Current Research Work on the Evolution of Quasars and Their Relation to Galaxies

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Follow up on cosmology and bandpass effects

- Friendly suggestion from Prof. Longair
  - Do not just use the “recipe” formulae I discussed yesterday without studying them thoroughly
  - Work out the effects for yourself so that you understand them
  - This will help greatly in avoiding mistakes

Outline

- Review recent observational work on the evolution of quasars and their relation to galaxies
  - Searches for high-z quasars
  - Studies of the chemical evolution of gas in and around quasars
  - Observations of the reionization epoch of the universe
  - The origin and evolution of AGNs

(Things I would like to know)

- Consider three main research areas and questions:
  - How and when did the initial seed black holes of quasars/AGNs form?
  - How did these seeds grow into the supermassive black holes that we see in galaxies today?
  - What was the relation between the formation and growth of the black holes and the host galaxies in which they live? How do the black holes and galaxies affect each other as they both evolve?

A bit more elaboration

- Seeds of primordial black holes
  - Were they the remnants of the first, massive, Population III stars that formed in the universe? If not, how did the seeds form?
  - Related question: How did the reionization of the universe proceed?

Growth of Black Holes

- Our general picture is that supermassive black holes (SMBHs) grow by accreting matter through a surrounding accretion disk
  - How exactly does the matter from the host galaxy lose angular momentum and get into the accretion disk, and then get accreted by the SMBH?
  - How much matter is expelled during the accretion/jet process? What impact does it have on the host galaxy? (In the literature, this is called "feedback," which also includes the effects of the radiated energy)

Coevolution of SMBHs and Their Host Galaxies

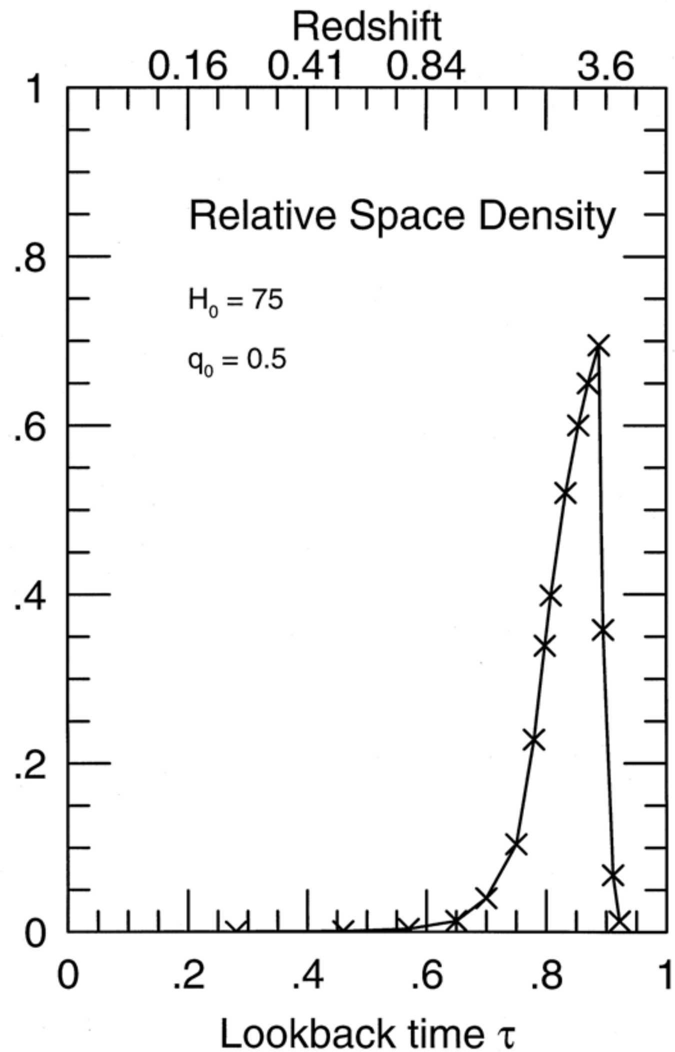
- Can we develop a self-consistent physical model of the various relations between the mass of the central SMBH and the surrounding bulge of the host galaxy?
  - e.g., the mass and velocity dispersion of the host galaxy, as we have been hearing at this conference
- Can we account for the growth history of SMBHs in the nearby galaxies we see today?

The Evolution of Quasar Activity

- In the introduction yesterday, I mentioned the first evidence for quasars having higher space density at higher redshift
- Here, let us review the current state of our knowledge, which is based on the massive surveys I described

Warren, Hewett, & Osmer 1994

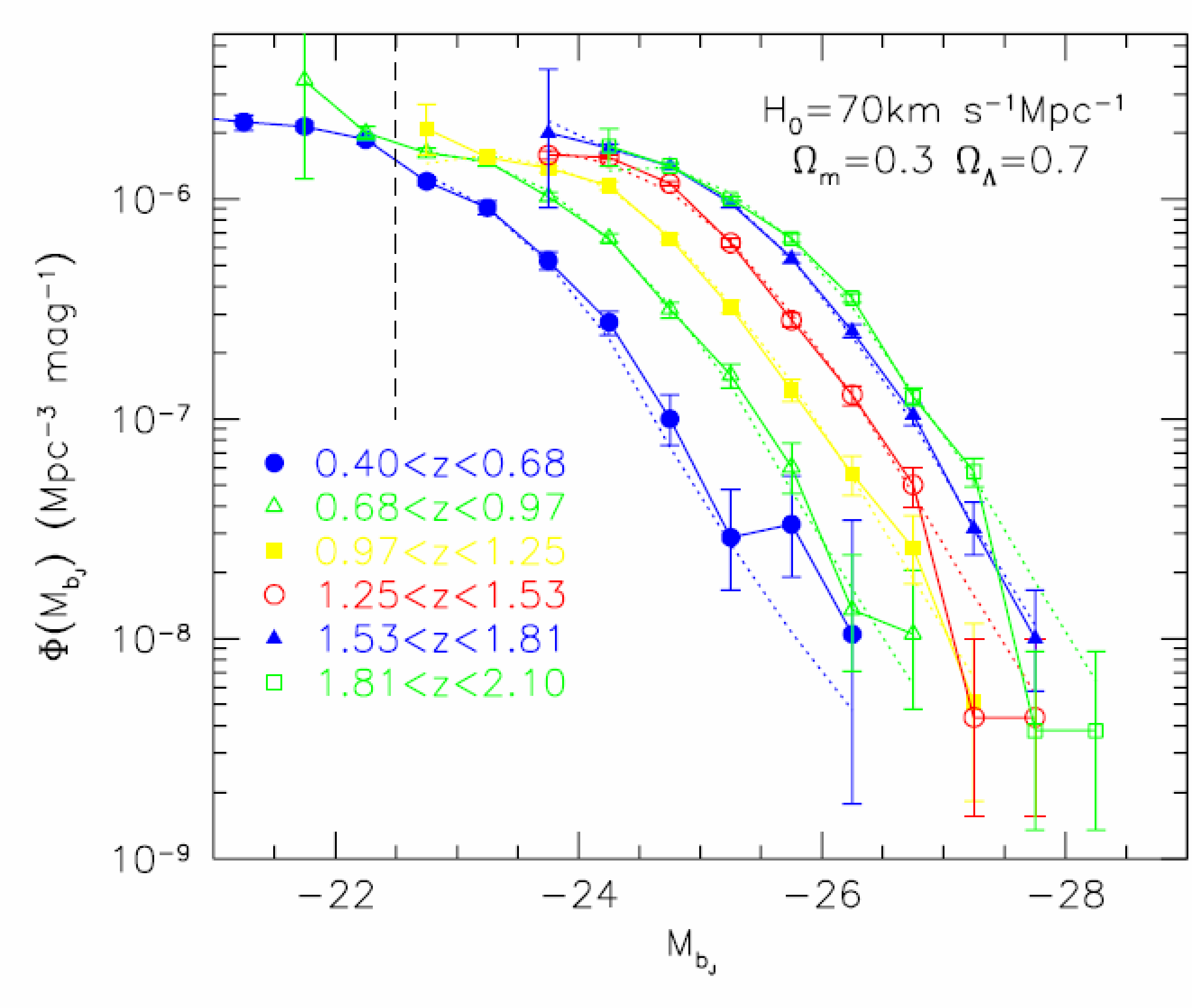
Schmidt, Schneider, & Gunn, 1995



2dF + 6dF QSO surveys Croom et al. 2004

- 24,000 QSOs, $16 < b_J < 20.85$, UVX selected, $0.4 < z < 2.1$, 700 deg^2
- Luminosity function well fit by luminosity evolution model

