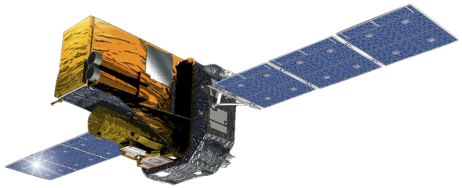
UNIVERSITÉ DE GENÈVE

OBSERVATOIRE DE GENÈVE FONDÉ EN 1772

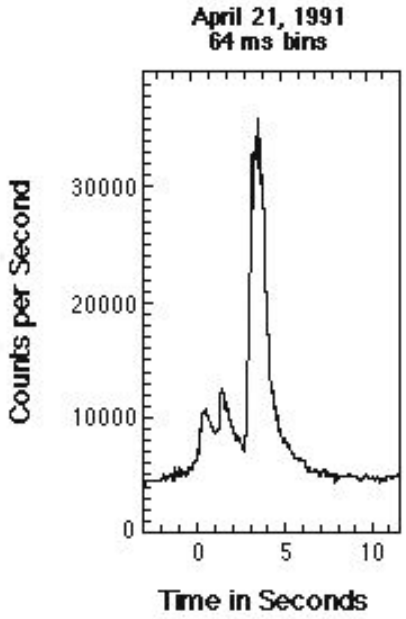


Elusive short and energetic multi-messenger transients

V. Savchenko

INTEGRAL conference
Geneva
11/02/2019

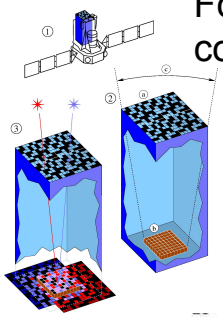
Gamma-ray bursts



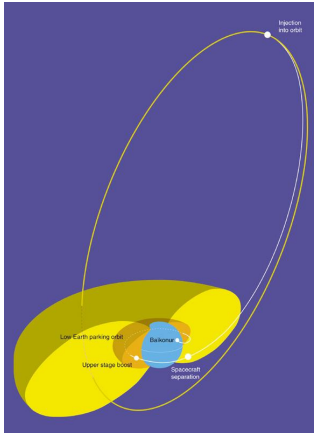
- First discovered in 1967 with military satellites searching for nuclear explosions
- Flashes of MeV gamma-rays outshining any other source in the sky in this energy range.
- Observed almost daily
- **Completely unpredictable, rapidly fading, and difficult to characterize**

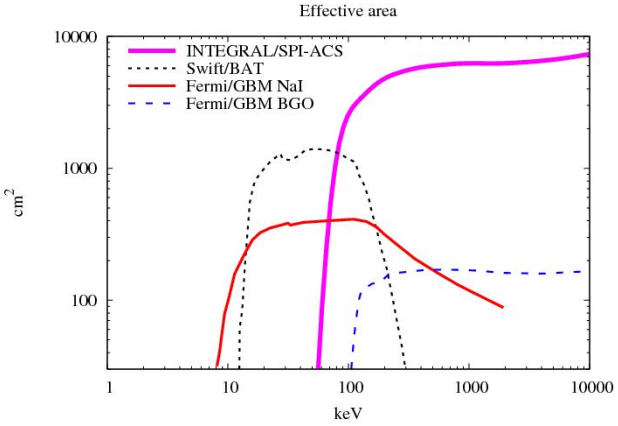
INTEGRAL all-sky GRB detection

- **Large effective area** but restricted data => **challenging background rejection** (VS 2012)
- **All-sky view** but need for a **calibrated all-sky response model**, especially to use for **all-sky signal decoding** (VS 2016)
- **Immediate data access** - demands **rapid and efficient analysis methods**

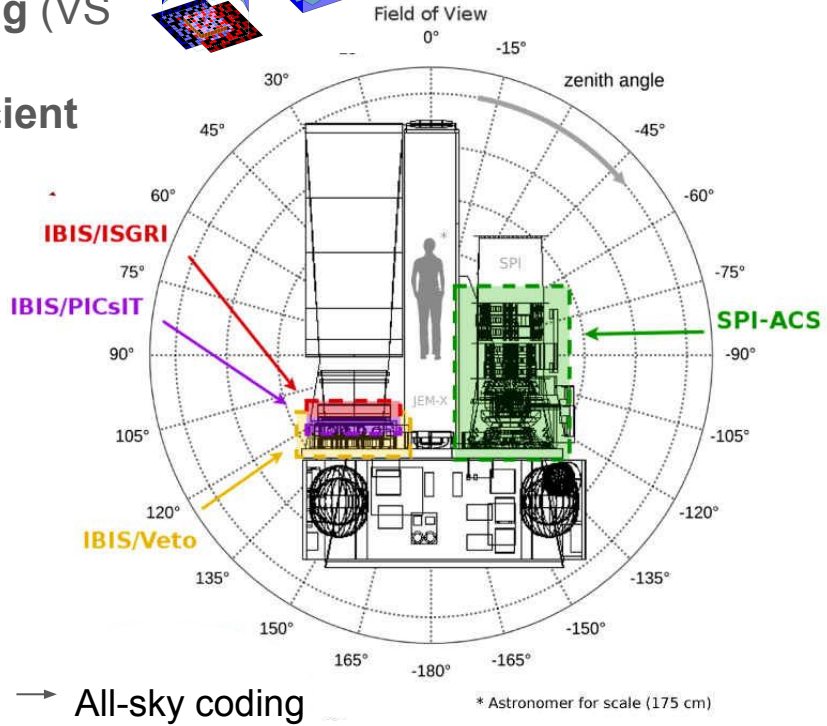


FoV coding ← Good to localize and characterize, 1% of the GRBs



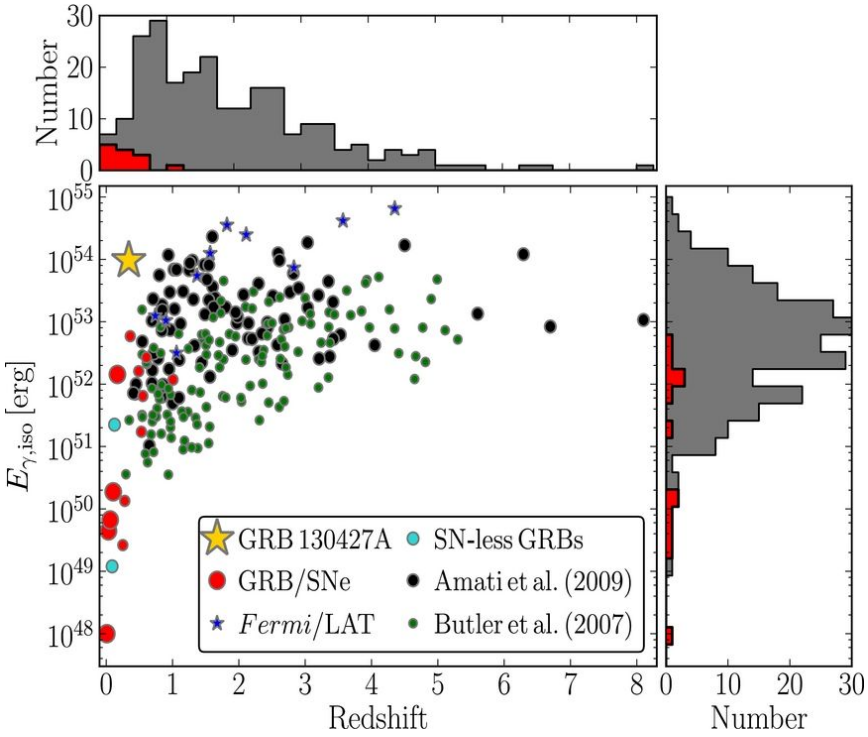


Good to catch 85%, hard to characterize → All-sky coding (off-label use)

