Galaxy Formation and Evolution

Lecture 1:
Historical Perspective

Course contents

1. <u>Historical introduction</u>
2. Challenges and recent advances
3. Galaxy formation in theory
4. Spectral synthesis and star formation indicators
5. The fossil record for local galaxies
6. Survey astronomy
7. The Madau Diagram and Lyman Break galaxies
8. Studying galaxy evolution in the IR/sub-mm
9. The evolution of early-type galaxies
10. Morphological evolution and spiral galaxies
11. AGN discovery and observed properties
12. AGNs and supermassive black holes
13. Black hole growth and formation
14. The triggering of AGN
15. AGN feedback and outflows
16. The link between star formation and AGN activity
17. The far frontier and outstanding challenges
18. The future of the Universe

Related courses

- **PHY104: Introduction to astrophysics**
- PHY213: Stellar structure and evolution
- **PHY216: Galaxies**
- PHY217: Techniques of observation
- PHY232: The dynamic interstellar medium
- PHY306: Introduction to cosmology
- PHY404: Cosmic origins
  - Star formation
  - Stellar evolution

Assessment

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- 70% exam (3 out of 5 questions)

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- 20% directed reading/paper summaries – Deadlines:
  - Friday 15th March 4pm (1st three summaries);
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- 20% directed reading/paper summaries – Deadlines:
  - Friday 15th March 4pm (1st three summaries);
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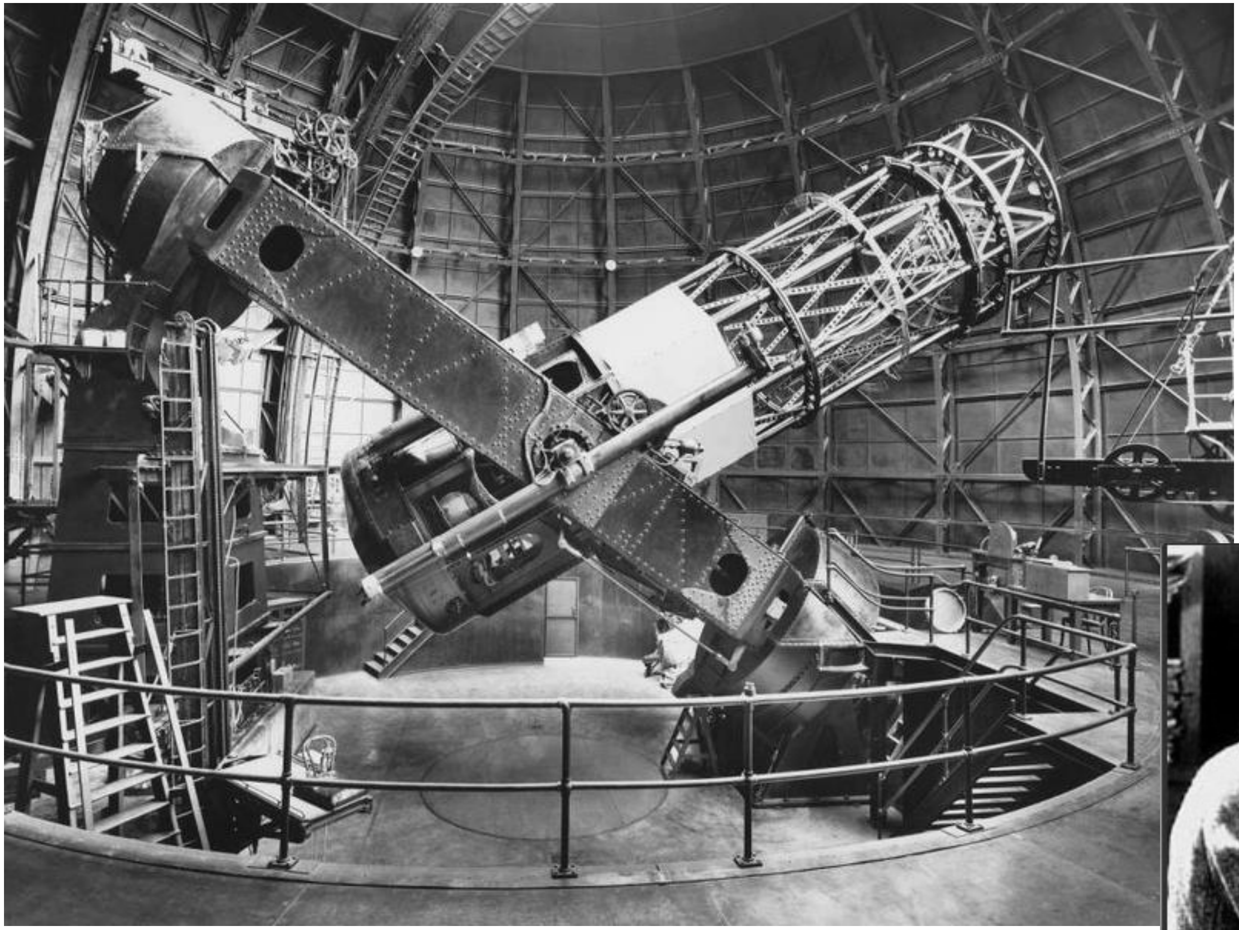
- 10% short 15+5m presentations on galaxy evolution topic to peers (w/c 6th May)

Lecture 1: learning objectives

- Appreciation and knowledge of the most important discoveries in studying galaxies and their evolution up to the 1980s
- Knowledge of the most important observational features of galaxies that need to be explained
- Knowledge and understanding of the early evidence for galaxy evolution (up to the 1980s)
- Understanding of the basic approach of observing the high redshift Universe to investigate galaxy evolution
- An appreciation of the impact of technology on studies of galaxy evolution

100-inch telescope at Mount Wilson (1917)



Edwin Hubble

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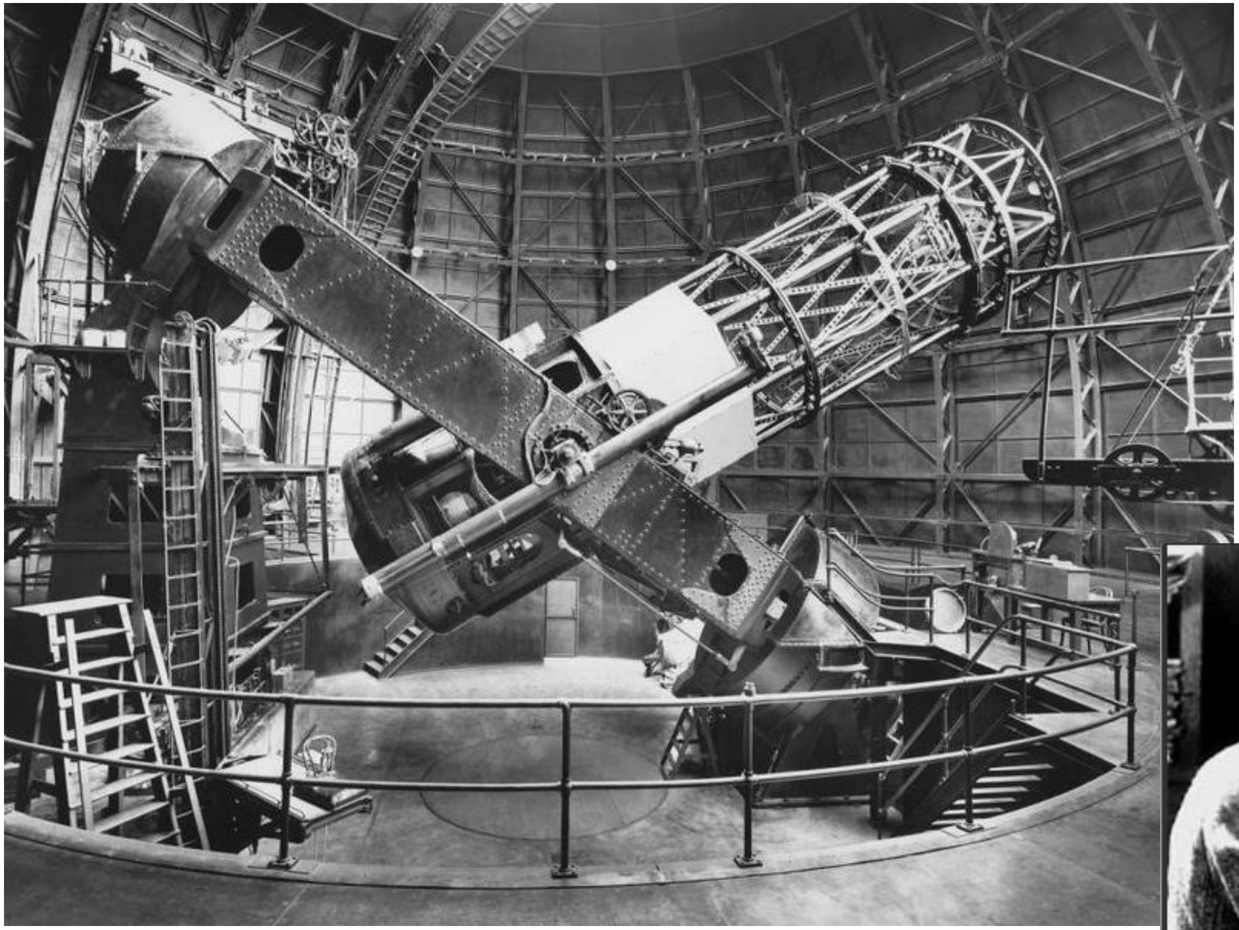

