

# Giant Ly $\alpha$ haloes around $z\sim 2.5$ radio galaxies: evidence for infall

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# Outline

- Investigate the nature of the giant, *kinematically quiescent* nebulae that surround  $z > 2$  radio galaxies
  - Evidence that the nebulae are in infall
- Infall/inflow of gas may also result in:
  - HI absorption features
  - Low surface brightness Ly $\alpha$  emission

# Motivation and sample

- Motivation
  - **Formation and evolution of massive elliptical galaxies**
  - **Symbiosis between host and AGN activity; feedback**
- 12 Ultra-steep spectrum radio galaxies at  $z > 2$ 
  - **Progenitors of gE galaxies we see at  $z \sim 0$ ?**
- Biased towards sources with very luminous...
  - emission lines
  - UV-optical continuum
  - radio continuum

# The Data

- Long slit spectroscopy along radio axis

- Keck II LRISp

- 10 sources
    - 2 – 8 hours per object
    - Ly $\alpha$  – [NeIV]2422

- VLT ISAAC

- 7 sources (6 of Keck ones)
    - J H K spectra
    - 0.5 – 4 hours per band
    - [OII], [OIII] and H $\alpha$

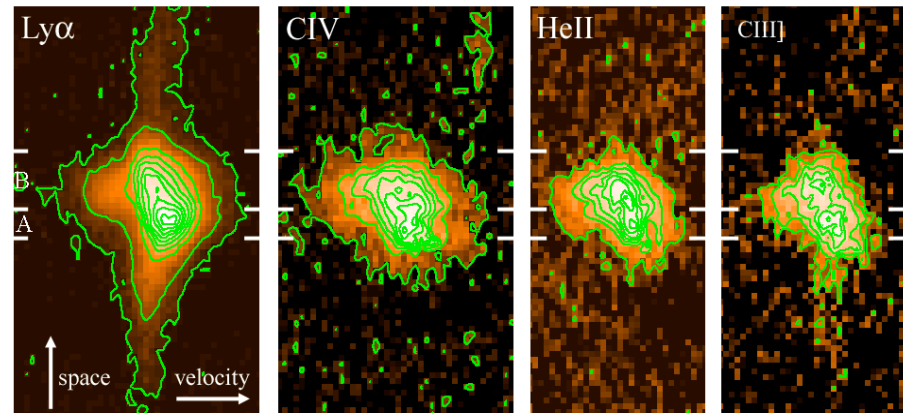
- 1" or 1.5 " slit

- Seeing ~0.5-1.5"

