GRBs in the era of multi-messenger astronomy

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Multi-messenger Observatories

New opportunity to study the Universe through different channels: photons, high-energy neutrinos, cosmic-rays, and gravitational waves.

New observatories are on-line or will be soon(ish):

HAWC, CTA

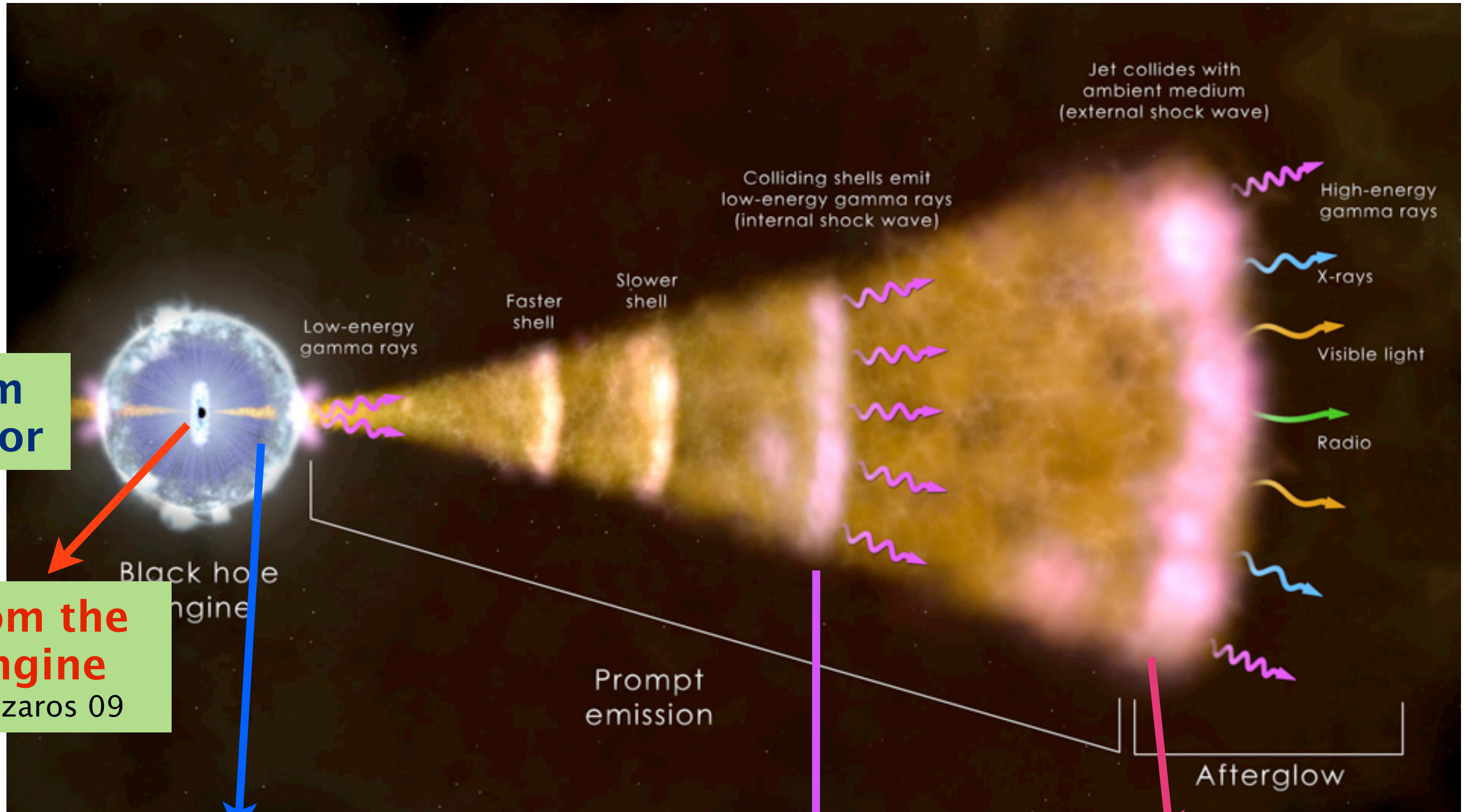
ICECUBE

Advanced LIGO/VIRGO, INDIGO

GWs and ν can **directly** probe regions unaccessible to EM observations.

