Ciências ULisboa

Complementary Astrophysics

L9 - Distance, Redshift

Ciências ULisboa

Evaluation Criteria

0.6 - Laboratory

0.4 - Exam

Laboratory Evaluation

Based on the work you do week after week:

0.35 = Practical Assignments: Laboratory

0.15 = Written Assignments: Resolution of exercise (the procedure that is chosen to solve them)

0.1 = Participation in the class

Exam

The final exam is done at the end and consists of:

0.4 = a short test about topics of the course

What did we learn?

Ciências ULisboa

What did we learn?

1. SFR-Gas Fraction
2. SF evolution
3. The physics of GMC
4. Star Formation Efficiency (SFE)
5. GMC timescale

Highlights

VLA-ALMA SPECTROSCOPIC SURVEY IN THE HUBBLE ULTRA DEEP FIELD (VLASPECS): TOTAL COLD GAS MASSES AND CO LINE RATIOS FOR Z=2–3 "MAIN SEQUENCE" GALAXIES

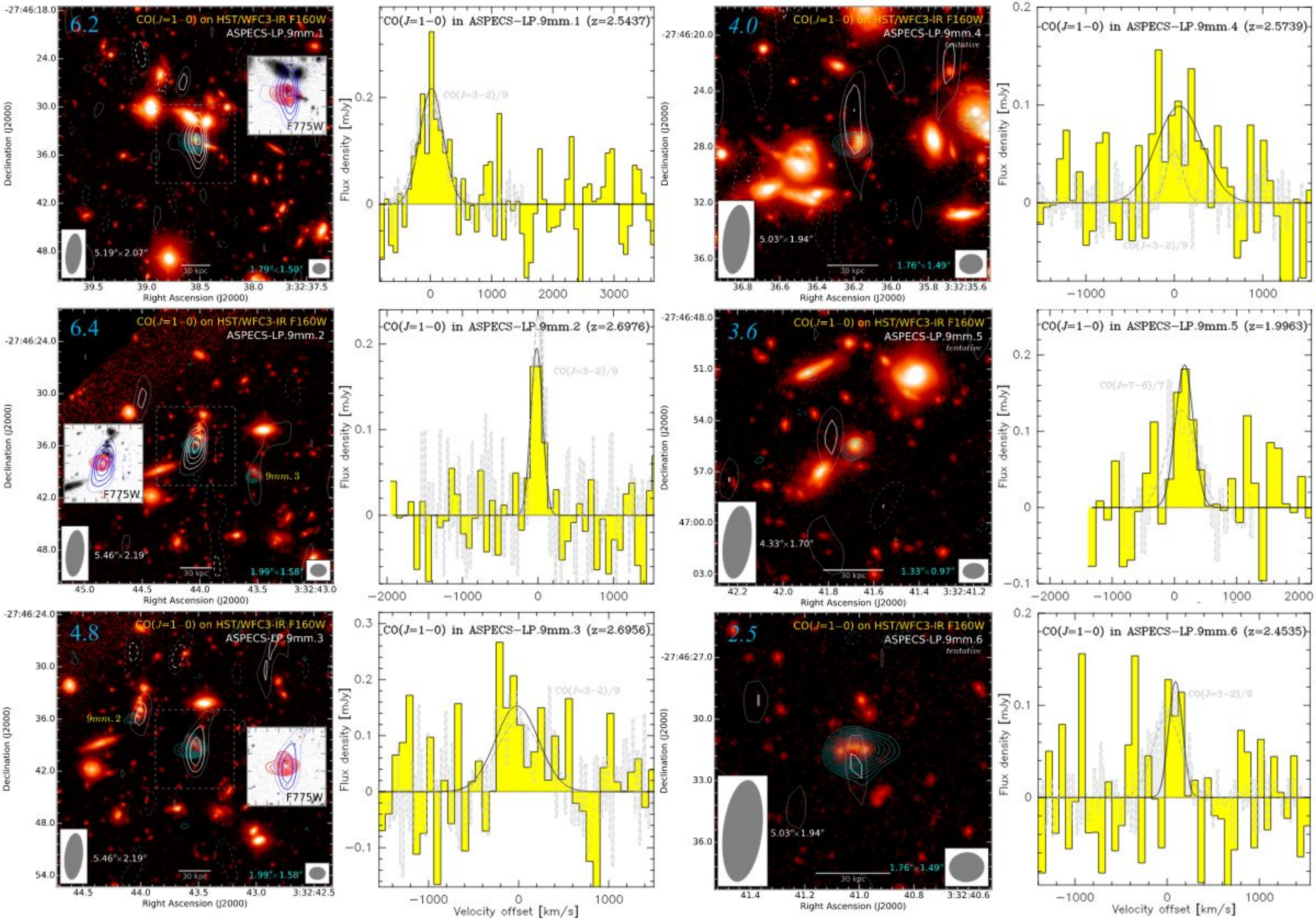
DOMINIK A. RIECHERS[1,2], LEINDERT A. BOOGAARD[3], ROBERTO DECARLI[4], JORGE GONZÁLEZ-LÓPEZ[5], IAN SMAIL[6], FABIAN WALTER[2,7], MANUEL ARAVENA[8], CHRISTOPHER L. CARILLI[7,9], PAULO C. CORTES[10,11], PIERRE COX[12], TANIO DÍAZ-SANTOS[8,13], JACQUELINE A. HODGE[3], HANAE INAMI[14], ROB J. IVISON[15], MELANIE KAASINEN[2,16], JEFF WAGG[17], AXEL WEISS[18], AND PAUL VAN DER WERF[3]

(Received 24/04/2020; Revised 18/05/2020; Accepted 19/05/2020)

ABSTRACT

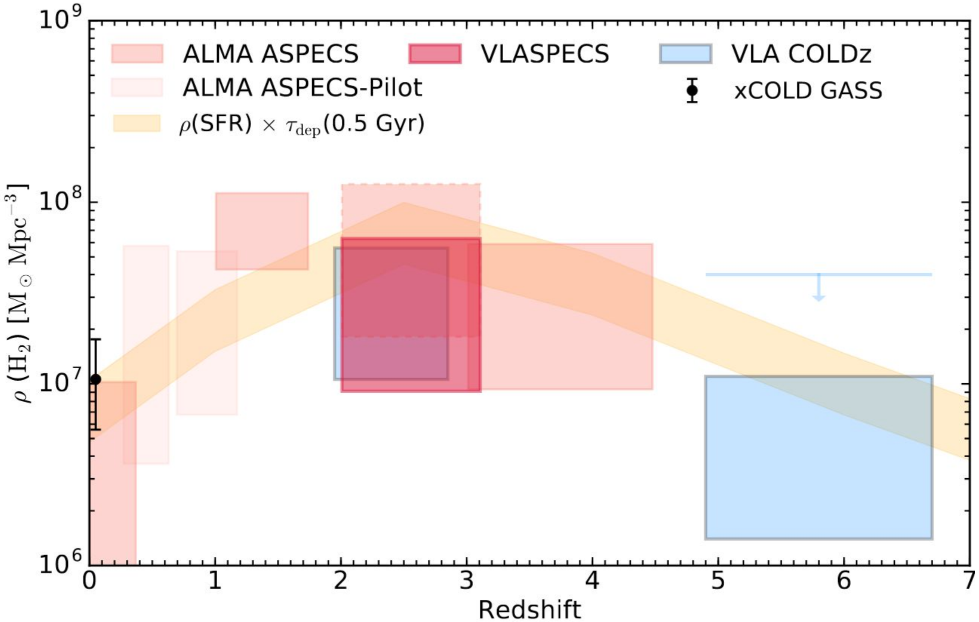
Using the NSF's Karl G. Jansky Very Large Array (VLA), we report six detections of CO(J=1→0) emission and one upper limit in z=2–3 galaxies originally detected in higher-J CO emission in the Atacama Large submillimeter/Millimeter Array (ALMA) Spectroscopic Survey in the Hubble Ultra Deep Field (ASPECS). From the CO(J=1→0) line strengths, we measure total cold molecular gas masses of $M_{\rm gas}$=2.4–11.6$\times10^{10}$ $(\alpha_{\rm CO}/3.6)\,M_\odot$. We also measure a median CO(J=3→2) to CO(J=1→0) line brightness temperature ratio of r_{31}=0.84$\pm$0.26, and a CO(J=7→6) to CO(J=1→0) ratio range of r_{71}<0.05 to 0.17. These results suggest that CO(J=3→2) selected galaxies may have a higher CO line excitation on average than CO(J=1→0) selected galaxies, based on the limited, currently available samples from the ASPECS and VLA CO Luminosity Density at High Redshift (COLDz) surveys. This implies that previous estimates of the cosmic density of cold gas in galaxies based on CO(J=3→2) measurements should be revised down by a factor of $\simeq$2 on average based on assumptions regarding CO excitation alone. This correction further improves the agreement between the best currently existing constraints on the cold gas density evolution across cosmic history from line scan surveys, and the implied characteristic gas depletion times.

