Gamma-Ray Bursts

An observational perspective of the prompt and early afterglow

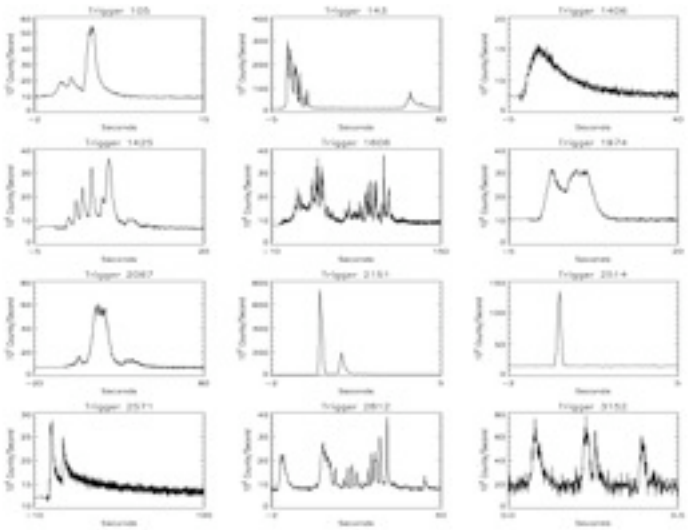
Michel Boër
Observatoire de Haute Provence

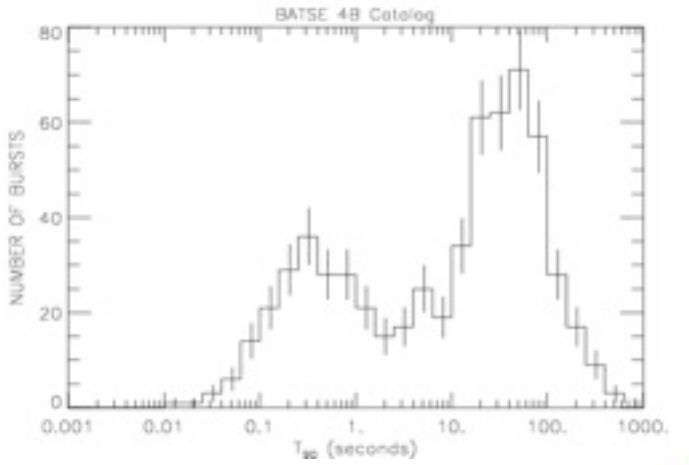
Discovered fortuitously

- First observed in 1969
  - VELA military satellites
  - Monitoring of atmospheric nuclear explosions, to enforce application of the nuclear test-ban treaty between USA and USSR
  - Unclassified in 1973
- Since then, many space experiments
  - USSR/Russia – USA – France – Italy - Germany

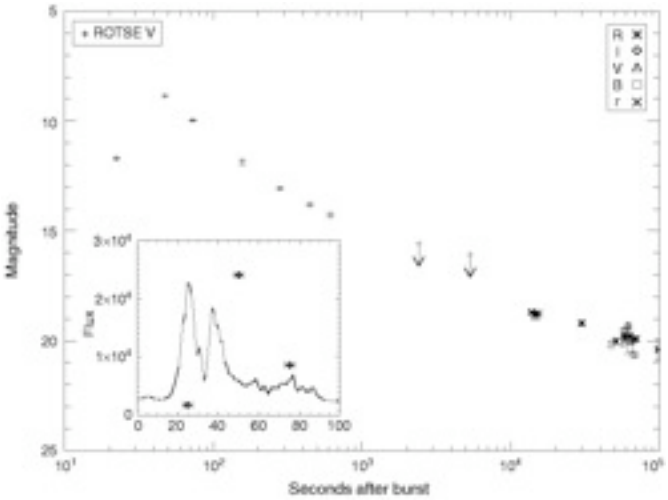
Gamma-Ray Bursts

- Prompt event: durations from 0.01 to 1000s
  - 2 populations (0.5s et 30s)
- Power law afterglow $t^{-1,-2}$
- ~ 2 GRB/d $>10^{-8}$erg/s.cm^{-2} .4πSter
  - SWIFT 150/y, GLAST 400/y
  - Local rate ~2 Gpc^{-3} yr^{-1}
- Panchromatic events: Spectrum peaks between < 10 and 1000 keV
- Total spectrum from 1mkeV to >? 20 GeV)
- Rapid variability (< 10ms)
- Cosmological origin (0.001 < z < 4.5 (measured) < 15??)
- Isotropic luminosity around $10^{51\text{-}52}$ergs, however, emission in jets imply luminosities ~10^{48}ergs



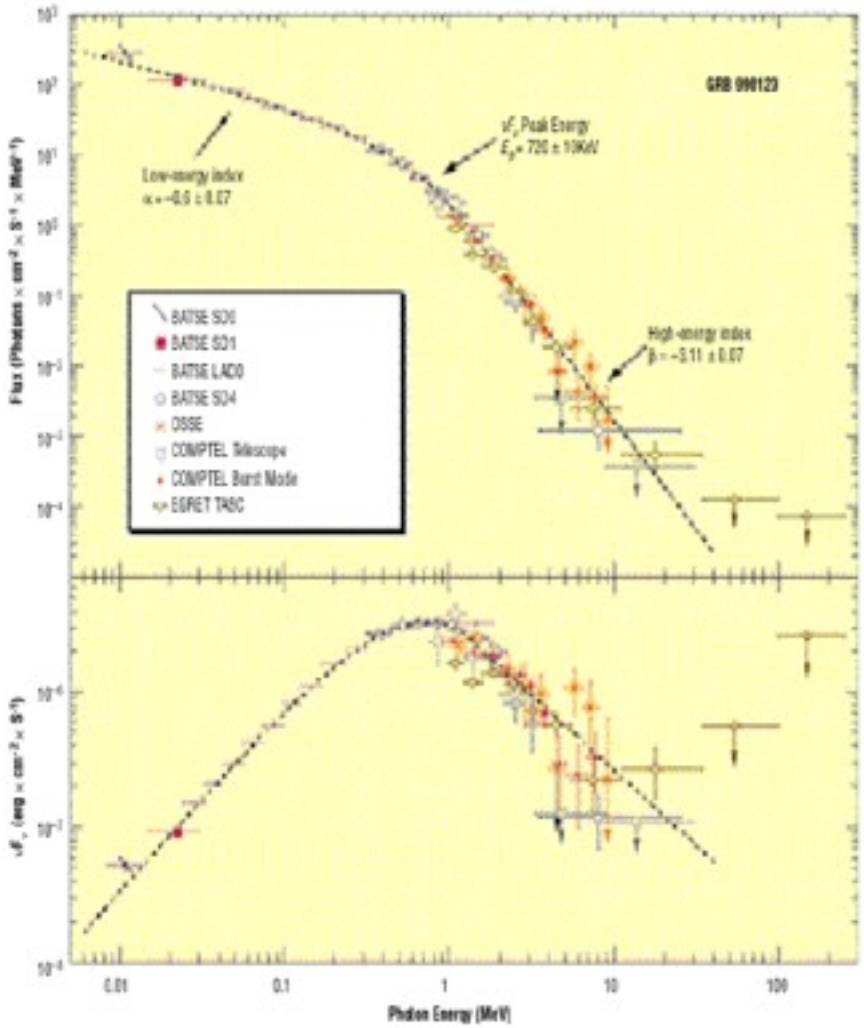


GRB 990123

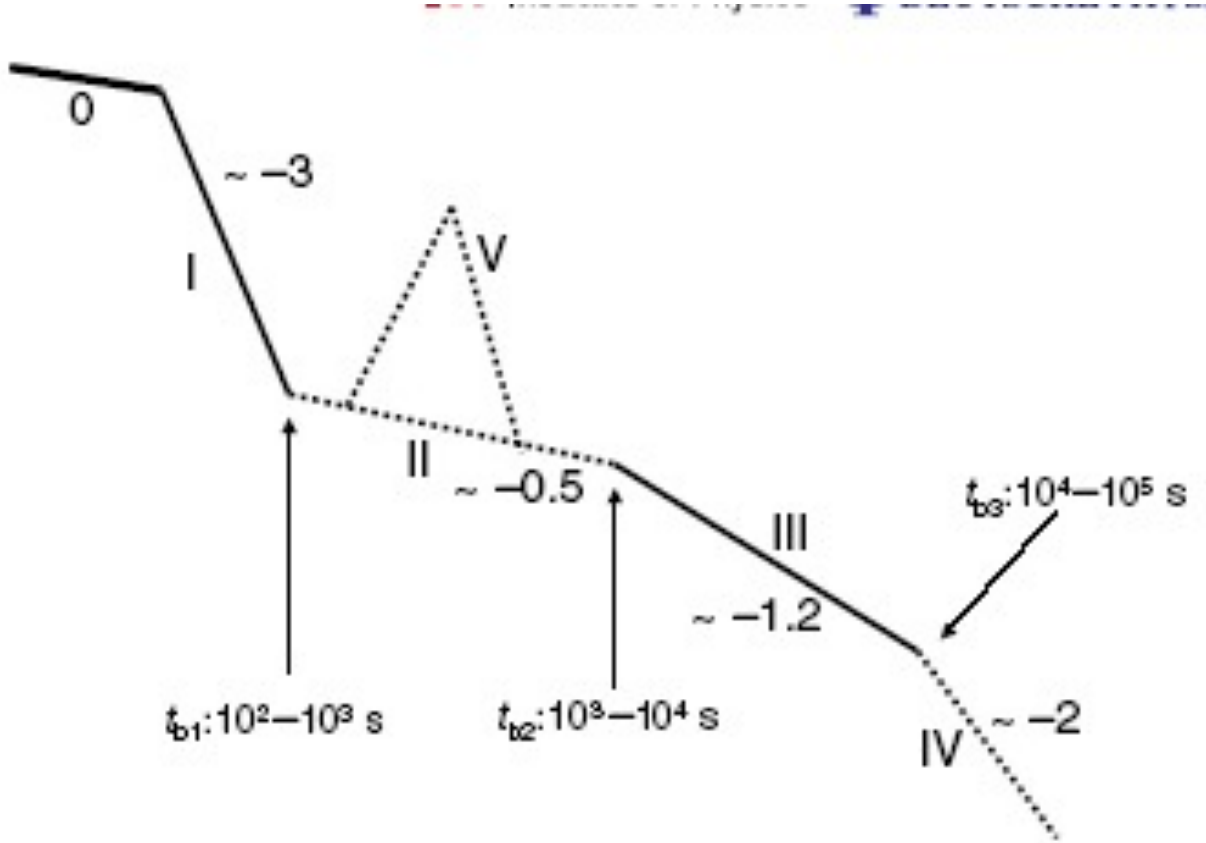


ROTSE-1 images
GRB 990123

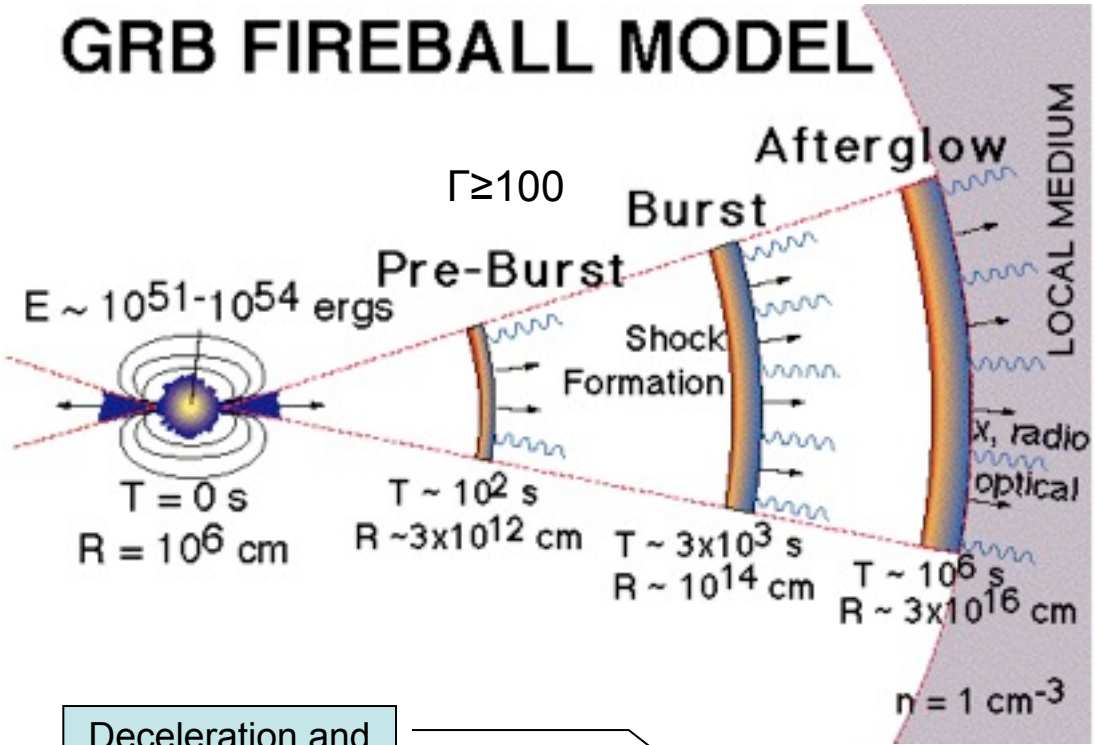
Dr. Carl Akerlof
University of Michigan
and
ROTSE collaboration



X-ray Afterglow large « swift » view



GRB FIREBALL MODEL



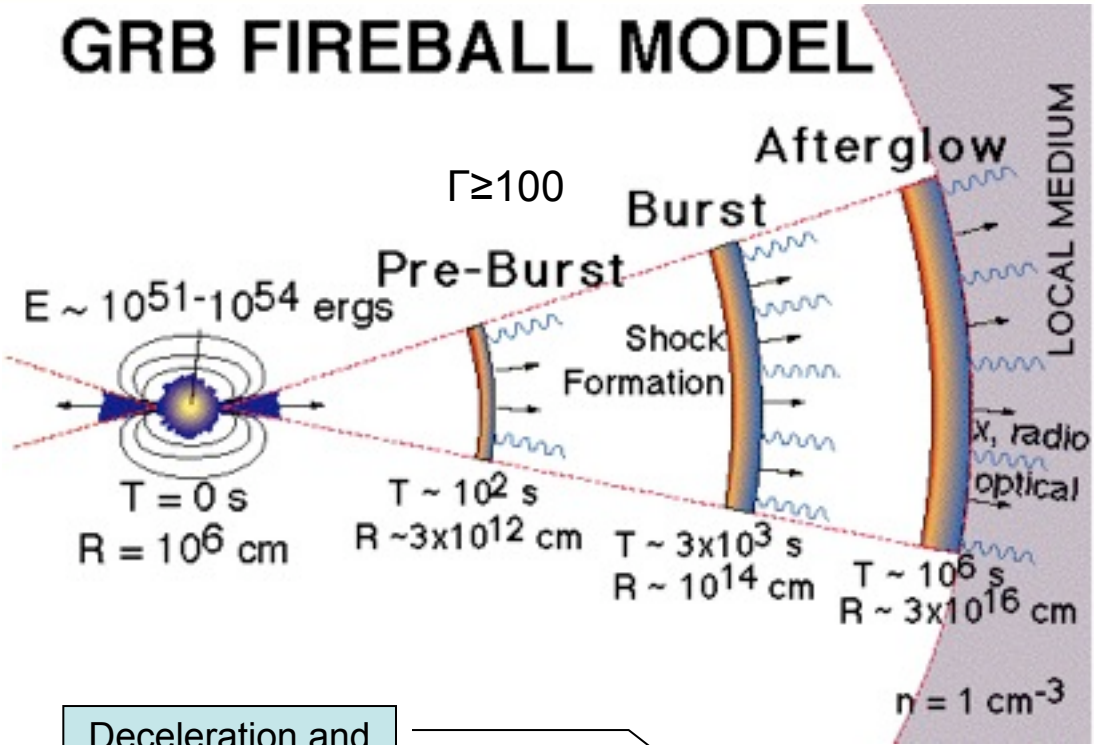
Deceleration and lateral spread

Γ≥100

Orphan afterglow (no GRB)

Gamma burst

GRB FIREBALL MODEL



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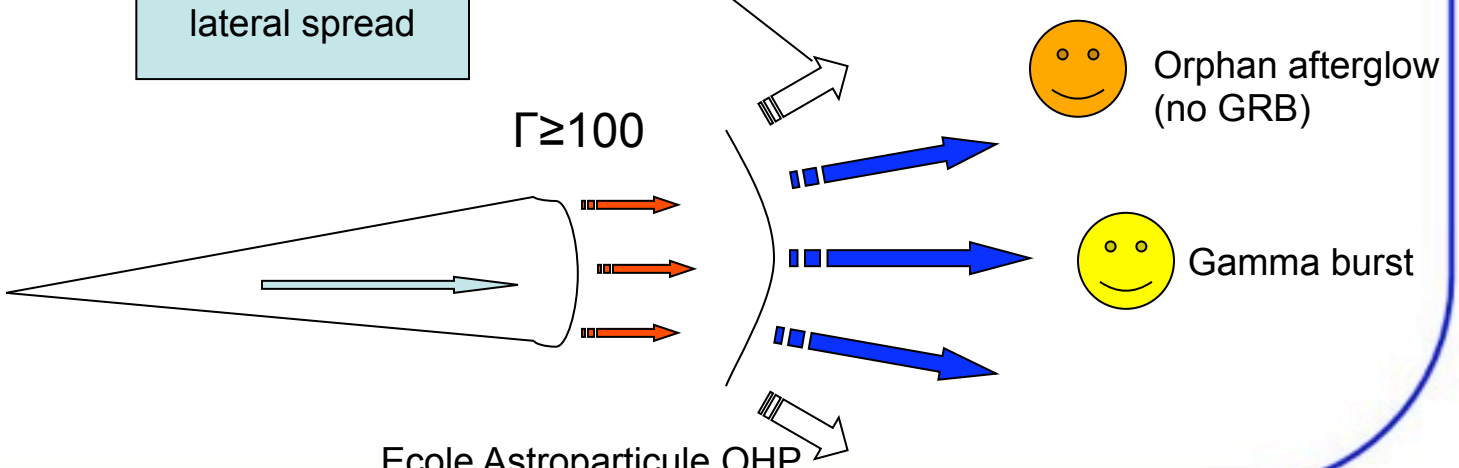
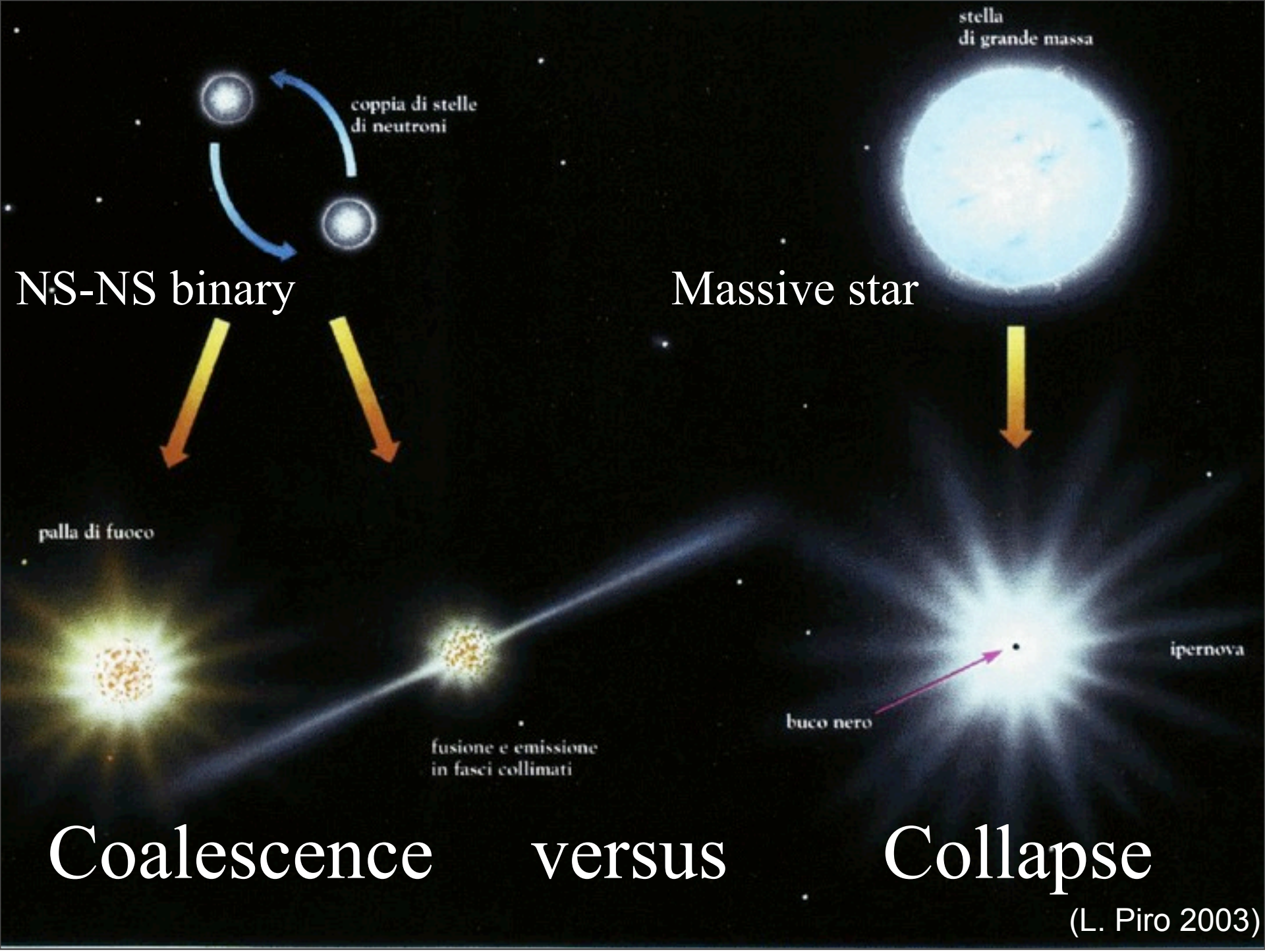



coppia di stelle
di neutroni
stella
di grande massa
NS-NS binary
Massive star
palla di fuoco
fusione e emissione
in fasci collimati
buco nero
ipernova
Coalescence versus Collapse
(L. Piro 2003)

