Lyman Alpha Blobs & Monte-Carlo Imaging Polarimetry of Lyα

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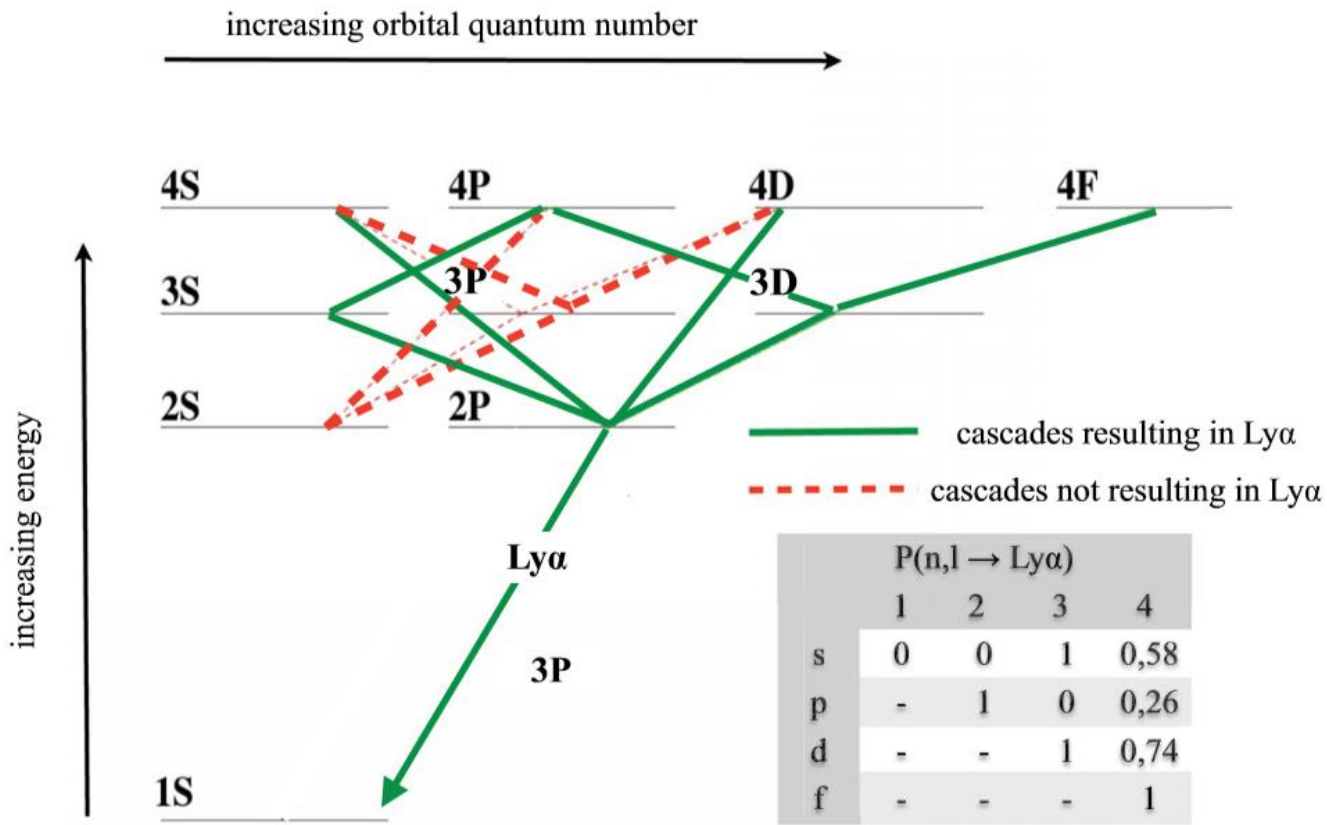
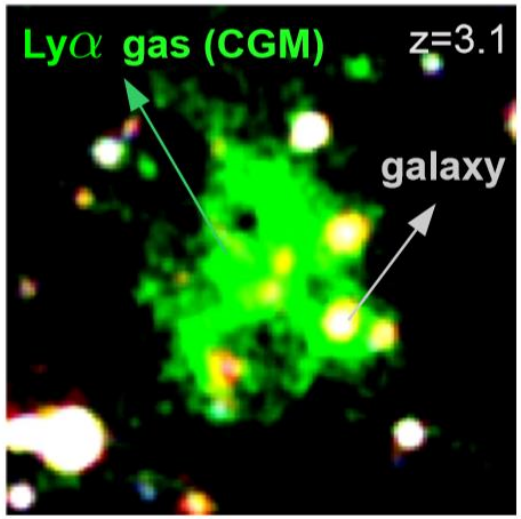
Contents

Why Lyα is Important



	P(n,l → Lyα)			
	1	2	3	4
s	0	0	1	0,58
p	-	1	0	0,26
d	-	-	1	0,74
f	-	-	-	1

Lyman Alpha Blobs



25″ ~ 200kpc
SSA22-LAB1
(Matsuda+04; Subaru)

?

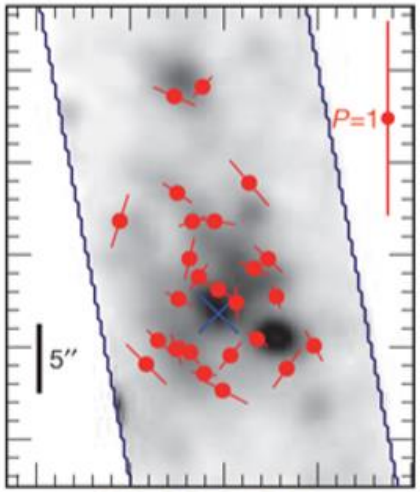
photo-ionization
by stars & AGN
(H II region in M33)

or

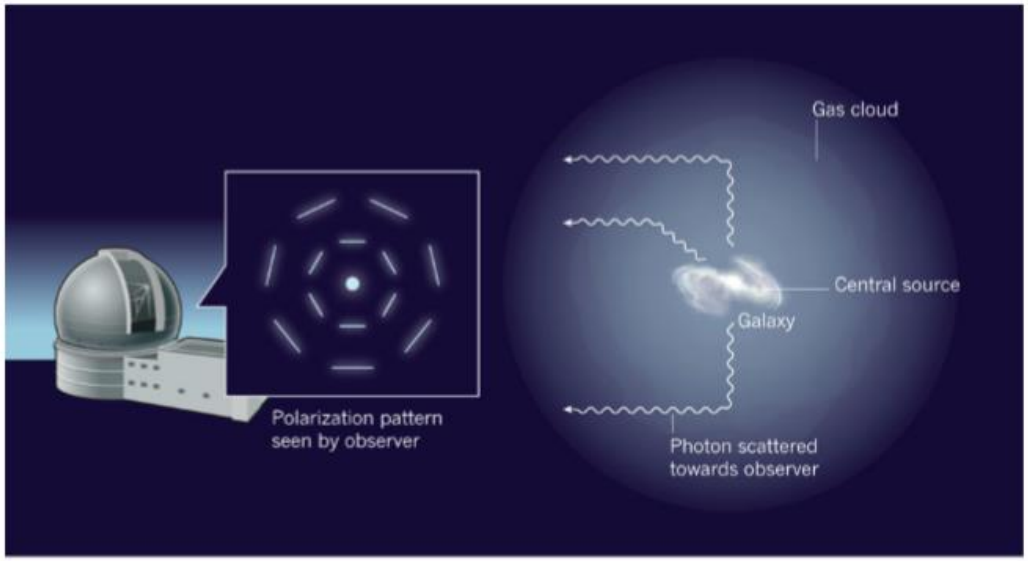
resonant scattering
(scattering by dust
in Egg Nebula)

- Lyα halo around radio galaxies, QSOs, submm galaxies. Lyα blobs.
- Direct 2D image of inter- or circum-galactic medium (IGM/CGM)
- Witnessing the formation of massive galaxies in groups, clusters
- **Polarization as a new observational and theoretical probe**
- **Powering mechanism: photo-ionization vs. resonant scattering?**

Polarization of LAB



SSA22-LAB1
(Hayes et al. 2011)

