GAS OUTSIDE OF GALAXIES

60 YEARS OF INTELLECTUAL HISTORY AND 20+ YEARS WITH HST

Jason Tumlinson
Space Telescope Science Institute

with help from:
STScI Librarian Jill Lagerstrom
Ben Oppenheimer (Leiden)
Britton Smith (Michigan St.)
Chris Thom (STScI)

THEMES

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In the field of observation, chance favors only the prepared mind.

[Pasteur]

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[Pasteur]

AND

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In the field of observation, chance favors only the prepared mind.

[Pasteur]

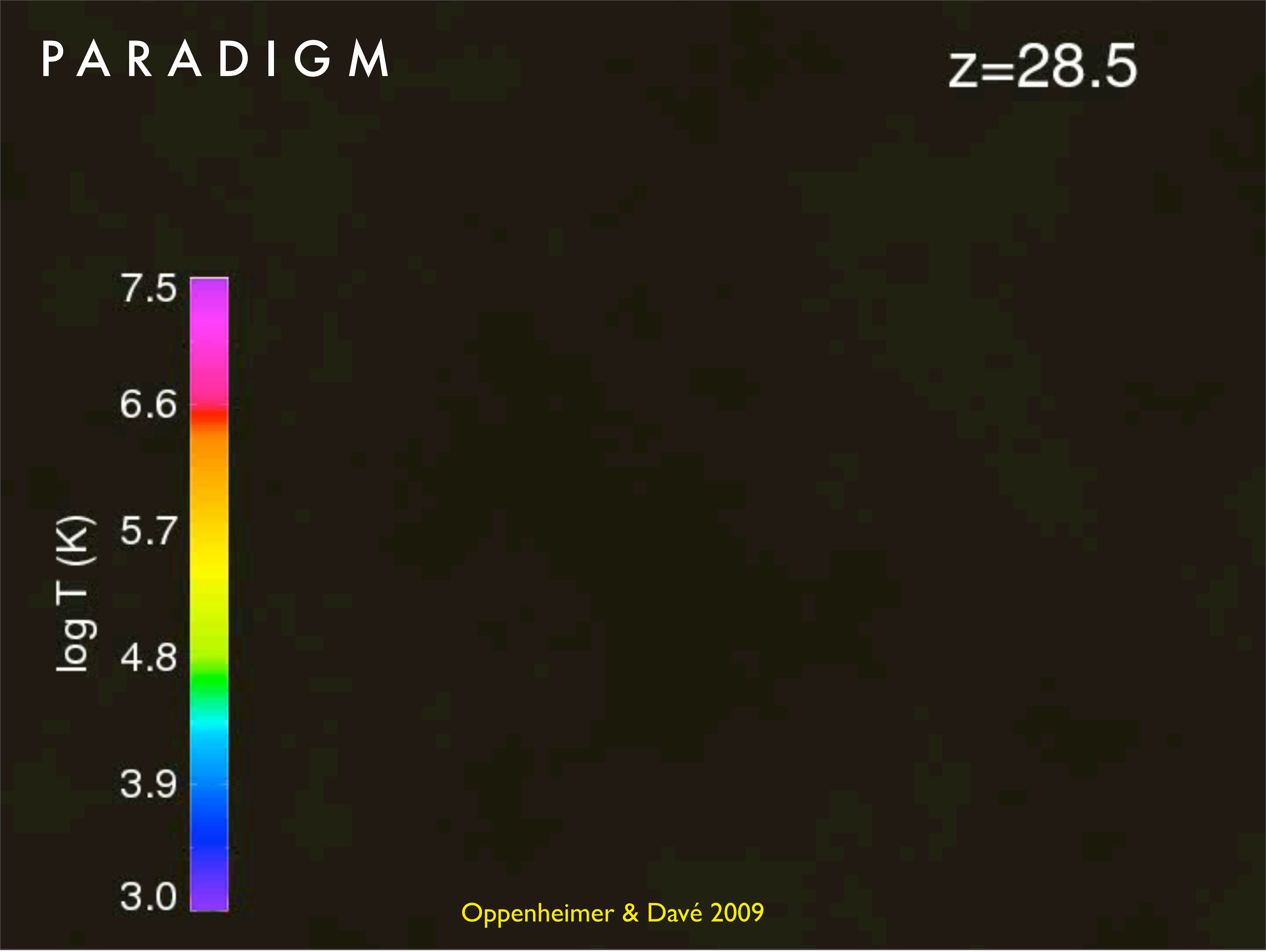
AND

There is no new thing under the Sun.

[Ecclesiastes]

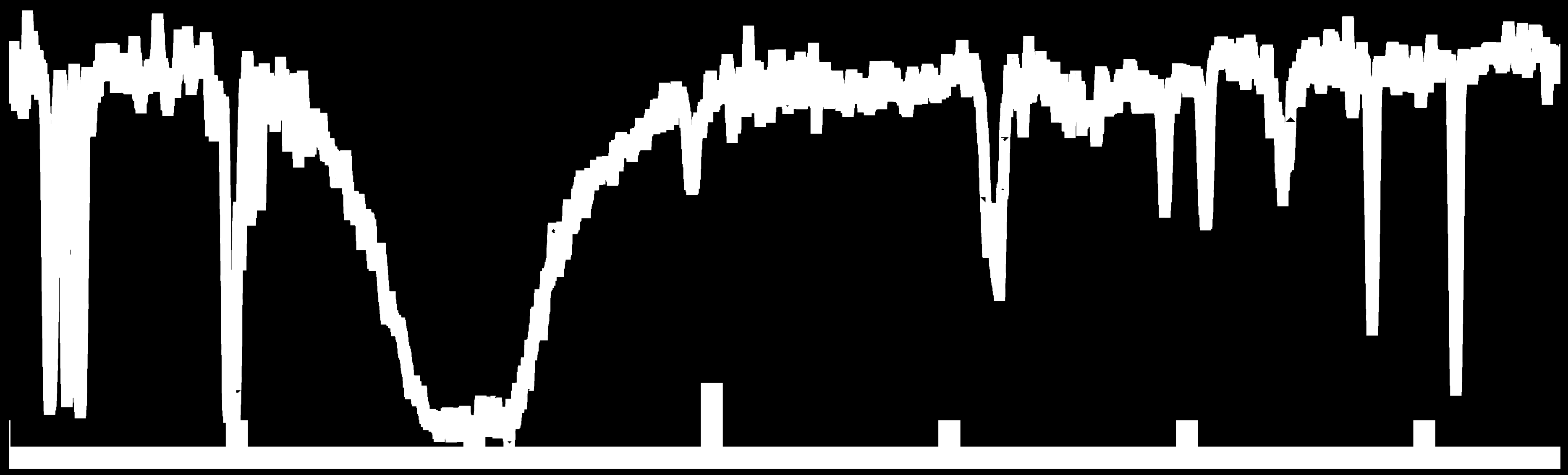
PARADIGM

PARADIGM



Oppenheimer & Davé 2009

METHOD Quasar Absorption Lines



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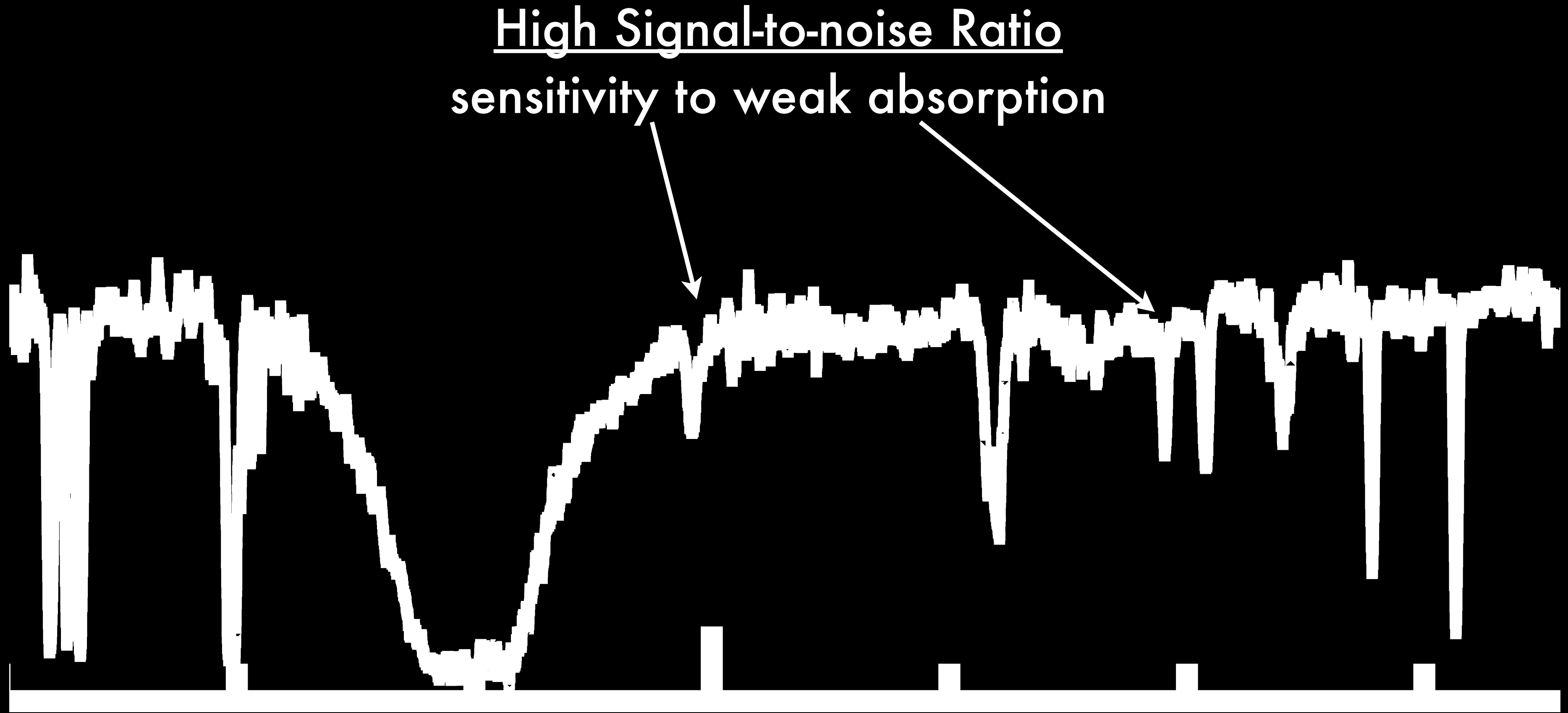

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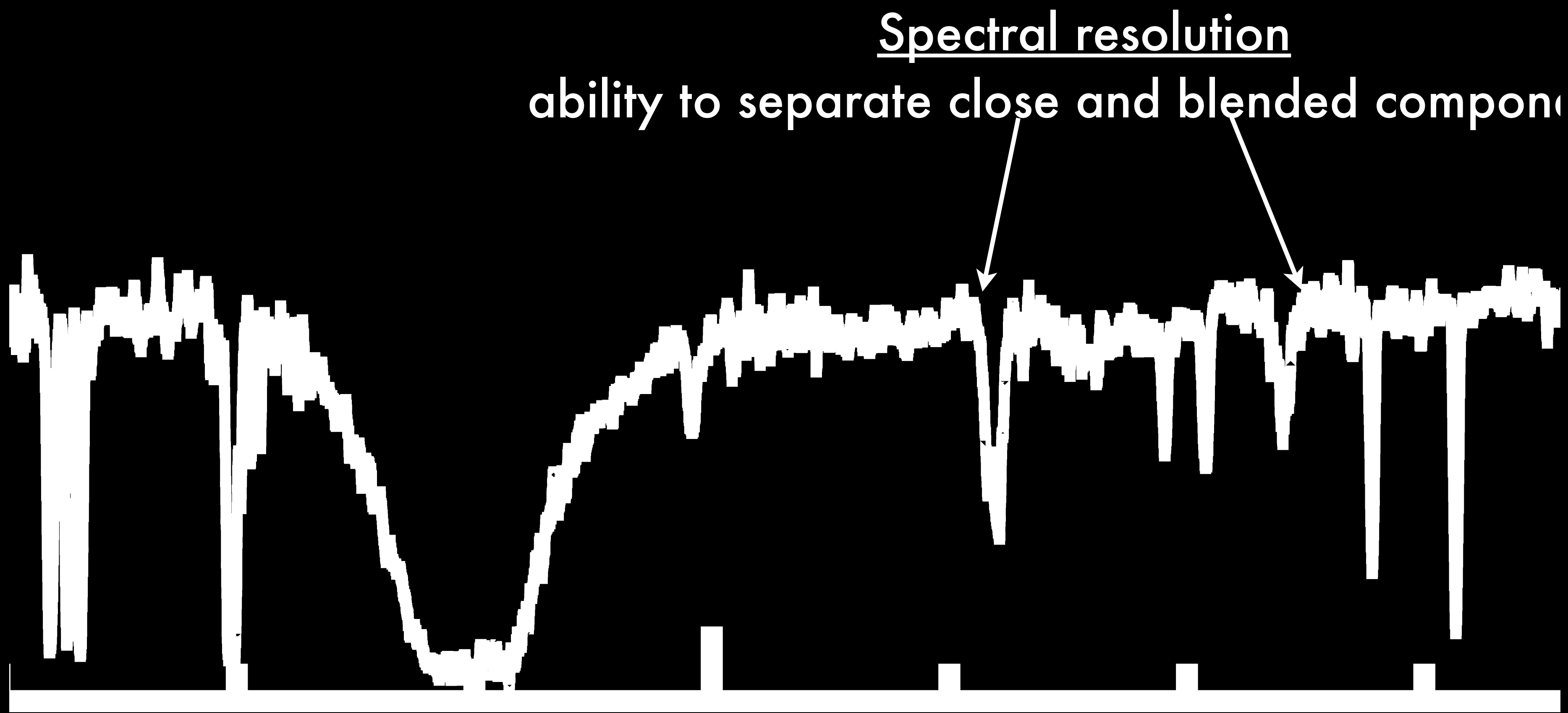

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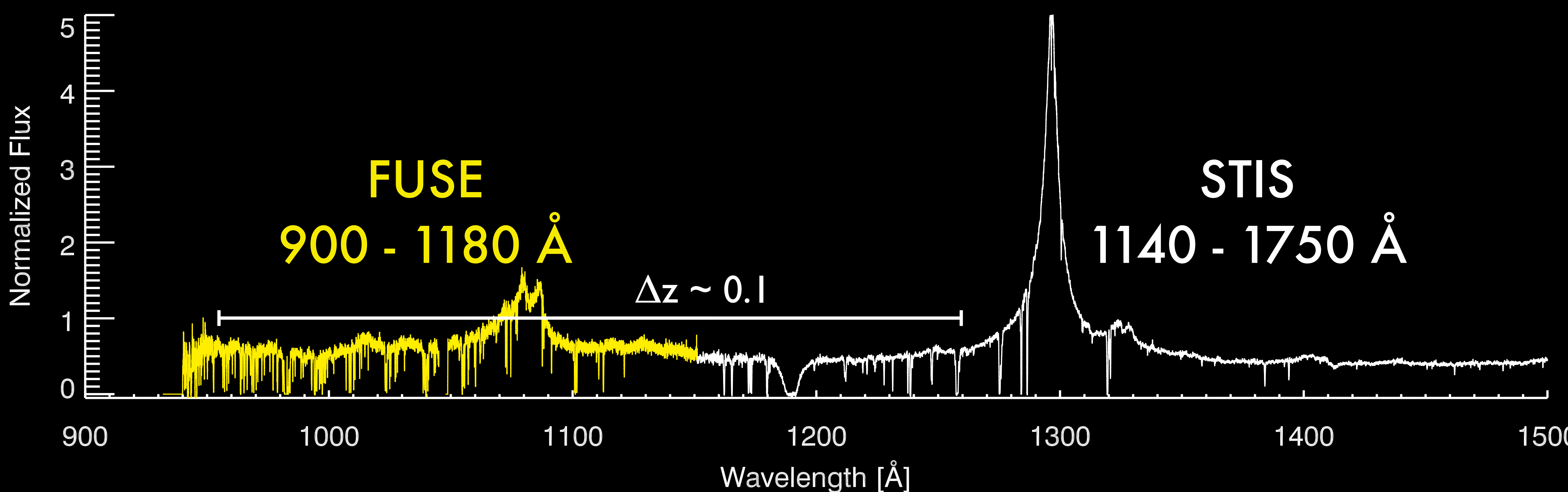


Critical factors for success:

Sensitivity to weak lines,

Spectral resolution to resolve components,

Wavelength coverage to build up total pathlength, and

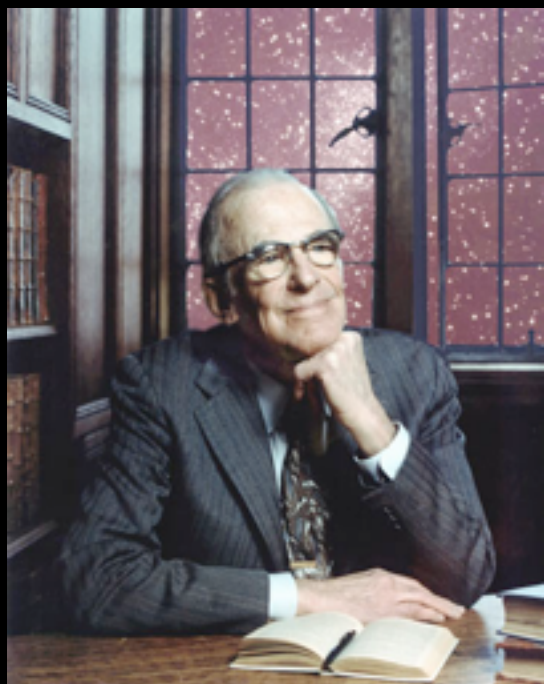
Access to UV wavelengths to measure physical diagnostics.

Part I

In which we see that gas outside galaxies occupied the minds that conceived and developed HST.

Spitzer's RAND Memo Proposes "LST" | Spitzer proposes a hot, extraplanar "Galactic Corona" | Quasars Discovered Schmidt & Oke | QSOALS / Lya Author

1946 | 1956 | 1963 | 19



The Astronomy Quarterly, Vol. 7, pp. 131-142, 1990
Printed in the USA.

0364-9229/90 $3.00+.00

ASTRONOMICAL ADVANTAGES OF AN EXTRA-TERRESTRIAL OBSERVATORY

LYMAN SPITZER, Jr. [1]

This study points out, in a very preliminary way, the results that might be expected from astronomical measurements made with a satellite vehicle. The discussion is divided into three parts, corresponding to three different assumptions concerning the amount of instrumentation provided. In the first section it is assumed that no telescope is provided; in the second a 10-inch reflector is assumed; in the third section some of the results obtainable with a large reflecting telescope, many feet in diameter, and revolving about the earth above the terrestrial atmosphere, are briefly sketched.

Spitzer's RAND Memo Proposes "LST" — 1946

Spitzer proposes a hot, extraplanar "Galactic Corona" — 1956

Quasars Discovered Schmidt & Oke — 1963

QSOALS / Lya Author — 19

Million degree coronal extragalactic gas may exist outside galaxies and be detectable via UV absorption!

ApJ, 124, 20

ON A POSSIBLE INTERSTELLAR GALACTIC CORONA*

LYMAN SPITZER, JR.
Princeton University Observatory

Received March 24, 1956

ABSTRACT

The physical conditions in a possible interstellar galactic corona are analyzed Pressure equilibrium between such a rarefied, high-temperature gas and normal interstellar clouds would account for the existence of such clouds far from the galactic plane and would facilitate the equilibrium of spiral arms in the presence of strong magnetic fields. Observations of radio noise also suggest such a corona.

At a temperature of 10^6 degrees K, the electron density in the corona would be $5 \times 10^{-4}/\mathrm{cm}^3$; the extension perpendicular to the galactic plane, 8000 pc; the total number of electrons in a column perpendicular to the galactic plane, about $2 \times 10^{19}/\mathrm{cm}^2$; the total mass, about $10^8 M_{\odot}$. The mean free path would be 4 pc, but the radius of gyration even in a field of 10^{-15} gauss would be a small fraction of this. Such a corona is apparently not observable optically except by absorption measures shortward of 2000 A.

