Kinetic Luminosity of Quasar Outflows and its Implications to AGN Feedback: HST/COS Observations

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The average luminous quasar
Has sub-relativistic outflows with:

- **Large scale (~1000 pc.)**
- **Large mass flow (100 $M_\odot$/yr)**
- **Kinetic luminosity sufficient for AGN feedback processes**

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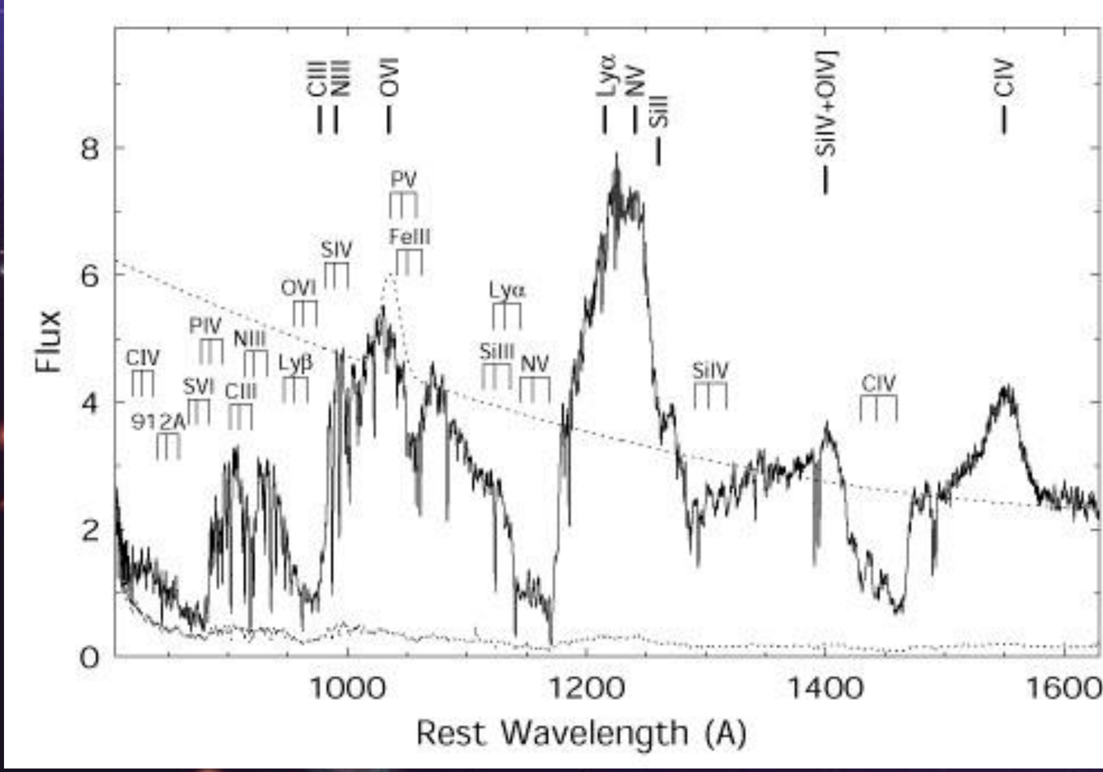
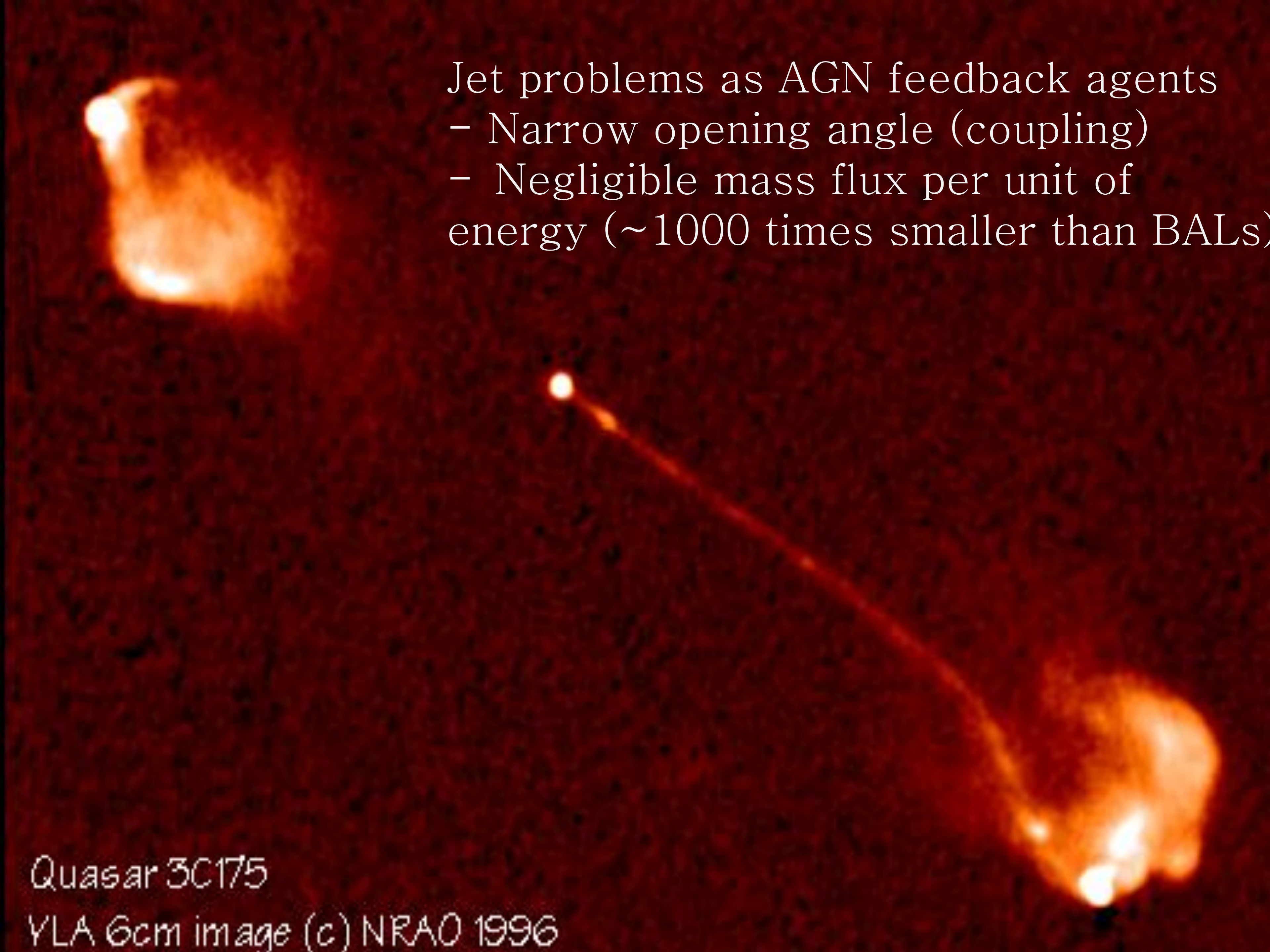


Jet problems as AGN feedback agents

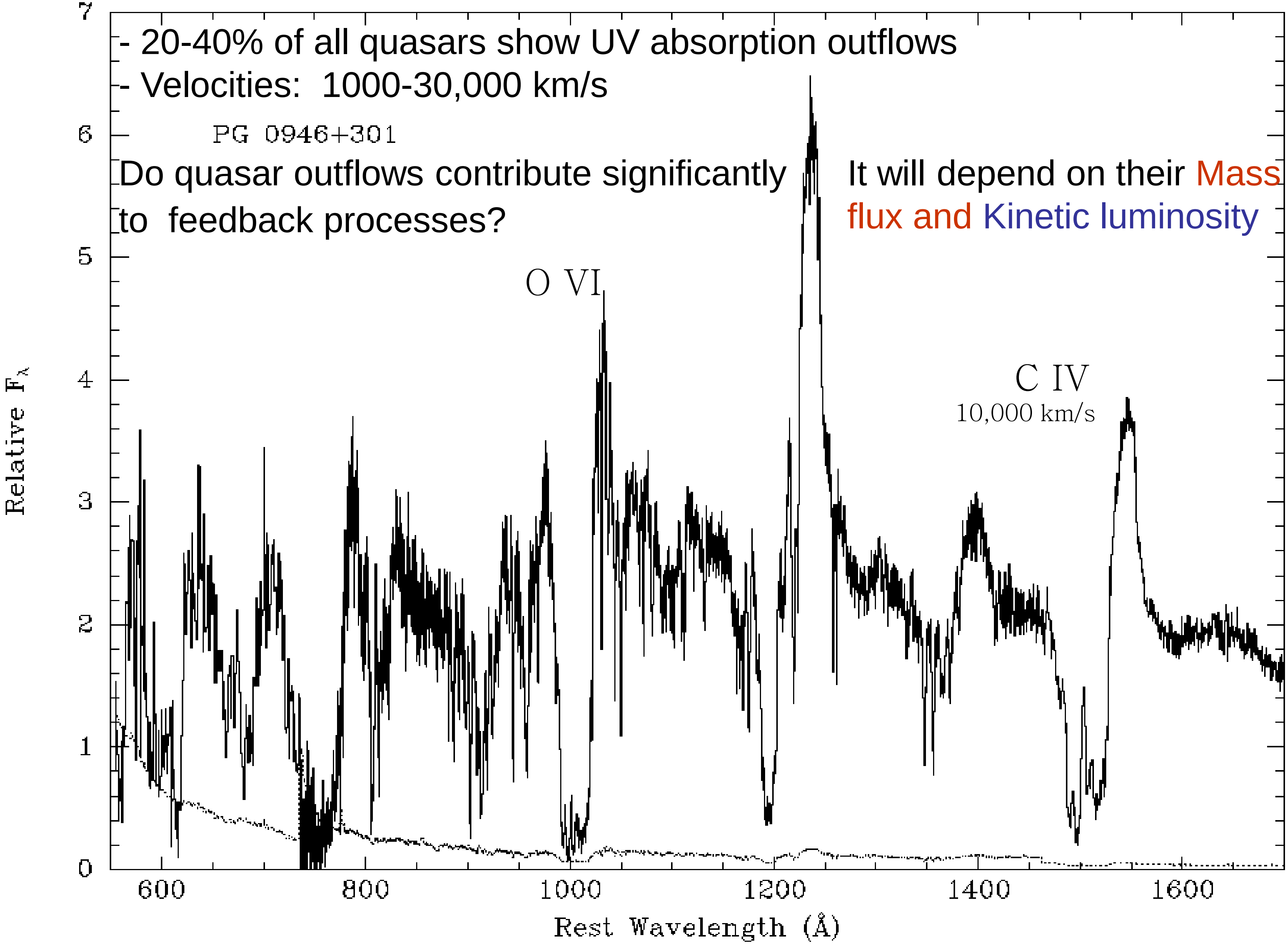
- Narrow opening angle (coupling)
- Negligible mass flux per unit of energy (~1000 times smaller than BALs)

