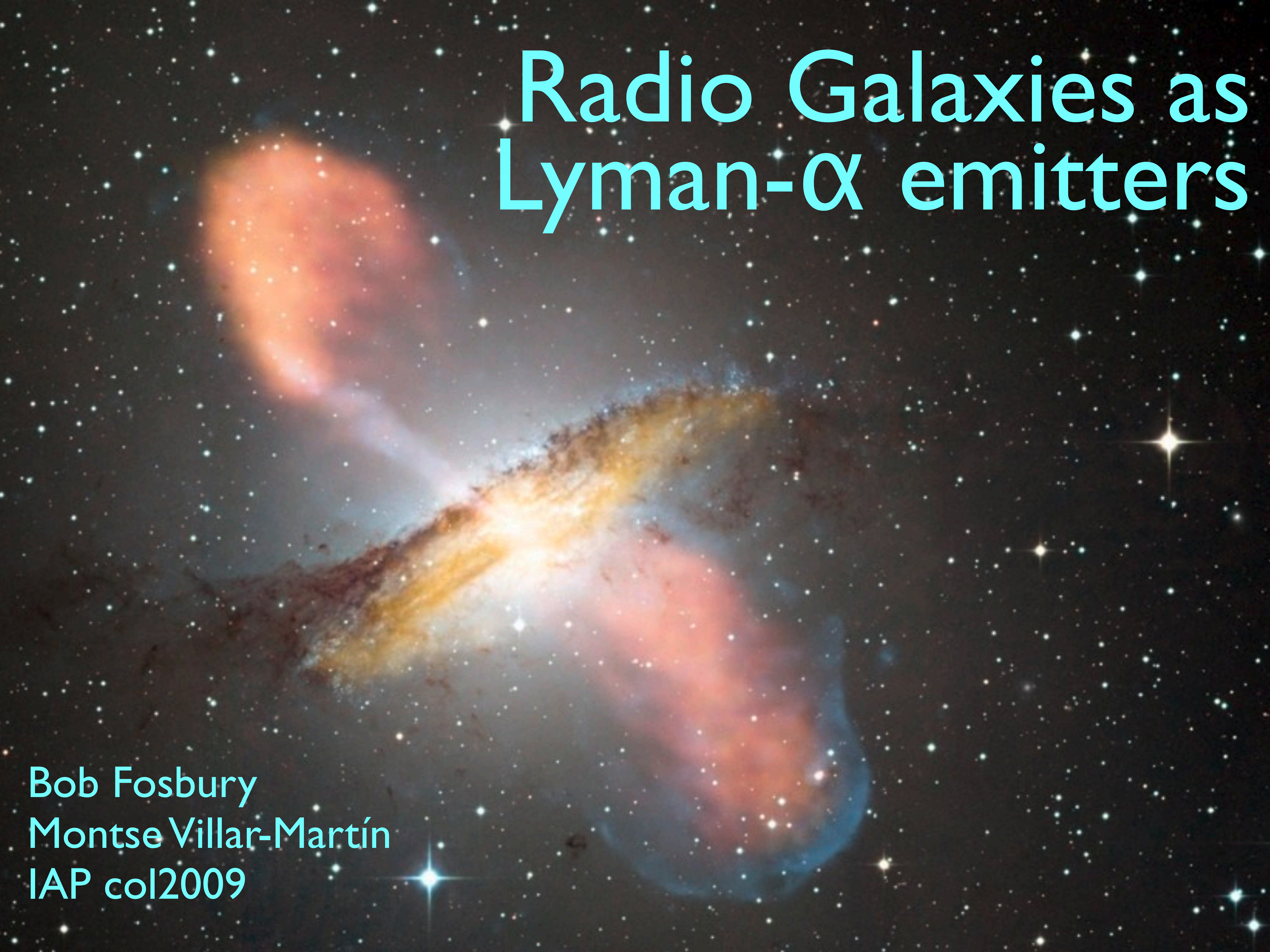
Radio Galaxies as Lyman-α emitters



Bob Fosbury
Montse Villar-Martín
IAP col2009

Peak

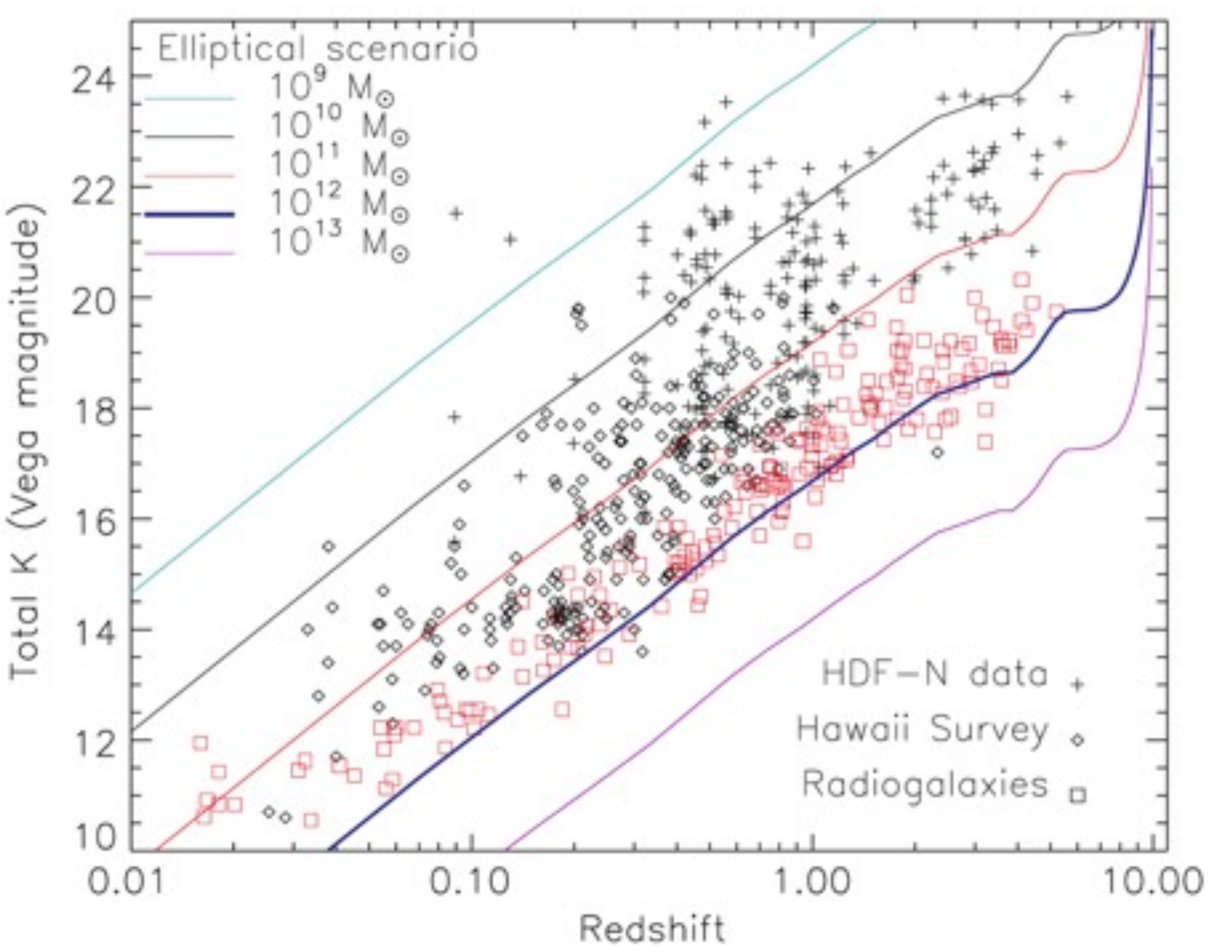
1338-1942

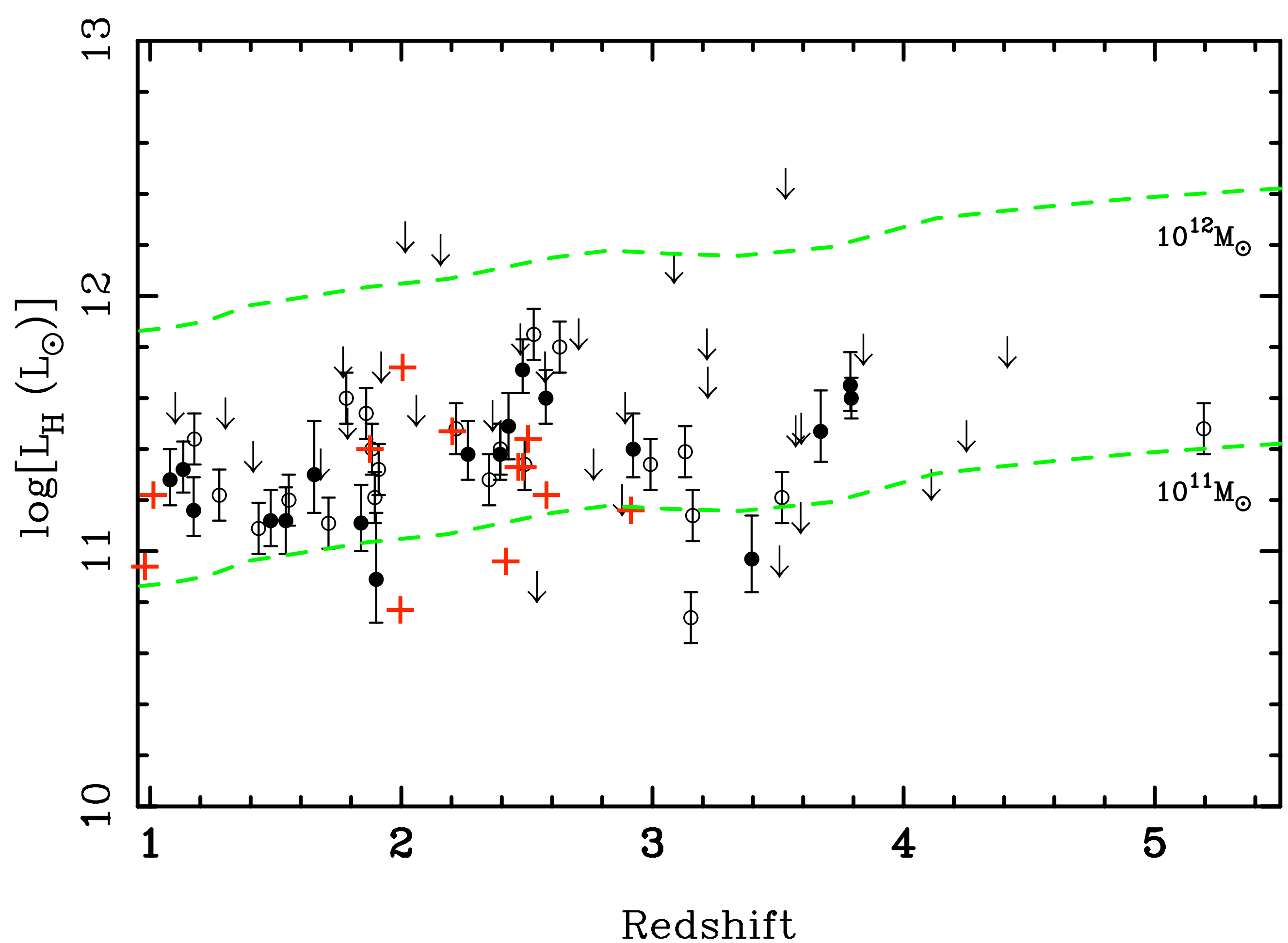
FORS1 specpol
Carlos de Breuck

(Hz) Radio Galaxies

SHzRGS

- Most massive galaxies at all redshifts
  (Rocca-Volmerange et al. 2004; Seymour et al. 2007)
  - Derived from Spitzer observations giving the restframe NIR (stellar) luminosities





