Cluster and Field SN Rates vs. Redshift

D. Maoz

with A. Gal-Yam, K. Sharon, D. Poznanski, A. Horesh

+ A. Filippenko, R. Guhathakurta, F. Prada, R. Foley, R. Chornock

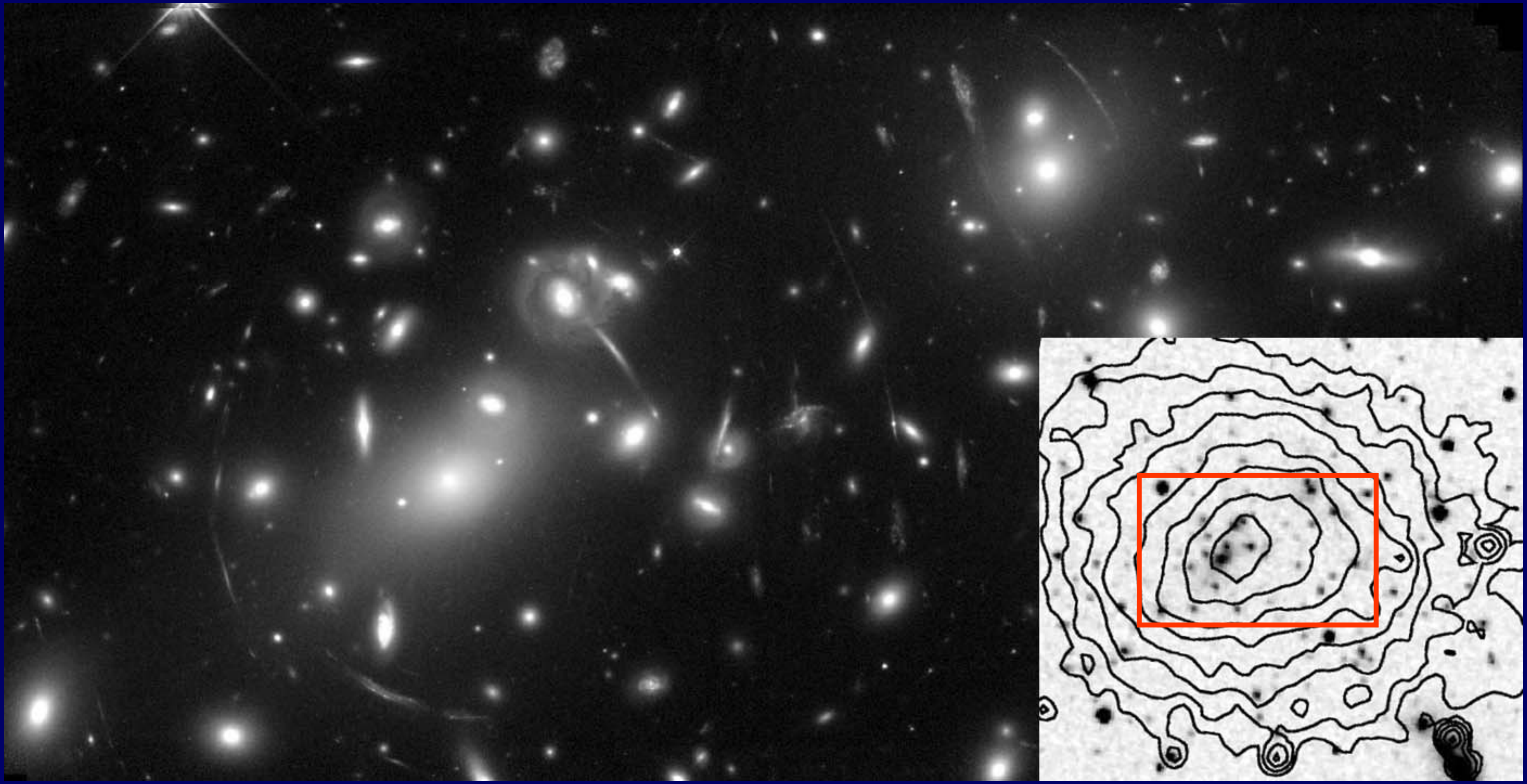
SN-Ia rates in galaxy clusters

Why study metal enrichment in clusters?

Simple, quiet, “Hotel California”s -- ideal for studying roles of different SN types in metal enrichment

+ lots of galaxies in one small area.

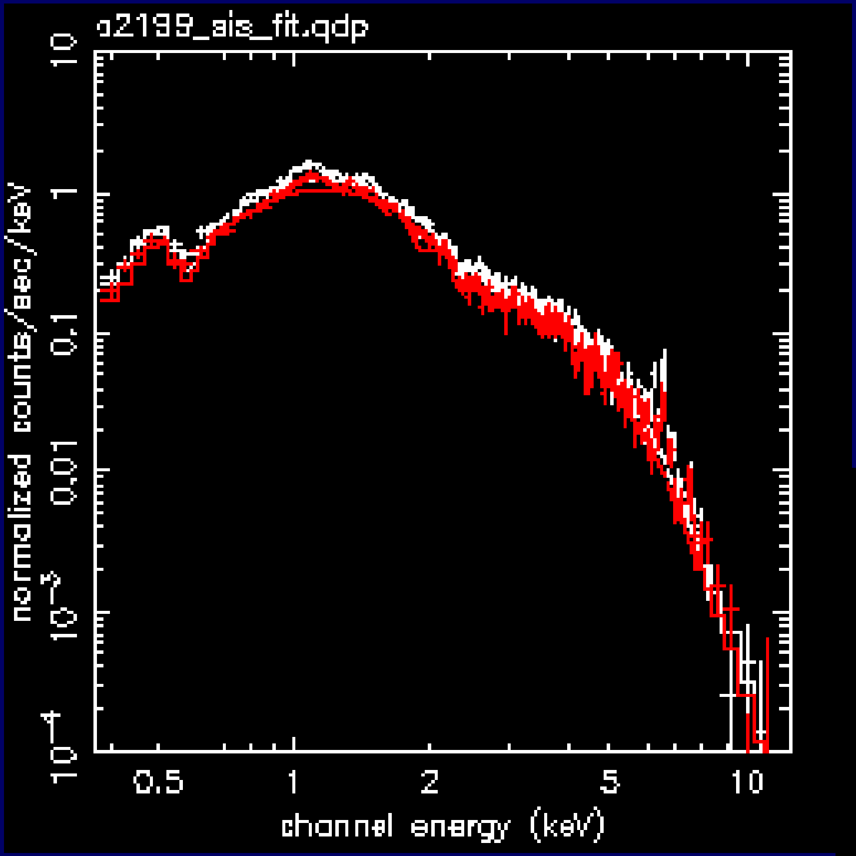
Most of the baryons are in the ICM

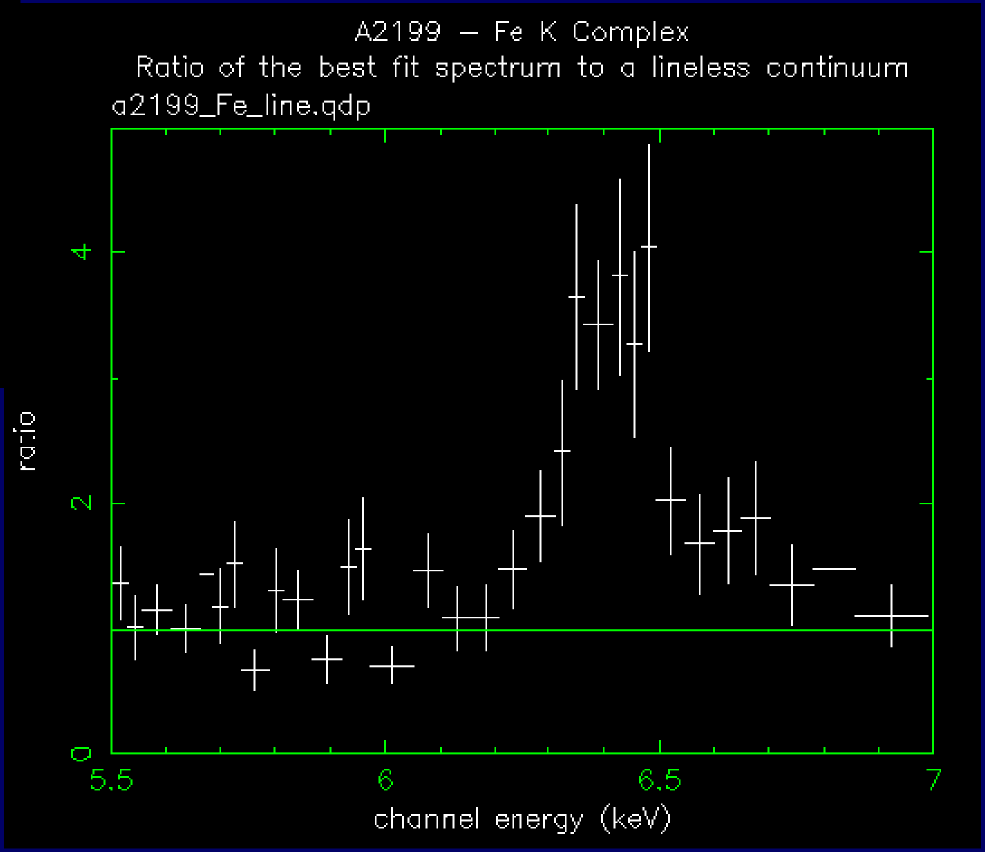


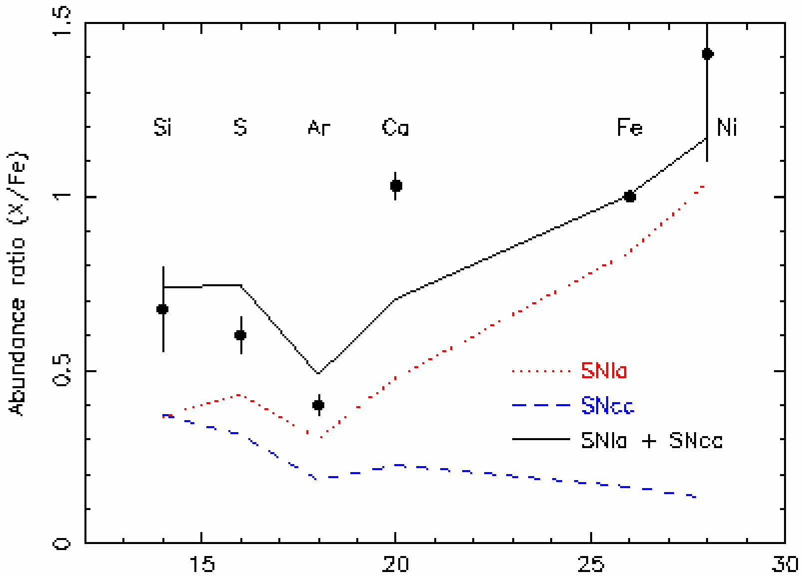
Govoni et al. 2004

Iron is easiest to detect and to

convert to abundance:







<u>"Fossil" studies</u>: e.g.,

De Plaa et al. 2007

15-40% of stars with m=3-8 M_sun go SN-Ia

Fig. 6. Abundance
We fit the superno
(Z=0.02 and Salp
while the dotted a
models respective

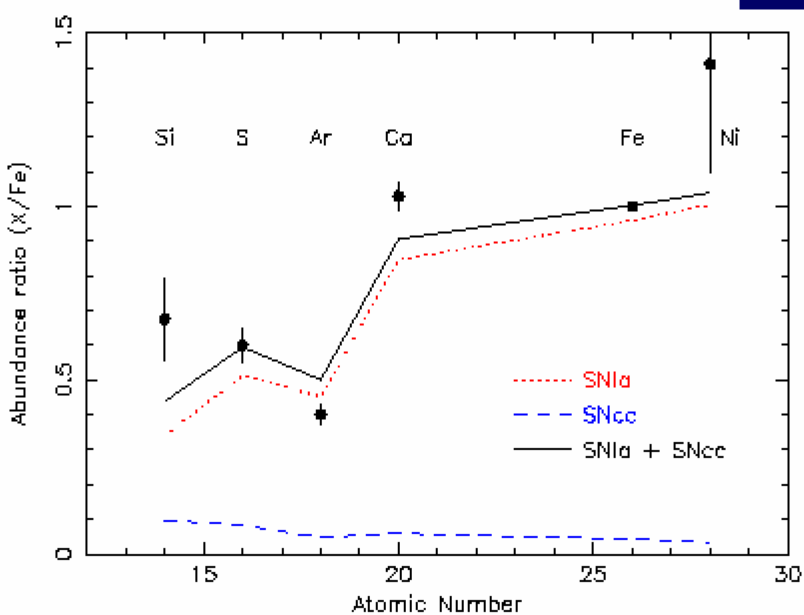


Fig. 7. Same as Fig 6, but now we fit the SNIa yields found in the Tycho supernova remnant by Badenes et al. (2006). The nickel yield of the Tycho SNIa model was kindly provided by Carles Badenes (priv. comm.).

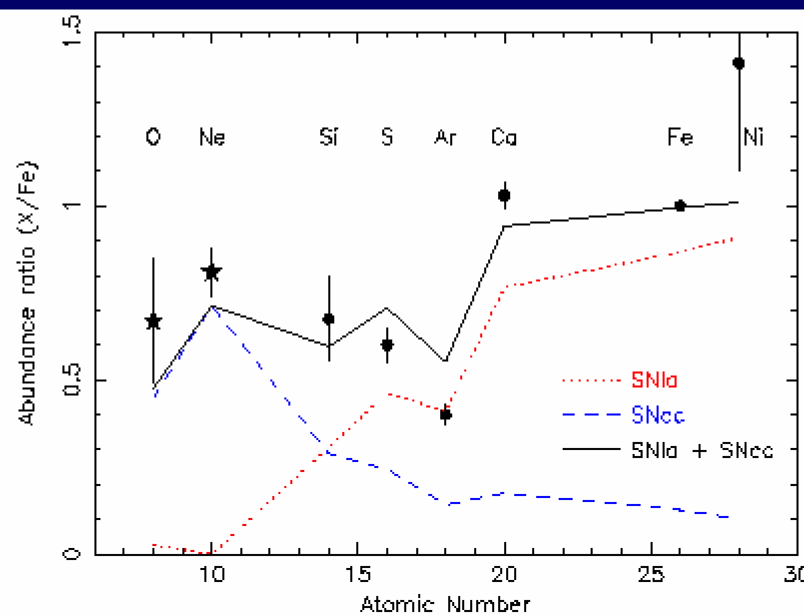


Fig. 8. Fit using the SNIa yields by Badenes et al. (2006), but now with additional oxygen and neon data points (stars) obtained from the RGS spectra of Sérsic 159-03 and 2A 0335+096. Here, the core-collapse model with Z=0.02 and Salpeter IMF is used.

Alternatively:

By measuring SN rates vs. redshift we can see cosmic metal enrichment in action!

+

Figure out what is exploding in type-Ia's

Prediction of SN-Ia rate vs. redshift in clusters:

In ICM: $Z_{Fe} = 0.3\ Z_{\odot}$ → Lots of iron!

In place by z~1 (Balestra et al. 2006, Maughan et al. 2007)

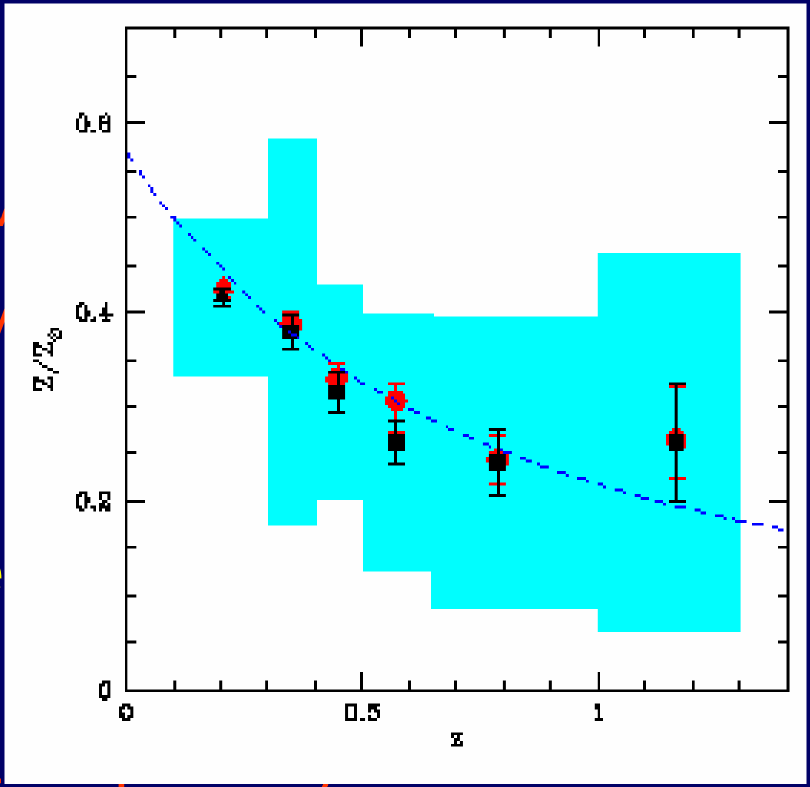
Iron yields known from SN

Core-collapse SNe: ~ 0.1 M

Type Ia SNe: ~ 0.7 M

For any standard IMF,

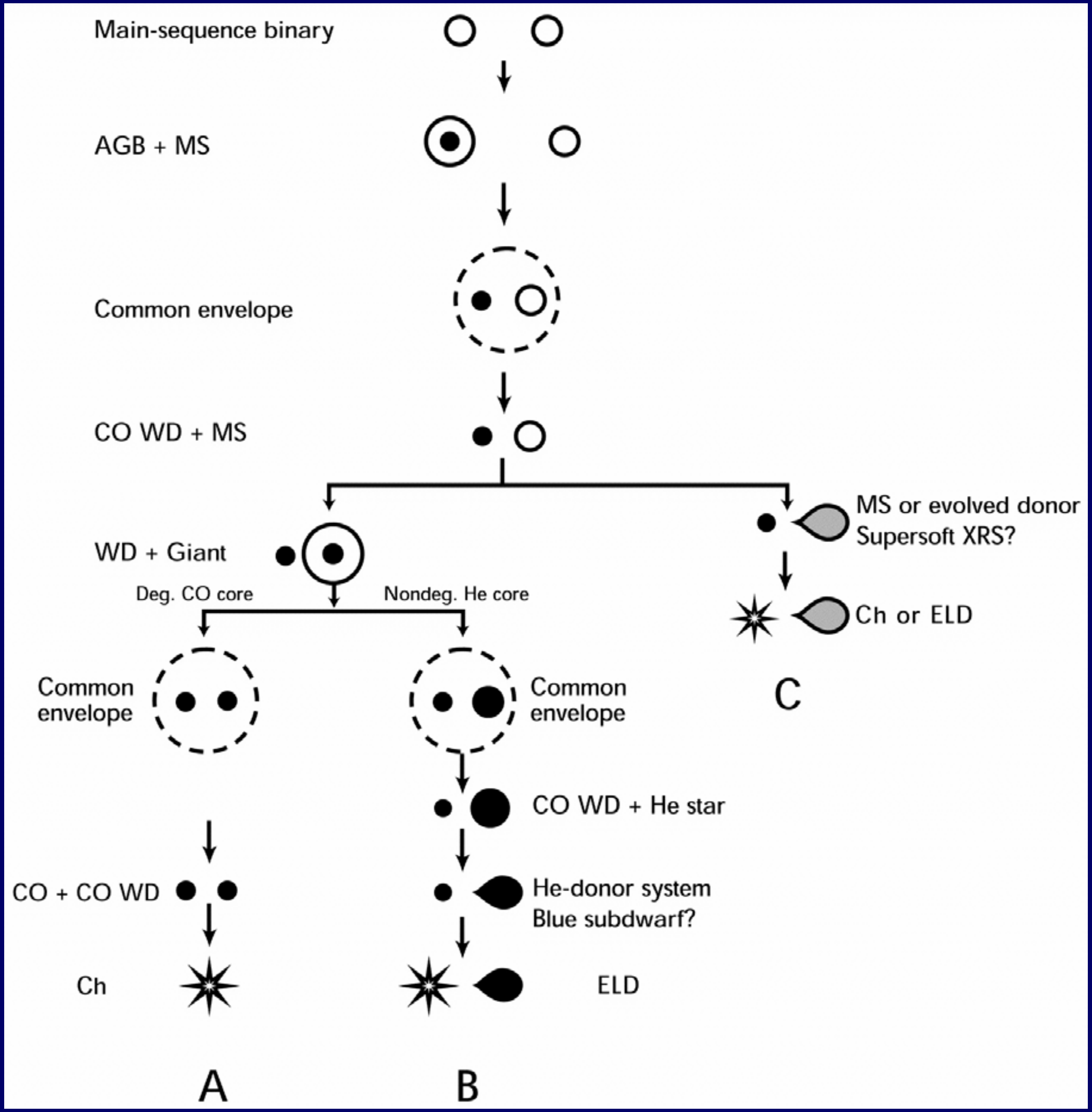
observed M(Fe) ~ 5x expe



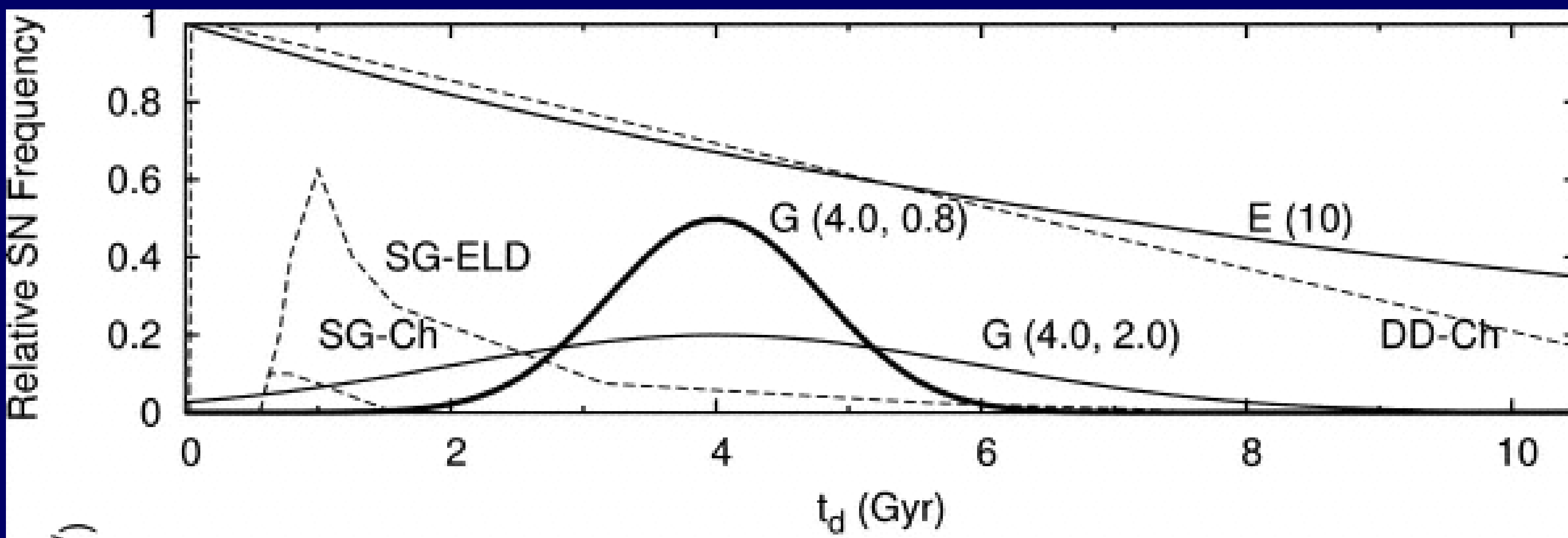
→ Solution 1

Solution 2: Most of iron is from SNe-Ia

Yungelson & Livio (2000)



D(t)



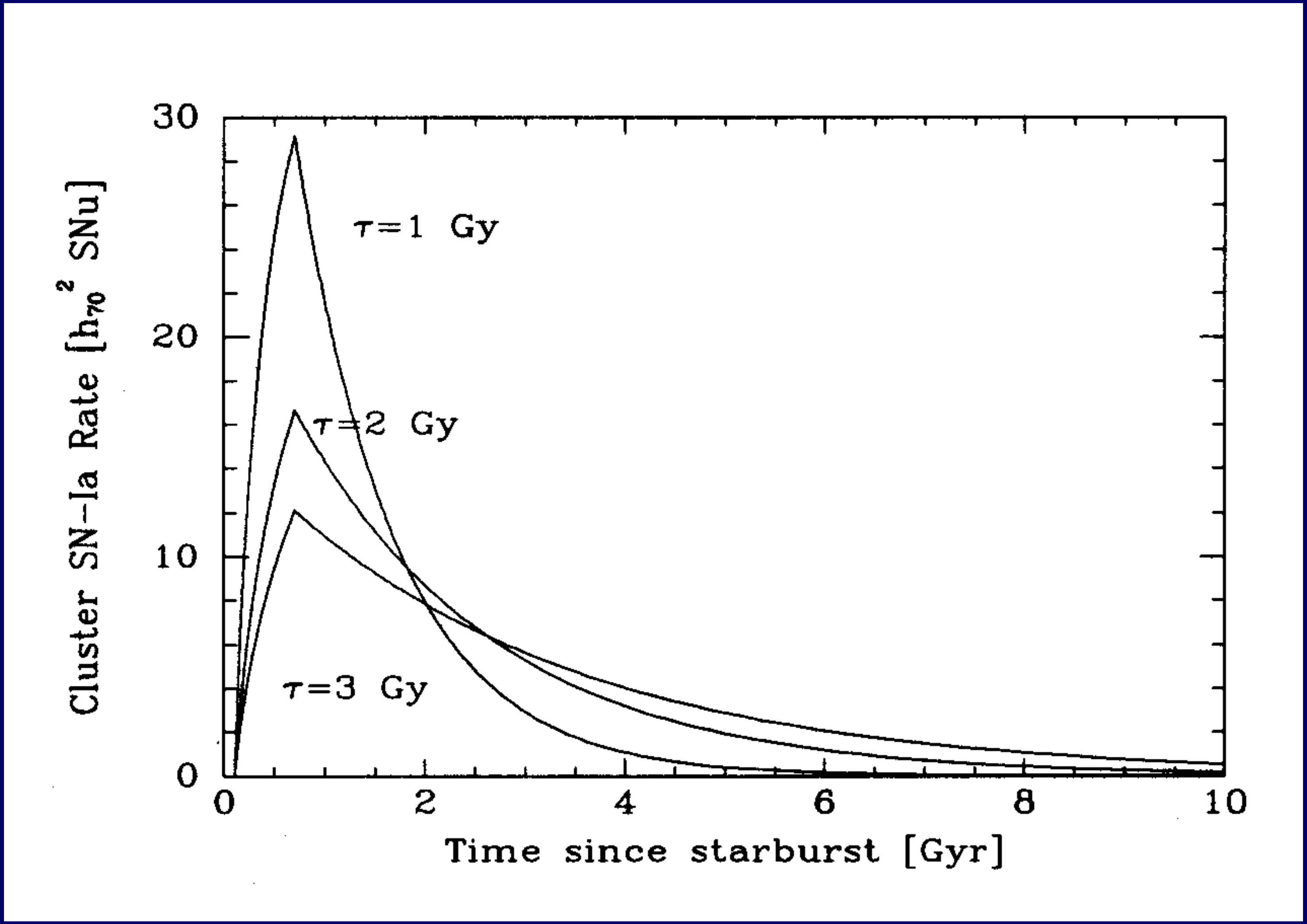
t

From Strolger et al. 2004, based on
Yungelson & Livio 2000

Maoz & Gal-Yam (2004),

following Madau, DellaValle, & Panagia (1998)

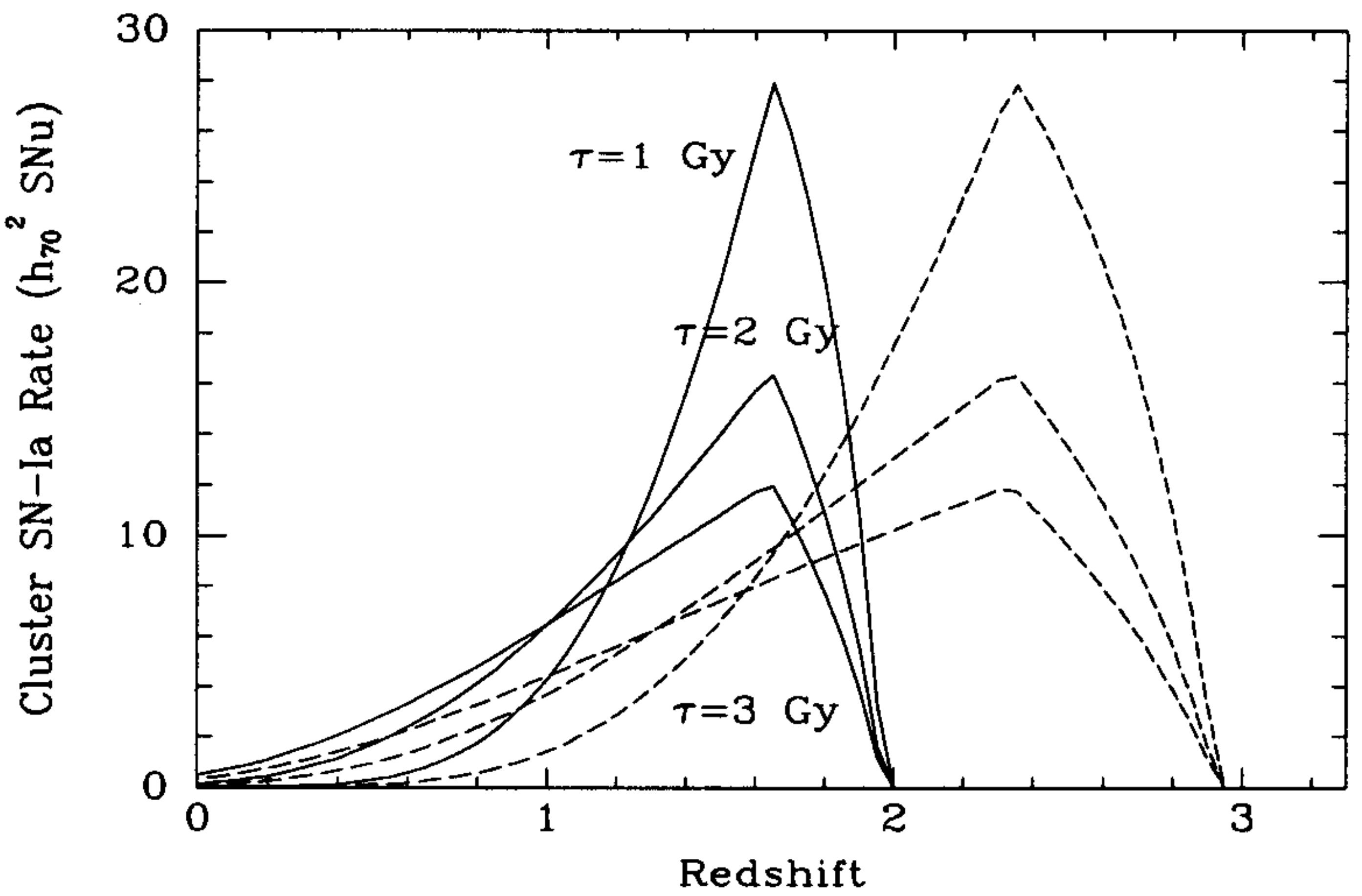
D(t)



t

Cluster SN-Ia rates vs. z depend on two parameters:

z_formation and τ

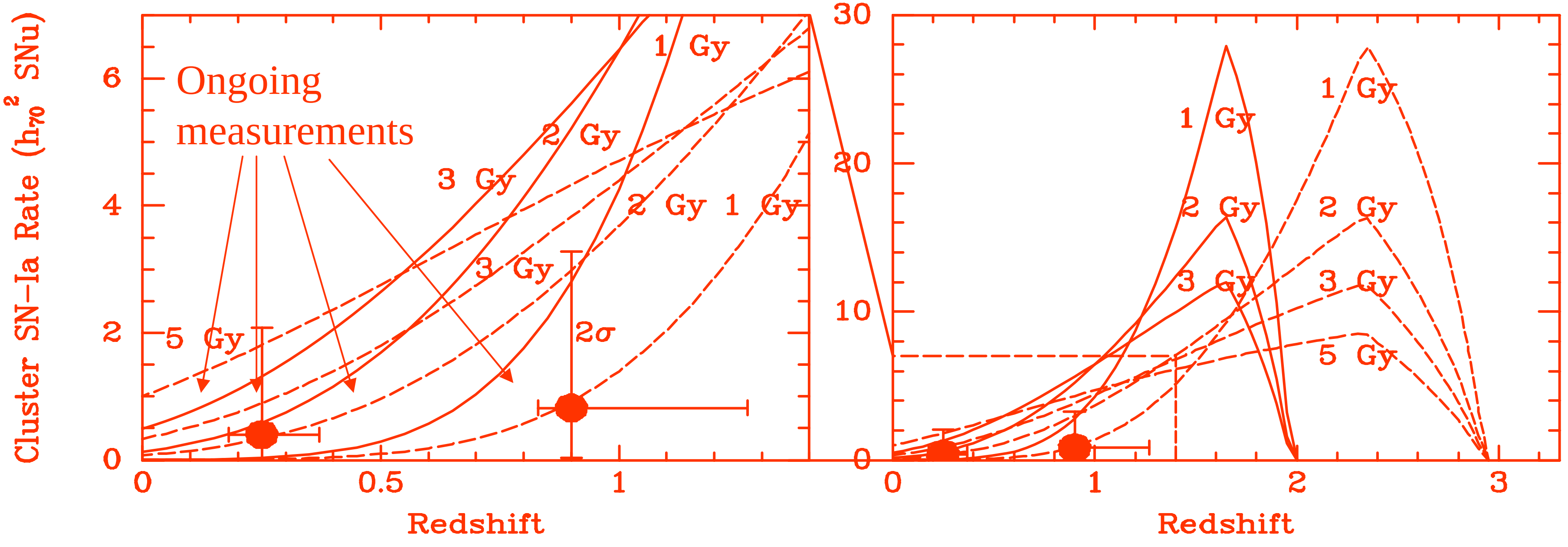


$$\frac{1}{L}\int \mathrm{SNR}_{Ia}(t)\; dt = \frac{M_{Fe}}{L\; m_{Fe-Ia}} = 0.04\;\frac{\mathrm{SN}}{L_\odot} = 40\;\mathrm{SNu\;Gyr}$$

(1 SNu=1 SN/century/10^{10} L_{Sun})

Cluster SN-Ia rate measurements 0<z<1

Gal-Yam, Maoz, & Sharon (2002)



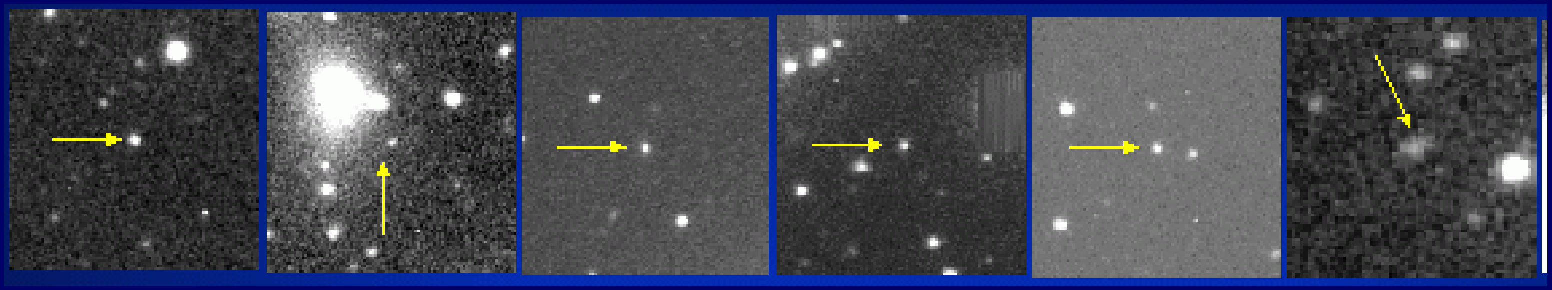
Ongoing rate measurements

z~0.1:

Wise Obs. 1m

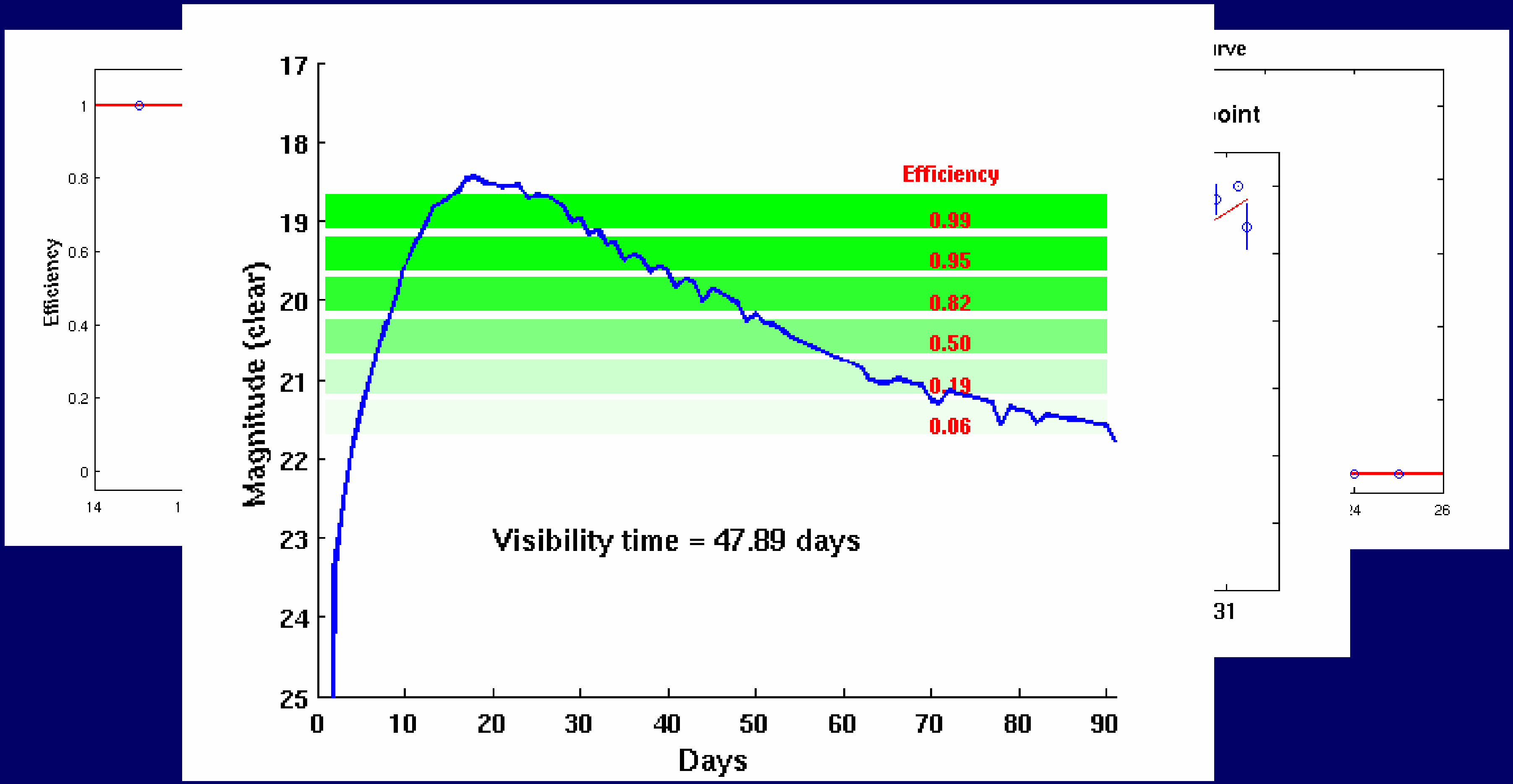
Discovery and followup:

Gal-Yam et al. (2003, 2007)



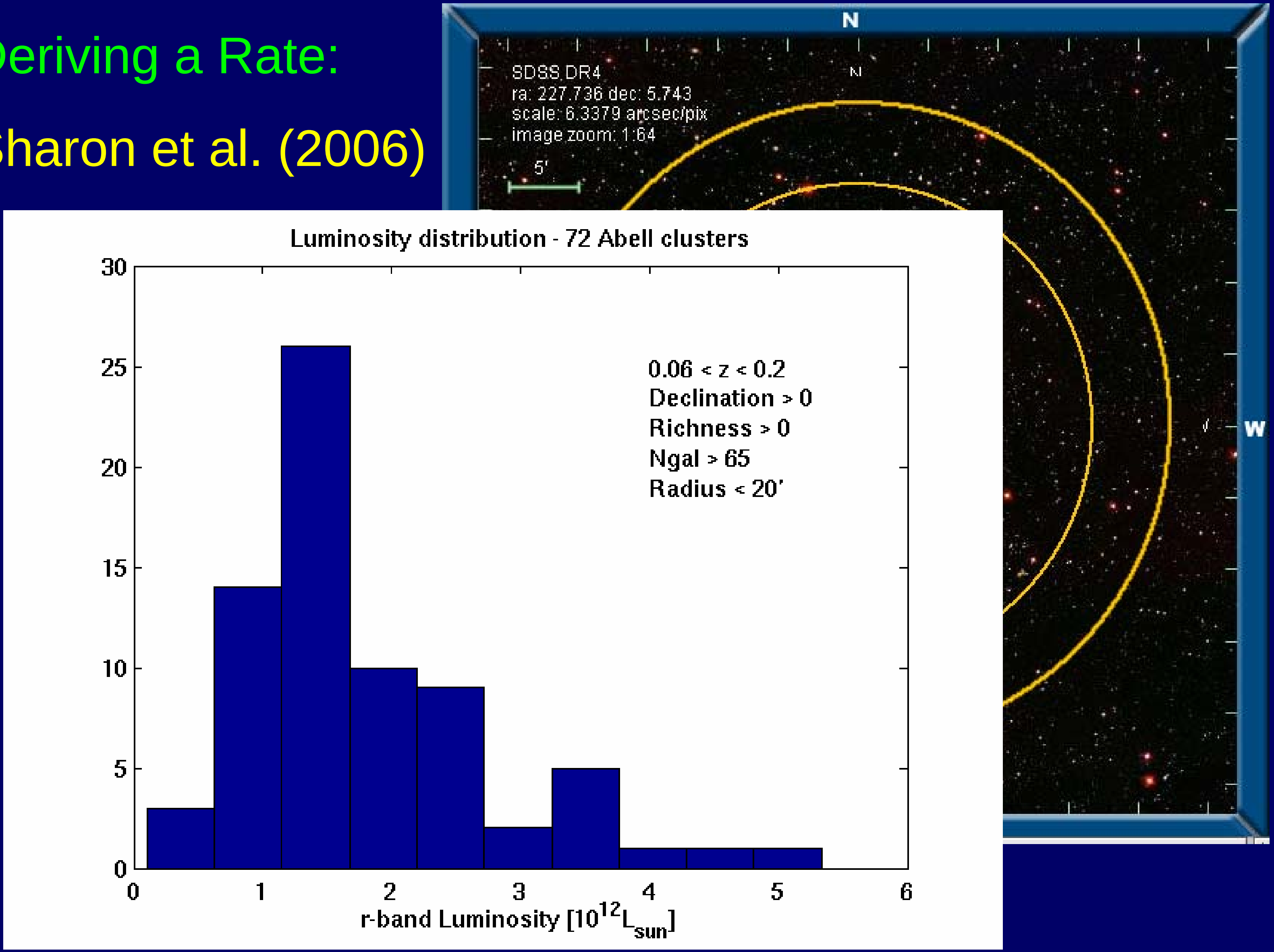
Deriving a Rate:

Sharon et al. (2006)



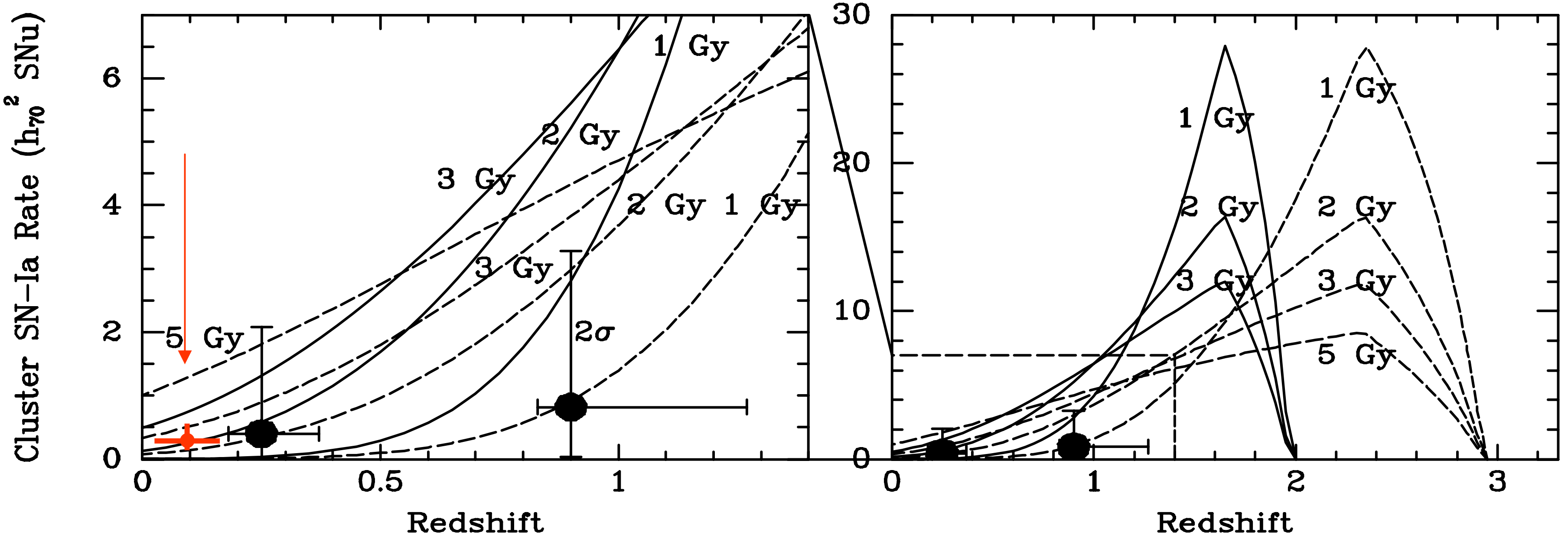
Deriving a Rate:

Sharon et al. (2006)



$SNR_{Ia}(z=0.1)=0.36^{+0.24}_{-0.16}\ SNu_B$

$=0.098^{+0.68}_{-0.48}$ SNuM (rate per mass)



$SNR_{Ia}(z=0.1)=0.36^{+0.24}_{-0.16}$ SNu_B Sharon et al. (2007)

E+S0 $SNR_{Ia}(z=0)=0.16^{+0.05}_{-0..05}$ SNu_B Capellaro et al. (1998)

SNRIa(z=0.1) $=0.098^{+0.68}_{-0.48}$ SNuM Sharon et al. (2007)

E+S0 $SNR_{Ia}(z=0)=0.038^{+0.014}_{-0.012}$ SNuM Mannucci et al. (2005)

Dependence of SN rate on environment in Capellaro et al. (1999) sample?

(Mannucci et al., in prep.)

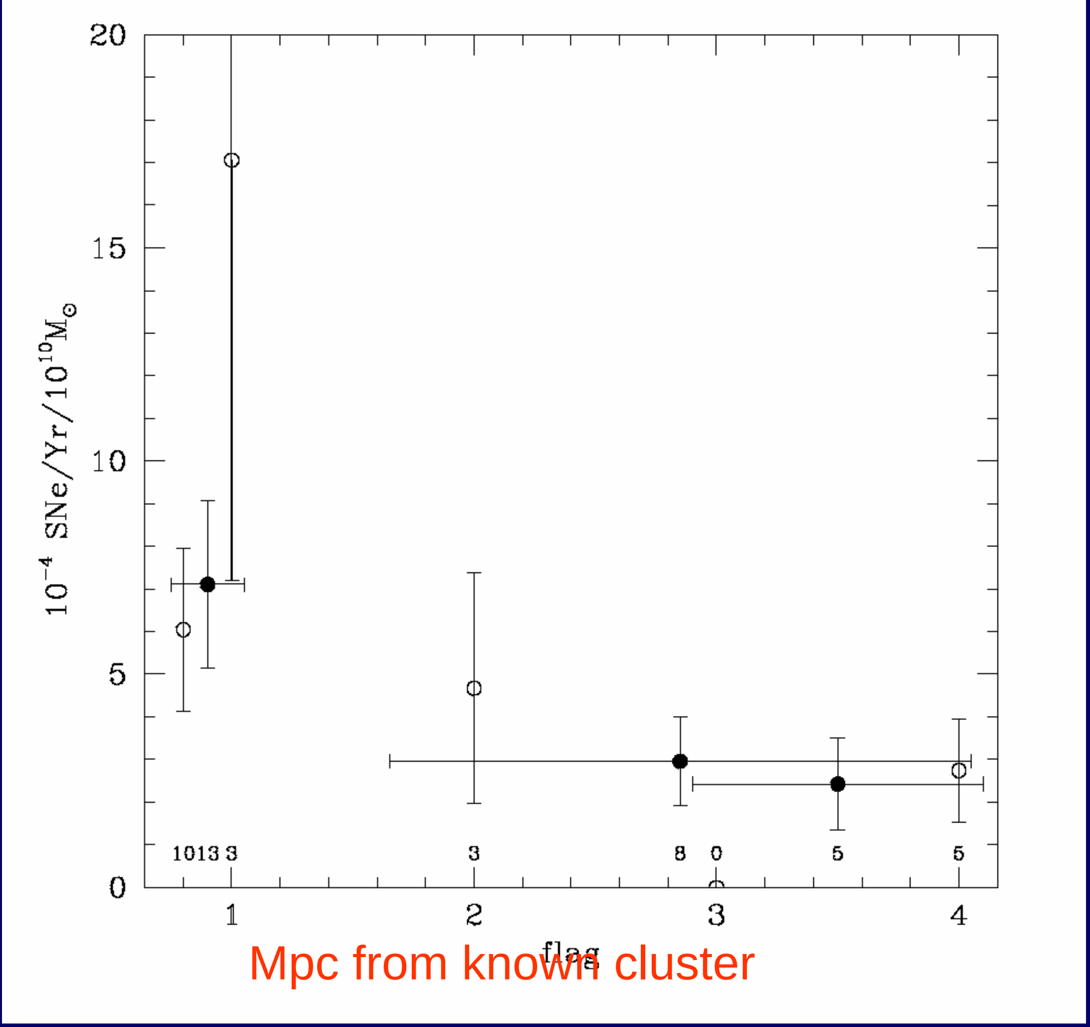
E+S0 $SNR_{Ia}(z=0)=0.038^{+0.014}_{-0.012}$ SNuM (Mannucci et al. 2005)

0.071 SNuM in clusters (14 SNe)

0.029 SNuM in field (8 SNe)

0.131 SNuM in clusters +radio-loud (6 SNe)

0.018 SNuM in field + radio quiet (4 SNe)


20
15
10
5
0
10^{-4} SNe/Yr/$10^{10}M_\odot$
1
2
3
4
flag
10 13 3
3
8
0
5
5
Mpc from known cluster

Ongoing rate measurements

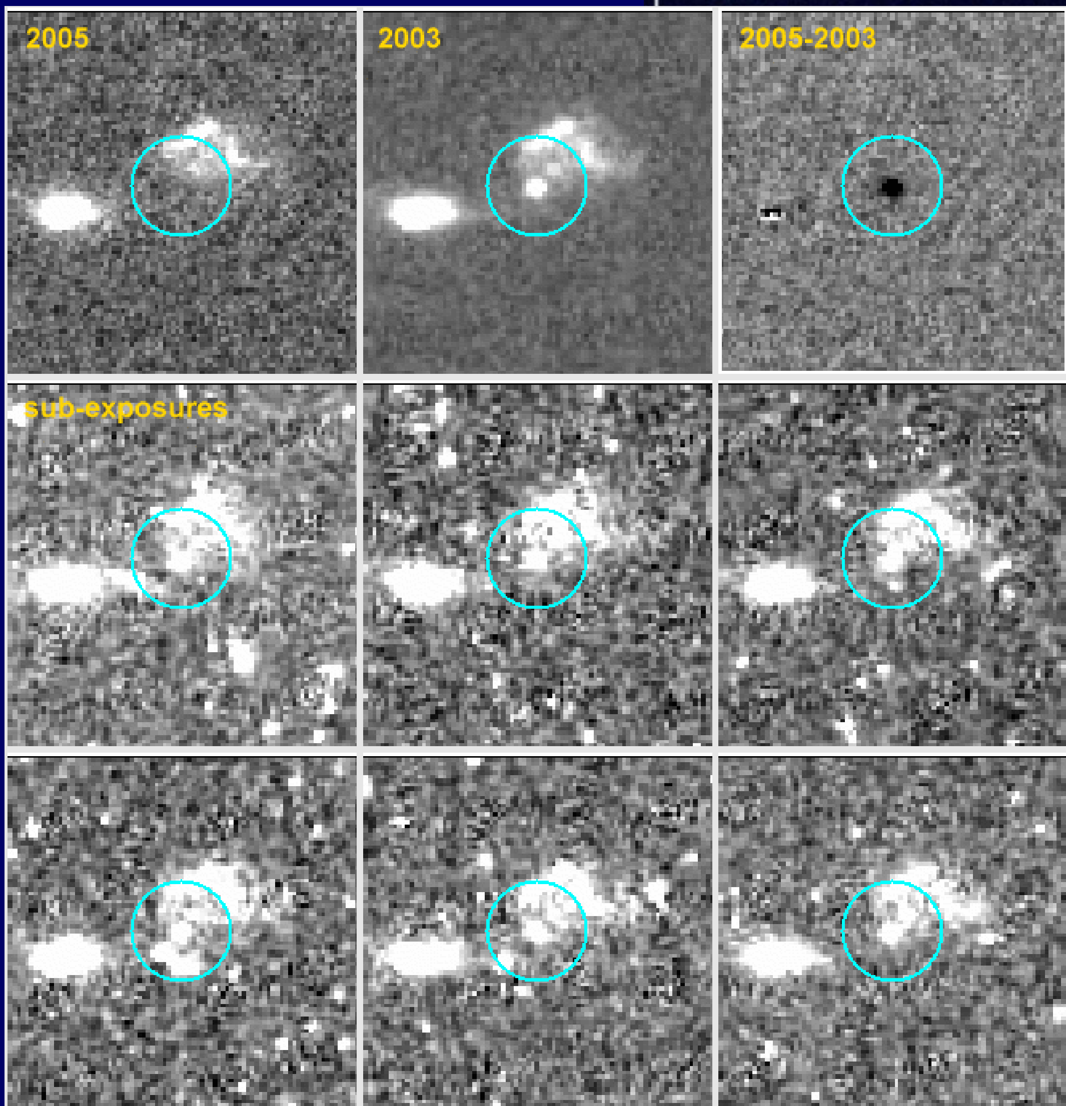
z~0.7:

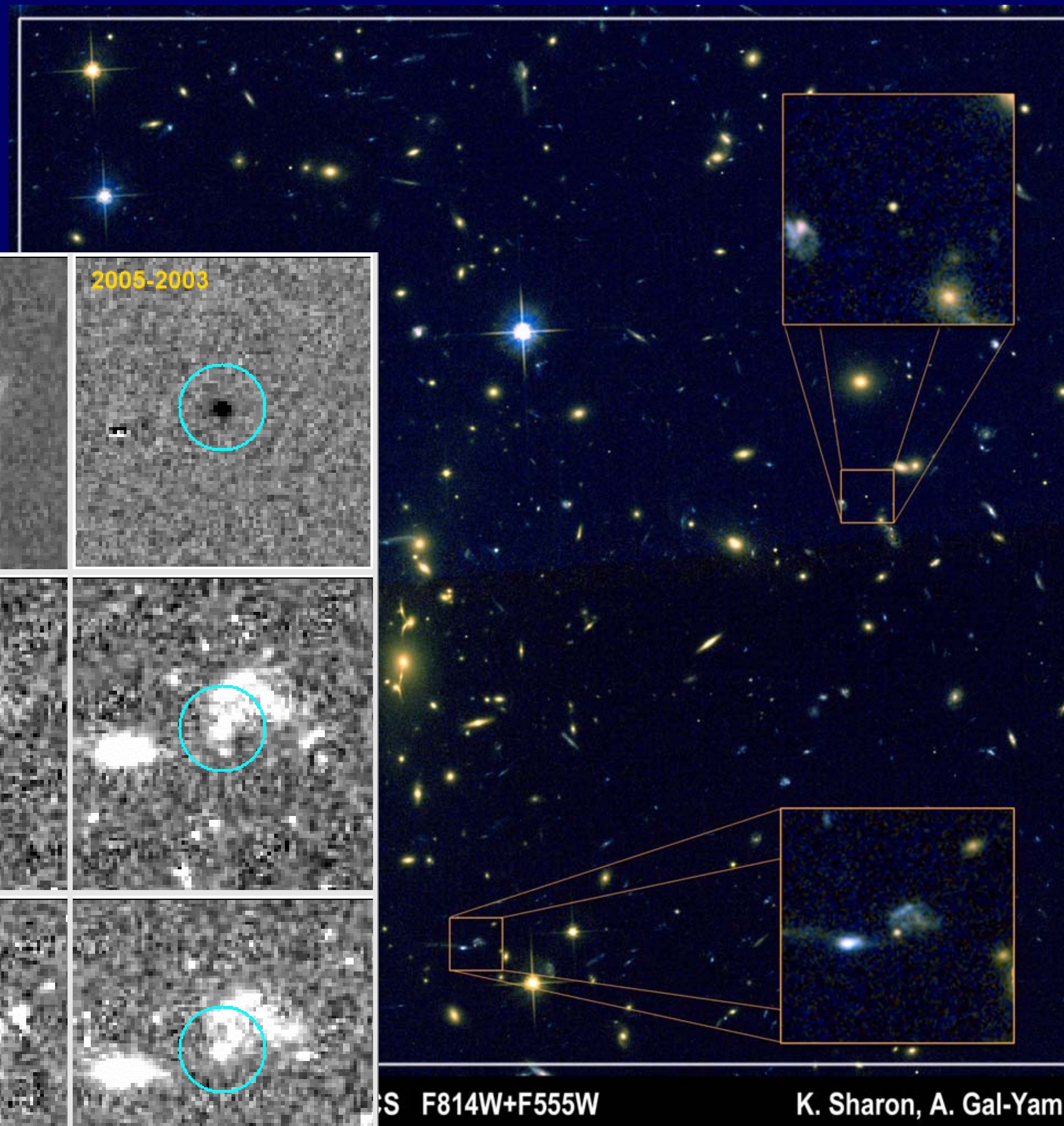
HST

PI: A. Gal-Yam

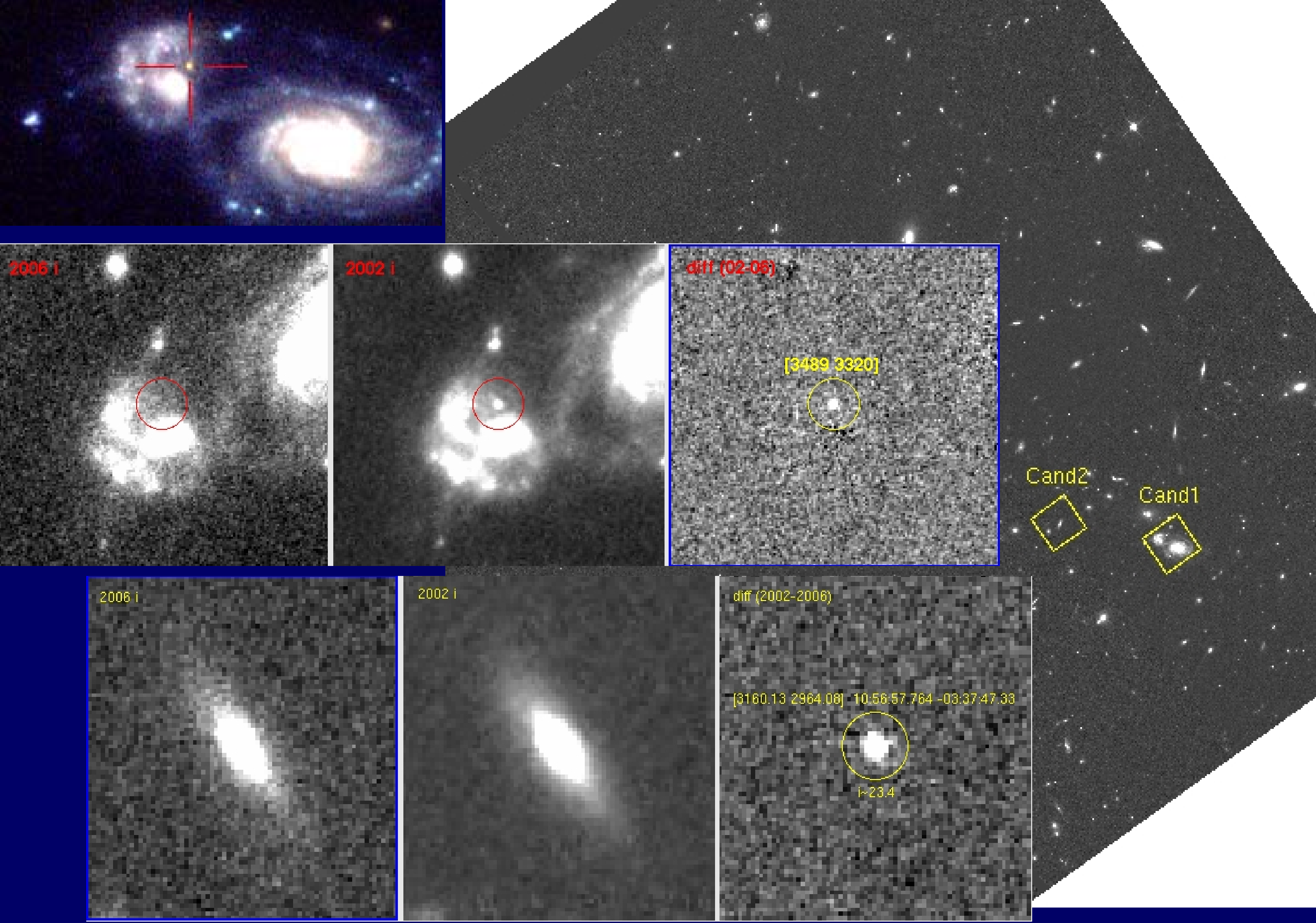
+ …, M. Donahue, H. Ebeling, R. Ellis, R. Foley, W. Freedman, J.-P. Kneib, R. Kirshner, T. Matheson, J. Mulchaey, M. Phillips, V. Sarajedini, M. Voit

Cycles 14, 15


2005
2003
2005-2003
sub-exposures

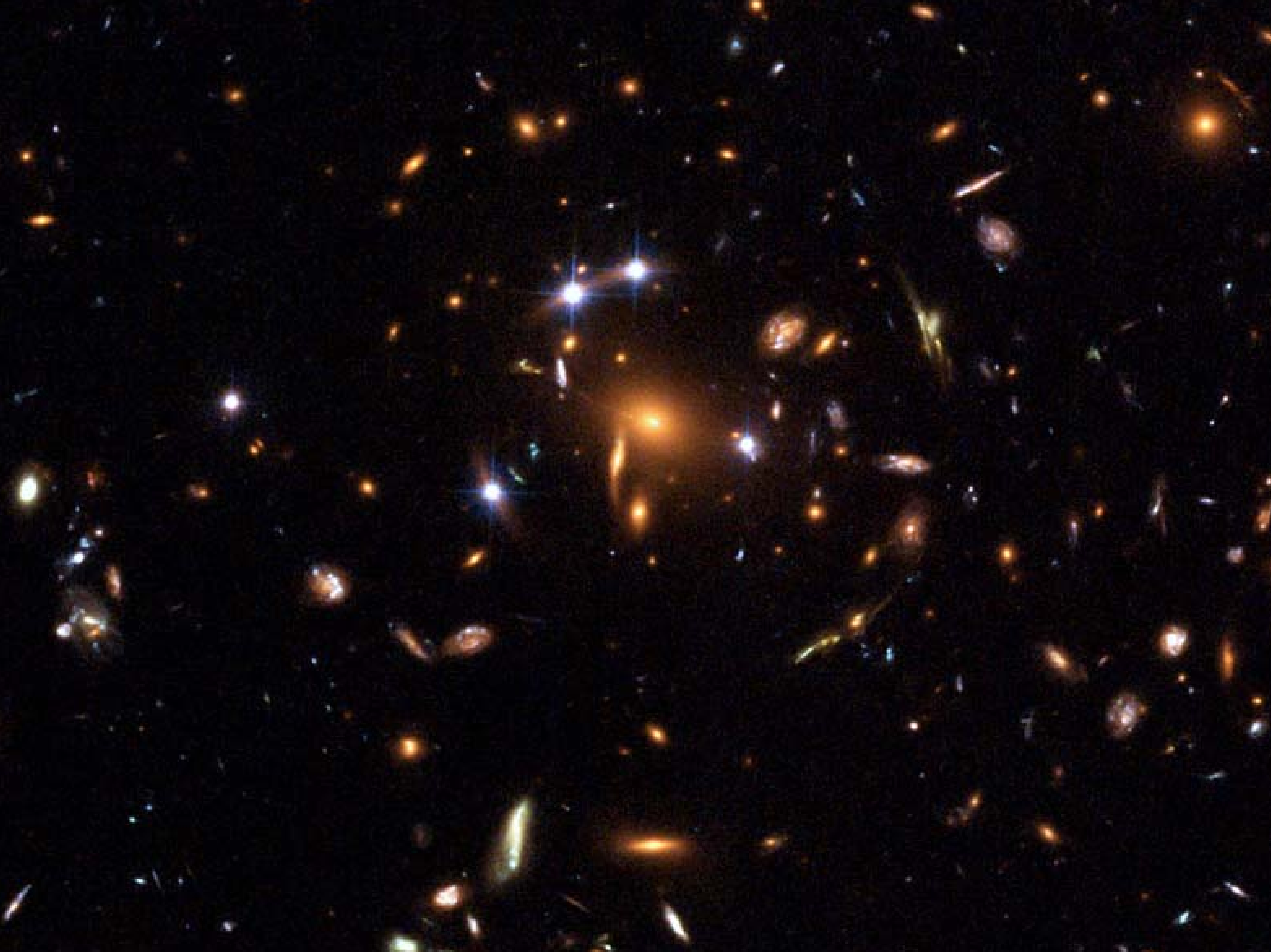

F814W+F555W
K. Sharon, A. Gal-Yam

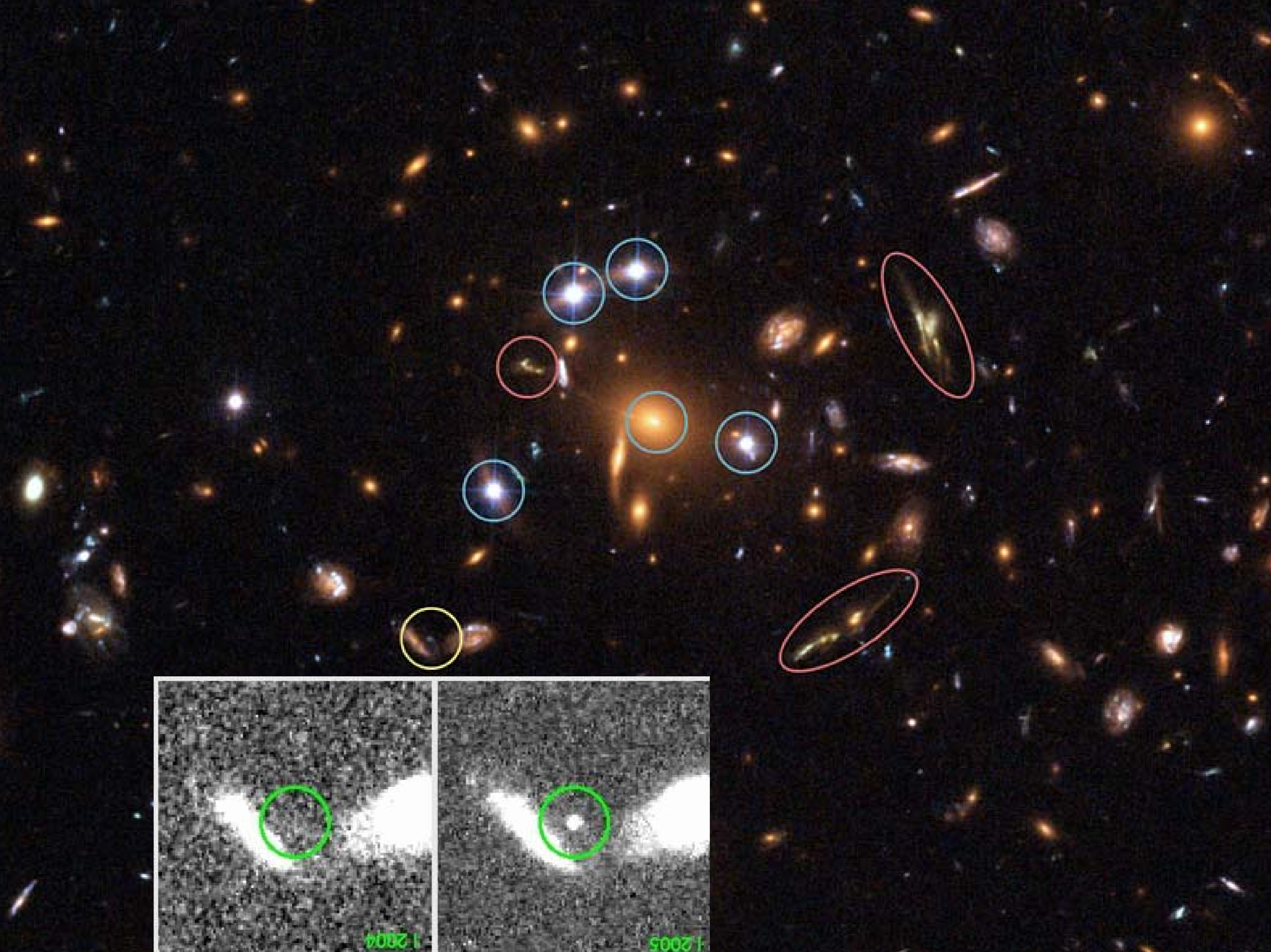
Z=0.57



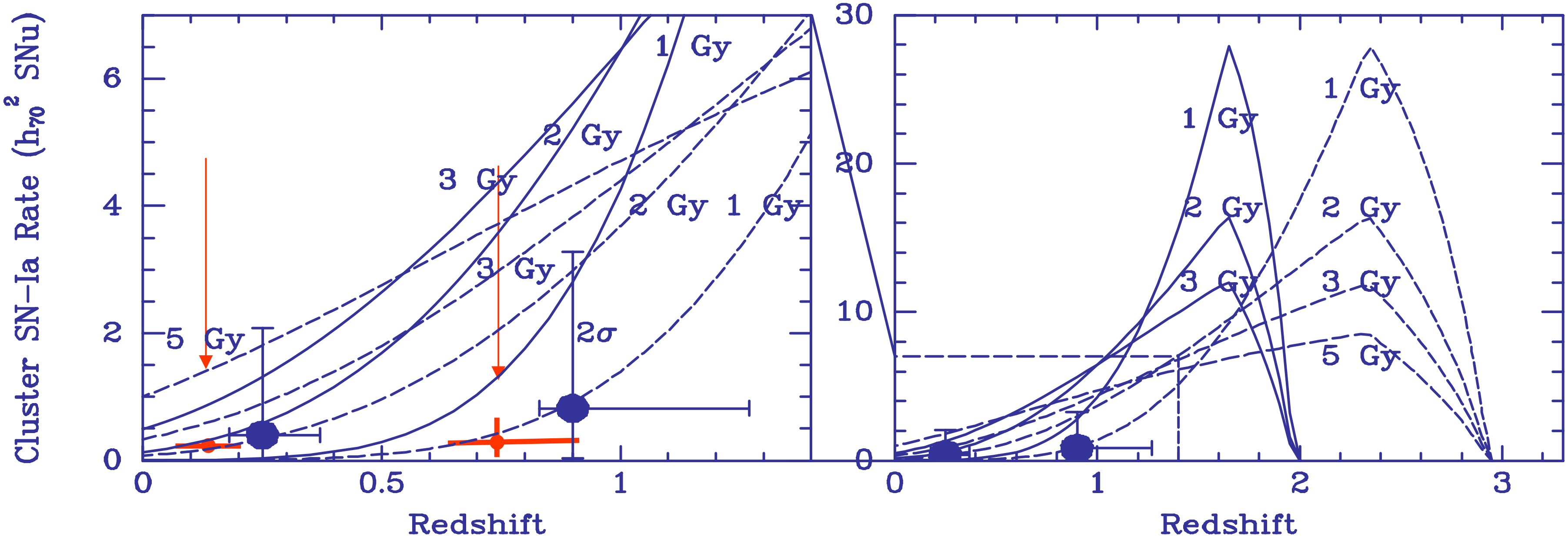
MS1054.4-0321 z=0.83

SDSS 1004+4112 z=0.68



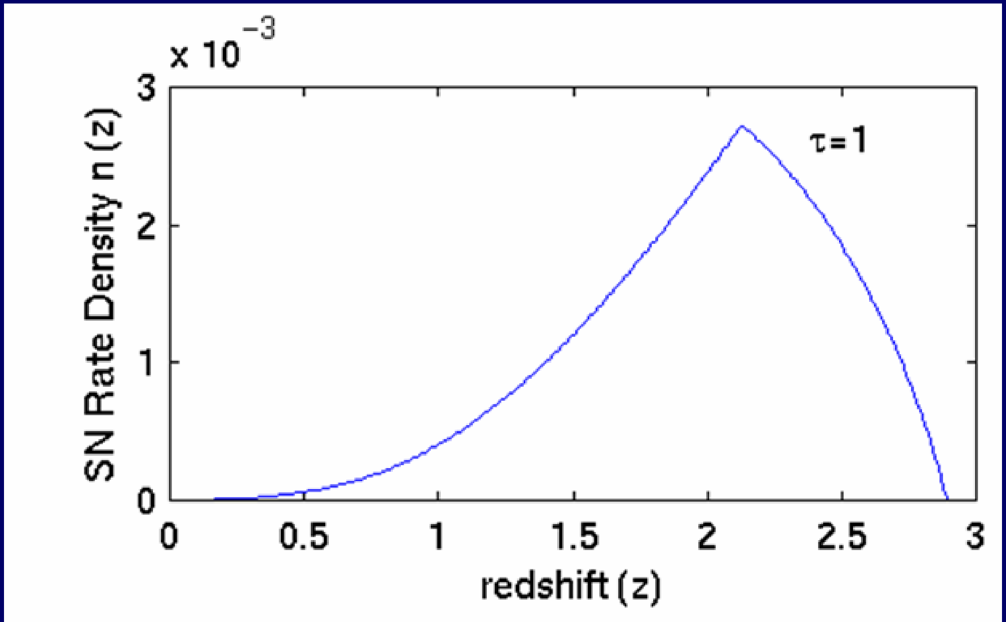


Low rates → Ia's can produce Fe only if **short** delay times.



FIELD   SN Rates

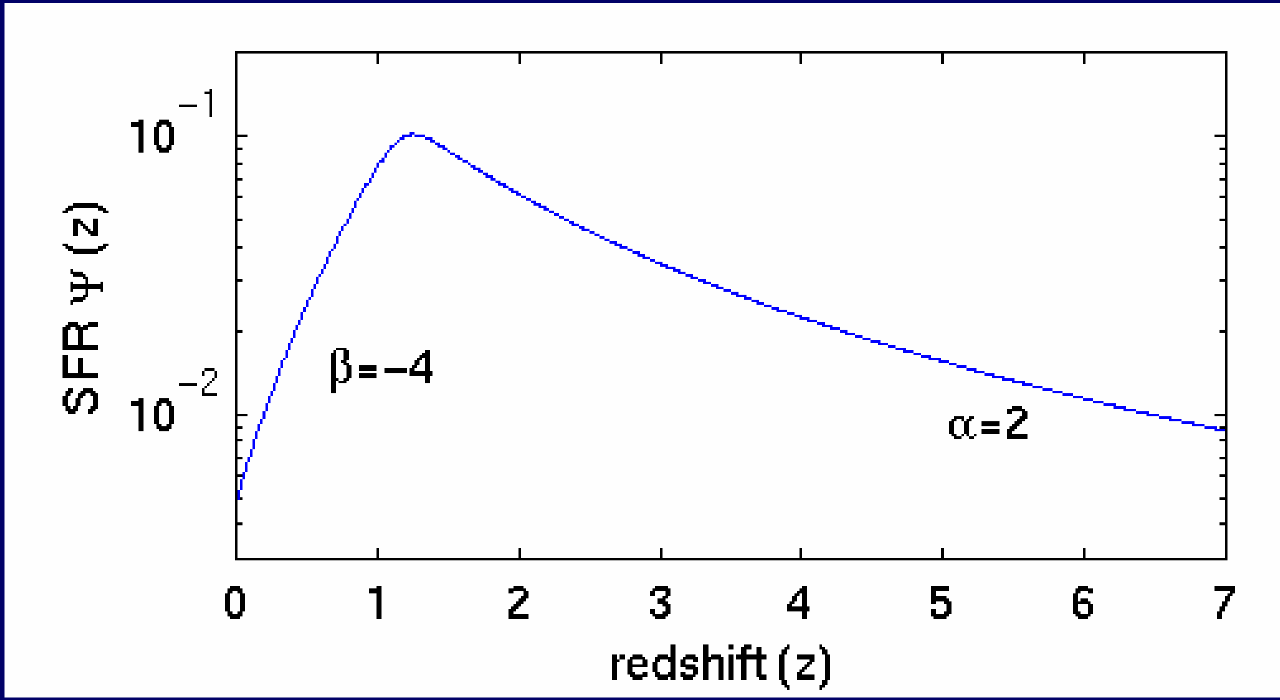
SN delay function



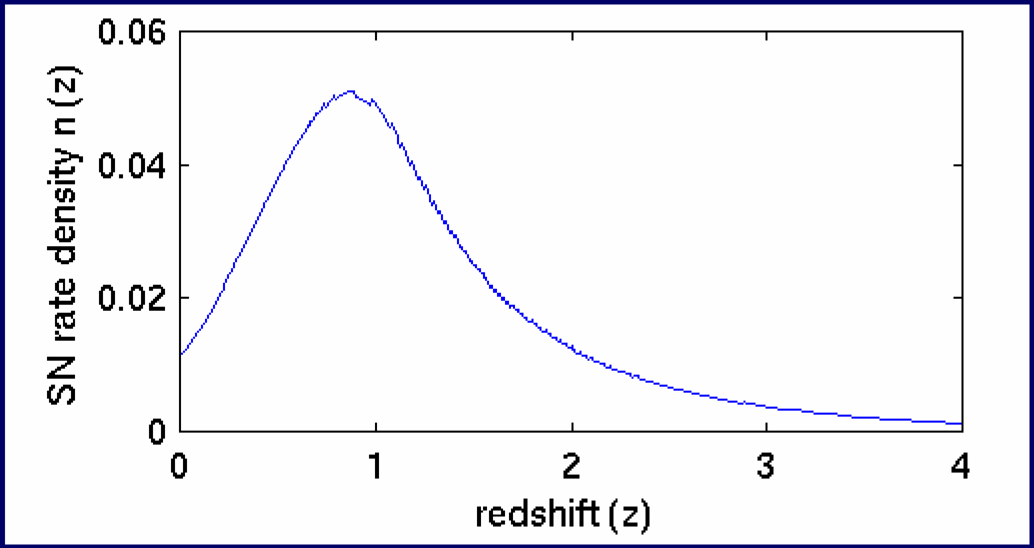
*

Star-formation history (z)

("Madau plot")



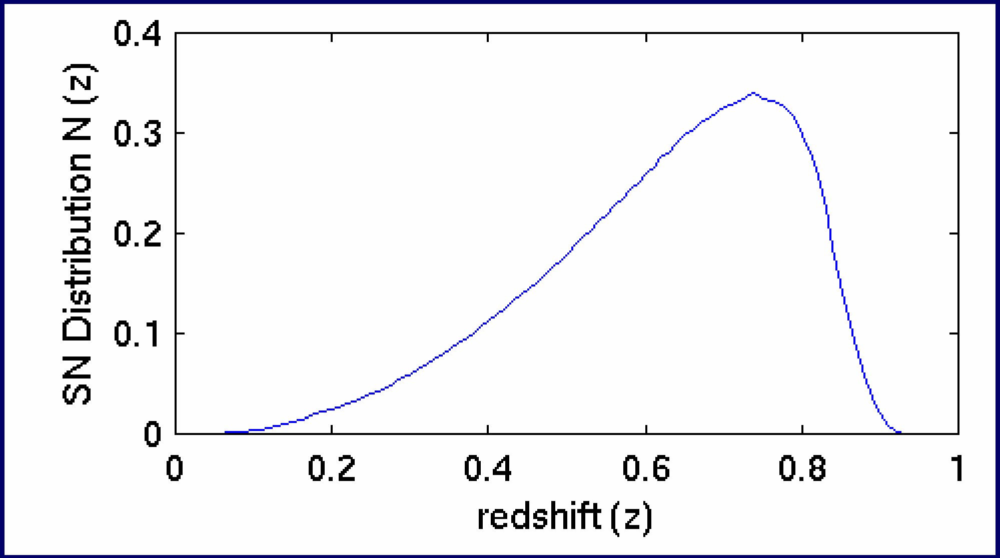
= SN rate (z)



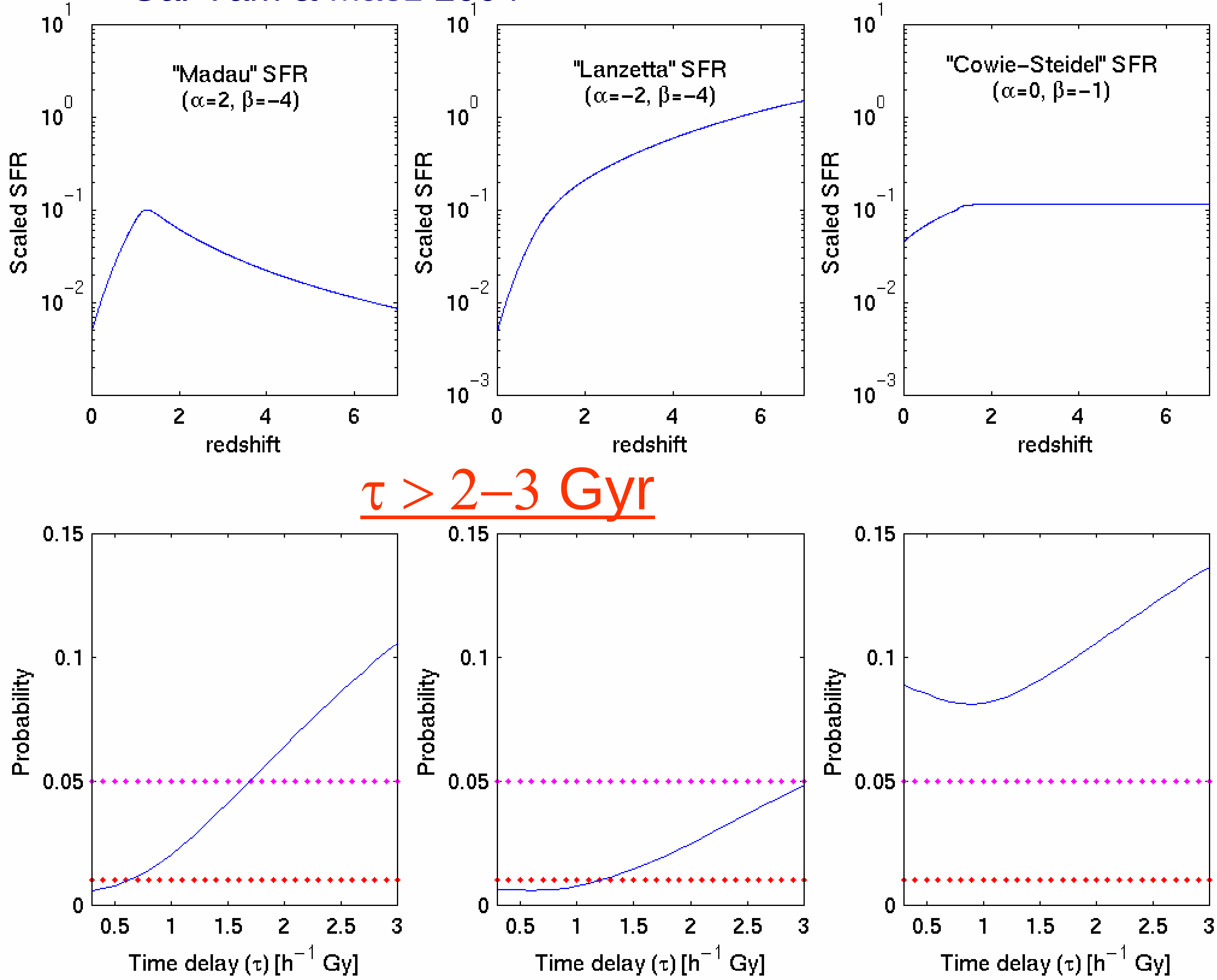
X $t(m_{lim}, z)$

visibility time

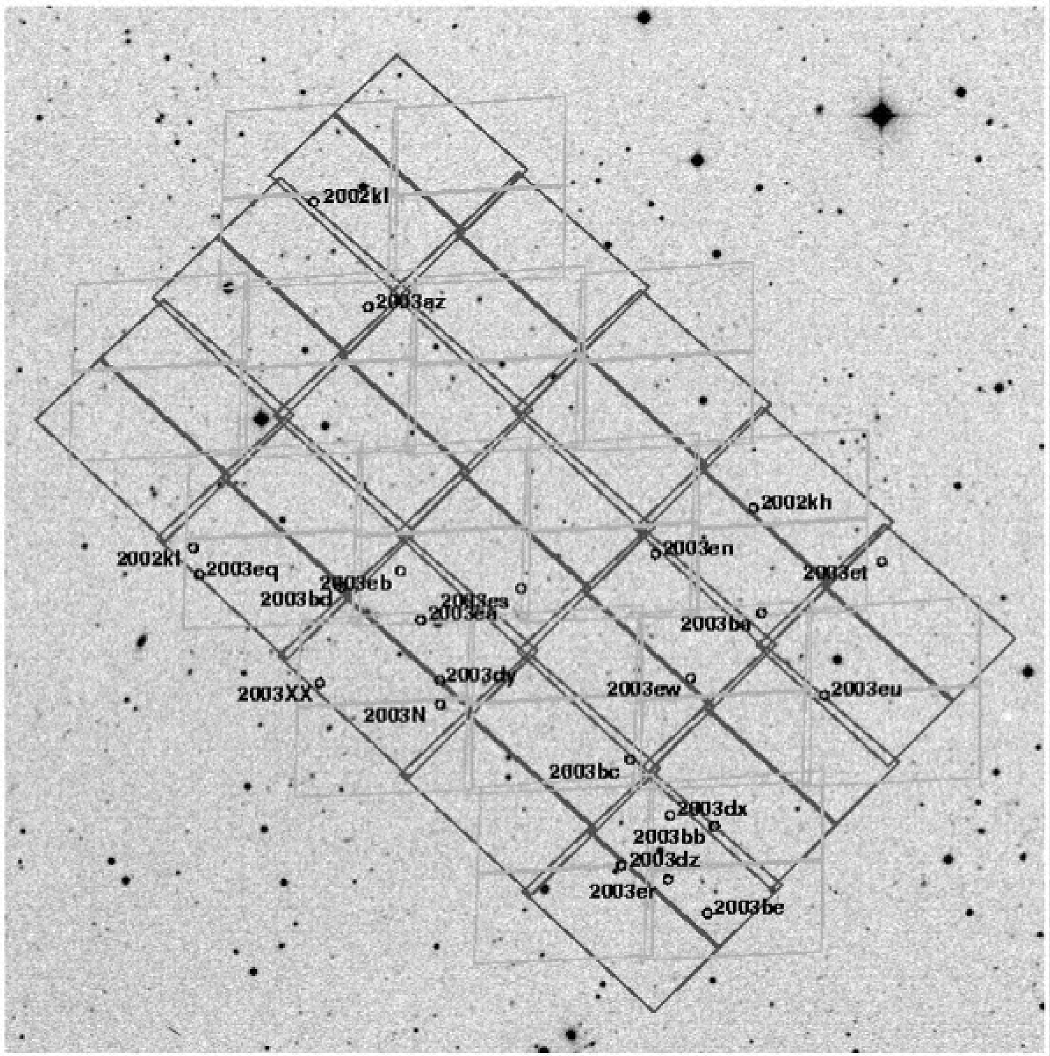
= SN number distribution (z)

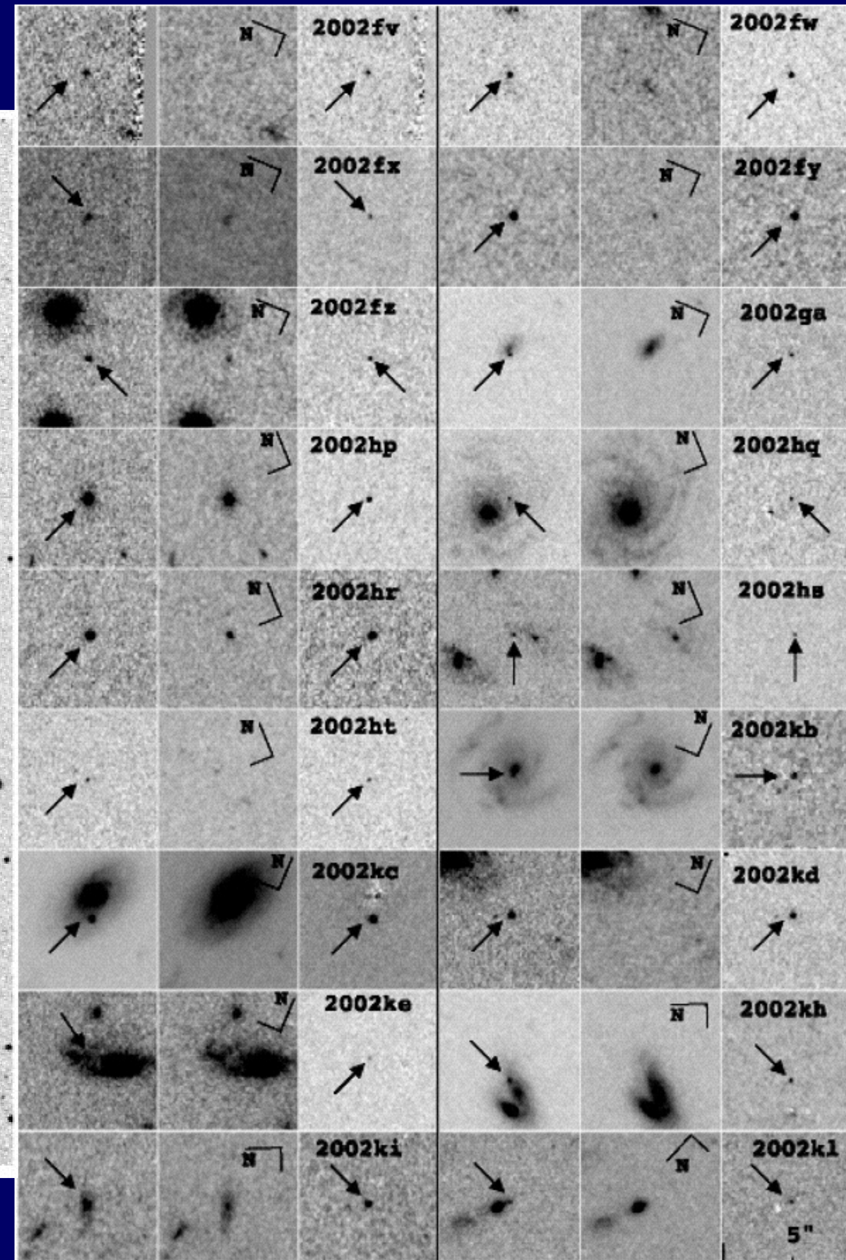


Gal-Yam & Maoz 2004

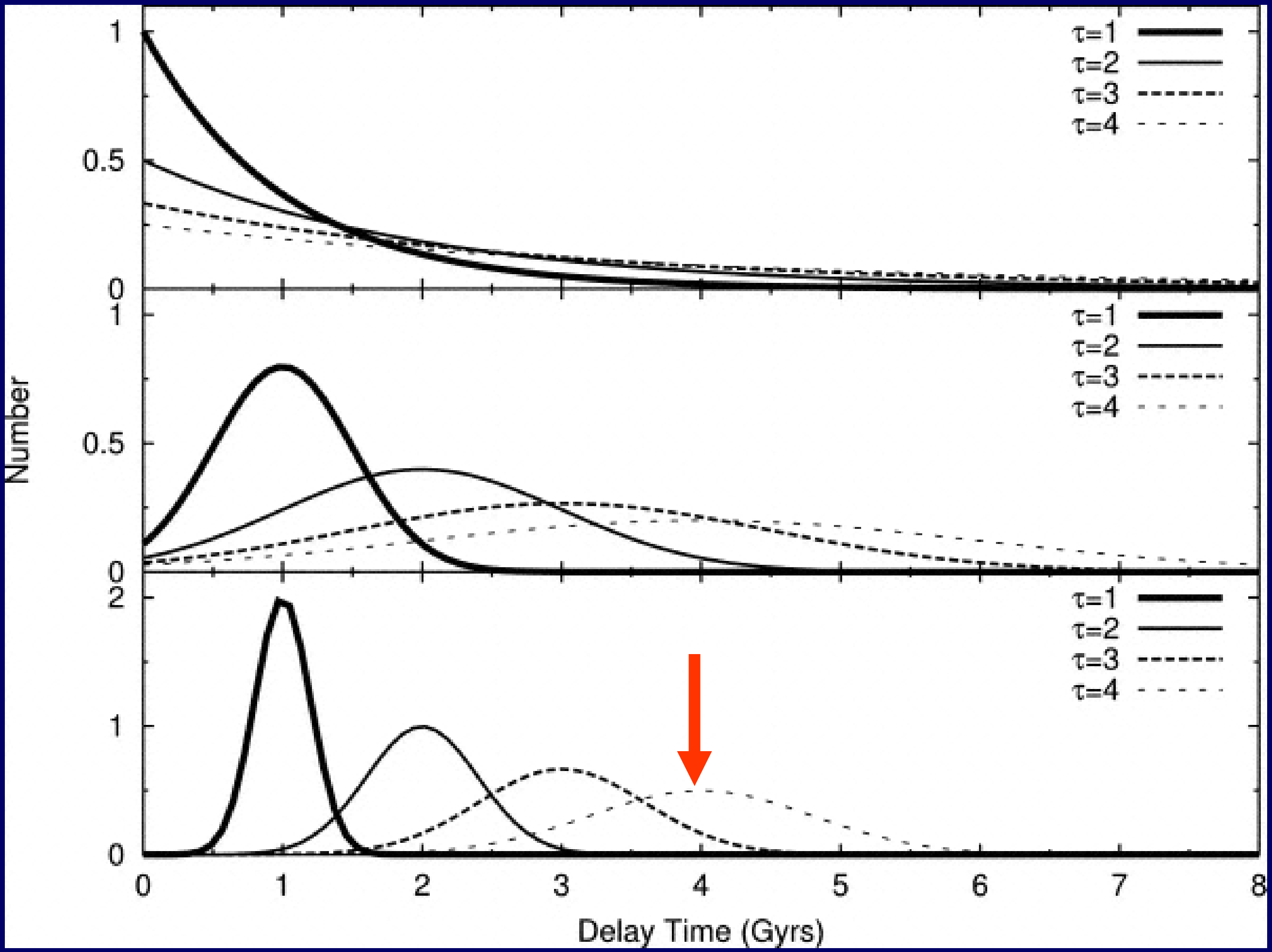


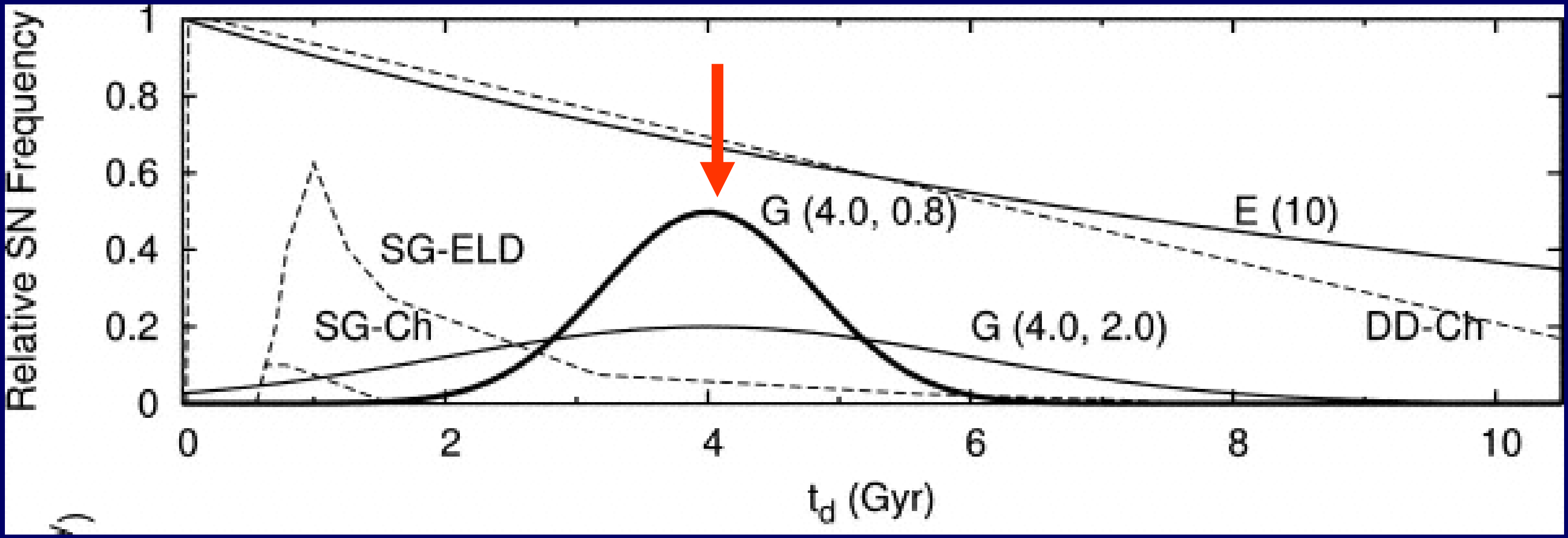
Strolger et al. 2004, HST-GOODS, 25 SNe-Ia



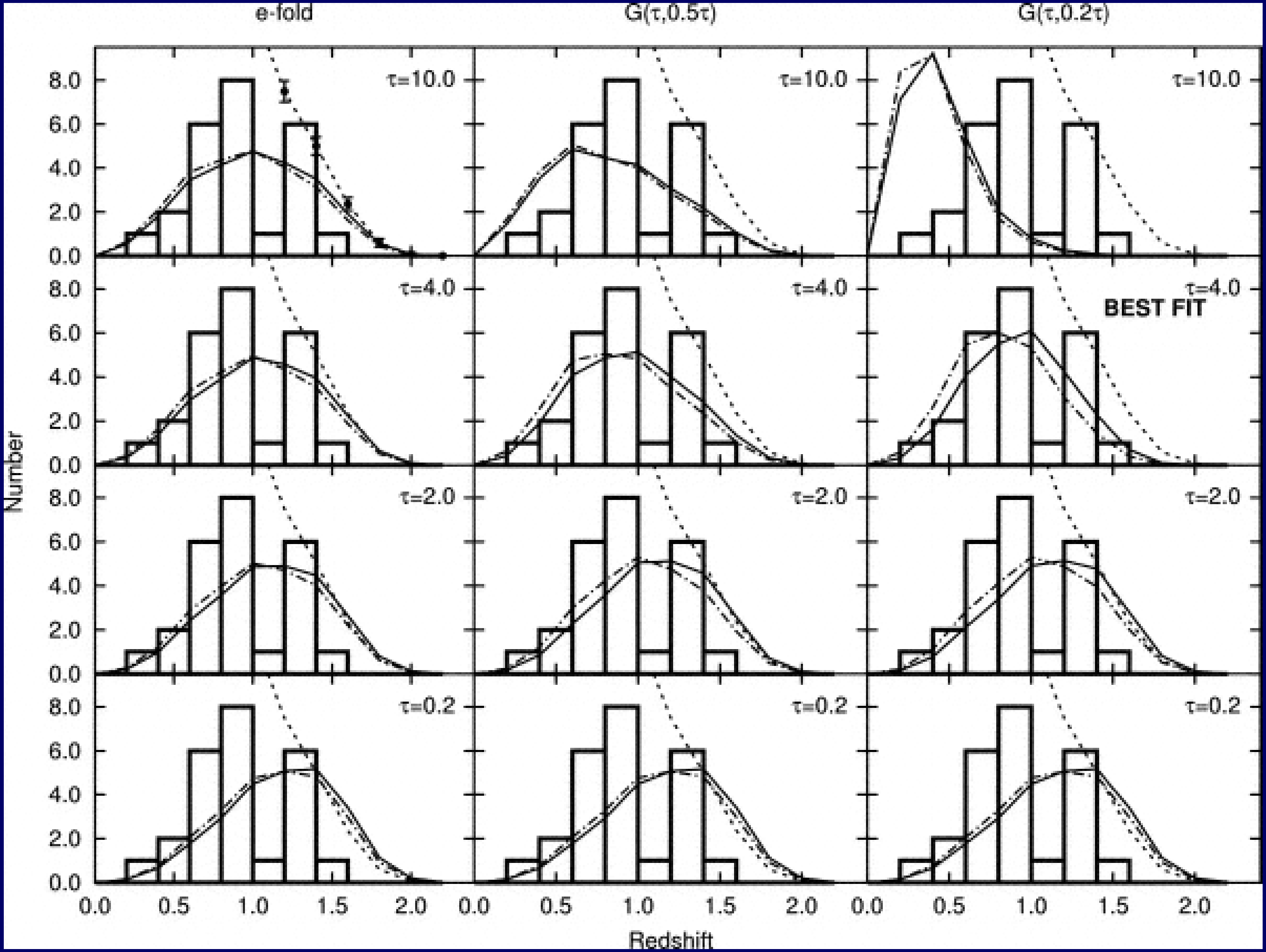


Strolger et al. 2004, HST-GOODS, 25 SNe-Ia





From Strolger et al. 2004, based on Yungelson & Livio 2000


e-fold
G(τ,0.5τ)
G(τ,0.2τ)
τ=10.0
τ=4.0
τ=2.0
τ=0.2
BEST FIT
Number
Redshift
0.0
2.0
4.0
6.0
8.0
0.5
1.0
1.5

Clusters: $\tau < 2$ Gyr, or Fe not from SNe Ia

Field:

Gal-Yam & Maoz (2004): $\tau > 2 - 3$ Gyr (for some SFHs)

GOODS:

Strolger et al. (2004) +

Dahlen et al. (2004): $\tau = 4$ Gyr

Barris & Tonry (2006): $\tau = 1$ Gyr

Foerster et al. (2006): can't tell -- depends on SFH!

Mannucci et al. (2004, 2005) + Scannapieco & Bildsten (2005)
+ Neill et al. + Sullivan et al. (2006): 2 populations with 2 τ's

Need better/larger samples.

but

HST/GOODS very expensive.

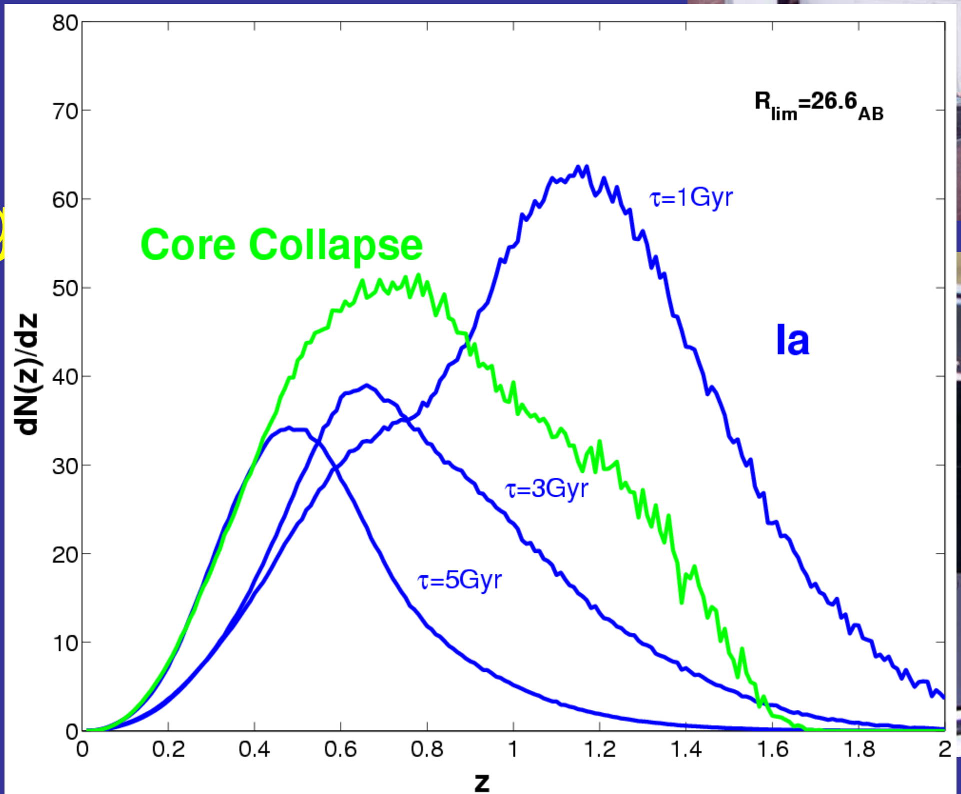
Also: at large z and/or huge SN samples (PanSTARRS, LSST) spectroscopy becomes difficult/impossible.

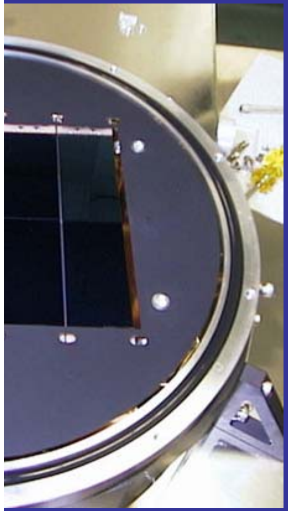
What can we do?

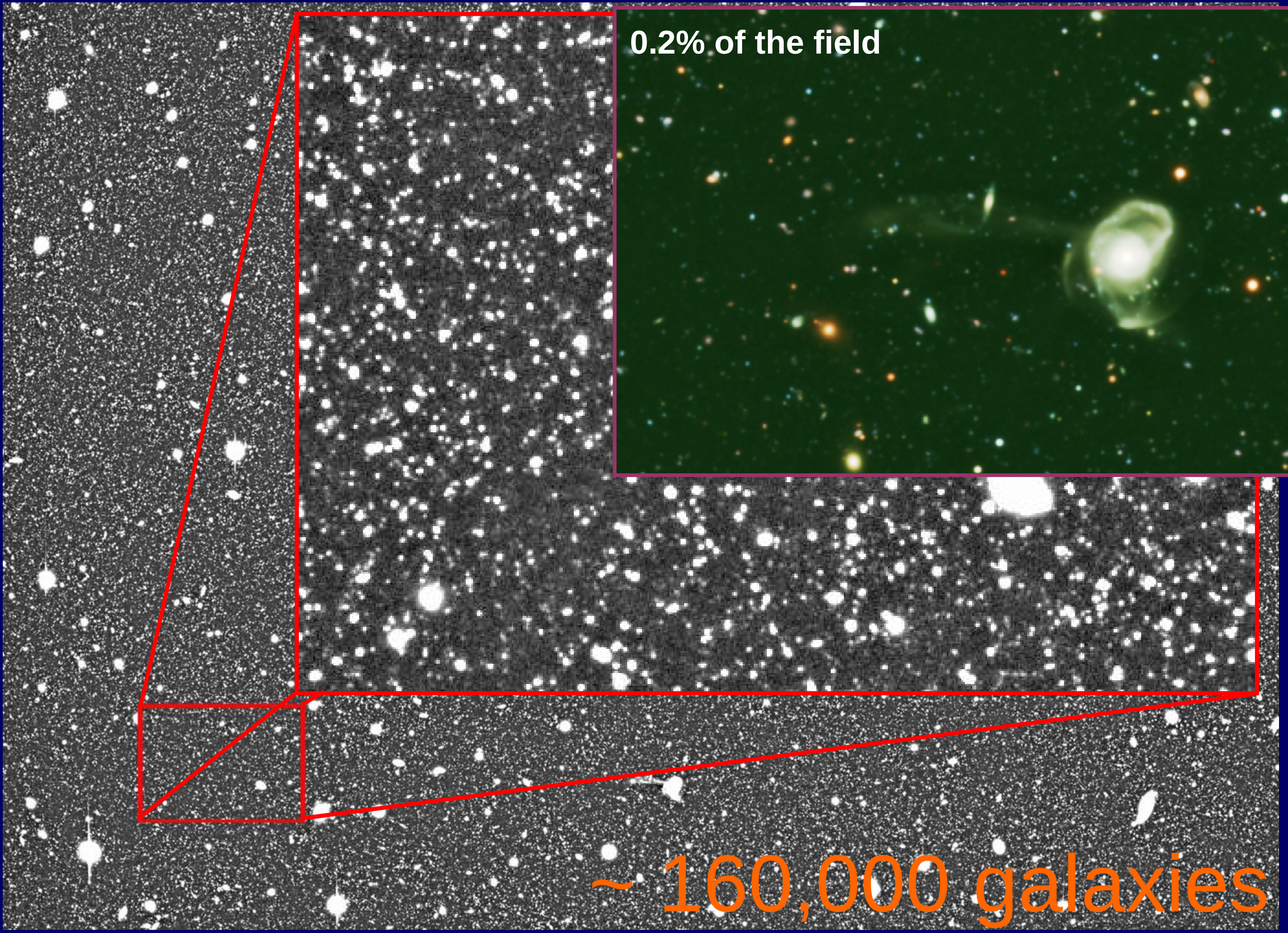
A deep SN survey in the Subaru Deep Field

D. Poznanski +
N. Yasuda, M. Fukugita, M. Doi, T. Totani, T. Morokuma & N. Arimoto, B. Jannuzi,

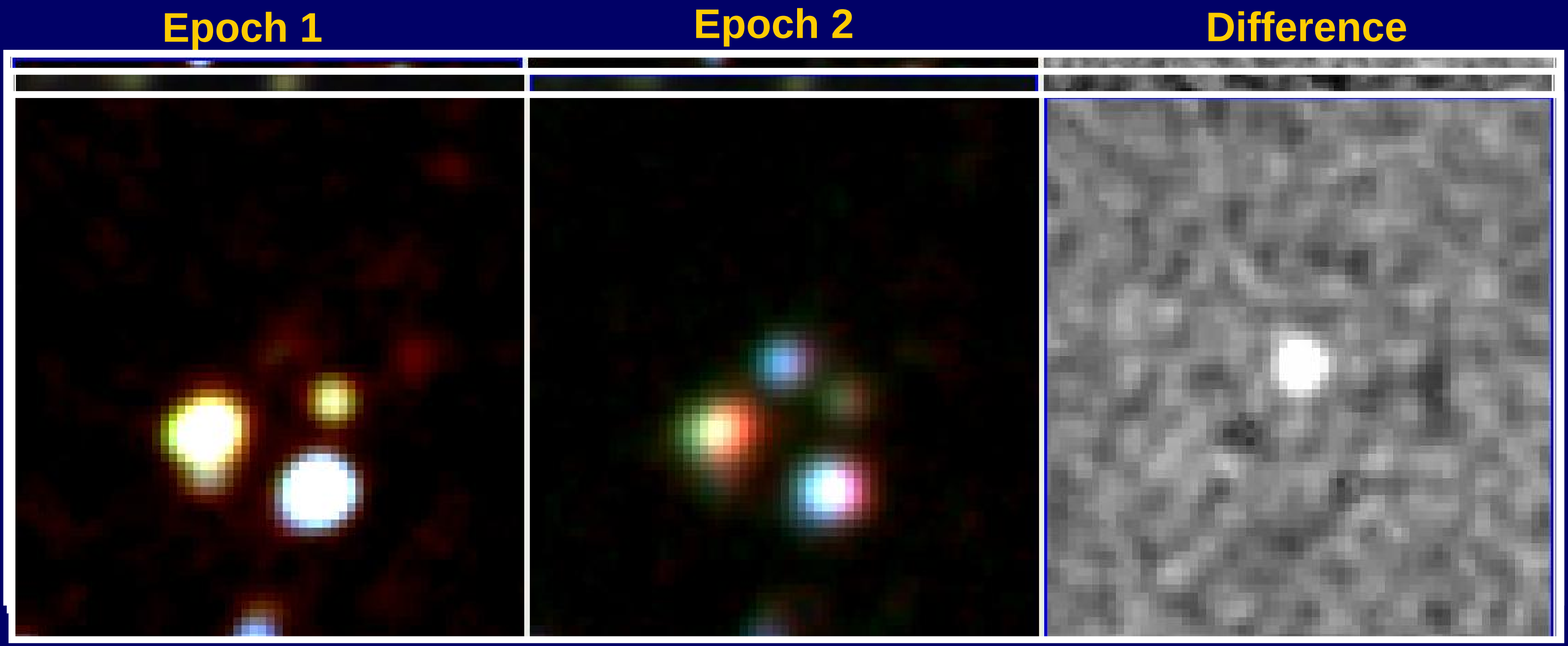
- 2 nights on the 8.2m Subaru, with Suprime-Cam, 0.25 deg^2 field
- Re-imaged the
  in r, i ~ 27 mag
- ~50 SNe
  up to $z \sim 1.5$

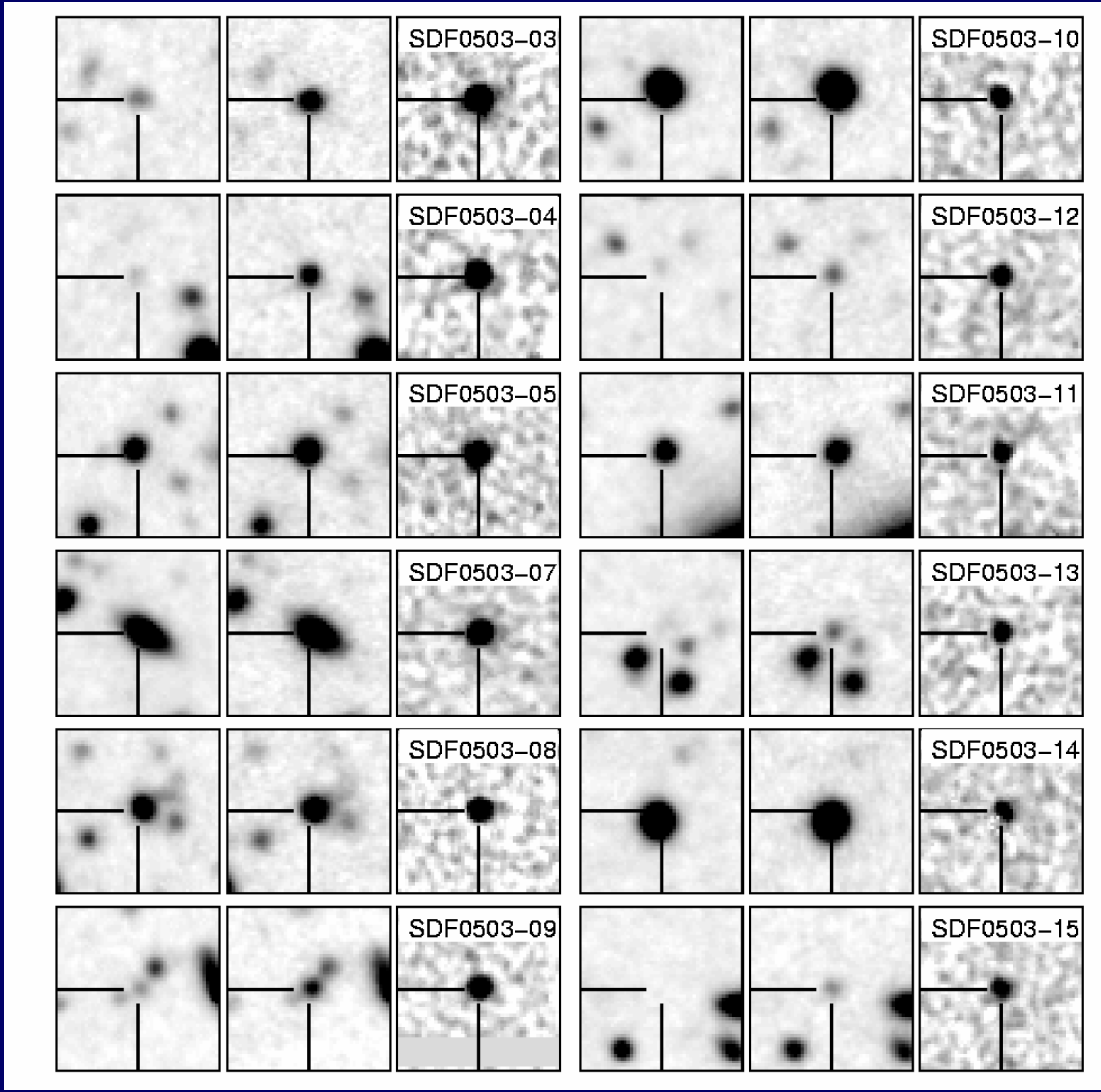




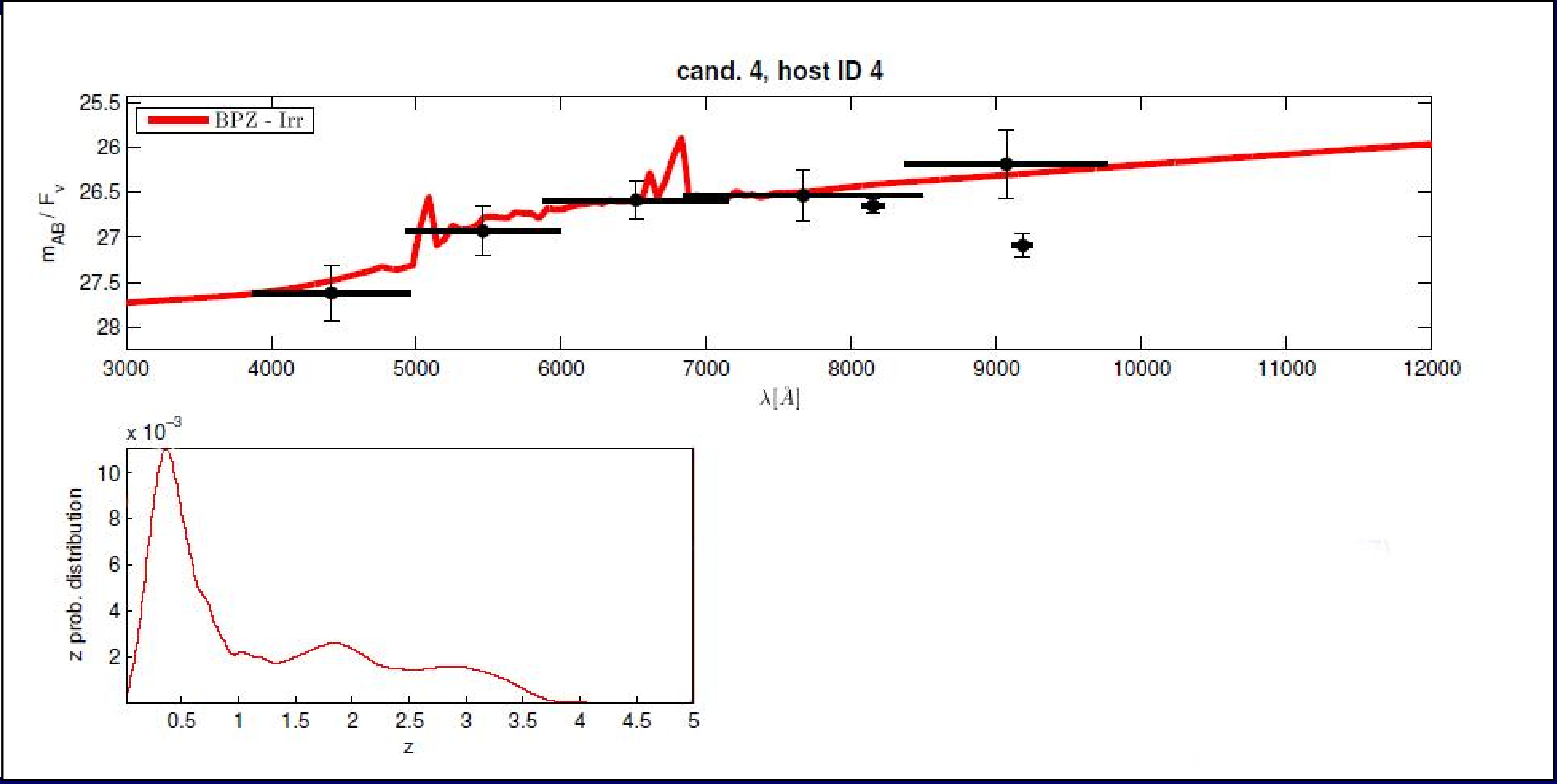

0.2% of the field
~ 160,000 galaxies

SN candidates



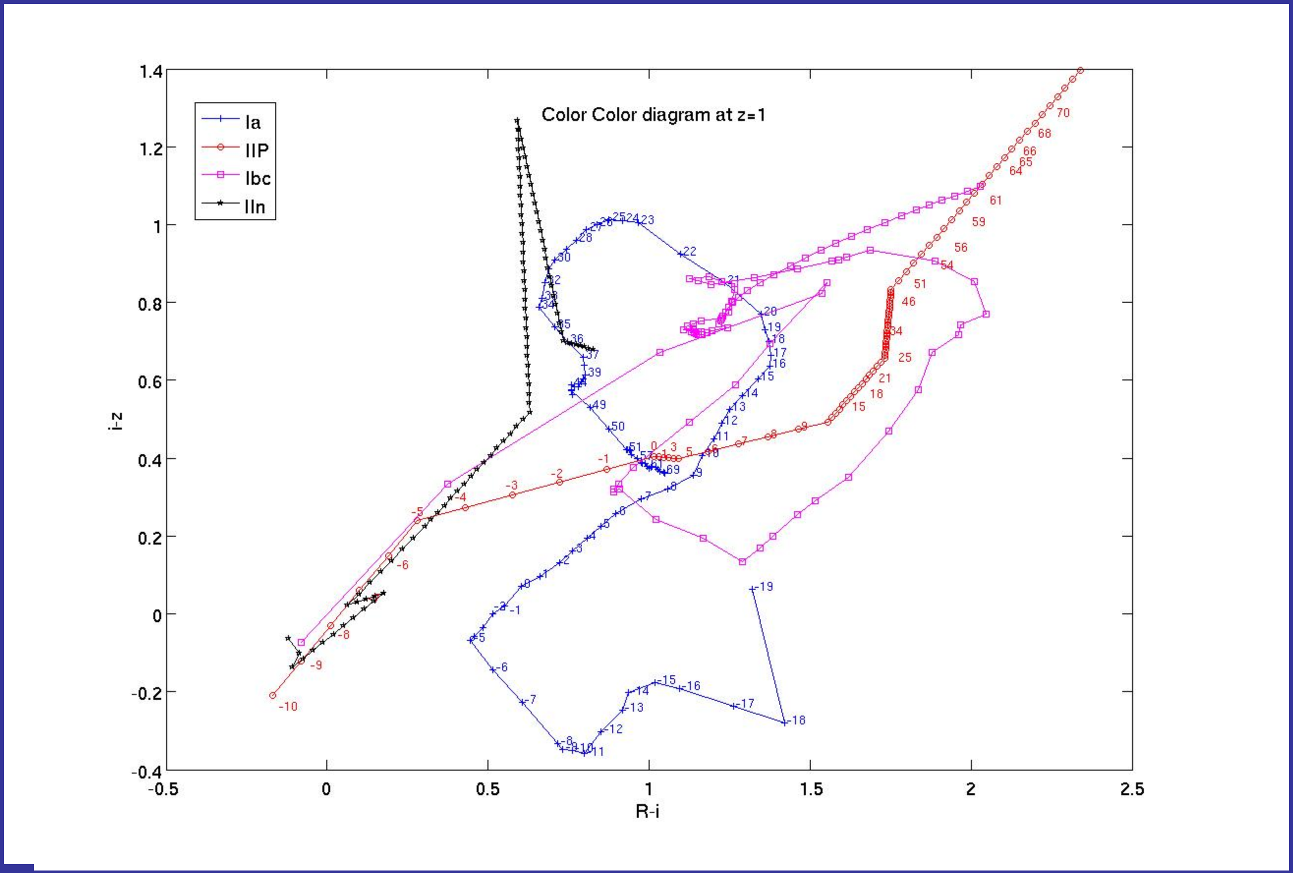

SDF0503-03
SDF0503-10
SDF0503-04
SDF0503-12
SDF0503-05
SDF0503-11
SDF0503-07
SDF0503-13
SDF0503-08
SDF0503-14
SDF0503-09
SDF0503-15

- **Host photometric redshift**



- Color-magnitude based classification:
  - Poznanski et al. 2002, Gal-Yam et al. (2005)

i - z

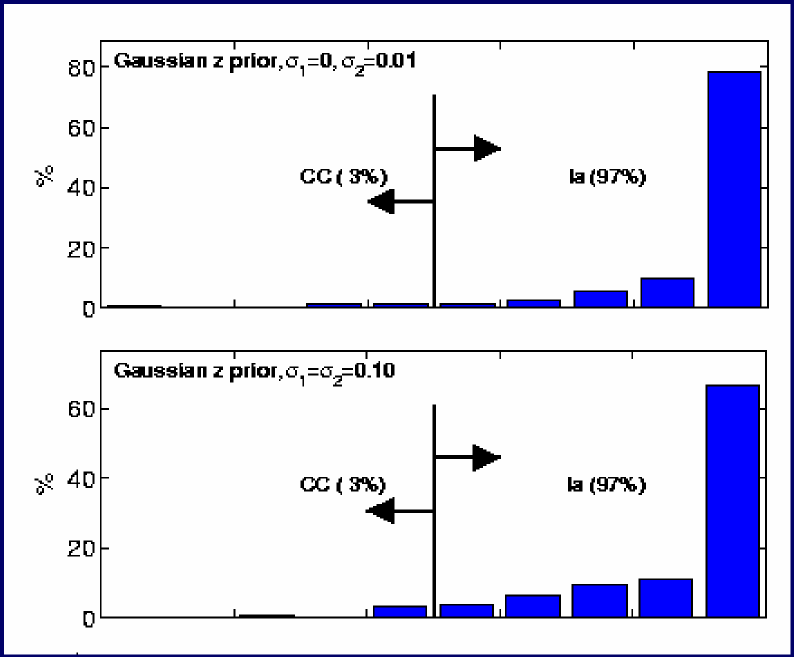


R - i

Poznanski et al. (2007)

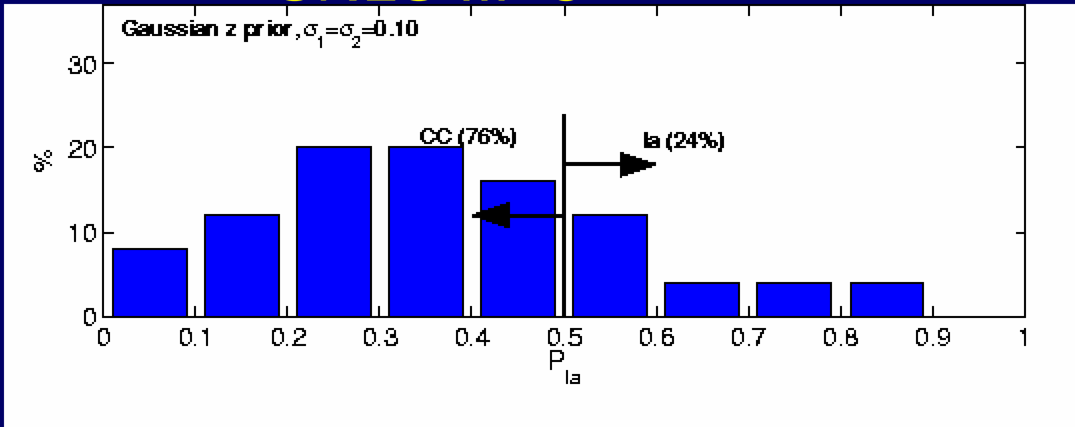
Photometric-only classification of SNLS SNe:

SNLS Ia's

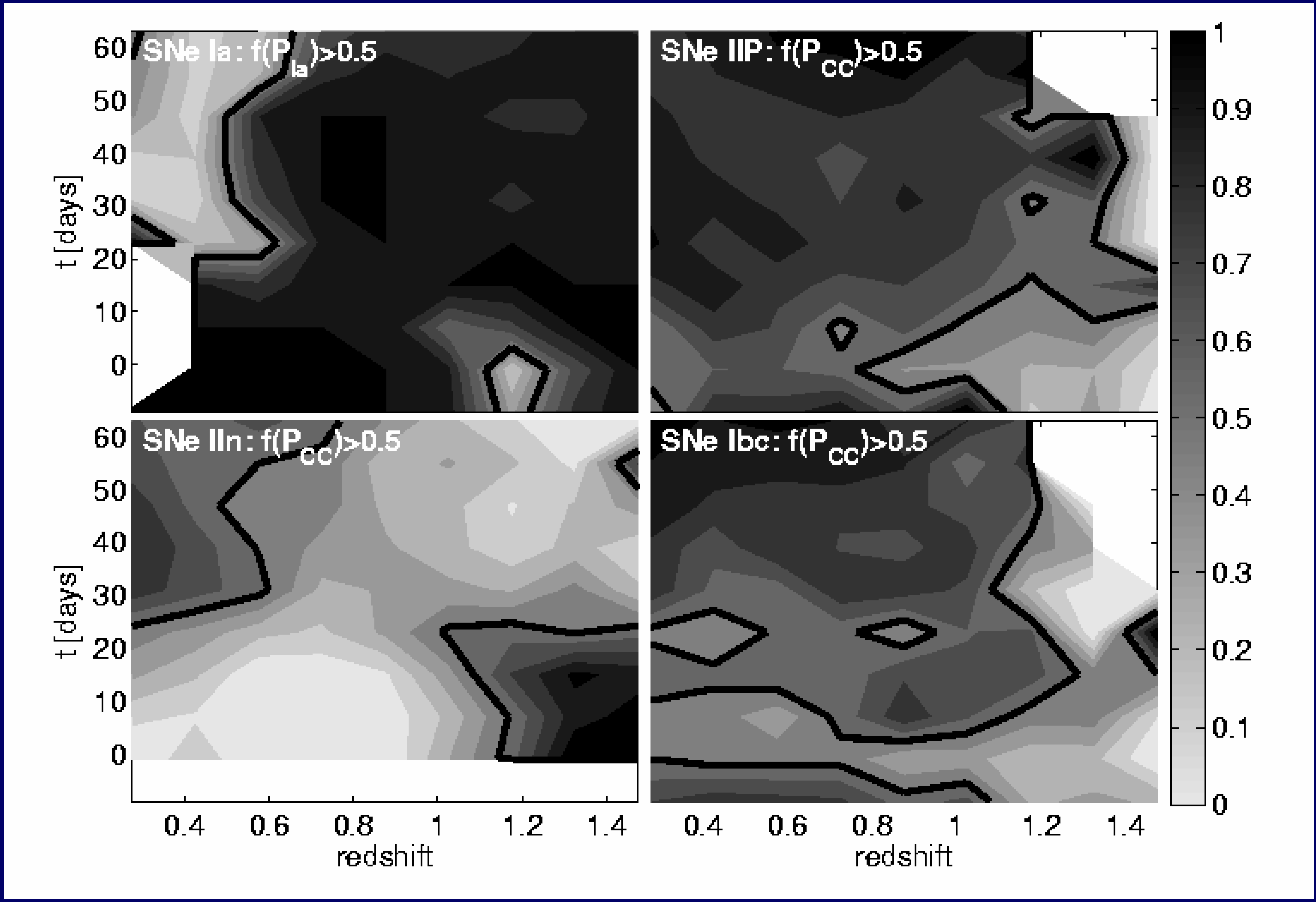


Prob. (Ia)

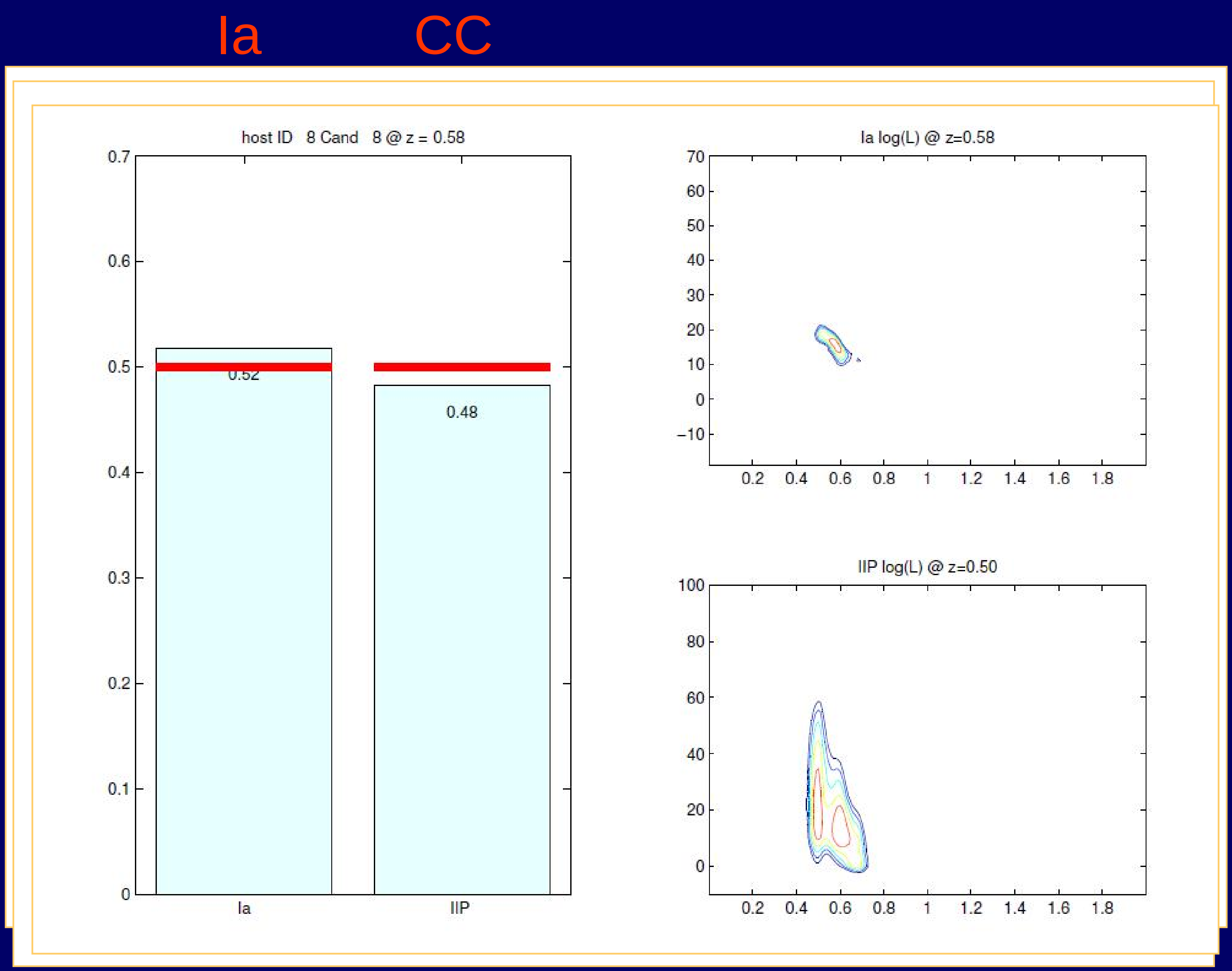
SNLS IIP's



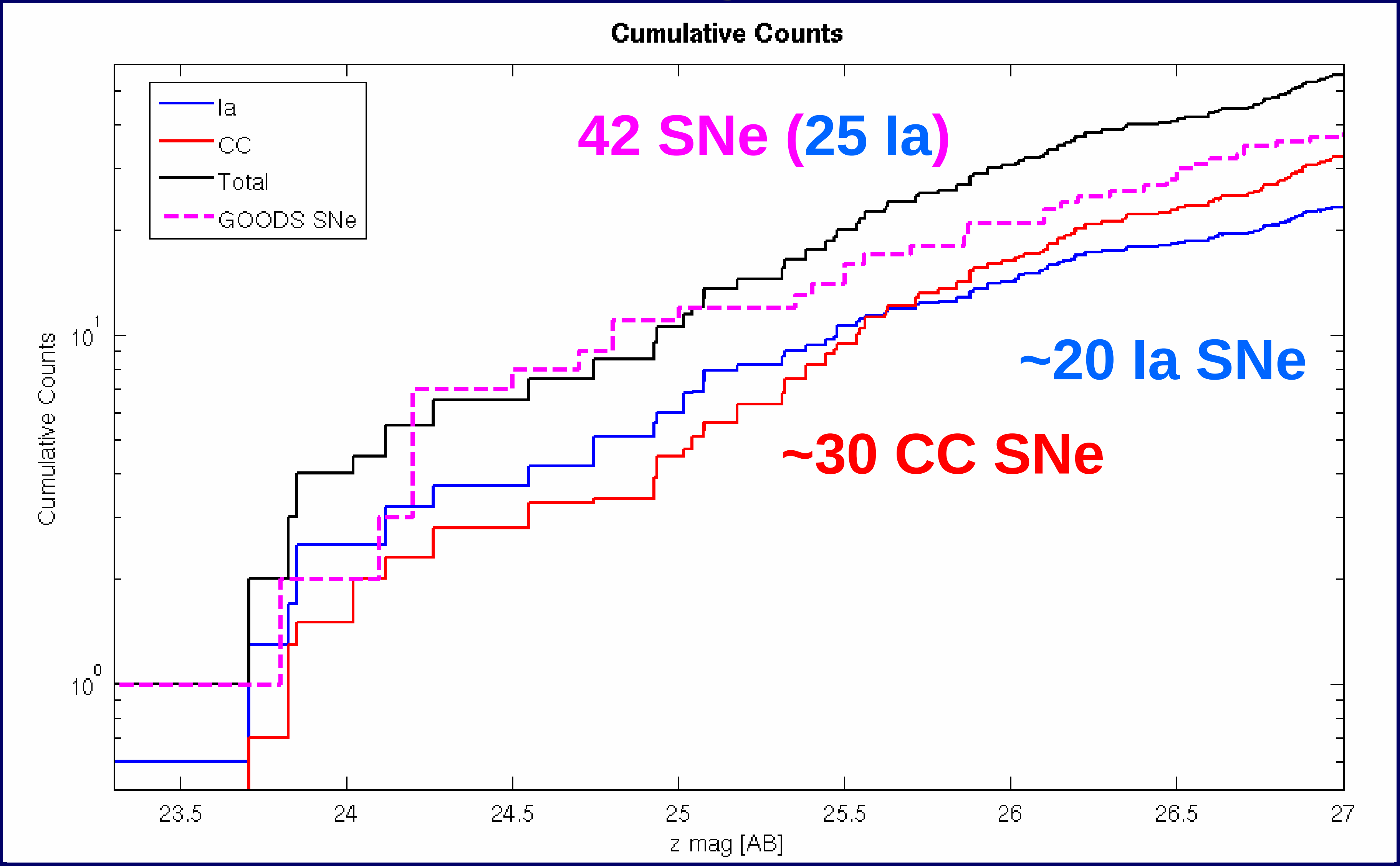
Prob. (Ia)

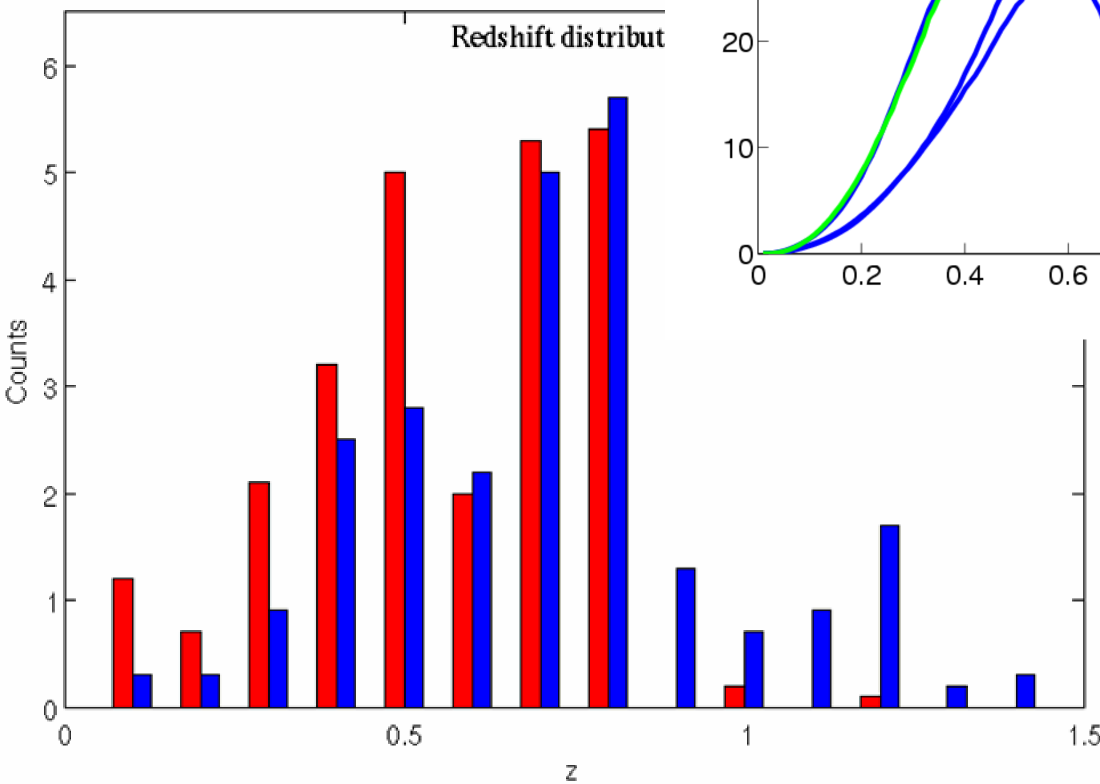

SNe Ia: f(P_Ia)>0.5
SNe IIP: f(P_CC)>0.5
SNe IIn: f(P_CC)>0.5
SNe Ibc: f(P_CC)>0.5
t [days]
redshift
60
50
40
30
20
10
0
0.4
0.6
0.8
1
1.2
1.4
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

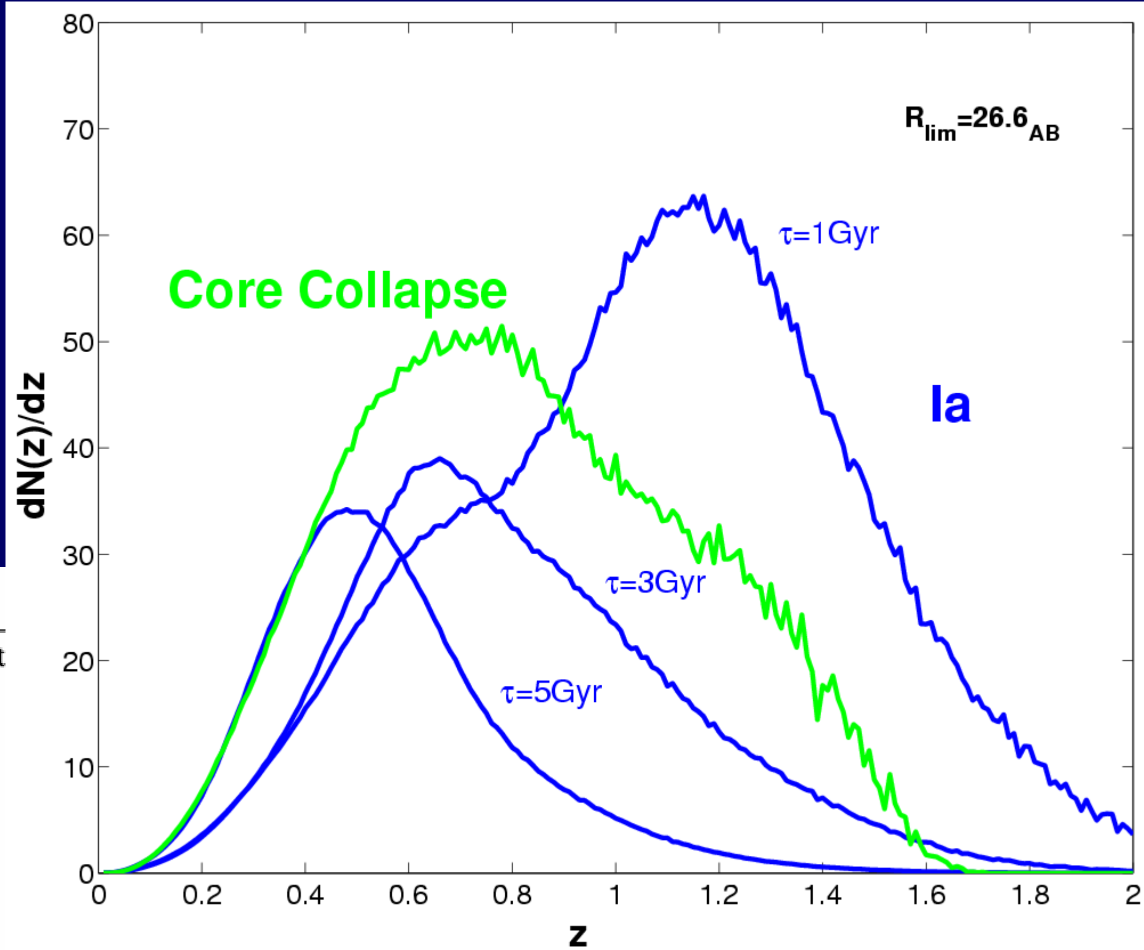
- **“Statistical” classification**



Preliminary Results




Redshift distribut
Counts
z


R_{lim}=26.6$_{AB}$
Core Collapse
Ia
τ=1Gyr
τ=3Gyr
τ=5Gyr
dN(z)/dz
z

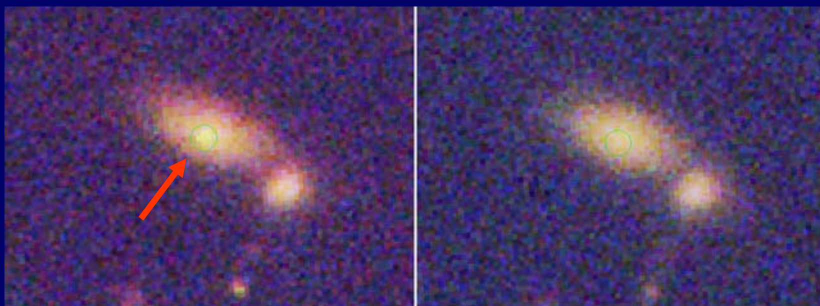
Every additional epoch will add ~40 SNe:

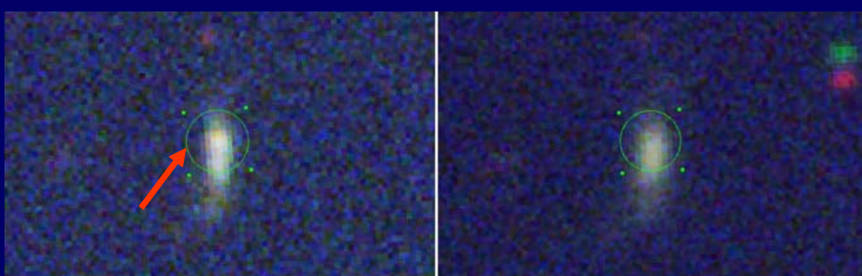
Low-cost large samples!

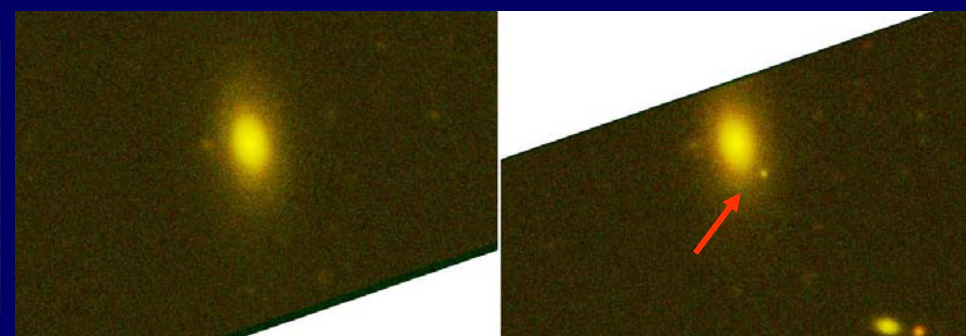
Another successful run in Feb 2007,

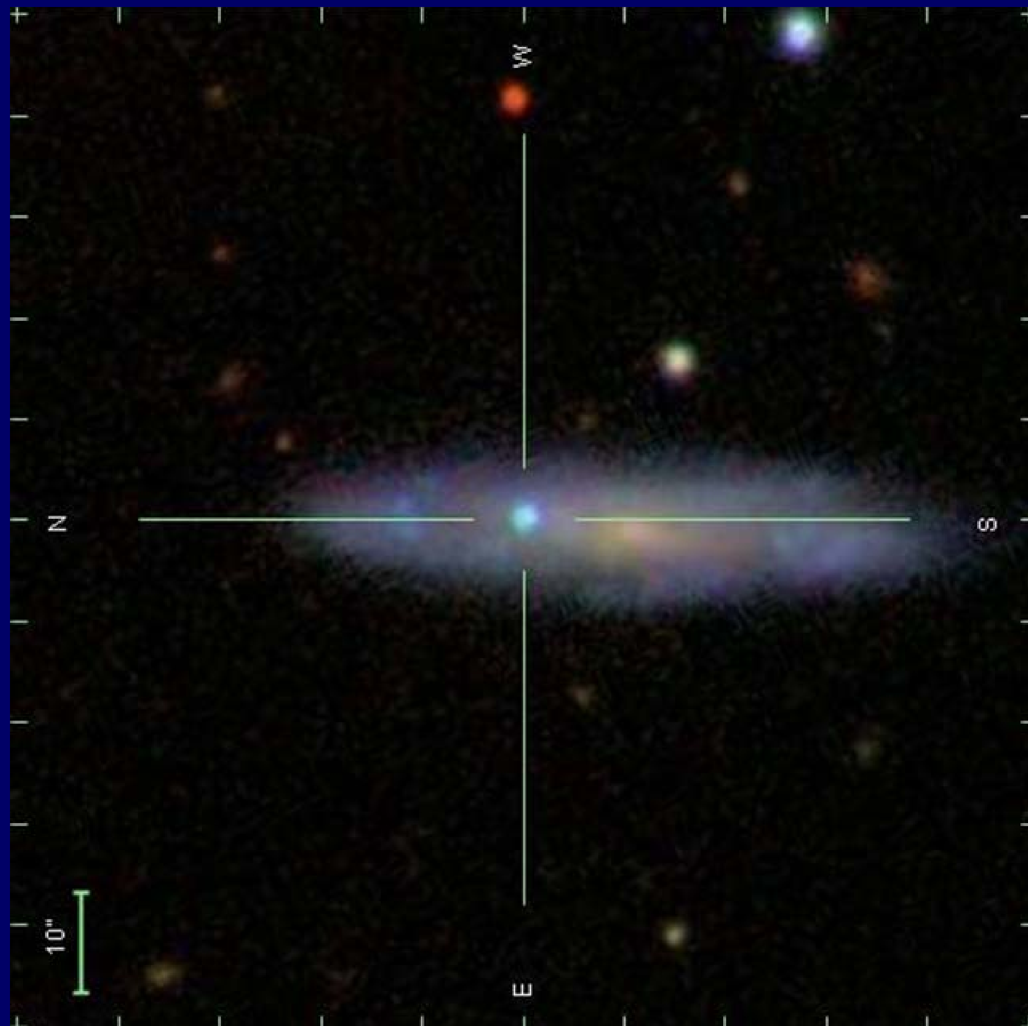
More scheduled for May 2007.

Supernovae in SDSS I ~1000 can be found!








W
N
S
E
10"

Conclusions:

1. Cluster SN-Ia progenitors have small delay,

or

SNe-Ia associated with present-day stellar population had minor role in ICM enrichment; early top-heavy IMF massive stars produced most metals in clusters.

2. Better cluster rates at low and high z can test this, and will give actual fraction of SN-Ia contribution.

3. SN-Ia rate in cluster Es higher than in field Es ?

3. Wide and deep field SN surveys are good way of getting star-forming histories AND delay functions/progenitor constraints.

What fraction of all stars with m_{init}=3-8 M_{sun} go SN-Ia?

5 - 7% -- Dahlen et al. (2004), comp. of SNR-Ia(z) to SFR(z).

8 - 10% -- Barris & Tonry (2006), “ “

15 - 40% -- de Plaa et al. (2007), cluster ICM relative abundances, compared to theoretical yields.

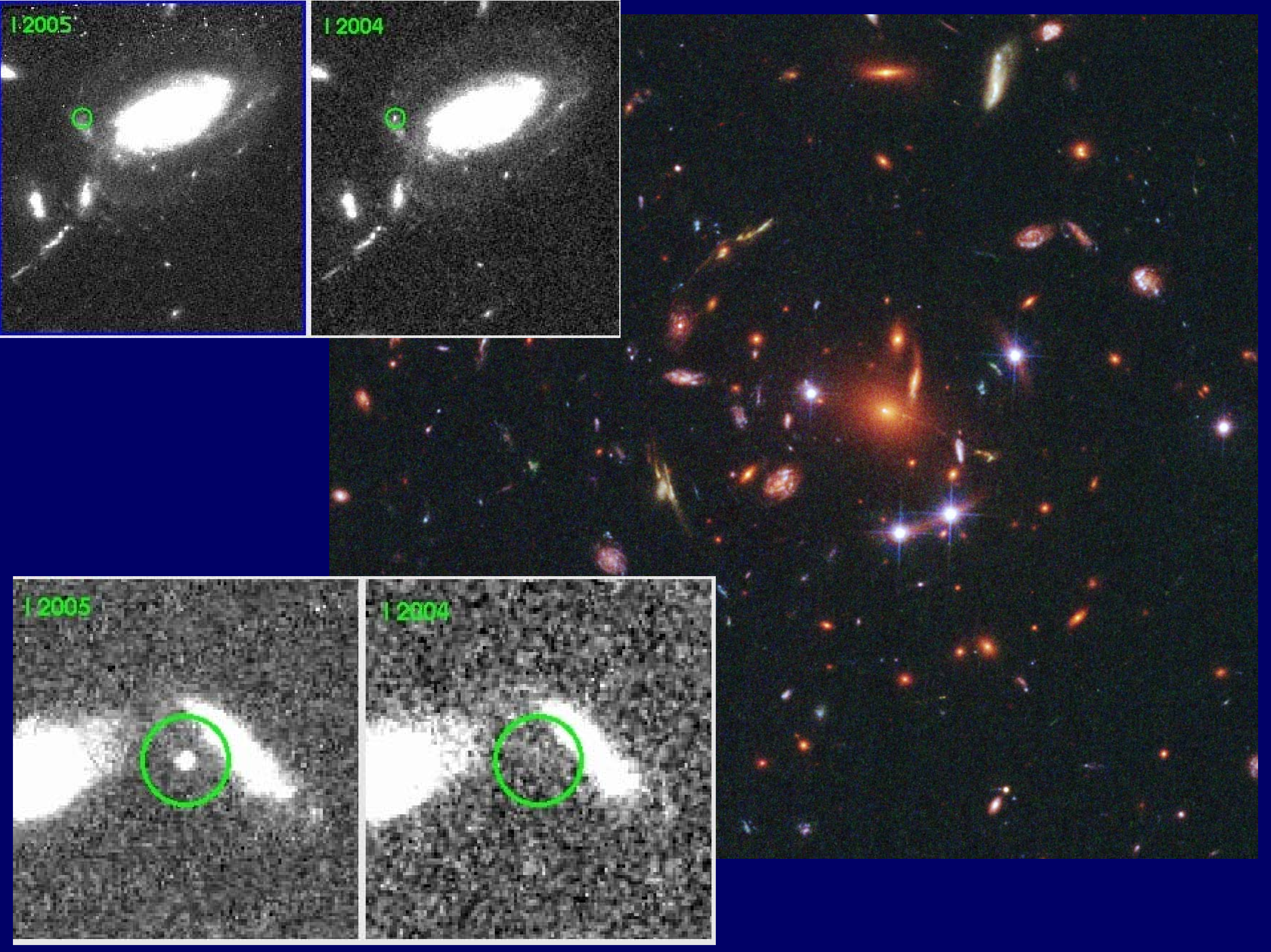
3 - 17 % -- DM, cluster Fe-mass/stellar-luminosity.

2% -- Sullivan et al. (2006), “fast” component (B).

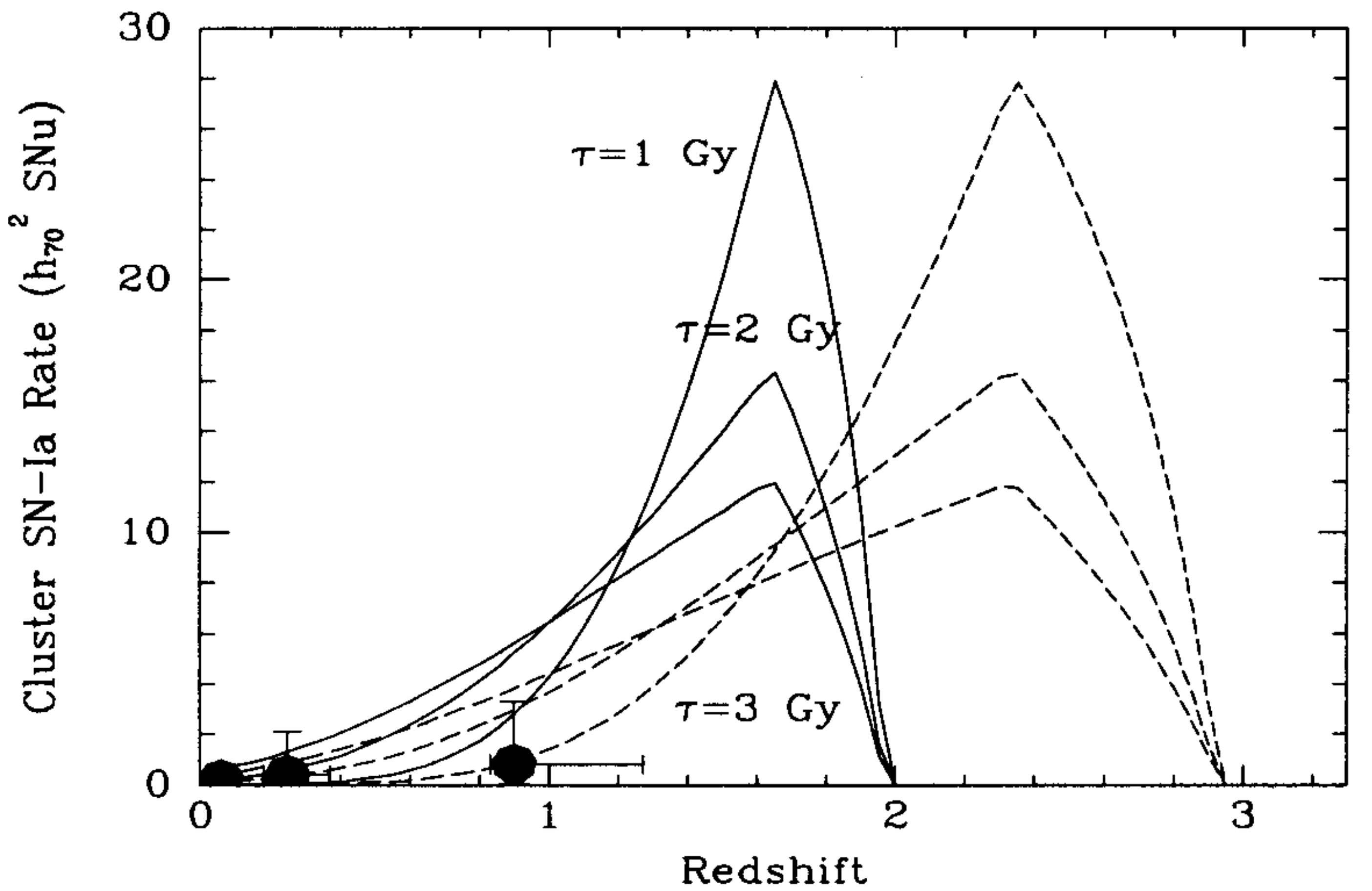
0.3% -- “ “ , “slow” component (A).

2 – 16 % -- Scannapieco & Bildsten (2005), “fast” component

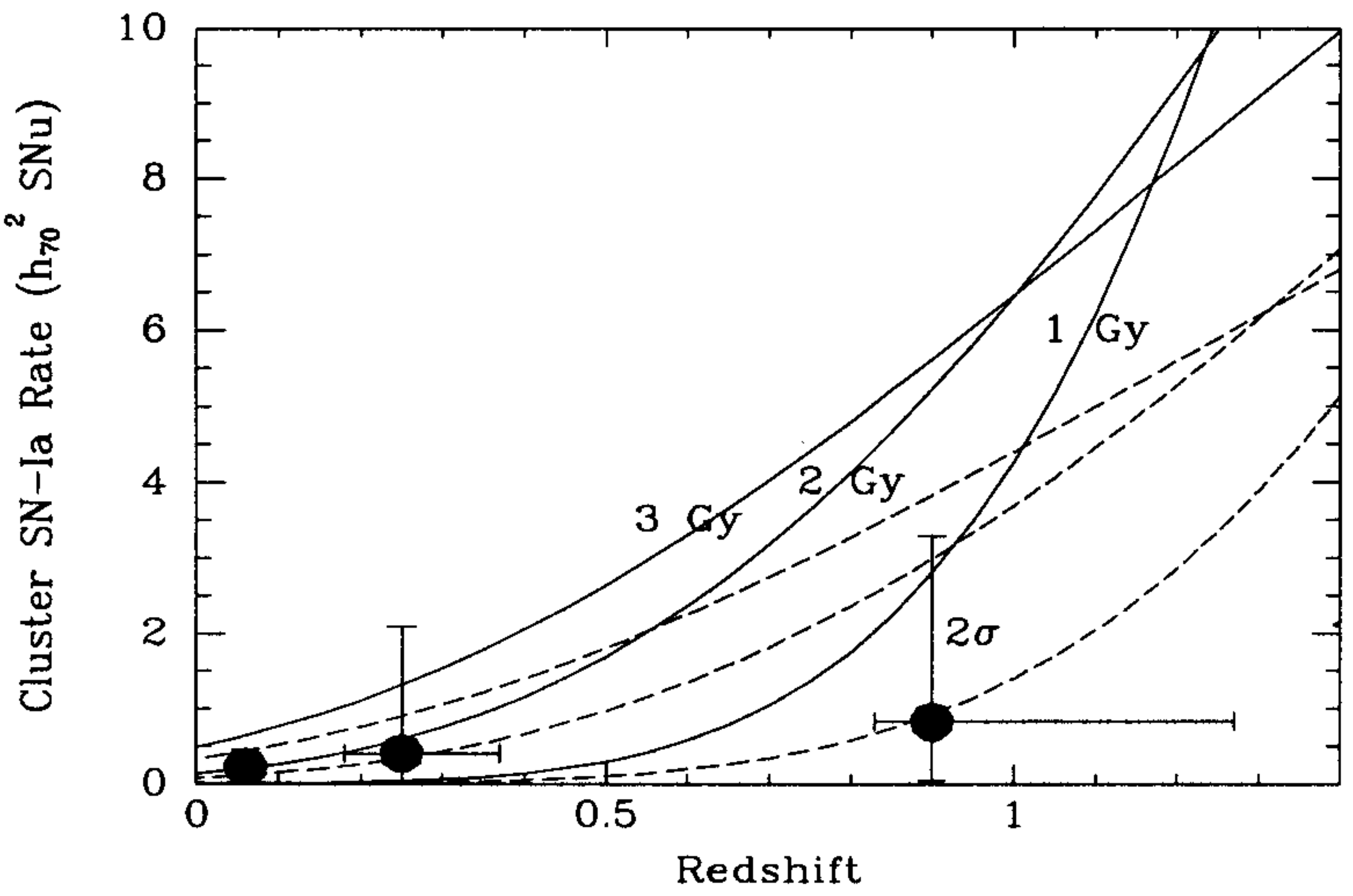
0.6% -- Sharon et al. (2007), cluster rate, if only slow component


I 2005
I 2004
I 2005
I 2004

Predictions vs. SNR(z) measurements



Predictions vs. SNR(z) measurements



CONCLUSIONS No. 2

Combining both results:

Either

1. Field SFH has changed much (>3x) since z~1

or

2. Cluster Fe was made by SNe-Ia

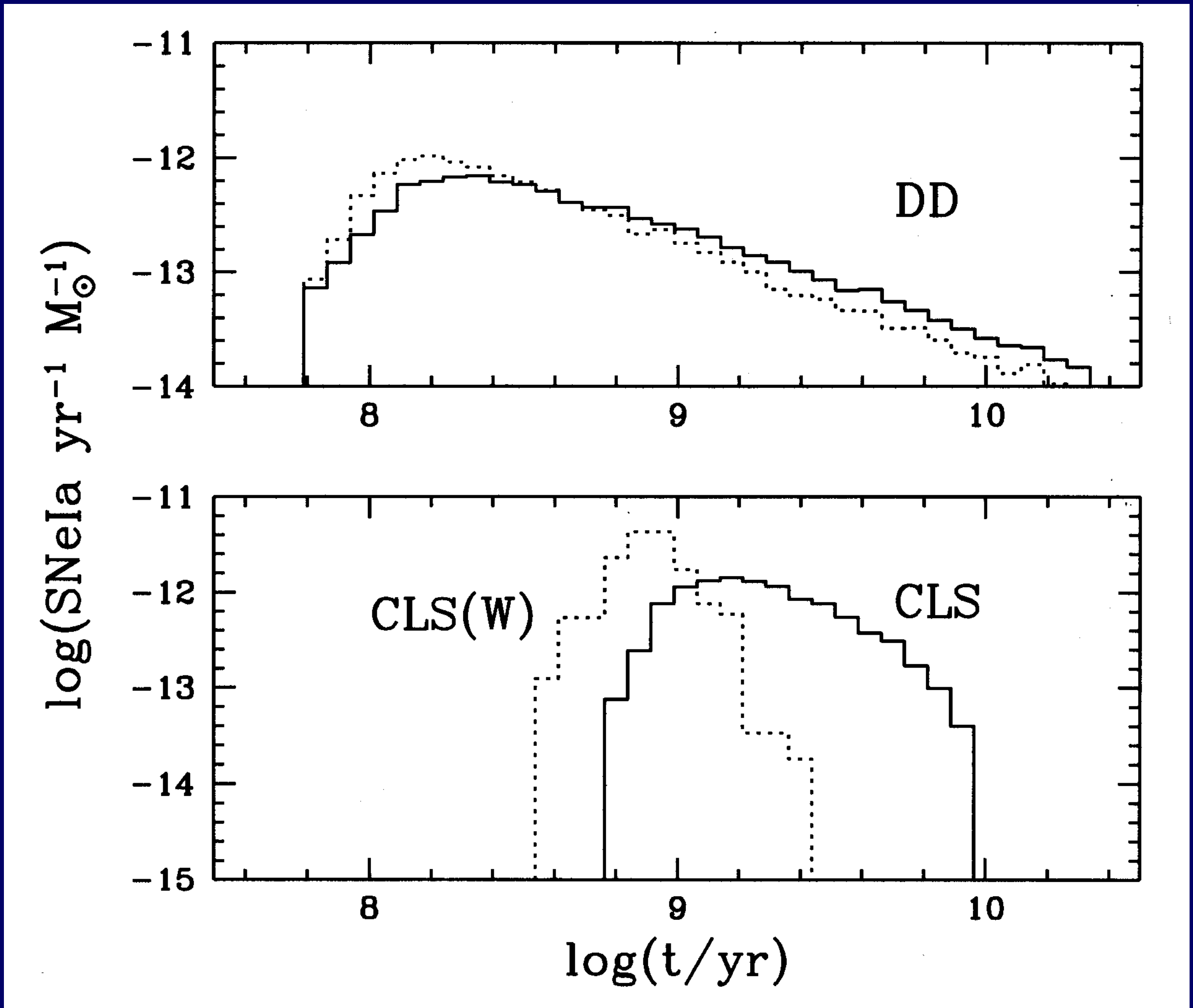
but not both !

(1.) → SNe-Ia have long delays; maybe WD mergers after all;

Iron in clusters (everywhere?) is direct relic of the first, top-heavy, population of stars.

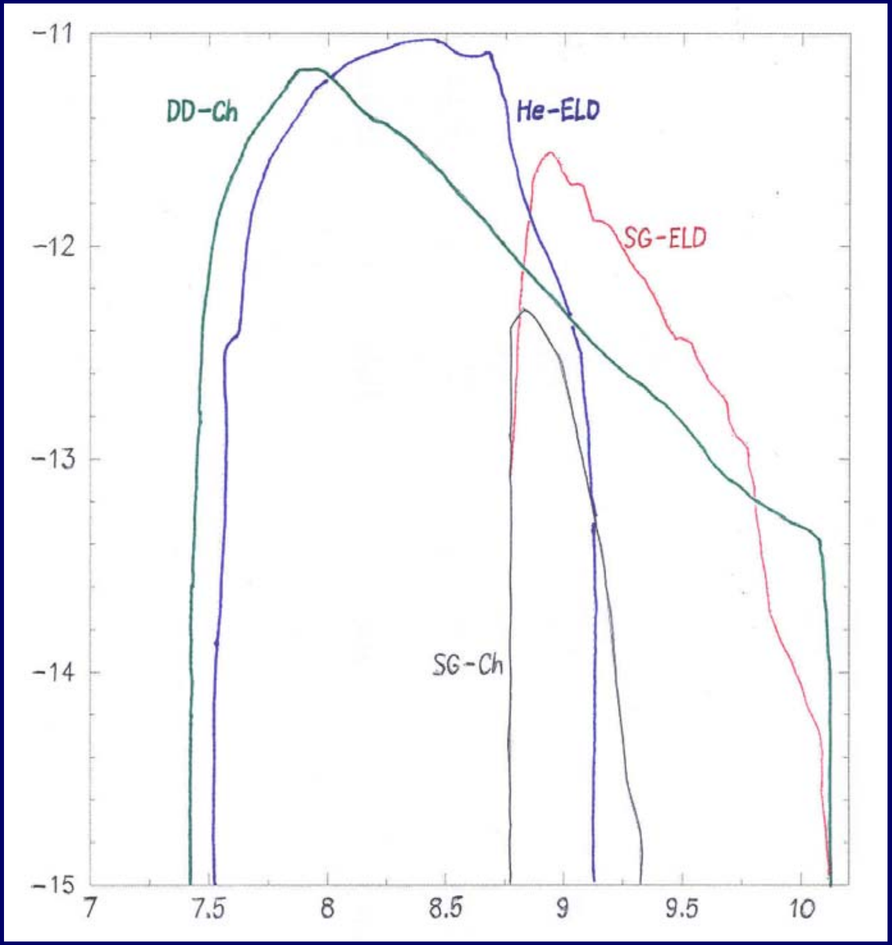
Ruiz-Lapuente & Canal (1998)

logD(t)



log(t/yr) since starburst

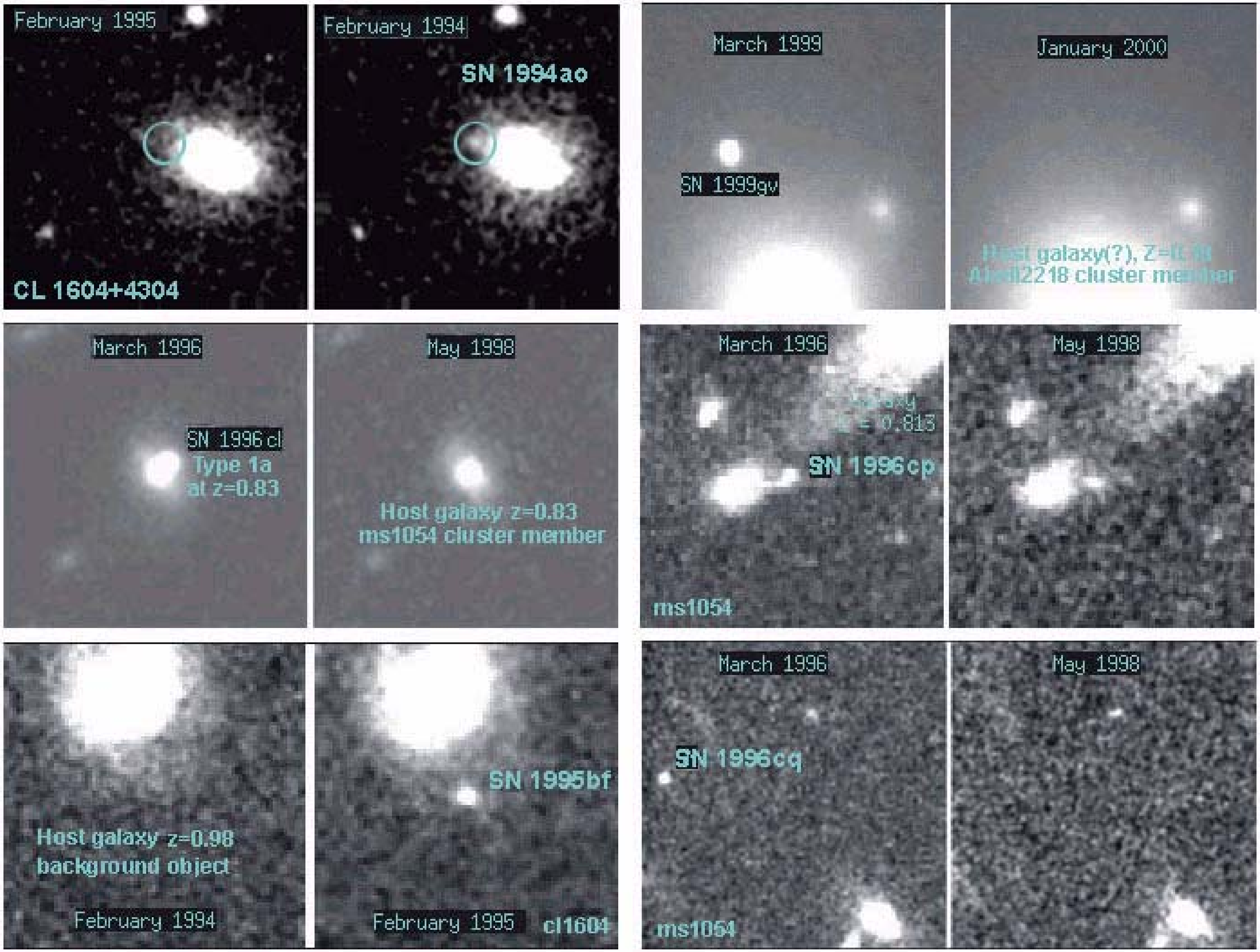
Yungelson & Livio (2000)



log D(t)

log (t/yr) since starburst

SNe candidates



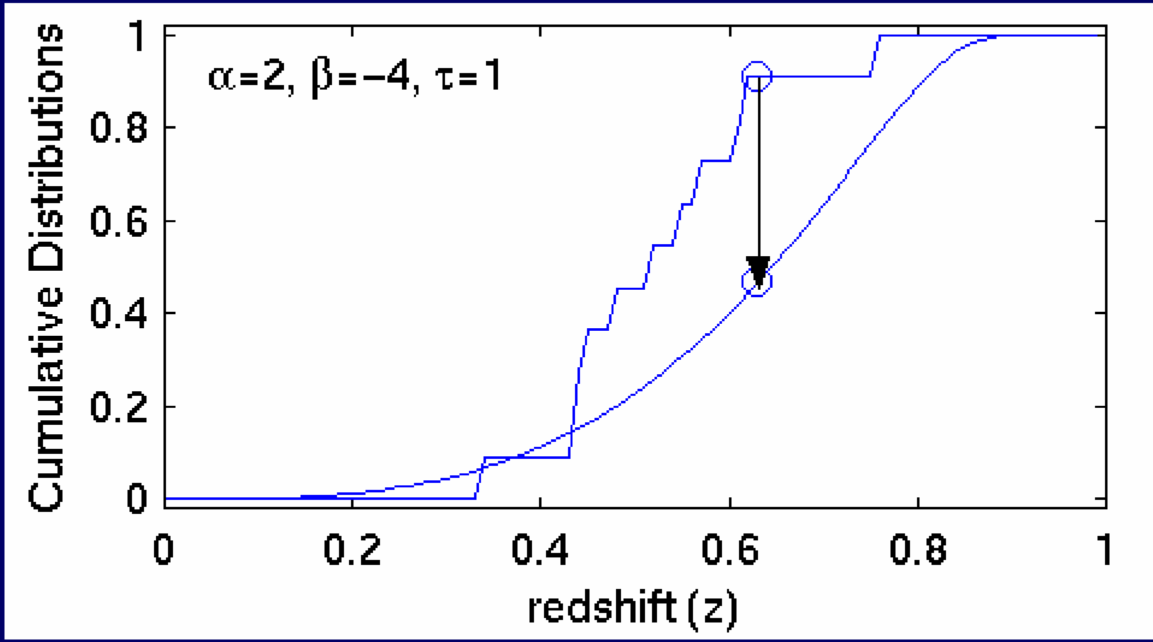
SNe in cluster fields

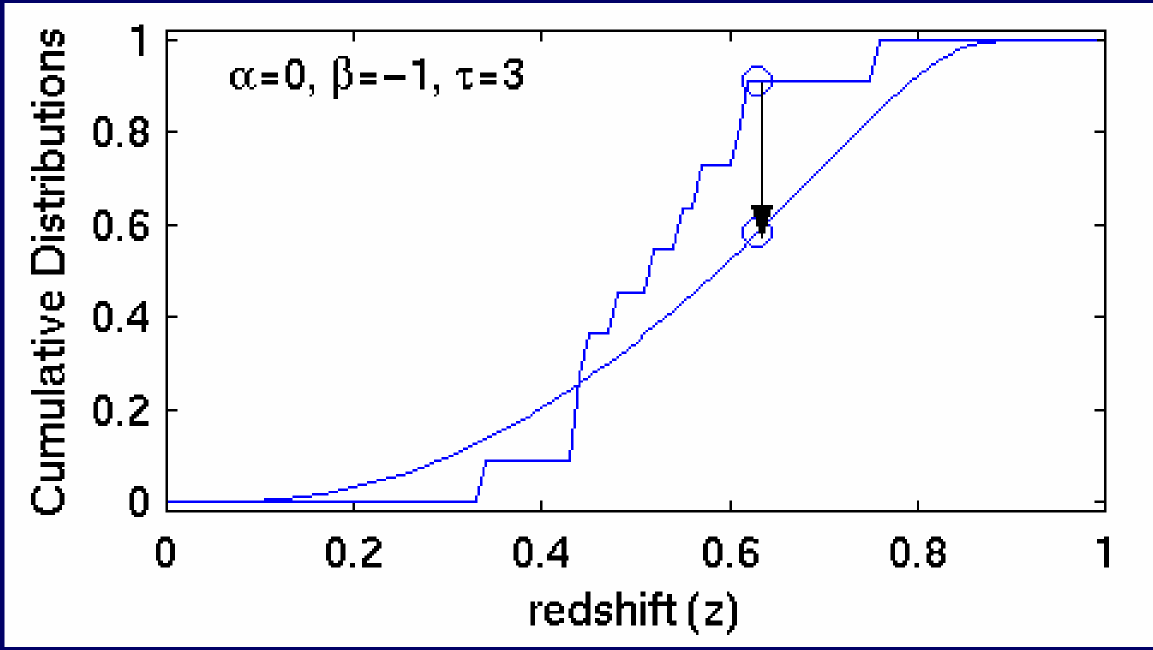
Gal-Yam & Maoz 2004

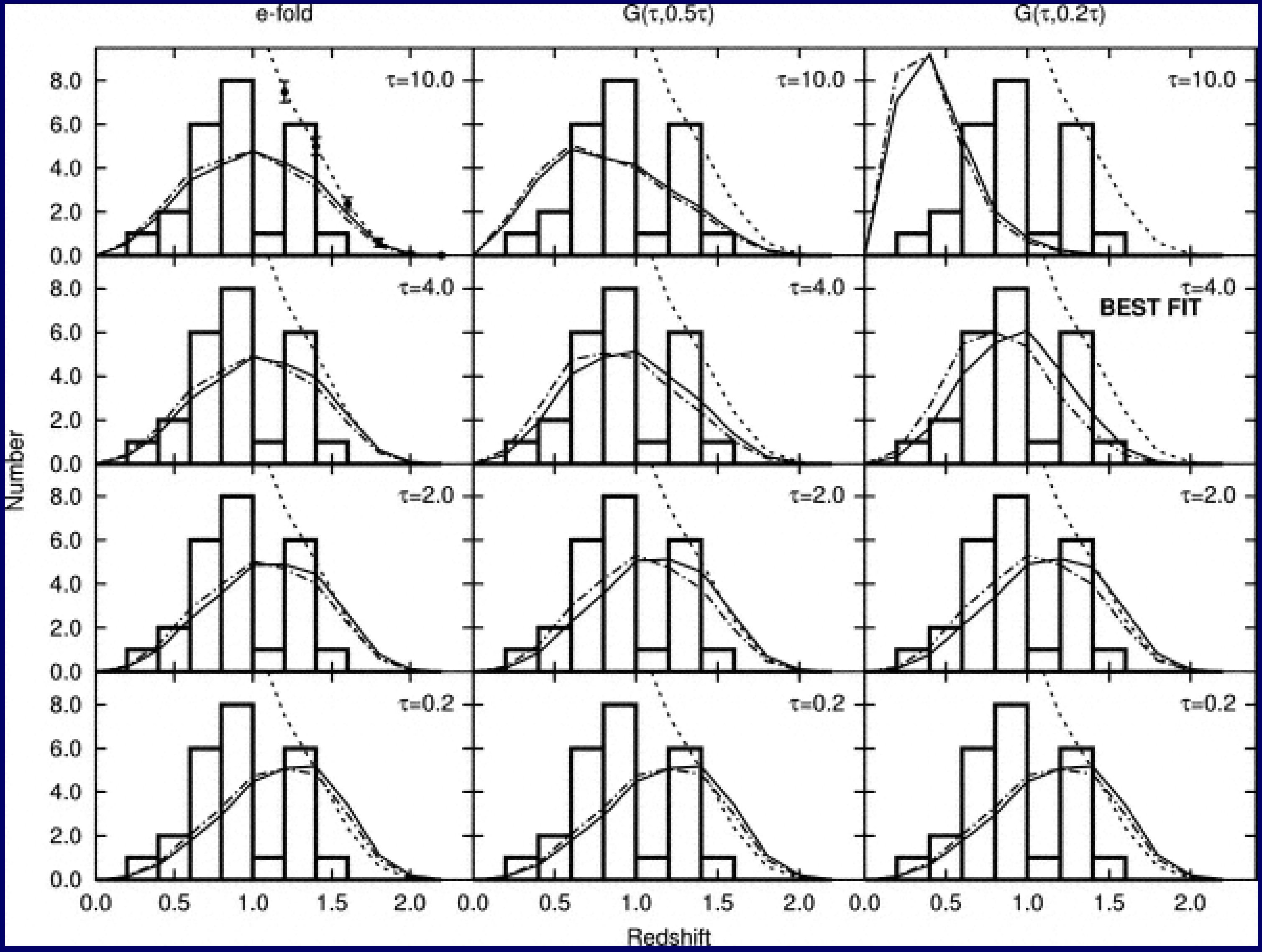
Comparison to data:

SCP SNe from

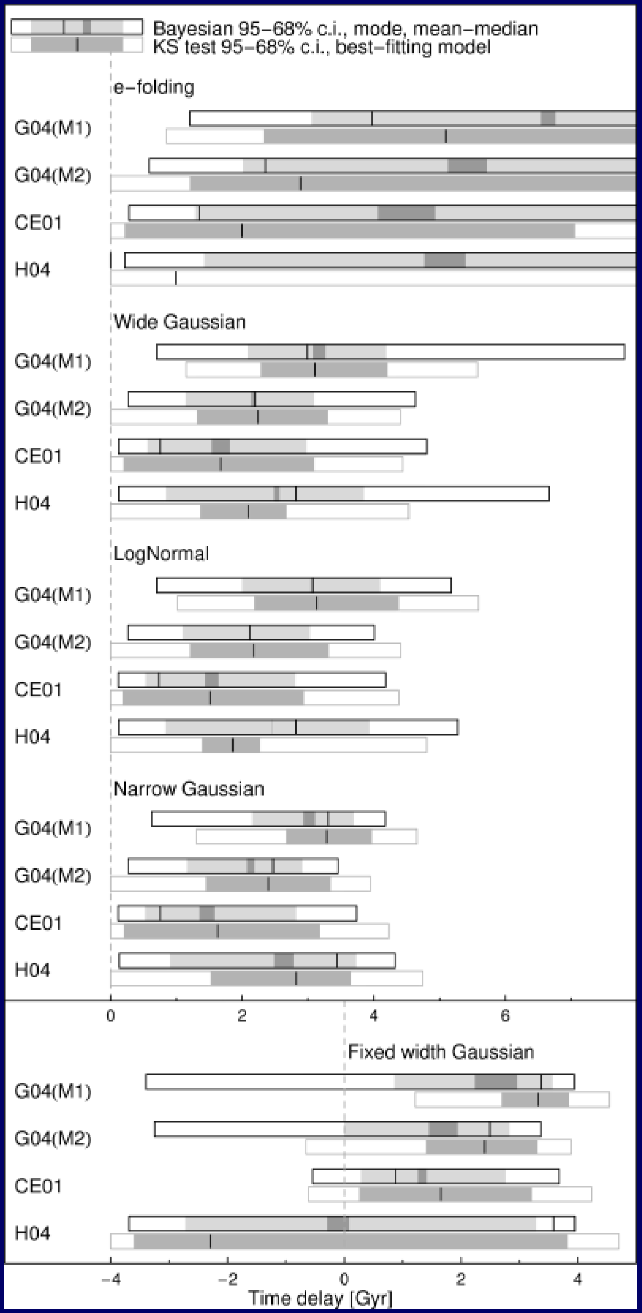
Pain et al. (2003)







e-fold
G(τ,0.5τ)
G(τ,0.2τ)
τ=10.0
τ=4.0
τ=2.0
τ=0.2
BEST FIT
Number
Redshift
0.0
2.0
4.0
6.0
8.0
0.5
1.0
1.5



Bayesian 95–68% c.i., mode, mean–median
KS test 95–68% c.i., best–fitting model
e–folding
G04(M1)
G04(M2)
CE01
H04
Wide Gaussian
G04(M1)
G04(M2)
CE01
H04
LogNormal
G04(M1)
G04(M2)
CE01
H04
Narrow Gaussian
G04(M1)
G04(M2)
CE01
H04
0
2
4
6
Fixed width Gaussian
G04(M1)
G04(M2)
CE01
H04
−4
−2
0
2
4
Time delay [Gyr]

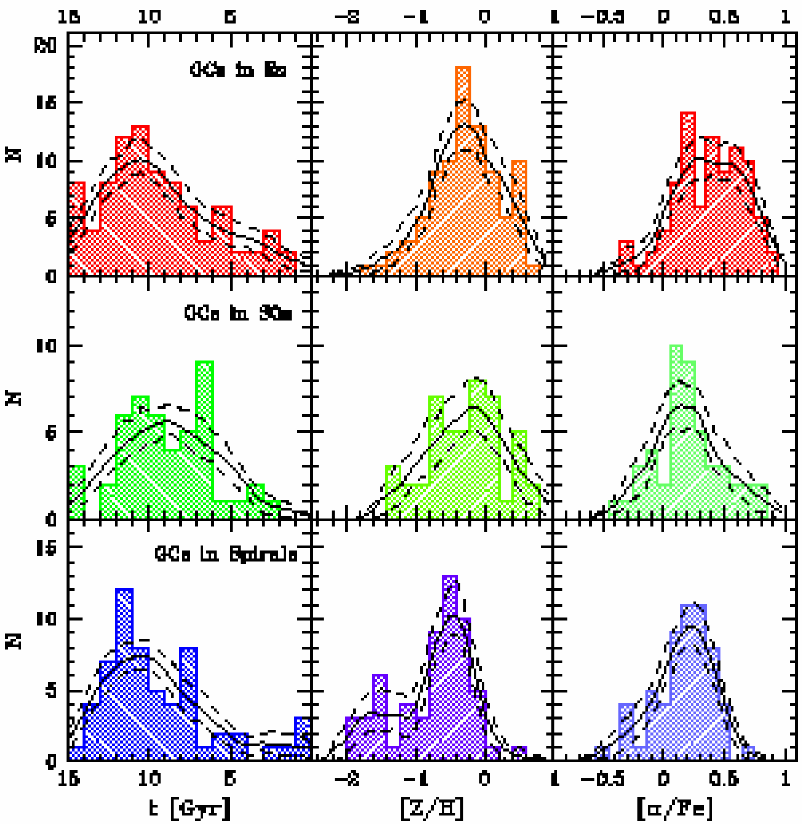
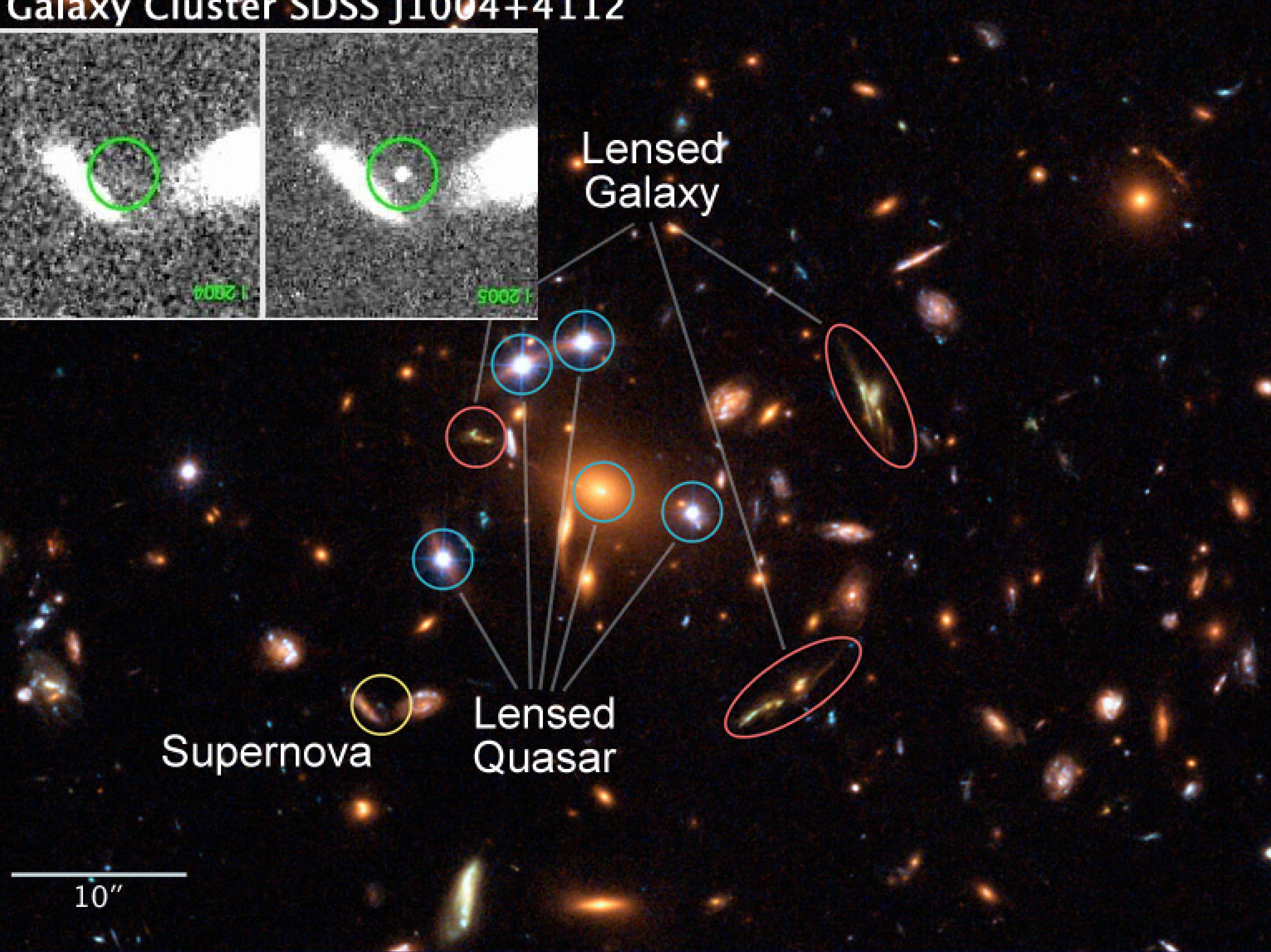


FIG. 2.— Age, metallicity, and [α/Fe] distributions of globular clusters in elliptical (*upper row*), lenticular (*middle row*), and spiral galaxies (*bottom row*). Solid curves are non-parametric probability density estimates with their 90% confidence limits indicated by dashed lines.

Puzia et al. 2006


Galaxy Cluster SDSS J1004+4112
Lensed Galaxy
Lensed Quasar
Supernova
10″