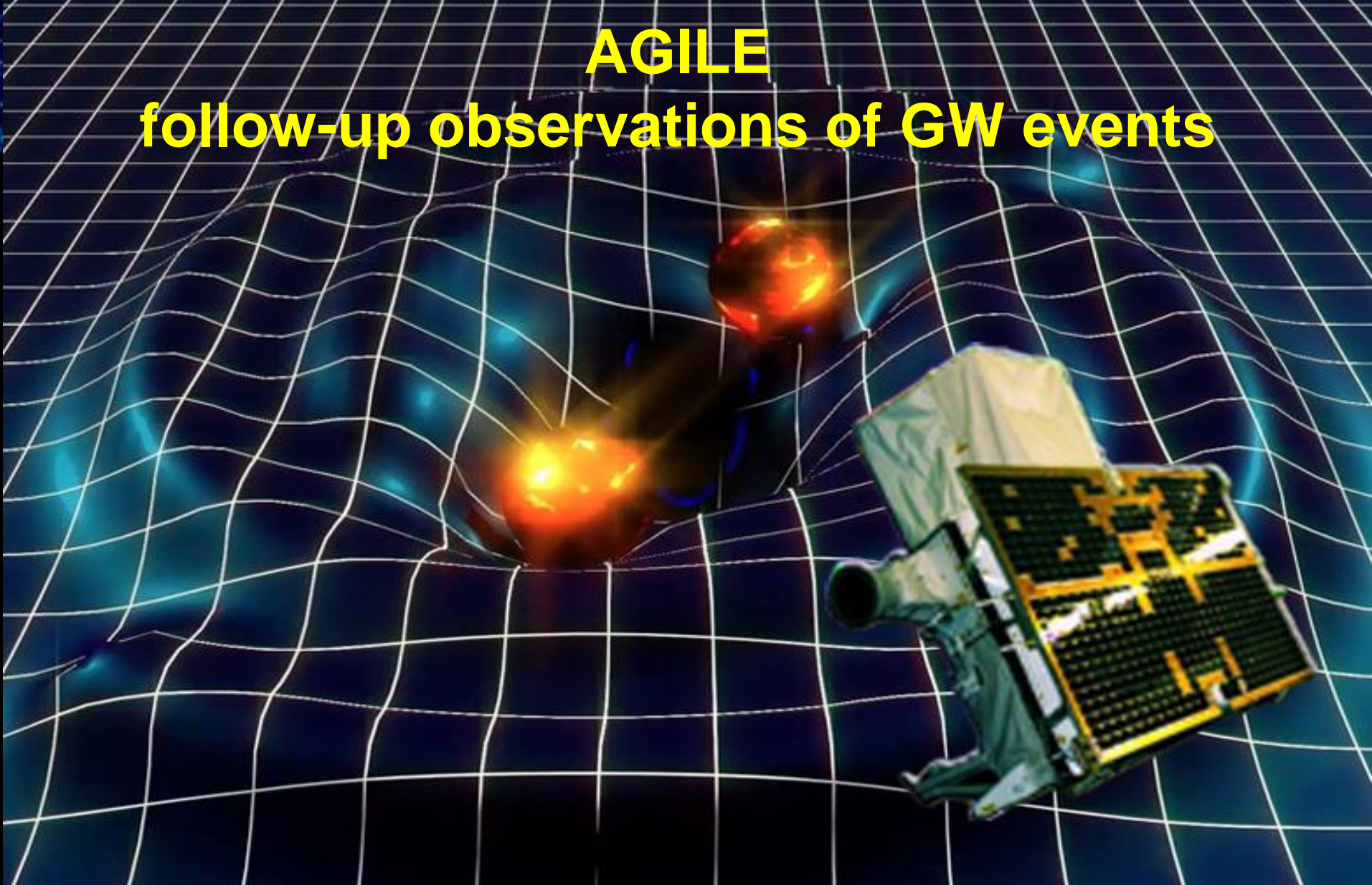
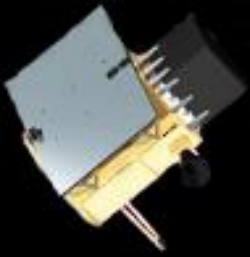


AGILE **follow-up observations of GW events**



Francesco Verrecchia, on behalf of the AGILE Team

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



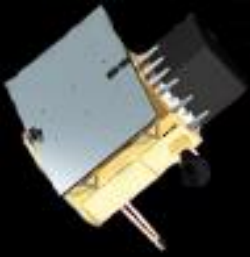
AGILE can play a crucial role in the search of GW source counterparts

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



AGILE has the shortest reaction time to bright gamma-ray transients

- **Blazars (fast ATels)**
- **Galactic transients (recently Cyg X-3 again...)**



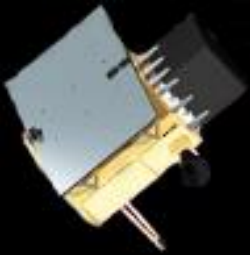
AGILE

Science Data Center

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 observation analysis (Tavani et al. 2016) accepted on ApJ

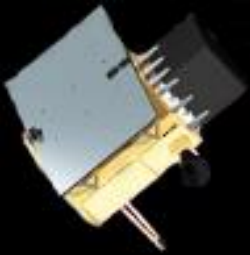


AGILE

Science Data Center

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)	~ 2×10^7 (cm ² sec)	(0.5 - 1) $\times 10^7$ (cm ² sec)

