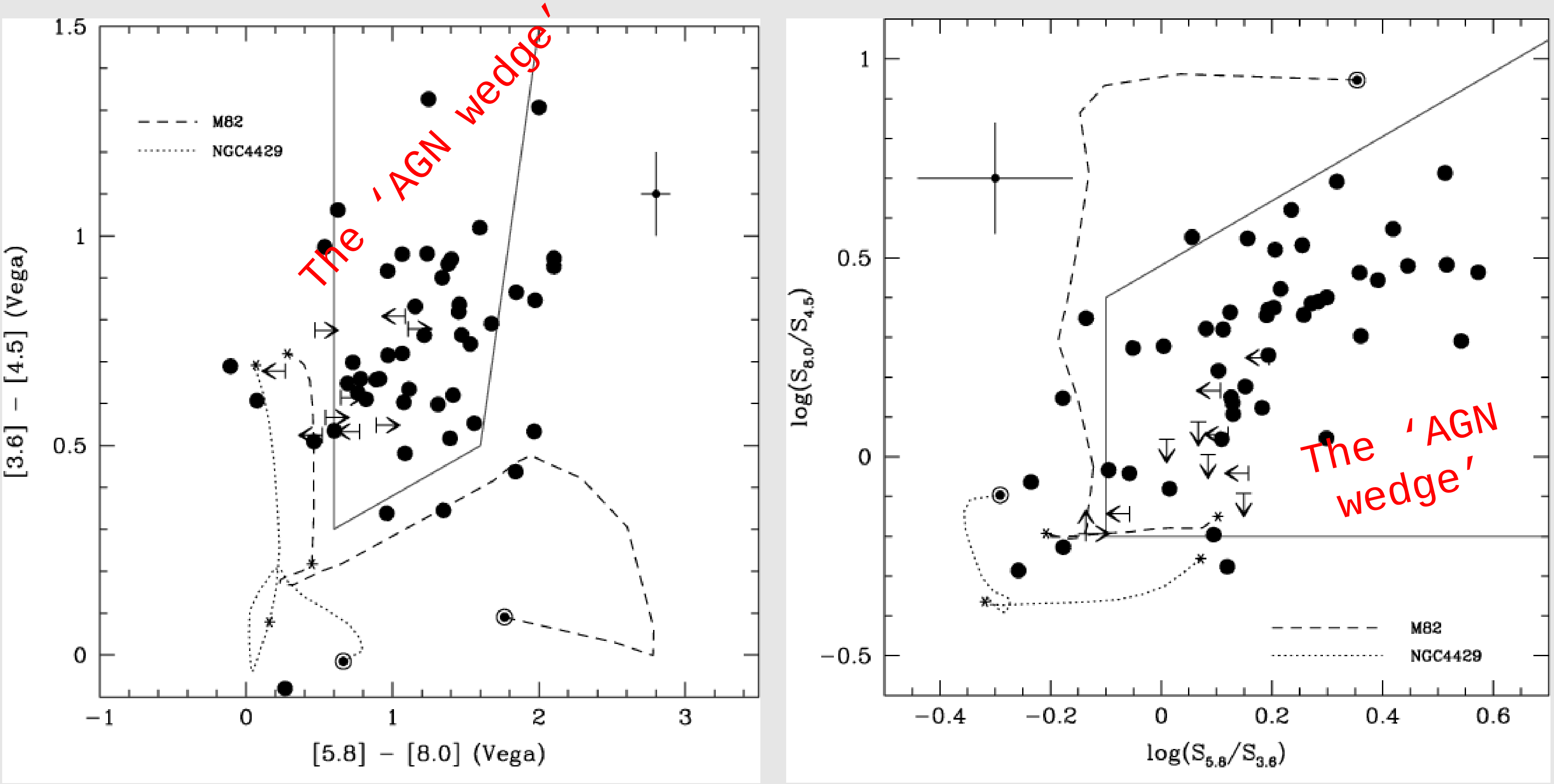
•*Circles*
HzRGs in our Spitzer sample with IRAC/IRS imaging

•*Squares*
MIPS observations as well, i.e. low Galactic background

•*Plusses*
parent sample of 225 HzRG from which our sample was drawn



The IRAC colours



- Stern et al. 2005, Lacy et al. 2004/6

These diagrams find (almost) equally type 1 (unobscured) and type 2 (obscured) AGN — why?