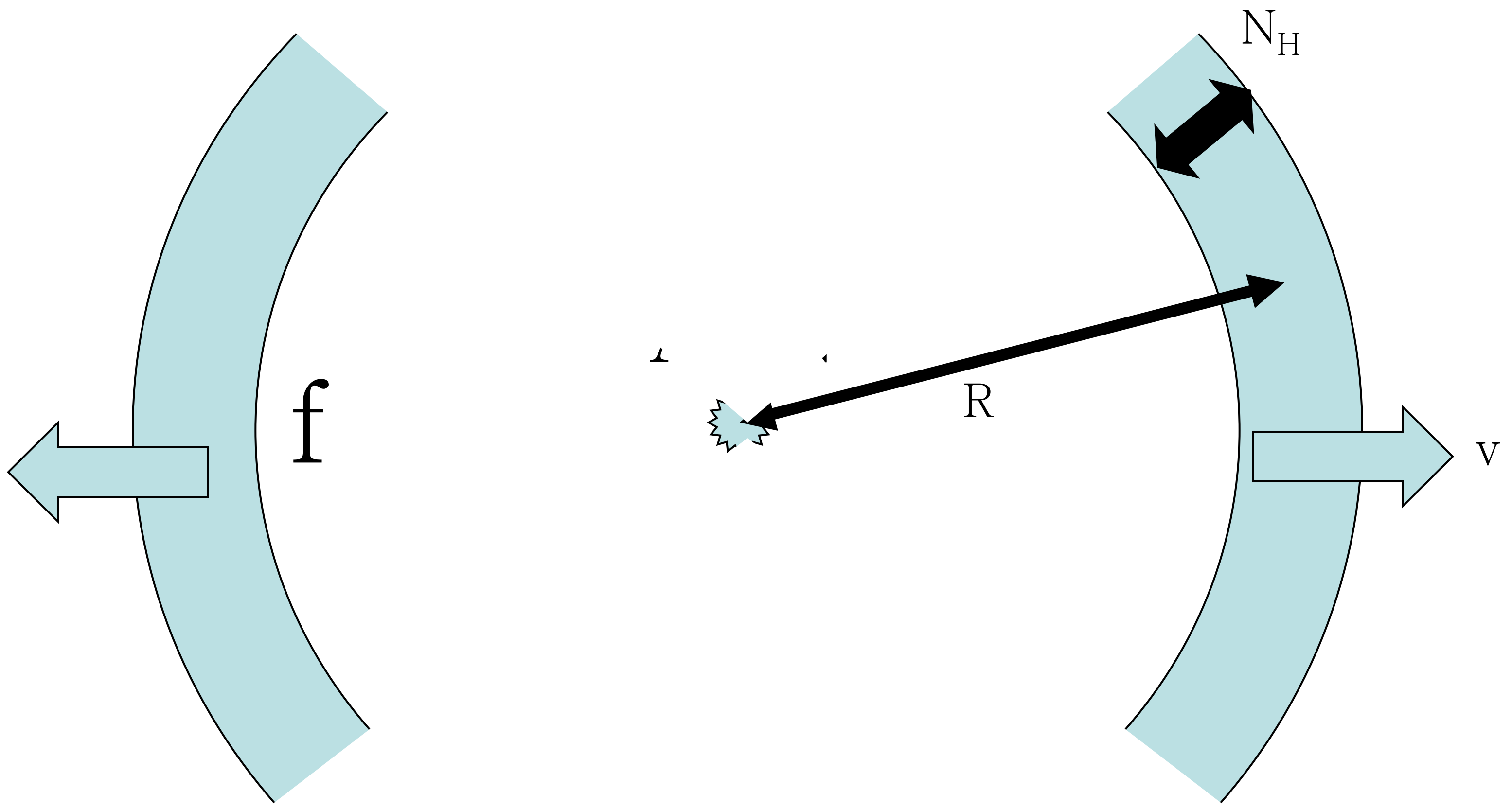


- 20-40% of all quasars show UV absorption outflows
- Velocities: 1000-30,000 km/s

Do quasar outflows contribute significantly to feedback processes?

It will depend on their Mass flux and Kinetic luminosity





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 about 5 years ago:

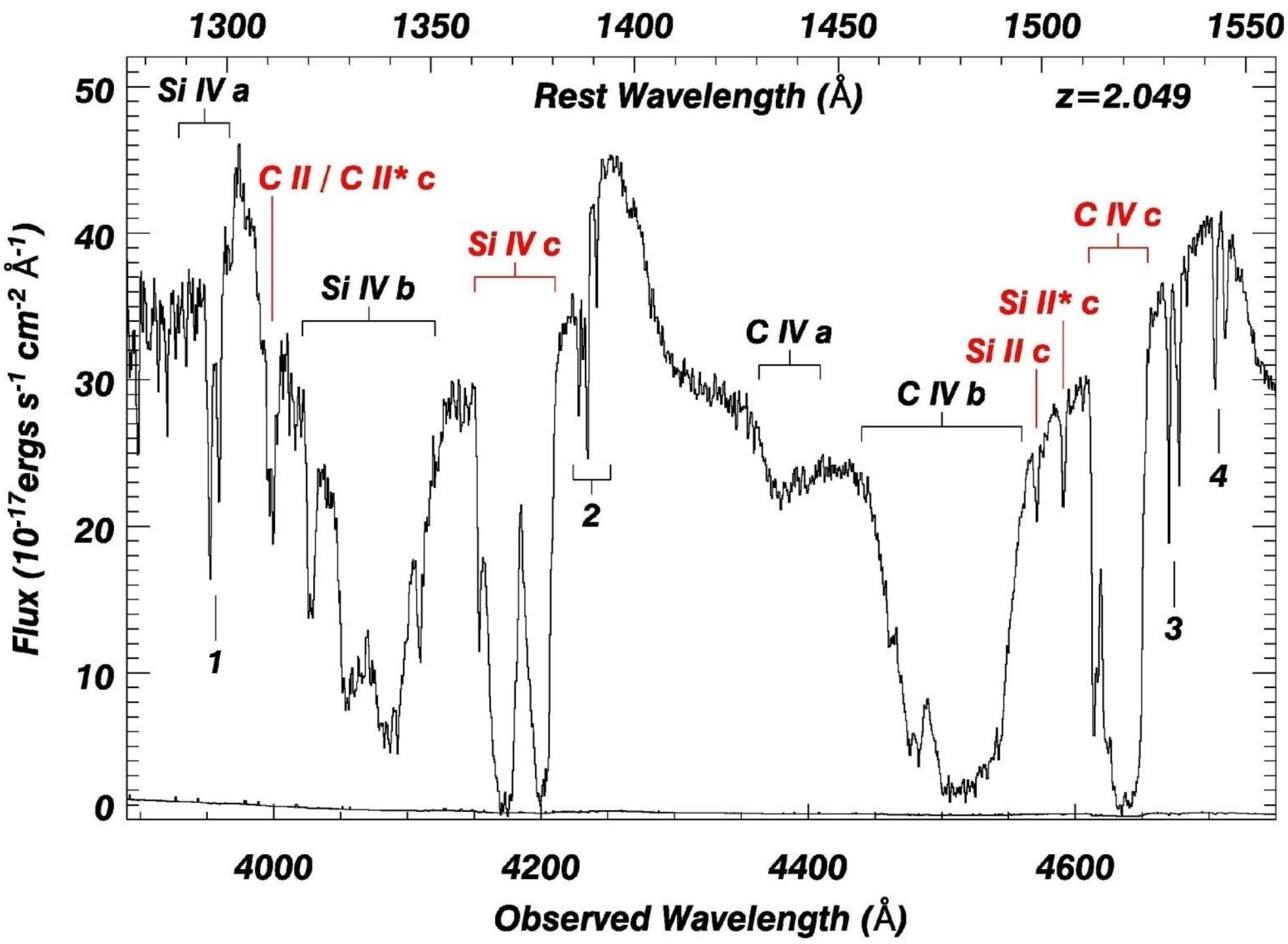
$$N_H \approx 10^{20-24} cm^{-2}$$

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

$$f \approx 0.2$$

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

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… (see also poster by Doug Edmonds)