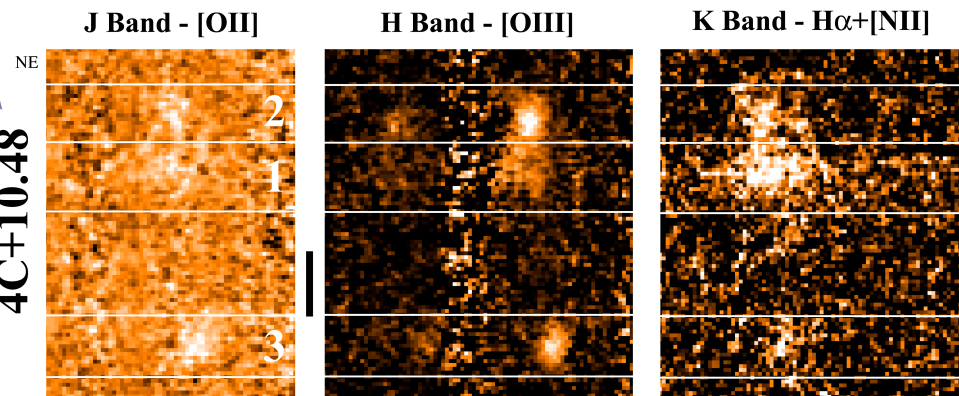
- IP FWHM~500-800 km s<sup>-1</sup>

- VLT + FORS: MRC 2104-244

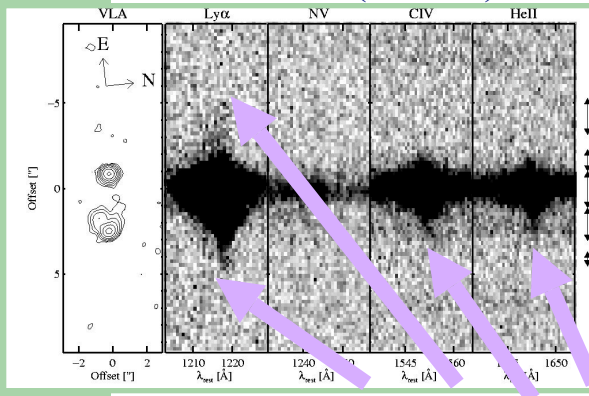
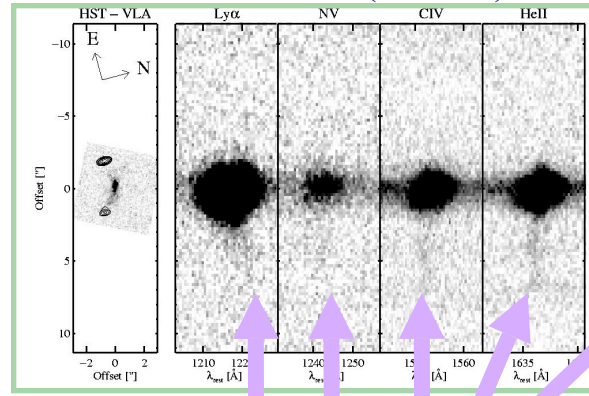
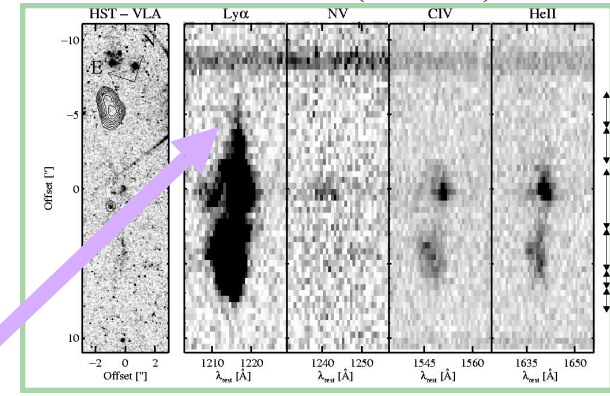
USS 0828+193



4C+10.48

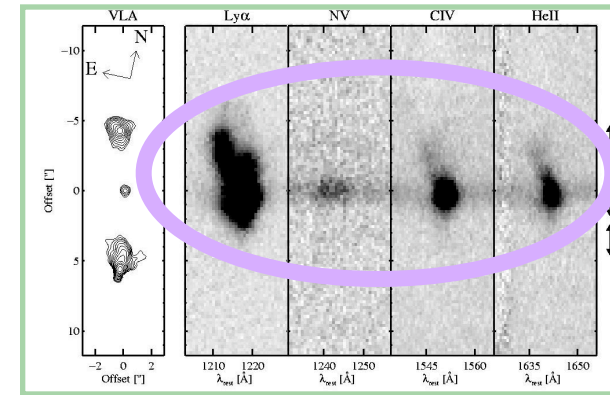


# Giant nebulae of ‘Quiescent’ gas

4C+40.36 ( $z=2.27$ )0943-242 ( $z=2.92$ )2104-242 ( $z=2.49$ )