Croom et al. 2004, 2dF + 6dF QSO Surveys



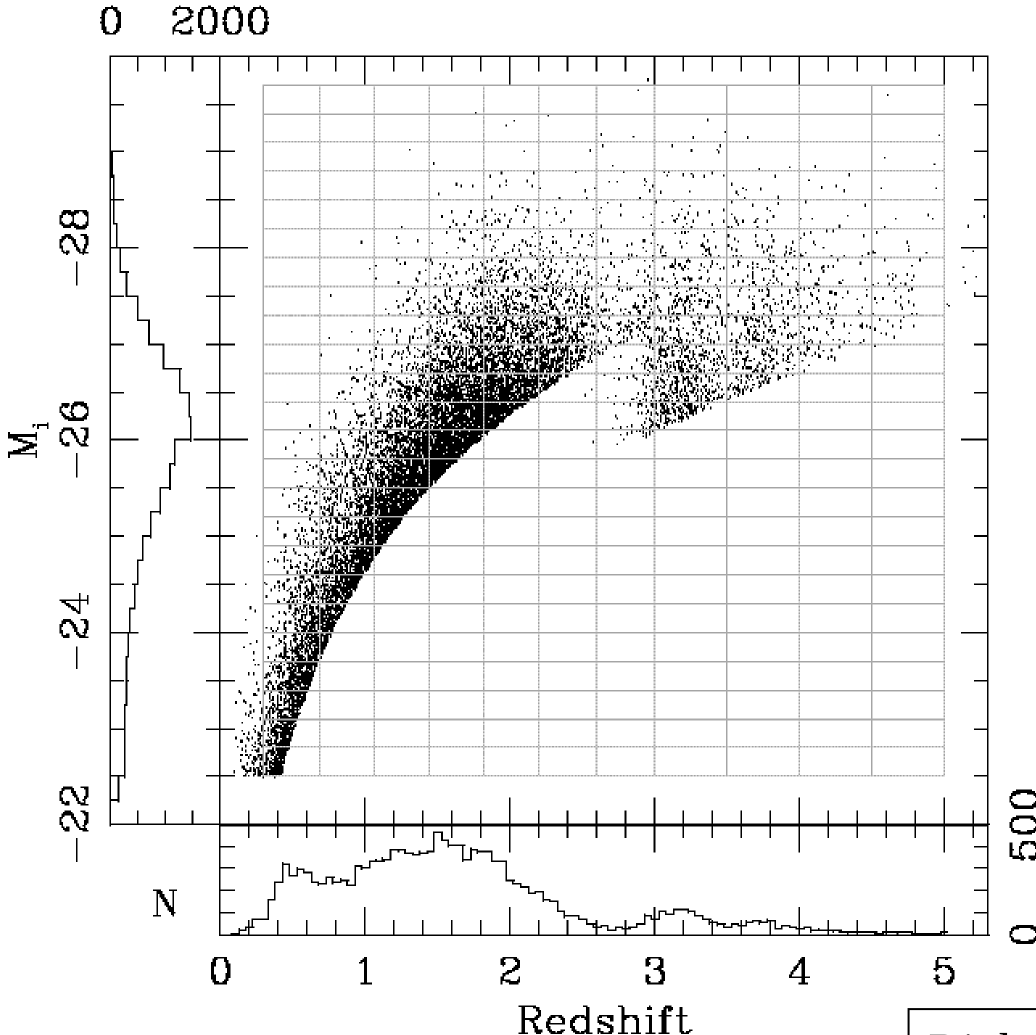
SDSS

Schneider et al. 2003, Fan et al. 2004

- Five filters, *u,g,r,i,z*, 17,000 quasars in DR1
- 6000 deg^2 now imaged in main survey (North Galactic Cap) to (*i, z)* of (22.5, 20.5)
  - 4600 deg^2 for the high-z survey
  - 11 quasars w. $z \approx 6$
  - 46 million objects, 23 million cosmic rays
- 270 deg^2 in SGP 1.5 mag deeper
- Search for *i* dropouts, $i - z > 2.2$

SDSS DR3 Sample: 46,000 quasars over 5000 deg^2

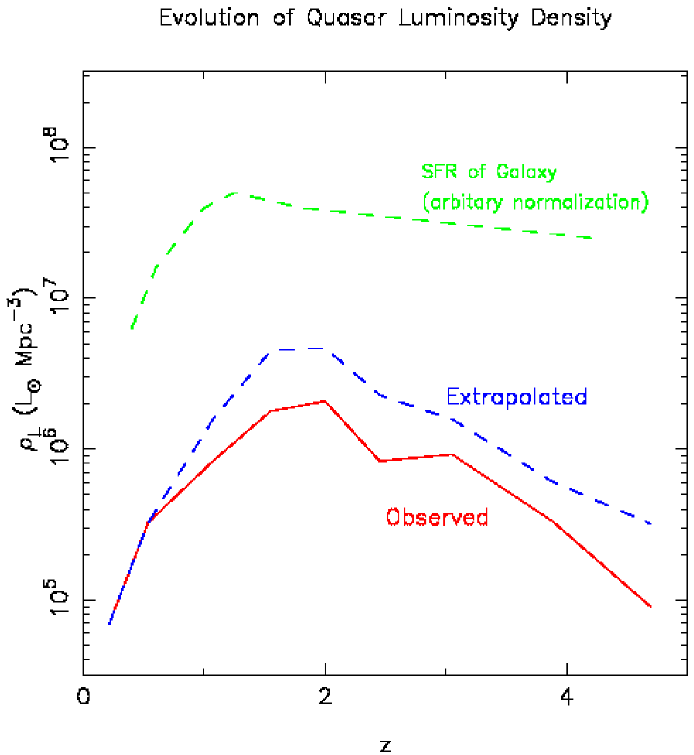
(Slide courtesy of X. Fan)

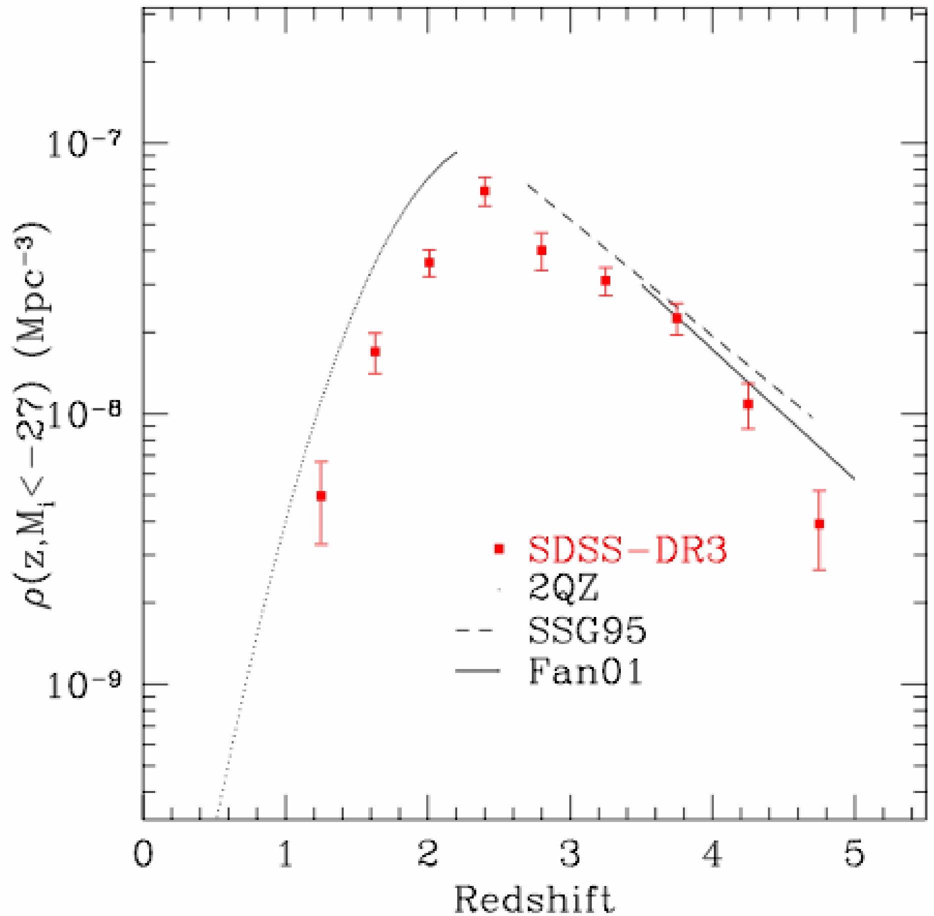


Richards et al. 2005

Slide from
X. Fan 2005
Elba workshop

Evolution of quasar densities



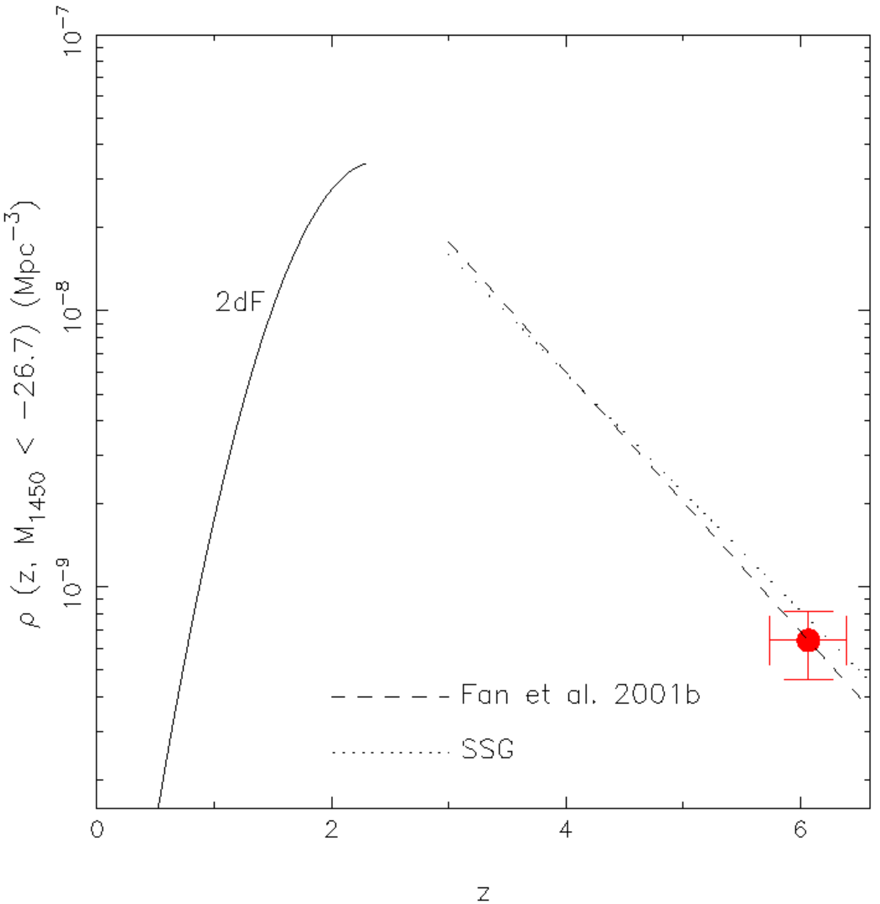


Exponential decline of quasar density at high redshift, different from normal galaxies

