γ-ray bursts in the ... GLAST/GBM.... era:

On the road to understanding

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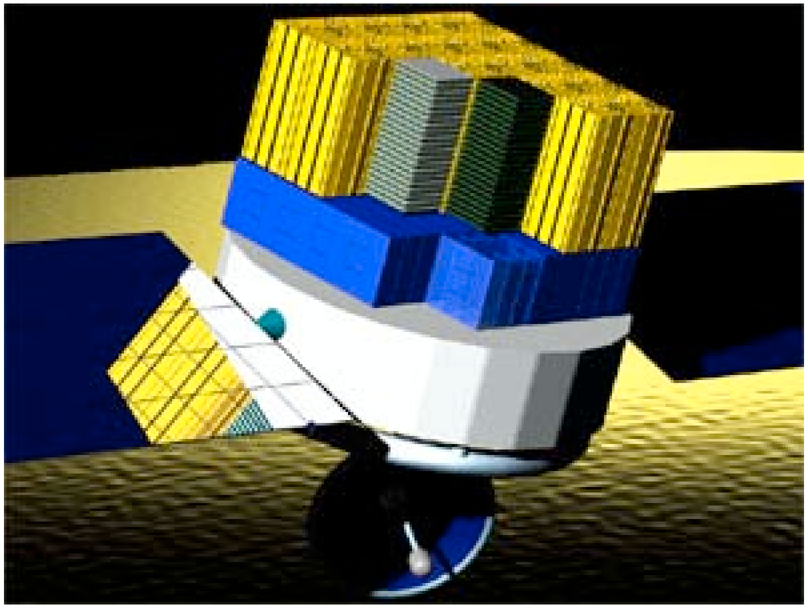
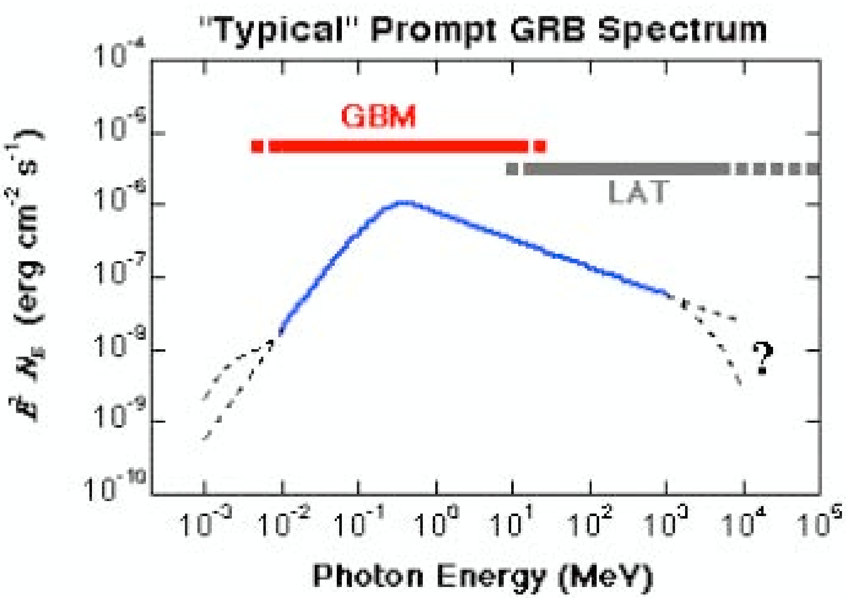
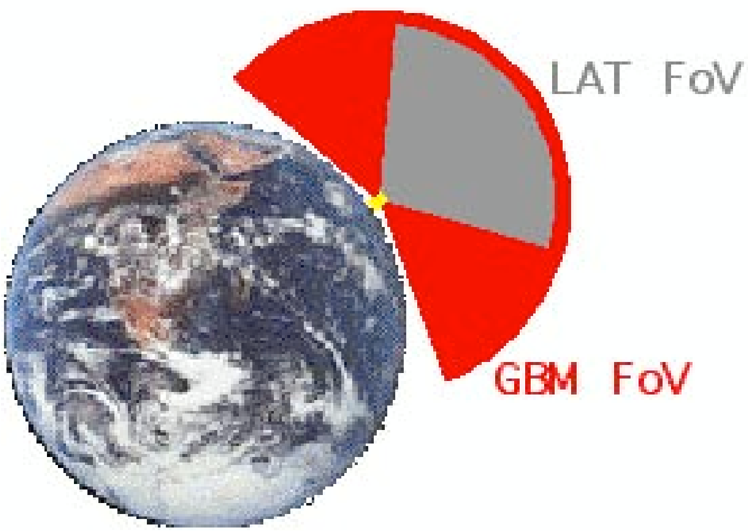
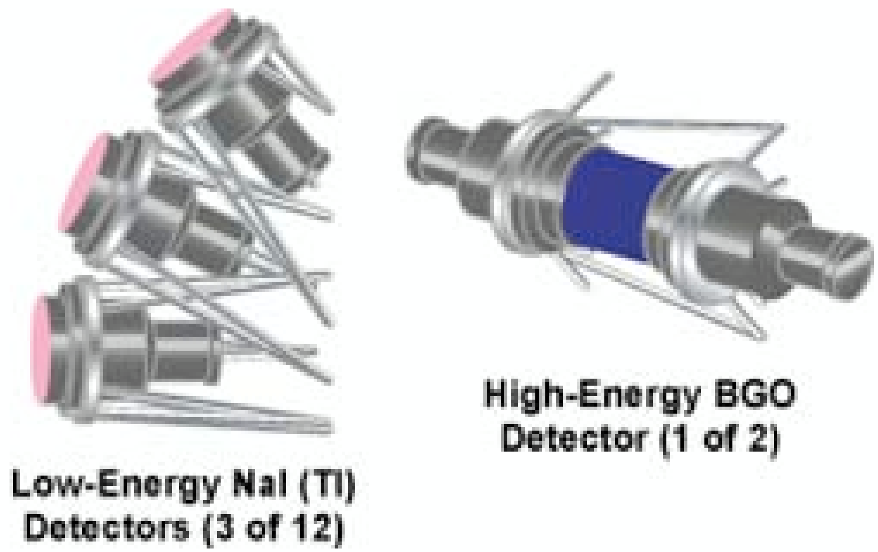
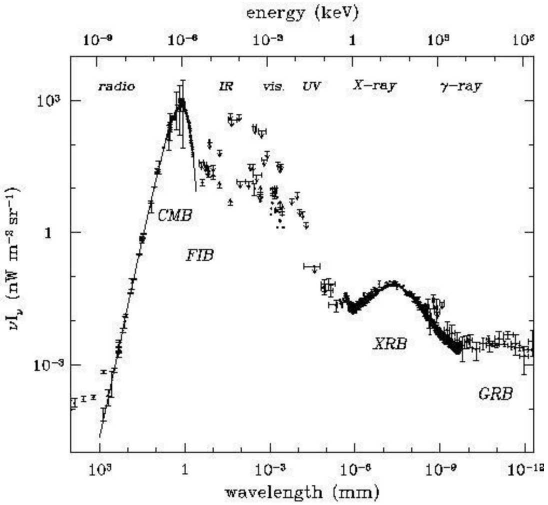
SWG meeting, Huntsville, AL, September 12-13, 2002




"Typical" Prompt GRB Spectrum
GBM
LAT
?
$E^2 N_E$ (erg cm^{-2} s^{-1})
Photon Energy (MeV)
10^{-3} 10^{-2} 10^{-1} 10^{0} 10^{1} 10^{2} 10^{3} 10^{4} 10^{5}

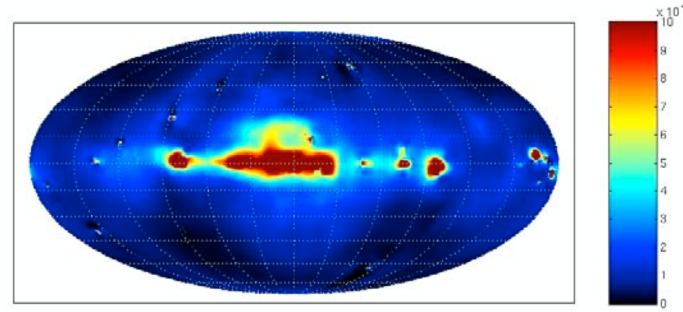

LAT FoV
GBM FoV

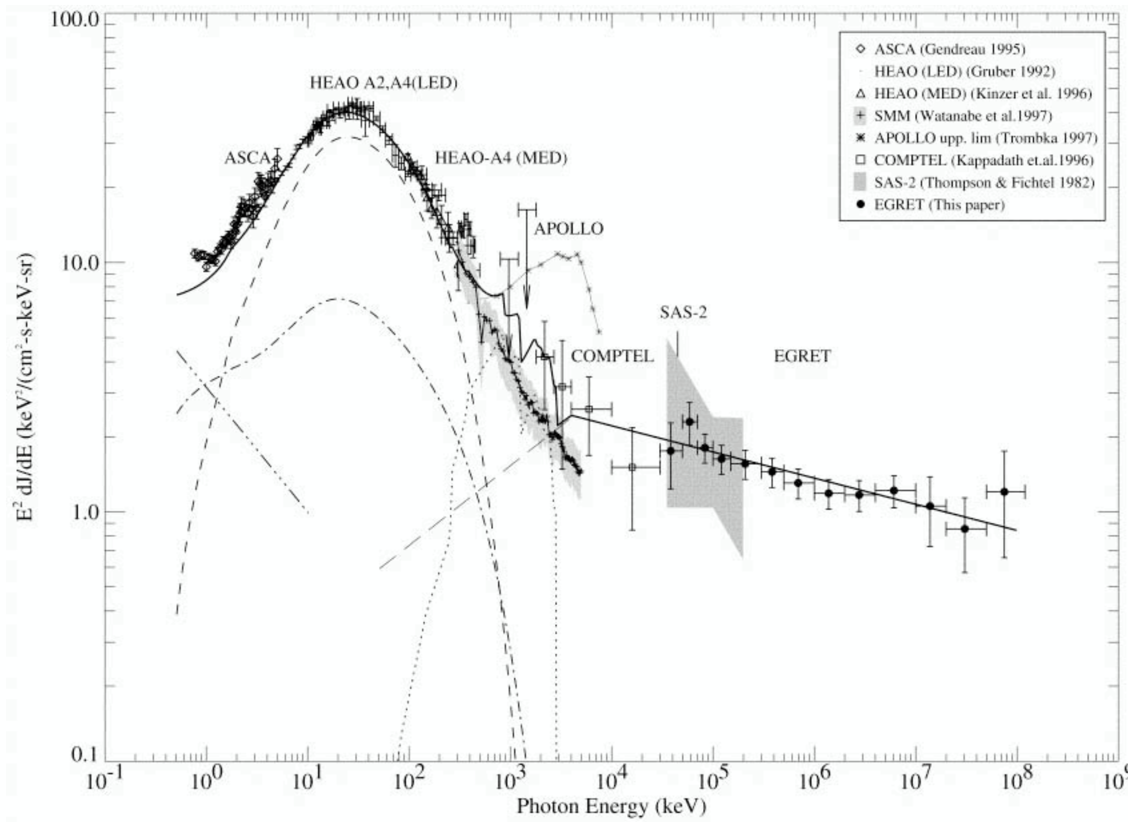

Low-Energy NaI (Tl)
Detectors (3 of 12)
High-Energy BGO
Detector (1 of 2)