restframe H-band

(Hz) Radio Galaxies

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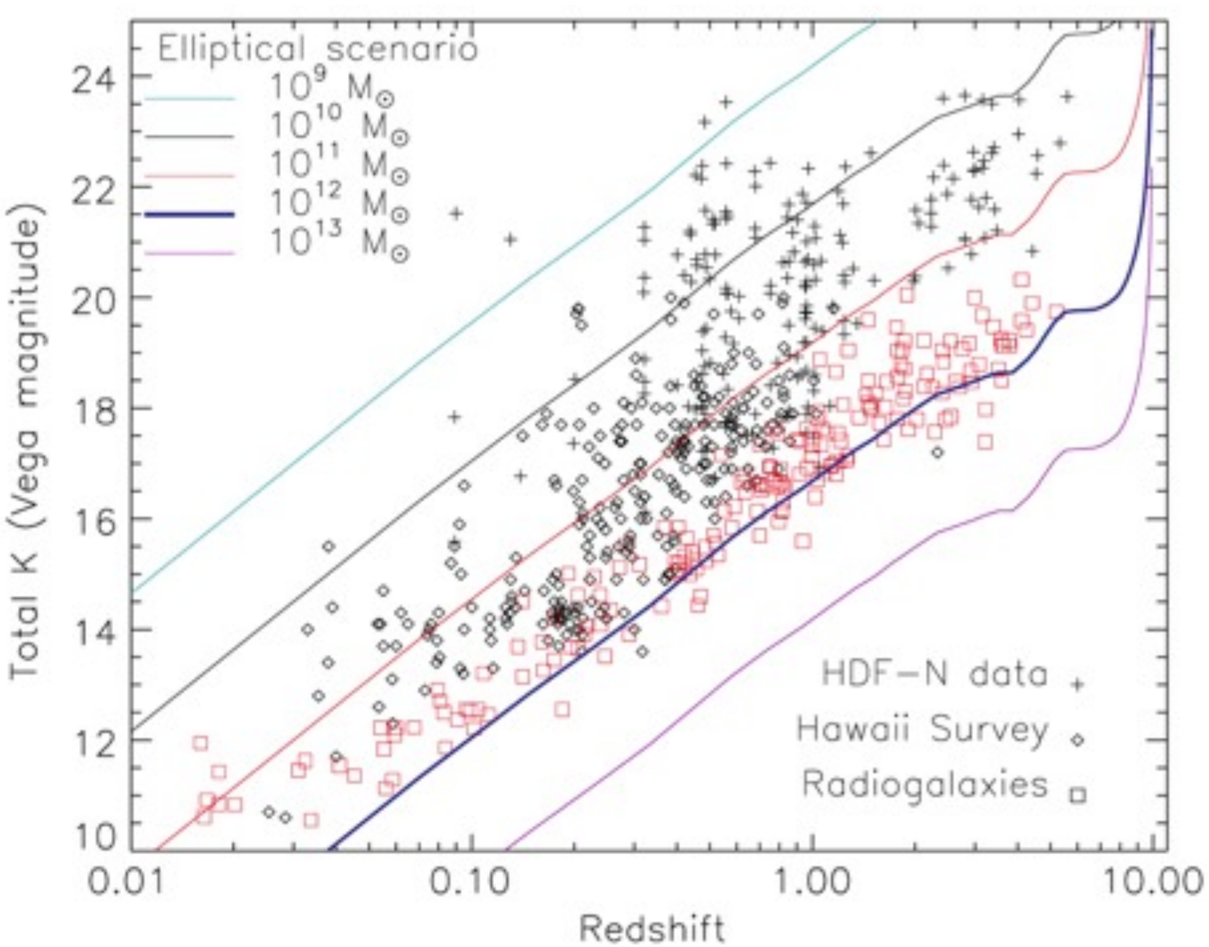
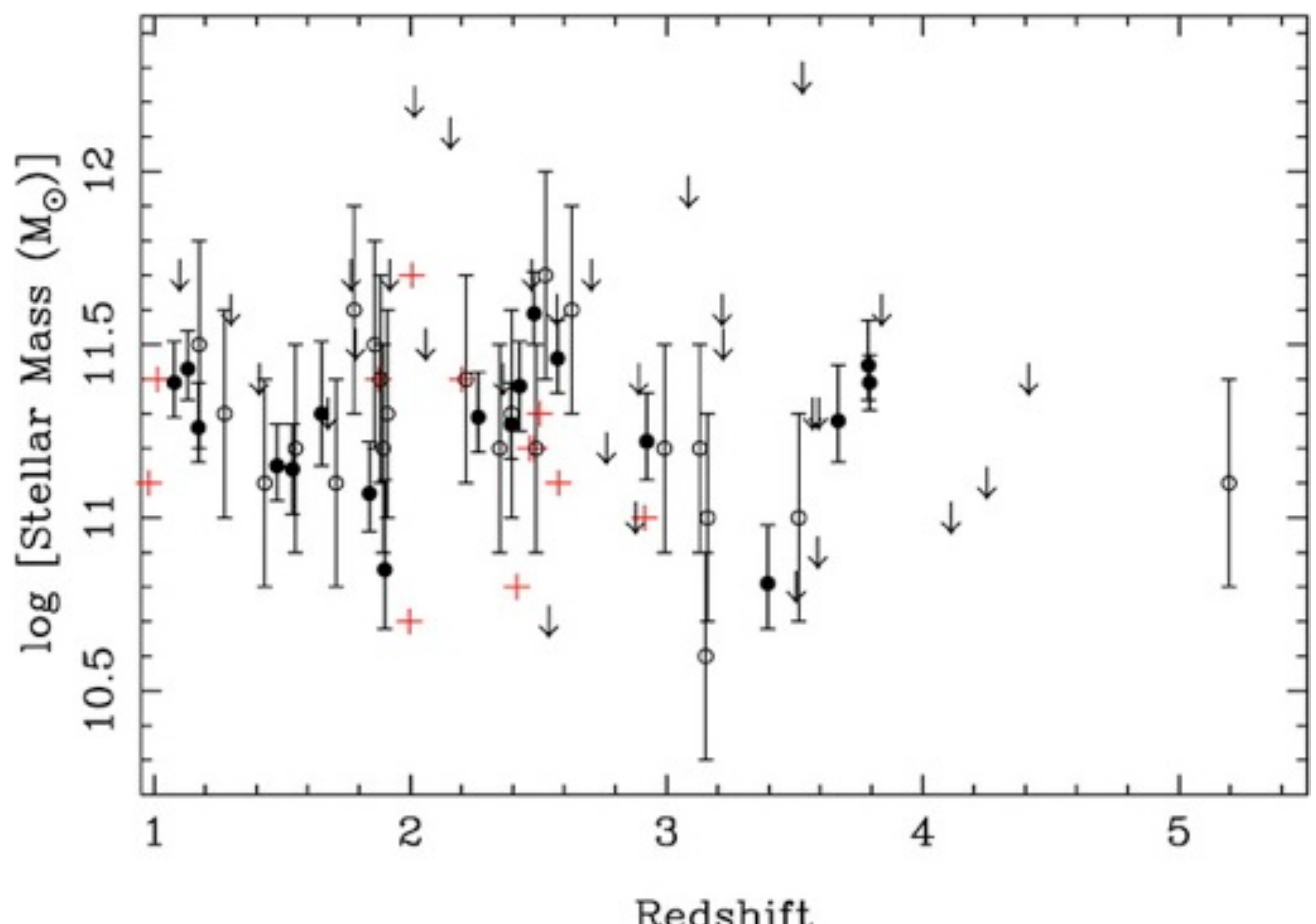
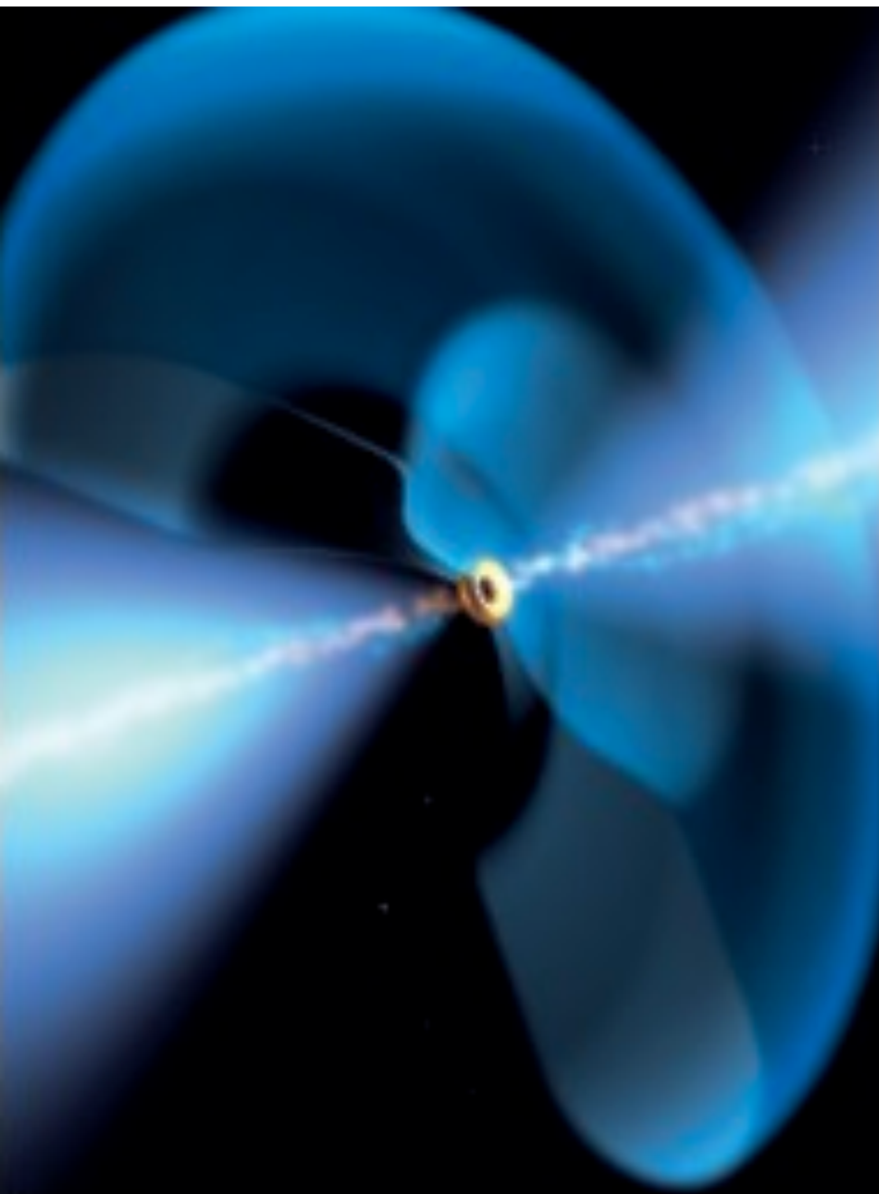


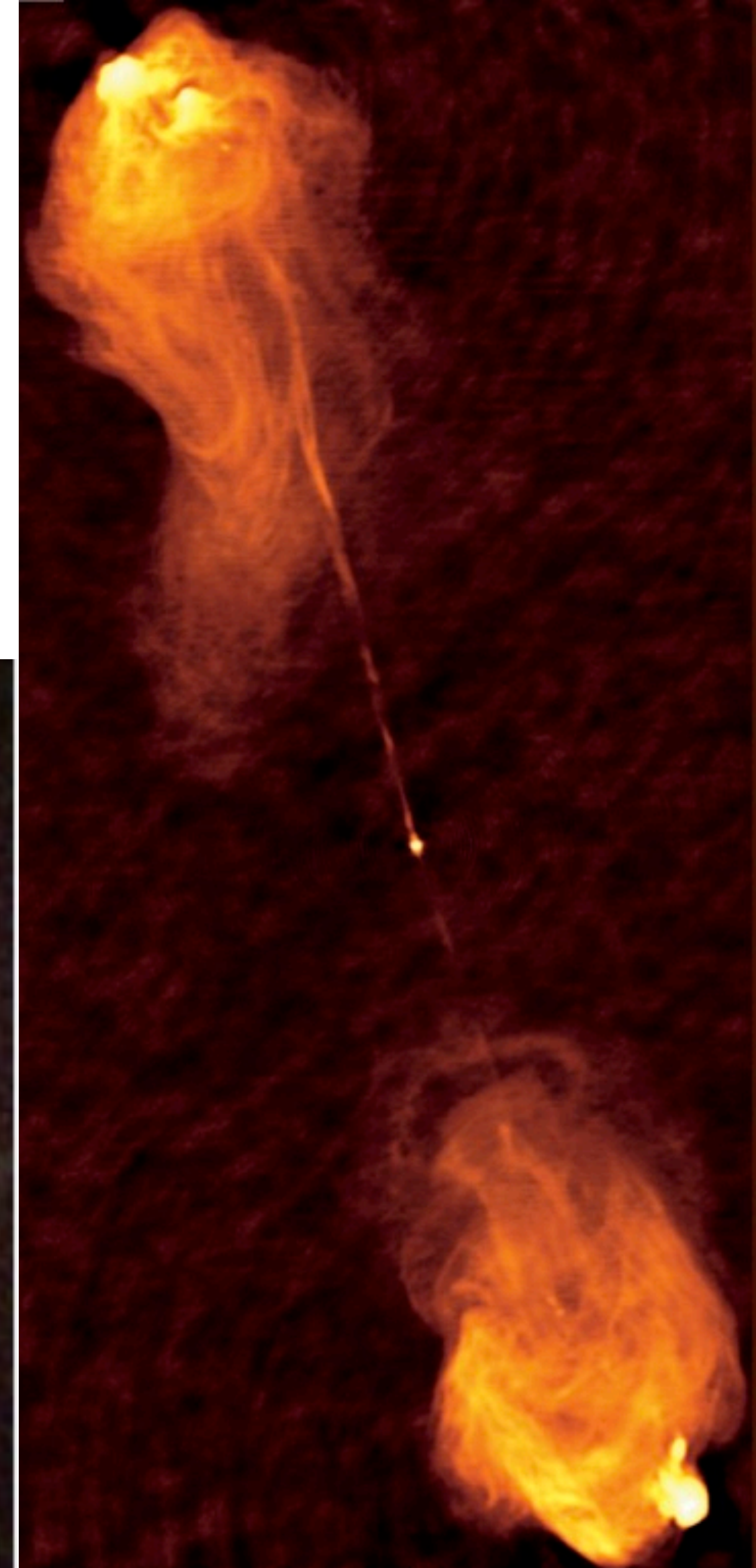


restframe H-band

- Hosts to the most massive SuperMassive Black Holes (SMBH) ~ 10^9 M_{sun}
- Parent population includes the radio quasars
- AGN is the source of copious ionizing radiation and the origin of jets that carry mechanical energy
- Associated with high star formation rates at high redshift
- At high-z, the RG reside in overdense regions and are may be embedded in protoclusters
- Progenitors of brightest cluster galaxies in the local Universe