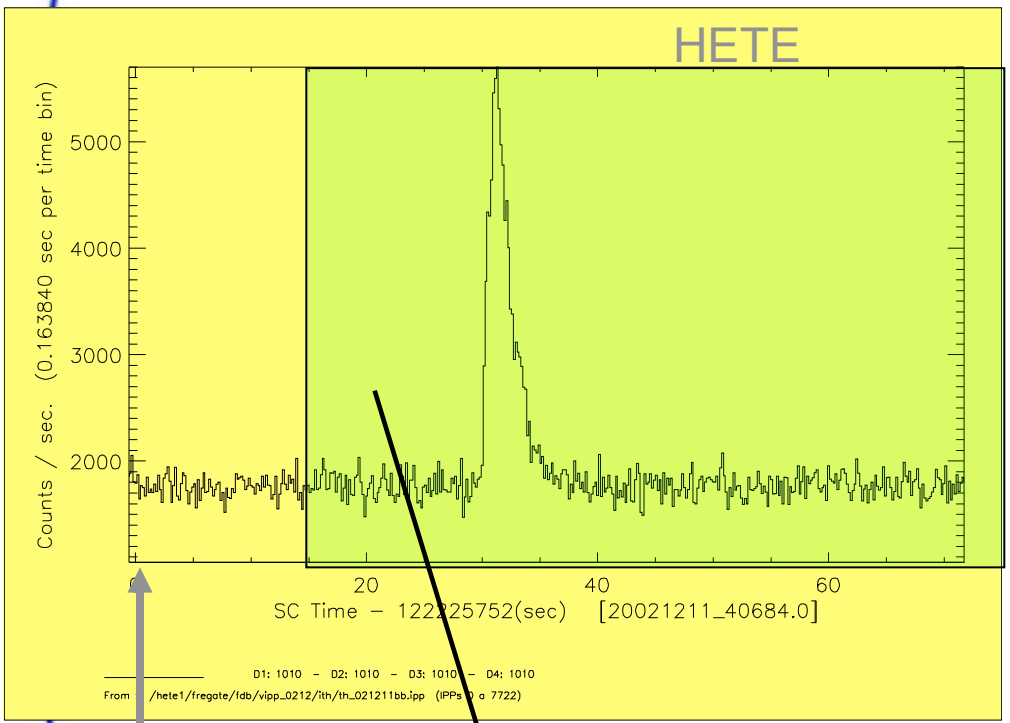
Why all this excitement about GRBs

- GRBs involve the fastest motion observed so far ($\Gamma > 100$)
- They signal the formation of a newborn black hole
- They are sources of non-photonic radiation (v, gravitationnal)
- They are the best cosmological probes of the early universe (z = 5-12)
- Most relativistic objects known to date

GRB from Earth and Space

- GRB are pan-chromatic phenomena
- From space
  - Prompt event
    - Detection and localization (HETE, INTEGRAL, SWIFT, Fermi, SVOM)
    - Gamma-ray and X-ray (HETE, SWIFT, Fermi, SVOM)
    - Precursor (HETE, Fermi, SVOM)
  - Afterglow
    - Early afterglow, when does it starts (SWIFT, SVOM)
    - Long lasting afterglow (HST/JWST)
    - X-ray (SWIFT, XMM, Chandra, SVOM),
    - Visible (SWIFT, SVOM),
- From ground
  - Prompt event (if > 10s, TAROT…)
  - GRB – SN association (Large telescopes)
  - Distance (Keck, VLT, GROND)
  - GRB/AG transition (TAROT)
  - Afterglow visible/IR (TAROT, REM, RAPTOR, GROND…)
  - Orphan afterglow (Not yet, LSS?)
  - Orphan OTs?
  - Radio, IR, Optical, VHECR (many)
  - Eventually neutrinos, UHECR, Gravitationnal waves

GRBs from Earth and Space

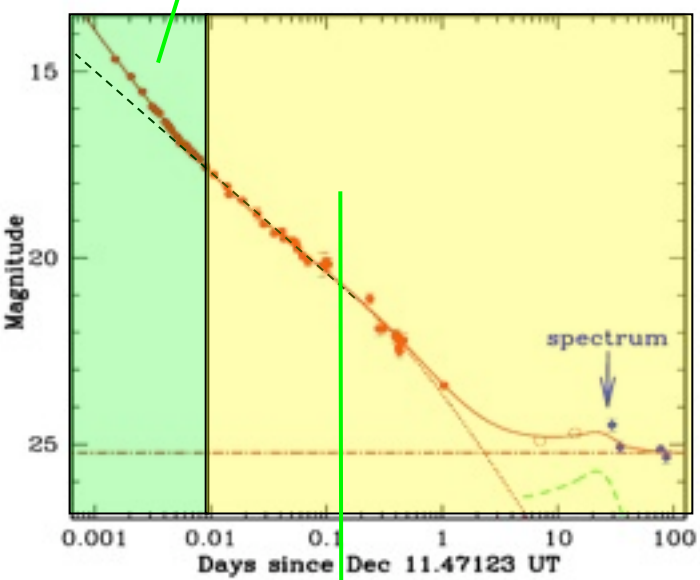


HETE Trigger

GRB 021211

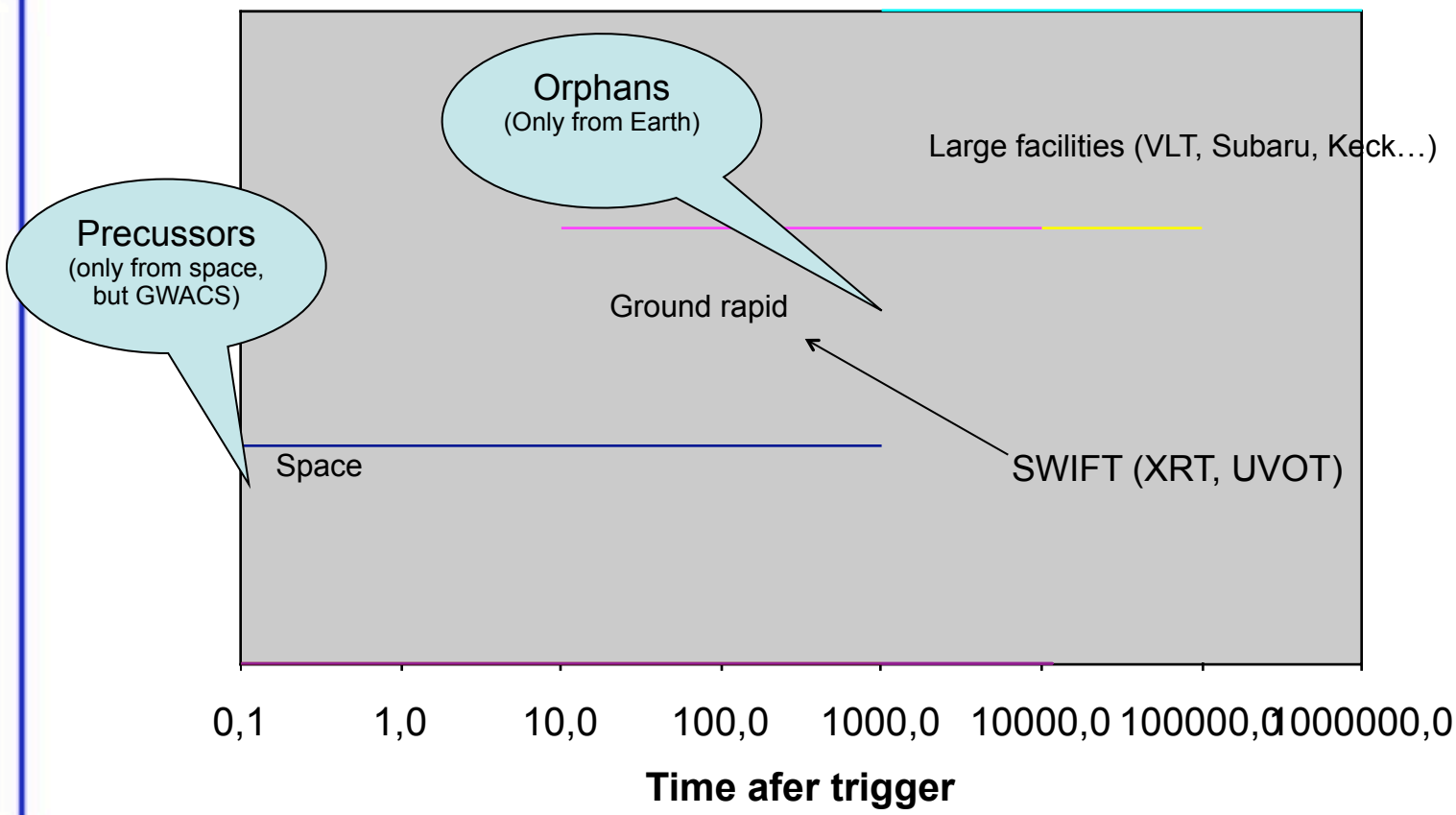
Rapid robitic telescopes start

Robotic telescopes

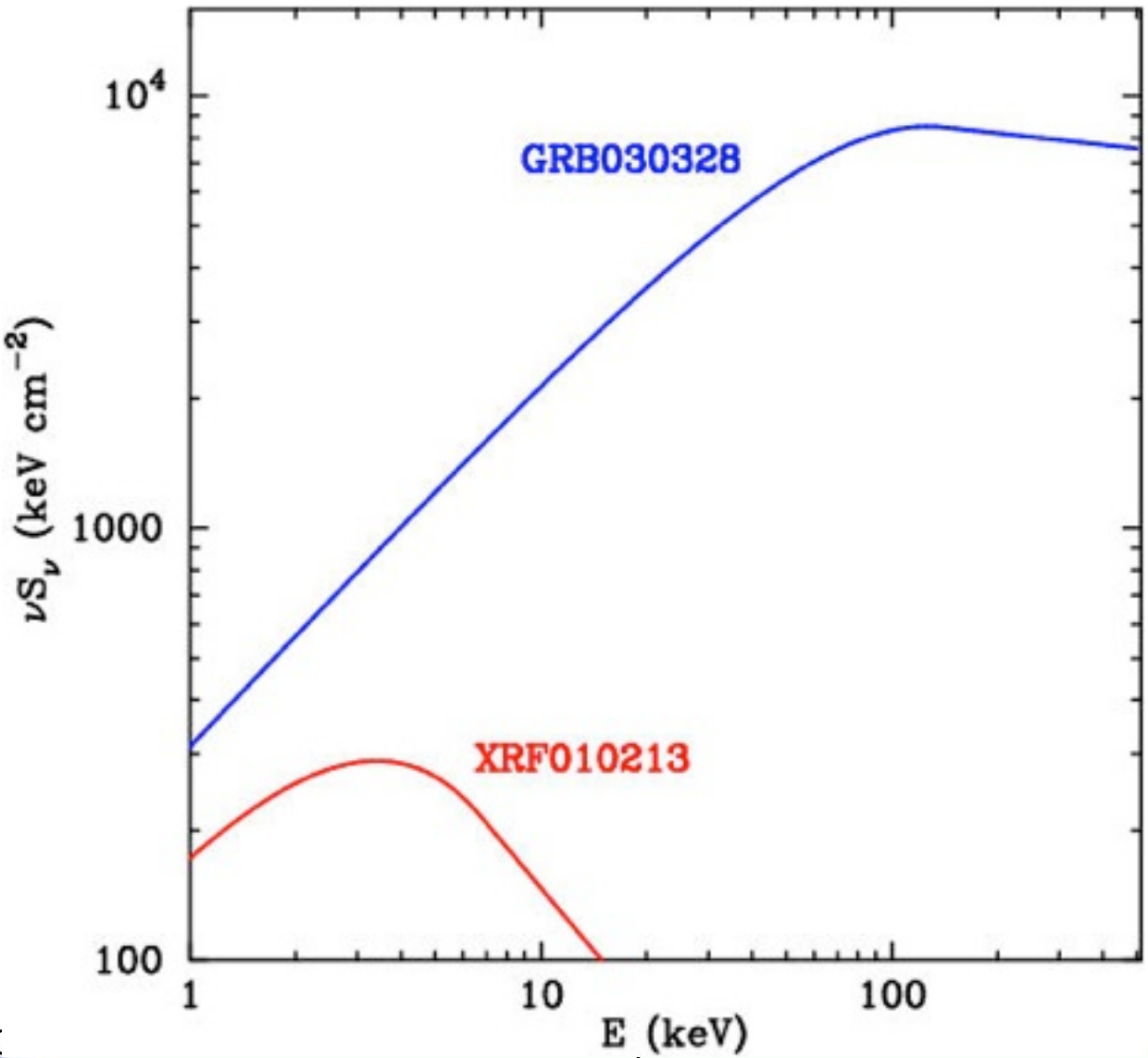


TOO with large telescopes

Della Valle et al., 2003


Orphans
(Only from Earth)
Large facilities (VLT, Subaru, Keck…)
Precussors
(only from space,
but GWACS)
Ground rapid
Space
SWIFT (XRT, UVOT)
0,1
1,0
10,0
100,0
1000,0
10000,0
100000,0
1000000,0
Time afer trigger

HETE-2 X-Ray Flashes vs. GRBs



Importance of wide energy range

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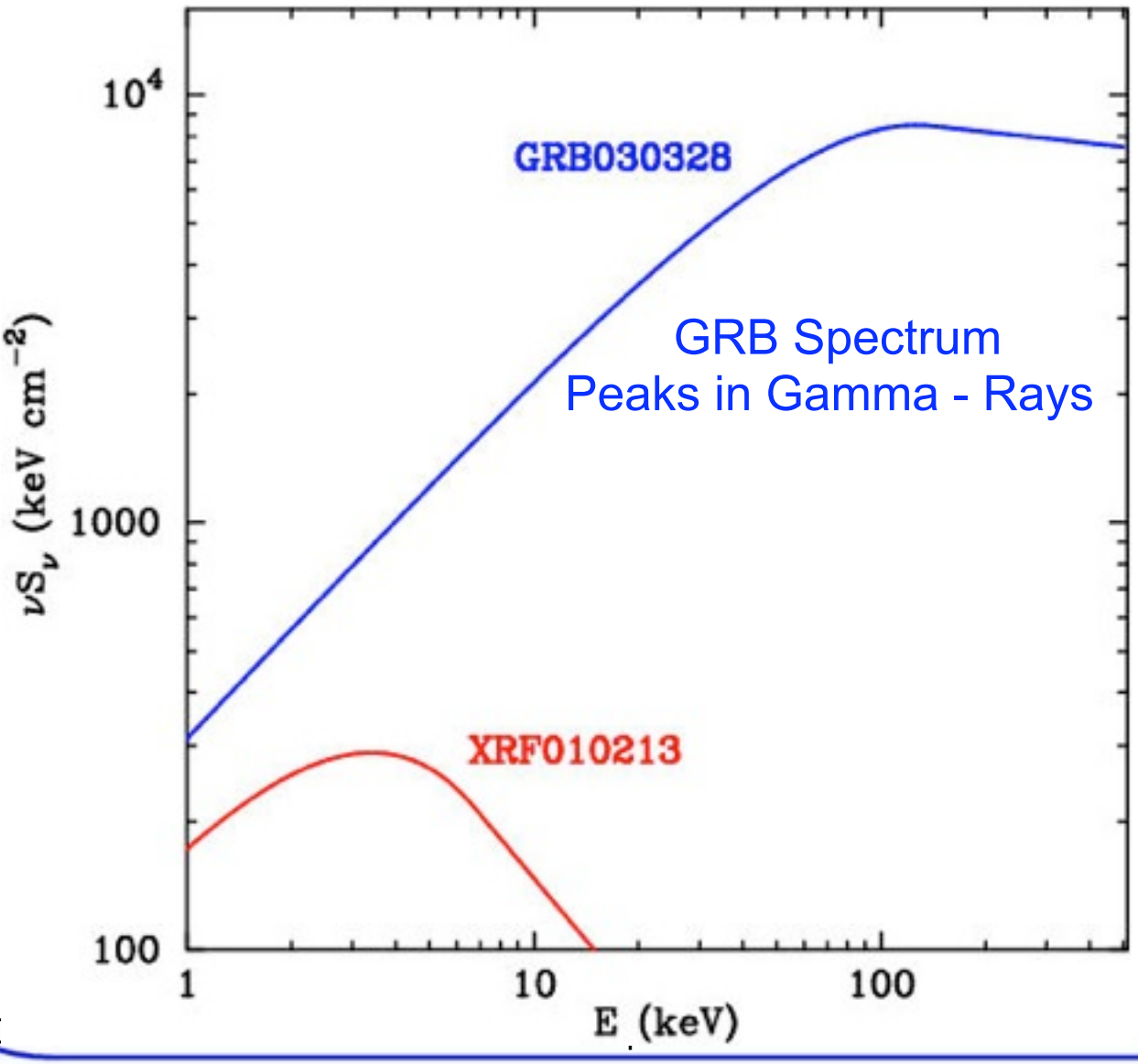

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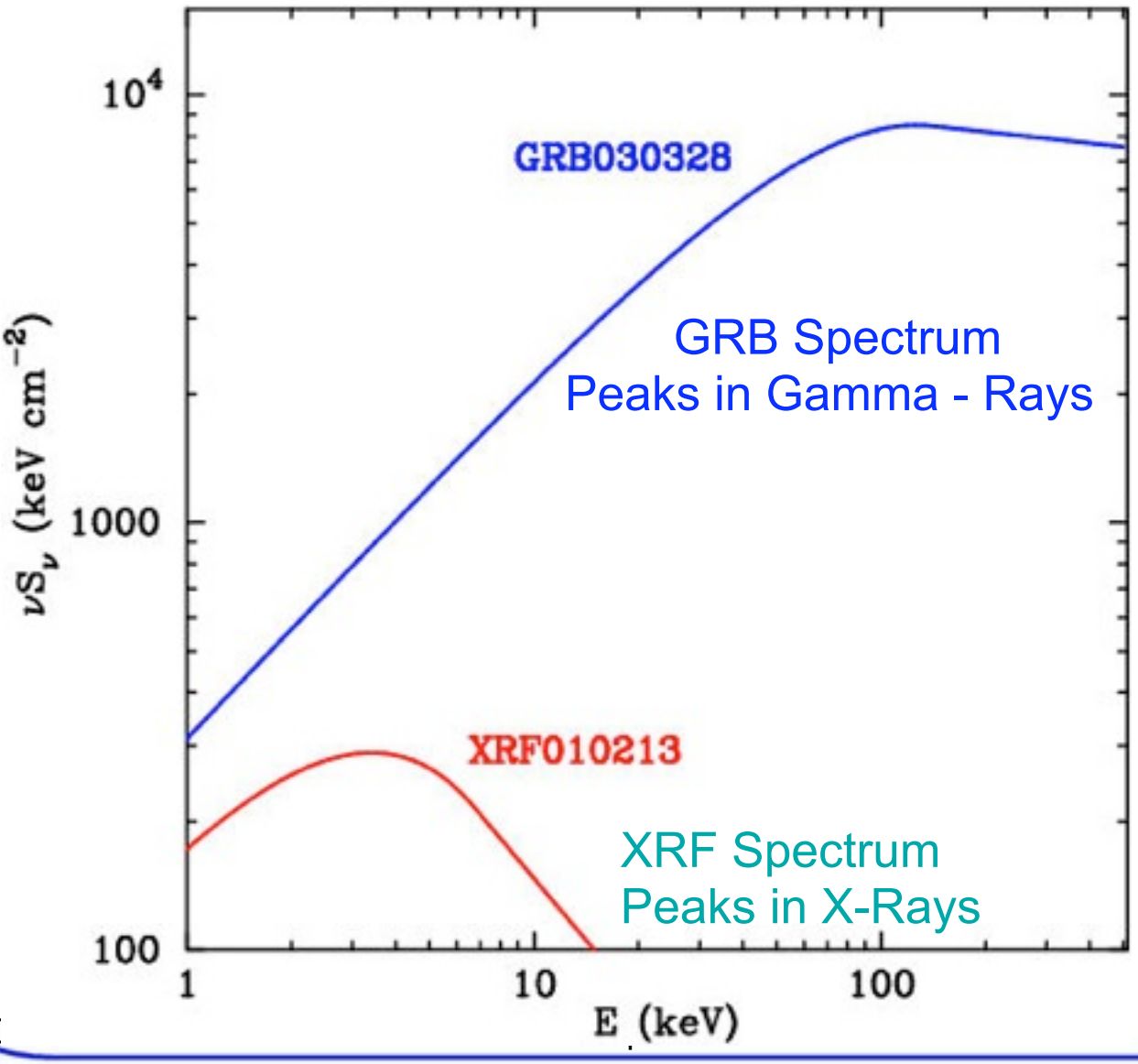

