RFI Response Summaries

6 Rapid Science Summaries

Topic: Intergalactic Medium

Todd Tripp

Steve McCandliss

Mike Shull

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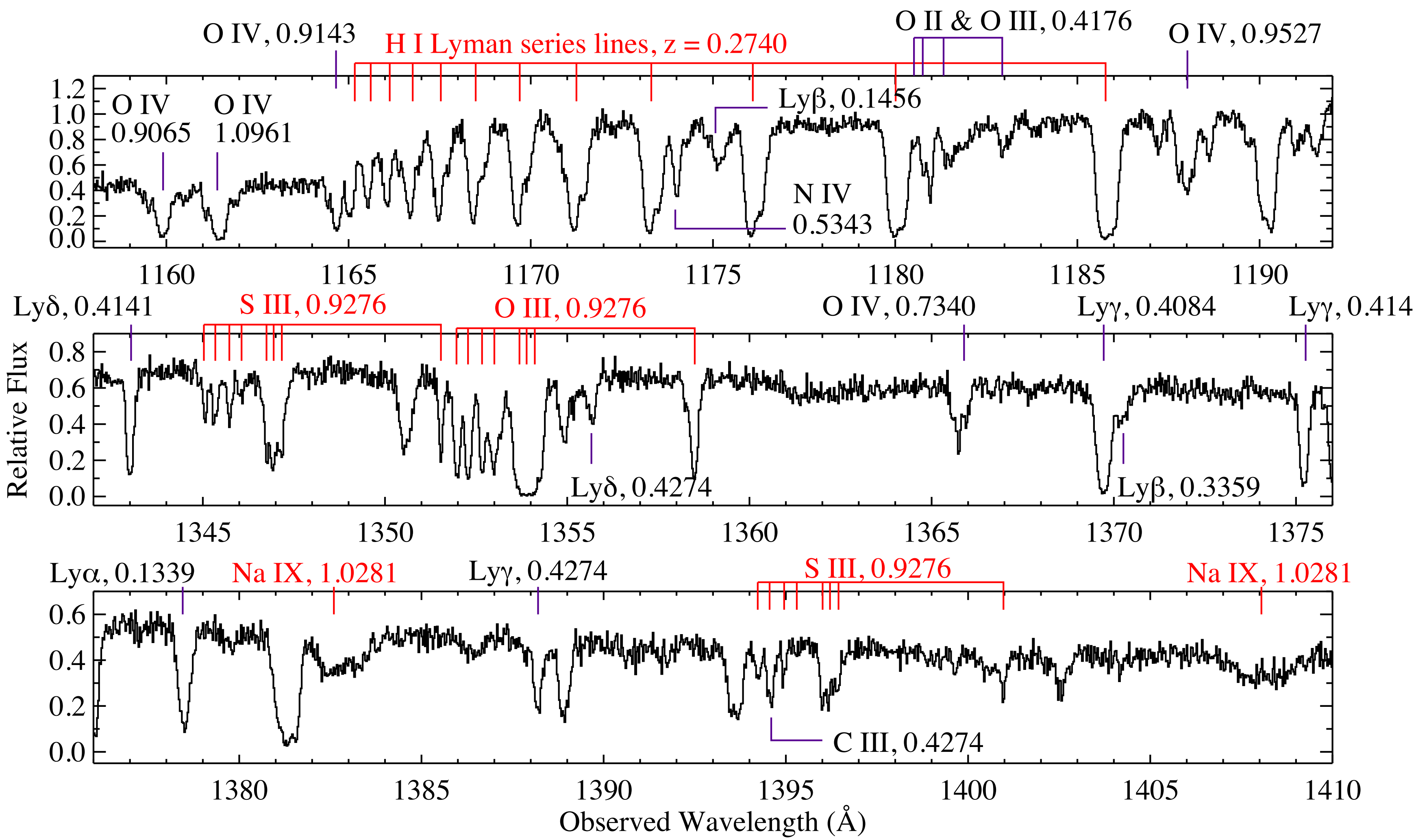
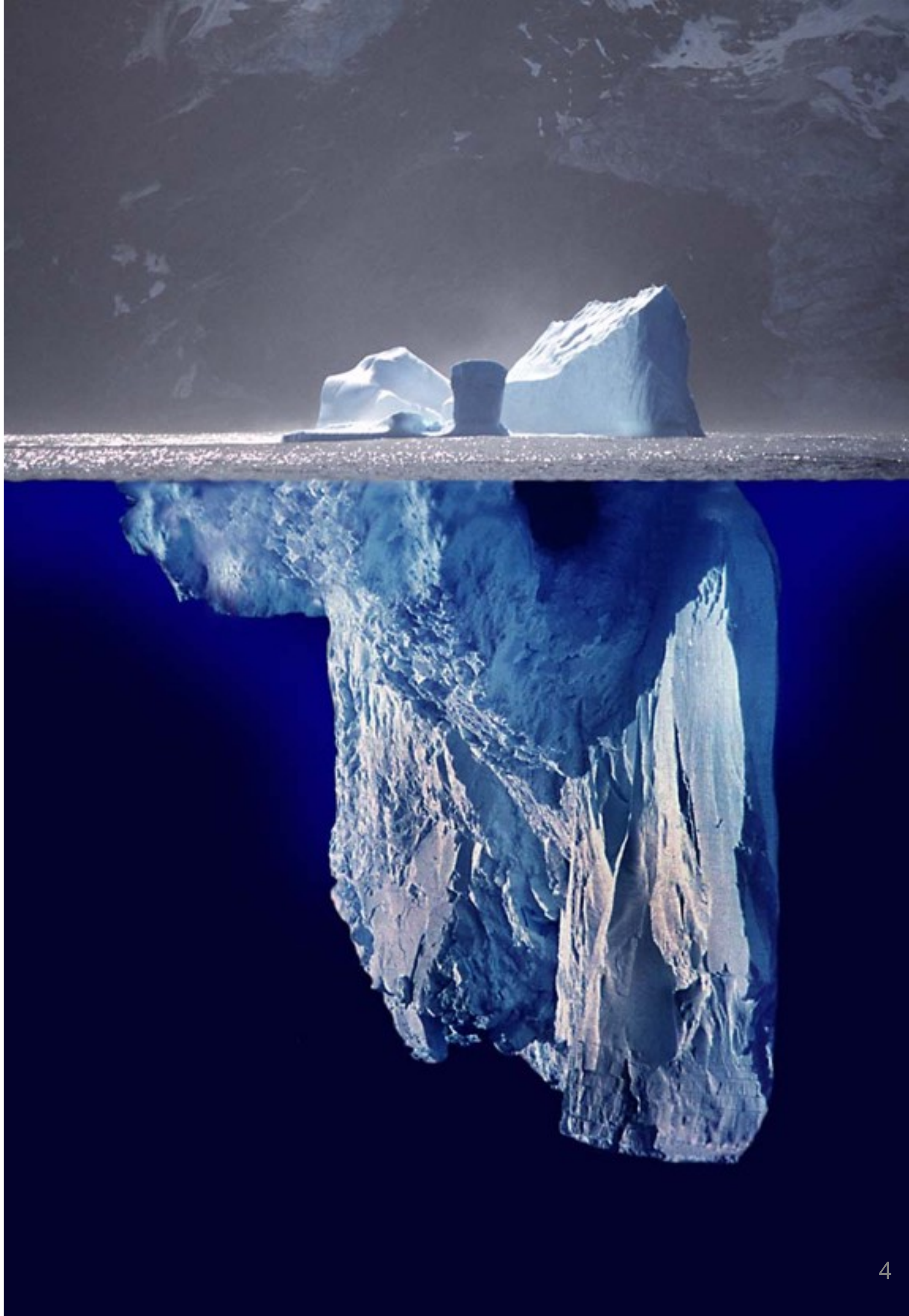
QSO Absorption Lines in the Far Ultraviolet: An Untapped Gold Mine for Galaxy Evolution Studies

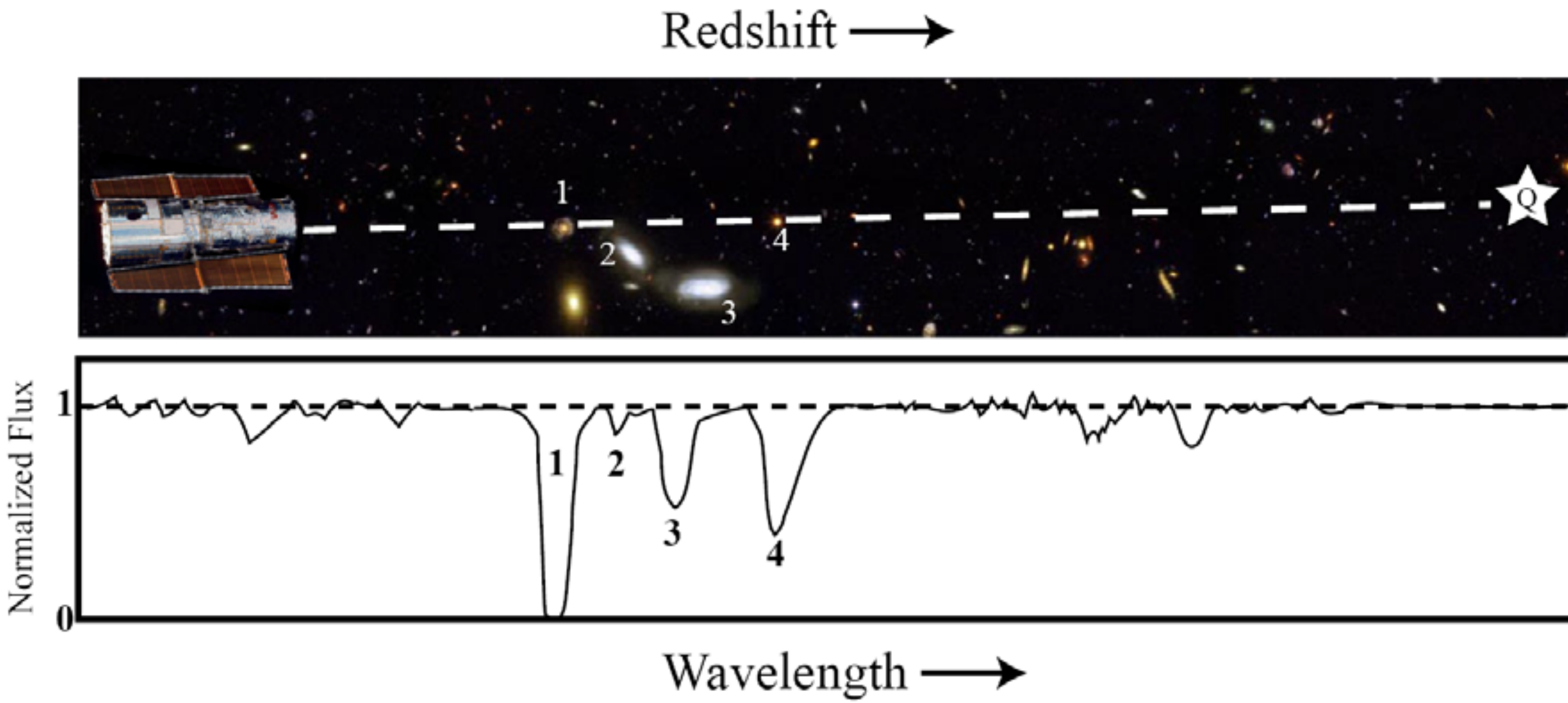
Todd Tripp (University of Massachusetts)



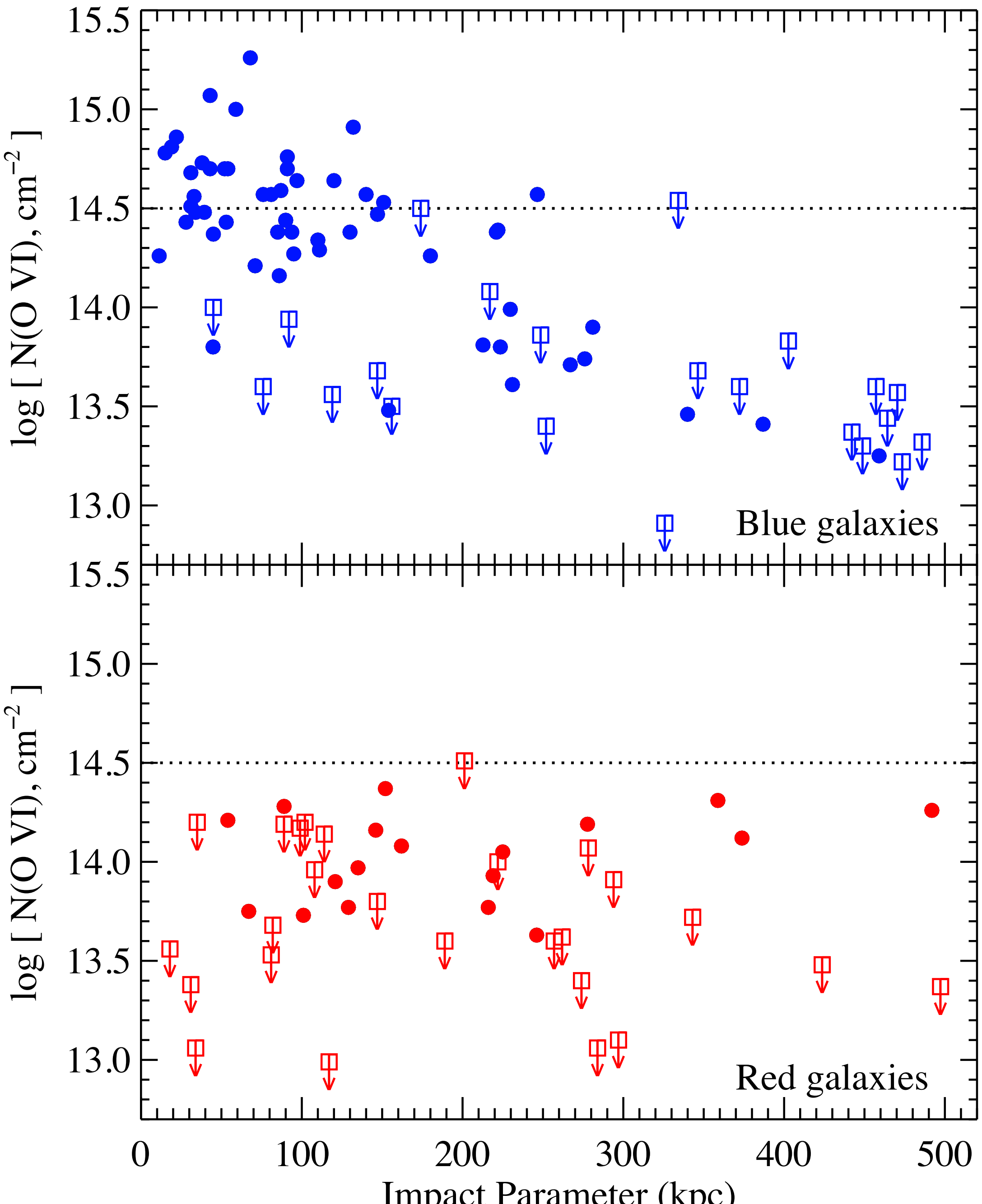
The problem: most of the ordinary (baryonic) matter in the Universe is very difficult to detect. Stars account for ≈ 10% of the baryonic material expected in a typical galaxy (e.g., Bell et al. 2003). **These missing baryons play crucial roles in galaxy evolution.**



The solution: use QSO absorption lines to probe the missing 90% of the matter!



