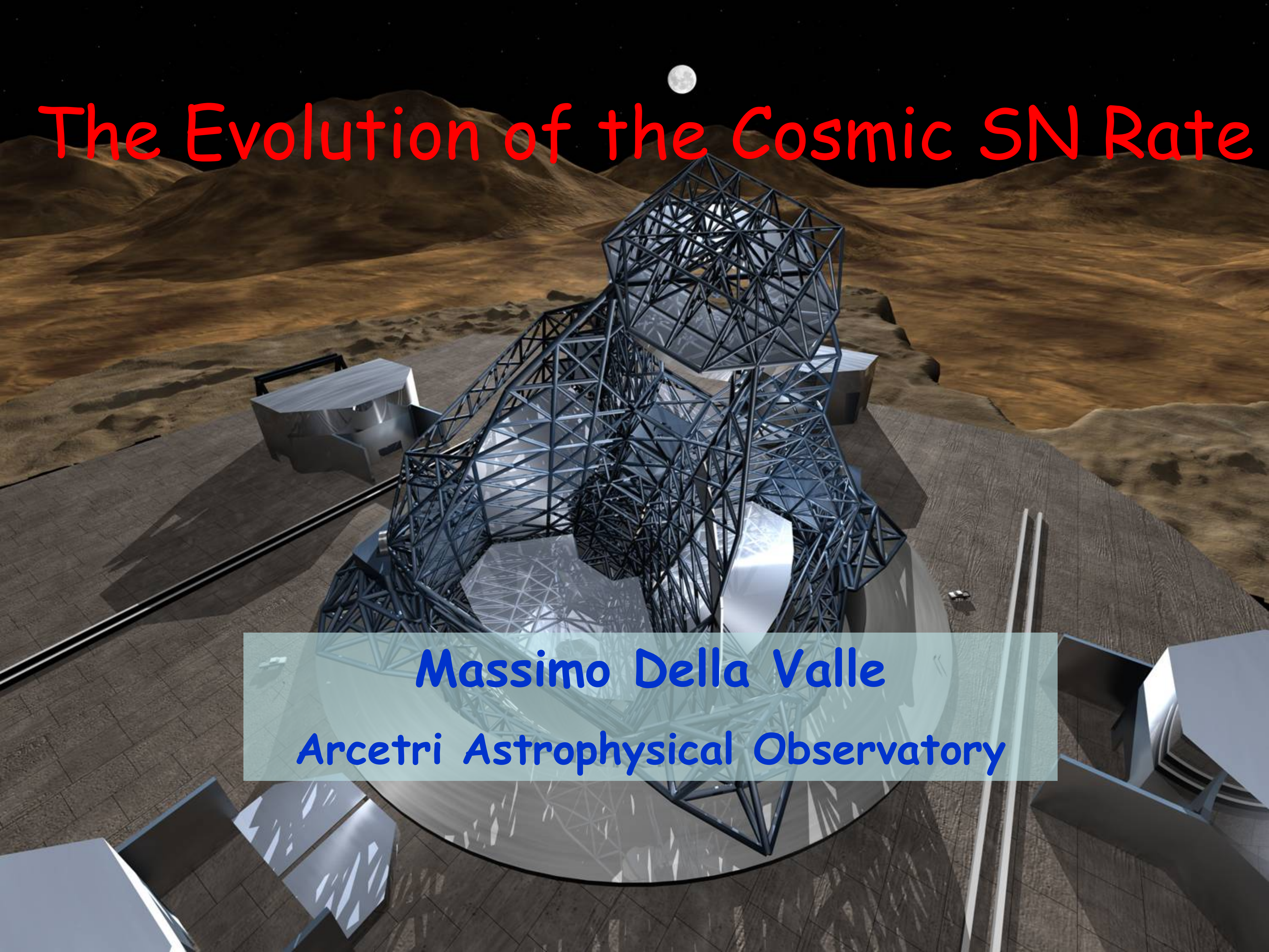


The Evolution of the Cosmic SN Rate

Massimo Della Valle

Arcetri Astrophysical Observatory

Roberto Gilmozzi, ESO

Nino Panagia, ESA/STScI

Jacqueline Bergeron, IAP

Piero Madau, UCSC

Jason Spyromilio, ESO

Philippe Dierickx, ESO

Science with OWL: a practical case

The cosmic SN rate up to z ~ 15

SNe as calibrated standard candles, (SNe-Ia, Phillips 1993) provide a direct measurement of q_o at z>0.3 (Perlmutter et al. 1998, 1999; Riess et al. 1999)

Science with OWL: a practical case

The cosmic SN rate up to z ~ 20

SNe as calibrated standard candles (Phillips 1993, SNe-Ia) provide a direct measurement of q_o at z>0.3 (Perlmutter et al. 1998, 1999, Riess et al. 1999)

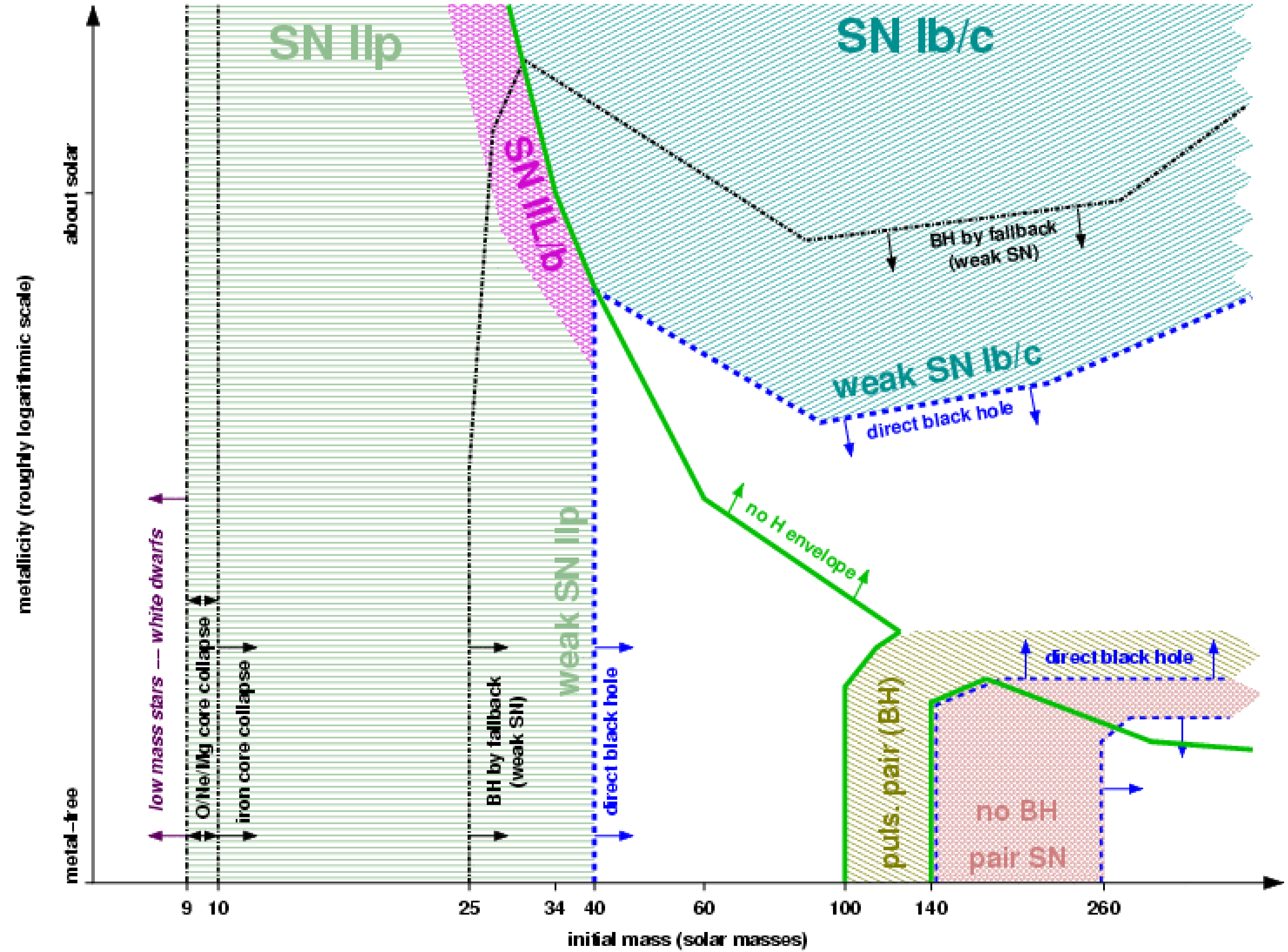
The evolution of the cosmic SN rate provides a direct measurement of the cosmic star formation rate.

SN Rate as Tracer of Star Formation Rate

a) The rate of CC SNe (II & Ib/c) is a direct measurement of the death rate of stars $M>8\ M_\odot$ (e.g. Iben & Renzini 1983)

$>40\ M_\odot$? Normal II SNe? Normal or Peculiar Ic/b? Collapsars?

Science with ELTs



Heger et al. 2001

SN Rate as Tracer of Star Formation Rate

a) The rate of CC SNe (II & Ib/c) is a direct measurement of the death rate of stars M>8 $M_\odot$ (>40 $M_\odot$? Normal II SNe? Normal or Peculiar Ic/b? Collapsars?)

b) The rate of type Ia SNe provide the history of star formation of moderate mass stars, 3-8 $M_\odot$

SN Rate as Tracer of Star Formation Rate

a) The rate of CC SNe (II & Ib/c) is a direct measurement of the death rate of stars $M > 8\ M_\odot$ ($>40\ M_\odot$? Normal II SNe? Normal or Peculiar Ic/b? Collapsars?)

b) The rate of type Ia SNe provide the history of star formation of moderate mass stars, $3\text{-}8\ M_\odot$

c) The evolution of the rate can clarify the nature of the progenitors of type Ia SNe (WD+WD or WD+MS) (Madau, Della Valle & Panagia 1998)

Science with ELTs

Science with OWL: a practical case

The cosmic SN rate up to z ~ 20

SNe as calibrated standard candles (Phillips 1993, SNe-Ia) provide a direct measurement of q_o at $z>0.3$ (Perlmutter et al. 1998, 1999, Riess et al. 1999)

The evolution of the cosmic SN rate provides a direct measurement of the cosmic star formation rate.

SN rate→ Star formation Rate

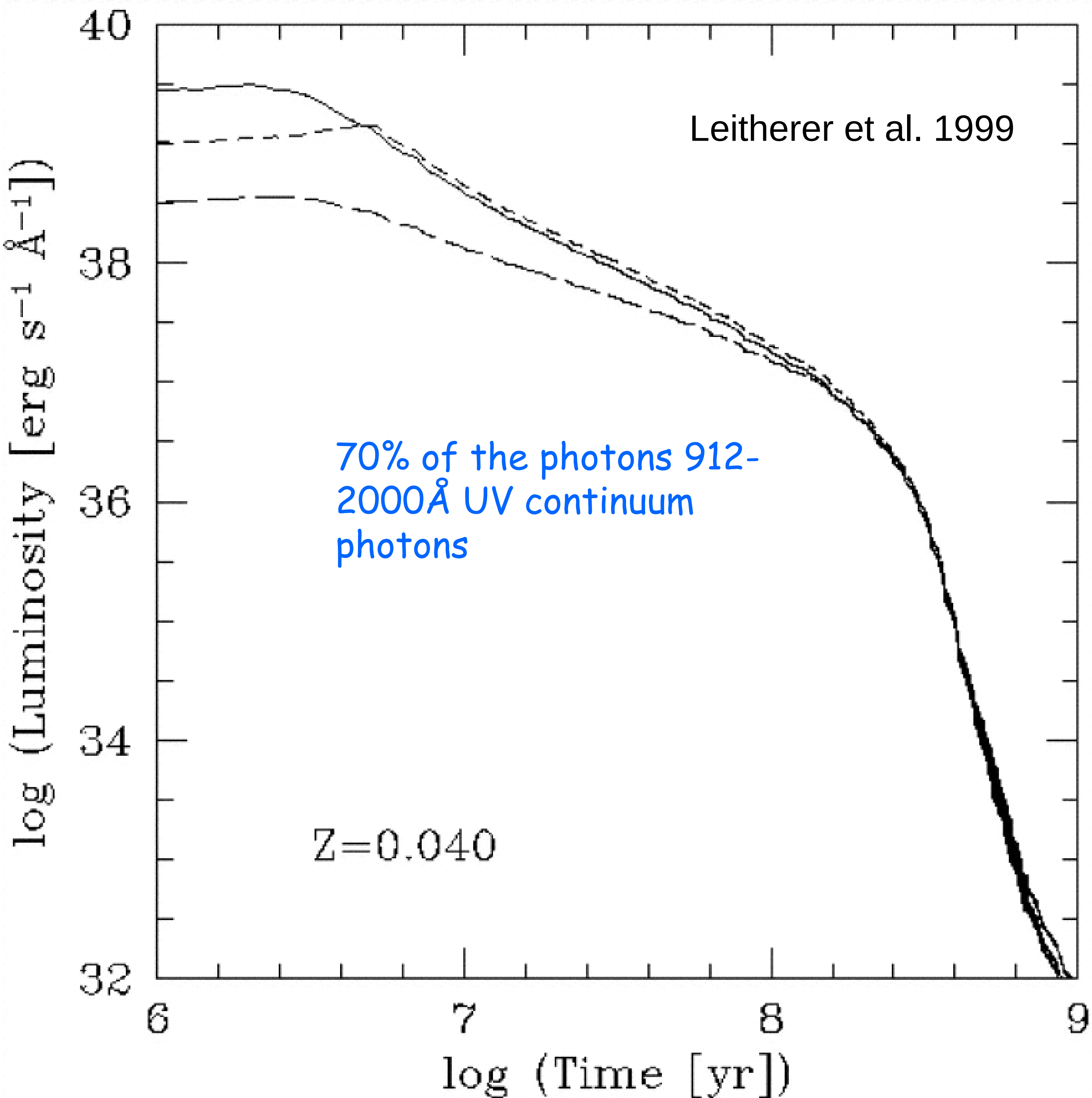
For a Salpeter IMF with $M_{up}=100\ M_\odot$ 50% of all SN II are produced by stars with $8< M_\odot <13$ and 50% of the mass produced in SNe is in the interval $8\text{-}22M_\odot$

A 13 $M_\odot$ MS star has $L=8000\ L_\odot$ and $T_{eff}=22000$ K

A 22 $M_\odot$ $L=35000\ L_\odot$ and $T_{eff}=27000$

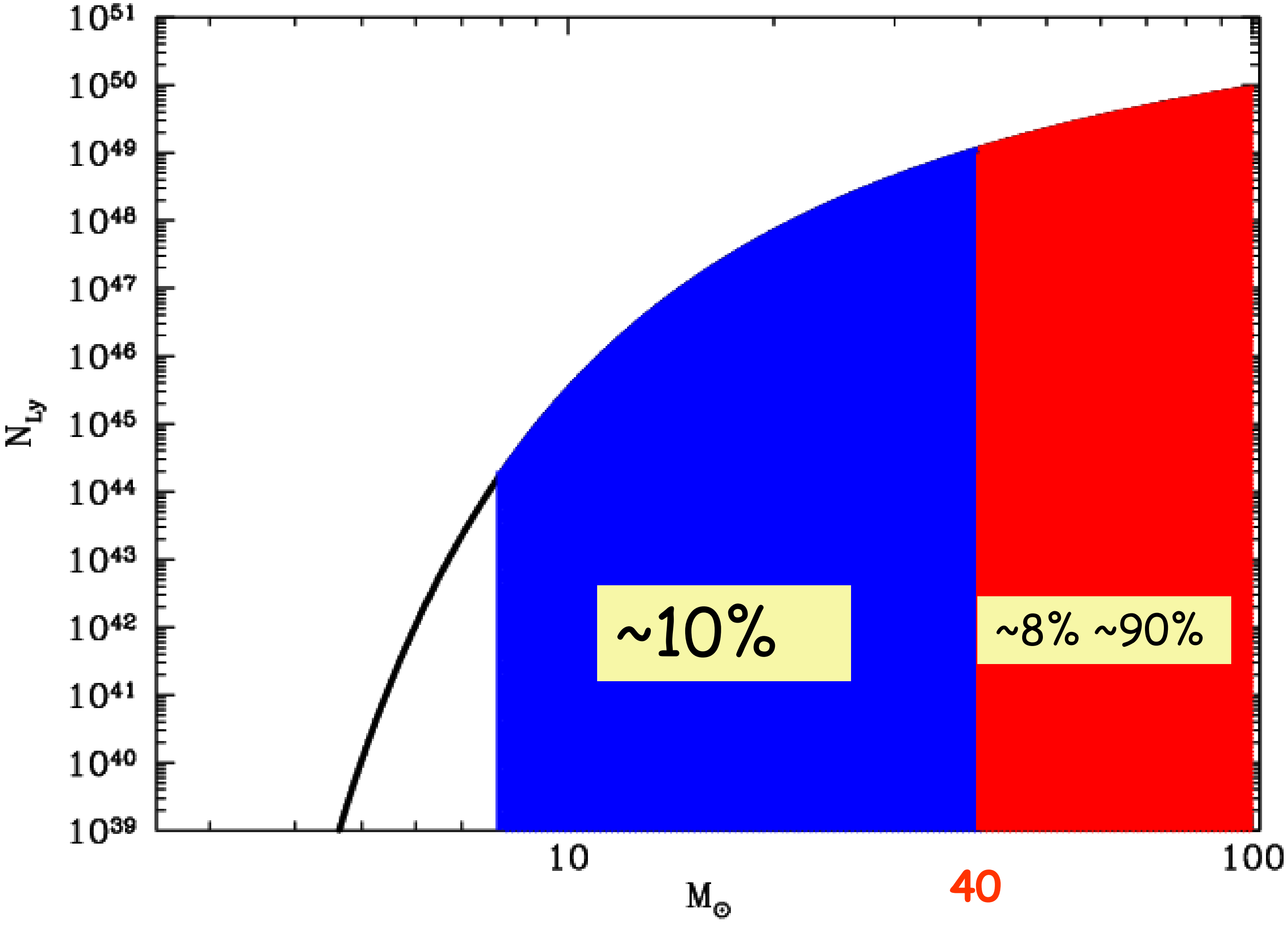
SN rate→ Star formation Rate

More than 50% of the stars producing SNe are poor sources of ionizing photons and of UV continuum photons