While the interstellar corona can apparently not be observed by its emission spectrum, the number of atoms is sufficient to produce a measurable absorption line. A column of interstellar gas containing 10^{12} sodium atoms/cm² produces measurable D lines. The difficulty with this technique in the case of the solar corona is that at a high kinetic temperature the atoms will mostly be highly ionized, and the ultimate lines will all be in the far ultraviolet. If the state of ionization is like that in the solar corona, the ultimate resonance doublet of Mg X, at 609 and 625 A, should be extremely strong, since the number of magnesium ions in the line of sight in all stages of ionization would be about $10^{16}/\mathrm{cm}^2$; if 1 per cent of these atoms were in the ionized state Mg X, this doublet would be heavily absorbed. However, it is uncertain whether much radiation shortward of the Lyman limit can reach the earth, in view of probable heavy absorption by neighboring H I clouds. The ion O VI, which is isoelectronic to Mg X, has a corresponding doublet at 1038 and 1032 A and might be sufficiently abundant to produce measurable absorption, especially since the ionization potential of O VII has the relatively high value of 739 volts. Similarly, the ultimate lines of N V and C IV, at about 1240 and 1550 A, respectively, might be observable. It would appear that, in principle, an interstellar corona could be detected and analyzed by means of spectroscopic measures from a satellite.

hot, extraplanar "Corona"	Quasars Discovered Schmidt & Oke	QSOALS / Lya Forest Discovered Schmidt, Greenstein, Burbidge(s)	QSOALS from Galaxy Bahcall & Spitzer
6	1963	1960s	1969

Nature, 197, 1040

3C 273: A STAR-LIKE OBJECT WITH LARGE RED-SHIFT

By DR. M. SCHMIDT

Mount Wilson and Palomar Observatories, Carnegie Institution of Washington, California Institute of Technology, Pasadena

THE only objects seen on a 200-in. plate near the positions of the components of the radio source *3C* 273 reported by Hazard, Mackey and Shimmins in the preceding article are a star of about thirteenth magnitude and a faint wisp or jet. The jet has a width of 1″–2″ and extends away from the star in position angle 43°. It is not visible within 11″ from the star and ends abruptly at 20″ from the star. The position of the star, kindly furnished by Dr. T. A. Matthews, is R.A. 12h 26m 33·35s ± 0·04s, Decl. + 2° 19′ 42·0″ ± 0·5″ (1950), or 1″ east of component *B* of the radio source. The end of the jet is 1″ east of component *A*. The close correlation between the radio structure and the star with the jet is suggestive and intriguing.

Spectra of the star were taken with the prime-focus spectrograph at the 200-in. telescope with dispersions of 400 and 190 Å per mm. They show a number of broad emission features on a rather blue continuum. The most prominent features, which have widths around 50 Å, are, in order of strength, at 5632, 3239, 5792, 5032 Å. These and other weaker emission bands are listed in the first column of Table 1. For three faint bands with widths of 100–200 Å the total range of wave-length is indicated.

The only explanation found for the spectrum involves a considerable red-shift. A red-shift $\Delta\lambda/\lambda_0$ of 0·158 allows identification of four emission bands as Balmer lines, as indicated in Table 1. Their relative strengths are in agreement with this explanation. Other identifications based on the above red-shift involve the Mg II lines around 2798 Å, thus far only found in emission in the solar chromosphere, and a forbidden line of [O III] at 5007 Å. On this basis another [O III] line is expected at 4959 Å with a strength one-third of that of the line at 5007 Å. Its detectability in the spectrum would be marginal. A weak emission band suspected at 5705 Å, or 4927 Å reduced for red-shift, does not fit the wave-length. No explanation is

Table 1. WAVE-LENGTHS AND IDENTIFICATIONS

λ	$\lambda/1{\cdot}158$	λ_0	
3239	2797	2798	Mg II
4595	3968	3970	$H\epsilon$
4753	4104	4102	$H\delta$
5032	4345	4340	$H\gamma$
5200–5415	4490–4675		
5632	4864	4861	$H\beta$
5792	5002	5007	[O III]
6005–6190	5186–5345		
6400–6510	5527–5622		

Oke in a following article, and by the spectrum of another star-like object associated with the radio source *3C* 48 discussed by Greenstein and Matthews in another communication.

The unprecedented identification of the spectrum of an apparently stellar object in terms of a large red-shift suggests either of the two following explanations.

(1) The stellar object is a star with a large gravitational red-shift. Its radius would then be of the order of 10 km. Preliminary considerations show that it would be extremely difficult, if not impossible, to account for the occurrence of permitted lines and a forbidden line with the same red-shift, and with widths of only 1 or 2 per cent of the wave-length.

(2) The stellar object is the nuclear region of a galaxy with a cosmological red-shift of 0·158, corresponding to an apparent velocity of 47,400 km/sec. The distance would be around 500 megaparsecs, and the diameter of the nuclear region would have to be less than 1 kiloparsec. This nuclear region would be about 100 times brighter optically than the luminous galaxies which have been identified with radio sources thus far. If the optical jet and component *A* of the radio source are associated with the galaxy, they would be at a distance of 50 kiloparsecs, implying a time-scale in excess of 10^5 years. The total energy radiated in the optical range at constant luminosity would be of the order of 10^{59} ergs.

hot, extraplanar
Corona"
6

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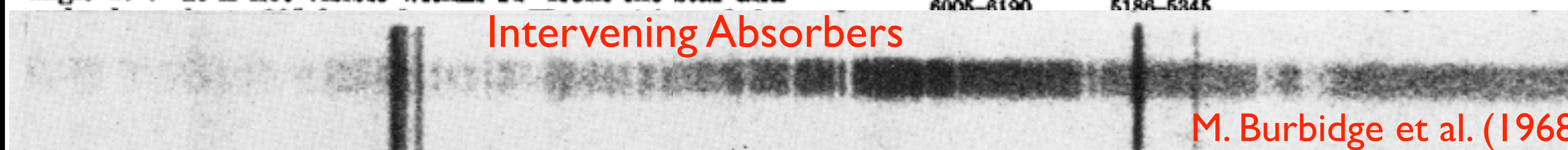

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Discovered Burbidge(s)	QSOALS from Galaxy Halos Bahcall & Spitzer	Science Case Built for HST Spitzer, Bahcall, et al.	HST Launched (STS-31)
	1969	late 60s - 1977	April 1990

ABSORPTION LINES PRODUCED BY GALACTIC HALOS

JOHN N. BAHCALL*
Institute for Advanced Study

AND

LYMAN SPITZER, JR.
Princeton University Observatory

Received March 24, 1969

ABSTRACT

We propose that most of the absorption lines observed in quasi-stellar sources with multiple absorption redshifts are caused by gas in extended halos of normal galaxies.

Recent work has established that some quasi-stellar sources have multiple redshift systems in absorption (Bahcall 1968; Bahcall, Greenstein, and Sargent 1968; Burbidge, Lynds, and Stockton 1968; Burbidge 1969; Bahcall, Osmer, and Schmidt 1969). A number of possible explanations have been suggested for this phenomenon (Bahcall *et al.* 1968; Burbidge *et al.* 1968; Peebles 1968), but none of the suggestions seem especially plausible when considered in the light of the observed features of the absorption systems. We propose that most of the absorption lines are caused by tenuous gas in extended halos of normal galaxies (see Spitzer 1956 for a review of some earlier work on galactic halos and for a preliminary discussion of the possibility of observing ultraviolet absorption lines formed in such halos).

Proposed that the QSOALS then known arose in extended galaxy halos: R = 100 kpc versus the 10-20 kpc then believed based on optical and radio measurements.

alaxy Halos
Spitzer

Science Case Built for HST
Spitzer, Bahcall, et al.

Key Projects
Identified

HST Launched
(STS-31)

Ground
Paloma

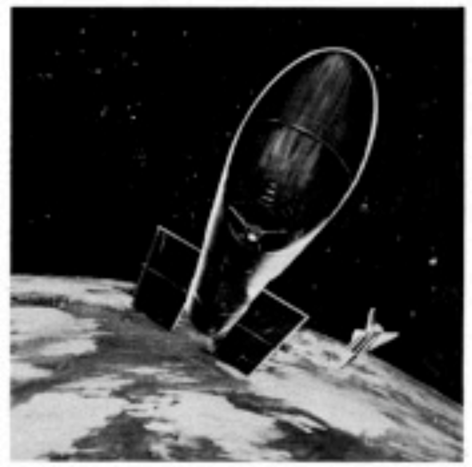
late 60s - 1977

1985

April 1990

1974

Large Space Telescope — a New Tool for Science



OBSERVING QUASARS WITH THE LST

E. Margaret Burbidge
University of California, San Diego
La Jolla, California

ABSTRACT

The quasi-stellar objects (QSOs) are still a mystery as far as their energy source and physical nature are concerned. An understanding of them might throw light on basic problems such as the behavior and interaction of matter and radiation in very strong gravitational fields, and the cosmogony of galaxies. The LST will open up exciting new ways to study QSOs, e.g., observation of the UV in the crucial region 912-1550 Å in QSOs with small redshifts. Searches for and studies of QSOs fainter than 20 mag and the removal of observational limits that restrict complete samples may help us to understand the nature of the redshifts.

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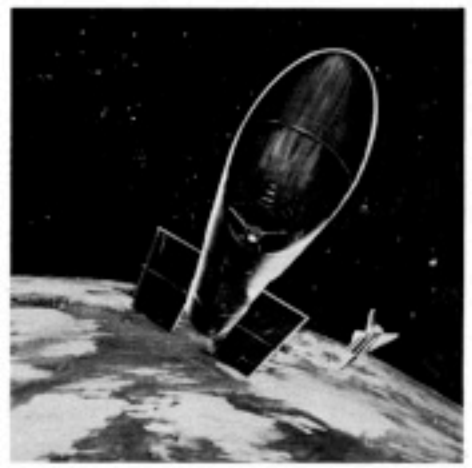

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1985

RECOMMENDATIONS OF THE SPACE TELESCOPE

WORKING GROUP ON THE ISM/IGM/SNR

C.F. McKee (Chair), E. Becklin, A. Boksenberg, J. Black,

L. Cowie, J. Danziger, E. Jenkins, R. Kirshner, R. McCray,

M. Peimbert, J. Raymond, P. Solomon, A. Vidal-Madjar, D. York

II Recommended Key Projects

1. Quasar Absorption Line Key Project

Two of the central problems in astrophysics are the distribution of matter in the Universe and the abundances of the elements. Observations of quasar absorption line—or, more generally, absorption lines in any bright, distant object—reveal the presence of diffuse baryonic matter which is not observable in emission. Ground—based observations have established the existence of three classes of quasar absorption line systems: (1) Lyman α systems, which are found to the blue of Lyman α in emission and show no evidence for metals. There is no evidence for clustering in redshift, as would be expected if the absorbing gas were associated with galaxies. These systems are interpreted as occurring in primordial intergalactic clouds, and

Lyman α systems:

- How do the number density and physical properties of these systems evolve with redshift for $z \lesssim 1.6$?
- Are any of the Lα systems actually high excitation metallic systems with OVI? Again, low redshifts are required to reduce confusion.

Distribution of gas in galactic halos, clusters of galaxies, and voids:

- What is the nature of the gas in the halo of the Galaxy, including the high-velocity clouds?
- How large are gaseous galactic halos, and how do they correlate with galaxy type? Such data could give insight into how gaseous halos affect galactic evolution, particularly the chemical evolution of the interstellar medium.

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Large Space

OB

Univ

La Jolla, California

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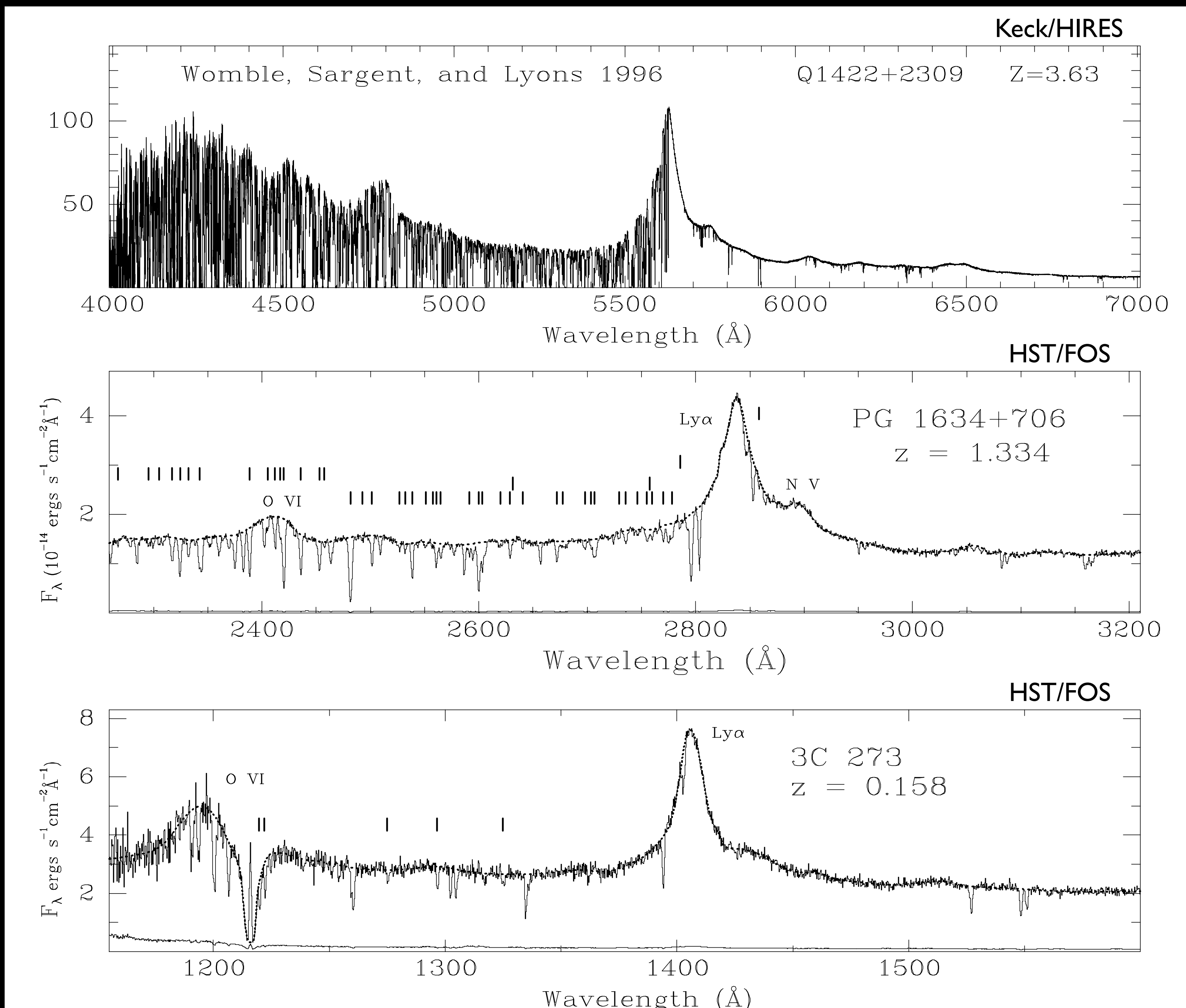
Lessons of Part I

The goal of studying gas between galaxies and in their halos was a prime motivator for HST and particularly for its spectrographs.

Part II

In which we see that HST identified the shape of the IGM, its physical state, and the distribution of chemical enrichment.

HST Launched (STS-31)	Ground-based work on Lya forest Palomar, Lick, MMT, KPNO, Keck	HST Key Project Quasar Absorption Lines
April 1990	80s, early 90s	1990-1995 (Cycles 1-4)



B. Jannuzi review at HST2 conference Paris

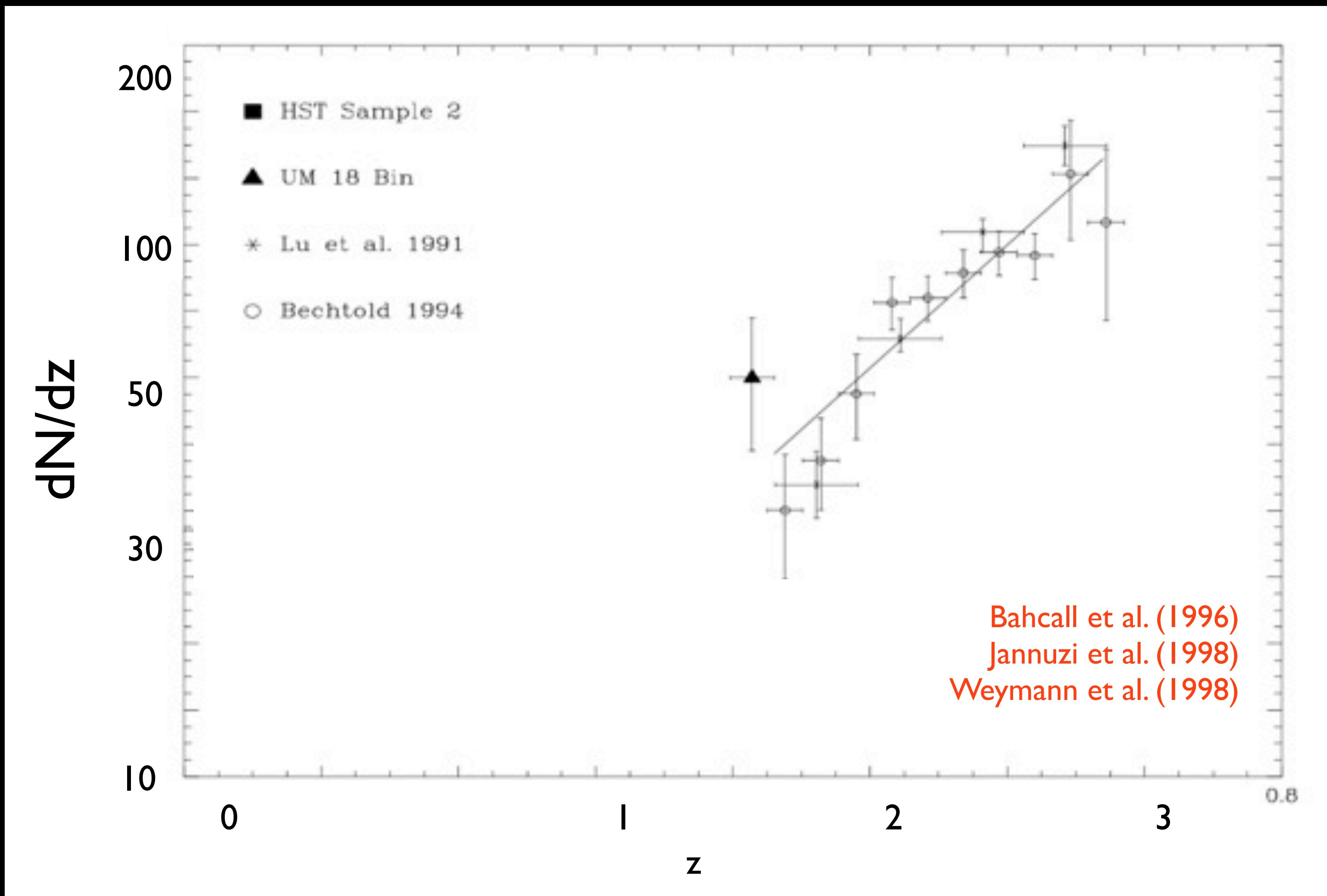
The HST Key Project on Quasar Absorption Lines
PI John Bahcall

250 Orbits with the FOS and GHRS

89 QSOs, 1600 - 3200 Å at R = 1300.
Typical limiting equivalent width 0.24 Å.

The “Lya forest” becomes a clearing, but not as quickly as expected!

