INTEGRAL follow up of the GW event: upper limits on γ-ray emission to GW150914 and observation of ***LVT 151012***

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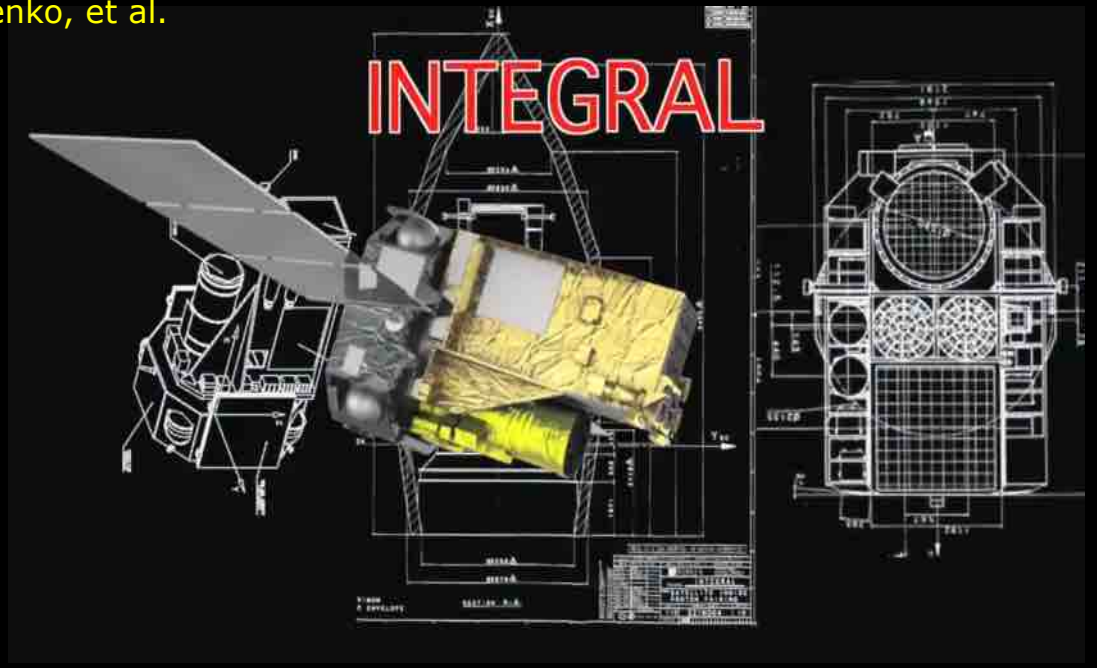
on behalf of the
INTEGRAL GW Team

Ligo-Virgo MoU 5/4/2014



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INTEGRAL UPPER LIMITS ON GAMMA-RAY EMISSION ASSOCIATED WITH THE GRAVITATIONAL WAVE EVENT GW150914

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ABSTRACT

Using observations of the *INTErnational Gamma-Ray Astrophysics Laboratory* (*INTEGRAL*), we place upper limits on the gamma-ray and hard X-ray prompt emission associated with the gravitational wave event GW150914, which was discovered by the LIGO/Virgo Collaboration. The omnidirectional view of the *INTEGRAL*/SPI-ACS has allowed us to constrain the fraction of energy emitted in the hard X-ray electromagnetic component for the full high-probability sky region of LIGO triggers. Our upper limits on the hard X-ray fluence at the time of the event range from $F_\gamma = 2 \times 10^{-8}$ erg cm^{-2} to $F_\gamma = 10^{-6}$ erg cm^{-2} in the 75 keV–2 MeV energy range for typical spectral models. Our results constrain the ratio of the energy promptly released in gamma-rays in the direction of the observer to the gravitational wave energy $E_\gamma/E_{GW} < 10^{-6}$. We discuss the implication of gamma-ray limits for the characteristics of the gravitational wave source, based on the available predictions for prompt electromagnetic emission.

RICAP2016, Villa Tuscolana Frascati,
23 giugno, 2016

INTEGRAL UPDATE

INTEGRAL main features:

- ✓ **3 keV-10 MeV energy range with unprecedented sensitivity**
- ✓ **2.7d uninterrupted observations**
- ✓ **wide FOV: ~100-1000 deg^2**
- ✓ **120 μs time resolution**
- ✓ **Arc min angular and keV energy resolution and**
- ✓ **Unique polarimetry capabity**

