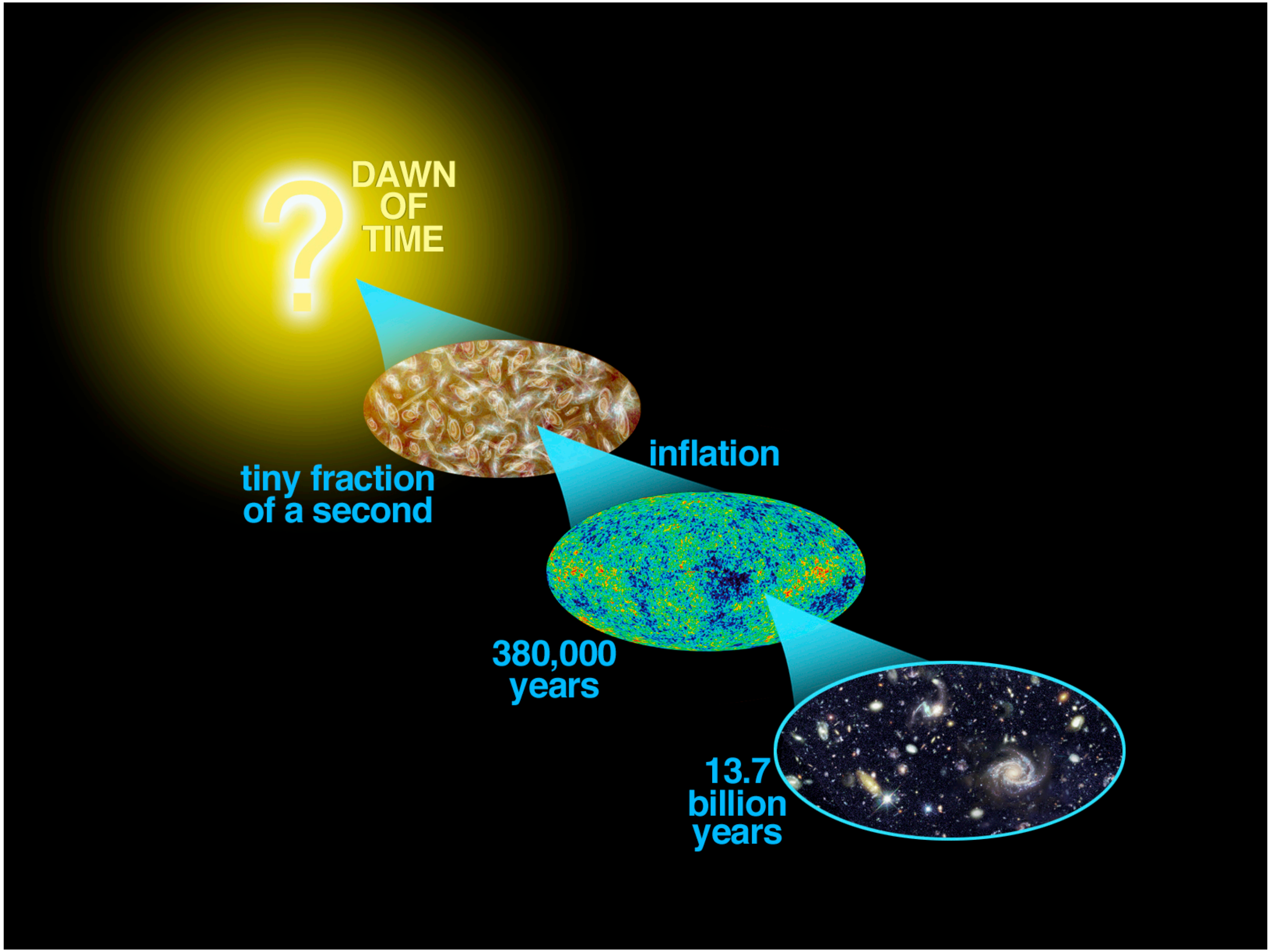
Questions?


DAWN
OF
TIME
inflation
tiny fraction
of a second
380,000
years
13.7
billion
years