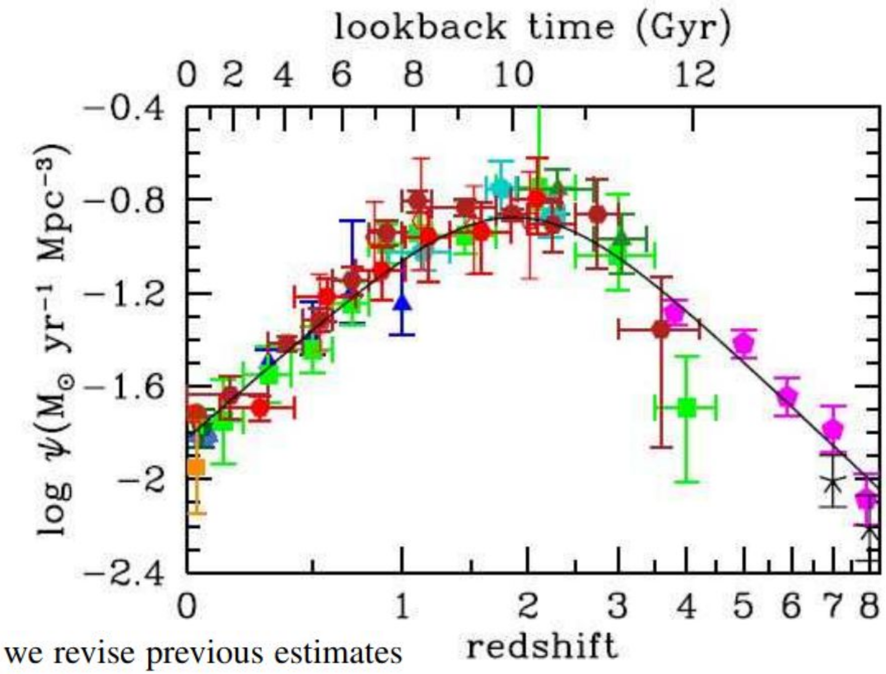
Keywords: cosmology: observations — galaxies: active — galaxies: formation — galaxies: high-redshift — galaxies: starburst — radio lines: galaxies



6.2
CO(J=1−0) on HST/WFC3-IR F160W
ASPECS-LP.9mm.1
F775W
5.19″×2.07″
30 kpc
1.79″×1.50″
Declination (J2000)
Right Ascension (J2000)
CO(J=1−0) in ASPECS−LP.9mm.1 (z=2.5437)
CO(J=3−2)/9
Flux density [mJy]
4.0
CO(J=1−0) on HST/WFC3-IR F160W
ASPECS-LP.9mm.4
tentative
5.03″×1.94″
30 kpc
1.76″×1.49″
CO(J=1−0) in ASPECS−LP.9mm.4 (z=2.5739)
CO(J=3−2)/9
6.4
CO(J=1−0) on HST/WFC3-IR F160W
ASPECS-LP.9mm.2
F775W
9mm.3
5.46″×2.19″
30 kpc
1.99″×1.58″
CO(J=1−0) in ASPECS−LP.9mm.2 (z=2.6976)
CO(J=3−2)/9
3.6
CO(J=1−0) on HST/WFC3-IR F160W
ASPECS-LP.9mm.5
tentative
4.33″×1.70″
30 kpc
1.33″×0.97″
CO(J=1−0) in ASPECS−LP.9mm.5 (z=1.9963)
CO(J=7−6)/7
4.8
CO(J=1−0) on HST/WFC3-IR F160W
ASPECS-LP.9mm.3
9mm.2
F775W
5.46″×2.19″
30 kpc
1.99″×1.58″
CO(J=1−0) in ASPECS−LP.9mm.3 (z=2.6956)
CO(J=3−2)/9
Velocity offset [km/s]
2.5
CO(J=1−0) on HST/WFC3-IR F160W
ASPECS-LP.9mm.6
tentative
5.03″×1.94″
30 kpc
1.76″×1.49″
CO(J=1−0) in ASPECS−LP.9mm.6 (z=2.4535)
CO(J=3−2)/9
Velocity offset [km/s]

Highlights





Based on these measurements, we revise previous estimates of the gas masses in this redshift bin down by a factor of two on average. These findings improve the agreement between measurements of the cold gas mass density evolution with redshift from the ASPECS and COLDz surveys, further demonstrating the reliability of the constraints obtained from millimeter-wave line scan surveys across large cosmic volumes. Comparing the ASPECS and COLDz samples (D. Riechers et al. 2020, in preparation), there may be a hint that CO(J=3→2) selected galaxies could have higher CO line excitation on average than CO(J=1→0) selected galaxies, but current sample sizes are too small to provide a firm conclusion.

Ciências ULisboa

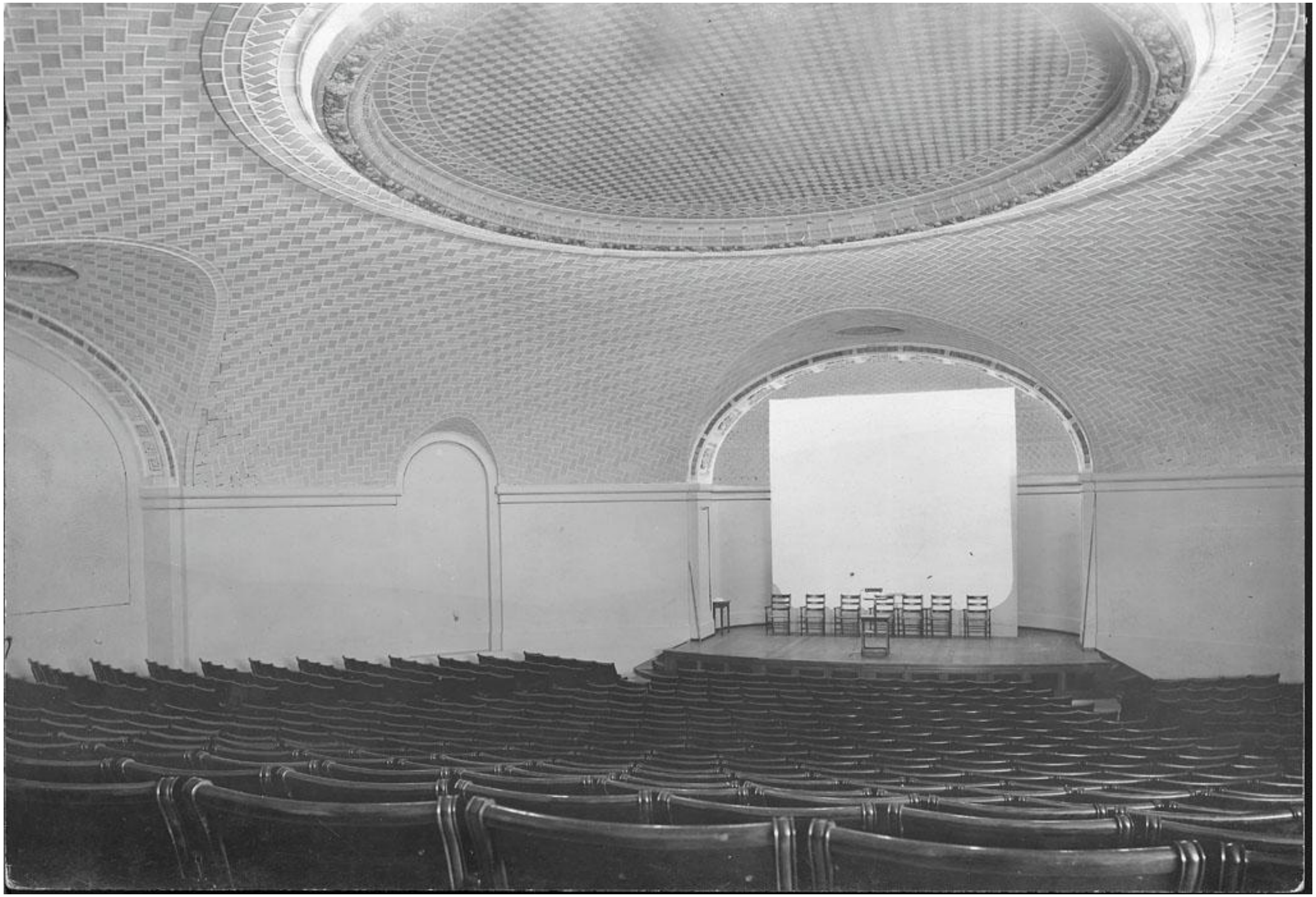
Outline of the course

1. History
2. Review of the general concepts
3. Galaxies in our local Universe
4. Galaxies kinematics
5. Scaling relations
6. Star formation
7. Interstellar Medium
8. Interstellar Medium – Behind the Scenes
9. **Distance and Redshift**

The Great Debate

Day: 26 April 1920

RING: BAIRD AUDITORIUM SMITHSONIAN MUSEUM OF NATURAL HISTORY – WASHINGTON D.C.