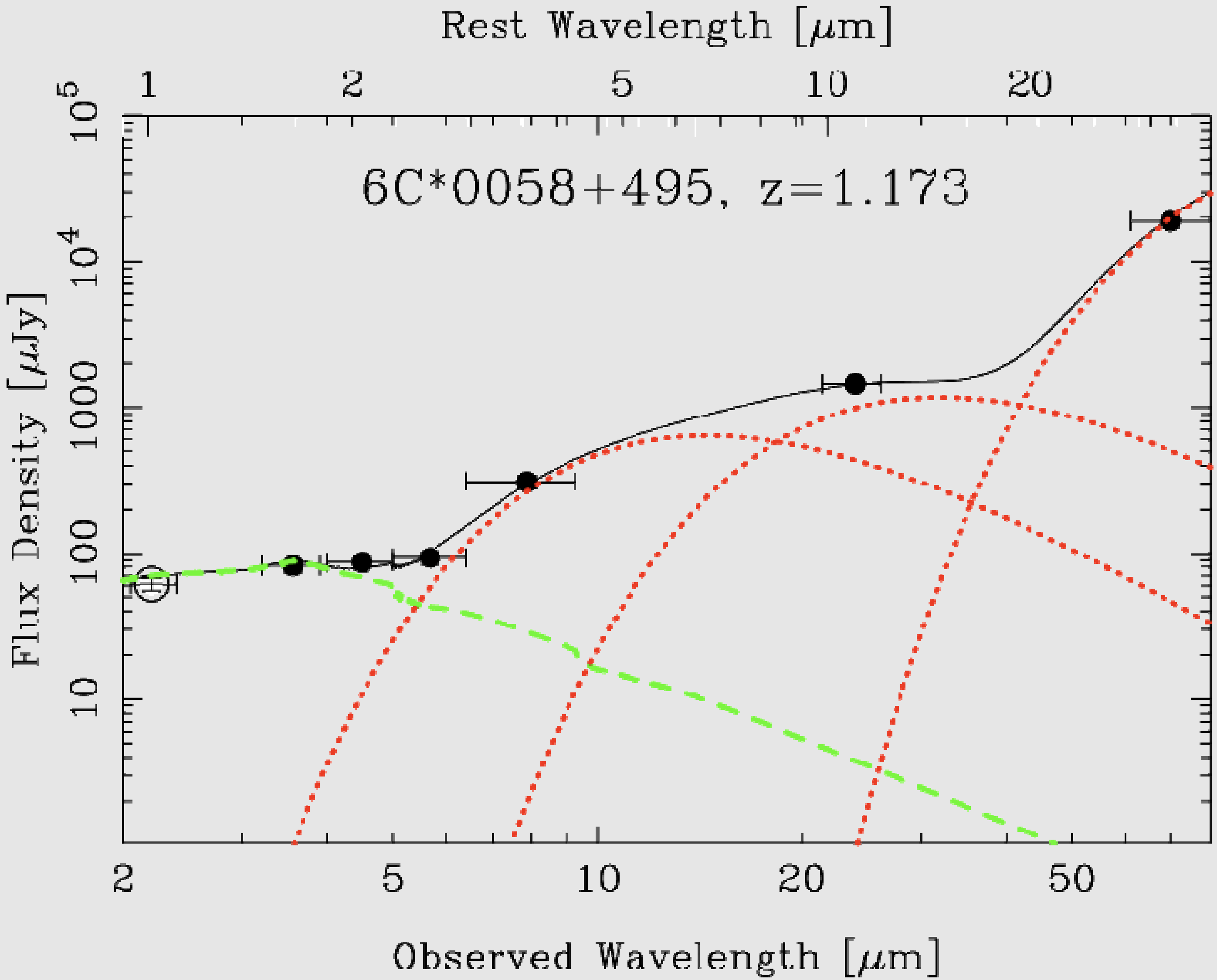
* on tracks correspond to z = 1 and 2 and 0 to z = 0