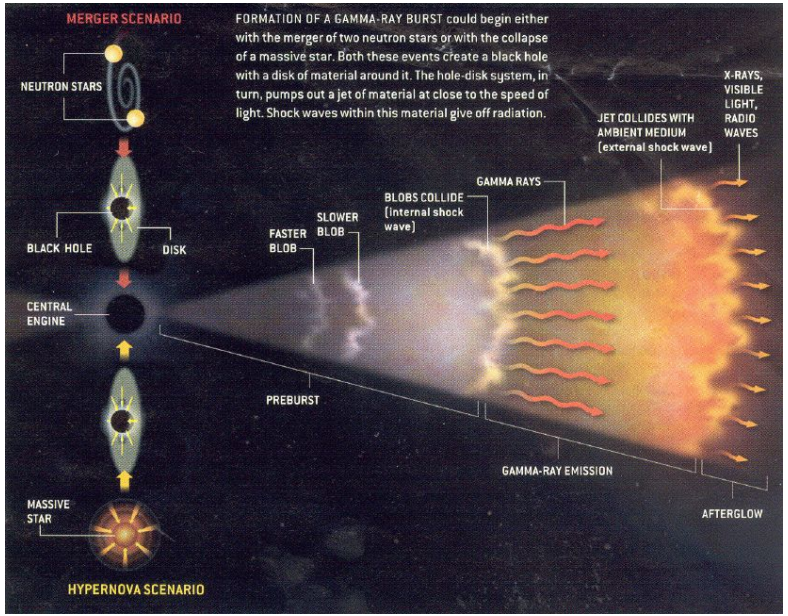


GRB engine: what we know so far

High-luminosity non-thermal emission from a small region requires **beamed relativistic jet**, **Γ ~ 1000**



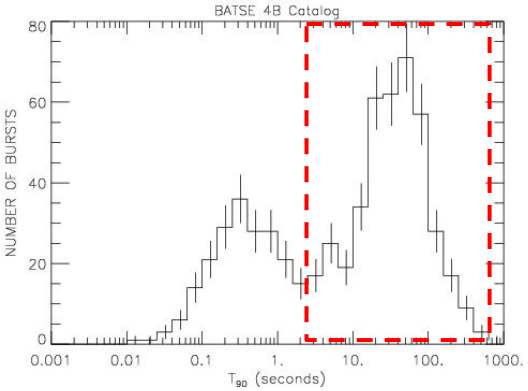
Short: duration<2s

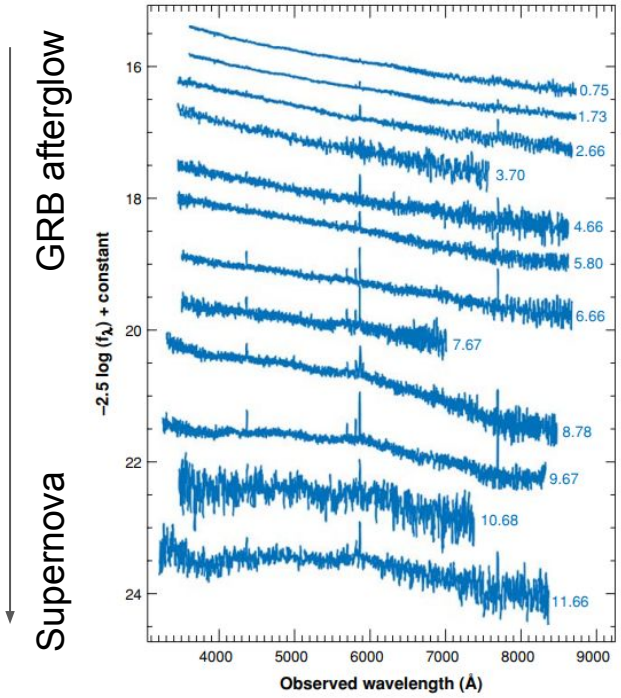


Long: duration>2s

Supernovae and long GRBs

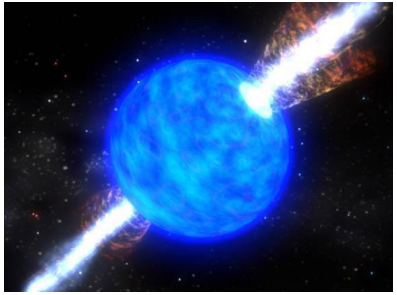
- The afterglow of several GRBs evolved into a Supernova Type II/b,c signal in optical for several cases of relatively nearby events.





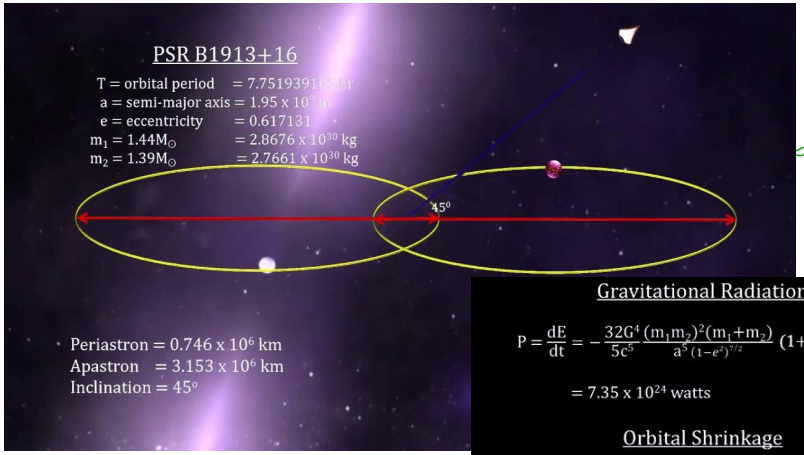
Woosley & Bloom (ARAA, 2006)

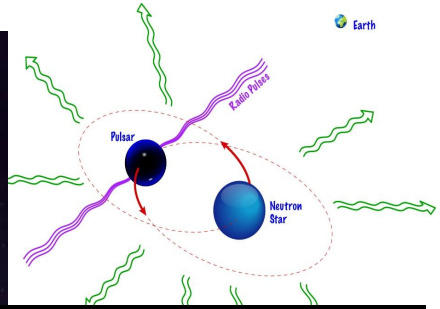
Emergence of SN 2003dh from the glare of the afterglow of GRB 030329.
Shown is the observed spectra, a combination of afterglow and supernova.
It's still **not quite clear what makes some SNe produce a GRB, but it likely involves high angular momentum**

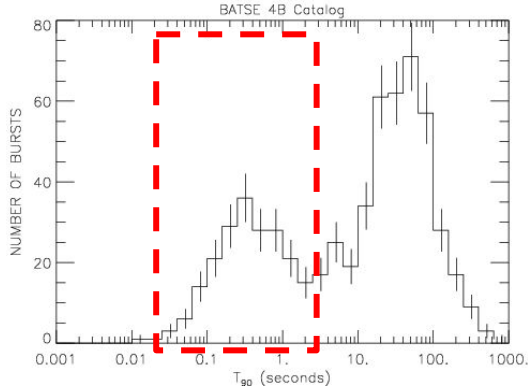


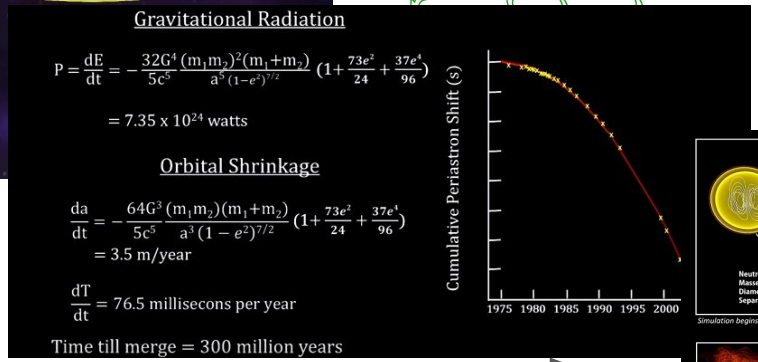
Binary neutron stars: from Hulse-Taylor pulsar to GRB

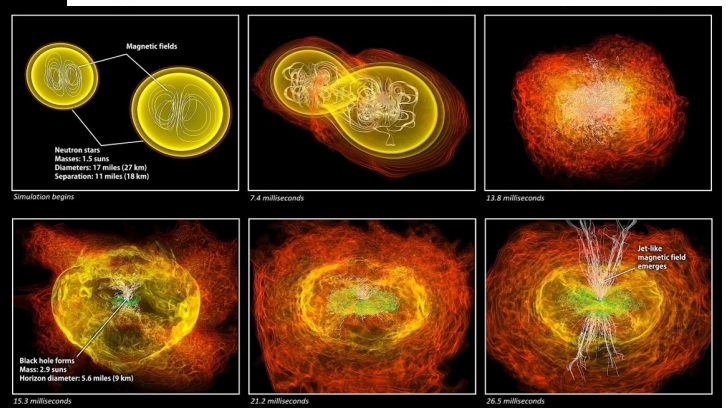
First evidence for gravitational wave radiation