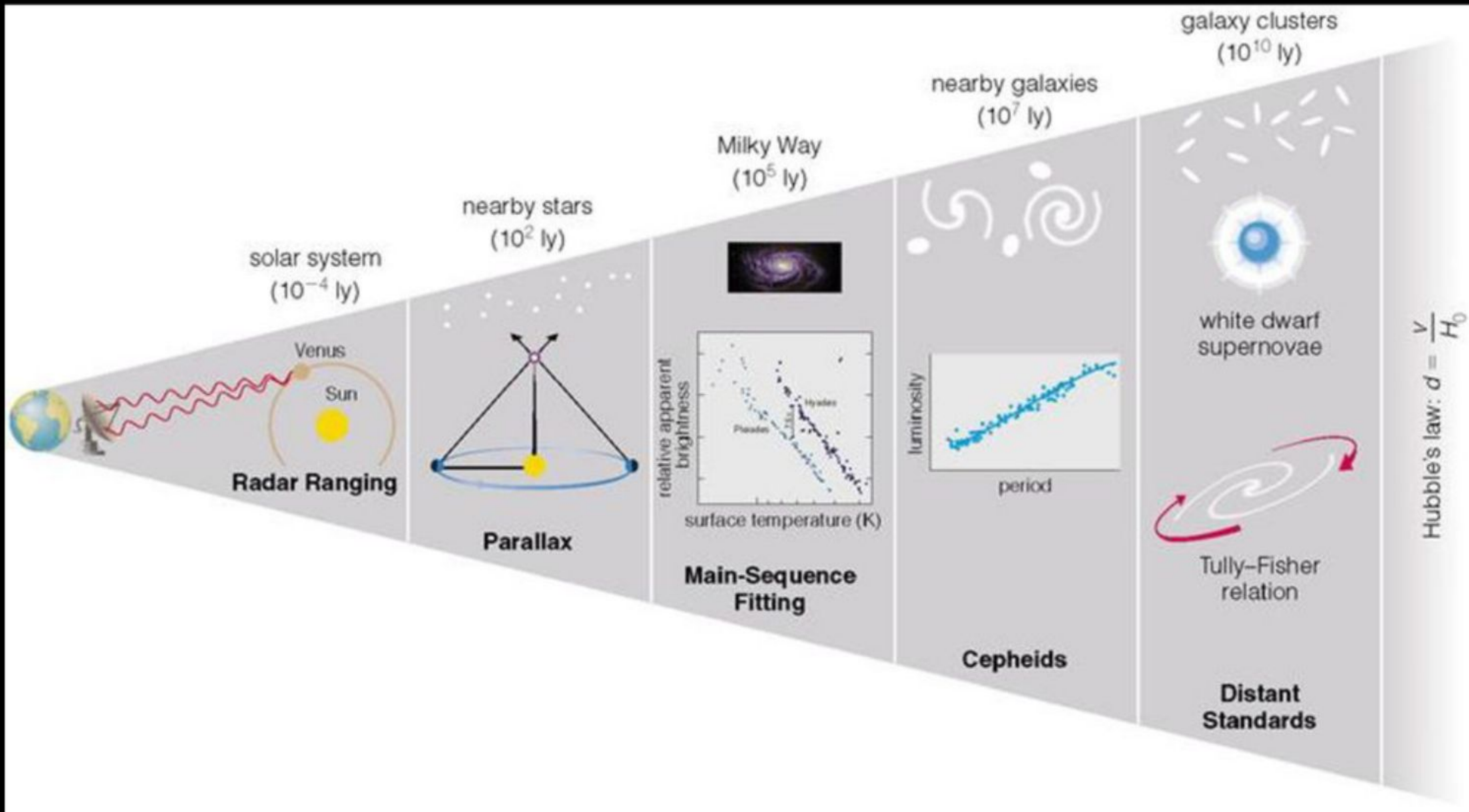
Towards the concept of galaxies

Milestones:

- 1912 – Vesto Sliper made spectrographic studies of the brightest spiral nebulae to study the chemistry of these objects…….surprisingly he found that object were red-shifted with a velocity above the escape velocity from the Milky Way
- 1917 – Heber Curtis found 11 more novae in the Andromeda nebula. They were 10 magnitudes fainter than the those occurred within our galaxy….so he estimated the distance of these objects well above the dimension of the Milky Way

EVERYTHING WAS READY FOR:

THE GREAT DEBATE

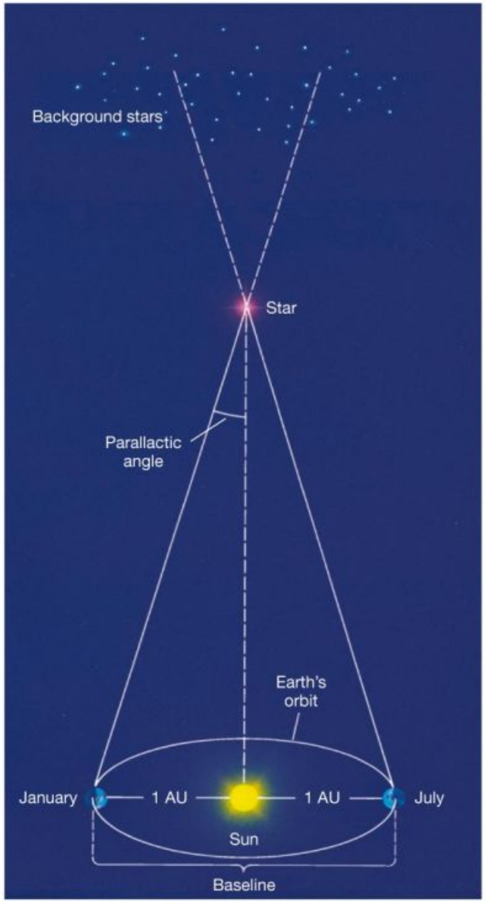

galaxy clusters
(10^{10} ly)
nearby galaxies
(10^{7} ly)
Milky Way
(10^{5} ly)
nearby stars
(10^{2} ly)
solar system
(10^{-4} ly)
Venus
Sun
Radar Ranging
Parallax
relative apparent brightness
surface temperature (K)
Main-Sequence Fitting
luminosity
period
Cepheids
white dwarf supernovae
Tully–Fisher relation
Distant Standards
Hubble's law: $d = \frac{v}{H_0}$

Ciências ULisboa

The Cosmic Distance Ladder

1) geometrical methods - parallax

$$d = 1\ AU / \theta$$

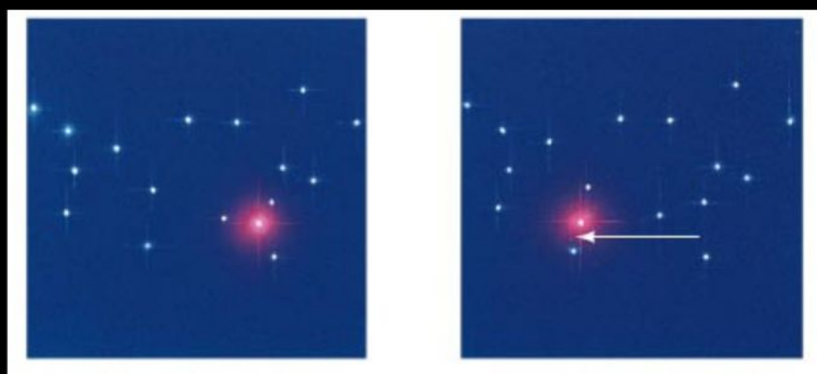


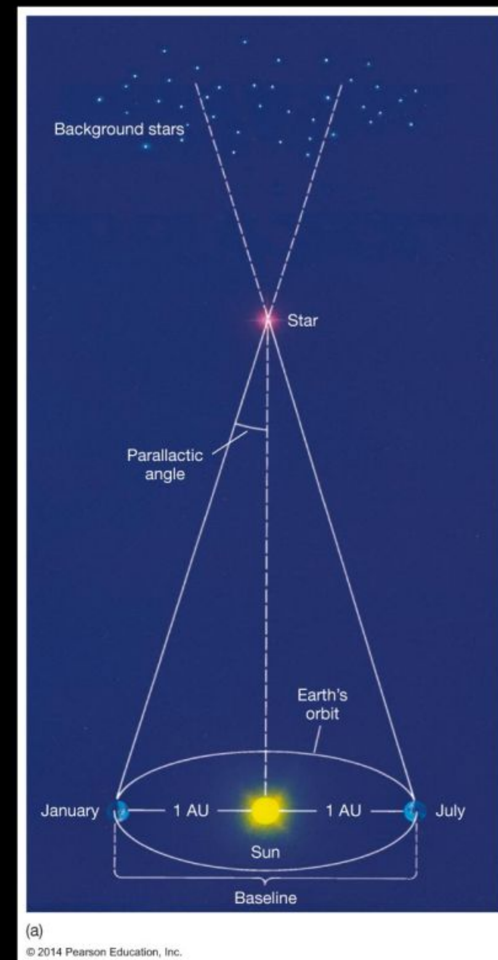
(a)