100” telescope at Mount Wilson

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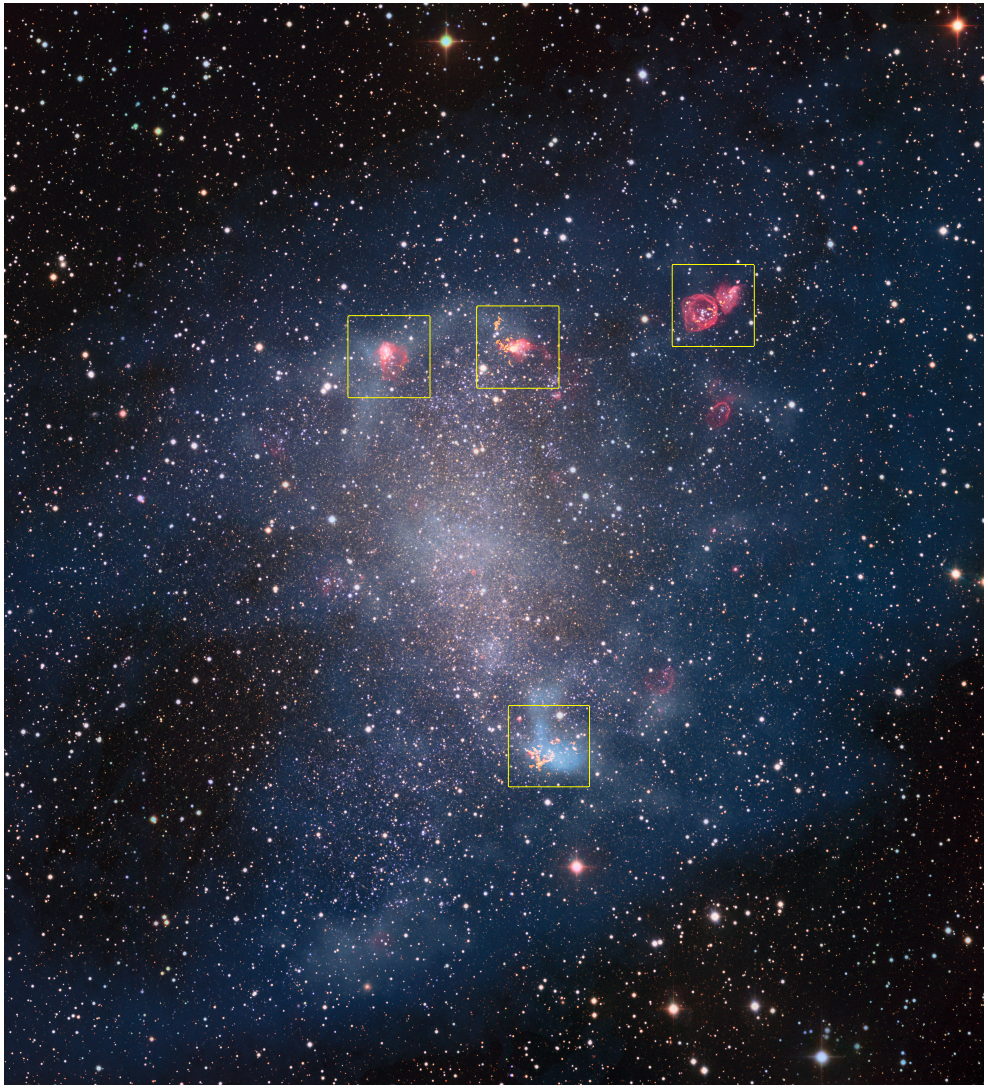
Distances to galaxies: NGC 6822

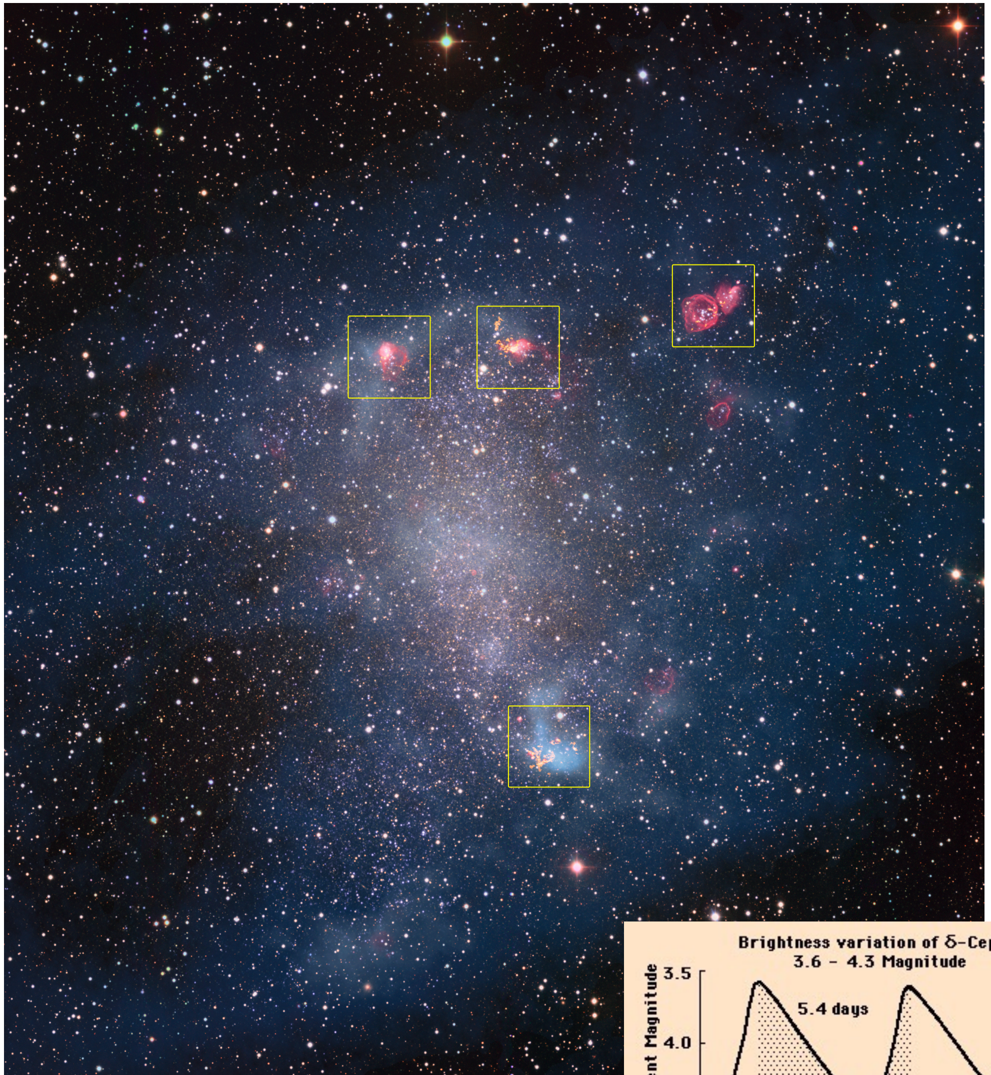


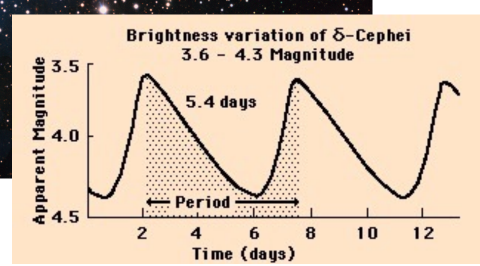
In 1924, Edwin Hubble used the period-luminosity relationship of Cepheid Variables to measure the distance to NGC 6822.

Measuring the flux (F) of a CV and knowledge of its intrinsic luminosity (L) allows us to calculate the distance (d) to a source:

$$F = \frac{L}{4\pi d^2}$$

Distances to galaxies: NGC 6822





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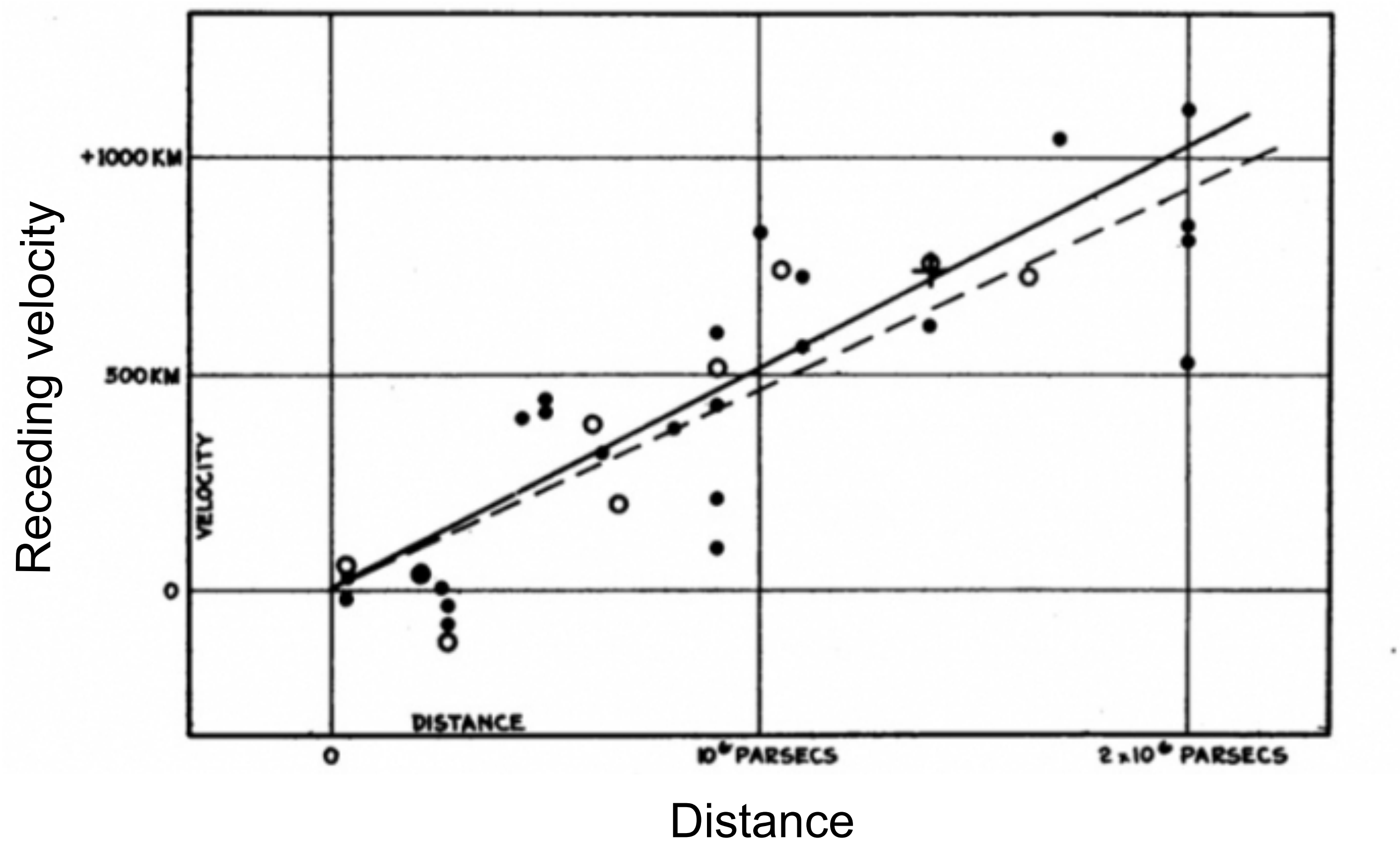
Hubble's law (1929)