SHzRGS

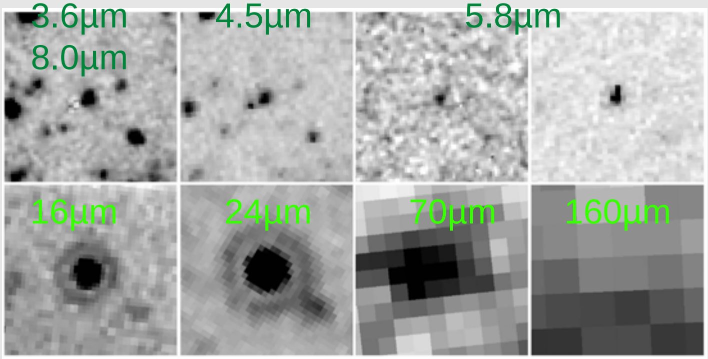
Modelling the restframe NIR SED

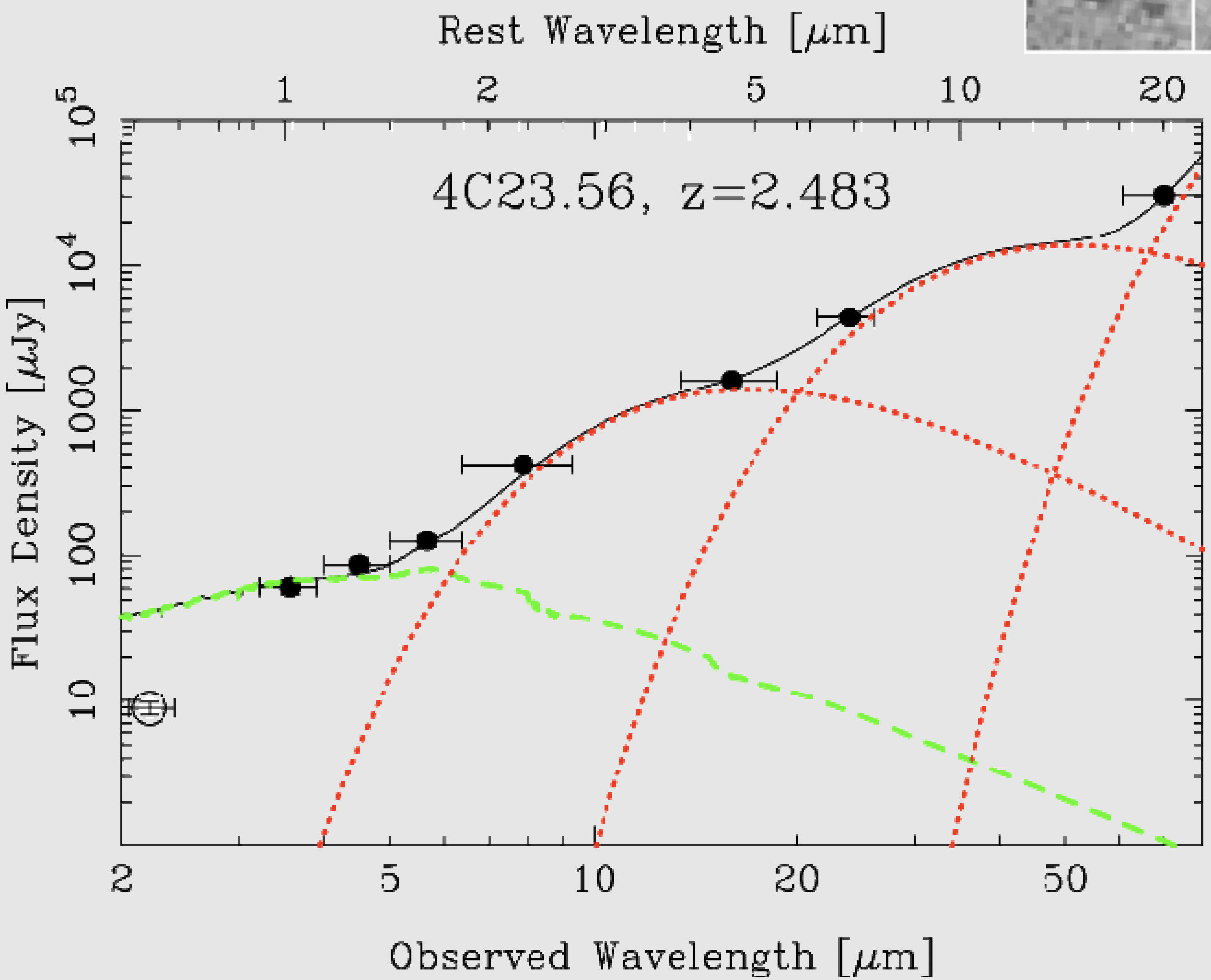
- Using only IRAC bands + 16µm + 24µm (26 sources)
- Fit elliptical templates of varying age from PEGASE 2 (assuming z_{form}=10, Eyles et al. 2007)
- Use 3 black-body components of dust at different temperatures: 60K and 250K, both fixed, and 600–1500K hot AGN-heated dust
- Use formal Ξ^2 fitting for results