The Cosmic Distance Ladder

1) geometrical methods - parallax

d = 1 AU / θ [radians] = 206265 AU / θ [arcsec]





Nearest Stars:

- Proxima Centauri at 1.3 pc (4.2 ly)
  - 0.77 arc-secs
- Barnard's Star at 1.8 pc (6.0 ly)
  - 0.55 arc-secs

The Cosmic Distance Ladder

1) geometrical methods - parallax

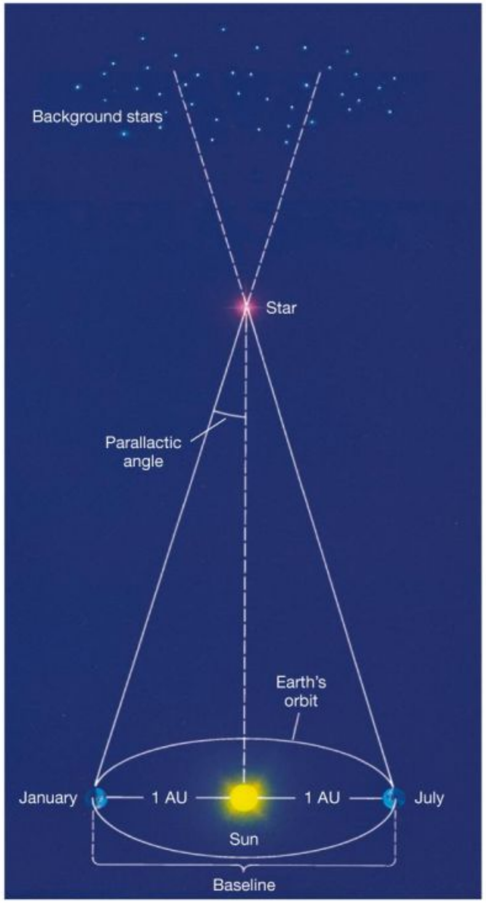
d = 1 AU / θ [radians] = 206265 AU / θ [arcsec]

Nearest Stars:

- Proxima Centauri at 1.3 pc (4.2 ly)
  - 0.77 arc-secs
- Barnard's Star at 1.8 pc (6.0 ly)
  - 0.55 arc-secs

Ground based parallaxes up to ~ 0.01”

out to 100 pc, ~ 1000 stars



(a)

Distance Measurements

Cepheid Variable Stars

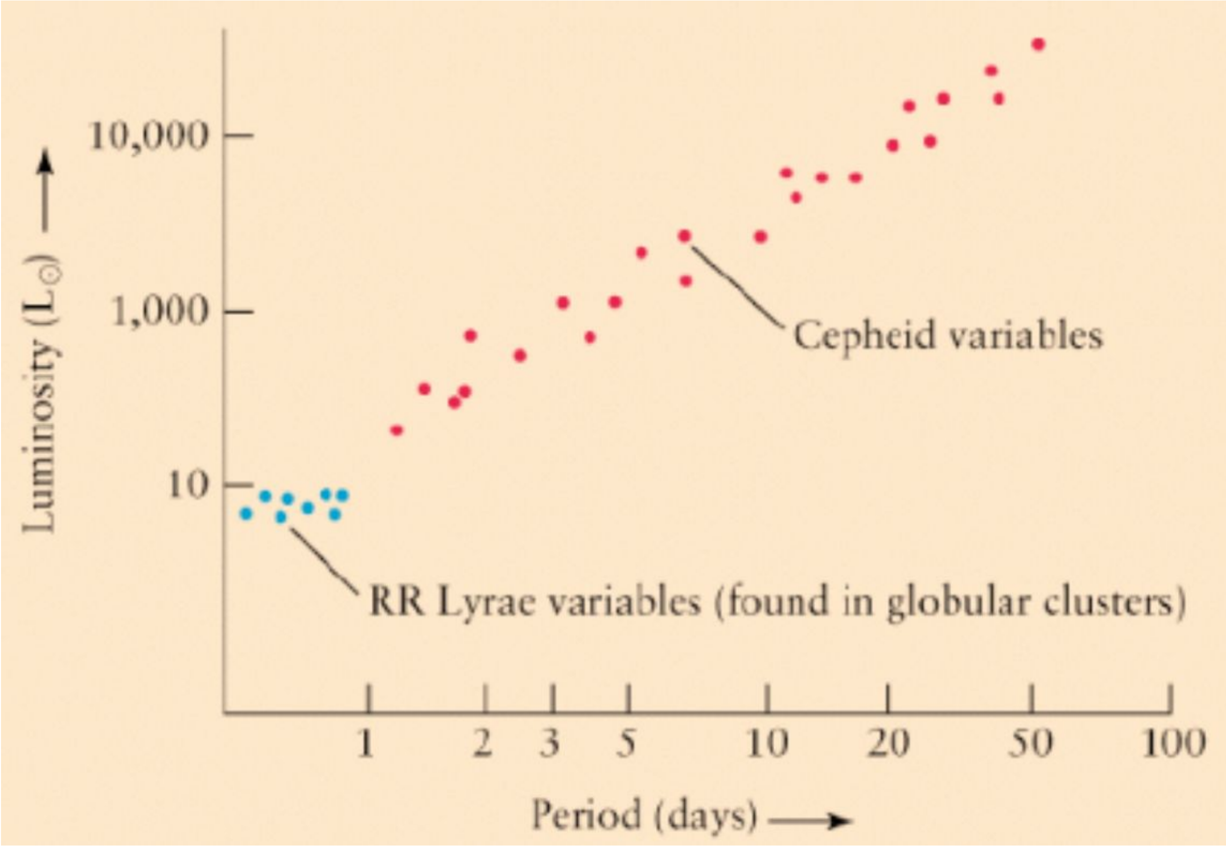
These are bright (Mv ~ -2), regularly pulsating stars (~few days)

$$\log_{10} P + 0.394\, M_V = -0.657$$

P = day

M_v = Abs Magnitude

Henrietta Leavitt 1912



Distance Measurements

Hubble collected images and spectra for many galaxies, estimating their distances.

- Plotting distance versus velocity he found that most galaxies recede and that more distant galaxies recede faster. The linear relationship between velocity and distance is called Hubble law:

$v = H_o \times d$

– v = velocity (km/s)
– d = distance (Mpc)
– H_o = The Hubble constant (km/s/Mpc)