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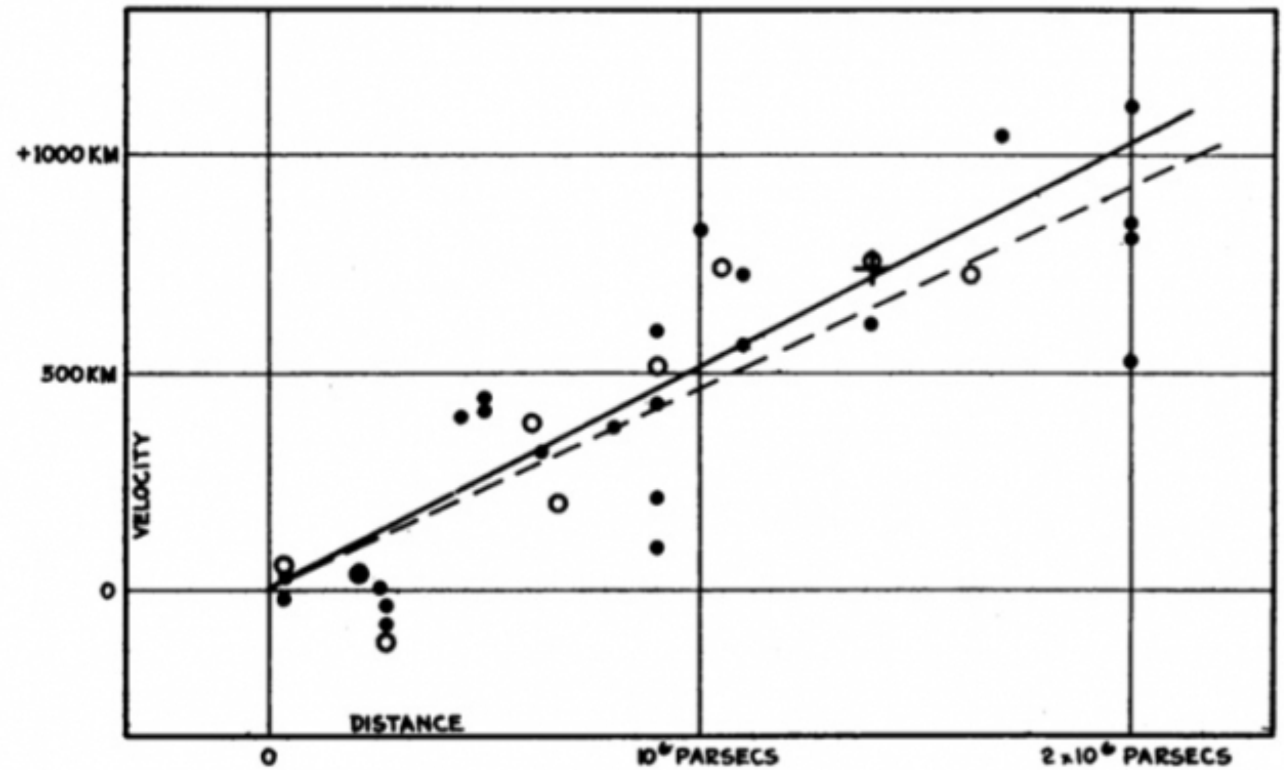
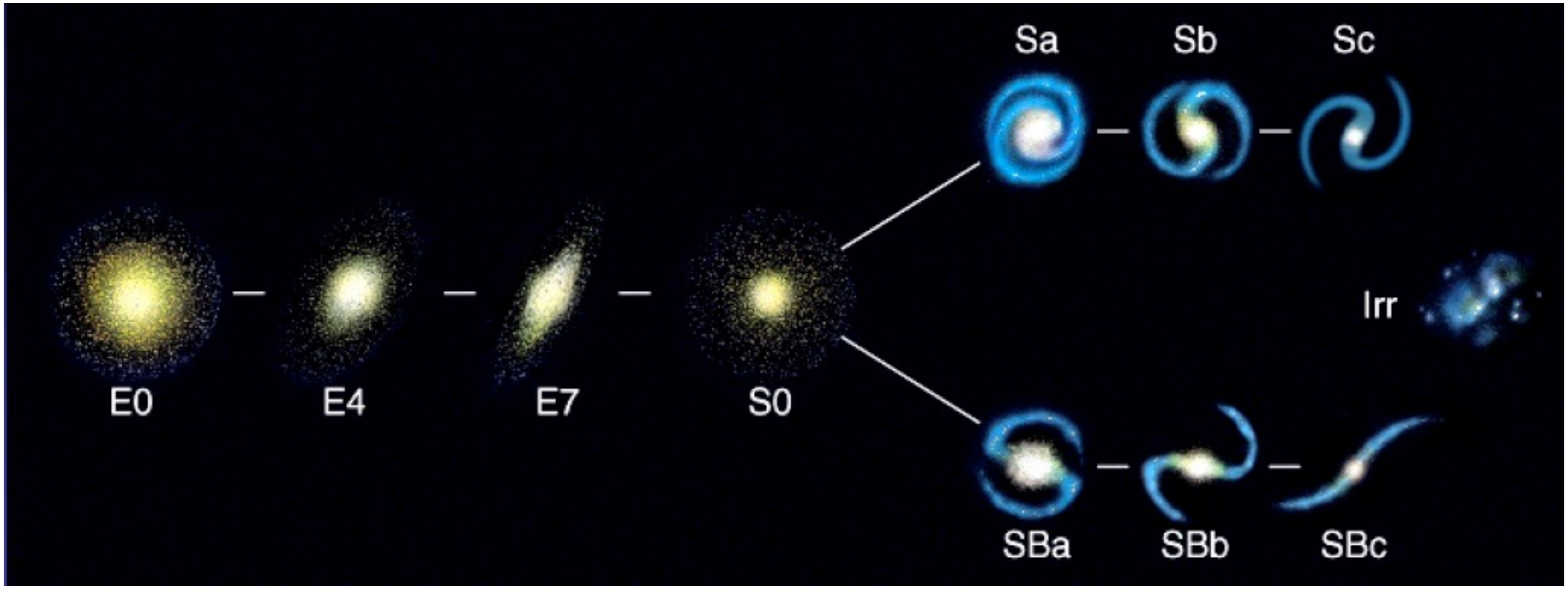


- Provides clear evidence that the Universe is *expanding* and also that it is *homogeneous*
- First clear sign that the Universe originated in a Big Bang (but not conclusive)
- Redshift allows accurate distances to galaxies to be determined.

The diversity of galaxies

We have now observed many millions of galaxies (of the trillions that exist in the observable Universe).

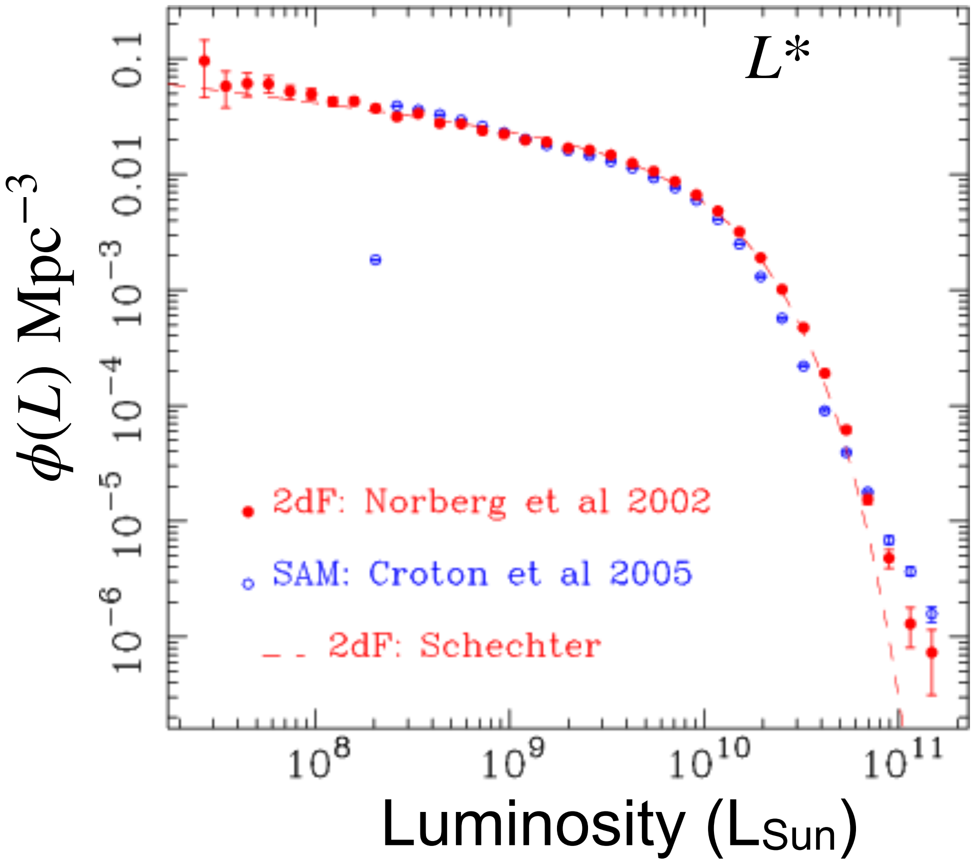
What we need to explain I



Hubble (1926)

