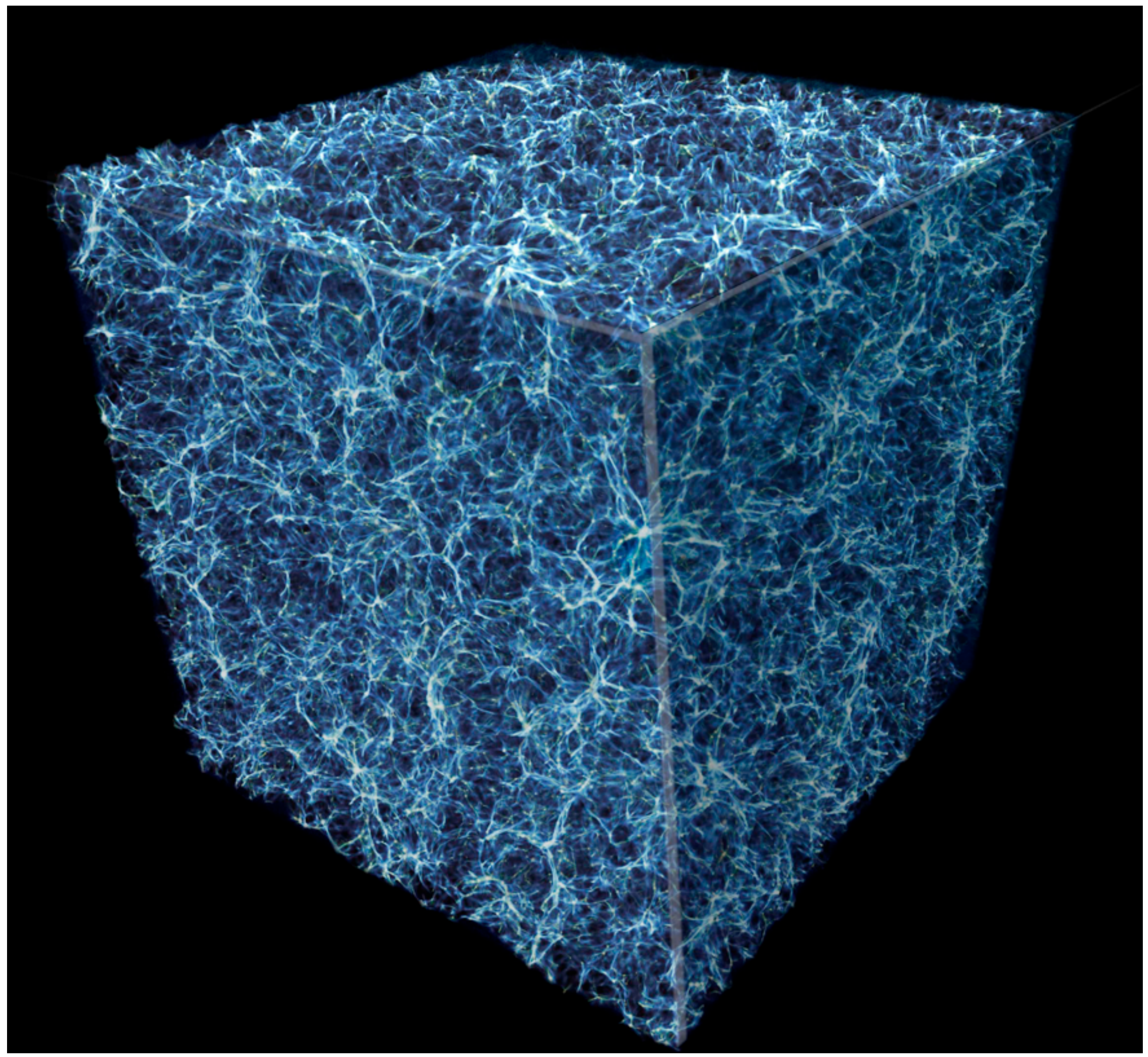
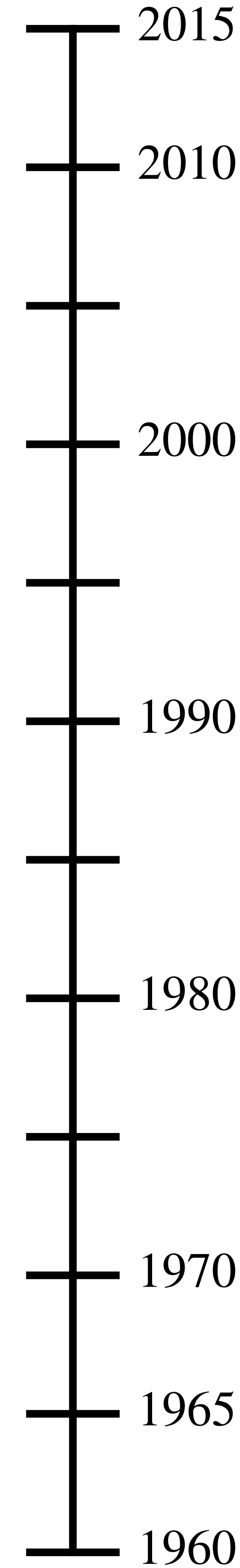
An Historical Overview of the Cosmic Web



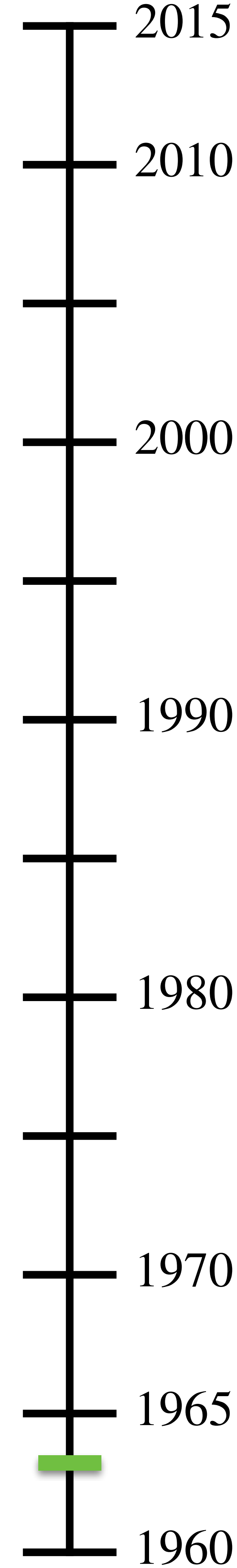
J. Xavier Prochaska
(IMPS; UC Santa Cruz)

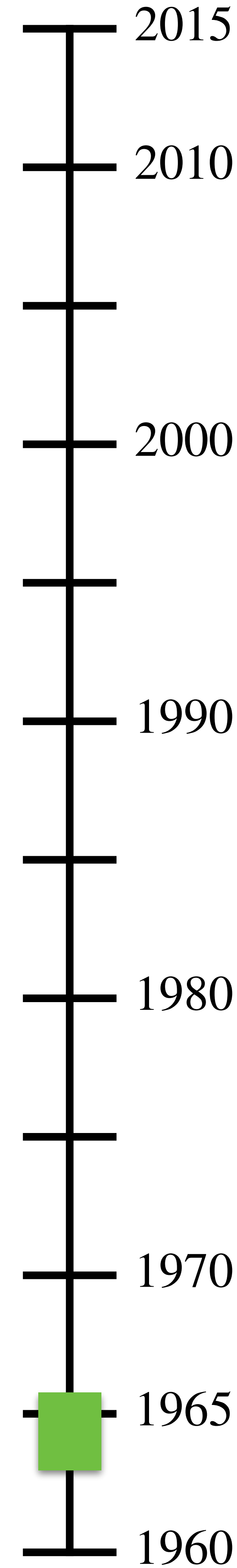


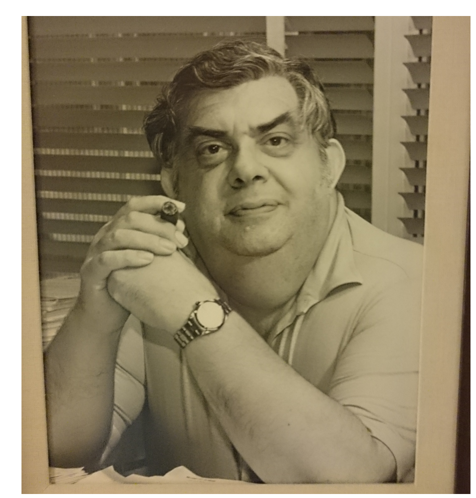
Thanks to the LOC for bringing us back!

Spineto 2009

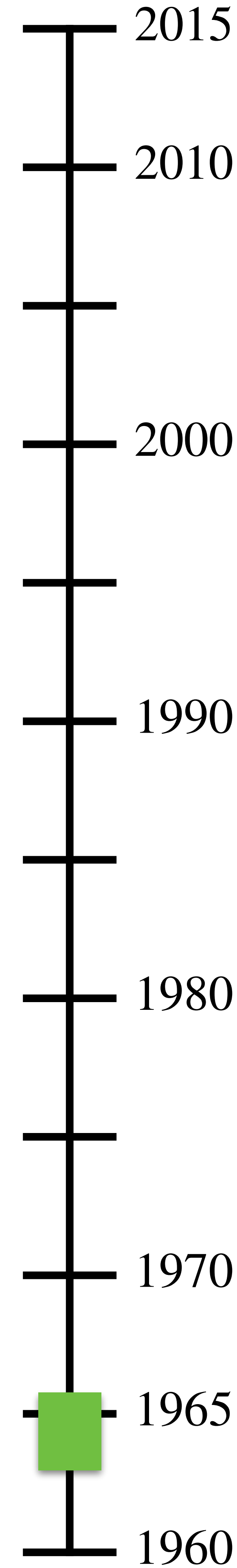

EXPLORING THE EDGE OF THE UNIVERSE
TIME
THE WEEKLY NEWSMAGAZINE
ASTRONOMER
MAARTEN SCHMIDT


2015
2010
2000
1990
1980
1970
1965
1960


2015
2010
2000
1990
1980
1970
1965
1960



Burbidge, Burbidge (1965+)



Burbidge, Burbidge (1965+)

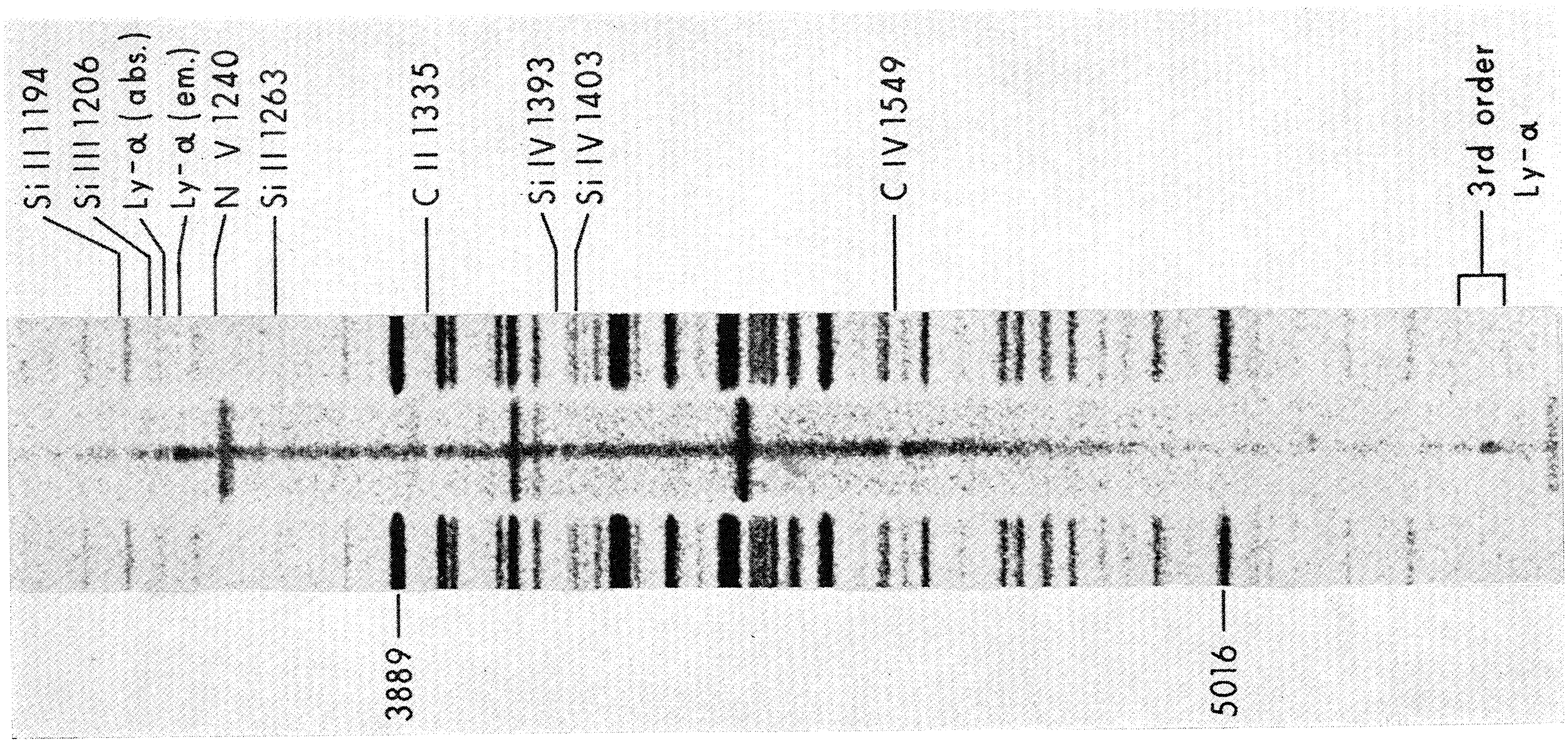
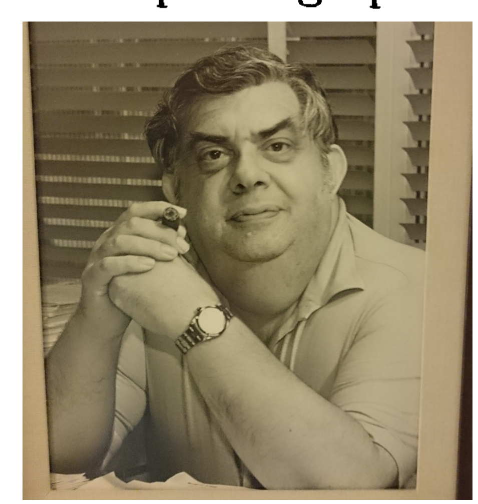
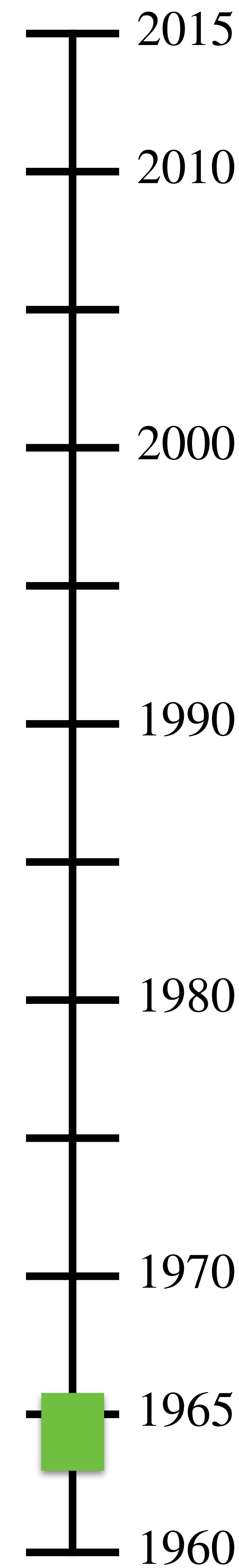
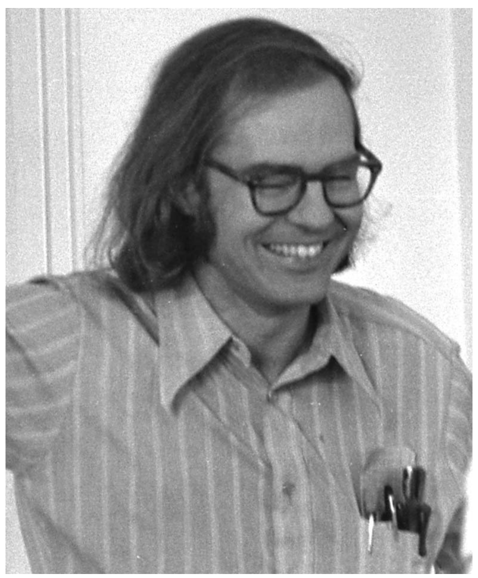


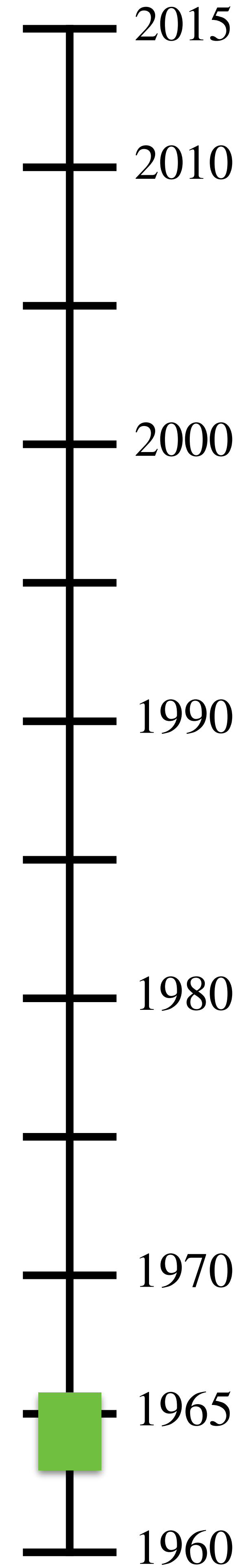
FIG. 2.—Lick spectrum of 3C 191 obtained in February, 1966, with the prime-focus spectrograph on the 120-inch telescope. The comparison spectrum shown is that of He + Ar.

Also: Schmidt spectrum of 3C 9 (1965)
Kinman (1966); Lynds & Stockton (1966)

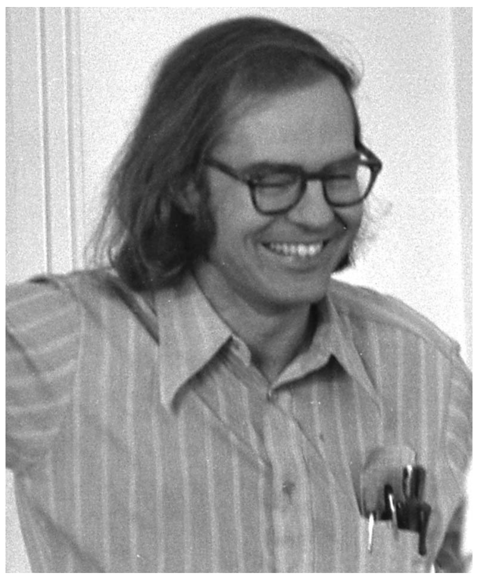


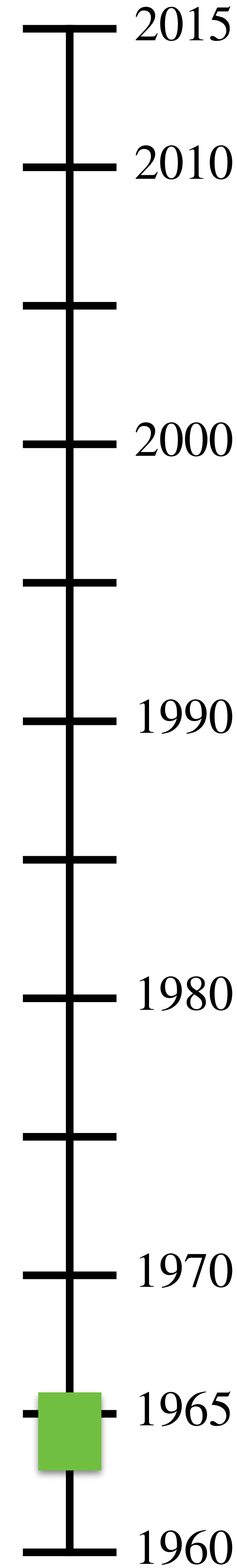





2015
2010
2000
1990
1980
1970
1965
1960

Gunn-Peterson (1965)

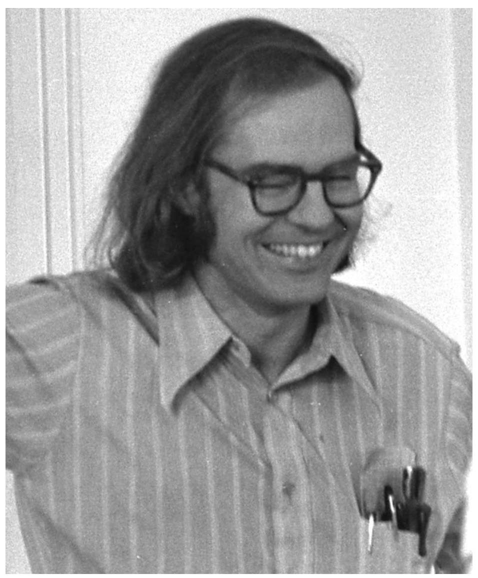




Gunn-Peterson (1965)

NOTES

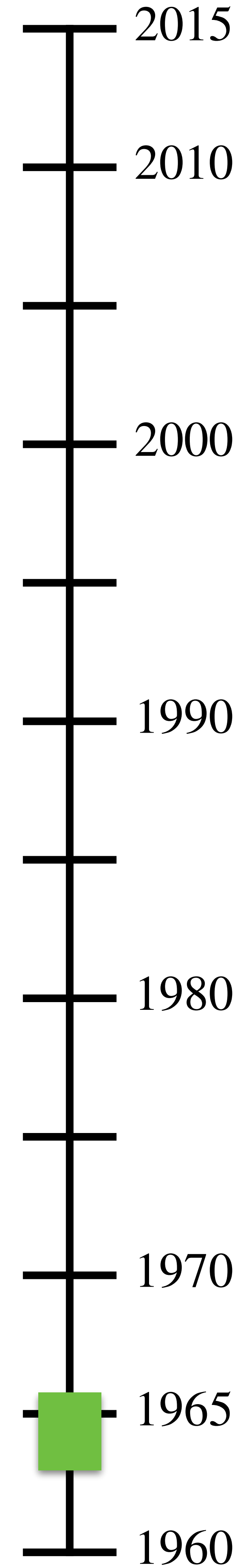
ON THE DENSITY OF NEUTRAL HYDROGEN IN INTERGALACTIC SPACE



Recent spectroscopic observations by Schmidt (1965) of the quasi-stellar source 3C 9, which is reported by him to have a redshift of 2.01, and for which Lyman-α is in the visible spectrum, make possible the determination of a new very low value for the density of neutral hydrogen in intergalactic space. It is observed that the continuum of the source continues (though perhaps somewhat weakened) to the blue of Ly-α; the line as seen on the plates has some structure but no obvious asymmetry. Consider, however, the fate of photons emitted to the blue of Ly-α. As we move away from the source along the line of sight, the source becomes redshifted to observers locally at rest in the expansion, and for one such observer, the frequency of any such photon coincides with the rest frequency of Ly-α in his frame and can be scattered by neutral hydrogen in his vicinity. The calculation of the size of the effect is very easily performed as follows:

Let us consider a cosmological model with the metric

$$ds^2 = dt^2 - R^2(t)\,(du^2 + \sigma^2(u)d\gamma^2)\,,$$



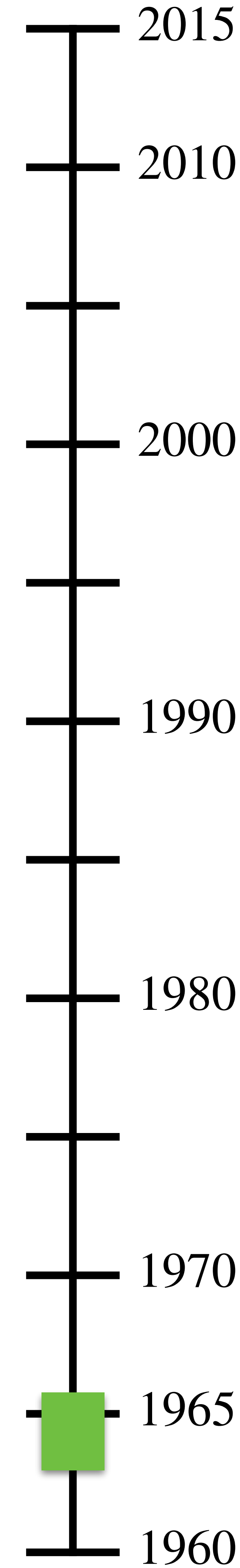
Gunn-Peterson (1965)

The function g is strongly peaked at zero; its width depends on the intergalactic temperature, but even at 10^6 °K its width expressed in velocity units is only $2 \times 10^{-4}\ c$ (compared to the redshift, which is of the order of 2). Thus we can take the factor in braces out of the integral, evaluated at $(1 + z) = \nu_a/\nu$; the integral that is left is unity, and we obtain (for $H_0 = 10^{-10}$ yr^{-1})

$$p = \frac{n_s}{(1+z)(1+2q_0 z)^{1/2}} \left(\frac{\pi e^2 f}{m\nu_a H_0}\right) \simeq (5 \times 10^{10}\ \text{cm}^3) \frac{n_s}{(1+z)(1+2q_0 z)^{1/2}}.$$

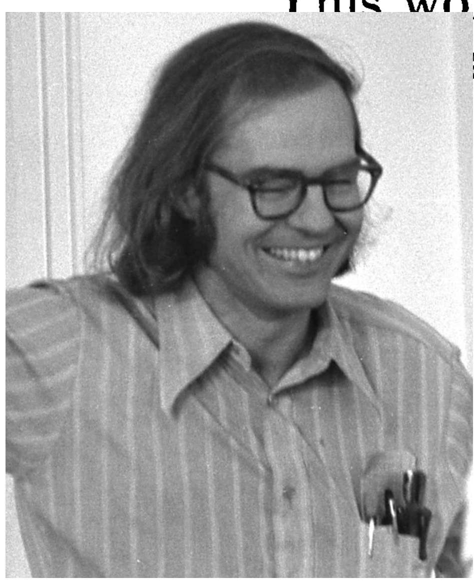
ere n_s is the number density of neutral hydrogen in the scattering region. The flux be reduced, of course, by a factor e^{-p}, but it is difficult to say just how large the t is on the plates of 3C 9. Intensity tracings were made of two plates, and tracings of neighboring night-sky spectra allowed approximate subtraction of the night-sky ribution. The blueward component and the wing of the line are noticeably depressed y are enhanced on the plates by a strong, broad night-sky feature at 3640 Å that s the line an almost symmetric profile before the sky is removed), but the exact unt is difficult to measure; best estimates place the depression at about 40 per cent, h corresponds to an optical depth of about $\frac{1}{2}$. This yields, for $q_0 = \frac{1}{2}$, a number density $n_s = 6 \times 10^{-11}$ cm^{-3}, or a mass density $\rho_s = 1 \times 10^{-34}$ gm cm^{-3}—a figure five orders of magnitude below the limit (for the *present* density, which should be 27 times smaller because of the expansion) obtained from 21-cm observations by Field (1962).

For the $q_0 = \frac{1}{2}$ model, the total density at $z = 2$ is 5×10^{-28} gm cm^{-3}; thus only about one part in 5×10^6 of the total mass at that time could have been in the form of intergalactic neutral hydrogen. For the steady-state model $\rho_s = 2 \times 10^{-35}$ and the (constant) total density is 4×10^{-29}; the factor here is somewhat less, about 2×10^6.



Gunn-Peterson (1965)

We would like to express our sincere thanks to Dr. Maarten Schmidt, who kindly put the 3C 9 plates at our disposal for measurement. The qualitative conclusions in the present version of this paper are in agreement with the analysis of Dr. J. Bahcall and Dr. E. Salpeter (to be published). We are indebted to Dr. J. Bahcall and Dr. E. Salpeter and also Dr. D. Sciama for pointing out numerical errors in the circulated preprint. This work was supported by the National Science Foundation and the National Aero- and Space Administration.



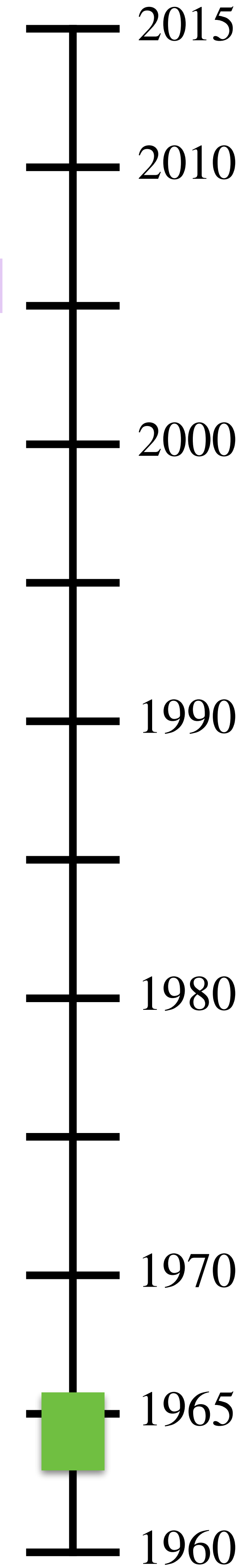
JAMES E. GUNN
BRUCE A. PETERSON

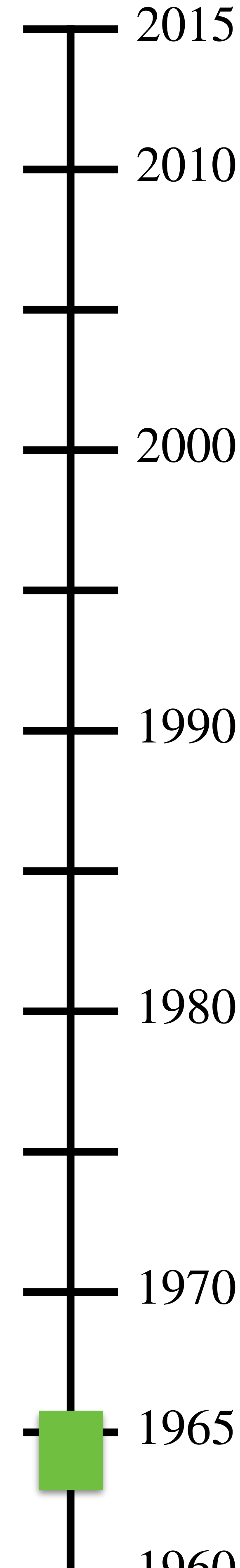
26, 1965; revised July 26 and in proof on October 8, 1965

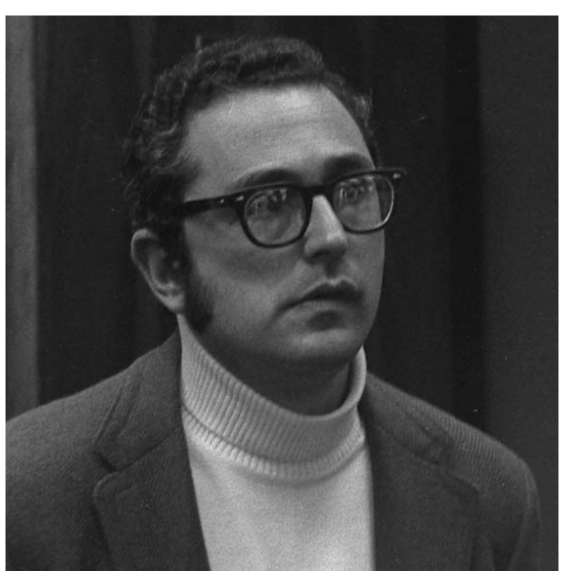
MOUNT WILSON AND PALOMAR OBSERVATORIES
CARNEGIE INSTITUTION OF WASHINGTON
CALIFORNIA INSTITUTE OF TECHNOLOGY

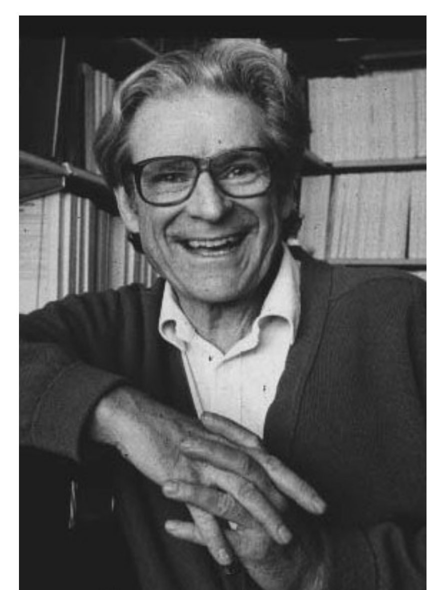
REFERENCES

Allen, C. W. 1963, *Astrophysical Quantities* (London: Athlone Press).
Field, G. 1962, *Ap. J.*, **135**, 684.
Field, G., and Henry, R. 1964, *Ap. J.*, **140**, 1002.
Karzas, W., and Latter, R. 1961, *Ap. J. Suppl.*, **6**, 167.
Sandage, A. 1961*a*, *Ap. J.*, **133**, 355.
———. 1961*b*, *ibid.*, **134**, 916.
Schmidt, M. 1965, *Ap. J.*, **141**, 1295.

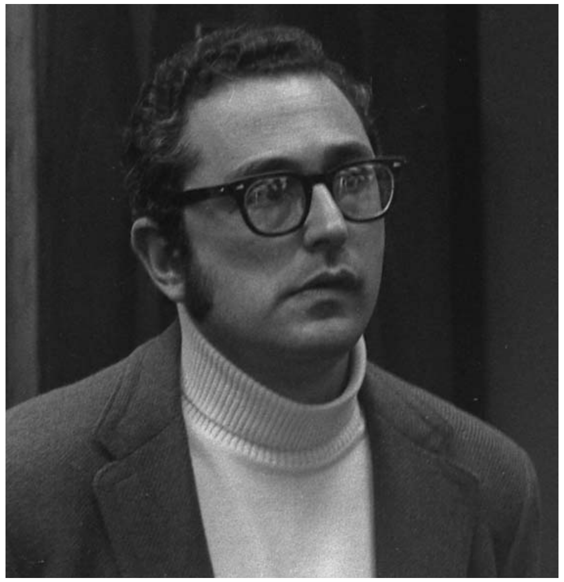


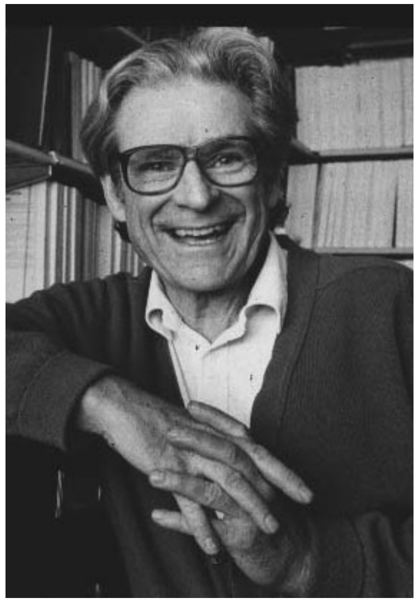

2015
2010
2000
1990
1980
1970
1965
1960

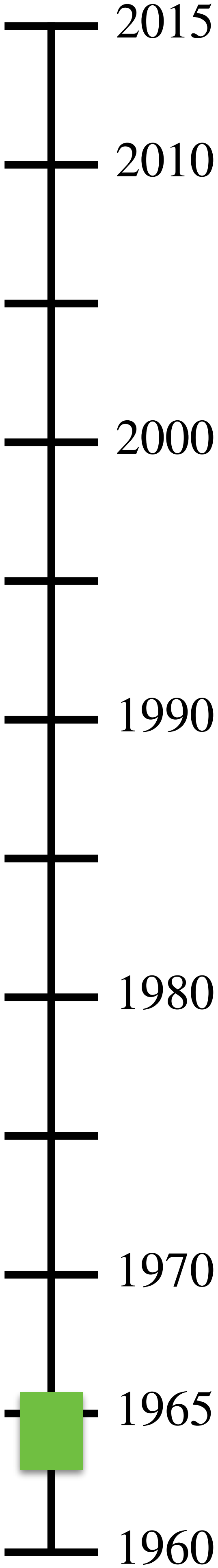




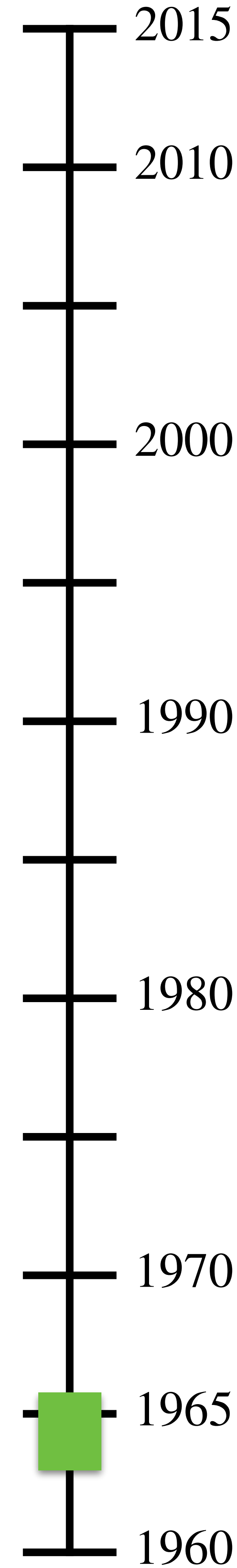
Bahcall & Salpeter (1965)







Bahcall & Salpeter (1965)

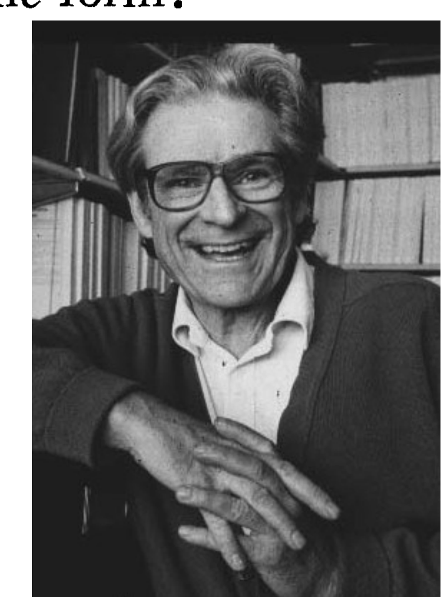


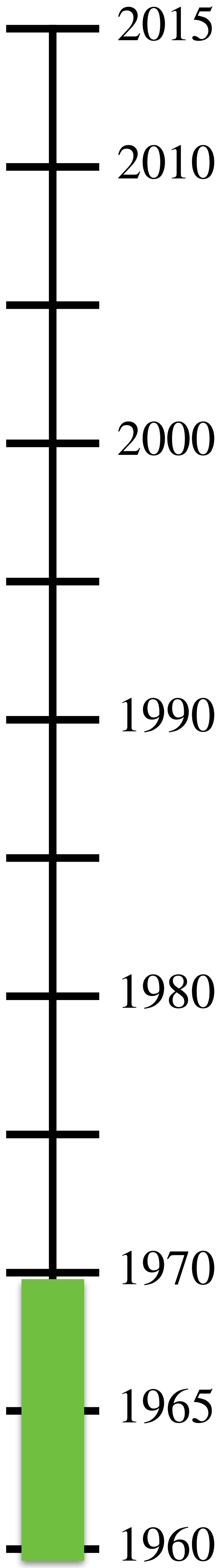
ON THE INTERACTION OF RADIATION FROM DISTANT SOURCES WITH THE INTERVENING MEDIUM

We discuss several ways that a distant radiation source (with a large redshift assumed due to the cosmological expansion) can provide information over a wide range of distances about the intervening medium. As we shall show [cf. Gunn and Peterson (1965)] neutral hydrogen (or other atoms) at various distances between the source and us will give rise to an "absorption trough" in the continuous spectrum of a distant source. If the neutral hydrogen is instead concentrated in clusters of galaxies, this trough is replaced by a number of sharp absorption lines. Besides discussing (i) absorption troughs and (ii) absorption lines from clusters, we also consider (iii) photon scattering by free electrons in the intervening medium and (iv) spreading of a radio beam due to inhomogeneities in the ionized gas that is traversed. Present observations furnish some stringent upper limits, and we suggest other feasible cosmological tests.