Ground-based work on Lya forest Palomar, Lick, MMT, KPNO, Keck	HST Key Project Quasar Absorption Lines	STIS Installed in HST SM2
80s, early 90s	1990-1995 (Cycles 1-4)	1997



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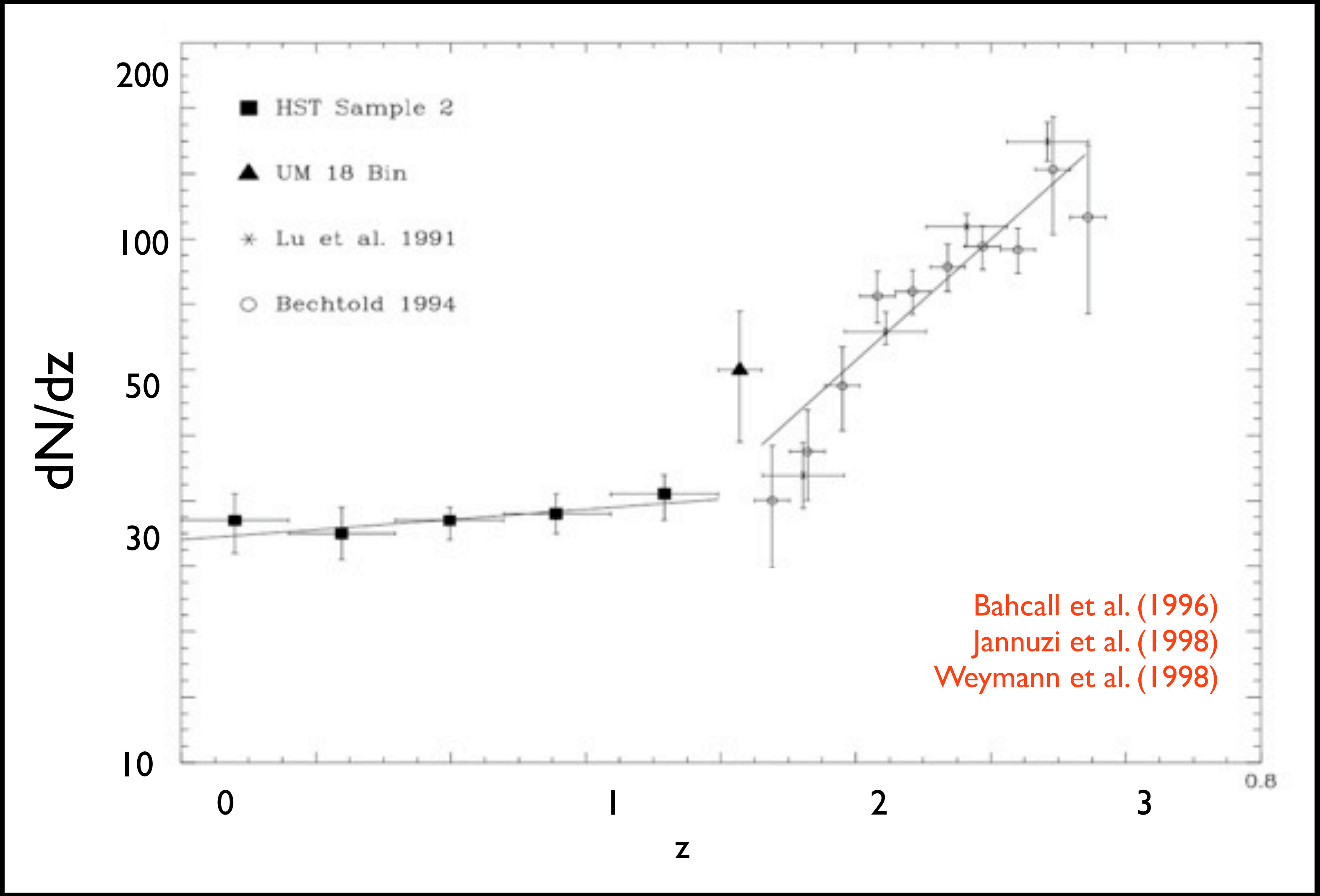

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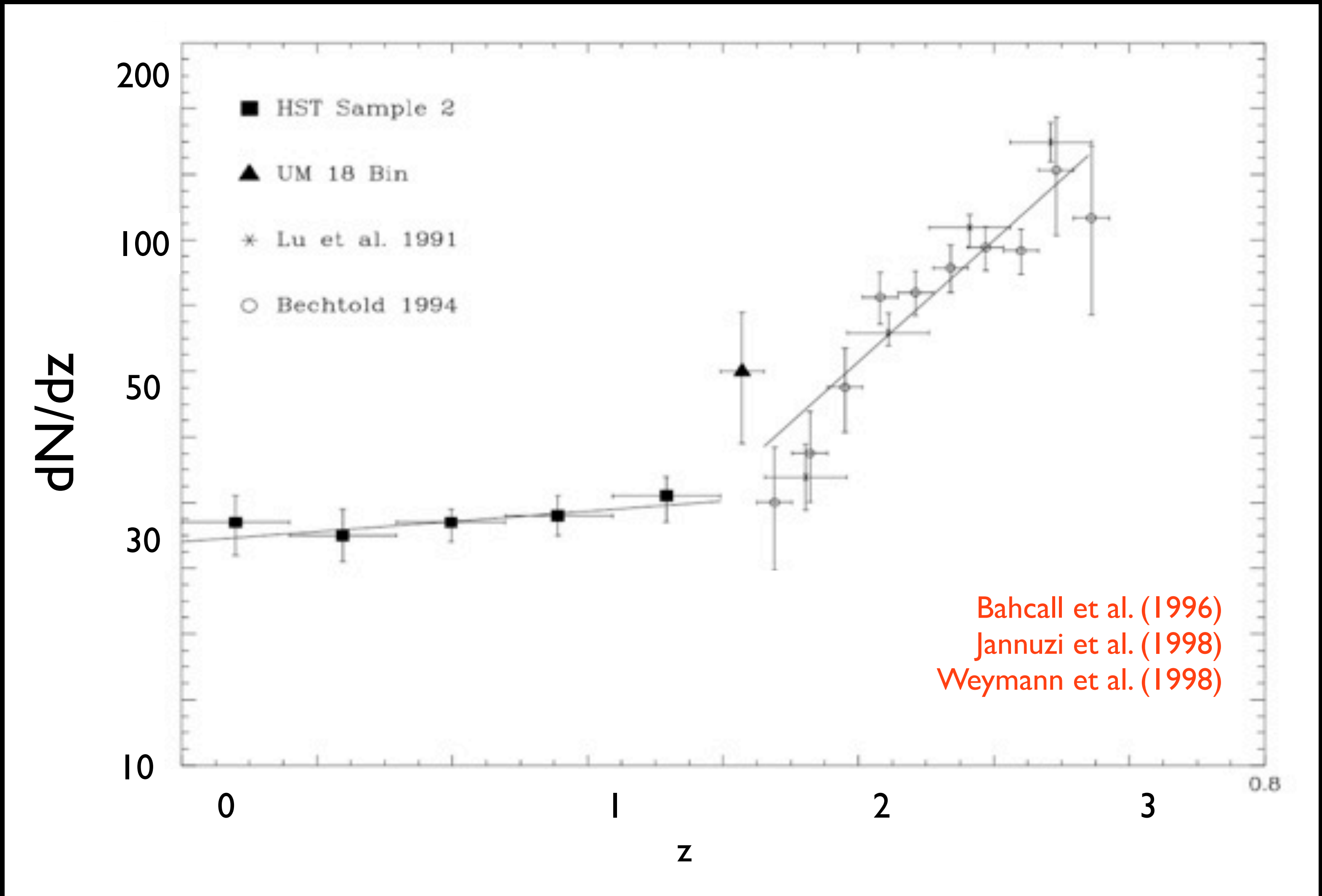
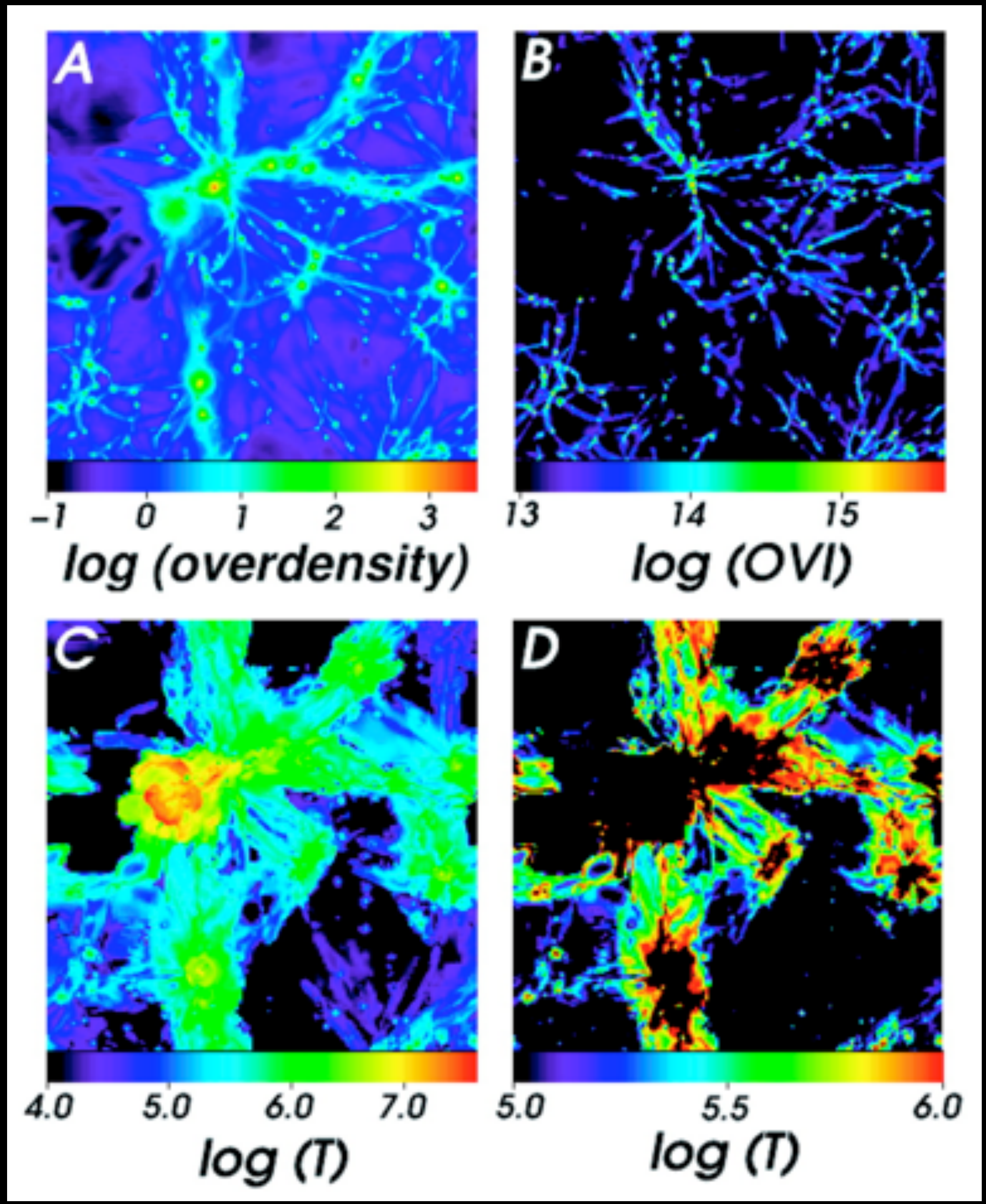


Fang & Bryan (2001)



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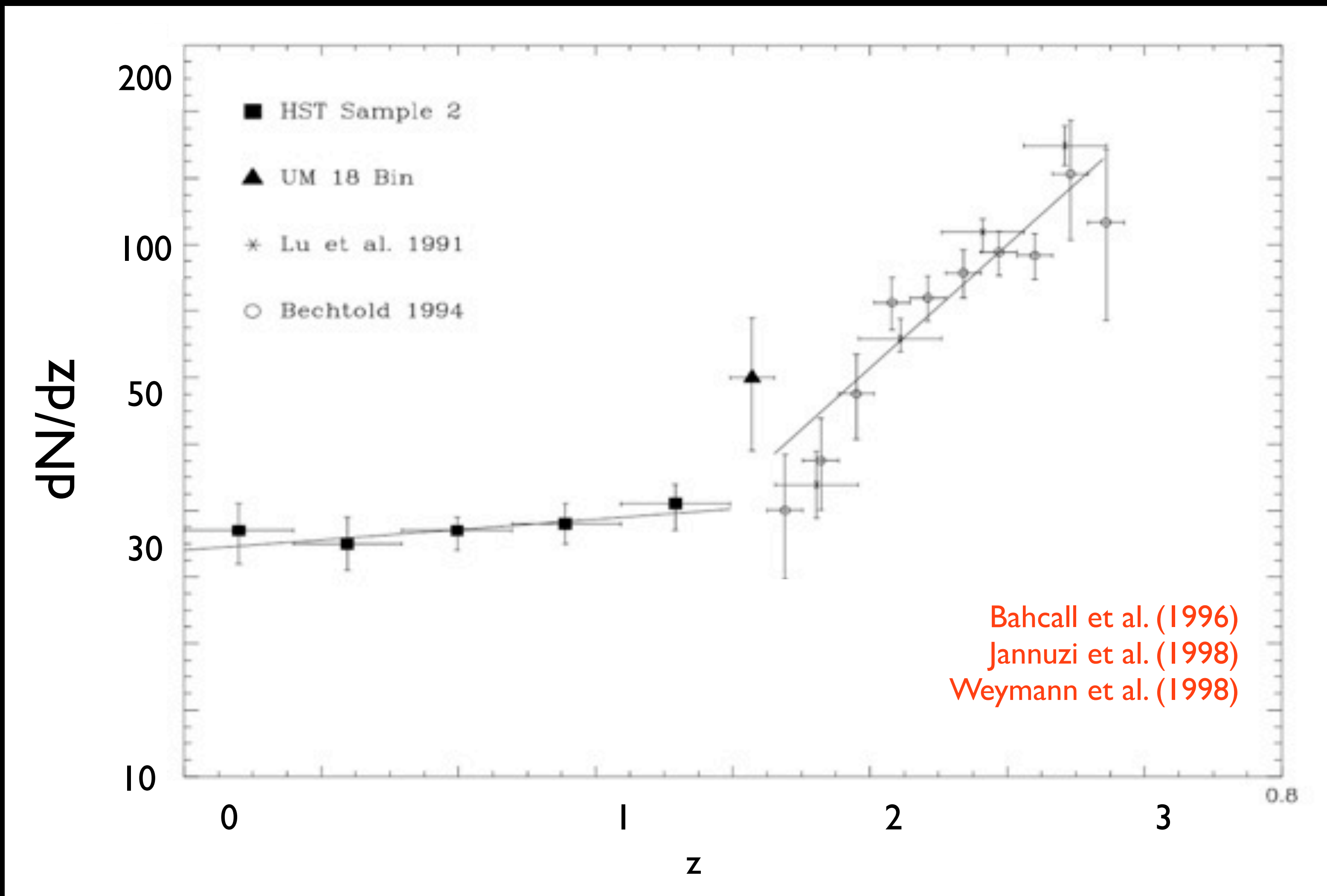

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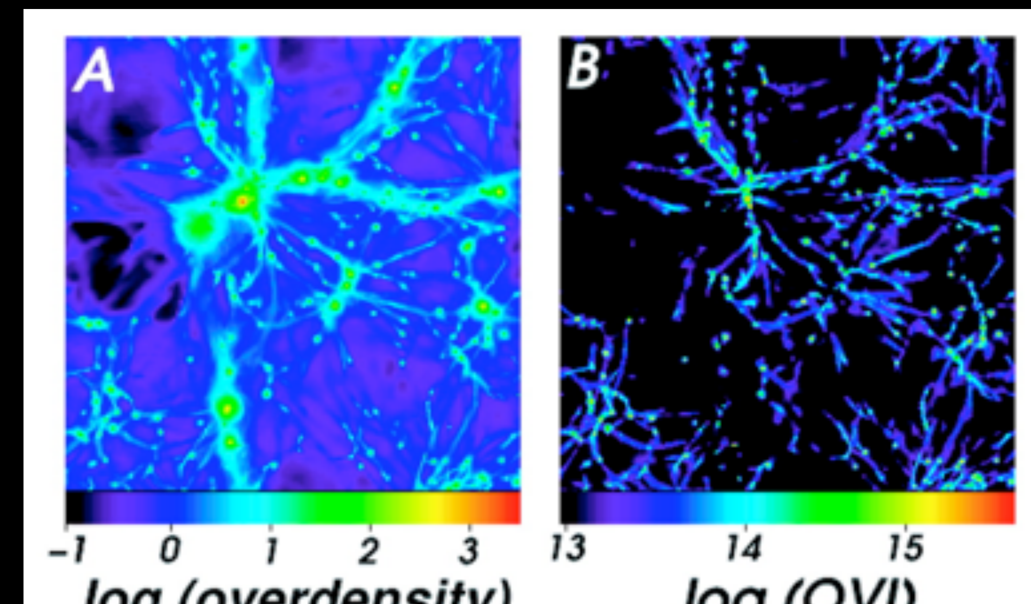
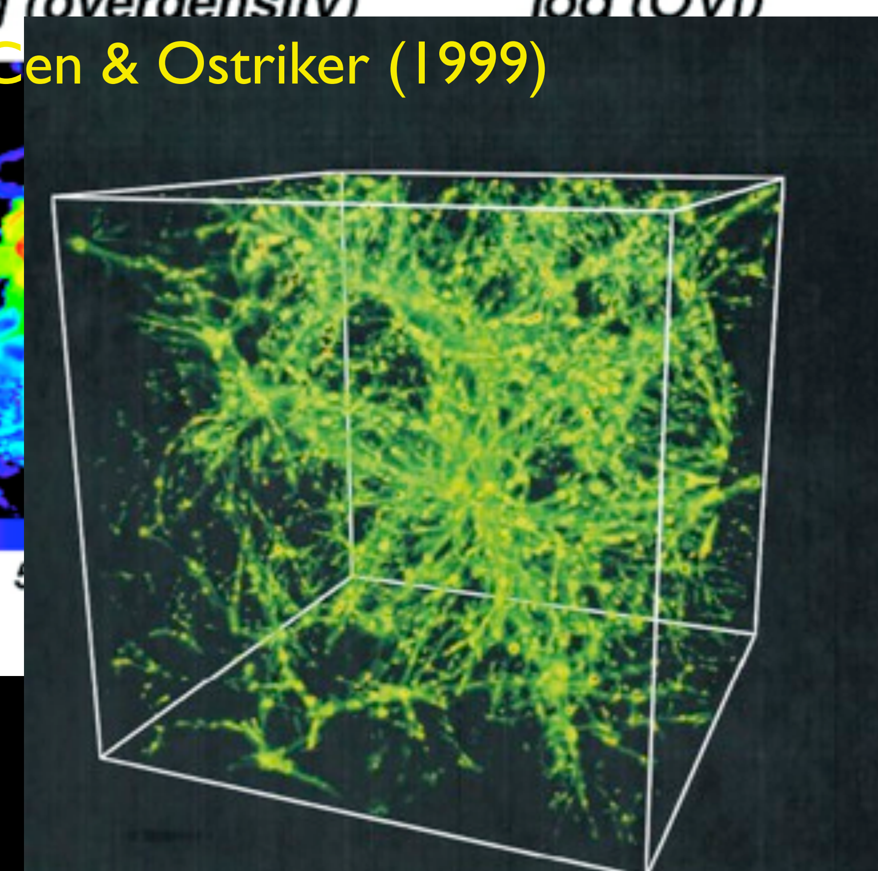


Cen & Ostriker (1999)



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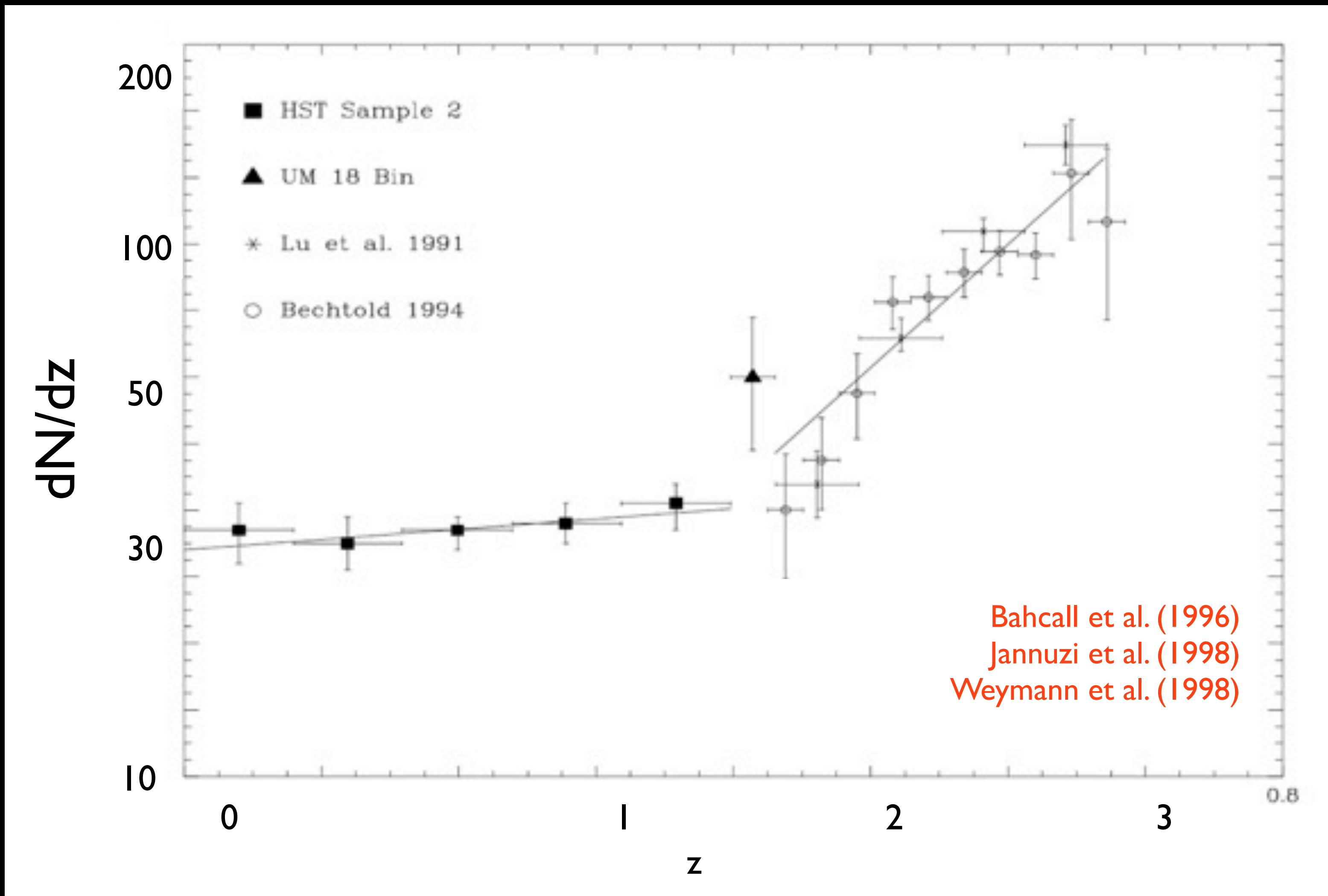
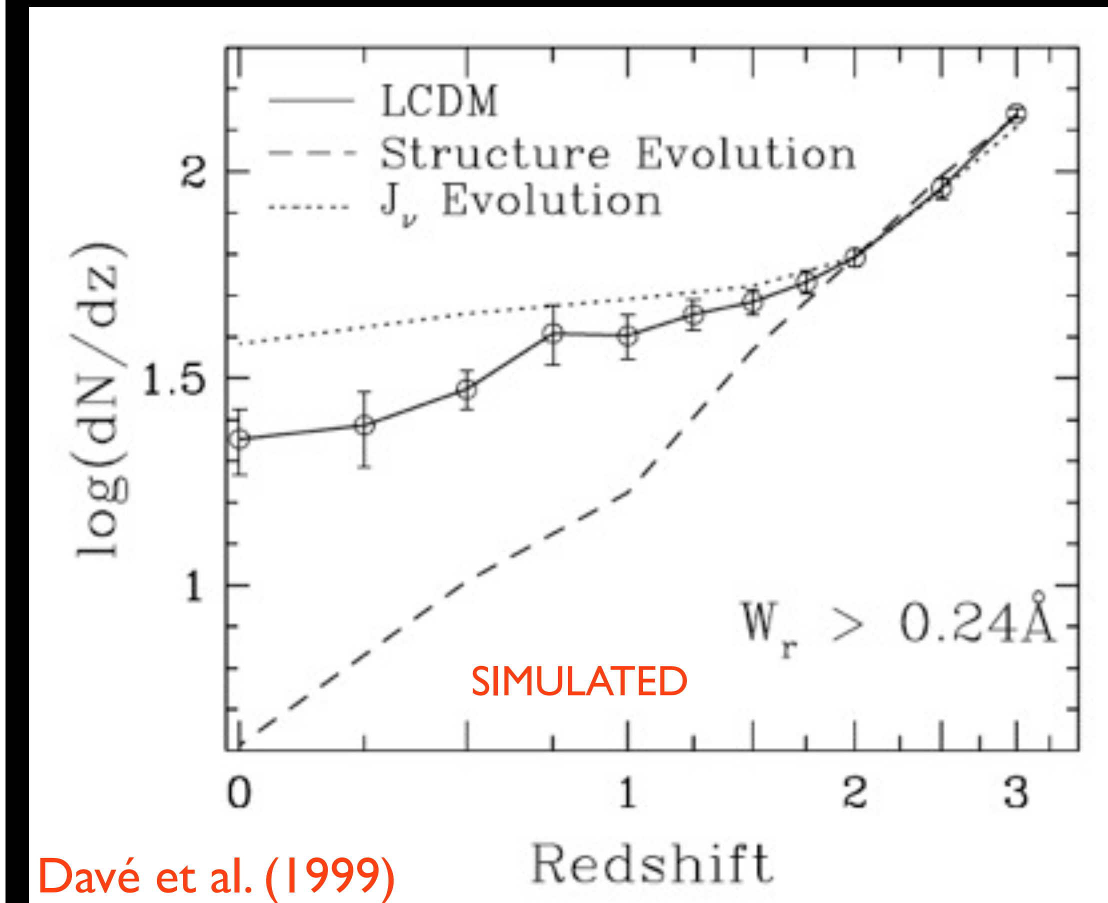