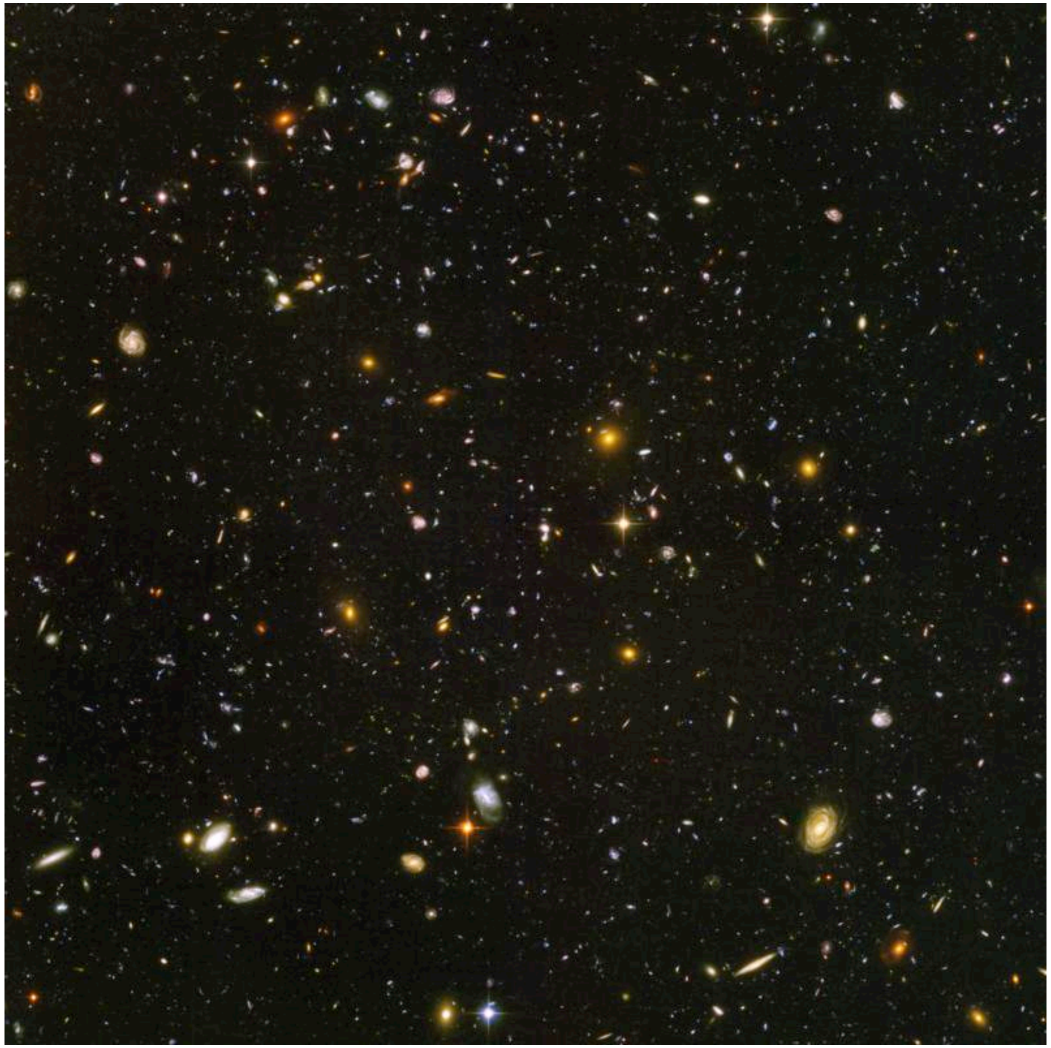
What do we mean by “the large-scale structure” of the Universe?

What is a “massive redshift survey”?

What is galaxy biasing?

What can we learn from studying the spatial galaxy distribution?

Courtesy of the HUDF team



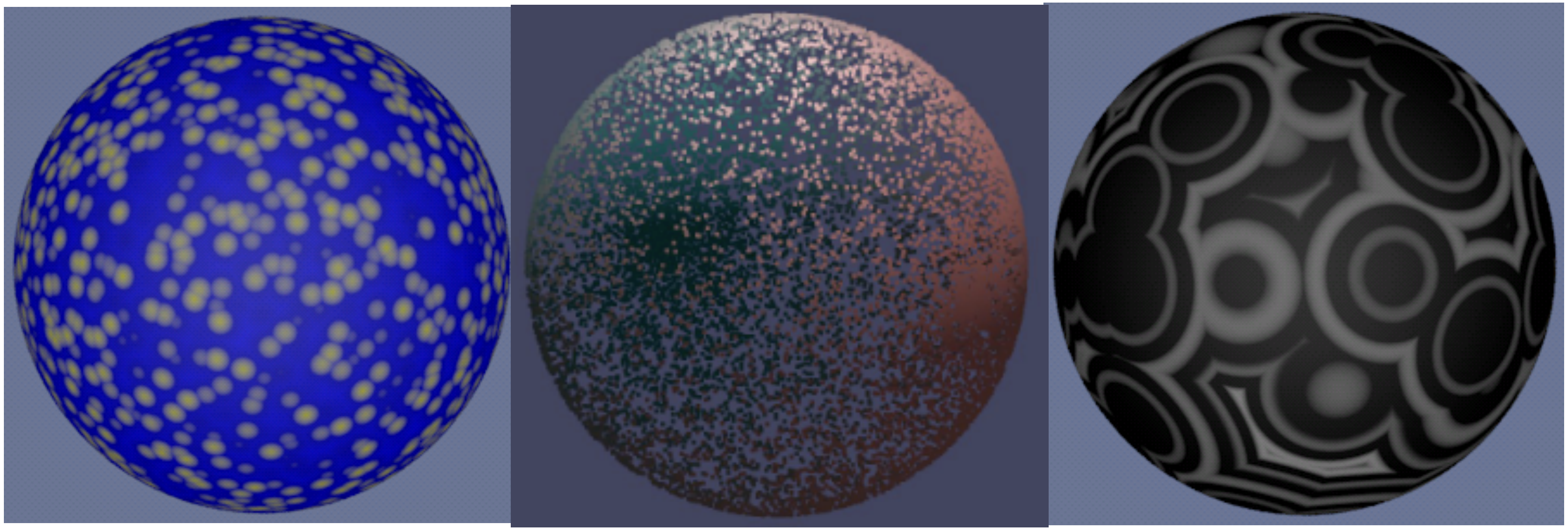
The deepest image of the universe in the optical waveband

It contains ~ 10^4 galaxies in a solid angle corresponding to 1/50 of the Moon

The whole sky corresponds to 12.7 million times more solid angle

Galaxies are the fundamental building blocks of the distribution of luminous matter

How are galaxies distributed on the sky?



