AGILE follow up observations of GW events

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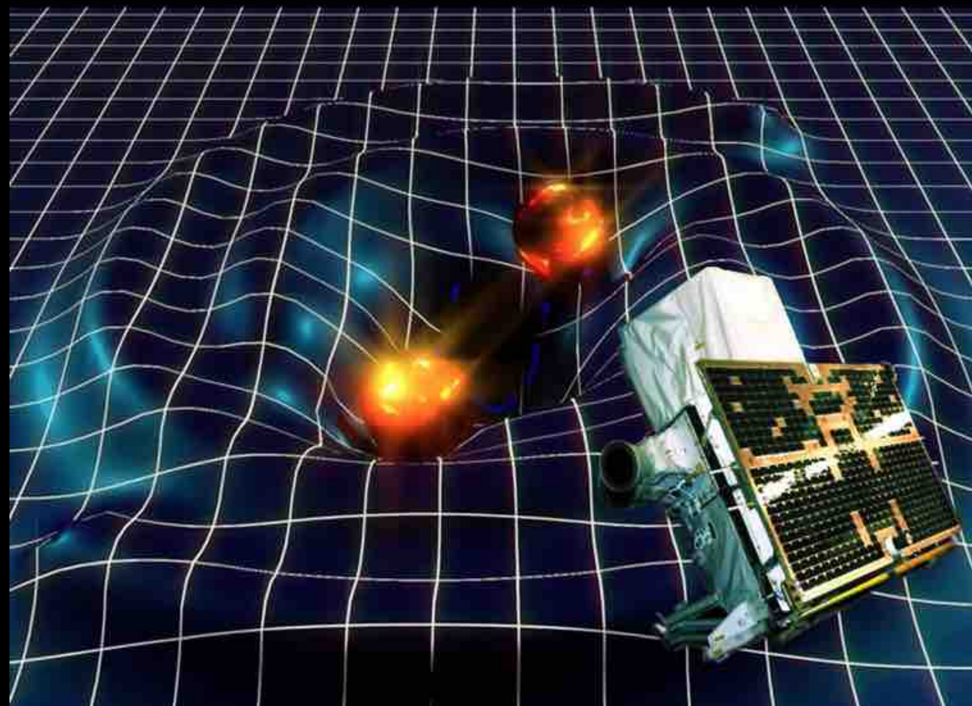
RICAP-2016, June 23 2016

14th **AGILE** Science Workshop
ASI Rome, 20 - 21 June 2016

AGILE ON THE WAVE



agenzia spaziale italiana
INAF
INFN
Consiglio Nazionale delle Ricerche

RECENT DETECTIONS

AGILE detection of a gamma-ray flare from the FSRQ PKS 2023-07
ATel # 8879

A new gamma-ray transient, AGL J1835-6040, detected by AGILE
ATel # 8866

AGILE confirms the enhanced gamma-ray emission from Cygnus X-3
ATel # 8597

AGILE detection of renewed gamma-ray activity from the blazar PKS 1502+106
ATel # 8593

AGILE detection of increased gamma-ray emission from the FSRQ PKS 1313-333
ATel # 8536

AGILE detection of enhanced gamma-ray activity from the CTA 102 region
ATel # 8476

Home | AGILE Team | AGILE in ASI | AGILE Data Center | Contacts | AT reserved

AGILE Launch

AGILE Principal Investigator and ASI Directors

Time elapsed since the AGILE launch on April 23, 2007 at 10:00 GMT

Days	Hours	Mins	Secs
3345	12	34	29

AGILE in its 9-th year of operations in space

- Gamma-ray detector (GRID)
- MCAL

fully operational, ideal in the range 50 MeV – 1 GeV, and active in:

- gamma-ray astrophysics
- terrestrial high-energy physics
- search of GW counterparts

AGILE can play a crucial role in the search of GW source counterparts

- **AGILE and GW150914 (and GW151226, LVT151012)**
- **Prospects for a first detection of prompt gamma-ray emission from GW sources**

AGILE is excellent for GW source searches

- **very large field of view (2.5 sr)**
- **200 passes/day over more than 80% of the sky**
- **high probability of prompt event coverage**

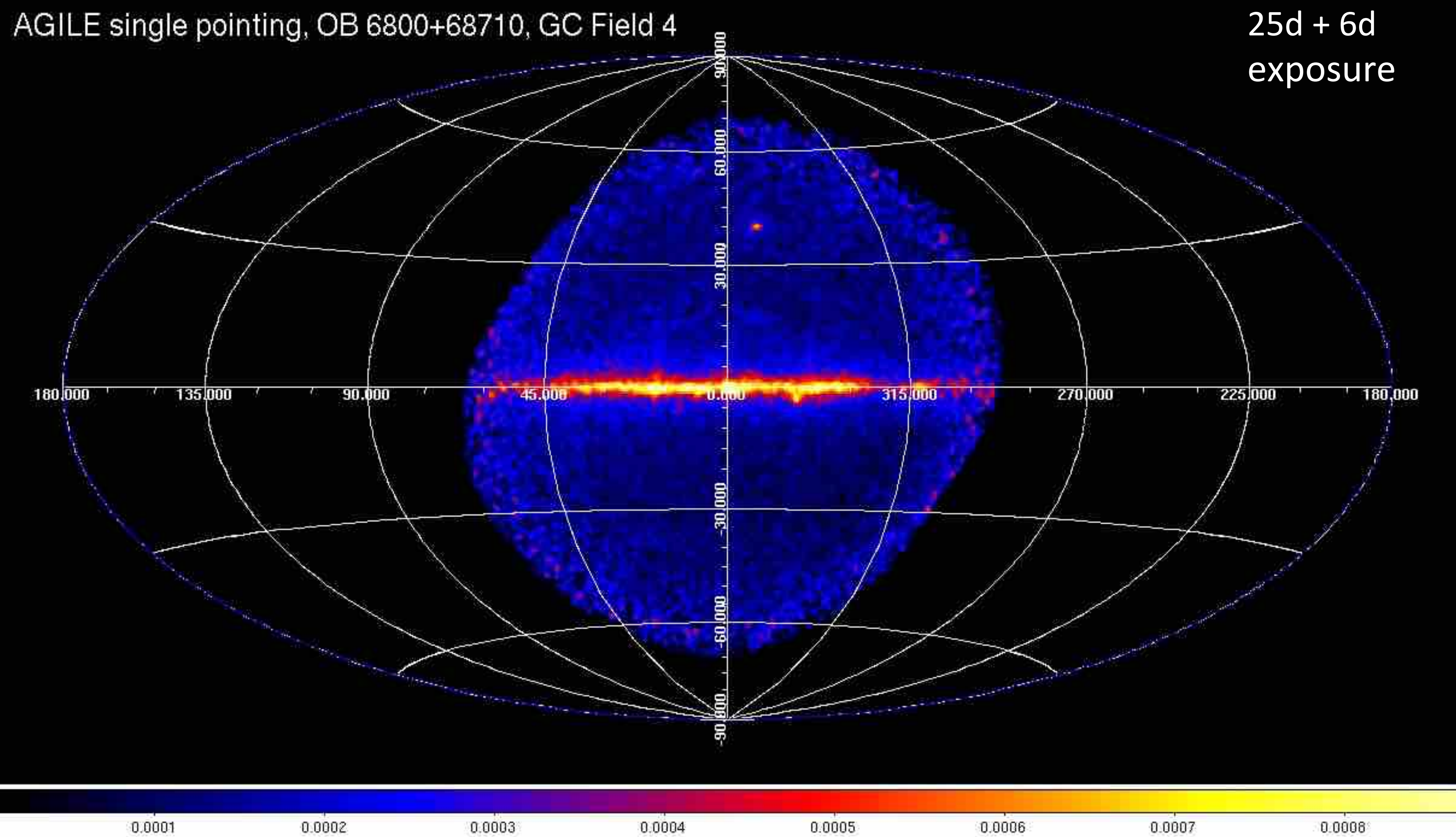
Recent publication of GW150914 observations by AGILE (Tavani et al. 2016), ApJ, in press

AGILE two "lives": pointing and spinning

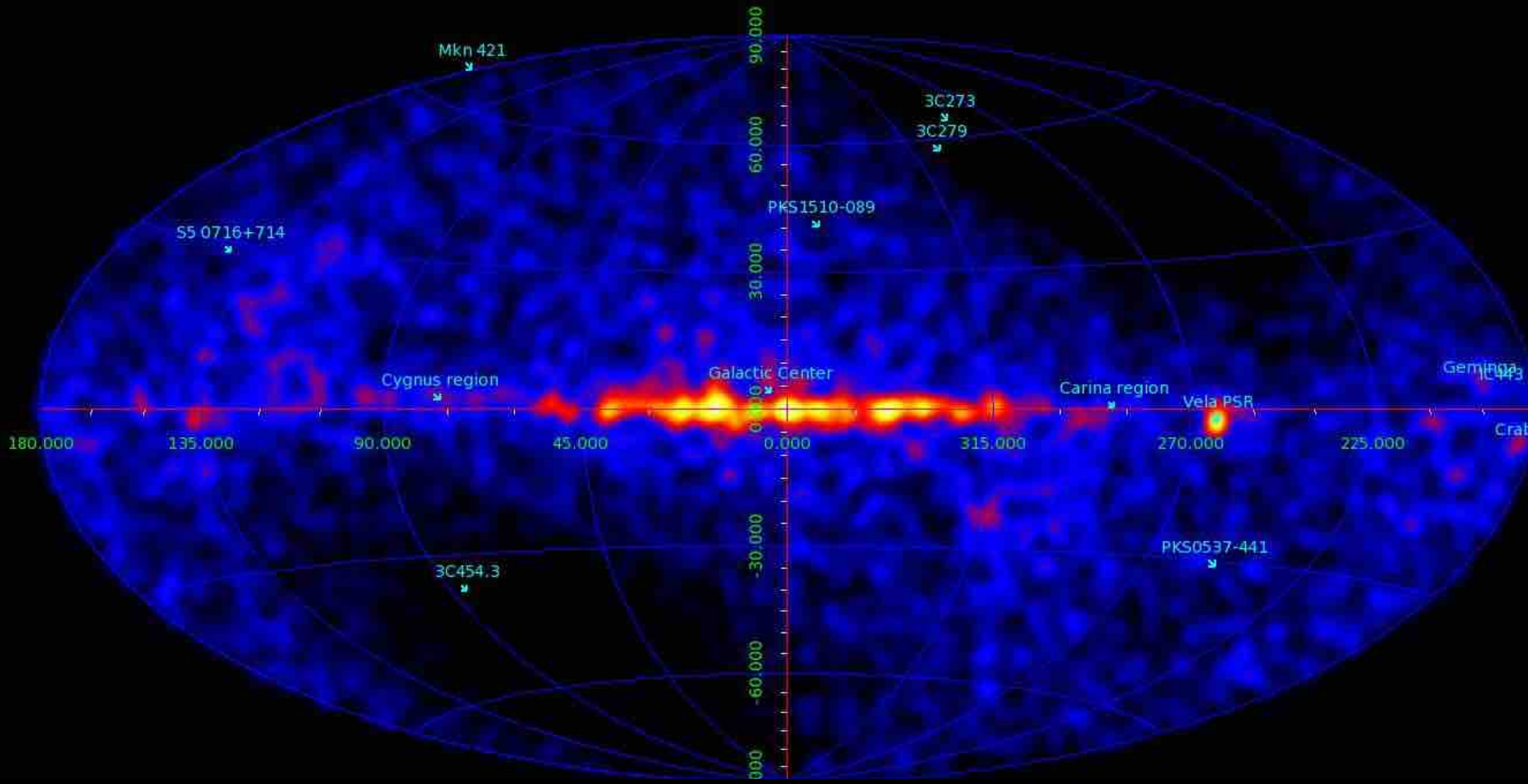
AGILE	POINTING	SPINNING
time period	Jul.07 – Oct.09	Nov. 2009 - today
attitude	fixed	variable (rotation ~ 0.8°/sec)
sky coverage	1/5	~ 70-80 %
1-day exposure (≤ 30 deg off-axis, @ 100 MeV)	~ 2 x 10^7 (cm^2 sec)	(0.5 - 1) x 10^7 (cm^2 sec)

pointing mode (2007-2009)