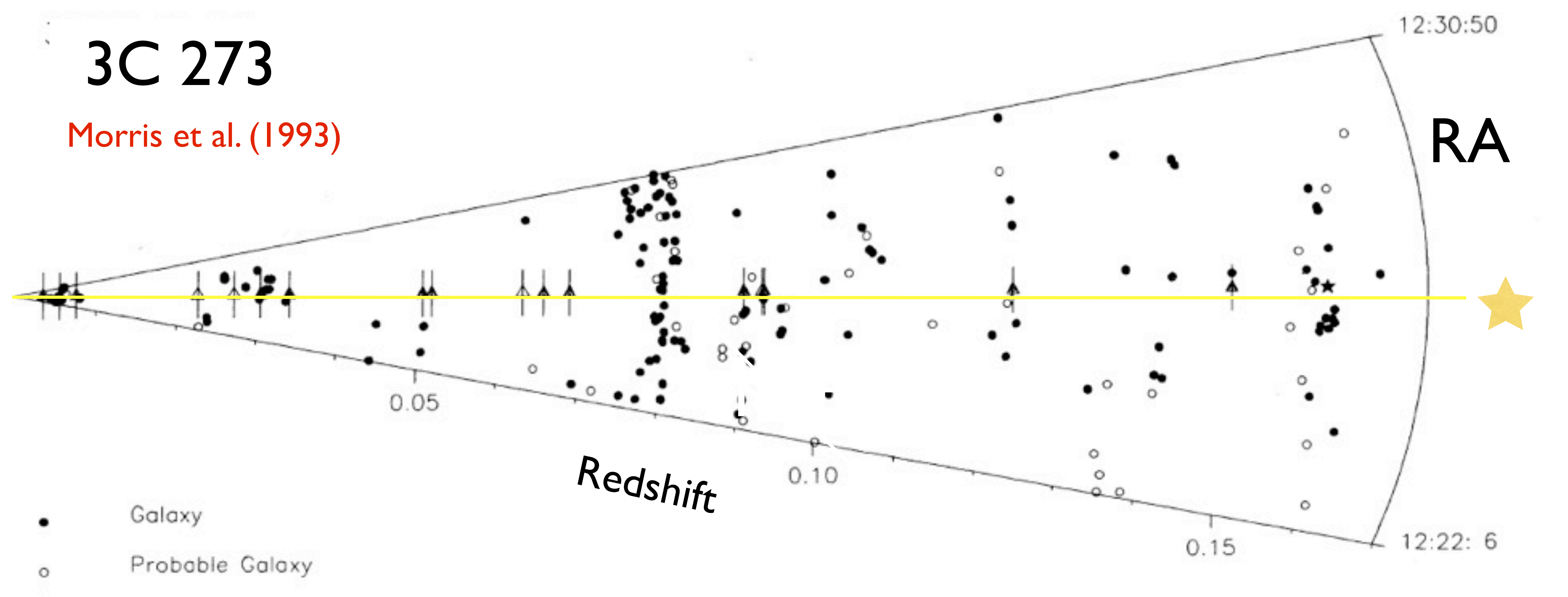
WHY?

(1) as the Universe expands, the recombination rate of ionized gas declines with the density so dN/dz goes DOWN. . .

(2) but the global SFR and the QSO luminosity function also decline, so the photoionization rate declines also in partial compensation.

This is crucial, since we now know the number density and ionization balance of the Lyα forest.

Ground-based work on Lya forest Palomar, Lick, MMT, KPNO, Keck	HST Key Project Quasar Absorption Lines	STIS Installed in HST SM2
80s, early 90s	1990-1995 (Cycles 1-4)	1997



Post-facto galaxy surveys, now routine with modern galaxy redshift surveys (e.g. CfA, SDSS), have revealed the distribution of the IGM with respect to galaxies.

Stocke et al. (2006) found a median distance ~200-300 kpc, but some metals are found > 1 Mpc from galaxies.

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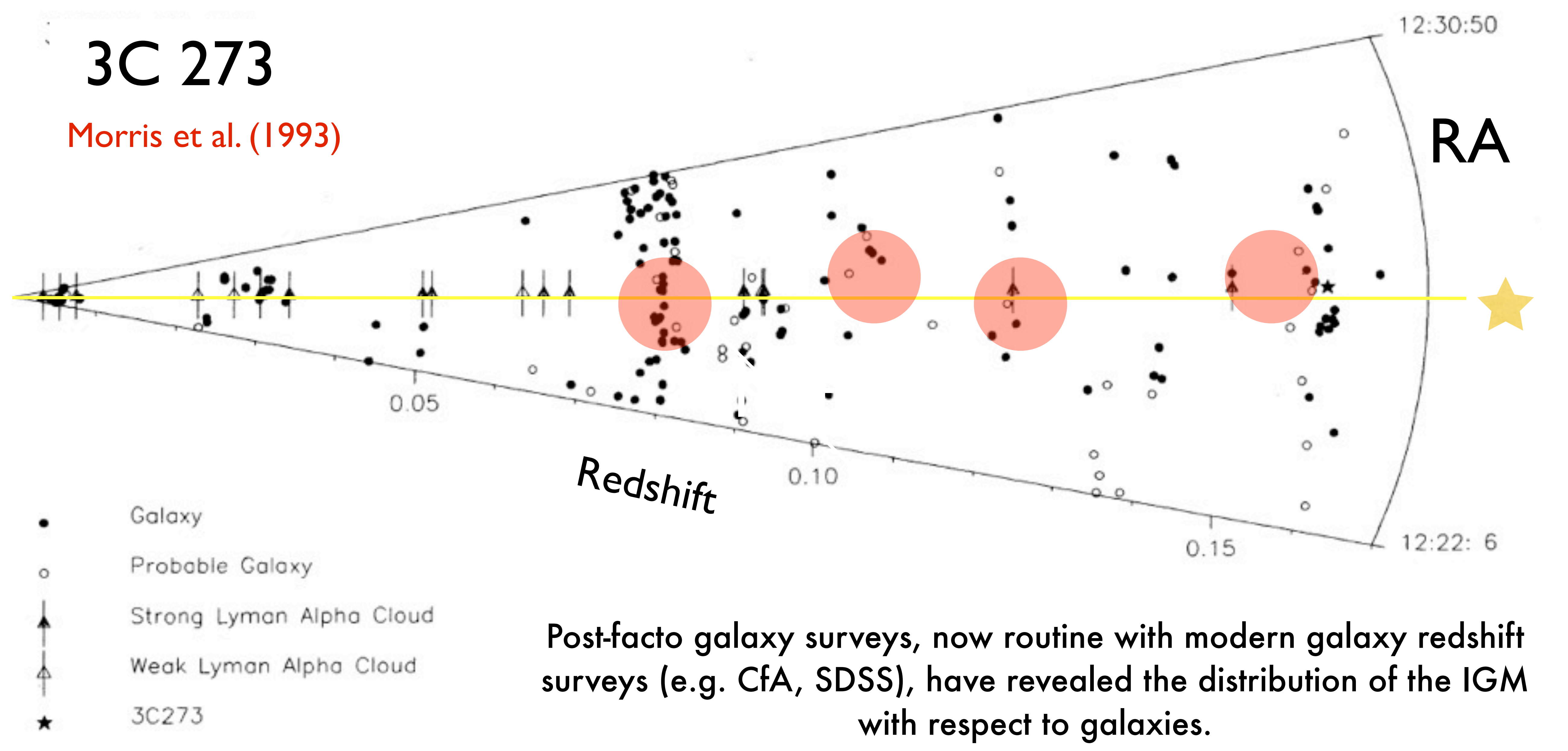

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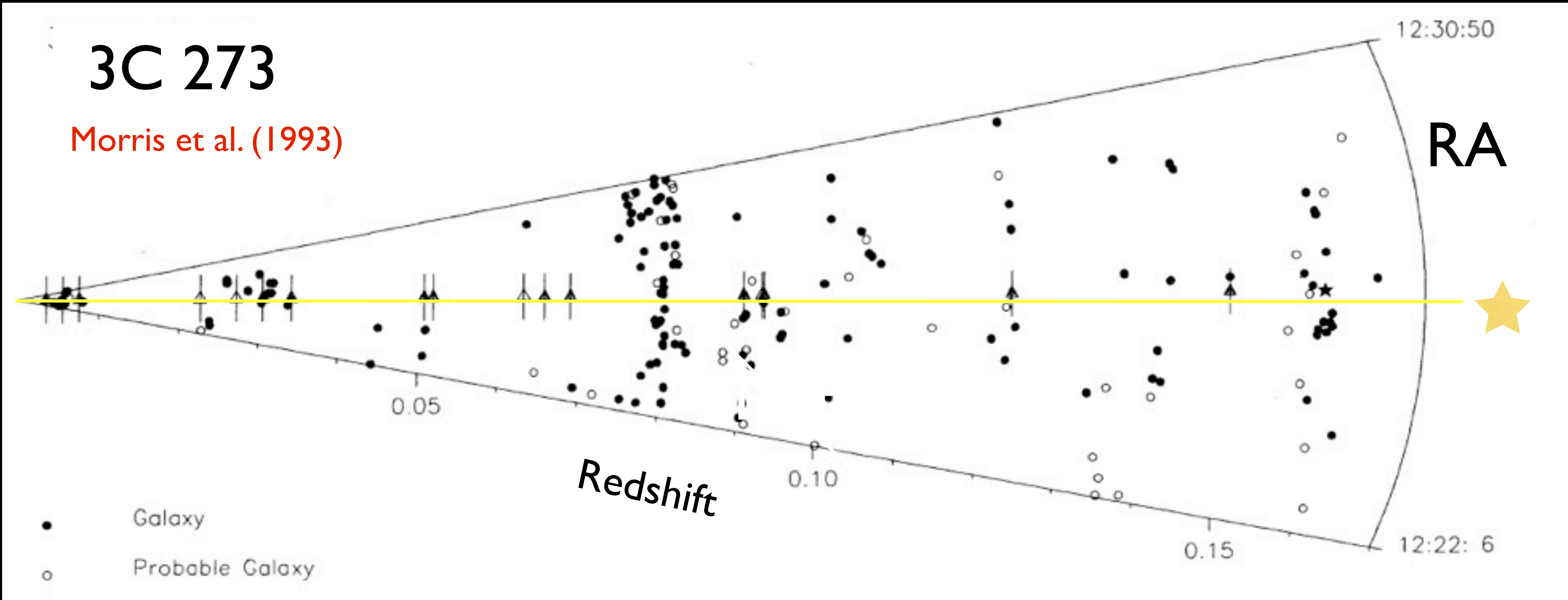

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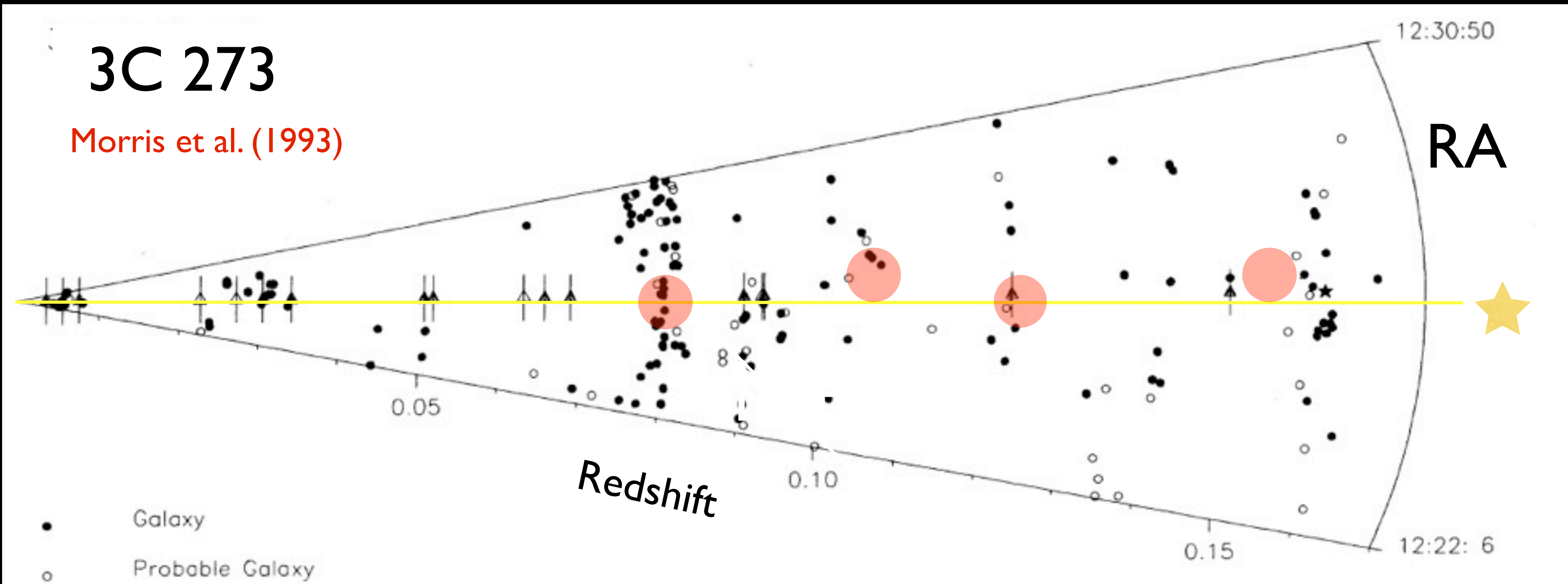

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Lessons of Part II

HST (FOS+GHRS) have now mapped the weblike structure of the IGM, measured its temperature and density, and constrained the spread of metals.

The IGM is now well understood. Right?

Part III

In which we see that most of the normal matter in the Universe goes missing and some of it gets found by HST.

STIS Installed in HST SM2	COS Selected for SM4	**Cosmic Baryon Budget Underruns**	FUSE Launches 1000-1200 A	Interveni Tripp e
1997	1997	**1998**	1999	200

THE COSMIC BARYON BUDGET

M. FUKUGITA

Institute for Advanced Study, Princeton, NJ 08540; and Institute for Cosmic Ray Research, University of Tokyo, Tanashi, Tokyo 188, Japan; fukugita@icrr.u-tokyo.ac.jp

C. J. HOGAN

Departments of Astronomy and Physics, University of Washington, Seattle, WA 98195; hogan@astro.washington.edu

AND

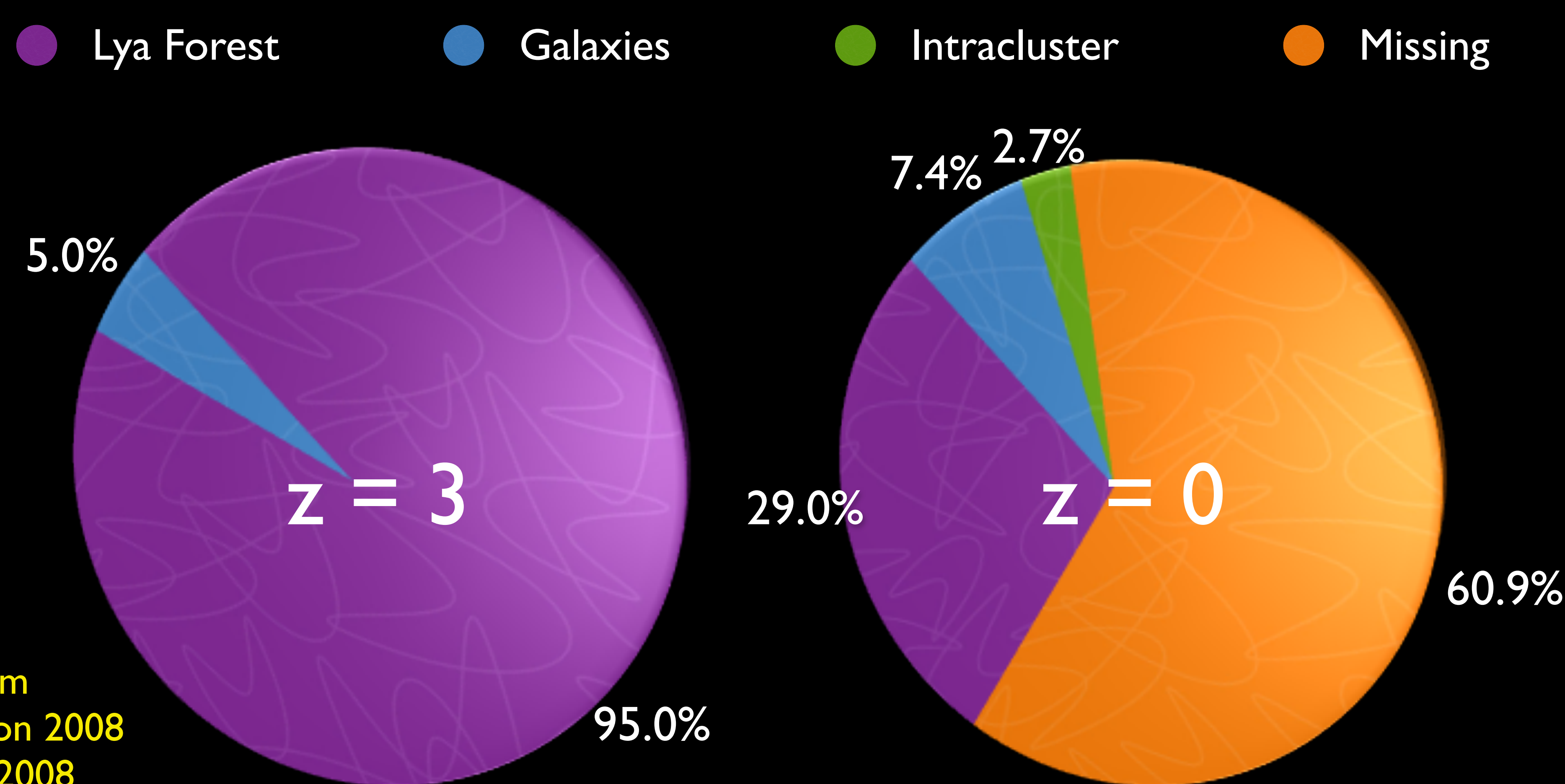
P. J. E. PEEBLES

Joseph Henry Laboratories, Princeton University, Princeton, NJ 08544; pjep@pupgg.princeton.edu

