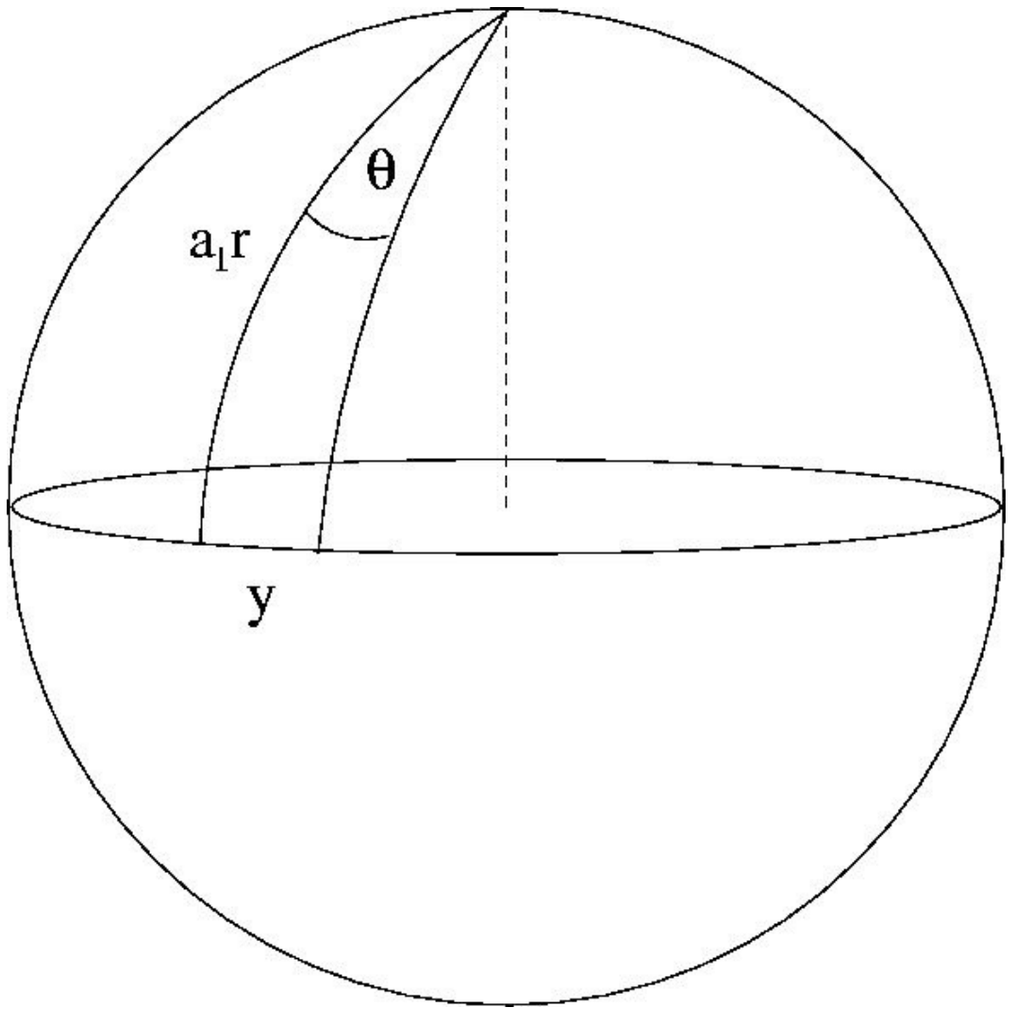
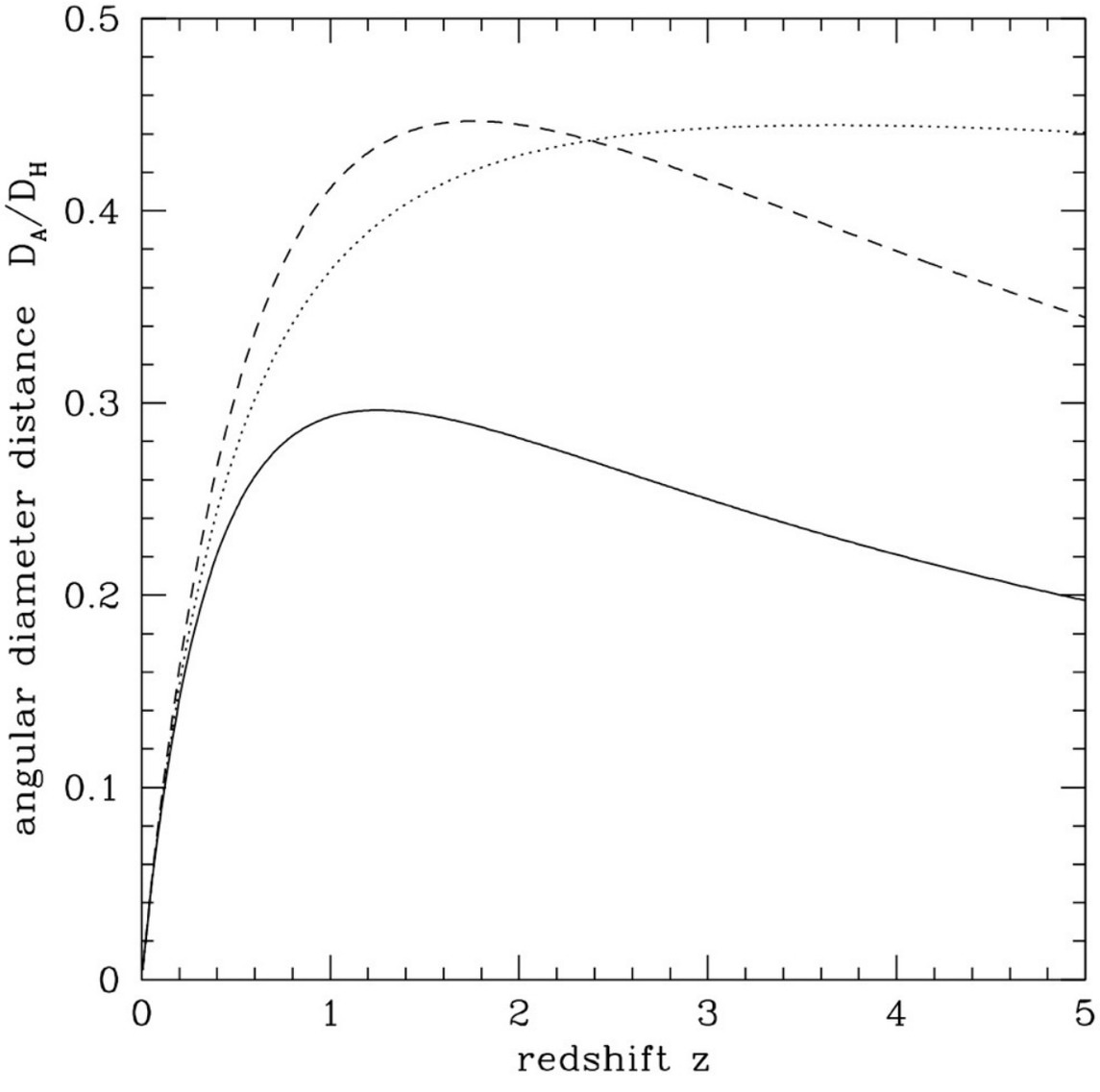
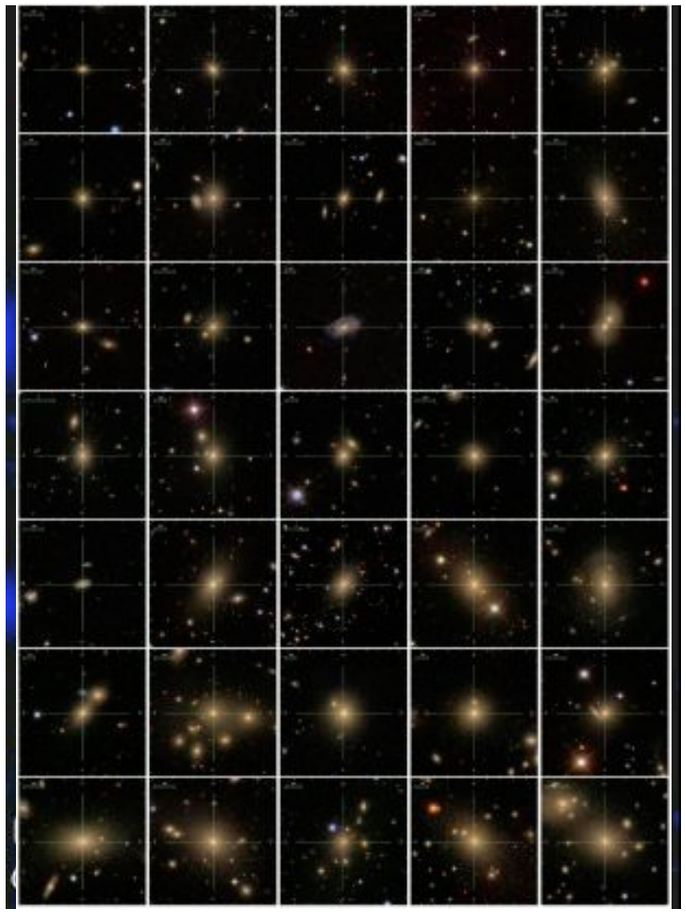
# 2. Measuring the universe

# Defining angular diameter distance:



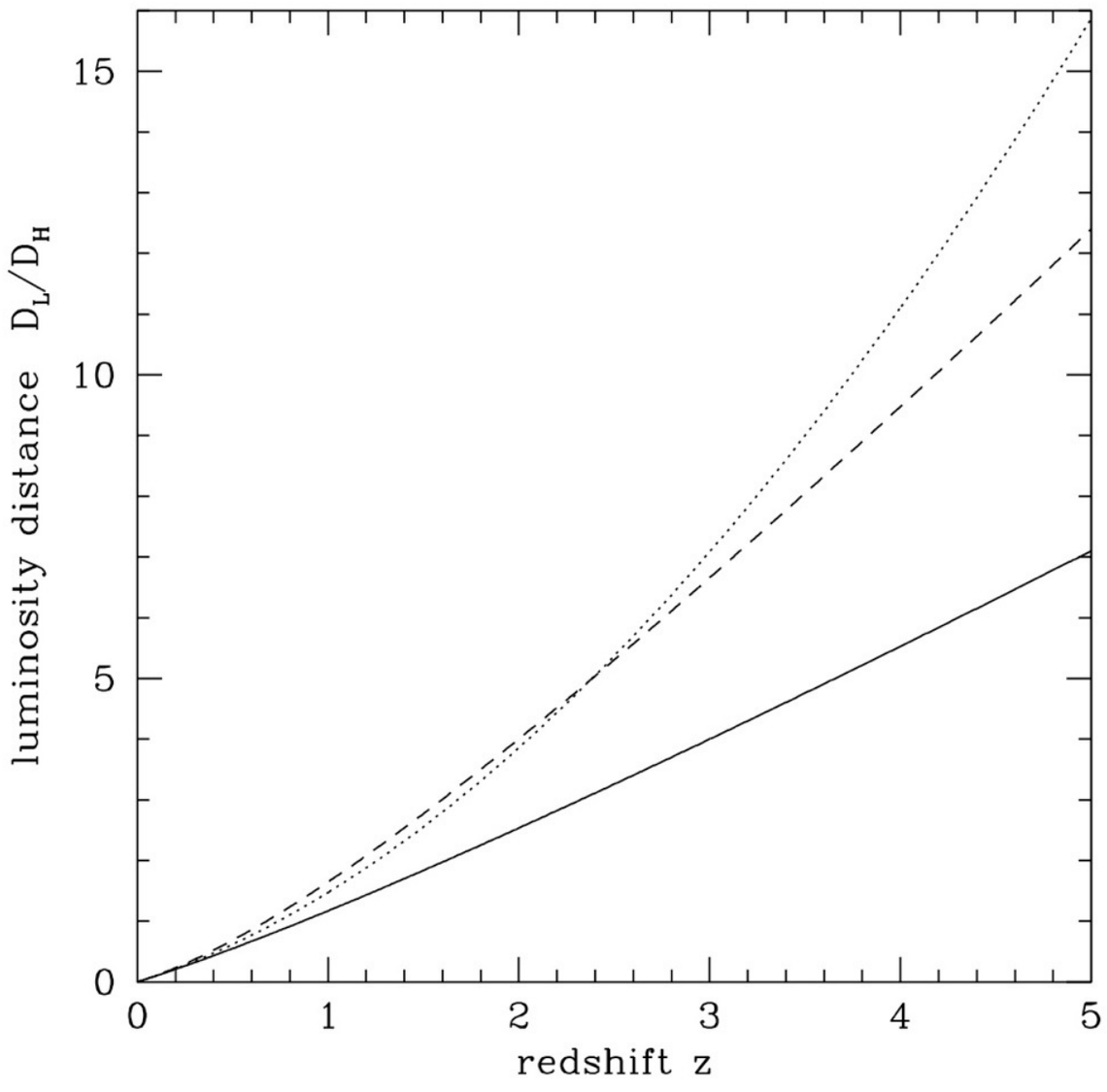
# Angular diameter distance tests:

