

INTEGRAL RESULTS ON GW COUNTERPARTS

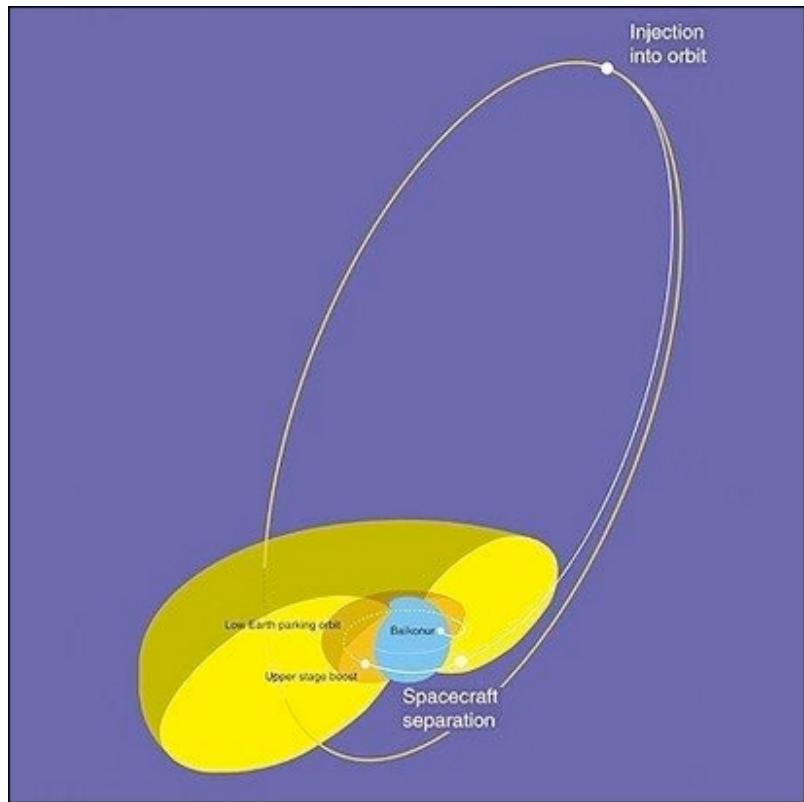
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IASF-Milano, INAF

**V.Savchenko, C.Ferrigno, E.Kuulkers, A.Bazzano, E.Bozzo, S.Brandt, T.Courvoisier, R.Diehl,
L.Hanlon, A. von Kienlin, L.Natalucci, P.Laurent, F.Lebrun, J.P.Roques, P.Ubertini,
G.Weidenspointner, J.Chevinez, A.Lutovinov, A.Martin-Carrillo, R.Sunyaev, et al.**

October 6, 2017 - Theseus Workshop - Napoli

INTEGRAL has unique capabilities for e.m. searches of GW and neutrino events



2.7 days orbit (since Jan 2015) with 85% useful observing time above radiation belts

Only very small fraction of sky occulted by Earth

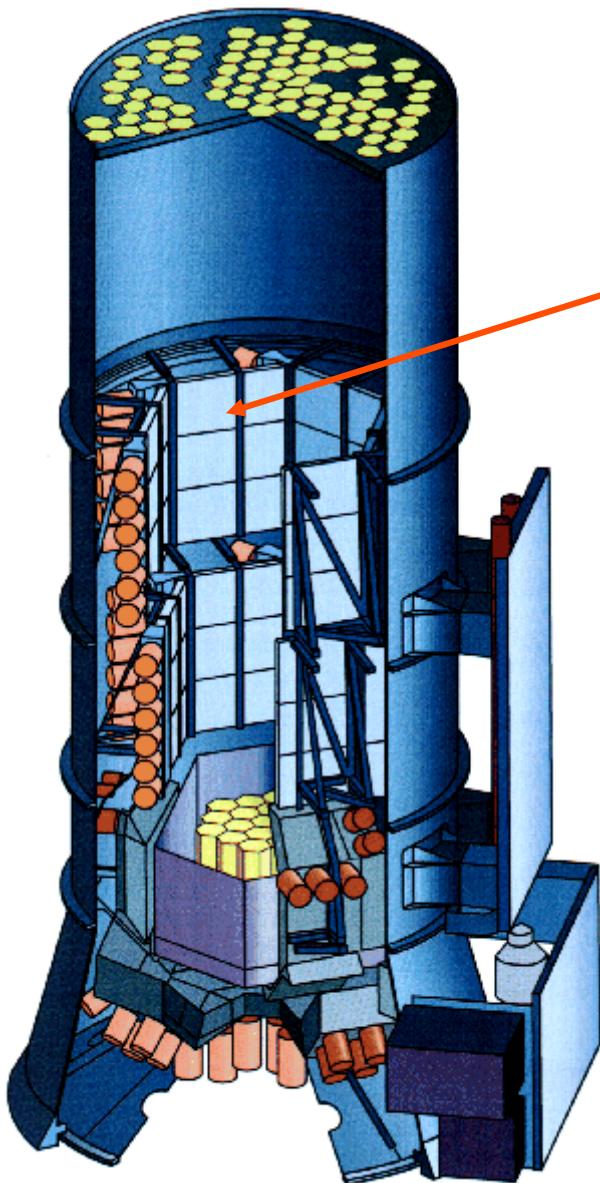
All data transmitted to ground in real time and analysed by IBAS within few seconds

Very good sensitivity with imaging in the FOV
+

Continuous all-sky coverage (4π) without imaging

INTEGRAL SPI /ACS

(von Kienlin+ 2003)



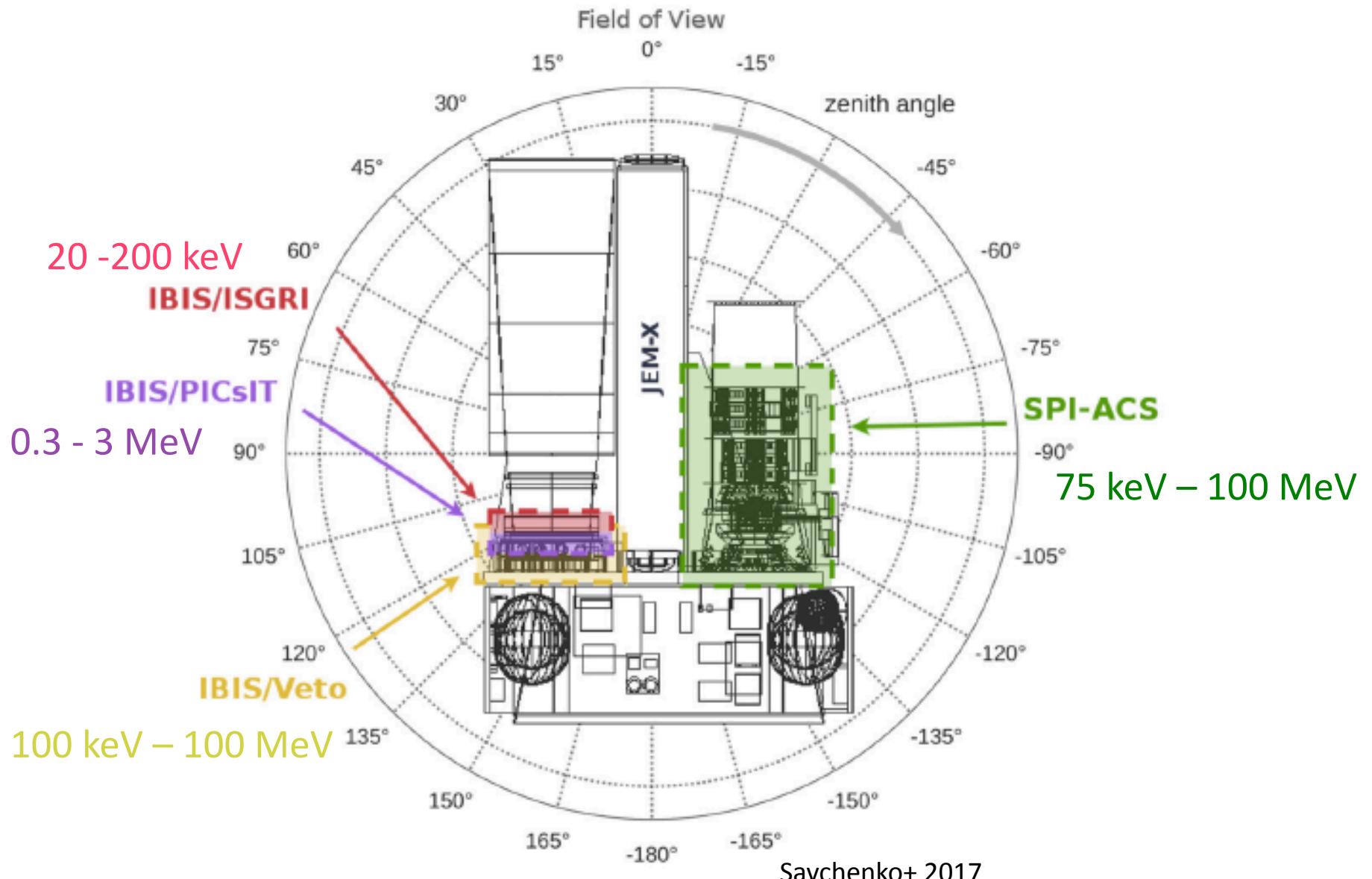
Anti Coincidence Shield (ACS)
(512 kg, 91 BGO blocks)