Received 1997 December 2; accepted 1998 March 26

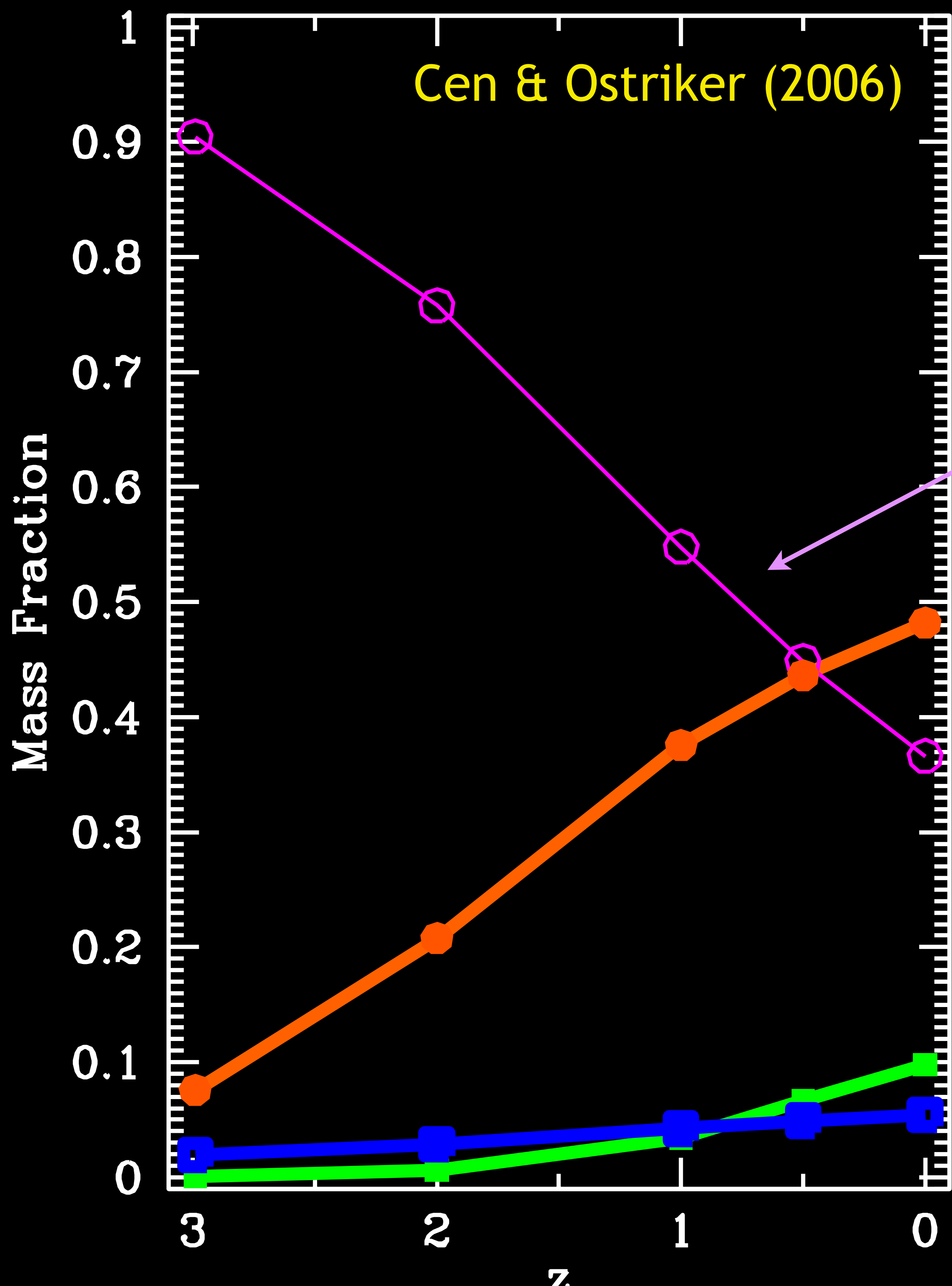
ABSTRACT

We present an estimate of the global budget of baryons in all states, with conservative estimates of the uncertainties, based on all relevant information we have been able to marshal. Most of the baryons today are still in the form of ionized gas, which contributes a mean density uncertain by a factor of about 4. Stars and their remnants are a relatively minor component, comprising for our best-guess

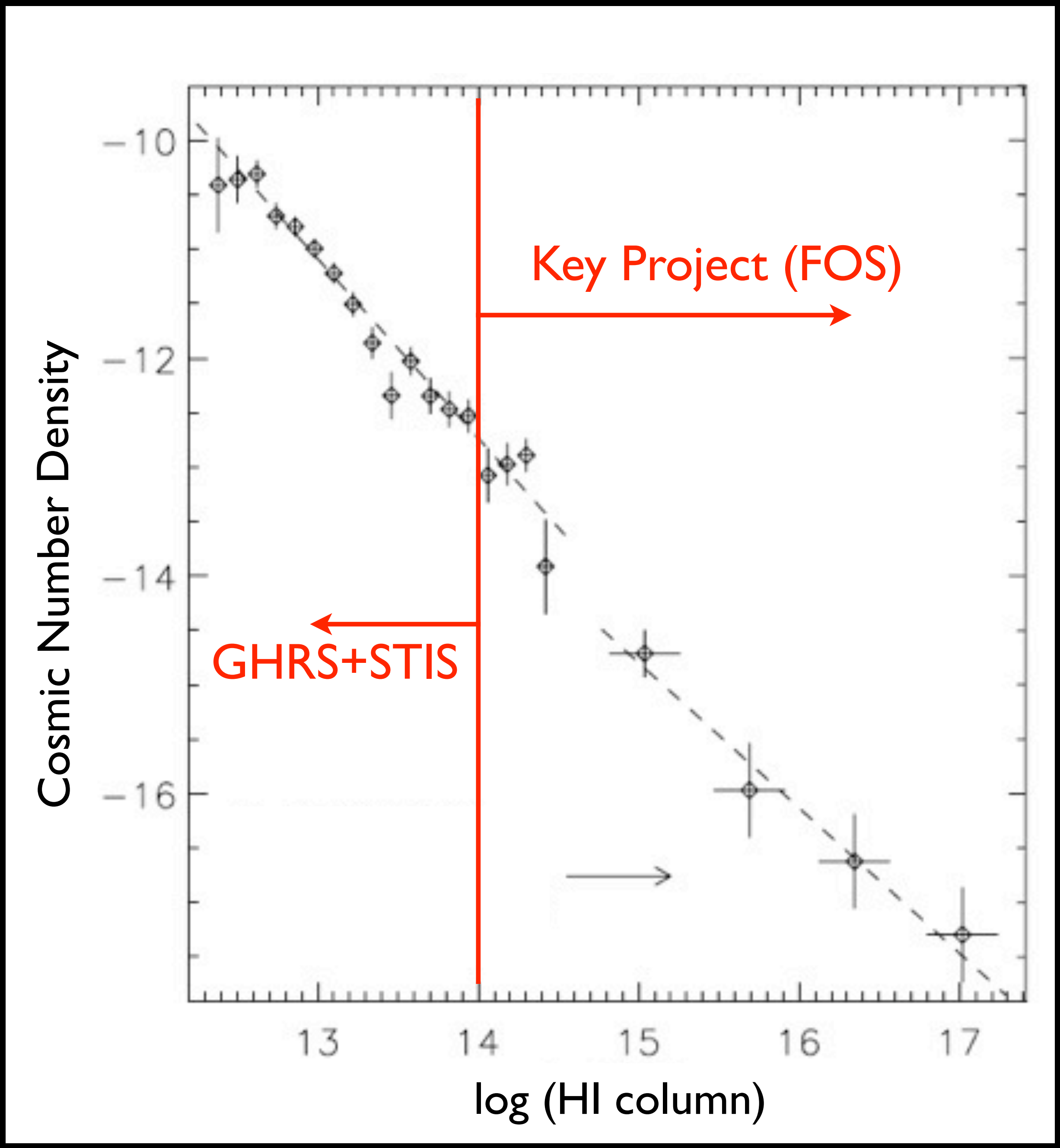


Accounting from
Prochaska & Tumlinson 2008
Danforth & Shull 2008

STIS Installed in HST SM2	COS Selected for SM4	Cosmic Baryon Budget Underruns	FUSE Launches 1000-1200 A	Intervenin… Tripp e…
1997	1997	1998	1999	200…



From z = 3 to 0, mass fraction in 10,000K gas ionized by stars and AGN declines from 90 to ~35%.



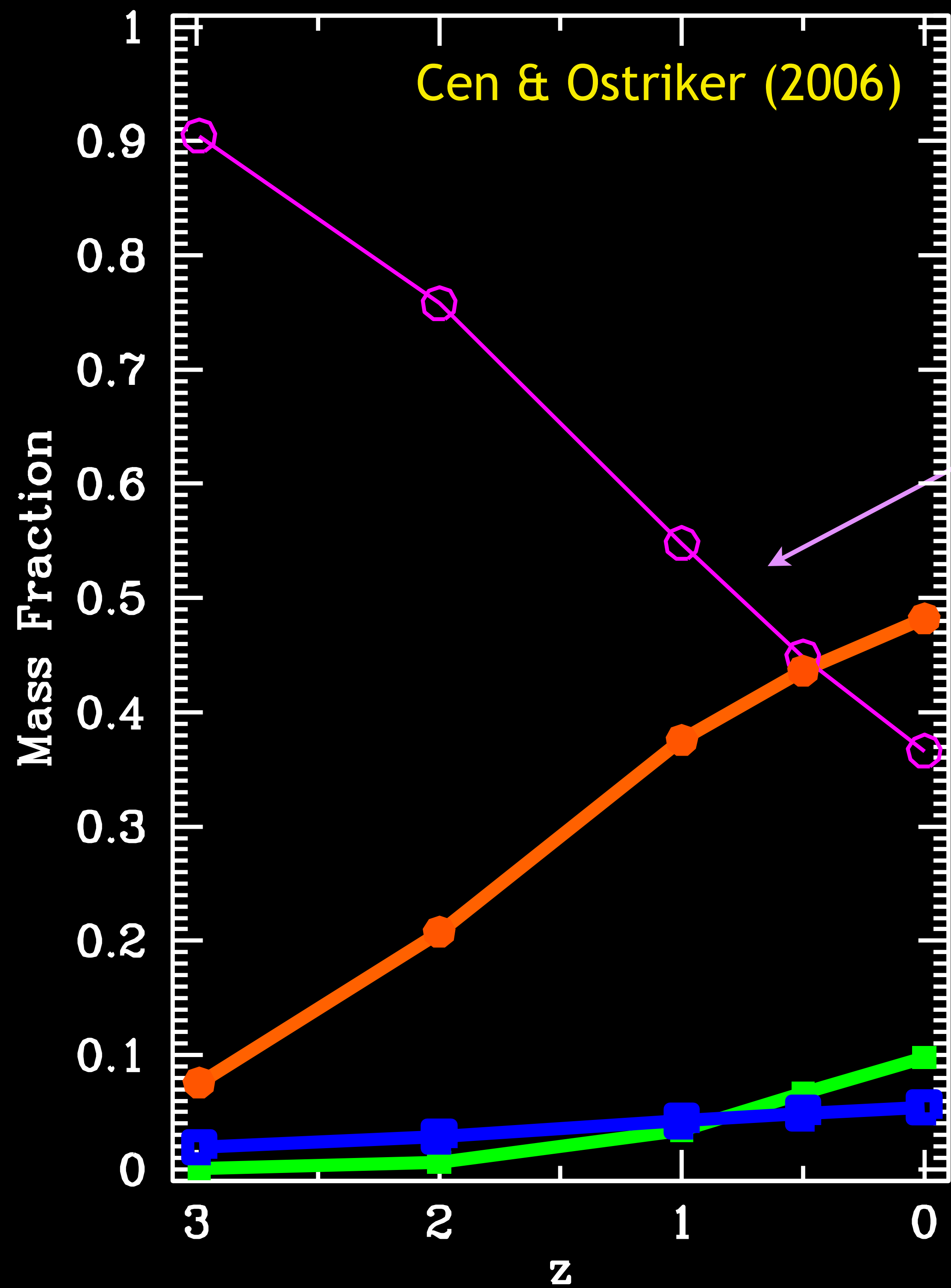
Penton, Stocke, & Shull (2000-2004) used GHRS and later STIS to examine weak Lyα clouds below the limits of the FOS Key Project.

After counting clouds and applying a photoionization correction checked against simulations, the found that:

$$\Omega_{Ly\alpha} = 29 \pm 4\ \%\ \text{of}\ \Omega_b$$

About 1/2, or 15% of baryons, are in absorbers too weak to have been detected by the FOS Key Project.

STIS Installed in HST SM2	COS Selected for SM4	**Cosmic Baryon Budget Underruns**	FUSE Launches 1000-1200 A	Intervenin Tripp e
1997	1997	**1998**	1999	200



From z = 3 to 0, mass fraction in 10,000K gas ionized by stars and AGN declines from 90 to ~35%.

$\Omega_{Ly\alpha}$ = 29 ± 4 % of Ω_b ✔

STIS Installed in HST SM2	COS Selected for SM4	Cosmic Baryon Budget Underruns	FUSE Launches 1000-1200 A	Interveni… Tripp e…
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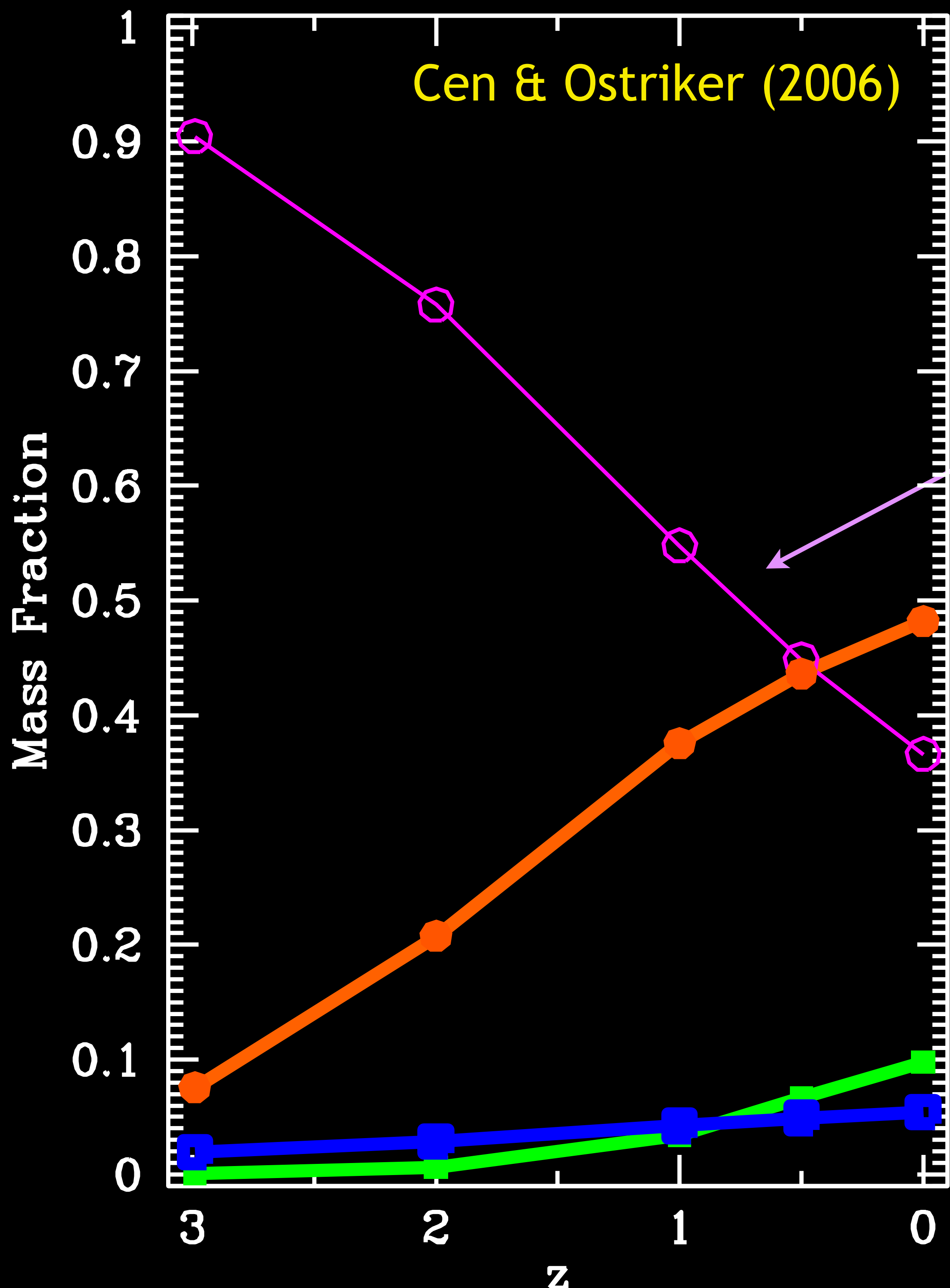


From z = 3 to 0, mass fraction in 10,000K gas ionized by stars and AGN declines from 90 to ~35%.

$\Omega_{Ly\alpha}$ = 29 ± 4 % of Ω_b ✔

While the mass fraction of gas at **T > 10^5 - 10^7 K** increases to ~40%

"Warm Hot Intergalactic Medium", or "WHIM" gas that is shock-heated to 10^{5-7} K by collapse into the dense regions of the "cosmic web".

STIS Installed in HST SM2	COS Selected for SM4	**Cosmic Baryon Budget Underruns**	FUSE Launches 1000-1200 A	Interveni[ng] Tripp e[t al.]
1997	1997	**1998**	1999	200[0]