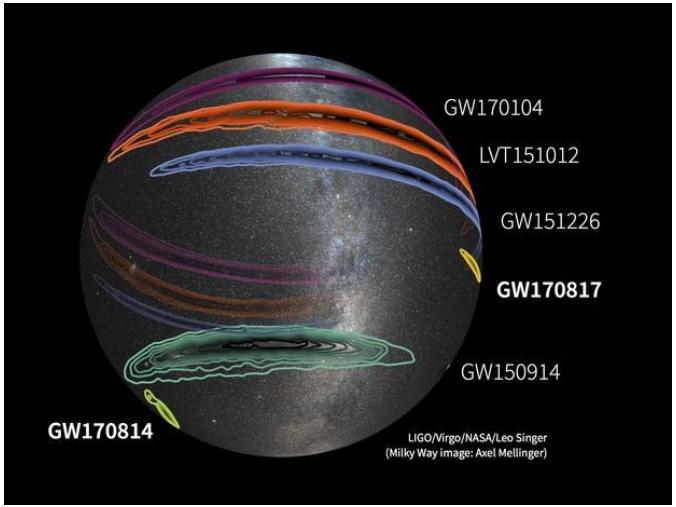


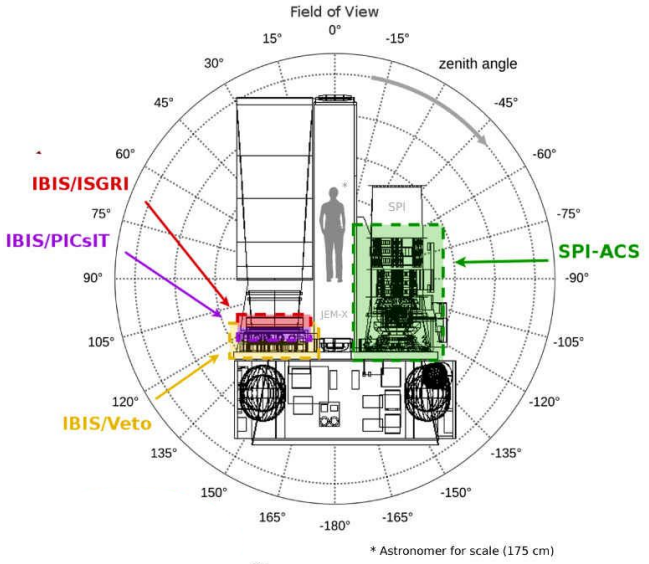
- Discovered in 1974
- Nobel Prize for physics in 1993

Will merge and make a GRB

(in 300 million years)

2015 onwards: direct GW detection and INTEGRAL

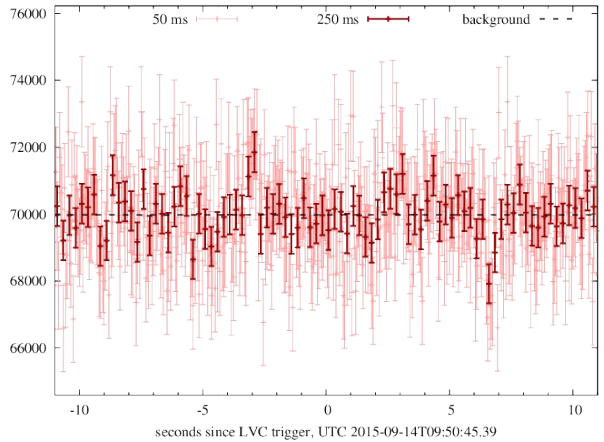


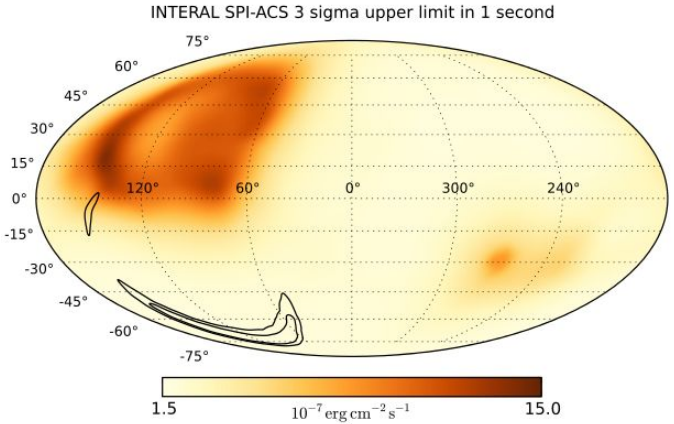


INTEGRAL has **~85% high chance of a successful, sensitive observation of the whole LIGO/Virgo localization region, available at T_0+15s**

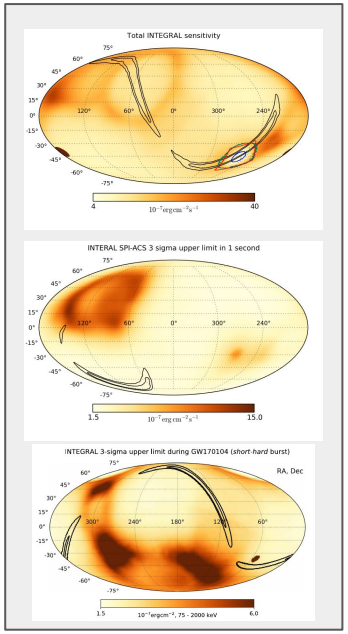
No signal from BBH seen by INTEGRAL

- Black-holes are pure curvature, no baryonic mass is present and thus no EM signal is expected, in principle
- **10^{-6} - ratio of energy in 75-2000 keV to GW energy**
- **GW150914**: a milestone observation, also establishing an example of INTEGRAL capabilities, SPI-ACS in this case, similar limits were obtained for LVT151012, GW170104, GW170814, and **20/25 GWTC-1 events**



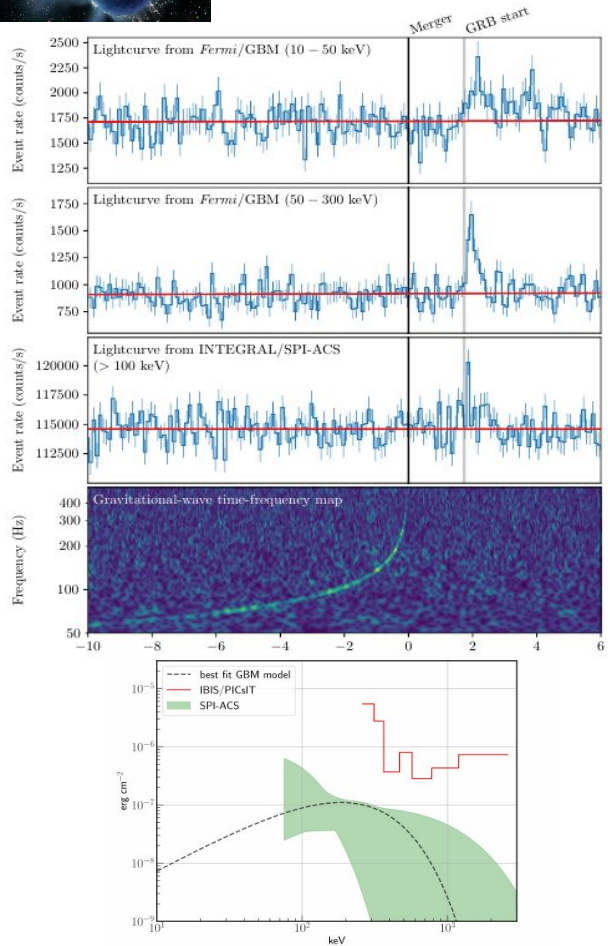


Other BBH



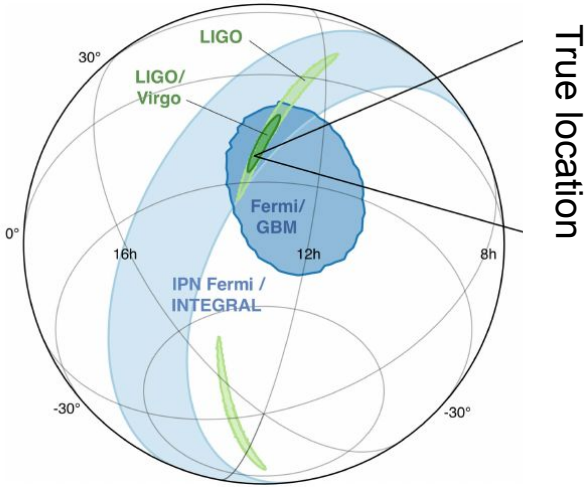
VS 2016, 2017a,b

GW170817 – GRB170817A



Binary Neutron Star merger GRB, despite an **unfavorable soft spectrum, low fluence** and unfavorable orientation, INTEGRAL confidently detected