EM observations increase the confidence in the detection, allow for redshift measurements, confirm the astrophysical nature.

GRBs as multi-messenger sources



GWs from progenitor

GWs from the inner engine
Corsi & Meszaros 09

TeV neutrinos from inside the star
Meszaros & Waxman, 01;
Razzaque+03

UHECRs and PeV neutrinos from internal shocks
Waxman & Bachall 97; Guetta+04;
Murase & Nagataki 06

UHECRs and EeV neutrinos from external shocks
Waxman & Bachall 00; Dermer 01

GRBs at the very high energies

We probed only the tip of the iceberg. Past studies mainly focused on the afterglow (radio to soft X-ray), and prompt emission (keV to few MeV).

GRB Physics:

- X-ray flares Abdo+09, Troja+14
- energy budget, 10^{52} erg and more? Cenko+10
- emission processes: synchrotron, IC, thermal?
- outflow composition: leptonic, hadronic?

see GRB 130427A, Ackermann+14, Preece+14, Maselli+14

These are critical input values to estimate the production of UHECRs and high-energy neutrinos from GRBs

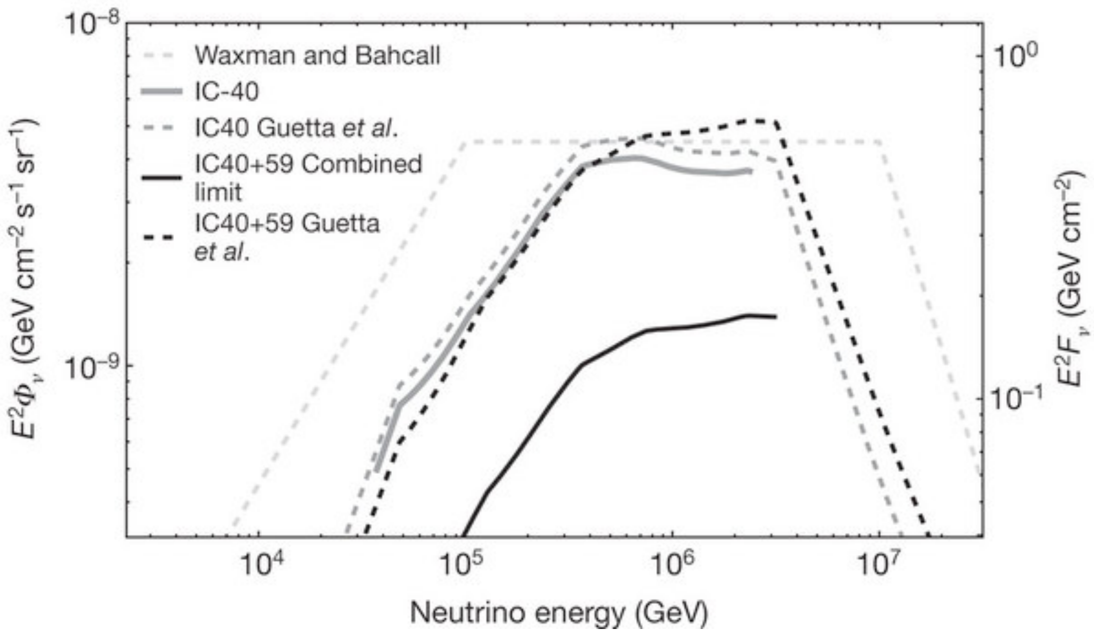
Constraints to the extra-galactic background light:
GRBs are competitive with AGNs, and probe higher redshifts