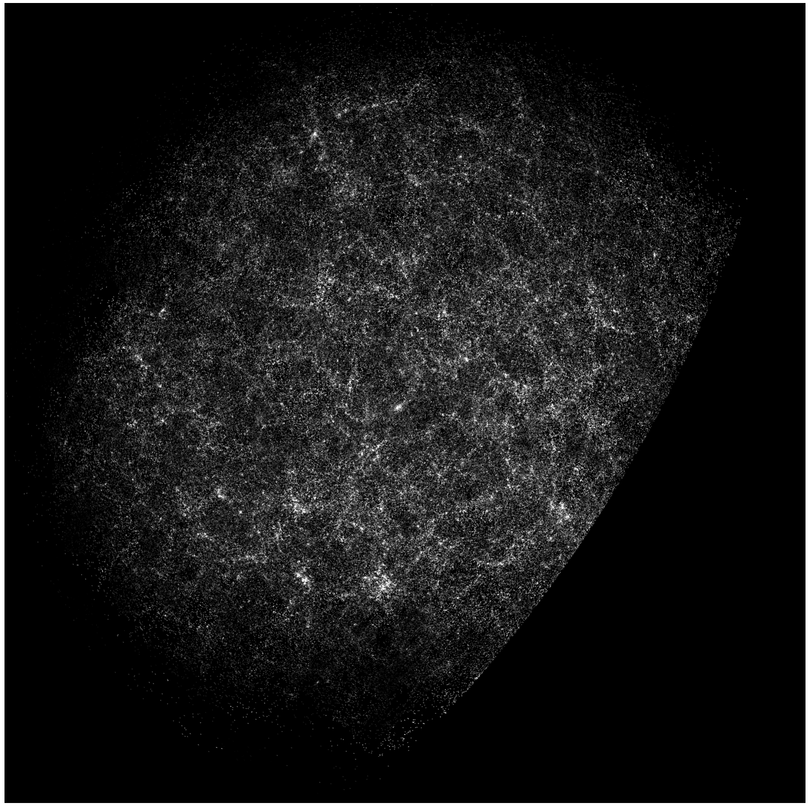
The Lick galaxy survey

The Lick survey conducted at the Lick observatory in Santa Cruz during the 1950s recorded the position of 10^6 galaxies in 10 years.

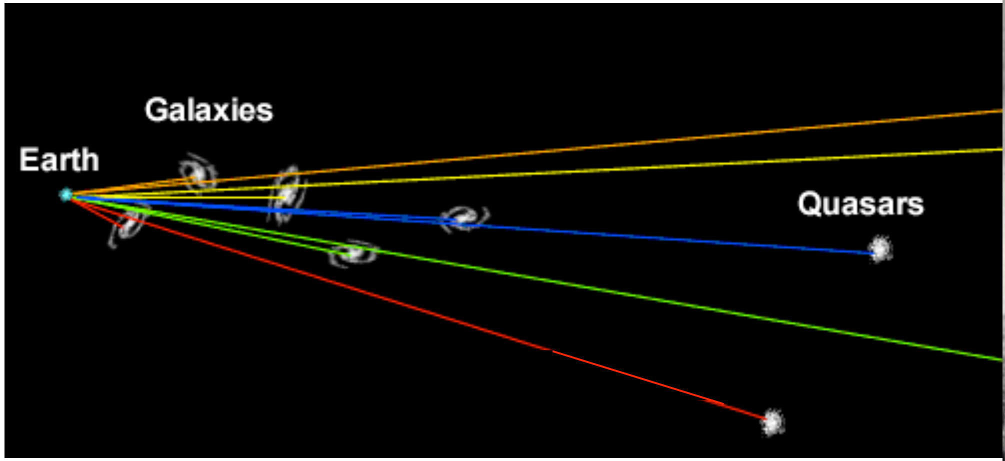
It provided the first evidence that galaxies are not distributed at random on the sky
(Totsuji & Kihara 1969, Peebles & Hauser 1974, Groth & Peebles 1977)

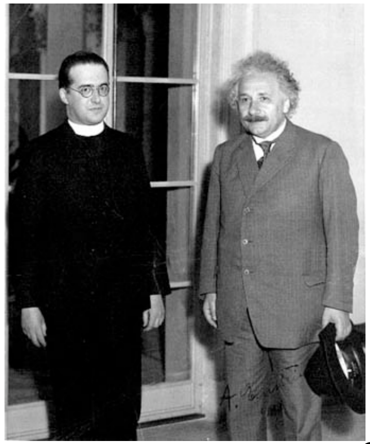
Projected filamentary structure is evident but what is the corresponding 3D distribution?