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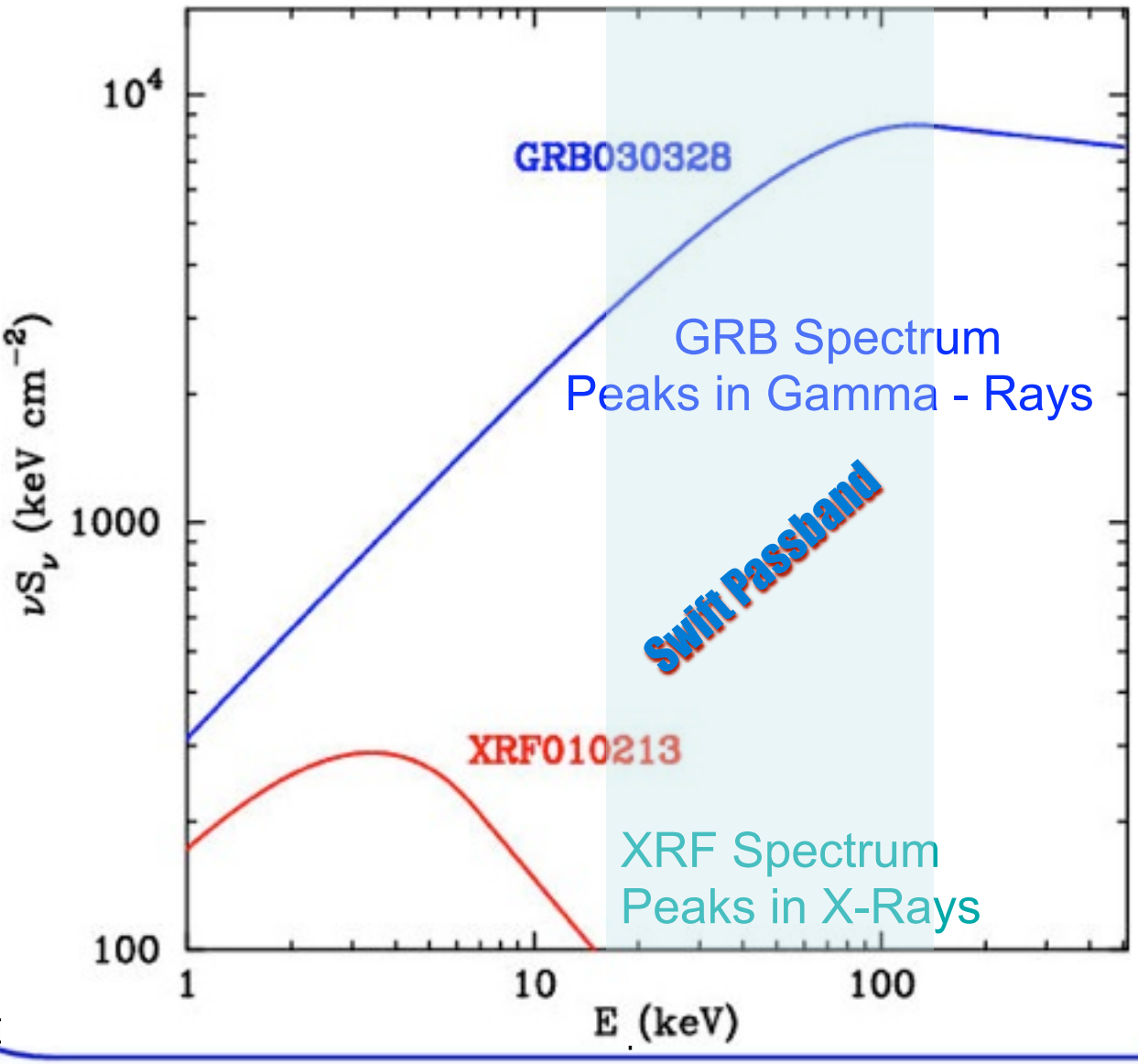
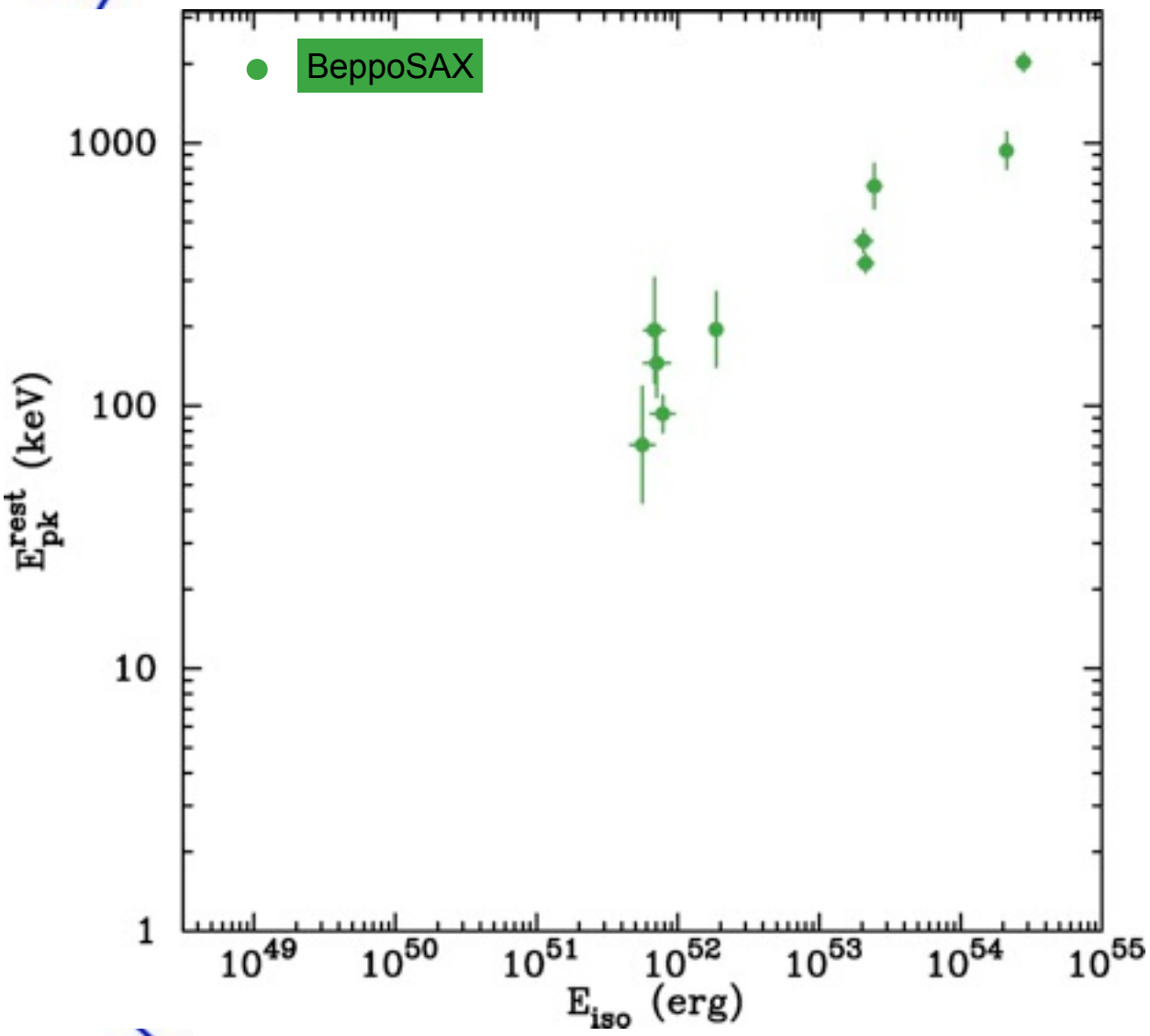


Importance of wide energy range

Dependence of GRB Peak Spectral Energy (E_{peak}) on Burst Isotropic Radiated Energy (E_{iso})



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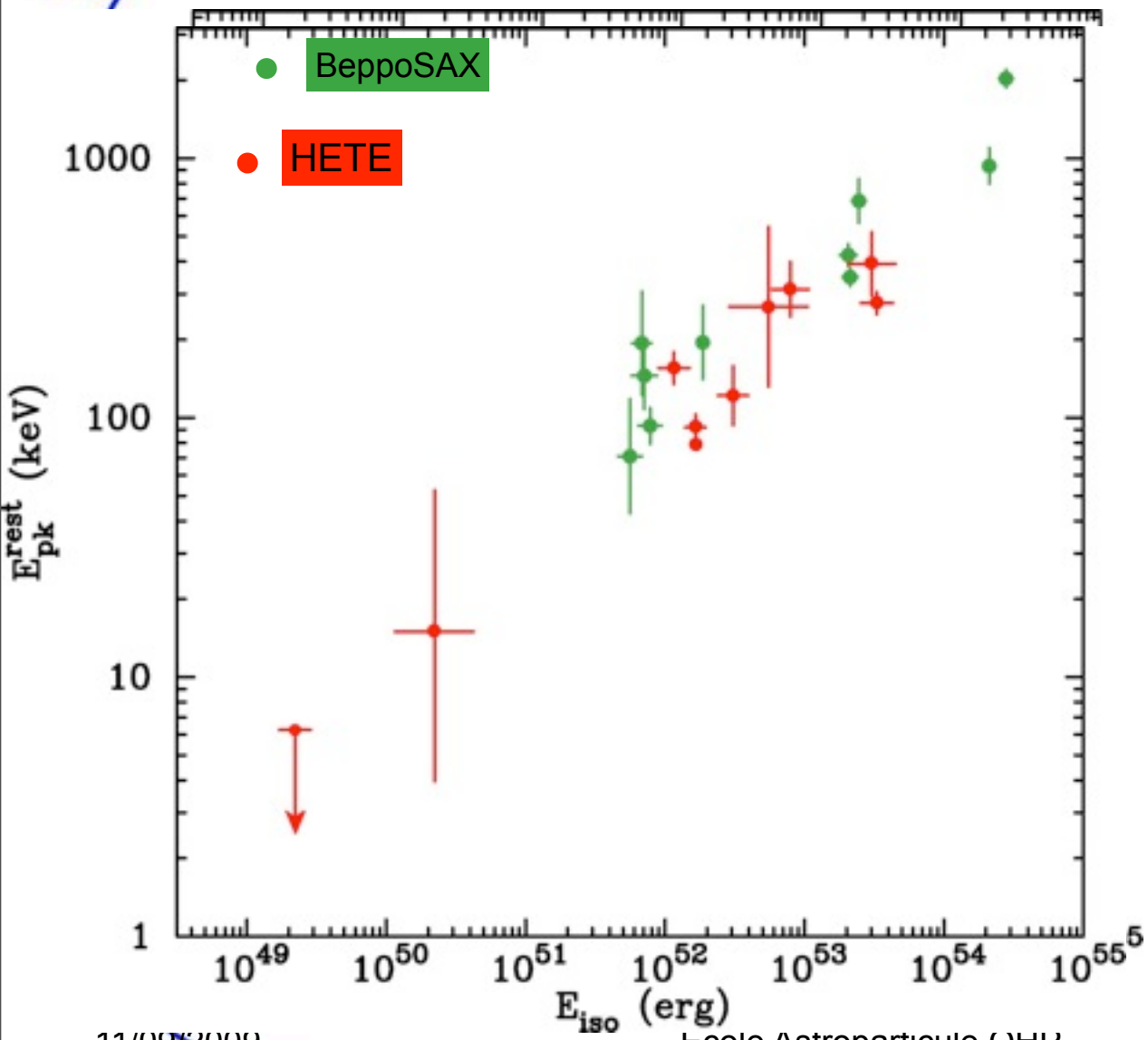

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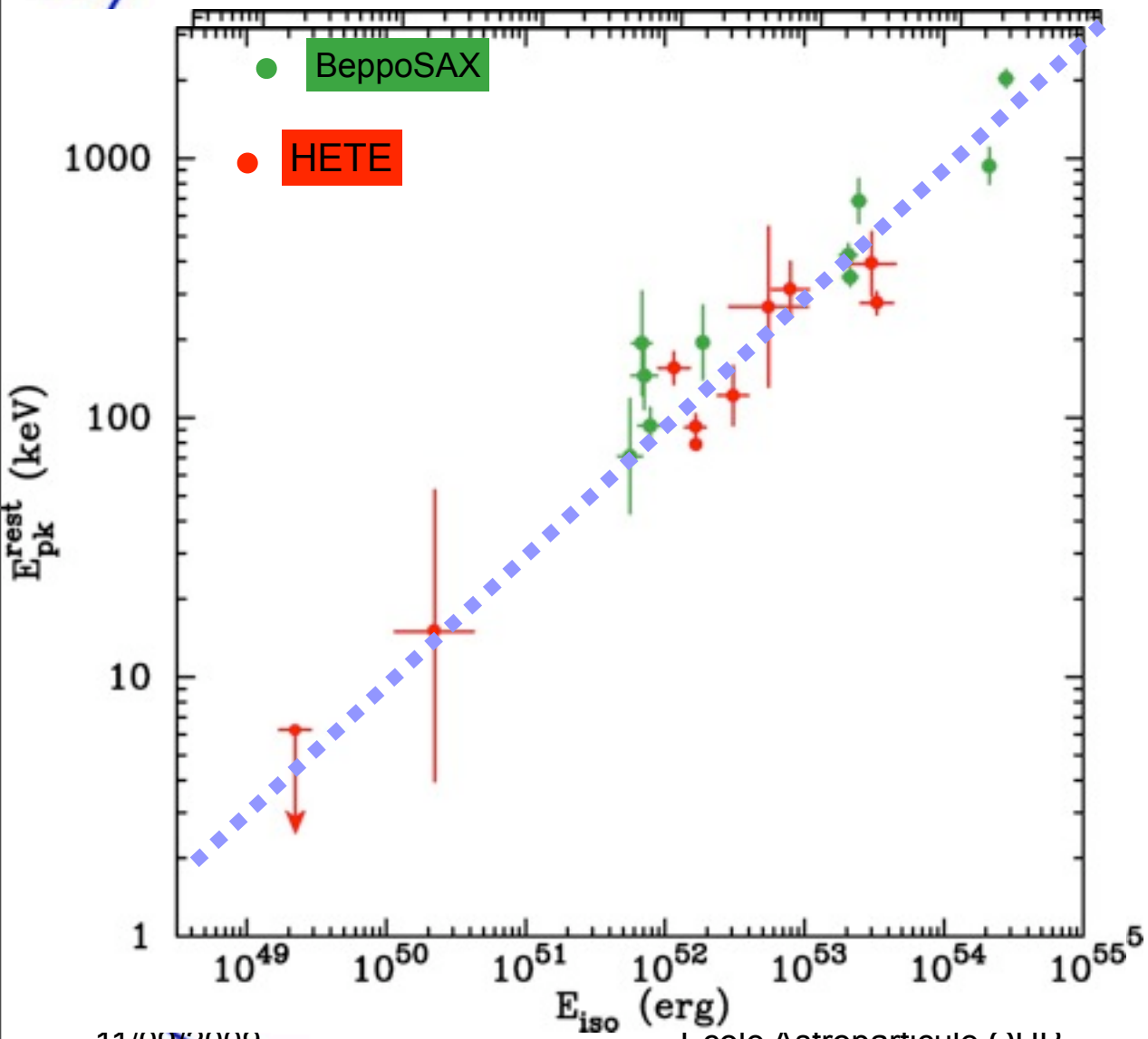

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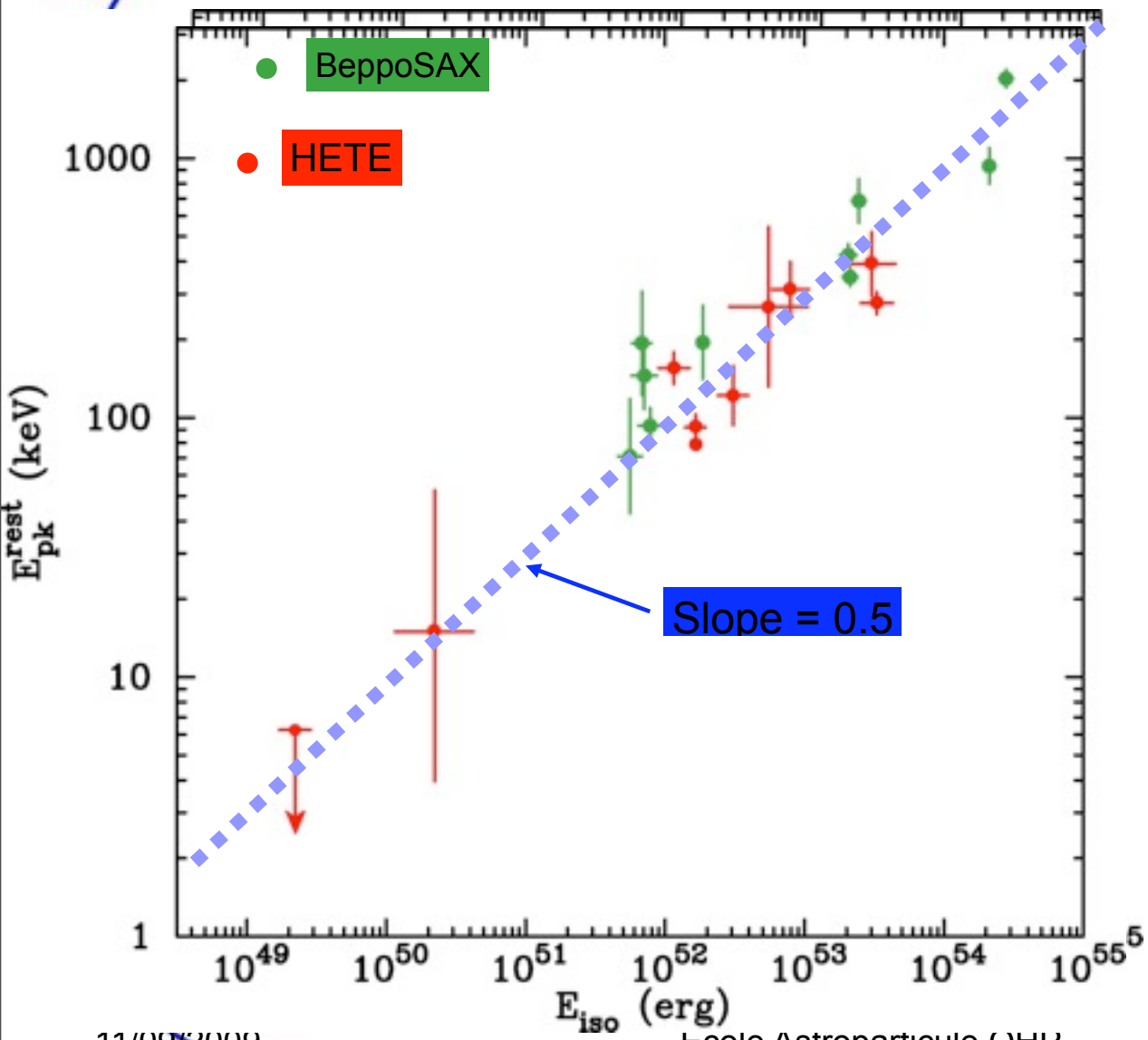

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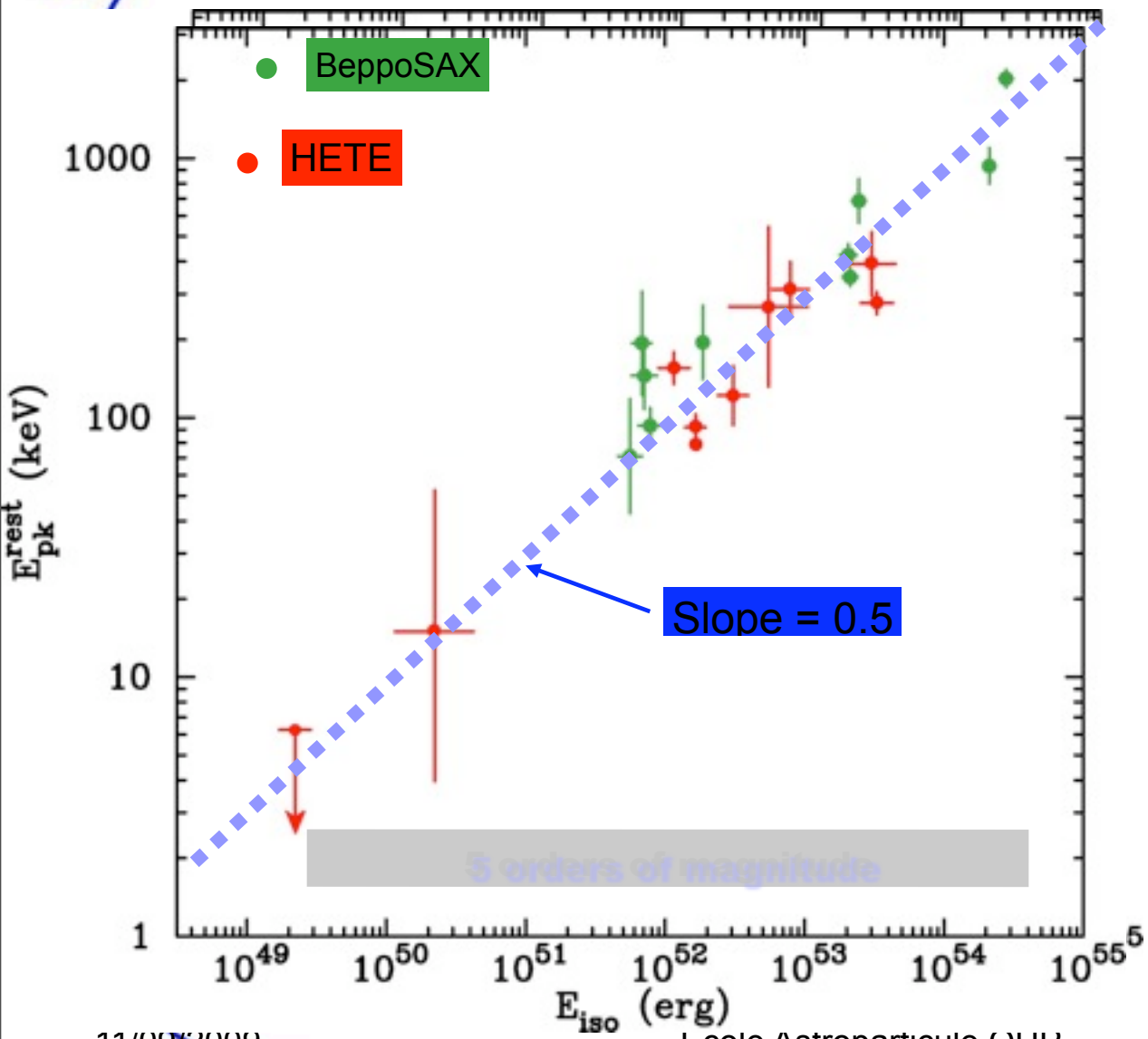

