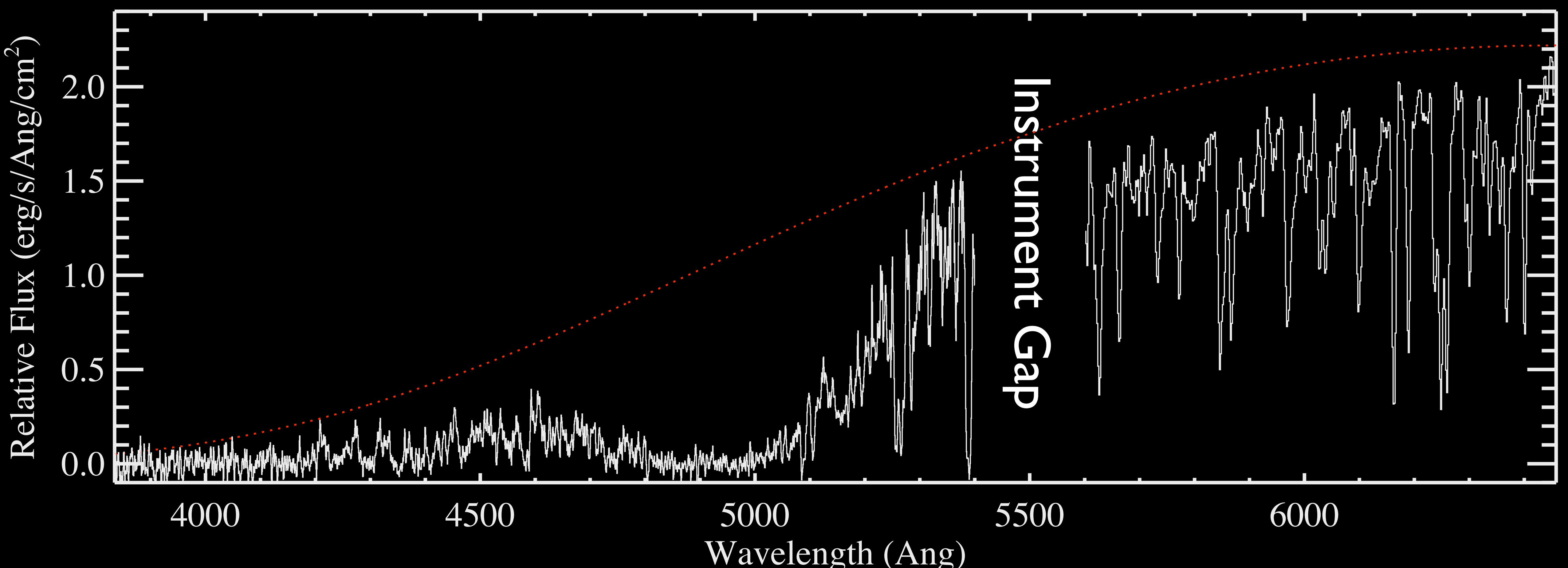
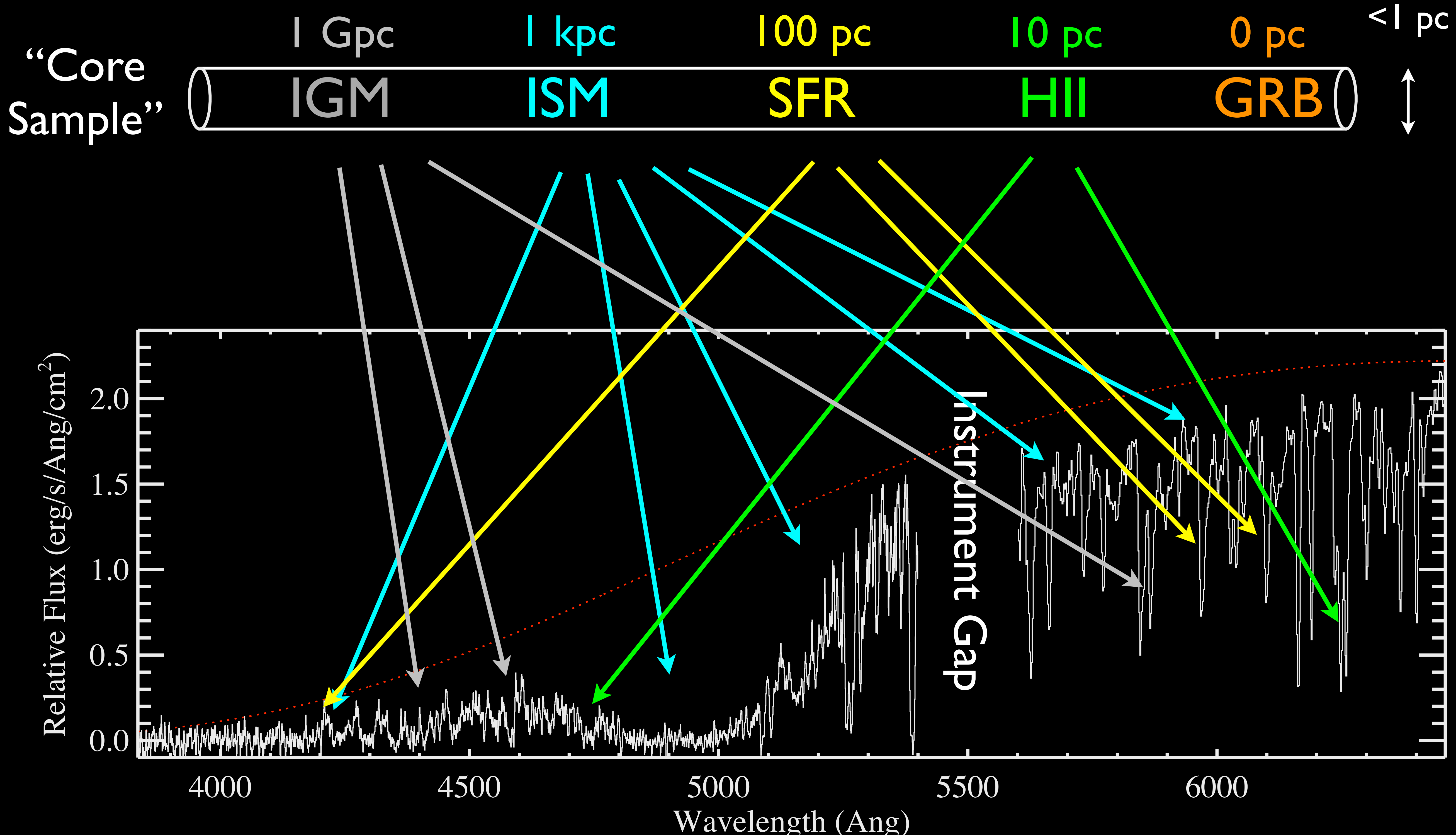
GRB Spectrum



Like a core sample of the Earth, the spectrum helps us study multiple layers of the Universe.

GRB Spectrum



But unlike a true core sample, the spectrum is encoded in wavelength, <u>not</u> depth, and the layers are mixed together.

Absorption Line Notation

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- How we name the transitions
  - Elements other than Hydrogen absorb light too
  - And we need to distinguish between ions

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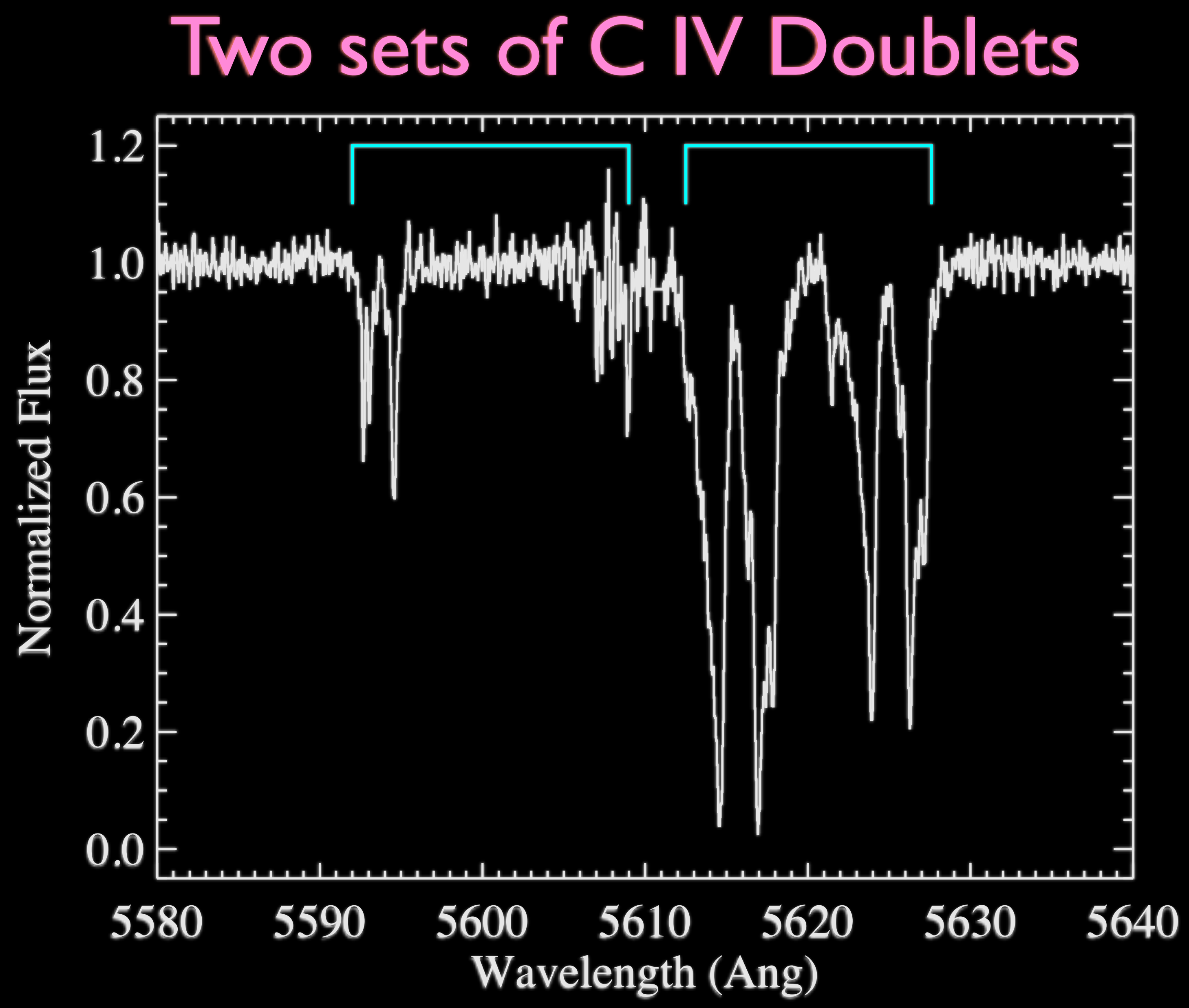
- Quibbling aside
  - Ions and atoms should be referred to as C^+, O^0 not CII and OI

Identifying Transitions

The Power of the Doublet

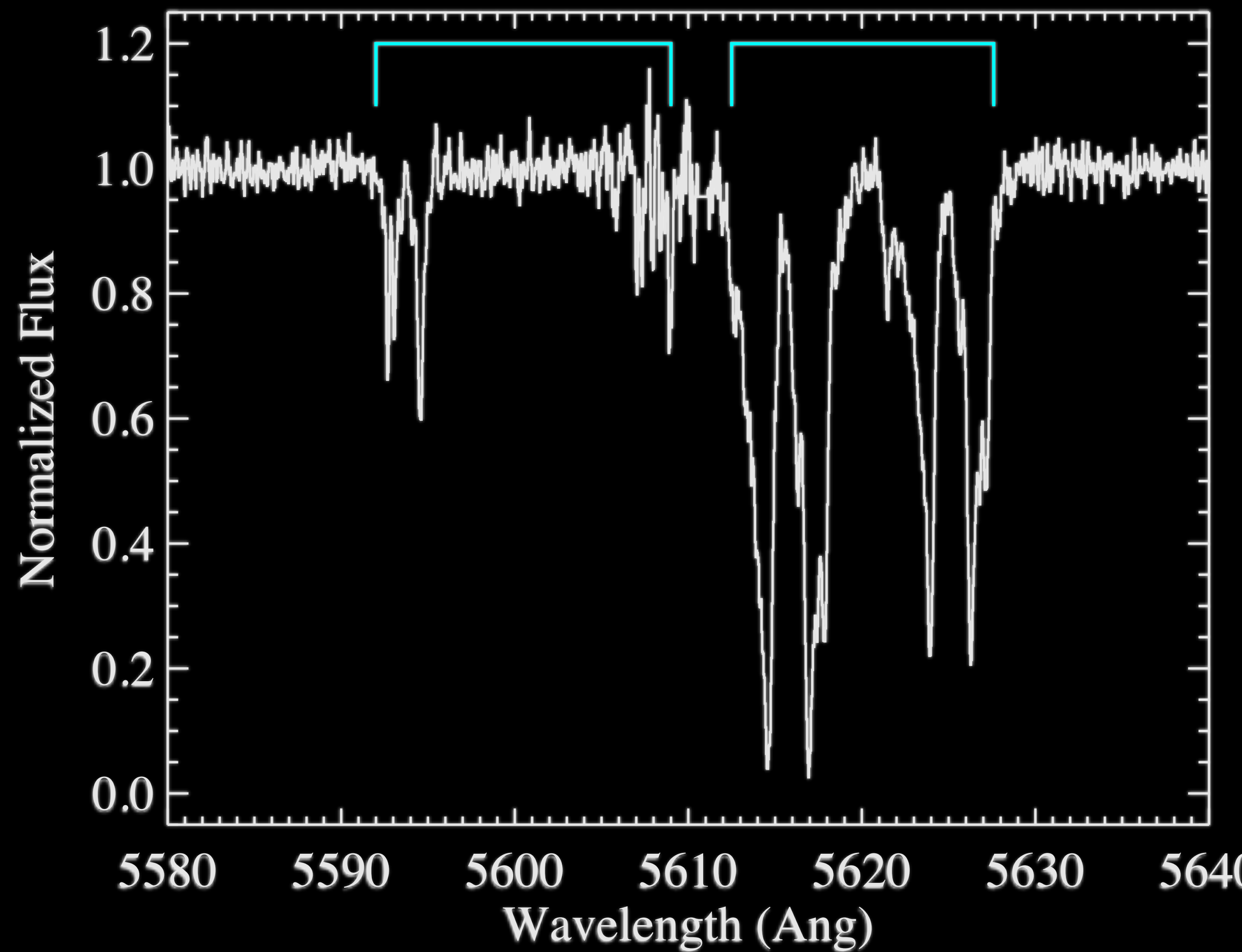


Identifying Transitions

The Power of the Doublet

- Many metal-line transitions come in pairs (or more)
  - Pairs = doublets
  - More = multiplets (e.g. Fe II)
- Alkali doublets
  - C IV, Si IV, Mg II (and Lyα!)
  - Oscillator strengths -- 2:1 ratio
    - Gives a 2:1 ratio for the optical depths

Two sets of C IV Doublets



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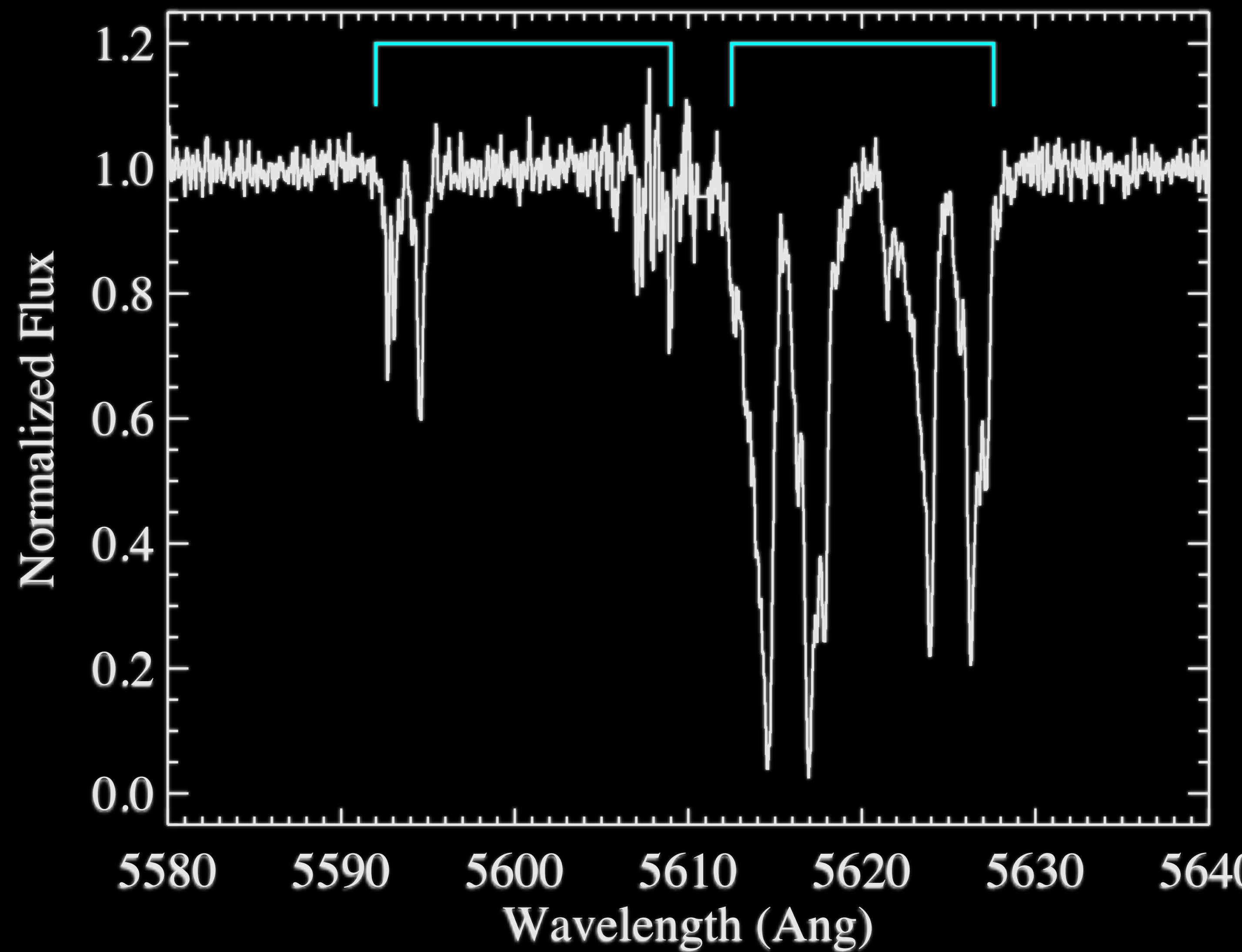
    - Gives a 2:1 ratio for the optical depths
- Velocity separation is unique
  - $\Delta v = (c \, \Delta\lambda) / \lambda$
  - Akin to a fingerprint
    - Unique, unambiguous identification
    - Especially combined with optical depth

Two sets of C IV Doublets



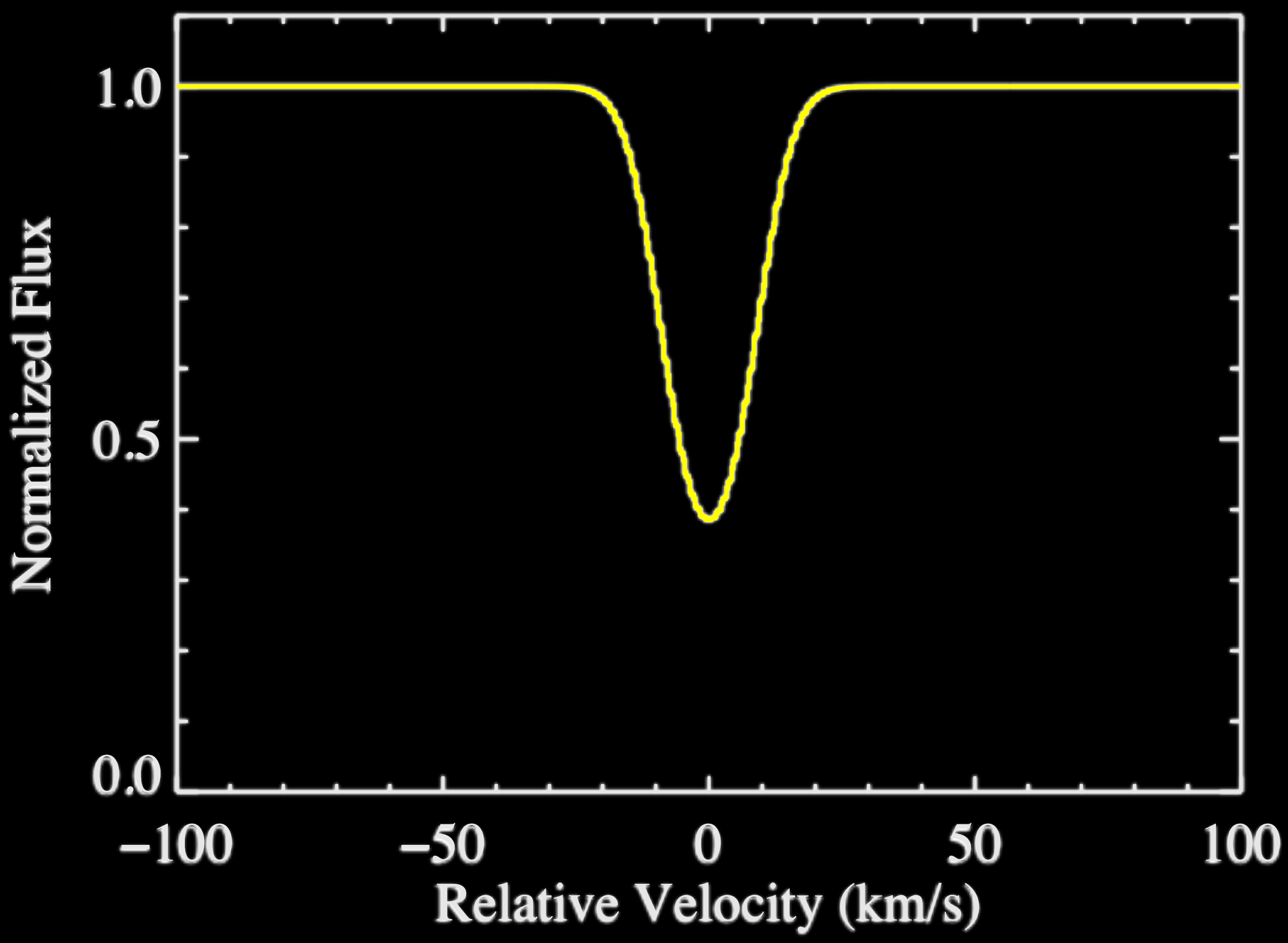
Equivalent Width

- **Definition: W_λ or EW**
  - Normalized fraction of light that has been absorbed
  - Measured in Angstroms
- **Formalism**

$$W_\lambda = \int_0^\infty \left[1 - \frac{I_\nu}{I_\nu^0}\right] d\lambda$$

- **True observable**
  - Value is independent of the spectral resolution
  - But what is its physical meaning?

(τ_0=1, b=10 km/s) Lyα line



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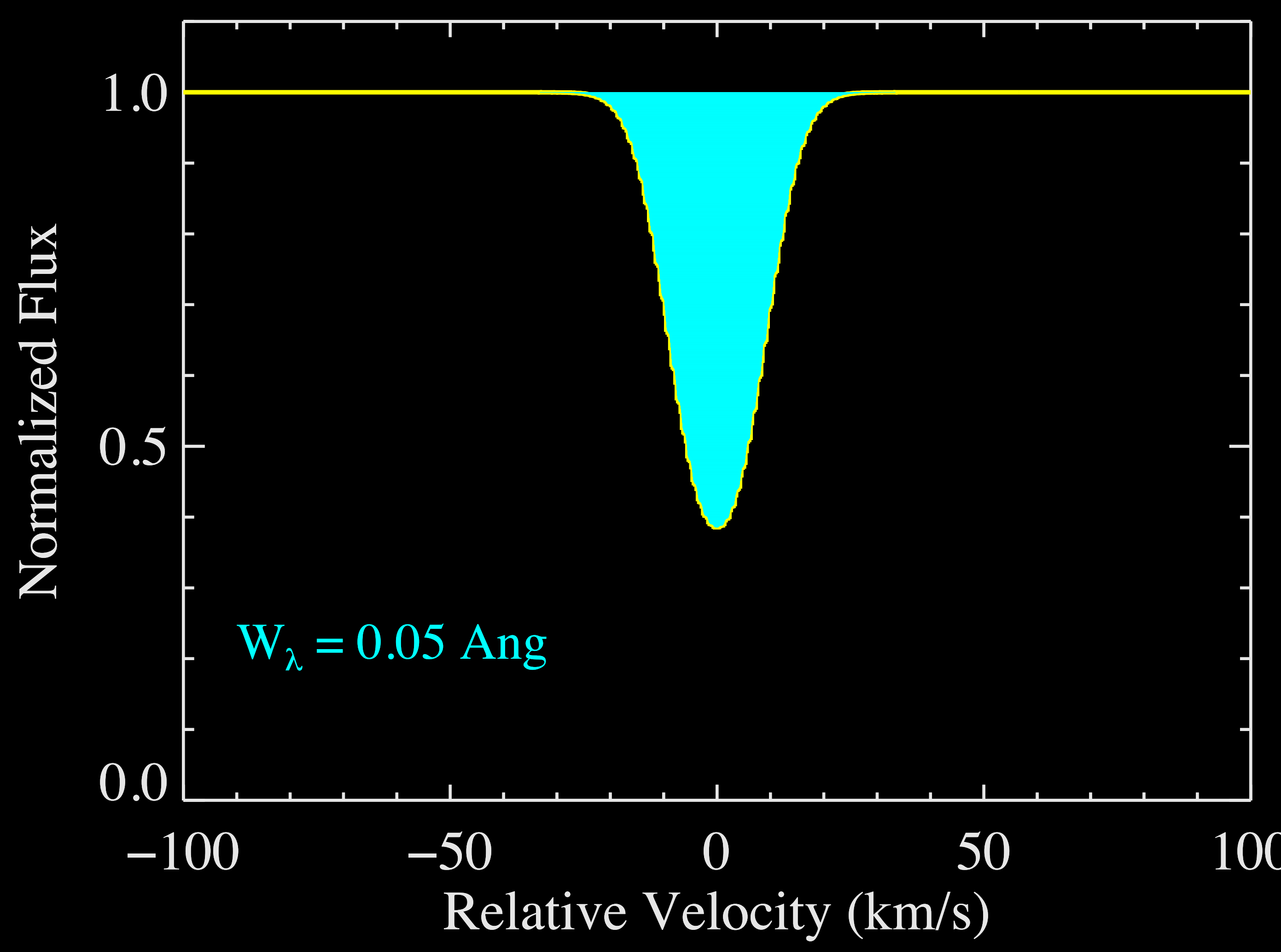

Curve of Growth

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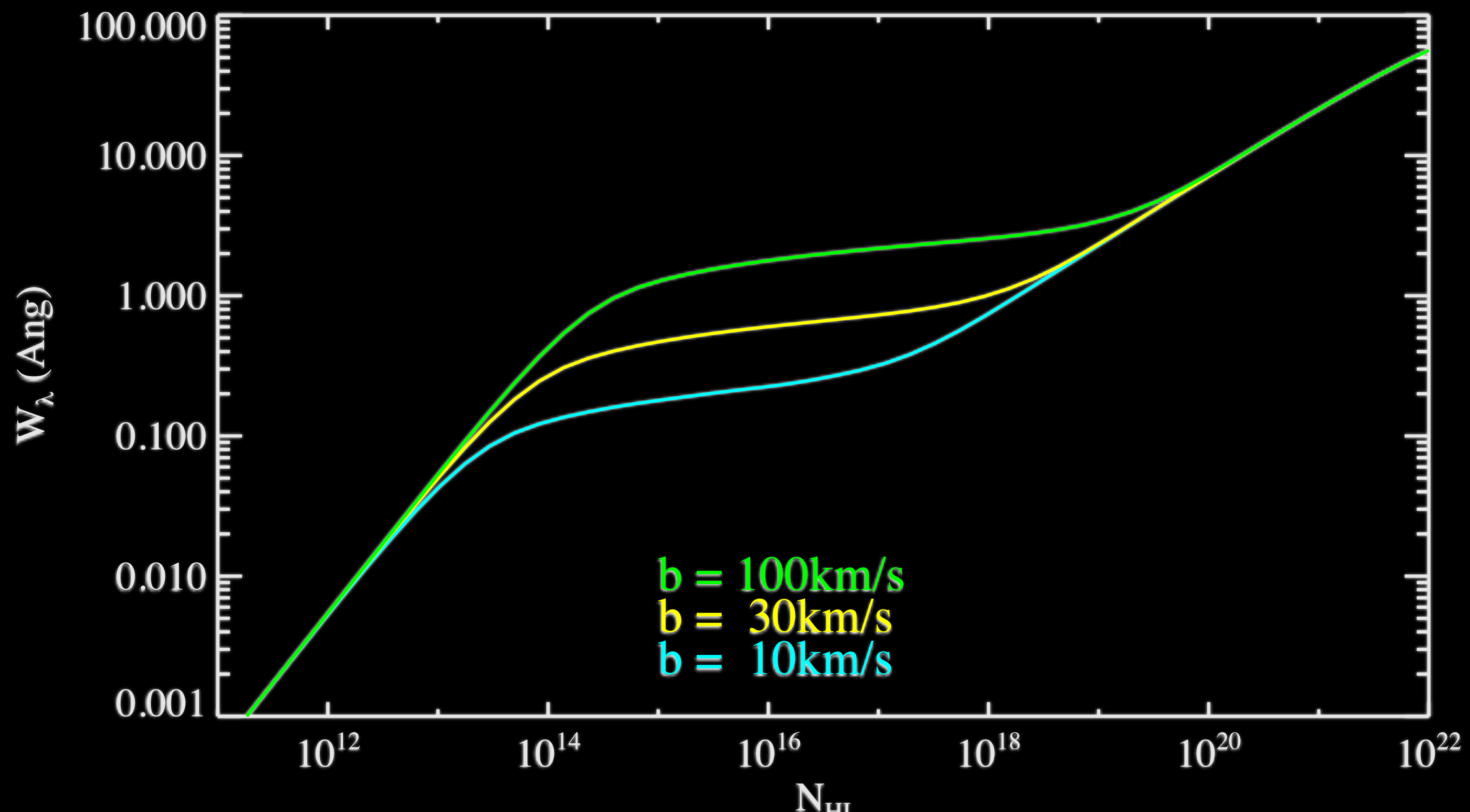

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  - Weak (linear) limit: $W \sim N$
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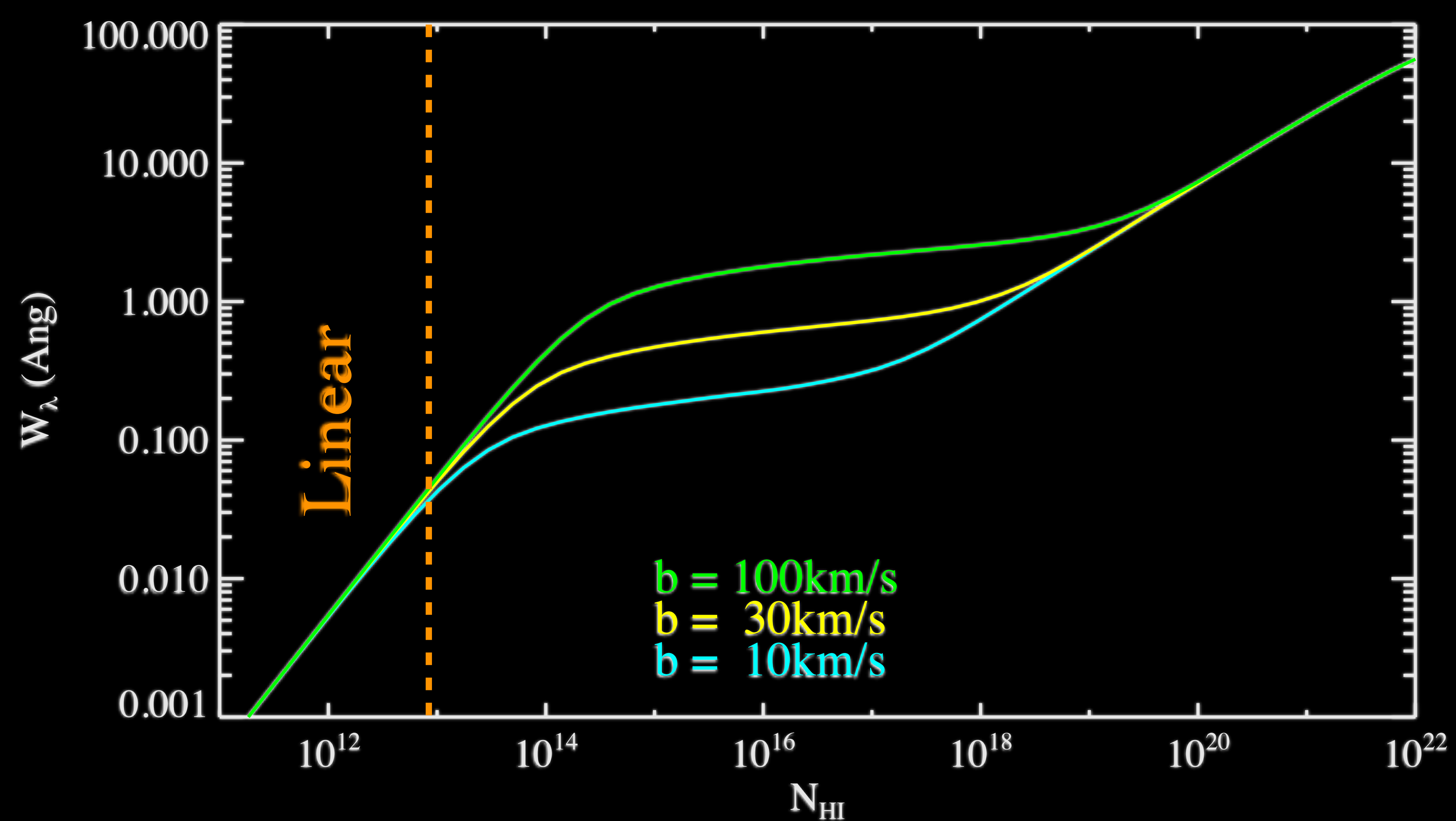

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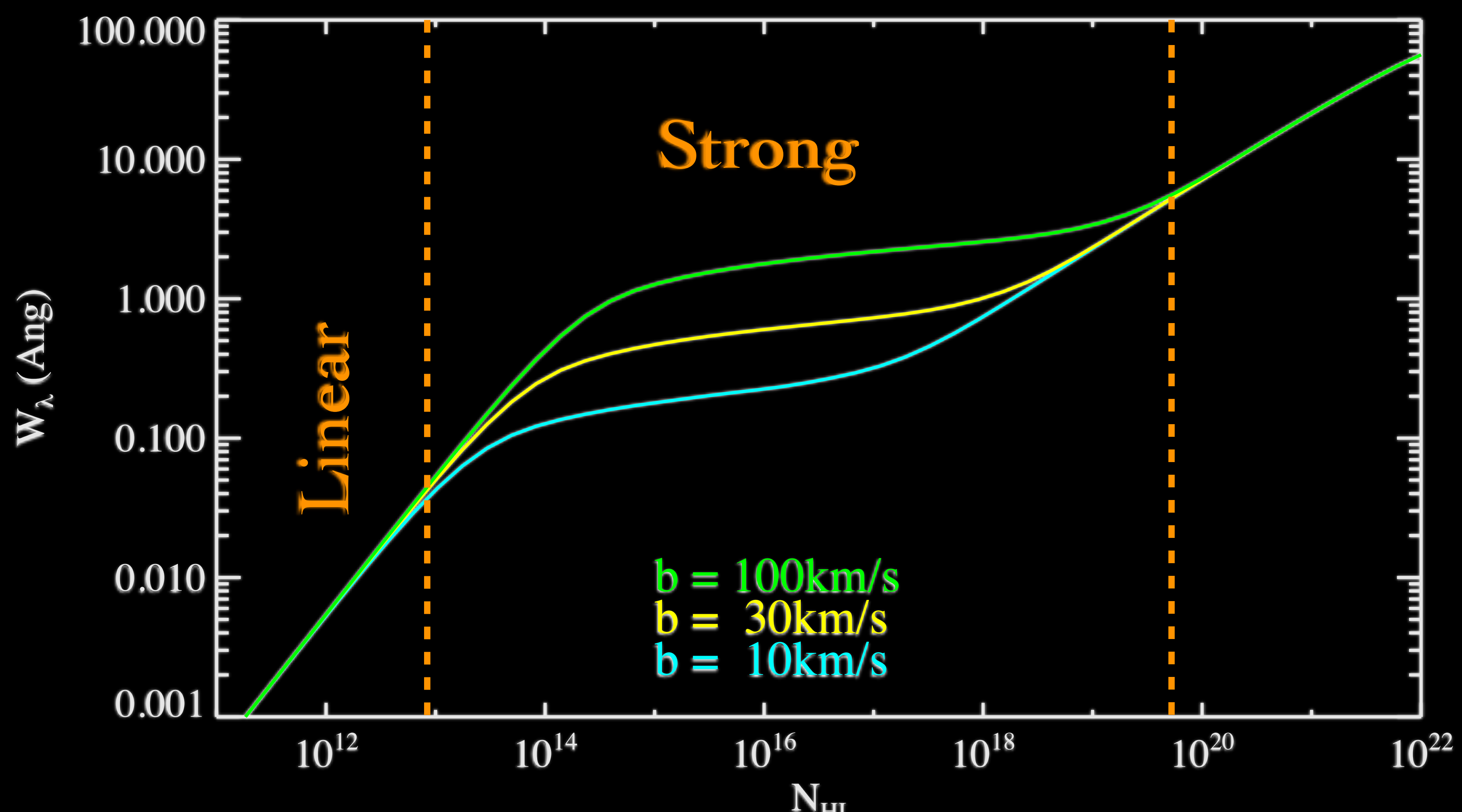

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  - Weak (linear) limit: W ~ N
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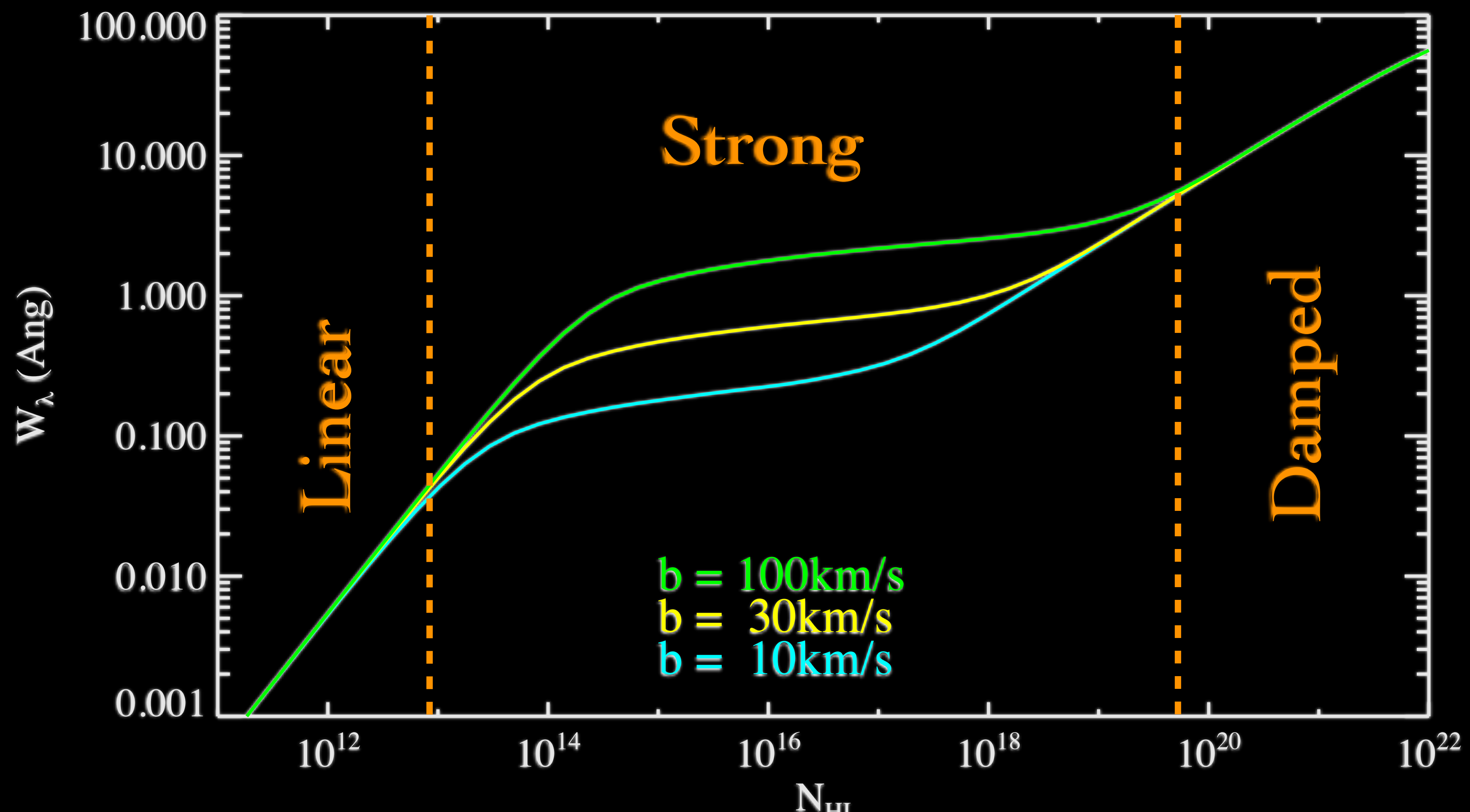
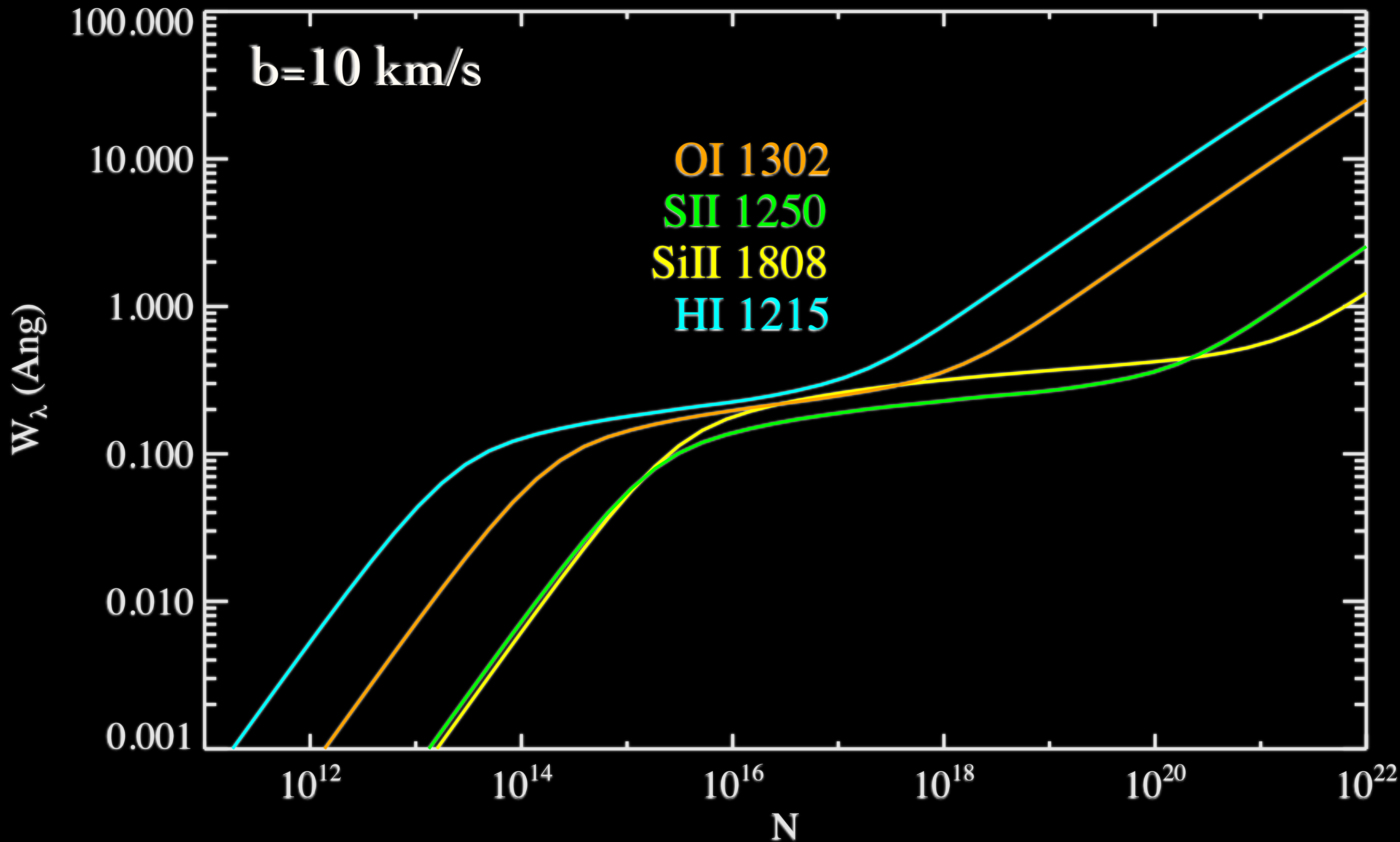
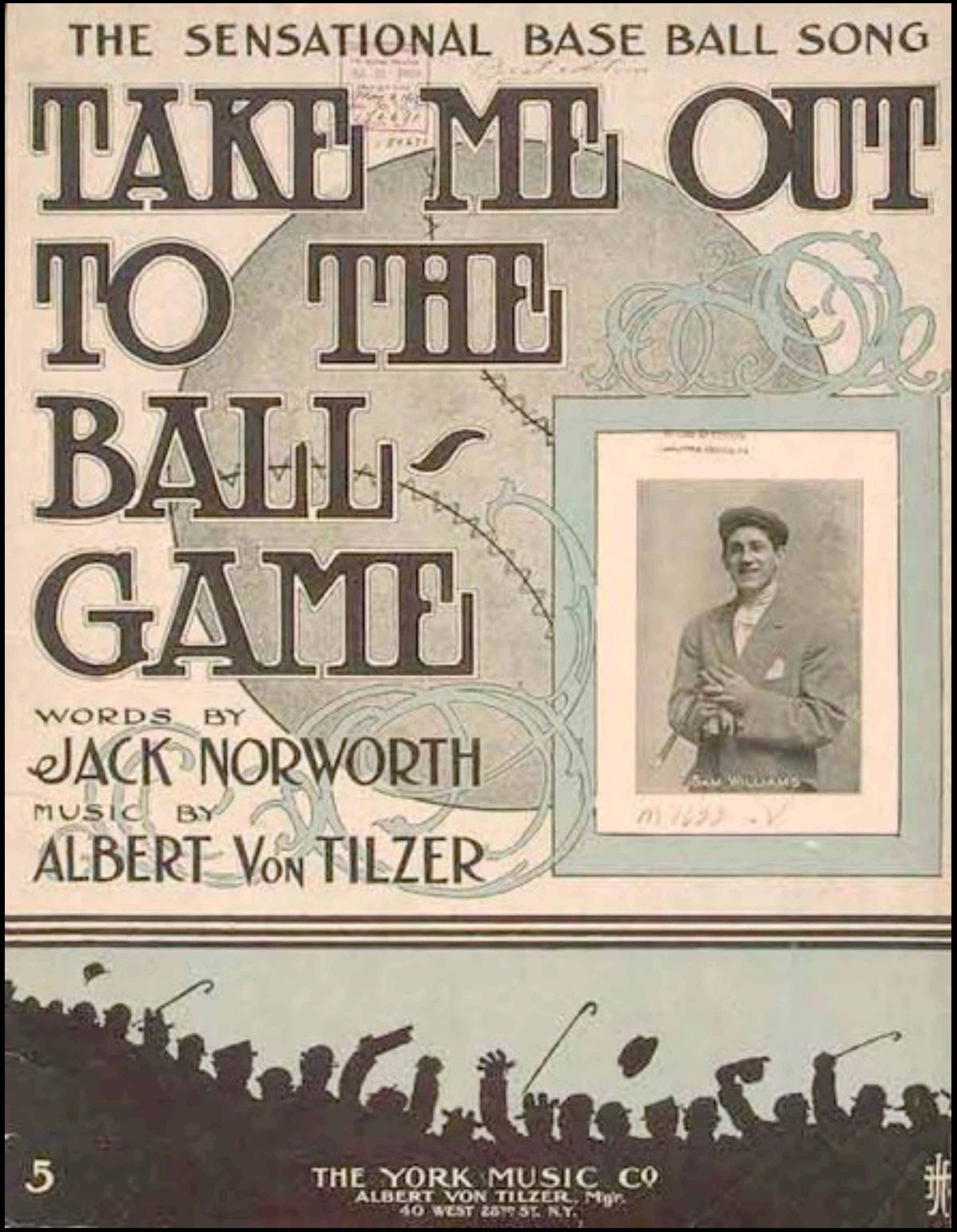
  - Strong limit: W ~ ln(N)
    - $\tau_\lambda = 1$ to 10^4 ($W_\lambda \sim 1$ Ang)
  - Damped limit: $W \sim N^{1/2}$
    - $\tau_\lambda > 10^5$ ($W_\lambda >> 1$ Ang)