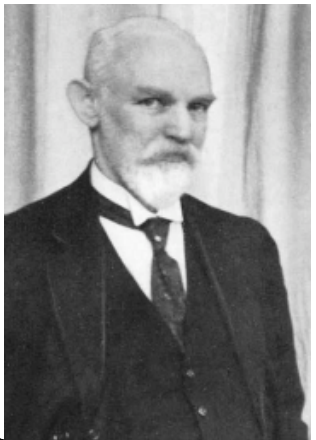
Shane & Wirtanen 1967

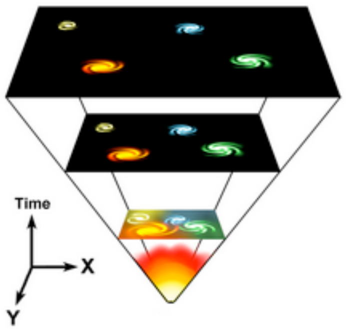


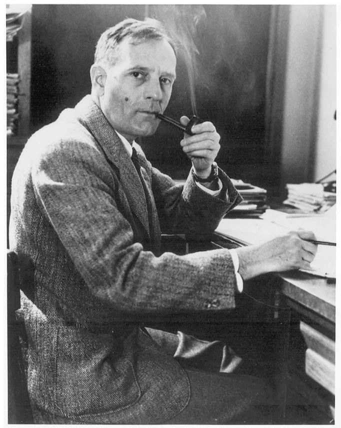
Adding the third dimension



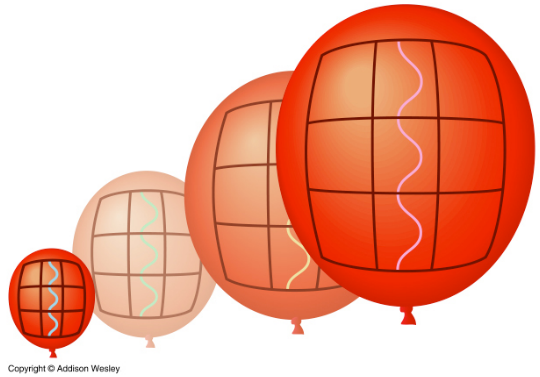


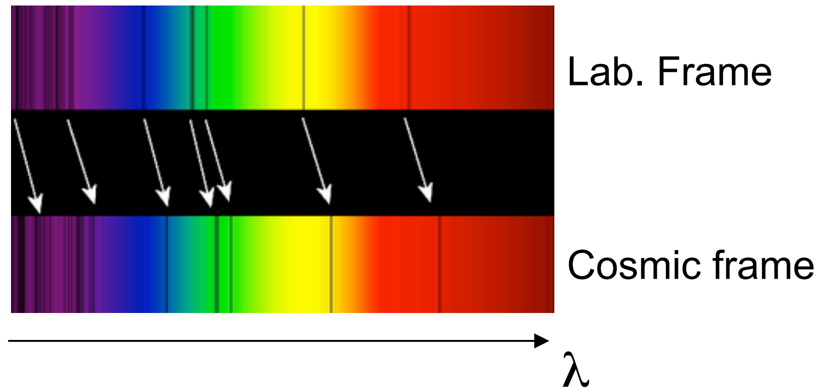






Adding the third dimension



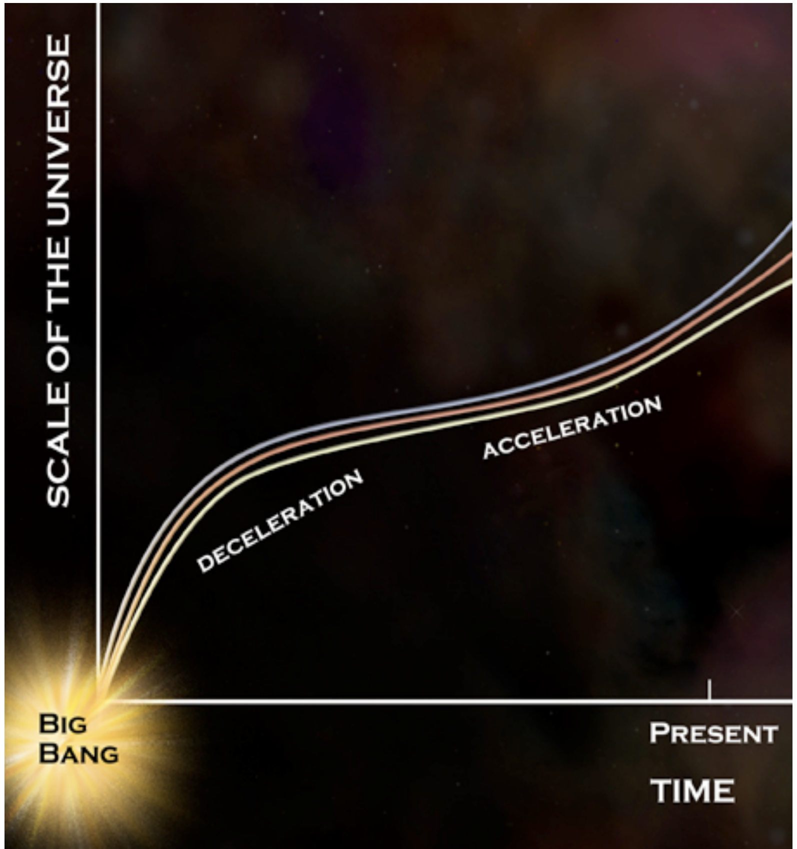


- Cosmological redshift: the wavelength of EM signals is stretched by the cosmic expansion.

- Spectra are shifted in frequency towards the red by a factor
  1+z = (present-day size of the universe)/(size at photon emission)=$a(t_0)/a(t_{em})$