The ACS is also used as an
omni-directional GRB detector
($E > 75$ keV)

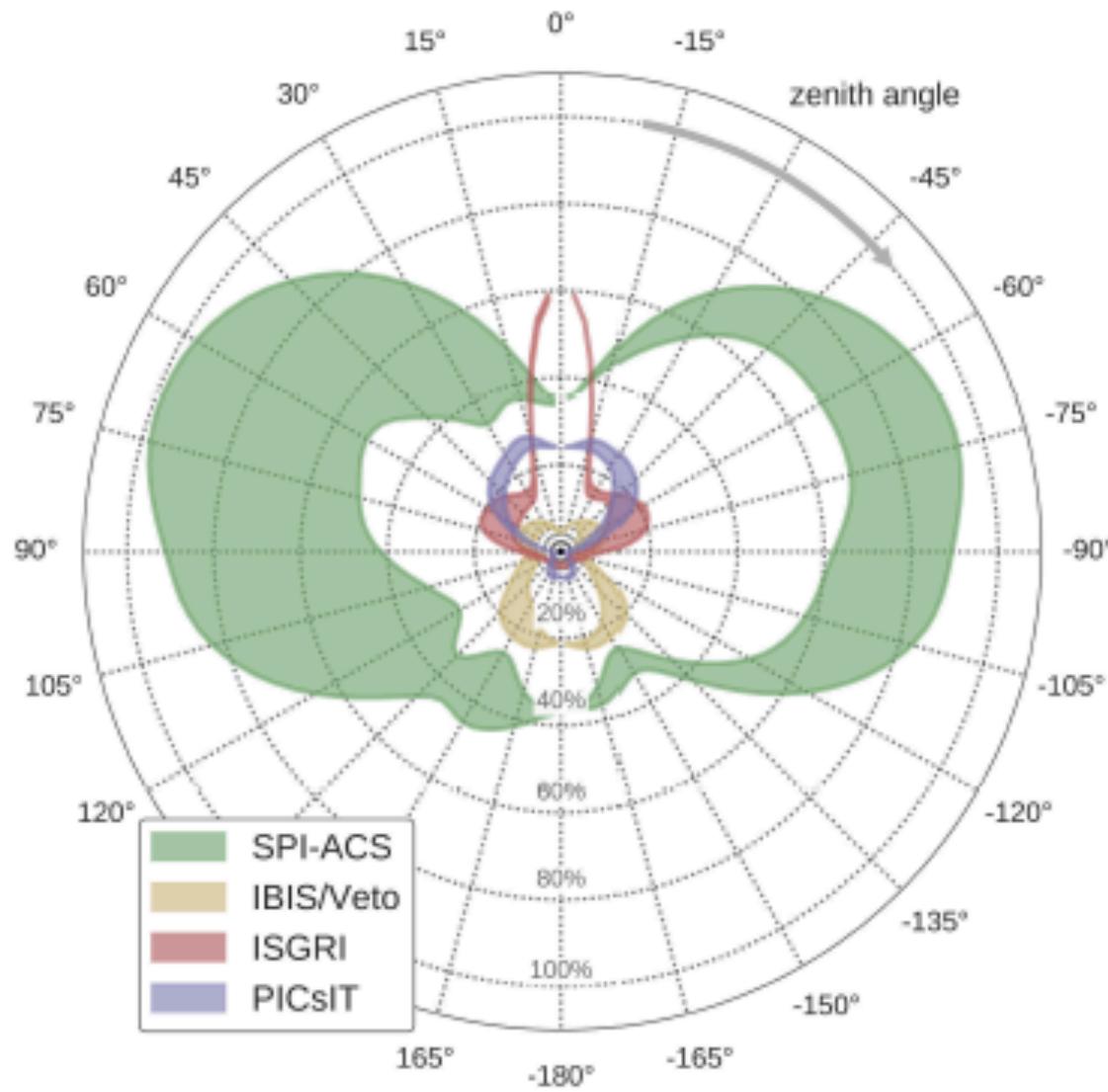
Provides:

- No direction information
- No energy information
- light curve in 50 ms bins
- Very stable BKG
 $\sim 3000/6000$ cts/bin

