Quasar Surveys, Cosmology, Introduction to the Evolution of Quasars

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Outline

- Techniques for finding quasars
- Some major surveys
- Cosmological concepts and calculations for observers
- Introduction to the evolution of quasars

References

- (In addition to those given in Lecture 1)
  - Osmer 2004, in “Coevolution of Black Holes and Galaxies,” ed. L. C. Ho, Cambridge Press
  - Others will be mentioned in the slides where they are discussed

Finding Quasars and AGNs

- The problem: AGNs are rare objects. How to find them among the much more numerous stars and galaxies on images of the sky?
- The solution: Use the observed ways that quasars/AGNs are "not stars."
  - Make use of SEDs, emission-line spectra, variability, or lack of proper motions to distinguish AGNs from stars & galaxies

Making use of spectral energy distributions (SEDs)

- Consider the radio, optical/UV, and X-ray emission from AGNs
- Normal stars and galaxies emit very weakly in radio and X-ray regions.
- Normal stars and galaxies in general have “red” colors at optical wavelengths
- How to use these properties in practice to find quasars/AGNs?

Begin with radio surveys

- Radio observations
  - led to the discovery of the first quasar
  - isolate a very important component of the quasar/AGN population
- Requirements for success
  - Radio surveys to faint flux limits
  - Wide sky coverage
  - Excellent positions
  - Corresponding optical imaging & spectroscopy

Examples of radio surveys

- Historically:
  - 3C & 4C, the third and fourth Cambridge surveys
  - PKS, the Parkes survey
- Modern:
  - NVSS, the NRAO VLA Sky Survey, > 1.8 million sources, www.cv.nrao.edu/nvss/
  - FIRST, VLA, 20 cm, 10,000 deg^2, to 1 mJy, 811,000 sources, see sundog.stsci.edu/

Needed Follow-up Observations

- The various surveys of all types need follow-up observations to confirm which objects are quasars/AGNs
  - Generally, this means optical spectroscopy to establish that candidates are indeed AGNS and to determine their redshifts

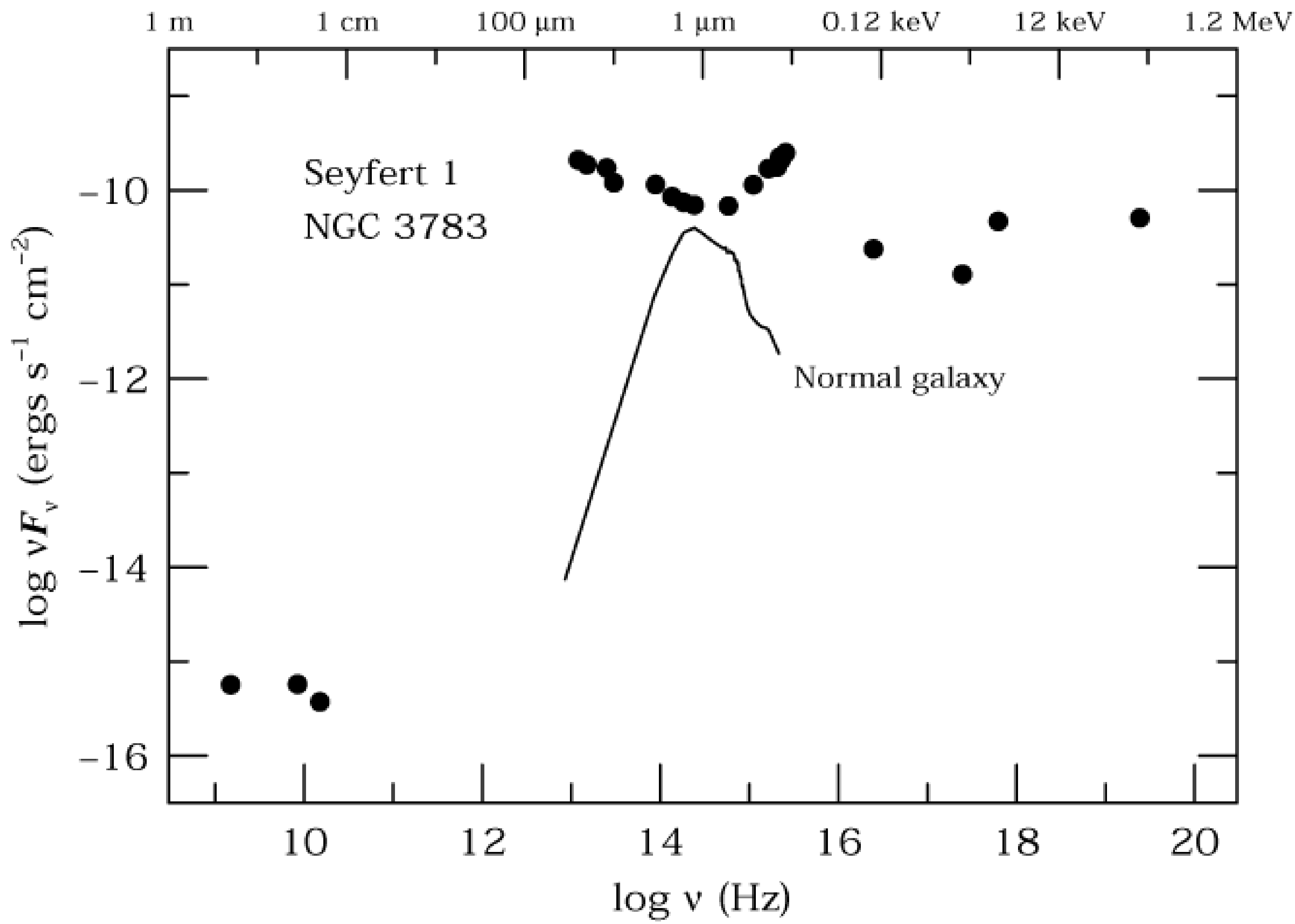
Additional survey requirements

- Surveys should now be quantifiable in their selection parameters
  - selection efficiency as f(brightness, wavelength)
- Surveys also need to be effective
  - efficient, obviously
  - but not overwhelmed with false positives, i.e, objects which meet criteria but are not AGNs
- This is all now possible with digitally based surveys