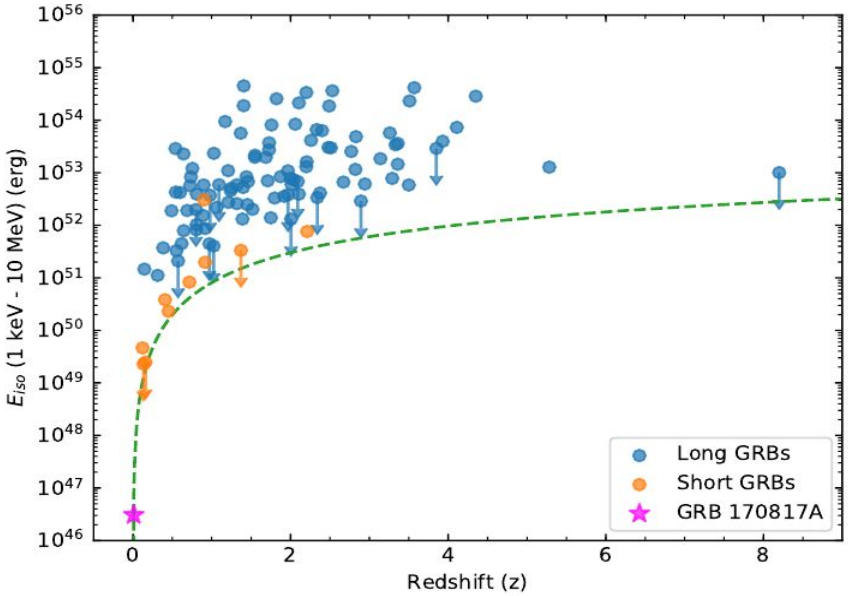
By comparing time of burst arrival to INTEGRAL, **improved joint GRB localization** can be produced, **hours before improved LIGO/Virgo location**

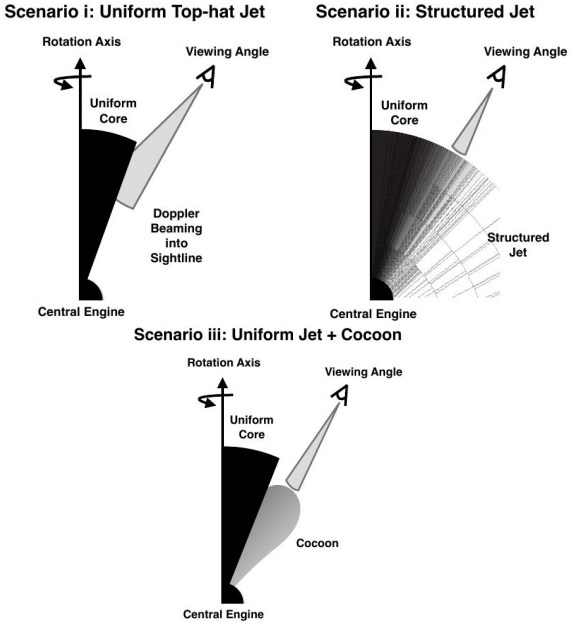


INTEGRAL and Fermi data available at < T_0 + 60 seconds

LVC+Fermi+INTEGRAL 2017

Numerous sub-luminous GRBs



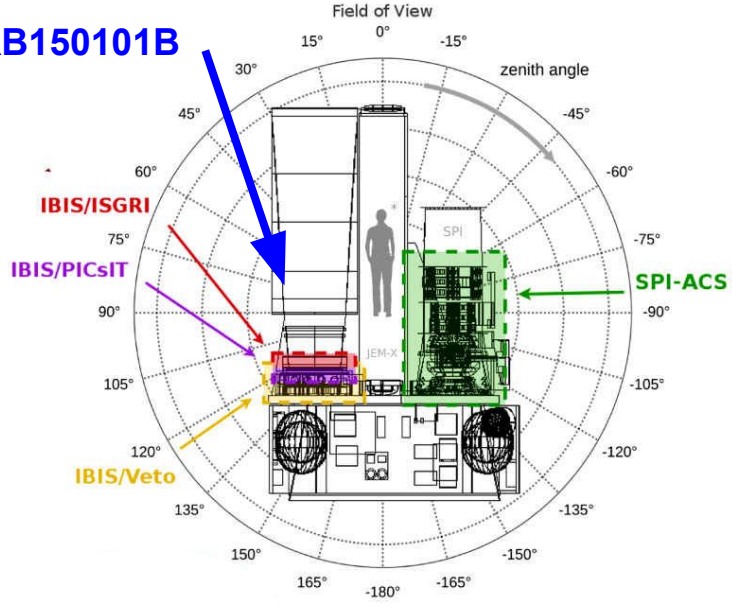


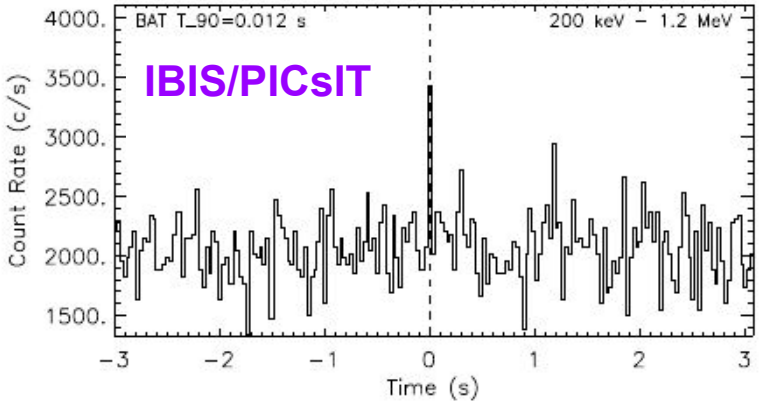
Distance of **40 Mpc** is much less than ever measured for any GRB (short or long).
This implies low luminosity, and Gamma-to-GW ratio of **$<10^{-6}$** is much less than that expected for other sGRB with known distances.

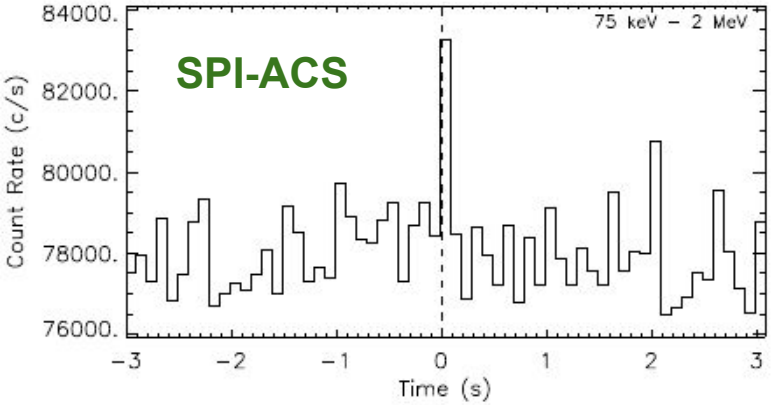
To establishing the true luminosity function we need more off-axis GRBs (see also von Kienlin 2019)

Possible slightly off-axis BNS merger GRB150101B

Possible off-axis GRB150101B (Burns 2018, Troja 2018) was also seen by INTEGRAL. Example of what may be observed in GW-Gamma as LV improves sensitivity.







