Technion - Israel Institute of Technology

Lower Limits on the Metallicity of SDSS BALQ Outflows

Alexei Baskin
&
Ari Laor

AGN Winds in Charleston, October 2011

Outline

- A “new” physical process:

  Metal enrichment through radiation pressure.

- A new method:

  Direct lower limit on the metallicity.

- Application to SDSS BALQs.

Introduction

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- Radiation pressure
  - Exerted on metal ions which have only 1% of the gas mass (for $Z_{\odot}$).
  - Metals coupled to Hydrogen by Coulomb force.
  - Separation of metals from Hydrogen gas in stellar winds was suggested by Springmann & Pauldrach (1992).
  - Can lead to very fast outflow of metals.
  - **Is the metal runaway scenario relevant for AGNs?**

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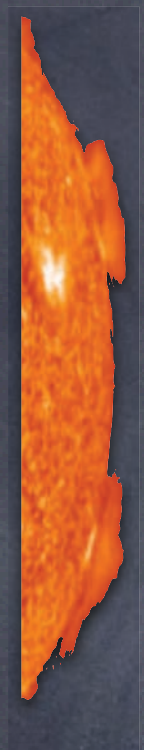
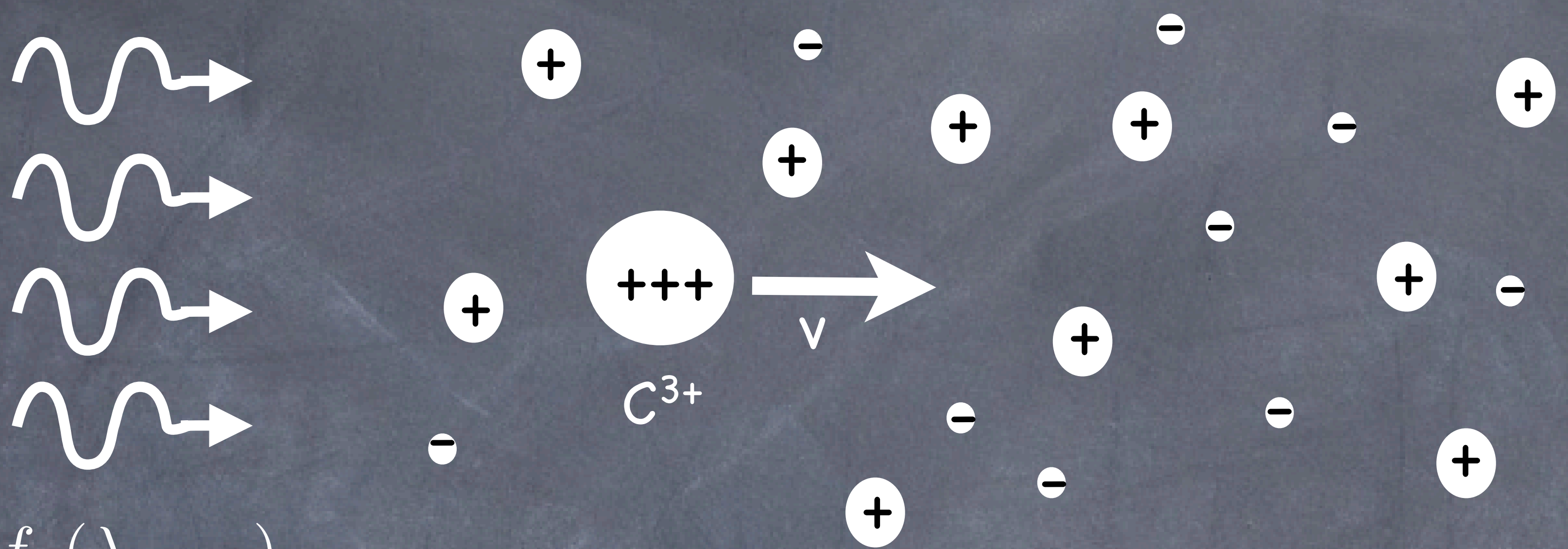
  - Can lead to very fast outflow of metals.
  - **Is the metal runaway scenario relevant for AGNs?**
- Metallicity estimates
  - Metallicity is usually estimated based on metal abundance ratio (e.g., NV/CIV).
  - Direct measure requires knowledge of Hydrogen column. Unknown.
  - **Can a robust lower limit on the metallicity be placed just using HI column (Lyα absorption)?**

Metal Enrichment through Radiation Pressure

A metal-ion test particle (C^{3+})





$f_\nu(\lambda_{\text{trans}})$

$\lambda_{\text{trans}} = 1549\text{Å}$

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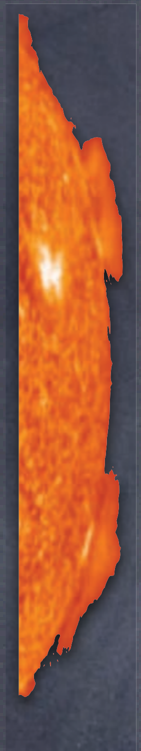

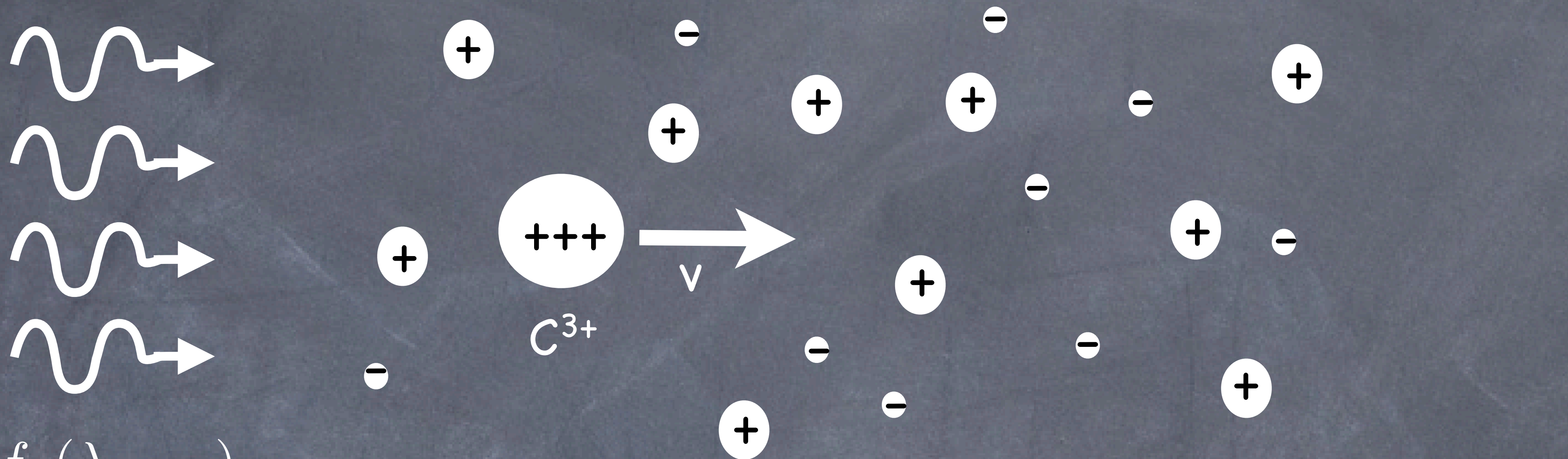

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Radiative acceleration by line absorption

$$\frac{h}{\lambda_{\rm trans} m_{\rm ion}} \times \frac{f_\nu(\lambda_{\rm trans})}{h\nu_{\rm trans}} \cdot A_{12} \frac{\pi e^2}{m_e c} f_{12} \lambda_{\rm trans} \sqrt{\frac{m_{\rm ion}}{2\pi k T}}$$

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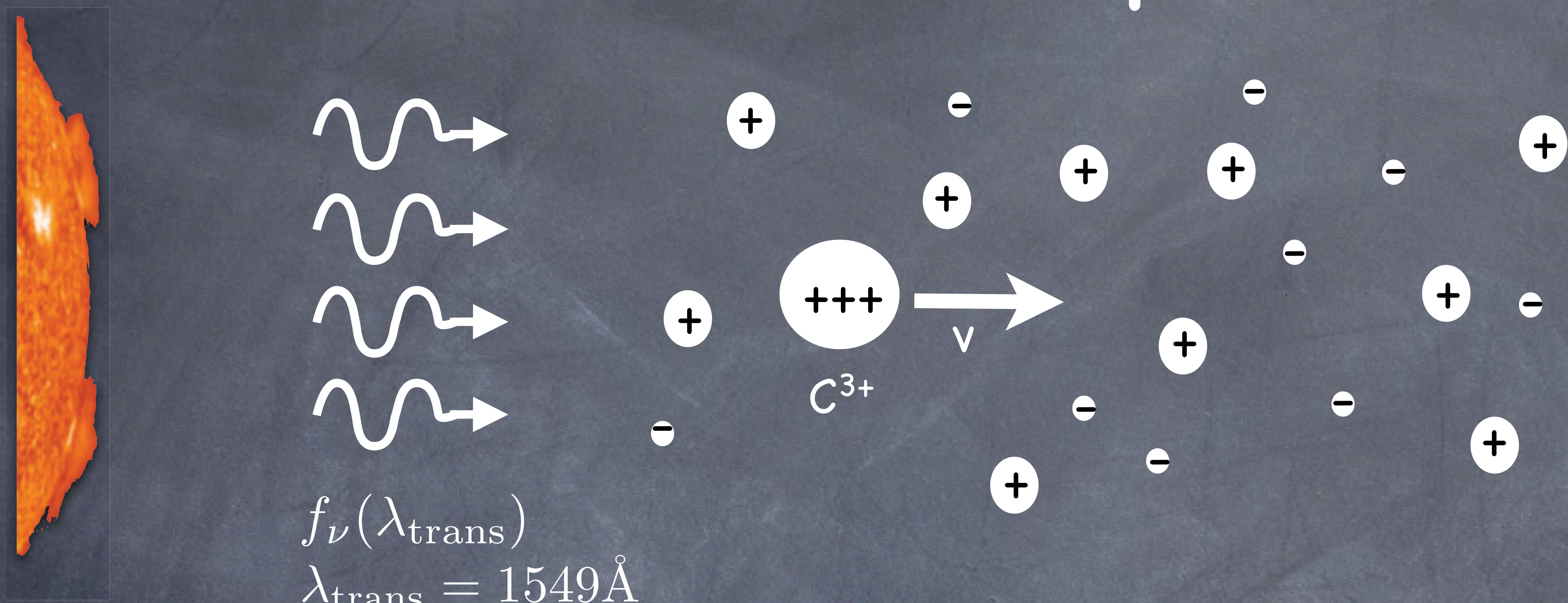

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per photon

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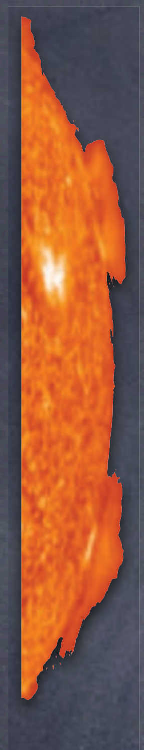

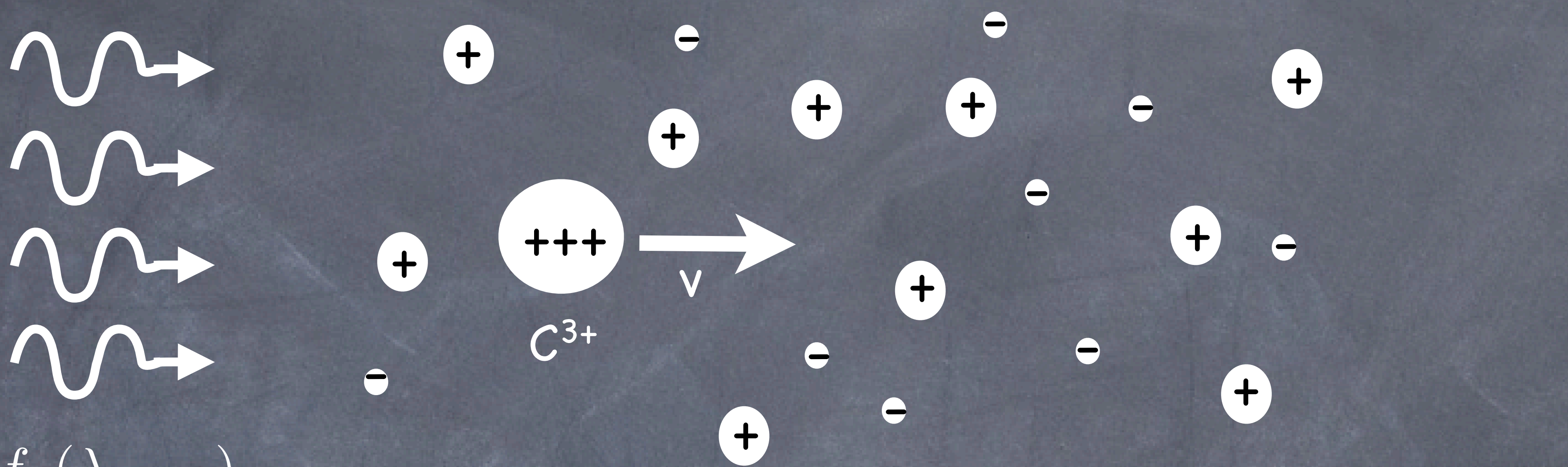

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absorption rate (photons/time) $\approx \int \frac{f_\nu}{h\nu} \sigma(\nu) d\nu$

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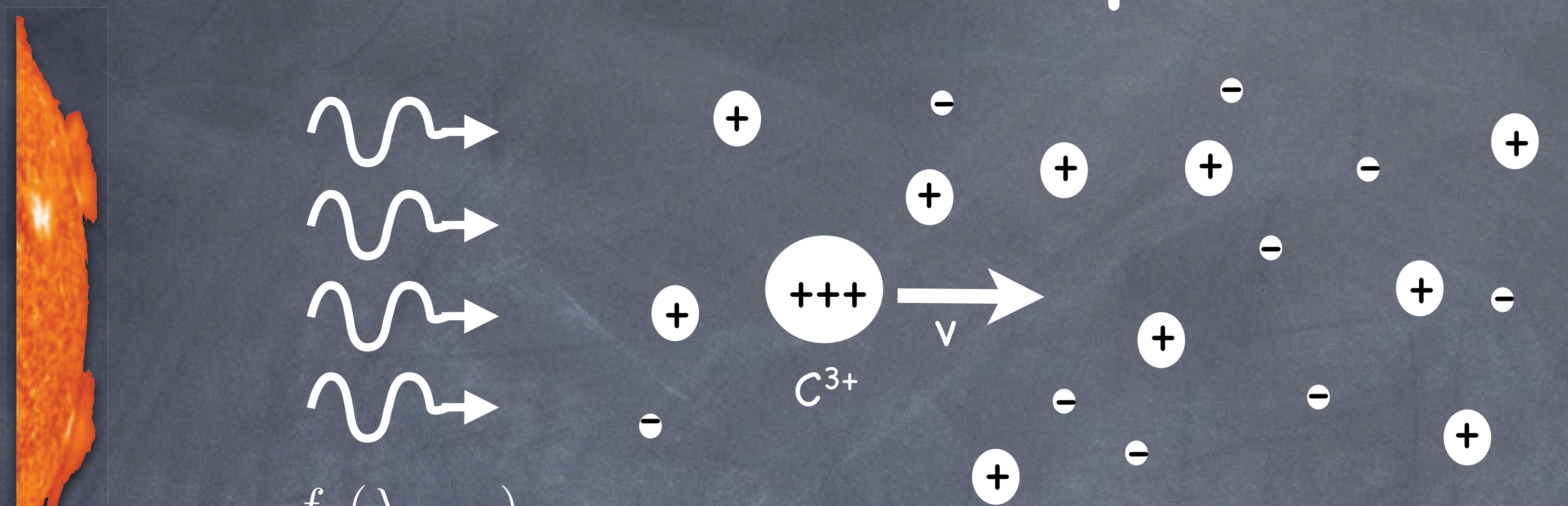