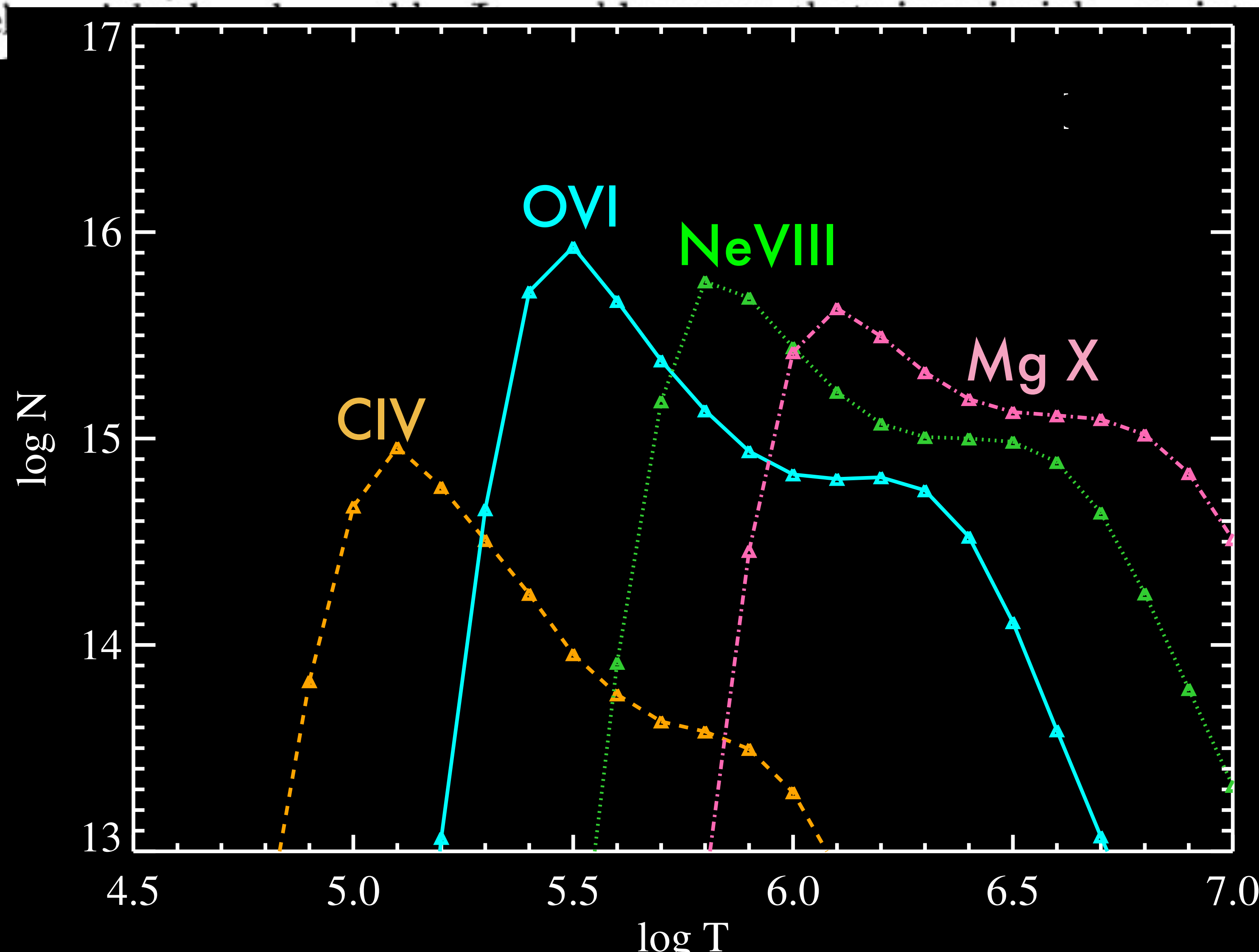
ApJ, 124, 20

ON A POSSIBLE INTERSTELLAR GALACTIC CORONA*

LYMAN SPITZER, JR.
Princeton University Observatory

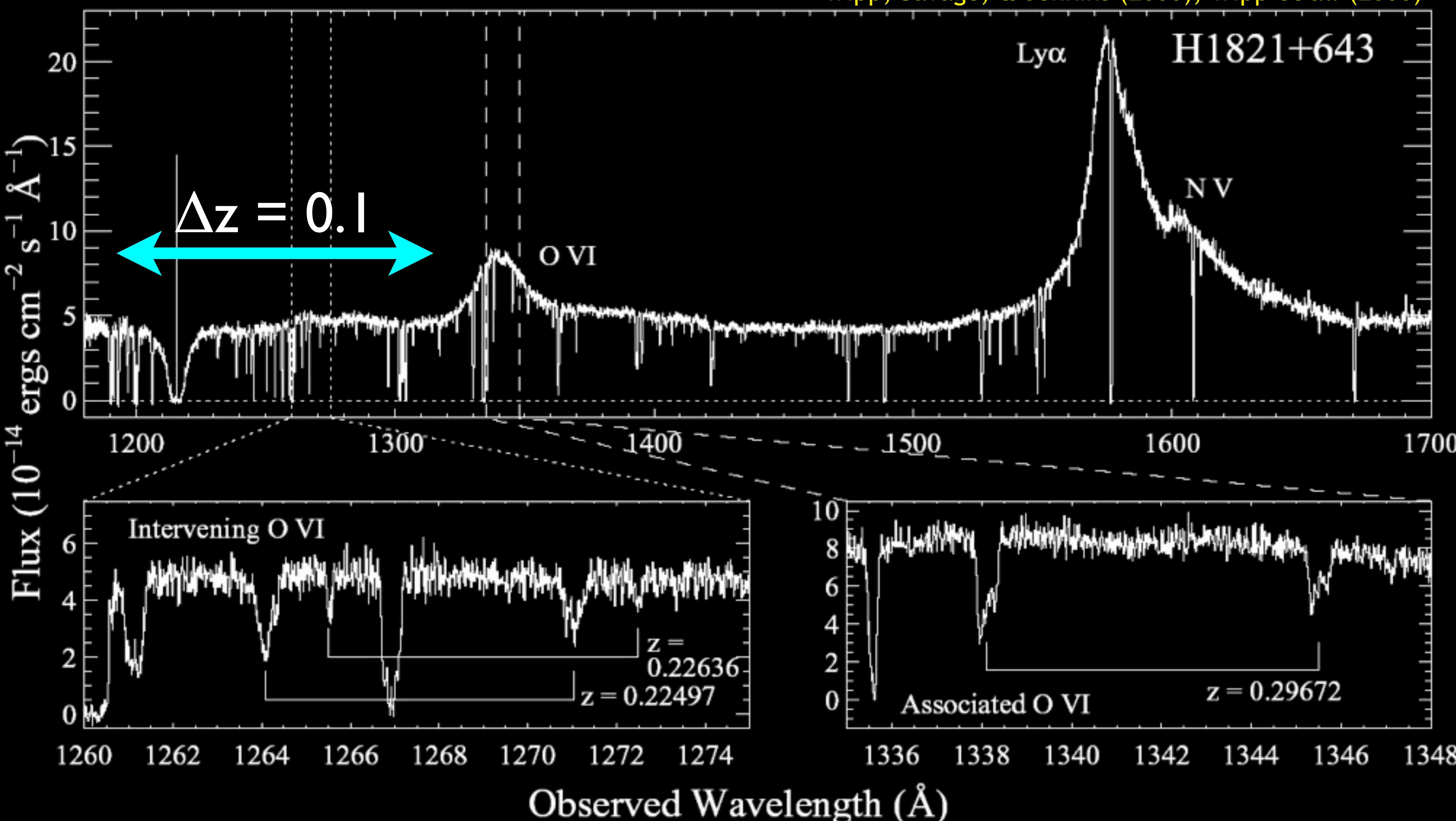
Received March 24, 1956

H I clouds. The ion O VI, which is isoelectronic to Mg X, has a corresponding doublet at 1038 and 1032 A and might be sufficiently abundant to produce measurable absorption, especially since the ionization potential of O VII has the relatively high value of 739 volts. Similarly, the ultimate lines of N V and C IV, at about 1240 and 1550 A, respective … rstellar

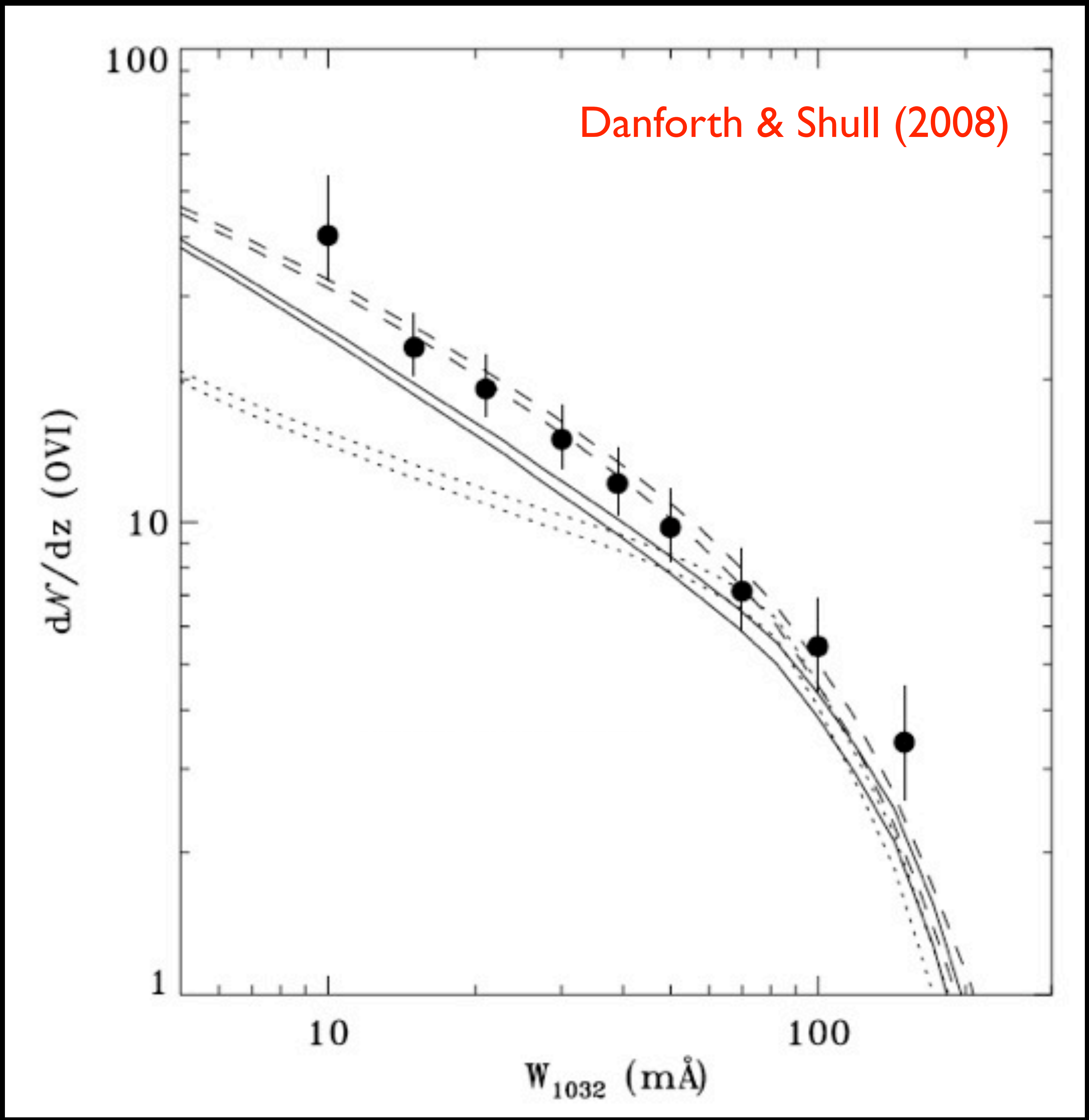


FUSE Launches 1000-1200 A	Intervening OVI Tripp et al.	Systematic O VI Surveys STIS+FUSE	COS Installed SM4	COS GTO IGM Pr
1999	2000	2000s	2009	20

Tripp, Savage, & Jenkins (2000), Tripp et al. (2000)



Intervening OVI Tripp et al.	Systematic O VI Surveys STIS+FUSE	COS Installed SM4	COS GTO and GO IGM Programs
2000	2000s	2009	2009+



$$\Omega_{OVI} / \Omega_b = 8 \pm 1\ \%$$

Danforth & Shull (2008)

$$\Omega_{OVI} / \Omega_b = 4 \pm 1\ \%$$

Thom & Chen (2008)

Systematic difference comes down to physical state.

How many O VI absorbers arise in hot gas, and how many are photoionized gas?

Lessons of Part III

Fortune favors the prepared mind: when most of the baryons went missing, we knew where to go looking.

HST (GHRS+STIS) has found 30 - 40 % of the baryons in diffuse, hot, ionized gas via absorption lines predicted 50 years ago.

Part IV

In which we move into the future, welcome COS into the fold, and see that there is no new thing under the Sun.

Systematic O VI Surveys STIS+FUSE	COS Installed SM4	COS GTO and GO IGM Programs	The Future With HST
2000s	2009	2009+	2010 - ???

TO DO

1) Find the rest of the missing baryons

    NeVIII, Mg X, and O VI-only absorbers as tracers of metal-enriched WHIM. Broad Lyman alpha clouds - hot gas with low metal abundance.

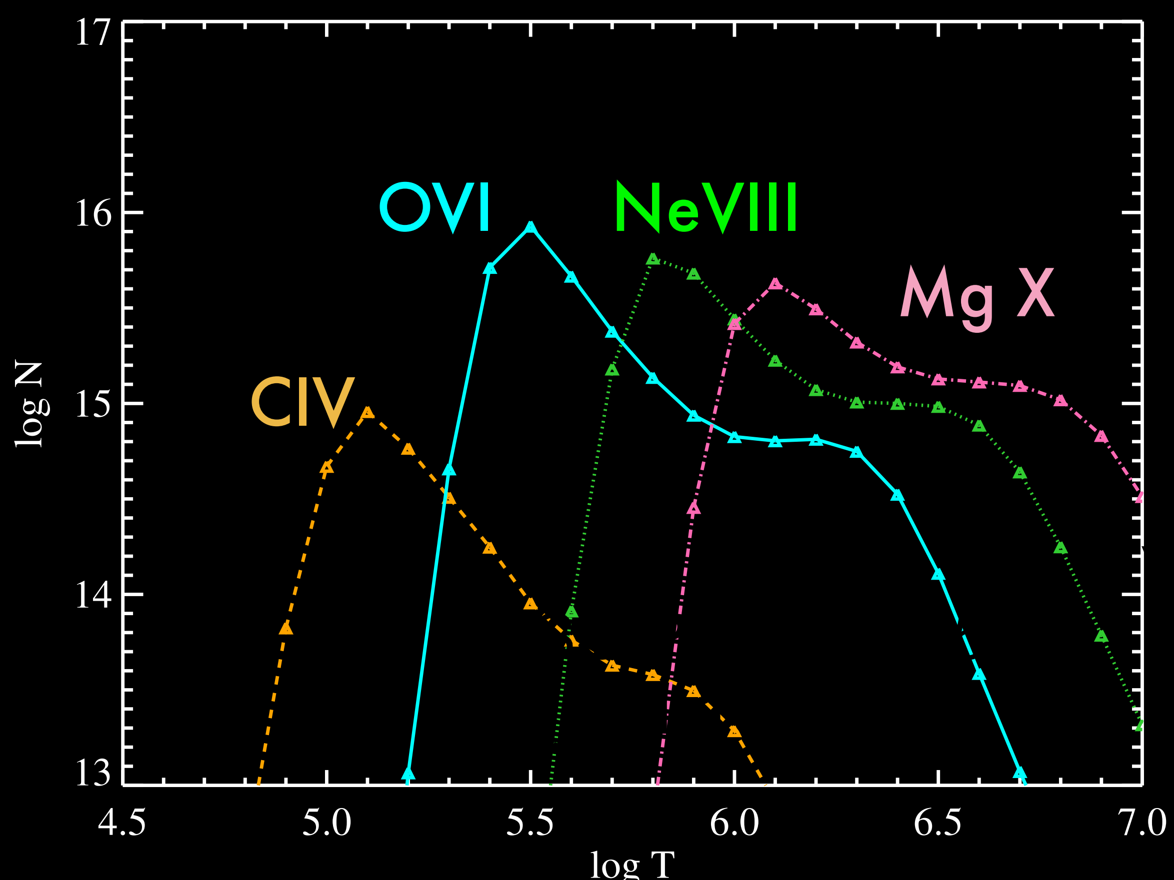
2) Learn what happens in the Circumgalactic Medium.

    Exploit QSO/galaxy pairs with COS to study regions close to galaxies.

3) Further constrain the distributions of metals

    Test galaxy feedback ("superwind") theories.

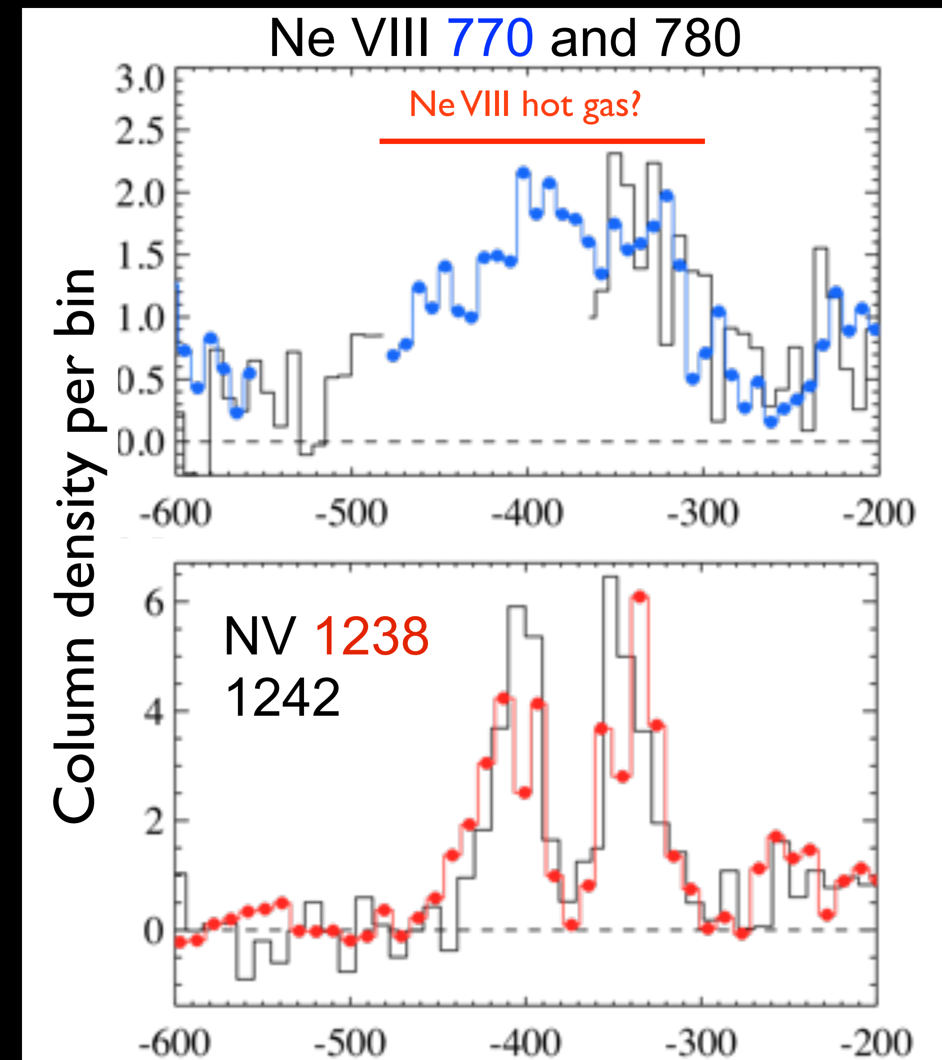
COS Installed SM4	COS GTO and GO IGM Programs	The Future With HST	The Future Without HST	The Future Beyond HST
2009	2009+	2010 - ???	2015 - ???	2020 - ???

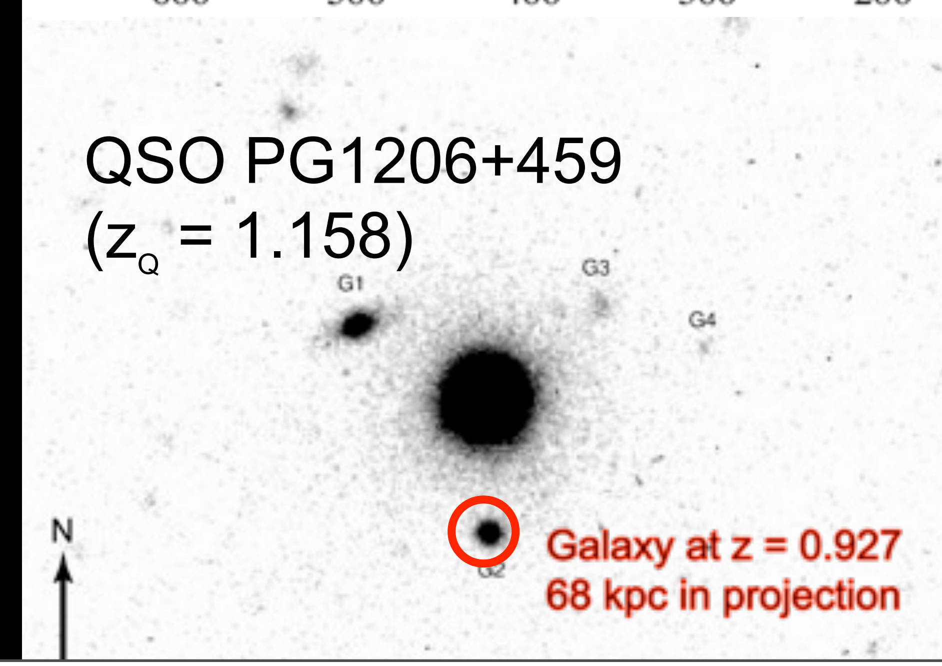


NeVIII traces WHIM gas at ~1 million degrees, but only for $z_{abs} > 0.5$.

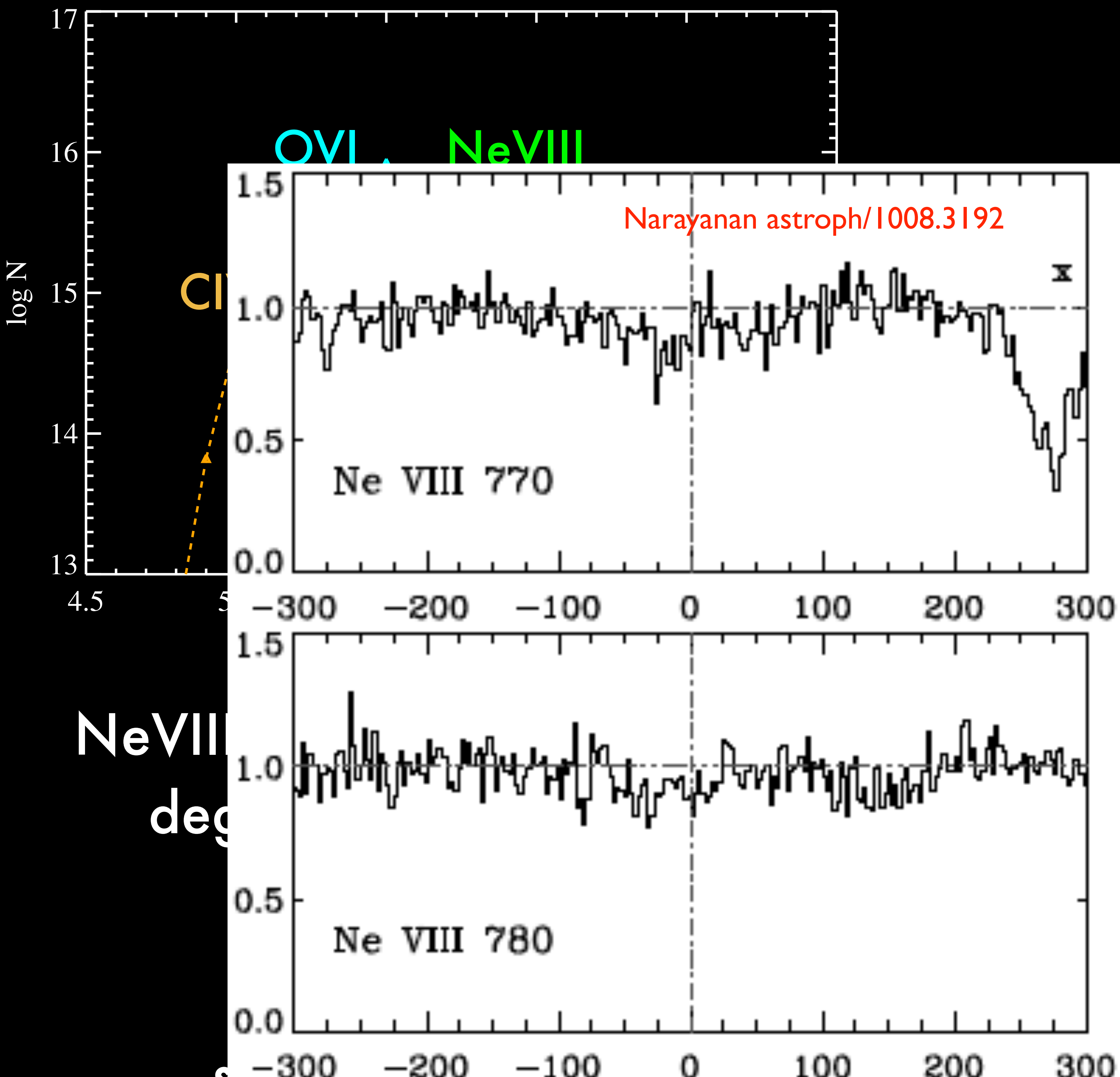
Tripp et al. Cycle 17 survey: $\Delta z = 5.5$ total.