Galaxy morphologies & the Hubble sequence

Local galaxy luminosity function:

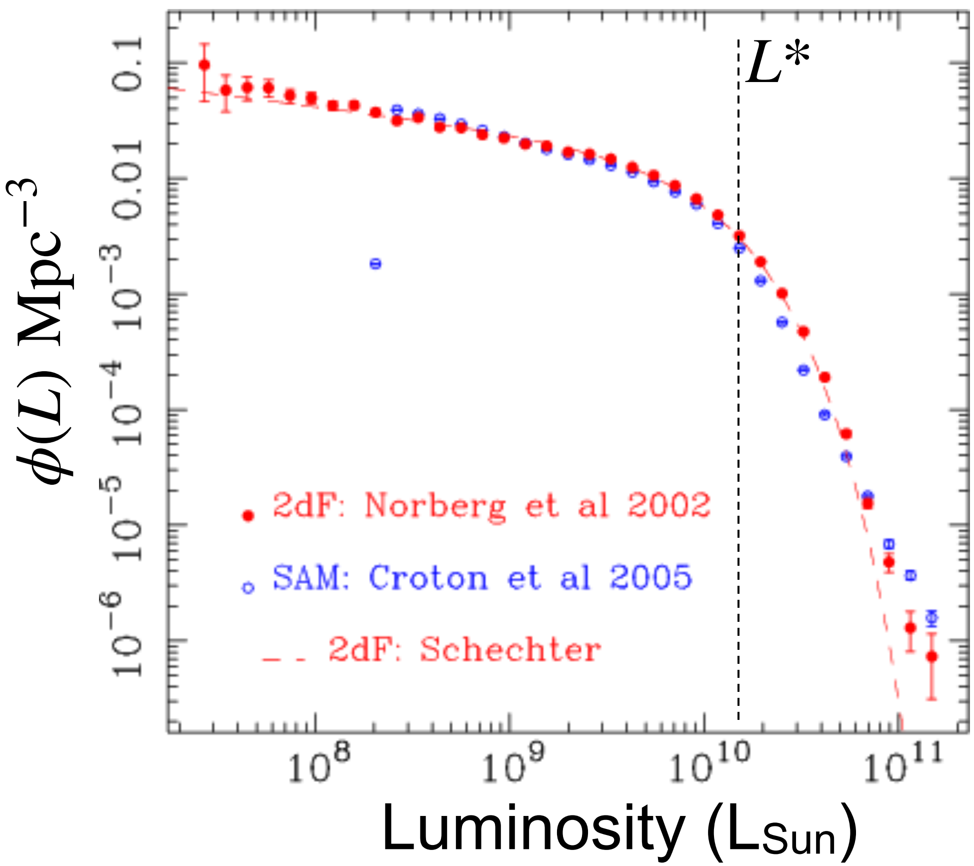


Schechter function: $\phi(L)dL = \phi^*(L/L^*)^{-\alpha}\exp(-L/L^*)dL/L^*$

L^*

What we need to explain II

Local galaxy luminosity function:



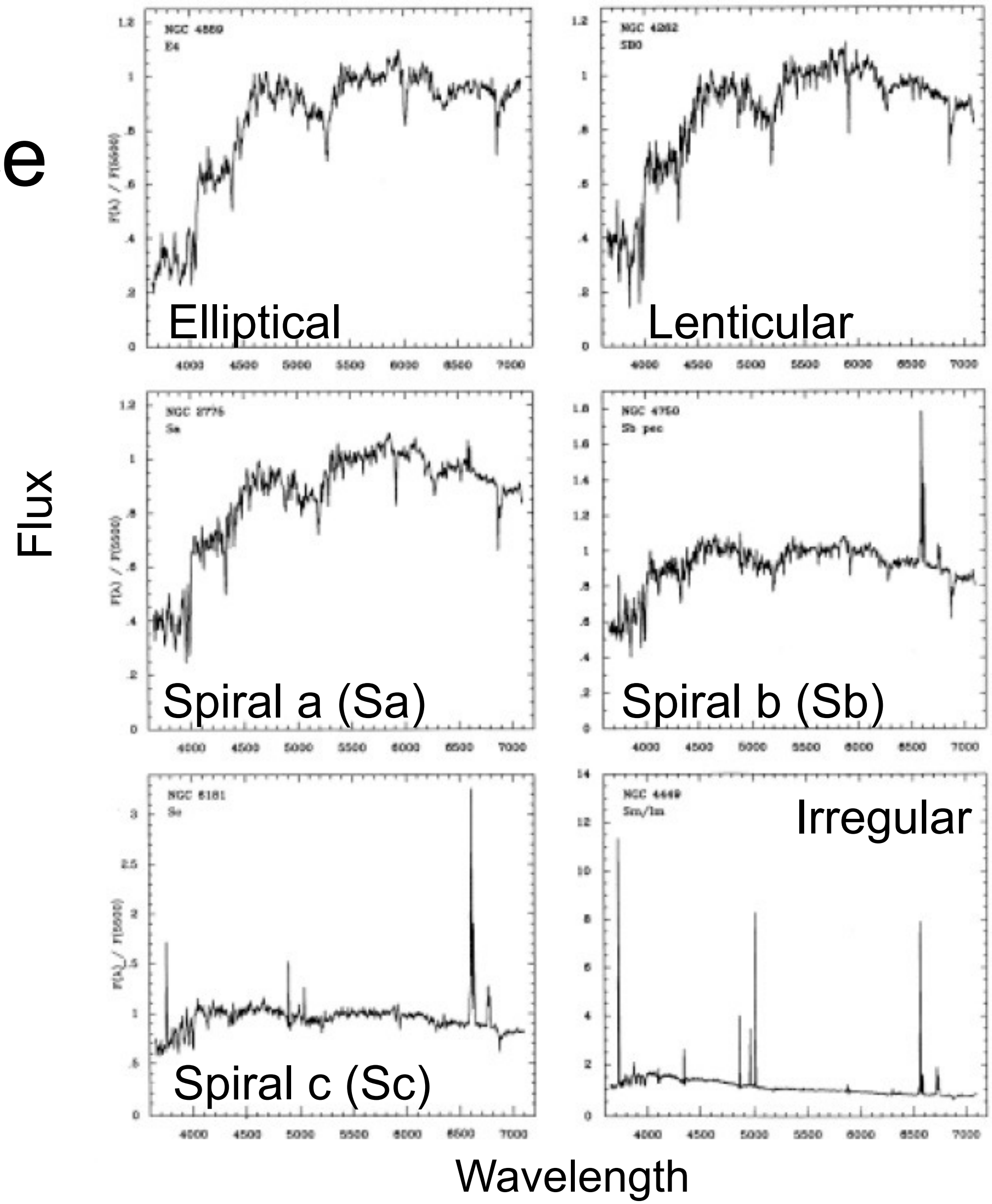
Schechter function: $\phi(L)dL = \phi^*(L/L^*)^{-\alpha}\exp(-L/L^*)dL/L^*$

Characteristic luminosity: L^*

Stellar populations along Hubble Sequence

The shape of the continuum and the strength of the absorption & emission lines in these spectra are related to the age of the stellar populations.

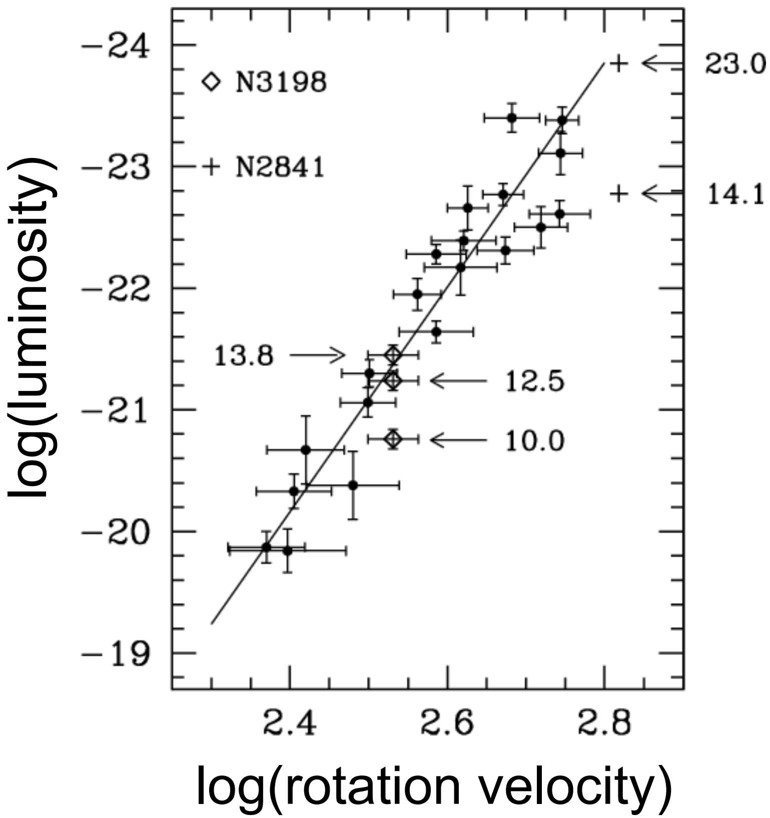
Different types of galaxies *tend* to have different age stellar populations.