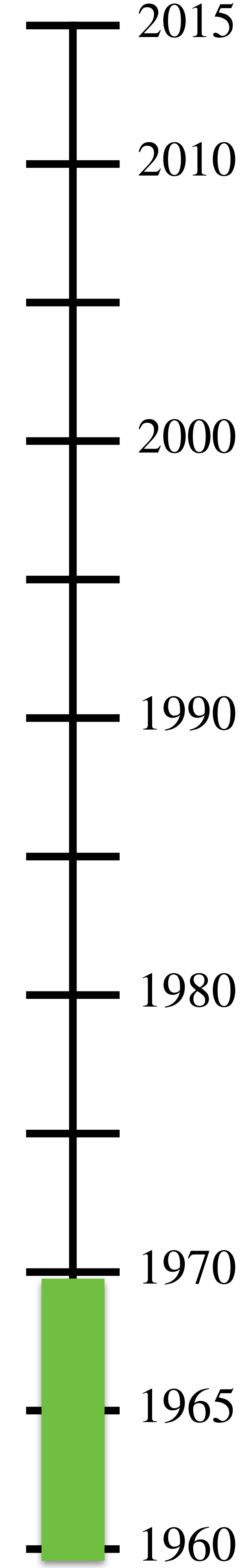
Let $z \equiv (\Delta\lambda/\lambda)$ be the "distance" or redshift measure, q_0 the deceleration parameter for the usual cosmological models (with cosmological constant equal to zero) that satisfy the field equations of general relativity (see, e.g., Bondi 1961, or Sandage 1961*a*, *b*), H the Hubble parameter with $H_0 \approx (10^{+10}\ \text{years})^{-1}$ (a subscript zero indicates a local value at the present epoch), and N the total density (in nucleons per cm^3). The evolving cosmologies[1] require that the *total* number density satisfy a relation of the form:

$$N(z) = (1+z)^3 N_0 \,, \qquad (1)$$




2015
2010
2000
1990
1980
1970
1965
1960

Field (1959+)



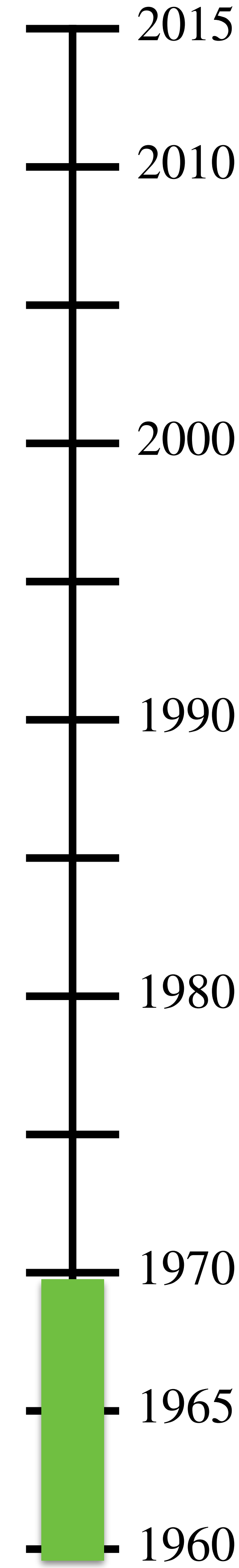
Field (1959+)

AN ATTEMPT TO OBSERVE NEUTRAL HYDROGEN BETWEEN THE GALAXIES

GEORGE B. FIELD
Princeton University Observatory
Received July 30, 1958; revised December 5, 1958

ABSTRACT

The 21-cm absorption by a neutral hydrogen gas between the galaxies has been searched for by means of observations of the extragalactic radio source Cygnus A. The negative results yield an upper limit on the opacity of 0.0075. This result implies that if a homogeneous distribution of neutral hydrogen is expanding with the universe, it has a density-temperature ratio less than 8.1×10^{-7} cm^{-3} deg^{-1}. The temperature referred to is the excitation temperature of the hydrogen hyperfine levels; it is shown in the following paper (Field 1959) that it is *not* simply equal to the gas kinetic temperature but can be calculated theoretically.



Field (1959+)

AN ATTEMPT TO OBSERVE NEUTRAL HYDROGEN BETWEEN THE GALAXIES

George B. Field
Princeton University Observatory
Received July 30, 1958; revised December 5, 1958

ABSTRACT

The 21-cm absorption by a neutral hydrogen gas between the galaxies has been searched for by means of observations of the extragalactic radio source Cygnus A. The negative results yield an upper limit on the opacity of 0.0075. This result implies that if a homogeneous distribution of neutral hydrogen is expanding with the universe, it has a density-temperature ratio less than 8.1×10^{-7} cm^{-3} deg^{-1}. The temperature referred to is the excitation temperature of the hydrogen hyperfine levels; it is shown in the following paper (Field 1959) that it is *not* simply equal to the gas kinetic temperature but can be calculated theoretically.

COSMIC-RAY HEATING OF THE INTERSTELLAR GAS

G. B. Field, D. W. Goldsmith, and H. J. Habing*
Department of Astronomy, University of California, Berkeley
Received December 16, 1968; revised January 17, 1969

ABSTRACT

We present a model of the interstellar medium based on detailed calculations of heating by low-energy cosmic rays. The model contains two thermally stable gas phases that coexist in pressure equilibrium, one at $T = 10^4$ ° K and one at $T < 300$° K. The hot gas occupies most of interstellar space. Gravitation in the z-direction compresses about 75 per cent of the gas into the cool, dense phase to form clouds. By choosing three parameters (the cosmic-ray ionization rate, the amount by which trace elements are depleted in sticking to dust grains, and the magnetic-field strength), we are able to predict six previously unrelated observational parameters to within a factor of 2.

Title:	The Physics of the Interstellar and Intergalactic Medium
Authors:	Field, G. B.
Publication:	Astrophysics and General Relativity, Volume 1. 1968 Brai of Congress Catalog Card Number 65-29011. Published by
Publication Date:	00/1969
Origin:	ADS
Bibliographic Code:	1969agr..conf...59F

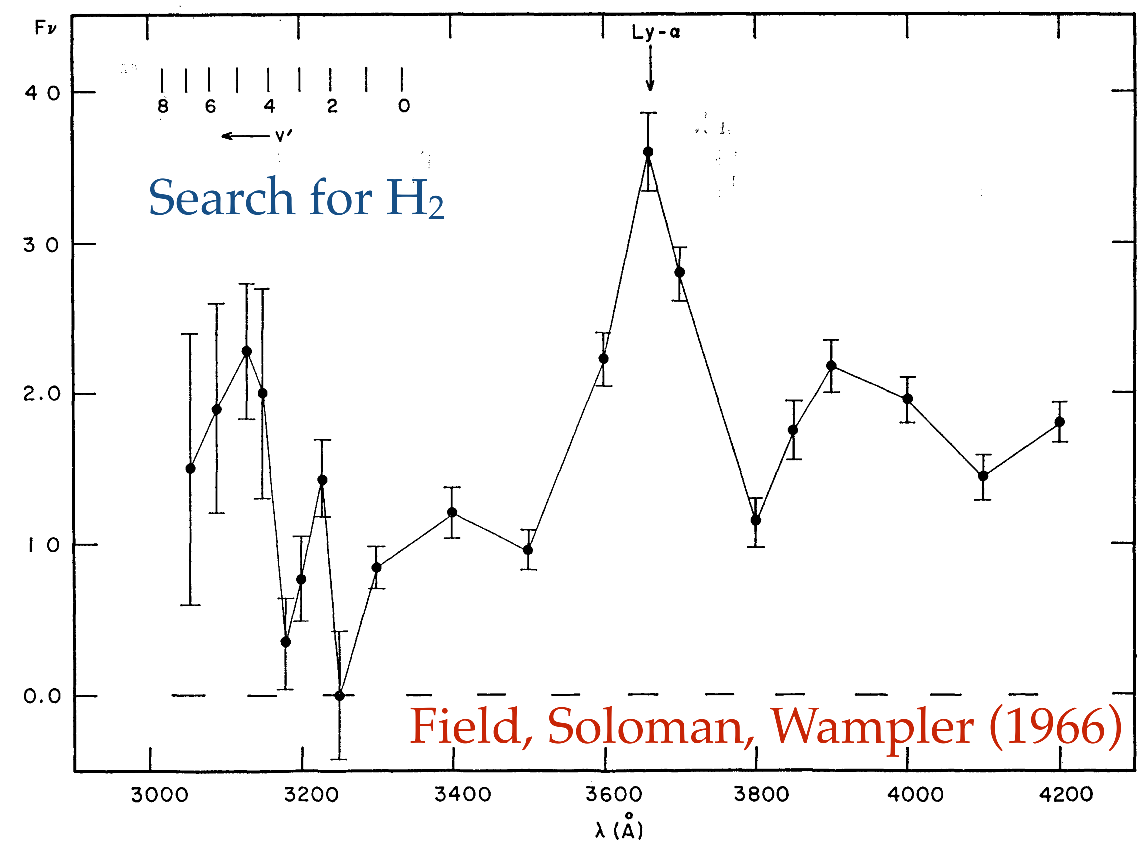
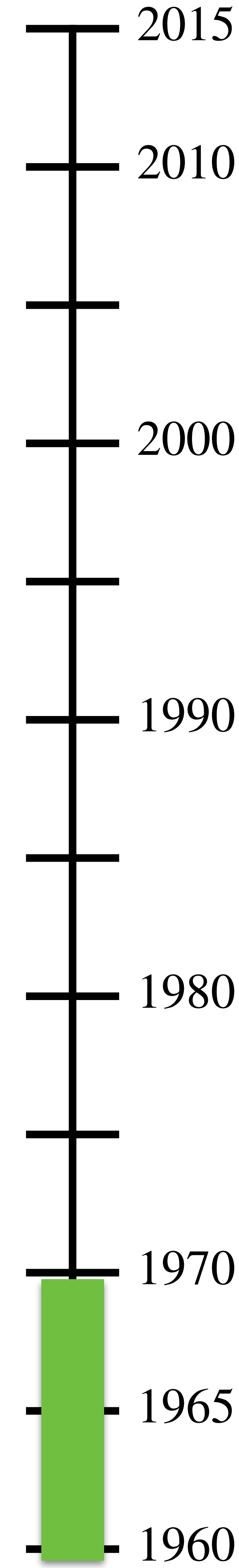
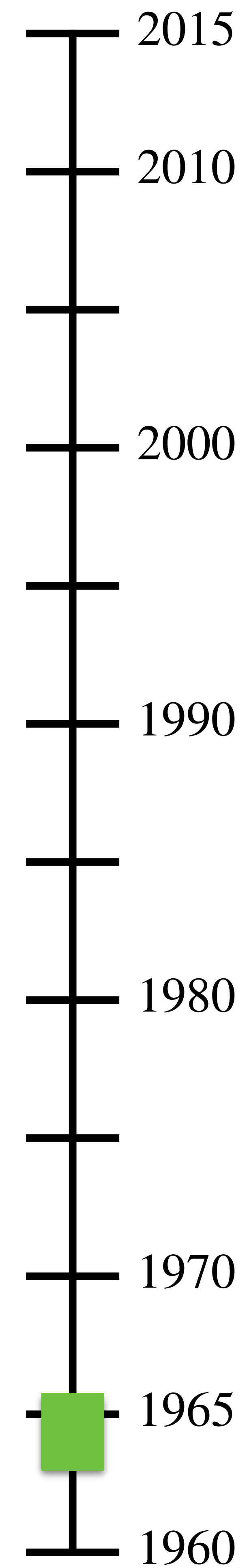


Fig. 2.—Fluxes reduced to outside the atmosphere observed with the photoelectric scanner of 3C 9.



Bahcall & Others (1966+)



ABSORPTION LINES IN THE SPECTRA OF DISTANT SOURCES

We discuss the properties of absorption lines that might appear in the continuum spectra of distant quasi-stellar sources (henceforth abbreviated "QSS") and outline what can be learned from a search for such lines. We consider first absorption by intergalactic gas in clusters of galaxies that are in the line of sight. We extend our previous discussion (Bahcall and Salpeter 1965)[1] of absorption lines caused by neutral hydrogen

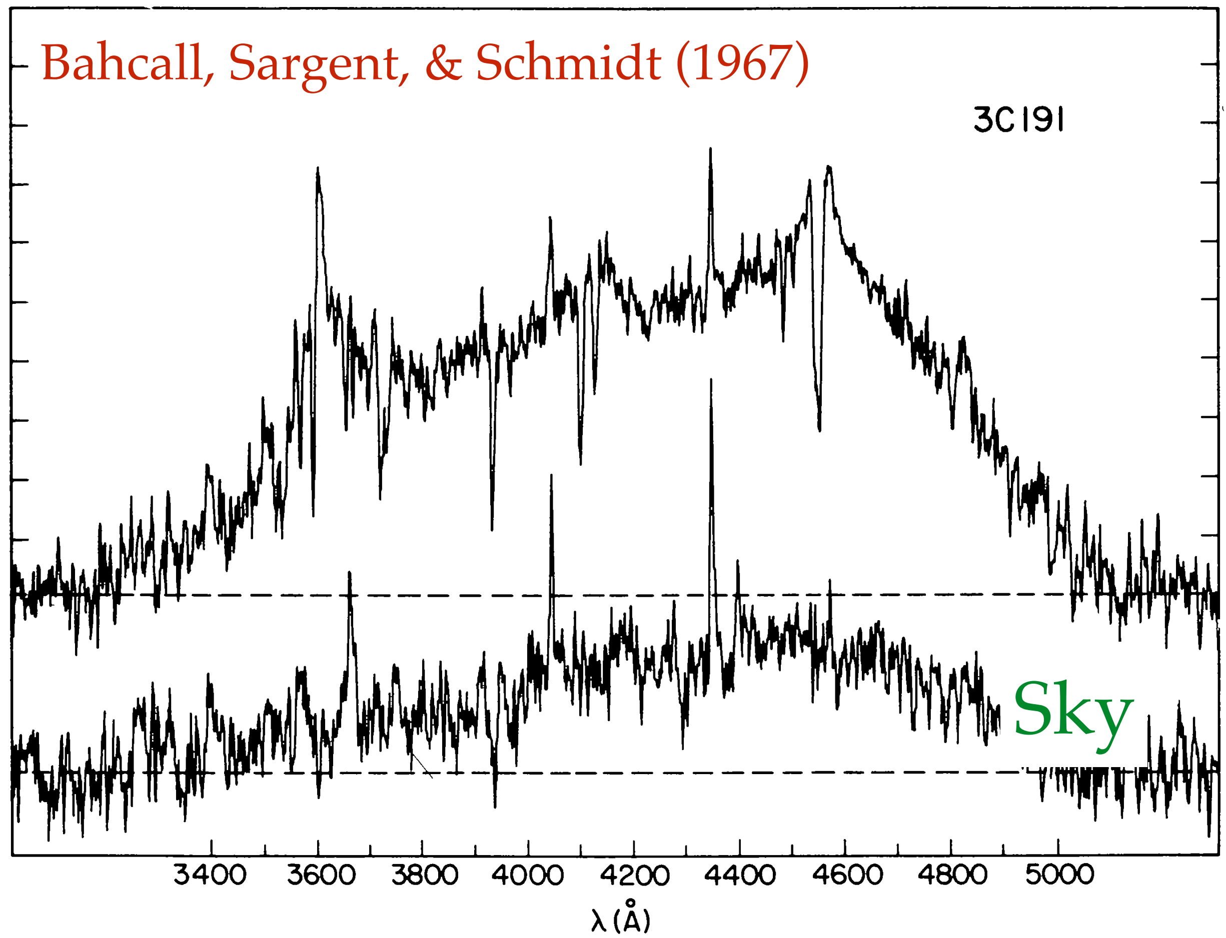
PHENOMENOLOGICAL LIMITS ON THE ABSORBING REGIONS OF QUASI-STELLAR SOURCES

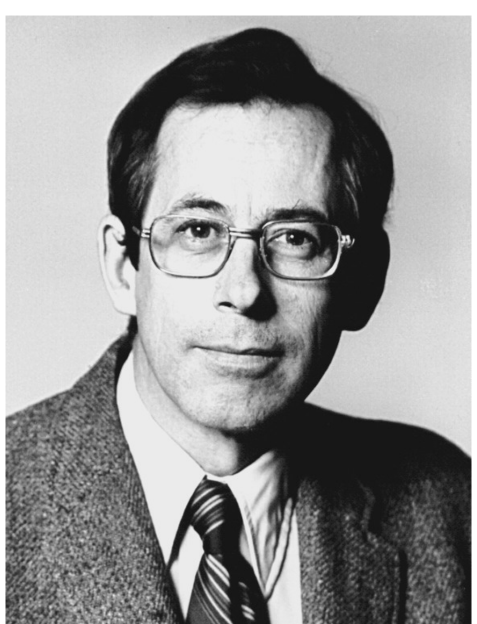
TABLE 1

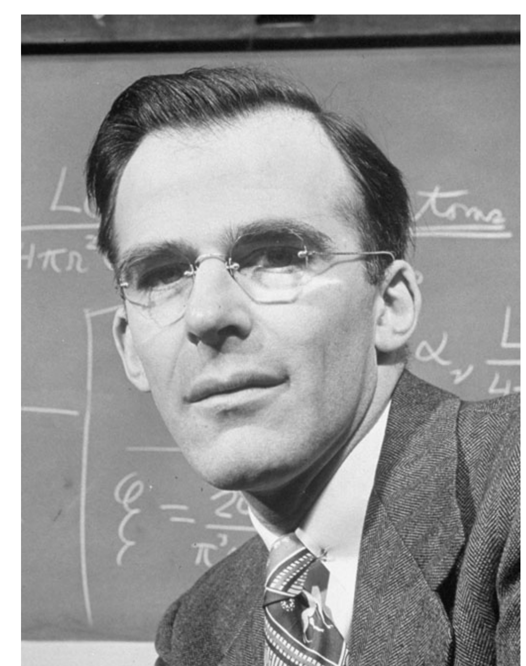
POSSIBLE ABSORPTION LINES

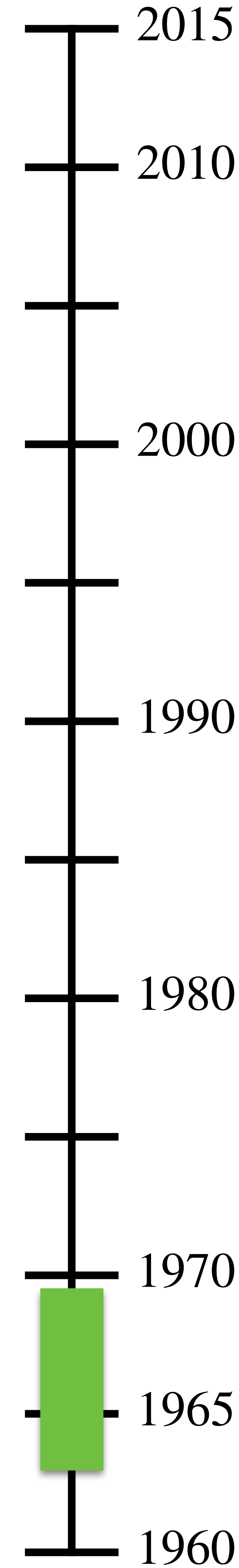
Ion	λ_{res} (Å)*	T_{min} (10^4 ° K)	T_{max} (10^4 ° K)
	A. Ionization Potential > 16 5 eV		
C II	1335	0 6	5
C IV	1549	4	20
N V	1240	7	30
Al II	1671	0 6	2
Al III	1857	2	3
Si III	1207	1	4
Si IV	1397	3	5
S II	1259	0 9	2
S III	1190	2	4
Fe III	1123	2	4
	B 13 6 eV $\lesssim$ Ionization Potential $\leq$ 16 5 eV		
H I	1216 (1027 etc)	0	40
N I	1200, 1135	0	3
O I	1302	0	2
Mg II	2799, 1240	0 7	2
Si II	1808, 1527, 1304, 1260, 1192	0 5	2
Fe II	2598, 2382, 2344, 1608, 1261, 1145	0 7	2
	C. Ionization Potential < 13 6 eV		
C I	1657, 1560, 1329, 1280, etc.	0	2
Mg I	2853, 2026, 1828, etc.	0	0 8
Si I	2515, 2209, 2066, 1978, etc.	0	0 8
S I	1807, 1474, 1425	0	1

* For the low densities of interest here, only the ground states (of any of the ions) have appreciable populations. Even the upper components of the ground-state fine-structure multiplets (with energy splittings $\gtrsim$ 20 cm^{-1}) decay to the lowest component by magnetic dipole transitions in times short compared to the collisional excitation times The wavelengths listed in Table 1 are average wavelengths from this lowest energy component to the various fine-structure components of the upper state weighted according to the strength of the line.

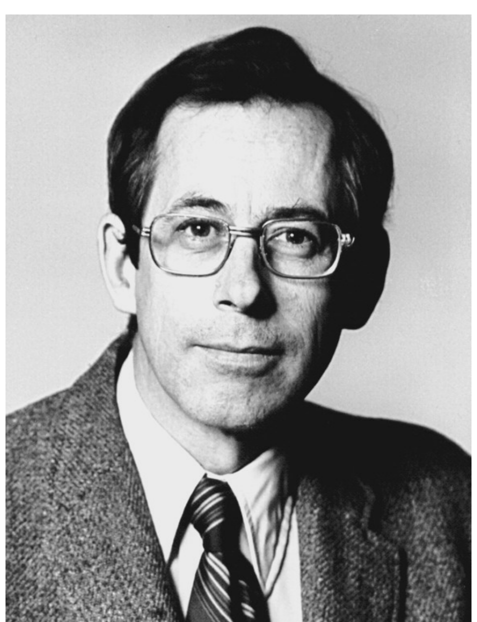


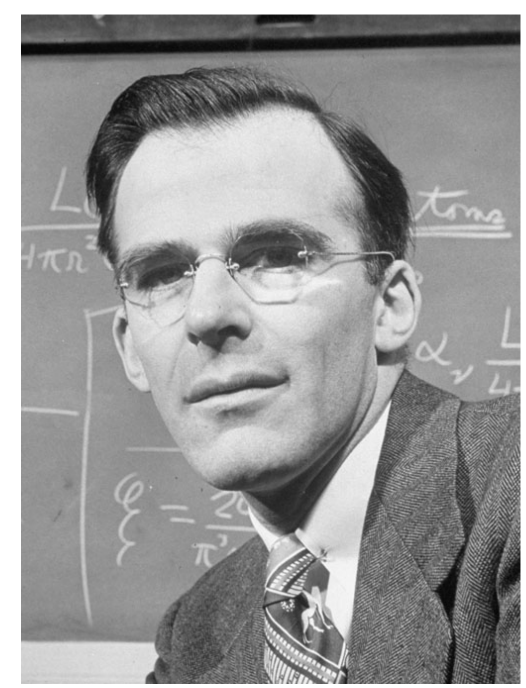


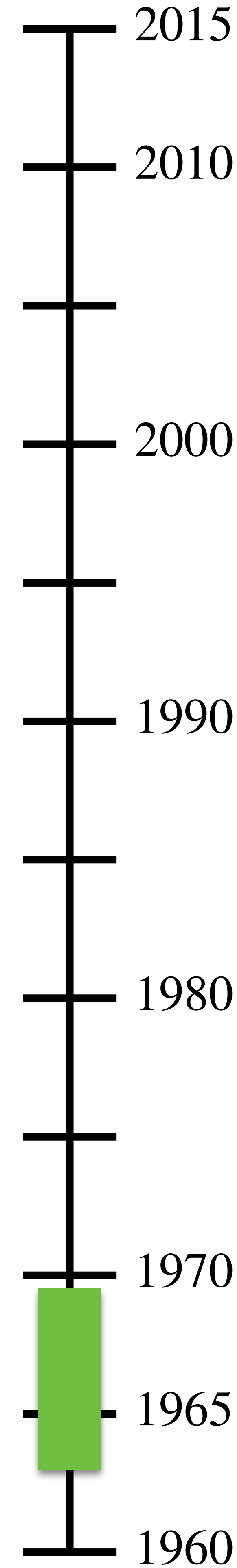



2015
2010
2000
1990
1980
1970
1965
1960

Early Halo Gas







Early Halo Gas

STATISTICAL TESTS FOR THE ORIGIN OF ABSORPTION LINES OBSERVED IN QUASI-STELLAR SOURCES*

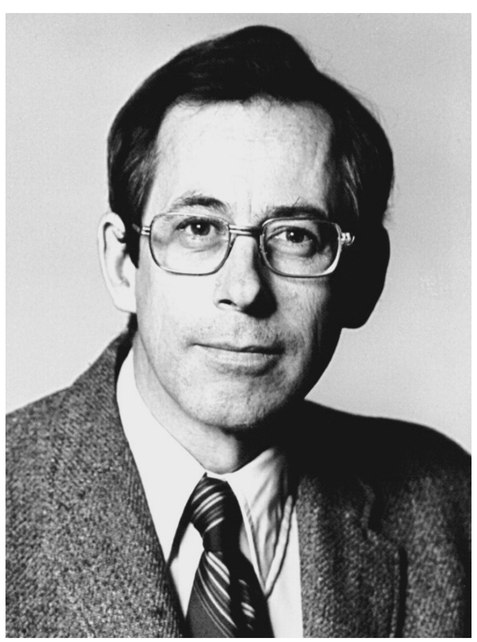
JOHN N. BAHCALL† AND P. J. E. PEEBLES†‡
California Institute of Technology, Pasadena, California
Received December 16, 1968; revised February 13, 1969

TEST 2

A difficulty with test 1 is that it requires constant detection efficiency for absorption redshifts in different objects. There is a second test, based on the relative frequency of occurrence of absorption redshifts as a function of z, for which the variation in detection efficiency is unimportant, although the detection efficiency in a given object must be constant in some range in z. An observed distribution function, $N_z \Delta z$, can be determined by counting the number of redshifts found in just one object, or, if z_c and z_{em} are constant, using all the redshifts found in a number of quasi-stellar sources. The relative detection efficiencies determine only the normalization and not the shape of the N_z curve. The simplest application of test 2 is to ask whether the observed N_z function can be represented by equation (1b) for approximately chosen q_0 and Λ/ρ_0.

The above procedure could be misleading, if, for example, combining the redshifts from different objects masked large variations from object to object. In order to test in more detail what the fully cosmological hypothesis implies for N_z, it is convenient to introduce the variable

$$X(z) = \int_0^z (1+z)^2 [H_0/H(z)] dz \,, \qquad (4)$$



ABSORPTION LINES PRODUCED BY GALACTIC HALOS

JOHN N. BAHCALL*
Institute for Advanced Study

AND

LYMAN SPITZER, JR.
Princeton University Observatory
Received March 24, 1969

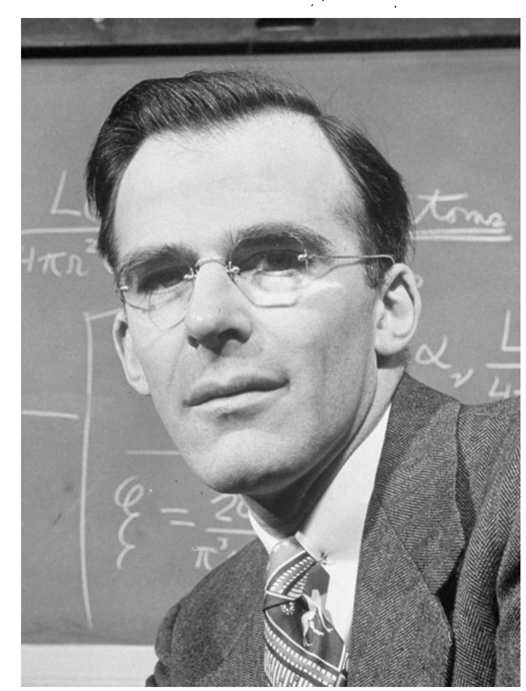
ABSTRACT

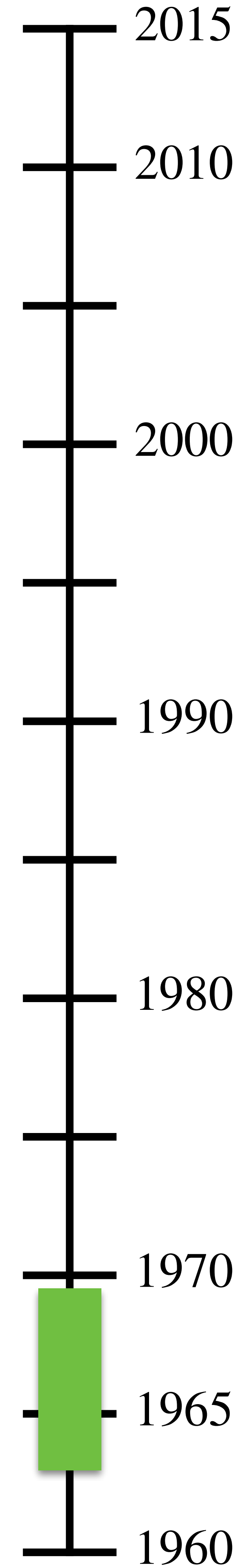
We propose that most of the absorption lines observed in quasi-stellar sources with multiple absorption redshifts are caused by gas in extended halos of normal galaxies.

For the sake of definiteness we assume that the halo has a radius of 100 kpc at a density of 3×10^{-5} particle cm^{-3}. A typical column of material is then, in agreement with observation, sufficient to produce dark absorption lines for the allowed transitions of the more abundant ions but not for rarer ions such as Sc III, Ti III, Cu II, Mn II, Ge III, and As II. Numerically, for a line of wavelength about 1500 Å,

$$\tau_{\rm abs} \sim 10^{+6} f_{\rm abs} \left[\frac{N_{\rm ion}}{N_{\rm total}}\right] \left[\frac{R_0}{10^2 \text{ kpc}}\right] \left[\frac{N_{\rm total}}{3 \times 10^{-5} \text{ cm}^{-3}}\right] . \qquad (2)$$

The total mass contained in the halo is $\sim 3 \times 10^9 M_\odot$. Evidently all these numerical estimates are tentative.





Early Halo Gas

STATISTICAL TESTS FOR THE ORIGIN OF ABSORPTION LINES OBSERVED IN QUASI-STELLAR SOURCES*

JOHN N. BAHCALL† AND P. J. E. PEEBLES†‡
California Institute of Technology, Pasadena, California
Received December 16, 1968; revised February 13, 1969

TEST 2

A difficulty with test 1 is that it requires constant detection efficiency for absorption redshifts in different objects. There is a second test, based on the relative frequency of occurrence of absorption redshifts as a function of z, for which the variation in detection efficiency is unimportant, although the detection efficiency in a given object must be constant in some range in z. An observed distribution function, $N_z \Delta z$, can be determined by counting the number of redshifts found in just one object, or, if z_c and z_{em} are constant, using all the redshifts found in a number of quasi-stellar sources. The relative detection efficiencies determine only the normalization and not the shape of the N_z curve. The simplest application of test 2 is to ask whether the observed N_z function can be represented by equation (1b) for approximately chosen q_0 and Λ/ρ_0.

The above procedure could be misleading, if, for example, combining the redshifts from different objects masked large variations from object to object. In order to test in more detail what the fully cosmological hypothesis implies for N_z, it is convenient to introduce the variable

$$X(z) = \int_0^z (1+z)^2 [H_0/H(z)] dz \,, \quad (4)$$

ABSORPTION LINES PRODUCED BY GALACTIC HALOS

JOHN N. BAHCALL*
Institute for Advanced Study
AND
LYMAN SPITZER, JR.
Princeton University Observatory
Received March 24, 1969

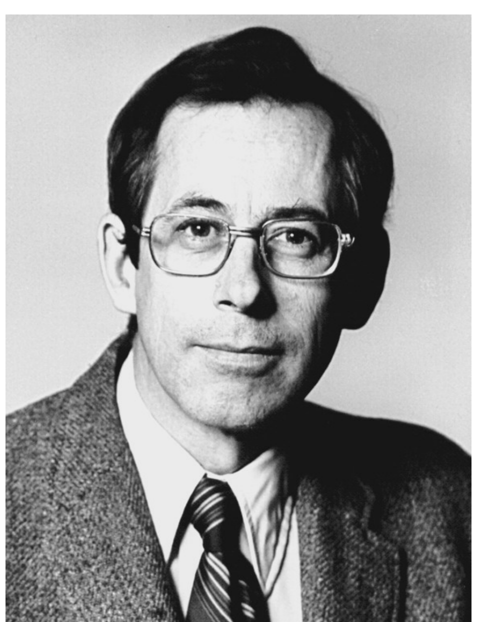
ABSTRACT

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.

For the sake of definiteness we assume that the halo has a radius of 100 kpc at a density of 3×10^{-5} particle cm^{-3}. A typical column of material is then, in agreement with observation, sufficient to produce dark absorption lines for the allowed transitions of the more abundant ions but not for rarer ions such as Sc III, Ti III, Cu II, Mn II, Ge III, and As II. Numerically, for a line of wavelength about 1500 Å,

$$\tau_{\rm abs} \sim 10^{+6} f_{\rm abs} \left[\frac{N_{\rm ion}}{N_{\rm total}}\right] \left[\frac{R_0}{10^2\ {\rm kpc}}\right] \left[\frac{N_{\rm total}}{3 \times 10^{-5}\ {\rm cm}^{-3}}\right] . \quad (2)$$

The total mass contained in the halo is $\sim 3 \times 10^9\ M_\odot$. Evidently all these numerical estimates are tentative.

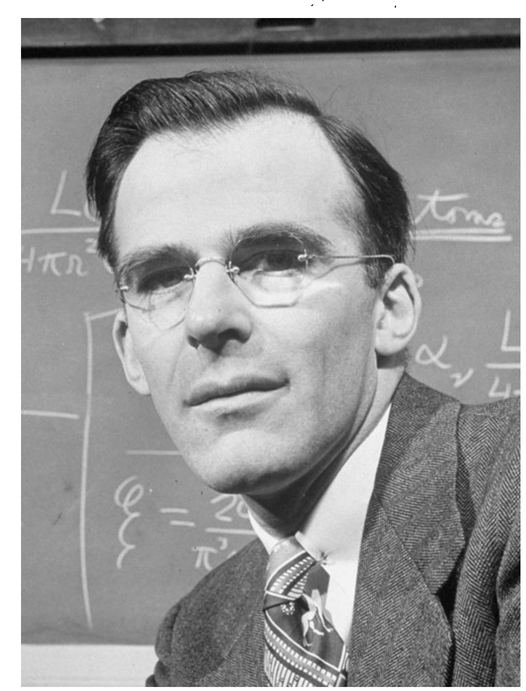


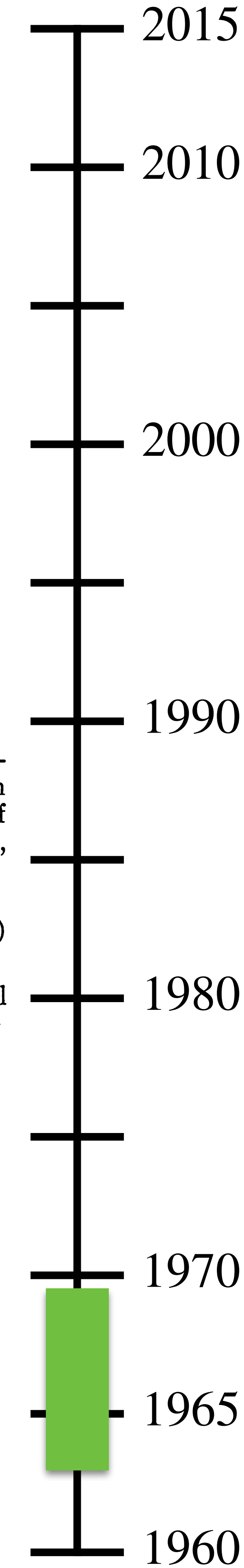
Astronomical Research with the Large Space Telescope

A space telescope of 120-inch aperture would be uniquely important for solving problems in astronomy.

Science 1968

Lyman Spitzer, Jr.





Early Halo Gas

STATISTICAL TESTS FOR THE ORIGIN OF ABSORPTION LINES OBSERVED IN QUASI-STELLAR SOURCES*

JOHN N. BAHCALL† AND P. J. E. PEEBLES†‡
California Institute of Technology, Pasadena, California
Received December 16, 1968; revised February 13, 1969

TEST 2

A difficulty with test 1 is that it requires constant detection efficiency for absorption redshifts in different objects. There is a second test, based on the relative frequency of occurrence of absorption redshifts as a function of z, for which the variation in detection efficiency is unimportant, although the detection efficiency in a given object must be constant in some range in z. An observed distribution function, $N_z \Delta z$, can be determined by counting the number of redshifts found in just one object, or, if z_c and z_{em} are constant, using all the redshifts found in a number of quasi-stellar sources. The relative detection efficiencies determine only the normalization and not the shape of the N_z curve. The simplest application of test 2 is to ask whether the observed N_z function can be represented by equation (1b) for approximately chosen q_0 and Λ/ρ_0.

The above procedure could be misleading, if, for example, combining the redshifts from different objects masked large variations from object to object. In order to test in more detail what the fully cosmological hypothesis implies for N_z, it is convenient to introduce the variable

$$X(z) = \int_0^z (1+z)^2 [H_0/H(z)] dz , \qquad (4)$$

ABSORPTION LINES PRODUCED BY GALACTIC HALOS

JOHN N. BAHCALL*
Institute for Advanced Study

AND

LYMAN SPITZER, JR.
Princeton University Observatory
Received March 24, 1969

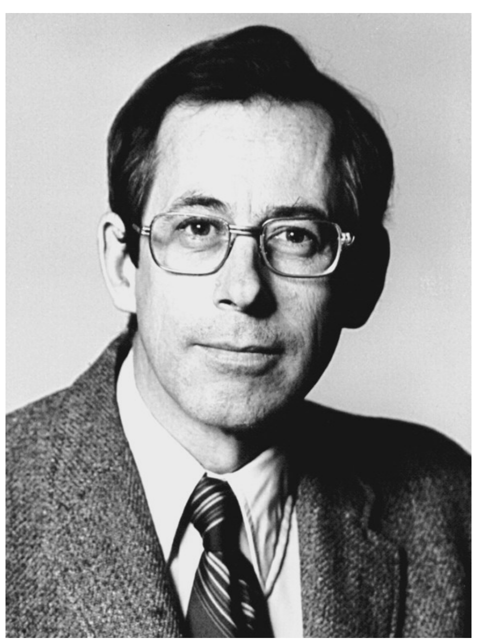
ABSTRACT

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.

For the sake of definiteness we assume that the halo has a radius of 100 kpc at a density of 3×10^{-5} particle cm^{-3}. A typical column of material is then, in agreement with observation, sufficient to produce dark absorption lines for the allowed transitions of the more abundant ions but not for rarer ions such as Sc III, Ti III, Cu II, Mn II, Ge III, and As II. Numerically, for a line of wavelength about 1500 Å,

$$\tau_{abs} \sim 10^{+6} f_{abs} \left[\frac{N_{ion}}{N_{total}}\right] \left[\frac{R_0}{10^2 \text{ kpc}}\right] \left[\frac{N_{total}}{3 \times 10^{-5} \text{ cm}^{-3}}\right] . \qquad (2)$$

The total mass contained in the halo is $\sim 3 \times 10^9 M_\odot$. Evidently all these numerical estimates are tentative.

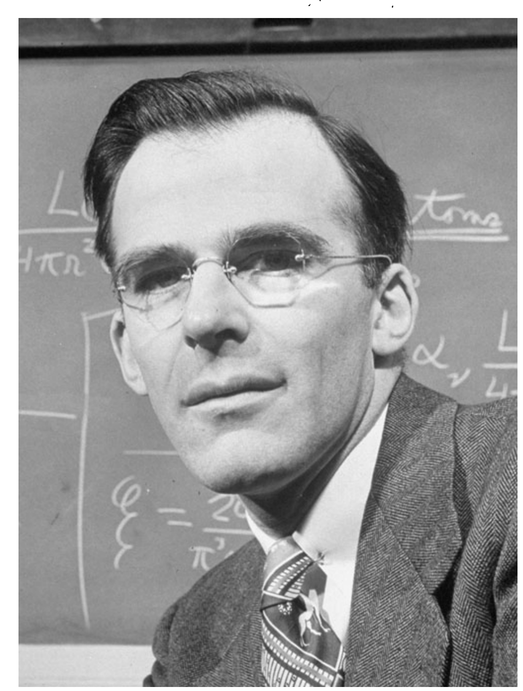


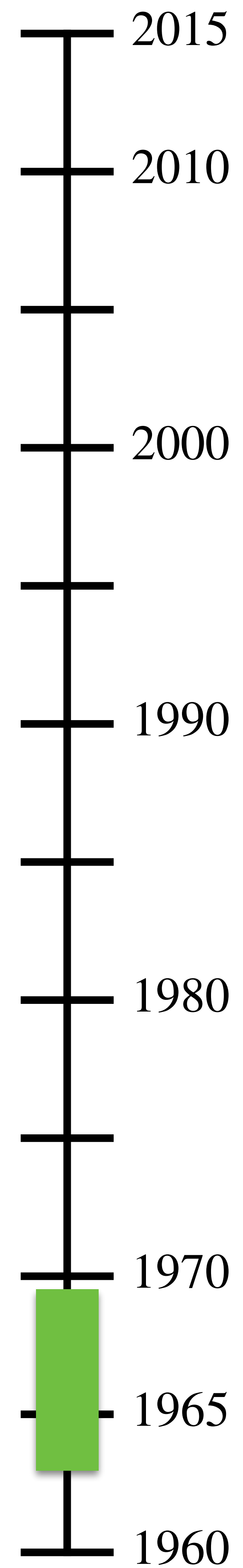
Astronomical Research with the Large Space Telescope

A space telescope of 120-inch aperture would be uniquely important for solving problems in astronomy.

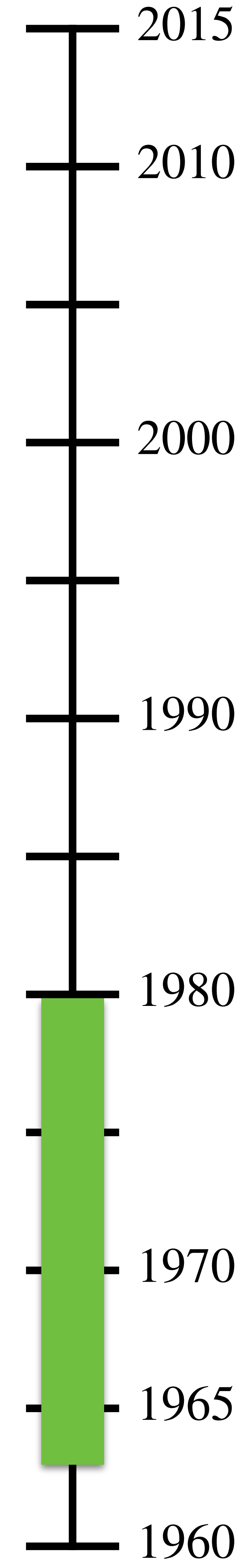
Lyman Spitzer, Jr.

Science 1968
4 citations!!

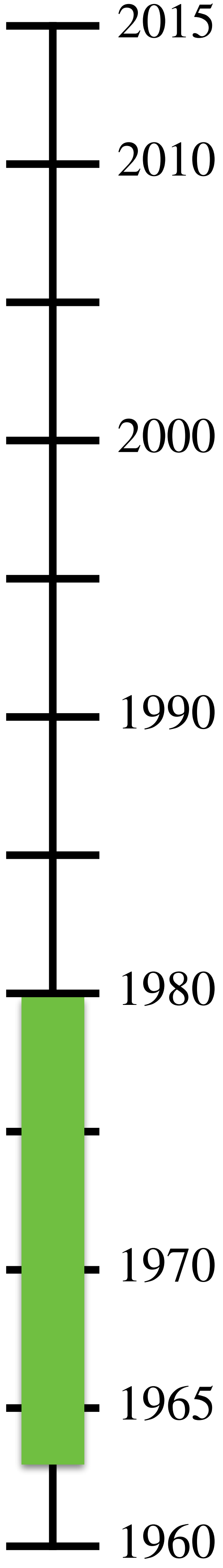




The Roaring 70's!