- Rare objects
  - few x 10^{-8} Mpc^{-3} $2 < z < 5$; almost non-existent at low-z
  - Agglomeration of high masses of stars, gas and AGN-components





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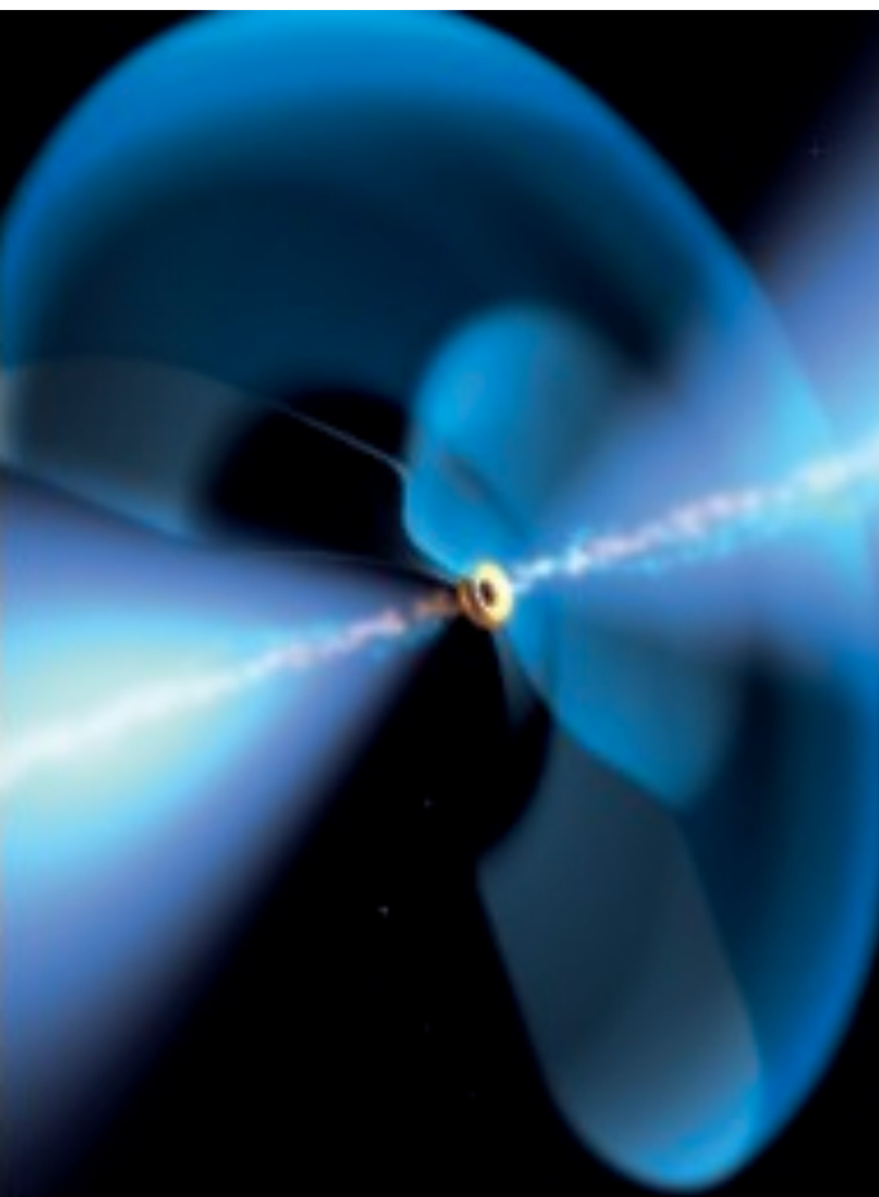
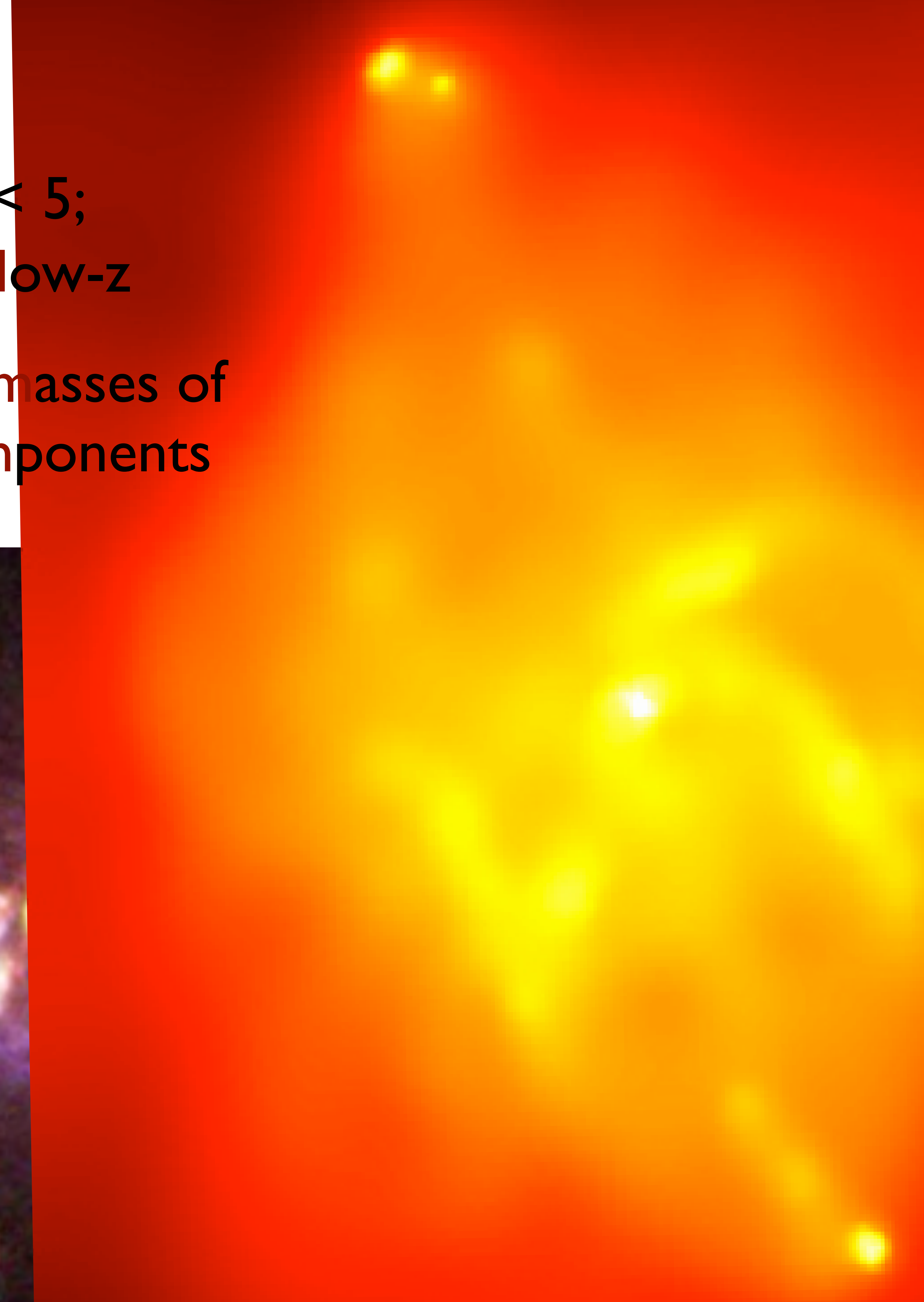


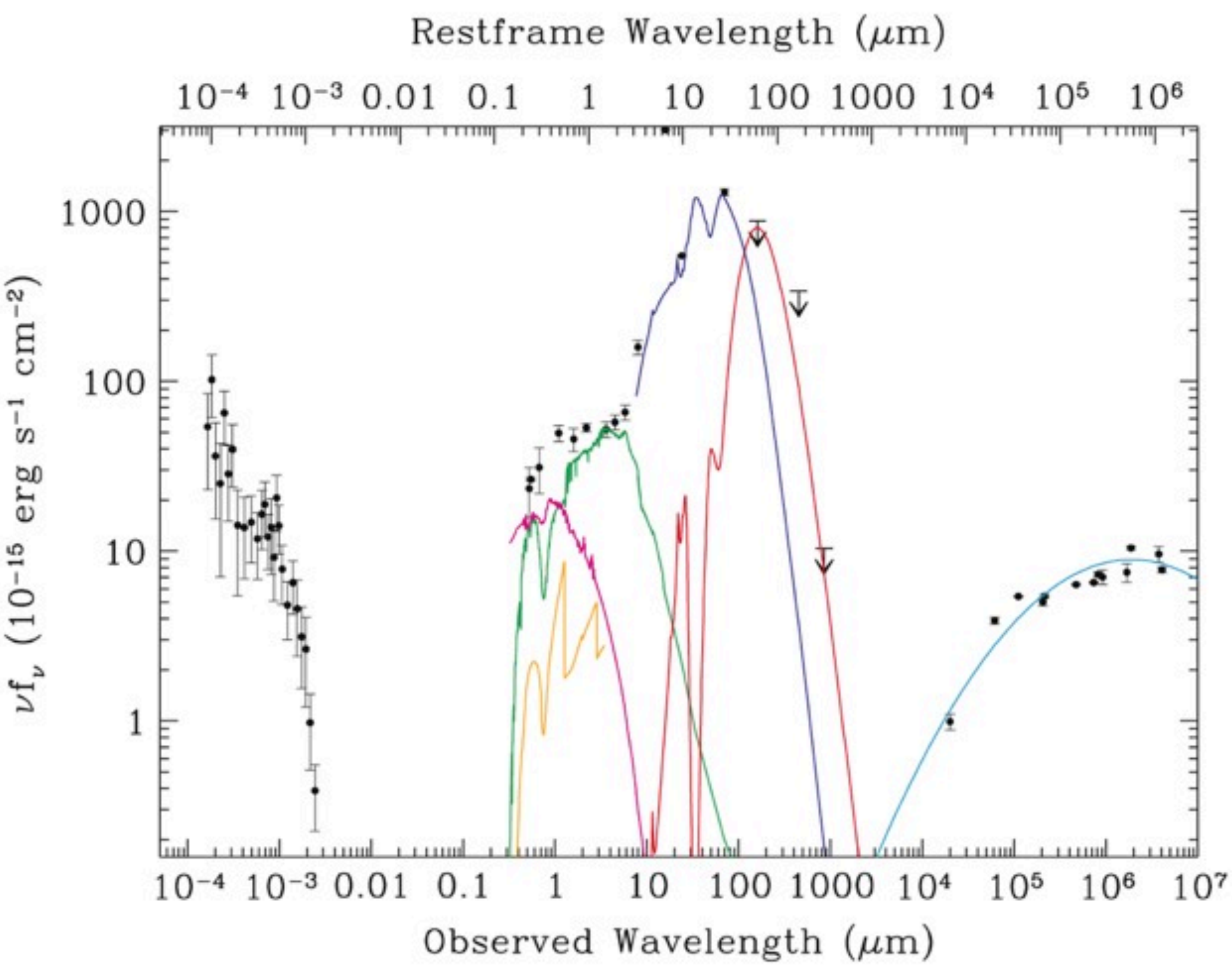


Constituent	**Properties** (K, cm^{-3})	**Observable**	**Log(Mass)** (M_{sun})
Relativistic plasma	$E \sim 10^{60}$ erg	Radio and X-ray continuum	
Hot ionized gas	$Log(T_e) \sim 7–8$ $Log(n_e) \sim -1.5$	Radio depolarization X-rays	11–12
Warm ionized gas	$Log(T_e) \sim 4–5$ $Log(n_e) \sim 0.5–1.5$	UV-opt emission lines and nebular continuum	9–10.5
Cool atomic gas	$Log(T_s) \sim 3$ $Log(n_{HI}) \sim 1$	HI and UV-opt absorption lines	7–8 (+)
Molecular gas and dust	$T \sim 50–500$ $Log(n_{H2}) > 2$	(Sub)mm lines/ctm UV-opt polarization	10–11
Old stars Young stars	t > 1 Gyr t < 0.5 Gyr	Opt/NIR ctm UV-opt ctm/Lyα	11–12 9–10
Quasar/SMBH		UV-opt BLR/ctm polarization radio etc.	9