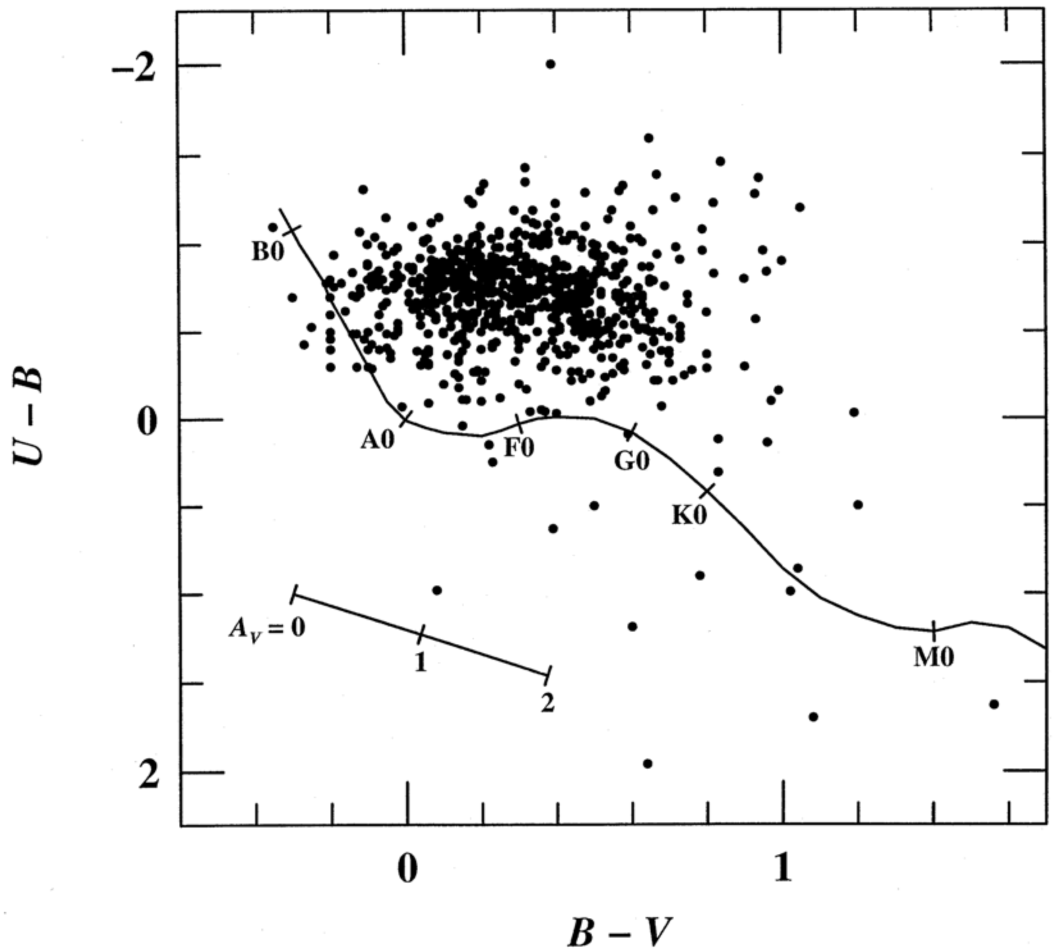
Optical surveys: Multicolor Techniques

- Historically:
  - Quasars are more bright in the ultraviolet than most stars
  - This allowed quasars to be found by their “UV excess”
  - Very effective for redshifts $z \leq 2.3$, but not higher, as Lyα moves into the UV passband
  - At higher redshifts, quasars differ from stars/galaxies at red and near-IR wavelengths

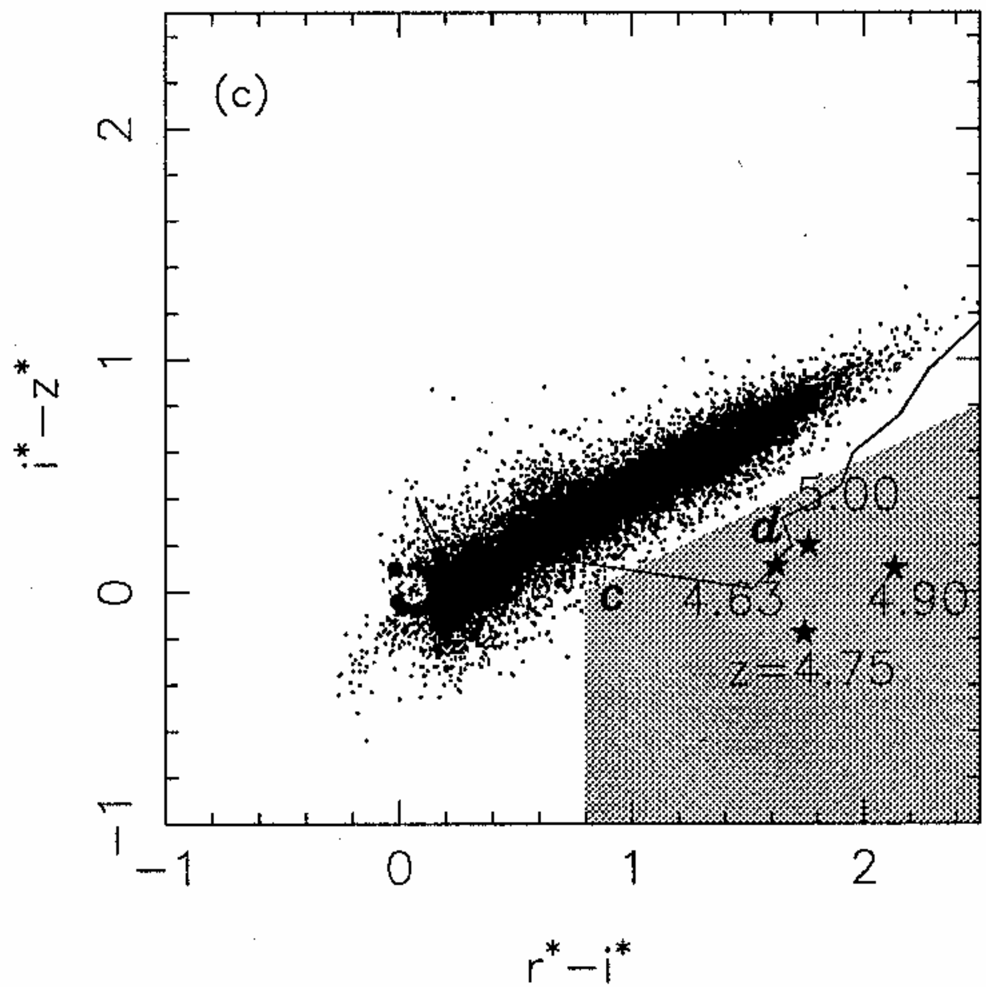
AGN Spectral Energy Distribution (Peterson 1997)