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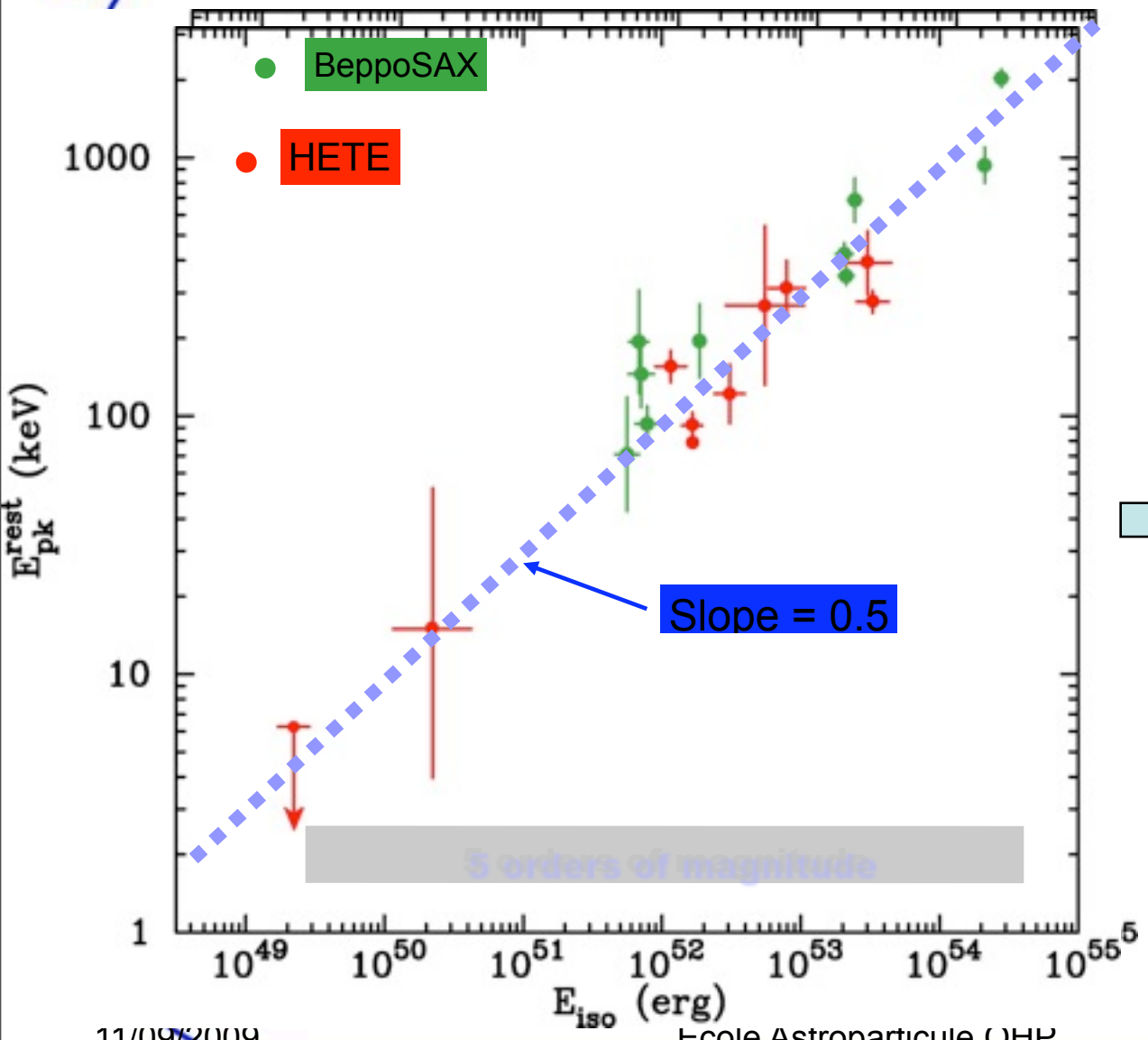
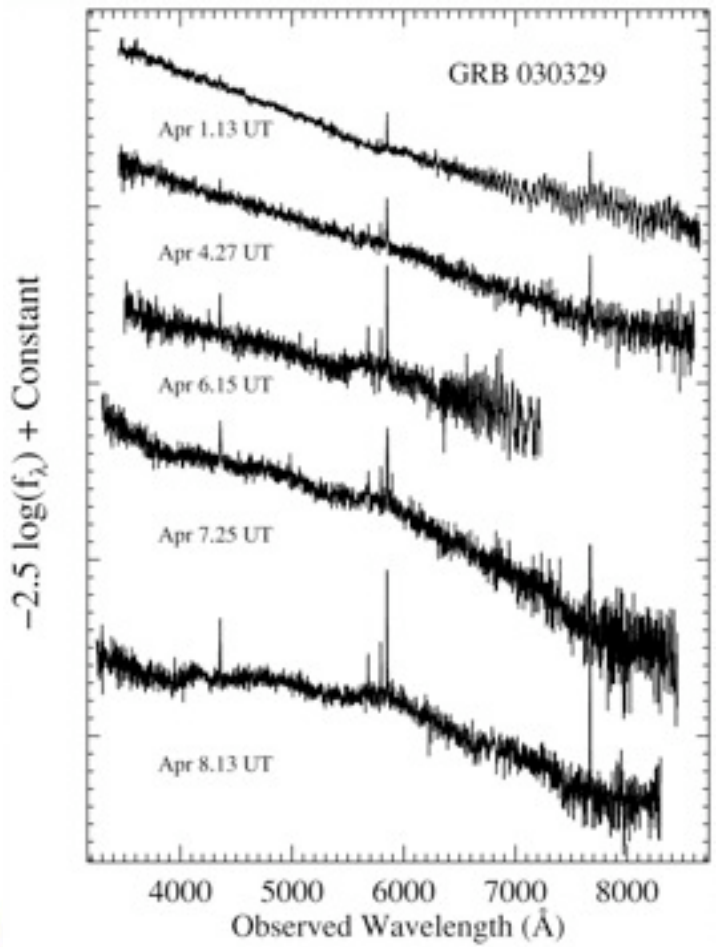


HETE results confirm & extend the Amati et al. (2002) rel'n:

$E_{peak} \sim \{E_{iso}\}^{0.5}$

GRB spectra can provide an empirical, predictive *redshift estimator* that is accurate to a factor of ~2 (Atteia 2003); indicated GRB031026 had z~14, but no optical counterpart found.

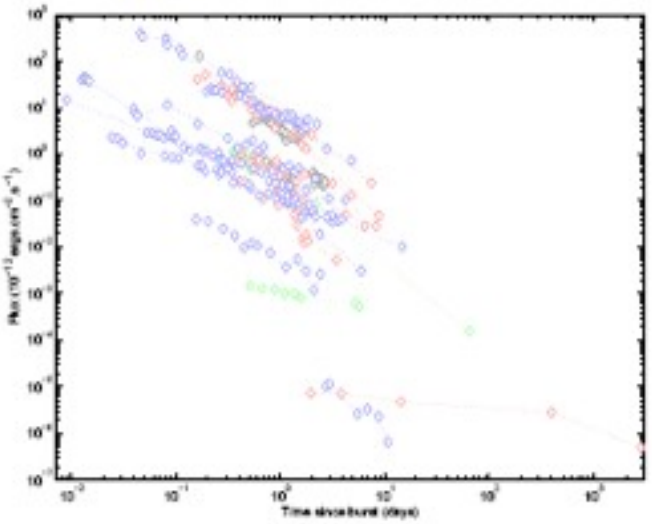
GRB 030329 = SN 2003dh

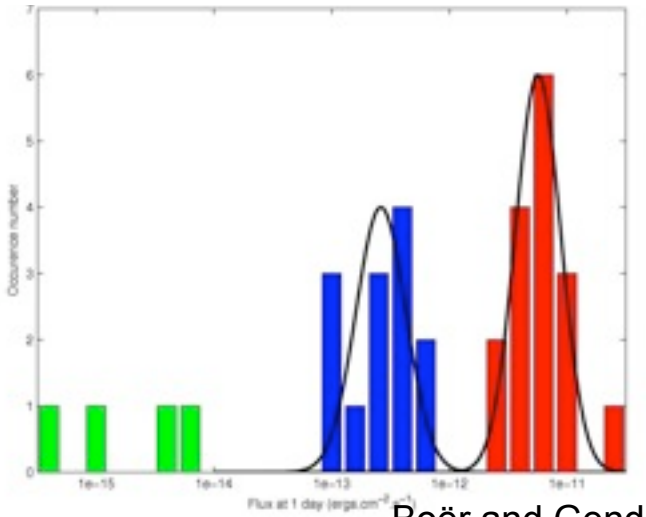


- Evolution of the GRB 03029/SN 2003dh spectrum,
  - from 2.64 9.64 days after the burst.
- Early spectra consist: power-law continuum ($F \sim \nu^{-0.9}$) with narrow emission lines
  - H II regions in the host galaxy (z=0.168)
- After April 5 development of broad peaks characteristic of a supernova.
- (Staneck et al., 2003)
- But not all GRBs display an embeded SN (Della Valle et al. 2006)

Multiwavelength properties of A/G

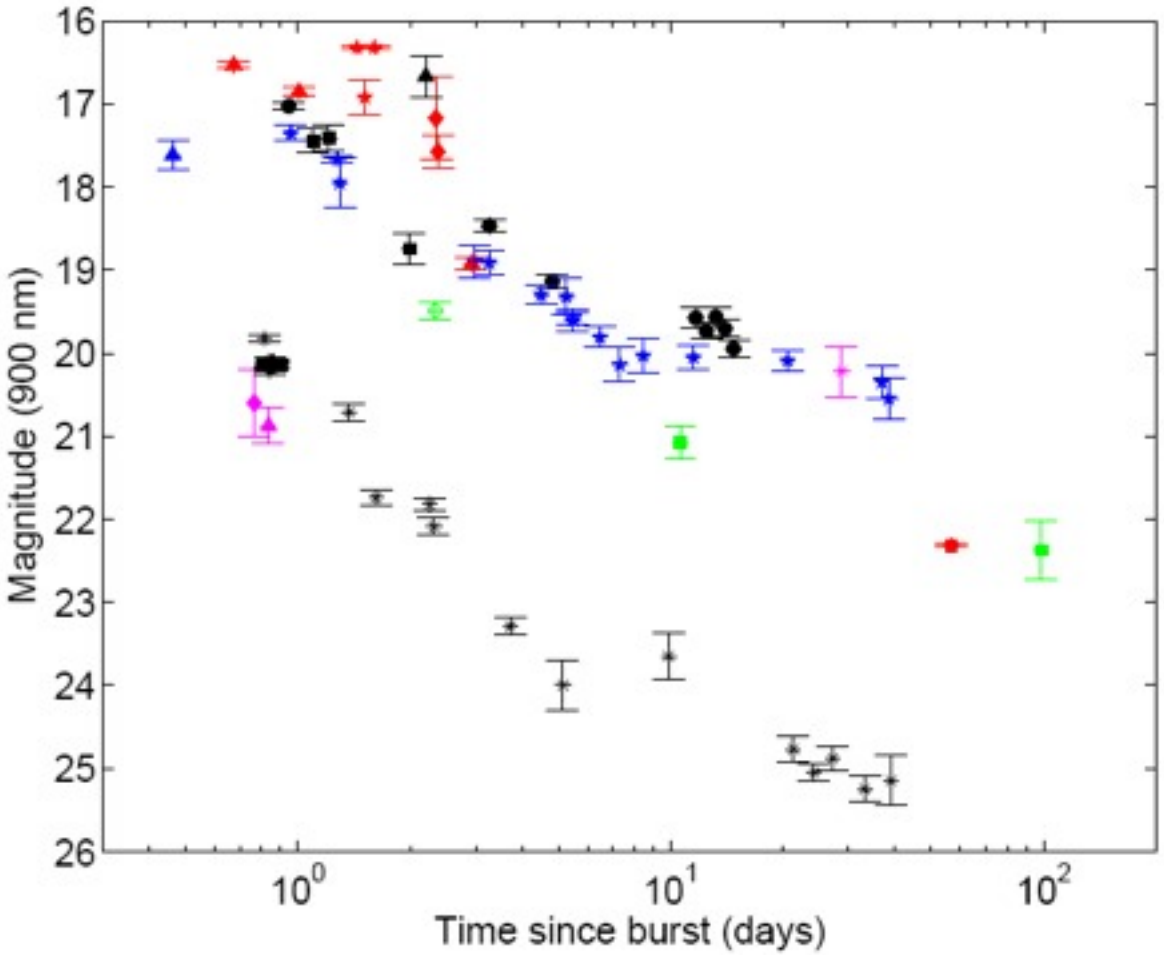
- Comparison of X-ray afterglows
- Rescaling at a common distance
- 2 classes of GRBs
- Maximum luminosity for X-ray A/G
- Reason?
- Confirmed at visible and infrared wavelengths (e.g. Nardini et al, 2006, Liang et al., 2006, Gendre et al., 2009)
- Another estimator for redshift





Boër and Gendre 2000,
Gendre and Boër, 2005
Gendre, Galli and Boër, 2008

IR light curve correlation



Gendre et al. 2009)

Rapid observations
Several experiments

- Rapid / less rapid telescopes
- Robotic / less robotic
- Sizes between 10 (ROTSE I) and 90cm → 8m
- Only two IR instrument(s)
- Japan
  - RIKEN (20cm)
  - Tokyo (20-30cm)
  - OAO (50 + 90)
- USA
  - ROTSE (network of 45cm)
  - SUPERLOTIS (60cm)
  - RAPTOR (10+25cm)
- Europe (including Chile)
  - TAROT network
  - REM (60cm)
  - X-Shooter (VLT T_0 + 15-30min)
- Australia
  - ROTSE IV
  - Zadko

- Five early detections (ROTSE + TAROT)
- Bumps and wiggles
- Refreshed shock? Two jets? ISM?
- Dark GRBs
  - BeppoSAX: 60%
  - HETE: 15%
- Few (if any) dark GRBs
- Probably many faint GRBs
- Need rapid AND deep observations
- Note: are they too few “dark GRBs” (HETE results)?
  - no obscuration in molecular clouds?
- Need consistent follow-up (cross calibration)

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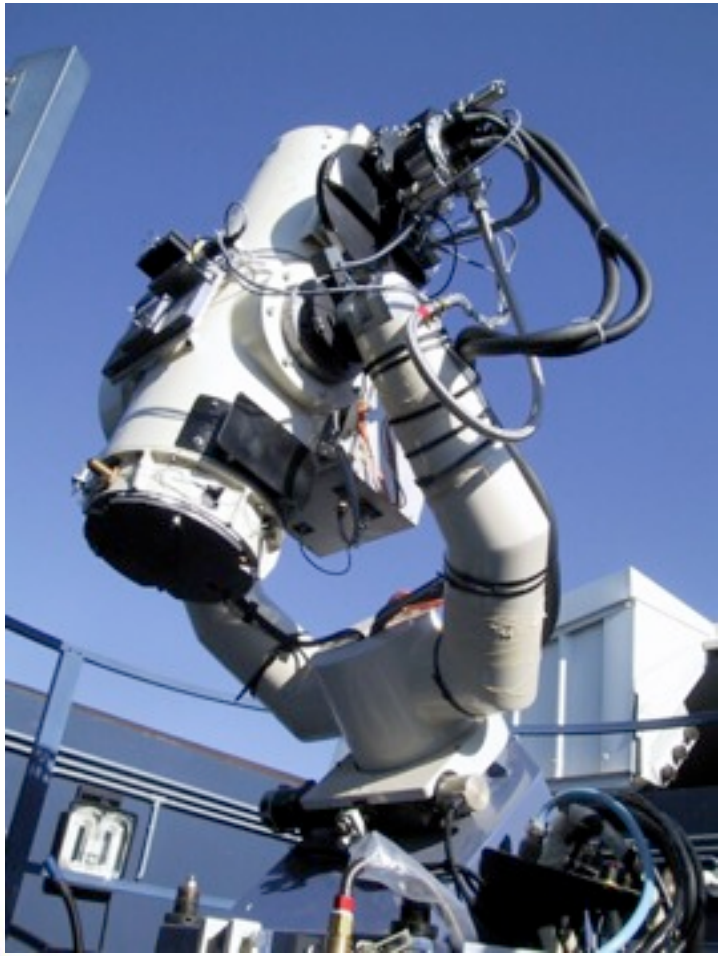
TAROTs

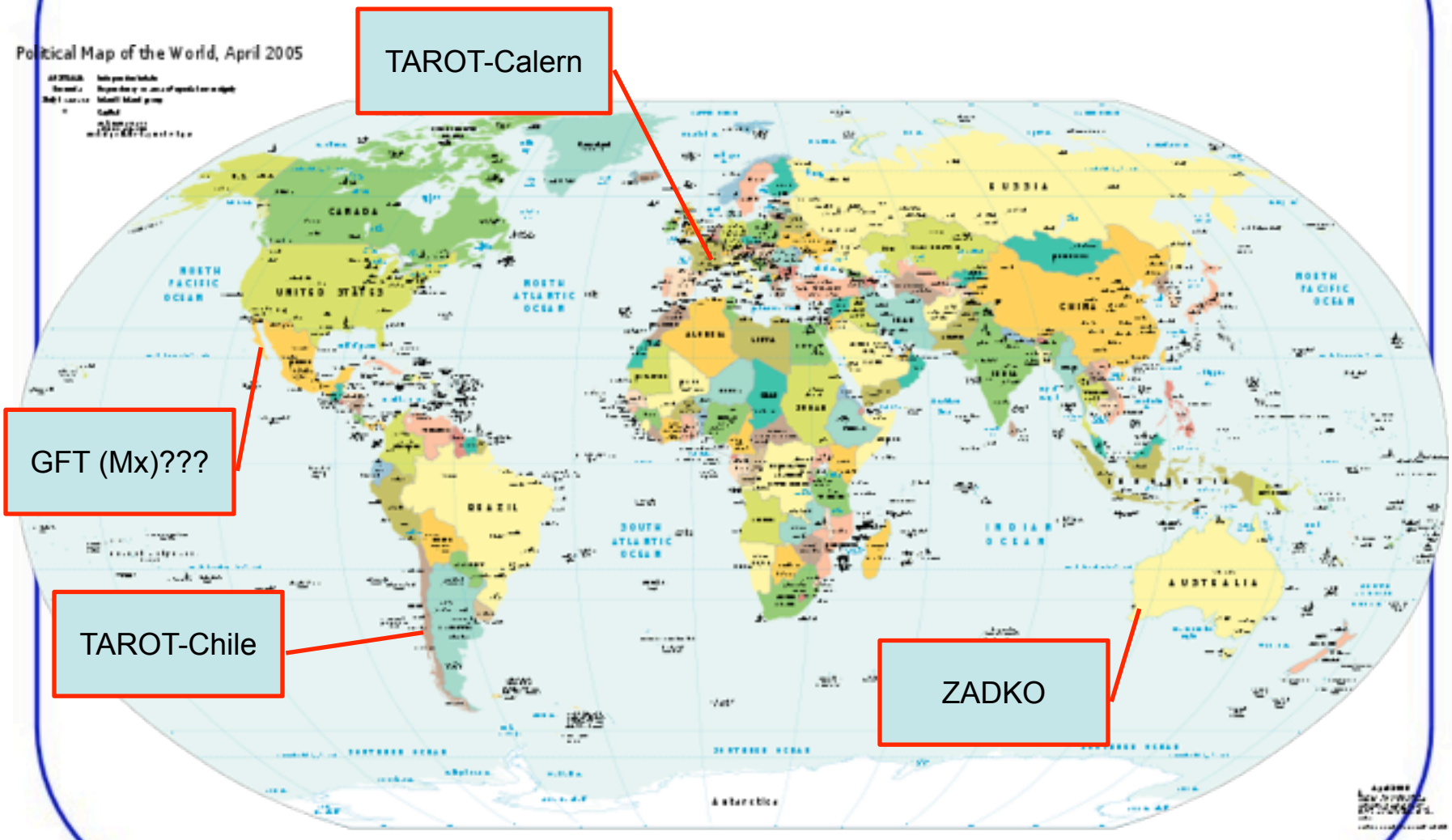
Calern, France



La Silla, Chile

COMING SOON: ZADKO, 1m, Australia

TAROT/ZADKO Network



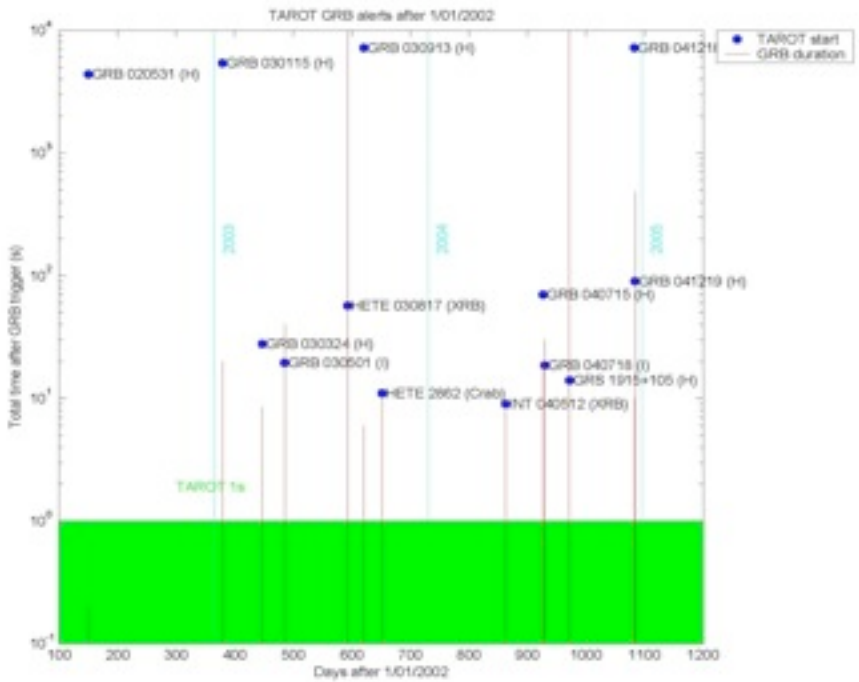
TAROT

Aperture	25 cm
Speed	F/3.5
Pointing time	1-2 sec. (60 °/s)
Acceleration	Up to 120°/s^2
Limiting magnitude	V = 17 in 10 sec., V > 20 over 30min
CCD Device*	EEV 42-40 (thinned)
CCD size	2048 x 2048 (3 x 3 cm)
Operating CCD temperature	-75°C
Readout speed	5 – 3 s
Readout noise	8 e^- @ 1Mz – 3 e^- @ 100kHz
Field of view	2 degrees (3.6 arcsec/pixel)