See also Savage et al. (2005)



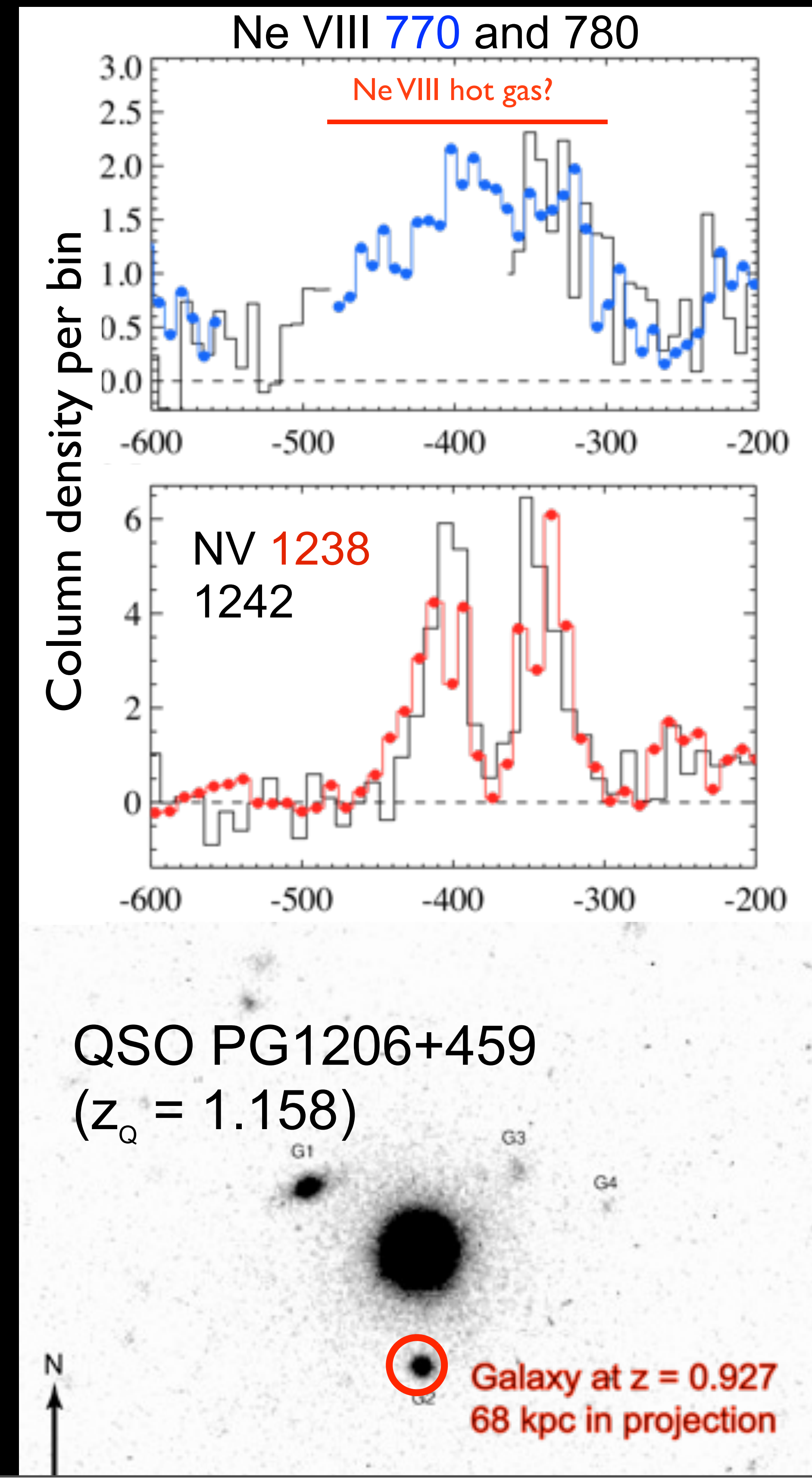


COS Installed SM4	COS GTO and GO IGM Programs	The Future With HST	The Future Without HST	The Future Beyond HST
2009	2009+	2010 - ???	2015 - ???	2020 - ???



NeVIII

deg



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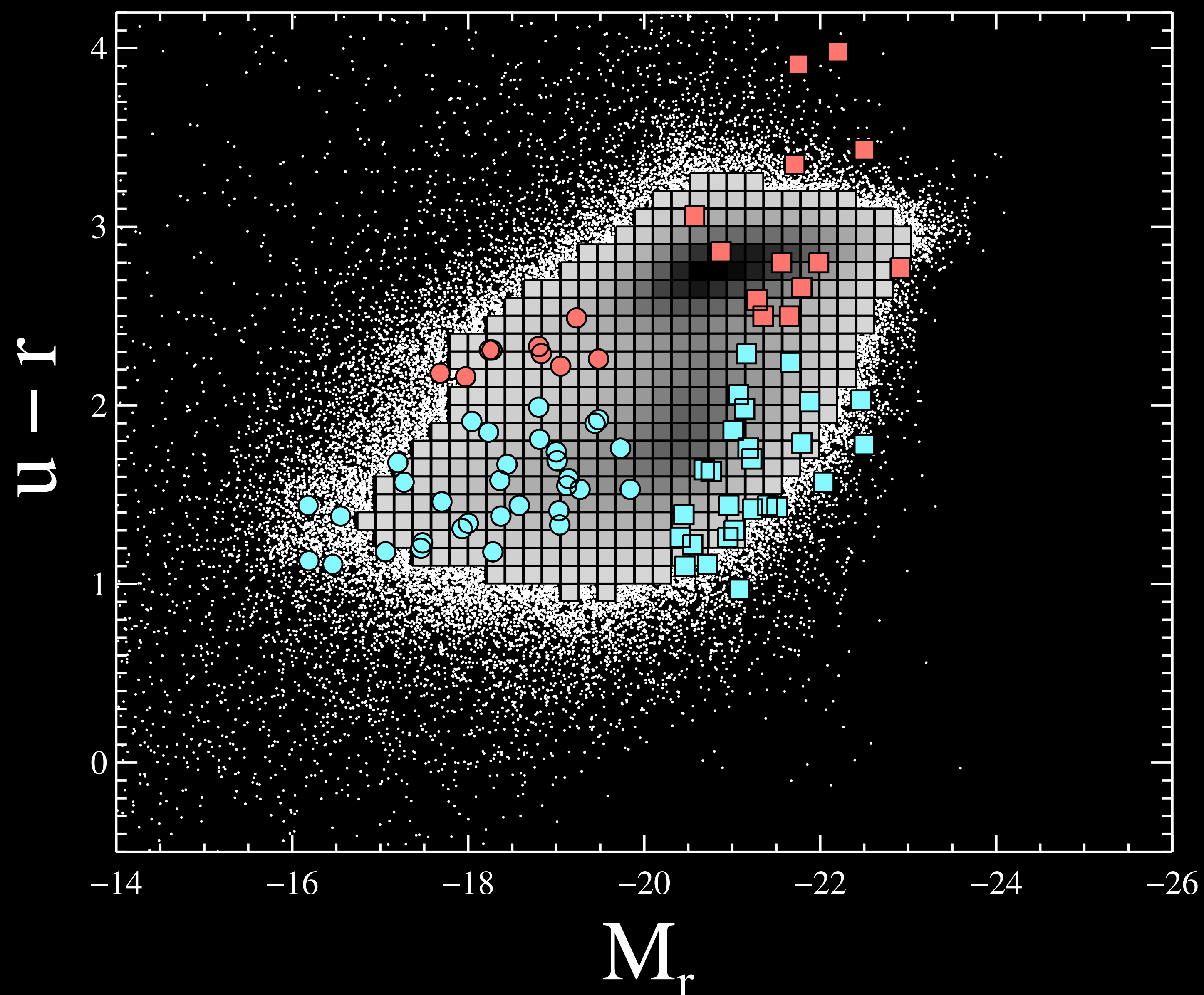


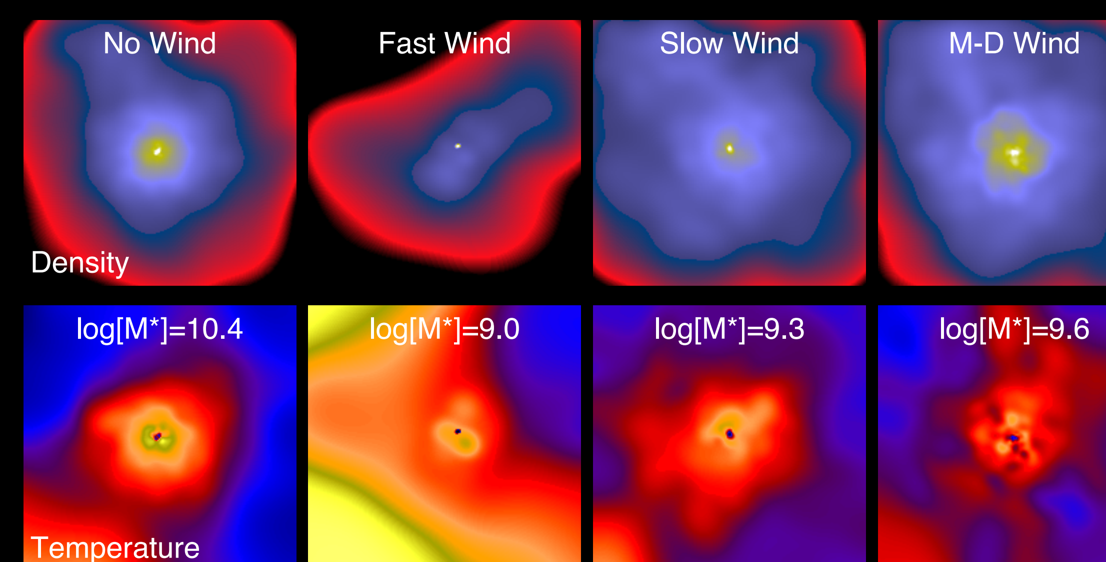
"COS-Halos": 39 L* galaxies surveyed from 10 - 150 kpc impact parameter with 134 COS orbits in Cycle 17

first results to be presented on Wednesday by Chris Thom

How do galaxies acquire their gas?
How do they return it to the IGM?
Why are some red and some blue?

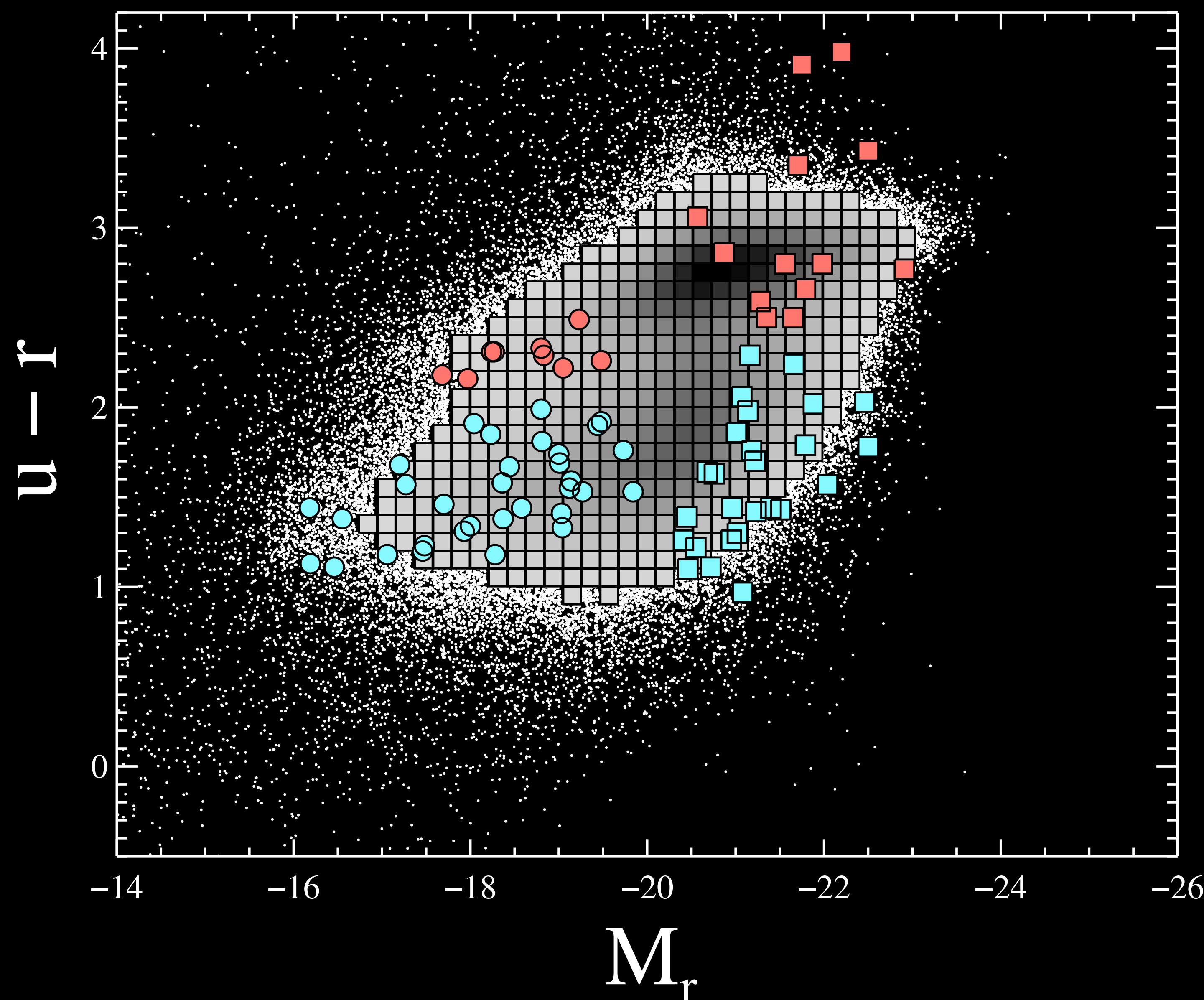
The unprecedented sensitivity of COS enables a key advance:

to study a population of galaxies with bright background QSOs, selected for specific galaxy properties instead of QSO magnitude.



Oppenheimer & Davé
galaxy superwind simulations

COS Installed SM4	COS GTO and GO IGM Programs	The Future With HST	The Future Without HST	The Future Beyond HST
2009	2009+	2010 - ???	2015 - ???	2020 - ???



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ABSORPTION LINES PRODUCED BY GALACTIC HALOS

John N. Bahcall*
Institute for Advanced Study

AND

Lyman Spitzer, Jr.
Princeton University Observatory
Received March 24, 1969

ABSTRACT

We propose that most of the absorption lines observed in quasi-stellar sources with multiple absorption redshifts are caused by gas in extended halos of normal galaxies.

Recent work has established that some quasi-stellar sources have multiple redshift systems in absorption (Bahcall 1968; Bahcall, Greenstein, and Sargent 1968; Burbidge, Lynds, and Stockton 1968; Burbidge 1969; Bahcall, Osmer, and Schmidt 1969). A number of possible explanations have been suggested for this phenomenon (Bahcall *et al.* 1968; Burbidge *et al.* 1968; Peebles 1968), but none of the suggestions seem especially plausible when considered in the light of the observed features of the absorption systems. We propose that most of the absorption lines are caused by tenuous gas in extended halos of normal galaxies (see Spitzer 1956 for a review of some earlier work on galactic halos and for a preliminary discussion of the possibility of observing ultraviolet absorption lines formed in such halos).

The Future with HST	The Future Without HST	The Future Beyond HST
2010 - ???	2015 - ???	2020 - ???

movies by Britton Smith (Colorado, MSU)

The Future with HST	The Future Without HST	The Future Beyond HST
2010 - ???	2015 - ???	2020 - ???

movies by Britton Smith (Colorado, MSU)

The Future
With HST

2010 - ???

The Future
Without HST

2015 - ???

The Future
Beyond HST

2020 - ???

The Future With HST

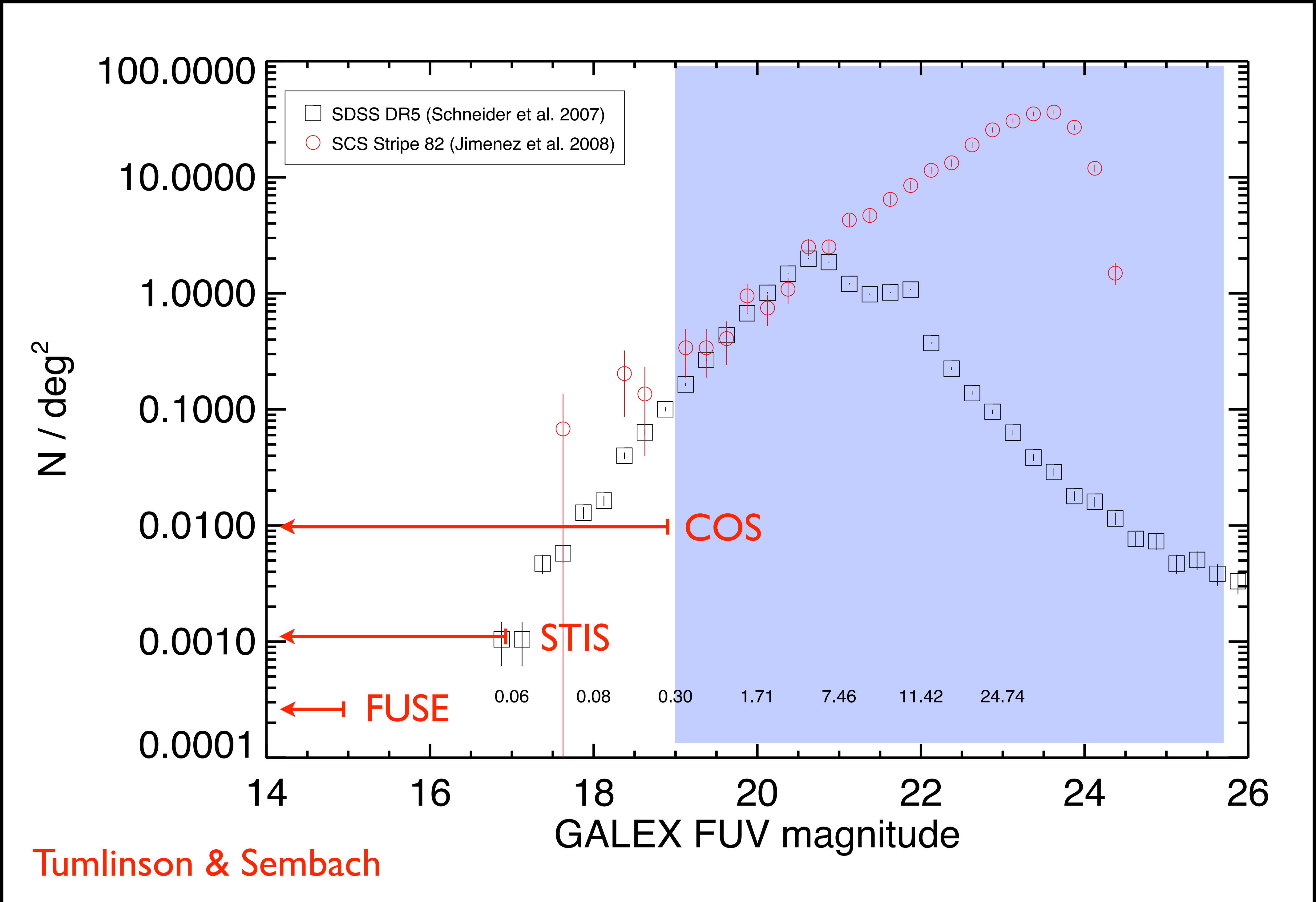
2010 - ???

The Future Without HST

2015 - ???

The Future Beyond HST

2020 - ???



The Future With HST	The Future Without HST	The Future Beyond HST
2010 - ???	2015 - ???	2020 - ???

The Future
With HST

The Future
Without HST

The Future
Beyond HST

2010 - ???

2015 - ???

2020 - ???

The Astronomy Quarterly, Vol. 7, pp. 131-142, 1990
Printed in the USA.

0364-9229/90 $3.00+.00

ASTRONOMICAL ADVANTAGES OF AN EXTRA-TERRESTRIAL OBSERVATORY

LYMAN SPITZER, Jr. [1]

This study points out, in a very preliminary way, the results that might be expected from astronomical measurements made with a satellite vehicle. The discussion is divided into three parts, corresponding to three different assumptions concerning the amount of instrumentation provided. In the first section it is assumed that no telescope is provided; in the second a 10-inch reflector is assumed; in the third section some of the results obtainable with a large reflecting telescope, many feet in diameter, and revolving about the earth above the terrestrial atmosphere, are briefly sketched.

The Future
With HST

2010 - ???

The Future
Without HST

2015 - ???

The Future
Beyond HST

2020 - ???