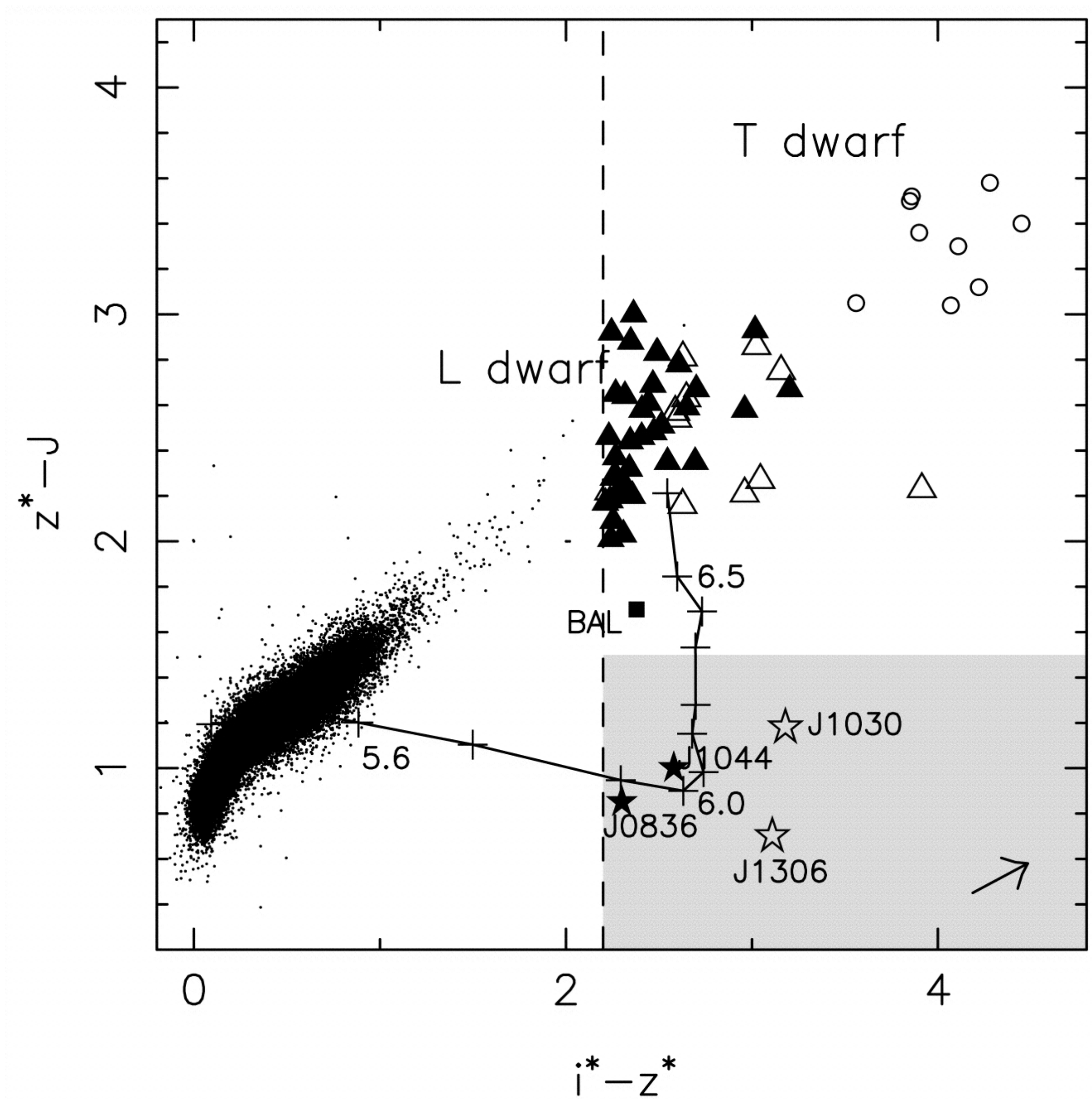
From Peterson 1997



SDSS Data for stellar objects, i* < 20, Fan et al. 1999



Fan et al. 2001



Some current Optical Surveys

- 2dF, UVX survey, 24,000 quasars, www.2dfquasar.org/
- SDSS, Multicolor survey, 46,000 quasars (en route to 100,000), www.sdss.org
- COMBO-17, 300 quasars to R < 24, www.mpia.de/COMBO/combo_index.html

Wolf et al. 2003

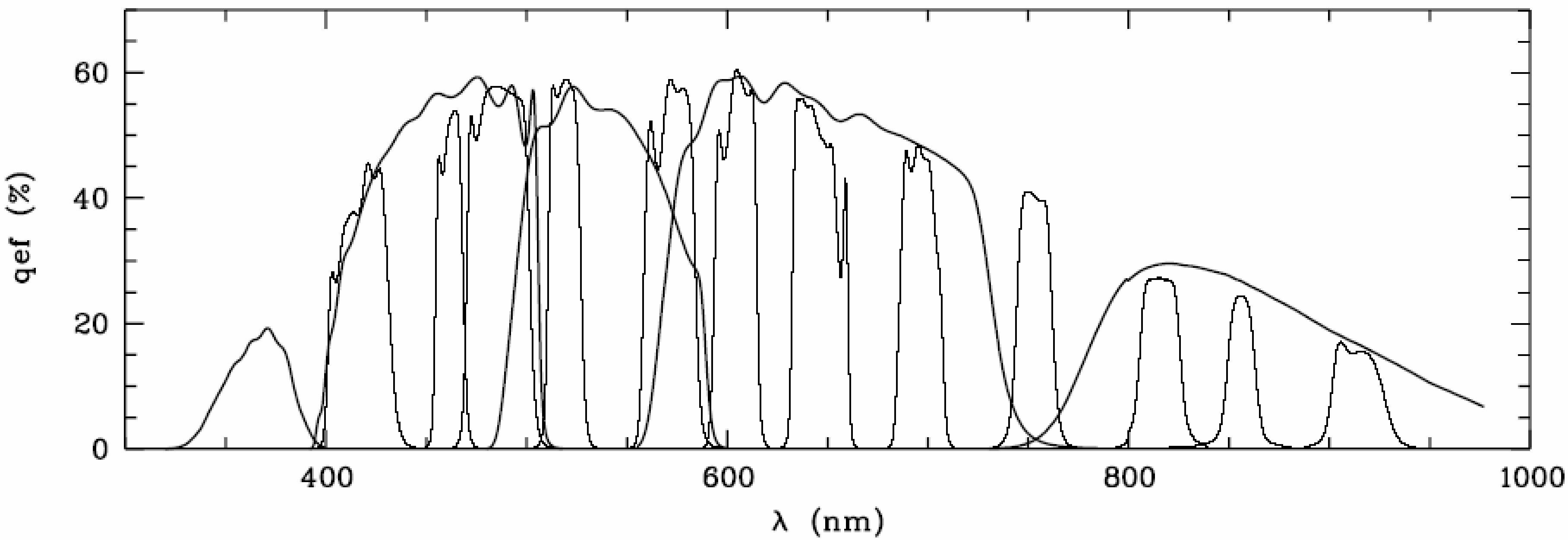
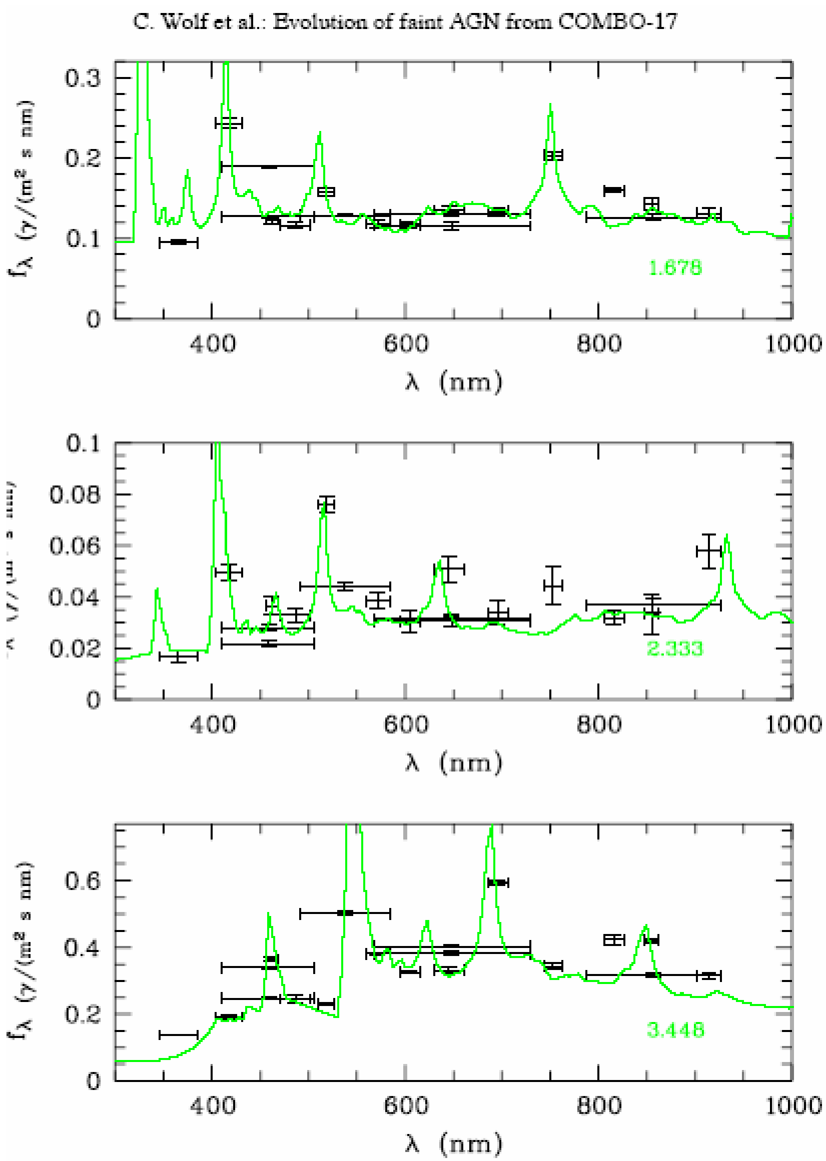


