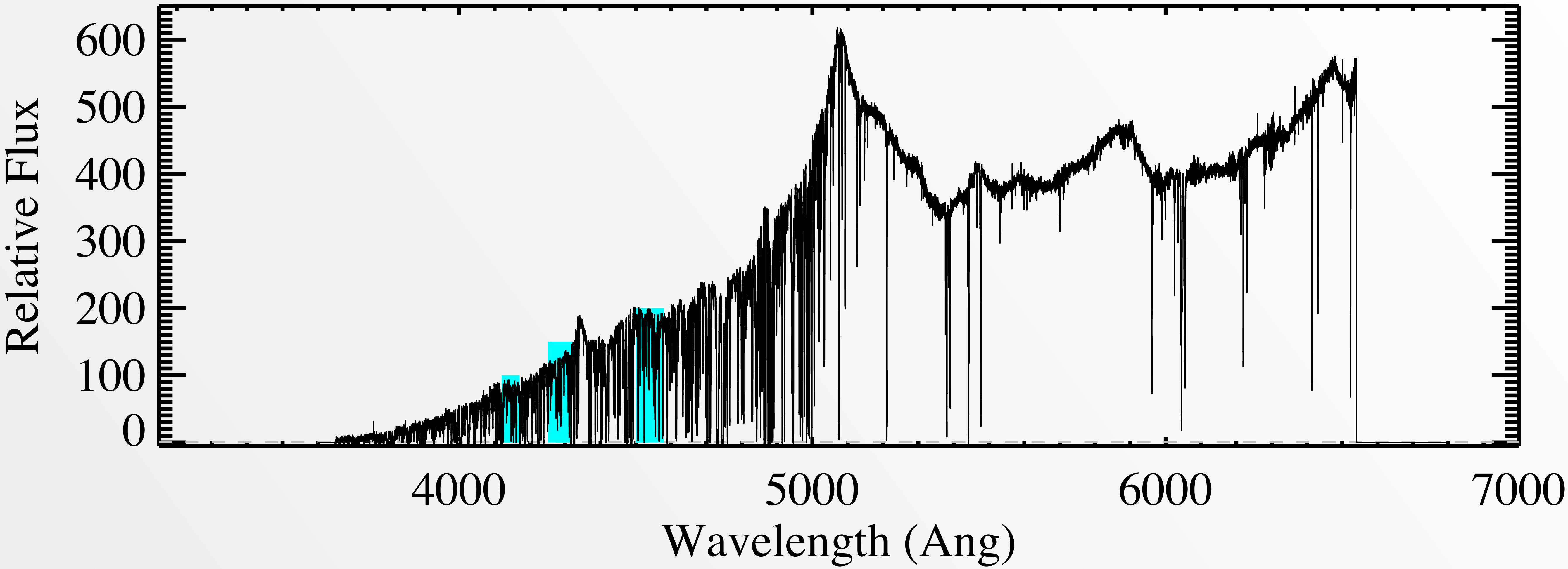
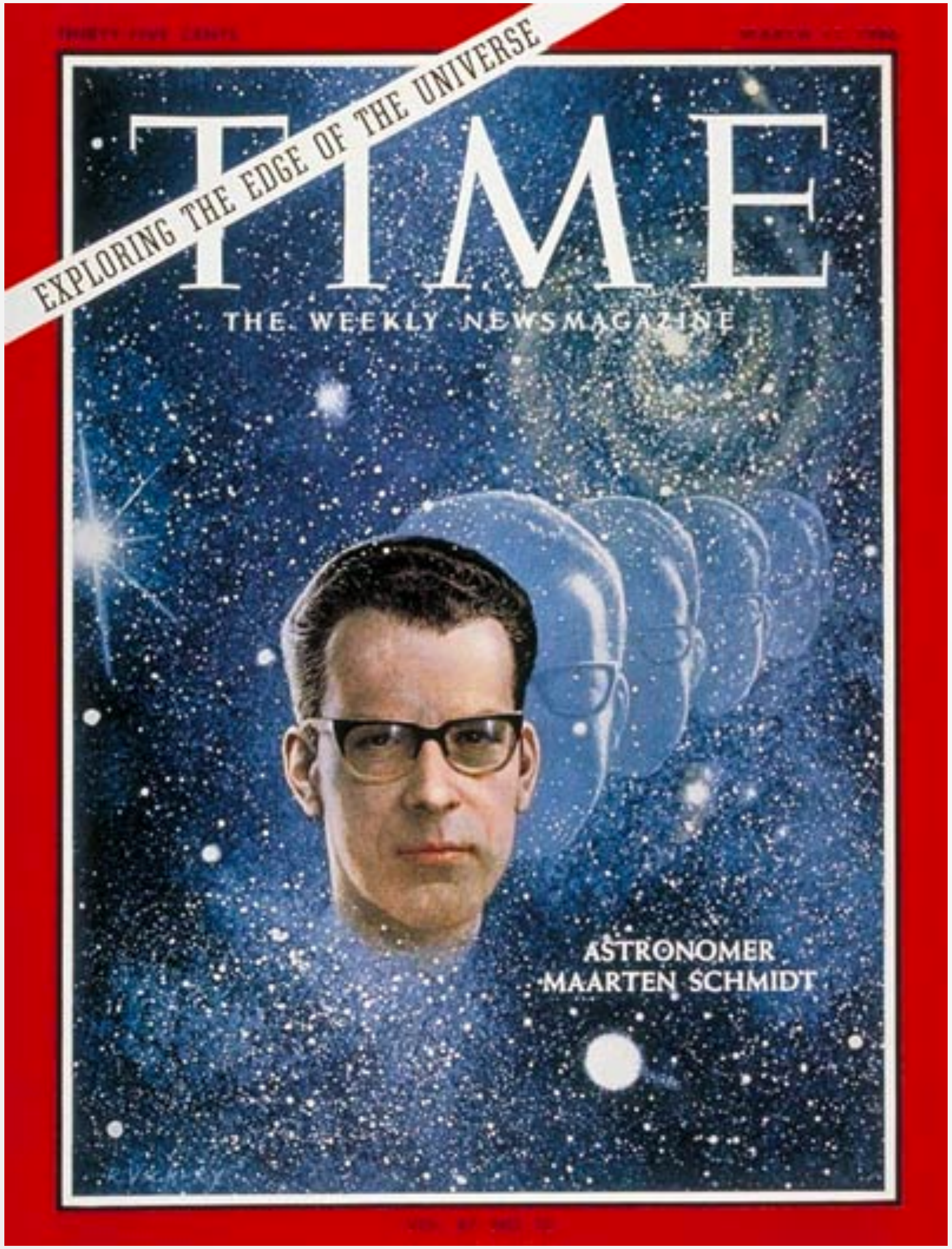
Introduction on HI Absorption



Discovery of Quasars (1963)



Burbidge, Burbidge (1965+)

Burbidge, Burbidge (1965+)

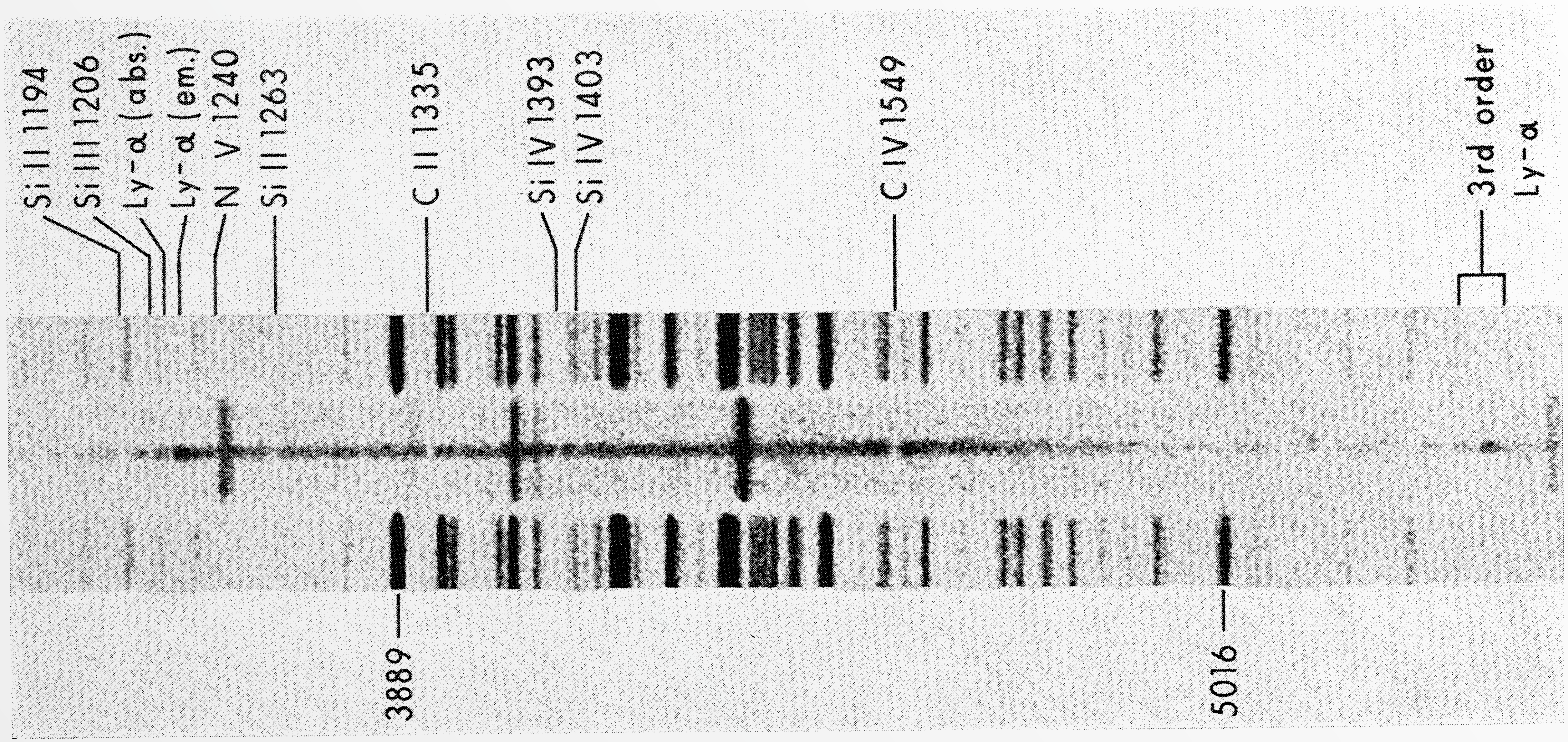


FIG. 2.—Lick spectrum of 3C 191 obtained in February, 1966, with the prime-focus spectrograph on the 120-inch telescope. The comparison spectrum shown is that of He + Ar.

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

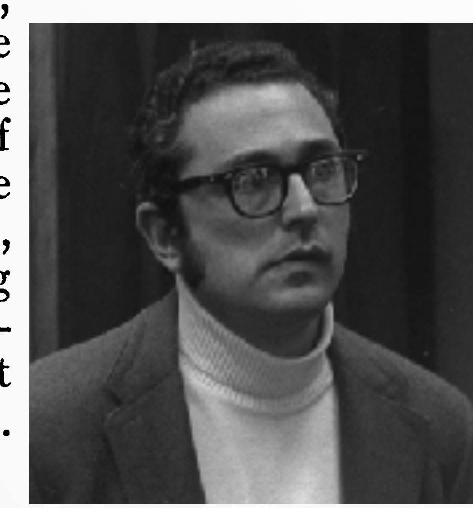
Gunn-Peterson (1965)

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:



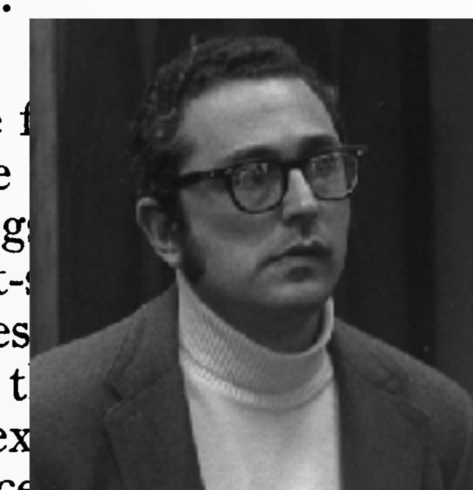
Let us consider a cosmological model with the metric

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

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})

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

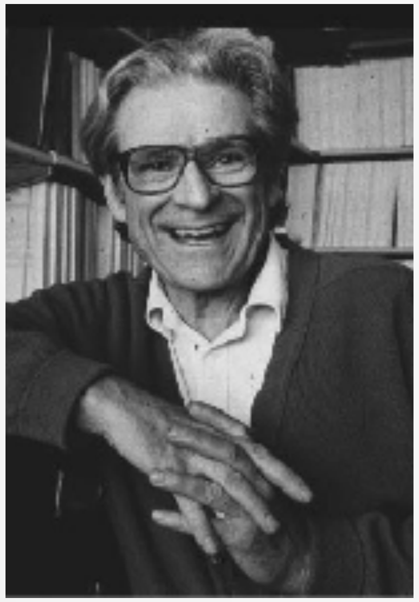


ere n_s is the number density of neutral hydrogen in the scattering region. The f
be reduced, of course, by a factor e^{-p}, but it is difficult to say just how large
t is on the plates of 3C 9. Intensity tracings were made of two plates, and tracing
neighboring night-sky spectra allowed approximate subtraction of the night-
ribution. The blueward component and the wing of the line are noticeably depres
y are enhanced on the plates by a strong, broad night-sky feature at 3640 Å t
s the line an almost symmetric profile before the sky is removed), but the ex
unt is difficult to measure; best estimates place the depression at about 40 per ce
which 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)

Bahcall & Salpeter (1965)



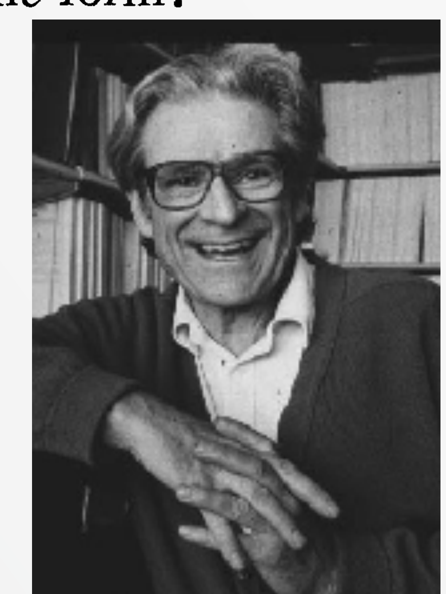
Bahcall & Salpeter (1965)

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:

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



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.