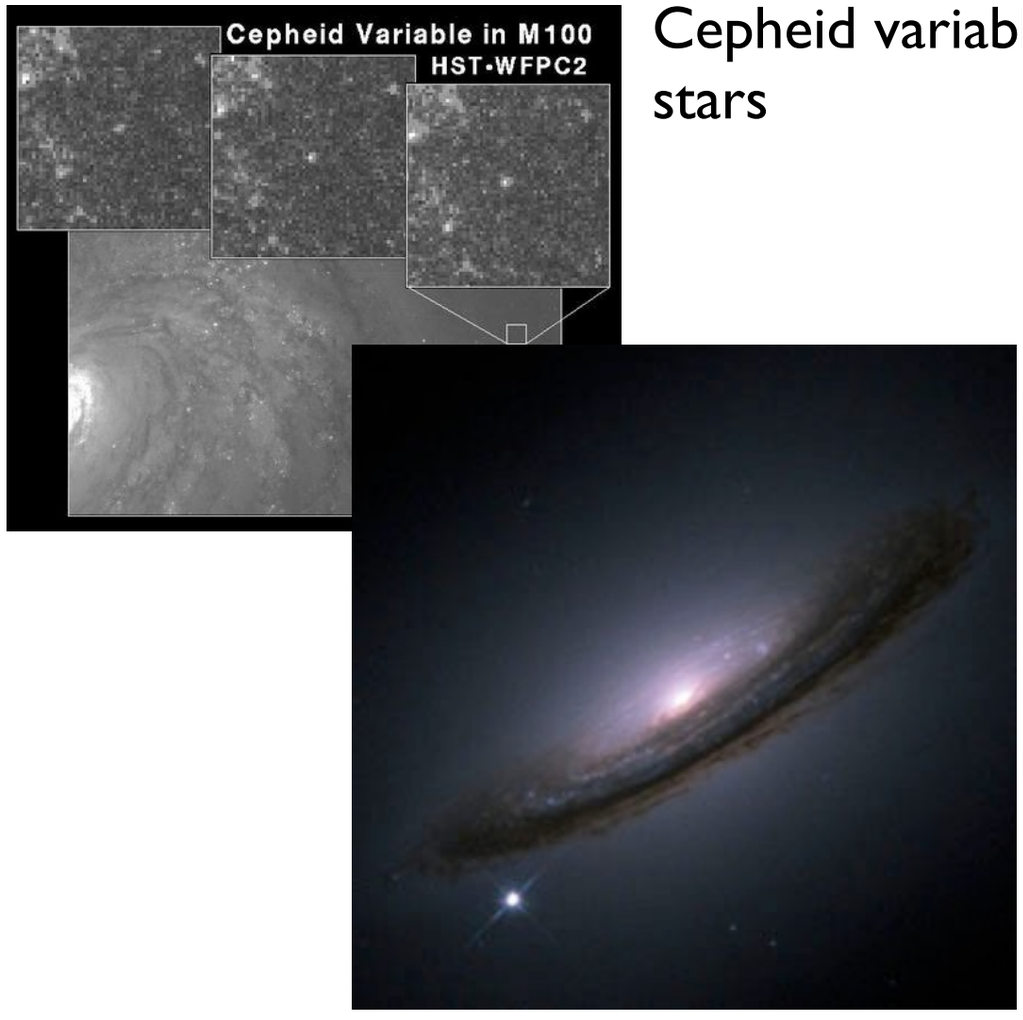


Angular size of BCGs versus redshift

# Luminosity distance tests:

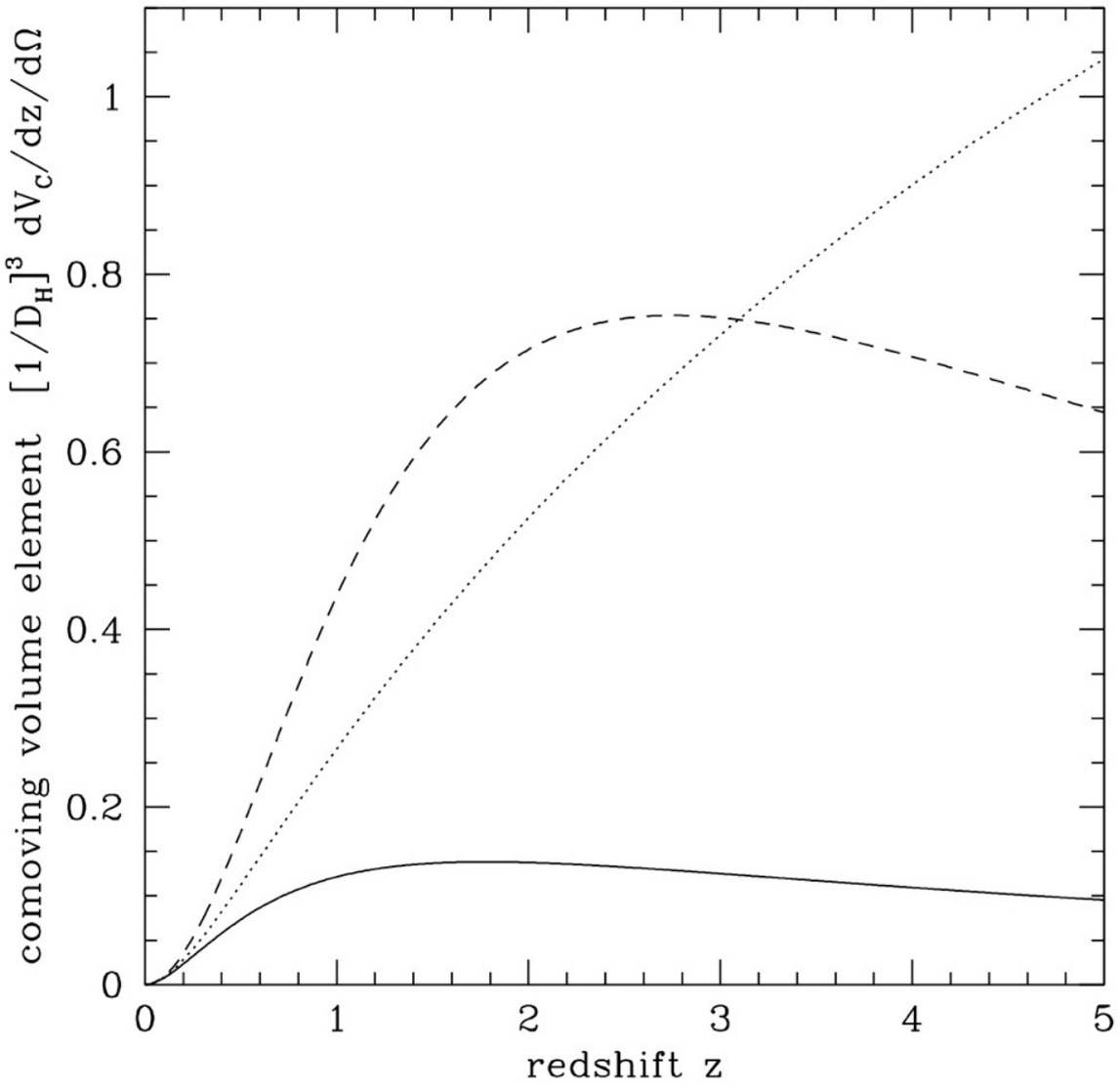


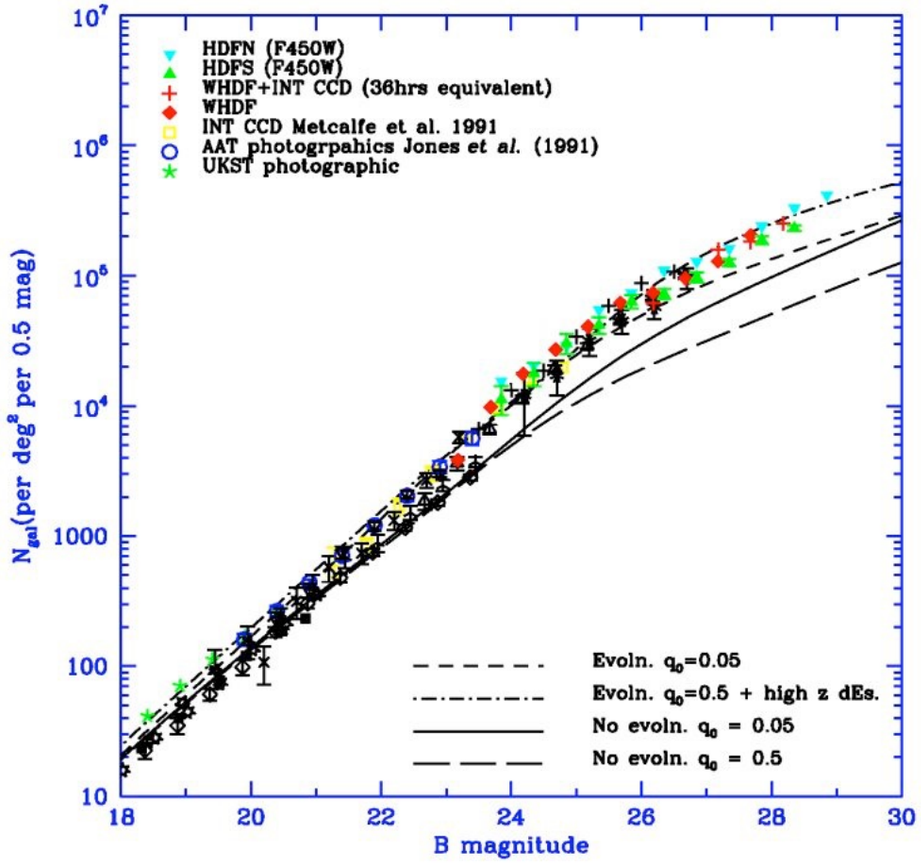




Cepheid variable stars

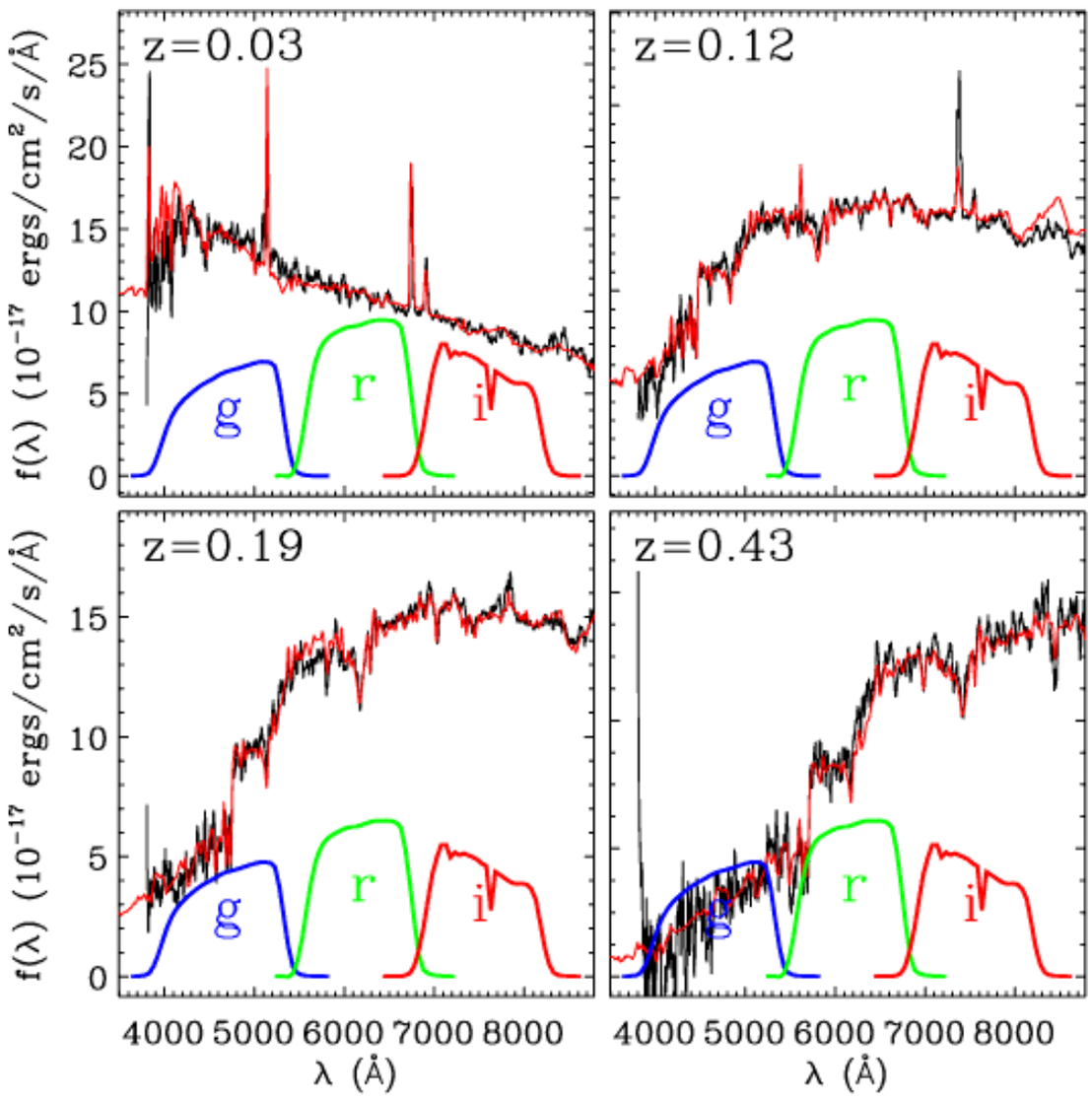
Type Ia Supernovae

