Shedding light on the «dark» Universe with Gamma-Ray Bursts

Lorenzo Amati
(INAF – OAS Bologna)
(Blois, 25 May 2022)

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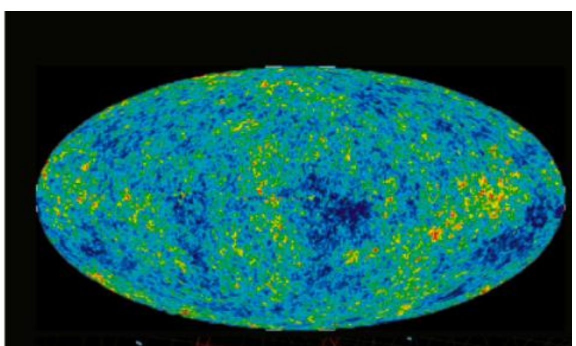
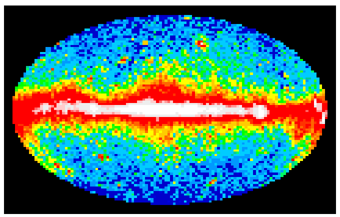
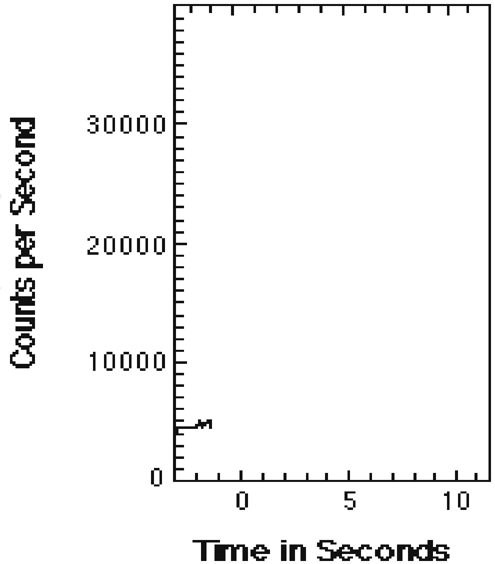
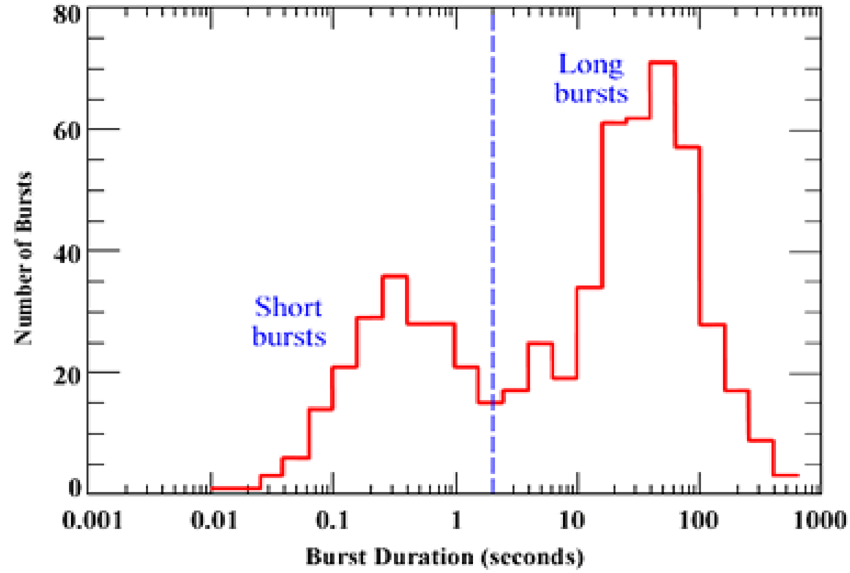


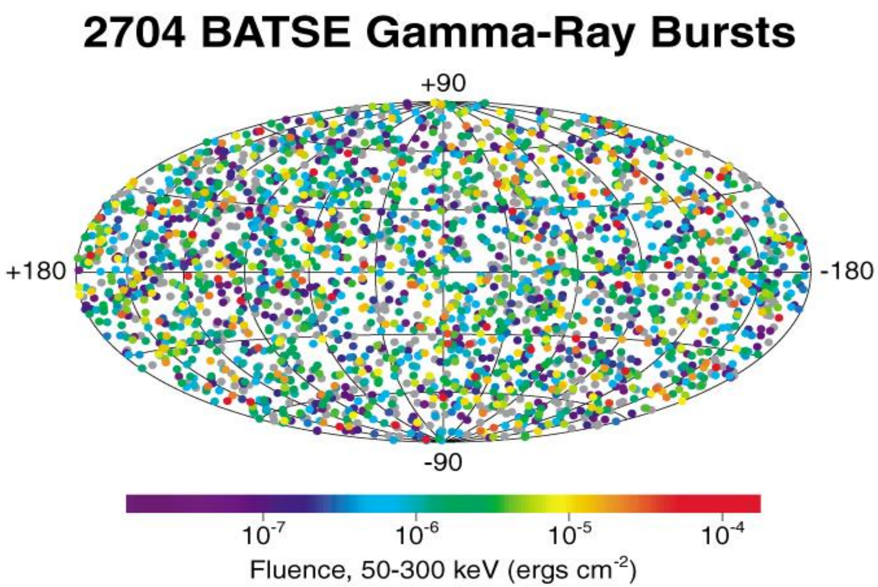
Exploring the Dark Universe
May 22nd - May 27th, 2022

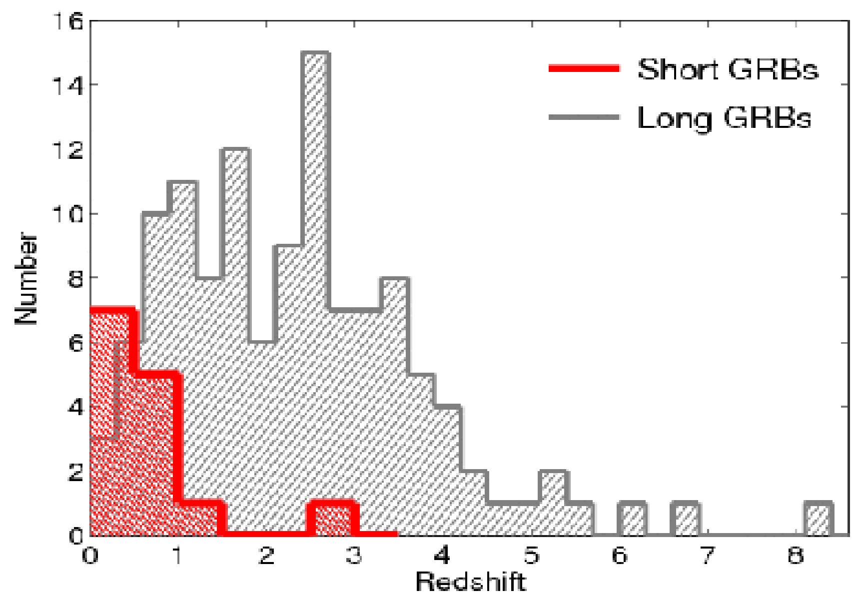
Gamma-Ray Bursts: the most extreme phenomena in the Universe







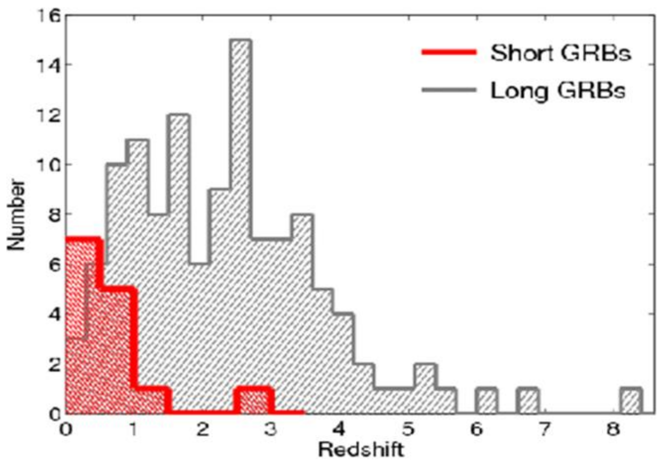


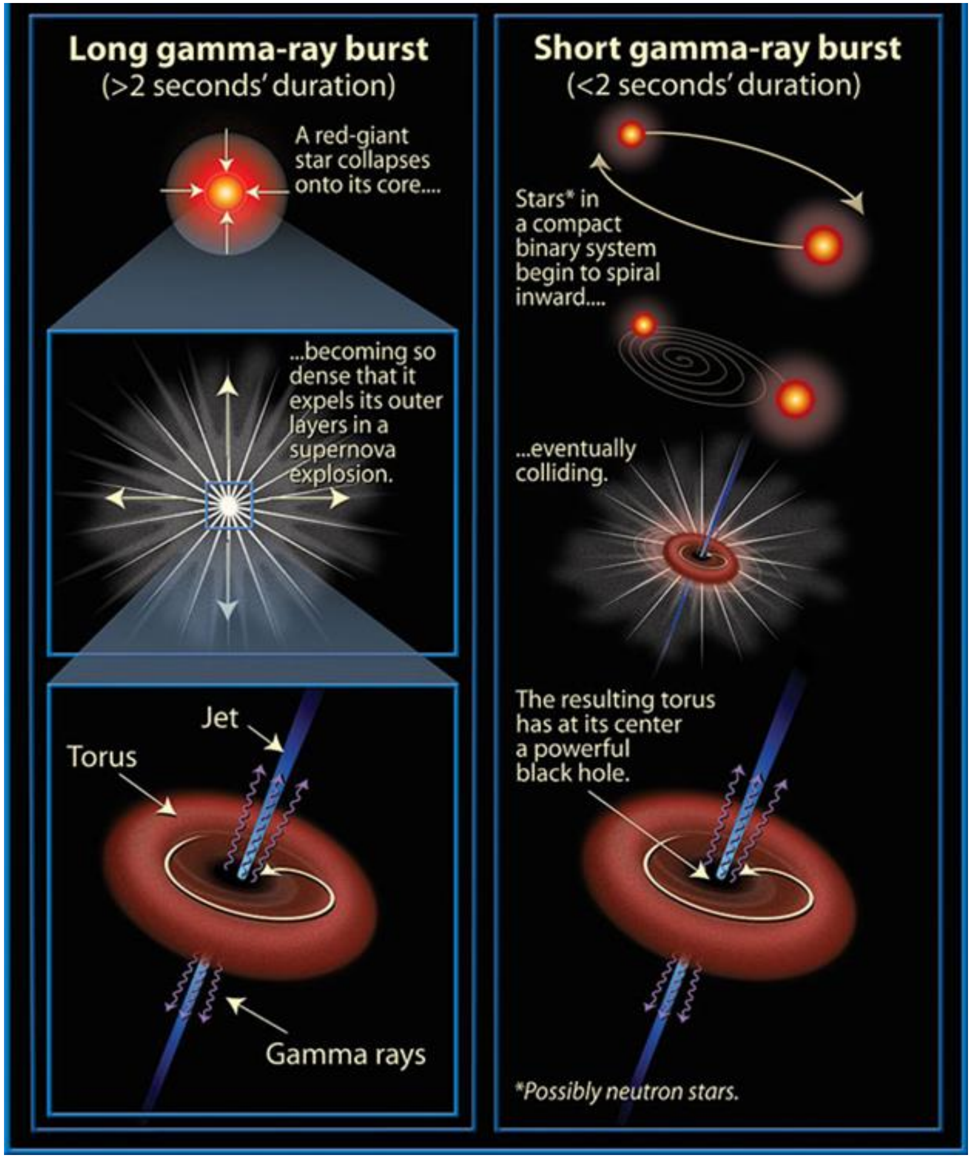


Gamma-Ray Bursts: the most extreme phenomena in the Universe

Long GRBs: core collapse of pecular massive stars, **association with SN**

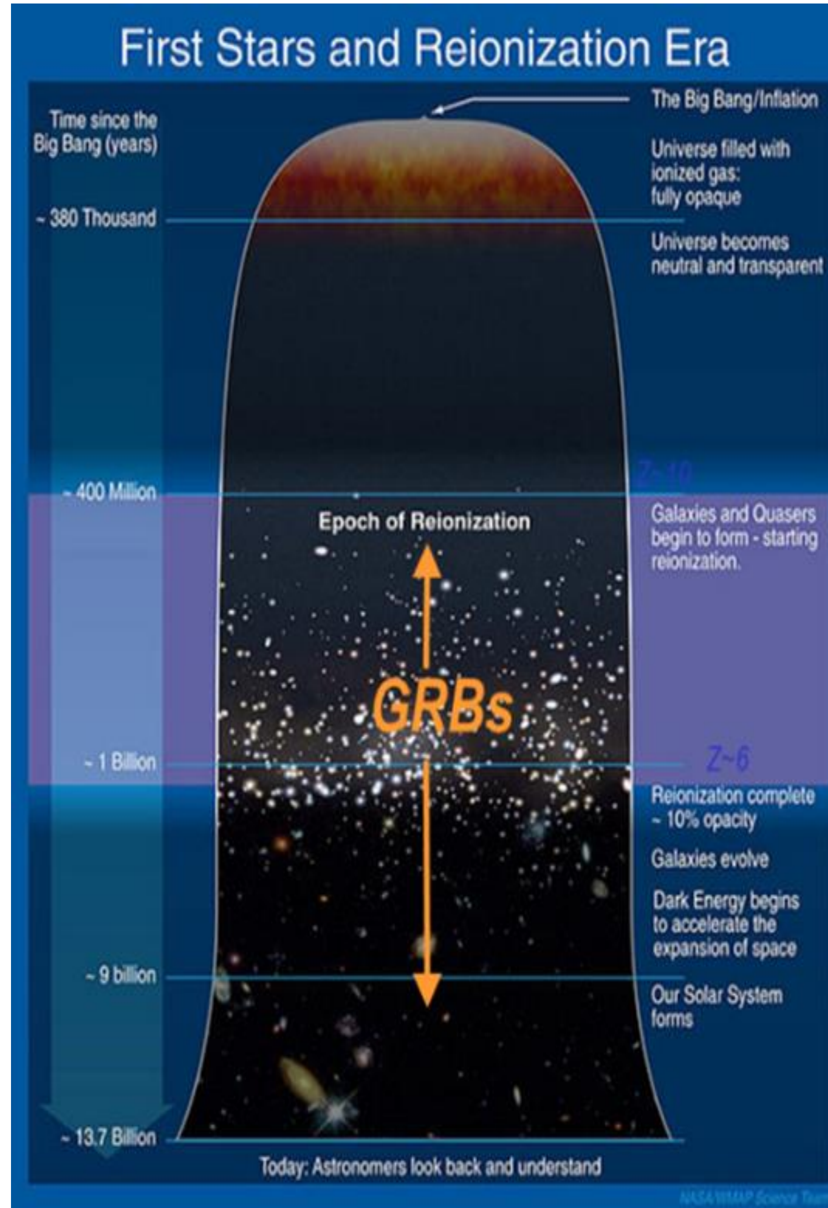
Short GRBs: NS-NS or NS-BH mergers, **association with GW sources**