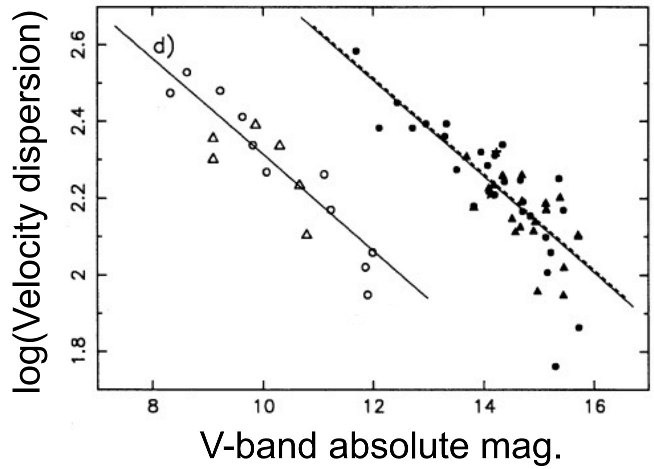
What we need to explain - IV

Galaxy Scaling Relationships

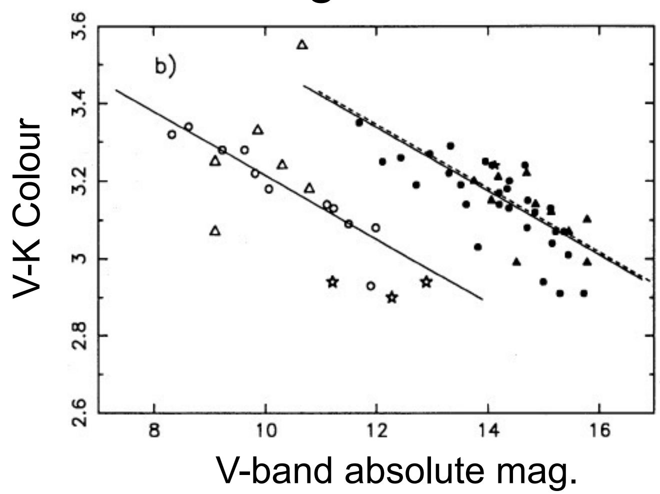
Spirals:
Tully-Fisher relationship



Ellipticals:
Faber-Jackson relationship



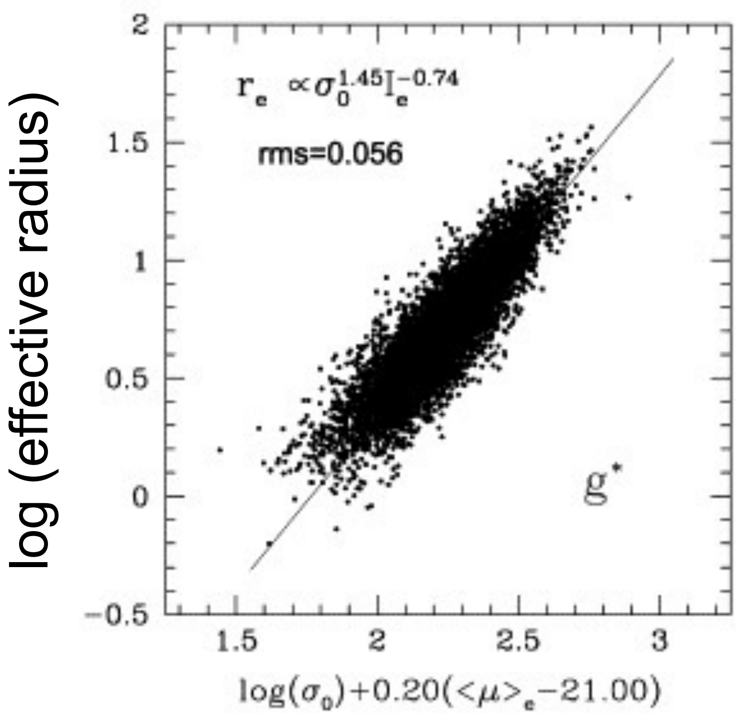
Colour - magnitude relationship



What we need to explain - IV (cont'd.)

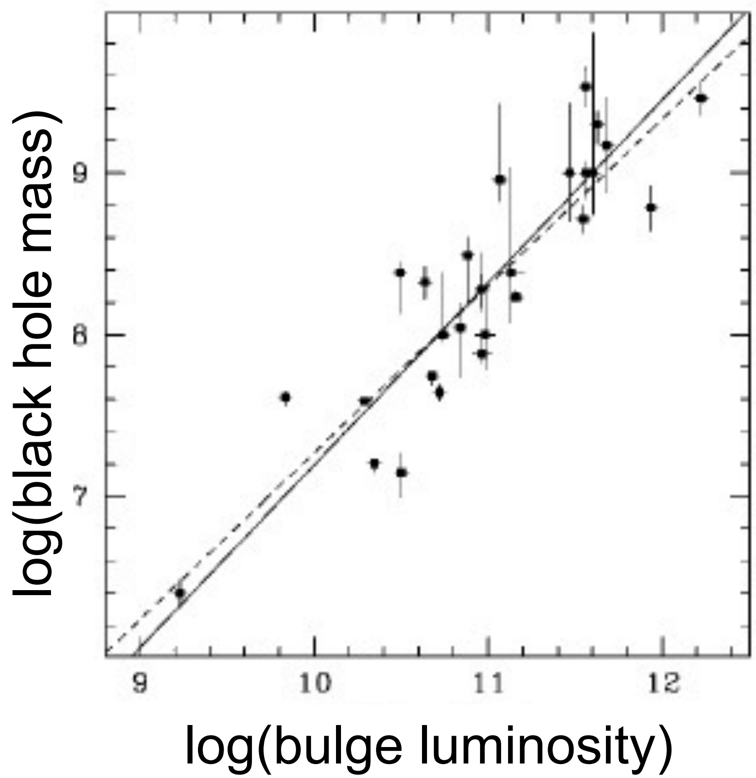
Galaxy scaling relationships

Fundamental plane (ellipticals)



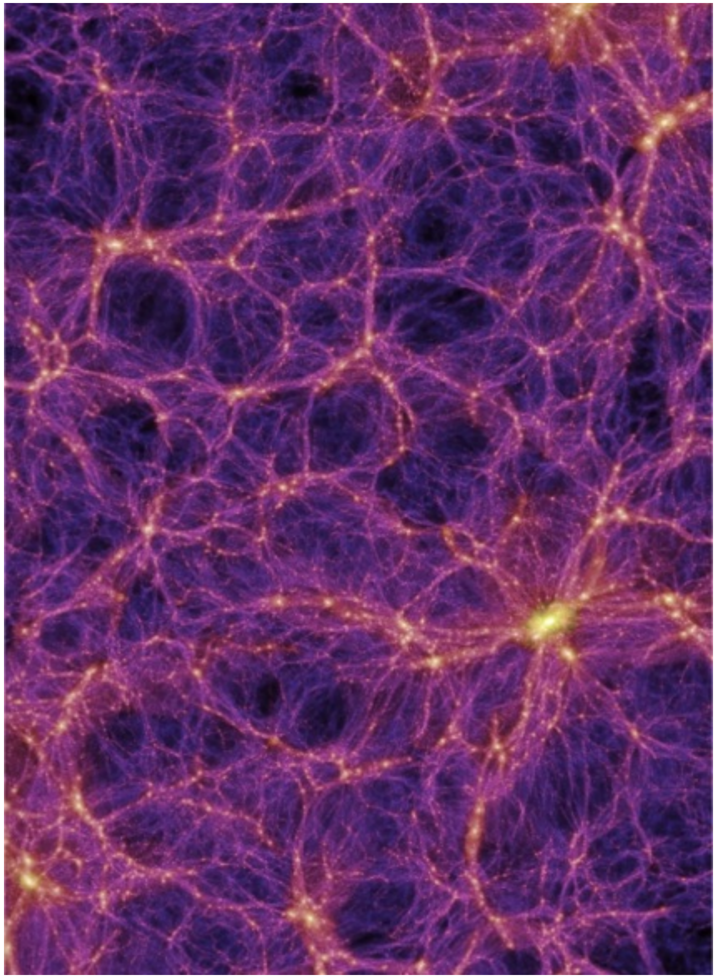
f(velocity dispersion, central surface brightness)

Black hole mass - bulge properties



What we need to explain - V

Galaxy clustering & large scale structure



Galaxies live in different environments. Some are relatively isolated, some live in small groups, some live in large clusters and superclusters.

From observations, we see that the physical properties of galaxies are related to their environment.

Galaxy evolution: what we want to explain

- Galaxy structures
- Galaxy luminosity function
- Galaxy scaling relationship (e.g. Tully-Fisher, Faber-Jackson, Colour-Magnitude etc.)
- Mix of galaxy types
- Stellar populations
- Elemental abundances
- Galaxy clustering properties

Studying galaxy evolution via observations

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- Fossil approach. Examining the detailed structures, stellar populations, abundance patterns of galaxies in the local Universe – the "fossil record" (see PHY216 course).