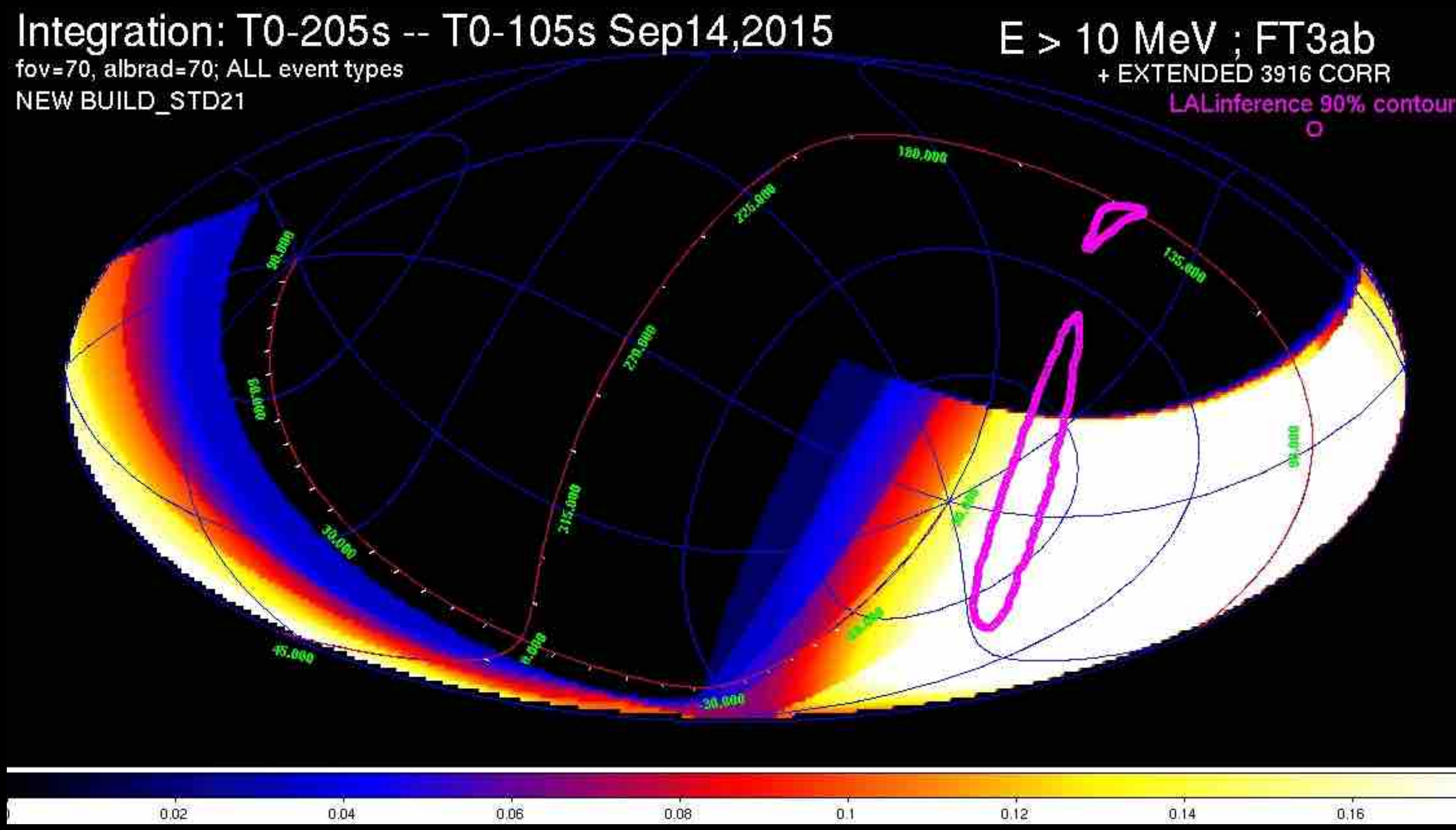
25d + 6d
exposure



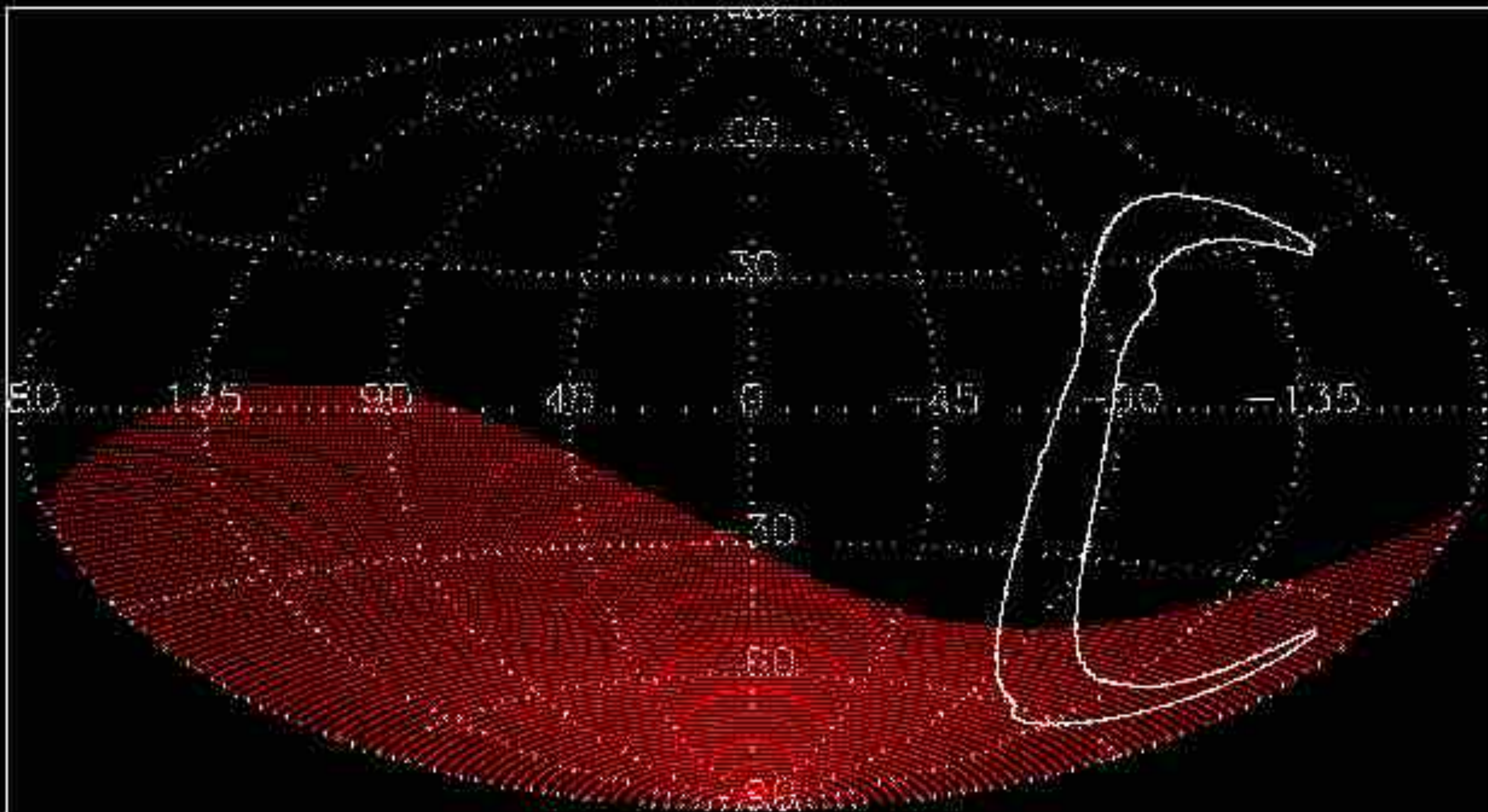
AGILE in spinning E > 100 MeV
(8-9 March, 2016)



AGILE in spinning: revolution including T_0 of GW150914



Earth occultation during one orbit (95 min)

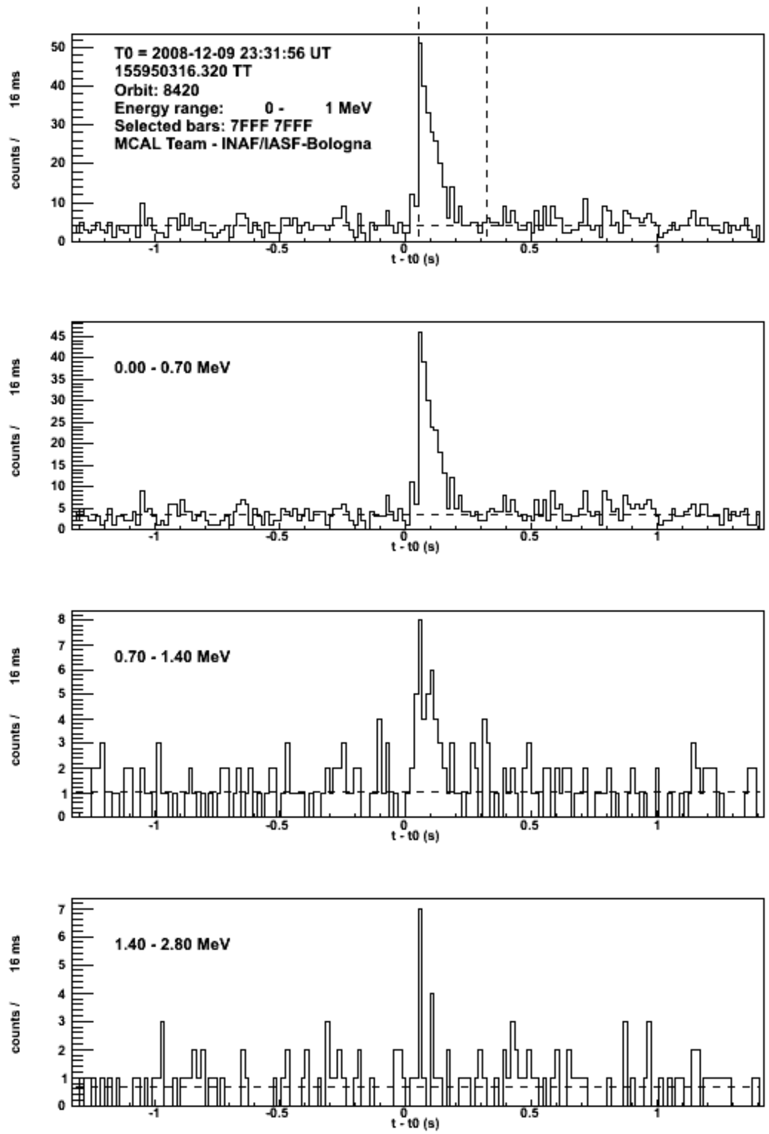


Search for gamma-ray transients

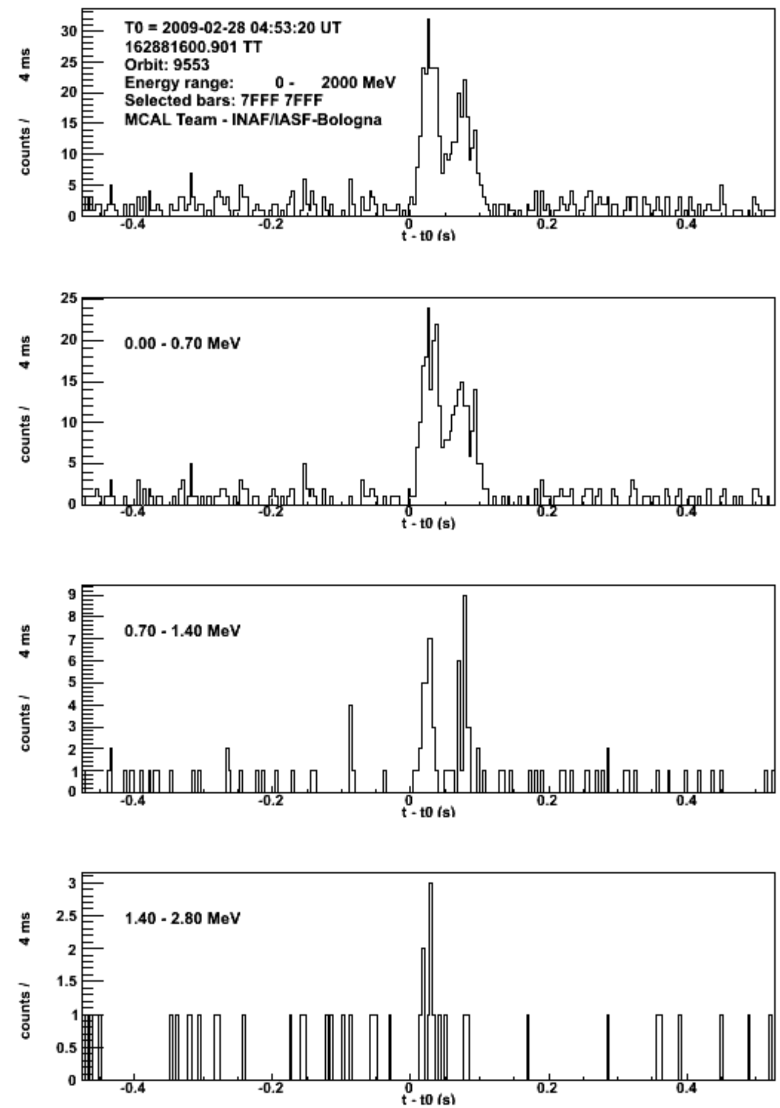
- gamma-ray imager: covers 80% of the sky
- 200 spinning rotations / day
- (Earth occultations, SAA) - > 120 useful passes
- passes of ~ 150 sec duration
- **sensitivity ~ (1-2) 10^{-8} erg cm^{-2} s^{-1} in 100 sec.**
- GRB – like searches, MCAL, AC