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COSMIC-RAY HEATING OF THE INTERSTELLAR GAS

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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

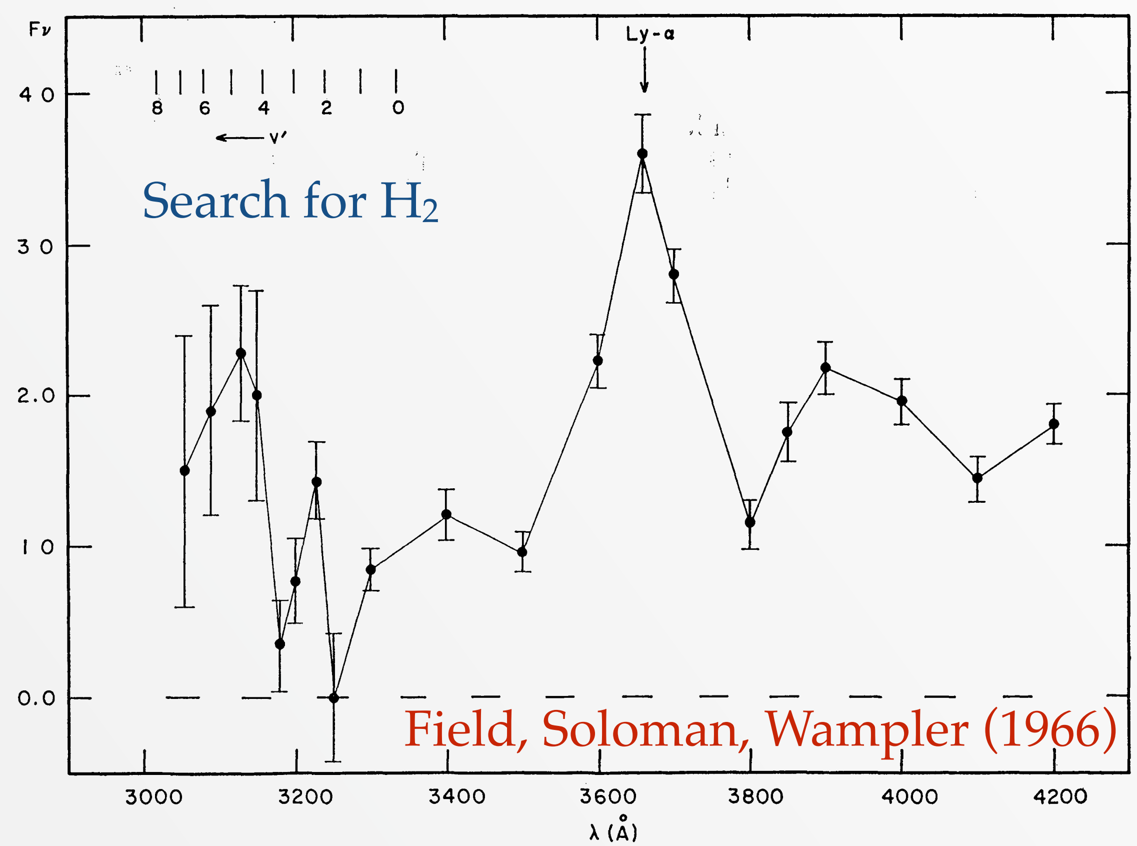
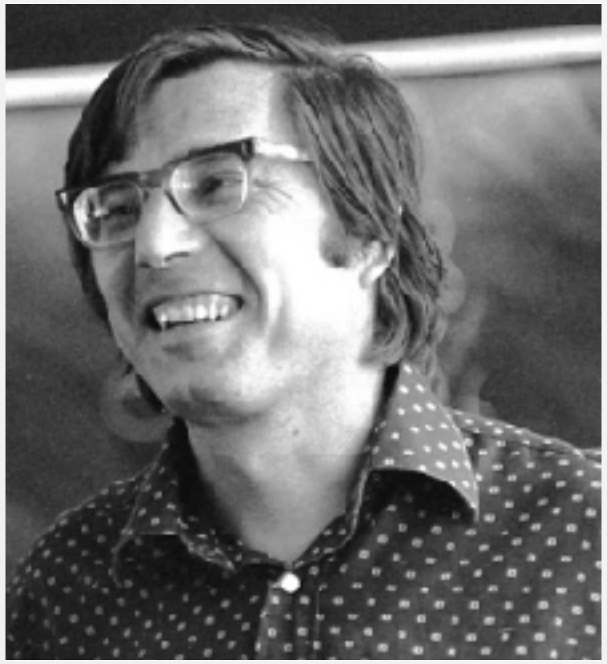
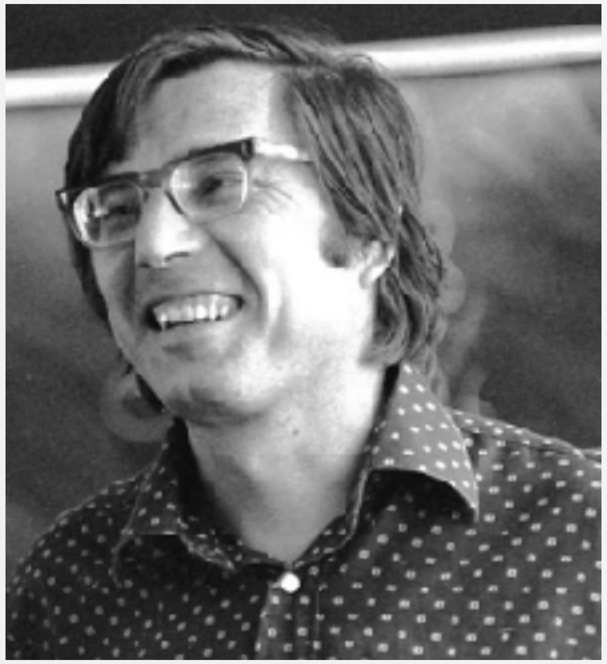


FIG. 2.—Fluxes reduced to outside the atmosphere observed with the photoelectric scanner of 3C 9.

The Lyα Forest



The Lyα Forest



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

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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.

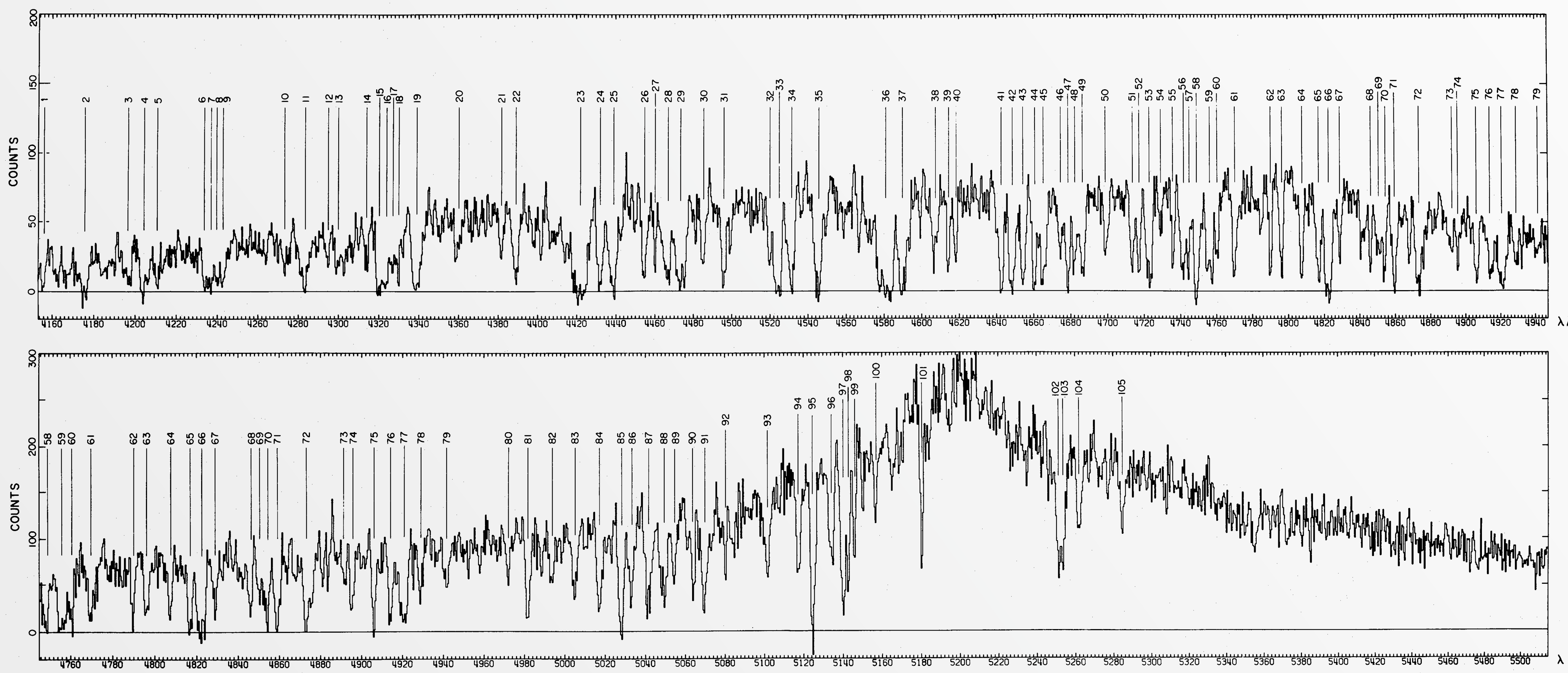

FIG. 1.—Spectrum of PKS 2126−158, showing four overlapping, independent observations covering the range 4153–6807 Å. Each bin is equivalent to 25.78 km s^{-1} (the wavelength axis is logarithmic). The zero intensity level in each observation is indicated by the horizontal lines. The 113 absorption lines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

The Lyman Limit Systems

The Lyman Limit Systems

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

ARTICLES

QSO Lyman limit absorption

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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 $-0.01 \leqslant v/c \leqslant 0.2$ 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 $z \geqslant 3.5, 4.2, 5.3$ or 6.9, due simply to absorption by high redshift LLS. Such are the limits of optical astronomy.

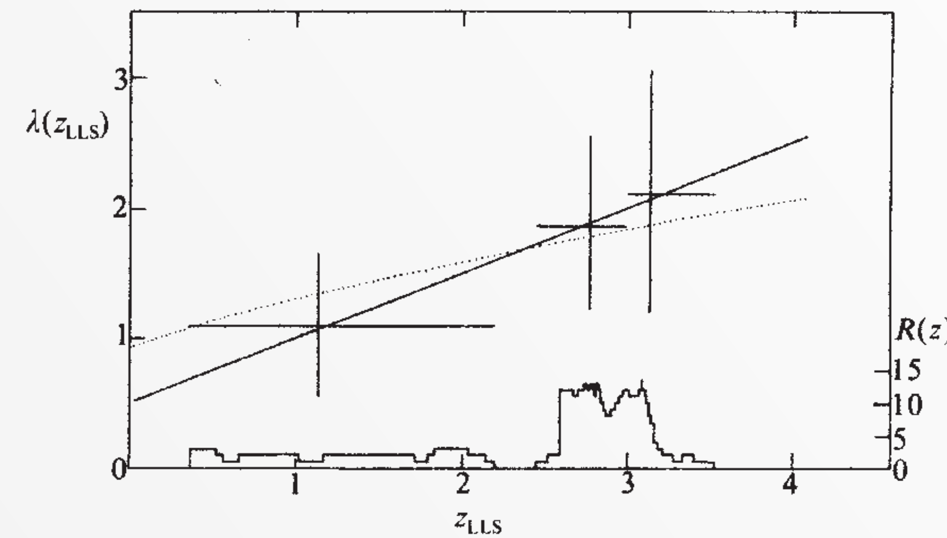
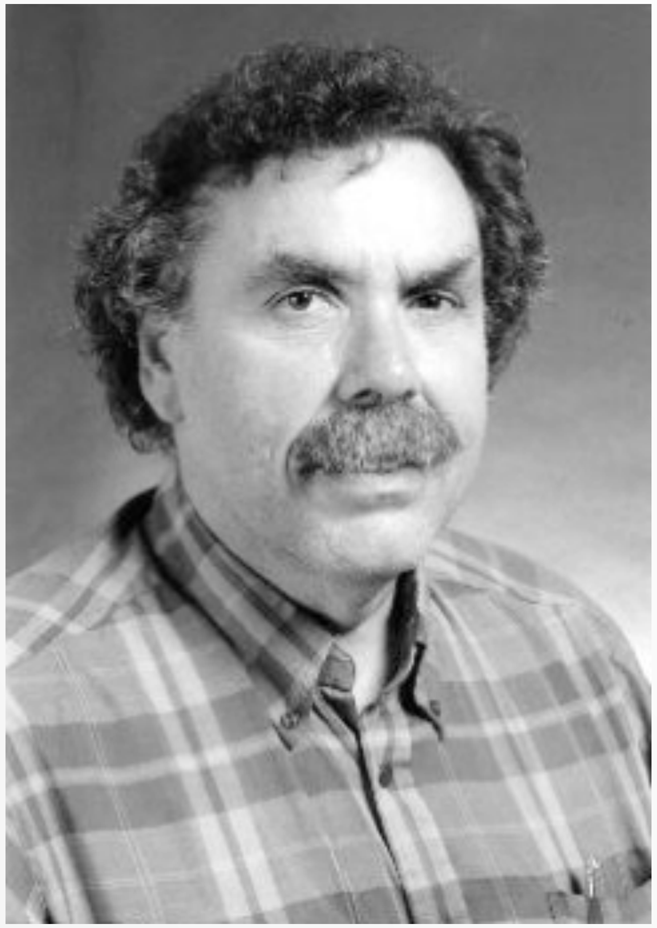


Fig. 4 LLS density as a function of redshift. The sample of 34 QSOs showing 18 LLS all with $z_{\rm LLS} < z_{\rm em}$ are included. The two QSOs with $z_{\rm LLS} > z_{\rm em}$ are excluded. Crosses indicate $\hat{\lambda}(\langle z_{\rm LLS}\rangle)$, the density of LLS per unit z, per QSO with 1σ asymptotic error bounds given by equation (10). $\langle z_{\rm LLS}\rangle$ 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 $z_{\rm em}$ and leaves at $z_{\rm LLS}$, or $z_{\rm min}$ if no LLS was observed.