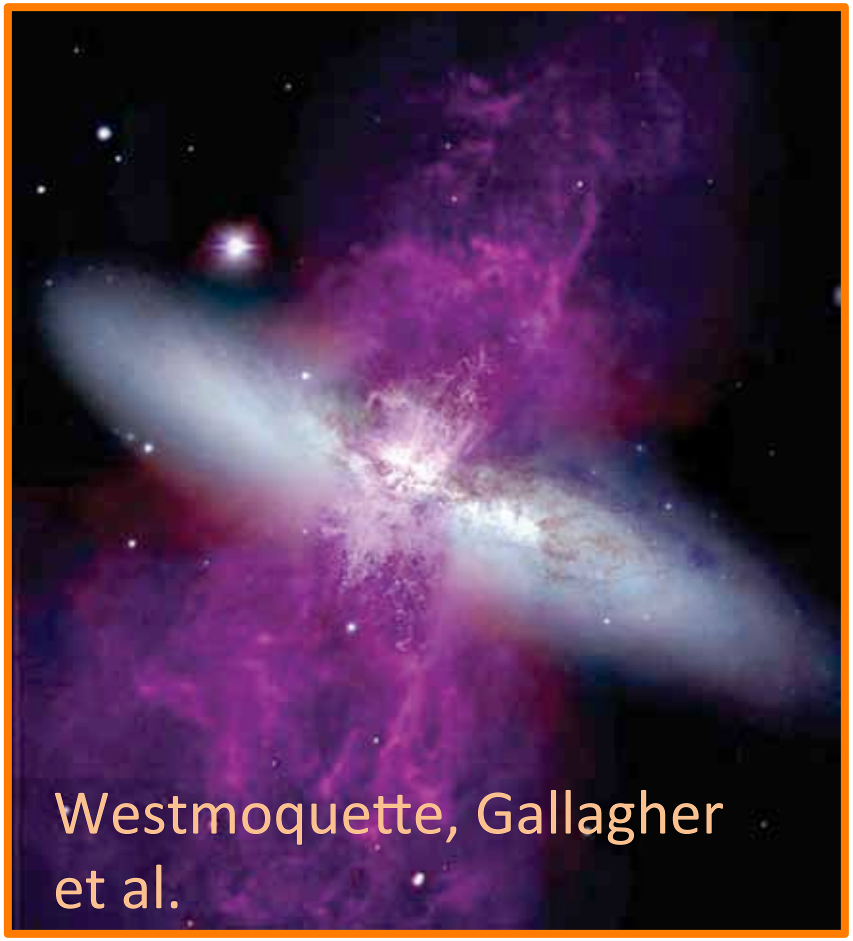
The challenge: to understand how the QSO absorption lines connect to the bigger picture, the useful lines to observed are predominantly in the ultraviolet.

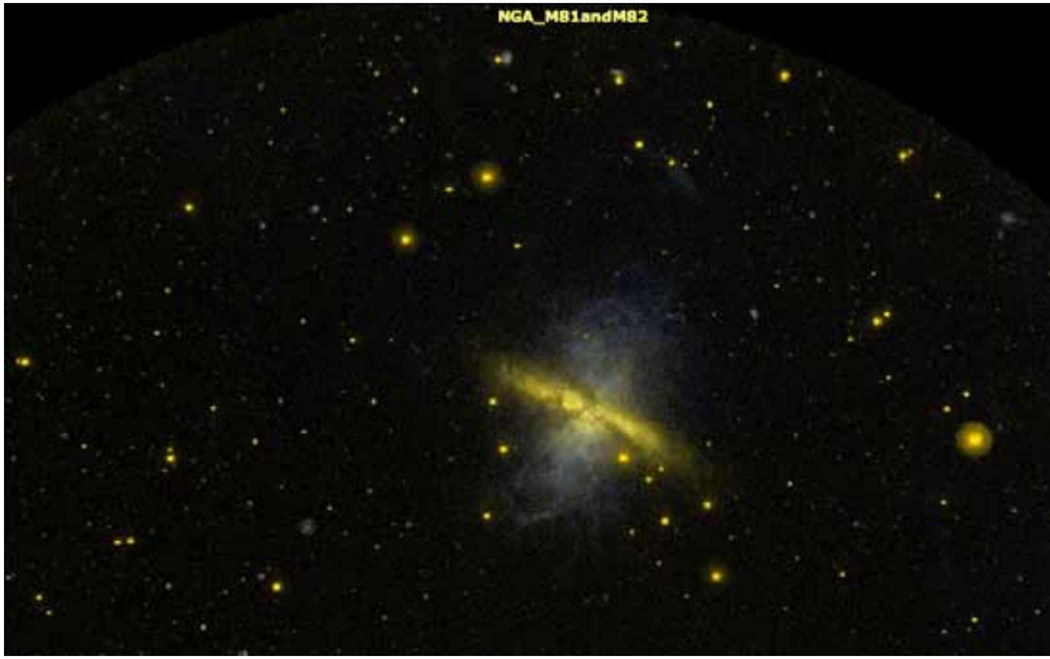


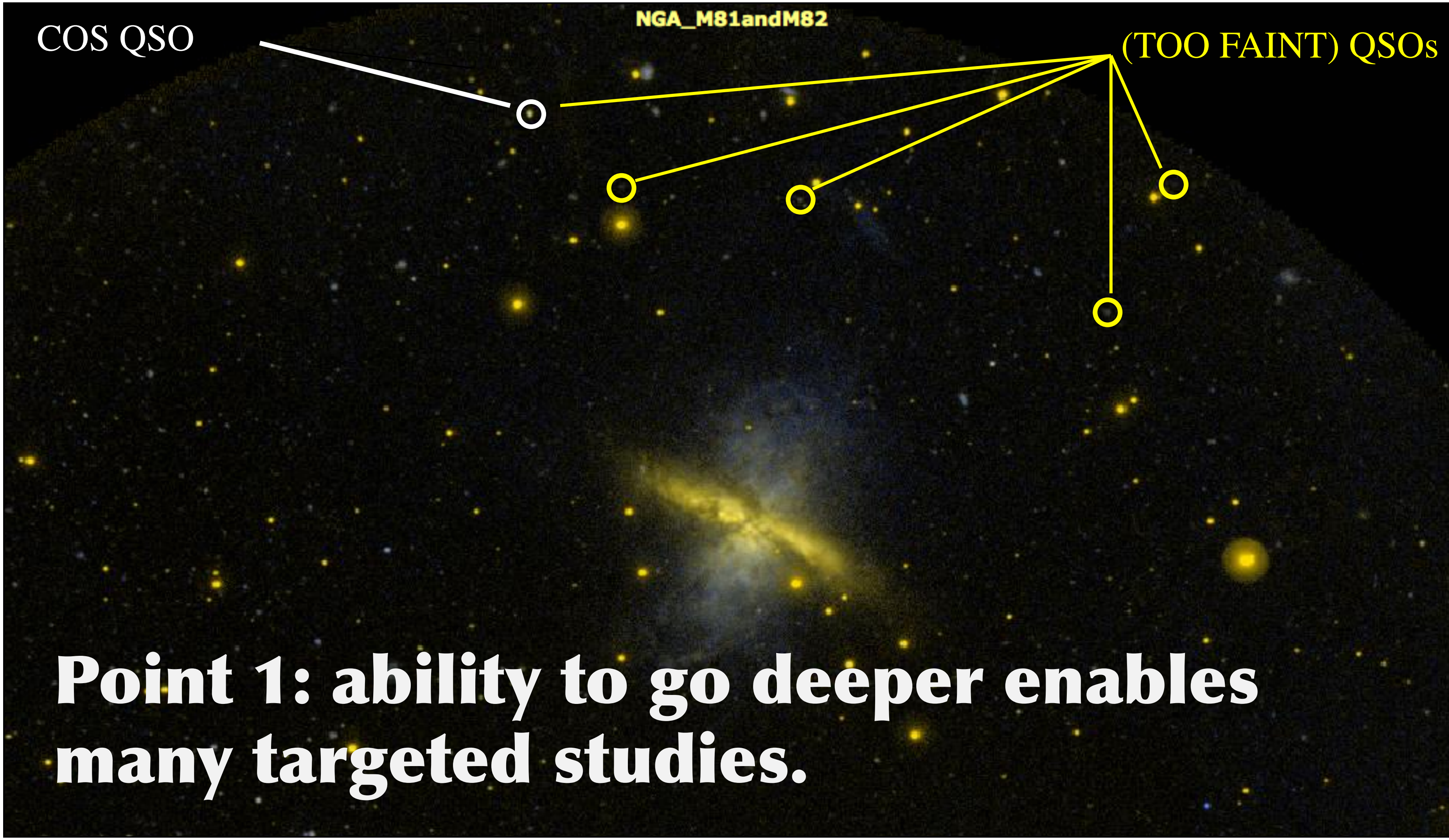
What has been done already?

- N(OVI) vs. impact from COS-Halos + CASBaH + Prochaska et al. (2011) + Chen & Mulchaey (2009)
- Kendall test, adapted to account for upper limits (a la Brown, Hollander, & Korwar 1974):
  - Blue galaxy null hypothesis probability < 0.0001
  - Red galaxy null hypothesis probability = 0.3751

The problem(s) with the solution: many QSOs can be found behind targets of interest, but they are usually too faint for current facilities.

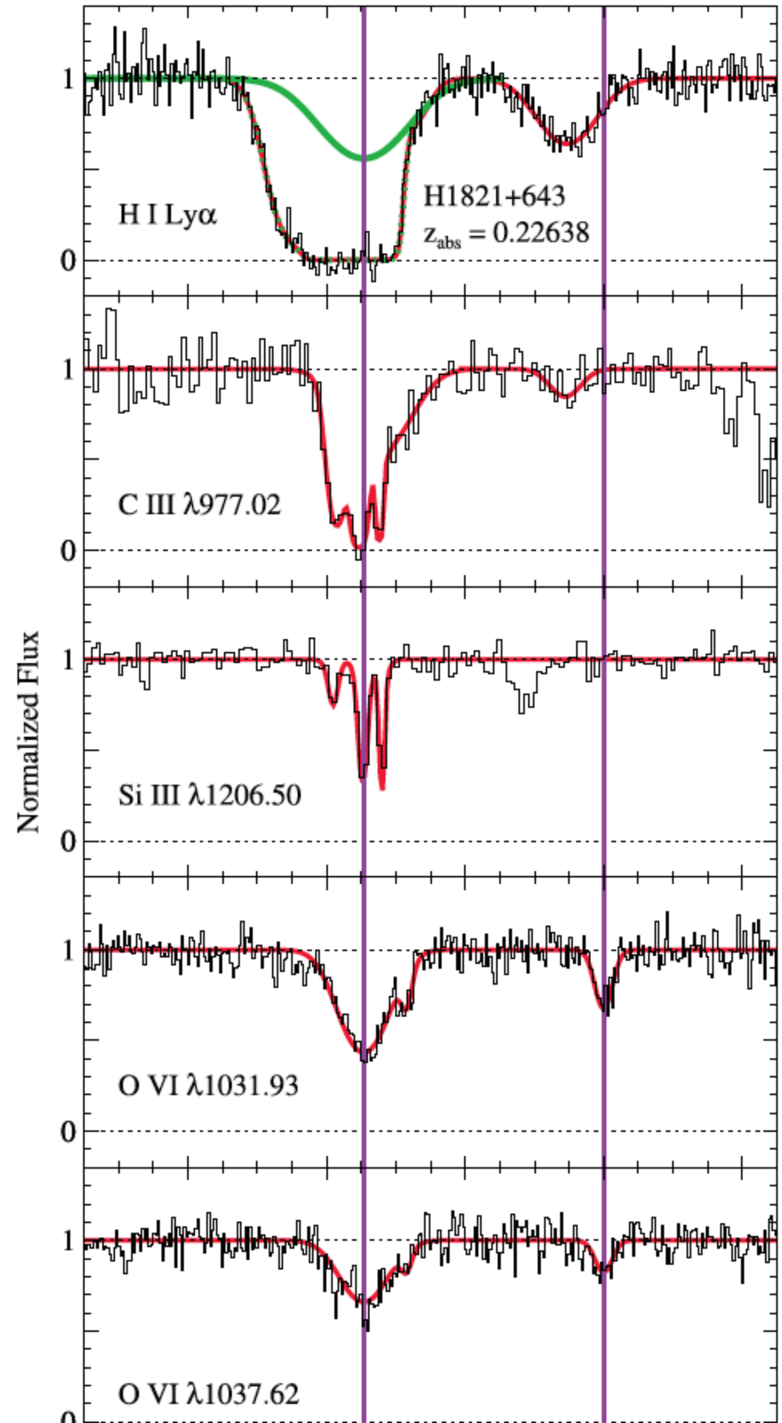

Westmoquette, Gallagher et al.



