# HST/COS results on quasar outflows: Implications to AGN Feedback

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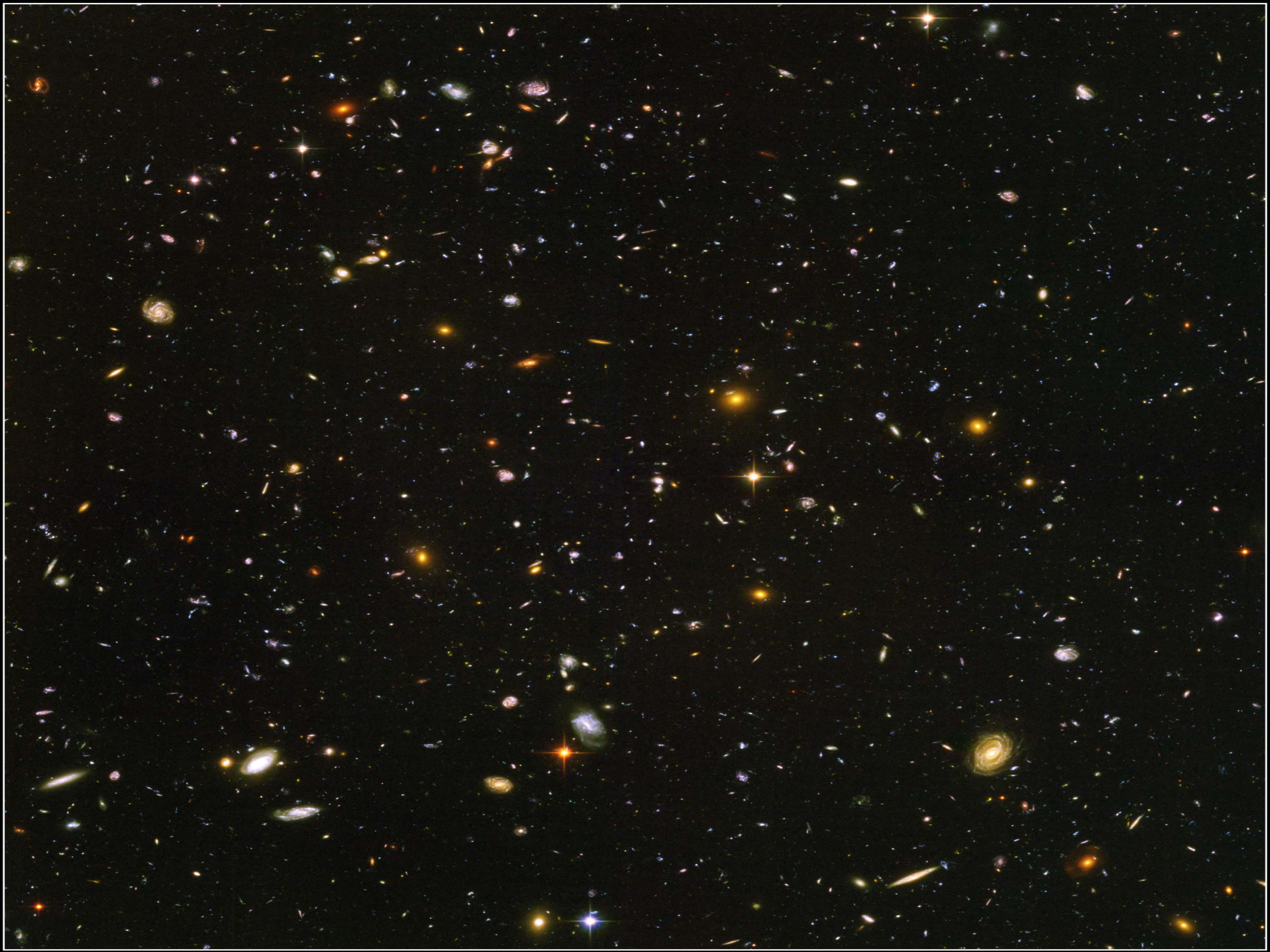
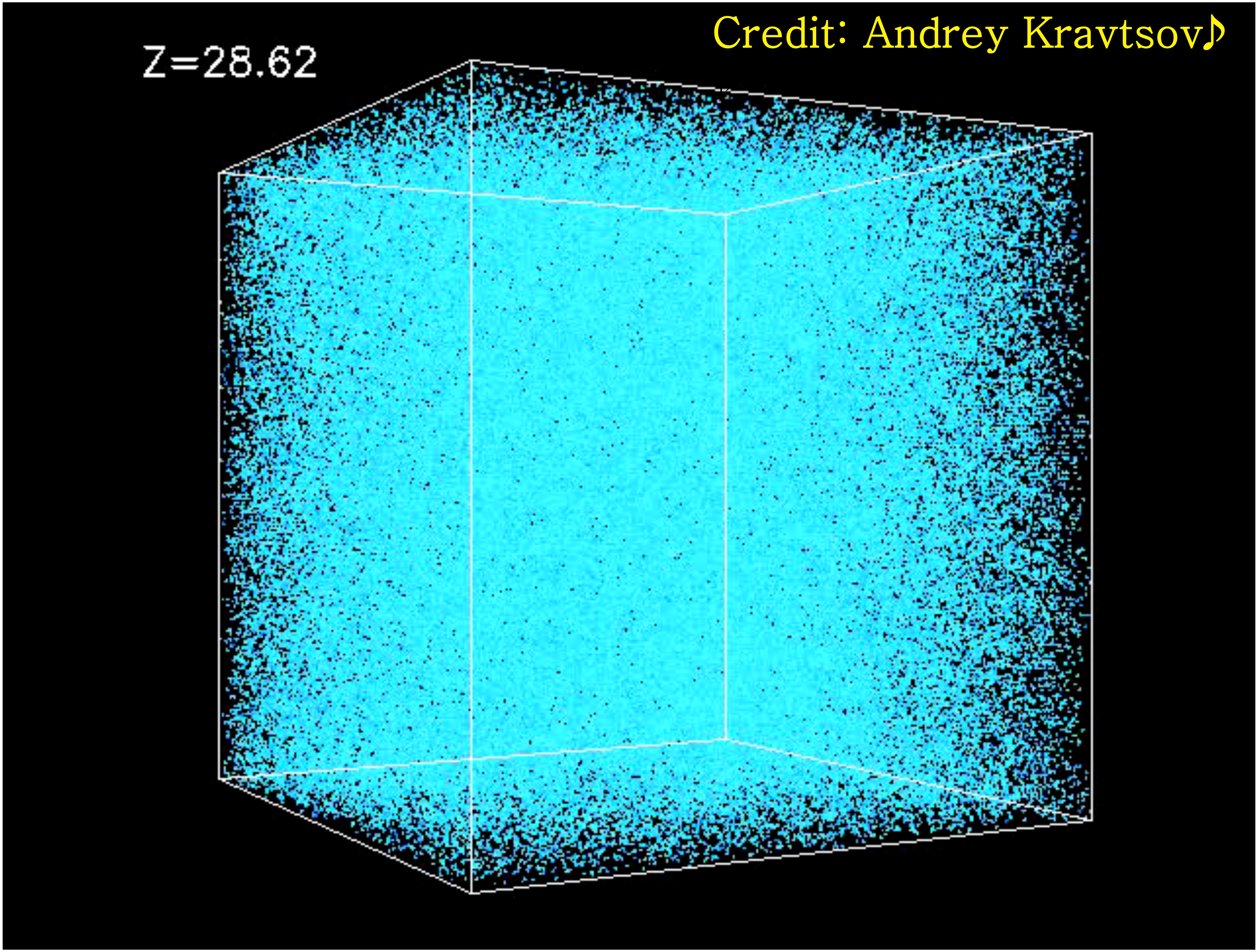
The average quasar
Has outflows with:
**Large scale**
**Large mass**
**Huge energy**

# AGN Feedback and cosmological structure formation♪

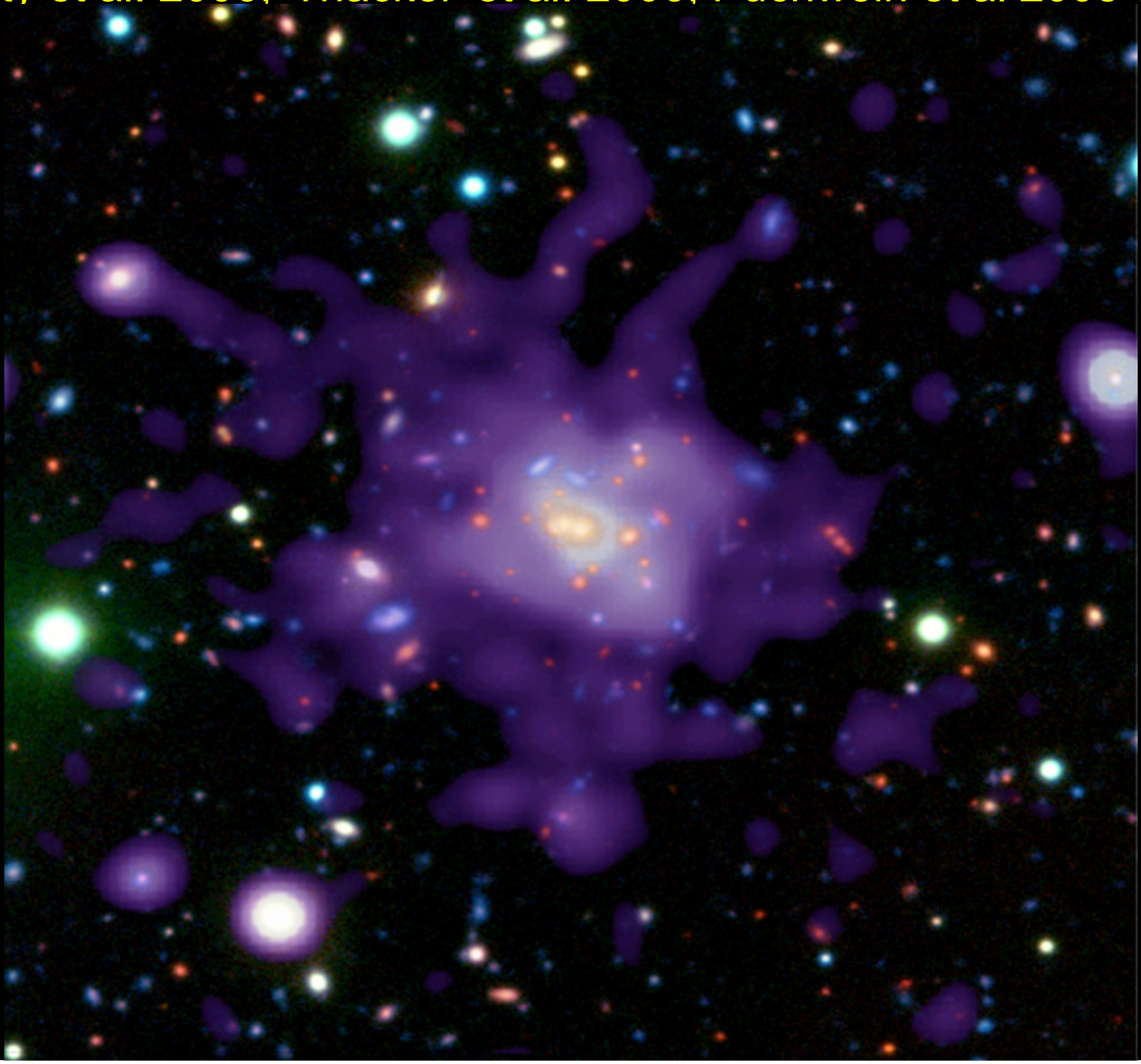


**Hubble Ultra Deep Field**
**Hubble Space Telescope** • Advanced Camera for Surveys


Z=28.62
Credit: Andrey Kravtsov

# Cluster cooling flows:

- Wu et al. 2000 ;Ciotti & Ostriker 2001; Bower et al. 2001 .; Vernaleo & Reynolds 2006; Rafferty et al. 2006; Thacker et al. 2006; Puchwein et al 2008 Soker et al 2010

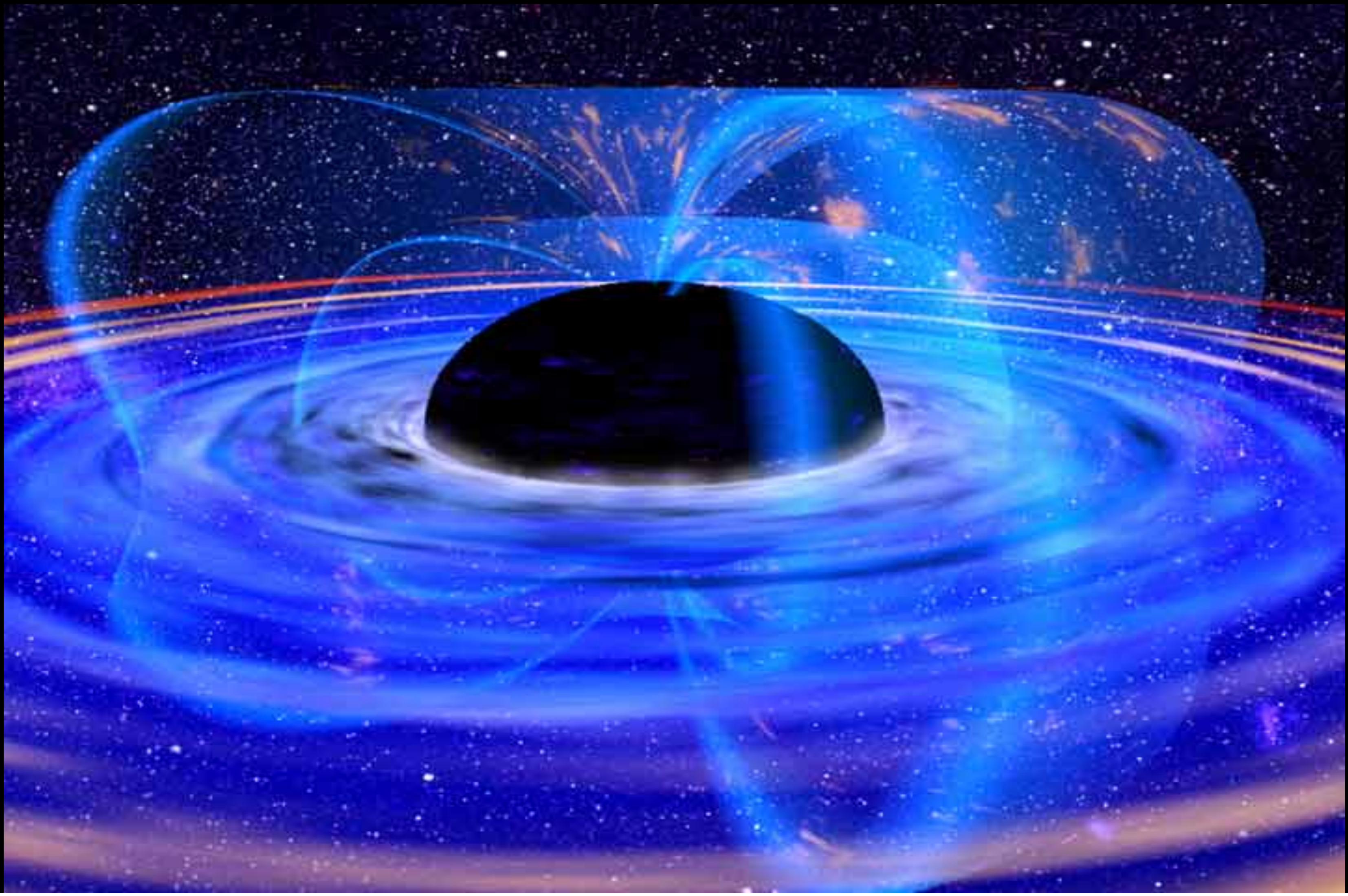


# Evolution of the host galaxy

- Scannapieco & Oh 2004;  Di Matteo et al. 2005;  Hopkins et al. 2005 ,2006; Springel et al. 2005; Menci et al. 2006; Haiman et al. 2006 Somerville et al. 2008,

