Peering Back in time:

Using Stellar explosions to chronicle the History of Our Universe

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Largest Bangs in the Universe....Since the Big One.

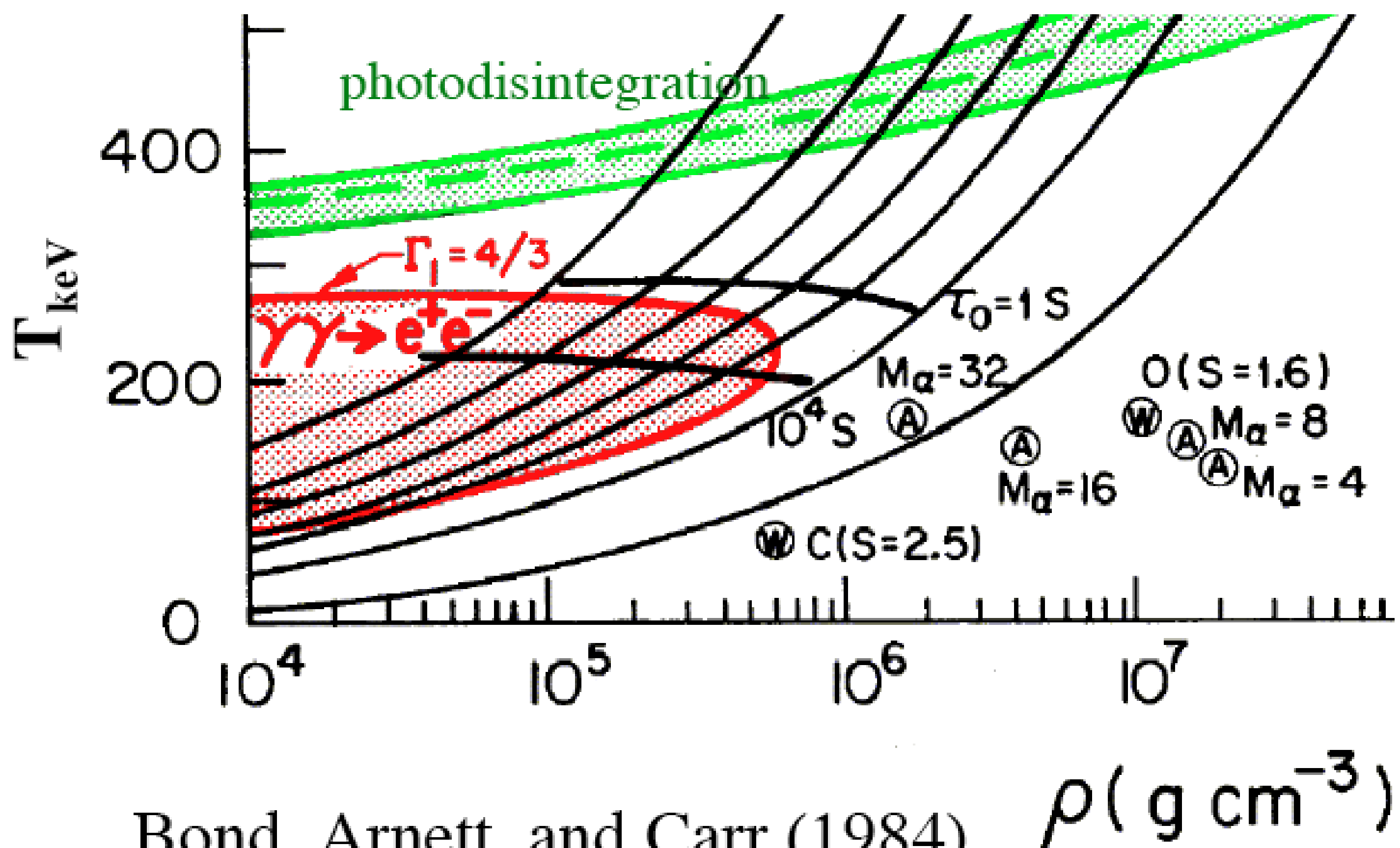
There exist very rare events which are extremely energetic. These include

Pair Production Supernova

Gamma Ray Bursts (two types)

Pair Instability

Stars of sufficiently high mass (central entropy) encounter a structural instability ($\Gamma < 4/3$) and collapse following the end of helium burning. Explosive C, O, Si burning can reverse the implosion and make a thermonuclear explosion



Bond, Arnett, and Carr (1984)

$$\mathrm{BE} \sim \frac{GM^2}{R}$$

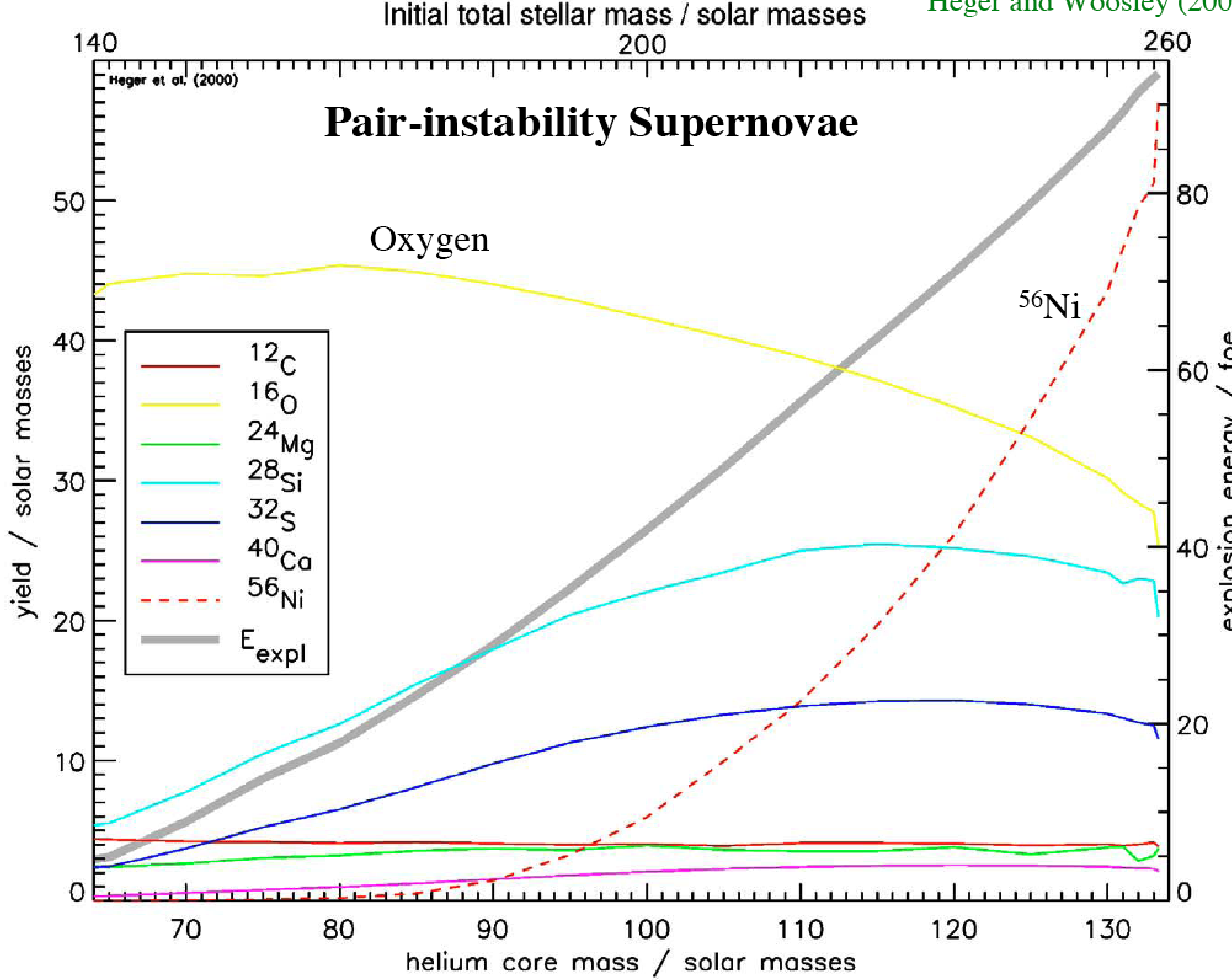
Nuclear energy $\sim f\ M$

Above some mass

hard to explode

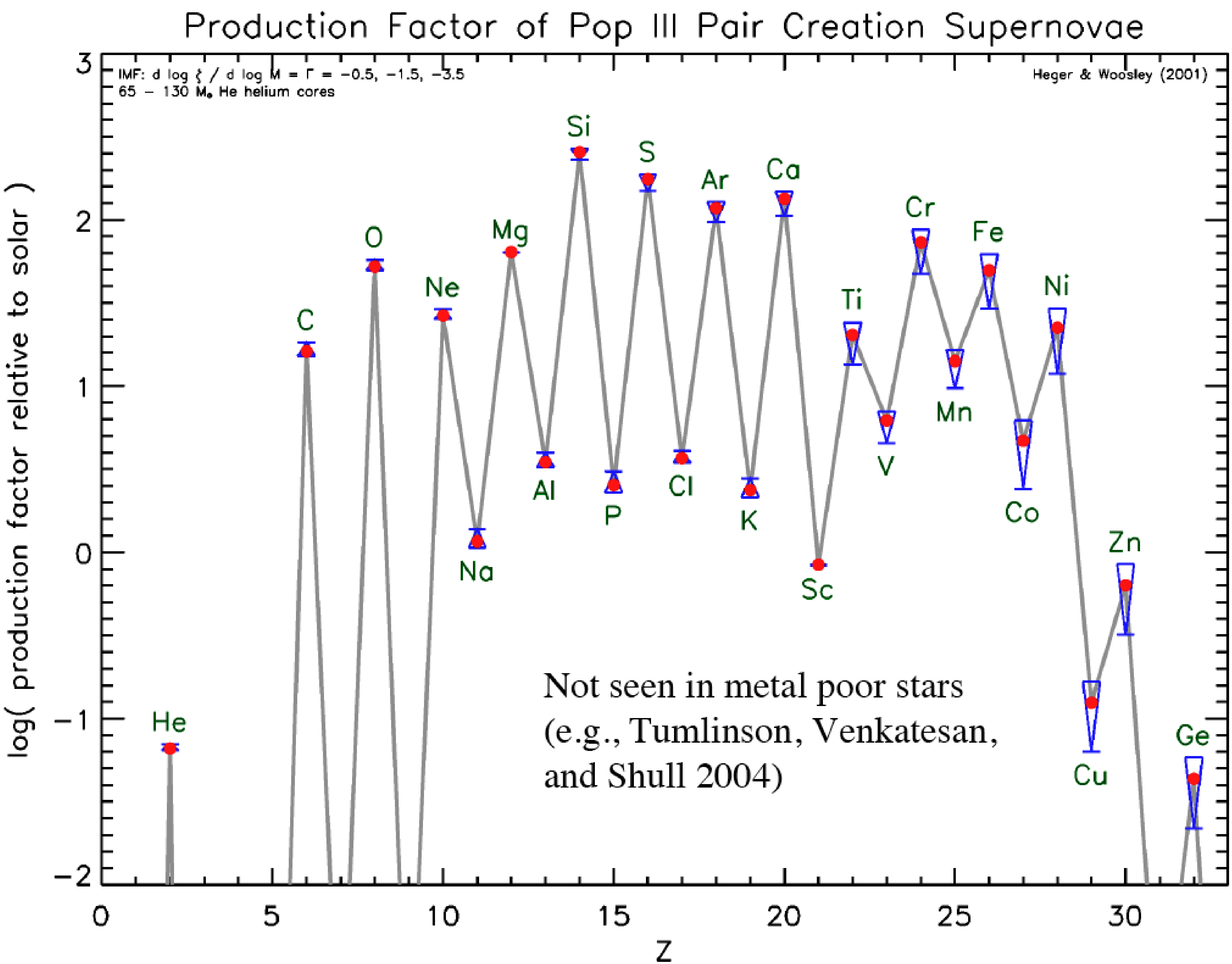
Woosley 2009

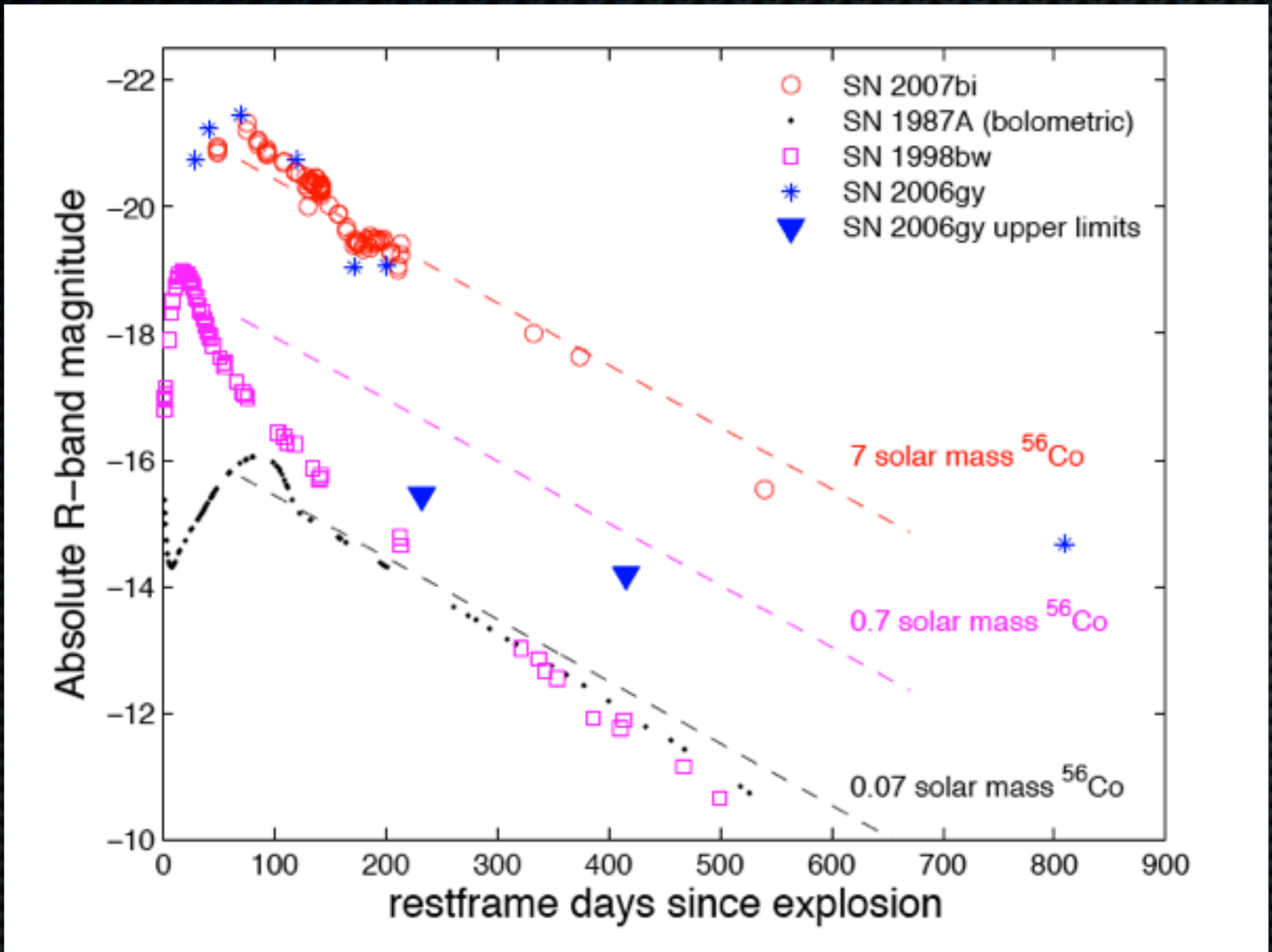
Heger and Woosley (2002)



Complications

- *Do they exist at all, and in what form?*
- *Mass loss: Eta Carina or $\dot{M} \propto Z^n$ or does convection and dredge up change things.*
- *Rotation - increases He core mass, increases mixing, and may dominate explosion process if high*
- *Binary - might eject envelope and affect core evolution*


Production Factor of Pop III Pair Creation Supernovae
IMF: d log ξ / d log M = Γ = −0.5, −1.5, −3.5
65 − 130 M☉ He helium cores
Heger & Woosley (2001)
log(production factor relative to solar)
Z
He
C
O
Ne
Na
Mg
Al
Si
P
S
Cl
Ar
K
Ca
Sc
Ti
V
Cr
Mn
Fe
Co
Ni
Cu
Zn
Ge
Not seen in metal poor stars
(e.g., Tumlinson, Venkatesan,
and Shull 2004)



But they do seem to be seen in Nature

at least something that looks like them - but very rare $<10^{-3}$ SN rate

Gal Yam 08

Gamma Ray Bursts

THE DISCOVERY

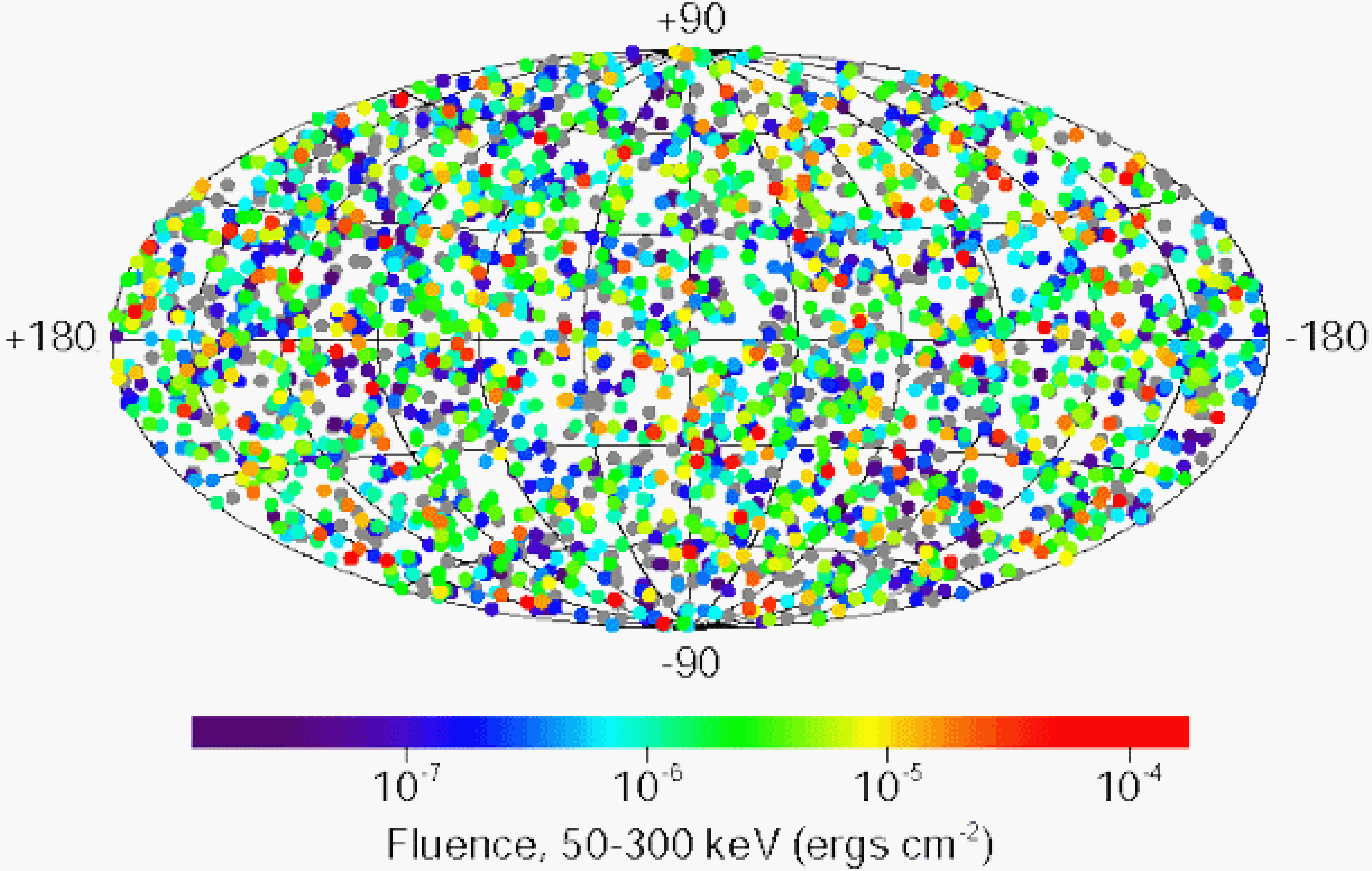
Gamma-Ray Bursts (GRBs) are Short (few seconds) bursts of 100keV-few MeV.

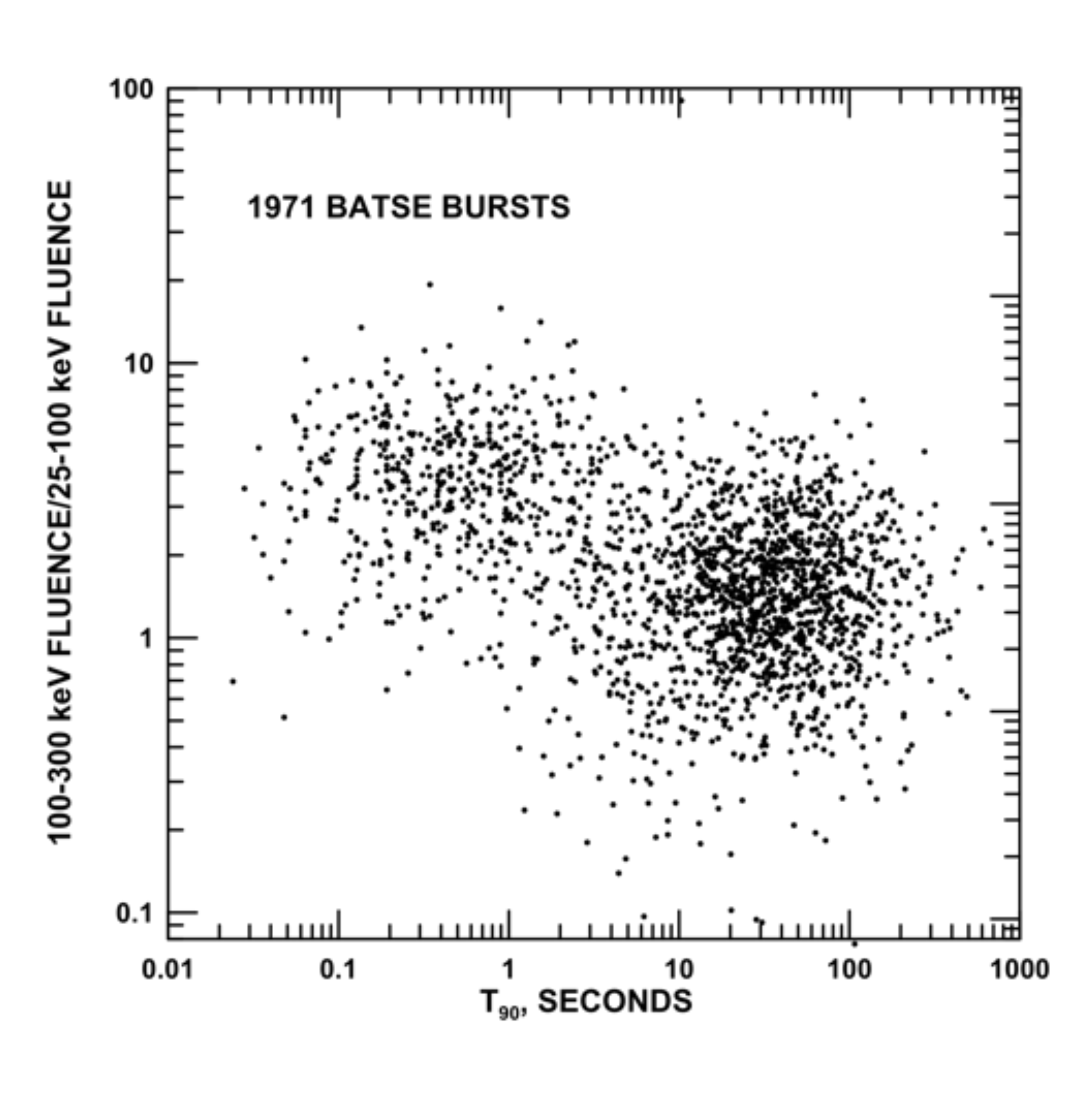
They were discovered accidentally by Klebesadal Strong and Olson in 1967 using the Vela satellites

(defense satellites sent to monitor Atomic Bomb tests).

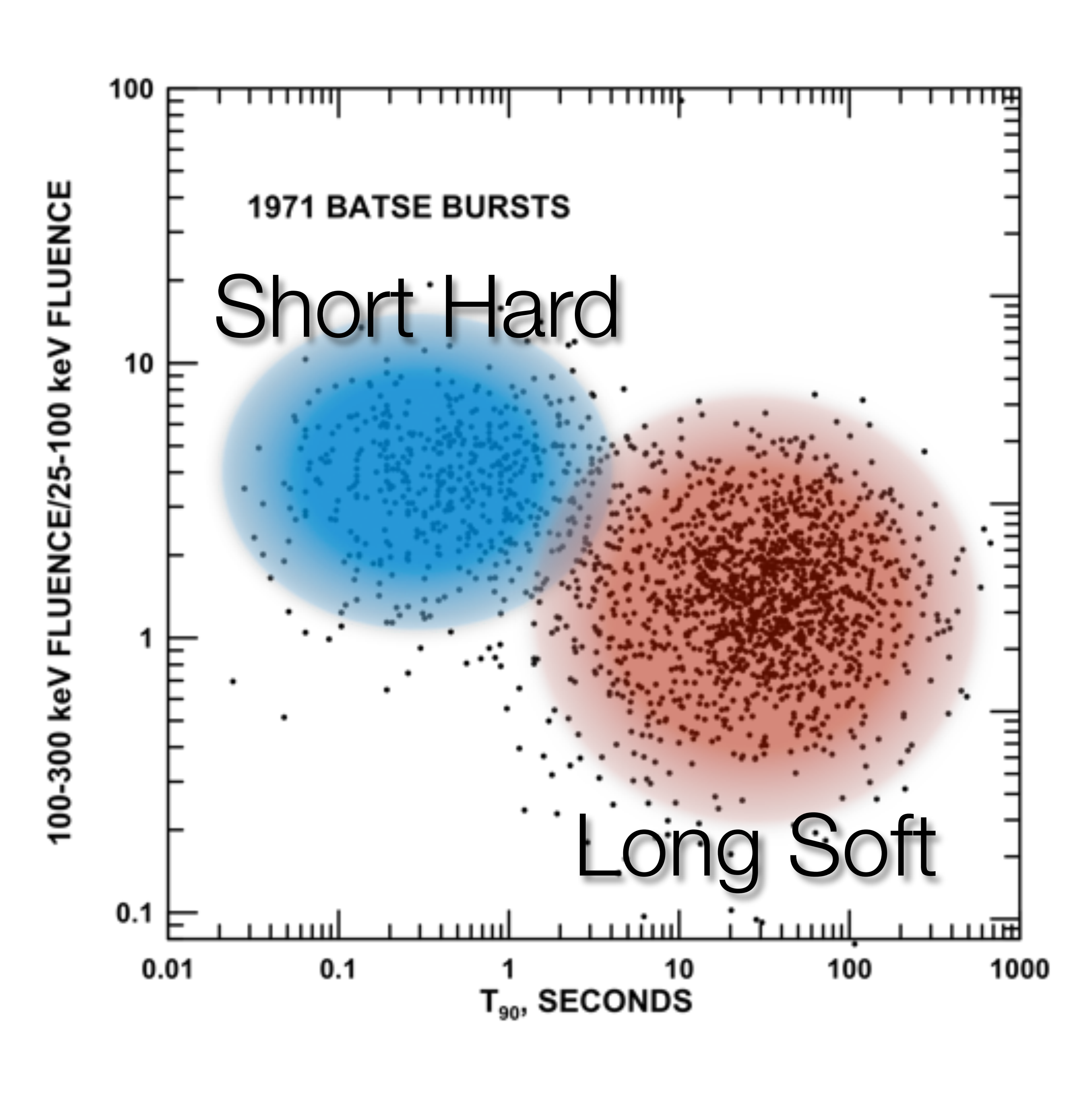
- The discovery was reported for the first time only in 1973.