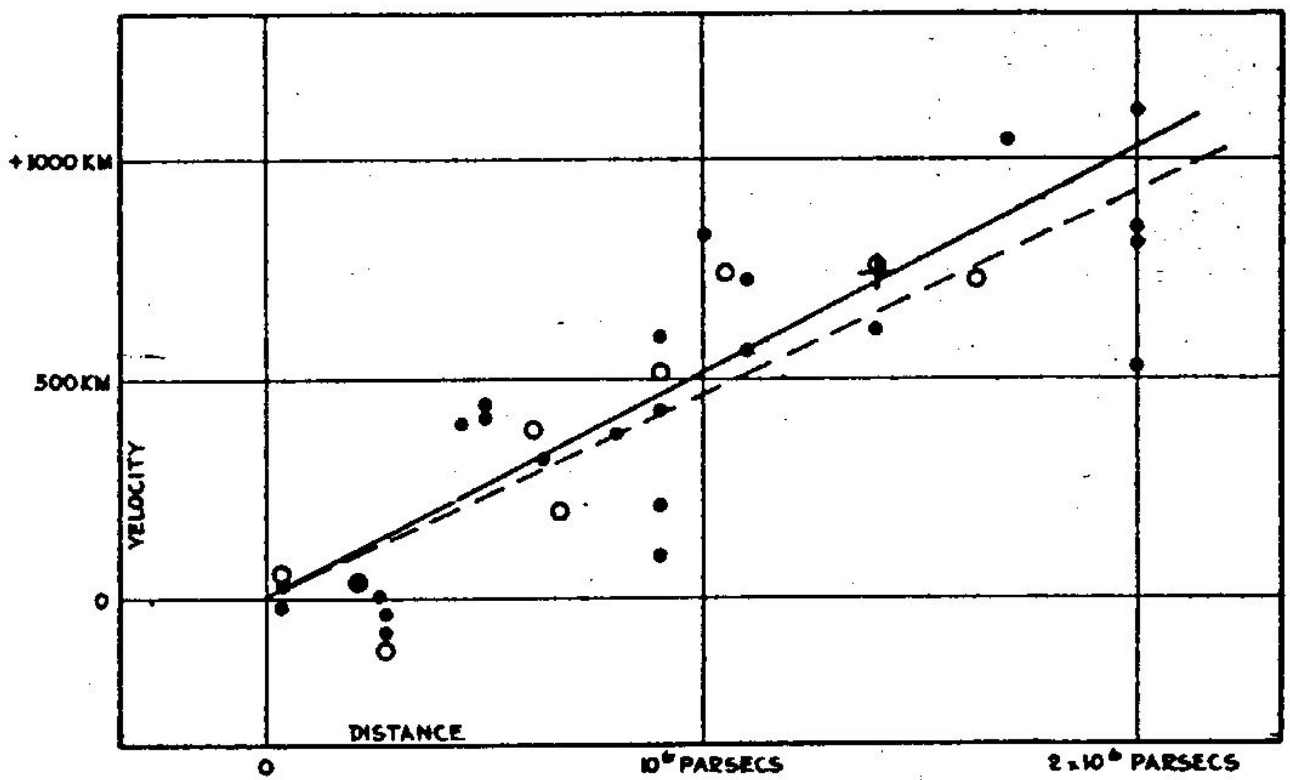


FIGURE 1

Redshift

There are two interesting implications of the Hubble law:

1) the Universe is expanding, everything is separating.

2) at some point everything should have occupied a small region (a point): in other word the Big Bang.

To quantify this effect we defined the redshift z:

$$z = \frac{\lambda - \lambda_o}{\lambda_o} = \frac{\Delta\lambda}{\lambda_o}$$

- This is analogous to the definition of Doppler shift such that: $z \equiv \frac{v}{c}$ from which follows: $d = \frac{zc}{H_o}$

- Although this is the wrong interpretation of redshift it is a good approximation for low-z ($z < 0.5$)

Ciências ULisboa

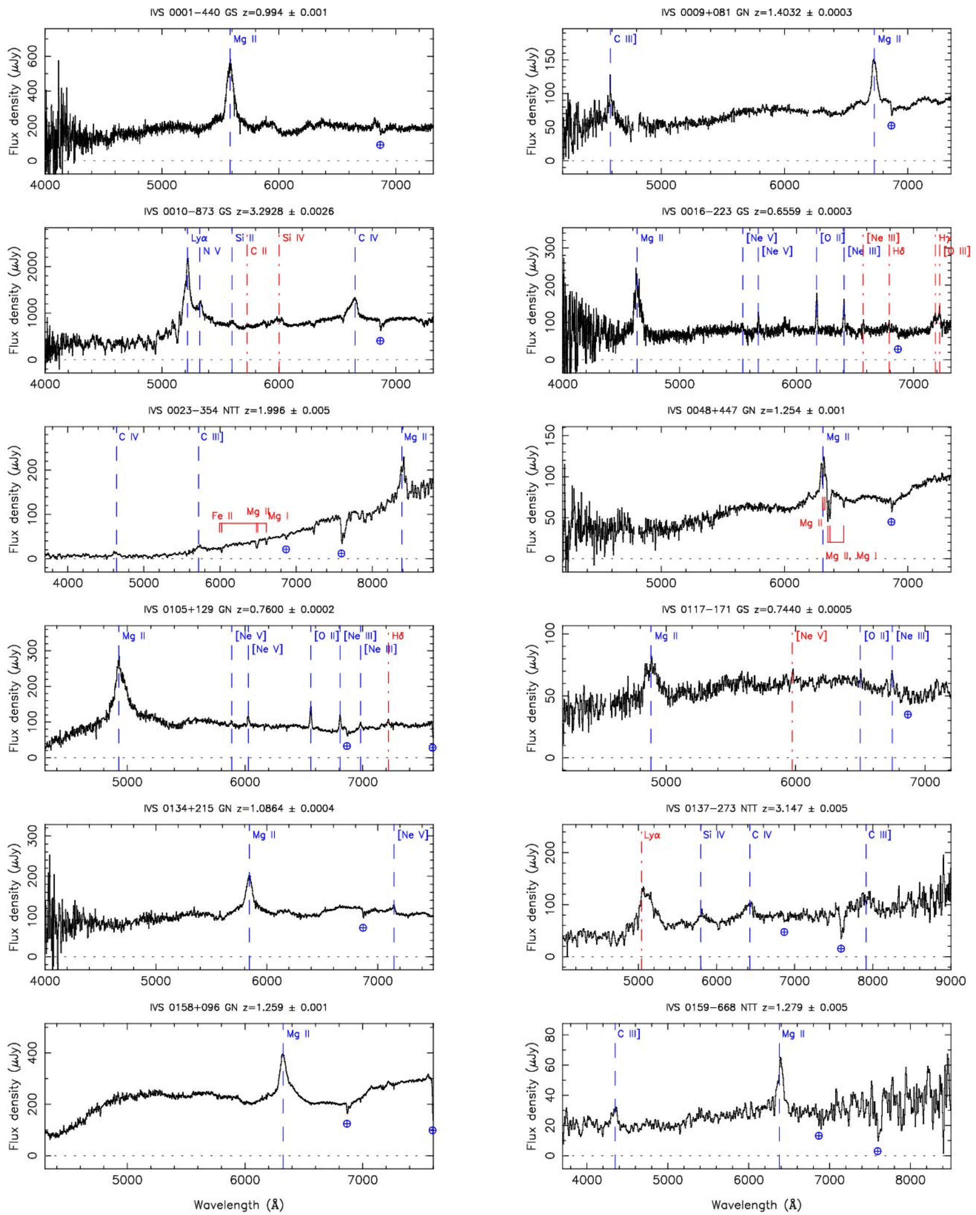
Redshift

So for objects at z < 0.5 we can find the distance from the redshift.

Suppose an object at

z = 0.1 → d = 0.1 x 3e5/75 = 400 Mpc.

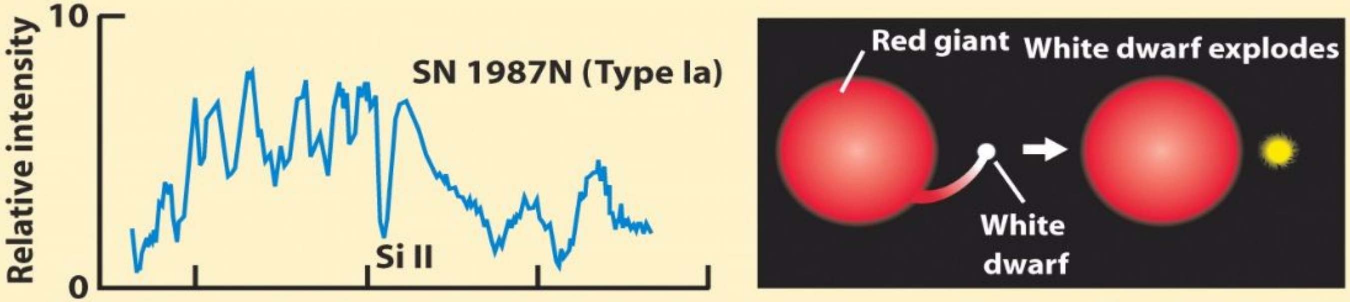
At the same time the spectra of this galaxy will be shifted by a delta lambda defined in the previous slide: the oxygen line at 3727 A will be shifted for example at 4100 A.