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
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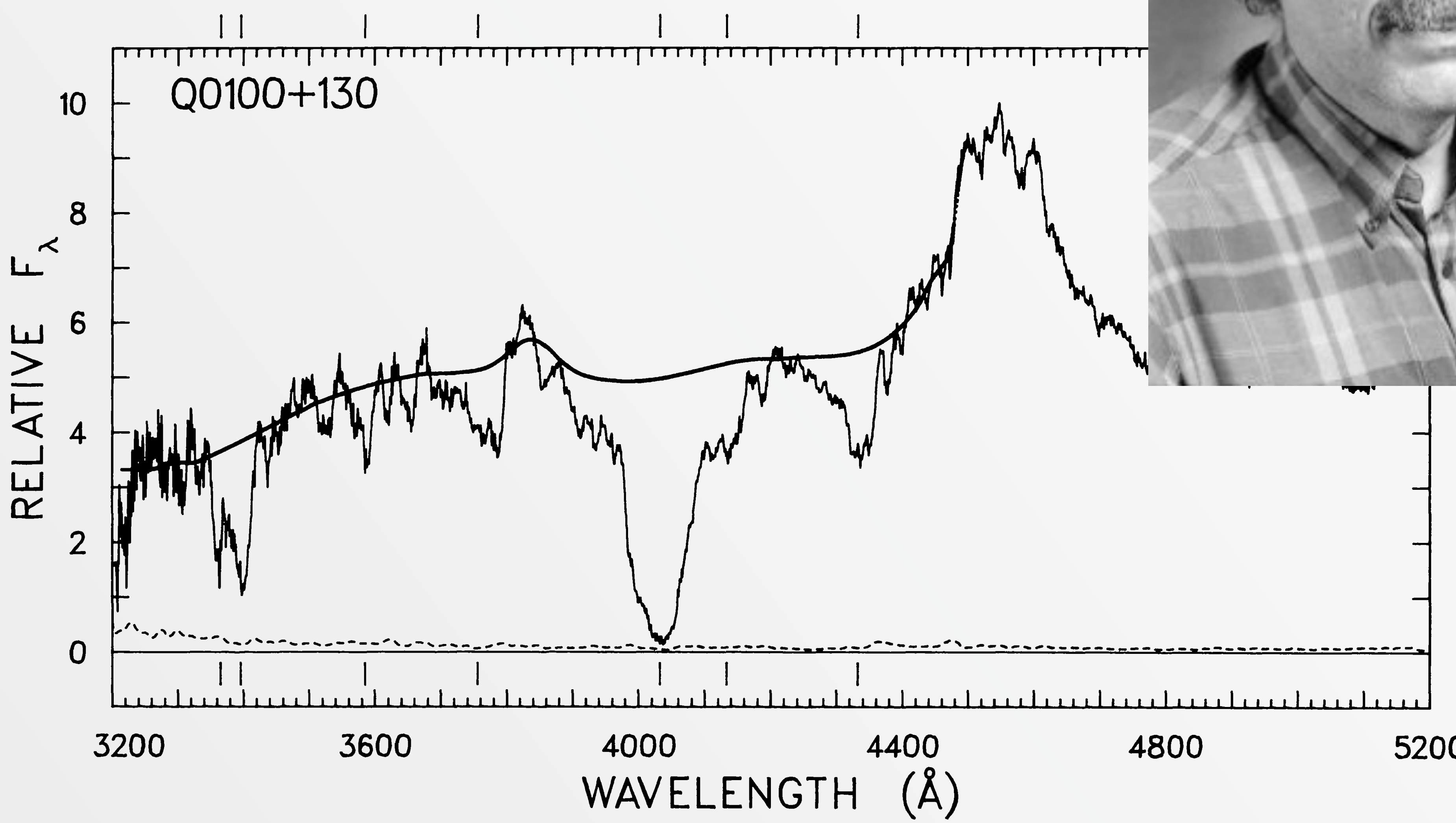
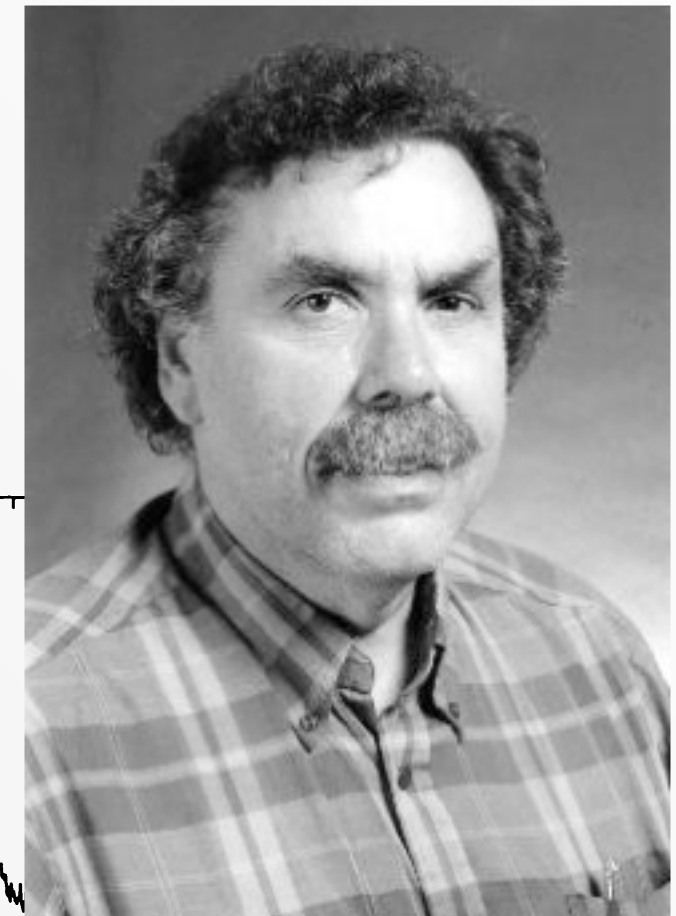
Space Telescope Science Institute

AND

HARDING E. SMITH AND ROSS D. COHEN
University of California at San Diego

Received 1985 August 1; accepted 1985 December 2





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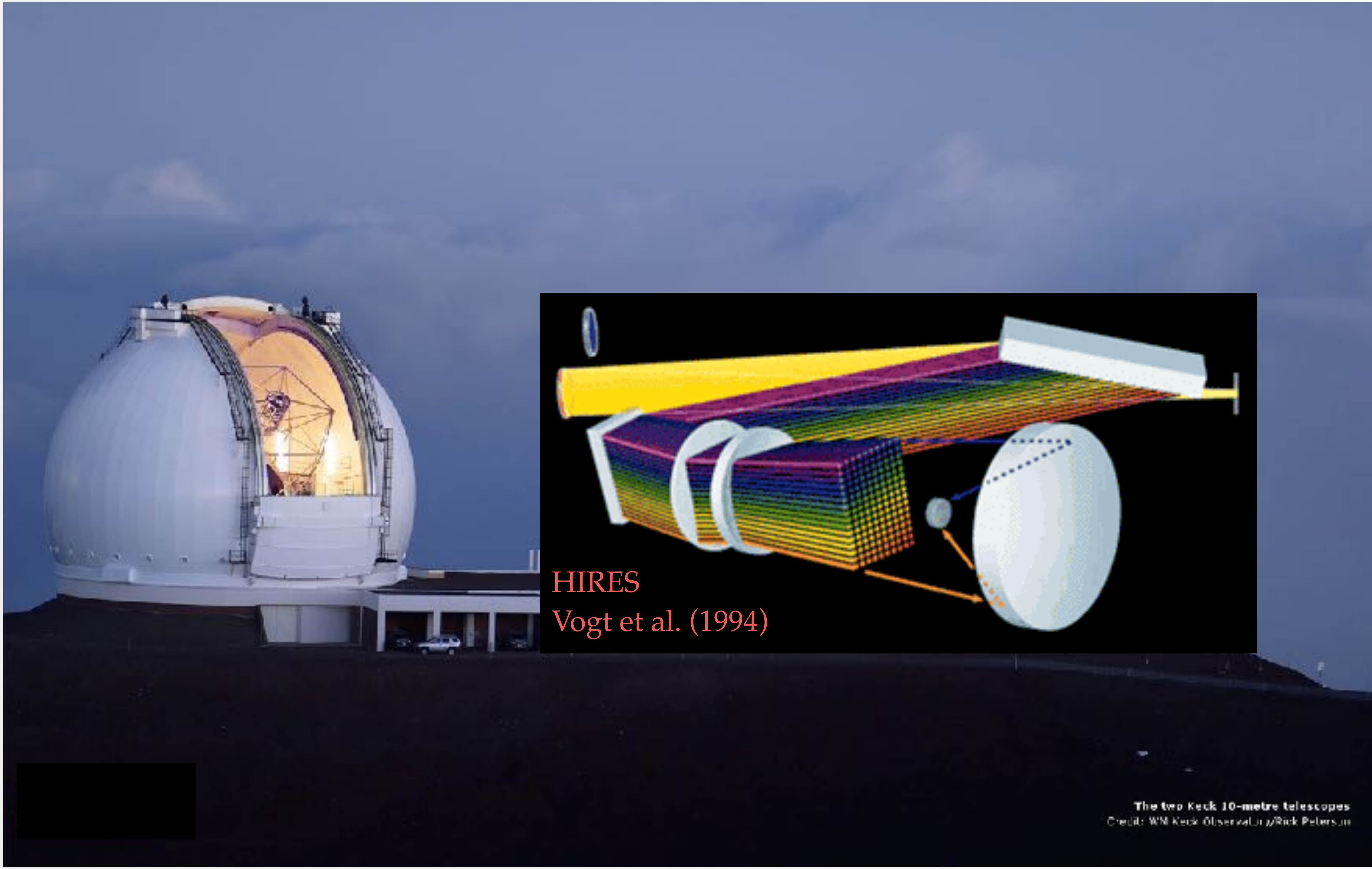
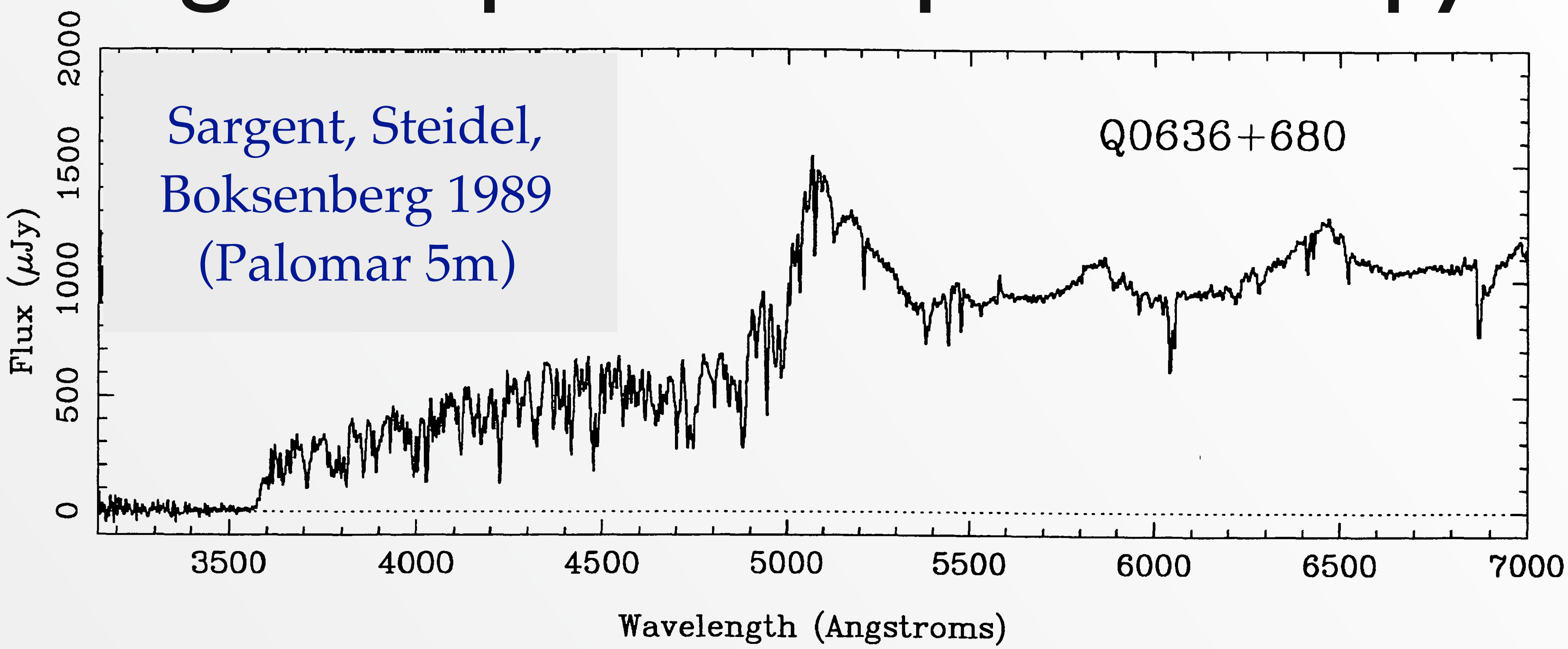
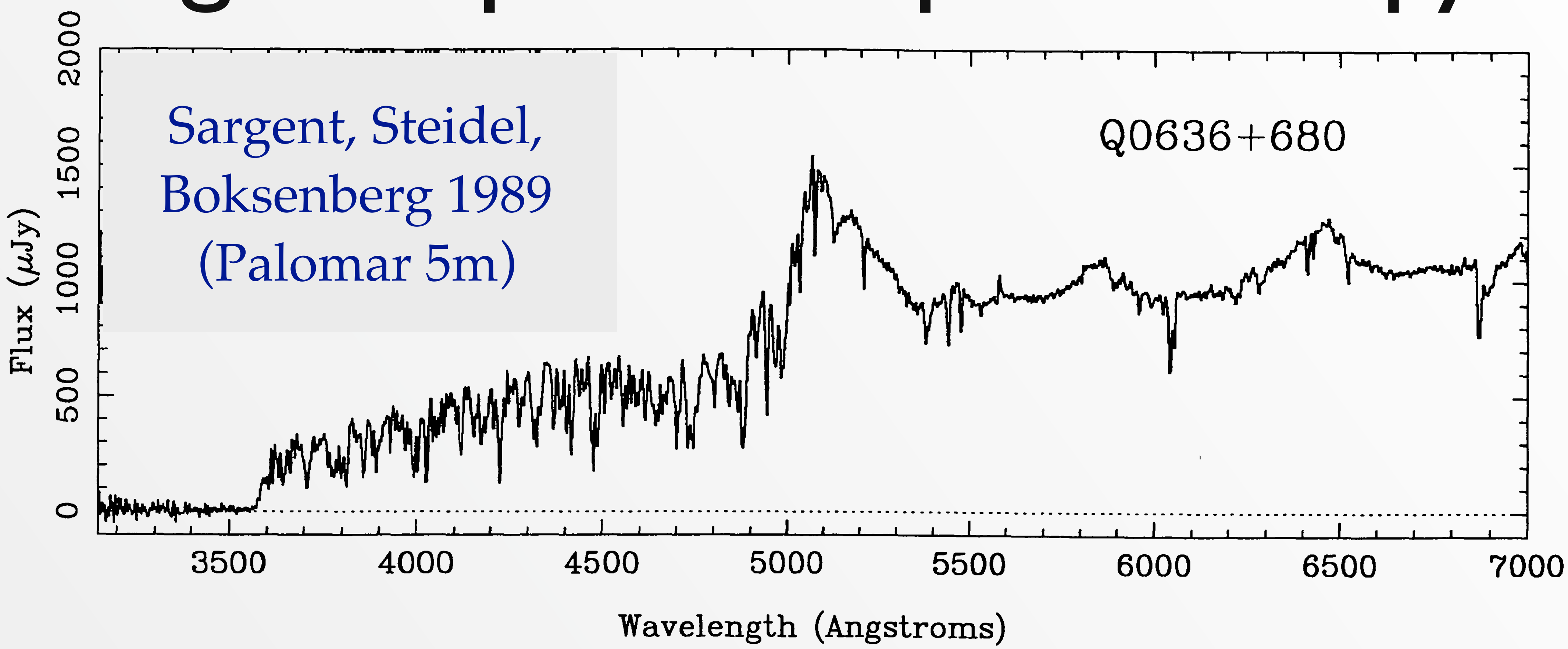
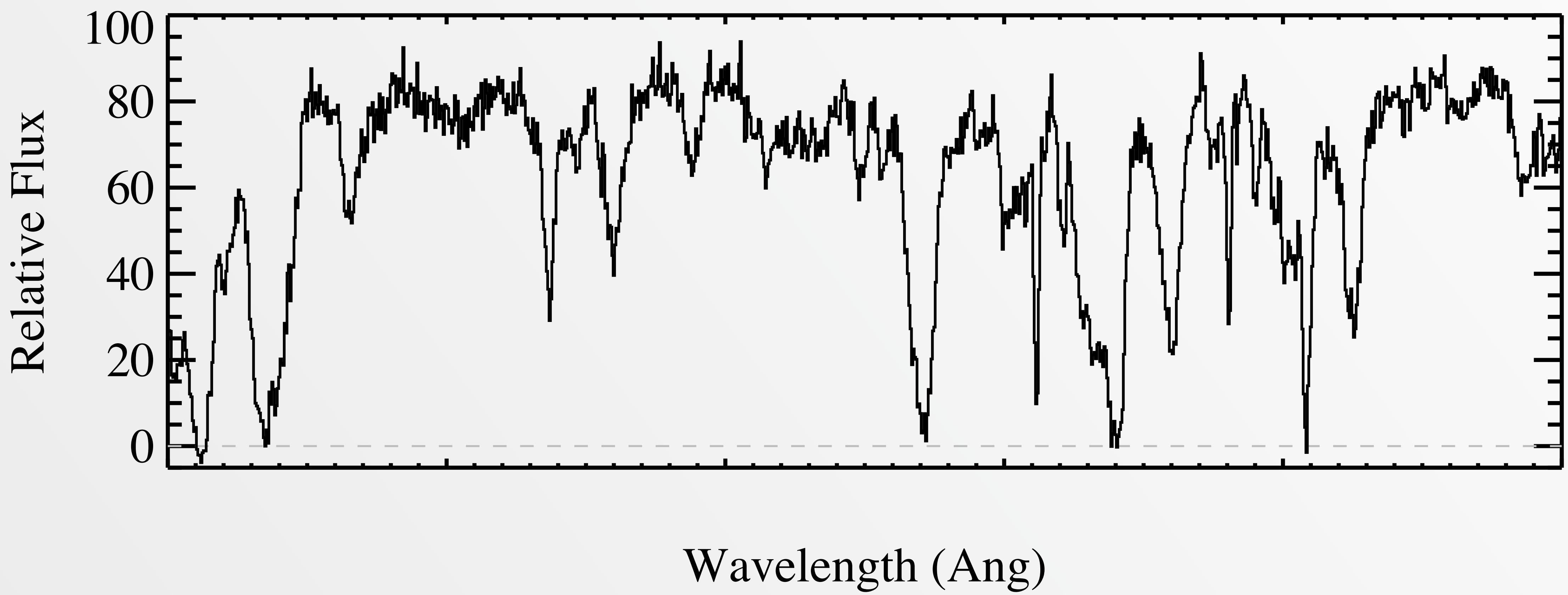