2704 BATSE Gamma-Ray Bursts



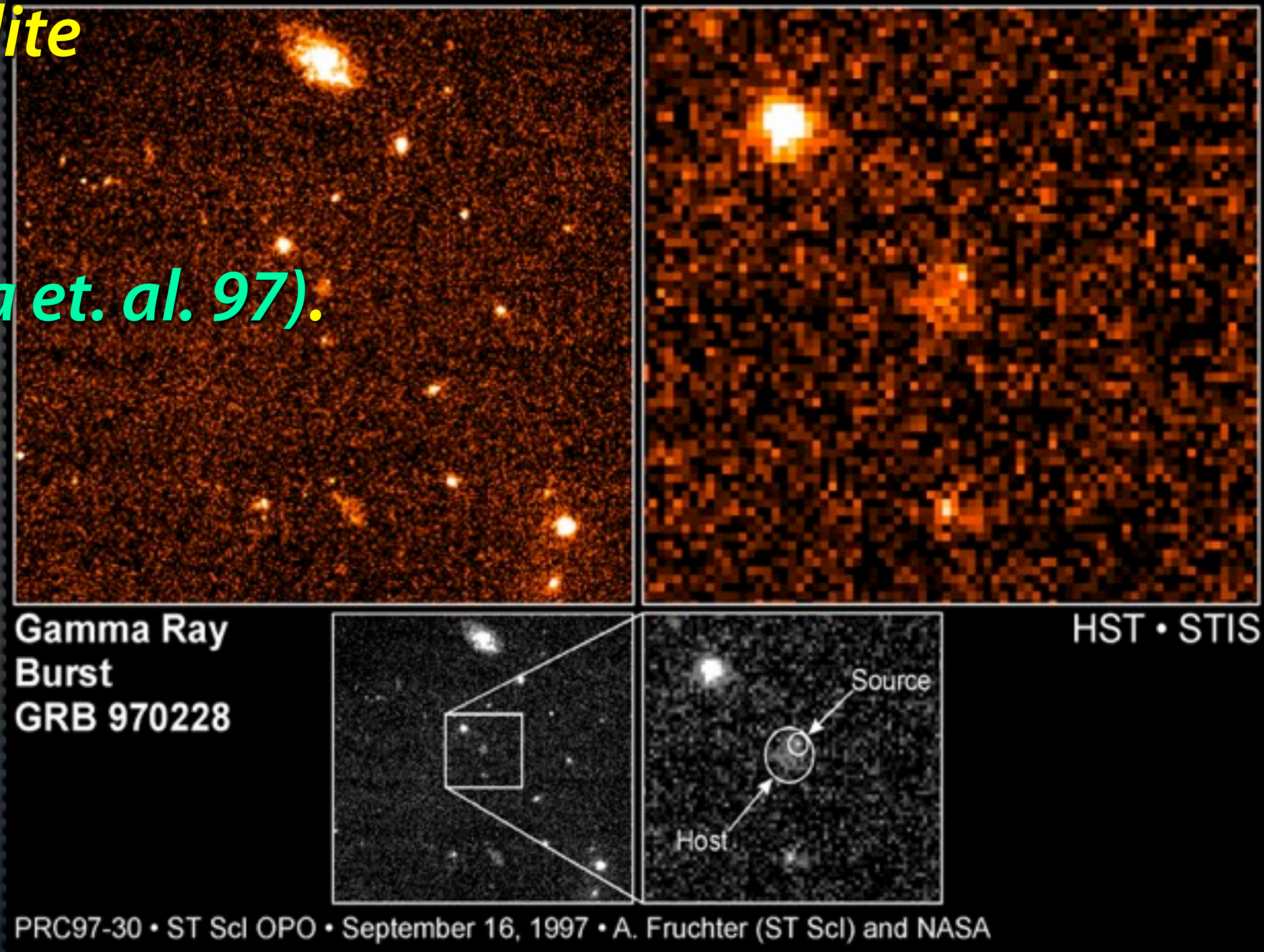


1971 BATSE BURSTS
100-300 keV FLUENCE/25-100 keV FLUENCE
100
10
1
0.1
0.01
0.1
1
10
100
1000
T_{90}, SECONDS


1971 BATSE BURSTS
Short Hard
Long Soft
100-300 keV FLUENCE/25-100 keV FLUENCE
100
10
1
0.1
0.01
0.1
1
10
100
1000
T90, SECONDS

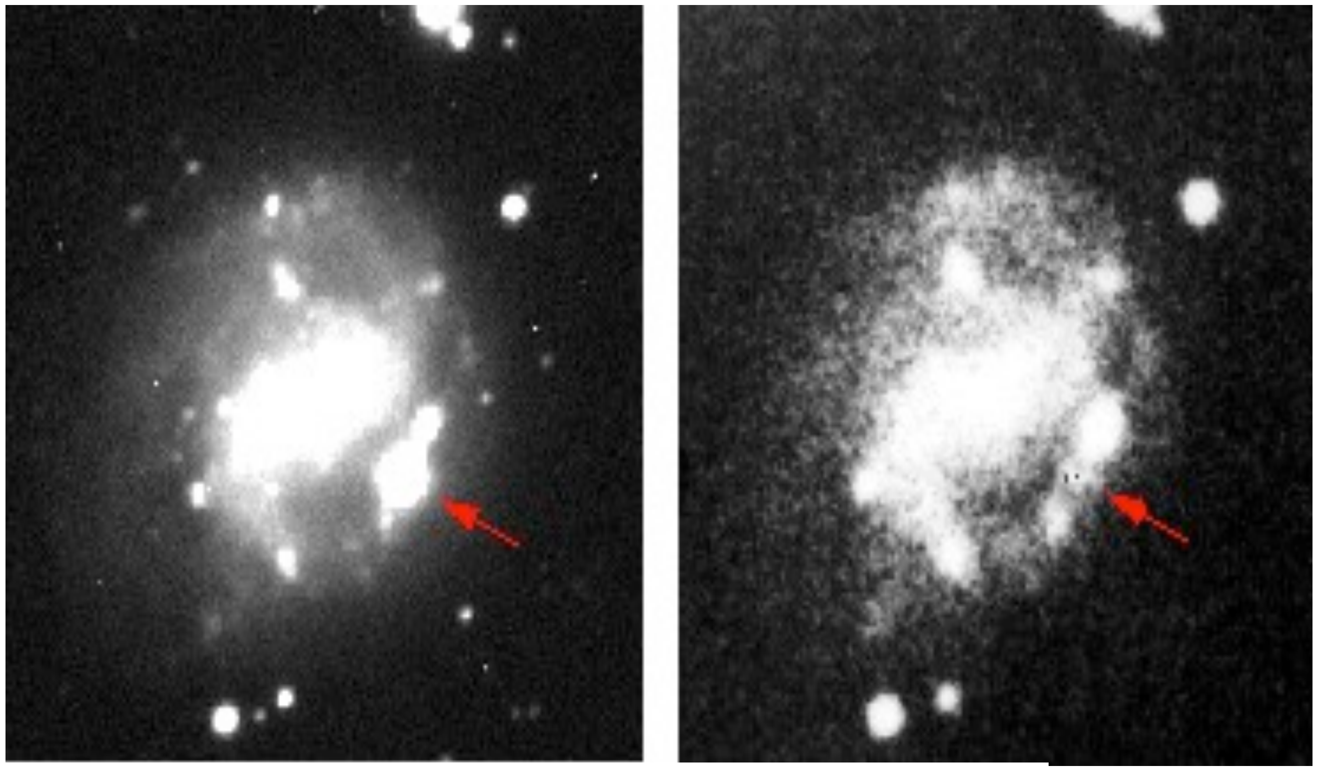
Cosmological Origin!

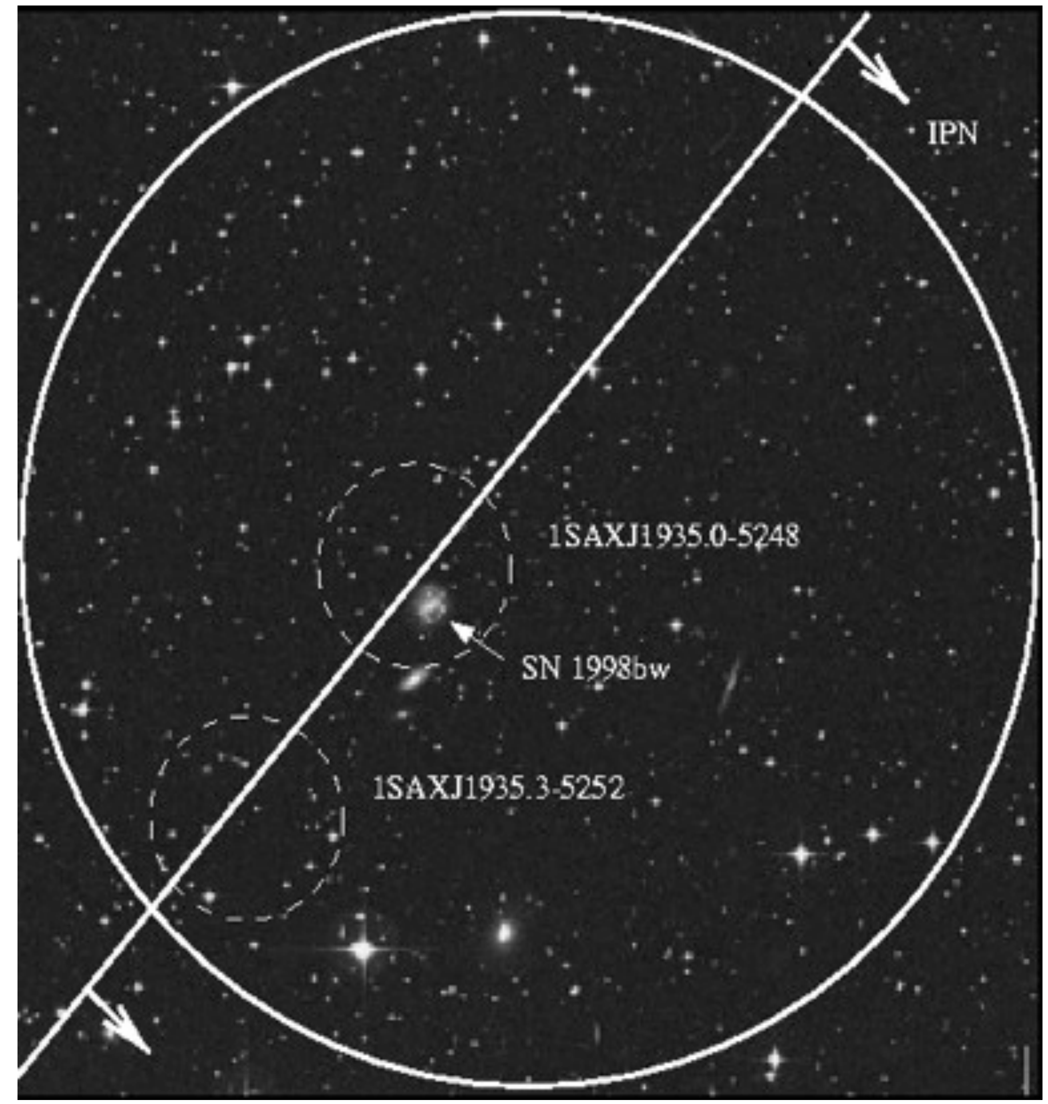
- *The Italian/Dutch satellite BeppoSAX discovered x-ray afterglow on 28 February 1997 (Costa et. al. 97).*
- *Immediate discovery of Optical afterglow (van Paradijs et. al 97).*

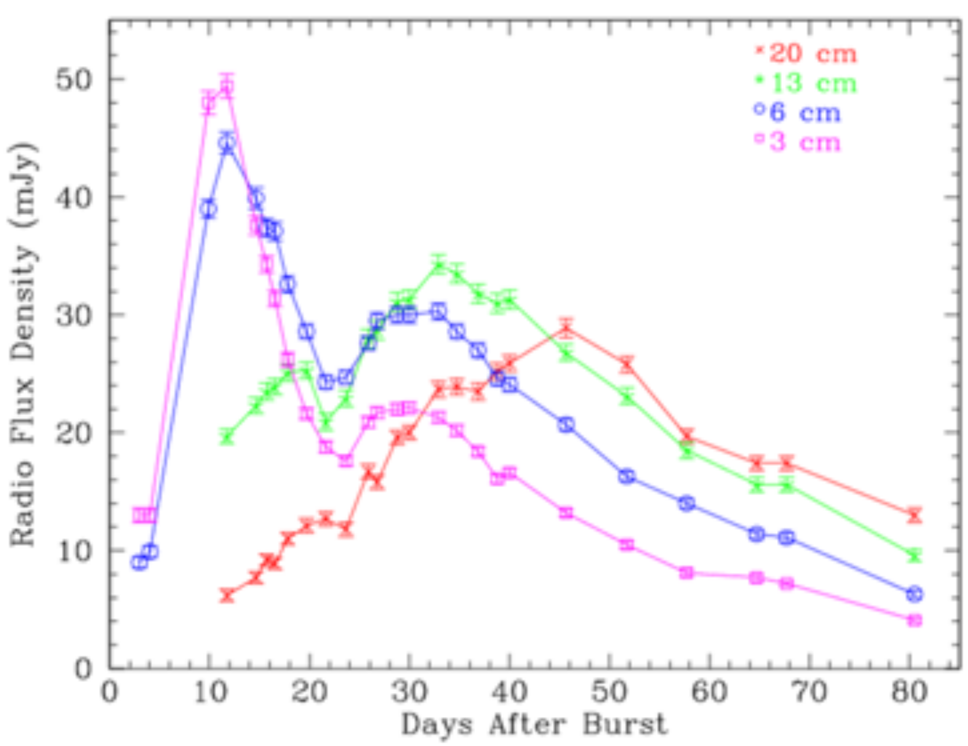


SN 1998bw was discovered in Gamma Rays

Beppo-Sax

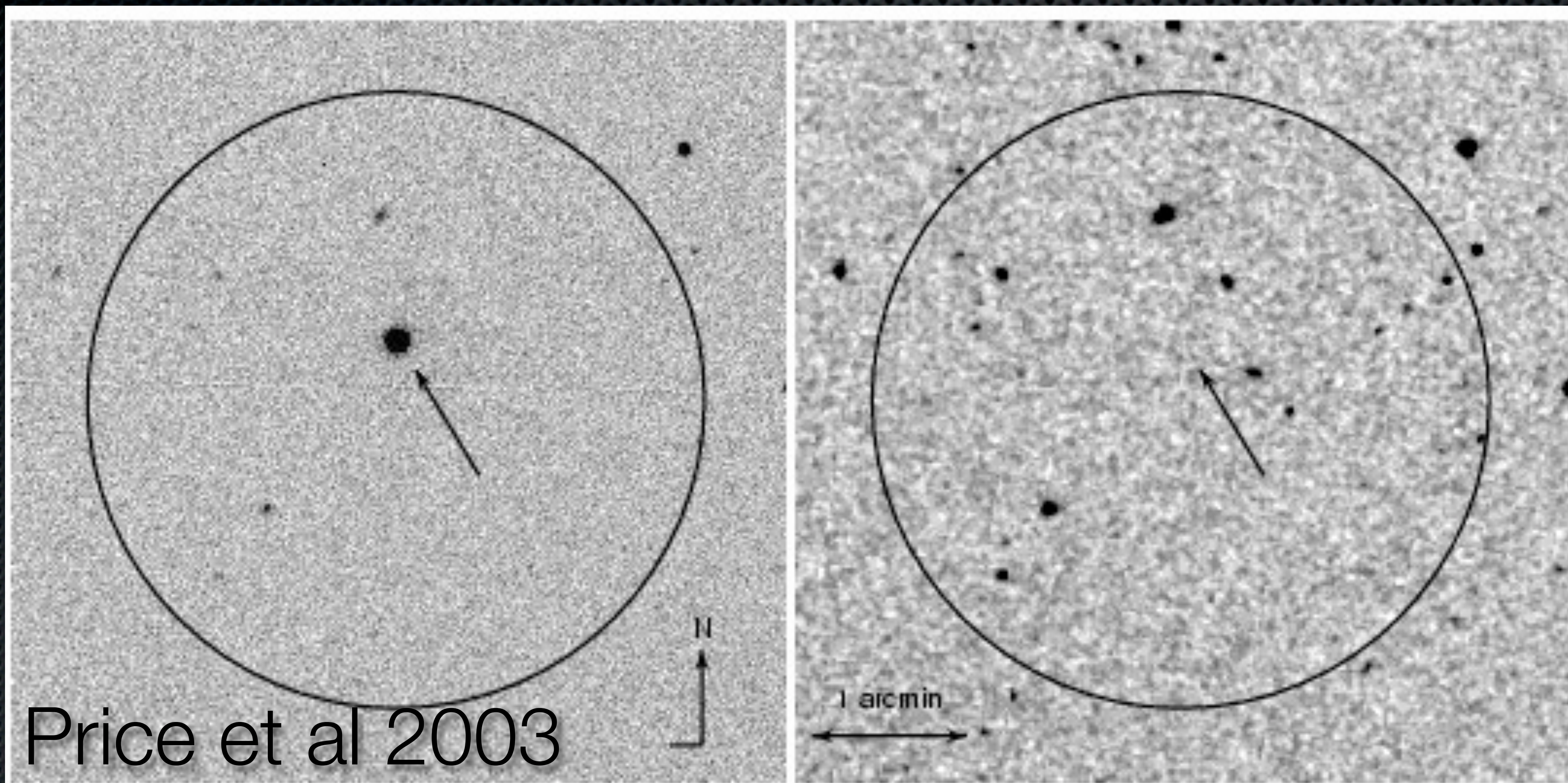






Brightest Radio SN ever – Measurement indicate relativistic Ejecta… funny very high velocity
Spectrum … within a day of GRB

SN 2003dh was also discovered in Gamma Rays and it was more typical GRB



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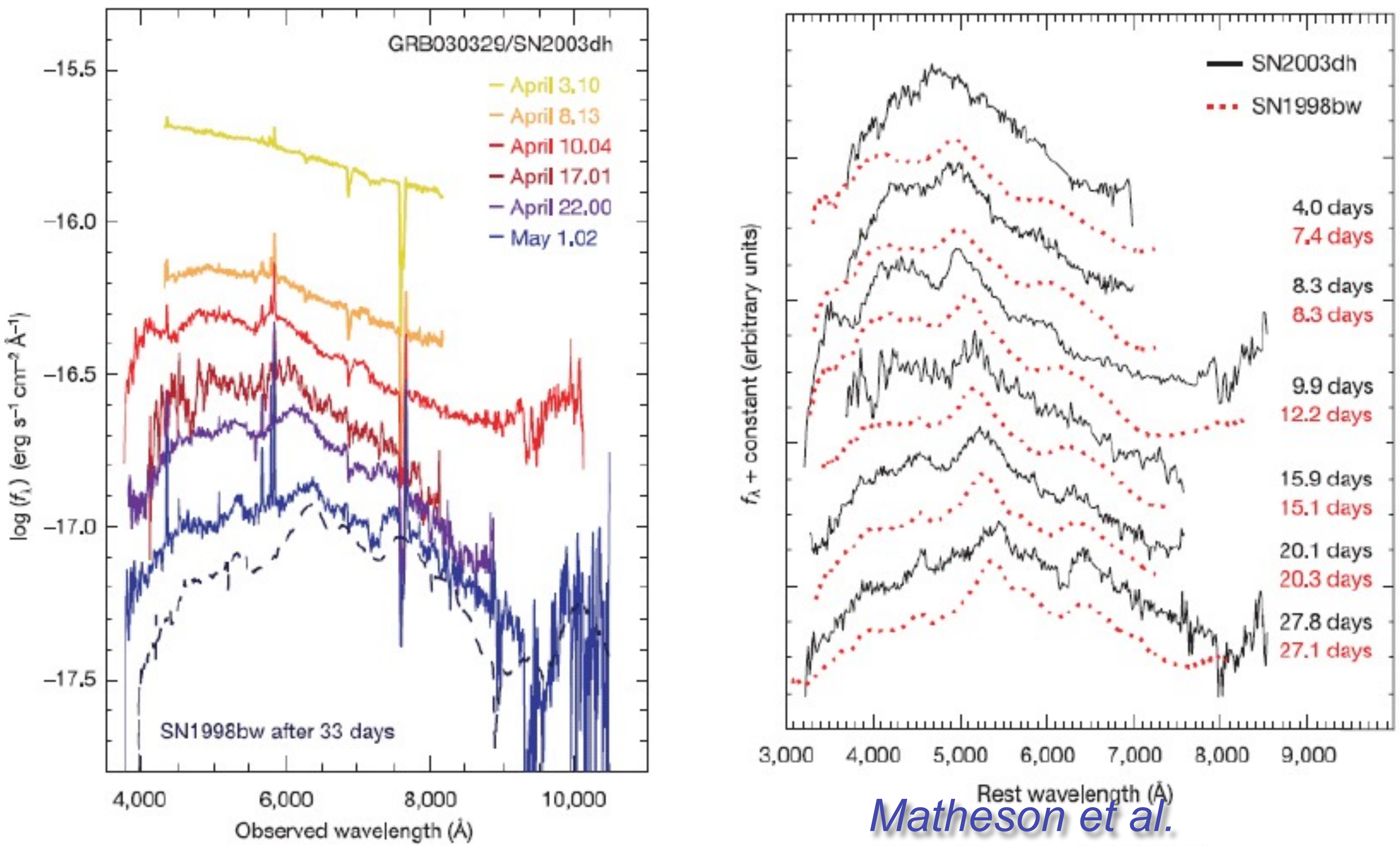
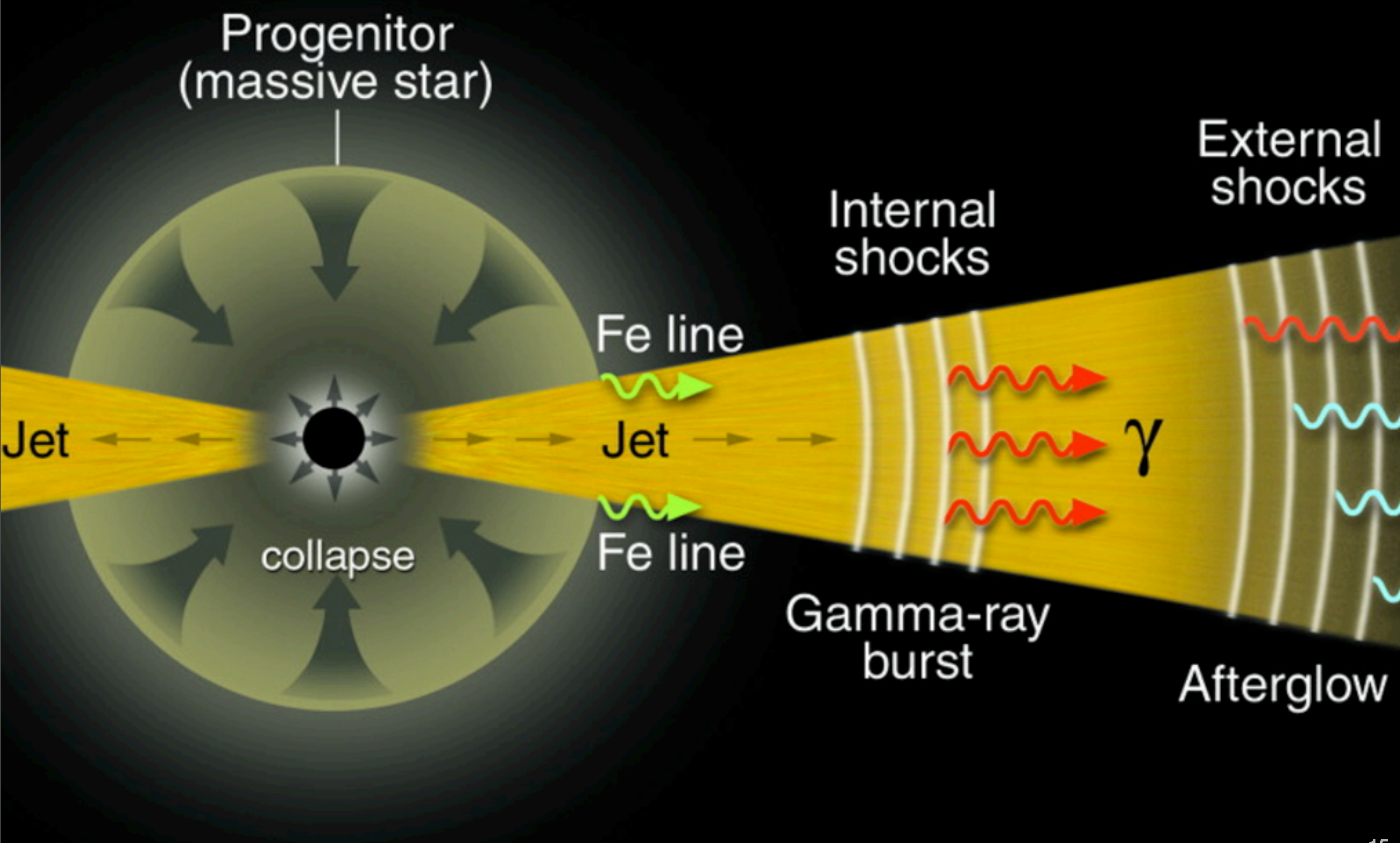


Matheson et al.

Hjorth et al (2003)

Toy Model for GRB



Afterglow Theory

Hydrodynamics: *deceleration of the relativistic shell by collision with the surrounding medium*
(Blandford & McKee 1976)

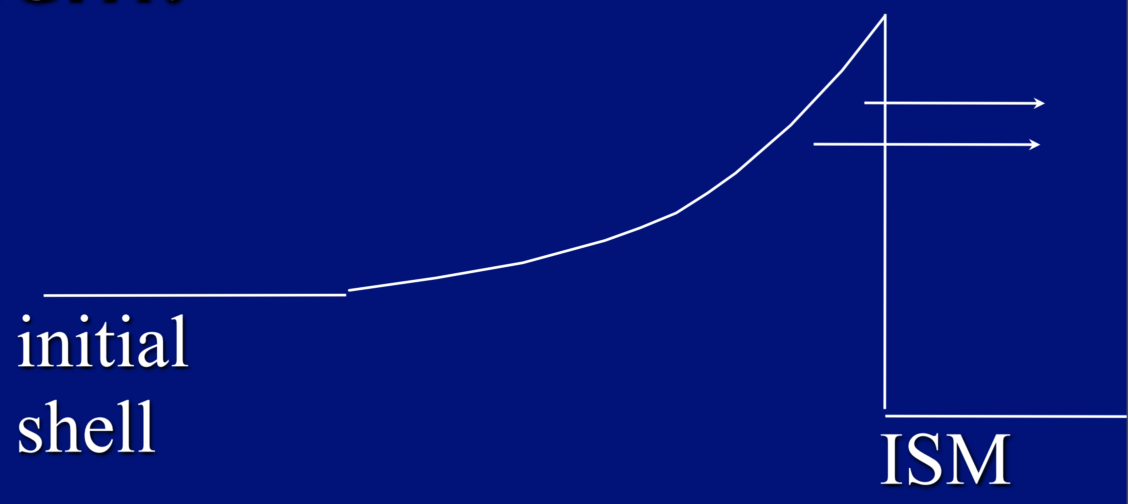
(Meszaros & Rees 1997, Waxman 1997, Sari 1997, Cohen, Piran & Sari 1998)

Radiation: *synchrotron + Inverse Compton Scattering*

(Sari, Piran & Narayan 98)

Clean, well defined problem.