Shedding light on the early Universe with GRBs

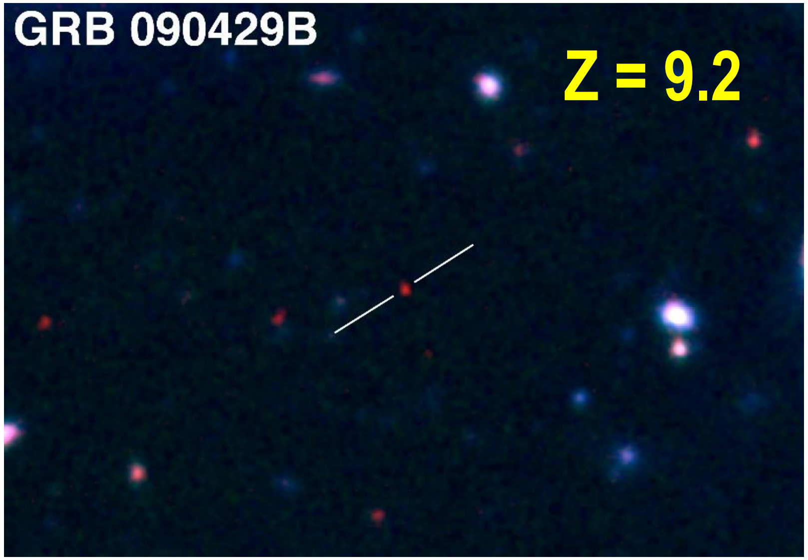
- **Long GRBs:** huge luminosities, mostly emitted in the X and gamma-rays
- **Redshift distribution** extending at least to z ~9 and association with exploding massive stars
- **Powerful tools for cosmology:** SFR evolution, physics of re-ionization, high-z low luminosity galaxies, pop III stars

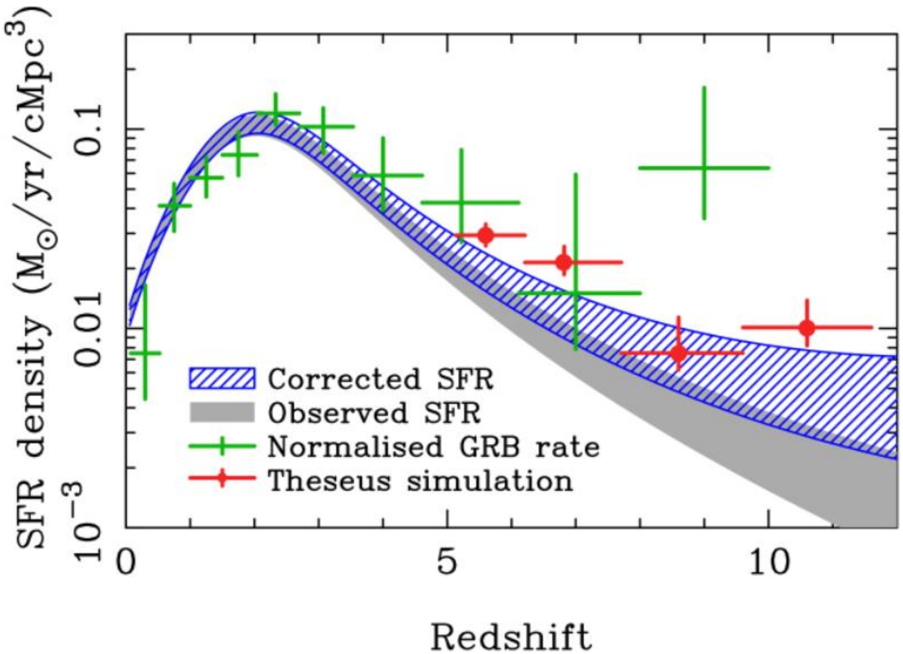


Shedding light on the early Universe with GRBs

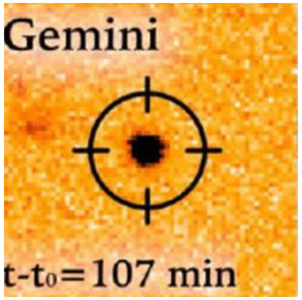
A statistical sample of high–z GRBs can provide fundamental information:

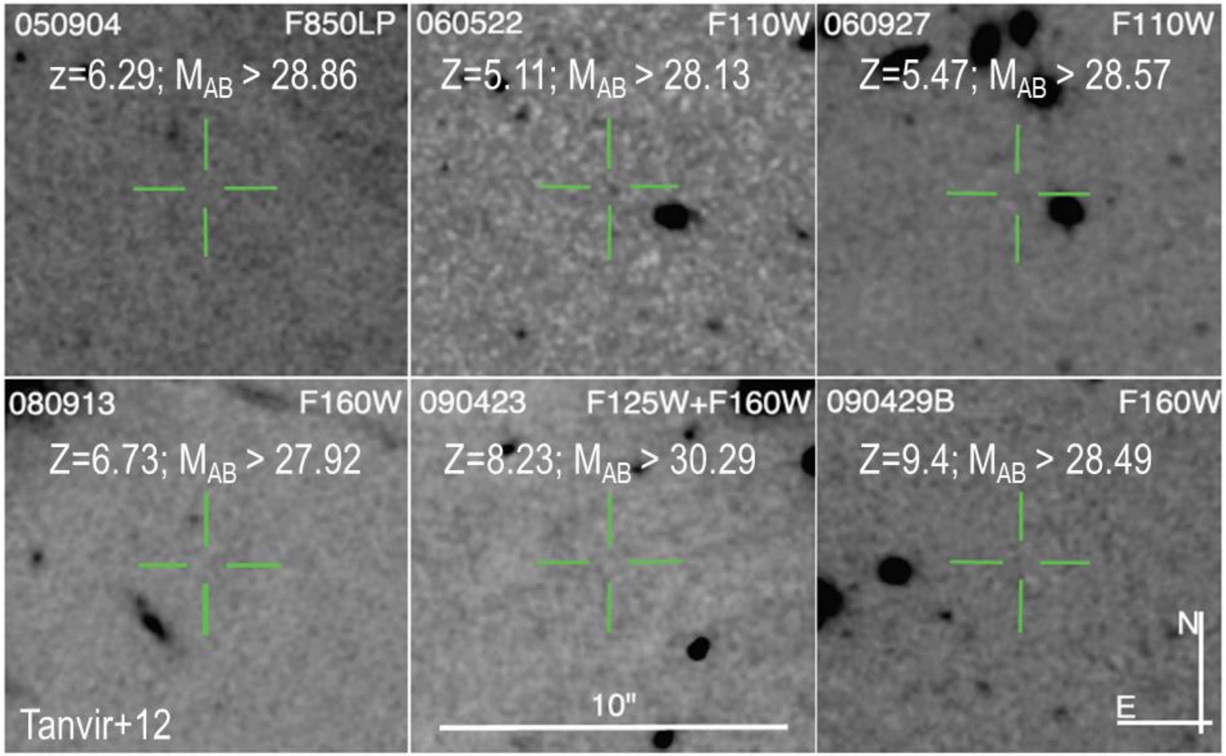
- measure independently the **cosmic star–formation rate**, even beyond the limits of current and future galaxy surveys
- directly (or indirectly) detect the **first population of stars (pop III)**





- **Detecting and studying primordial invisible galaxies**

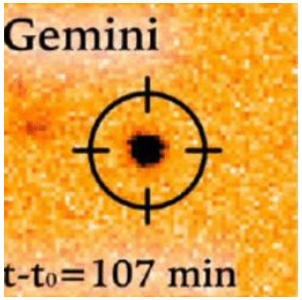


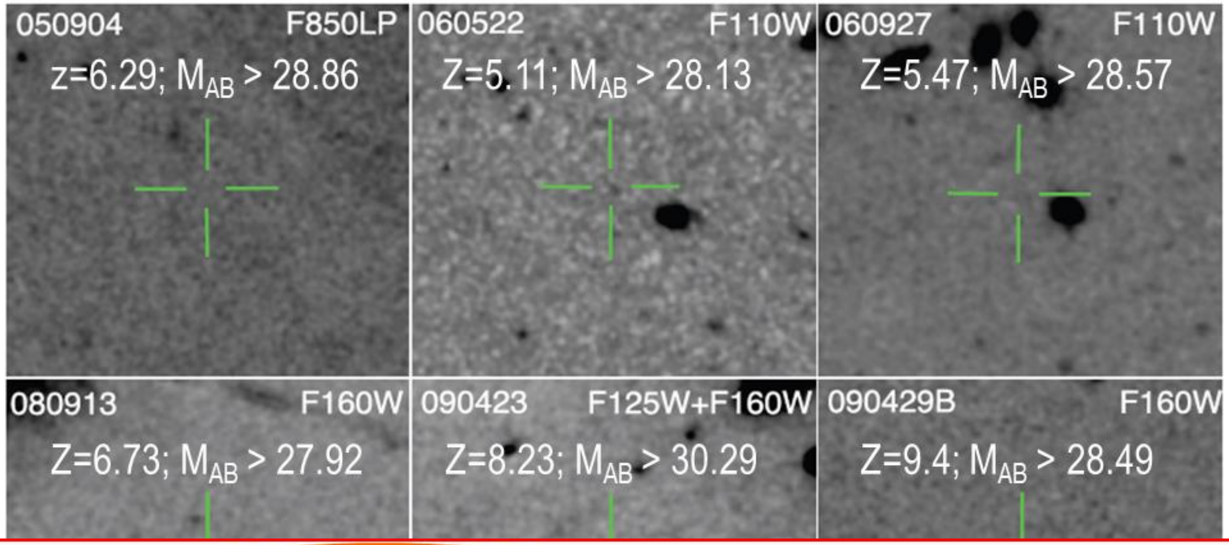


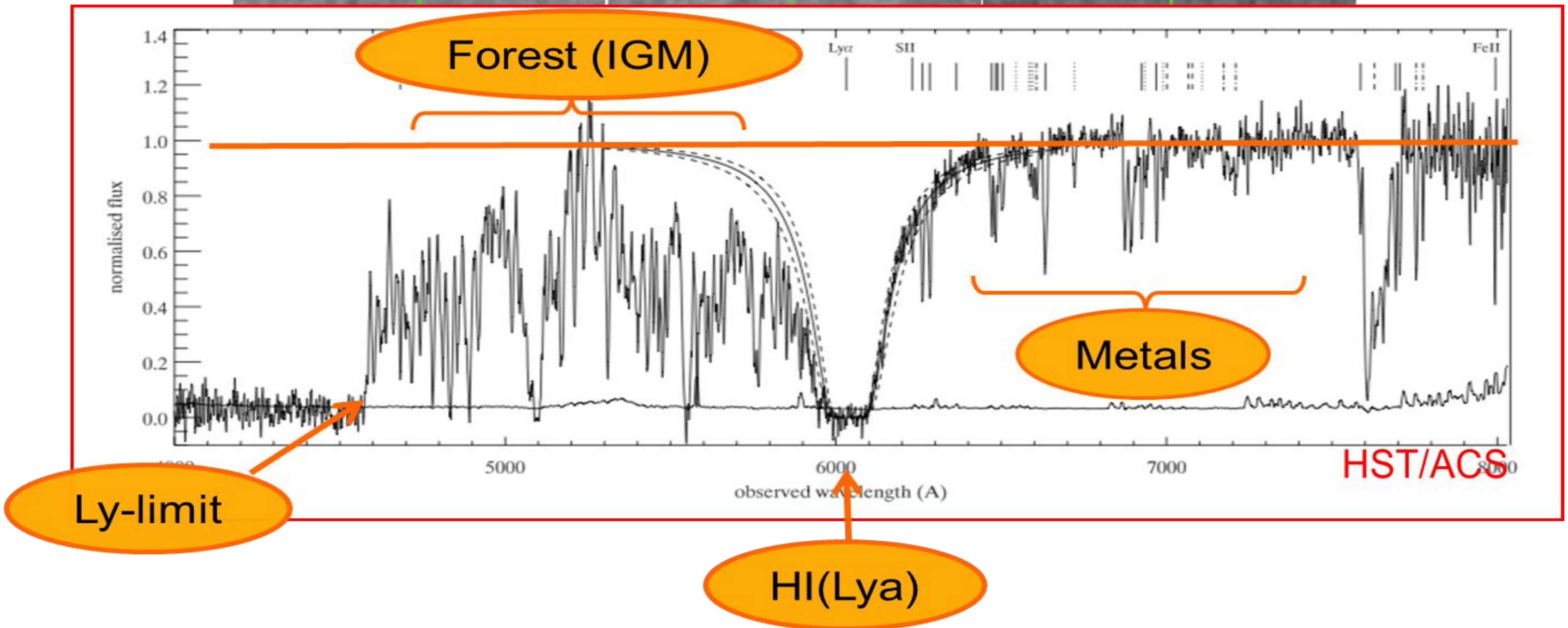
Robertson&Ellis12

Even JWST and ELTs surveys will be not able to probe the faint end of the galaxy Luminosity Function at high redshifts (z>6-8)

- **Detecting and studying primordial invisible galaxies**







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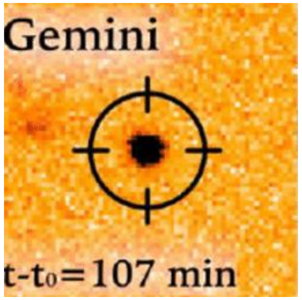
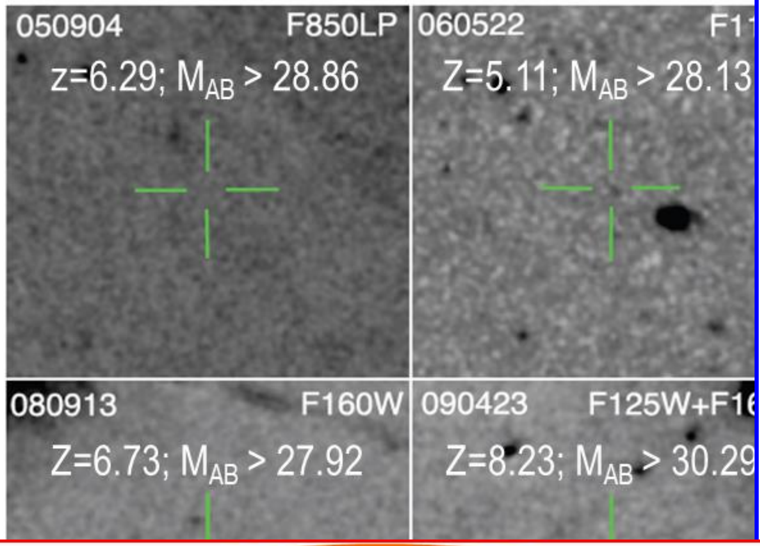
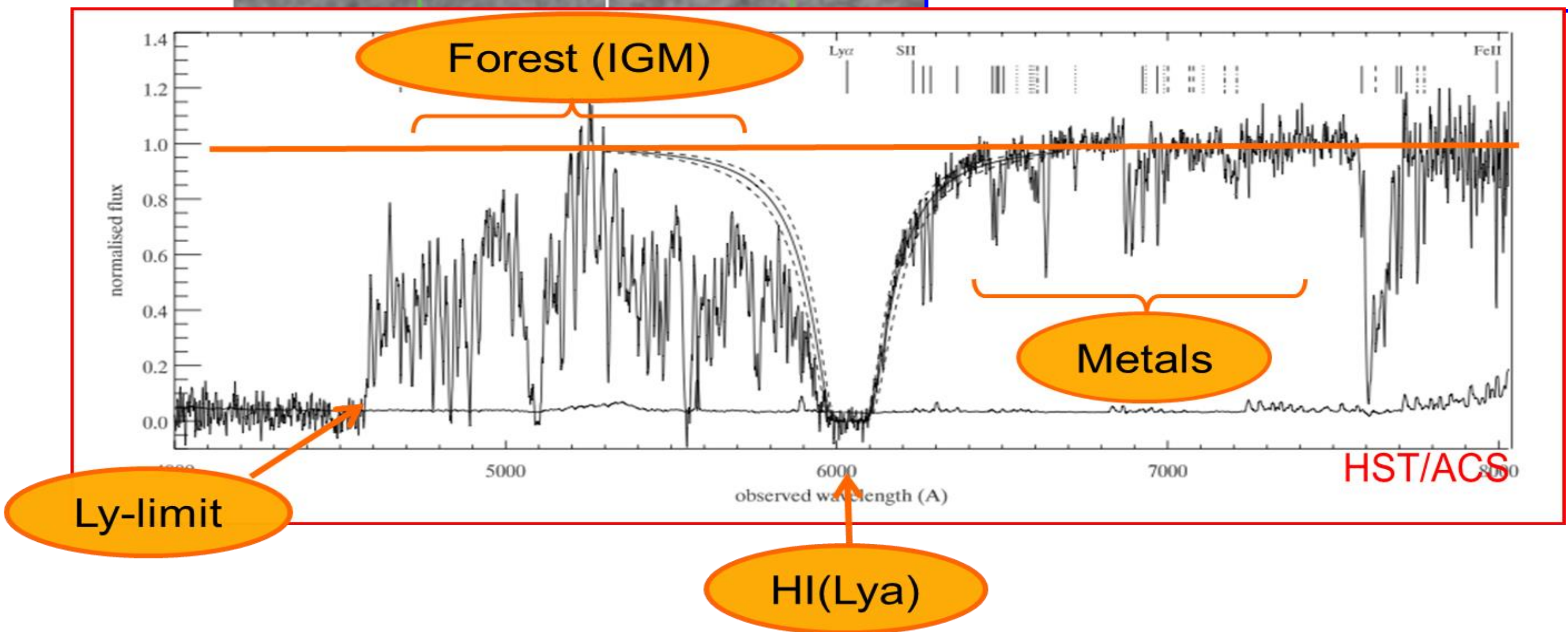