Rodi, VS, et al 2018

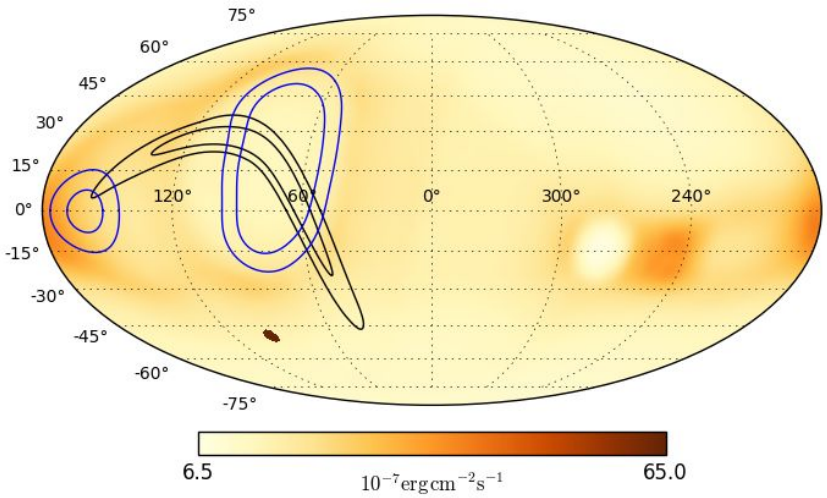
Suppressed response of SPI-ACS, optimal for IBIS/PICsIT

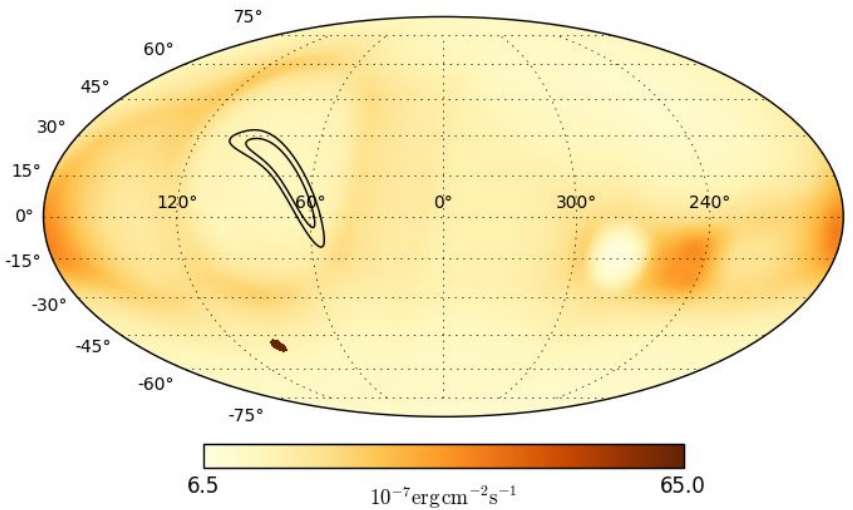
For IBIS, see also talks of James Rodi

All-sky localization: synthetic NS merger event at 200 Mpc

Comparing signal in IBIS and SPI-ACS allows to improve LIGO/Virgo localization

INTEGRAL-only localization

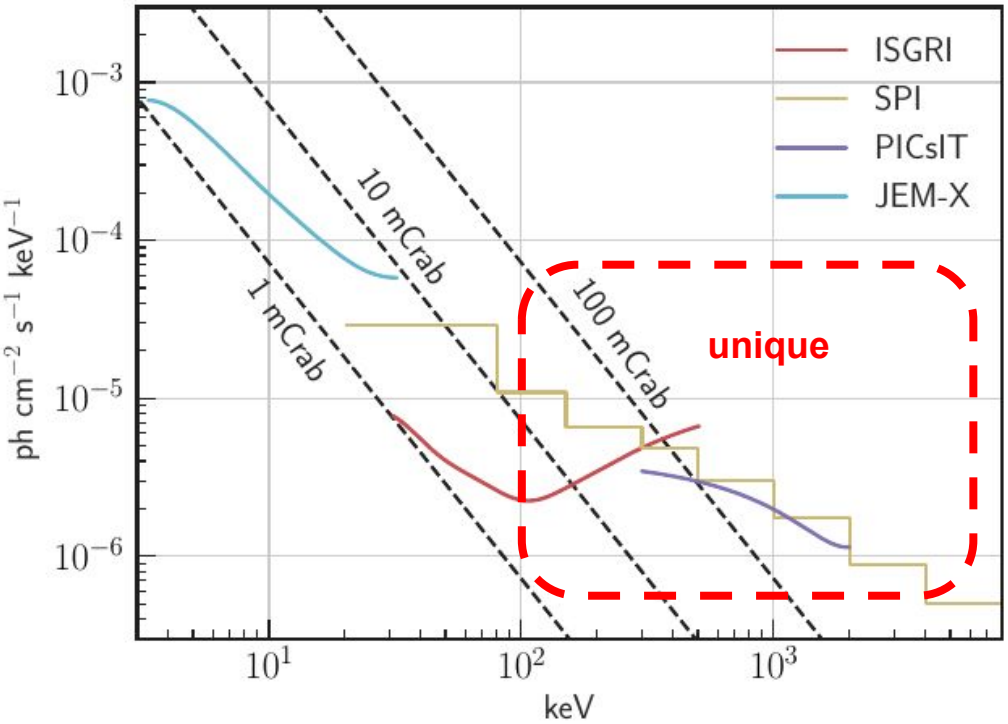


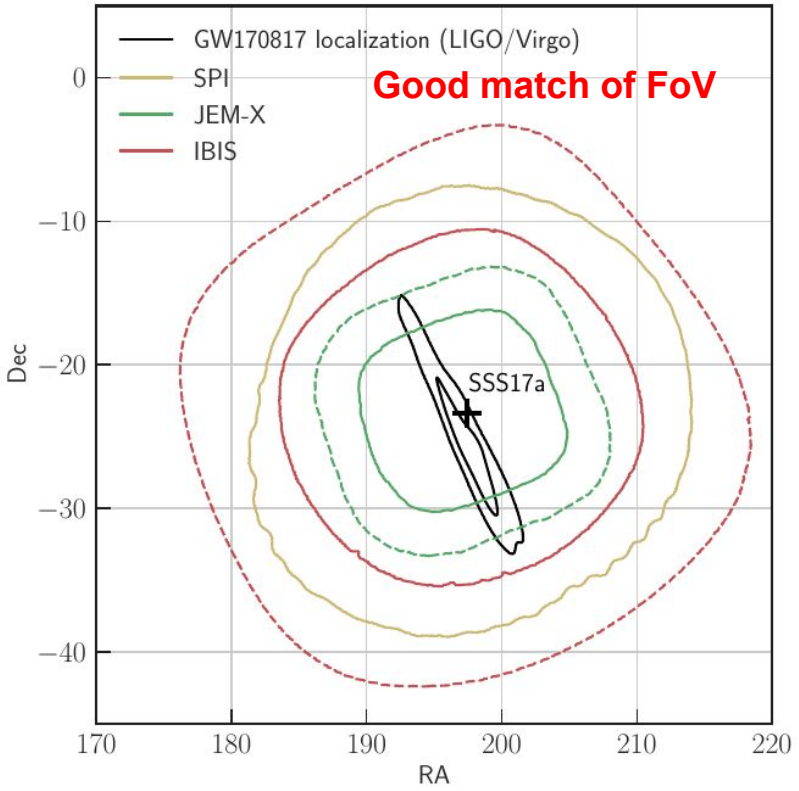


synthetic NS merger event at 200 Mpc

INTEGRAL pointed follow-up (IBIS, SPI, JEM-X)

A GRB at 40 Mpc could have produced bright **hard X-ray/gamma-ray afterglow** and **gamma-ray lines** of the kilonova from **3 keV to 8 MeV.**