The Future With HST

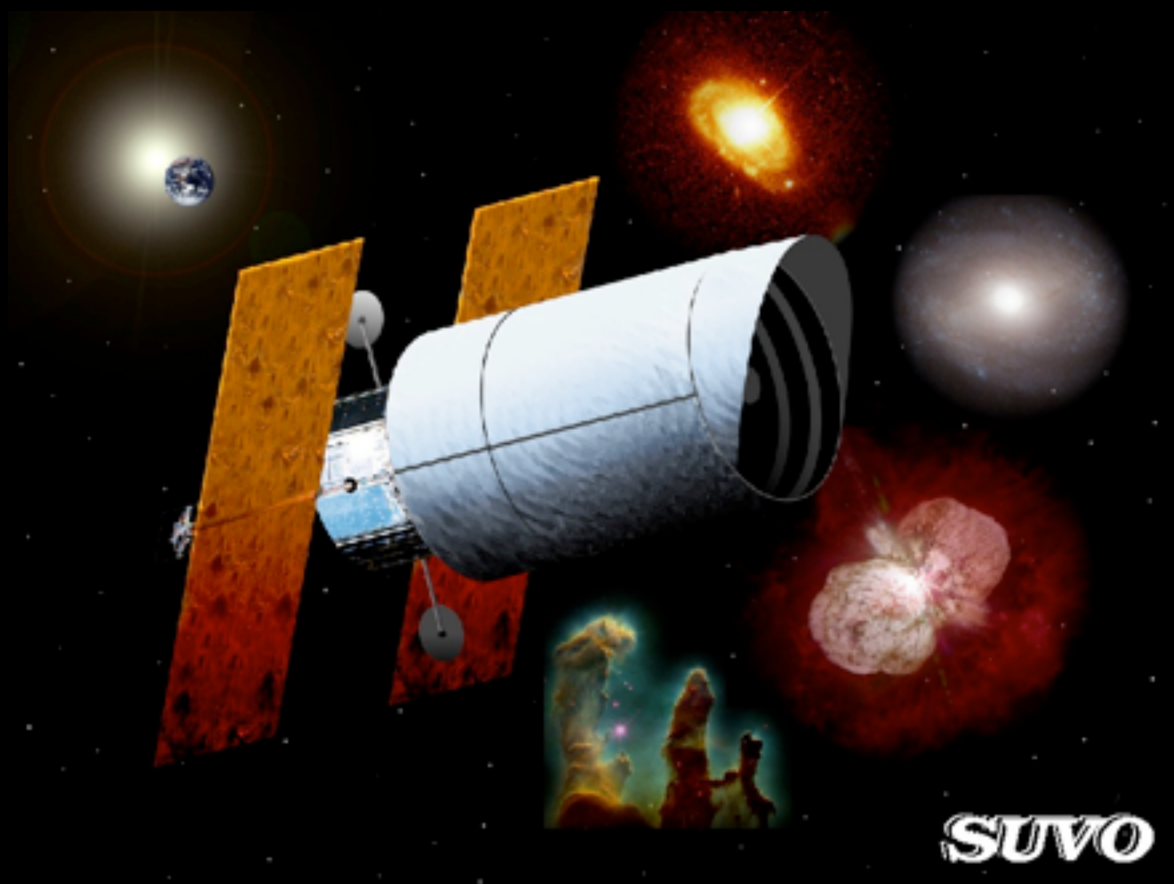
2010 - ???

The Future Without HST

2015 - ???

The Future Beyond HST

2020 - ???



The Future
With HST

2010 - ???

The Future
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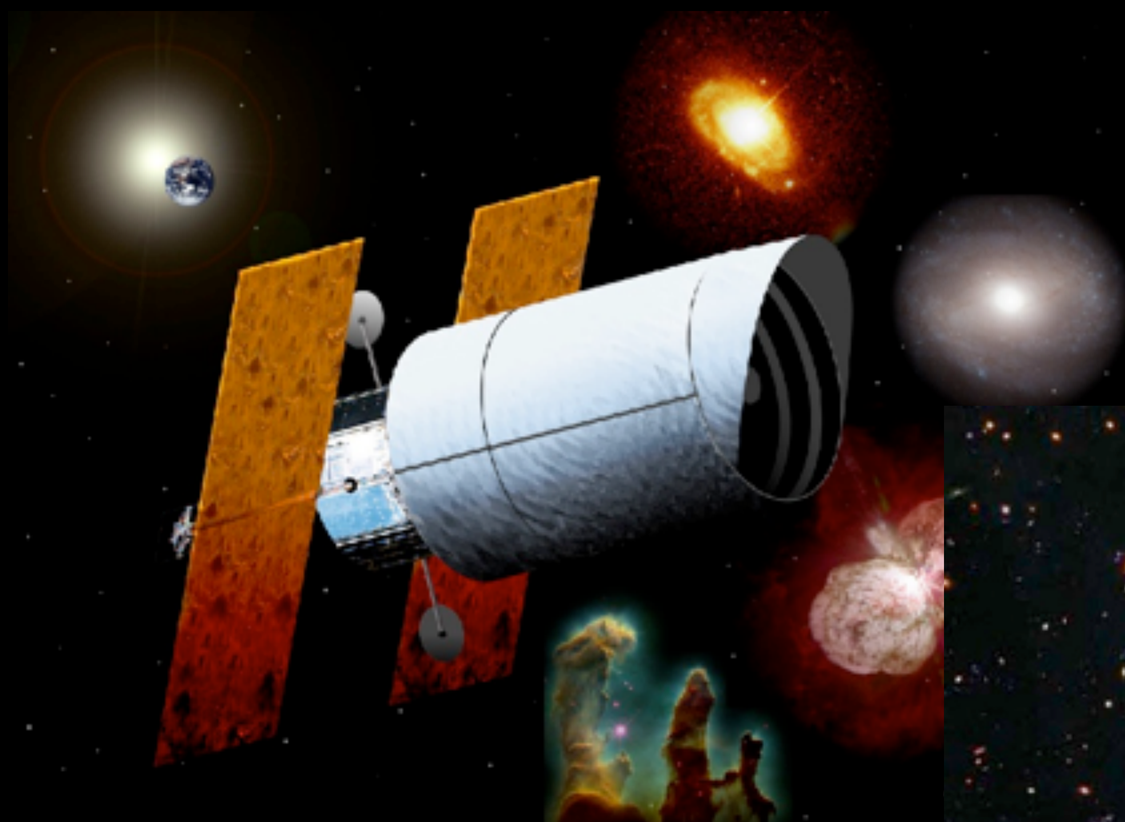
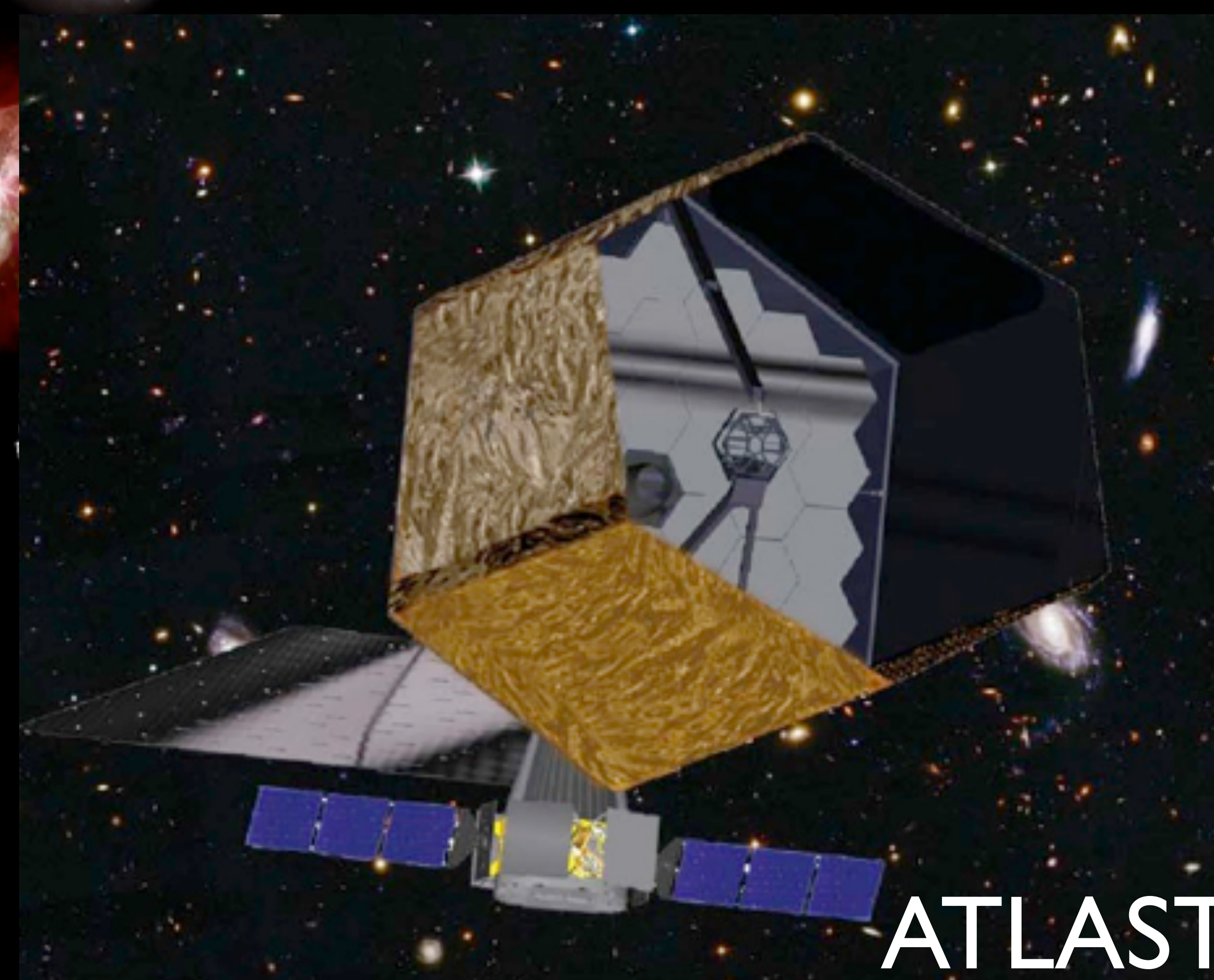
2015 - ???

**The Future
Beyond HST**

2020 - ???





The Future
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2010 - ???

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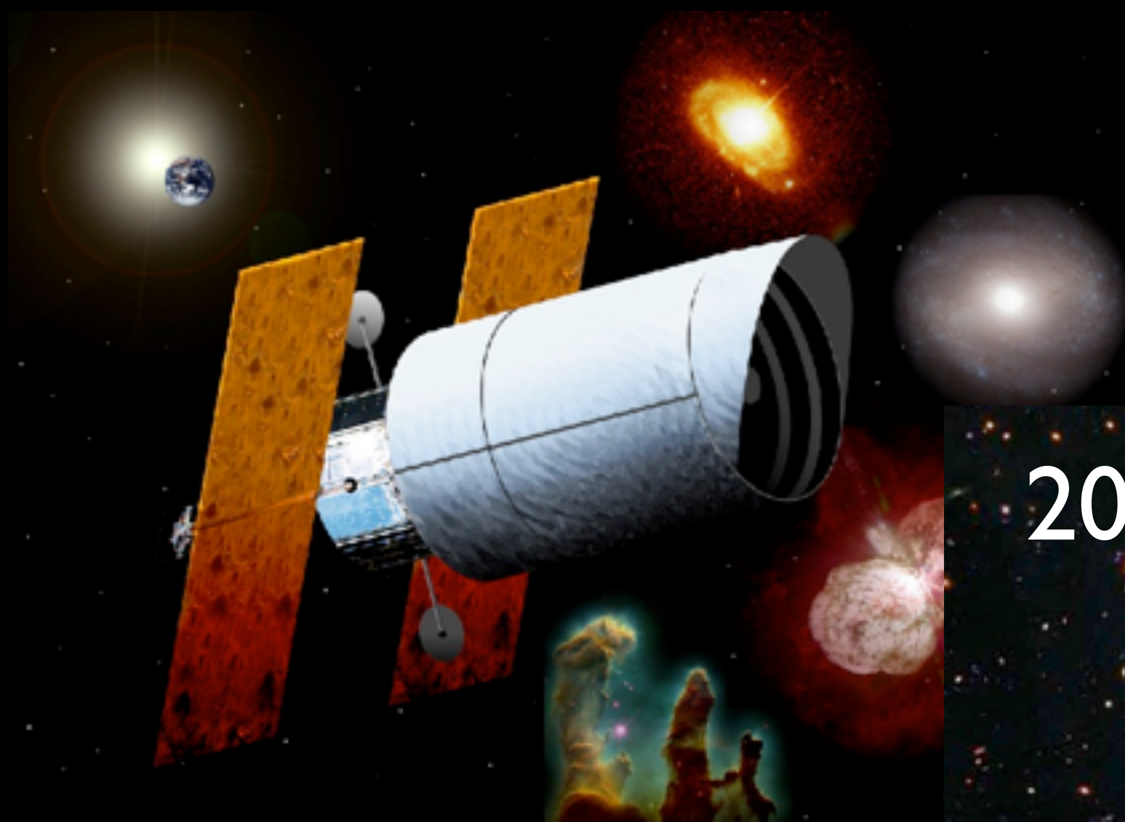
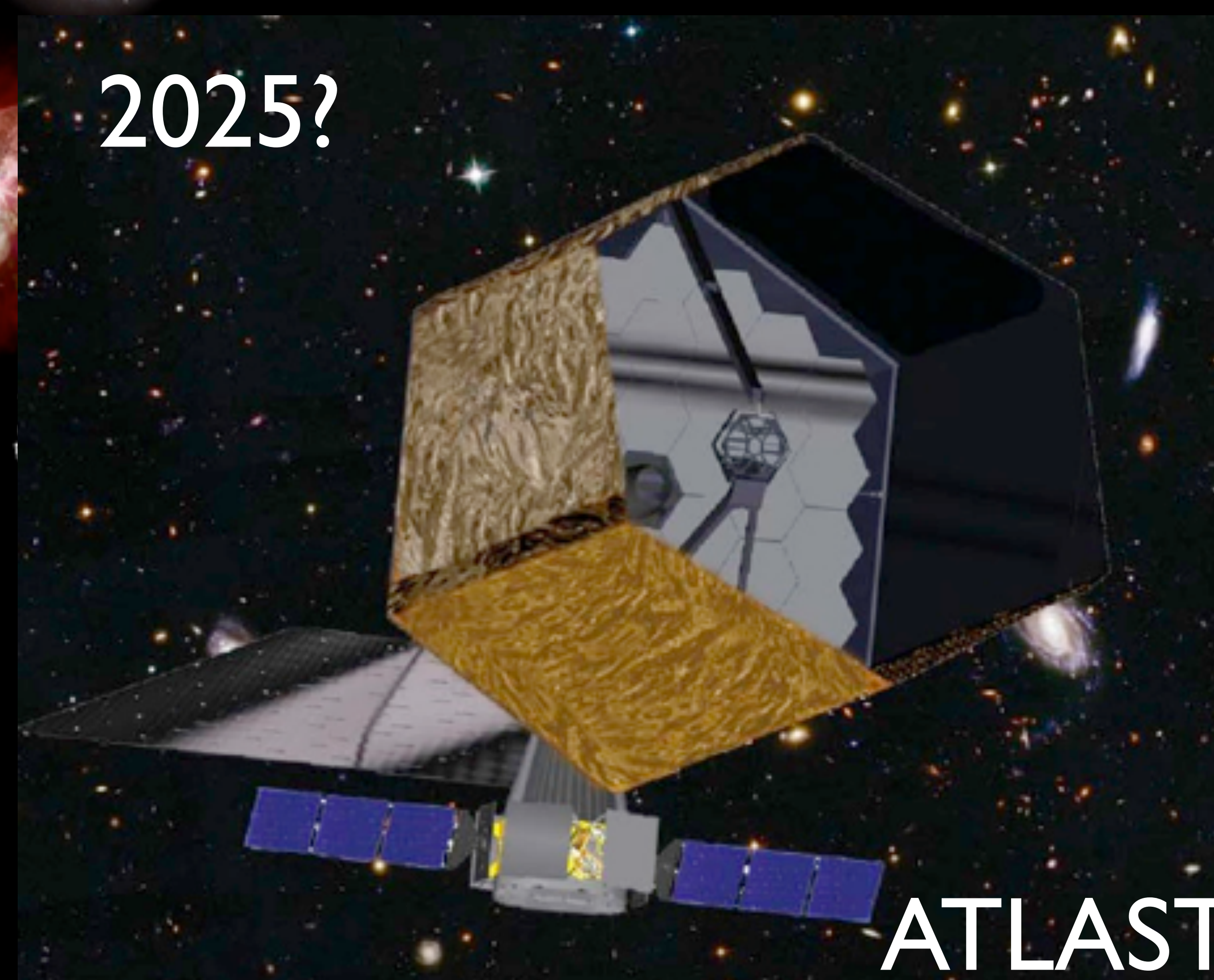
2015 - ???

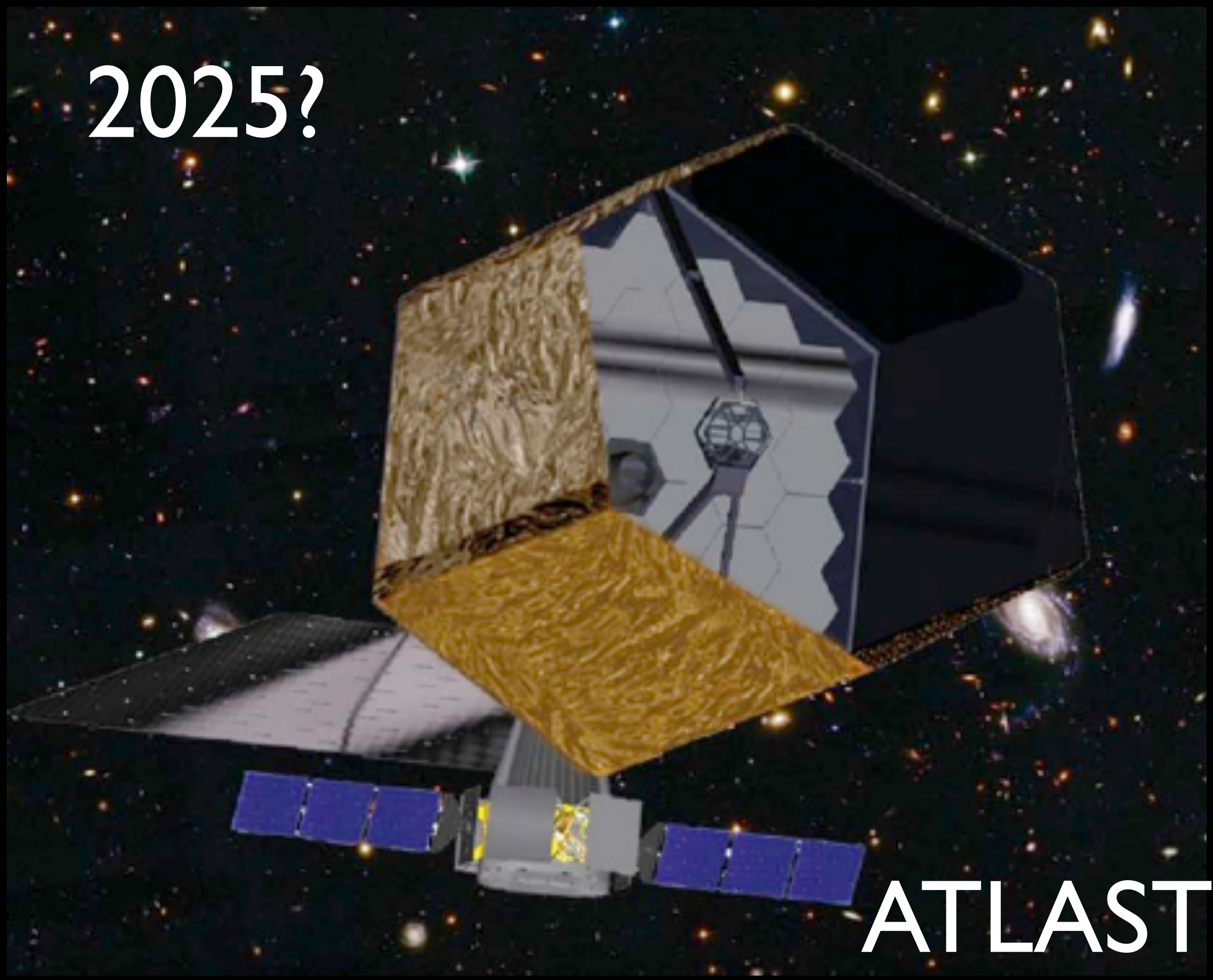
The Future
Beyond HST

2020 - ???





The Future With HST	The Future Without HST	The Future Beyond HST
2010 - ???	2015 - ???	2020 - ???



The Future With HST | The Future Without HST | The Future Beyond HST

2010 - ??? | 2015 - ??? | 2020 - ???

2025?

The Future With HST

2010 - ???

The Future Without HST

2015 - ???

The Future Beyond HST

2020 - ???

The Future With HST	The Future Without HST	The Future Beyond HST
2010 - ???	2015 - ???	2020 - ???

Let us prepare for the future. . .

The Future
With HST

2010 - ???

The Future
Without HST

2015 - ???

The Future
Beyond HST

2020 - ???

Let us prepare for the future. . .

. . . recalling that fortune favors the prepared mind. . .

The Future With HST	The Future Without HST	The Future Beyond HST
2010 - ???	2015 - ???	2020 - ???

Let us prepare for the future. . .

. . . recalling that fortune favors the prepared mind. . .

. . . and work to ensure that future.

GRAZIE MILLE

[MANY THANKS]