The Snoring 70's…



The Snoring 70's…

21-CENTIMETER ABSORPTION AT $z = 0.692$ IN THE QUASAR 3C 286

Robert L. Brown and Morton S. Roberts
National Radio Astronomy Observatory,* Charlottesville, Virginia
Received 1973 June 11

ABSTRACT

The 21-cm hydrogen line has been detected in absorption at 839.407 MHz in the quasar 3C 286; this corresponds to a redshift of $z_{abs} = 0.692154$. The narrow velocity dispersion of the line, $\Delta v = 8.2$ km s^{-1}, together with the large inferred column density of neutral hydrogen $N_H = 2.6 \times 10^{18}\ T_g$ cm^{-2}, suggest that the most likely origin of the absorption is an intervening galaxy. With this interpretation we conclude that at least 81.5 percent of the emission-line redshift of 3C 286 ($z_{em} = 0.849$) is cosmological.

Subject headings: galaxies — intergalactic medium — redshifts

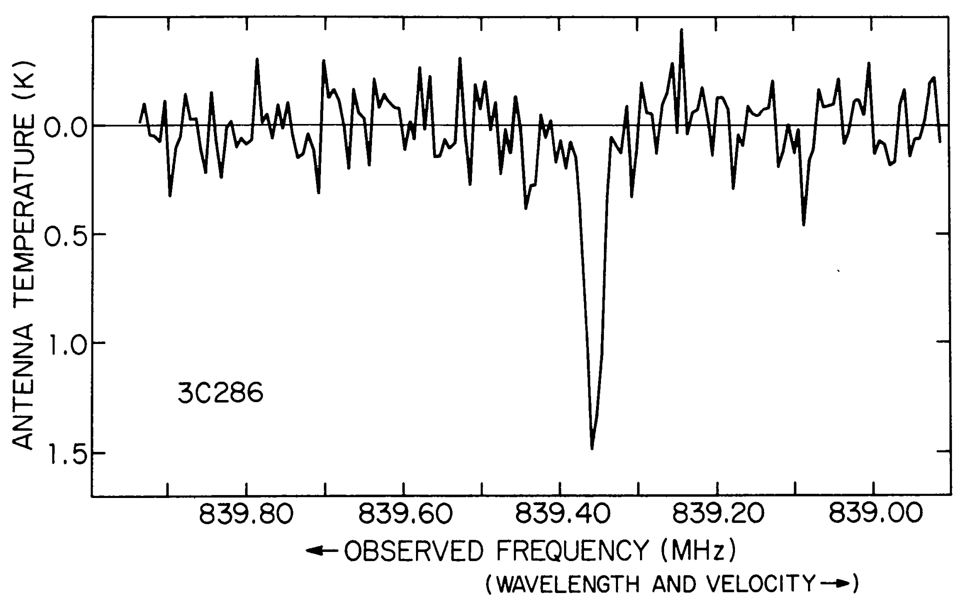
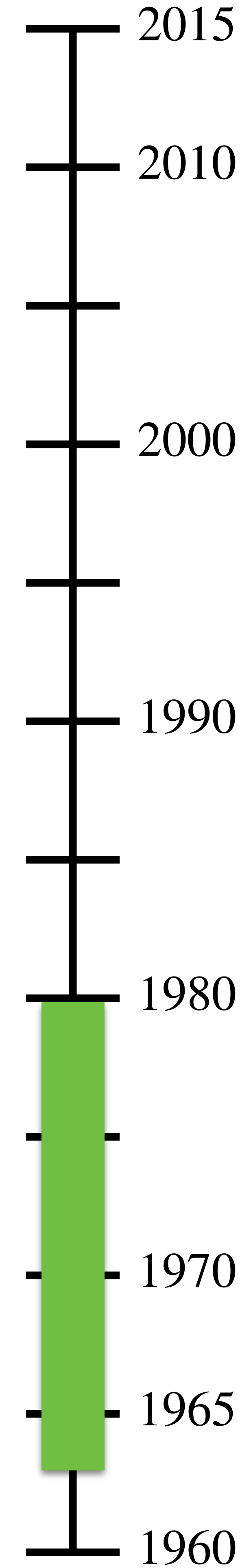


Fig. 1.—Velocity profile in the direction of 3C 286. The channel spacing is 6.5 kHz, the effective resolution is 7.9 kHz. Note that the scale is in the usual optical sense of increasing wavelength (decreasing frequency) to the right. The *observed* frequency is shown here. Frequencies given in the text are corrected for the Earth's motion.



The Snoring 70's…

21-CENTIMETER ABSORPTION AT $z = 0.692$ IN THE QUASAR 3C 286

ROBERT L. BROWN AND MORTON S. ROBERTS
National Radio Astronomy Observatory,* Charlottesville, Virginia
Received 1973 June 11

ABSTRACT

The 21-cm hydrogen line has been detected in absorption at 839.407 MHz in the quasar 3C 286; this corresponds to a redshift of $z_{abs} = 0.692154$. The narrow velocity dispersion of the line, $\Delta v = 8.2$ km s^{-1}, together with the large inferred column density of neutral hydrogen $N_H = 2.6 \times 10^{18}\ T_g$ cm^{-2}, suggest that the most likely origin of the absorption is an intervening galaxy. With this interpretation we conclude that at least 81.5 percent of the emission-line redshift of 3C 286 ($z_{em} = 0.849$) is cosmological.

Subject headings: galaxies — intergalactic medium — redshifts

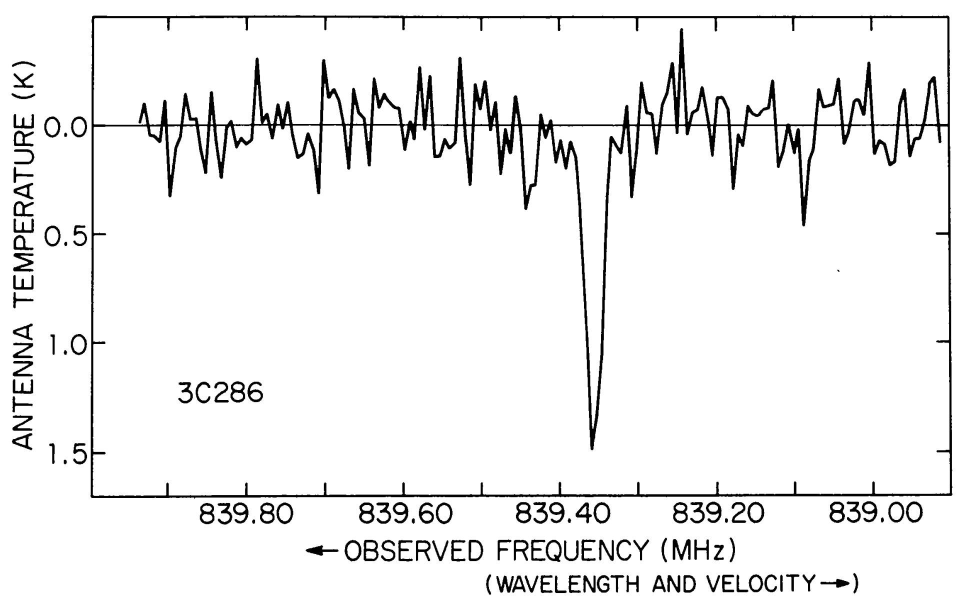


FIG. 1.—Velocity profile in the direction of 3C 286. The channel spacing is 6.5 kHz, the effective resolution is 7.9 kHz. Note that the scale is in the usual optical sense of increasing wavelength (decreasing frequency) to the right. The *observed* frequency is shown here. Frequencies given in the text are corrected for the Earth's motion.

Detection at $z \approx 0.5$ of a 21-cm absorption line in AO 0235+164: The first coincidence of large radio and optical redshifts

M. S. Roberts, R. L. Brown, W. D. Brundage, and A. H. Rots
National Radio Astronomy Observatory, Green Bank, West Virginia 24944*

M. P. Haynes
Department of Astronomy, Indiana University, Bloomington, Indiana 47401

A. M. Wolfe
Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, Pennsylvania 15260
(Received 25 February 1976)

We report the detection of redshifted neutral hydrogen in absorption against the BL Lac-type quasar AO 0235+164. The line occurs at 932.116±.005 MHz corresponding to a redshift $z = 0.52385 \pm 0.00001$, a value identical, to within the errors, to the optically derived redshift. This is the first instance in which both radio and optical high-redshift absorption lines are measured. The coincidence of these redshifts yields stringent limits to the constancy of the wavelength invariance of the Doppler expression, supports the optical line identifications, and yields limits on the variation of certain atomic quantities over cosmic time scales. The Mg/H abundance is derived as is a lower limit to the location of the absorbing cloud with respect to the quasar.

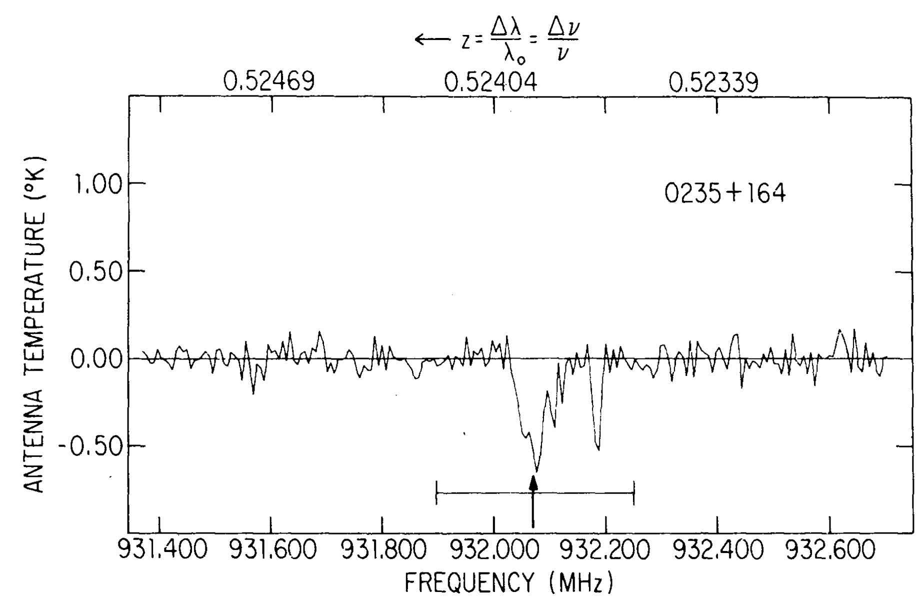
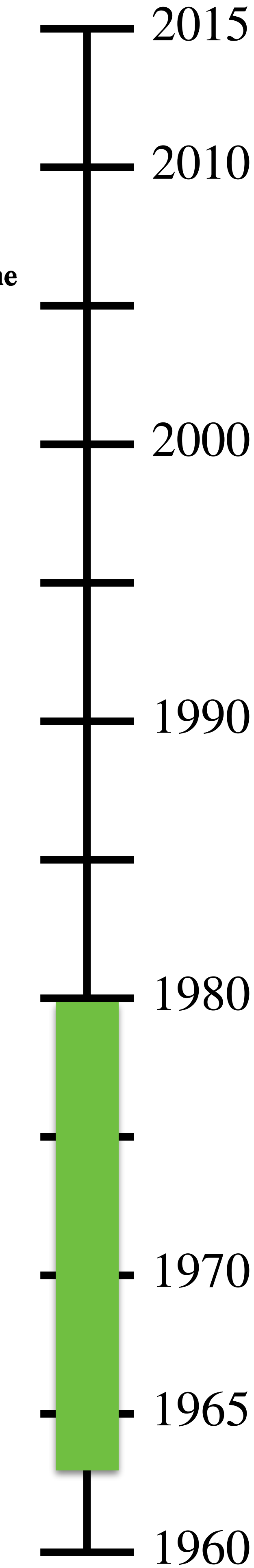
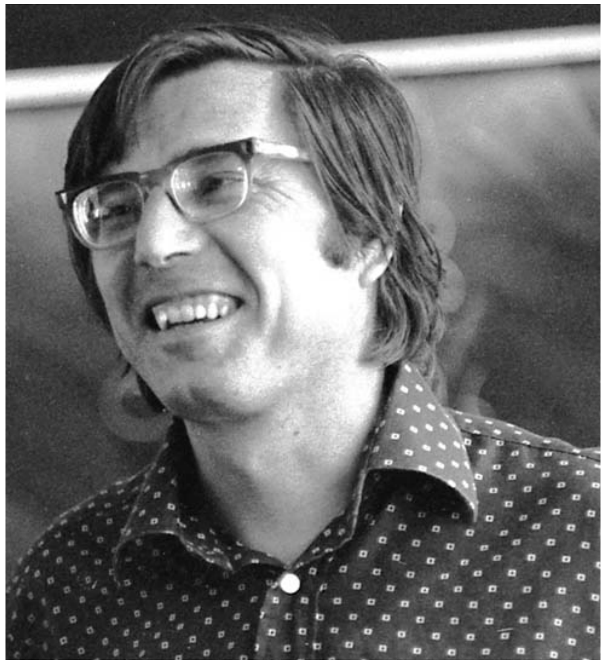
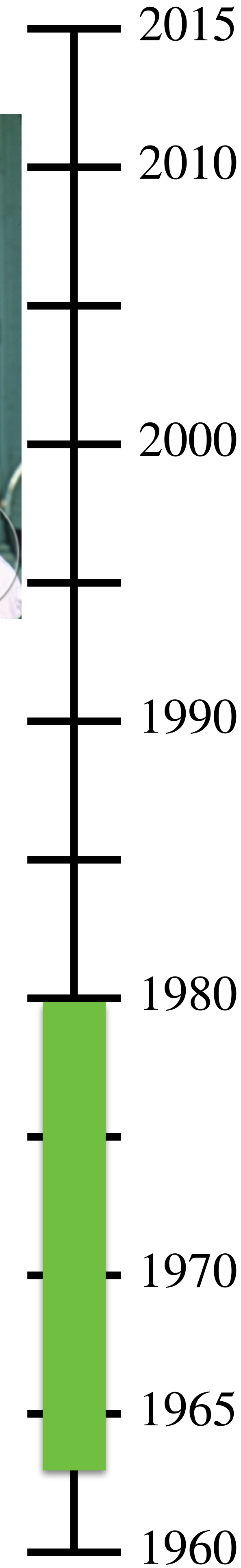


FIG. 1. Absorption hydrogen line profile in the direction of the radio source AO 0235+164. The frequency and redshift (z) scales are heliocentric. The arrow locates the optically measured redshift and its associated error (Burbidge *et al.* 1976).

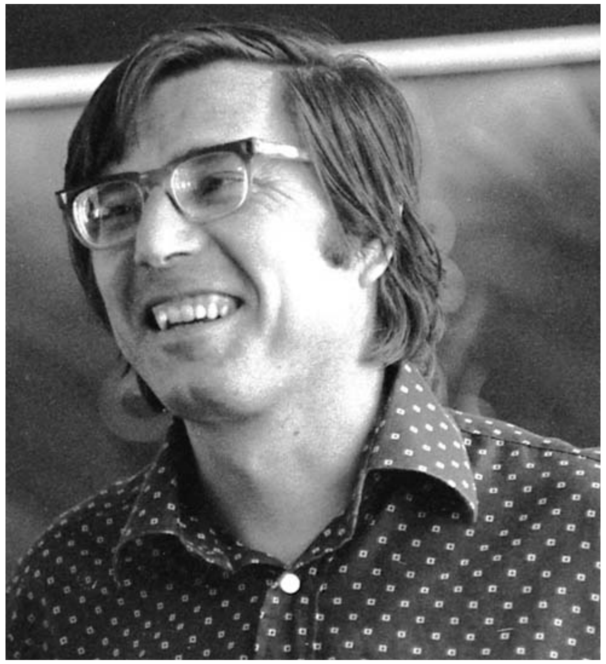





Emilio
Segrè
Visual
Archives


2015
2010
2000
1990
1980
1970
1965
1960

The Lyα Forest



A HIGH-RESOLUTION STUDY OF THE ABSORPTION SPECTRUM OF PKS 2126−158

PETER J YOUNG AND WALLACE L. W. SARGENT
Hale Observatories, California Institute of Technology, Carnegie Institution of Washington
A. BOKSENBERG
Department of Physics and Astronomy, University College London
AND
R. F. CARSWELL AND J. A. J. WHELAN
Institute of Astronomy, Cambridge University
Received 1978 July 5; accepted 1978 November 21

ABSTRACT

Observations of the QSO PKS 2126−158 (z_{em} = 3.280) at 0.8 Å resolution from 4153 Å to 6807 Å reveal 113 absorption lines. There are two certain absorption-line systems at z_{abs} = 2.6381 and 2.7685, and a possible third system at z_{abs} = 2.3938. The ions H I, C II, C IV, O I, Al II, Si II, Si III, Si IV, and Fe II are observed in these systems; no excited fine-structure lines Si II* are seen, but C II* is almost certainly present in the z_{abs} = 2.7685 system. These three systems lead to the identification of all 12 lines longward of the Lα emission line. However, only 22 out of 101 absorption lines shortward of Lα are thereby identified.

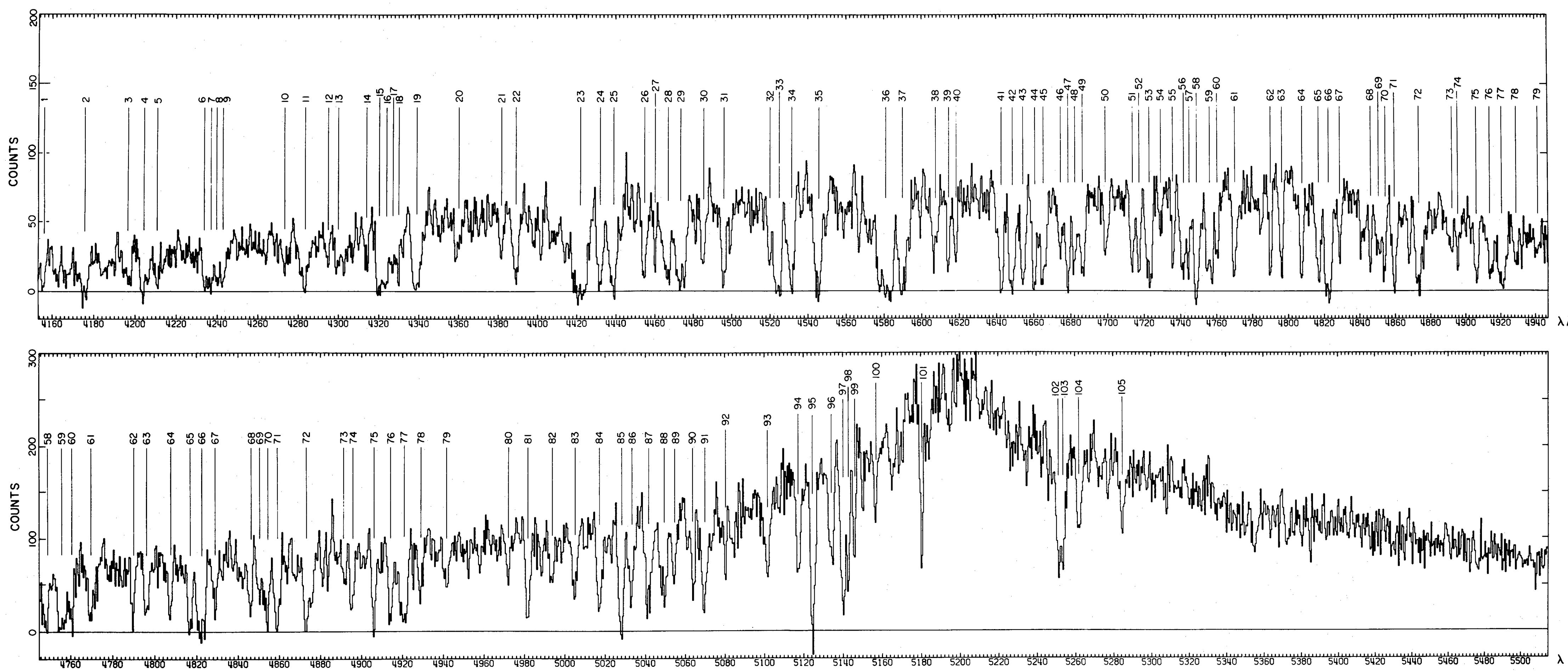
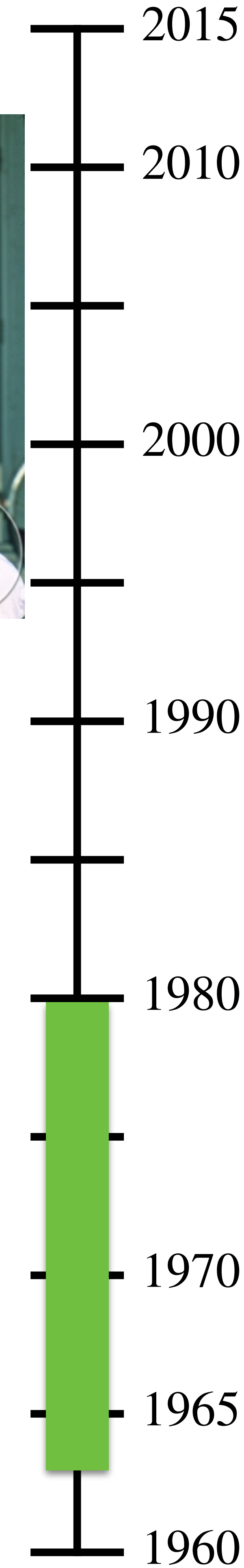
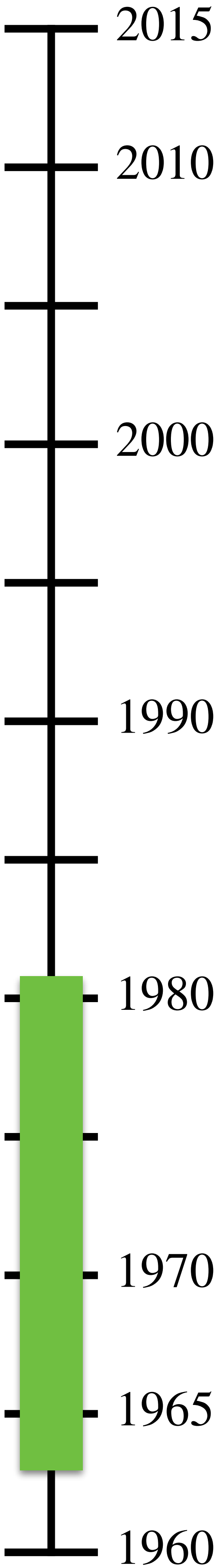
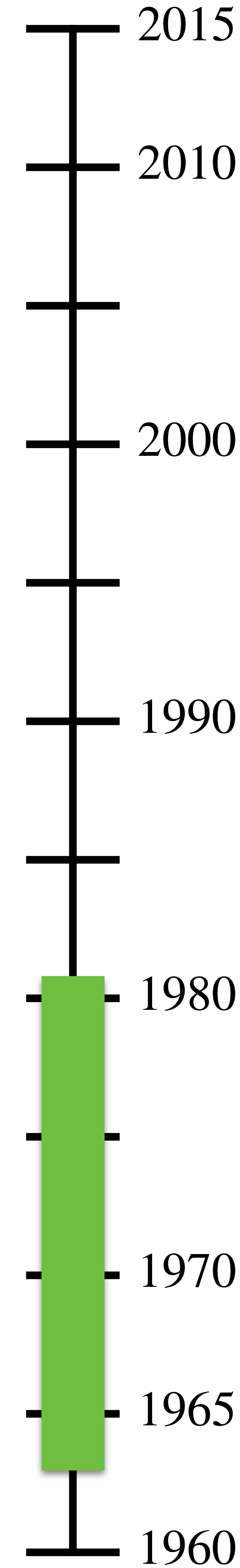


FIG. 1.—Spectrum of PKS 2126−158, showing four overlapping, independent observations covering the range 4153–6807 Å. Each bin is equivalent to 25.78 km s^{-1} (the wavelength axis is logarithmic). The zero intensity level in each observation is indicated by the horizontal lines. The 113 absorption lines listed in Table 3 are marked and labeled.




2015
2010
2000
1990
1980
1970
1965
1960

The Lyman Limit Systems



The Lyman Limit Systems

Nature Vol. 298 29 July 1982 **427**

ARTICLES

QSO Lyman limit absorption

David Tytler

Department of Physics and Astronomy, University College London, Gower Street, London WC1E 6BT, UK

The redshift distribution of QSO absorption systems which are optically thick in the Lyman continuum matches that of a non-evolving population of absorbers in a standard Friedmann cosmological model over the redshift range 0.4–3.5. The density of absorbers per unit velocity in the QSO rest frame is roughly constant for $-0.01 \lesssim v/c \lesssim 0.2$ *and shows a rapid increase with QSO emission redshift, in accord with an 'intervening' origin for the absorbers but contrary to expectation were the material intrinsic to the QSOs.*

The present analysis shows that the QSOs and LLS are apparently separate, uncoupled populations. There is then every reason to expect the LLS to exist at $z > 3.5$, and perhaps continuing to show little evolution. This being the case I predict that little radiation (QSO, protogalaxy or otherwise) will be observed in the optical *U*, *B*, *V*, or *R* bands originating from $z \gtrsim 3.5, 4.2, 5.3$ or 6.9, due simply to absorption by high redshift LLS. Such are the limits of optical astronomy.

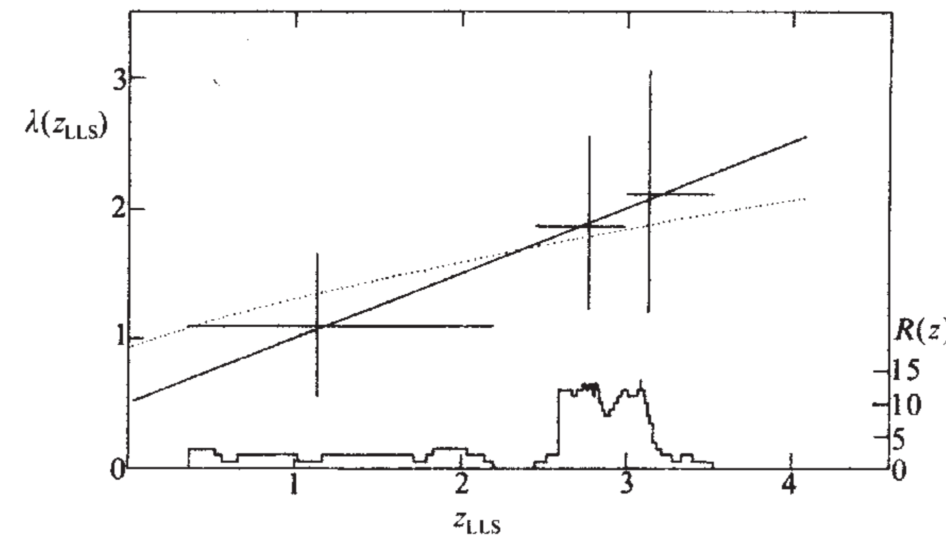
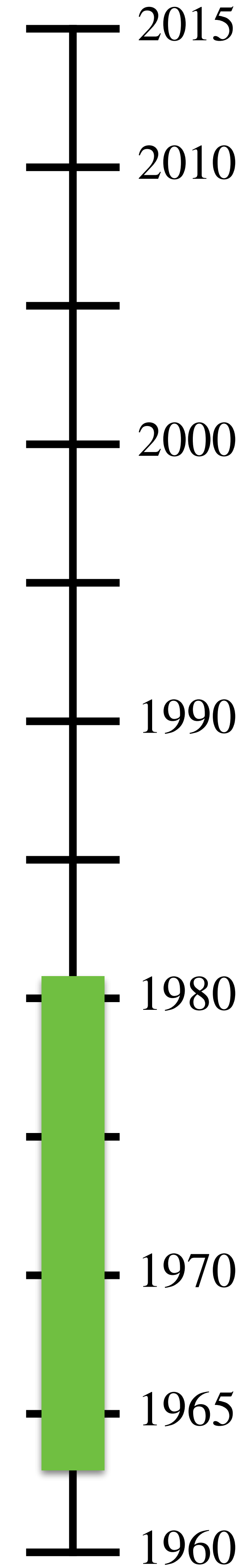
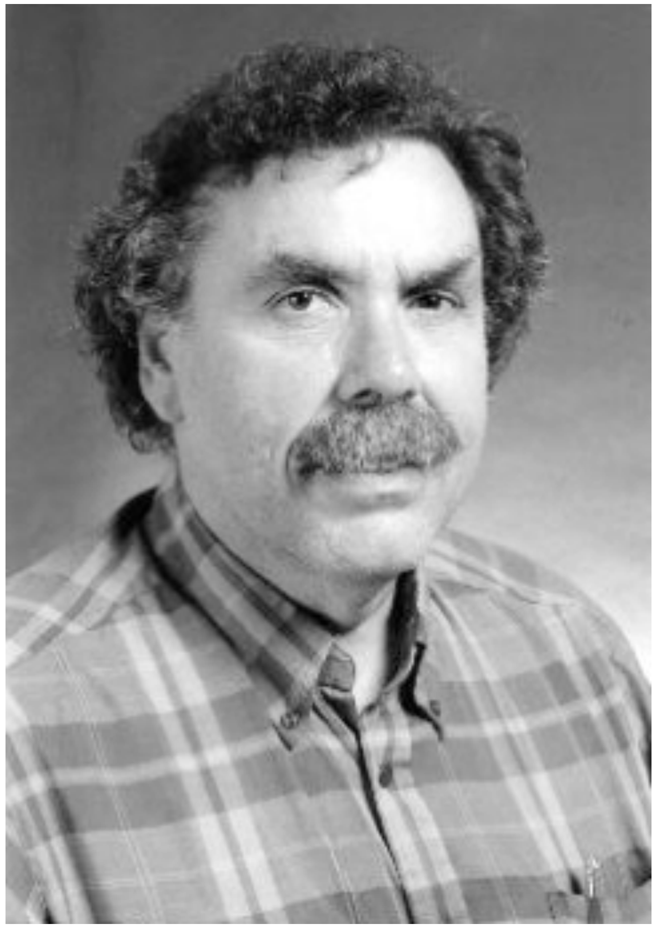
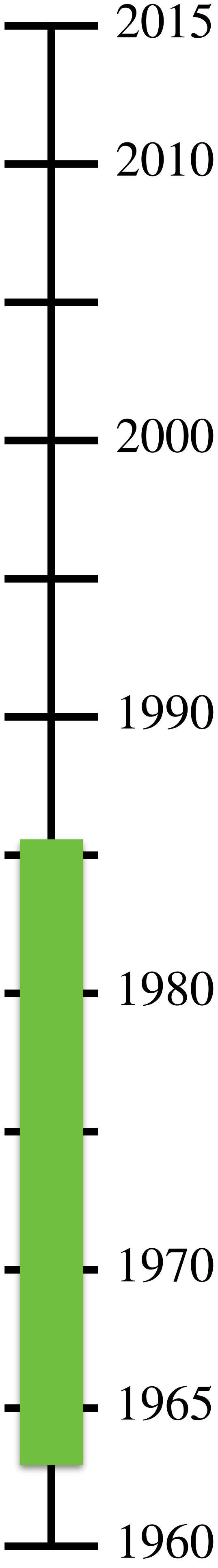


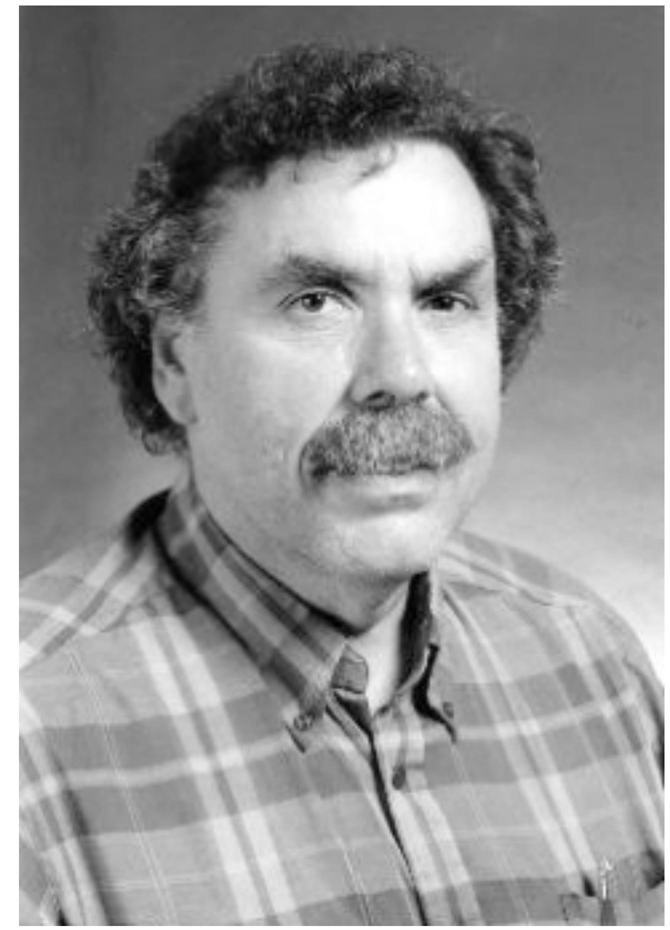
Fig. 4 LLS density as a function of redshift. The sample of 34 QSOs showing 18 LLS all with $z_{LLS} < z_{em}$ are included. The two QSOs with $z_{LLS} > z_{em}$ are excluded. Crosses indicate $\hat{\lambda}(<z_{LLS}>)$, the density of LLS per unit *z*, per QSO with 1σ asymptotic error bounds given by equation (10). $\langle z_{LLS} \rangle$ is the *a priori* mean redshift sampled by the QSOs in each bin. The straight solid line is $\lambda(z) = \lambda_0(1+z)$ with $\lambda_0 = 0.50$, the expected distribution of non-evolving absorbers in a Friedmann model with zero cosmological constant and $q_0 = 0$. The dotted curve is $\lambda(z) = \lambda_0(1+z)^{1/2}$ with $\lambda_0 = 0.93$, appropriate for $q_0 = \frac{1}{2}$. In both instances $\lambda_0 = \lambda(z = 0)$ was estimated using the maximum likelihood method applied to the unbinned data. The lower histogram shows $R(z)$, the *a posteriori* risk set: the number of QSOs towards which a LLS could have been observed as a function of redshift. A QSO enters the risk set at z_{em} and leaves at z_{LLS}, or z_{min} if no LLS was observed.

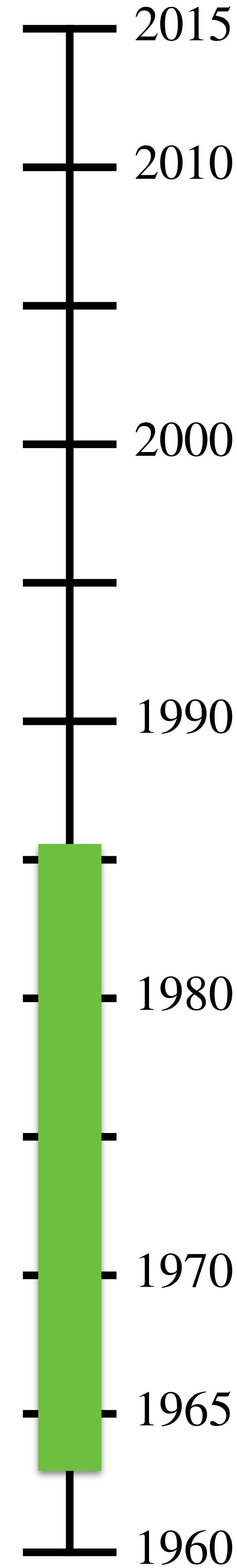





2015
2010
2000
1990
1980
1970
1965
1960

The Damped Lyα Systems

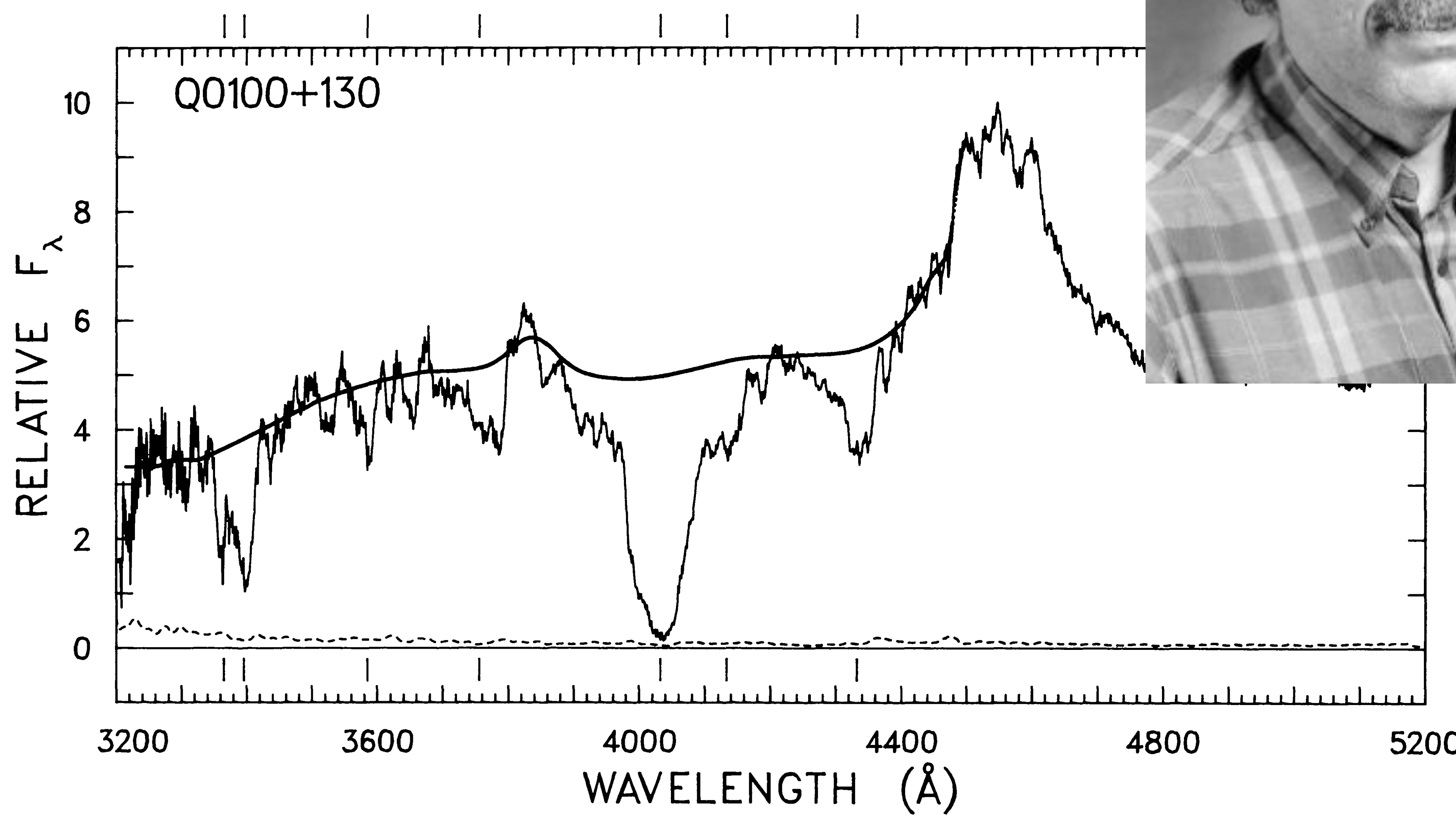


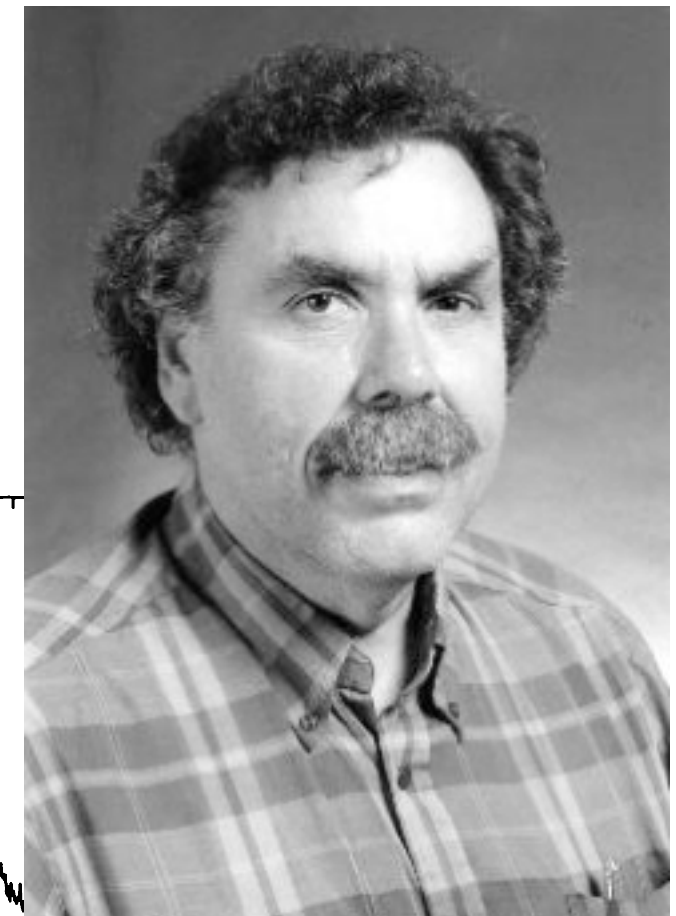


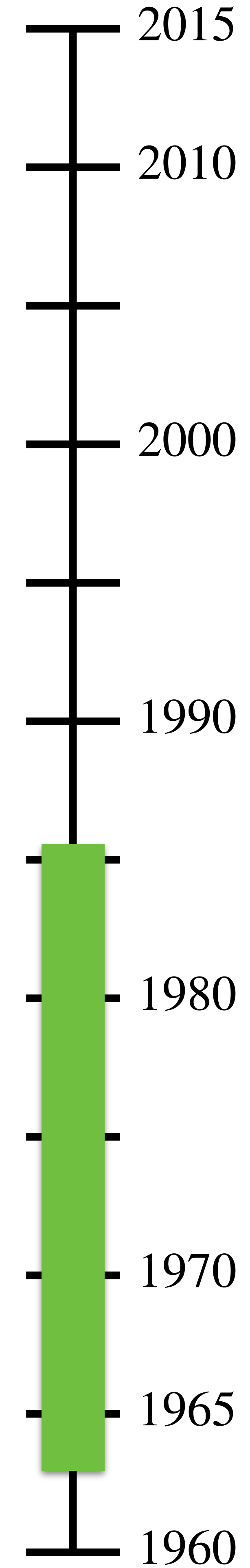
The Damped Lyα Systems

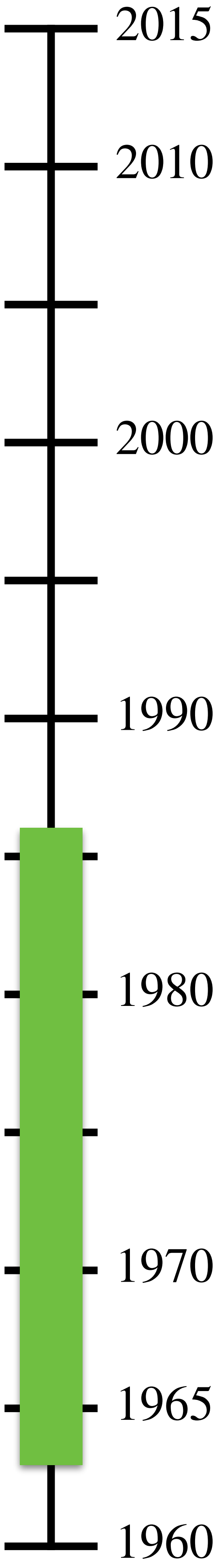
DAMPED LYMAN-ALPHA ABSORPTION BY DISK GALAXIES WITH LARGE REDSHIFTS.
I. THE LICK SURVEY