## • Quiescent haloes

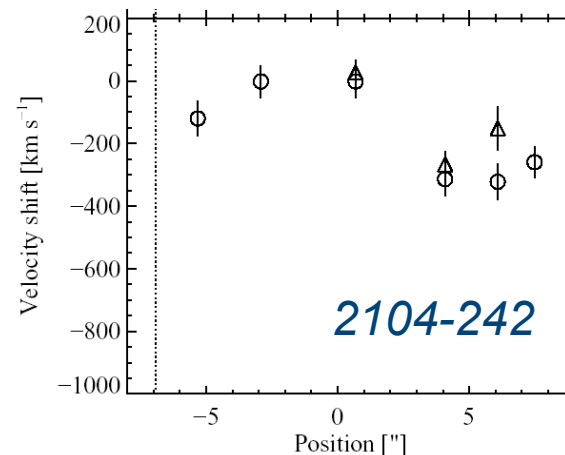
- Consistent with gravitational motion in massive elliptical
- Low FWHM and  $v_s$ :  $<700 \text{ km s}^{-1}$
- 65-140kpc, some extend beyond radio structure
- Metal enriched
- Common feature of this sample

0731+438 ( $z=2.43$ )

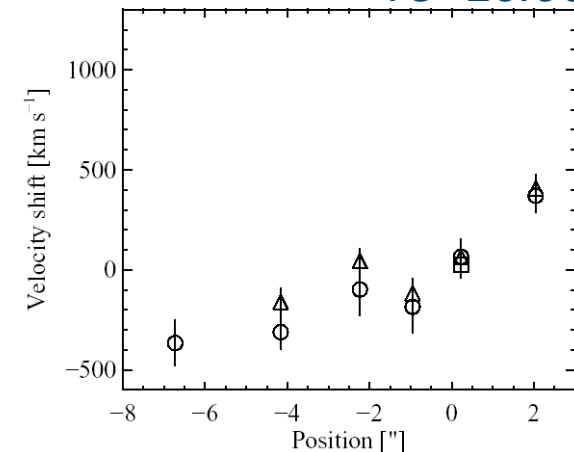
# 'Quiescent' nebulae velocity curves

- Consistent with:

- Rotation?
- Infall?
- Outflow?