Omnidirectional sky coverage with complementary detectors in hard X-/γ-ray



Relative sensitivity as a function of zenith angle

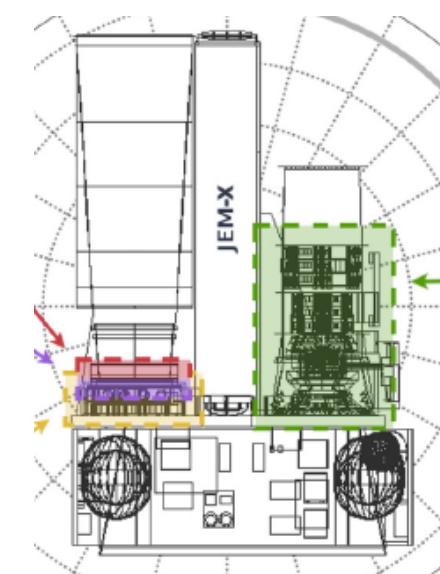


Savchenko+ 2017

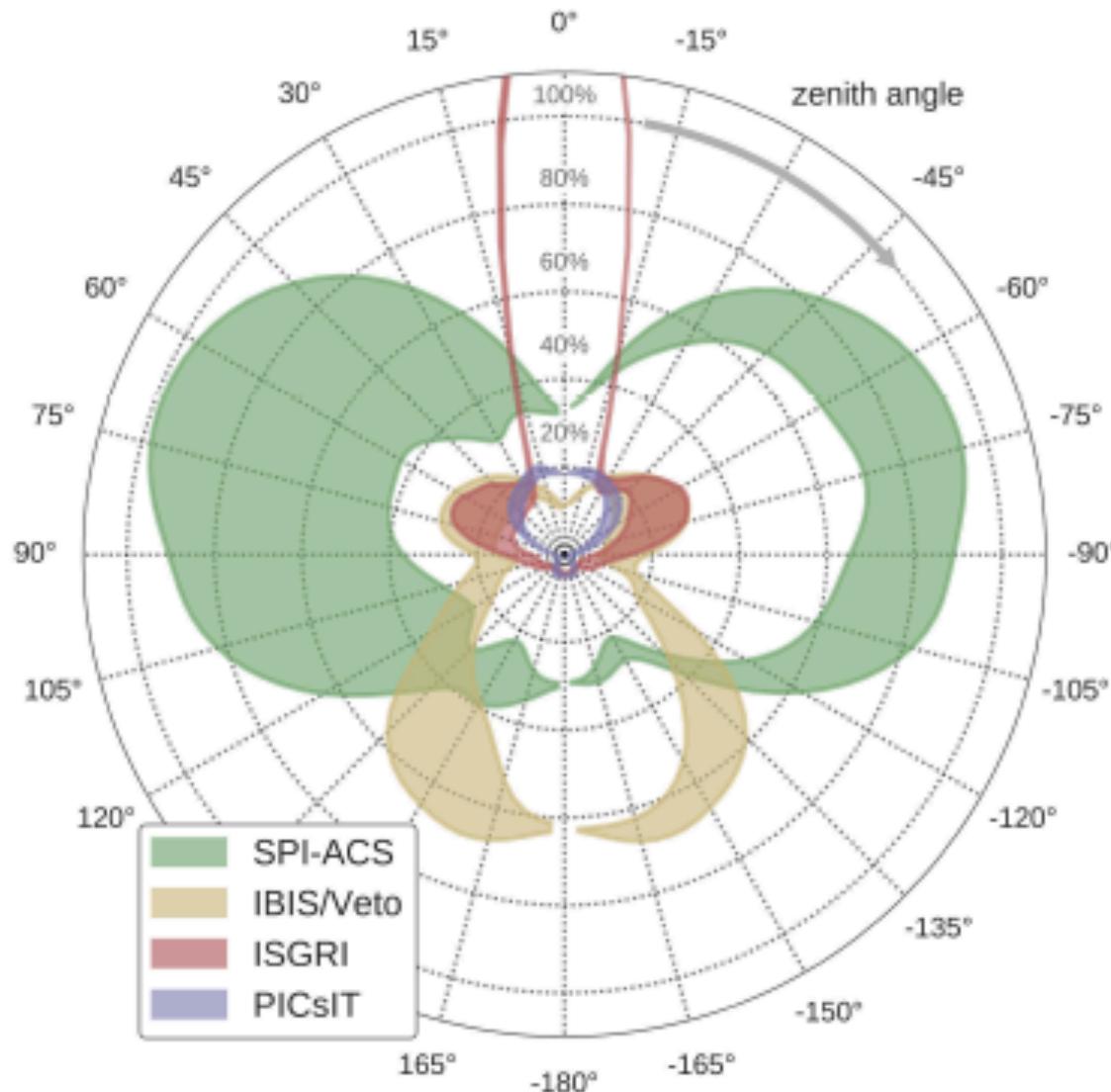
Short hard burst

1 sec

CPL $\alpha=-0.5$ $E_p=600$ keV



Relative sensitivity as a function of zenith angle

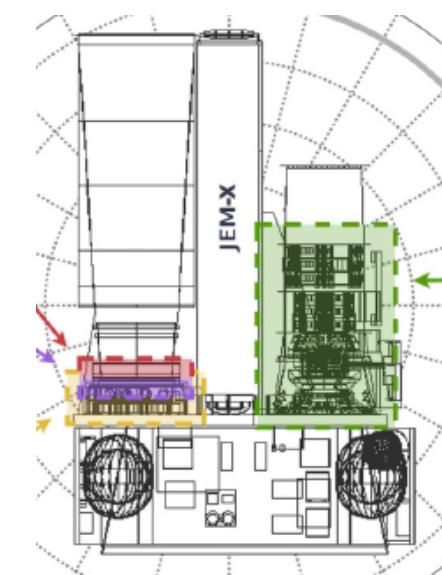


Savchenko+ 2017

Long burst

8 sec

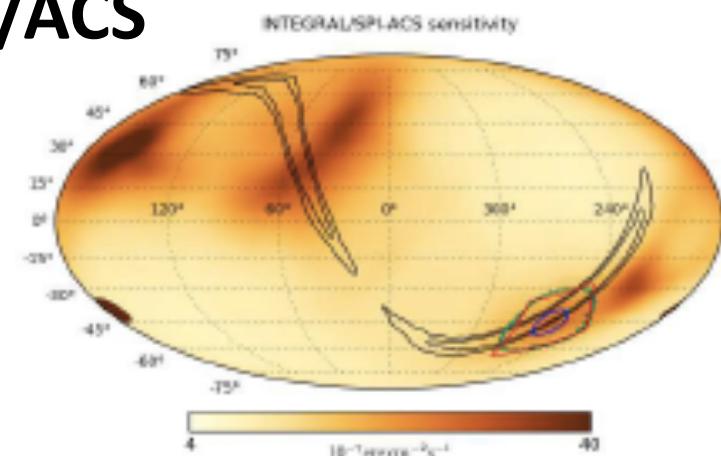
$\alpha=-1$ $\beta=-2.5$ $E_p=300$ keV



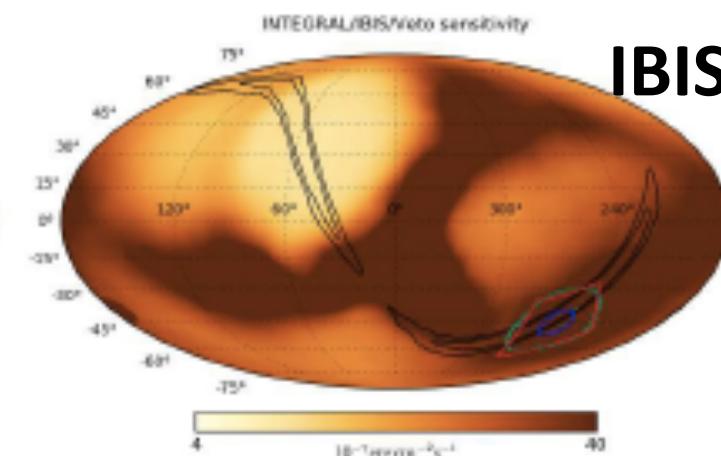
LTV 151012

Complementary use of several (quasi)-
omnidirectional instruments on board INTEGRAL

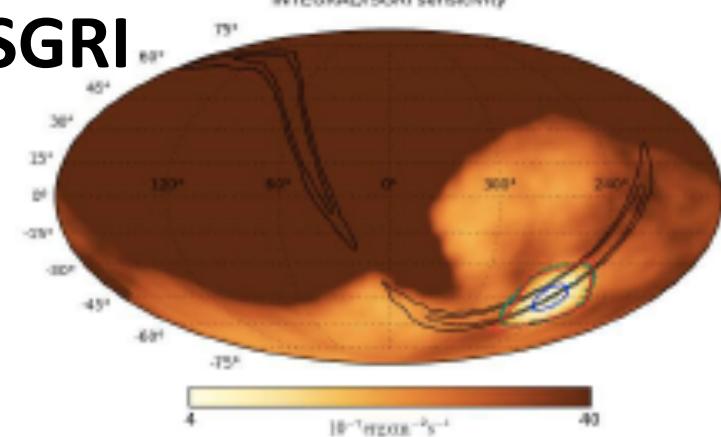
SPI/ACS



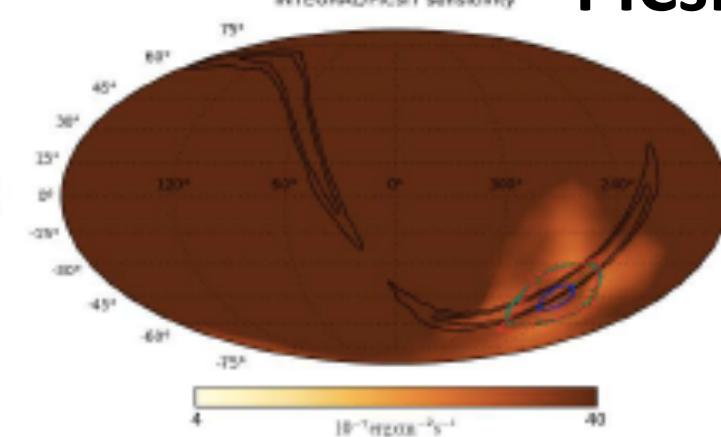
IBIS/VETO



ISGRI

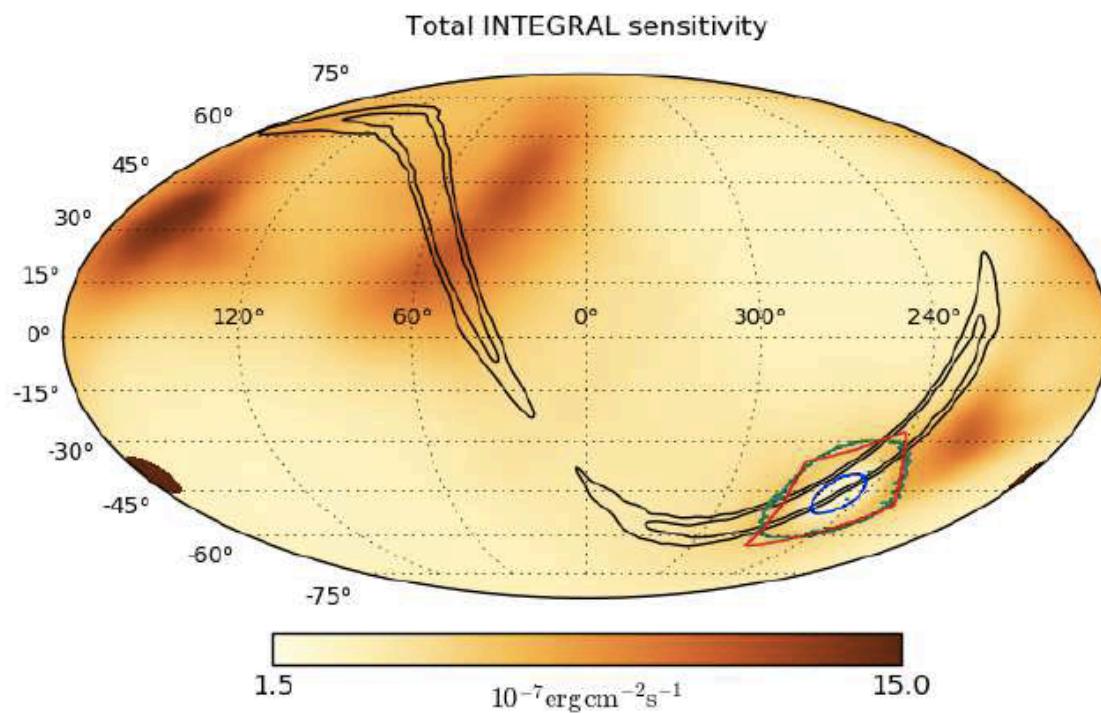


PICsIT



LTV 151012

Complementary use of several (quasi)- omnidirectional instruments on board INTEGRAL