ARTHUR M. WOLFE
University of Pittsburgh
DAVID A. TURNSHEK
Space Telescope Science Institute
AND
HARDING E. SMITH AND ROSS D. COHEN
University of California at San Diego
Received 1985 August 1; accepted 1985 December 2

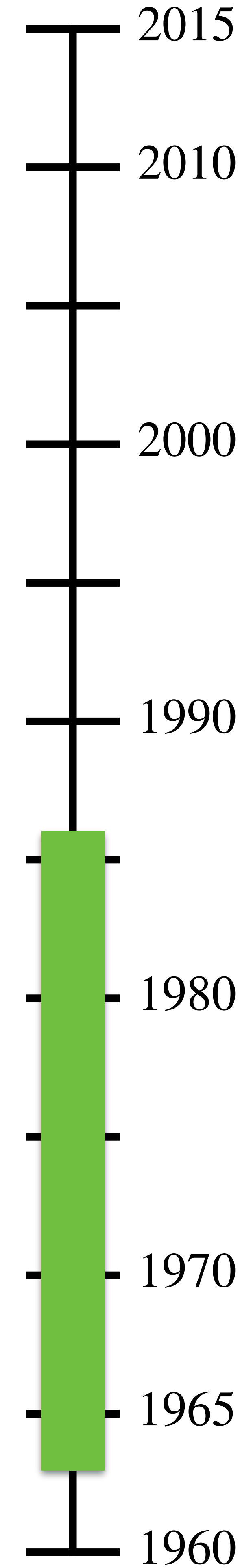







2015
2010
2000
1990
1980
1970
1965
1960

Halo Gas (CGM) Confirmed



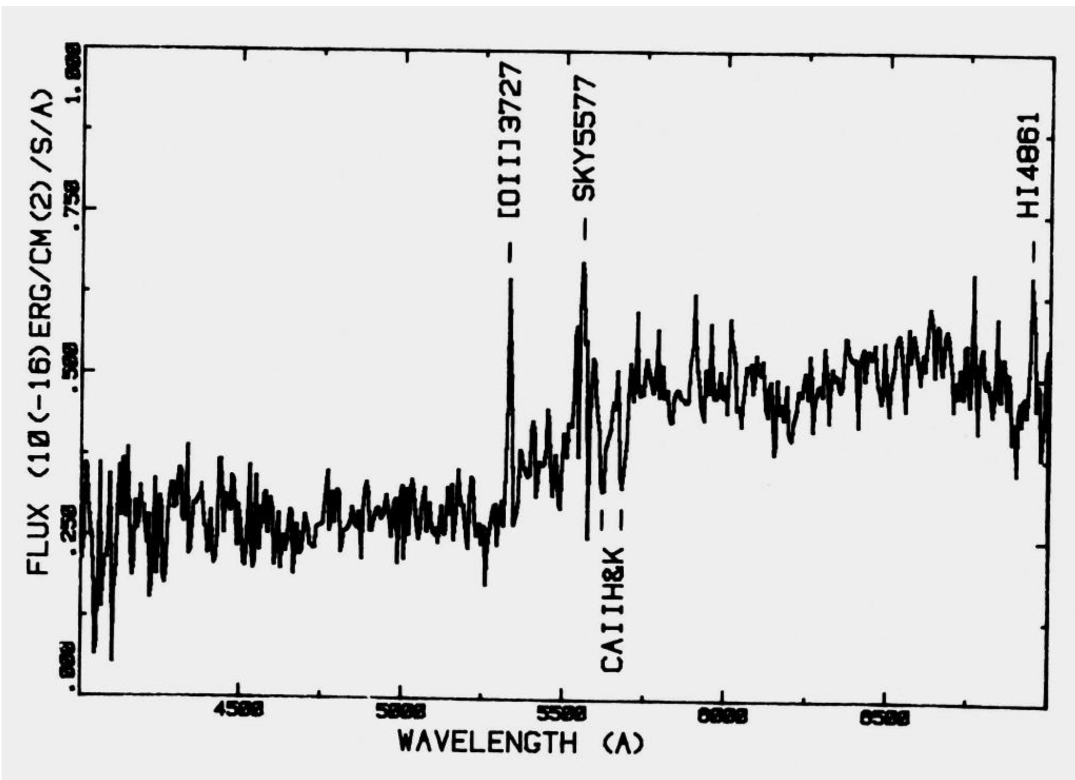
Halo Gas (CGM) Confirmed

Letter to the Editor

The Mg II absorption system in the QSO PKS 2128-12: a galaxy disc/halo with a radius of 65 kpc⋆

J. Bergeron

Institut d'Astrophysique, 98 bis Bd Arago, F-75014 Paris, France



PROFILE OF A KEY PROGRAMME

Identification of High Redshift Galaxies with Very Large Gaseous Halos

J. BERGERON[1], S. CRISTIANI[2], M. PIERRE[3], P. SHAVER[3]

[1]Institut d'Astrophysique de Paris, France; [2]Osservatorio Astronomico, Asiago, Italy; [3]ESO

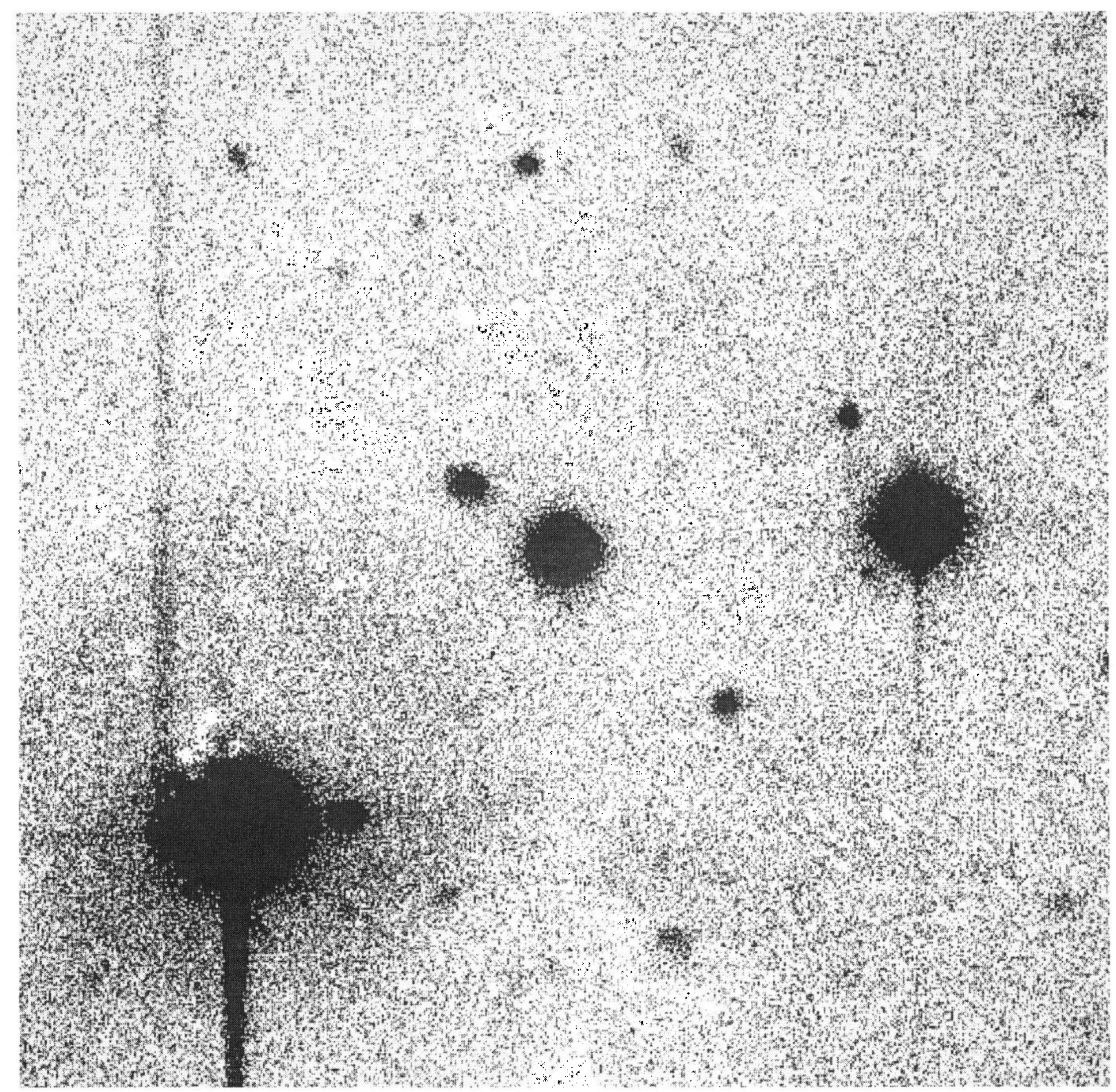
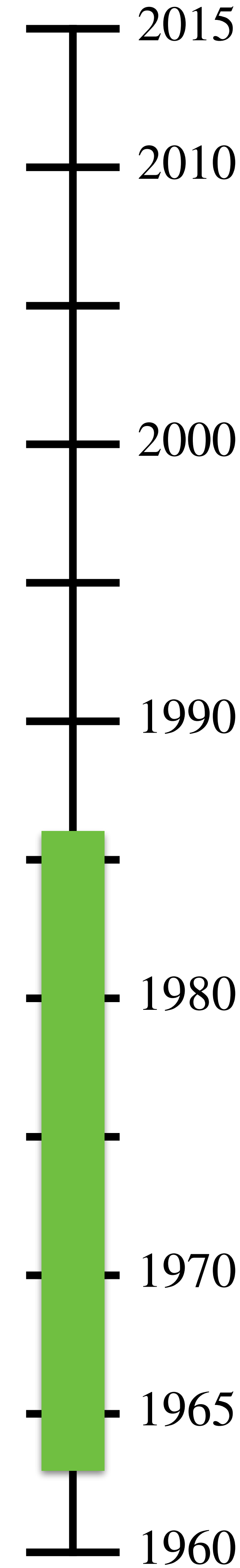
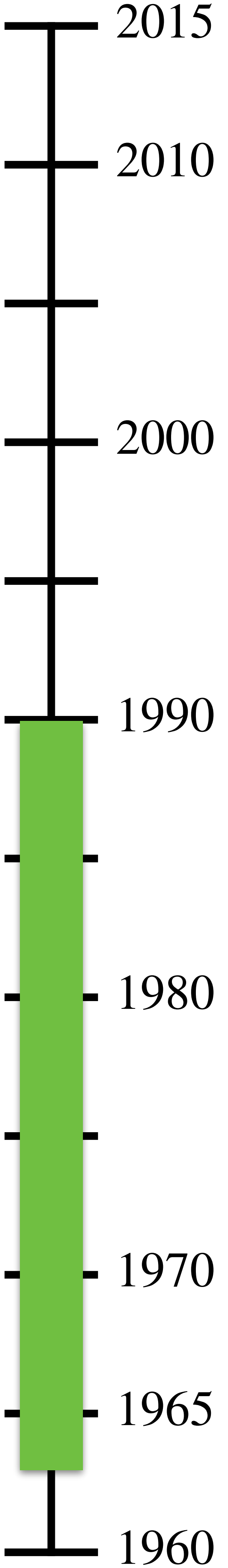


Figure 1: *r image of an 80 × 80 arcsec field centred on the quasar Q 2128-123. North-east is at the top left corner. The Mg II absorbing galaxy is the resolved object 8.6 arcsec north-east of the quasar. The spatial resolution is FWHM = 0.95 arcsec.*



Theory Rumbles..



Theory Rumbles..

GALAXY FORMATION IN AN INTERGALACTIC MEDIUM DOMINATED BY EXPLOSIONS

JEREMIAH P. OSTRIKER AND LENNOX L. COWIE
Princeton University Observatory
Received 1980 July 21; accepted 1980 October 16

ABSTRACT

The explosive energy released at the death of massive stars in forming stellar systems will propagate into the intergalactic medium. There, under certain circumstances, a dense cooled shell will form with mass many times greater than the original "seed" system, whereupon gravitational instability and fragmentation of the shell can lead to the formation of new stellar systems. For $z \lesssim 5$ and for masses $10^8 \leq M/M_\odot \leq 10^{12}$, a very large amplification of original perturbations is possible, with galaxies naturally forming in small groups having velocity dispersions of order 200 km s^{-1}. Explosions before $z \approx 5$, which cool primarily because of the inverse Compton interaction with background radiation, will lead to production of very massive stars. The most interesting speculative predictions (not unique to this model) are that intergalactic space will be dusty, with significant absorption likely for objects seen from $z > 3$, that unvirialized groups should lie on two-dimensional surfaces, that black holes with masses 10^2–10^4 $M_\odot$ may be common, and that very large (100 Mpc radius) cavities may have been produced by early explosions.
Subject headings: cosmology — galaxies: formation — galaxies: intergalactic medium

ARE COSMOLOGICALLY DISTANT OBJECTS OBSCURED BY DUST?
A TEST USING QUASARS

J. P. OSTRIKER AND J. HEISLER
Princeton University Observatory
Received 1983 June 20; accepted 1983 August 18

QUASAR IONIZATION OF LYMAN-ALPHA CLOUDS: THE PROXIMITY EFFECT, A PROBE OF THE ULTRAVIOLET BACKGROUND AT HIGH REDSHIFT

STANISLAW BAJTLIK,[1] ROBERT C. DUNCAN, AND JEREMIAH P. OSTRIKER
Princeton University Observatory
Received 1987 June 1; accepted 1987 October 6

VOIDS IN THE Lyα FOREST

ROBERT C. DUNCAN, JEREMIAH P. OSTRIKER, AND STANISLAW BAJTLIK[1]
Princeton University Obse
Received 1988 August 15; accepte

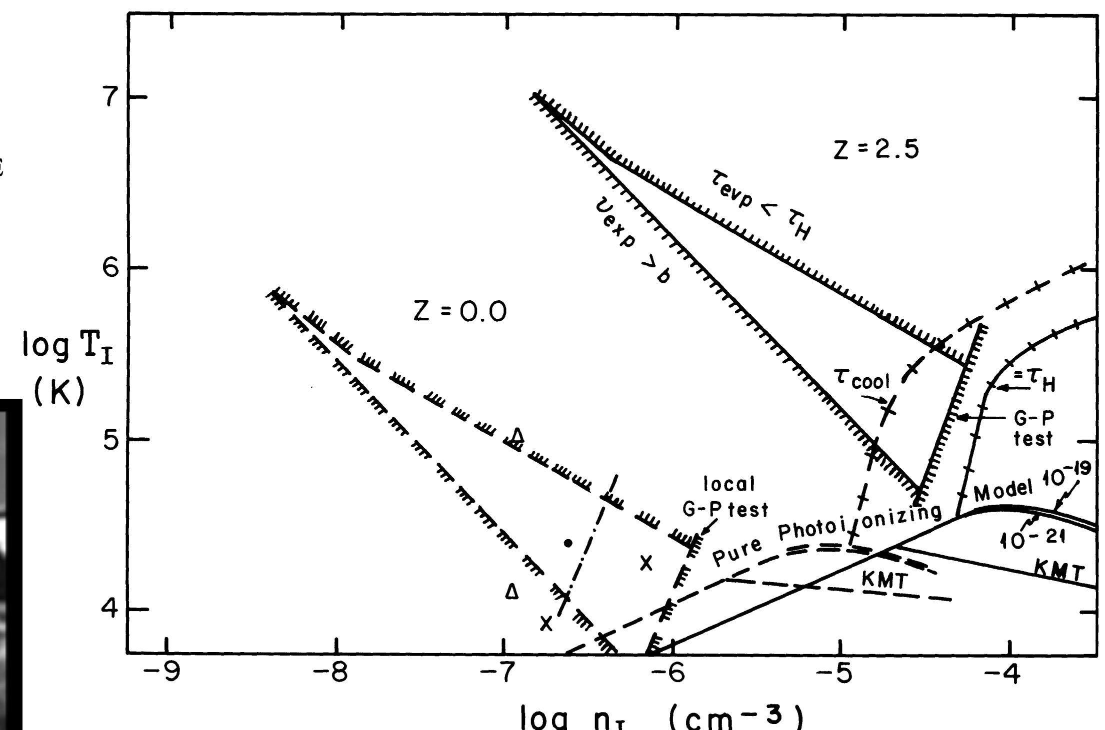
PHYSICAL PROPERTIES OF THE INTERGALACTIC MEDIUM
AND THE LYMAN-ALPHA ABSORBING CLOUDS

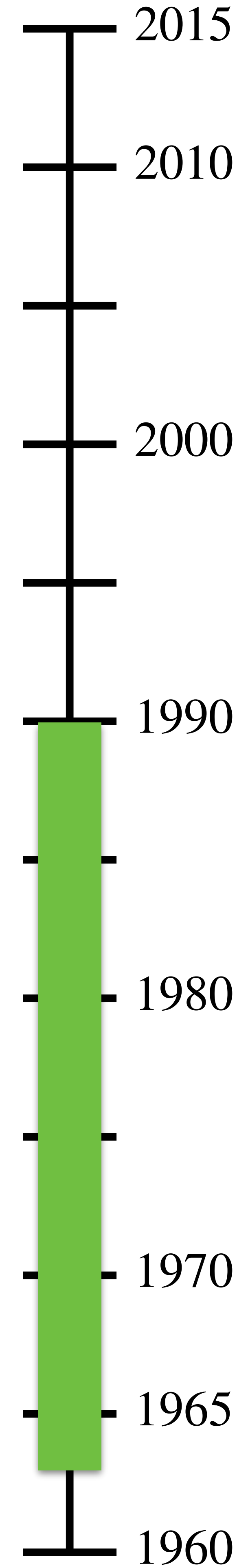
JEREMIAH P. OSTRIKER AND SATORU IKEUCHI
Princeton University Observatory
Received 1982 October 4; accepted 1983 January 13

ABSTRACT

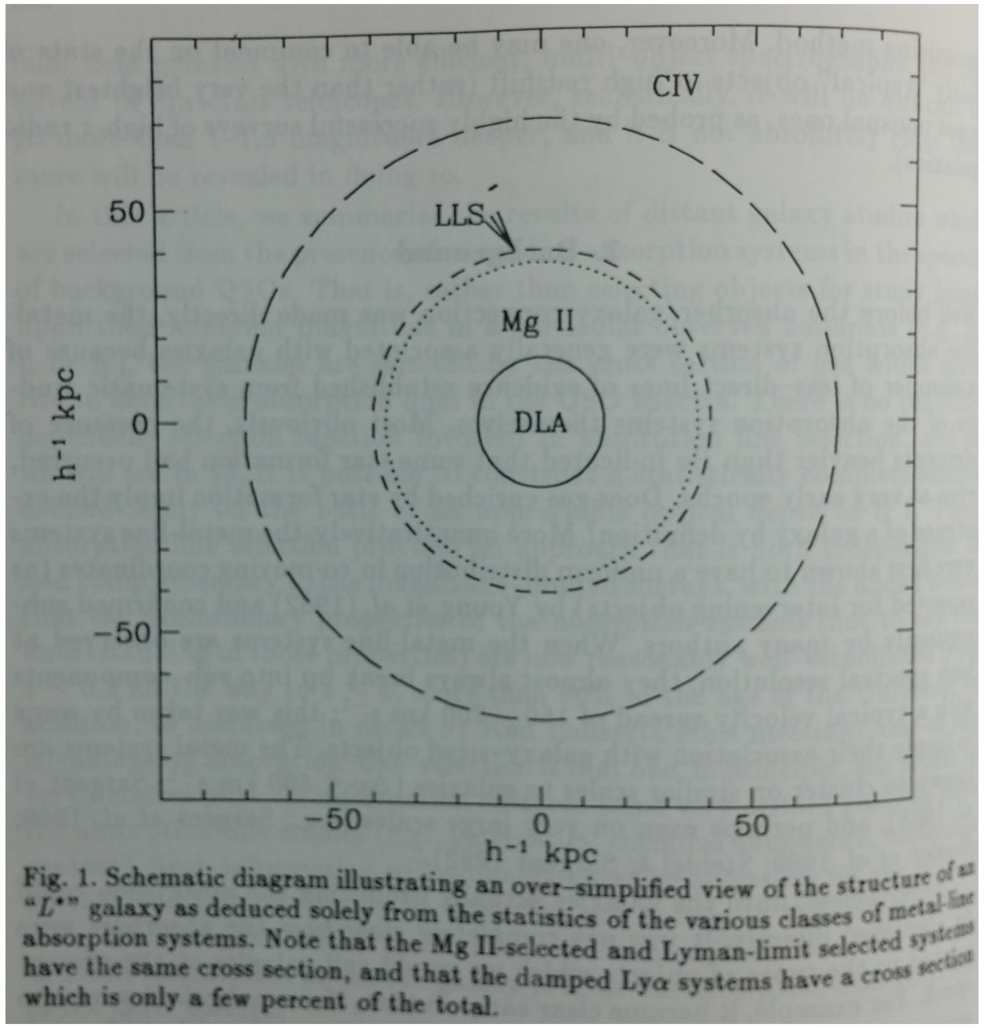
Following the interpretation of Sargent *et al.* that the Lyα absorbing systems seen in quasars are due to intergalactic clouds confined by the pressure of a general intergalactic medium, we determine the physical properties of that medium and of the clouds on the basis of a variety of theoretical and observational constraints, with best estimates of the present intergalactic pressure and temperature being $P/k = 10^{-2 \pm 0.2}$ cm^{-3} K and $T = 10^{4.5 \pm 0.5}$ K. Both the clouds and the background intergalactic medium have a density too low to be cosmologically interesting.

At the same time, we show that a model of the intergalactic medium based on UV heating fails and that some explosive events must have occurred which shock-heated the medium during the epoch $z = 3 \sim 7$. We propose three specific, if difficult, observations to check the interpretation developed: a search for the He^+ Gunn-Peterson line at 304 Å, a better determination of the Doppler width of the normal Lyα lines, and a search for low equivalent width Lyα lines.
Subject headings: cosmology — galaxies: intergalactic medium — quasars

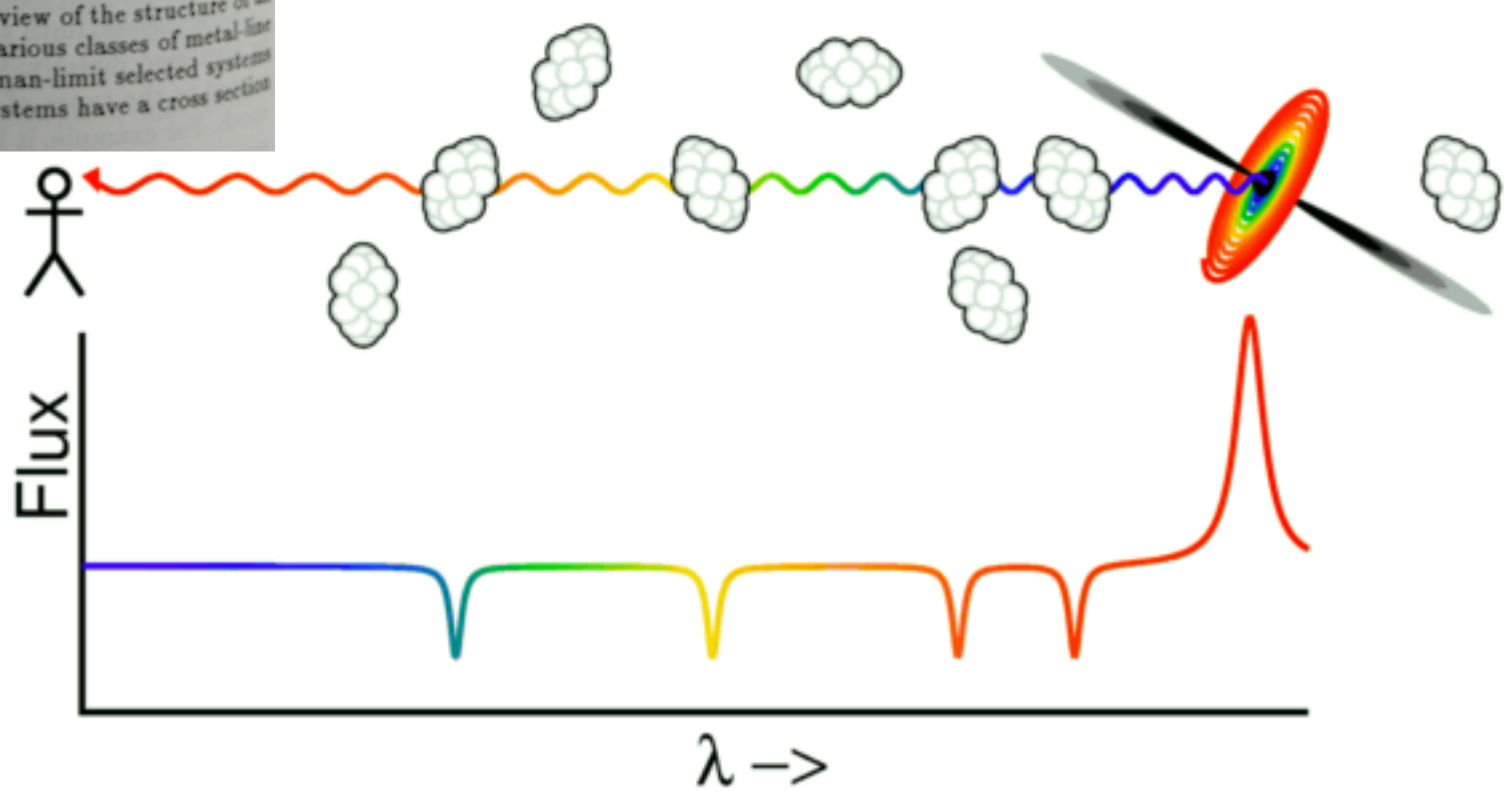


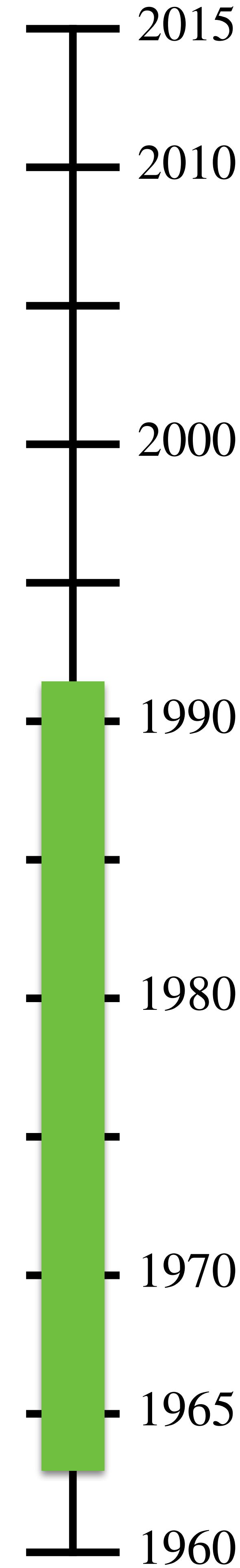


But the IGM is still a cartoon

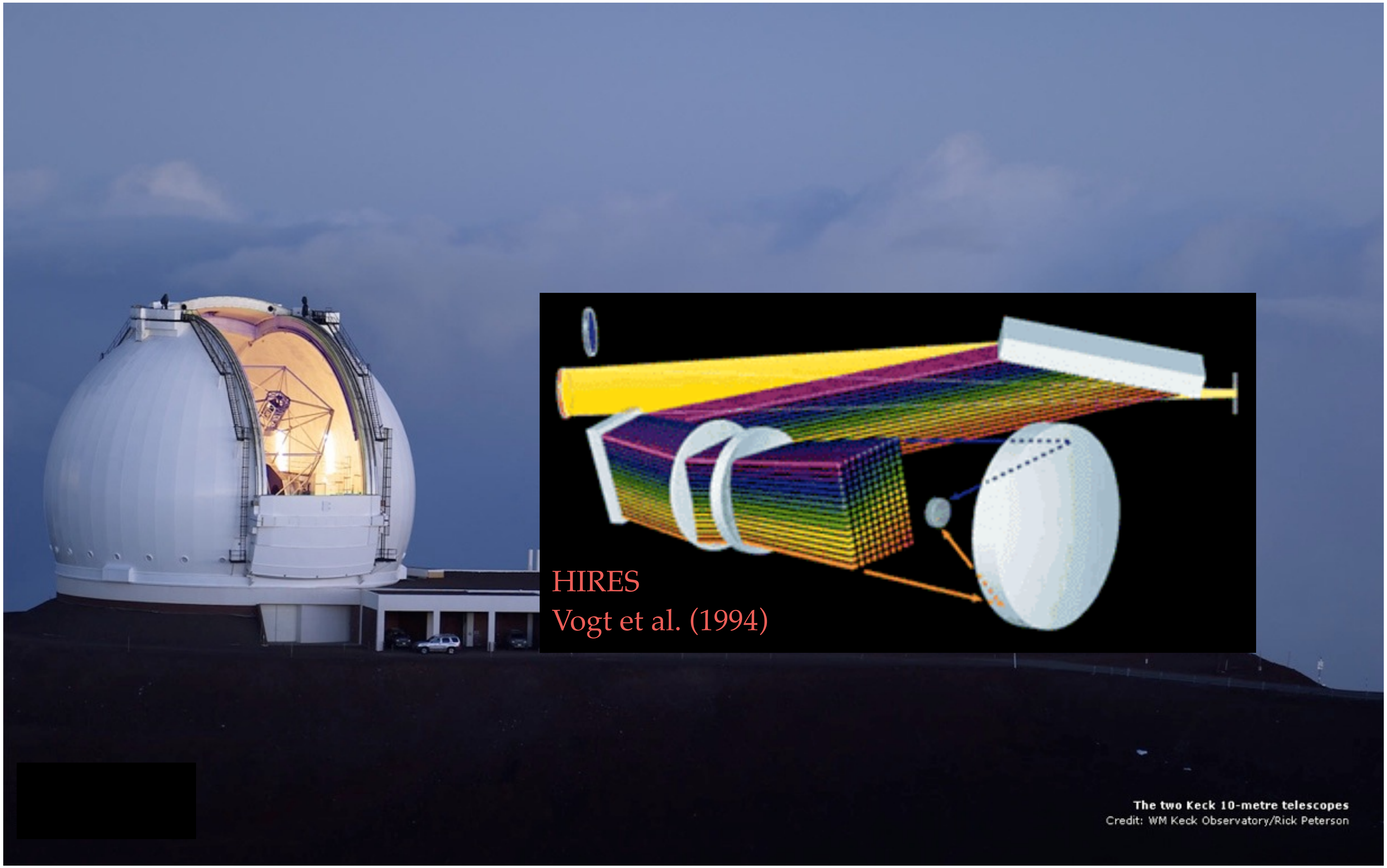


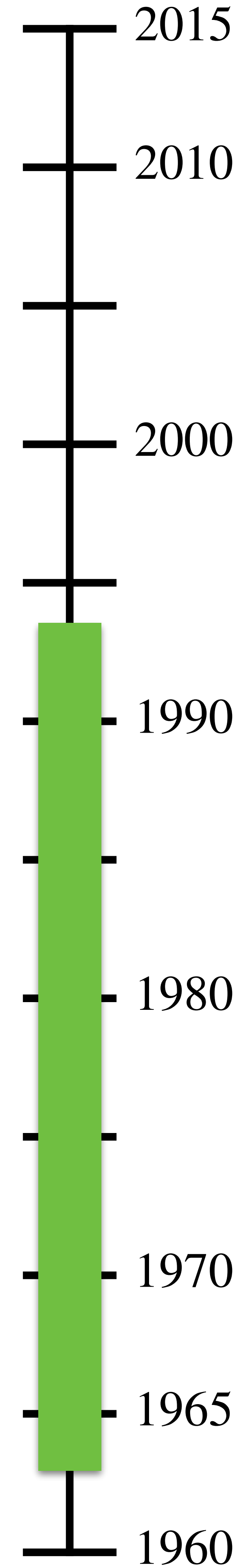
Steidel 1992



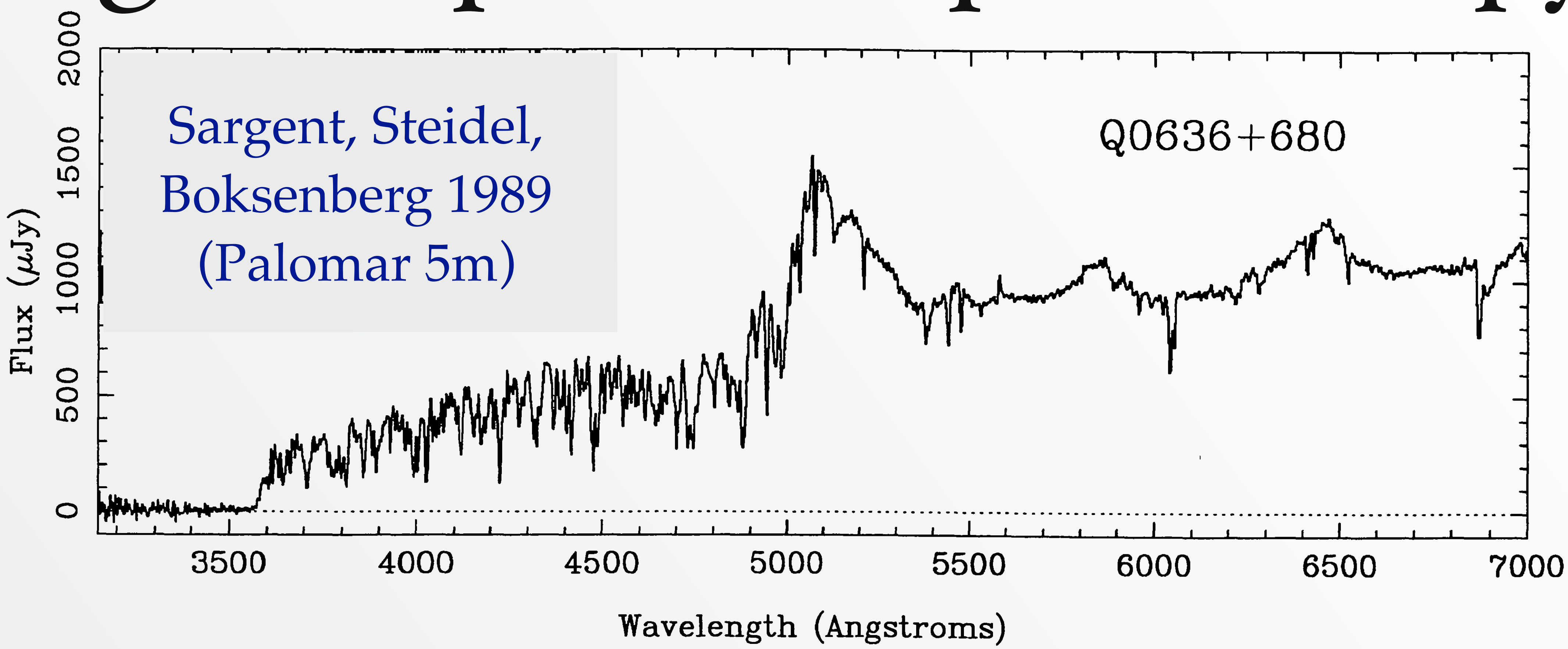


1993

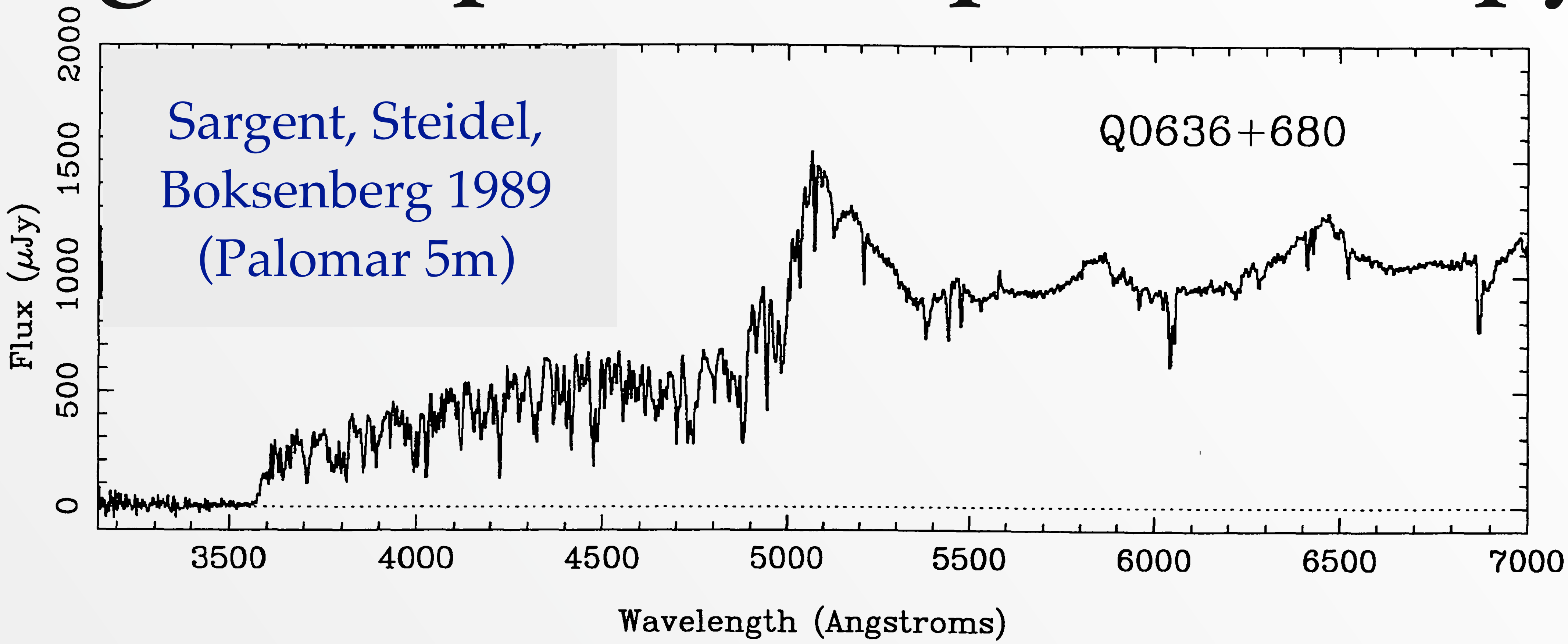

HIRES
Vogt et al. (1994)
The two Keck 10-metre telescopes
Credit: WM Keck Observatory/Rick Peterson