High Dispersion Spectroscopy



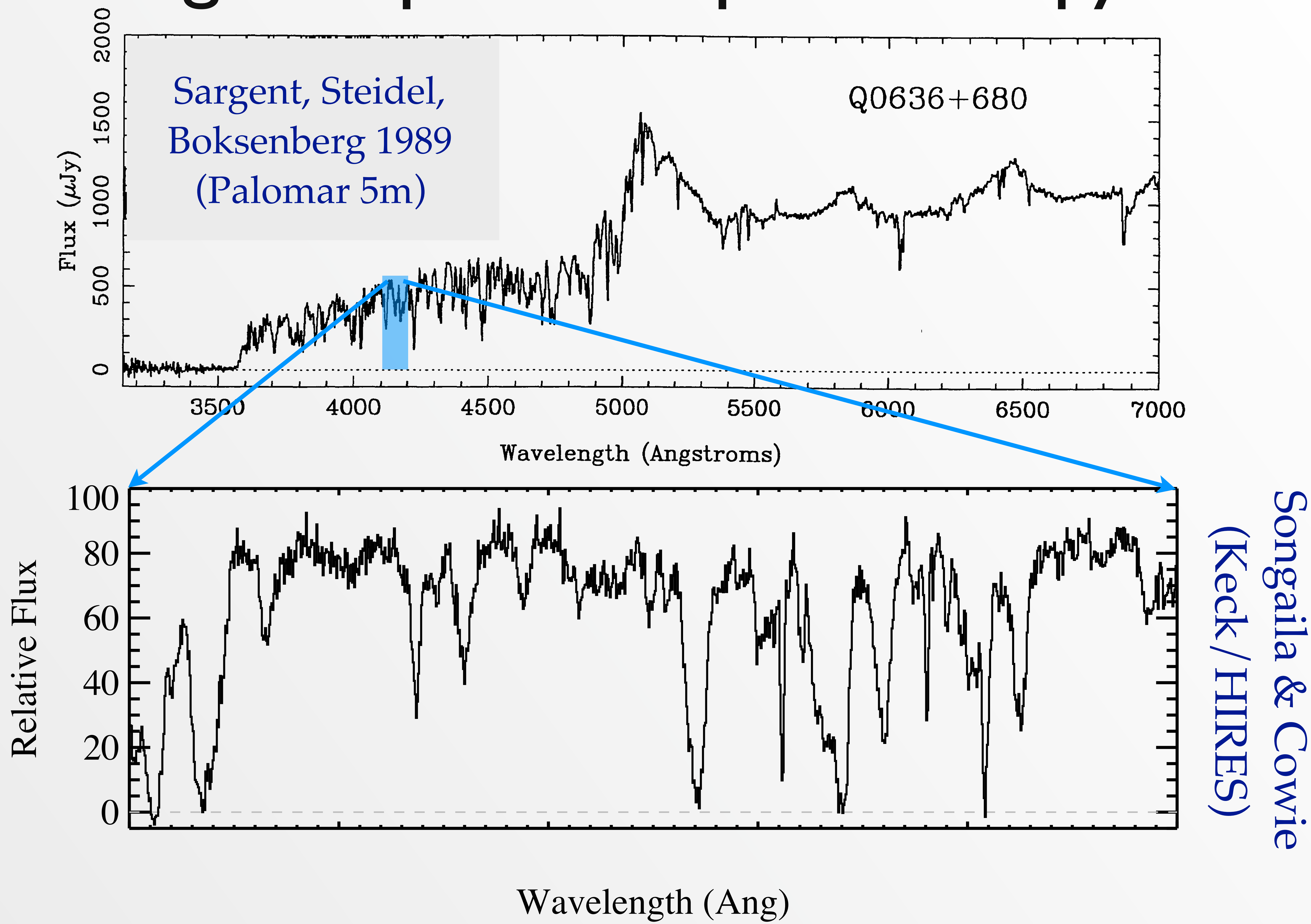
High Dispersion Spectroscopy





Songaila & Cowie
(Keck/HIRES)

High Dispersion Spectroscopy



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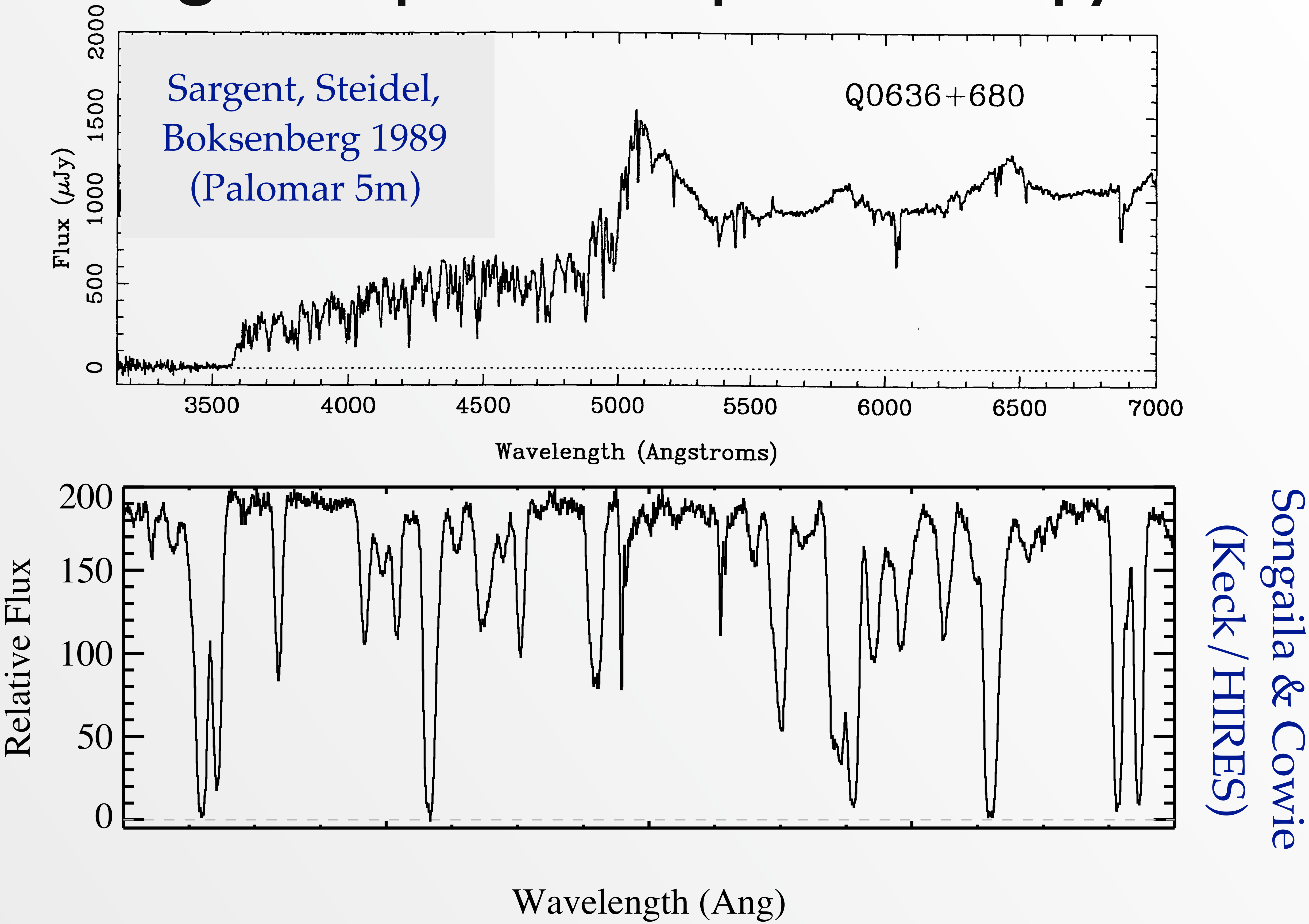

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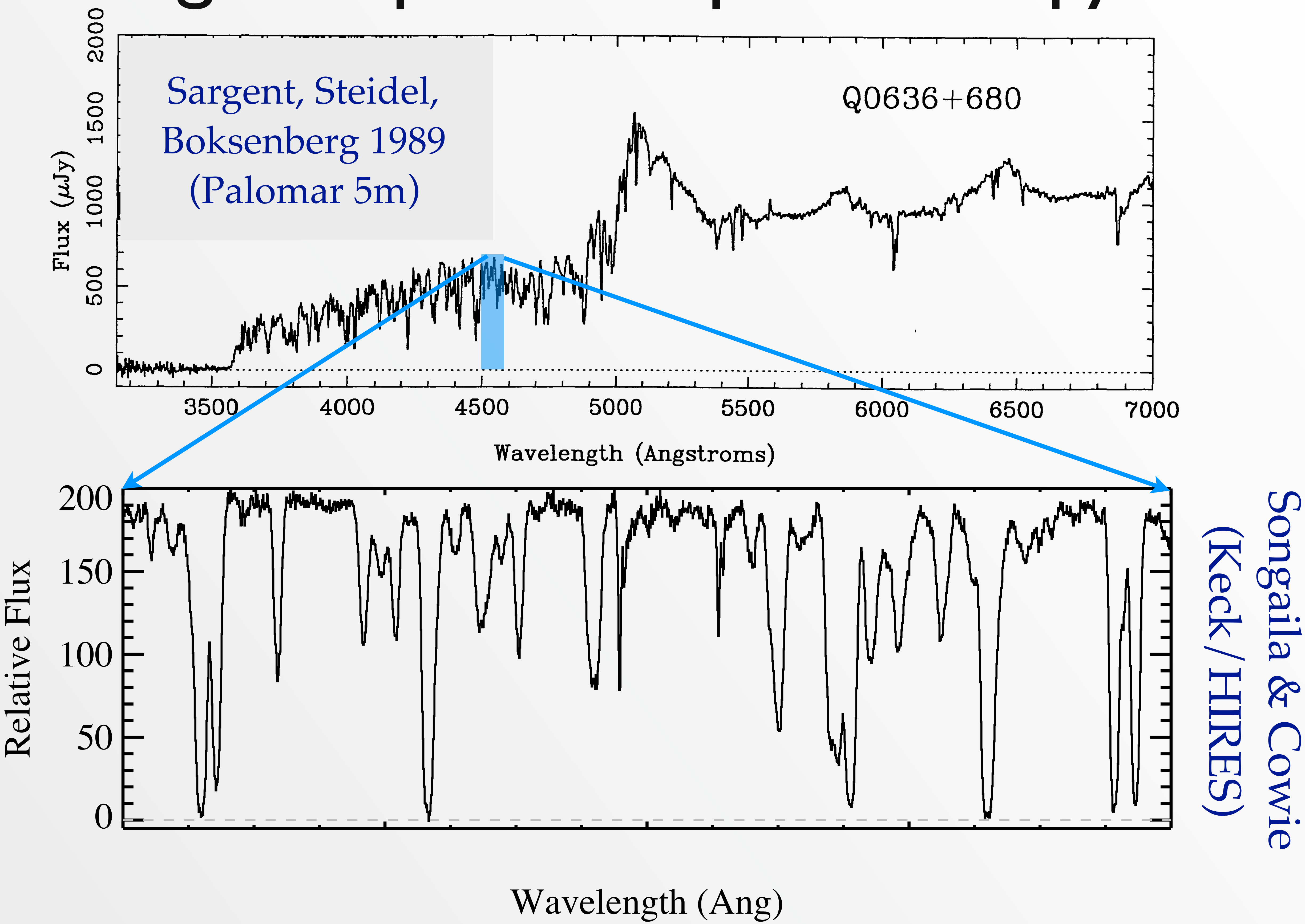