- neutral hydrogen fraction
- escape fraction of UV photons from high-z galaxies
- early metallicity of the ISM and IGM and its evolution

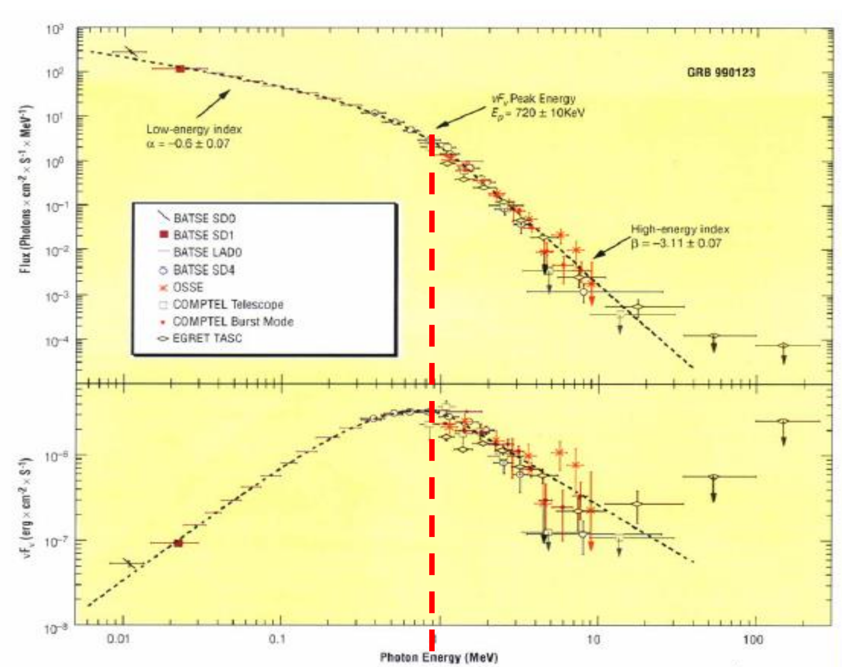


Measuring cosmological parameters with GRBs

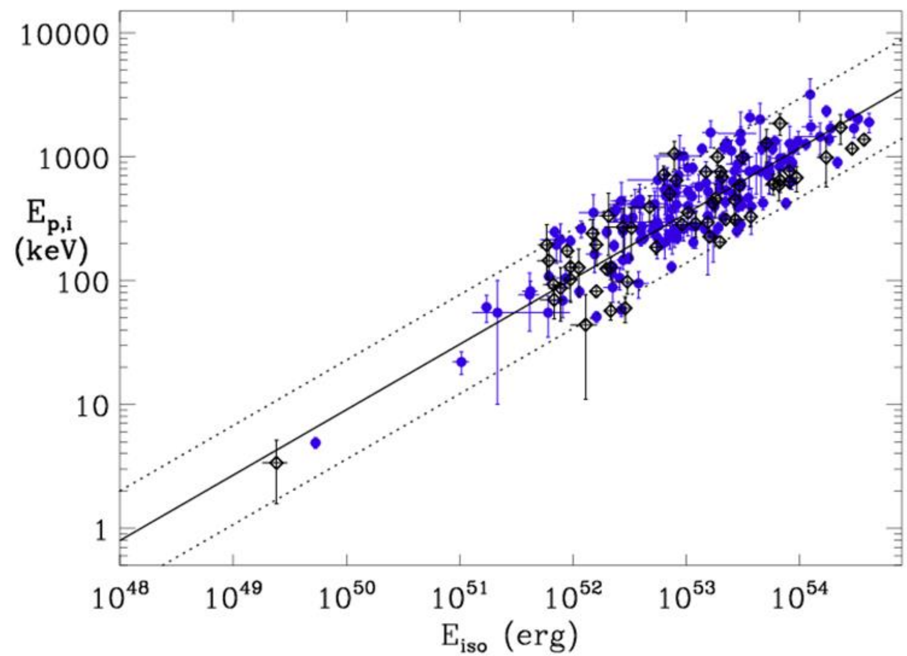
- GRB νFν spectra typically show a peak at a characteristic photon energy E_p
- **measured spectrum + measured redshift -> intrinsic peak enery and radiated energy**

$$E_{p,i} = E_p \times (1 + z)$$

$$E_{\gamma,iso} = \frac{4\pi D_l^2}{(1+z)} \int_{1/1+z}^{10^4/1+z} E\,N(E)\,dE \quad \text{erg}$$



Ep



Amati et al. (2002,2006,2008, 2013)

❑ “Standardizing” GRBs through the Ep-Eiso correlation

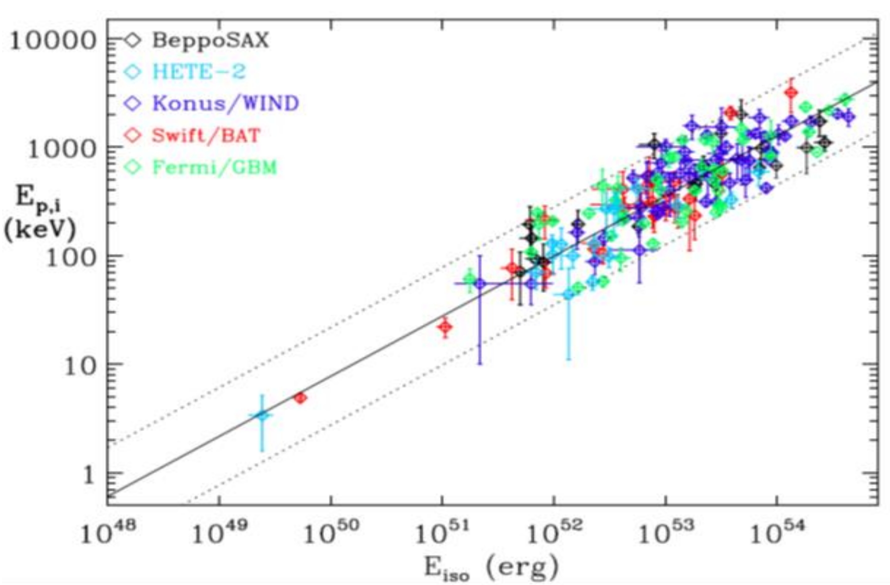
$$E_{p,i} = E_{p,obs} \times (1 + z)$$

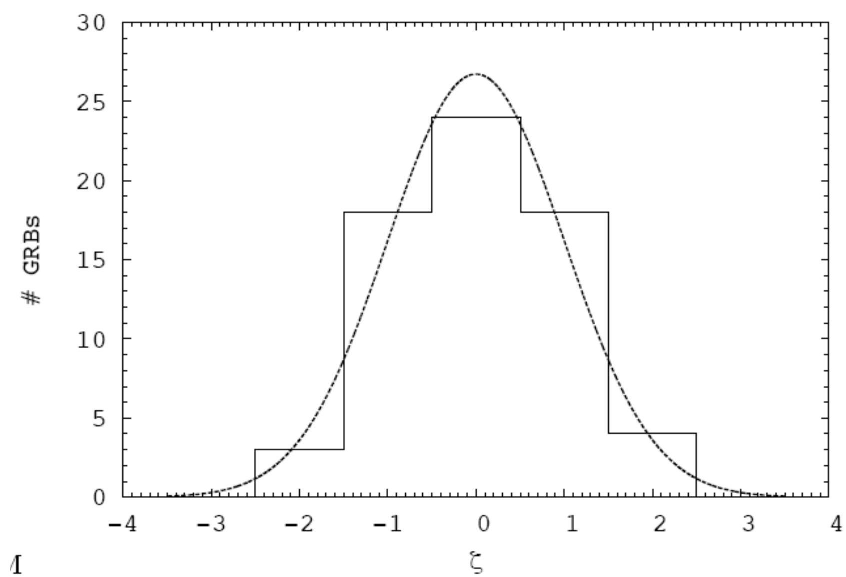
$$E_{\gamma,iso} = \frac{4\pi D_l^2}{(1+z)} \int_{1/1+z}^{10^4/1+z} E\,N(E)\,dE \quad \text{erg}$$

→ $D_l = D_l(z\,,\,H_0,\,\Omega_M,\,\Omega_\Lambda,\ldots)$

- **not enough low-z GRBs for cosmology-independent calibration -> circularity is avoided by fitting simultaneously the parameters of the correlation and cosmological parameters**

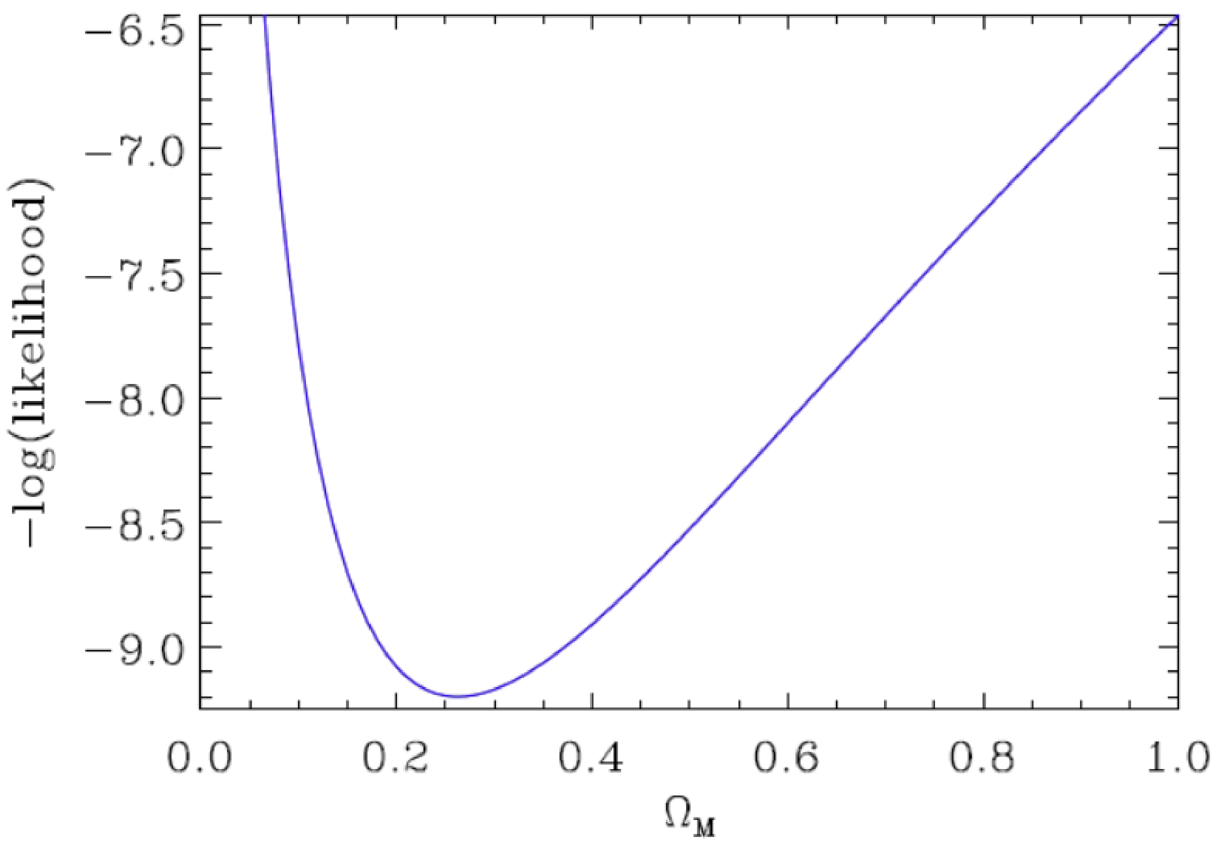
- **does the extrinsic scatter and goodness of fit of the Ep,i-Eiso correlation vary with the cosmological parameters used to compute Eiso ?**





- a fraction of the extrinsic scatter of the $E_{p,i}$-E_{iso} correlation is indeed due to the cosmological parameters used to compute E_{iso}

- **Evidence, independent on other cosmological probes, that, if we are in a flat Universe , Ω_M is lower than 1 and around 0.3**