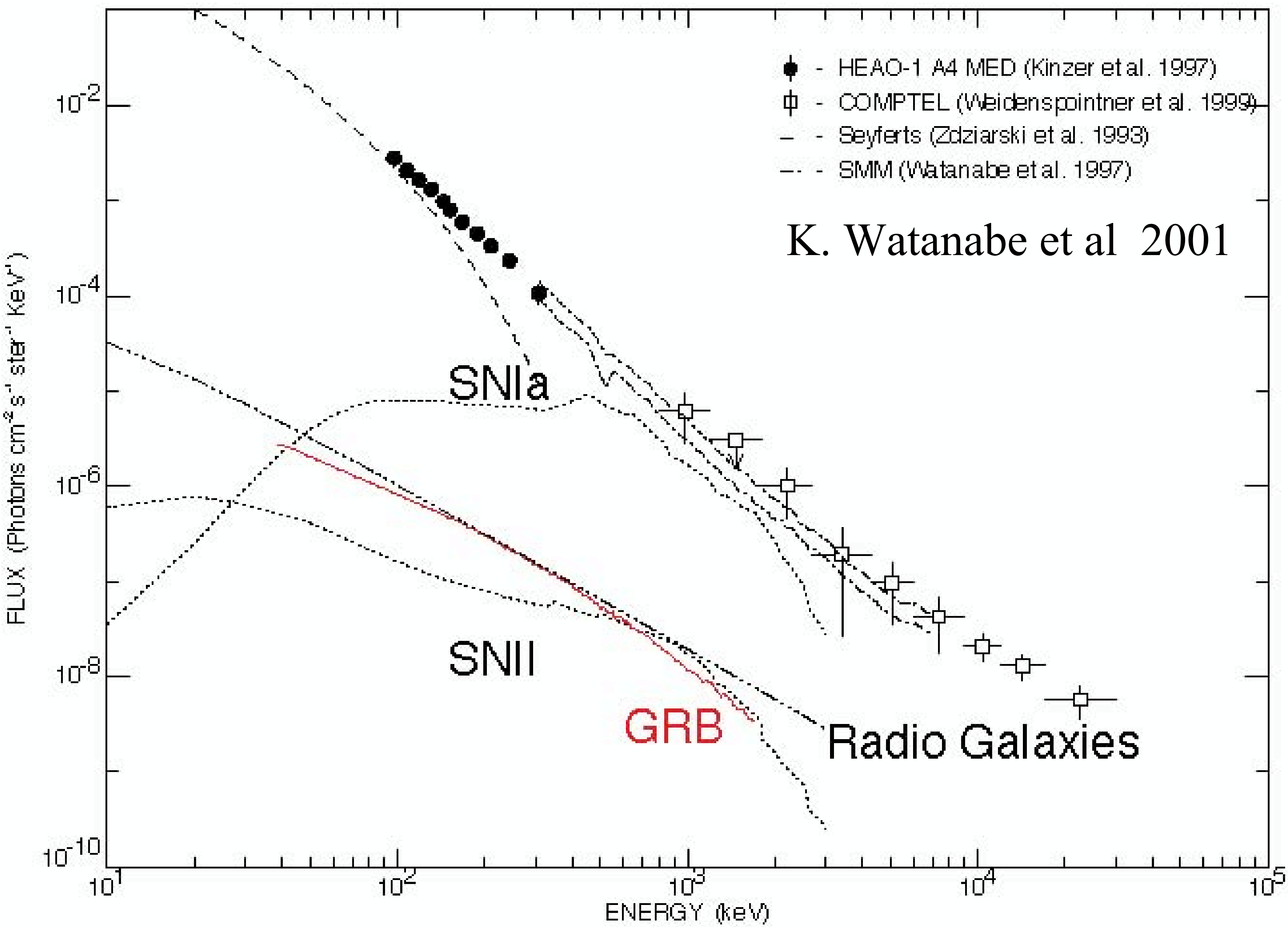
energy (keV)
radio
IR
vis.
UV
X−ray
γ−ray
CMB
FIB
XRB
GRB
wavelength (mm)

Background

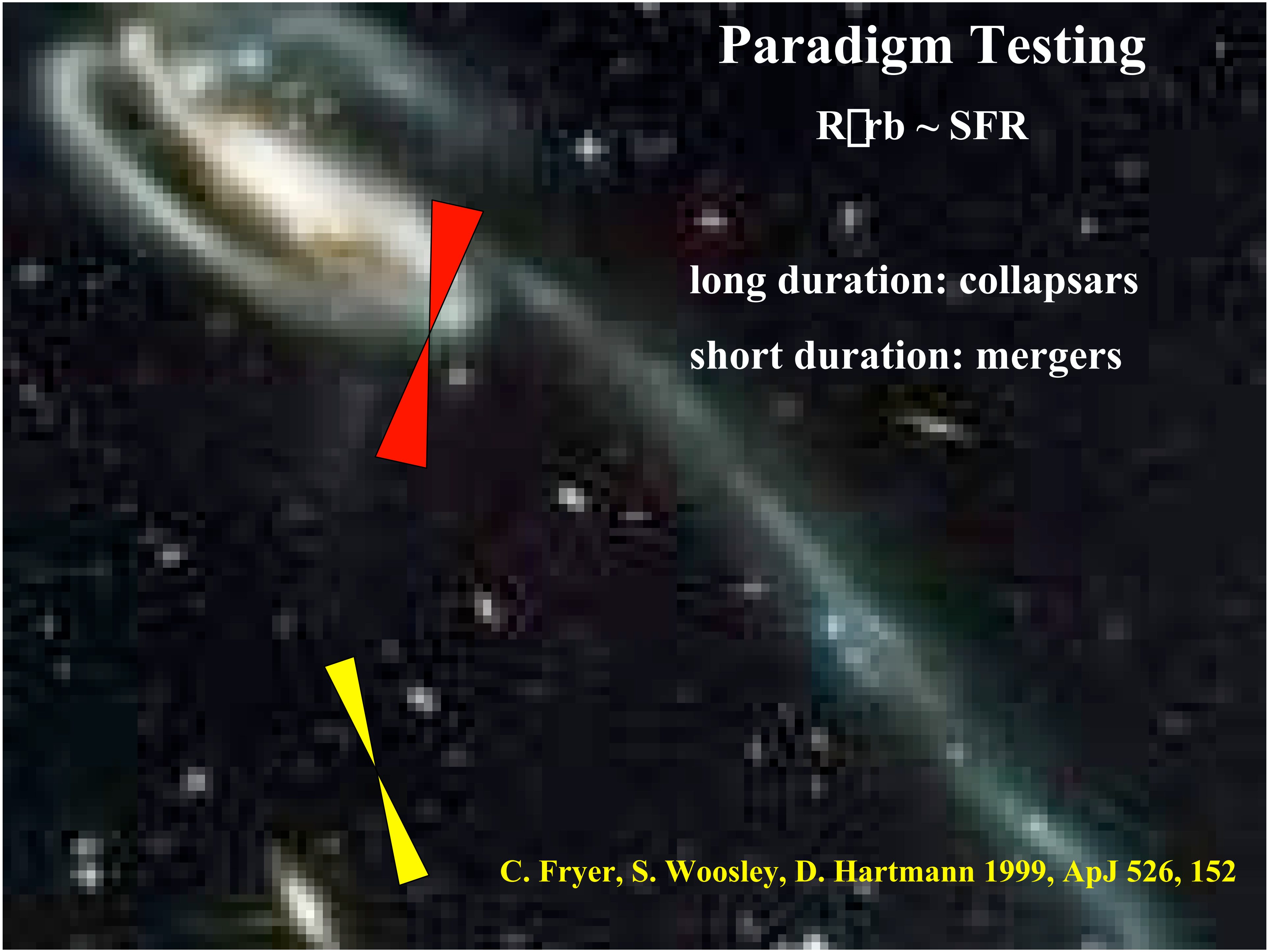


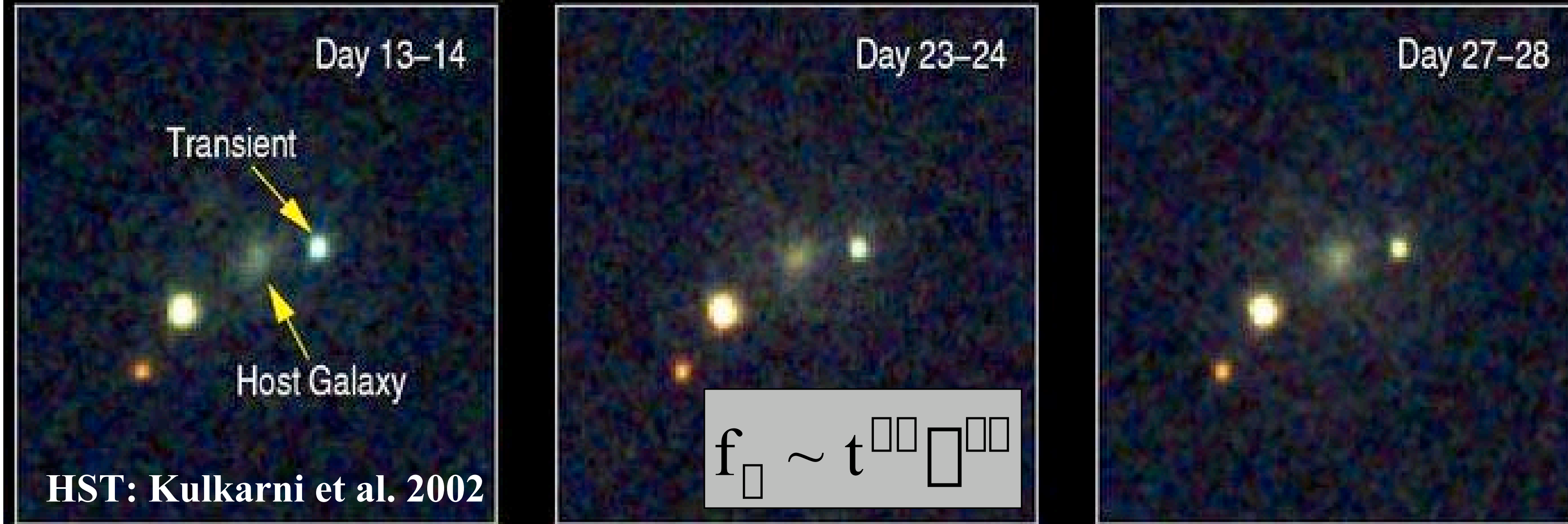


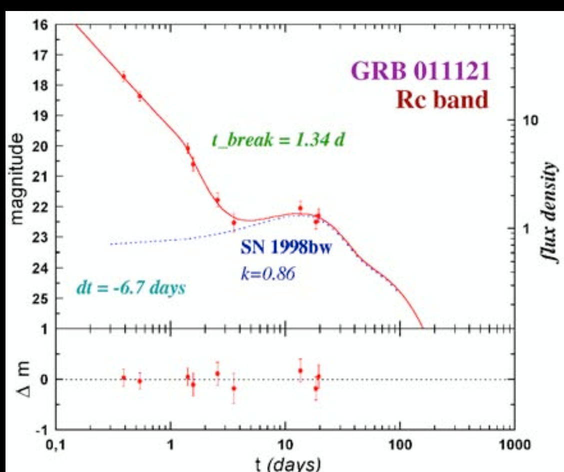
ASCA (Gendreau 1995)
HEAO (LED) (Gruber 1992)
HEAO (MED) (Kinzer et al. 1996)
SMM (Watanabe et al.1997)
APOLLO upp. lim (Trombka 1997)
COMPTEL (Kappadath et.al.1996)
SAS-2 (Thompson & Fichtel 1982)
EGRET (This paper)
HEAO A2,A4(LED)
ASCA
HEAO-A4 (MED)
APOLLO
COMPTEL
SAS-2
EGRET
E² dJ/dE (keV²/(cm²-s-keV-sr)
Photon Energy (keV)



HEAO-1 A4 MED (Kinzer et al. 1997)
COMPTEL (Weidenspointner et al. 1999)
Seyferts (Zdziarski et al. 1993)
SMM (Watanabe et al. 1997)
K. Watanabe et al 2001
SNIa
SNII
GRB
Radio Galaxies
FLUX (Photons cm⁻² s⁻¹ ster⁻¹ keV⁻¹)
ENERGY (keV)
10⁻²
10⁻⁴
10⁻⁶
10⁻⁸
10⁻¹⁰
10¹
10²
10³
10⁴
10⁵


Paradigm Testing
R□rb ~ SFR
long duration: collapsars
short duration: mergers
C. Fryer, S. Woosley, D. Hartmann 1999, ApJ 526, 152





Greiner et al. 2002

Afterglow Physics

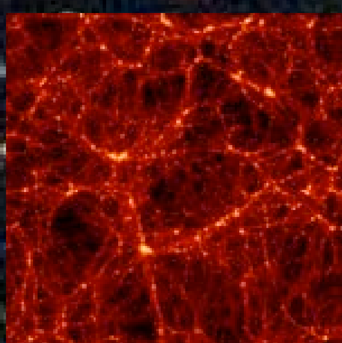
jet breaks □ beaming angles □ energetics

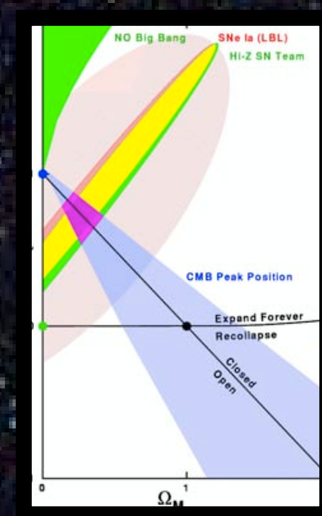
□-□,p: □rb environment & e-acceleration

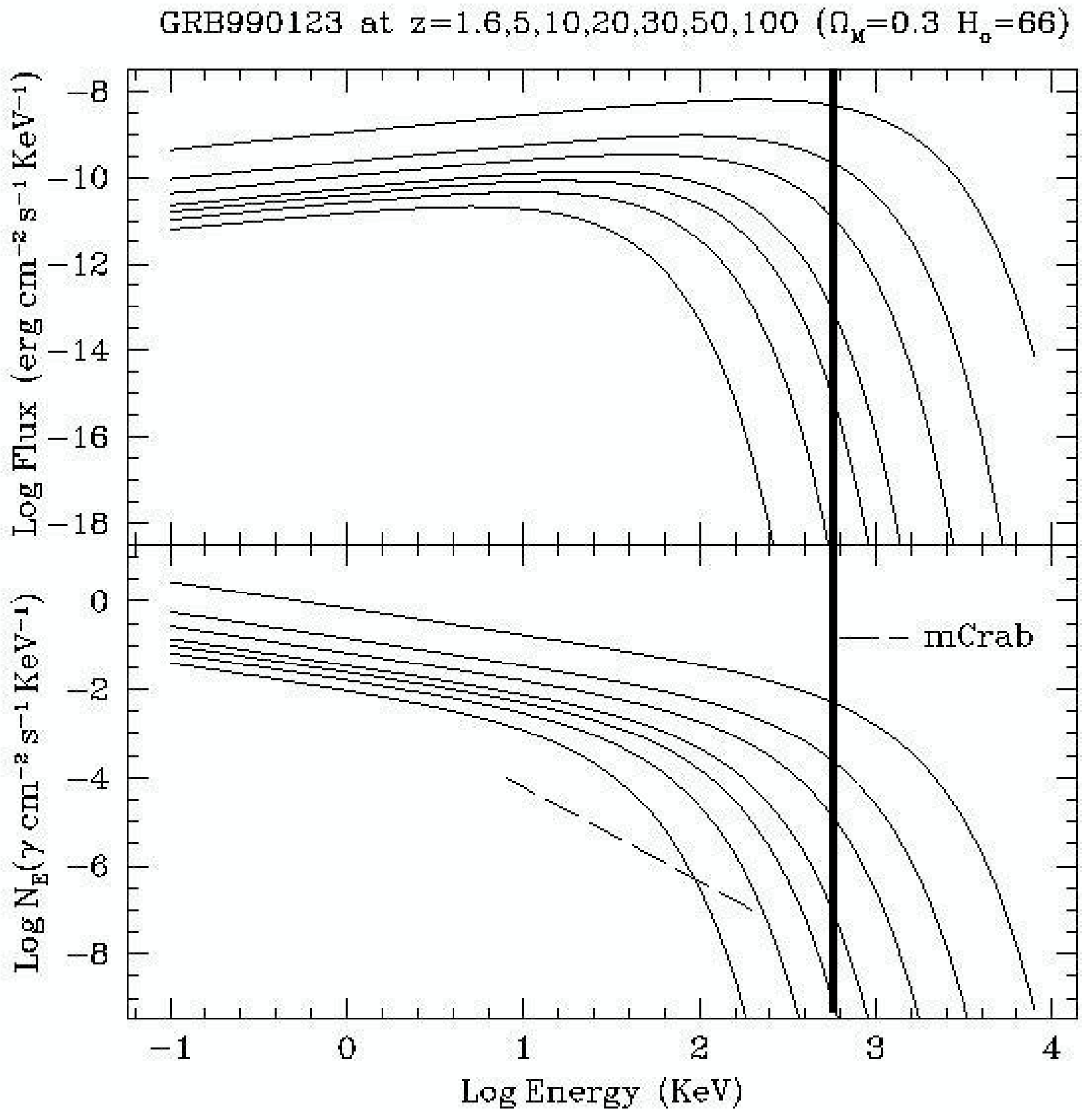
Properties of associated "hypernovae"