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Coulomb coupling (deceleration)

$$\sum_{i=p,e} n_i \frac{4\pi e^4 Z_{\rm ion}^2}{kT m_{\rm ion}} \ln\Lambda G[x_i(v/v_{{\rm th},i})]$$

(Spitzer 1962)

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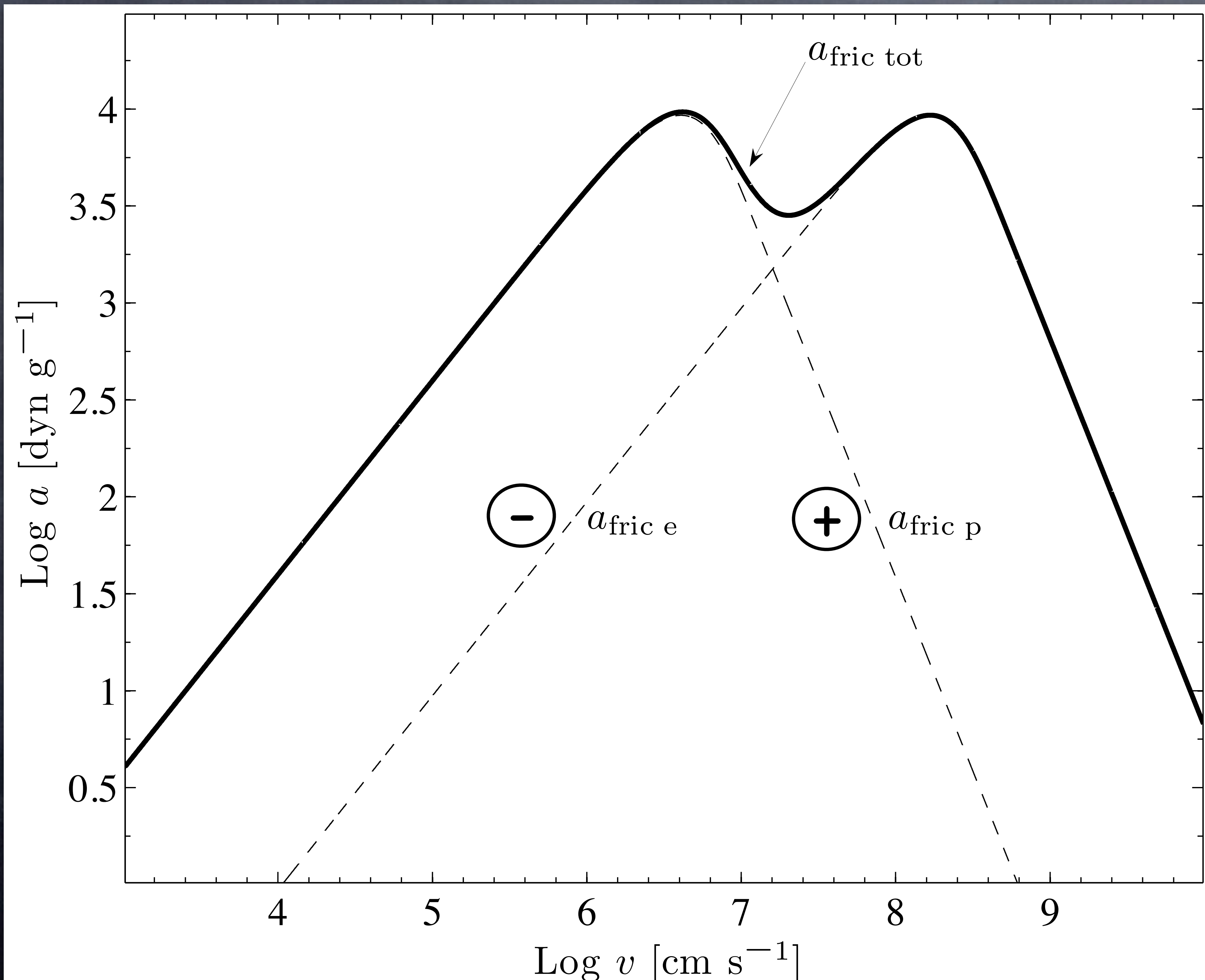

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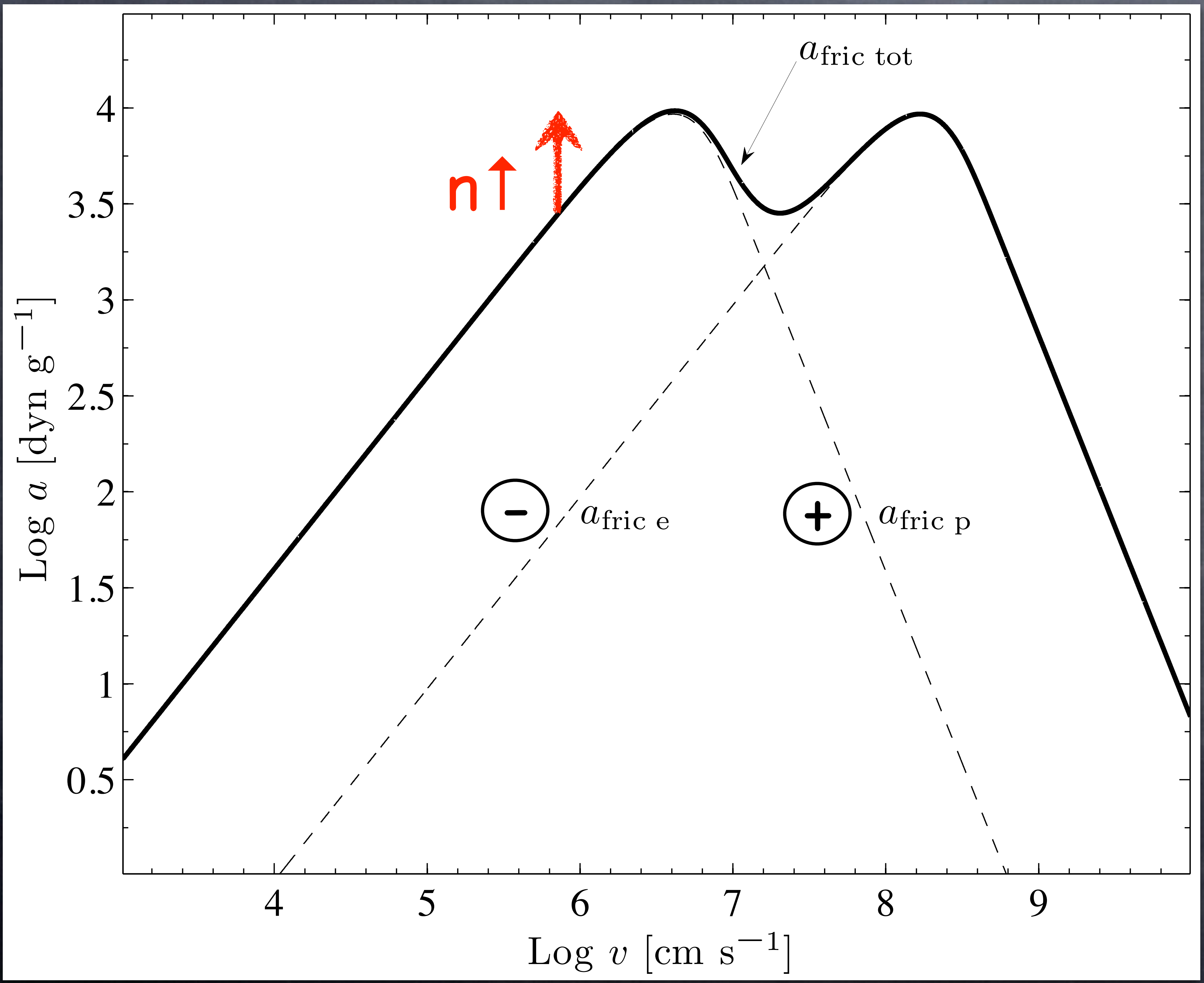

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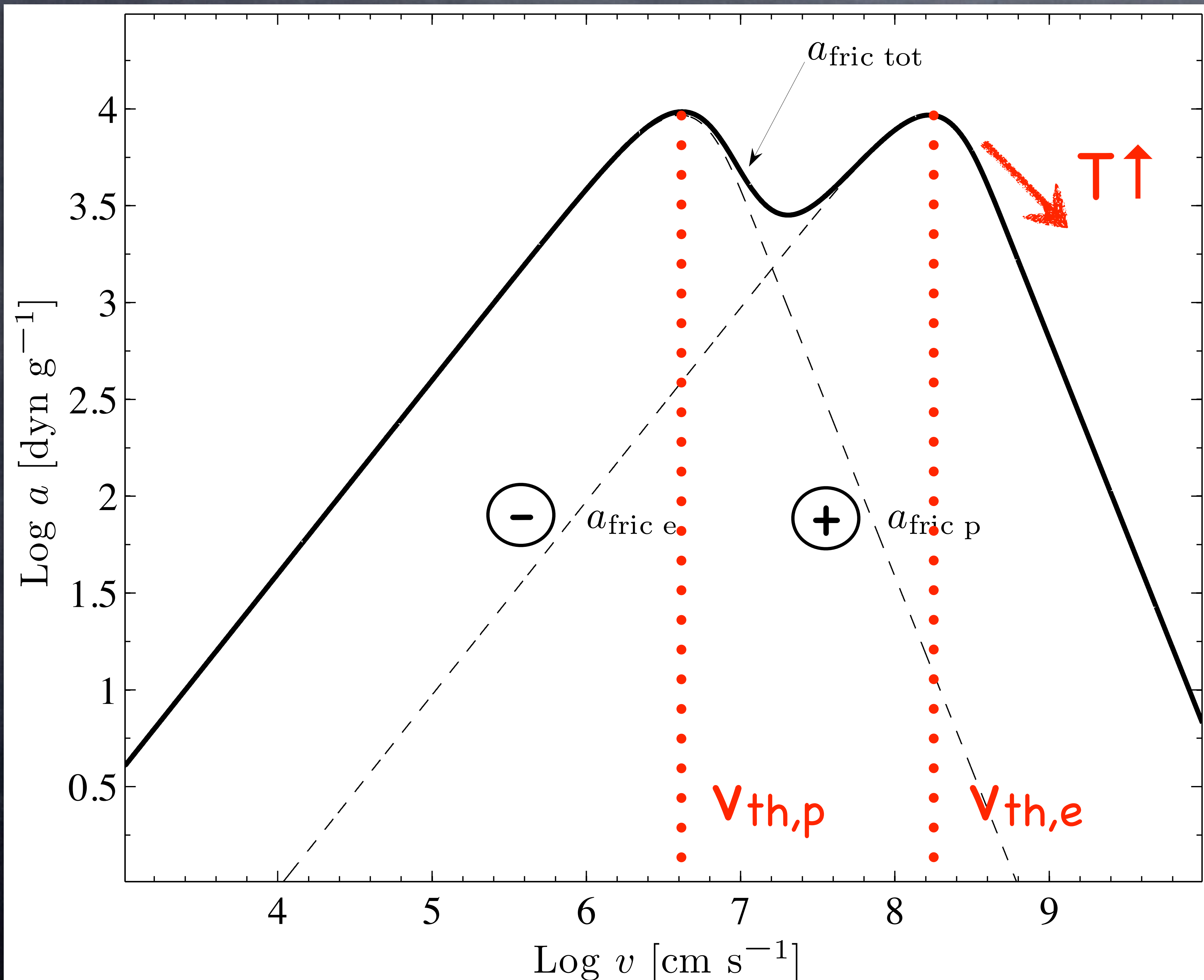

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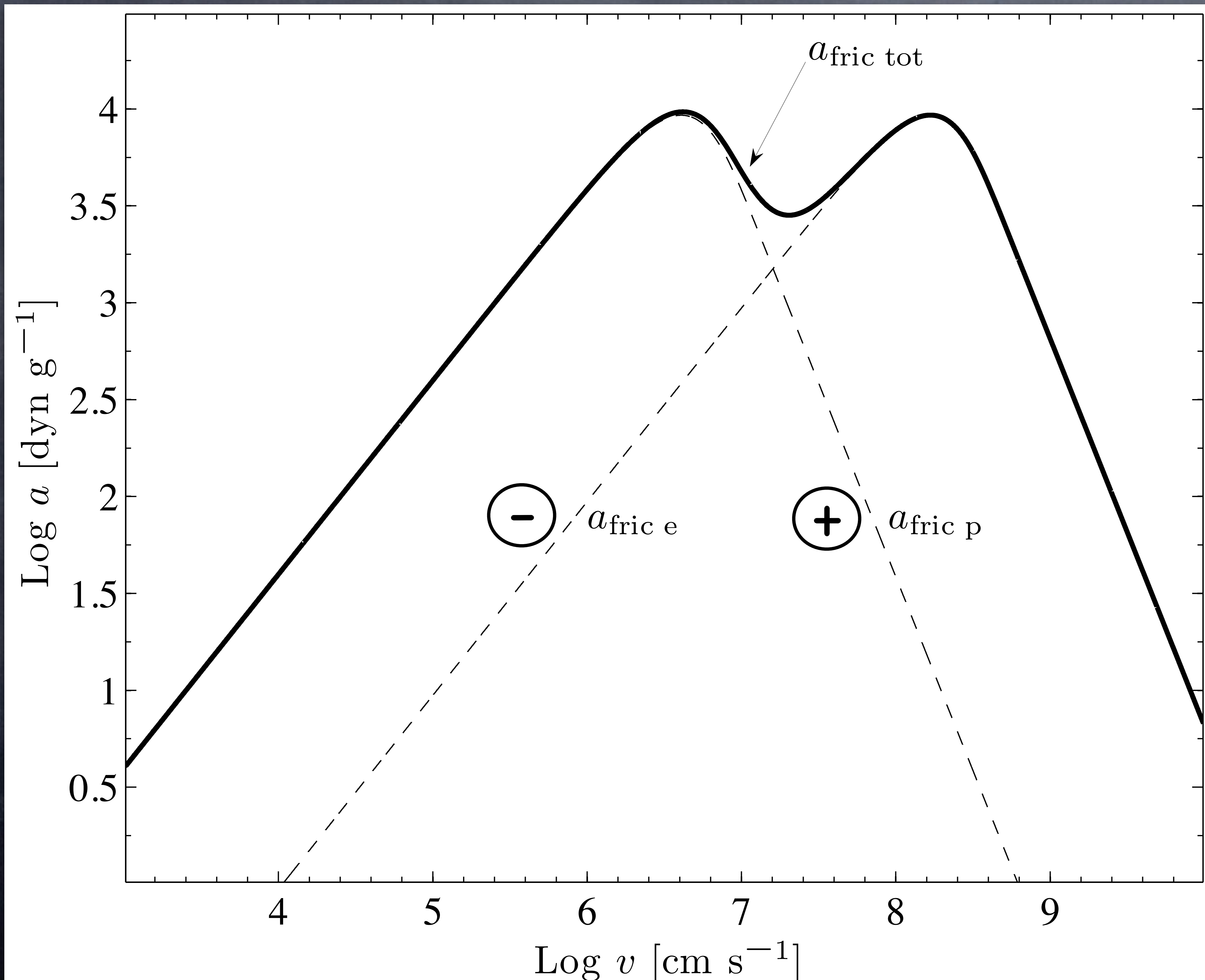