COG for Various Ions



7th Inning Stretch



Part II: GRB Science with Abs. Lines

Redshift

HI Surface Density

Molecules

Metallicity

Chemical Abundances

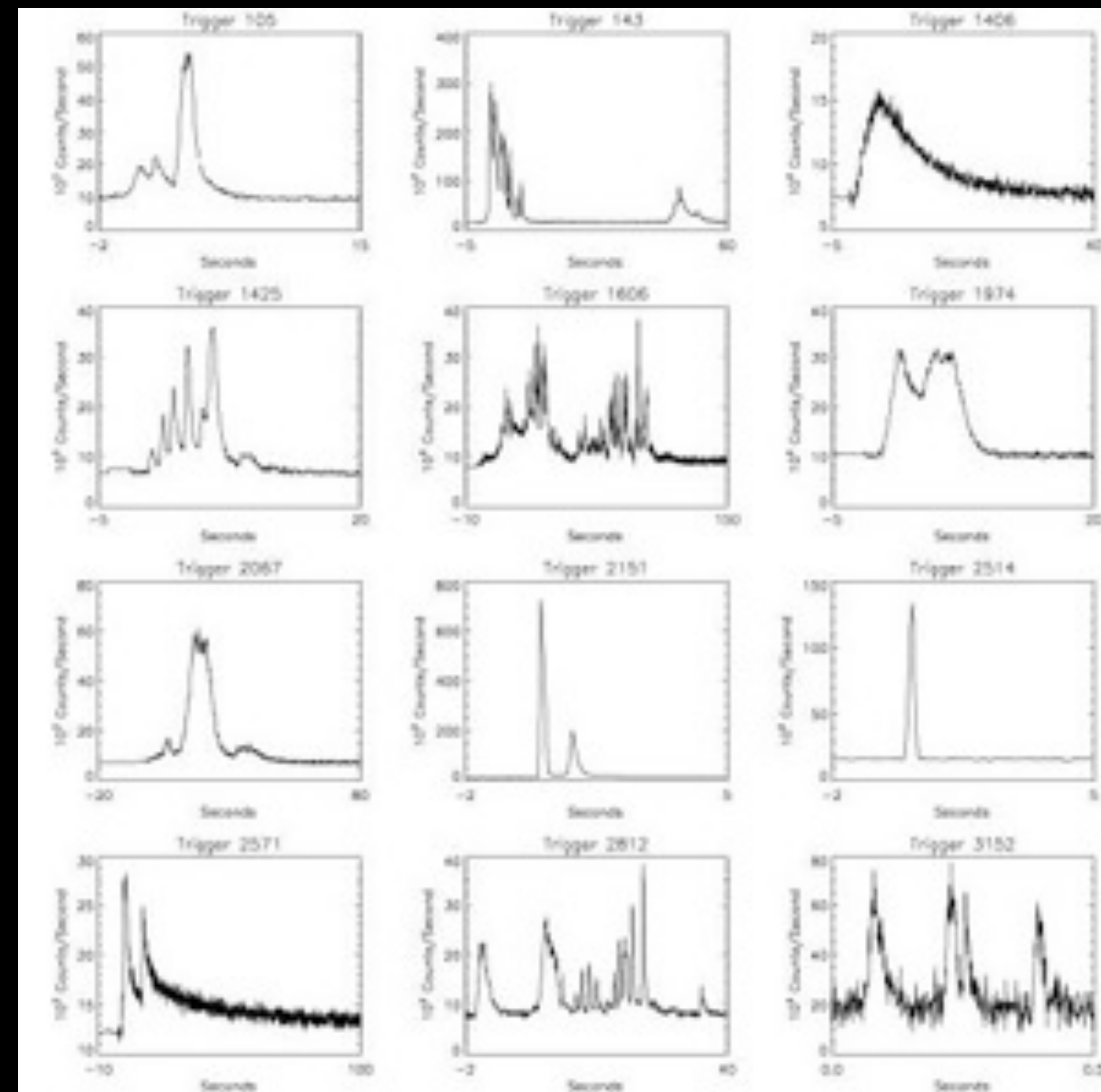
Progenitor environment

Kinematics

IGM

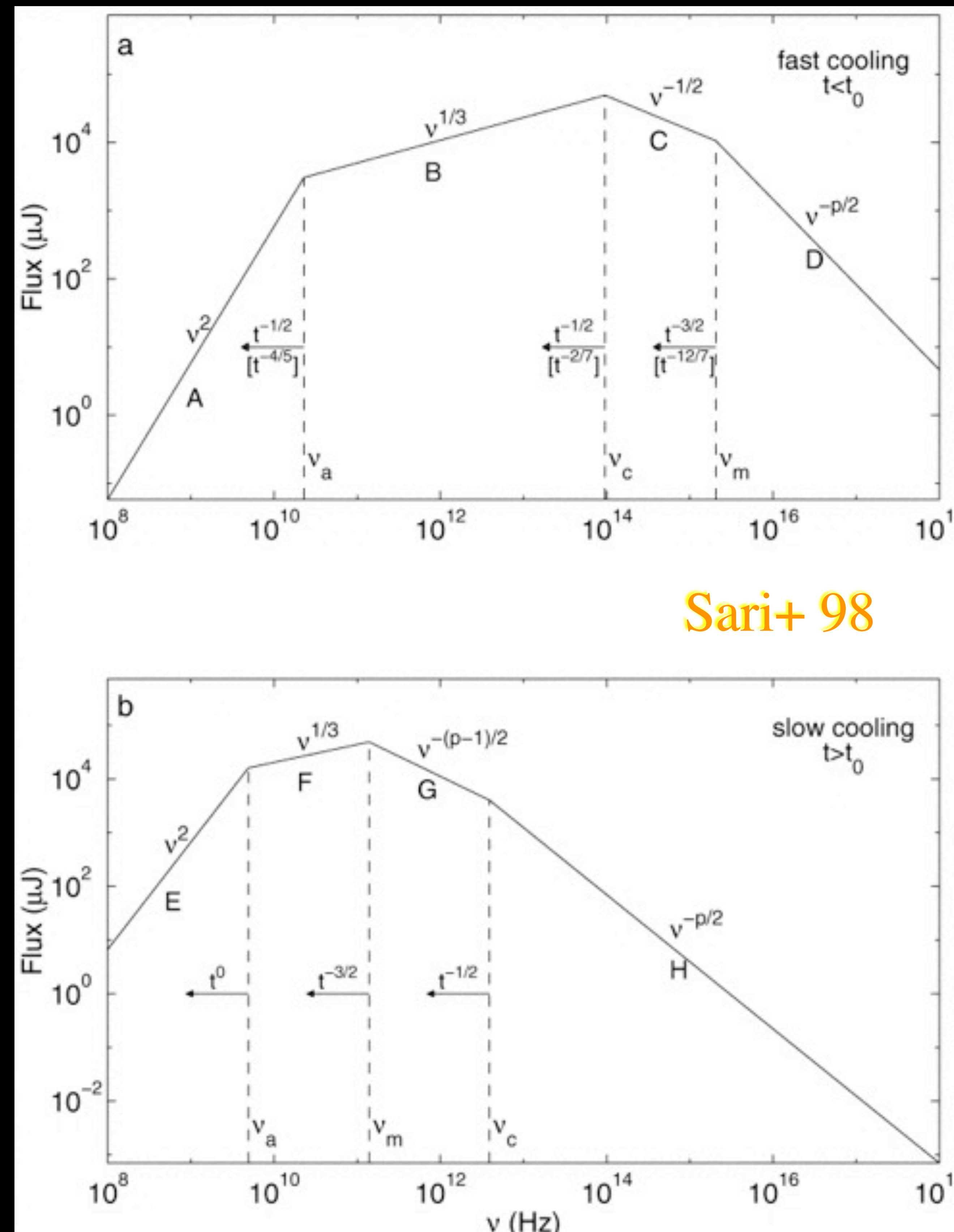
Science: Redshift of the GRB (z_{GRB})

- **Establish the GRB energetics**
  - At least E_{iso}
  - And critical for E_{peak}
- **Connect the event to a galaxy**
  - Including our own!
- **Connect gas in the spectrum to the event**
  - This enables the absorption line science...



Challenge: The Afterglow is a power-law

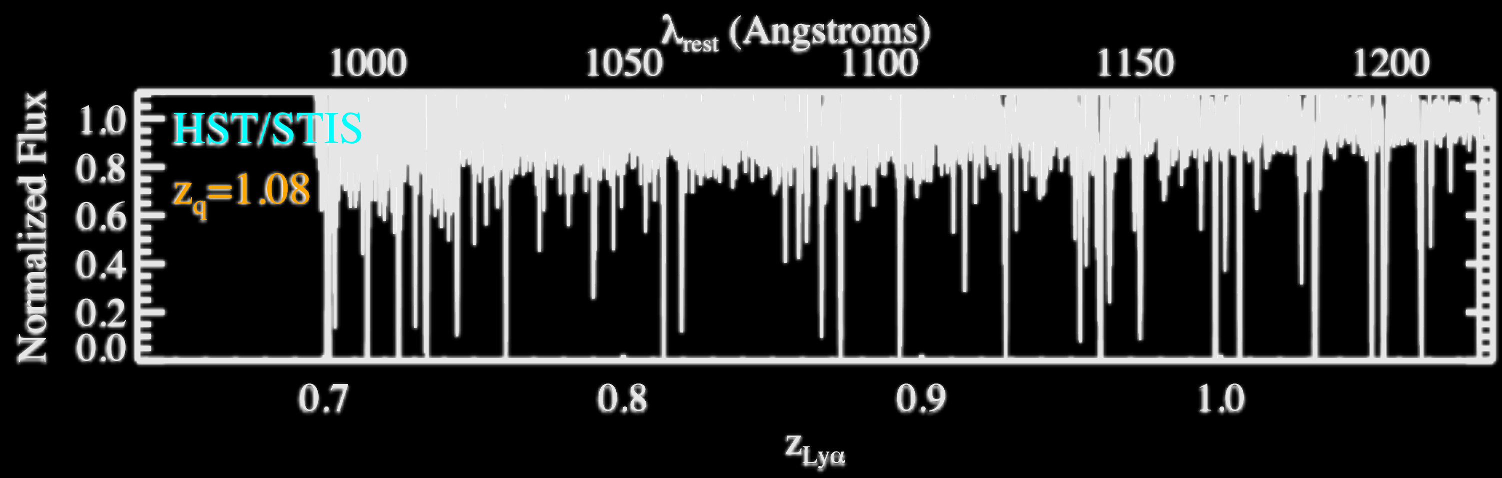
- **Featureless**
  - No emission lines
  - Breaks occur at uncertain and evolving frequencies
- **No redshift information**
  - Need absorption lines!



Sari+ 98

Intergalactic Medium

- **IGM**
  - a.k.a., the "cosmic web"
  - The gas that fills the space between galaxies
  - The IGM is highly ionized
    - $n_{HI} / n_H \sim 10^{-5}$
- **Lyα forest**
  - Absorption from the trace HI atoms in the IGM
  - Source of Lyα absorption (and Lyβ, Lyγ, Lyδ, ..)
  - Increasing opacity with z
- **Metals in the IGM**
  - Galaxies and the gas around them contain metals



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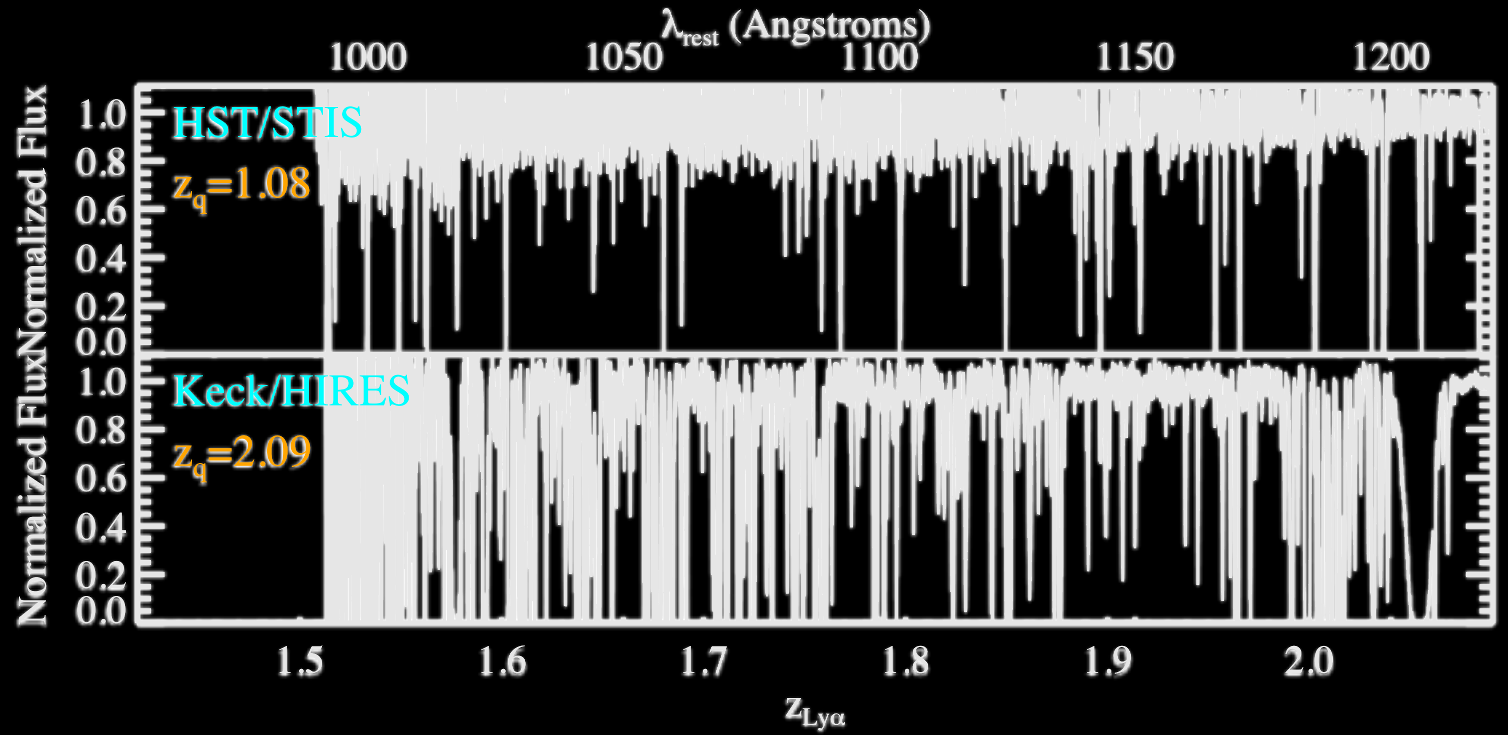

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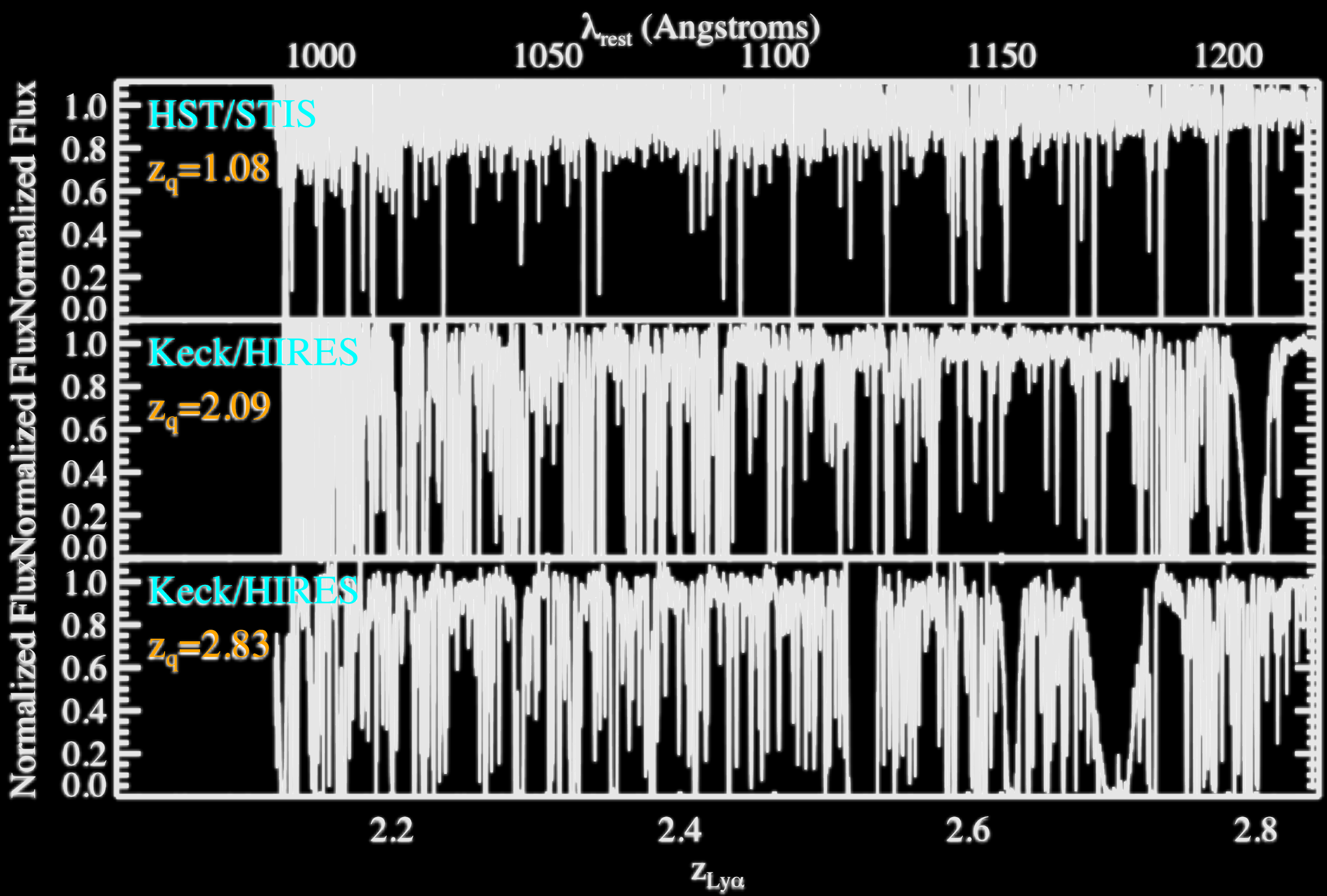

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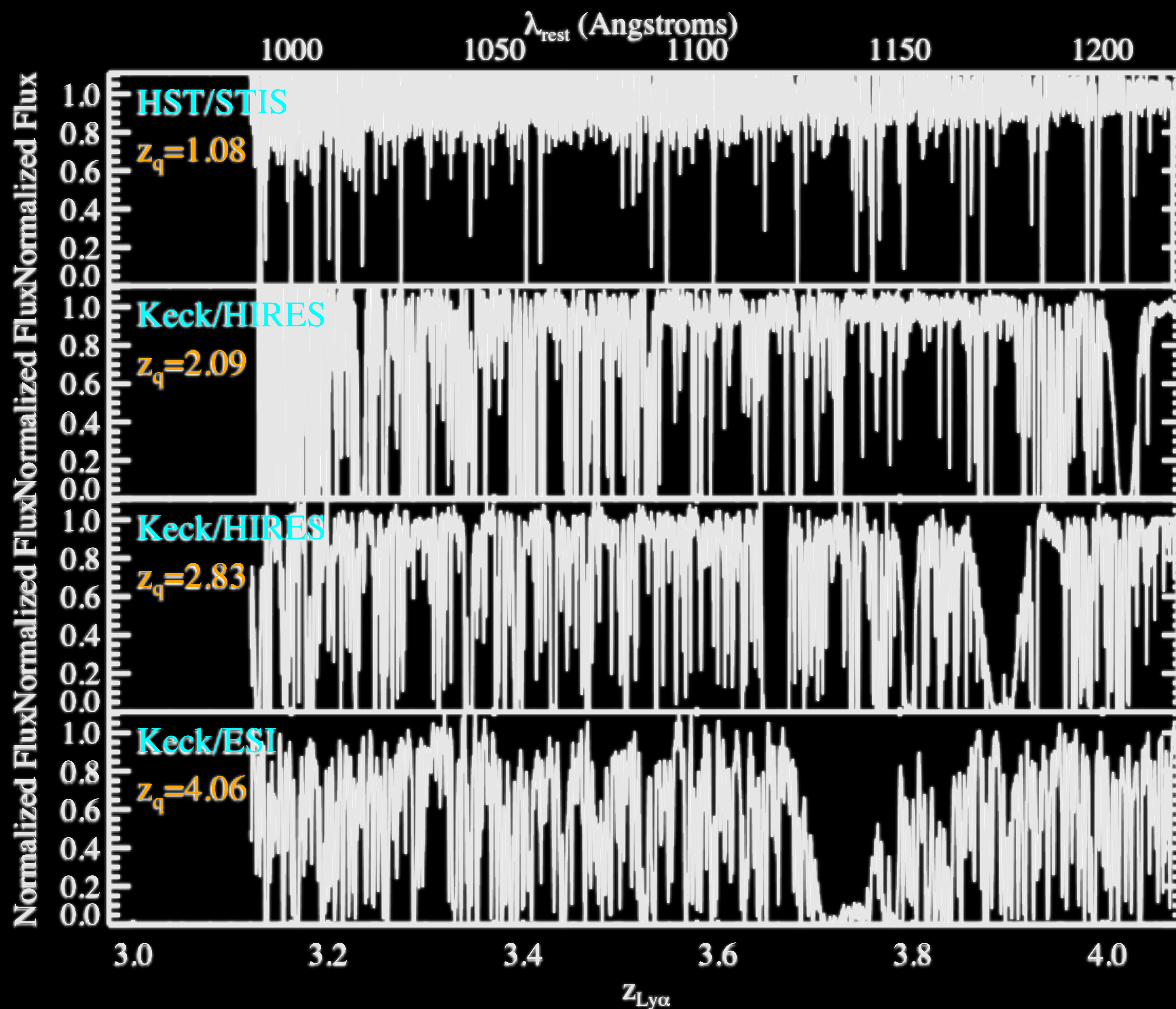

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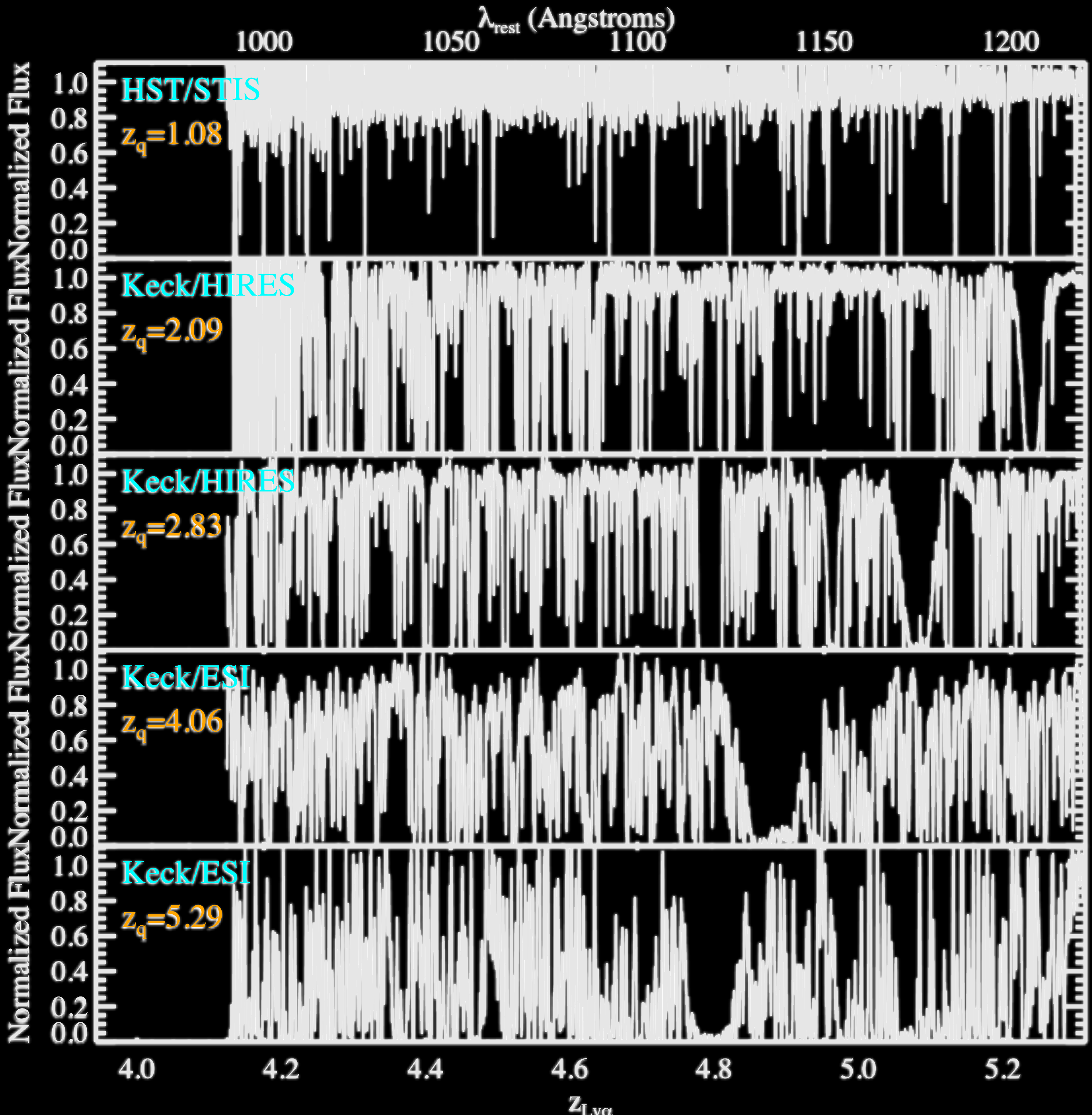
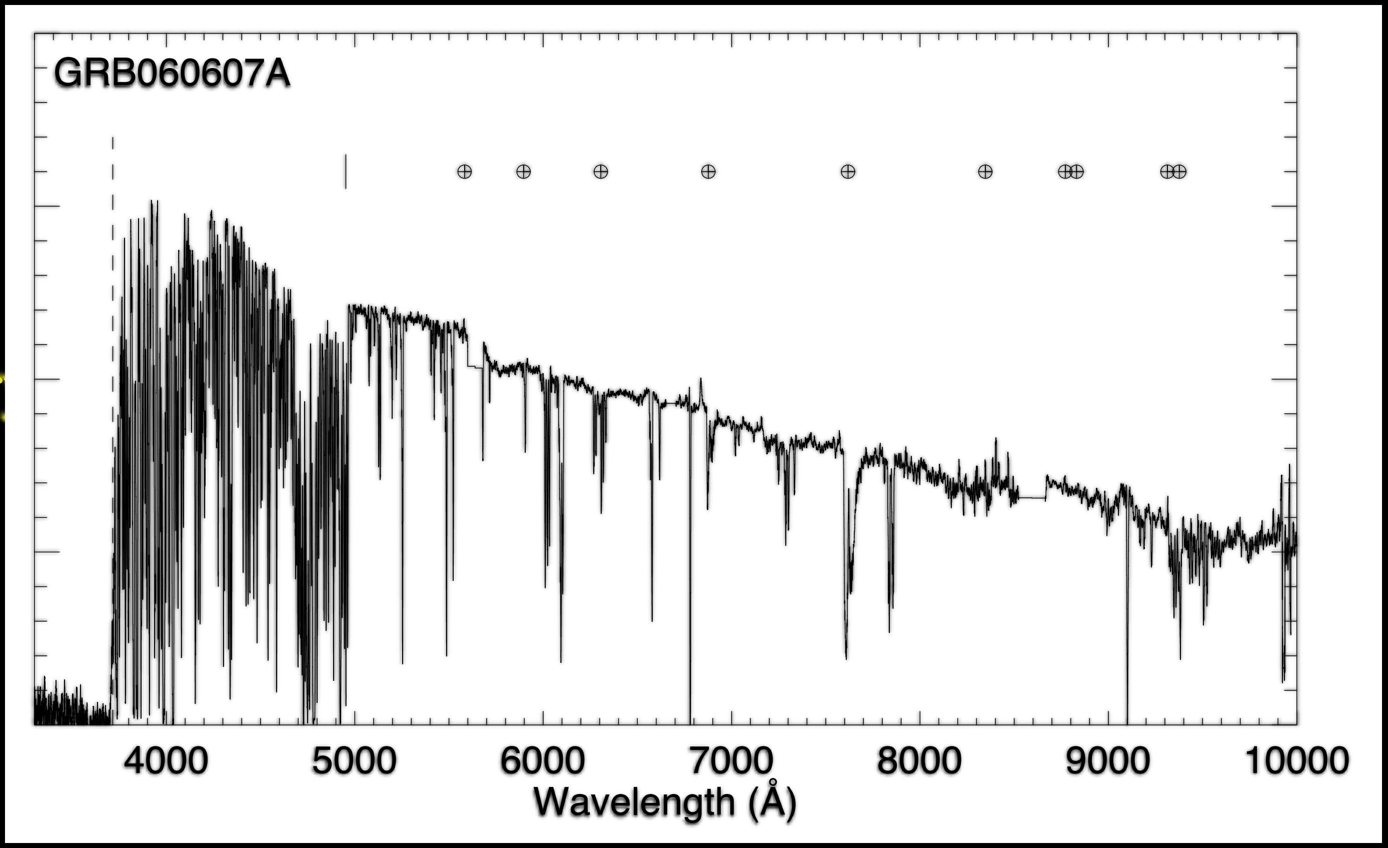


z_{GRB} from the Lyα Forest

- 100% robust technique
  - IGM exists in all directions
  - Unmistakeable signature
  - IGM is strong for higher z_{GRB}
    - Permits good photo z's from photometry
- Good precision
  - z_{GRB} known to a few 1000 km/s
  - Sufficient for most applications
- Only drawback
  - Requires $z_{GRB} > 2$
    - For spectra that covers to 4000Ang
  - Absence of IGM demands $z_{GRB}<2$

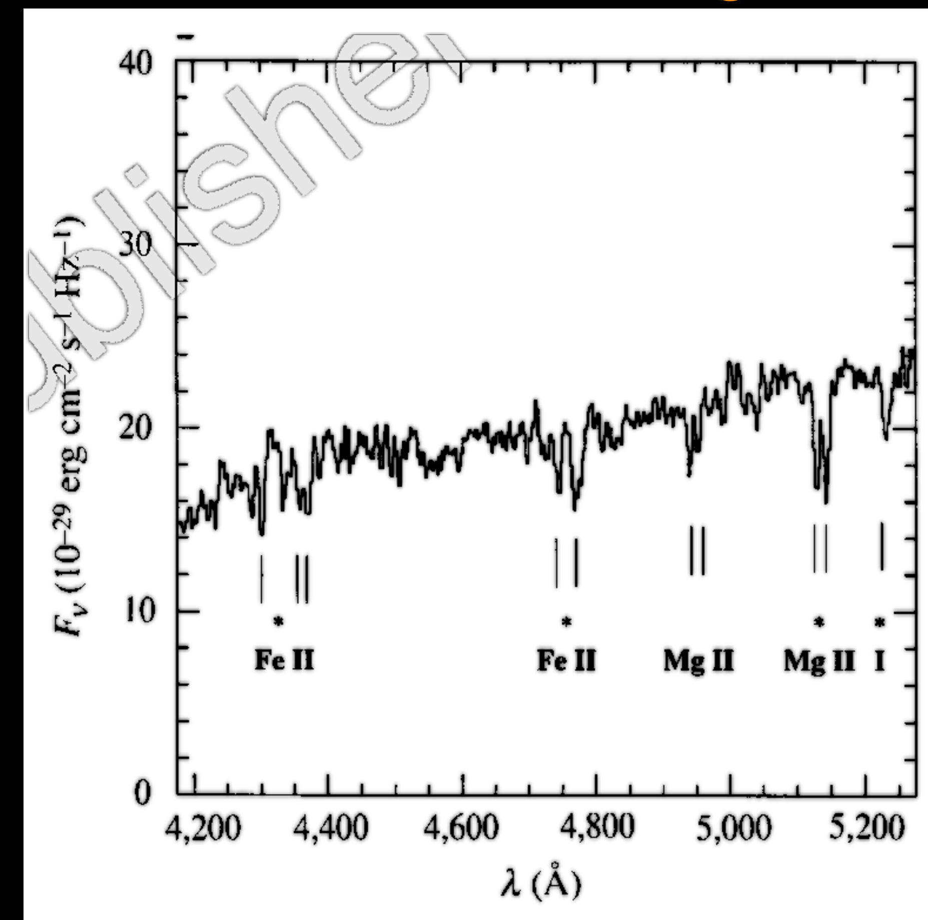


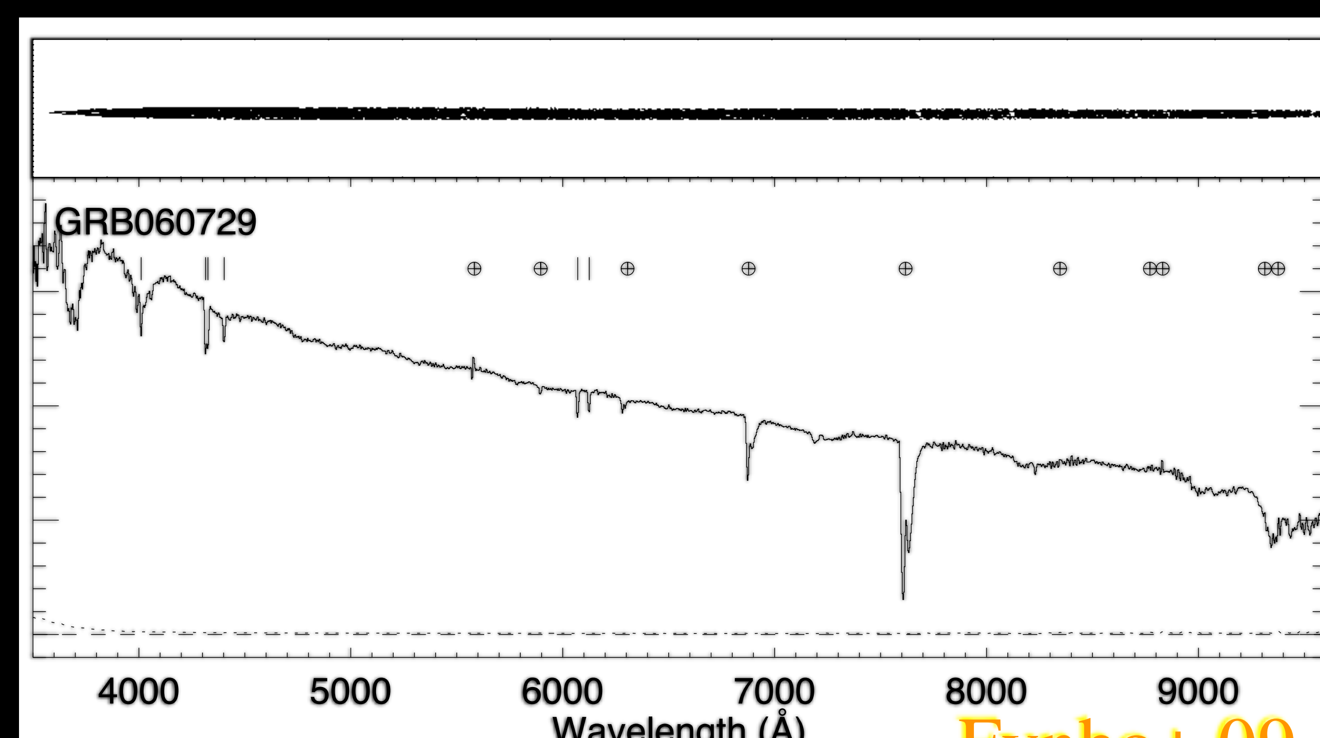
Fynbo+ 09

z_{GRB} from IGM Metals

- 100% Robust technique
  - z_{GRB} must equal or exceed z_{max} of the metals detected
- Poor precision
  - z_{GRB} can be much higher than z_{max}
    - Of course, absence of the Lyα forest will impose an upper limit
  - Can (likely) confirm with follow-up galaxy spectrum
- Absence of metal-absorption
  - Not a definitive constraint of any kind

Metzger+ 97





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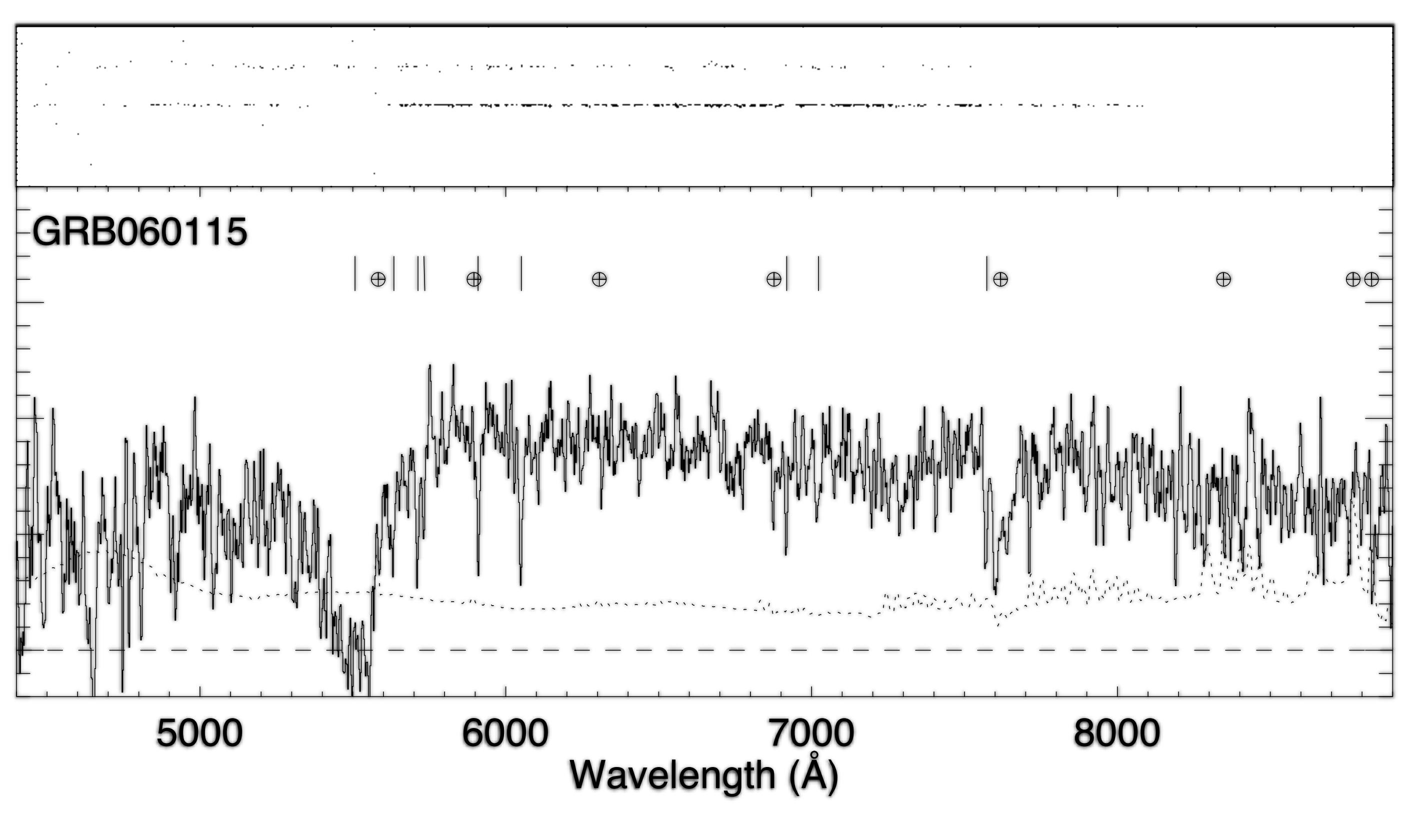
z_{GRB} from Damped Lya Absorption (DLA)

- The majority of GRBs exhibit very strong, DLA
  - $N_{HI} > 10^{21}$ cm^{-2}
    - This is a very rare event in the IGM
  - Strong damping wings
    - Easy to identify even in poor spectra
- This occurs at the <u>end</u> of the observed Lyα forest
  - Nearly 100% robust
  - Precise to a few 100 km/s
  - Also limited to $z_{GRB} > 2$



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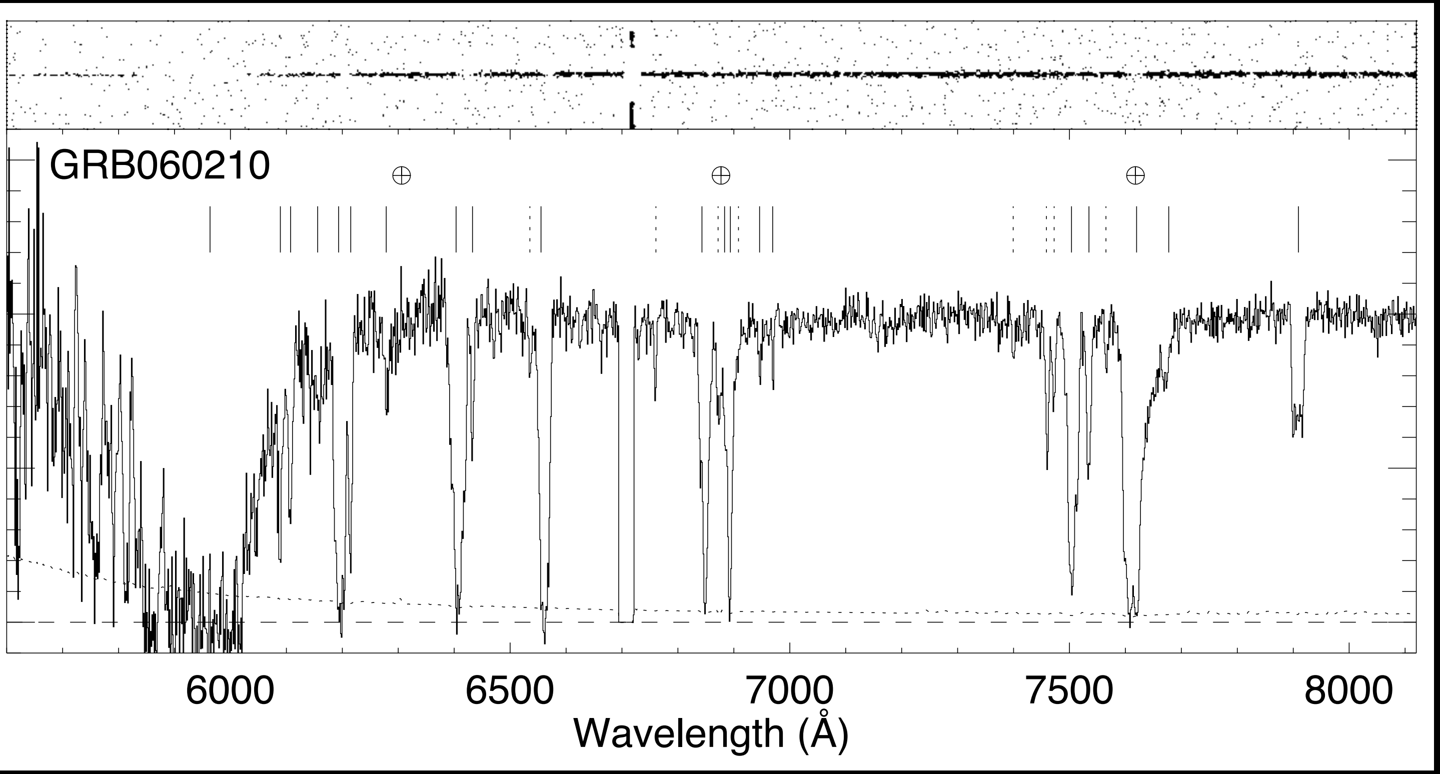
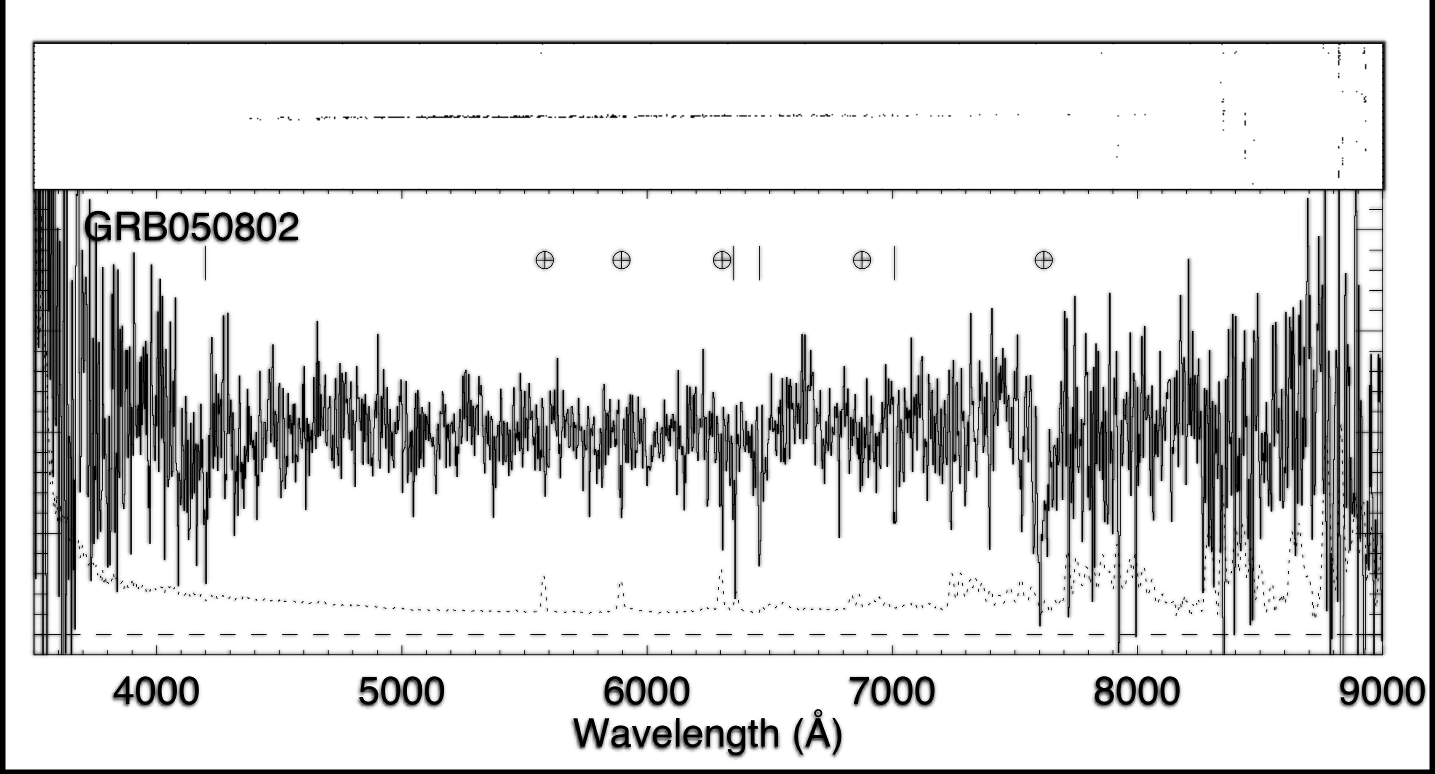
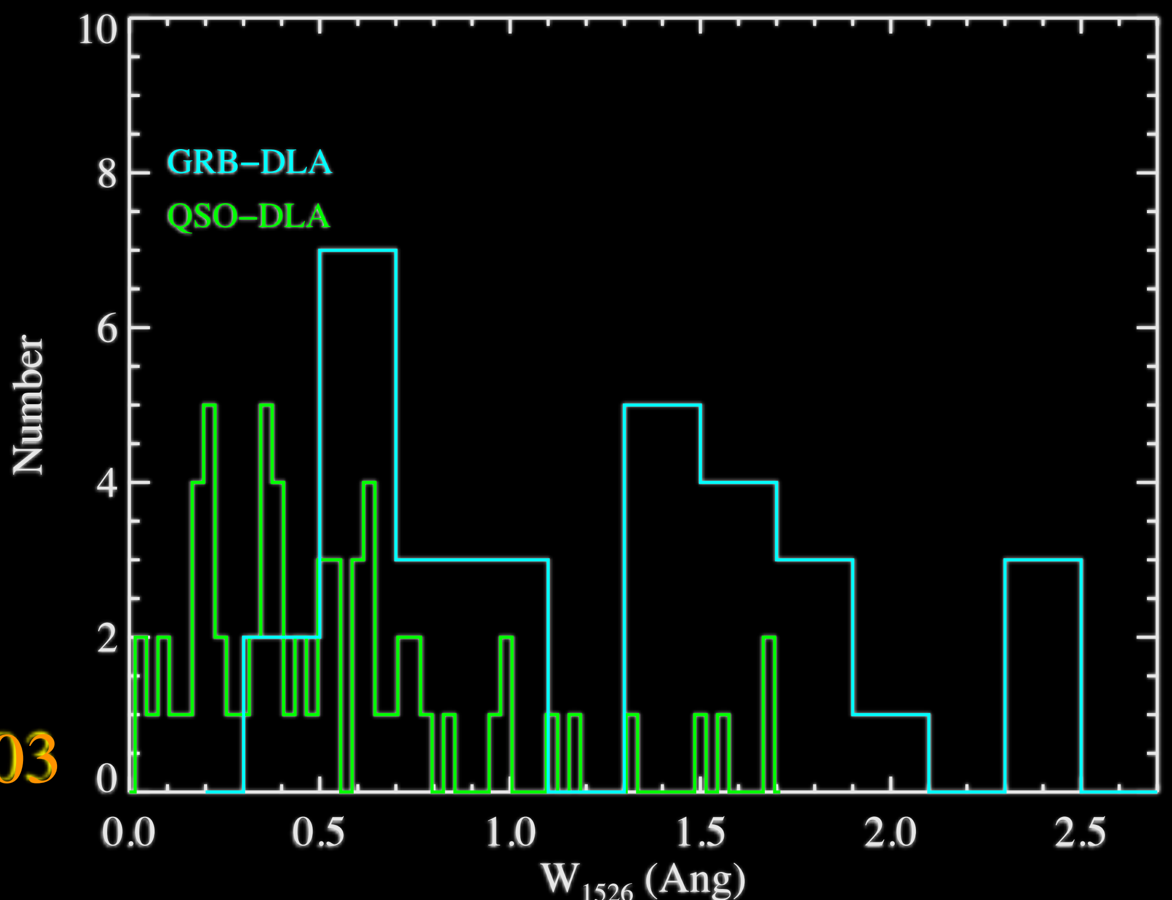


z_{GRB} from Strong Metal Absorption

- The majority of GRBs show metal lines with large EW
  - C IV, C II, Mg II, Si II
    - EW > 1 Ang
  - Combine highest redshift with the strong line
- Not 100% robust
  - Many galaxies in the universe show strong metal absorption
- High precision (if correct)
  - Few tens of km/s