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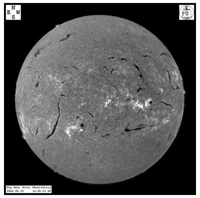
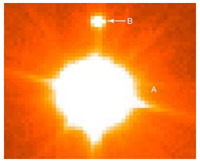
- High redshift approach. Examining the properties of distant galaxies as a function of redshift/lookback time.

Looking back in time

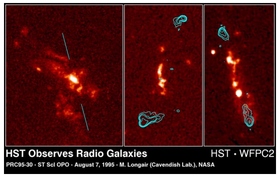


The Sun
152 million km



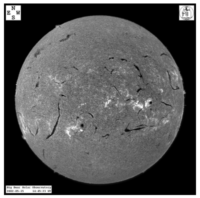
The nearest stars
~4 light years

The nearest galaxy
~ 1 million light years



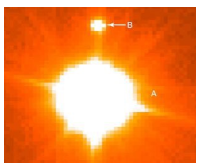
The most distant galaxies
~12 billion light years

Looking back in time



The Sun
152 million km

Seen as it was
8 minutes ago



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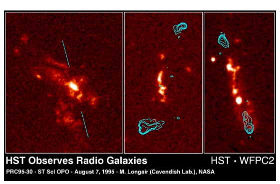

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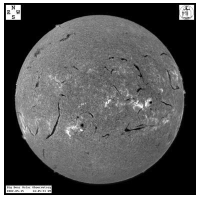

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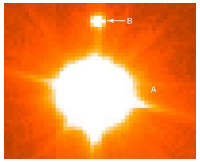

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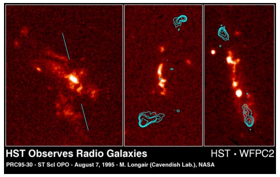

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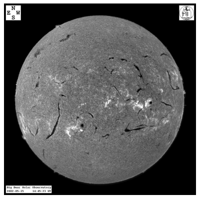

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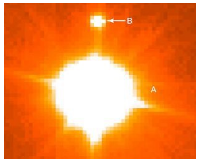

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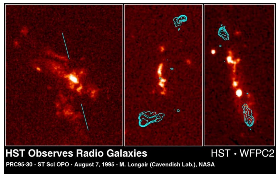

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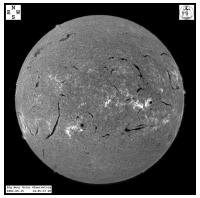

The Sun
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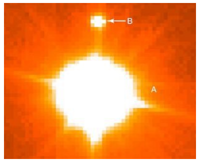

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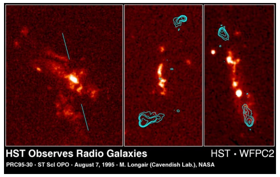
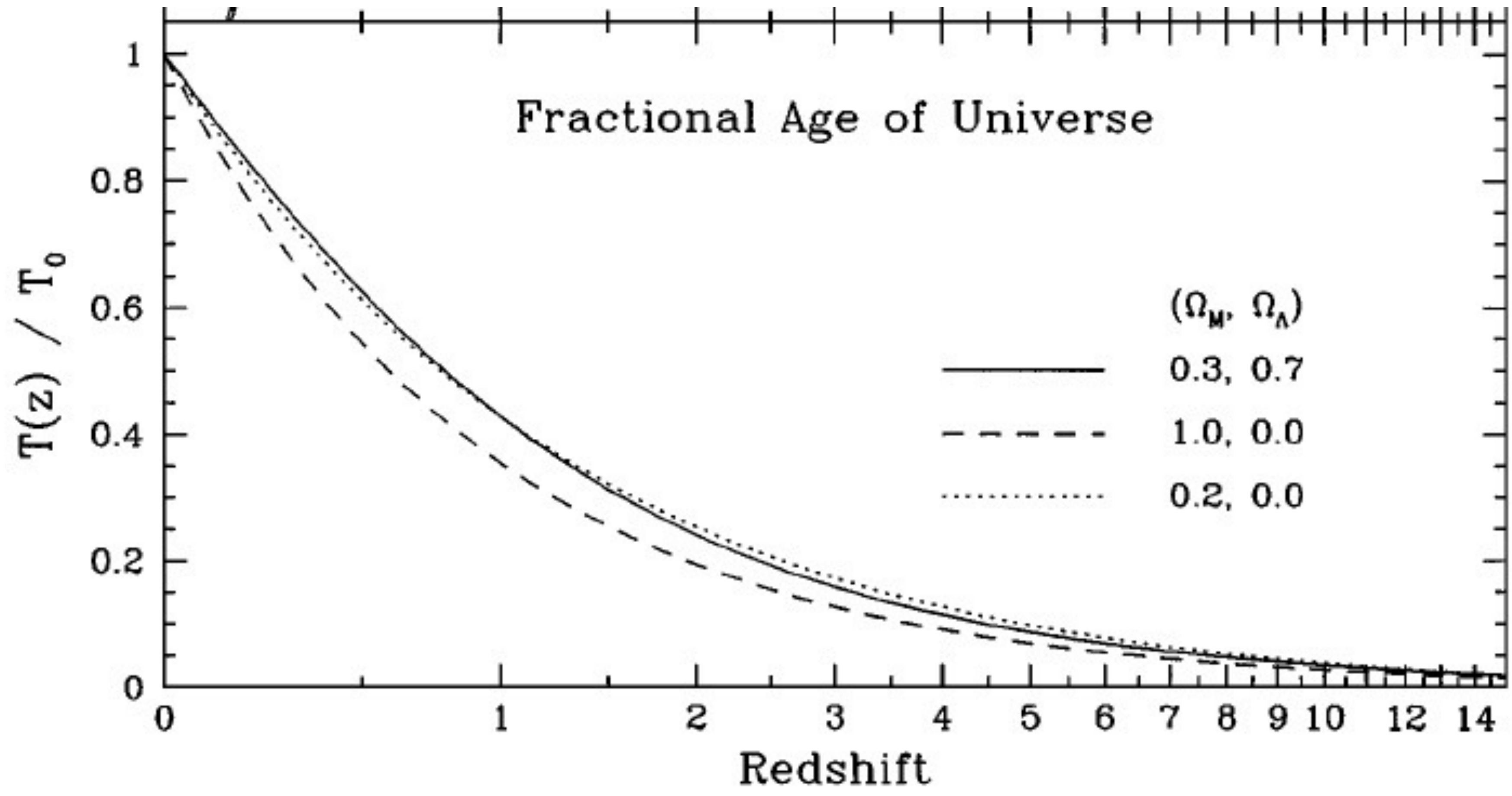


The most distant galaxies
~12 billion light years → 12 billion
years ago

Lookback time vs. redshift



Early evidence for an evolving Universe I

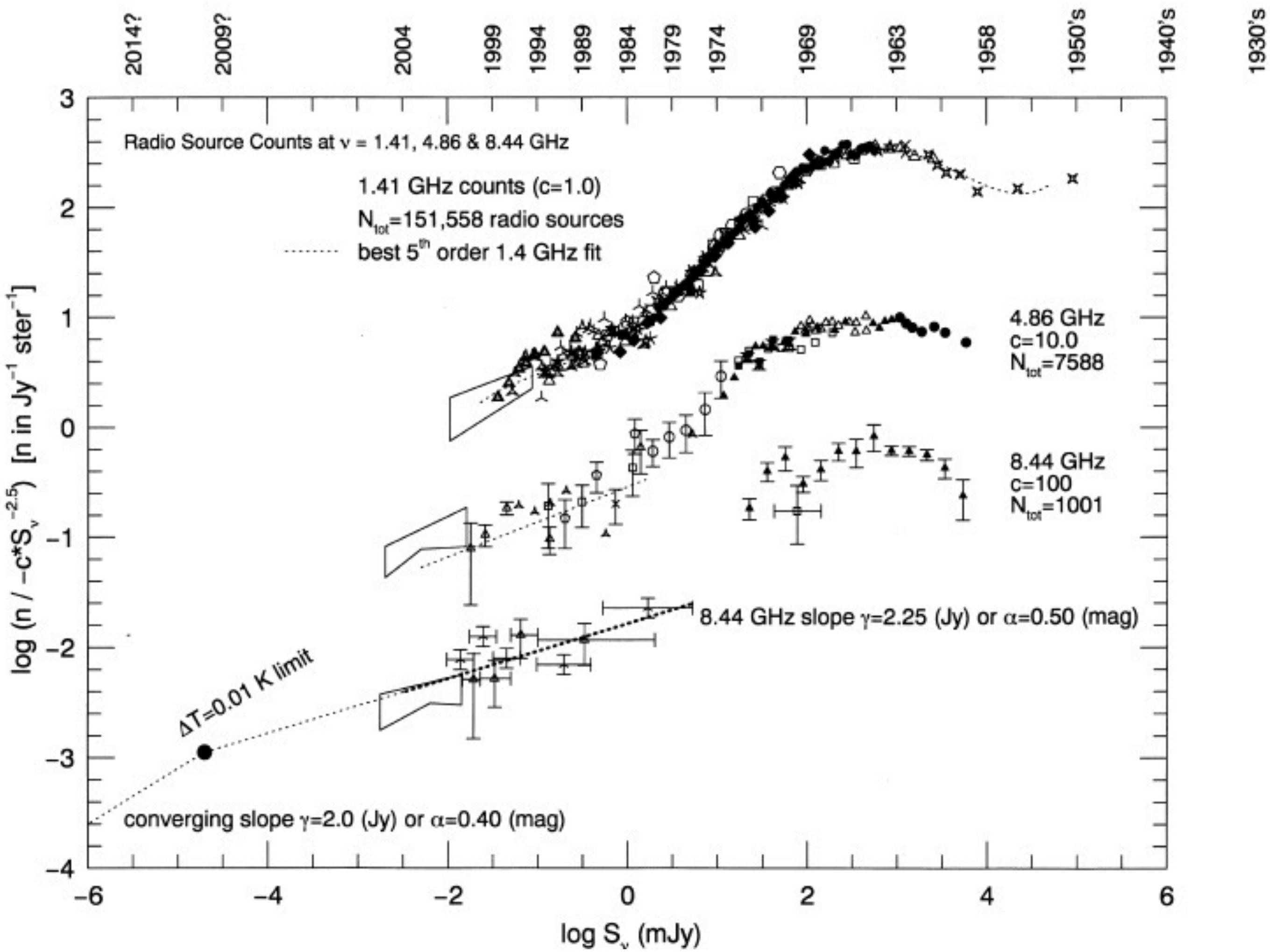
Olber’s paradox (1826)