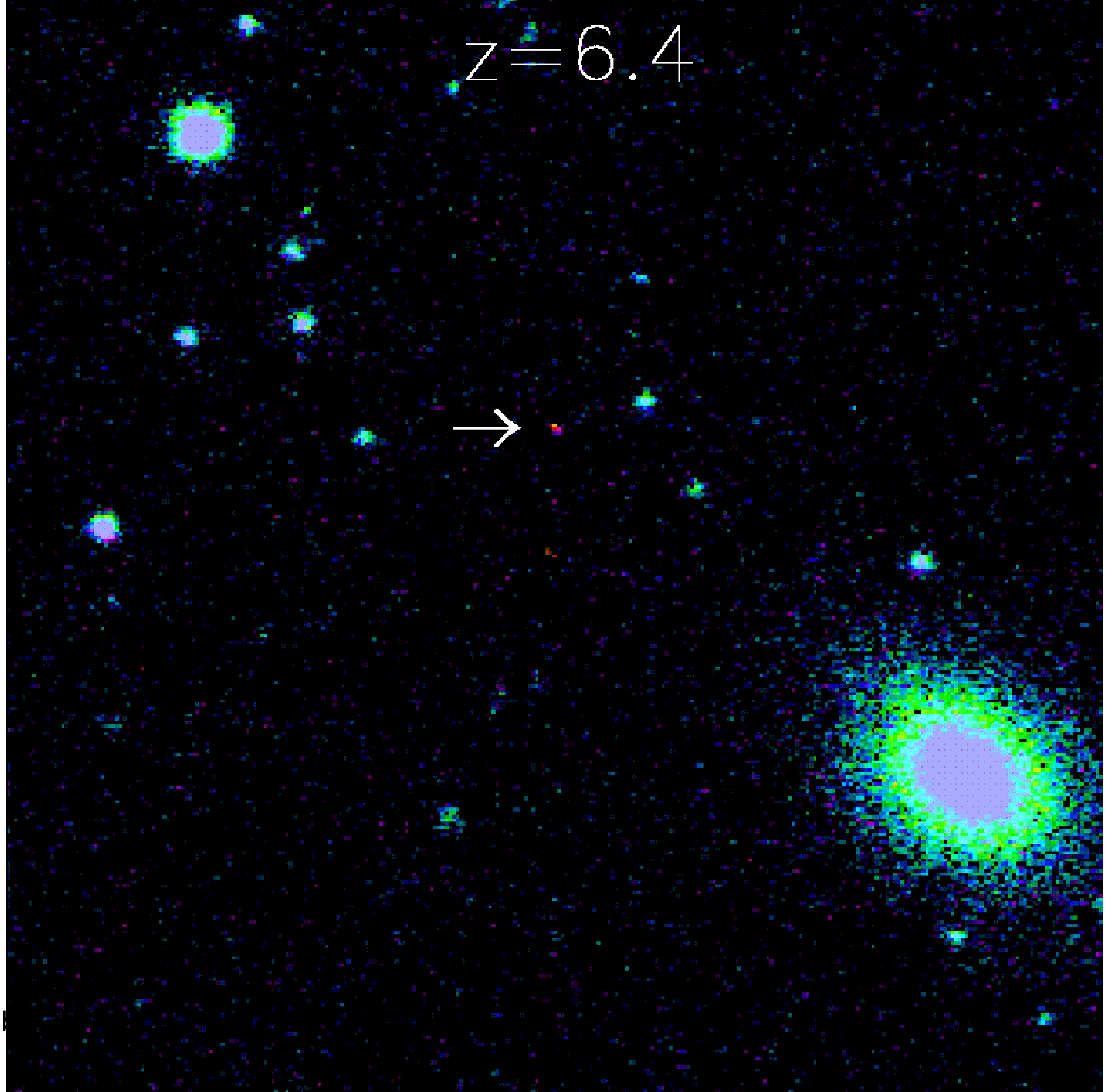
Richards et al. 2005

High-z evolution from SDSS
X. Fan 2005, Elba Workshop

- From SDSS i-dropout survey
  - Density declines by a factor of ~40 from between z~2.5 and z~6



Fan et al. 2004


z=6.4

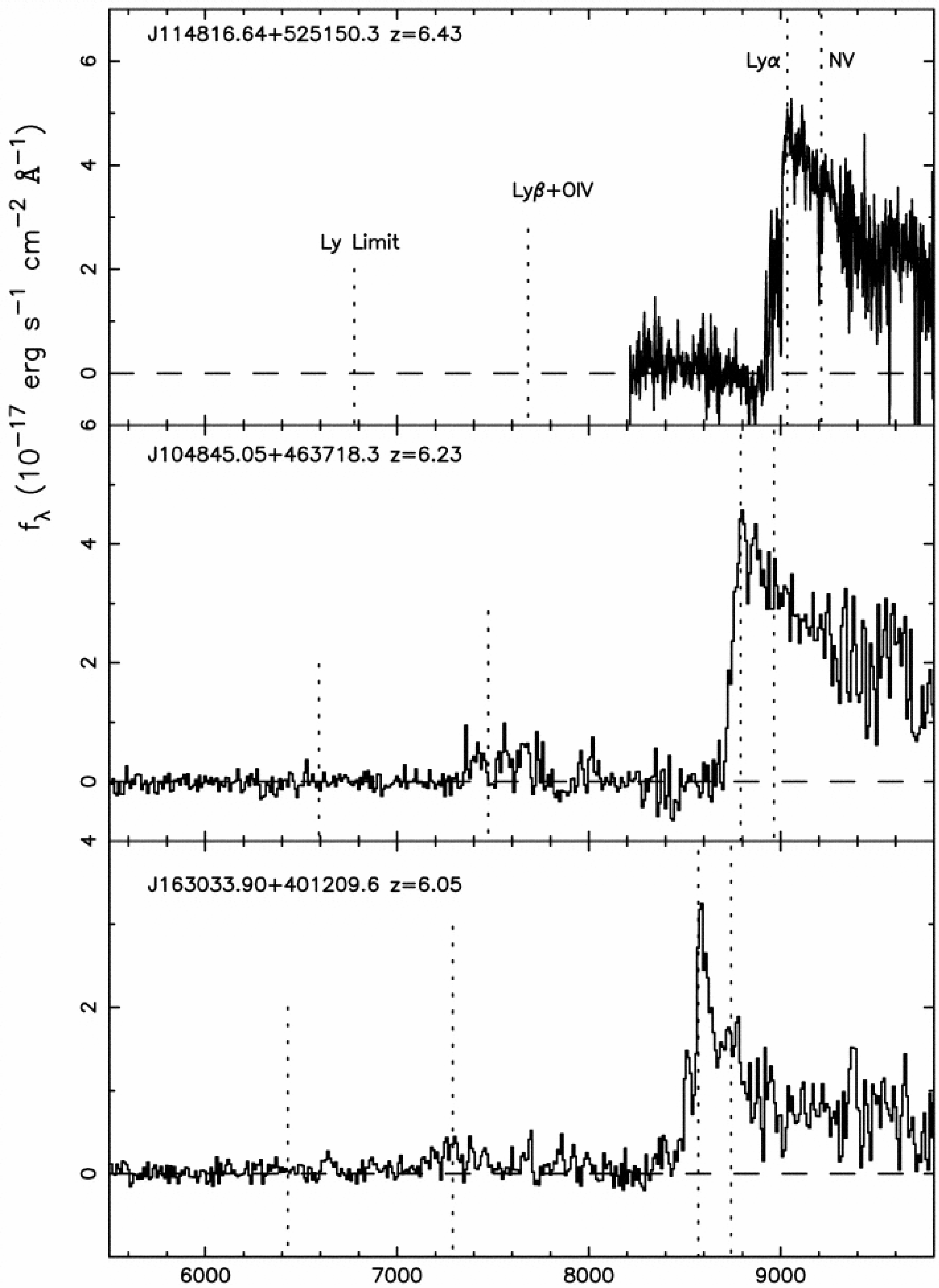
The Gunn-Peterson Effect

- Recall that
  - Hydrogen is the most abundant element in the universe
  - In its neutral state, it is a very effective absorber of radiation
  - especially at 1216Å from the Lyα transition and beyond 912Å, the Lyman limit

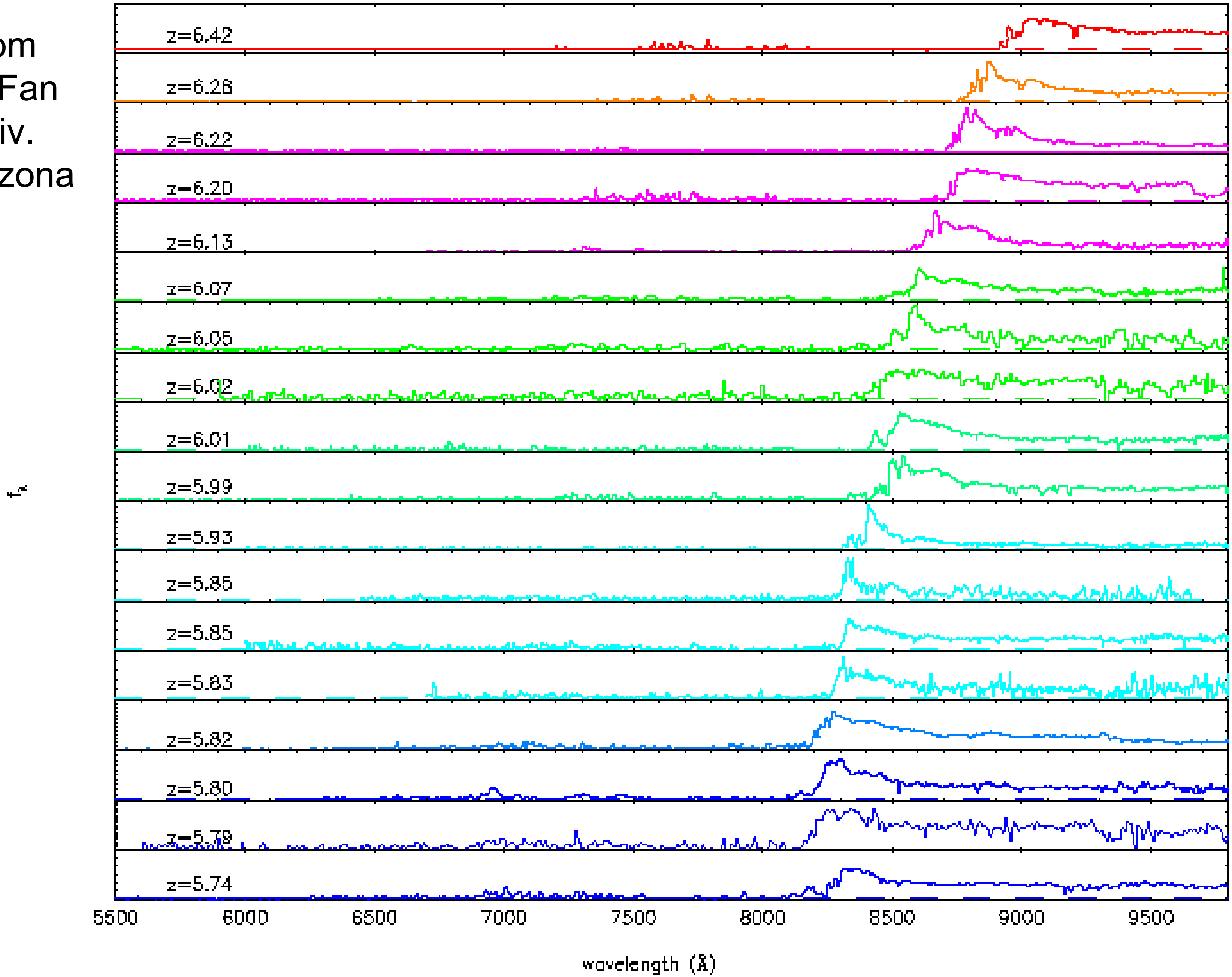
- Gunn & Peterson in 1965 realized that neutral hydrogen in the intergalactic medium (IGM) would depress the continuum spectra of quasars at wavelengths shortward of Lyα
- Until recently, observations of quasars have shown only a mild depression, increasing with redshift, indicating that the IGM is largely ionized

- As we approach redshift 6, however, the SDSS observations show a strong Gunn-Peterson effect