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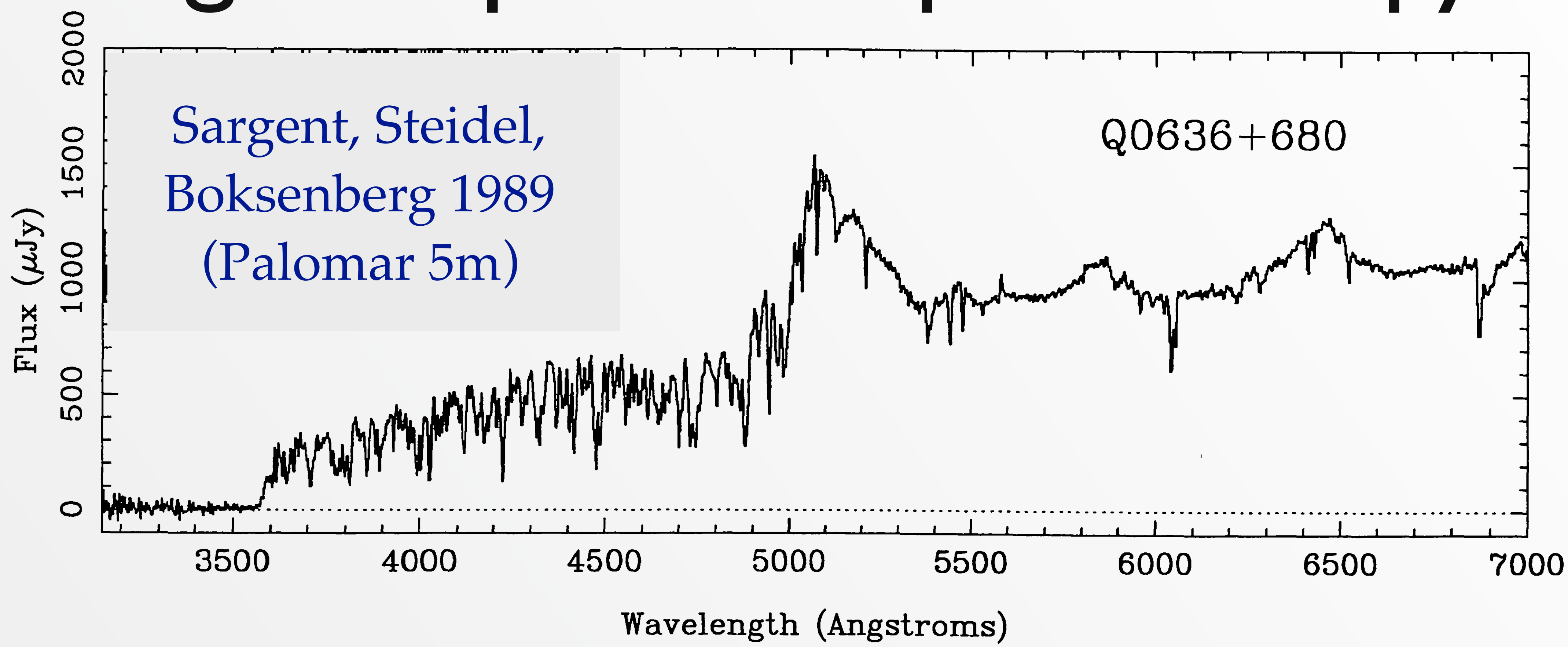

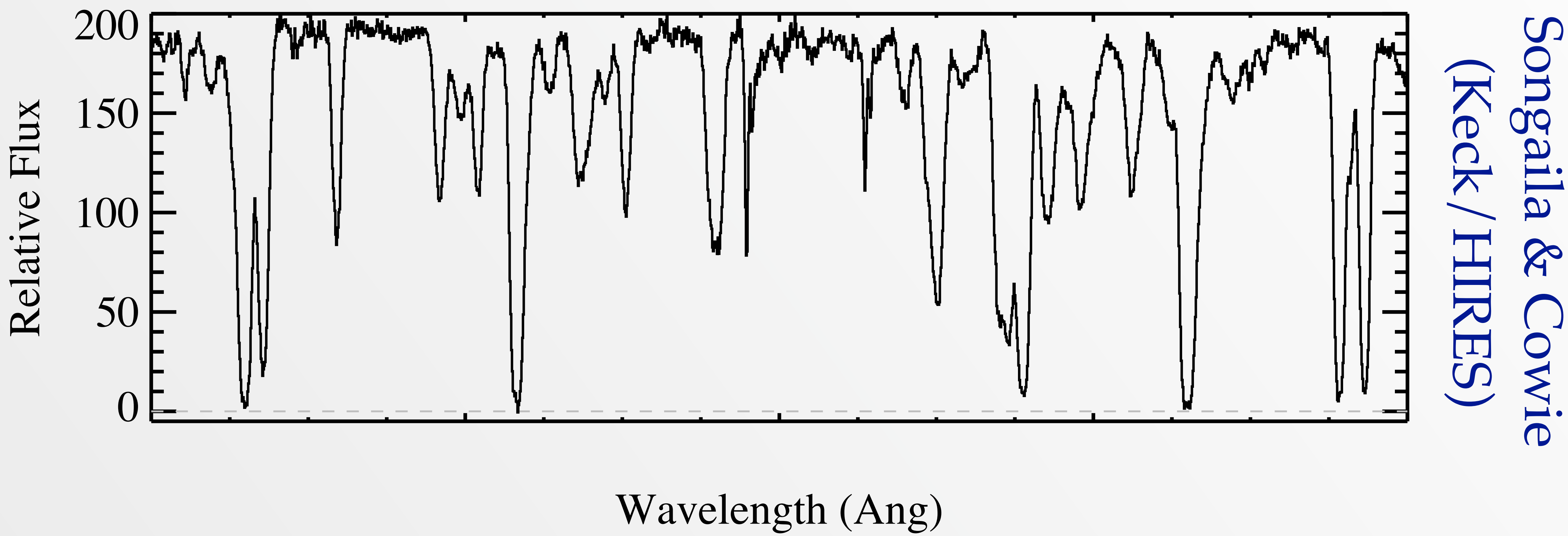

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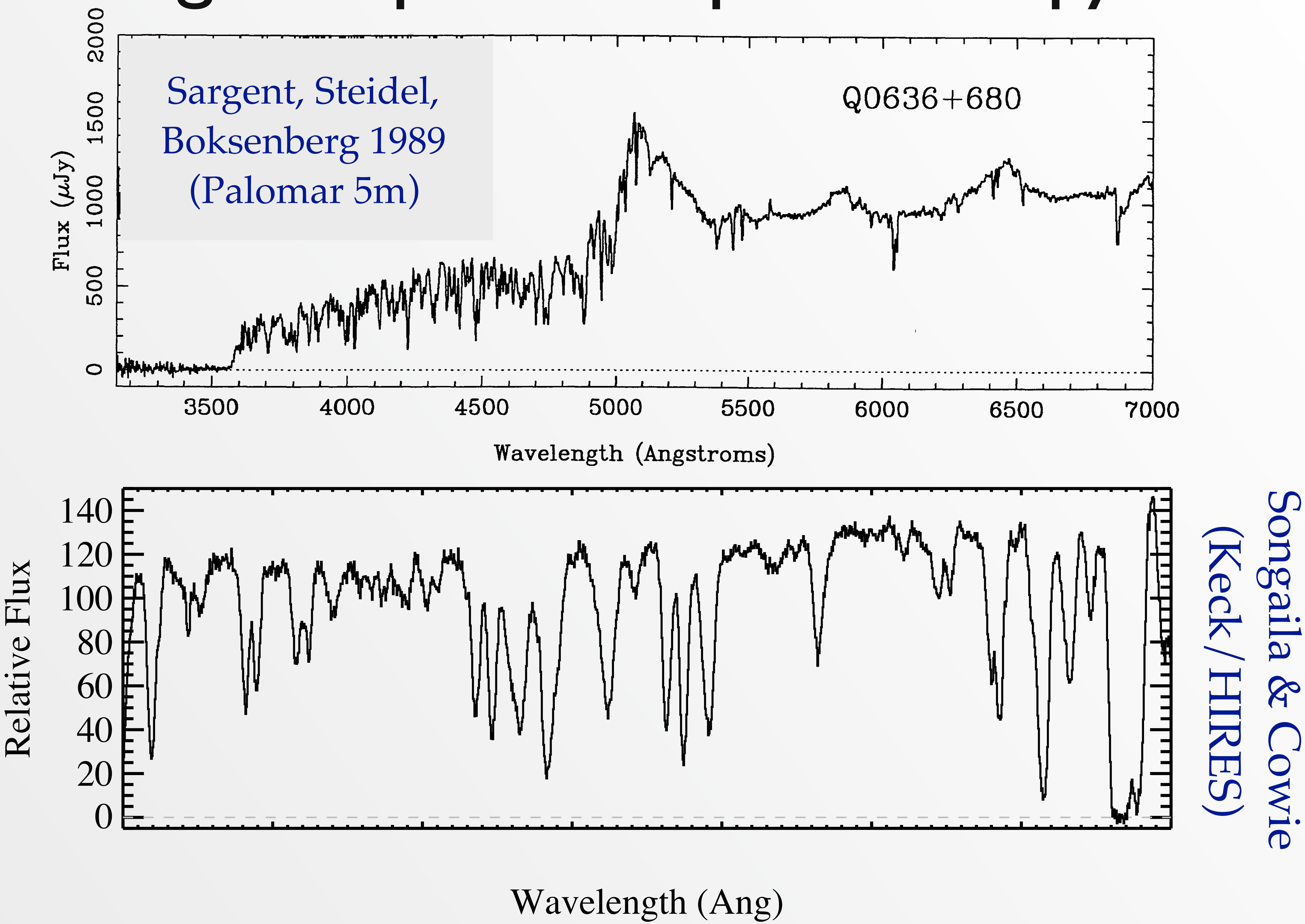