# Co-moving volume tests:

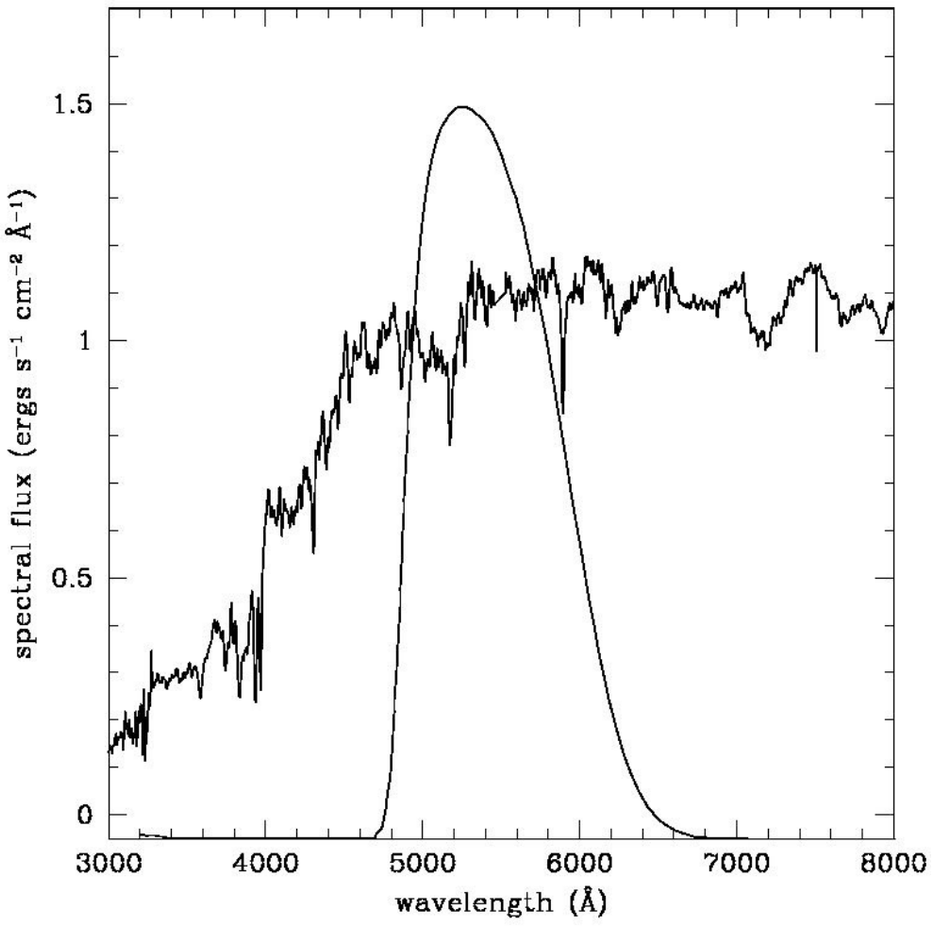


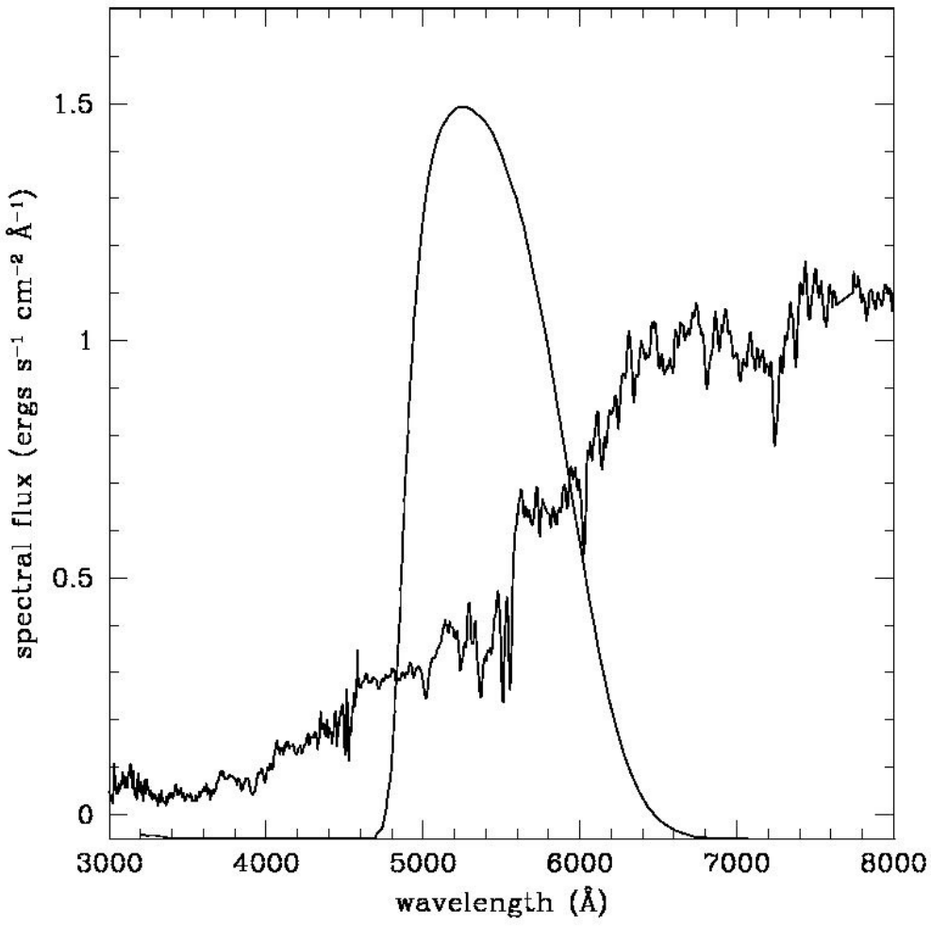
# Understanding k-corrections:

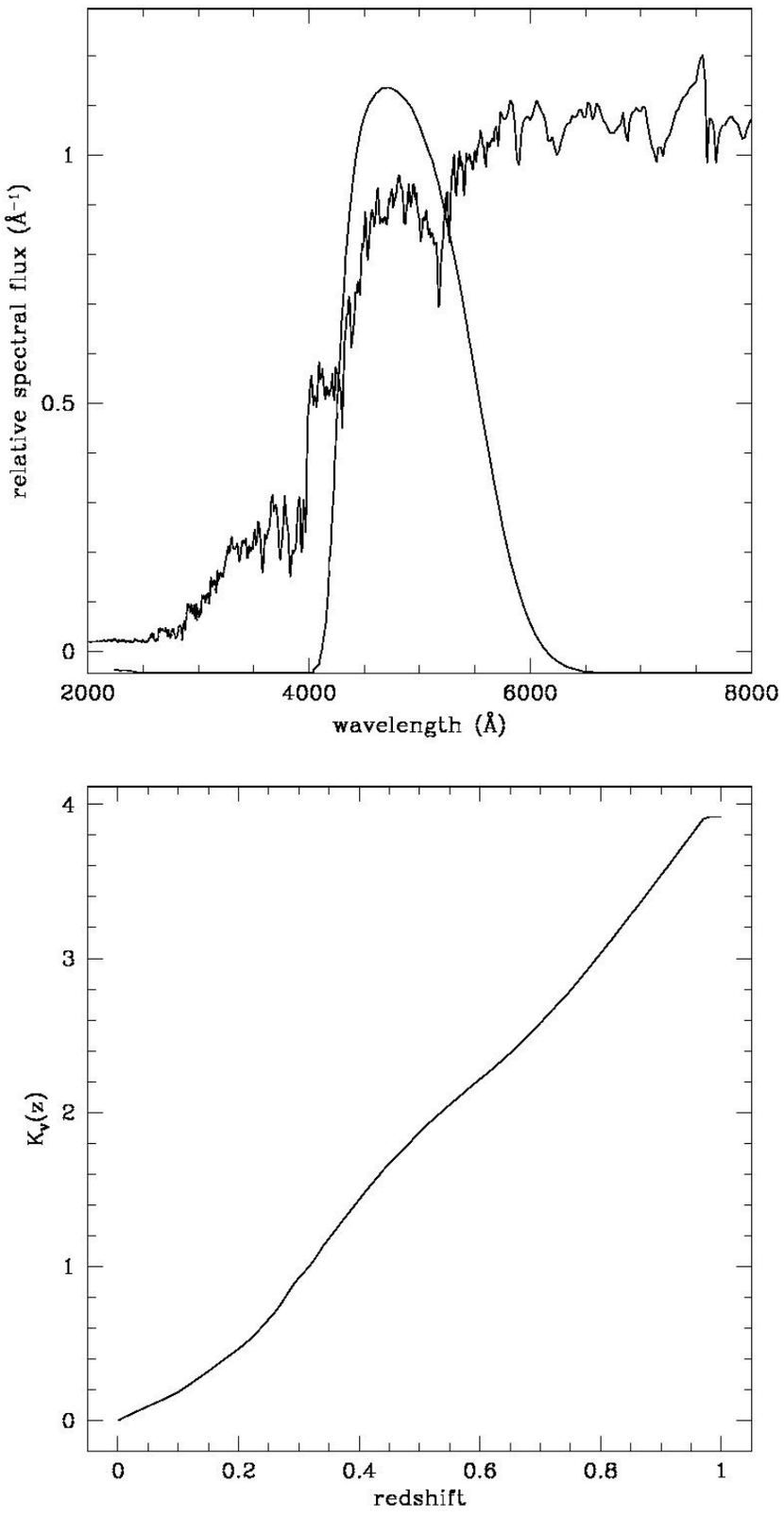


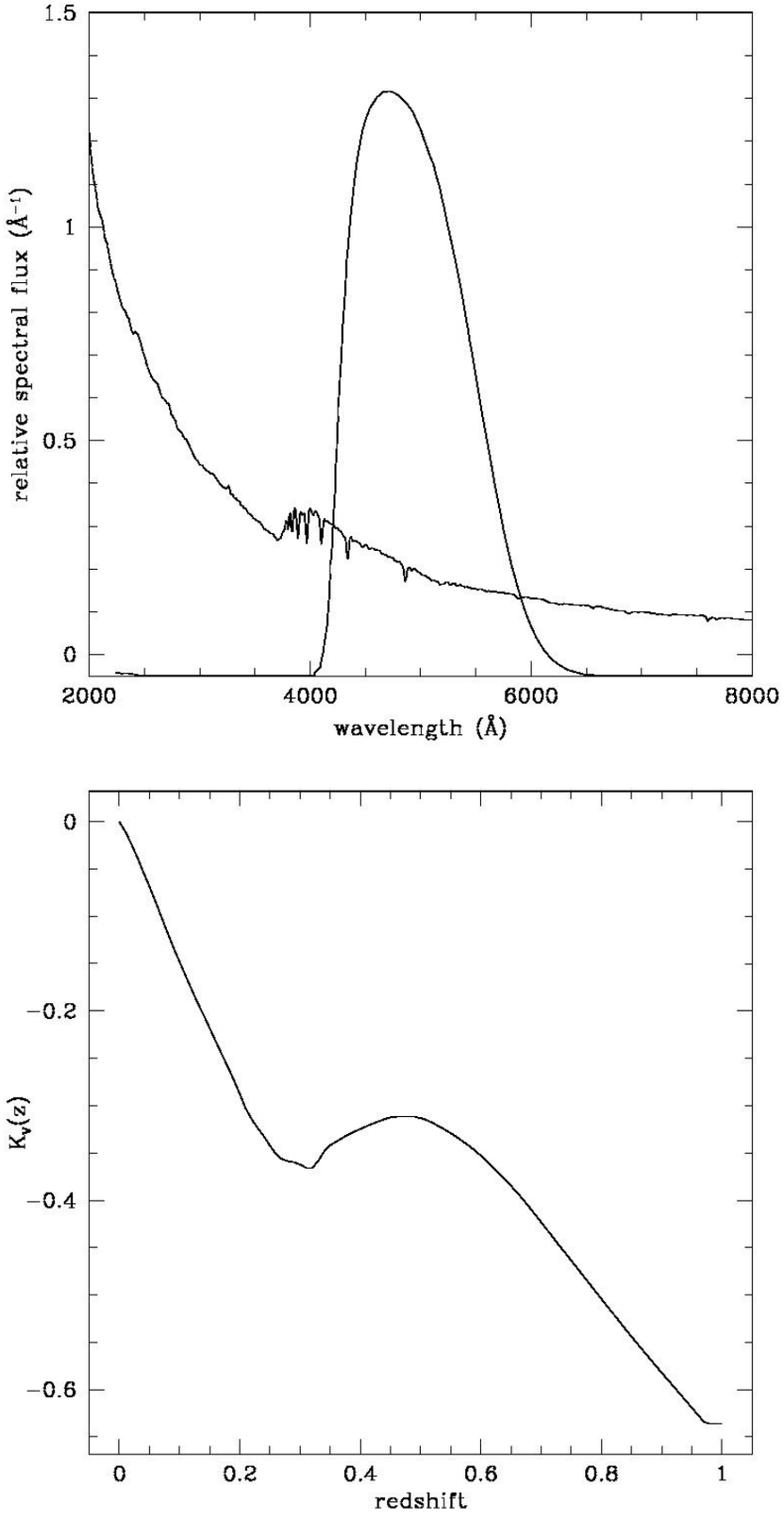
Elliptical at z=0 viewed with R-band filter