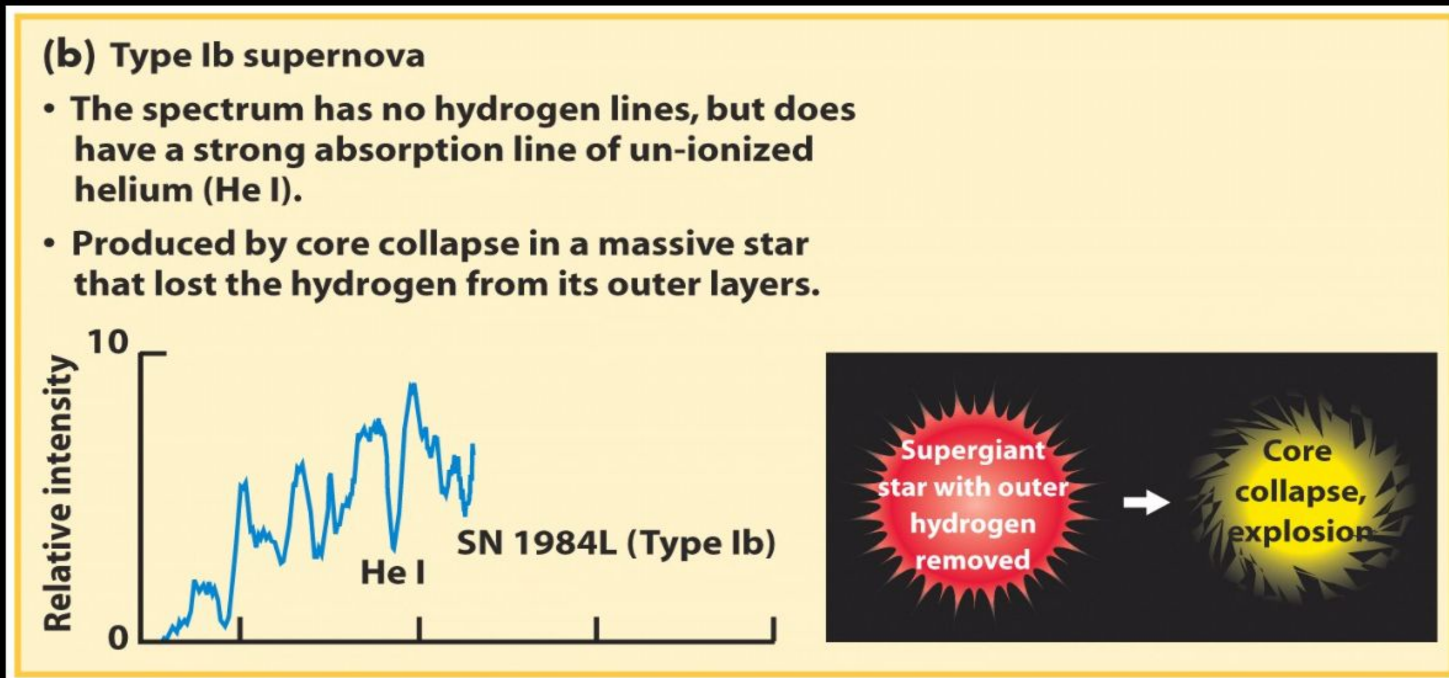
Determinação de distâncias cosmológicas

(a) Type Ia supernova

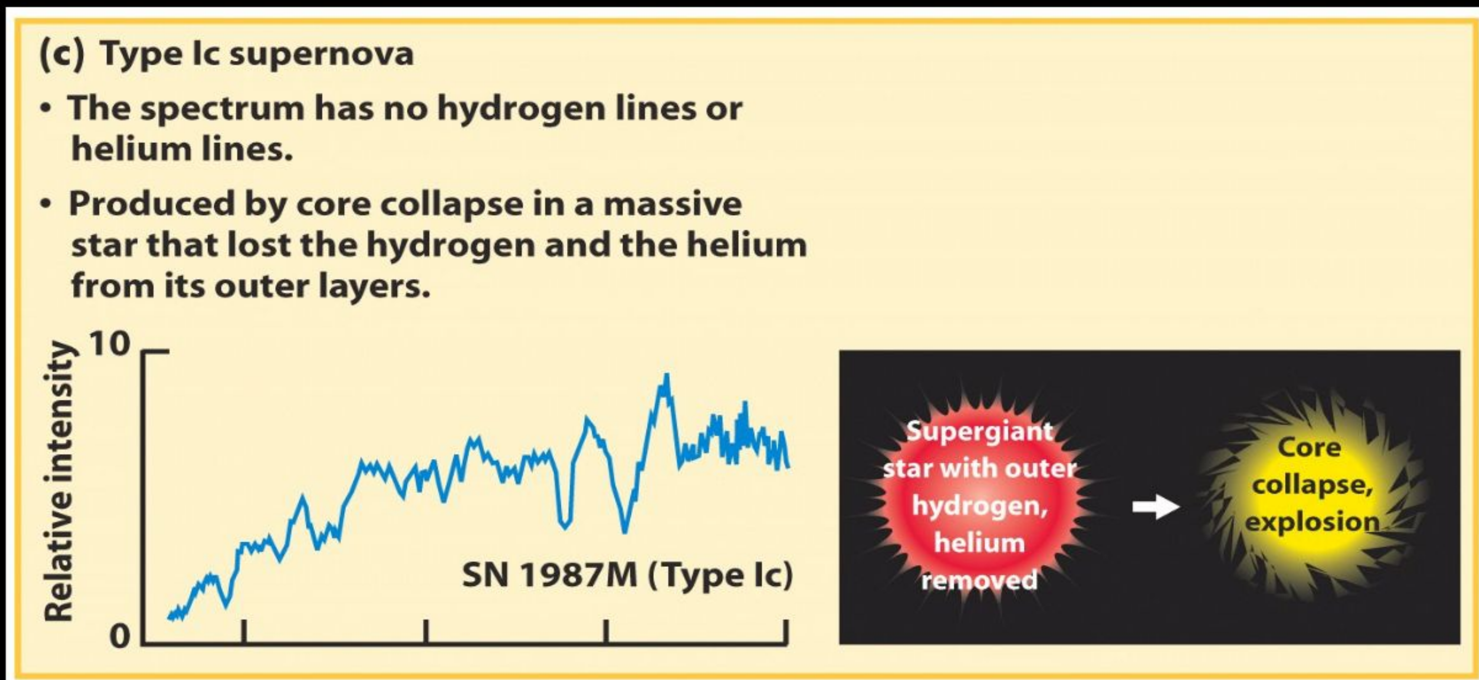
- The spectrum has no hydrogen or helium lines, but does have a strong absorption line of ionized silicon (Si II).
- Produced by runaway carbon fusion in a white dwarf in a close binary system (the ionized silicon is a by-product of carbon fusion).