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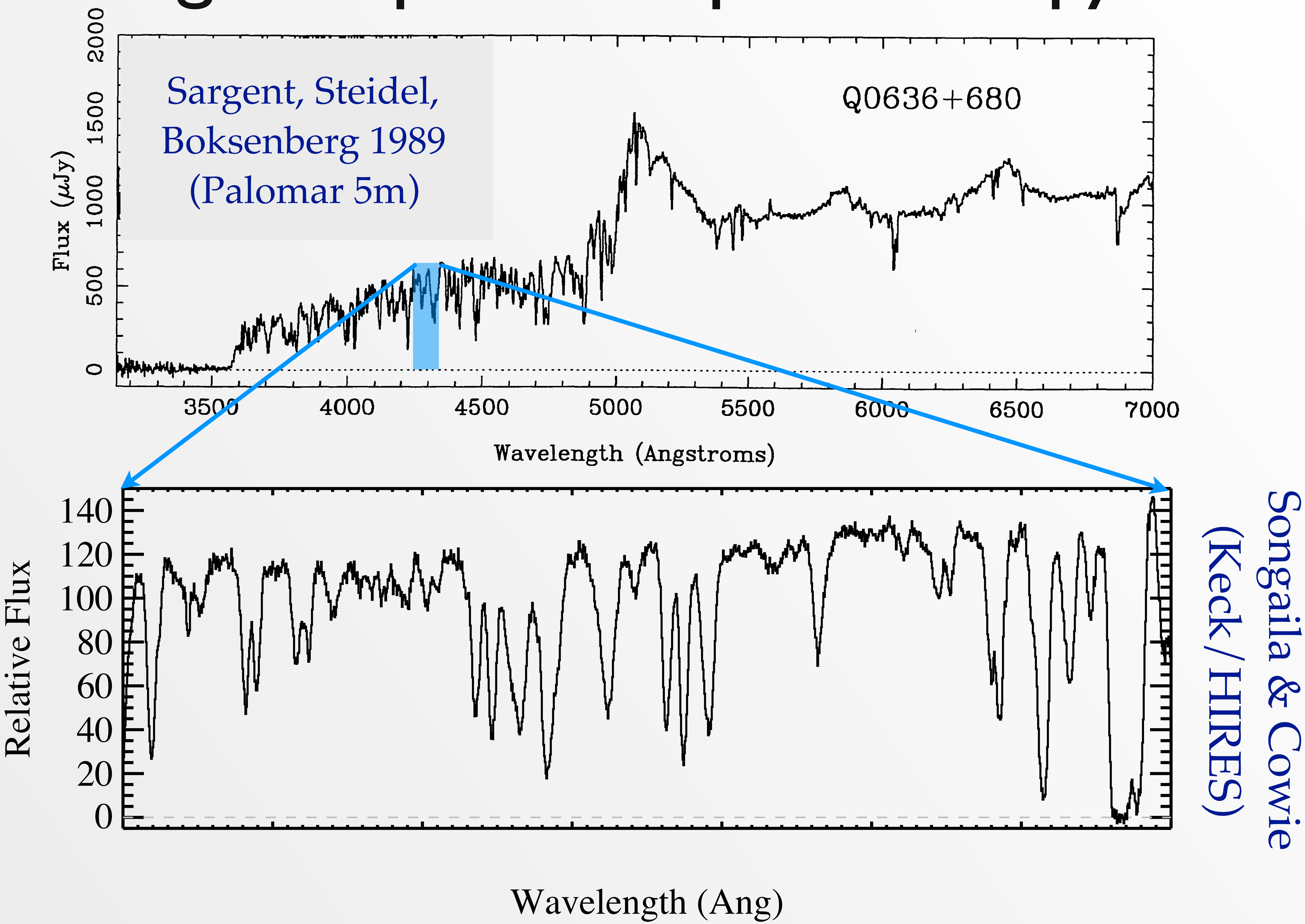
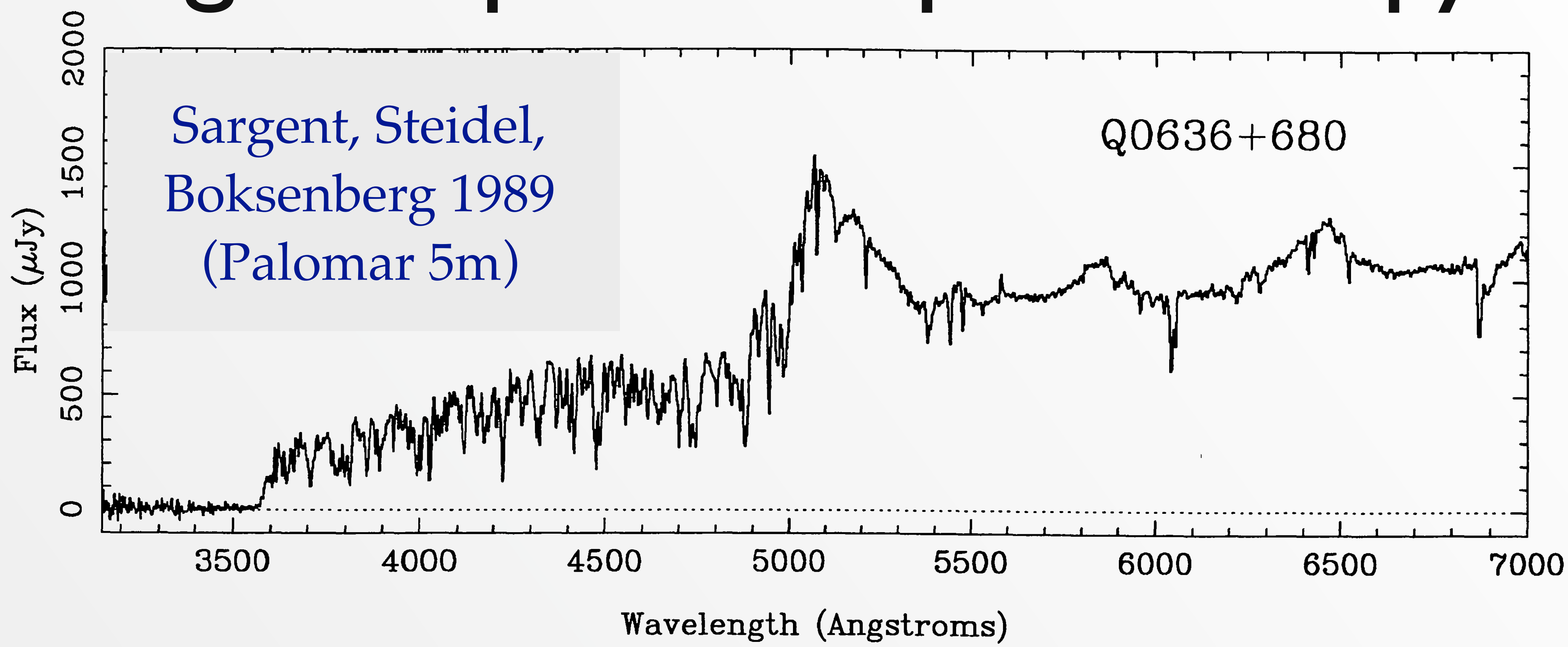
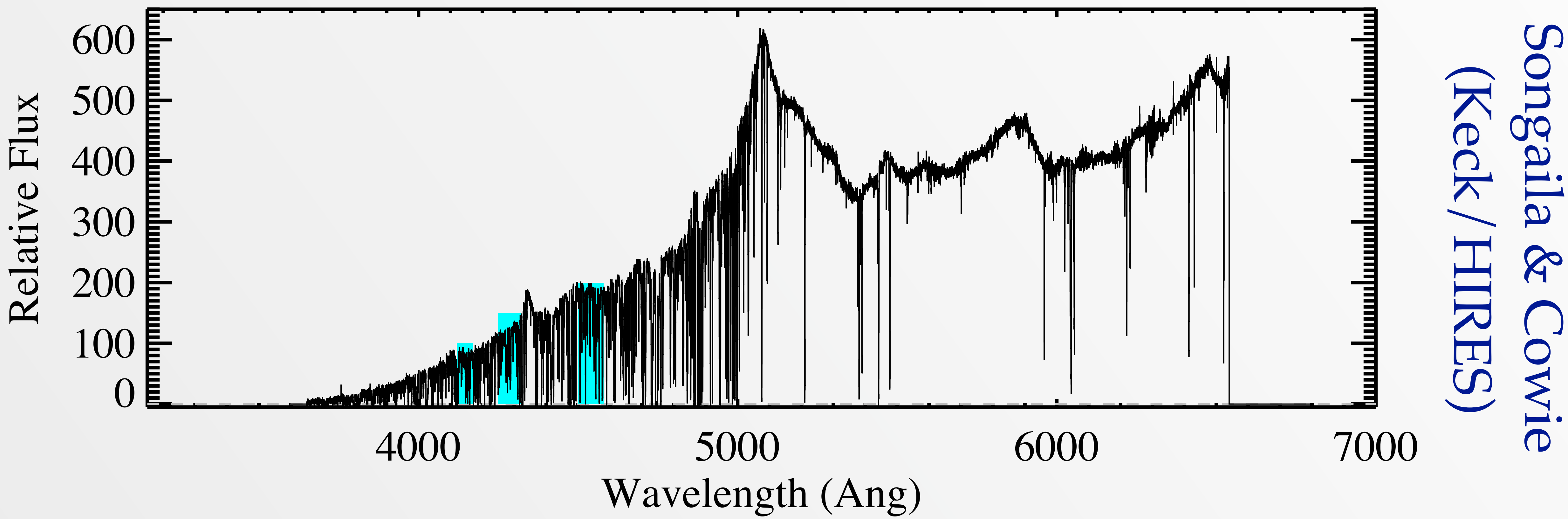
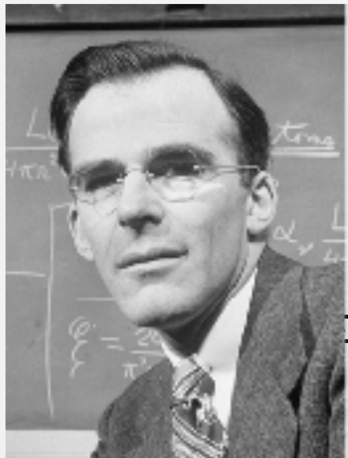


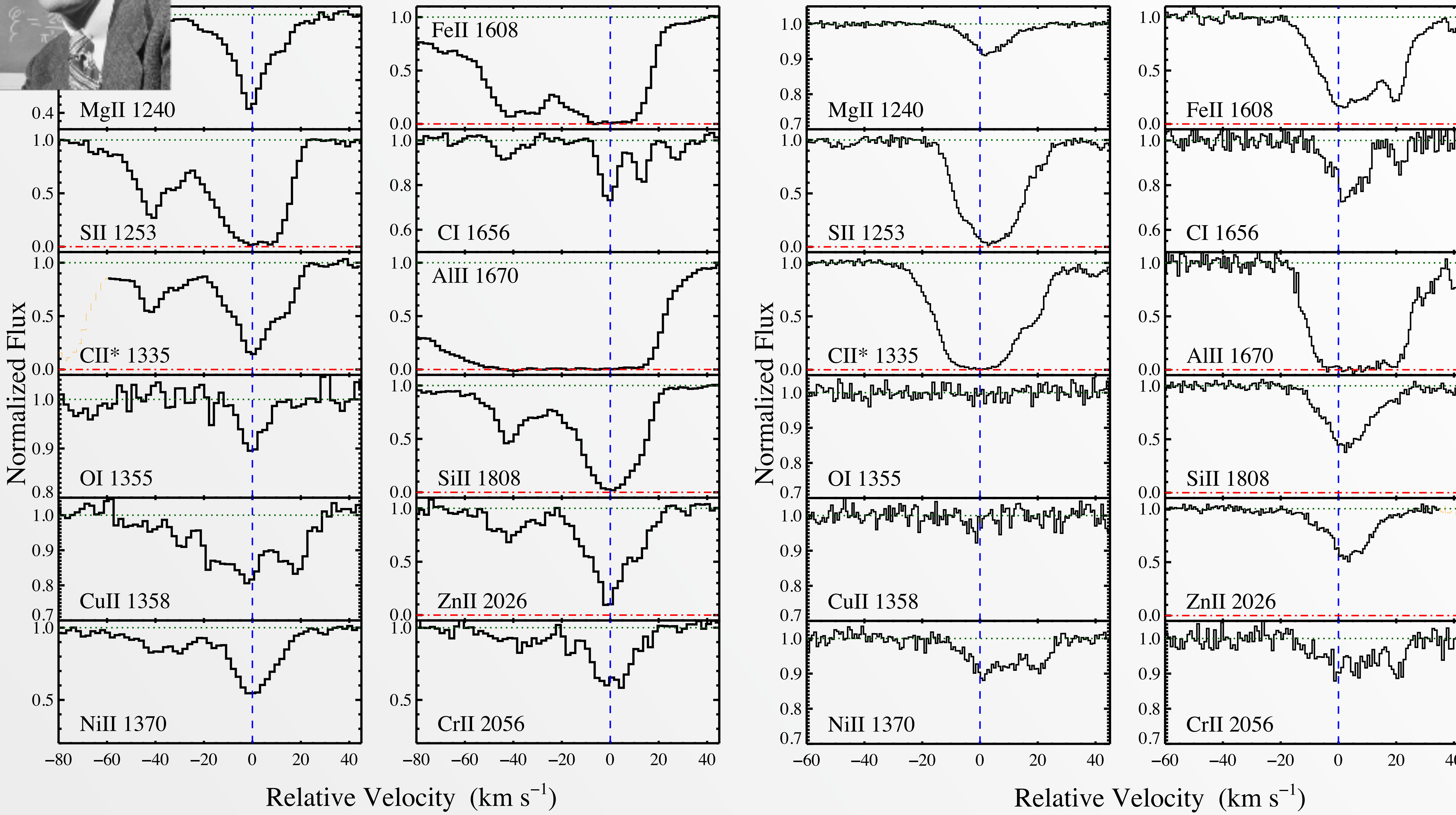
High Dispersion Spectroscopy





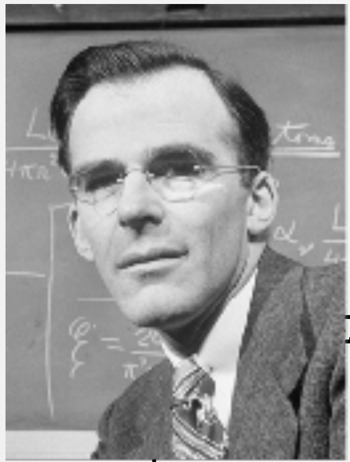
The Interstellar Medium

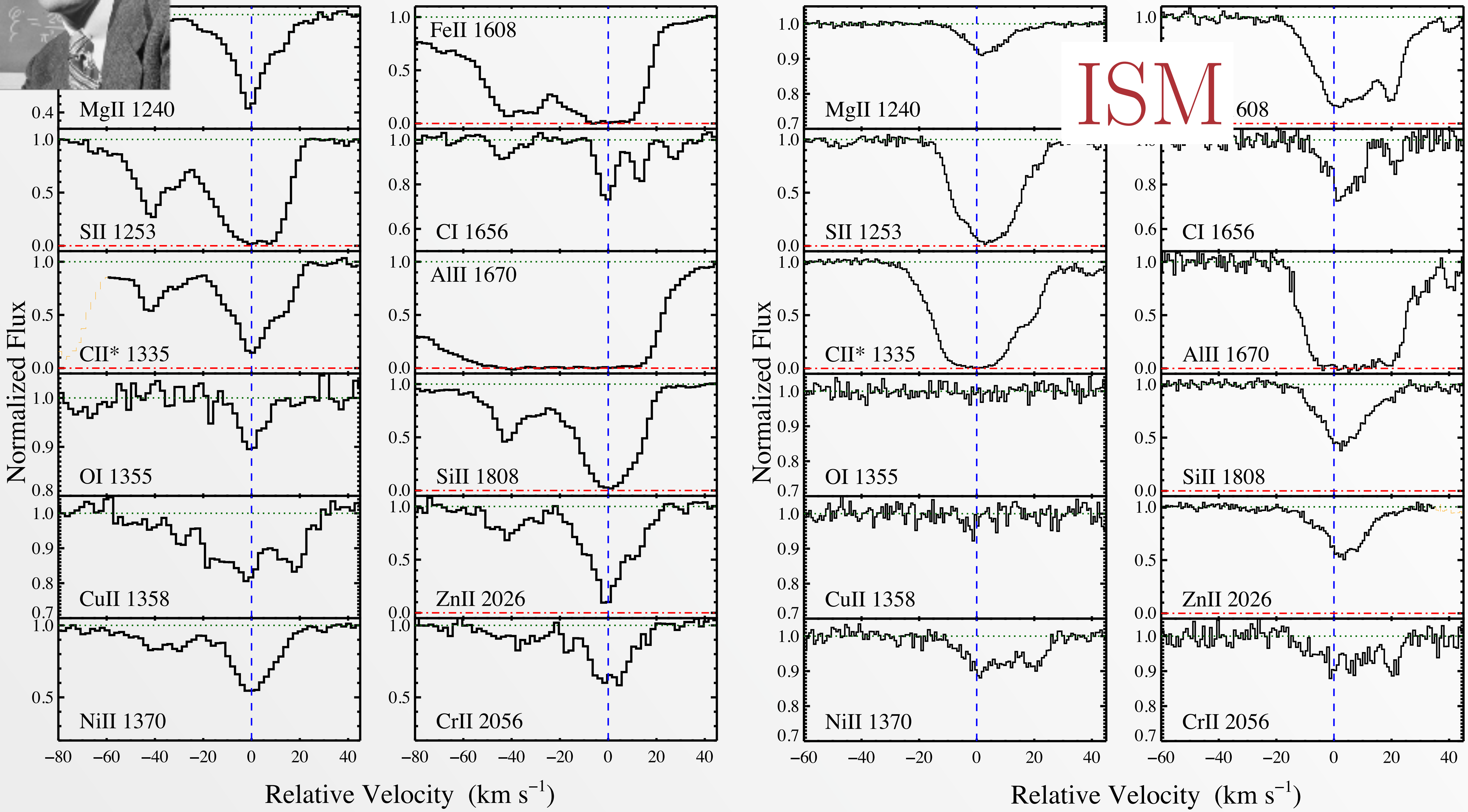




Scientists of the ISM pioneered many of the techniques in the true UV before we applied them to the IGM and distant galaxies