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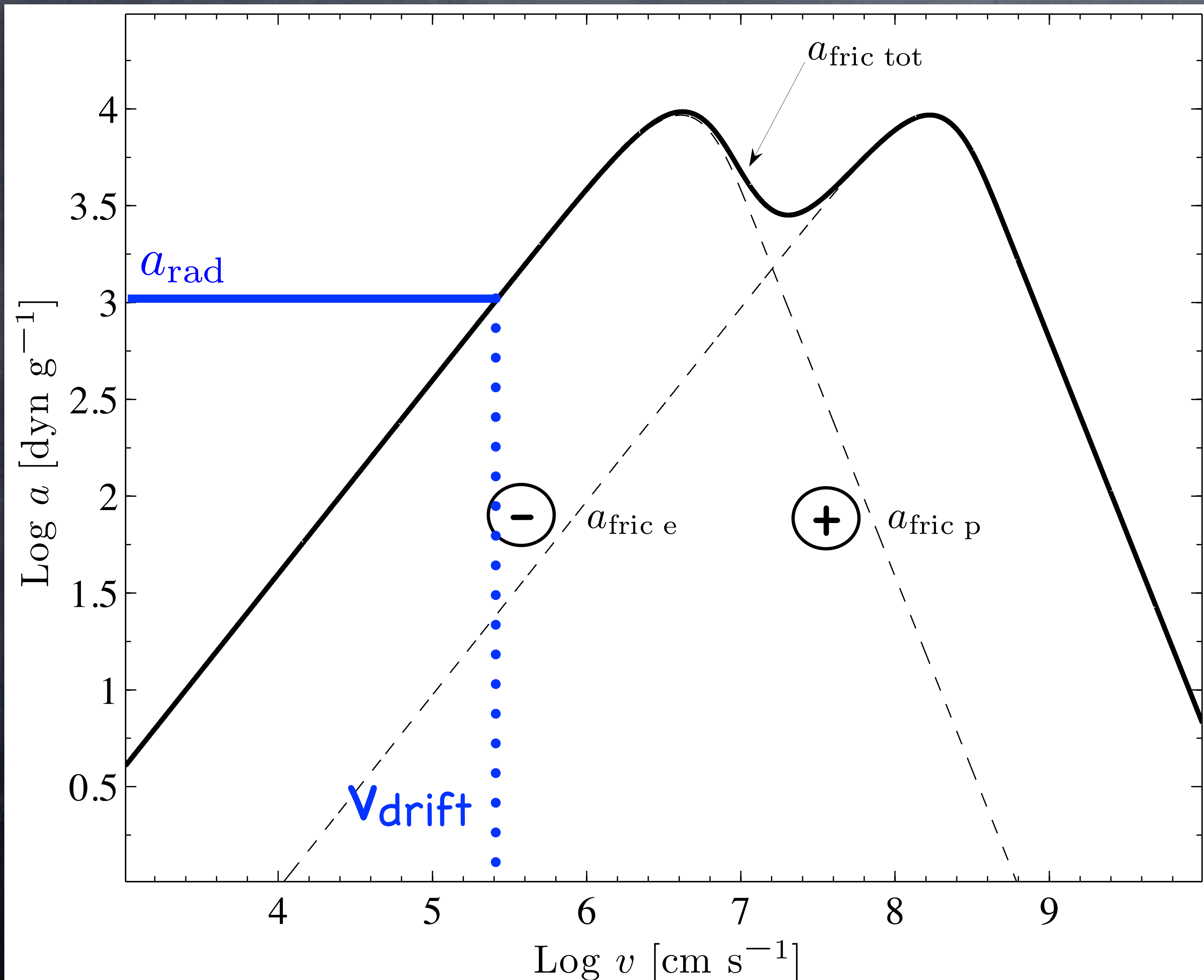

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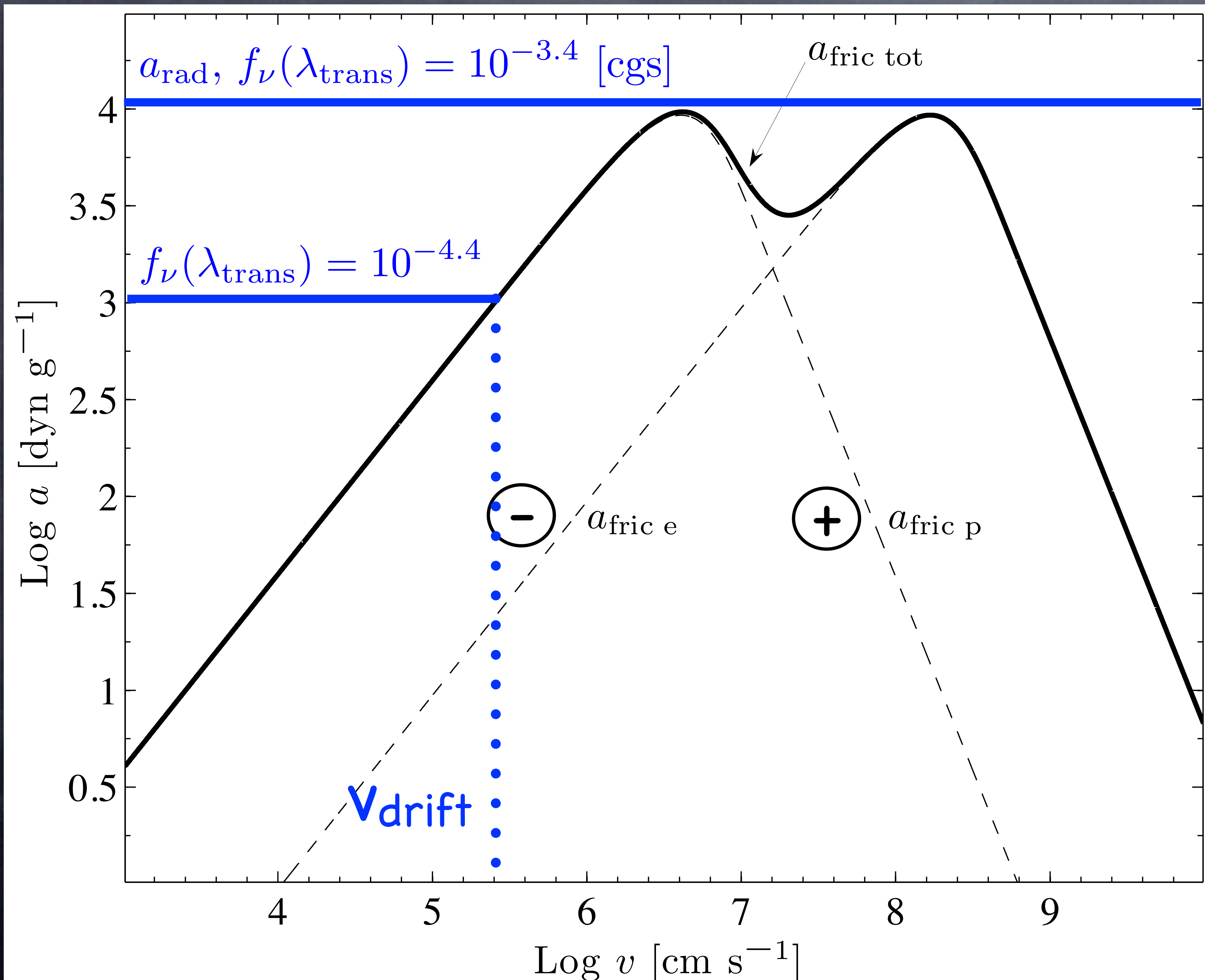

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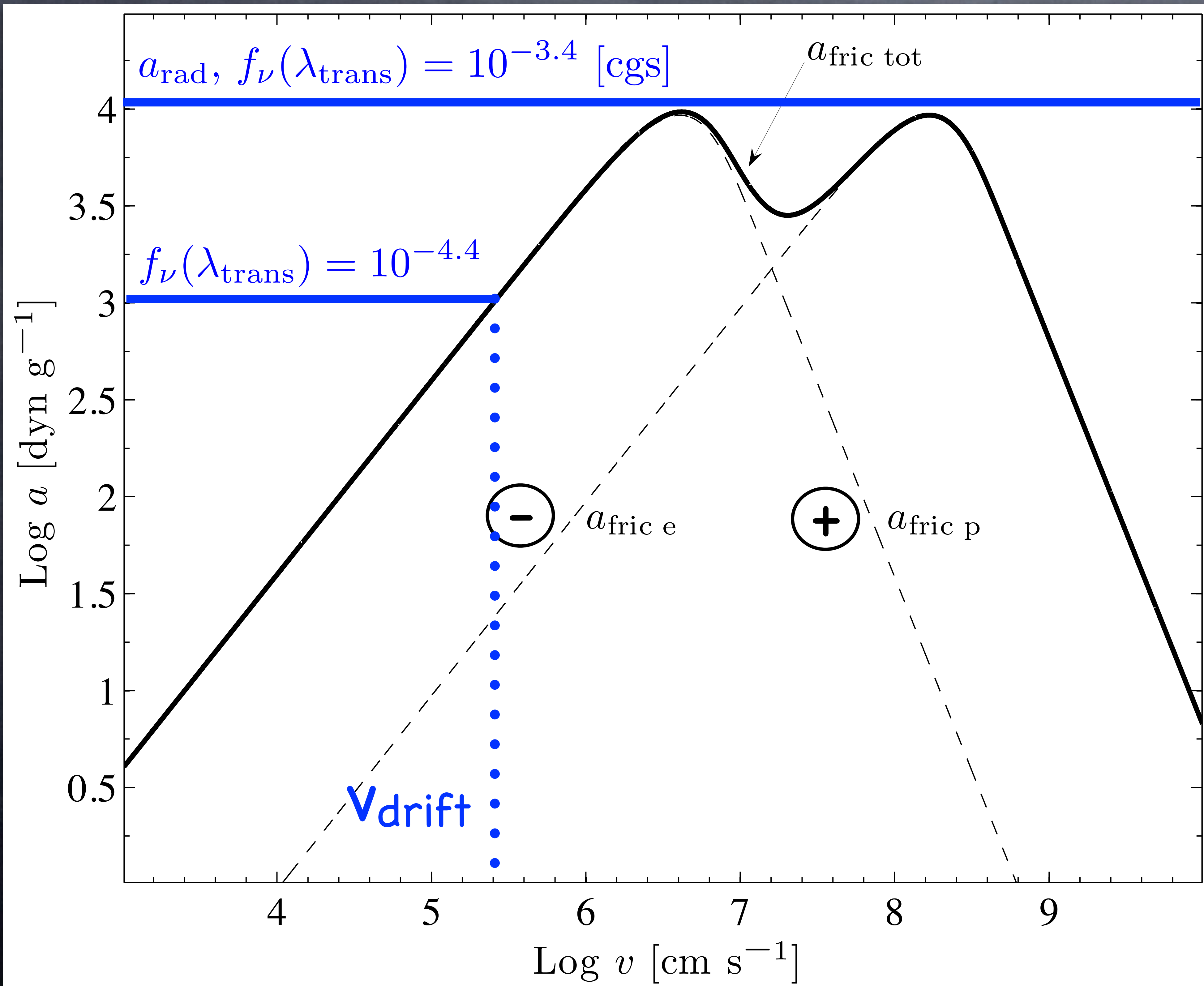

log U ~ 7 for AGN SED

=> Gas exposed to non-ionizing continuum (filter, outer AD?)

For runaway:

$$\log f_\nu(\lambda_{\rm trans}) > \log n_{\rm H} - 0.5 \log T - 6$$

Direct Lower Limit on the Metallicity

Motivation & Considerations

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- Measure directly the minimal N(metal)/N(H).
  - Take a given metal line and infer the minimal possible Lyα absorption within the same absorber.
  - Compare with the observed Lyα absorption.
  - If the observed Lyα absorption is weaker, scale-up Z.

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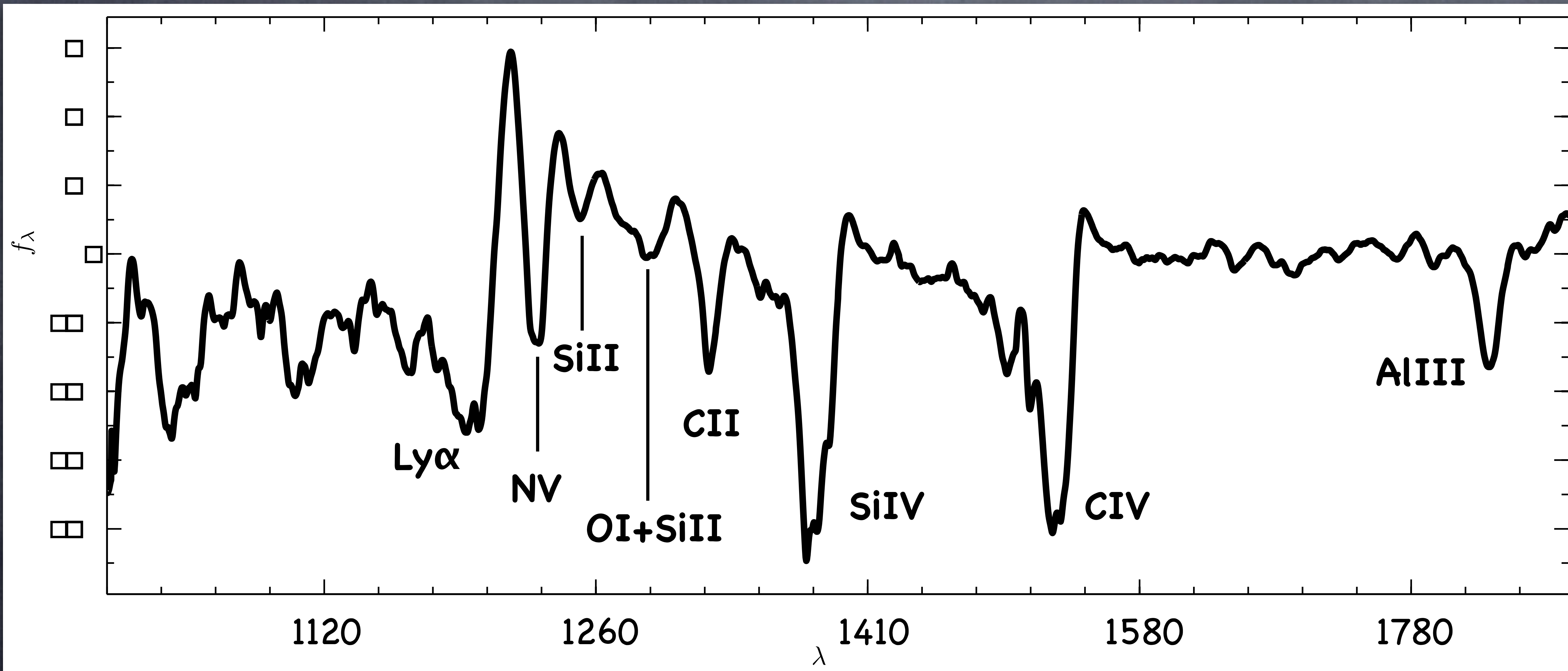
  - Compare with the observed Lyα absorption.
  - If the observed Lyα absorption is weaker, scale-up Z.
- Which metal line to use?
  - Not far in λ from Lyα.
  - Prominent and isolated.
  - Of relatively low ionization (higher HI/H).