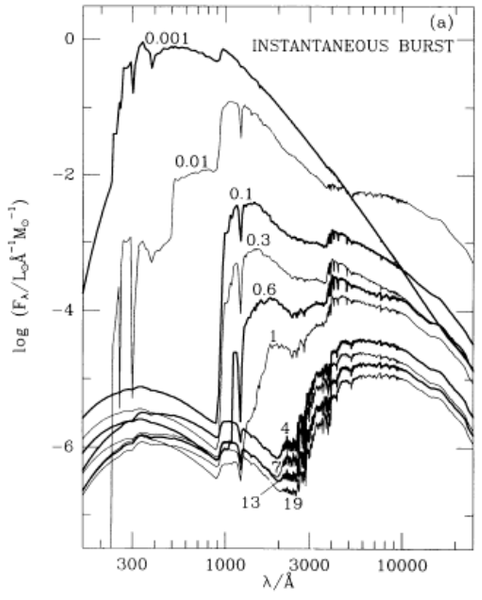


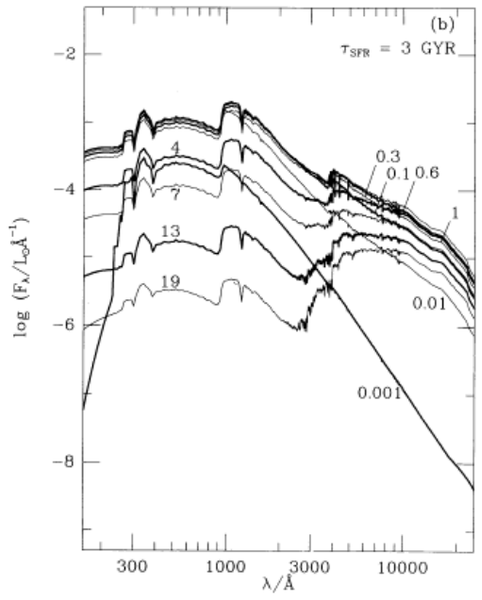

Elliptical at z=0.4 viewed with R-band filter

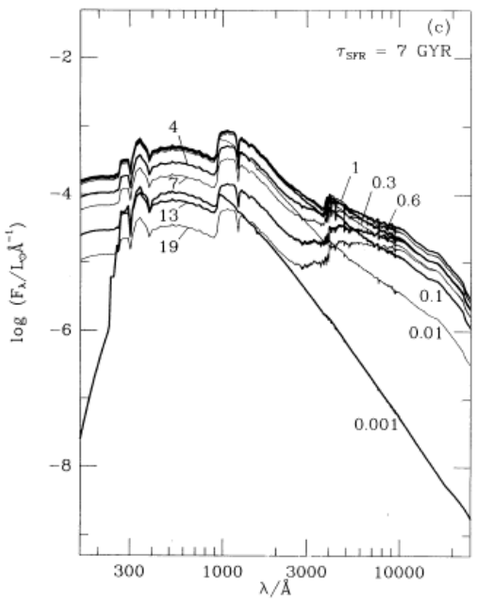


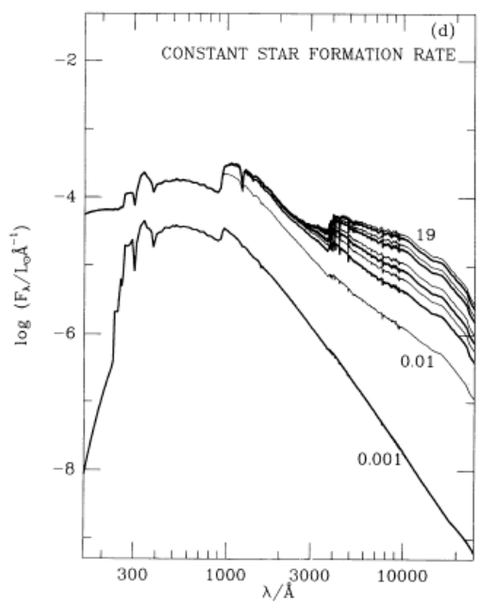

relative spectral flux (Å$^{-1}$)
wavelength (Å)
redshift
$K_\nu(z)$


relative spectral flux (Å$^{-1}$)
wavelength (Å)
redshift
$K_\nu(z)$

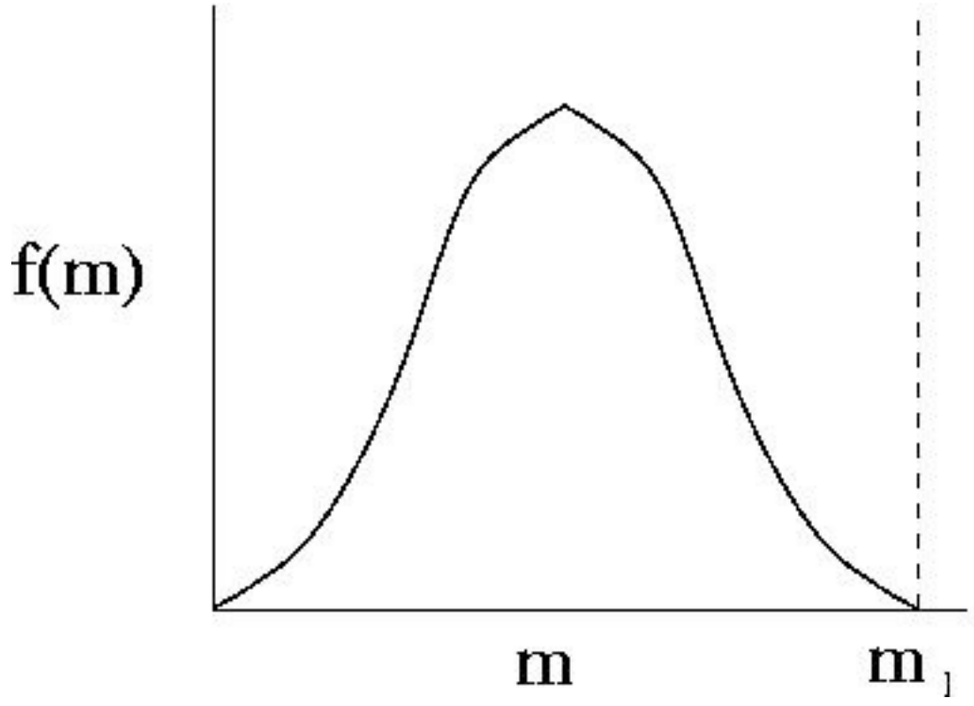

(a)
INSTANTANEOUS BURST
0.001
0.01
0.1
0.3
0.6
1
4
7
13
19
0
−2
−4
−6
log (F_λ/L_⊙Å^−1 M_⊙^−1)
300
1000
3000
10000
λ/Å

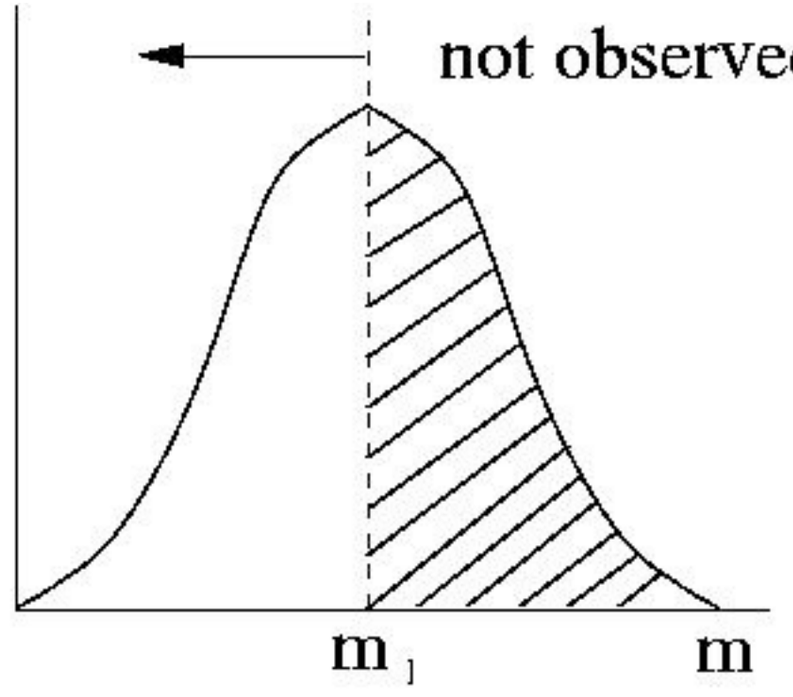

(b)
τ_SFR = 3 GYR
4
7
13
19
0.3
0.1
0.6
1
0.01
0.001
−2
−4
−6
−8
log (F_λ/L_⊙Å^−1)
300
1000
3000
10000
λ/Å

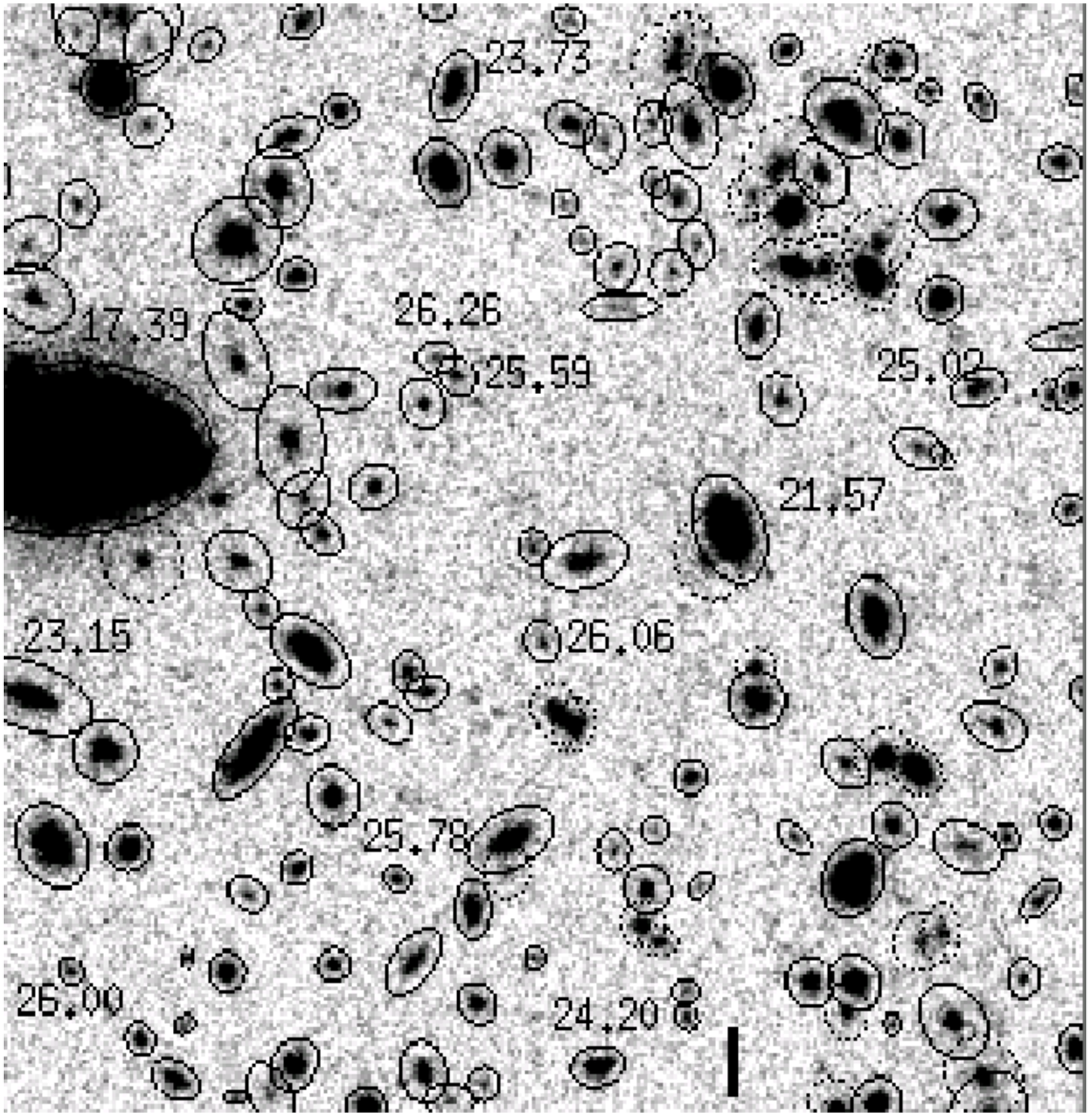

(c)
τ_SFR = 7 GYR
4
7
13
19
1
0.3
0.6
0.1
0.01
0.001
−2
−4
−6
−8
log (F_λ/L_⊙Å^−1)
300
1000
3000
10000
λ/Å