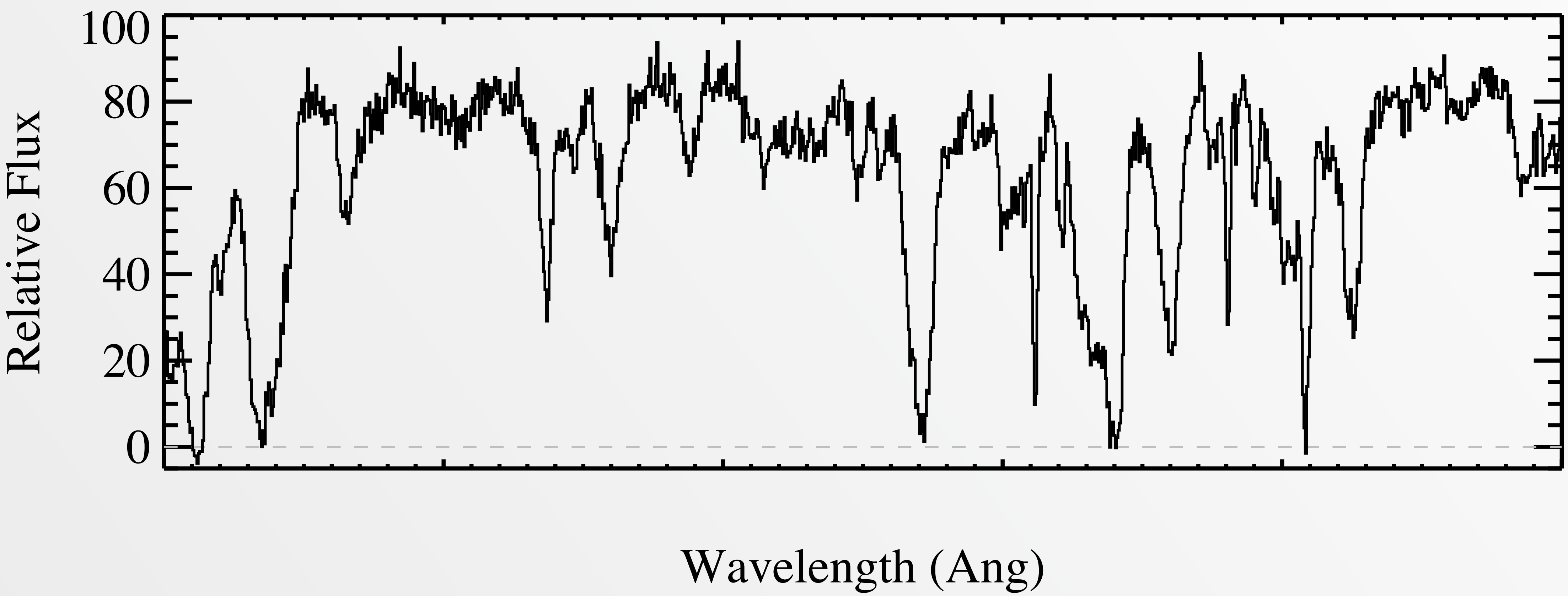

2015
2010
2000
1990
1980
1970
1965
1960

High Dispersion Spectroscopy



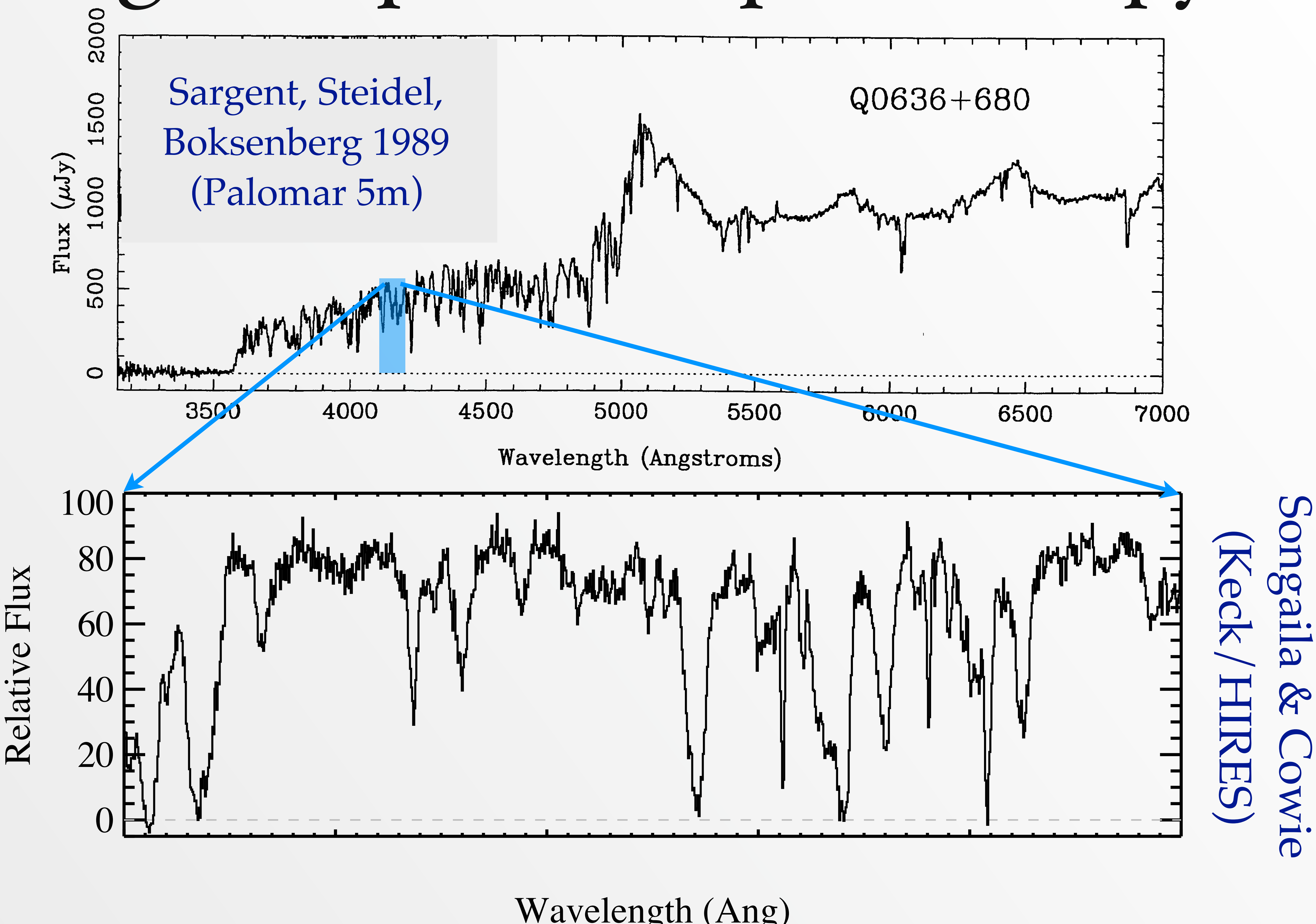
High Dispersion Spectroscopy



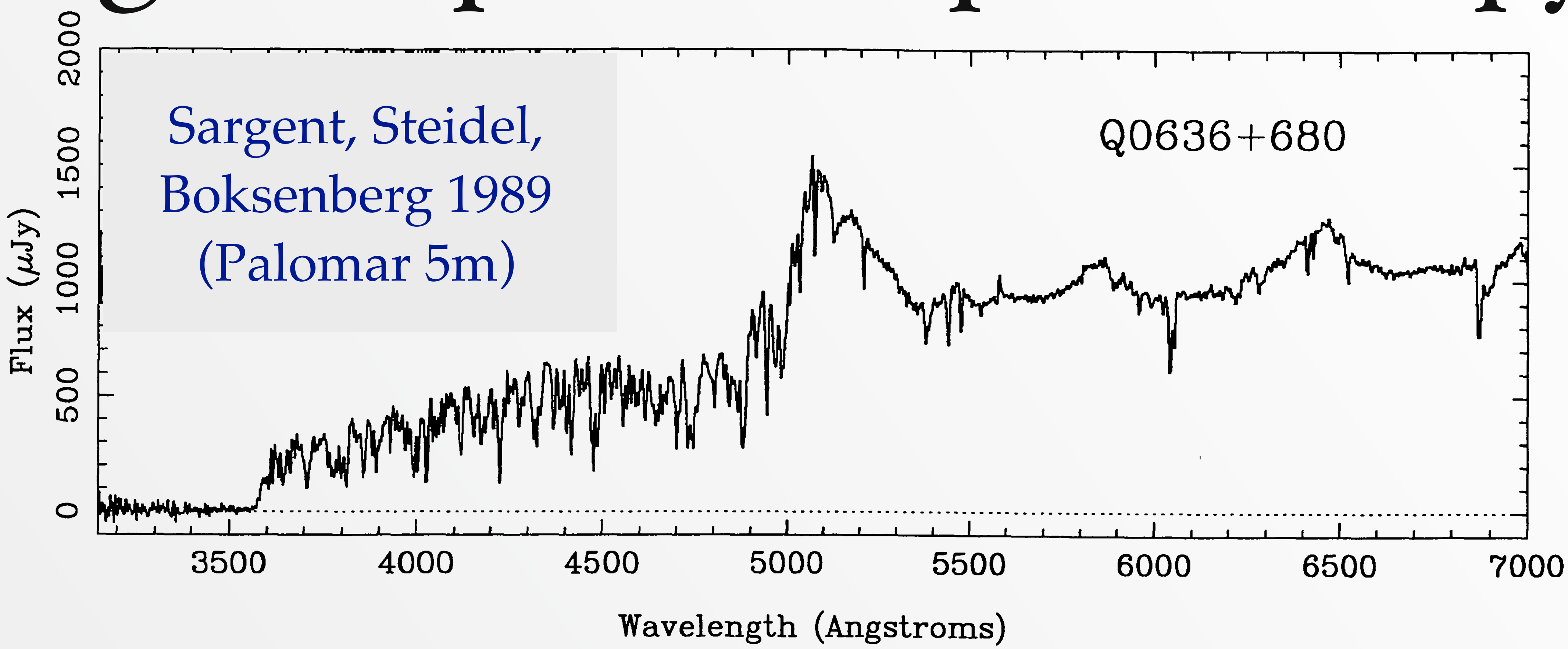


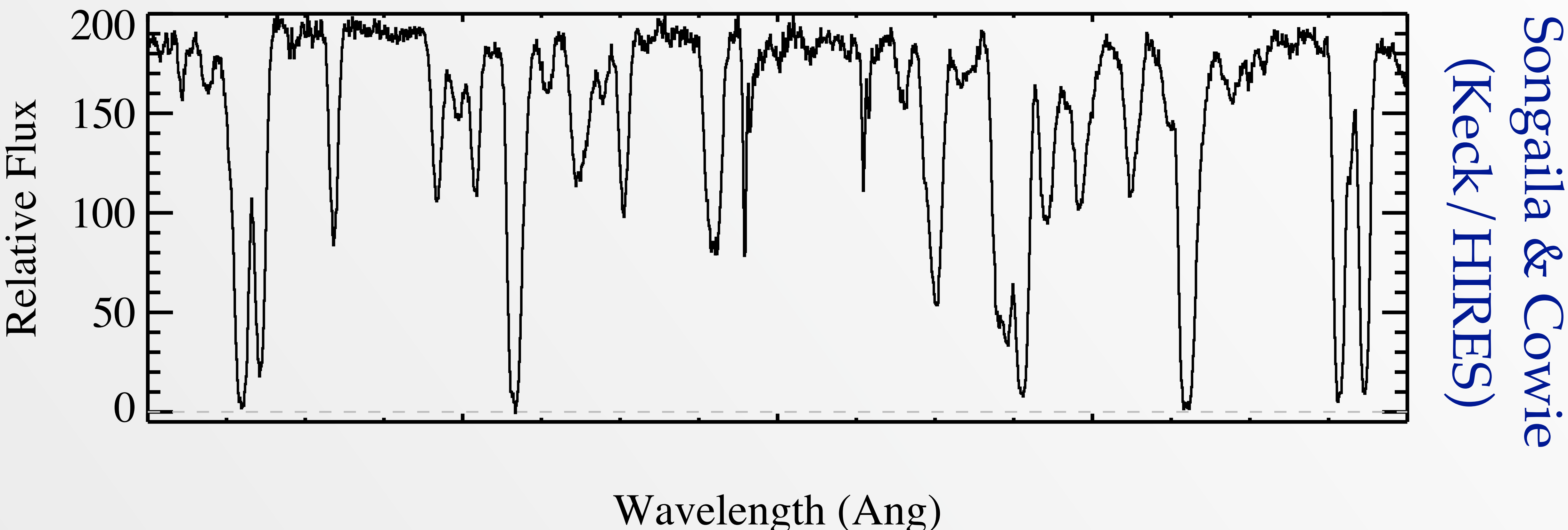
Songaila & Cowie
(Keck/HIRES)

High Dispersion Spectroscopy

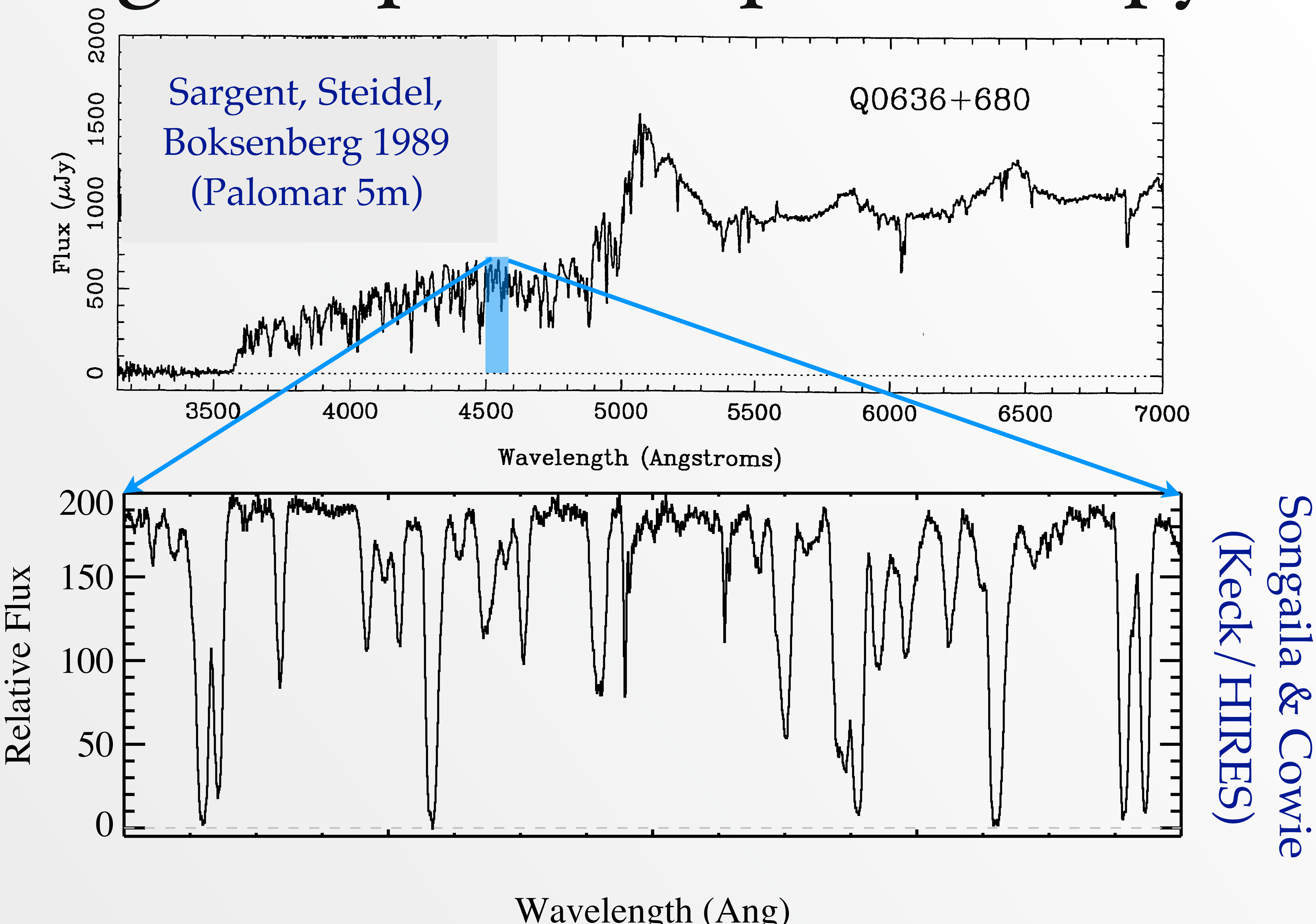


High Dispersion Spectroscopy

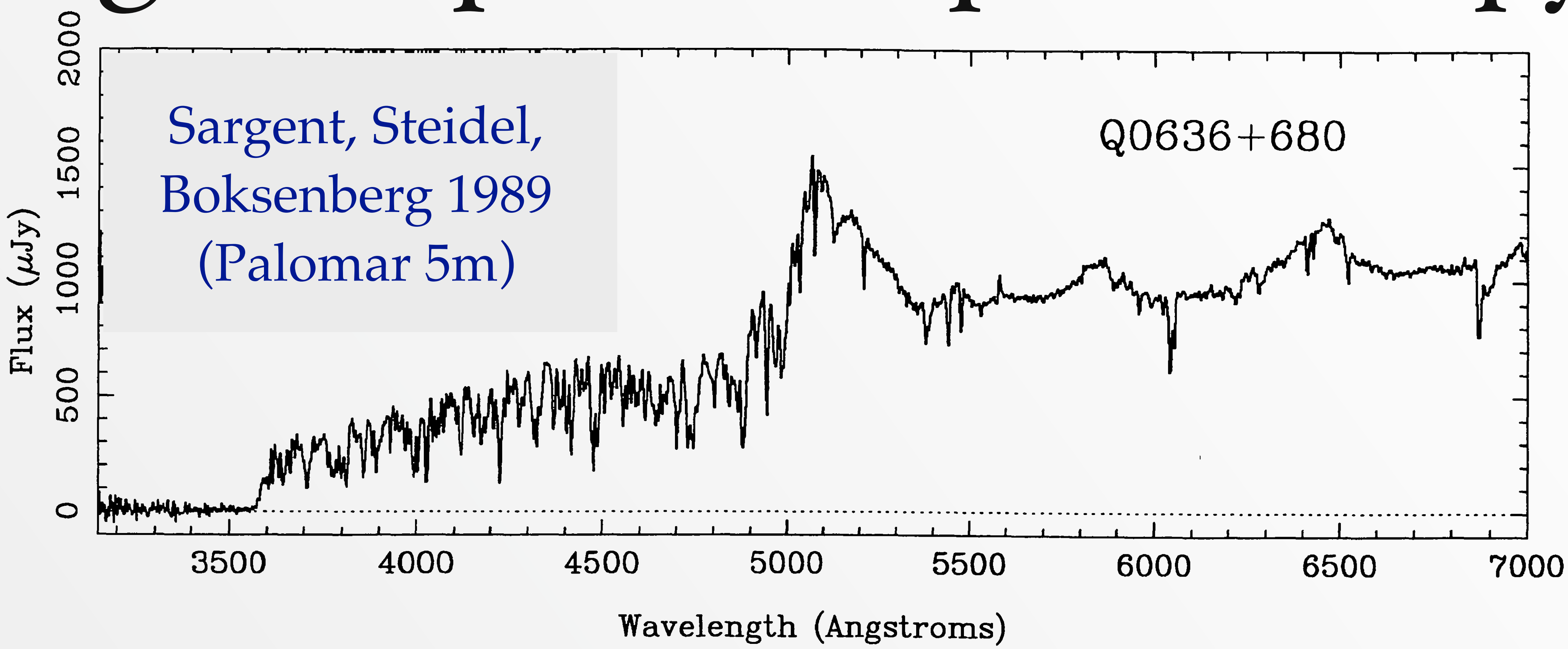


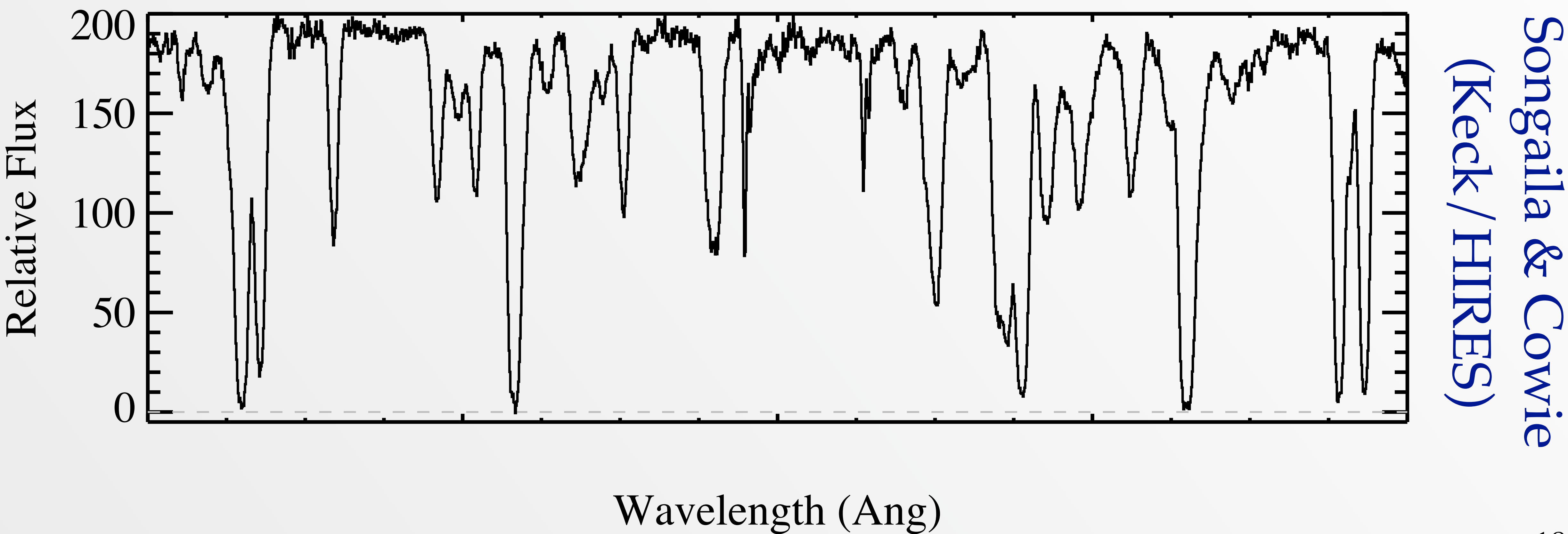


High Dispersion Spectroscopy

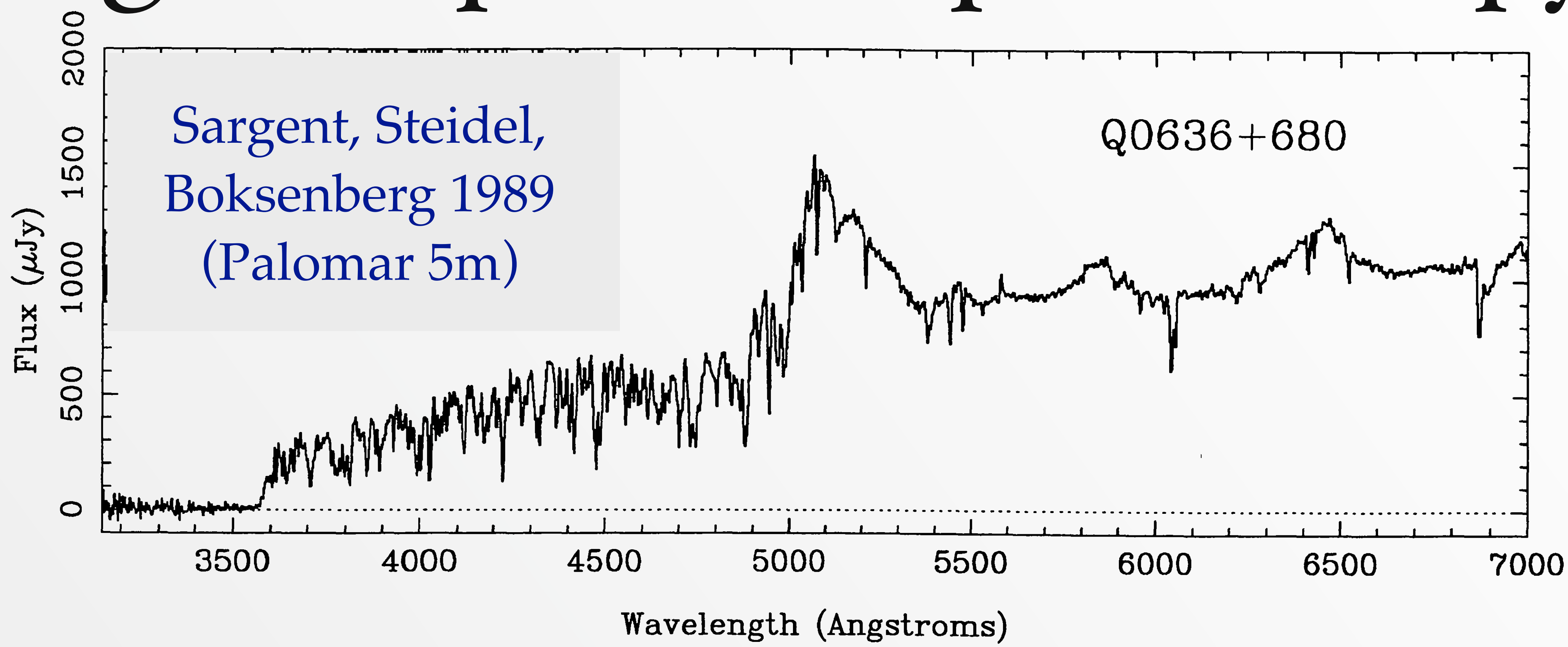


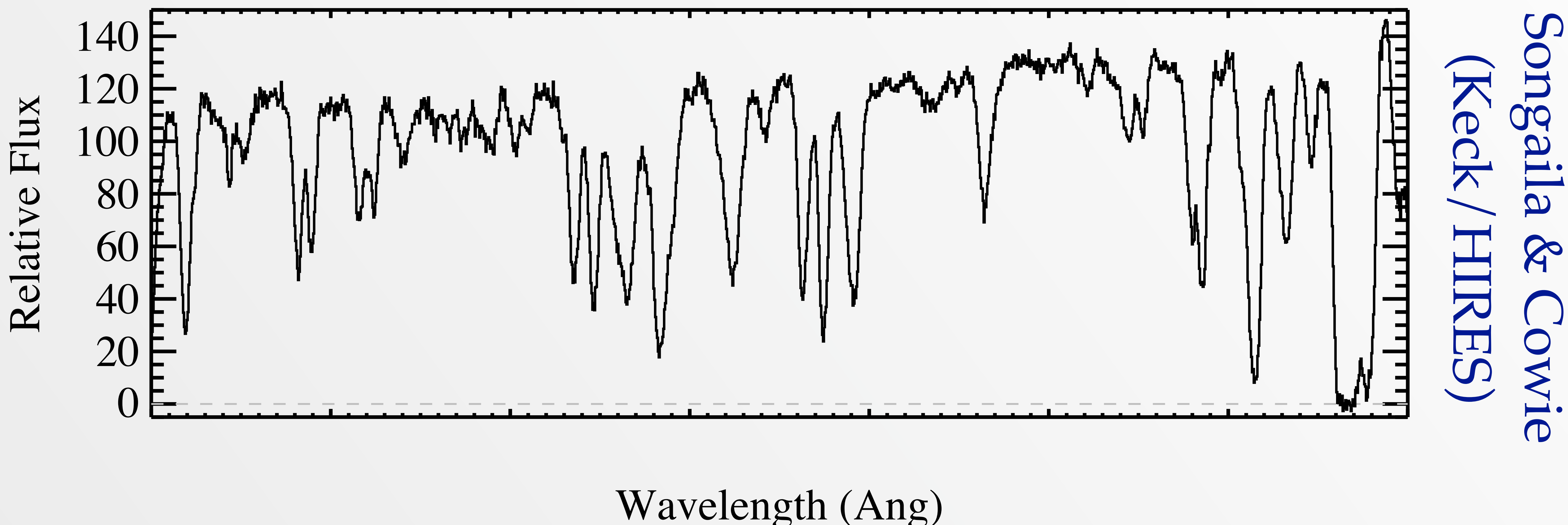
High Dispersion Spectroscopy



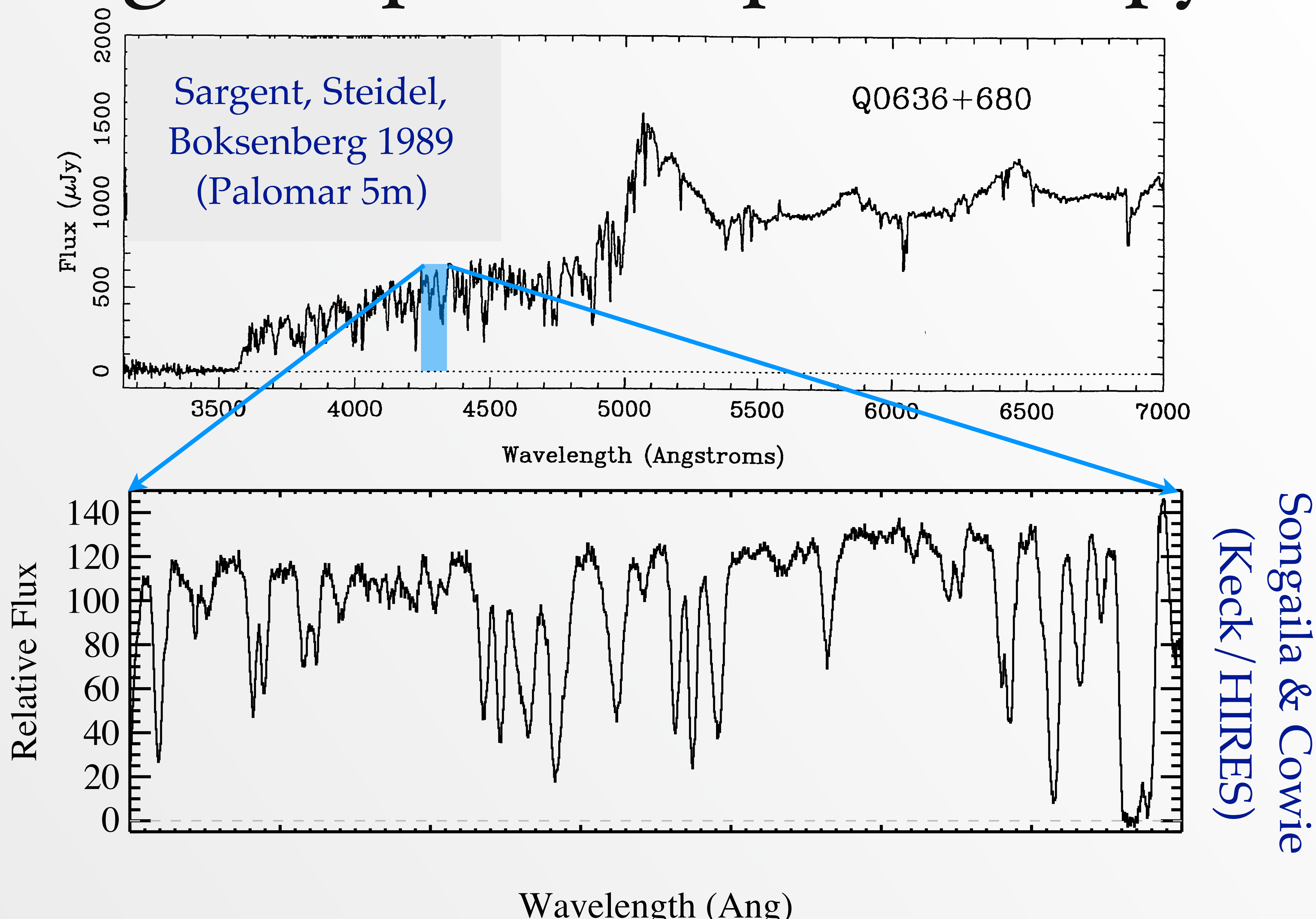


High Dispersion Spectroscopy

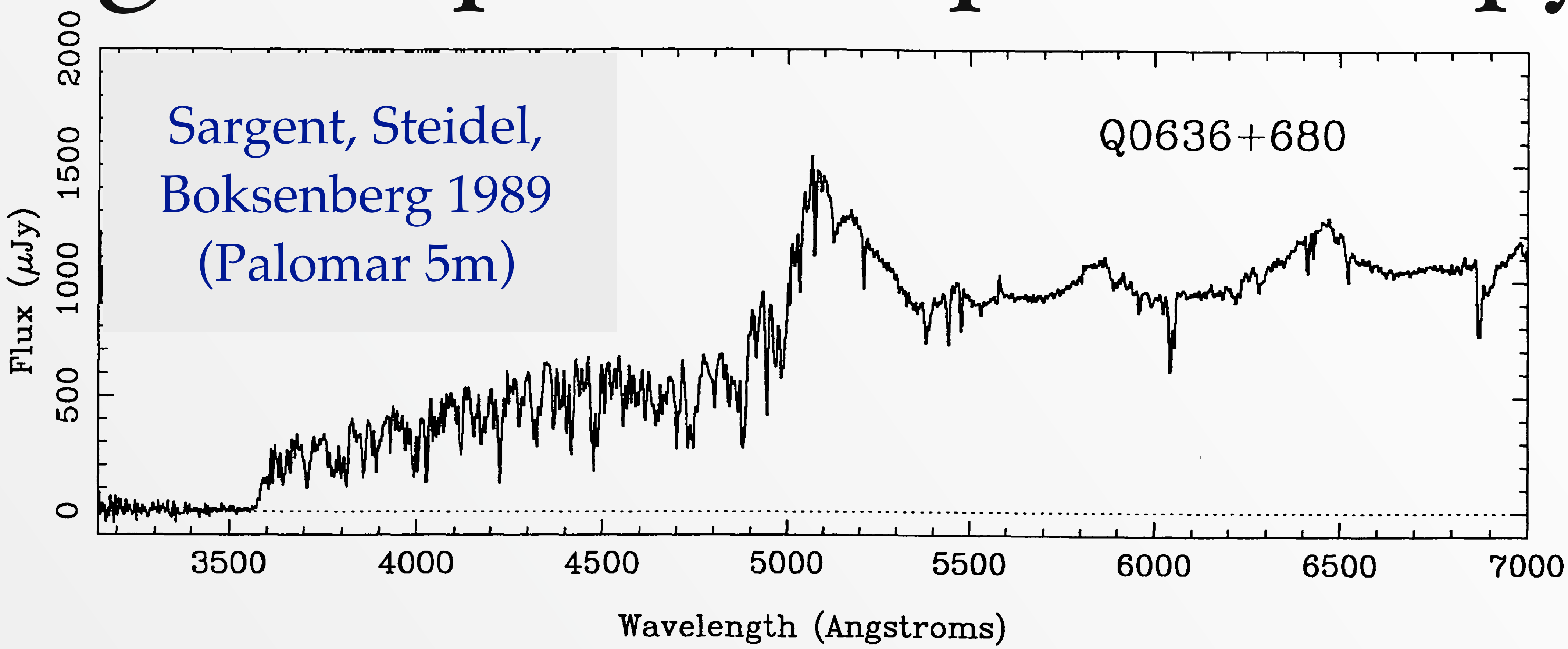


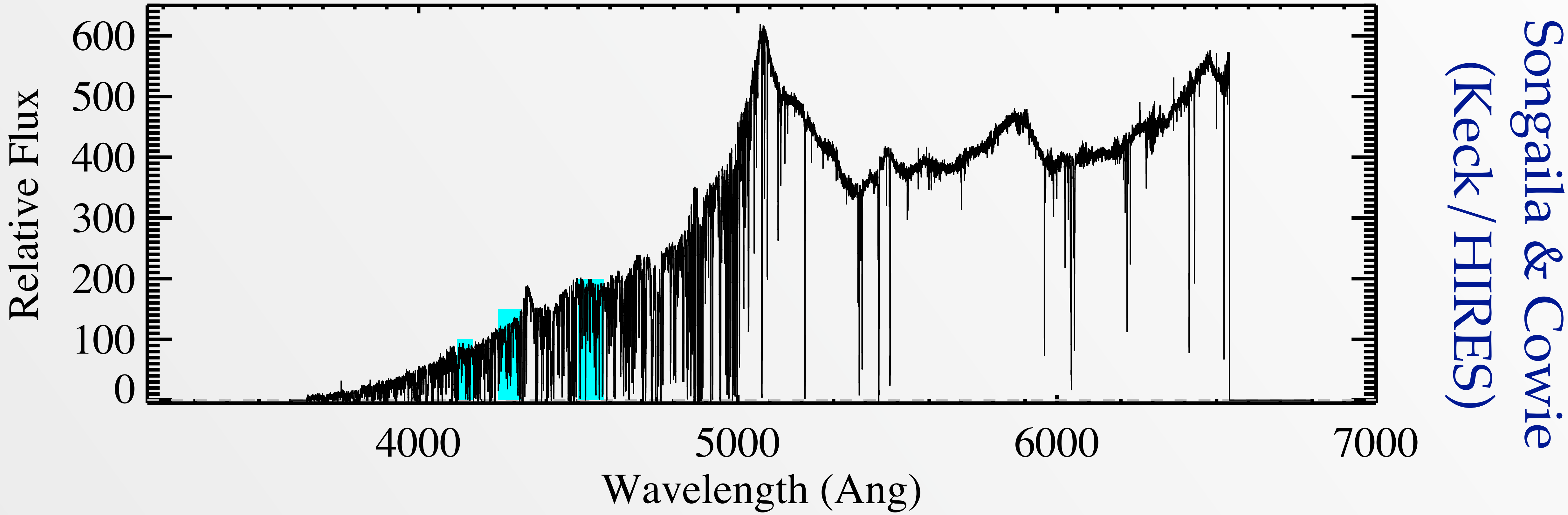


High Dispersion Spectroscopy

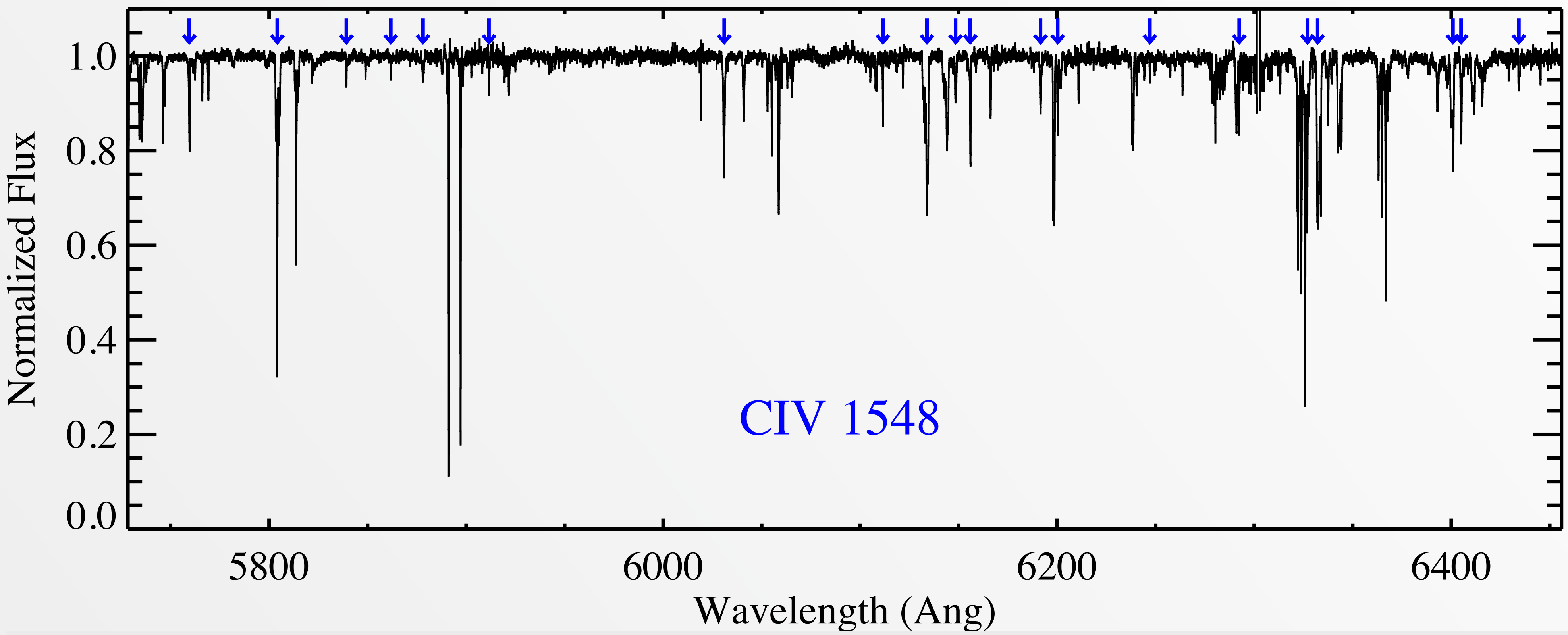


High Dispersion Spectroscopy





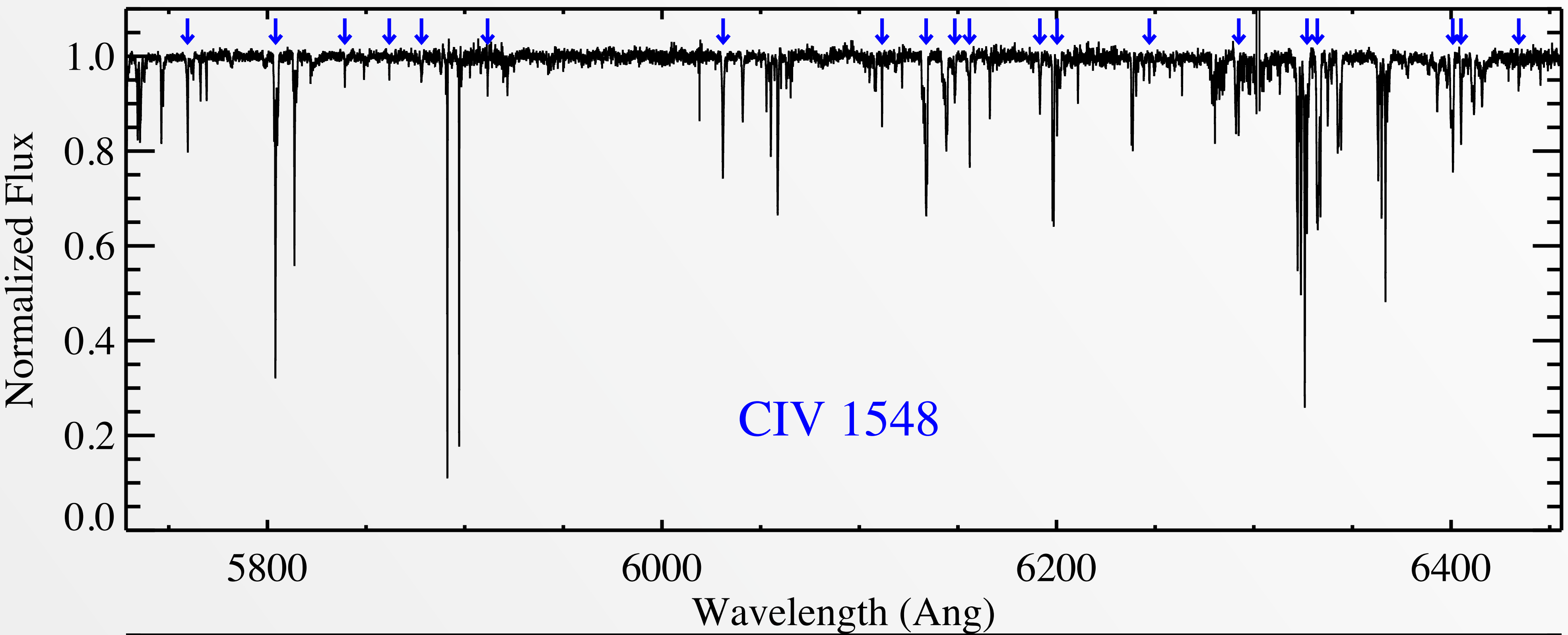
Enrichment of the IGM



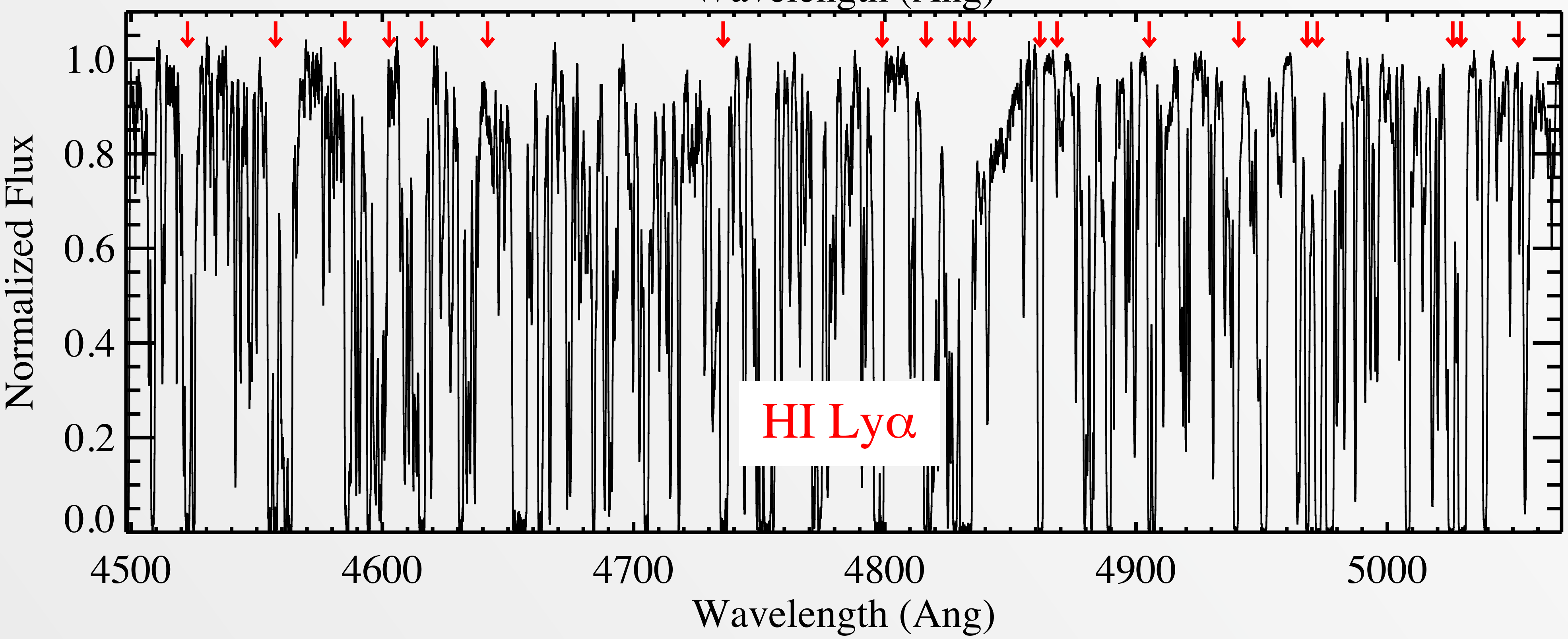
- CIV: Ubiquitous in Keck/HIRES spectra
- Carbon in galaxies occurs in much lower ionization states (CI,CII)