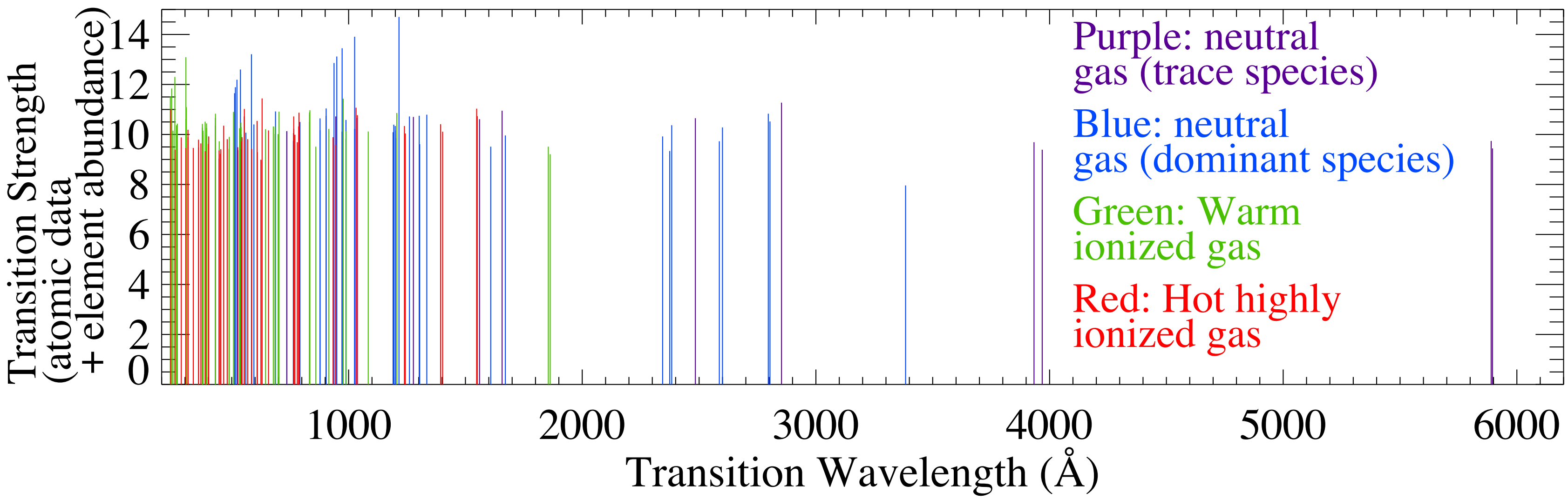

COS QSO
NGA_M81andM82
(TOO FAINT) QSOs
Point 1: ability to go deeper enables many targeted studies.

The problem(s) with the solution: the typically detected absorption lines do not yield unambiguous results.

Point 2: again, ability to go deeper, and to obtain higher S/N, can solve this problem.

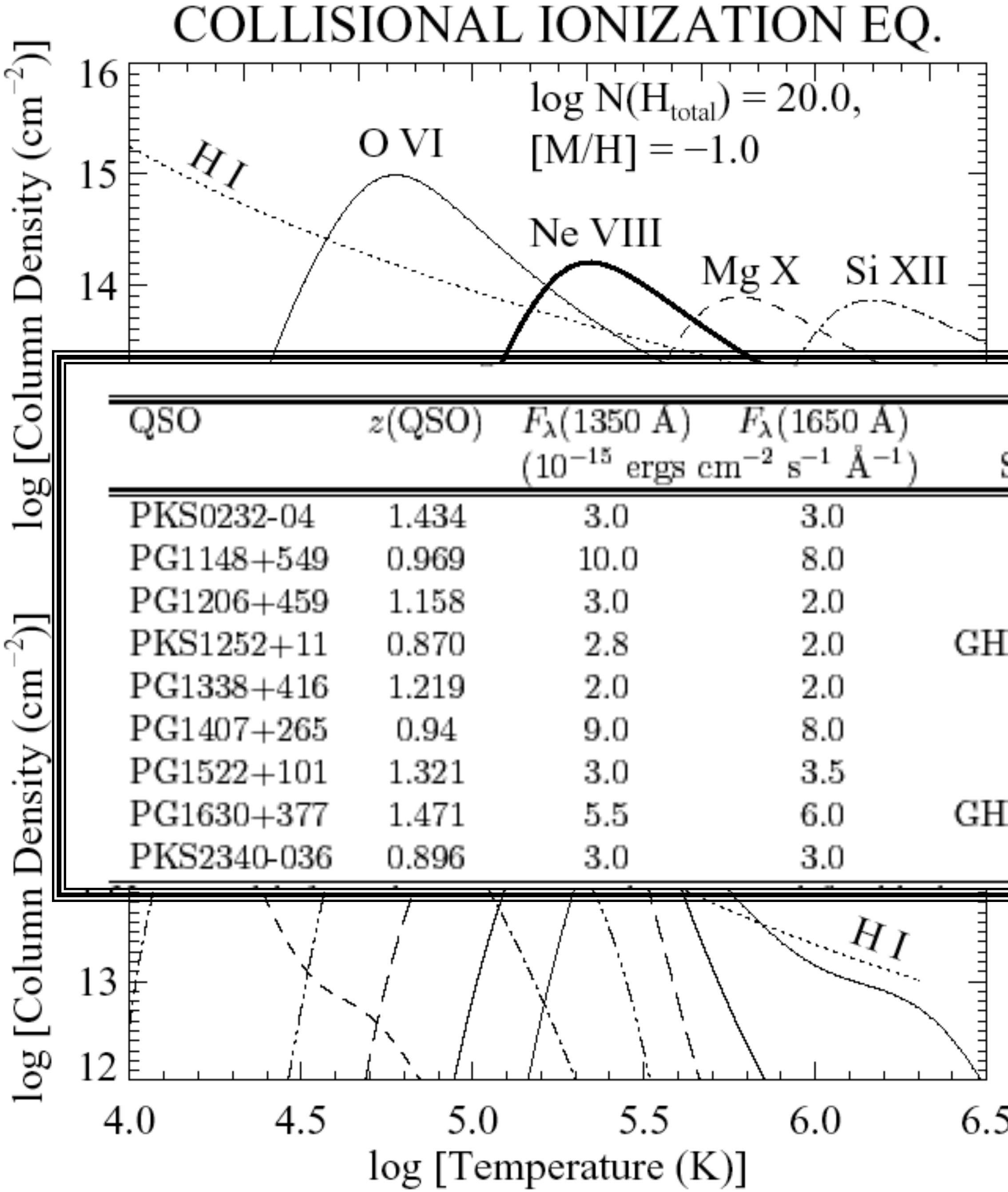


A New Discovery Space: The Extreme UV



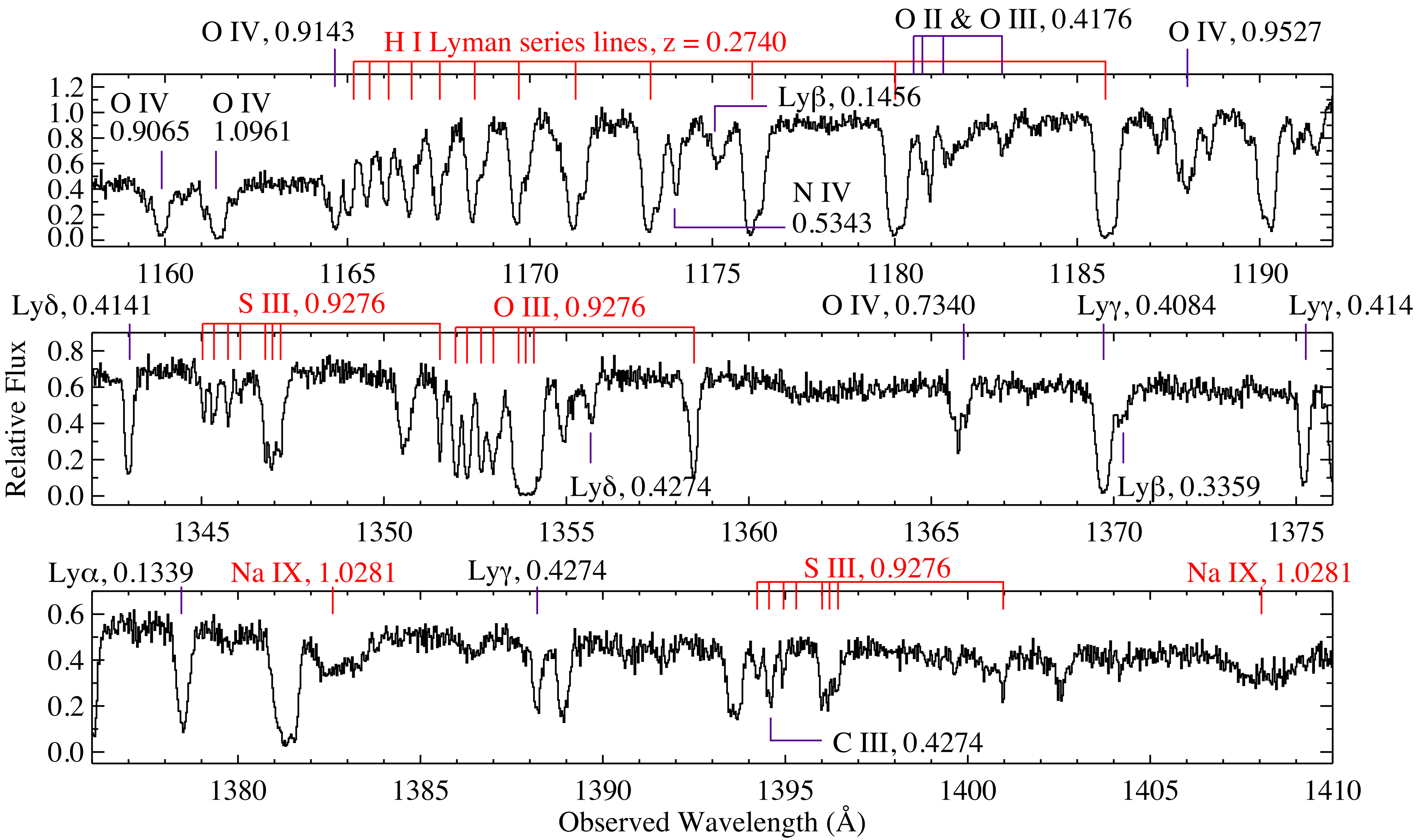
The high density of lines in the EUV provides an Extraordinary array of gas diagnostics.

Diagnostic Power of the Extreme UV



QSO	z(QSO)	F_λ(1350 Å)	F_λ(1650 Å)	Flux Source	Total path Δz O VI	Total path Δz Ne VIII	Total path Δz Mg X
		(10^{-15} ergs cm^{-2} s^{-1} Å^{-1})					
PKS0232-04	1.434	3.0	3.0	FOS	0.607	0.784	0.488
PG1148+549	0.969	10.0	8.0	FOS	0.607	0.448	0.052
PG1206+459	1.158	3.0	2.0	FOS	0.607	0.638	0.212
PKS1252+11	0.870	2.8	2.0	GHRS+FOS	0.607	0.349	...
PG1338+416	1.219	2.0	2.0	FOS	0.607	0.700	0.275
PG1407+265	0.94	9.0	8.0	FOS	0.607	0.419	0.052
PG1522+101	1.321	3.0	3.5	FOS	0.607	0.784	0.375
PG1630+377	1.471	5.5	6.0	GHRS+FOS	0.607	0.784	0.326
PKS2340-036	0.896	3.0	3.0	FOS	0.607	0.375	0.010

What has been done already? (proof of concept)



New facility requirements

- Sensitivity, sensitivity, sensitivity
- **Sensitivity in the ultraviolet, at least down to 1150 Å, preferably down to 1000 or even 912 Å**
- Good spectral resolution: at least as good as COS (R = 20,000). For some problems, R > 100,000 is required.
- Ability to achieve high S/N (i.e., ability to mitigate/remove fixed-pattern noise).