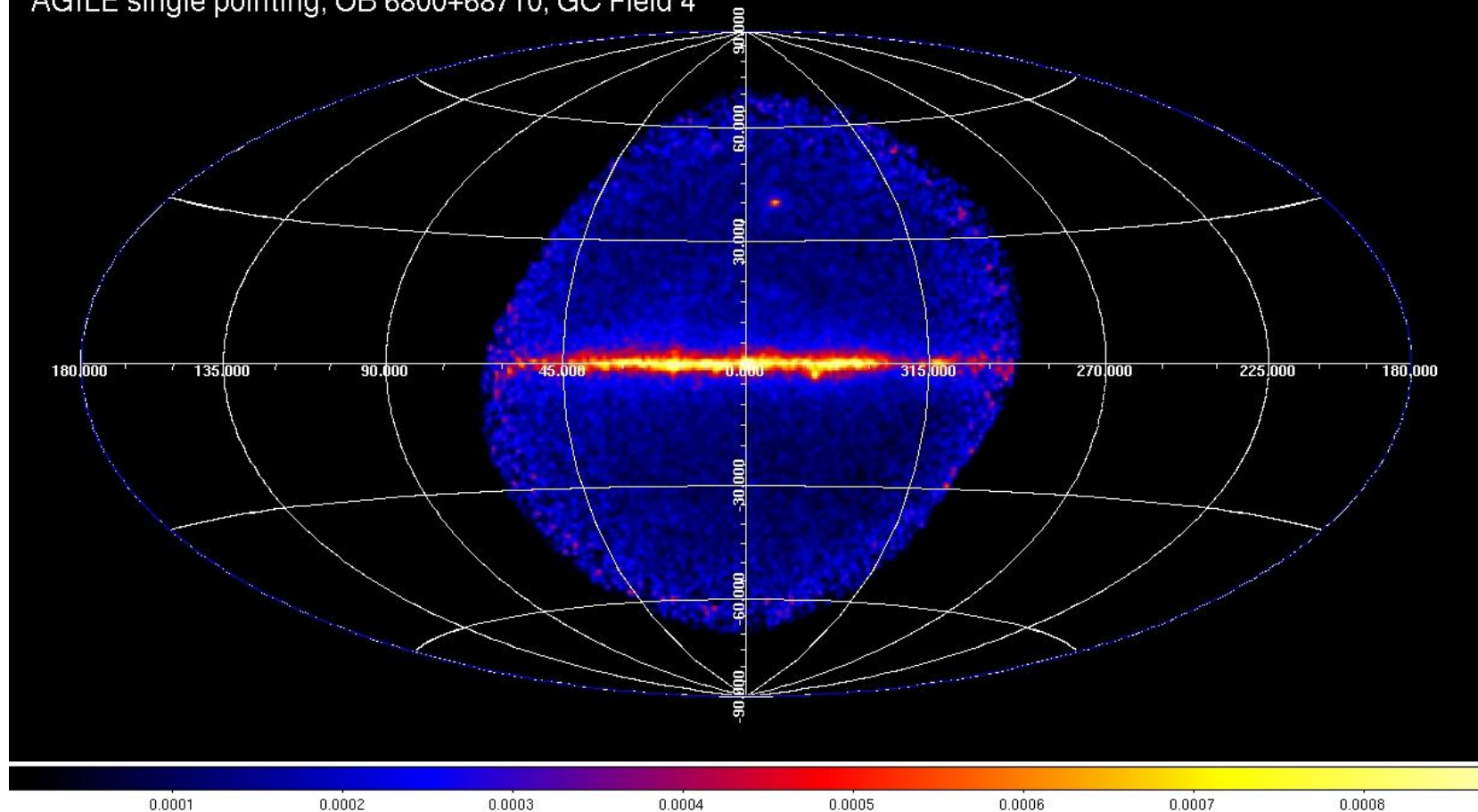


AGILE

Science Data Center

AGILE two "lives": pointing

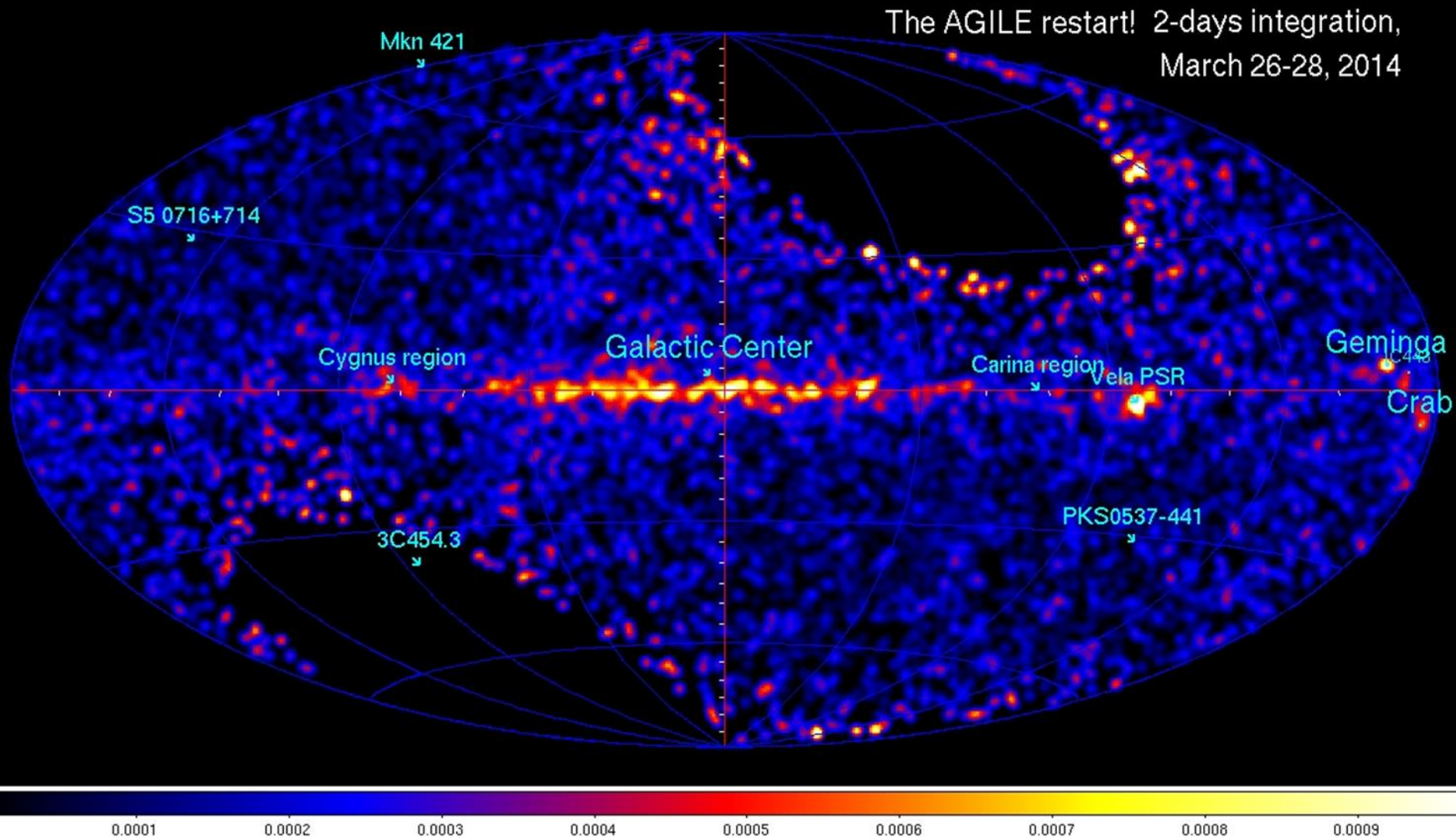
AGILE single pointing, OB 6800+68710, GC Field 4