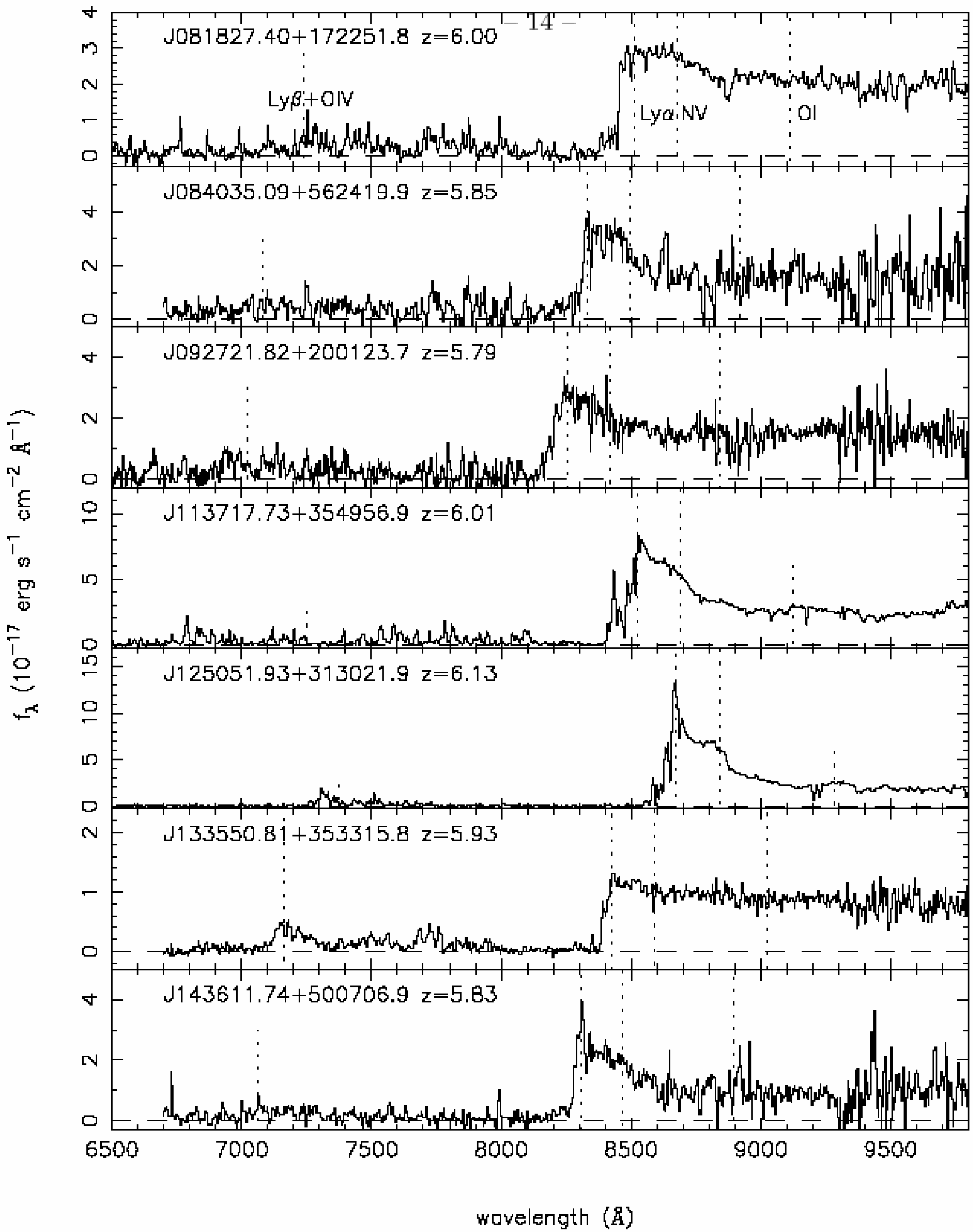
Fan et al., 2003, AJ, 125, 1649



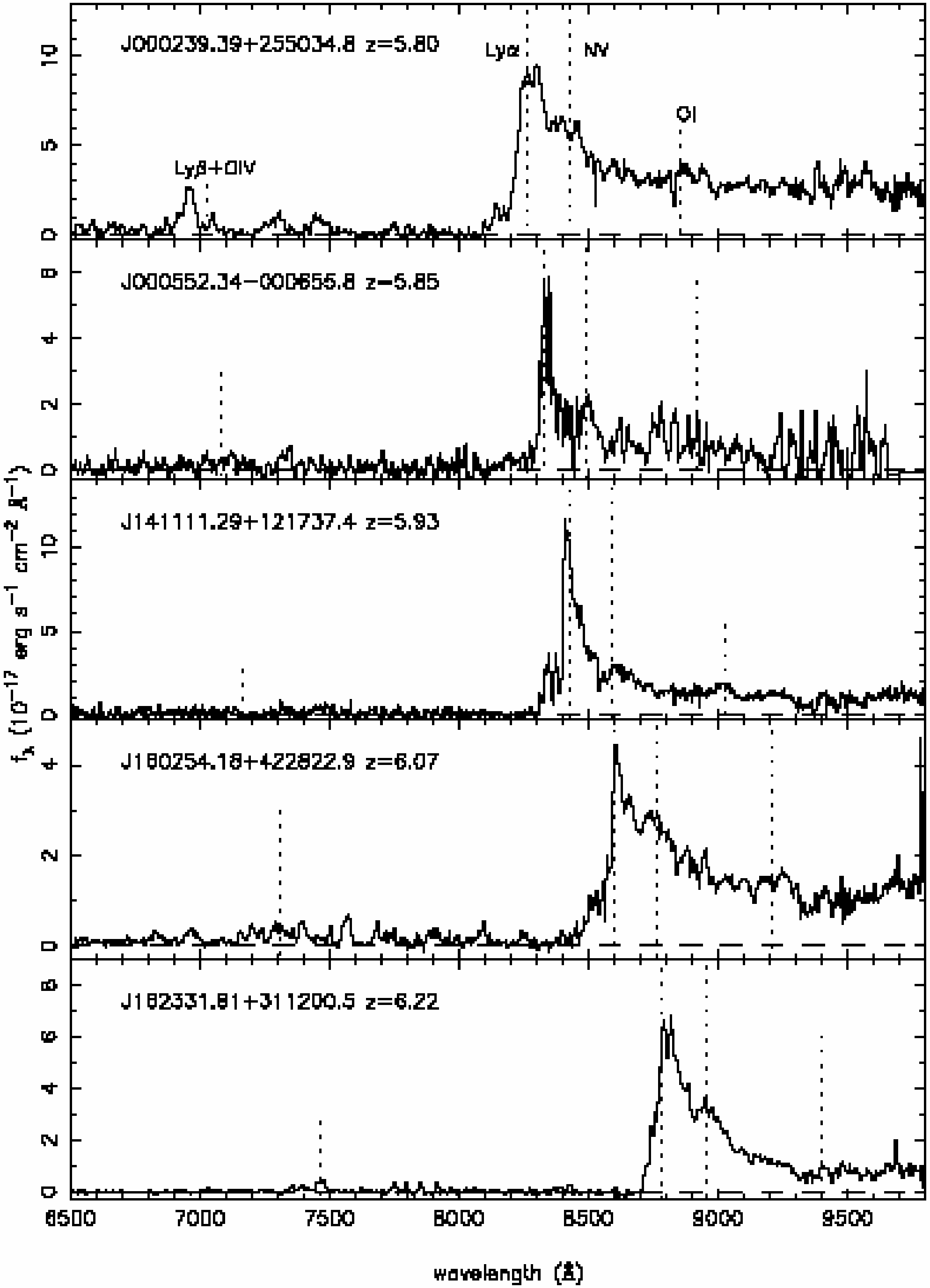
From
X. Fan
Univ.
Arizona



Fan et al.
2005



Fan et al. 2004, newest z > 5.8 quasars



Summary

- The observations show a strong Gunn-Peterson effect at $z \approx 6$, which is evidence for the end of the reionization of the universe
- WMAP observations provide indirect evidence for the first ionizing sources starting to form around $z = 15\text{-}20$
- This is a very active area of research

What about the chemical evolution of the gas around quasars?

- Our observations of quasars now span the range from the present epoch back to within about 800 million years of the Big Bang
- We might expect to see changes in the emission-line spectra of quasar and evidence for evolution of the chemical abundance of the gas

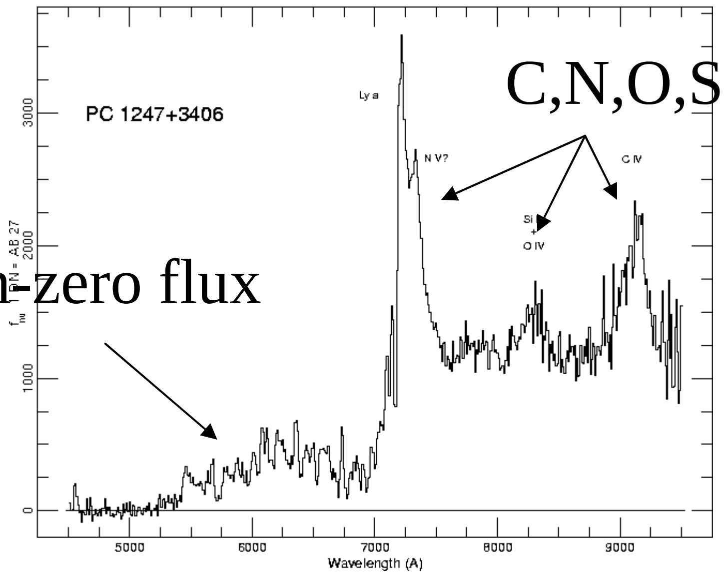
Chemical Evolution

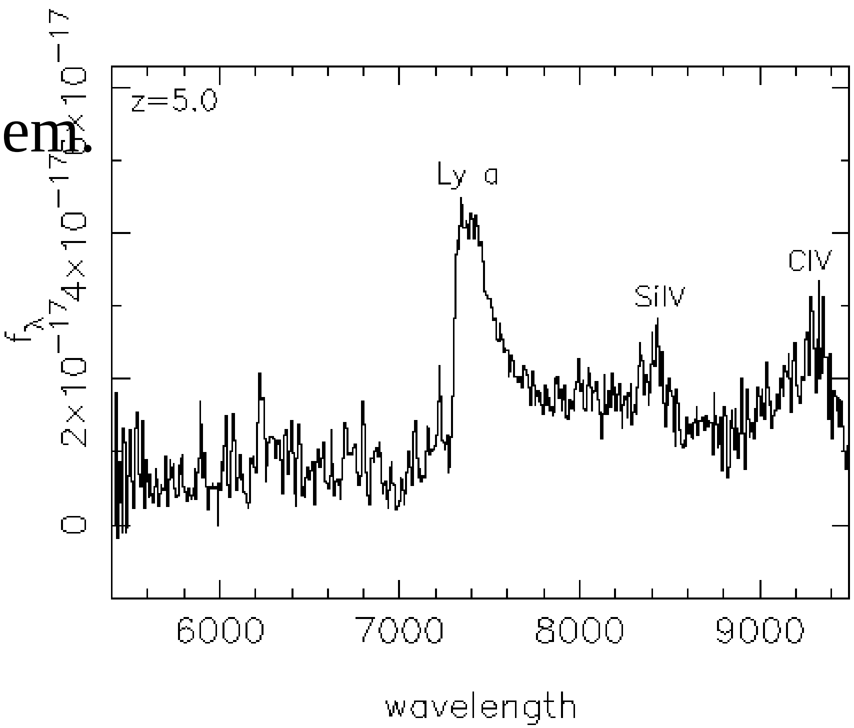
- The overall abundances are a major topic
  - How to produce >solar abundances in the emission line gas at $z>4$, i.e., in 1 billion years or so?
- The Fe/Mg question
  - Mg II λ2798 and Fe II emission complexes are prominent in quasar spectra
  - How to produce enough Fe at high z

QUASARS at $z \approx 5$

C,N,O,Si em.