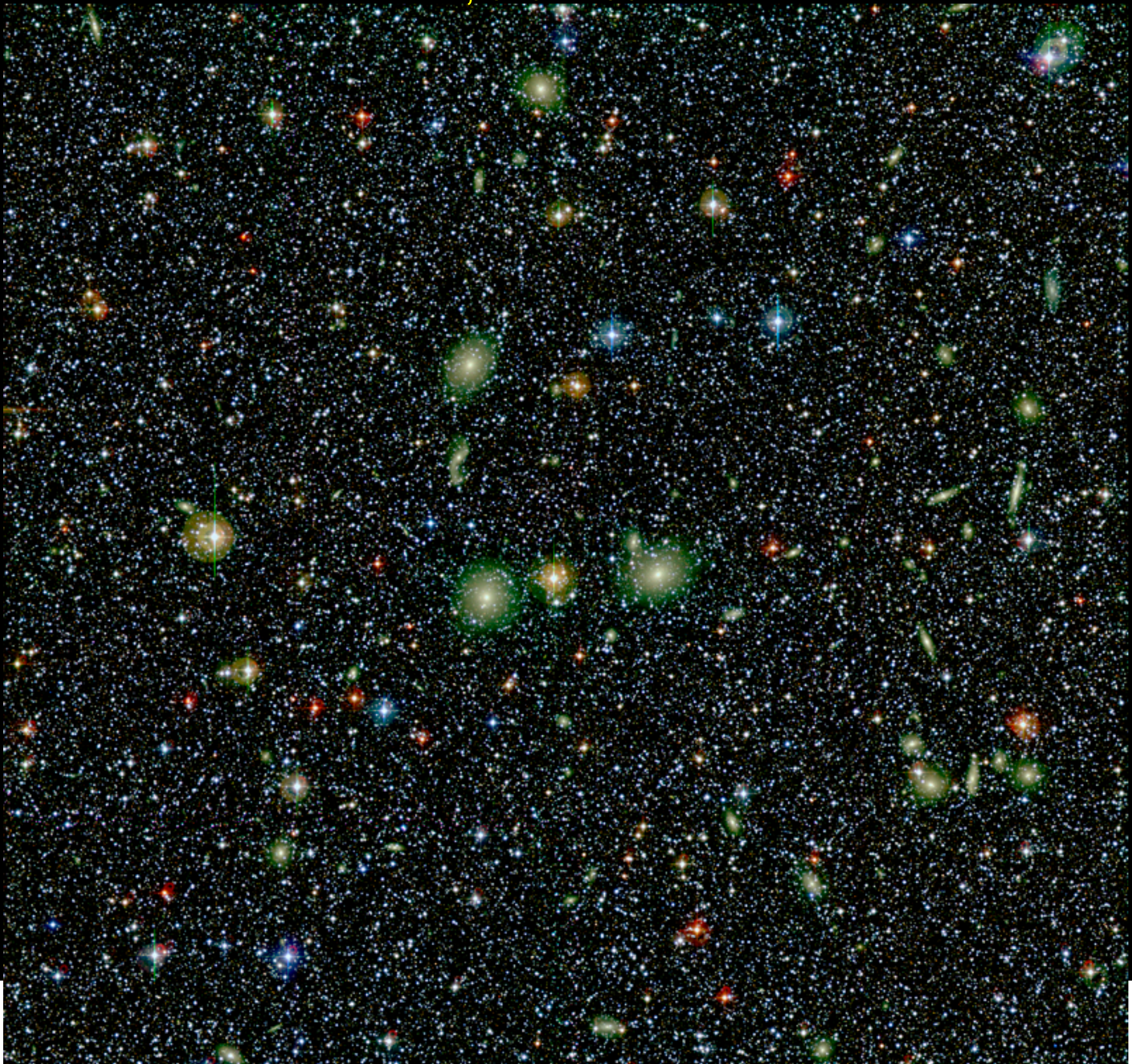
# Growth of super-massive black holes

Silk & Rees 1998; Blandford & Begelman 1999, 2004; King 2003 ; Cattaneo et al. 2005; Hopkins et al. 2007; Ostriker et al. 2010



# Enrichment of the intergalactic and intracluster medium

Furlanetto & Loeb 2001; Cavaliere 2002 Yuexing et al.; 2006; D'Odorico et al. 2006; Li, et al. 2007