The Interstellar Medium





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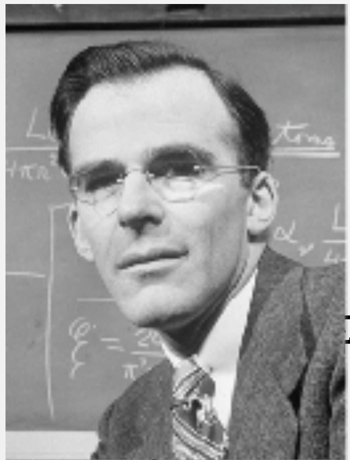
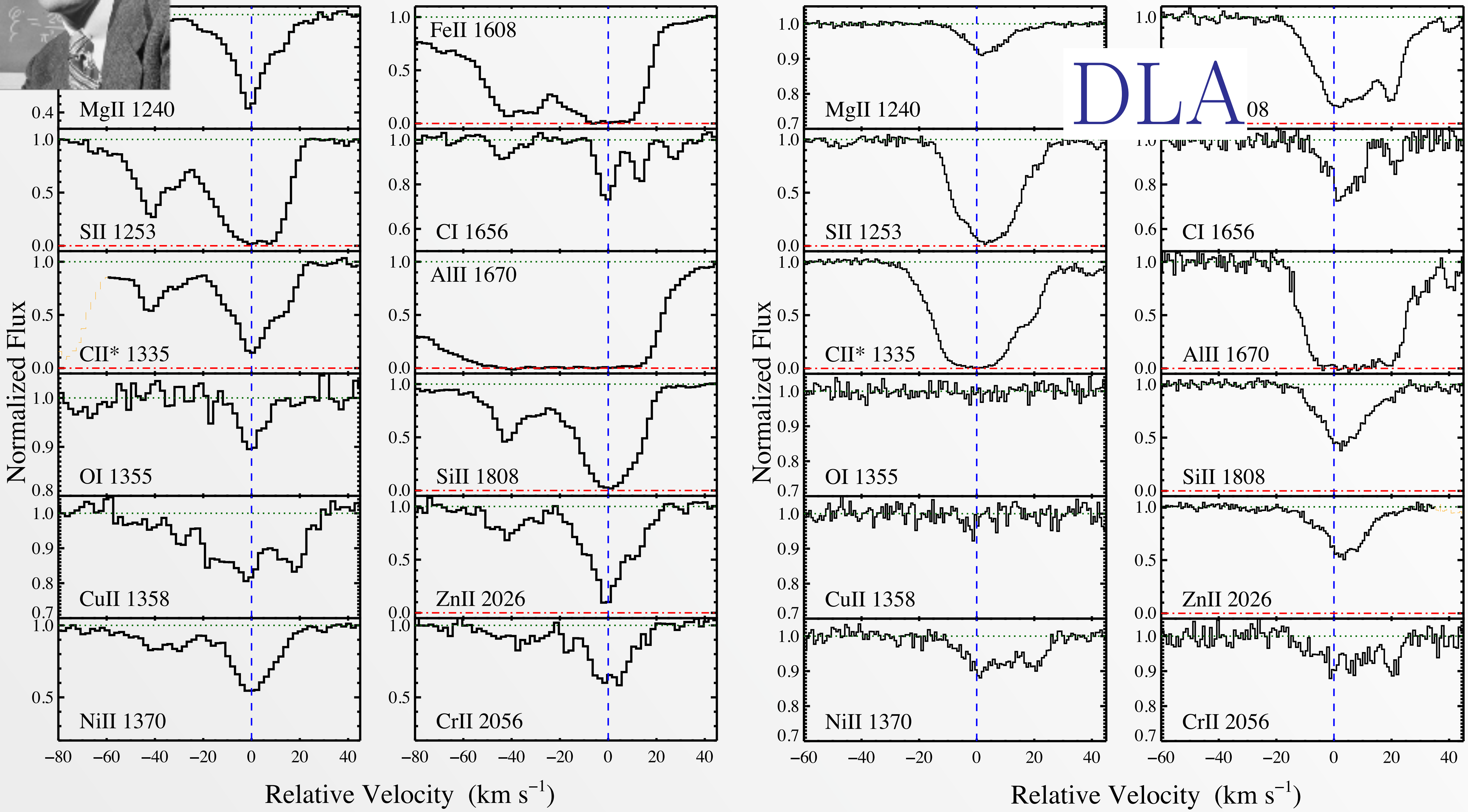


The Interstellar Medium



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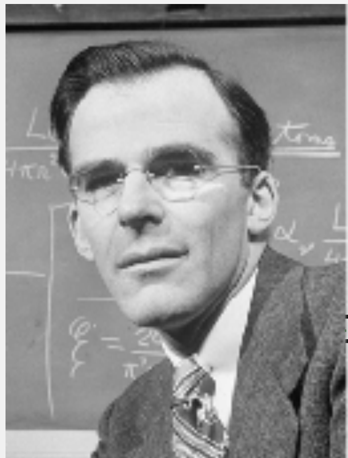
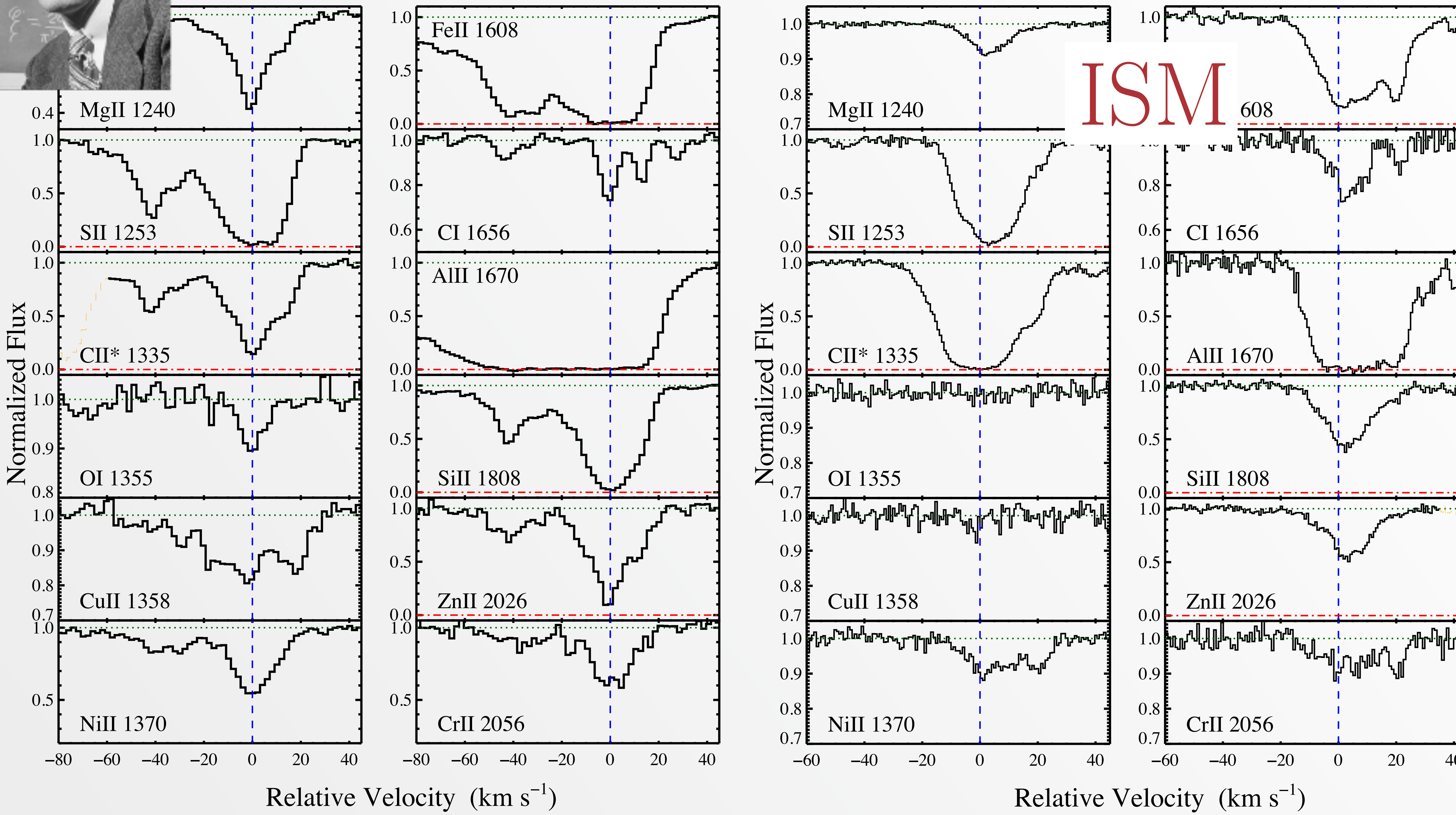
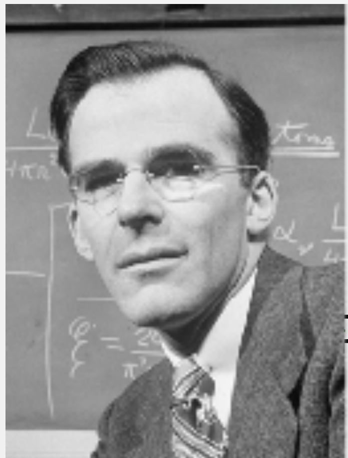
The Interstellar Medium

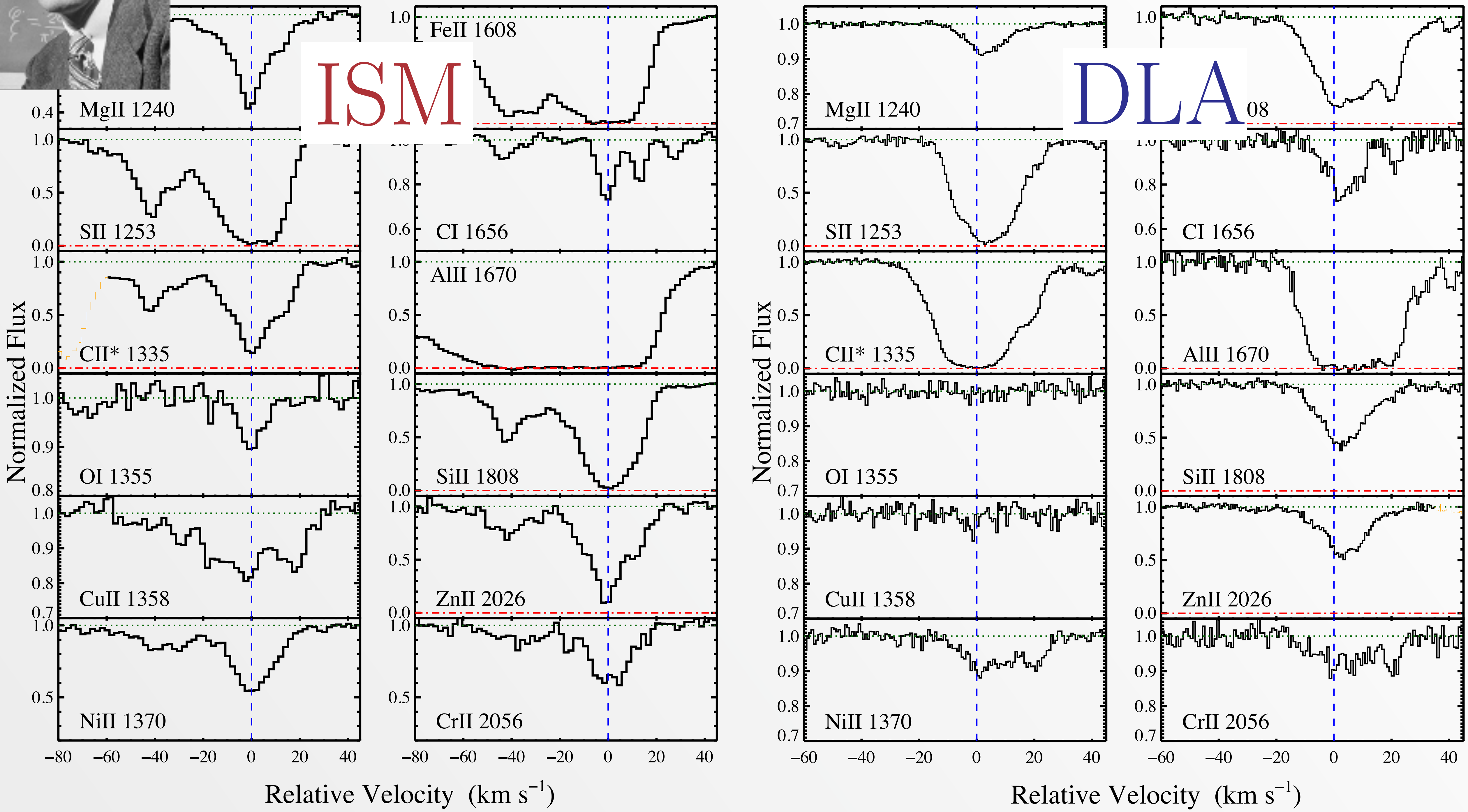




Scientists of the ISM pioneered many of the techniques in the true UV before we applied them to the IGM and distant galaxies



The Interstellar Medium



Scientists of the ISM pioneered many of the techniques in the true UV before we applied them to the IGM and distant galaxies

The Cosmic Web Emerges

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

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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.