(d)
CONSTANT STAR FORMATION RATE
19
0.01
0.001
−2
−4
−6
−8
log (F_λ/L_⊙Å^−1)
300
1000
3000
10000
λ/Å

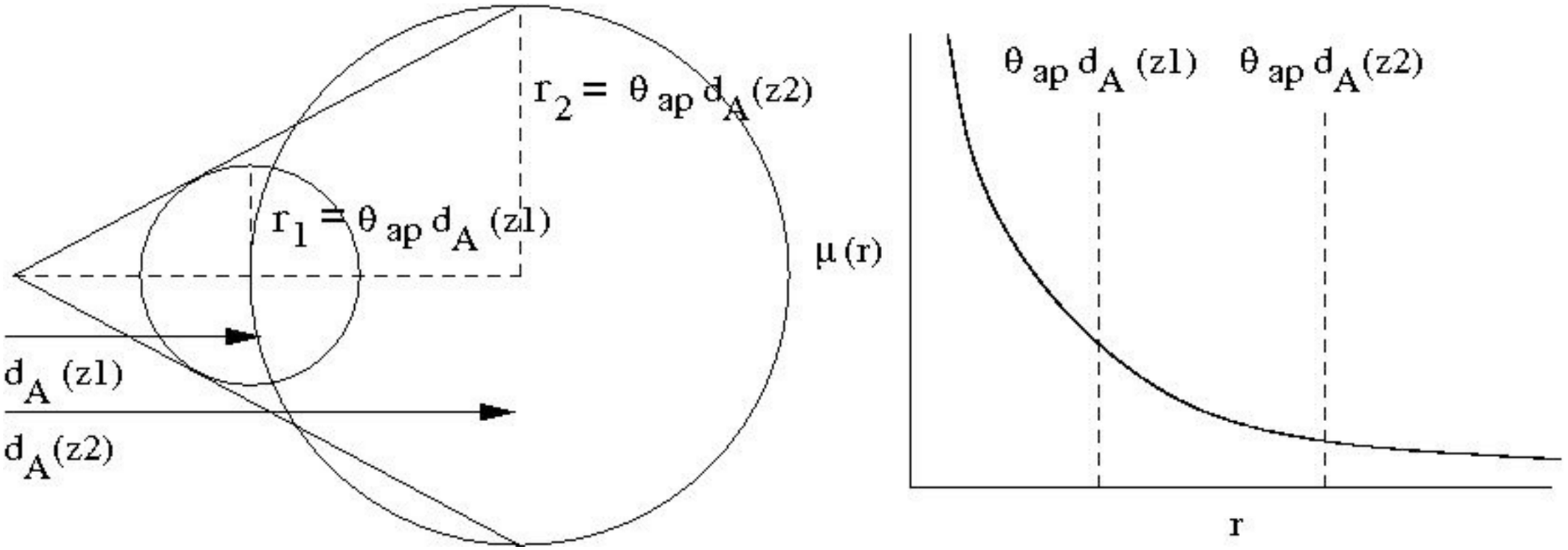
# Malmquist bias:



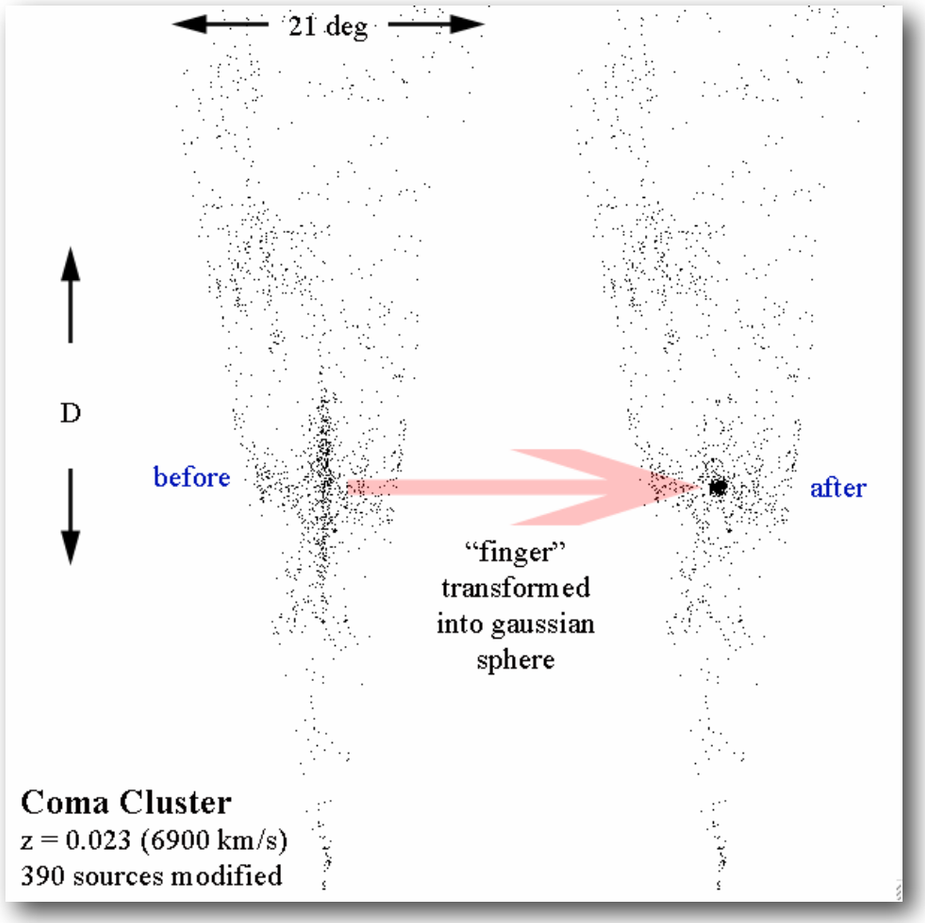




23.73
17.39
26.26
25.59
25.02
21.57
23.15
26.06
25.78
26.00
24.20

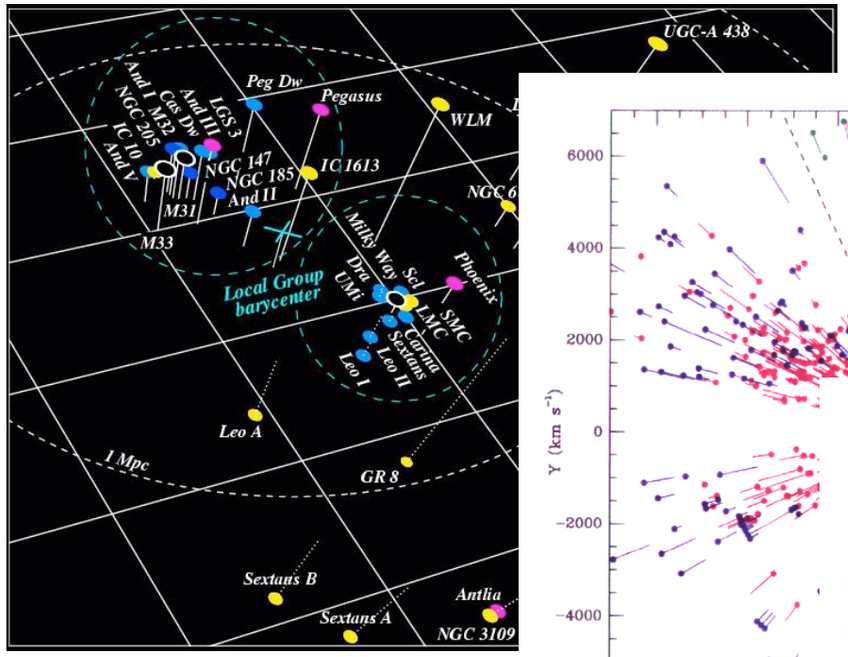
# Aperture bias:



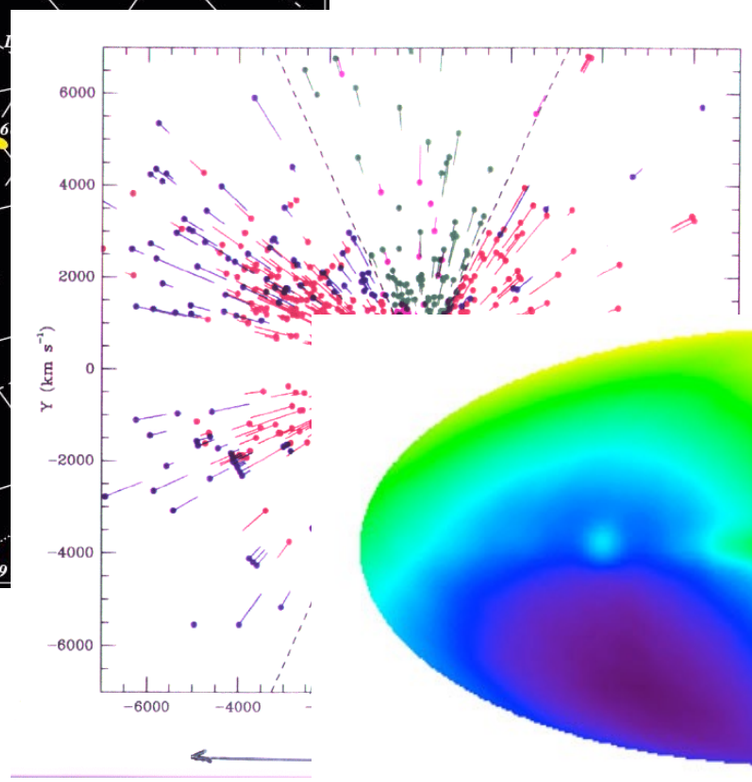
# Peculiar velocities:



# Peculiar velocities:



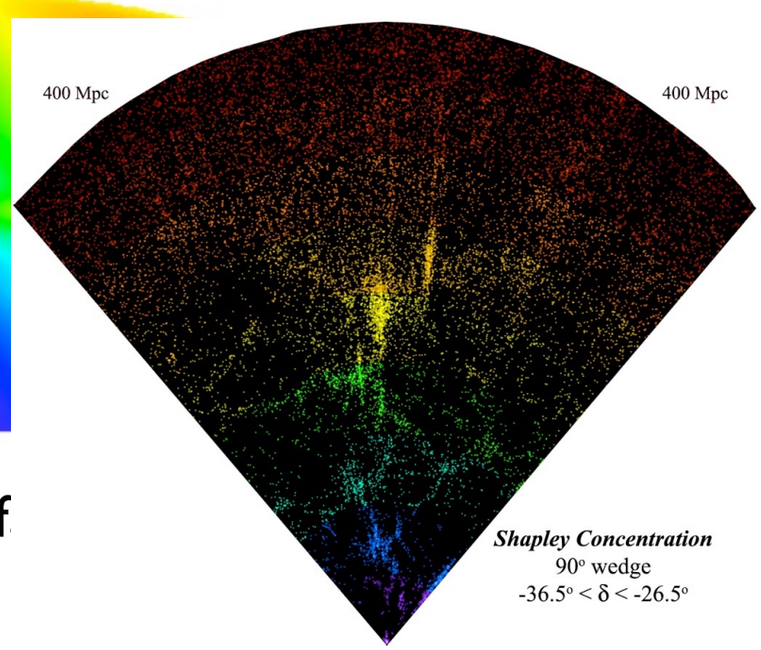

The Local Group



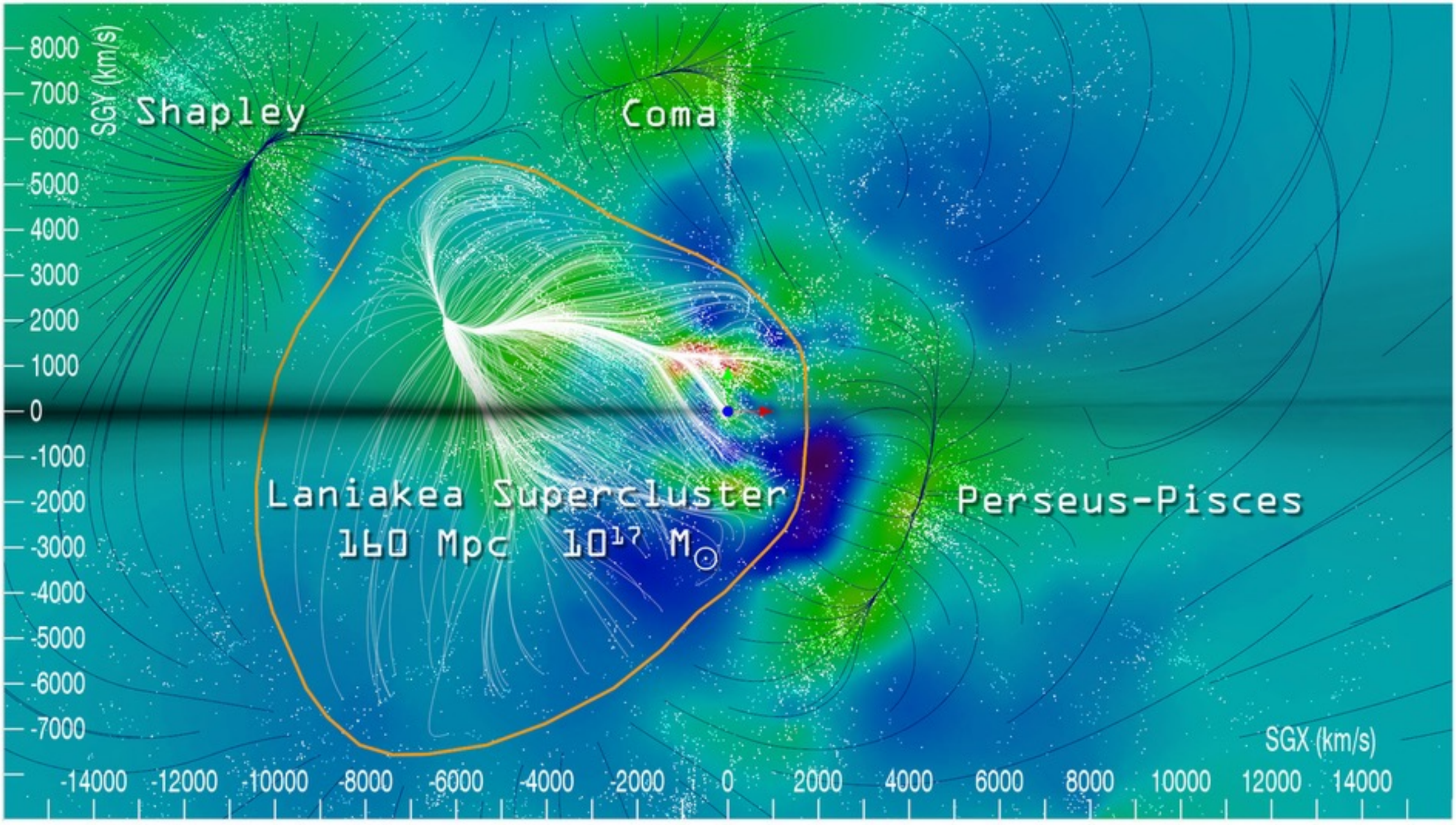

The local velocity field - Virgo inf

The CMB dipole





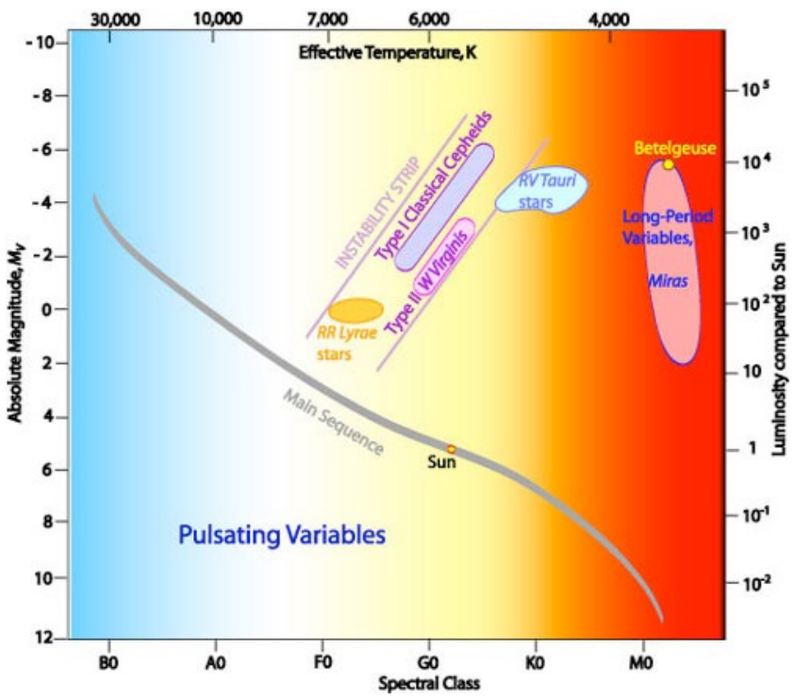

Redshift space distortions

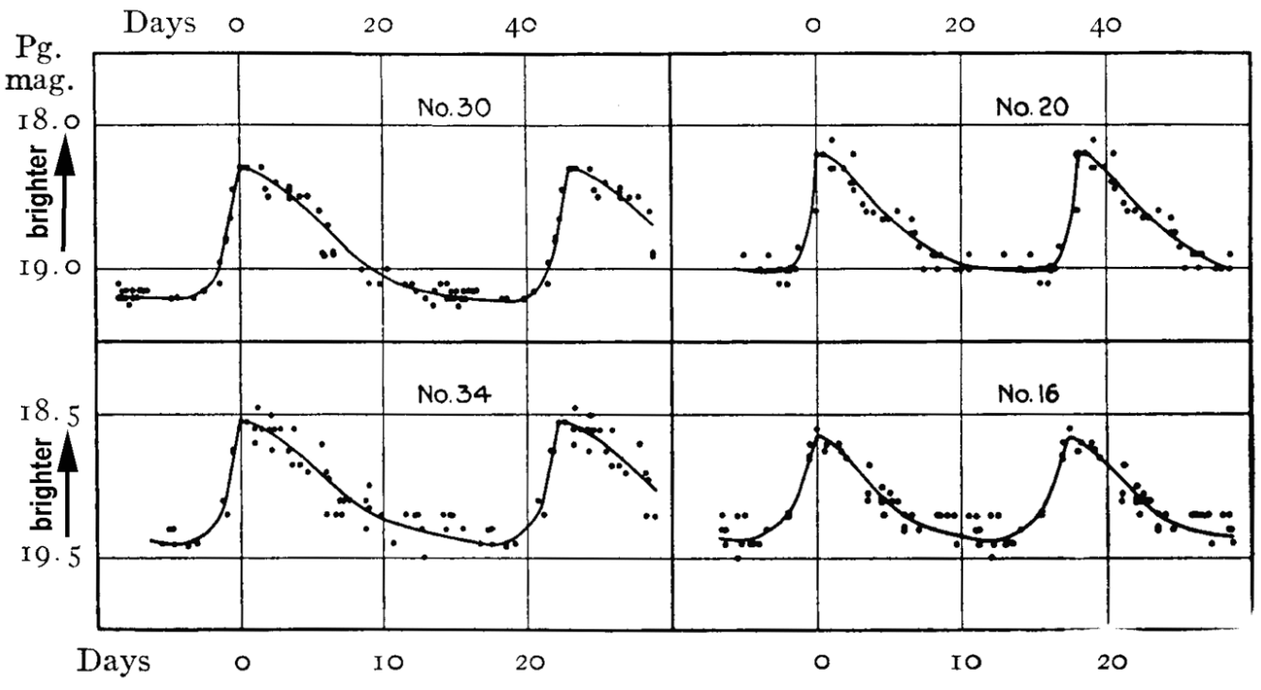

SGY (km/s)
8000
7000
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000
-5000
-6000
-7000
Shapley
Coma
Laniakea Supercluster
160 Mpc 10¹⁷ M⊙
Perseus-Pisces
SGX (km/s)
-14000
-12000
-10000
-8000
-6000
-4000
-2000
0
2000
4000
6000
8000
10000
12000
14000

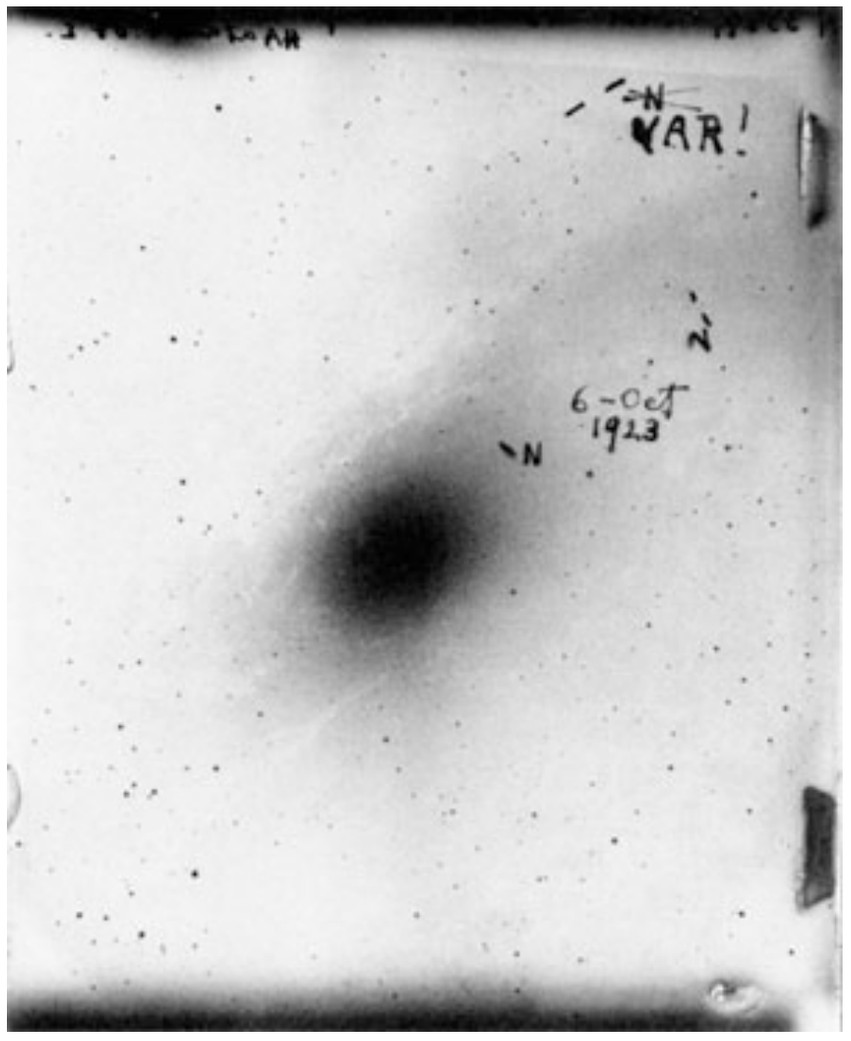
# Standard candles:

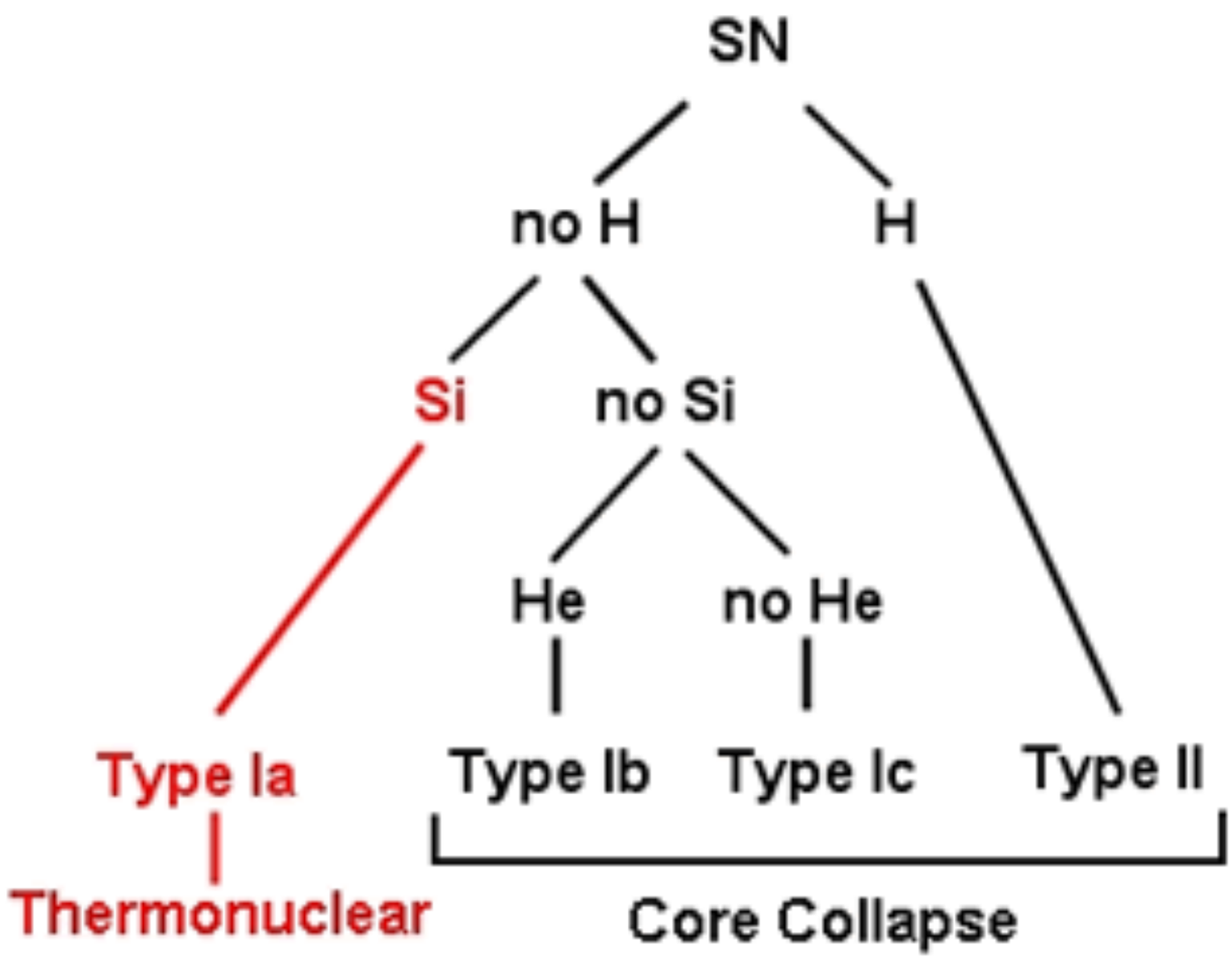
- Novae
- Cepheid variables
- Brightest galactic star
- Mean magnitude of galaxy cluster members
- Brightest cluster galaxies
- Radio galaxies
- Tully-Fisher relation / Dn-sigma
- Tip of red giant branch
- Type Ia supernovae (SNeIa)