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Project Lyman: Quantifying 11 Gyrs of Metagalactic Ionizing Background Evolution

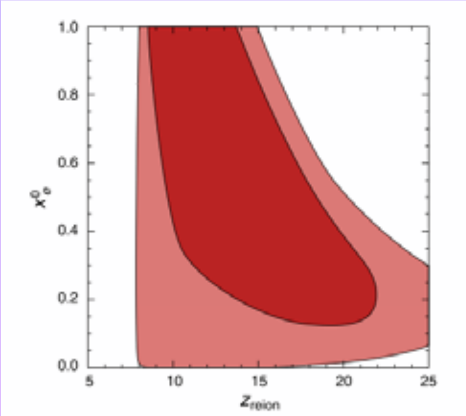
Solving the Mystery of How Did the Universe Come to be Ionized

Stephan R. McCandliss (jhu.edu), B-G Andersson (usra.edu), Nils Bergvall(uu.se), Luciana Bianchi(jhu.edu), Carrie Bridge(caltech.edu), Milan Bogosavljevic (caltech.edu), Seth H. Cohen (asu.edu), Jean-Michel Deharveng (oamp.fr), W. Van Dyke Dixon (jhu.edu), Harry Ferguson (stsci.edu), Peter Friedman (caltech.edu), Matthew Hayes (unige.ch), J. Christopher Howk (nd.edu) Akio Inoue (osaka-sandai.ac.jp), Ikuru Iwata (nao.ac.jp), Mary Elizabeth Kaiser (jhu.edu), Gerard Kriss (stsci.edu), Jeffrey Kruk (nasa.gov), Alexander S. Kutyrev (gsfc.nasa.gov), Claus Leitherer (stsci.edu), Gerhardt R. Meurer (uwa.edu.au), Jason X. Prochaska (ucolick.edu), George Sonneborn (gsfc.nasa.gov), Massimo Stiavelli (stsci.edu), Harry I. Teplitz (caltech.edu), Rogier A Windhorst (asu.edu)

Observational Imprint of Reionization

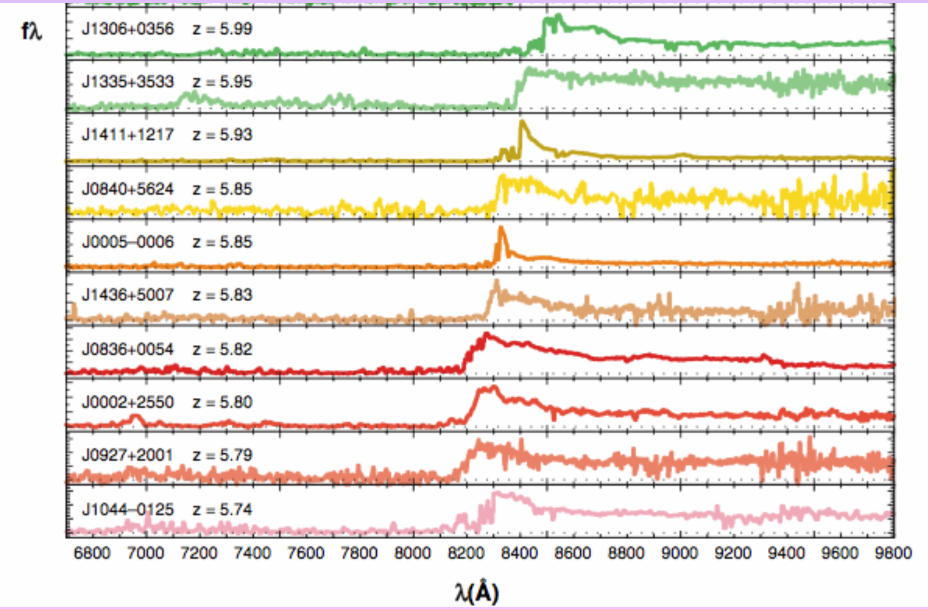
- Thomson scattering of CMB photons by free electrons creates polarization detected by WMAP
  - Indicates that reionization started at redshifts z > 11

- Break up of black Hydrogen absorption troughs in Sloan Digital Sky Survey QSO
  - Indicates that reionization was mostly complete around z ~ 6



Spergel et al. 2007

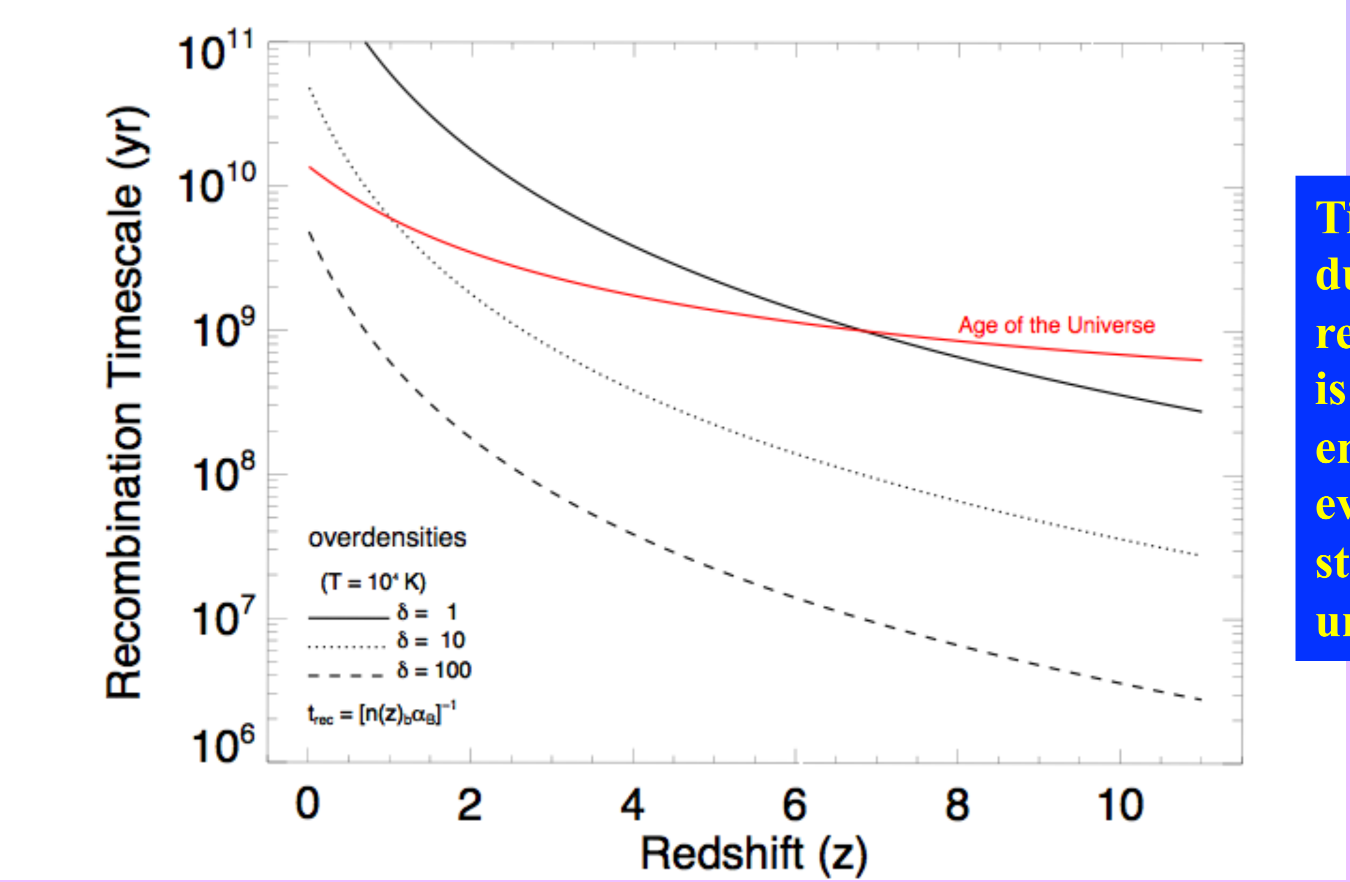
Confidence intervals for ionization fraction x_e as a function of redshift.



Fan, Carilli and Keating 2006

Hydrogen Recombination Timescales

Overdensity and the metagalactic ionizing background



Timing and duration of the reionization epoch is crucial to the emergence and evolution of structure in the universe.

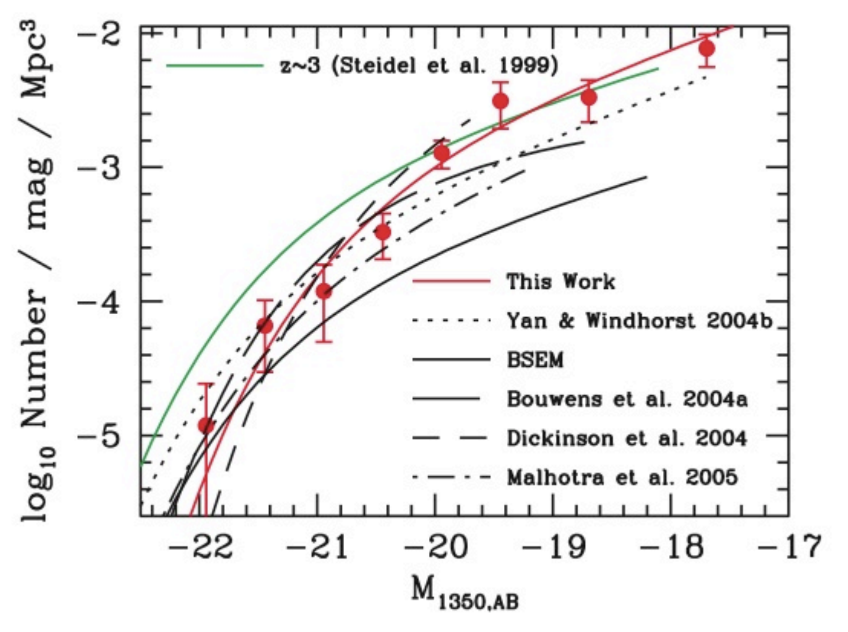
The fundamental question is:

How did the universe come to be reionized and how long did it take?

LyC escape from the smallest (faintest) galaxies is thought to power reionization

- Depends on
  - Faint end slope of LF
    - ($\alpha \leq -1.7$)
  - Clumping parameter
    - $1 < C < 30$ $(C \equiv \langle n_{HII}^2 \rangle / \langle n_{HII} \rangle^2, 1 < C < 30)$
  - LyC escape fraction
    - $f_e \sim 10$ - 100%
- At z = 6
  - Faint end of galaxy luminosity function (LF) dominates LyC production.
  - QSO too few in number.
  - Bouwens et al. 2006 find
    - $\rho^{SFR} = 0.043\ M_{\odot}\ yr^{-1}\ Mpc^{-3}$
    - $\Rightarrow C/f_{esc} \approx 50$
- At z =7
  - Galaxies may not be able to initiate reionization.
  - Labbe et al. 2010 find
    - $\rho^{SFR} = 0.012\ M_{\odot}\ yr^{-1}\ Mpc^{-3}$
    - $\Rightarrow C/f_{esc} \approx 9$; **TENSION**
    - **New Physics?**

Bouwens et al. 2006 LF at z = 6

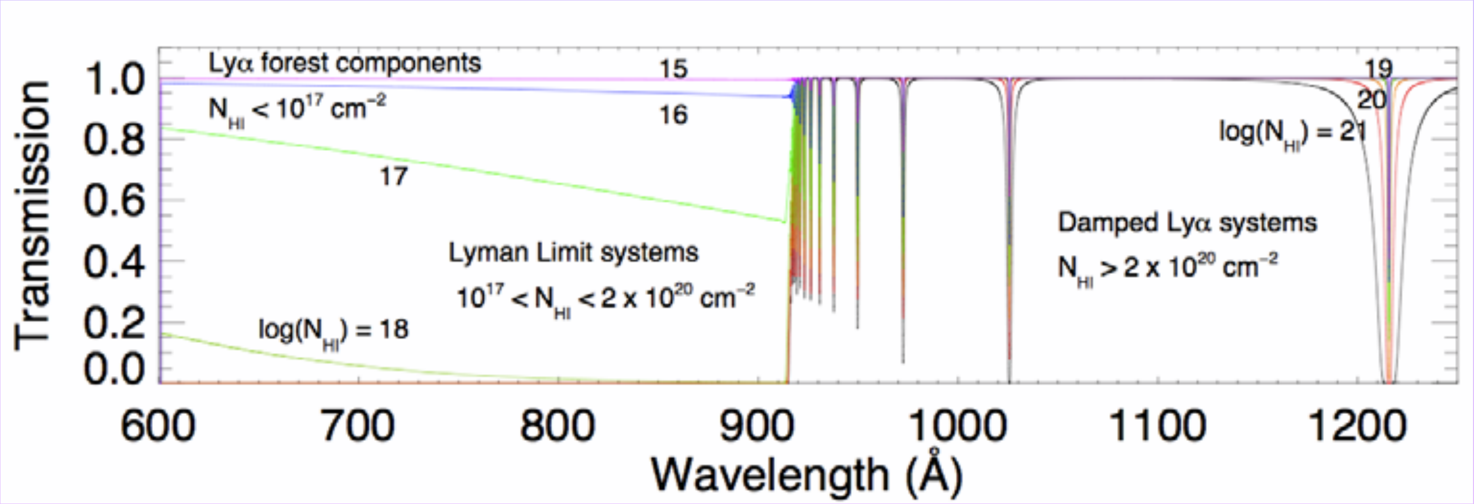


Integrate, assume galaxy assemblage time and Mass/Light ratio and compare to--

Critical Star-formation rate; one ionizing photon per baryon (Madau et al. 1999)

$$\rho_{cr}^{SFR} = \frac{0.04}{f_{esc}} \left(\frac{C}{30}\right) \left(\frac{1+z}{8}\right)^3 M_{\odot}\ yr^{-1}\ Mpc^{-3}$$

How LyC and Lyα escape from galaxies is a great mystery

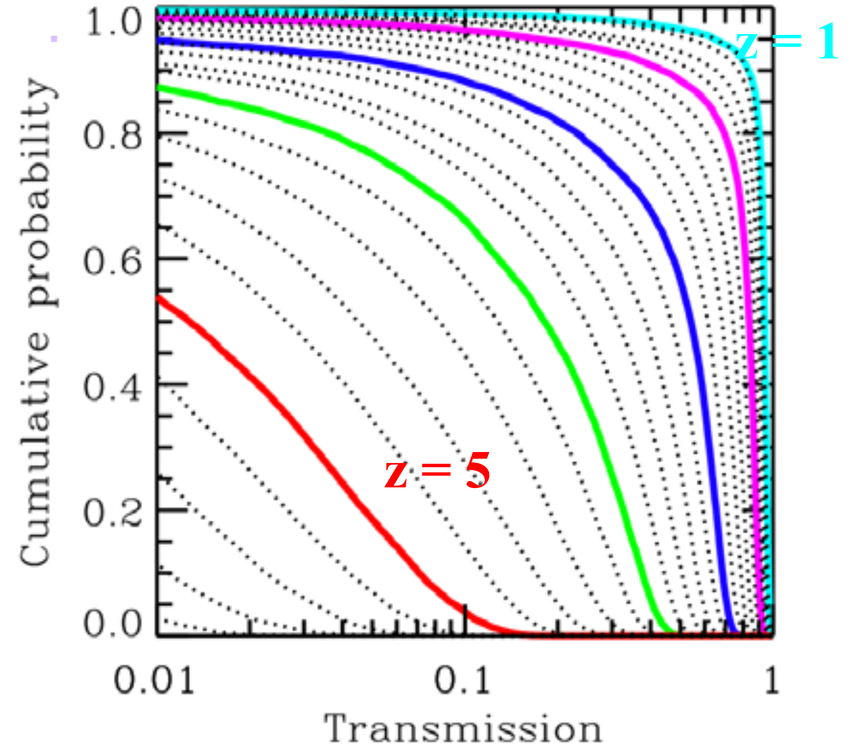


- Reionization requires LyC escape from galaxies
- Yet most star forming galaxies are optically thick to LyC photons (n_{HI}>10^{20}cm^2), **which should trap all the ionizing radiation and prevent escape**
  - $\tau_{\lambda<912} = N_{HI}\, 6.3 \times 10^{-18} (\lambda/912)^3$
  - $\tau_{Ly\alpha} = N_{HI}\, 6.3 \times 10^{-14}$ (Vdop = 12 km s^{-1})
- Theoretical suggestions for f_{esc}, $f_{Ly\alpha}$:
  - LyC escape aided by galaxy porosity; low density, high ionization voids created by supernovae or integrated winds from stellar clusters
  - Lyα escape aided by velocity gradients and resonance scattering in a multi-phase media
- **Observations desperately needed to ground the models**