NV 1240	SiII 1263	SiII 1308	OI 1303
CII 1335	SiIV 1397	CIV 1549	AlIII 1857

Composite BALQ spectrum



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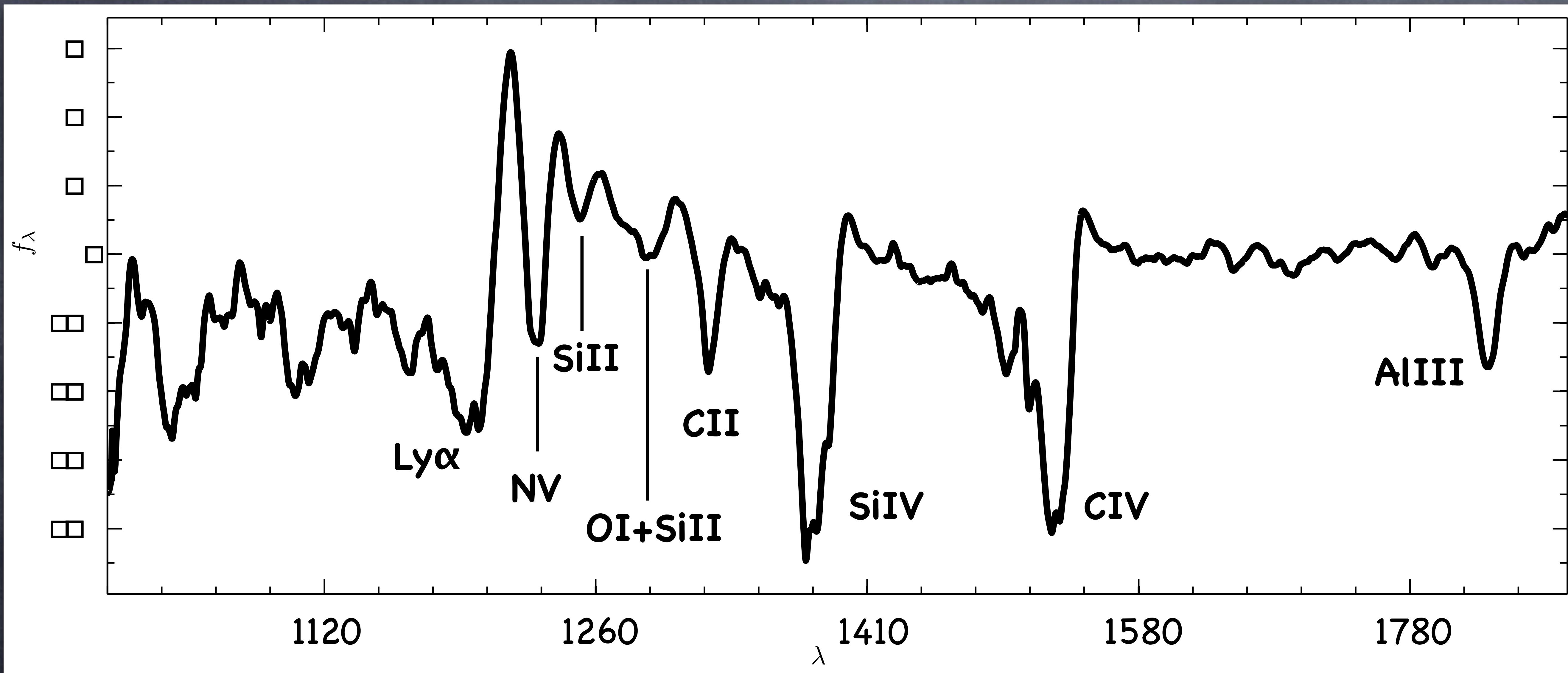

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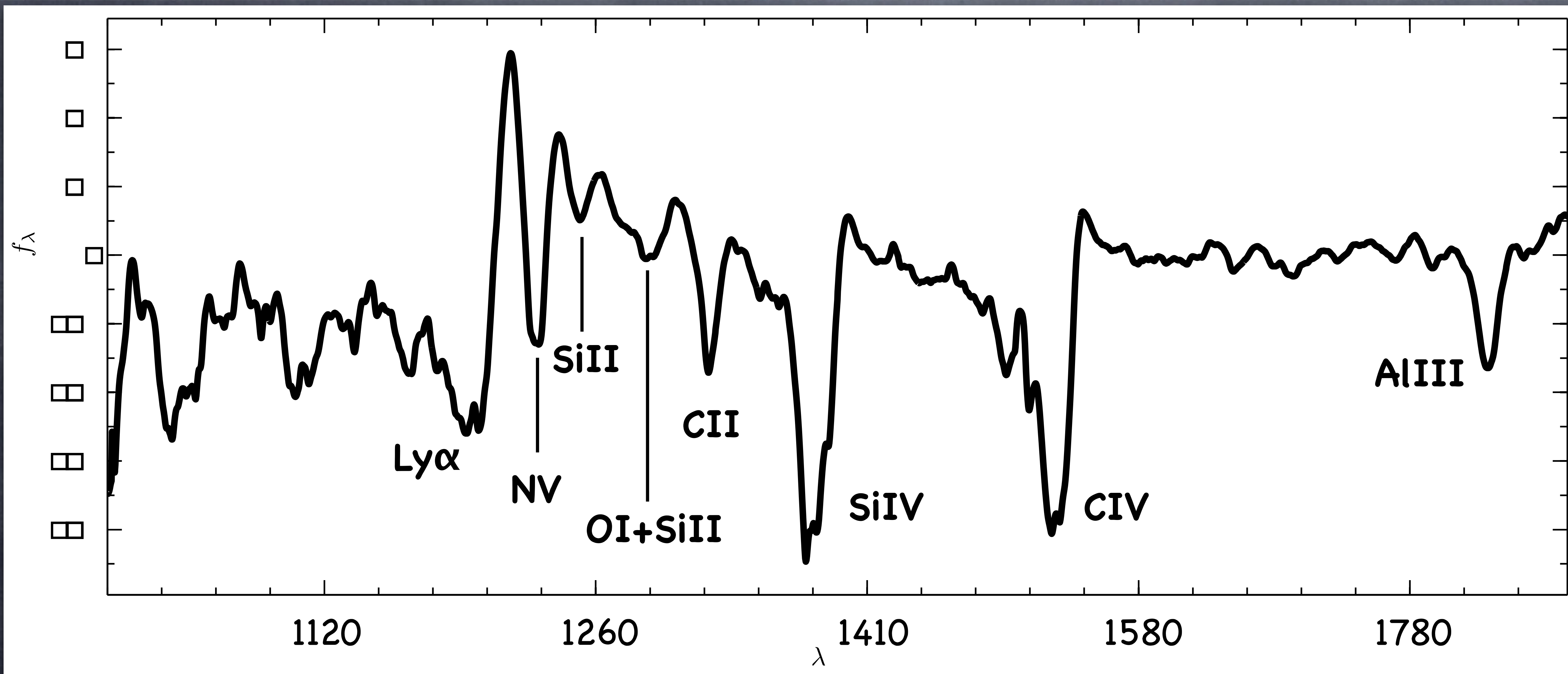

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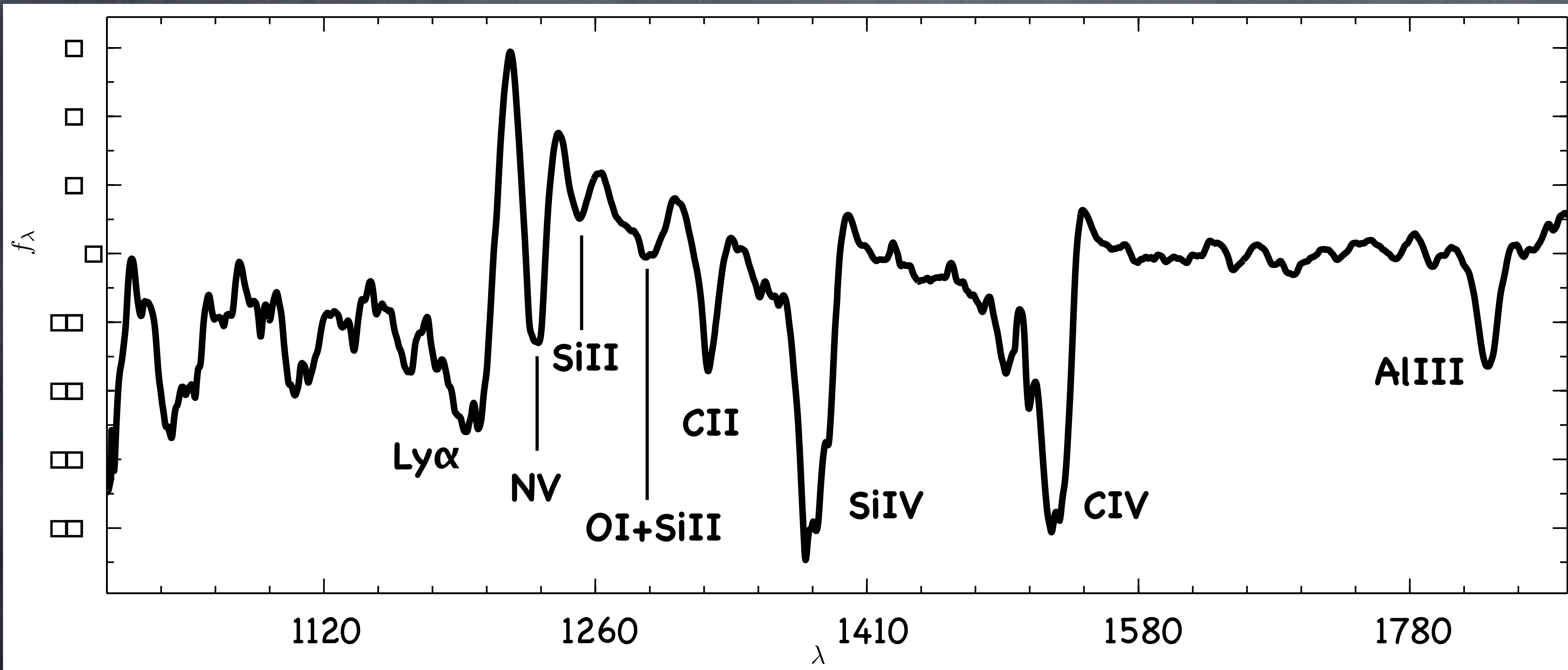

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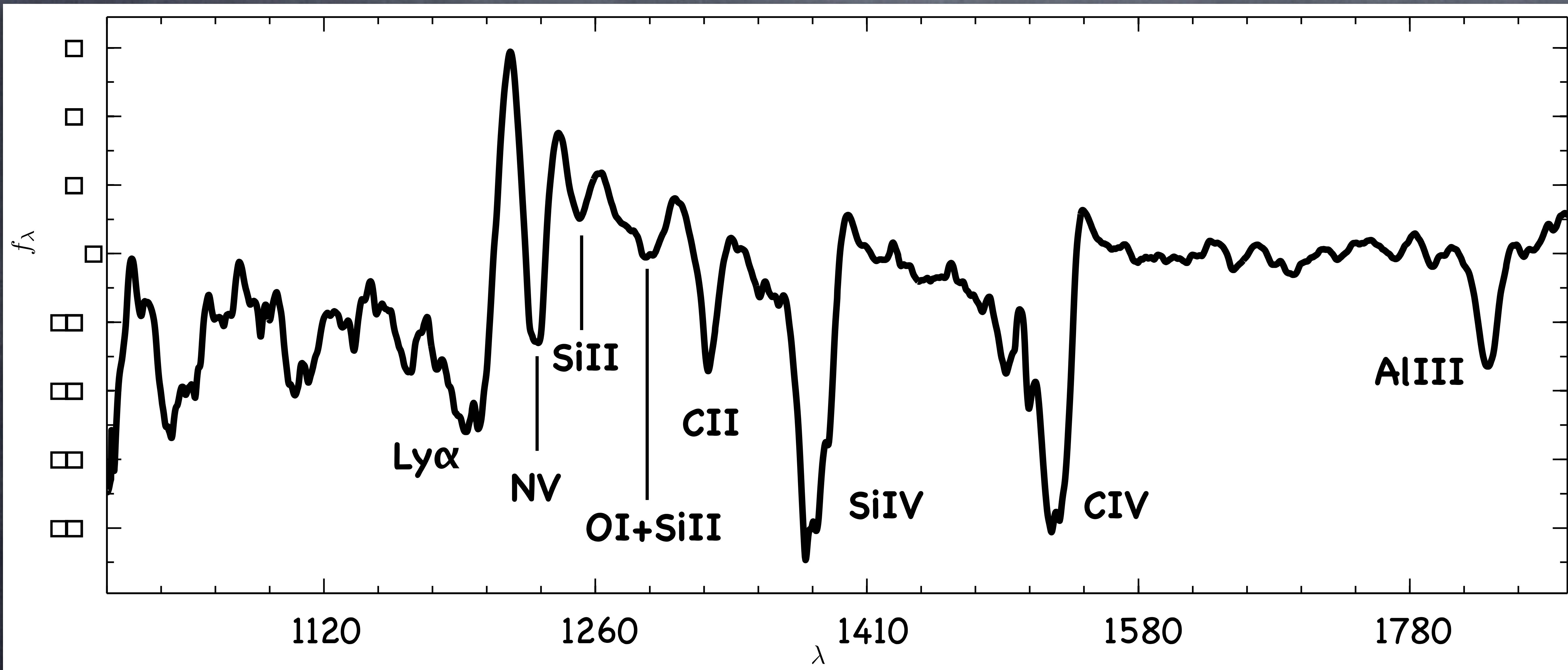

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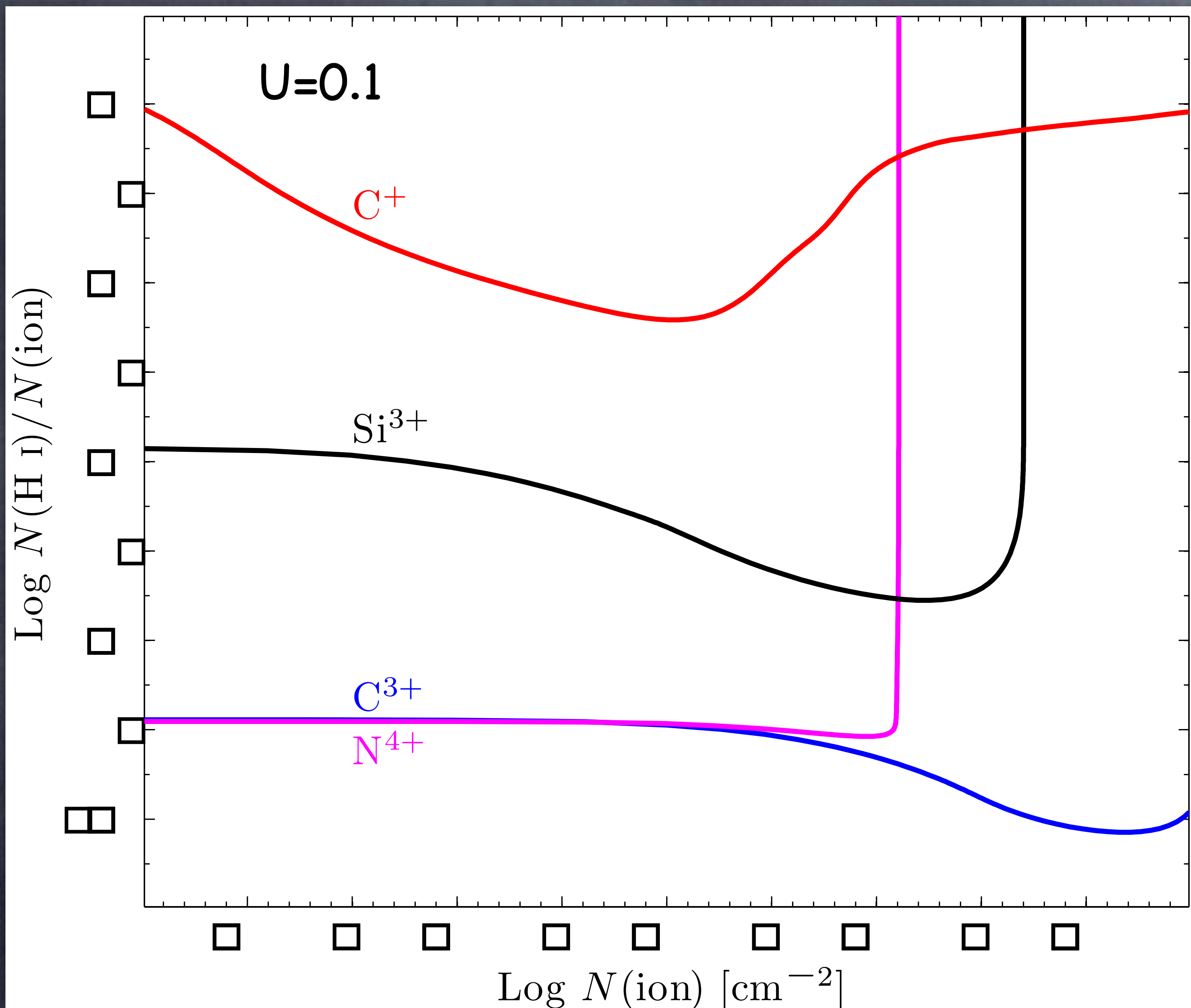
Implied N(HI) vs. N(ion)