AGILE detection of short GRBs

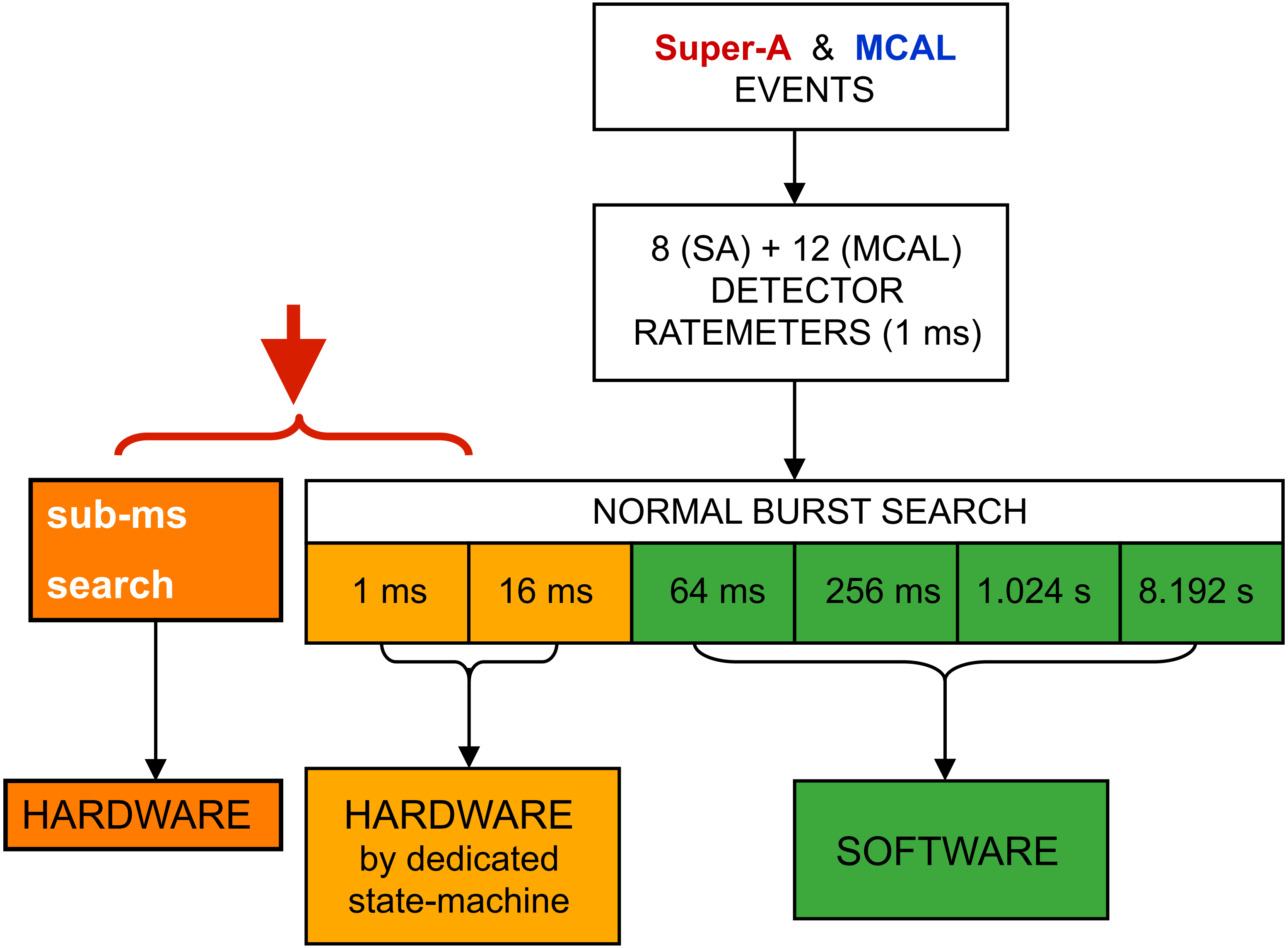
GRB 081209



GRB 090228



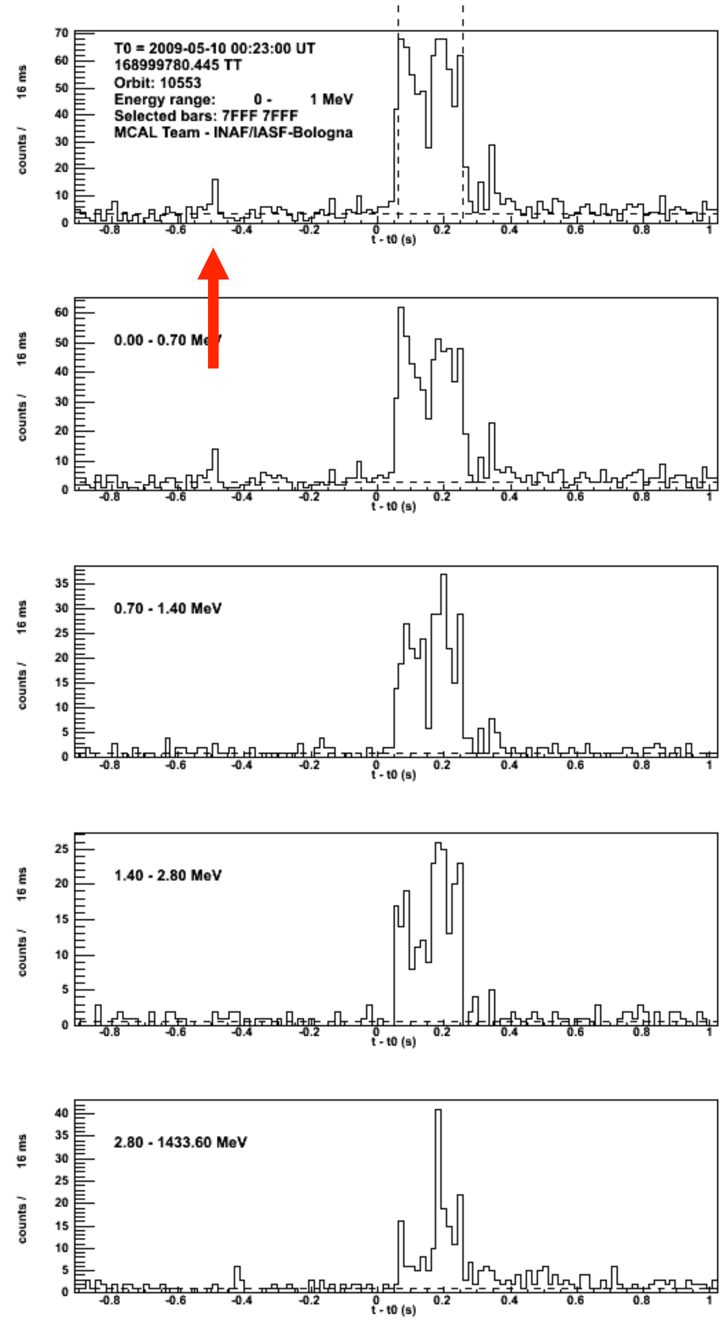
AGILE GRB ON-BOARD SEARCH PROCEDURE



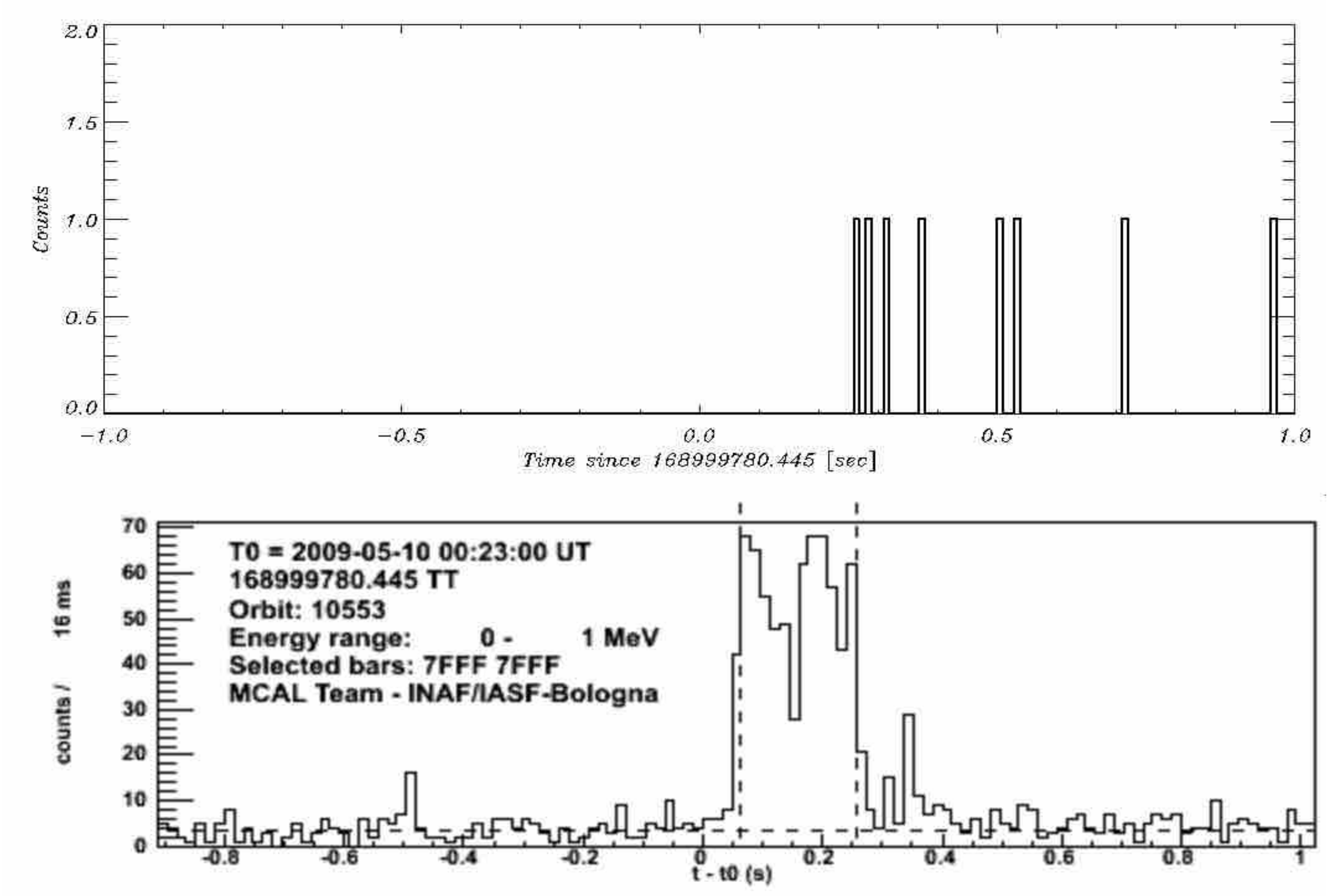
AGILE
and
the "short"
GRB 090510

(Giuliani et al. 2010)

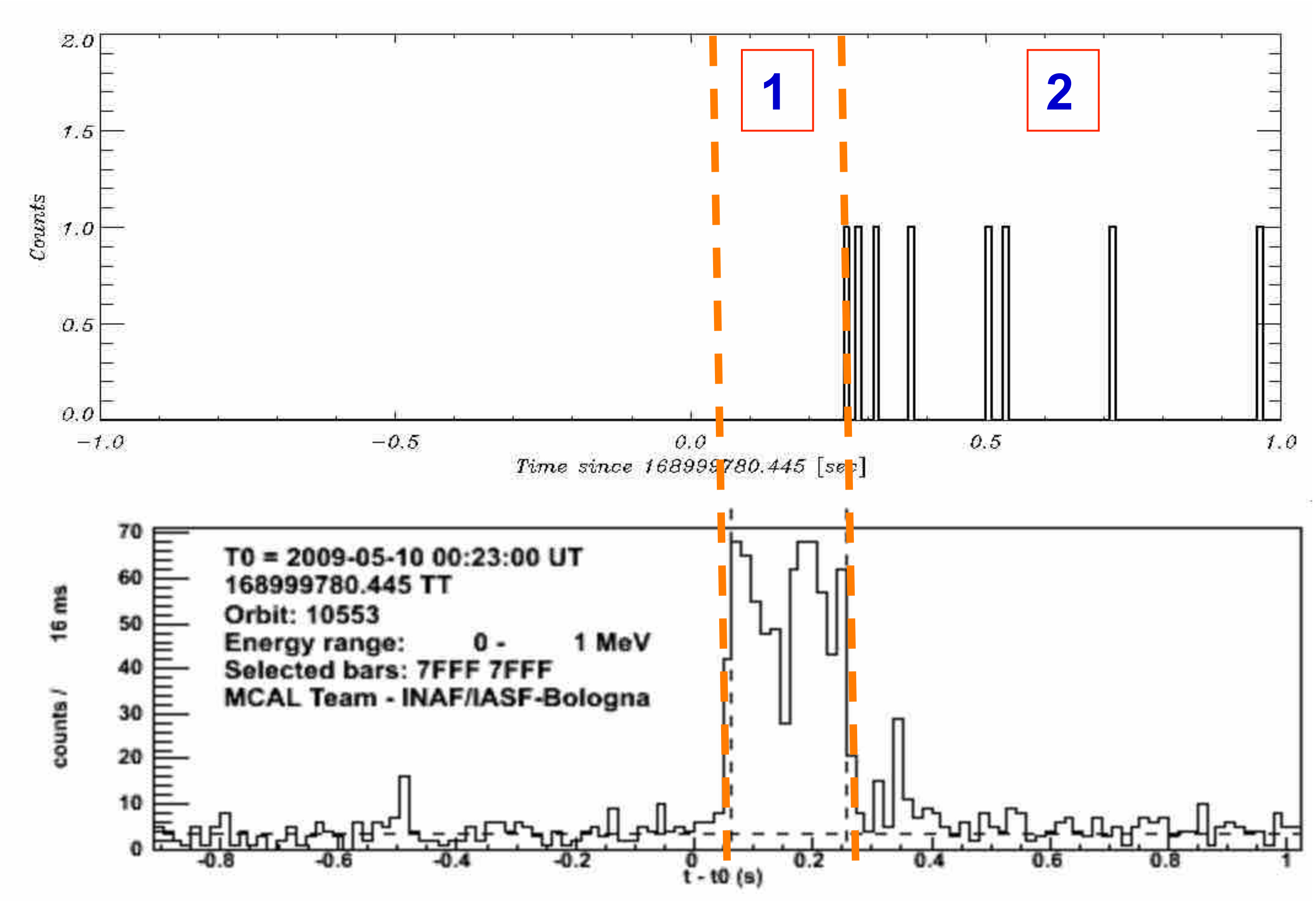
$z = 0.9$


T0 = 2009-05-10 00:23:00 UT
168999780.445 TT
Orbit: 10553
Energy range: 0 - 1 MeV
Selected bars: 7FFF 7FFF
MCAL Team - INAF/IASF-Bologna
0.00 - 0.70 MeV
0.70 - 1.40 MeV
1.40 - 2.80 MeV
2.80 - 1433.60 MeV
counts / 16 ms
t - t0 (s)

The short GRB 090510 (61 degree off-axis)

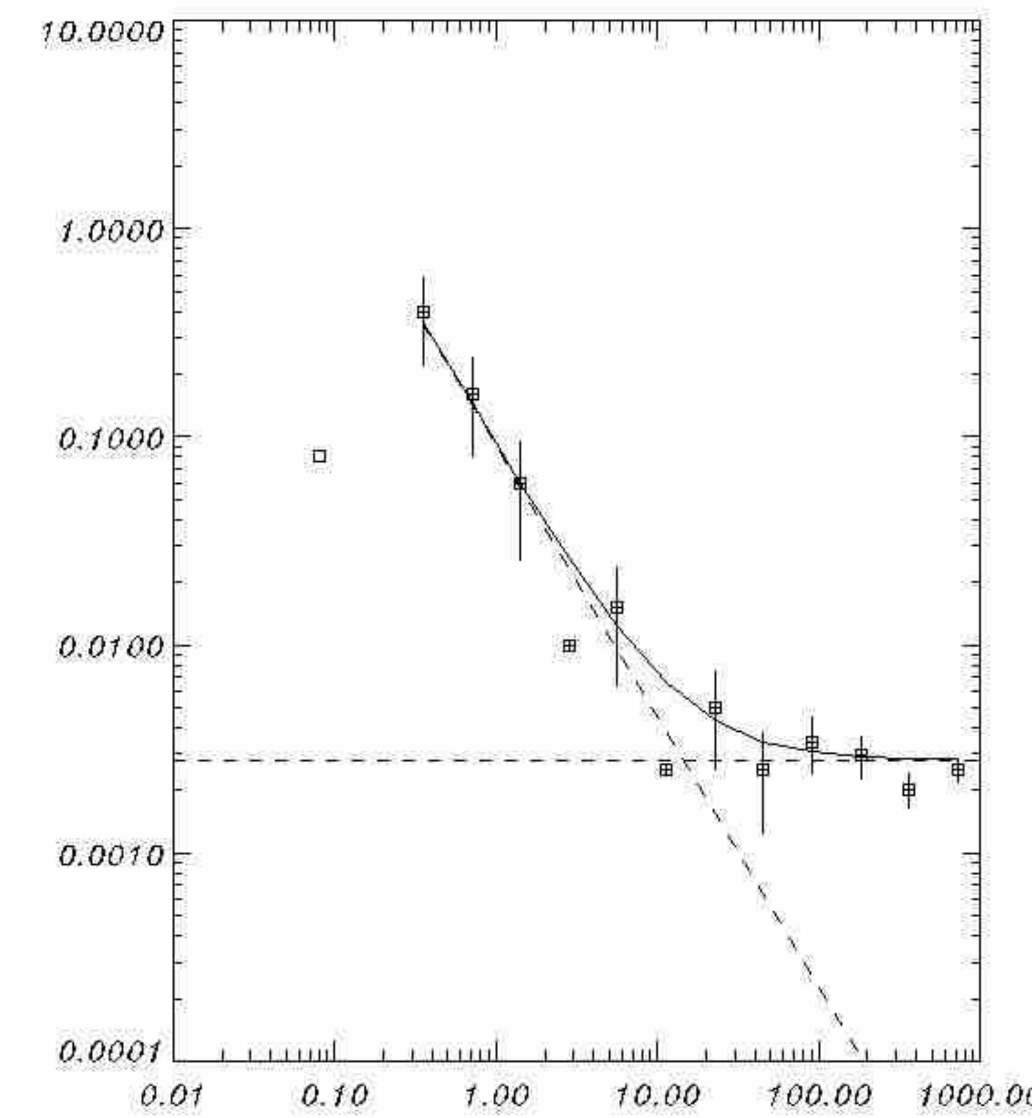


AGILE: GRB 090510

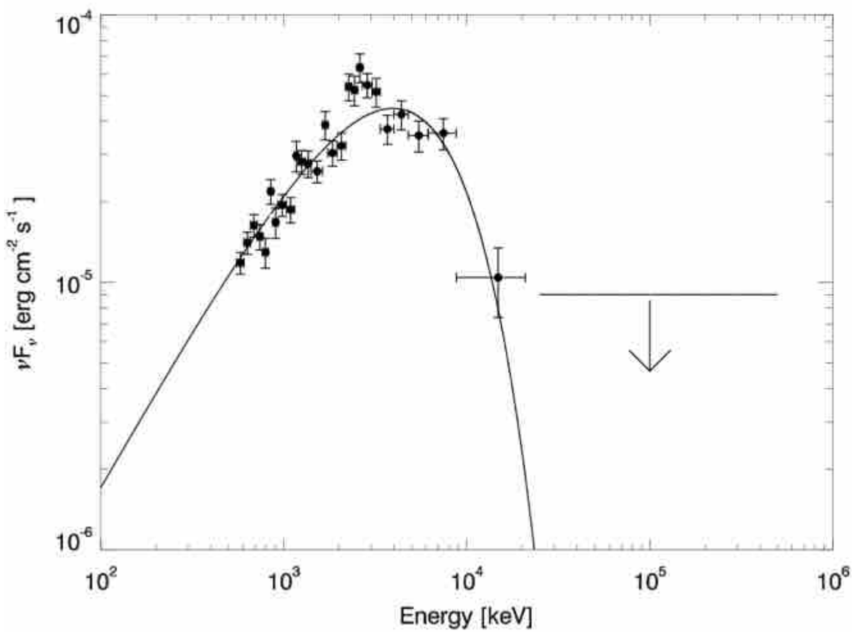


Gamma-ray tail (delayed emission)

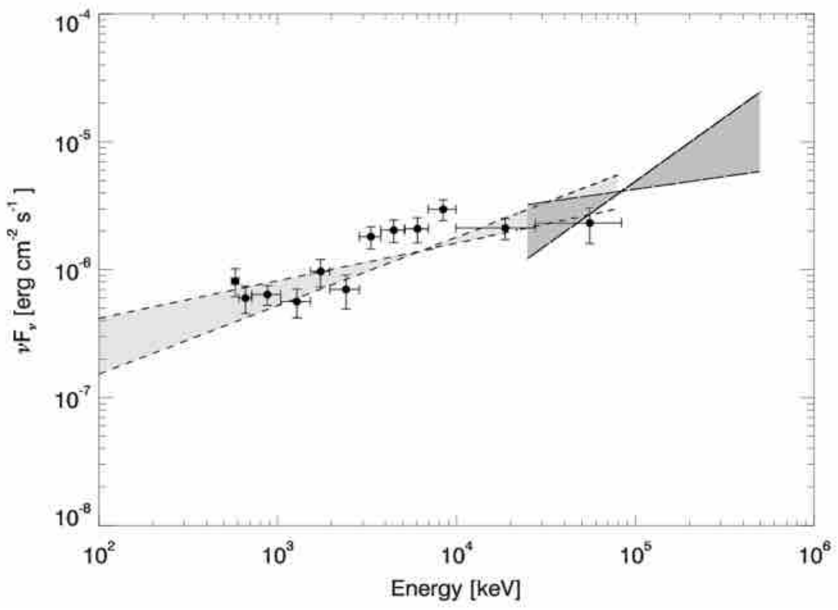
$F = t^{-1.32}$



Interval 1



Interval 2



on the “short” GRB 090510…

- one of the shortest events with remarkable high-energy emission

- For a z~0.9, E(iso) = 10^{52} ergs

- MeV and gamma-ray emission above 100 MeV
  - Interval 1: E(peak) ~ 3 MeV
  - Interval 2: E(peak) > 50 MeV
    - » **$F = t^{-1.3}$**

AGILE and GW150914

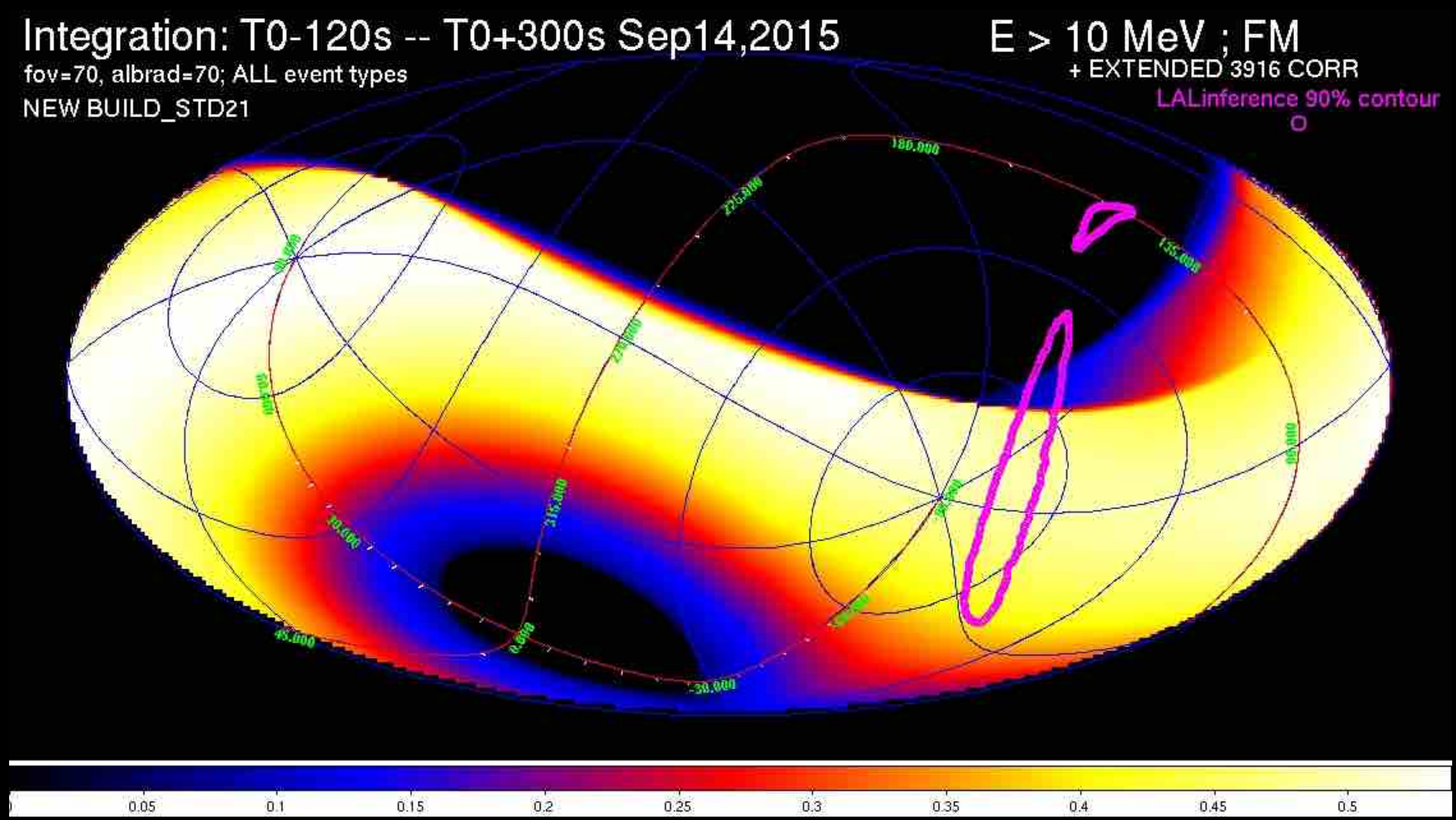
A. Argan, A. Bulgarelli, E. Del Monte, I. Donnarumma,
V. Fioretti, Y. Evangelista, F. Lucarelli, M. Marisaldi,
G. Piano, C. Pittori, M. Tavani, A. Trois, F. Verrecchia, A. Zoli

GW150914

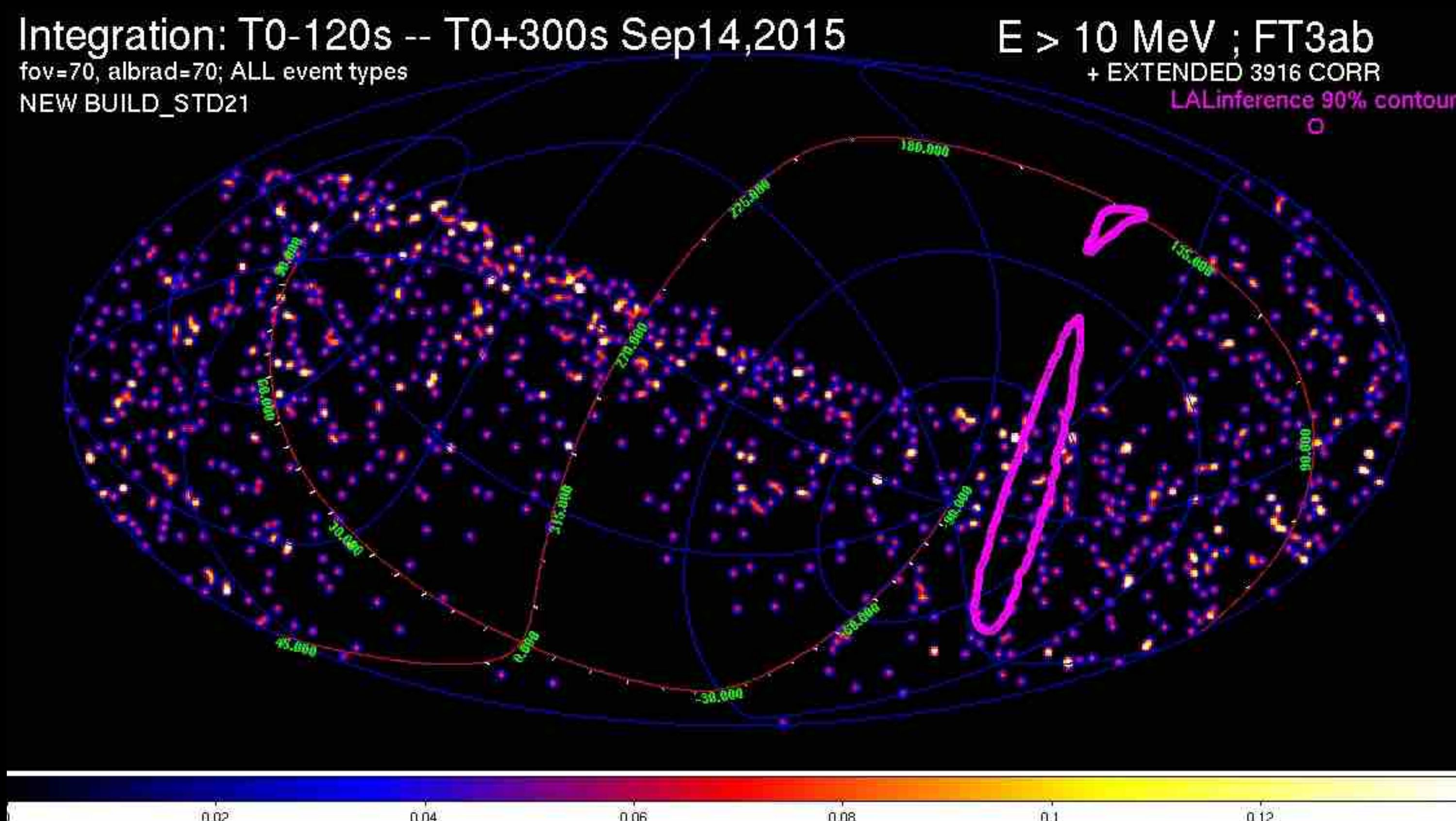
T_0 = 9:50:45 UT, 14 September, 2015

- **learned about the event on Feb. 11, 2016 (no MoU active yet)**
- **archival search**

exposure: revolution -120/+300 sec from T_0

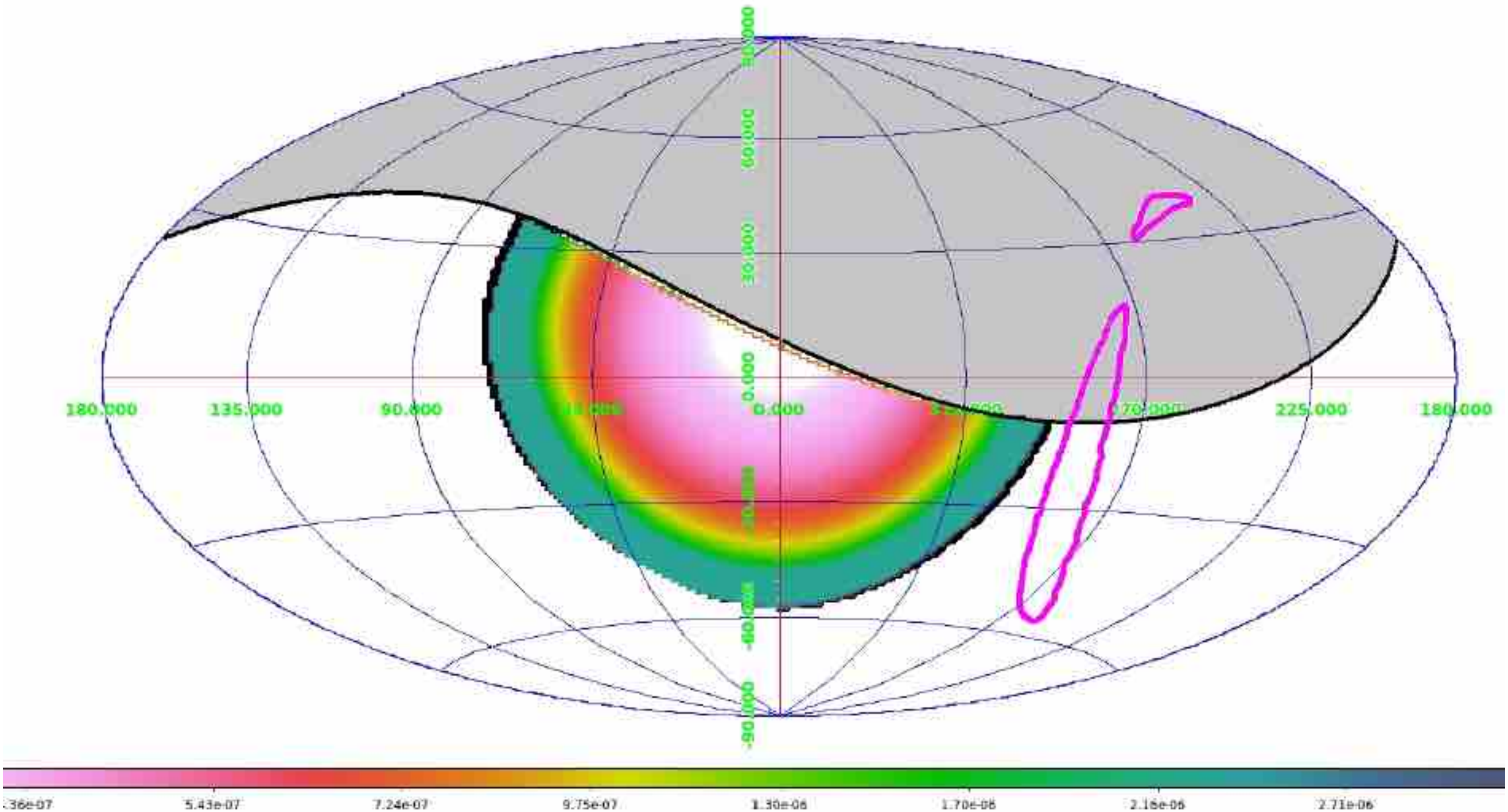


exposure: revolution -120/+300 sec from T_0



AGILE exposure at T_0 = 09:50:45 UT

just missed… (-2 / +2 sec)