Detections of LyC leak at z > 3 are frustrated by Ly Limit Systems

(thickening of the Lyα forest) Inoue and Iwata (2008)

Probability that the intergalactic transmission of the LyC is greater than the abscissa



90% chance that the magnitude decrement for the LyC at z =1 will be smaller than 1.5

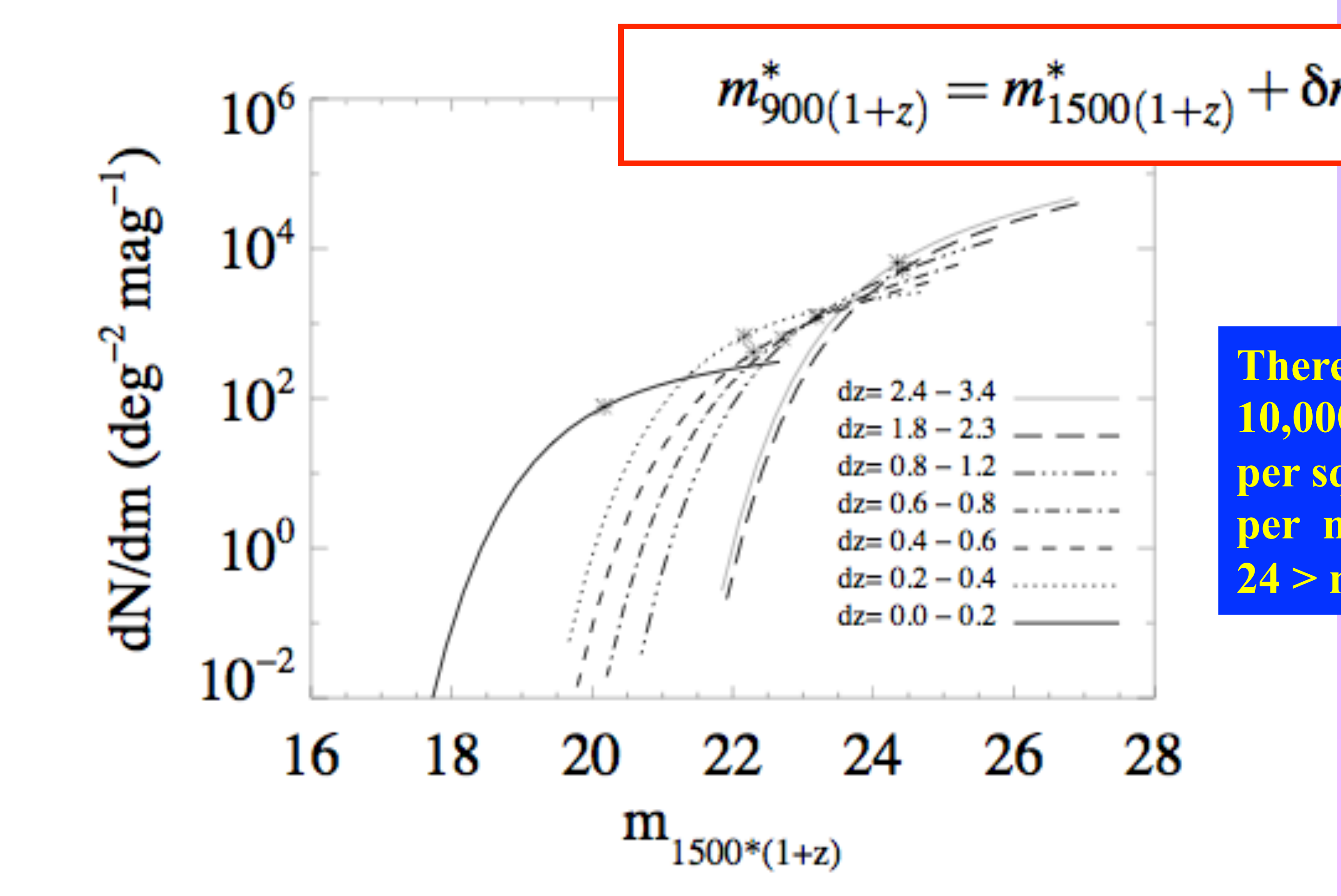
Same concept expressed as a magnitude decrement

	$m_{LC}^{limit} - m_{UV}^{obs}$ (AB)						
z_S	1.5	2.0	2.5	3.0	3.5	4.0	4.5
1.0	90	96	98	99	99	99	99
2.0	49	88	92	94	96	97	97
3.0	0	52	73	81	86	89	91
4.0	0	0	19	45	59	70	76
5.0	0	0	0	0	1	7	17

Detecting escaping Lyman continuum photons is a problem for UV/Optical

Far-UV has the advantage of small Ly limit system corrections

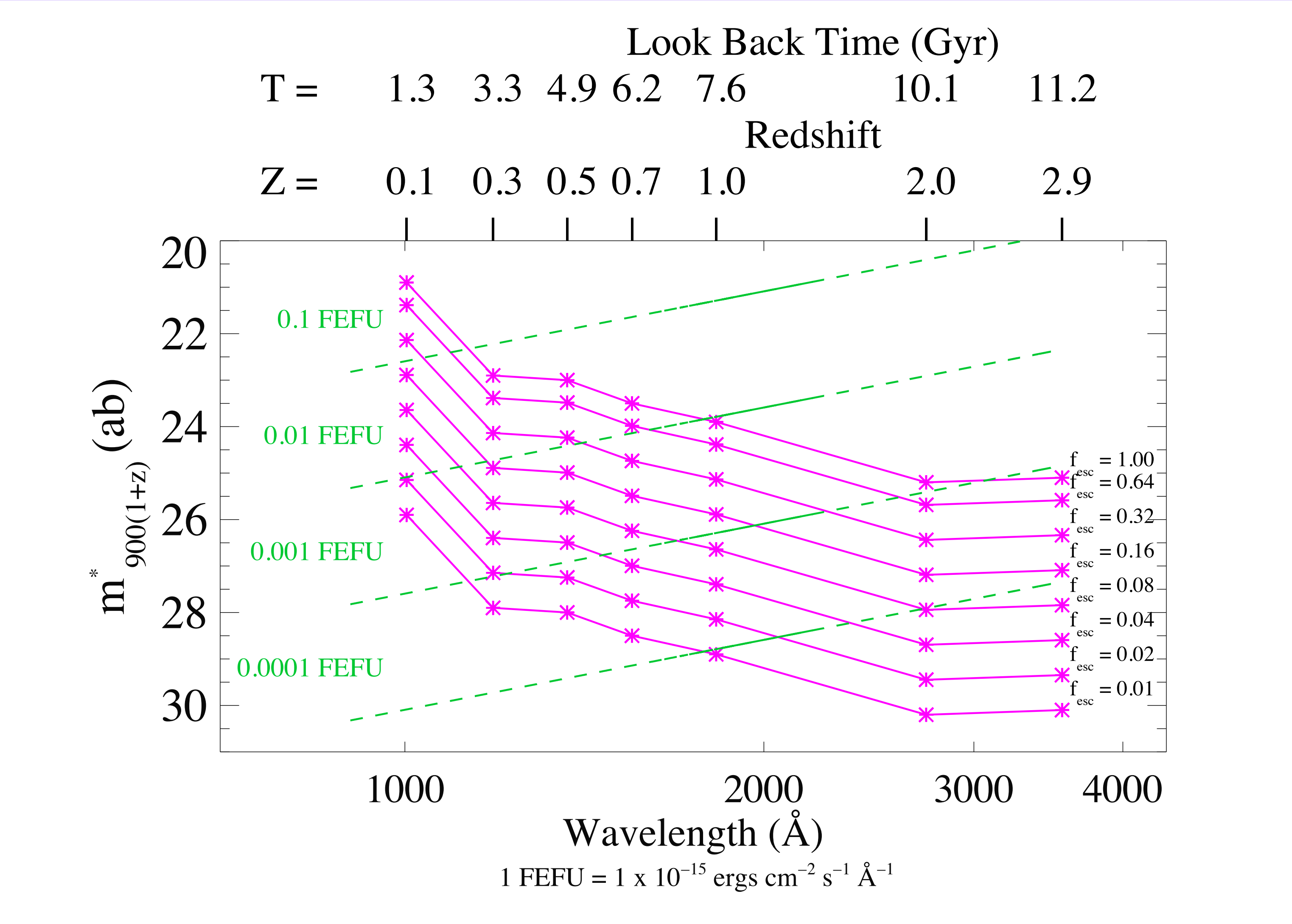
Evolution of Galaxy UV luminosity function
$0 < z < 3$ (Arnouts et al 2005)



$$m^*_{900(1+z)} = m^*_{1500(1+z)} + \delta m_{900}^{1500} + \delta m_{esc}$$

There are 100's to 10,000's of galaxies per square degree per magnitude with $24 > m^*_{1500(1+z)} > 20$

LyC Detection Requirements for L^*_{uv} galaxies



Top Science Questions

1) What are the relative contributions of star-forming galaxies, AGN and quasars to the MIB over the past 11 Gyrs ($z < 3$)?
2) What local and global environmental factors aid escape?
   - Gas, dust, metallicity, clumpiness of interstellar medium, velocity fields, intergalactic neighborhood, star formation history
3) Are there local relic analogs to the sources of reionization?
4) What is the relation between Lyα and LyC escape?
   - This is critical to the JWST key project seeking the source(s) of reionization.

Ancillary measurements from star-forming galaxies: Project Balmer

From Space with Project Lyman

- LyC flux (F_{LyC}) - rest frame
  - LyC escape, $f_{esc} \propto F_{LyC}/N_{LyC}$
- Lyα flux, ($F_{Ly\alpha}$)
  - Lyα escape, $f_{Ly\alpha} \propto F_{Ly\alpha}/F_{H\alpha}$
- Continuum shape 912 - 1800 (F_λ); Slopes: $\beta_{1500,}$ β_{1100}
  - UV Extinction, τ_λ
  - Gas, $N(H_{tot})$
  - Age of young stellar population

From Ground with Project Balmer

- Optical emission lines [OIII], H_β, [NII], H_α
  - Total LyC photons $N_{LyC} \propto F_{H\alpha}$, corrected for dust, $F_{H\alpha}/ F_{H\beta}$
  - Metallicity, Z
  - QSO, Star-forming Galaxy discriminator
- Optical continuum
  - Dust, τ_V, Mass and age of old stellar population