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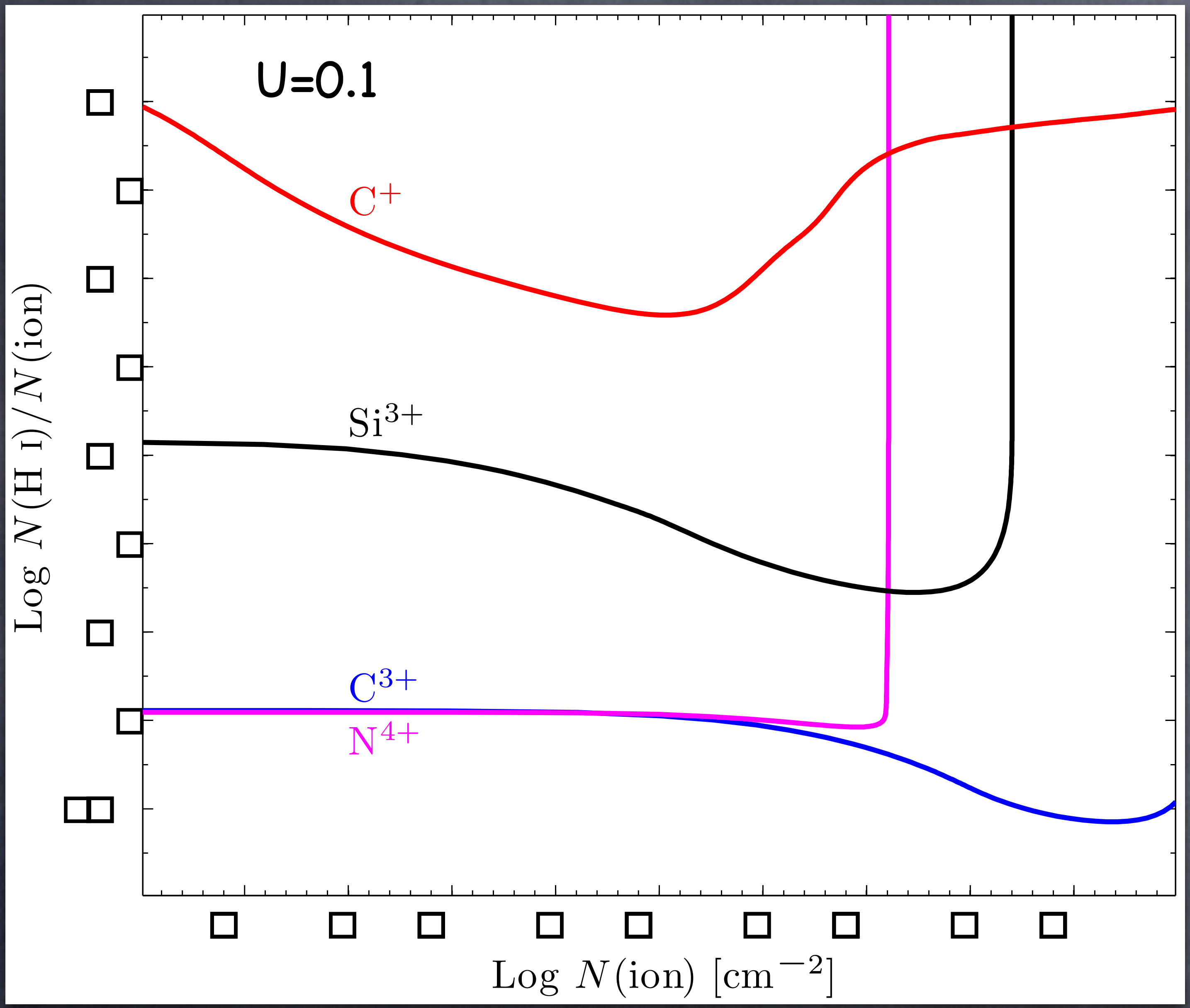

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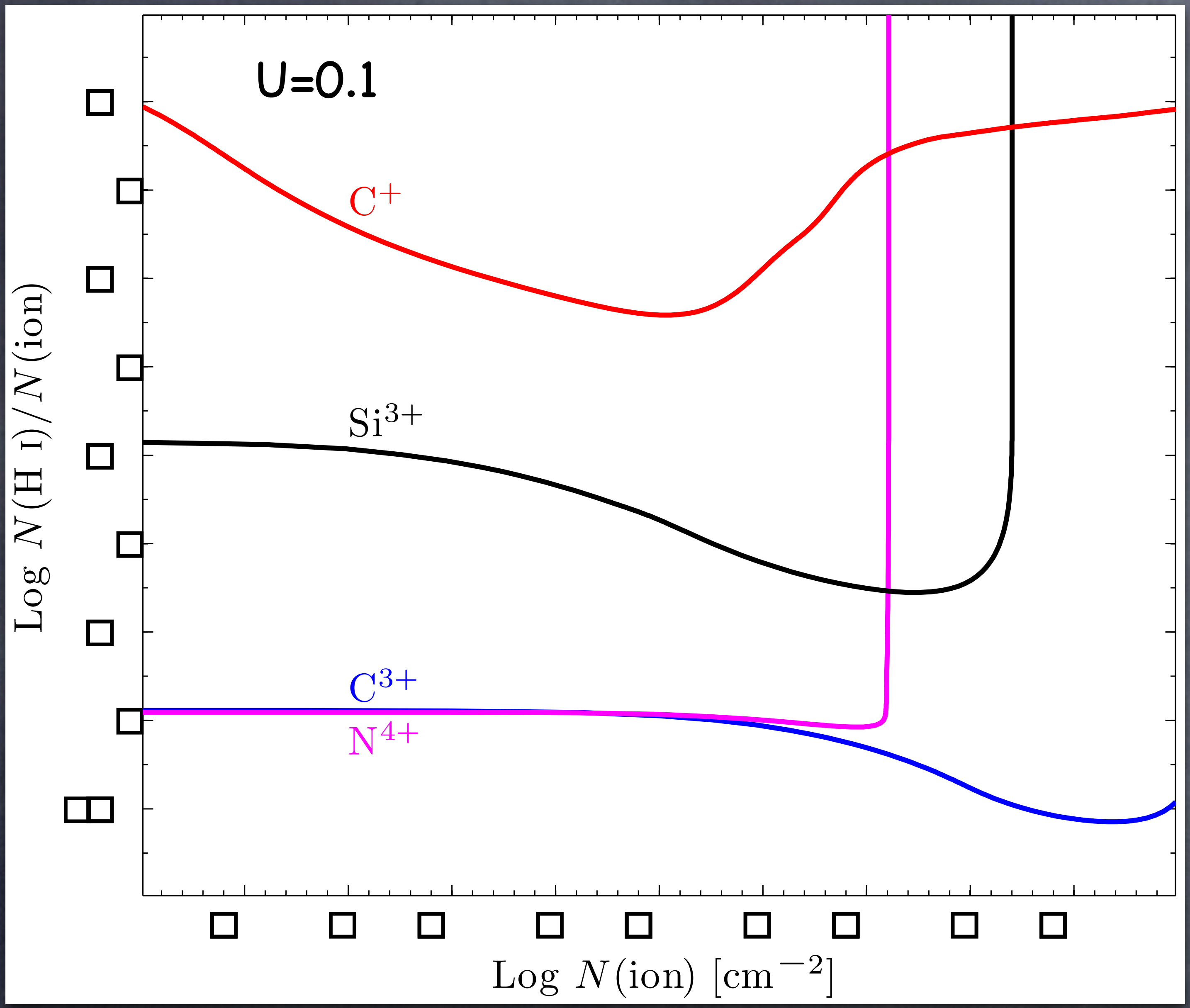

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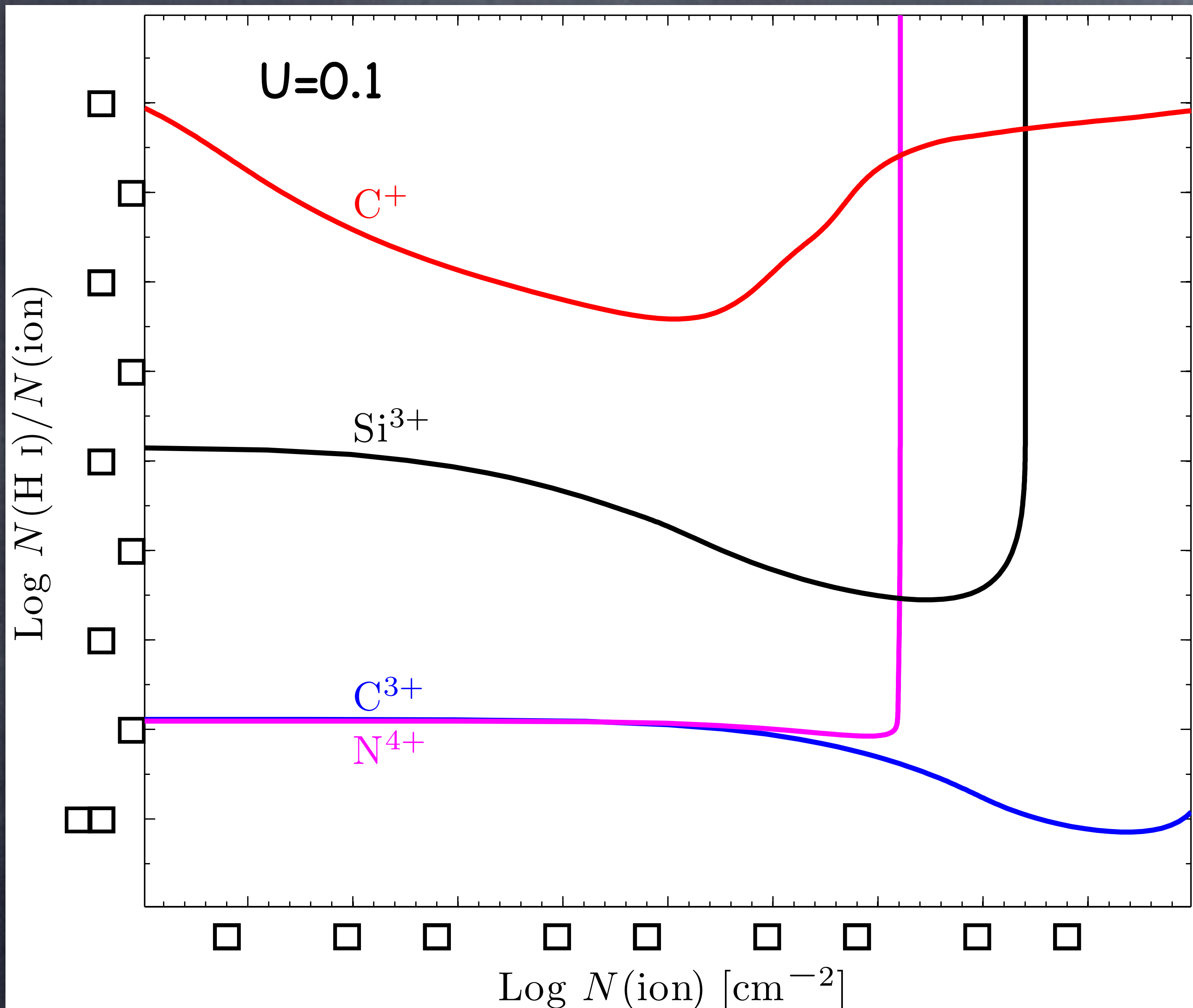

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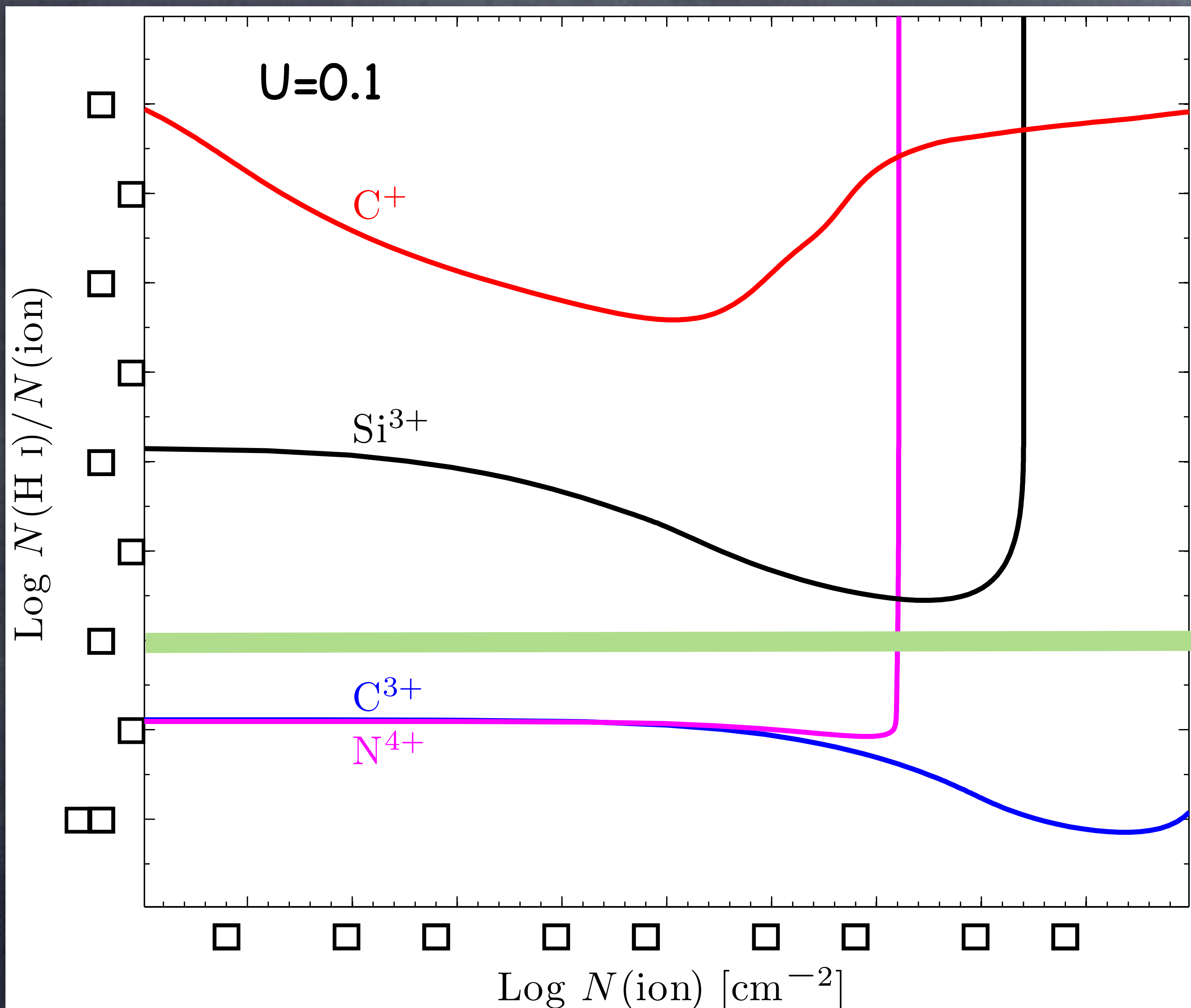

N(HI)/N(Si^{3+}) absolute lower limit for U≲1 => [illegible](Lyα)>[illegible](SiIV)