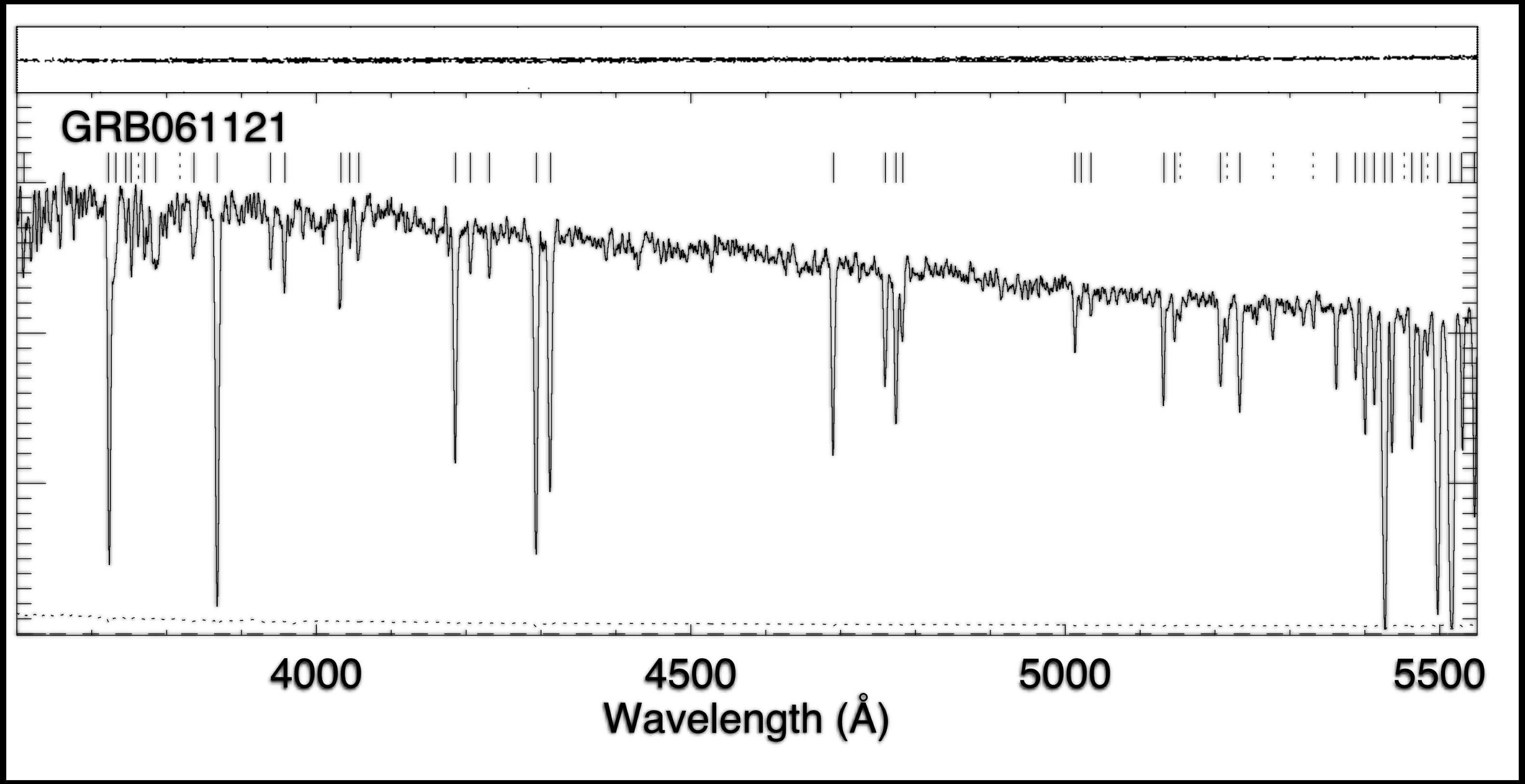


Savaglio+03

Pro+ 07

z_{GRB} from Fine-Structure Absorption

- The majority of GRBs show metal absorption from fine-structure levels
  - e.g. FeII*, SiII*, OI*
  - These are produced by the afterglow
- 100% robust
  - Only GRBs show this
    - Or gas very close to QSOs
- High precision
  - Few tens of km/s
- Challenge
  - Typically not very strong
    - i.e., requires higher quality data

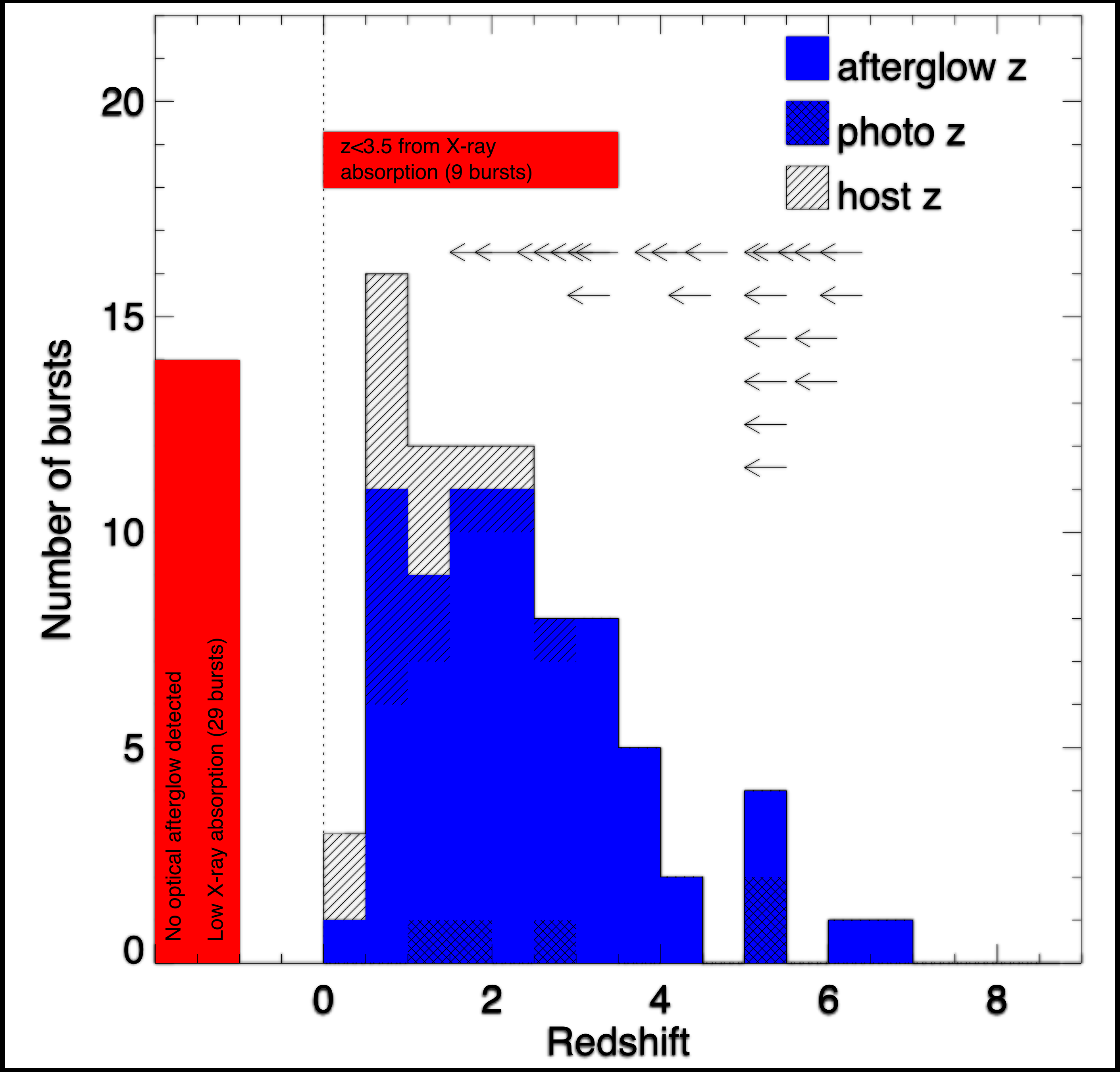


Pro+ 06

Fynbo+ 09

zGRB Distribution

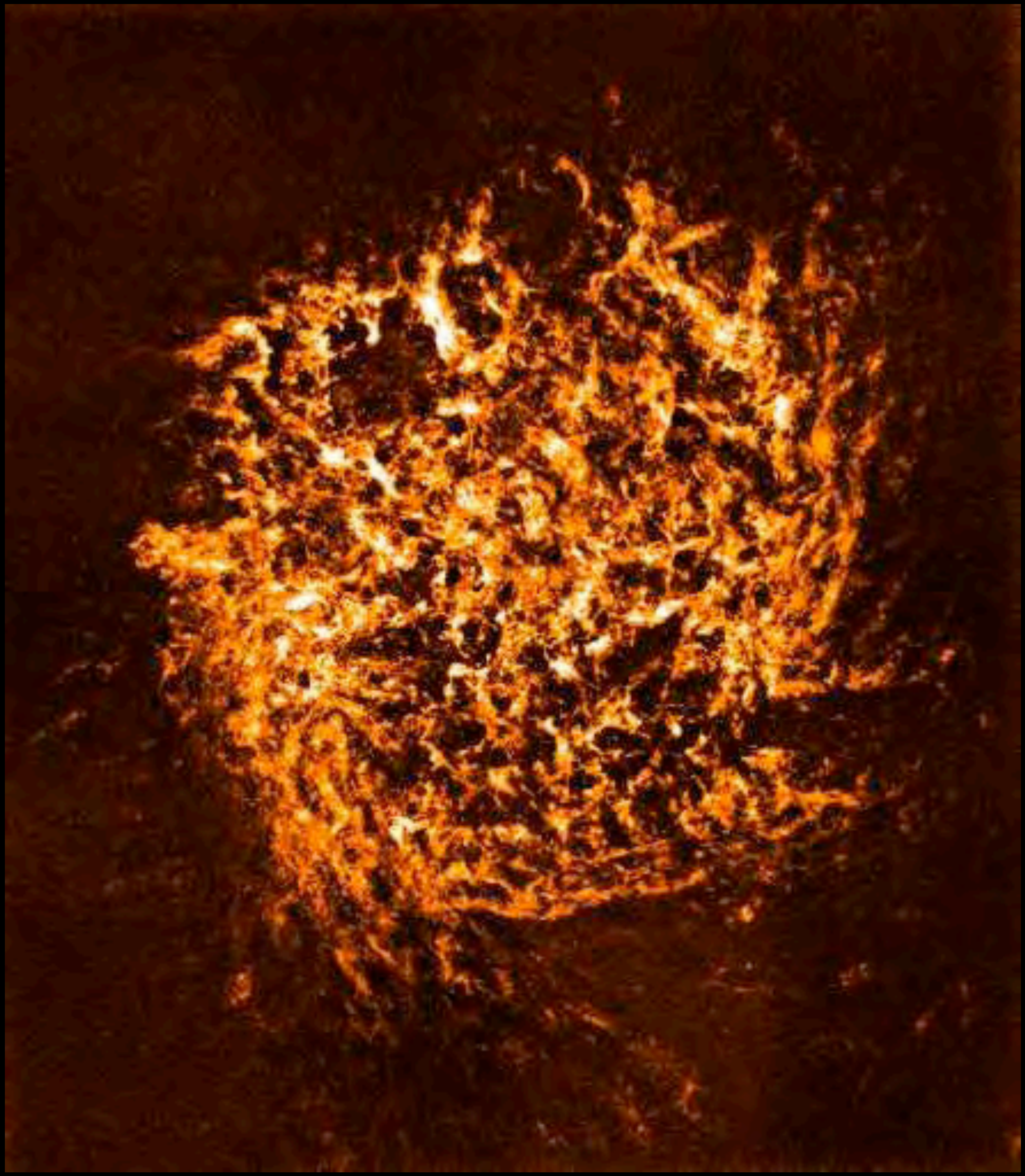
- Observations
  - Afterglow spectroscopy dominates
  - Host spectra contribute
  - Upper limits
    - Constraints include absence of IGM
- Science?
  - Attempt to trace star-formation history
  - Many complicated selection criteria
    - GRB trigger, afterglow spectrum, etc.



Fynbo+ 09

Science: HI Column Density (N_{HI})

- Surface density of the galaxy
  - Mass distribution
  - Characteristics of high z, star-forming regions and ISM
- Starting point for metallicity
  - Bulk of the gas
- f_{esc}
  - Reionization of the universe
  - See lecture by H-W Chen



N_{HI} Measurements

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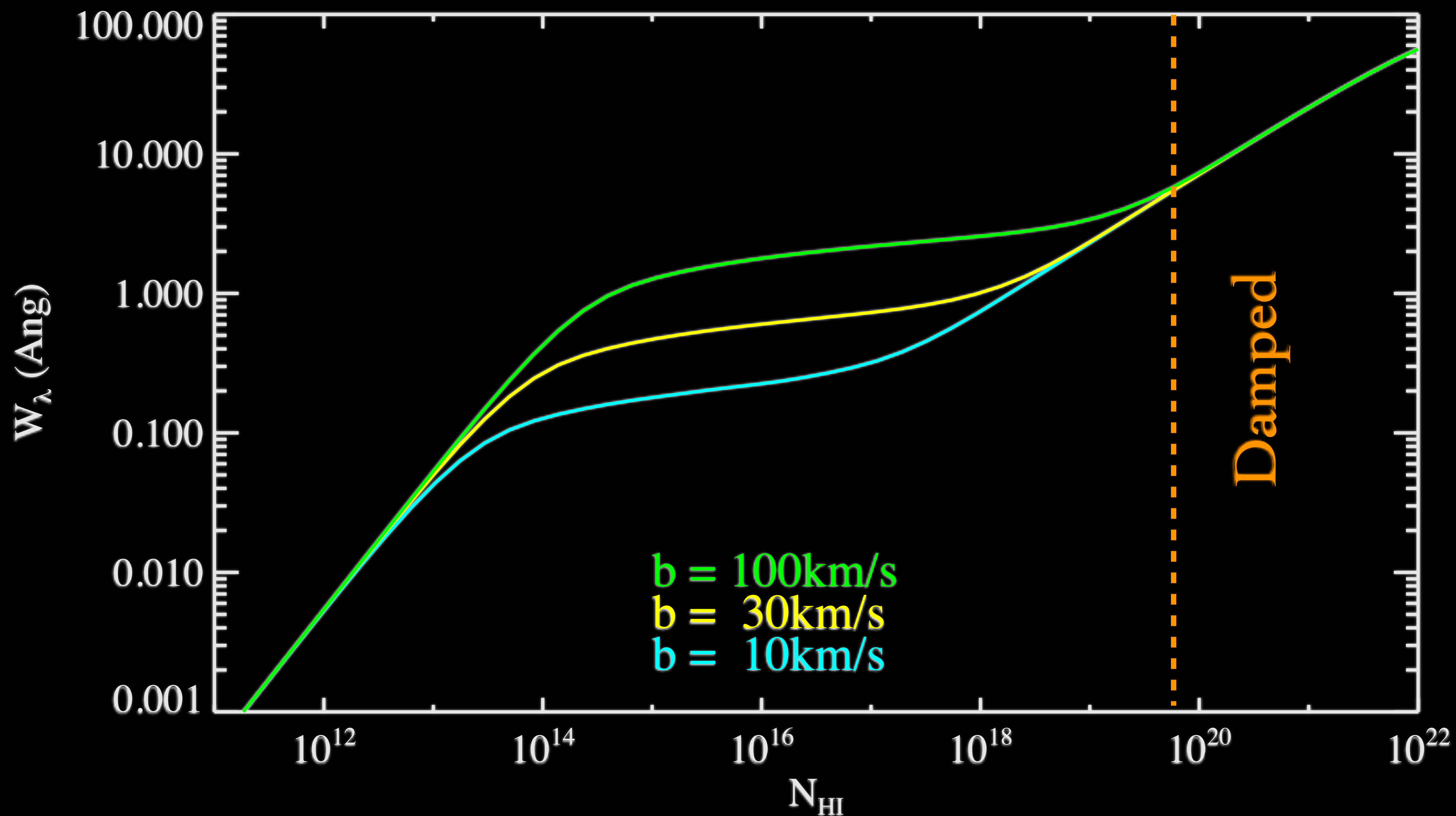
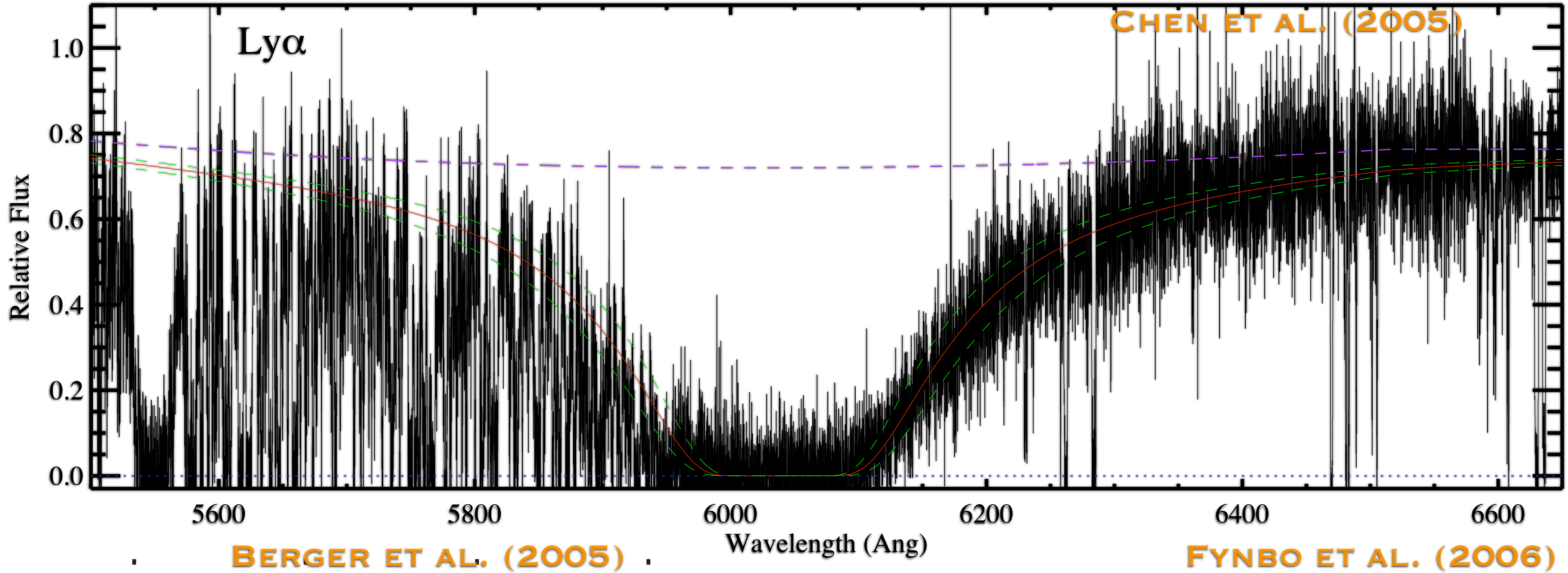
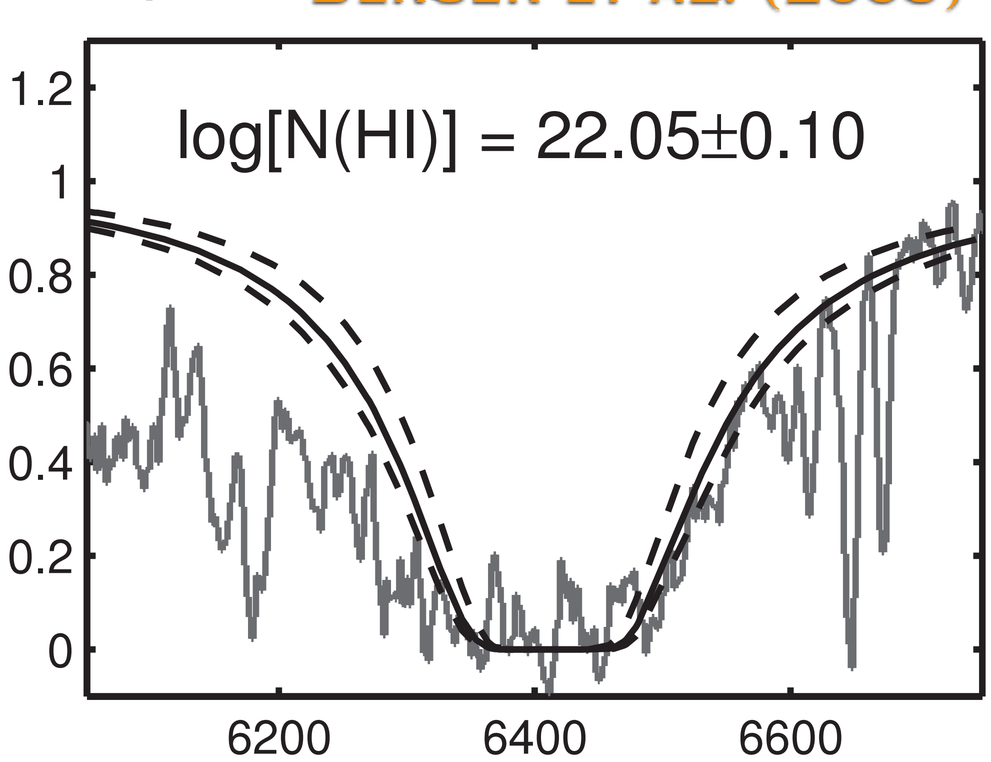
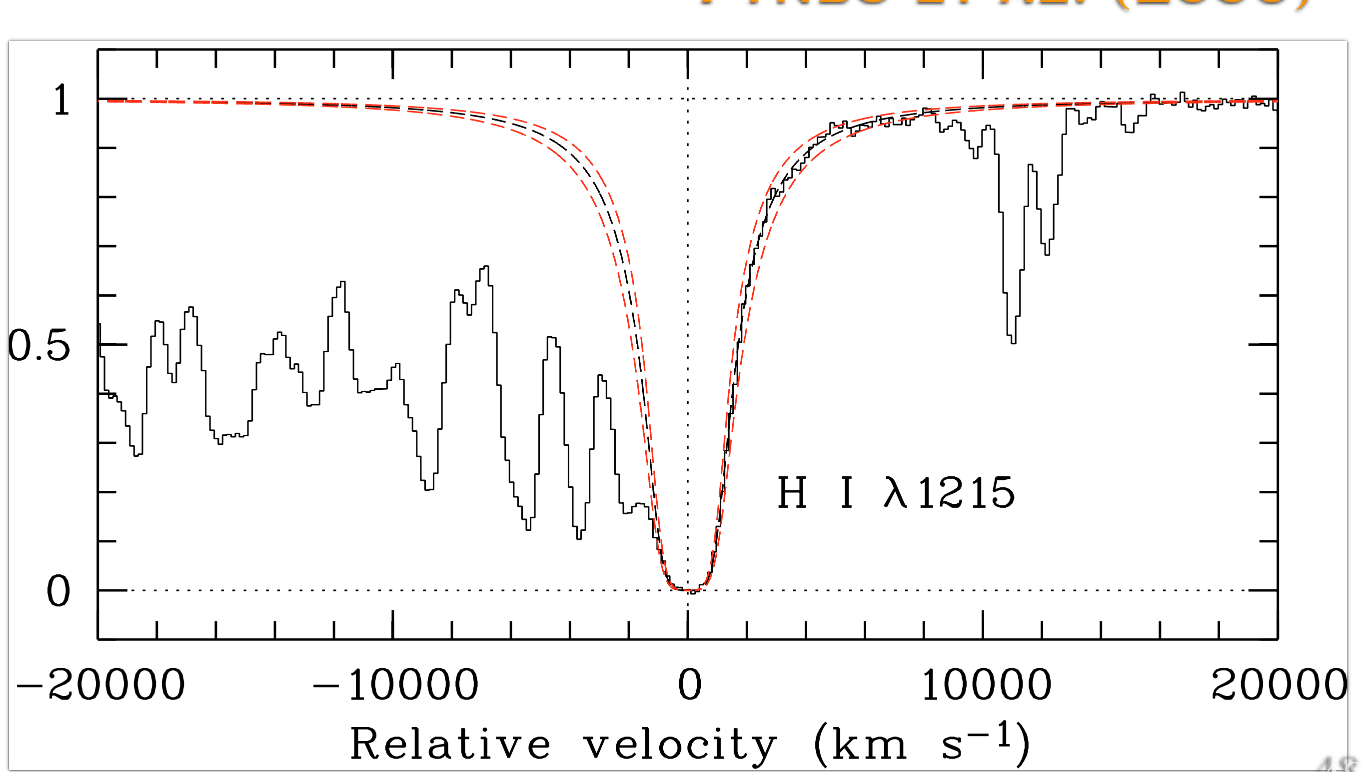


N_{HI} Measurements (DLAs)

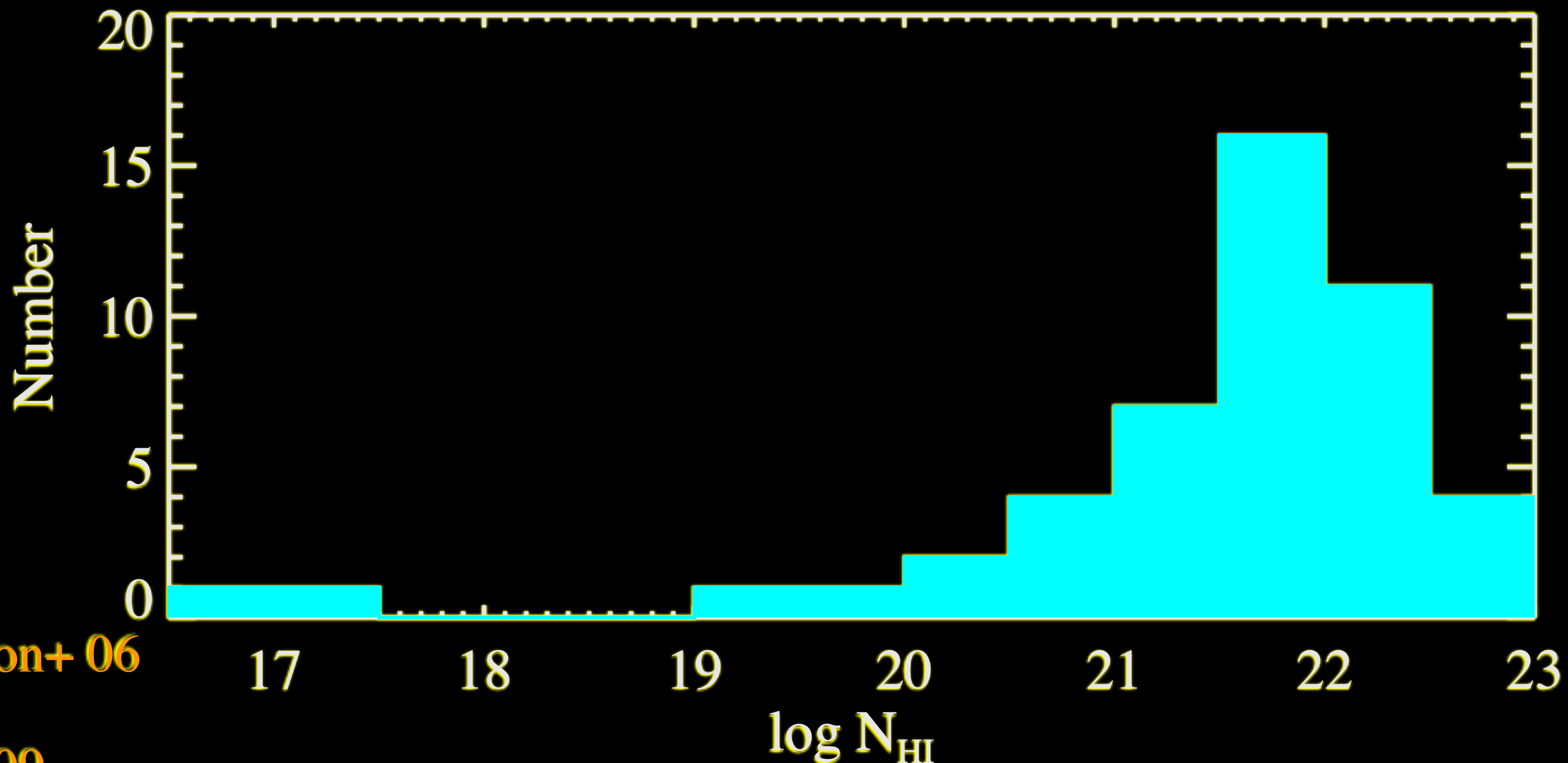






N_{HI} Distribution for GRBs

- Majority (>80%) have large Σ_H
  - Characteristic of Giant Molecular Clouds and HI disks
  - As expected for events occuring in SF regions
- Small subset with modest N_{HI}
  - Characteristic of a galactic 'halo'?
  - Key for reionization studies
- Two that are optically thin!
  - Non-zero escape fraction



Jakobsson+ 06
Pro+ 07
Fynbo+09

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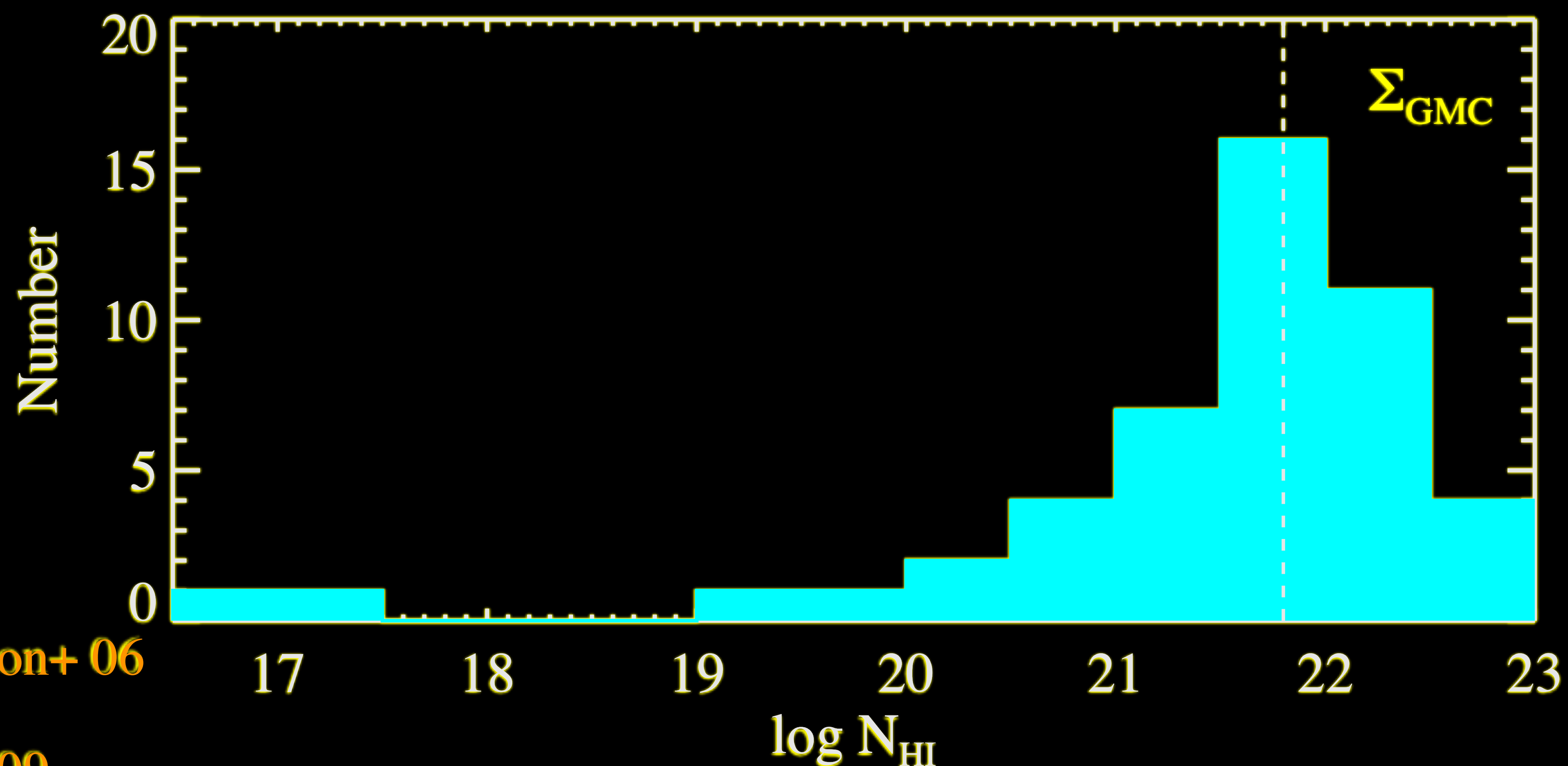

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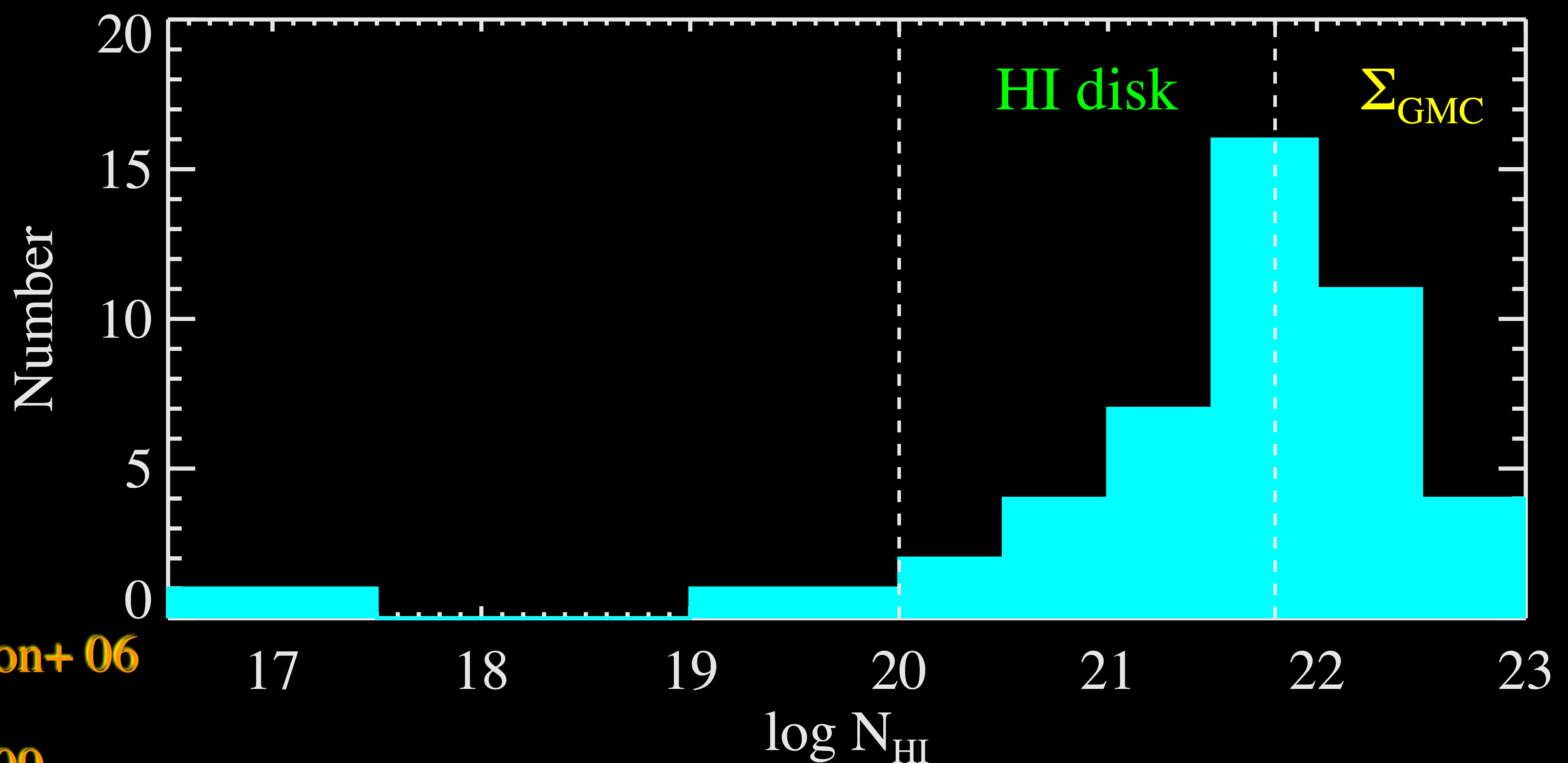

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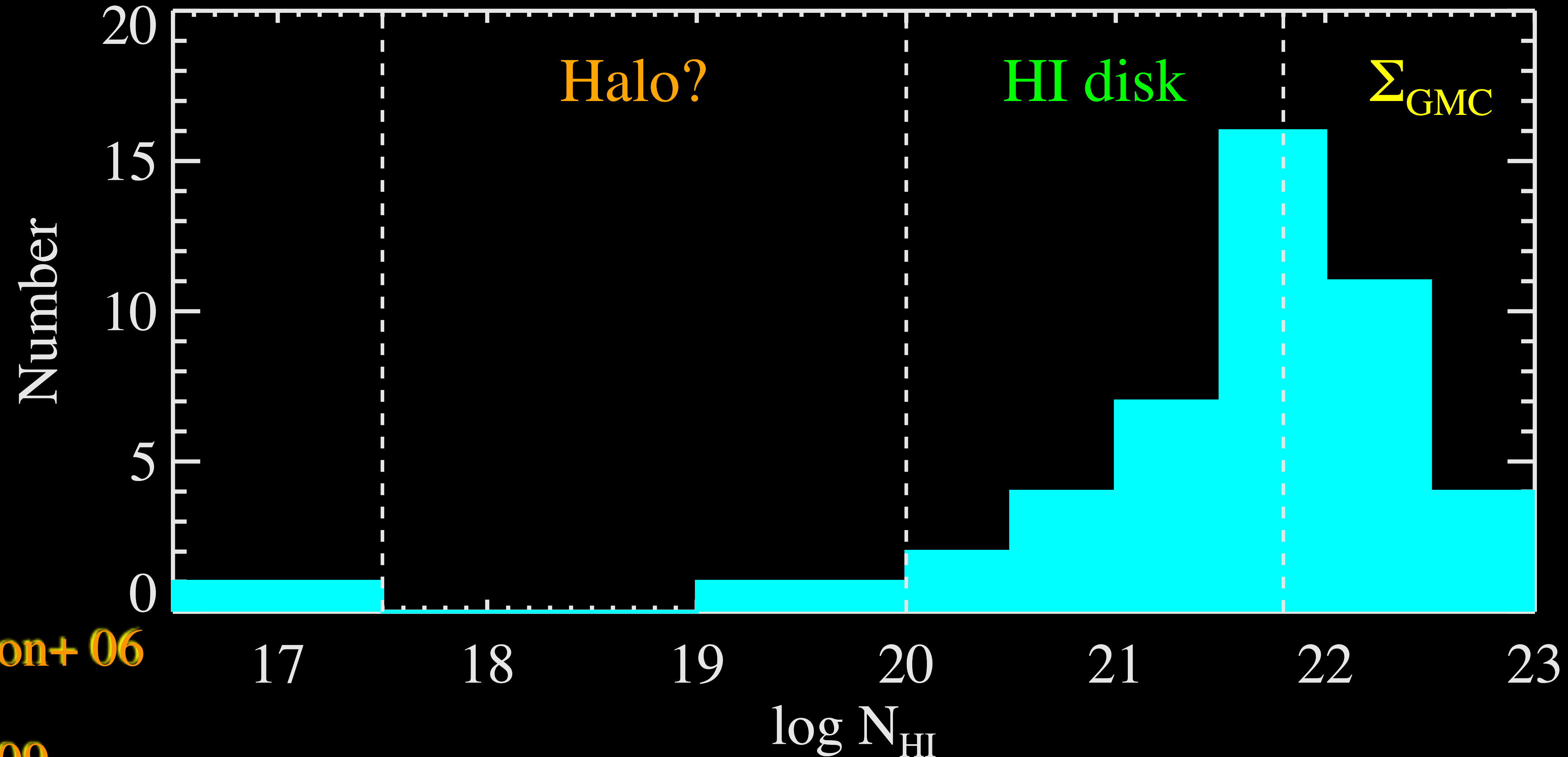

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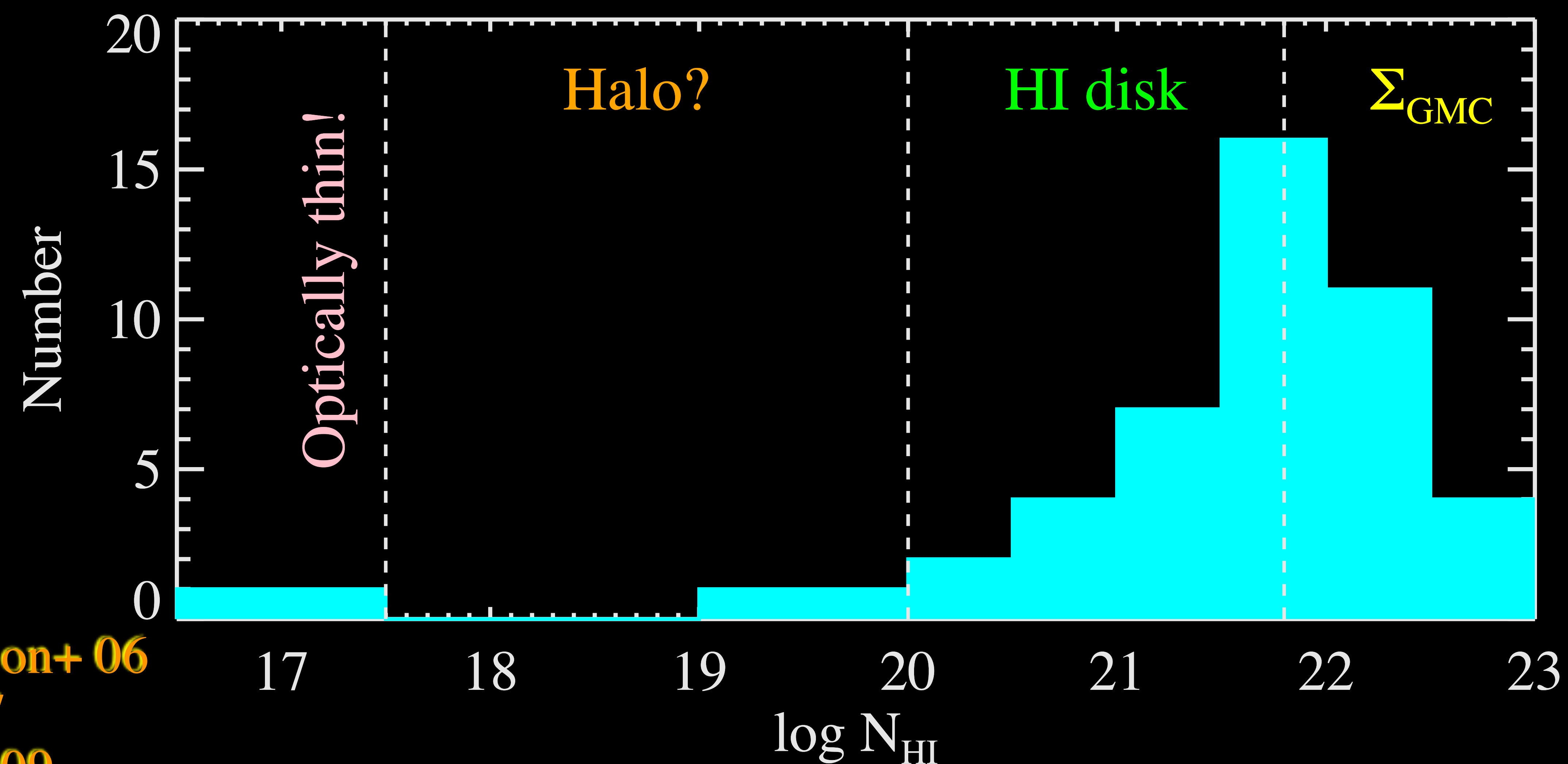
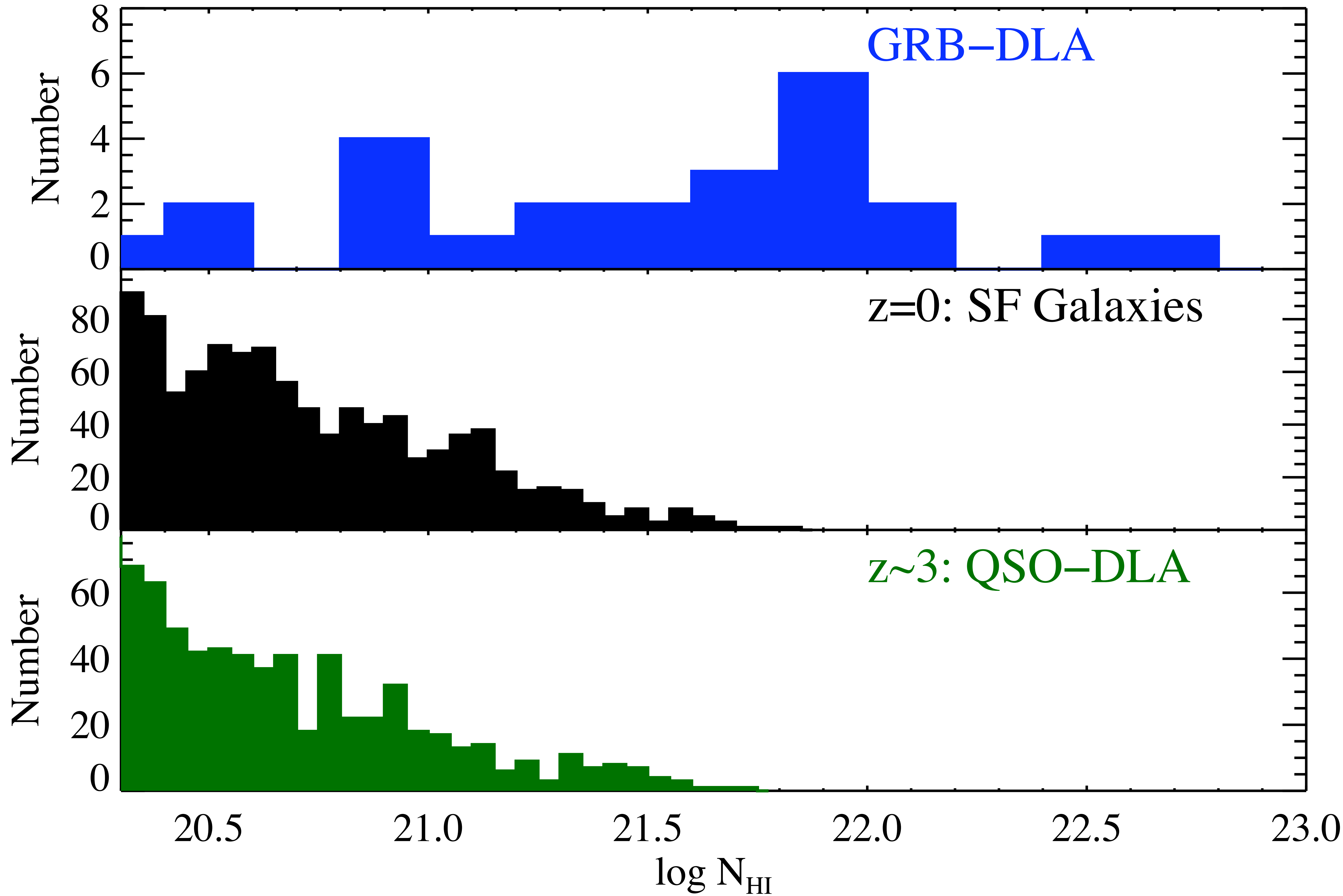