- Rapid: reaction time dominated by S/C alert
- Wide fov: accomodate BATSE (mosaic), HETE, SWIFT, INTEGRAL, AGILE, Fermi-LAT, etc…
- Limit: Mag. 17 in 10s
- ANDOR EEV BI camera (42-40)

TAROT observations

- 1999: start full operations
- For BATSE mosaic observations had to be performed
- 3 INTEGRAL alert
- 9 HETE alerts, 6 corresponding to GRBs
- 1 short hard (GRB 030531)
- GRB 030324 & GRB 030501: TAROT observations start while GRB active
- So far
- Calern (since 99)
  - 41 alerts
  - 8 counterparts detected
  - 10 GRB sources observed during prompt emission
  - Of which 3 OT detections
- Chile (since 10/06)
  - 12 alerts
  - 1 counterpart detected
  - 2 GRB sources observed during prompt emission
  - No OT detection



*Final position in TAROT images

* *Rapid (<60s) notifications

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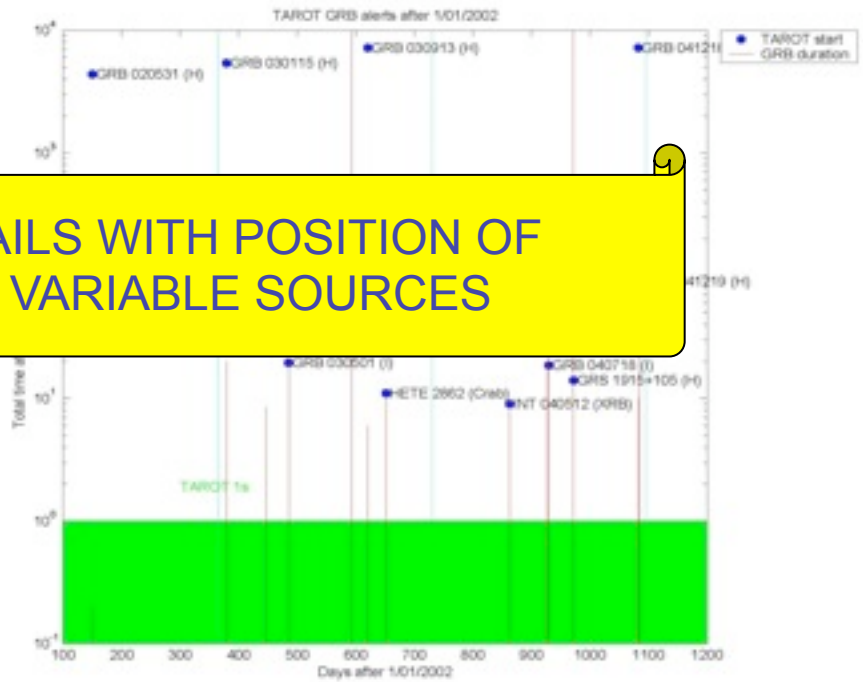
AUTOMATIC MAILS WITH POSITION OF TRANSIENT / VARIABLE SOURCES



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TAROT, astronomy while you sleep

- TAROT gets you up in the middle of the night
- Example: yesterday, 02:37am

TAROT, astronomy while you sleep

- TAROT gets you up in the middle of the night
- Example: yesterday, 02:37am

Boer, M. and Klotz, A., on behalf of a larger coordination communicate:

Following an alert SWIFT GRB070913 (received at 00:37:02 UT) TAROT La Silla observatory, Chile observed the field.
Candidate list will be send later if found. See:

Individual images : http://195.221.212.76/ros/GRB070913_003702_SWIFT

Sum of images http://195.221.212.76/ros/GRB070913_003702_SWIFT/sum.html

Differential photometry http://195.221.212.76/ros/GRB070913_003702_SWIFT/photometry.html

GRB parameters are in http://195.221.212.76/ros/GRB070913_003702_SWIFT.txt

TITLE: GCN CIRCULAR
NUMBER: 6783
SUBJECT: GRB 070913: TAROT La Silla observatory optical observations
DATE: 07/09/13 01:23:01 GMT
FROM: Alain Klotz at CESR-CNRS <Alain.Klotz@free.fr>

Klotz, A. (CESR-OMP), Boer M. (OHP), Atteia J.L. (LATT-OMP) report:

We imaged the field of GRB 070913 detected by SWIFT (trigger 290843) with the TAROT robotic telescope (D=25cm) located at the European Southern Observatory, La Silla observatory, Chile.

The observations started 87.3s after the GRB trigger (69.4s after the notice). The elevation of the field decreased from 35 degrees above horizon and weather conditions were good.

The date of trigger : t0 = 2007-09-13T00:36:44.064

The first image is 30.0s exposure in tracking mode.
We do not detect any OT with a limiting magnitude of:
t0+87.3s to t0+117.3s : R > 17.8

We co-added a series of exposures:
t0+123.6s to t0+576.5s : R > 18.4

Further observations are in progress.

Magnitudes were estimated with the nearby USNO-B1 stars and are not corrected for galactic dust extinction.

N.B. Galactic coordinates are lon=340.2109 lat=+27.9232 and the galactic extinction in R band is 0.4 magnitudes estimated from D. Schlegel et al. 1998ApJ...500..525S.

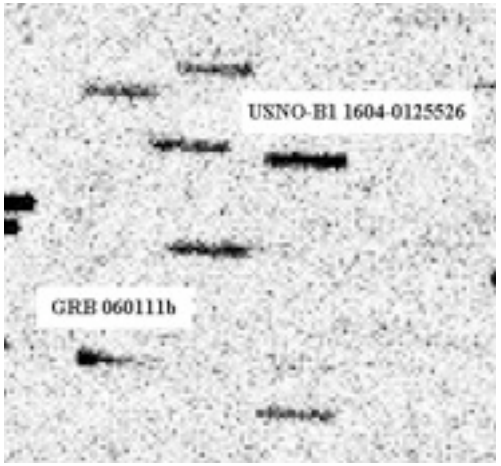
This message may be cited.

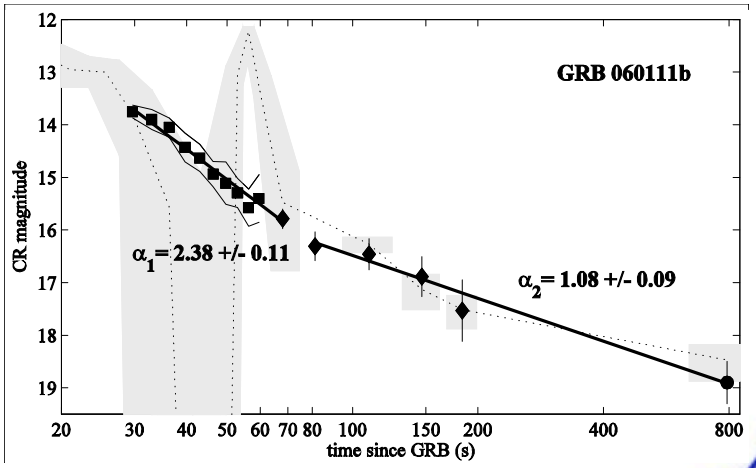
Prompt emission

- Access to source dynamics
- Signature of forward internal and reverse shock
- Ground observations give extended spectrum (e.g. synchroton peak vs. time)
- Evolution of light curve GRB vs. OT
    - Absolute need of more detaille OT l.c.
- Transition from prompt to A/G: tomography of material surrounding GRB, and of material left by precursor
  - When does the afterglow start ?
  - Polarization of GRBs?
  - E.g. GRB 050904 at z = 6.4: evidences for interaction of fireball with stellar wind (Boër et al., 2006; Gendre et al., 2006)
- Difference in arrival time between HE GRB and OT may probe quantum gravity
- Neutrinos (km^3, Ice^3) gravitational radiation (VIRGO, LIGO), prompt VHE

Needs for prompt and early afterglow emissions observation

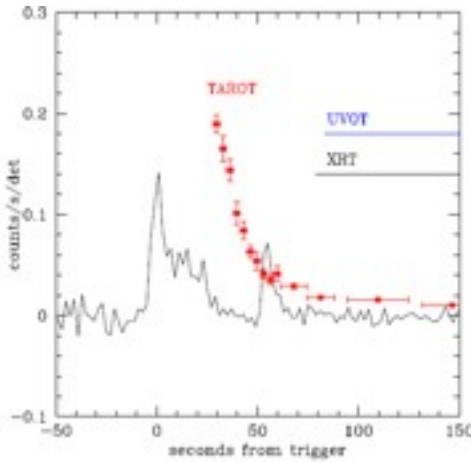
- GRB 060111
- For observation of prompt emission A/G transition
  - Rapid observation (starts during GRB)
    - Fast moving (telescope)
    - Prompt notification (spacecraft)
    - Wide fov (errors on early localizations)
    - SWIFT will start UVOT observation after 1-2 min
    - Short GRB A/G
  - Fast sampling of light curve
    - Comparison with high energy
    - “Large” telescope
    - No dead time (rapid CCD/detector)
  - Spectroscopy / Filters / IR to optical coverage
    - Allows more detailed study
    - Set of telescopes (e.g. TAROT+REM)?
    - GROND, GFT
  - Start of afterglow vs. prompt emission
  - Evidence for reverse shock

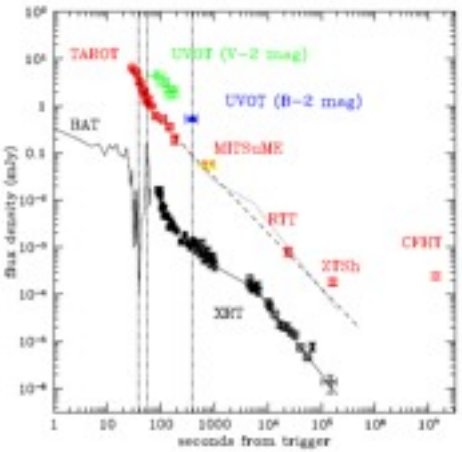




GRB 060111

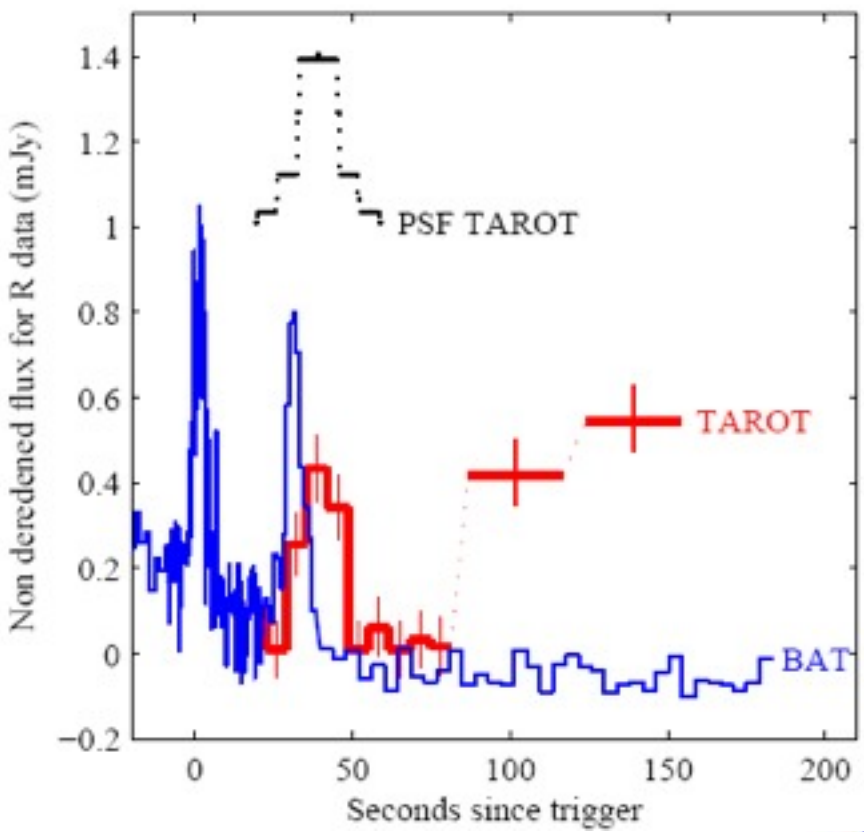
- Klotz et al. 2006, Stratta et al., 2008
- No correlation between high energy and R-band flux
- z = 2; Av = 2.7mag
- Γ = 200 – 300
- Evidences for reverse shock





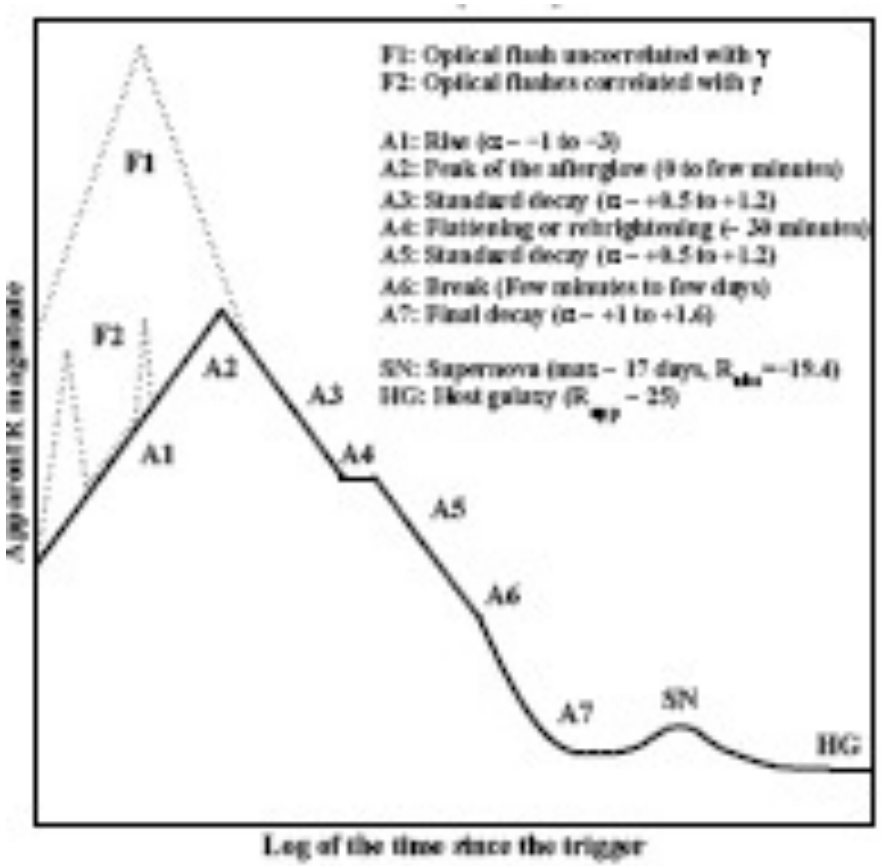
GRB 081126

- First TAROT image at To + 20s
- In « trailed mode » (3.3s/pixel)
- Evidence for a time lag of 8.4 +- 3.9 between gamma and optical
- Strong correlation gamma/ optical
- Difficult to explain in standard model
- In fireshell?

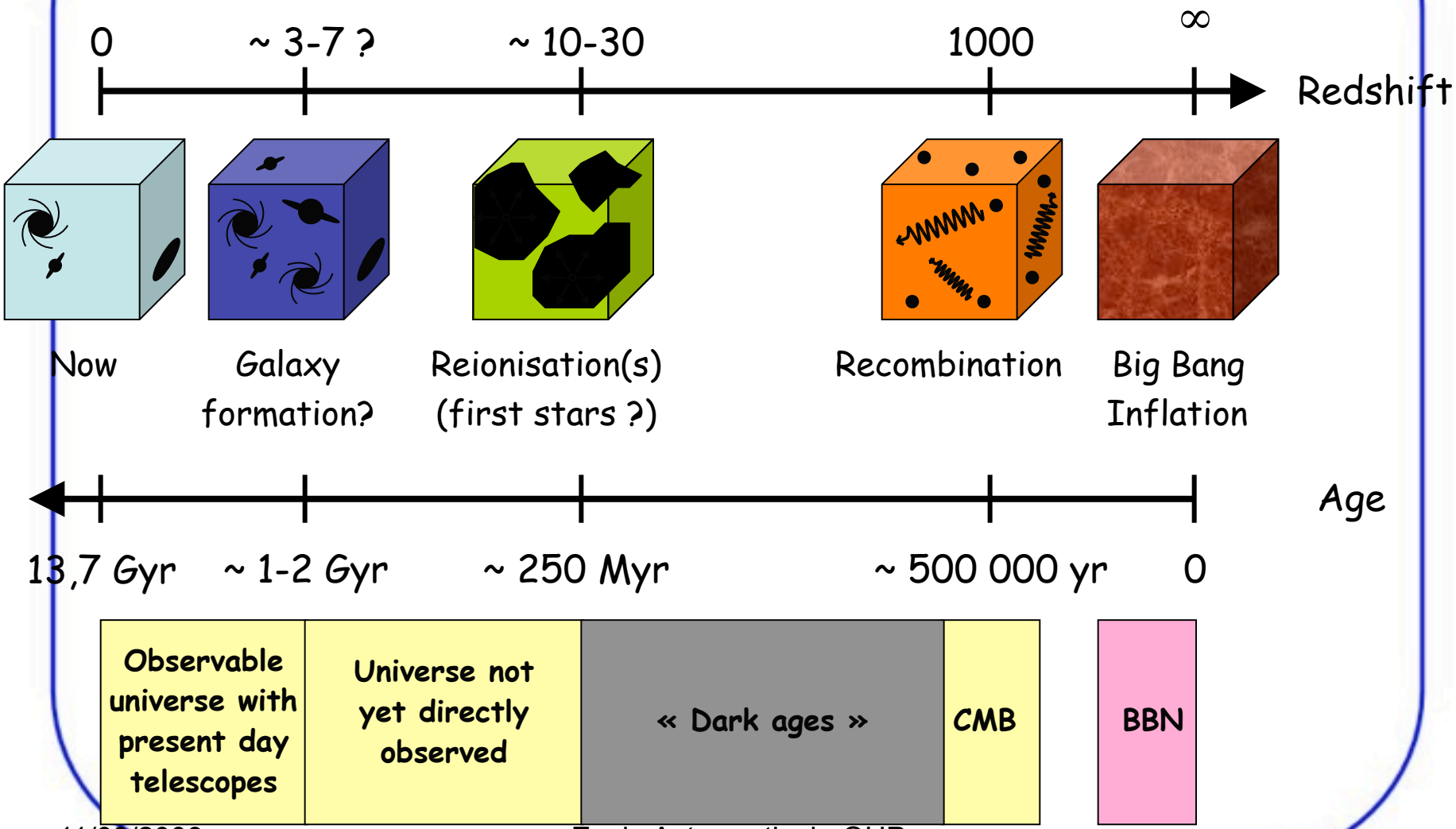


GRB canonical optical l.c.

