INTEGRAL Discovery of GRB from NS coalescence

Pietro Ubertini, Lorenzo Natalucci

on behalf of the INTEGRAL multi-messenger team

FRONTIER OBJECTS IN ASTROPHYSICS AND PARTICLE PHYSICS
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The INTEGRAL Space Observatory

- Launched in 2002 by ESA in the framework of the Horizon 2000 program
- INTEGRAL is providing advanced spectral and imaging capabilities in the X-ray/soft γ−ray band
- INTEGRAL has provided, so far, a detection of the prompt emission of GRB170817 and the tightest upper limits on the EM energy emission GW150914

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INTEGRAL Detection of the First Prompt Gamma-Ray Signal Coincident with the Gravitational-wave Event GW170817

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Abstract

We report the *INTernational Gamma-ray Astrophysics Laboratory* (*INTEGRAL*) detection of the short gamma-ray burst GRB 170817A (discovered by *Fermi*-GBM) with a signal-to-noise ratio of 4.6, and, for the first time, its association with the gravitational waves (GWs) from binary neutron star (BNS) merging event GW170817 detected by the LIGO and Virgo observatories. The significance of association between the gamma-ray burst observed by *INTEGRAL* and GW170817 is 3.2σ, while the association between the *Fermi*-GBM and *INTEGRAL* detections is 4.2σ. GRB 170817A was detected by the SPI-ACS instrument about 2 s after the end of the GW event. We measure a fluence of $(1.4 \pm 0.4 \pm 0.6) \times 10^{-7}$ erg cm^{-2} (75–2000 keV), where, respectively, the statistical error is given at the 1σ confidence level, and the systematic error corresponds to the uncertainty in the spectral model and instrument response. We also report on the pointed follow-up observations carried out by *INTEGRAL*, starting 19.5 hr after the event, and lasting for 5.4 days. We provide a stringent upper limit on any electromagnetic signal in a very broad energy range, from 3 keV to 8 MeV, constraining the soft gamma-ray afterglow flux to $<7.1 \times 10^{-11}$ erg cm^{-2} s^{-1} (80–300 keV). Exploiting the unique capabilities of *INTEGRAL*, we constrained the gamma-ray line emission from radioactive decays that are expected to be the principal source of the energy behind a kilonova event following a BNS coalescence. Finally, we put a stringent upper limit on any delayed bursting activity, for example, from a newly formed magnetar.

Key words: gamma rays: general – gamma-ray burst: general – gravitational waves

Savchenko et al. 2017, ApJ 848:L15

The INTEGRAL team for multi-messenger science

V. Savchenko, C. Ferrigno, E. Kuulkers, A. Bazzano, E. Bozzo, S. Brandt, J. Chenevez, T. J.-L. Courvoisier, R. Diehl, A. Domingo, L. Hanlon, E. Jourdain, P. Laurent, F. Lebrun, A. Lutovinov, S. Mereghetti, L. Natalucci, J. Rodi, J.-P. Roques, R. Sunyaev, and P. Ubertini

Active collaborations:

- LVC and Fermi/GBM (GW counterparts)
- Icecube (search for neutrino counterparts)

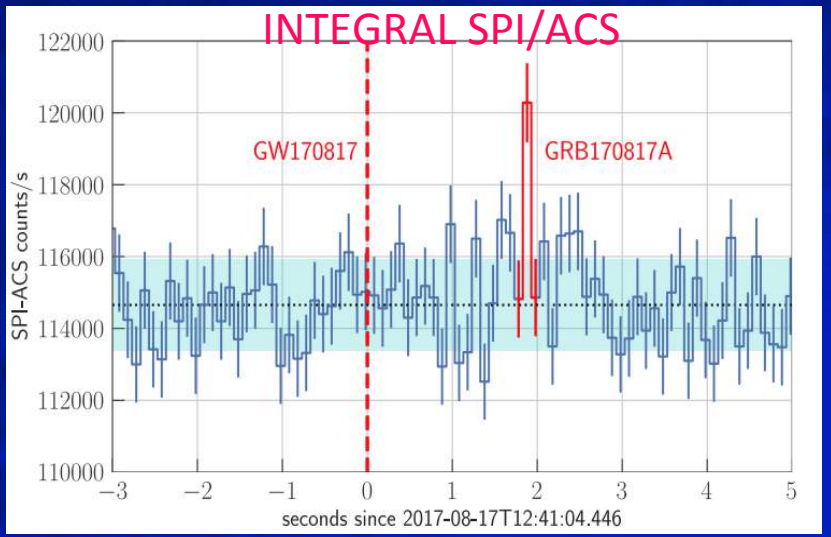


Image Credit: LIGO/Virgo/NASA

Detection of the first gamma-ray counterpart of a GW source during LIGO-Virgo O2

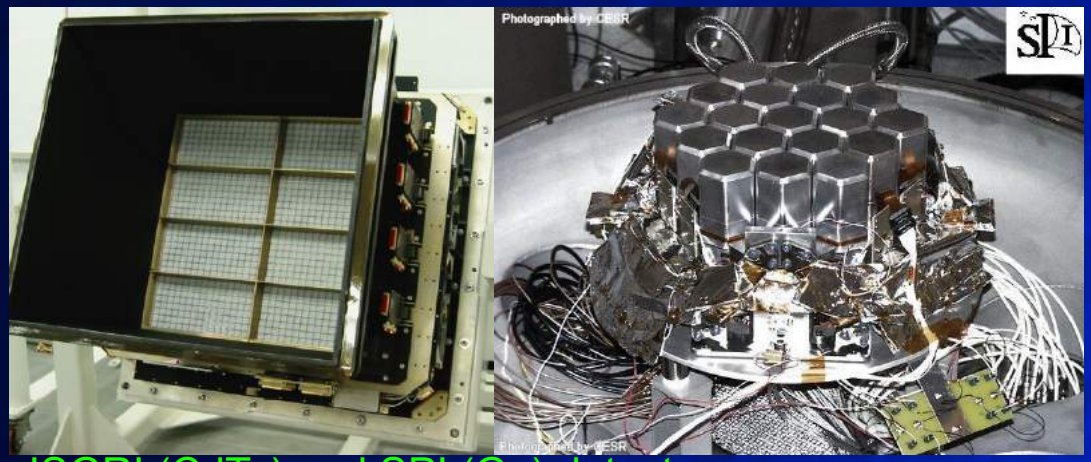
Savchenko+17, ApJ 848, L15

INTEGRAL main features

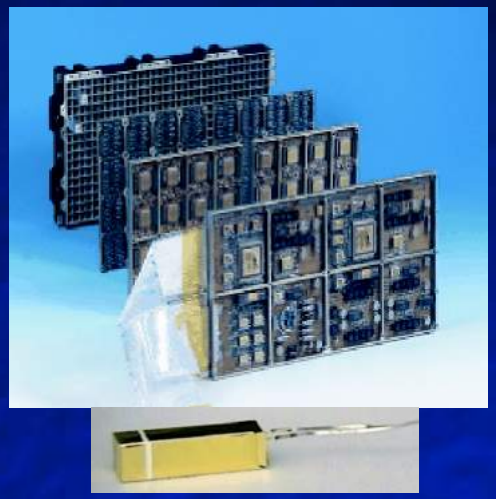
- 3 keV-10 MeV energy range with unprecedented sensitivity
- Wide FOV: ~100-1000 deg^2, plus:
- All sky monitoring capability in the 0.08-2.5 meV band
- 120 μ s absolute time resolution
- arc min angular and keV energy resolution and
- unique polarimetric capability
- 2.7 days uninterrupted observations (>85% duty cycle)
- INTEGRAL is the link between the soft X-ray and high energy γ-ray sky

The INTEGRAL high energy detectors

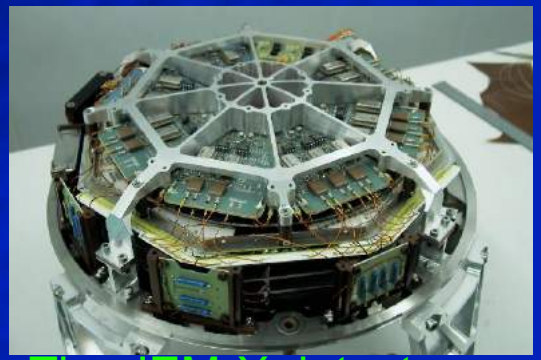
- IBIS carries two stacked imaging detector arrays: ISGRI (0.02-1MeV) based on room temperature CdTe semiconductor detectors. PICsiT (0.2-10 MeV) based on CsI scintillators
- SPI (0.02-10 MeV), Ge cooled detectors provide high resolution spectra
- JEM-X (3-35 keV) based on two identical high pressure microstrip gas chambers is providing low energy extension and arcmin resolution images