Constraints to (some) Lorentz Invariance Violation theories

Neutrinos from GRBs

GRBs have been proposed as a major source of high energy cosmic-rays, provided that a substantial fraction of protons are accelerated in the shocks regions.
Bursts from PopIII stars are predicted to be brighter ν sources than normal long GRBs. Schneider+02, Suwa+09

First results from ICECUBE already constraints some of the fireball predictions:



Neutrinos from failed GRBs

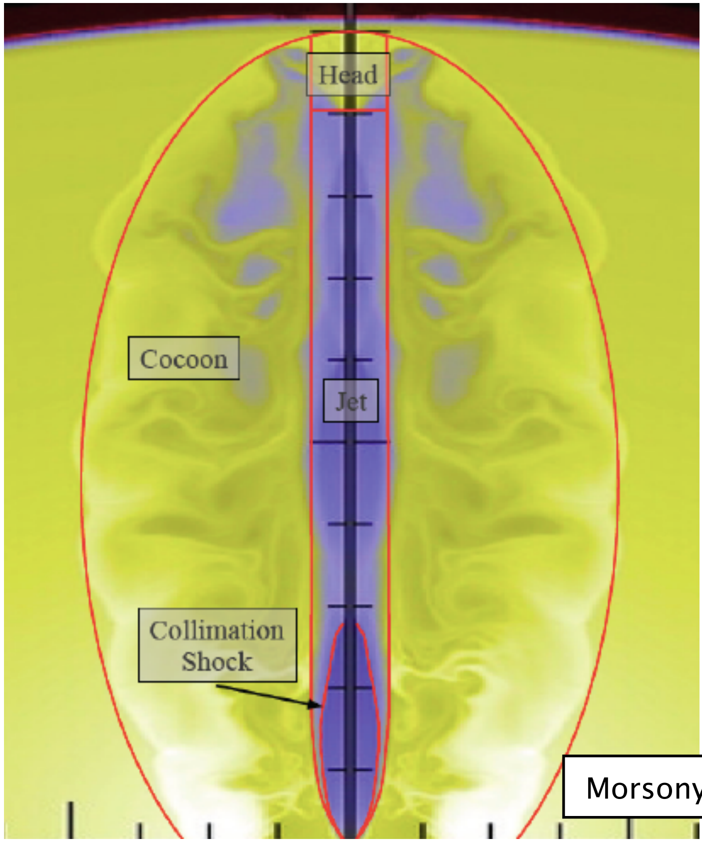
In order for the jet to break out of the stellar envelope, the central engine must remain active for a period longer than the break out time. Matzner+03, Bromberg+10

Failed GRBs are far more numerous than normal GRBs, but much harder to find in the EM range:

- sub-luminous X-ray transients (maybe GRB 060218?), visible by Swift only in the local Universe Campana+06

- SNe surveys, search for relativistic ejecta. Soderberg+08, Cenko+13, Corsi+13

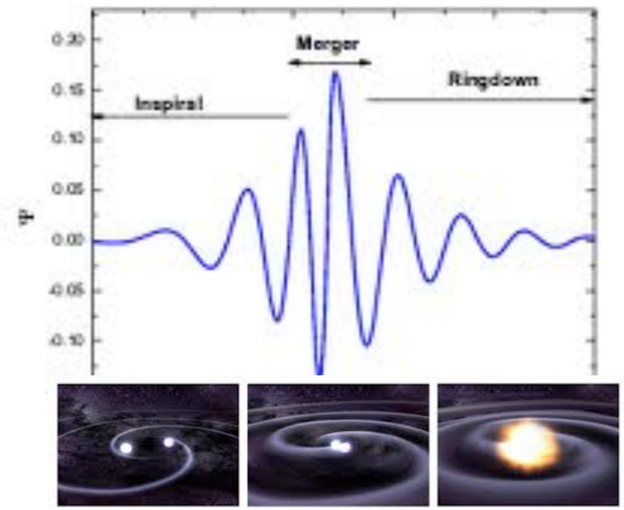
Neutrino triggered searches could help finding such exotic transients.