Amati et al. 2008, Amati & Della Valle 2013, Moresco, Amati et al. 2022

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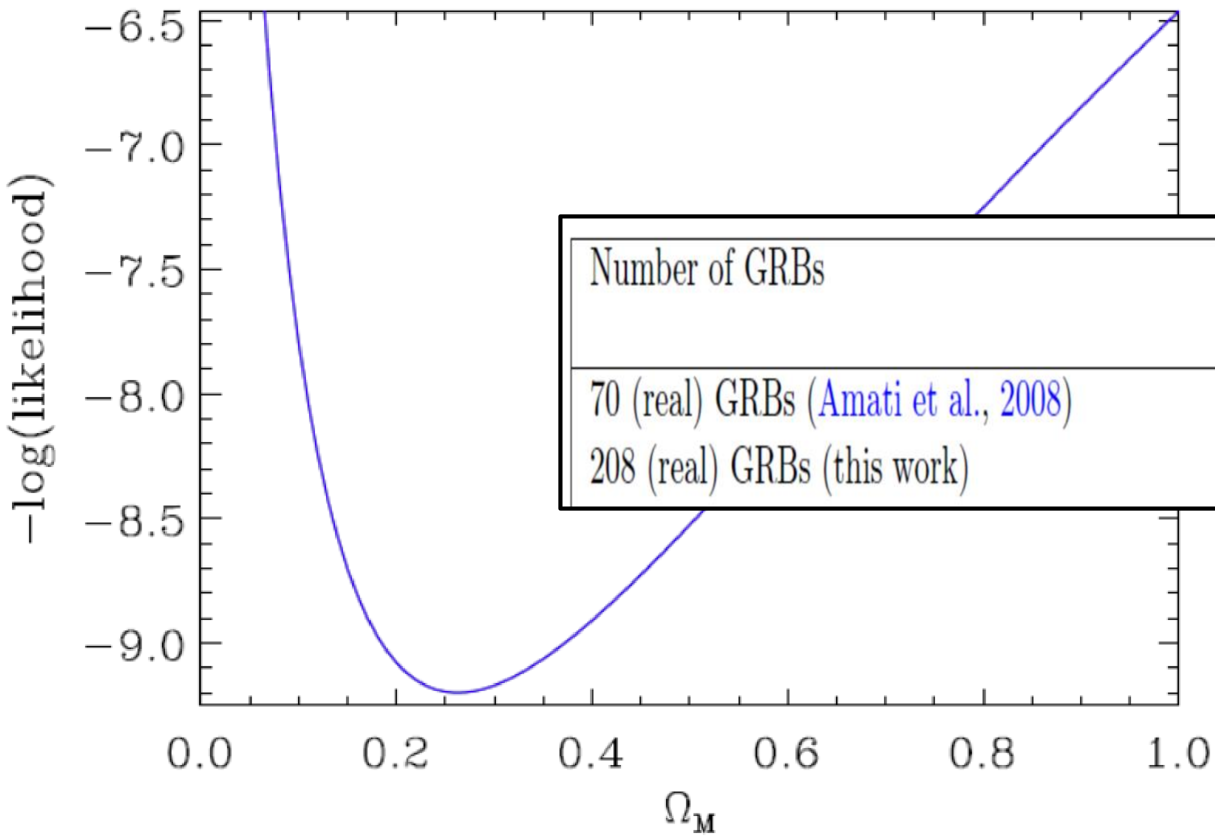
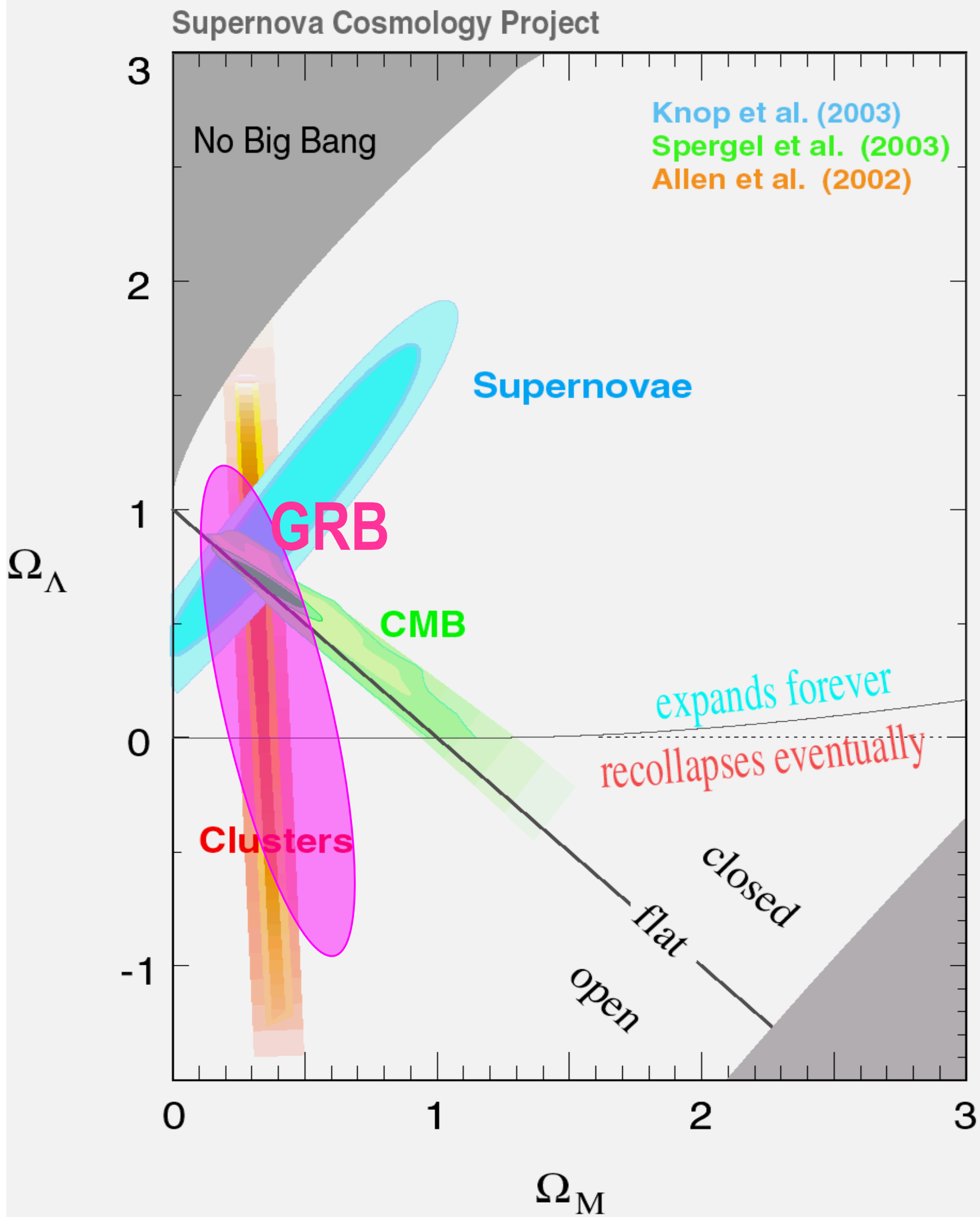


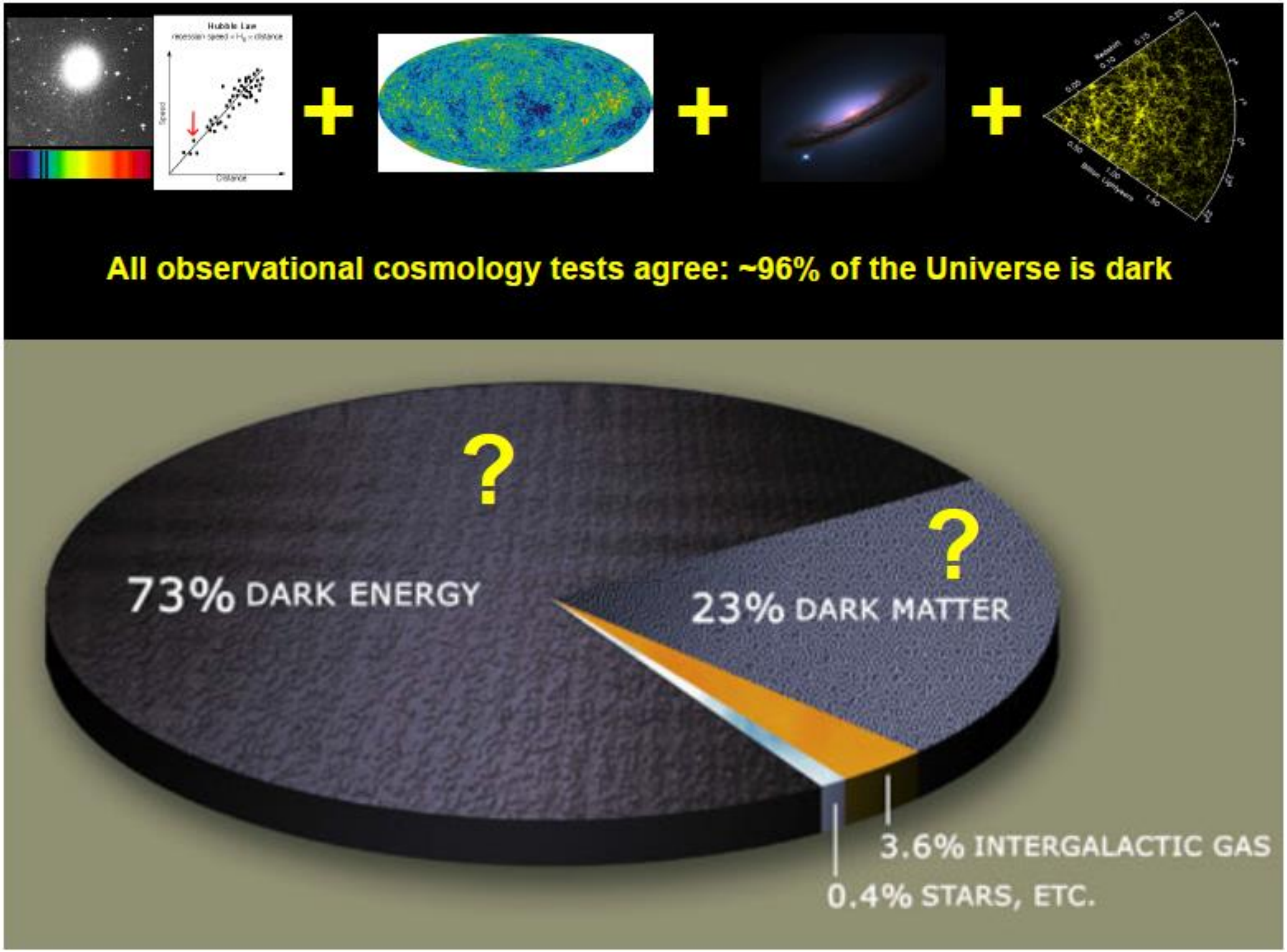
Number of GRBs	Ω_m (flat)
70 (real) GRBs (Amati et al., 2008)	$0.27^{+0.38}_{-0.18}$
208 (real) GRBs (this work)	$0.26^{+0.23}_{-0.12}$

Amati et al. 2008, Amati & Della Valle 2013, Moresco, Amati et al. 2022



Supernova Cosmology Project
No Big Bang
Knop et al. (2003)
Spergel et al. (2003)
Allen et al. (2002)
Supernovae
GRB
CMB
Clusters
expands forever
recollapses eventually
closed
flat
open
3
2
1
0
-1
0
1
2
3
Ω_Λ
Ω_M

What we are aiming at ?



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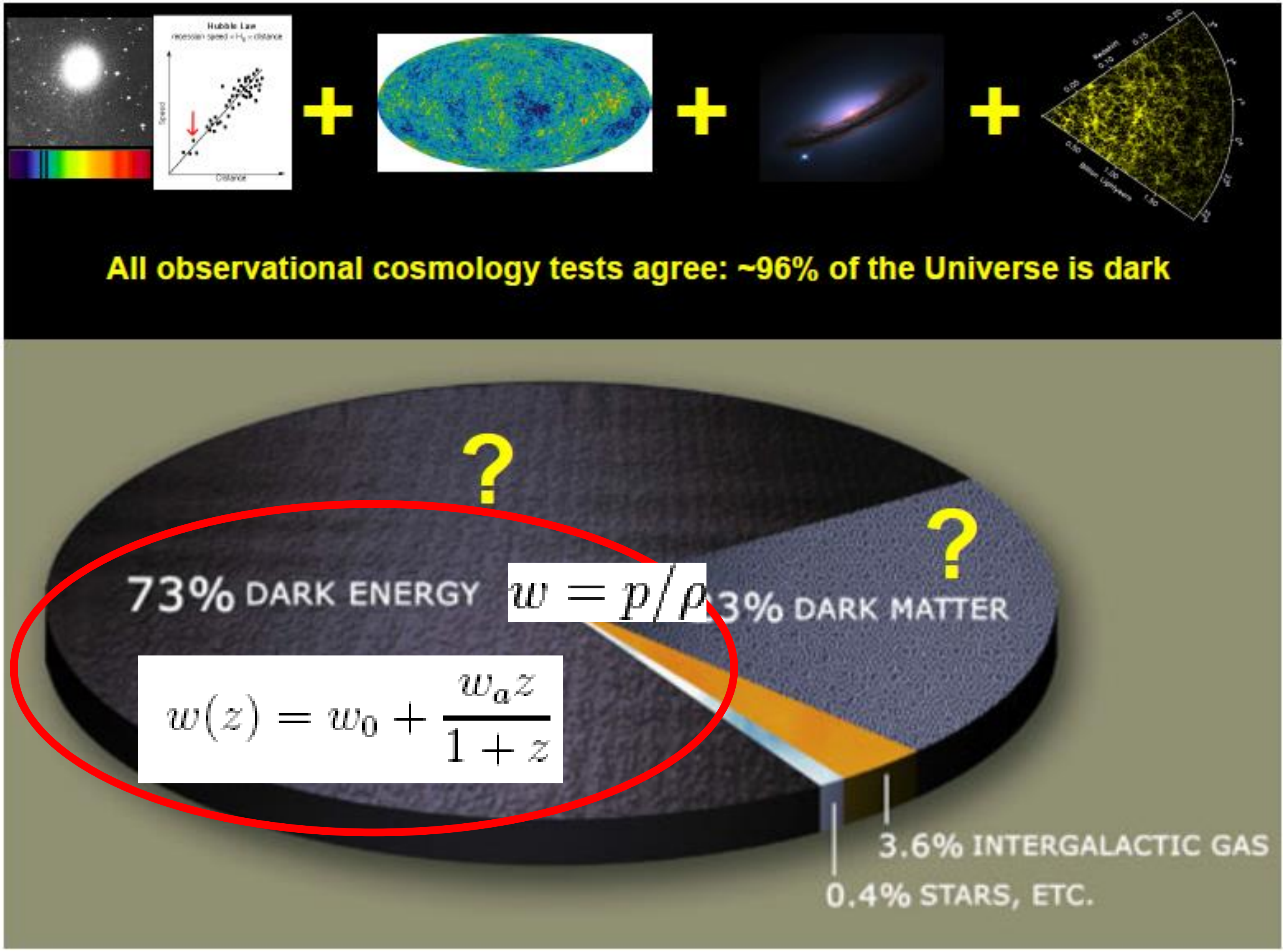
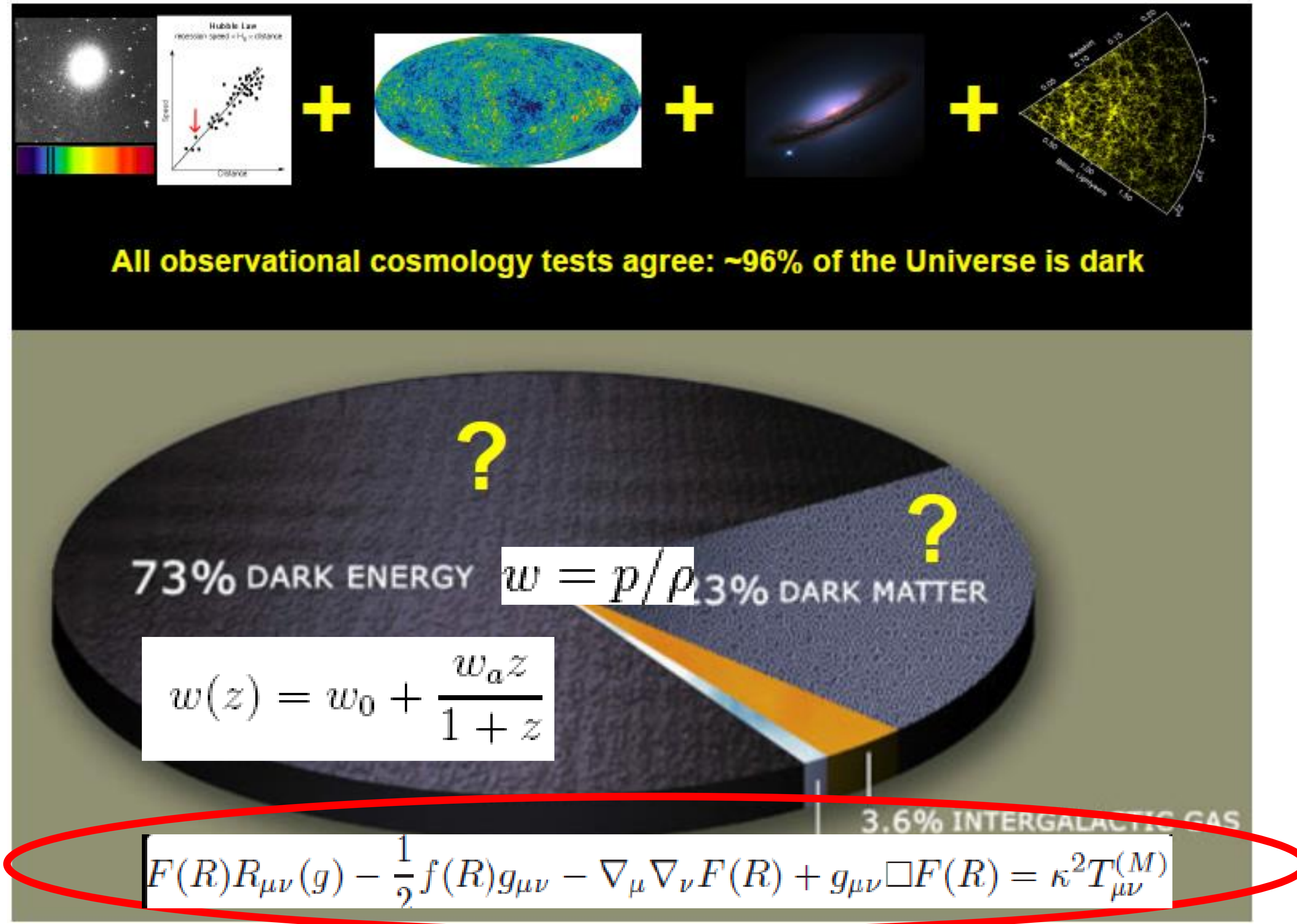


What we are aiming at ?