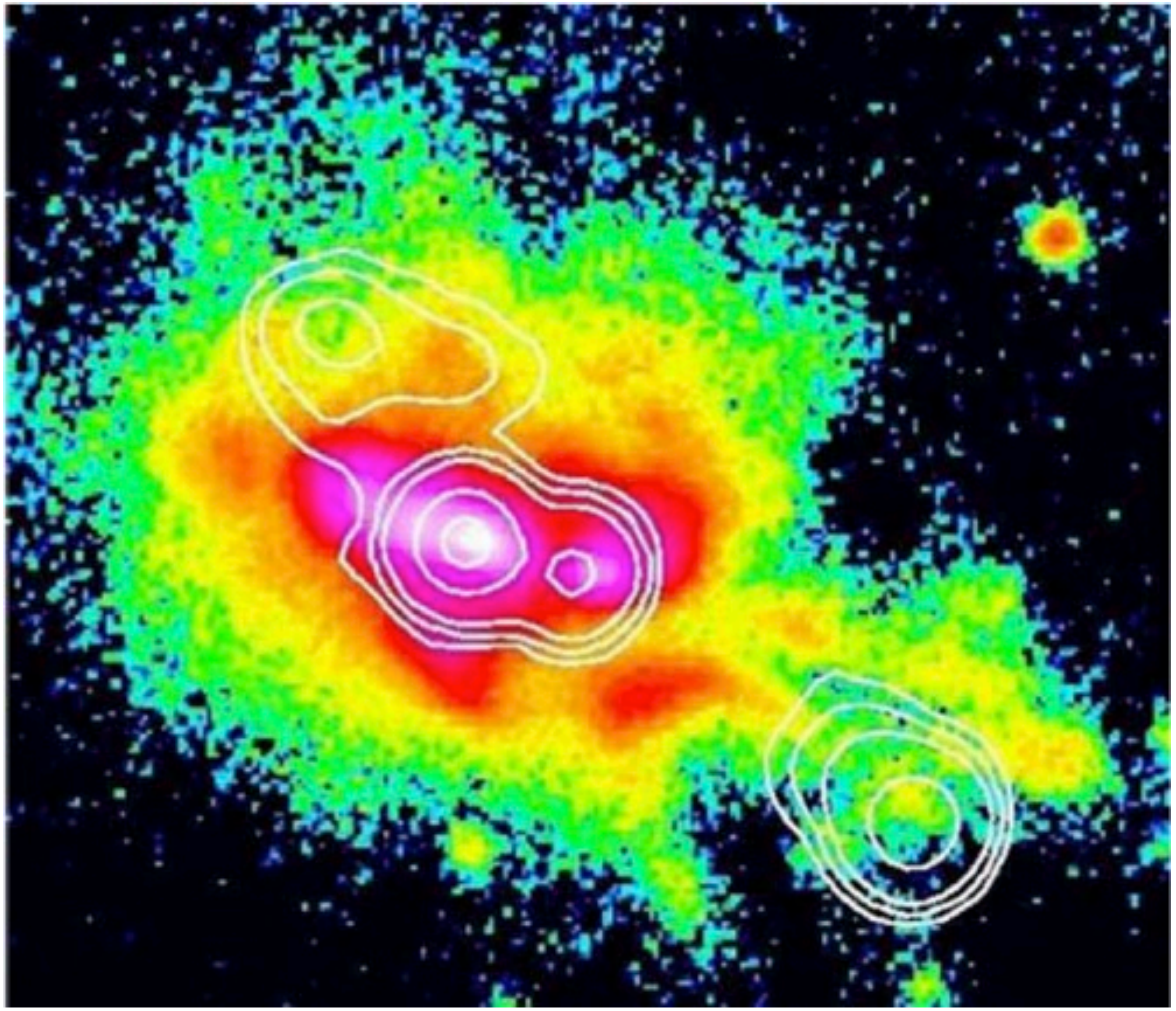
After Miley & De Breuck, 2008)

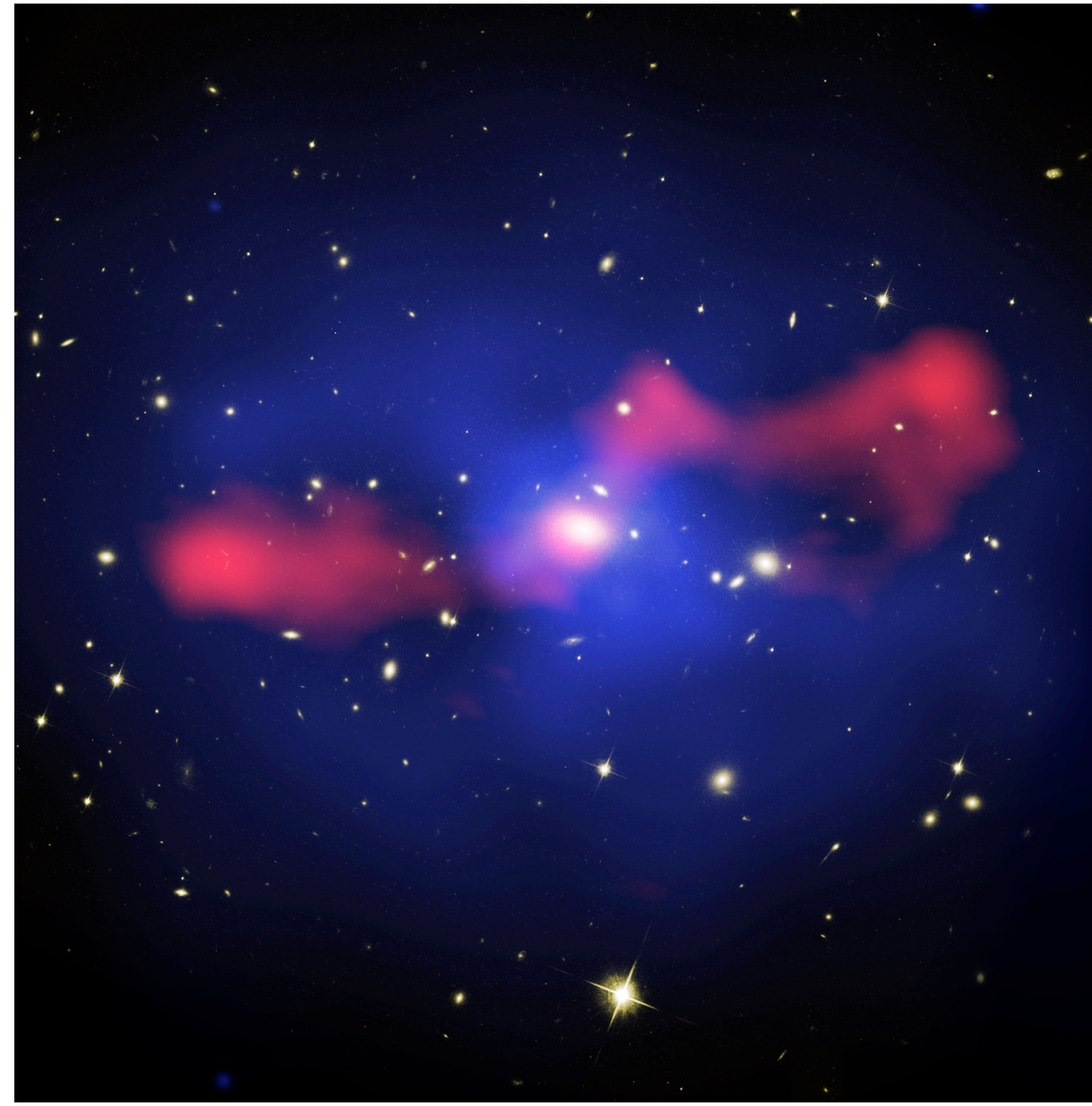
Composite SED of 4C 23.56 at z = 2.5

De Breuck et al.



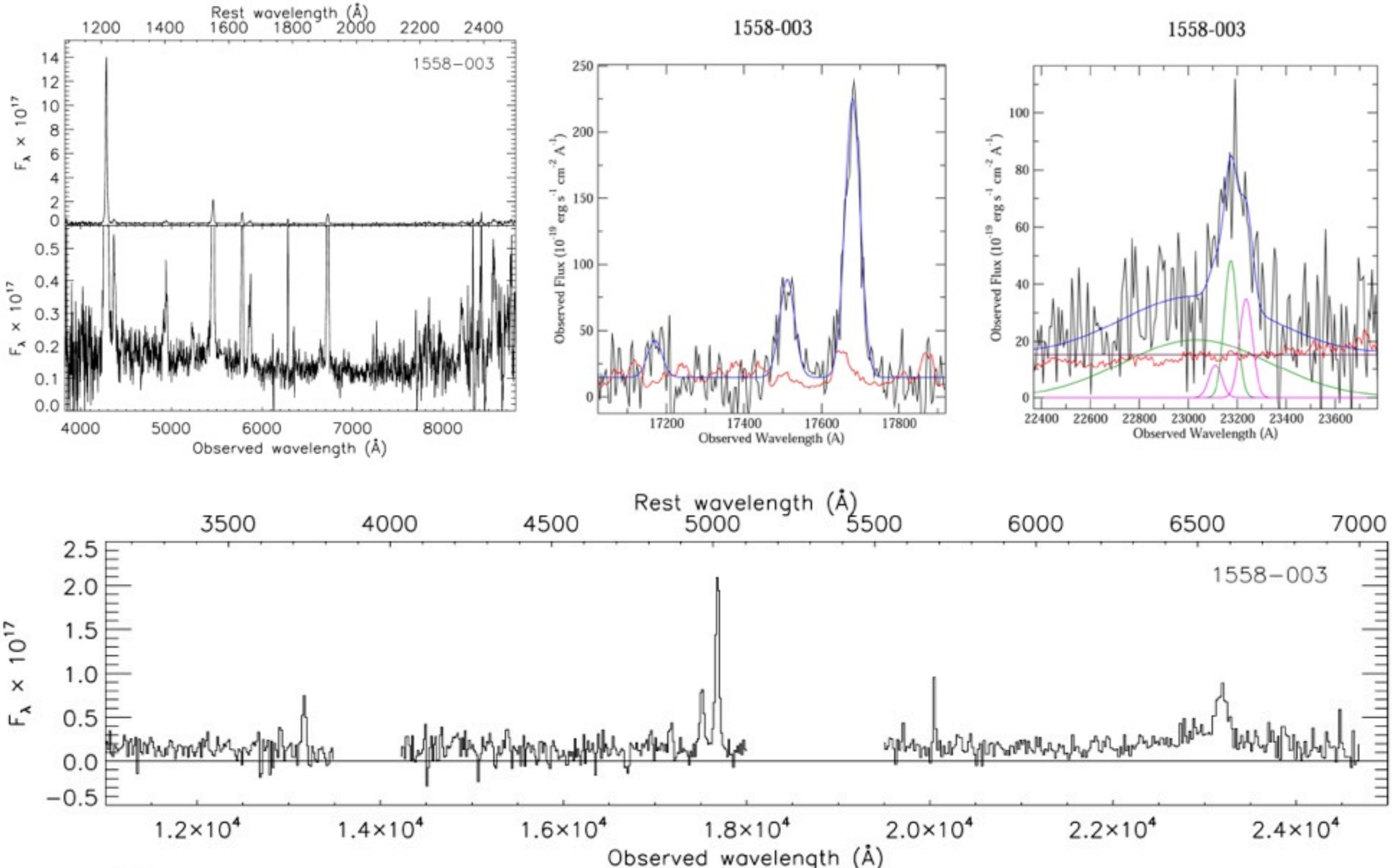
Left: absorbed non-thermal X-ray
Yellow: nebular continuum
Green: stars
Blue: AGN-heated dust
Red: starburst-heated dust
Magenta: scattered quasar
Cyan: radio synchrotron





4C 41.17, z = 3.8
Contours 1.4 GHz VLA; colour map Keck redshifted Lyα
Radio size 90 kpc
Reuland et al. 2003

MS 0735.6+7421, z = 0.216
HST/ACS, VLA (red), Chandra (Blue)
Credit: X-ray: NASA/CXC/Univ. Waterloo/B.McNamara; Optical: NASA/ESA/STScI/Univ. Waterloo/B.McNamara; Radio: NRAO/Ohio Univ./L.Birzan et al.



Keck LRISp + VLT ISAAC

Emission spectra

- Predominantly AGN-photoionized
- N/H ~ Solar with variation < x 2 from a sample of nine z ~ 2.5 RG (*Humphrey et al. 2008*)
  - Comparable with low-z RG (*Robinson et al. 1987*)
- *See also Reuland et al. 2003, 2007*

Lyα emitting warm gas story

- How is it distributed?
- How is it moving?
- How is it ionized?
- Where did it come from (chemical composition)?
- What do we learn?