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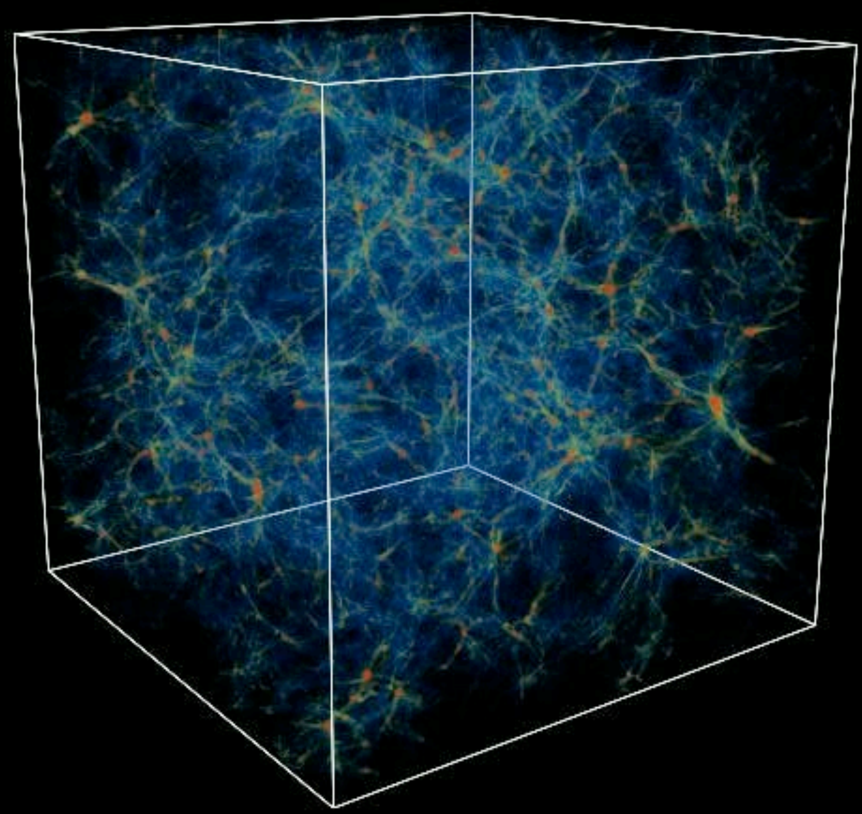
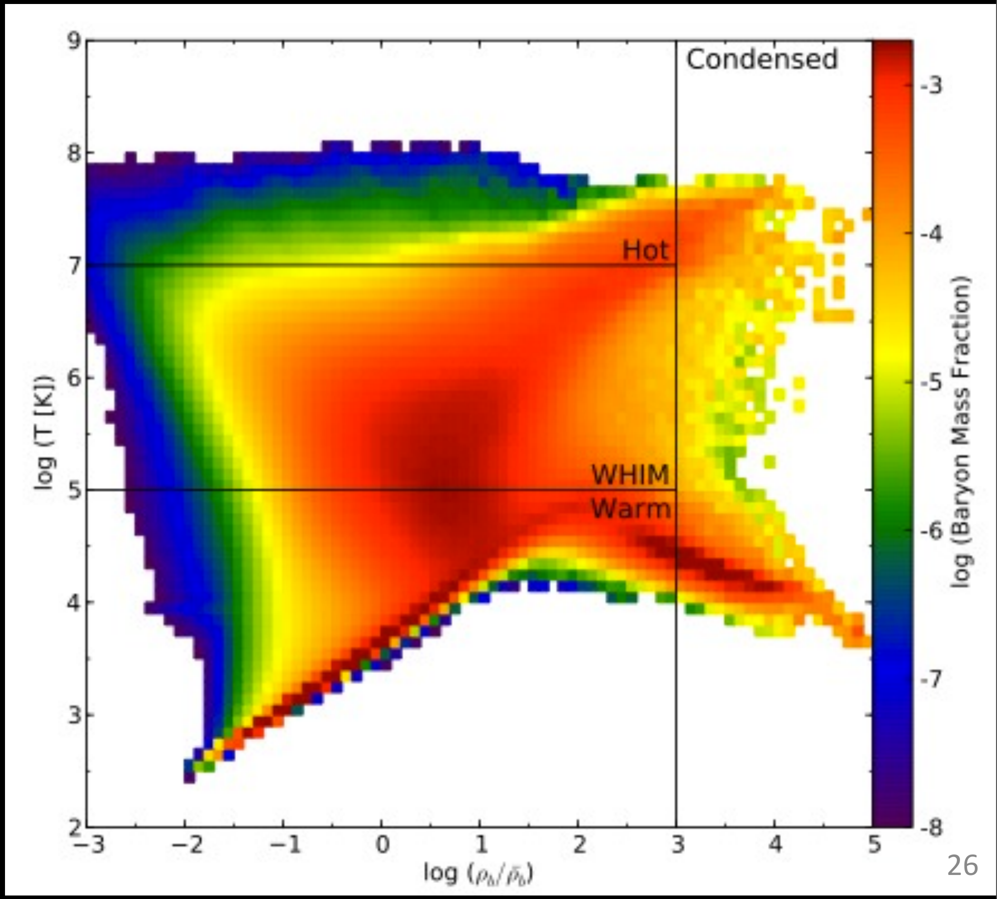
Identifying the Baryons in a Multiphase Intergalactic Medium

Michael Shull & Charles Danforth
Univ of Colorado (Astrophysics)





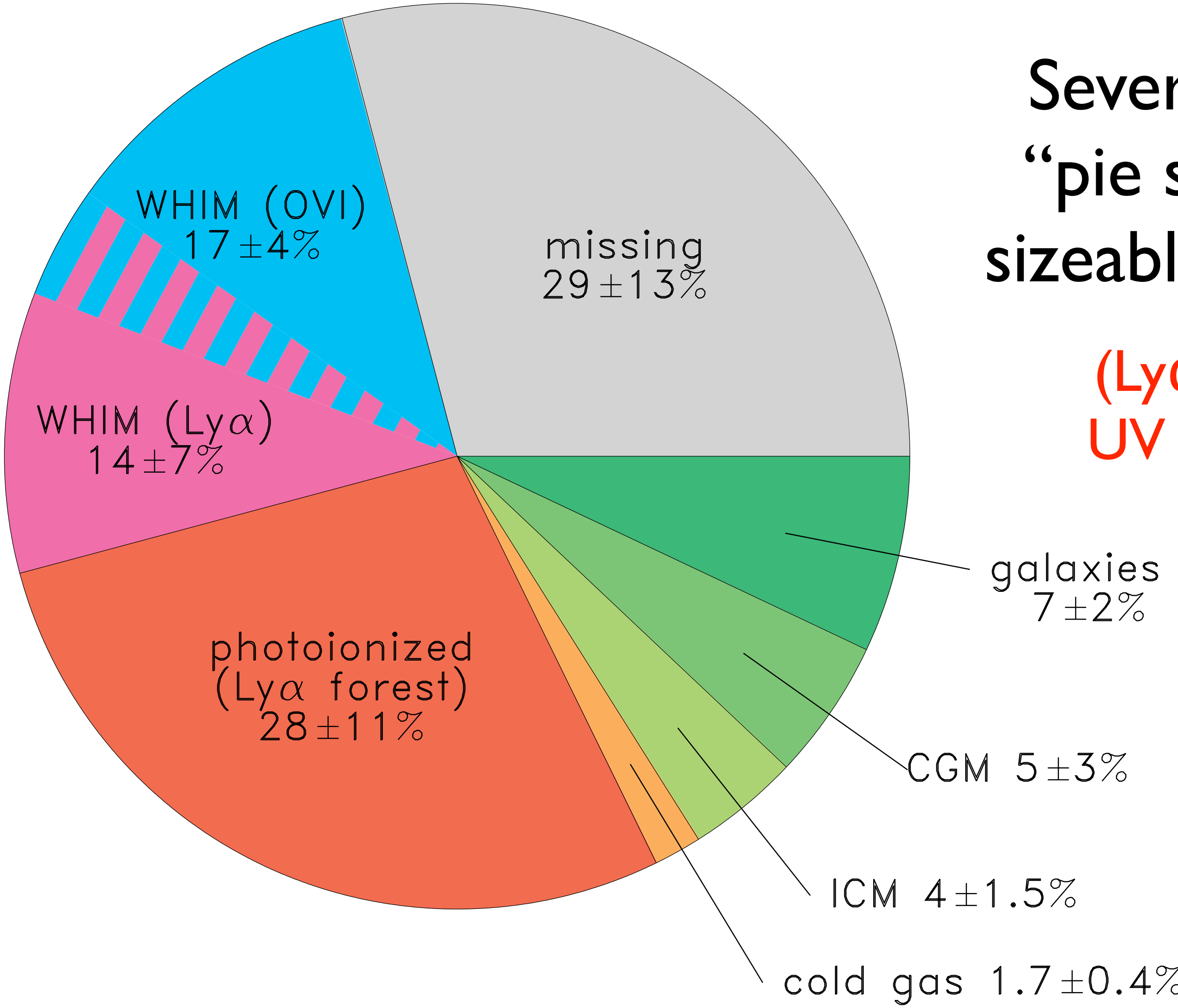
Scientific Issues:

What is the census of baryonic matter in the low-redshift universe, compared to the cosmological measured value of $\Omega_b = 0.046$?

Is the observed baryon deficit in galaxies resolved by gas in halos, the multiphase intergalactic medium (IGM), and metal-enriched circumgalactic medium (CGM) ?

Where are the “missing baryons” and how do they affect galaxy assembly and ongoing star formation?

Current Status of Low-z Baryon Census



Several of these "pie slices" have sizeable error bars

(Lyα and O VI UV absorbers)

Shull, Smith, & Danforth 2012, ApJ, in press (arXiv:1112.2706)

What needs to be done?

Current (short-term):

Deep (S/N > 30) UV spectroscopic surveys of Lyα, O VI, Ne VIII, and other metal-line absorbers (IGM, CGM)

Probe weak absorbers in cosmic web, with column densities $N_{HI} < 10^{13}$ cm^{-2} and $N_{OVI} < 10^{13.5}$ cm^{-2}

Longer-term (new facility):

UV Mission (far-UV: 912-3100 A) spectrograph with high throughput ($A_{eff} > 3\times10^4$ cm^2) and high spectral resolution ($R = \lambda/\Delta\lambda > 40,000$)

Probably with 6-8 meter aperture

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The Role of Dwarf Galaxies in Reionization

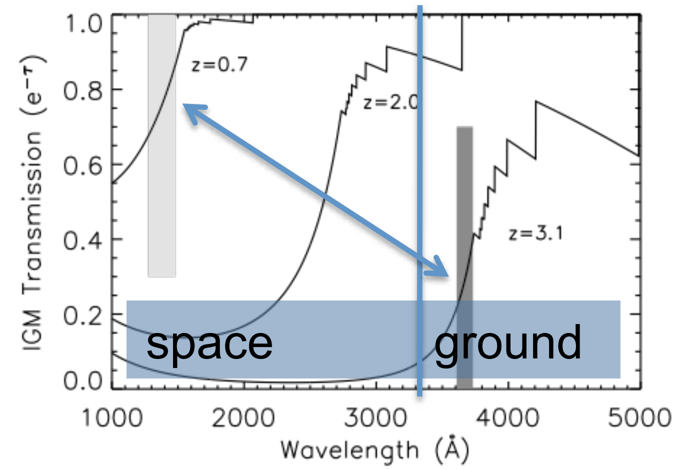
Claudia Scarlata, Harry Teplitz, Brian Siana

and

Ferguson H., Vanzella E., Conselice C., Finkelstein S., Fontana A., Giavalisco M., Hathi N., Lucas R., Rafelski M., Ryan R.

The **reionization** of the IGM is a landmark event in the history of the Universe.

The understanding/modeling of this process depends on the fraction of ionizing photons – f_{esc} – that are able to escape from galaxies.



f_{esc} cannot be measured during the reionization epoch. At z<3 the Lyman limit is in the UV.

Huge investment of telescope time shows:

z>3, imaging/spectroscopy with ground-based large telescopes: high $f_{esc,rel}$ ~ 1 in ~10% (Steidel et al. 2001, Shapley et al. 2006, Iwata et al. 2008, Bogosavljevic et al. 2009, Nestor et al. 2011, Vanzella et al. 2010, 2011). <u>Contamination is a problem: Keck spectroscopy rules out 5/6 detections!</u>

z<3, imaging/spectroscopy with HST (>300 orbits):

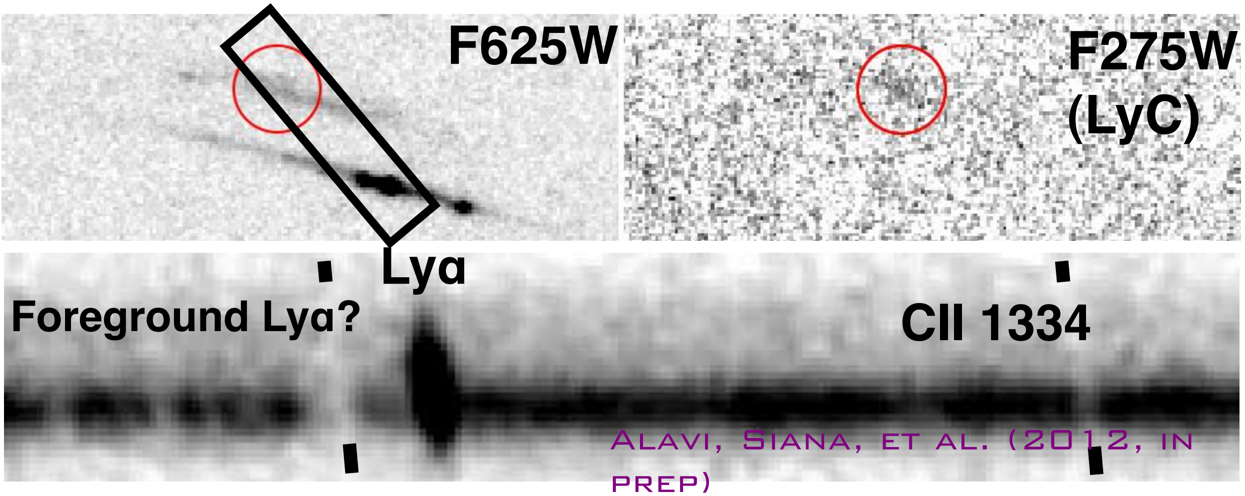
stringent limit on f_{esc} < 1.8%, (Teplitz et al. 2006, Siana et al. 2007, Siana et al. 2010, Bridge et al. 2010)

Conclusion:
Lyman Continuum not from bright LBGs

Lensing magnification is the best (only?) way to study the faint galaxies that are likely to be the strongest LyC emitters

First candidate detection in a lensed **z~2.5 dwarf galaxy** (NUV~27 AB; mag=82x).

Limited by small volumes and uncertain lensing model



ALAVI, SIANA, ET AL. (2012, IN PREP)

We need to probe LyC in **a large number of dwarf galaxies**.
Ideal redshift 1<z<2: lower contamination, higher IGM transmission, availability of Hα.
Requires UV observations!