Jakobsson+ 06
Pro+ 07
Fynbo+09

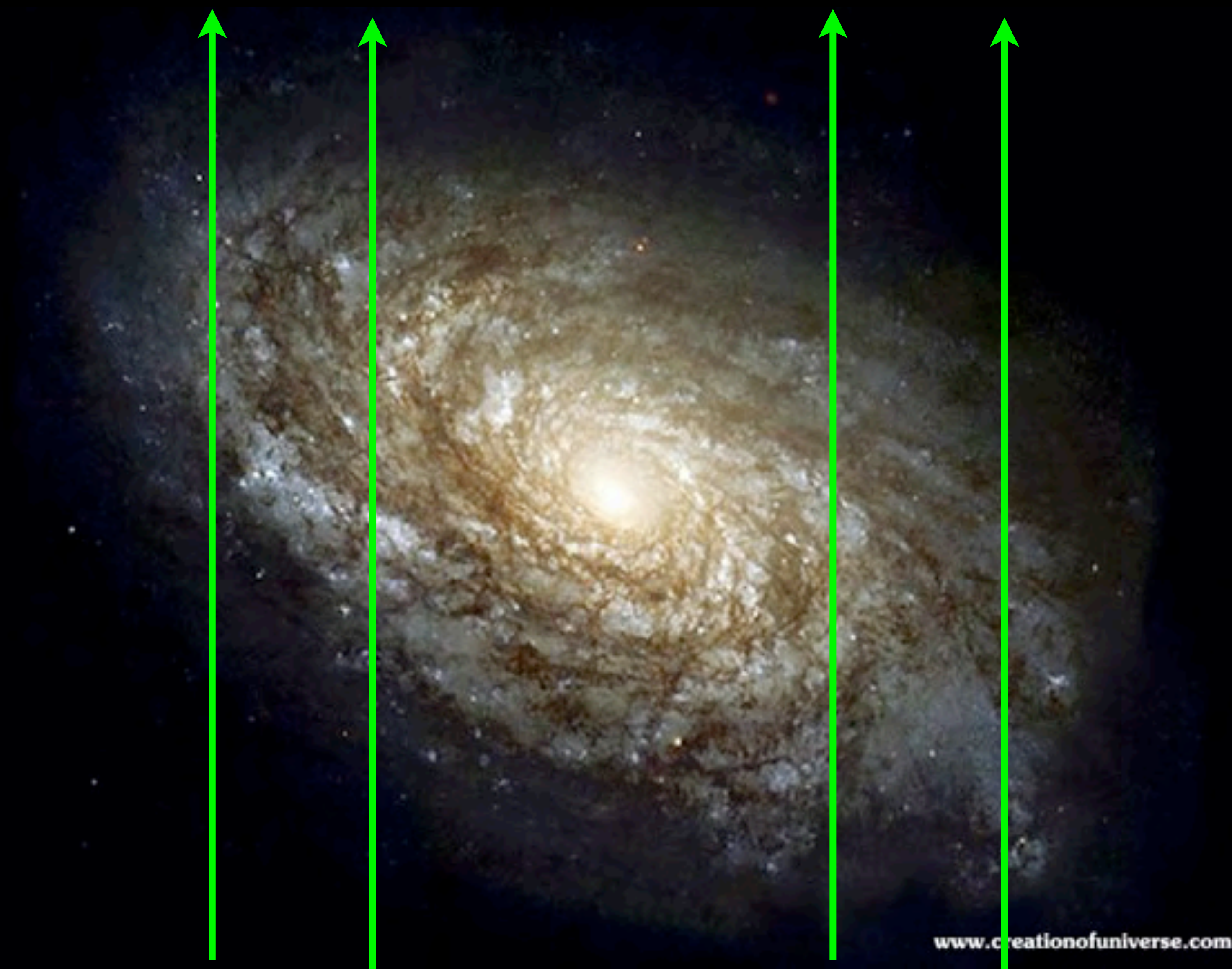
GRB N_{HI} vs. SF Galaxies



Understanding the Difference

Pro+05
Jakobsson+06
Pro+07

- QSO-DLAs (green)
  - Random sightlines through ~1000 high z galaxies
    - Cross-section selected
  - None with $N_{HI} > 10^{22}$ cm^{-2}
- GRB-DLA (orange)
  - Systematically larger N_{HI}
  - Larger than most HI surface densities today
- Implications
  - Association with SF regions
    - But not H_2 clouds
  - Random sightlines from the center of a galaxy



Understanding the Difference

Pro+05
Jakobsson+06
Pro+07

- QSO-DLAs (green)
  - Random sightlines through ~1000 high z galaxies
    - Cross-section selected
  - None with $N_{HI} > 10^{22}$ cm^{-2}
- GRB-DLA (orange)
  - Systematically larger N_{HI}
  - Larger than most HI surface densities today
- Implications
  - Association with SF regions
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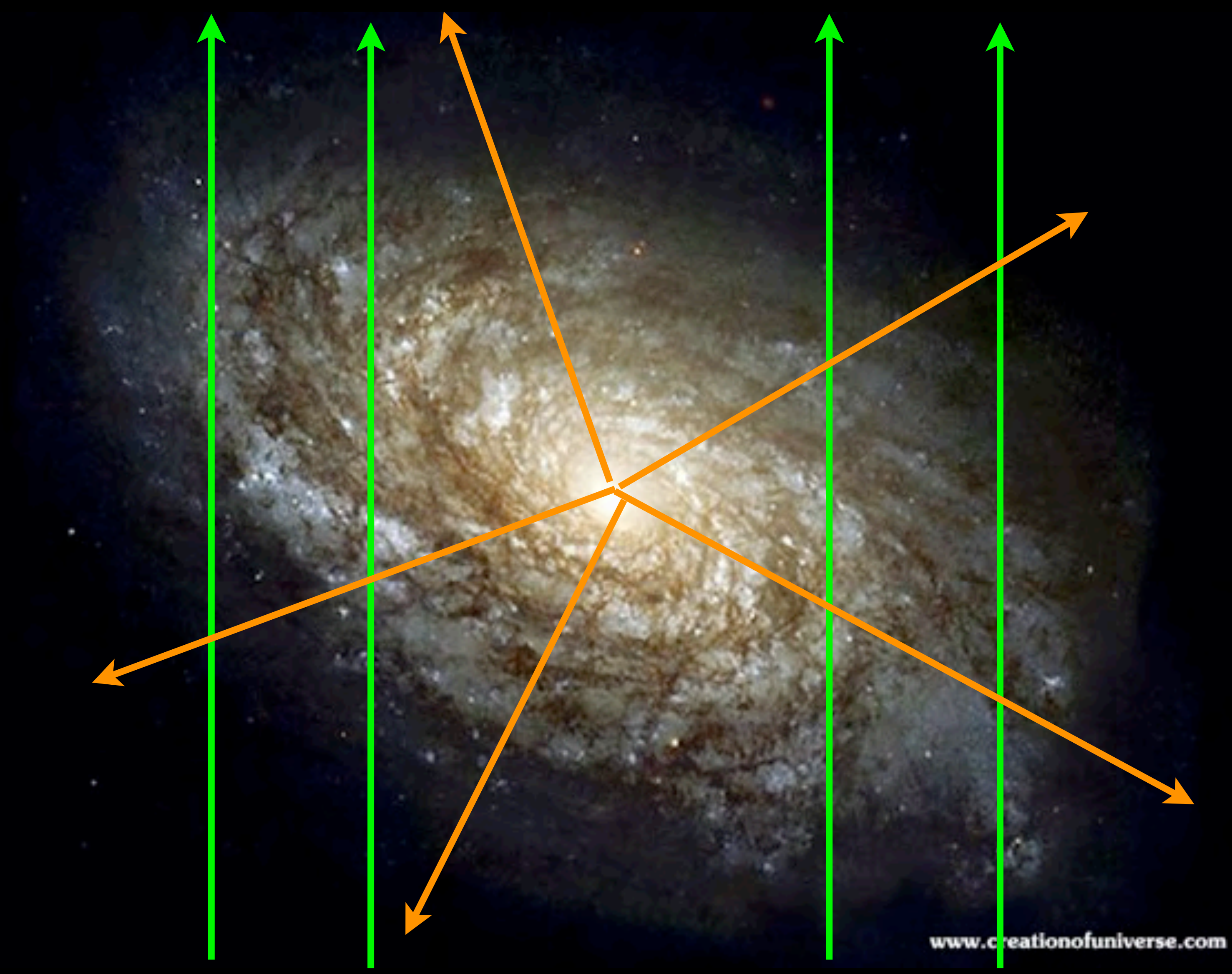
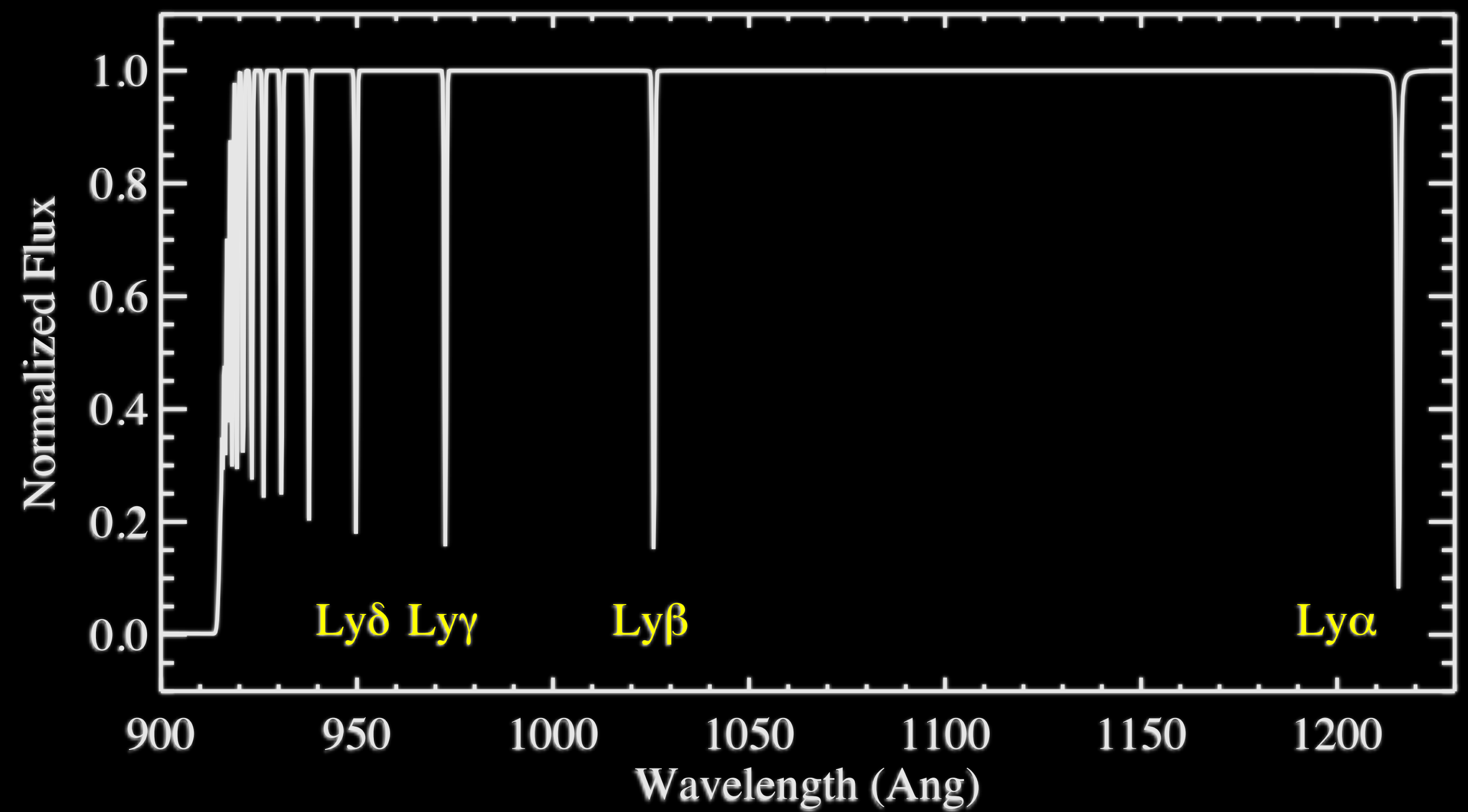
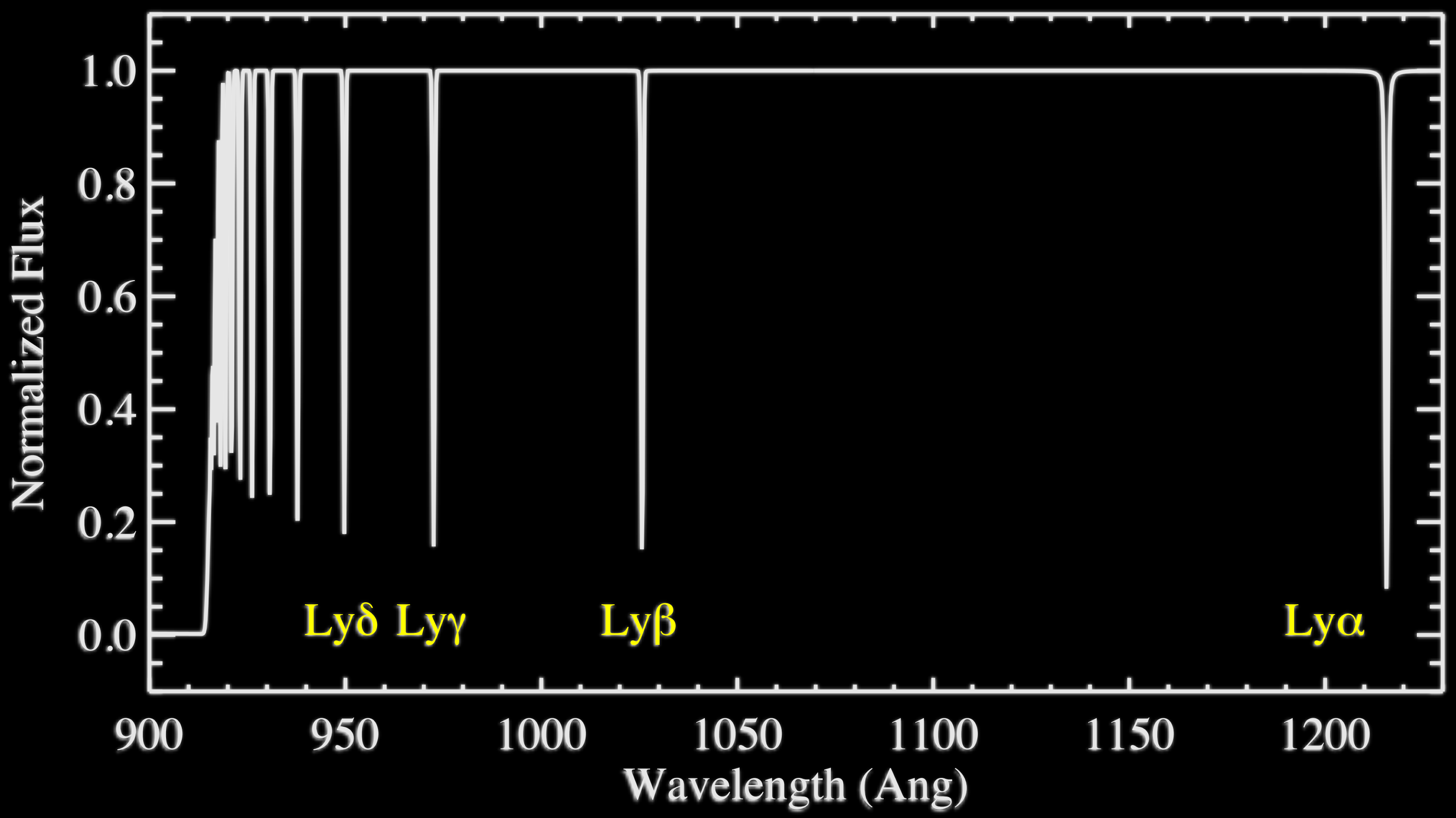


Searching for Molecules



Searching for Molecules

- HI: Lyman series
  - 912 to 1025 Angstroms
  - ~10 useful lines
  - Mostly focus on Lyα



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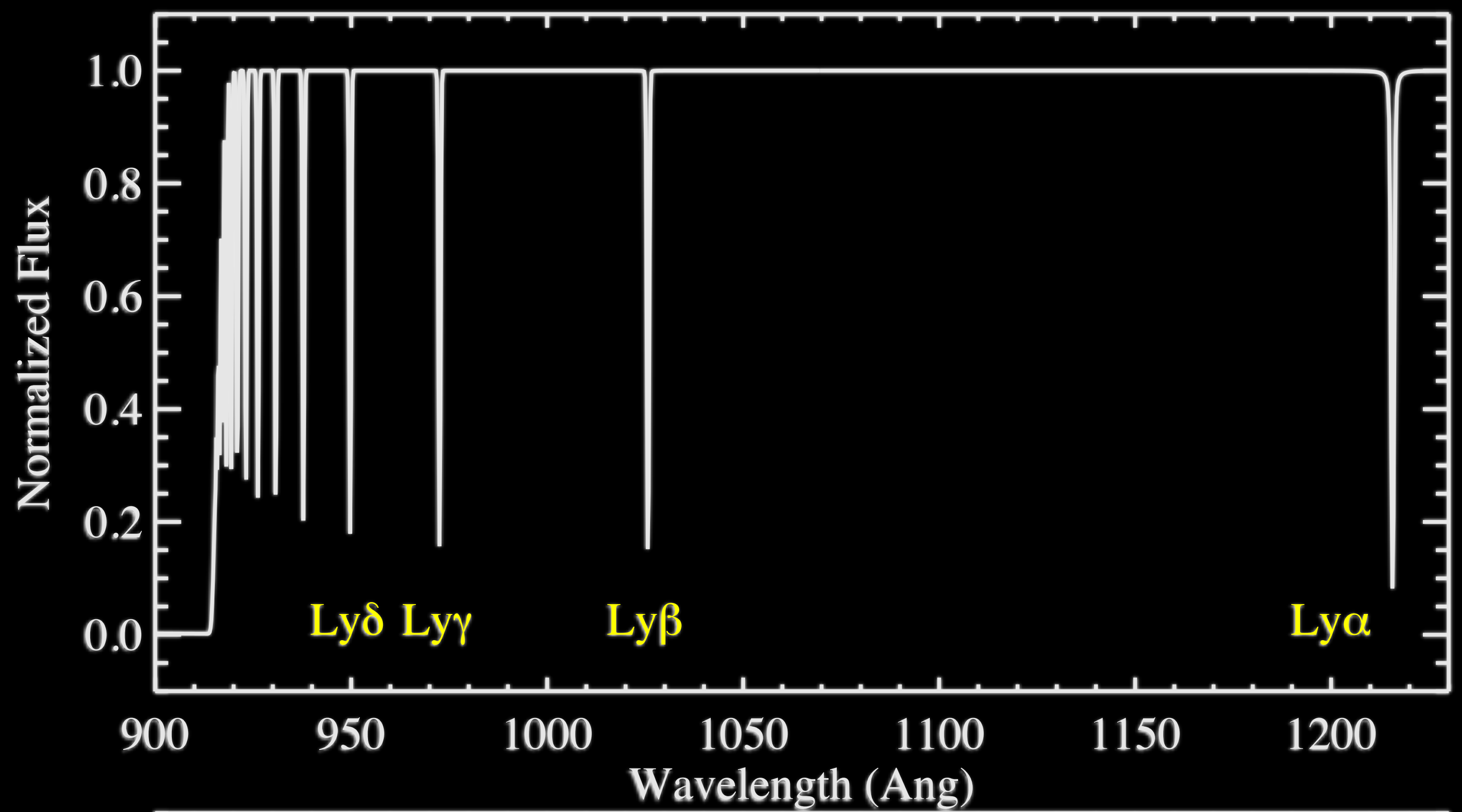
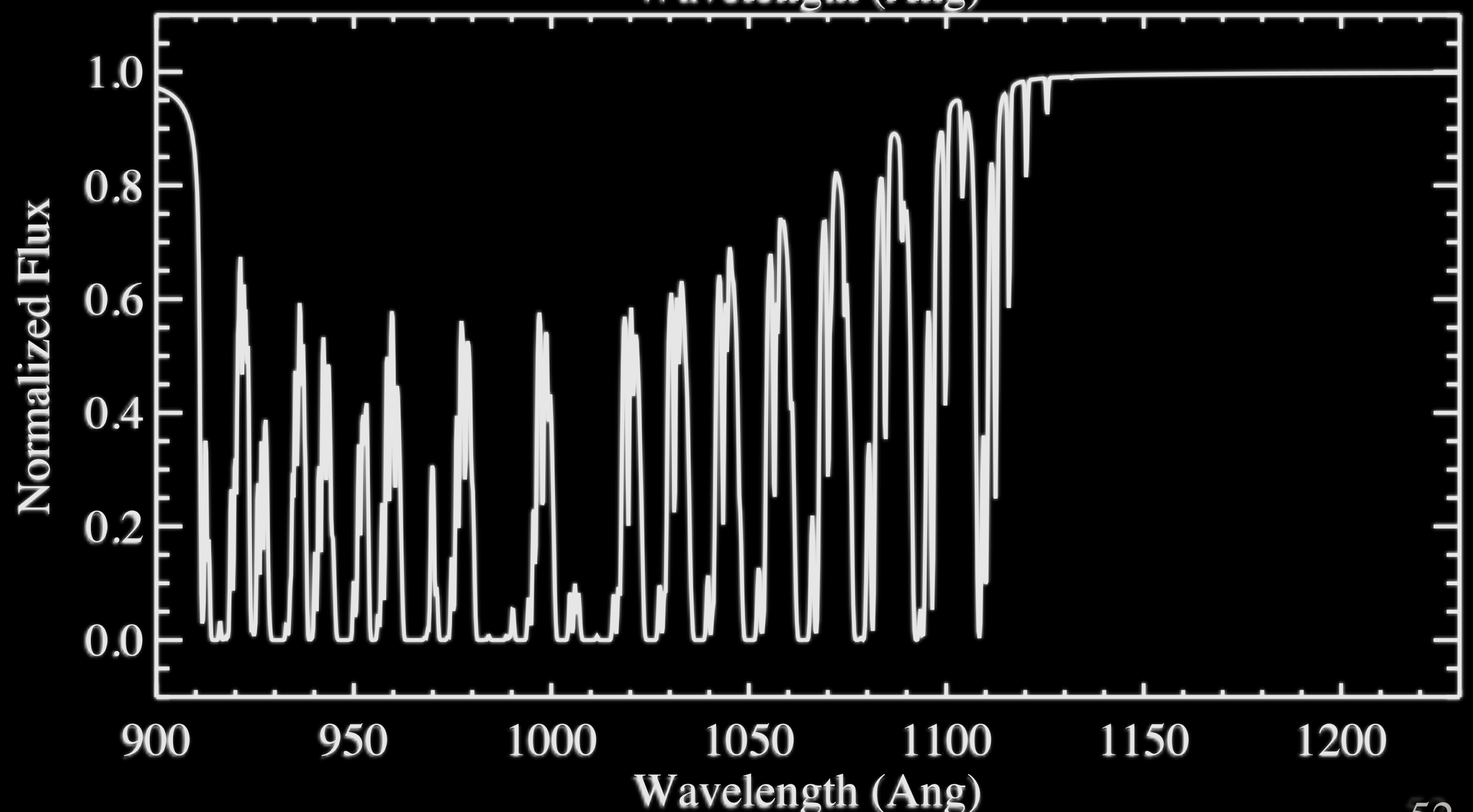
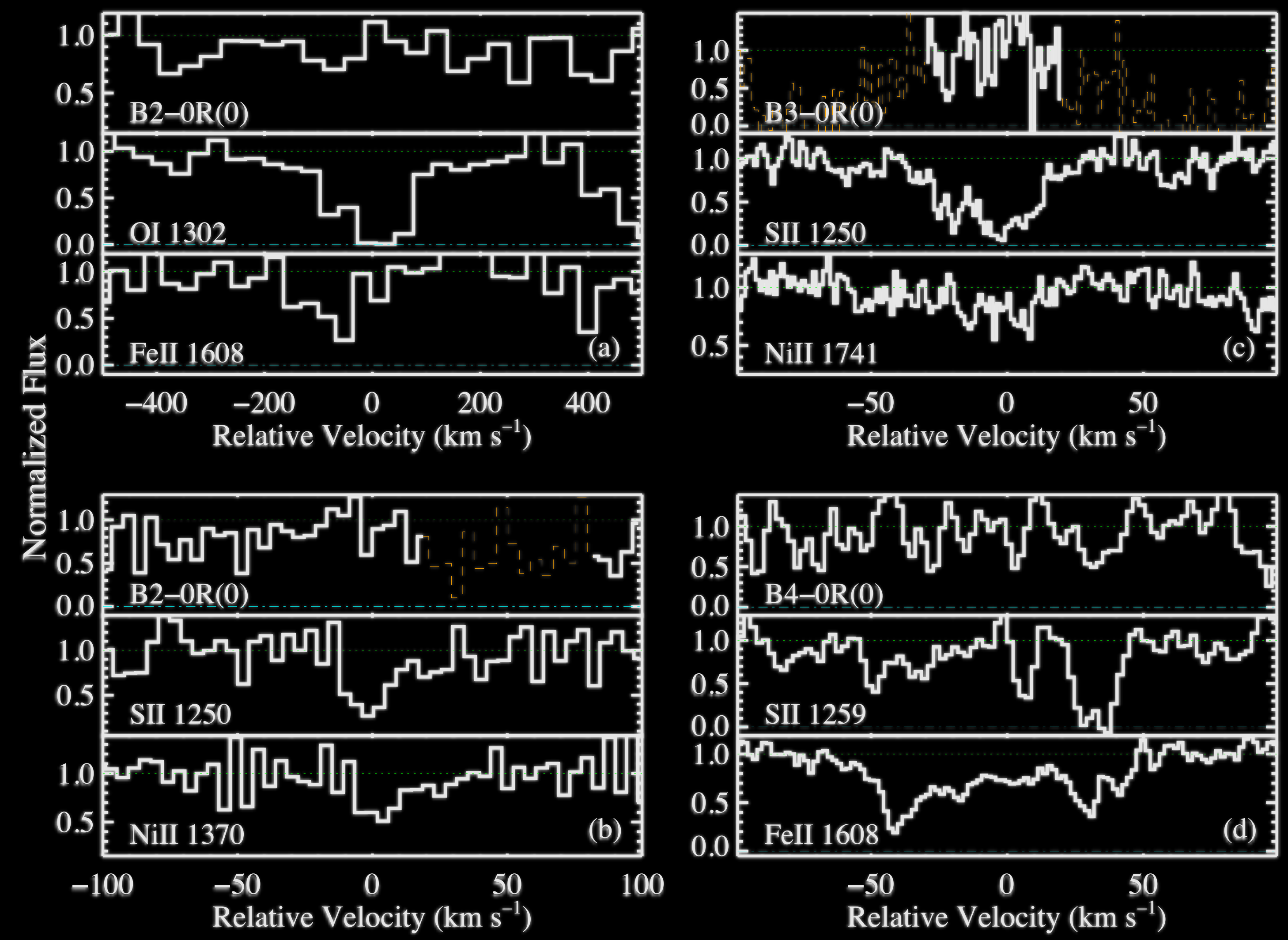


- **H_2: Lyman-Werner bands**
  - 900-1100 Angstroms
  - In principle, hundreds of lines



H_2 in GRBs

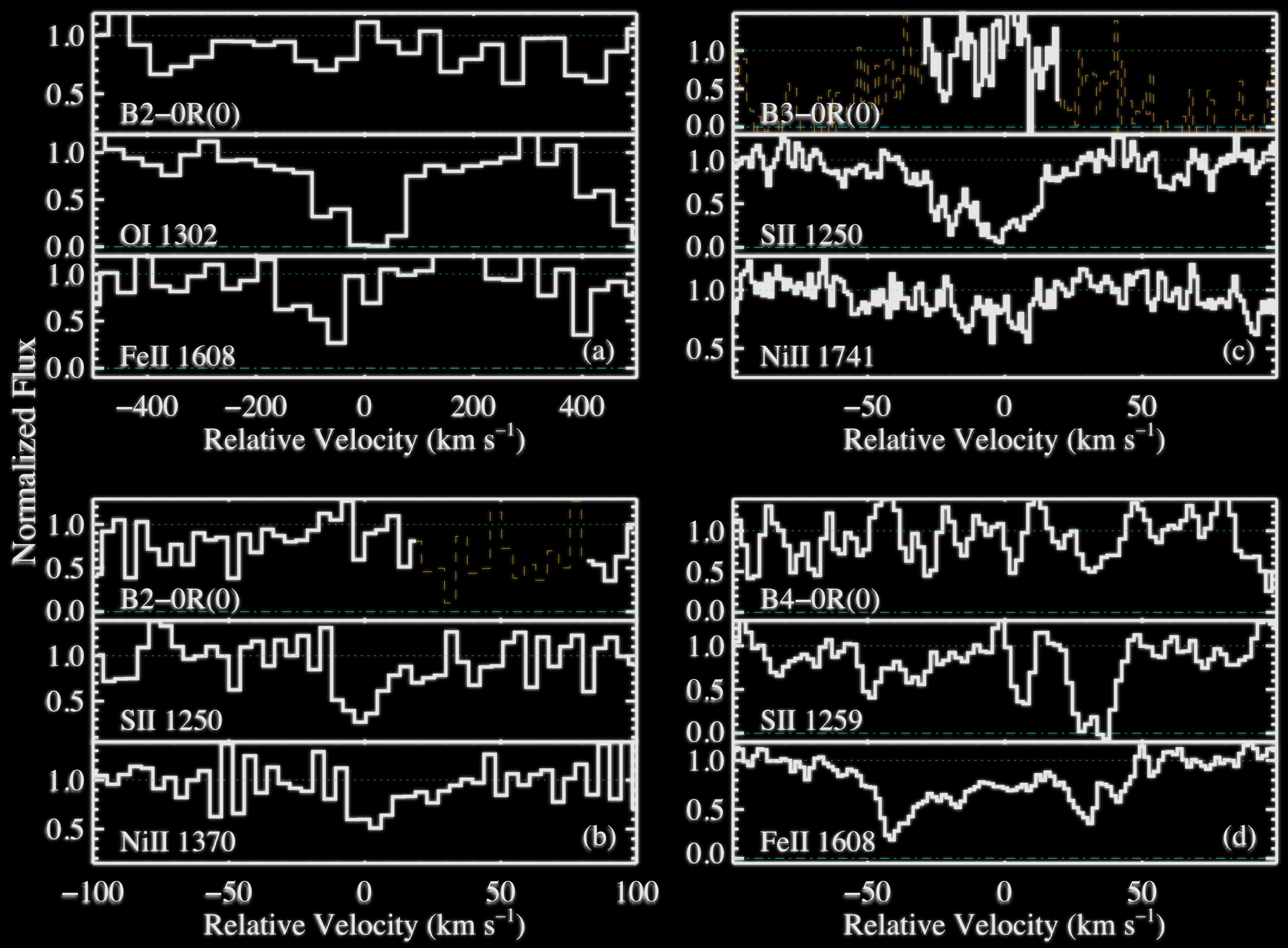
Tumlinson+07



H$_2$ in GRBs

- **Generally absent**
  - $N(H_2) < 10^{16}$ cm^{-2}
  - Even when $N_{HI} > 10^{21}$ cm^{-2}

Tumlinson+07



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  - GRB 080607 (CO too!)
  - Highly extinguished+reddened

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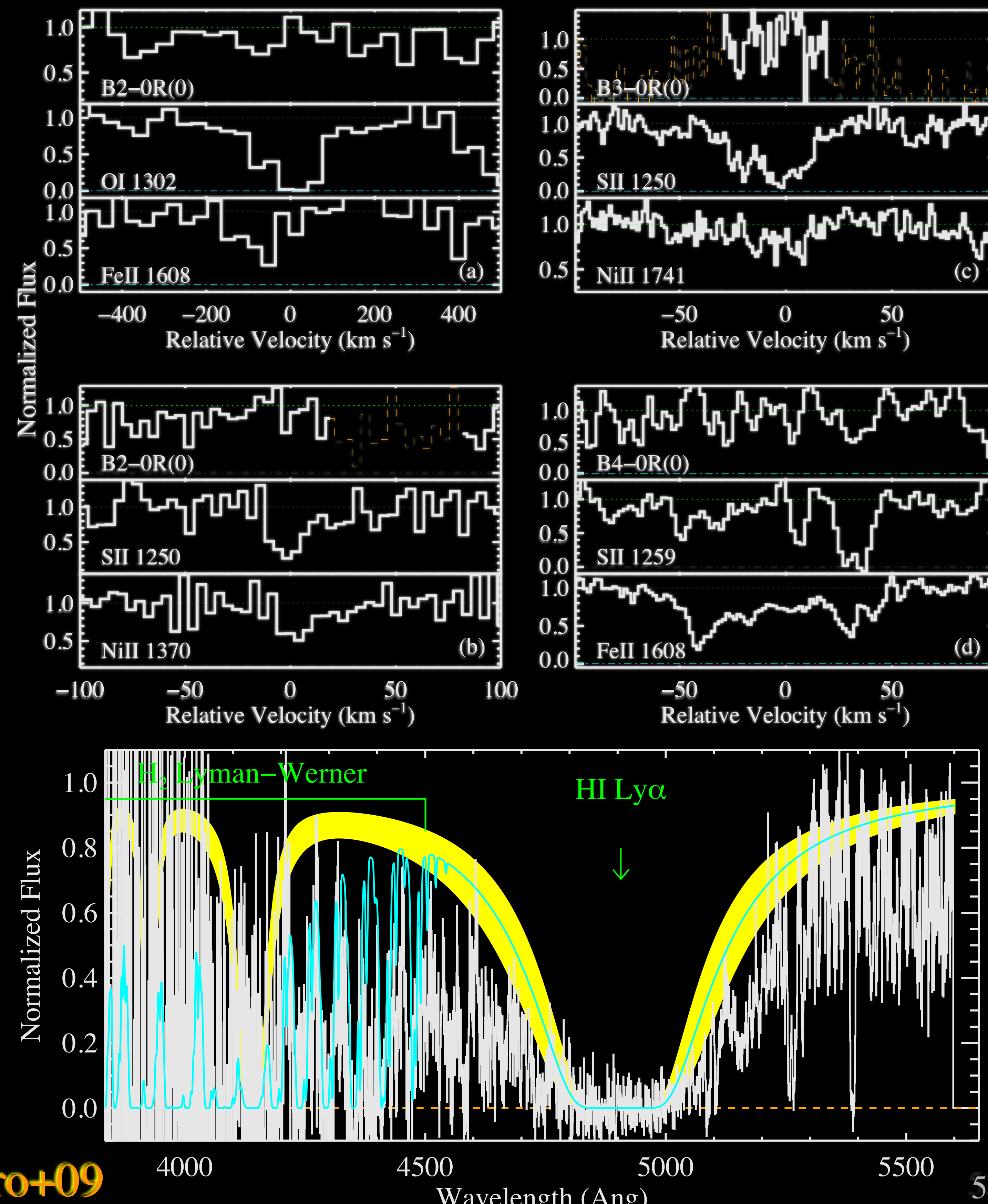


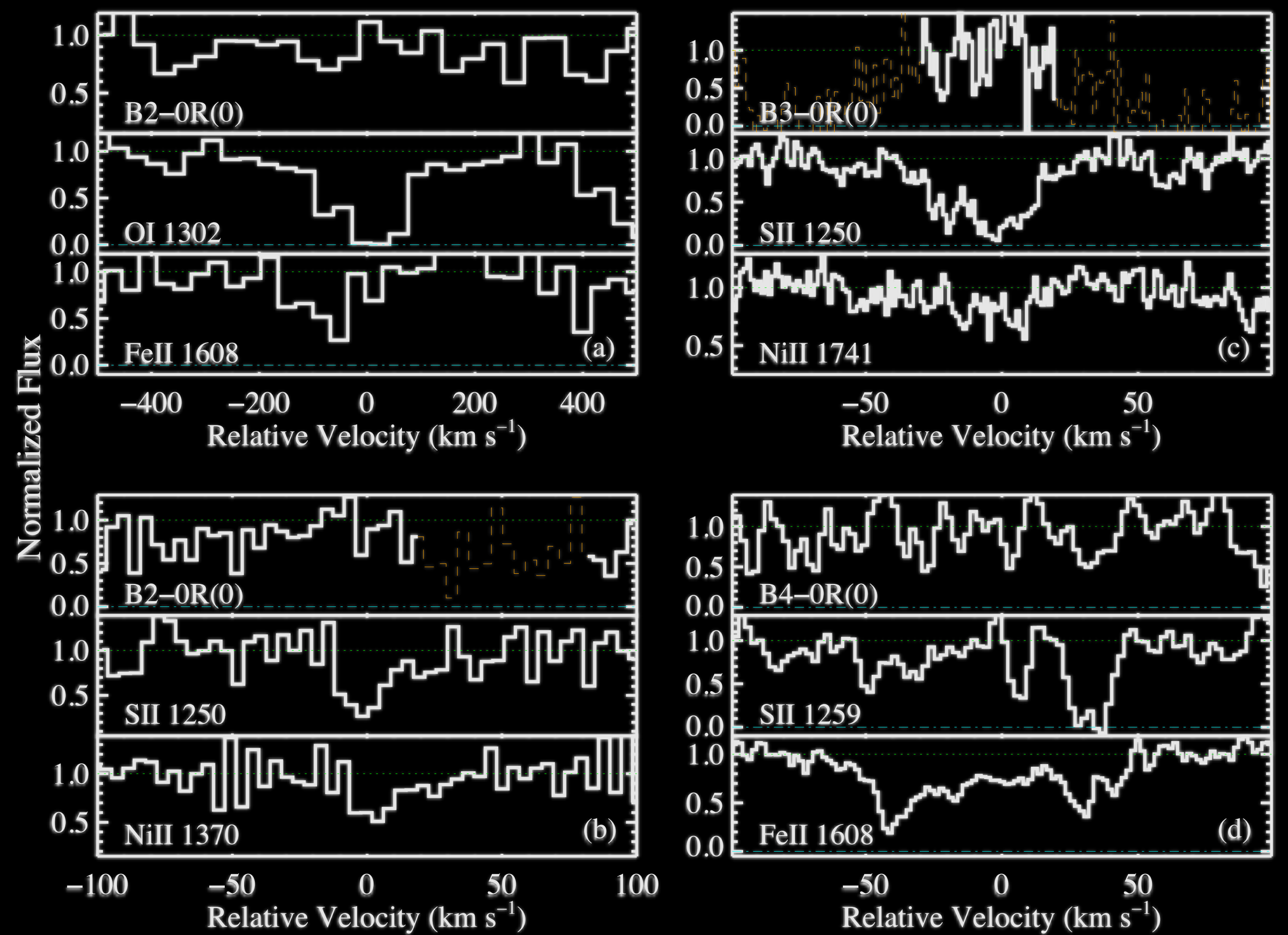
Pro+09

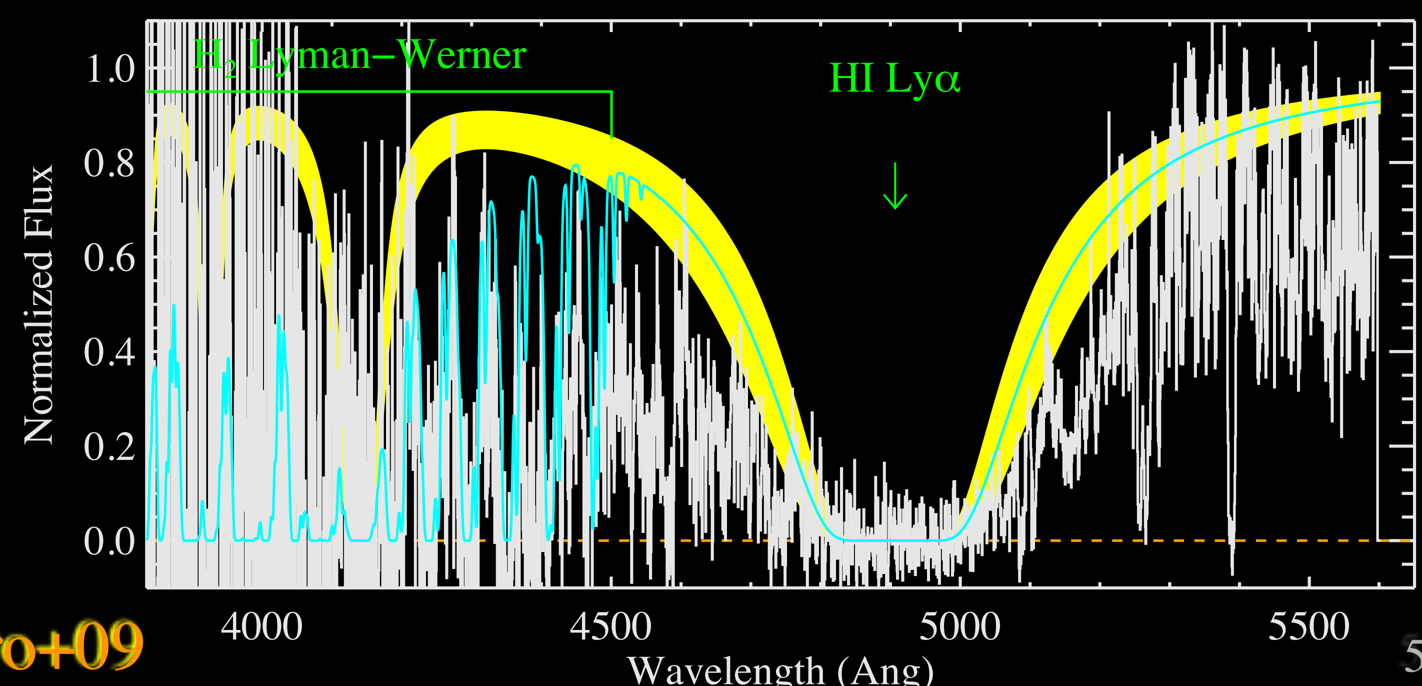
H_2 in GRBs

- Generally absent
  - $N(H_2) < 10^{16}$ cm^{-2}
  - Even when $N_{HI} > 10^{21}$ cm^{-2}
- There are a few exceptions
  - GRB 080607 (CO too!)
  - Highly extinguished+reddened
- Bimodal distribution
  - Very dusty => high $N(H_2)$
    - Very difficult to observe
    - These likely dominate dark GRBs
  - Low dust (and metallicity)
    - Majority of events
    - Where did the H_2 go?
      - ➡ Photoionized by the GRB progenitor