$$1+z=\lambda_{obs}/\lambda_{em}$$

Adding the third dimension - II

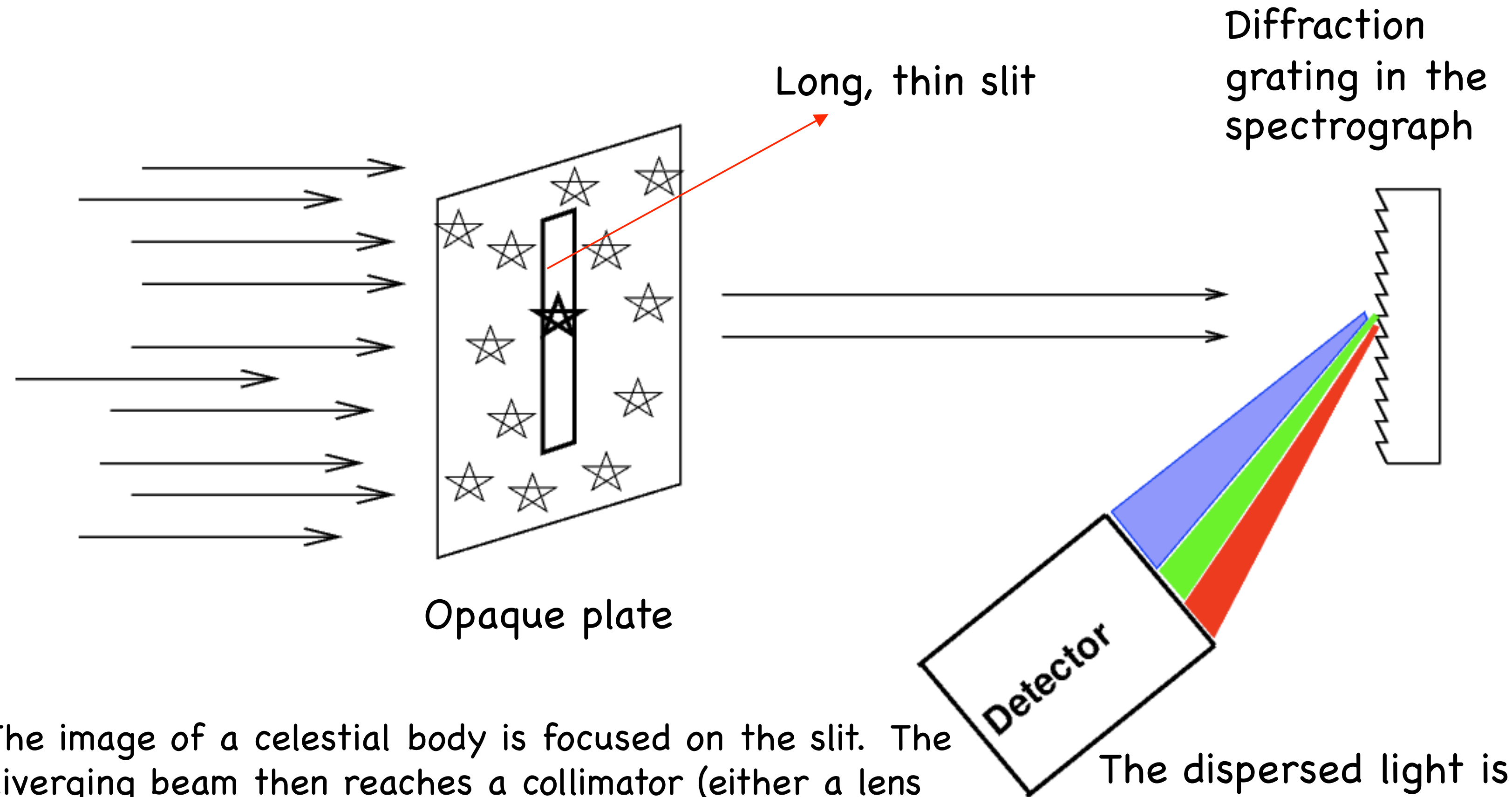


- Knowing the cosmic expansion history, a(t), would allow us to convert the ratio of scale factors into a look-back time: $t_{now} - t_{em}$

- Then, taking into account that EM signals propagate at constant velocity, c, one could derive the radial distance on our past-light cone corresponding to a given cosmological redshift.

- Measuring redshifts is then necessary to study the galaxy distribution in three dimensions

Slit spectroscopy

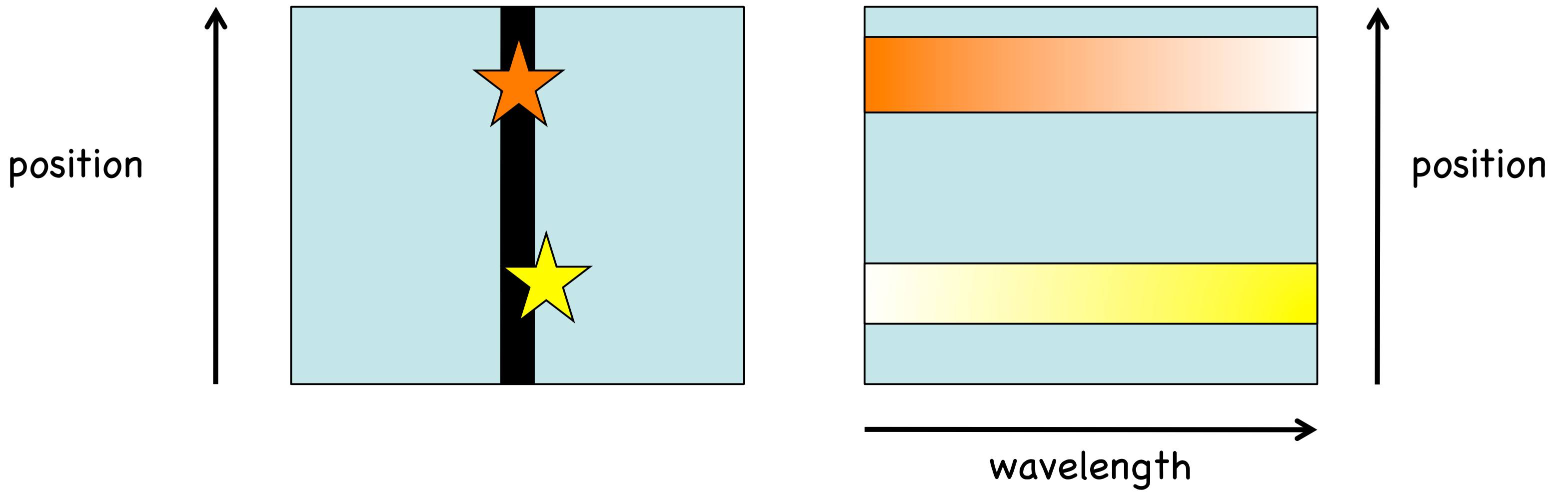


The image of a celestial body is focused on the slit. The diverging beam then reaches a collimator (either a lens or a mirror - not shown -). This produces parallel light which is then dispersed by a diffraction grating.