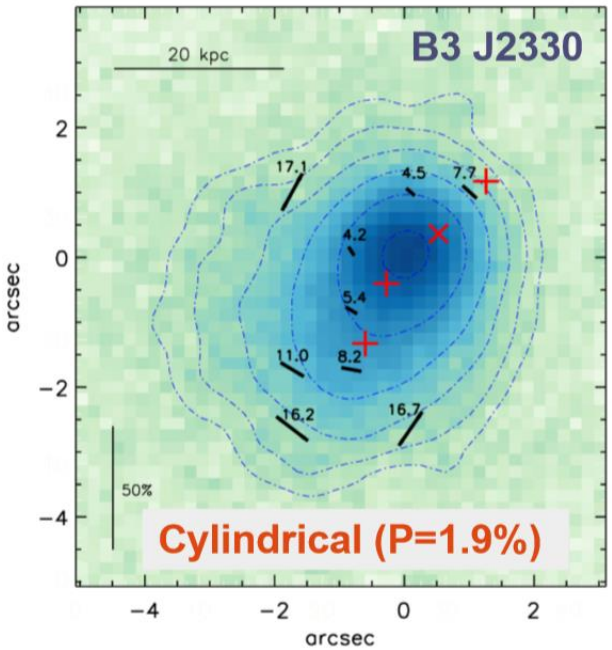


(R. Bower 2010)

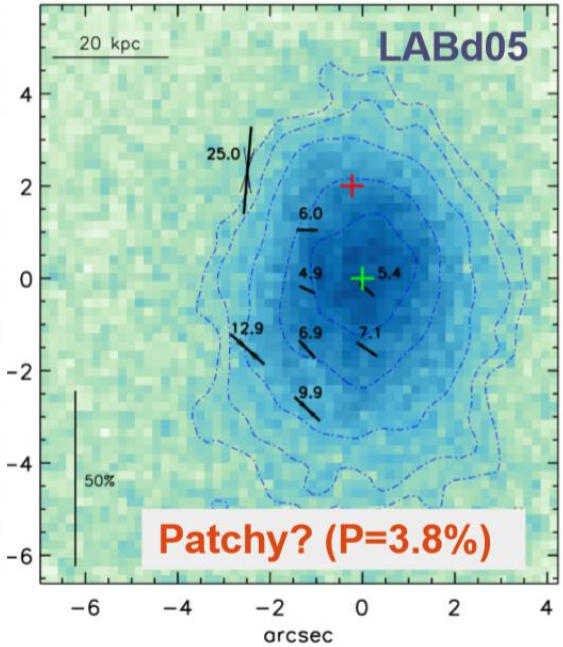
- **Photo-ionization:** *in-situ* production of Lyα
  → no Lyα line polarization signal
- **Scattering:**
  production of Lyα within a central source and scattering by neutral hydrogen
  → concentric Lyα line polarization angle. *P* increases outwards

Theory: **Lee & Ahn (1998)**, Dijkstra & Loeb (2008), Trebitsch+2016, **Chang+2017**, Eide+2018
Obs: Prescott+2011, Hayes+2011, Humphrey+2013, Beck+2016, **You+2017, Kim et al. in prep.**