Fig. 1. COMBO-17 filter set: total system efficiencies are shown in the COMBO-17 passbands, including two telescope mirrors, camera, CCD detector and average La Silla atmosphere. Combining all observations provides a low-resolution spectrum for all objects in the field.

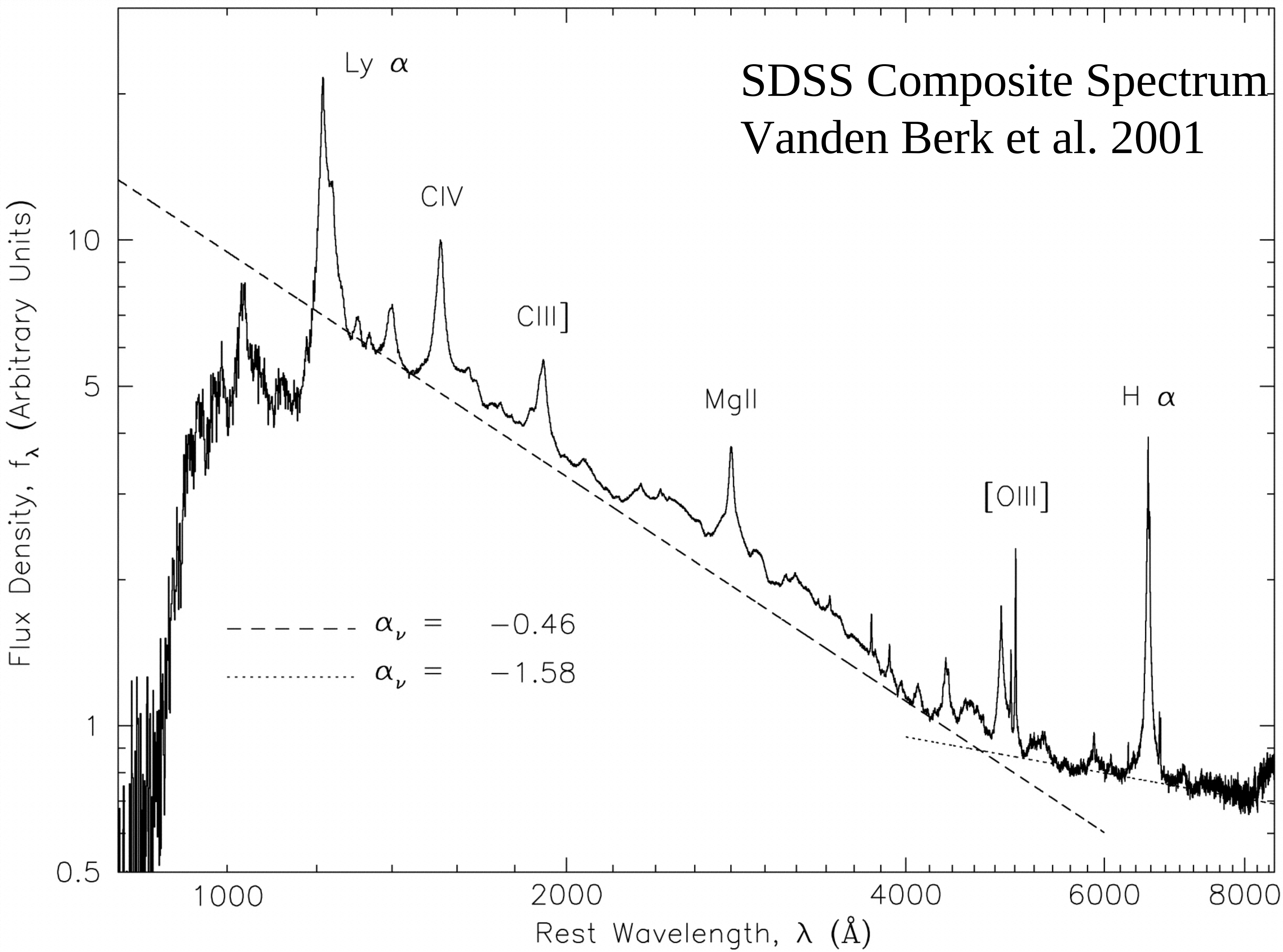
Wolf et al. 2003



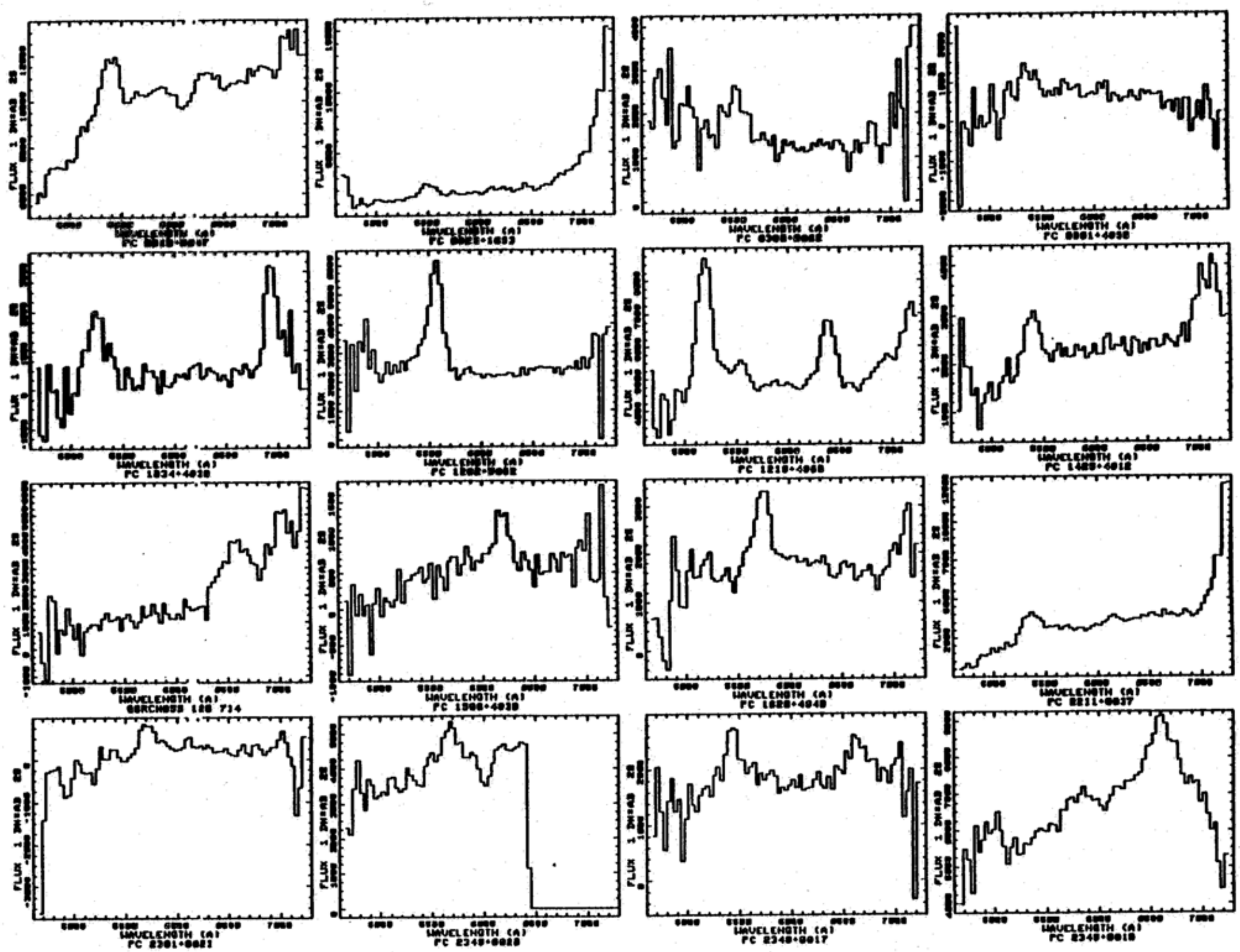
- COMBO-17 is an example of a survey which can do its own follow-up effectively
  - i.e., its photometric redshifts are very good

Optical Surveys: Spectroscopic Techniques

- Quasars/AGNs have strong, broad emission lines, different from emission regions ionized by stars
  - This led Smith (1975) and Osmer & Smith (1976) to develop the slitless spectrum technique:
  - Very effective for finding quasars at $z > 2$ via direct detection of Lyα emission
  - Schmidt, Schneider, Gunn 1986; deep digital survey with slitless spectra


SDSS Composite Spectrum
Vanden Berk et al. 2001
Ly α
CIV
CIII]
MgII
[OIII]
H α
α_ν = −0.46
α_ν = −1.58
Flux Density, f_λ (Arbitrary Units)
Rest Wavelength, λ (Å)
0.5
1
5
10
1000
2000
4000
6000
8000

Schmidt, Schneider, & Gunn 1986



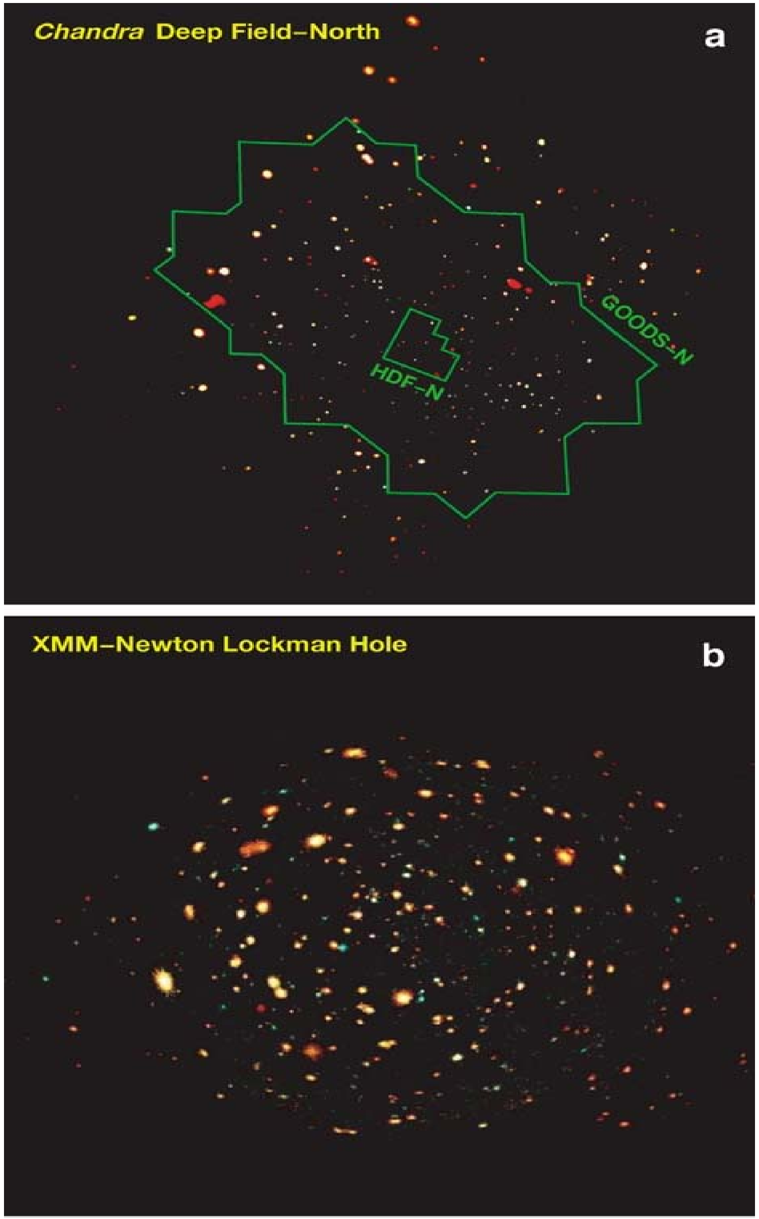
X-Ray Surveys

- X-Ray emission is perhaps the most common and distinctive feature of AGNs & quasars
  - Historically, the first satellites did not have the sensitivity and spatial resolution needed for AGN surveys
  - Now, thanks to Chandra and XMM, deep X-Ray surveys yield the highest surface densities of all techniques

Current Work

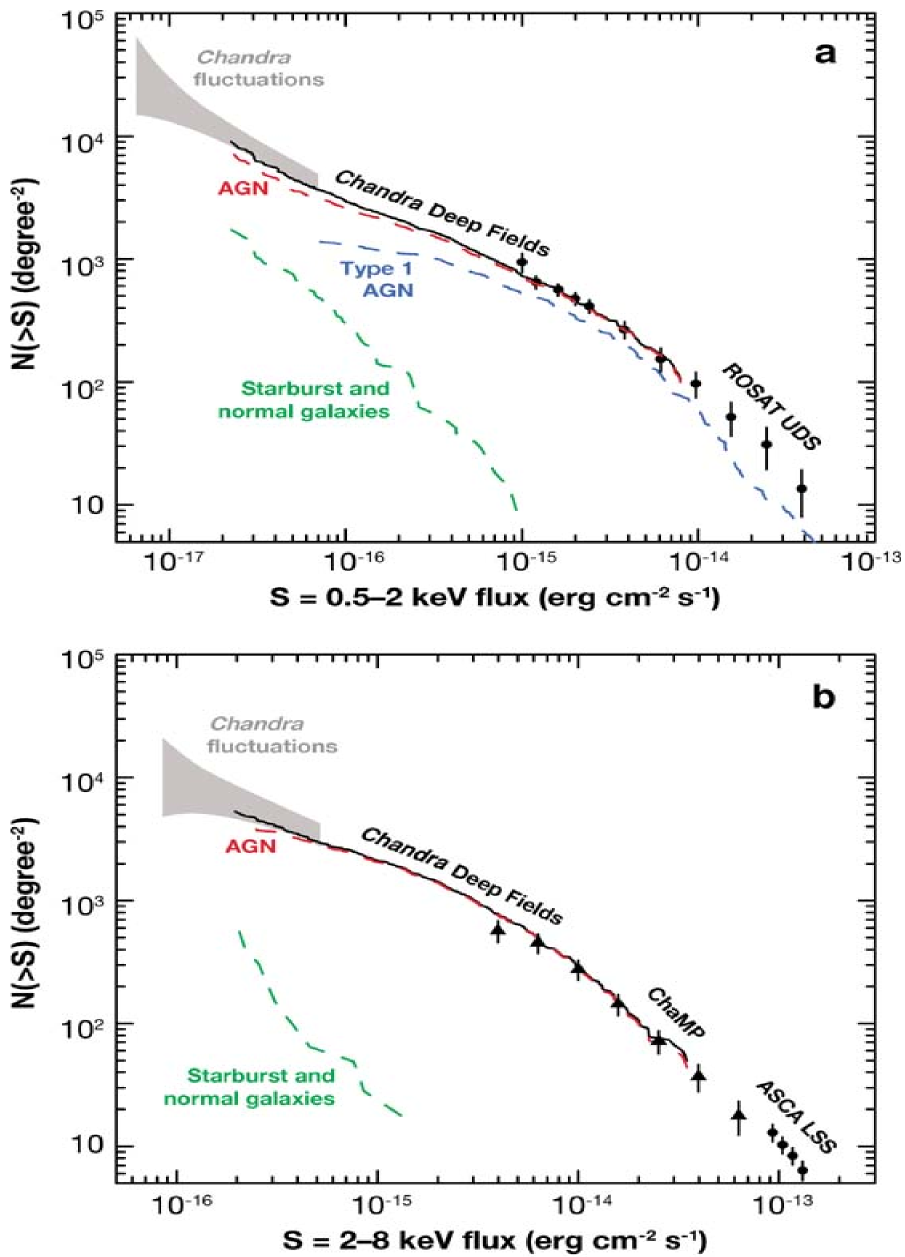
- See review by Brandt & Hasinger, 2005, Annual Reviews for a good summary
- Examples of important surveys:
  - ROSAT
  - ASCA
  - *Beppo*SAX
  - Chandra Deep Fields
  - XMM-Newton

From Brandt & Hasinger 2005



Brandt, WN and Hasinger, G. 2005
Annu. Rev. Astron. Astrophys. 43: 827–59

From Brandt & Hasinger 2005



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Summary for Surveys

- We have discussed some of the main techniques and requirements for finding quasars and AGNs
- They have provided the basis for observations to date
- They have enabled us to map the main observable properties of quasars.

Cosmological Concepts and Calculations

- There are many available texts on cosmology, and you may have your favorite. Peterson's text gives a good description for the "classical" approach
- For the current "concordance" model, with a cosmological constant, I find the article by Hogg (1999), astro-ph/9905116, to very useful

Some of the main concepts

- Observables: redshift, apparent brightness/flux as f(λ), angular size (e.g., for quasar host galaxy)
- What do wish to know?
  - Distance
  - Lookback time
  - Emitted flux or luminosity
  - Physical size
  - Volume elements

- How do we transform between the observed and emitted or physical parameters?
  - Most theorists consider this to be “trivial”
  - And they’re right, except that it is easy to make mistakes
  - Thus Hogg’s paper is an invaluable reference
  - Remember, also, that for quasars we have to assume values of H_0 and now Ω_M and Ω_Λ

More basic concepts

- The redshift, z, and the expansion factor of the universe are related as (1+z)
  - i.e., at z=4, the universe was 1/5 its current size
- In general, comoving coordinates scaled to the present epoch are used, but physical coordinates at time of emission are needed for sizes of hosts, galaxy cross sections, scales of radio jets, etc

Hogg (1999)

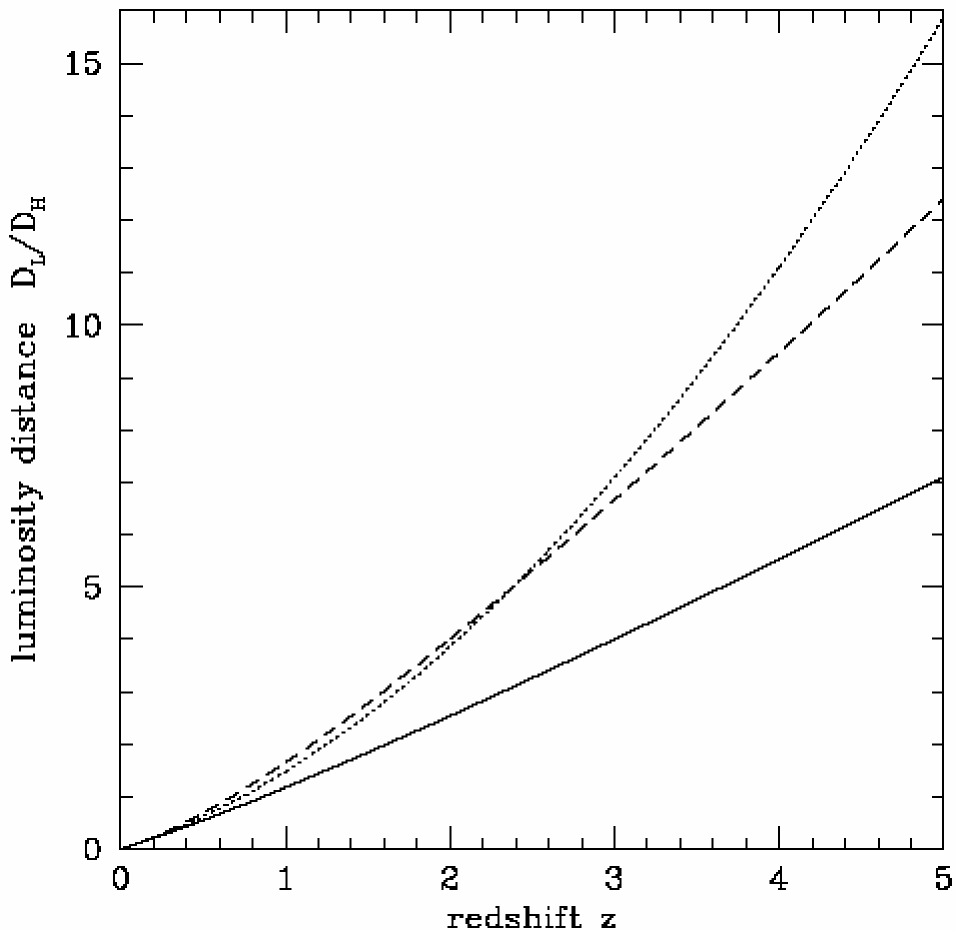


Figure 3: The dimensionless luminosity distance D_L/D_H. The three curves are for the three world models, $(\Omega_M, \Omega_\Lambda) = (1, 0)$, solid; $(0.05, 0)$, dotted; and $(0.2, 0.8)$, dashed.

Hogg (1999)

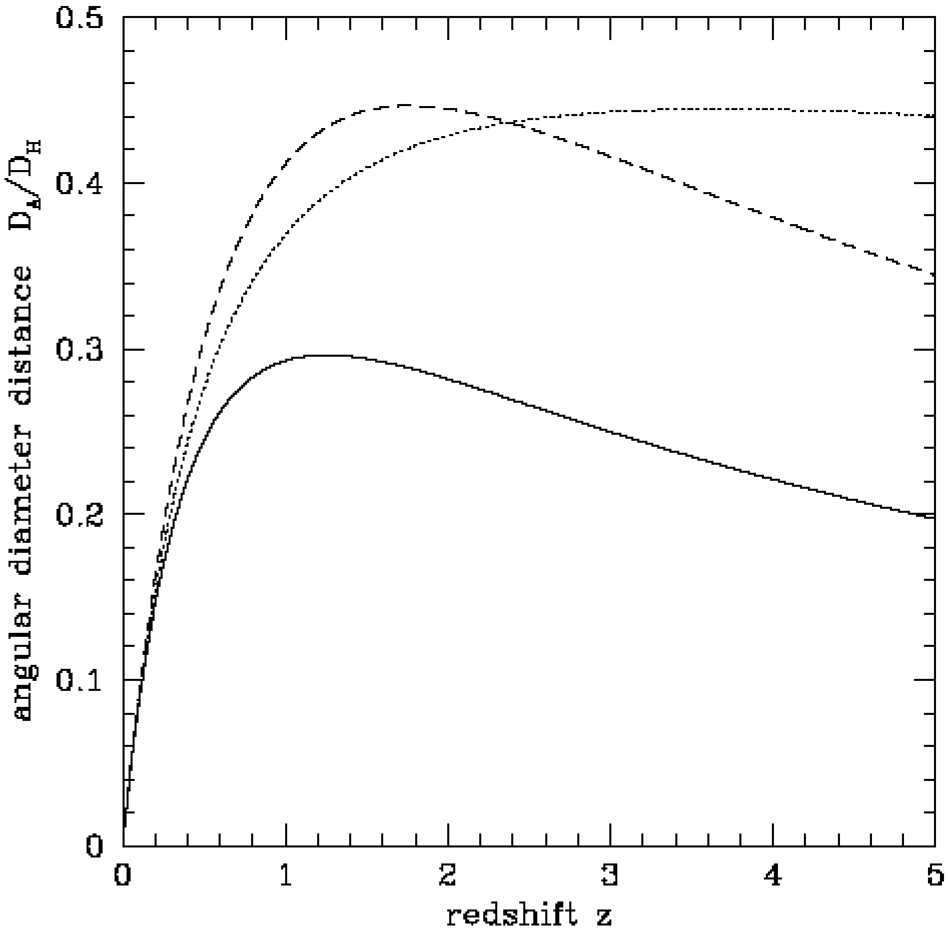


Figure 2: The dimensionless angular diameter distance D_A/D_H. The three curves are for the three world models, $(\Omega_M, \Omega_\Lambda) = (1, 0)$, solid; $(0.05, 0)$, dotted; and $(0.2, 0.8)$, dashed.

Hogg (1999)

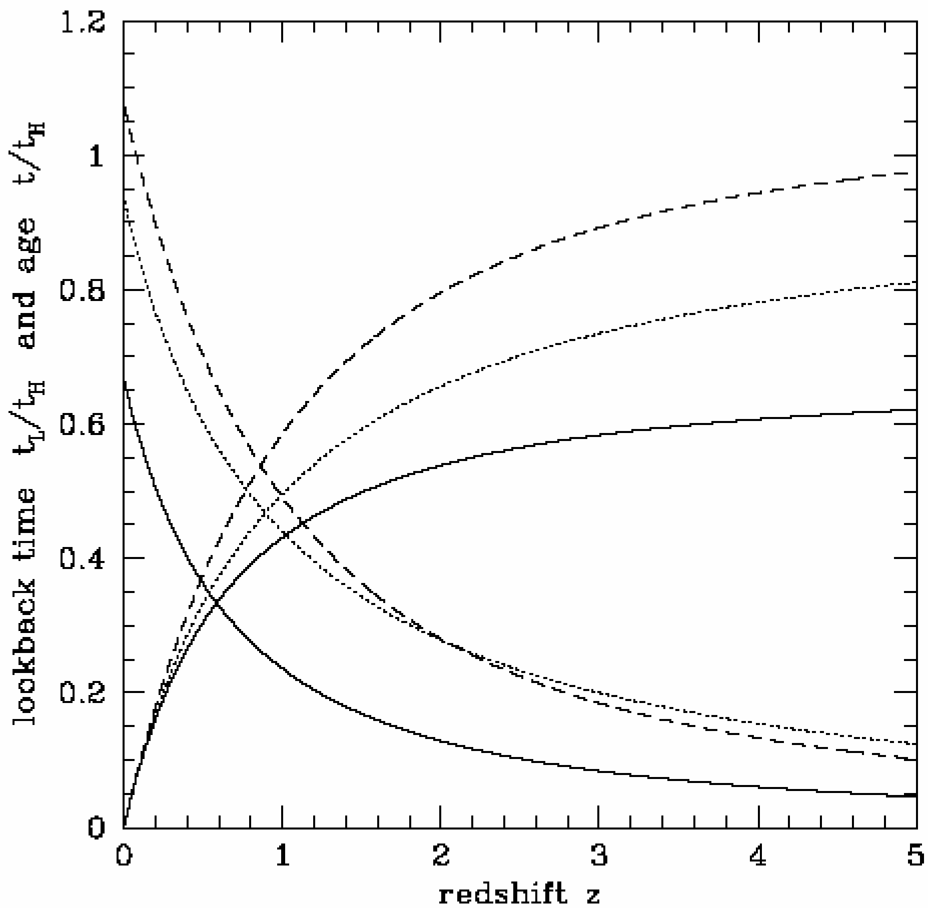
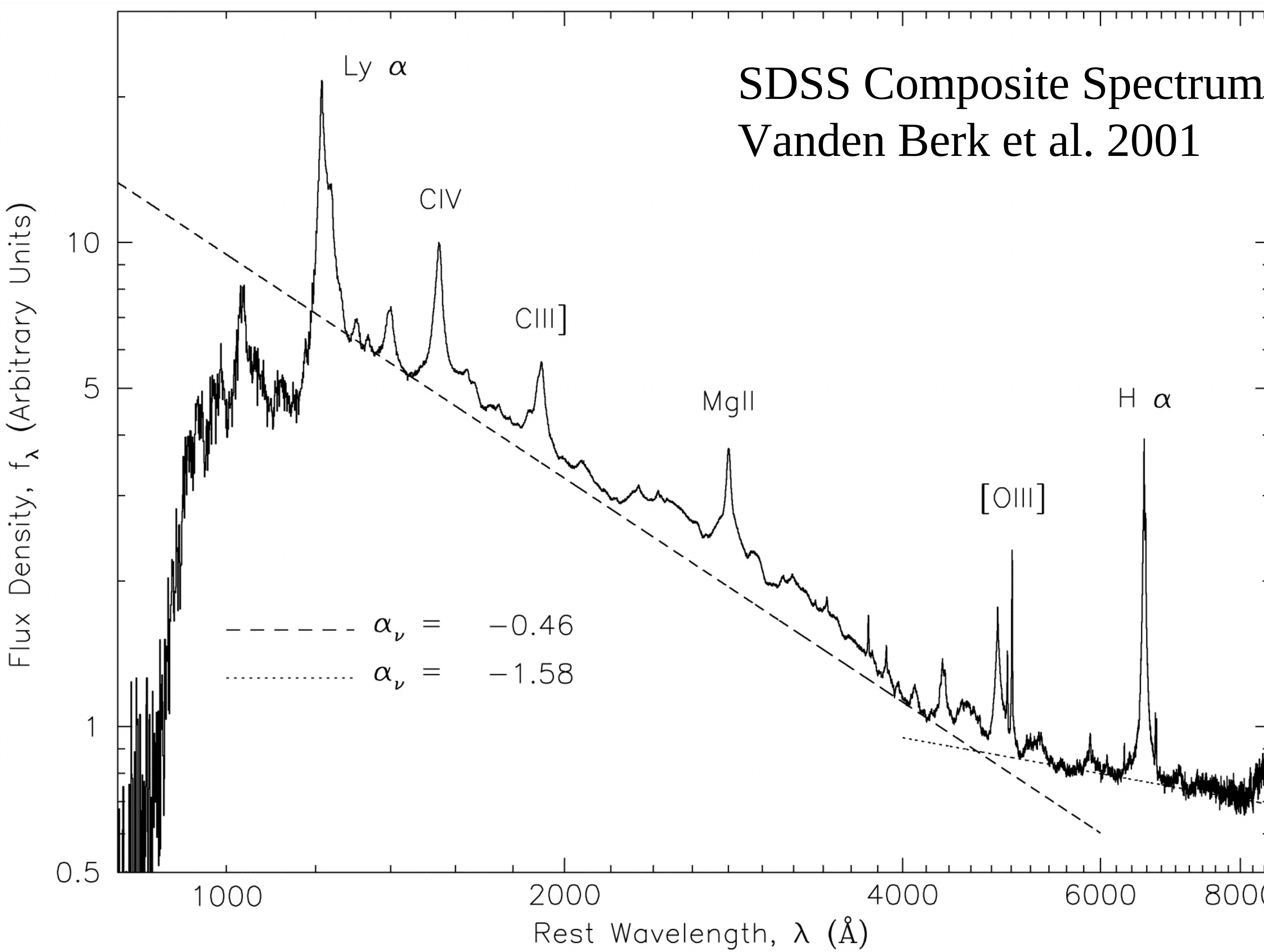


Figure 6: The dimensionless lookback time t_L/t_H and age t/t_H. Curves cross at the redshift at which the Universe is half its present age. The three curves are for the three world models, $(\Omega_M, \Omega_\Lambda) = (1, 0)$, solid; $(0.05, 0)$, dotted; and $(0.2, 0.8)$, dashed.

“Bandpass effects”

- It is also important to keep track of the “bandpass” effects as one transforms between the observed and emitted frames
  - Relations are different for total luminosities and for filters with a specific bandpass
  - Important to remember that transforms from observed “B” magnitudes to emitted “B” magnitudes, for example, involve either an assumption or a measurement of the SED



SDSS Composite Spectrum
Vanden Berk et al. 2001
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1
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- See Peterson text, Ch. 9, and Schmidt & Green 1983 ApJ for the details

$$M_B = B - 5\log A(z) + 2.5(1+\alpha)\log(1+z) - 43.89,$$

(From Schmidt & Green)

Introduction to Evolution

- The lifetime of quasars/AGNs is estimated to be ≈ 10^8 years? How did the activity evolve with time in the universe?

Historical Notes

- Schmidt's work in 1968 and 1970 showed a very surprising result:
  - the space density of quasars at $z \approx 2$ was 100 times greater than at $z = 0$
  - the effect was strong enough to be seen in samples as small as 20 objects
  - In addition, he developed the V/V_m test for this work, a test that is still applied to new categories of objects

Cosmological implications

- The activity of quasars at z=2 was much greater than at present.
- What does this tell us about the evolution of quasar activity? Why is it occurring?
- Today, the questions can be posed in terms of relating the observed evolution of quasars and AGNs to their *physical* evolution, which will be topics to cover tomorrow

Summary

- Today we have reviewed the main techniques for finding quasars and some of the main sources and catalogs for current work. The growth in numbers has been explosive in the last decade.
- We also reviewed how to do the basic calculations needed to transform between observed and emitted properties

- Finally, we introduced the subject of the evolution of quasars, which is a theme covering much of current research on both quasars and galaxies. It is a topic we will take up in more detail tomorrow.