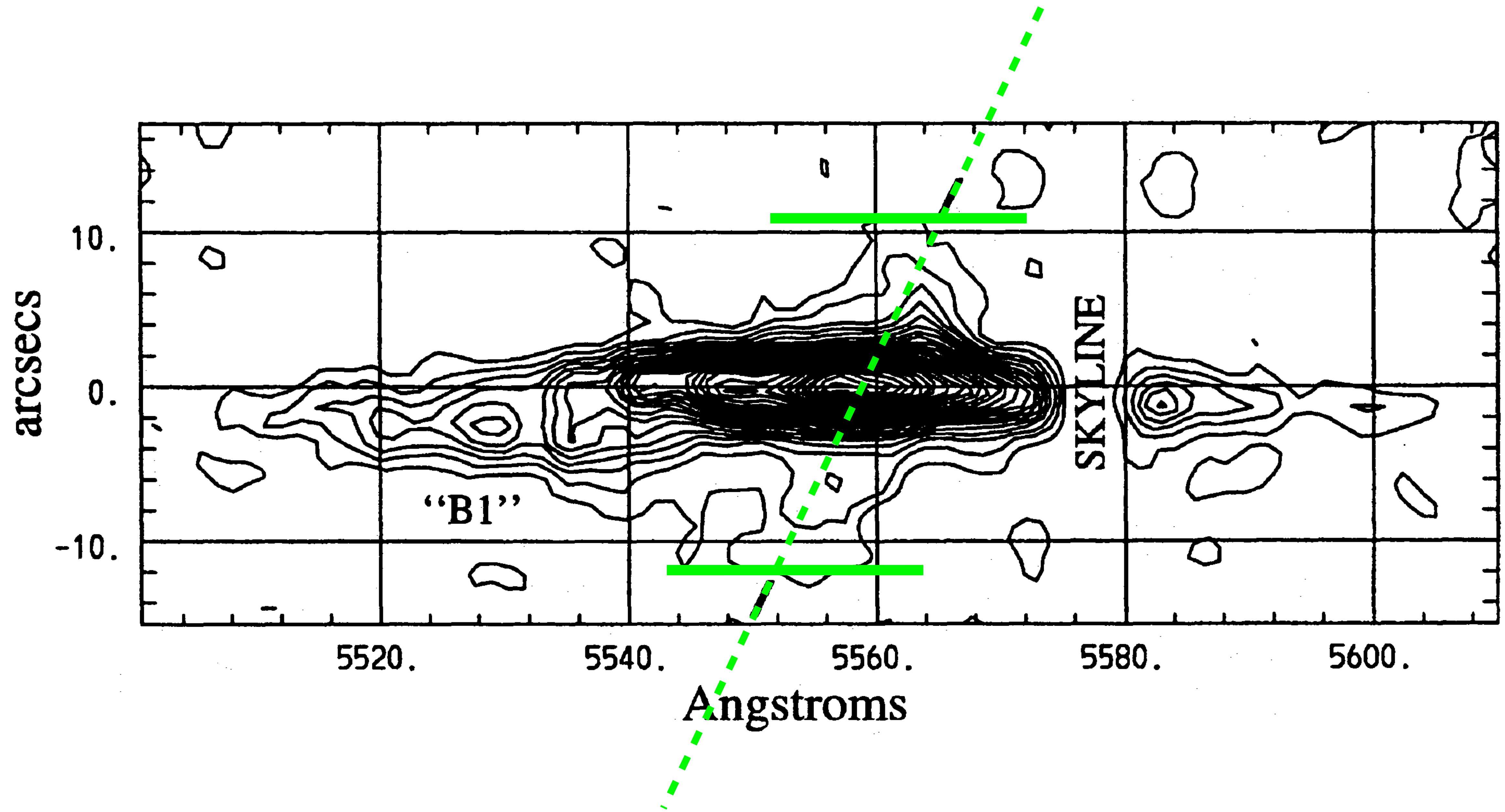
Distribution

- Large scale
  - 100 kpc and greater, can be extended beyond radio source
- Two Components
  - Disturbed — associated with jets, high Δv
    - Inner parts close to radio jets are clumpy with velocity spreads of $\geq$ 1000 km s^{-1}
  - Quiescent — low Δv
    - Outer parts appear more quiescent with Δv ~ few hundred km s^{-1}

- Subject to extended absorption, especially among the smaller radio sources
- Filling factor ~ 10^{-5} (cf unity for the hot gas)
  - ~ 10^{12} clouds each about 40 light days in size (van Ojik et al. 1997)
  - Covering factor unity (abs line) over > 100 kpc scale, column density $10^{18-19.5}$ cm^{-2}

Kinematics (quiescent component)

- Velocity gradient ≈ velocity ‘dispersion’
- Inflow, outflow or rotation?
  - Arguments based on correlated and uncorrelated asymmetries



4C 03.24 (=1234+036) z = 3.6

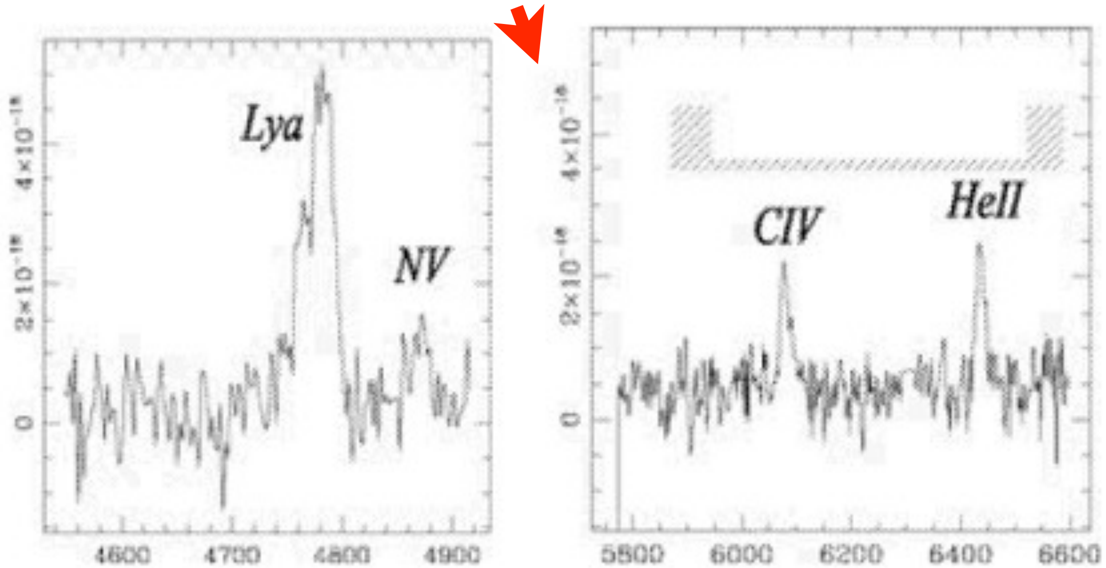
showing extended, quiescent Lyα halo

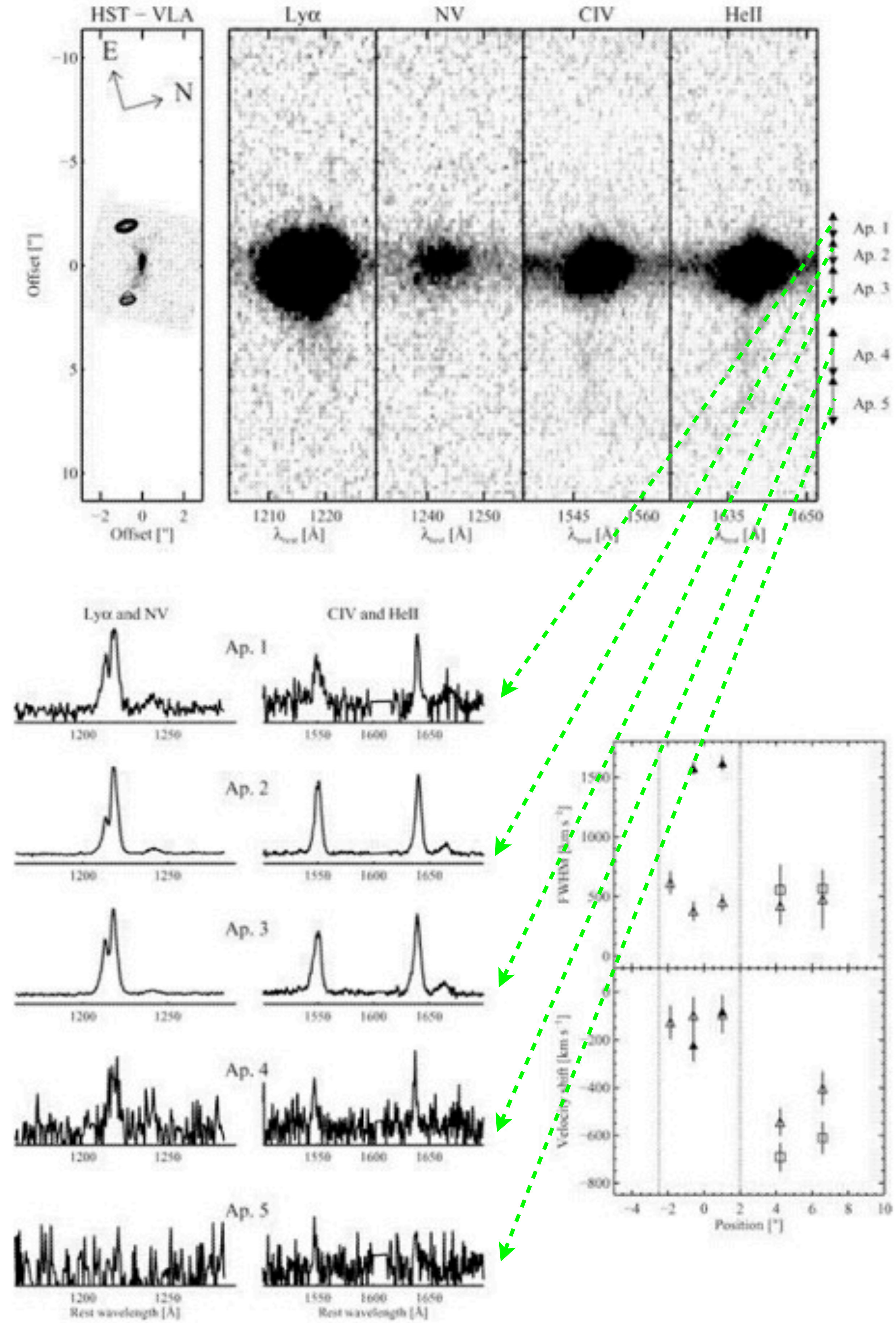
$\text{Log}(L_{Ly\alpha}) = 44.2$; size = 148 kpc

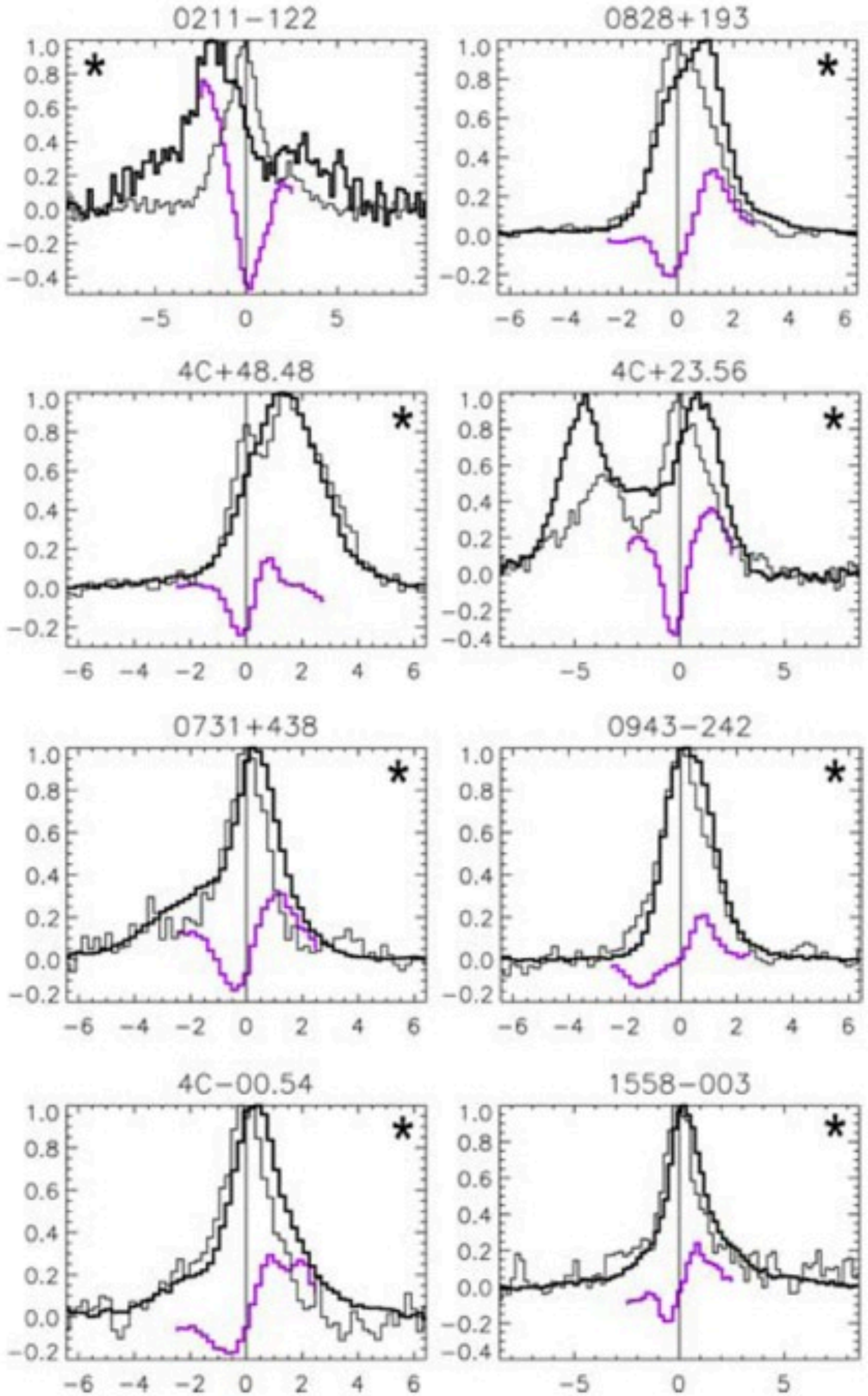
van Ojik et al. 1996

Giant (extending beyond the radio source), metal-enriched halos at z ~ 2.5 (0943-242)