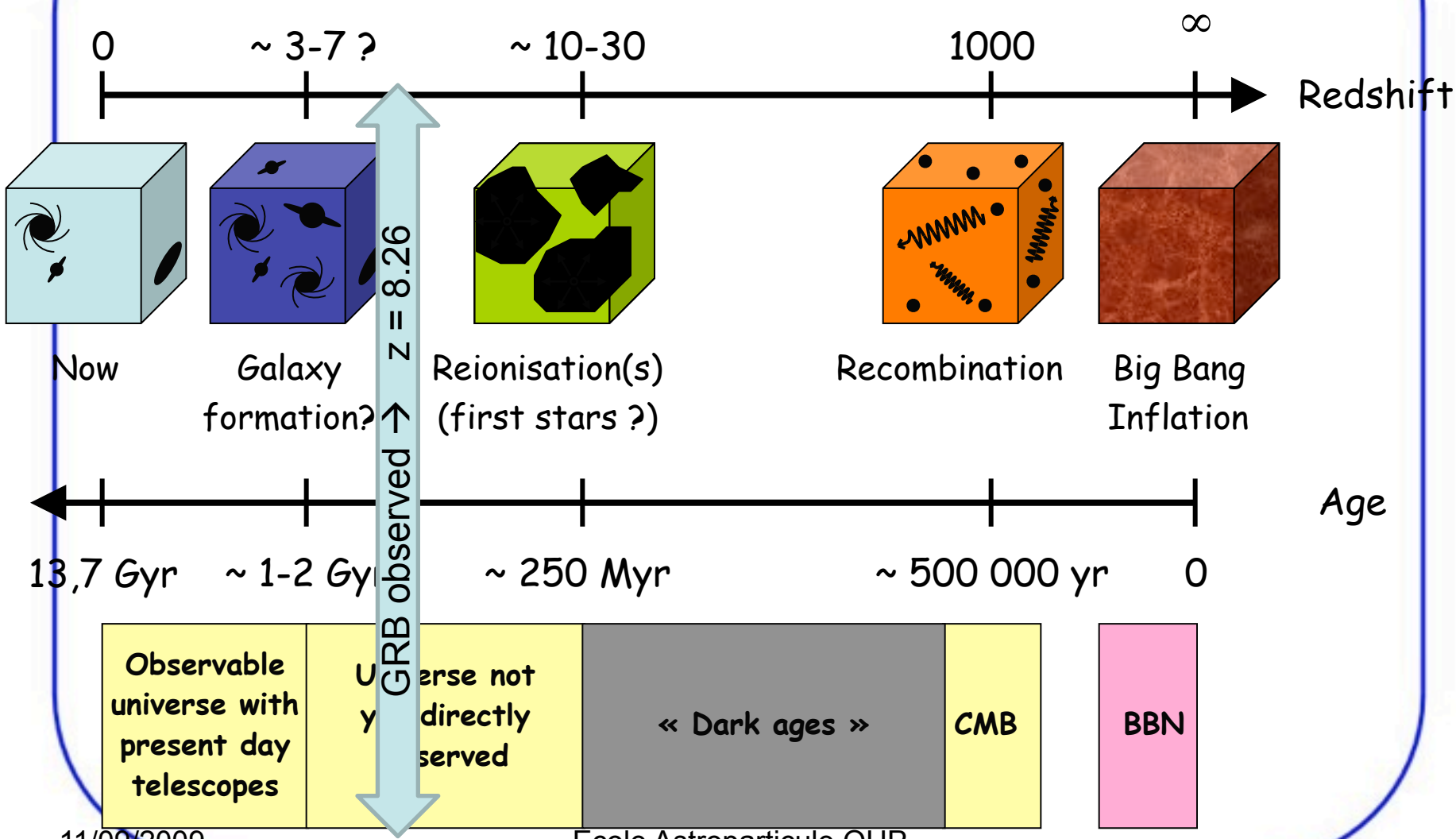
- 1000 first seconds of GRBs revealed thanks to TAROT
- Optical l.c. is has usually a different behaviour than X-rays