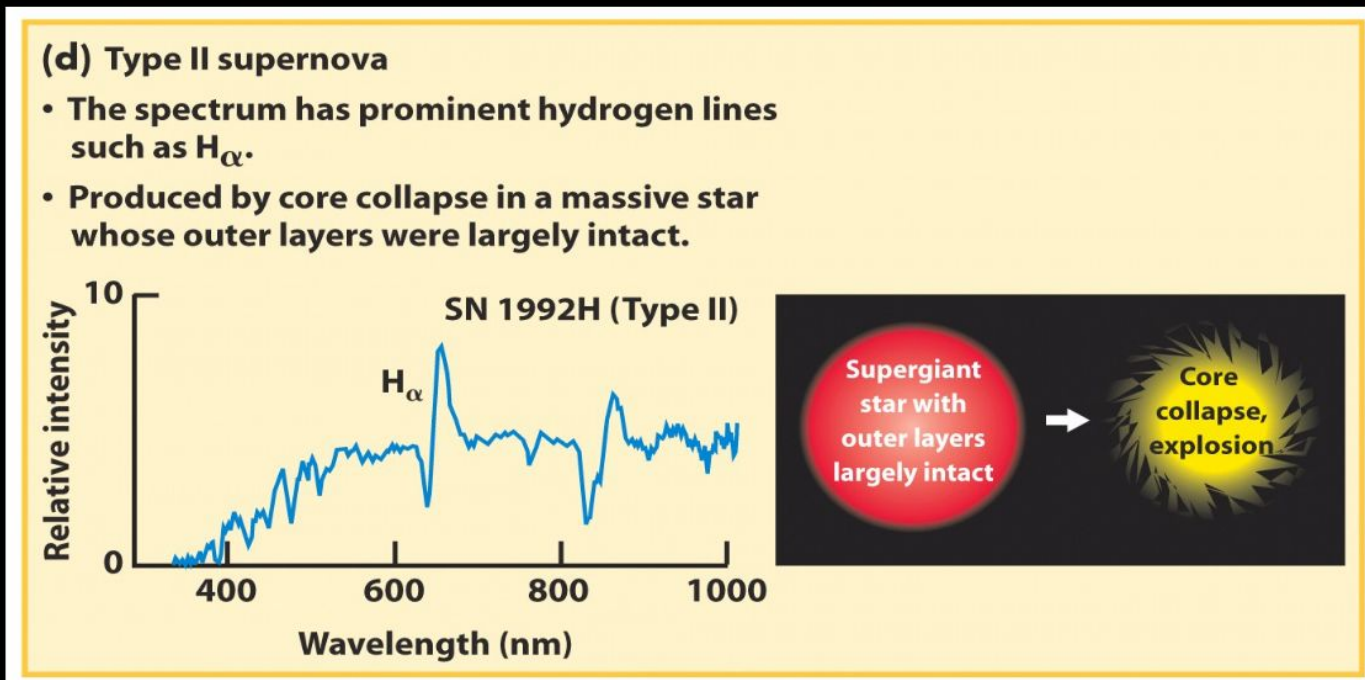
Determinação de distâncias cosmológicas



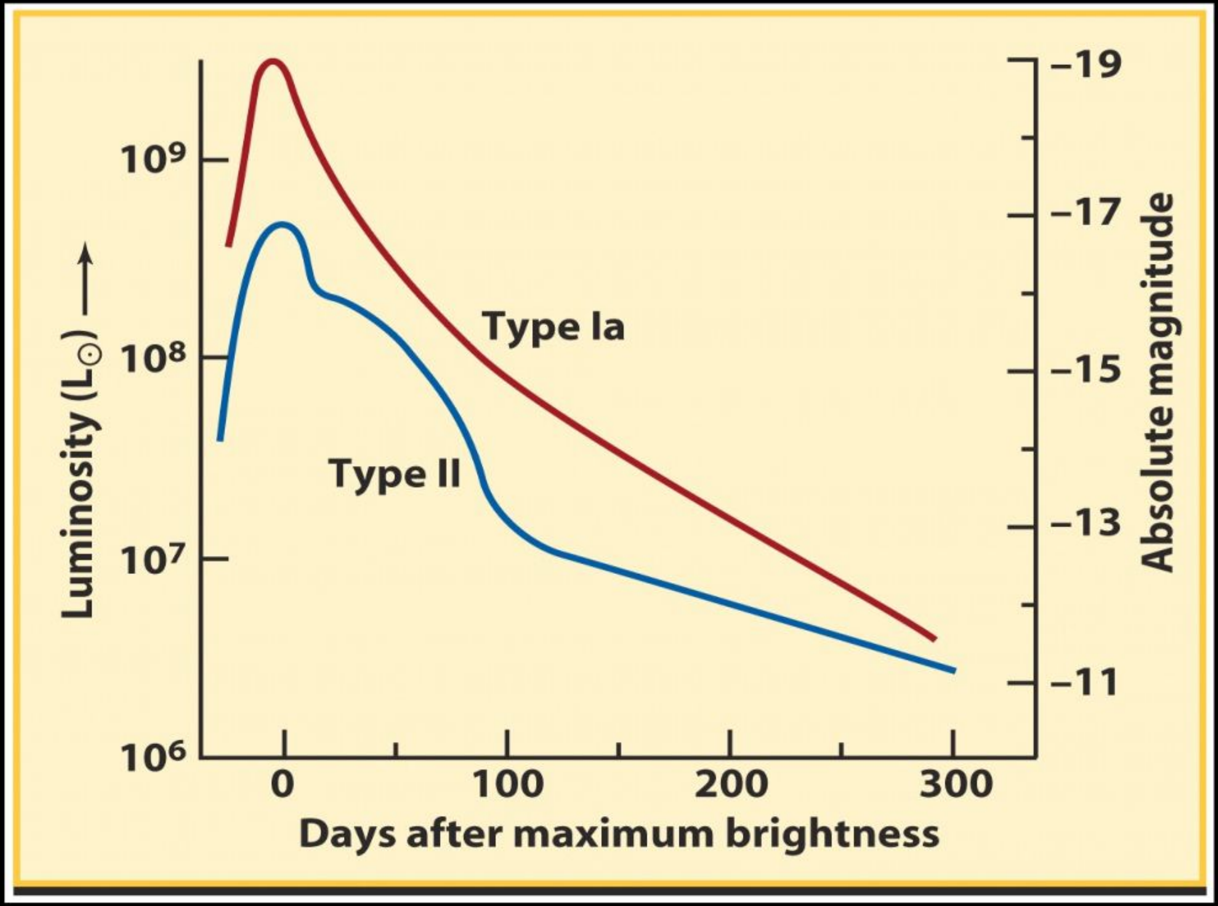
Determinação de distâncias cosmológicas



Determinação de distâncias cosmológicas



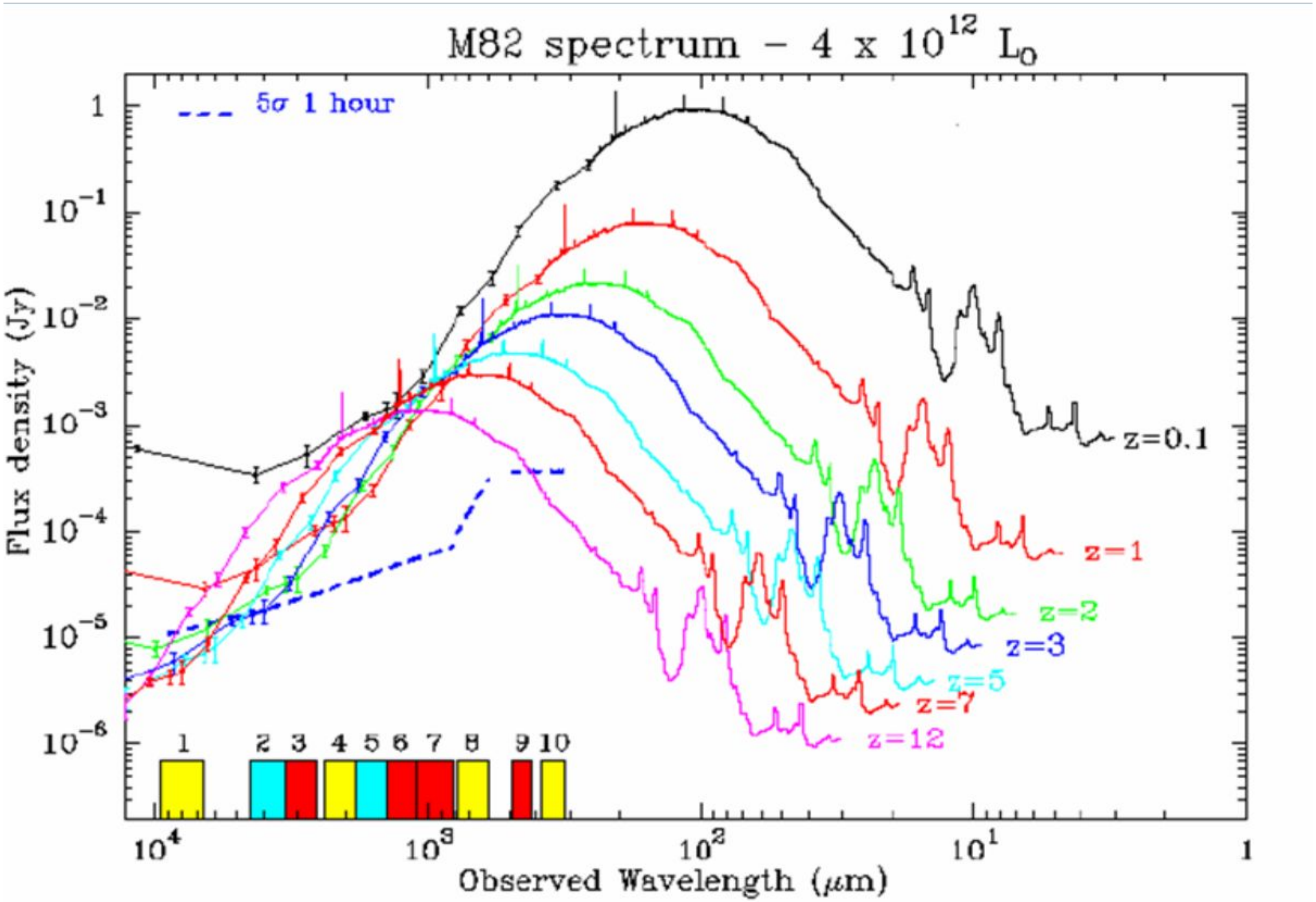
Determinação de distâncias cosmológicas



Spectral evolution

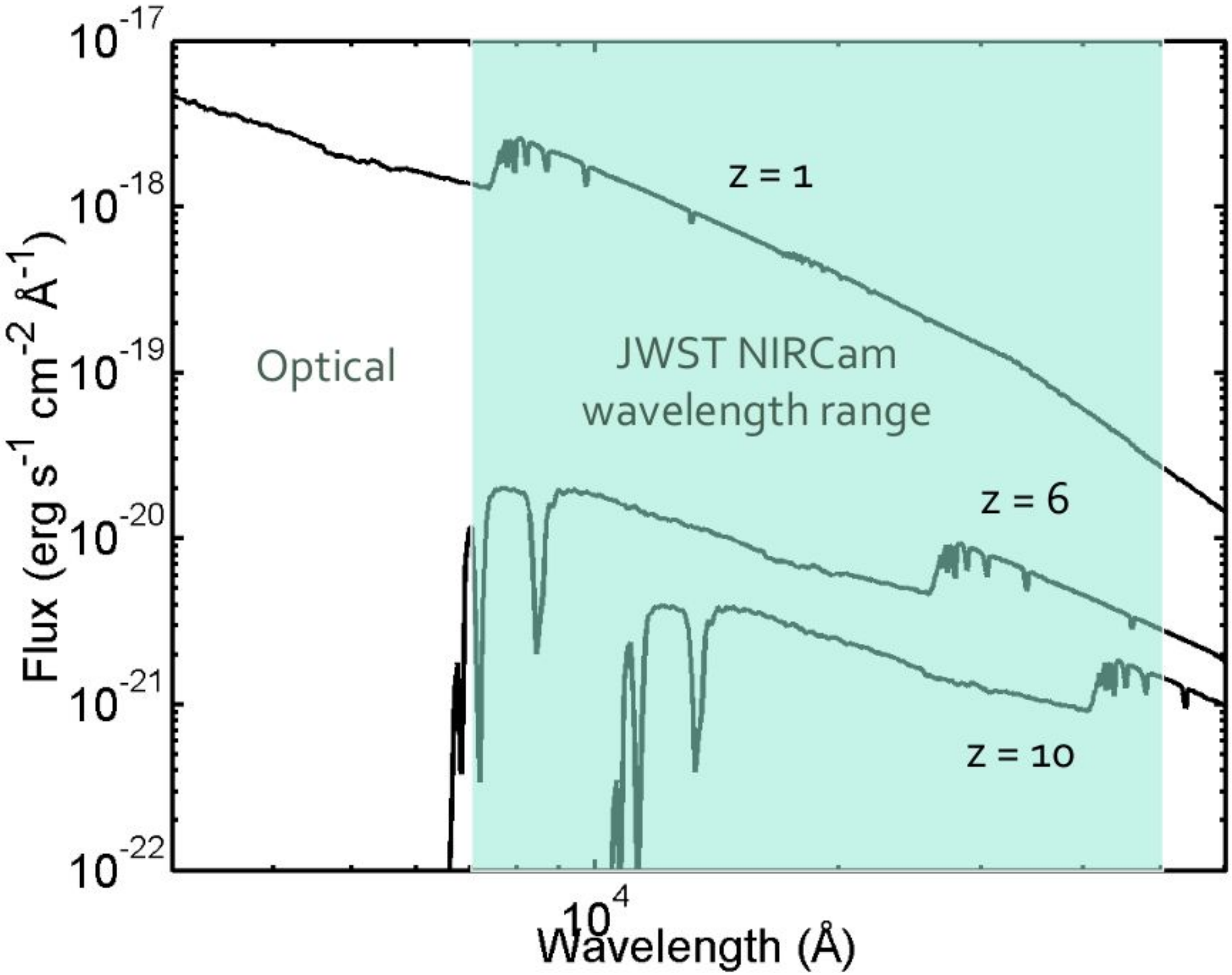
ALMA Receivers – De Breuck+05 -

Dust continuum flux drops slowly with z (if no source evolution).



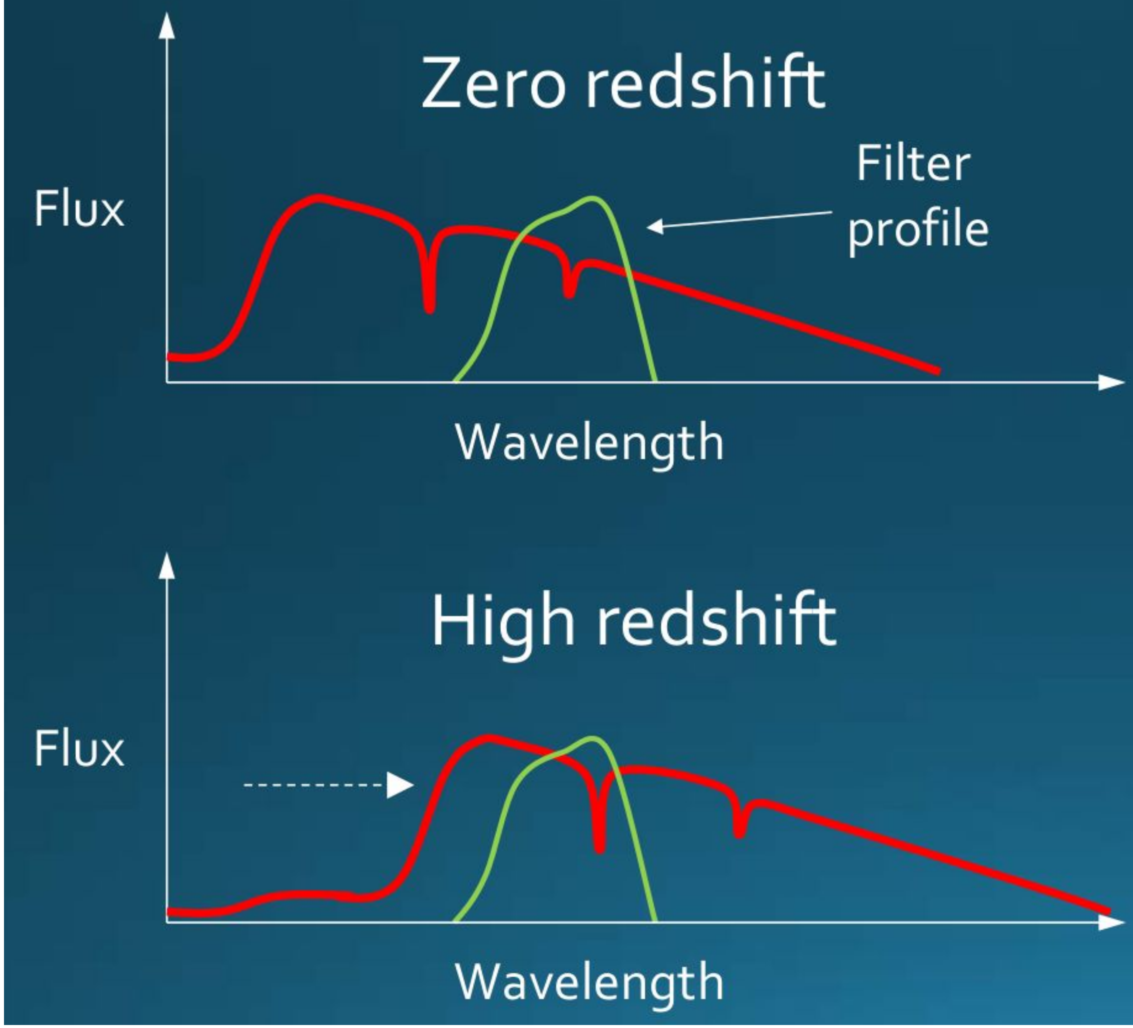
De Breuck +05

Spectral evolution



Zackrisson+01

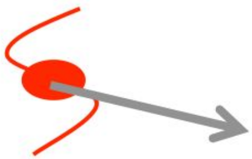
Further Complications

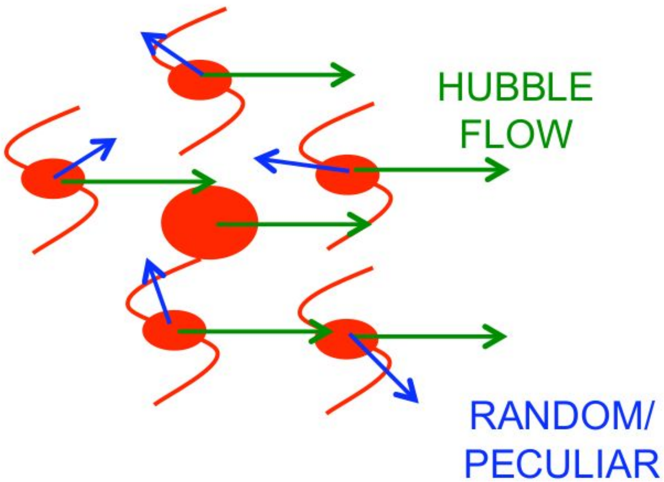


- Same filter probe different parts of spectrum at high and low redshifts
- Two galaxies with identical morphologies at a given rest wavelength may appear to have different morphologies

Further Complications

- Can attempt to remove peculiar velocities of sample out by observing large samples:





- However infall velocity is a systematic
- Measuring large numbers reduces the random peculiar velocities but not the systematic infall (I.e., our galaxies motion relative to local space-time).
- Thankfully CMB dipole provides an accurate measure.

What did we learn?

1. Distance Measurements
2. Redshift
3. Spectral Evolution
4. Complications

Assignments

1. A Cepheid pulsates with a period of 2.5 days and has an apparent peak magnitude of 18.6 V mags. Discuss the possibility that the star be within the MW.

2. Andromeda, at 0.9 Mpc, has a Cepheid of P=3 days. What is its apparent magnitude?