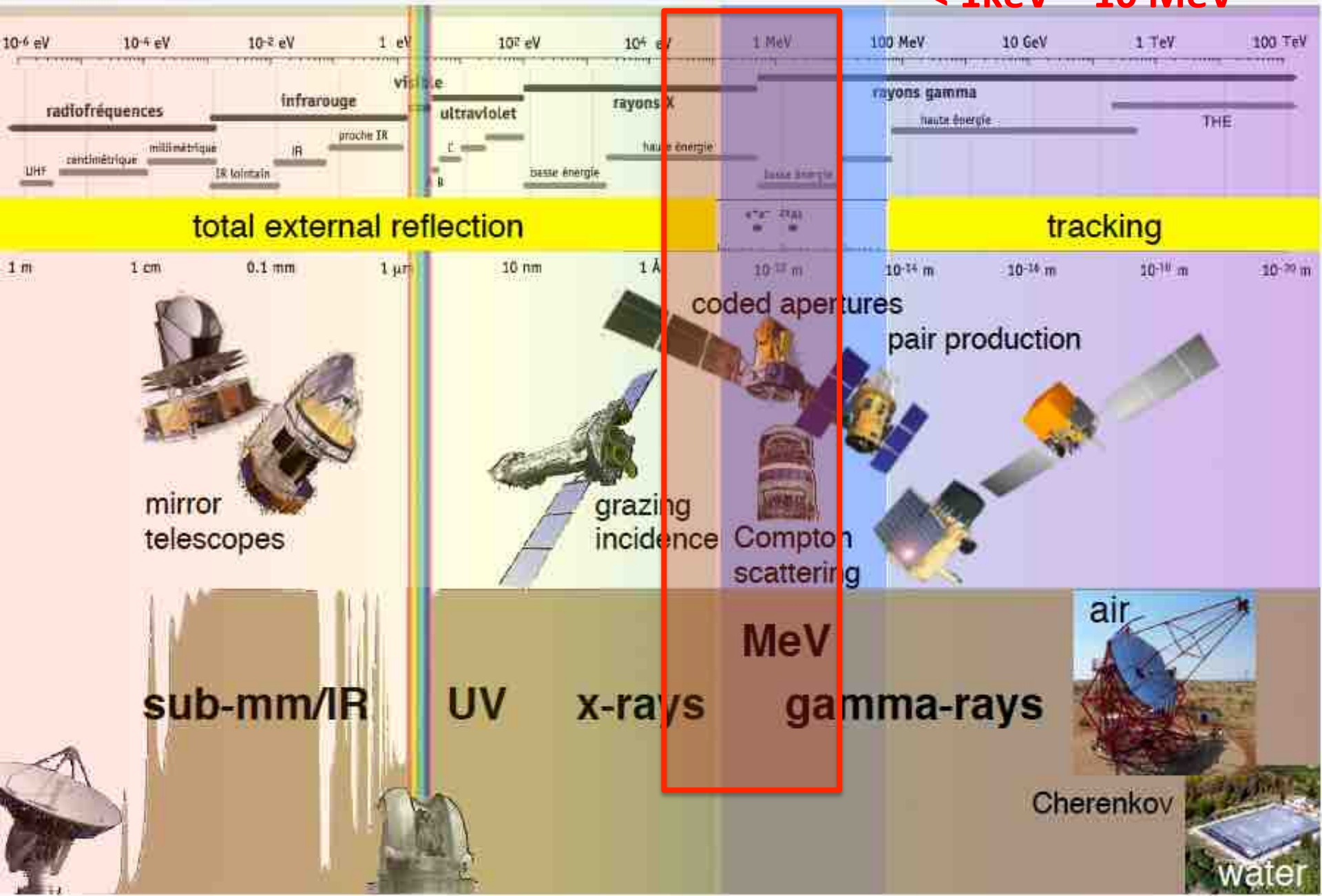
INTEGRAL is the link between the soft X-ray and high energy γ-ray

So far ~1000 INTEGRAL papers published
102+7 on-going PhD thesis (15+1 Italy)
and 100+ press release


Cos-b
August 1975
Exosat
May 1983
BEPPO-SAX
April 1996
XMM-Newton
December 1999
Integral
October 2002
Swift
November 2004
Agile
April 2007
Fermi
June 2008
From BeppoSAX increasing the energy range in the last 20 years → XMM → INTEGRAL → AGILE → and CTA to exploit very high energy gamma ray science
Now: hunting Gravitational Wave astrophysical counterparts

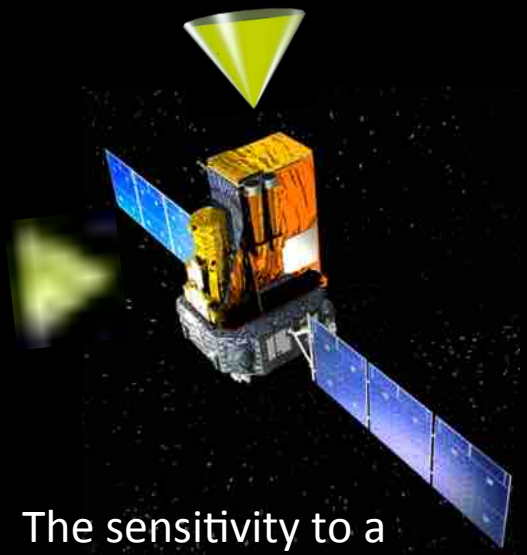
Electromagnetic Astronomy

SWIFT-INTEGRAL
< 1keV – 10 MeV

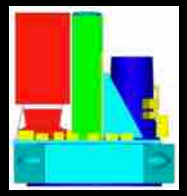


The SPI/ACS detectors view ~4π solid angle of the sky.
E>75 keV, Tres=50ms
Effective area: up to 1m^2

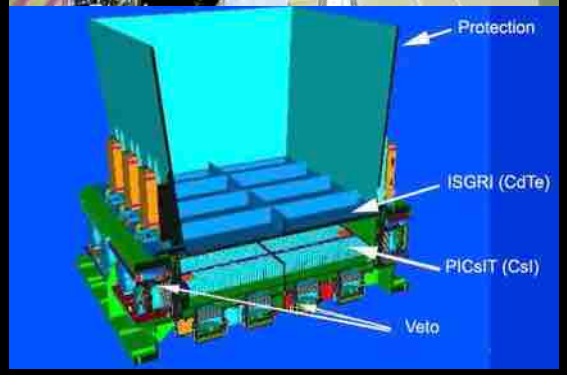
The IBIS detectors ISGRI and PICsIT have max sensitivity to directions normal to SPI/ACS
factor of 5 at least