•Sources *with* MIPS data



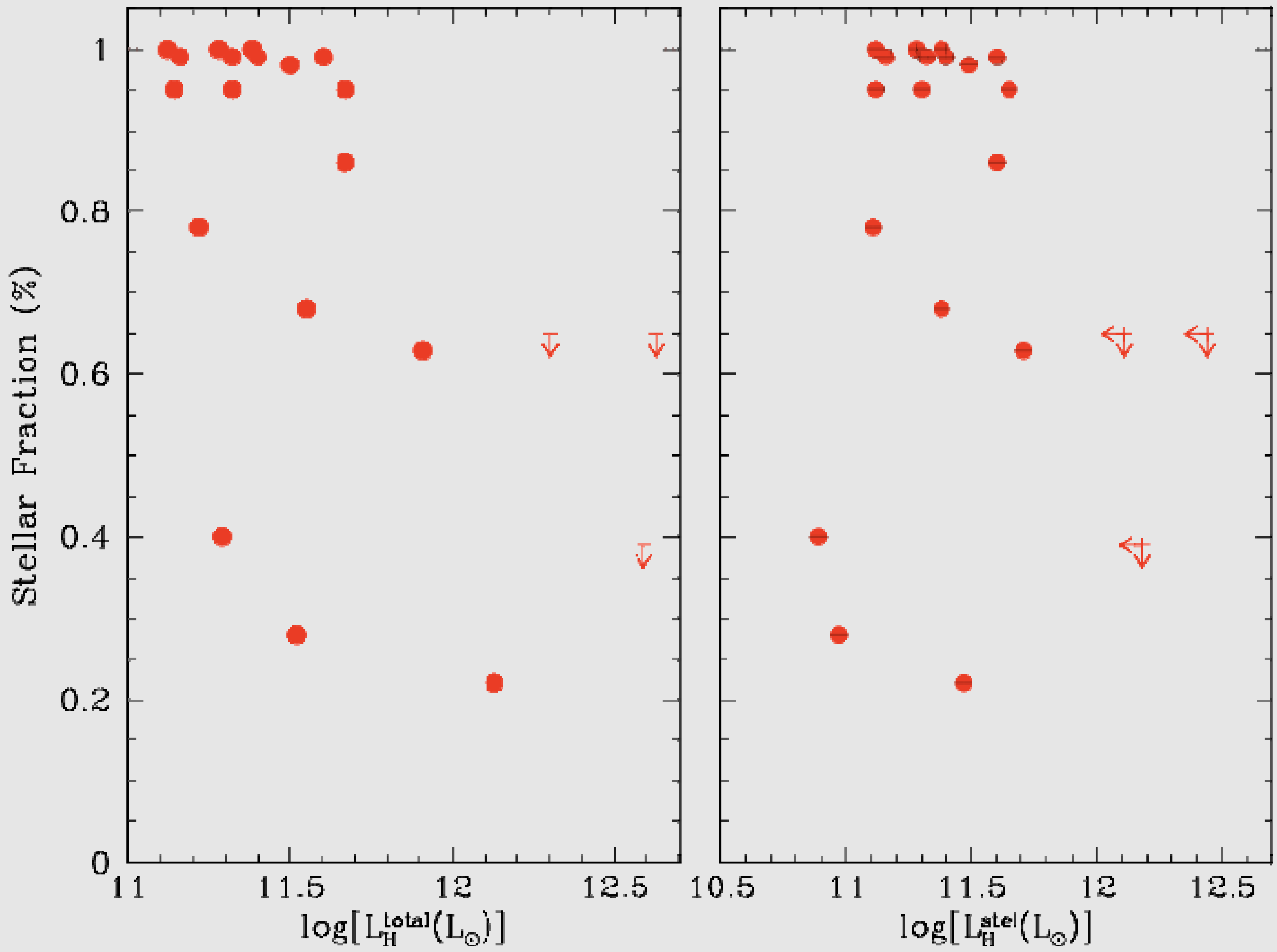
SHzRGS


3.6µm
4.5µm
5.8µm
8.0µm
16µm
24µm
70µm
160µm


Rest Wavelength [µm]
1
2
5
10
20
4C23.56, z=2.483
Flux Density [µJy]
10
100
1000
10^4
10^5
2
5
10
20
50
Observed Wavelength [µm]