Few parameters:



- **Adiabaticity:** $$E_0 = Mc^2\gamma^2 = (4\pi/3)R^3c^2\gamma^2$$
- **Arrival time:** $$t_{obs} = R/2\gamma^2$$
- **Energy densities:** $$e_e = \varepsilon_e e = \varepsilon_e n_0 c^2\gamma^2$$

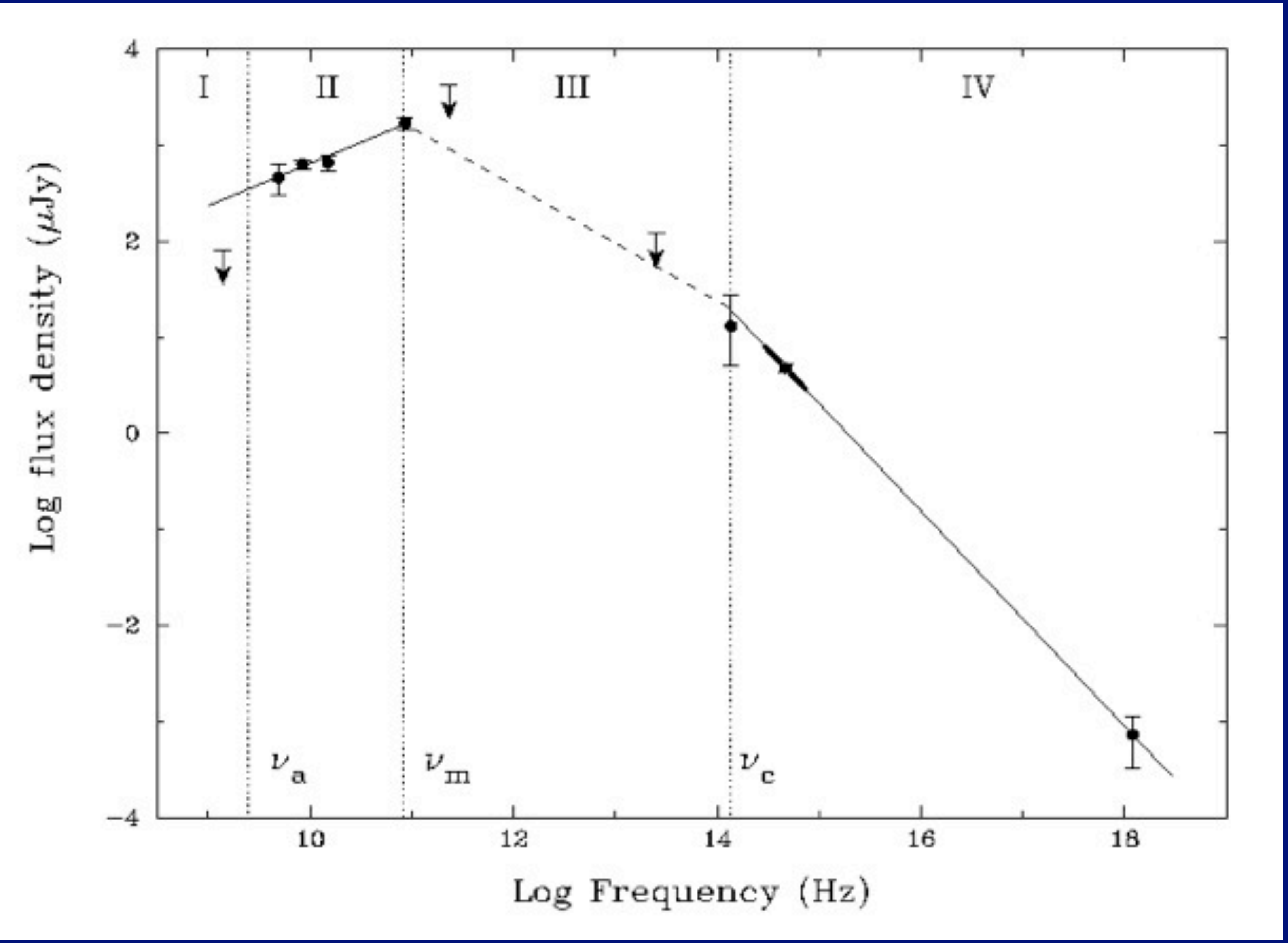
$$e_B = \varepsilon_B e = \varepsilon_B n_0 c^2\gamma^2$$

- **Electron distribution:**

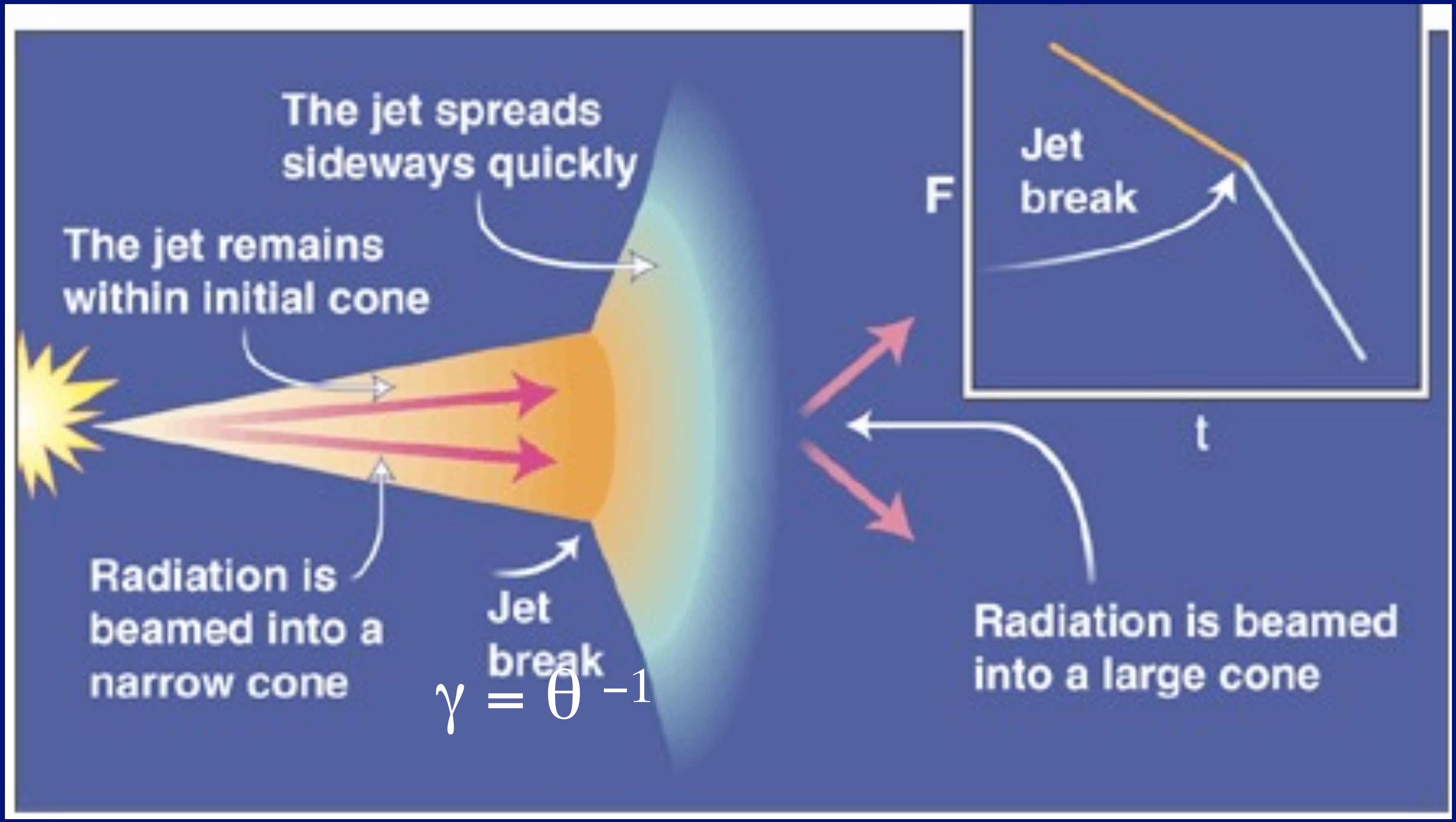
$$n(\gamma) \propto \gamma^{-p} \quad \text{for } \gamma > \gamma_{\min} \propto e_e$$

Comparison with Observations

(Sari, Piran & Narayan 98; Wijers & Galama 98; Granot, Piran & Sari 98)



JETS and BEAMING



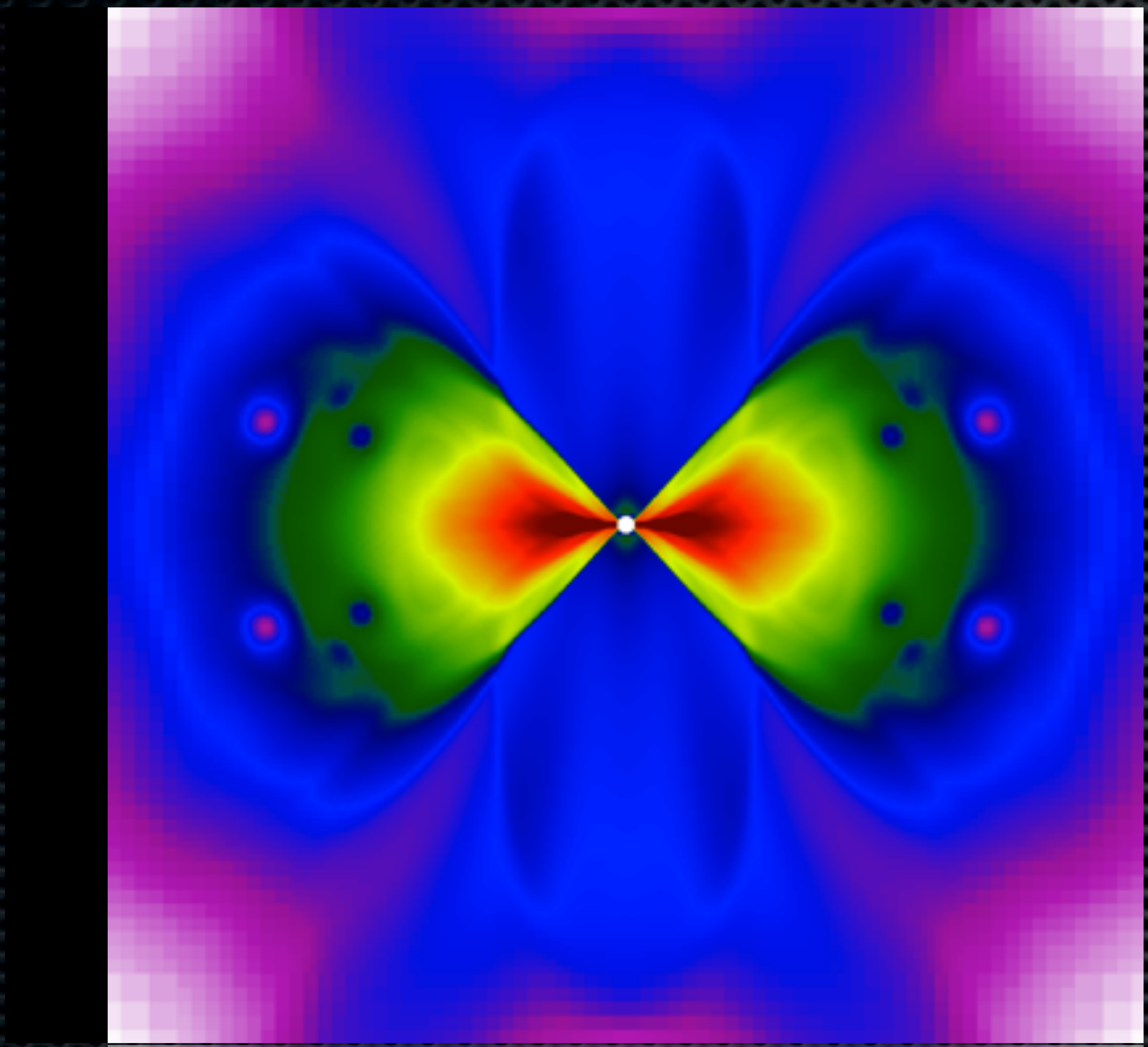
$\gamma = \theta^{-1}$

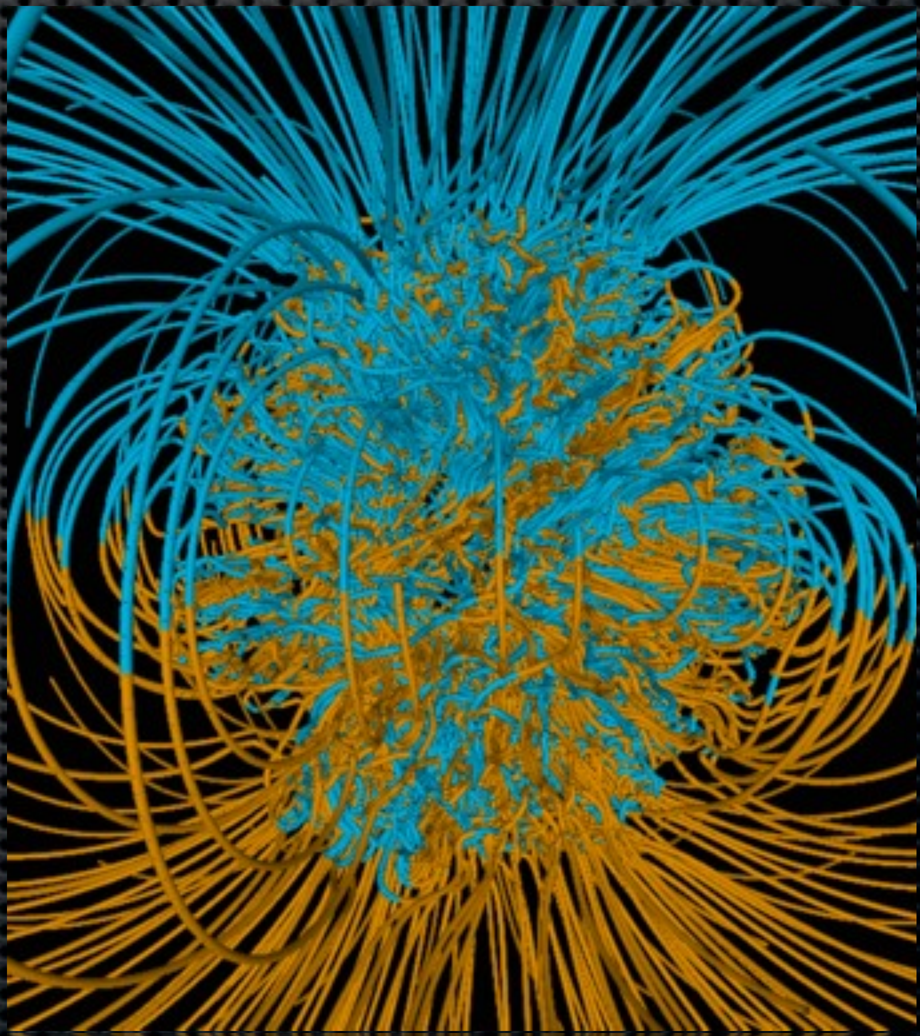
Jets with an opening angle q expand forwards until $\Gamma = \theta^{-1}$ and then expand sideways rapidly lowering quickly the observed flux (Piran, 1995; Rhoads, 1997; Wijers et al, 1997; Panaitescu & Meszaros 1998).

Observations of time of jet break can give estimate of **θ**

Today, there are two principal models being discussed for GRBs of the "long-soft" variety:

The collapsar model **The millisecond magnetar**





The ultimate source of energy in both is rotation and both produce relativistic jets

Do all Long GRBs have a SN?

- Only a few normal GRBs seen close enough
- Several Faint GRBs seen - all have had a SN
- At present, GRB-SNe seem to be energetic Ib/c SN... that have a wide dispersion in energy and mass
- There are a few cases where no SN has been seen.

GRBs formed by some very massive stars. Possibly some form blackholes directly, with no explosion. (This is a prediction of collapsar model)

Exploding Stars as Cosmic Beacons

- Want spectra R>2000 (preferably R=30000)
- Will take anything as a backdrop...
  - GRBs..Bright SN..
  - Aim - probe the gas in the GRB host galaxy.
  - GRB should probe relative normal galaxies at z>>0 (locally, occure preferentially in low metallicity environments)

GRBs as backdrops

- Rare...we have had 5 objects in 5 years at $z>6$
- Bright $J=15\text{-}20$ for several hours, and $J<22$ for several days
- IR echelle on 8m could catch the next one, but ELTs could do many very well...if we can find enough of them in the future.

Already we are making progress.

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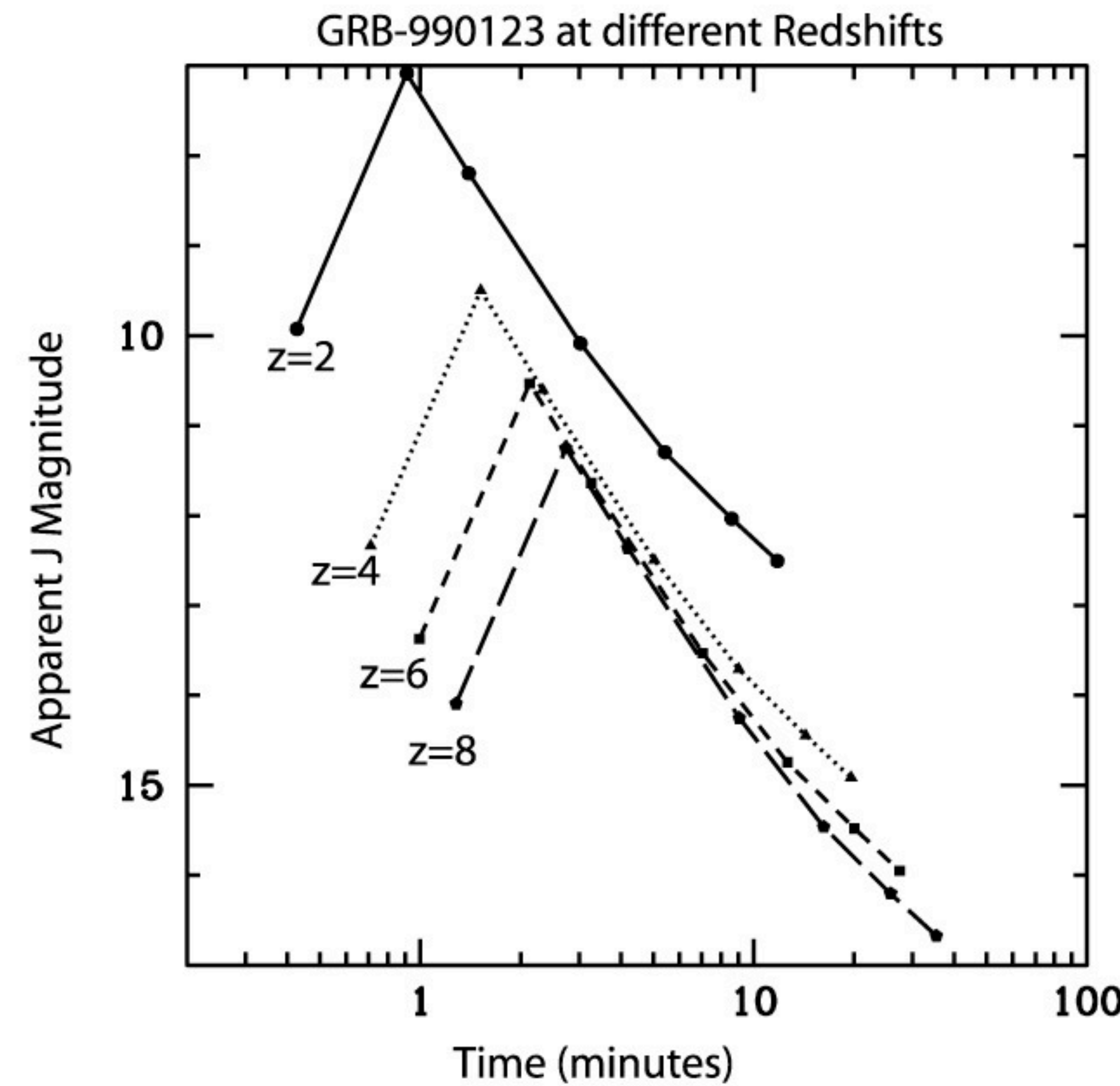
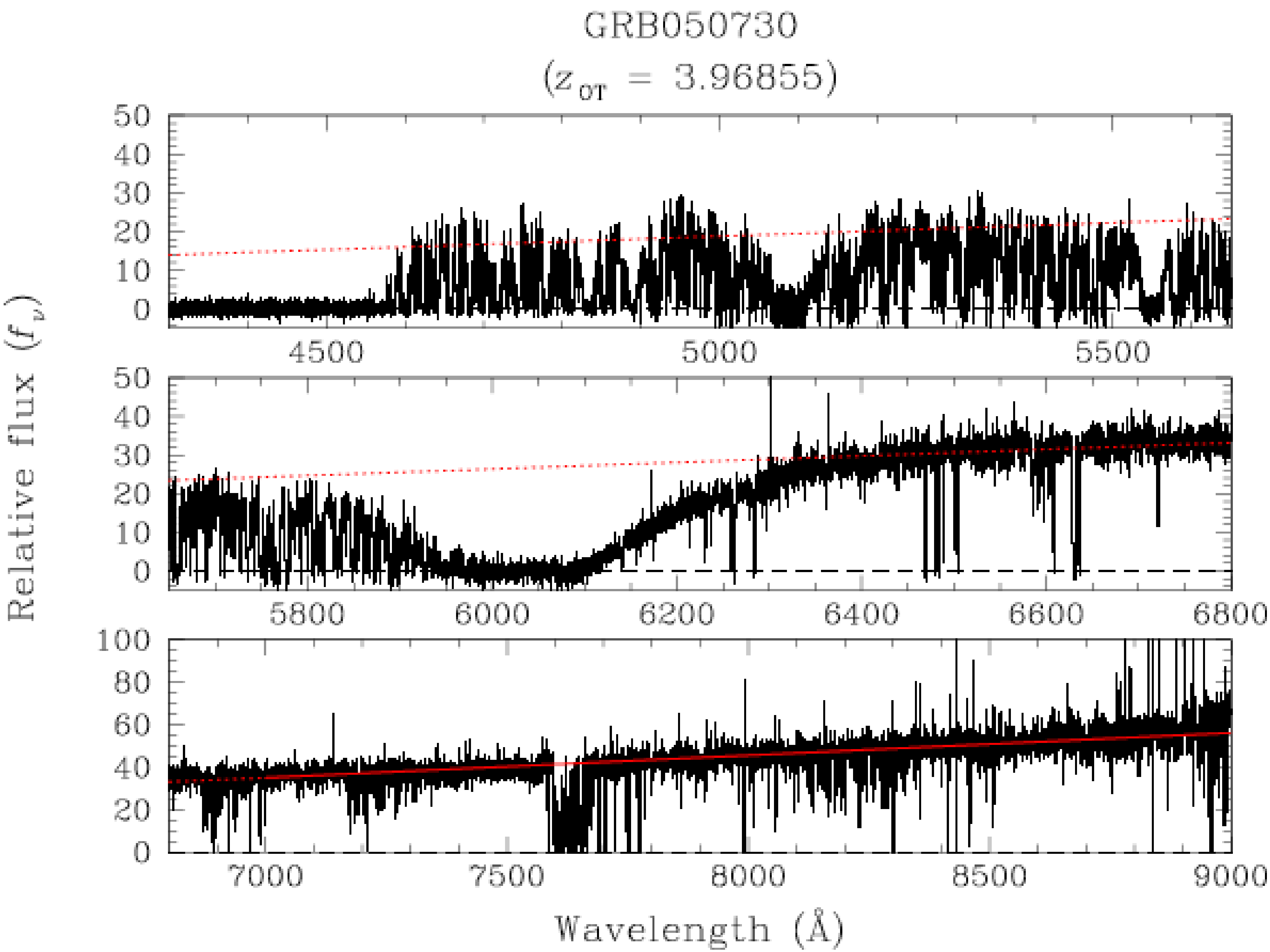
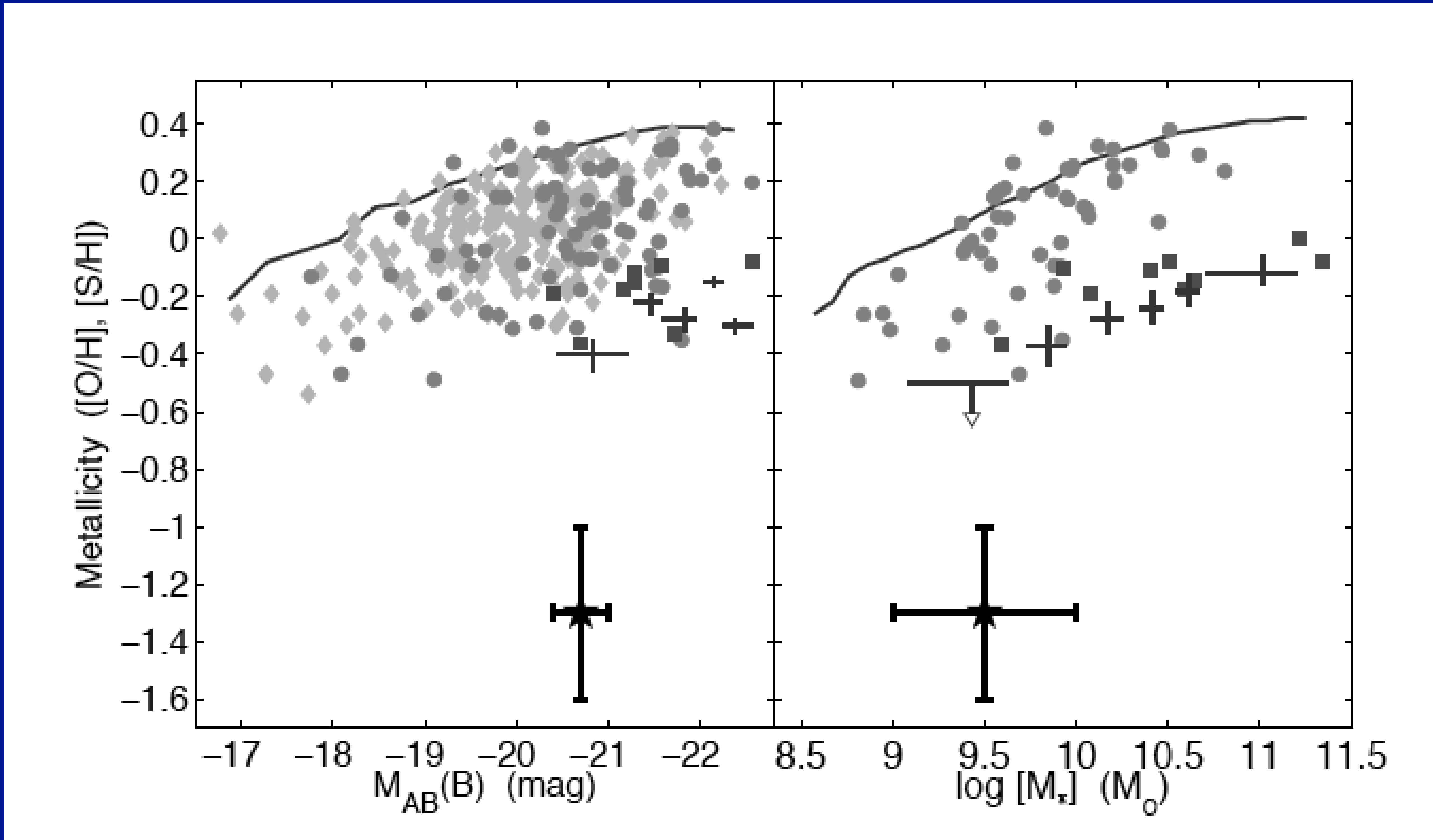


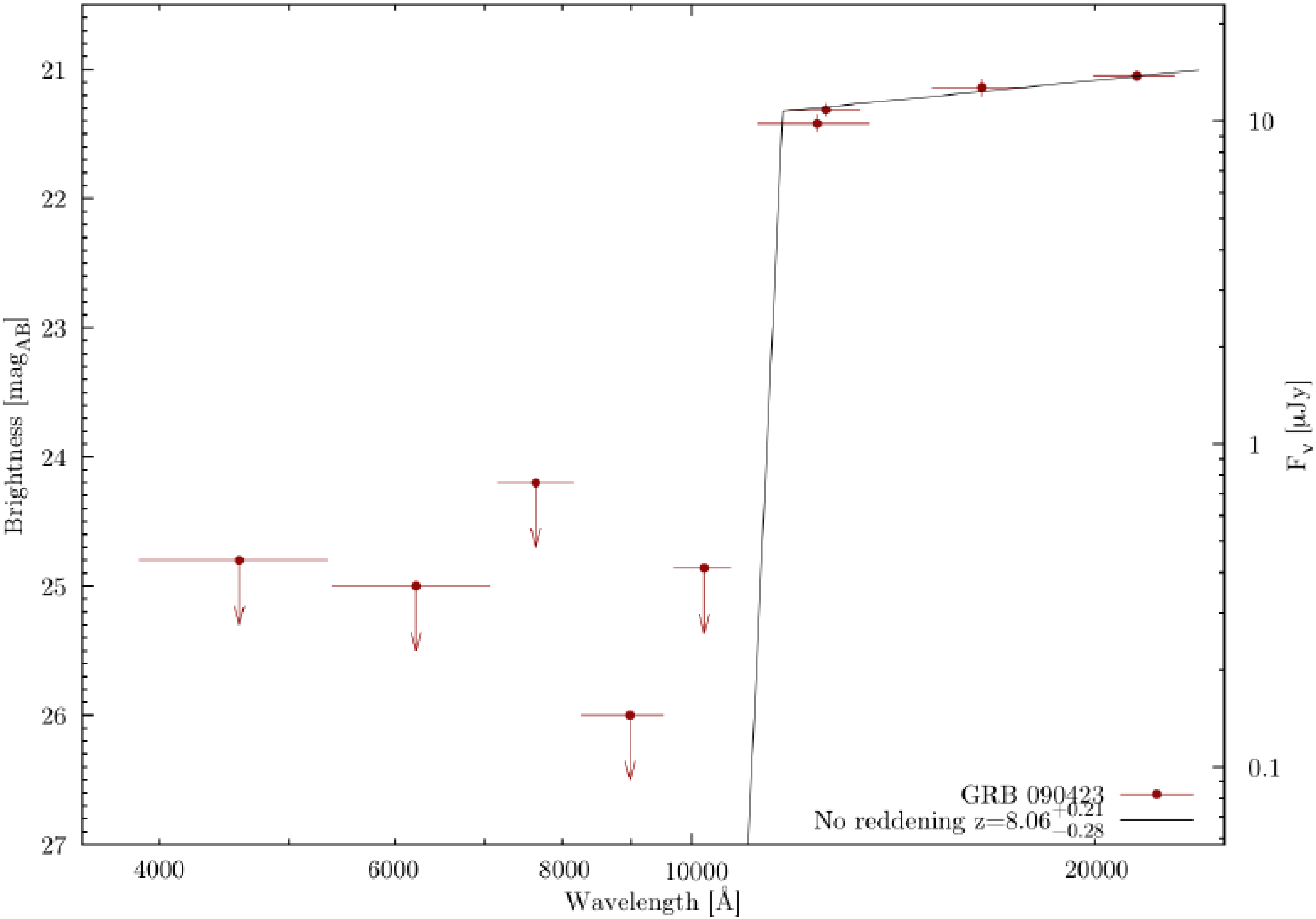
Chen et al.

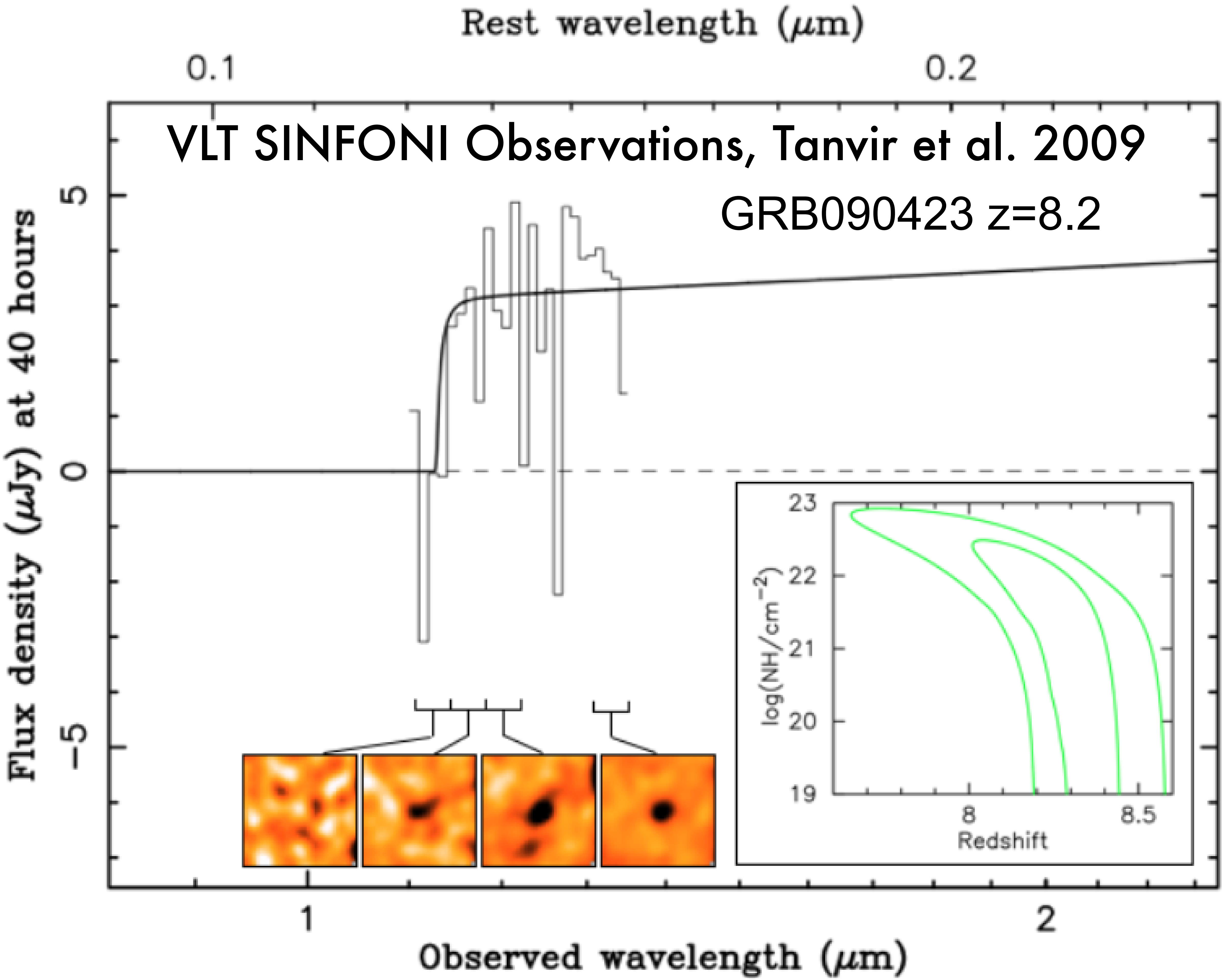

GRB050730
(z_{OT} = 3.96855)
Relative flux (f_ν)
Wavelength (Å)
4500
5000
5500
5800
6000
6200
6400
6600
6800
7000
7500
8000
8500
9000



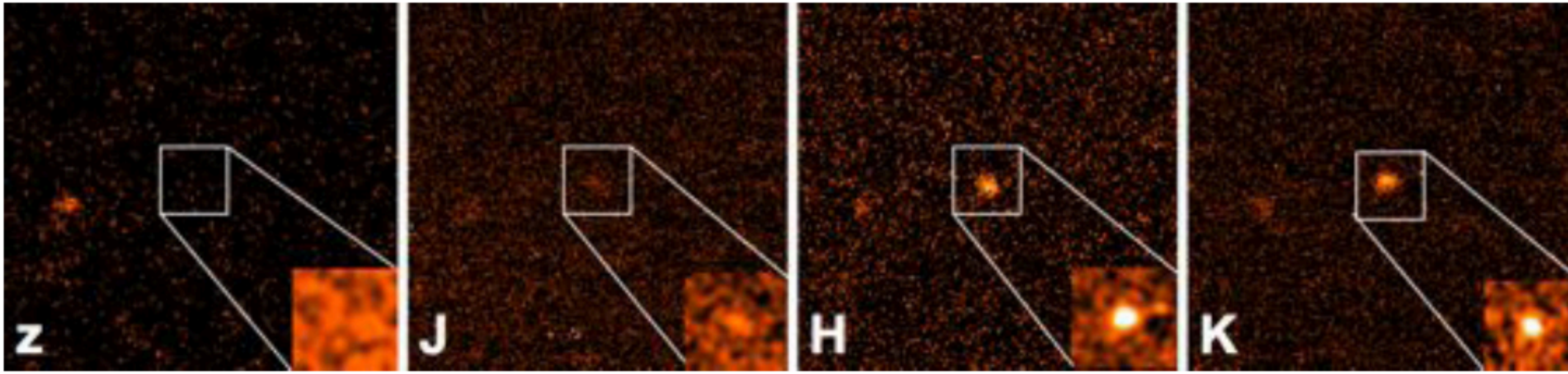
GRB050904 at 6.29, Kawai 06, Berger 06

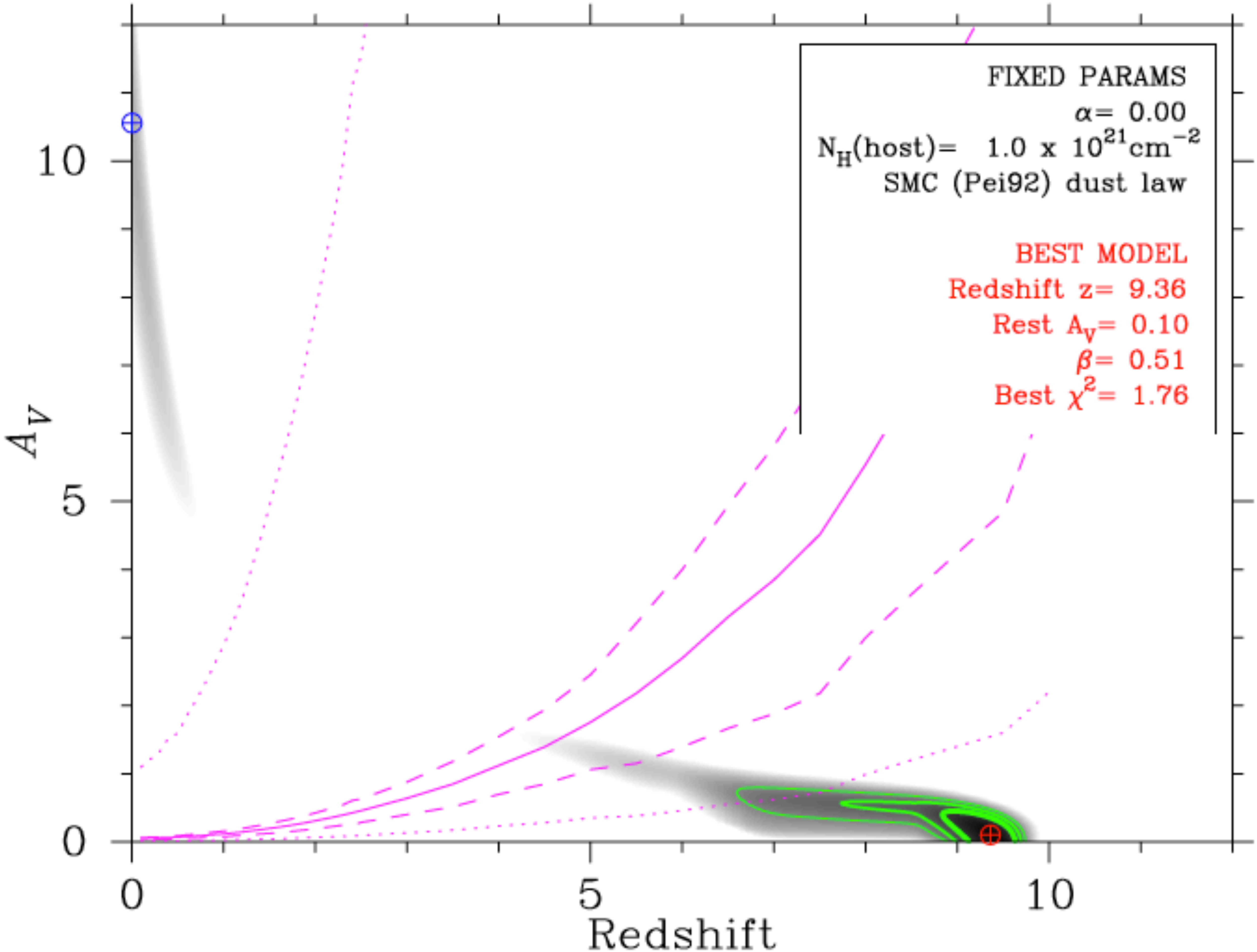
Tanvir et al. 2009




Rest wavelength (μm)
0.1
0.2
VLT SINFONI Observations, Tanvir et al. 2009
GRB090423 z=8.2
Flux density (μJy) at 40 hours
5
0
−5
log(NH/cm−2)
23
22
21
20
19
8
8.5
Redshift
1
2
Observed wavelength (μm)

GRB 090429B z=9.4?



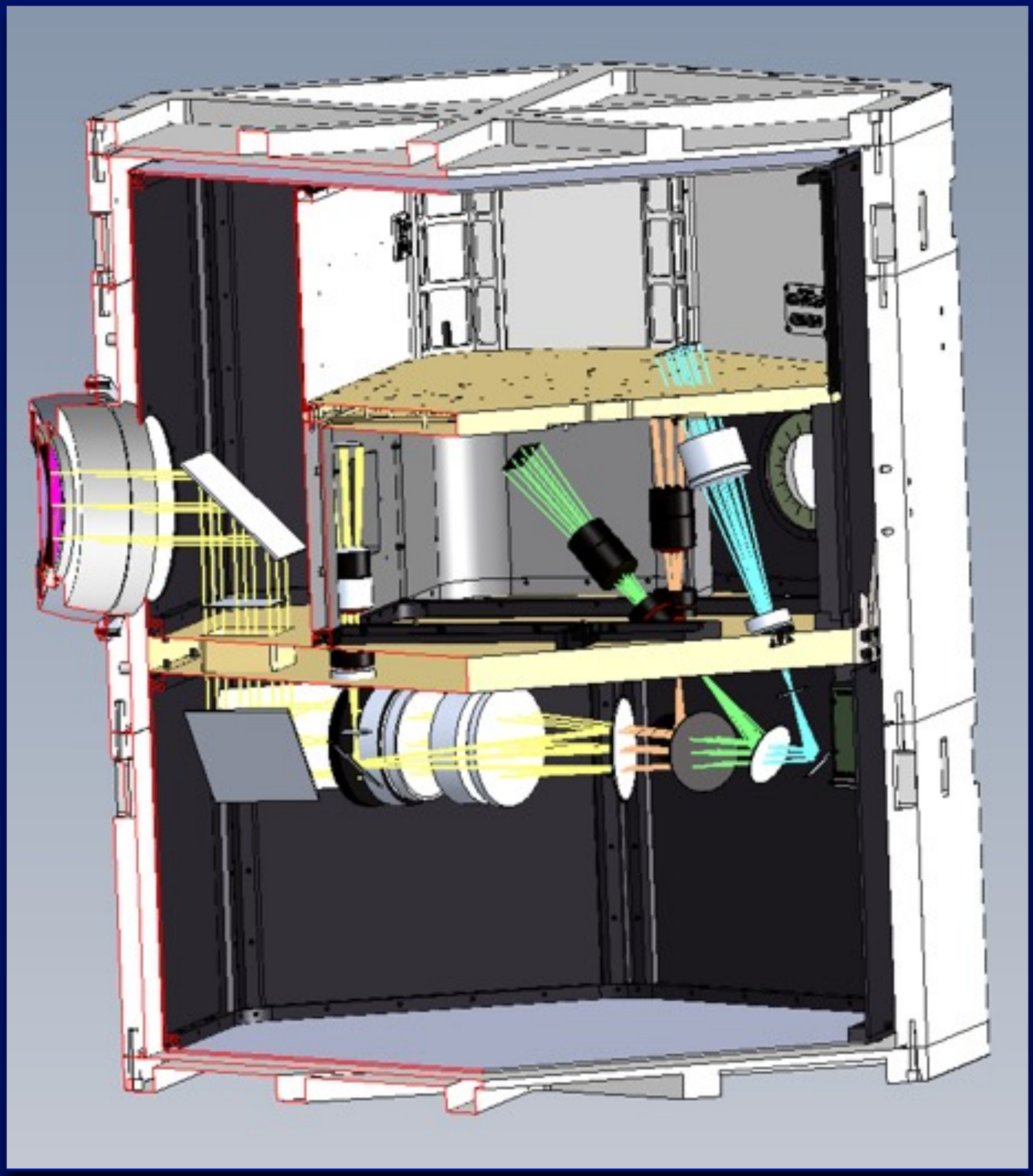

FIXED PARAMS
α= 0.00
N_H(host)= 1.0 x 10^{21}cm^{-2}
SMC (Pei92) dust law
BEST MODEL
Redshift z= 9.36
Rest A_V= 0.10
β= 0.51
Best χ^2= 1.76
A_V
Redshift
0
5
10
0
5
10

Lots of Lost Opportunities

- 5 objects now discovered - but we have never gotten spectroscopy quick enough - always >>5 hrs
- Need a dedicated instrument on an 8-m to identify these objects quickly, or wait for an ELT...

MultiBand Imager

- 4 channel IR imager
- High Throughput (50%)
- Z J H K simultaneous
- stable, immediate automated data reduction
- Good for GRBs, planets, SN Ia... but not Gemini...



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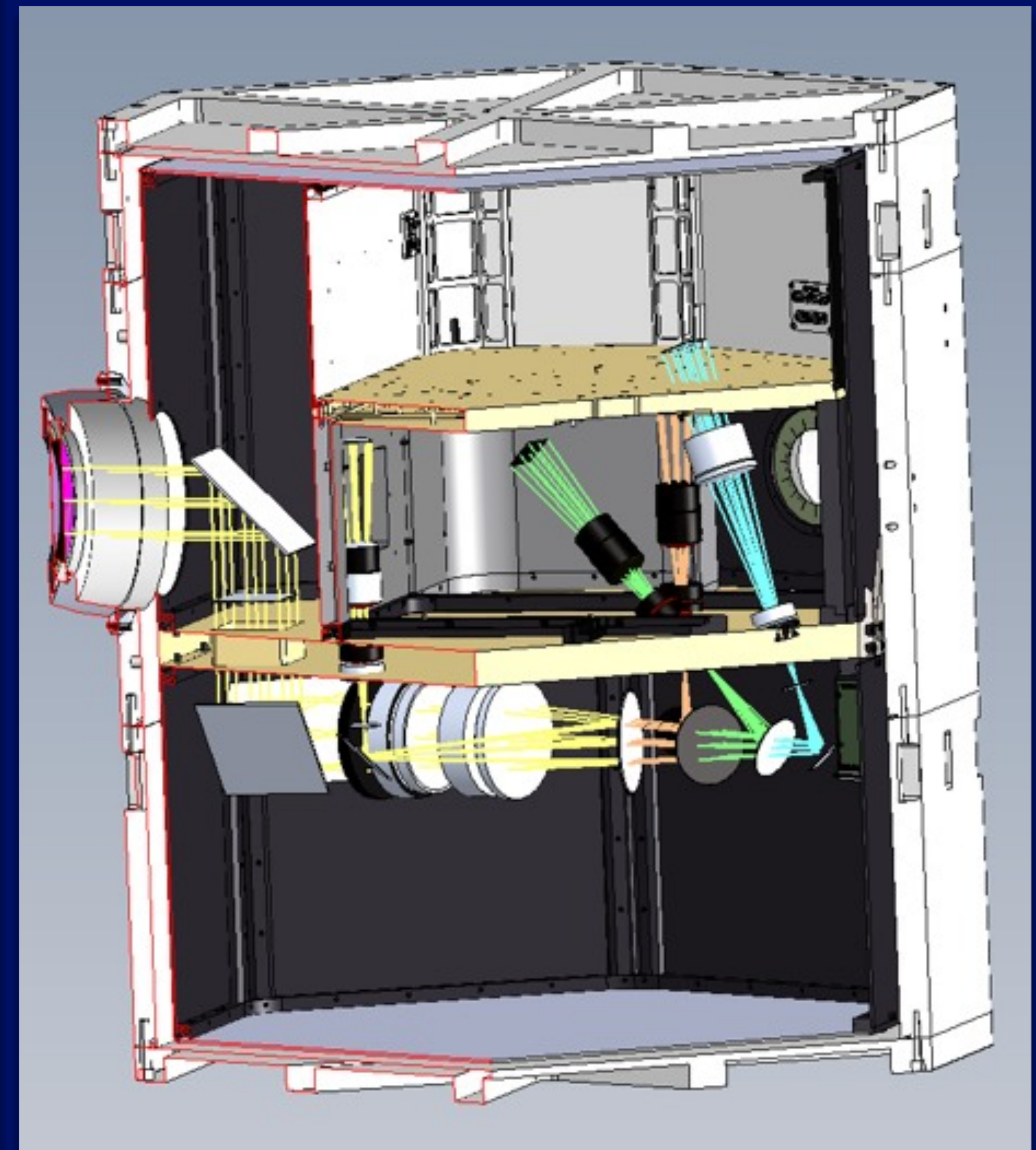
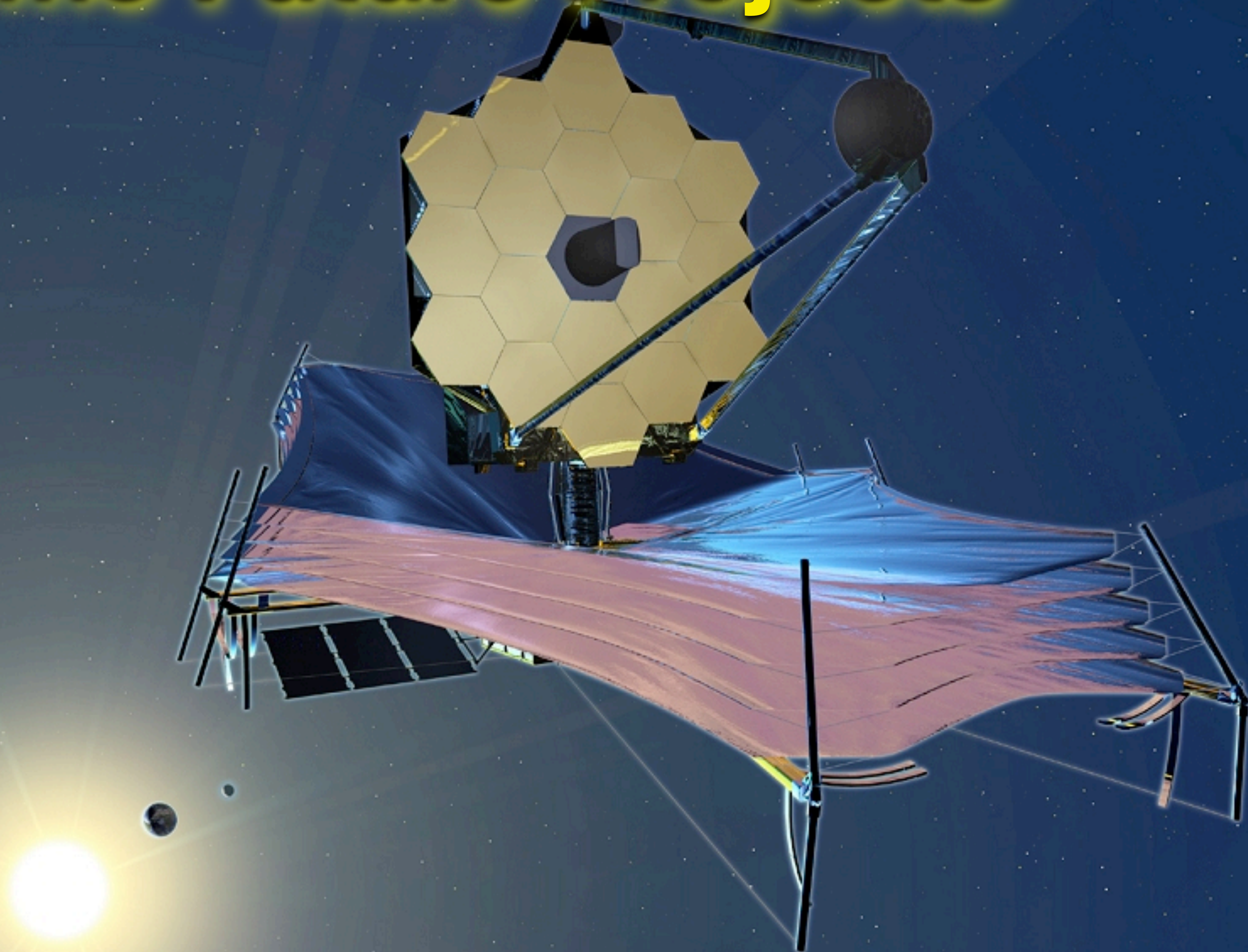
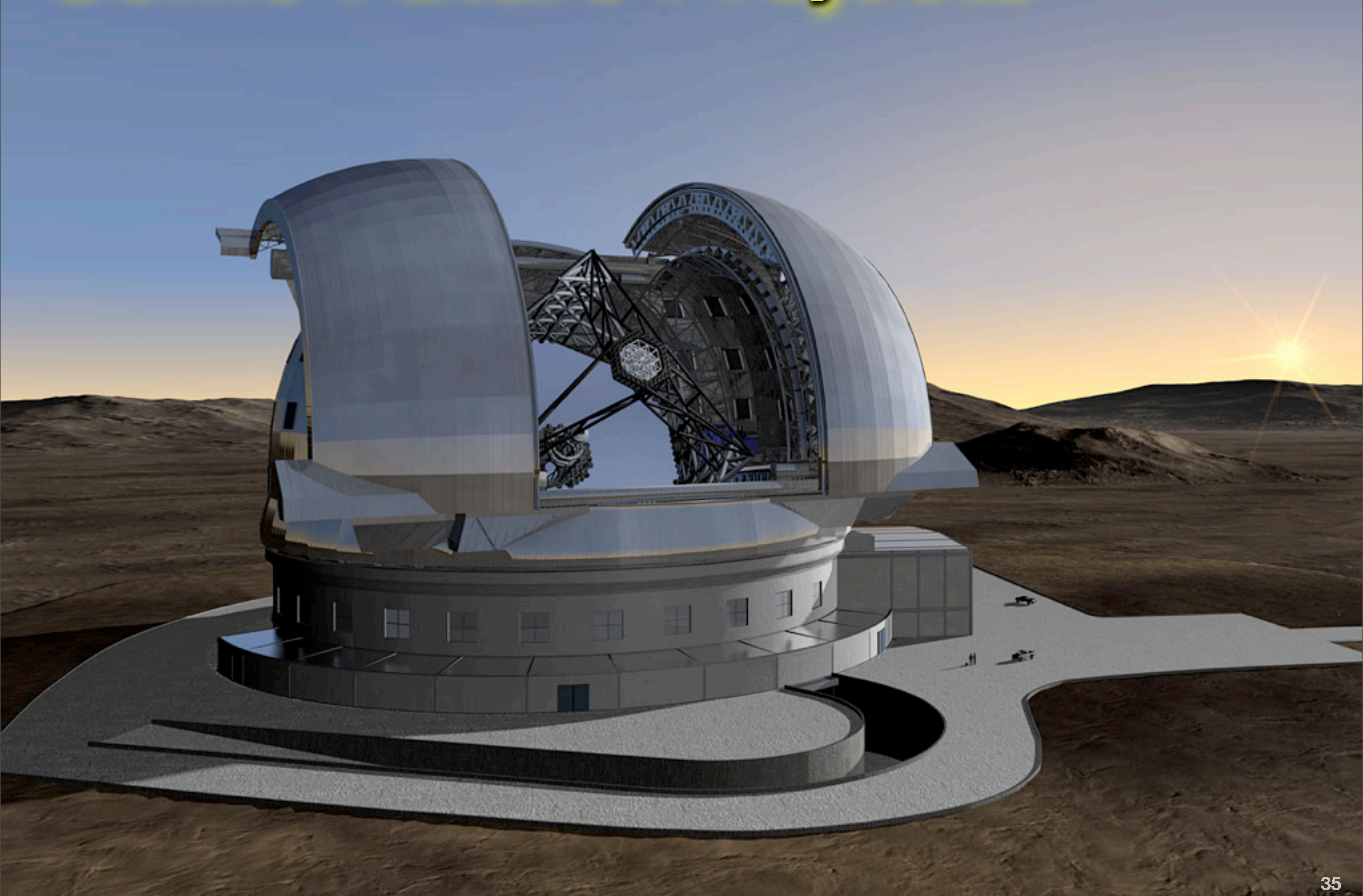


Australian Astronomy's highest priority... to Join ESO and to build the SKA

Some Future Projects



Some Future Projects



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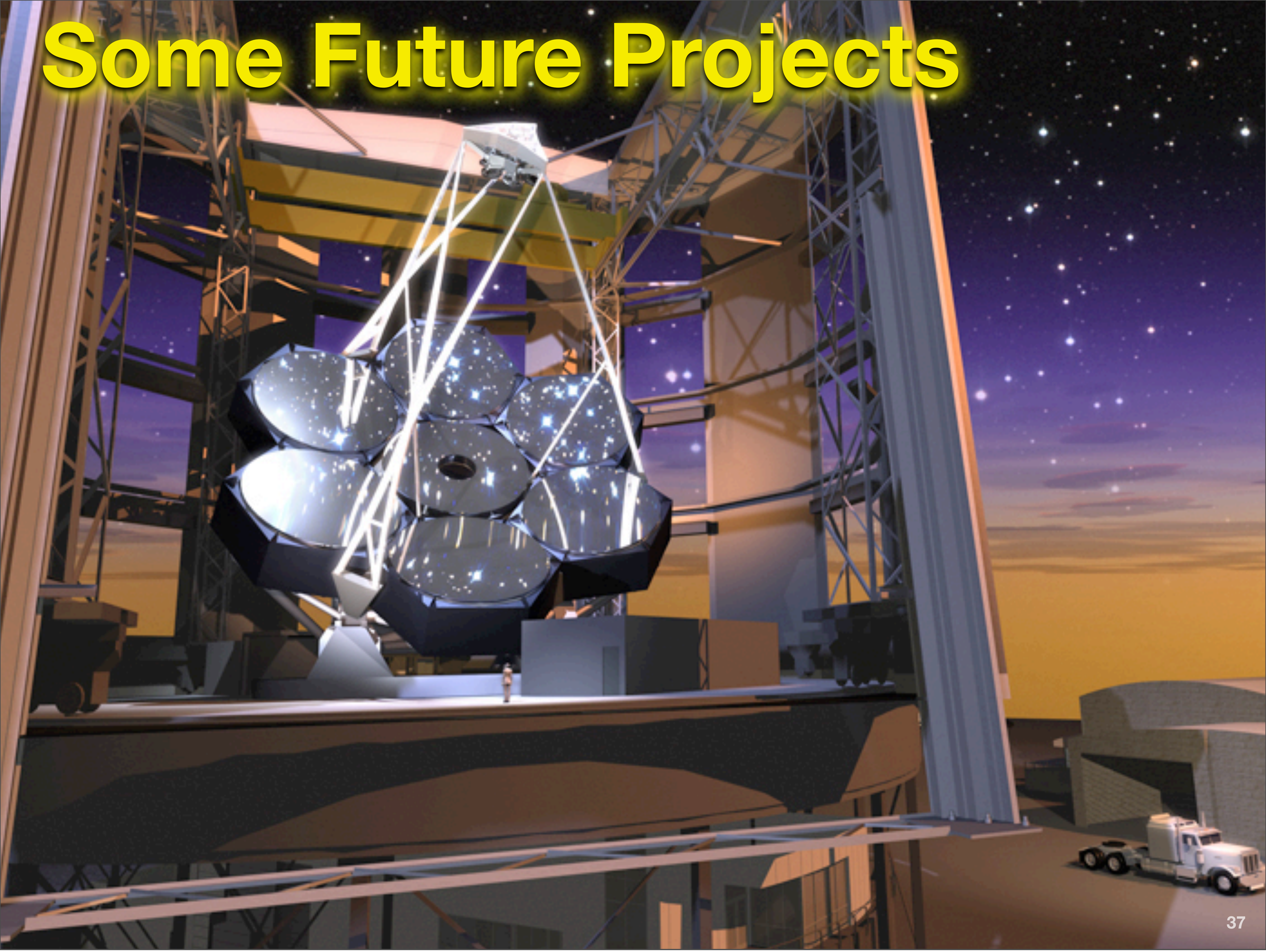
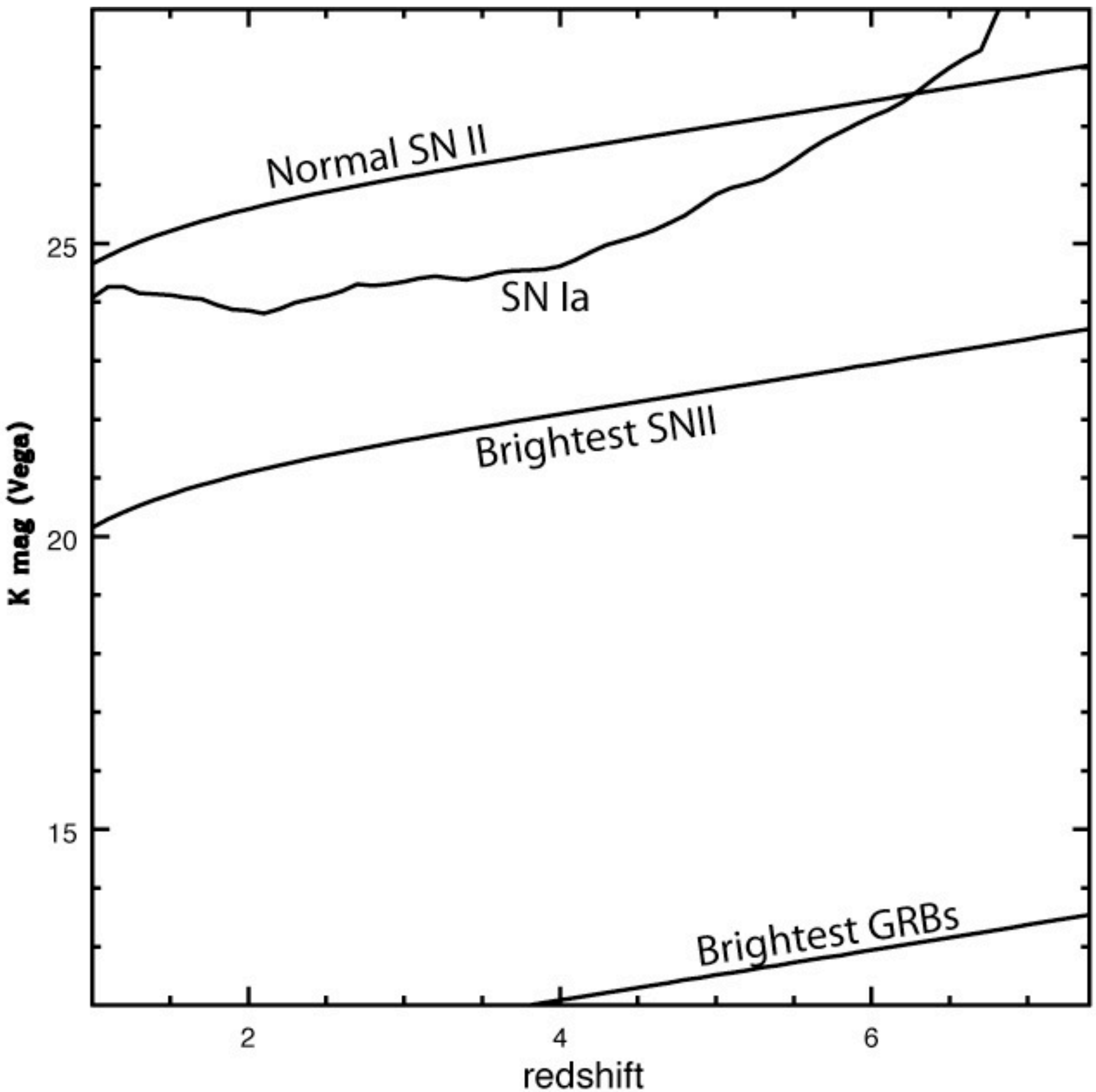
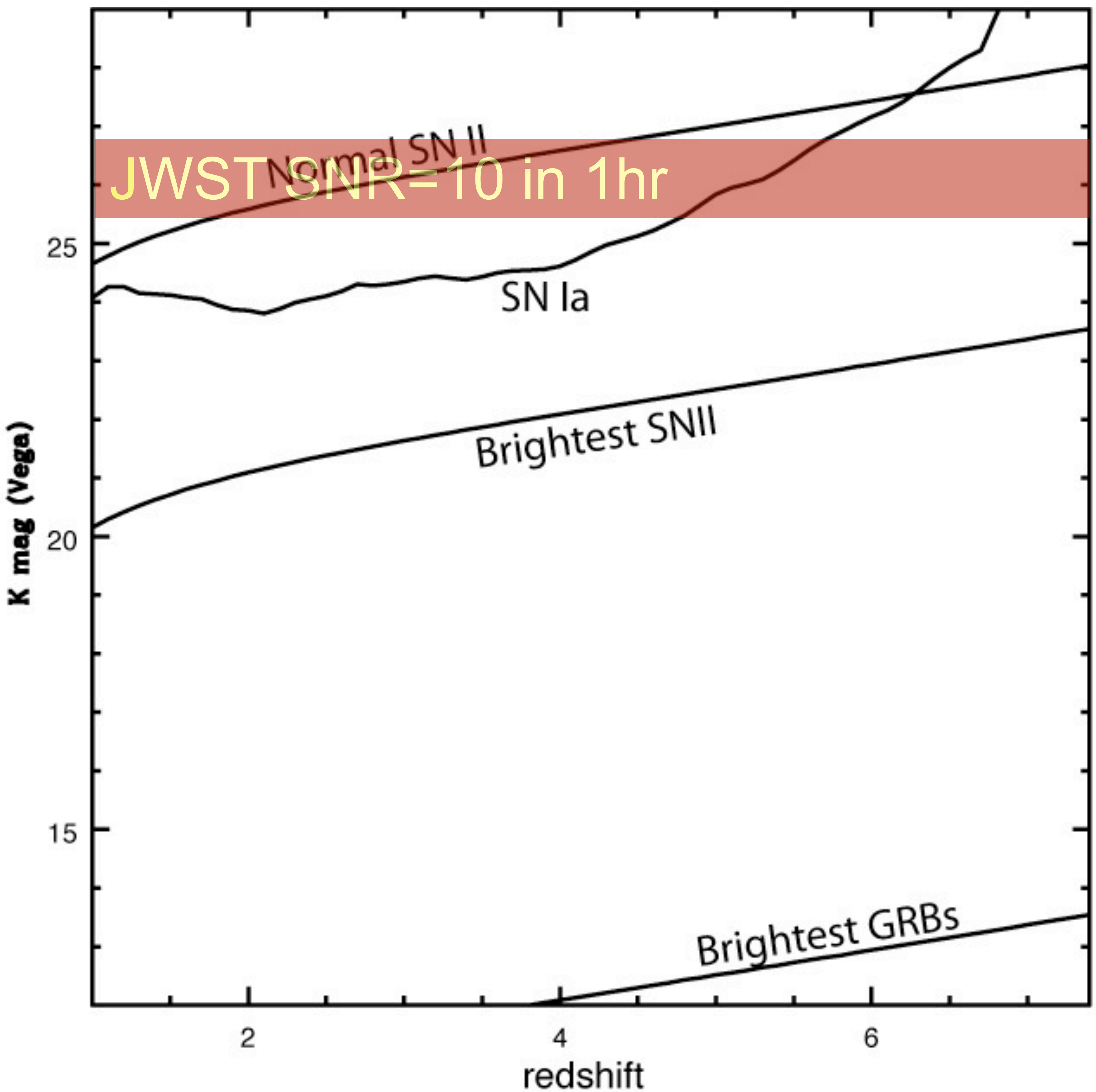


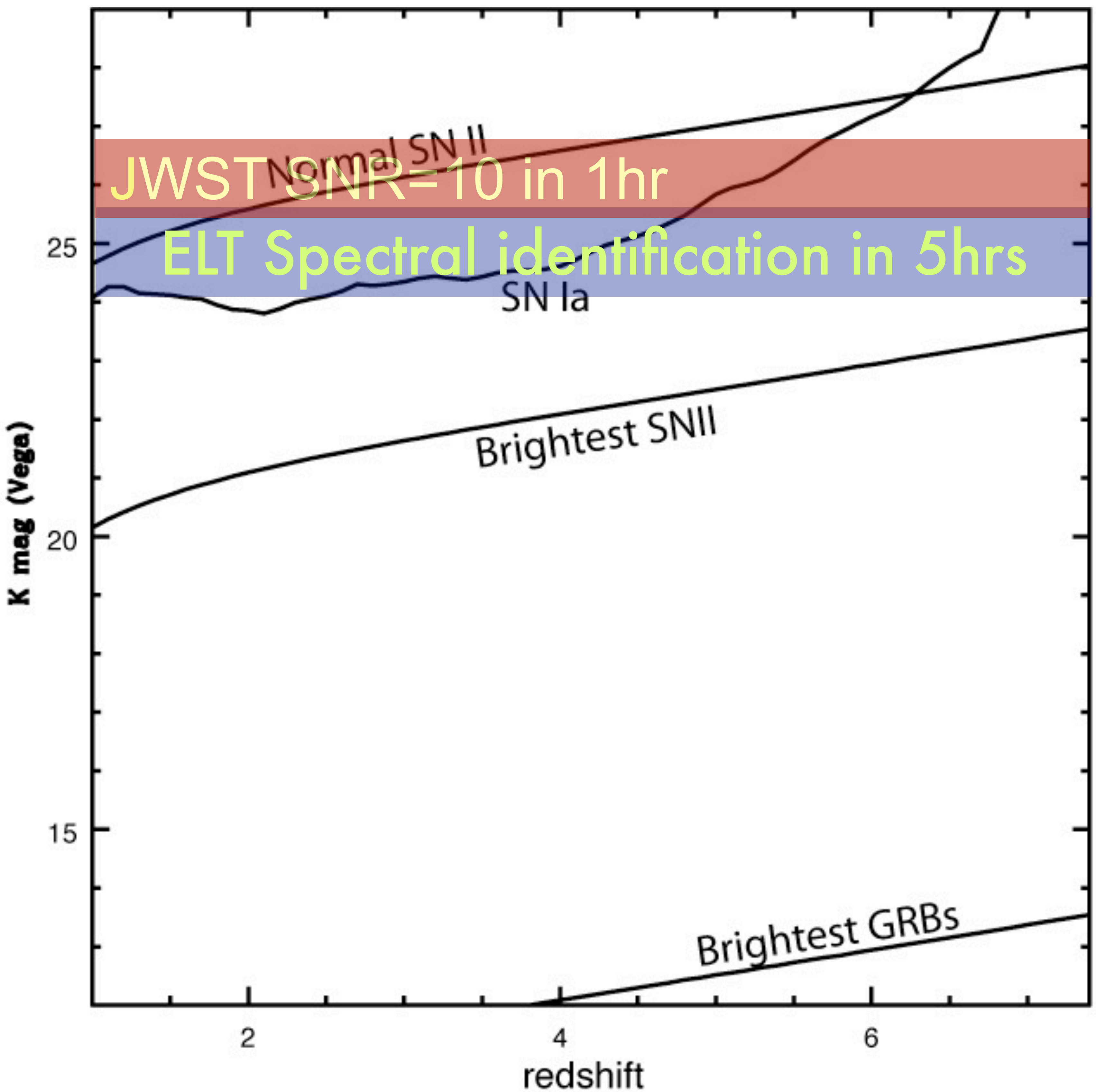
Brightness of Supernovae



Brightness of Supernovae



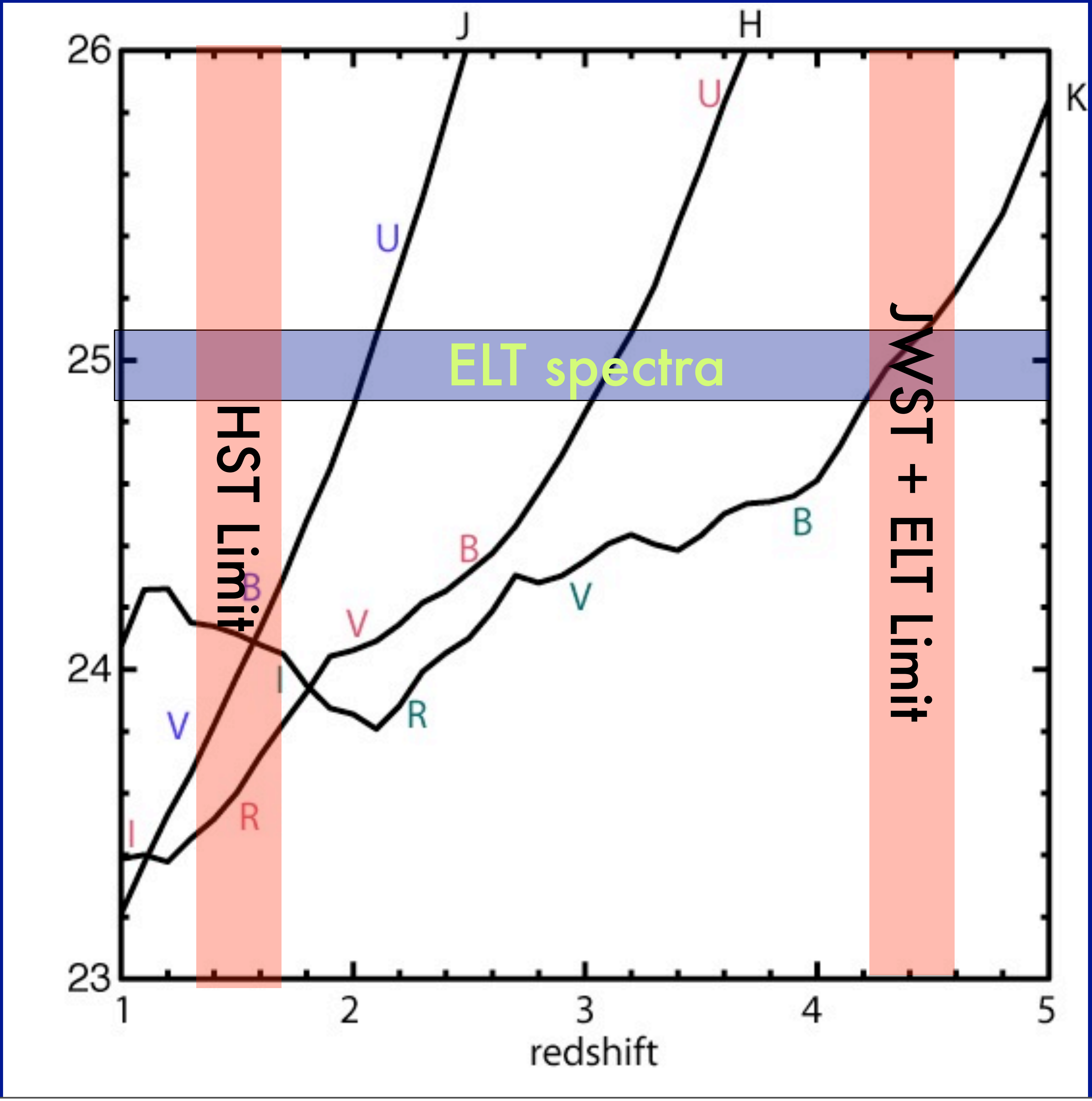
Brightness of Supernovae



Project: Cosmology with SN Ia

- Extend SN Ia distances to z>1 to look for depending on your perspective...
  - early time evolving Dark Energy (crazy theorists)
  - independent measure of Ω_M (Cosmological number crunchers)
  - Evolution of SN Ia population (Skeptics..me!)
- Current SN Ia data extend to z=1.2-1.5 but data are really very poor, despite the HST salesmanship.

Type Ia brightnesses



Project: When do SN Ia turn on?

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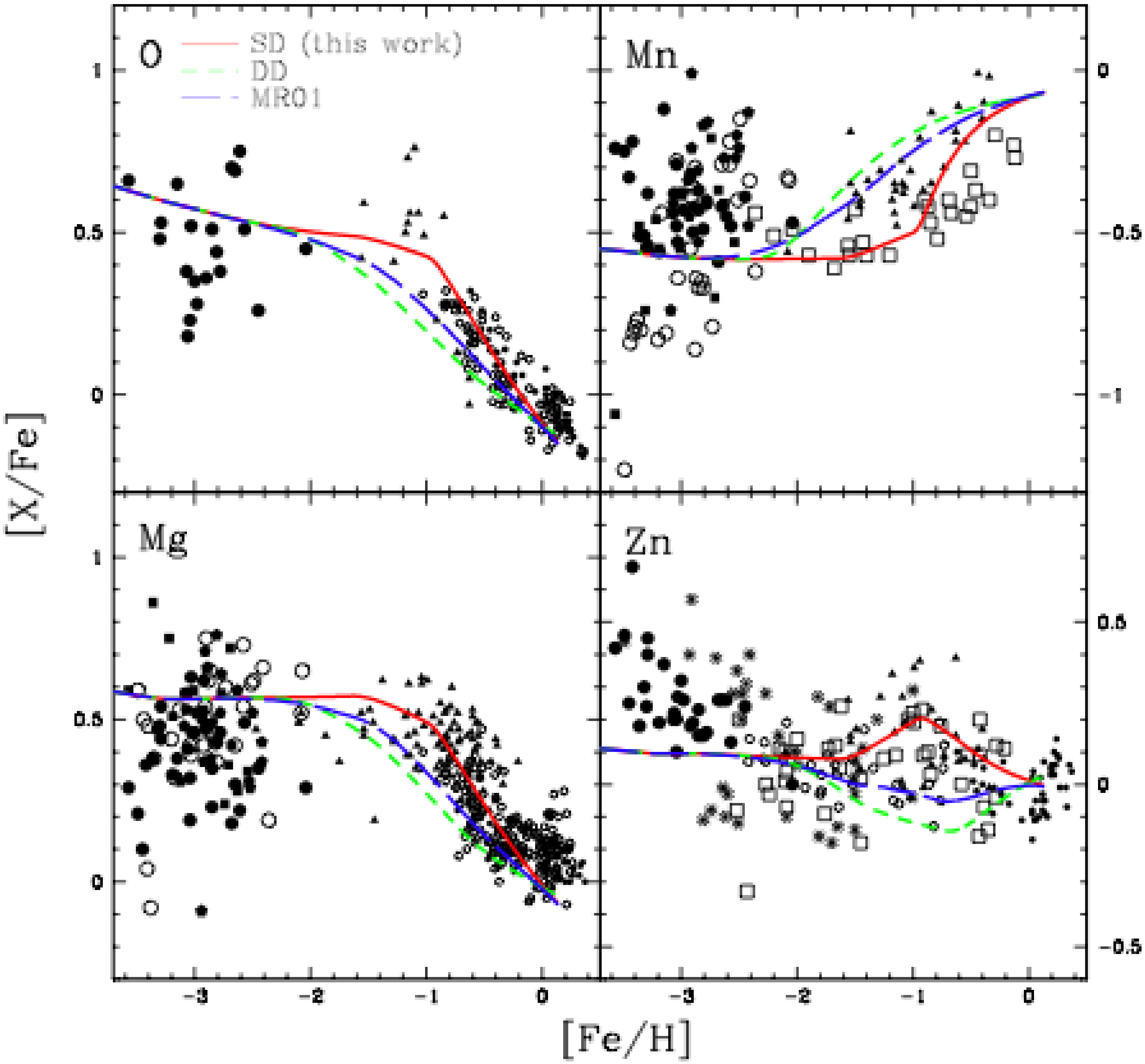
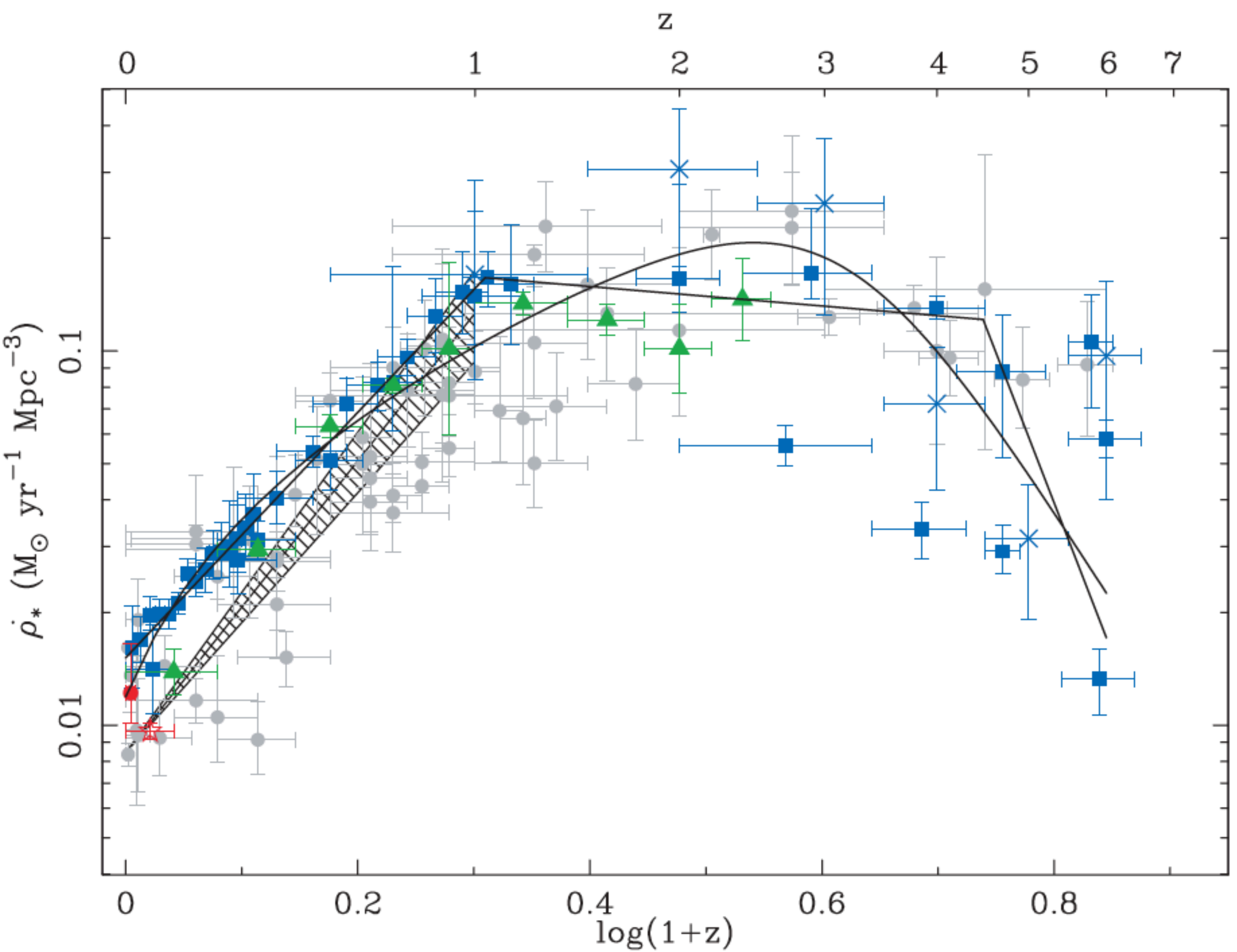
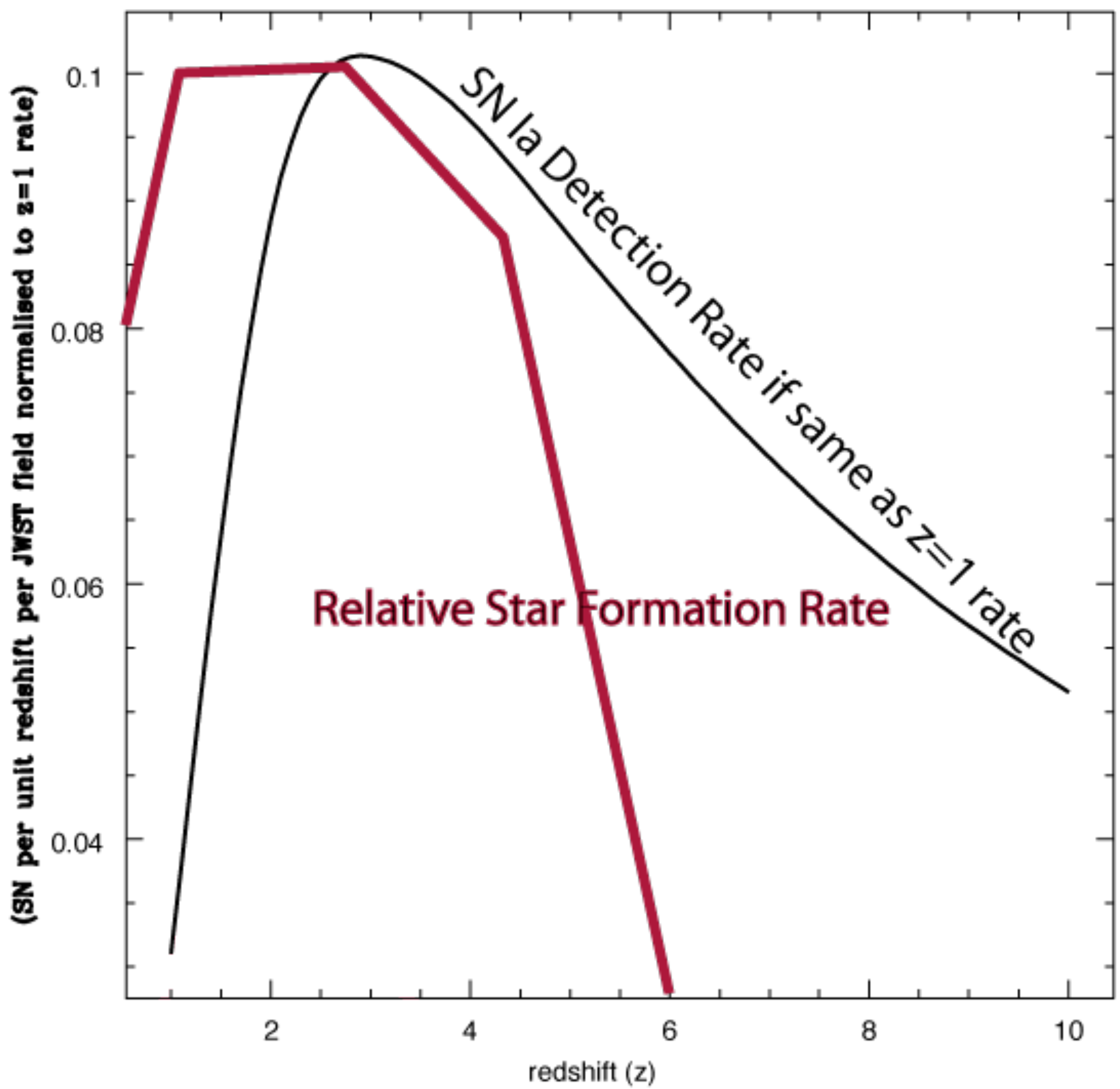
- Astronomers use α/Fe to characterise the chemical evolution of the Universe.
- SN Ia are responsible for 70% of the Fe in the current Universe.
- Find when the SN Ia turn on and we will understand the timescale of galactic chemical enrichment. (May depend on time and metallicity)