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 moderate 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

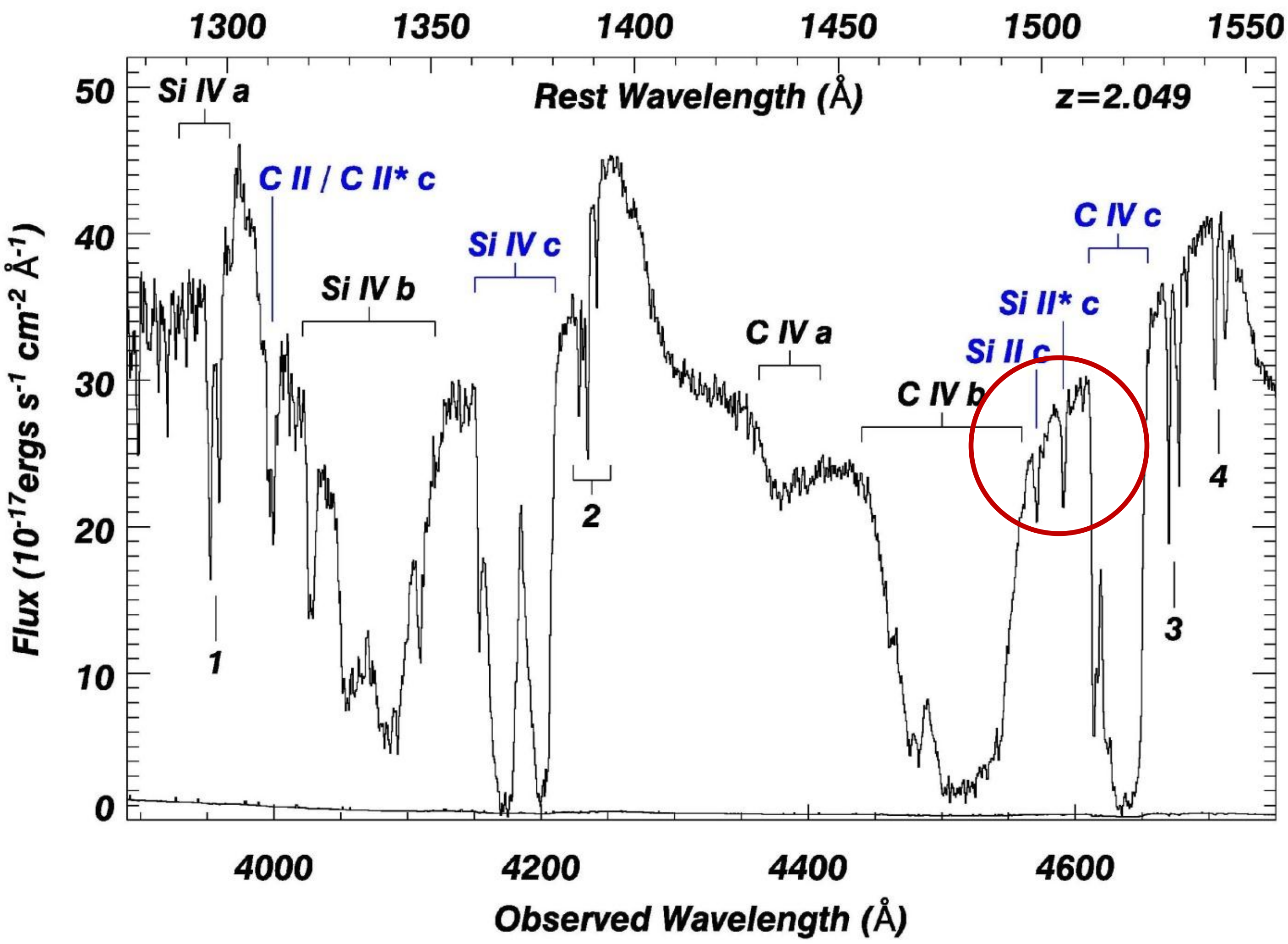
Less than 40% statistical error

AGN feedback models need kinetic luminosity ~0.5-5%LBOL

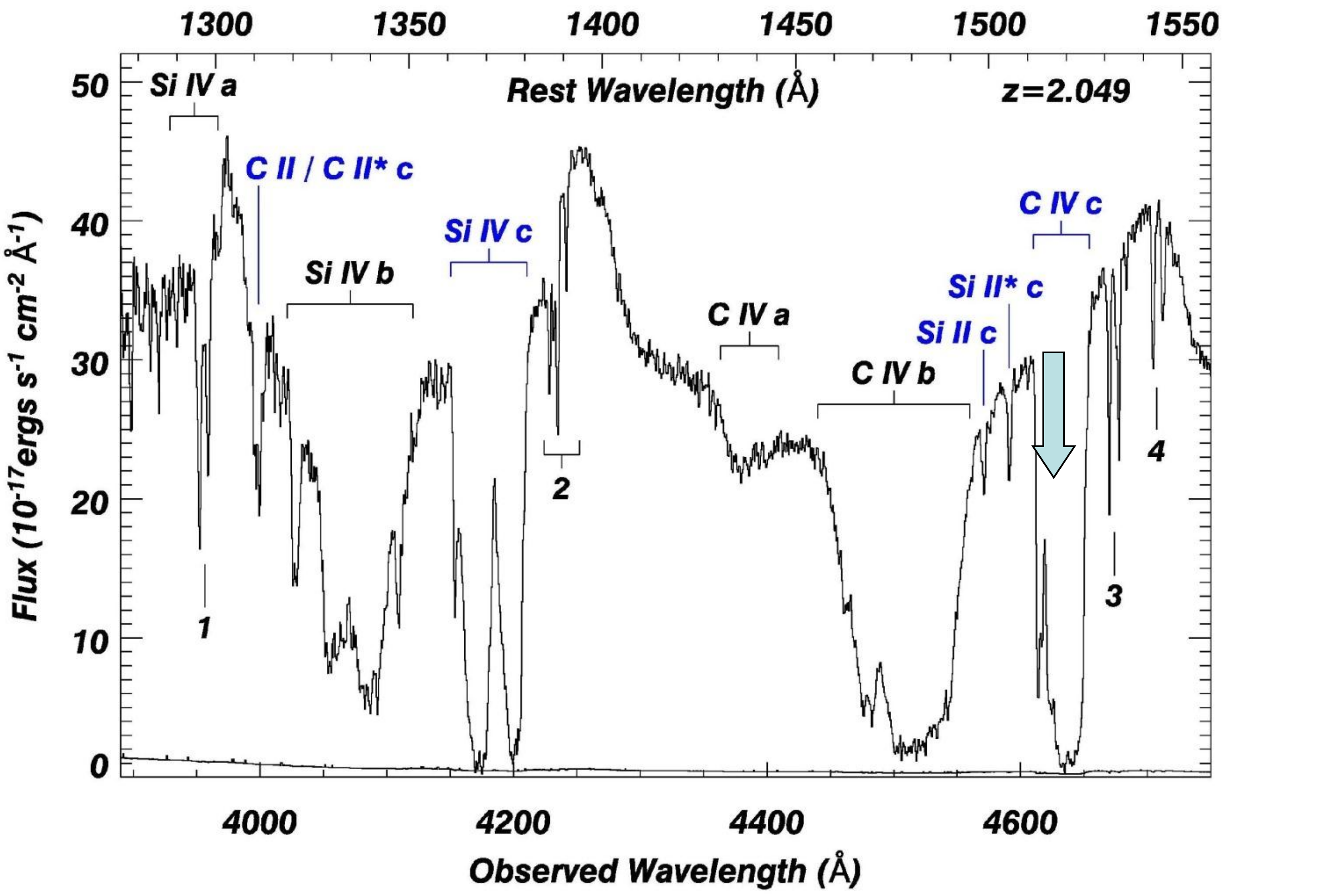
What about the solid angle subtended by the wind?

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 see poster by Benoit Borguet)

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

3. 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.