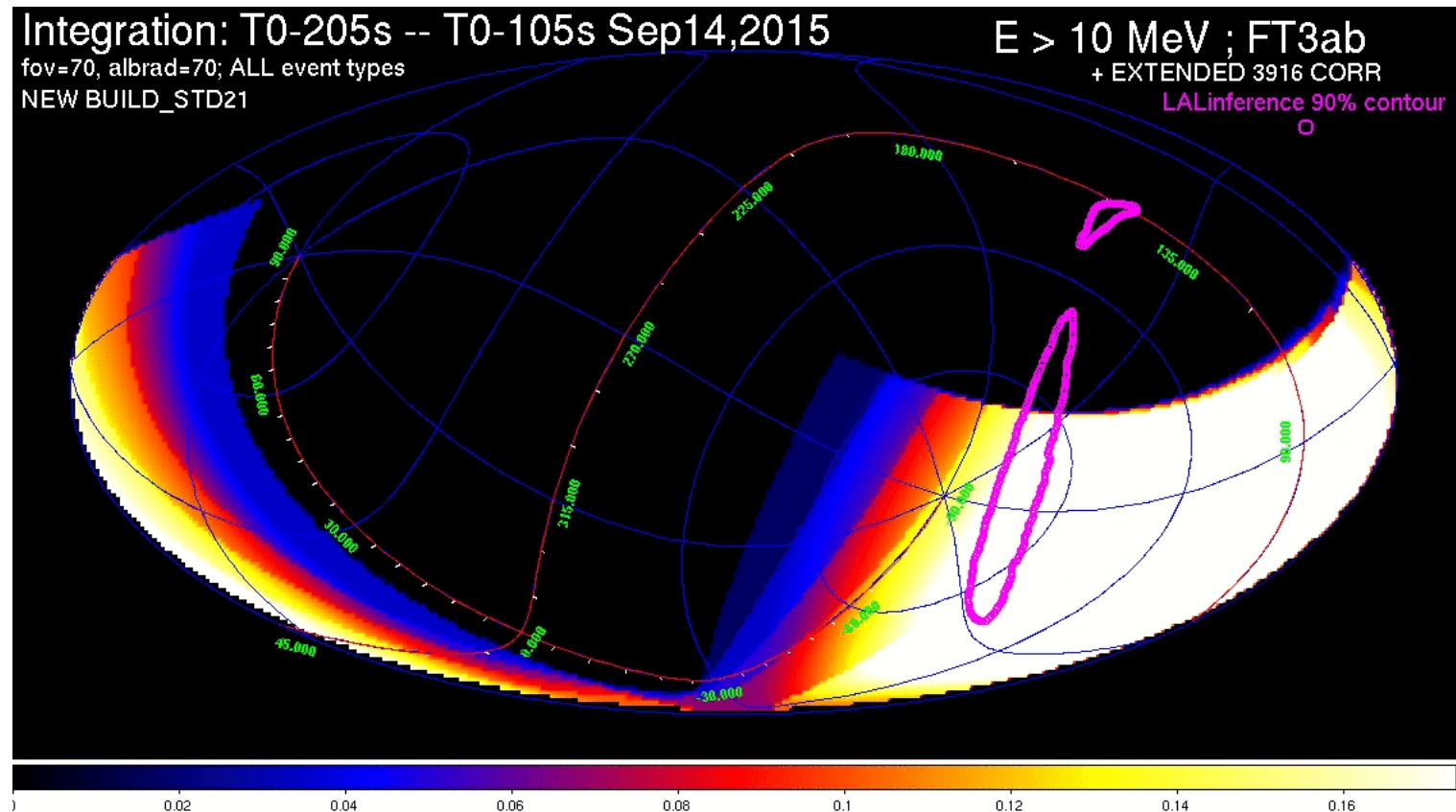
25d + 6d
exposure

Spinning example: AGILE data acquisition restart, 26 Mar 2014

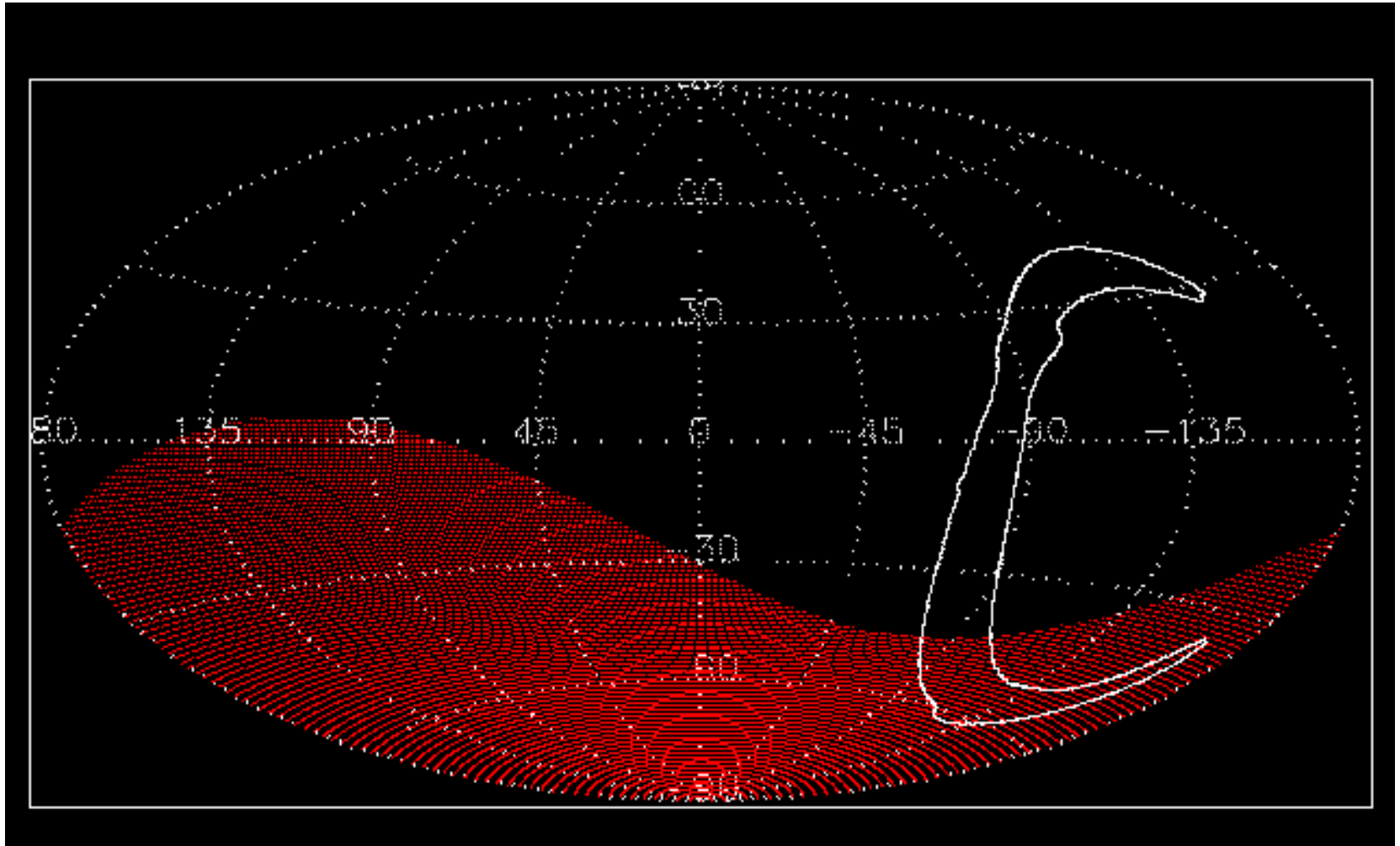
(2d)



AGILE in spinning: revolution including T0 of GW150914



Earth occultation during one orbit (95 min)