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 in the ~0.25-2.6 MeV band.
PICsIT: T_res=15.6ms
Effective area up to ~900cm^2



INTEGRAL is similar to BeppoSAX for GW counterpart search…

SUBMITTED TO APJS
Preprint typeset using LaTeX style AASTeX6 v. 1.0

SUPPLEMENT: LOCALIZATION AND BROADBAND FOLLOW-UP OF THE GRAVITATIONAL-WAVE TRANSIENT GW150914

THE LIGO SCIENTIFIC COLLABORATION AND THE VIRGO COLLABORATION,
THE AUSTRALIAN SQUARE KILOMETER ARRAY PATHFINDER (ASKAP) COLLABORATION, THE BOOTES COLLABORATION,
THE DARK ENERGY SURVEY AND THE DARK ENERGY CAMERA GW-EM COLLABORATIONS, THE *Fermi* GBM COLLABORATION,
THE *Fermi* LAT COLLABORATION, THE GRAVITATIONAL WAVE INAF TEAM (GRAWITA), THE *INTEGRAL* COLLABORATION,
THE INTERMEDIATE PALOMAR TRANSIENT FACTORY (iPTF) COLLABORATION, THE INTERPLANETARY NETWORK,
THE J-GEM COLLABORATION, THE LA SILLA–QUEST SURVEY, THE LIVERPOOL TELESCOPE COLLABORATION,
THE LOW FREQUENCY ARRAY (LOFAR) COLLABORATION, THE MASTER COLLABORATION, THE MAXI COLLABORATION,
THE MURCHISON WIDE-FIELD ARRAY (MWA) COLLABORATION, THE PAN-STARRS COLLABORATION,
THE PESSTO COLLABORATION, THE PI OF THE SKY COLLABORATION, THE SKYMAPPER COLLABORATION,
THE *Swift* COLLABORATION, THE TAROT, ZADKO, ALGERIAN NATIONAL OBSERVATORY, AND C2PU COLLABORATION,
THE TOROS COLLABORATION, AND THE VISTA COLLABORATION

(See the end matter for the full list of authors.)

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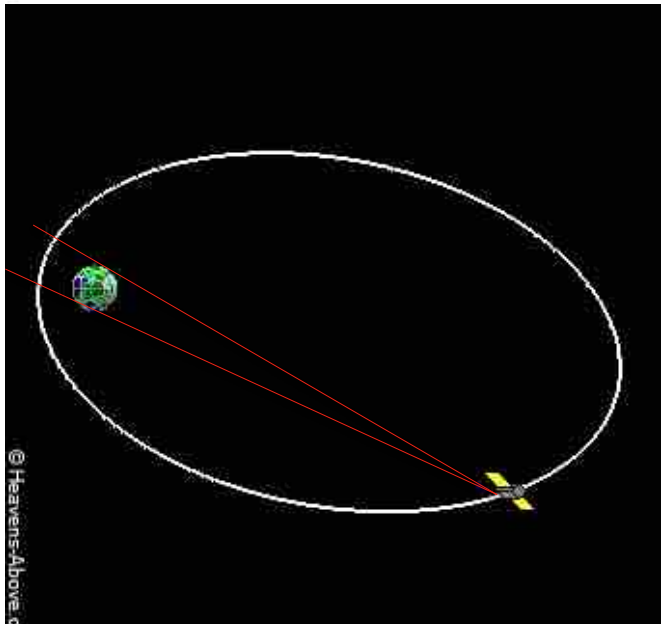
Optical spectroscopy and narrow-field radio observations are indicated with darker tick marks and boldface text. More detailed information on the timeline of observations is reported in Table 2.