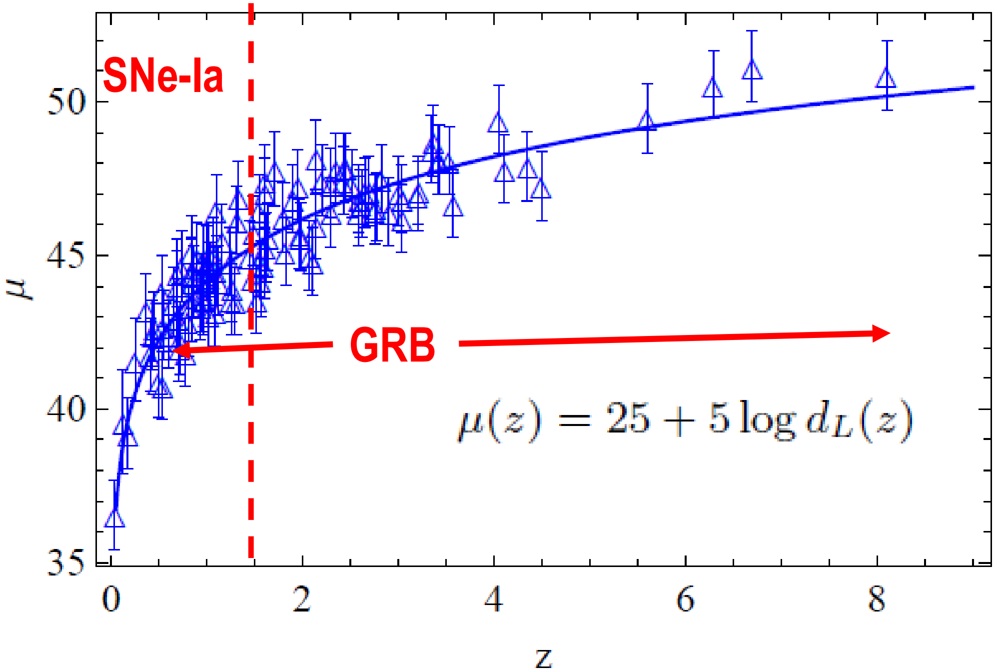


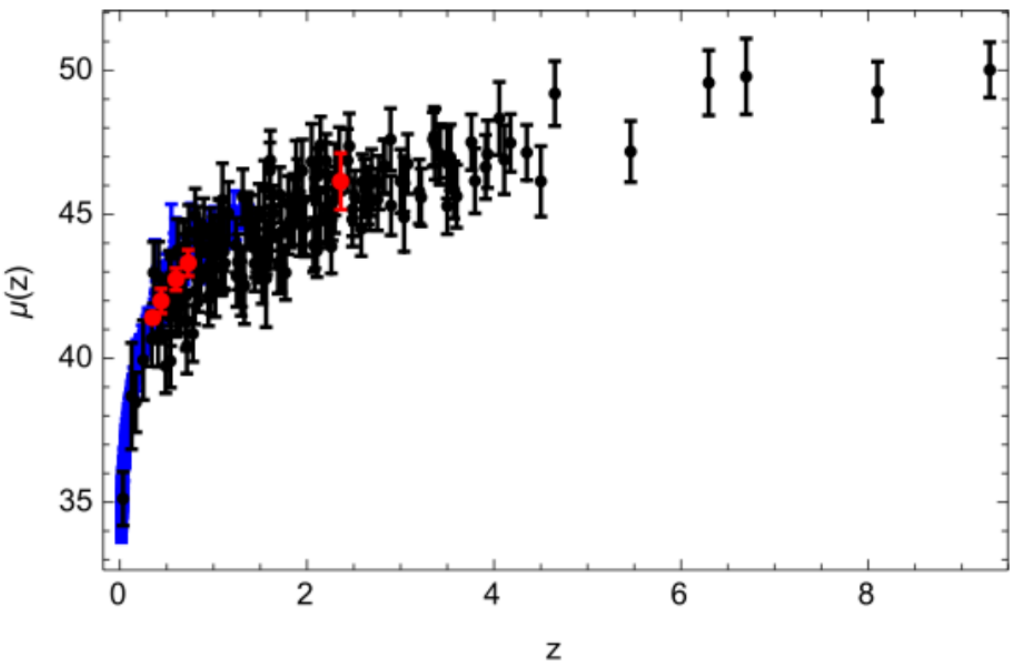
❑ Calibration with Sne-Ia

- The GRB Hubble diagram extends to much higher z w/r to SNe Ia

- **The GRB Hubble diagram is consistent with SNe Ia Hubble diagram and BAO points at low redshifts: reliability**

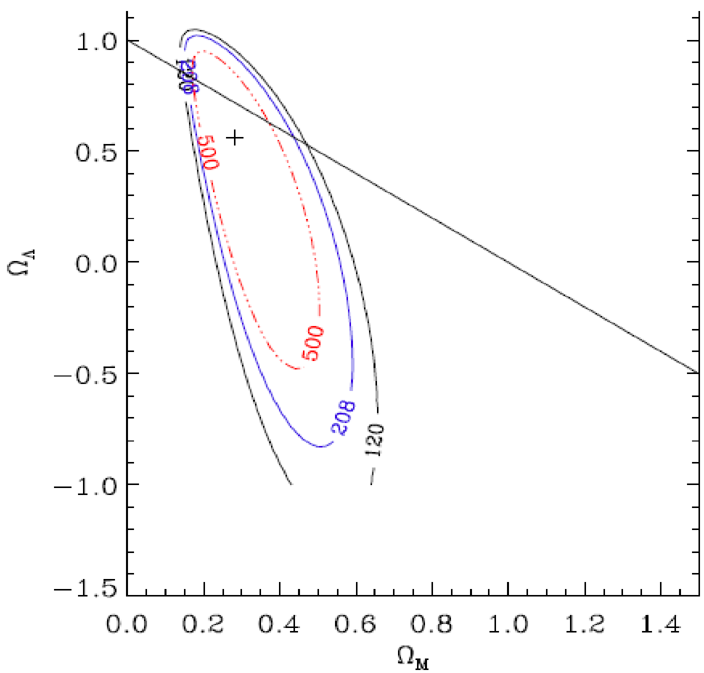
- e.g., Capozziello et al., Kodama et al., Tsutsui et al., Demianski et al.):

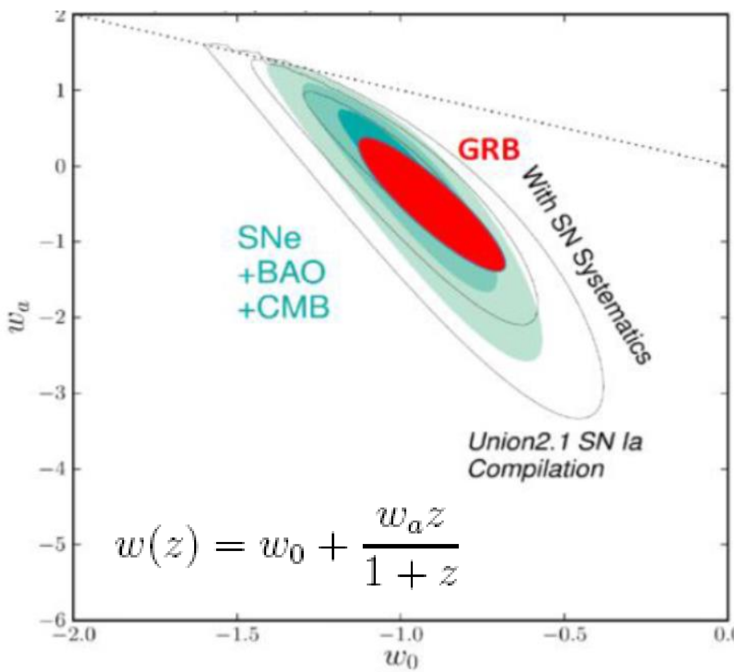




- Future GRB experiments (e.g., SVOM, HERMES, THESEUS, …) and more investigations (in particular: reliable estimates of jet angles and self-calibration) will improve the significance and reliability of the results and allow to go beyond SN Ia cosmology (e.g. investigation of dark energy)

Number of GRBs	$\Omega_{\rm m}$ (flat)	w_0 (flat, $\Omega_{\rm m}$=0.3,w_a=0.5)
70 (real) GRBs (Amati et al., 2008)	$0.27^{+0.38}_{-0.18}$	<-0.3 (90%)
208 (real) GRBs (this work)	$0.26^{+0.23}_{-0.12}$	$-1.2^{+0.4}_{-1.1}$
500 (208 real + 292 simulated) GRBs	$0.29^{+0.10}_{-0.09}$	$-0.9^{+0.2}_{-0.8}$
208 (real) GRBs, calibration	$0.30^{+0.06}_{-0.06}$	$-1.1^{+0.25}_{-0.30}$
500 (208 real + 292 simulated) GRBs, calibration	$0.30^{+0.03}_{-0.03}$	$-1.1^{+0.12}_{-0.15}$

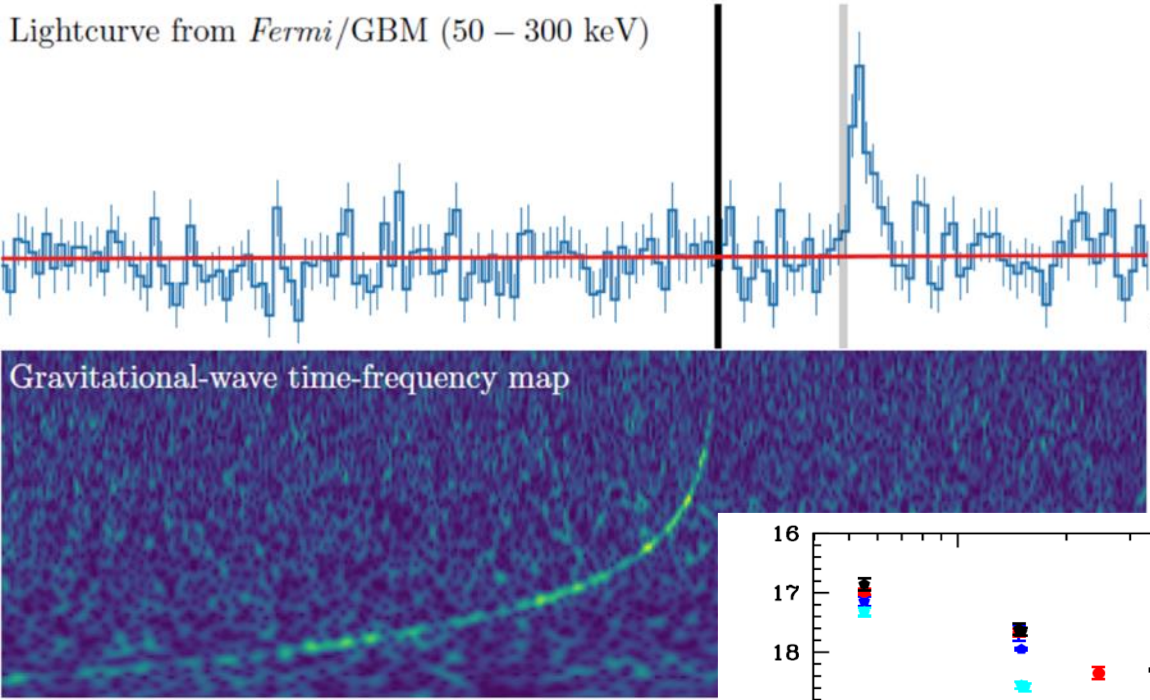


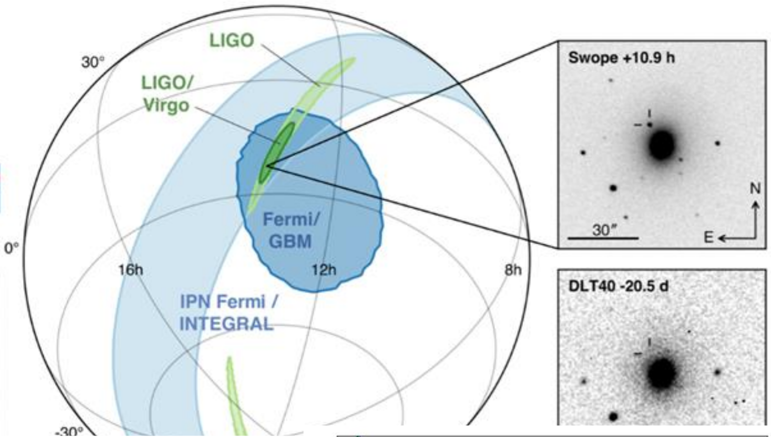


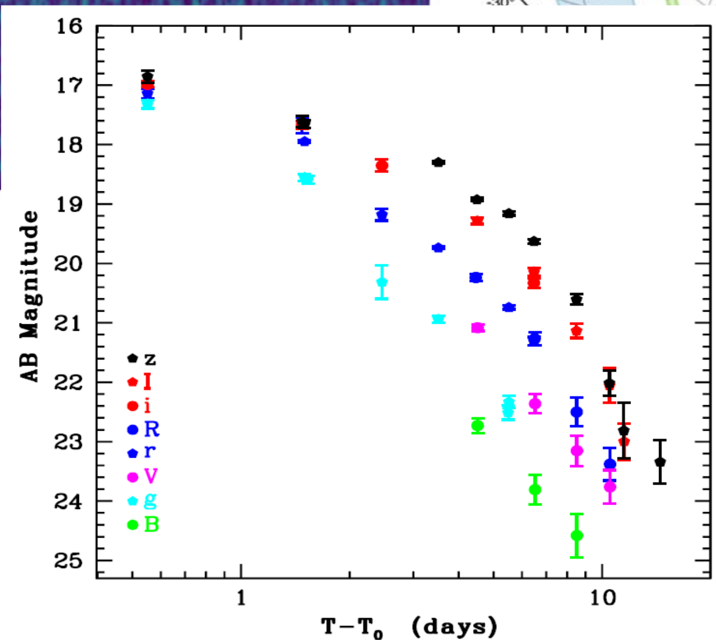
Short GRBs and multi-messenger astrophysics