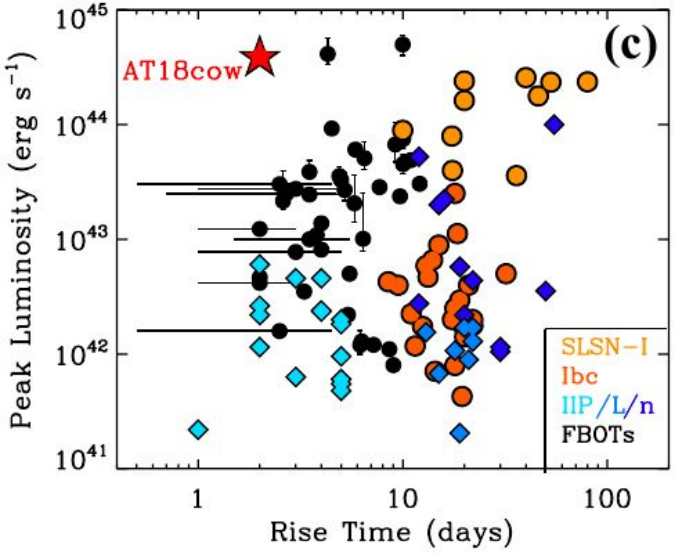


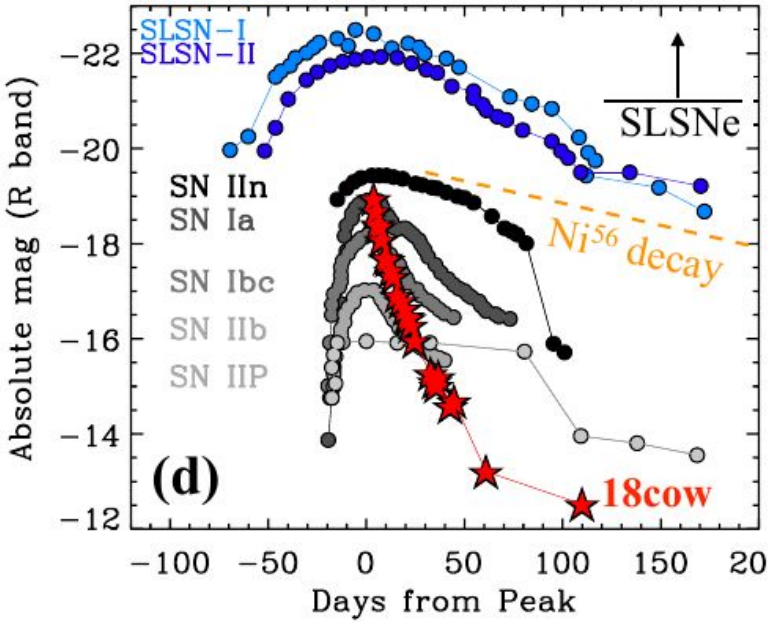
VS 2017

AT2018cow: a Fast Blue Optical Transient

Recently, high-cadence surveys uncovered diverse rapidly-evolving transients **associated with peculiar supernovae** (e.g., Ofek et al. 2010, Whitesides et al. 2017), or the **afterglows of GRB**.

Many were found in **retro-analysis of archives,** but AT2018cow is the **first real-time detection of a nearby (60 Mpc) FBOT**





No GRB seen: INTEGRAL, Fermi, IPN

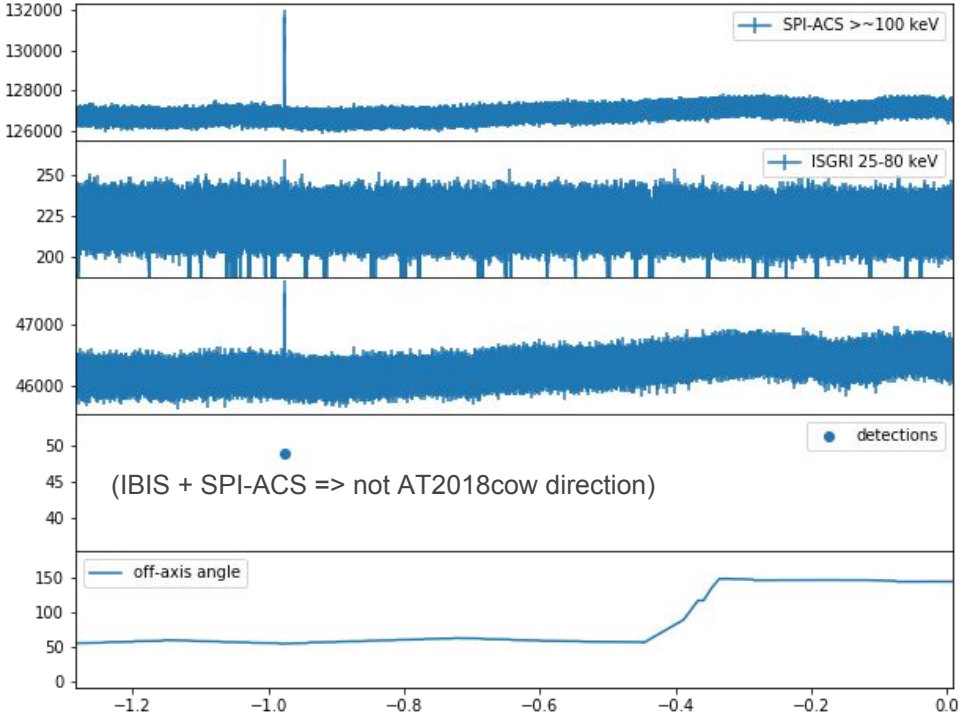
Some SNe are accompanied by GRB. Which ones exactly is not clear. Asymmetry likely plays a major role in GRB formation.

No GRB in AT2018cow might suggest lack of relativistic jet.

INTEGRAL all-sky GRBs monitors from all sky, **99%** coverage during the AT2018cow search period.

Will we see off-axis long GRB like GRB170817A?

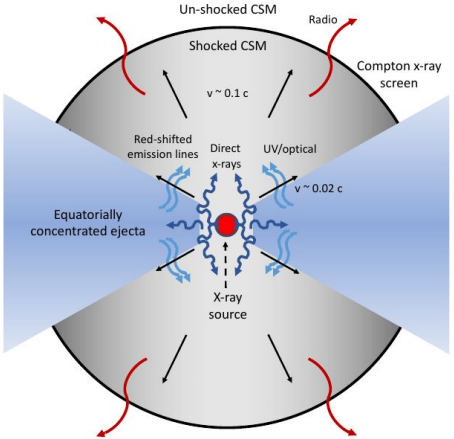
Very aspherical SNe may produce GW!

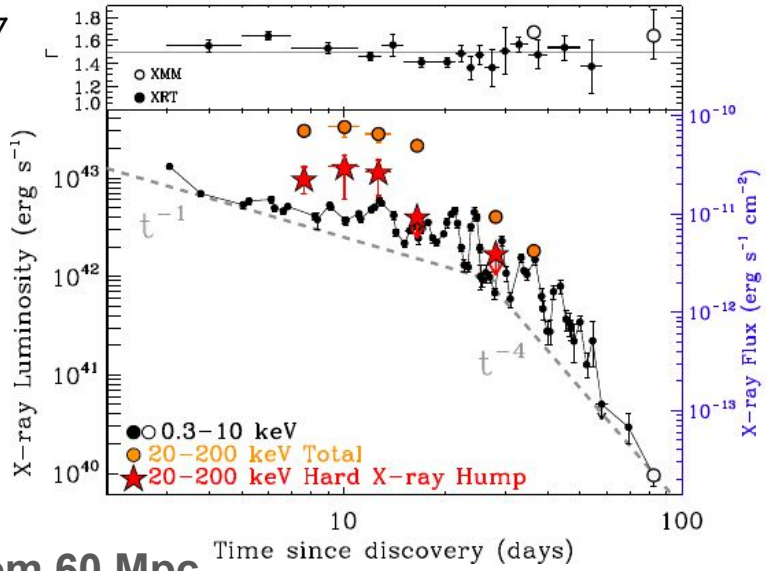


X-ray from central source?

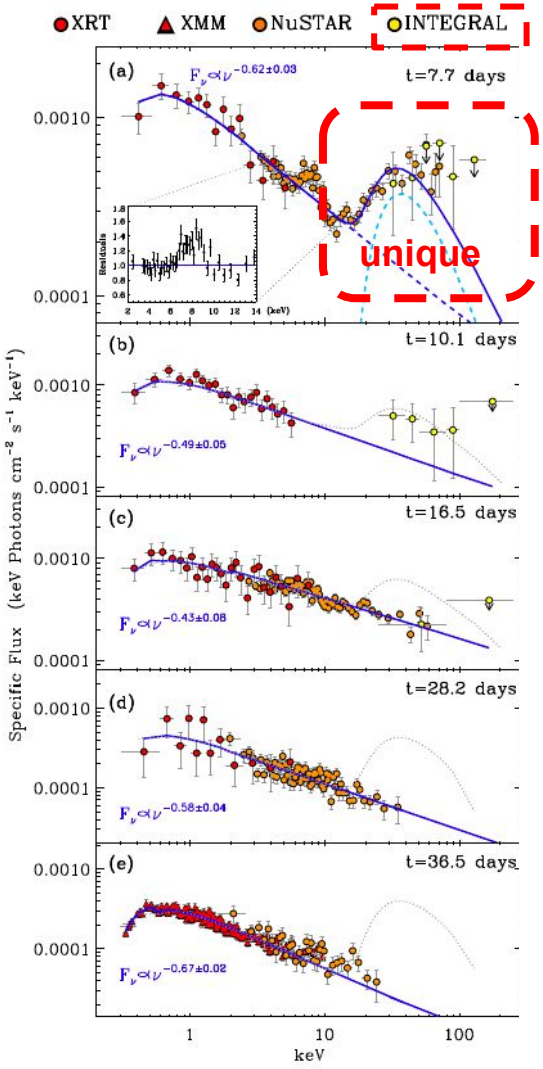
Asphericity might be the key (also key for **GW and GRB**)