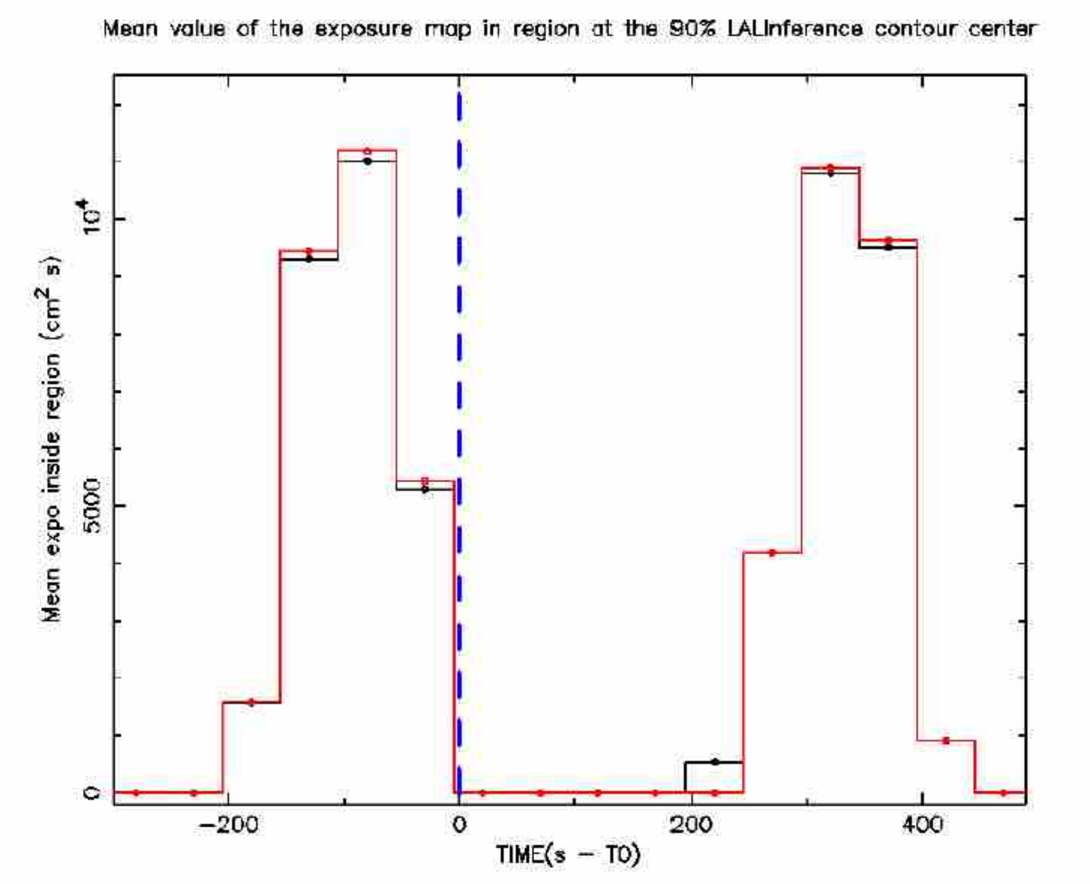


Central LIGO contour exposure scan: from T_0 -300s to T0 +500s

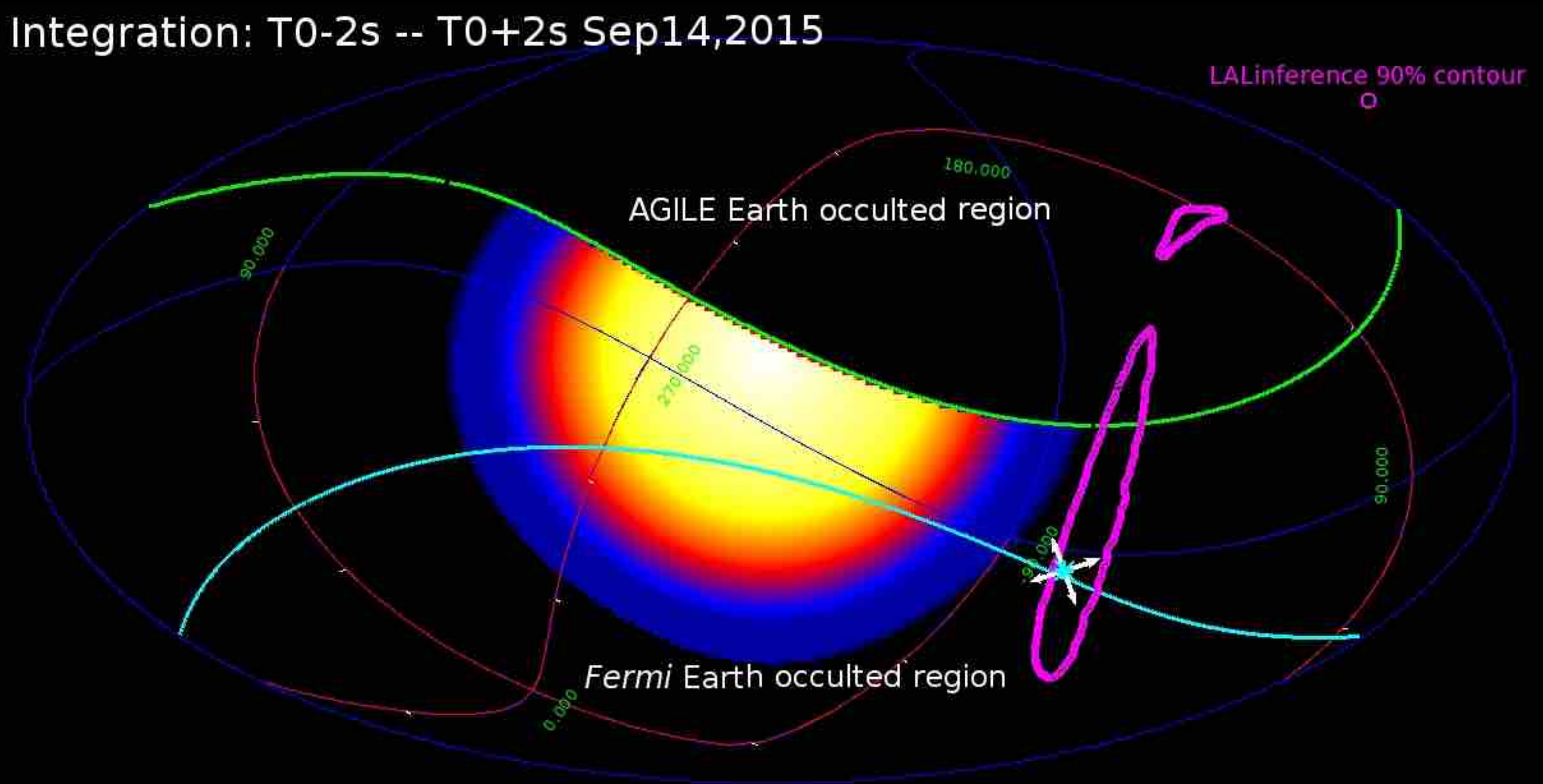
Mean exposure within 7° x 25° region (black) and 10° radius circular region (red) at about the LIGO contour center

100s exposure scan

65% of LIGO contour covered ~10-60s before T0



AGILE-MCAL and Fermi-GBM exposure at the GW150914 prompt time



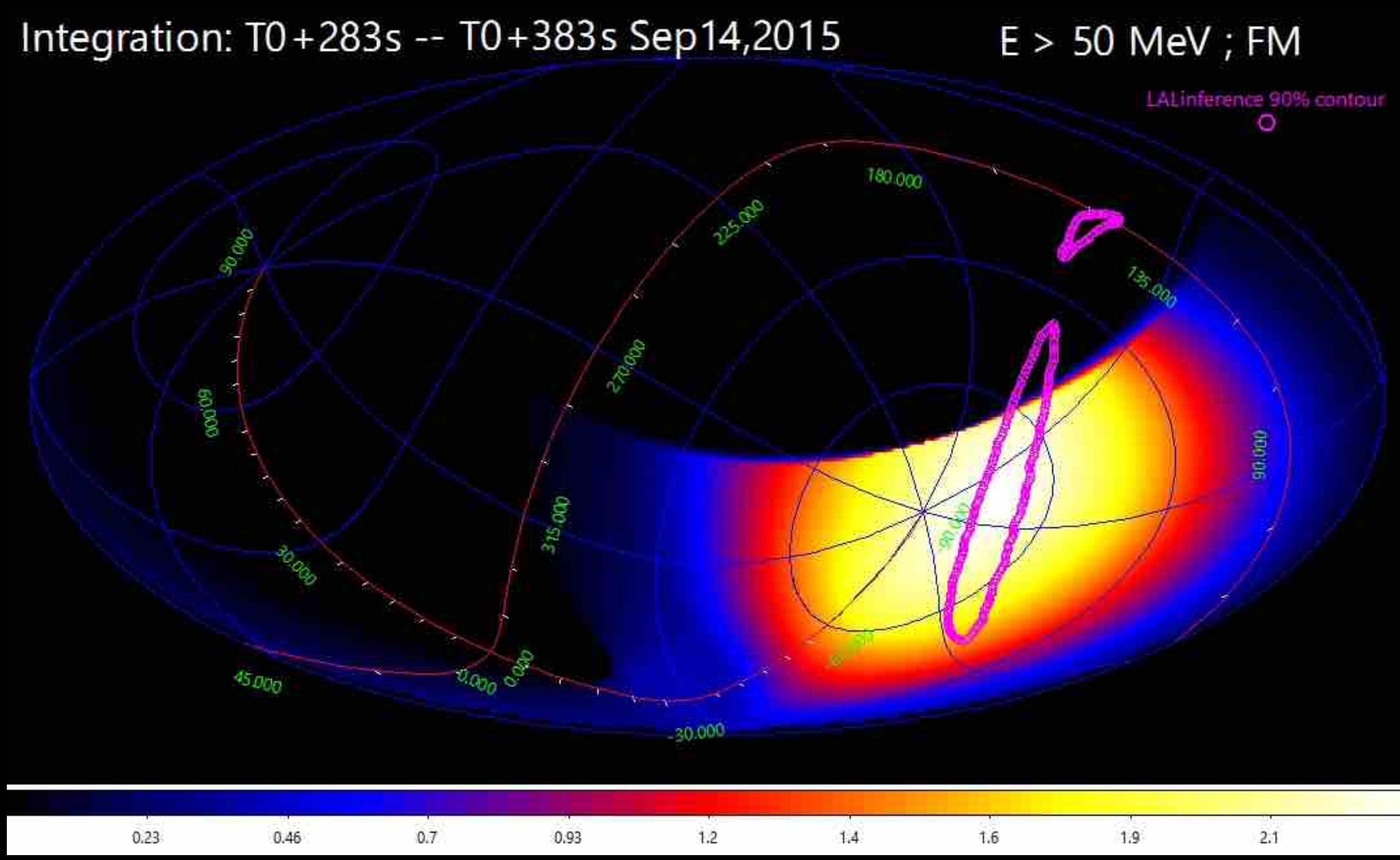
AGILE does not detect the Fermi-GBM transient

- at the GW150914 prompt time (T_0 + 0.4s), best GBM position region at about 90° off-axis for AGILE GRID and MCAL
- limited exposure of MCAL
- **AGILE 5-sigma MCAL upper limit**
  F_{GBM} = 2 x10^{-6} erg cm^{-2} (0.45 – 100 MeV),

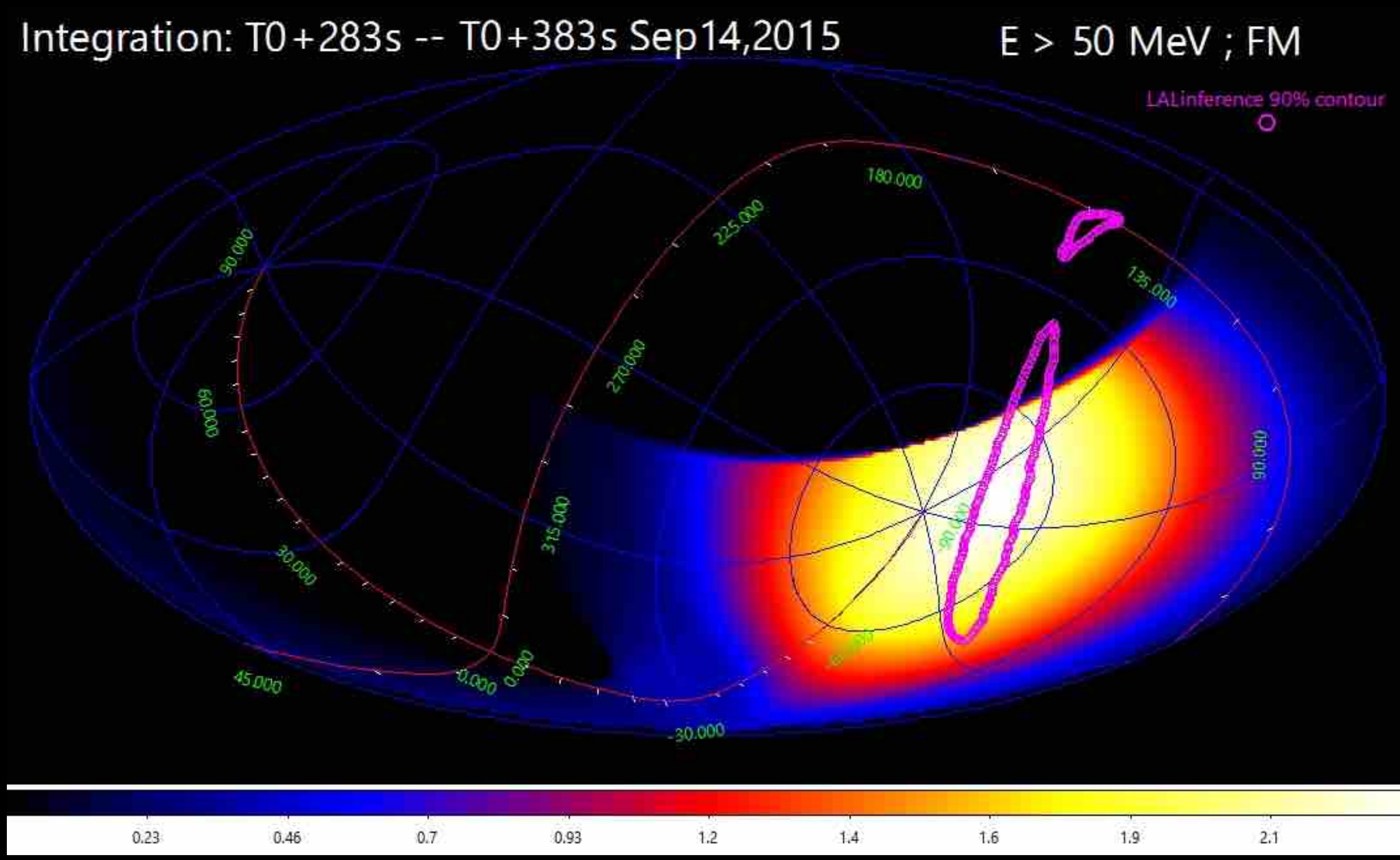
- **2-sigma upper limit 2.3 times larger than GBM event extrapolation at 1 MeV**
  F_{GBM} = (2 ± 1) x10^{-7} erg cm^{-2} (10 keV – 1 MeV),
  photon index 1.4 (Connaughton+ 2016)

300 sec later…

AGILE exposure at T_0+330 sec (+/- 50 sec)



AGILE exposure at T_0+330 sec (+/- 50 sec)