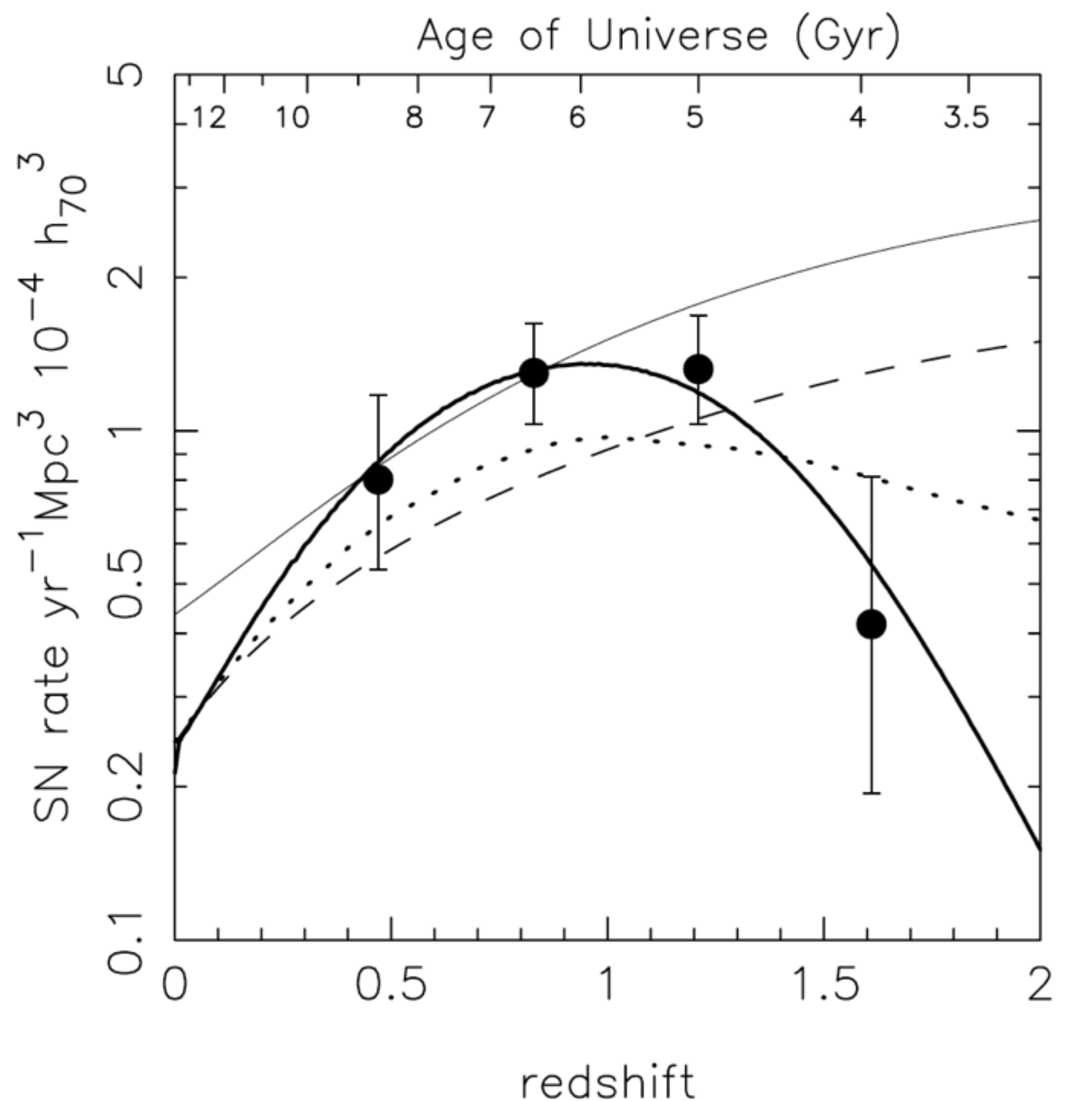


O
SD (this work)
DD
MR01
Mn
Mg
Zn
[X/Fe]
[Fe/H]
1
0.5
0
−3
−2
−1
−0.5
−1



z
0
1
2
3
4
5
6
7
0.1
0.01
$\dot{\rho}_*$ ($M_\odot$ yr^{-1} Mpc^{-3})
0
0.2
0.4
0.6
0.8
log(1+z)

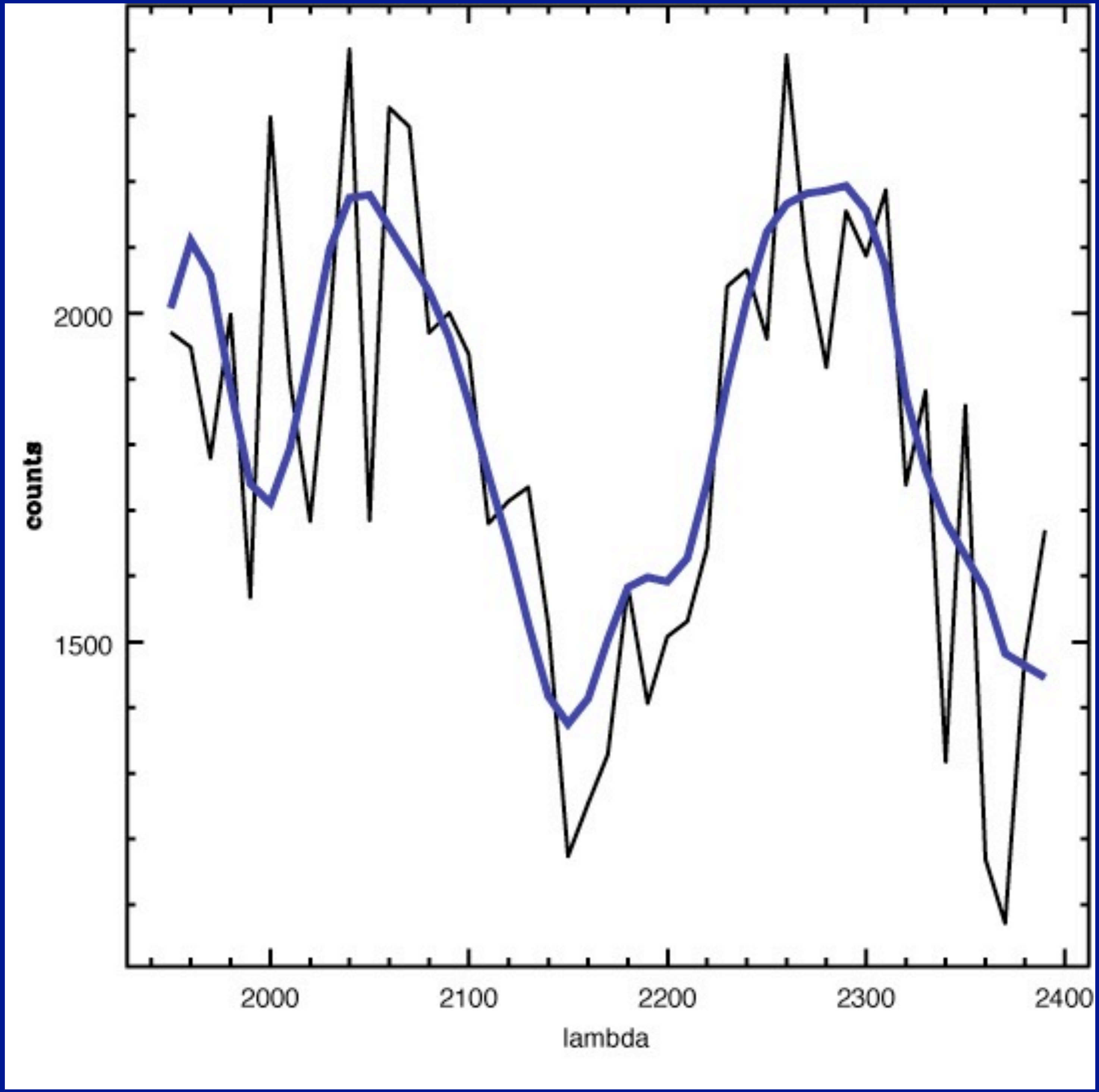

SN Ia Detection Rate if same as z=1 rate
Relative Star Formation Rate
(SN per unit redshift per JWST field normalised to z=1 rate)
redshift (z)
0.1
0.08
0.06
0.04
2
4
6
8
10


Age of Universe (Gyr)
12
10
8
7
6
5
4
3.5
SN rate yr^{-1}Mpc^{3} 10^{-4} h$_{70}^{3}$
0.1
0.2
0.5
1
2
5
0
0.5
1
1.5
2
redshift

Project: SN Ia

- Requirements:
  - SN Discovery
  - SN Photometry (5% requirement)
  - SN Spectroscopy (R=300) for redshift and type confirmation.
- Plan: Discovery is straightforward (JWST) or MCAO on ELTs ... 1 SN Ia per 2-20 JWST Fields
- spectroscopy is harder, work between the lines, then bin up to required resolution

20000s, 22m R=200



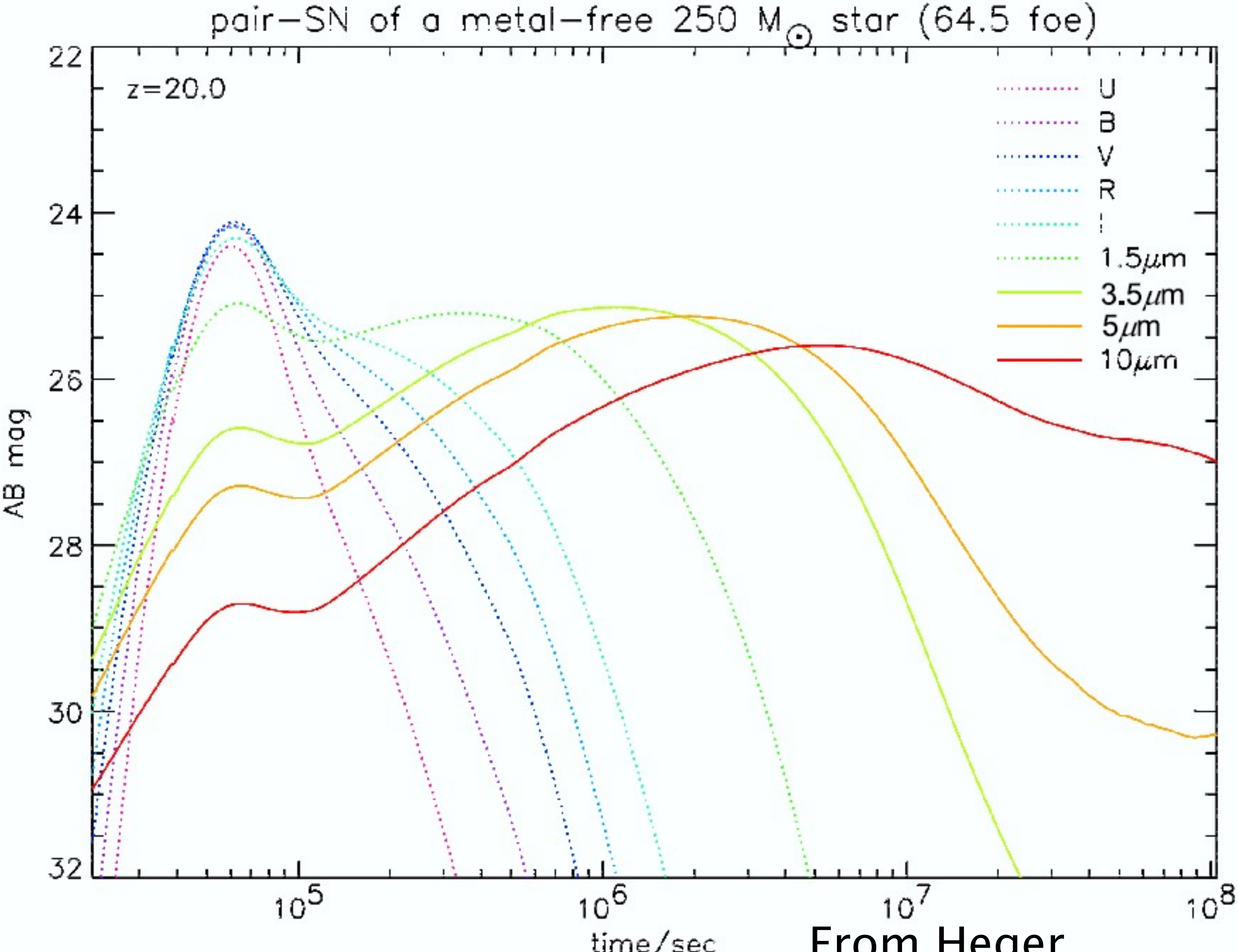
Using Bright SN to probe the First Stars

- SN track star formation, and they are by far the easiest things to track the first stars
- GRBs are also possibly reasonable tracers of star formation - but extremely rare
- Hydrogen dominated SN are bright in the UV, have broad features, and are suitable continuum sources to undertake absorption spectroscopy to measure chemical abundances and kinematics and see how galaxies are built up.

First Exploding Stars

- Detection...
  - Measure redshift from Gunn-Peterson effect. (K-band)

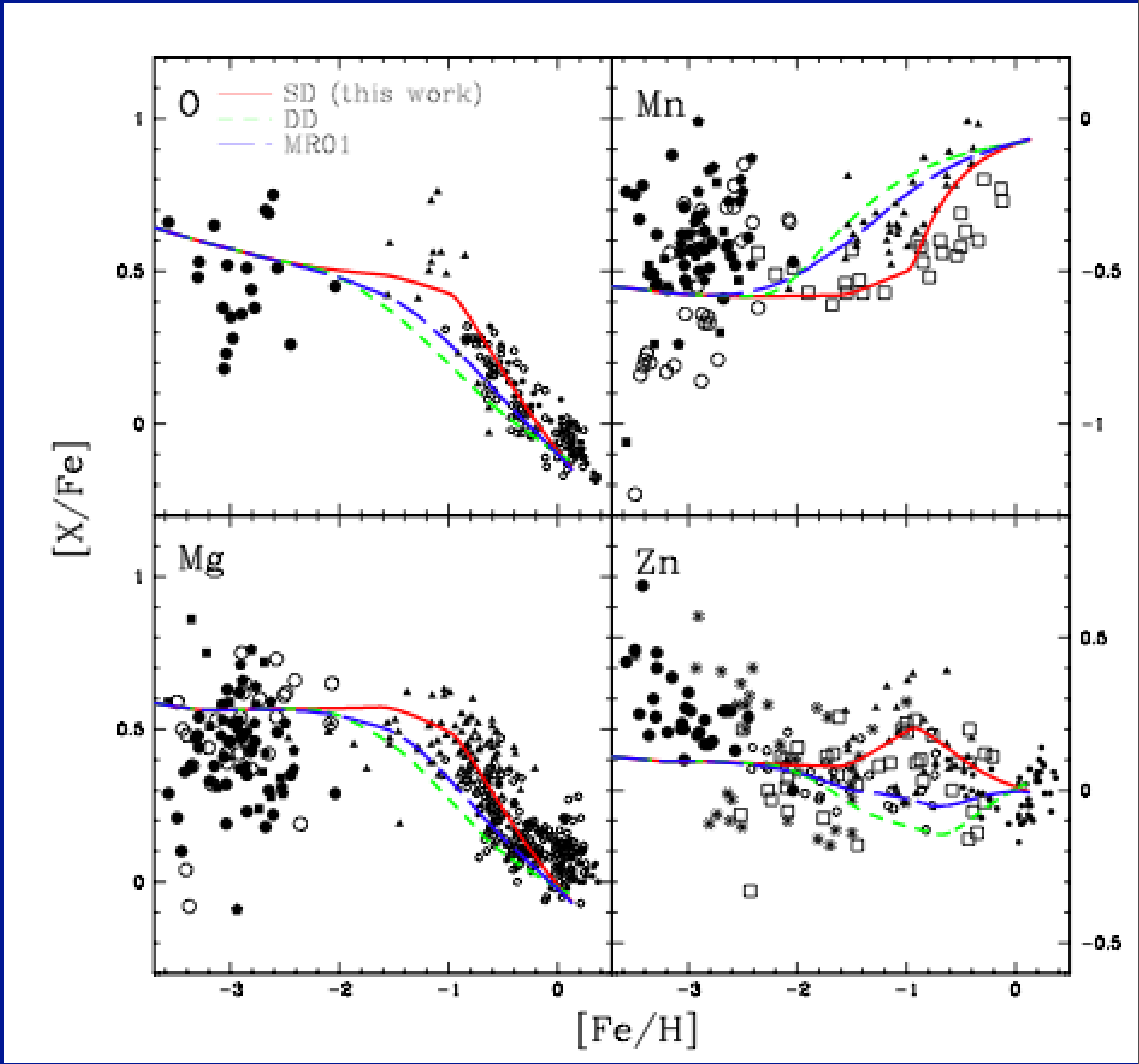
- But what are we going to detect?


pair−SN of a metal−free 250 $M_\odot$ star (64.5 foe)
z=20.0
U
B
V
R
I
1.5μm
3.5μm
5μm
10μm
AB mag
22
24
26
28
30
32
10^5
10^6
10^7
10^8
time/sec

From Heger

Chemistry of Stars at Fe/H<-2.5 is consistent with relatively normal (e.g. not Pair-Production) SN.

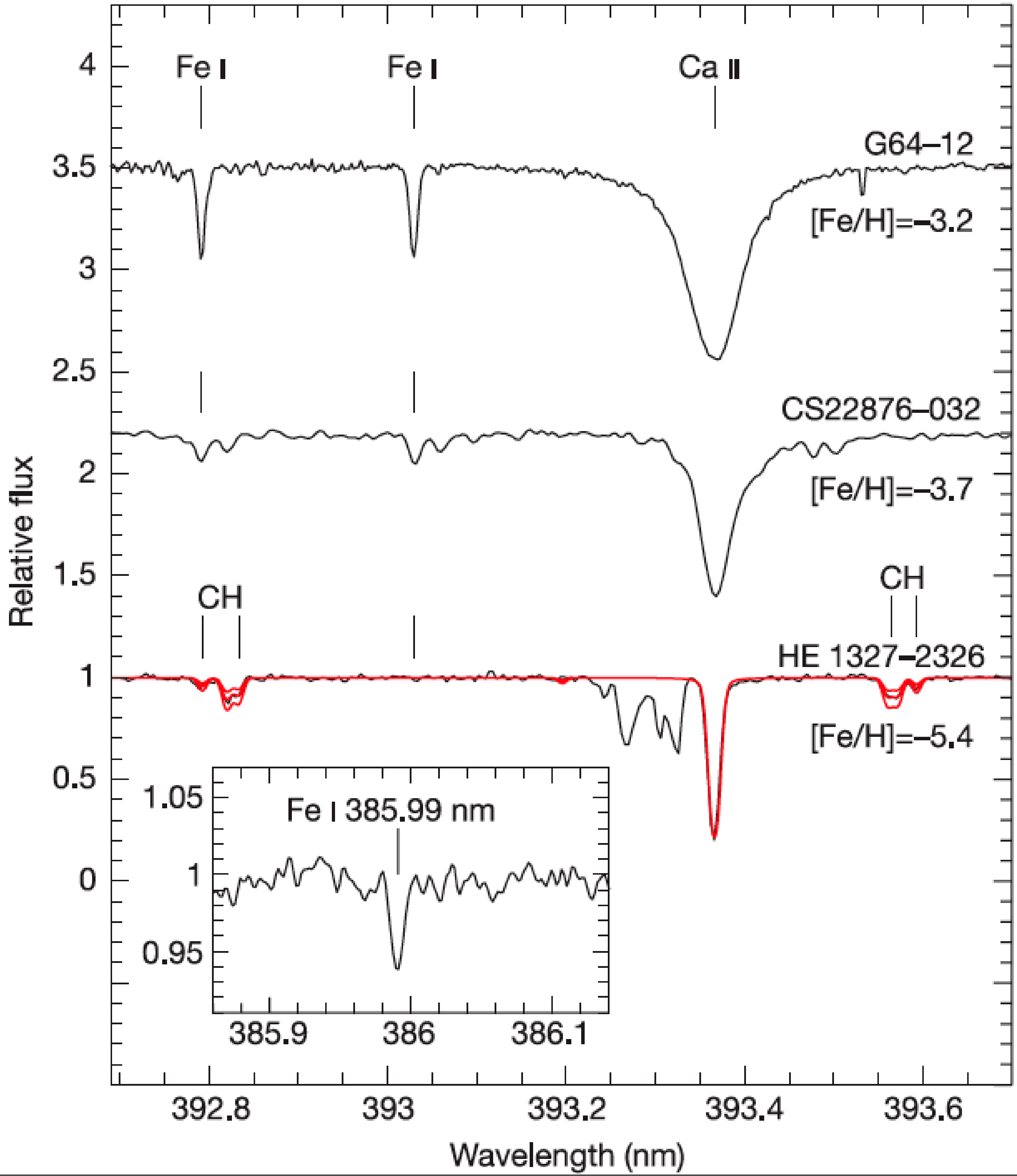
My best guess is that most SN at high-Z will be your run-of-the mill objects and consequently very hard to see!



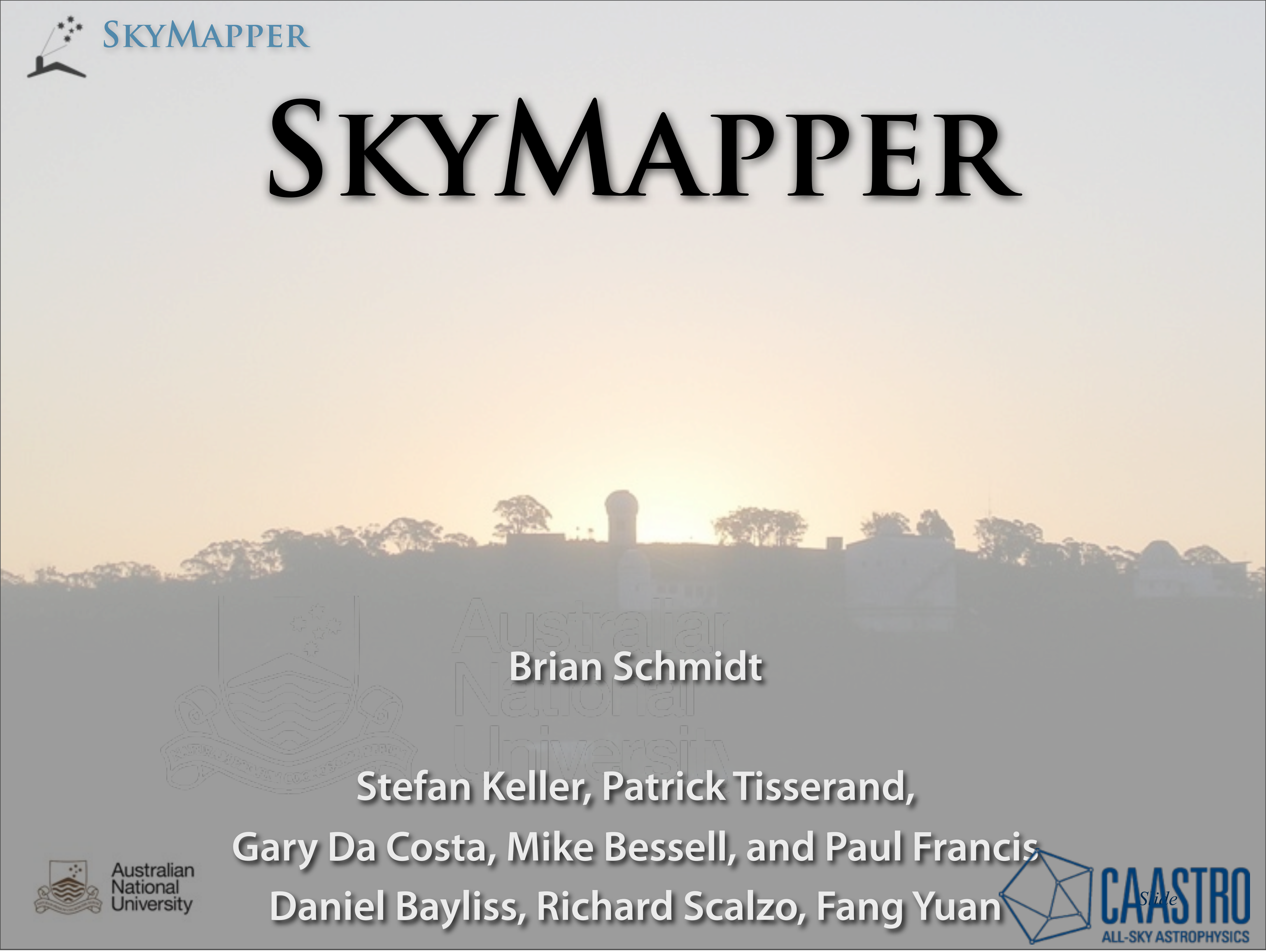
The most metal-poor stars show huge excess of Carbon and Oxygen, relative to Fe.