Powerlar < 10 keV = directly from the source though transparent region, Hard X-ray hump = Compton down-scattering from >100 keV





ISGRI sees supernova from 60 Mpc



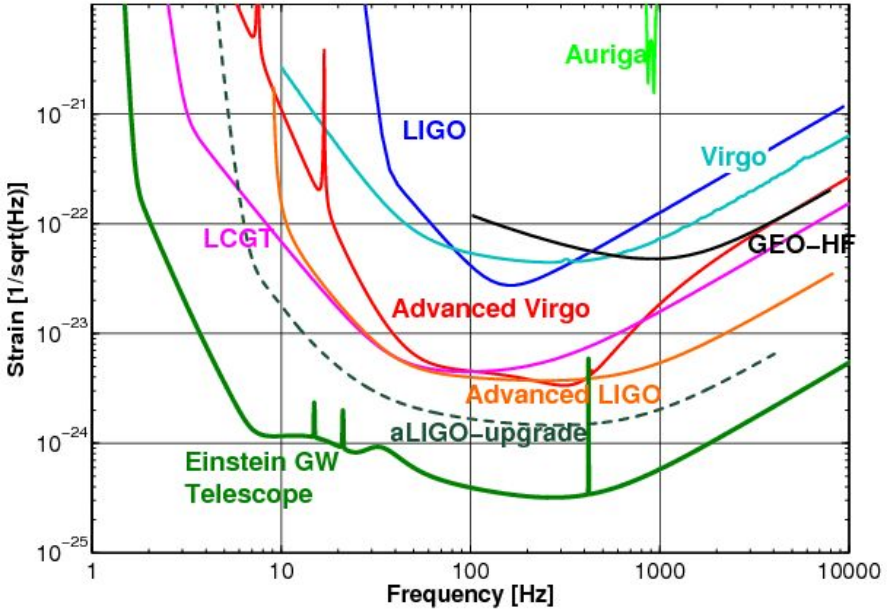
Future ground-based GW detectors

LIGO/Virgo O3 will start 2019 with improved sensitivity

Still searching for:

- NS-BH merger
- “Burst“ GW: e.g. **supernova**
- Persistent kHz GW: pulsars

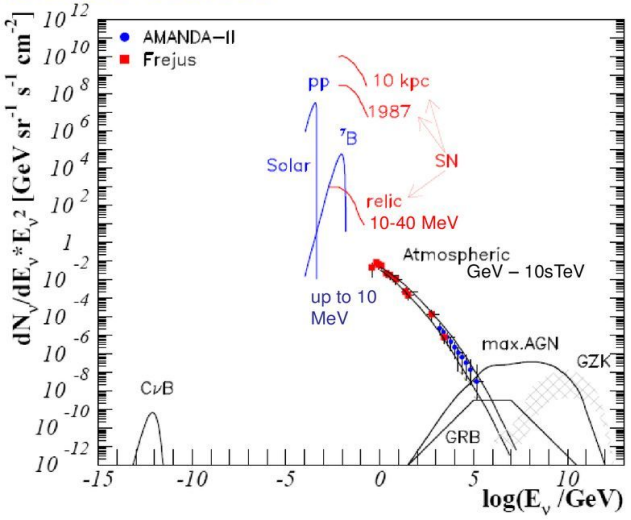
Ground-based interferometers will keep improving beyond LIGO/Virgo (squeezed light, cryogenic detectors): e.g. Einstein Telescope (ET)



Astrophysical Neutrinos: many sources

- Connected with **hadronic processes, origin of cosmic rays** and **GeV emission**
- One confirmed source - **flaring GeV blazar**

Neutrino sources



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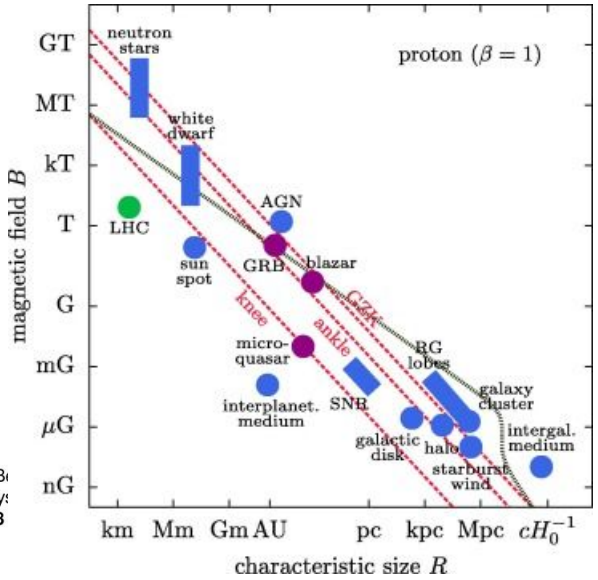
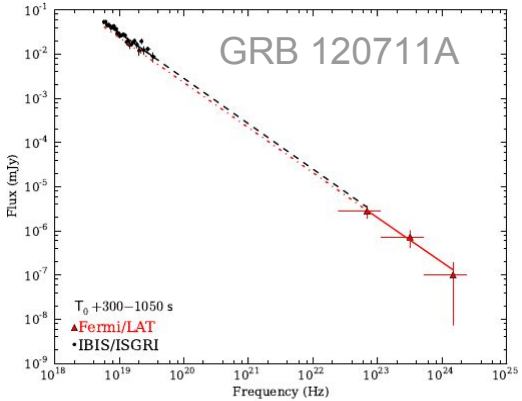