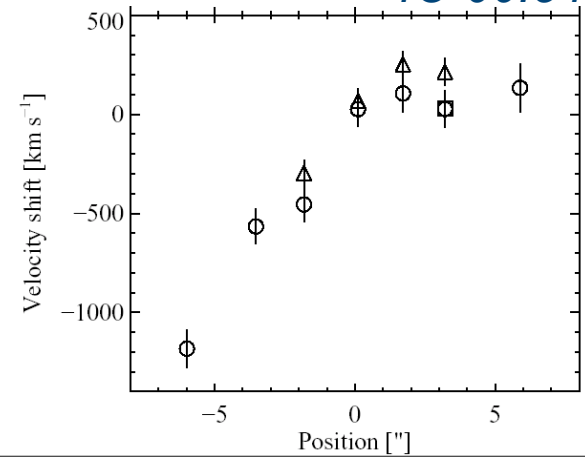
4C+23.56



- Compare against orientation dependent properties – radio and Ly $\alpha$

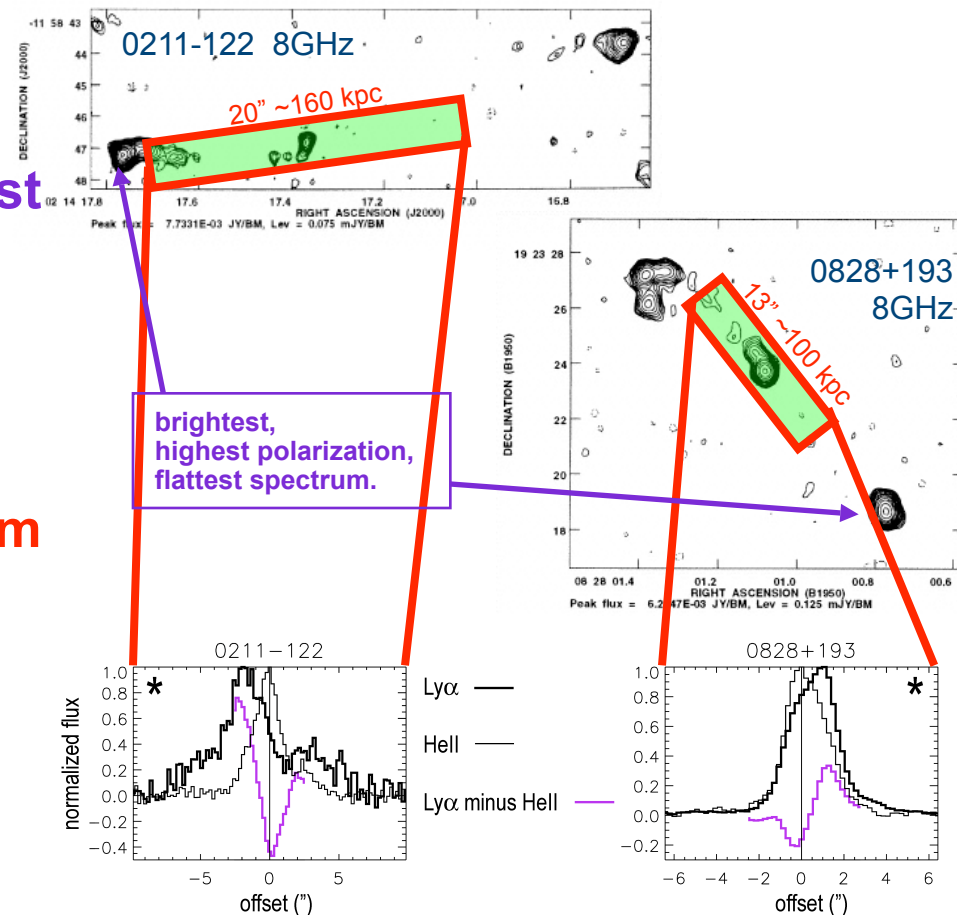
- If motion is radial, we might expect a trend between orientation and the velocity curve
- If instead the haloes are rotating, the velocity

4C-00.54



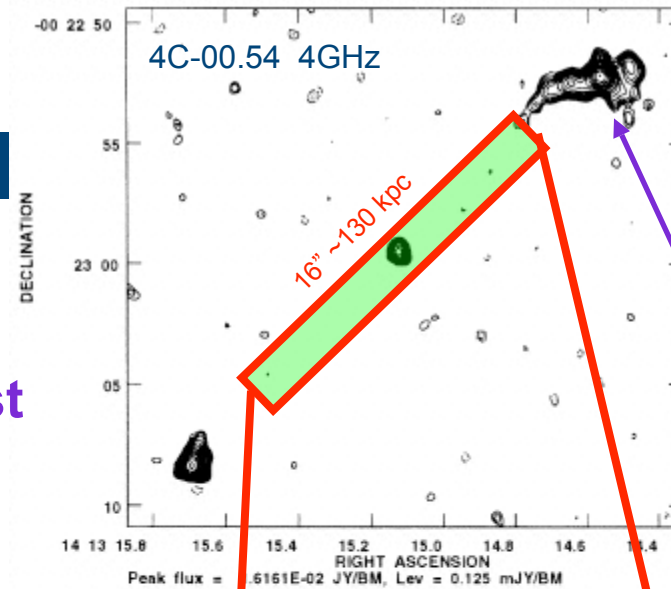
# Correlated asymmetries in $z > 2$ radio galaxies: results

- On the side of the **brightest** hotspot:
  - Radio polarization highest (7/9)**
    - 15/22 in overall Carilli/Pentericci sample..
    - Similar to Laing-Garrington effect?
  - $\text{Ly}\alpha$  brighter relative to other lines and continuum (8/8)**
    - $z \sim 2.5$  quasars (9/10)

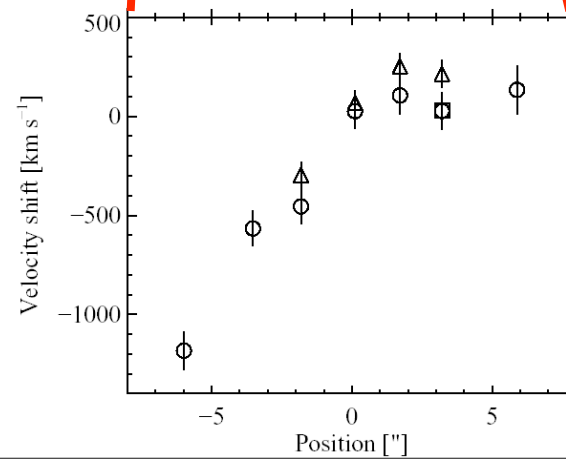


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    - $z \sim 2.5$  quasars (9/10)
  - Quiescent nebula has its highest redshift (12/12)**
    - 27/30 including  $z < 2$  sources