# Cepheid variables:

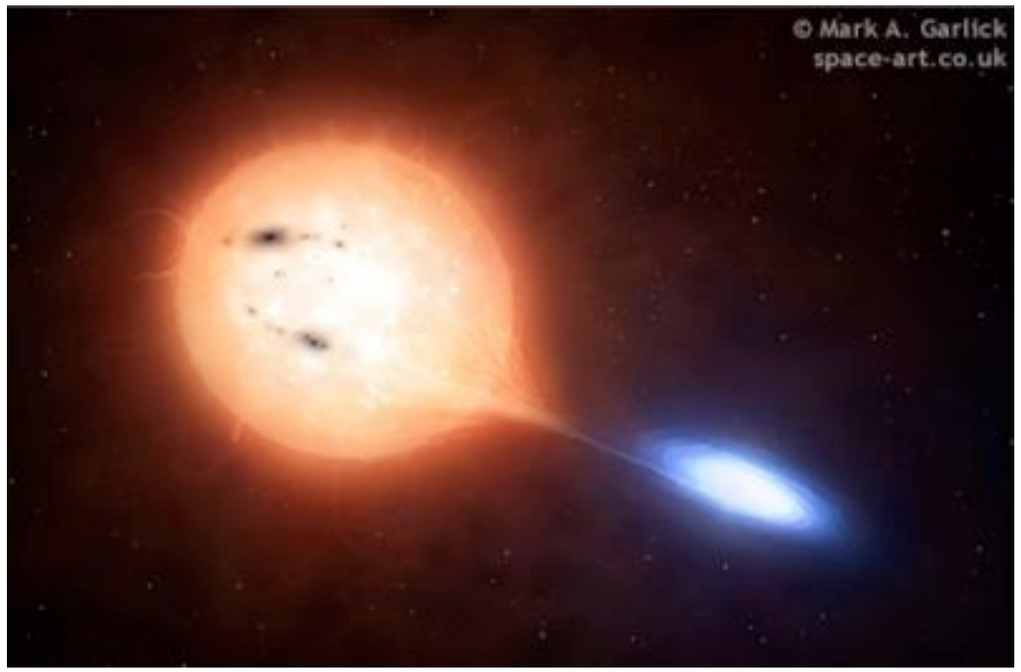


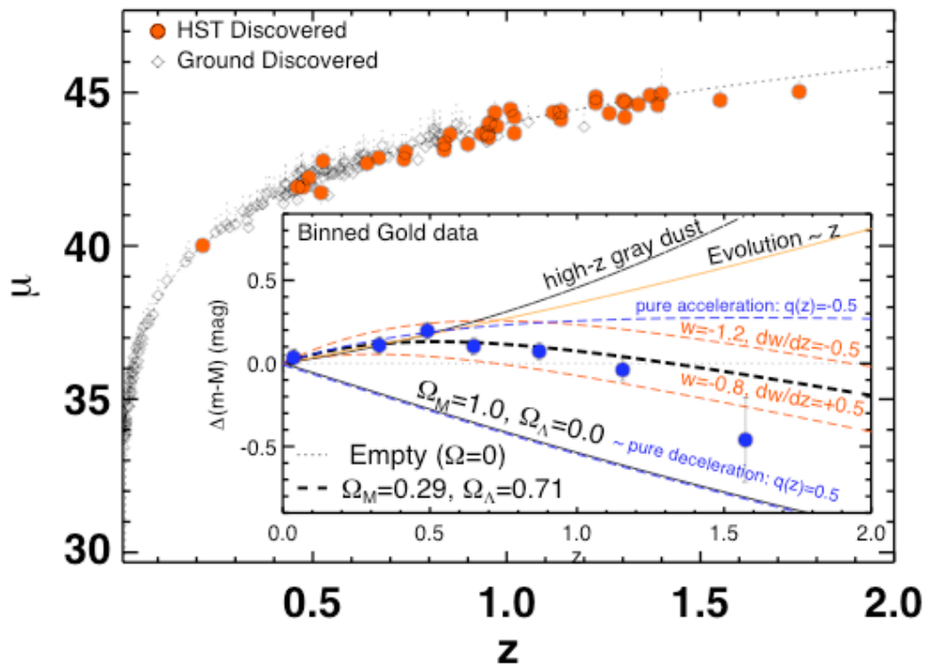



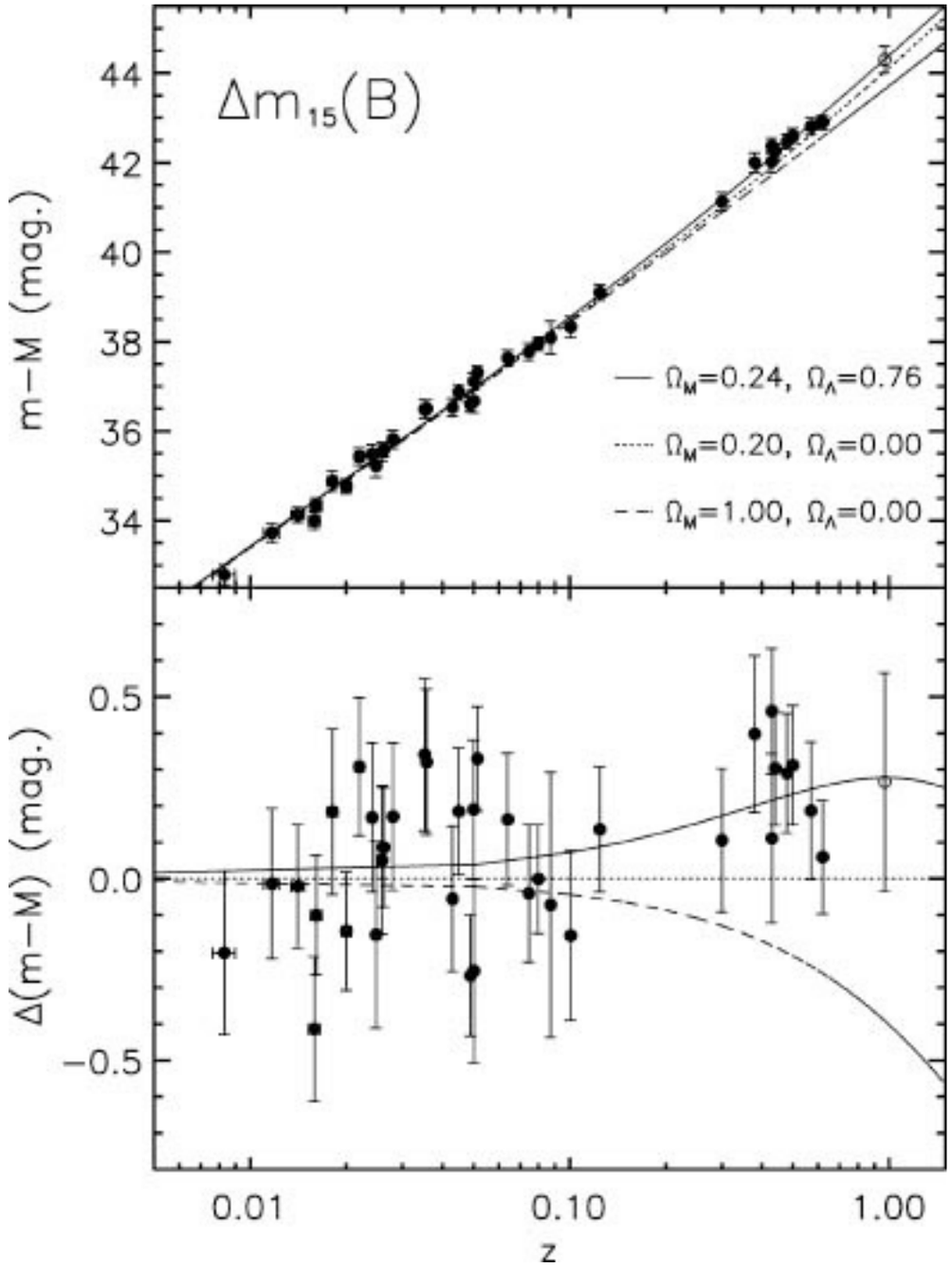



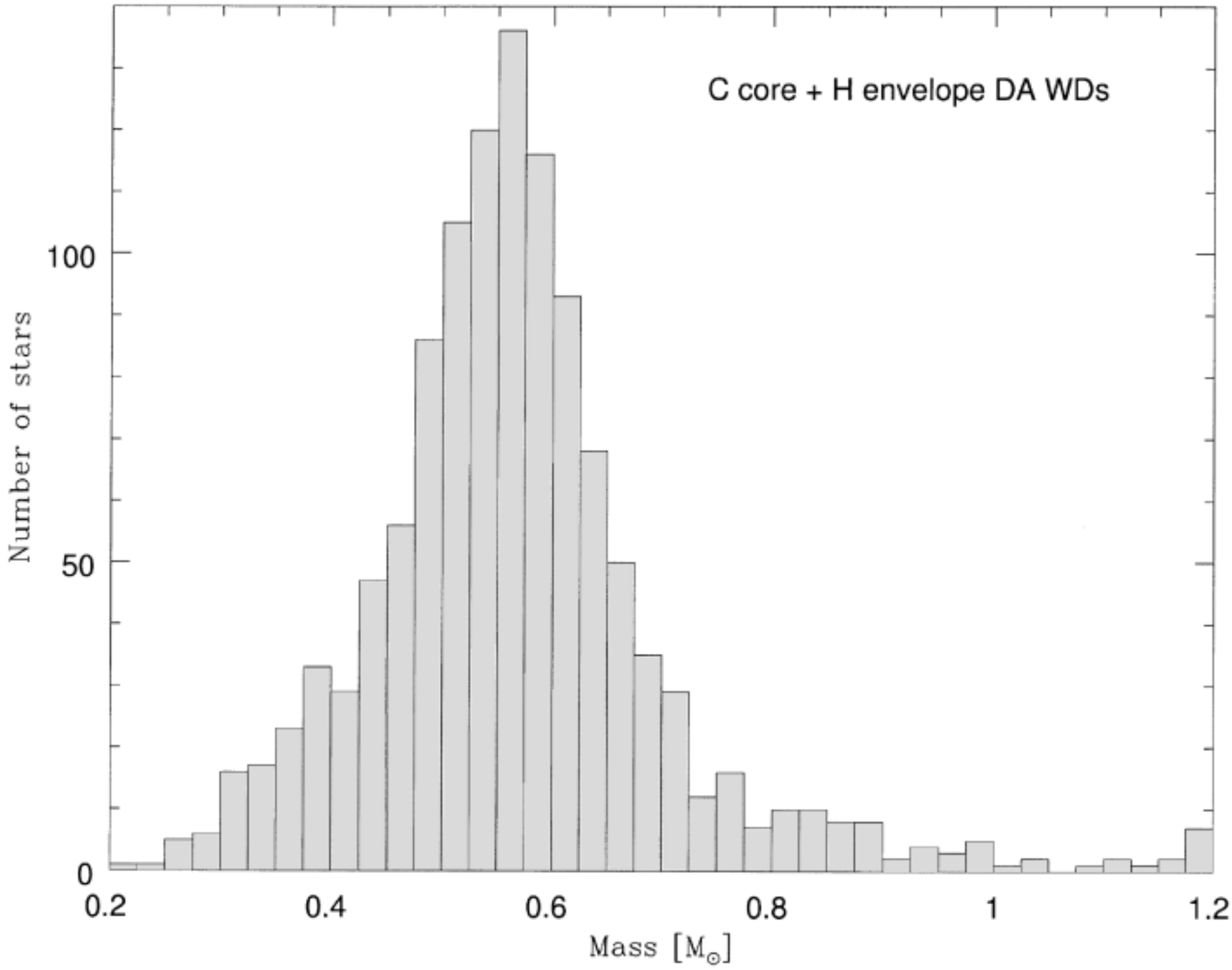

SN
no H
H
Si
no Si
He
no He
Type Ia
Type Ib
Type Ic
Type II
Thermonuclear
Core Collapse

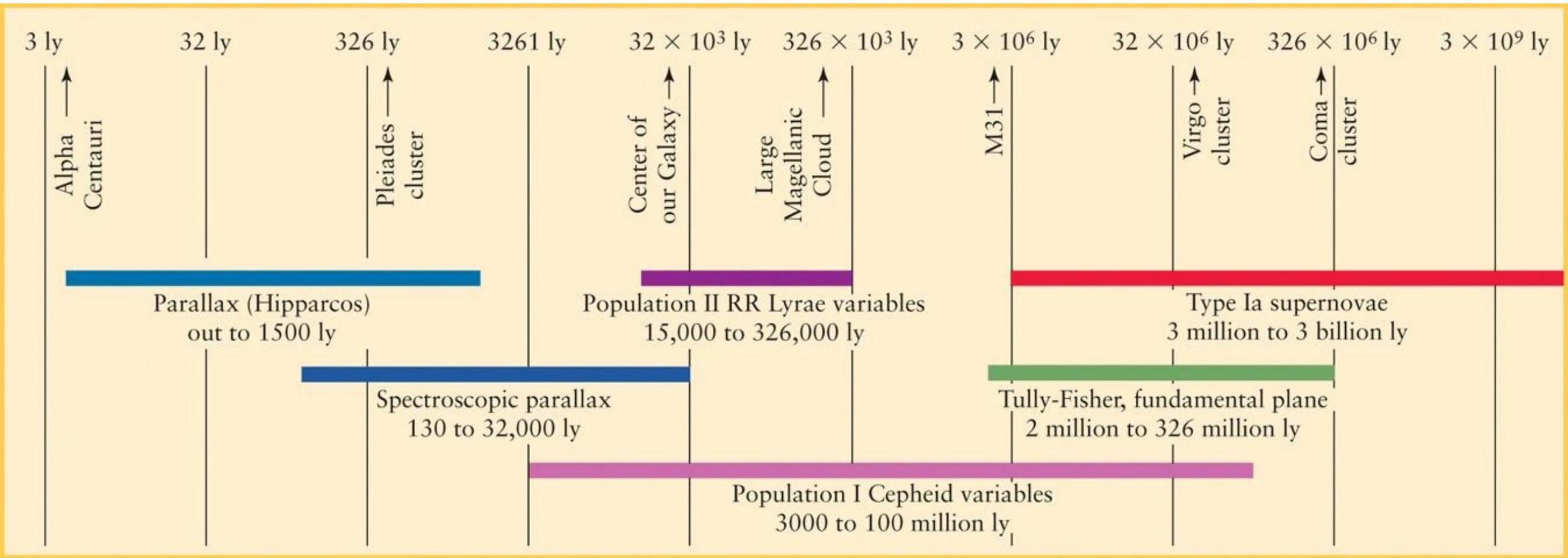
# Type Ia supernovae:



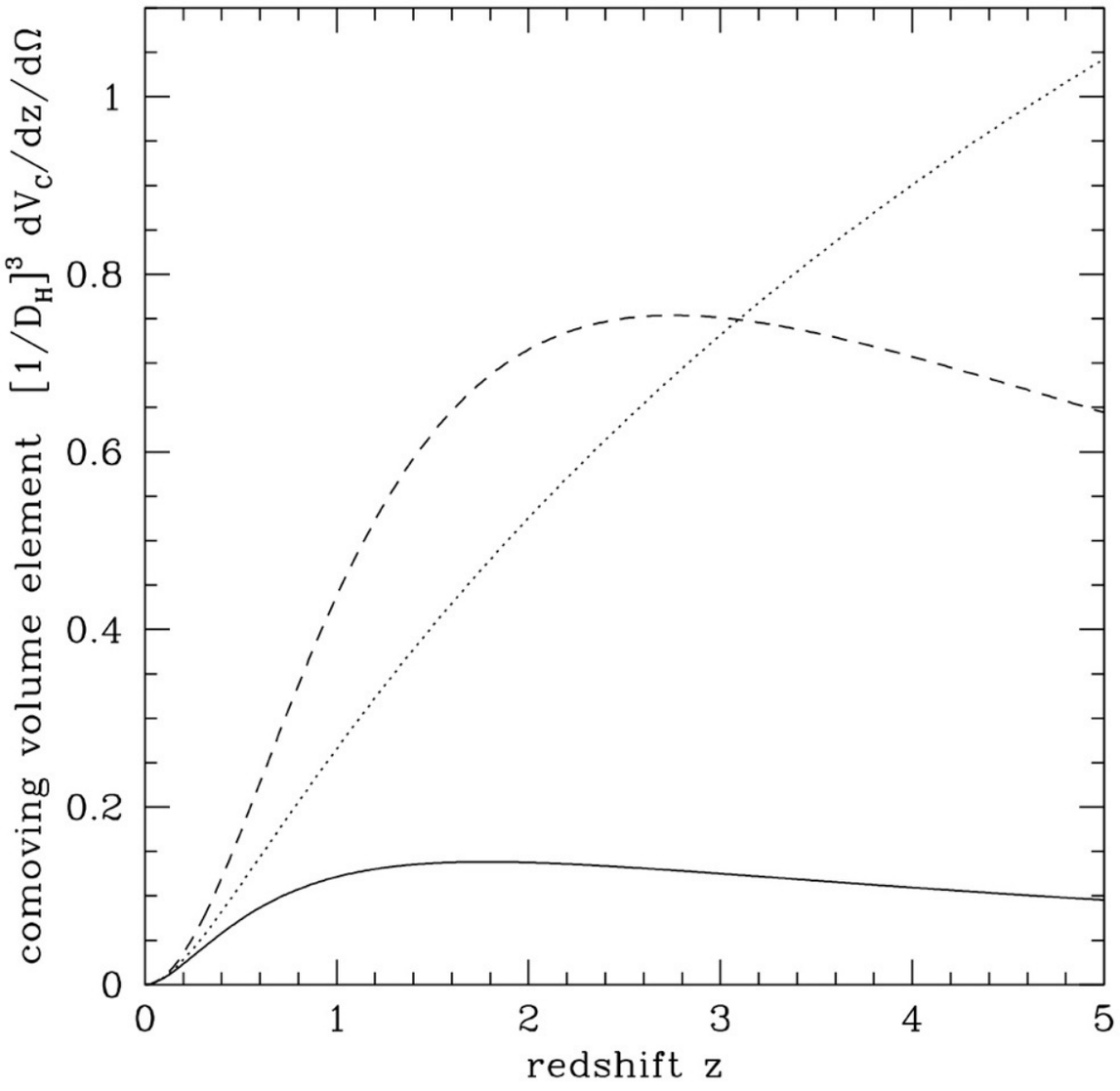



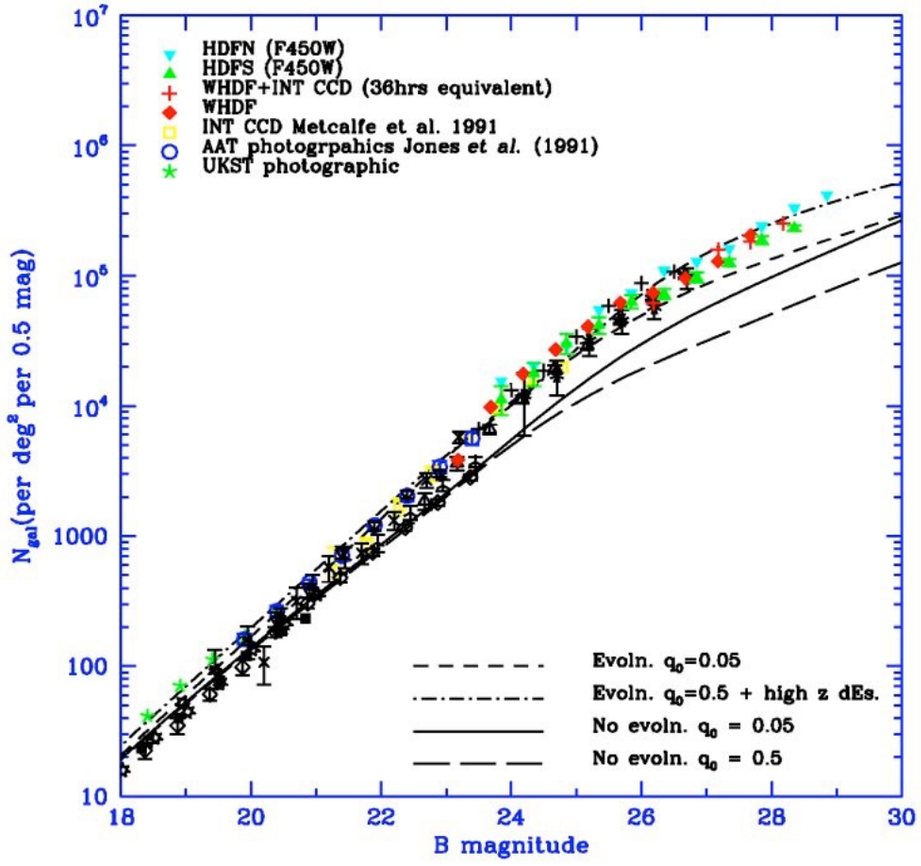




C core + H envelope DA WDs
Number of stars
100
50
0
0.2
0.4
0.6
0.8
1
1.2
Mass [M⊙]


3 ly
32 ly
326 ly
3261 ly
32 × 10³ ly
326 × 10³ ly
3 × 10⁶ ly
32 × 10⁶ ly
326 × 10⁶ ly
3 × 10⁹ ly
Alpha Centauri
Pleiades cluster
Center of our Galaxy
Large Magellanic Cloud
M31
Virgo cluster
Coma cluster
Parallax (Hipparcos) out to 1500 ly
Population II RR Lyrae variables 15,000 to 326,000 ly
Type Ia supernovae 3 million to 3 billion ly
Spectroscopic parallax 130 to 32,000 ly
Tully-Fisher, fundamental plane 2 million to 326 million ly
Population I Cepheid variables 3000 to 100 million ly

# Co-moving volume tests:



# Eddington bias: