A MULTI-WAVELENGTH VIEW OF LYMAN-ALPHA NEBULAE: STUDYING THE GLOWING CGM IN DENSE ENVIRONMENTS

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LYMAN-ALPHA NEBULAE — THE OPPORTUNITY

• Lyα nebulae are a unique window into:
  • the CGM in emission over 10s or 100s of kpc
  • an active phase of galaxy formation (precursors to galaxy groups/clusters)
• To leverage this opportunity, need to know what is lighting them up — not always obvious!

Q2) What are the morphological and physical properties of the CGM?

Q3) What are the physical processes that shape the CGM on both large (kpc) and small (pc) scales?
LYMAN-ALPHA NEBULAE — THE CHALLENGE

• Ly\(\alpha\) nebulae are challenging to interpret:

  • in massive halos, messy, energetic regions

  • many processes at work — shock-heating, gravitational cooling, resonant scattering, and AGN/SF photoionization

  • difficult to disentangle, given uncertainties in both data and models
A MULTI-WAVELENGTH VIEW OF LYMAN-ALPHA NEBULAE

- Using multi-wavelength data on individual Lyα nebulae as a window into the CGM in dense regions:
  - **Environment** — census of nearby galaxies (& AGN)
  - **Kinematics** — map out how the gas is moving
  - **Physical conditions** — metallicity, density, source of ionization
A MULTI-WAVELENGTH VIEW OF LYMAN-ALPHA NEBULAE

• Using multi-wavelength data on individual Ly$\alpha$ nebulae reveals a more complete picture of the CGM in dense regions:

  • Environment — census of nearby galaxies (& AGN)
    galaxy redshifts, multi-wavelength coverage to find AGN

  • Kinematics — map out how the gas is moving

  • Physical conditions — metallicity, density, source of ionization
ENVIRONMENT: LYMAN-ALPHA NEBULAE LIVE IN OVERDENSE REGIONS

- Environments of Lyα nebulae overdense on large (~50 Mpc) scales
- Early circumstantial evidence: first examples found in surveys of dense regions (Francis+1999, Steidel+2000)
- Subsequent follow-up showed Lyα nebulae:
  - are strongly clustered (Yang+2009)
  - have low space densities (Saito +2006, Prescott 2009, Yang+2010)

(also see Cai+2016, 2017)
ENVIRONMENT: LYMAN-ALPHA NEBULAE LIVE IN OVERDENSE REGIONS

- On smaller scales, the local environment is overdense
- Large population of associated galaxies and a nearby obscured AGN
- Factor of ~4 galaxy overdensity on ~50-100 kpc scales

Found a similar situation even in a Ly$\alpha$ nebula that was previously thought to be alone...
A “COOLING” LYMAN-ALPHA NEBULA?

LABn06 z=3.157

Nilsson+2006 discovered an unusual Ly\(\alpha\) nebula:
- No associated galaxies
- No associated AGN
- Surface brightness profile similar to early “gravitational cooling” model predictions
- Became known as the “best candidate for a Ly\(\alpha\) nebula powered by cold accretion”

\textbf{Nilsson+2006}…because what else could it be?
Much has changed since the discovery

- New data - 3D-HST spectra, CANDELS imaging, much improved photo-zs, improved IRAC/MIPS fluxes, Herschel measurements
- New understanding of AGN identification using MIR, X-ray
- New theoretical predictions for Ly$\alpha$ nebulae powered by “cold accretion”

Drastically changed our understanding of this system - ostensibly the poster child of a gravitationally powered nebula

Nilsson+2006
LYMAN-ALPHA NEBULA DOES HAVE ASSOCIATED GALAXIES

- 7 photo-z neighbors within R<10” and dz<0.15
- 1 has a grism-z with a faint [OII] detection at the redshift of nebula
- Still no visible central galaxy, closest galaxy part of a foreground structure (z=1)
- Local region (R<10”) is overdense

NMSU student Agnar Hall finding similar results
THERE IS A NEARBY OBSCURED AGN

- IRAC/MIPS source with power-law MIR SED, consistent with being an obscured AGN
- Lower surface brightness Ly$\alpha$ emission encircles obscured AGN
- AGN redshift poorly constrained, but highly suggestive of an association

Prescott+2015b
AGN COMING OUT OF HIDING

• The more carefully we look, the more AGN we find

• AGN often offset from the Ly$\alpha$ emission

• Demonstrates importance of multi-wavelength coverage to get a full census of the local region