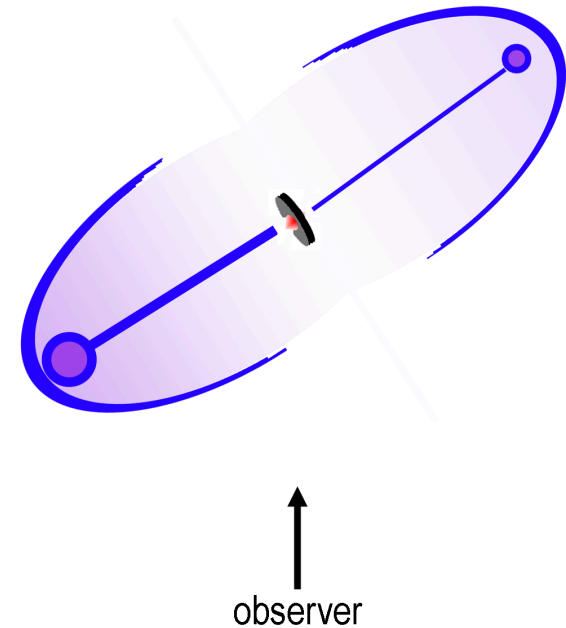
brightest,  
highest polarization,  
flattest spectrum.





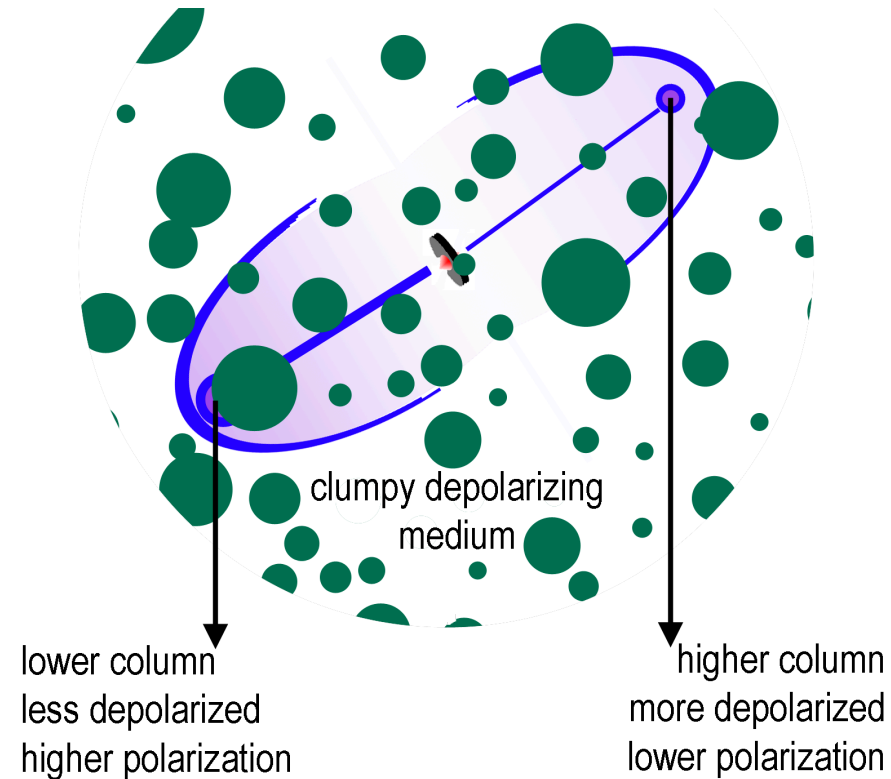
# Scenario: orientation effects

- The scenario:
  - (a) Doppler boosting
    - Approaching hotspot appears brighter