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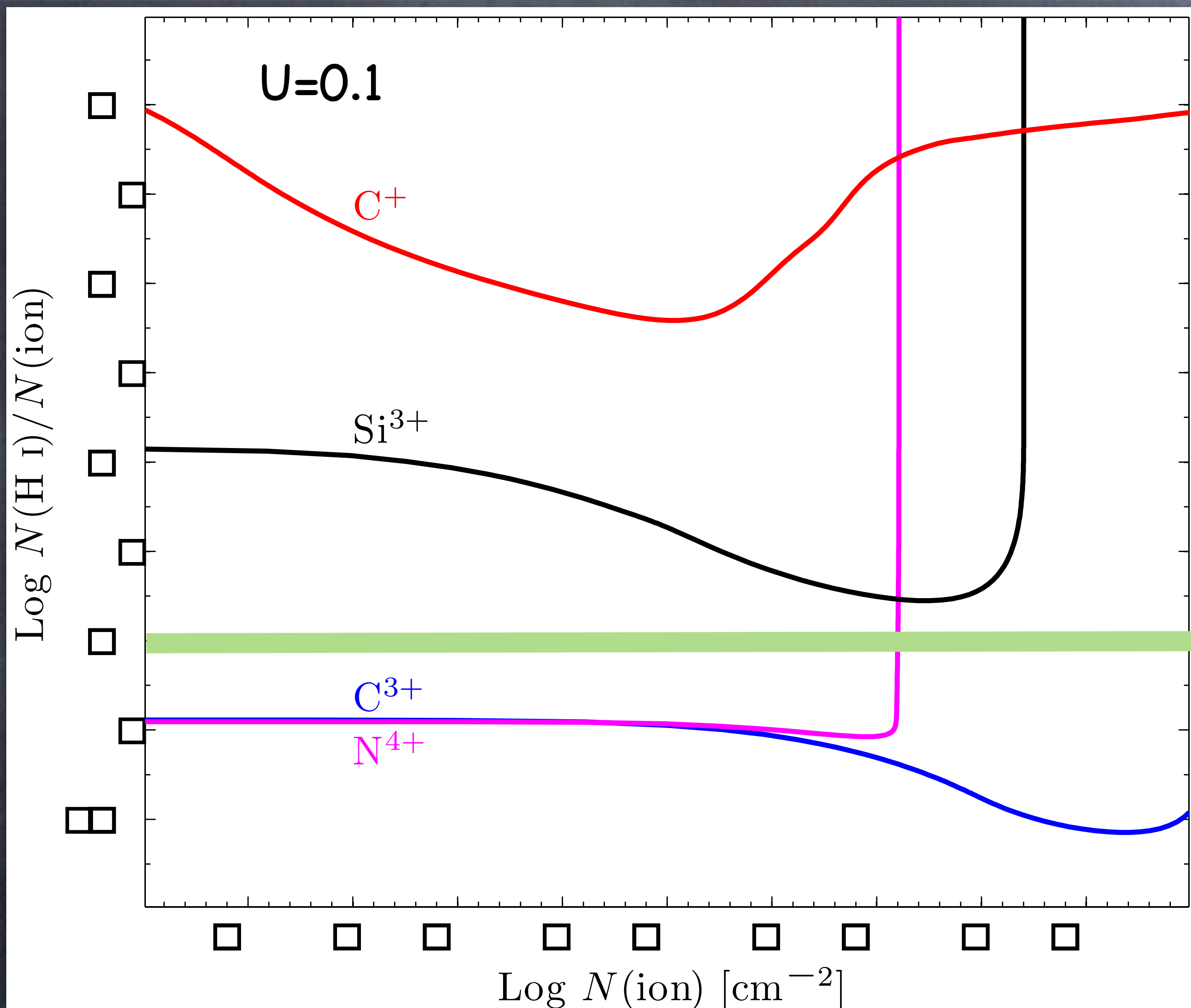

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=>I_{abs}(Lyα)≥I_{abs}(SiIV)

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Application to SDSS BALQs

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- Forming SDSS BALQ sample with strong SiIV absorption:

1. Choosing from DR5 BALQ catalog of Scaringi et al. (2009; N=3552).
2. z>2.7 (leaves N=973).
3. Broad (~3000 km/s) and deep (I<0.5) SiIV absorption (N=139).
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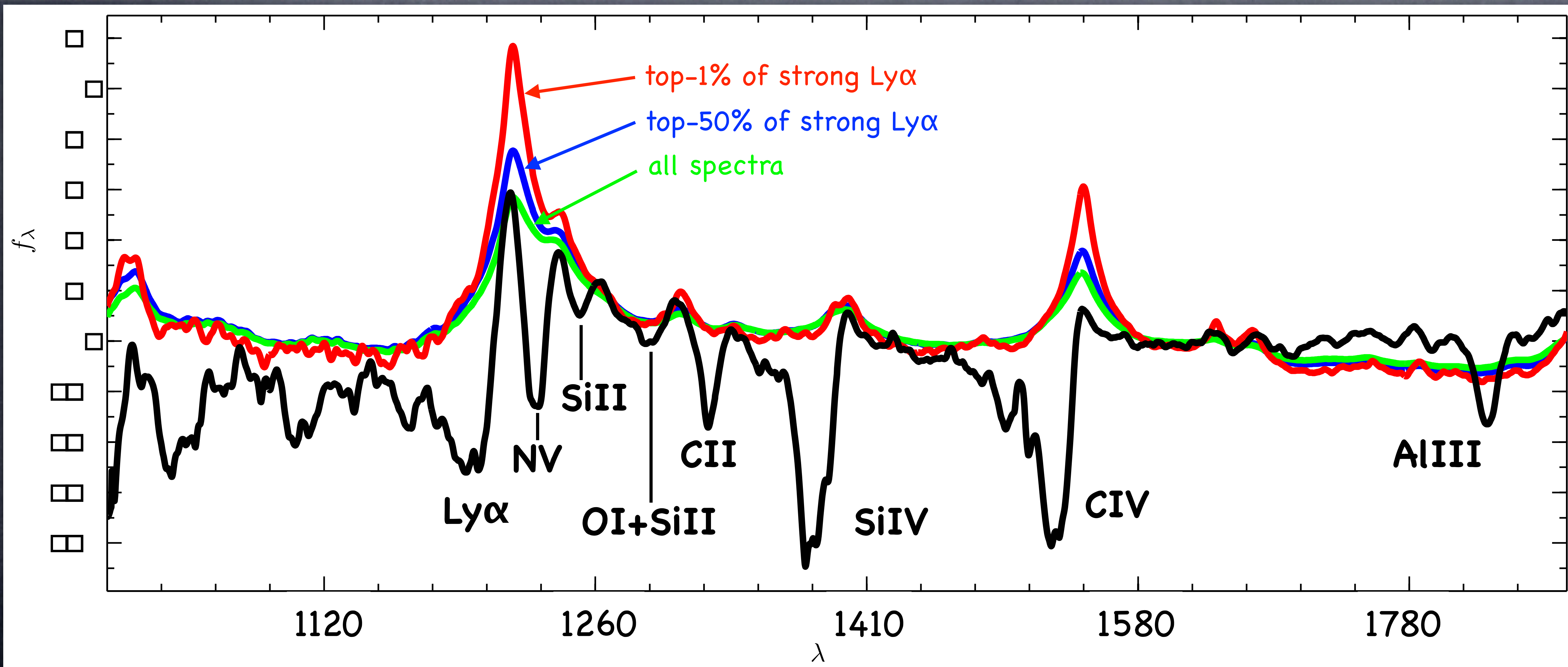
- Additional criteria:
  6. Similarity in: profile (N=11), z (N=9), and M_i (N=8).
     - **Final sample, N=8: 2.7<z<3.07, −27.7<M_i<−26.2.**

A Control Sample

- Objects from DR7 quasar catalog of Schneider et al. (2010).
- BALQs excluded.
- S/N>3.
- Same range of z and M_i as BALQ sample.
- **Spectra averaged based on Lyα emission strength.**

Composite BALQ + control samples



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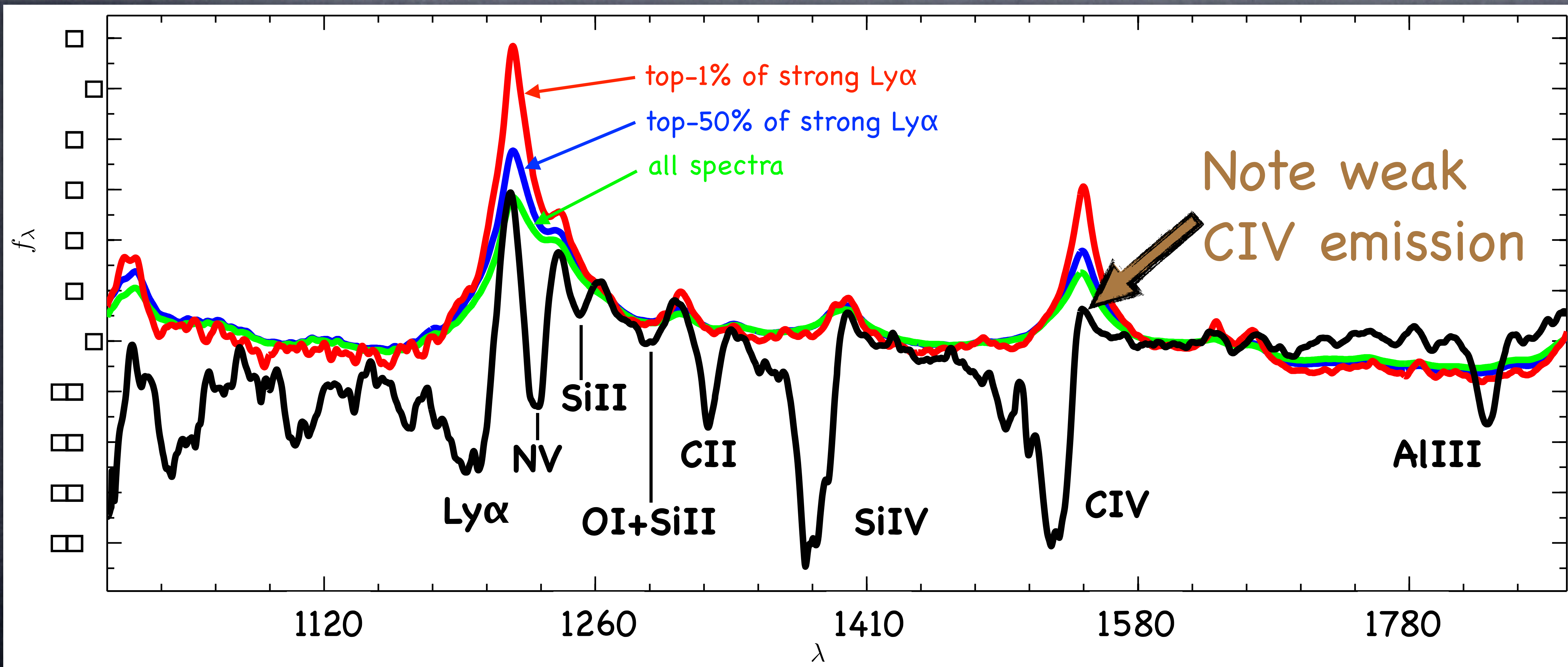

Results

- Metallicity conservative lower limits:
  - 3 objects consistent with $Z_{\odot}$ for average control spectrum.
  - 2 objects imply $Z>Z_{\odot}$, but consistent with $Z_{\odot}$ for top-30% control spectrum.
  - 1 object consistent with $Z_{\odot}$ only for top-1%.
  - 1 object requires $Z>2Z_{\odot}$ even for top-1% control spectrum.
- 1 object has an observed Lyα emission stronger than the top control object (wavelength calibration?).

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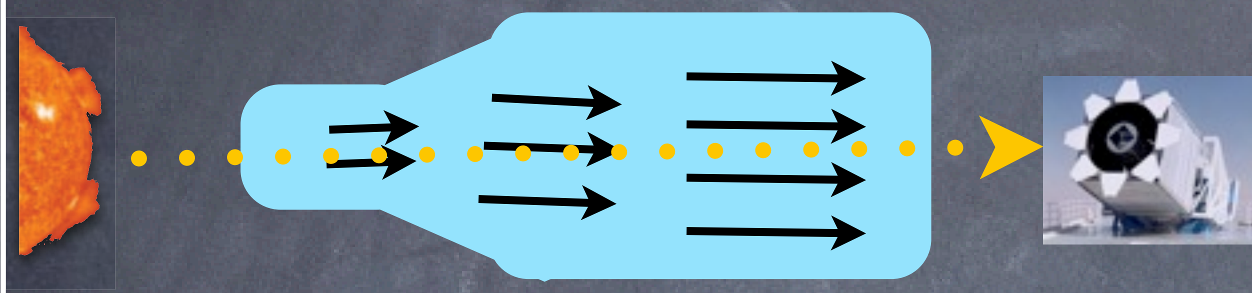

(v) set by N_{tot} and b; global CF

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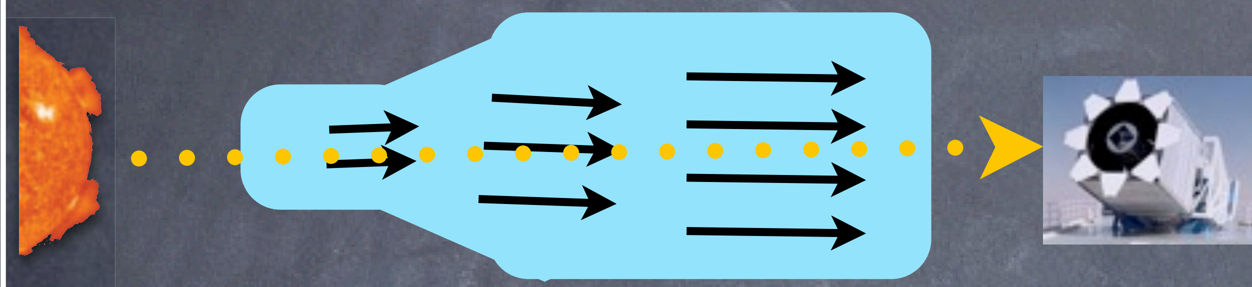

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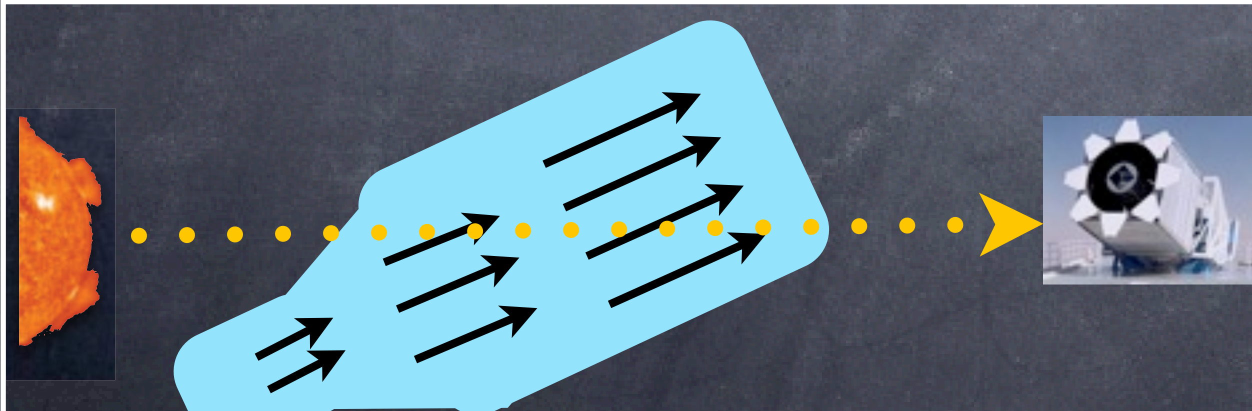

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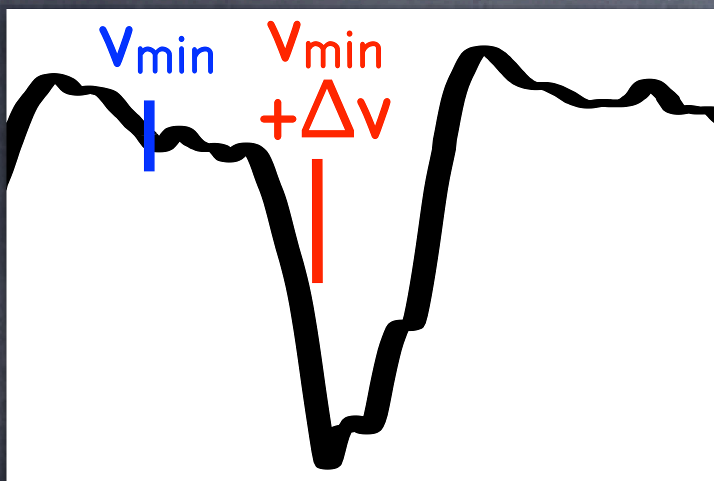