ISGRI (CdTe) and SPI (Ge) detectors



PICsIT module & CsI crystal glued to its photodiode



The JEM-X detector

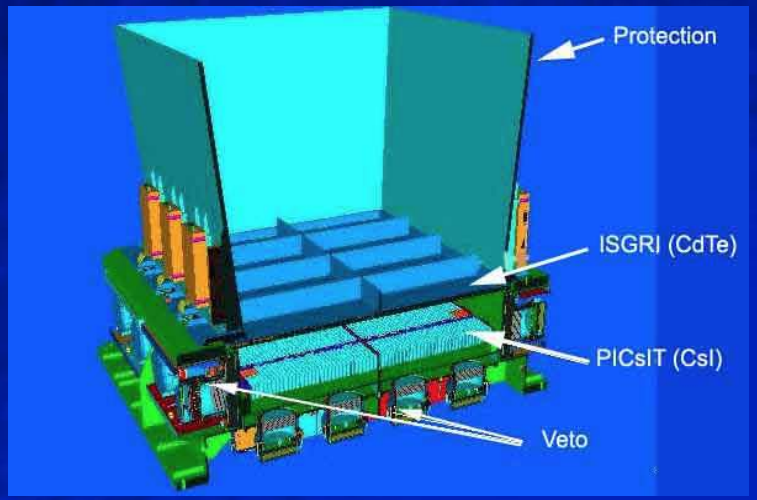
INTEGRAL to hunt γ-ray transients

The SPI/ACS detectors view ~4π solid angle of the sky.
E>75 keV, Tres=50ms
Effective area: up to 1m^2

The IBIS detectors ISGRI and PICsIT have max sensitivity to directions normal to SPI/ACS factor of 5 at least

The sensitivity to a gamma-ray transient depends on sky position and its evaluation must take into account the payload and satellite masses distribution

Outside the IBIS FOV (~30x30 deg^2) the ISGRI and PICsIT detectors also view ~4π up to 2.6 MeV.
PICsIT: T_res=15.6ms
Effective area up to ~900cm^2



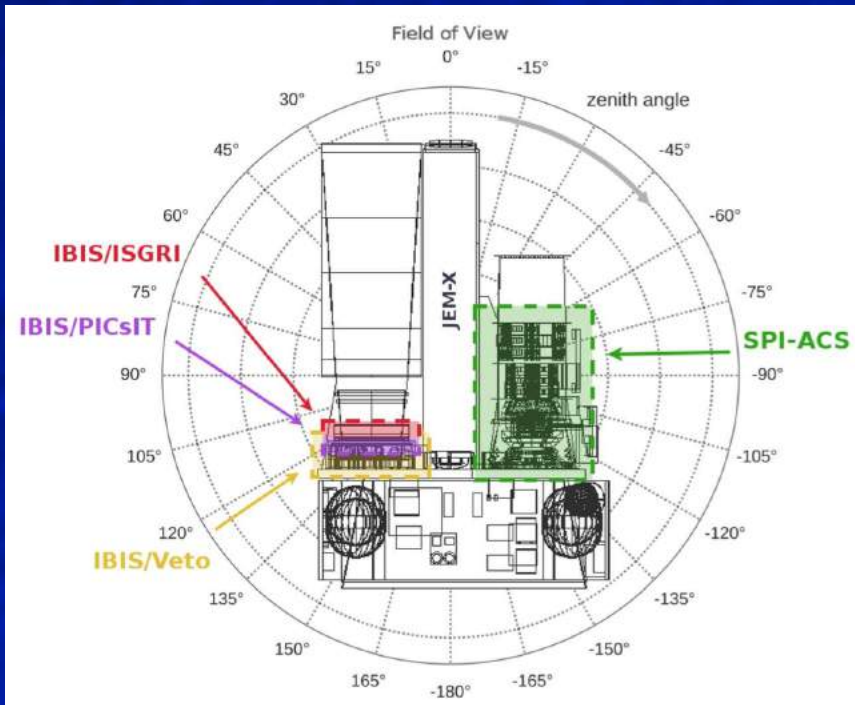
INTEGRAL is similar to BeppoSAX for GW counterpart search…

X/ γ-ray follow-up of GW triggers

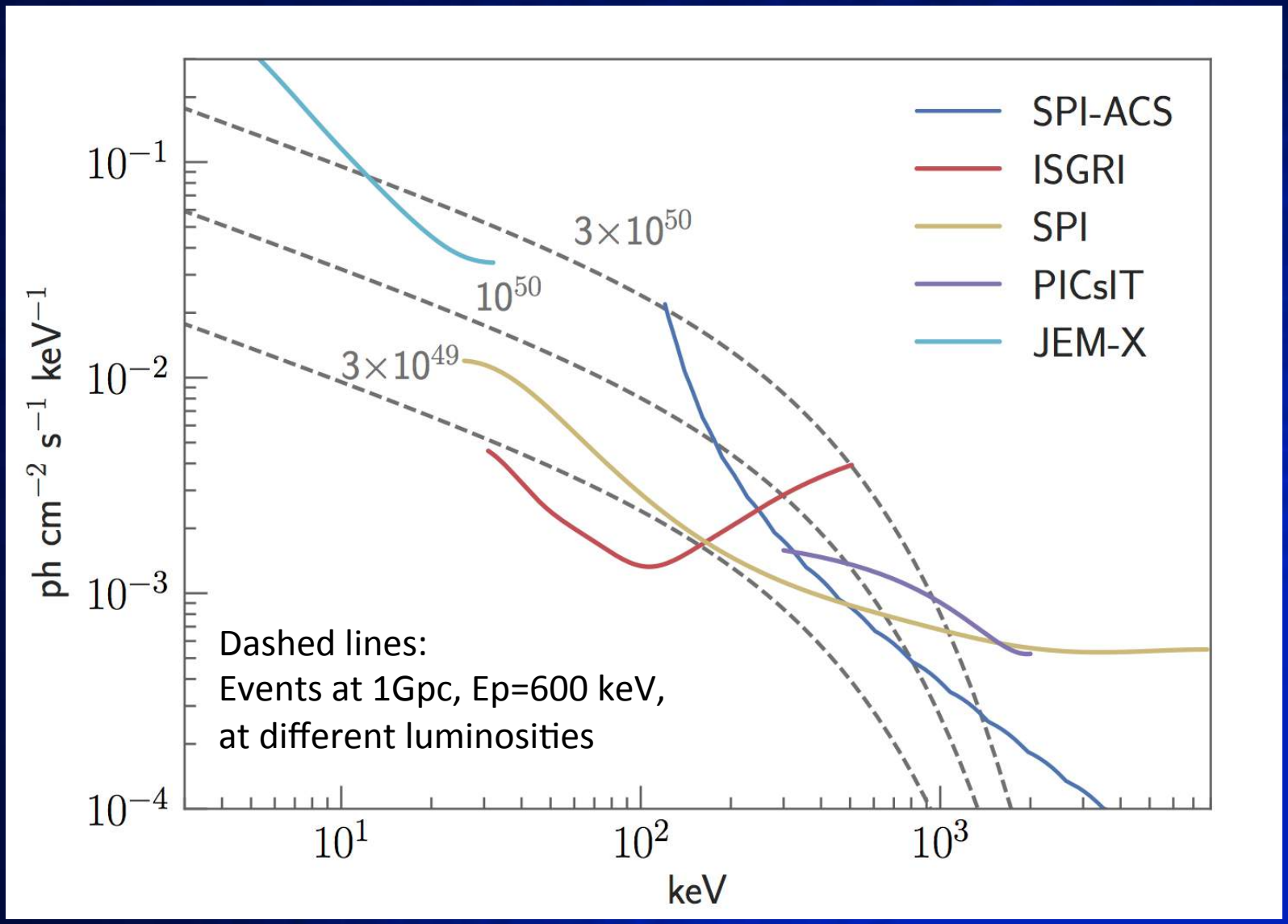
Needs combination of large sky coverage and good sensitivity

Three main approaches:

1. Detecting a γ-ray prompt signal within FoV (INTEGRAL GRB rate in FoV is ~few/ year)
2. Detecting a γ-ray prompt signal out of FoV: SPI-ACS, IBIS/PICsIT and VETO, IBIS Compton mode
3. Detecting an X/ γ-ray delayed emission (ToO)



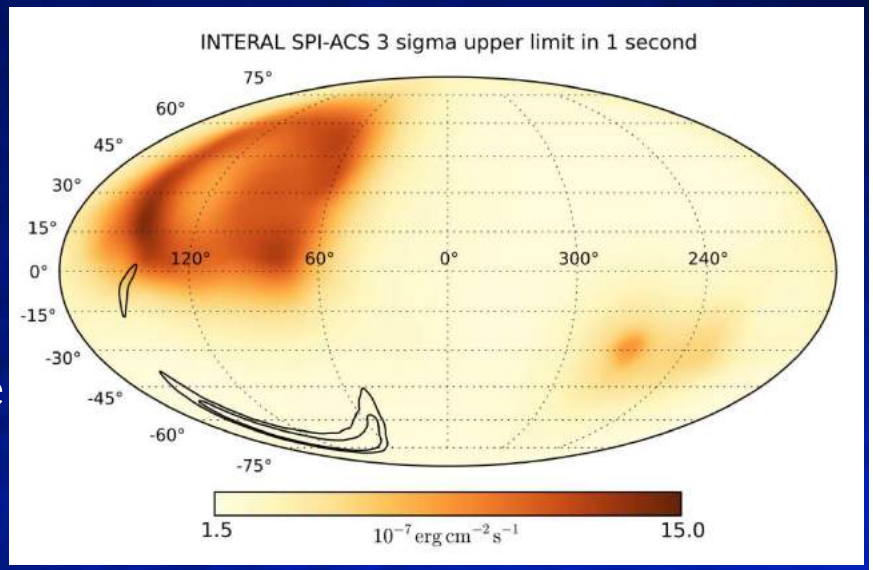
1s burst sensitivity



Savchenko+17, A&A 603

INTEGRAL Upper Limits on the γ-ray emission of GW 150914

- Localization by the LIGO/Virgo collaboration yields a very large region…
- The SPI/ACS sensitivity in FOV vary up by a factor 5, but its optimal value applies to 75% of the sky
- GW150914: U.L. range is 0.2-4.5x10^{-7} erg cm^{-2} for event durations of 0.05 to 10s, respectively (applies to 95% of the Adv. LIGO error region)

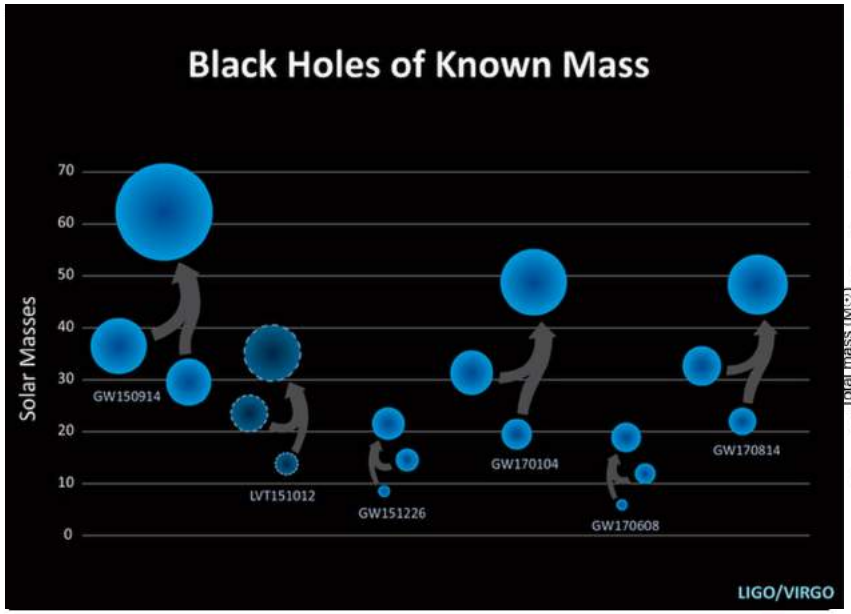


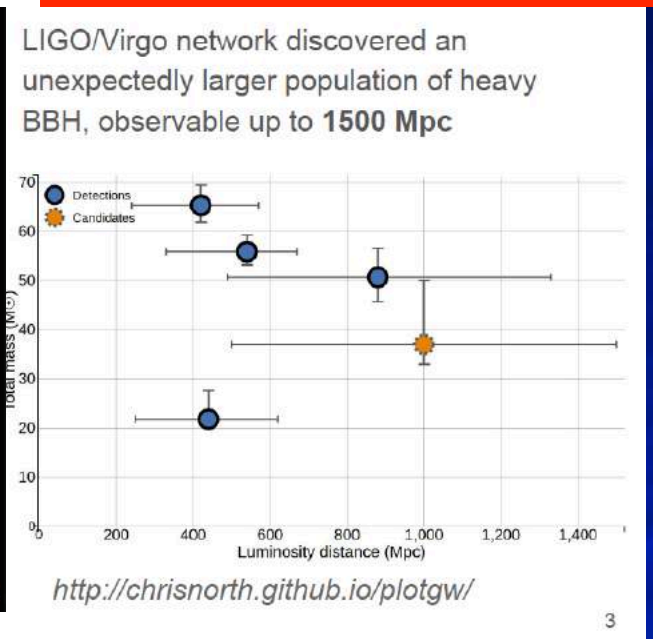
Savchenko+16, ApJL

- The ratio of e.m. to gravitational energy is $R_{\gamma/g}$= 0.2-5x10^{-6}
- In case of events in the ~300 sq.deg FOV of INTEGRAL, the search flux limits would decrease by a factor ~5 at least

LIGO/Virgo 2015- August 2017:
5 binary black holes

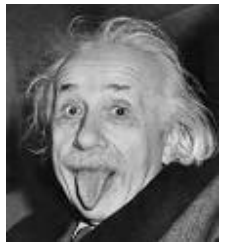
In fact, INTEGRAL has observed
5 out of 6 BH-BH mergers

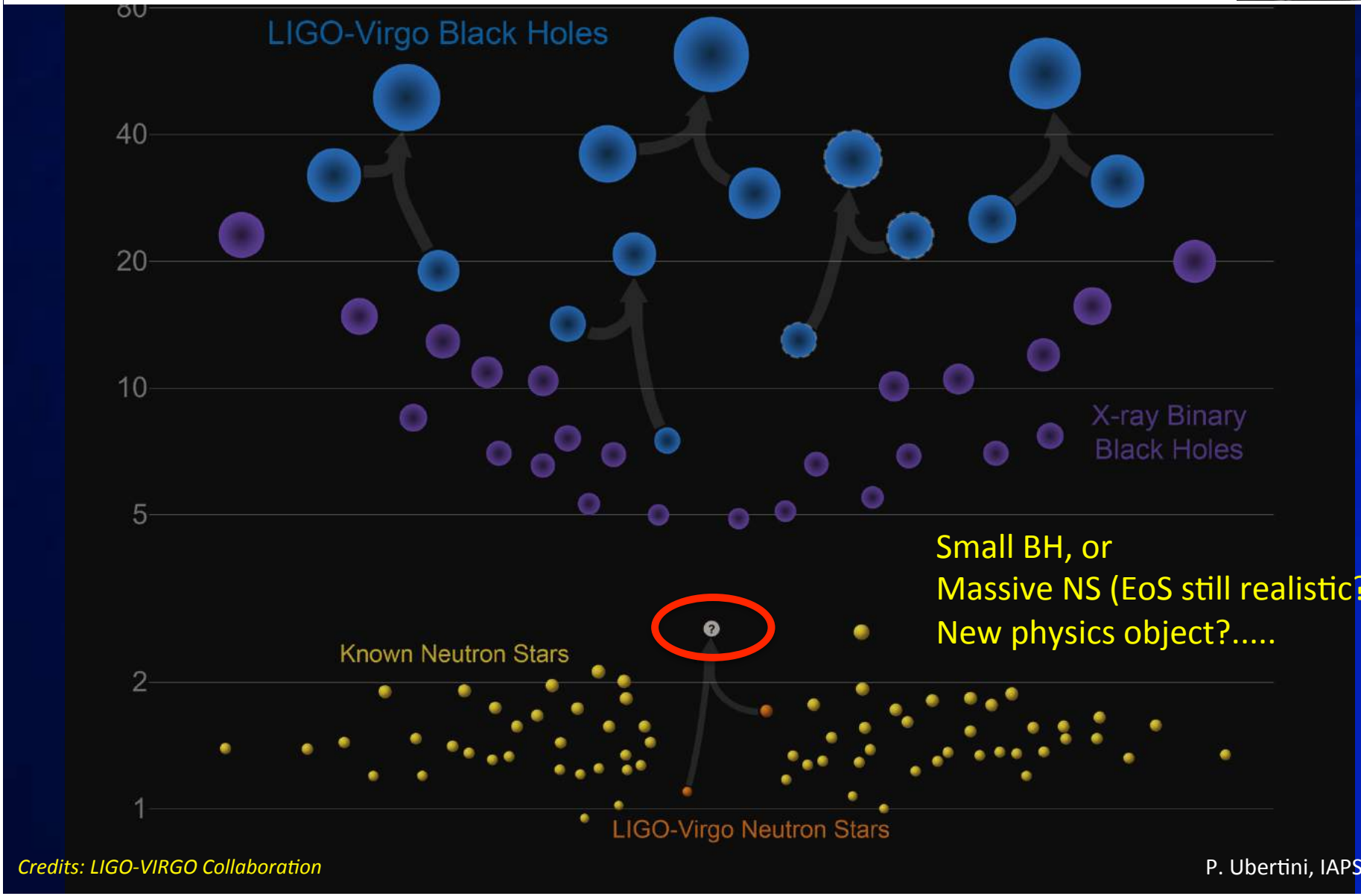




LIGO-VIRGO detection	**INTEGRAL Observation**
GW150914	Savchenko+16, ApJL 820; Abbott+16, ApJL 826 Abbott +16, ApJS 225
LVT151012	Savchenko+17, A&A 603
GW151226	Missed, perigee passage
GW170104	Savchenko+17, ApJL
GW170814	Savchenko et al., GCN
GW170817, NS-NS Inspiral	**Savchenko+17, ApJL 848, L15; Abbott+17, ApJL 848, L12** **Abbott+17, ApJL 848, L13**

However , one of the main expected source of GW is the inspiral of binary NS: GW170817 = GRB170817A is the text book case!!

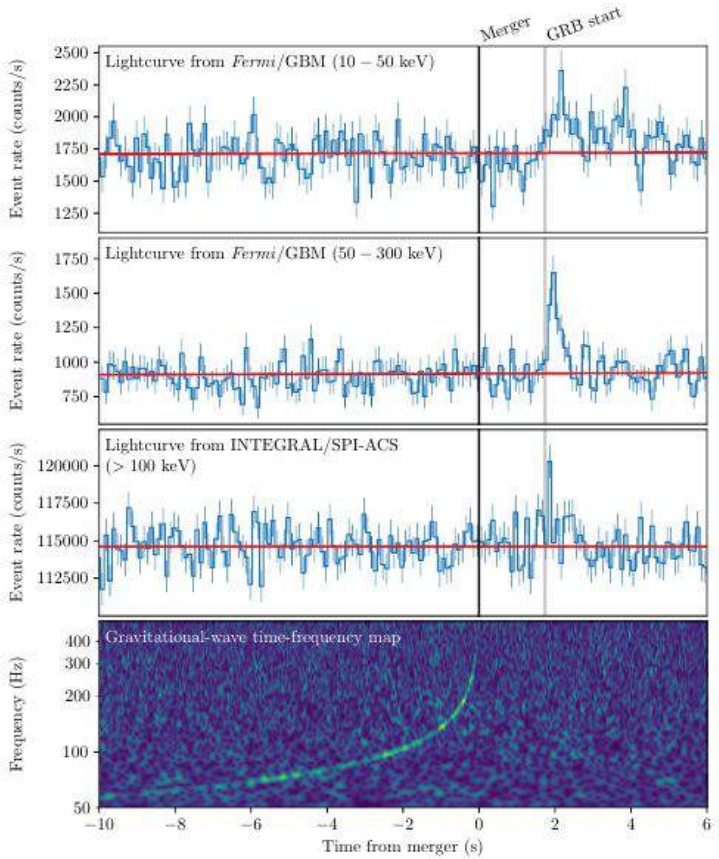




Credits: LIGO-VIRGO Collaboration

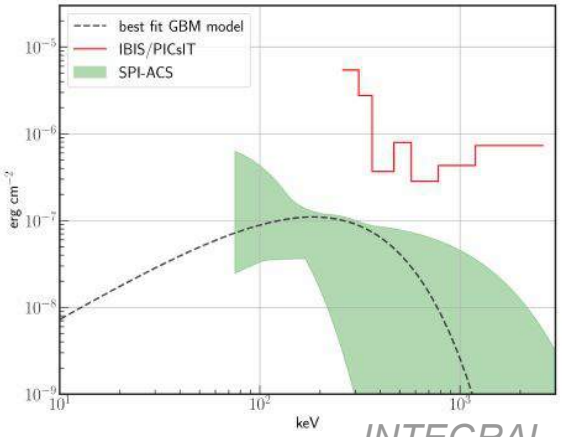
INTEGRAL detects prompt gamma ray emission quasi-contemporary to GWs

GW170817+GRB170817A



LVC+Fermi+INTEGRAL 2017

Binary Neutron Star merger, discovered by Fermi/GBM and LIGO, independently observed by INTEGRAL/SPI-ACS, in good agreement with Fermi/GBM



INTEGRAL 2017

Despite **soft GRB spectrum** and moderately favorable orientation, INTEGRAL achieved confident detection

INTEGRAL/GW coincidence probability is 3.2σ

B. P. Abbott et al. 2017 ApJL 848 L13

V. Savchenko et al. 2017 ApJL 848 L15

Fundamental consequences

This is the **first multimessenger detection, with total of 5.3 sigma GW-GRB association significance**

At least some **short GRBs are associated to BNS mergers**

The 2 s delay comparing to 130 Mly distance implies that **speed of gravity** can be constrained to unprecedented precision:

$$-3 \times 10^{-15} \leq \frac{\Delta v}{v_{\rm EM}} \leq +7 \times 10^{-16}$$

Such a consistency between GW speed and speed of light, implies stringent **limits on Lorentz Invariance Violation**

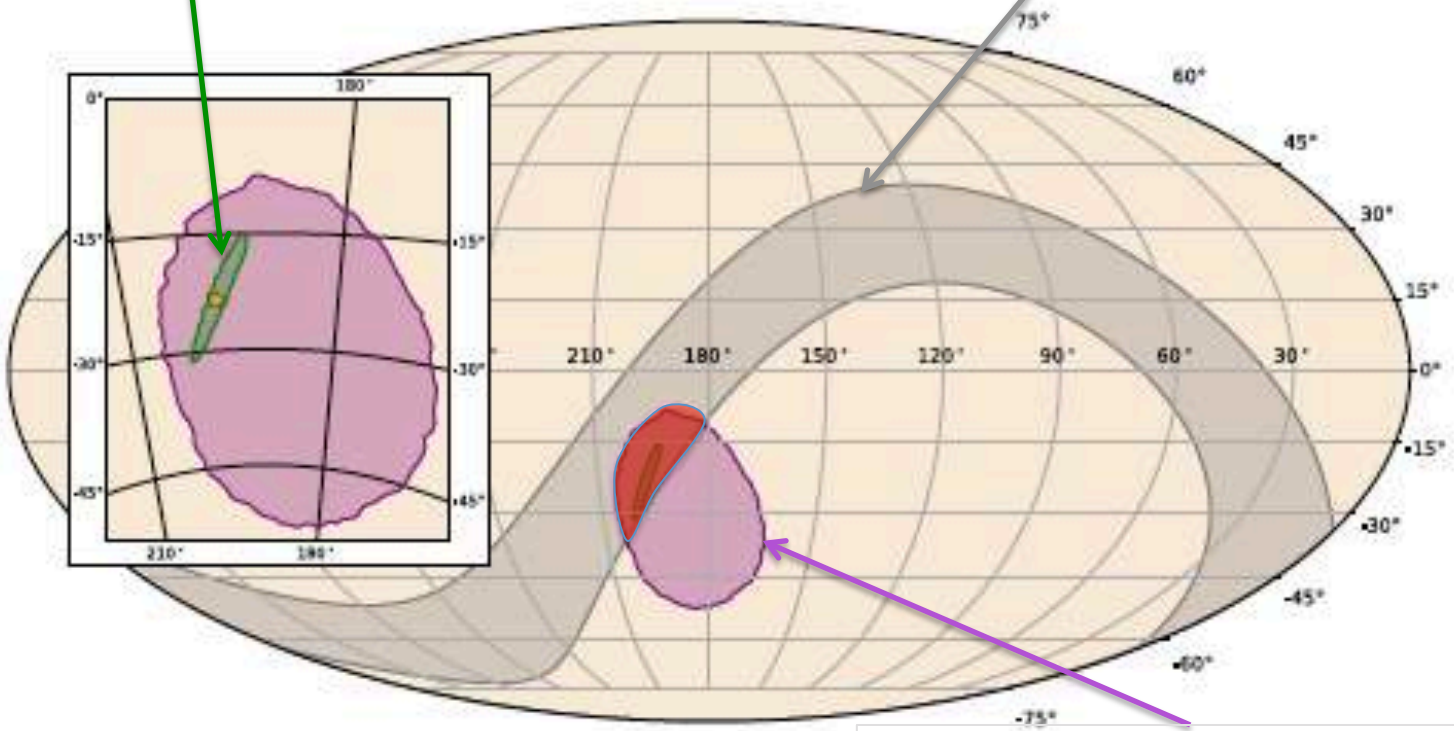
This observation provides the **new insights into the EoS of the neutron matter**