Whalen+08

Tumlinson+07

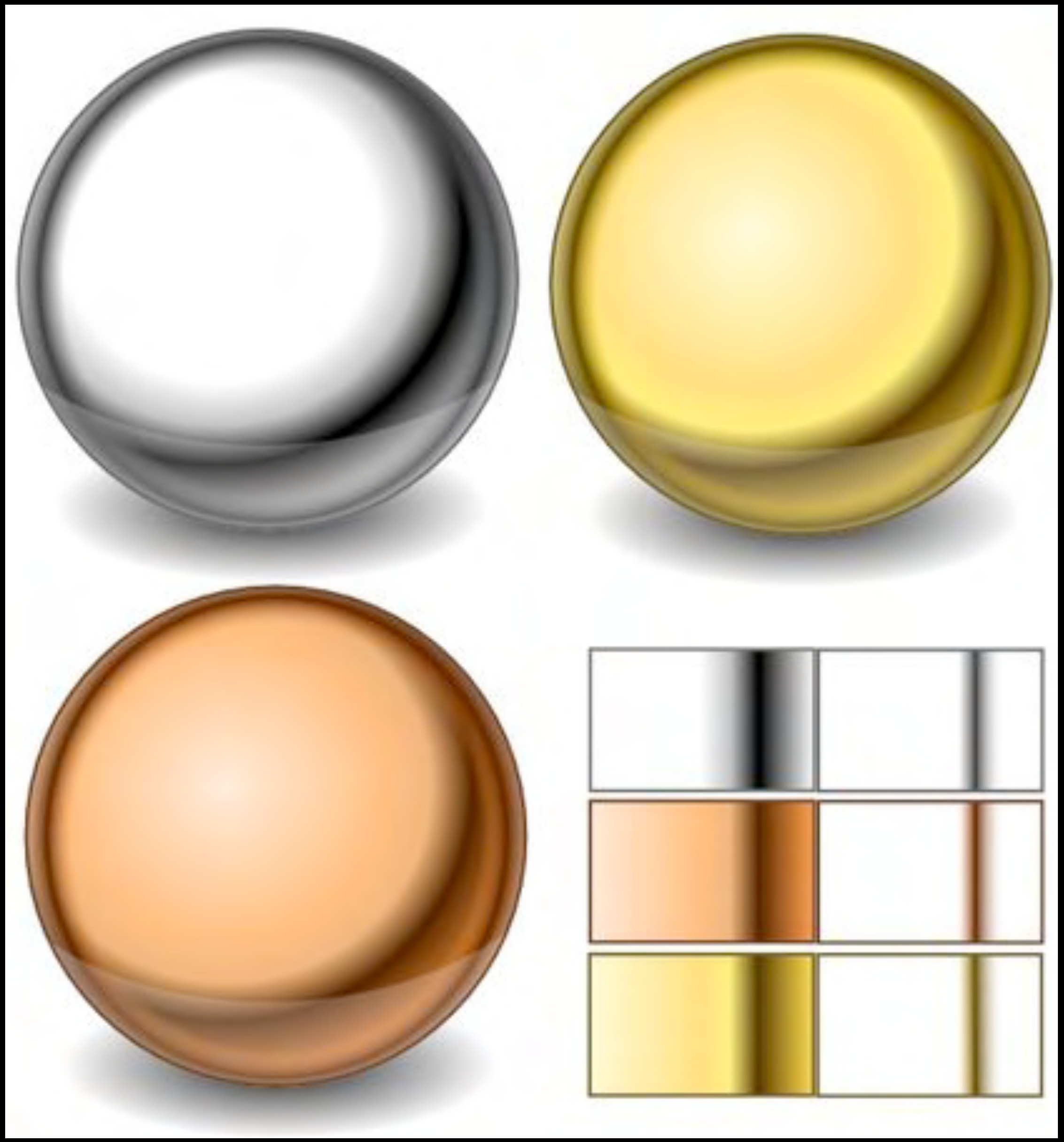




Pro+09

Science: Metallicity

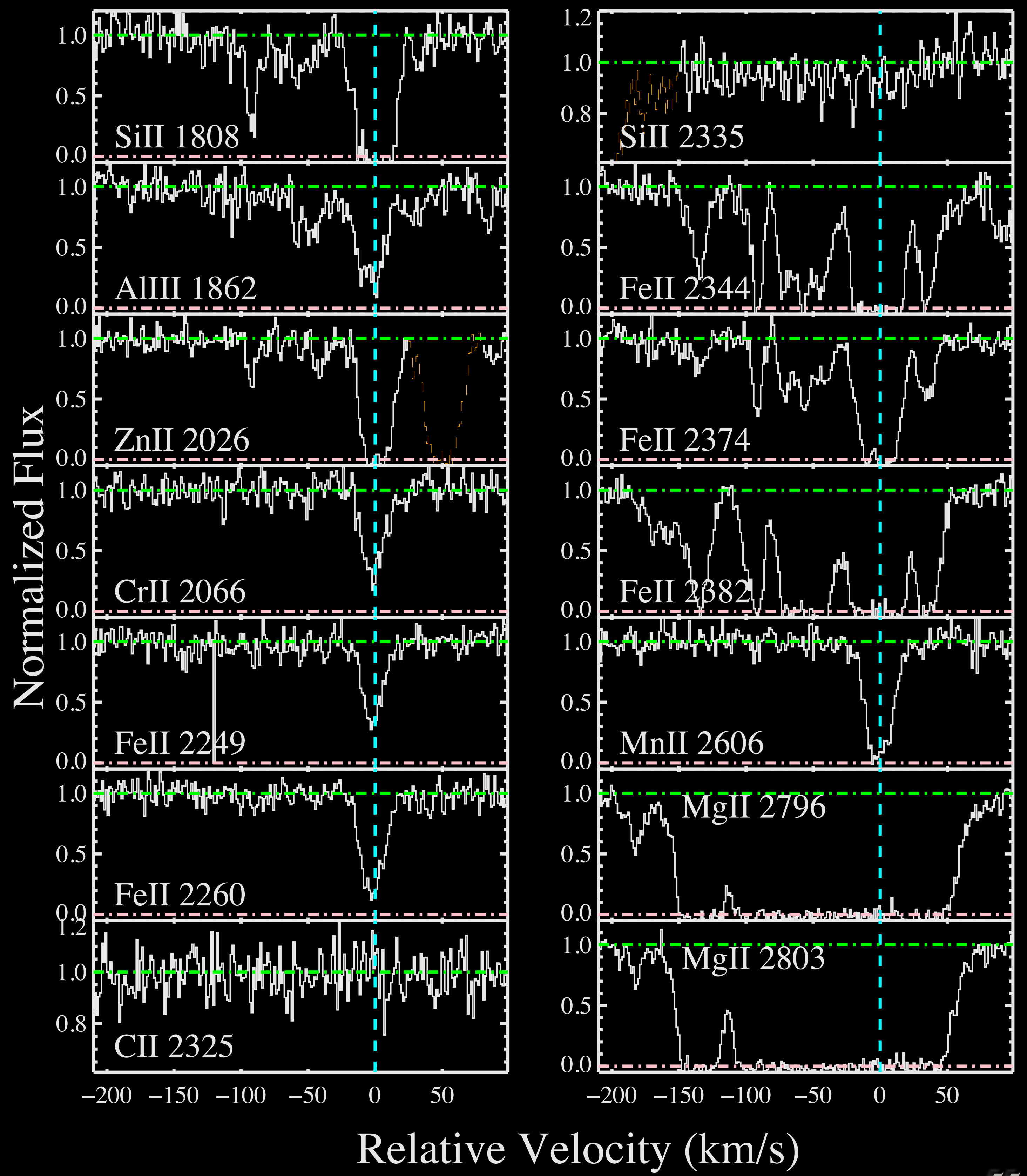
- Key characteristic of the GRB host galaxy
  - Past/recent star-formation
- Clues to the progenitor
  - Can GRBs form from metal-rich, massive stars?
- Relative abundances
  - Dust content
  - Star-formation history



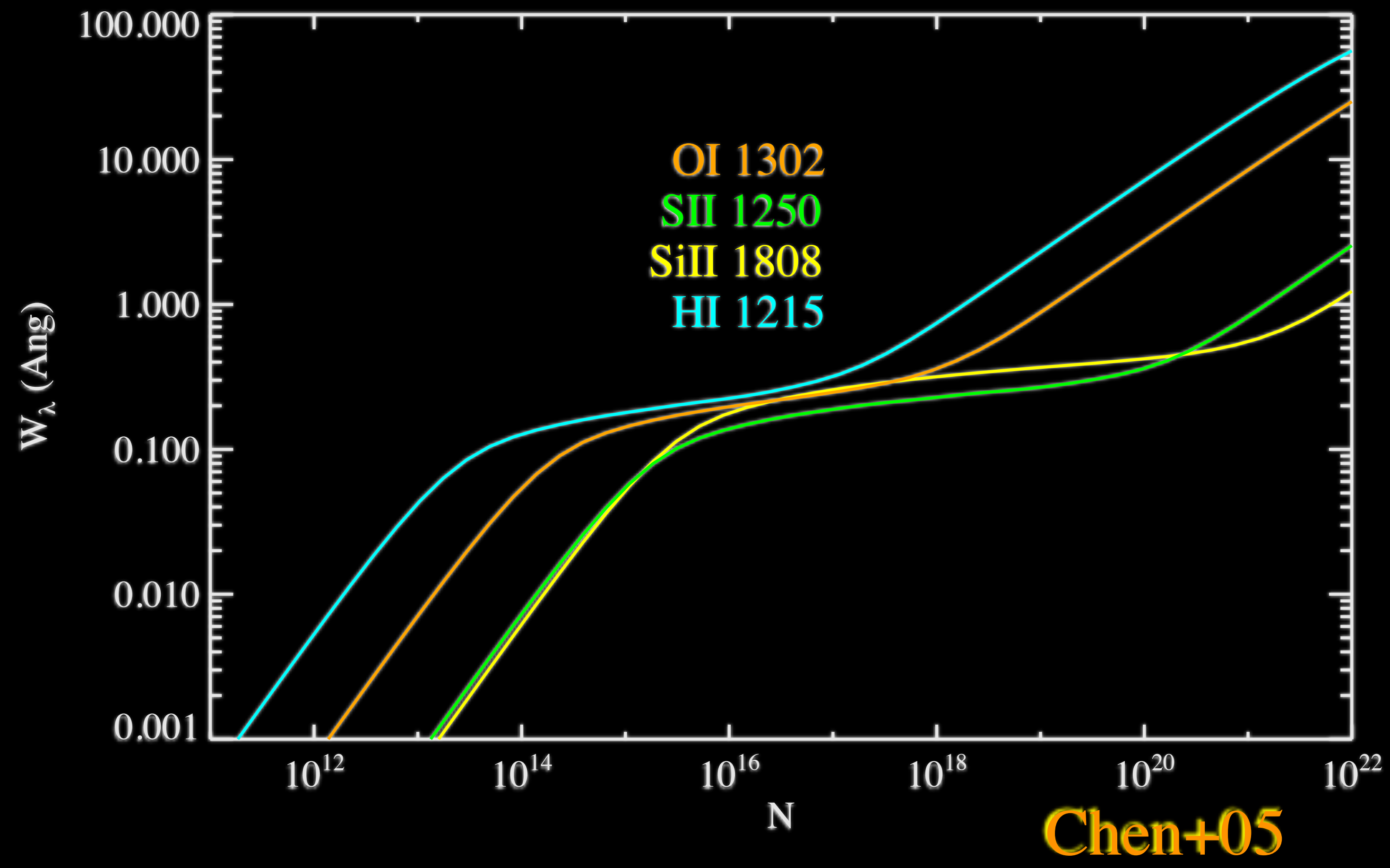
Metallicity Measurements

- **Definition**
  - Amount of metals per amount of gas
    - Typically done by number (not mass)
- **Amount of gas**
  - Dominate by HI gas
  - Well measured from Lyα (N_{HI})
  - Forced to z>2
- **Amount of metals**
  - Need a column density for one or more elements
    - Avoid highly refractive elements (Fe)
    - Focus on ions that trace neutral gas
  - Low-ions
    - First ionization stage beyond 1 Ryd
    - Fe^+, Si^+, O^0, Zn^+, C^+

Pro+06

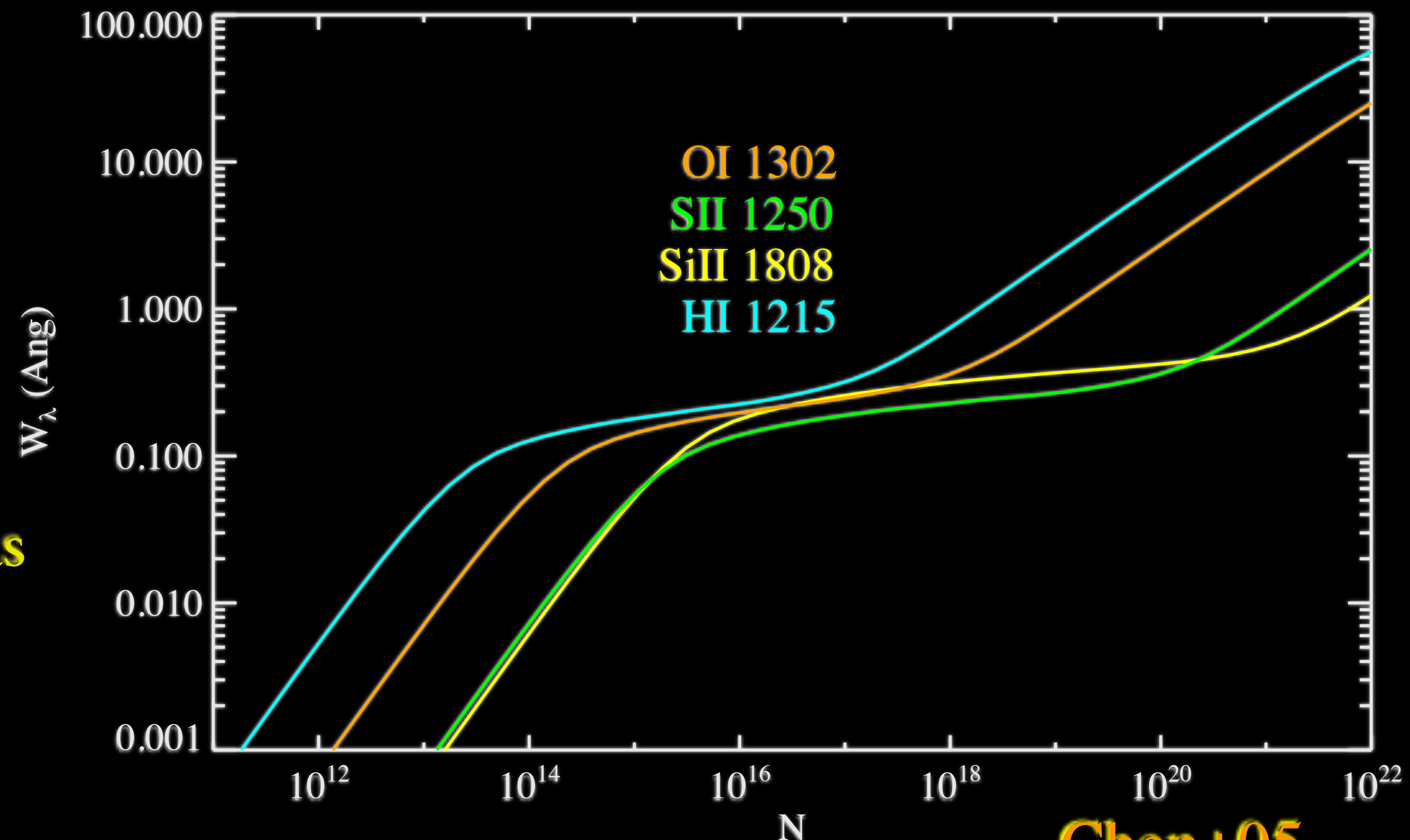


Metallicity: Metal column densities



Metallicity: Metal column densities

- Recall the Curve of Growth
  - No metal lines are strong enough to show damping wings
  - Weak limit
    - $W_\lambda << 1$ A
    - Low-dispersion spectrograph often has a detection limit exceeding 0.1 A



Chen+05

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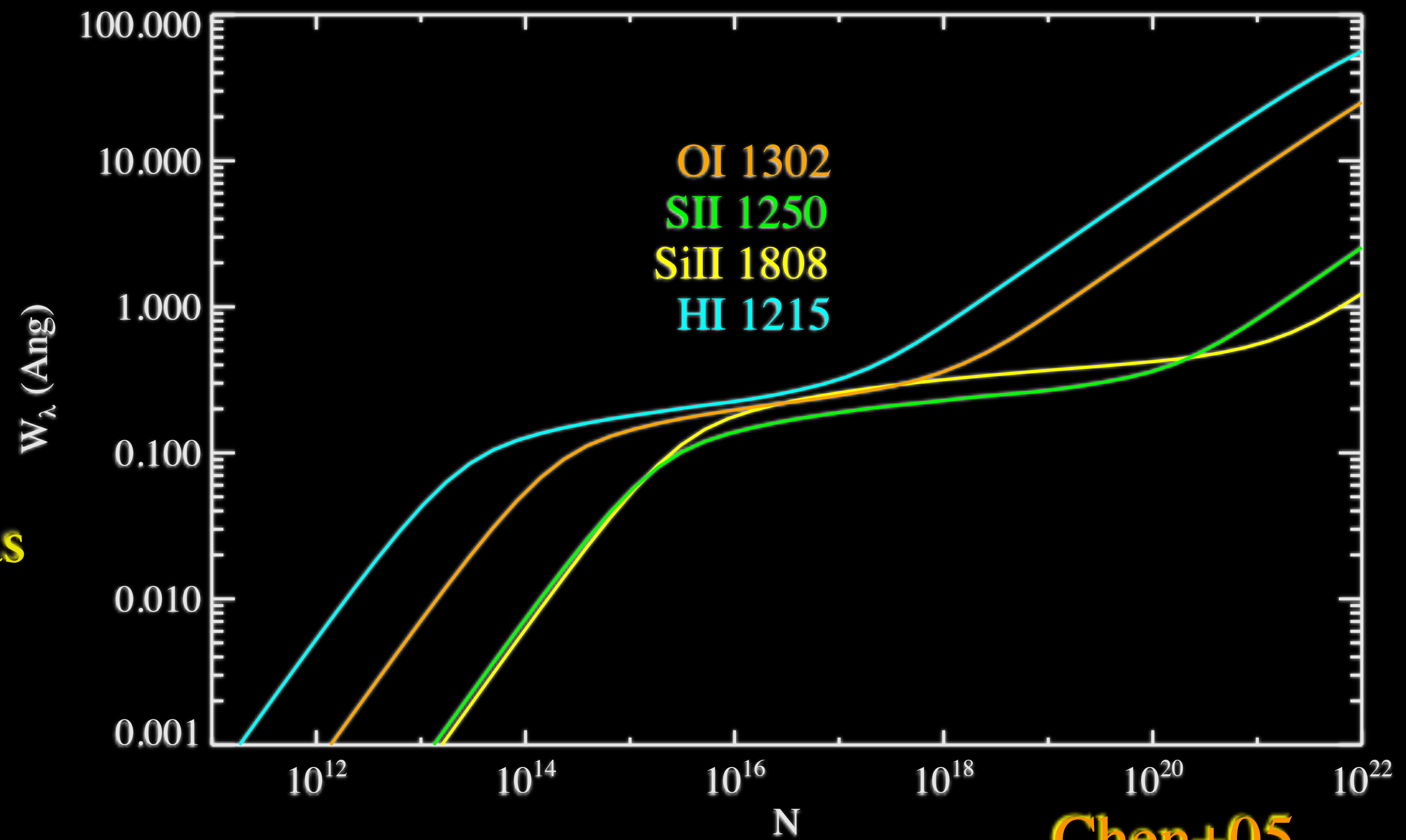
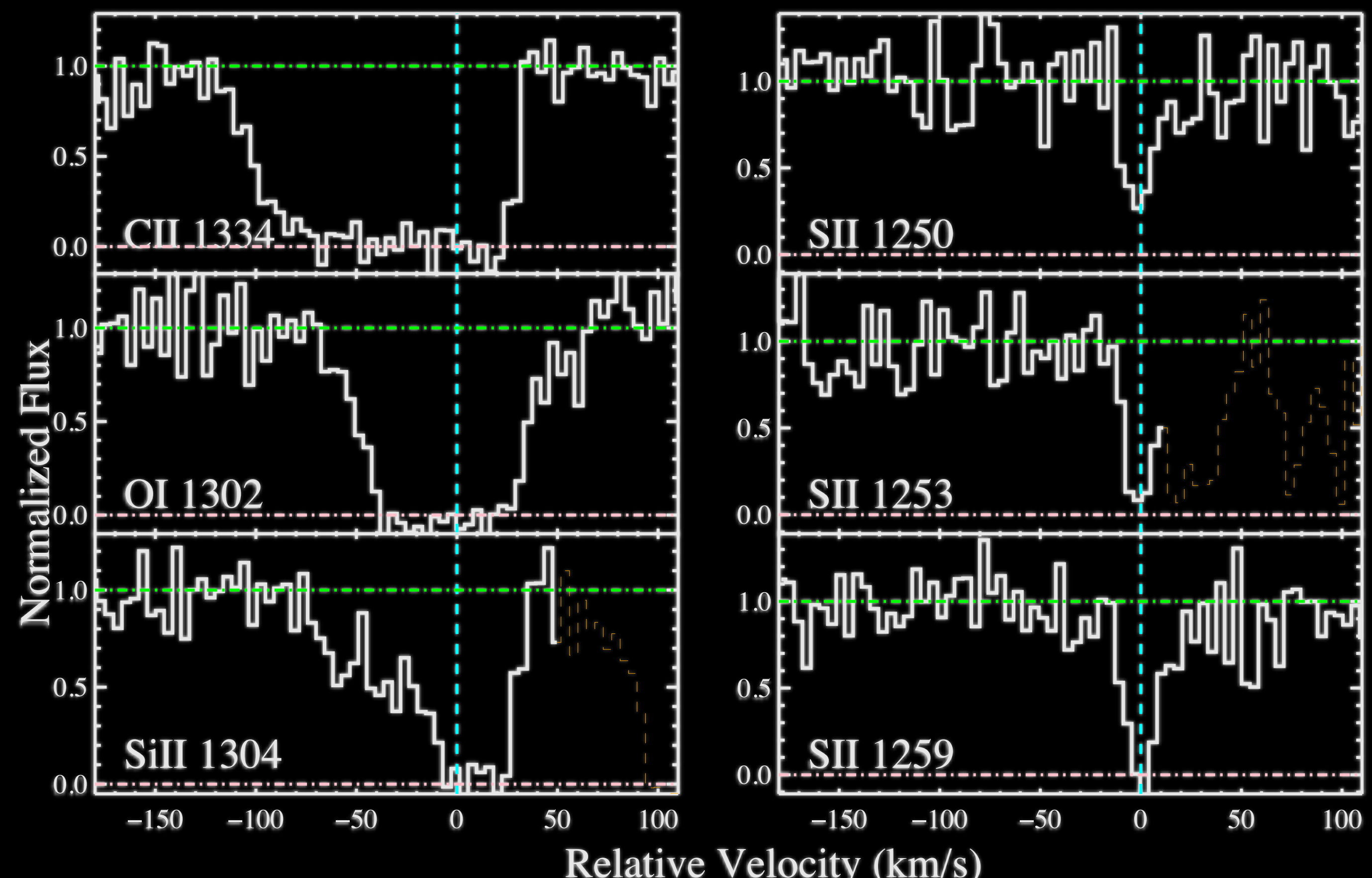
- Optimal approach
  - High dispersion, high S/N data
  - Focus on weak lines
    - Add up the optical depth
    - Or even just the equivalent width



Chen+05



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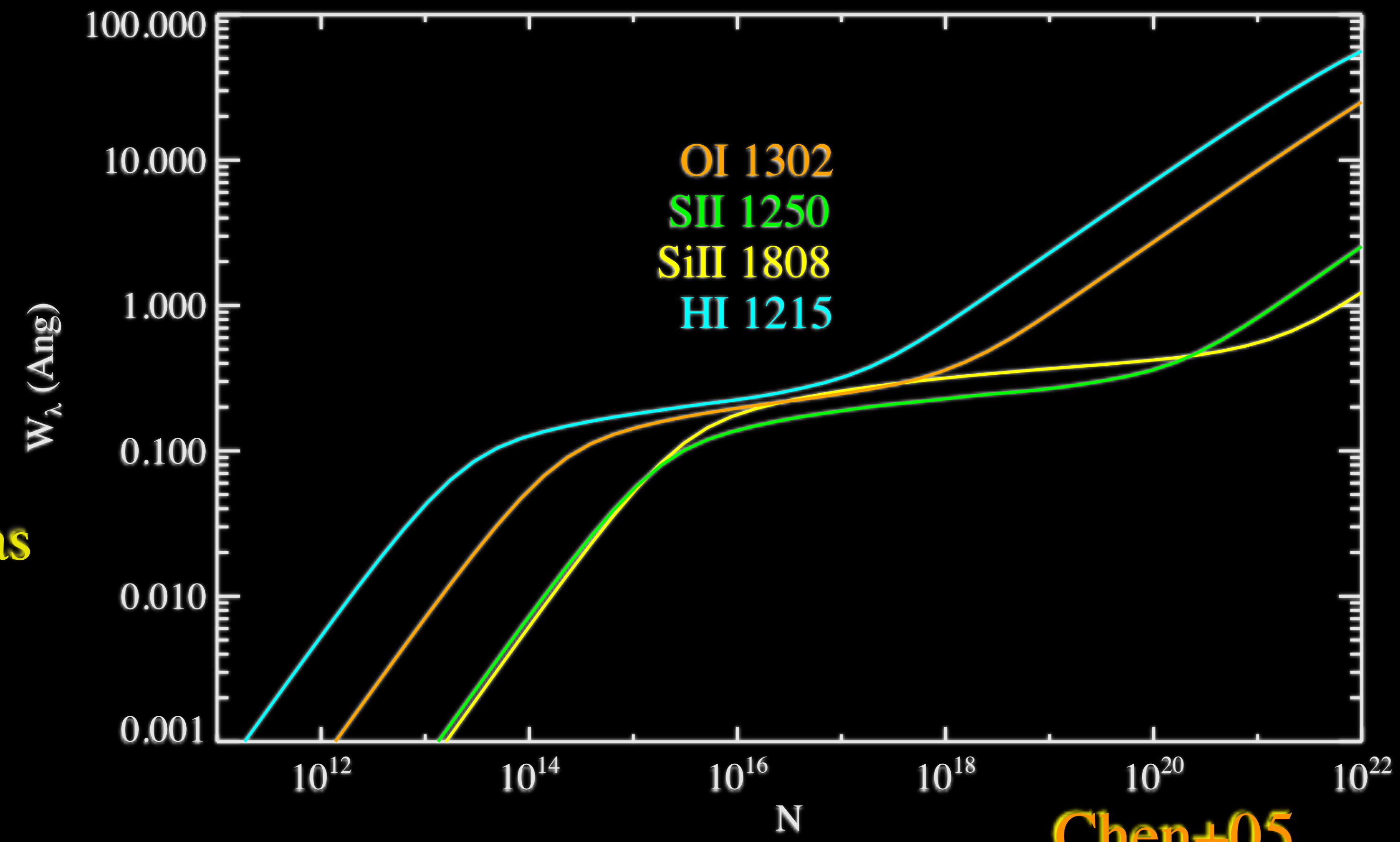
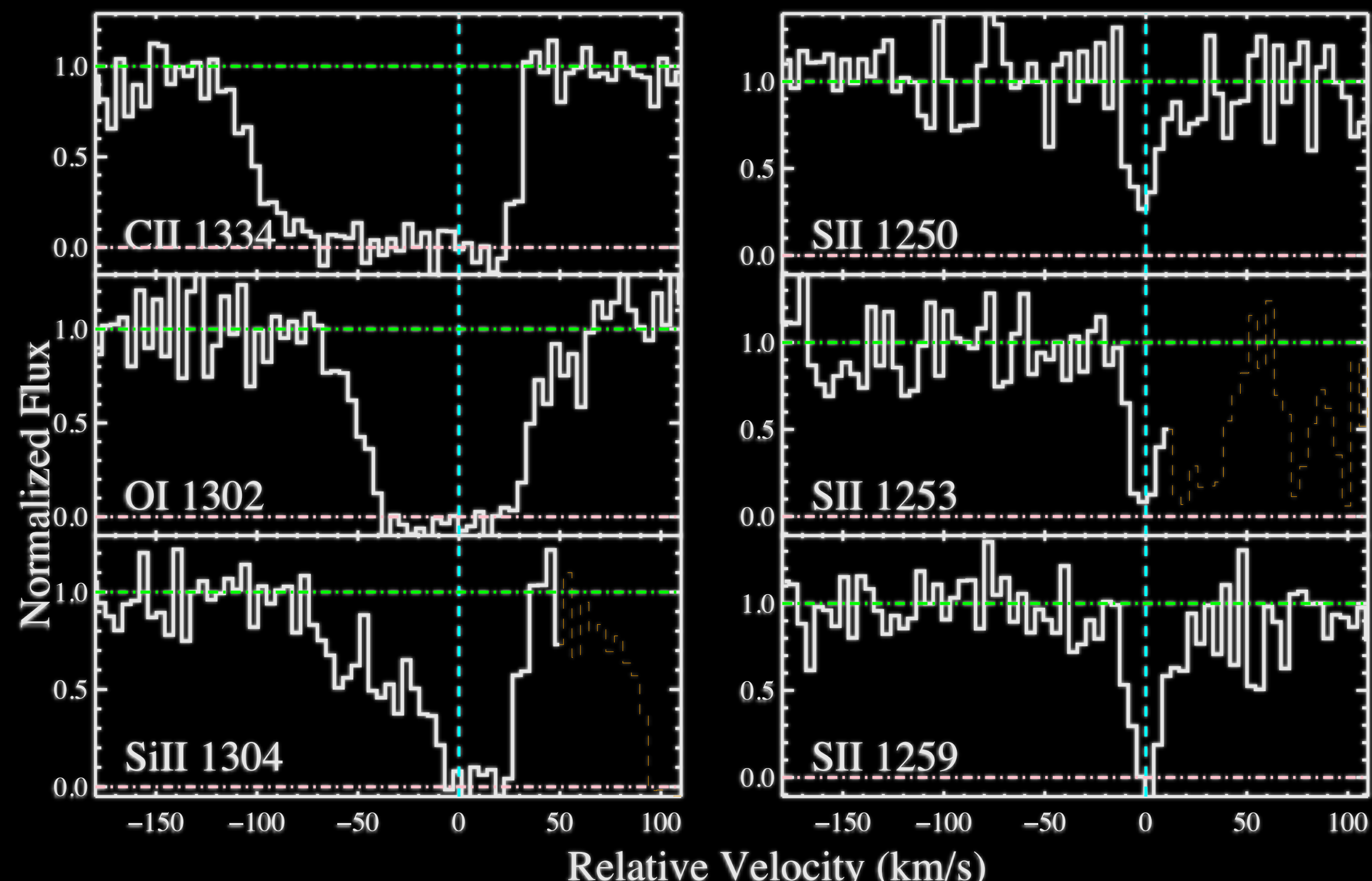
- Optimal approach
  - High dispersion, high S/N data
  - Focus on weak lines
    - Add up the optical depth
    - Or even just the equivalent width
- Alternate approach
  - COG analysis
    - Model observed W_λ values
    - Assume a single `cloud'
  - Estimate N, but it is strictly a lower limit   Pro 06



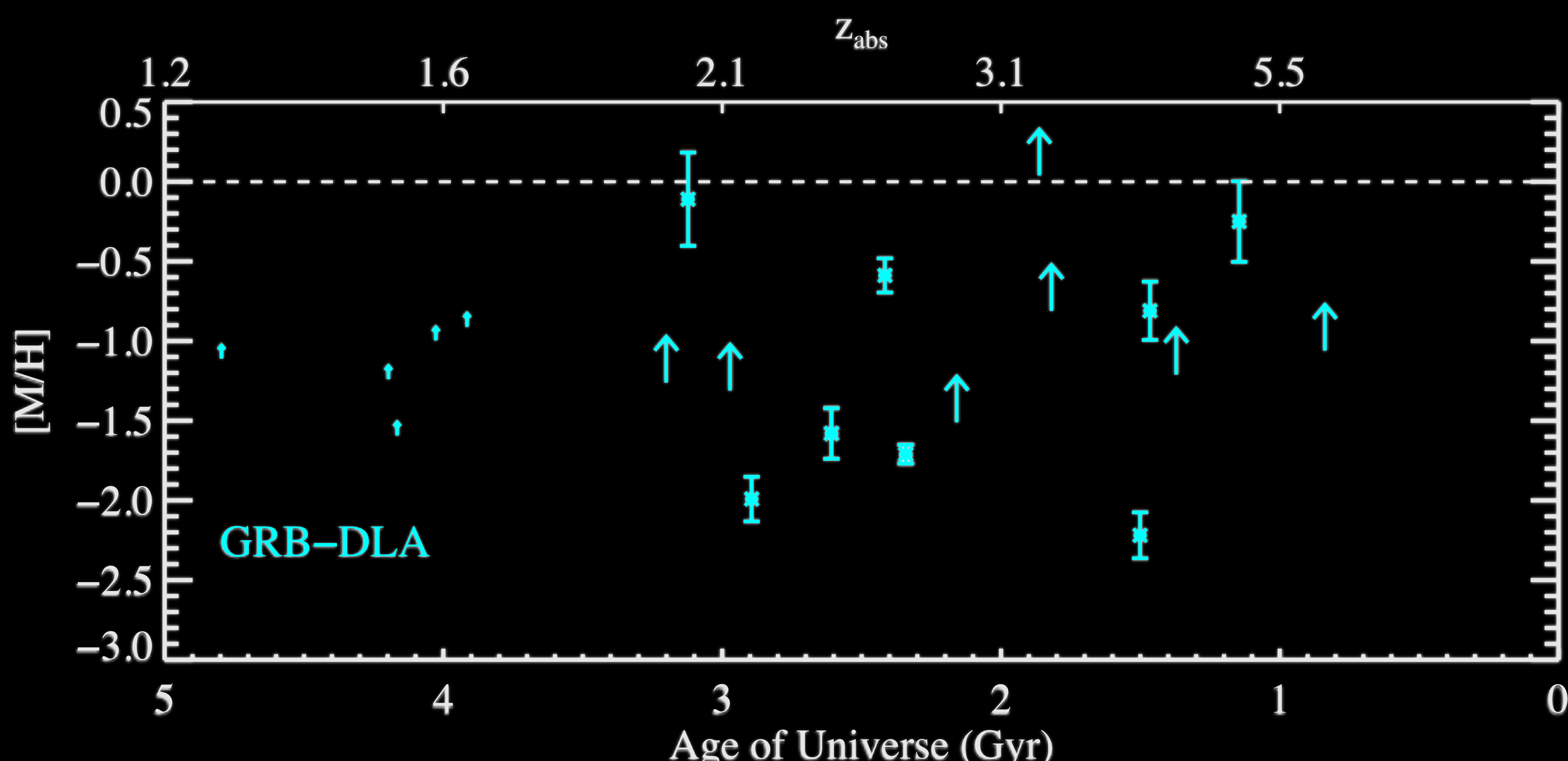
Chen+05



Metallicity: GRB Measurements

- Large dispersion
  - About a factor of 100
    - Unlikely to be metallicity gradients
    - Diverse set of host galaxies
- Median value
  - ~1/10 solar abundance
  - Metal-poor
- No floor at 1/10 solar
  - Several cases with solar abundance
    - These are also highly reddened
- No obvious redshift evolution

$[M/H] = \log(N_M) - \log(N_{HI}) - \log(M/H)_{Sun}$ (M is S, Si, Zn and/or O)



Metallicity: Comparison to Other Galaxies

- DLAs toward QSOs
  - i.e., HI-selected galaxies
    - Same techniques — Pro+03
    - Mean = Metallicity of neutral gas
  - GRBs vs. QSO-DLA
    - Same spread of [M/H]
    - GRBs show higher [M/H]
- LBGs
  - Gas-phase measurements
    - 1/3 to 1/2 solar
  - Brightest galaxies only

Pettini+01, Dessauges-Zavadsky+10

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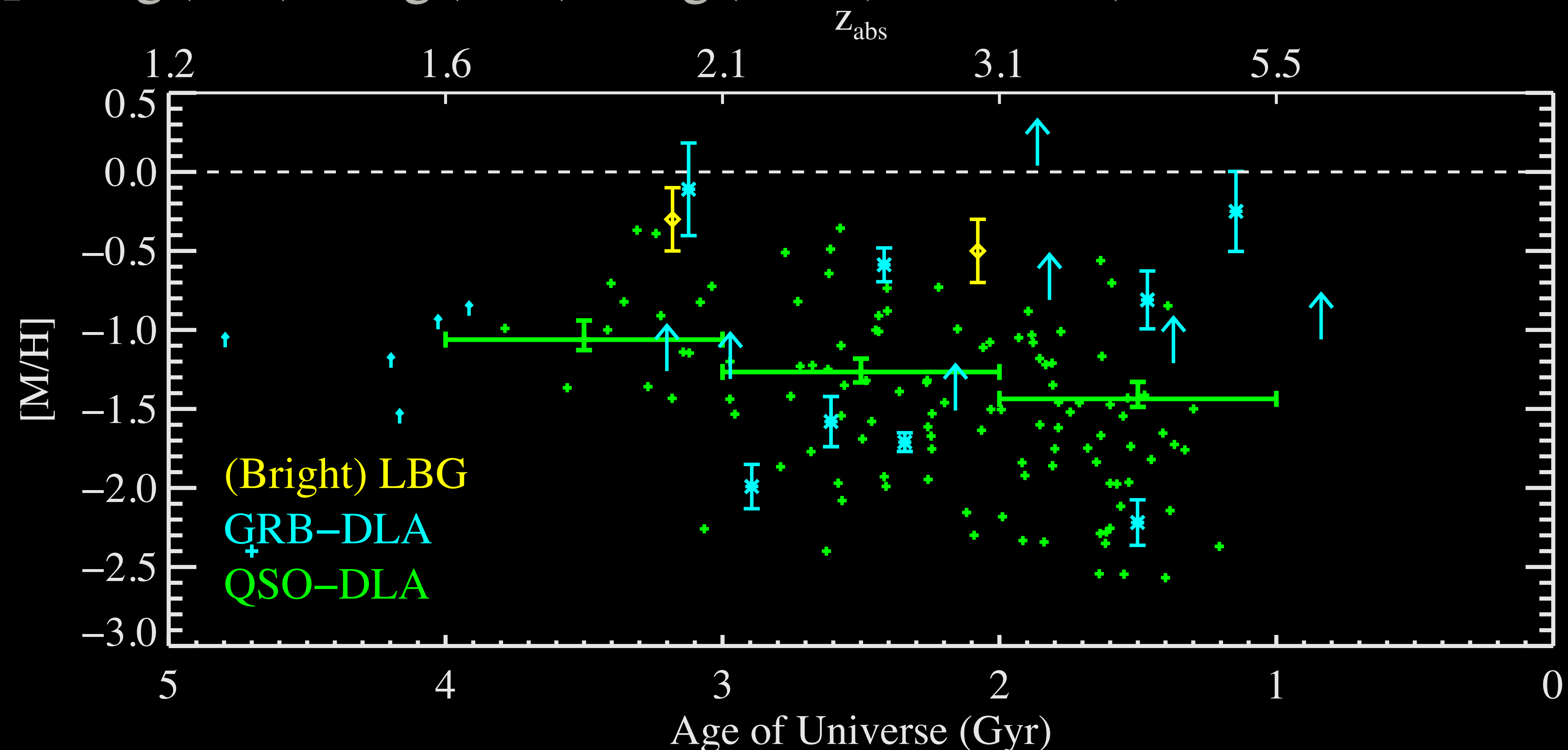

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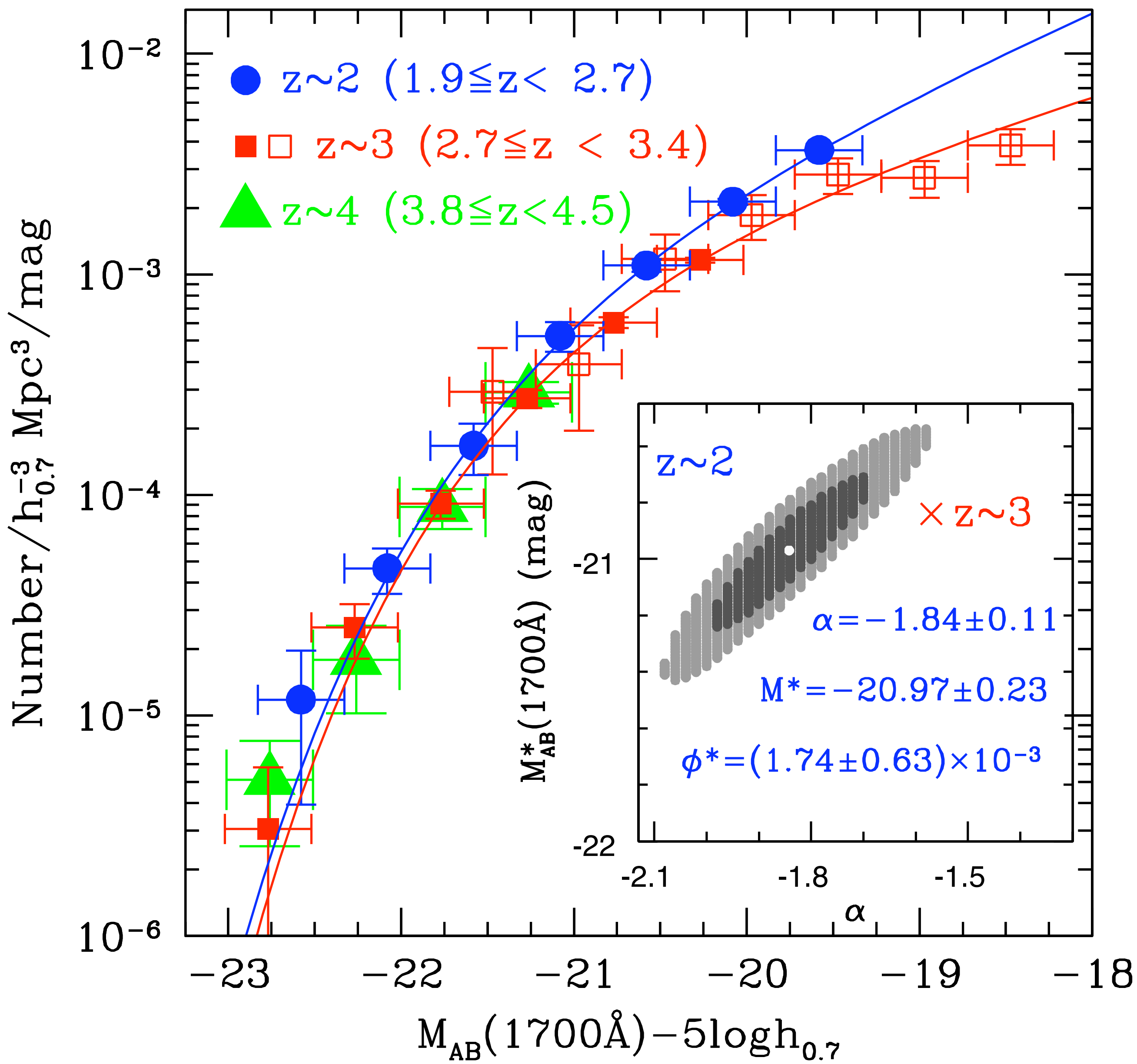
$$\phi(L_{UV}) \propto (L_{UV}/L_*)^{-1.6} \exp(-L_{UV}/L_*)$$

  - Assume SFR ~ L_{UV}

Reddy+07



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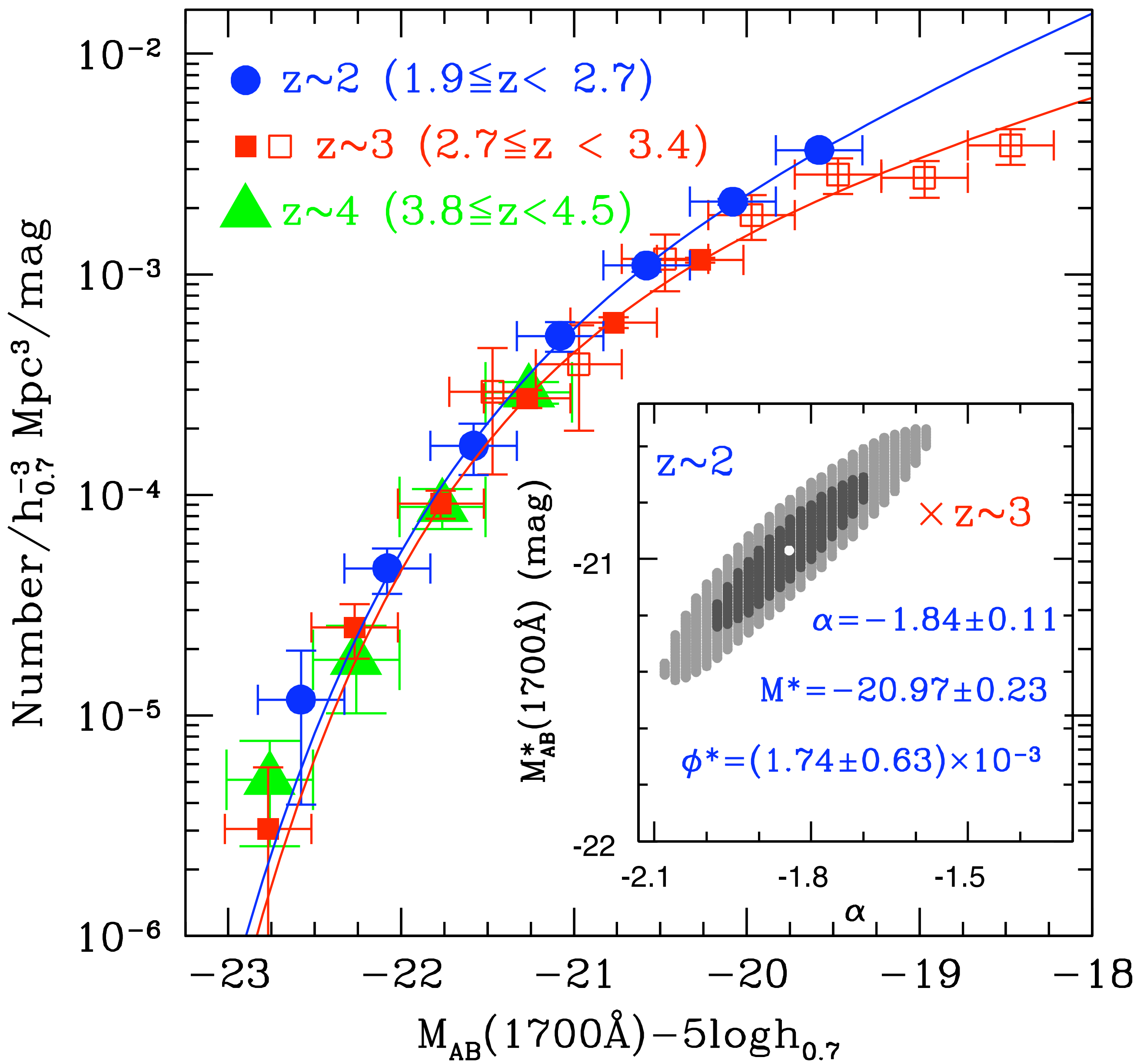
- **Z/Luminosity Relation**
  - Follow empirical relations

$$Z = Z_*(L/L_*)^{0.5}$$

  - Normalize by LBG values
    - Z(L*) = Z* = 1/2 solar (Pettini et al. 2001)