Leitherer et al. 1999

70% of the photons 912-2000Å UV continuum photons


10^{51}
10^{50}
10^{49}
10^{48}
10^{47}
10^{46}
10^{45}
10^{44}
10^{43}
10^{42}
10^{41}
10^{40}
10^{39}
N_{Ly}
~10%
~8% ~90%
10
40
100
$M_\odot$

The bulk of the UV radiation both in the Balmer and in the Lyman continuum is produced by stars more massive than 40 $M_{\odot}$

SN rate→ Star formation Rate

Both the Halpha fluxes and the UV fluxes measure only the very upper part of the IMF [>40 $M_\odot$→ 8% ($M_\odot$>8)]

therefore:

SN rate→ Star formation Rate

Both the Halpha fluxes and the UV fluxes measure only the very upper part of the IMF [>40 $M_{\odot}$→ 8% ($M_{\odot}$>8)] therefore:

They are NOT good star formation rate indicators because

a) they require a huge extrapolation to lower masses

b) the extrapolation depends on the value of Mup which is not well known and may be not a constant quantity in different environment (Bressan et al. 2002) or at different z (Heger et al. 2002)

SN rate → Star formation rate

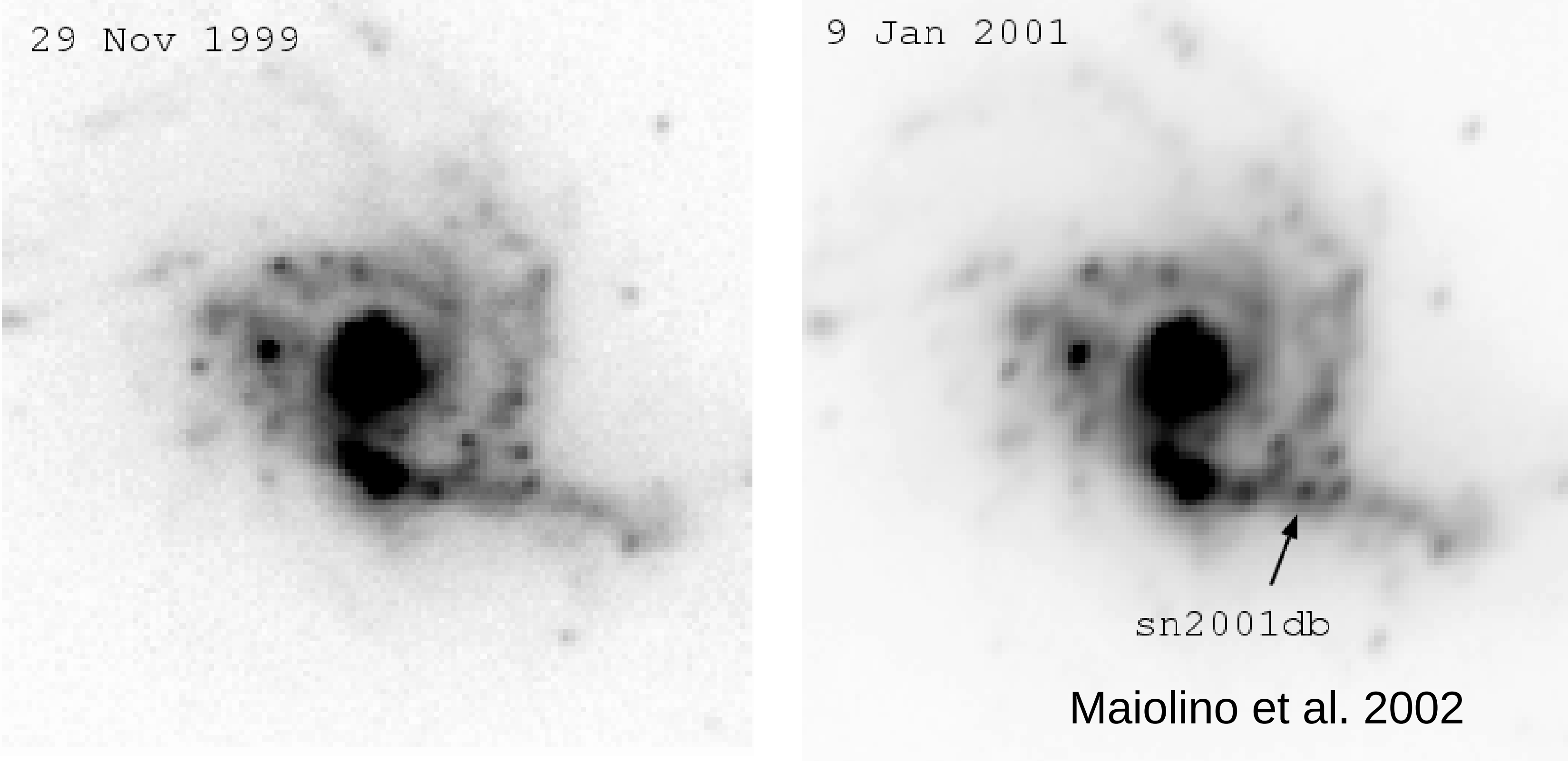
SNe provides a measurements of the star formation rate which is:

1. Independent of other possible determinations
2. More direct, because the IMF extrapolation is much smaller
3. More reliable because it is based on counting SN explosions rather than relying on identifying and measuring

the sources of ionization (if using H-alpha flux) or the sources of UV continum

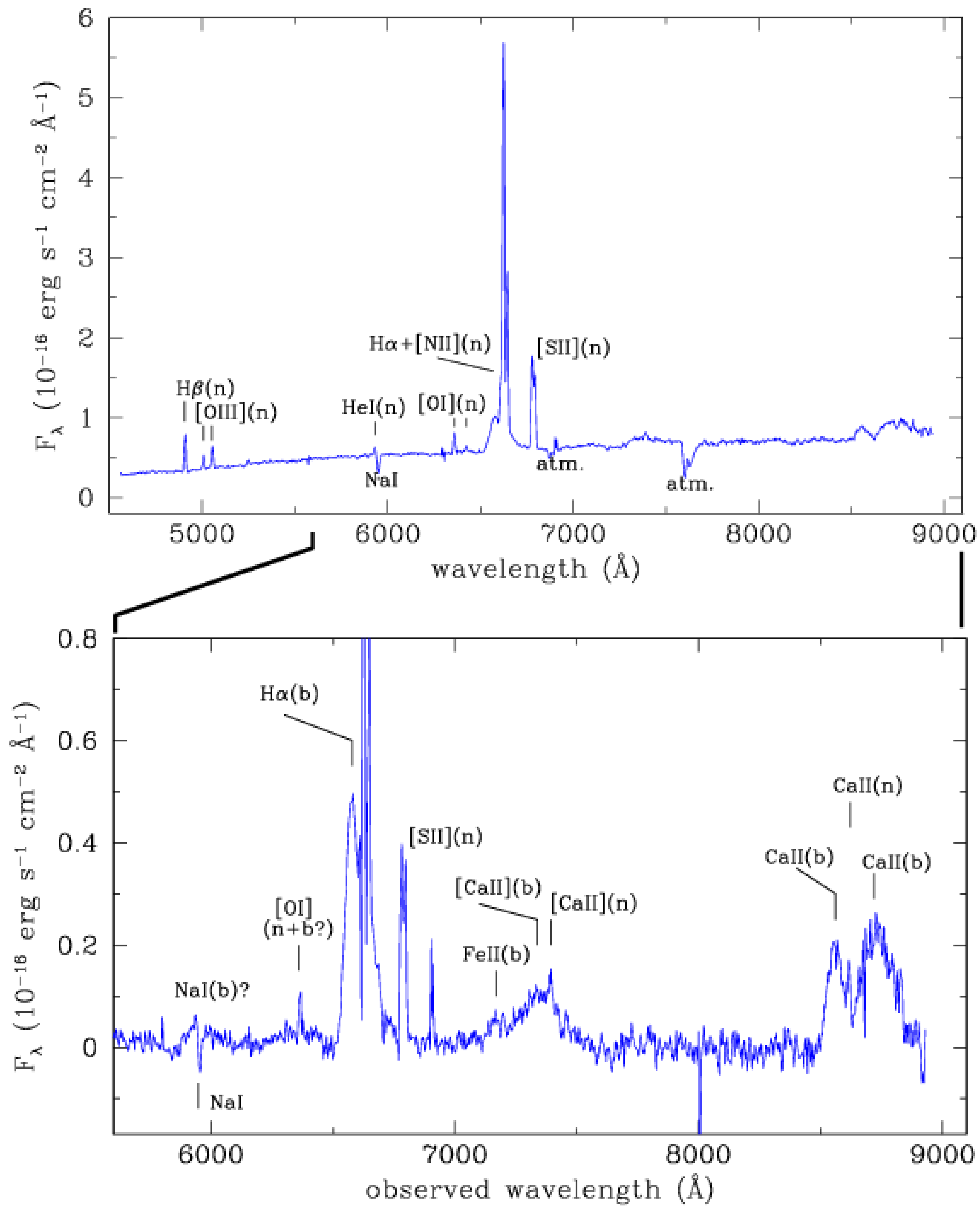
Drawbacks…..

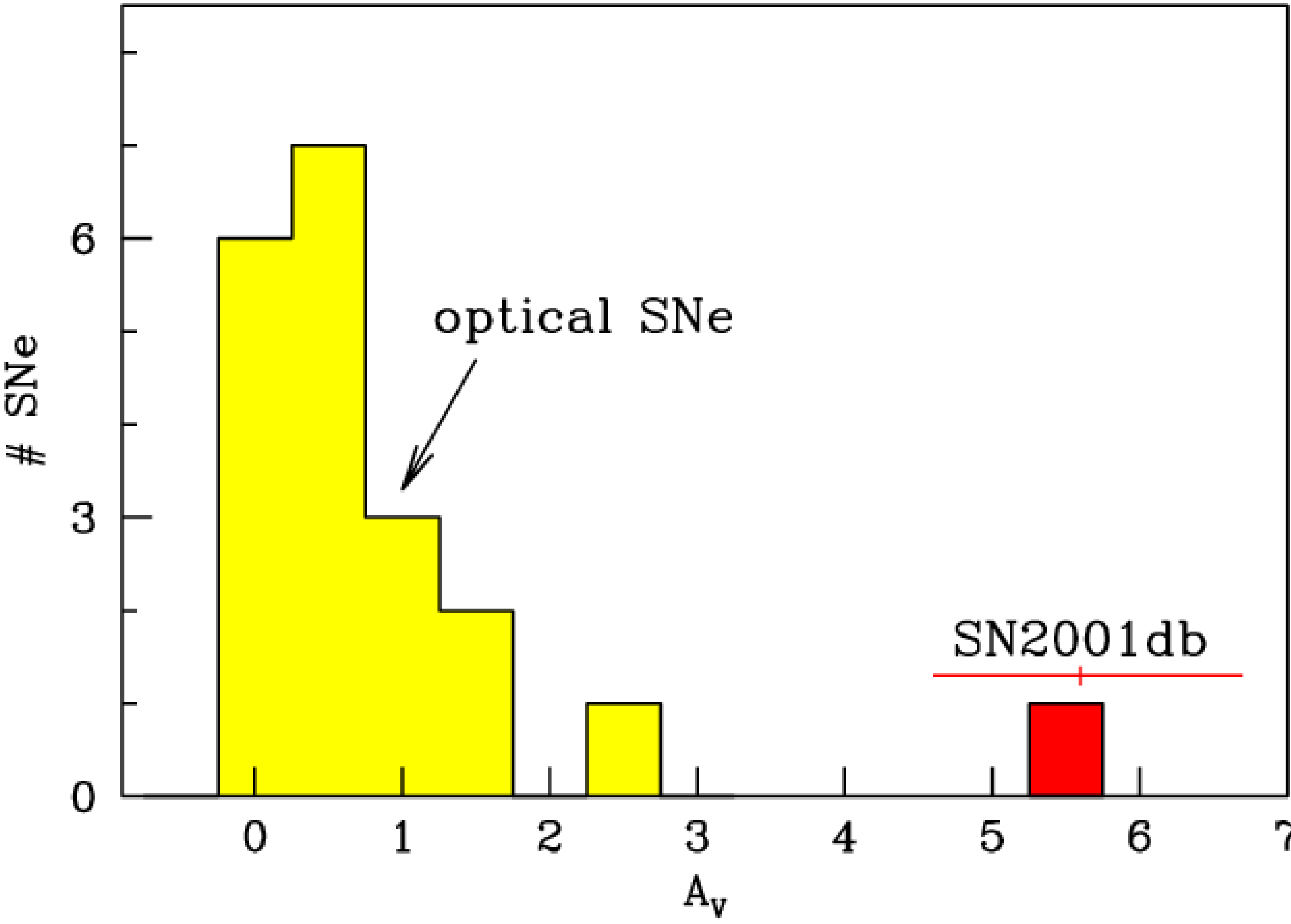
Supernovae can be missed because of the extinction



Maiolino et al. 2002

Science with ELTs




optical SNe
SN2001db
SNe
0
3
6
0
1
2
3
4
5
6
A_V

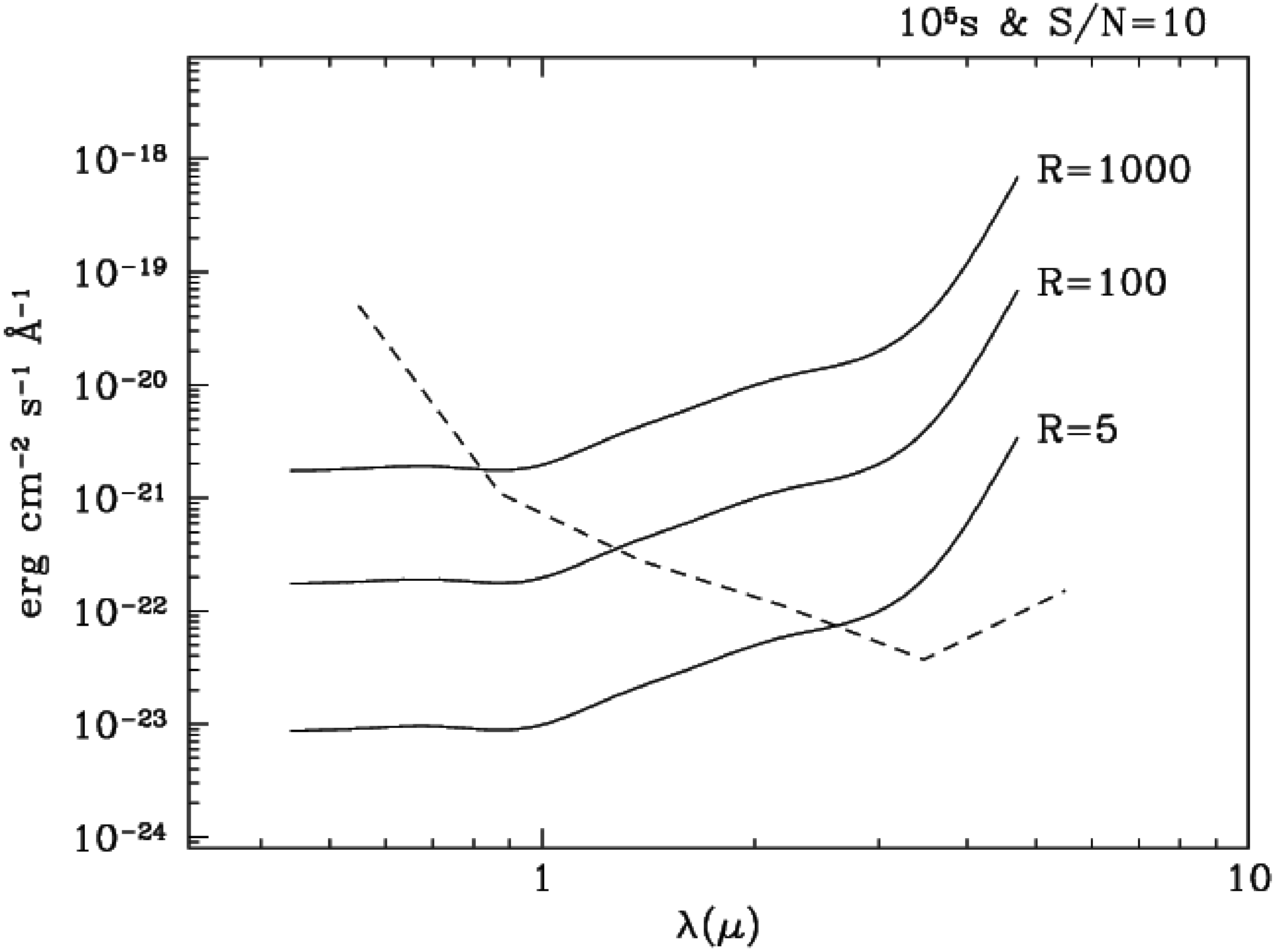
Ingredients of the simulation

1. OWL Performances: the imaging and spectroscopic limit of OWL as a function of S/N ratio and integration time
2. OWL Field: 2x2 arcmin (K)
3. Number of SNe expected in a single OWL Frame
4. SED of SNe (type II, Ia, Ib/c, Pop III)
5. Morphology of lightcurves and absolute magnitude at maximum of SNe (Control Time)
6. Distribution of SNe into the different spectroscopic types
7. Cosmology (Ω_m =0.3 Ω_Λ =0.7)

1.OWL Performances

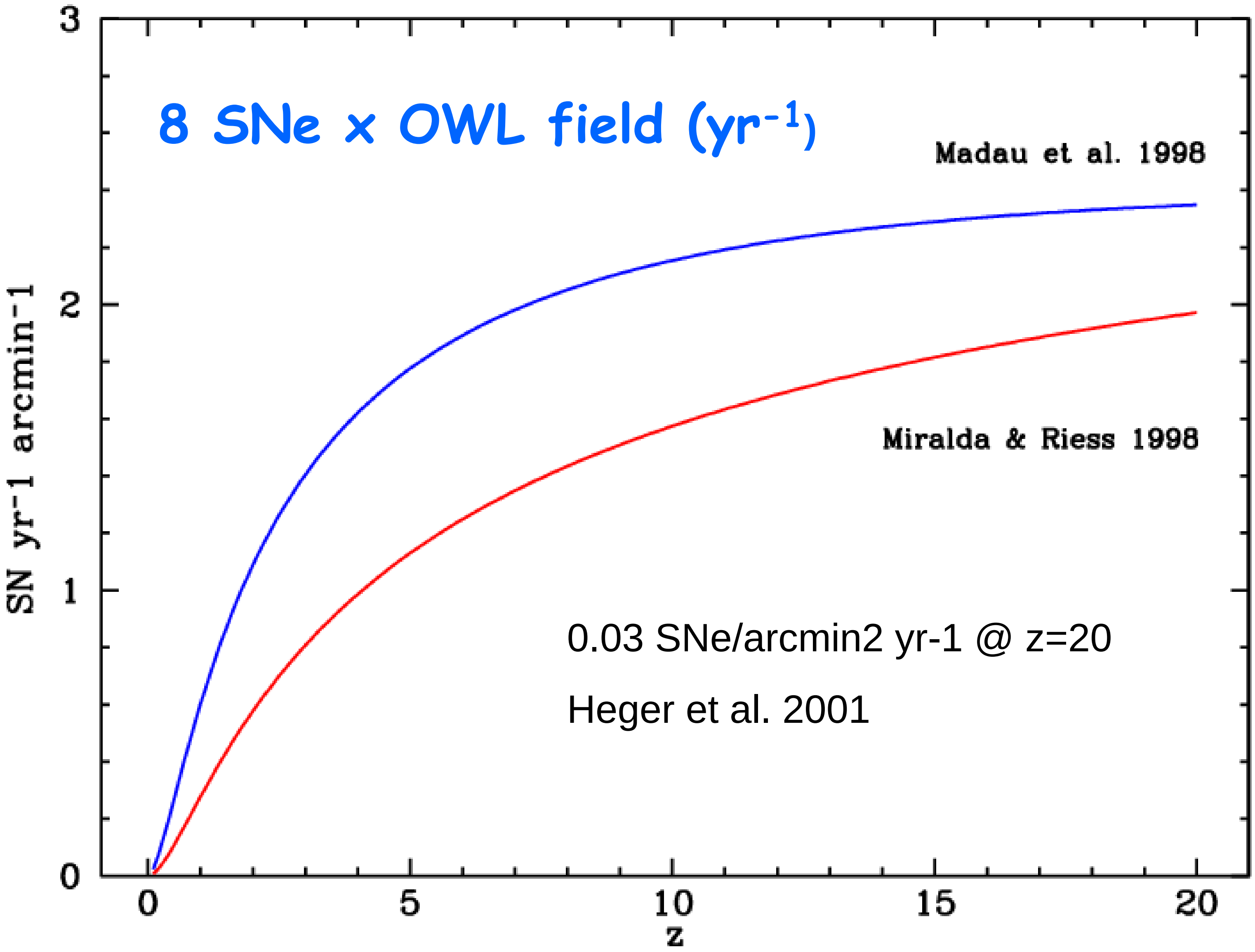
http://www-astro.physisc.ox.ac.uk/imh/ELT

JWST: (Panagia 2003, Stiavelli 2003)



Science with ELTs

2.& 3.Number of SNe in a single OWL Frame



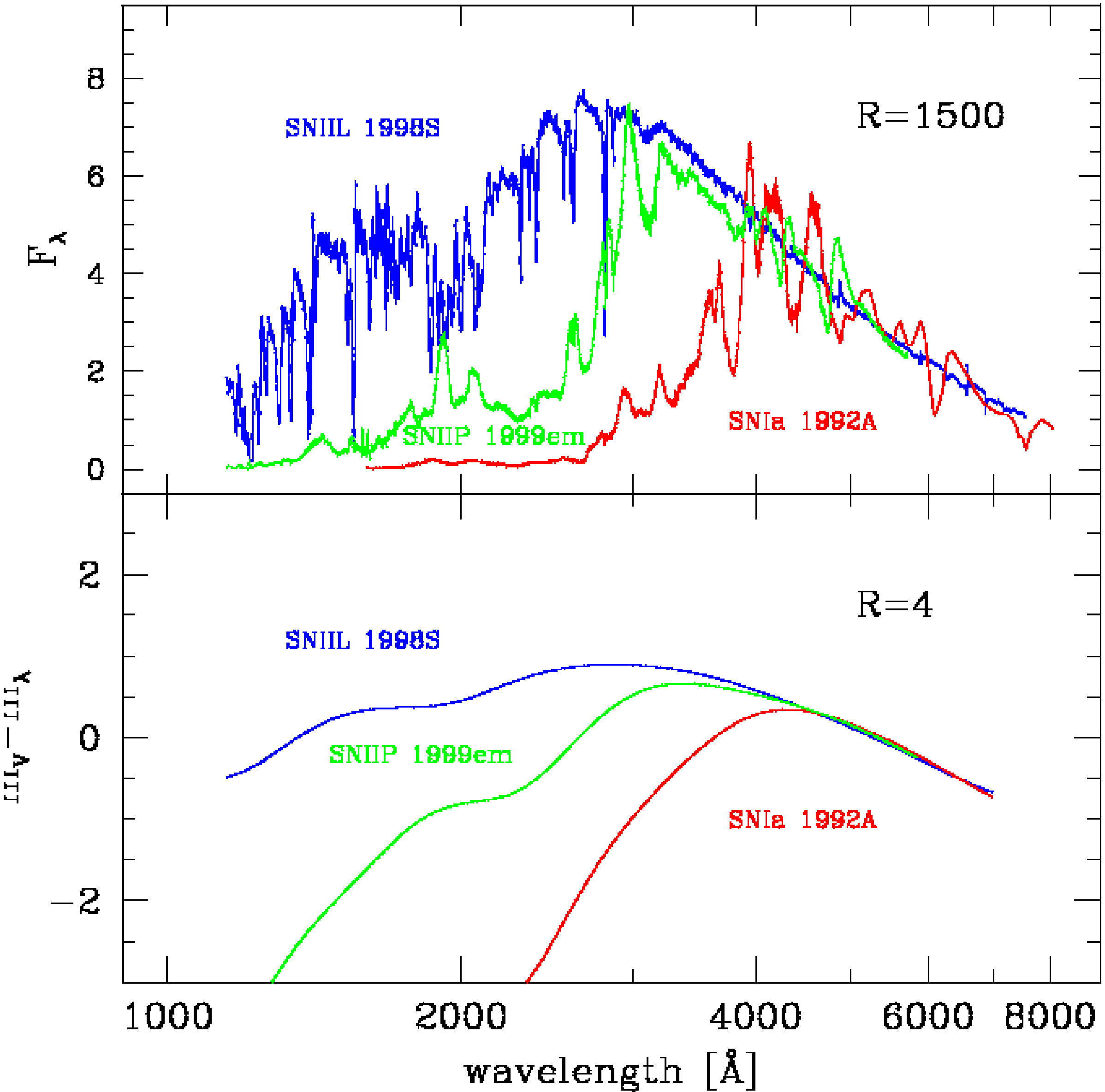
8 SNe x OWL field (yr^{-1})

0.03 SNe/arcmin2 yr-1 @ z=20

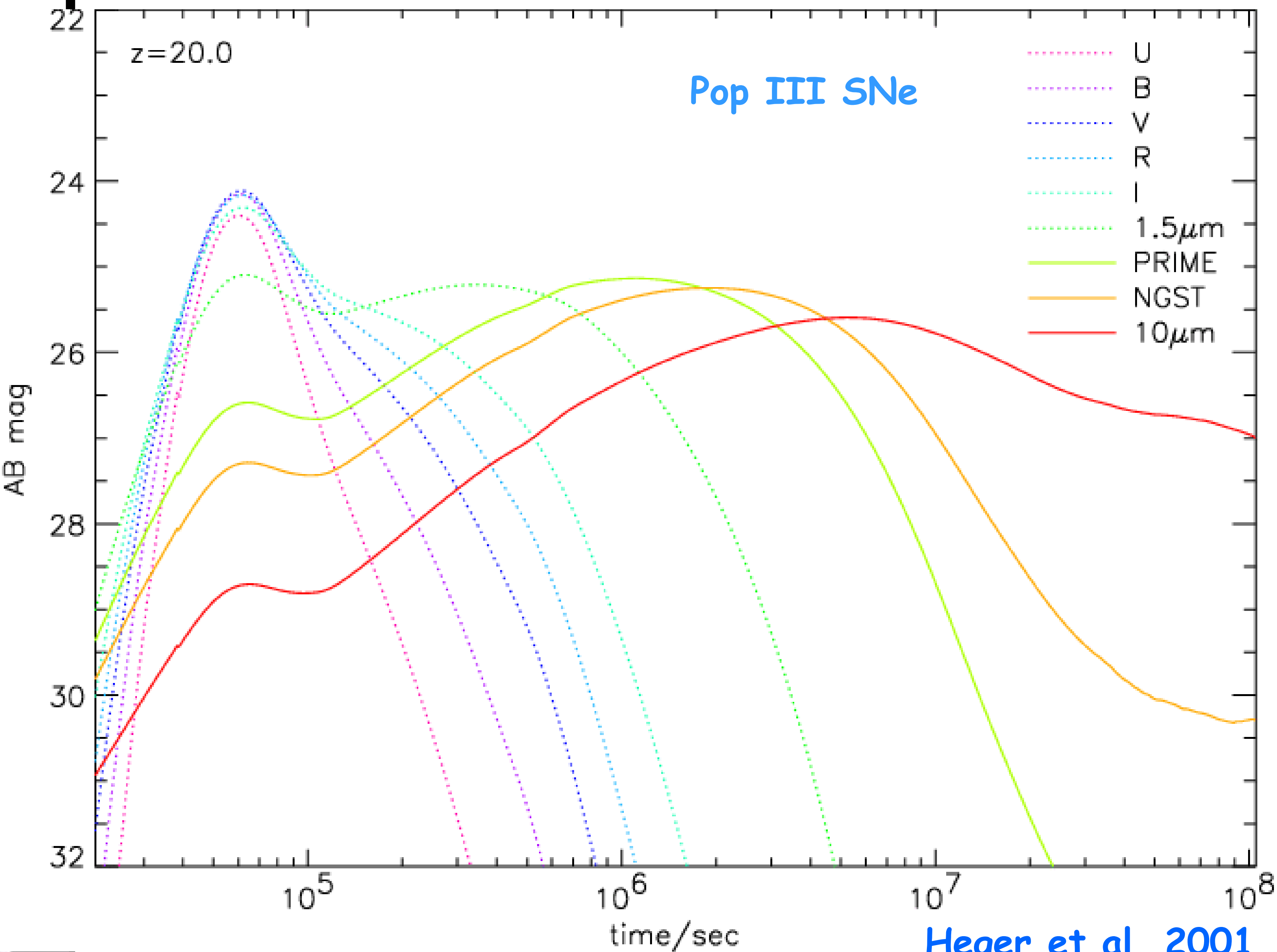
Heger et al. 2001

4.Spectral Distribution Energy

(Panagia 2003)



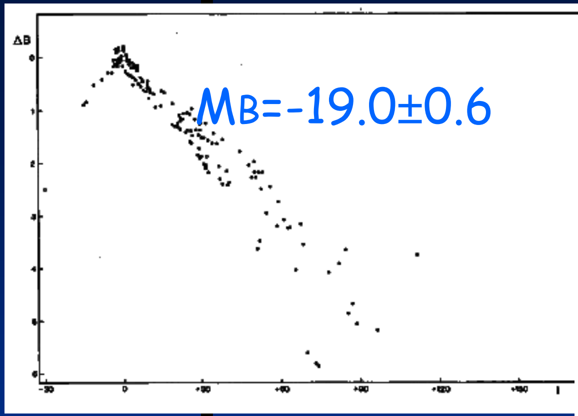
Science with ELTs

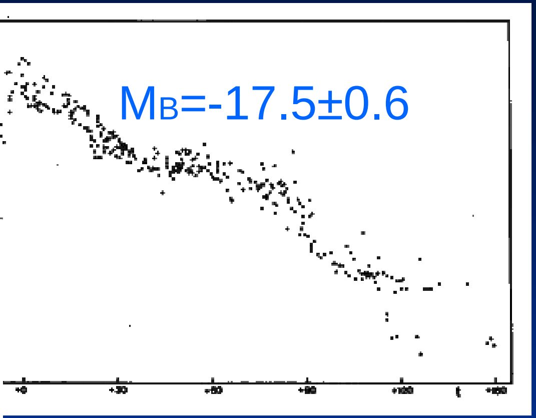


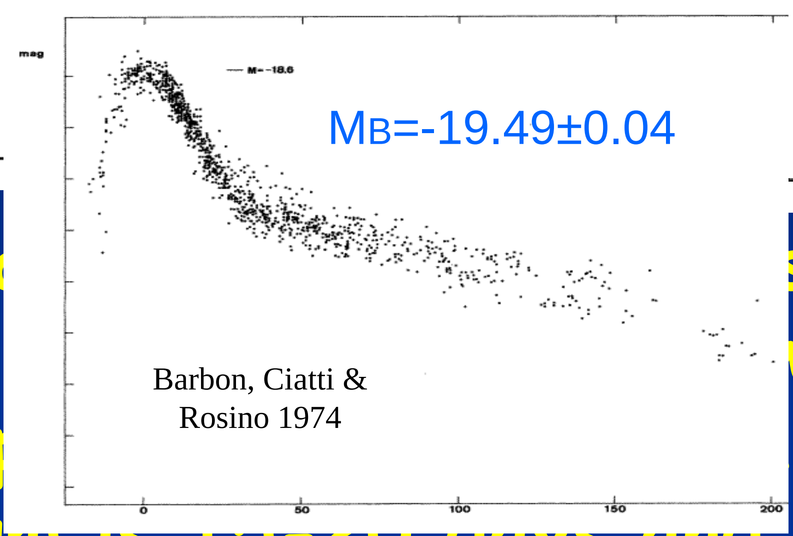
Pop III SNe

Heger et al. 2001

rves & Absolut







Barbon, Ciatti & Rosino 1974

Science with

Observ sed on the
control vicky 1936).
The typ around
maximum is 15-20 days and most SNe will occur at z<5 → light-curve width in the observer rest-frame about 100-120 days. 4 exposures at time intervals of 3 months will cover 1 year

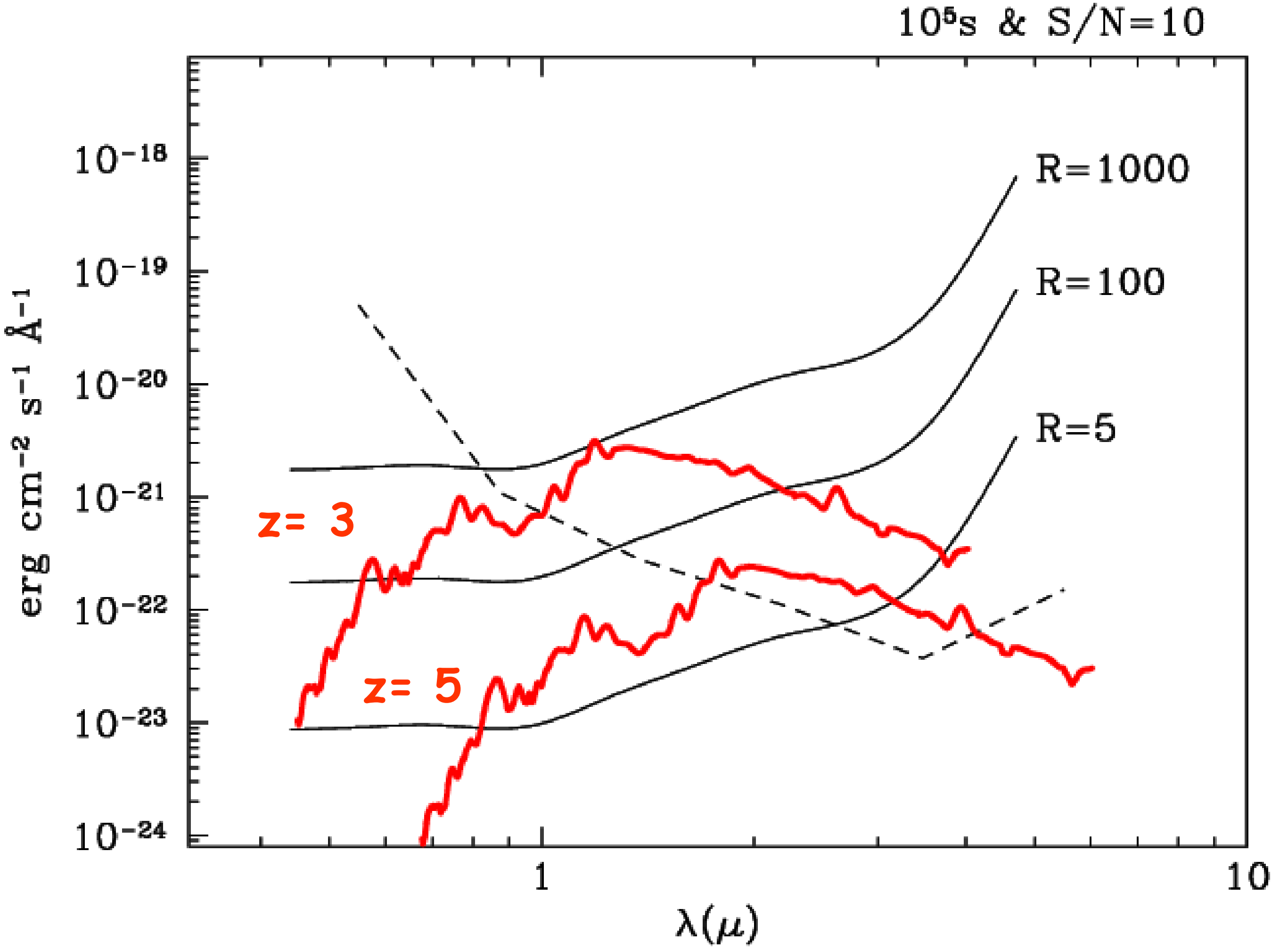
(Saha et al. 2001; Patat et al. 1994)

% of SNe in the different types

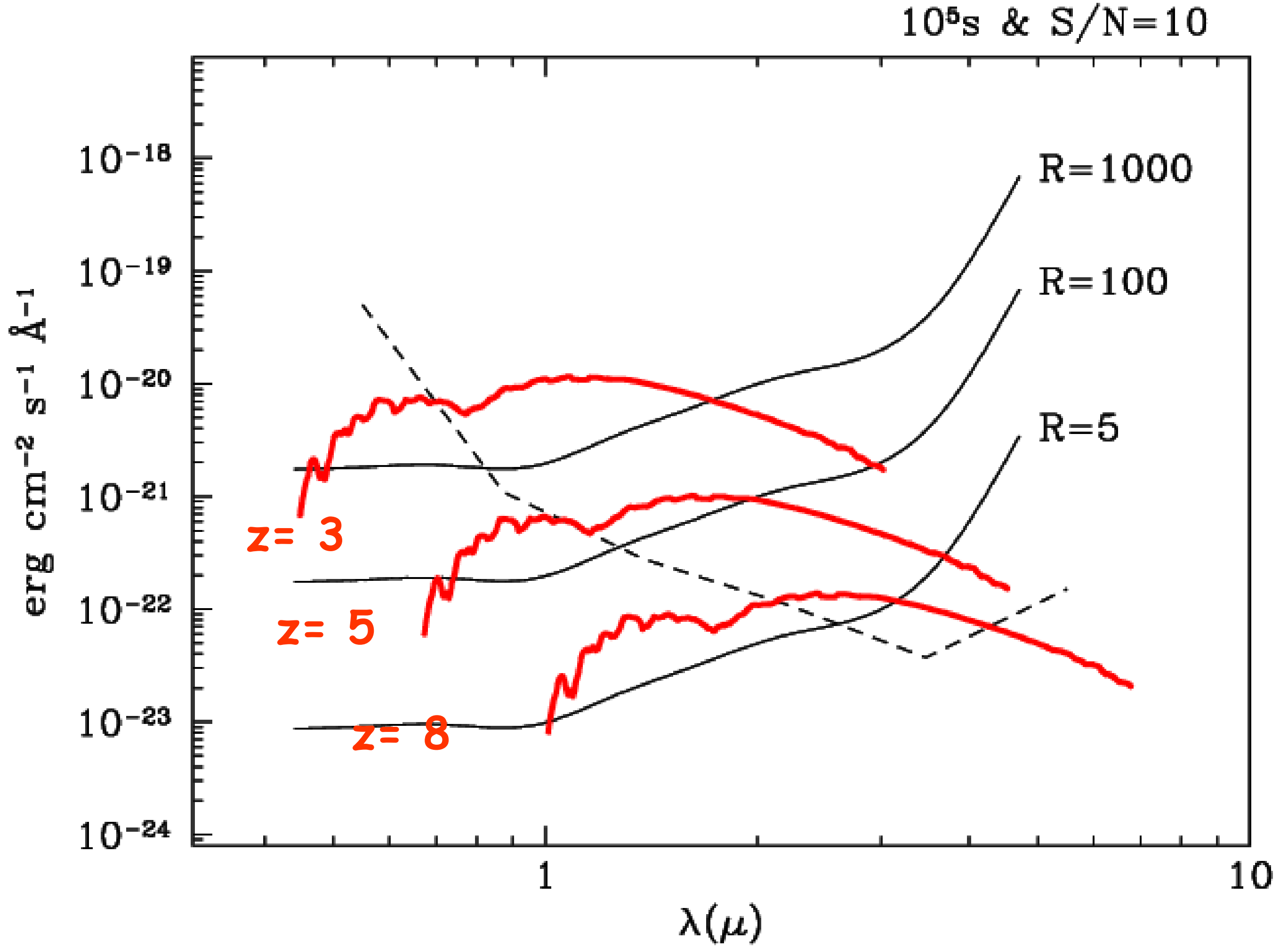
46% type II Normal (mostly plateau)
16% type II Bright (mostly linear)
20% type Ia
15% type Ib/c
0.5% hypernovae
1.5% SNe from Pop III

Mannucci et al. 2004; Della Valle et al. 2004; Heger et al. 2001; Podsiadlowski et al. 2004; Cappellaro et al. 1997

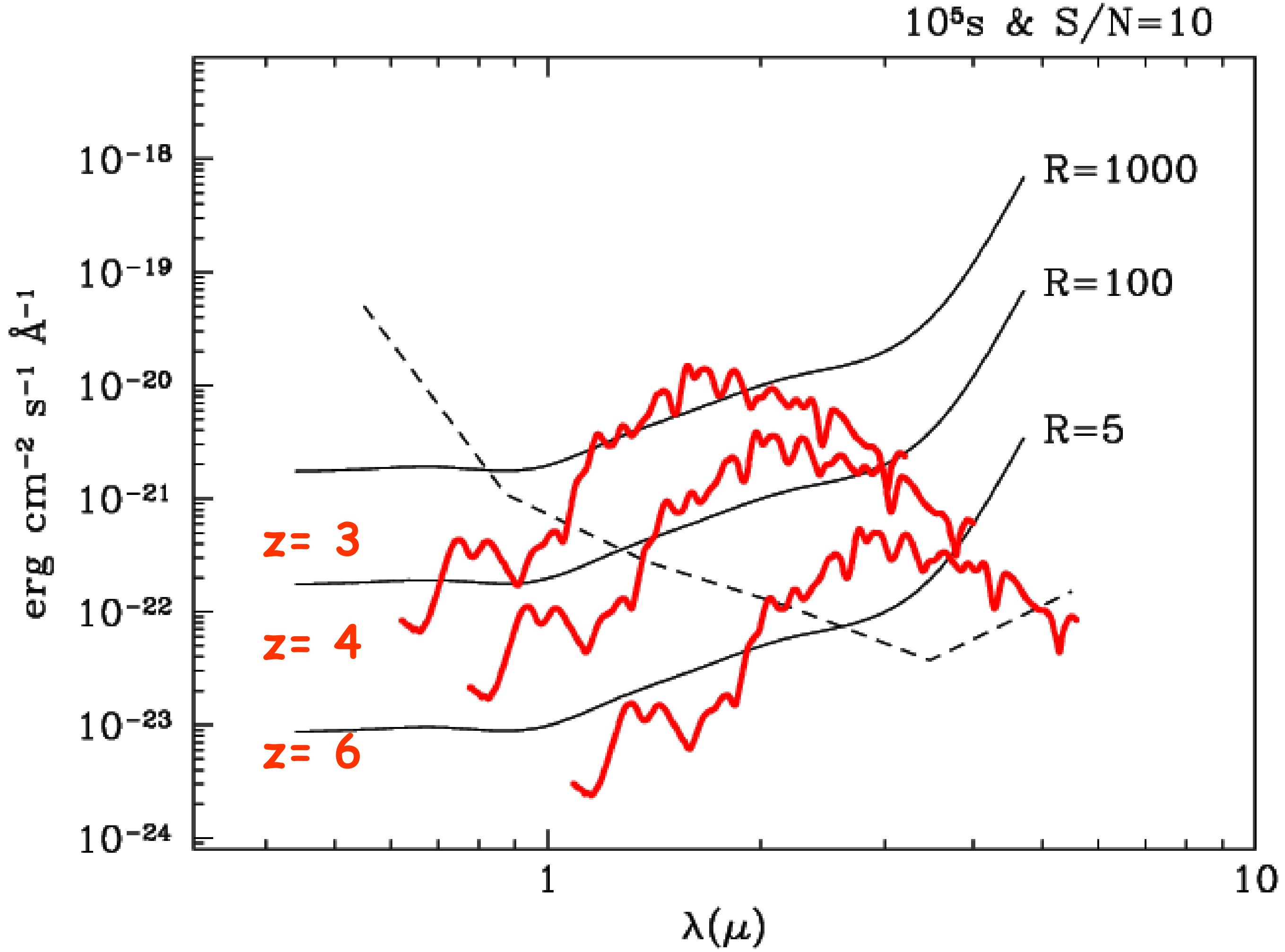
SNe-II Normal

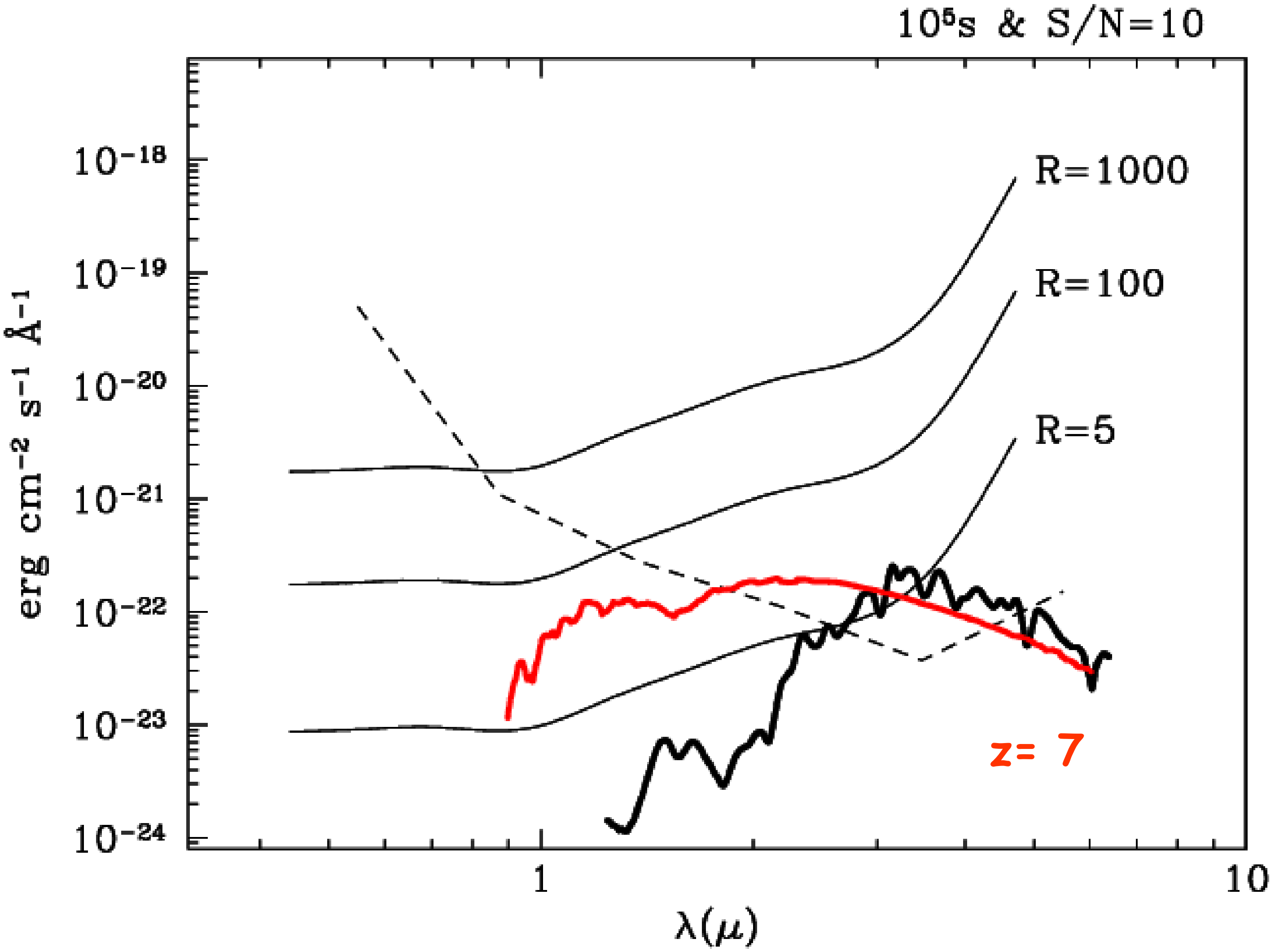


SNe II-Bright

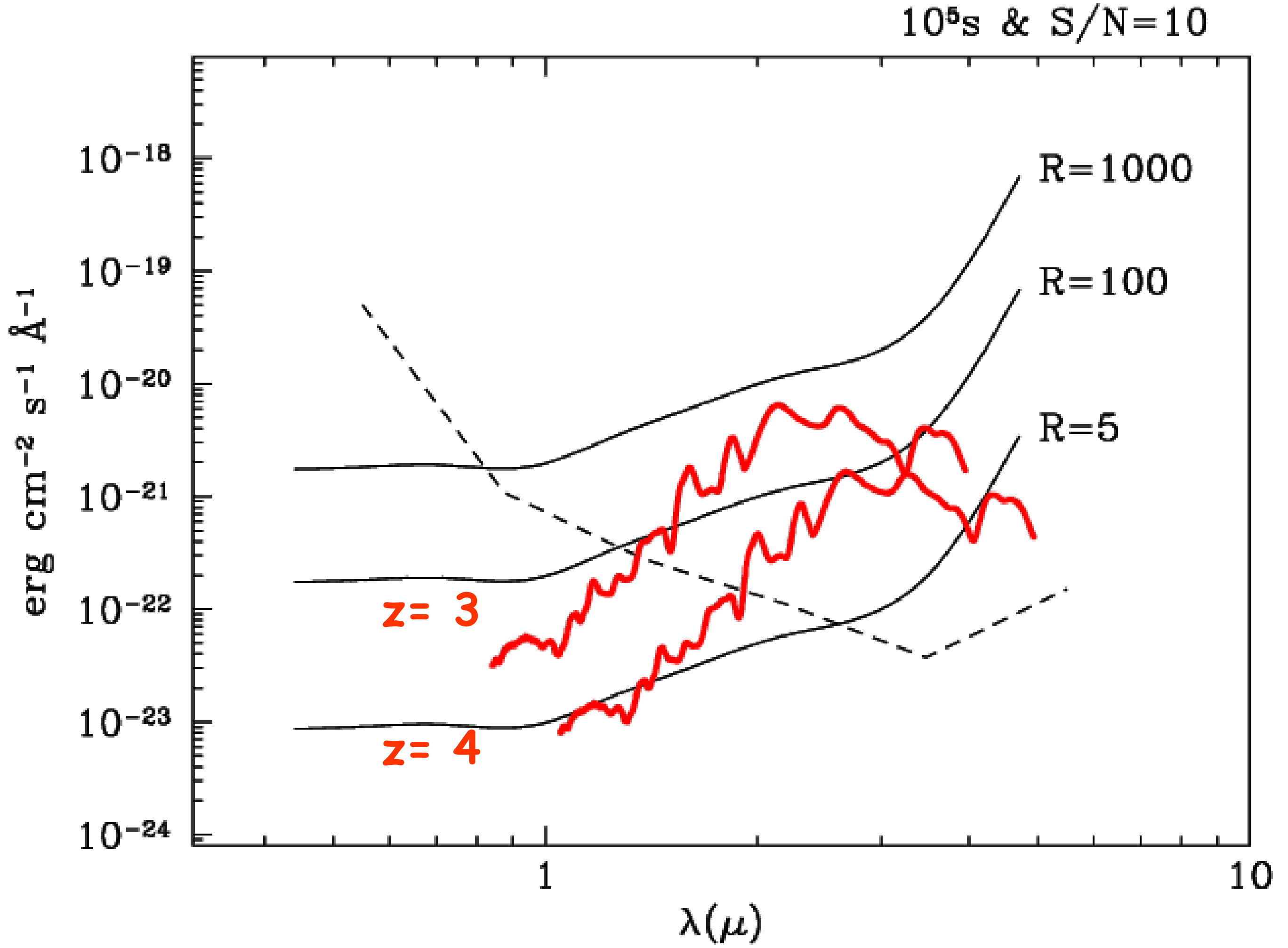


SNe Ia

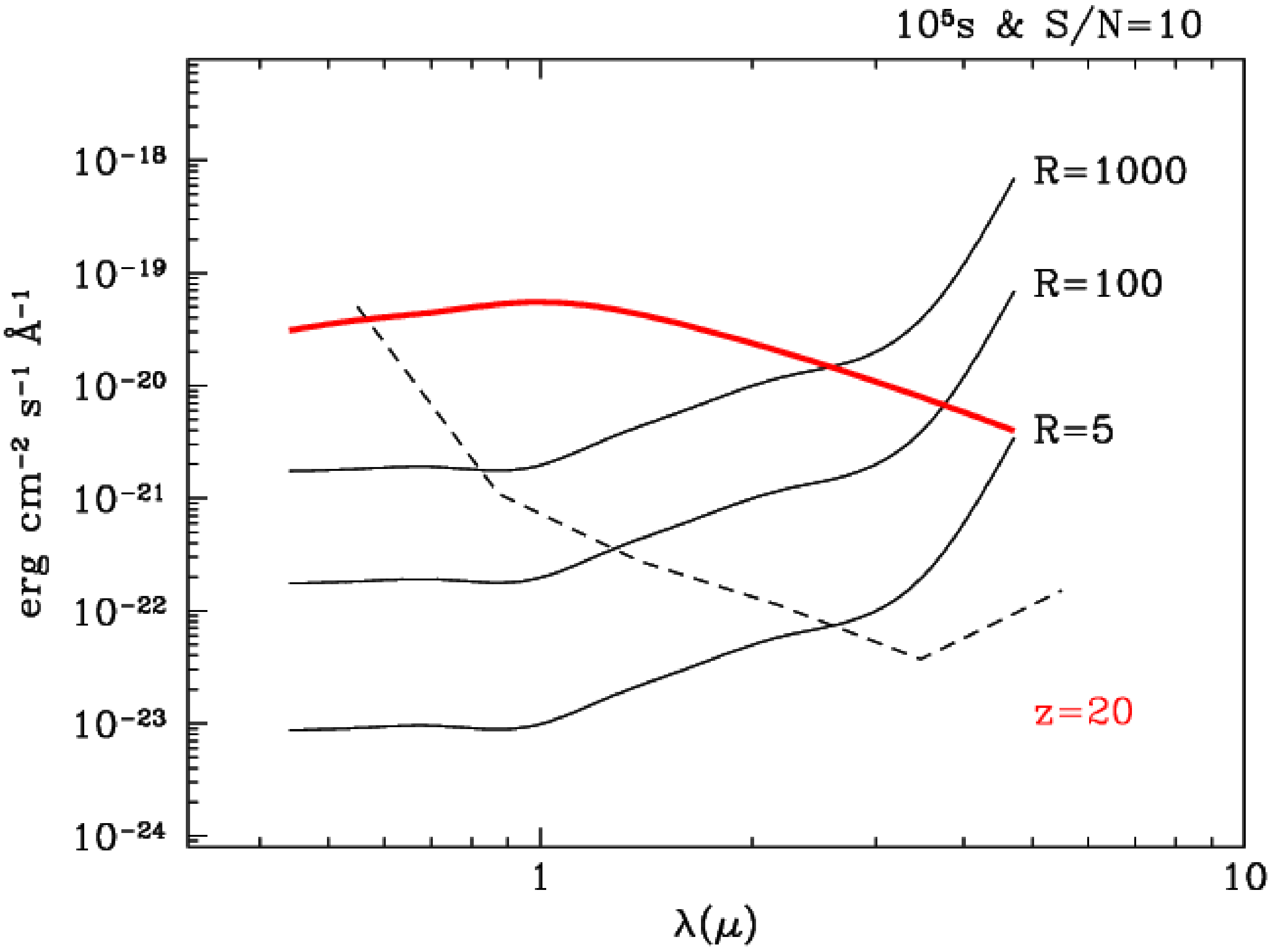

10⁵s & S/N=10
R=1000
R=100
R=5
z= 3
z= 4
z= 6
10⁻¹⁸
10⁻¹⁹
10⁻²⁰
10⁻²¹
10⁻²²
10⁻²³
10⁻²⁴
erg cm⁻² s⁻¹ Å⁻¹
1
10
λ(μ)


10^5s & S/N=10
erg cm^{-2} s^{-1} Å^{-1}
10^{-18}
10^{-19}
10^{-20}
10^{-21}
10^{-22}
10^{-23}
10^{-24}
R=1000
R=100
R=5
z= 7
1
10
λ(μ)

SNe Ib/c


10⁵s & S/N=10
R=1000
R=100
R=5
z= 3
z= 4
10⁻¹⁸
10⁻¹⁹
10⁻²⁰
10⁻²¹
10⁻²²
10⁻²³
10⁻²⁴
erg cm⁻² s⁻¹ Å⁻¹
1
10
λ(μ)

Pop III SNe


10⁵s & S/N=10
10⁻¹⁸
10⁻¹⁹
10⁻²⁰
10⁻²¹
10⁻²²
10⁻²³
10⁻²⁴
erg cm⁻² s⁻¹ Å⁻¹
R=1000
R=100
R=5
z=20
1
10
λ(μ)

SN types vs. redshift

SNe Ia (3-8 $M_\odot$) visible up to z ~ 5 Blind below 2400A, K last useful band

SNe II (8-40 $M_\odot$) visible up to z ~ 8 Strong UV emitters (time-dilated UV flash)

Pop III SNe (100-300 $M_\odot$) visible to z ~20 (<15)

(Heger & Woosley 2002)

The Simulation

We plan to image 50 fields in the J, H and K bands (1h each) at 4 different epochs (="SN search") +

3 epochs in the K band for the photometric follow-up (i.e. seven K photometric points for each SN) +

4h for each SN (z< 4.5-5) to get the spectroscopic classification +

4h for each SN (z~15; 4 epochs 120h)

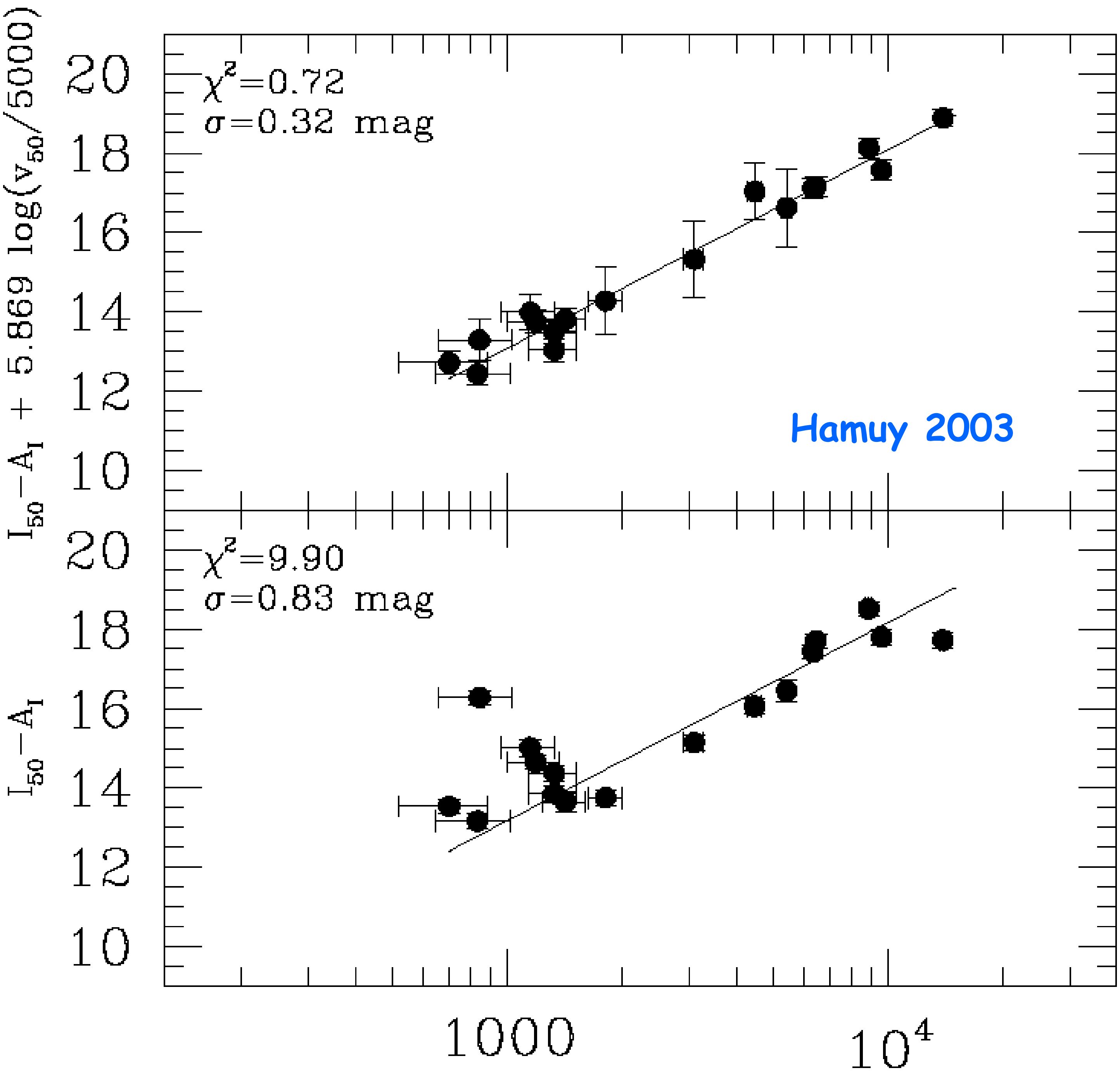
Grand Total=600h (search)+150h (K follow-up)+200h(spectr. II & Ia)+120h (spectr. Pop III SNe)=1070h+10%

Results of the Simulation

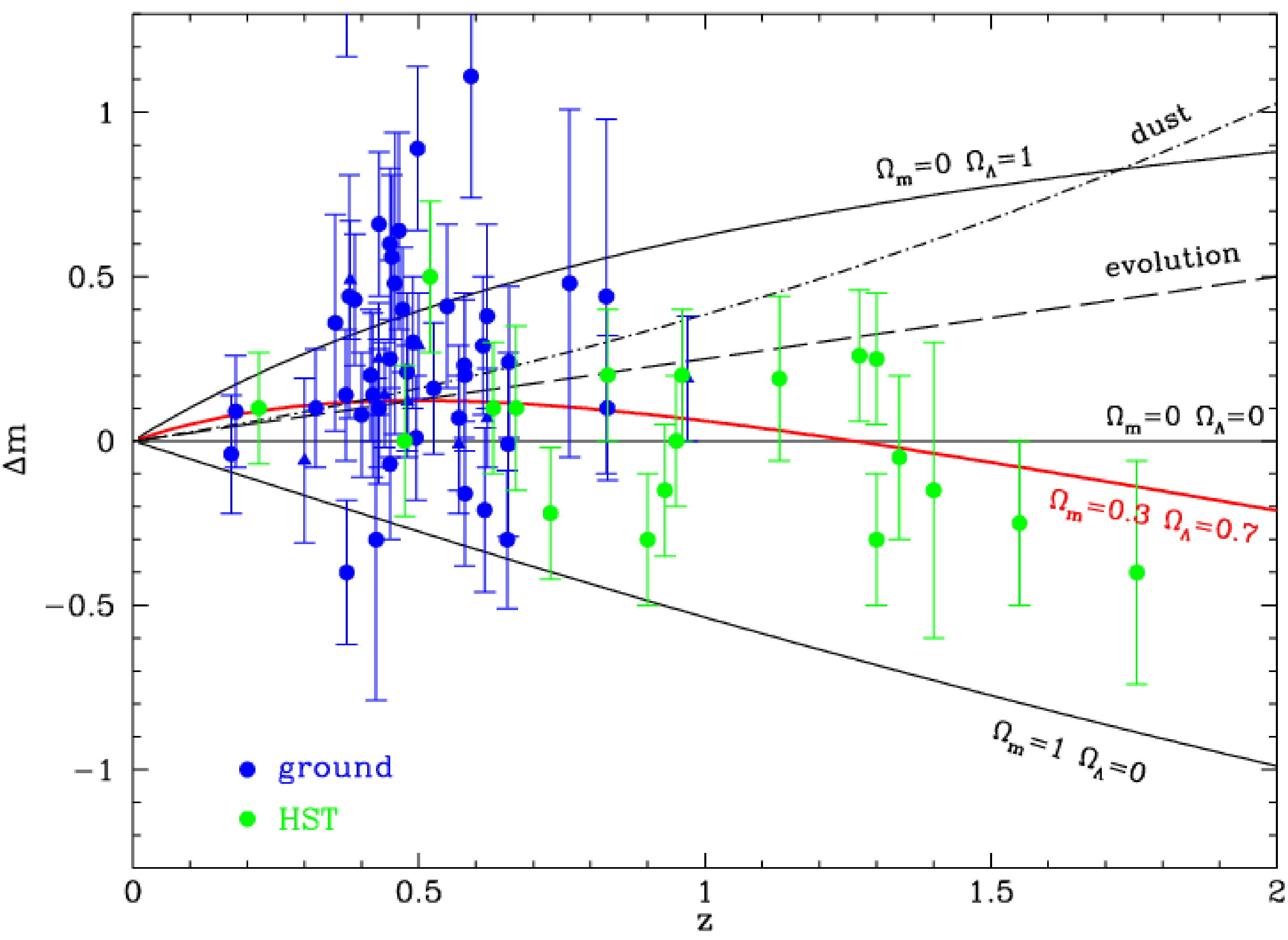
1200h or 150 nights to study 400 SNe up to z =15