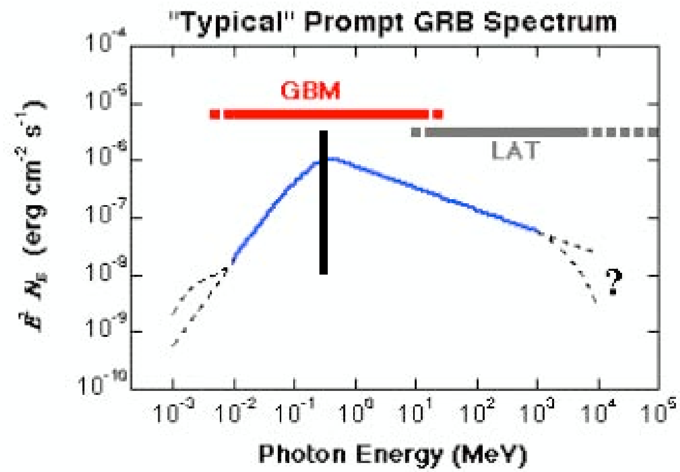
97ef, 97ey, 98bw, 01ke, 02ap

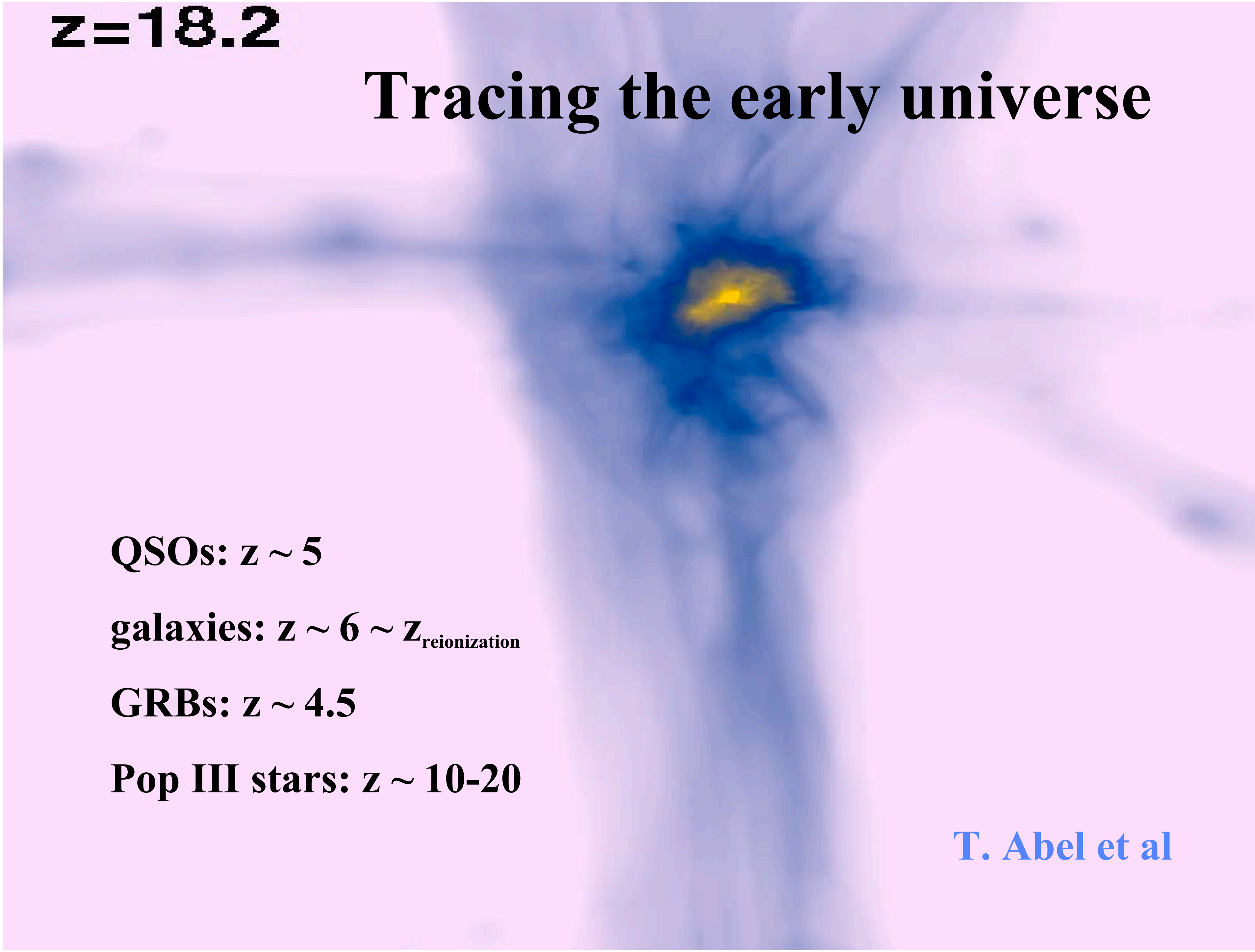
Cosmology with GRBs






GRB990123 at z=1.6,5,10,20,30,50,100 (ΩM=0.3 Ho=66)
Log Flux (erg cm⁻² s⁻¹ KeV⁻¹)
−8
−10
−12
−14
−16
−18
Log NE(γ cm⁻² s⁻¹ KeV⁻¹)
0
−2
−4
−6
−8
mCrab
−1
0
1
2
3
4
Log Energy (KeV)


"Typical" Prompt GRB Spectrum
GBM
LAT
?
E² NE (erg cm⁻² s⁻¹)
Photon Energy (MeV)



Tracing the early universe

QSOs: z ~ 5

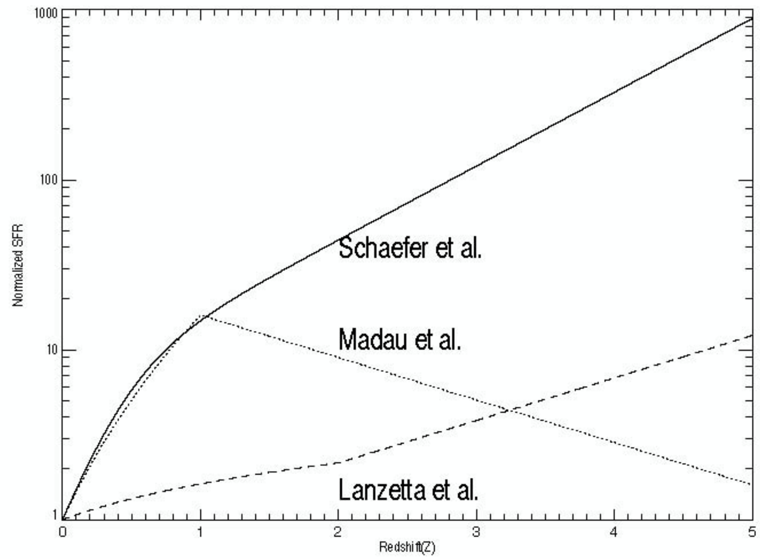
galaxies: z ~ 6 ~ $z_{reionization}$

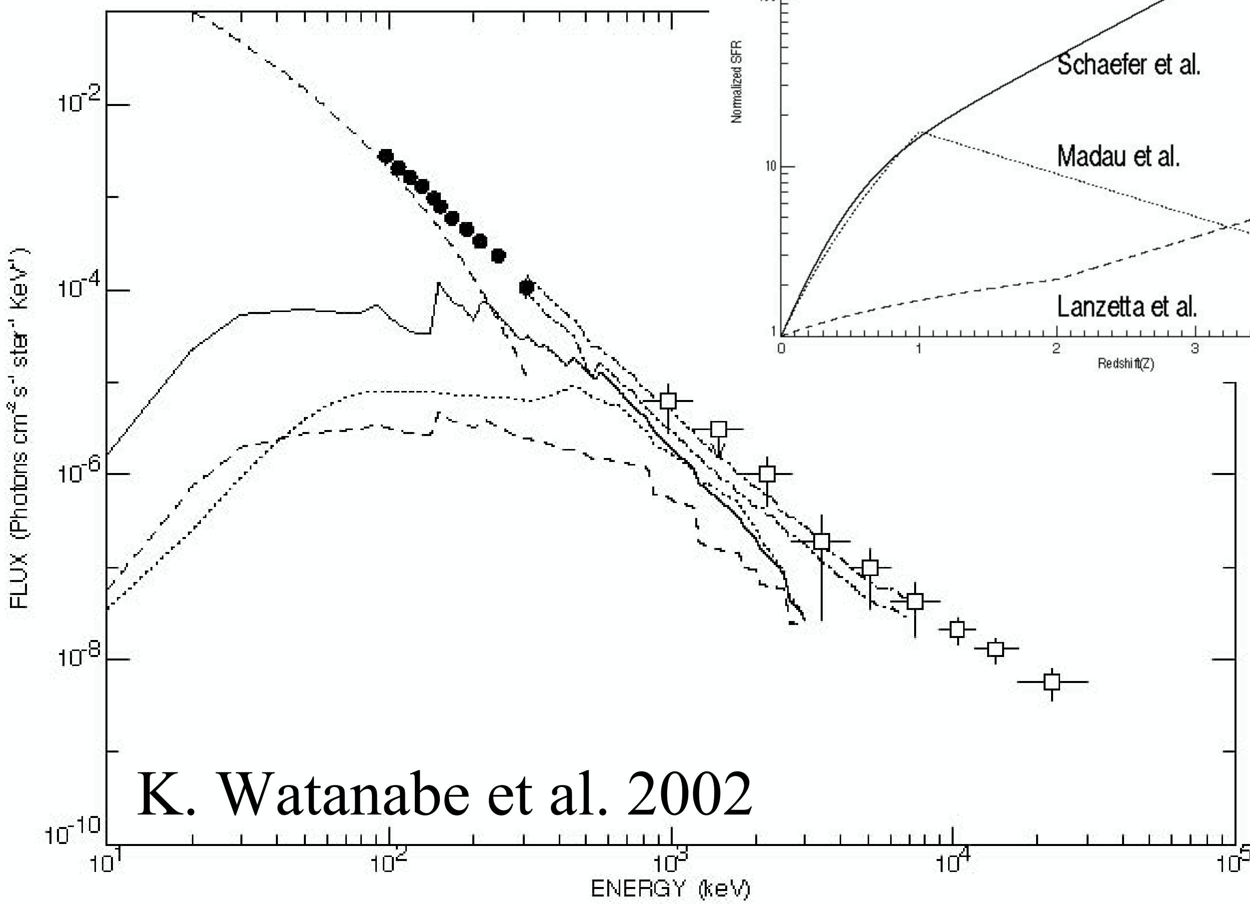
GRBs: z ~ 4.5

Pop III stars: z ~ 10-20

T. Abel et al

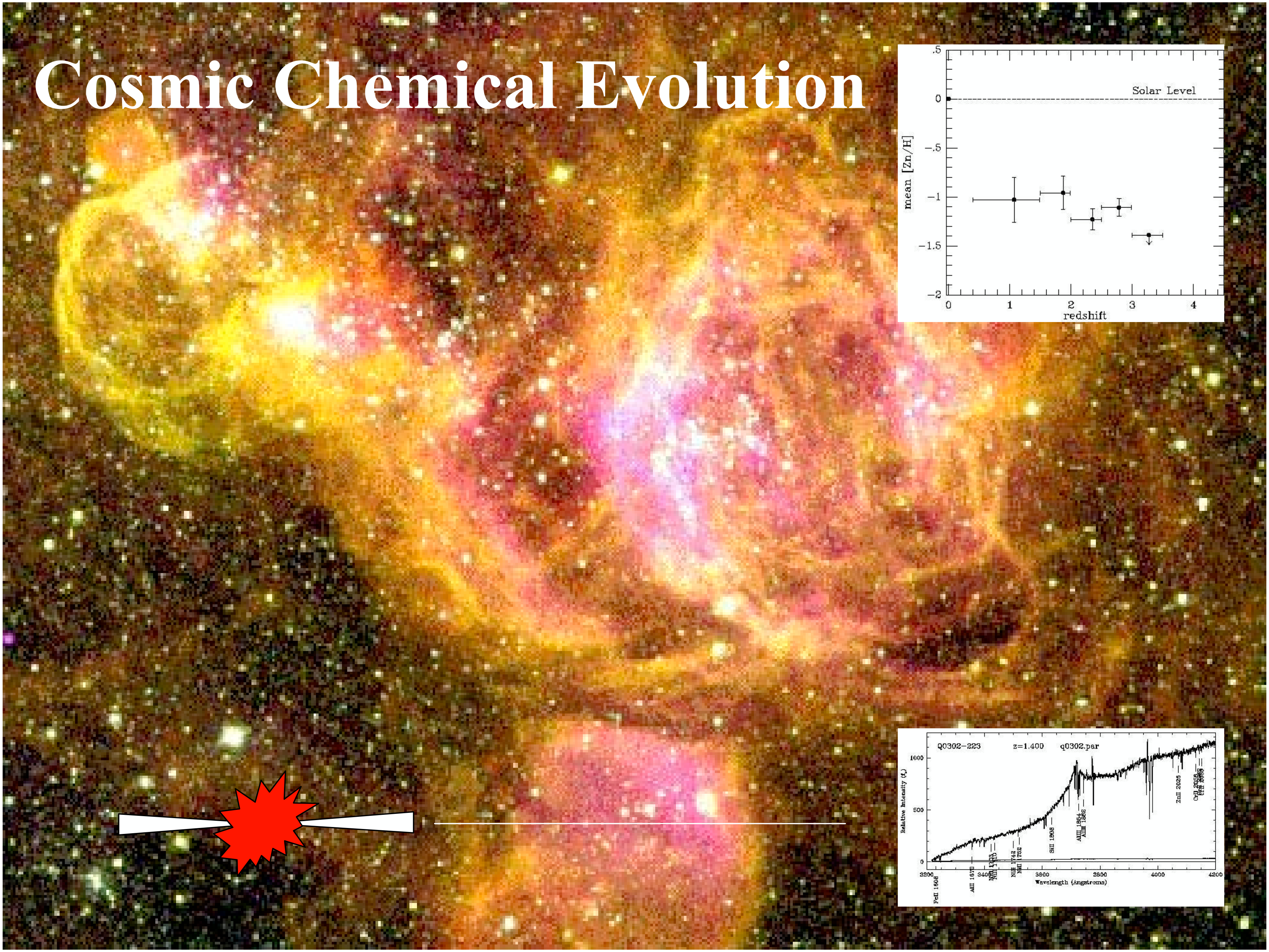
□rbs □ The Cosmic Star Formation Rate





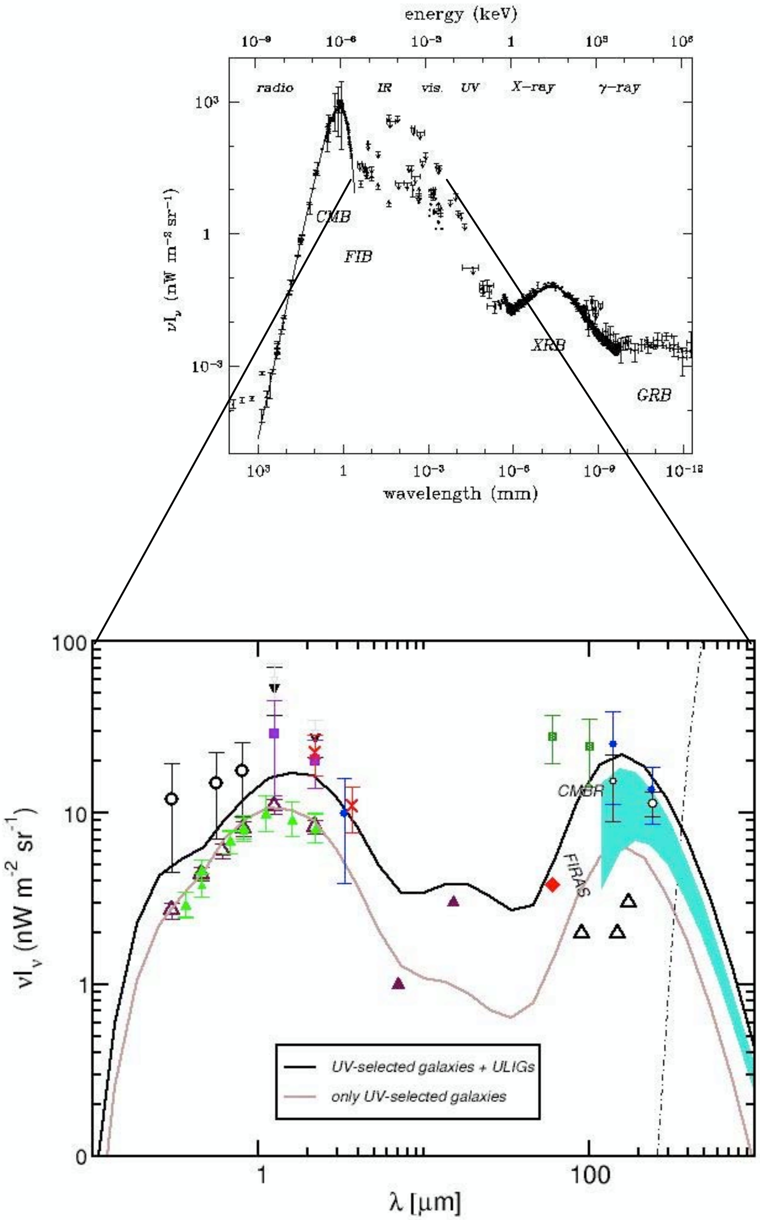
K. Watanabe et al. 2002

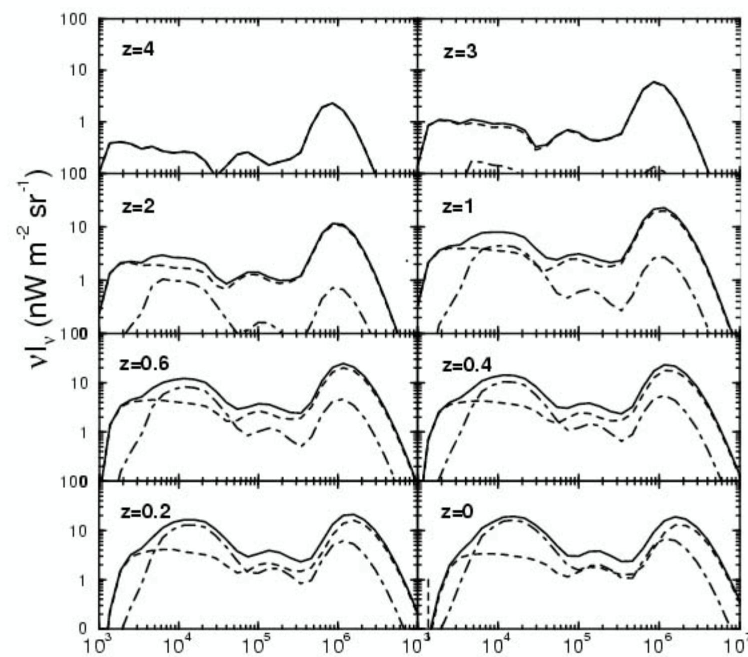
Cosmic Chemical Evolution



The evolving cosmic radiation background

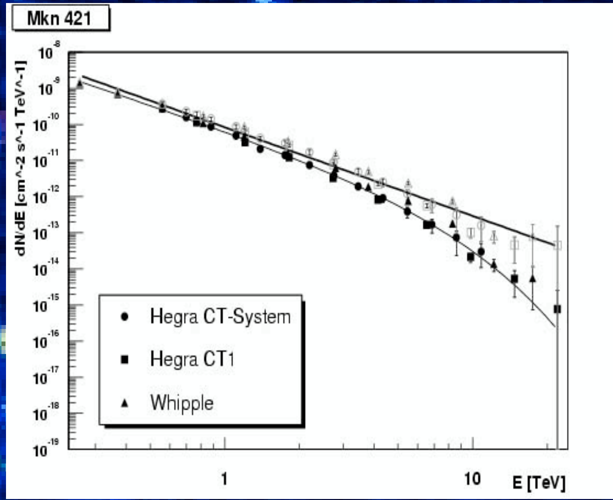
□ **optical depth at E ~ TeV**

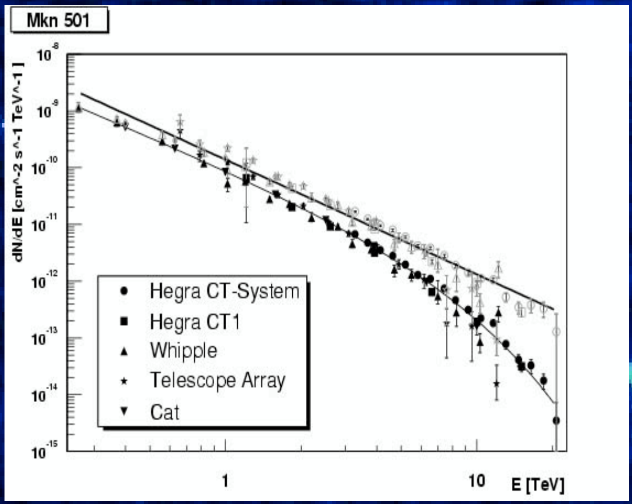




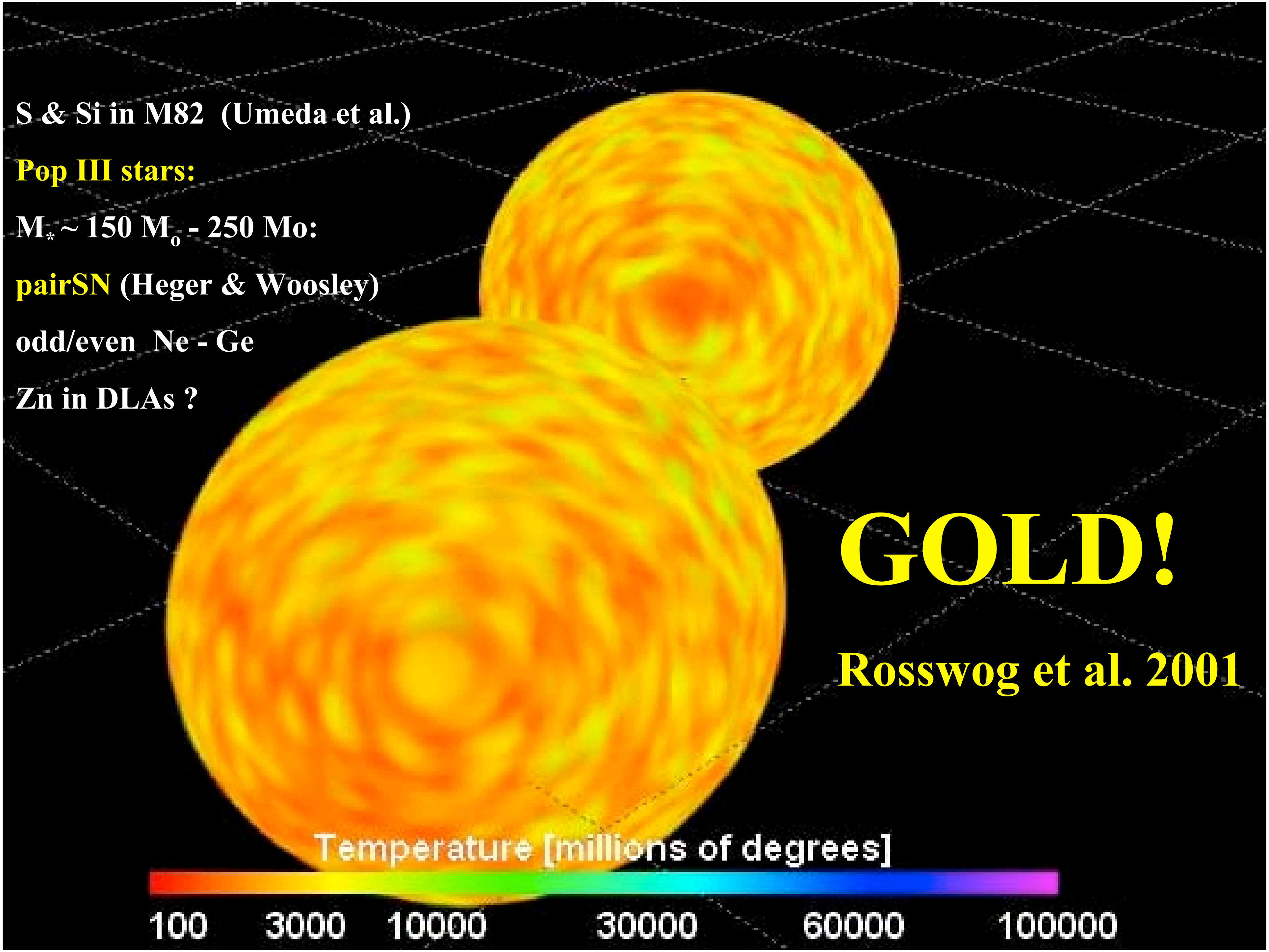
Kneiske, Mannheim, Hartmann 2002, A&A 386, 1

High energy absorption of GRB spectra

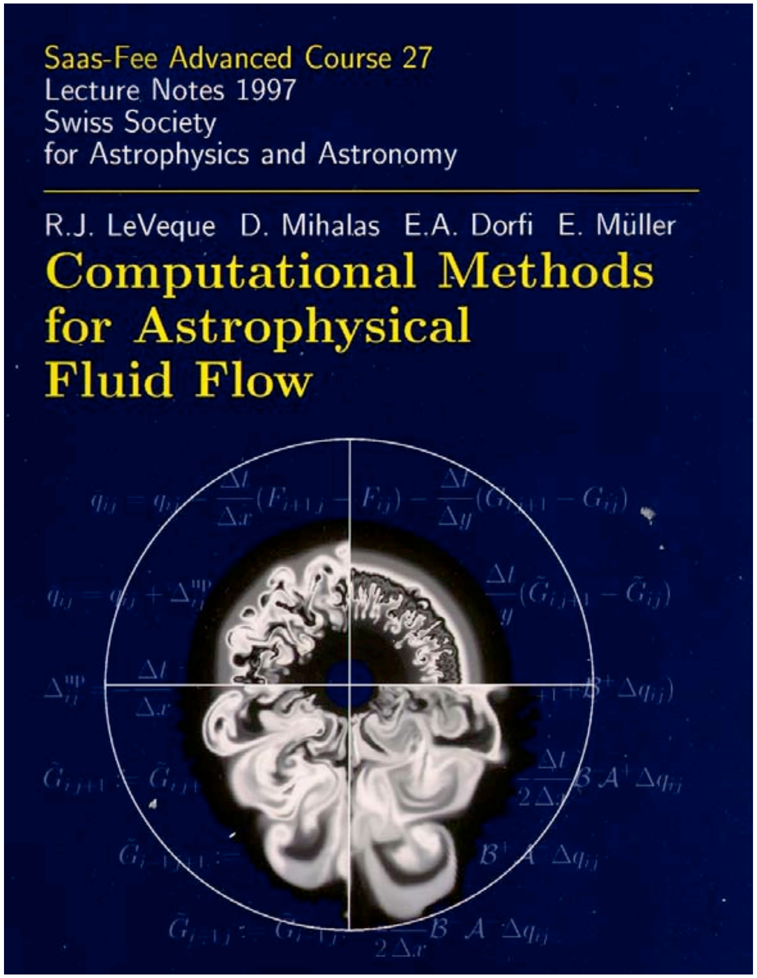


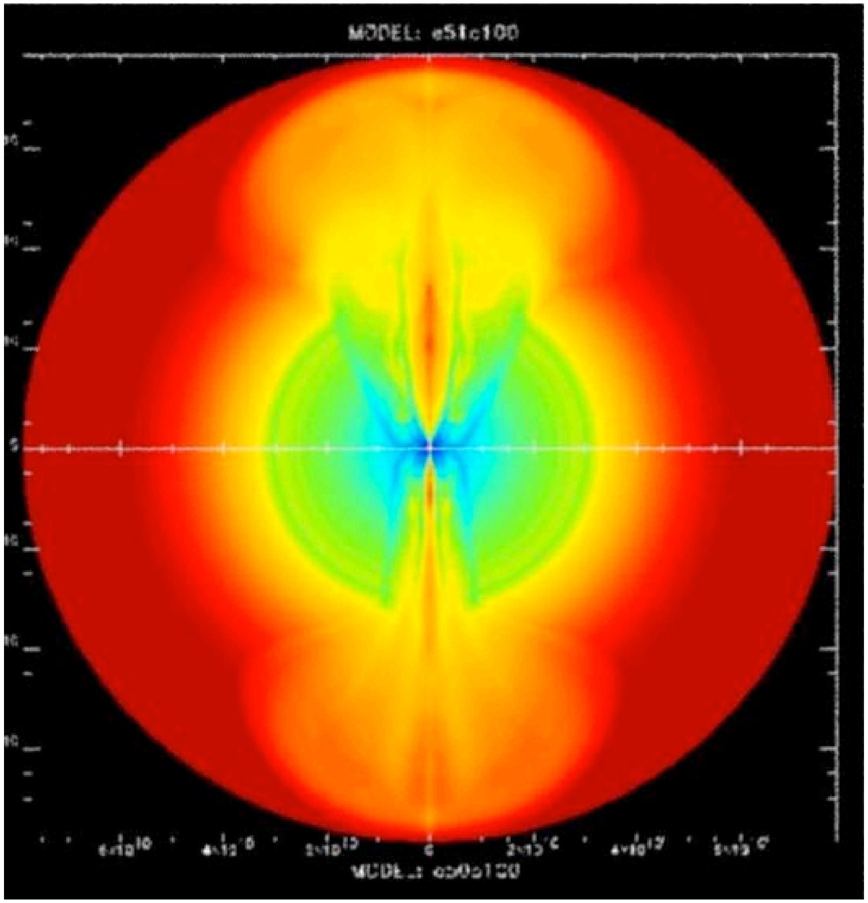


Kneiske, Mannheim, Hartmann


S & Si in M82 (Umeda et al.)
Pop III stars:
$M_* \sim 150\ M_o$ - 250 Mo:
pairSN (Heger & Woosley)
odd/even Ne - Ge
Zn in DLAs ?
GOLD!
Rosswog et al. 2001
Temperature [millions of degrees]
100 3000 10000 30000 60000 100000