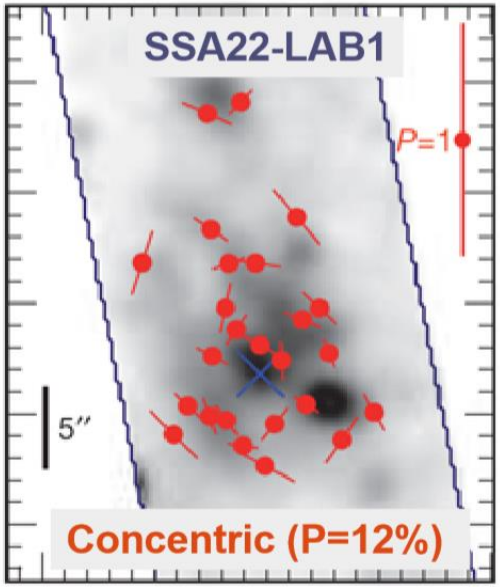
Polarization of LAB



You et al 2017

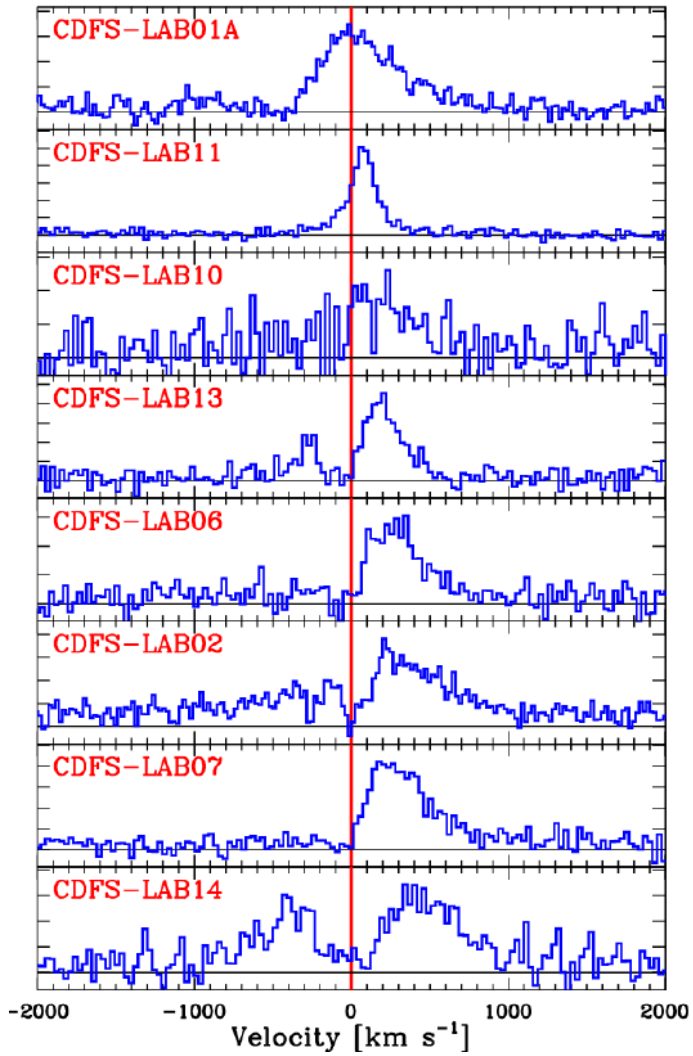


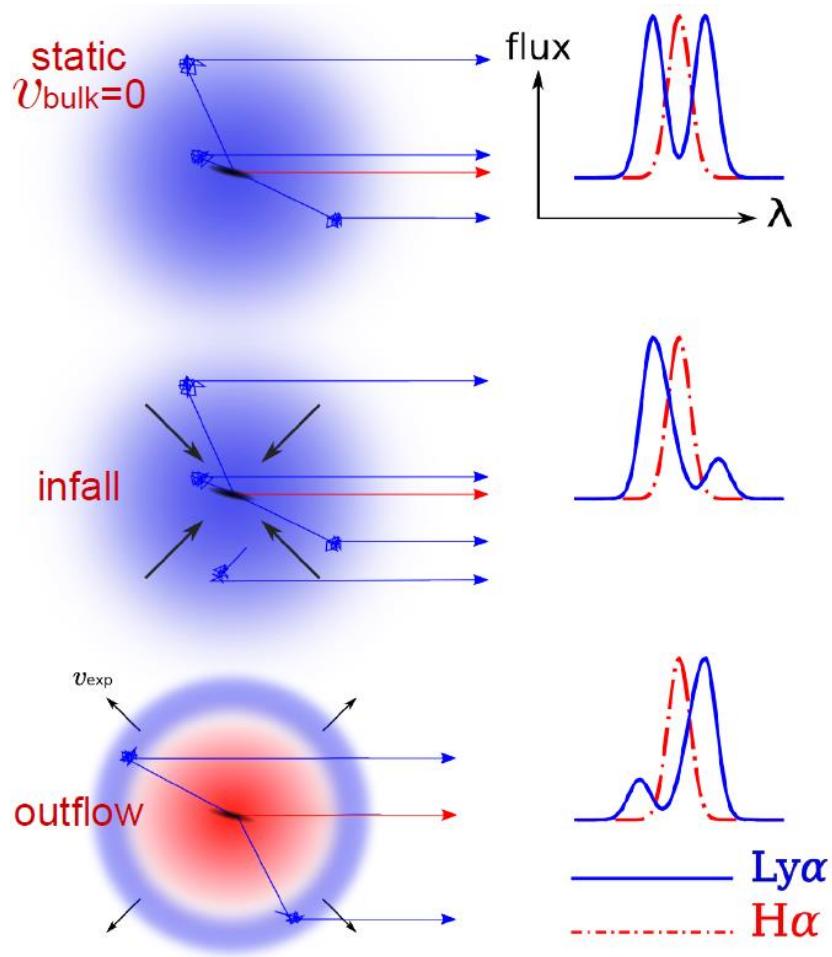
Kim et al in prep



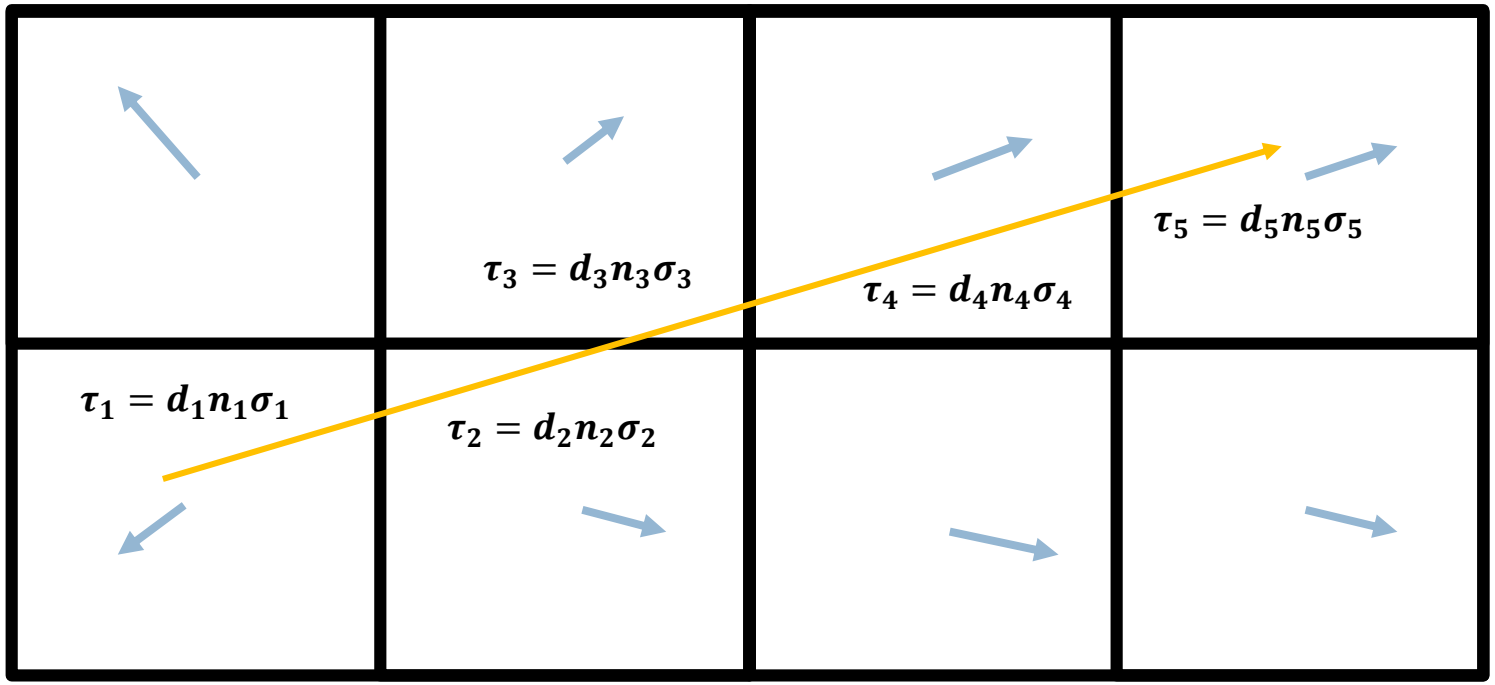
(Hayes et al. 2011)