Upper limits
on fluence (1 s)

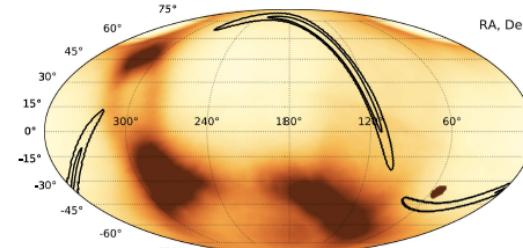
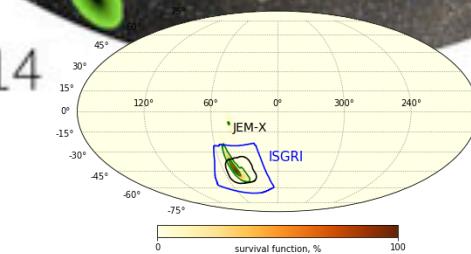
$< 2 \cdot 10^{-8} \text{ erg/cm}^2$
in field of view

$< 4 \cdot 10^{-7} \text{ erg/cm}^2$
in worst directions

INTEGRAL OBSERVATIONS

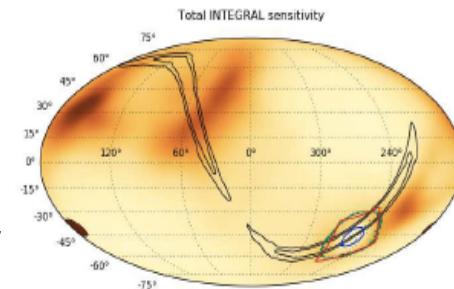


GW170814
Pointed
follow-up



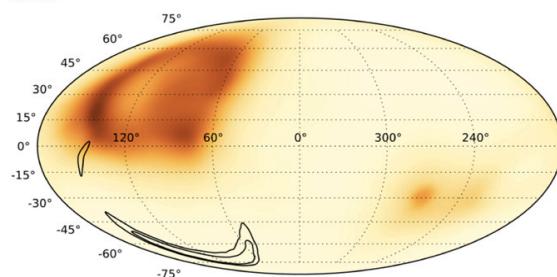
GW170104

LVT151012
Partially in FoV



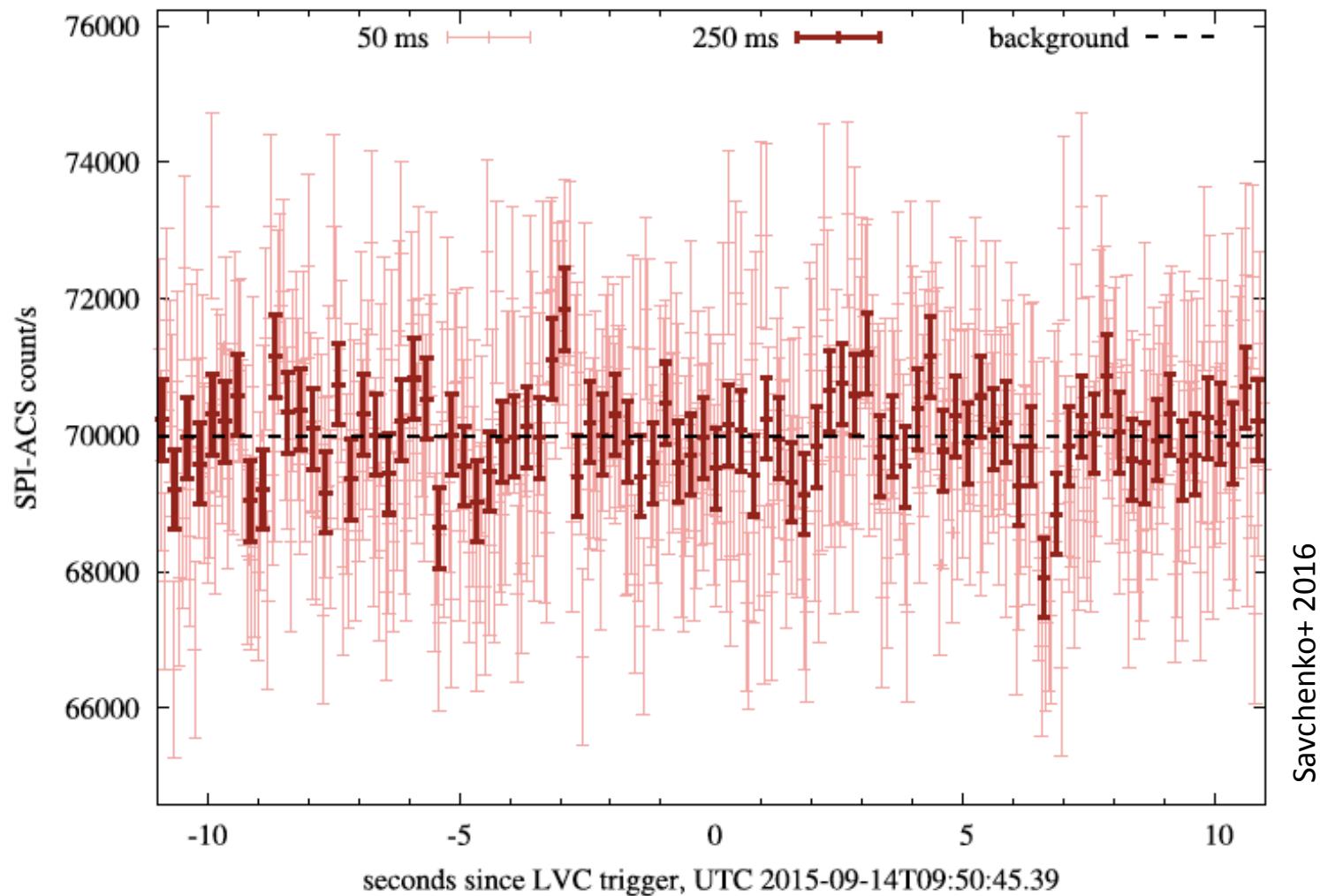
GW151226
NO DATA
(in Radiation Belts)

GW150914



GW 150914

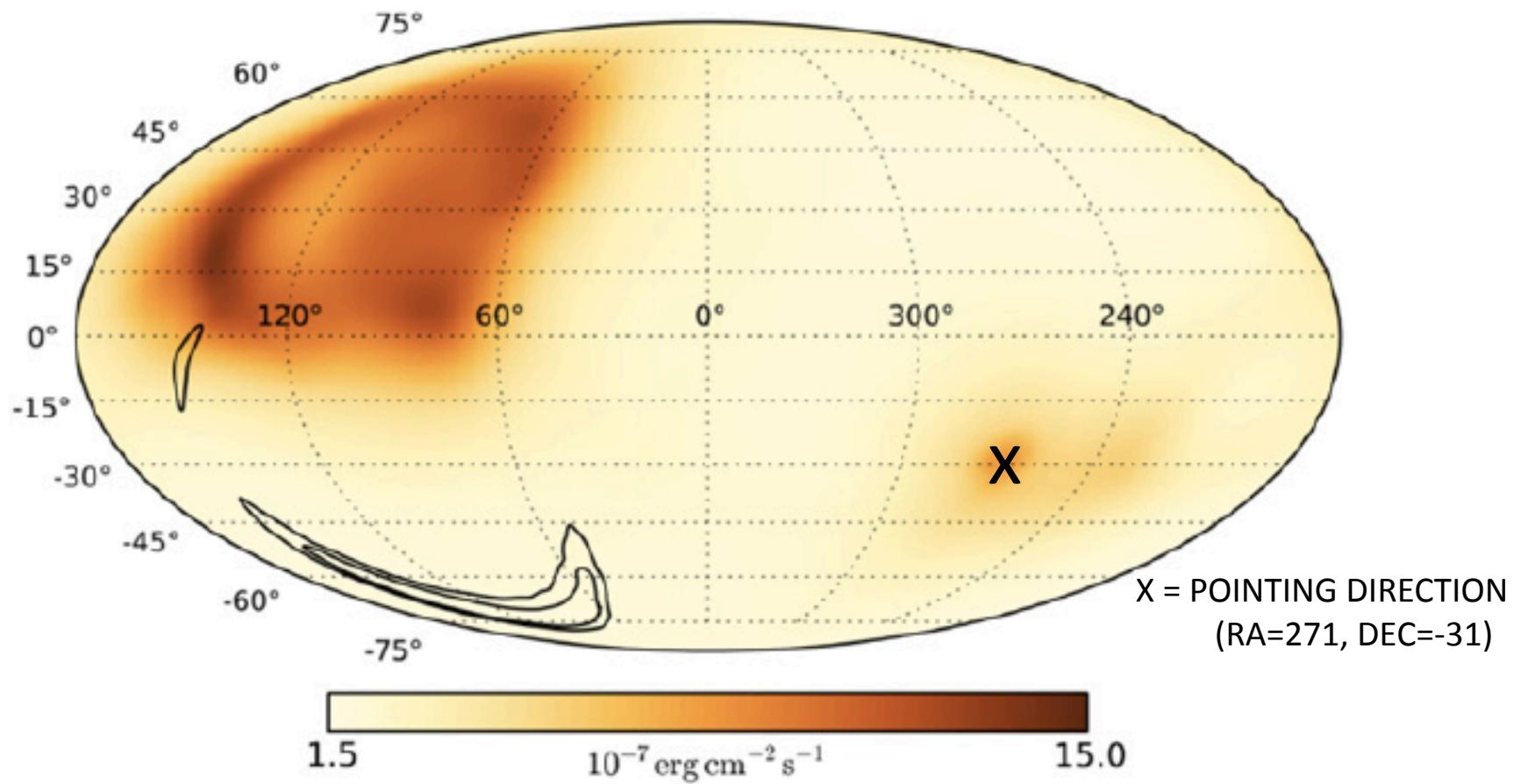
SPI-ACS light curve (>75 keV) around GW150914 trigger time