Rest wavelength: 500, 600, 700, 1150, 1600

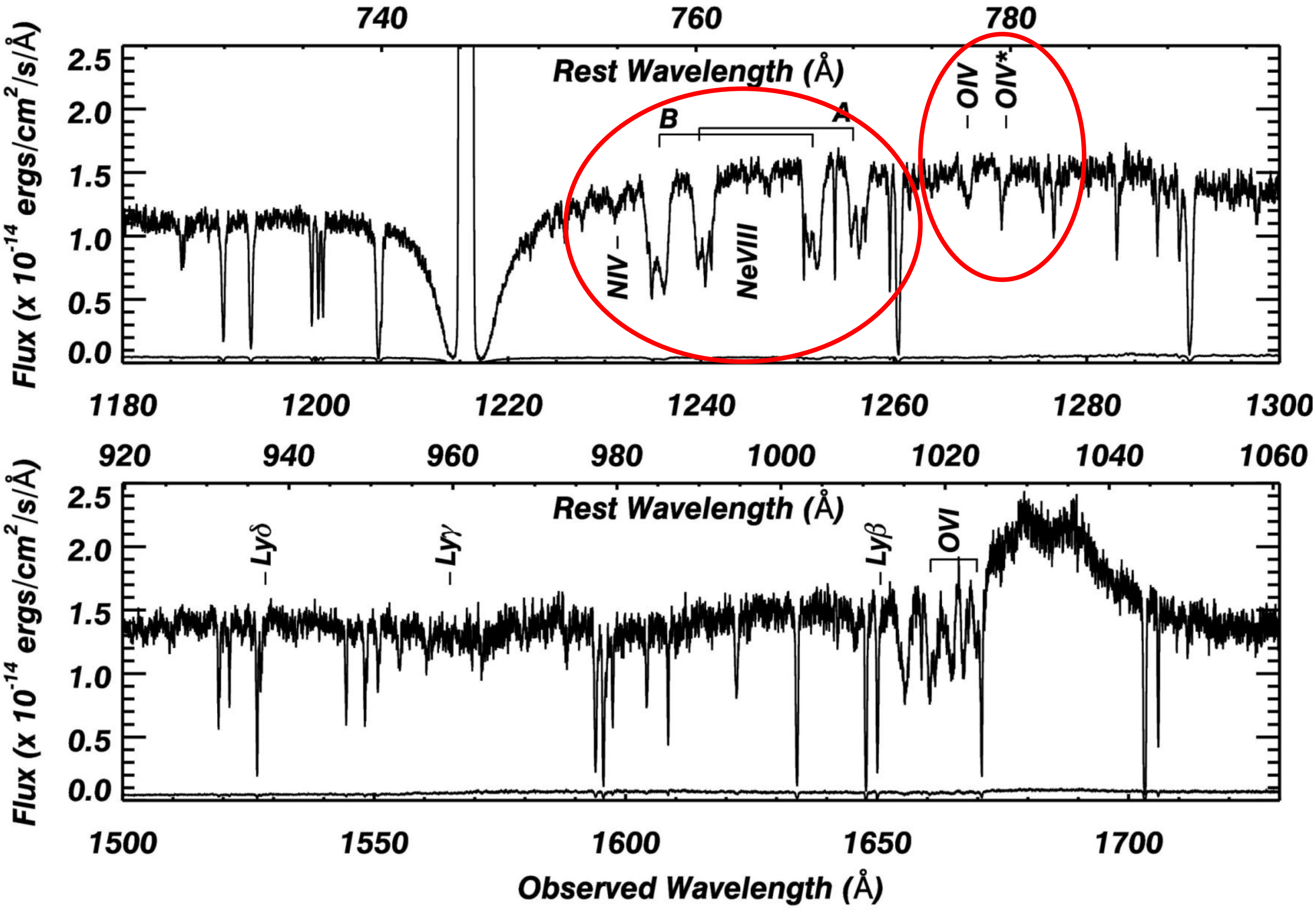
Redshift: 1.2, 0.5, 0.3, 0.1, 0.0

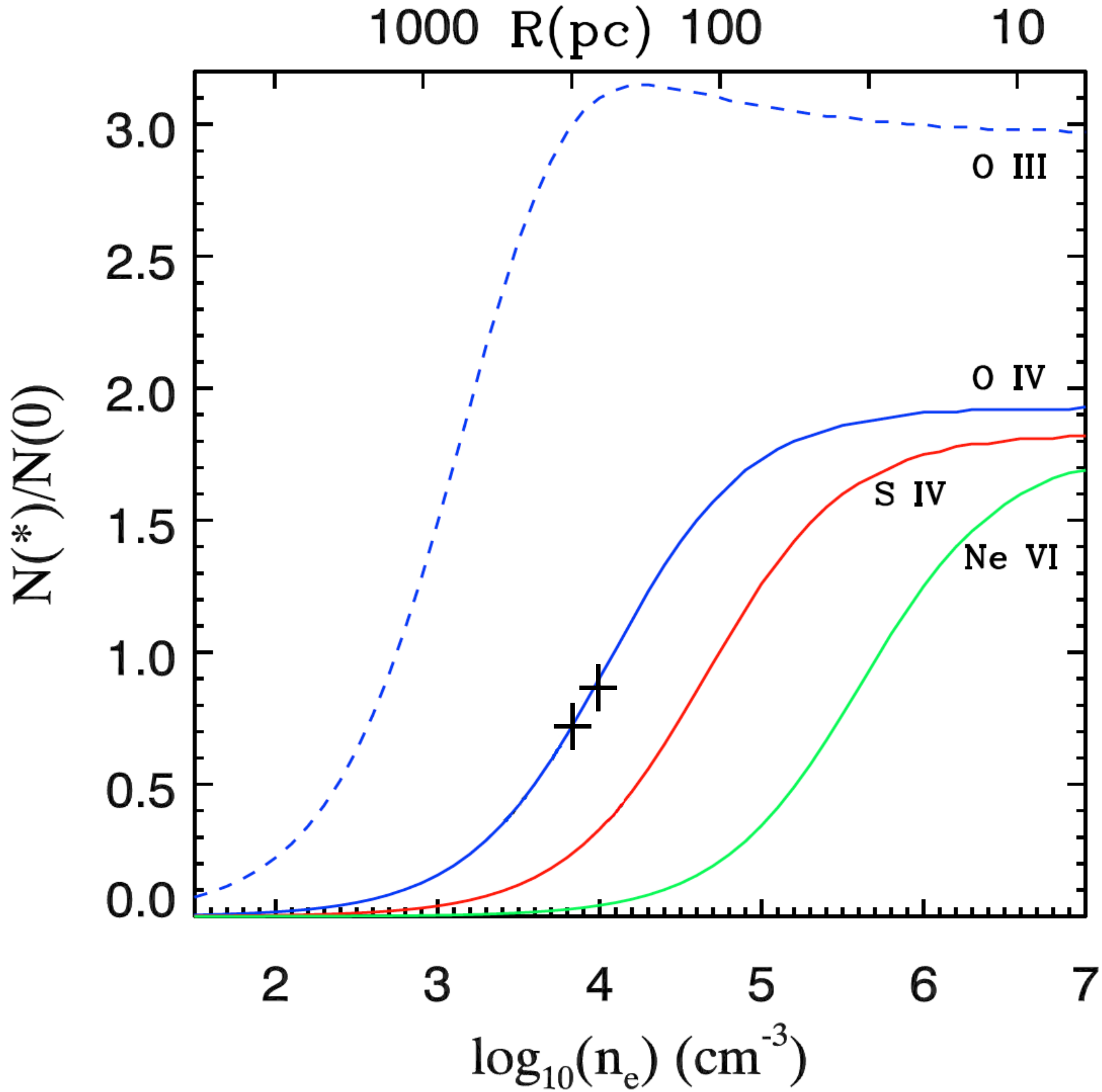
Major lines	Secondary lines	Science diagnostics: **Distance**	**Warm absorber**	**Ionization Abundances**