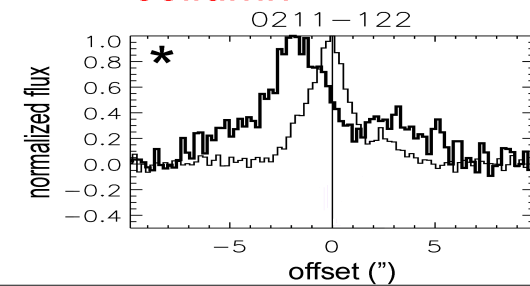
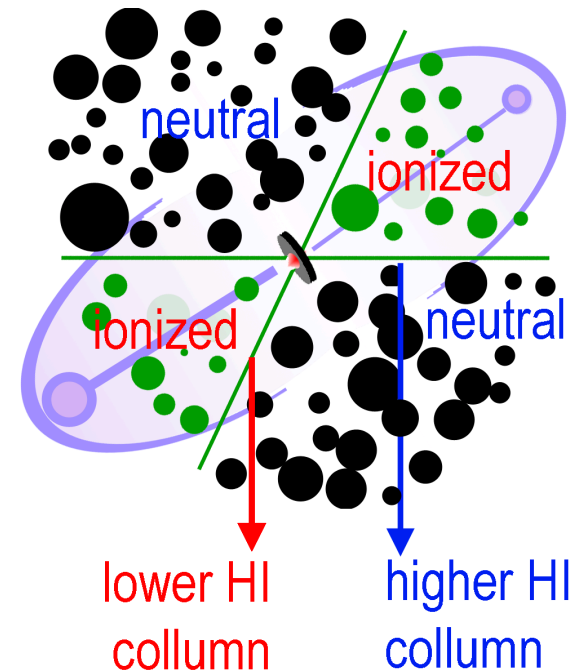
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- The scenario:
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  - (b) Differential Faraday rotation
    - Approaching hotspot seen through less material → **less depolarized**



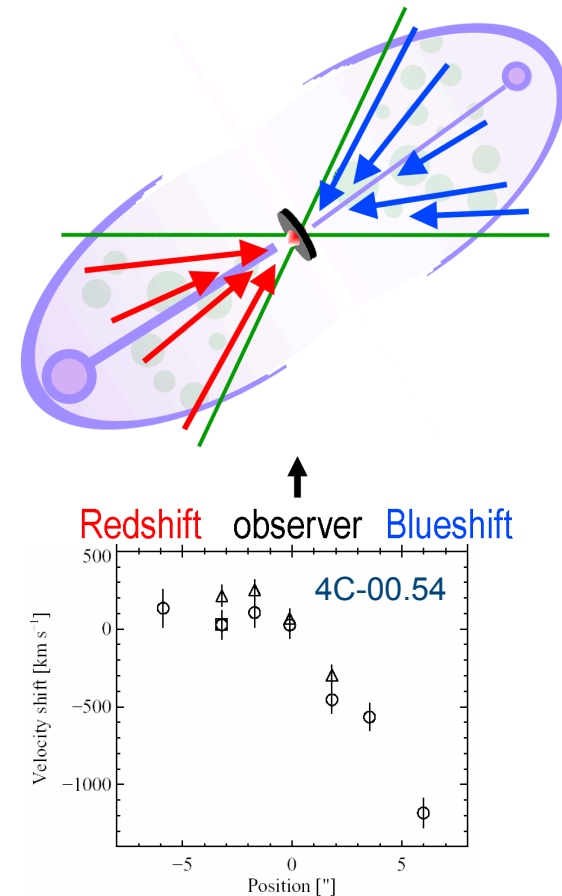
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  - Doppler boosting  
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→ less depolarized
  - $\text{Ly}\alpha$  from cone is less absorbed  
- Lower HI column this side →  
**brighter  $\text{Ly}\alpha$**