Reddy+07



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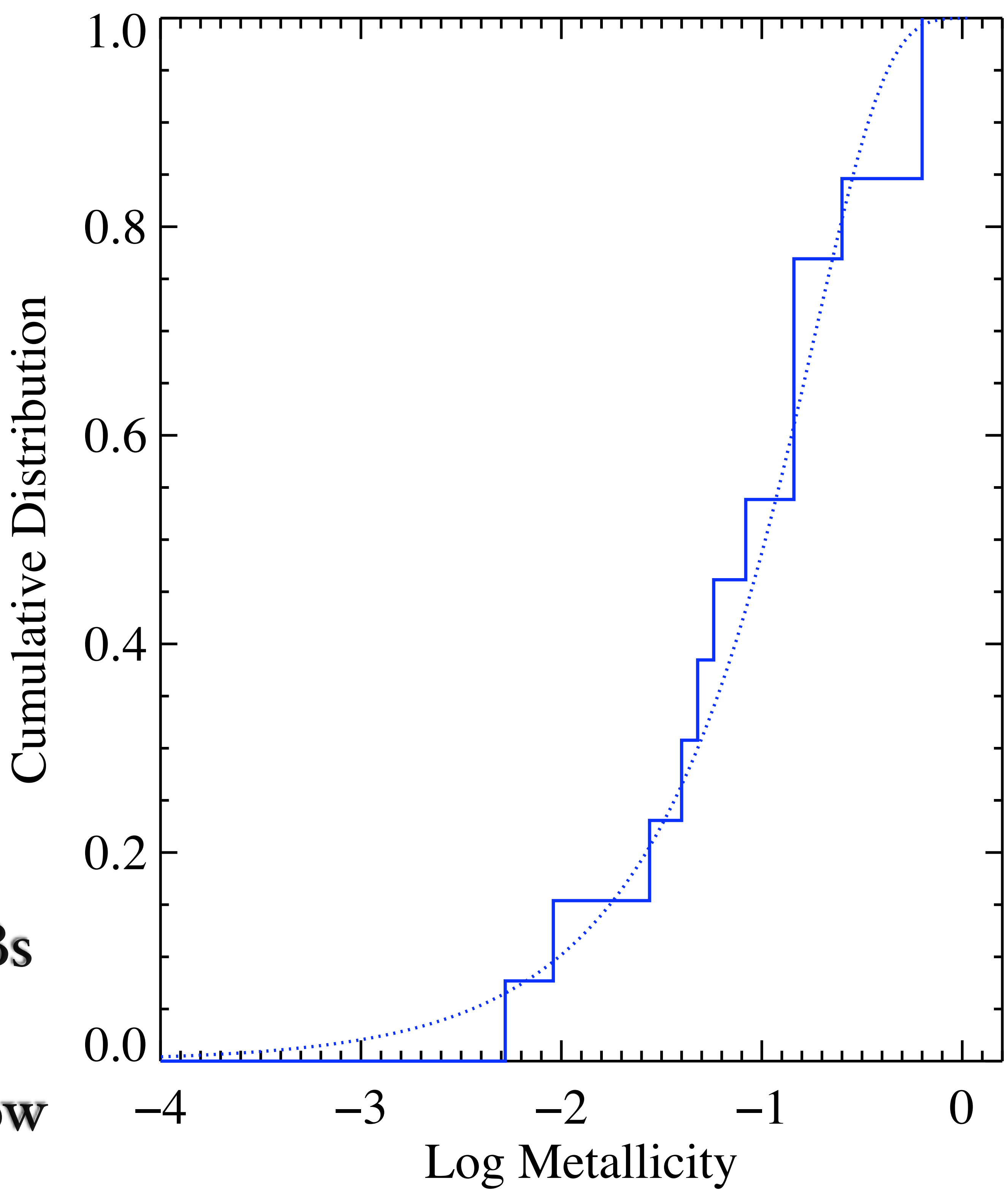
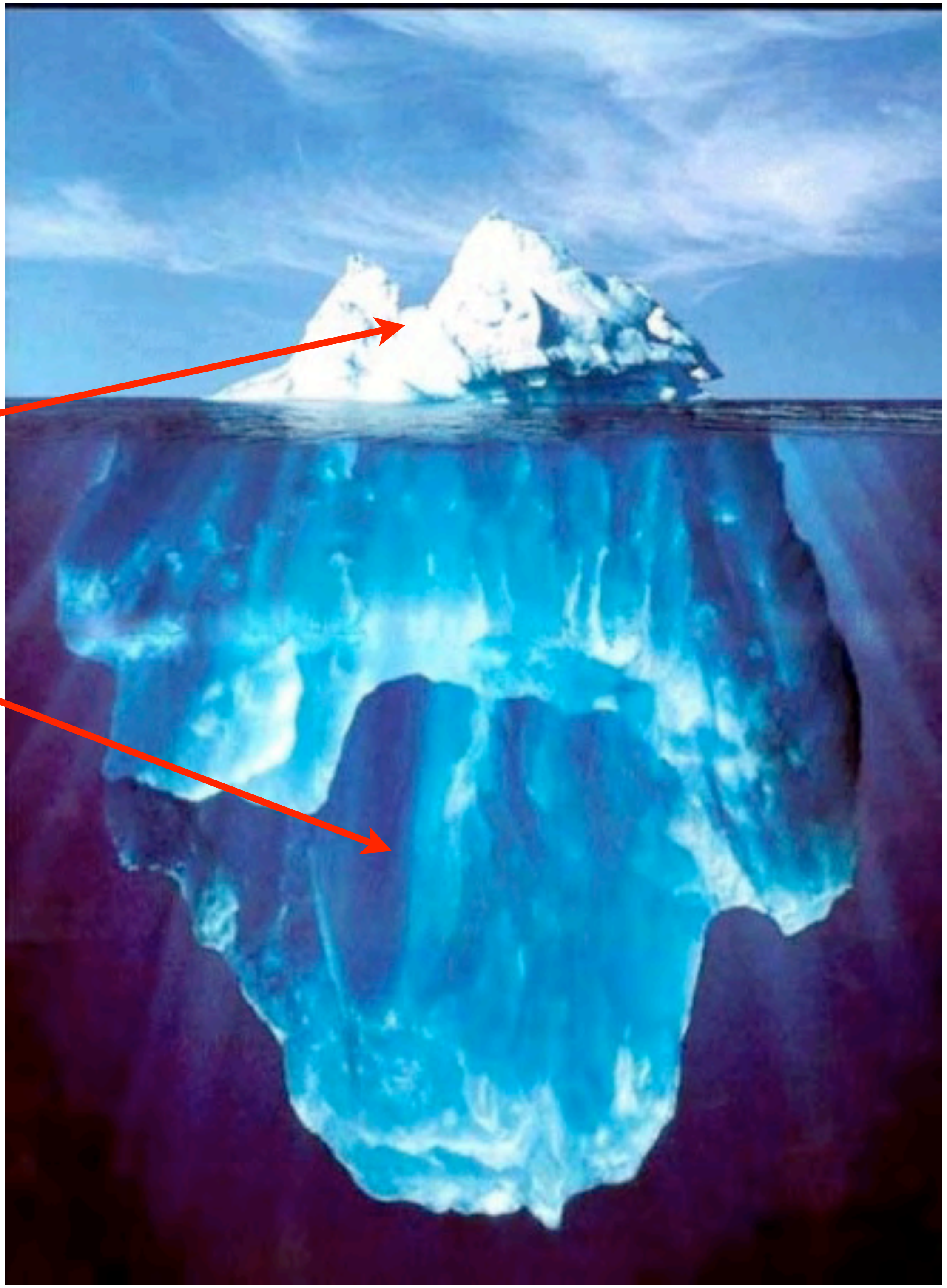
    $$Z = Z_*(L/L_*)^{0.5}$$
  - Normalize by LBG values
    - Z(L*) = Z* = 1/2 solar (Pettini et al. 2001)
- Result
  - Excellent agreement assuming GRBs trace z~3 SF galaxies
  - Unobscured GRB metallicities follow the unobscured SF in galaxies

Fynbo+08



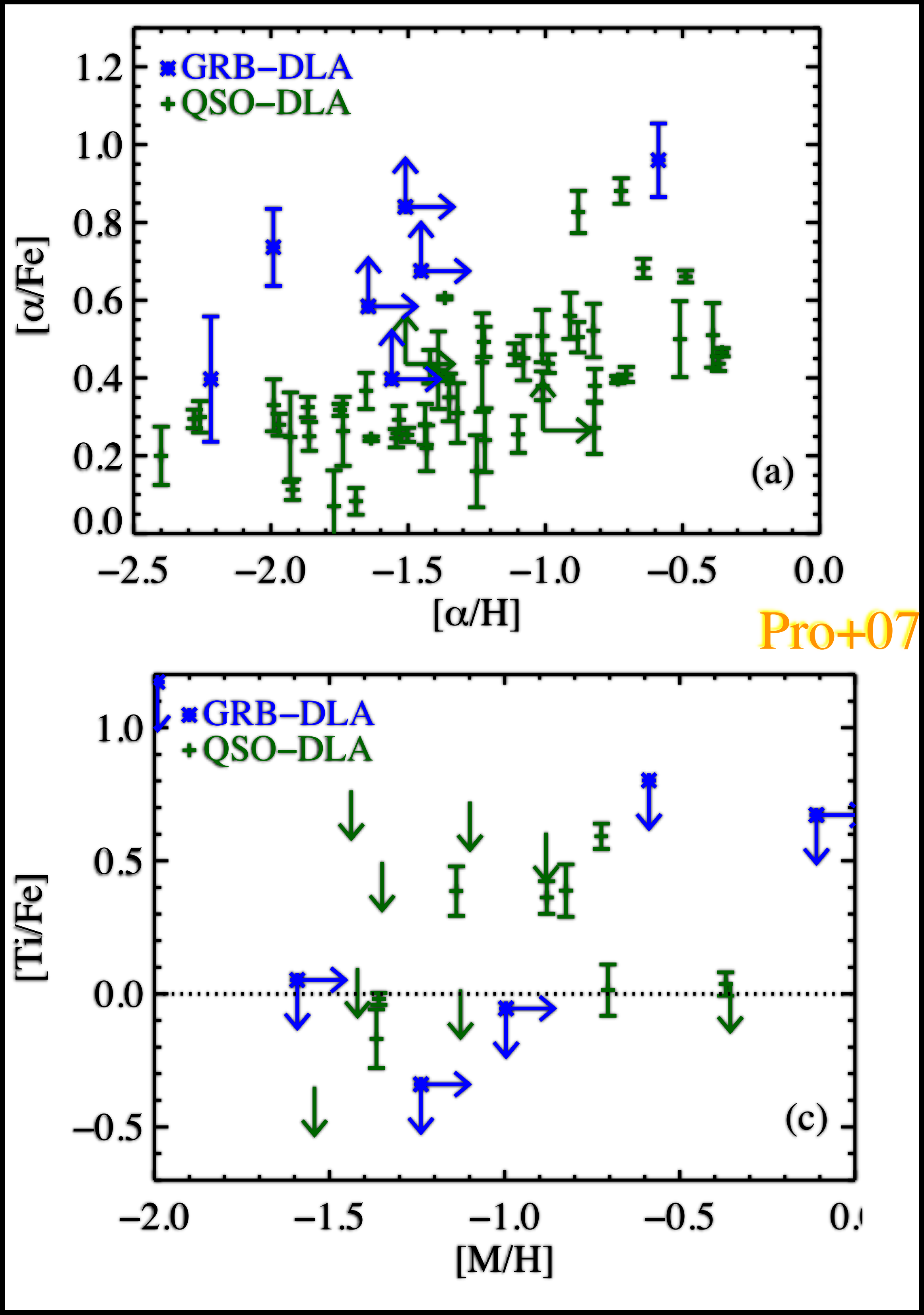
Bright Galaxies are the Tip of the SF Iceberg

$$\phi(L_{UV}) \propto (L_{UV}/L_*)^{-1.6} \exp(-L_{UV}/L_*)$$



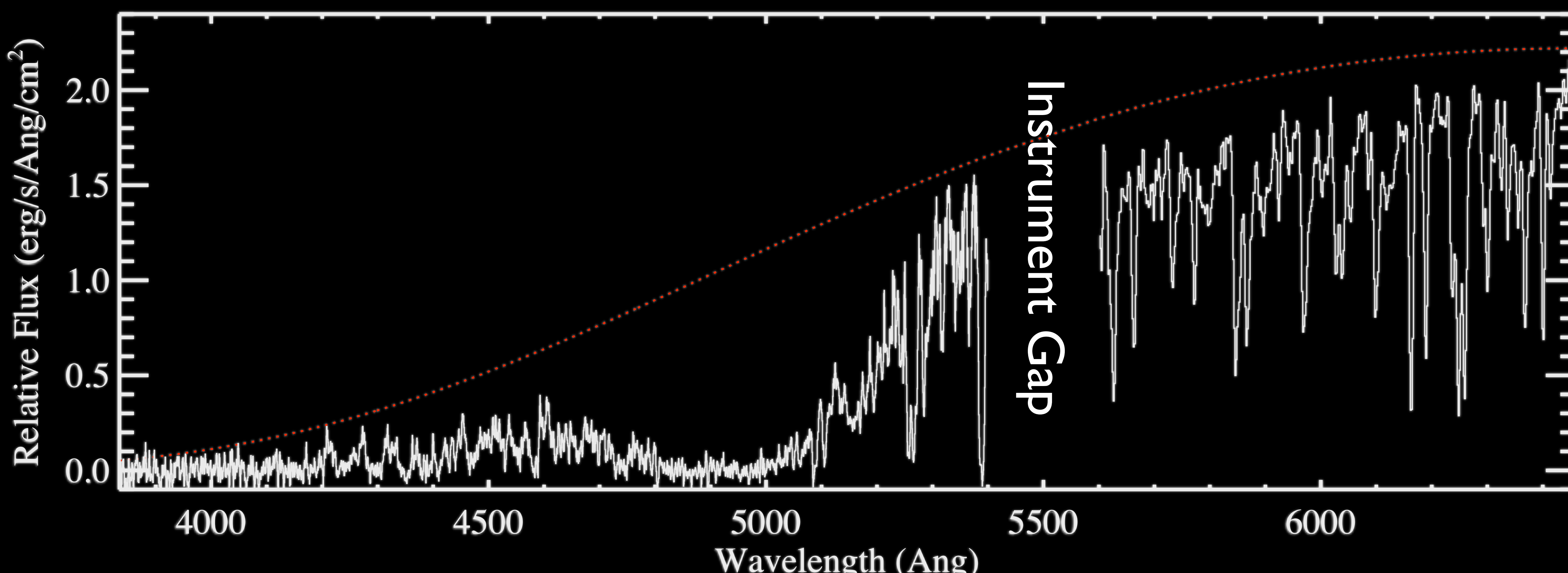
Metallicity: Relative Abundances

- Examine the ratio of two elements
  - Plot vs. metallicity
  - Clues to dust and enrichment history
- Si/Fe (α/Fe)
  - Enhanced at all metallicity
  - Indicative of gas enriched by massive stars
- Ti/Fe
  - Two refractive elements
  - Ti/Fe under-abundance can only be explained by differential depletion



Distance: Where are these gas and metals?

- Large N_{HI} suggests SF region
  - But, where are the molecules?
  - Let's test this hypothesis
- Do the abundances reflect the progenitor environment?



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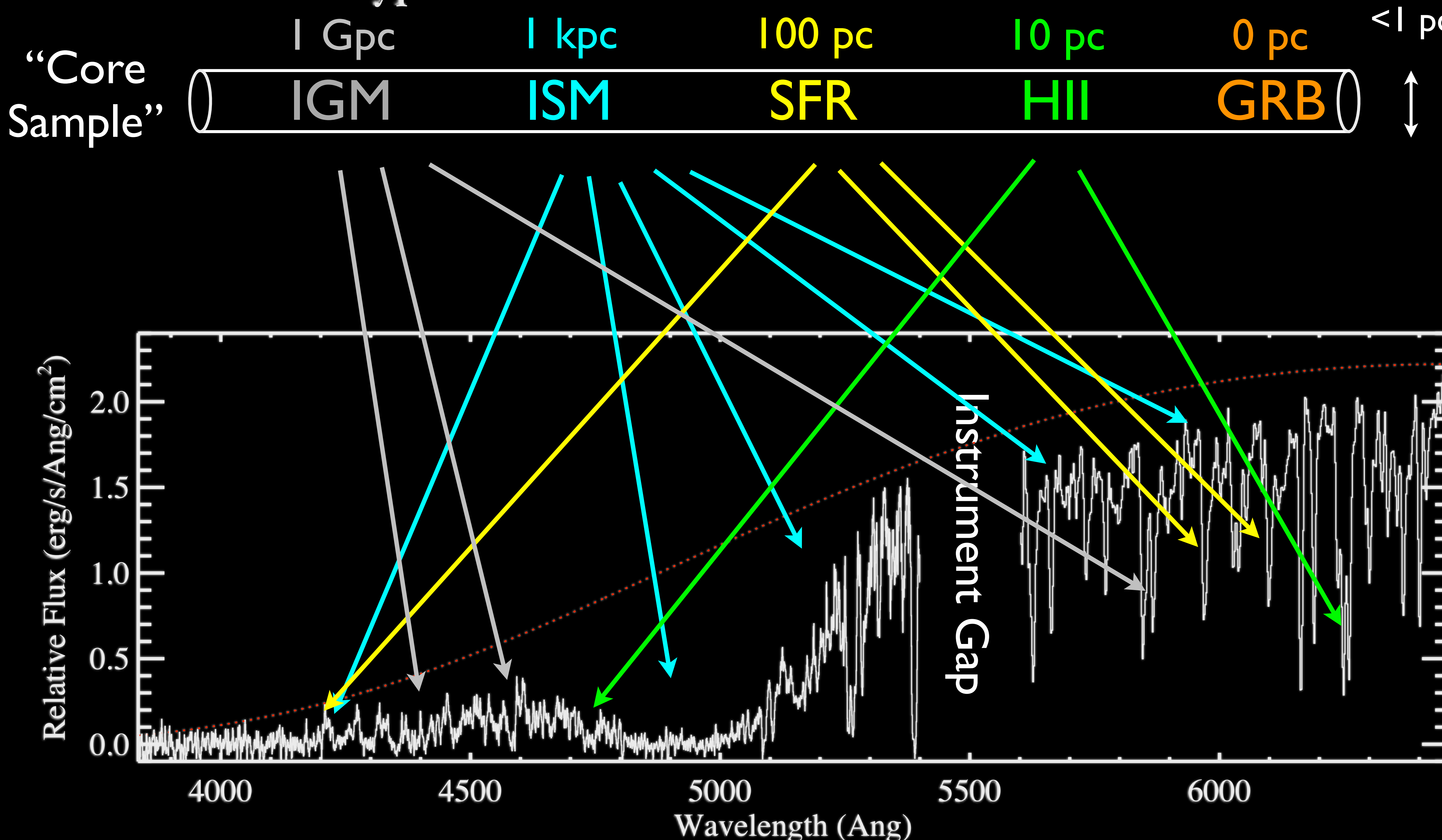
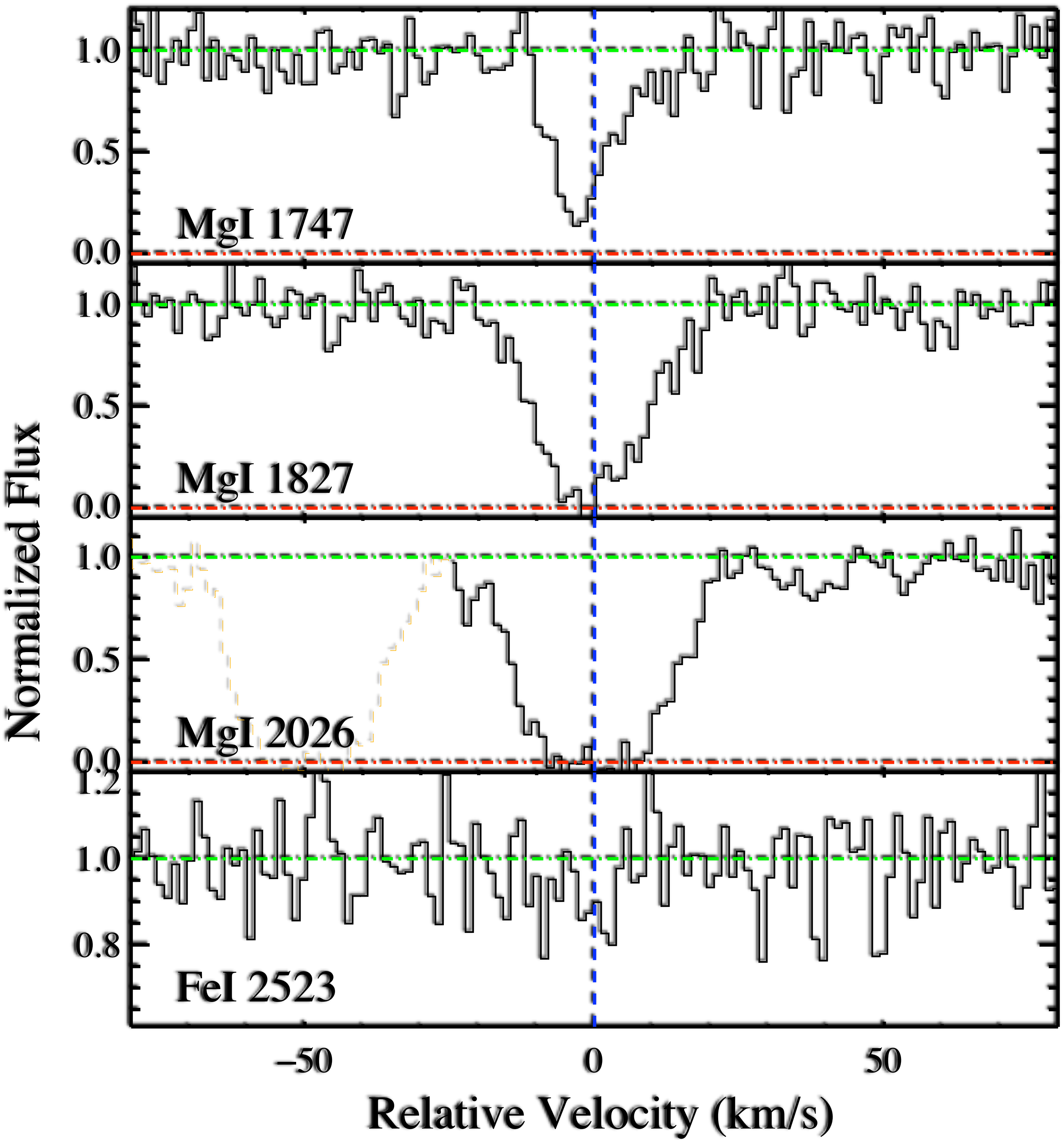


Distance: Lower limit from Mg^0

- Very large Mg^0 column
  - Detected in several transitions
  - $N(Mg^0) = 10^{14.7}$ cm^{-2}
- $IP(Mg^0) = 7.7$ eV
  - Galaxies are optically thin at this energy
- At r=50pc, 99.99% of Mg^0 is ionized in <1000s
  - Generic result for GRBs
  - Detection of Mg^0 places the neutral gas at >50pc
  - Variations in $N(Mg^0)$?
    - ✦ None found: r>80pc



Mirabal et al. (2003)
Prochaska, Chen, & Bloom (2006)

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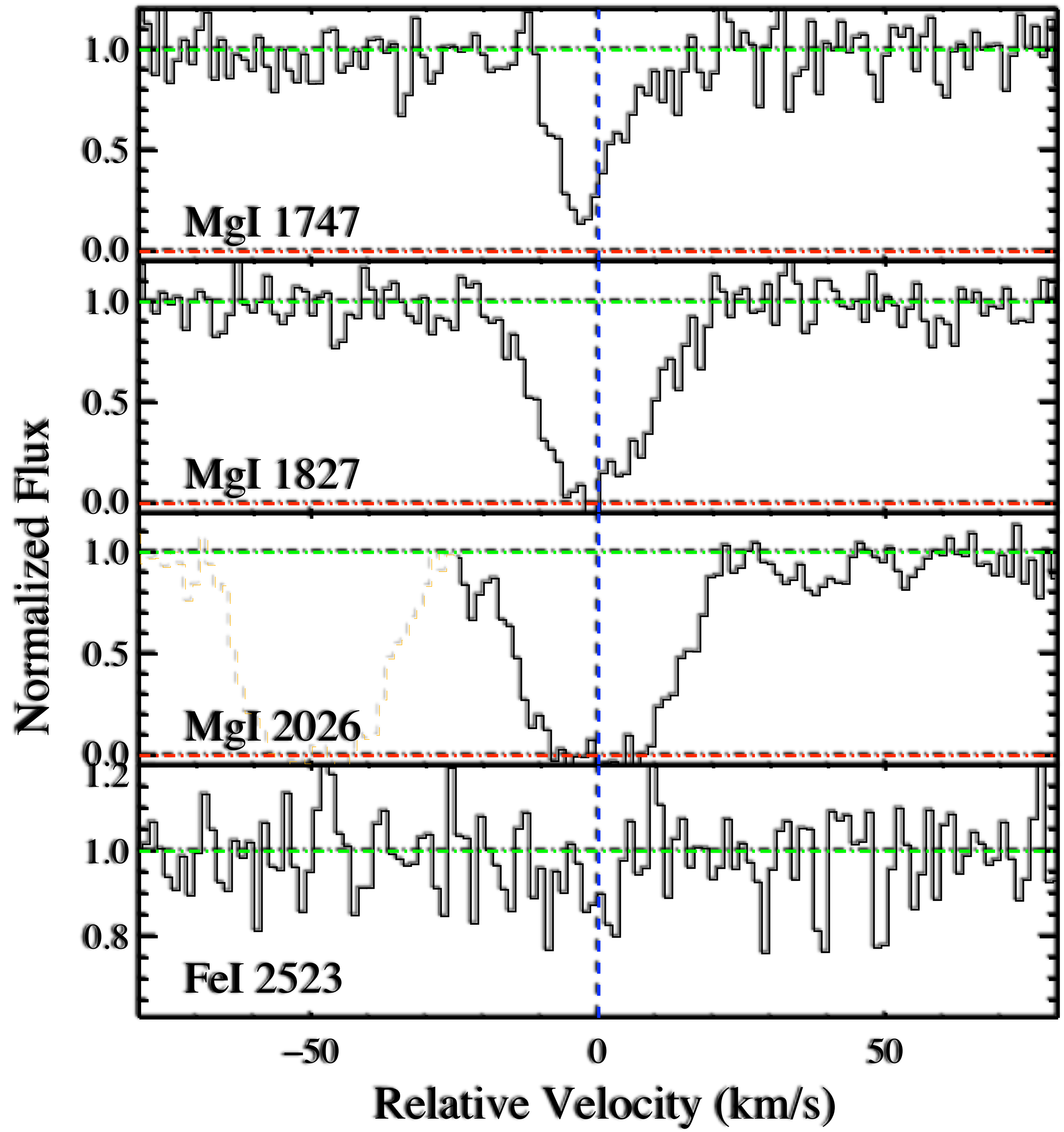
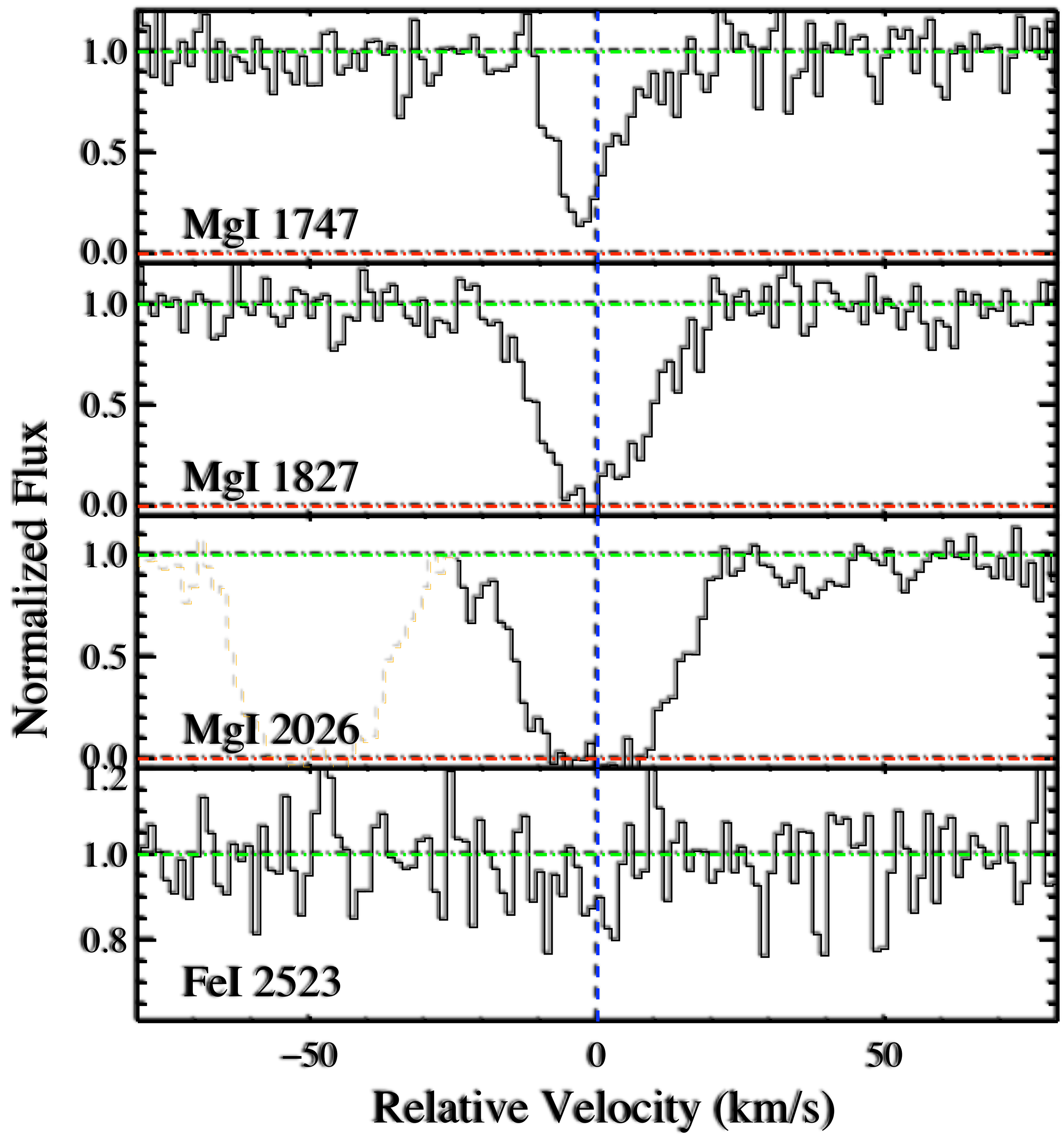


Mirabal et al. (2003)
Prochaska, Chen, & Bloom (2006)

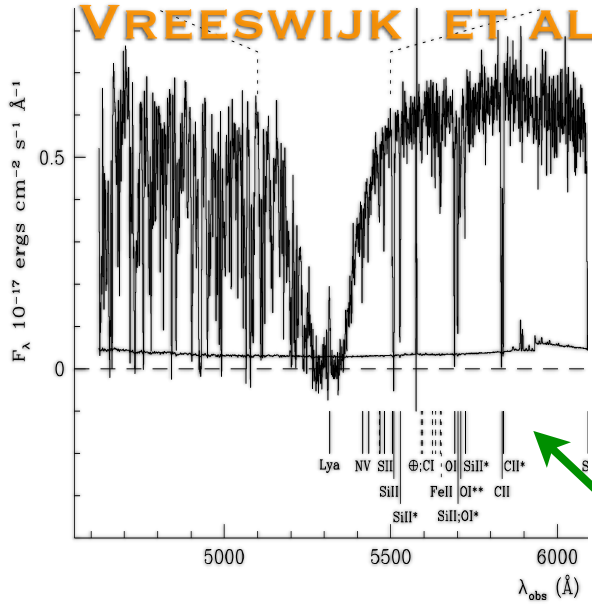
Distance: Mg^0 implies >100pc

- Strong Mg^0 is generally detected
  - Majority of neutral gas lies at r > 100pc
  - How far away is it?
- Implications
  - SF region has been predominantly ionized
    - Not the GRB afterglow
    - Pre-existing HII region
    - Same as H_2 gas
      - Whalen et al. (2008)
  - Observations mainly constrain the properties of the neighboring ISM
    - Not the direct progenitor region

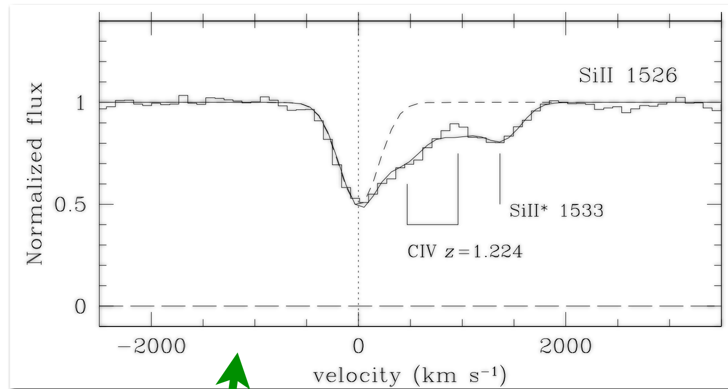


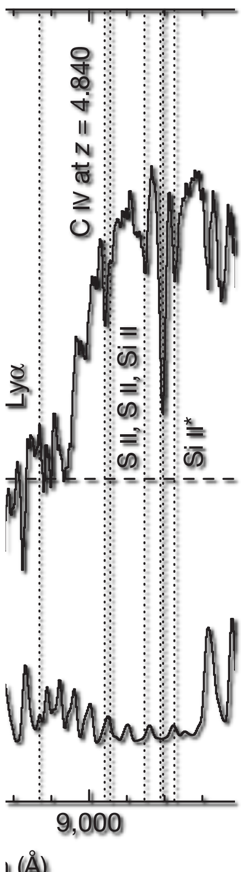
Distance: Fine-structure lines

Vreeswijk et al. (2004)



Barth et al. (2003)





Kawai et al. (2005)

Fynbo et al. (2006)

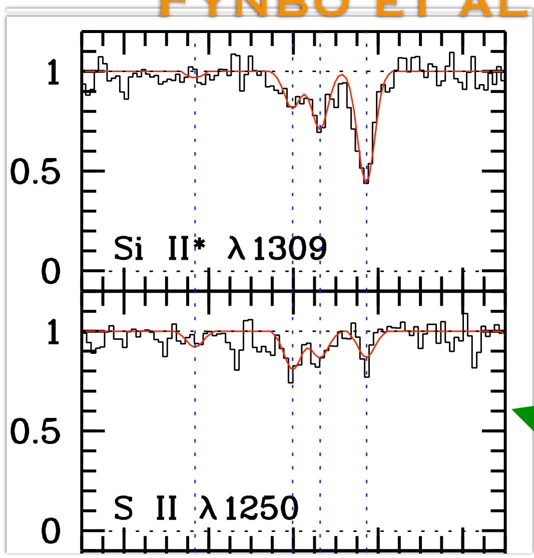
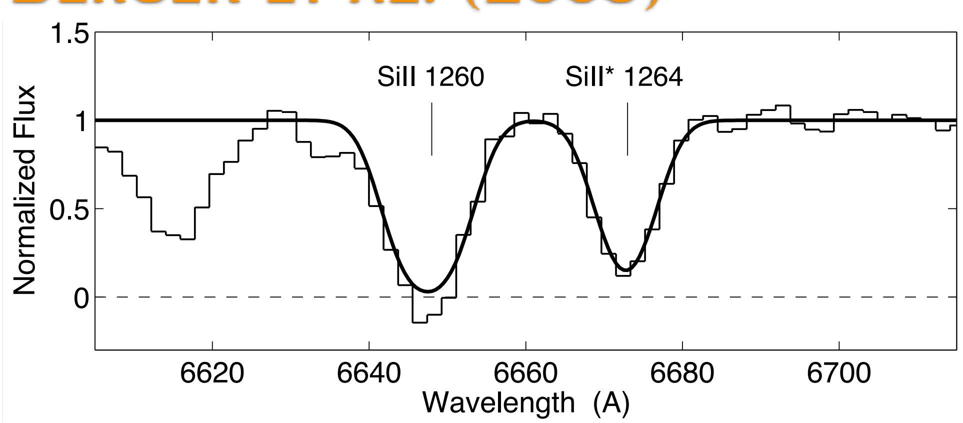
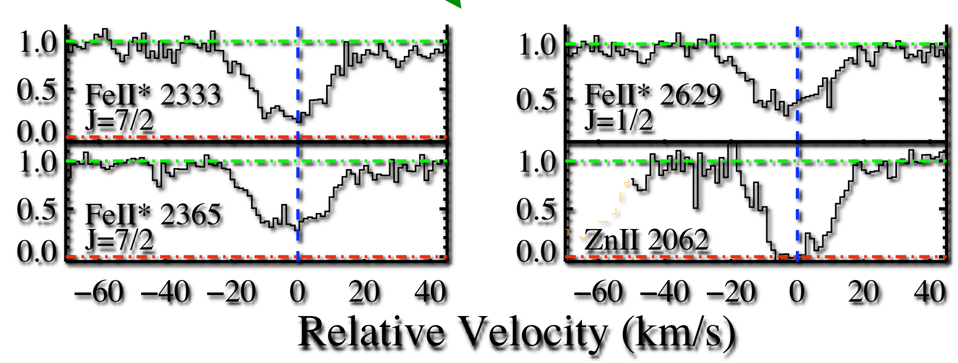


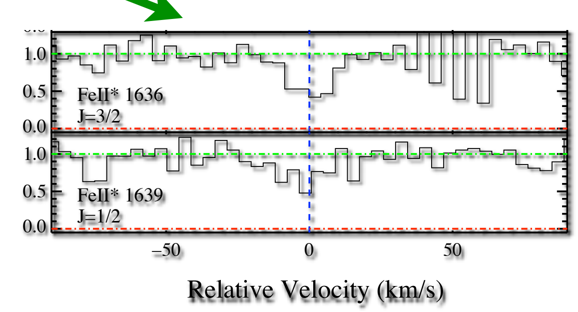
Table 3. Constraints on Circumburst Distances of Observed Neutral Gas

GRB	z	α	β	Ref	$\log L_\nu^a$ (cgs)	r^b_{MgI} (pc)	r^c_{excite} (pc)
010222	1.477	0.80	0.89	1	31.39	40	190
020813	1.254	0.85	0.92	2	31.09	30	140
021004	2.328	1.05	1.05	3	32.21	140	620
030323	3.372	1.56	0.89	4	32.85	540	2330
030329	0.169	1.10	1.00	5	31.38	60	250
050408	1.236	0.79	1.30	6	29.93	10	40
050730	3.969	0.30	1.80	7	32.16	70	340
050820	2.615	0.95	1.00	8	31.97	100	430
051111	1.549	0.87	0.60	9	31.32	40	180
060206	4.048	1.01	0.51	10	32.41	170	730

Berger et al. (2005)

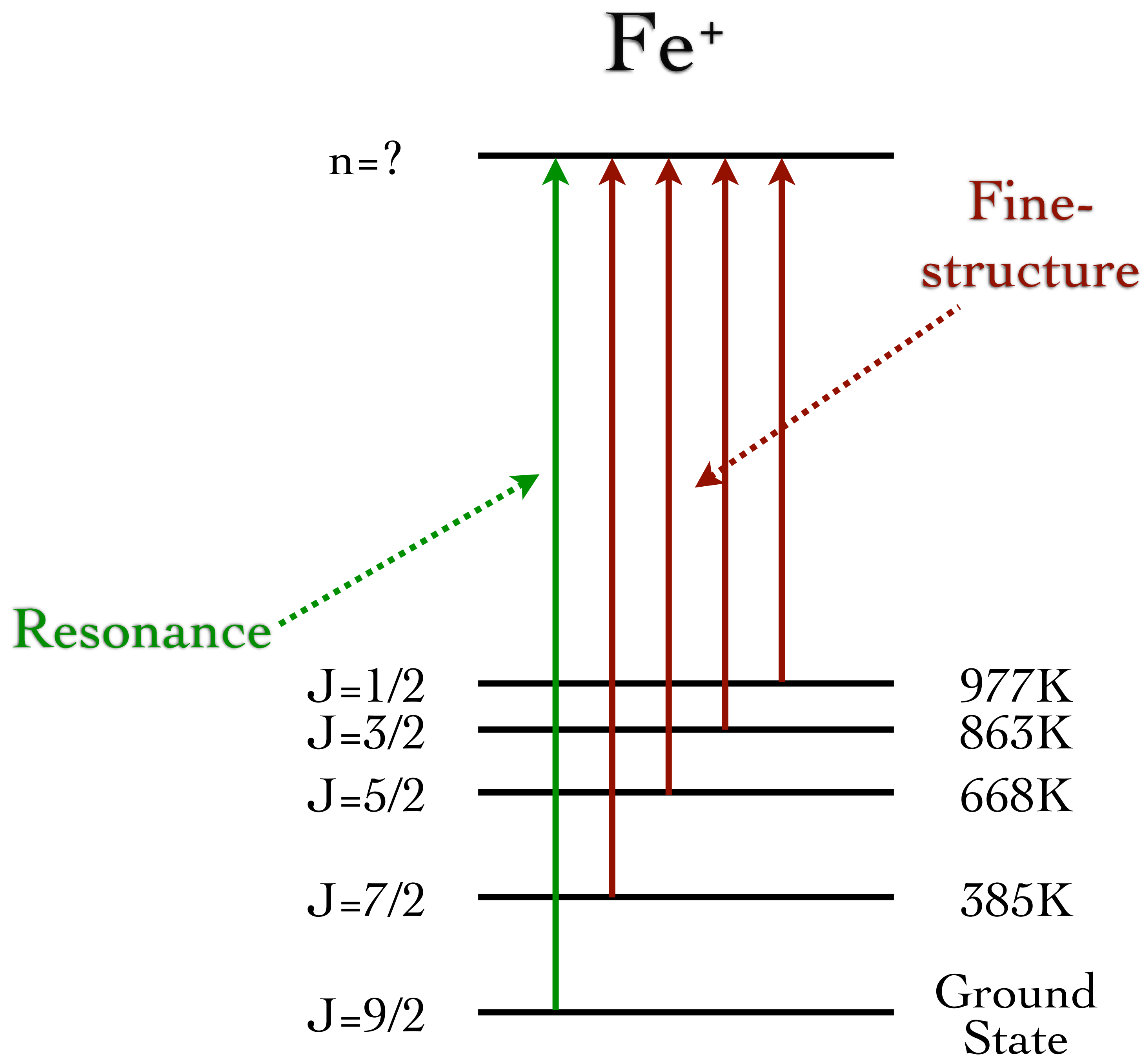






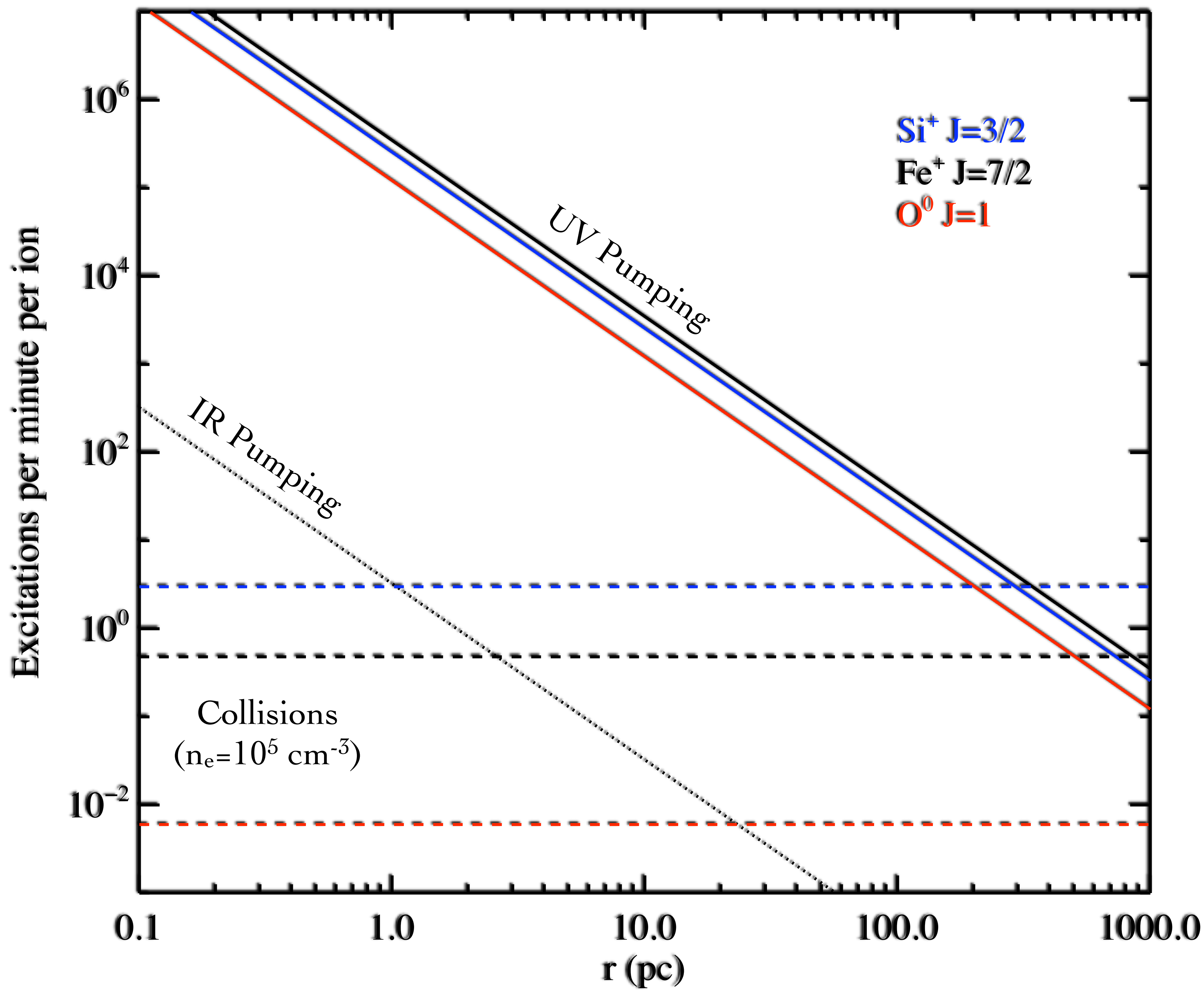
Fine-Structure Excitation

- Indirect pumping
  - UV transition to upper level
  - Cascade down to excited state
  - Electric-dipole forbidden
    - Multiple generations?
- Direct Pumping
  - IR transition from J=9/2
  - Magnetic-dipole transition
    - J=9/2 to 7/2
    - J=7/2 to 5/2, etc.
  - Possible, but unlikely
- Collisional excitation
  - Electrons should dominate
  - Key: Density and temperature



UV Pumping Dominates out to 1kpc

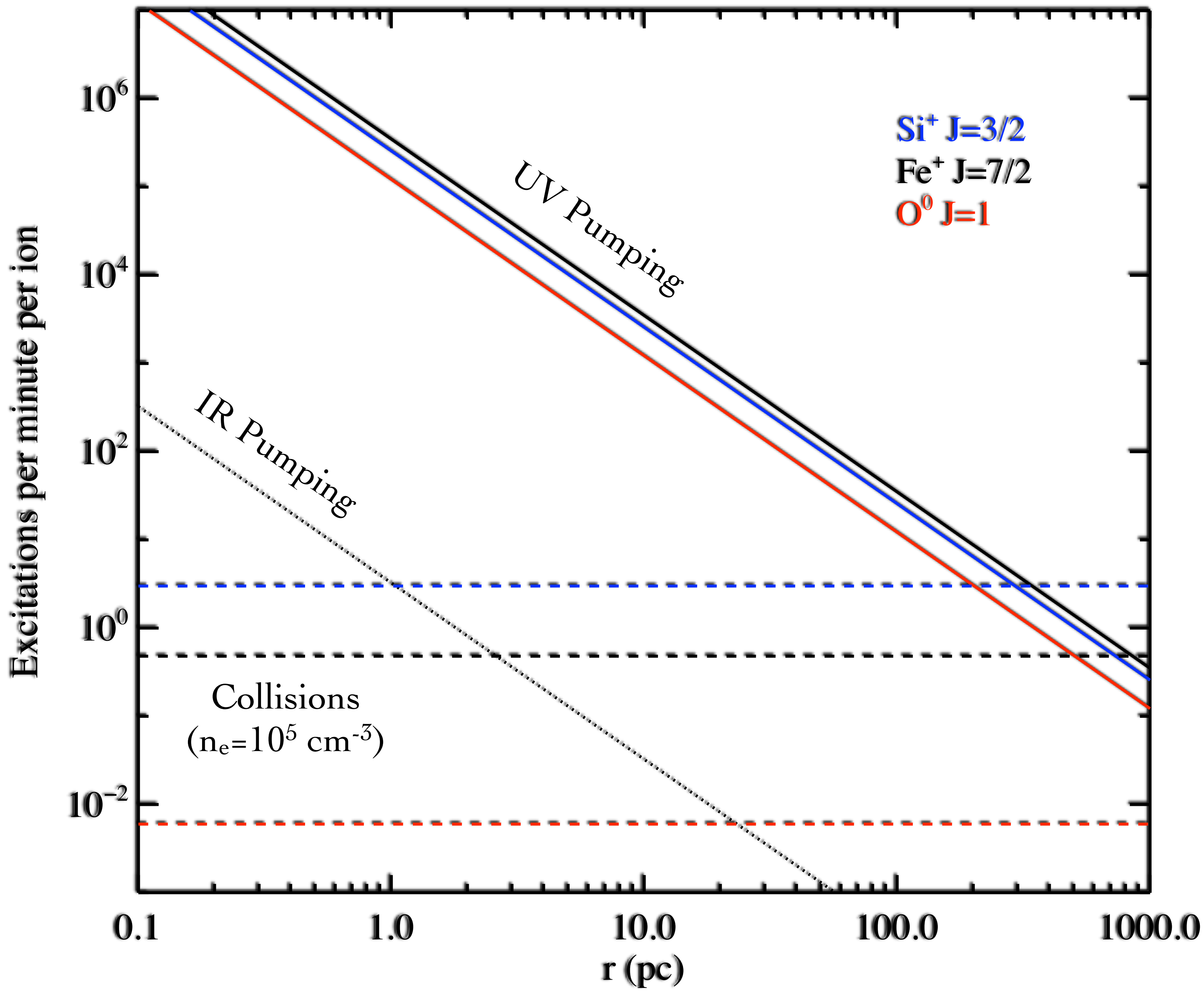
- UV dominates over collisions and IR pumping
  - The gas is not high density CSM
- Is collisional excitation viable?
  - Not really
  - Consider a high density clump
    - $n_H \sim 10^5$ cm^{-3}
    - $r \sim N_{HI} / n_H \sim 10^{15}$ cm
    - But, d > 10^{20} cm for collisions to dominate



Prochaska, Chen, & Bloom (2006)