GW 150914

SPI-ACS 3 σ upper limit in 1 second

$F_{75-2000} < (1.2 - 1.7) \cdot 10^{-7}$ erg/cm² for 95% of error region



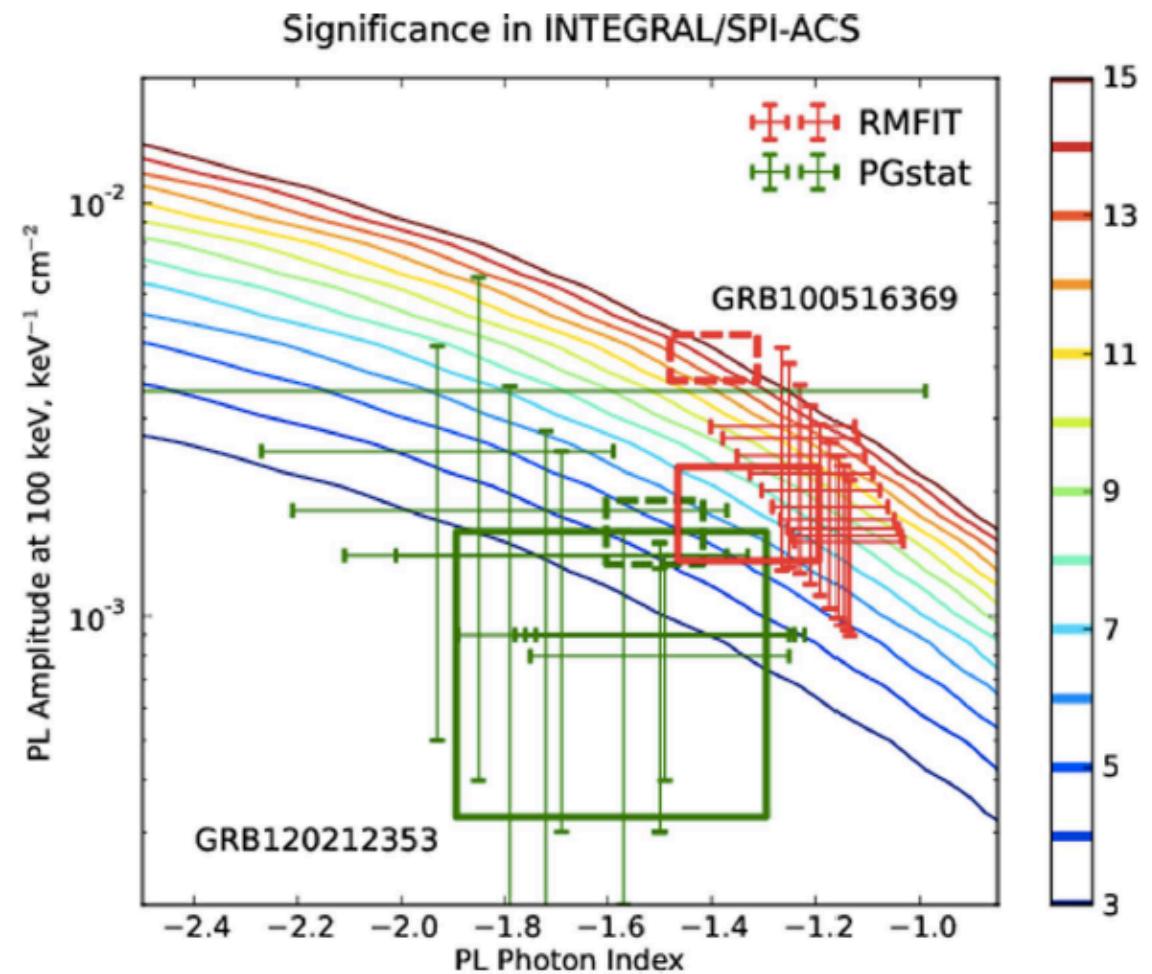
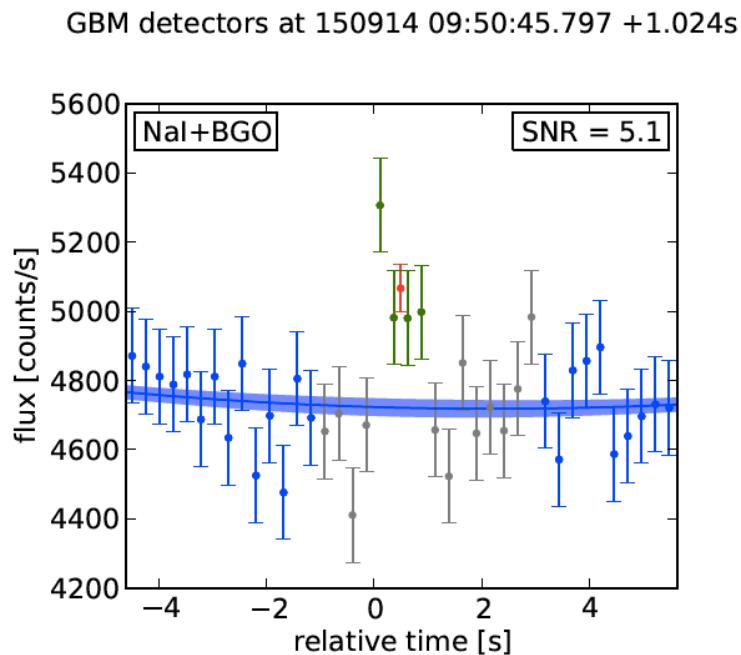
for $\alpha = -0.5$, $\beta = -2.5$, $E_p = 1.5$ MeV

GW 150914

COMPARISON WITH Fermi/GBM results

Greiner et al. 2016

Connaughton et al 2016



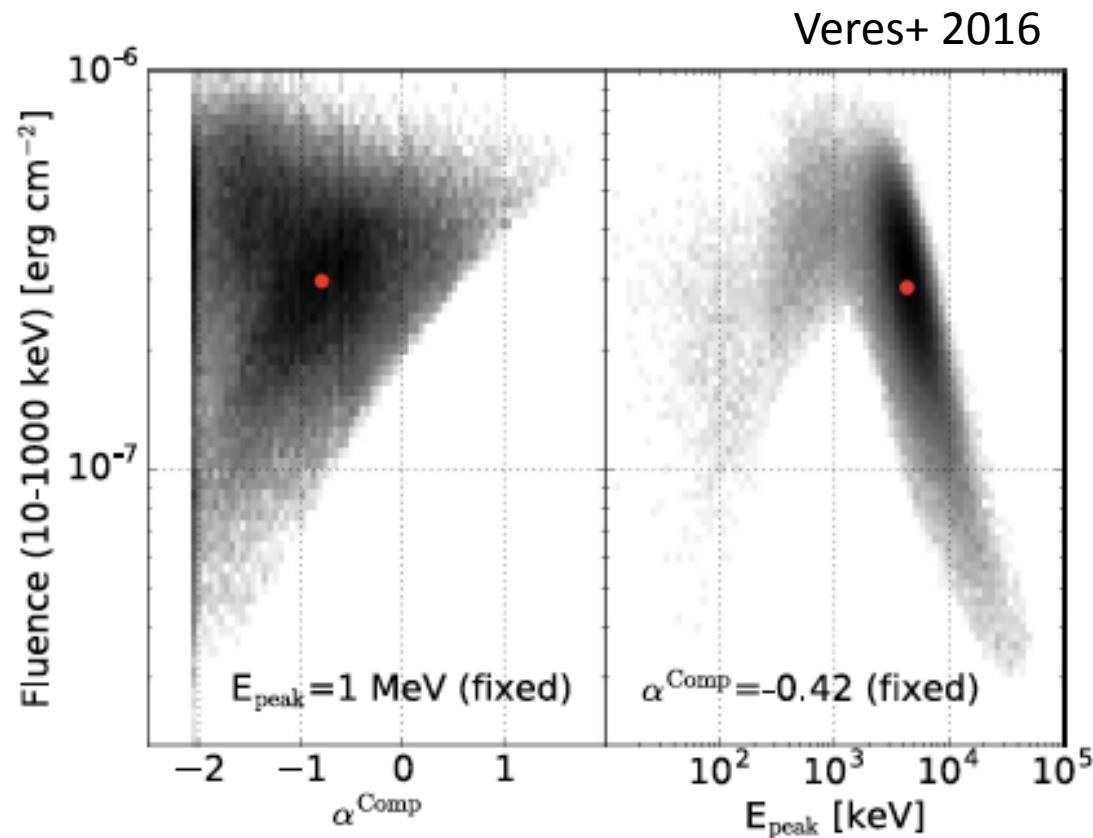
GW 150914

COMPARISON WITH Fermi/GBM results

Distribution of parameters allowed by observations, as found in Montecarlo simulations