$\sim$60-80% AGN

Ly$\alpha$ nebulae

Overzier+2013
A MULTI-WAVELENGTH VIEW OF LYMAN-ALPHA NEBULAE

• Using multi-wavelength data on individual Lyα nebulae reveals a more complete picture of the CGM in dense regions:

  • **Environment** — census of nearby galaxies (& AGN)

  • **Kinematics** — map out how the gas is moving

    multiple emission lines, Lyα vs. less optically thick lines

  • **Physical conditions** — metallicity, density, source of ionization
Velocity offsets of Ly\(\alpha\) vs. non-resonant lines (e.g., H\(\alpha\), [O\textsc{iii}]) encode information about outflow/infall.

Low velocity offsets measured for LAEs.

Low velocity offsets for embedded galaxies within Ly\(\alpha\) nebulae.

Prescott+2015a

KINEMATICS - LOW VELOCITY OFFSETS IN LYMAN-ALPHA NEBULAE

PA=52.44°

Lyα HeII CIV CIII]

11 arcsec - 94 kpc

z=1.67

7.4 arcsec = 63 kpc

PRG1

Prescott+2015a
KINEMATICS - LOW VELOCITY OFFSETS IN LYMAN-ALPHA NEBULAE

- Low velocity offsets for LAEs and embedded galaxies in Lyα nebulae
- Measure similarly low velocity offsets within the diffuse gas in Lyα nebulae
- Lyα roughly tracing the systemic velocity

Prescott+2015a
KINEMATICS — SIGNS OF ROTATION IN LYMAN-ALPHA NEBULAE

- Large-scale velocity shear suggestive of rotation
- Similar to predictions for recently accreted gas

(Also see talks by F. Arrigoni-Battaia, D. C. Martin)

Stewart+2013

Prescott+2015a
A MULTI-WAVELENGTH VIEW OF LYMAN-ALPHA NEBULAE

• Using multi-wavelength data on individual Lyα nebulae reveals a more complete picture of the CGM in dense regions:
  
  • **Environment** — census of nearby galaxies (& AGN)
  
  • **Kinematics** — map out how the gas is moving
  
  • **Physical conditions** — metallicity, density, source of ionization

  multiple emission lines, emission line diagnostics, comparisons to photoionization models
PHYSICAL CONDITIONS — IONIZATION

- B1 - IFU data, split nebula into two large apertures
- — consistent with AGN photoionization

Overzier+2013

\[ z = 2.38 \]
PHYSICAL CONDITIONS — IONIZATION

- PRG1 — deep spectroscopy from 2 nights on Keck/LRIS allows us to use many spatial apertures across the nebula
- — consistent with AGN photoionization

Prescott, Martin, & Dey in prep. (overplotted on Feltre+2016)

Ly\(\alpha\) 11 arcsec - 94 kpc

CIV 7.4 arcsec = 63 kpc

HeII

CIII\]

PRG1
PHYSICAL CONDITIONS — METALLICITY, DENSITY, IONIZATION

PRG1

PA = 52.44°

Preliminary

Z ~ 0.03 - 0.1 Z_0

n_H ~ 3 - 10 cm^{-3}

log U ~ -1 to -2

assuming AGN powering, fit CIV+HeII+CIII] measurements using grid of *Cloudy* photoionization models

Prescott et al., in prep.
PHYSICAL CONDITIONS — METALLICITY, DENSITY, IONIZATION

PRG1
PA=146.0°

- $Z \sim 0.03 - 0.1 Z_\odot$
- $n_H \sim 3 - 10 \text{ cm}^{-3}$
- $\log U \sim -1 \text{ to } -2$

assuming AGN powering, fit CIV+HeII+CIII] measurements using grid of Cloudy photoionization models

Prescott et al., in prep.
A MULTI-WAVELENGTH VIEW OF LYMAN-ALPHA NEBULAE — SUMMARY

• Using multi-wavelength data on individual Lyα nebulae as a window into the CGM in dense regions:

  • Environment — live in regions that are overdense in galaxies; the closer we look, the more AGN we find

  • Kinematics — low velocity offsets and evidence for large-scale rotation

  • Physical conditions — evidence for AGN powering, constraints on metallicity, density, ionization across central 30-40 kpc

Q2) What are the morphological and physical properties of the CGM?

Q3) What are the physical processes that shape the CGM on both large (kpc) and small (pc) scales?