Search for gamma-ray transients

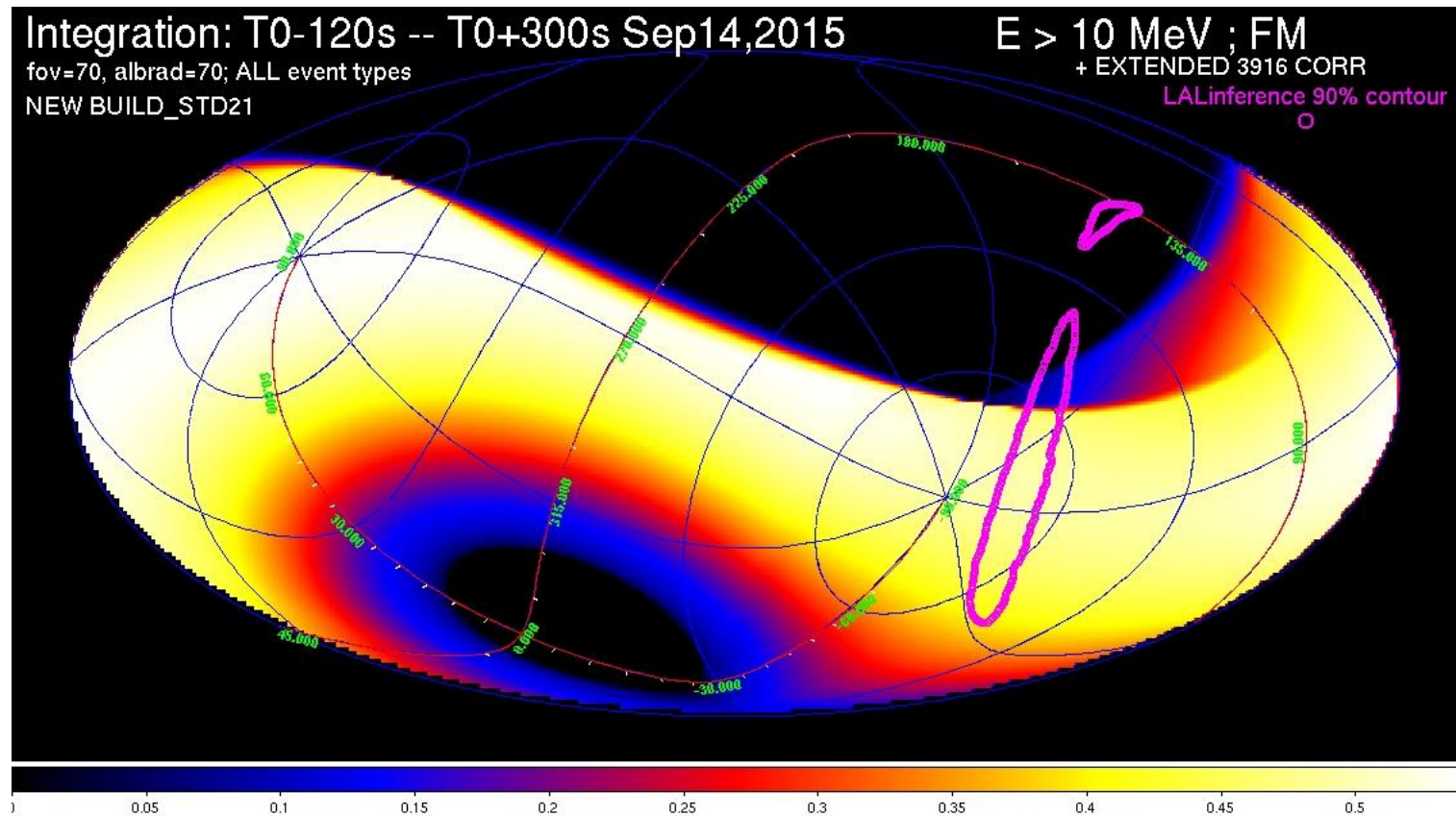
- gamma-ray imager: covers 80% of the sky
- 200 spinning rotations / day
- (Earth occultations, SAA) - > 120 useful passes
- passes of ~ 150 sec duration
- **sensitivity ~ (1-2) 10^{-8} erg cm $^{-2}$ s $^{-1}$ in 100 sec.**
- GRB – like searches, MCAL, AC

GW150914

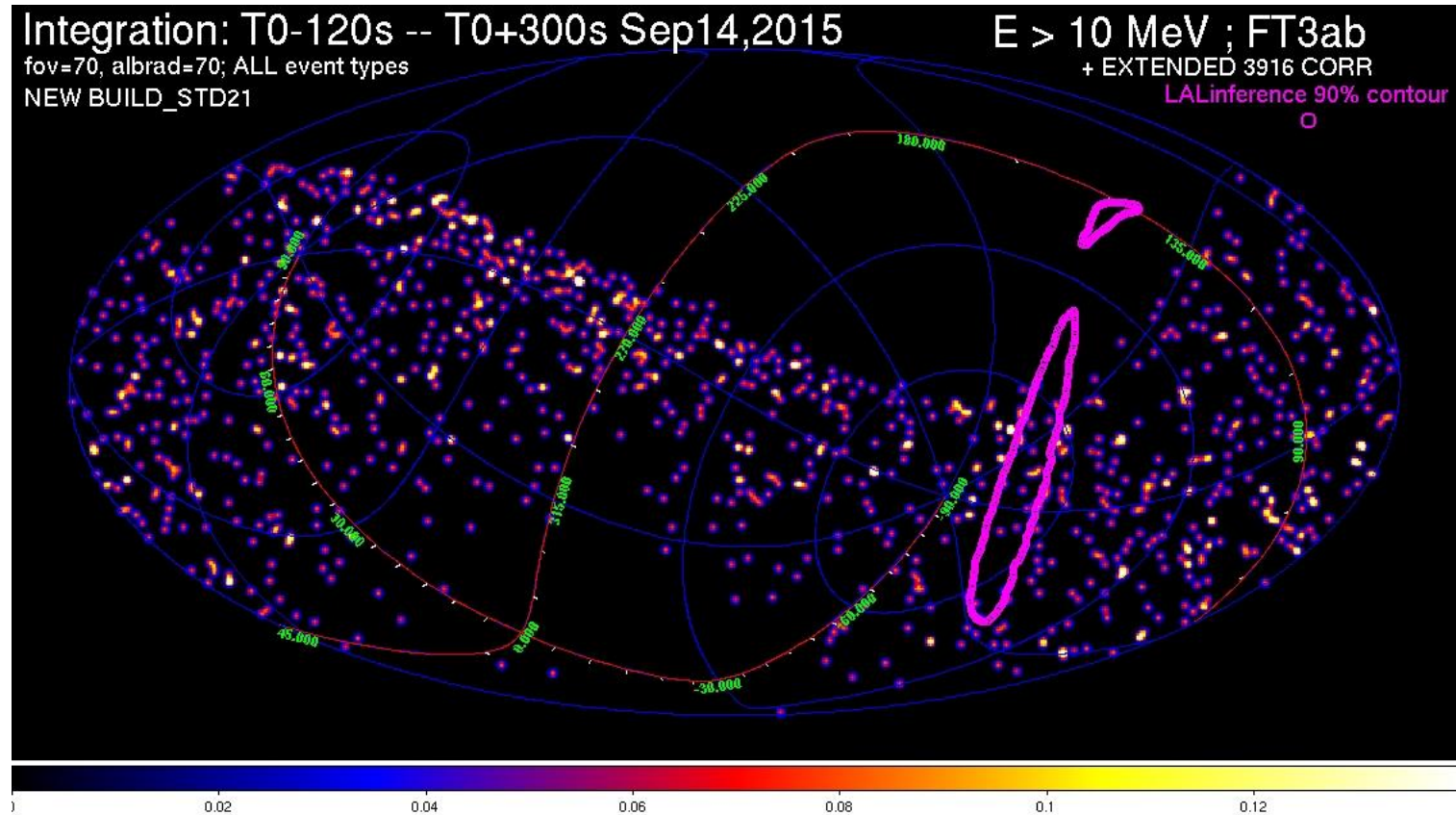
$T_0 = 9:50:45$ UT, 14 September, 2015

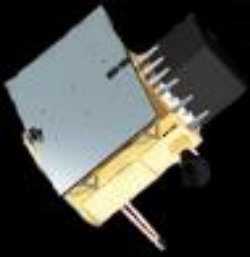
- **learned about the event on Feb. 11, 2016 (no MoU active yet)**
- **archival search**