LVC+Fermi+INTEGRAL 2017

GW170817=GRB170817A localization

90% final LIGO-Virgo error region

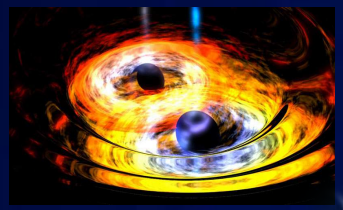
90% *Fermi-INTEGRAL* error region (timing)



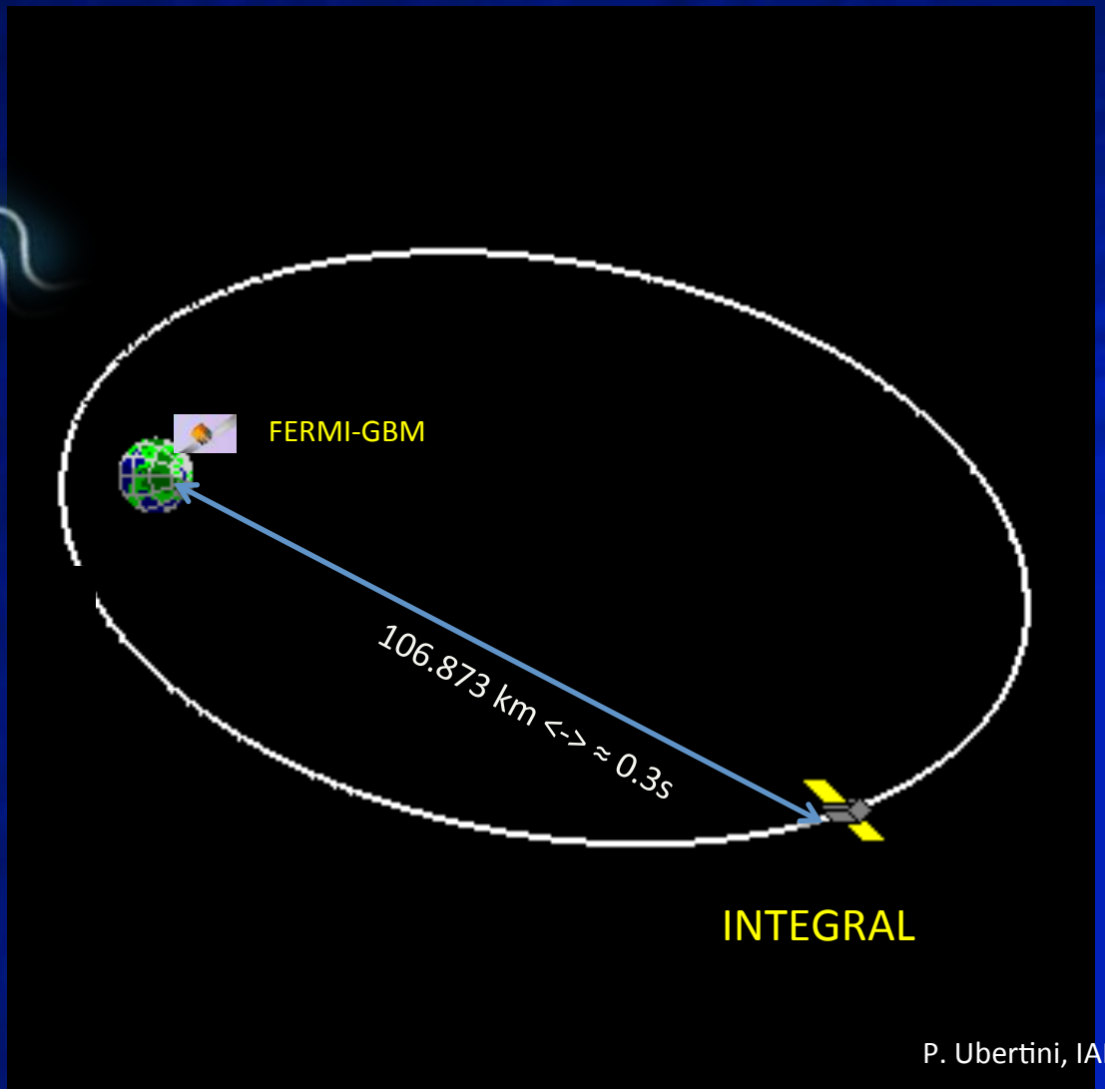
90% *Fermi/GBM* targeted search localization

Abbott+17; Savchenko+17

GW170817 and GRB170817A arrival sequence



- Virgo (Pisa)
- FERMI LEO
- Geo Centre
- LIGO Livingston
- LIGO Hartford
- INTEGRAL HEO