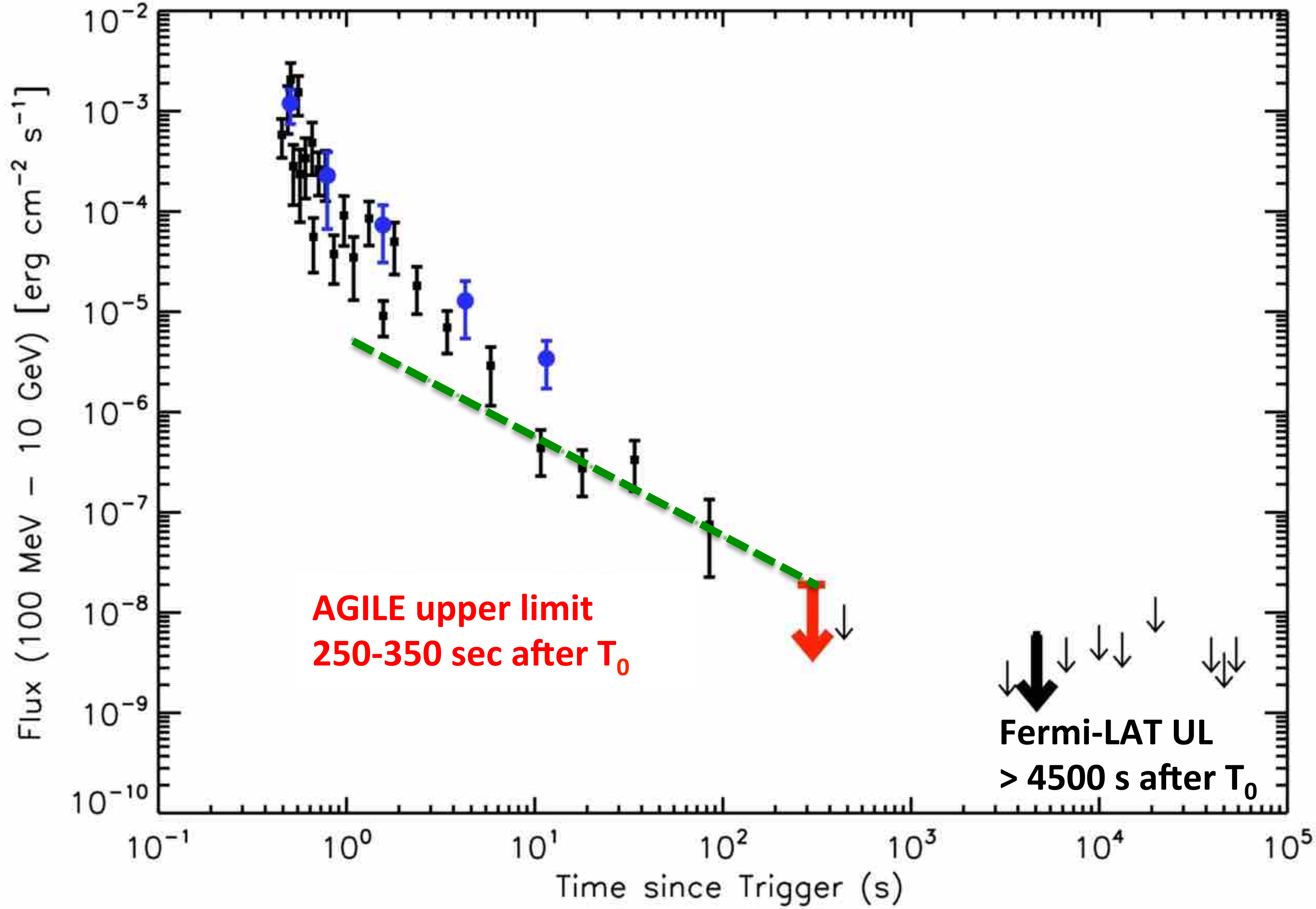


2-sigma upper limit (E > 50 MeV) = 1.9 x 10^{-8} erg cm^{-2} s^{-1}

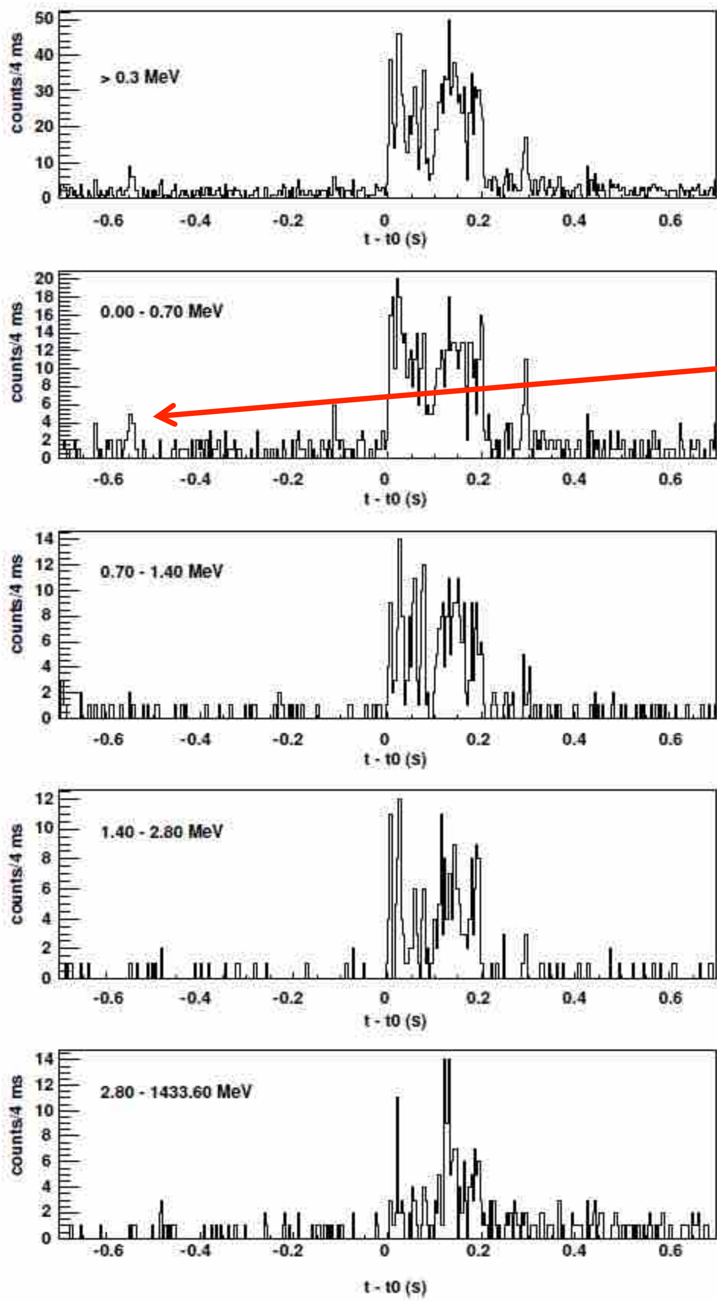
AGILE and Fermi-LAT upper limits in the sGRB 090510 light curve

(repositioned at z = 0.1, adapted from Fermi-LAT Collab., 2016)

AGILE-GRID blu, Fermi/LAT black, light curve



AGILE-MCAL GRB090510 light curve



GRB090510 light curve as detected by AGILE-MCAL (4ms bin), Giuliani + 2010

->15ms soft precursor at T=T0 - 0.55s (E < 0.7MeV)

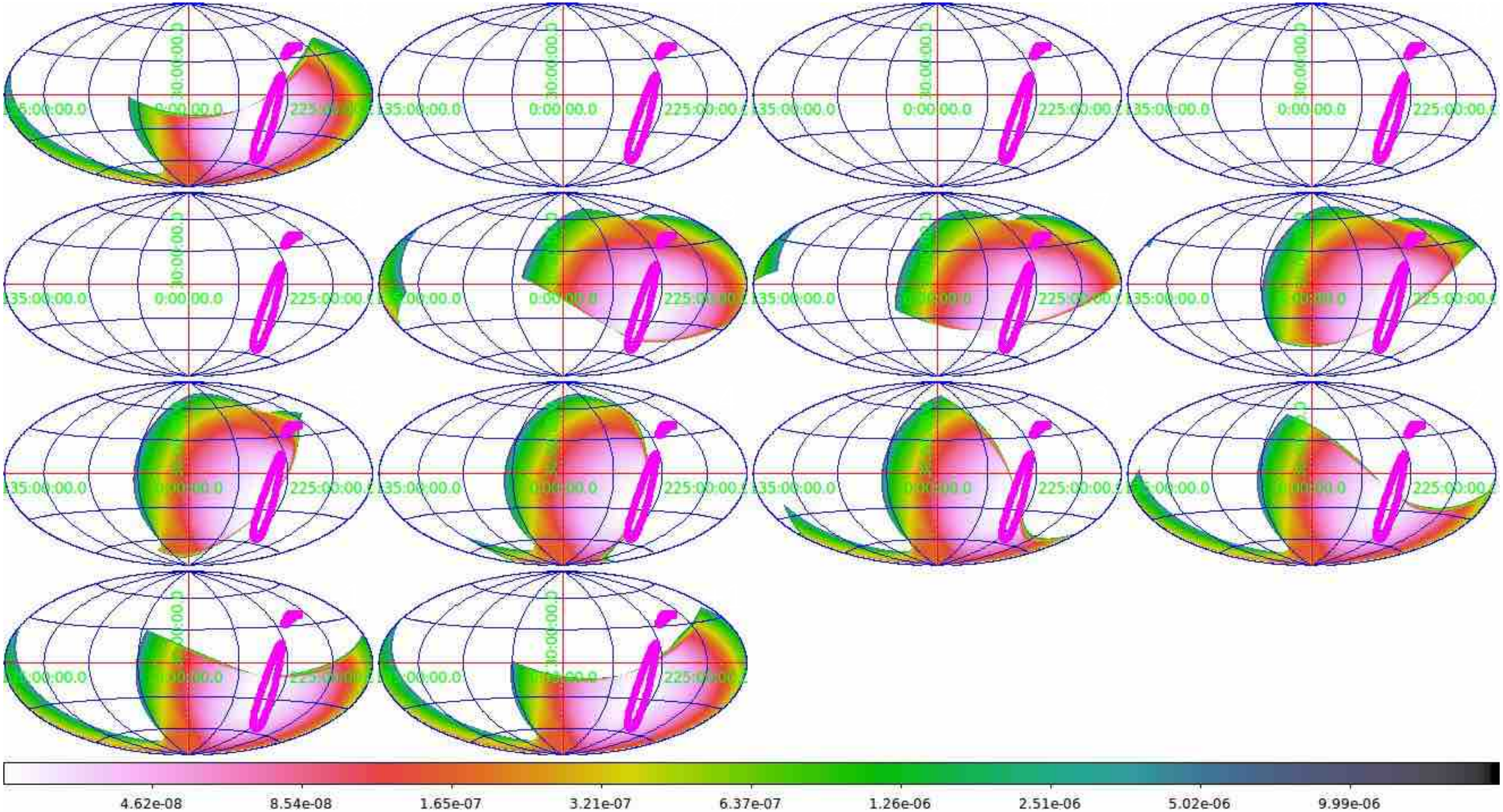
AGILE needs to re-optimize the MCAL on-board trigger to make sure to detect precursor-like (faint) events

precursor search

Table 1: Analysis of individual passes over the GW150914 error box

Interval number	Central time bin (**)	Duration (sec)	2σ UL (*) ($10^{-8}\,\mathrm{erg\,cm^{-2}\,s^{-1}}$)	Comments
-13	-5203	100	2.7	88% of error box not-occulted by the Earth
-12	-4779	100	–	affected by SAA
-11	-4355	100	–	affected by SAA
-10	-3931	100	–	affected by SAA
-9	-3507	100	–	affected by SAA
-8	-3083	100	2.3	93% of error box not-occulted by the Earth
-7	-2663	100	4.5	78% of error box not-occulted by the Earth
-6	-2235	100	1.5	68% of error box not-occulted by the Earth
-5	-1807	100	1.5	65% of error box not-occulted by the Earth
-4	-1379	100	1.5	20% of error box not-occulted by the Earth
-3	-951	100	1.0	48% of error box not-occulted by the Earth
-2	-523	100	1.0	56% of error box not-occulted by the Earth
-1	-95	100	1.5	65% of error box not-occulted by the Earth
+1	+333	100	1.9	75% of error box not-occulted by the Earth

precursor search (passes -13/+1, 95 minutes)



Long time-scale search

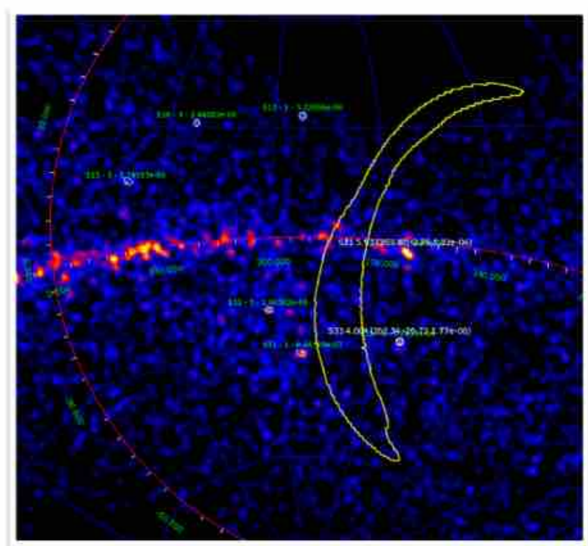
Table 2: Long-integration time analysis of the GW150914 localization region

Interval name	Duration	2σ UL (*) ($10^{-9}\,\mathrm{erg\,cm^{-2}\,s^{-1}}$)	Comments
-3d	3 days	0.3	
-2d	2 days	0.5	
-1d	1 day	0.7	
-12h	12 hours	0.8	
-6h	6 hours	2.5	
-3h	3 hours	3.5	
+3h	3 hours	–	telemetry interruption (**)
+6h	6 hours	3.5	with telemetry interruption (**)
+12h	12 hours	1.8	with telemetry interruption (**)
+1d	1 day	1.1	with telemetry interruption (**)
+2d	2 days	0.9	with telemetry interruption (**)
+3d	3 days	0.7	with telemetry interruption (**)
+5d	5 days	0.4	with telemetry interruption (**)

Long-time scale search:

- hours
- days

=>no significant detection



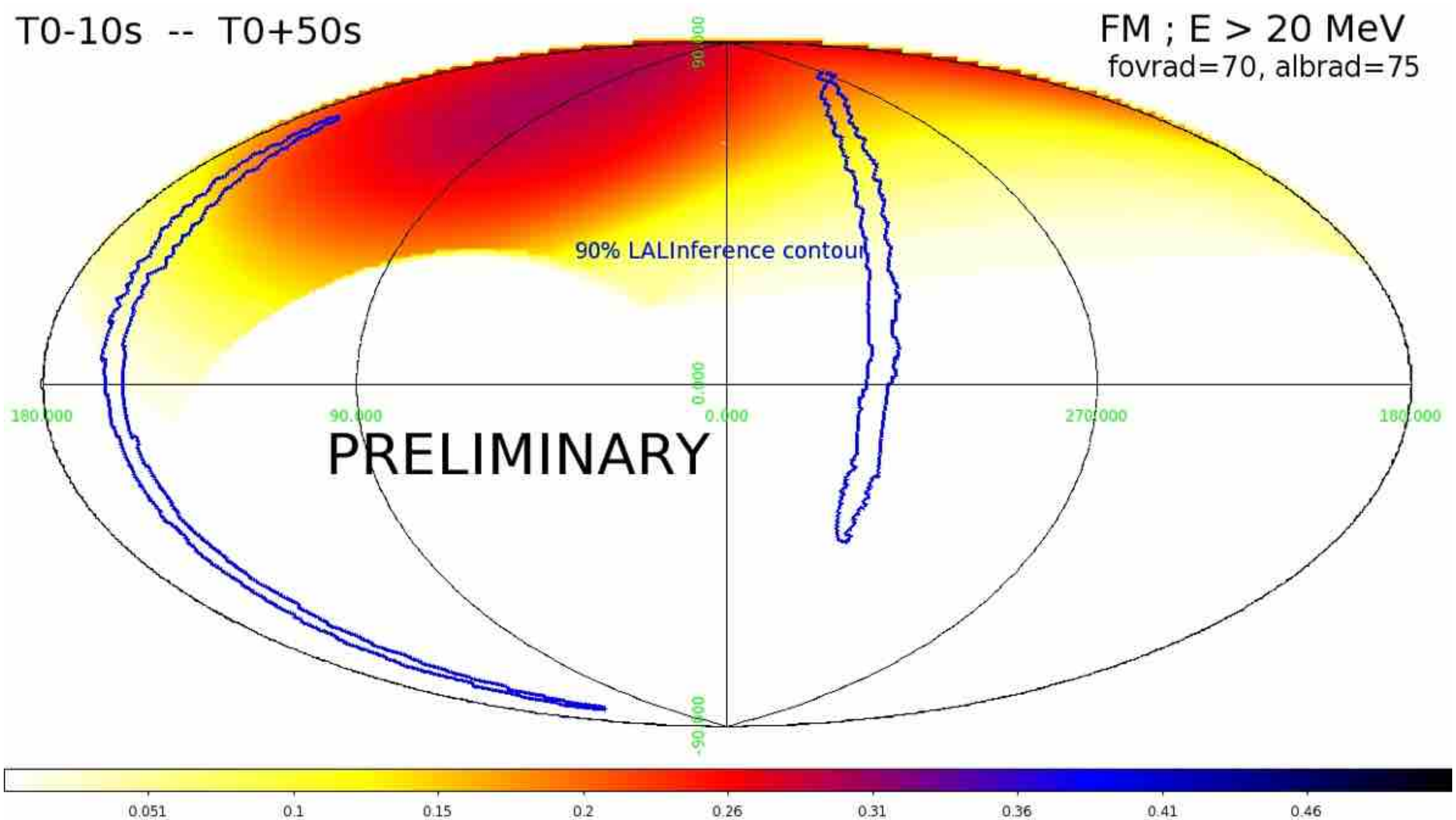
Other two GW events: G211117, LVT151012, PRELIMINARY results

G211117

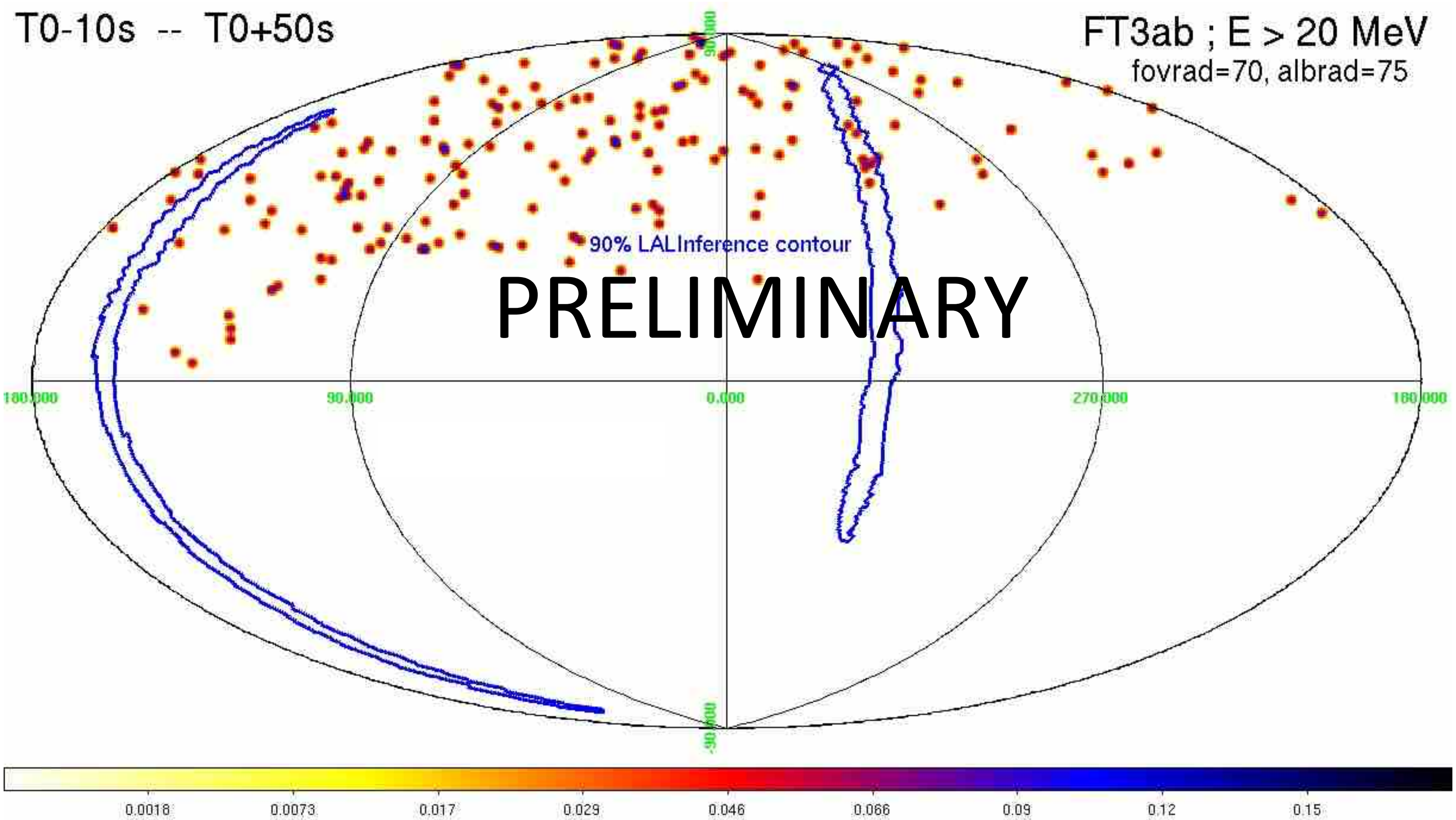
- T_0 = 3:38:54 UT, 26 December, 2015

- learned about the event on May 23, 2016 (after MoU activation)
- on-going archival search & analysis

G211117


T0-10s -- T0+50s
FM ; E > 20 MeV
fovrad=70, albrad=75
90% LALInference contour
PRELIMINARY
90.000
0.000
-90.000
180.000
90.000
0.000
270.000
180.000
0.051
0.1
0.15
0.2
0.26
0.31
0.36
0.41
0.46

G211117

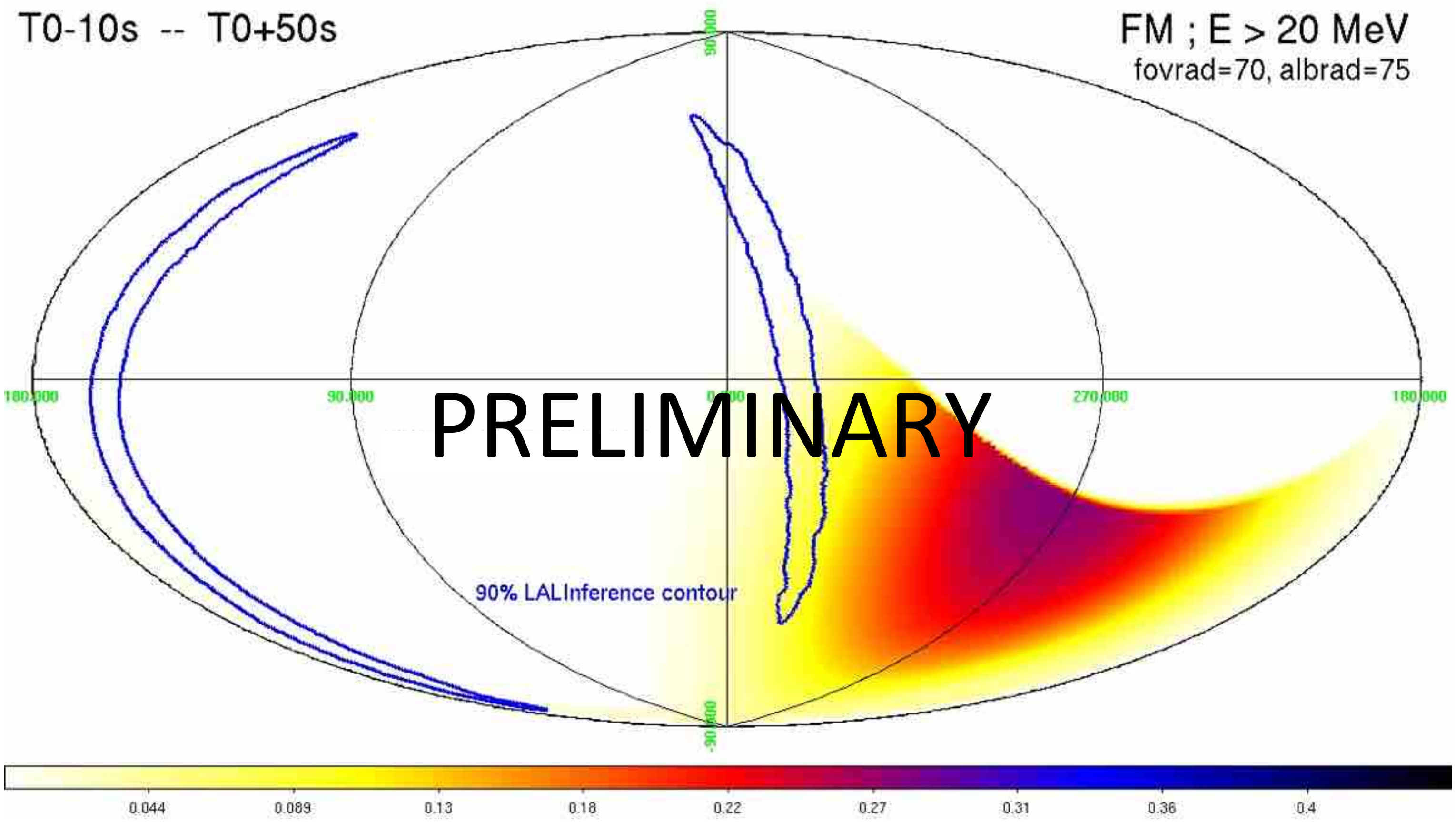

T0-10s -- T0+50s
FT3ab ; E > 20 MeV
fovrad=70, albrad=75
90% LALInference contour
PRELIMINARY
90.000
180.000
90.000
0.000
270.000
180.000
-90.000
0.0018
0.0073
0.017
0.029
0.046
0.066
0.09
0.12
0.15

LVT151012

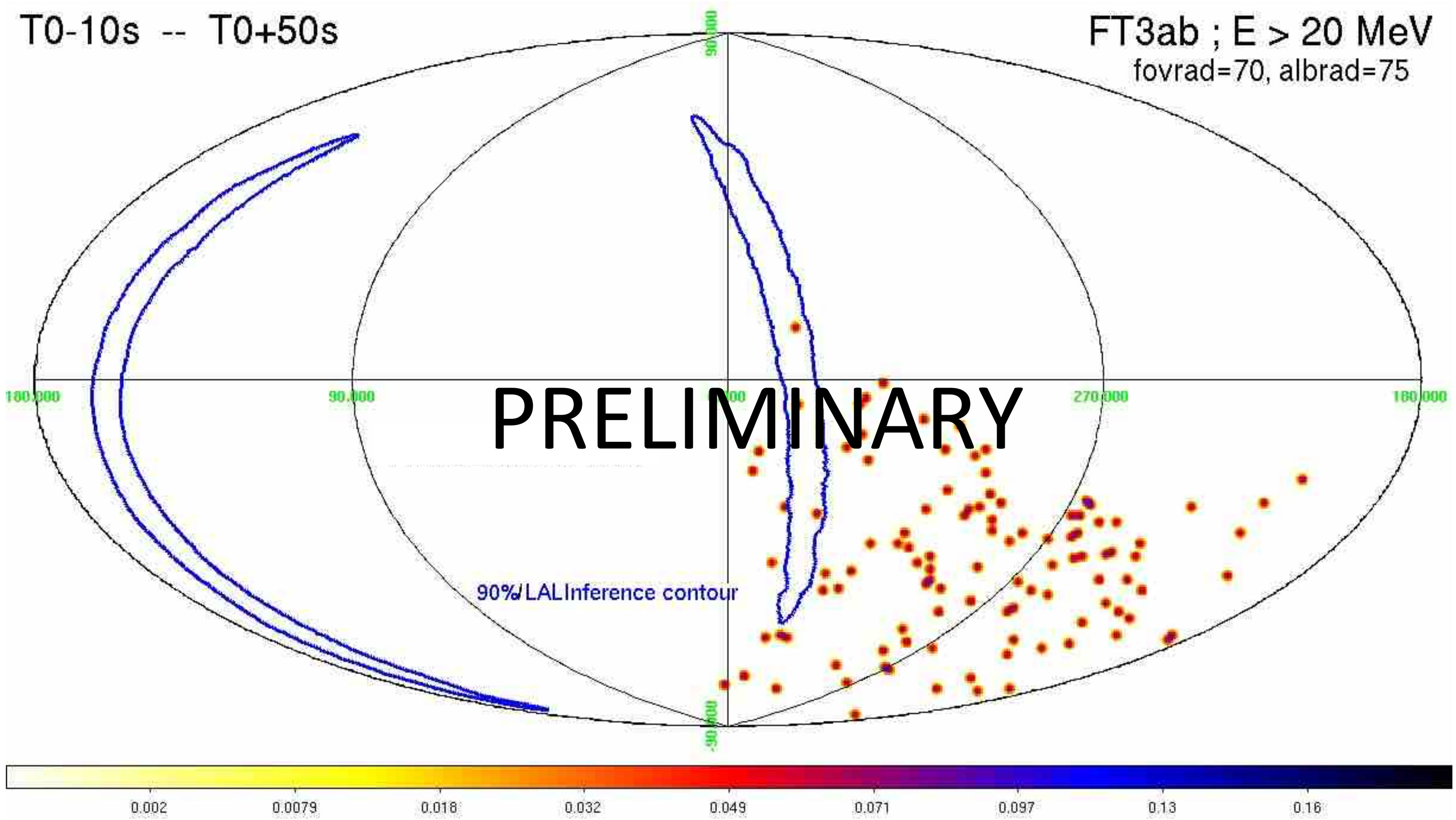
- T_0 = 9:54:43 UT, 12 October, 2015; candidate

- learned about the event recently
- archival search

LVT151012


T0-10s -- T0+50s
FM ; E > 20 MeV
fovrad=70, albrad=75
PRELIMINARY
90% LALInference contour
0.044
0.089
0.13
0.18
0.22
0.27
0.31
0.36
0.4

LVT151012


T0-10s -- T0+50s
FT3ab ; E > 20 MeV
fovrad=70, albrad=75
90.000
180.000
90.000
270.000
180.000
-90.000
PRELIMINARY
90% LALInference contour
0.002
0.0079
0.018
0.032
0.049
0.071
0.097
0.13
0.16

bright perspectives for AGILE

- LIGO-VIRGO MoU with AGILE signed and now fully operative.
- AGILE observations of GW events are part of a strategy of collaboration between space and ground observatories
(in Italy: INAF, INFN, ASI).
- The large AGILE-GRID FoV (120° diameter) and the 200 passes/day are crucial assets.