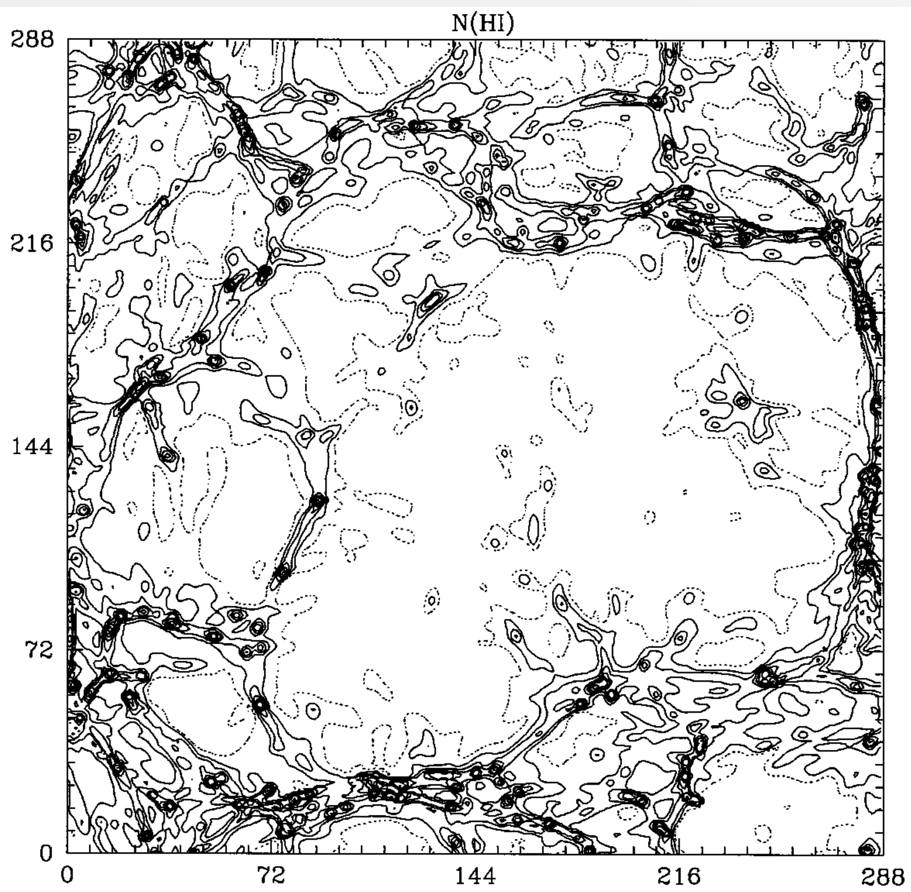


FIG. 2*c*

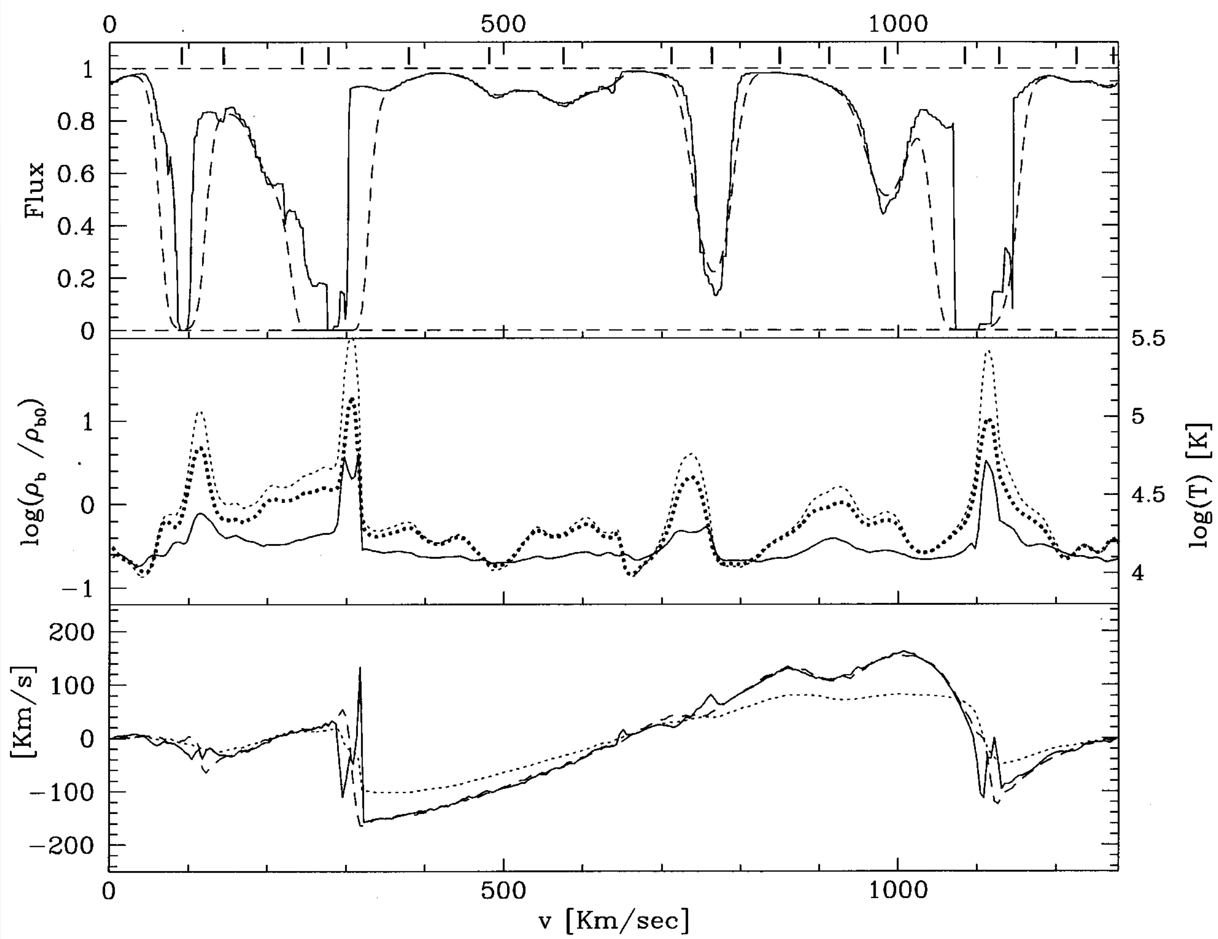
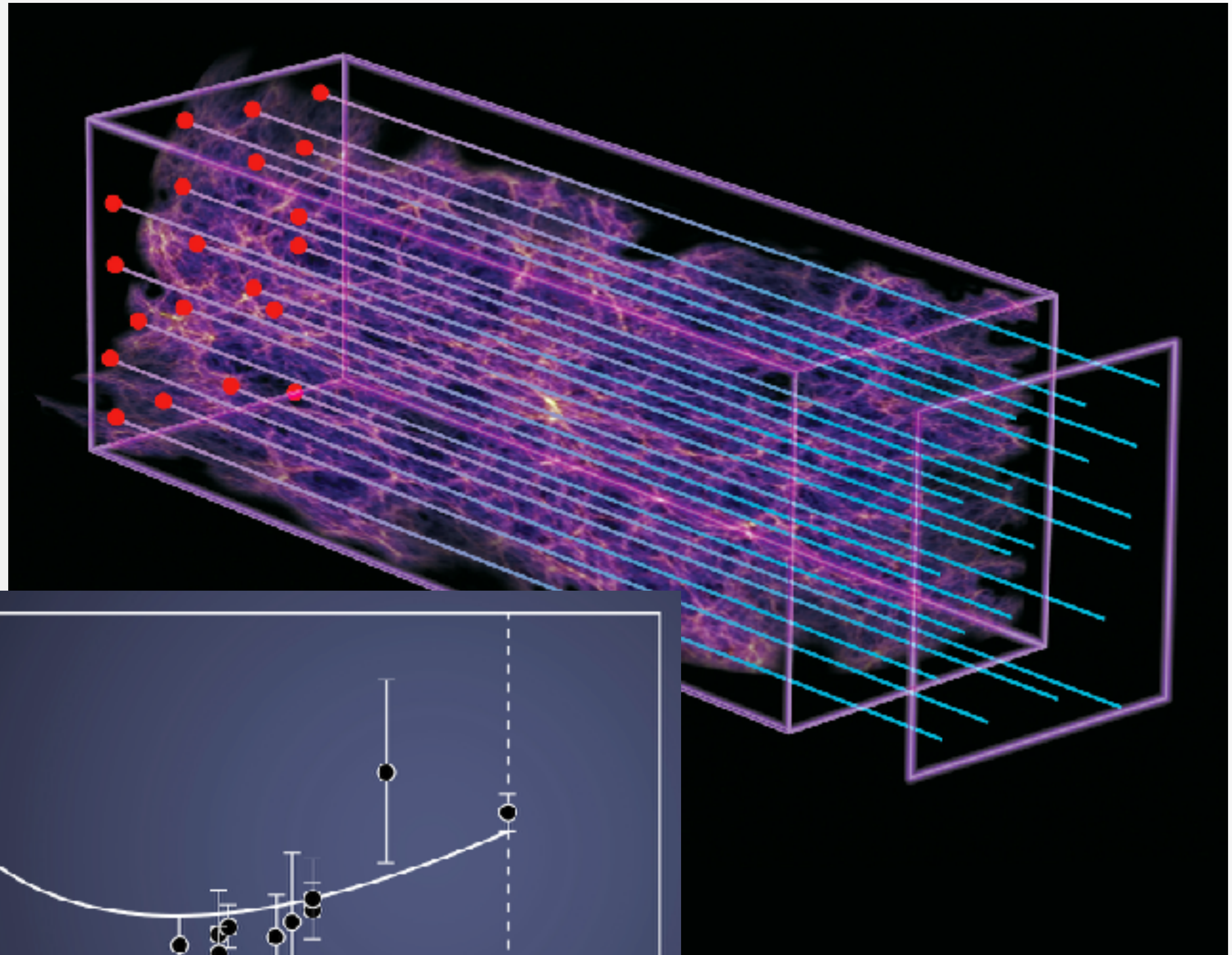
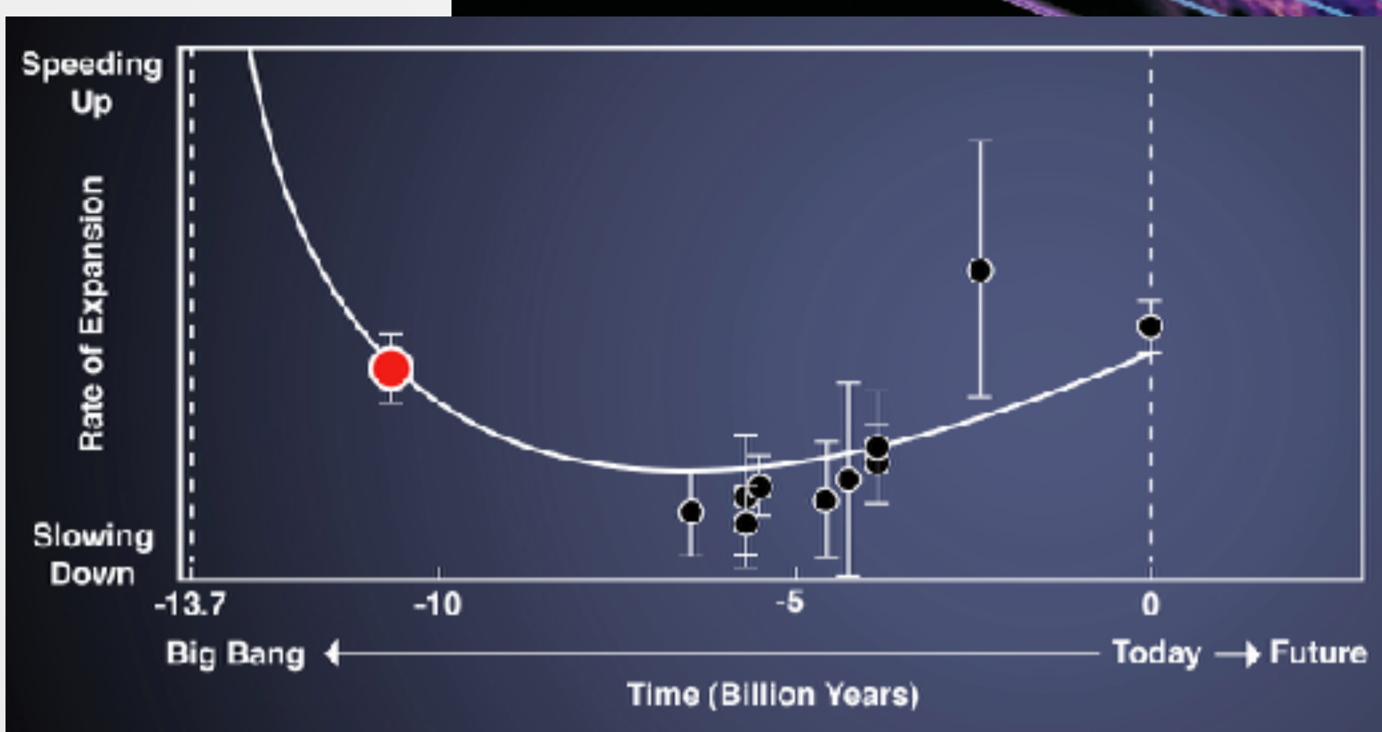


FIG. 6*c*

IGM as a Cosmological Tool

BAO





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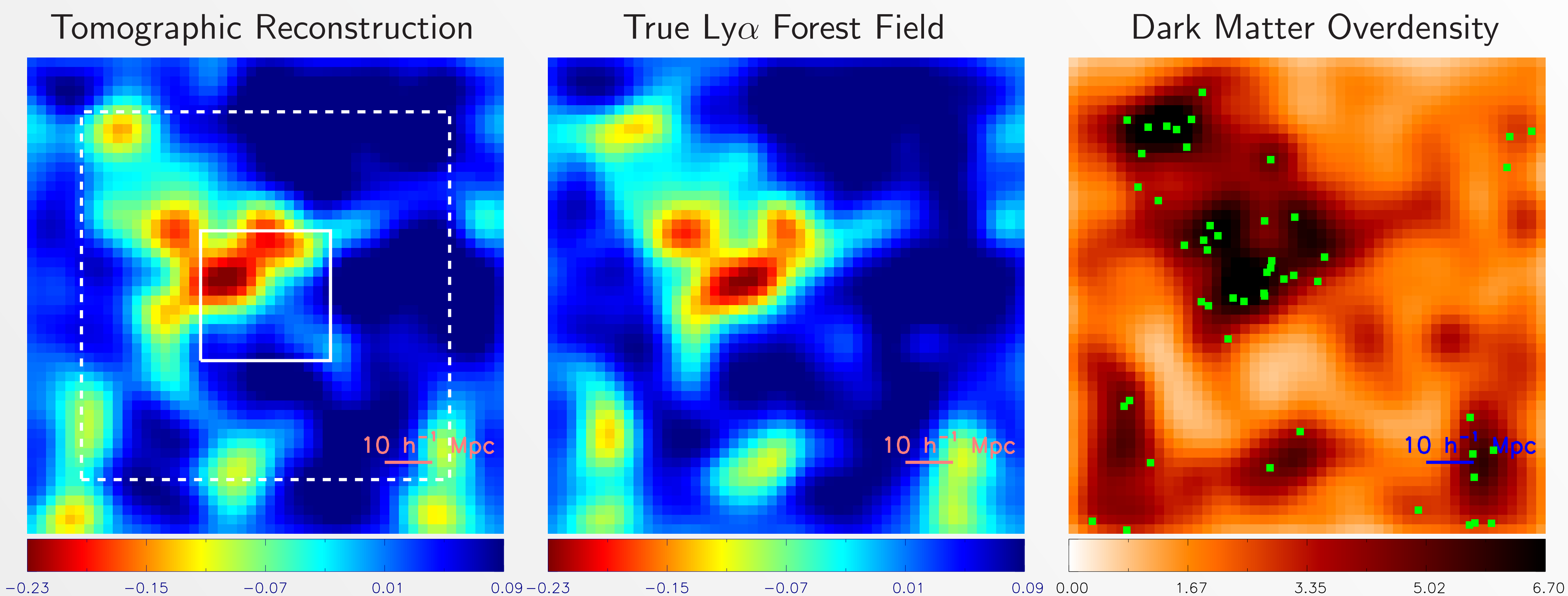

Tomography; Lee+ 2014