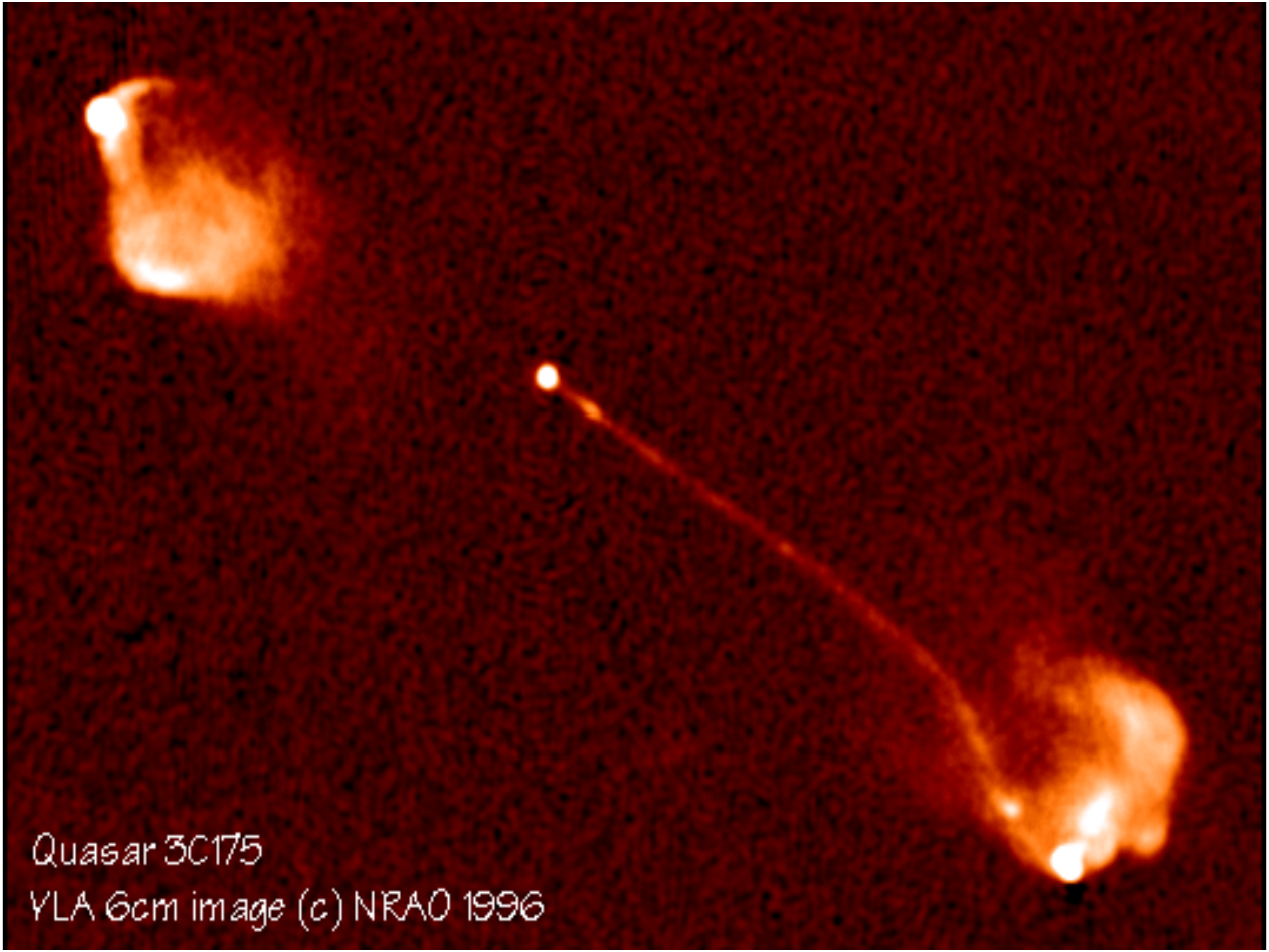


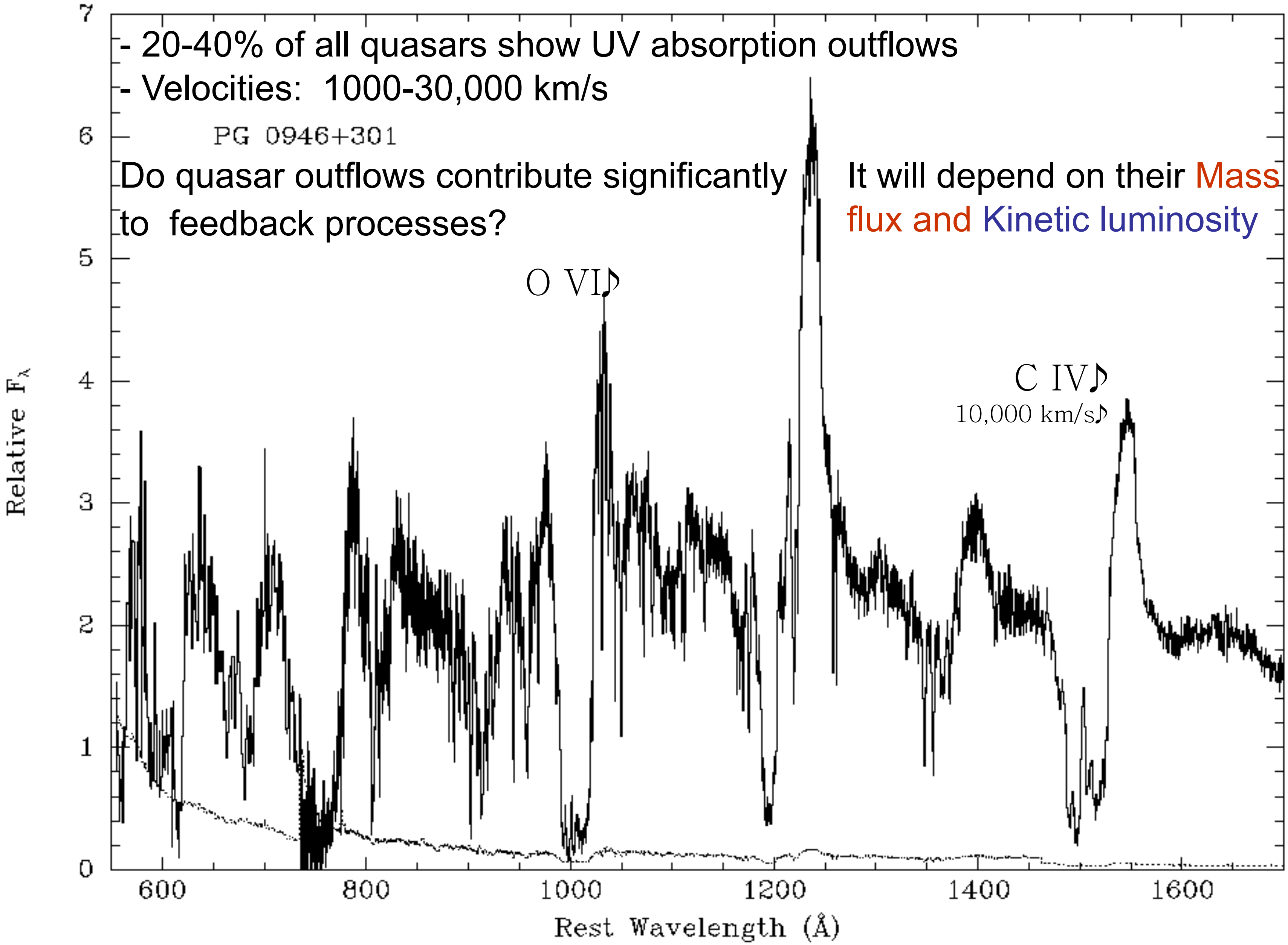
# Self Regulation

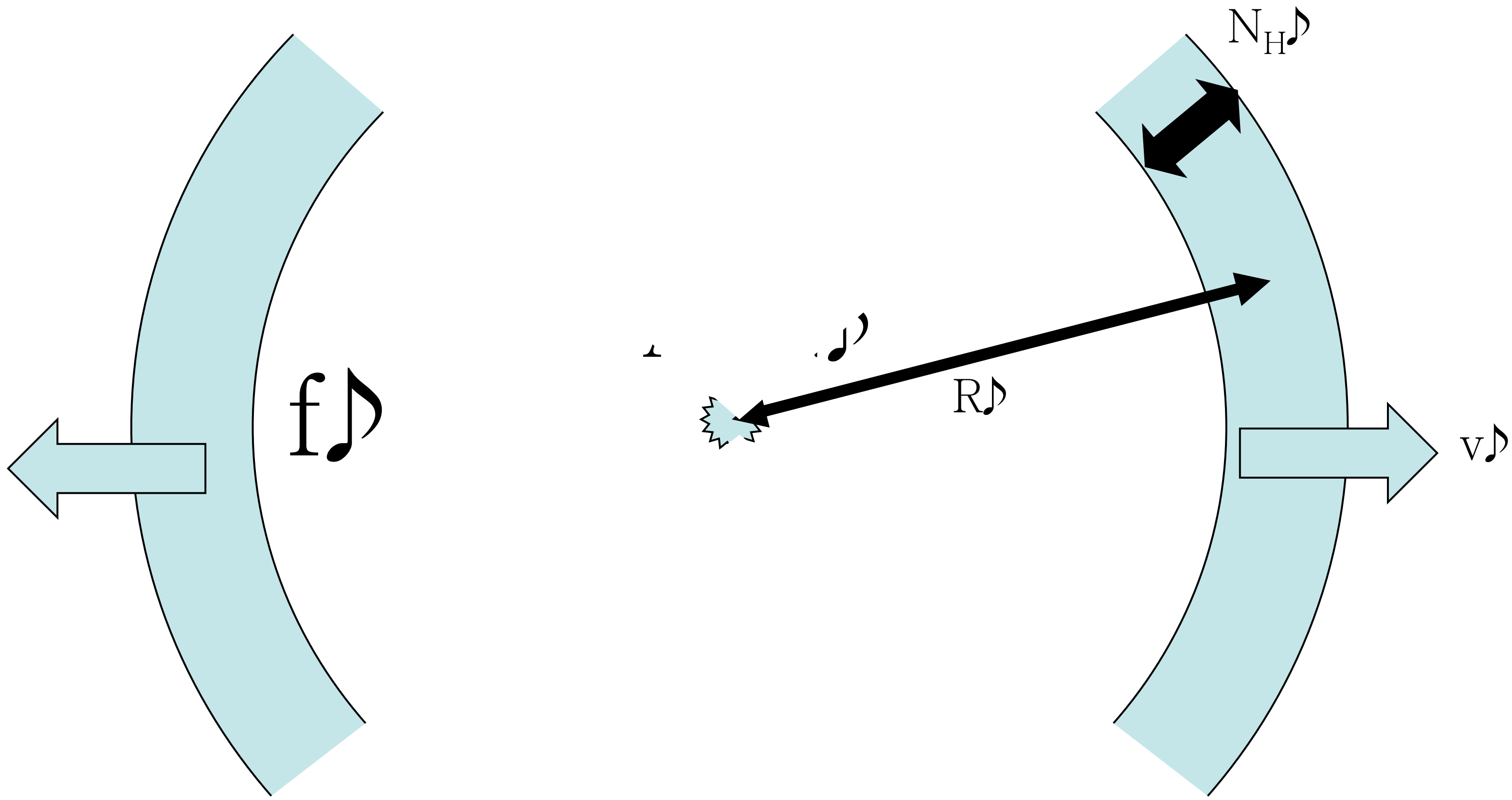
- $M_{BH} \leq 10^{-4} M_{gal}$ Gravitationally insignificant.
- However, the black hole binding energy can be larger than the galaxy's!

$$v^2{}_{*}/c^2 \approx 10^{-6}$$

- As soon as the central BH accretes large quantities of gas so as to significantly increase its mass, it releases large amounts of energy that would suppress further accretion onto it. In short, the BH growth is self-regulated.
- This energy may be sufficient to curtail the growth of the galaxy and to heat up the cluster gas. This is called AGN Feedback.


Quasar 3C175
YLA 6cm image (c) NRAO 1996


- 20-40% of all quasars show UV absorption outflows
- Velocities: 1000-30,000 km/s
PG 0946+301
Do quasar outflows contribute significantly to feedback processes?
It will depend on their Mass flux and Kinetic luminosity
O VI
C IV
10,000 km/s
Relative F$_\lambda$
Rest Wavelength (Å)
0
1
2
3
4
5
6
7
600
800
1000
1200
1400
1600



$N_H$♪
f♪
R♪
v♪

# Kinetic luminosity of absorption outflows

$$\dot{E}_k = \frac{1}{2}\dot{m}v^2 \approx 2\pi f\, R N_H 1.4 m_p v^3$$

Up until a few years ago:

$$N_H \approx 10^{20-24}\, cm^{-2}$$

$$R \approx 0.01 - 10000\, pc$$

$$f \approx 0.2$$

Exceptions: De Kool + (3 objects); Hamann 3c191♪

# kinetic luminosity of component C in the SDSS 0838+2955 outflow (Moe+2009)

$$N_H = 10^{20.8} cm^{-2}$$

$$R = 3500\, pc$$

$$v = 4900\, km/s$$

**Only the Low ionization phase is probed**

**Systematic uncertainties**

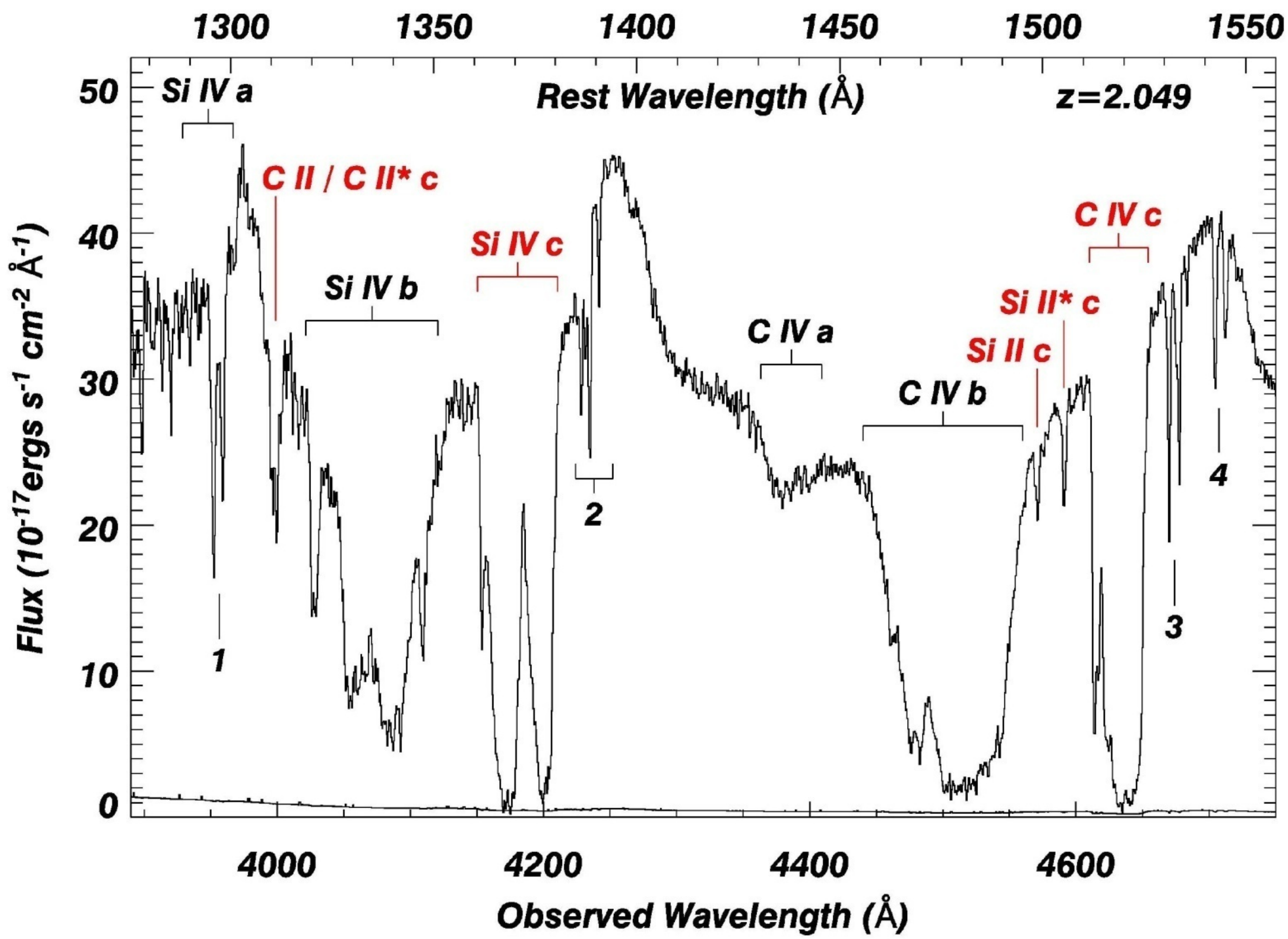
$\dot{E}_k = 2.5 \times 10^{45} \times f_{0.2}$ ergs/s =♪ $1\% L_{BOL}$

$\dot{M} = 300 \times f_{0.2}$ Solar masses/yr♪

**Less than 40% statistical error**

AGN feedback models need kinetic luminosity ~5%LBOL♪

# How do we go from the spectrum to measuring the kinetic luminosity?



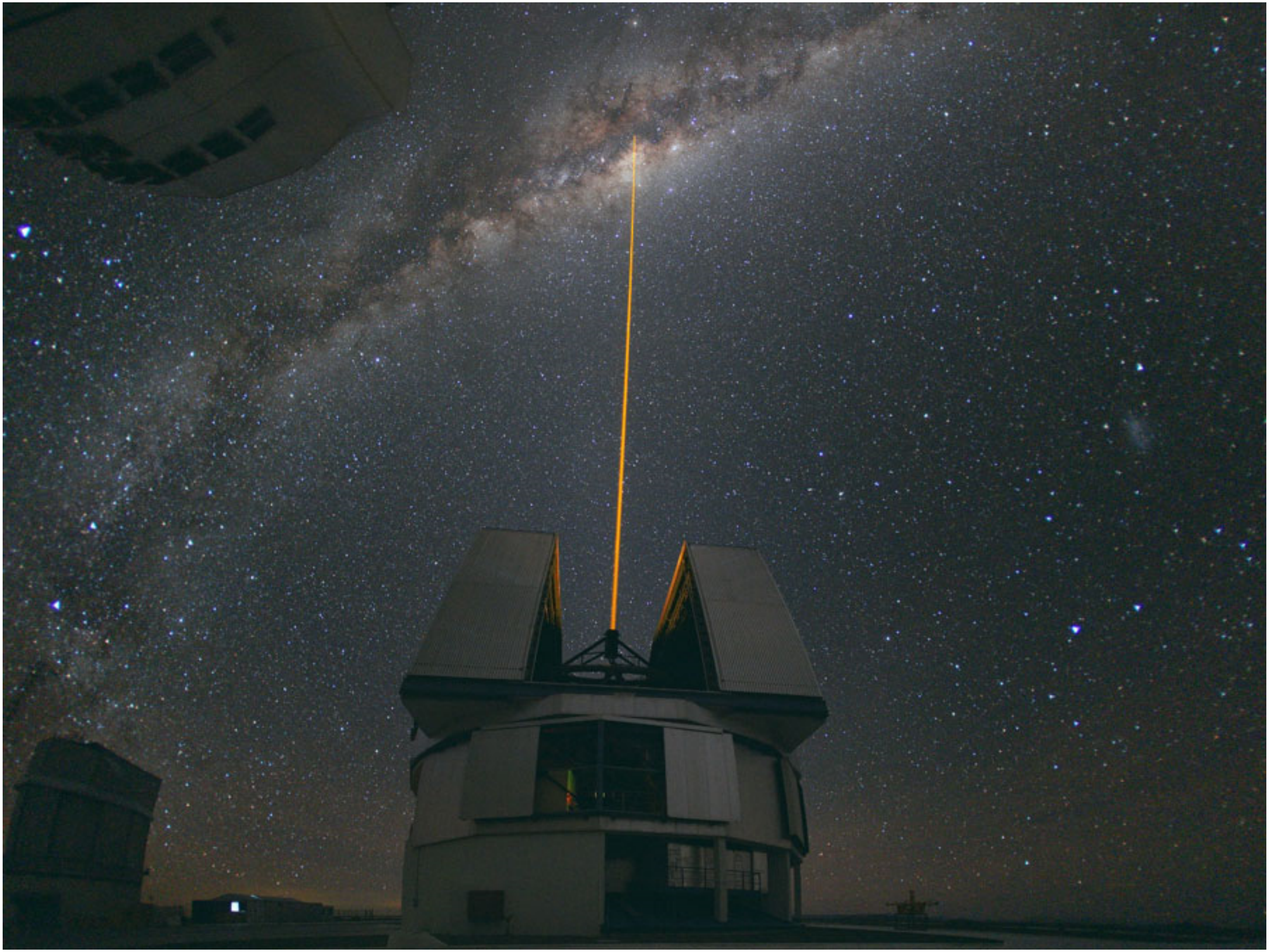
# From absorption troughs to kinetic luminosity

- Reliable measurements of $N_{ion}$ cannot use EW, $tau_{ap}$
- Photoionization modeling to convert $N_{ion}$ to $N_H$ and U