Villar-Martín et al. 2003







SPATIAL PROFILES

Normalized Lyα and HeII
Difference shown in violet

* represents the side with the brightest radio hot-spot

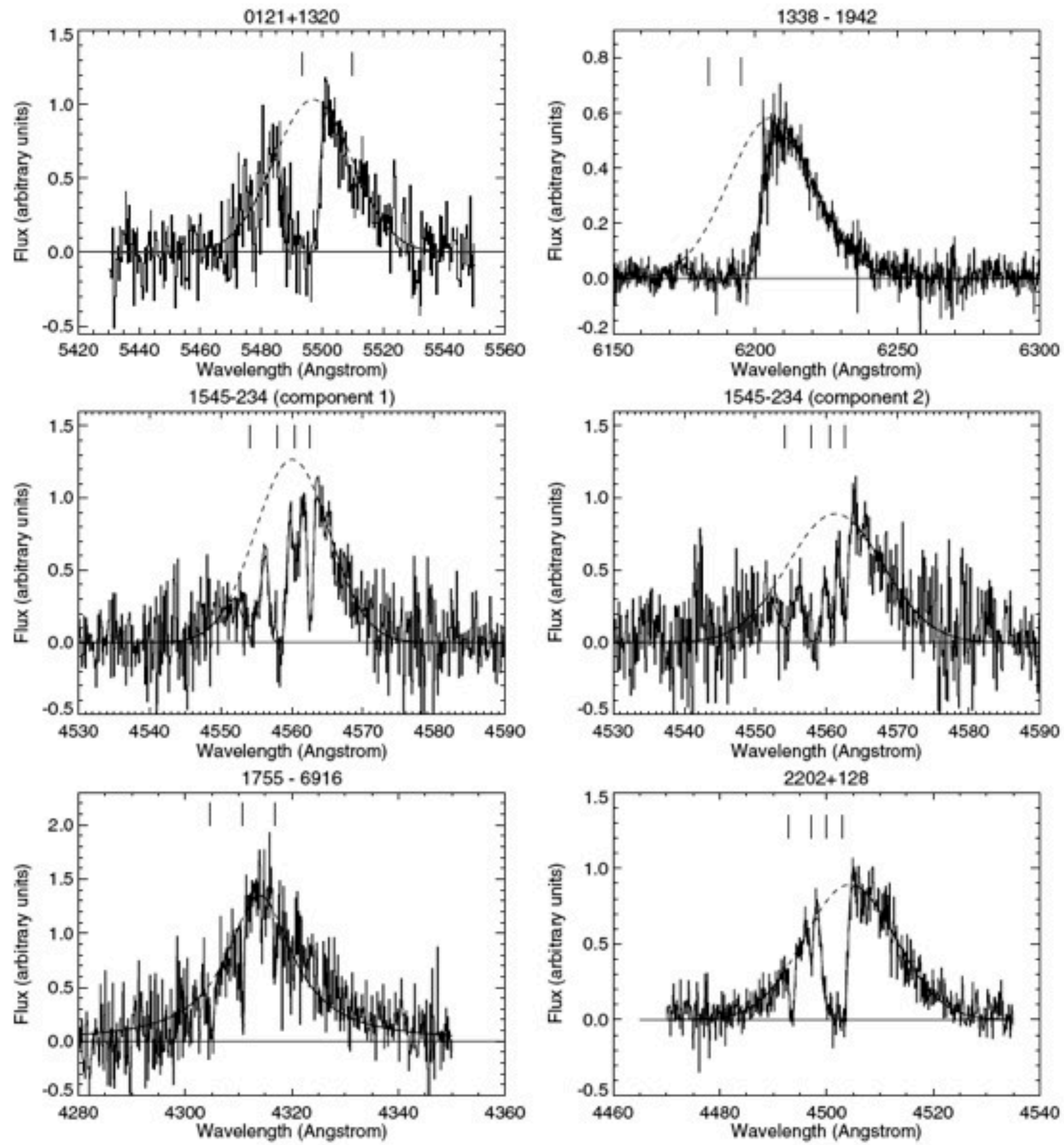
The continuum centroid is taken as the NIR continuum peak

Evidence for inflow

Humphrey et al. 2007

Hi-res spectroscopy

- *Wilman et al. 2004*
- Bimodal column density distribution
  - $N_{HI} \approx 10^{18\text{–}20}$ cm^{-2} — intrinsic to RG
  - $N_{HI} \approx 10^{13\text{–}15}$ cm^{-2} — Lyman forest



Massive infalling HI halo

- B2 0902+34 *Adams et al. 2009*
- 3D optically-thick resonance scattering model explains both the Lyα emission and the 21cm absorption in the context of a very massive (>10^{12} M_{sun}) neutral hydrogen halo within which is embedded an HII bi-cone
- The stellar mass is unusually small for this source => it is in an early mass-building phase

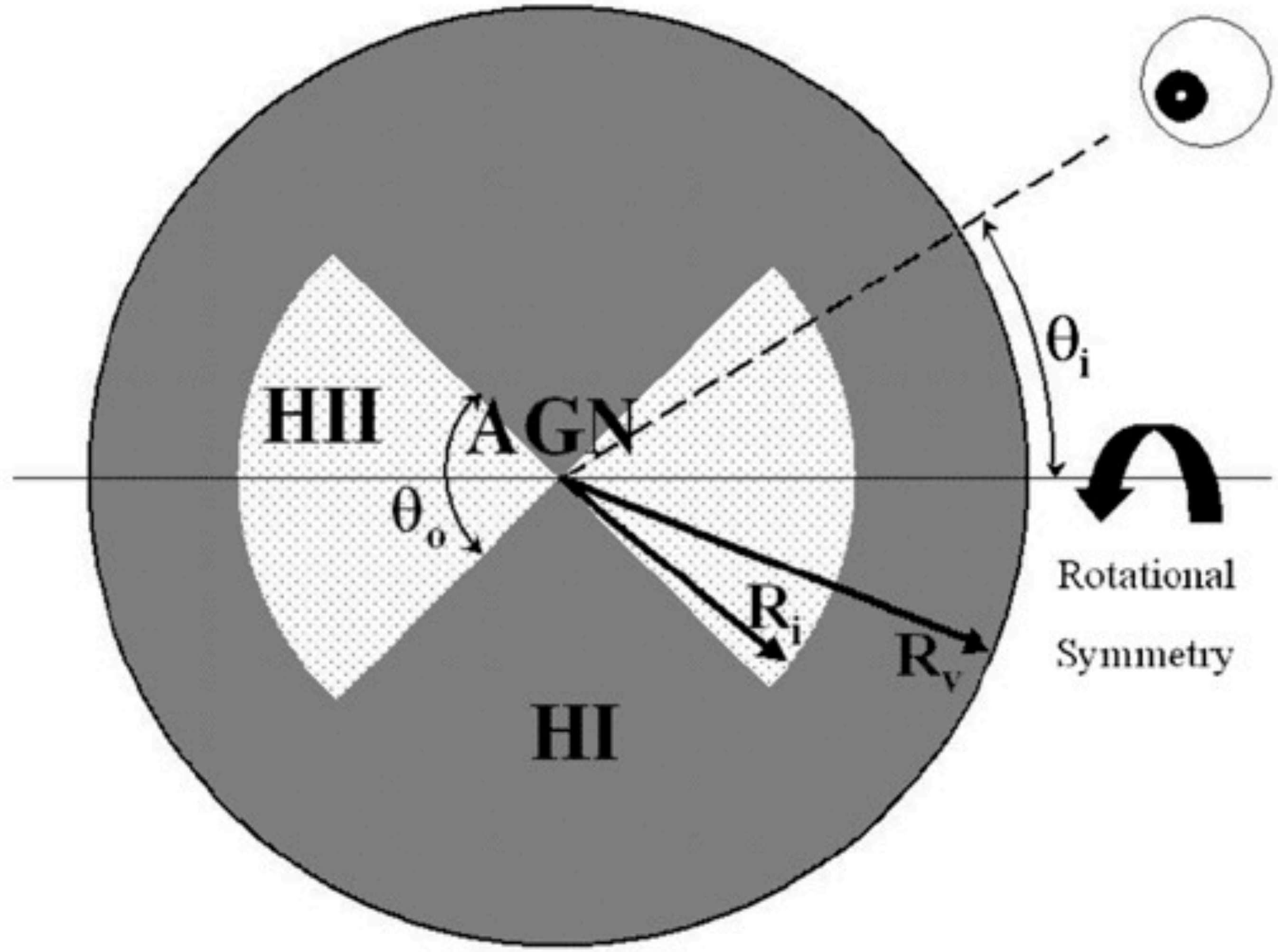


Figure 5. Geometry of our simulation. θ_i is the inclination as constrained by Carilli (1995). R_v is the system's virial radius. R_i is the ionization radius of the cones. θ_o is the opening angle of the ionization cones assumed here to be 90°. R_i, R_v, θ_o, and two variables controlling the velocity field are the model's five tunable parameters.

Ionization

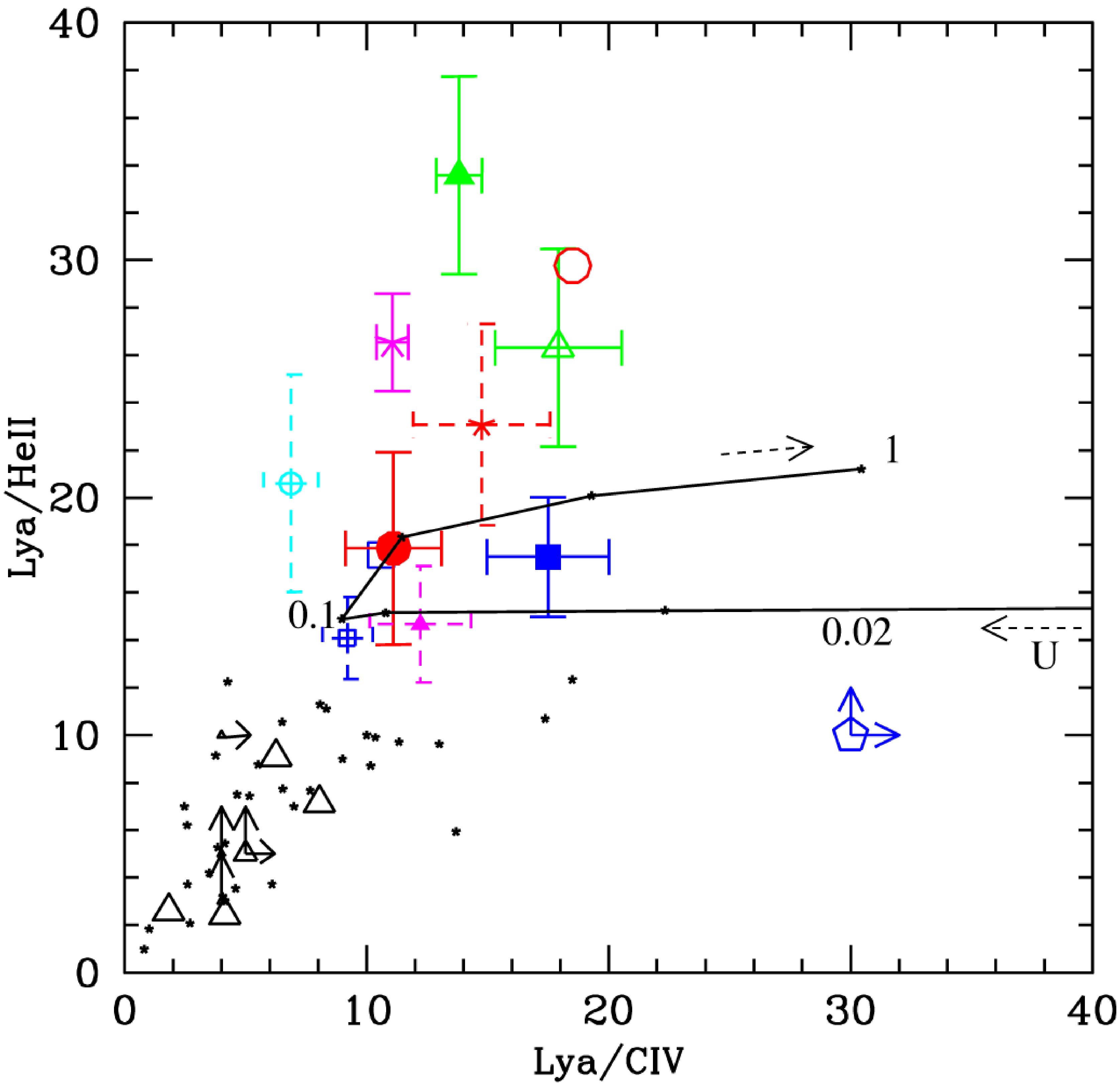
- Possibilities
  - Young stars
  - AGN — photons and jet-driven shocks
  - Gravitational infall / shocks (cooling radiation)
- Luminous quasars are capable of producing highly luminous Lyα emission from their host galaxies but is this the only mechanism operating?