exposure: revolution -120/+300 sec from T_0



exposure: revolution -120/+300 sec from T_0



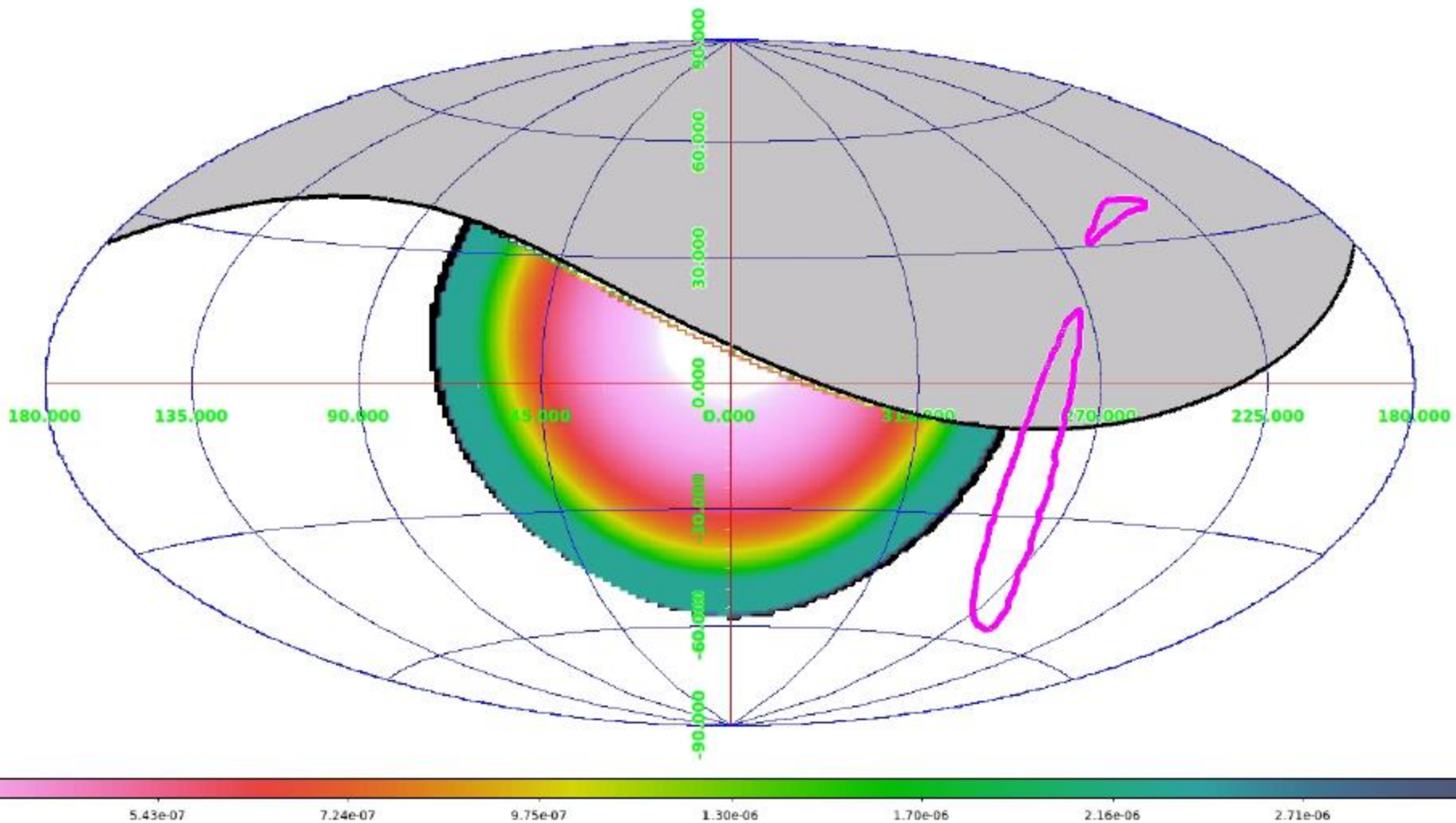


AGILE

Science Data Center

AGILE field at $T_0 = 09:50:45$ UT

just missed it (-2 / +2 sec)

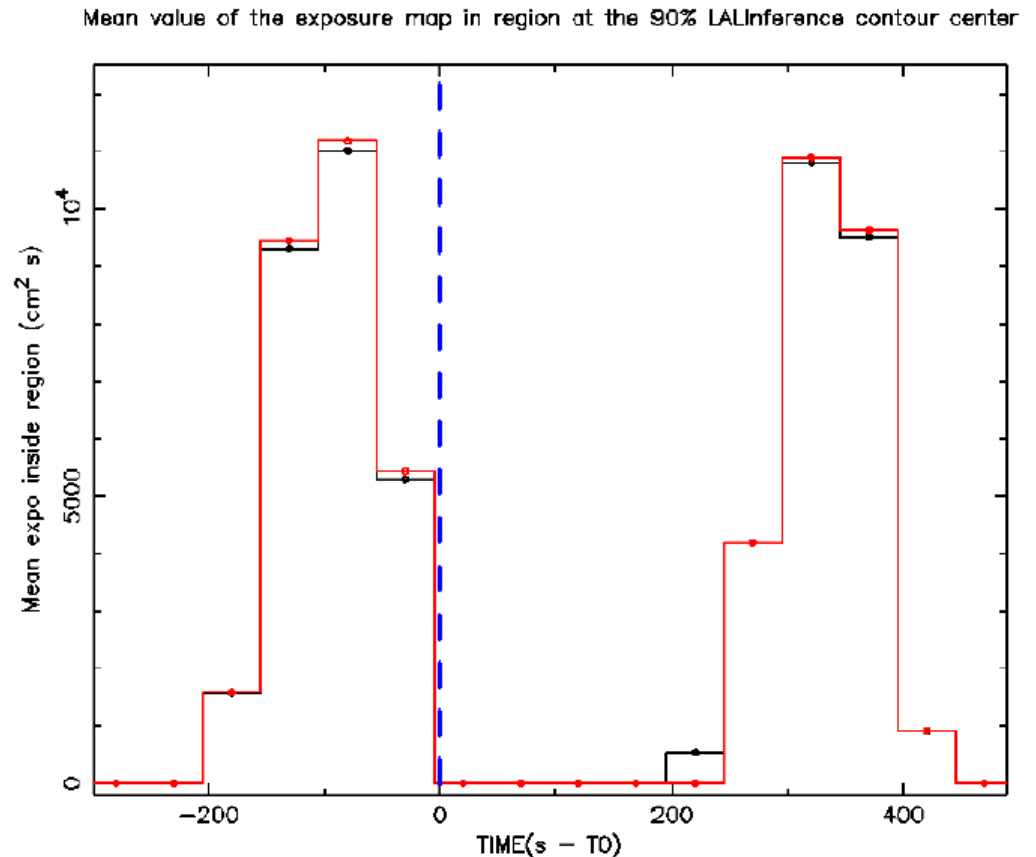


Central LIGO contour exposure scan: from $T_0 - 300\text{s}$ to $T_0 + 500\text{s}$

Mean exposure within $7^\circ \times 25^\circ$
region (black) and 10° radius
circular region (red) at about
the LIGO contour center

100s exposure scan

65% of LIGO contour
covered $\sim 10\text{-}60\text{s}$ before T_0



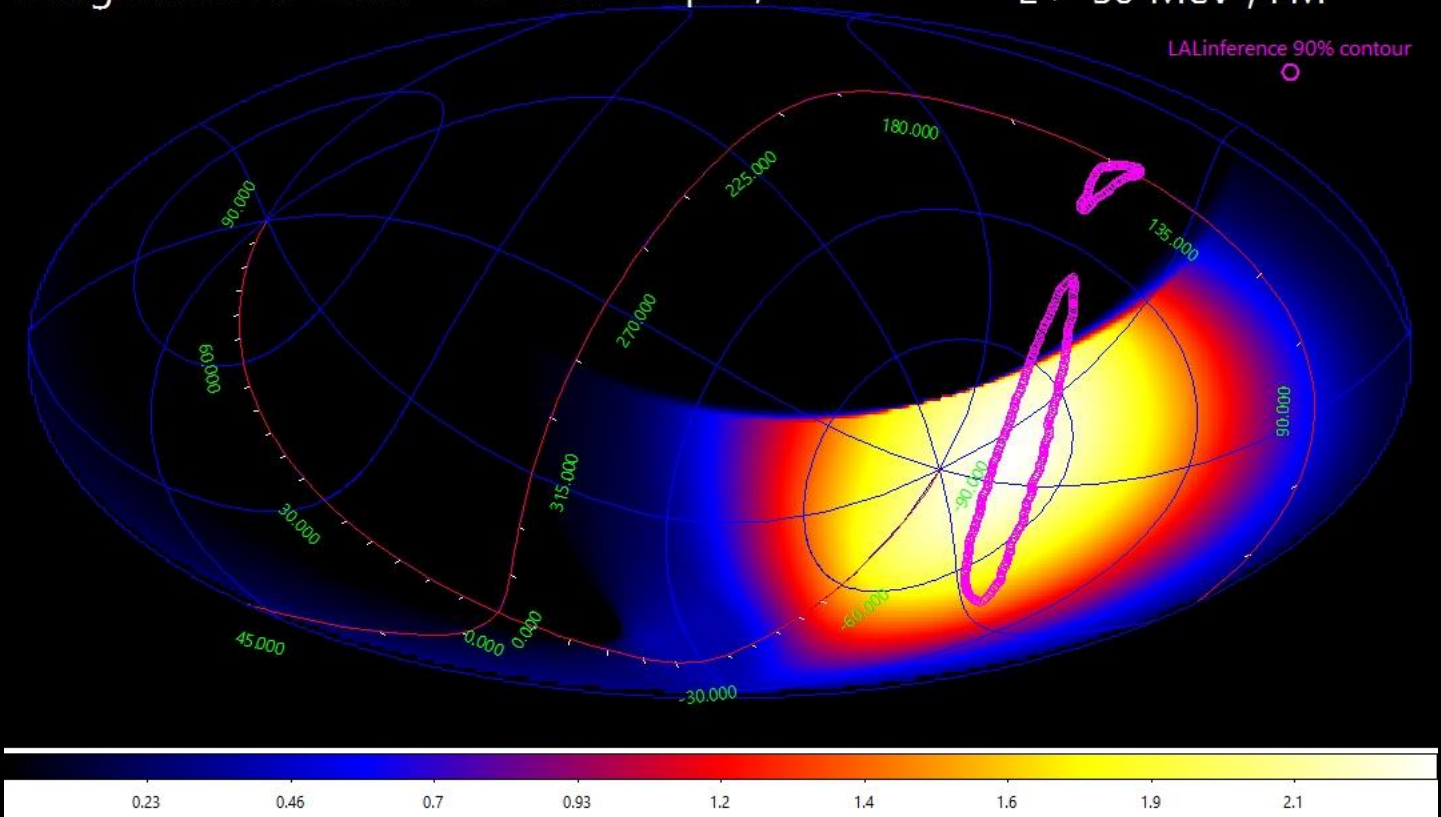
AGILE observation of GW150914

- **probability of covering with the imaging GRID-FoV the region (error box) of the prompt GW event: ~ 10% ($\frac{1}{2} \times \frac{1}{5}$)**
- **much larger than any other imaging large-FoV (2-2.5 sr) instruments in space (Swift-BAT, Fermi-LAT)**
- **even larger than < 1-sr FoV instruments of INTEGRAL and NuStar**

AGILE exposure at T_0+330 sec (± 50 sec)

Integration: T_0+283 s -- T_0+383 s Sep14,2015

$E > 50$ MeV ; FM

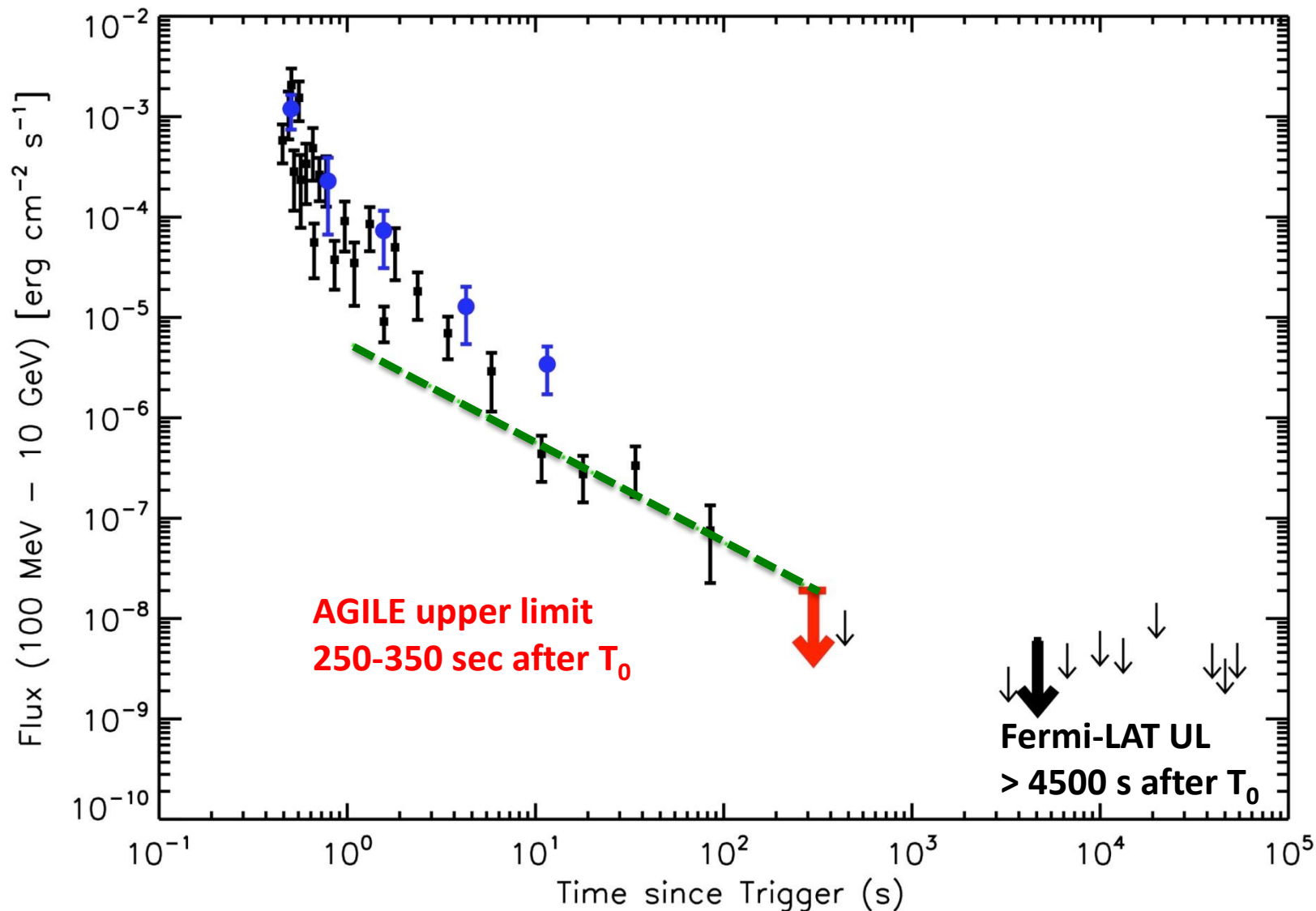


2-sigma upper limit ($E > 50$ MeV) = 1.5×10^{-8} erg cm $^{-2}$ s $^{-1}$

AGILE and Fermi-LAT upper limits in the GRB090510 light curve

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

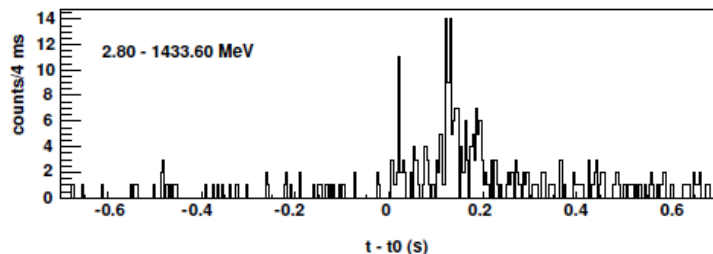
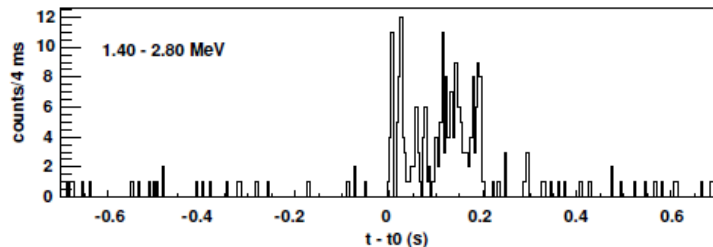
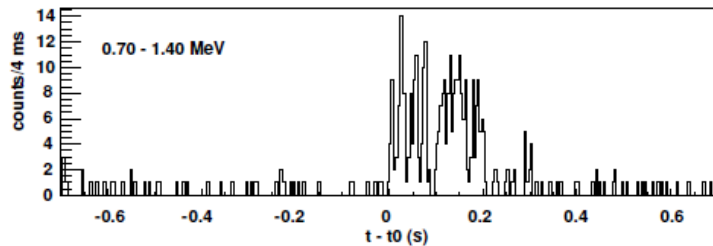
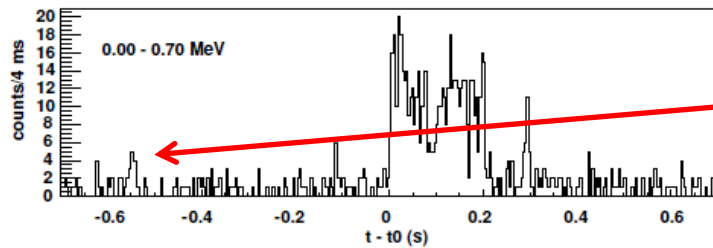
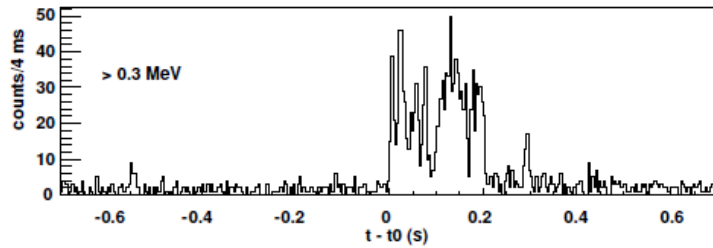
AGILE-GRID blu, Fermi/LAT black, light curve



AGILE-MCAL GRB090510 light curve

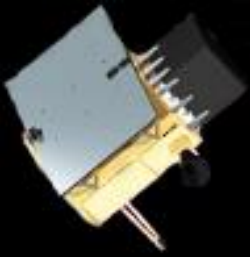
GRB090510 light curve as detected by MCAL (4ms bin), Giuliani + 2010

->15ms soft precursor at $T=T_0 - 0.55s$ ($E < 0.7MeV$)



AGILE does not detect the Fermi-GBM transient

- at the GW150914 prompt time ($T_0 + 0.4\text{s}$), best GBM position region at about 90° off-axis for AGILE GRID and MCAL
- limited exposure of MCAL
- **AGILE 5-sigma MCAL upper limit**
 $F_{\text{GBM}} = 2 \times 10^{-6} \text{ erg cm}^{-2} (0.45 - 100 \text{ MeV}),$
- 2.3 times larger than GBM event extrapolation at 1 MeV
 $F_{\text{GBM}} = (2 \pm 1) \times 10^{-7} \text{ erg cm}^{-2} (10 \text{ keV} - 1 \text{ MeV}),$
photon index 1.4 (Connaughton+ 2016)



AGILE

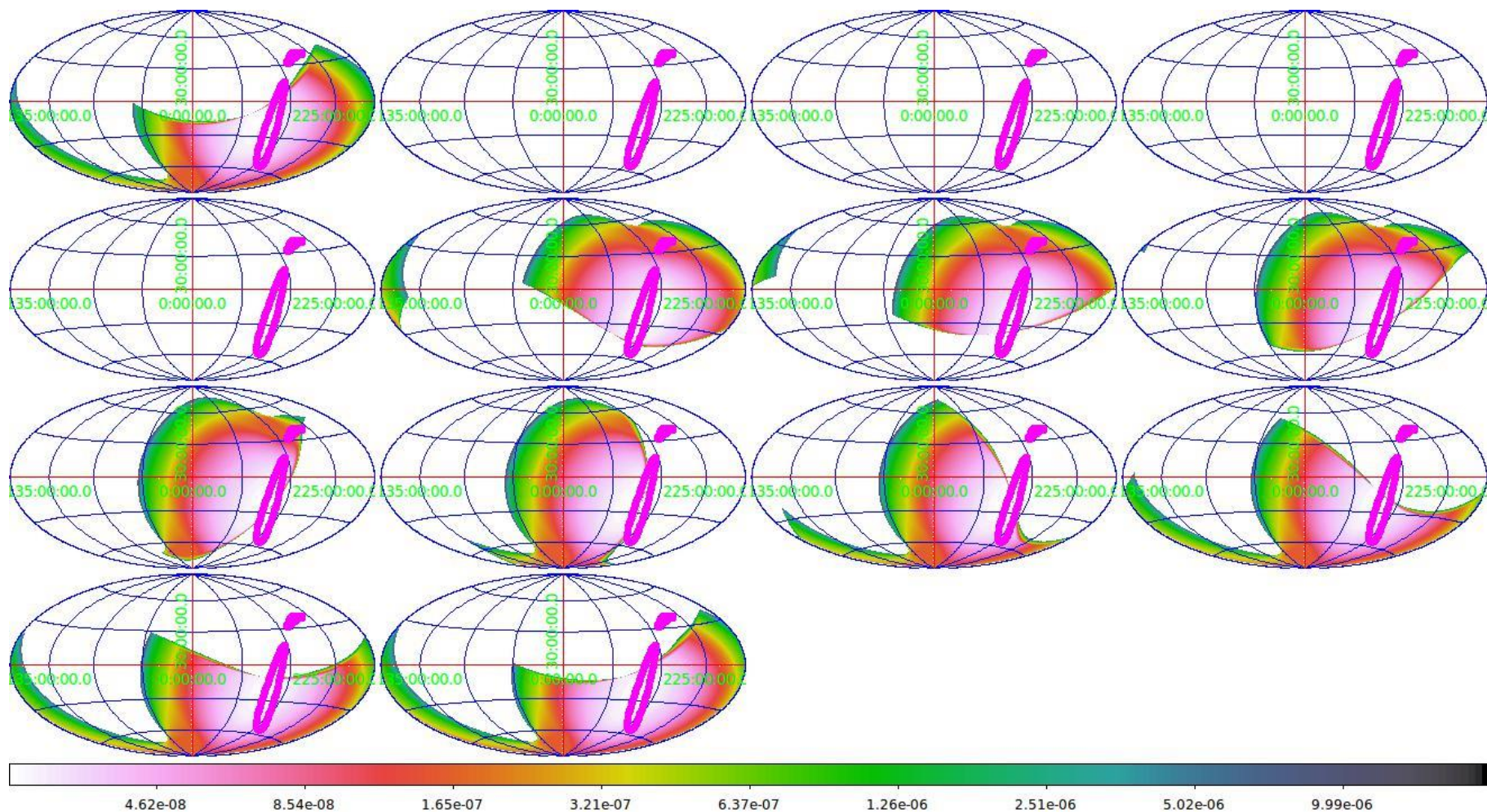
Science Data Center

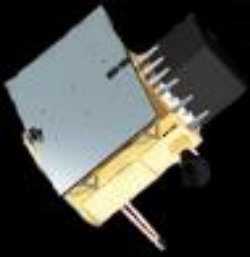
precursor search

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

Interval number	Central time bin (**)	Duration (sec)	2σ UL (*) (10^{-8} 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)





AGILE

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Long time-scale search

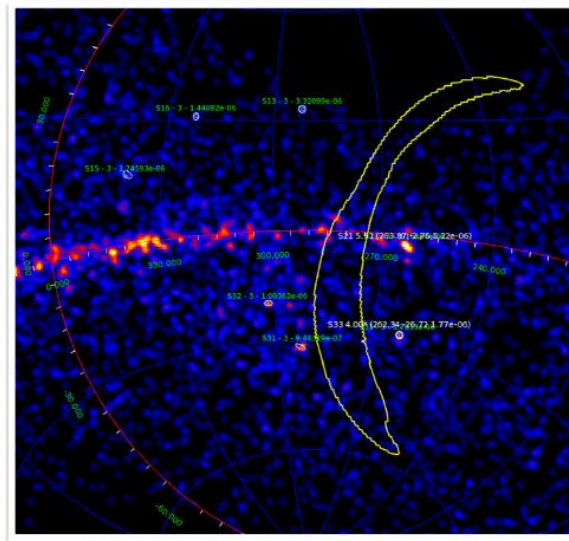
Table 2: Long-integration time analysis of the GW150914 localization region

Interval name	Duration	2σ UL (*) (10^{-9} 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

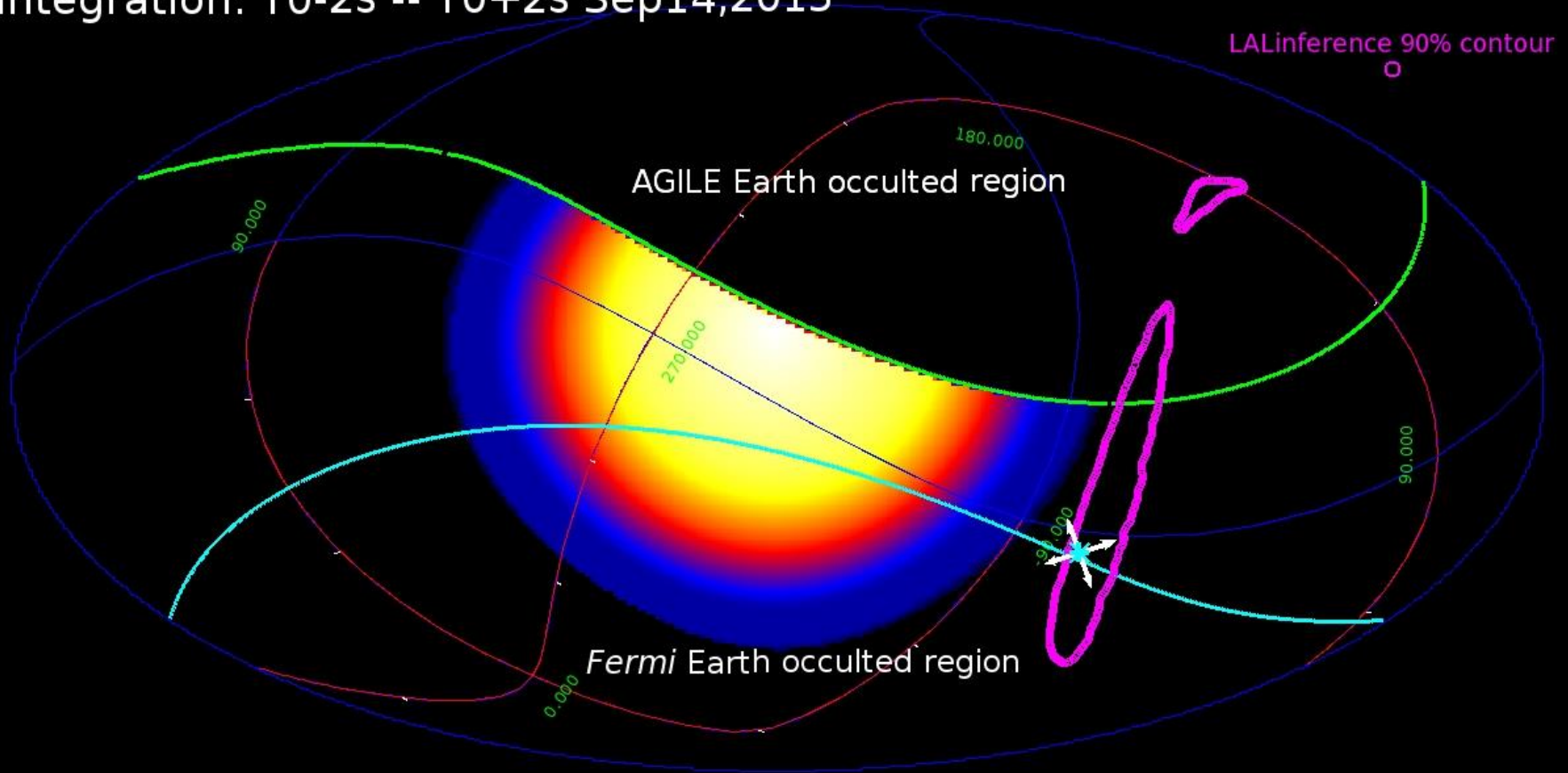
=>no
significant
detection



Bulgarelli talk

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

Integration: T0-2s -- T0+2s Sep14,2015



**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**

LVT151012

- $T_0 = 9:54:43$ UT, 12 October, 2015; candidate
- learned about the event recently
- started archival search

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.**

bright perspectives for AGILE

- **large probability of covering with the imaging GRID-FoV the region (error box) of a prompt GW event: ~ 10% ($\frac{1}{2} \times \frac{1}{5}$)**
- **further optimization of the MCAL trigger (0.4-100 MeV)**
- **very fast data processing, 2-3hr, to be improved....**

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.**



Thank you