arxiv1602.08492

V. Savchenko et al., 2016 ApJL, 820,L36
Abbott, B. P et al, 2016 ApJL

INTEGRAL UL on γ-ray emission from GW150914

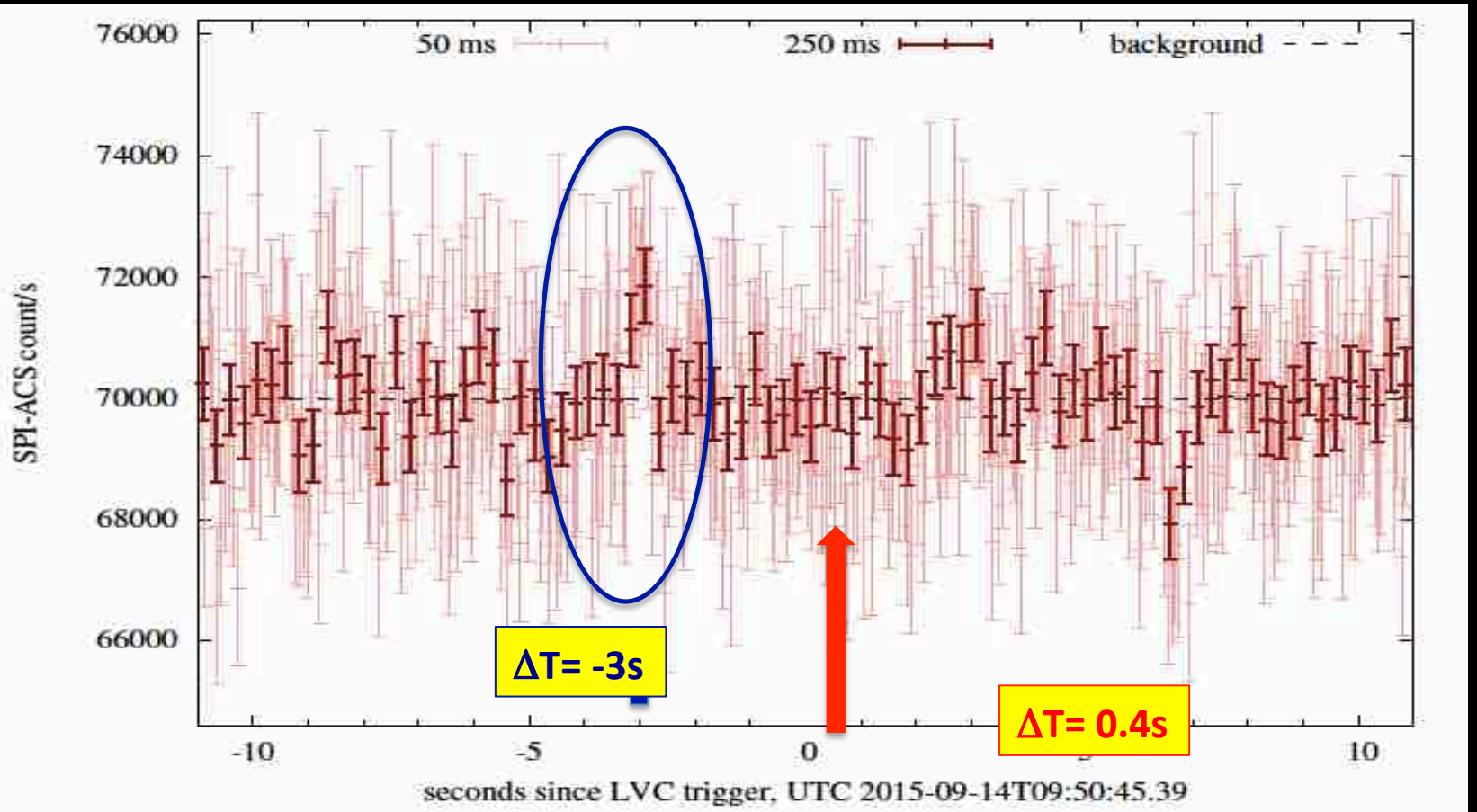
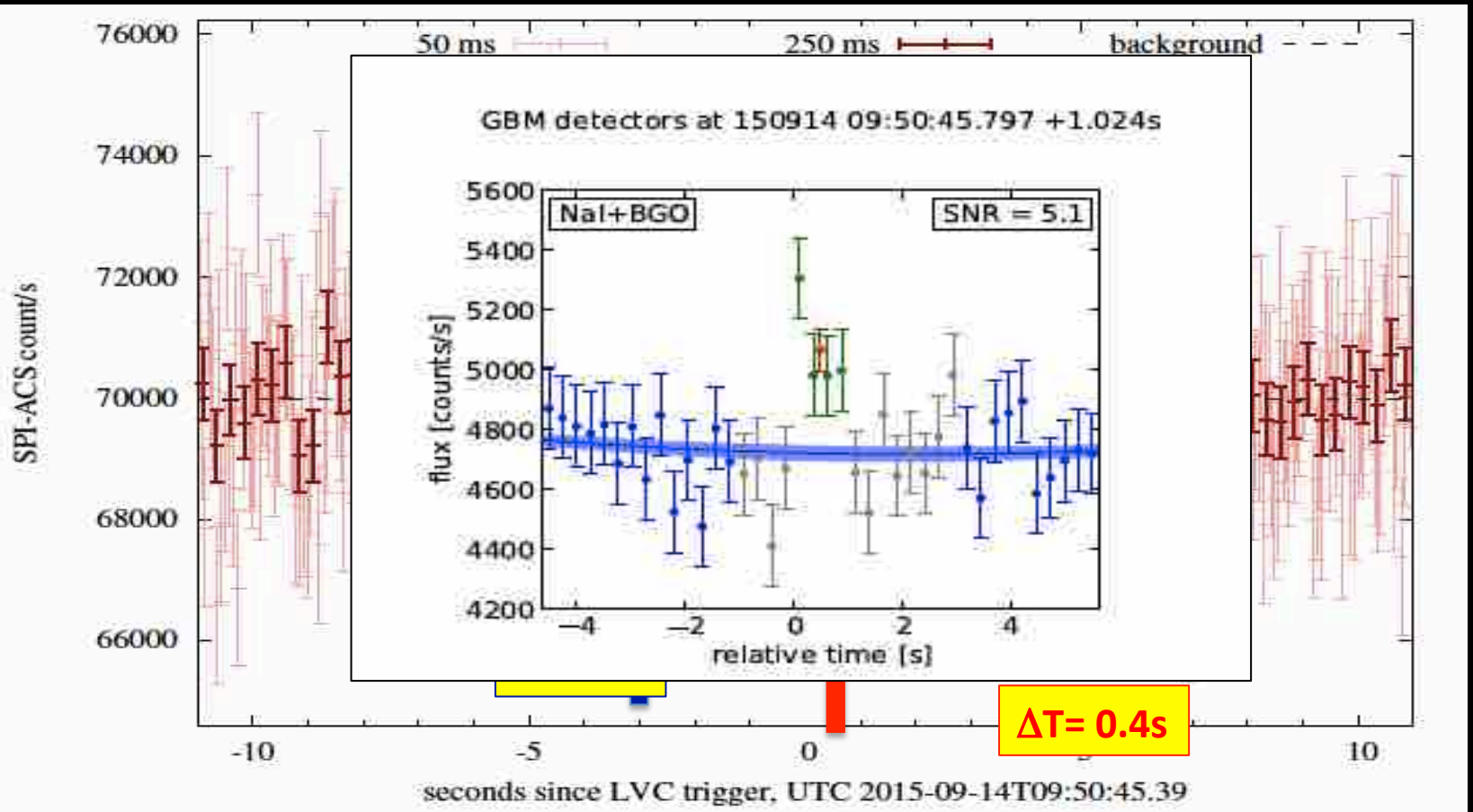


Fig. 1.— INTEGRAL/SPI-ACS lightcurve in ±10 s around GW150914 trigger time. Light red symbols represent the measurements at the natural instrument time resolution of 50 ms; dark red points are rebinned to 250 ms. The dashed black curve is the background level estimated from a long-term average.

http://arxiv.org/abs/1602.04180

INTEGRAL UL on γ-ray emission from GW150914



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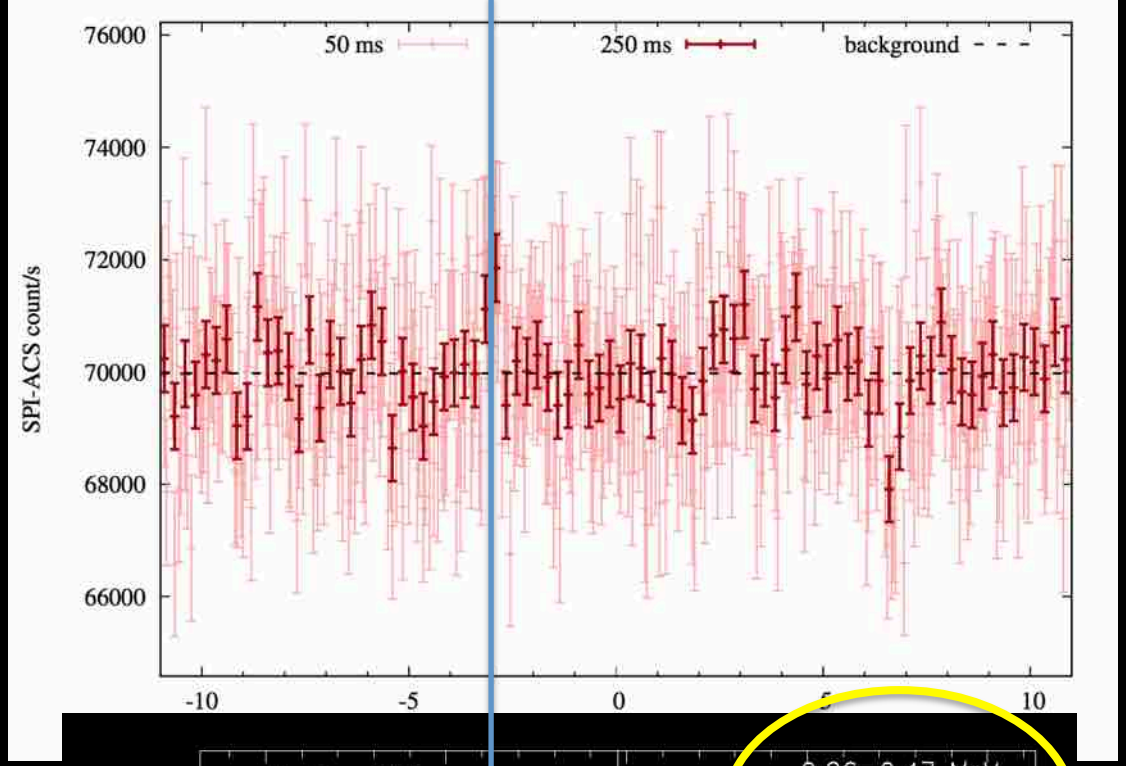