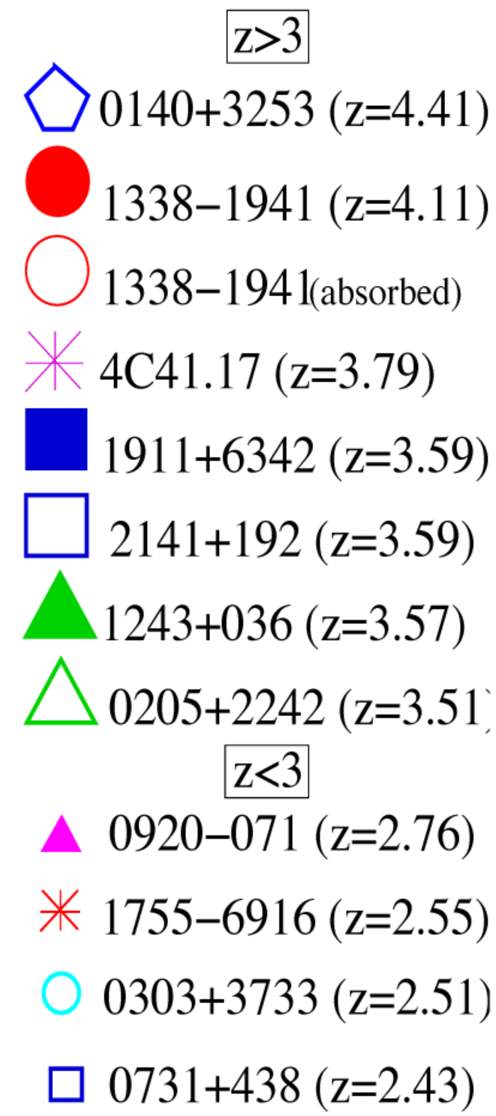
Lyman-Alpha Excess at high z

- 54% of z > 3 and 8% of 2 < z < 3 Radio Galaxies show Ly-α emission stronger than can be explained by the standard AGN photionization models: we call these LAEx objects
  - Definition: we use Ly-α/HeII > 14 - which is 90% of the minimum case B value predicted by the AGN photoionization models
  - Ly-α absorption will tend to lower this ratio
- LAEx's show lower restframe UV continuum linear polarization
- sub-mm detection rate is higher for z > 3

Villar-Martín et al. 2007

power law
index -1.5
solar abundances
U-sequence



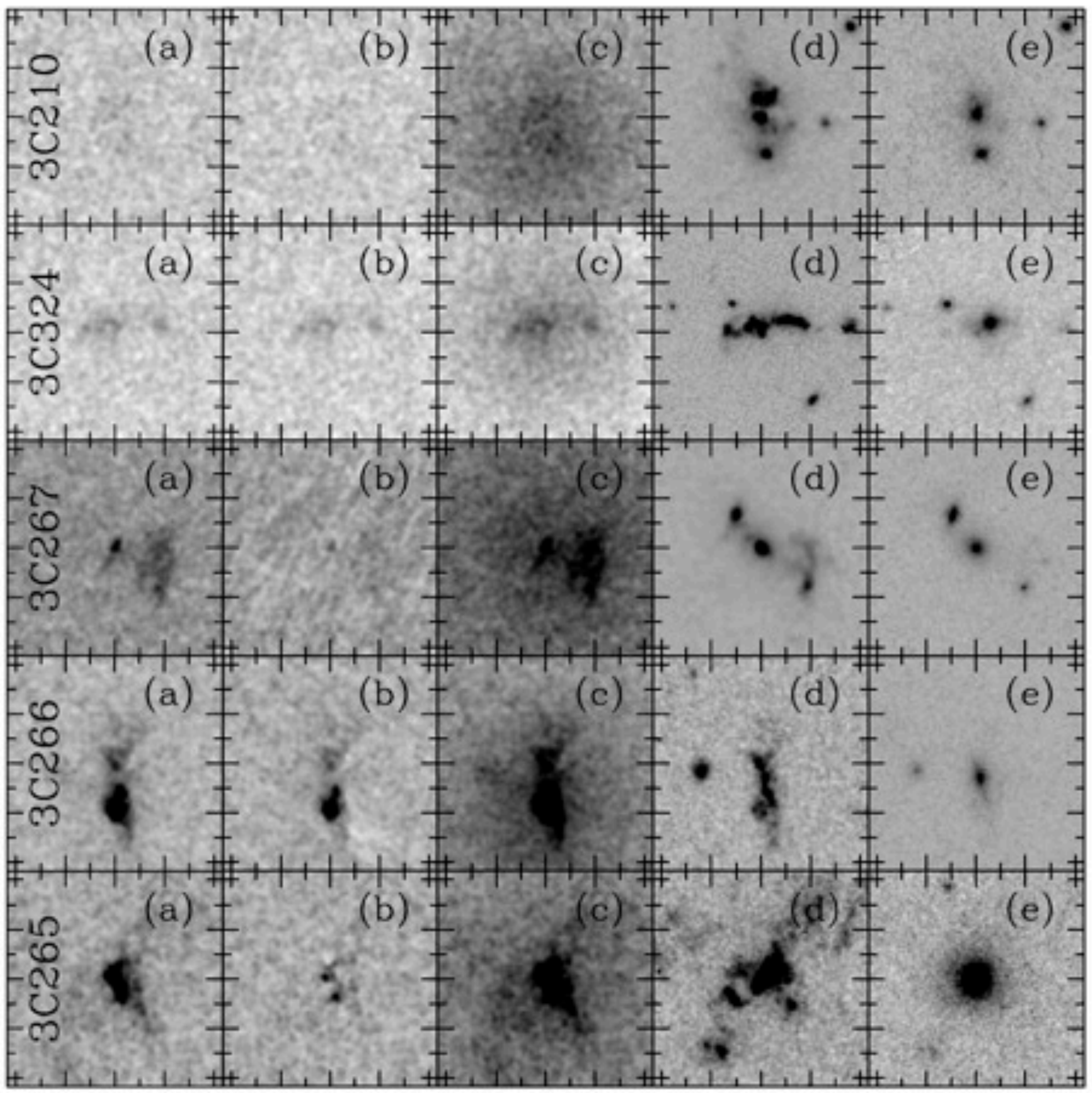


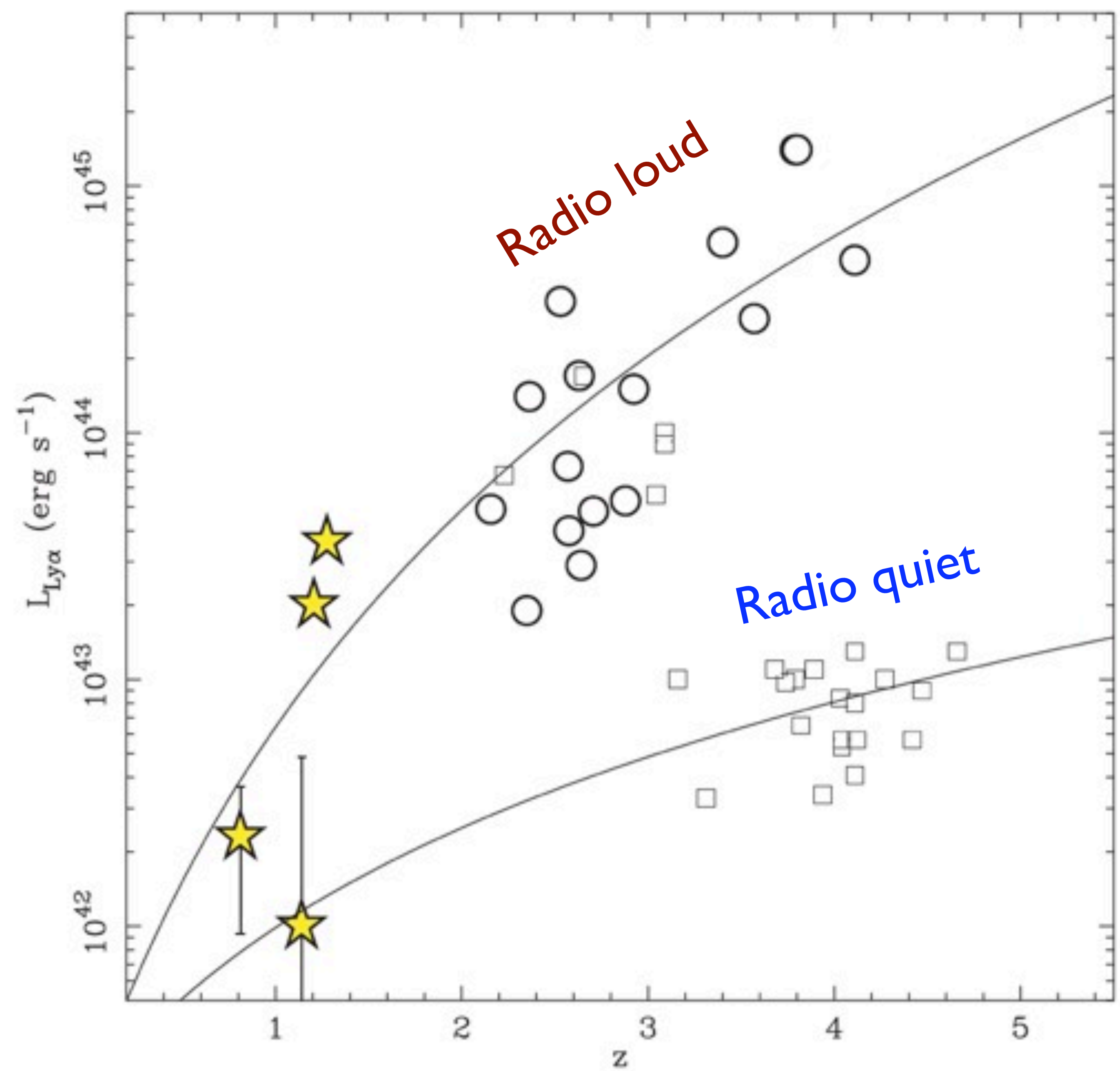
Note that the Ly-α/CIV is more U-dependent than Ly-α/HeII
Small symbols for z < 3

Lyα halos in z ~ 1 Radio Galaxies

Zirm et al. 2009; HST/ACS prism observations

| Lyα prism |Opt |NIR |

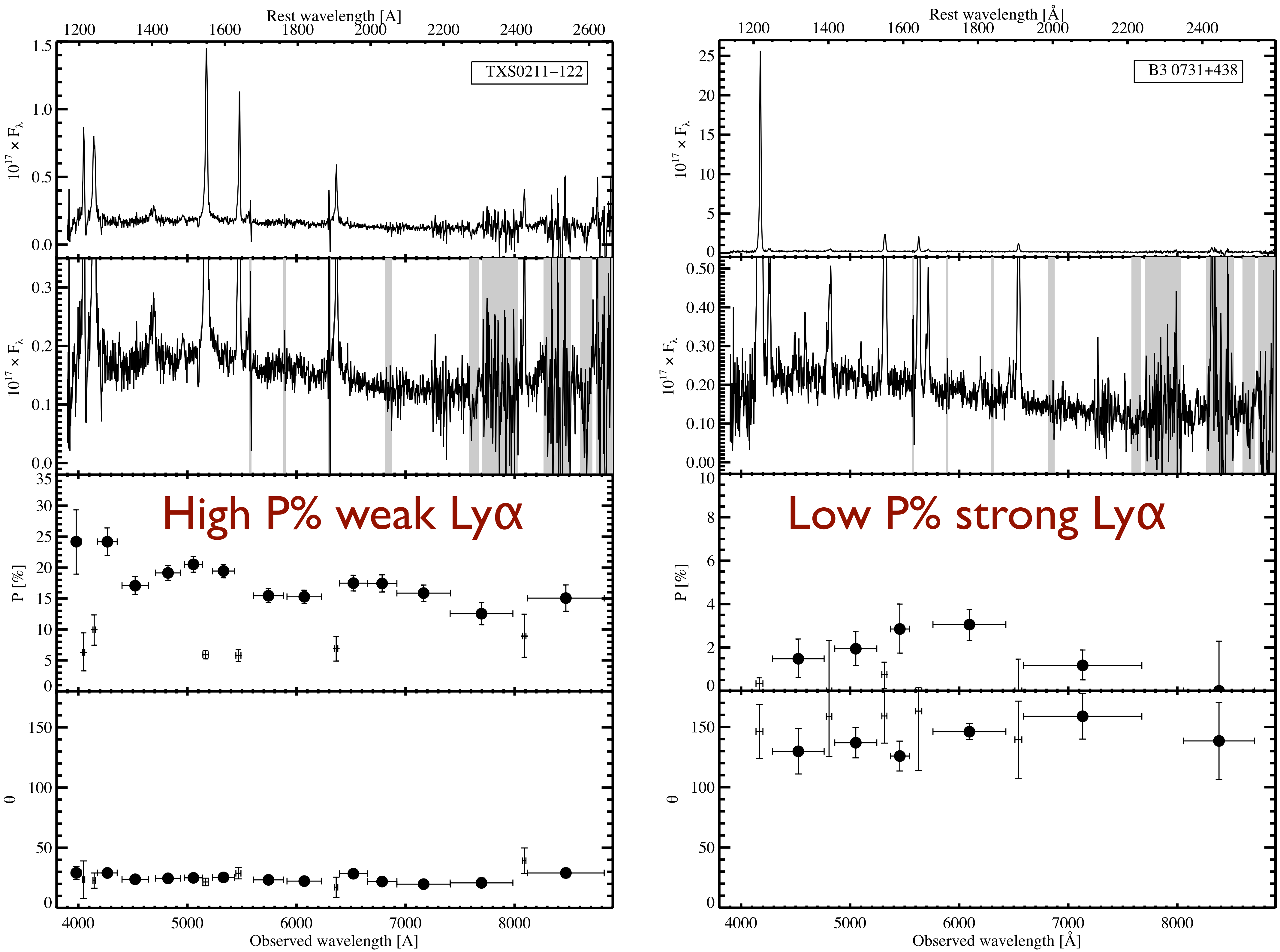




Flux

P(%)