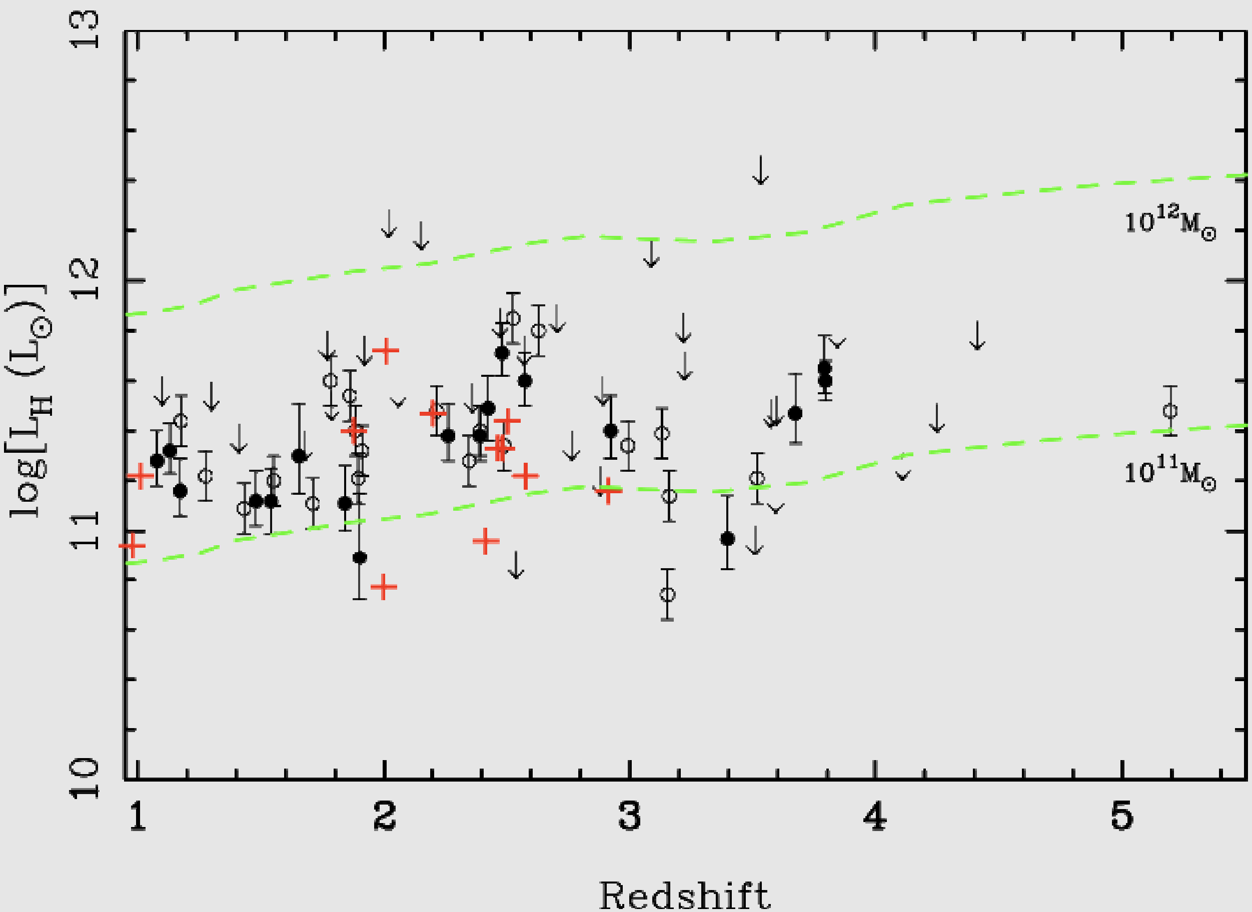
SHzRGS

•Stellar fraction of restframe H-band light



Total luminosity Stellar luminosity