Not feasible with HST: compact sources with NUV~31-32. Deepest NUV images reach ~29.5 (UV-UDF Teplitz et al. in prep, Abell 1689 Siana et al. in prep)

Minimum Science Requirements

- **Increased UV sensitivity**
  - Detect <0.1 L* without lensing
    - About 10x HST sensitivity at <3000 AA
    - Lower read noise
  - Imaging local galaxies at ~1000 AA (FUV large FoV)
- **Substantially improved CTE**
  - This is a major limitation of HST deep UV surveys
  - Slower rate of degradation?
- **Larger UV field of view**
  - 3 to 10 times WFC3/UVIS
  - Capability for wide field UV survey
- **More UV filters**
  - Probe more redshifts with imaging
  - Possibly narrow- or medium-bands, depending on redshift
    - Red cutoff is most important

Desired Science Requirements

- **R>5000 spectroscopy below the Lyman limit at z~1-2**
  - Constrain the IGM absorption along the specific line of sight
  - Measure physical properties of dwarfs

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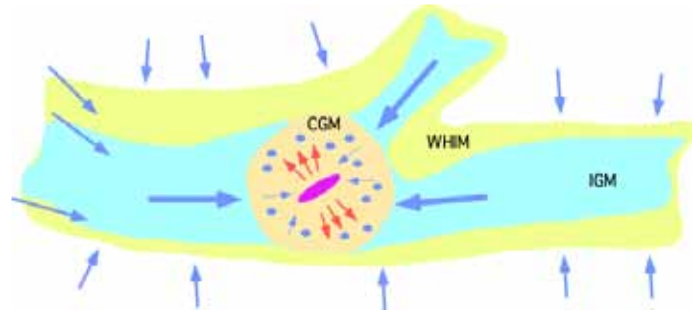
SCIENCE FROM IGM/CGM EMISSION MAPPING

D. C. Martin (Caltech) & D. Schiminovich (Columbia)

with J. Schaye (Leiden), C. Steidel (Caltech), T. Heckman (JHU), R. Cen, J. Ostriker (Princeton), C. Martin (UCSB), J. Kollmeier (Carnegie)

Science from IGM/CGM Emission Mapping

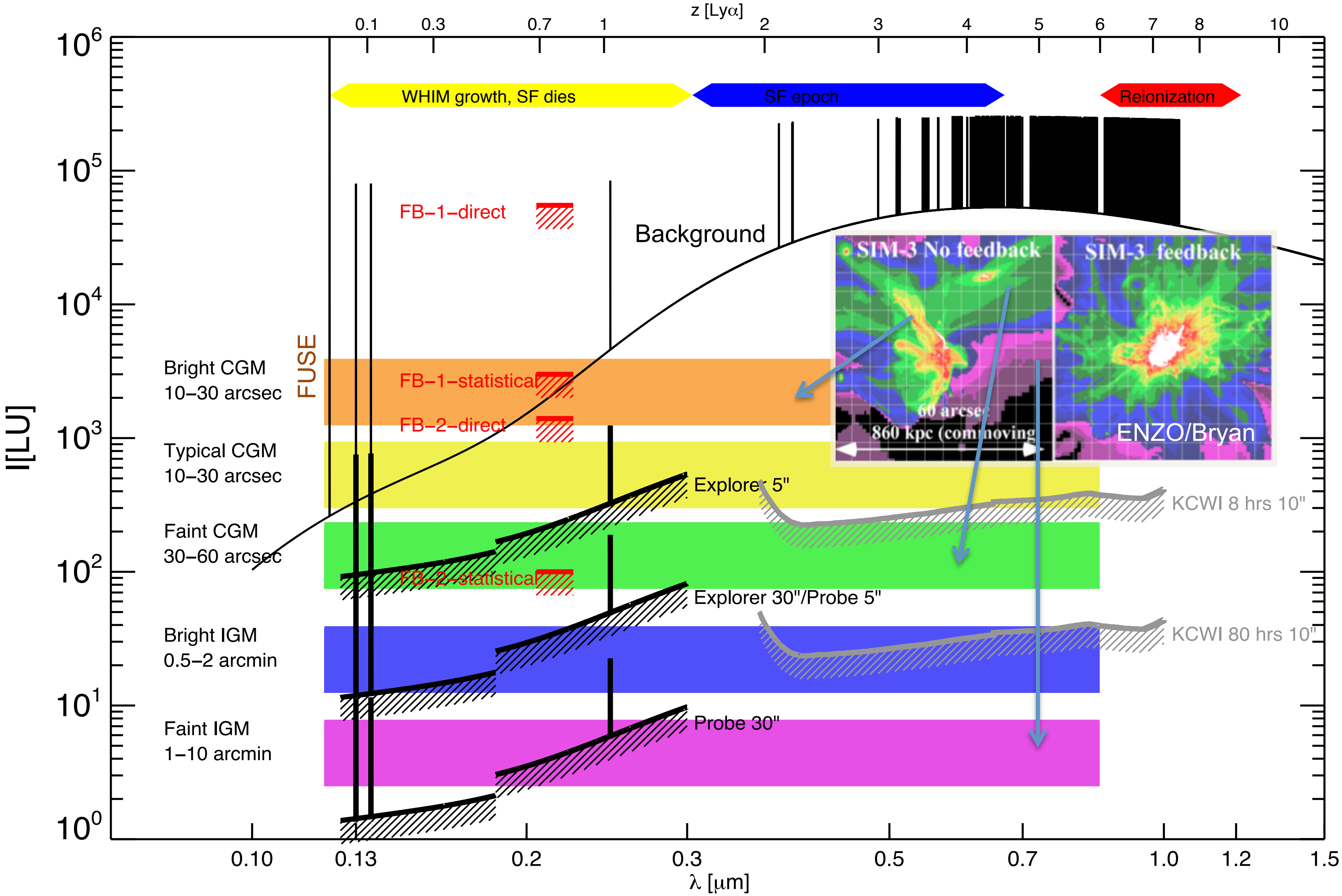
- A Probe of Baryonic Structure Formation
  - How does baryonic matter collapse, cool and fuel galaxies over cosmic time?
  - How strong is IGM emission, what is its relationship with absorption and can emission mapping offer a new and powerful cosmological tool?



	Component			
Property	**Cosmic Web**	**Web/ Halos**	**Dark Halos**	**Galaxies**
Baryon & structure tracer	IGM *fuel*	WHIM *baryons* *metals*	CGM *infall* *winds* *metals*	*XUV disk* *gal. winds, SF*
δ	1-100	1-100	10^2-10^5	$>10^6$
Size [Mpc]	0.3-30	1-30	0.1-0.3	0.03-0.1
T[K]	10^4-10^5	10^5-10^7	10^4-10^6	
QSO absorption	Lα forest	OVI, broad Lα	Ly limit Metal lines	Damped Lα
Emission	Photon pumping (PP)	Collisional excitation (CE), PP	CE, PP, Lα fluorescence	UV cont CE from feed-back
Intensity [LU]	1-100	1-100	10^2-10^4	

Figure 1: *IGM/CGM emission probes all these components of the IGM, yet to be mapped.*

IGM/CGM Emission Mapping
Current vs. Future Capabilities

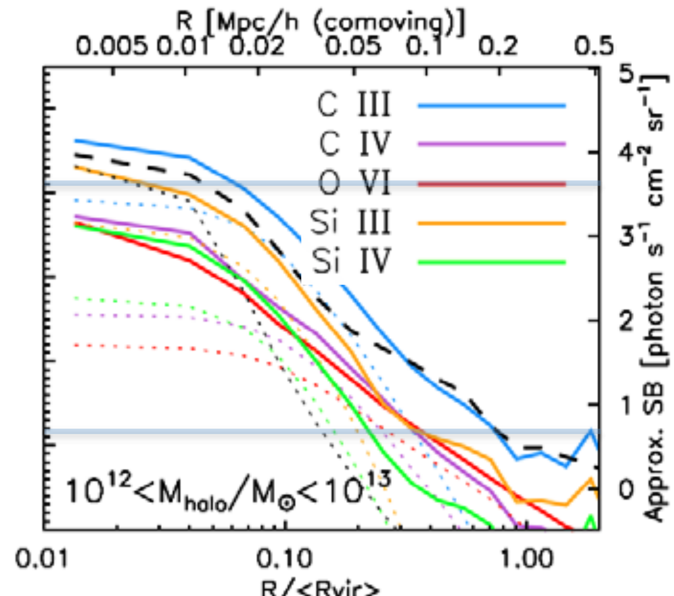


IGM/CGM Emission Mapping Science Goals and Requirements

IGM Emission Roadmap	Discovery and Preliminary Characterization of Emission from the IGM, WHIM, CGM, CQM	Physical Properties of the IGM, WHIM, CGM, CQM	Tracing Baryon Structure Formation using IGM and CGM Emission
Map IGM/WHIM [N1, N2, A3, A4]	**O1a. Discover IGM emission** from the hidden baryons in the Universe. Preliminary mass census.	**O1b. Characterize IGM emission** from the hidden baryons in the Universe. Mass census.	**O1c. Exploit IGM emission** to map baryonic structure formation in cosmic web
Map CGM [N1, A1, A2]	**O2a. Discover CGM emission** to explore IGM-galaxy co-evolution	**O2b. Characterize CGM emission** to determine physical conditions, gas flows and reservoirs	**O2c. Deep, multi-object surveys of galaxy/CGM emission regions** to explain IGM-galaxy co-evolution
Map Circum-QSO Medium (CQM) [N1, N2, A1-A4]	**O3a. Discover CQM emission** to explore QSO gas environment.	**O3b. Characterize CQM emission** to determine physical properties of QSO gas environment.	**O3c. Deep maps of multiple QSO CQM regions** to determine how QSOs are formed and evolved, and in what environments.
Surveys	**Moderately deep imaging and multi-object spectroscopic surveys** of 10-100s of halos/galaxies and filaments.	**Very deep imaging and multi-object spectroscopic surveys** of 10-100's of objects and filaments.	**Wide, deep imaging and multi-object surveys** of 100-1000's of halos, filaments, and regions.
R1. Diffuse UV sensitivity: (LU = ph cm^{-2} s^{-1} sr^{-1})	IGM 10-200 LU (5 arcsec). CGM: 100-5000 LU (5 arcsec)	IGM: 5-100 LU (5 arcsec). CGM: 100-5000 LU (2 arcsec)	IGM 5-100 LU (5 arcsec). CGM: 100-5000 LU (1 arcsec)
R2a. Spectral Mapping (IFS): Contiguous survey regions	Field of view: ~4x4 $arcmin^2$	Field of view: ~2x2 $arcmin^2$	Field of view: ~2x2 $arcmin^2$
R2b. Spectral Mapping (MOS): Wide-field, multi-object mapping of galaxies and their CGM halos. Wide-field surveys of filamentary emission from cosmic web.	Field of view: (10-20) x (10-20) $arcmin^2$	Field of view: (2-5) x (2-5) $arcmin^2$	Field of view: (2-5) x (2-5) $arcmin^2$
R3. Cosmic volume (at low z)	IFS/MOS: 10^4 / 10^5 Mpc^2	IFS/MOS: 10^4 / 10^5 Mpc^2	a) IFS/MOS: 10^5 / 10^6 Mpc^2
R4. Spectral range	Observe Lyα, OVI1033, CIV1550 over $0.2 < z < 1$	Observe Lyα, OVI1033, CIV1550 over $0.2 < z < 1$	Observe Lyα, OVI1033, CIV1550 over $0.05 < z < 1.5$
R5. Velocity resolution	100-300 km/s	50-100 km/s	50-100 km/s
R6. Spatial resolution sufficient to resolve CGM components from central galaxy (~5-20 kpc)	20-40 kpc (~5 arcsec)	10-20 kpc (~3 arcsec)	3-7 kpc (~1 arcsec)

IGM/CGM Emission Mapping Science Requirements

- <u>Mode</u>: Spectroscopy
- <u>Field of View</u>:
  - IFU: 4x4 arcmin^2 for contiguous IGM/CGM regions.
  - MOS: 20 x 20 arcmin^2 - Wide field cosmic web surveys. Multi-object mapping of galaxies and CGM halos
- <u>Physical / angular resolution:</u>
  - 1-5 arcsec^2
  - 3-40 kpc over $0.2<z<1.5$
- <u>Spectral resolution:</u>
  - R ~ 1000-5000
- <u>Wavelength band:</u>
  - 1250-3200Å (Lyα, CIV, OVI @ $0.2<z<1$)
  - Goal: 1000-4000Å; $0.05<z<1.5$
- <u>Sensitivity:</u>
  - CGM: 100-5000 LU (1 LU = 1 photon s^{-1} cm^{-2} sr^{-1})
  - IGM: 5-100 LU



Metal Lines van de Voort & Schaye (2012)

RFI Response Summaries

6 Rapid Science Summaries

Topic: Intergalactic Medium

Todd Tripp

Steve McCandliss

Mike Shull

Claudia Scarlata

David Schiminovich

Gerard Kriss

Synergistic Astrophysics in the Ultraviolet using Active Galactic Nuclei

Gerard Kriss (STScI),
Nahum Arav (Virginia Tech), Anton Koekemoer (STScI),
Smita Mathur, Bradley M. Peterson (Ohio State),
Jennifer E. Scott (Towson University)

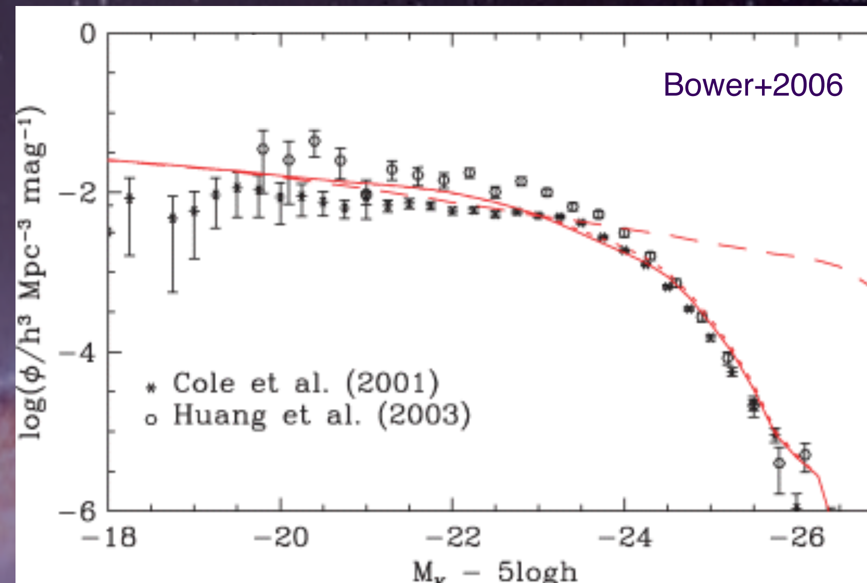
9/17/2012

Observations of AGN Fulfill Multiple Scientific Objectives

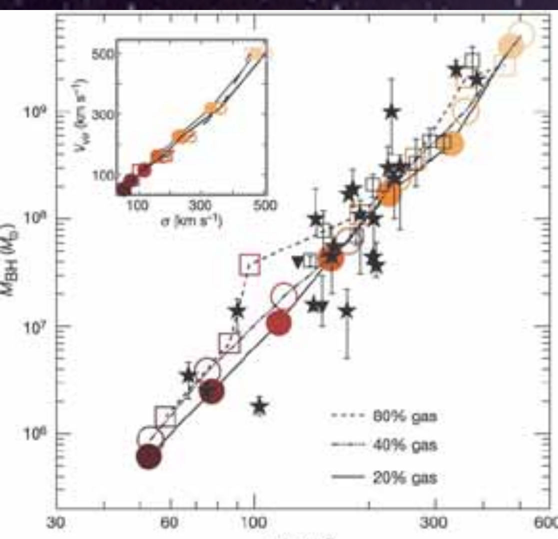
- ★ **How do black holes accrete matter, grow through cosmic time and influence their host galaxies?**
- ★ **AGN are ideal background light sources for studying the intergalactic medium (IGM), the circumgalactic medium (CGM), the interstellar medium (ISM), and galactic halos.**
- ★ **Observations of well defined samples of AGN can be used to probe foreground gas while doing all of the following simultaneously:**
  - Reverberation mapping of the BLR in nearby AGN, and quantifying the kinetic luminosity of outflows seen in absorption.
  - Survey and quantify outflows in intermediate redshift AGN, ascertain the shape of the continuum in the extreme ultraviolet, and study radiation reprocessing near the black hole and accretion disk.
- ★ **Observations of ~200 local AGN have defined a basic paradigm. We need greatly expanded samples with real measurements to test it.**