Non-zero flux

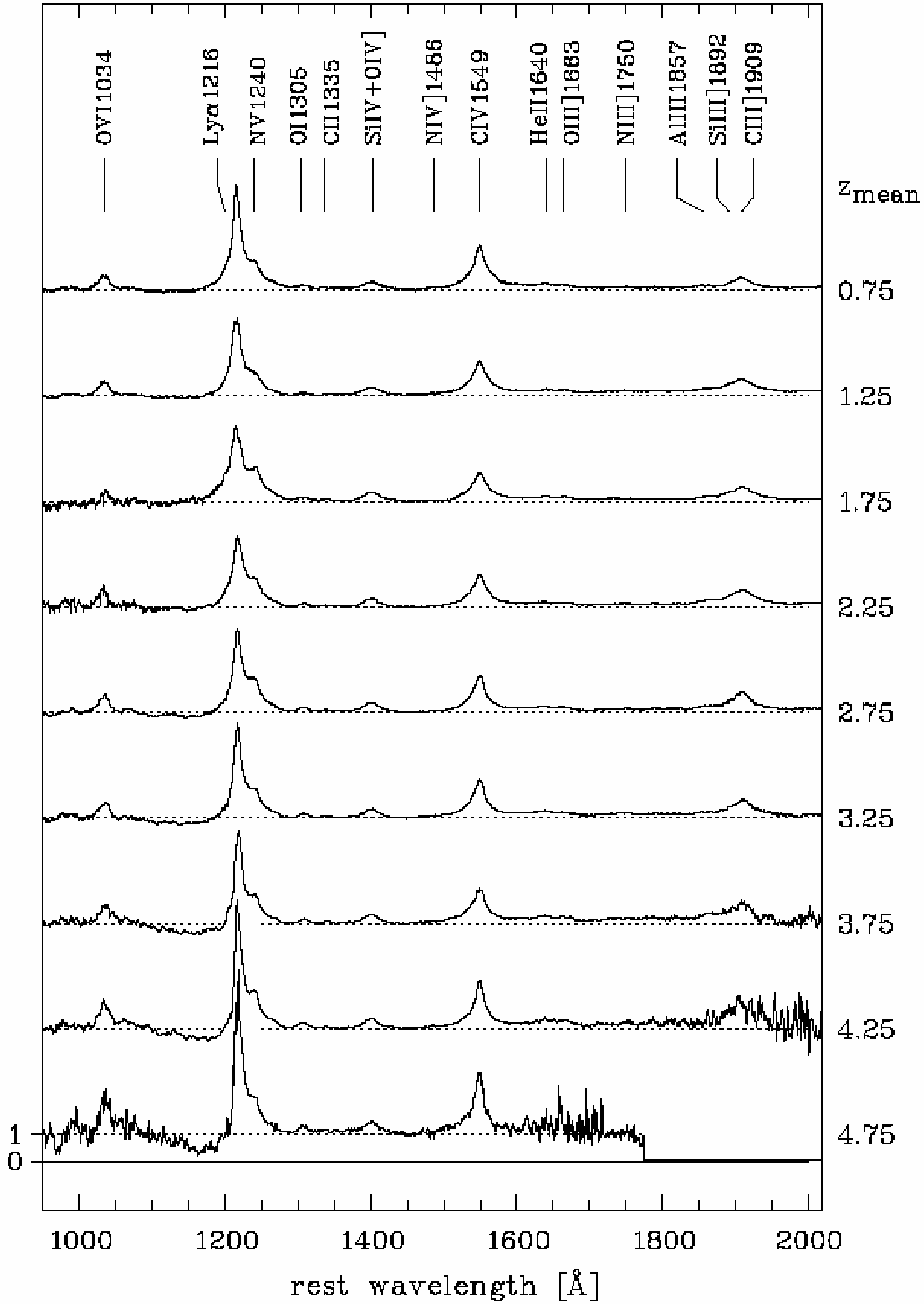




z = 4.9, Schneider et al 1991

z = 5.0, Fan et al. 1999 (SDSS)