Most spectra are hard and should have been seen by SPI/ACS

Intercalibration work ongoing



$$\frac{dN_{\text{ph}}}{dE} = A \left(\frac{E}{100 \text{ keV}} \right)^{\alpha^{\text{Comp}}} \exp \left(-\frac{E(\alpha + 2)}{E_{\text{pk}}^{\text{Comp}}} \right).$$

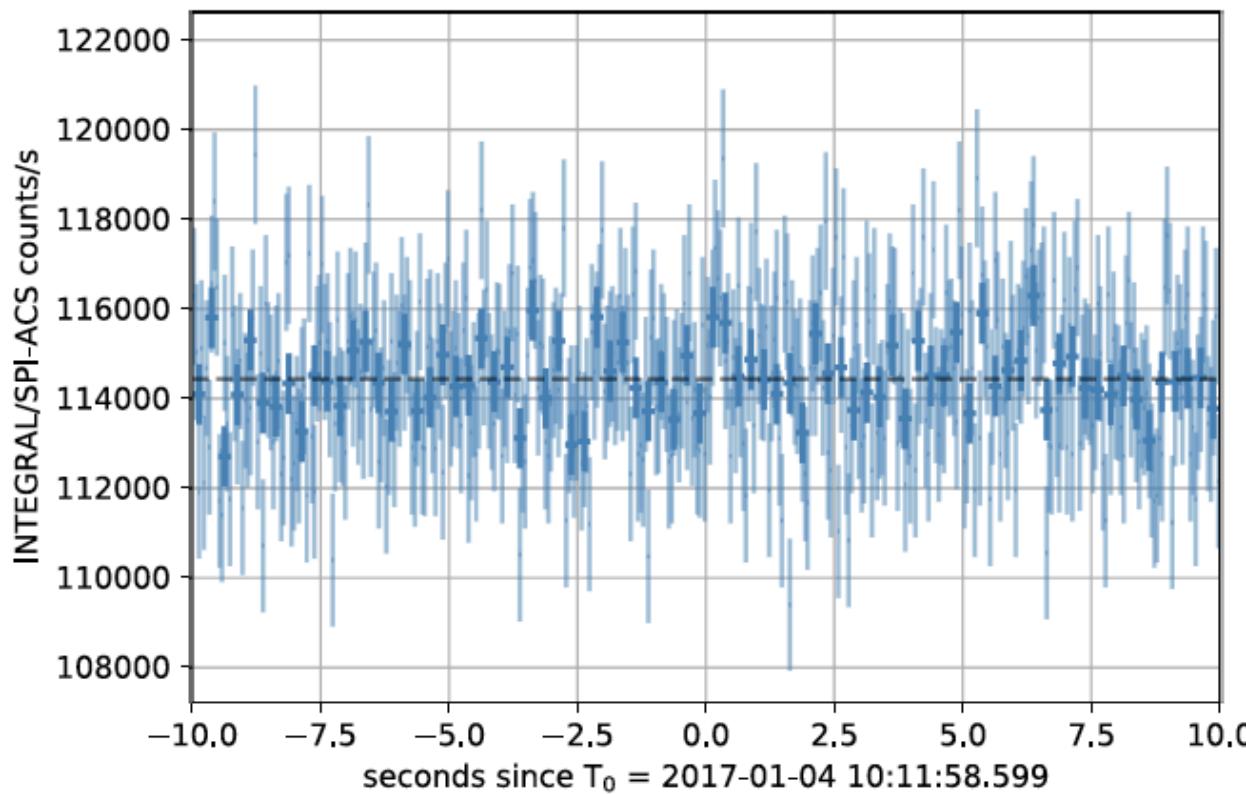
GW 170104

$$31.2 + 19.4 \rightarrow 48.7 M_{\odot}$$

$$d = 880 \text{ Mpc} \quad z=0.18$$

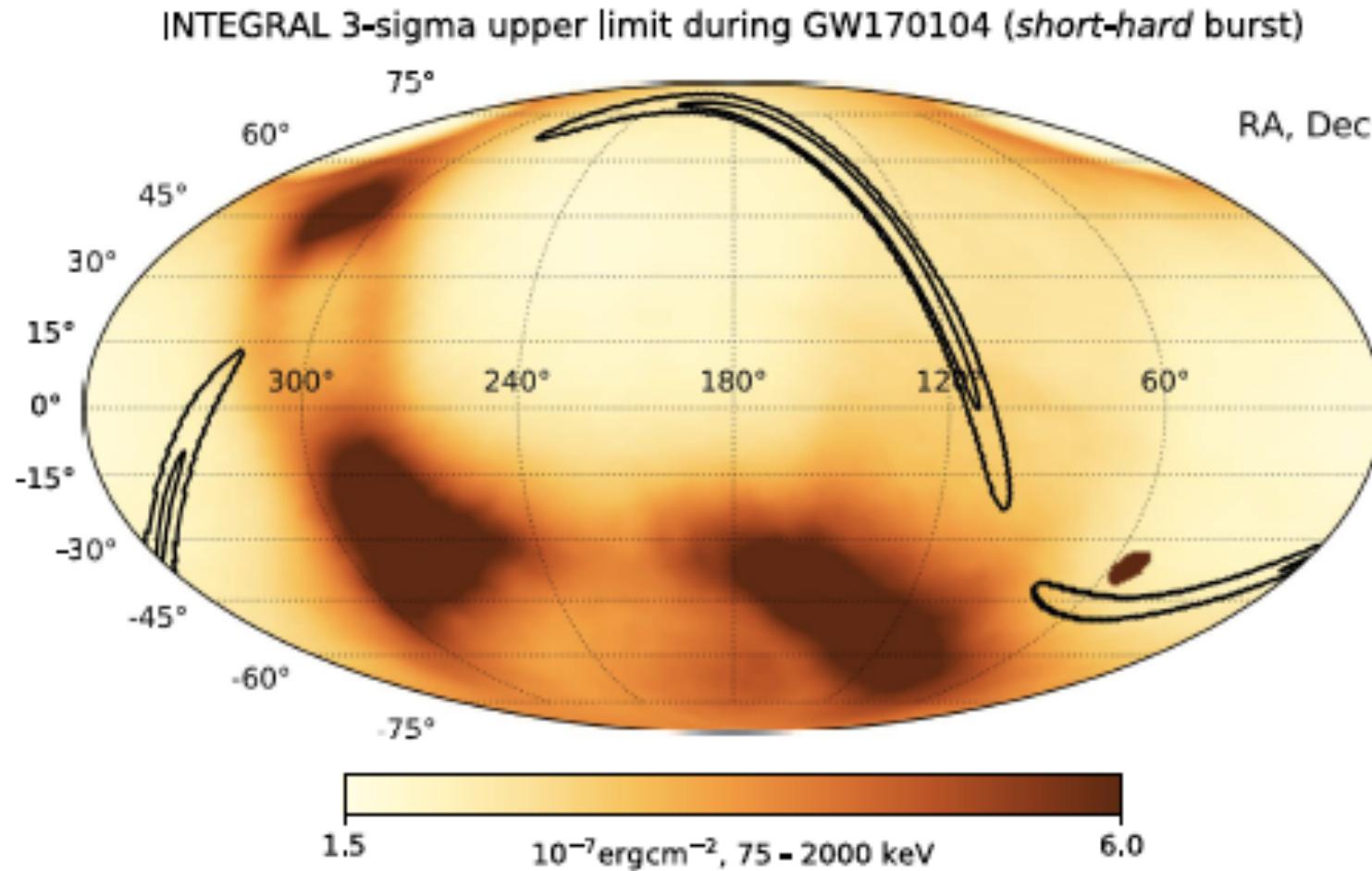
$$\text{FAR} < 1.4 \cdot 10^{-5} \text{ yr}^{-1}$$