- Olber’s paradox concerns the question of why the night sky is dark
- In an infinite, non-evolving Universe, we would expect the entire sky to be as bright as the Sun, because every sightline would intercept a star or galaxy
- This paradox can be resolved if the Universe is finite, expanding and/or evolving

  (But not conclusive evidence for an evolving universe…)

Early evidence for an evolving Universe II

Quasar and radio galaxy number counts



Early evidence for an evolving Universe III

V/V_{max} test for quasars and radio galaxies

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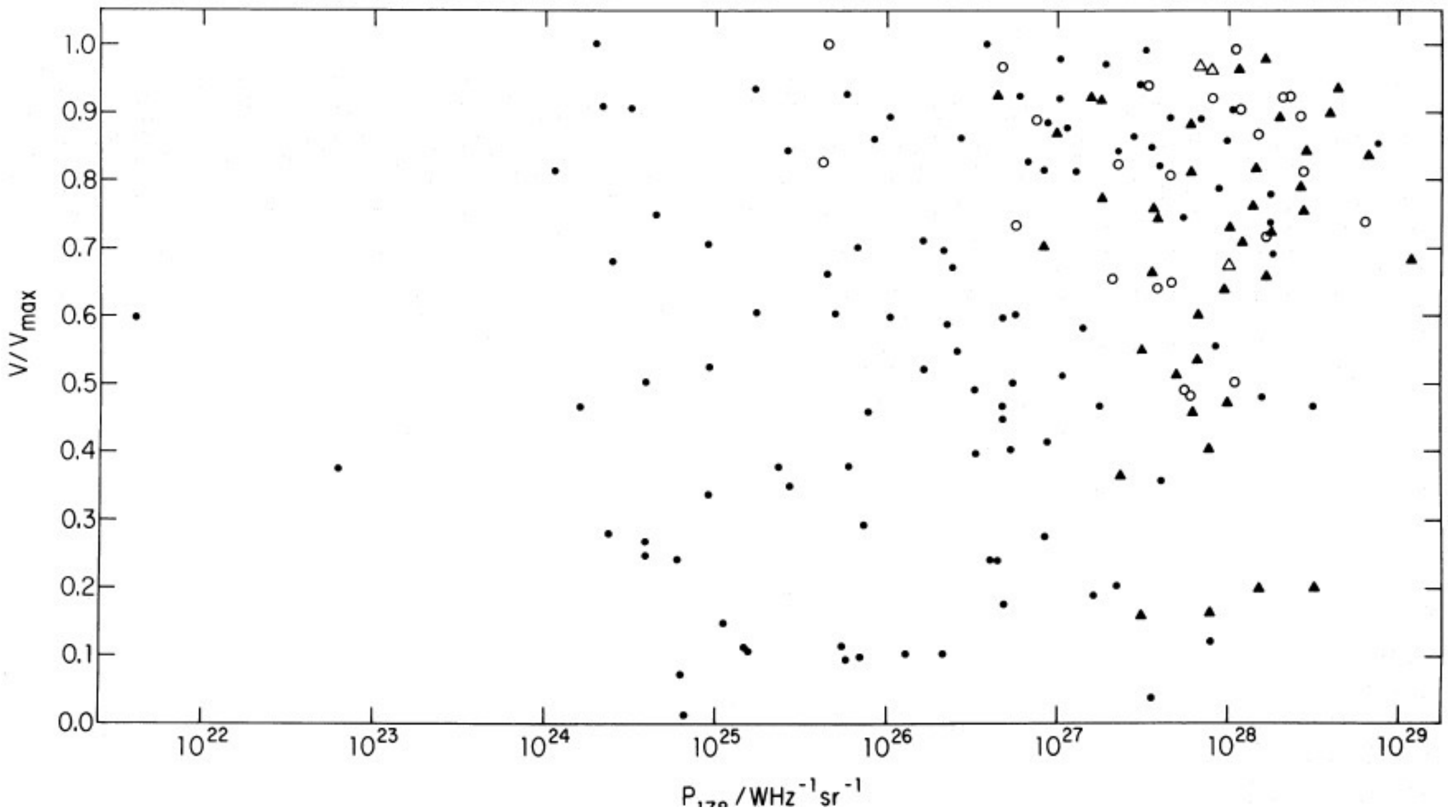
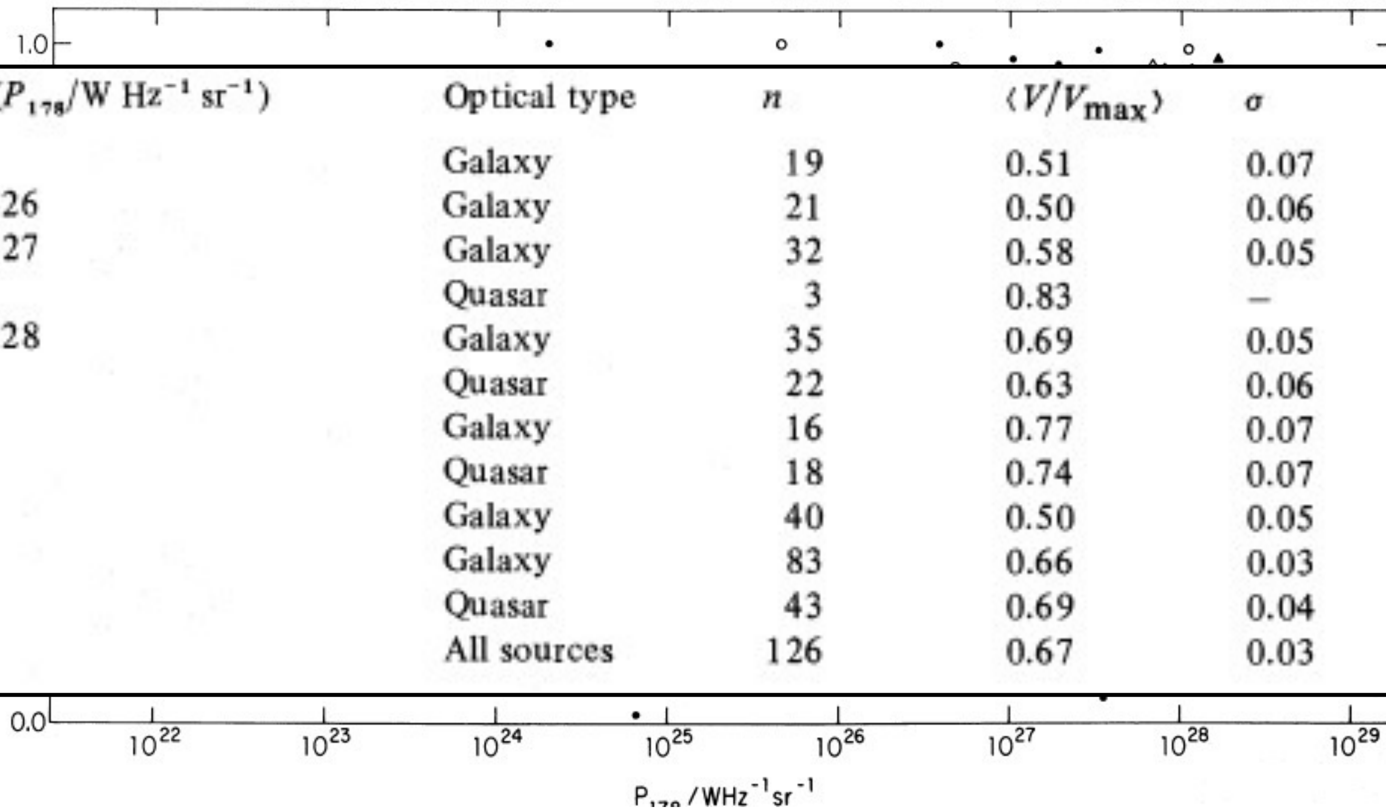