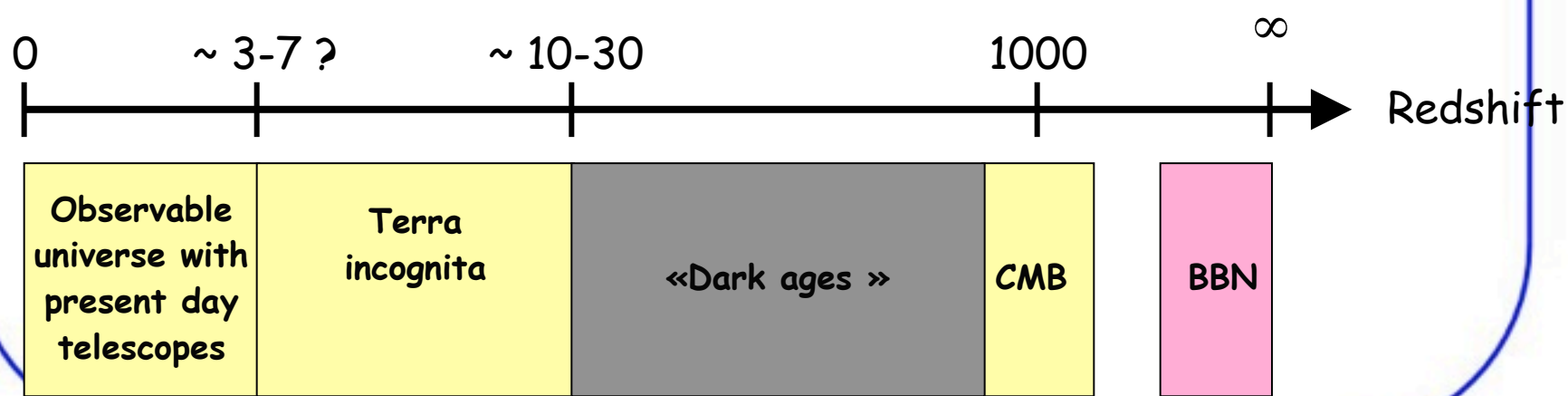
Cosmic history



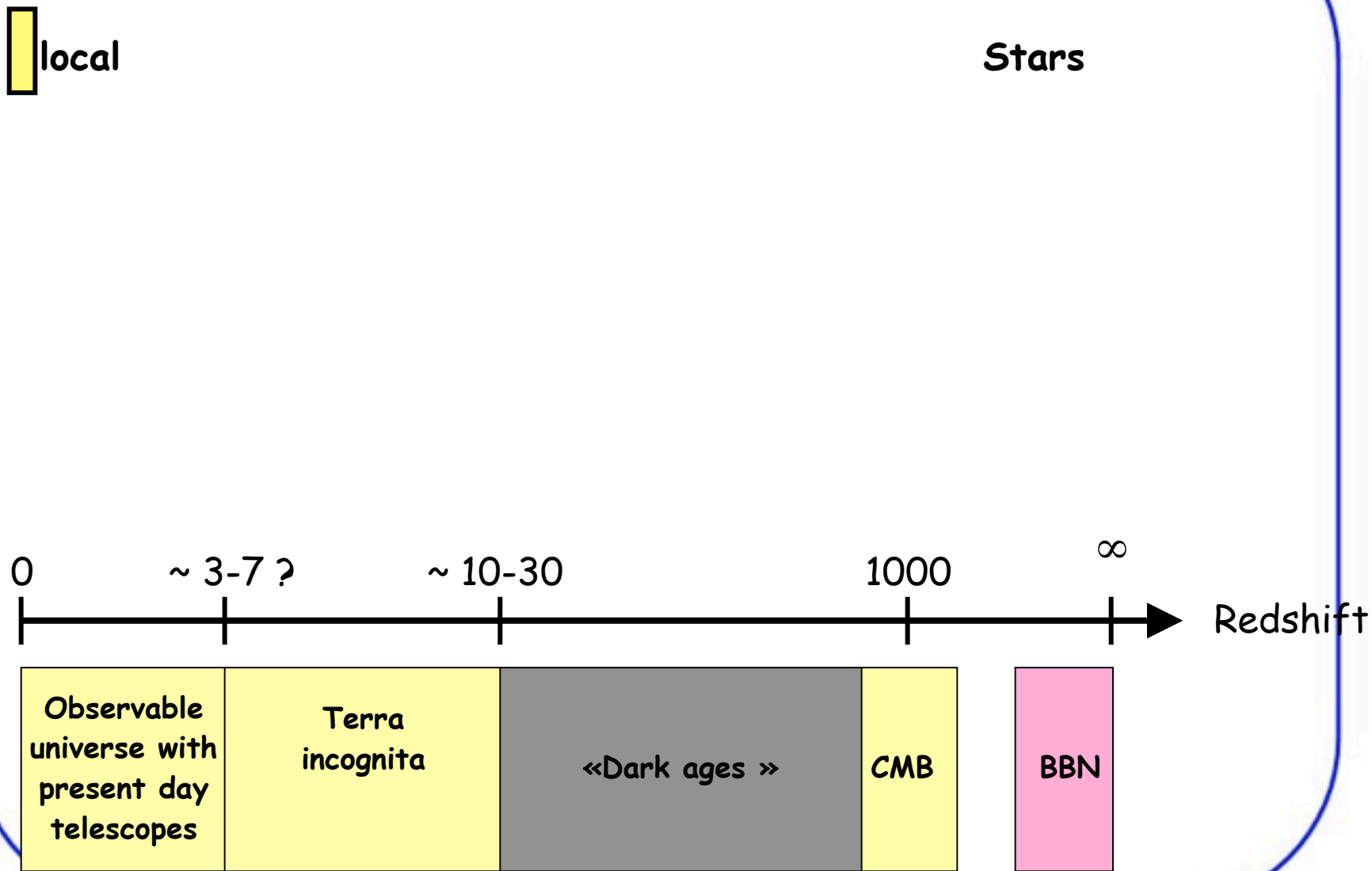
Cosmic history



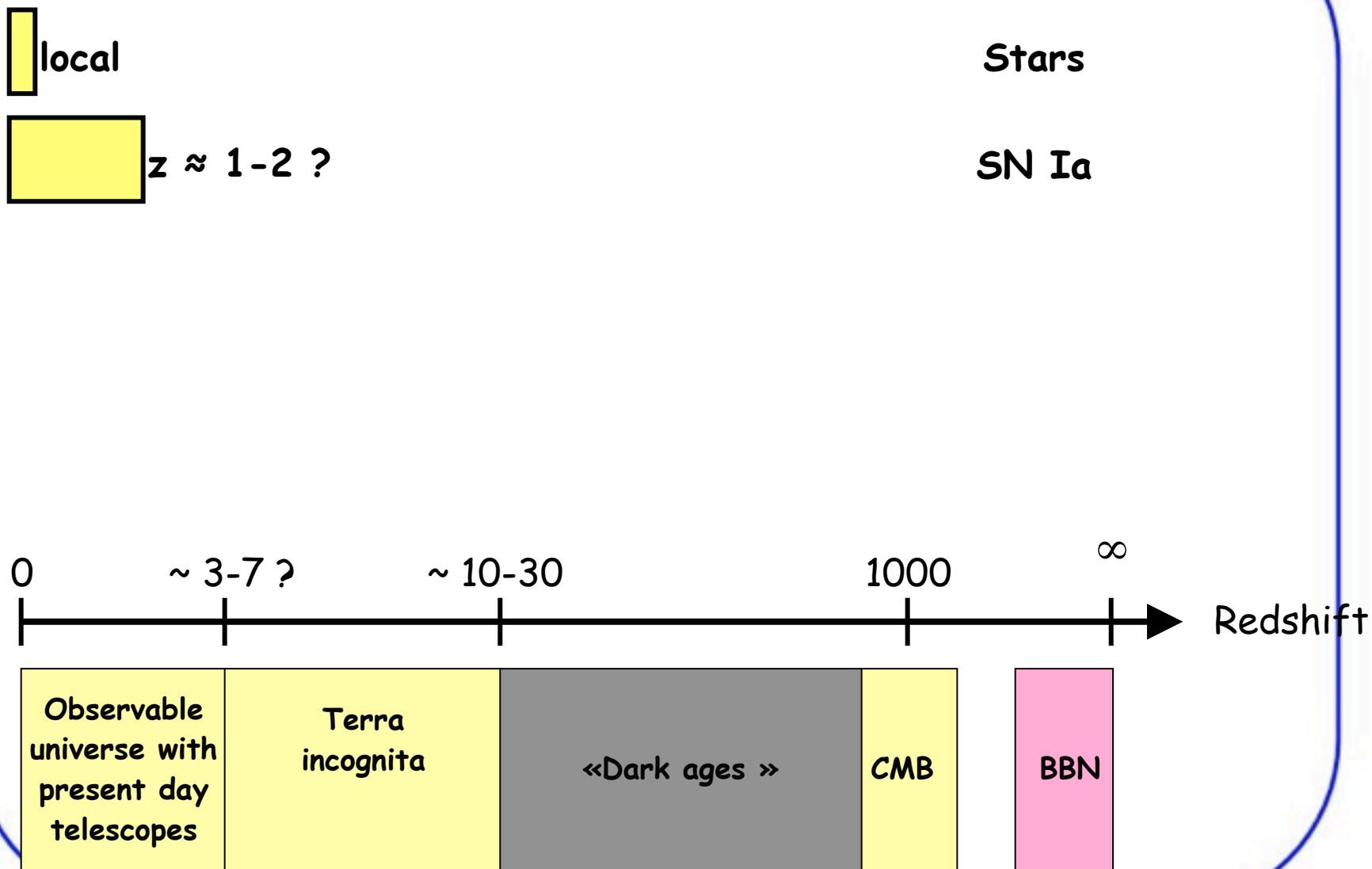
Maximum distance of detection



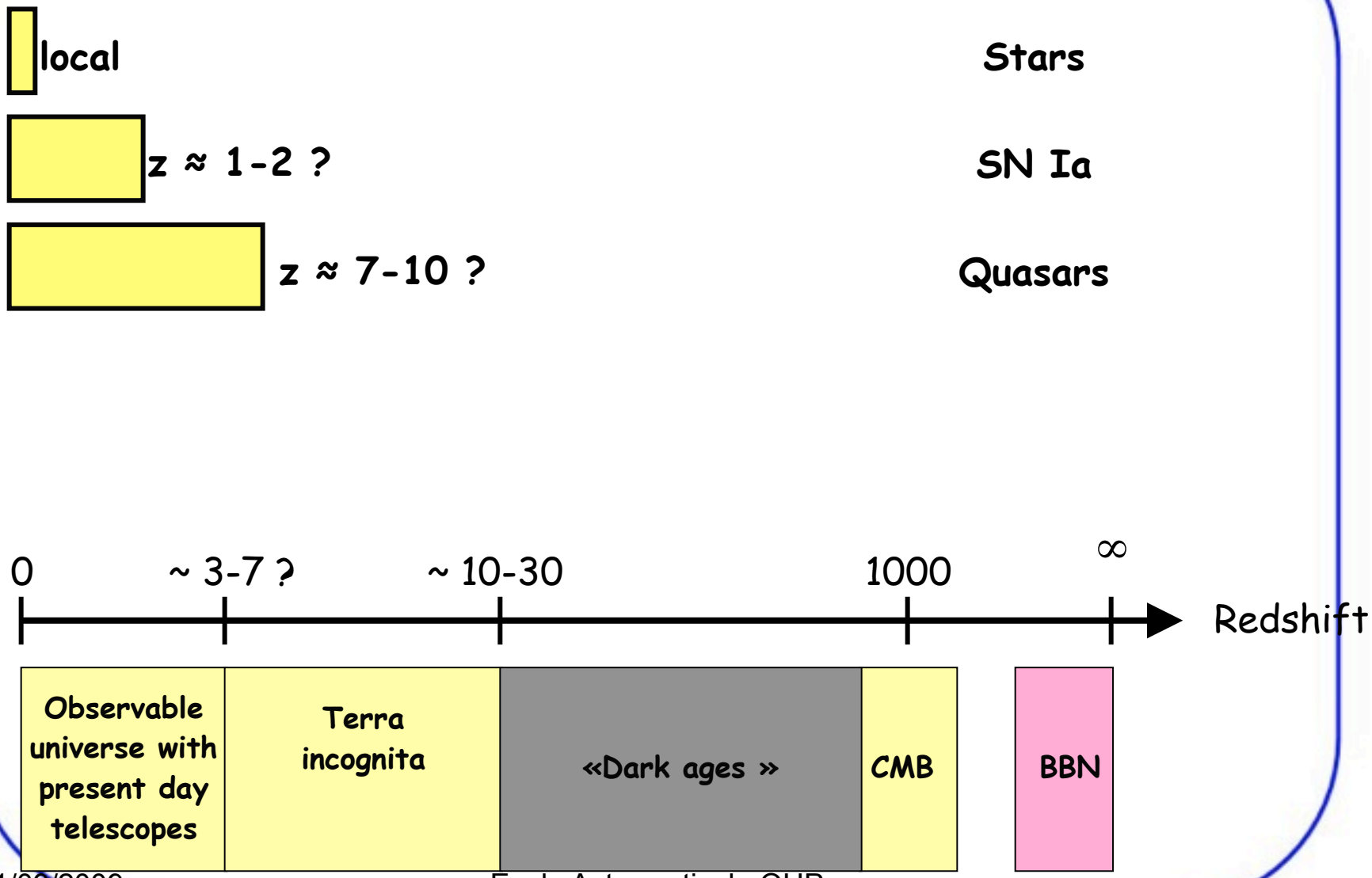
Maximum distance of detection



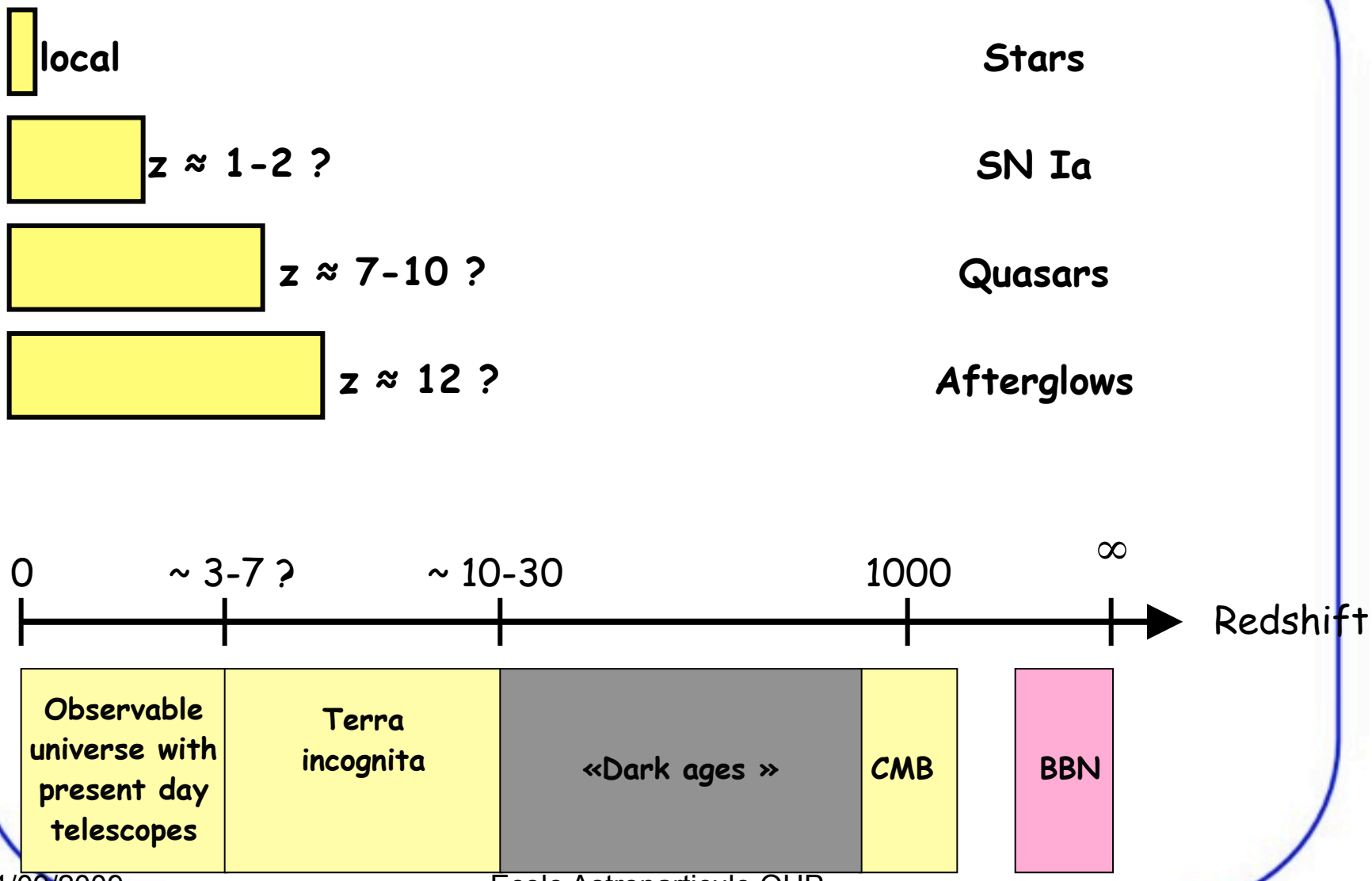
Maximum distance of detection



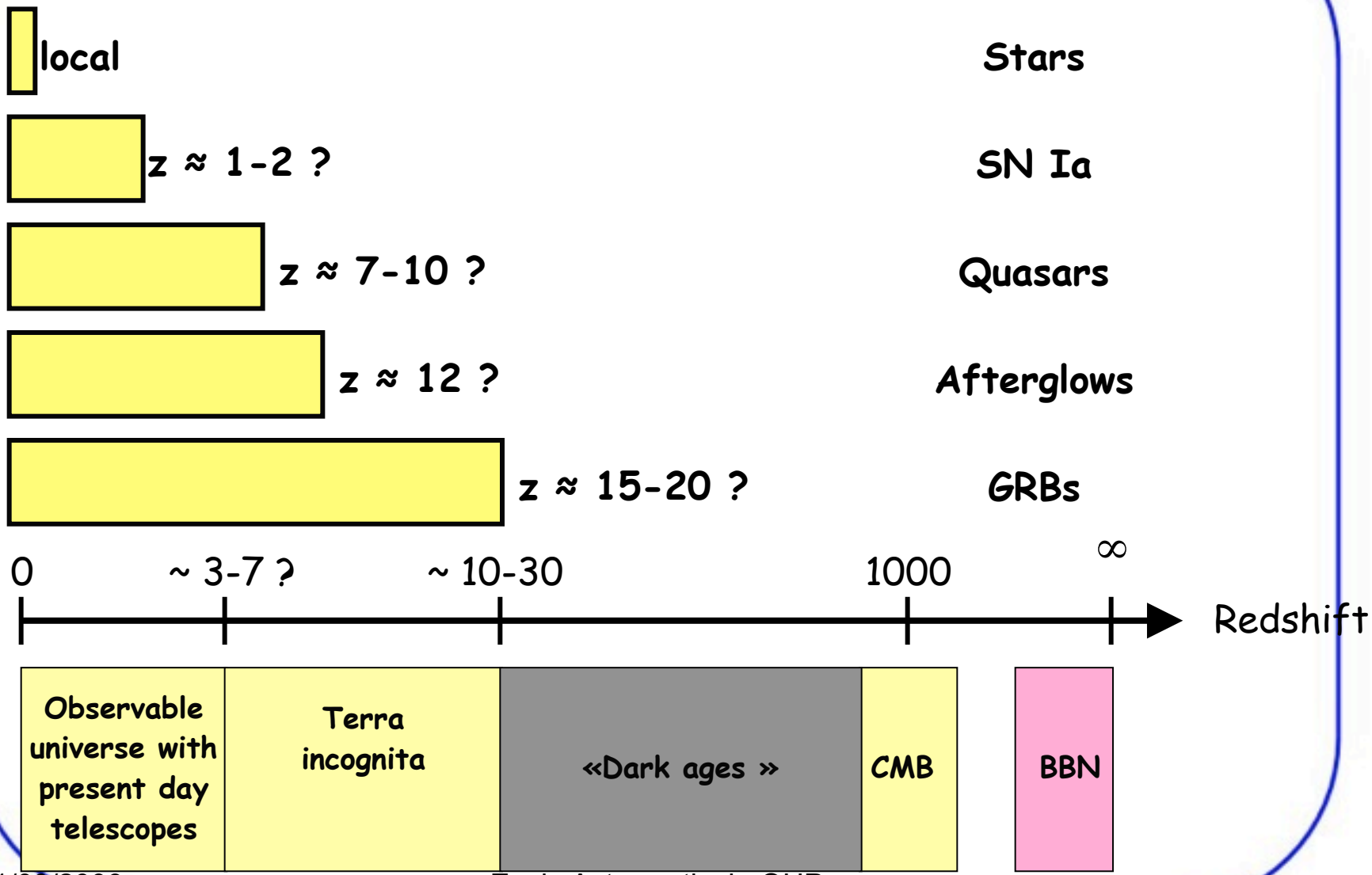
Maximum distance of detection



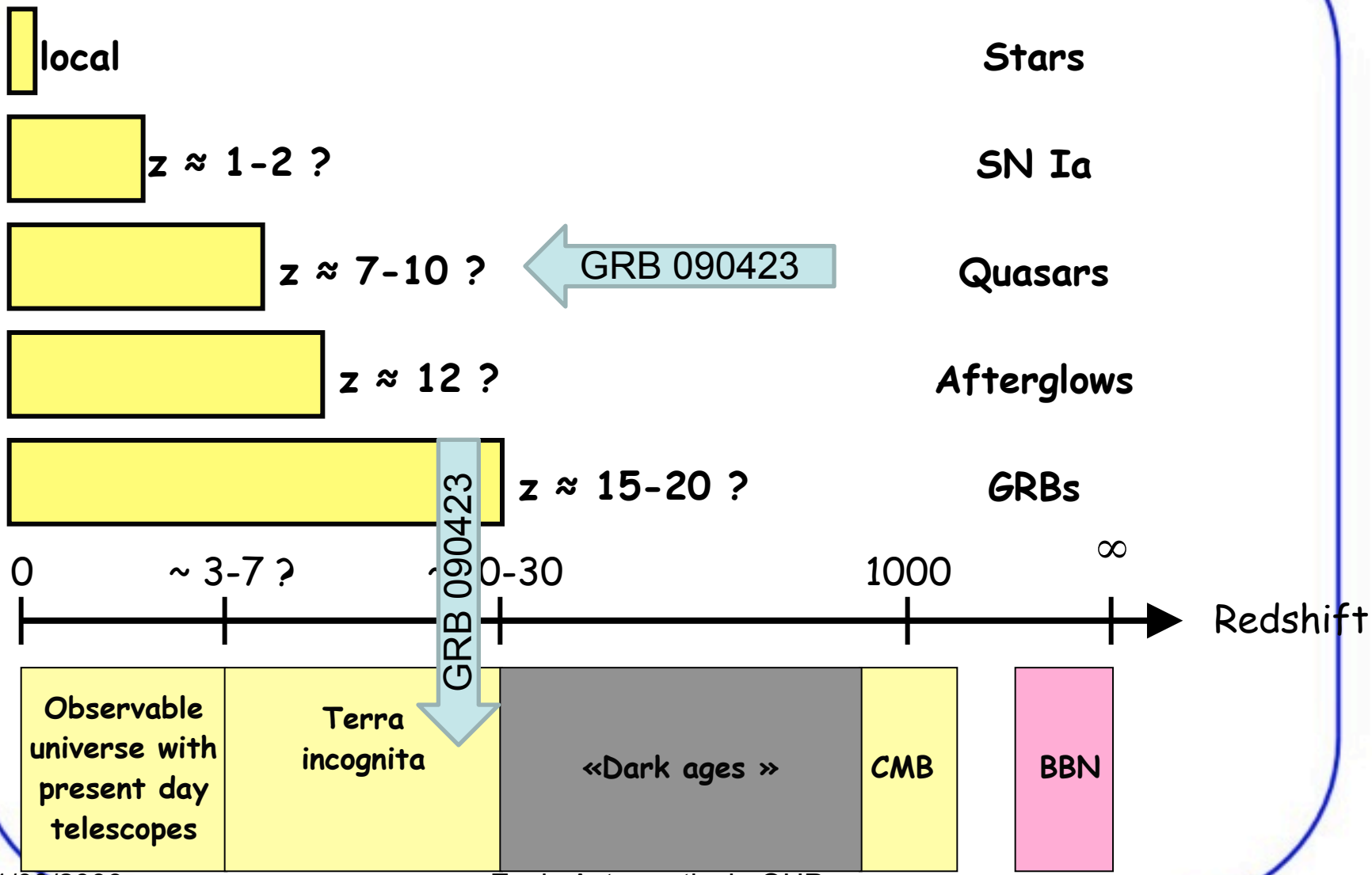
Maximum distance of detection

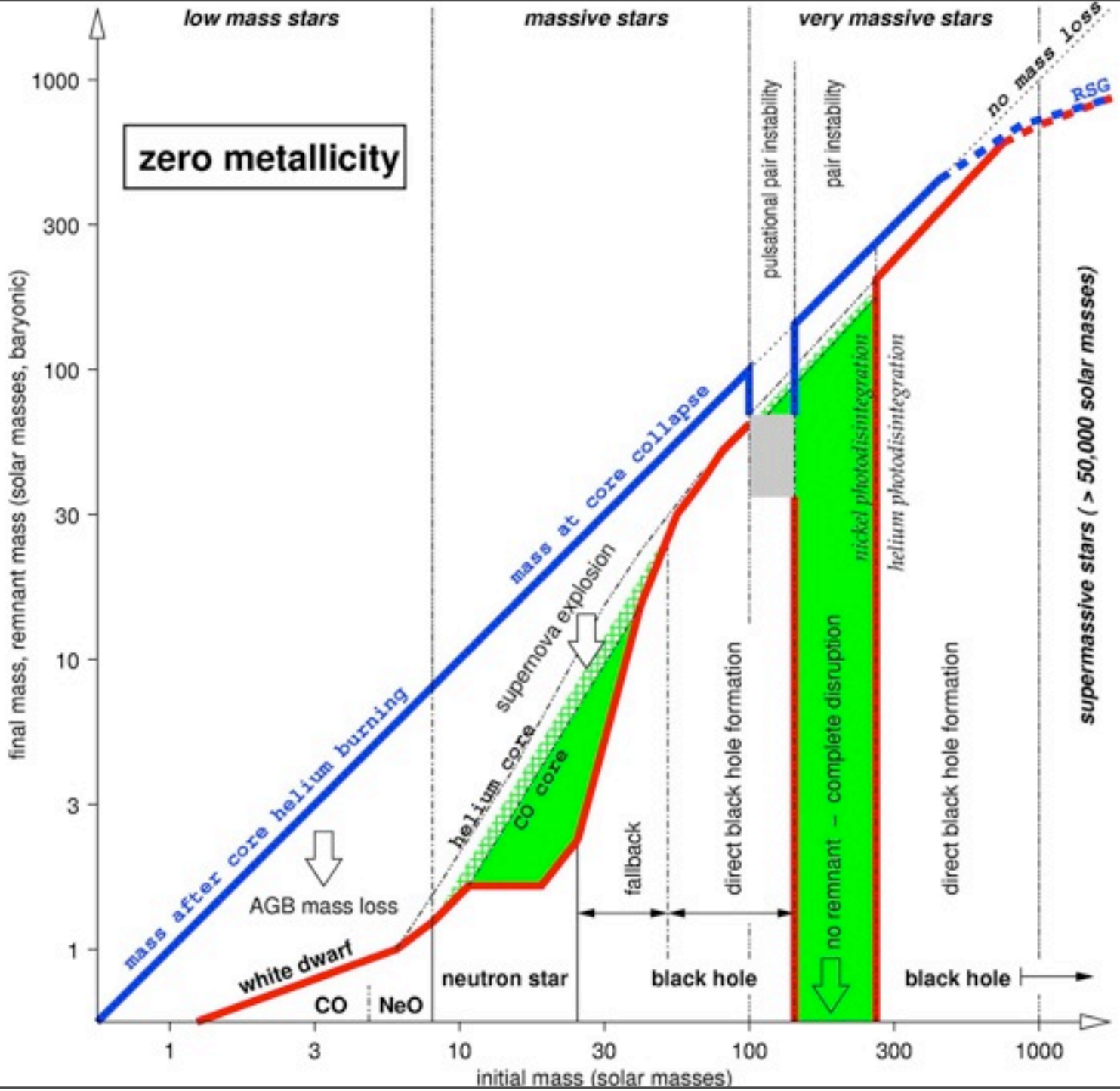


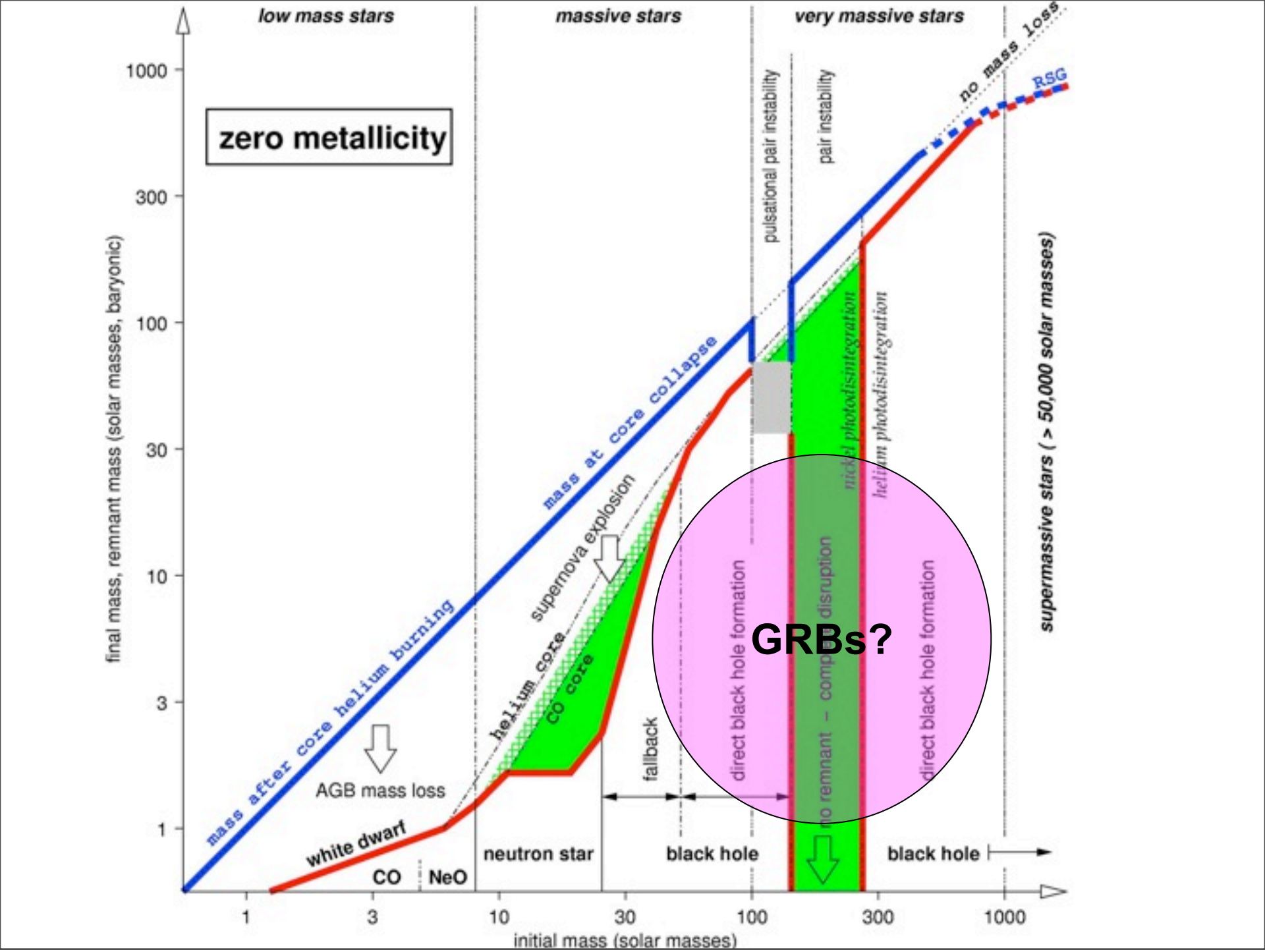
Maximum distance of detection



Maximum distance of detection




low mass stars
massive stars
very massive stars
zero metallicity
final mass, remnant mass (solar masses, baryonic)
initial mass (solar masses)
1000
300
100
30
10
3
1
1
3
10
30
100
300
1000
mass after core helium burning
mass at core collapse
no mass loss
RSG
pulsational pair instability
pair instability
supernova explosion
helium core
CO core
nickel photodisintegration
helium photodisintegration
AGB mass loss
white dwarf
CO
NeO
neutron star
fallback
direct black hole formation
black hole
no remnant – complete disruption
direct black hole formation
black hole
supermassive stars (> 50,000 solar masses)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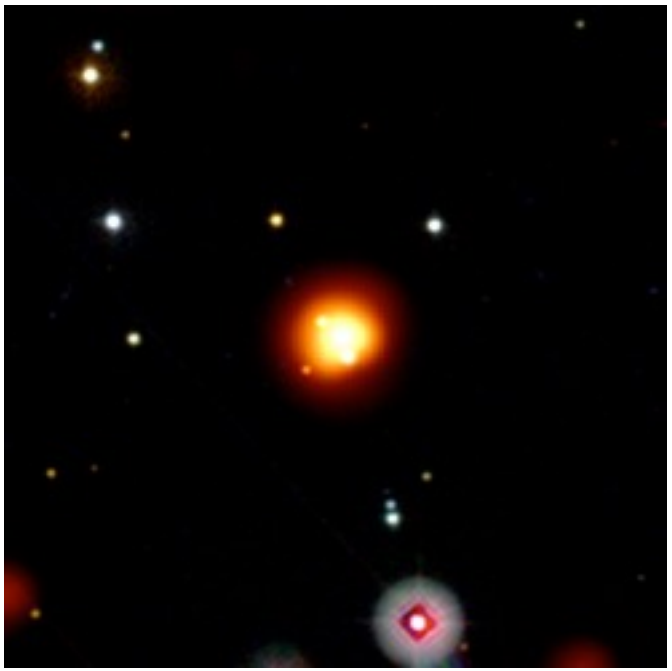
black hole
black hole
nickel photodisintegration
helium photodisintegration
direct black hole formation
no remnant – complete disruption
direct black hole formation
supermassive stars (> 50,000 solar masses)
GRBs?

GRB 080913: the farthest

- On 13/09/08 at 06:46:54 Swift/BAT triggers on GRB 080913
- T + 2 m: Swift/XRT and Swift/UVOT observe the GRB (X-ray & visible)
- T + 3 m: GROND observes the GRB field in the visible and NIR band
- Shady et al., GCN 8217, 2008
- The farthest ever GRB: z = 6.7
- Soon, SVOM + GFT will be able to localize GRBs in the 3 dim during the first minute



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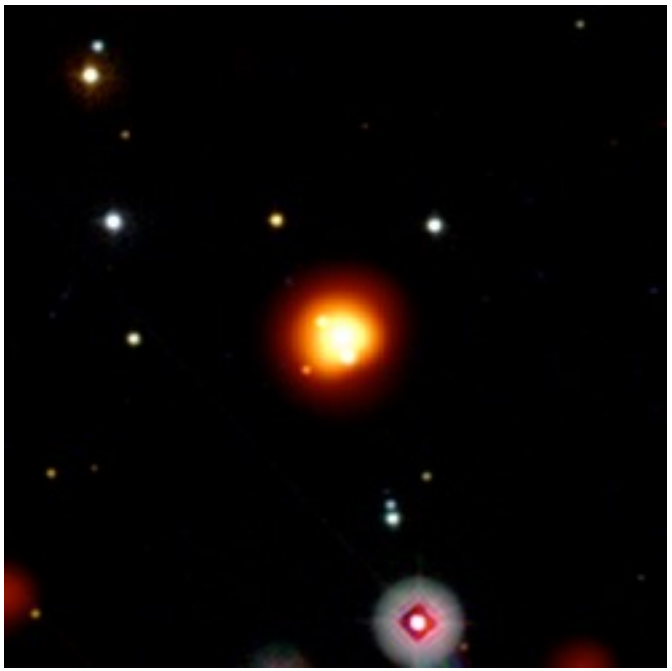
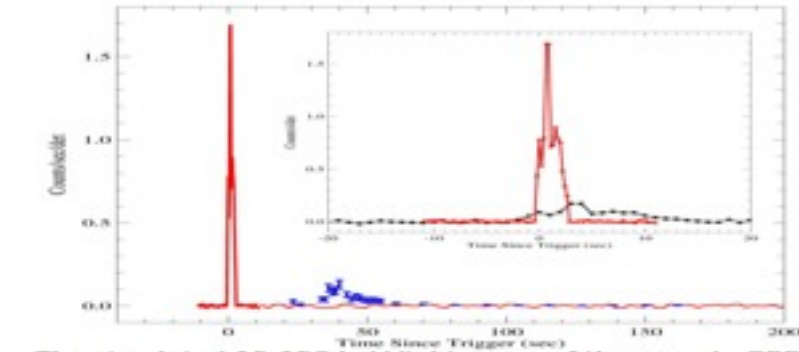


GRB 090423: the farthest ('til now)

- Découvert par SWIFT
- Décalage from TNG
- Redshift 8.2
- Lasted 10s, i.e. around 1s at source distance



The simulated 15-150 keV light curve of the pseudo GRB obtained by placing GRB 090423 at z = 1. The red curve displays the extrapolated BAT data, and the blue data points show the extrapolated XRT data. Inset: a comparison of the light c