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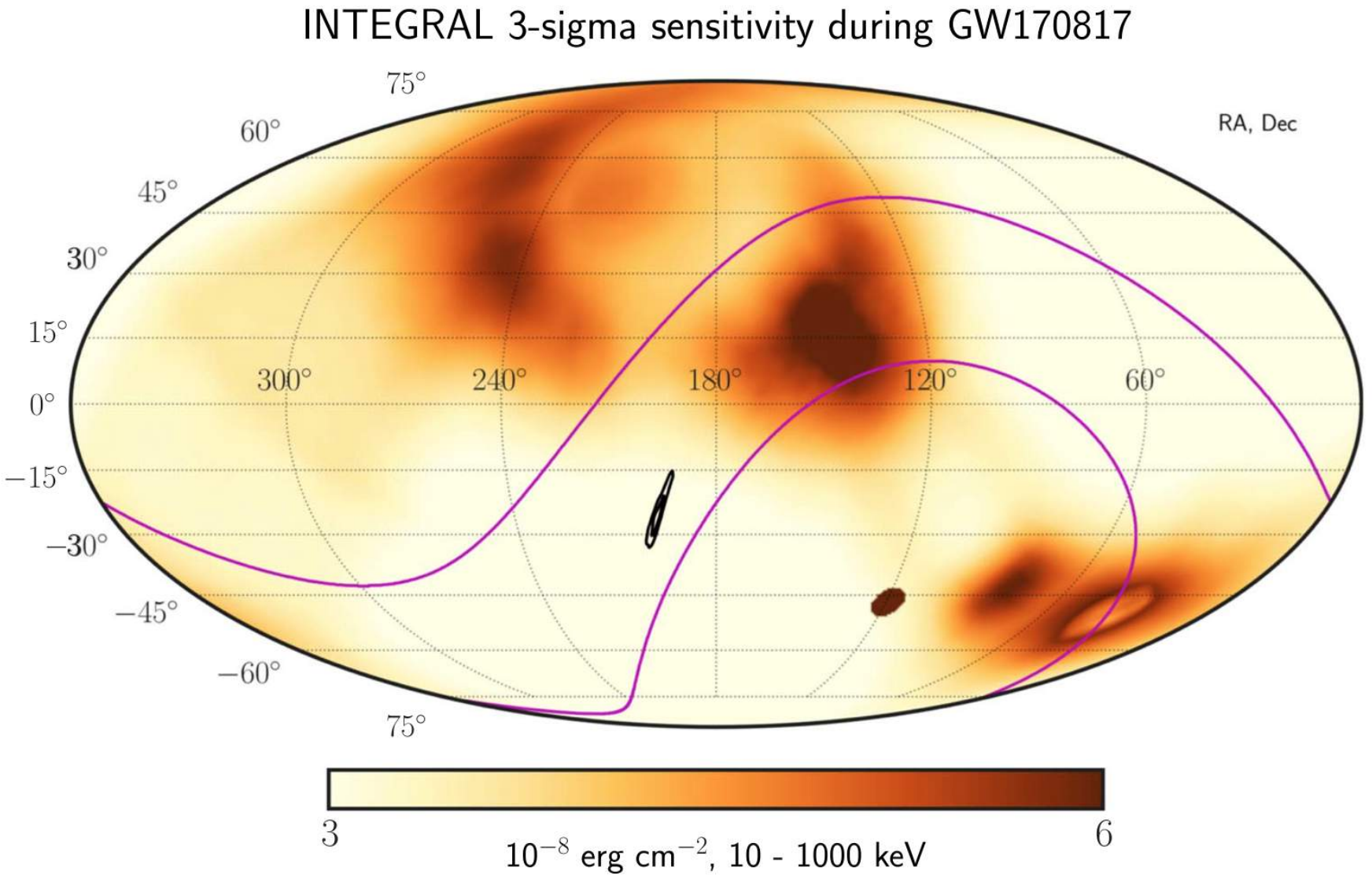
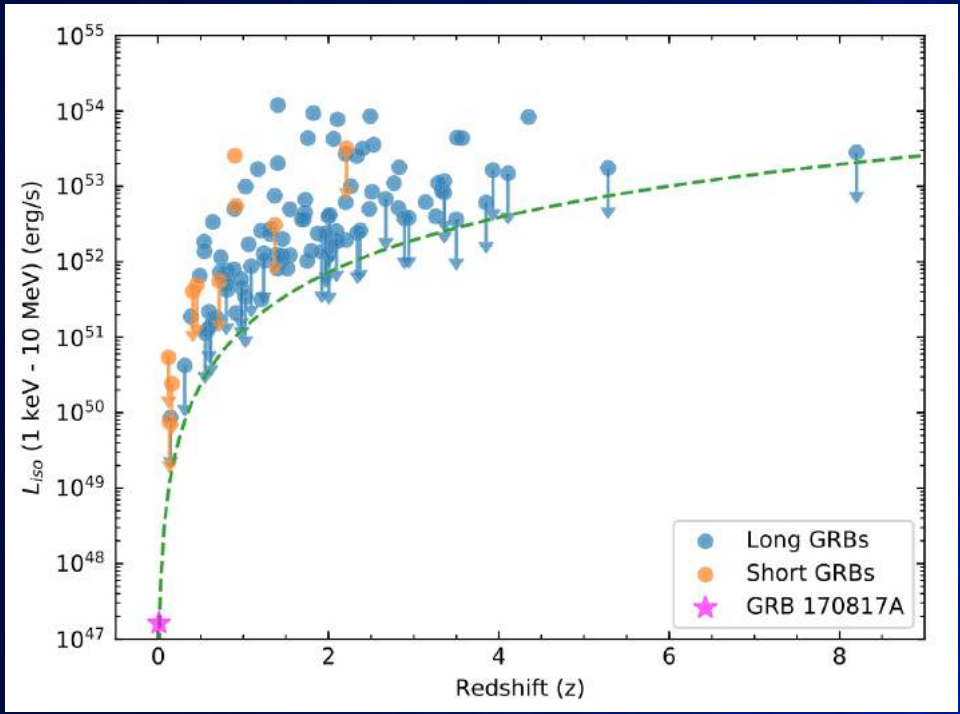

INTEGRAL 3-sigma sensitivity during GW170817
75°
60°
45°
30°
15°
0°
−15°
−30°
−45°
−60°
75°
300°
240°
180°
120°
60°
RA, Dec
3
6
10−8 erg cm−2, 10 - 1000 keV

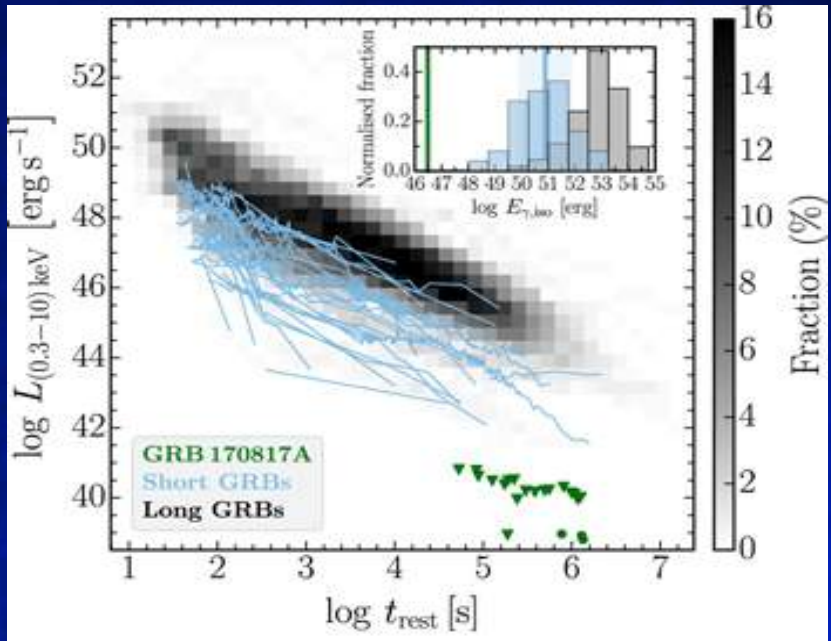
GRB170817A extremely low luminosity

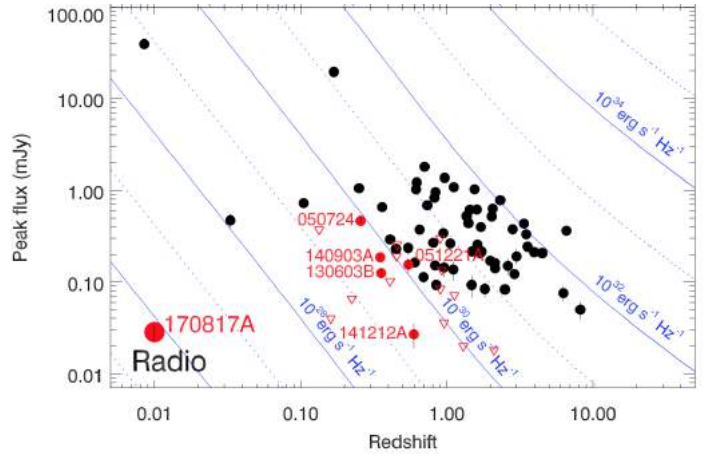
Prompt emission (γ-rays)



Abbott+17, ApJ848,L13

Afterglow (X-rays & radio)