- Distance of the Outflow from the Central Source:

$$U \propto \frac{L}{n_H R^2}$$

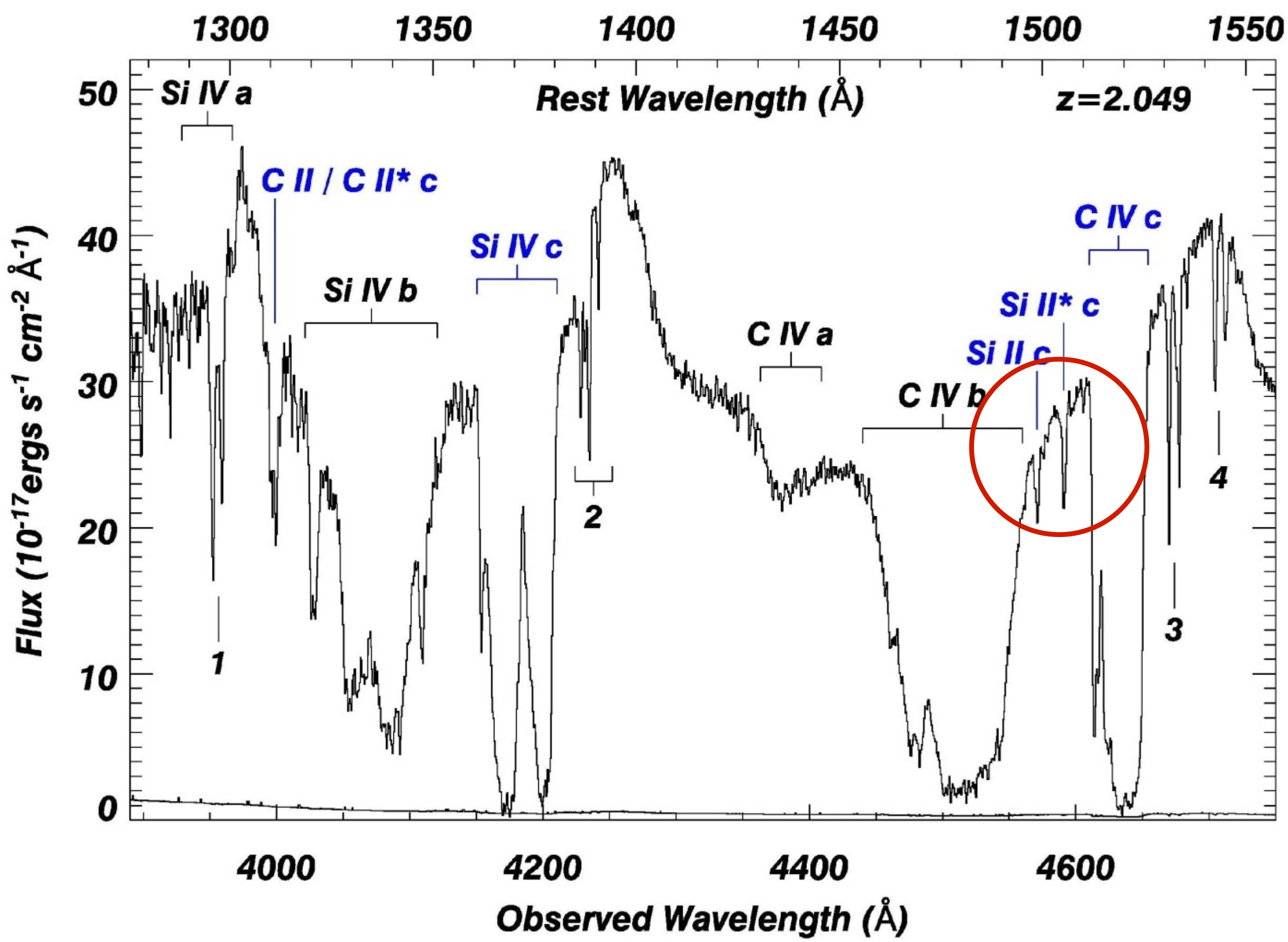
- Number Density via Troughs from metastable levels
- Fe II* UV1, UV2…; Si II* 1264, 1533…



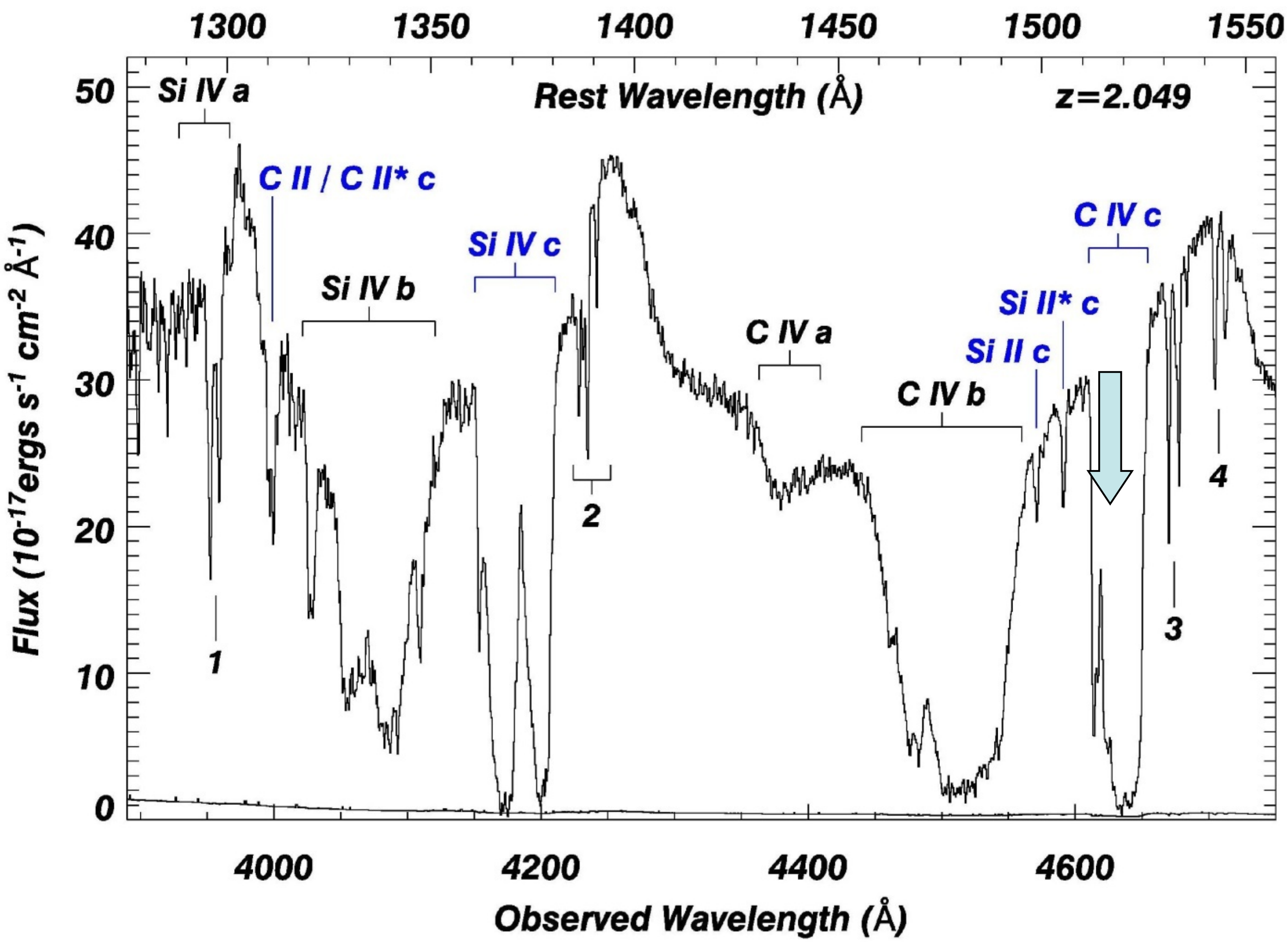
# What about the solid angle subtended by the wind?

20-40% of quasars show high ionization (C IV) winds $\rightarrow f \cong 0.2 - 0.4$

But only 20% of all outflows show low ionization species (Dai+ 2010)



# What is the full kinetic luminosity of the SDSS 0838+2955 outflow?



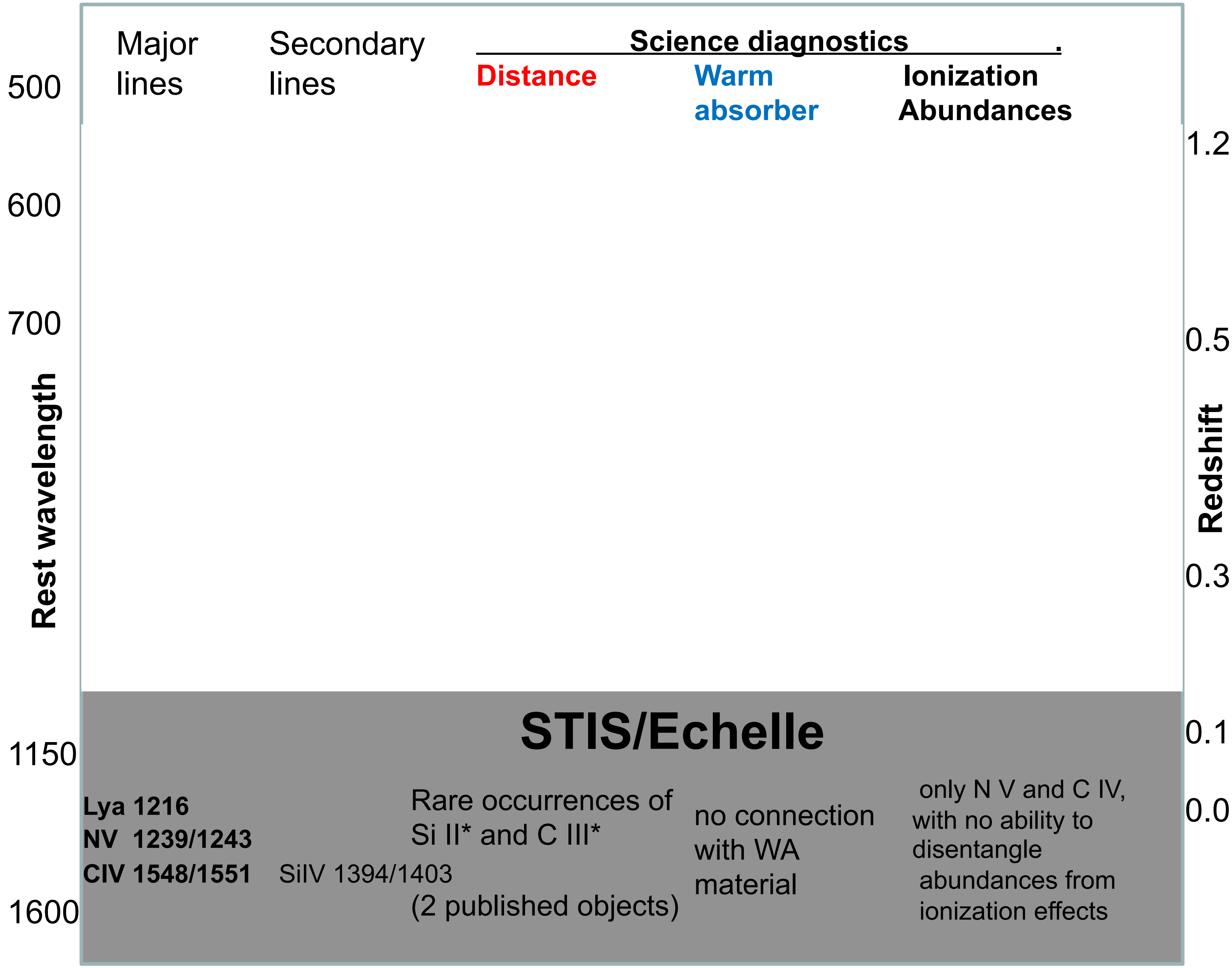
# Summery of problems

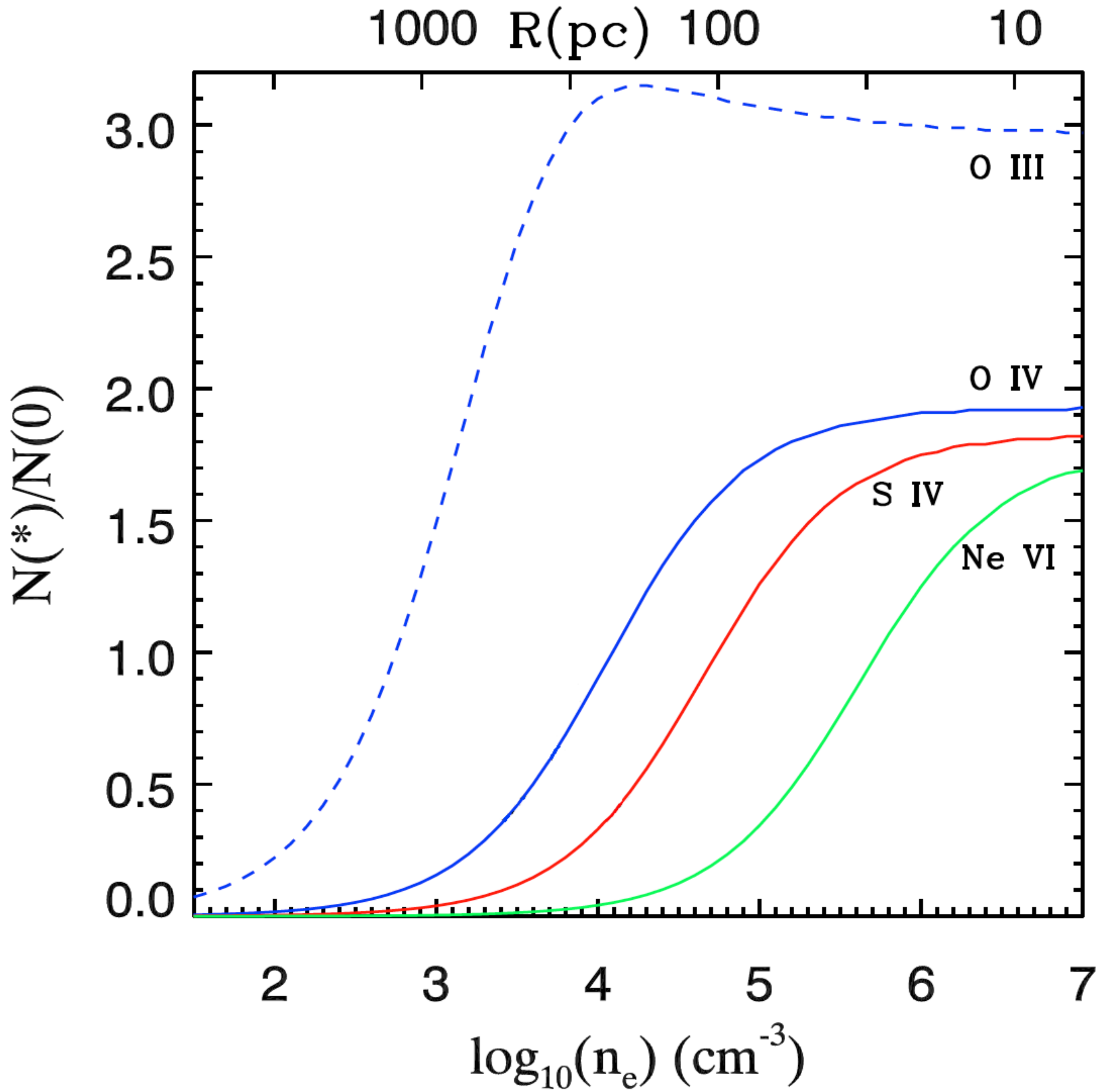
1. Longwards of 1150 AA (HST band), most excited troughs are observed from Singly ionized species (Fe II, Si II, C II), which appear in only 10% of the outflows **Problems**: Solid angle and relevance to high ionization are model dependent.