THEORY

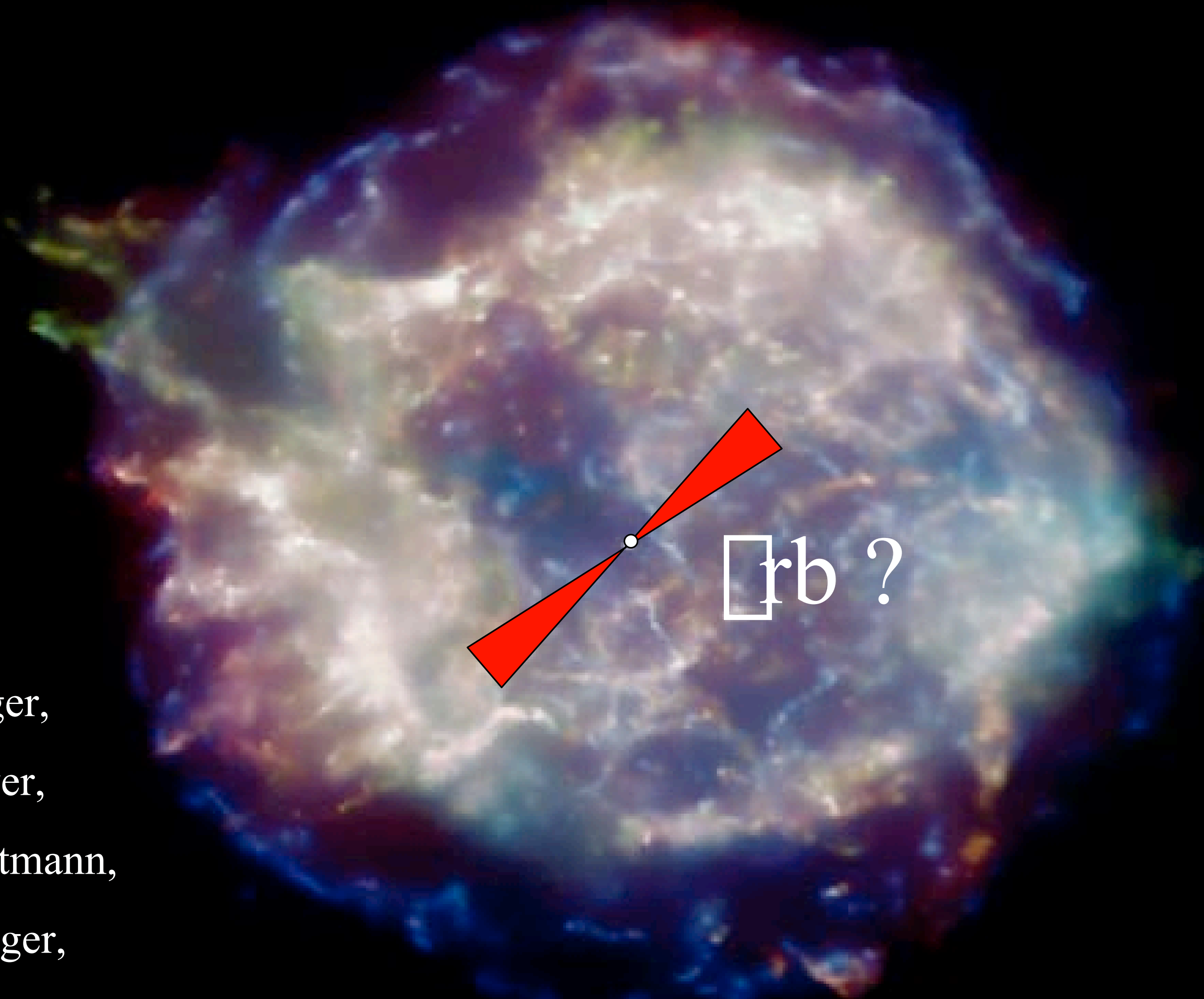




Relativistic Hydrodynamics

Special & General Relativity

How massive **single** stars end their life



A. Heger,

C. Fryer,

D. Hartmann,

N. Langer,

S. Woosley   2002, in preparation

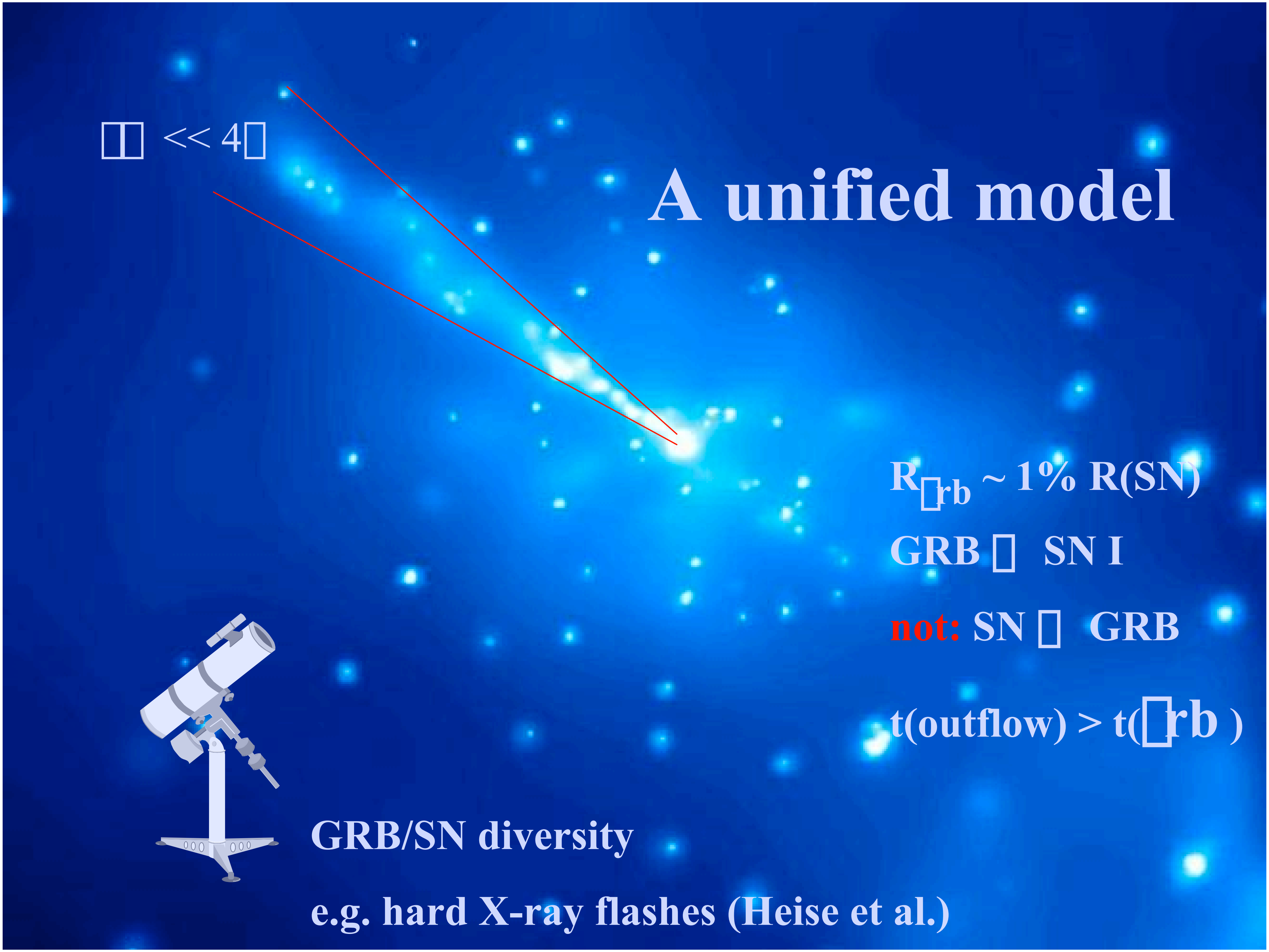
The BHAD central engine

E_0 ~10^{52} ergs:

SN

GRB

AG



□□ << 4□
A unified model
R□rb ~ 1% R(SN)
GRB □ SN I
not: SN □ GRB
t(outflow) > t(□rb)
GRB/SN diversity
e.g. hard X-ray flashes (Heise et al.)

Collapsars 101- Woosley 1993, ...

Rotating massive stars (no H envelope) $\dot{M}(Z(z))$

Ang. Momentum: central BH with accretion disk (BHAD

Jet formation (□, BZ) $\dot{J}(B)$ □ $\mathrm{Spruit}(2001)$

collimated outflow, breakout, $\dot{J}[\dot{M}(Z(z))]$

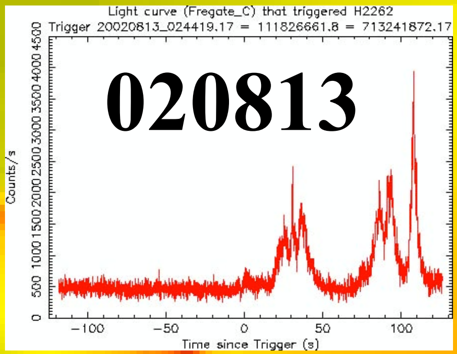
□ >> 1 if mass loading is low

Standard $E_0(M_{BH}, M_{acc})$ - jet-SN shuts off accretion

At least three progenitor routes

Detailed predictions to test the model remain TBD

Light Curve Structure



Variations of energy input where the jet is born, do not manifest themselves in gre GRB lightcurve

Jet-Star Interaction:

Relativistic KH Instability

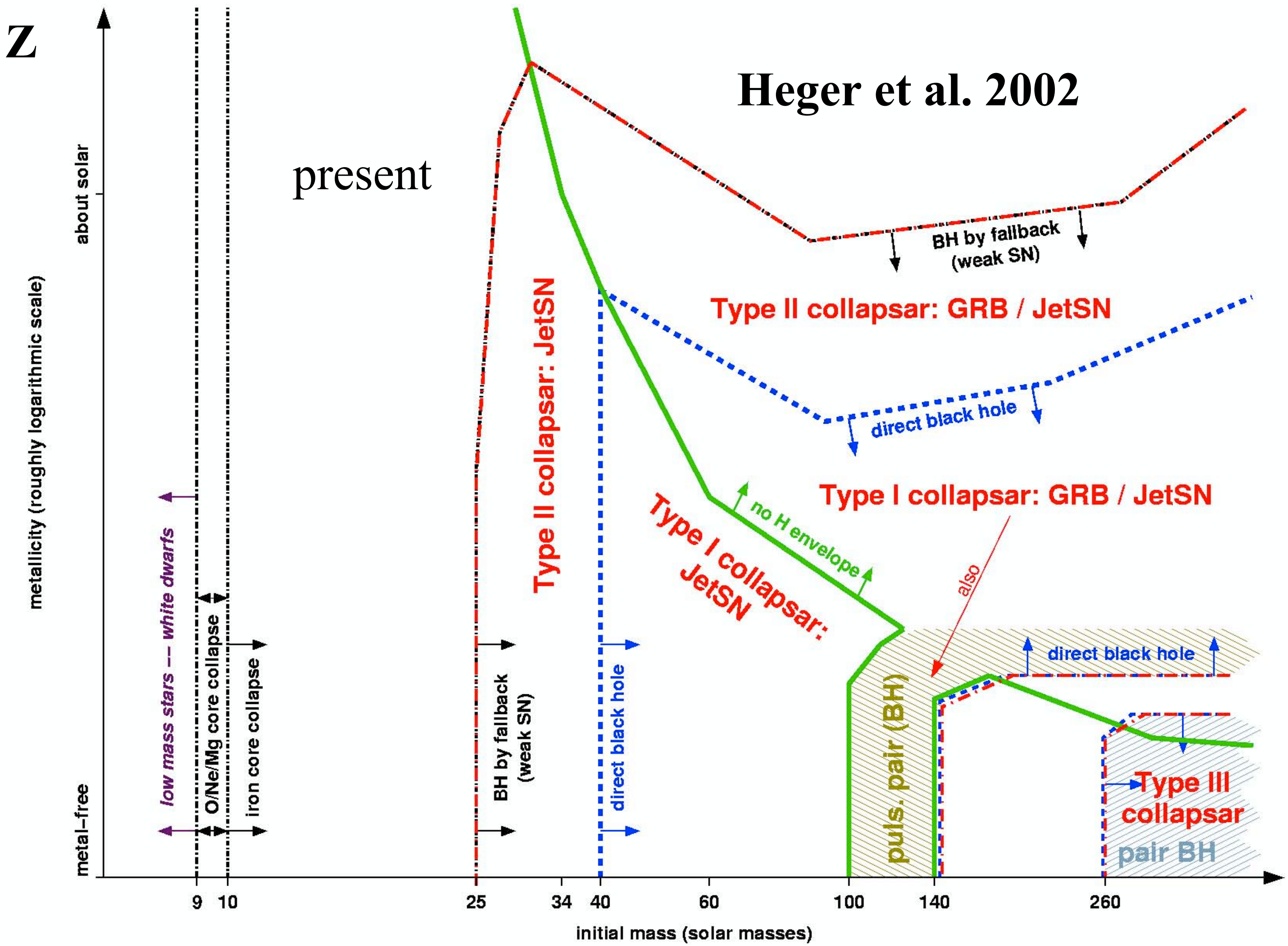
- baryon loading of the flow

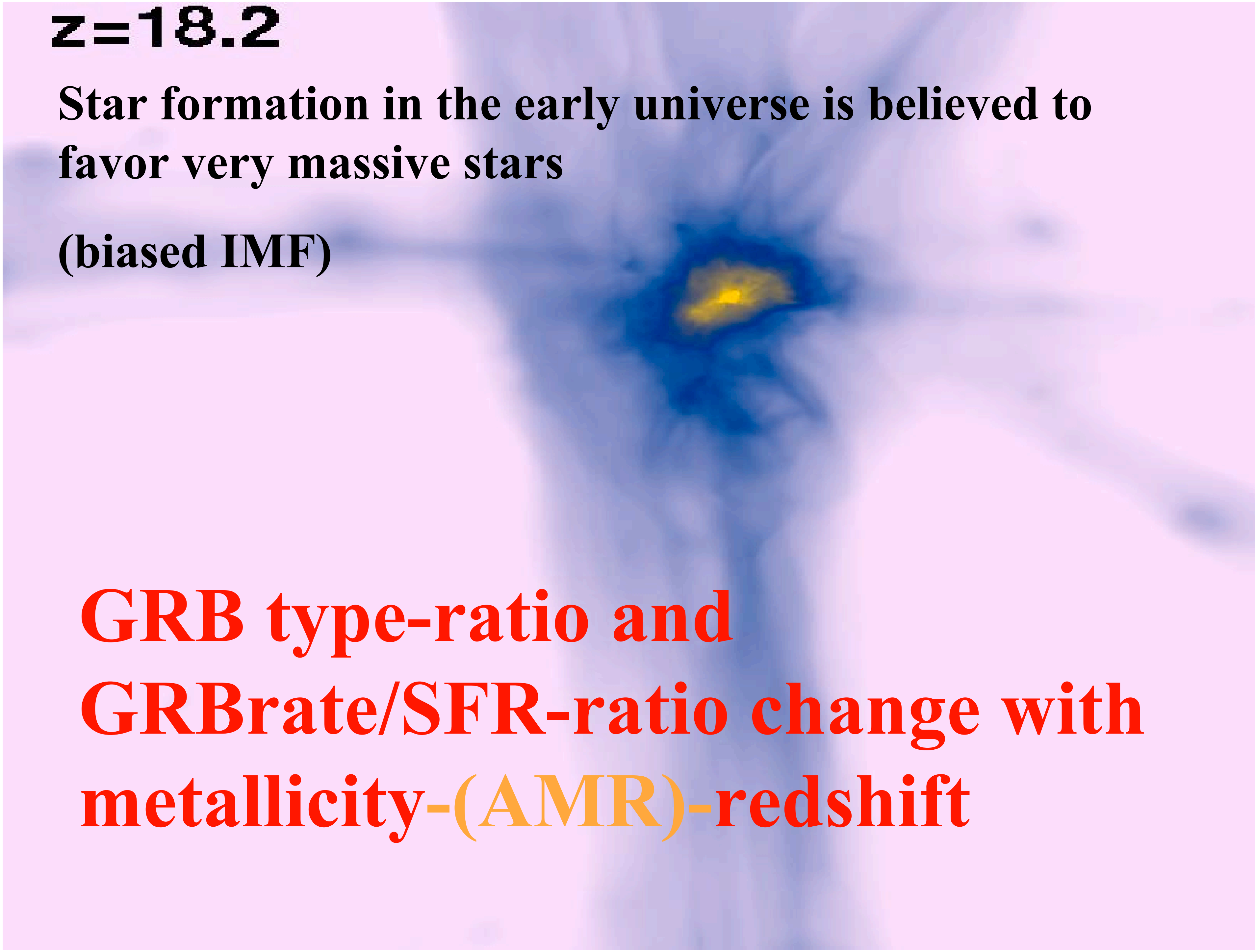
- Lorentz factor spectrum

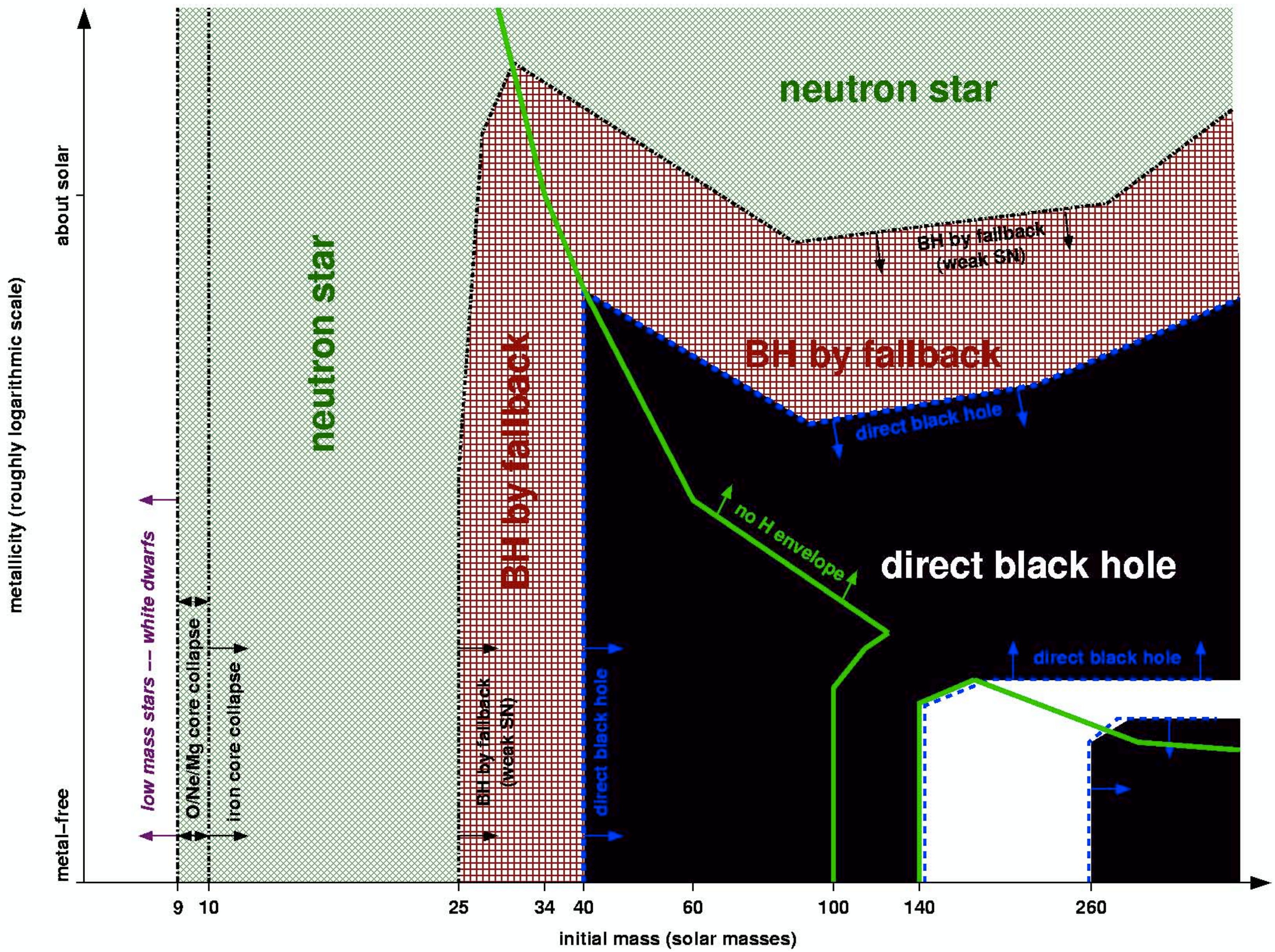
$$\mathrm{Var} \sim \mathrm{KH} \sim \frac{A_{jet}}{V_{jet}} \sim \Gamma_{jet}^{-1} \sim \mathrm{Lum}$$

Three Types of Collapsars

- CI - **M(He) ~ 10-40 M_o: prompt BH formation, no successful shock after cc, M_{BH} ~ few M_o. dM/dt ~ 0.1 M_o/s, □t ~ 10 s, temp. proto-NS formation = f(eos), □-flux smothered: low Z reduce dM/dt, and thus increases M(He)**
- CII ~ CI - **Delayed BH formation (fall back) with t ~ min-hrs; similar parameters**
- CIII - **Pop III stars: M > M_{crit}(□) ~ 250 Mo, BH mass ~ 100 M_o, dM/dt ~ 0.1 M_o/s for 10(1+z) s**


Z
Heger et al. 2002
present
about solar
metallicity (roughly logarithmic scale)
metal-free
low mass stars -- white dwarfs
O/Ne/Mg core collapse
iron core collapse
BH by fallback (weak SN)
Type II collapsar: JetSN
direct black hole
Type I collapsar: JetSN
no H envelope
BH by fallback (weak SN)
Type II collapsar: GRB / JetSN
direct black hole
Type I collapsar: GRB / JetSN
also
direct black hole
puls. pair (BH)
Type III collapsar
pair BH
9
10
25
34
40
60
100
140
260
initial mass (solar masses)


z=18.2
Star formation in the early universe is believed to favor very massive stars
(biased IMF)
GRB type-ratio and GRBrate/SFR-ratio change with metallicity-(AMR)-redshift


neutron star
neutron star
BH by fallback
BH by fallback
BH by fallback (weak SN)
BH by fallback (weak SN)
direct black hole
direct black hole
direct black hole
direct black hole
no H envelope
low mass stars -- white dwarfs
O/Ne/Mg core collapse
iron core collapse
metallicity (roughly logarithmic scale)
about solar
metal-free
9
10
25
34
40
60
100
140
260
initial mass (solar masses)


Conclusions
Once you have seen one GRB,
... you have seen one GRB !