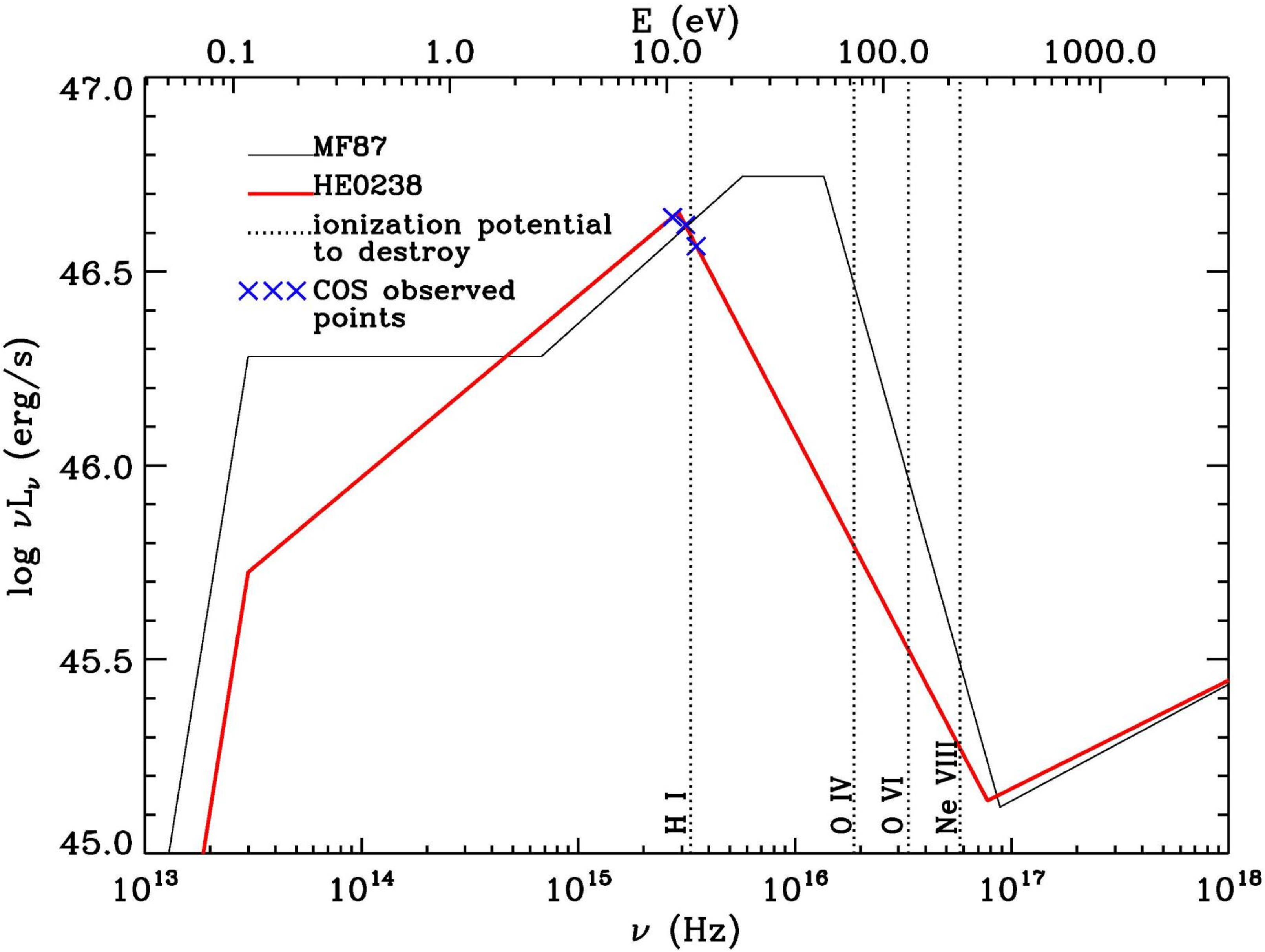
STIS/Echelle

Major lines	Secondary lines	Distance	Warm absorber	Ionization Abundances
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