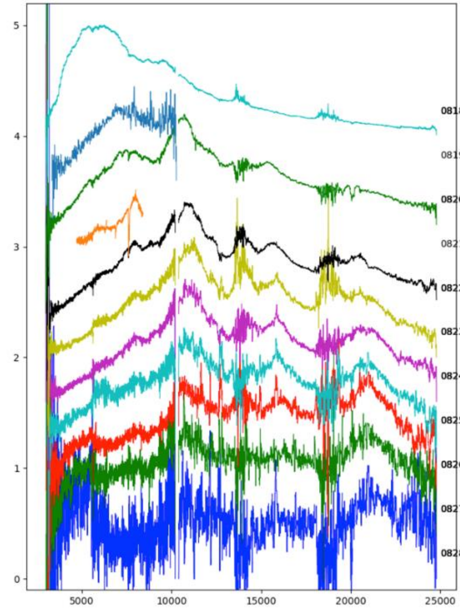
GW170817 + SHORT GRB 170817A + KN AT2017GFO (~40 Mpc):

the birth of multi-.messenger astrophysics









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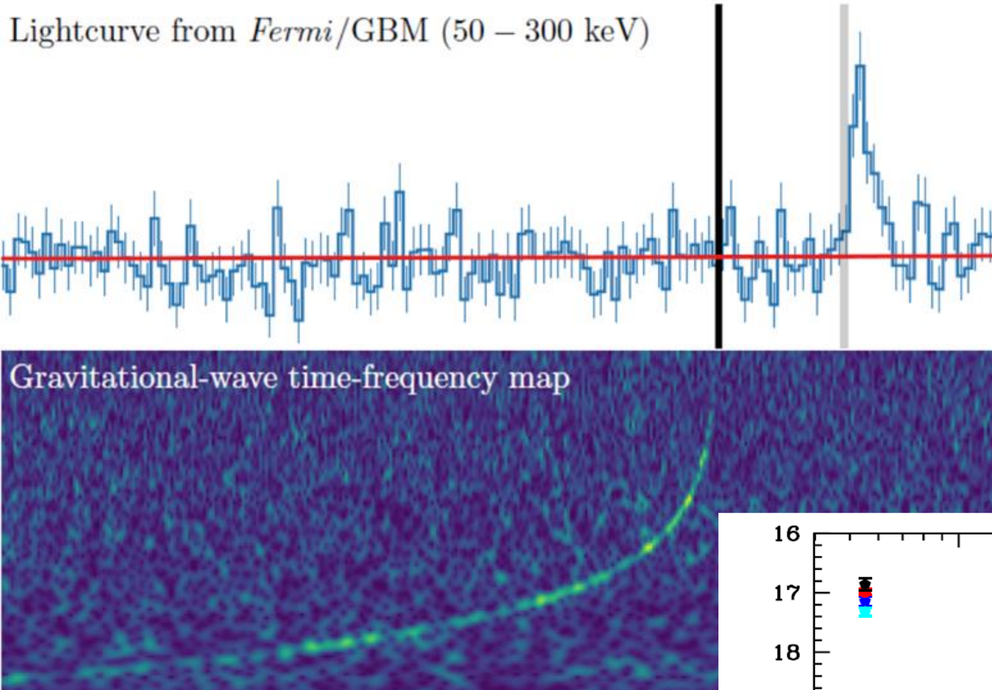
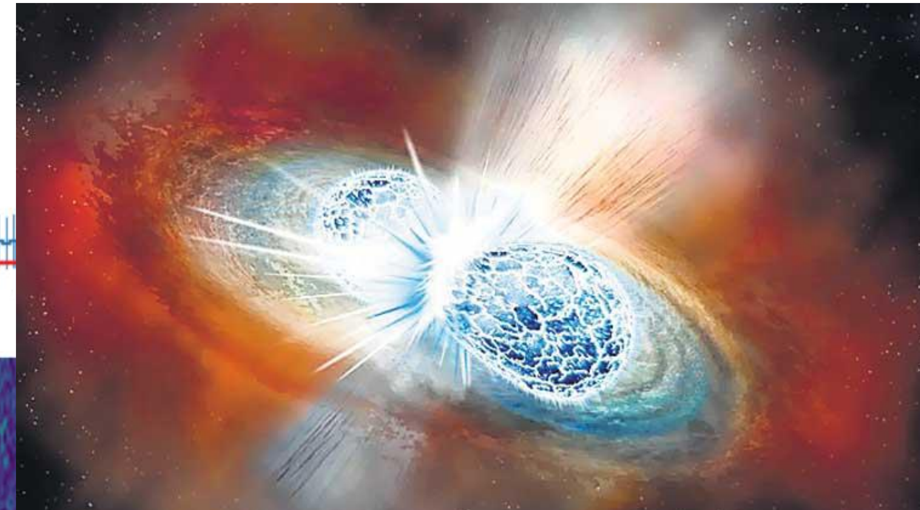
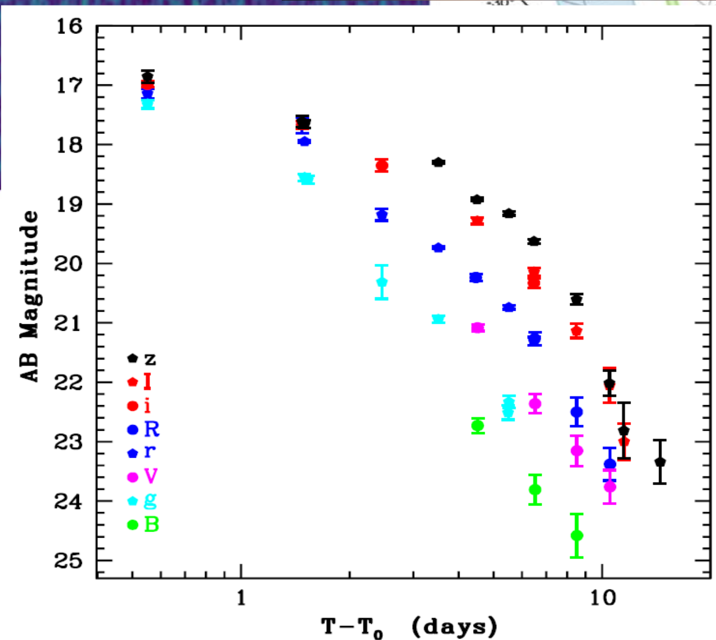
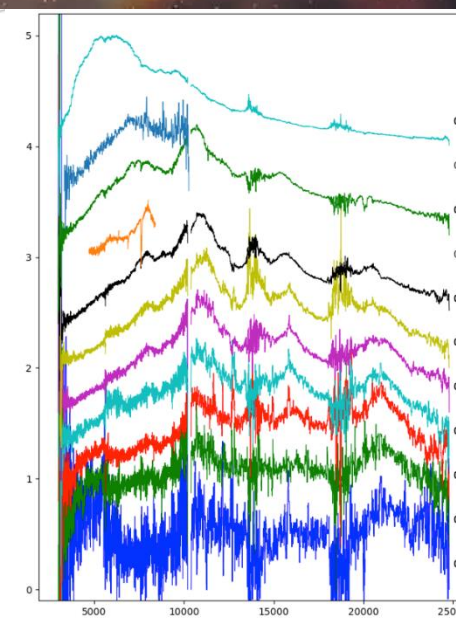


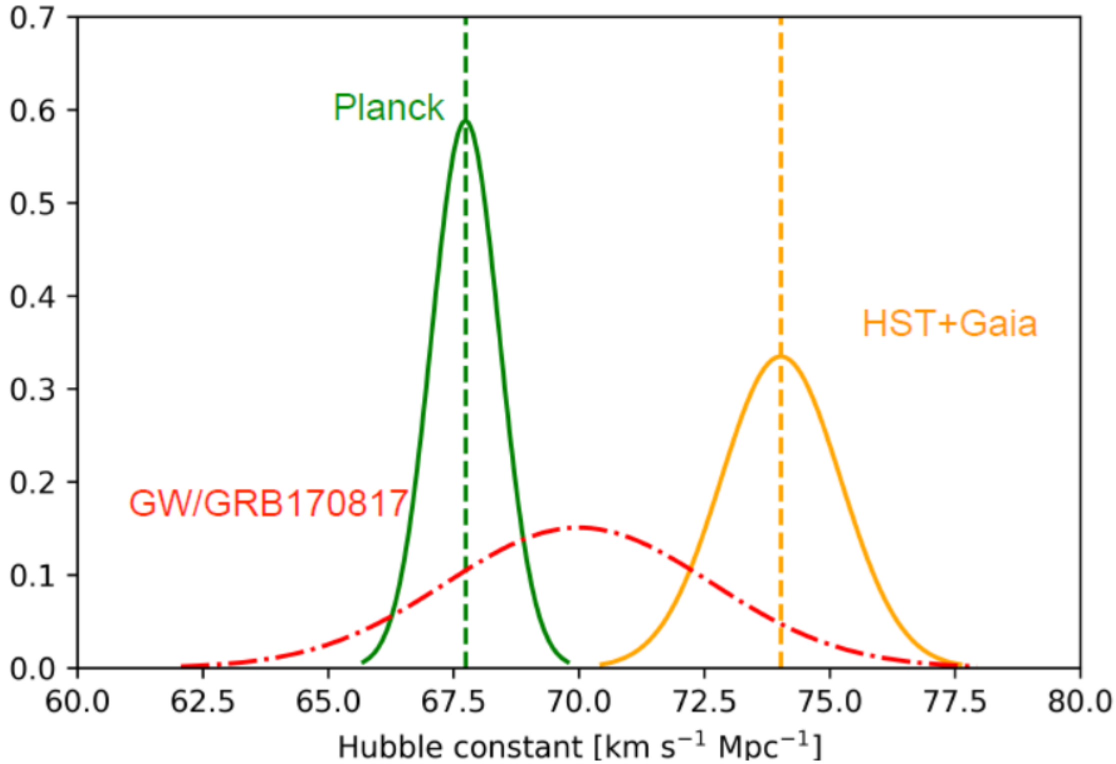






Multi-messenger cosmology through GRBs

MEASURING THE EXPANSION RATE AND GEOMETRY OF SPACE-TIME



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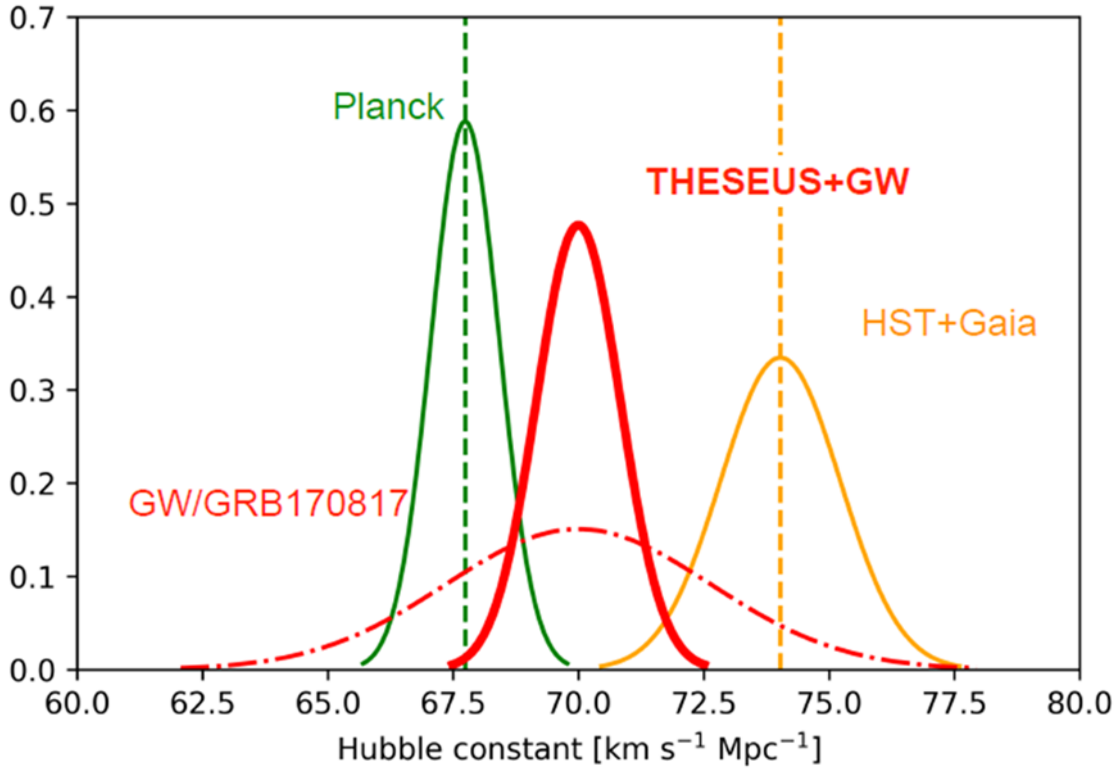
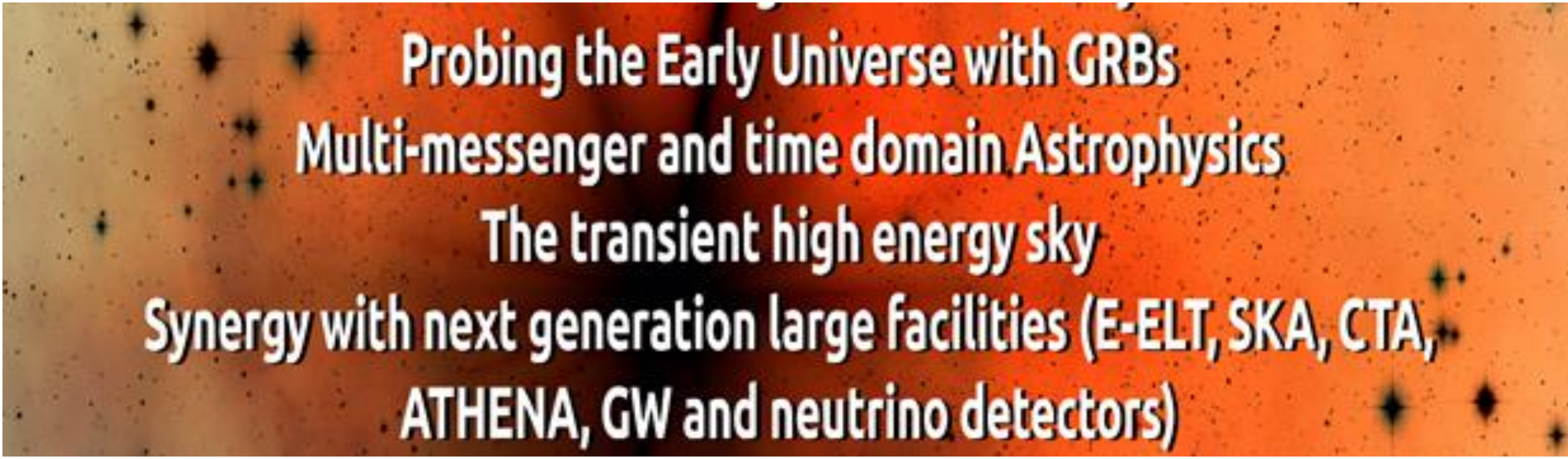


~20 joint GRB+GW events

Future GRB missions (late'20s and '30s)

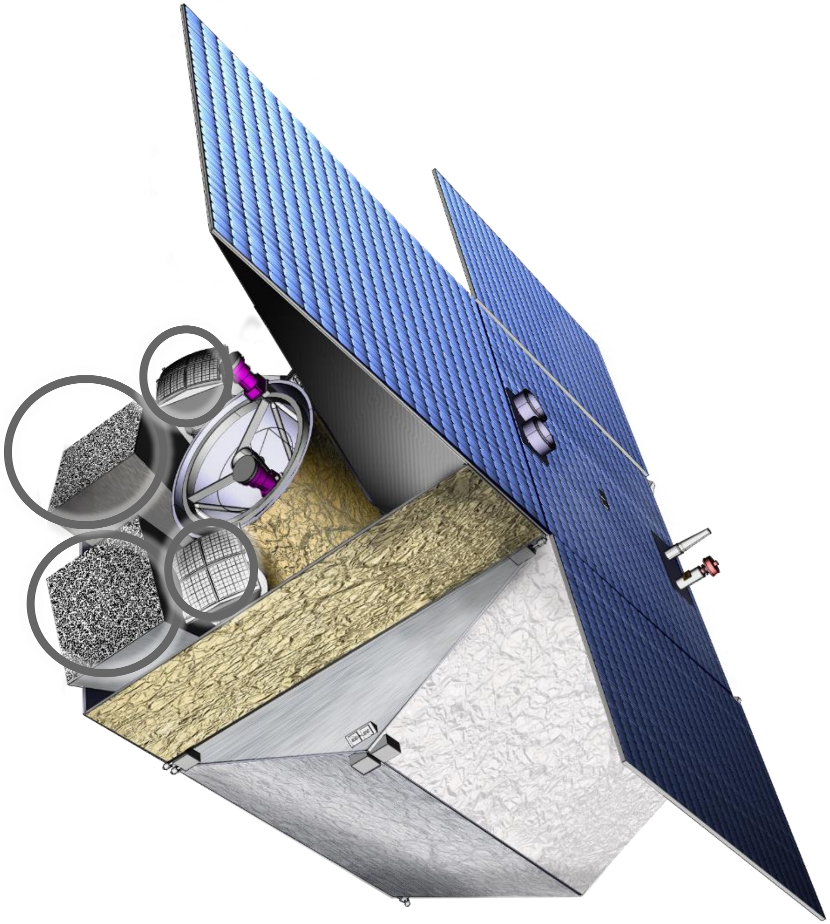


- **THESEUS** (studied for ESA Cosmic Vision / M5), **HiZ-GUNDAM** (JAXA, under study), **TAP** (idea for NASA probe-class mission)**, Gamow Explorer** (proposal for NASA MIDEX)**: prompt emission down to soft X-rays, source location accuracy of few arcmin**, **prompt follow-up with NIR telescope**, **on-board REDSHIFT**

Future missions: the case of THESEUS

THIS BREAKTHROUGH WILL BE ACHIEVED BY A MISSION CONCEPT OVERCOMING MAIN LIMITATIONS OF CURRENT FACILITIES

Set of innovative wide-field monitors with **unprecedented combination of broad energy range, sensitivity, FOV and localization accuracy**



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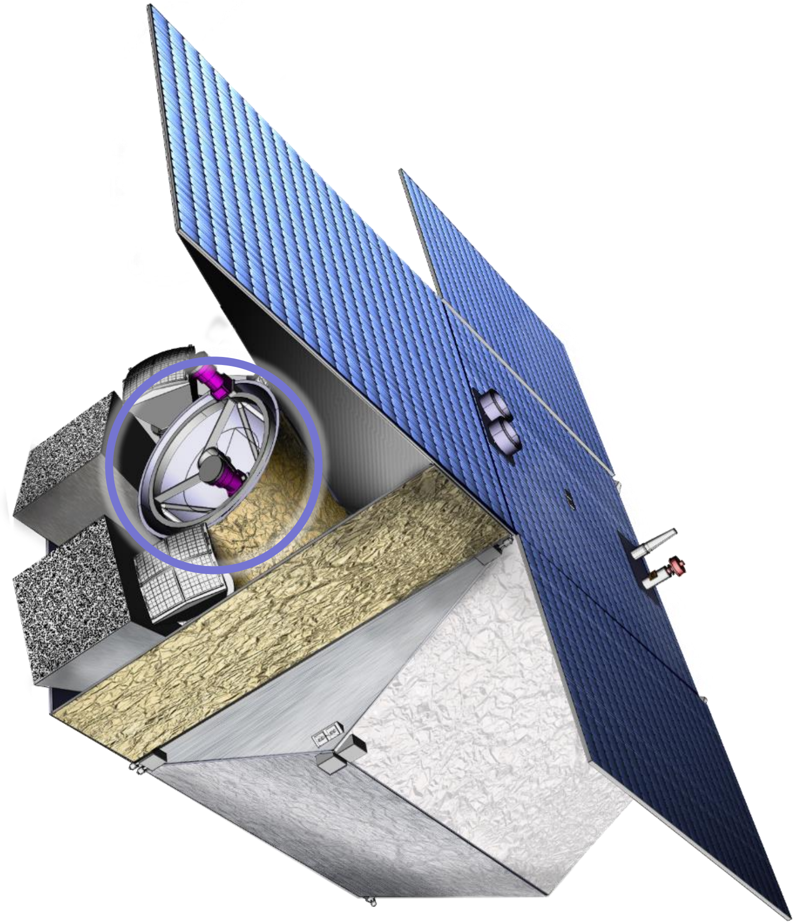
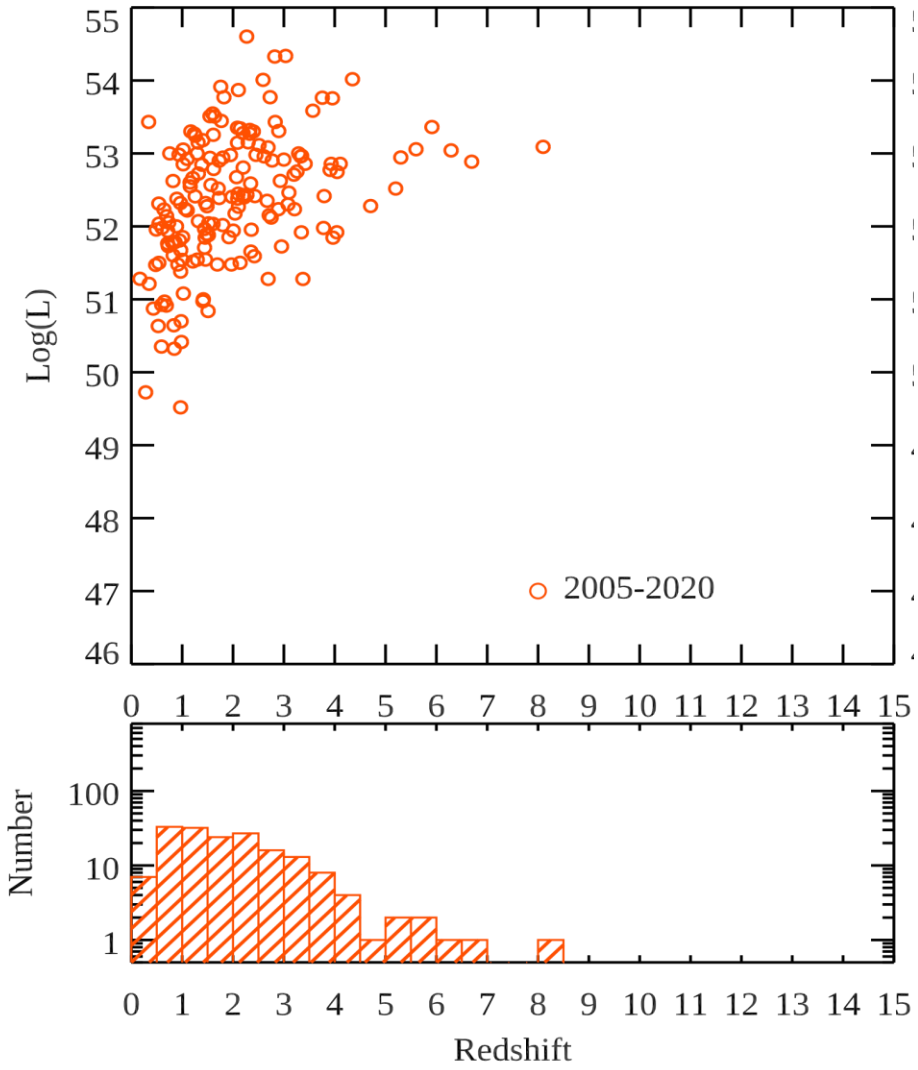
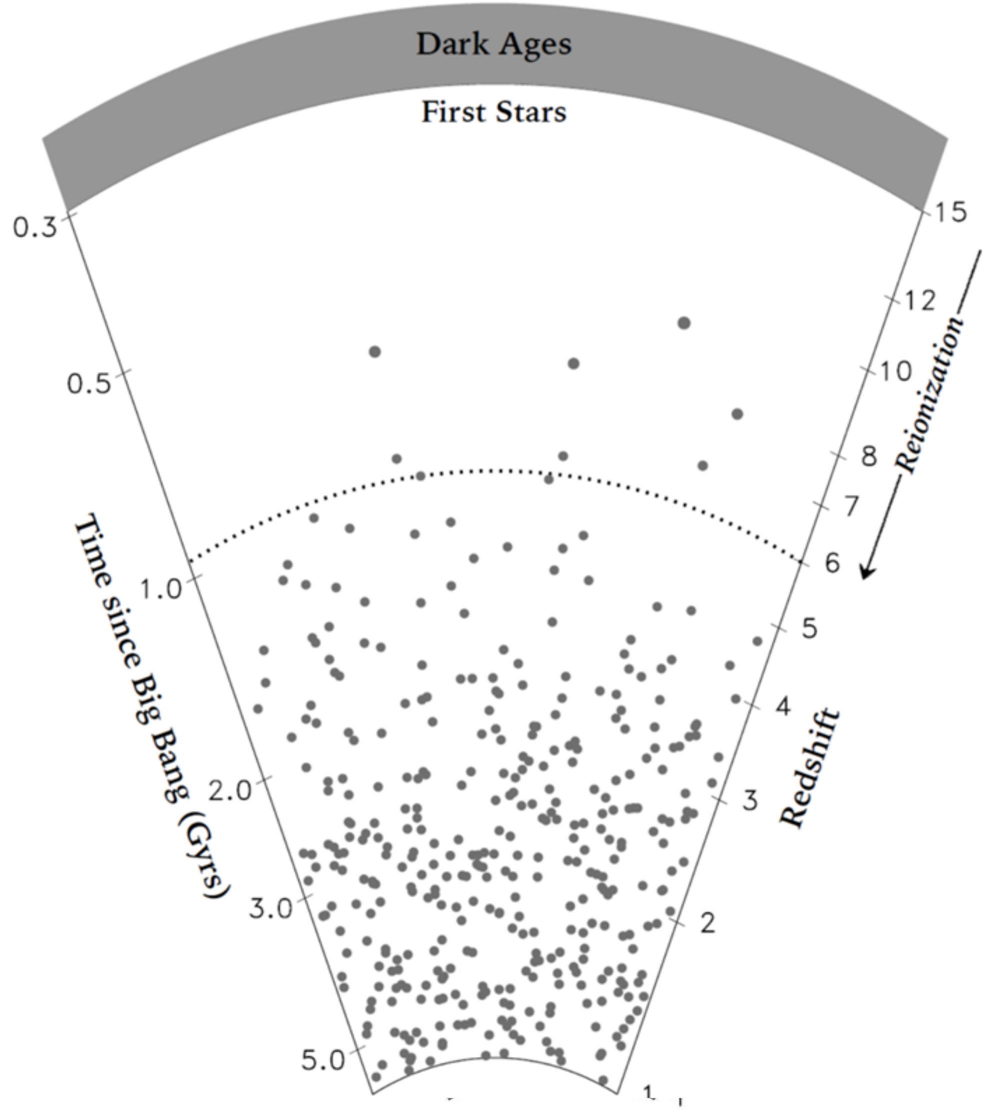
Set of innovative wide-field monitors with **unprecedented combination of broad energy range, sensitivity, FOV and localization accuracy**

On-board **autonomous fast follow-up** in optical/NIR, arcsec location and **redshift measurement** of detected GRB/transients