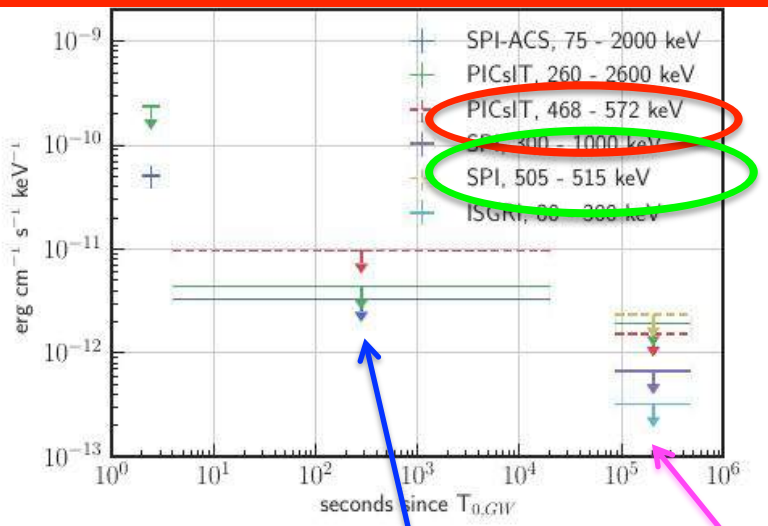


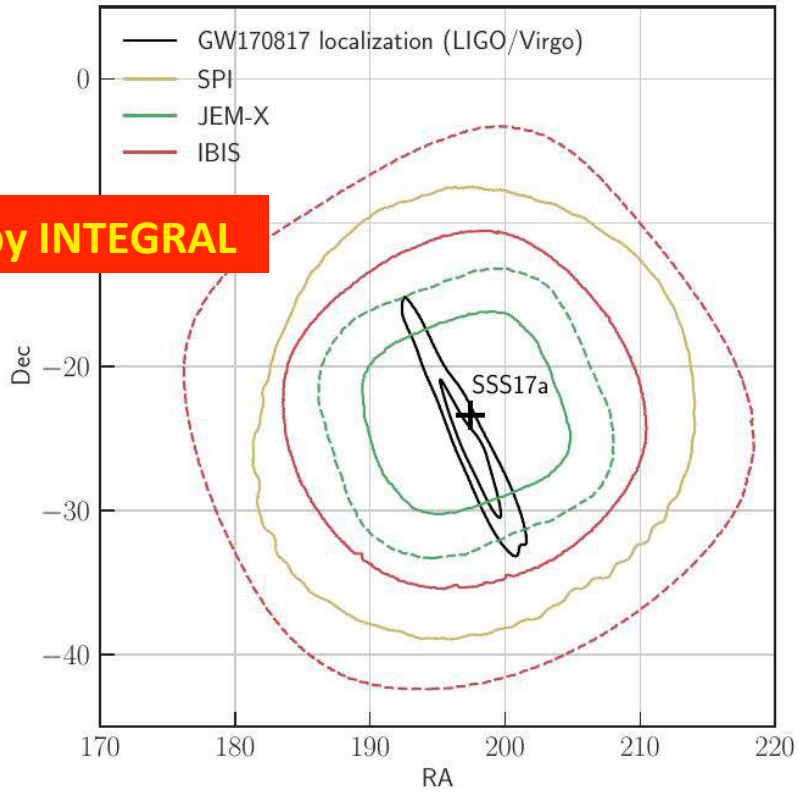
Kim+18

INTEGRAL pointed follow-up

A GRB at 40 Mpc could have produced bright hard X-ray afterglow. INTEGRAL can constrain new flux at least from T_0 to T_0+20ks.

No spectral feature, no gamma-ray lines detected by INTEGRAL





All-sky monitoring
SPI-ACS + IBIS-PICsIT + IBIS-VETO

Pointed observations
SPI + IBIS +
JemX +OMC

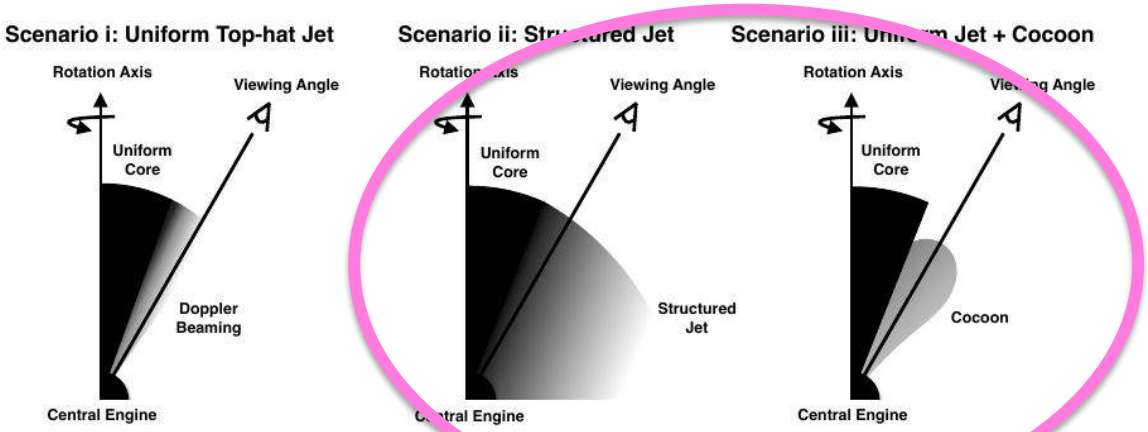
- After T_0, INTEGRAL spent initially ~20ks observing with the same aspect.
- It was then repointed toward the most probable error-box (known at that time)
- And finally, to cover the refined error region for about 5 days

Possible interpretation of GRB prompt emission

Possible models

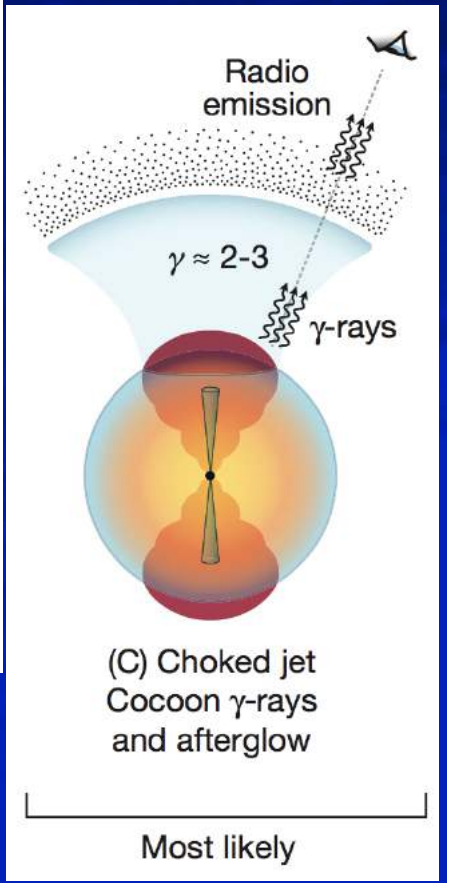
These were the best models available at the 30 November GSSI meeting

As revealed by LIGO/Virgo data, the merger was observed at **20-60 deg off-axis,** proving that a considerable amount of gamma-ray energy is emitted far from the symmetry axis of the system



To establishing the true luminosity function we need more off-axis GRBs

LVC+Fermi+INTEGRAL 2017



Mooley+18

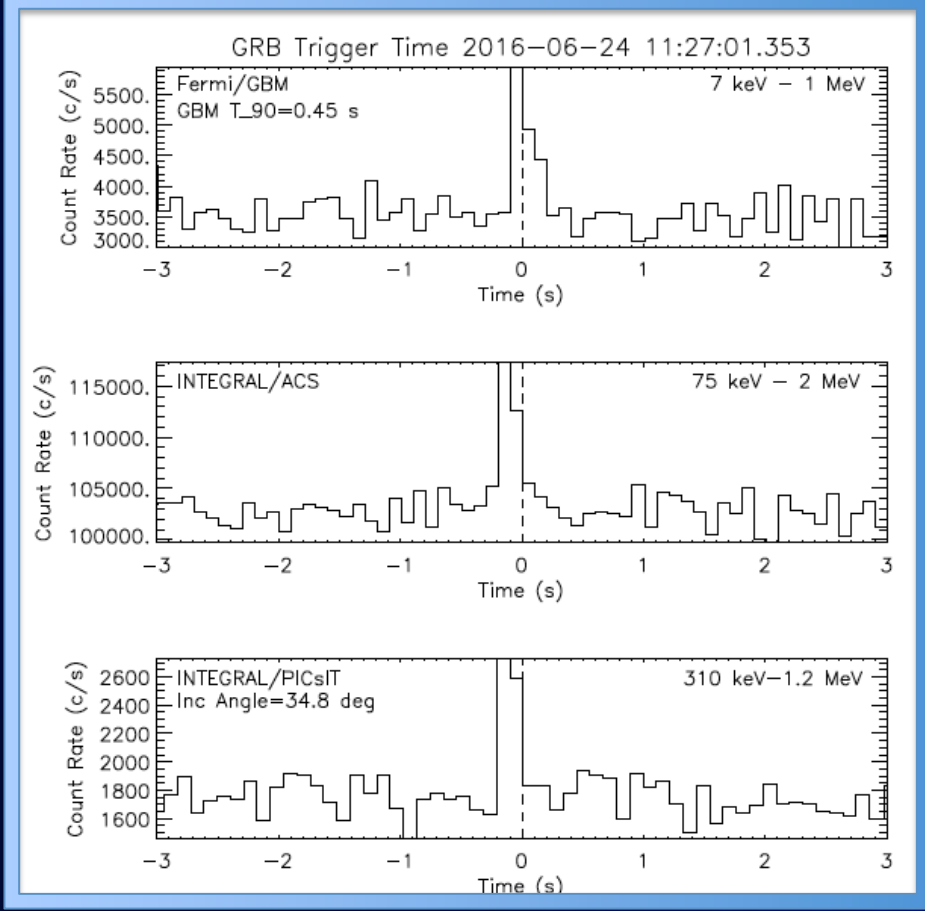
Other relevant papers have been published on explaining GRB and afterglow emission,e.g.:
Troja+17, Nature; Kasliwal+17, Science; Kim+17, ApJ850,L21,
Mooley+18, Nature