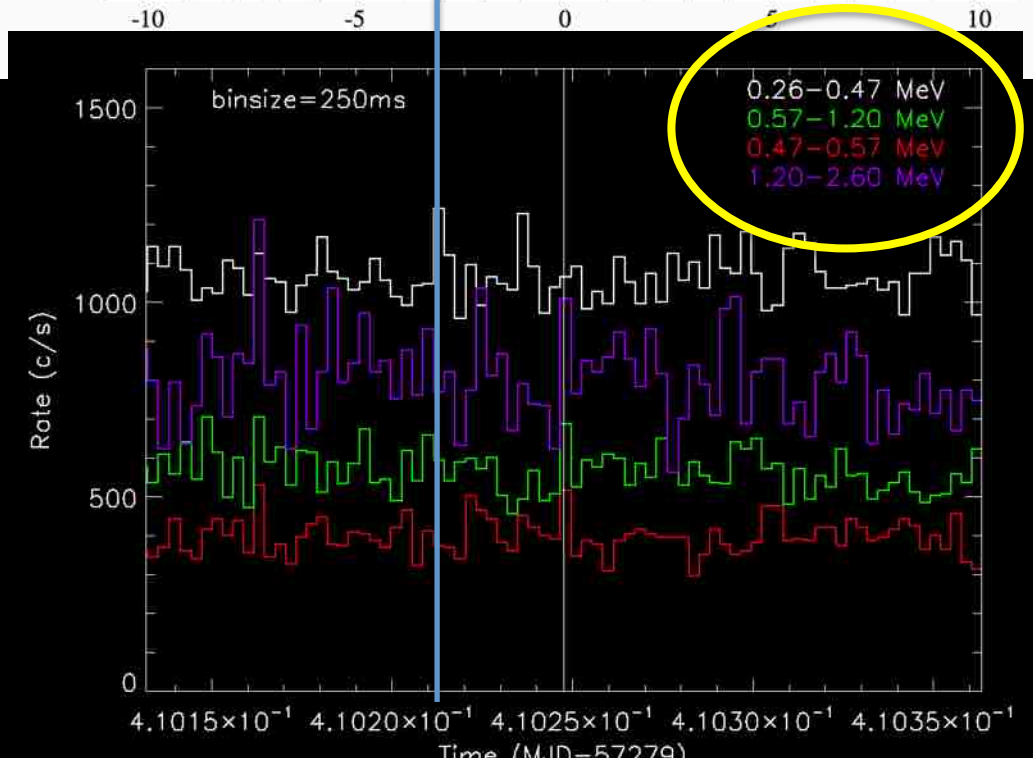

PICSIT Spectral Timing data
260 keV – 2.6 MeV

16ms time resolution

INTEGRAL UL on γ-ray emission from GW150914

- ✓ The Real-time IBAS GRB trigger system has not been triggered by the GW event. Off-line analysys has then been performed.

- ✓ INTEGRAL has observed the whole sky in the range from 50KeV to 2MeV before and after the reported GW150914 event

- ✓ Using the omni-directional view of the INTEGRAL/SPI-ACS and the IBIS-PICSIT side FoV we have obtained tight upper limits on

  the hard X-ray/γ-ray prompt emission

- ✓ INTEGRAL, FERMI and SWIFT data strongly constrain the fraction of energy emitted in the high energy electromagnetic component from the full *high-probability sky region* of LIGO/Virgo trigger

LVT 151012

- Event with associated false alarm probability of 0.02
- Location compatible to be within INTEGRAL FoV
- Possible binary BH merger, with masses 23^{+18}_{-6} $M_\odot$ and 13^{+4}_{-5} $M_\odot$ and redshift $0.21^{+0.09}_{-0.09}$

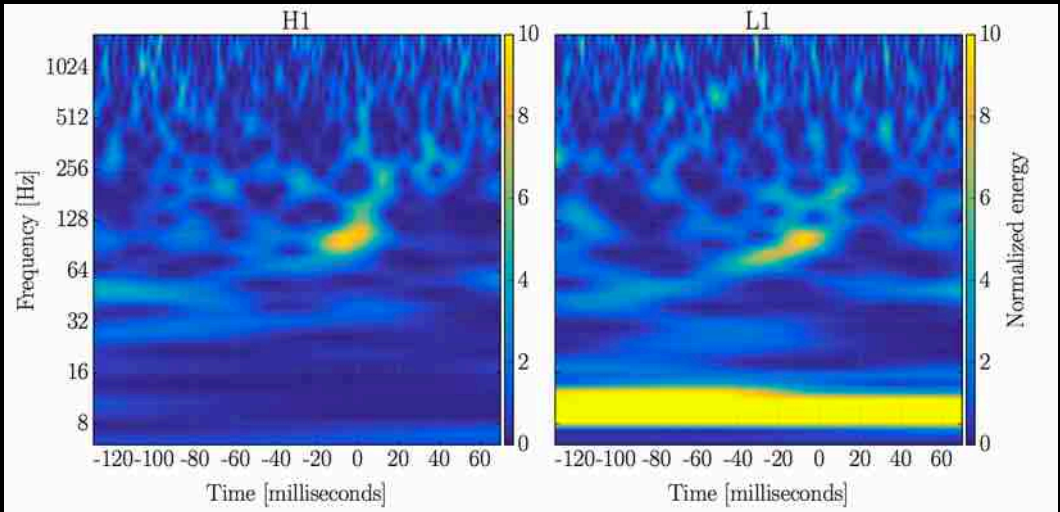

Figure 13: Normalized spectrograms of LVT151012 in LIGO-Hanford (left) and LIGO-Livingston (right) $h(t)$ data with the same central GPS time. Note these spectrograms have a much smaller normalized energy scale than those in Figure 10.

Abbott+16, arXiv:1602.03844v3

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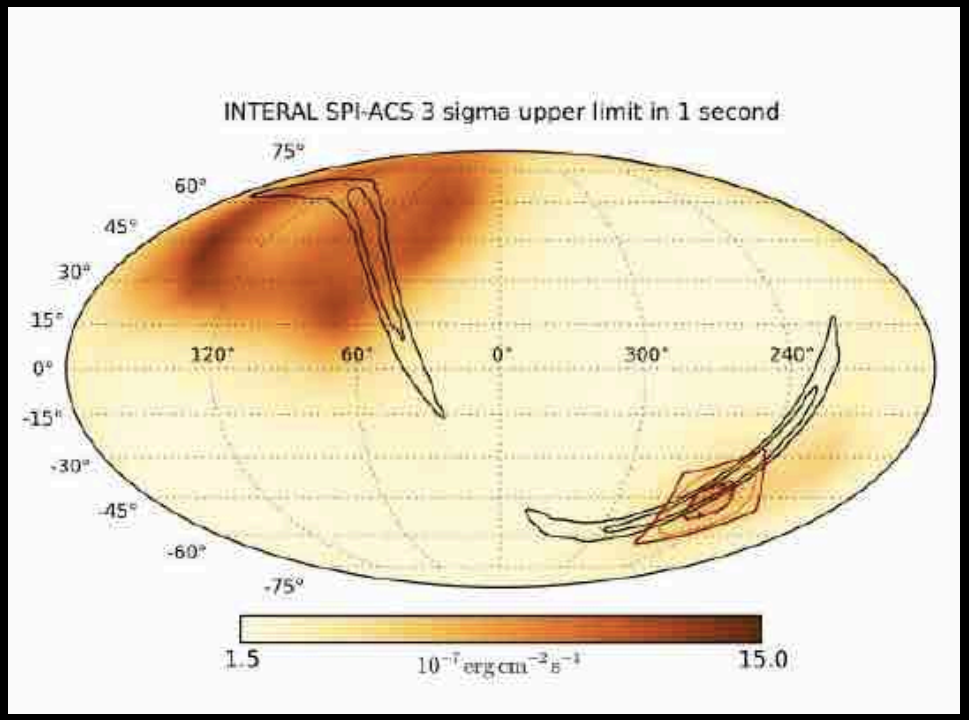
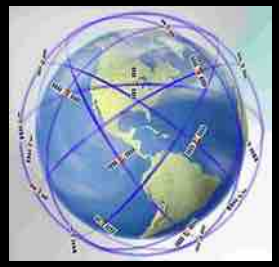