Might be these stars are unusual SN, but low Fe amounts probably means not bright objects.

In summary, we really are not sure what we are going to find until we look.



SkyMapper



Brian Schmidt

Stefan Keller, Patrick Tisserand,
Gary Da Costa, Mike Bessell, and Paul Francis
Daniel Bayliss, Richard Scalzo, Fang Yuan

Australian National University

CAASTRO ALL-SKY ASTROPHYSICS

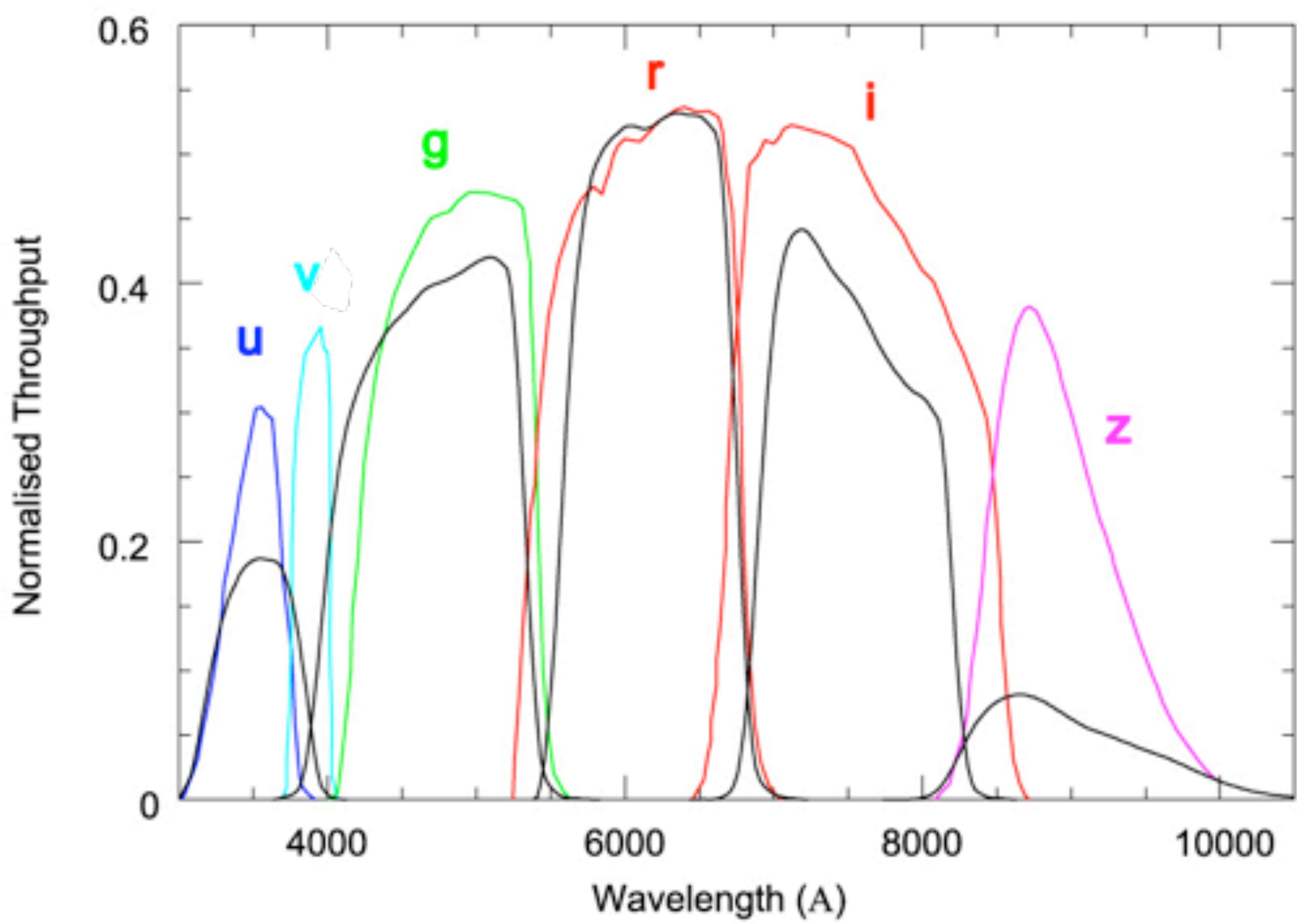
Slide

SKYMAPPER

SkyMapper

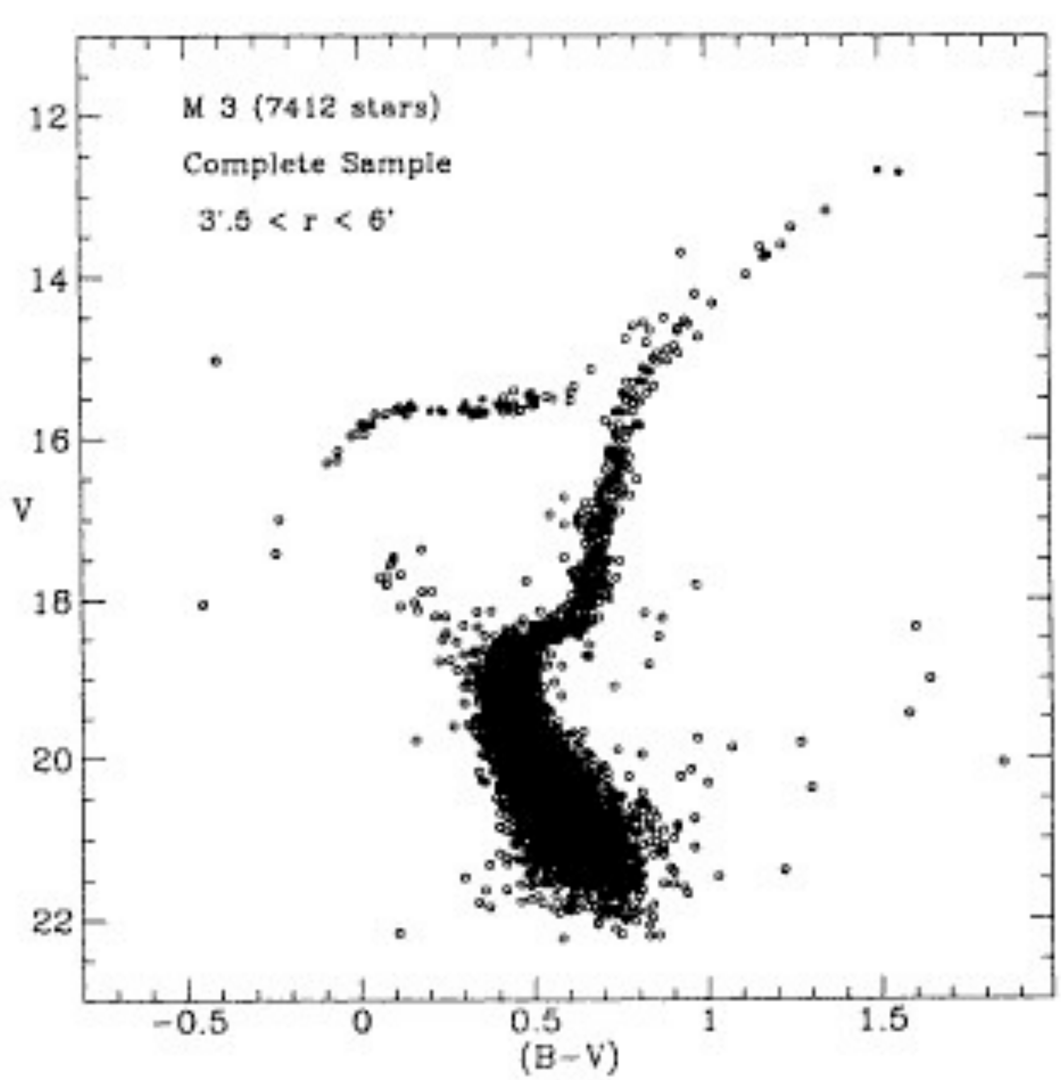
Optimised for Stellar Astrophysics

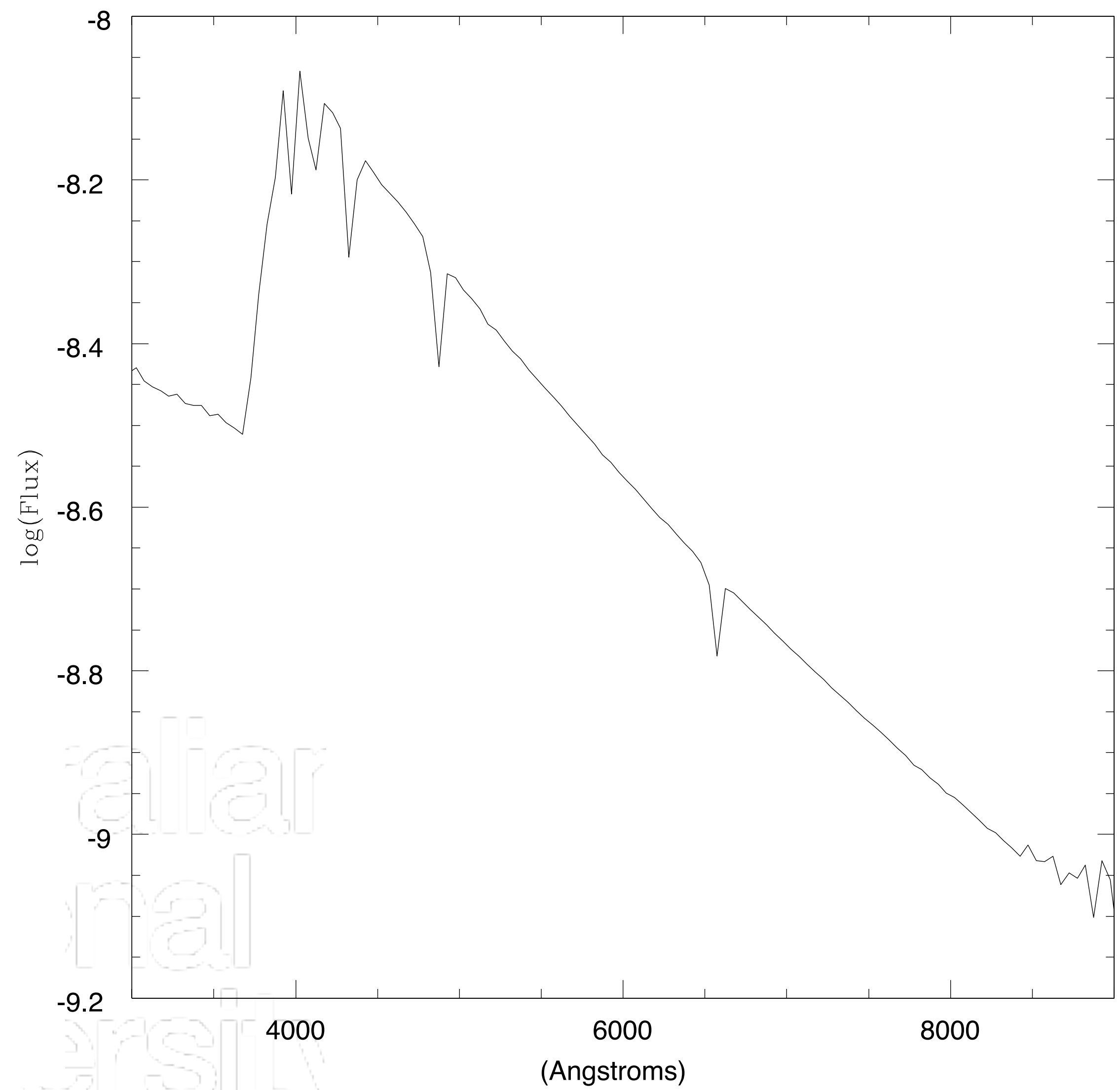
- Encoded in the spectrum of each star
- Using filters we can isolate portions of the spectrum
- In designing our survey we sought to optimise our ability to determine the three important stellar parameters (T,log(g), Z)
- so SkyMapper not only compliments survey efforts in the northern hemisphere but enables us to tackle important astrophysics in an exciting new way.



Australian National University

SkyMapper Filter Set is sensitive to Stellar Parameters



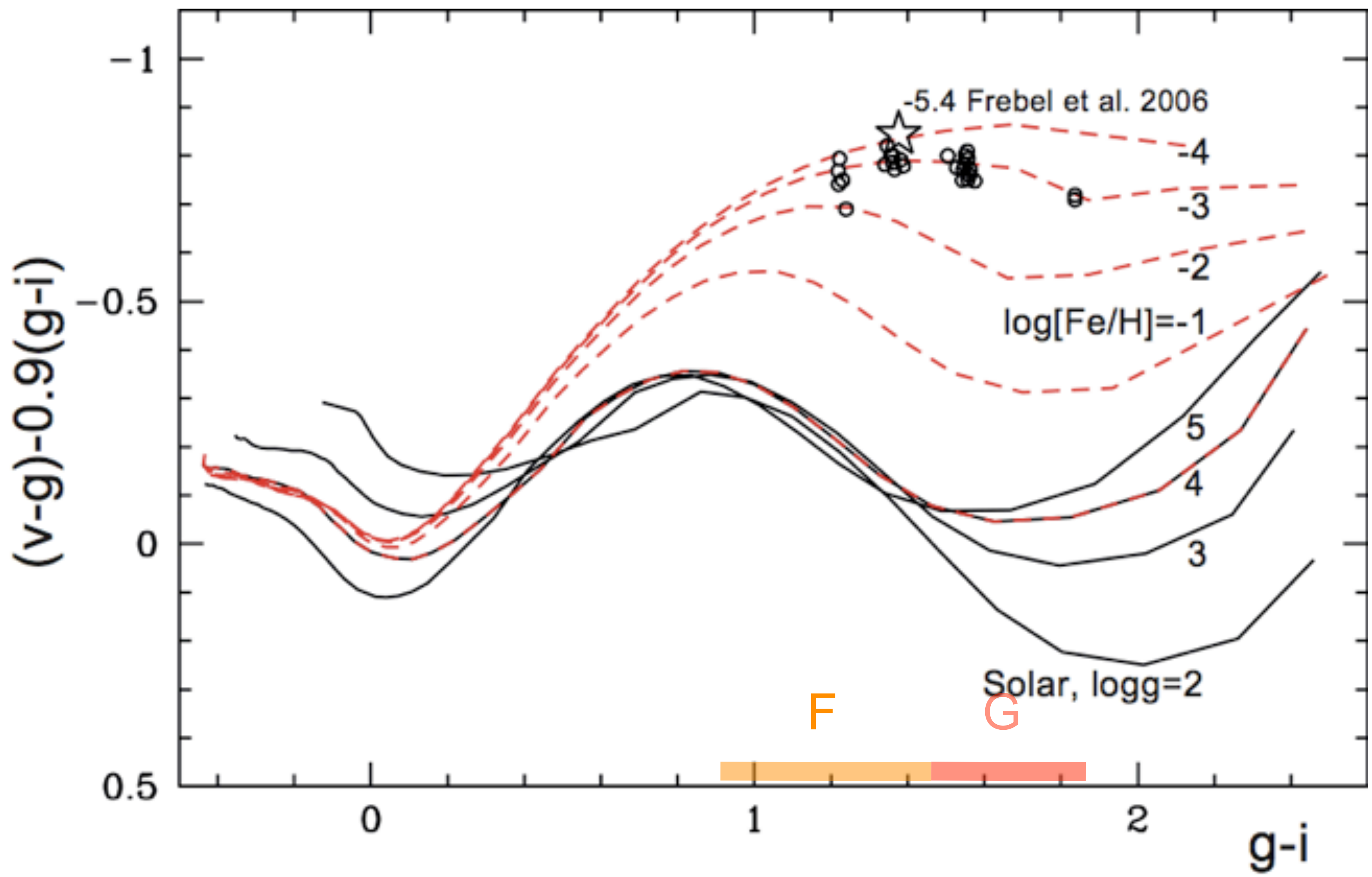


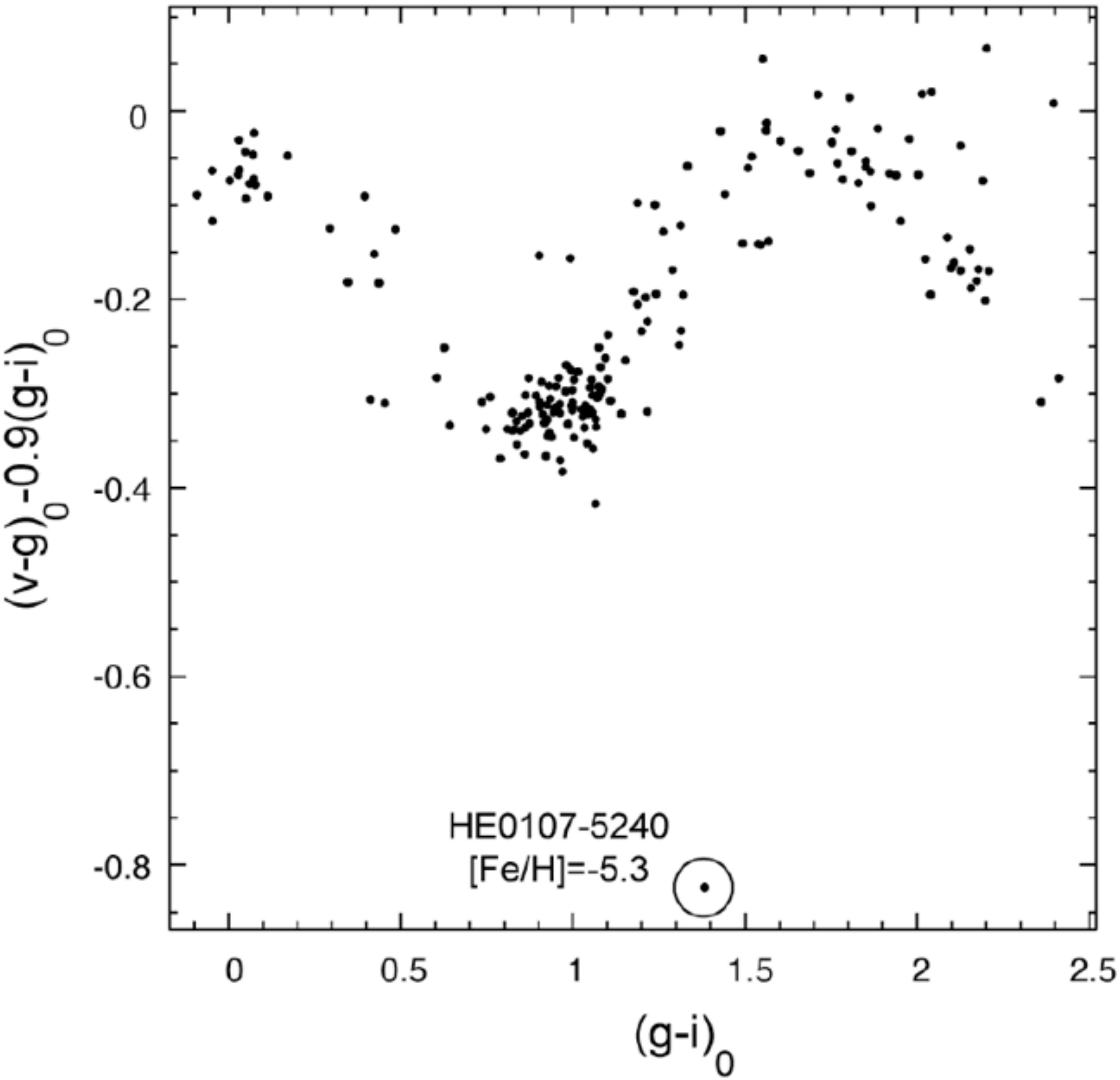
Extremely Metal-poor Stars in the Halo

• Goal: find the first stars to have formed in the Universe: tell us about the assembly and chemical enrichment of the Galaxy

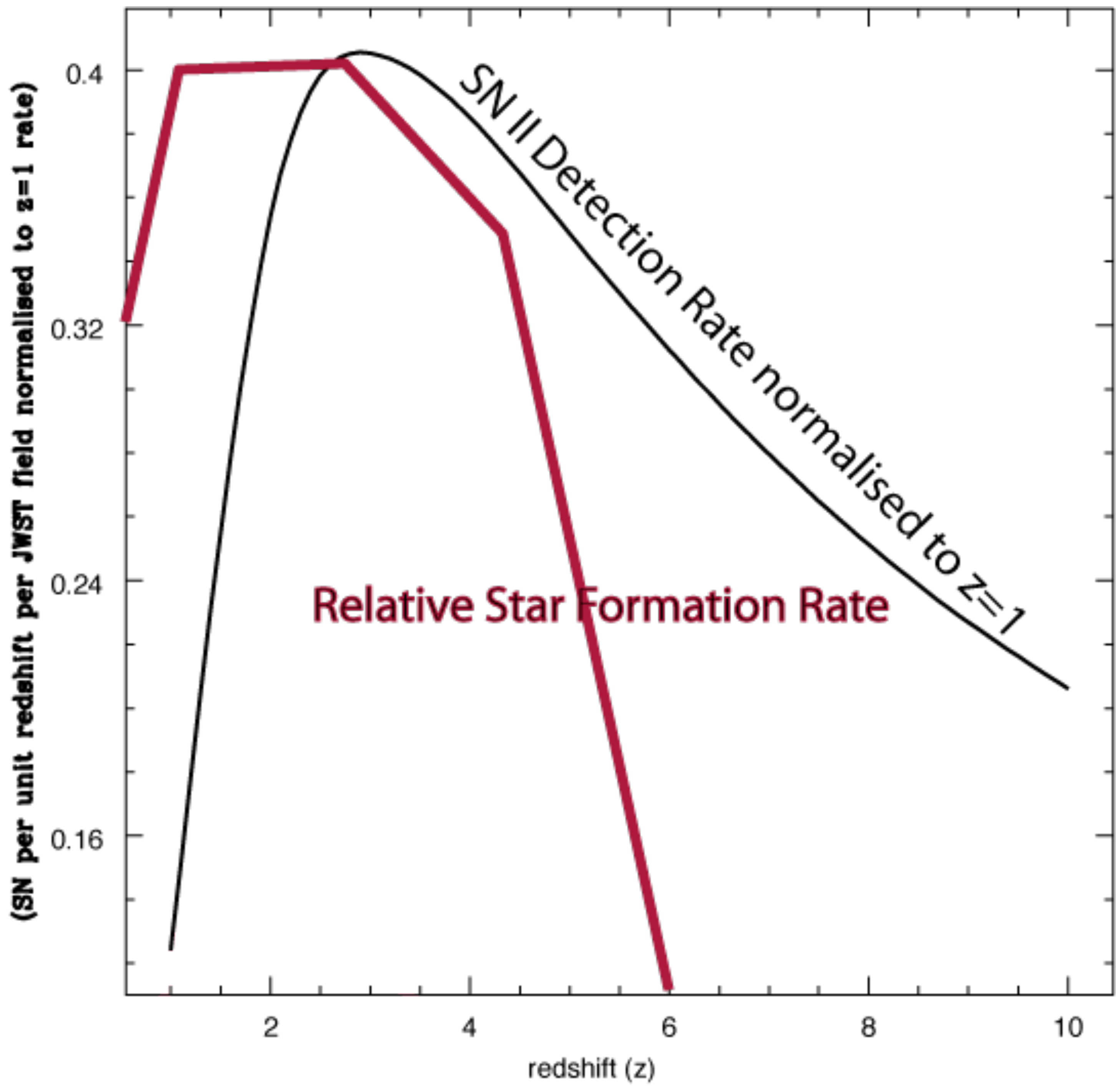
• v-g is dependent on the level of metal line blanketing in the blue continuum

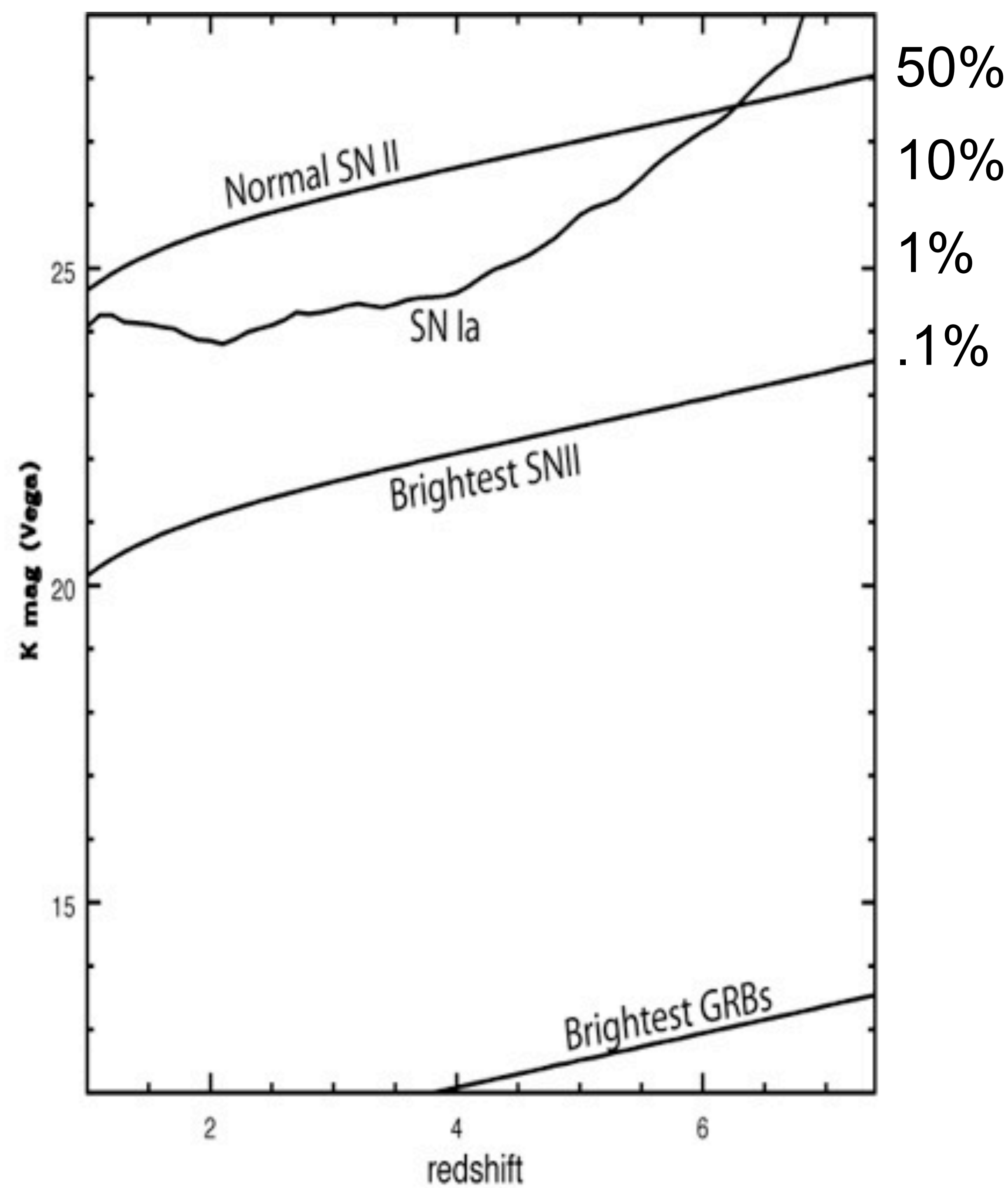
✓ not perturbed dramatically by C-enhancement, chromospheric emission as affects objective-prism surveys