Spectra of Lyman Alpha Blobs



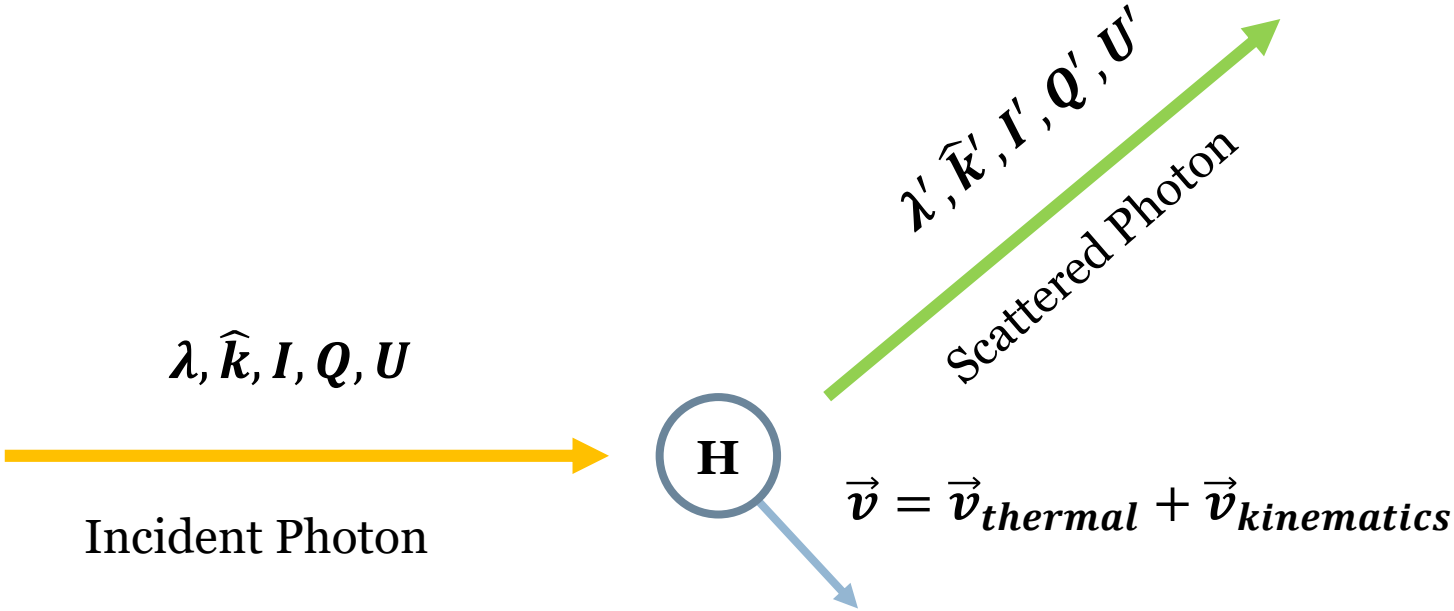


Grid-Based Radiative Transfer

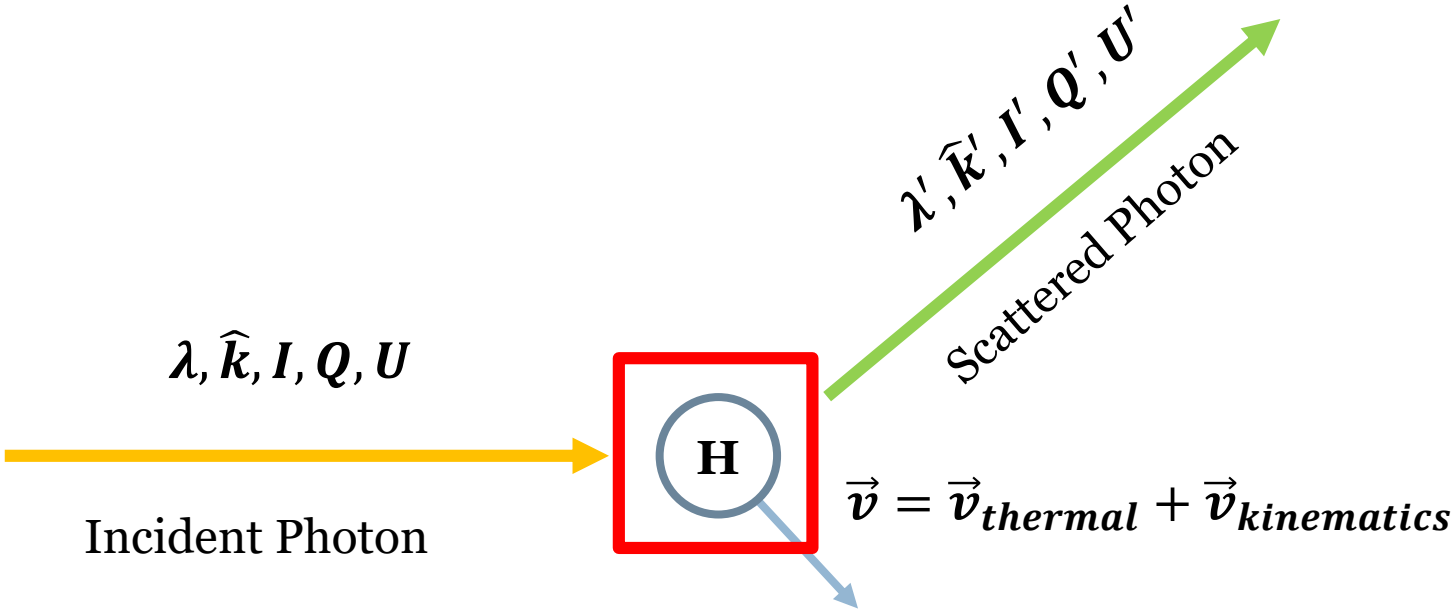


$$\tau = \tau_1 + \tau_2 + \tau_3 + \tau_4 + \tau_5$$

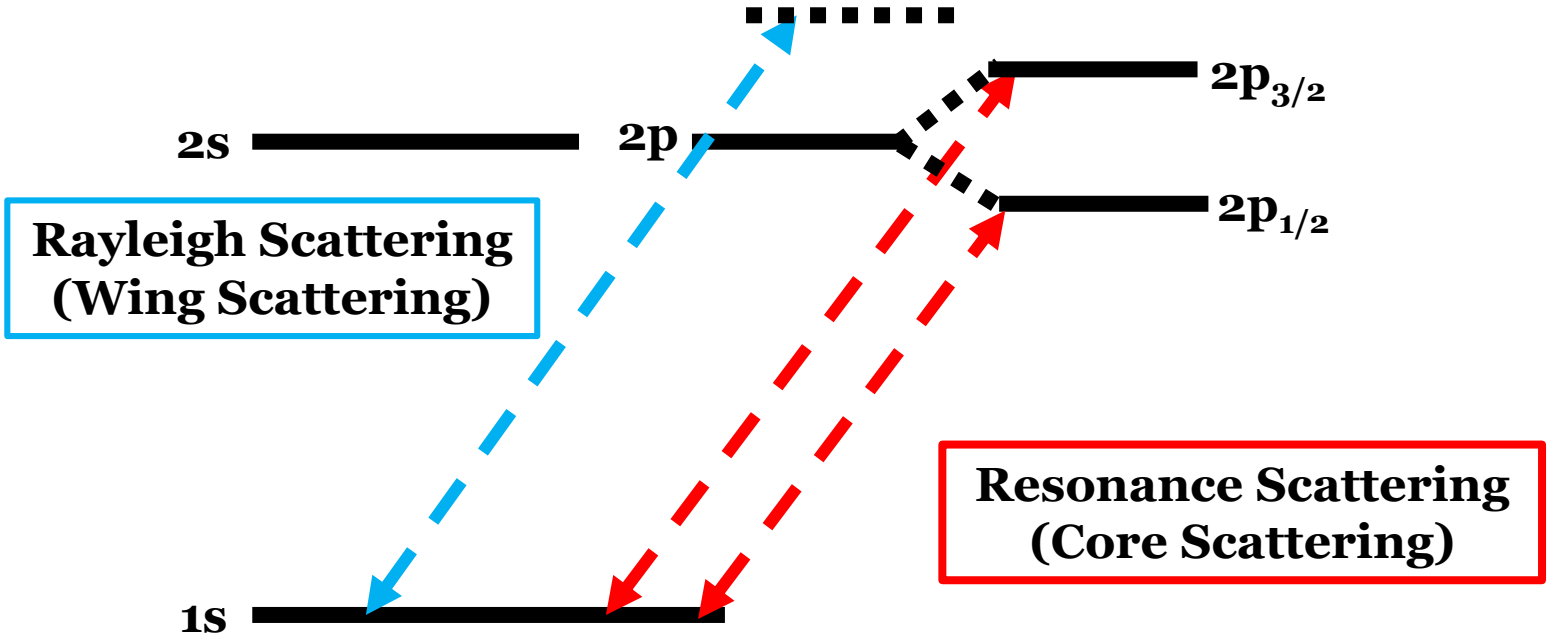
Lyman Alpha Radiative Transfer



Lyman Alpha Radiative Transfer



Lyman Alpha Radiative Transfer

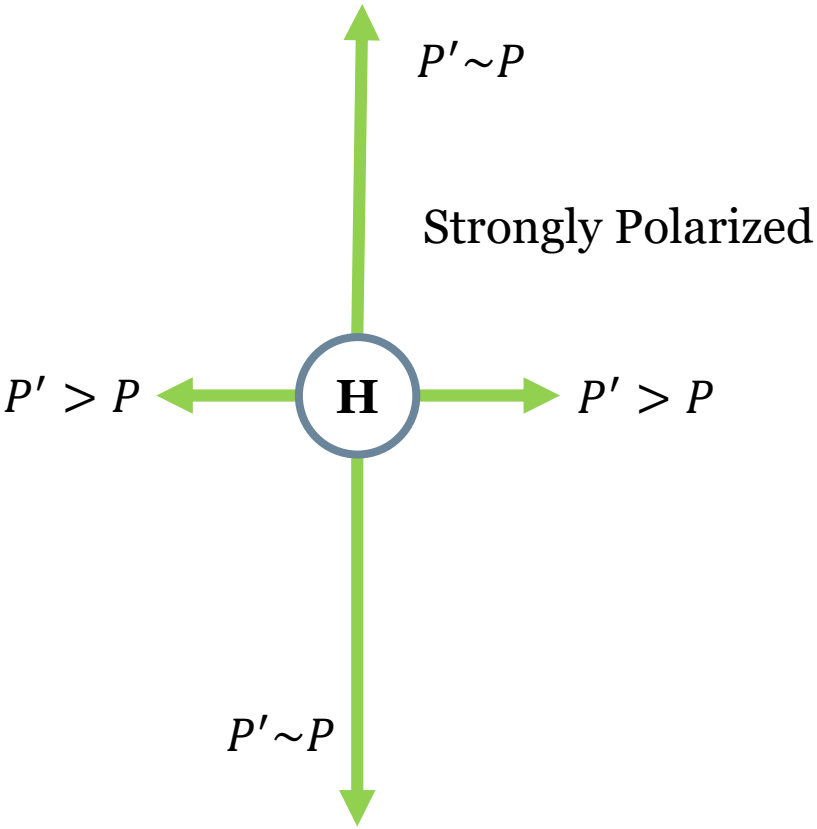


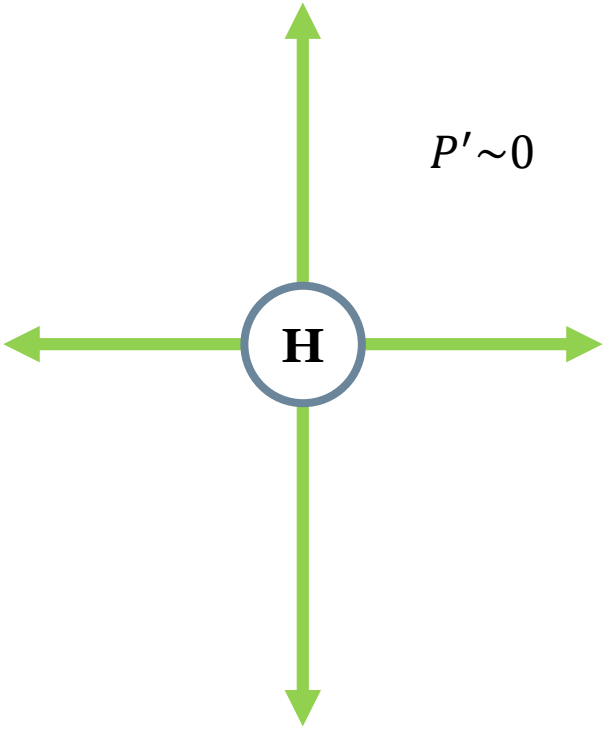
Rayleigh Scattering (Wing Scattering)

Resonance Scattering (Core Scattering)

Weakly Polarized : $1s - 2p_{3/2}$

Un-Polarized : $1s - 2p_{1/2}$



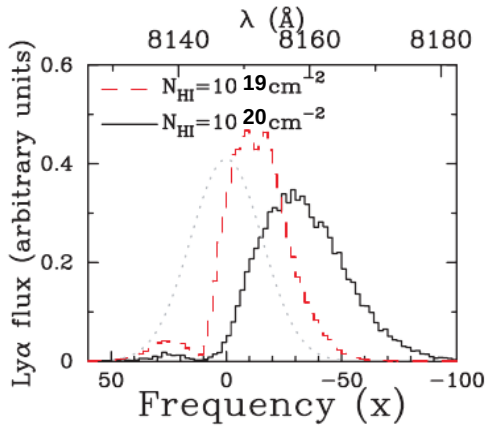


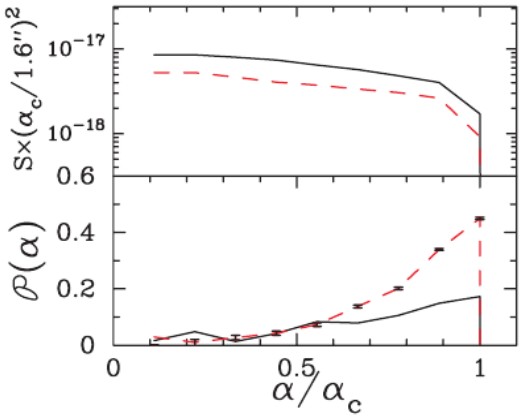
$$\Phi(\cos\varphi) = \frac{3}{8}(1 + \cos\varphi)$$