Shedding light on the early Universe with GRBs





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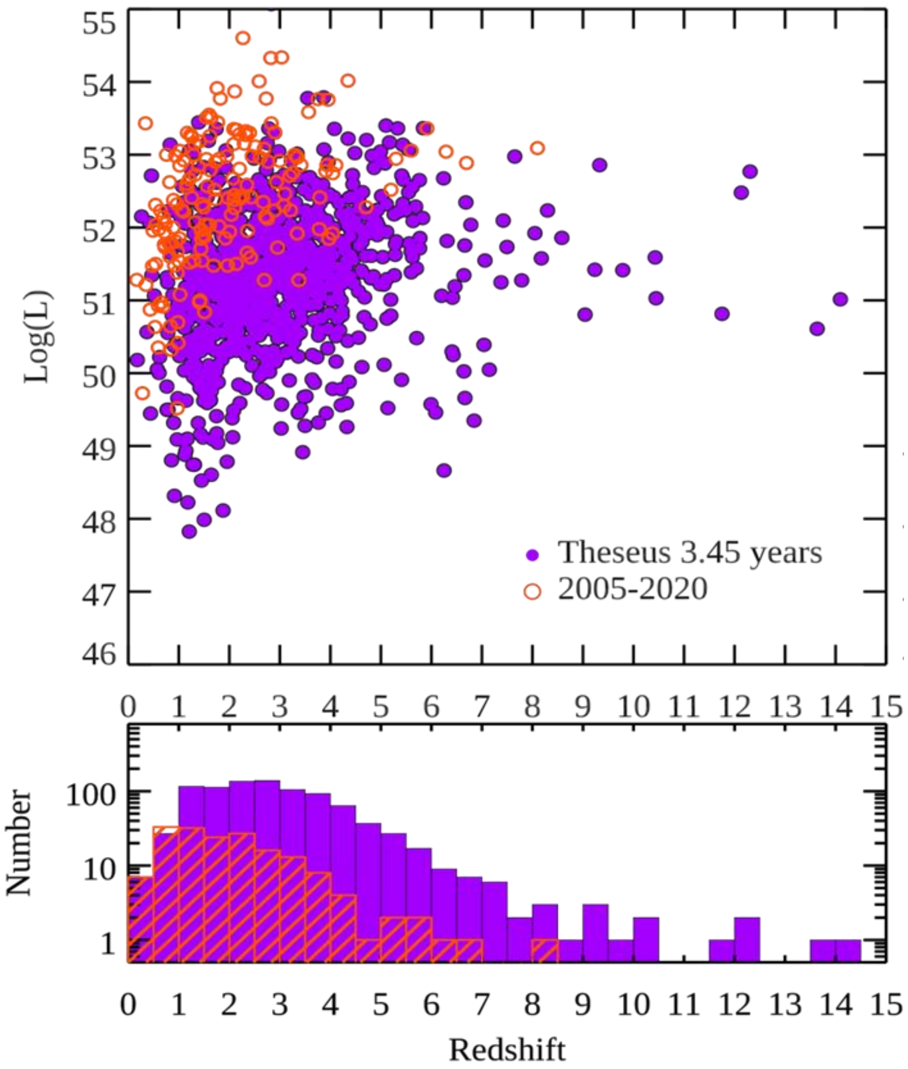
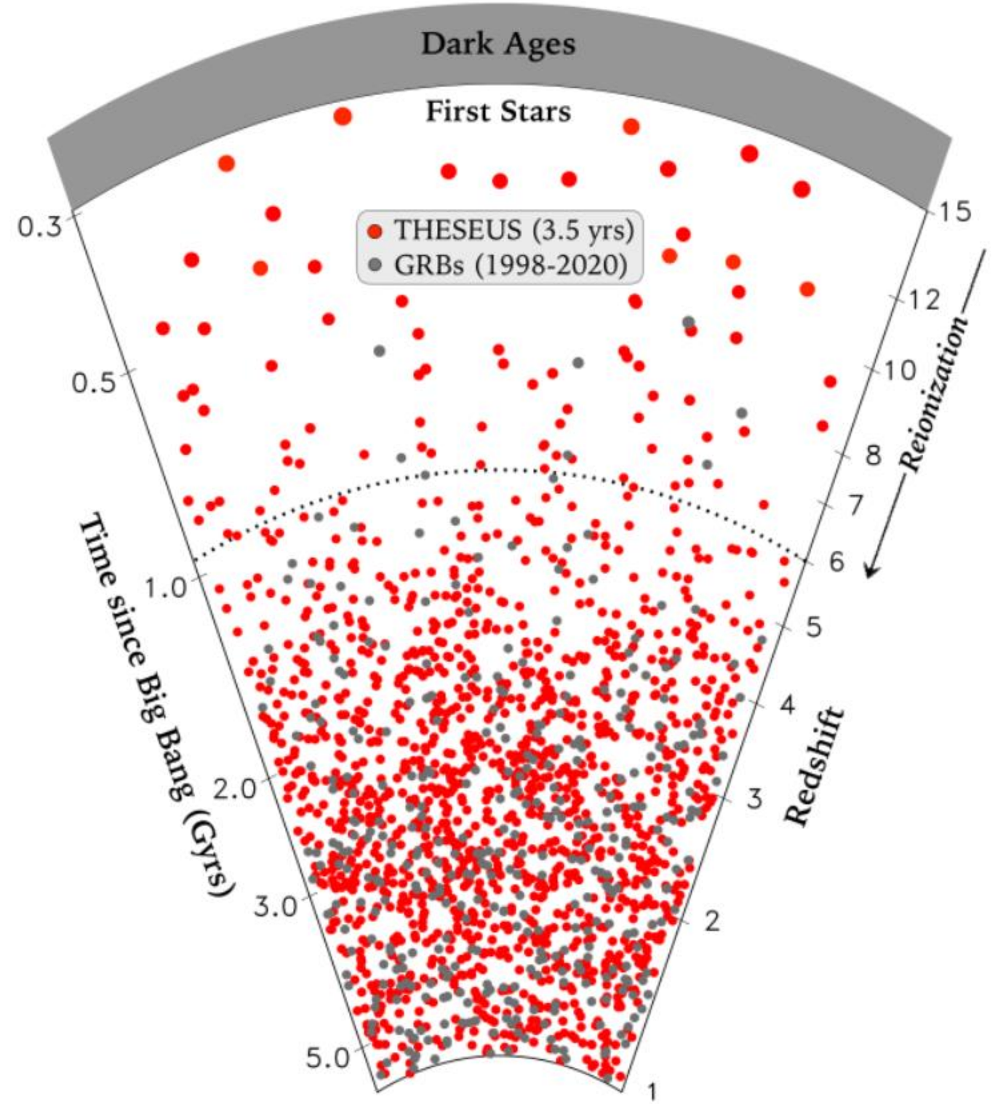
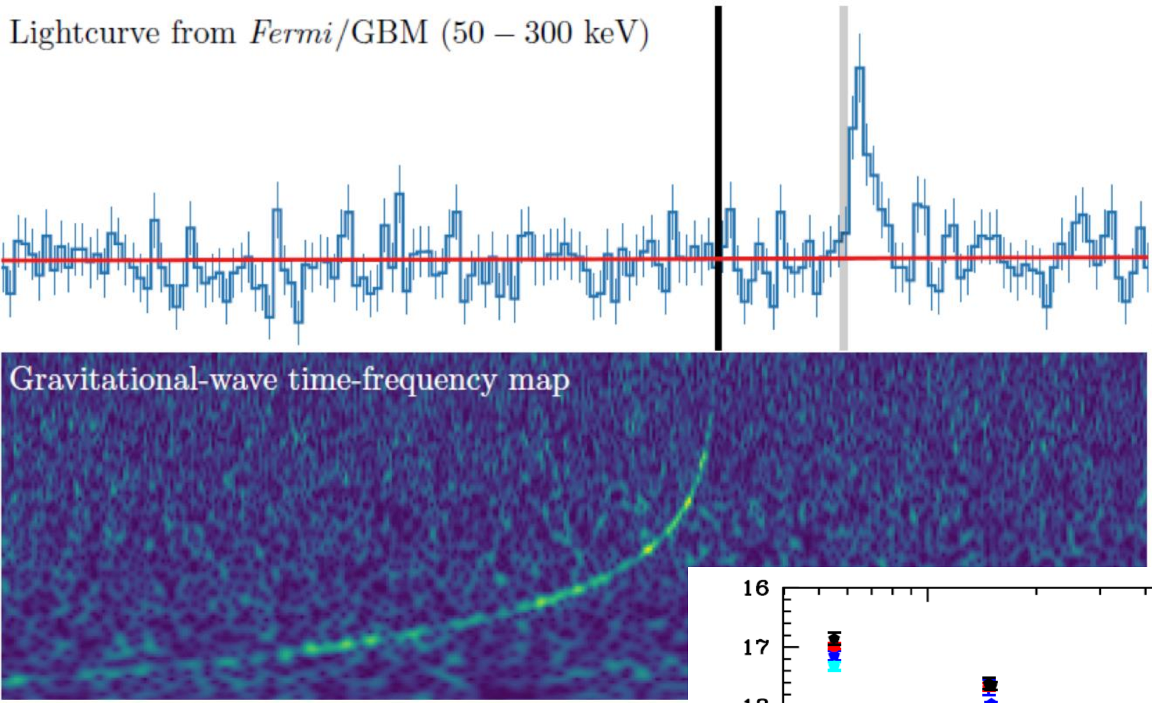
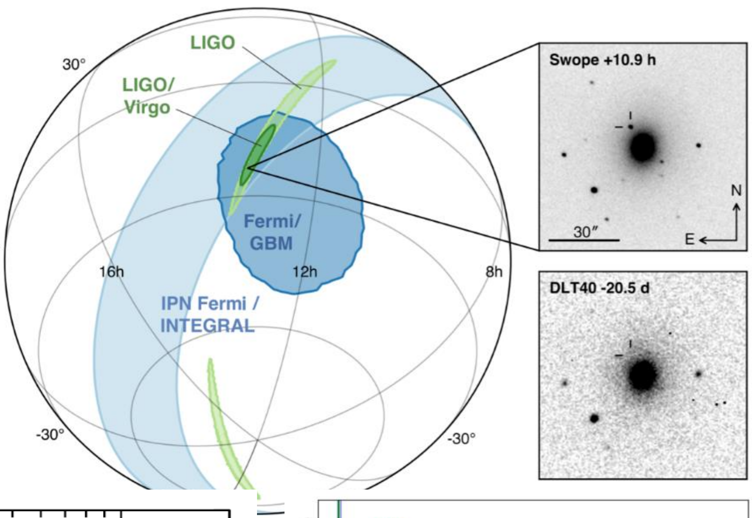
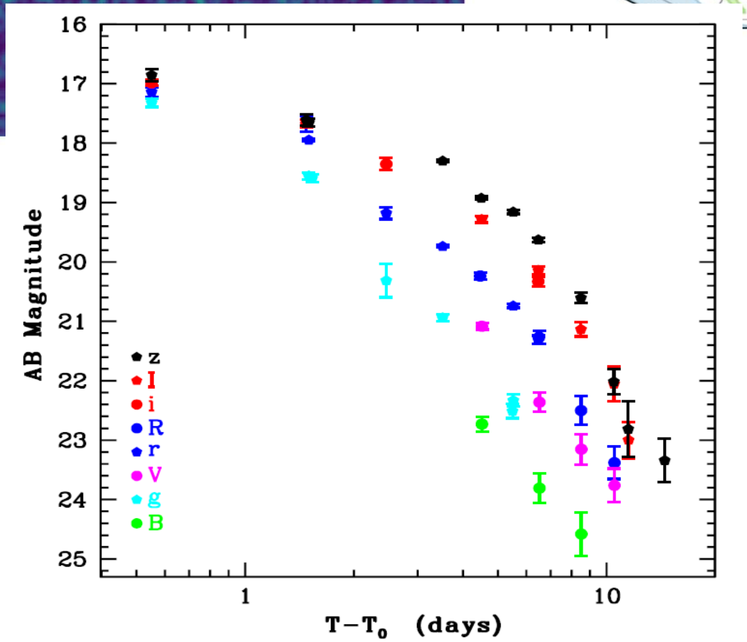


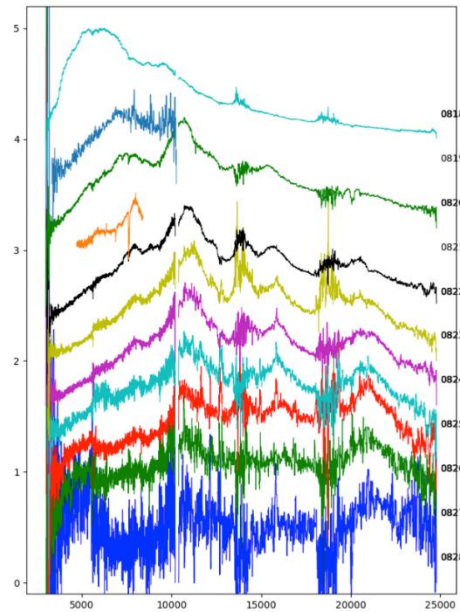


LIGO, Virgo, and partners make first detection of gravitational waves and light from colliding neutron stars



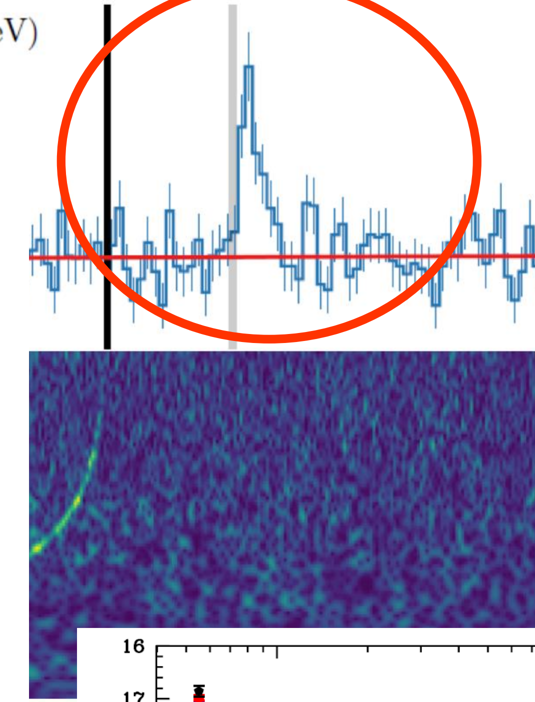


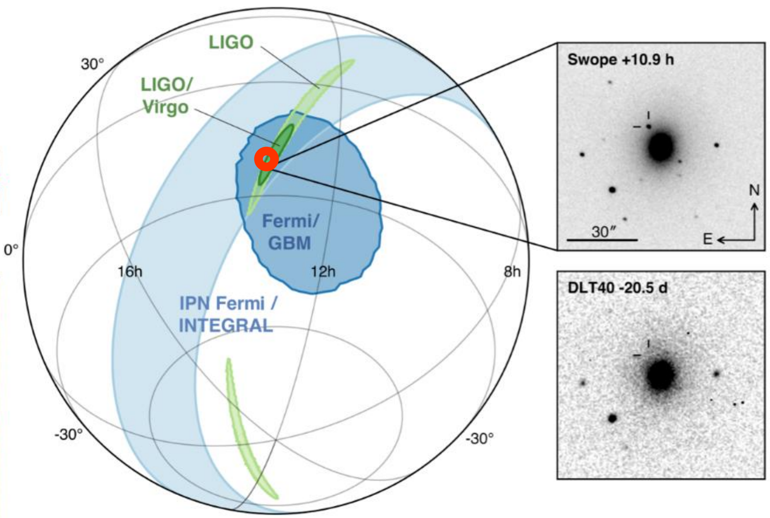




LIGO, Virgo, and partners make first detection of gravitational waves and light from colliding neutron stars

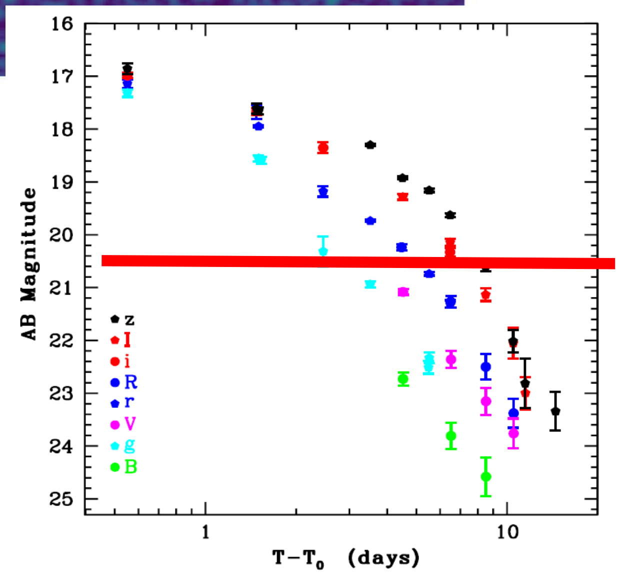
Lightcurve from *Fermi*/GBM (50 – 300 keV)

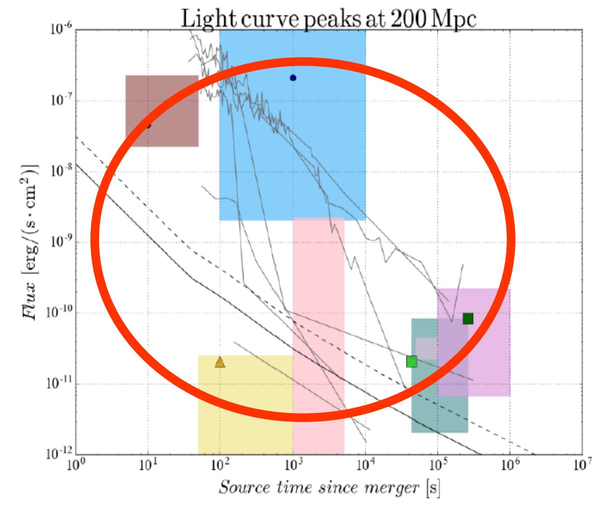




THESEUS:

- ✓ **short GRB detection over large FOV with arcmin localization**
- ✓ **Kilonova detection, arcsec localization and characterization**
- ✓ **Possible detection of weaker isotropic X-ray emission**





In summary

- GRBs are a key phenomenon for cosmology (ealry Universe, cosmological parameters), multi-messenger astrophysics (GW, neutrinos) and fundamental physics

- Next generation GRB missions, like THESEUS, developed by a large European collaboration and already studied by ESA (M5 Phase A) will fully exploit these potentialities and will provide us with unprecedented clues to GRB physics and sub-classes.

- THESEUS is a unique occasion for fully exploiting the European leadership in time-domain and multi-messenger astrophysics and in related key-enabling technologies

- THESEUS observations will impact on several fields of astrophysics, cosmology and fundamental physics and will enhance importantly the scientific return of next generation multi messenger (aLIGO/aVirgo, LISA, ET, or Km3NET;) and e.m. facilities (e.g., LSST, E-ELT, SKA, CTA, ATHENA)

- **THESEUS Phase A study by ESA very successful and base for further dev.**

SPIE articles on instruments and Exp.Astr. Articles on science on arXiv

http://www.isdc.unige.ch/theseus/