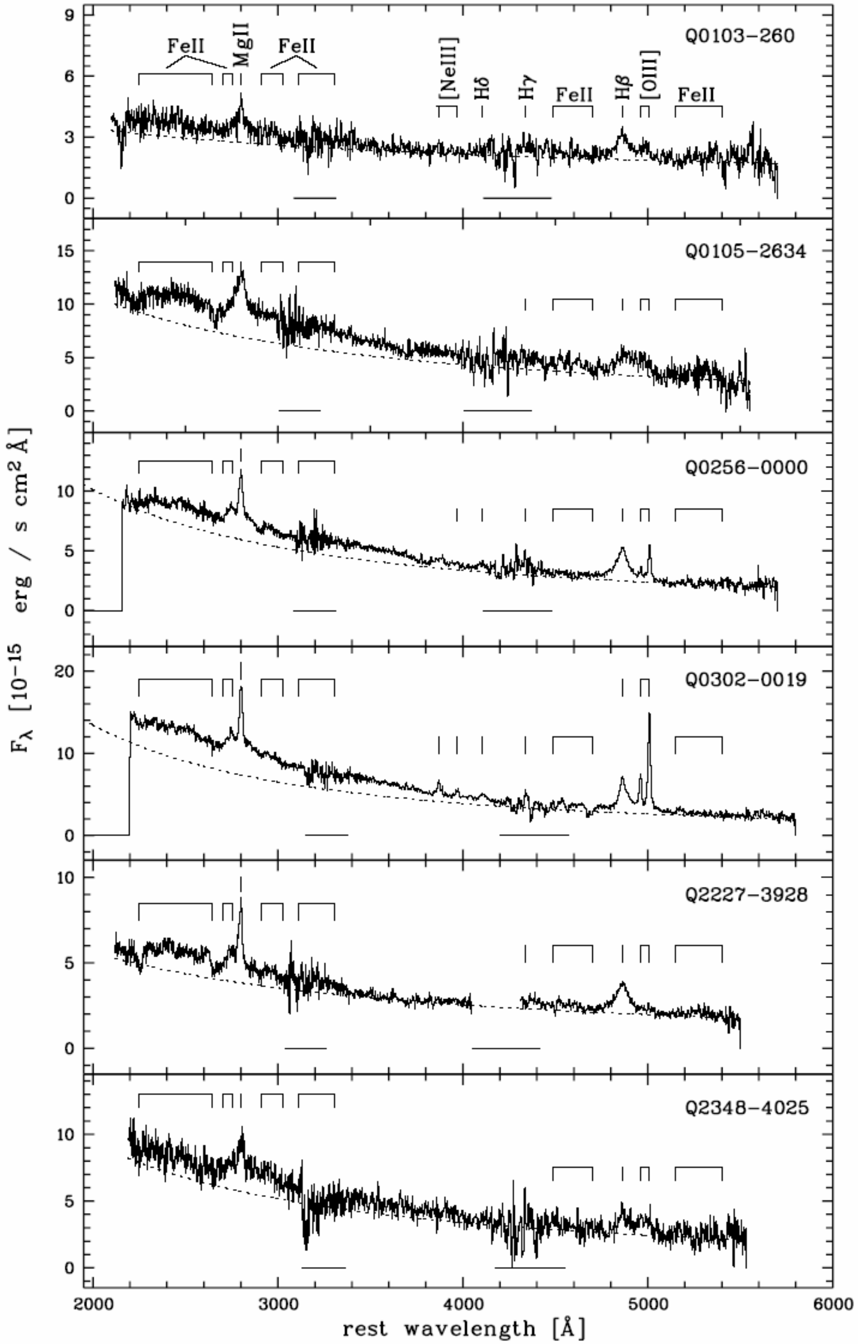
Dietrich et al 2002



Dietrich, Appenzeller, Vestergaard, Wagner, 2002

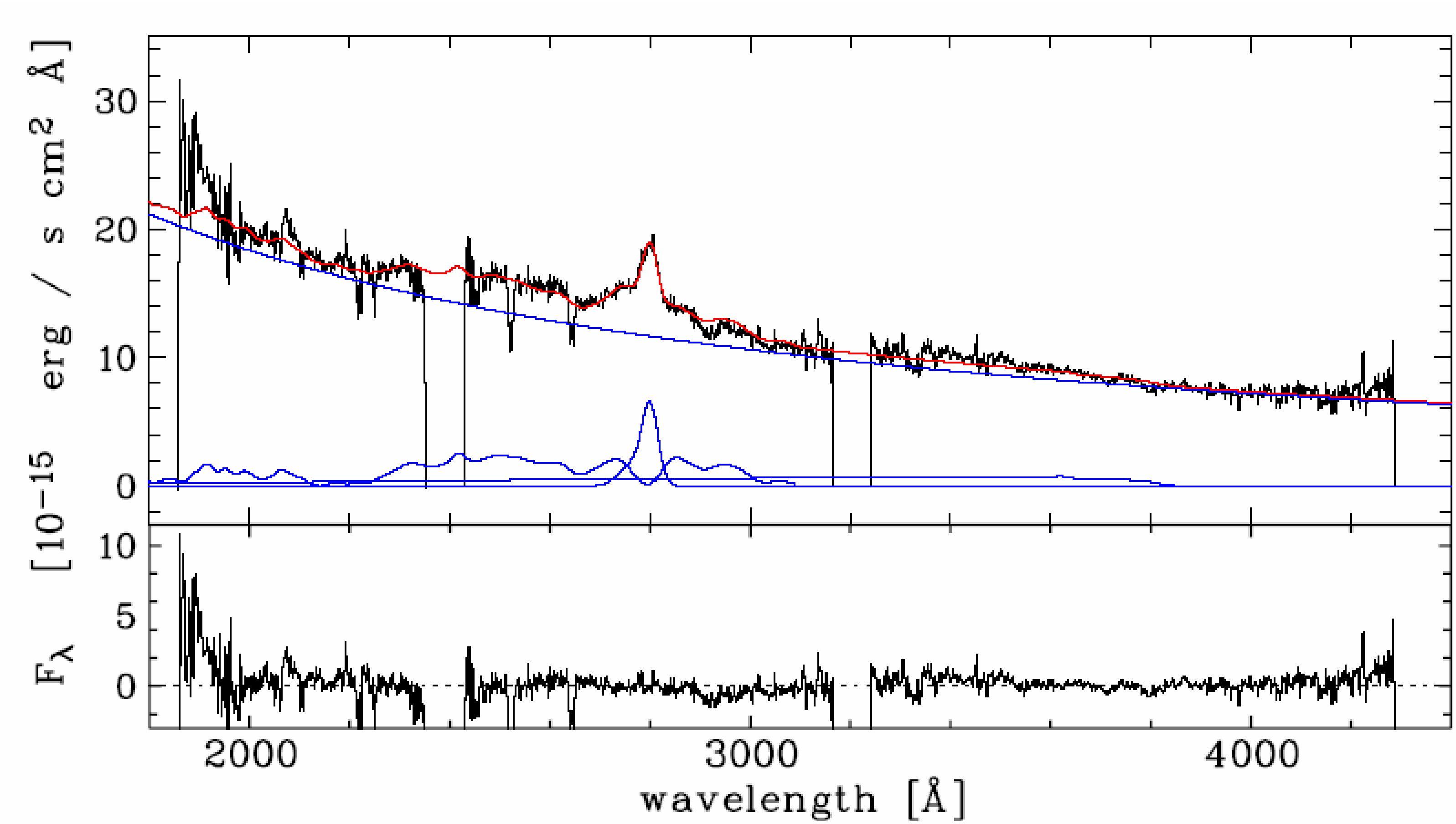
NTT, SOFI data

Near IR spectra used for Fe II/Mg II ratio

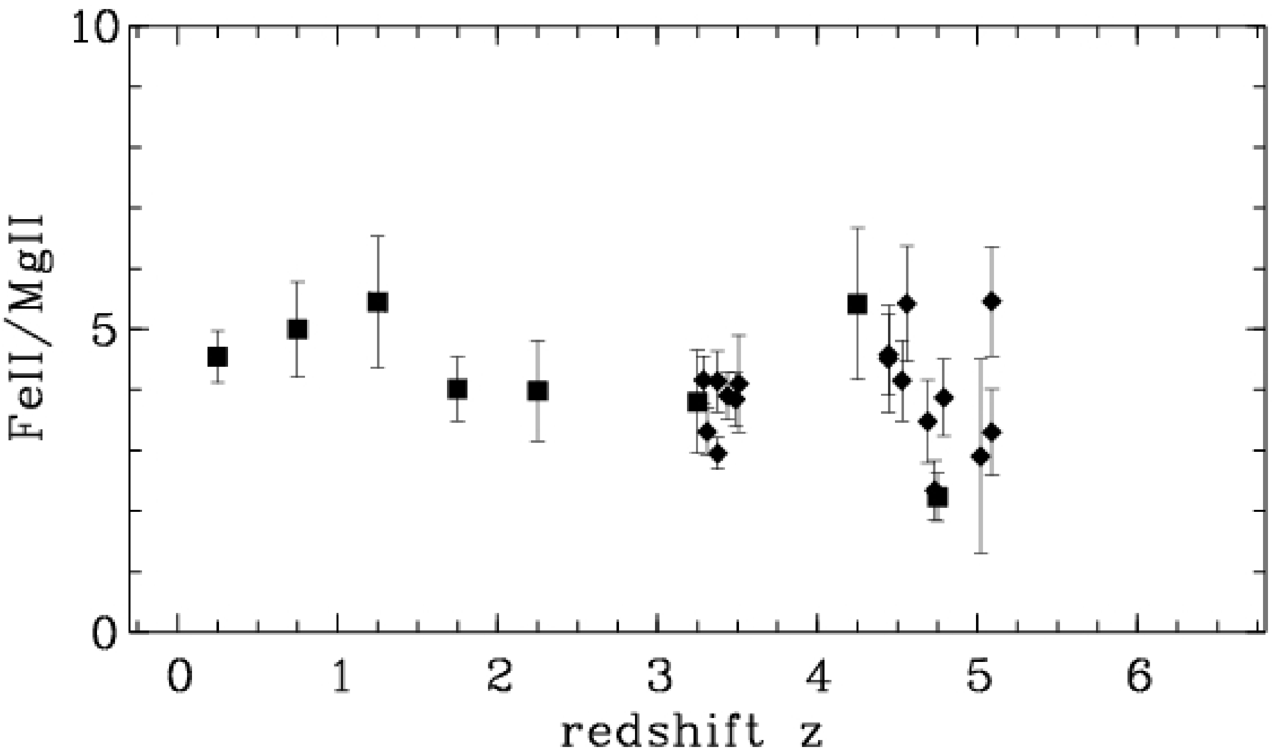


Dietrich, Hamann, Appenzeller 2005
VLT ISAAC spectrum of BR0305-4957

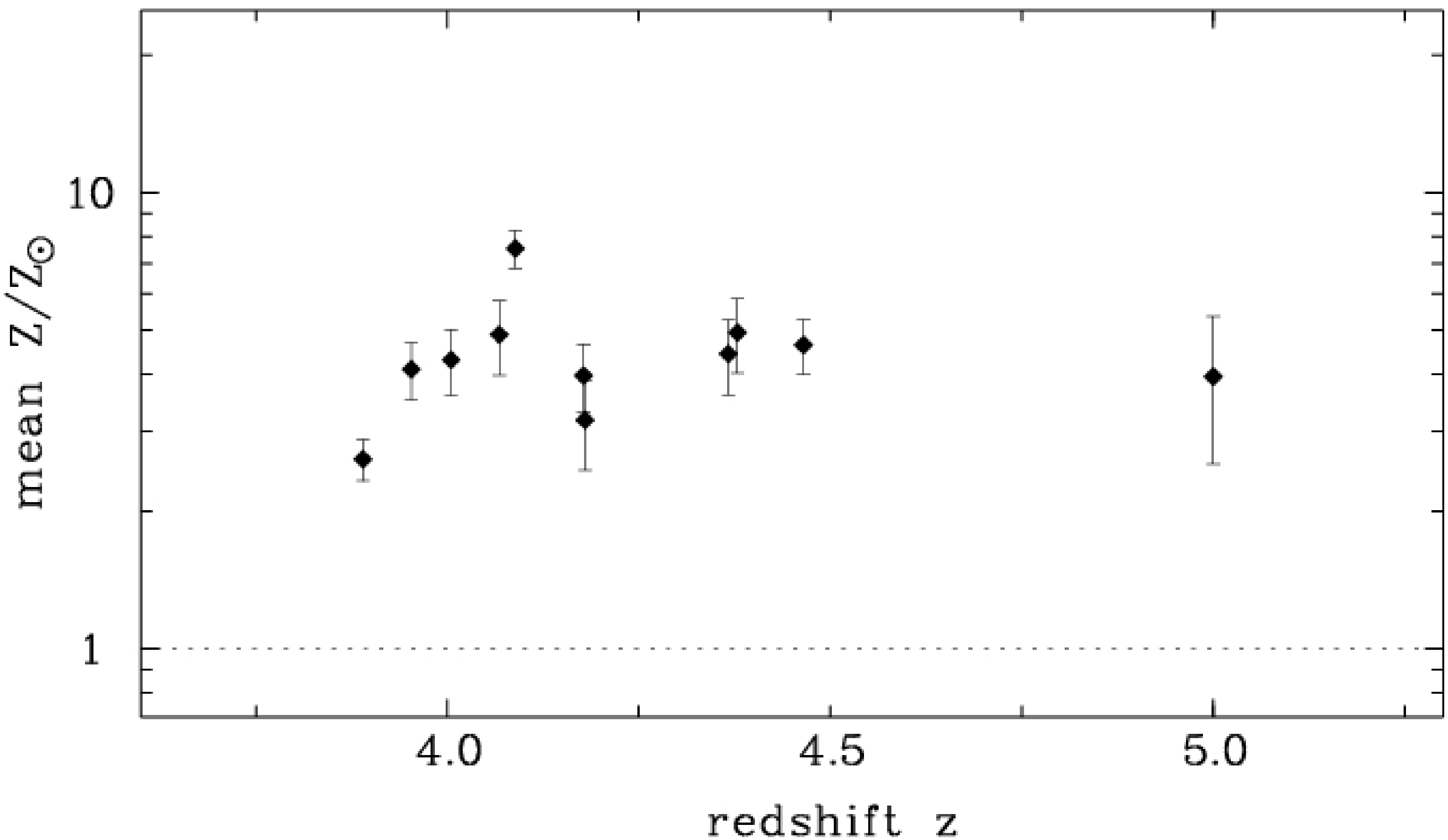
Multi-component fit yields excellent estimate of FeII and MgII emission