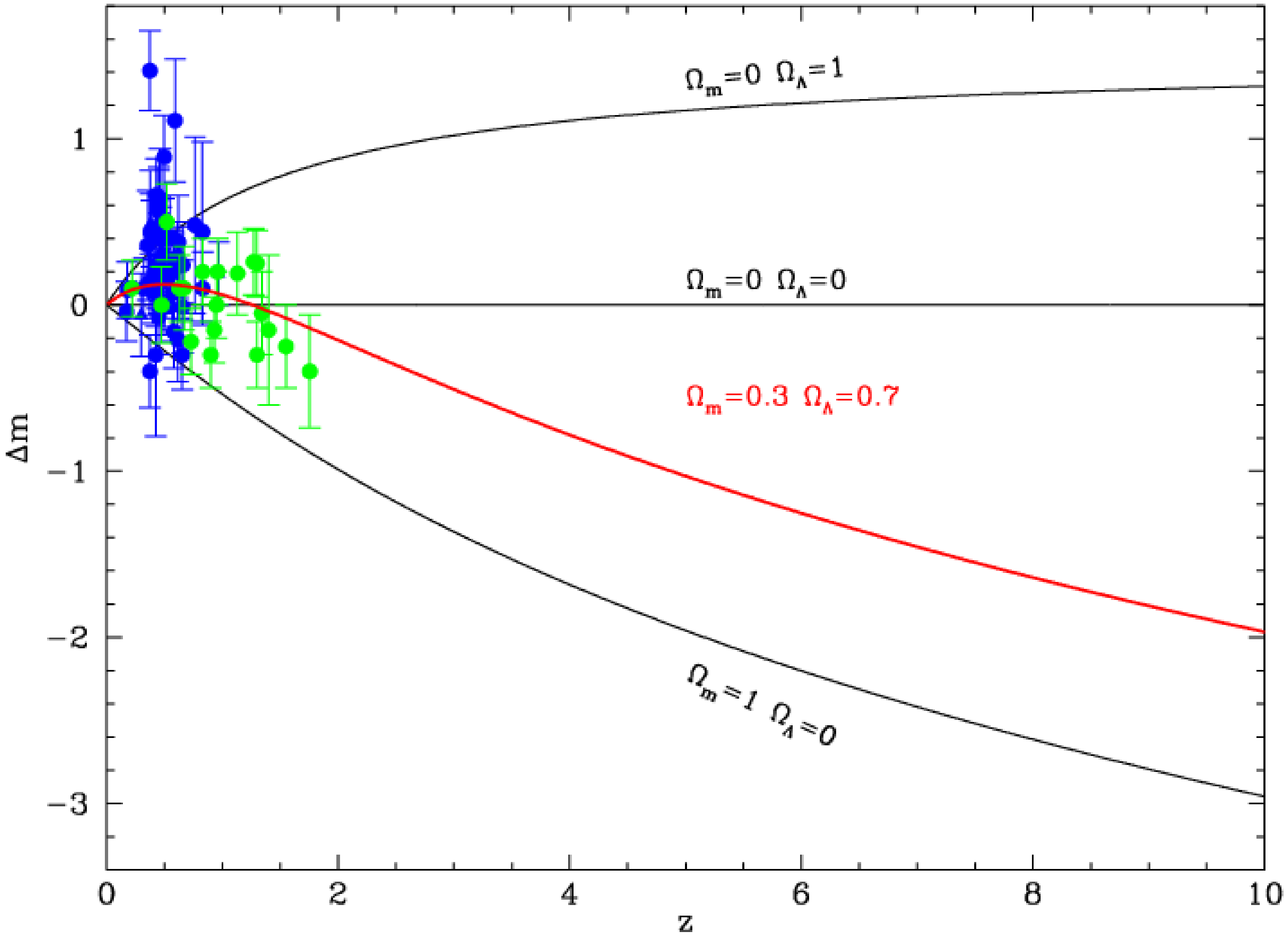
This is about twice as much the size of a current Treasury programme (450 orbits) and it is comparable with SNAP (now Join Dark Energy Mission), about 2000 SNe (Ia) in 2 yr (z<1.7).

1200h+200h (II epoch spectroscopy)

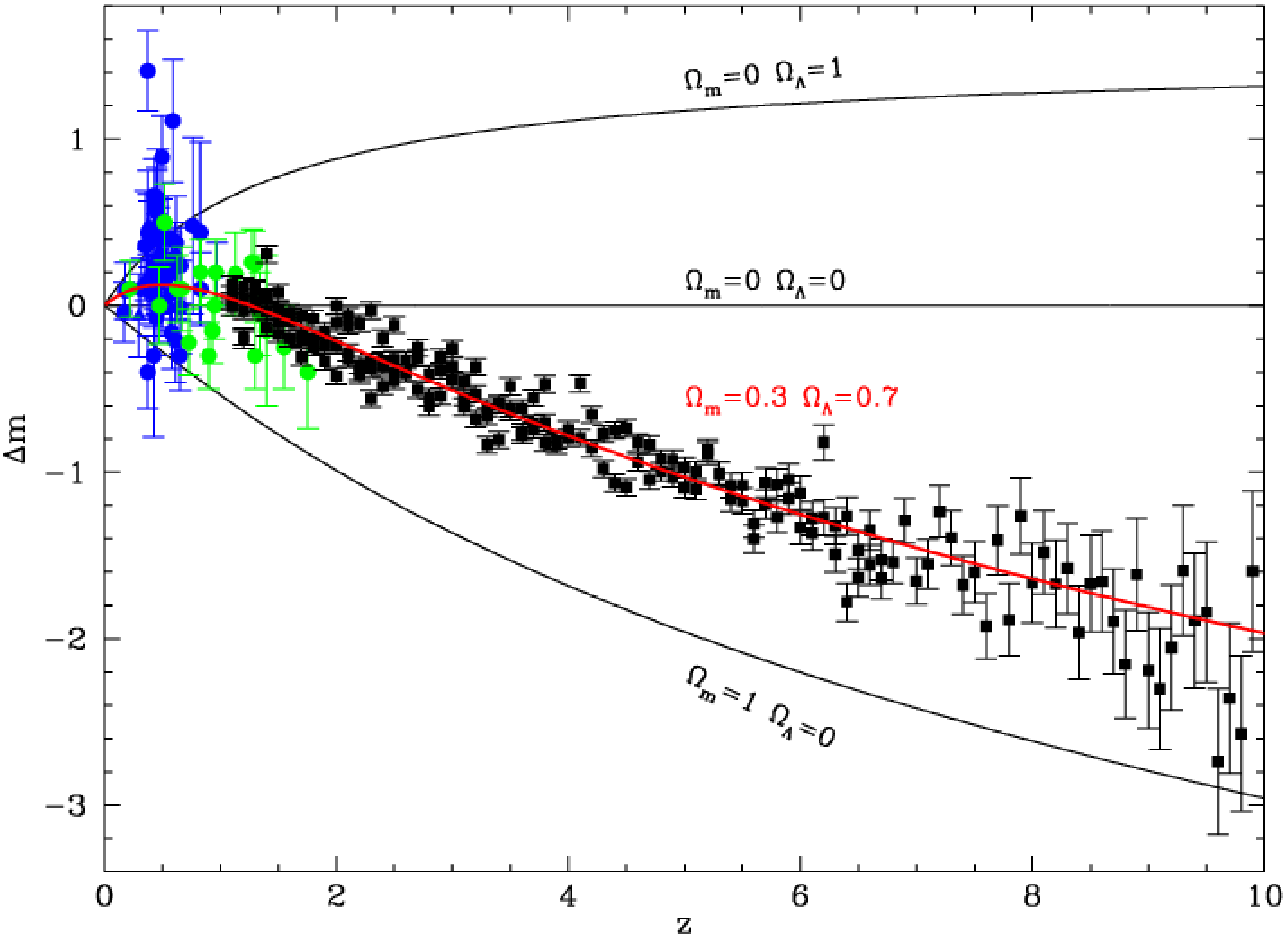

$\chi^2=0.72$
$\sigma=0.32$ mag
$I_{50}-A_I + 5.869\ \log(v_{50}/5000)$
20
18
16
14
12
10
$\chi^2=9.90$
$\sigma=0.83$ mag
$I_{50}-A_I$
20
18
16
14
12
10
1000
10^4

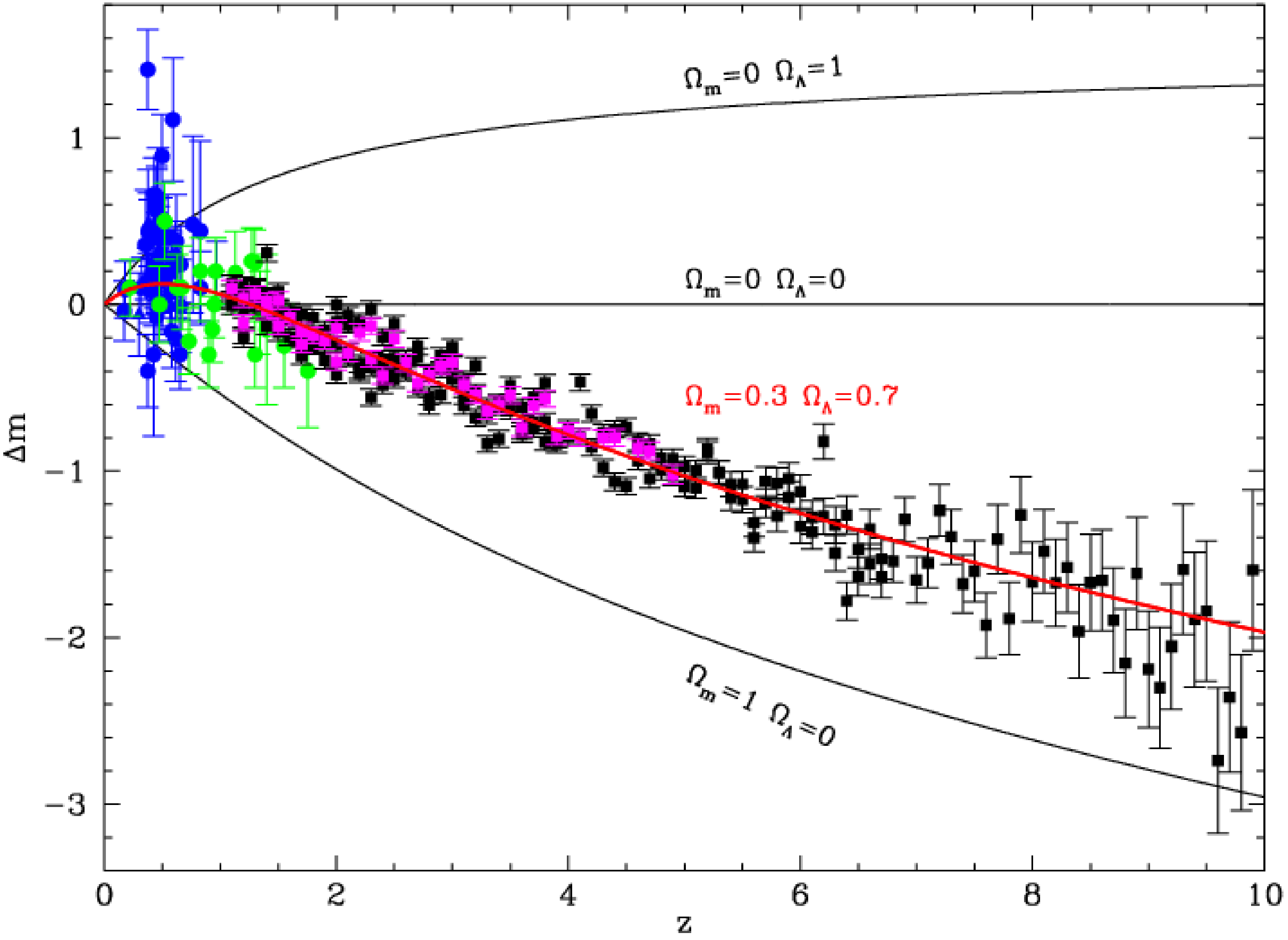
Hamuy 2003

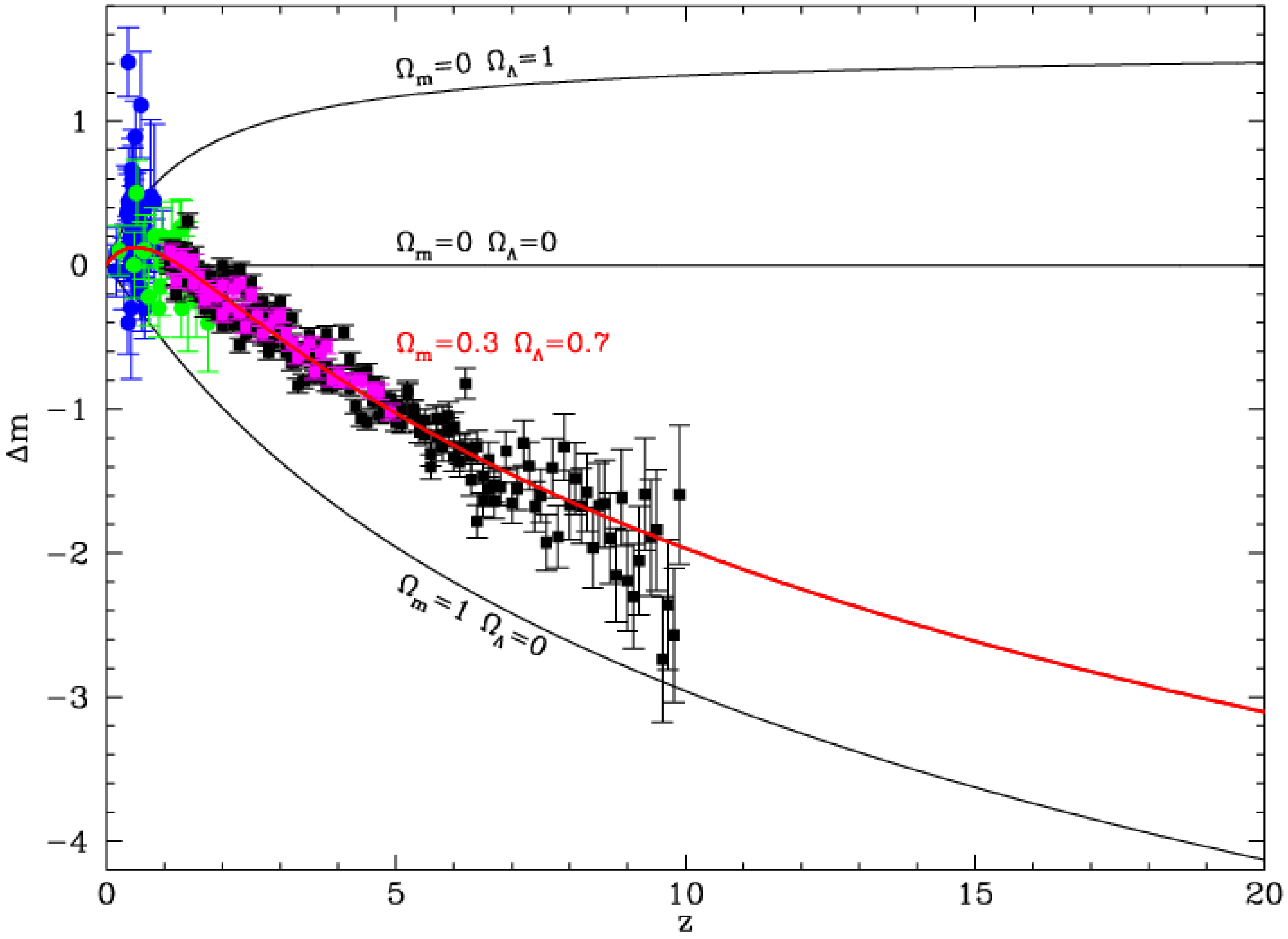

Δm
z
1
0.5
0
−0.5
−1
0
0.5
1
1.5
2
dust
$\Omega_m=0$ $\Omega_\Lambda=1$
evolution
$\Omega_m=0$ $\Omega_\Lambda=0$
$\Omega_m=0.3$ $\Omega_\Lambda=0.7$
$\Omega_m=1$ $\Omega_\Lambda=0$
● ground
● HST