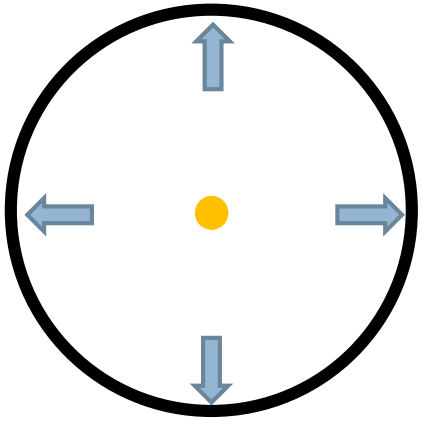
$$\Phi(\cos\varphi) \sim const$$

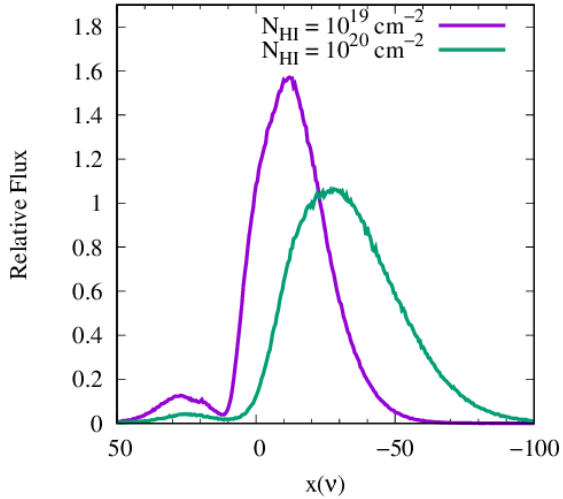
$$\cos\varphi = \hat{k} \cdot \hat{k}'$$