Songaila+, Lu+, Tytler+, Sargent+, Ellison+, Schaye+, Aguirre+

Enrichment of the IGM



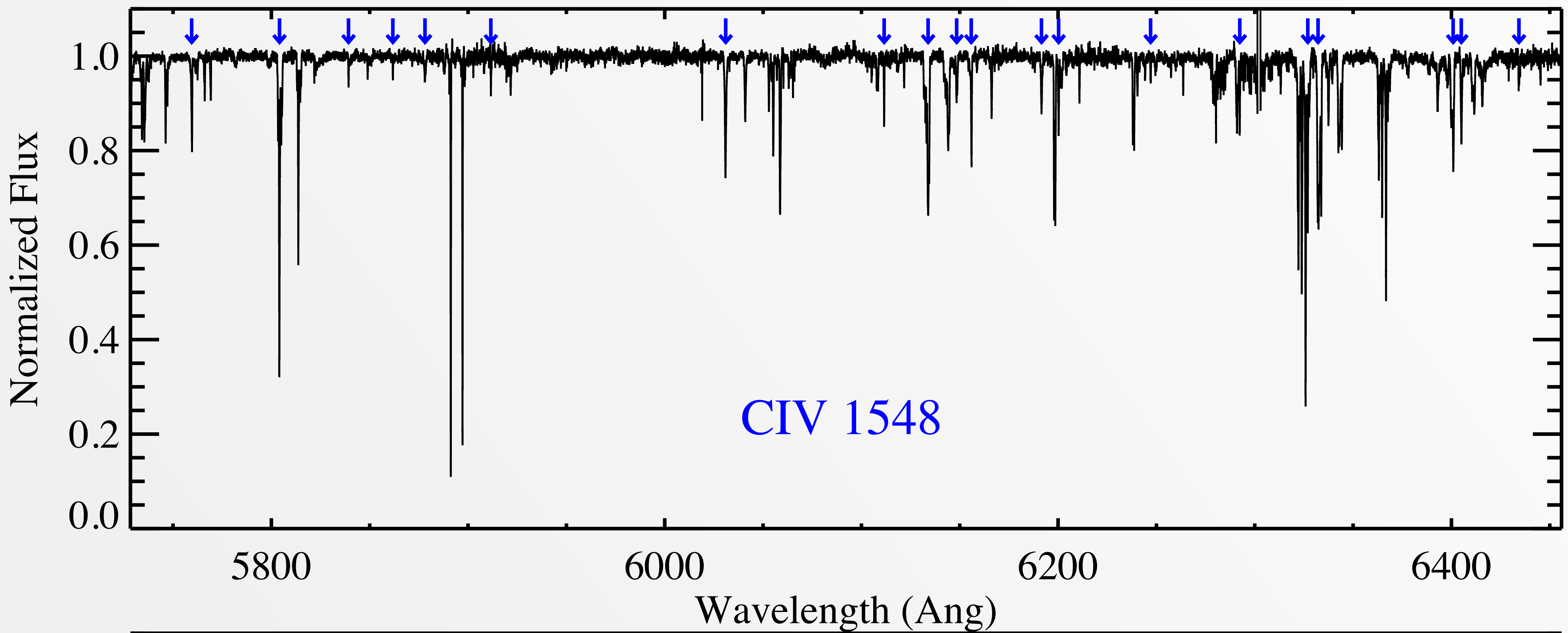
- CIV: Ubiquitous in Keck/HIRES spectra
- Carbon in galaxies occurs in much lower ionization states (CI,CII)

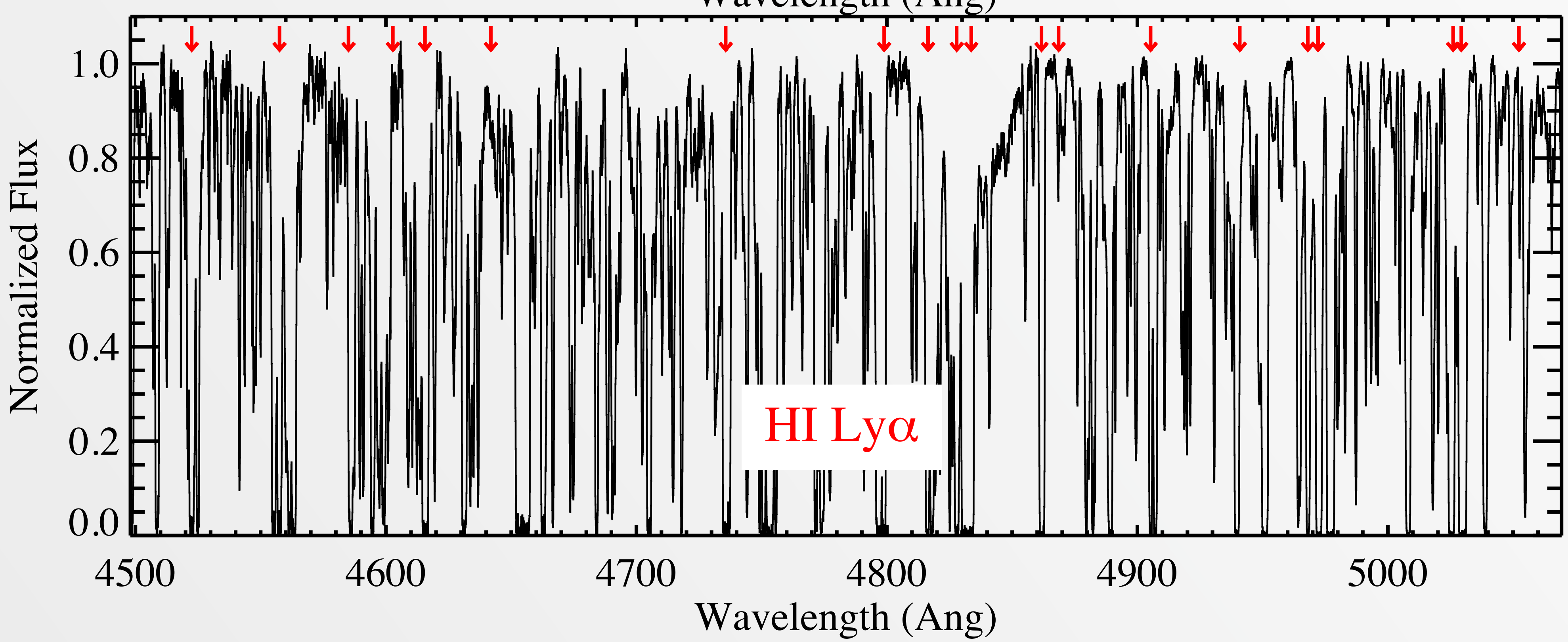


- Associated N_{HI} is 1,000,000x lower than that in galaxies.
- These metals must exist <u>outside</u> galaxies.

Songaila+, Lu+, Tytler+, Sargent+, Ellison+, Schaye+, Aguirre+

Enrichment of the IGM



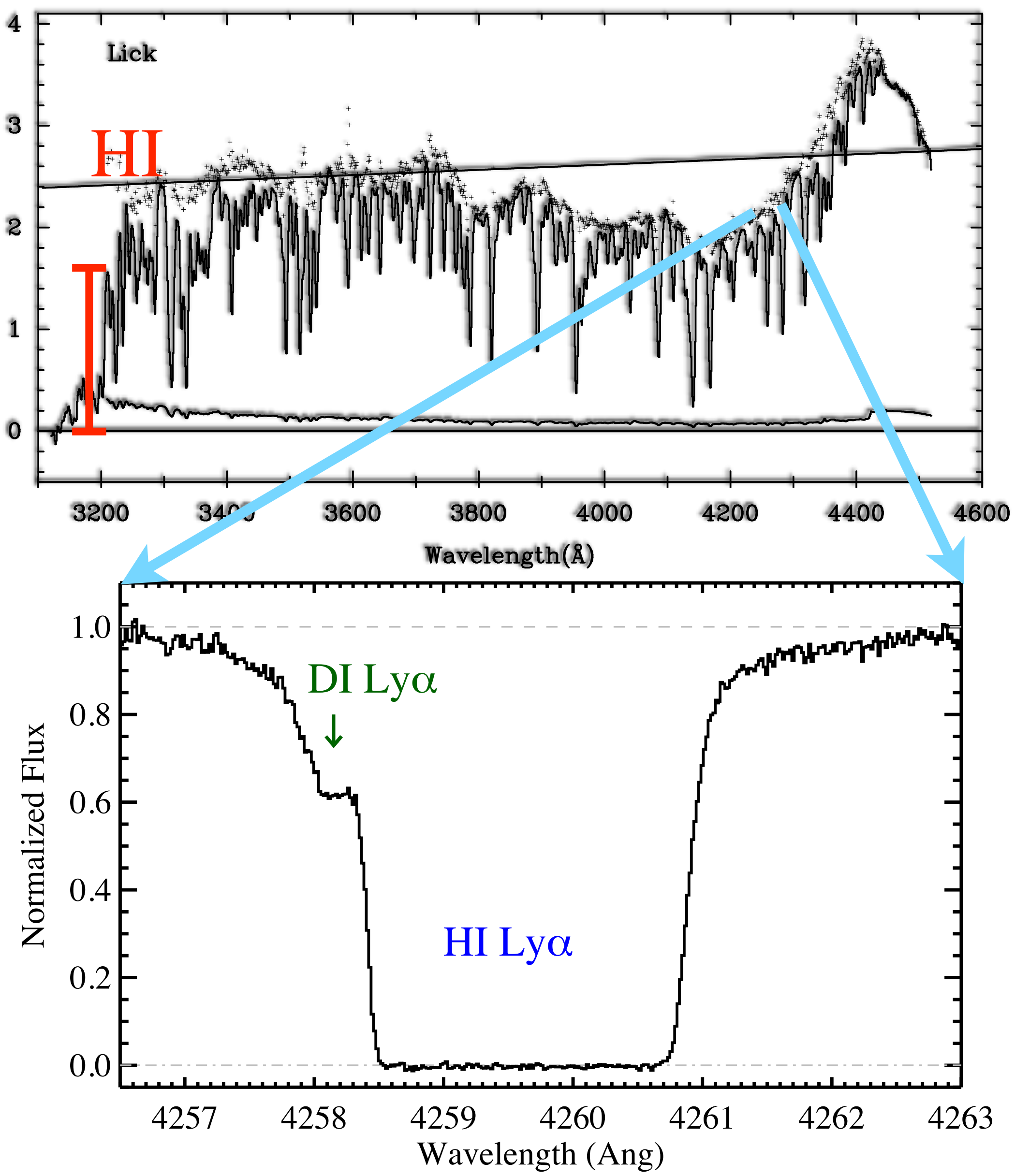


- CIV: Ubiquitous in Keck/HIRES spectra
- Carbon in galaxies occurs in much lower ionization states (CI,CII)
- Associated N_{HI} is 1,000,000x lower than that in galaxies.
- These metals must exist outside galaxies.

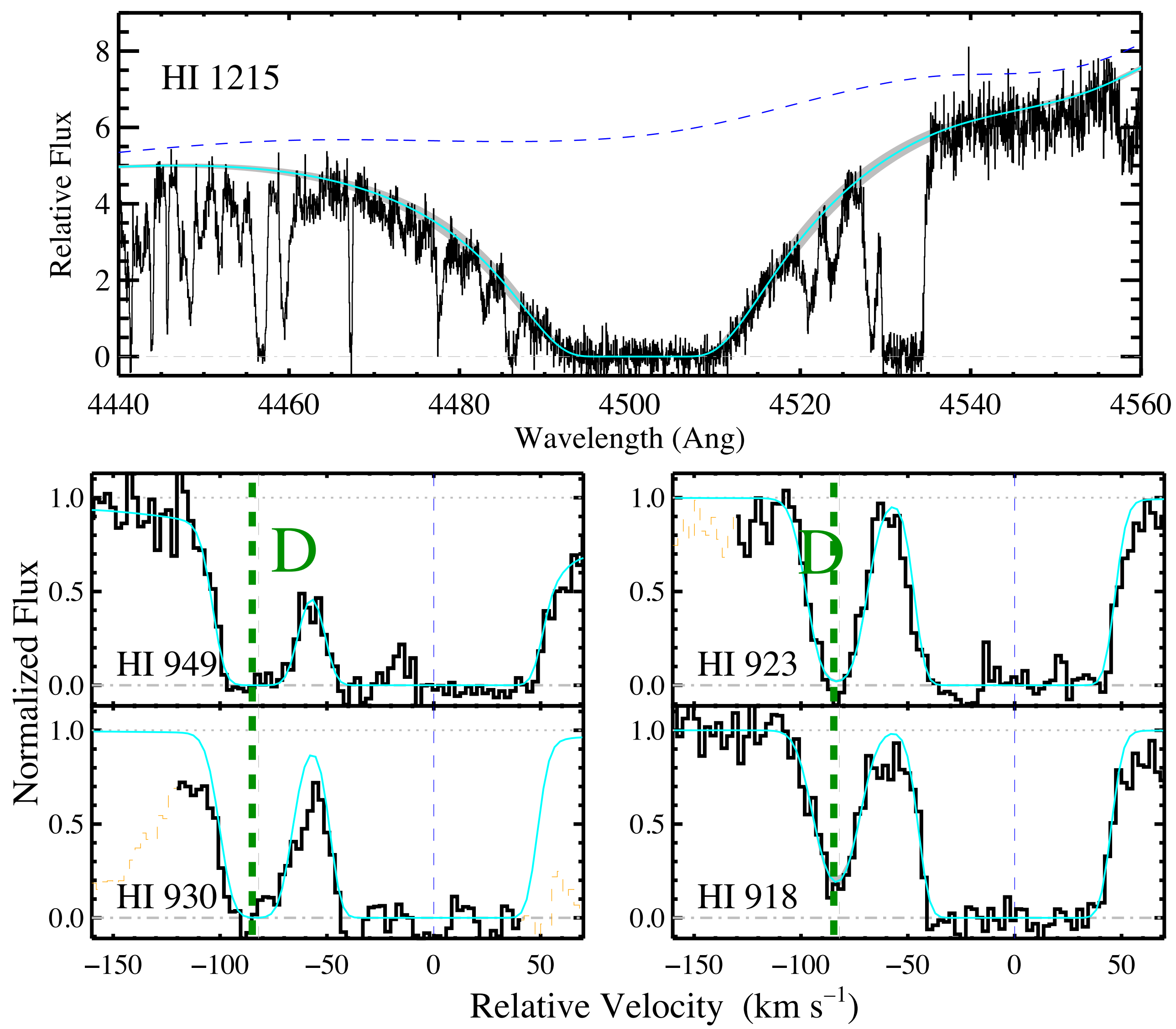
$$(C/H)_{IGM} \sim (C/H)_{Sun}/1000$$

Songaila+, Lu+, Tytler+, Sargent+, Ellison+, Schaye+, Aguirre+

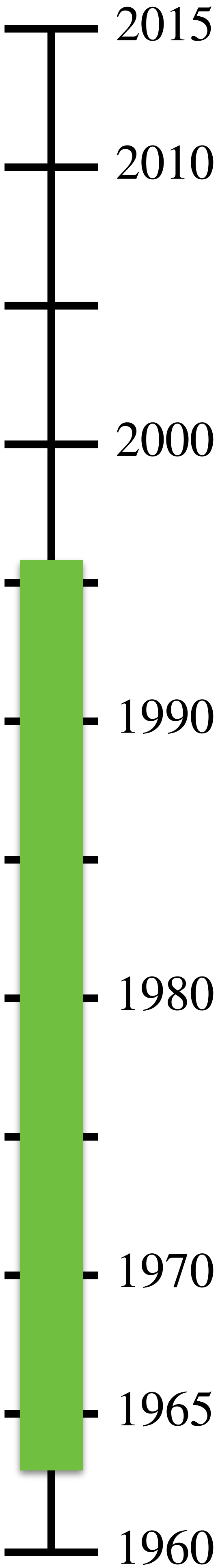
Ω_b from D / H
(Precision Cosmology)



Tytler et al. (1996); Burles & Tytler (1998)



O'Meara et al. (2001, 2006)



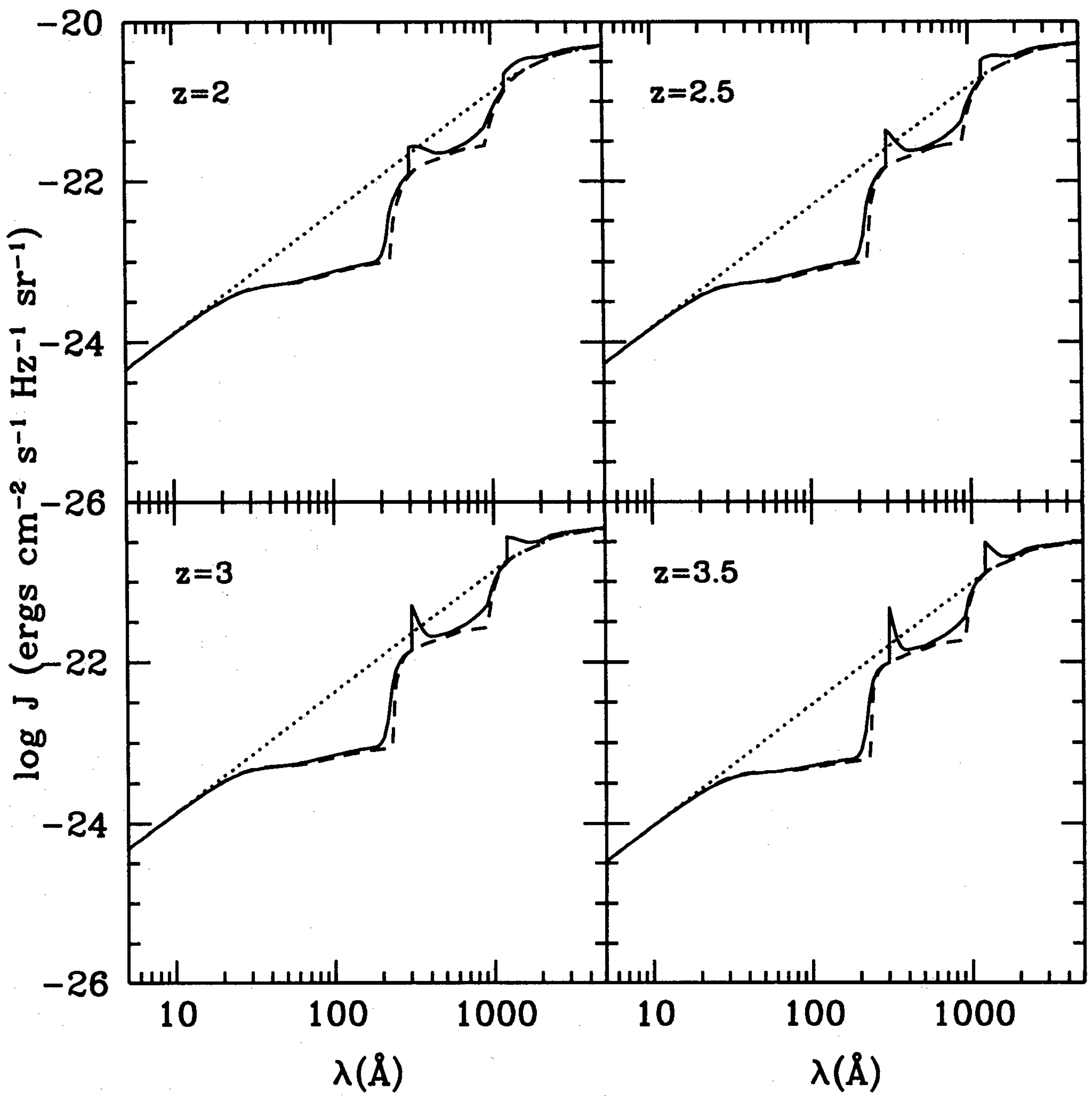
The EUVB

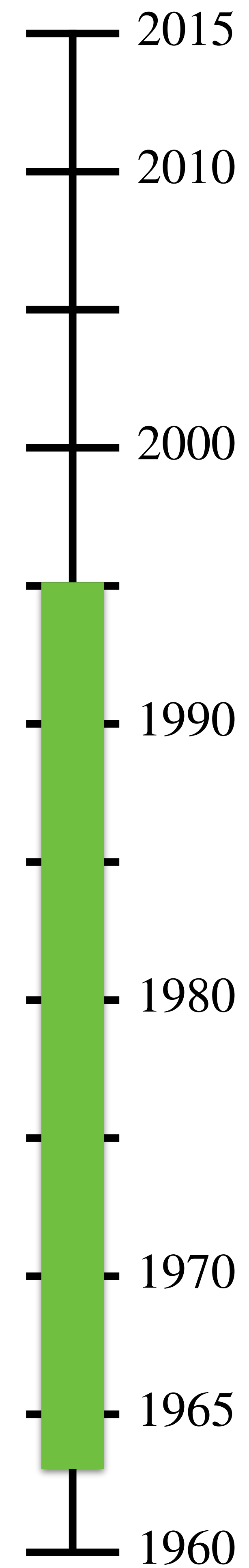
RADIATIVE TRANSFER IN A CLUMPY UNIVERSE. II. THE ULTRAVIOLET EXTRAGALACTIC BACKGROUND

FRANCESCO HAARDT[1,2,3] AND PIERO MADAU[1]

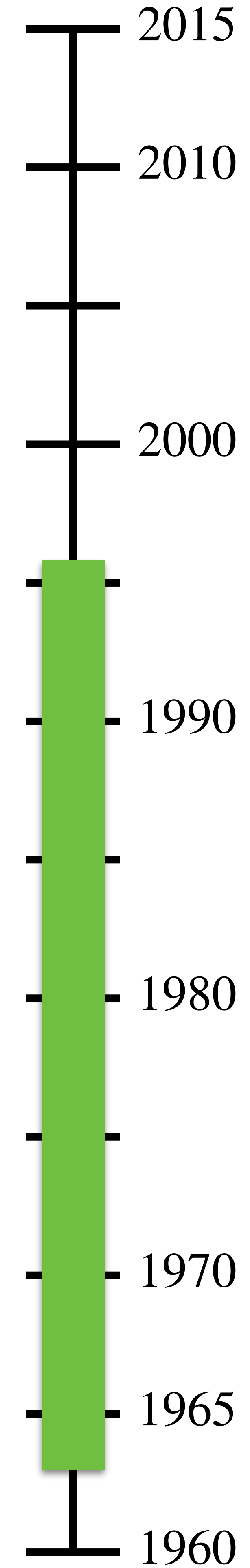
Received 1995 June 1; accepted 1995 October 18

Also:
Rauch+ 96





The Cosmic Web Emerges



THE Lyα FOREST FROM GRAVITATIONAL COLLAPSE IN THE COLD DARK MATTER + Λ MODEL

JORDI MIRALDA-ESCUDÉ,[1] RENYUE CEN,[2] JEREMIAH P. OSTRIKER,[2] AND MICHAEL RAUCH[3,4]

Received 1995 October 30; accepted 1996 May 24

ABSTRACT

We use an Eulerian hydrodynamic cosmological simulation to model the Lyα forest in a spatially flat, *COBE*-normalized, cold dark matter model with $\Omega = 0.4$. We find that the intergalactic, photoionized gas is predicted to collapse into sheetlike and filamentary structures which give rise to absorption lines having characteristics similar to the observed Lyα forest. A typical filament is $\sim 500\ h^{-1}$ kpc long with thickness $\sim 50\ h^{-1}$ kpc (in proper units), and baryonic mass $\sim 10^{10}\ h^{-1}\ M_{\odot}$. In comparison our cell size is (2.5, 9) h^{-1} kpc in the two simulations we perform, with true resolution perhaps a factor of 2.5 worse than this. The gas temperature is in the range 10^4–10^5 K, and it increases with time as structures with larger velocities collapse gravitationally.

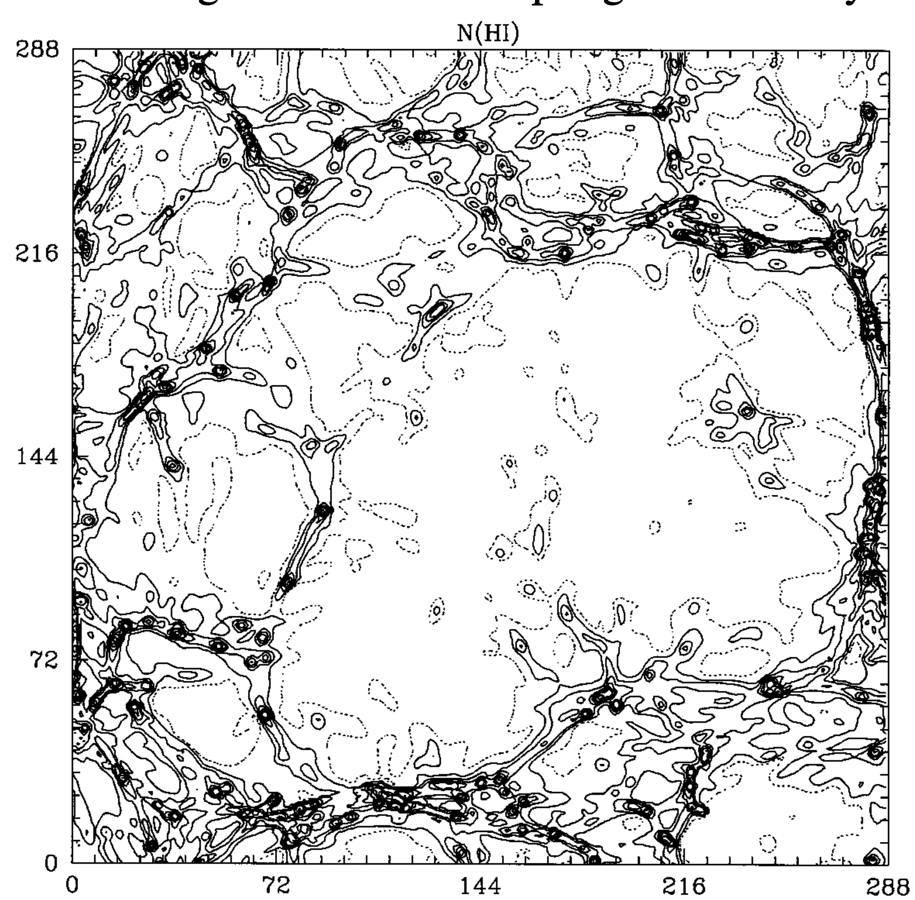


FIG. 2*c*

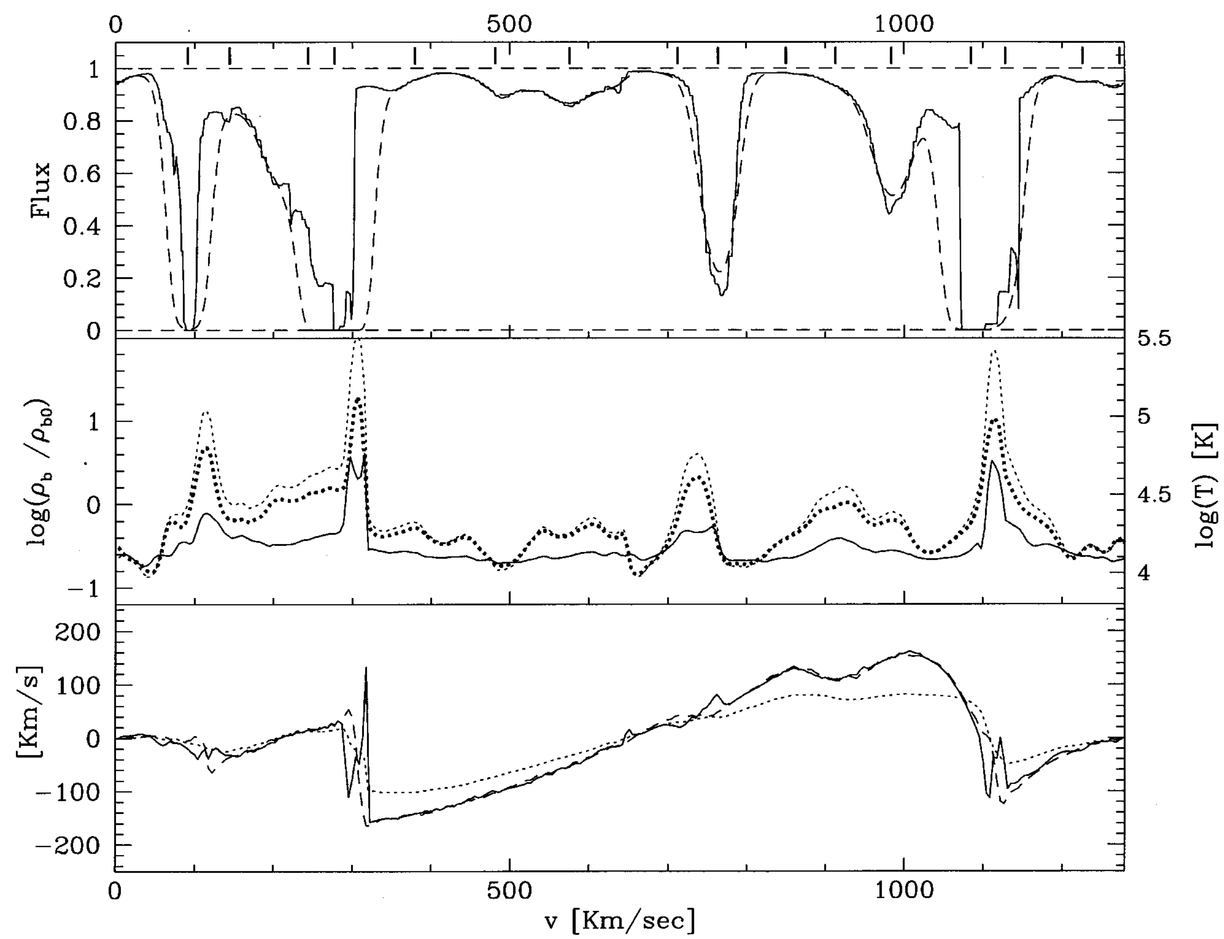


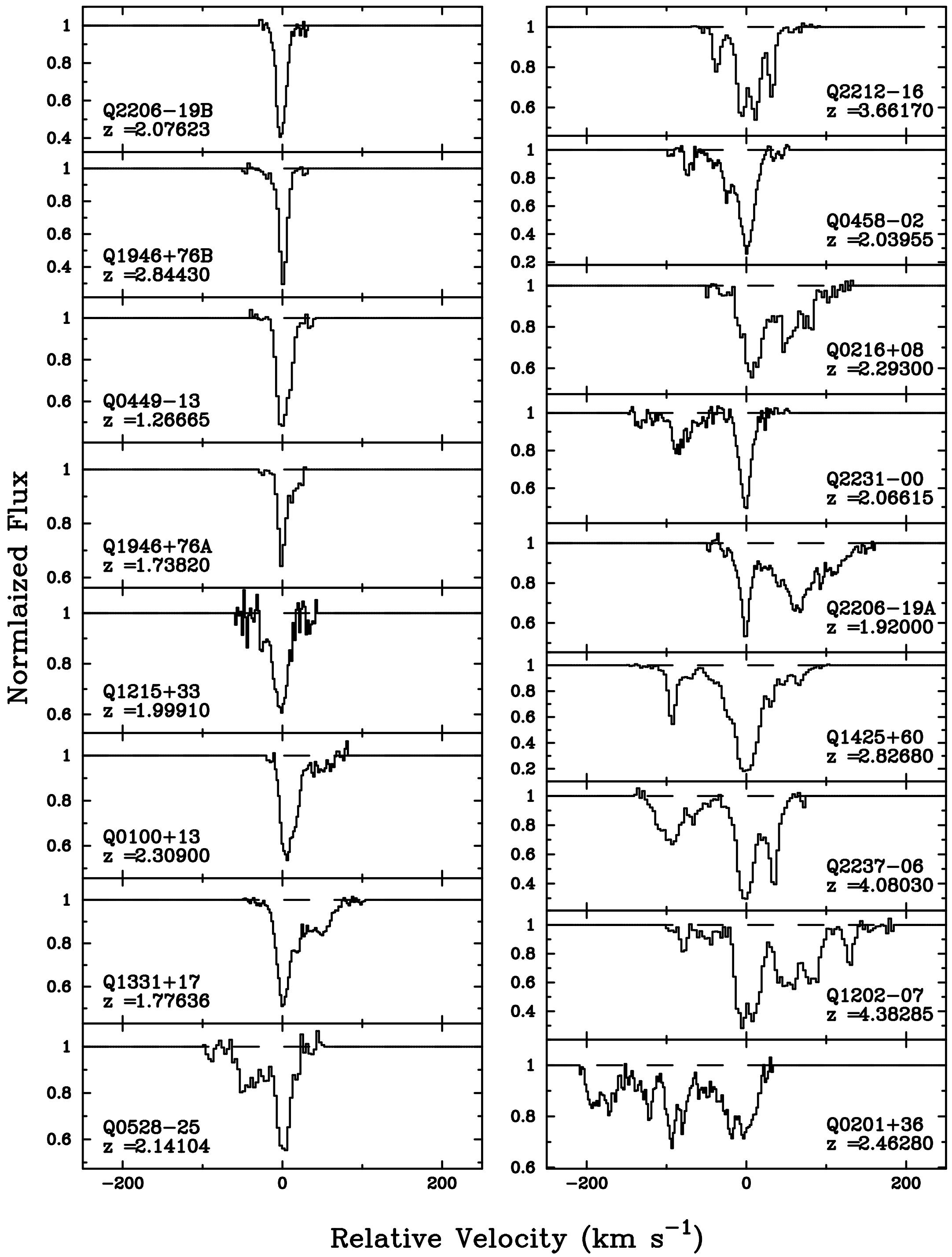
FIG. 6*c*

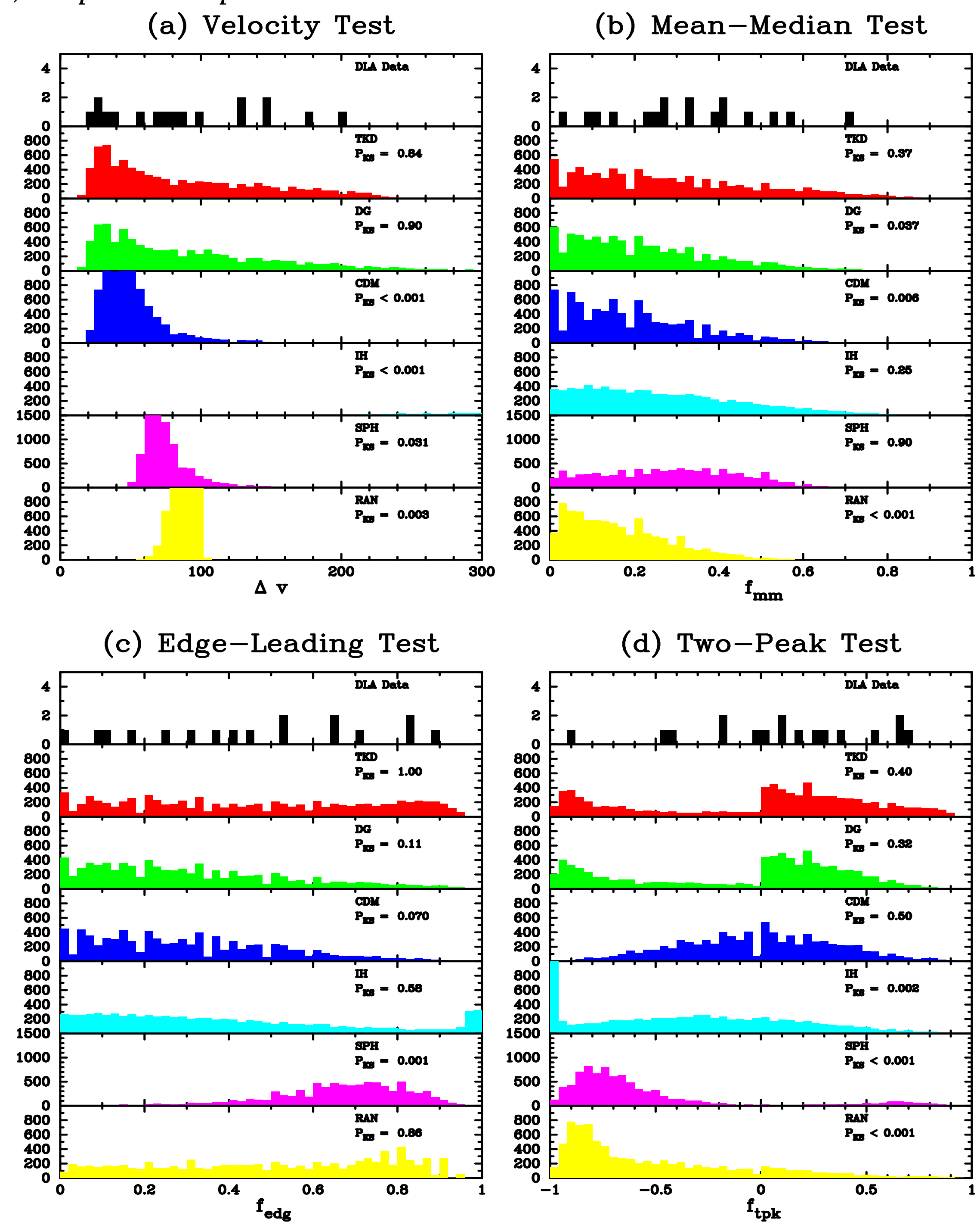
CDM Challenged..