Enter He0238-1914

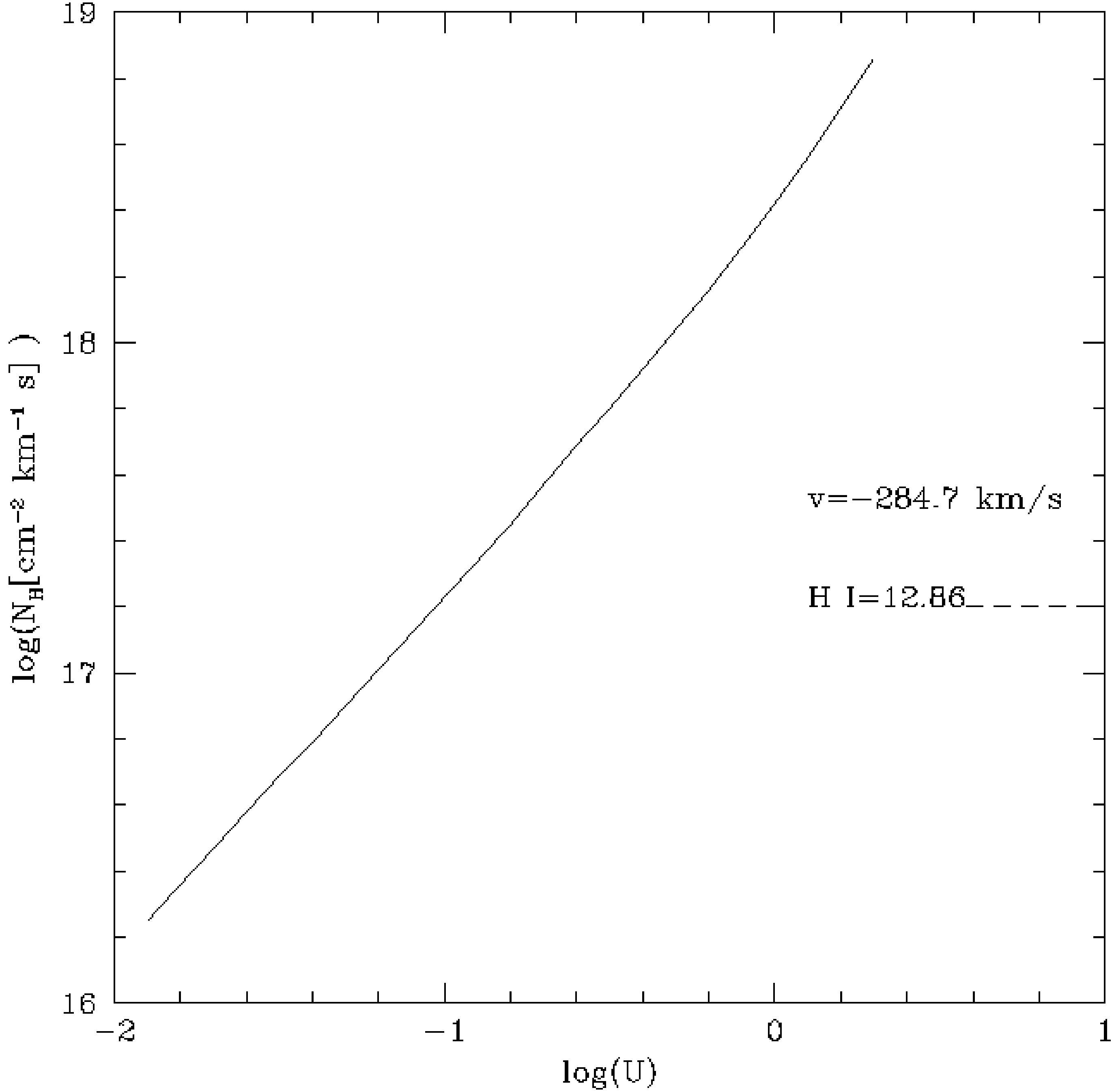


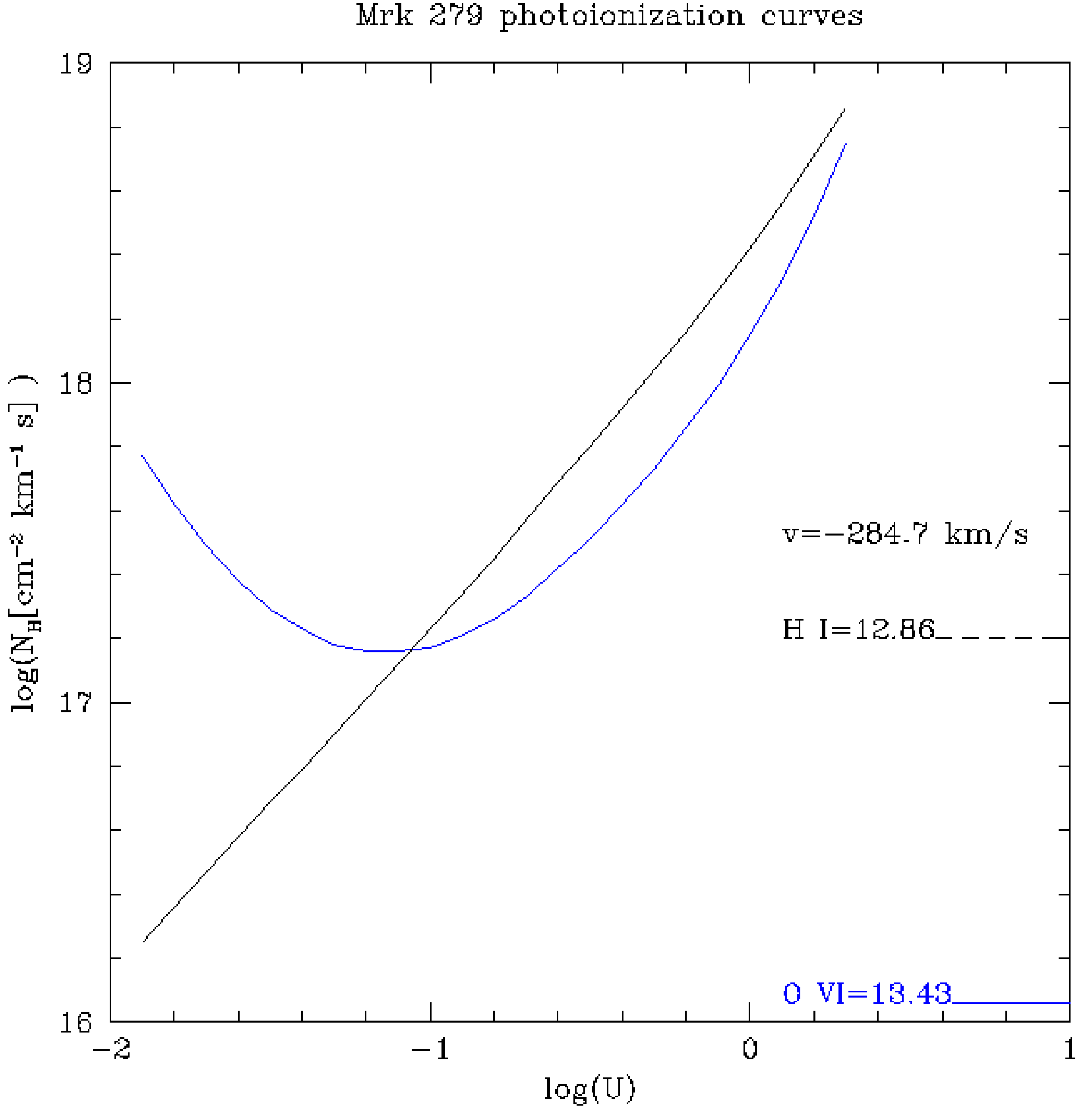

1000 R(pc) 100 10
3.0
2.5
2.0
1.5
1.0
0.5
0.0
O III
O IV
S IV
Ne VI
N(*)/N(0)
2 3 4 5 6 7
$\log_{10}(n_e)$ (cm^{-3})



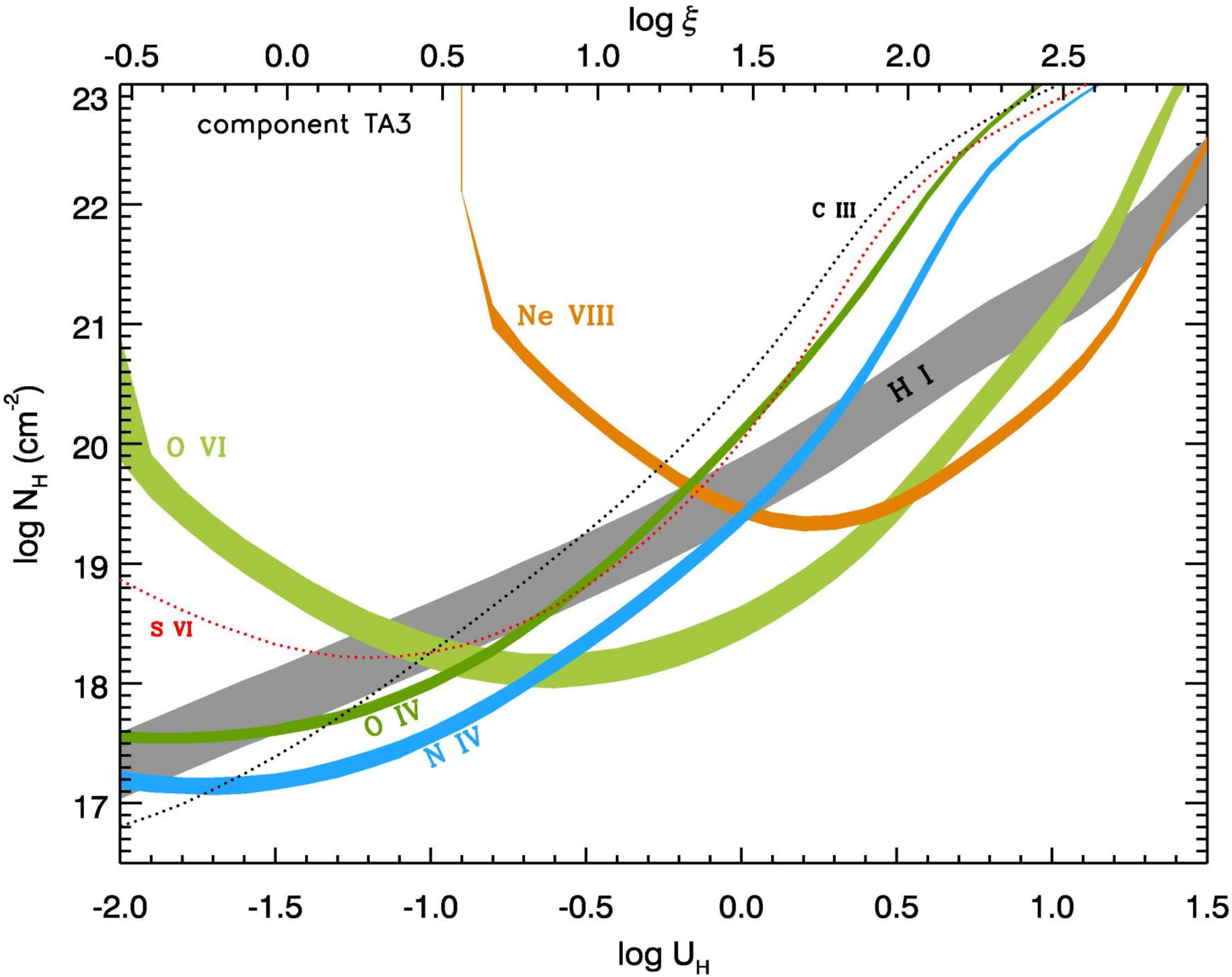
E (eV)
0.1
1.0
10.0
100.0
1000.0
47.0
46.5
46.0
45.5
45.0
MF87
HE0238
ionization potential
to destroy
COS observed
points
log νL_ν (erg/s)
H I
O IV
O VI
Ne VIII
10^{13}
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}
ν (Hz)

Mrk 279 photoionization curves

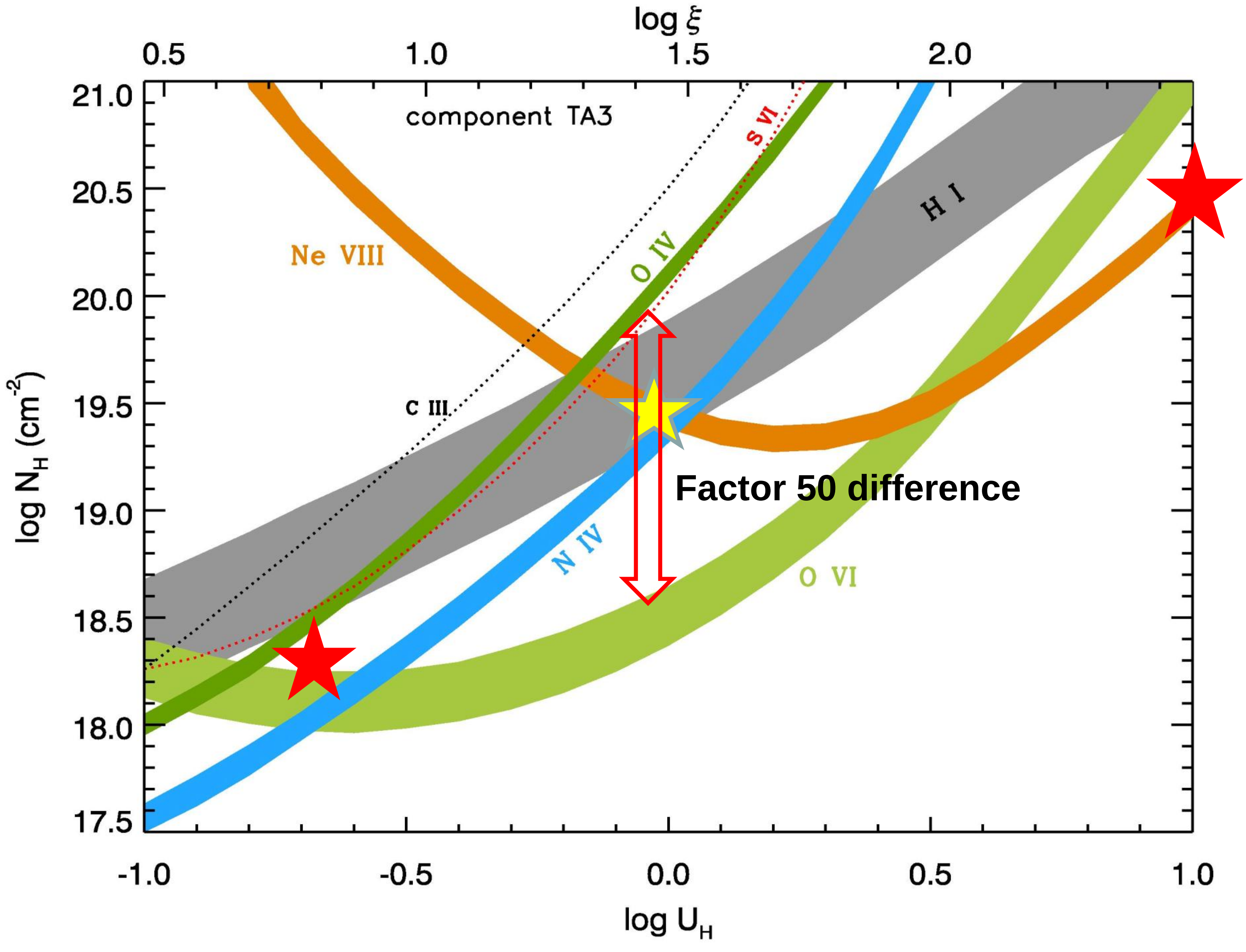




Mrk 279 photoionization curves
19
18
17
16
−2
−1
0
1
log(U)
log(N_H[cm^-2 km^-1 s])
v=−284.7 km/s
H I=12.86
O VI=13.43