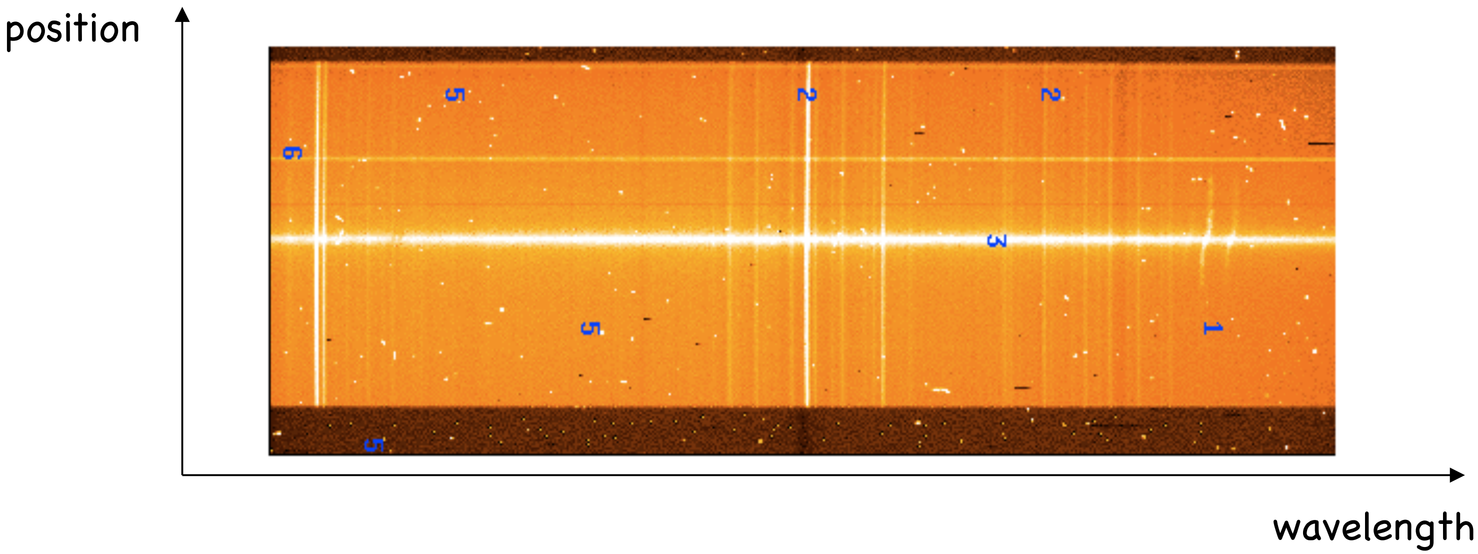
The dispersed light is imaged on a detector (typically a CCD)

Slit spectroscopy

- Why using a slit? To keep out as much as background light as possible
- How does the output look like? 2D spectrum



A raw galaxy spectrum



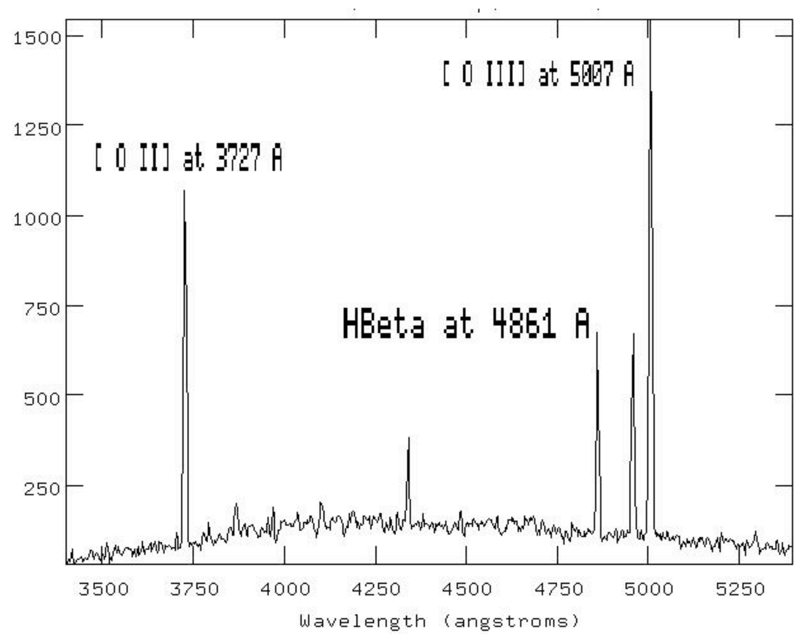
- This is the typical output of a spectrograph mounted on a telescope.

- Can you identify the origin of the different features?