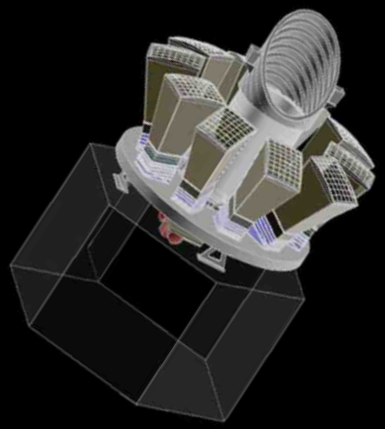
Abbott+16, arXiv:1602.03844v3

What's next:
OP2 →1 trigger/week



INTEGRAL-SWIFT
Large Observatories
>10 years operations

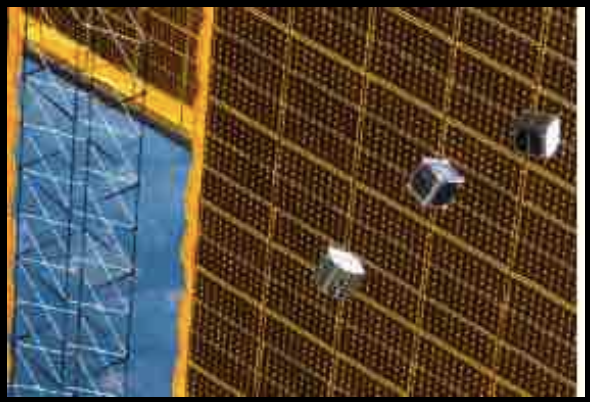
Low cost!..INAF support essential



LOBSTER (NASA)
Theseus (ESA)

Lobster eye X-Ray
+ gamma-ray trigger
10-50 grb High Z

10y dev. Cost
100-500M€



The HERMES mission
High Energy Rapid Modular Experiment Satellites

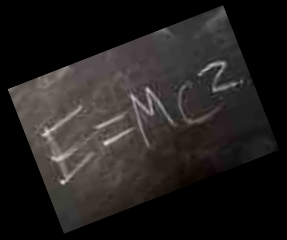
Cubesat sworm constellation
Arcsec positioning

Short turnaround
Moderate cost, modularity:
100cubesat

CONCLUSIONS

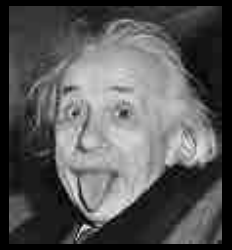
- INTEGRAL operation was changed after GW 150914 to IMMEDIATELY follow-up the NEXT GW trigger.

- INTEGRAL has constrained the energy emitted in the high energy electromagnetic component from the full *high-probability* sky region of LIGO/Virgo trigger to:

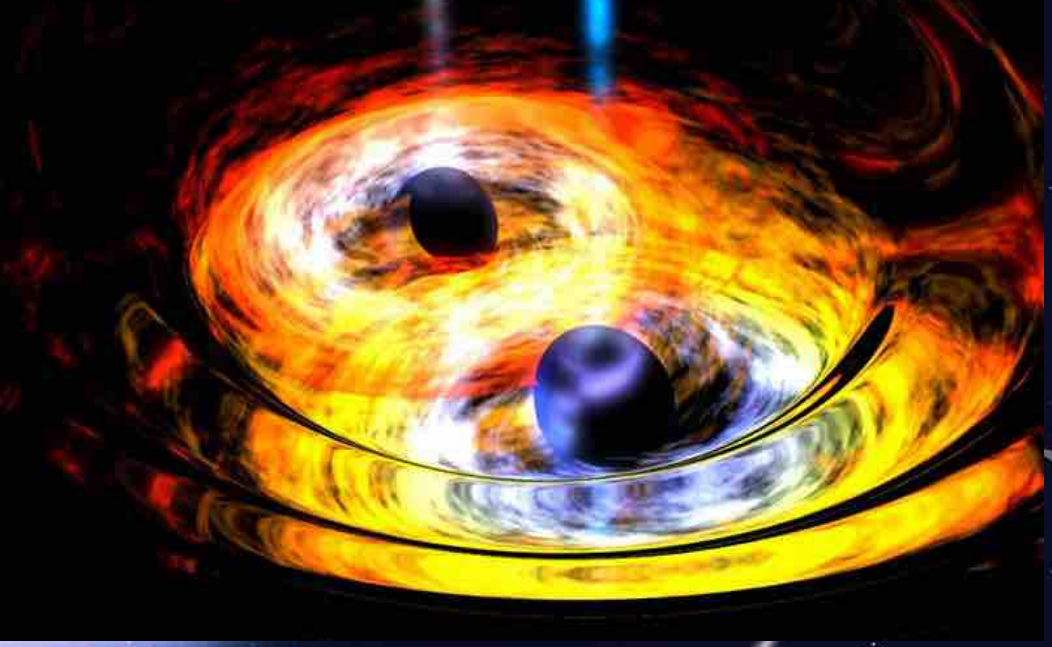


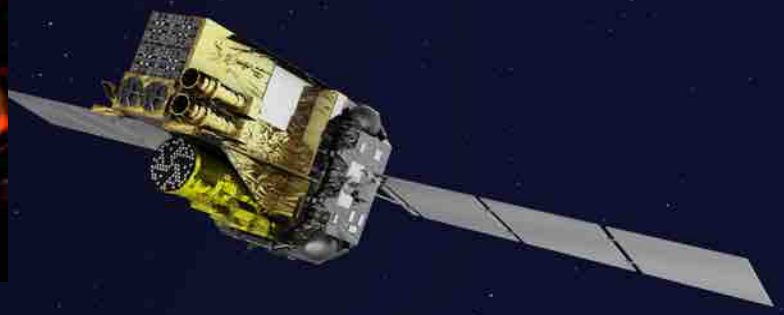
$$E_g/E_{GW} < 10^{-6}$$

$$L_{iso} \leq 10^{46}\ erg/s$$

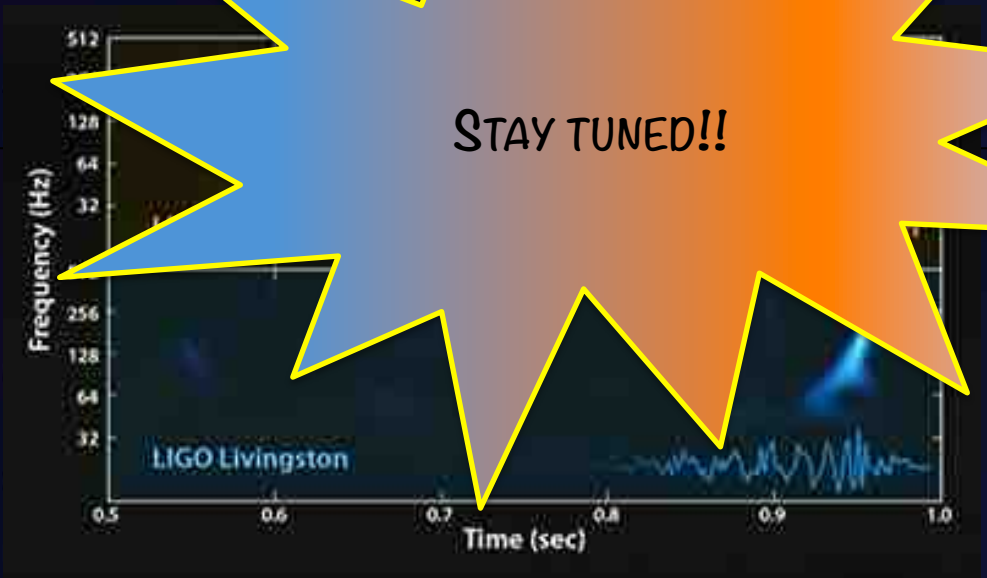


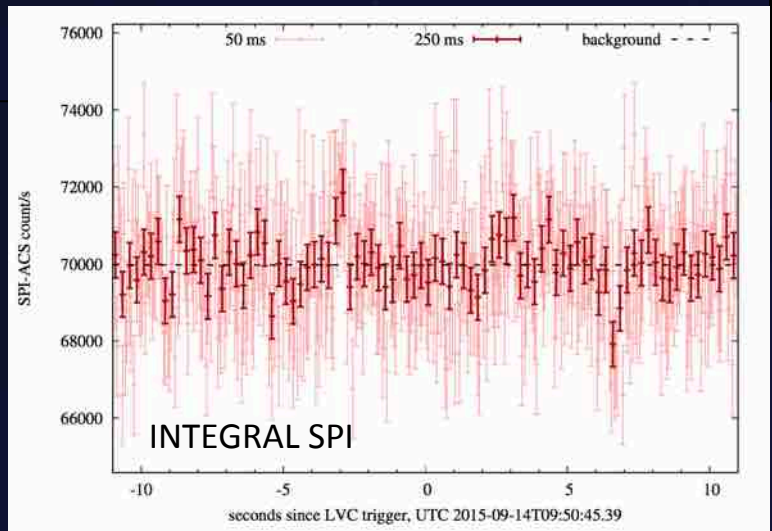
- *INTEGRAL has observed with the allsky monitor LVT 151012 and a large part of the LIGO/VIRGO error box is within the FoV!! →*
- *best chance for a signal→looking for the data NOW or...*
- *More stringent upper limit to come...*





STAY TUNED!!


Frequency (Hz)
512
128
64
32
256
128
64
32
LIGO Livingston
0.5
0.6
0.7
0.8
0.9
1.0
Time (sec)


50 ms
250 ms
background
SPI-ACS count/s
76000
74000
72000
70000
68000
66000
INTEGRAL SPI
-10
-5
0
5
10
seconds since LVC trigger, UTC 2015-09-14T09:50:45.39