   (C III* is rare and kinematically undesirable and S IV* is rare )

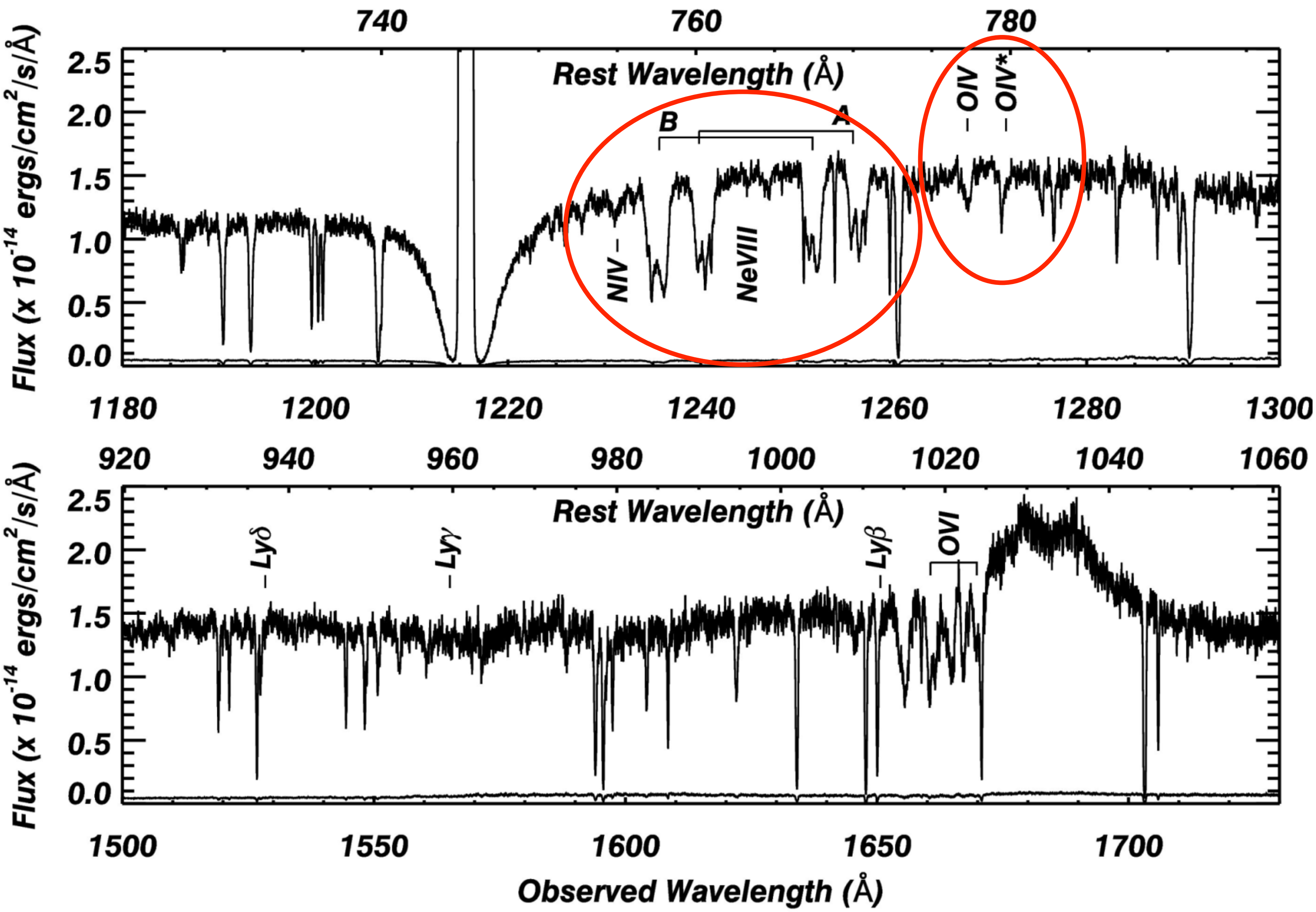
1. No Handle on the very high ionization phase that dominates $N_H$ in warm absorbers.

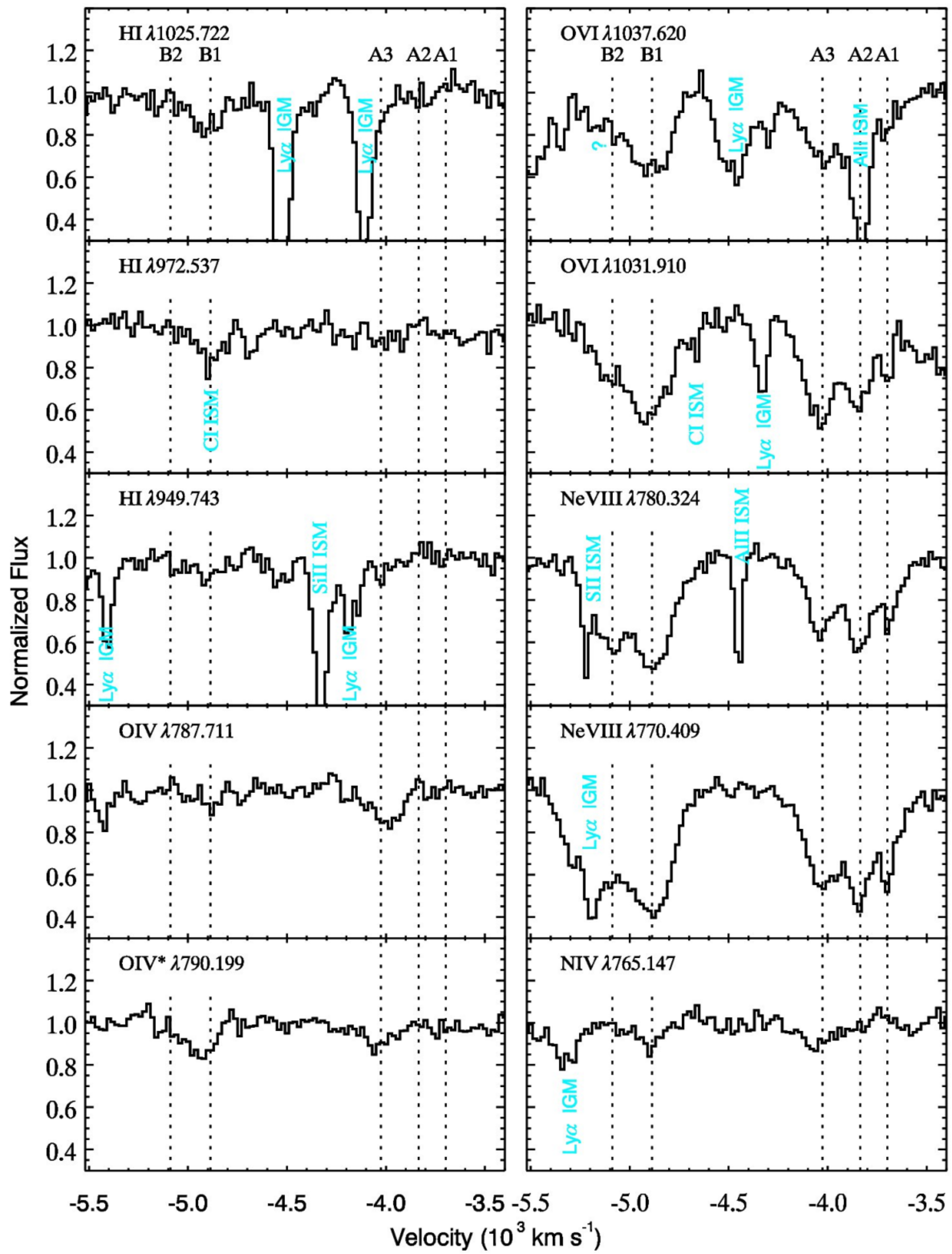
2. Difficulties in separating photoionization from abundances and dust depletion effects due to the lack of troughs from two or more ions from the same element.


Major lines
Secondary lines
Science diagnostics
Distance
Warm absorber
Ionization Abundances
500
600
700
Rest wavelength
1150
1600
1.2
0.5
Redshift
0.3
0.1
0.0
STIS/Echelle
Lya 1216
NV 1239/1243
CIV 1548/1551
SiIV 1394/1403
Rare occurrences of Si II* and C III*
(2 published objects)
no connection with WA material
only N V and C IV, with no ability to disentangle abundances from ionization effects