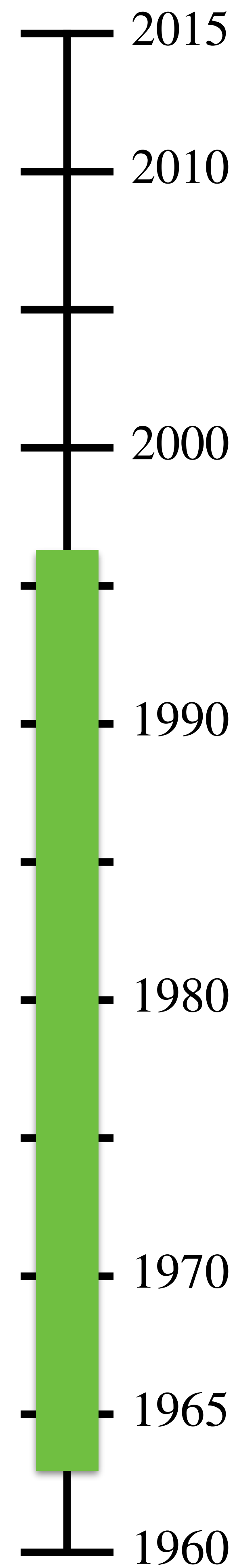
ON THE KINEMATICS OF THE DAMPED LYMAN-α PROTOGALAXIES

J. Xavier
~~JASON X.~~ PROCHASKA[1] AND ARTHUR M. WOLFE[1]
Department of Physics and Center for Astrophysics and Space Sciences, University of California, San Diego, C-0424, La Jolla, CA 92093

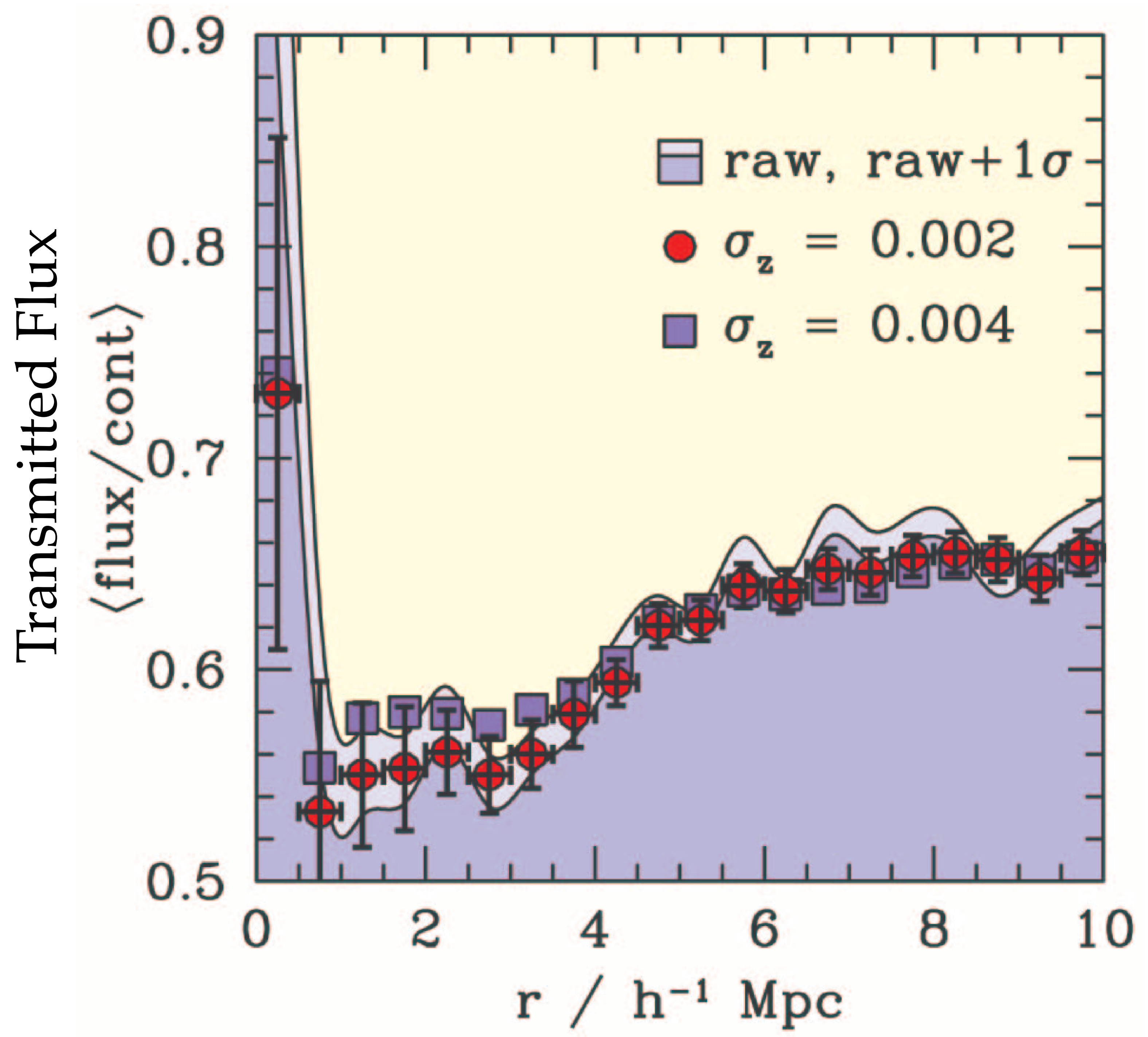
Received 1996 December 30; accepted 1997 April 18



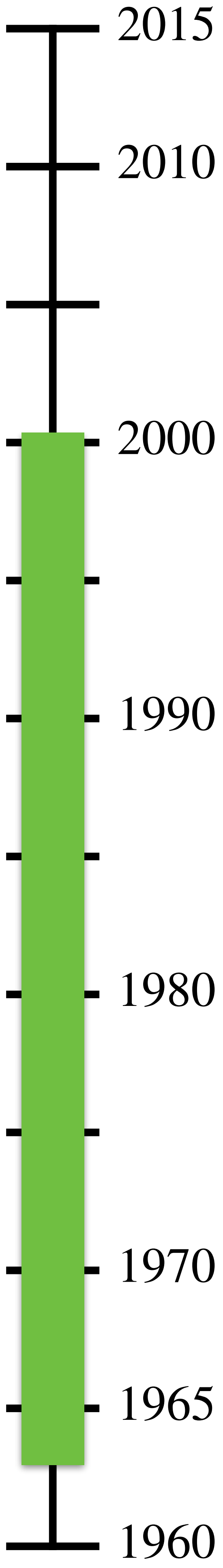




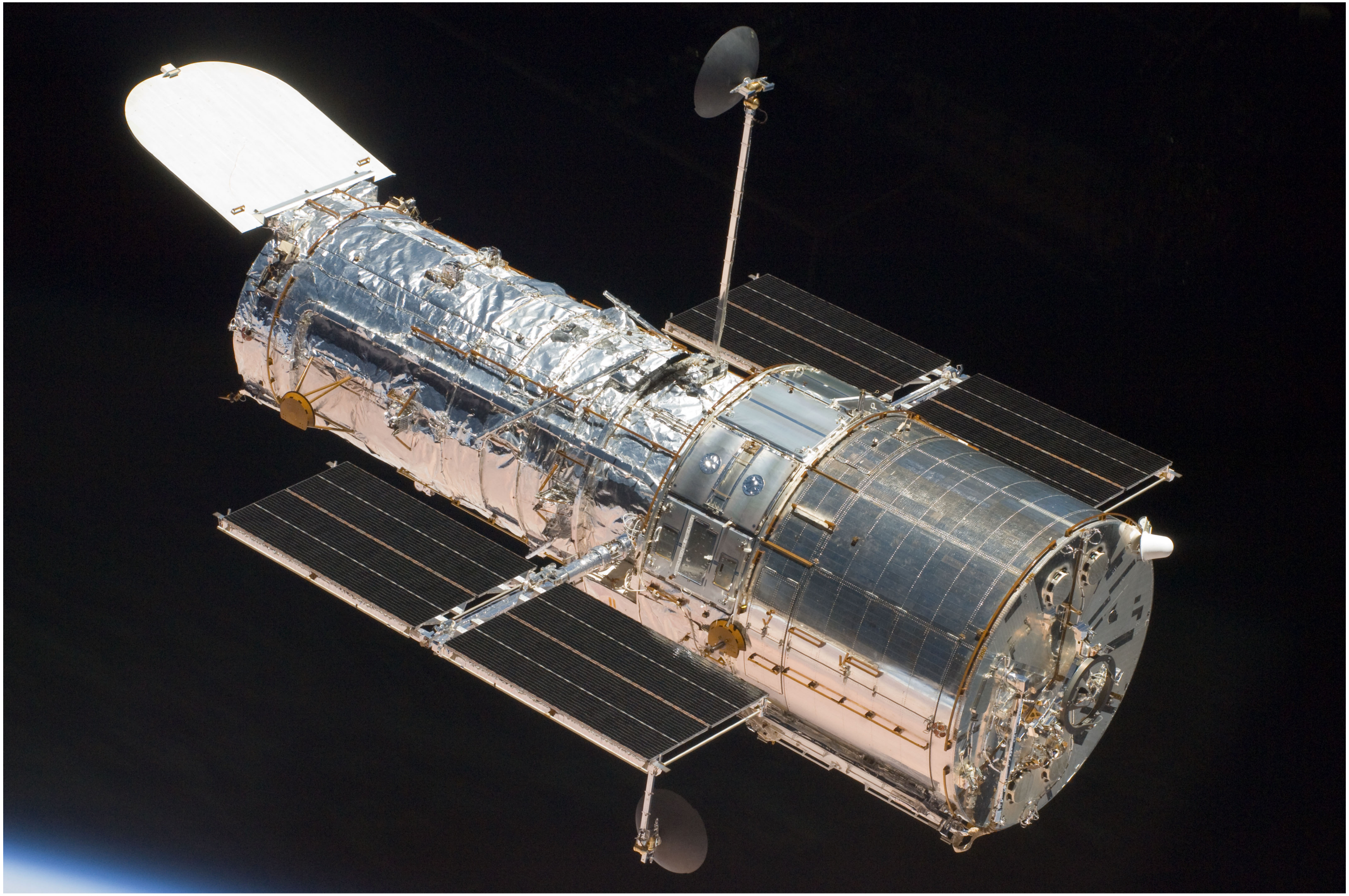
IGM/Galaxy Connection



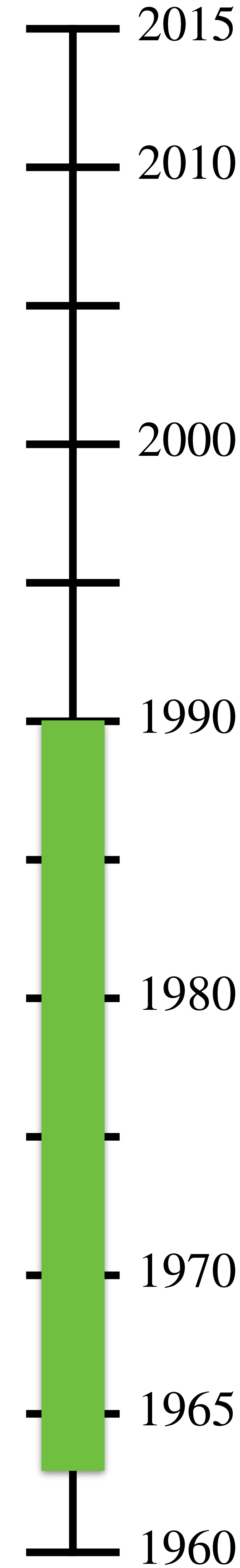
Adelberger+ (2003)



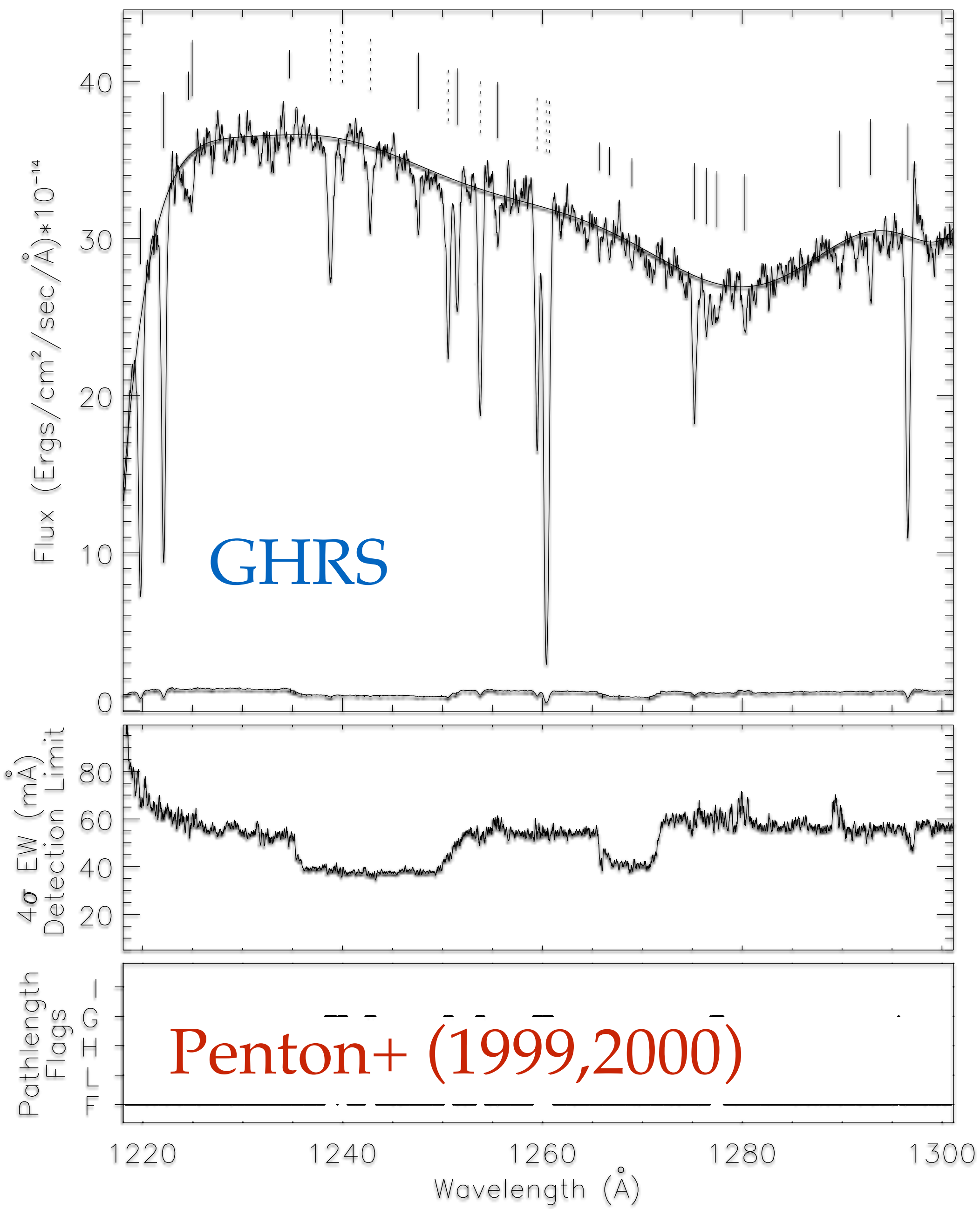
1990

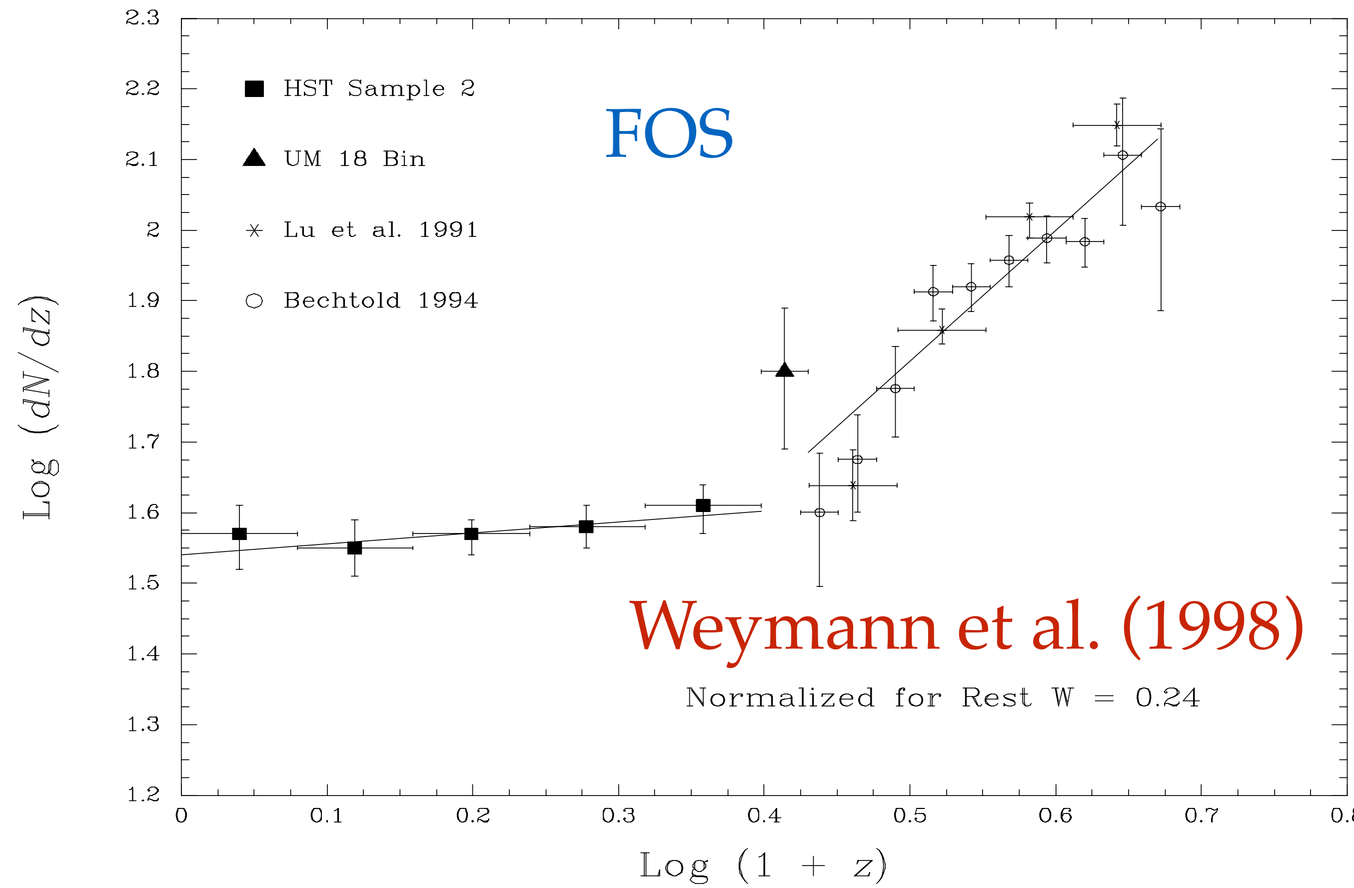


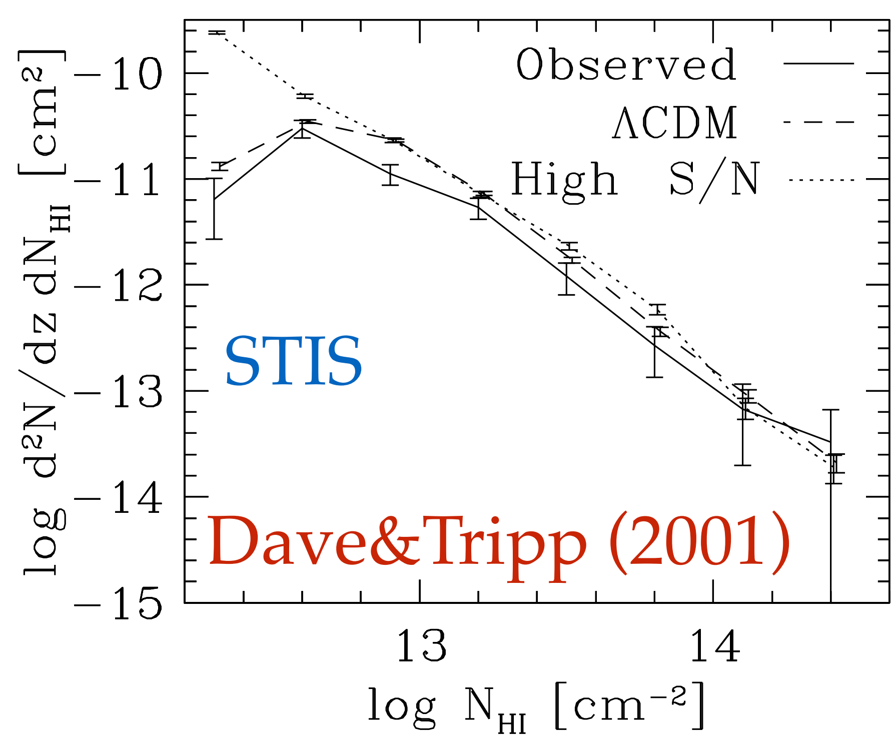
S125E012033

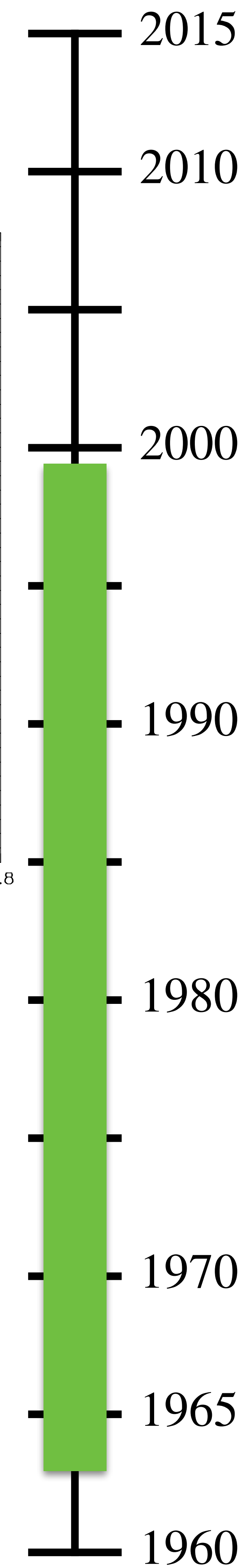


Low-z IGM

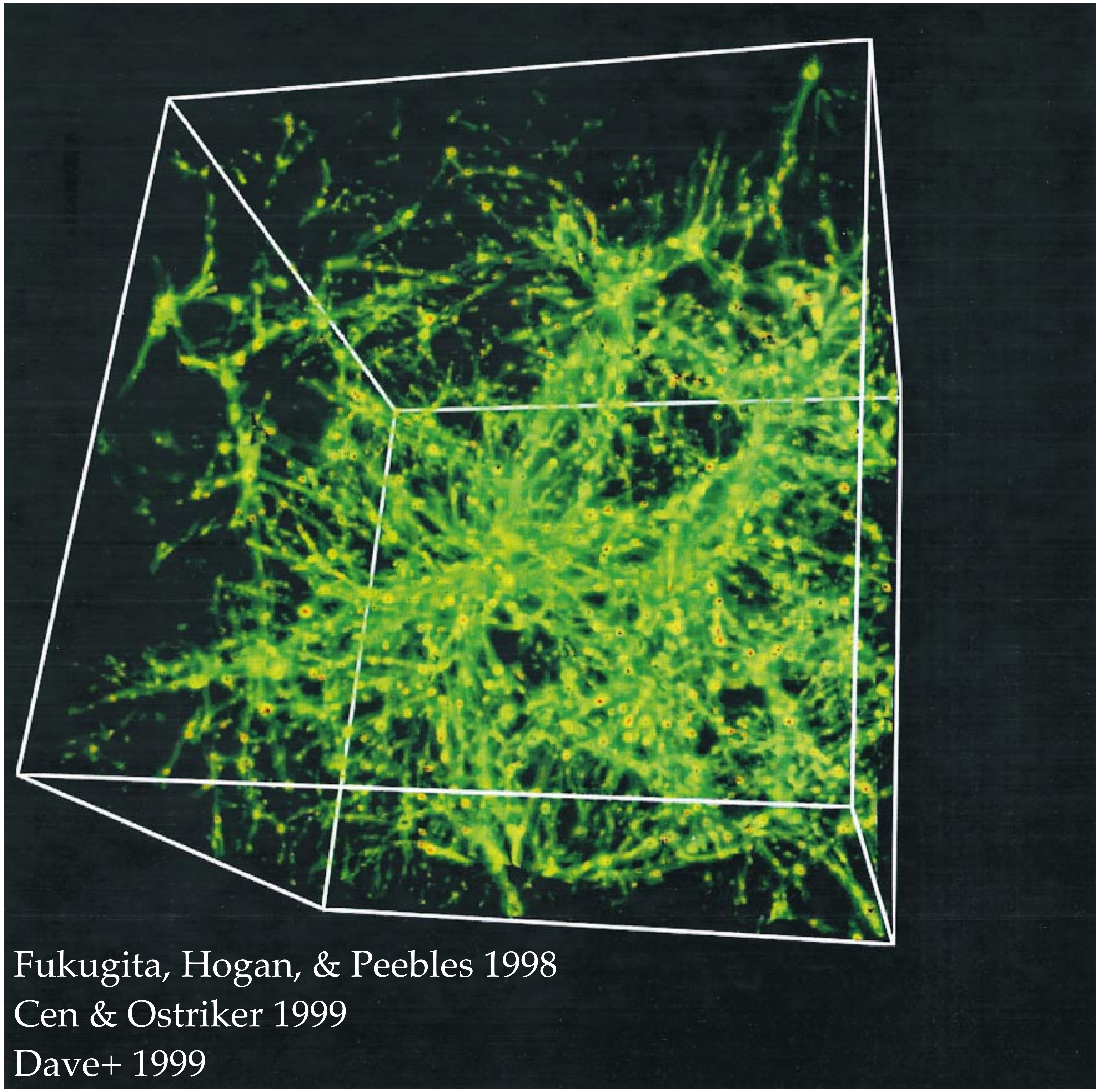

GHRS
Penton+ (1999,2000)
Flux (Ergs/cm²/sec/Å)*10⁻¹⁴
4σ EW (mÅ) Detection Limit
Pathlength Flags
Wavelength (Å)
1220
1240
1260
1280
1300

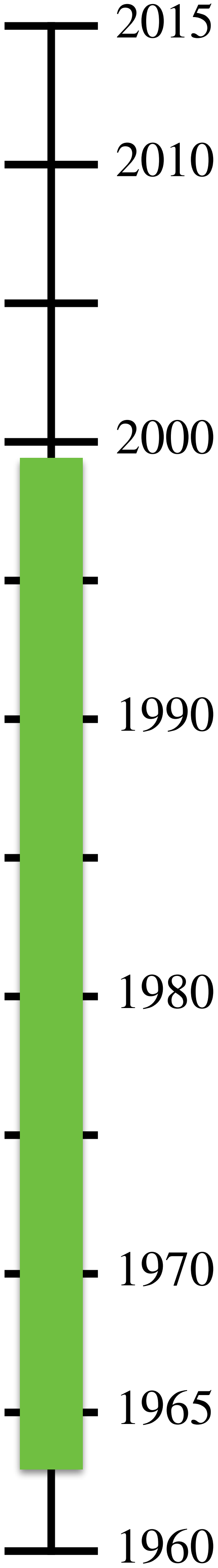

FOS
Weymann et al. (1998)
HST Sample 2
UM 18 Bin
Lu et al. 1991
Bechtold 1994
Normalized for Rest W = 0.24
Log (dN/dz)
Log (1 + z)


STIS
Dave&Tripp (2001)
Observed
ΛCDM
High S/N
log d²N/dz dN_HI [cm²]
log N_HI [cm⁻²]

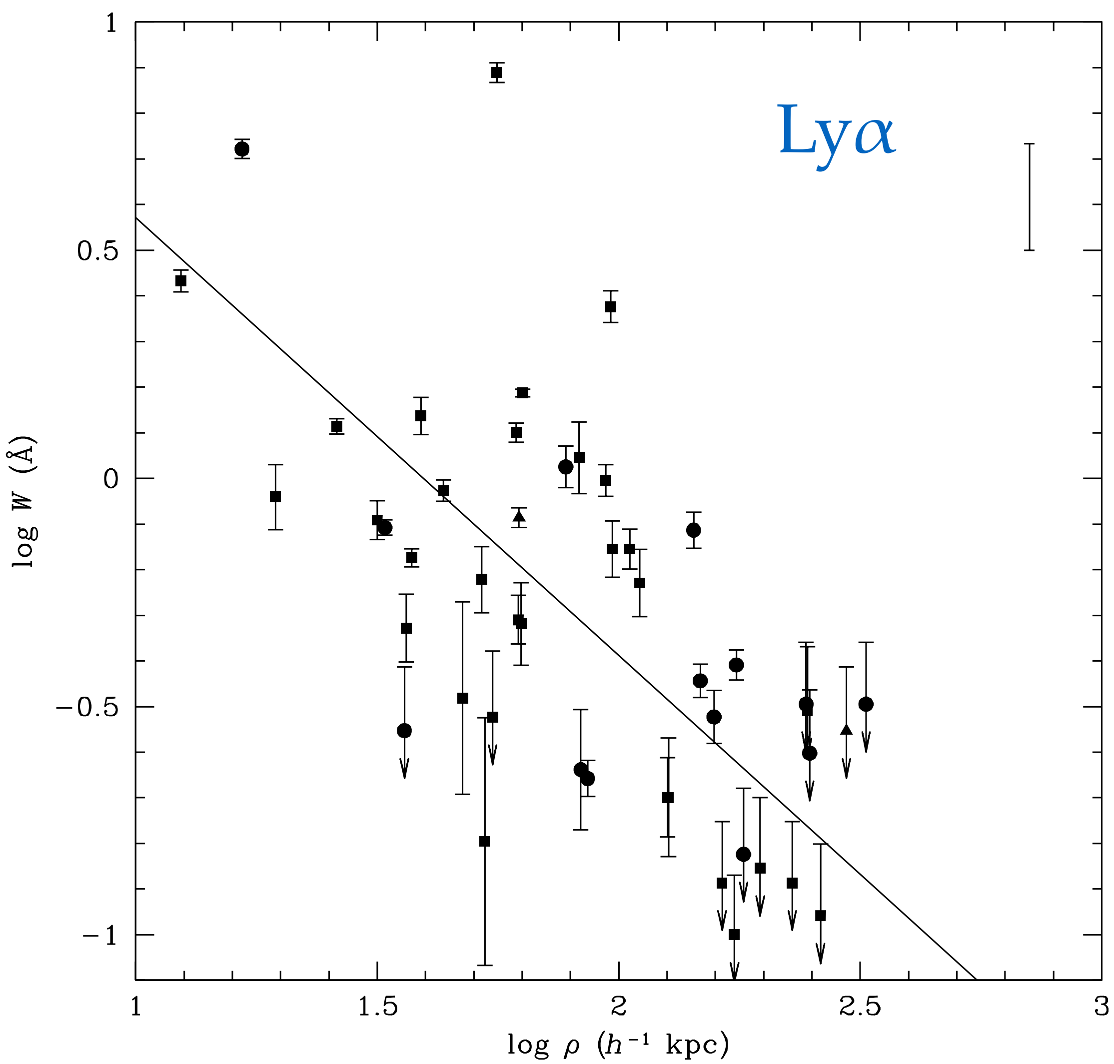

2015
2010
2000
1990
1980
1970
1965
1960

The WHIM

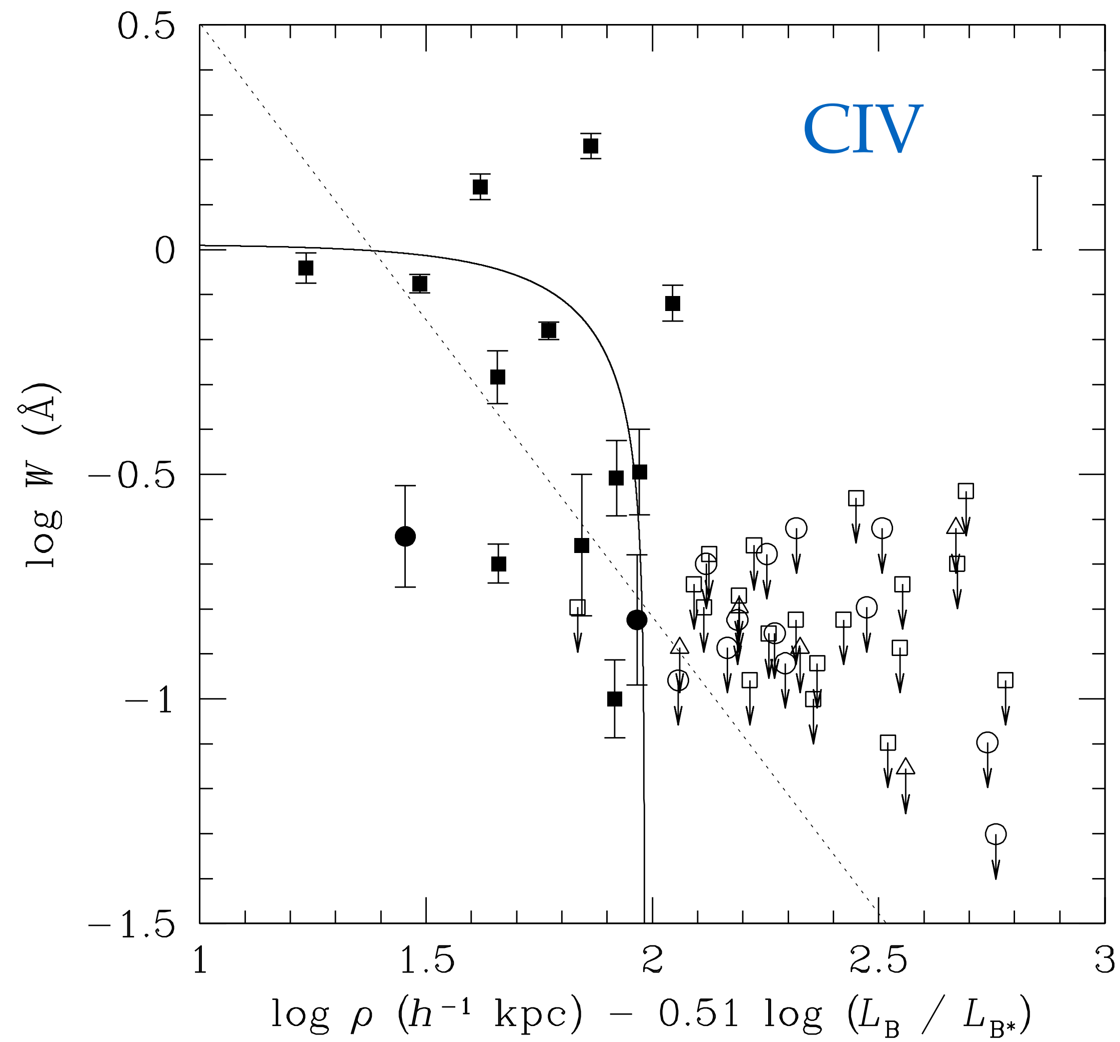

Fukugita, Hogan, & Peebles 1998
Cen & Ostriker 1999
Dave+ 1999


2015
2010
2000
1990
1980
1970
1965
1960

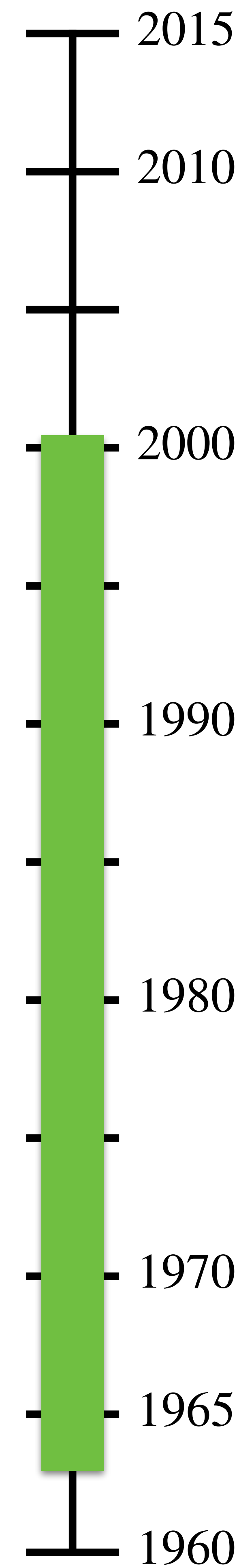
HI, CIV, etc. in Halos



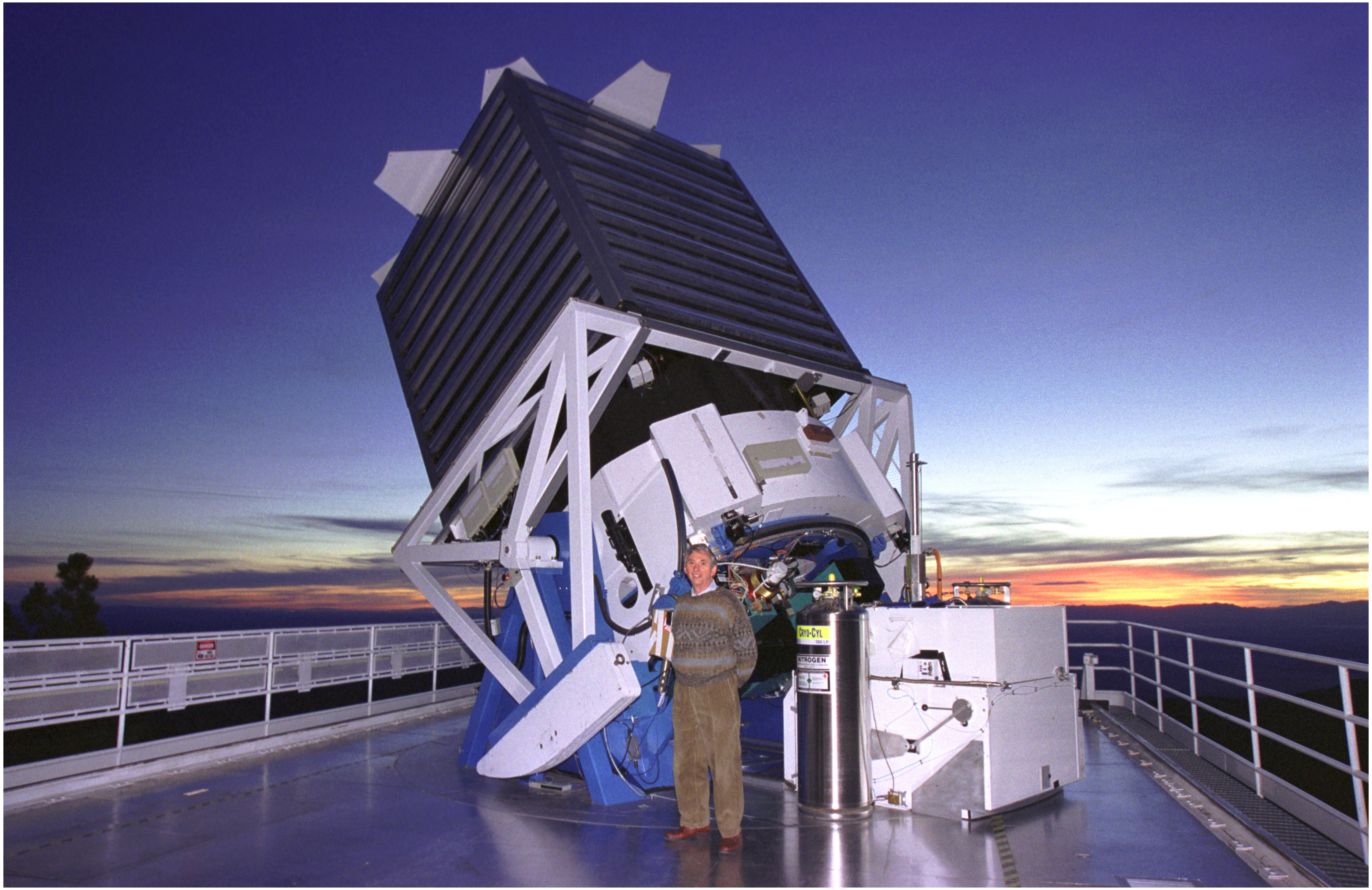
Lanzetta+ (1995)
Chen+ (2001a)
Penton+ (2002)

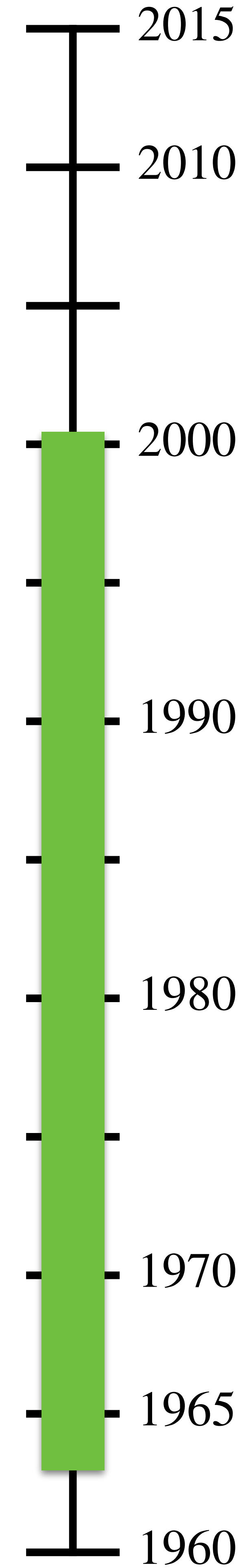


Chen+ (2001b)



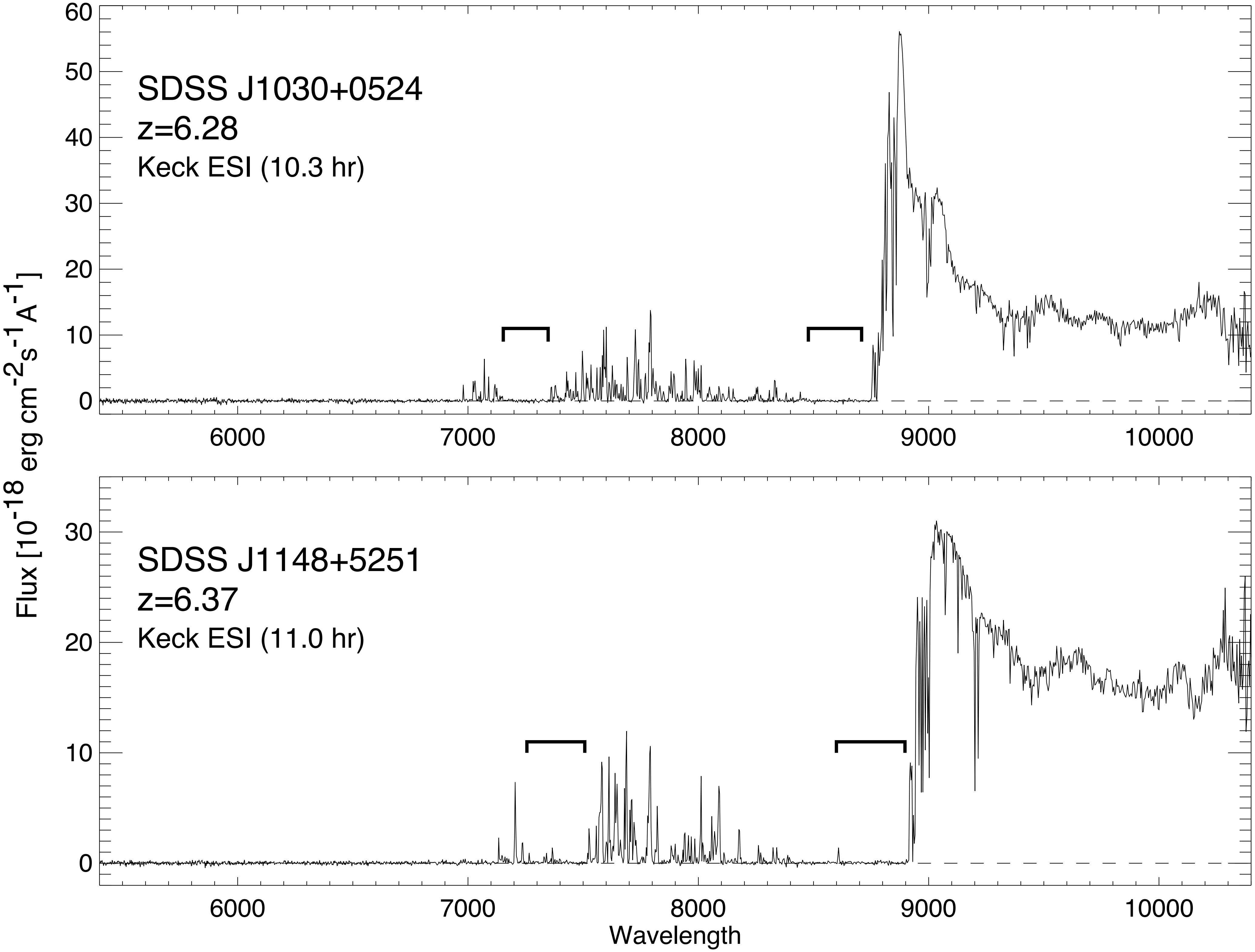
2001

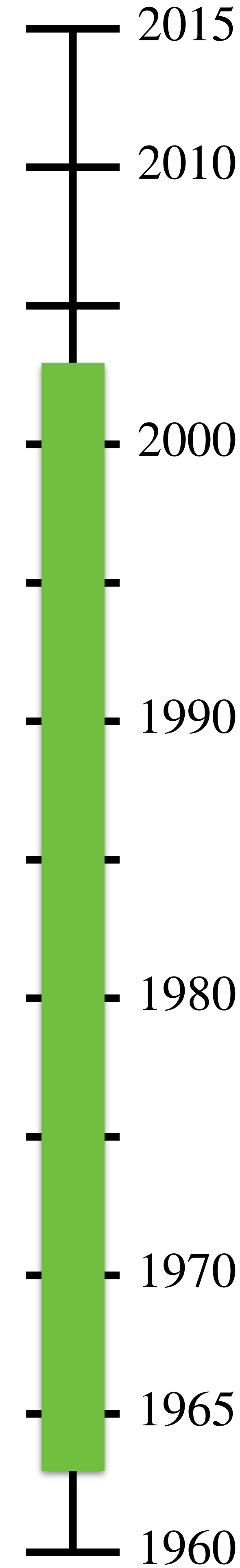




Gunn + York

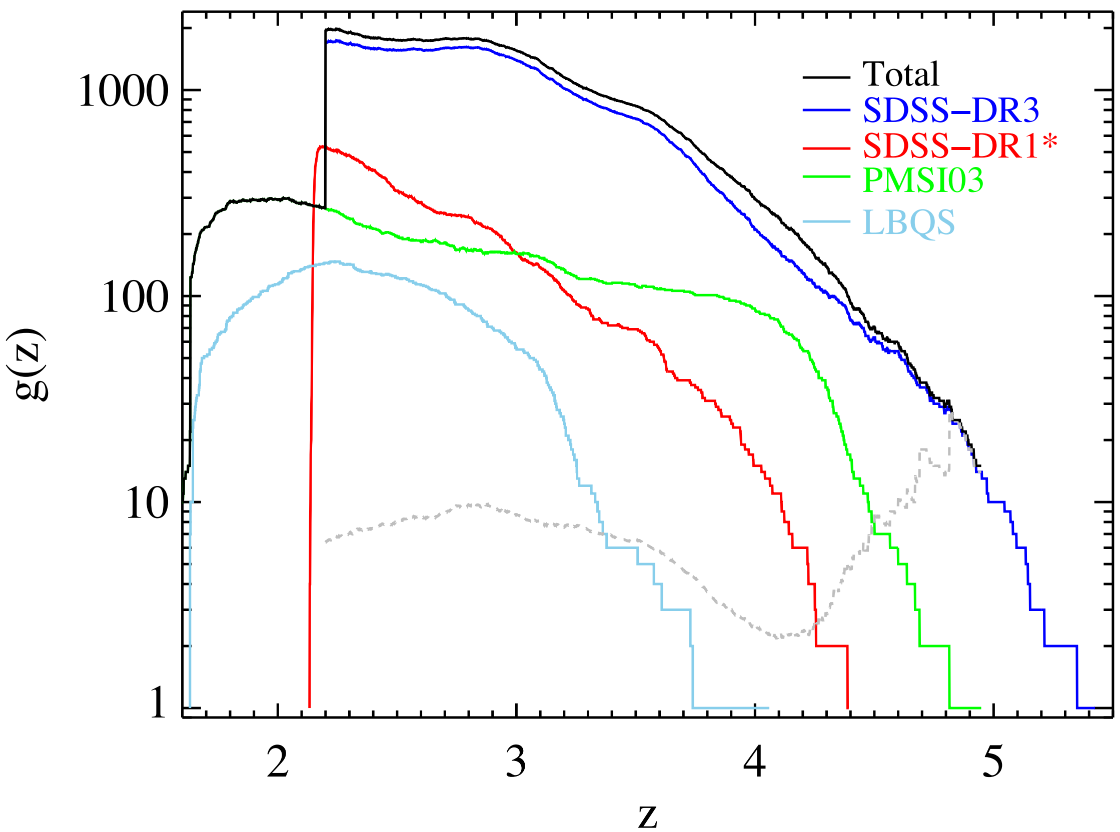
HI Reionization?