SVOM
Fast and panchromatic

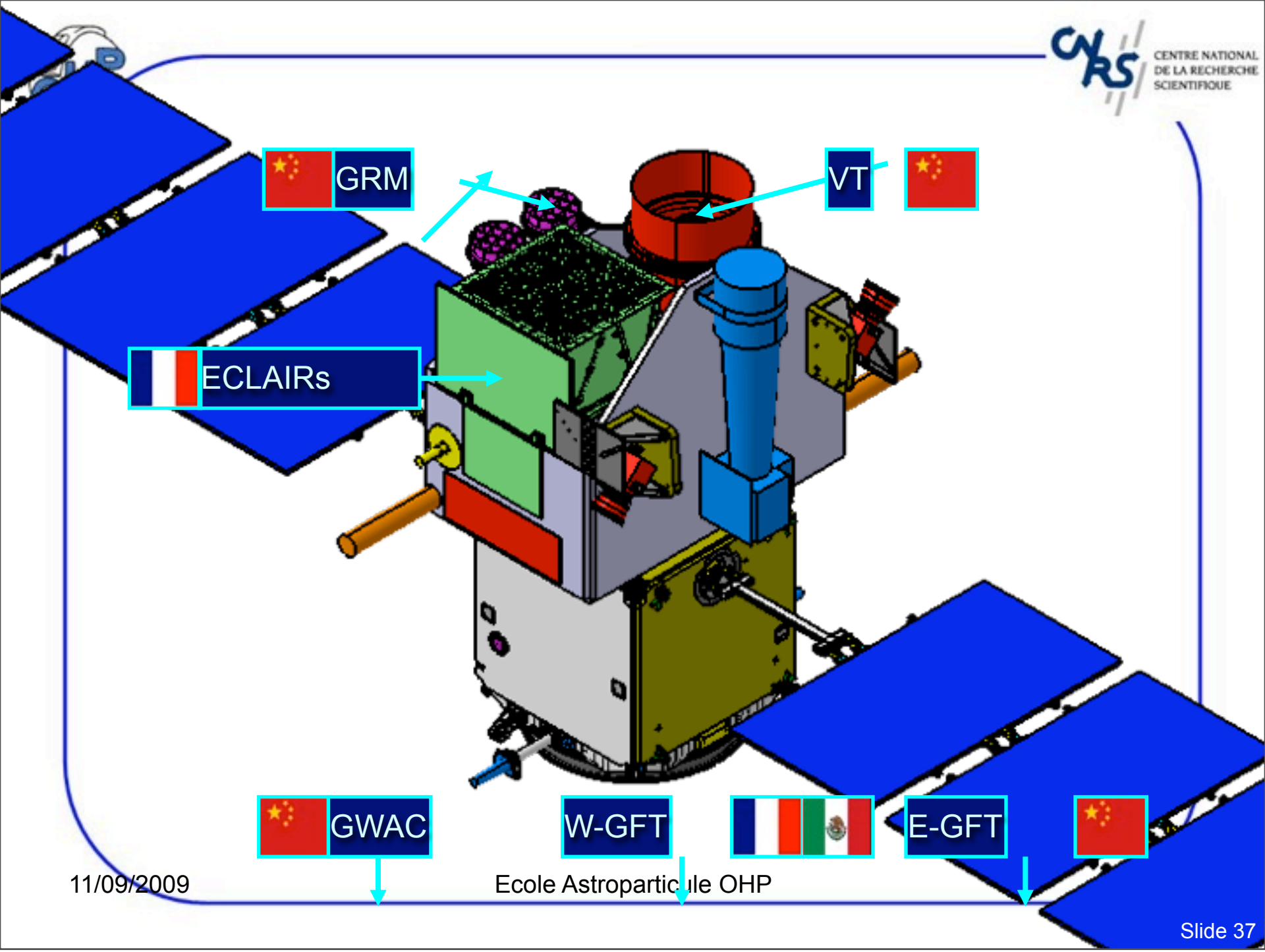
SVOM
Fast and panchromatic

- A wide field-of-view camera [R1] to trigger on GRBs present within its field-of-view in the X-ray and soft gamma-ray band [R2,R3,R6]
- A spectro-photometer to observe simultaneously in the gamma-ray band the trigger camera field-of-view [R3]
- A narrow field-of-view telescope to quickly observe in the soft X-ray band the error box provided by the trigger camera [R5,R7]
- A narrow field-of-view telescope to quickly observe in the visible band the error box provided by the trigger camera [R5,R7b]
- A set of ground-based wide field-of-view cameras to observe simultaneously in the visible band the trigger camera field-of-view [R4]
- Two ground-based narrow field-of-view telescopes to quickly observe in the visible and near infrared bands the error box provided by the trigger camera [R9]

SVOM scientific instruments

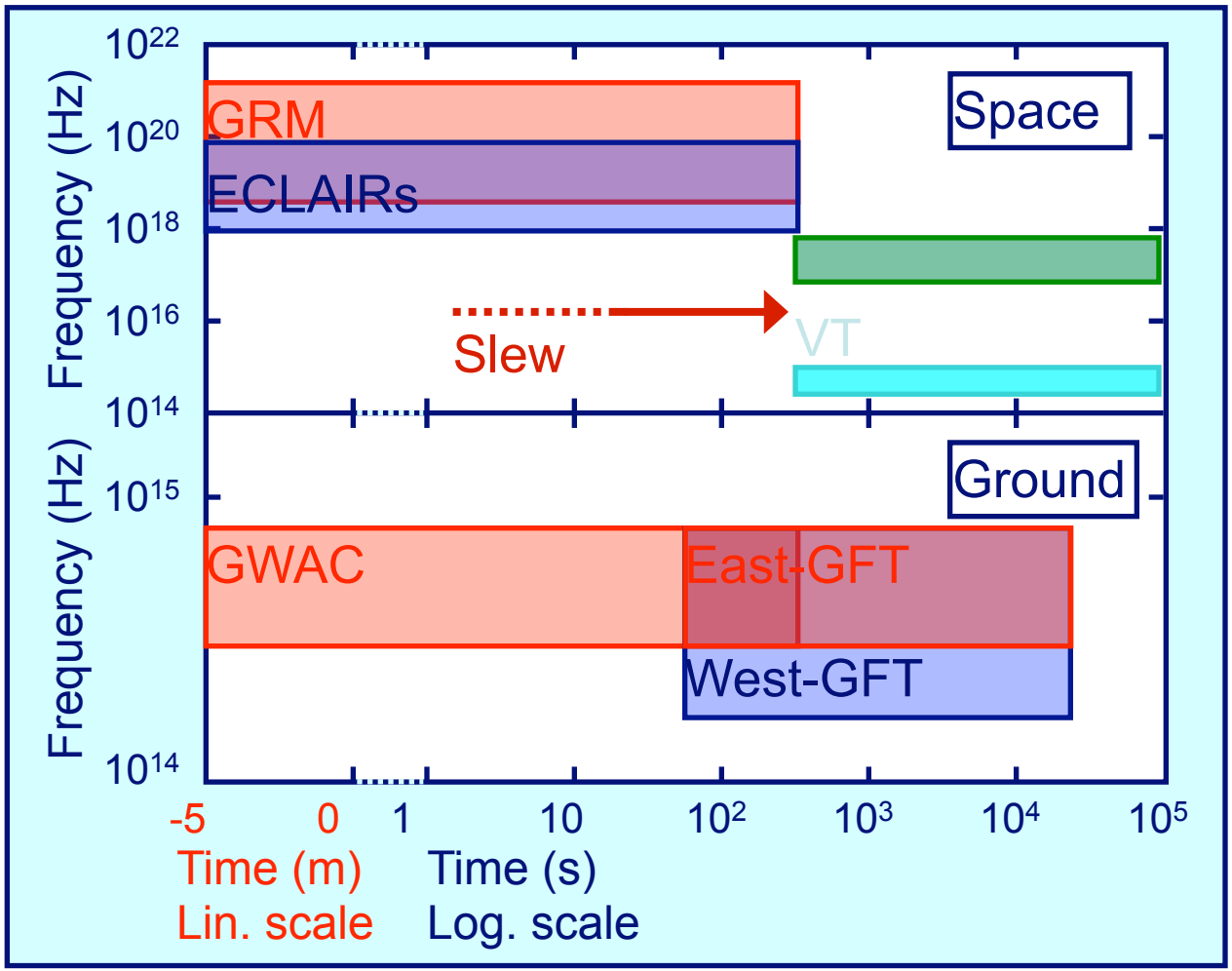
SVOM scientific instruments

- **ECLAIRs**, the X-ray and soft gamma-ray trigger camera
  SAp/IRFU, Saclay; CESR, Toulouse; APC, Paris
- **GRM**, the gamma-ray spectro-photometer
  IHEP, Beijing
-
- **VT**, the visible telescope
  XIOMP, Xian; NAOC, Beijing
- **GWAC**, an array of ground wide angle cameras
  NAOC, Beijing
- **East-GFT**, the Chinese ground follow-up telescope
  NAOC, Beijing
- **West-GFT**, the French/Mexican ground follow-up telescope
  LATT, Toulouse; OHP, Saint Michel; LAM, Marseille; UNAM


GRM
VT
ECLAIRs
GWAC
W-GFT
E-GFT

SVOM multi-wavelength capabilities

SVOM multi-wavelength capabilities



Space and ground instruments join to enable a unique coverage

SVOM Observation Strategy

SVOM Observation Strategy

Space

ECLAIRs and GRM observe X/gamma prompt emission

Ground

GWAC (prompt in the V band)

SVOM Observation Strategy

Space

ECLAIRs and GRM observe X/gamma prompt emission

GRB trigger provided by ECLAIRs at time T_0

Ground

GWAC (prompt in the V band)

SVOM Observation Strategy

Space

ECLAIRs and GRM observe X/gamma prompt emission

GRB trigger provided by ECLAIRs at time T_0

Ground

T_0 + < 5 min

T_0 + 1 min

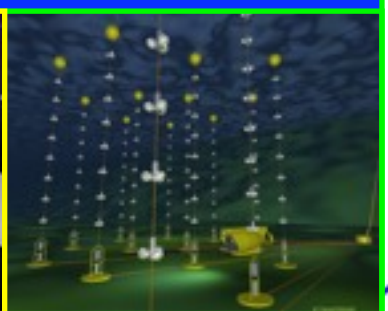
VT (V and R bands)

Robotic telescopes

GWAC (prompt in the V band)

GFT (B, V, R, I, J, H bands)

Multi messenger follow-up

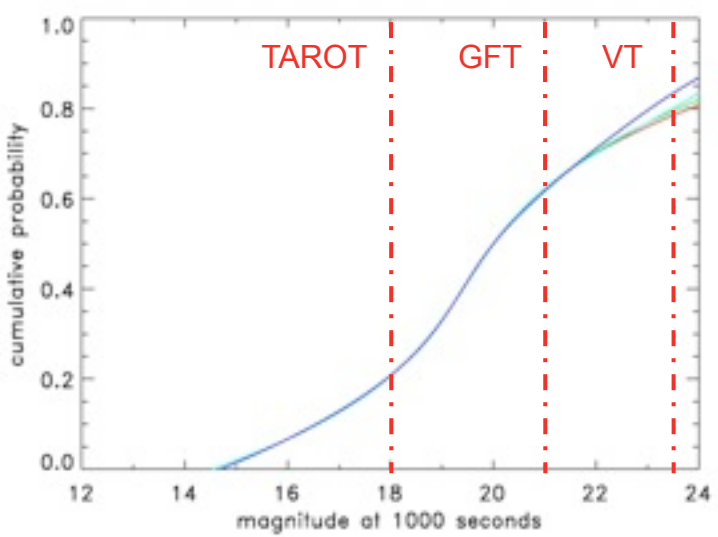


The Ground Follow-up Telescope

A 1m telescope allows the detection of A/G brighter than R = 19 in 10s or 21 in 5min (65%)

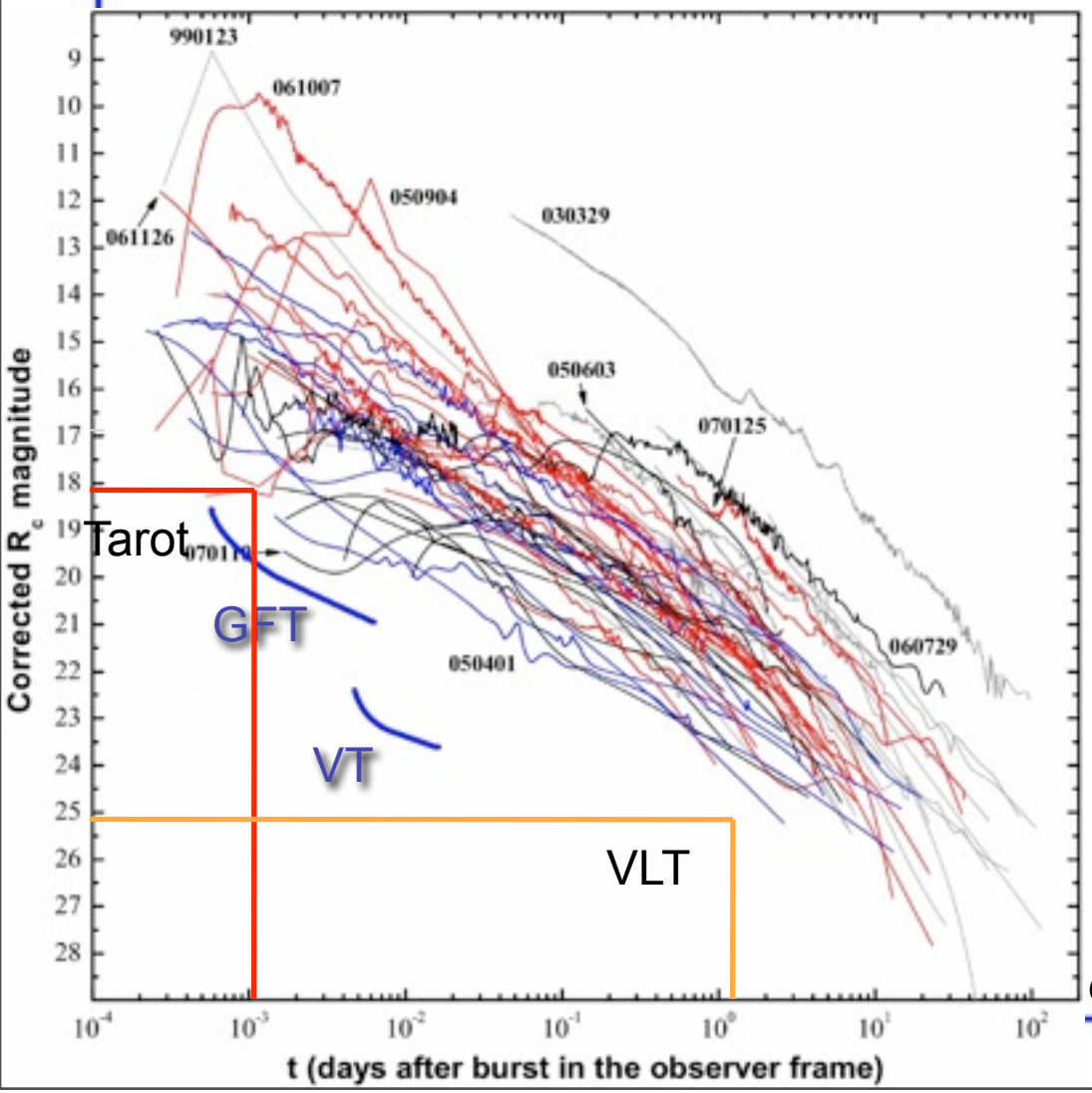
NIR obserations enable detection of obscured or distant sources

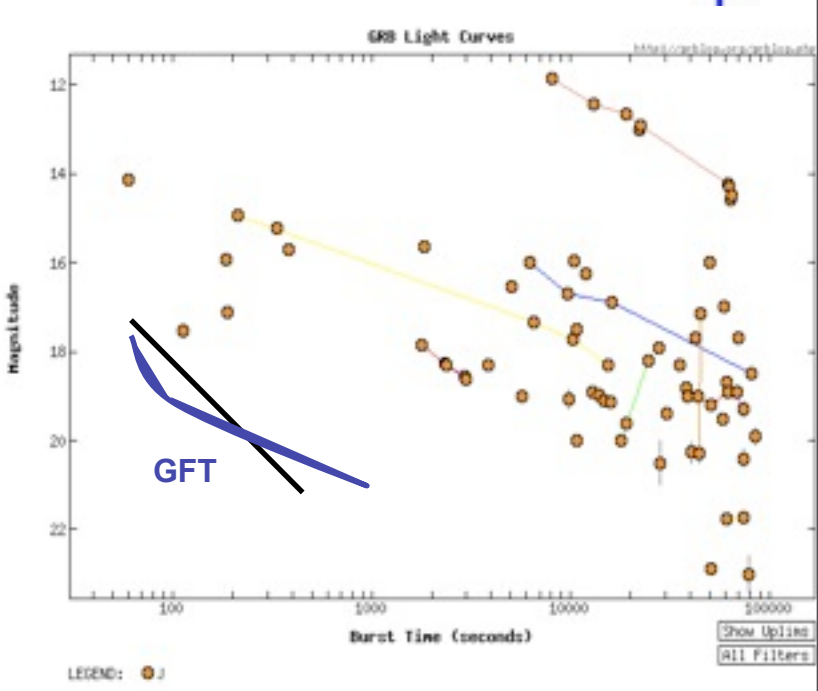
.



Nom	F-GFT
Diamètre	1.0
Champ de vue	30' x 30'
Monture	Alt-Az
Vitesse de pointé	10°/sec
Disponibilité	90%
Site	Mexico ou Chili (TBC)
Fraction de GRBs observable rapidement	20-25%
Bandes photométriques	B, V, R, I, J, H
Nombre de voies	3 (2 visibles + 1 NIR)
Magnitude limite (30 sec, 5σ)	R = 20.0 J = 18.8
Durée de l'analyse temps-réel	<4 min
Catalogues de référence	USNO-B (visible) 2MASS (NIR)

The GFT and current observations

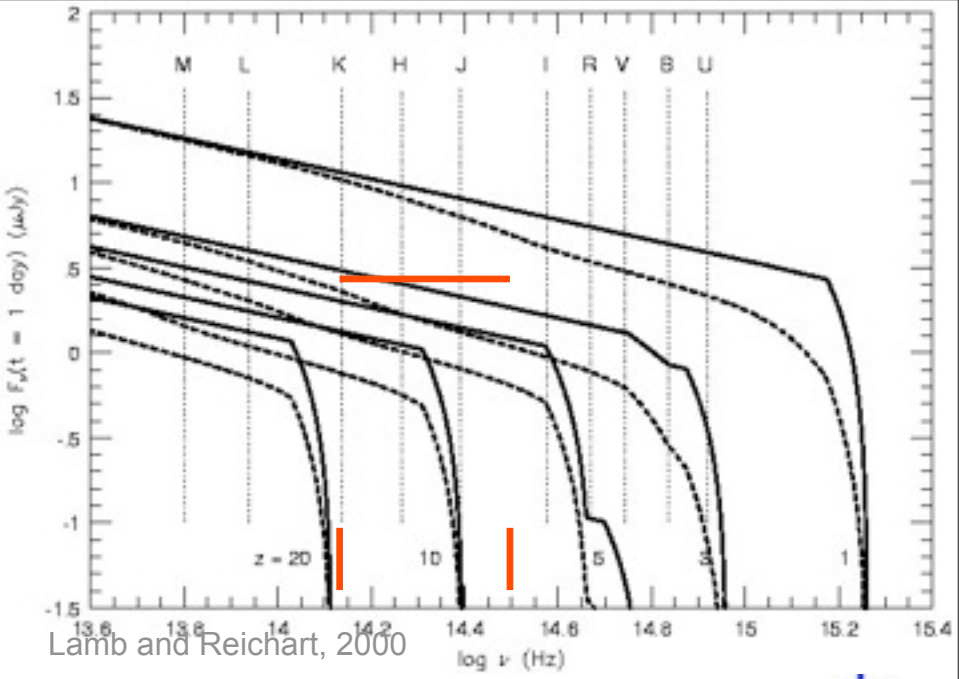




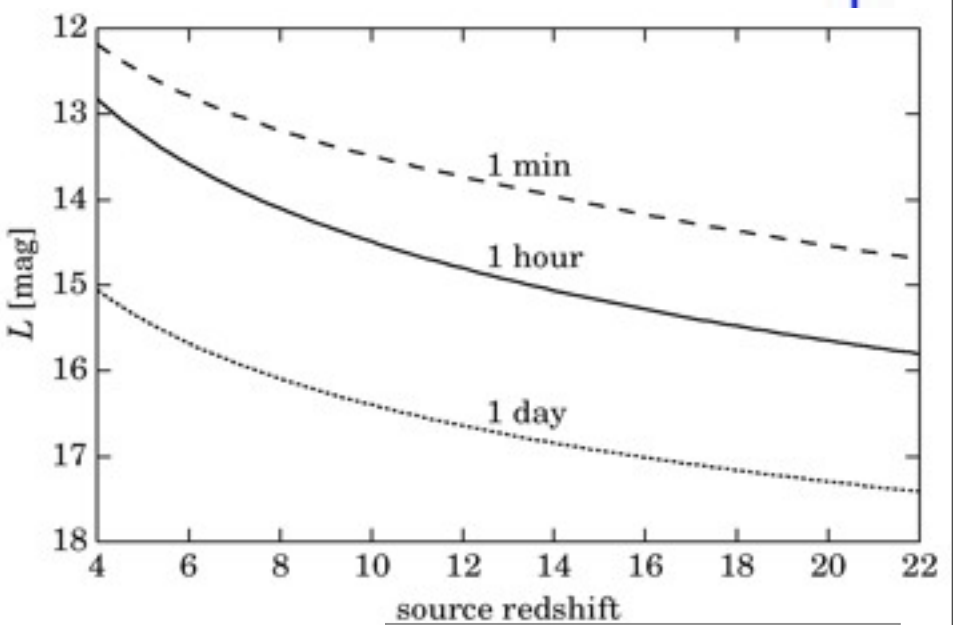
OHP

SVOM and GFT

- Continuous time coverage
- Panchromatic coverage (IR to vis.)
  - Dust embeded GRBs
  - Dark GRBs
  - GRBs for cosmology, photometric redshifts
  - Need both good sensitivity and good site
  - Access to mid-IR
    - K: z= 15
    - I: z = 7
    - Example: re-ionization history in 1 or 2 passes
    - Granularity of neutral / ionized medium
    - Origin?



Lamb and Reichart, 2000



Inoue, Yamazaki, Nakamura, 2003

Conclusion

- Ground based GRB astronomy now well established
  - As usual for GRBs, large dispersion in size: 0.1 to 10m are useful
  - Physics of GRBs
  - Cosmology with GRBs
  - Test of fundamental physics
  - GRBs need both space/ground coordinated observations for their understanding
- Present standard collapsar model needs some fine tuning to fit with rapid observations or multiwavelength data
- Complementarities between space and ground based instruments
- For the future need more rapid, faster instrun
  - Continuous coverage for over 1 day
  - Fast sampling
  - Rapid spectral/polarization evolution
- Several progress
  - X-shooter and VLT rapid mode
  - Networks of rapid telescopes (TAROT/Zadko ROTSE, REM)
  - Chinese GWAC
  - SVOM/GFT
- Some needs
  - Real network of (0.2 – 1m) rapid telescopes
  - Simultaneous visible – IR – X-ray coverage
  - Coverage of precursor events (GWAC)