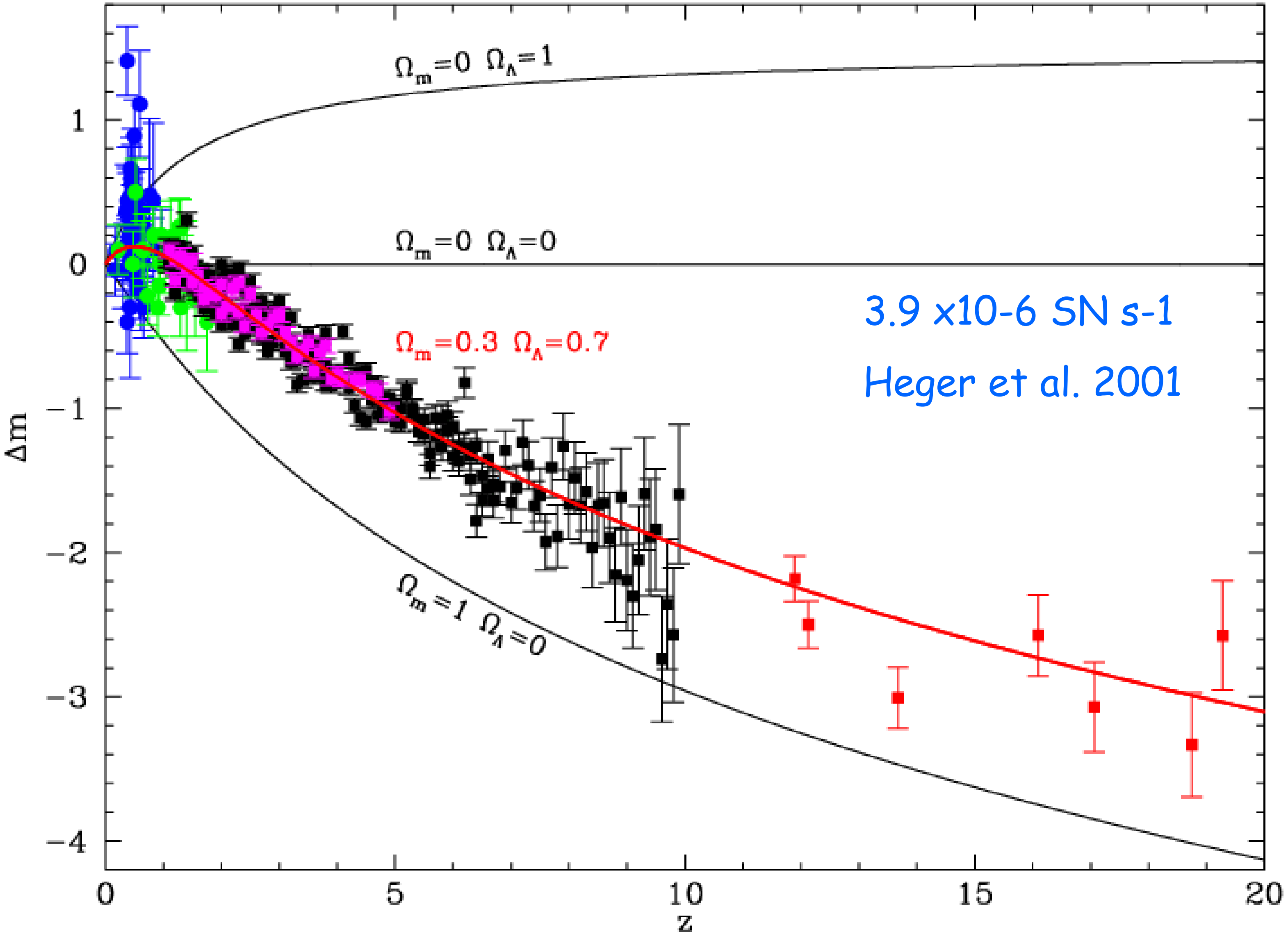

$\Omega_m=0\ \Omega_\Lambda=1$
$\Omega_m=0\ \Omega_\Lambda=0$
$\Omega_m=0.3\ \Omega_\Lambda=0.7$
$\Omega_m=1\ \Omega_\Lambda=0$
Δm
1
0
−1
−2
−3
0
2
4
6
8
10
z

Science with ELTs



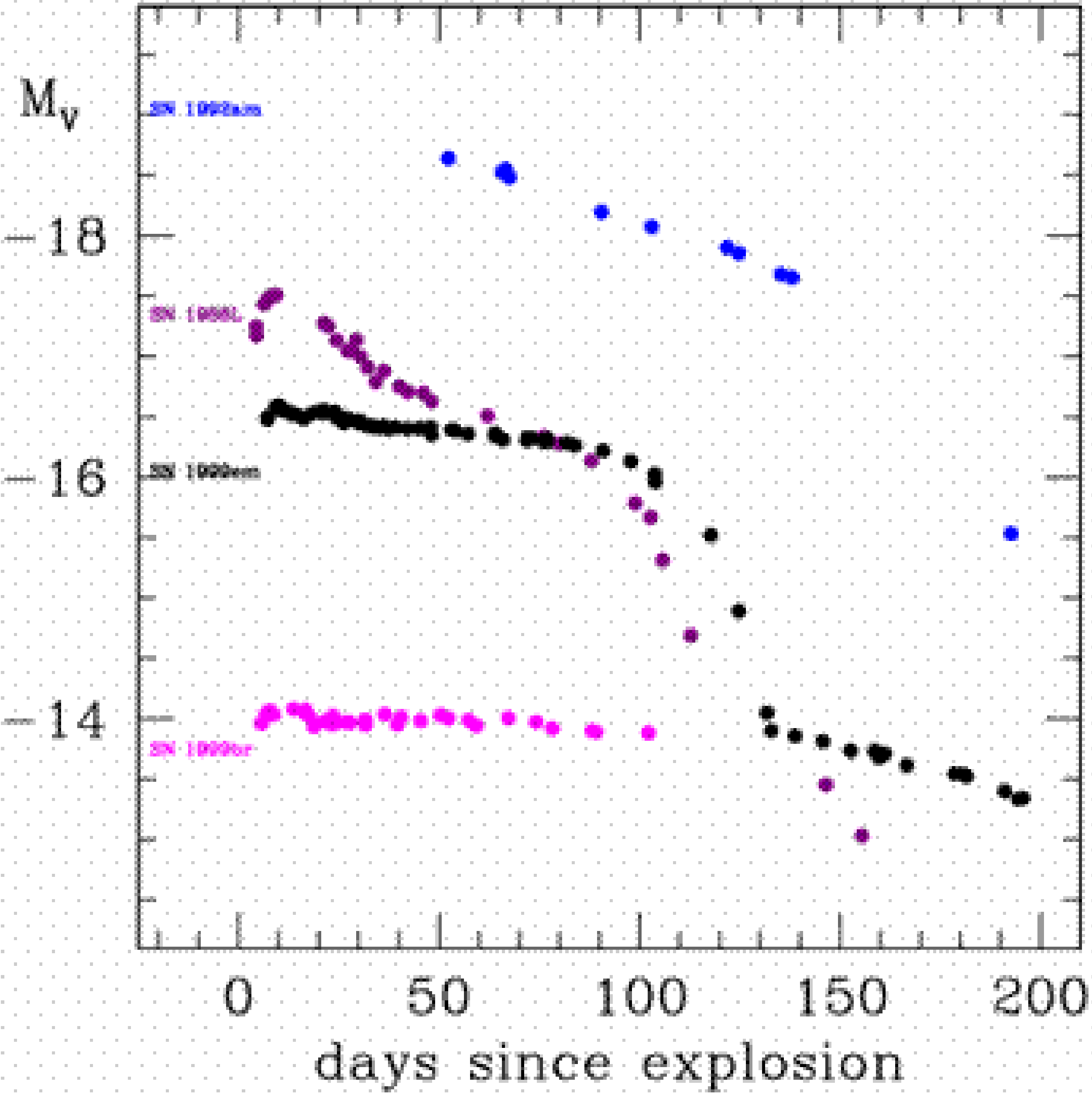

$\Omega_m=0\ \Omega_\Lambda=1$
$\Omega_m=0\ \Omega_\Lambda=0$
$\Omega_m=0.3\ \Omega_\Lambda=0.7$
$\Omega_m=1\ \Omega_\Lambda=0$
Δm
z
1
0
−1
−2
−3
0
2
4
6
8
10


$\Omega_m=0\ \Omega_\Lambda=1$
$\Omega_m=0\ \Omega_\Lambda=0$
$\Omega_m=0.3\ \Omega_\Lambda=0.7$
$\Omega_m=1\ \Omega_\Lambda=0$
Δm
z
1
0
−1
−2
−3
−4
0
5
10
15
20

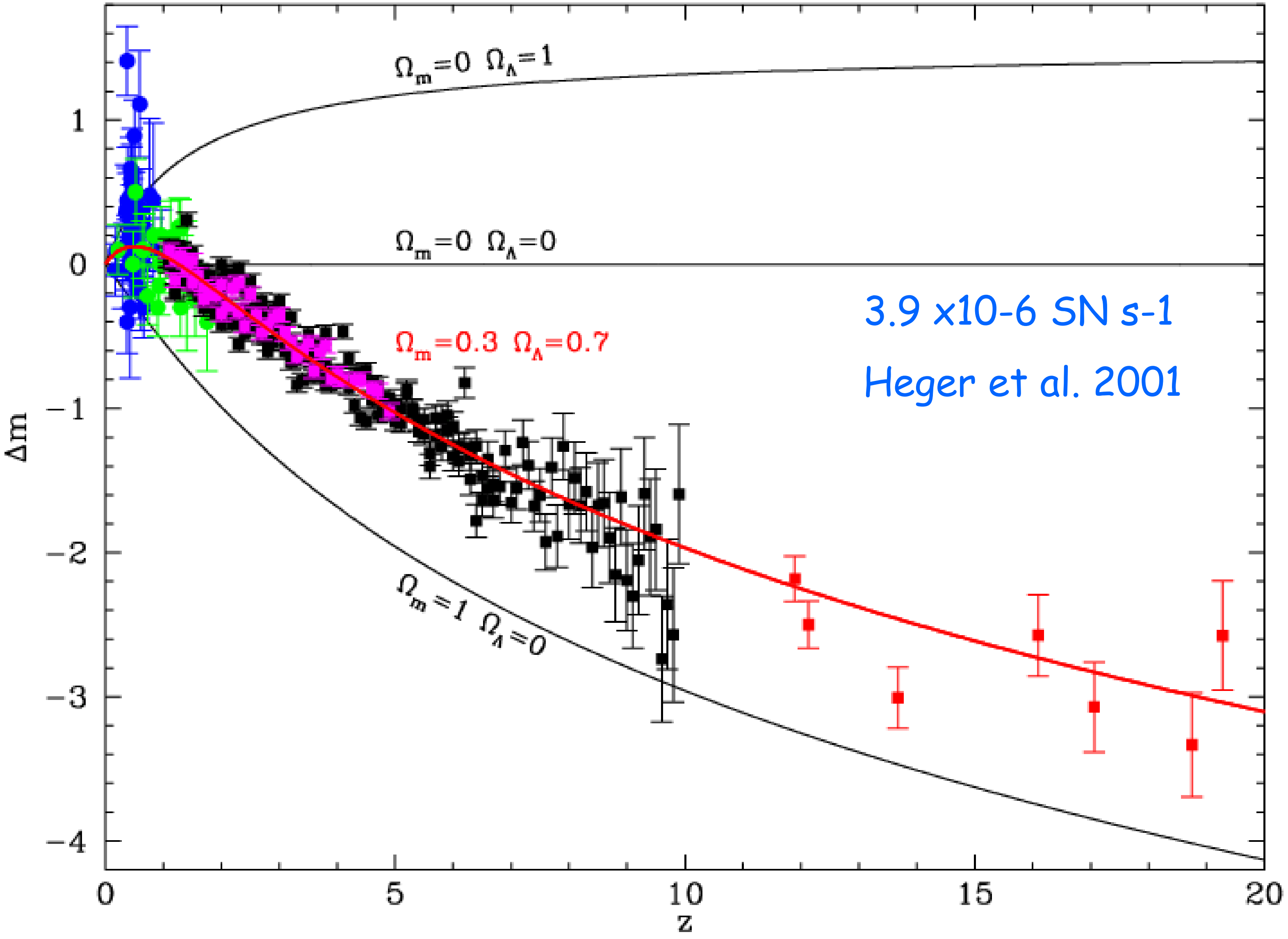


3.9 x10-6 SN s-1

Heger et al. 2001


M$_V$
SN 1992am
SN 1986L
SN 1999em
SN 1999br
−18
−16
−14
0
50
100
150
200
days since explosion