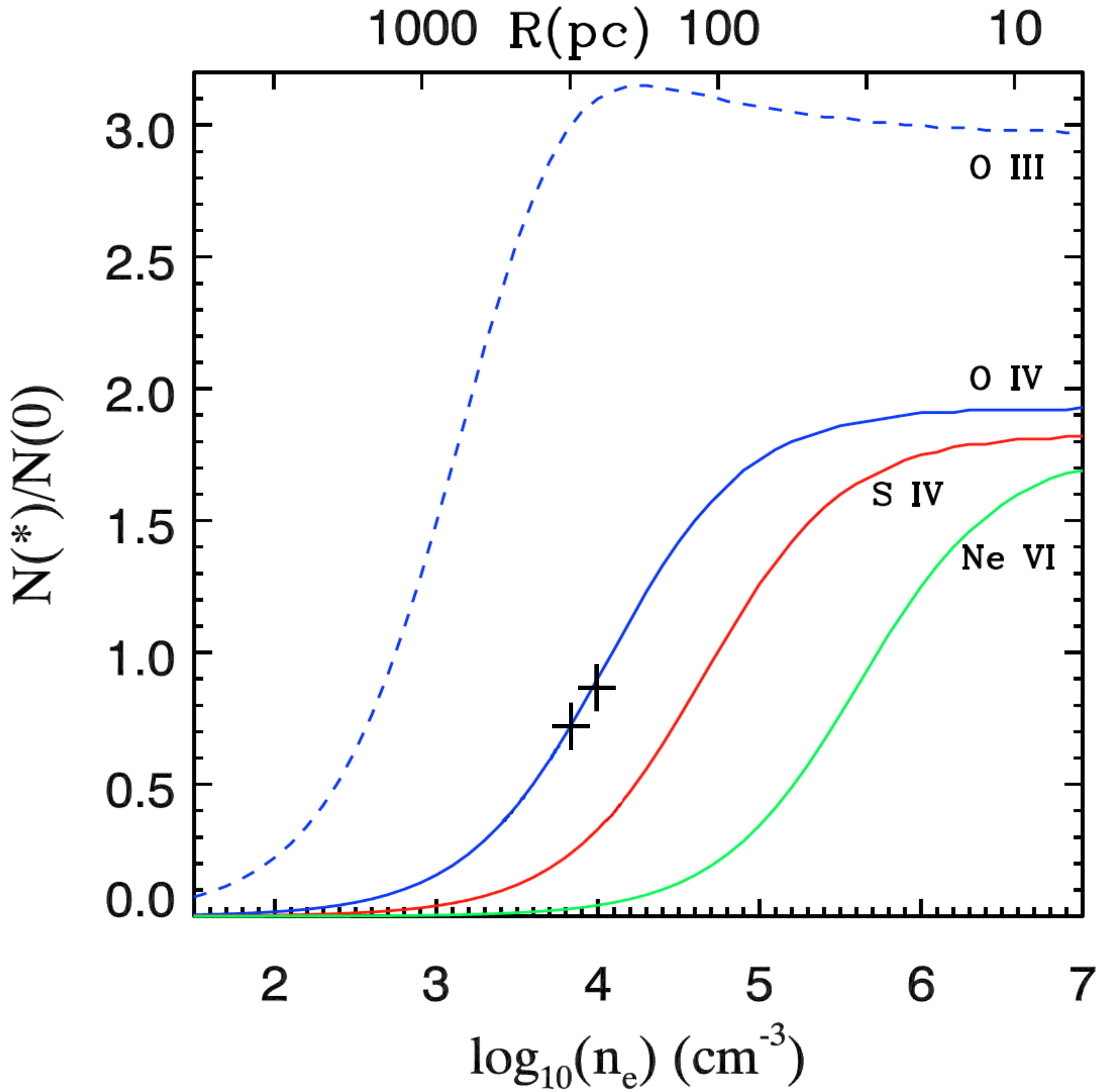

1000 R(pc) 100 10
3.0
2.5
2.0
1.5
1.0
0.5
0.0
N(*)/N(0)
O III
O IV
S IV
Ne VI
2 3 4 5 6 7
log10(ne) (cm-3)

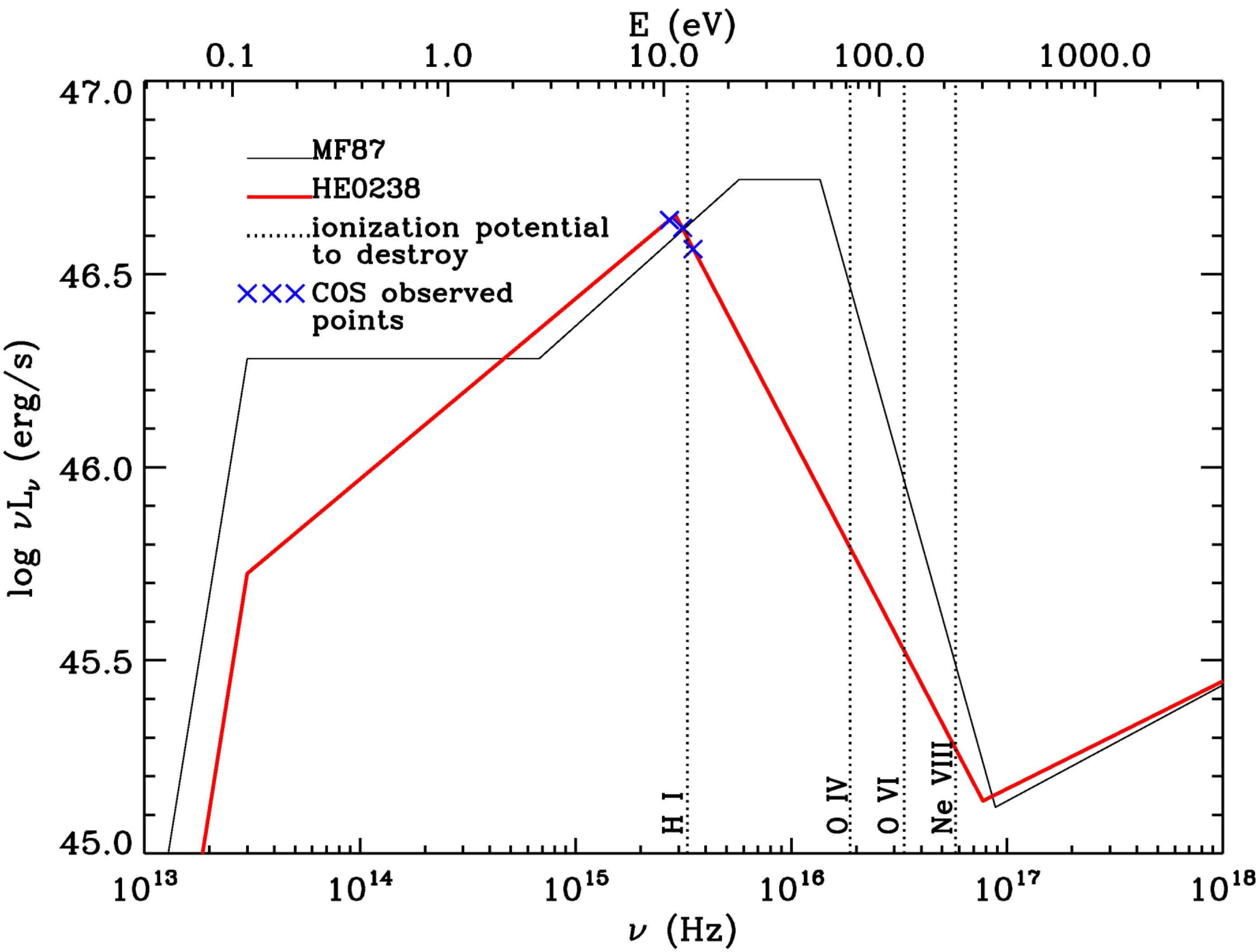
# Enter He0238-1914



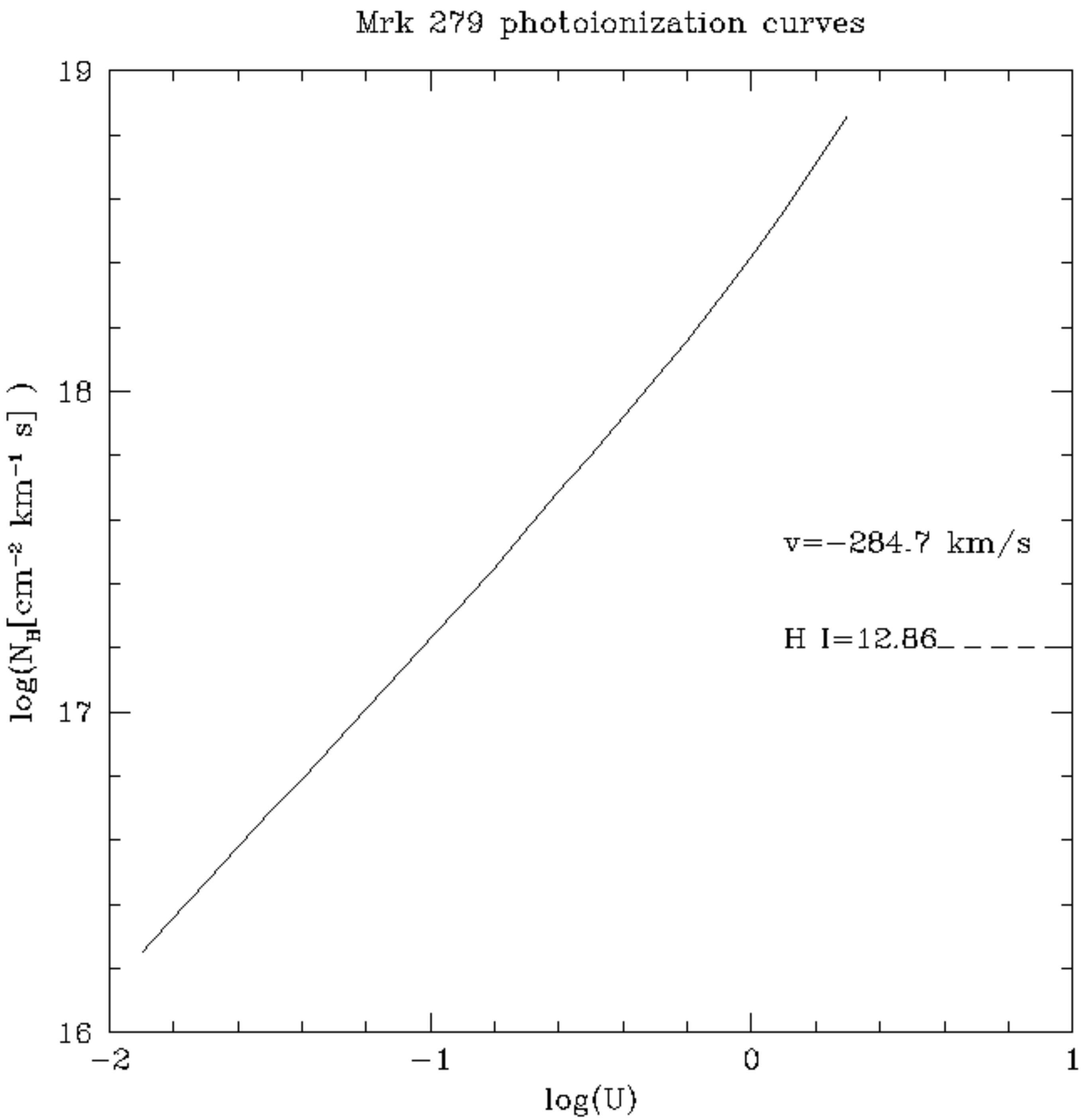


HI λ1025.722
HI λ972.537
HI λ949.743
OIV λ787.711
OIV* λ790.199
OVI λ1037.620
OVI λ1031.910
NeVIII λ780.324
NeVIII λ770.409
NIV λ765.147
B2 B1 A3 A2 A1
Lyα IGM
CI ISM
SiII ISM
AlII ISM
SII ISM
Normalized Flux
Velocity (10^3 km s^-1)

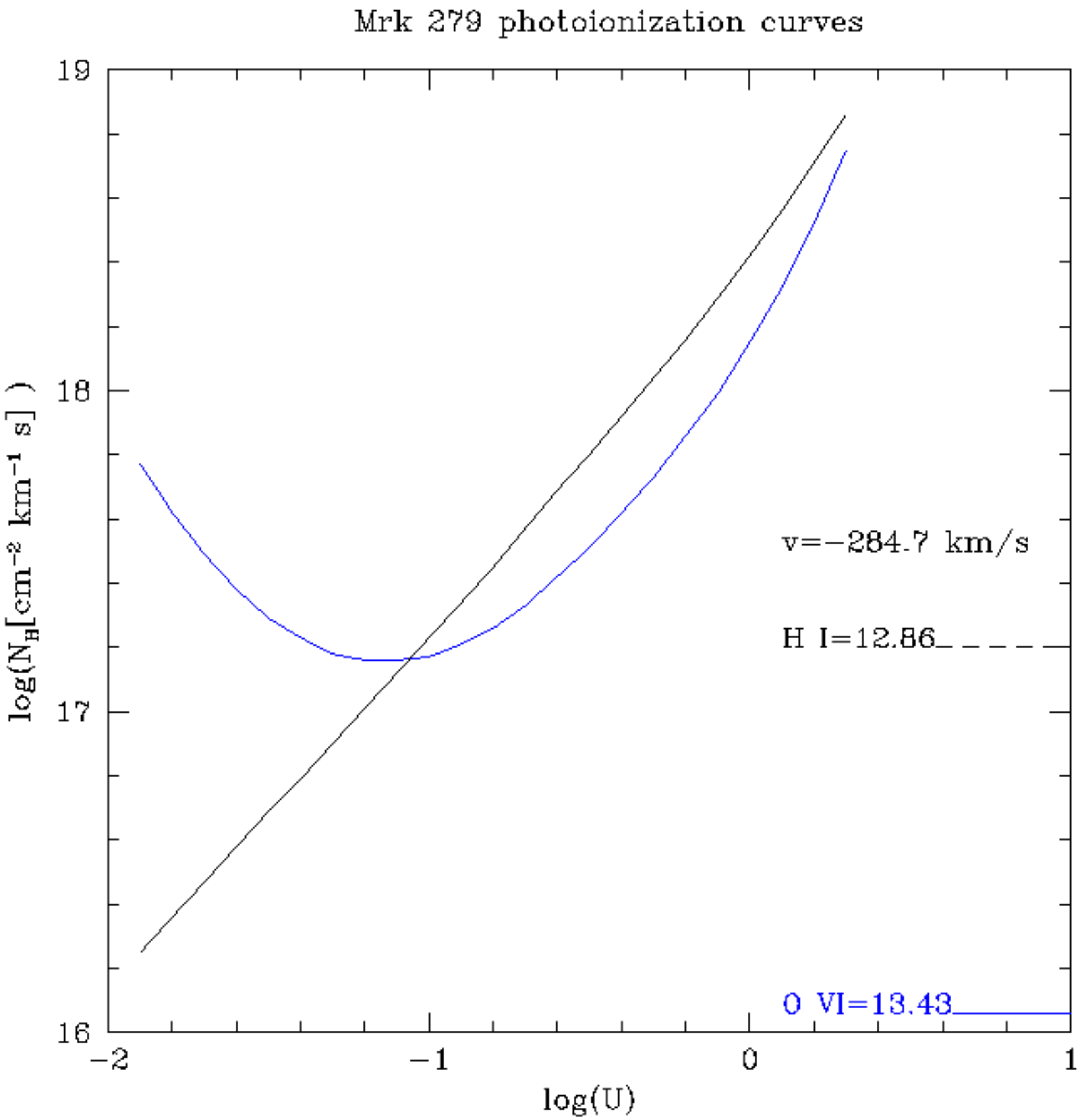

1000 R(pc) 100 10
3.0
2.5
2.0
1.5
1.0
0.5
0.0
N(*)/N(0)
O III
O IV
S IV
Ne VI
2 3 4 5 6 7
log10(ne) (cm-3)



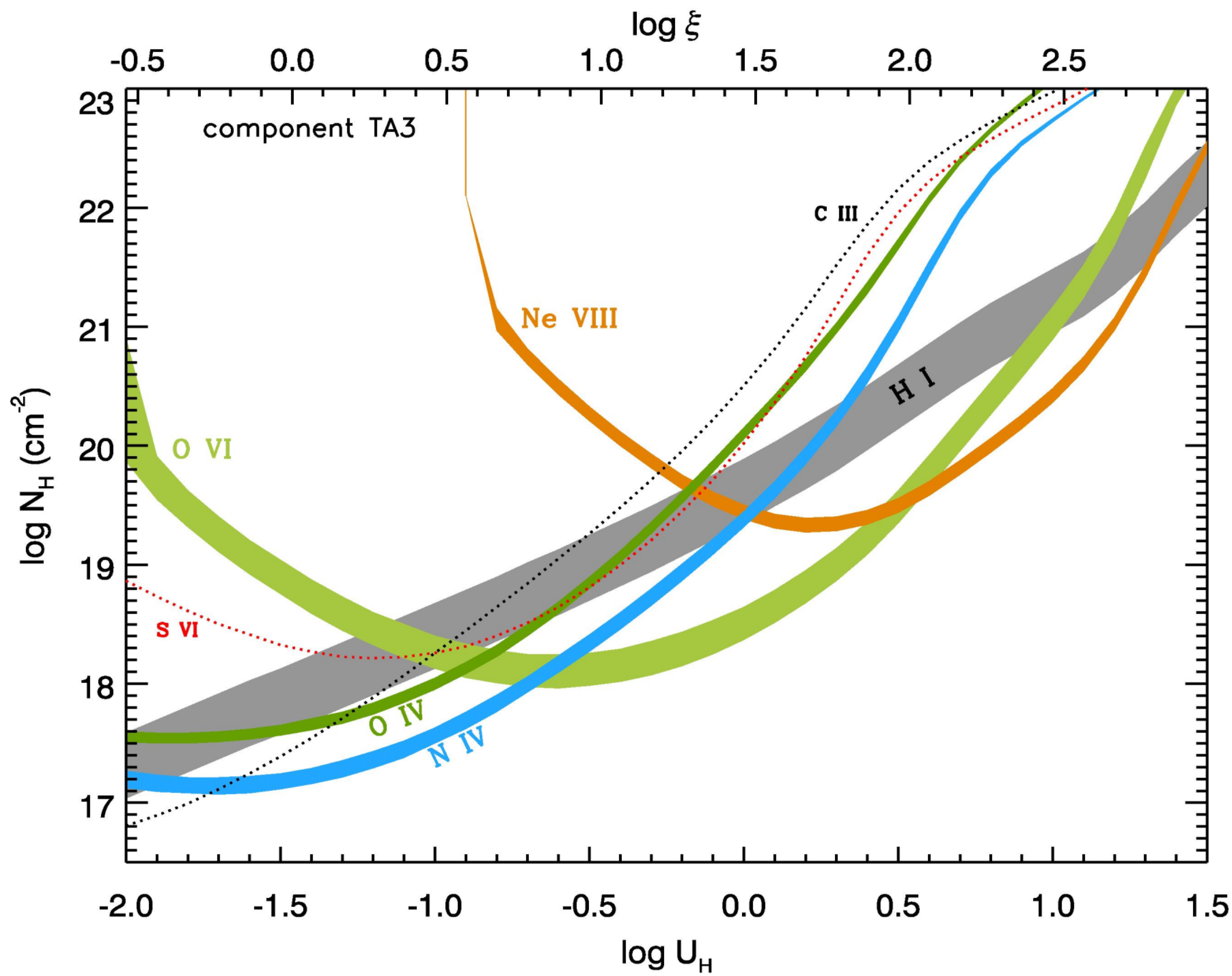
E (eV)
0.1
1.0
10.0
100.0
1000.0
47.0
46.5
46.0
45.5
45.0
log νL_ν (erg/s)
MF87
HE0238
ionization potential
to destroy
COS observed
points
H I
O IV
O VI
Ne VIII
10^13
10^14
10^15
10^16
10^17
10^18
ν (Hz)