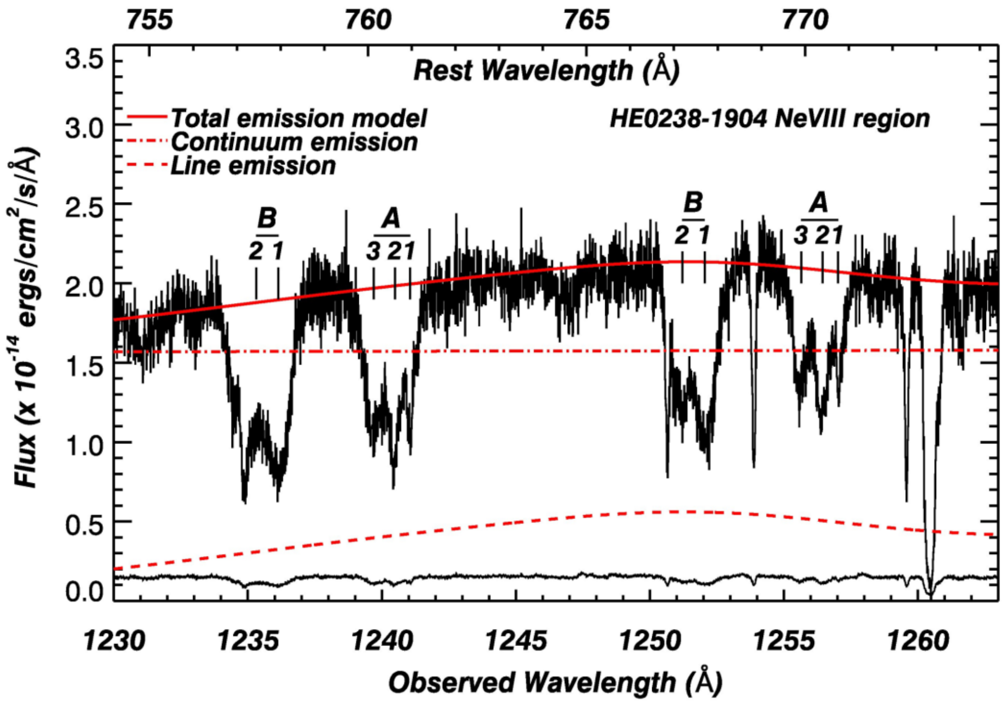


log ξ
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
component TA3
C III
Ne VIII
H I
O VI
S VI
O IV
N IV
log N_H (cm^-2)
23
22
21
20
19
18
17
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
log U_H



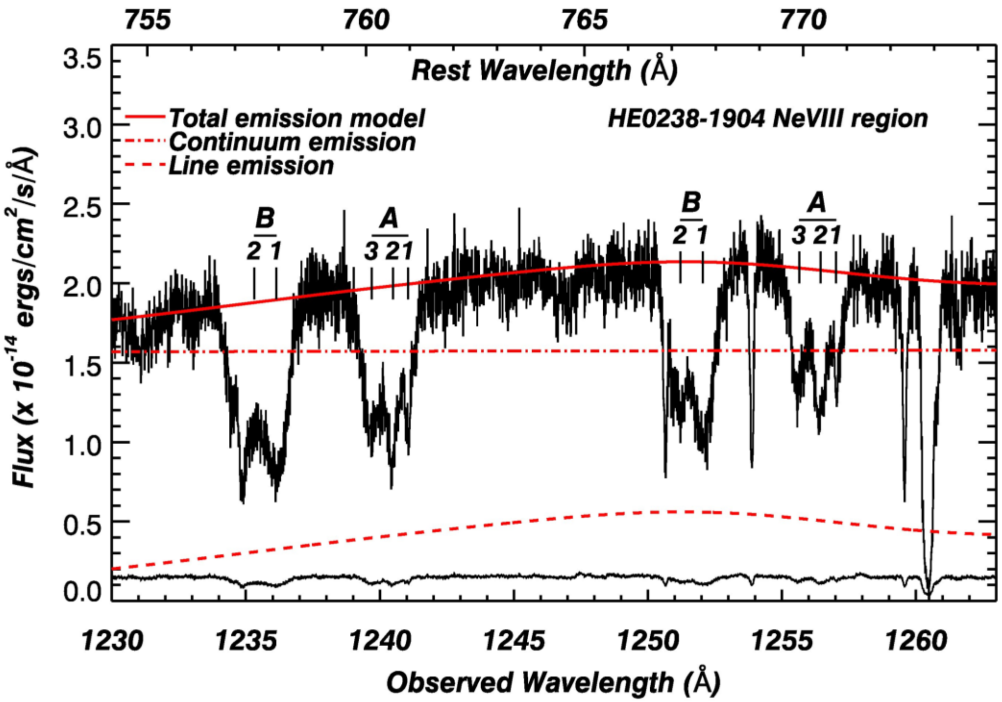
log ξ
0.5
1.0
1.5
2.0
component TA3
Ne VIII
O IV
S VI
H I
C III
N IV
O VI
Factor 50 difference
21.0
20.5
20.0
19.5
19.0
18.5
18.0
17.5
log N_H (cm^{-2})
-1.0
-0.5
0.0
0.5
1.0
log U_H

Physical parameters of the outflow

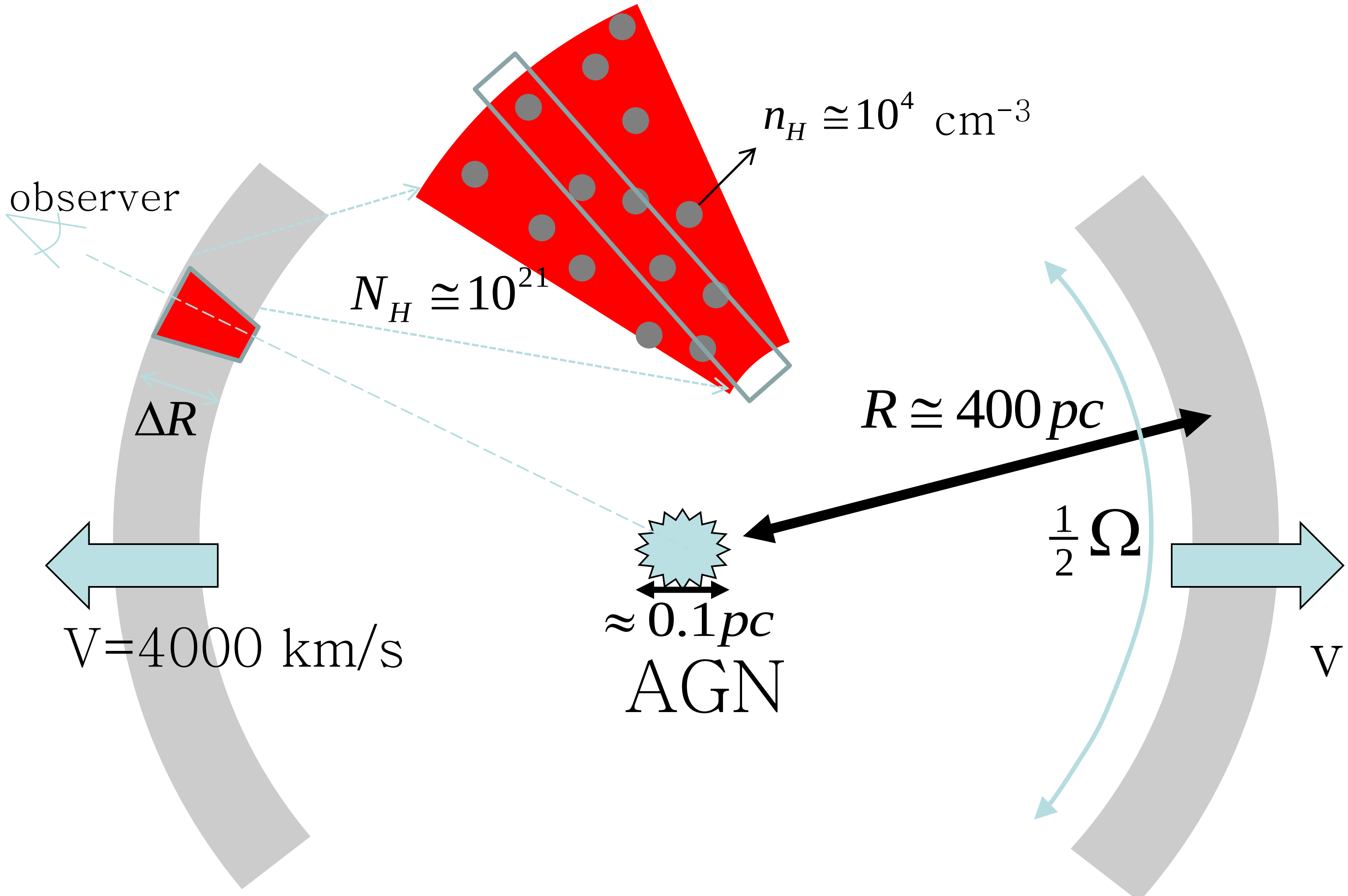


	Log (n_e)	R(pc)	M_{dot}	L_k 10^{44} erg/s	v km/s
A	3.8	800	100	4 (0.5%L_{BOL})	4000
B	3.9	300	250	20 (2%L_{BOL})	5000