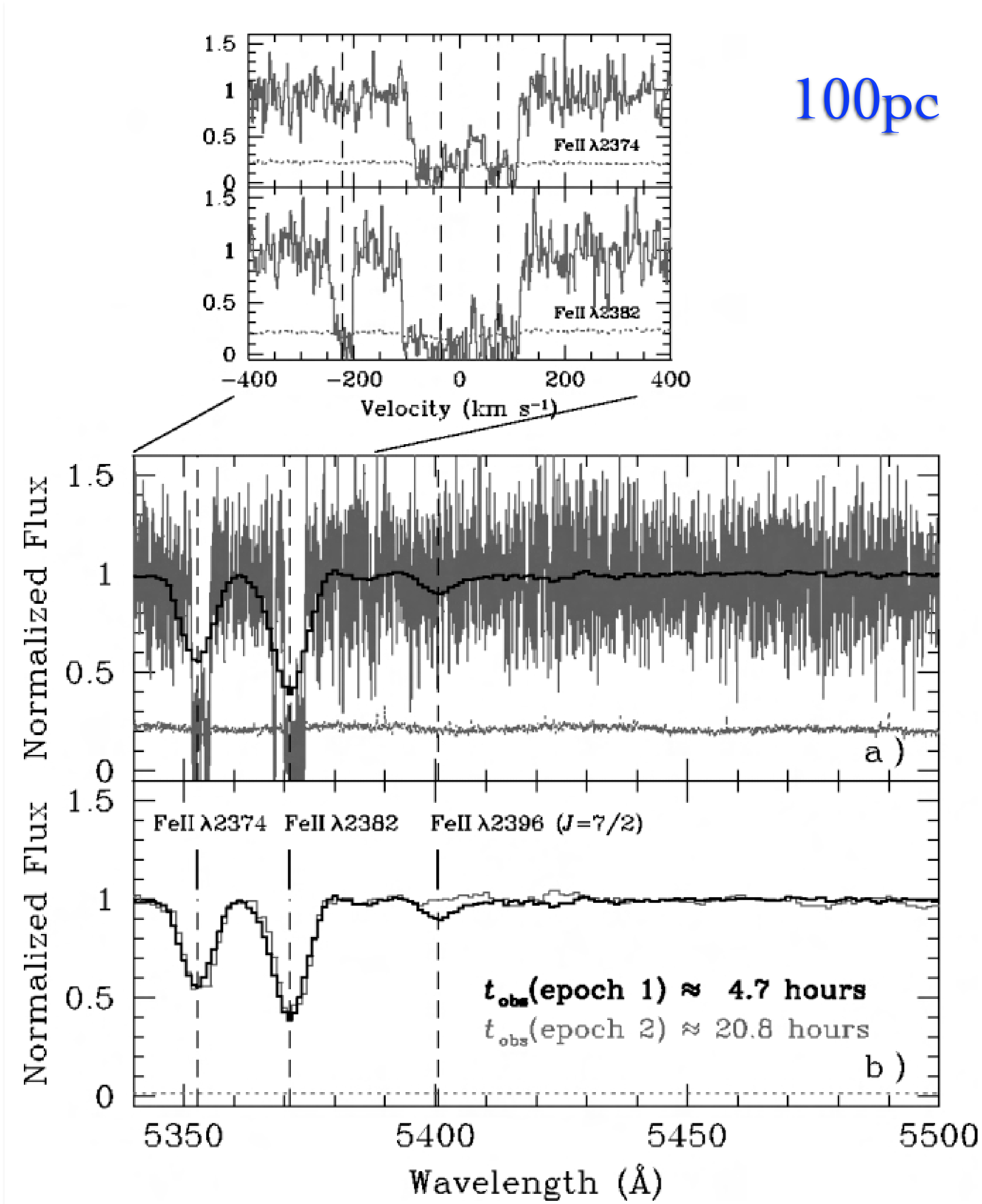
Distance: Fine-structure lines

- Turn the problem around
  - Fine-structure detected
    - The gas arises within ~1kpc of the GRB
  - Fine-structure absent
    - The gas lies beyond ~1kpc from the GRB



Distances: Fine-structure lines

- **Line variability**
  - t=0: No fine-structure lines
  - Lines should appear
    - Timescale of <few min
  - Lines should decay
    - t(Fe^+) ~ 1 hr
- **Distance constraint from variability**
  - Difficult calculation
    - But the observations provide key constraints
  - d = 100pc to several kpc
  - This gas is not within the SF region of the GRB
    - Currently, no signatures of the CSM (Chen+07)



Dessauges-Zavadsky+06

Distances: Fine-structure lines

- **Line variability**
  - t=0: No fine-structure lines
  - Lines should appear
    - ✦ Timescale of <few min
  - Lines should decay
    - ✦ $t(Fe^{+}) \sim 1$ hr
- **Distance constraint from variability**
  - Difficult calculation
    - ✦ But the observations provide key constraints
  - d = 100pc to several kpc
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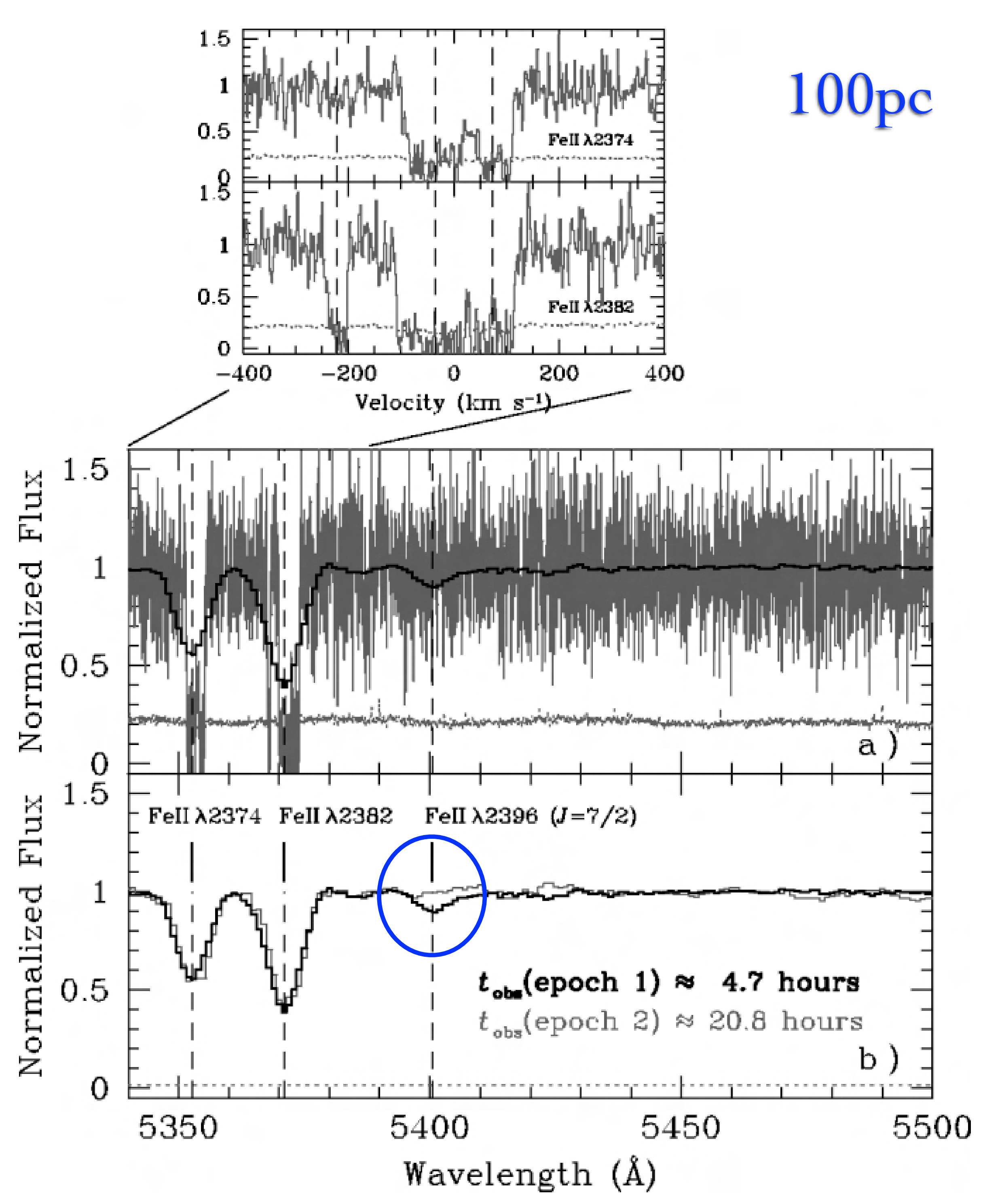

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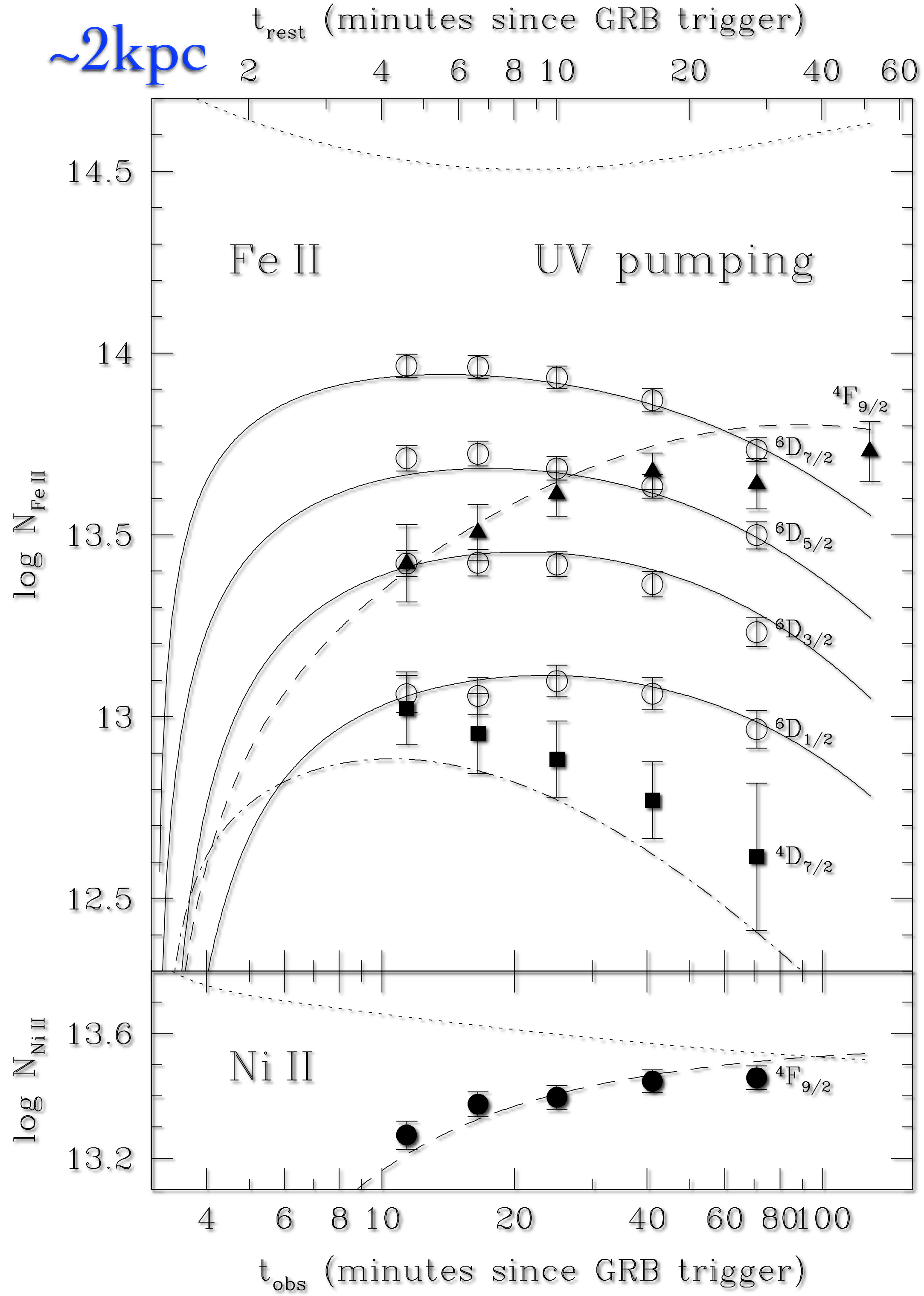
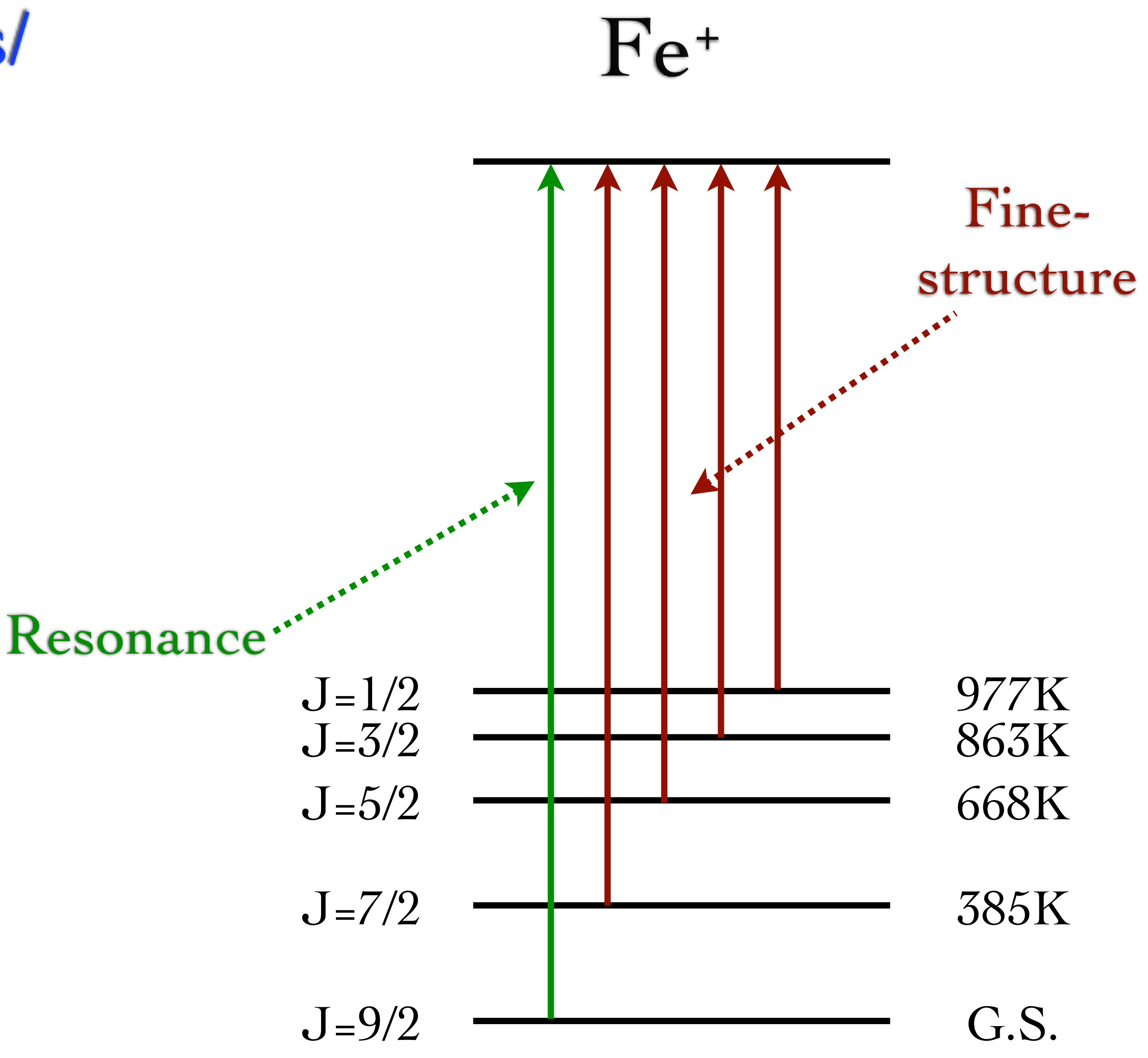
~2kpc



Vreeswijk+07

Distance: Implications

- Fact: GRB afterglows UV pump Fe, C, Si and O atoms/ ions out to several kpc
- Implications
  - Expect and observe variability
  - Observations probe the ambient ISM
- Distance diagnostic
  - Presence of fine-structure indicates r <~ 1kpc
  - Absence of fine-structure indicates r >> 1 kpc
    - Rules out putative CSM gas



Poor man's animation

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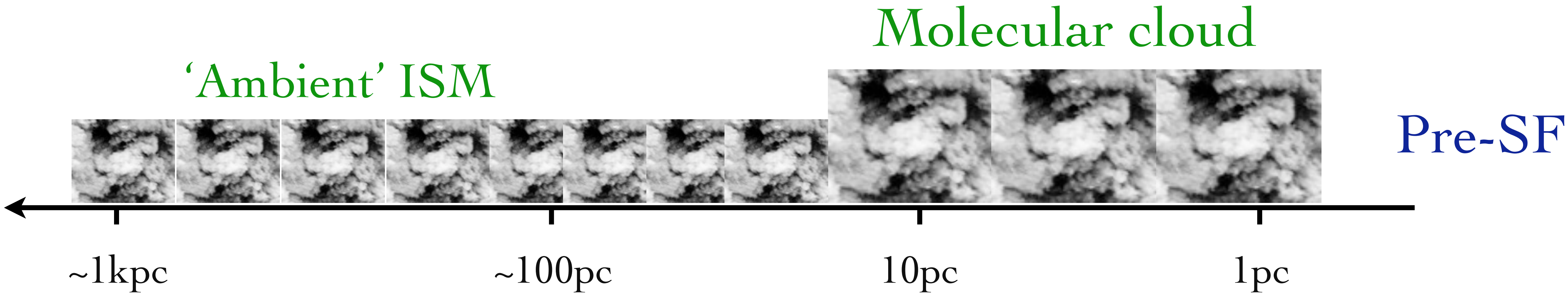

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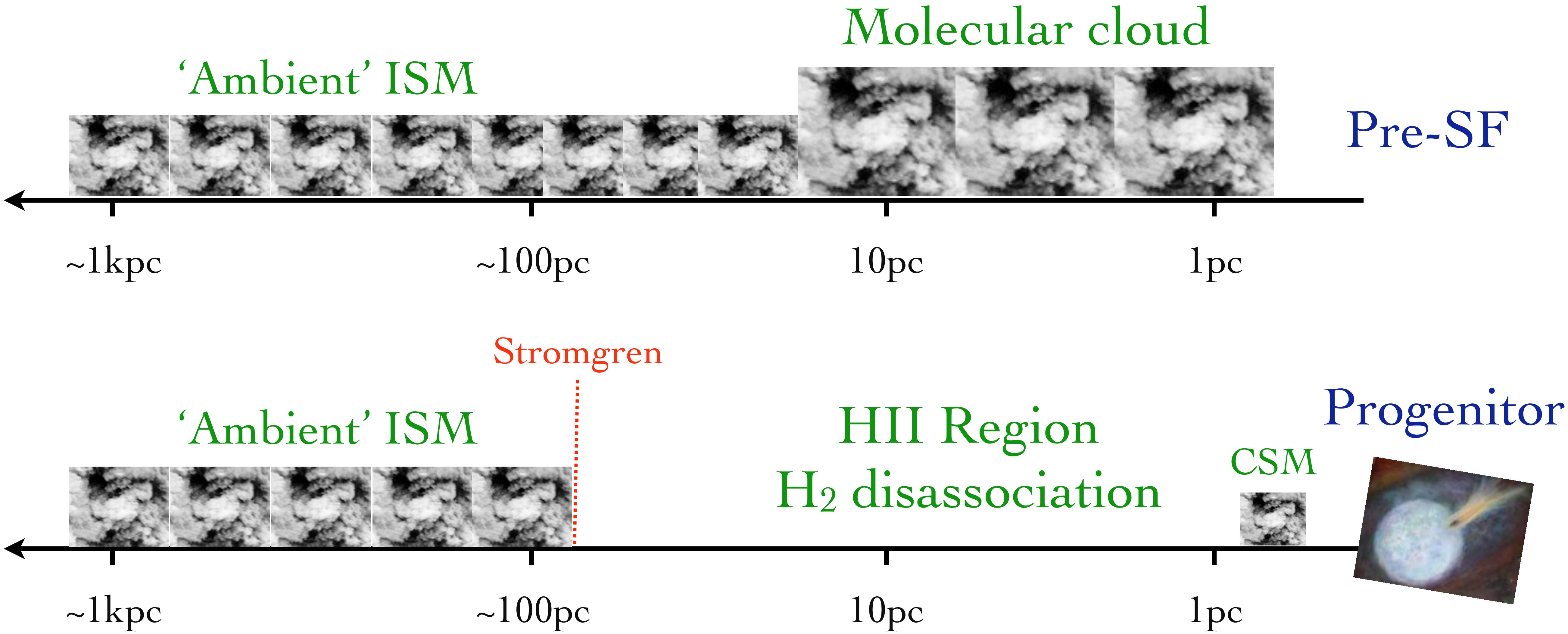

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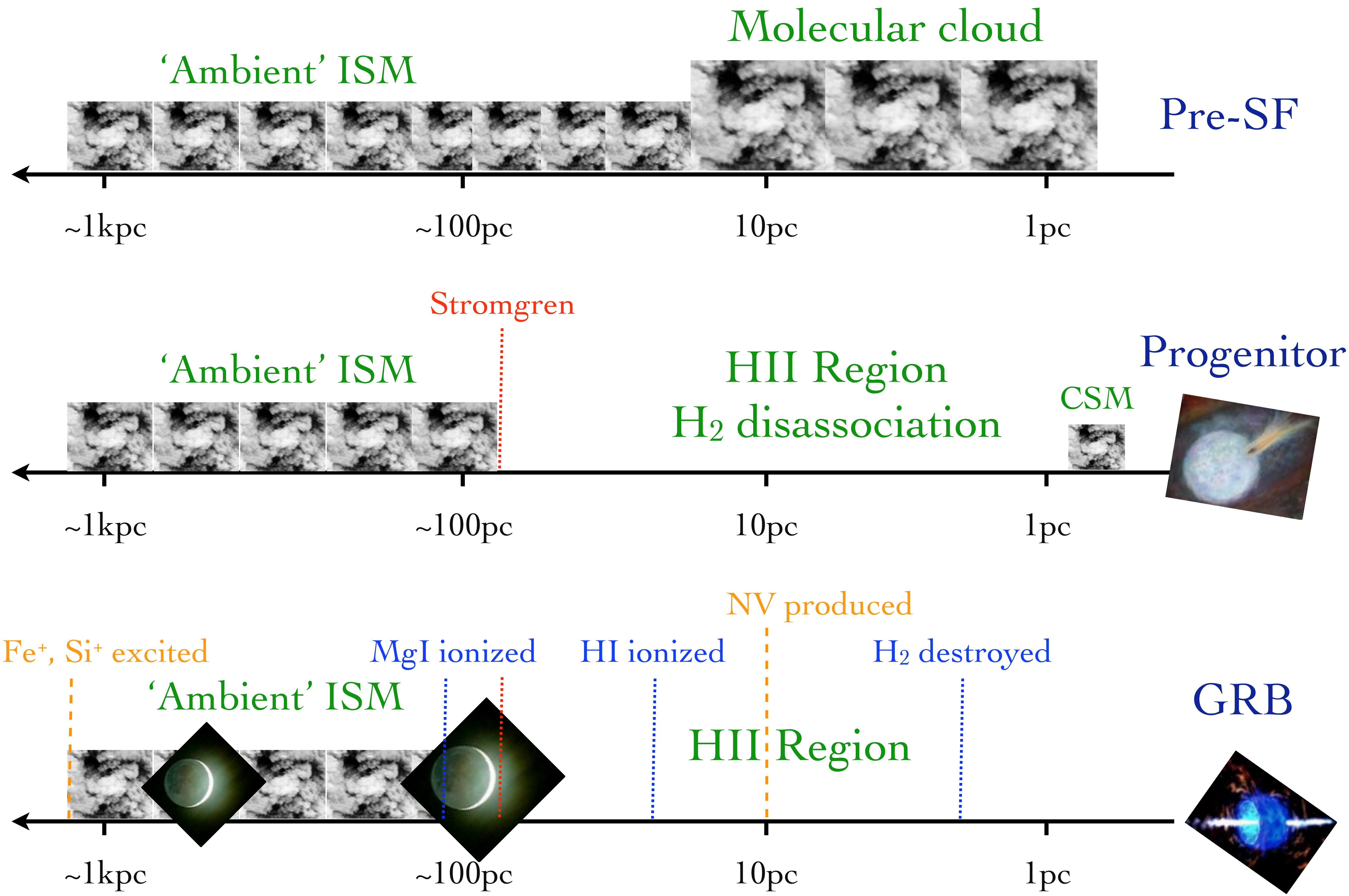
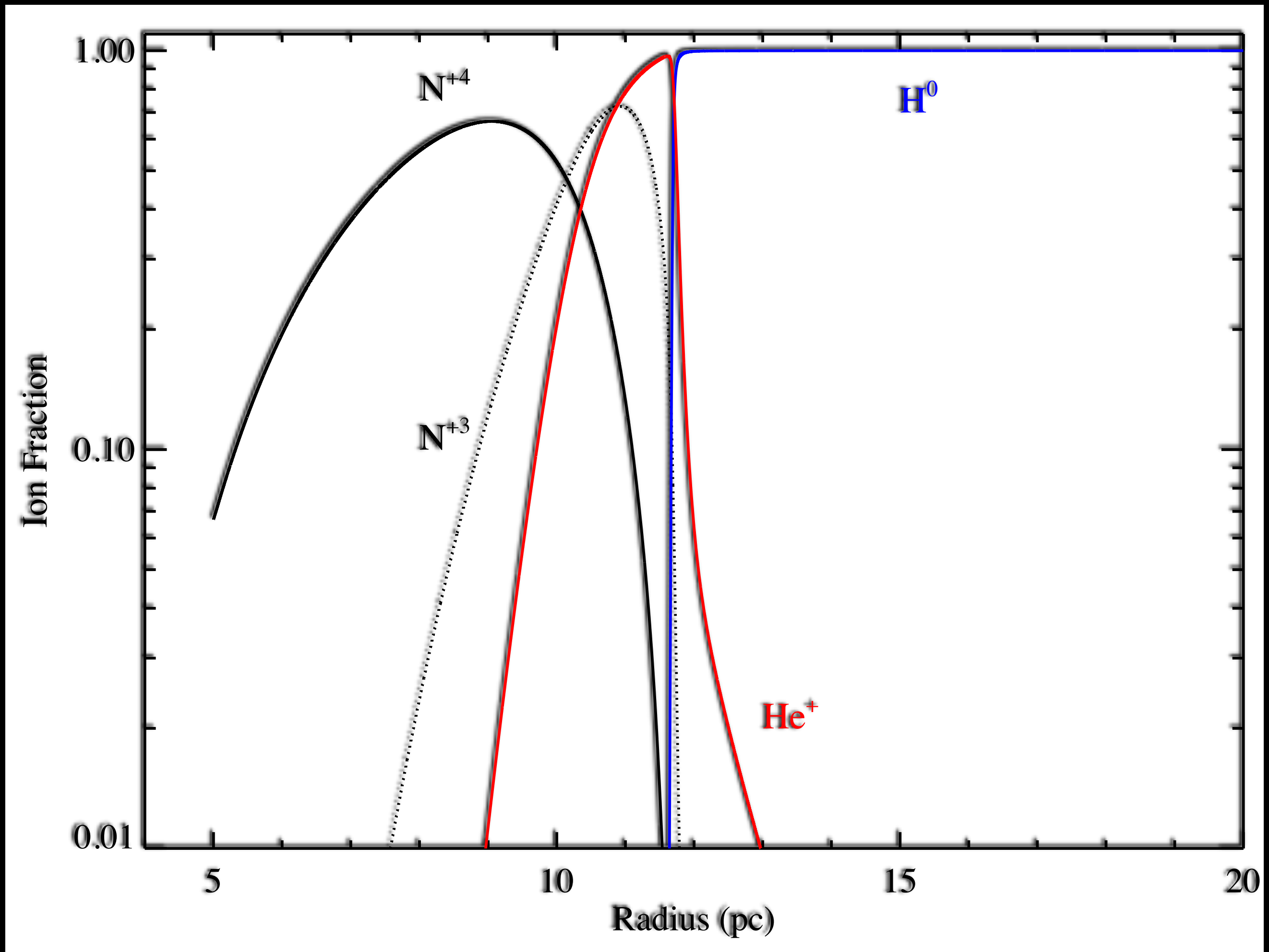


Progenitor Environment

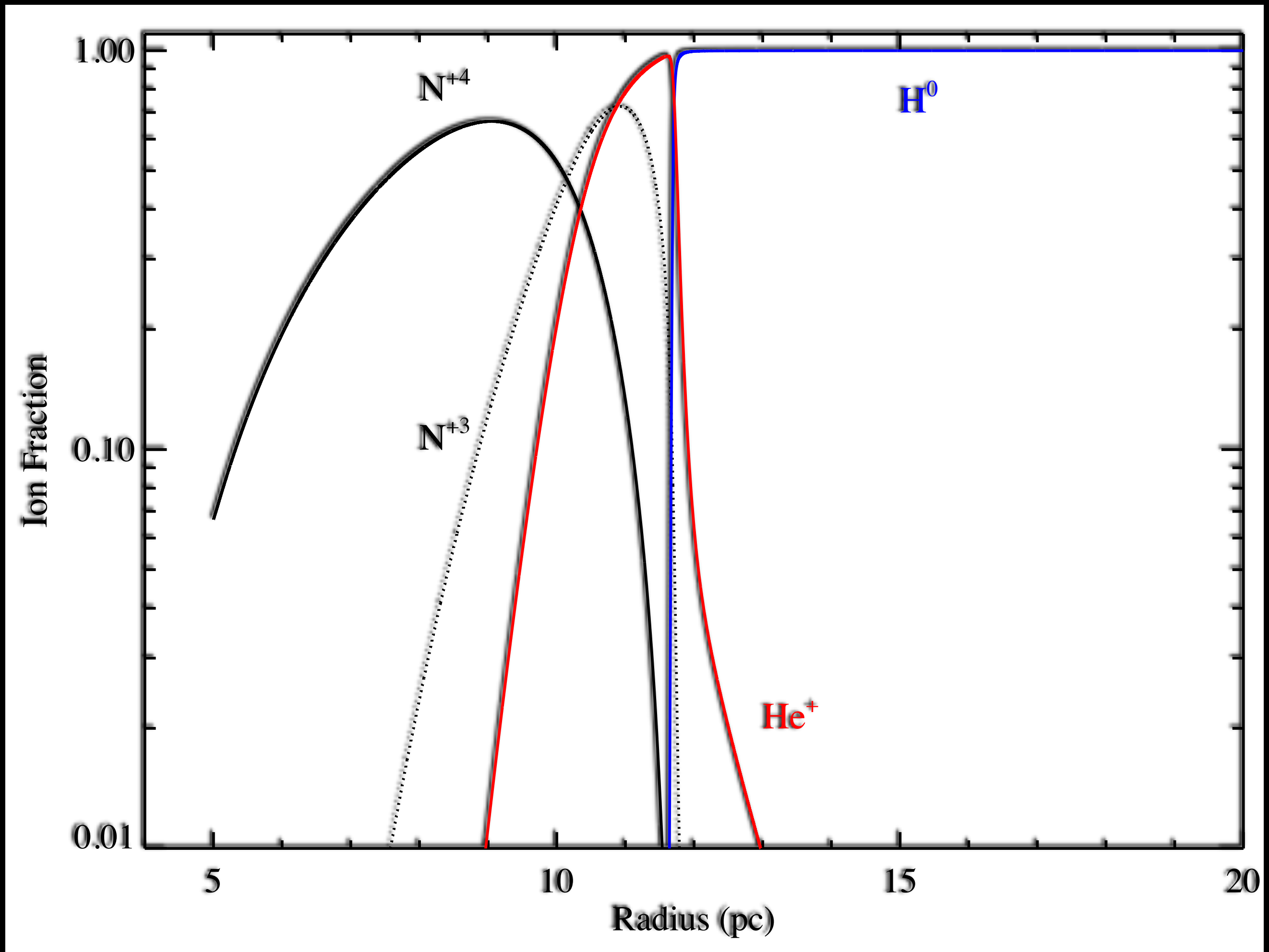


Pro+08

Fox+08

Progenitor Environment

- Majority of the gas lies at beyond 100pc from the GRB
  - Metallicity need not reflect the GRB progenitor
  - But these galaxies are usually young



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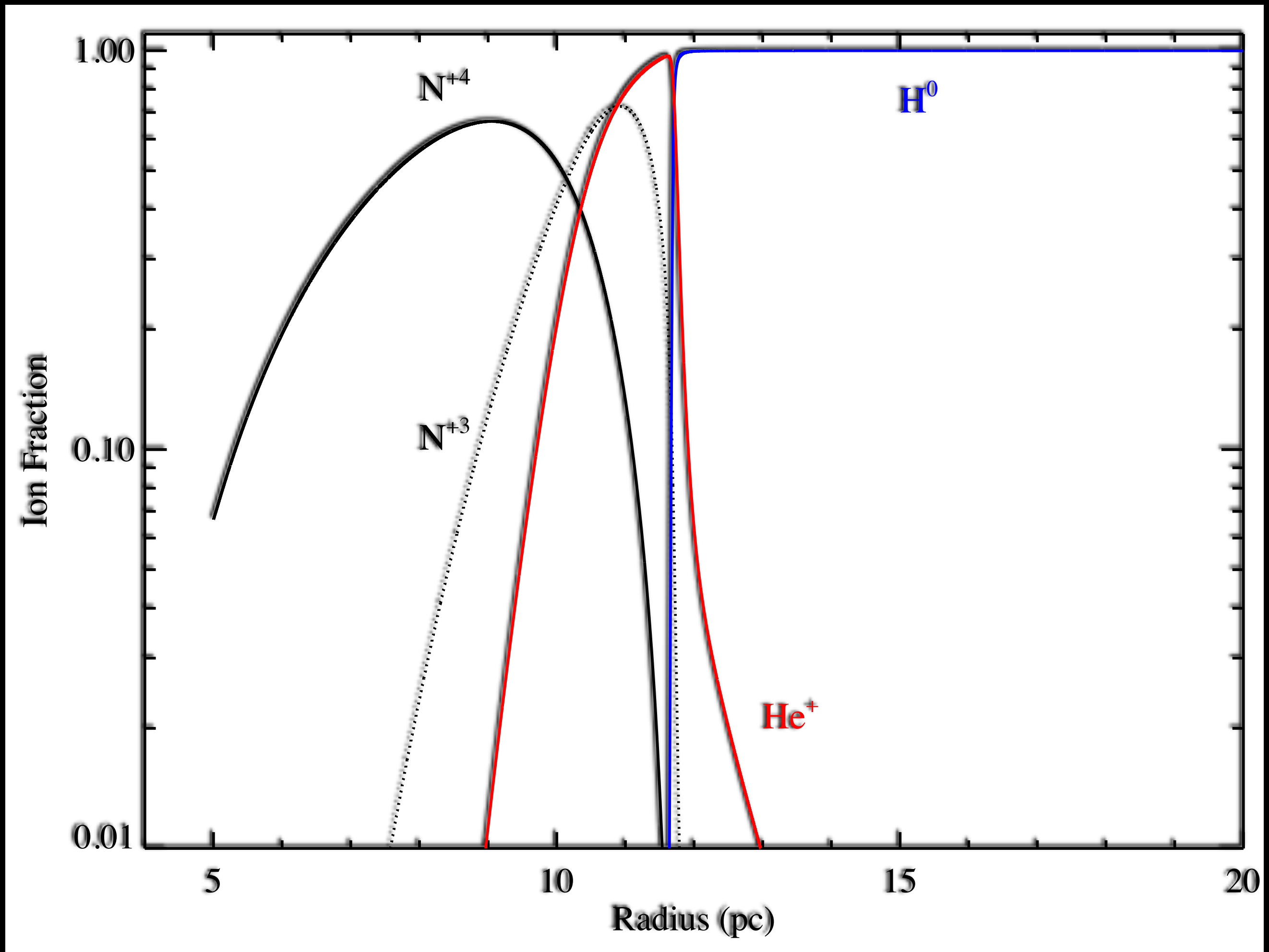
  - Most of these ions need X-Ray spectroscopy (Xenia)
  - A few are possible with UV: N V



Pro+08

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- GRB itself will photoionize gas to several tens of pc
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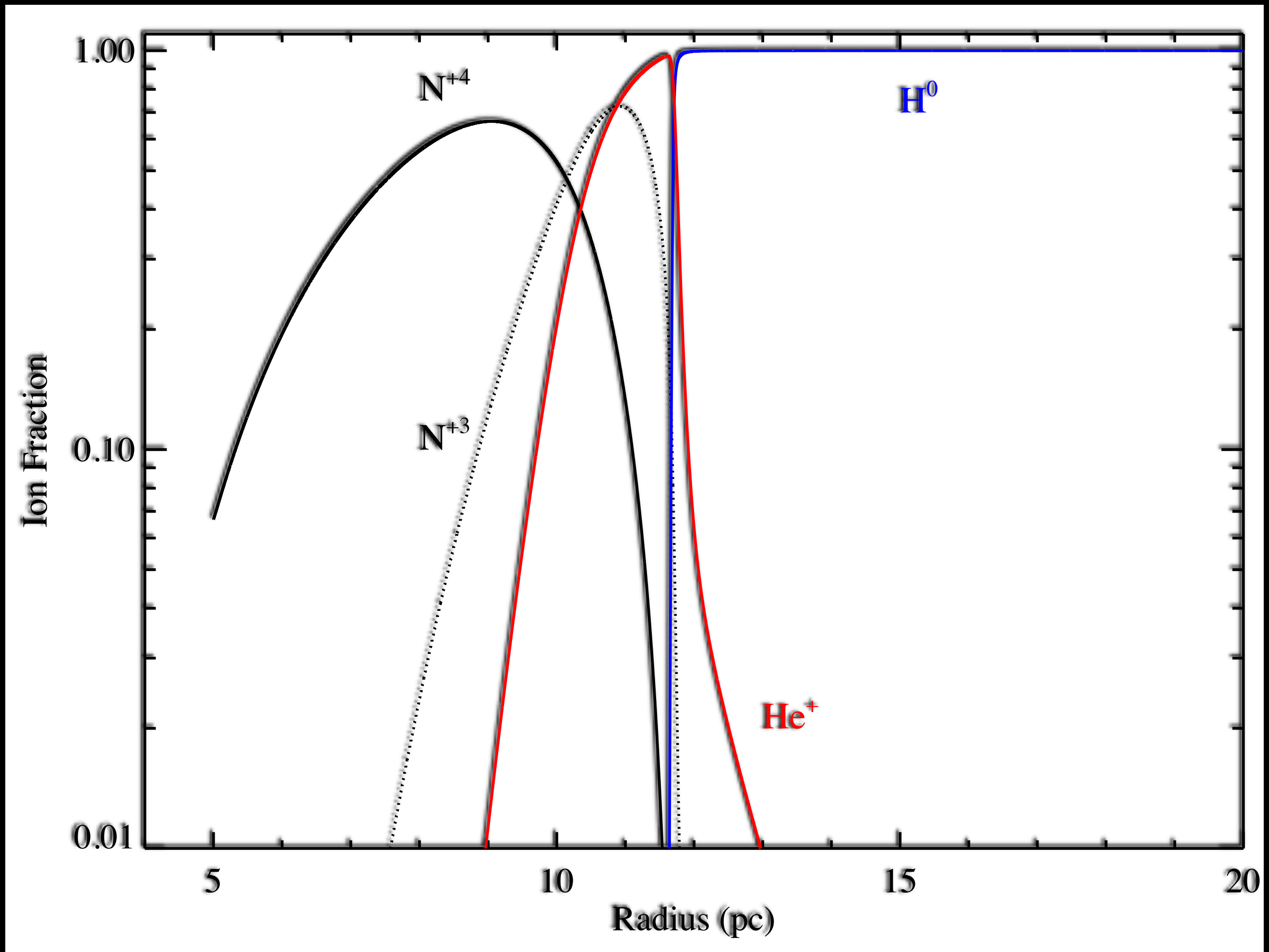
  - A few are possible with UV: N V
- Narrow N V is frequently observed
  - Possibly gas at ~10pc
  - Not the progenitor wind

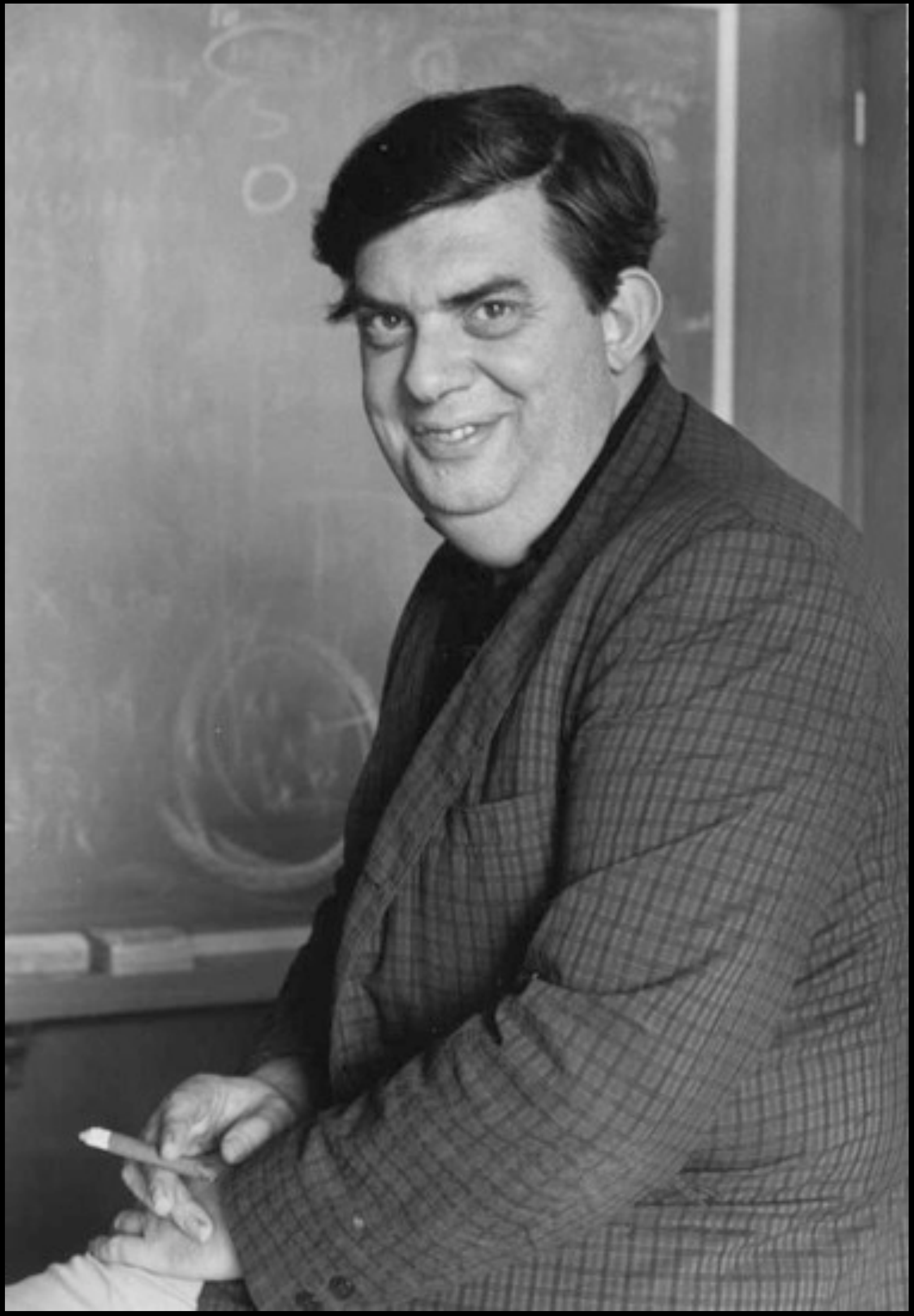


Pro+08

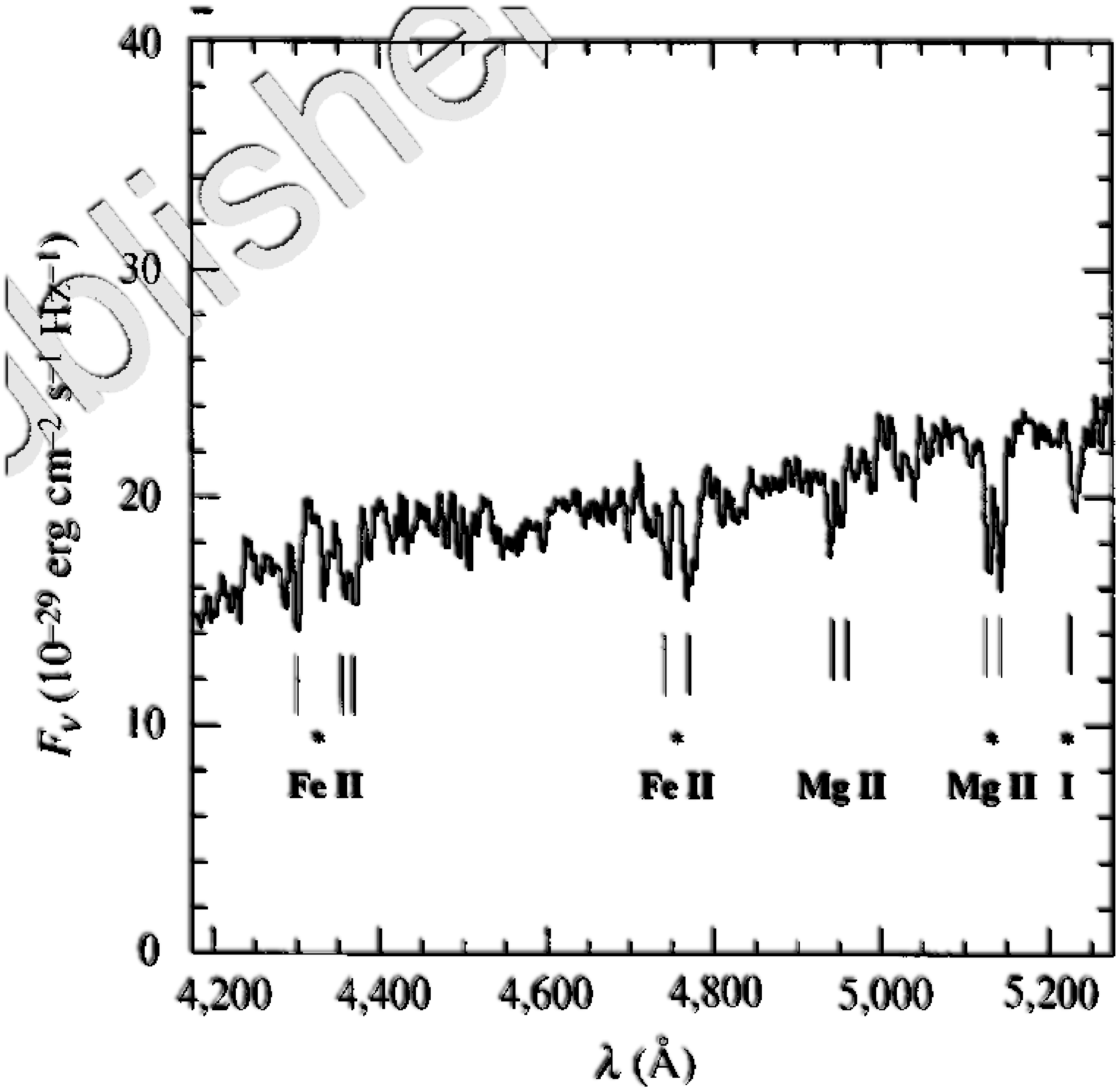
Fox+08

Science: GRB and the IGM

- Repeat science that is traditionally done with QSOs
  - e.g. Lya forest, metal-lines
  - Take advantage of the simpler spectrum that GRBs offer
- Potentially much higher S/N
  - Brightest GRBs are *much* brighter than QSOs at z>3
    - Albeit for a short amount of time
- Push to z>6
  - i.e. reionization
  - Formation of the first stars