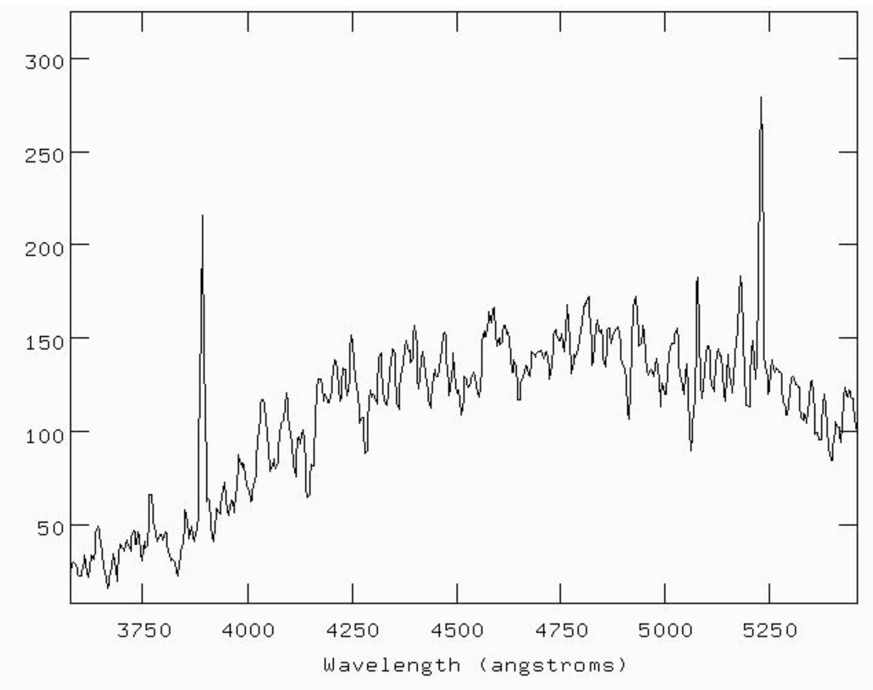
Answer

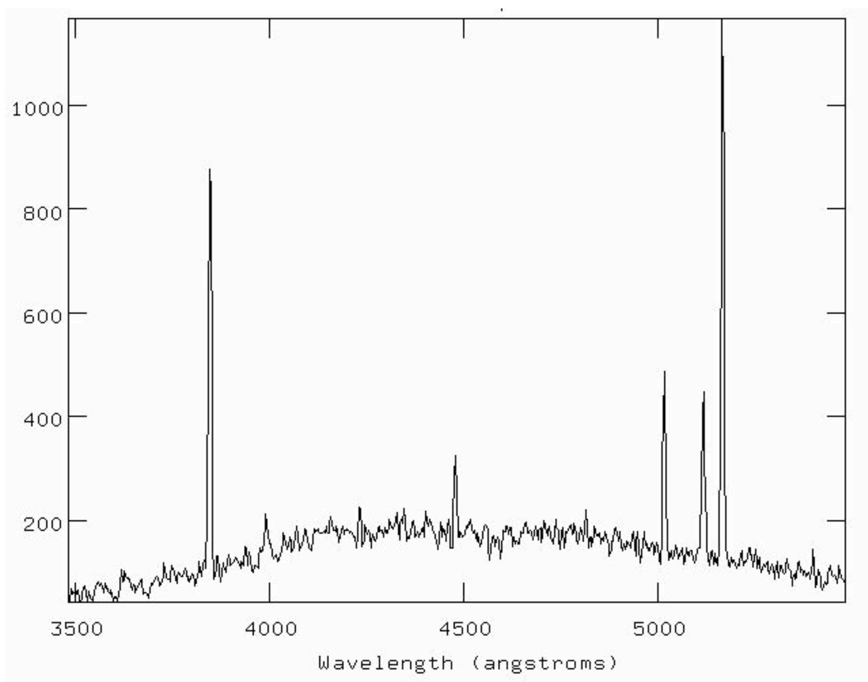
1. Emission lines from the observed galaxy (note that the galaxy is rotating)
2. Emission lines from the Earth's night sky
3. Continuum from the observed galaxy
4. -
5. Cosmic rays
6. Continuum from a nearby star