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bright perspectives for AGILE

- large probability of covering with the imaging GRID-FoV the region (error box) of a prompt GW event: ~ 10% (½ x 1/5)
- further optimization of the MCAL trigger (0.4-100 MeV)

- very fast data processing, 2-3hr, to be improved….

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perspectives for AGILE after the summer

ASI announced further support to AGILE mission

- **14 downlinks/day**
- **Super-AGILE (20-60 keV) turned on again**
- **very fast data processing, dedicated team for GW fast reaction.**

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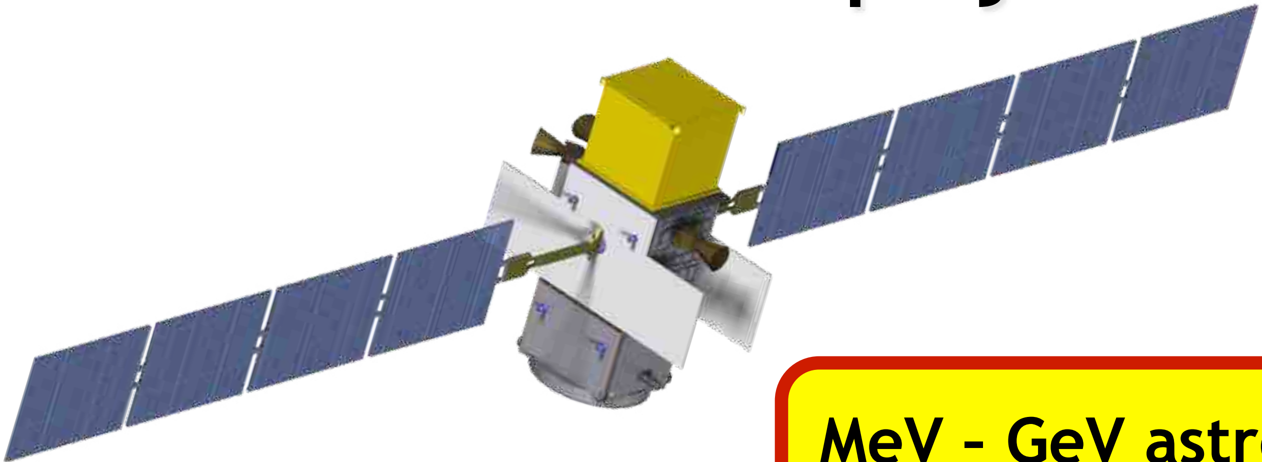
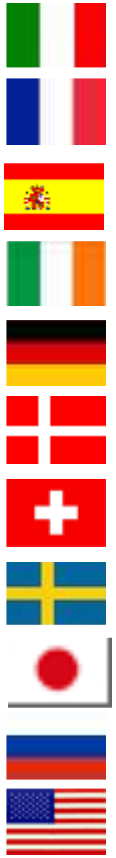
the future: e-ASTROGAM

The next gamma-ray MeV-GeV mission: the e-ASTROGAM project





MeV - GeV astrophysics
MeV - GeV community

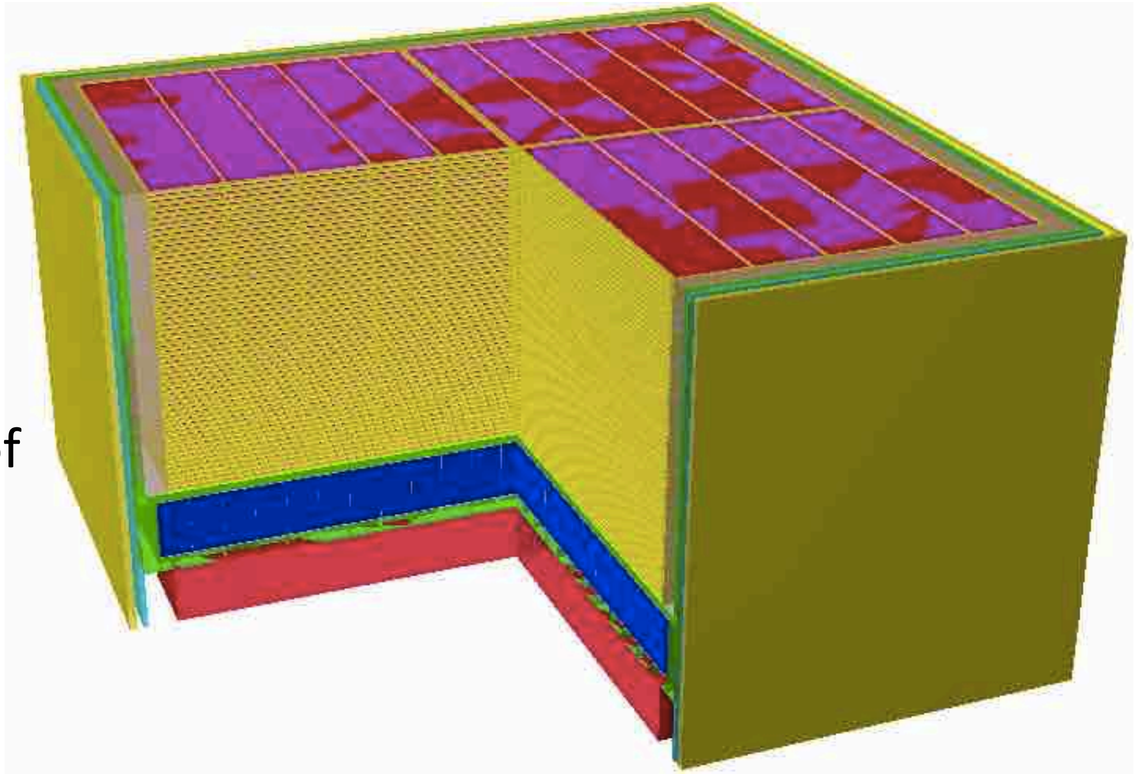
LoI submitted to ESA M5 call on June 6th;

e-ASTROGAM is focused on gamma-ray astrophysics in the range 0.3-100 MeV with excellent capability up to GeV energies.

e-ASTROGAM Sensitivity (M5)

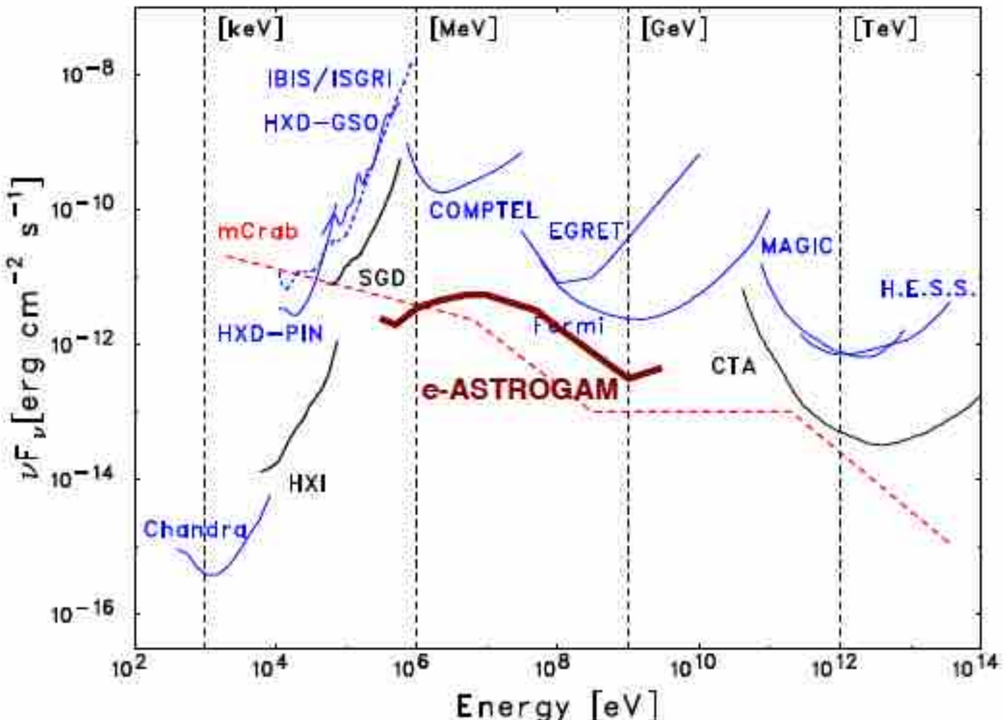
- **4 towers**
- **50 layers** of 5×5 double sided Si strip detectors
- Each DSSD has a total area of 9.5×9.5 cm^2, a thickness of 400 (500) μm, readout pitch of 240 μm (384 strips per side), and a guard ring of 1.5 mm
- Spacing of the Si layers: 7.5 mm
- The DSSDs are wire bonded strip to strip to form 2-D ladders

⇒ 900.000 electronic channels



LEO orbit of altitude 520-550 km
2.5 – 3 sr FoV
Launch 2029 – 2030
3-yr mission

e-ASTROGAM Sensitivity (M5)



Adapted from Takahashi et al. (2013)

- **ASTRO-H/SGD**: S(3σ) for 100 ks exposure of an isolated point source
- **COMPTEL** and **EGRET**: sensitivities accumulated during the whole duration of the CGRO mission (9 years)
- **Fermi/LAT**: 5σ sensitivity for a high Galactic latitude source and after 1 year observation in survey mode
- **ASTROGAM** − 3σ/5σ sensitivity for a 1-year effective exposure of a high Galactic latitude source

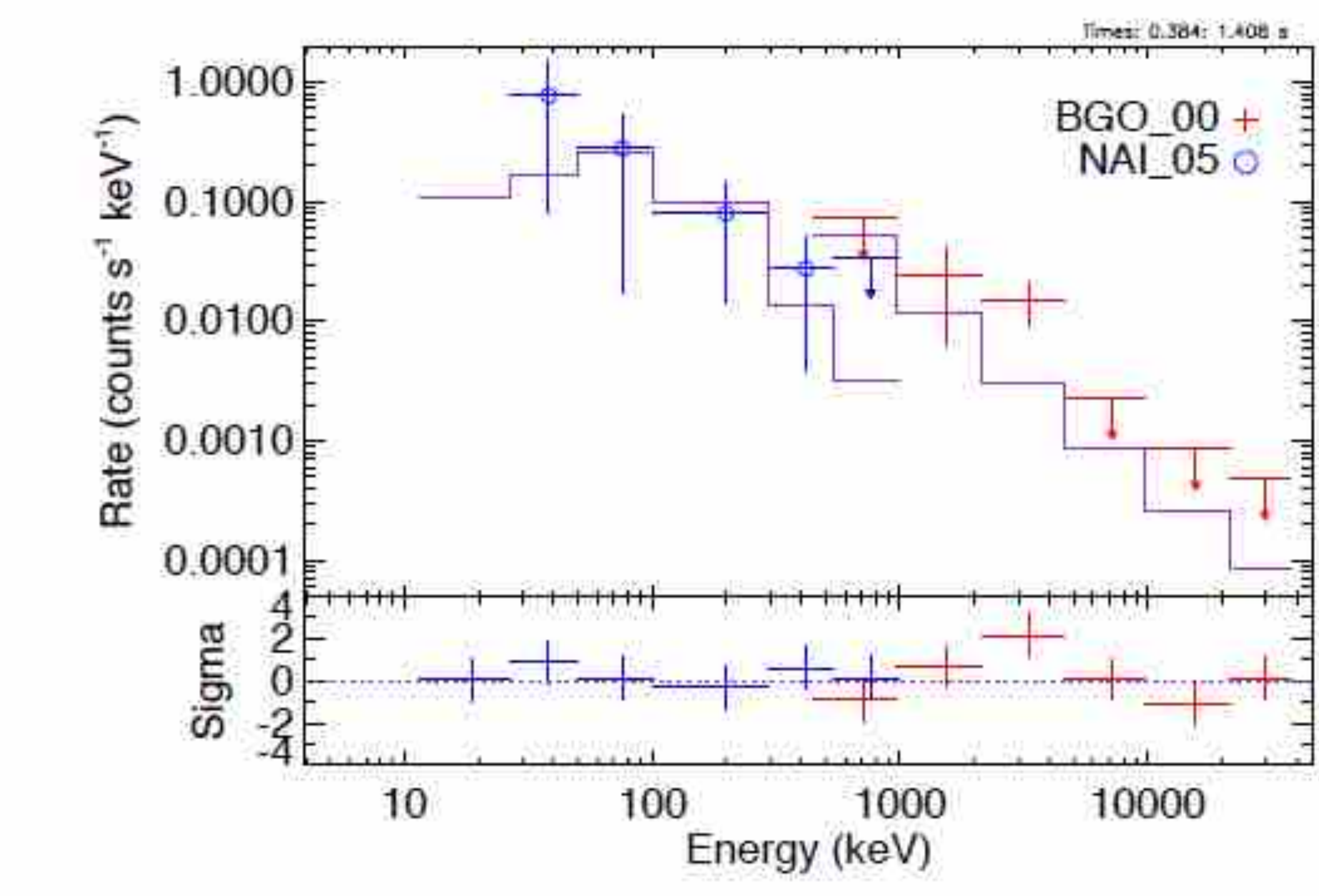
Table 1. e-ASTROGAM line sensitivity (3σ in 10^6 s) compared to that of *INTEGRAL*/SPI

E (keV)	FWHM (keV)	Origin	SPI sensitivity (ph cm^{-2} s^{-1})	e-ASTROGAM sens. (ph cm^{-2} s^{-1})	Improvement factor
511	1.3	Narrow line component of the e+/e- annihilation radiation from the Galactic center region	5.2×10^{-5}	4.1×10^{-6}	13
847	35	^{56}Co line from thermonuclear supernovae	2.3×10^{-4}	3.5×10^{-6}	66
1157	15	^{44}Ti line from core-collapse supernova remnants	9.6×10^{-5}	3.6×10^{-6}	27
1275	20	^{22}Na line from classical novae of the ONe type	1.1×10^{-4}	3.8×10^{-6}	29
2223	20	Neutron capture line from accreting neutron stars	1.1×10^{-4}	2.1×10^{-6}	52
4438	100	^{12}C line produced by low-energy cosmic rays in the inner Galaxy	1.1×10^{-4}	1.7×10^{-6}	65

e-ASTROGAM will gain a factor 10−60 in line sensitivity compared to INTEGRAL/SPI

The e-ASTROGAM core science

- **Extreme phenomena in the era of new astronomy**
  Gravitational waves ……
- **The mysteries of the GC and Inner Galaxy**
  Central BH, compact objects, anti-matter
- **Supernovae, nucleosynthesis, and Galactic chemical evolution**


Times: 0.384: 1.408 s
BGO_00
NAI_05
Rate (counts s⁻¹ keV⁻¹)
1.0000
0.1000
0.0100
0.0010
0.0001
Sigma
4
2
0
-2
-4
10
100
1000
10000
Energy (keV)