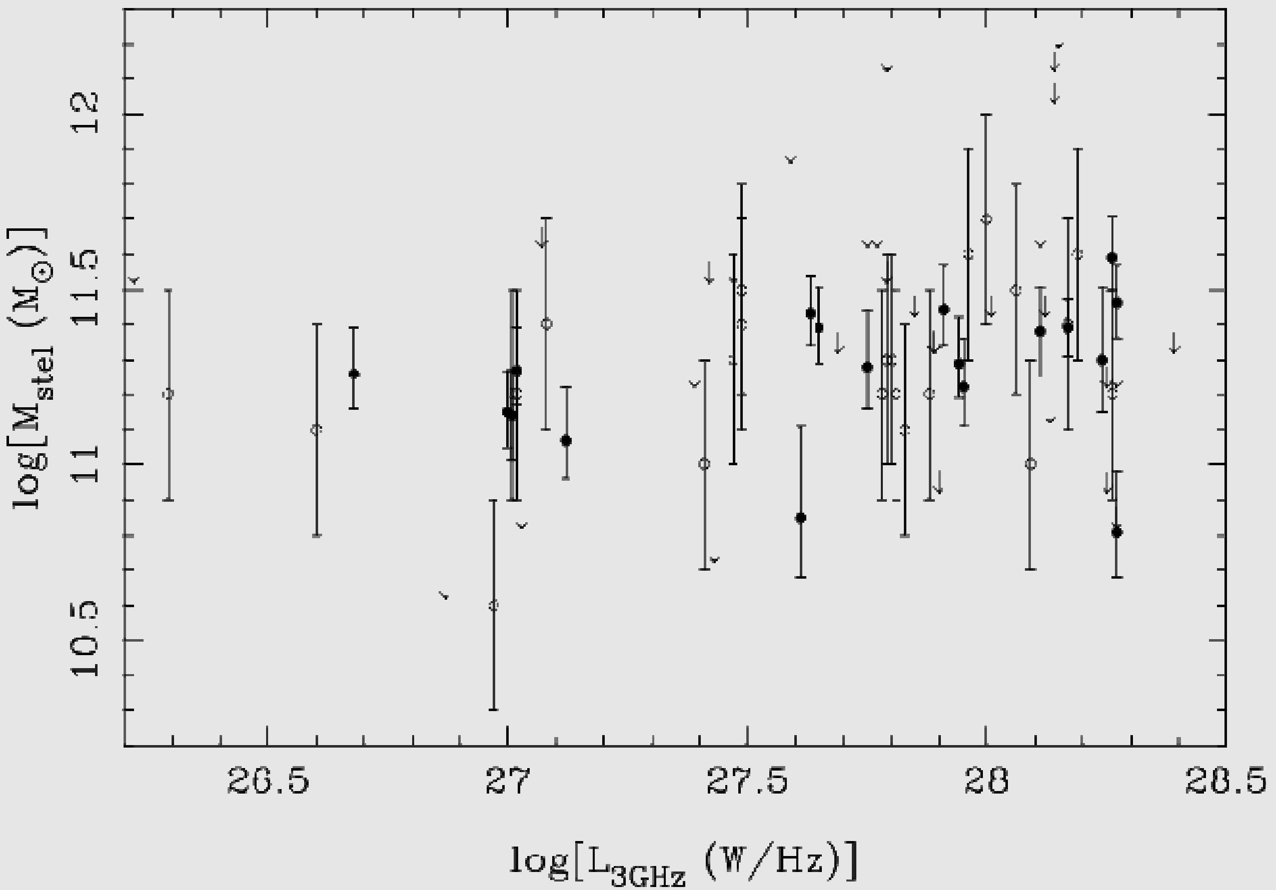
Restframe H-band stellar luminosity vs. redshift from the SED-fitting