Measuring galaxy redshifts



Template spectrum at z=0

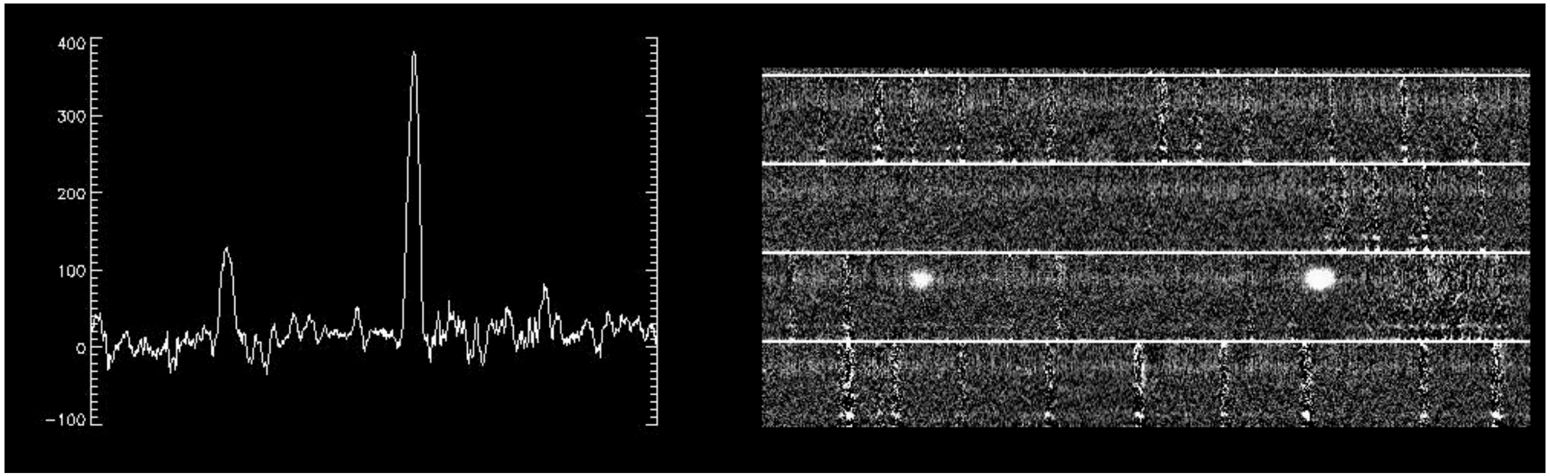




Spectrum of a galaxy with a faint continuum

1D spectrum

2D spectrum



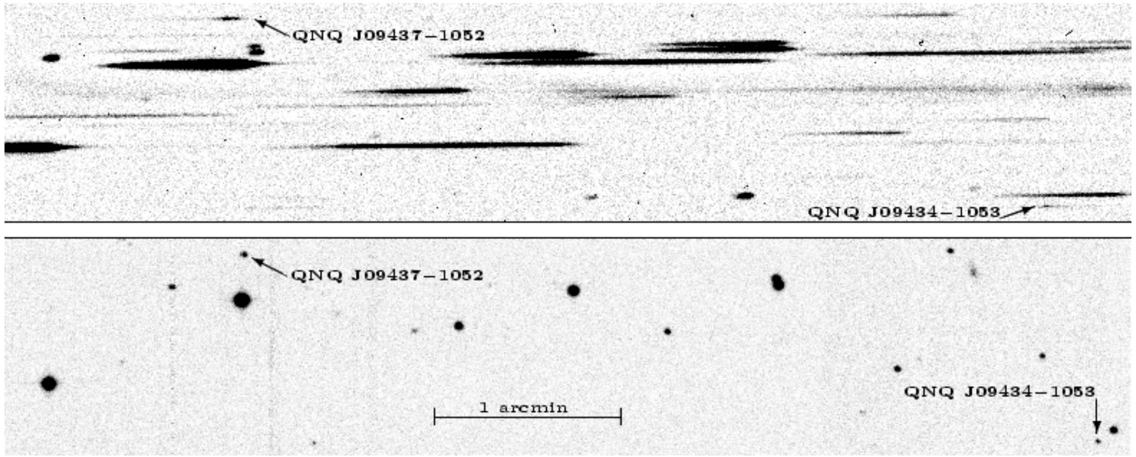
wavelength

Quality flags
an example from the zCOSMOS survey

Confidence Class	Description	Spectroscopic verification	ZEBRA photo-z consistency within Δz=0.1(1+z)
Class 4	Very secure redshift	>99.5%	97%
Class 3	Secure redshift	>99.5%	97%
Class 9	One line either Ha or [OII] 3727 (best guess)	95%	90%
Class 8	Unidentifed one line (best guess)		
Class 2	Probable redshift	92%	93%
Class 1	Insecure redshift	70%	72%

Confidence class	spectroscopic/photometric consistency
.5	Spectroscopic redshift consistent within 0.1(1+z) of the photometric redshift
.4	No photometric redshift available, includes all spectroscopic AGN and stars
.3	Special case for Class 9: Consistent with photo-z only after the redshift changed to the alternate redshift, a switch which is then applied
.1	Spectroscopic and photometric redshifts are not consistent at the level of 0.1(1+z)

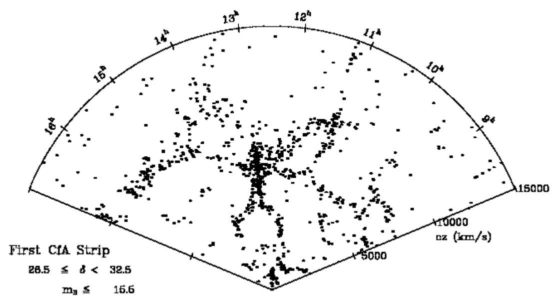
Slitless spectroscopy

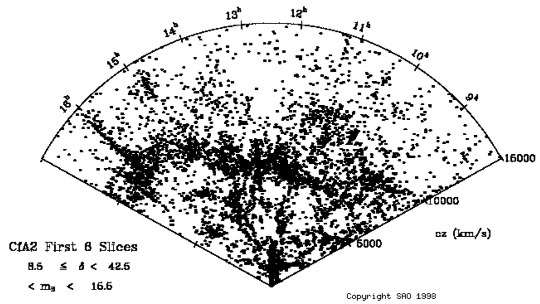


- It is possible to take spectra of all objects in the field of view that are brighter than a given threshold level (determined by the background)
- This is done using a dispersion element directly in combination with a telescope
- The disadvantage is that the background is high and that in crowded fields many spectra will overlap
- Filters are often used to isolate the spectral region of interest and reduce crowding and sky background intensity

Early redshift surveys: revealing the LSS

- Taking spectra of faint galaxies needs large telescopes and long integration times!
- The first redshift surveys were completed in the 1980s and 1990s (e.g. CfA, IRAS, Las Campanas)
- They measured 10^3 to 10^4 galaxy redshifts. Demonstrated the existence of LSS but not good enough for statistics
- No astronomer would have predicted the complexity of the galaxy distribution that was revealed!





Huchra, Davis, Geller et al. 1982-1998

Measuring galaxy redshifts

- Measuring galaxy redshifts in the optical band is not easy
- Using a telescope of diameter 1.5m (the standard in the 1970s), it takes nearly 5 minutes of integration time to measure the redshift of a bright emission line galaxy (from HII regions). Nearly 20% of the local galaxy population presents such strong emission features.
- For most galaxies, redshifts must be determined from absorption lines (from the integrated contribution of stellar atmospheres). This requires measuring the continuum and needs 15-60 minutes of integration on a 1.5m telescope
- In 1972 (≈60 years after the discovery of redshifts) there were only ≈1000 galaxy redshifts known (mostly in galaxy clusters)

John Huchra (1948-2010)

- "The universe is what it is, and we are trying to find out what it is"
- "The explorers of the new world weren't trying to prove theories, they were looking at what was out there"
- "I could make telescopes sit up and take data"

Mapmaker, Mapmaker Make Me a Map

John P. Huchra

(Harvard-Smithsonian Center for Astrophysics)

I love being on mountaintops. Next best thing to being in space. I guess I also love counting things, whether the things are 4000 footers in New England, cards in games of chance, or galaxies on my observing list. There in, of course, lies the tale.

It all started because I was a little kid much more interested in reading than in sports.