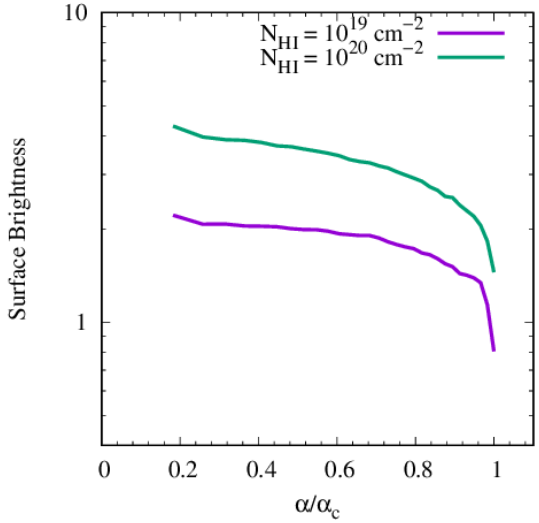
Code Check – Dijkstra & Leob 2008

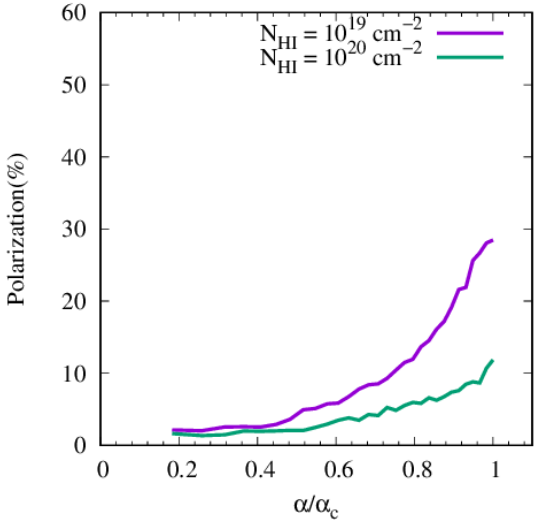




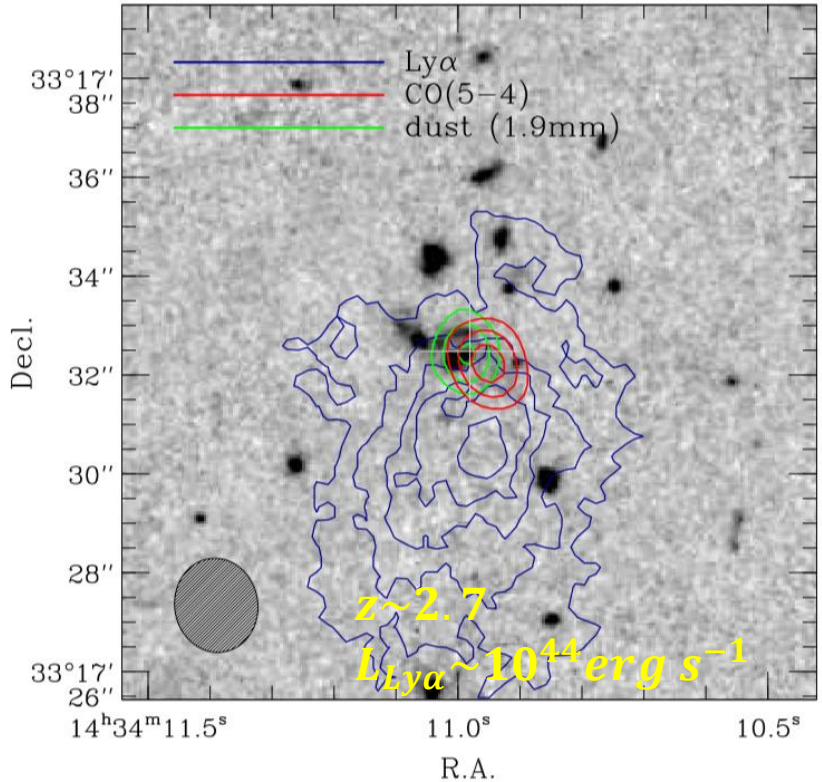


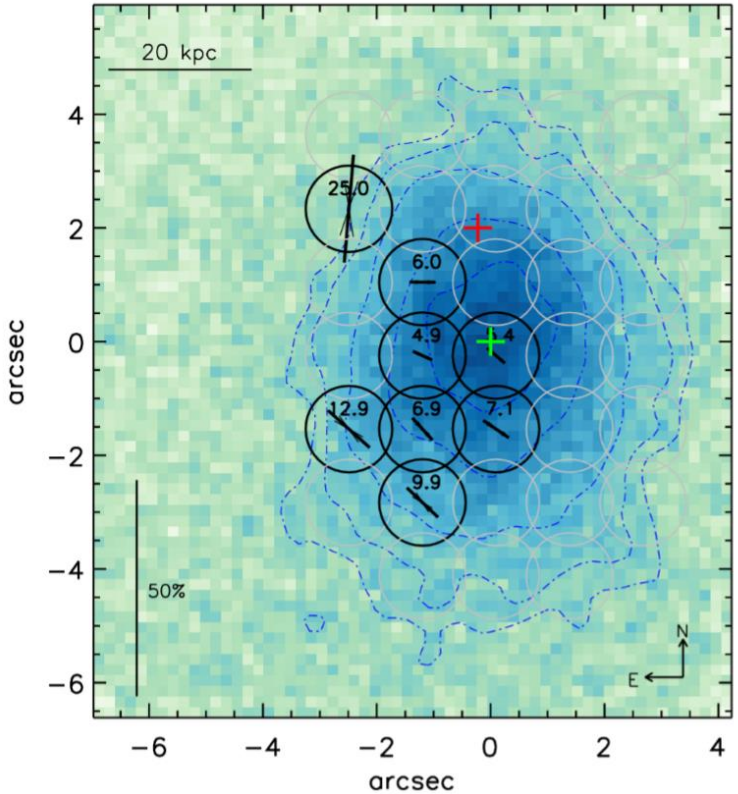






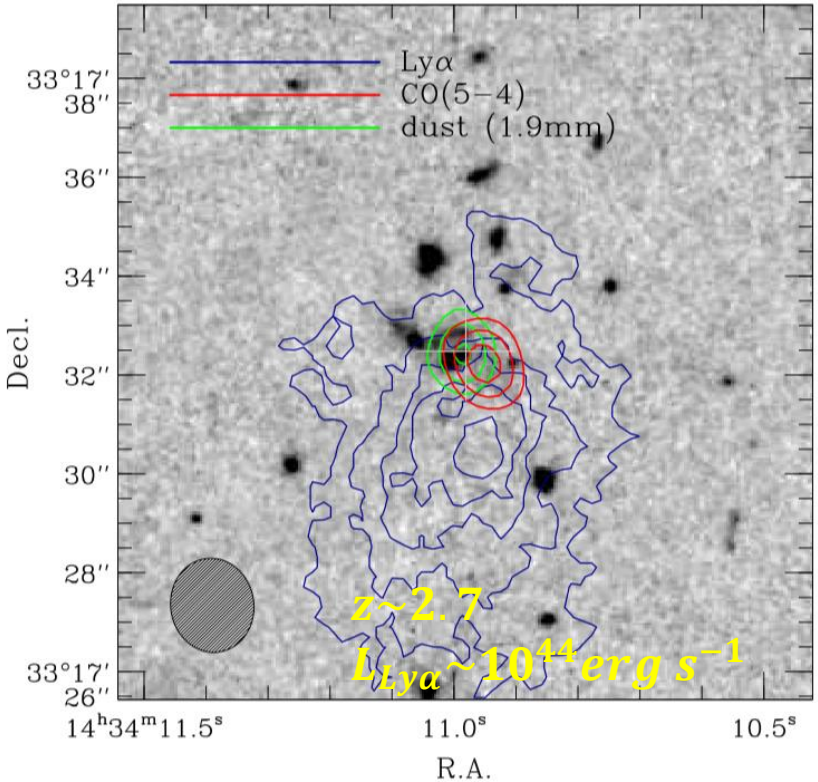
LABd05

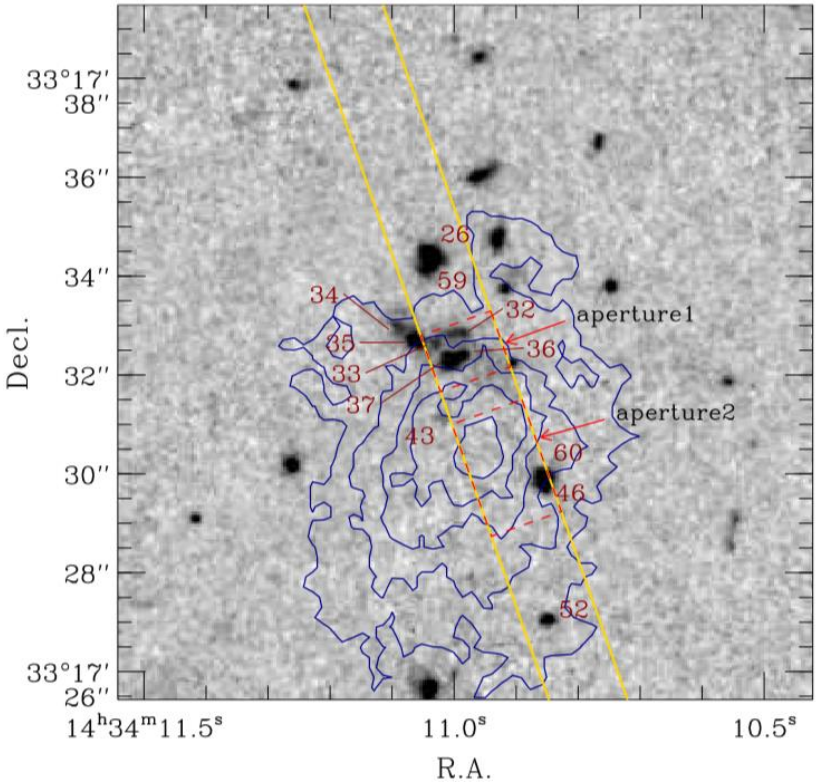




1. Galaxies and AGN in this region show spatial offset from the Lya peak. (Dey et al 2005, Yang et al 2014)
2. CO and dust are concentrated on Galaxy 36.
3. Galaxy 36 is obscured AGN.

LABd05





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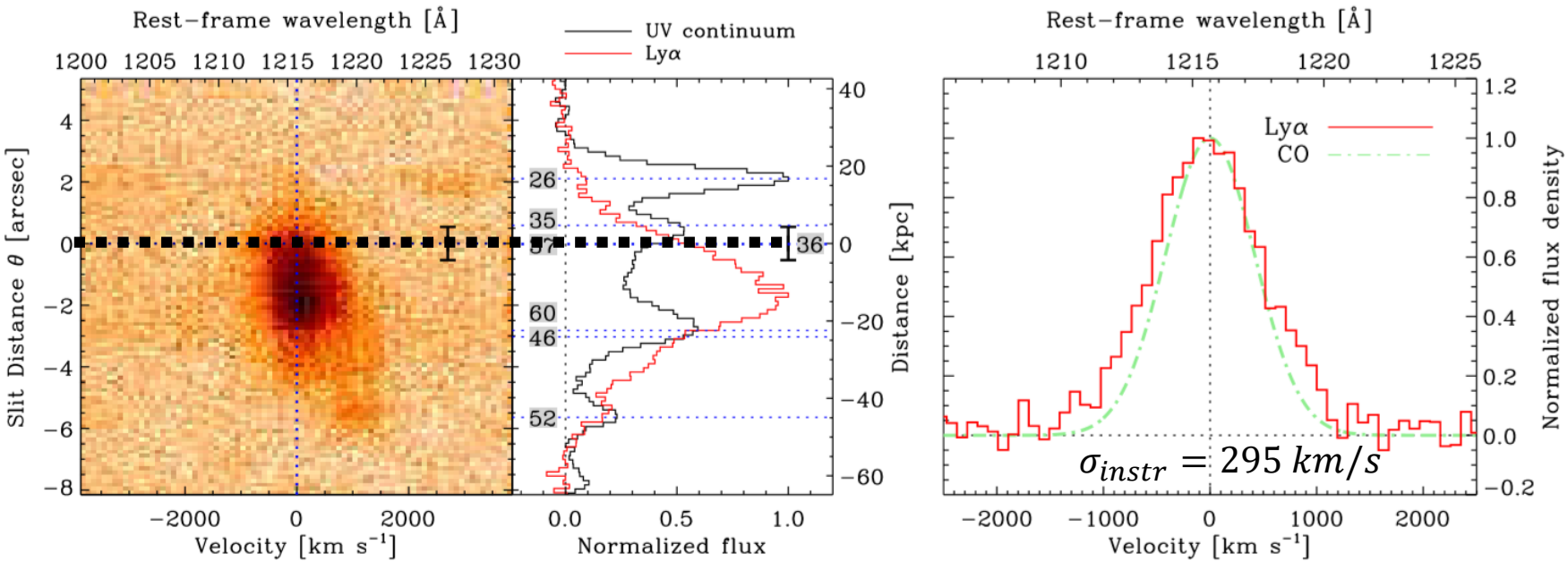
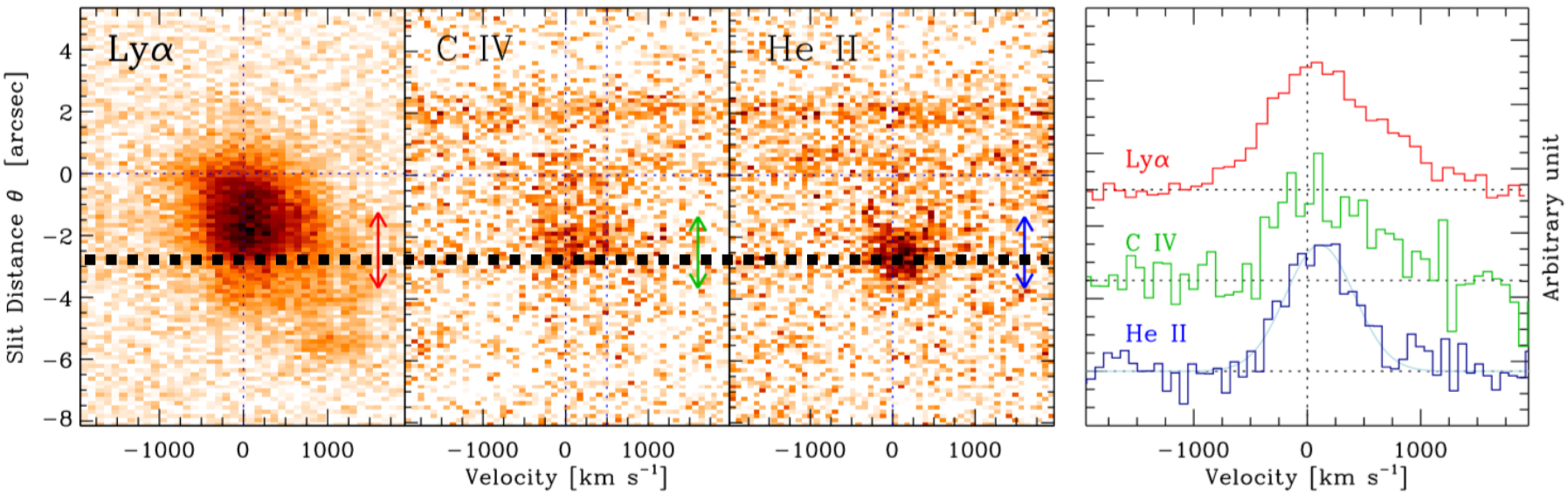
2D-Spectrum of LABd05