Morsony+07

Gravitational waves

NS mergers are the most promising candidates of GWs.

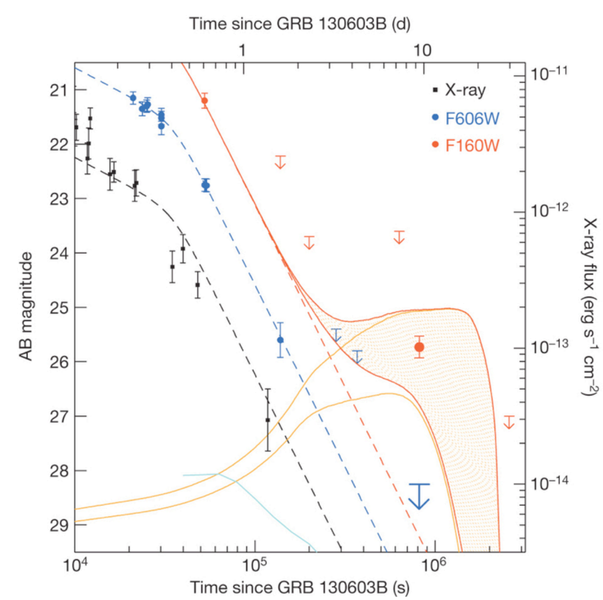


Rate predictions: 0.2 – 300 yr^{-1}
Abadie+10

Connection between short GRBs and NS mergers:

- environment
- lack of SN

recently reinforced by the possible detection of a kilonova. Tanvir+14



Short GRBs in the local Universe should be accompanied by a strong GW signal (but not viceversa).

Main challenge: localization

All the GW and neutrino observatories will provide coarse localizations, from a few to ~hundreds of square degrees.

Wide field of views:

HAWC (15% of the sky)

Swift/BAT (2.2 sr), Fermi/GBM (9 sr), Interplanetary Newtork

PTF, TAROT, QUEST, RAPTOR, ...

- sensitive to the on-axis GRBs emission

LOFAR, SKA

- promising for the detection of off-axis events

X-rays: the big absent

The role of Swift

Swift/XRT does not have the large field of view of some ground-based facilities.

Swift/XRT does not reach the sensitivity of Chandra or XMM.

However, Swift is the only facility which allows for:

- **rapid reaction**:
  ~10 hrs XMM, ~days Chandra, ~12 hours from ground (+ weather)

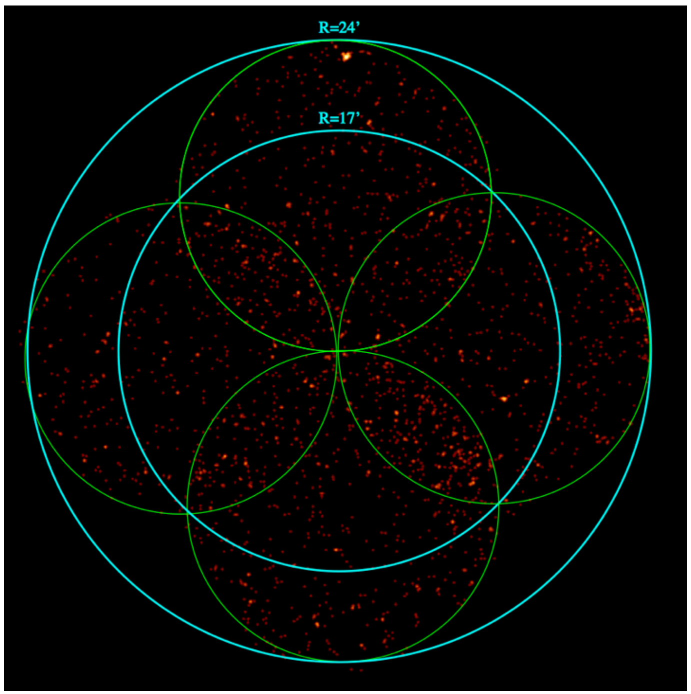
- **fast data downlink and processing**:
  ~2 weeks XMM

- **tiled ToO observations:** use narrow FoV to tile the error region

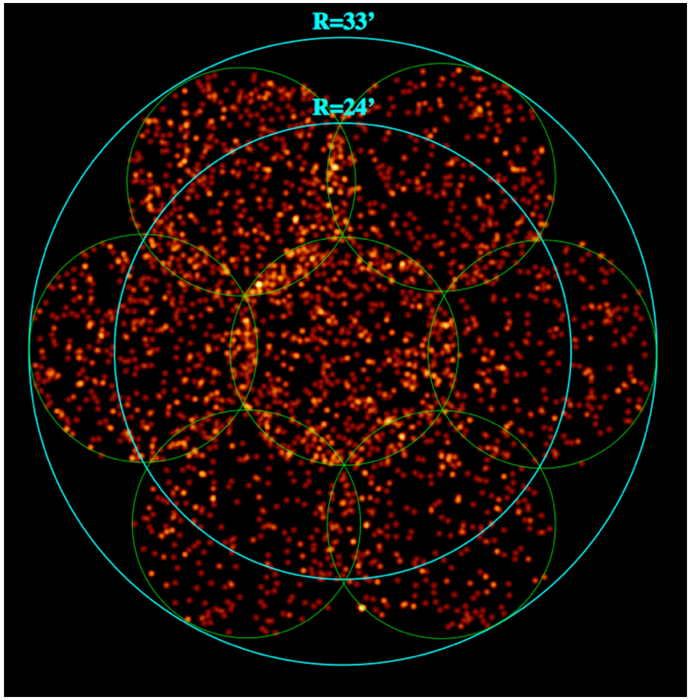
- **rapid and public dissemination of the results**: unique

Swift Tiling mode

Implemented in 2010, used 11 times to follow-up poorly localized GRBs (mainly LAT, and MAXI):
1 in 2010, 1 in 2011, 2 in 2012, **7 in 2013**



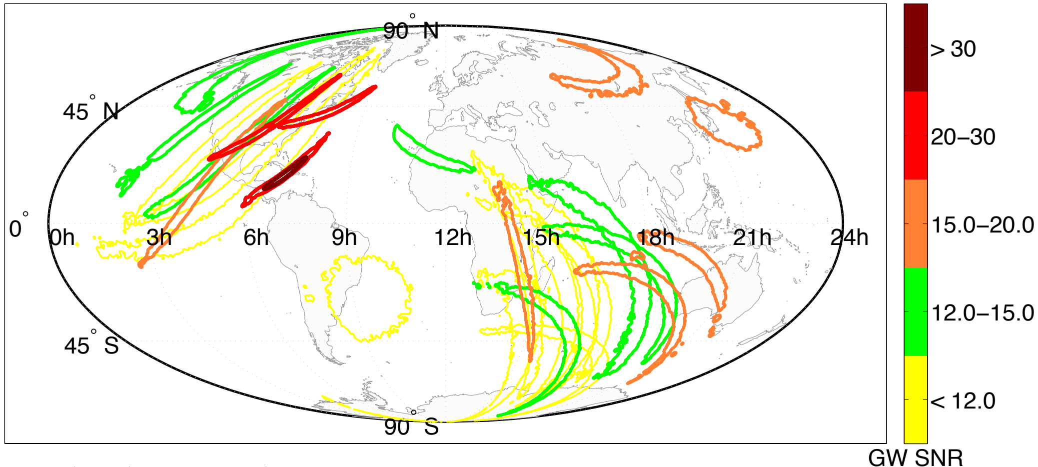
4 tiles pattern (x9)