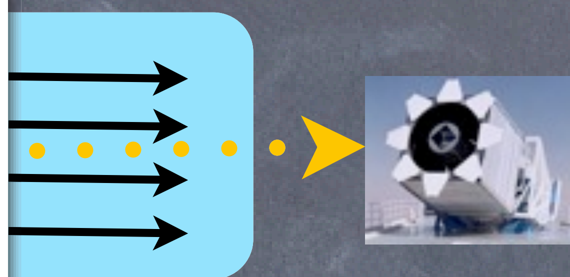

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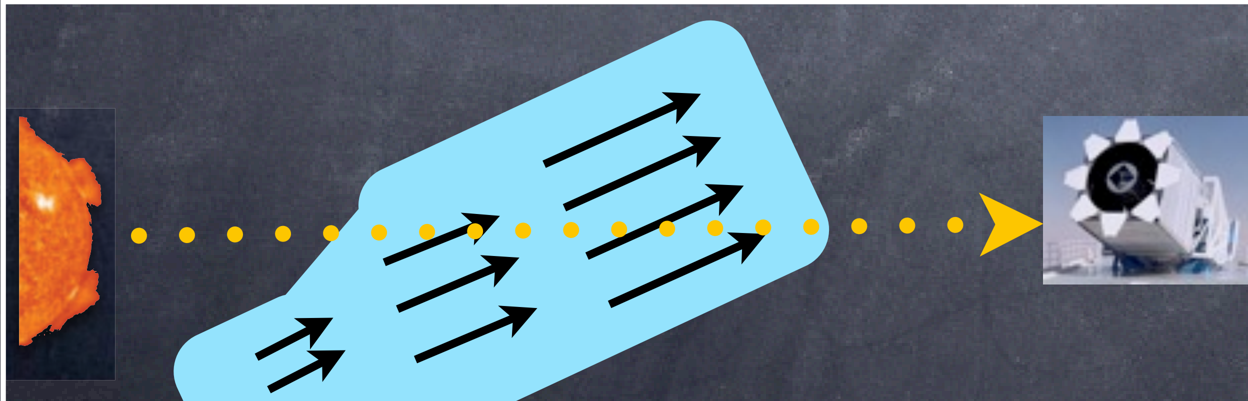

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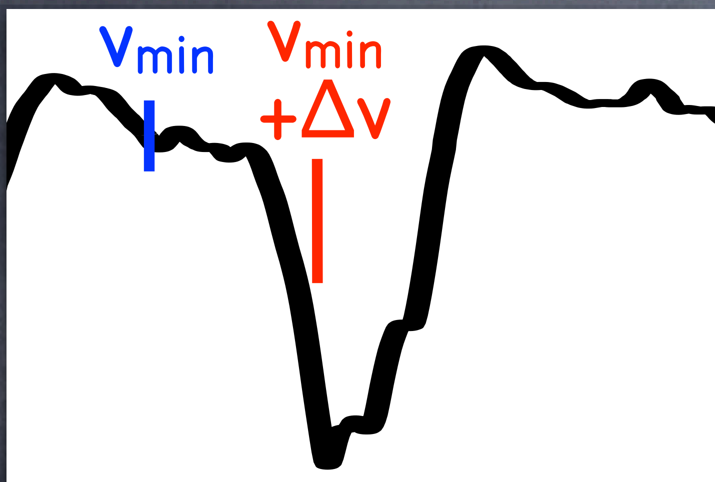

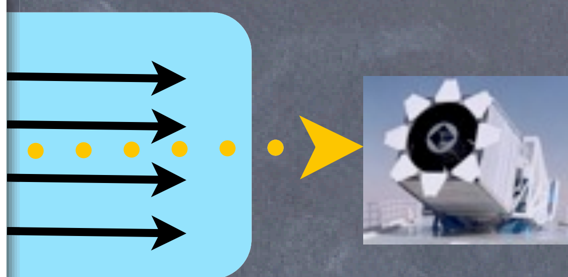

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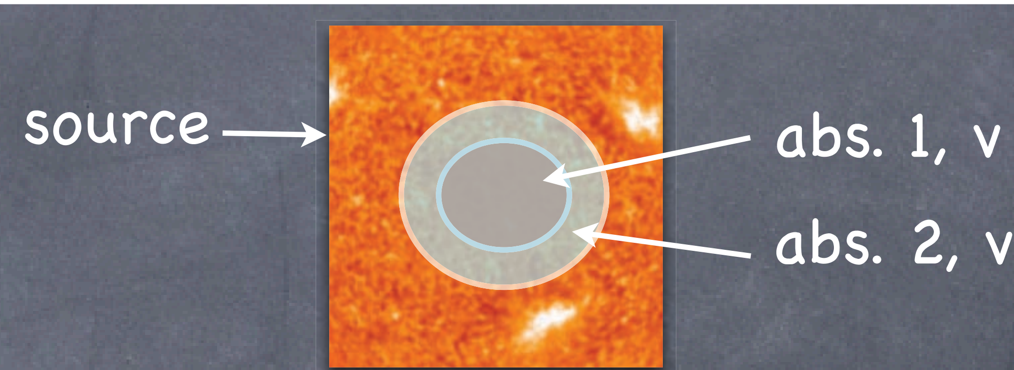

$$I(v) = [1 - \mathrm{CF}(v) + \mathrm{CF}(v)e^{-\tau(v)}]$$
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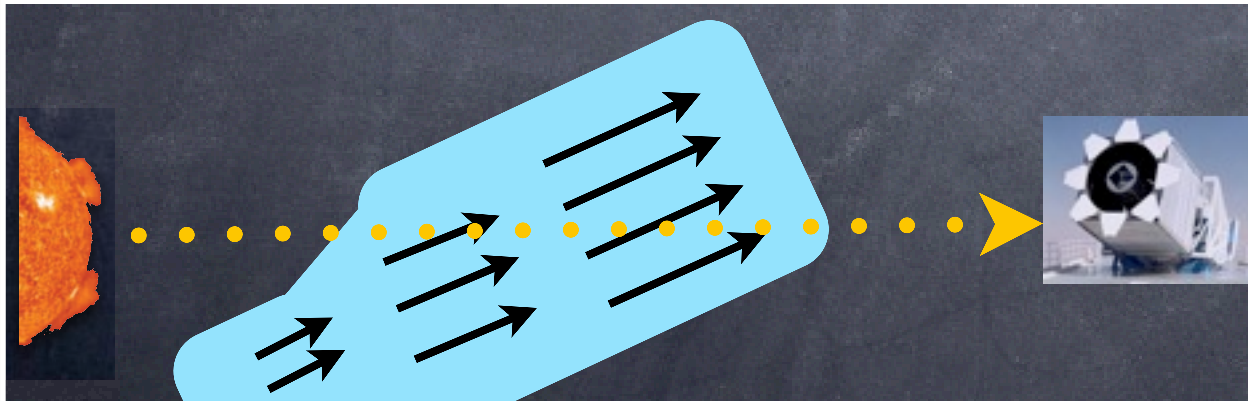
$$v' = v - 1940 \text{ km s}^{-1}$$



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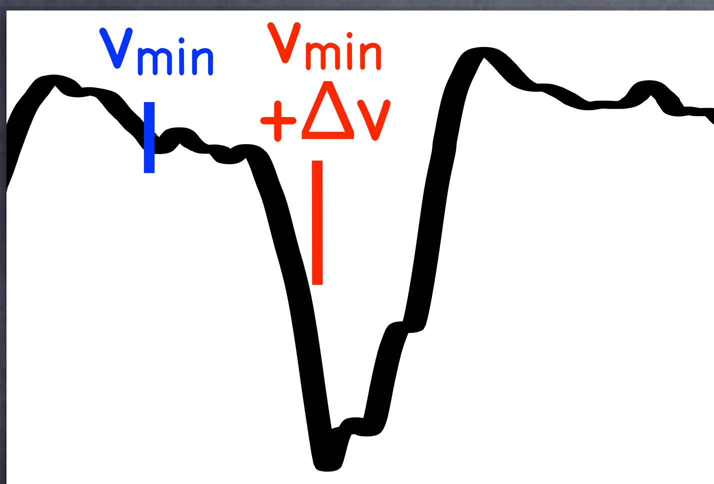

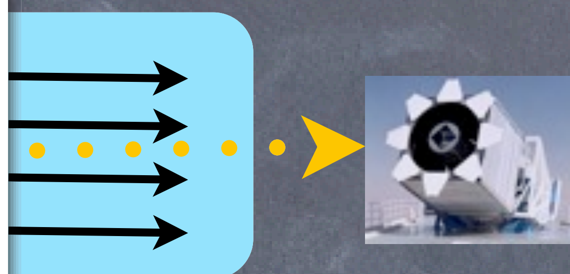

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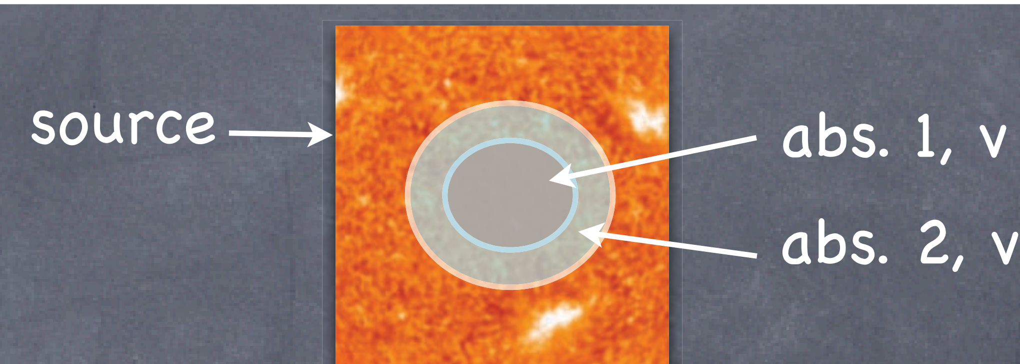

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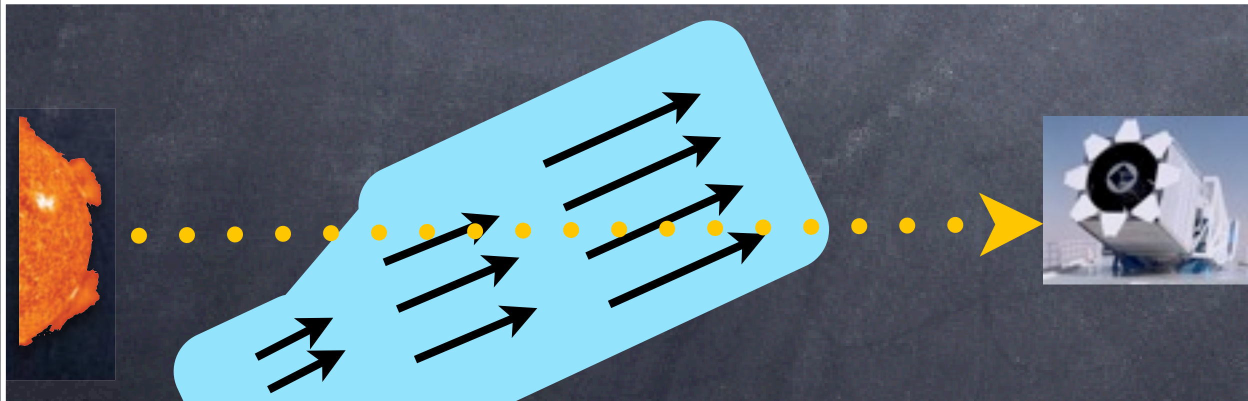

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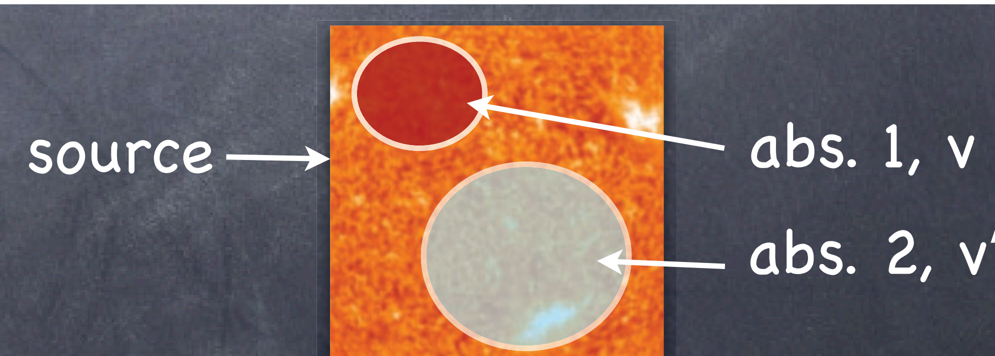