Savchenko+ 2017b



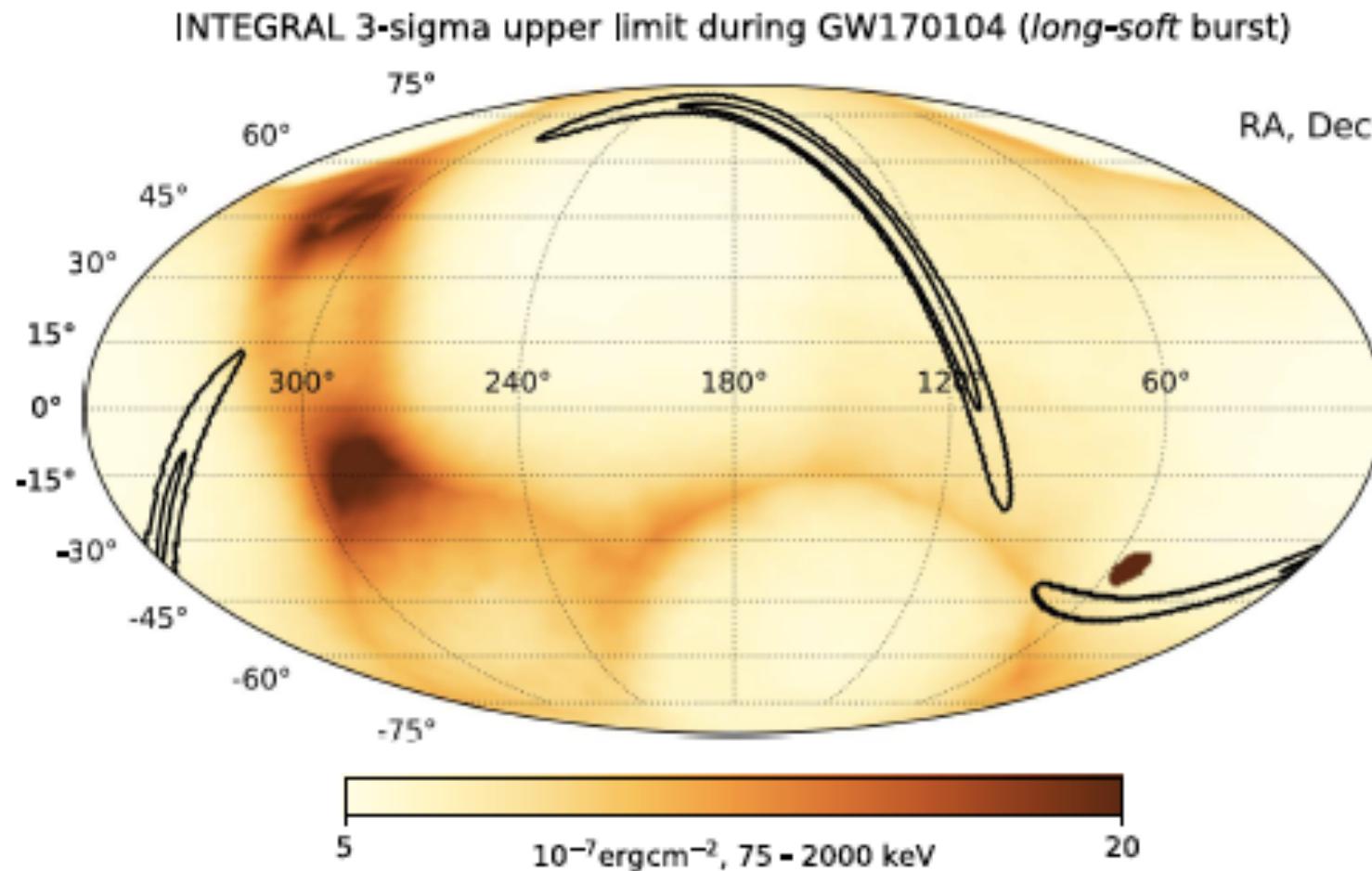
No significant
excess in SPI/ACS
light curve

GW 170104



Short-hard GRB: 1 s Cut-off PL $\alpha = -0.5$ $E_p = 600 \text{ keV}$

GW 170104

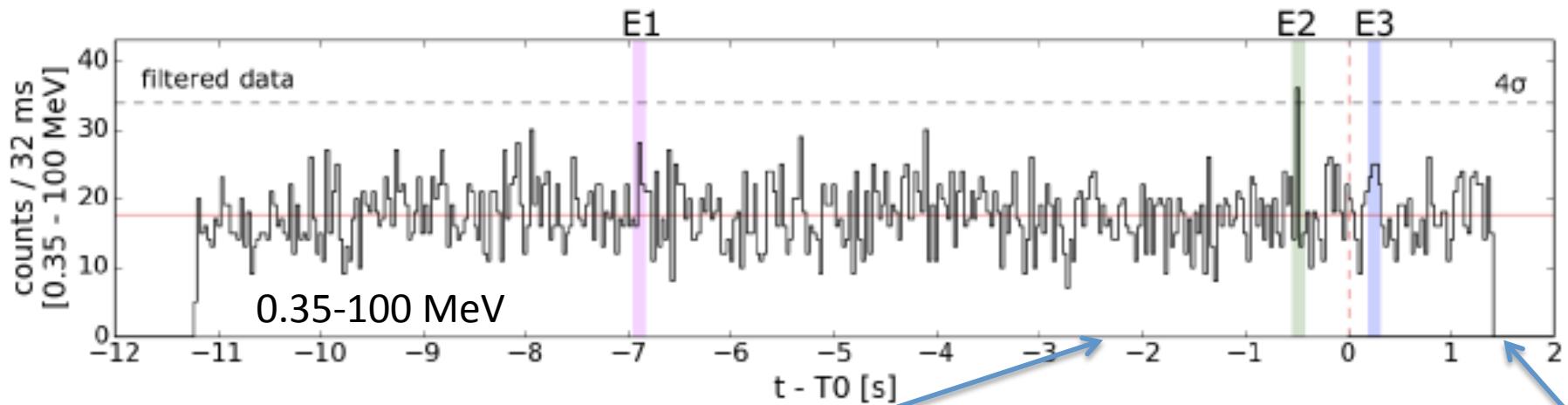


Long GRB: 8 s $\alpha = -1$, $\beta = -2.5$, $E_p=300$ keV

GW 170104

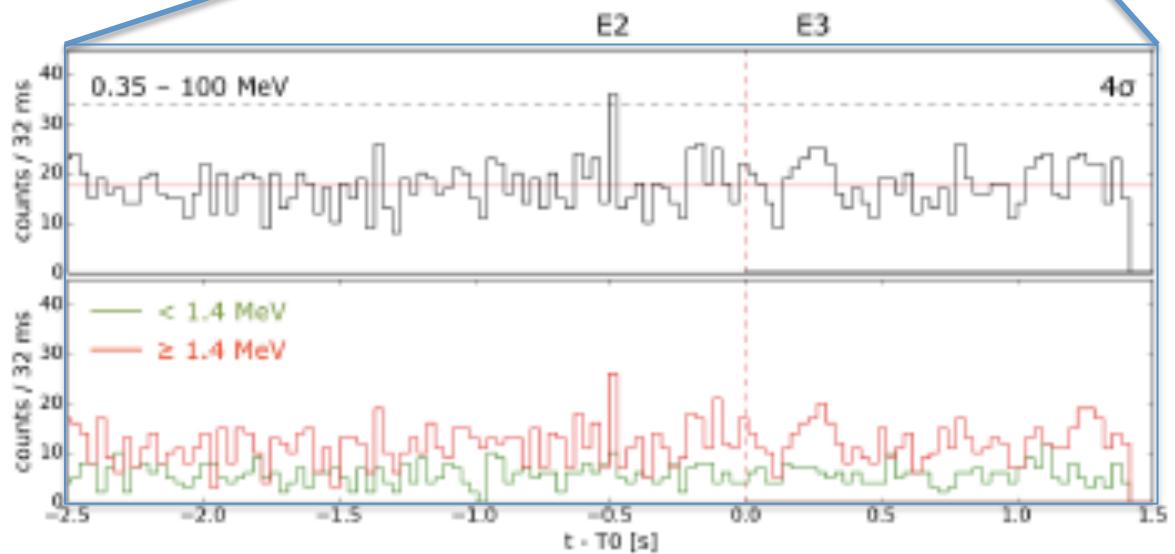
Interesting event in AGILE/MCAL 0.46 s before T_0

(Verrecchia+ 2017)