Galaxy Evolution, AGN and Feedback

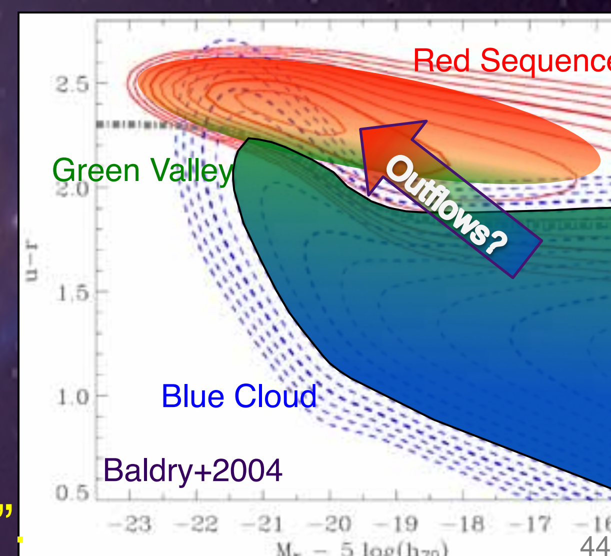
★ Downsizing: AGN feedback limits galaxy growth.



DiMatteo+2005



★ M_{BH}-σ : Feedback couples black hole growth to galaxy growth, leading to the correlation.



★ Color Evolution: Outflows can help AGN move from the “Blue Cloud” across the “Green Valley” and onto the “Red Sequence”.

Quantifying Outflows in Nearby AGN

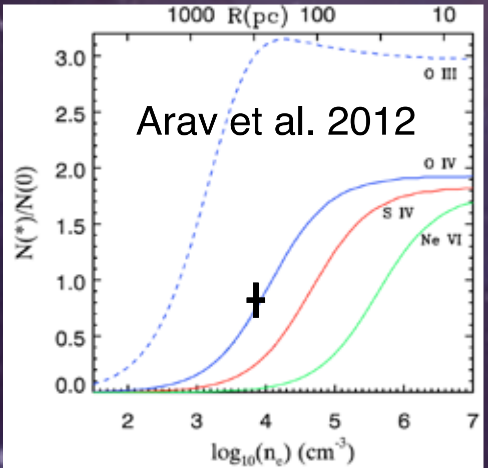
★ **The key quantities we need to measure are**

- The mass flux, $\dot{M}_{out} = 4\pi\ \Delta\Omega\ r\ N_H\ \mu m_p\ v_{out}$
- The kinetic luminosity, $L_k = ½\ \dot{M}_{out} v_{out}^2$

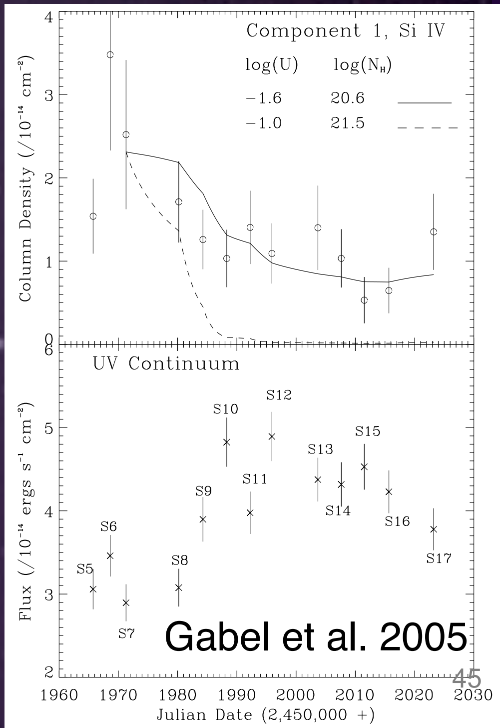
★ **The SED plus photoionization modeling gives us a density-dependent distance through the ionization parameter:**

$$\xi = \frac{L_{ion}}{n\ r^2}$$

★ **Density can be measured via density-sensitive lines**



or t_{rec}.

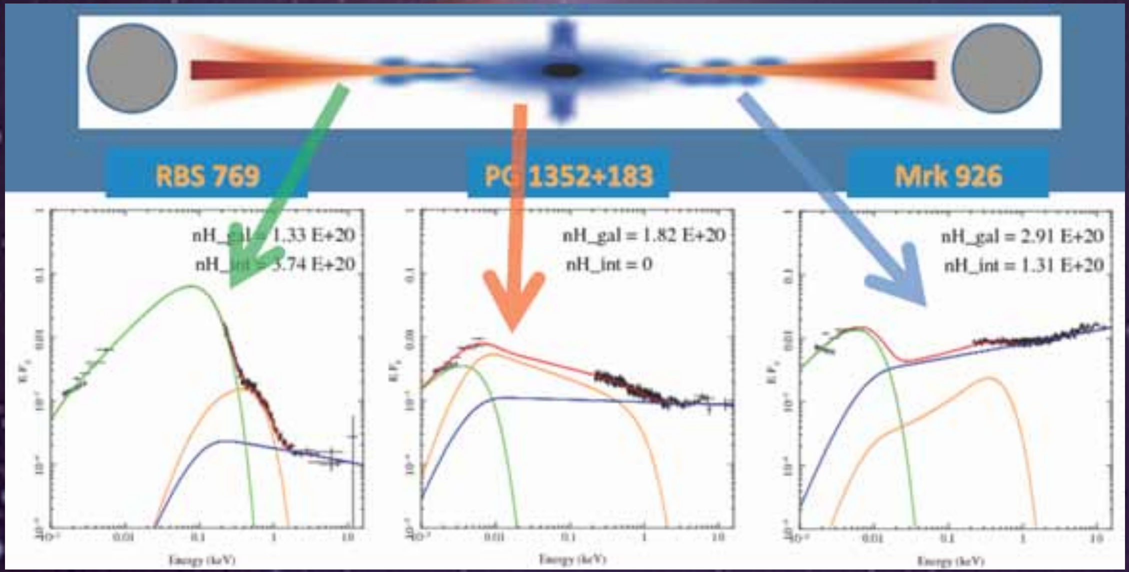


Outflows in AGN at Intermediate Redshift

- Observations of local AGN show that the bulk of the mass and kinetic energy in the outflows is in high-ionization gas seen in the X-ray.
- At moderate redshifts (z~1) X-ray diagnostic lines such as O VII and O VIII are absorbed by the local ISM, and X-ray fluxes are too low for spectroscopy. This makes studying the evolution of outflows difficult.
- High-ionization lines such as Ne VIII λλ770,780, Mg X λλ610,625 and Si XII λλ499,521 probe gas at ionization levels comparable to the O VII and O VIII features commonly seen in X-rays from local AGN.
- Equally importantly, high-ionization excited-state transitions provide density diagnostics: O IV λλ608,610, O IV λλ788,790.
- UV observations can achieve higher sensitivity and resolution.

The Physics of the Accretion Disk in the Extreme UV

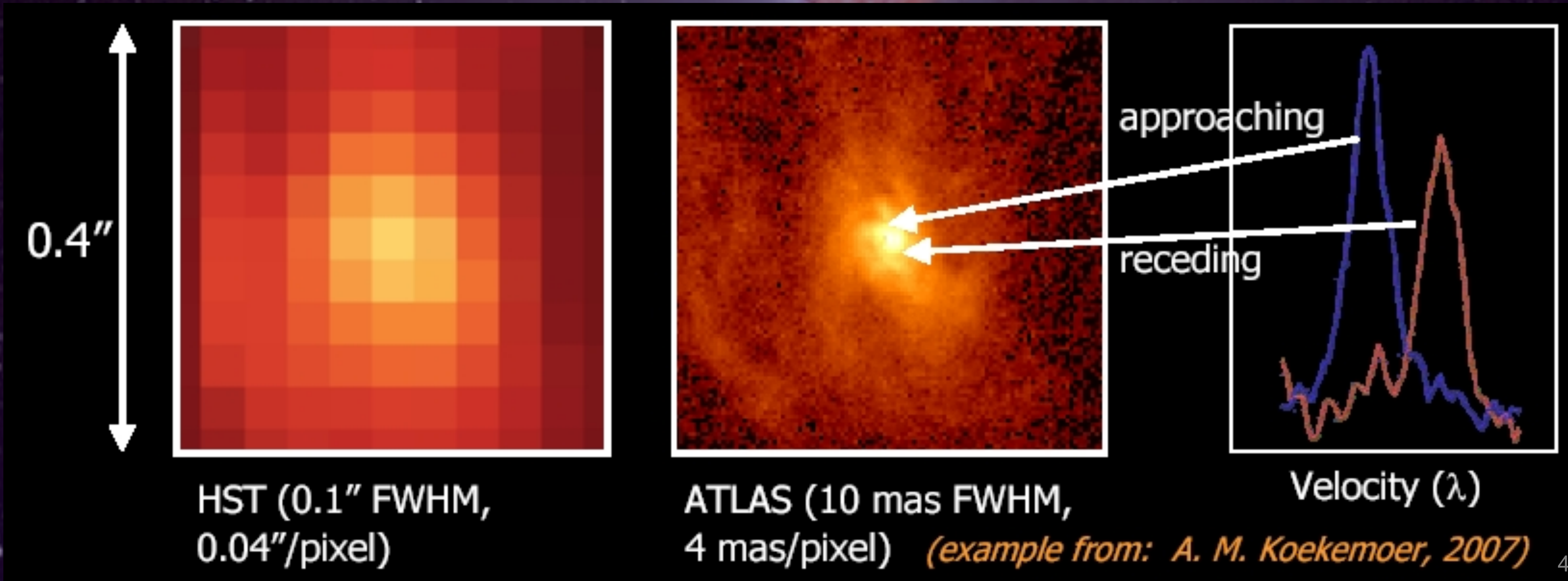
- ★ Sensitivity down to 1000 Å would allow direct observation of the continuum in a large sample of AGN at moderate redshift.
- ★ Existing ground-based observations (e.g., SDSS DR7) would give fundamental parameters such as M_{BH} and L_{edd}.
- ★ Simultaneous ground-based observations would allow direct correlation of the soft seed photons from the disk with the Compton-scattered EUV.
- ★ Correlated lags yield the geometry of the scattering region.



Jin, Done & Ward 2012

Direct Black Hole Mass Measurements to Cosmological Distances

- Batcheldor & Koekemoer (2009) show that the resolution and low sky brightness afforded by the Lyα emission line in the UV is more efficient than 30-m ground-based telescopes in the IR.
- An 8-m space-based telescope can observe a disk with the Lyα surface brightness of M87 to a limiting redshift of z=1.5.



Next Steps for Probing AGN in the UV

- Probing AGN outflows requires R~15,000 and S/N~30 in the continuum.
- Quantitative observations of large numbers of objects requires short exposure times (hours, not days).
- COS can reach flux levels of $F_\lambda > 6\times10^{-14}$ in 2000 s. This is equivalent to i=13.5 for the SDSS composite QSO spectrum. However, only a handful of AGN are this bright.
- At i<17, and predicted $F_\lambda > 1\times10^{-15}$, SDSS DR7 has over 250 AGN with $0.89 < z < 1.50$ (to see Mg X at $\lambda > 1150$ Å and Lyα at $\lambda < 3200$ Å). This requires ~60 times the throughput of COS.
- Sensitivity to 912 Å would allow observations of Mg X at $z > 0.51$.

Far Ultraviolet Observations of AGN Science Requirements

- **Spectroscopy with time resolution of 1000 s**
- **Field of View: <1”**
  - Point source observations can use a single aperture
  - Black-hole masses require integral field spectroscopy over 1” × 1”
- **Physical / angular resolution(s)**
  - Most targets are point sources
  - Measuring black hole masses requires angular resolution of 10 mas @ 3000 Å.
- **Spectral resolution(s)**
  - Required: R=15,000 / Desired: R=40,000
  - Integral Field Unit required for black-hole mass measurements w/ R=1000
- **Wavelength band(s)**
  - Required: 1150—3200 Å / Desired: 912—3200 Å
- **Sensitivity**
  - Required: 1×10^{-15} erg cm^{-2} s^{-1} per resolution element in 2000 s at 1150 Å
  - Desired: 5×10^{-16} erg cm^{-2} s^{-1} per resolution element in 2000 s at 912 Å
- **Dynamic Range**
  - Required: 30:1 / Desired: 100:1

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Topic: Intergalactic Medium

Open Discussion