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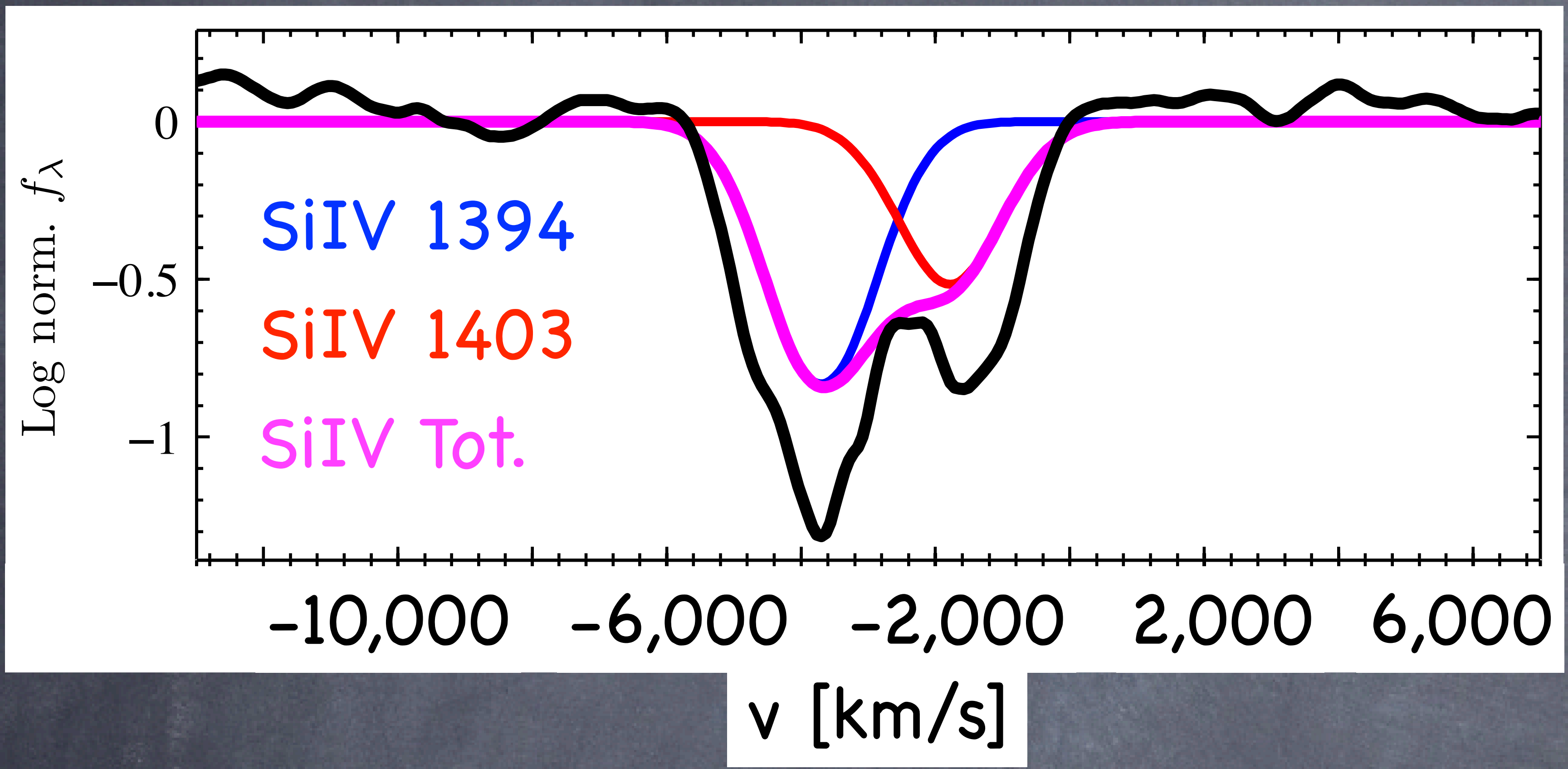
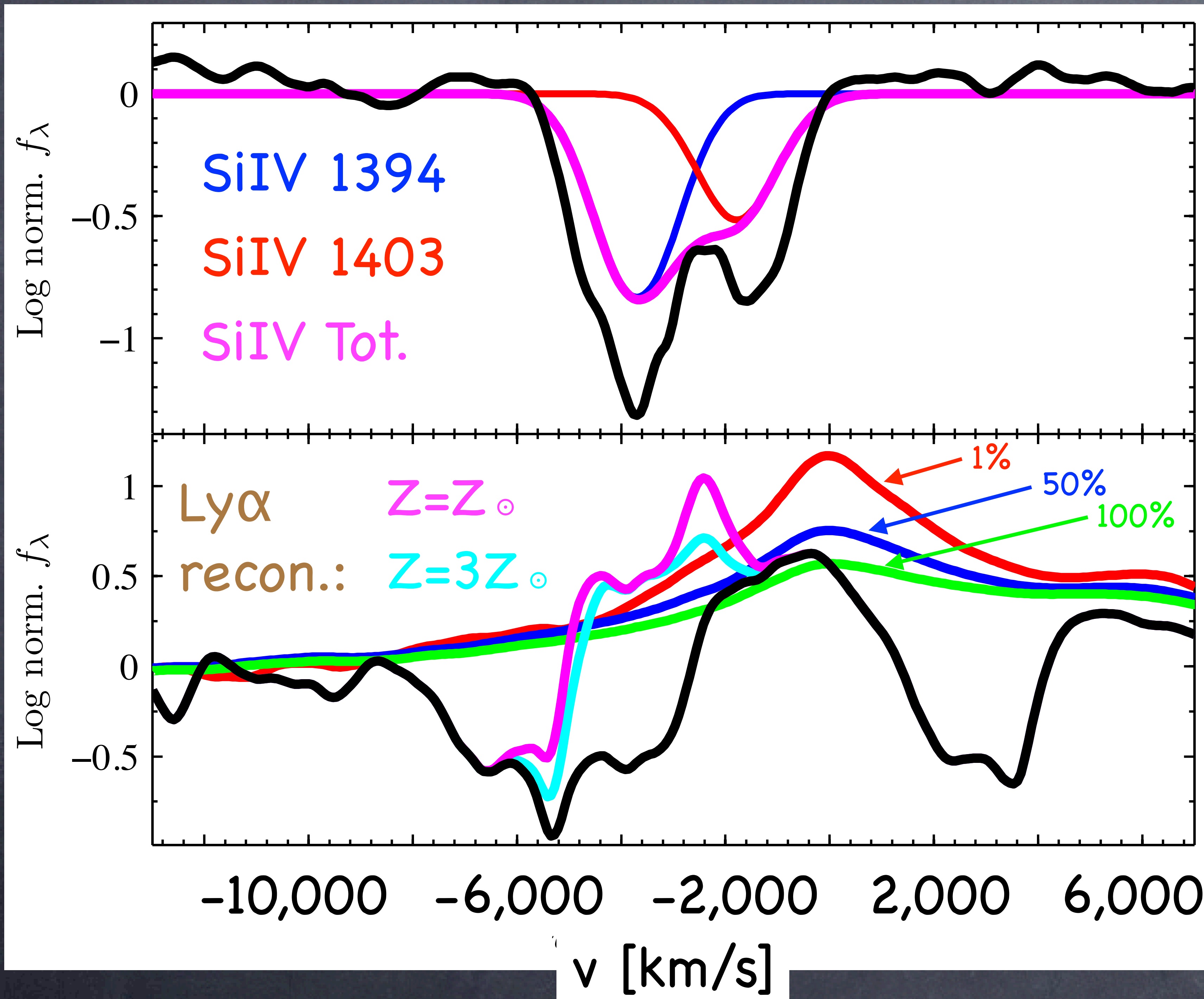
SDSS J102321



Single abs. system with b=1000 km/s, $N_{tot}(SiIV)=3\times10^{15}$ cm^{-2}, and global CF=0.9.

SDSS J102321



Single abs. system with b=1000 km/s, N_{tot}(SiIV)=3x10^{15} cm^{-2}, and global CF=0.9.

If global CF=1, Z>6Z☉.

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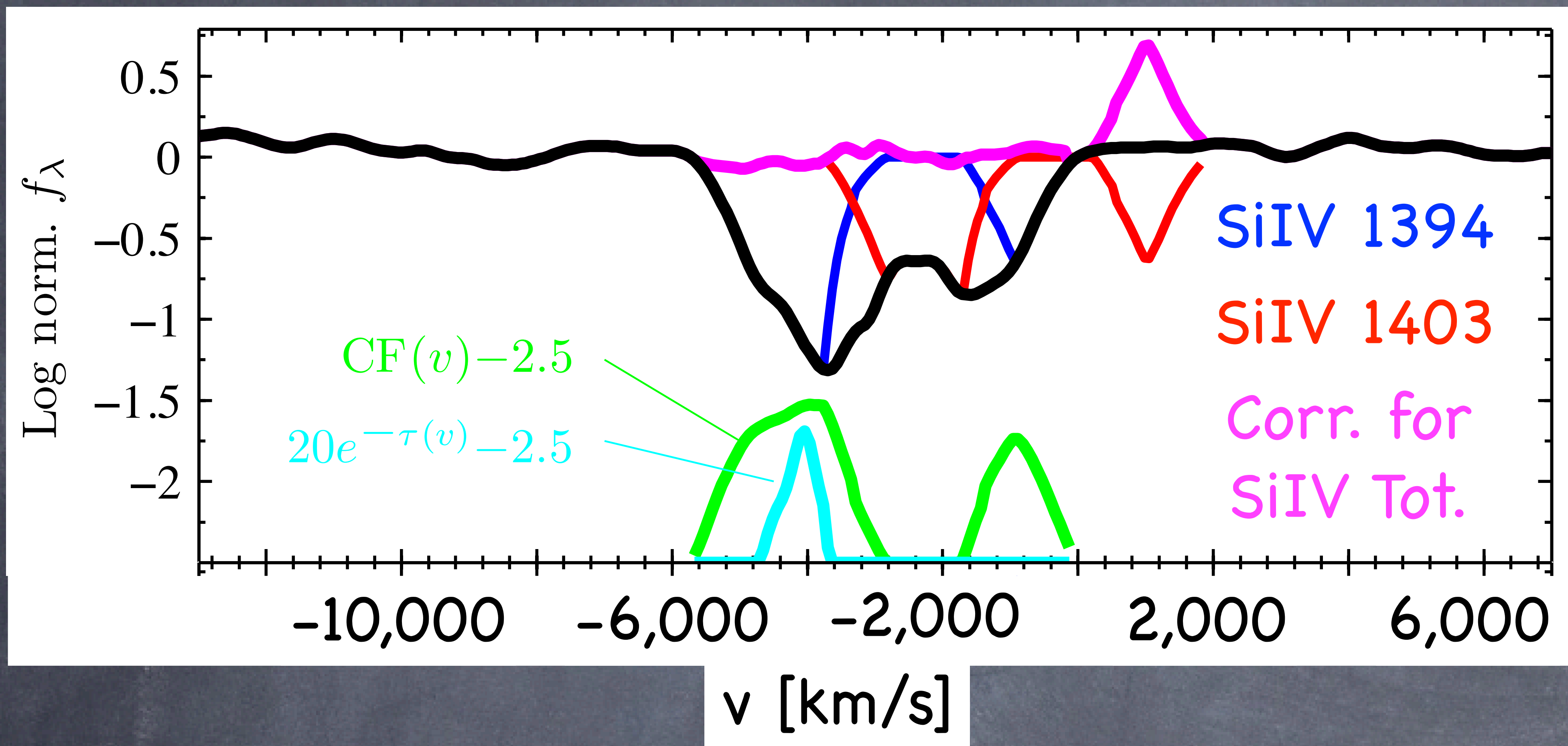

CF(v) model

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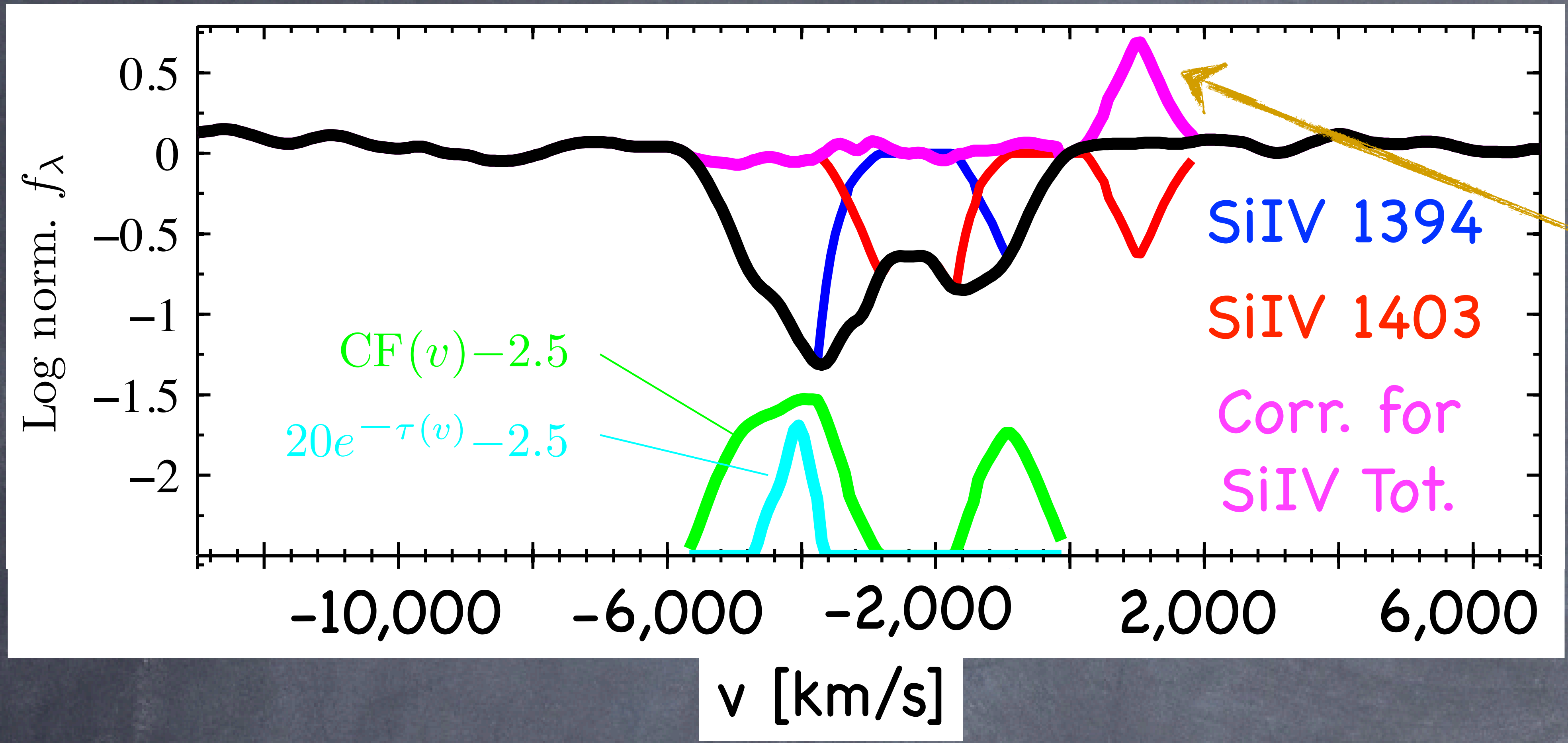

CF(v) model

Partial reconstruction of SiIV emission?

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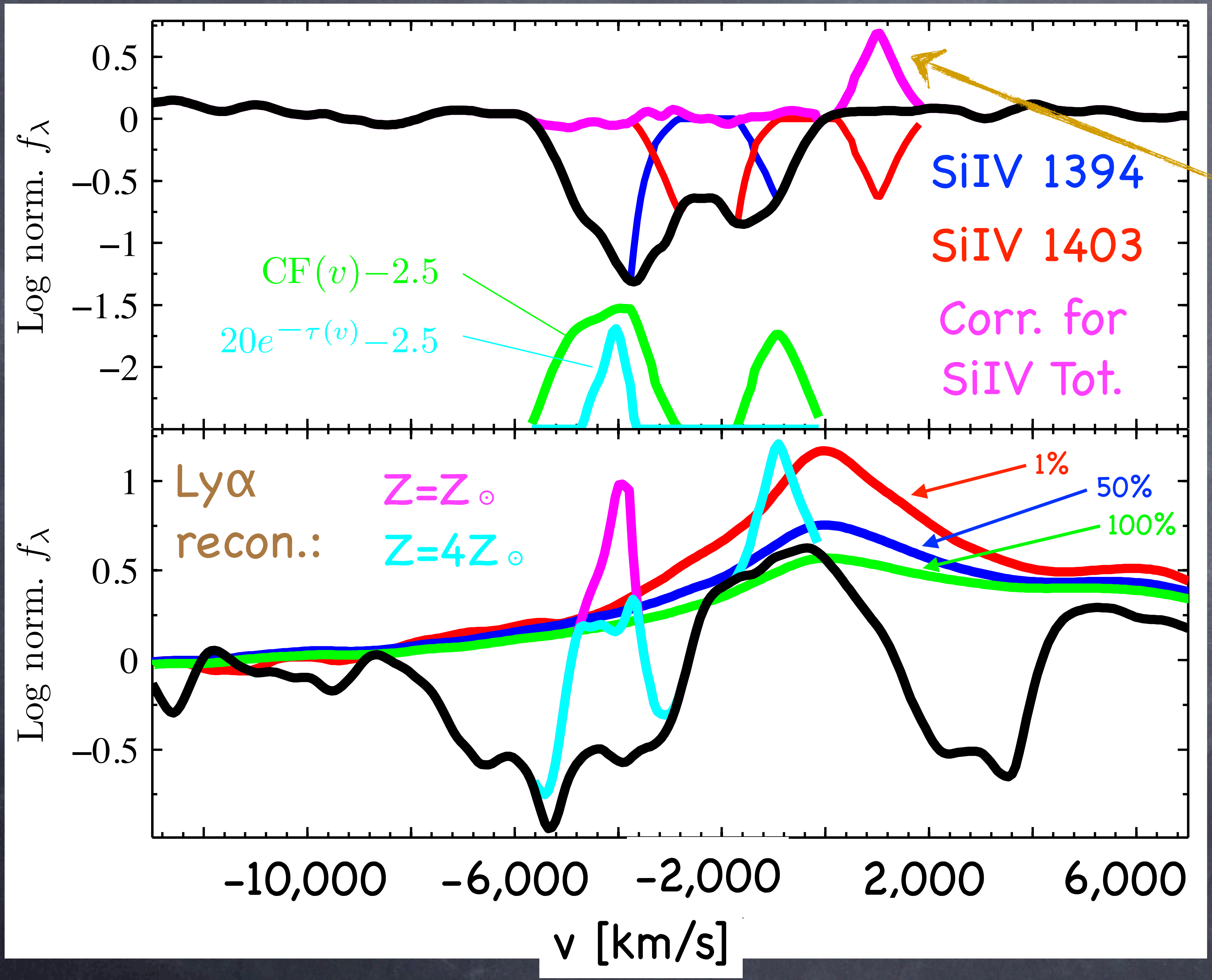

CF(v) model

Partial reconstruction of SiIV emission?

Conclusion & Future Prospects

- The metal runaway scenario is theoretically possible for AGNs.
- But, there is (yet) no observational confirmation.
- More theoretical and observational work is needed:
  - Incorporation of the decoupling process in outflow simulations.
  - New high S/N UV observations of z~1 objects:
    - Benefit: smoother Lyα profiles and less intervening Lyα absorption.
    - Select candidates based on a prominent AlIII 1857 absorption observed from the ground.