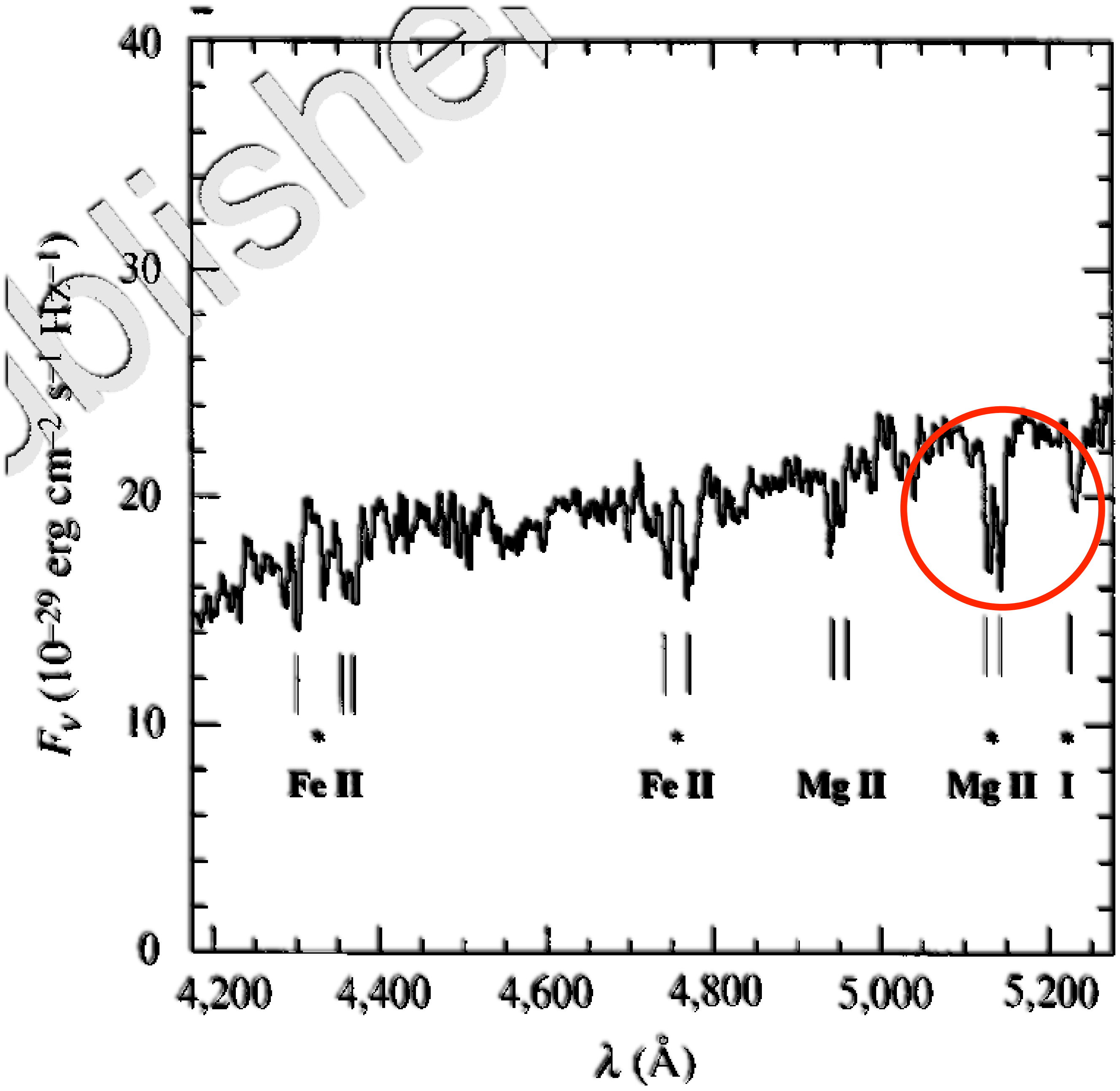
GRB MgII



F_ν (10^{-29} erg cm^{-2} s^{-1} Hz^{-1})
40
30
20
10
0
Fe II
Fe II
Mg II
Mg II
I
4,200
4,400
4,600
4,800
5,000
5,200
λ (Å)

GRB MgII

- **MgII**
  - Often establishes the GRB redshift (z<2.5)
    - EW > 2A in most cases



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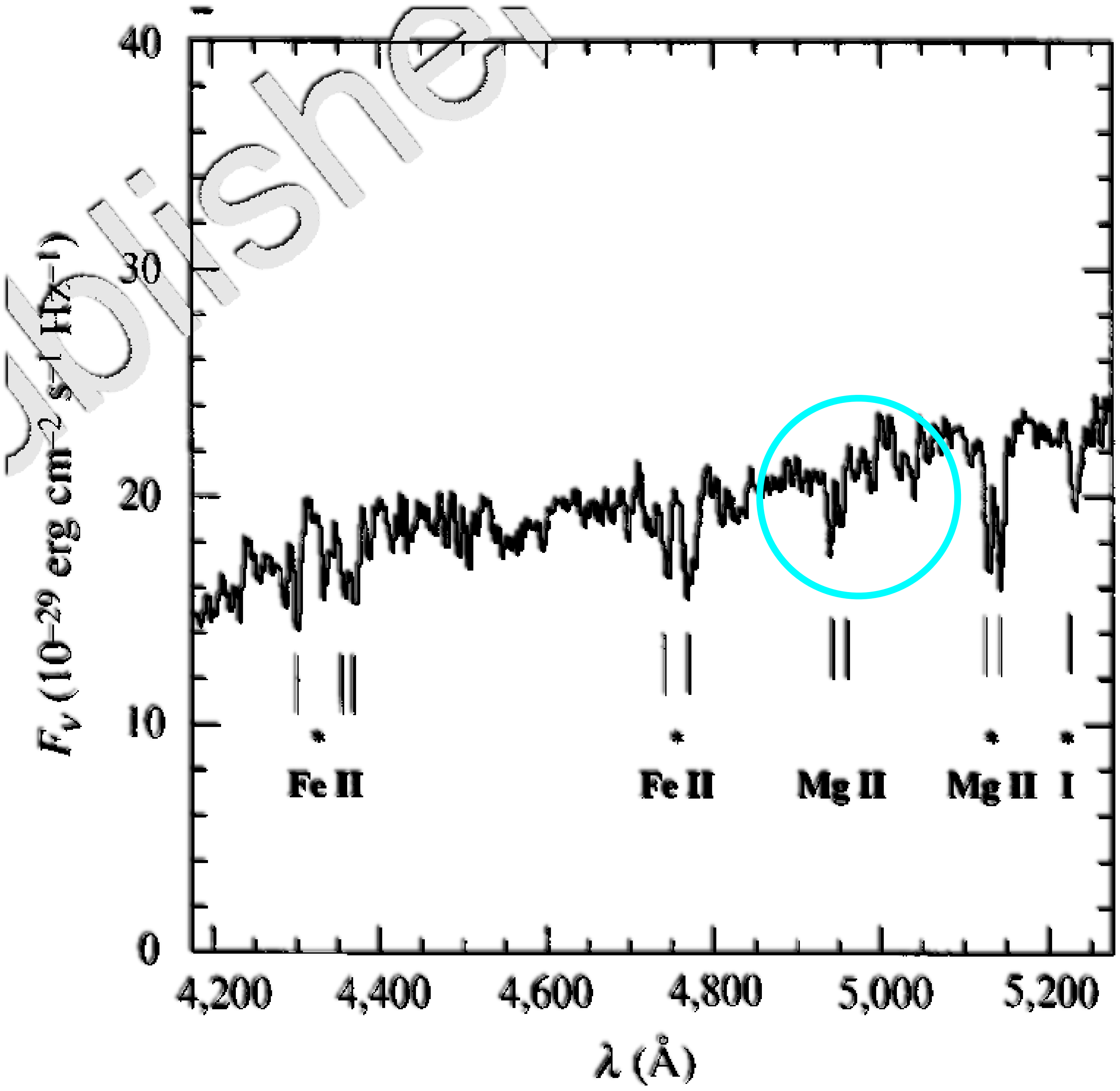
- Intervening MgII
  - Easy to identify
    - Even with low-res data
  - Limited to large EW systems in many cases



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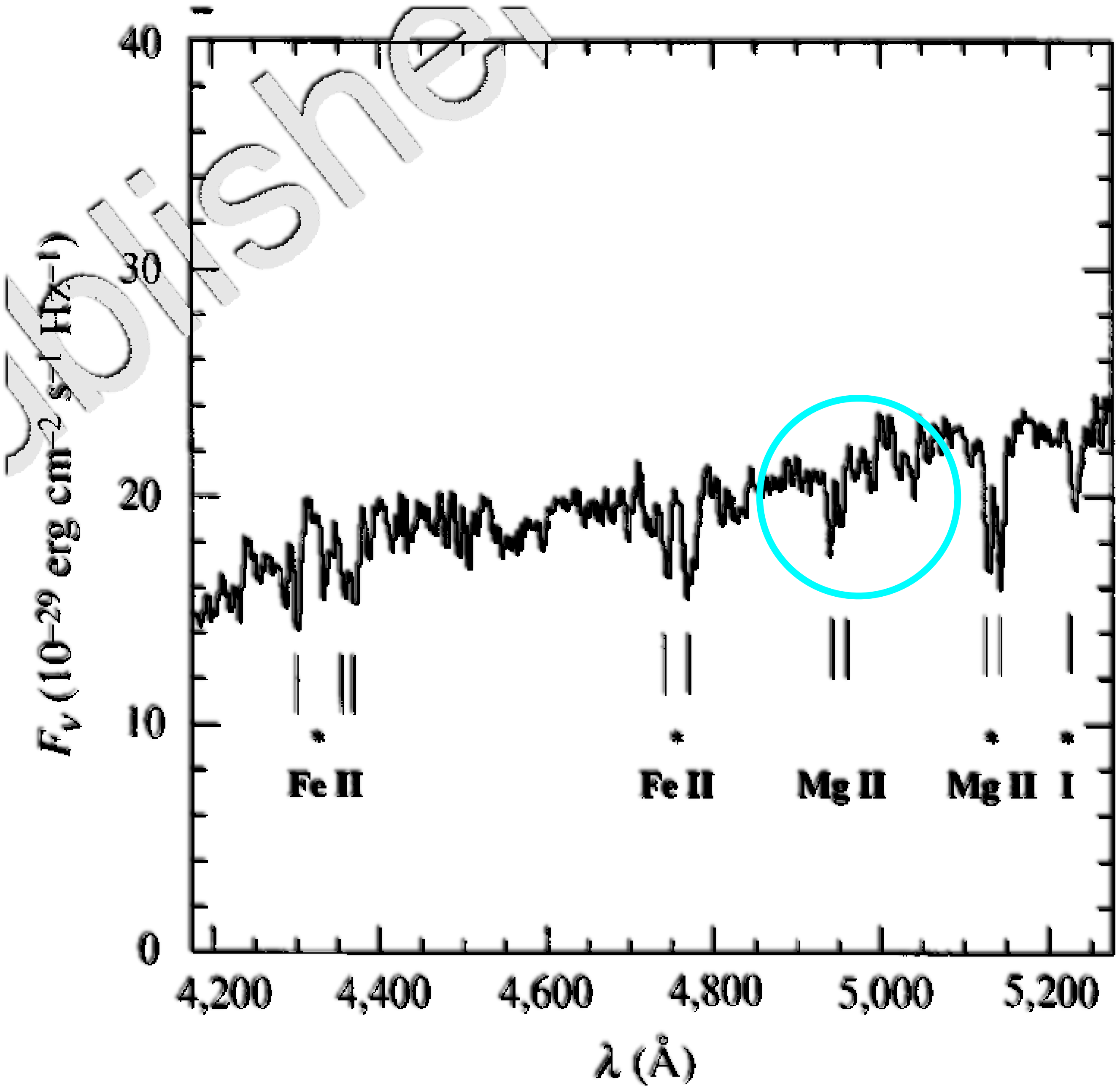
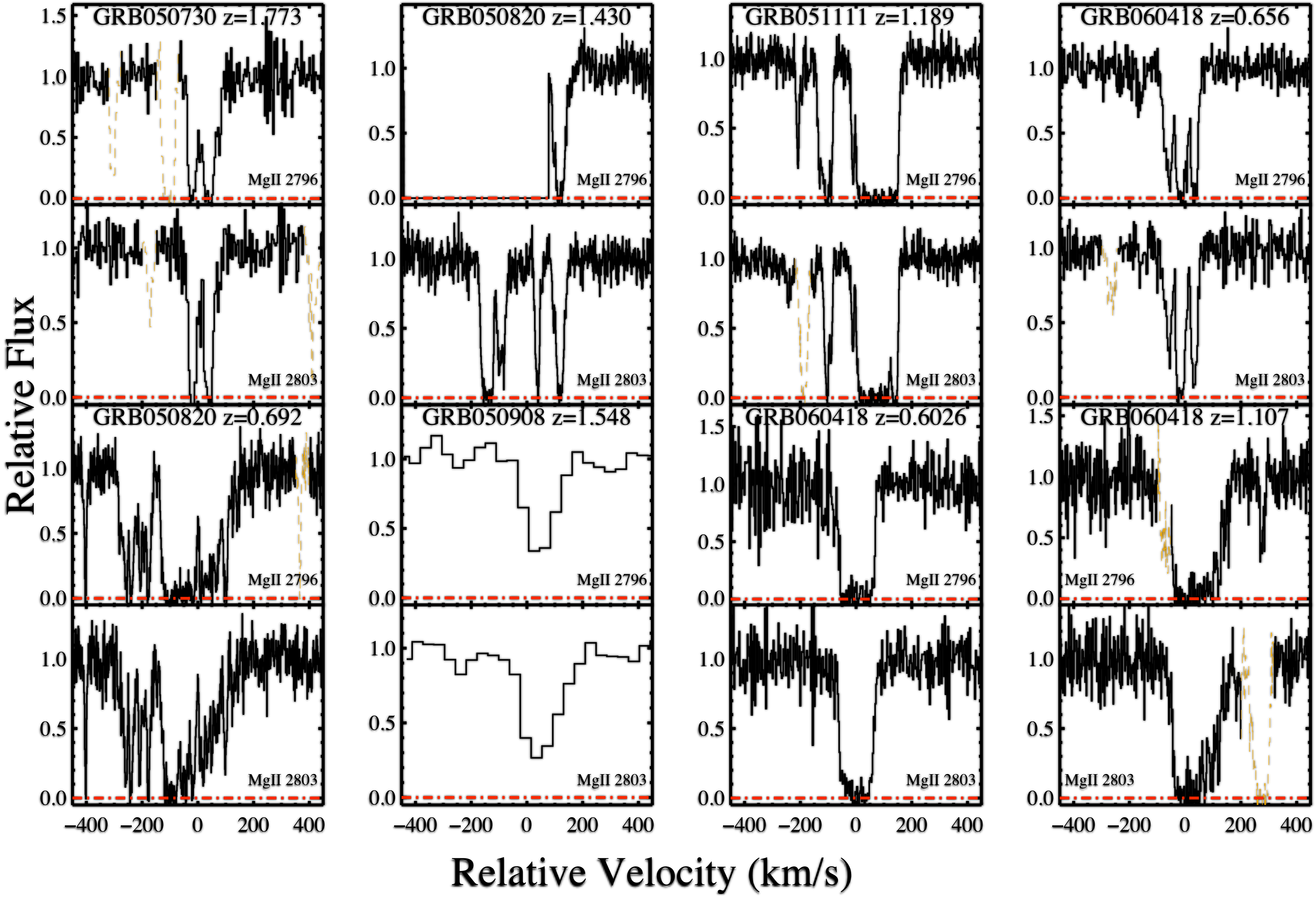
- GRB 970508
  - Even an example in the first optical spectrum



GRAASP Swift Sample



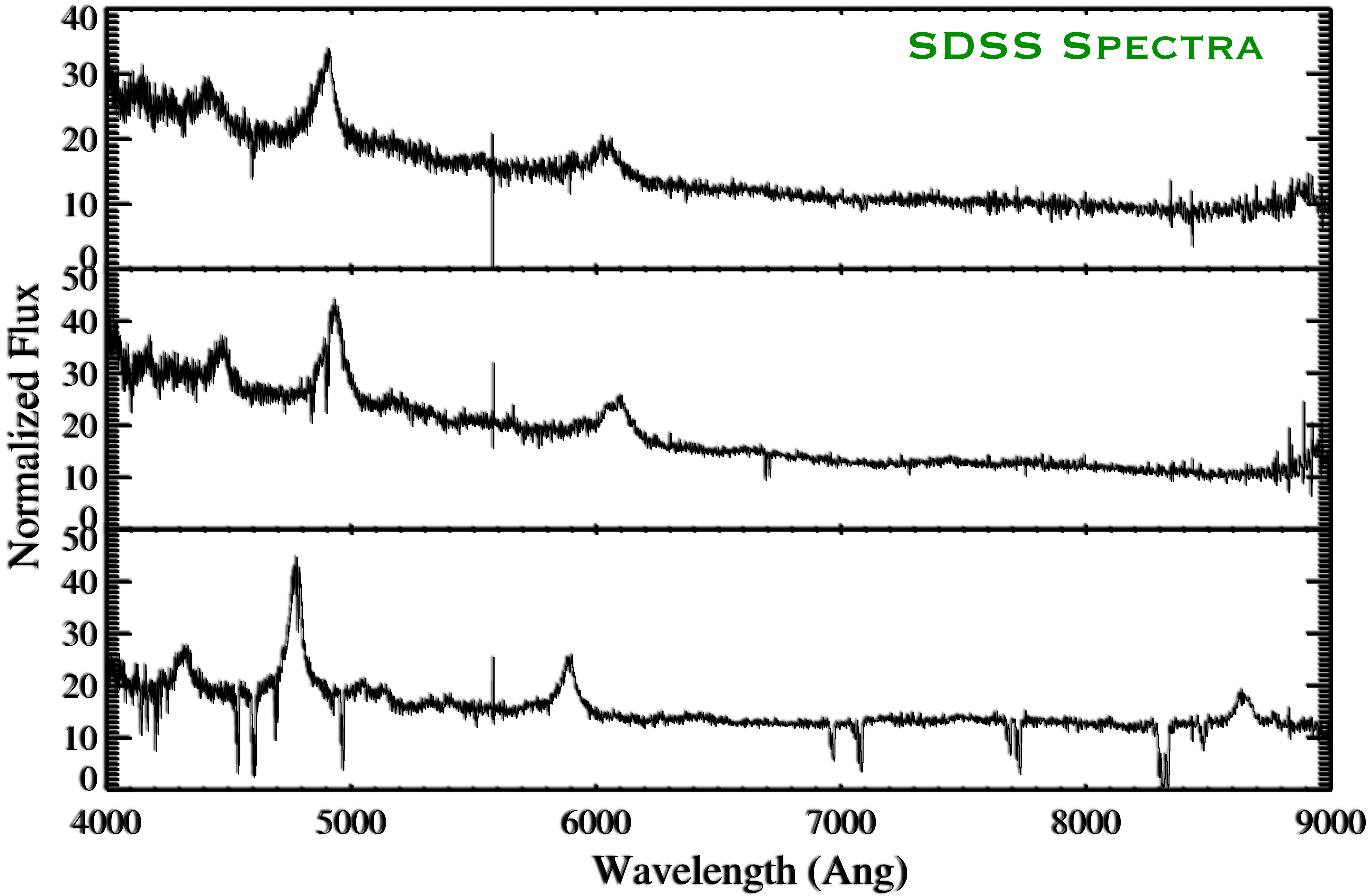
Prochter+06

GRB MgII Sample

Table 1. Survey Data for Mg II Absorbers Along GRB Sightlines

GRB	z_{GRB}	z_{start}	z_{end}	z_{abs}	W_r(2796 Å)	Δv (km s^{-1})	Reference
$W_r(2796) \geq 1$ Å Mg II Statistical Sample							
000926	2.038	0.616	2.0				8
010222	1.477	0.430	1.460	0.927	1.00 ± 0.14	74,000	1
				1.156	2.49 ± 0.08	41,000	
011211	2.142	0.359	2.0				2
020405	0.695	0.359	0.684	0.472	1.1 ± 0.3	65,000	11
020813	1.255	0.359	1.240	1.224	1.67 ± 0.02	4,000	3
021004	2.328	0.359	2.0	1.380	1.81 ± 0.3	97,000	4
				1.602	1.53 ± 0.3	72,000	
030226	1.986	0.359	1.966				
030323	3.372	0.824	1.646				7
050505	4.275	1.414	2.0	1.695	1.98	176,000	6
050730	3.97	1.194	2.0				
050820	2.6147	0.359	1.850	0.692	2.877 ± 0.021	192,000	
				1.430	1.222 ± 0.036	113,000	
050908	3.35	0.814	2.0	1.548	1.336 ± 0.107	147,000	
051111	1.55	0.488	1.533	1.190	1.599 ± 0.007	45,000	
060418	1.49	0.359	1.473	0.603	1.251 ± 0.019	124,000	
				0.656	1.036 ± 0.012	116,000	
				1.107	1.876 ± 0.023	50,000	

MgII Search in QSO Spectra



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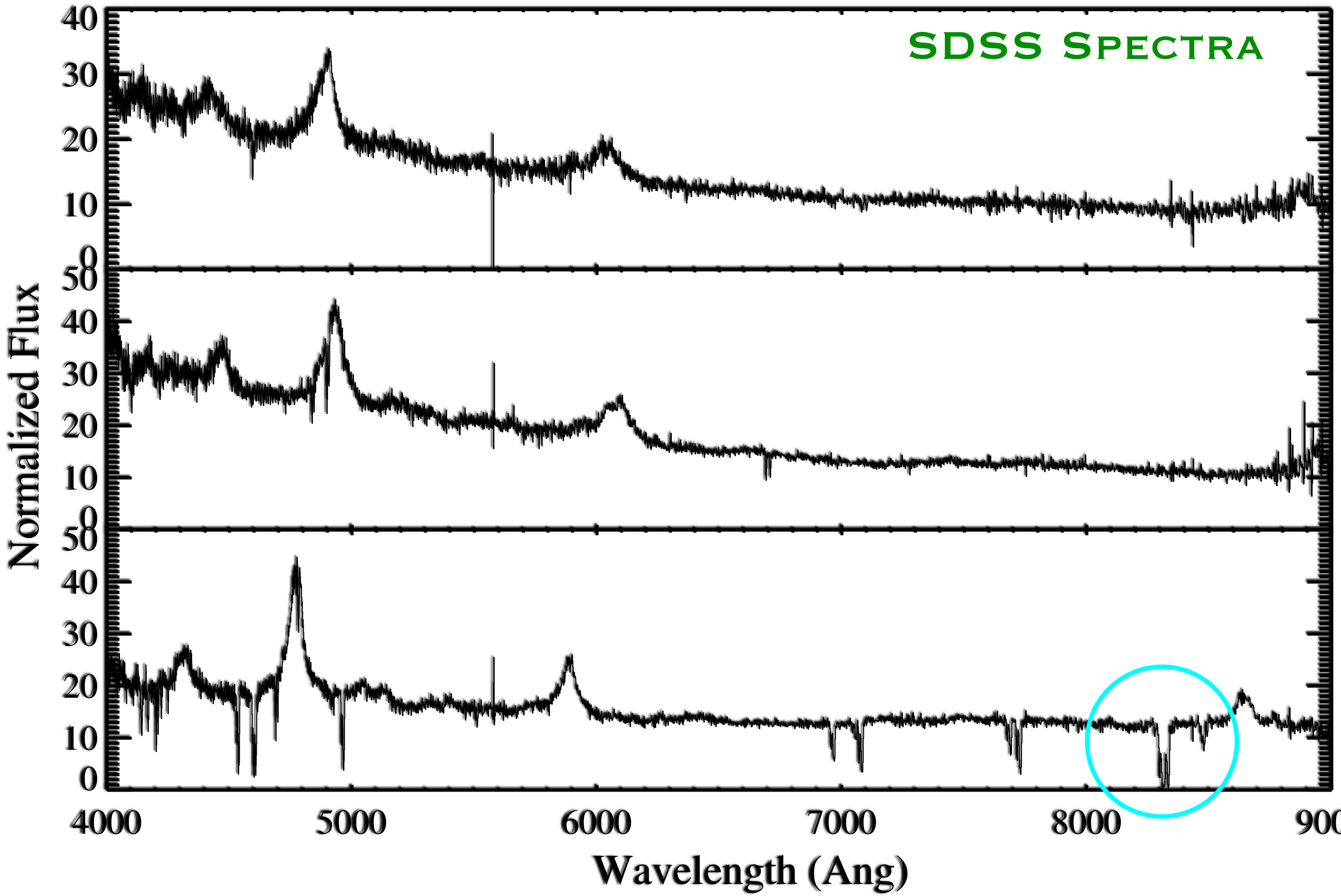

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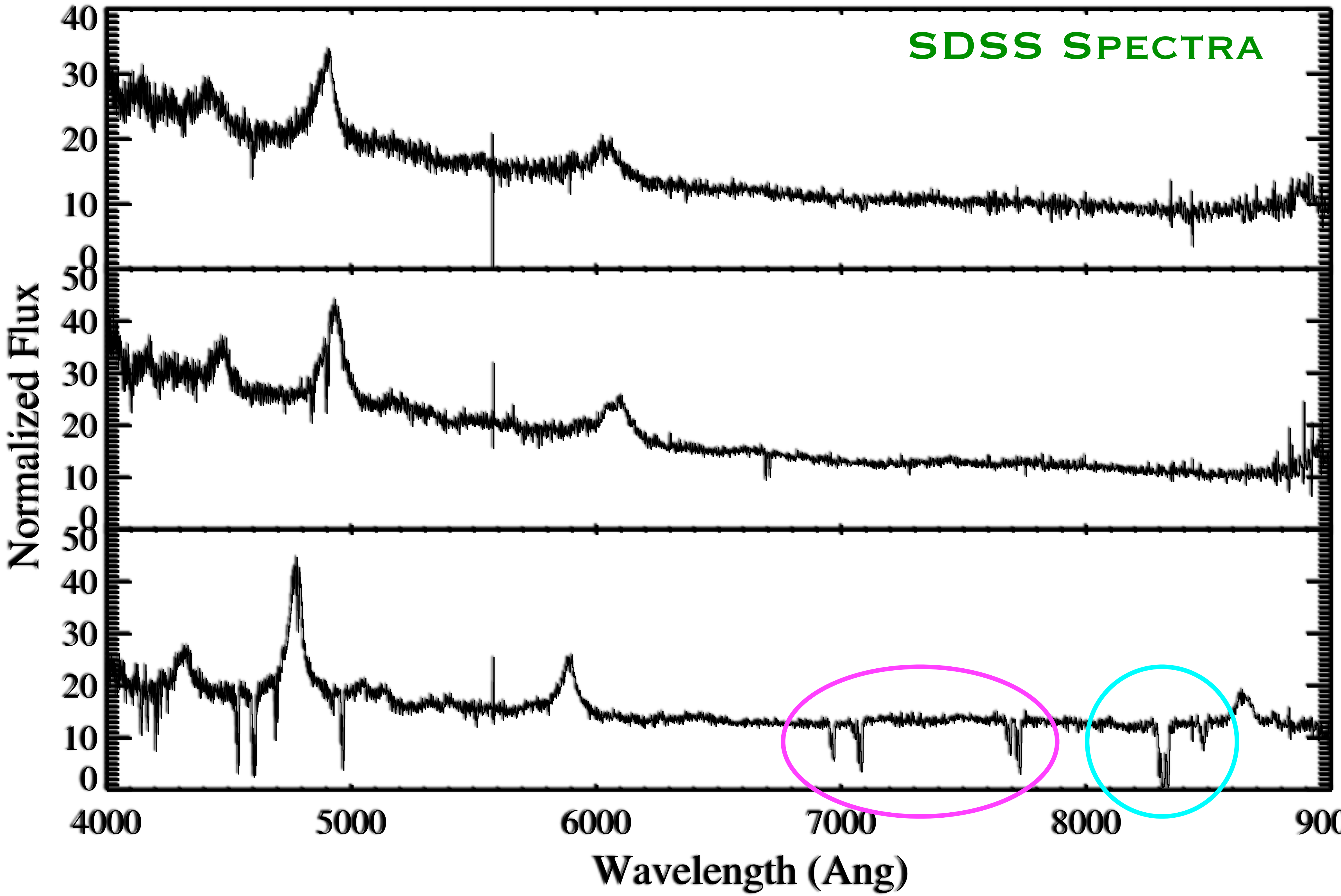
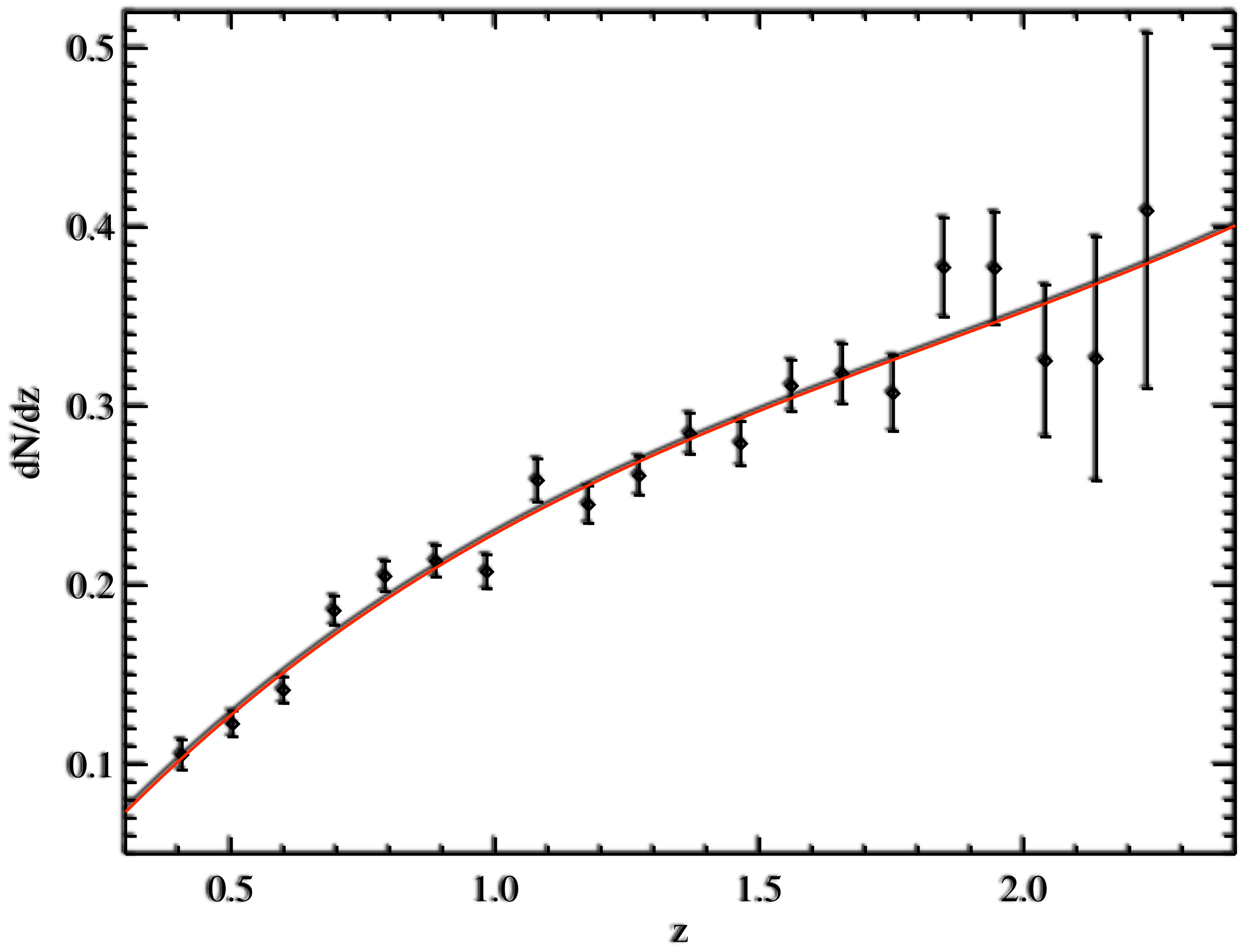


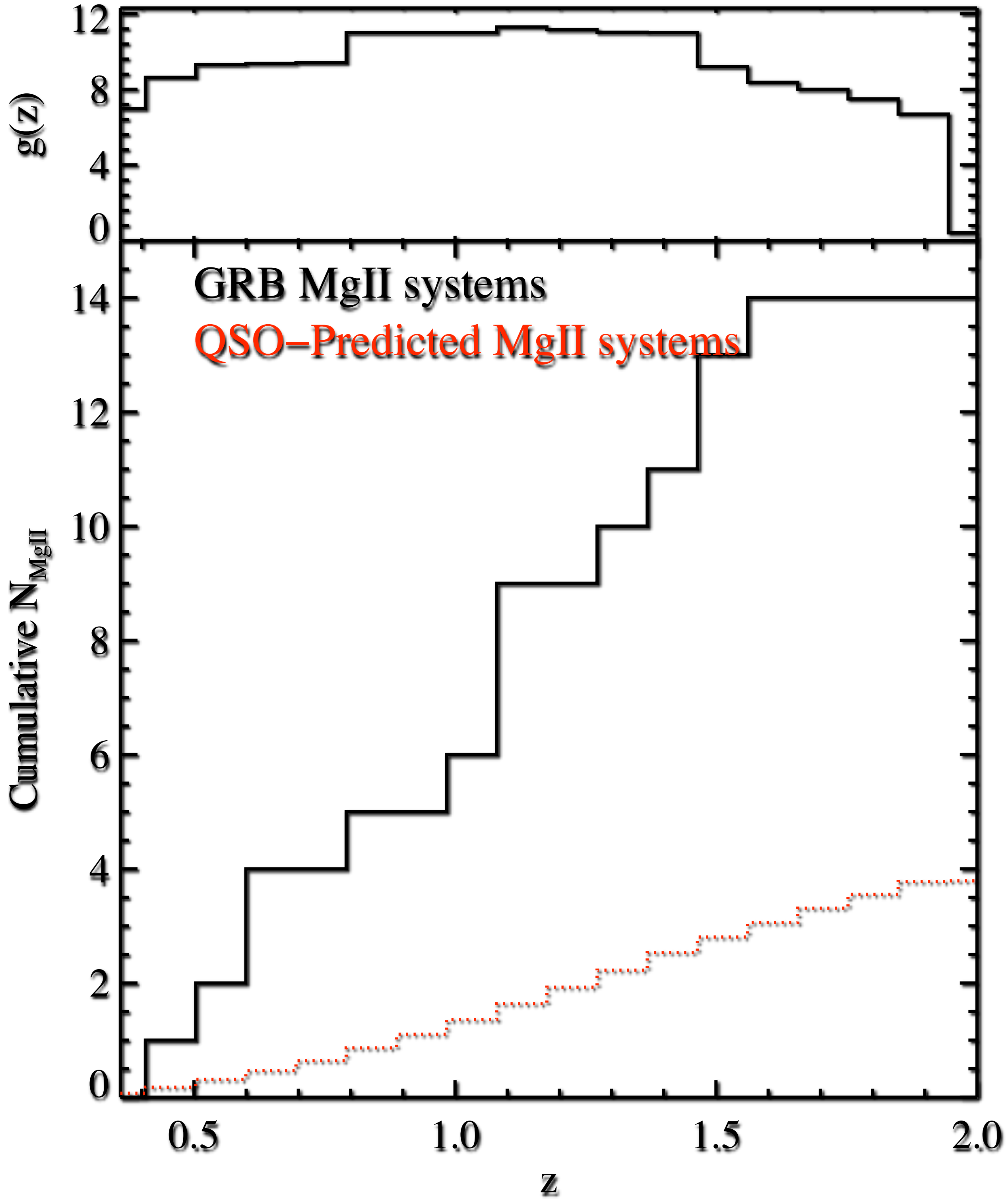
dN/dz of MgII

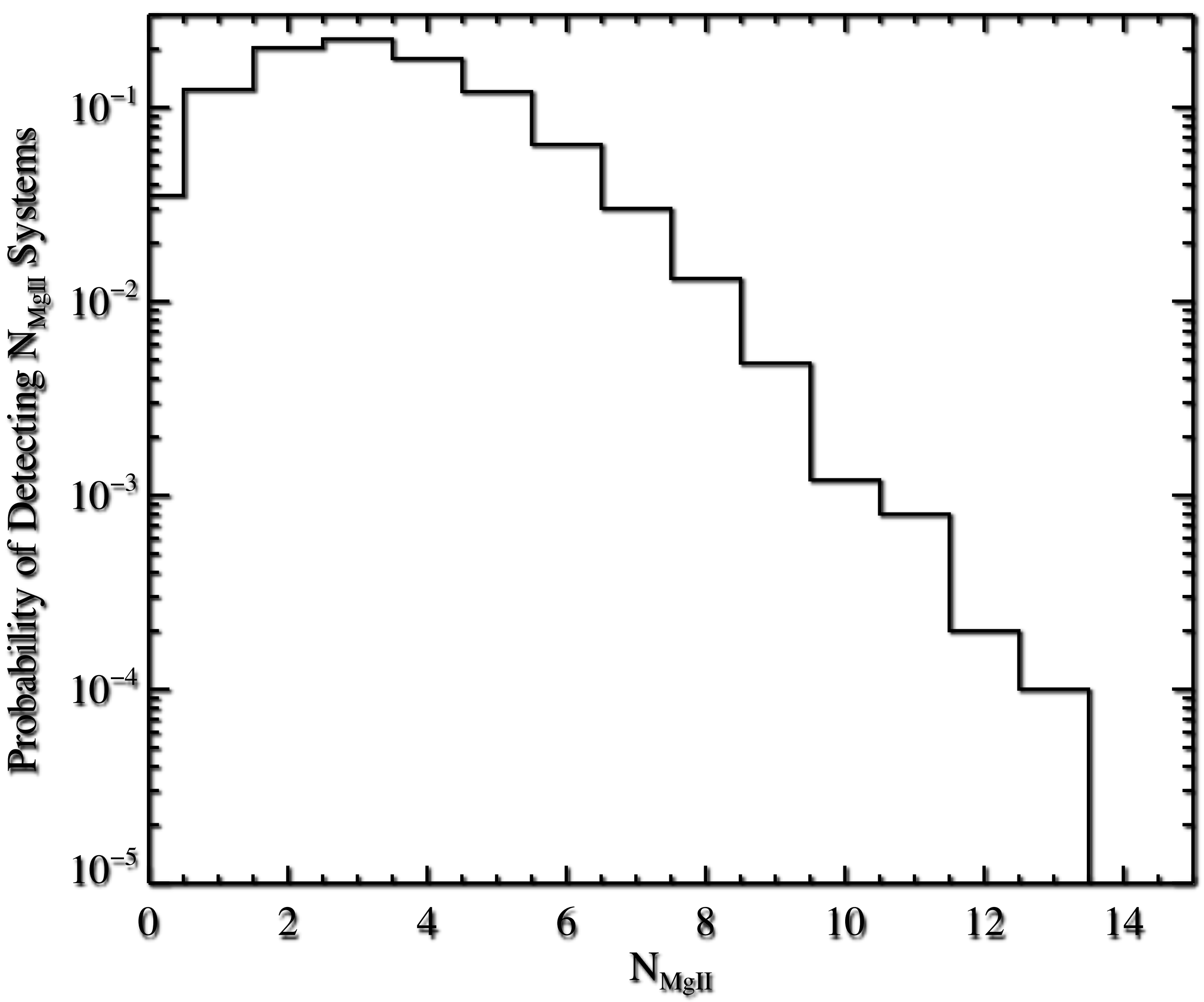
- *dN/dz*
  - Number of absorbers per unit redshift
  - Roughly, 1 QSO has 1 unit of redshift coverage
- SDSS
  - 20,000 quasars with sufficient SNR
    - Automatically identify 10,000 MgII systems
    - Stat sample is 7000 with Rest EW > 1A



Prochter+07

Comparing: Higher incidence to GRBs!



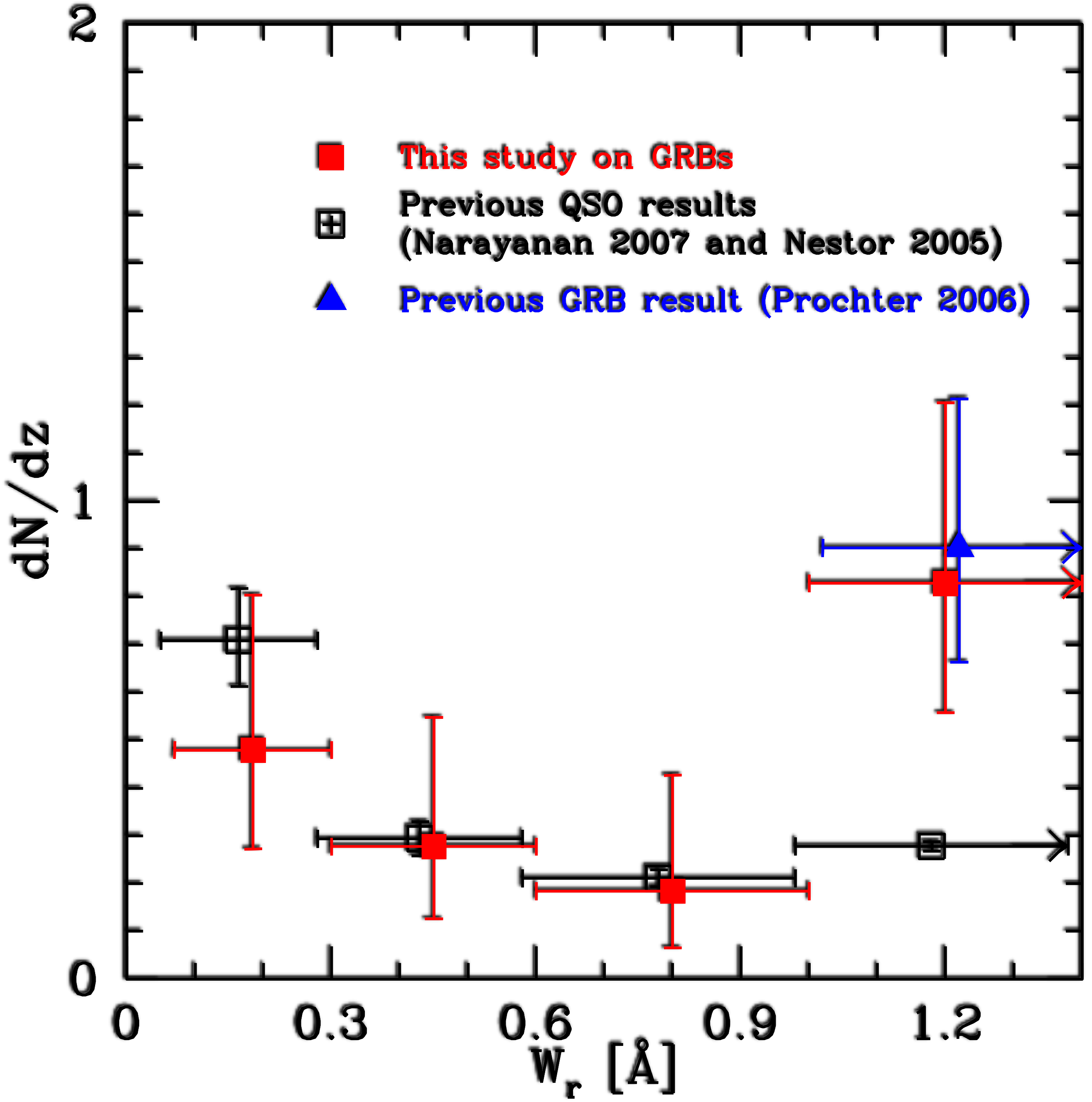


Chance result?
Less than 1 in 10,000

Also see Vergani+09

Other clues...

- C IV systems
  - More highly ionized gas
  - No enhancement observed
- Weak MgII systems
  - Also not enhanced
- More recent studies
  - Enhancement is still there
  - But not as strong as originally
    - Vergani+09



Tejos+07,09
Sudilovsky+07
Vergani+09

Possible Explanations

Prochter+06
Frank+06
Menard+07
Porciani+07
Pontzen+07
Tejos+07
Sudilovsky+07
Cucchiara+08
Pollack+08
Sudilovsky+09
Chen+09
Tejos+09
Vergani+09
Wythe+10

Possible Explanations

- Dust obscuration? No
  - MgII absorbers contain dust
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  - But, dust content is low
    - Effect is small

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  - MgI detections rules this out
  - Galaxies have been identified

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  - One MgII per sightline
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  - But, flux counts are flat

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- Beam size? Not likely
  - No partial covering observed
  - No difference in QSO emission lines

Prochter+06
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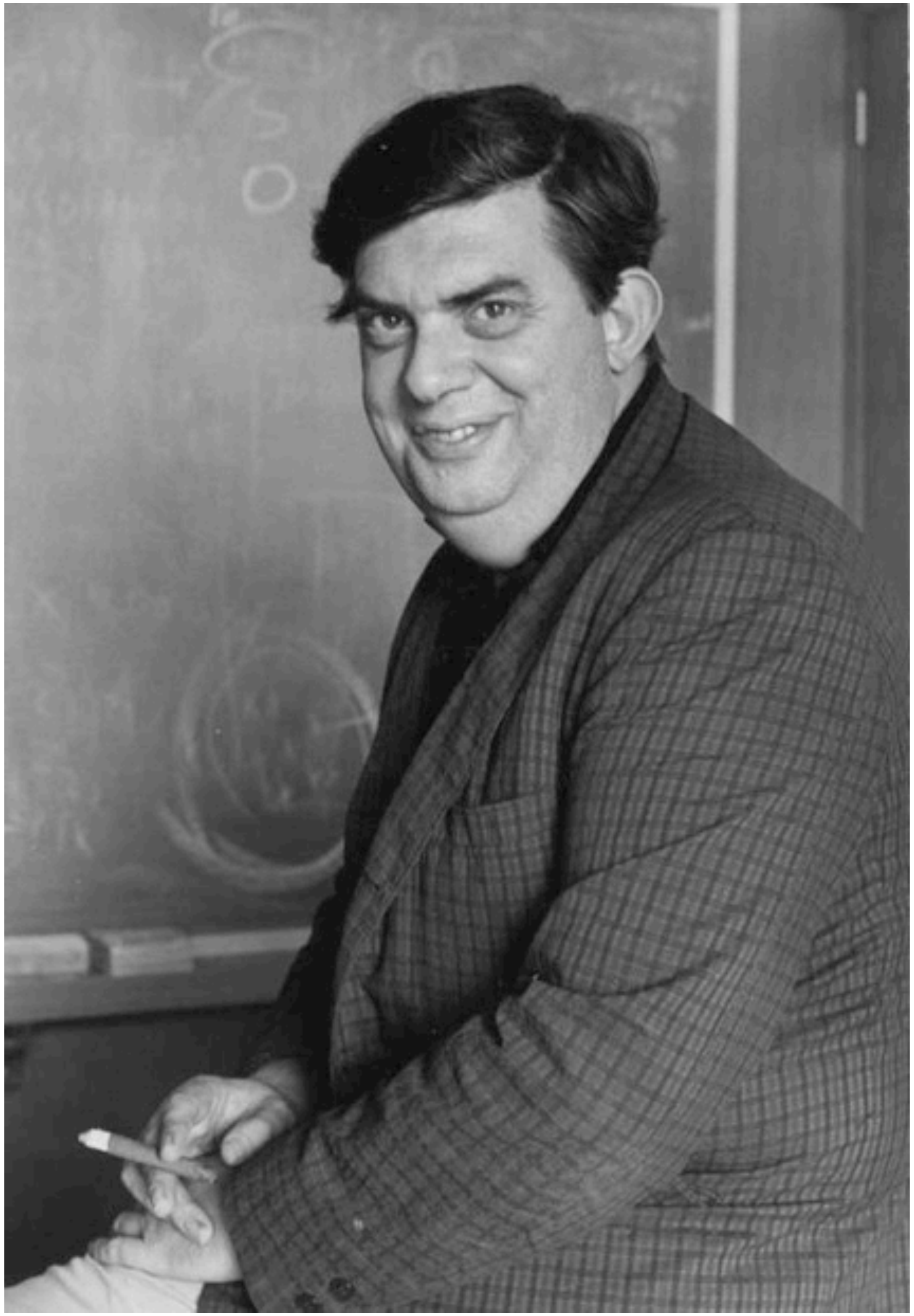
Spooky First Result from the IGM



Some Open Questions (that puzzle me):

- How do the absorption-line abundances compare to the emission lines?
- Why do X-Ray absorption measurements often show higher metal column densities?
- Is gray dust really required in some (many?) GRB sightlines?
- Is this spooky MgII enhancement real? If so how?
- What is the origin of the events with very low N_{HI}?
- Why is there such a larger dispersion of metallicities?
- Is there a way to probe the progenitor environment (<10pc)?