Ly $\alpha$  —H $\alpha$  —

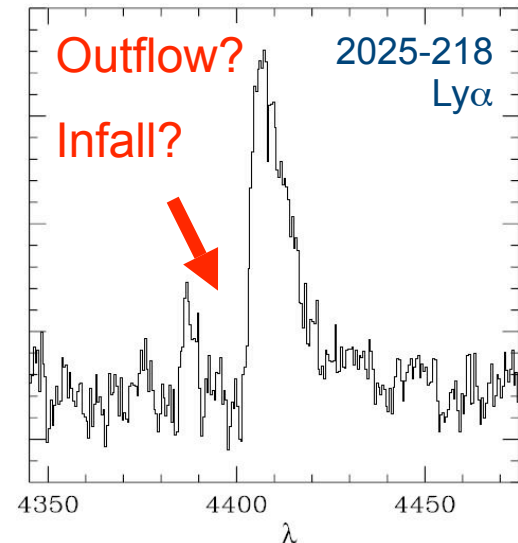
# Scenario: orientation effects

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  - (a) Doppler boosting
    - Approaching hotspot appears brighter
  - (b) Differential Faraday rotation
    - Approaching hotspot seen through less material → **less depolarized**
  - (c) Ly $\alpha$  from cone is less absorbed
    - Lower HI column this side → **brighter Ly $\alpha$**
  - (d) **Quiescent nebula is infalling**
    - Line emission from the cone is redshifted relative to the counter-cone



# Infall: other possible signatures

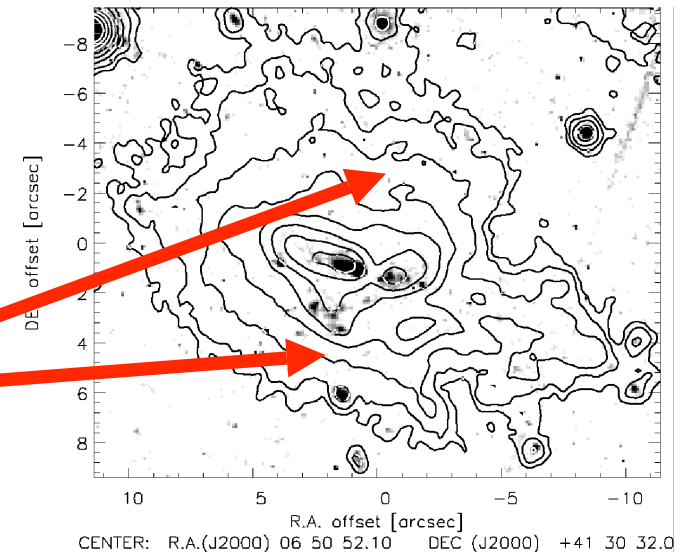
- **Absorbers associated with an ‘accretion shock’**
  - Infalling streams collide at supersonic speeds → **shock wave**
  - **HI absorption feature** from gas about to cross the shock front (Barkana & Loeb 2003)
  - Absorption should be redshifted relative to systemic velocity  
...but do we know the systemic velocity?
  - **Could some of the absorbers around  $z > 2$  radio galaxies be in infall?**



# Infall: other possible signatures

- **Ly $\alpha$  cooling radiation**

- Release of gravitational binding energy (Haiman et al. 2000)
- **$\sim$ few  $\times 10^{-17} - 10^{-18}$  erg s $^{-1}$  cm $^{-2}$  arcsec $^{-2}$  within a few arcsec of the AGN**
  - $\rightarrow$  barely detectable with 8-10m 'scopes
- **Faint Ly $\alpha$  emission seen outside of any plausible ionization cones** (e.g. 4C41.17: Reuland et al. 2003)



# Concluding remarks

- We have identified a trend such that on the side of the brightest radio hotspot:
  - Radio polarization is higher
  - Ly $\alpha$  is brighter relative to the other lines
  - **The kinematically quiescent gas has its highest redshift**
- The giant, kinematically quiescent nebulae around  $z > 2$  radio galaxies appear to be **in infall**
- Infall/inflow of gas may also result in:
  - **HI absorption features**
  - **Low surface brightness Ly $\alpha$  emission**