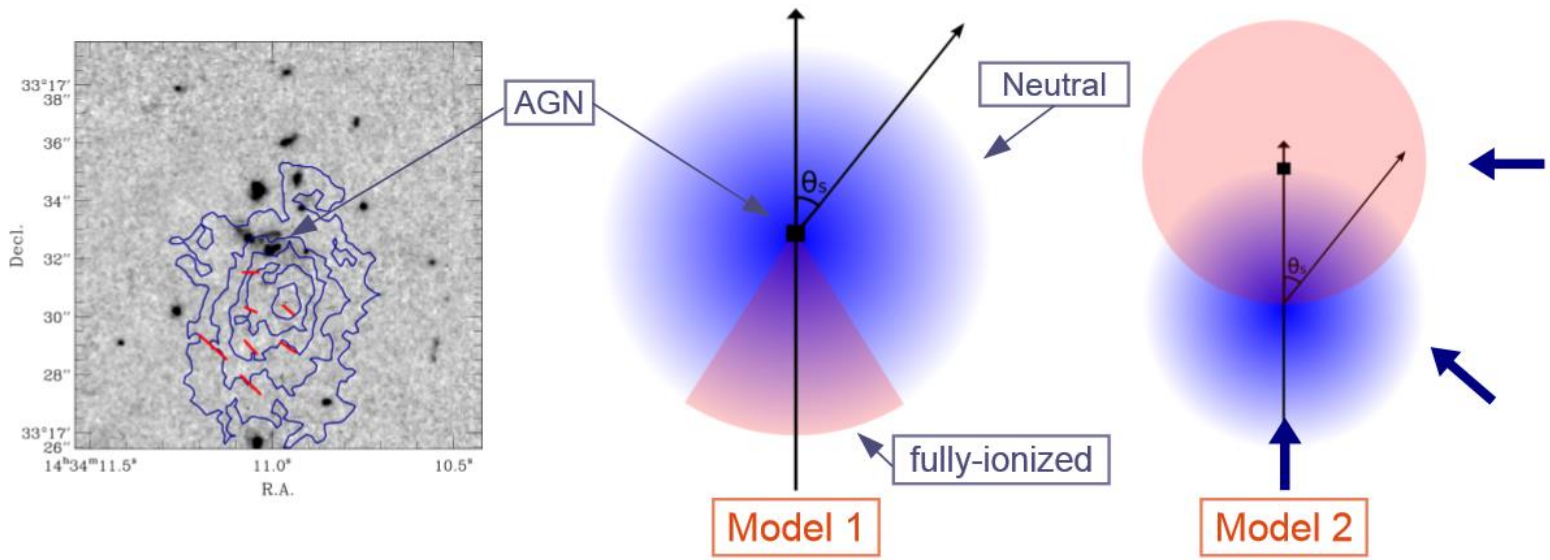
1. The profiles of Lya and CO is symmetric.
2. The peaks of Lya and UV show offset.

2D-Spectrum of LABd05



1. The peaks of Lya and He II show small offset.
2. The profile of Lya show red asymmetry.

Polarimetric Modeling



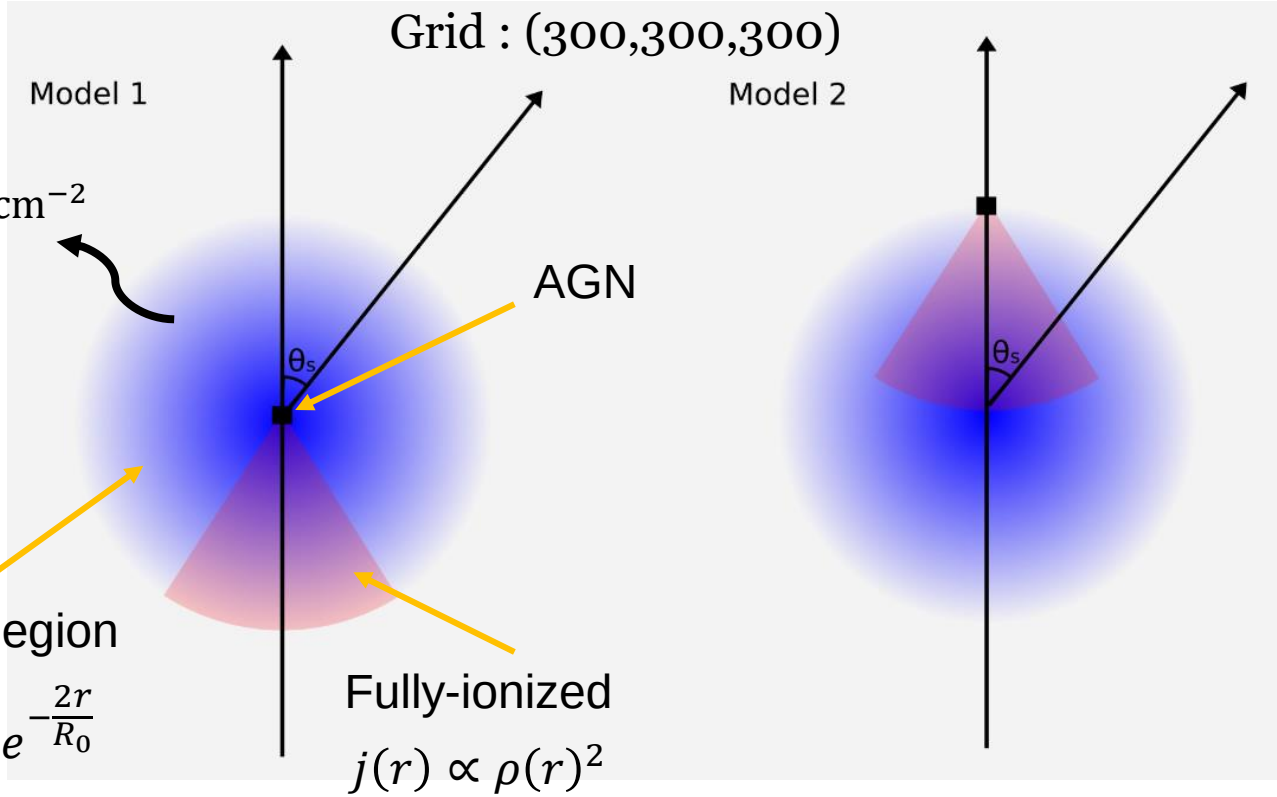
Model / fit (1) Lyα SB, (2) velocity profile, and (3) polarization simultaneously.

Constrain geometry, ionization structure, (column) density and temperature of CGM.

Seok-Jun's RT+Pol code produces **3D Lyα datacube (Stokes I)+Stokes Q&U datacube.**

- Model 1: Anisotropic ionization cone from the obscured AGN
  Lyα follows ionizing radiation (radiation-bound).
- Model 2: Isotropic ionization cone from the obscured AGN
  Galaxies (DM?) are displaced from gas.
  Lyα follows gas (matter-bound).