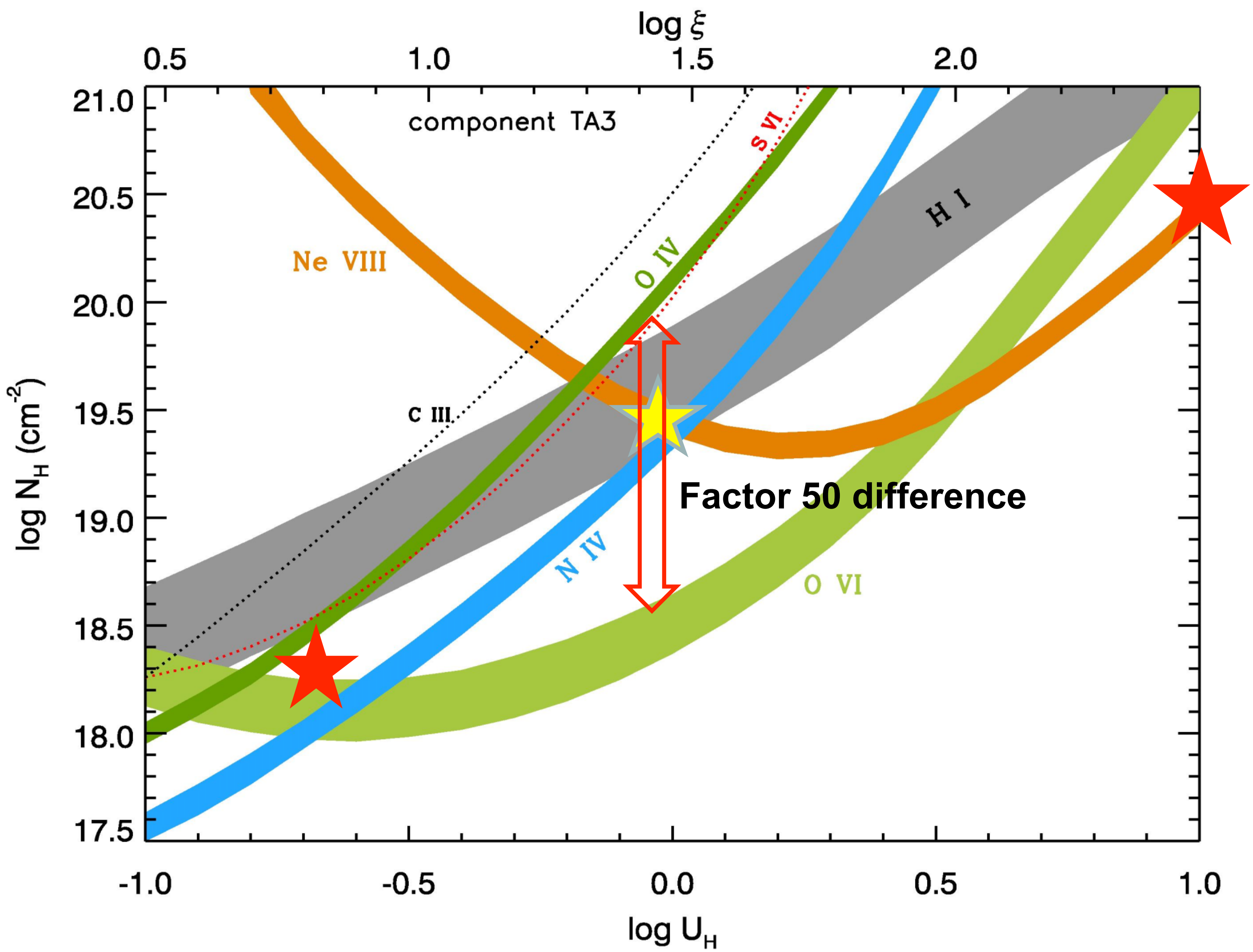
Mrk 279 photoionization curves
19
18
17
16
log(N_H[cm^-2 km^-1 s] )
-2
-1
0
1
log(U)
v=-284.7 km/s
H I=12.86



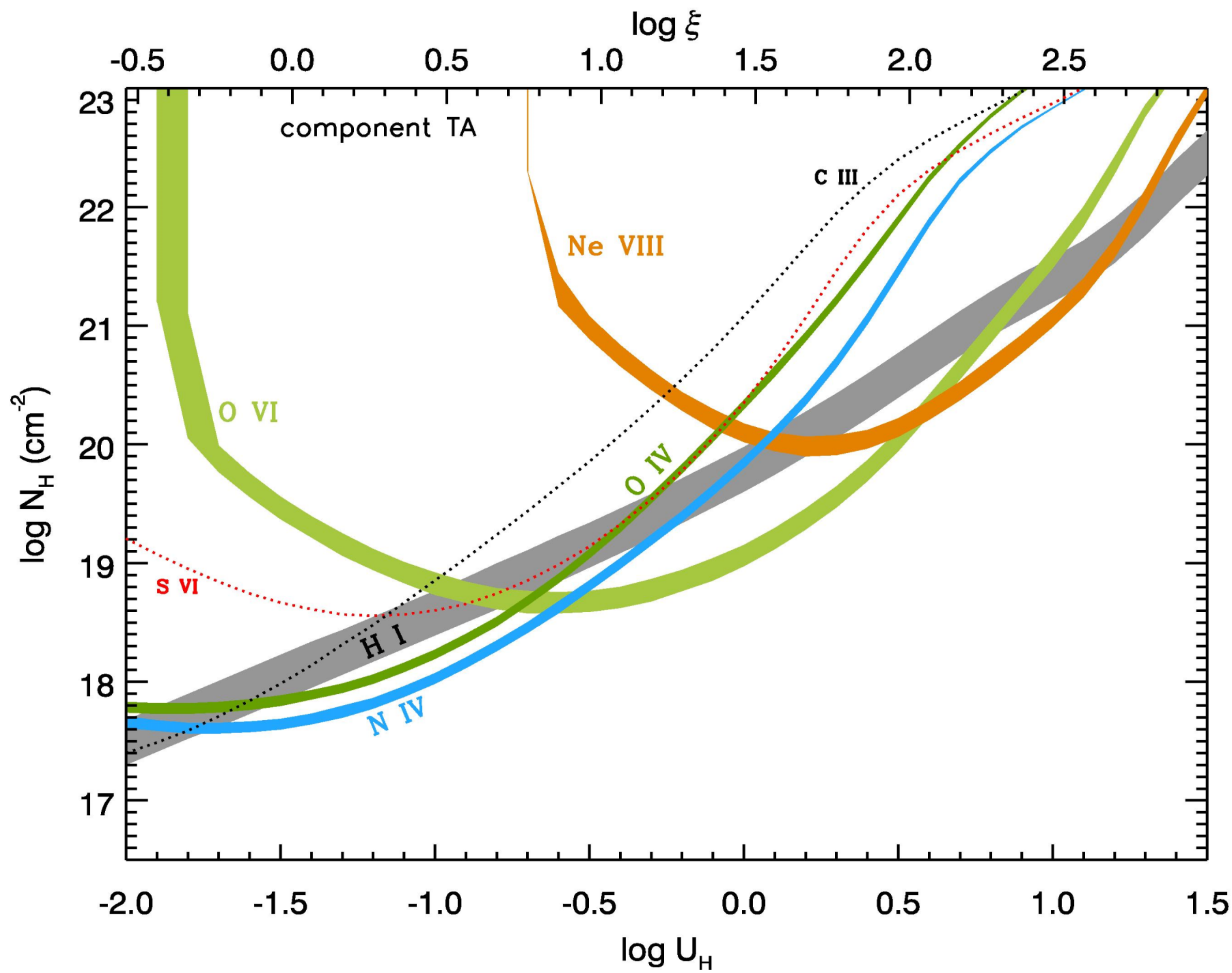
Mrk 279 photoionization curves
19
18
17
16
−2
−1
0
1
log(U)
log(N_H[cm^-2 km^-1 s] )
v=−284.7 km/s
H I=12.86
O VI=13.43



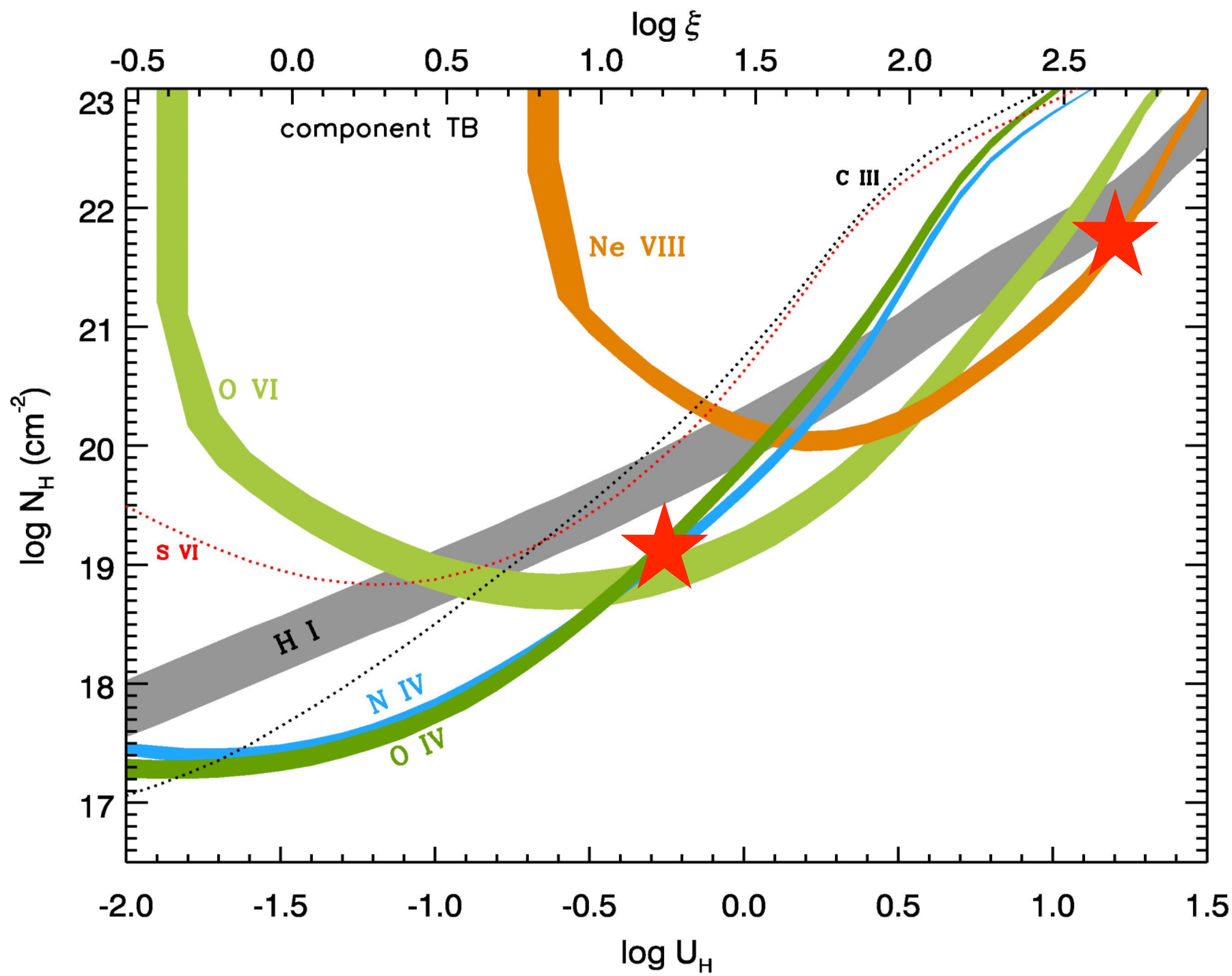
log ξ
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
component TA3
C III
Ne VIII
H I
O VI
S VI
O IV
N IV
log N_H (cm^-2)
23
22
21
20
19
18
17
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
log U_H



log ξ
0.5
1.0
1.5
2.0
21.0
20.5
20.0
19.5
19.0
18.5
18.0
17.5
log N_H (cm^-2)
component TA3
S VI
Ne VIII
O IV
H I
C III
Factor 50 difference
N IV
O VI
-1.0
-0.5
0.0
0.5
1.0
log U_H

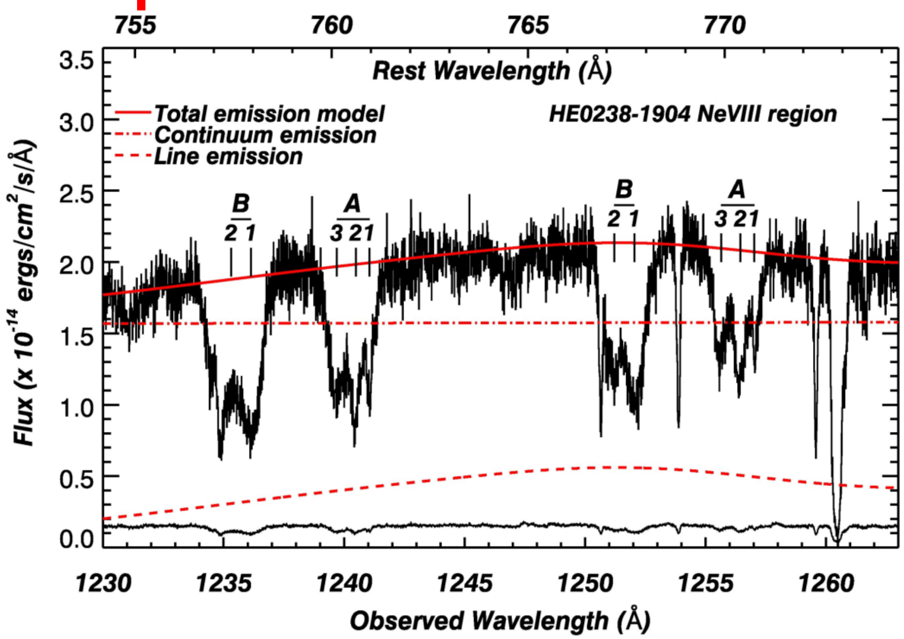


log ξ
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
component TA
C III
Ne VIII
O VI
O IV
S VI
H I
N IV
23
22
21
20
19
18
17
log N_H (cm^-2)
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
log U_H