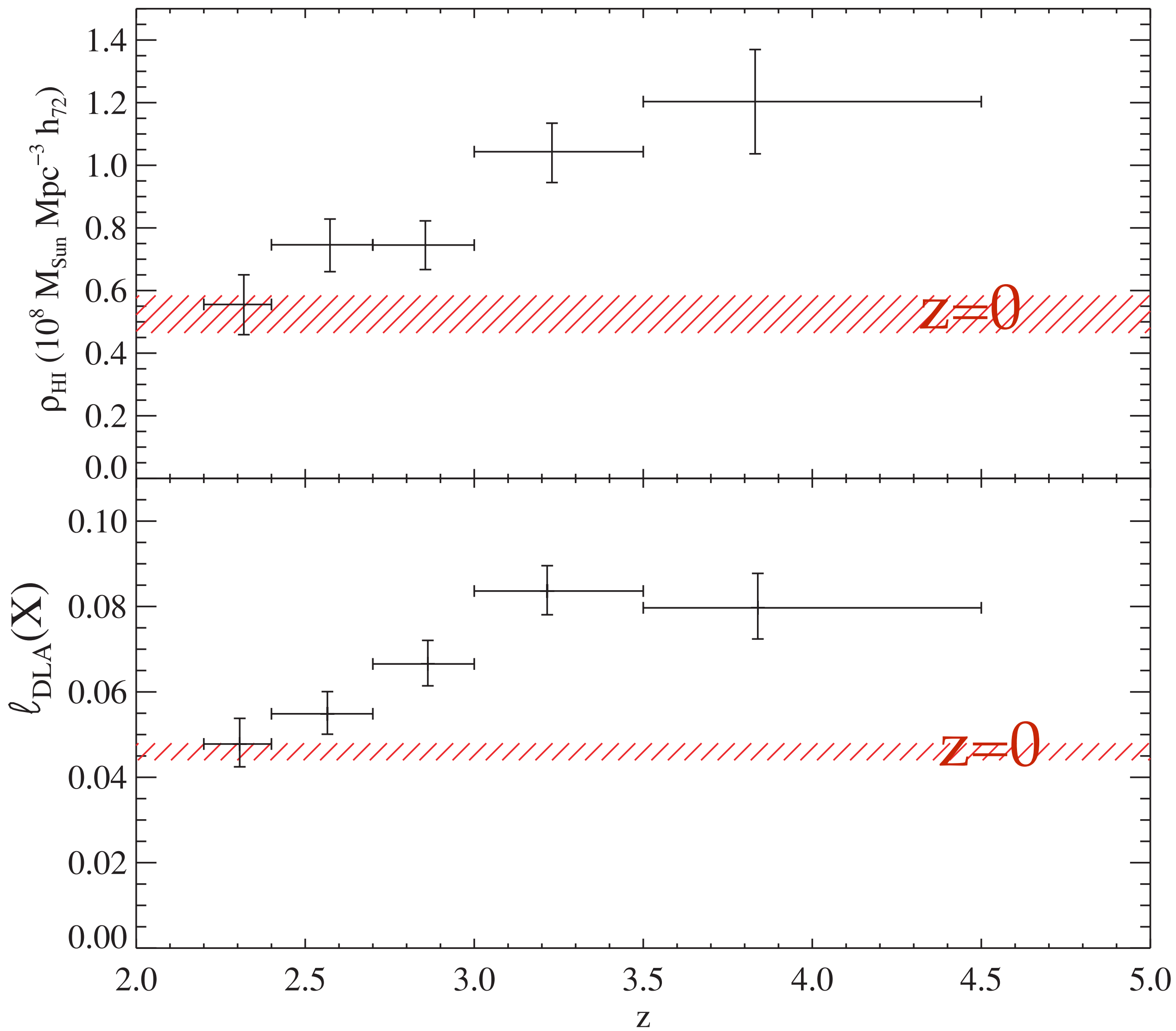


Fan+ 2002
White+ 2003

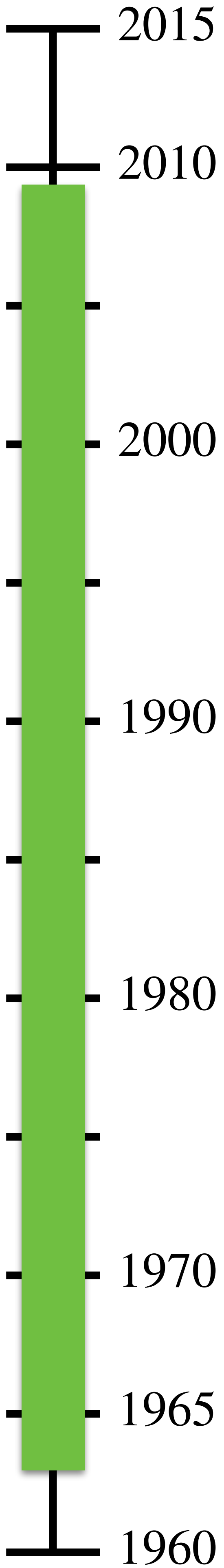
HI Evolution in Galaxies



PHW (2005)

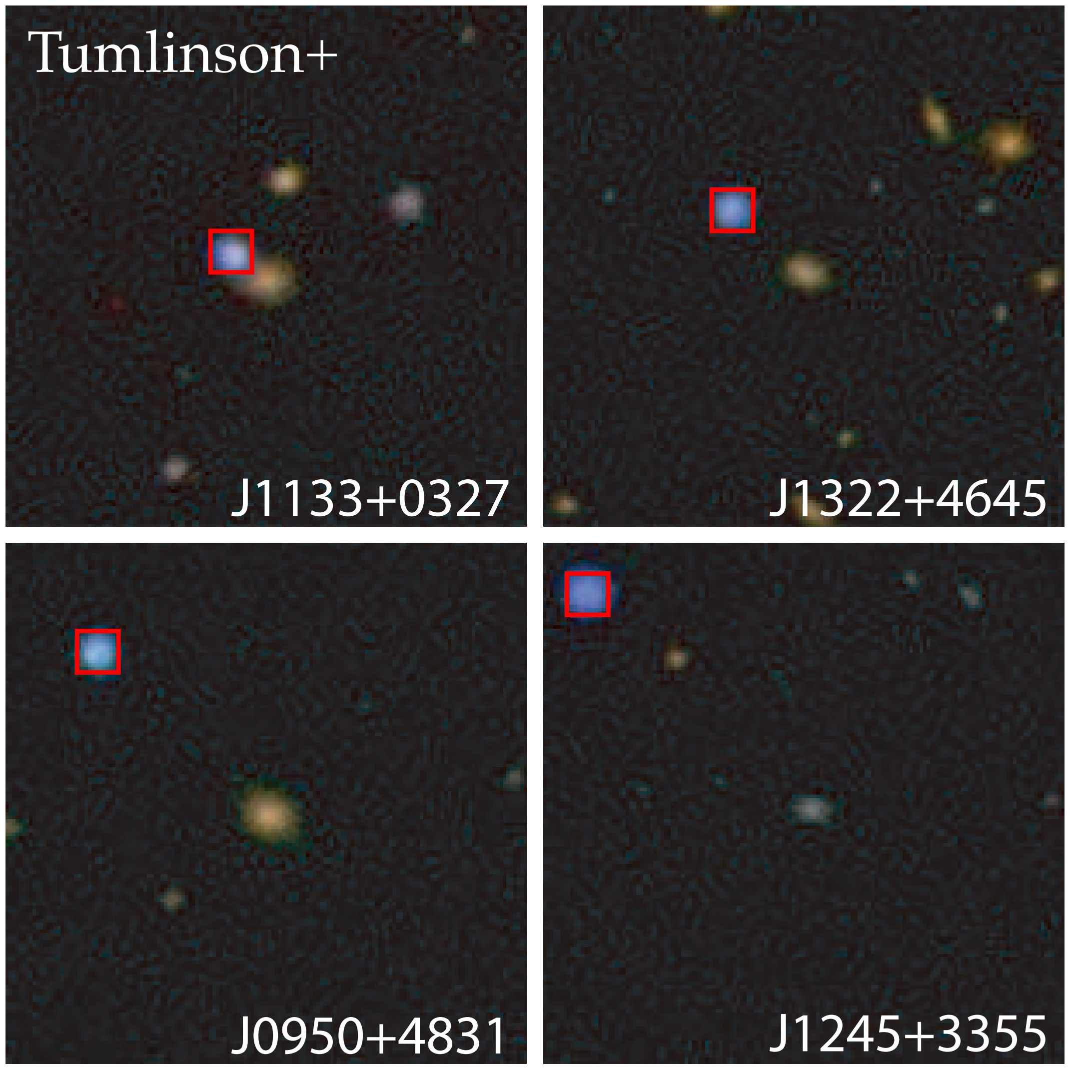


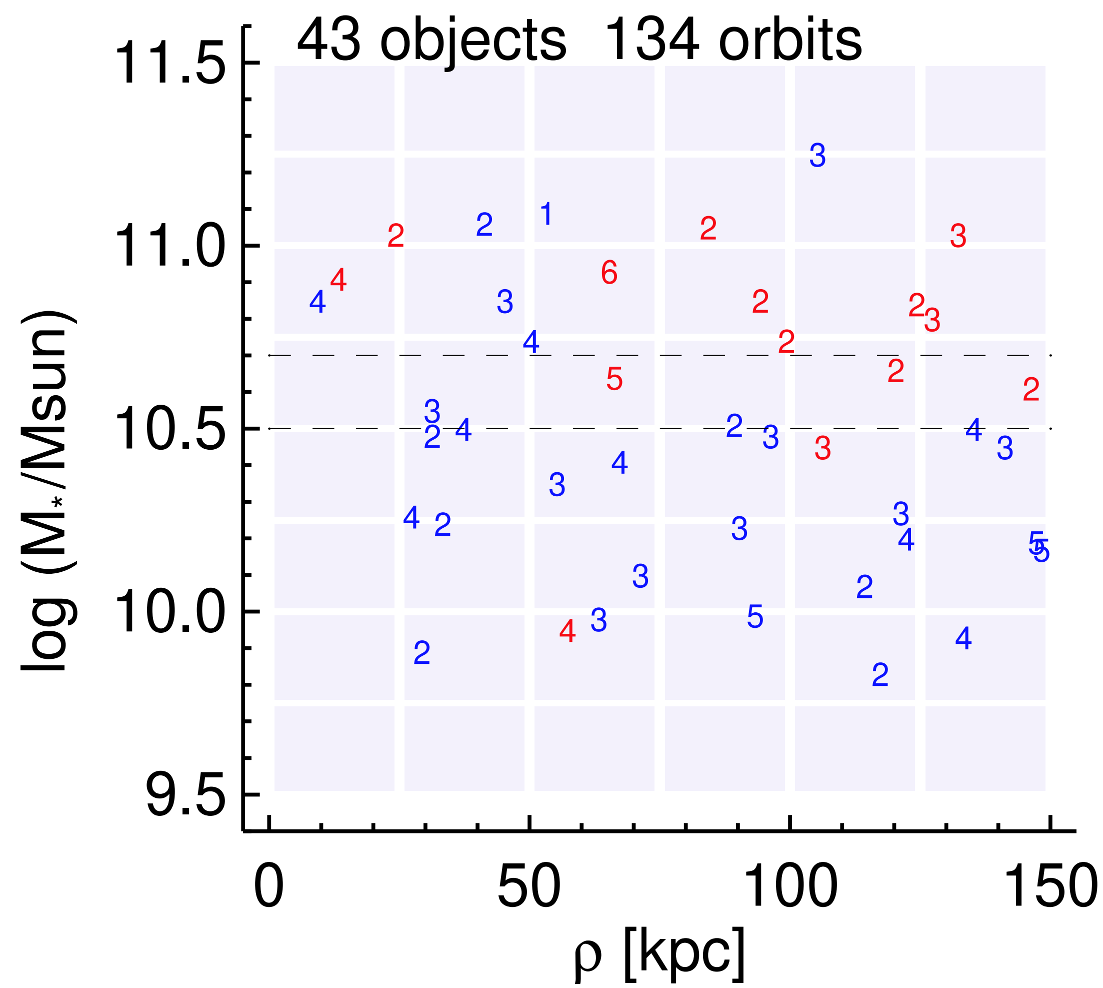
PW (Spineto 2009)

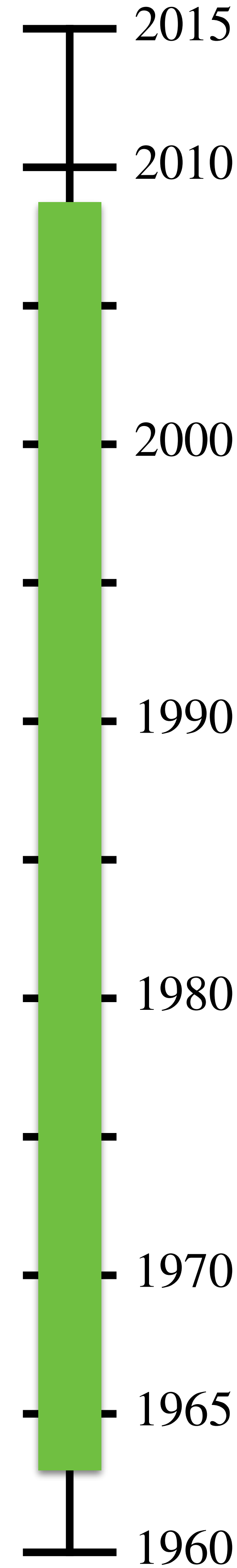


The CGM Revitalized

Great thanks to GALEX too



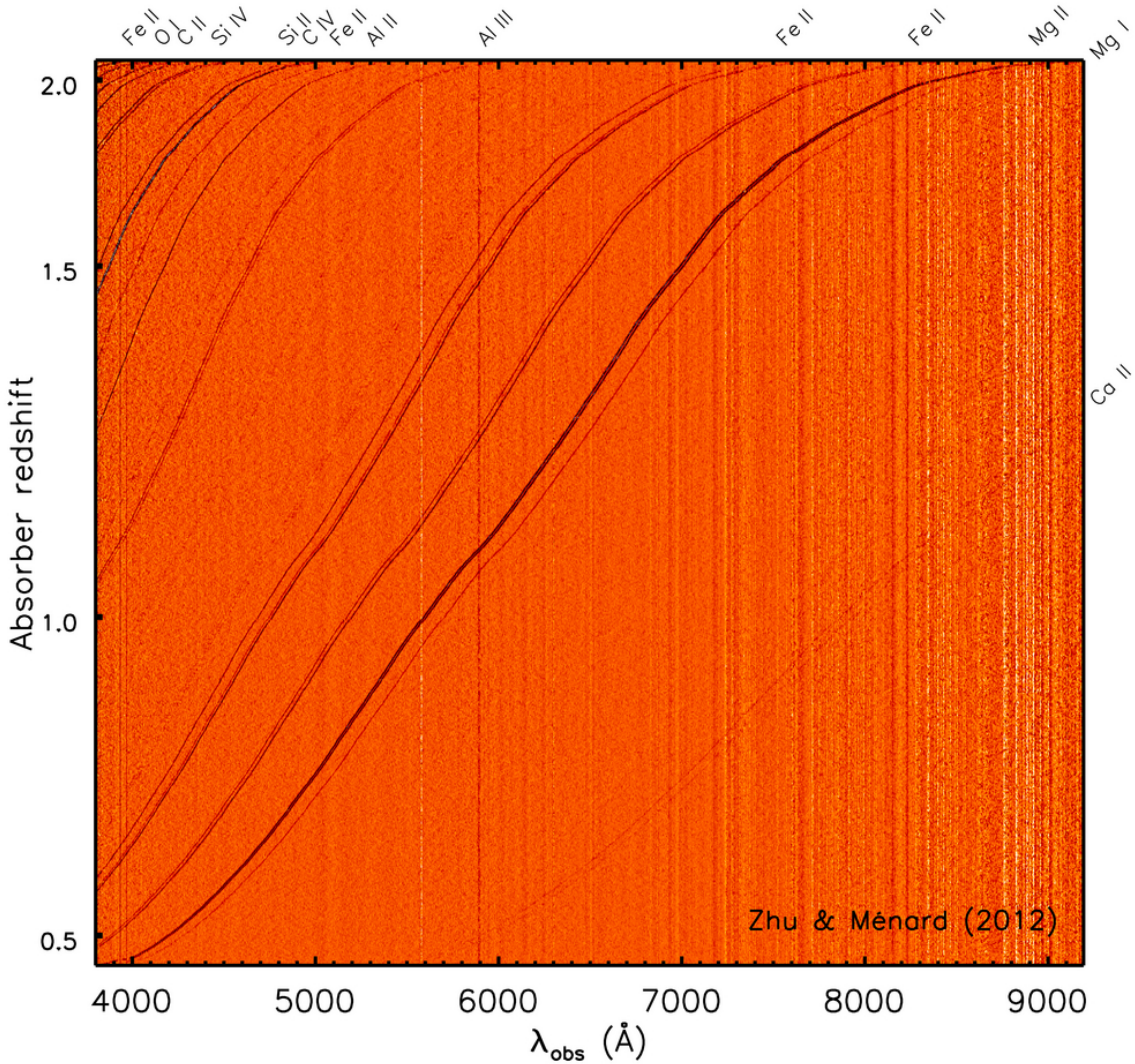


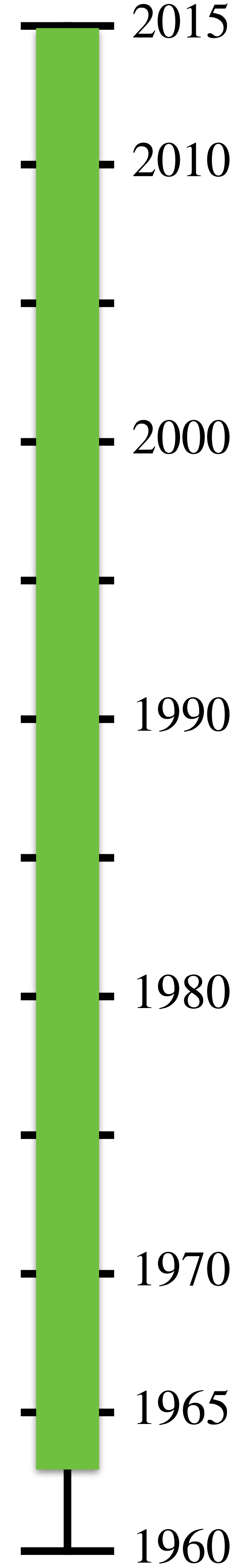


COS-Halos

BOSS

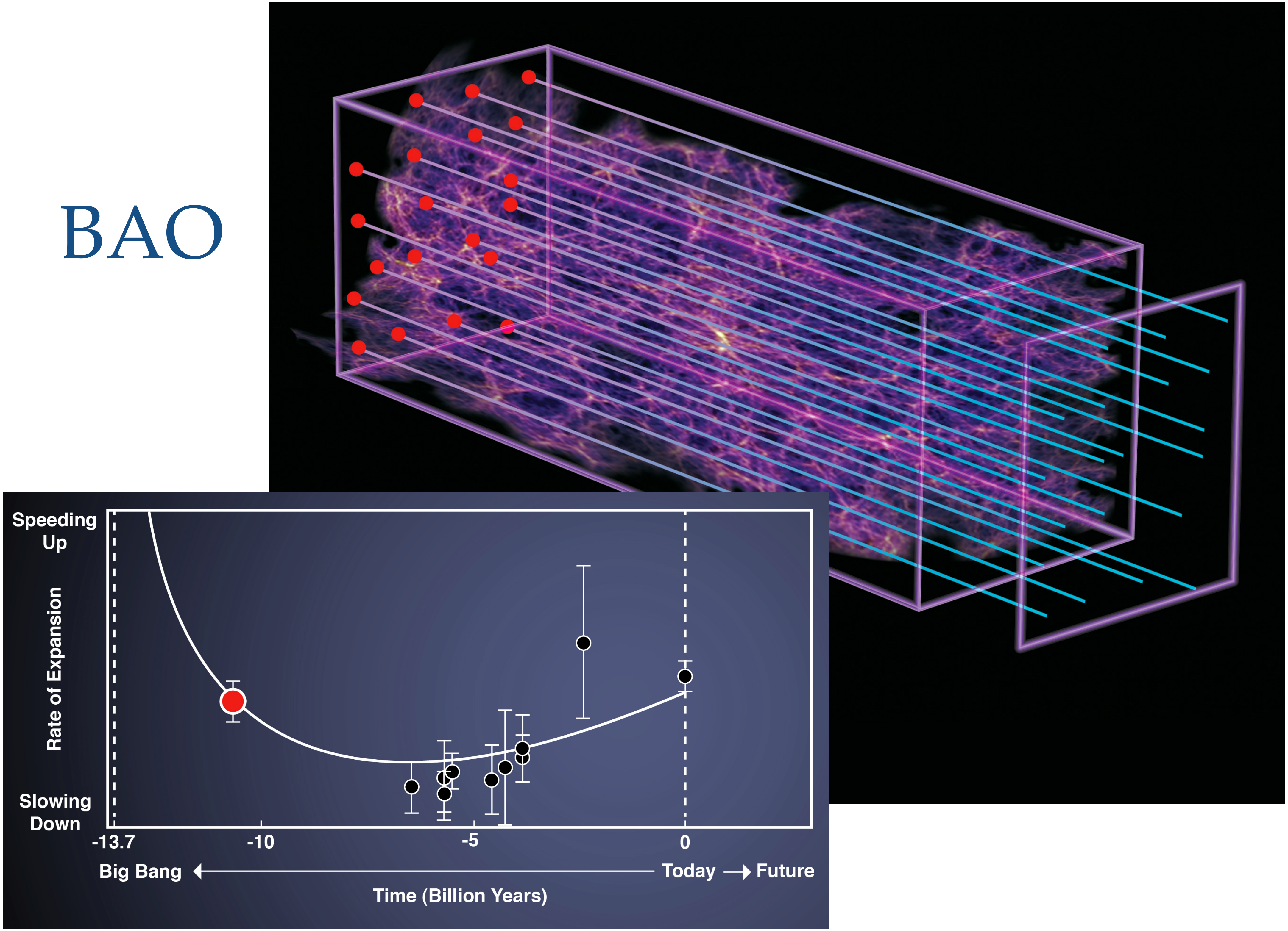
Every pixel is sacred!

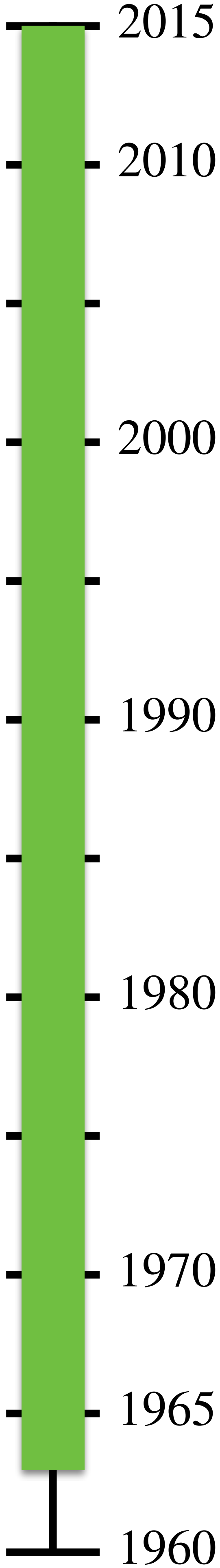




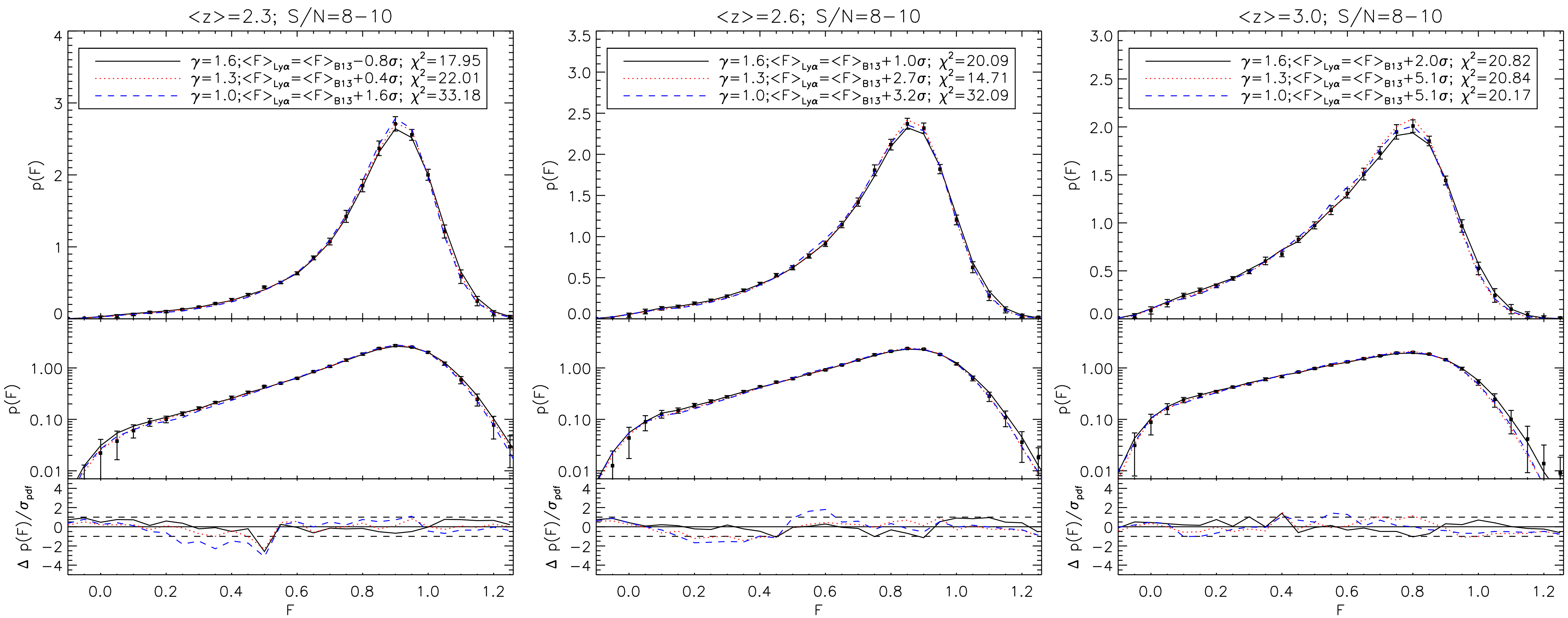
IGM as a Cosmological Tool

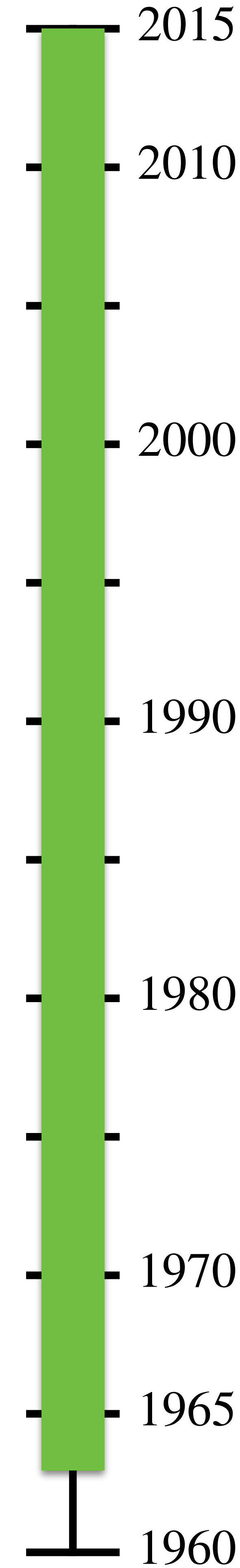
BAO





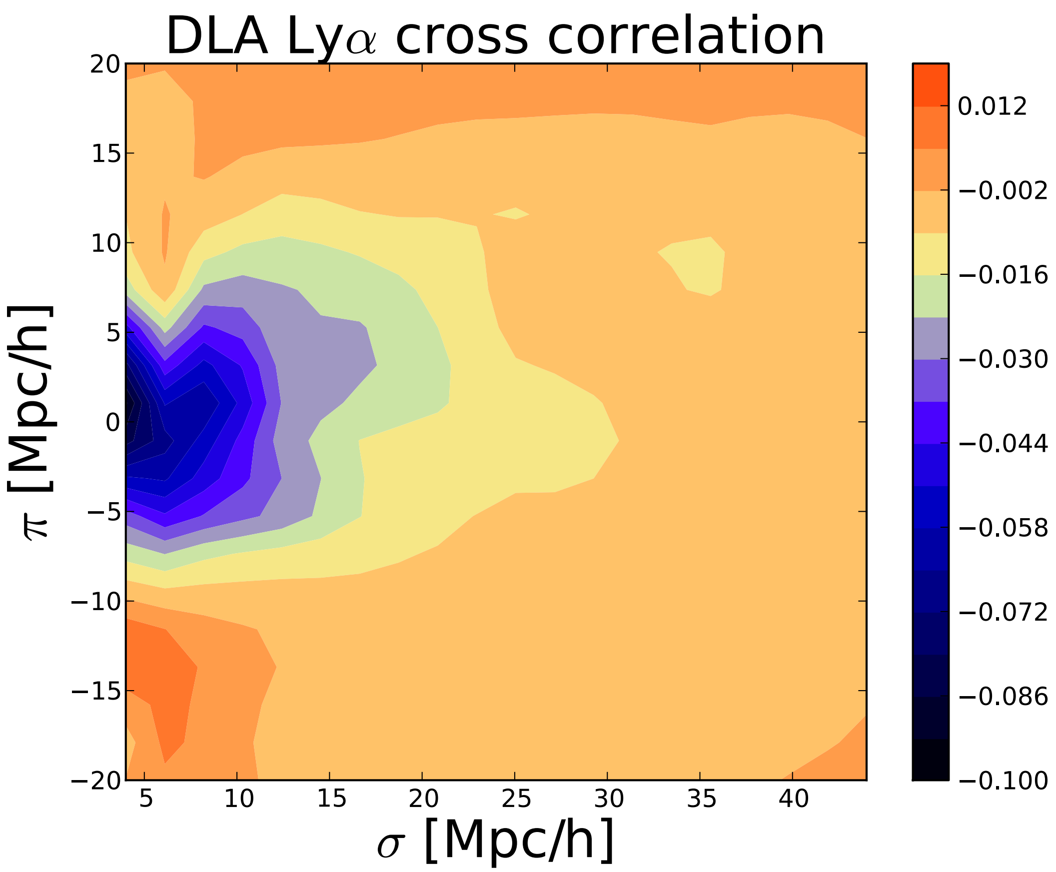
IGM as a Cosmological Tool



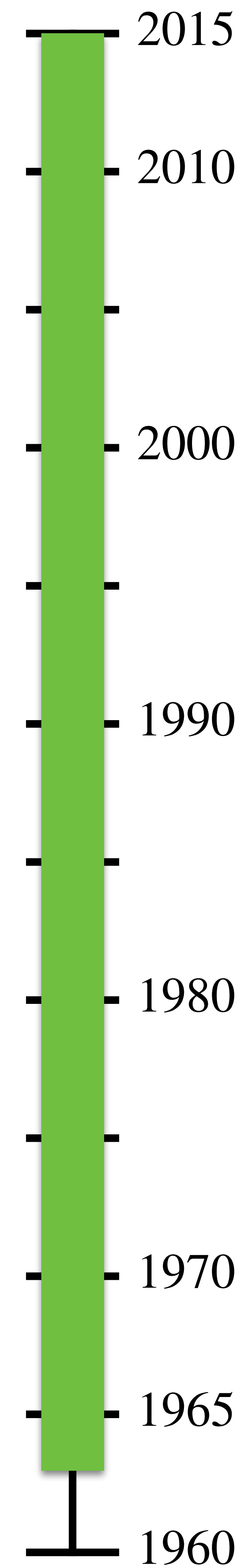


Flux PDF; Lee+ 2015

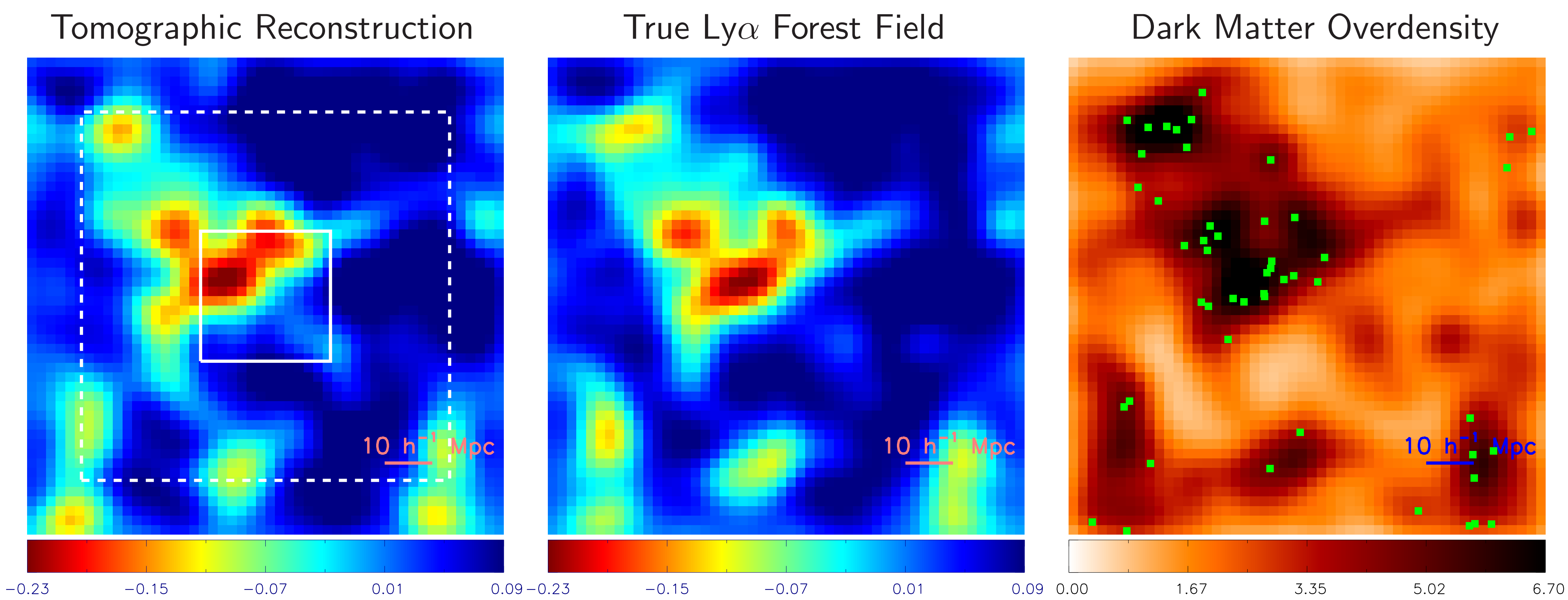
IGM as a Cosmological Tool

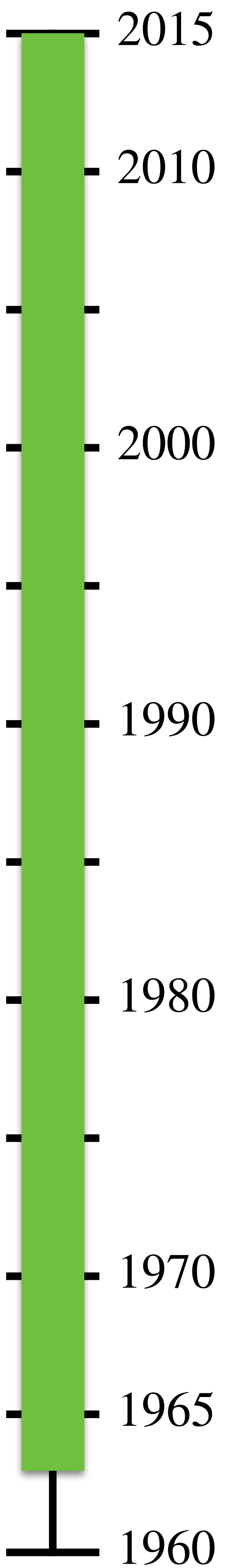


Clustering; Font+ 2012



IGM as a Cosmological Tool





Tomography; Lee+ 2014

Five Open IGM Questions

1. What fraction of the IGM is enriched?
   - By mass and volume
   - Feedback
   - Early star formation
   - Nucleosynthesis
2. What is its thermal history?
   - HI, HeII Reionization
   - First stars, AGN
3. What is theory getting right?
4. What drives its interactions with galaxies?
   - CGM
   - Feedback
   - Magnetic fields, CRs, …
5. What aspects have we missed altogether?!
   - Blazars
   - Magnetic fields
   - Mini-quasars
   - Mini-halos