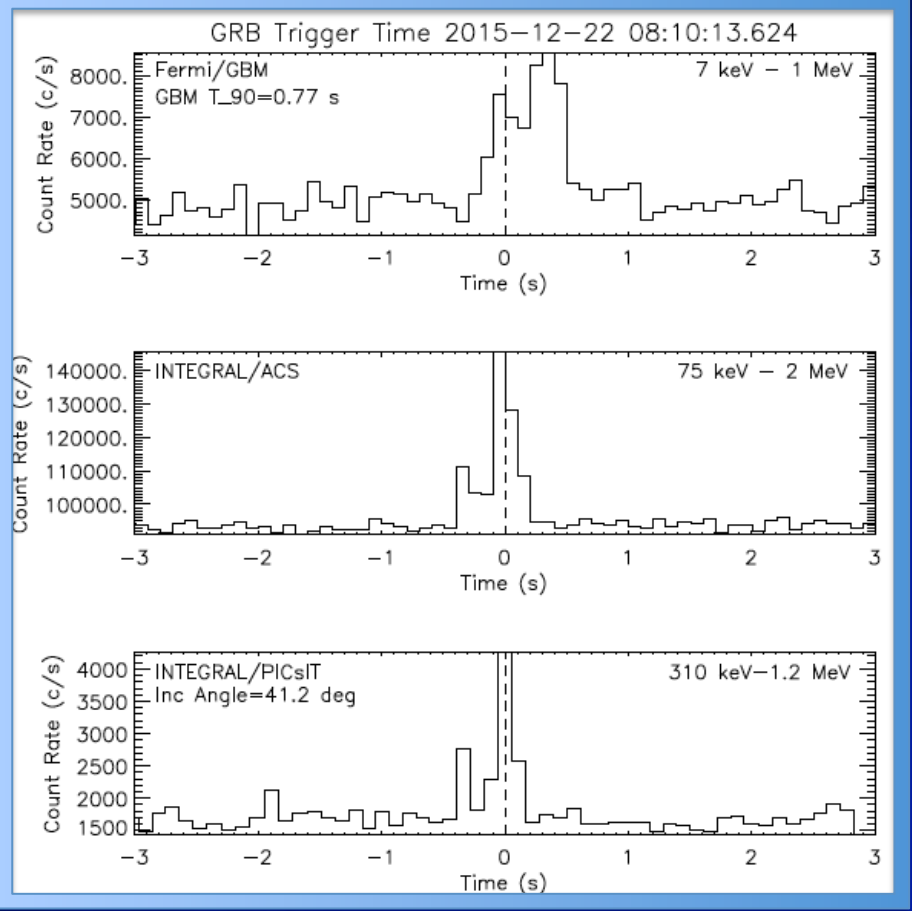
Current work

- Common search of sub-threshold Ligo-Virgo signals coincident with INTEGRAL sGRBs
- Search for past INTEGRAL/PICsIT GRBs previously reported by other instruments, focus on short GRBs
- Spectral analysis of soft gamma-ray spectrum above ~300 keV to extend Fermi/GBM results
- Search of INTEGRAL/PICsIT and SPI/ACS data for faint SGRBs below trigger threshold
- Develop Real-Time analysis to search for and report bursts immediate web alert

SGRBs seen by INTEGRAL & Fermi/GBM

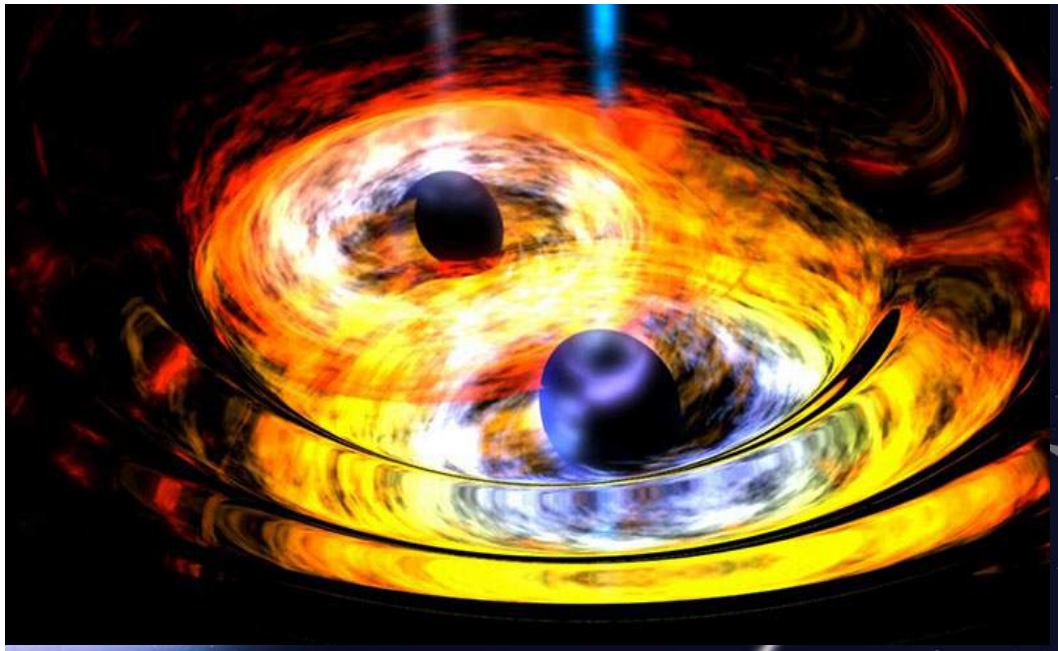
The accurate measurement of the arrival time of GRB from *INTEGRAL*, *AGILE*,*Fermi*, *Swift*, etc may allow an accurate determination of the arrival direction of GW

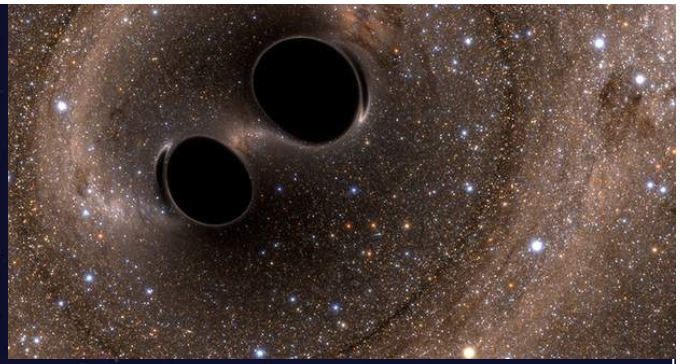


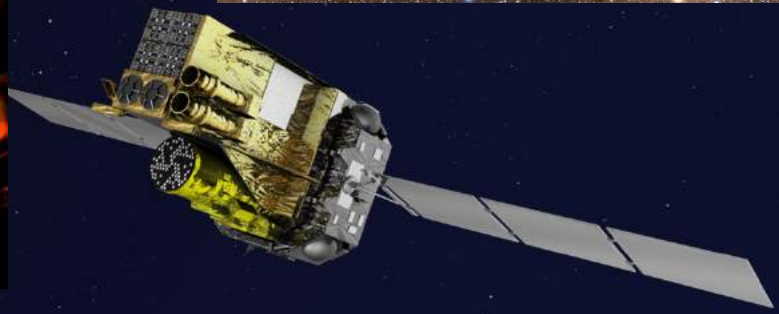


Summary

- INTEGRAL followed-up full GW localization region 5 out of 6 reported events, as expected with 85% duty cycle.
- Combination of the high duty cycle and high sensitivity is unique, and allowed us to contribute to the first joint GRB-GW Detection
- Detection of a GRB from an off-axis merger implies much more frequent GRB-BNS associations, which might happen regularly in O3, the bright triggers are expected immediately public
- Early GRB-GW detection: be prepared for unexpected optimistic scenario!
- Multimessenger observations open possibilities for studying processes in energetic events involving compact objects, implications that go beyond BNS mergers.
- Neutrino follow-ups remain very promising and tentative MM detections
- Might soon reach the level of solid evidence







THANKS FOR YOUR ATTENTION.. &..

STAY TUNED!!