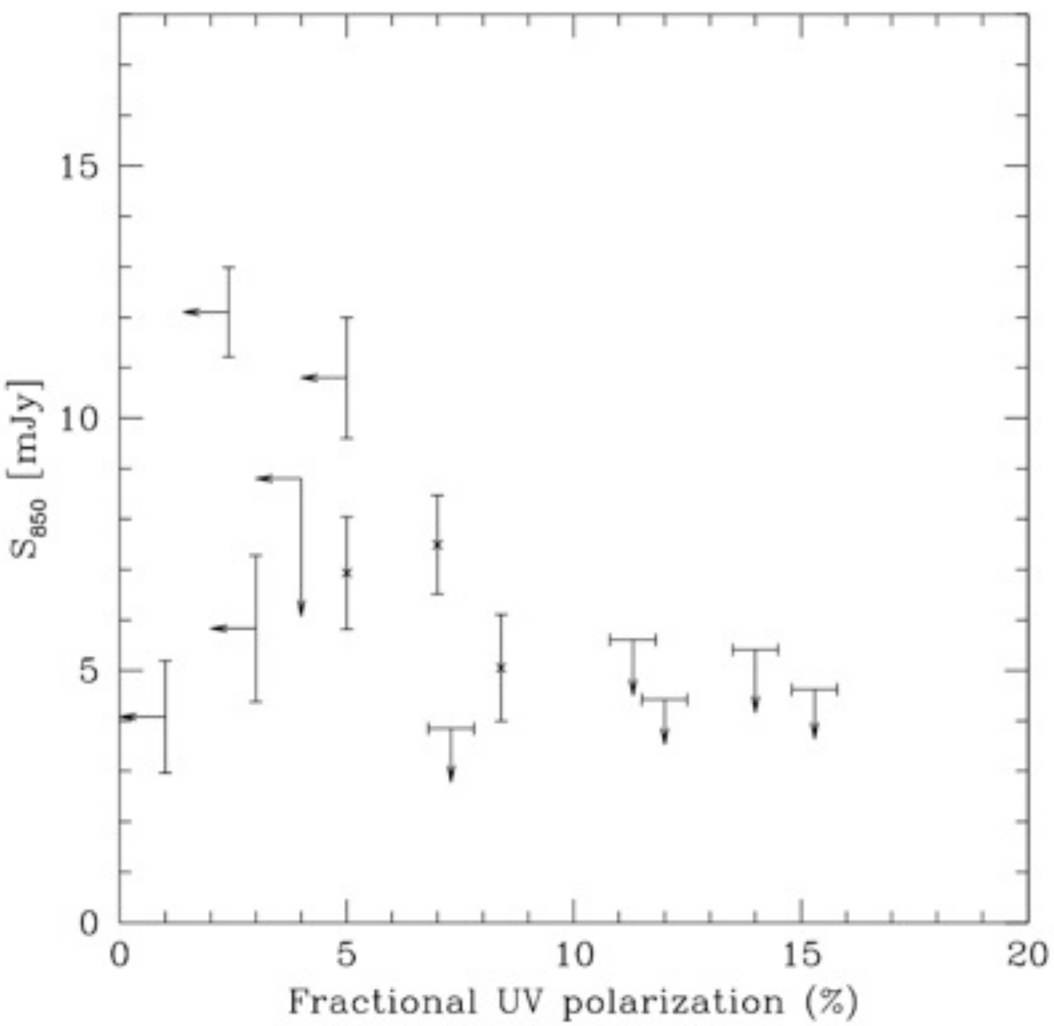
PA



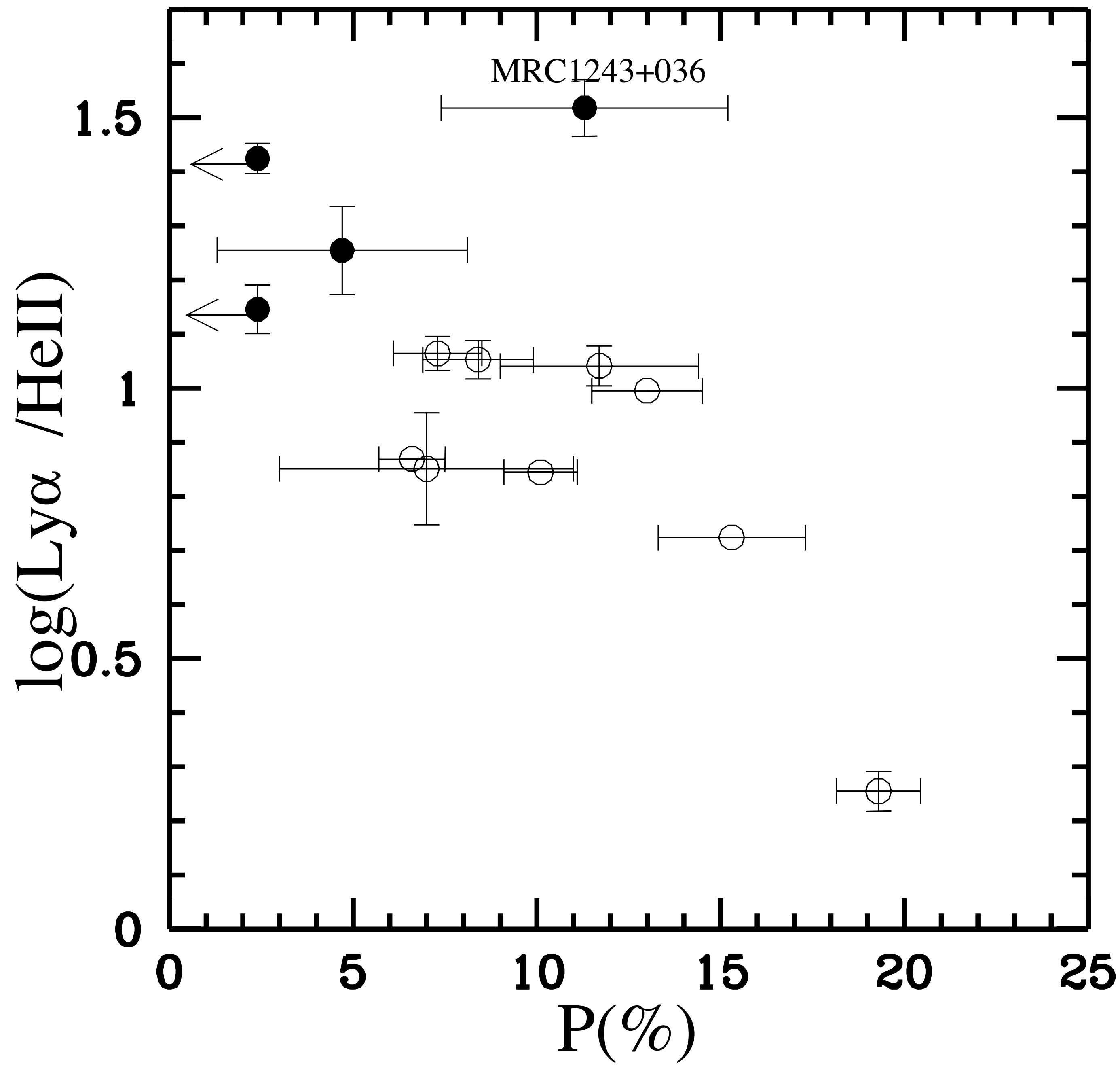
Keck LRISp spectropolarimetry

Vernet et al. (2001)

Anticorrelations with fractional, restframe UV continuum polarization
Dust re-emission and Ly-α + (unpolarized) UV continuum indicating star formation in LAEx

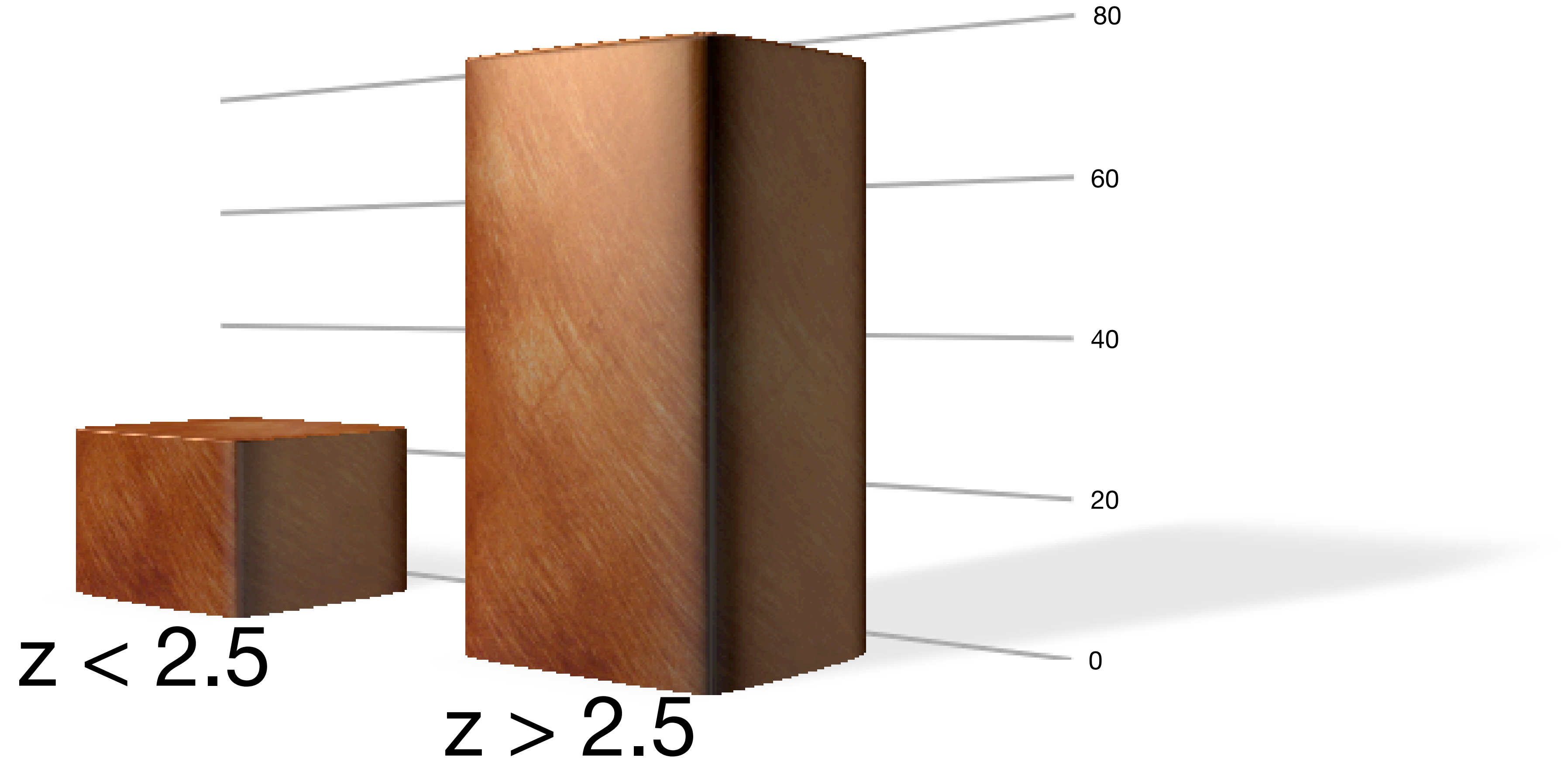


Reuland et al. 2004, MNRAS, 353, 377



RG sub-mm detection rate

*Archibald et al. 2001, MNRAS, **323**, 417*



- High rates of (massive) star formation proceeding in the most massive galaxies at z > 3
- Evidenced by:
  - ~ 10^{44} erg s^{-1} of Ly-α emission
  - unpolarized UV continuum diluting the scattered quasar
  - sub-mm emission with $L_{850\mu} \sim 10^{23.5}$ W Hz^{-1} Sr^{-1}
- Is this '*merger-triggered*'? Small radio sizes argue for recent triggering events

Conclusions

- The warm gas emitting/scattering the RG Lyα halos is one of several components that constitute the most massive of galaxies
- The high Lyα *luminosities* suggest that, at $z \geq 3$, the line is driven by star formation in addition to the AGN and gravitational collapse/cooling
- Kinematic and morphological studies suggest both outflows (driven by jets and starbursts) and massive gravitational inflows — a tracer of 'feedback'