GeV is connected to hard X-ray

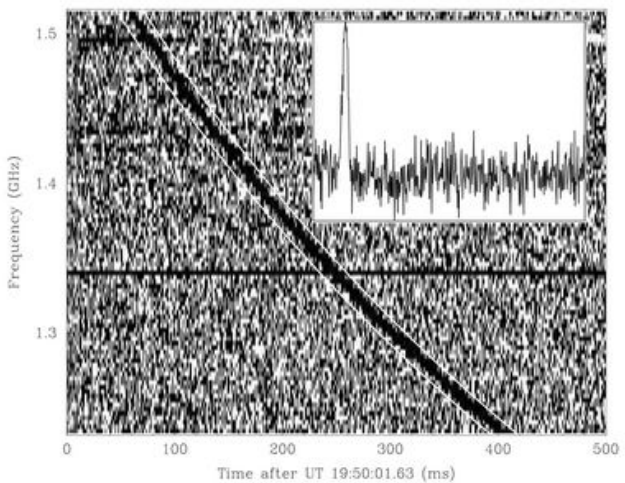


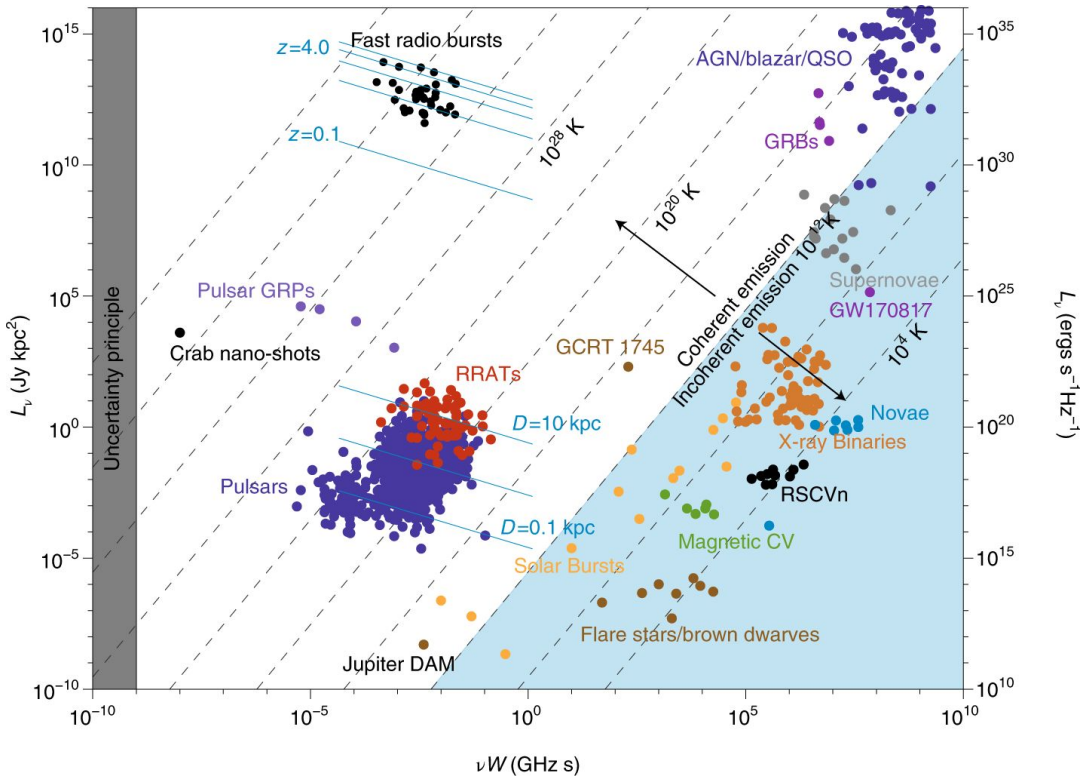
Martin-Carrillo et al 2014

Recent first TeV detection of **GRB190114C** may point towards **CR and neutrino in some GRB**

Fast Radio Bursts

- Discovered in the old data (legacy archive analysis)
- Cosmological distances, 2 found to repeat
- Variable to microsecond
- A report of Hard X-ray counterpart
- Sources unknown





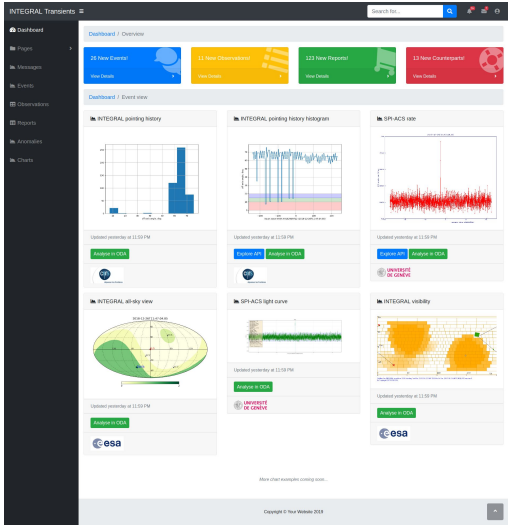
Real-time detection and localization

Future BNS merger (or SN-GRB) are more likely to have low S/N in GW

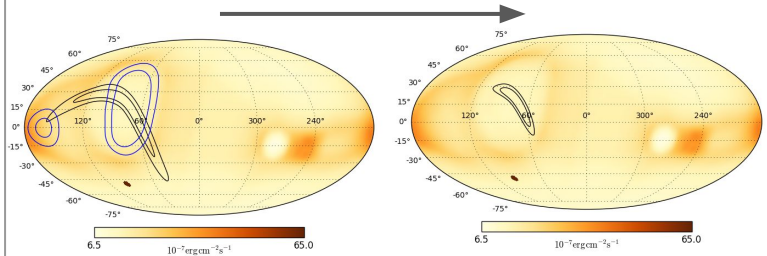
GRB confirmation and localization will stimulate and guide the MW follow-up

Doing it rapidly and openly is vital for maximal impact

INTEGRAL transient dashboard

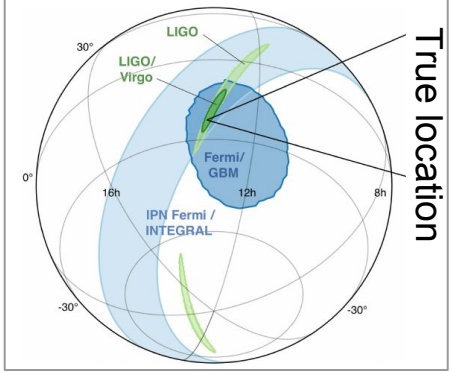


INTEGRAL localization, : synthetic BNS merger at 200 Mpc

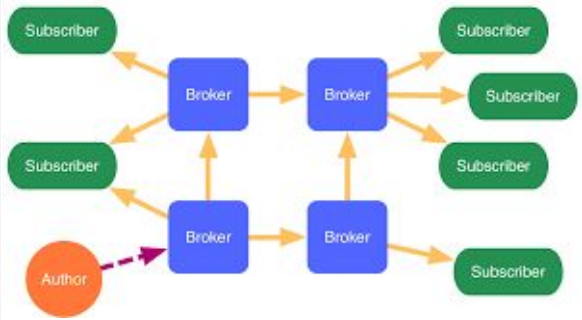


synthetic NS merger event at 200 Mpc

IPN (Fermi-INTEGRAL, etc)



Realtime interoperability: GCN, VOEvent



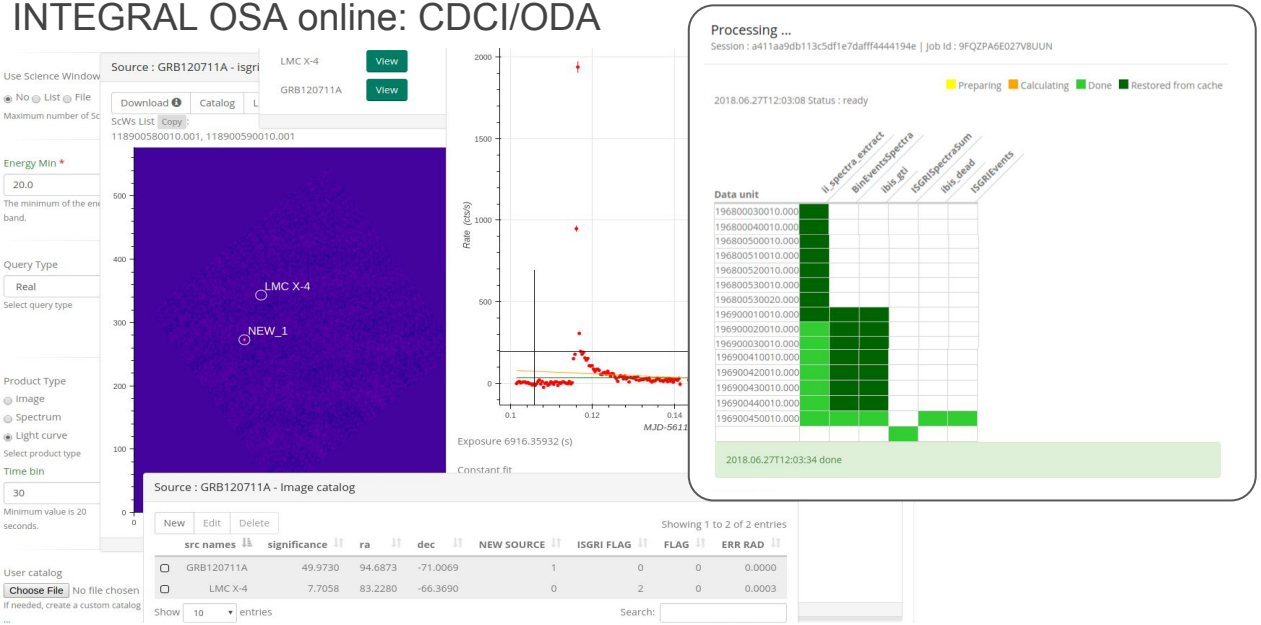
Summary

- INTEGRAL combines features critical in multi-messenger transient astronomy:
  - natural energy range for compact object multi-messenger studies
  - high sensitivity
  - all-sky view
  - rapid reaction
- Next steps:
  - further develop interoperability with all parties: rapid and automated, understandable
  - more BNS, NS-BH mergers
  - First SNe GW sources
  - Neutrino counterparts
  - FRB counterparts
  - High-cadence optical surveys
  - archive searches for retroactively reported events

Open re-analysis of INTEGRAL data

Data analysis should be possible to re-analyse while following provenance and credits

INTEGRAL OSA online: CDCI/ODA



INTEGRAL transient dashboard