- Solid points for sources *with* MIPS data

- Red + are sub-mm sources from Borys et al. (2005) derived in the same fashion

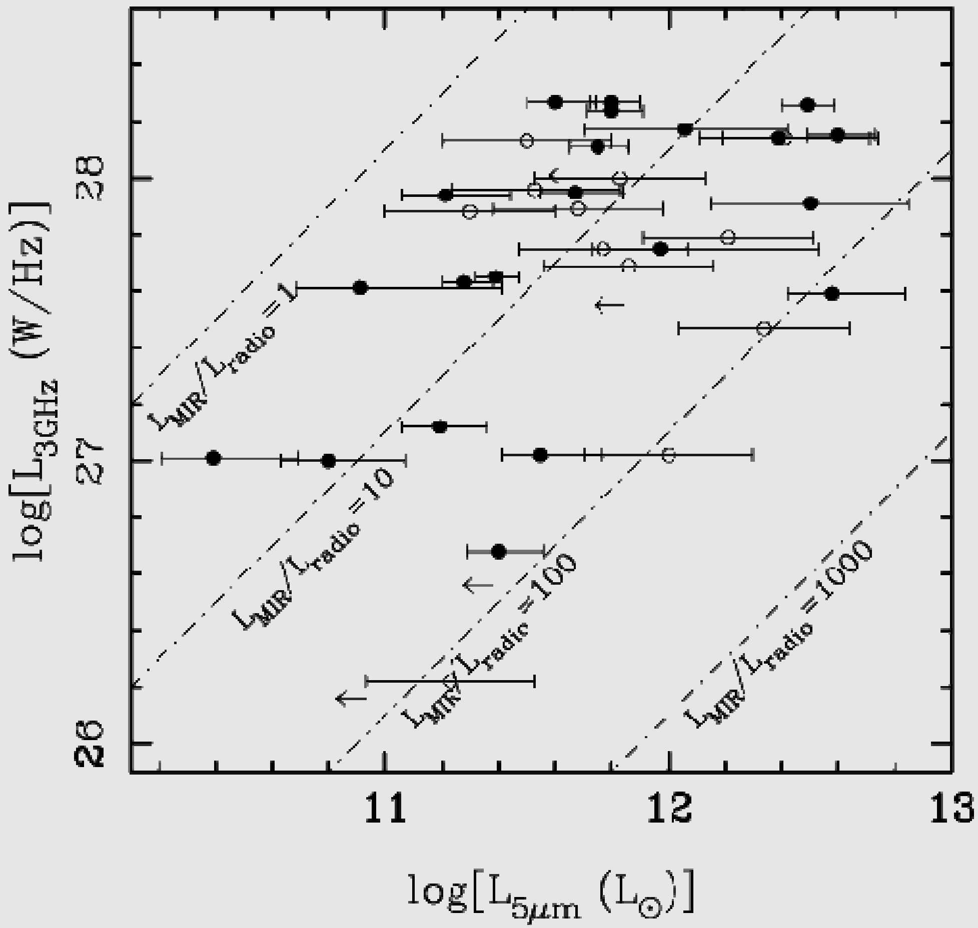
- Green dashed lines are luminosities of elliptical galaxies with z_{form} = 10, from PÉGASE.2 models (assuming Kroupa 2001 IMF) normalised to 10^{11} and 10^{12} Msun



- Marginally significant correlation of stellar mass with radio luminosity that would imply that the more massive galaxies host more powerful AGN

SHzRGS

Radio/MIR luminosities



- Both MIR and Radio emission trace AGN power — but possibly with a time-delay (Ogle et al. 2006)

SHzRGS

Principal results

- The hosts of powerful radio galaxies comprise a homogeneous population with stellar masses between 10^{11} and 12^{12} M_{sun}
- The powerful RG have similar MIR colours to the unobscured AGN
  - Most would be classified as LIRG or ULIRG
- Marginal evidence for higher mass galaxies to have higher radio (AGN) power

The parts

- A massive, old stellar population
- A radio loud AGN with axial symmetry and a mixture of isotropic and anisotropic emissions
- Active star formation (at least at $z > 2$–3) largely obscured by dust
- Hot and warm halos enriched by outflows

ToDo/In Progress

- Better SED fitting using shorter wavelength data and estimated of stellar population age (eg. from 4000Å break)
- Obtain MIPS data for more of the sample
- Decomposition of the stellar and AGN bolometric luminosities
- Study of the environments using optical, NIR and MIR imaging