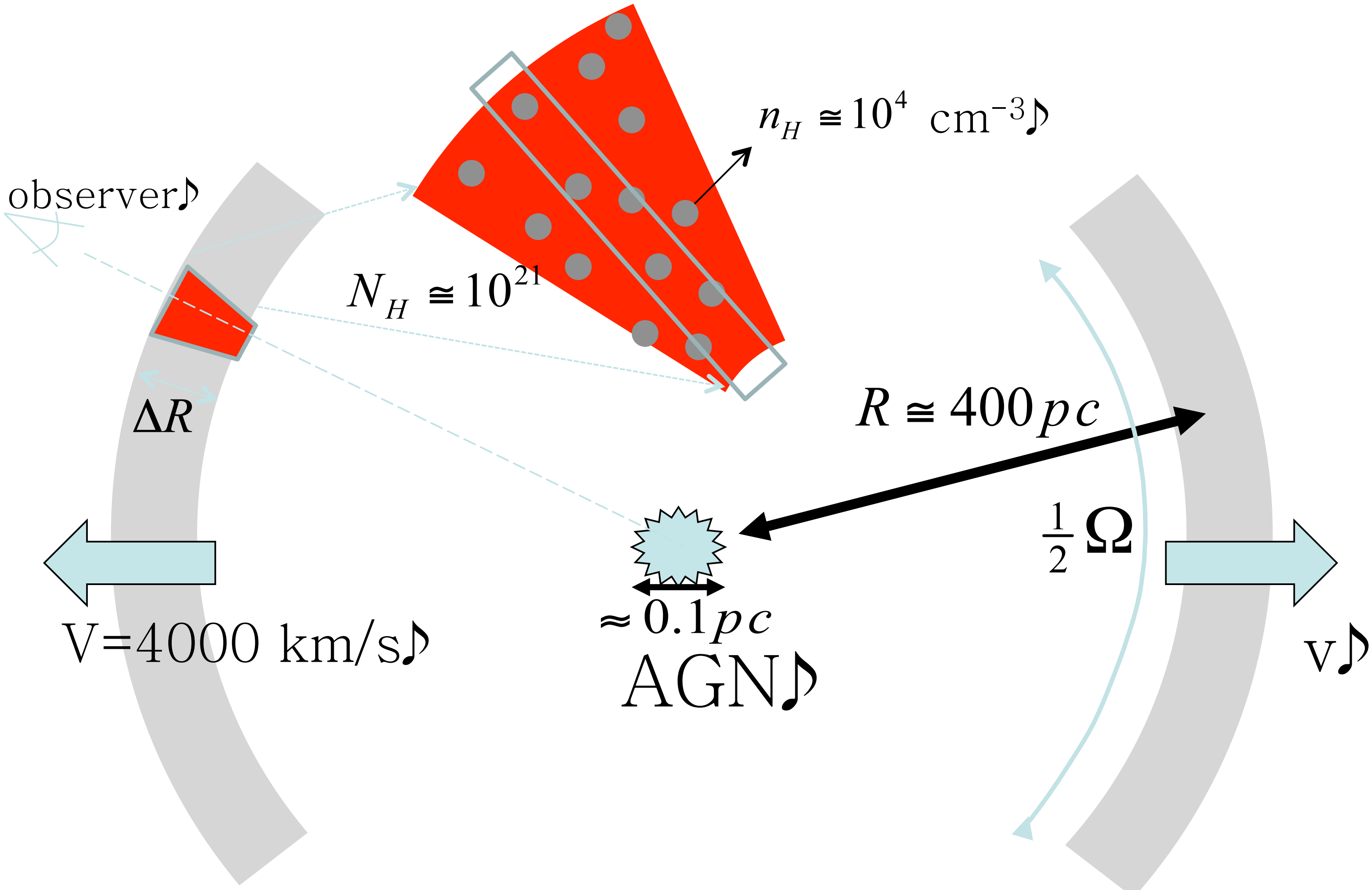


log ξ
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
component TB
C III
Ne VIII
O VI
S VI
H I
N IV
O IV
23
22
21
20
19
18
17
log $N_H$ ($cm^{-2}$)
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
log $U_H$

# Physical parameters of the outflow



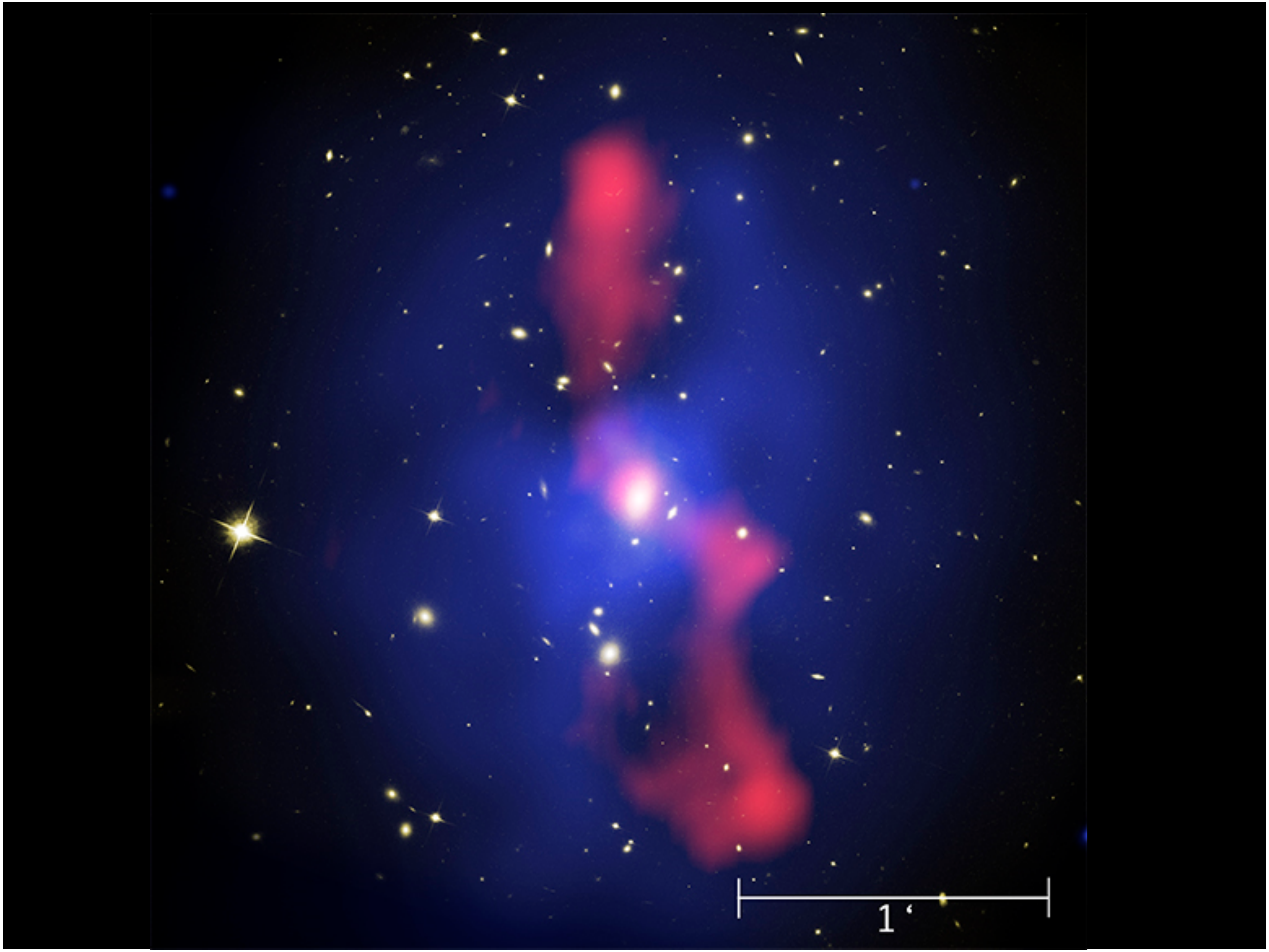

| | Log ($n_e$) | R(pc) | $M_{dot}$ | $L_k$ $10^{44}$ erg/s | v km/s |
|---|---|---|---|---|---|
| A | 4.0 | 400 | 70 | 5 | 4000 |
| B | 3.9 | 300 | 100 | 12 | 5000 |



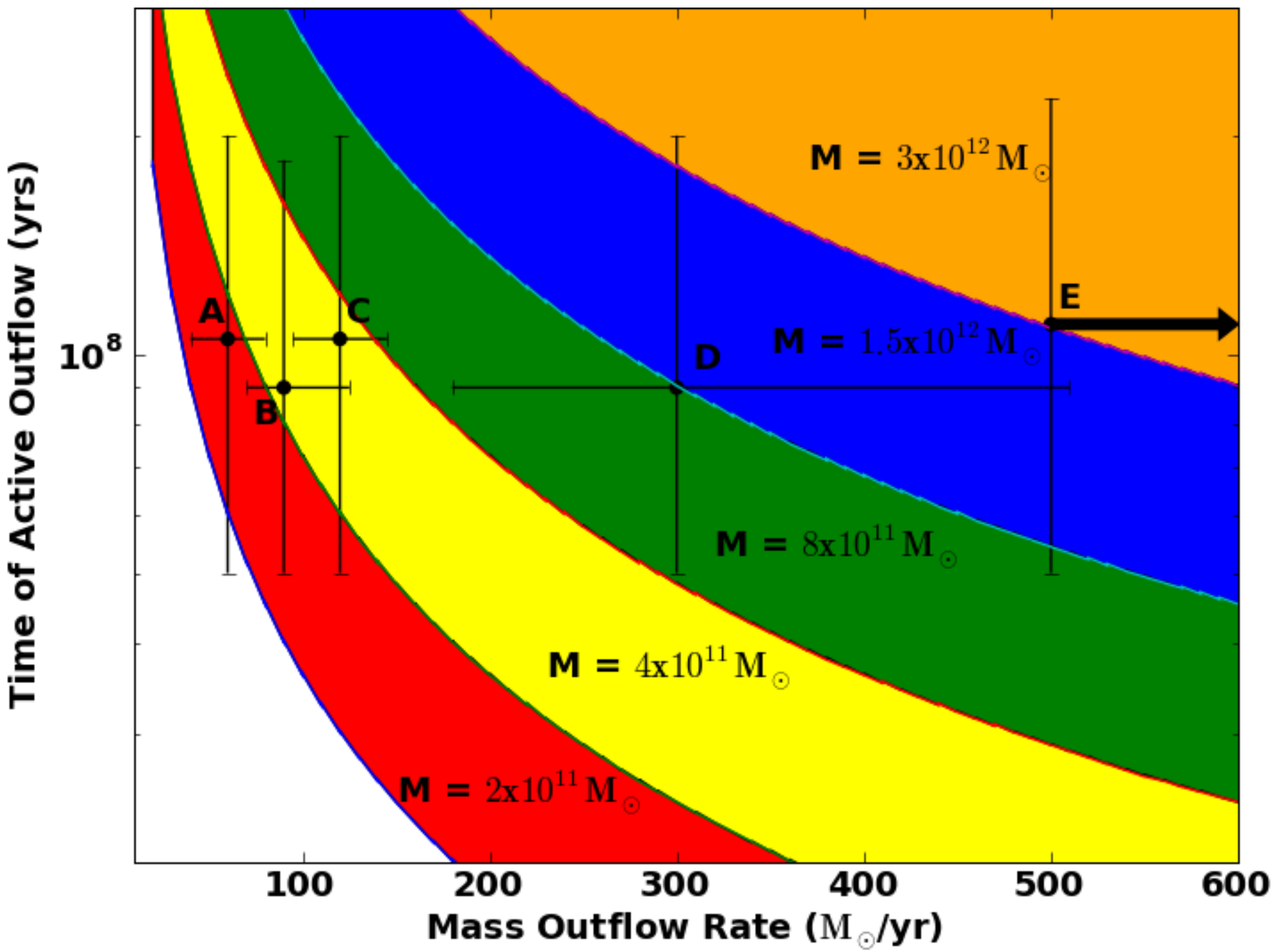
$n_H \cong 10^4$ cm$^{-3}$♪
observer♪
$N_H \cong 10^{21}$
$\Delta R$
$R \cong 400\,pc$
$\frac{1}{2}\Omega$
$\approx 0.1\,pc$
V=4000 km/s♪
AGN♪
v♪

# Consequences for AGN feedback

- Over $10^8$ years quasar duty cycle, such kinetic luminosity ($2x10^{45}$ ergs/s) will yield a total kinetic energy of $10^{61}$ ergs. Enough to inflate the largest observed X-ray bubbles.


1 ‘

# Intracluster chemical enrichment (Eric Hellman, Harvard)♪



# Summary

Quasar outflows are a major component of AGN feedback, reaching kinetic luminosities of a few percent of $L_{BOL,}$ with mass flux of hundreds of solar masses per year.

Due to their larger opening angle and higher mass fluxes, absorption outflows may be more efficient for AGN feedback processes than AGN jets.

**COS targeting objects at $0.5<z<1.5$ eliminate the solid angle issue and allow to measure the high ionization phase**

$$\dot{M} = 4\pi f R^2 \rho v = 4\pi f R^2 n_H 1.4 m_p v \;=\; 4\pi f \frac{L}{\xi} 1.4 m_p v V_{ff}$$

$$n_H V_{ff}$$

$$\xi = \frac{L}{n_H R^2}$$

$$1 \geq V_{ff} > 10^{-6}$$