Polarimetric Modeling



$N_{HI} = 10^{20}\mathrm{cm}^{-2}$

AGN

Neutral Region

Fully-ionized

$\rho(r) = \rho_0 e^{-\frac{2r}{R_0}}$

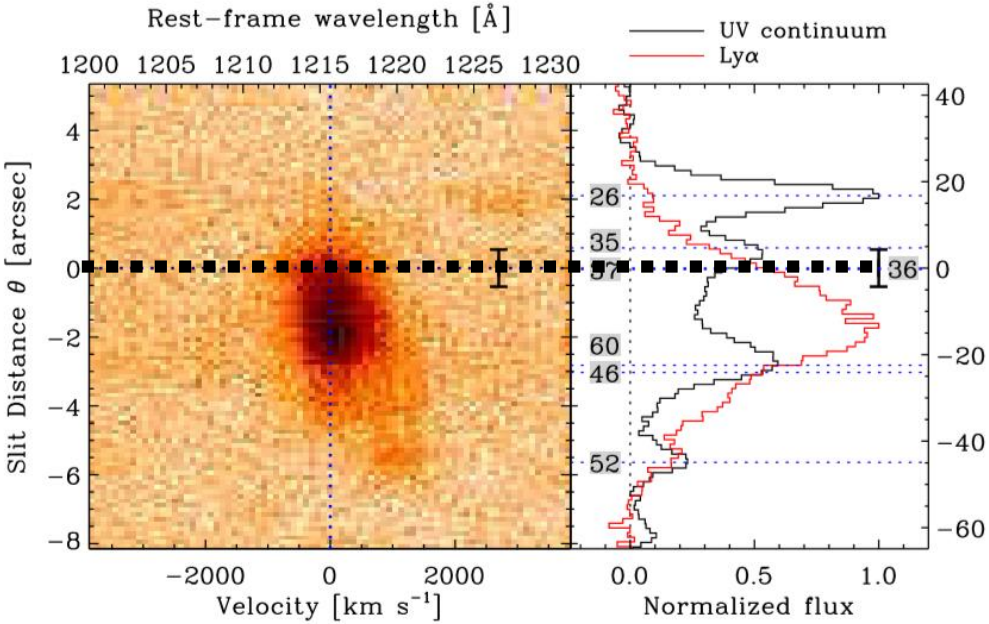
$j(r) \propto \rho(r)^2$

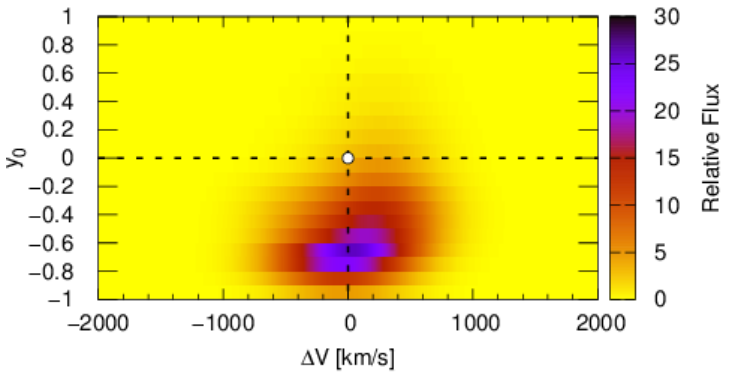
$v(r) = v_0 r$

$v_0 = 100\ \mathrm{km/s}$

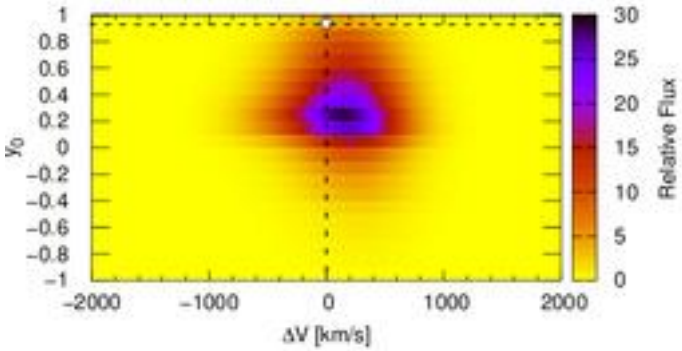
$\text{Covering Factor} = \frac{1}{4}$

Comparison with Observation and Simulation



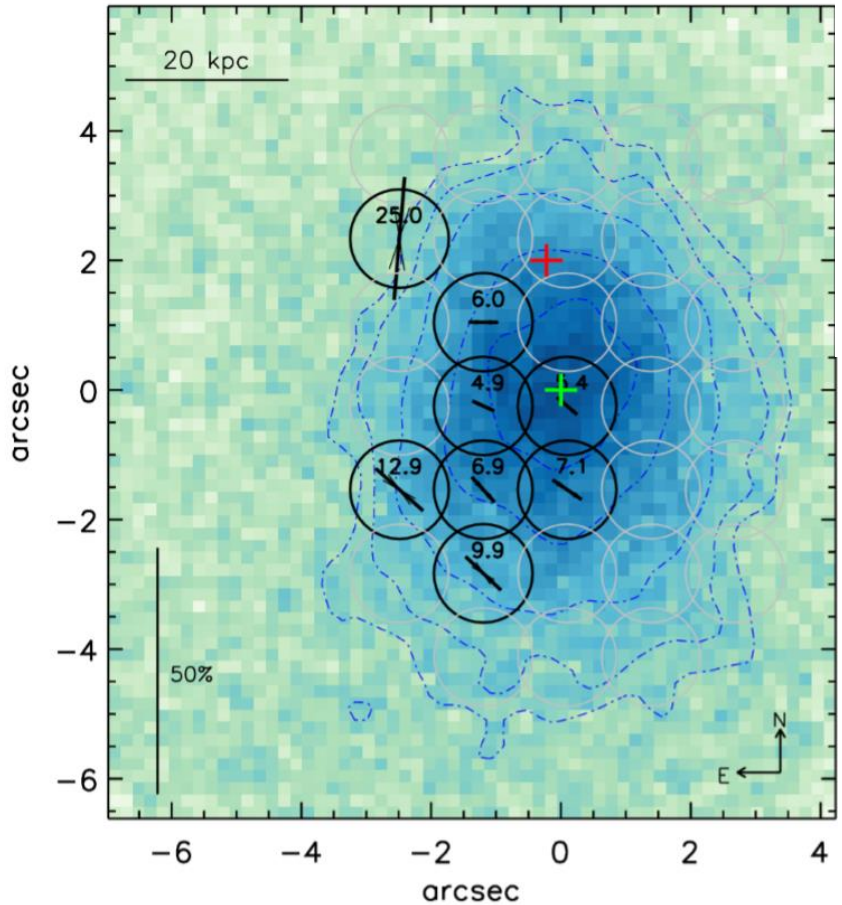


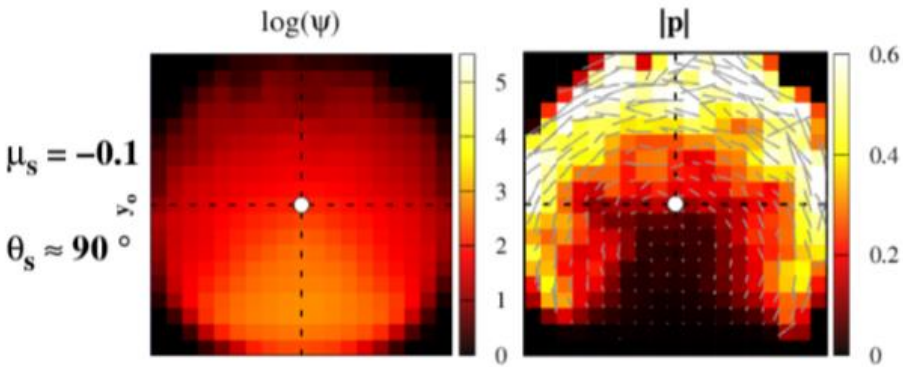
Model 1



Model 2

Comparison with Observation and Simulation





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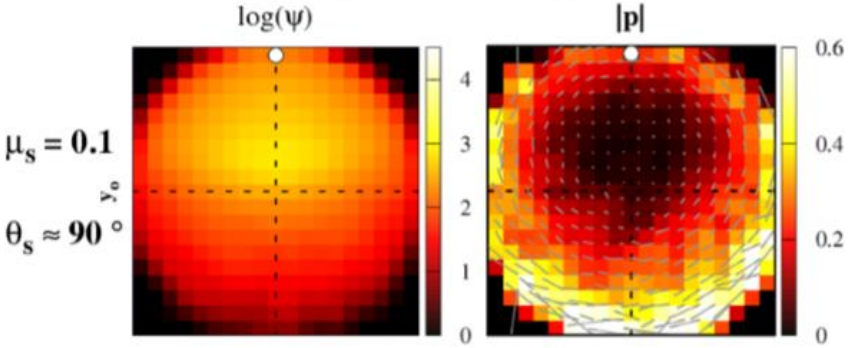

Model 2

Summary & Future Work

1. Lyα is good tool to investigate the early universe.
2. We expect that LABs are extended through the scattering by atomic hydrogen
3. Our Lyα RT code provides (I,Q,U)[x,y,λ] datacube.
4. LABd05 shows the offset between the obscured AGN and the peak of Lyα
5. We consider more accurate and various models to analyze LABd05.
6. We will adopt the photoionization model to our simulation.