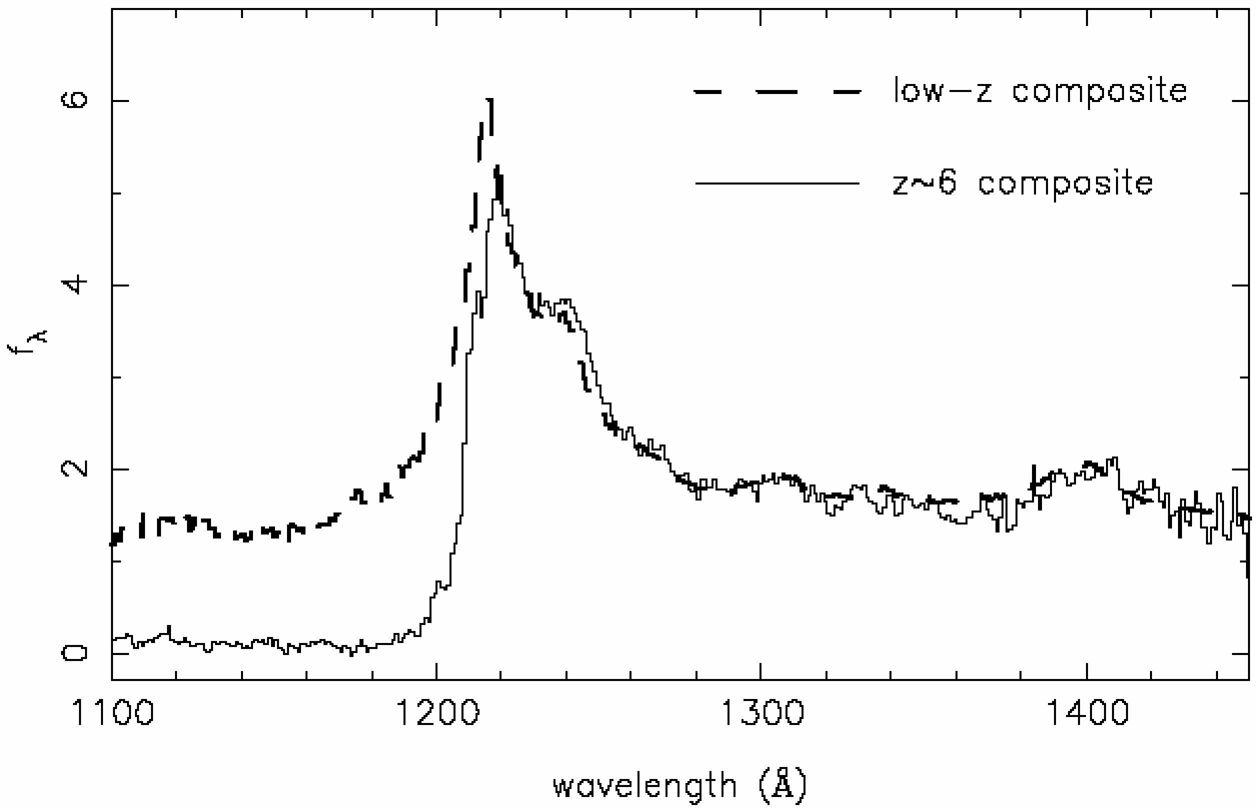
Dietrich, Appenzeller, Vestergaard, Wagner 2002



Dietrich, Appenzeller, Hamann, et al. 2003
Abundance estimates at z>4



Fan et al. 2004, SDSS
Composite, 11 z ≈ 6 QSOS



Summary of Chemical Evolution

- If the gas around quasars really does have greater than solar abundances, that is evidence for the existence and evolution of stars well at cosmic epochs of around 500 million years after the Big Bang
- The discovery of such objects is one of the main goals of current research and of the James Webb Space Telescope

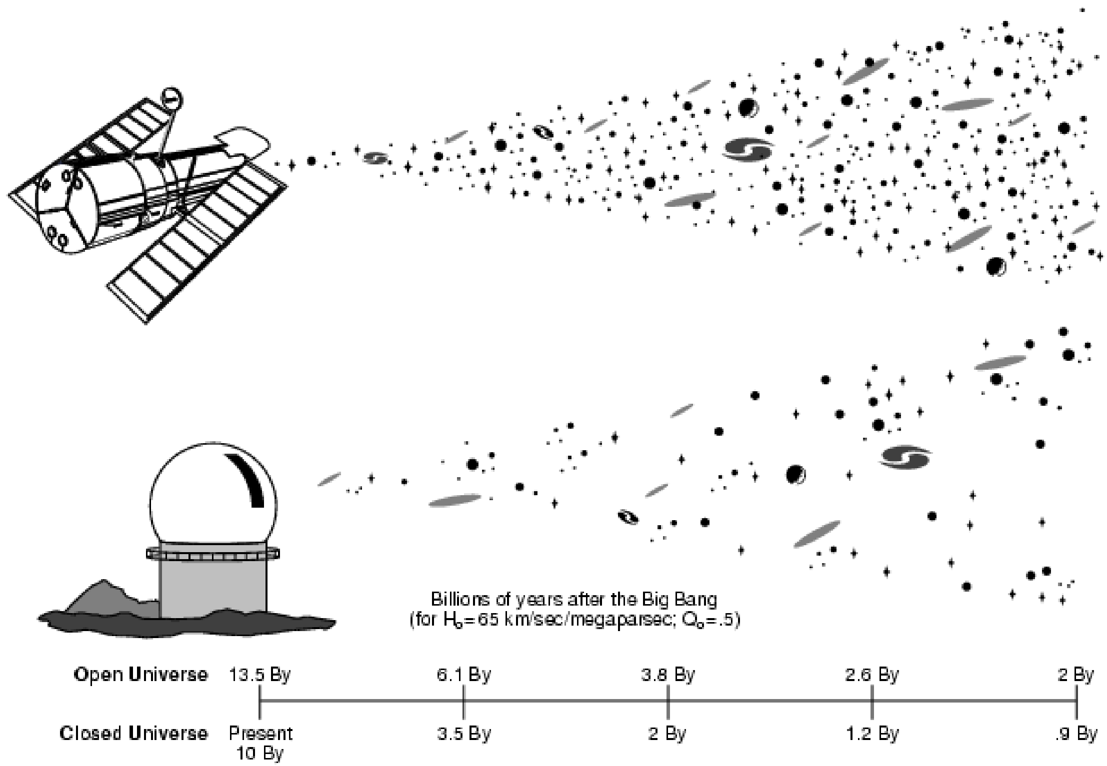
The Coevolution of Black Holes and Galaxies

- (Recall book of same name edited by L. C. Ho)
- While this is a big subject, let me mention two aspects of the problem here
  - Can we account for the local mass density of SMBHs in galaxies?
  - Can we account for the X-ray background?
- Both are what I call integral constraints on accretion and emission in the universe

- To be more specific
  - Does our knowledge of the quasar/AGN luminosity function and its evolution with time yield the local mass density of SMBHs?
  - Does it also account for the observed X-ray background, which is (mostly) the integrated brightness of AGNs over cosmic time in the universe

- In both cases, we have to address the longstanding question “How many obscured quasars/AGNs are there in the universe?”
- This actually involves several questions, but answers are starting to come in.
  - Refer to the very nice work of E. Treister et al. 2004, 2005

- Treister has developed a model showing that a ratio of about 3/1 for obscured/unobscured sources and the unified picture of AGN is quite successful



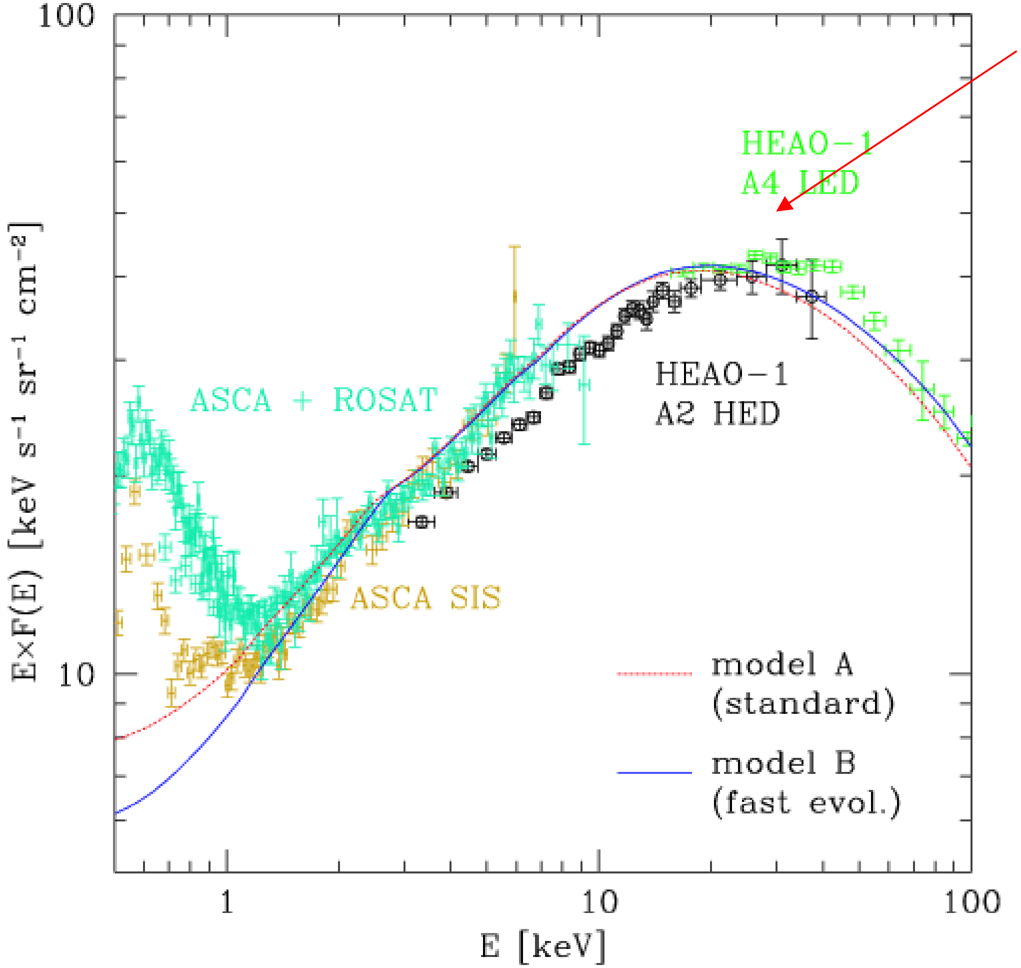
The Hubble Deep Field uncovered much fainter objects in the universe (down to nearly 30th magnitude) than seen previously from ground-based telescopes. Some of the dim objects along Hubble's line-of sight may be intrinsically faint, foreground galaxies. Others, however, are dim because they are extremely distant. Some of the faintest galaxies in the survey existed when the universe was a fraction of it's present age.

- Historical reference:
  - Soltan 1982 showed how to integrate the contributions of luminous sources over cosmic time to obtain a relation between emitted energy and current energy density
  - The result is independent of cosmological model
- Current reference
  - Pub. of conference on “Growing Black Holes,” 2004

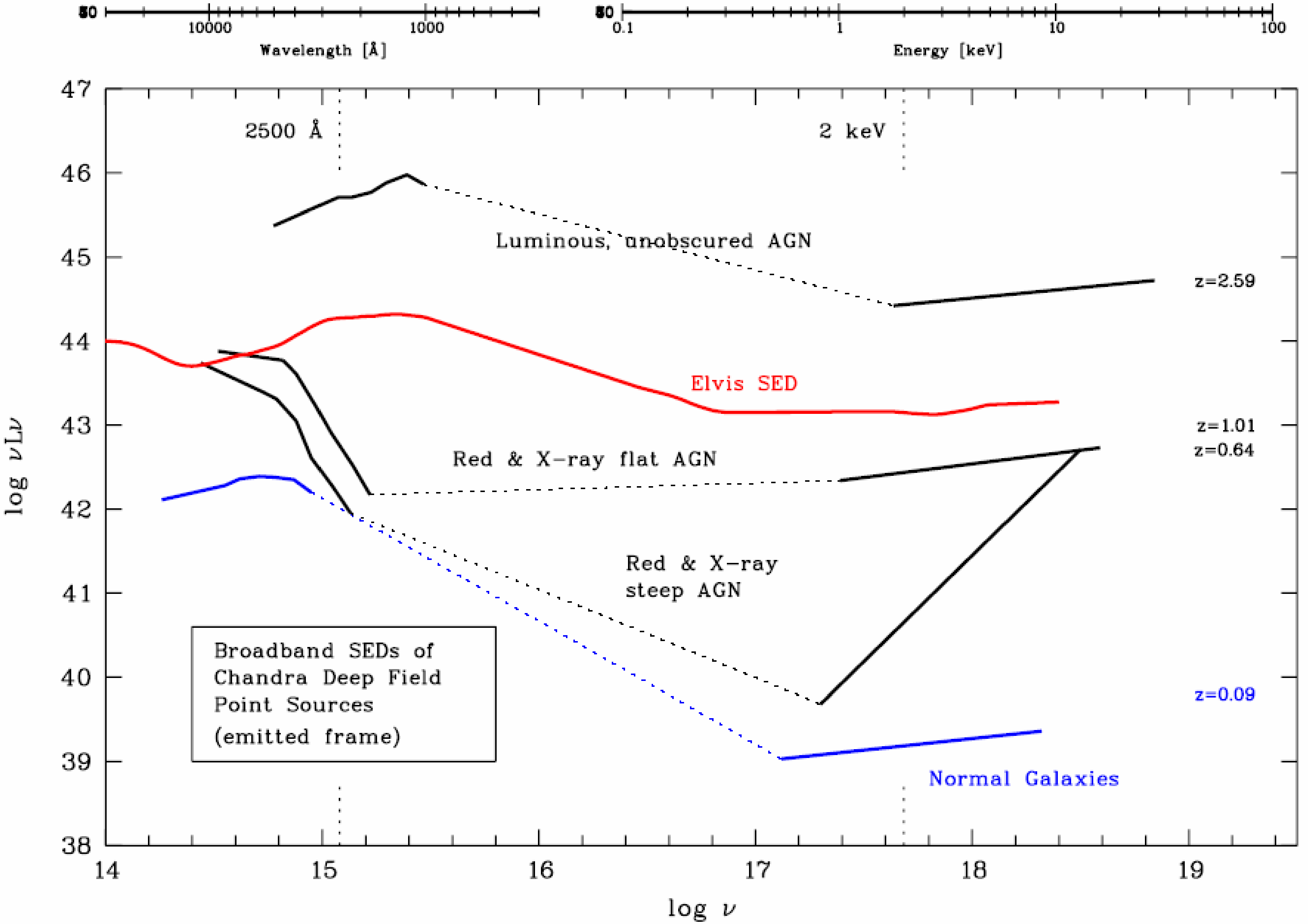
The X-Ray Background

From Gilli, Salvati, Hasinger 2001

What produces the 30 keV peak?



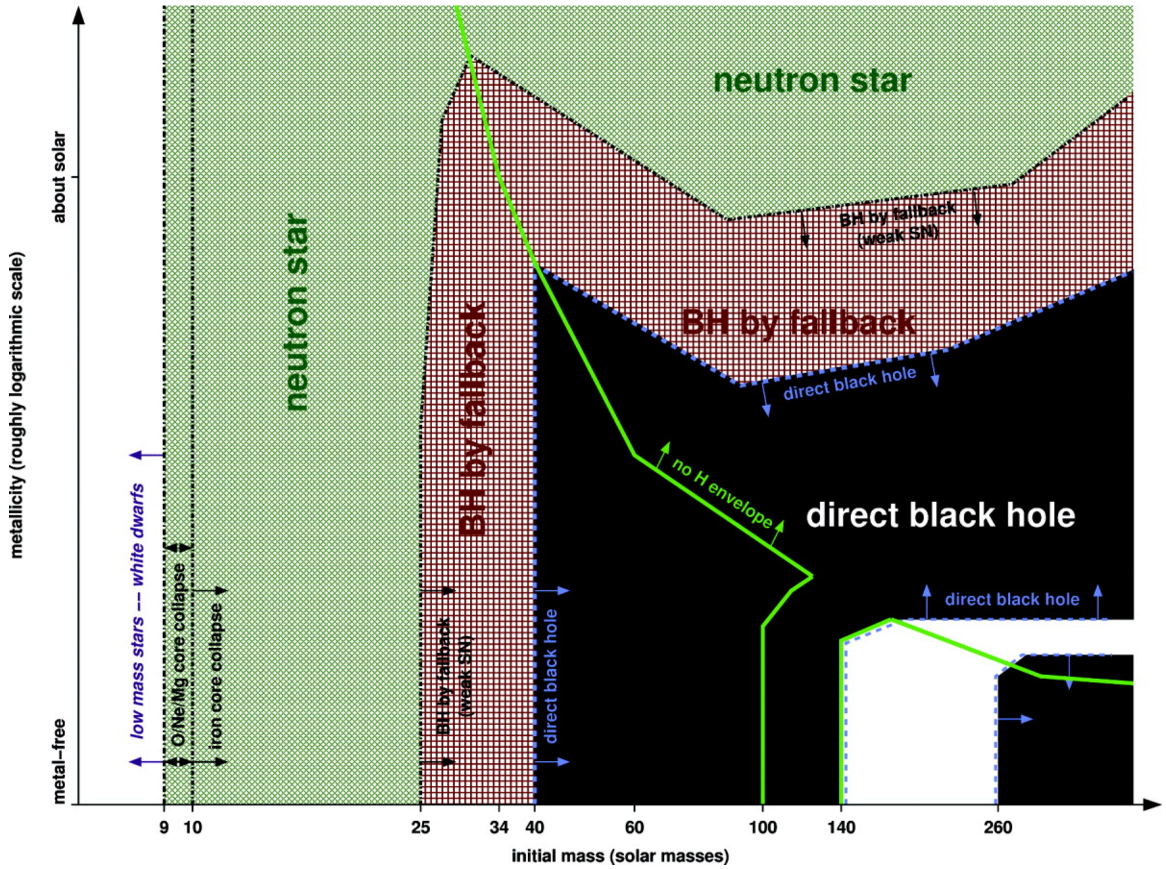
Work in progress by S. Frank and P. Osmer



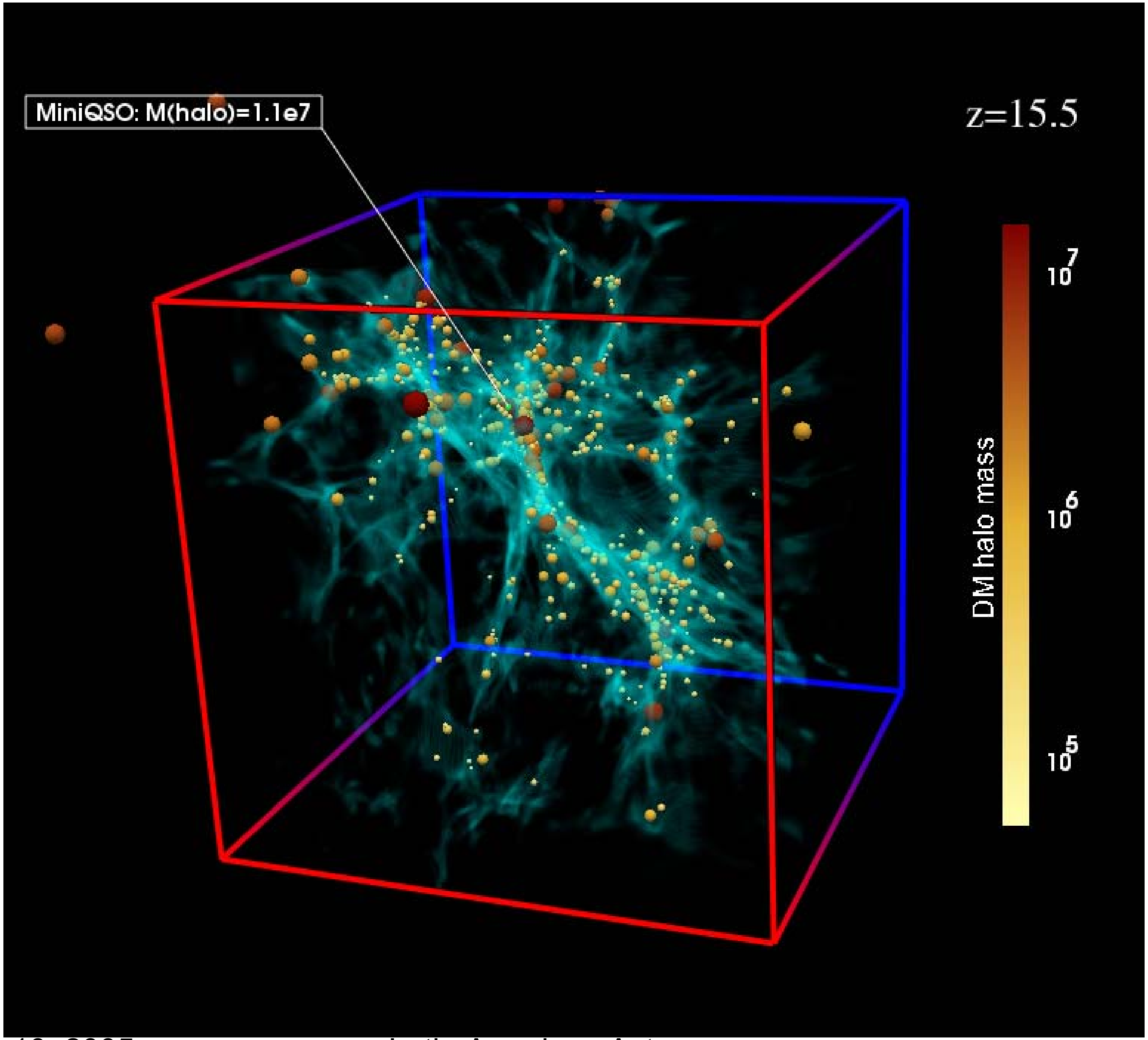
How did Quasars/AGNs form in the universe?

- Possibly from BH remnants left by the death of the first, very massive, Pop. III stars.

From Heger et al. 2003



Simulation by Kuhlen & Madau 2005



Summary

- In these lectures, I have covered highlights of:
  - The discovery, history, and main properties of quasars and AGNs
  - How we discover and work with them
  - Their evolutionary properties and some current, key research questions
- I hope I have communicated to you the wonderful research opportunities that exist in these subjects

Thanks

- I would like to thank
  - the organizers for all their efforts in making the school such a success
  - Felix Mirabel for his overall leadership and creativity for the school
  - You the students for your participation and interest in these forefront areas of astronomy and astrophysics