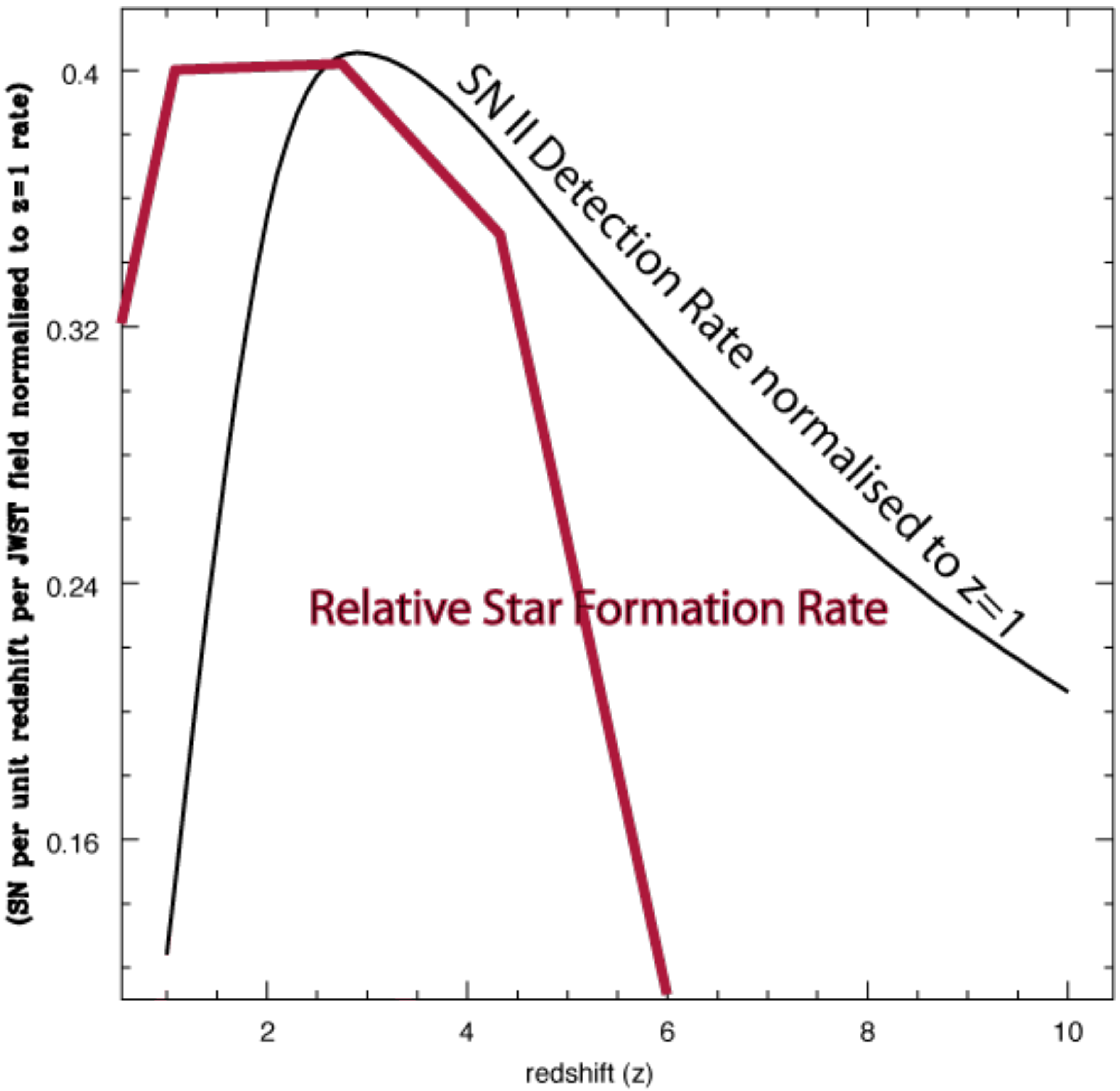

0
-0.2
-0.4
-0.6
-0.8
(v-g)$_0$-0.9(g-i)$_0$
0
0.5
1
1.5
2
2.5
(g-i)$_0$
HE0107-5240
[Fe/H]=-5.3

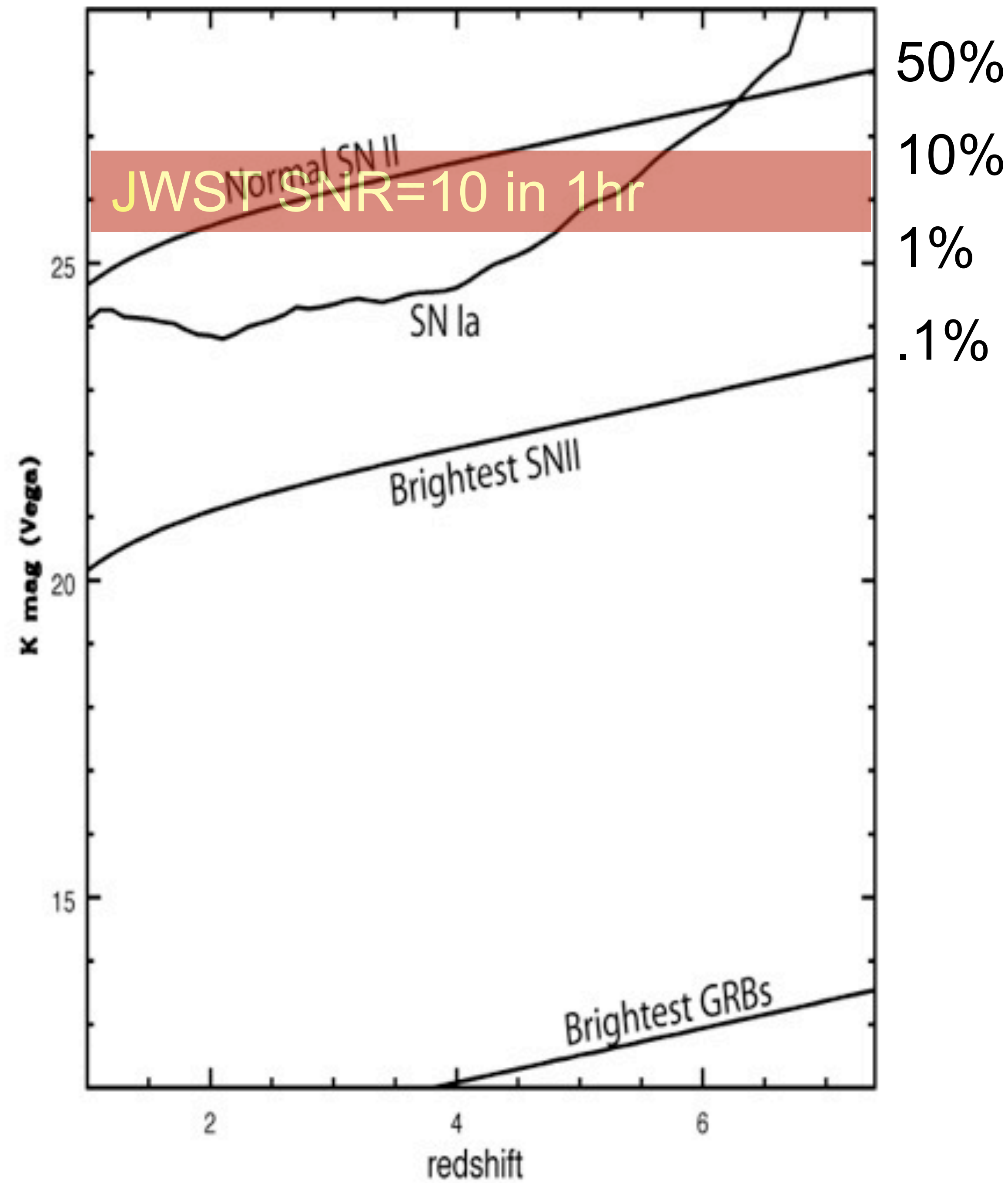
JWST can count SN as a function of redshift to z>6





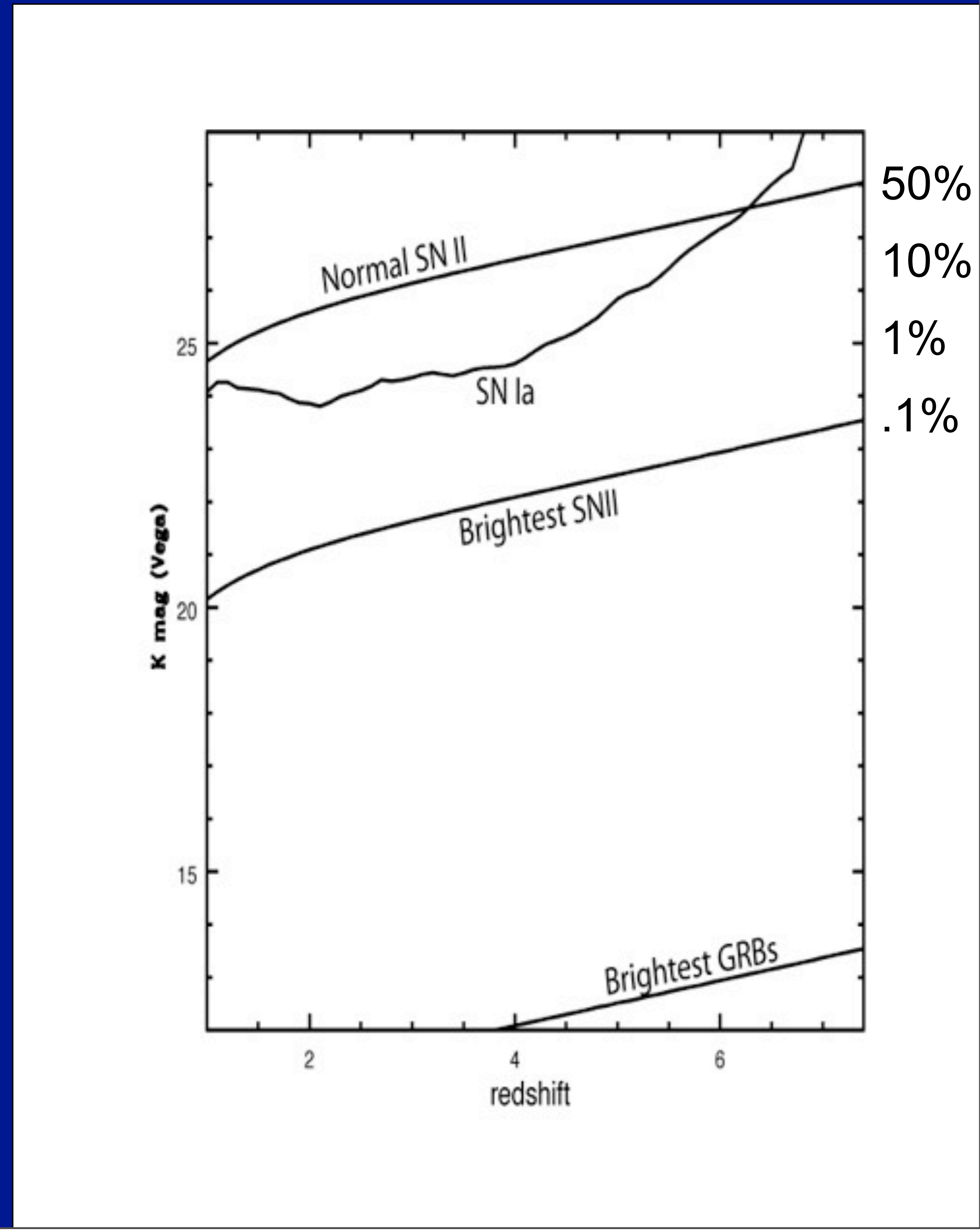
JWST can count SN as a function of redshift to z>6





Spectra of SN at z>4 is tough

If they are bright spectra can be obtained to understand the nature of the SN - but GRBs probably still required to study host galaxy gas -



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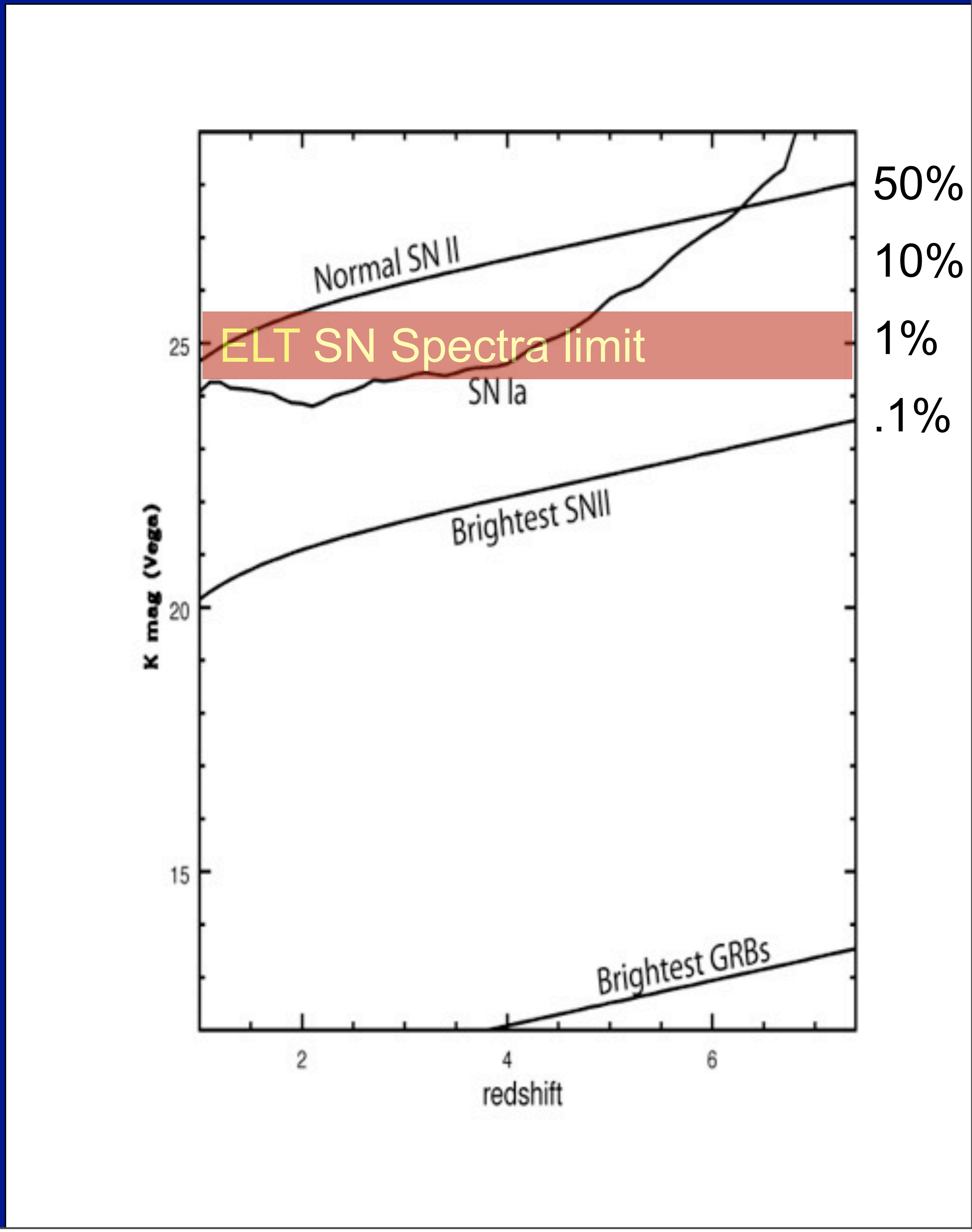
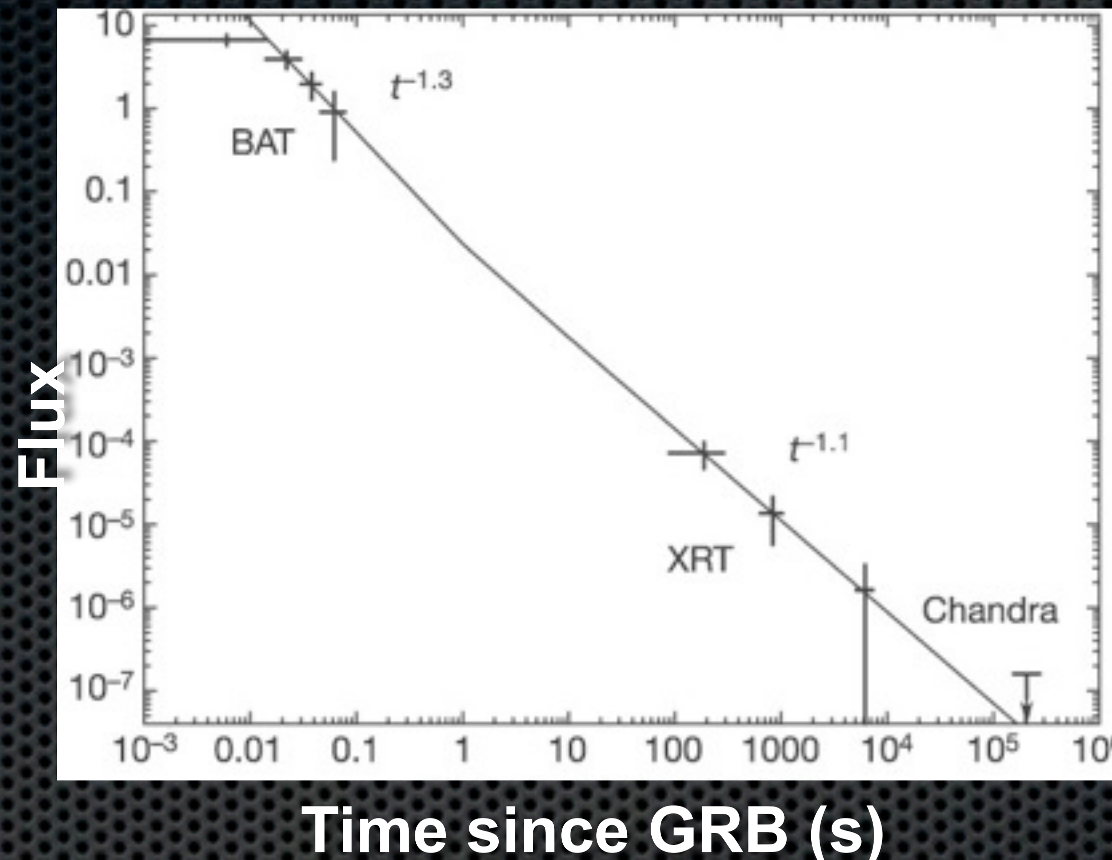
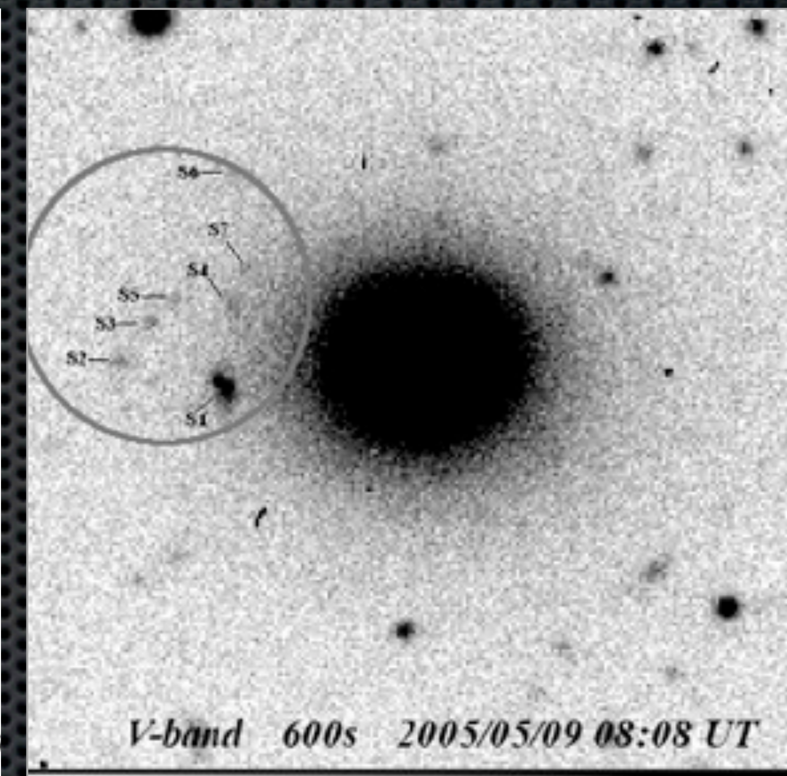


Short Hard Bursts

GRB 050509B first short GRB X-ray afterglow very faint!

Gehrels et al. 2005





GRB 050724 – the bright one: optical + X-ray

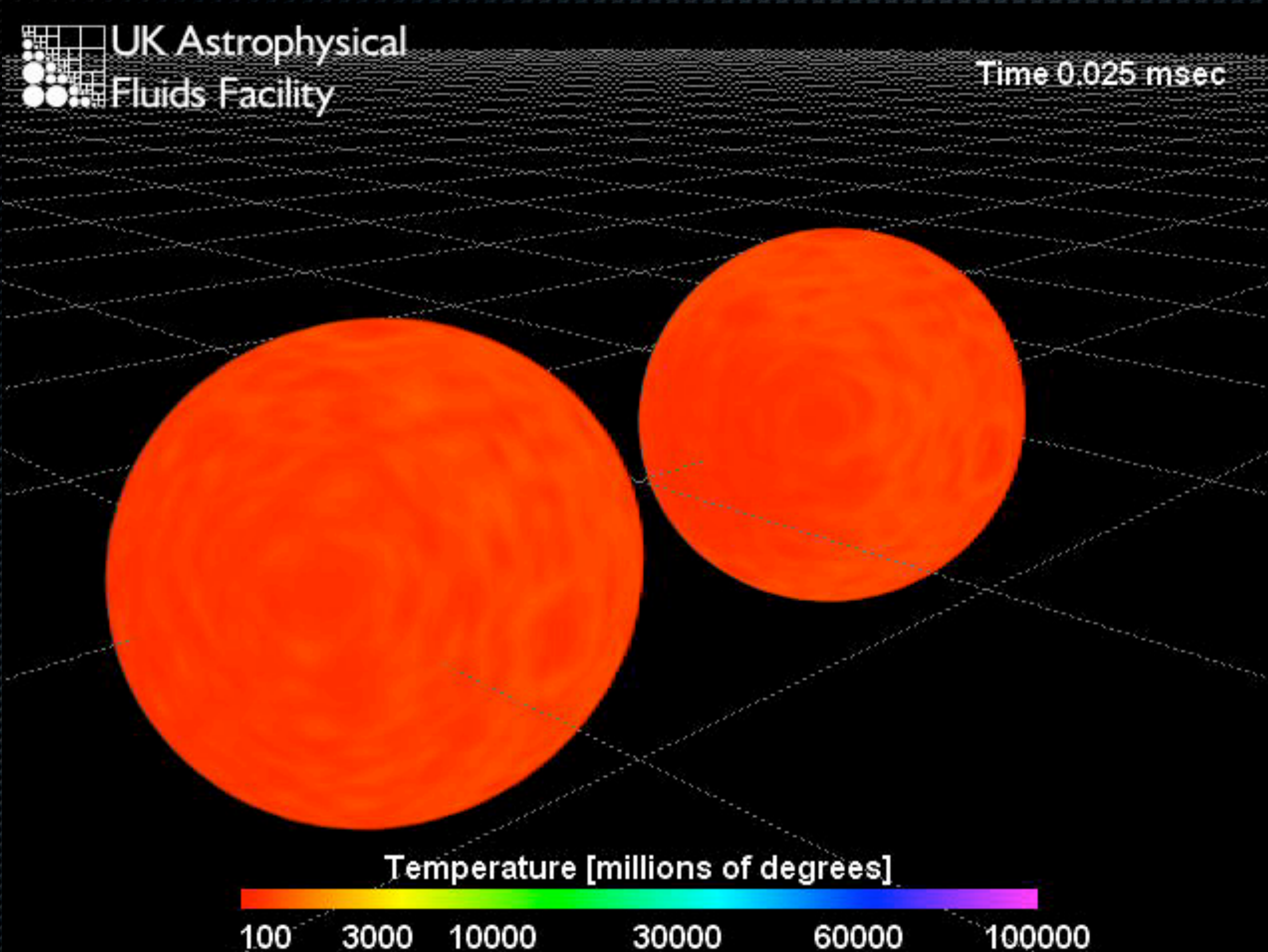
– z = 0.258

and studies may be in new areas...

Short Hard Bursts

In 2005 - 2006, several short hard bursts were localized by SWIFT and HETE-2 and coordinated searches for counterparts were carried out. The bursts were GRB 050509b ($z = 0.2248$, elliptical galaxy), 050709 ($z = 0.161$) and 050724 ($z = 0.258$)

- The bursts were either on the outskirts of galaxies or in old galaxies with low star formation rate
- There was no accompanying supernova
- The redshifts were much lower than for the long soft bursts and thus the total energy was about two orders of magnitude less (because they are shorter as well as closer).
- All this is consistent with the merging neutron star (or merging black hole neutron star) paradigm.


UK Astrophysical
Fluids Facility
Time 0.025 msec
Temperature [millions of degrees]
100
3000
10000
30000
60000
100000

But Life is not so simple

- Since then, several Short GRBs have been found at high redshift, with the same energy as Long GRBs (Maybe two things make Short GRBs)
- And emission several hours was seen in Gamma Rays, which violates predictions of Neutron Star merger (which take a few seconds)...This now maybe explained from debris taking a long time to fall onto the merged Blackhole..
- But clearly a population of z~0.3 objects in old galaxies does exist

Probing Gravitation Wave Radiation with Short GRBs

- Short Hard GRBs probably have average <z>~0.3 with BATSE finding 170 objects across the Sky per year.
- When advanced LIGO gets going, this suggests, if Short-Hard GRBs are NS/BH mergers, a signal is likely to be seen for at least some of them. This will open up a new regime of physics - probably starting in 2015...

Future really is bright!

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E-ELT 100m

Future really is bright!

E-ELT 42m

Future really is bright!

E-ELT 37m

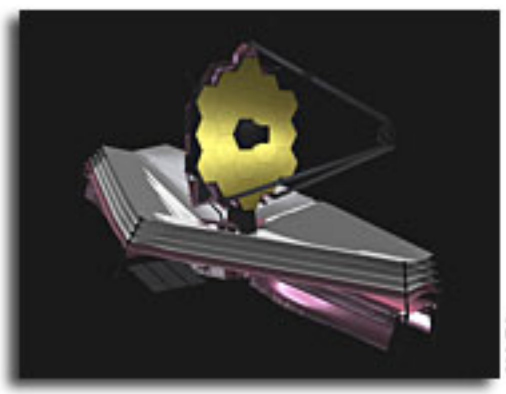
Future really is bright!

Future really is bright!

NASA May Slip Webb Space Telescope Launch as Late as 2024

unsubstantiated

By Keith Cowing   Posted Thursday, May 19, 2011



rumours

Industry sources report that Northrop Grumman will begin to layoff personnel working on the James Webb Space Telescope (JWST) next month for budgetary and scheduling reasons. JWST was originally supposed to have been launched in 2007. This launch date has officially slipped to no earlier than 2017-2018. According to sources, NASA Associate Administrator Chris Scolese told a group of aerospace executives this week that running JWST at a rate of $375 million a year would result in a launch date of 2022-2024.

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Astronomical Deficit Forces Downsizing of U.S. Telescope Projects

The federal fiscal crisis is pushing NASA and National Science Foundation officials to make painful choices between present and proposed astronomy programs

By John Matson | May 26, 2011 | 16

Future really is bright!

ABSTRACT

On May 27th 2010, the Italian astronomical community learned that the National Institute for Astrophysics (INAF) was going to be suppressed, and that its employees were going to be transferred to the National Research Council (CNR). It was not clear if this applied to all employees (i.e. also to researchers hired on short-term contracts), and how this was going to happen in practice. In this letter, we give a brief historical overview of INAF and present a short chronicle of the few eventful days that followed. Starting from this example, we then comment on the current situation and prospects of astronomical research in Italy.

Future really is bright!

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Make sure to capitalise on the scientific opportunities available today

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making sure to invest some of your effort in the scientific possibilities of tomorrow. Knowing that ...

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