Early evidence for an evolving Universe III

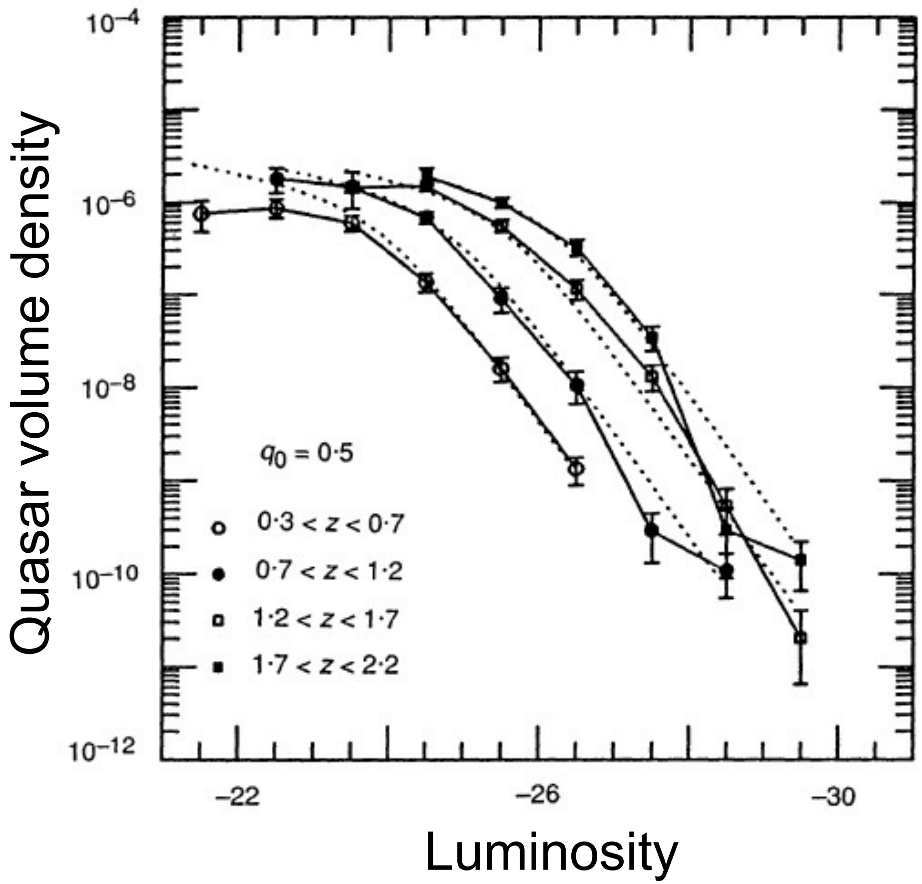
V/V_{max} test for quasars and radio galaxies



$\log_{10}(P_{178}/\mathrm{W\ Hz^{-1}\ sr^{-1}})$	Optical type	n	$\langle V/V_{max}\rangle$	σ	D
≤25	Galaxy	19	0.51	0.07	0.1
25–26	Galaxy	21	0.50	0.06	0.03
26–27	Galaxy	32	0.58	0.05	1.6
	Quasar	3	0.83	–	–
27–28	Galaxy	35	0.69	0.05	4.0
	Quasar	22	0.63	0.06	2.1
>28	Galaxy	16	0.77	0.07	3.7
	Quasar	18	0.74	0.07	3.5
≤26	Galaxy	40	0.50	0.05	0.06
>26	Galaxy	83	0.66	0.03	5.2
	Quasar	43	0.69	0.04	4.3
	All sources	126	0.67	0.03	6.7

Early evidence for an evolving Universe IV

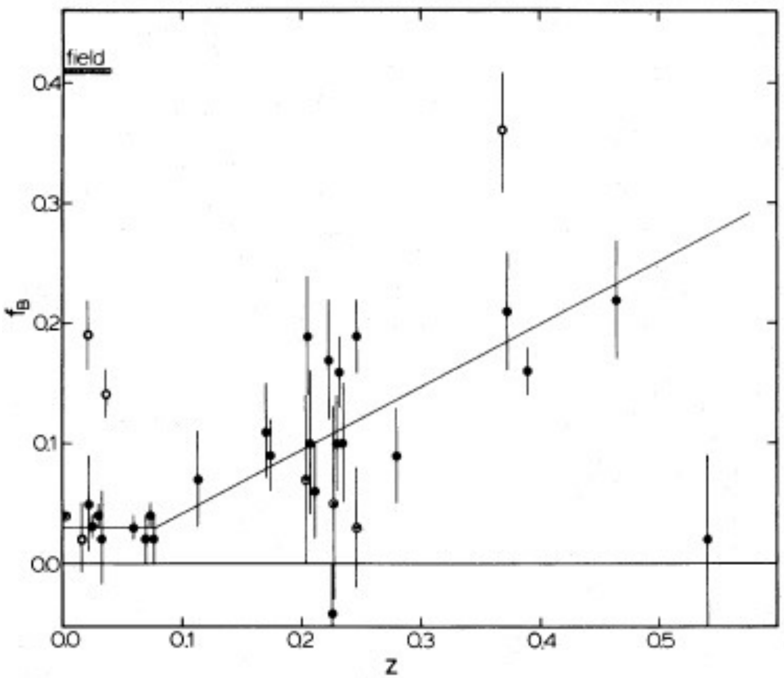
Quasar luminosity function



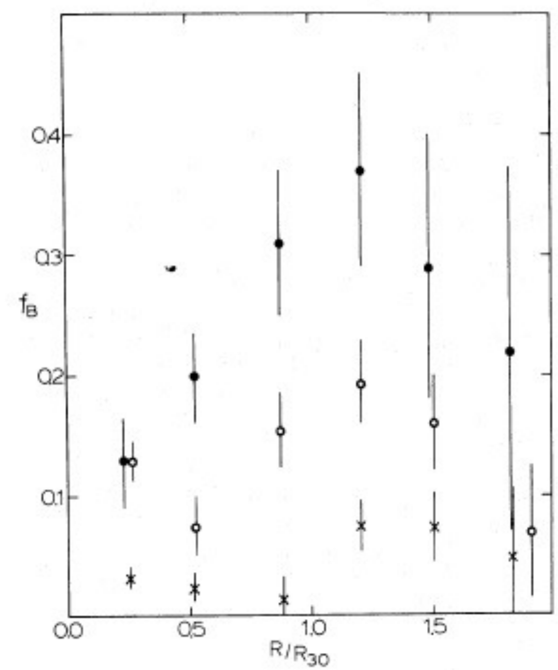
The quasar luminosity function shows substantial luminosity evolution: there is a larger number of luminous quasars at high redshifts
– Boyle (1988)

Evidence for an evolving universe V

Butcher-Oemler effect (1984)



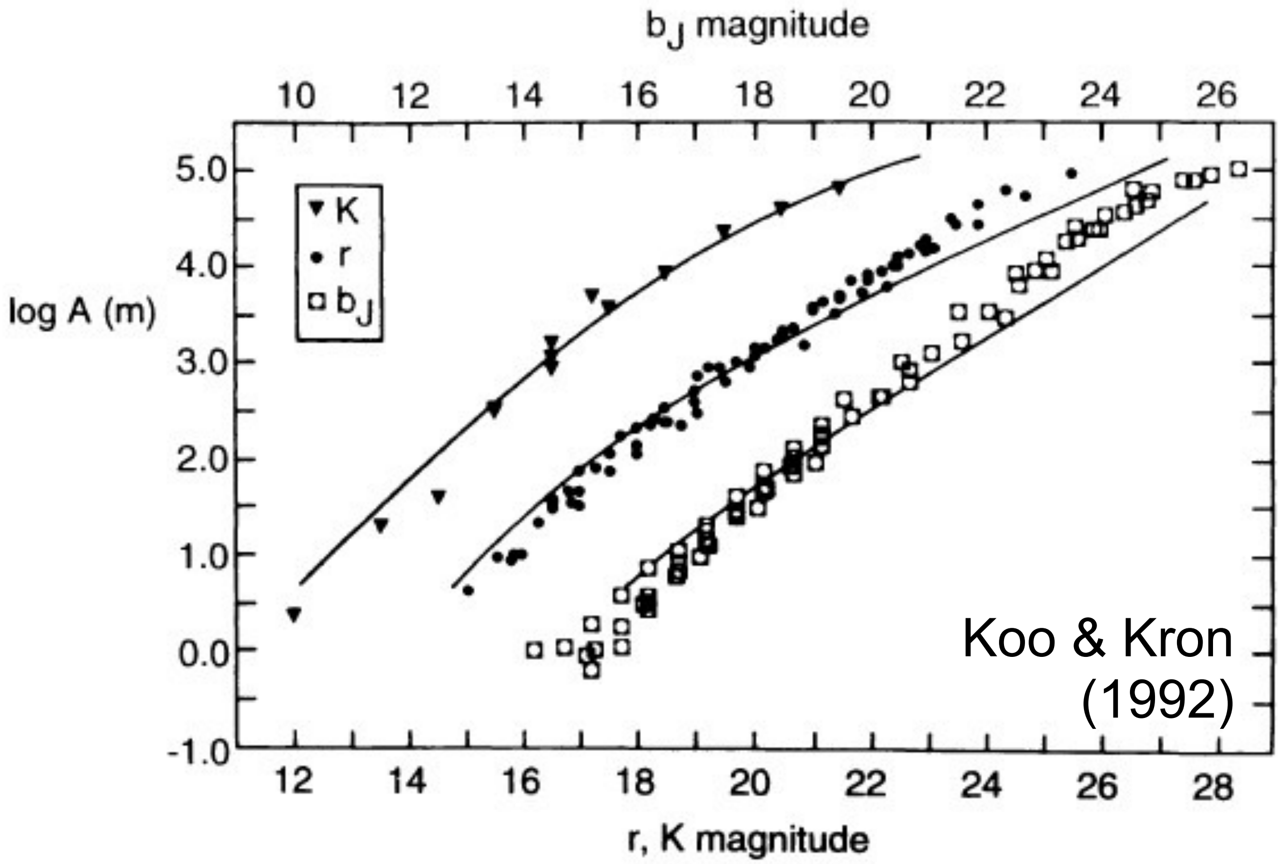
The fraction of blue galaxies in clusters increases with redshift



The fraction of blue galaxies increases with radius within the cluster – galaxies in the outskirts tend to be bluer than those in the central regions.

Early evidence for an evolving Universe VI

Galaxy number counts



Number counts of faint blue galaxies falls above the predictions of no evolution models at faint magnitudes

Progress up to early-1990s

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- By 1990 there was substantial evidence for evolution in the number density and luminosity function of quasars and radio galaxies
- Evidence was also starting to emerge for evolution in the “normal” galaxy populations from faint galaxy number counts and the Butcher-Oemler effect
- Also, in late 1980s and early 1990s the results of the first deep spectroscopic surveys of faint field galaxies (out to z~0.4) started to be reported

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