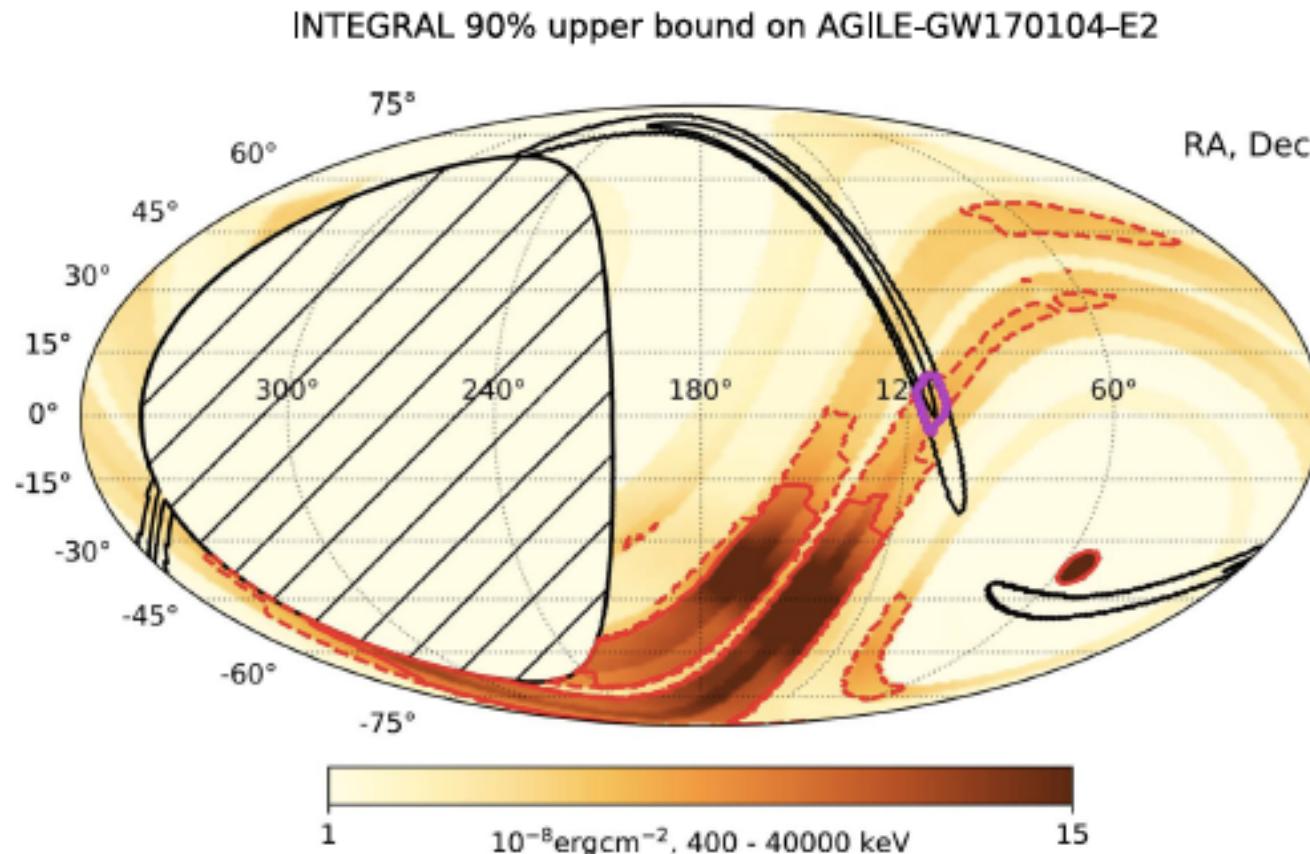
E2 post-trial
coincidence probability
between 2.4σ and 2.7σ

Fluence $\sim 10^{-7}$ erg/cm²
(0.4-40 MeV)



GW 170104

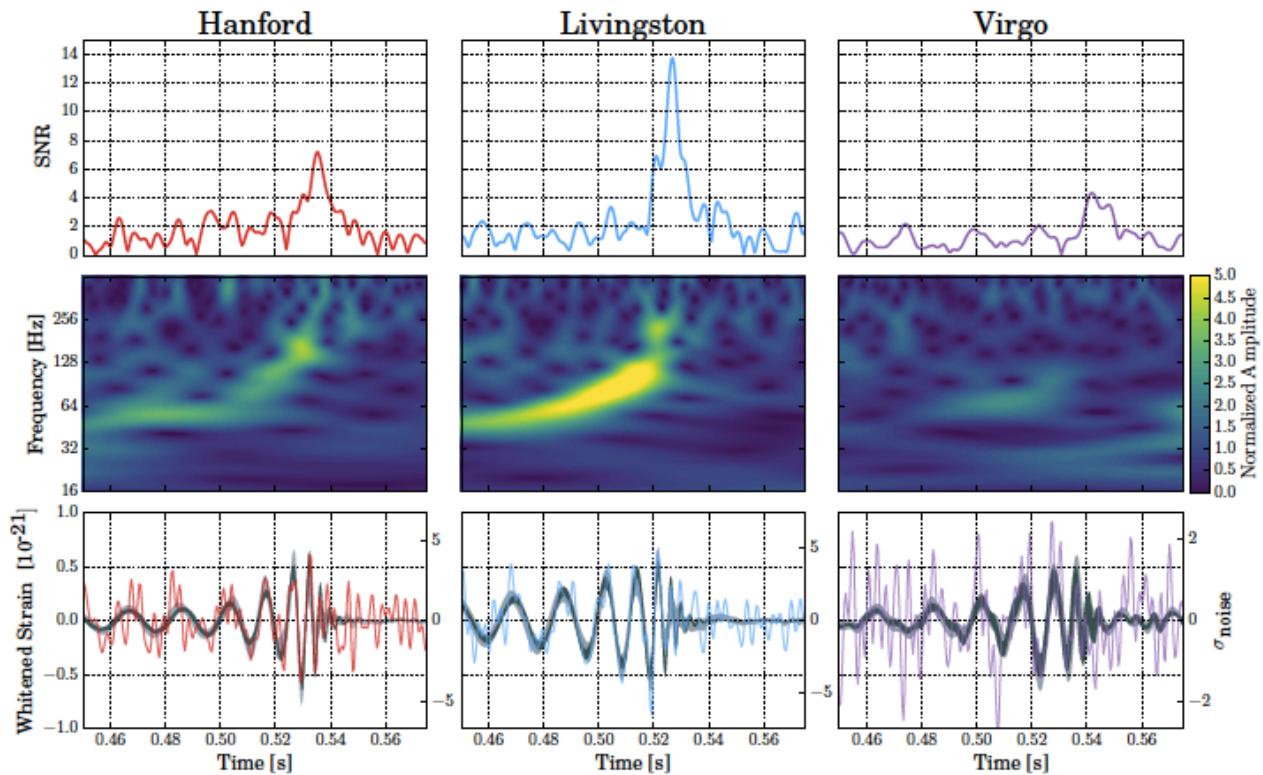
SPI/ACS ul on possible AGILE event
(for PL spectrum with slope -2)



Only within red contours u.l.
compatible with AGILE event
fluence

Savchenko+ 2017b

GW 170814



INTEGRAL pointed follow-up
92% of LIGO/Virgo localization region covered

From To + 47 hr Duration 1.3 days $\rightarrow \sim 100$ ks net exposure

NO NEW SOURCES U.L. few mCrabs
- exact value depends on energy range
(see GCN 21695)

INTEGRAL LIMITS ON E_γ/E_{GW}

	150914	151226	170104	170814
M_1	36 +5 -4	14.2 +8.3 -3.7	31.2 +8.4 -6.0	30.5 +5.7 -3.0
M_2	29 +/- 4	7.5 +/- 2.3	19.4 +5.3 -5.9	25.3 +2.8 -4.2
M_{FINAL}	62 +/- 4	20.8 +6.1 -1.7	48.7 +5.7 -4.6	53.2 +3.2 -2.5
E_{GW}	3 +/- 0.5	1.0 +0.1 -0.2	2 +0.6 -0.7	2.7 +0.4 -0.3
D_L	410 +160 -180	440 +180 -190	880 +450 -390	540 +130 -210
z	0.09	0.09	0.18	0.11
E_γ / E_{GW}	$< \sim(0.1 - 3.4) \times 10^{-7}$	No data (perigee)	$< (5 - 9) \times 10^{-6}$ (short burst) $< (1 - 3) \times 10^{-5}$ (long burst)	

CONCLUSIONS

INTEGRAL great capabilities for multi-messenger follow-up

- High duty cycle, uninterrupted $>\sim 2$ -day long observations in stable background
- Whole sky coverage
- Real time data
- Highly competitive all-sky sensitivity, down to 10^{-7} erg cm $^{-2}$ s $^{-1}$ (75 - 2000 keV) with complementary role of every instrument
- Sensitivity for broad and narrow gamma-ray lines