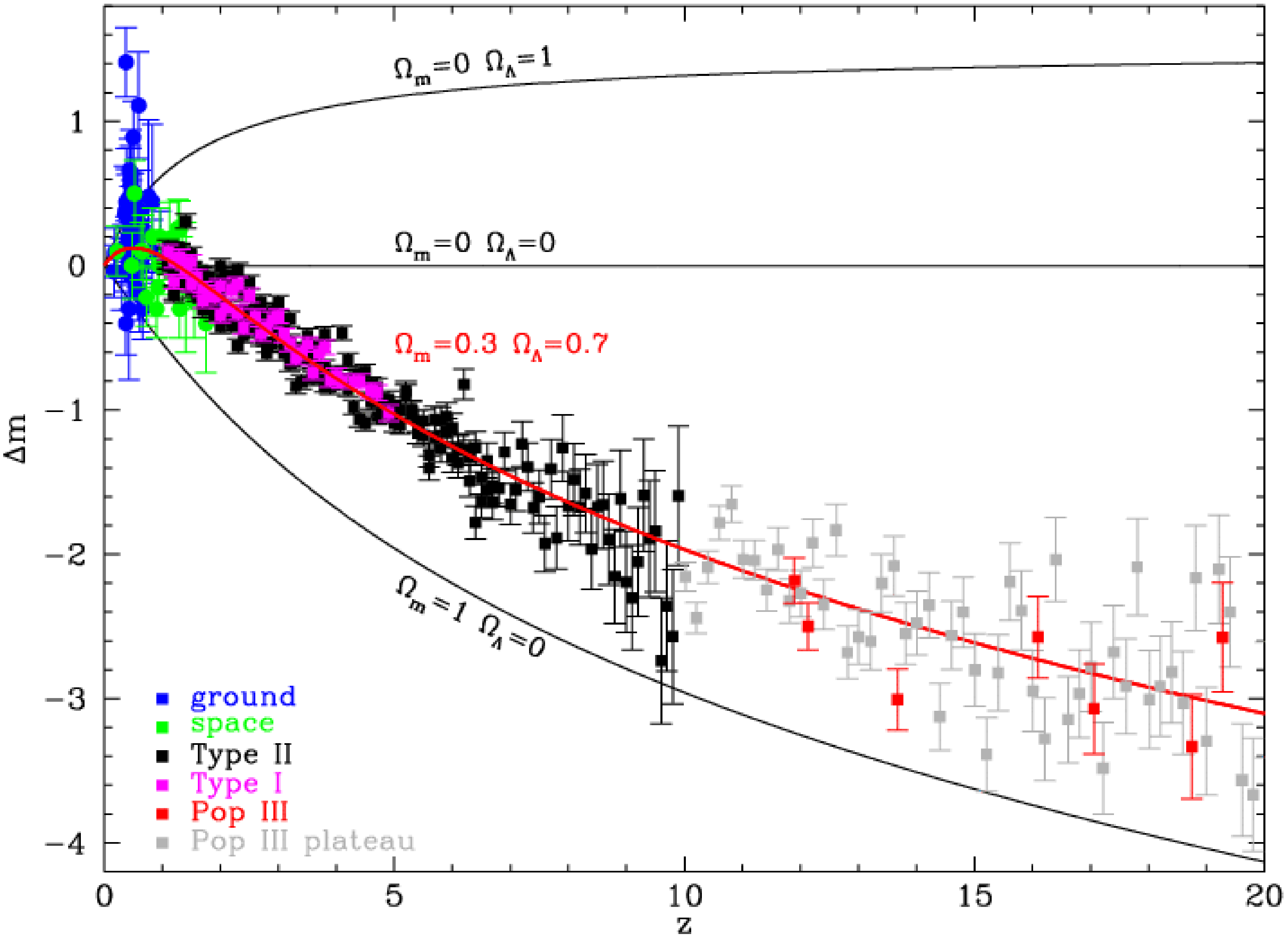
Science with ELTs



3.9 x10-6 SN s-1

Heger et al. 2001

Science with ELTs



Conclusions

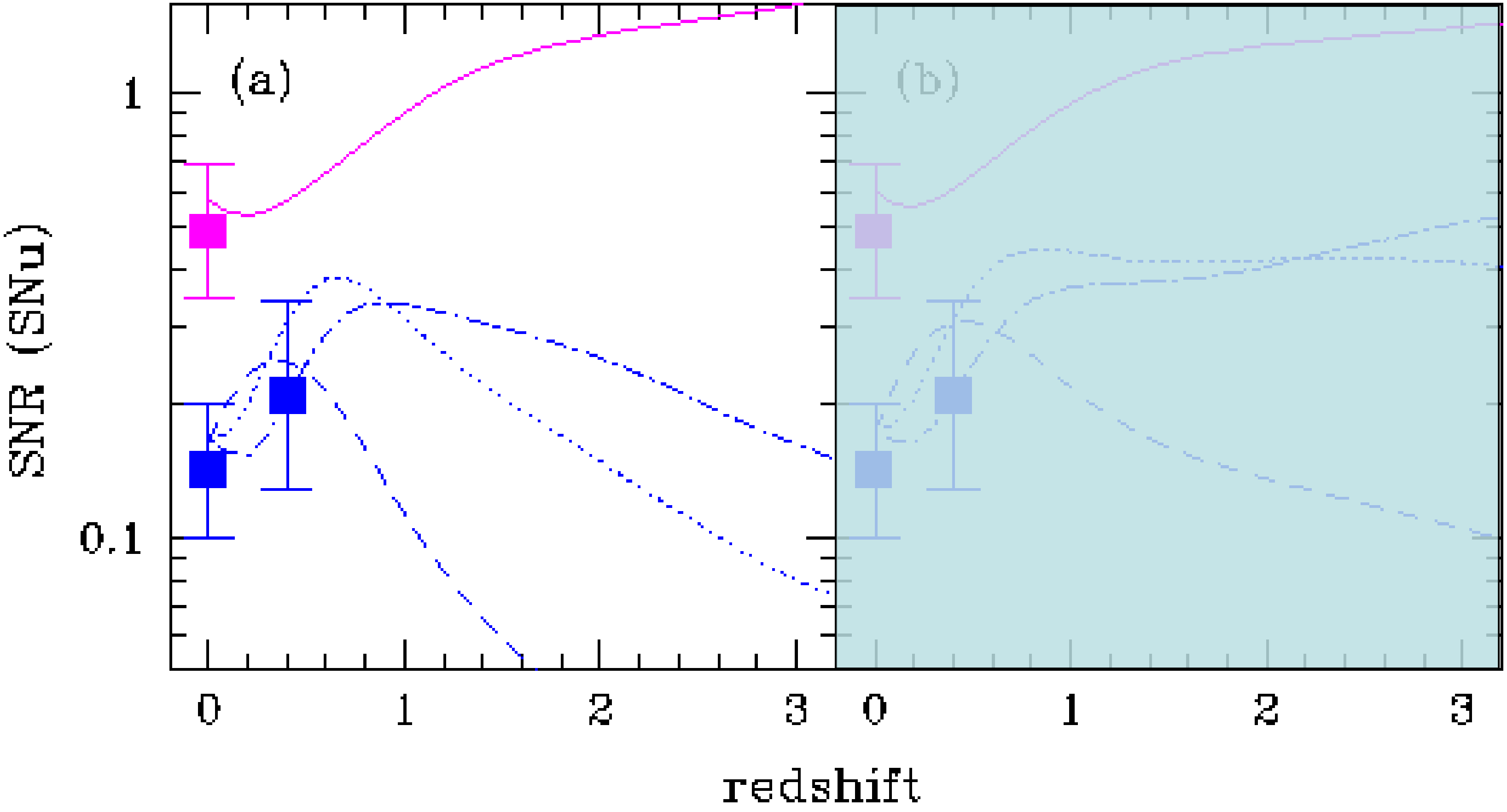
An ELT sample of SNe provides a measurements of the star formation rate up to z=15 which is:

1. Independent of other possible determinations
2. More direct –because the IMF extrapolation is much smaller
3. More reliable because it is based on counting SN explosions rather than relying on identifying and measuring the source of ionization (if using H-alpha flux) or the source of UV continuum
4. We can learn to what extent the IMF was more skewed toward massive stars (relatively to a normal Salpeter) at low metallicities

Conclusions II

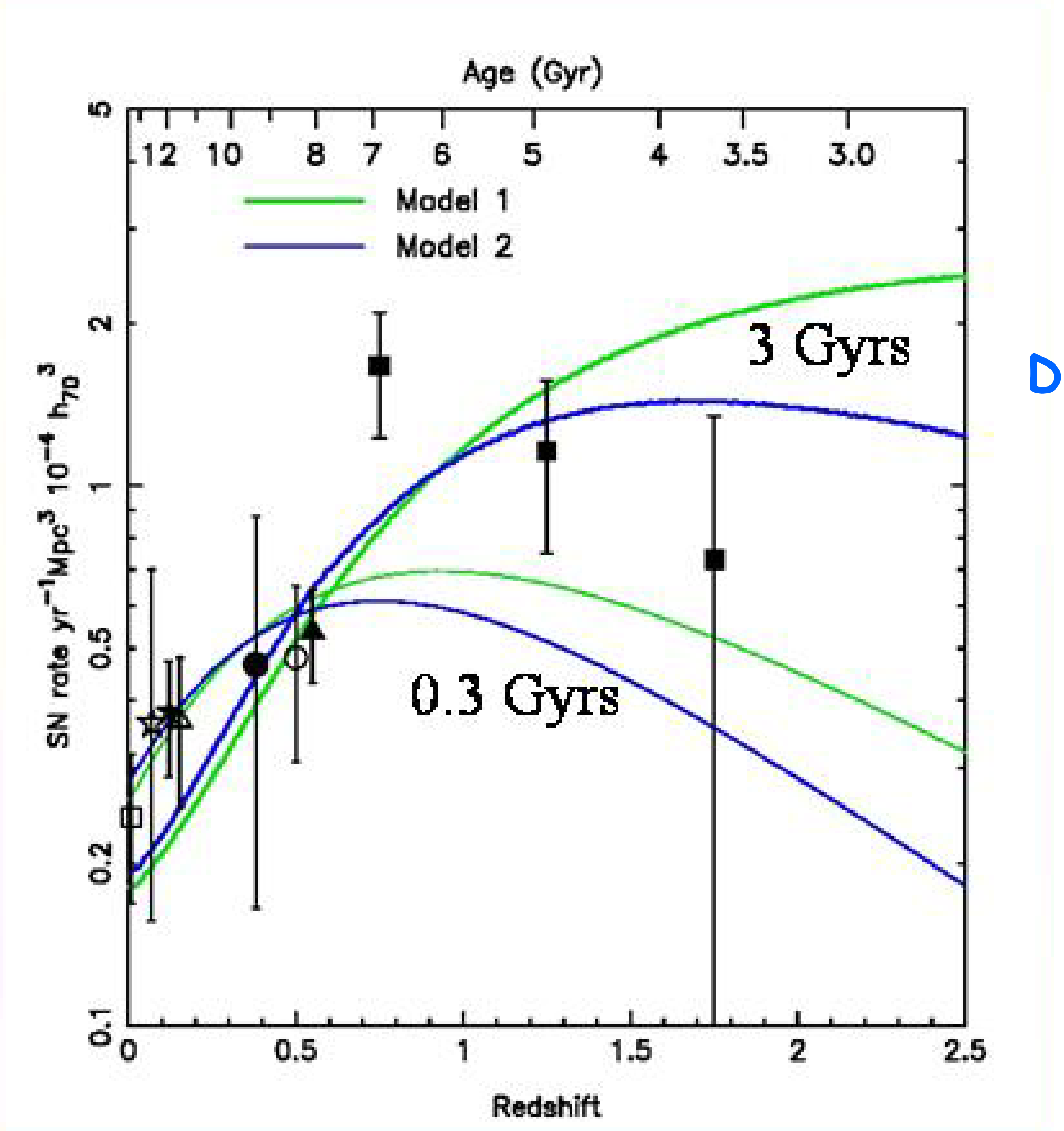
5. Disentangling models alternative to Λ
   - Supernovae at z up to ~10: quintessence (?)
6. Also ideal to probe the progenitors of type Ia SNe (sd *vs* dd)
7. To probe the physical properties of the ISM and IGM at z>10 through high spectral resolution (R~10^4) of Pop III SNe (feasible with 50-100m)
8. To explore the metal enrichment of the IGM at early epochs (up to z~4) via observations of bright type II and Ia at resolution of ~ 1000 (with 50-100m)

Science with ELTs



Madau, Della Valle & Panagia 1998

Science with ELTs



Dahlen et al. 2004

LIGO Gravitational Wave Observatory (see also Virgo, Geo, Tama 300 and Aciga)

$M = 100\text{-}300\ M_\odot$ $E_{GW} \sim 10^{-3} M_\odot c^2$

$\rightarrow h \sim 10^{-22}$

Measure of cosmic parameters with primary distance indicators

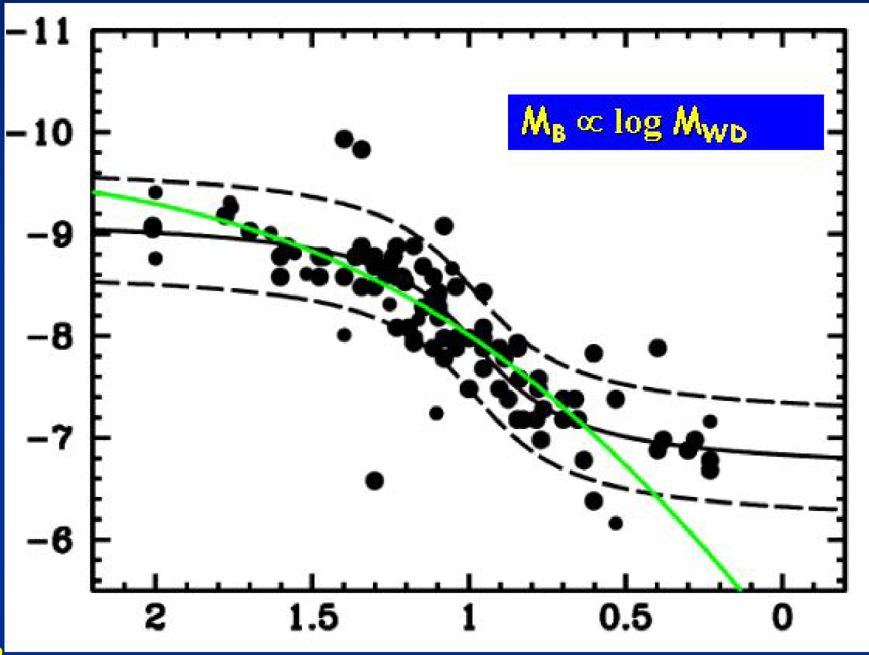
- Note: NOT H_NOT ☺
- Complex SNe Ia calibration
  - Derived + calibrated standard candles
  - Phillips relationship (1993):
    - Empirical relation M_{max} *vs* rate of decline
    - Difficult to calibrate at high *z*
  - Progenitors: single or double degenerate?
- OWL provides several alternatives

Cosmological parameters cont'd

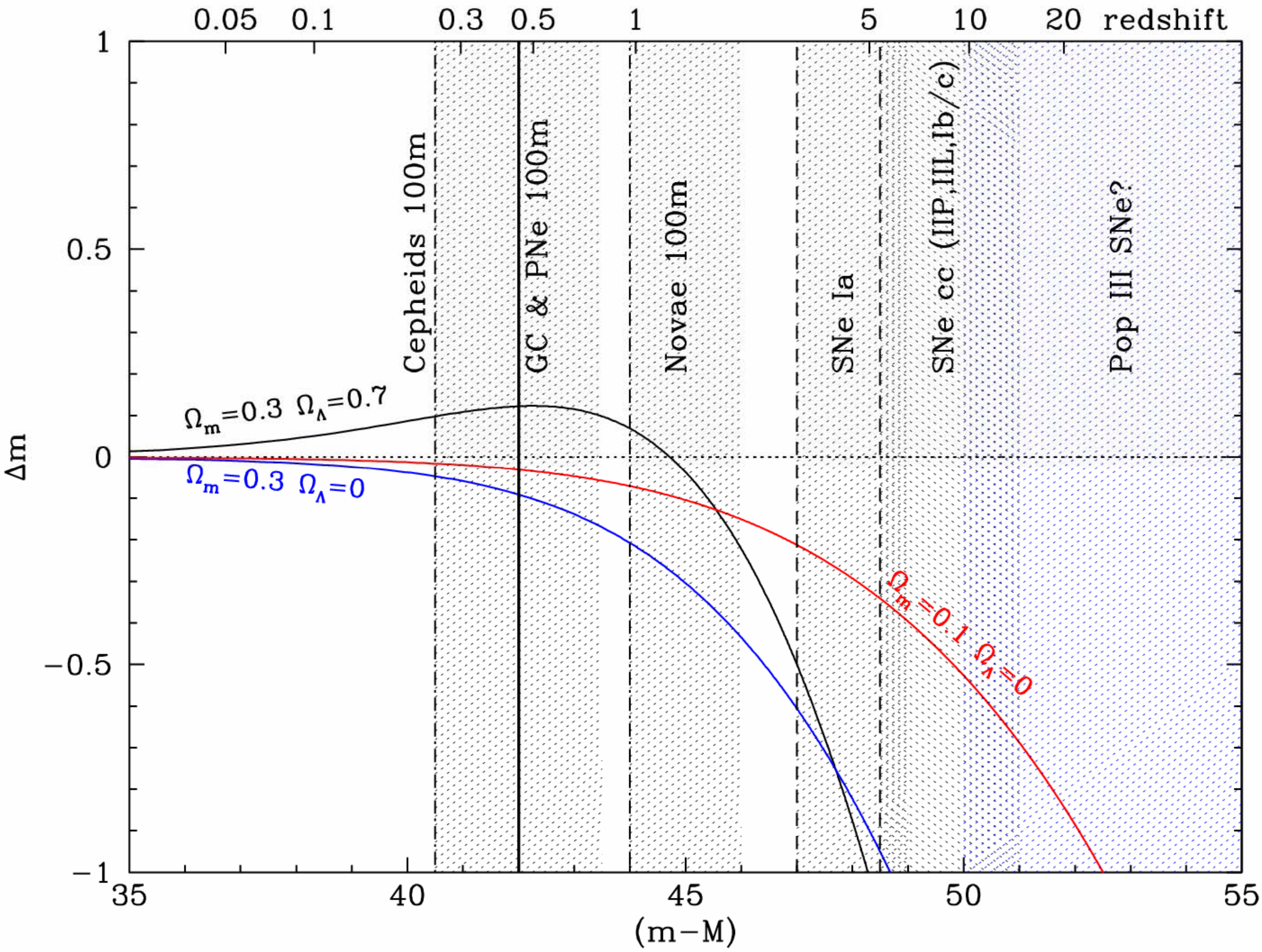
- **Disentangling models at $z \sim 1$**
  - Domain of <u>primary</u> indicators:
    - **Cepheids**: P-L
      - (direct SFR; analog to HST@Virgo)
    - **Globular Clusters**: turnover mag of LF
    - **Bright PNe**: cutoff mag of LF
    - **Novae**: MMRD
      - (visible in *all* galaxy types)

Novae: 3rd largest explosions in the Universe

- **Maximum Magnitude vs Rate of Decline:**
  - Tool for distances
  - Any galaxy type



- **Mass spectrum of WDs**
- **Frequency of occurrence**
- **Useful to calibrate the magnitude at max of all types of SNe**


0.05
0.1
0.3
0.5
1
5
10
20
redshift
1
0.5
0
−0.5
−1
Δm
35
40
45
50
55
(m−M)
Cepheids 100m
GC & PNe 100m
Novae 100m
SNe Ia
SNe cc (IIP,IIL,Ib/c)
Pop III SNe?
Ω_m=0.3 Ω_Λ=0.7
Ω_m=0.3 Ω_Λ=0
Ω_m=0.1 Ω_Λ=0