Photoionization models for extreme Lyα and HeII ratios in quasar halos

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Montserrat Villar-Martín, Luc Binette, Rahul Raj

Humphrey et al., submitted

Humphrey et al., in prep.

Galactic Labyrinths, Crete
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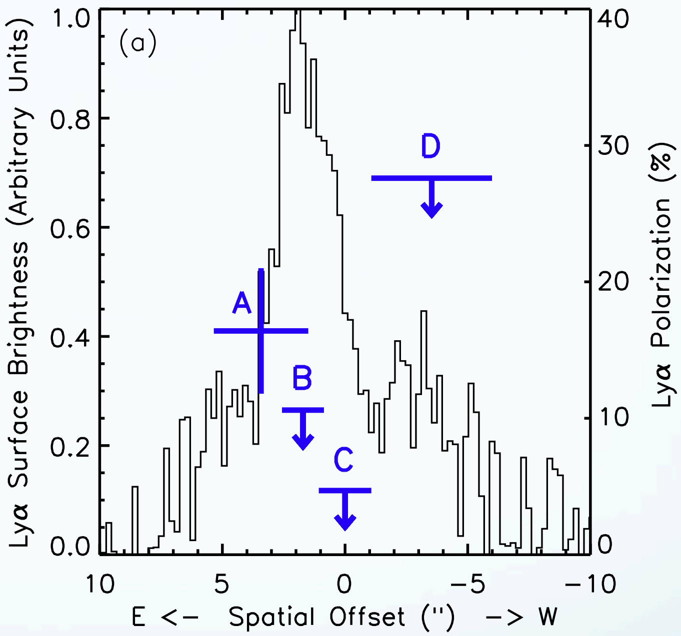
Motivating questions

Unusually high (extreme) Lyα/HeII in some AGN Lyα halos

- e.g. z>2 radio galaxy halos: Villar-Martín et al. (2007) Lyα / HeII > 30
- e.g. Borisova et al. (2016) Lyα/HeII ~100 or more in some high-z quasar halos
- Compared to **Lyα/HeII ~ 20** for Solar metallicity gas ionized by a powerlaw at moderate to high ionization parameter

Mechanisms to "enhance Lyα" above Case B recombination values (AGN)

- Collisional excitation e.g. Villar-Martin et al. (2007)
- Resonant scattering e.g. Cantalupo et al. (2014)
- Ionizing SED shape e.g. Humphrey et al. (2008), Arrigoni Battaia et al. (2015)



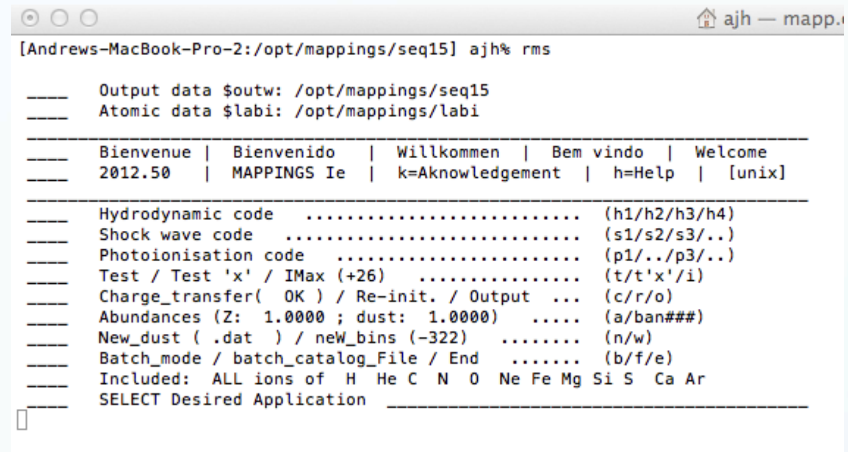
Highly polarized (P=16.4%) extended Lyα emission around a z=2.3 AGN (Humphrey et al. 2013)

Motivating questions:

→ Can these effects work together to produce "extreme" Lyα ratios?

→ Required range of parameters/conditions?

The MAPPINGS 1e Photoionization model grid



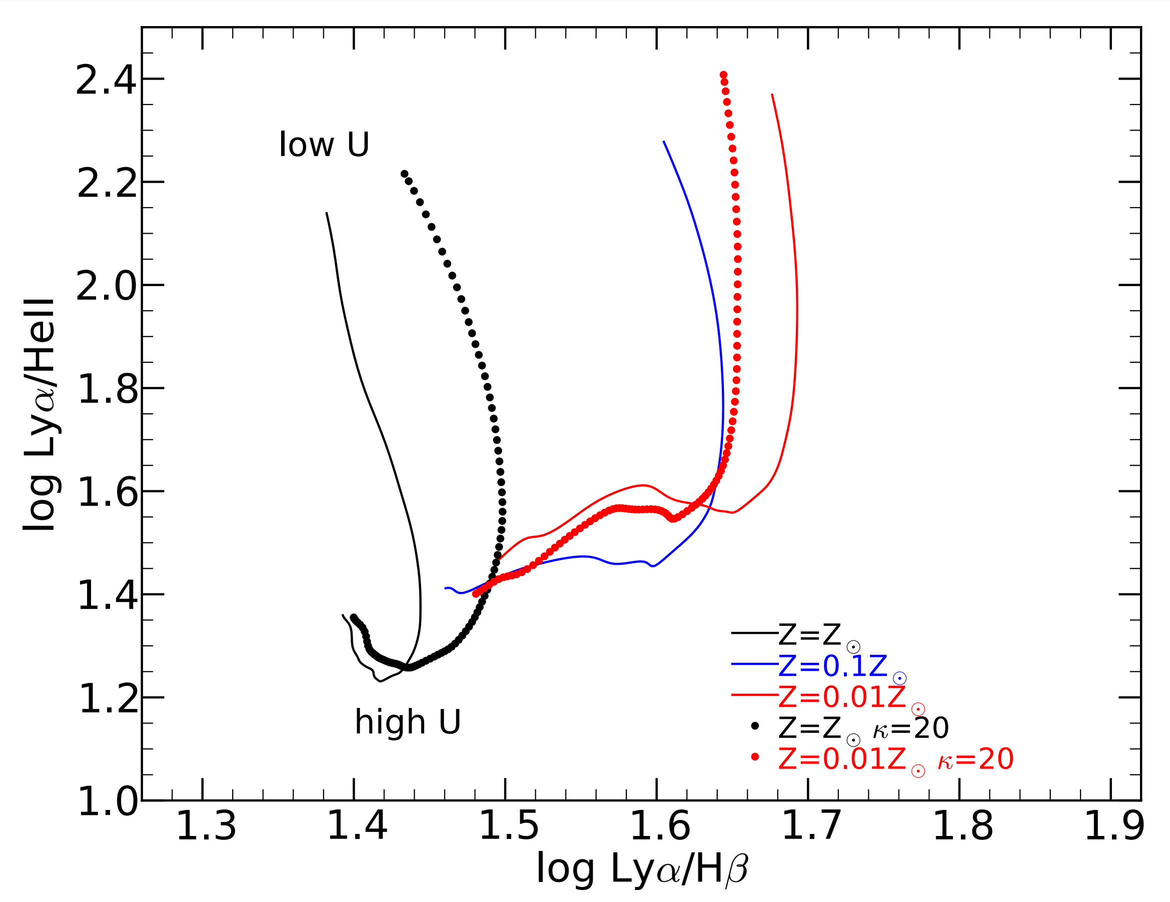
- MAPPINGS 1e code (Luc Binette)
- Single-slab, ionization-bounded
- n_H=1 or 100 cm^{-3}
- Varied parameters:
  - log U = -5 to +0.25
  - Ionizing power-law α=-1.0,-1.5,-2.0
    - $S_\nu \propto \nu^\alpha$
    - Or α=-1.5 powerlaw filtered by optically thin screen (F_{esc} = 0.90, 0.74, 0.50, 0.28)
  - Gas metallicity 0.01, 0.1 or 1.0 x solar
  - κ-distributed electron energies **or** Maxwell-Boltzmann

    → κ=20 … future paper to look in detail at the impact of κ in AGN

Enhanced Lyα /HeII : Low U, low metallicity, and κ

Gas metallicity, ionization parameter U, and choice of electron energy distribution all make a difference to Lyα/HeII

- Lower metallicity results in higher Lyα/HeII flux ratios
- Lower U results in higher Lyα/HeII
- κ-distribution may enhance or decrease Lyα/HeII depending on position in U and metallicity-space
- Lyα/HeII up to ~200



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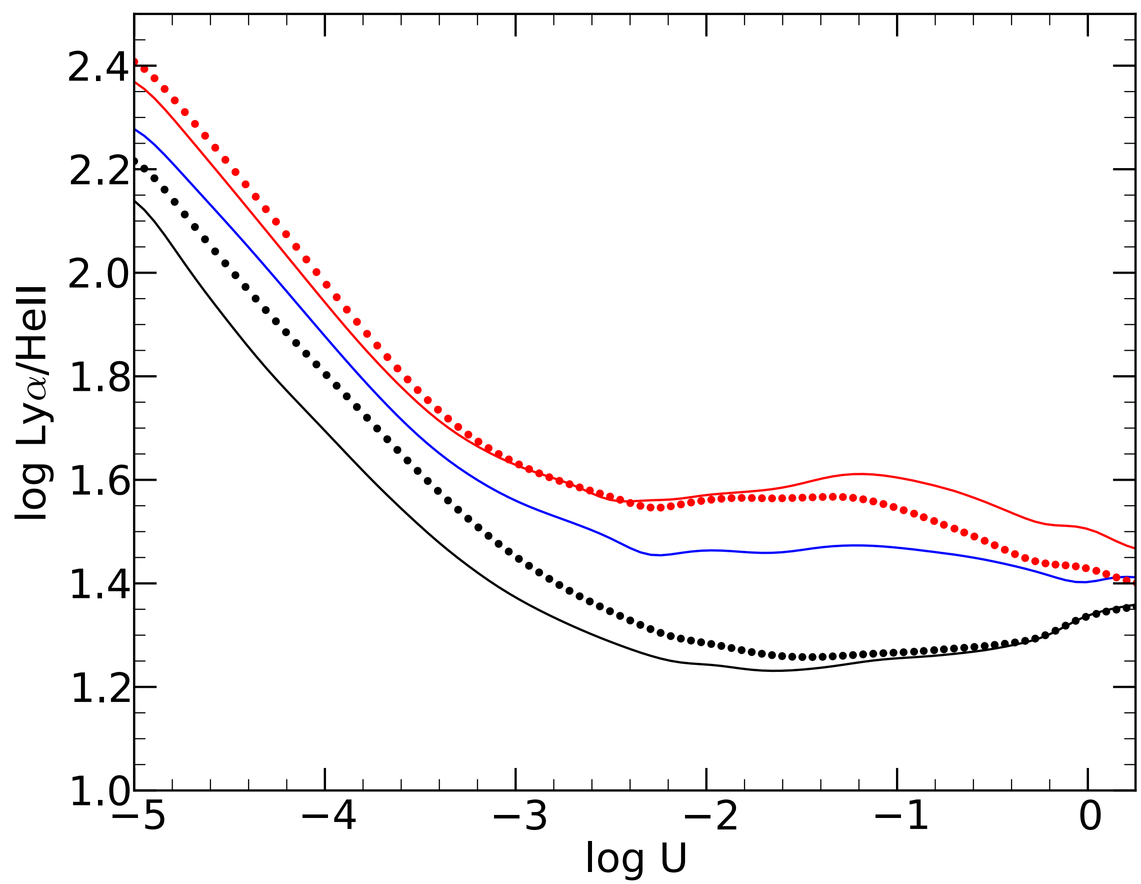


Enhanced Lyα **production**: Low U, low metallicity, and κ

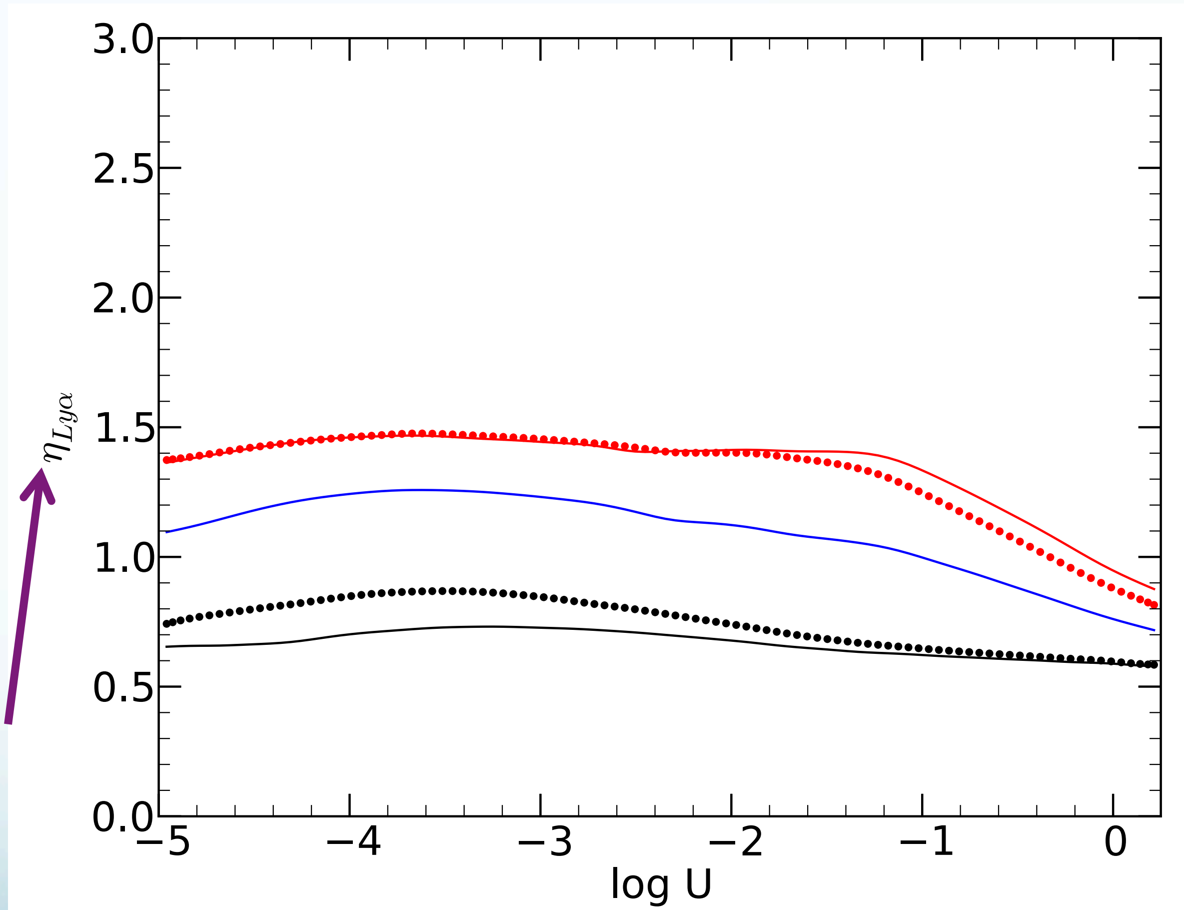
At low gas metallicity, the higher T_e results in more collisional excitation of Lyα

Likewise, κ-distribution enhances Lyα at high metallicity (~solar)

I.e., more Lyα photons produced per incident ionizing photon

$\eta_{Ly\alpha}$ = ratio of incident ionizing photons to Lyα photons

$\eta_{Ly\alpha}$ up to ~1.5 (collisional excitation dominated)

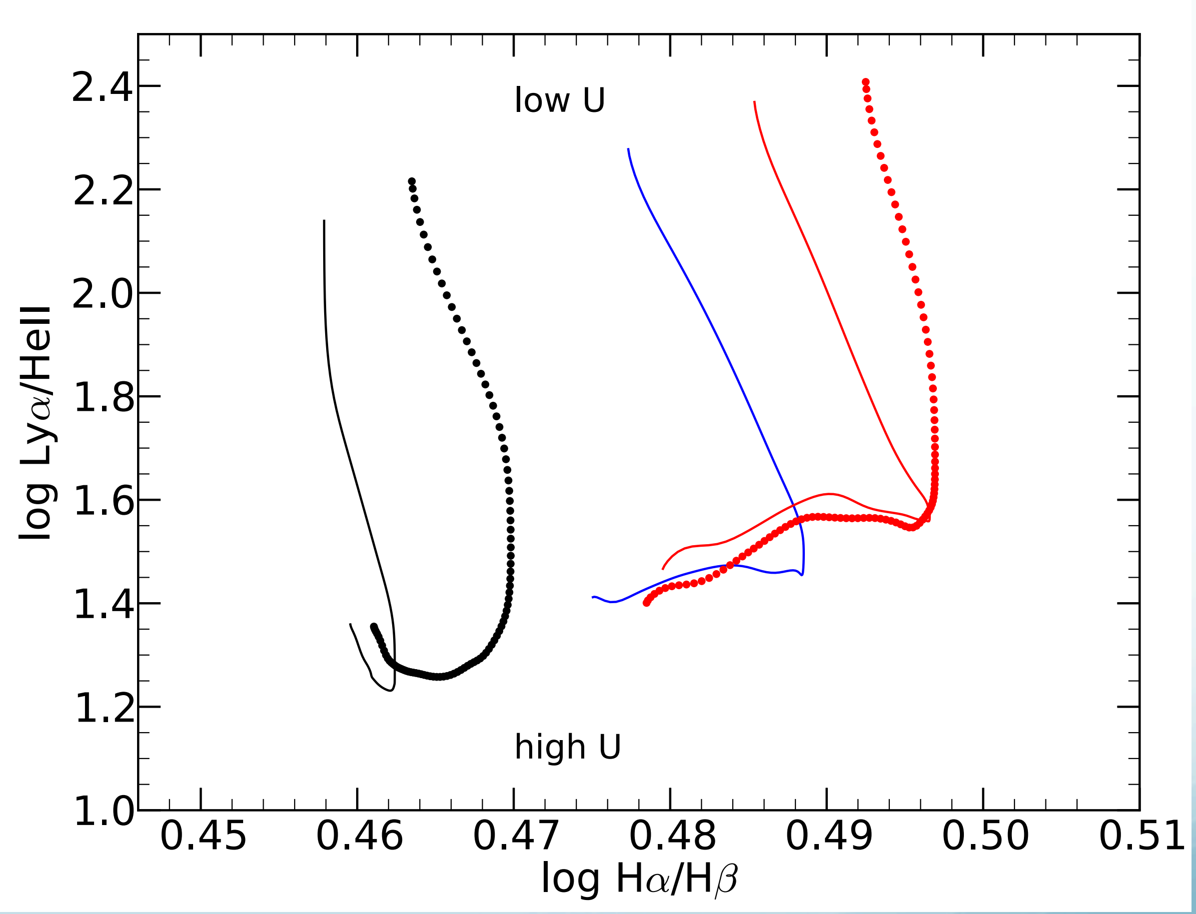


Enhanced Lyα emission: Low U, low metallicity, and κ

Hα/Hβ ratio confirms increased effect of collisional excitation

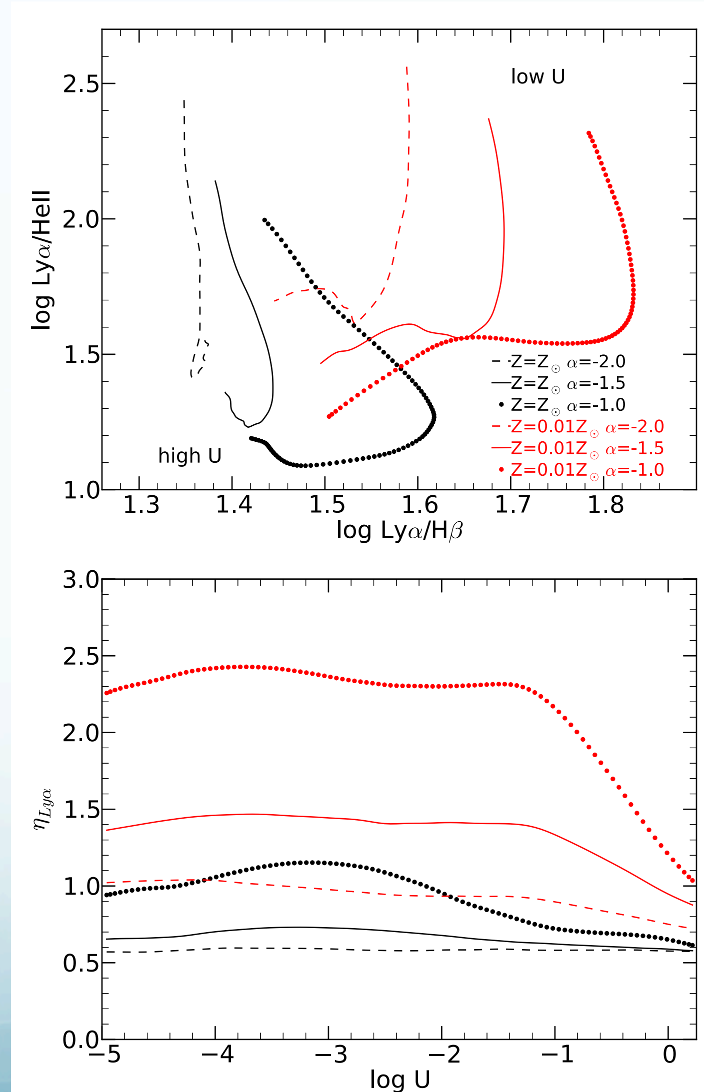
→ at lower metallicity

→ with κ-distribution



Powerlaw index α

- Softer SED (e.g. α= –2) results in higher Lyα/HeII
  - due to lower He^{++} / H^{+}



- ... but harder SED (e.g. α=-1) results in more Lyα photons per incident ionizing photon
  - extra collisional excitation due to higher T_e **and** higher H neutral fraction

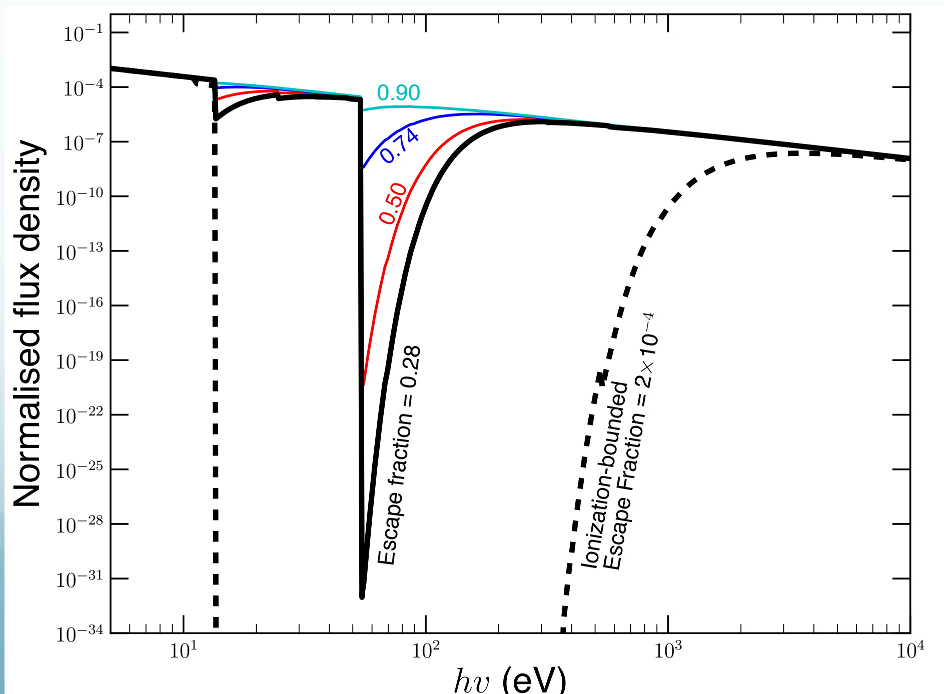
Powerlaw pre-filtered by a Lyman-leaking screen

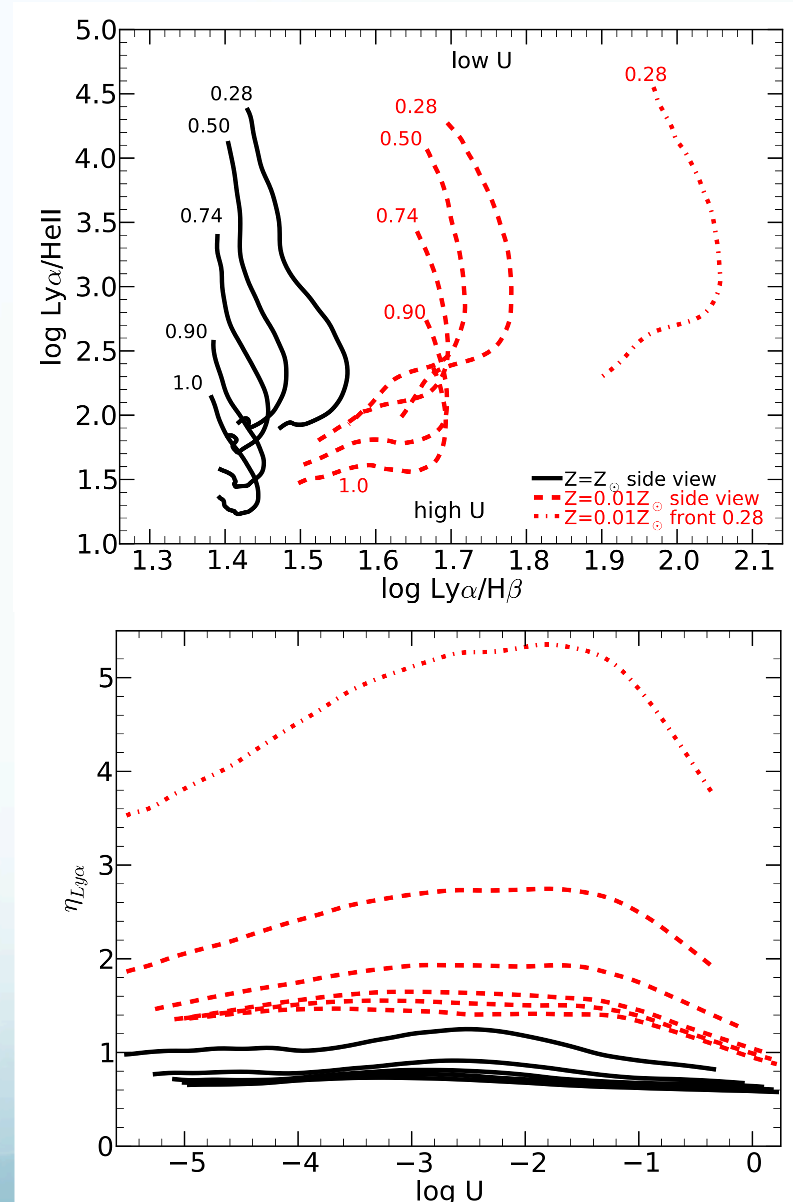
Less efficient photoionization of H

- → higher neutral fraction
- → higher temperature
- → more collisional excitation of Lyα

Change in He++ / H+ ratio

Lyα/HeII up to ~25000 and $\eta_{Ly\alpha}$ up to ~2.7





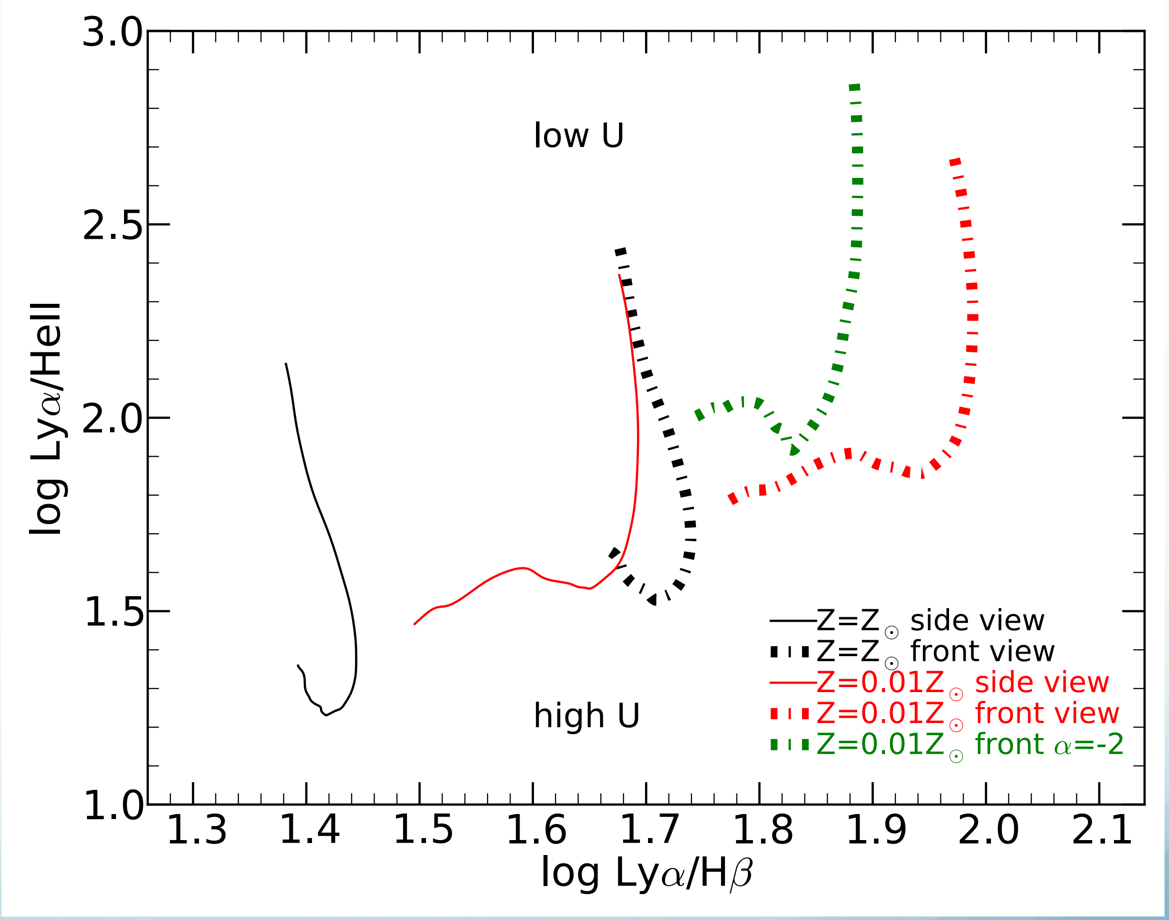
Cloud viewing angle: reflection by HI at rear of cloud

'front' view increases observed Lyα flux by factor of ~2

→ mimics Lyα/HeII of much lower gas metallicity

→ … or a softer SED

Caveat: this is not the ONLY possible Lyα scattering geometry



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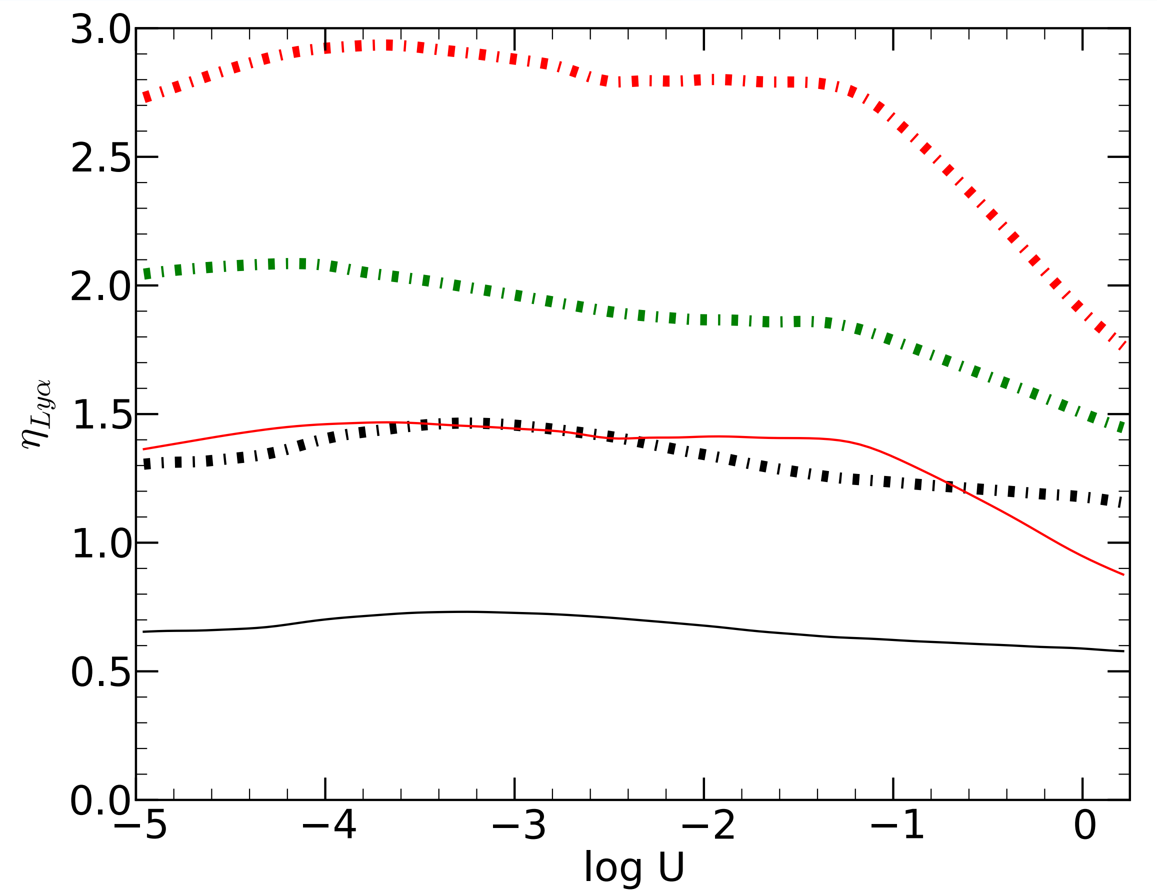


Some possible implications

- Does this lead to biases in surveys for high-z Lyα nebulae?

  → It should be easier to detect Lyα nebulae with higher rates of collisional excitation of Lyα. E.g., low metallicity halos, harder ionizing SED, etc.

- Lyα escape fraction in high-z galaxies

  → Case B values are not always appropriate. Enhancement of Lyα via collisional excitation needs to be taken into account, particularly if the gas metallicity is low and/or the ionizing SED is hard.

Can OV] 1213.8,1218.3 and HeII 1215.1 contaminate Lyα ?

- Highly-ionized, optically-thin BLR clouds (Shields et al. 1995)
  - OV] / Lyα up to ~1
  - HeII 1215.1 / Lyα up to ~0.2
- What about in low density NLR / Lyα halos?

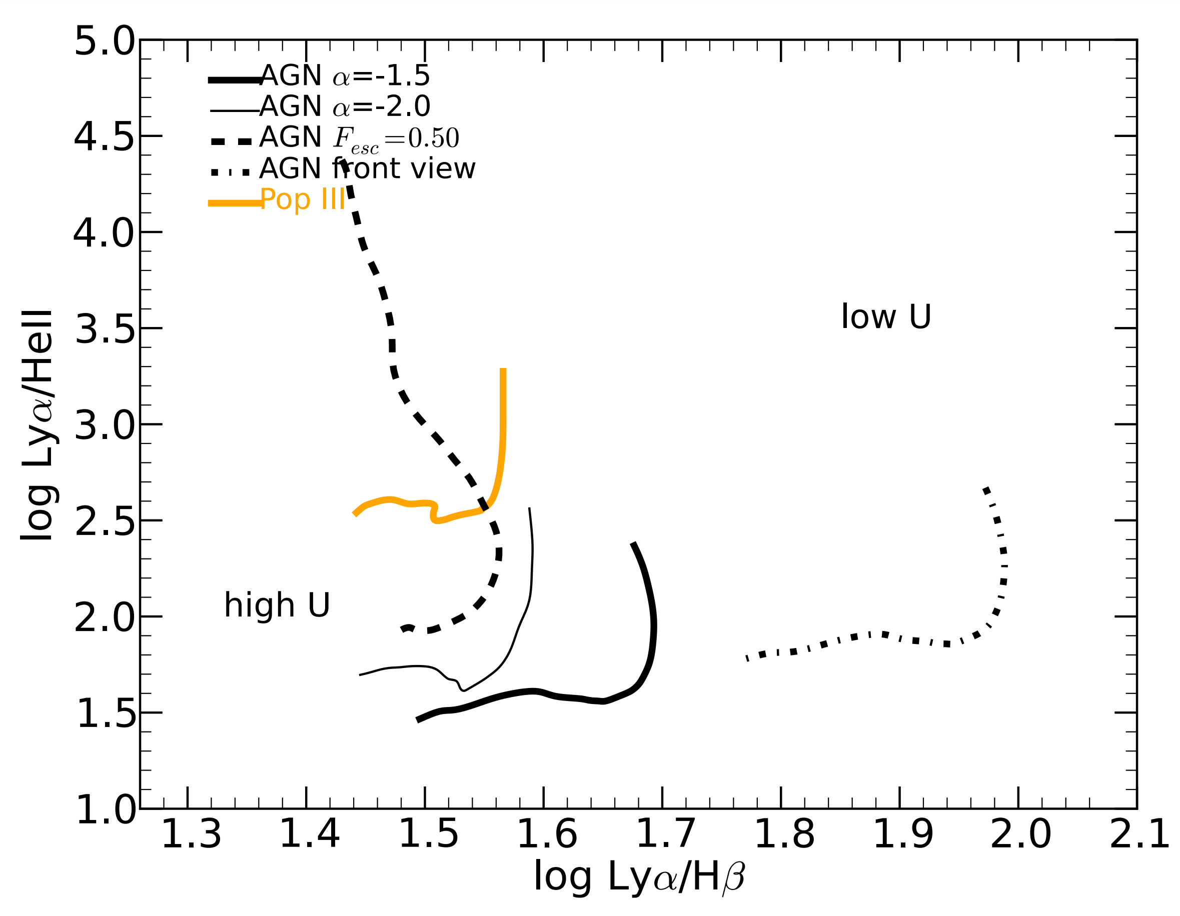
Pop III vs low metallicity AGN

Pop III models

- T_{BB} = 67200 K (equivalent to Teff = 80,000 K)
- log U = -5 to +0.25
- $Z/Z_\odot$ = 0.01

AGN models

- 4 AGN SEDs
  - α=-1, -1.5, -2
  - or filtered F_{esc}=0.5
- 2 viewing angles
  - 'side' or 'front' view
- Other parameters
  - log U = -5 to +0.25
  - $Z/Z_\odot$ = 0.01

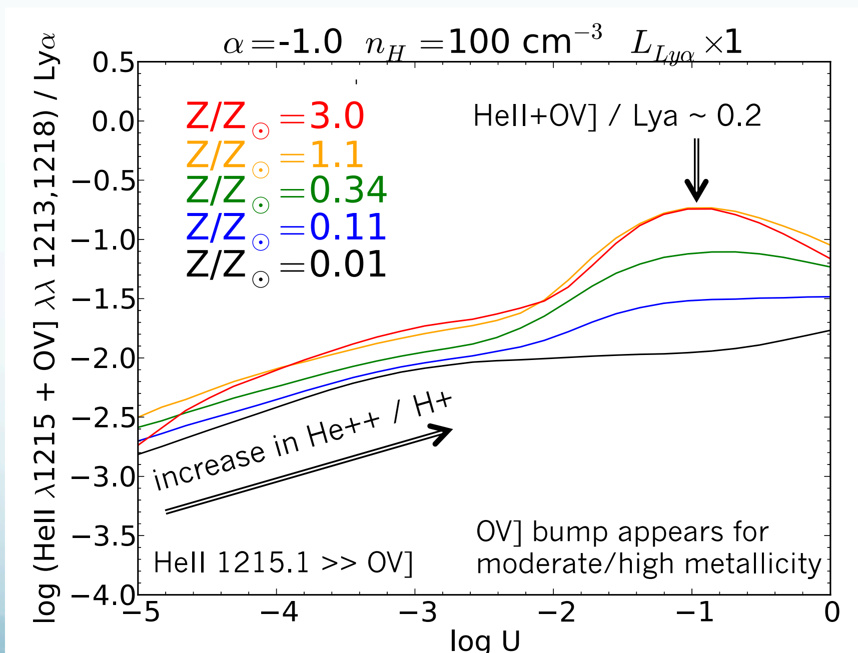


Lyα. HeII and Hβ together separate Pop III and AGN powerlaw models

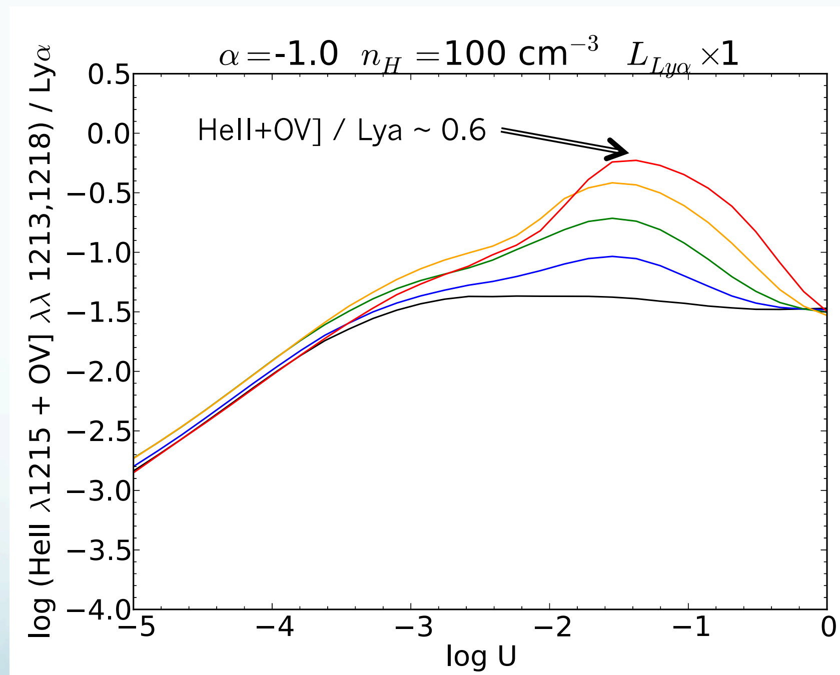
A degeneracy between Pop III and filtered AGN SED

(HeII 1215.1 + OV]) / Lyα as a function of U and metallicity

- MAPPINGS 1e AGN photoionization models
  - log U from –5 to 0
  - gas metallicity ($Z/Z_\odot$) from 0.01 to 3.0 x Solar
  - ionizing powerlaw α = –1.0 (similar results for other powerlaws)
  - gas density n_H = 100 cm^{-3} (similar results for other densities, i.e. 1 or 10^4 cm^{-3})



Optically thick models



Optically thin models (95% escape fraction)

A candidate OV] + HeII dominated object

Radio-loud type 2 quasar TXS 0211-122 (z=2.34) from Vernet et al. (2001)

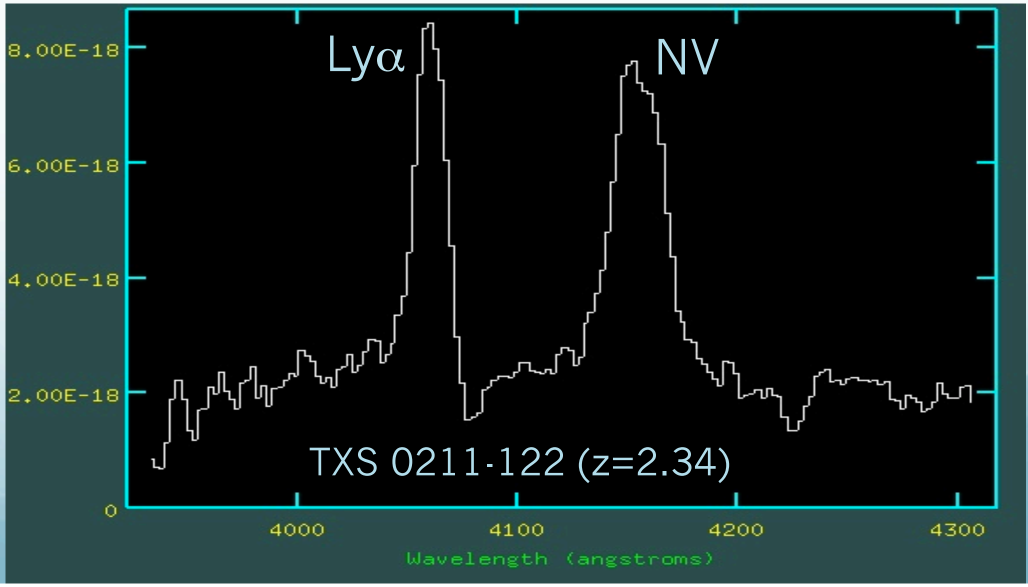
Observed:		Ionization model (U=0.03, α=-1.0, 3 x Solar)
Lyα/NV = 0.6	←	OV]/NV = 0.5
Lyα/CIV = 0.3	←	OV]/CIV = 0.3
Lyα/HeII 1640 = 0.6	←	OV]/HeII 1640 = 0.7

Theoretical (T=20,000K): HeII 1215.1/HeII 1640 = 0.33

UV continuum polarization of 19 % implies dusty ISM

Line ratios consistent with dust-quenched Lyα

Dominant OV] + HeII ?



Summary and Conclusions

- We have explored mechanisms to produce extremely high Lyα/HeII flux ratios, or to enhance the observed number of Lyα photons per incident ionizing photon, in extended AGN-photoionized nebulae at high-z

- **High Lyα/HeII:**
  - **low gas metallicity** (higher Te → more collisional excitation of Lyα)
  - **low ionization parameter** (higher HII / HeIII abundance ratio)
  - **soft ionizing SED** (higher HII / HeIII abundance ratio)
  - **filtered ionizing SED** (higher Te + higher HI fraction + higher HI / HeIII)
  - **κ-distributed electron energies** (collisional excitation of Lyα)

- **High $\eta_{Ly\alpha}$ (ratio of Lyα to incident ionizing photons):**
  - **low gas metallicity** (collisional excitation of Lyα)
  - **filtered ionizing SED SED** (higher Te + higher HI fraction + higher HI / HeIII)
  - **κ-distributed electron energies** (collisional excitation of Lyα)

- **Combining multiple effects can produce large enhancements**

- **OV] 1213.8,1218.3** doublet expected to significantly contaminate Lyα flux when the gas has **high metallicity, high U** and/or **low optical depth**