Physical parameters of the outflow



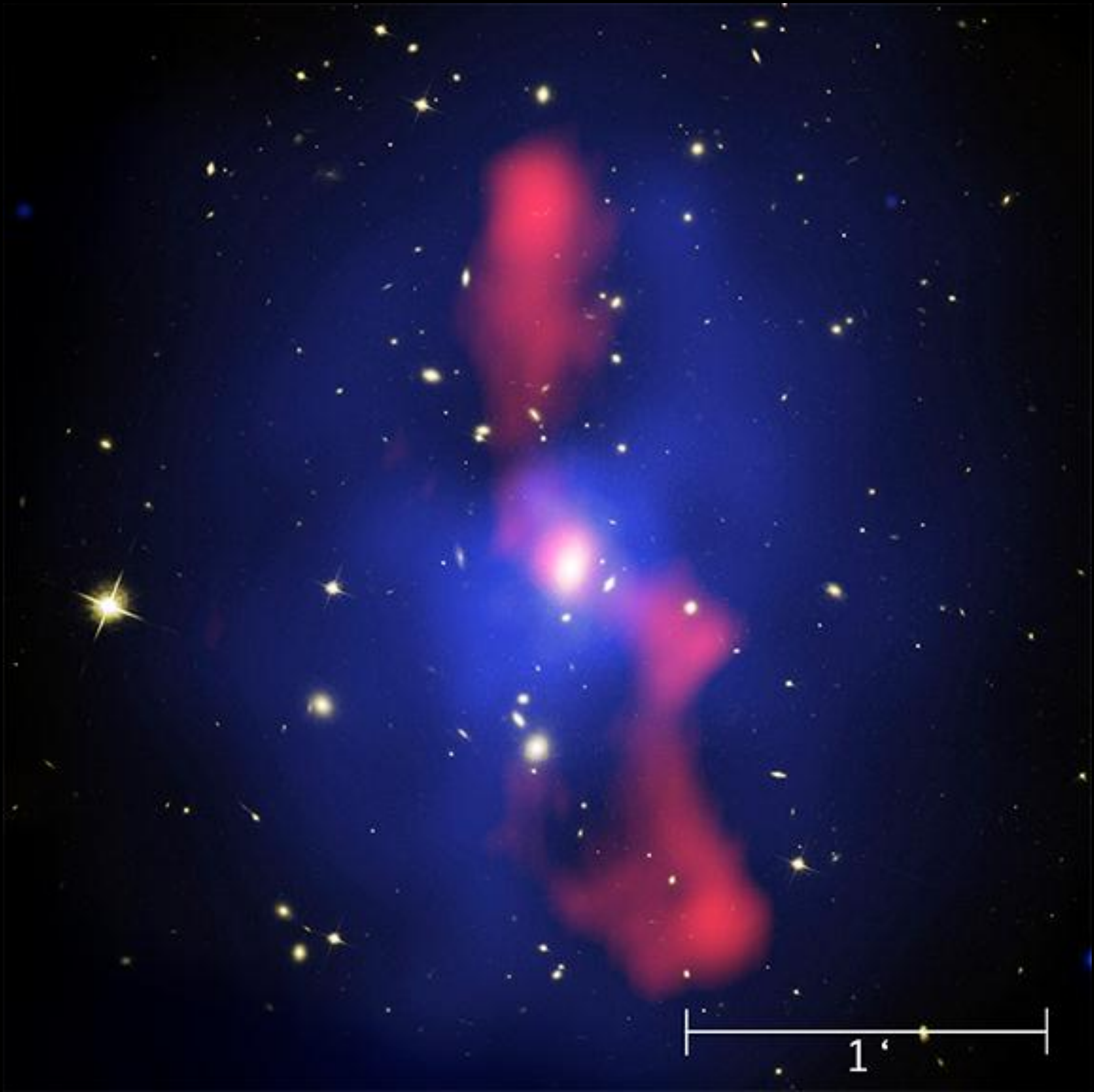
	Log (n_e)	R(pc)	M_{dot}	L_k 10^{44} erg/s	v km/s
A	3.8	800	100	4±0.4dex	4000
B	3.9	300	250	20±0.8dex	5000



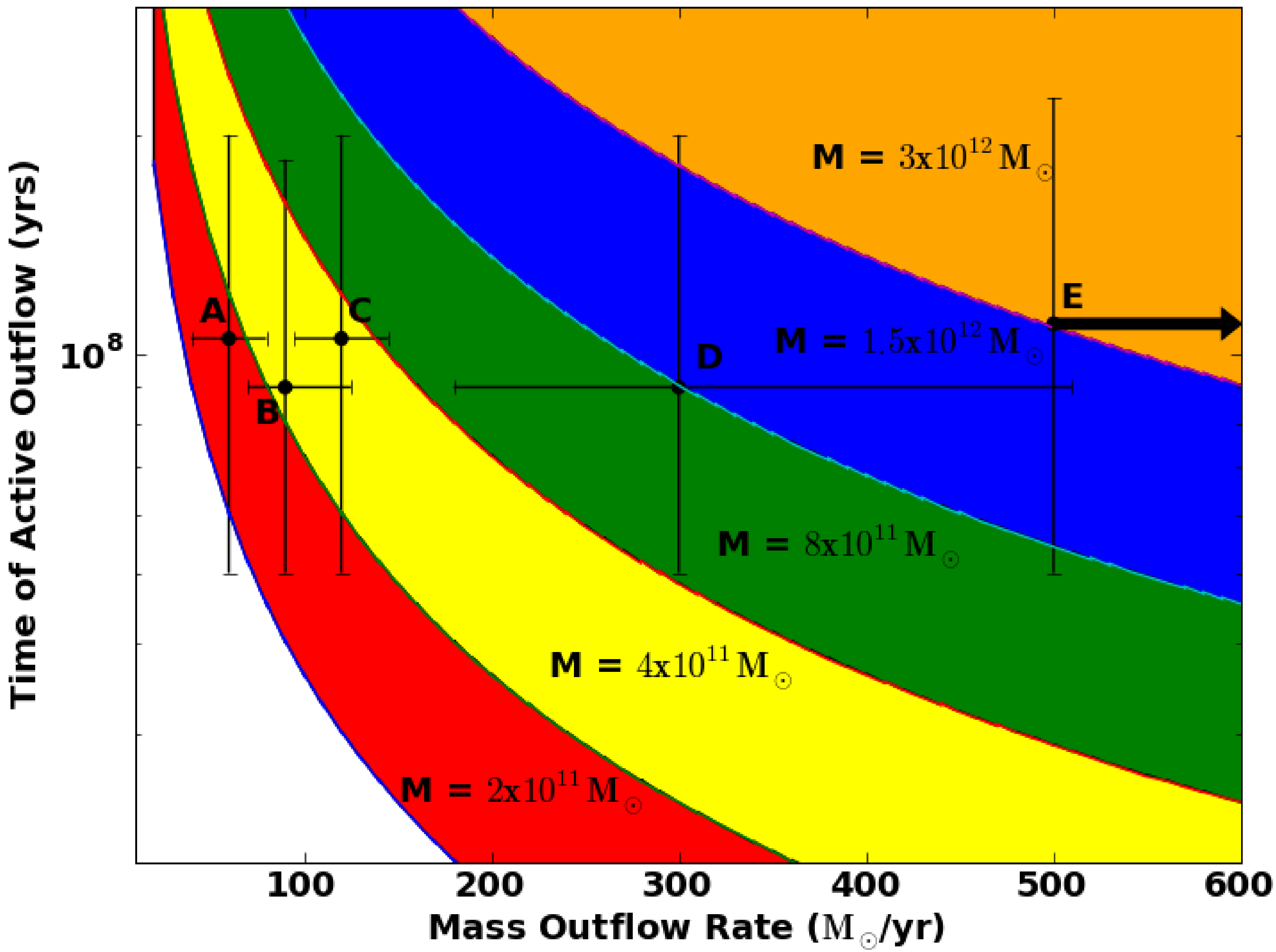
observer
$n_H \cong 10^4$ cm^{-3}
$N_H \cong 10^{21}$
ΔR
$R \cong 400\,pc$
$\frac{1}{2}\Omega$
$\approx 0.1pc$
AGN
V=4000 km/s
V

Consequences for AGN feedback

- Over 10^8 years quasar duty cycle, such kinetic luminosity (2×10^{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)



For dynamical modelers

In most determined cases the outflows are $10^2 – 10^4$ pc from the AGN, far away from their presumed acceleration zone.

- Instead of calculating detailed absorption profiles for an accelerating winds, we need models that create and maintain absorption troughs at ~1000 pc away from the AGN

(Claude-André Faucher-Giguère + 2011)

- For **Gas Flows in Galaxies**

Most galaxies experienced a violent period of high-energy high-speed outflows during their active quasar phase that influenced at least their inner 1-10kpc .

These episodes might have been the most important events in the relationship between the SMBH and the galaxy and other structure around it

Summary

Kpc scale 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 $0.5<z<1.5$ is the way to go!

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

$$n_H V_{ff}$$

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

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