7 tiles pattern (x1)

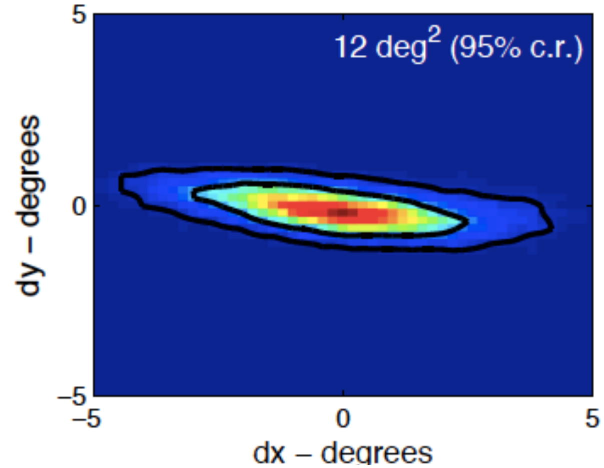
aLIGO: what to expect

2015



Kasliwal & Nissanke 2013

2020



Nissanke et al. 2010

2015: several hundreds of square degrees, limited volume (40-80 Mpc). Galaxy strategy: ~100 pointings

2020: improved localizations, tens of square degrees, larger volume >200 Mpc. Galaxy catalogues not complete (yet). Tiling strategy: >100 tiles

Chance of detection?

GRB triggered search:

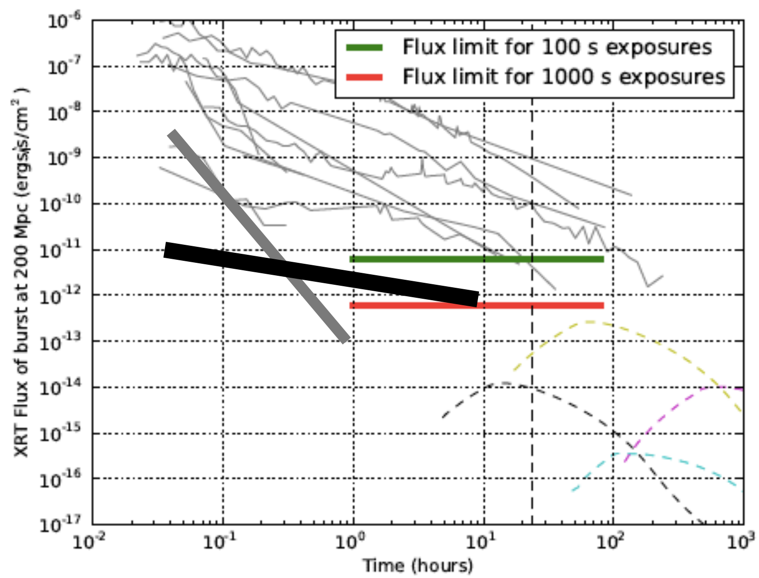
Estimated rate of observable GRBs within the aLIGO/Virgo horizon: **0.1 – 10 yr^{-1}** with the Fermi/GBM

On-going Swift and Fermi initiatives aimed at doubling the number of short GRBs.

GW triggered search:

Localizations from triangulation ~minutes

Bayesian parameters estimations ~hours to days



Cosmological GRBs are visibile for days Kanner+11
however the local population is dominated by faint bursts Troja+14

Summary

GRBs are beacons for **multi-messenger astronomy**:
bright sources from radio to GeV and possibly TeV energies, neutrinos, and GWs

Promising discovery potential:
- direct detection of GRB progenitors and central engines
- origin of UHECRs
- new exotic transients (chocked GRBs)
- test of General Relativity
- cosmological probes

Tiled observations already show that Swift can cover large sky areas, and successfully identify the X-ray counterpart.
Future experiments with GBM or HAWC transients will help to test the tiling observations on even larger area.

Rapid dissemination of the positions from other observatories is critical.