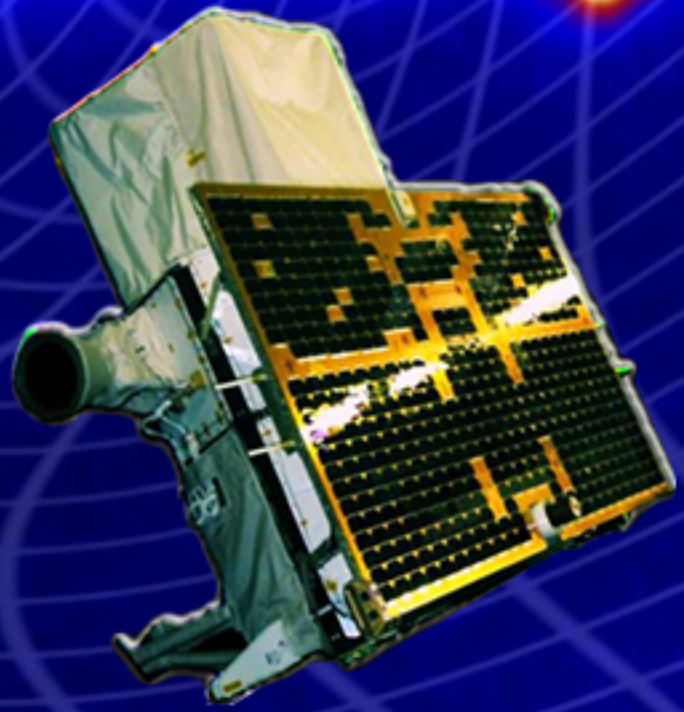
Multi messenger astronomy with the γ-ray satellite AGILE: gravitational wave events and ultra high energy astrophysical neutrinos

Paolo W. Cattaneo, INFN Pavia on behalf of the AGILE Team

CRIS 2018, Porto Palo di Capo Passero, June 18, 2018



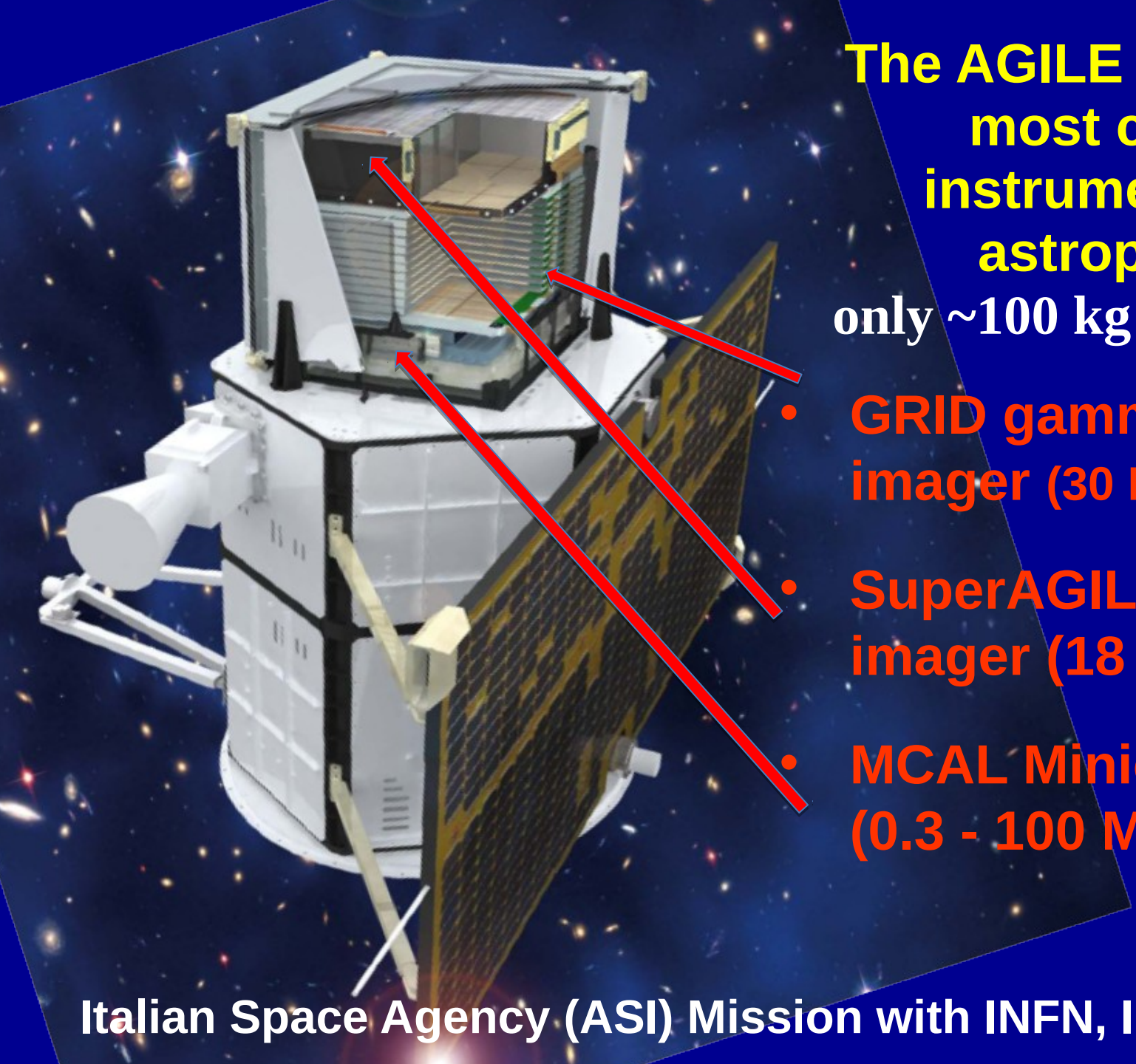
Prepared with help from C.Pittori, F.Verrecchia and F.Lucarelli

AGILE mission

Science Data Center

Launched from Sriharikota (India) on 23th April 2007.

Orbit at ~500 km
Period ~90 minutes
Inclined 2.5° on Equator
80% of sky every 7 minutes
100-150 passes each region

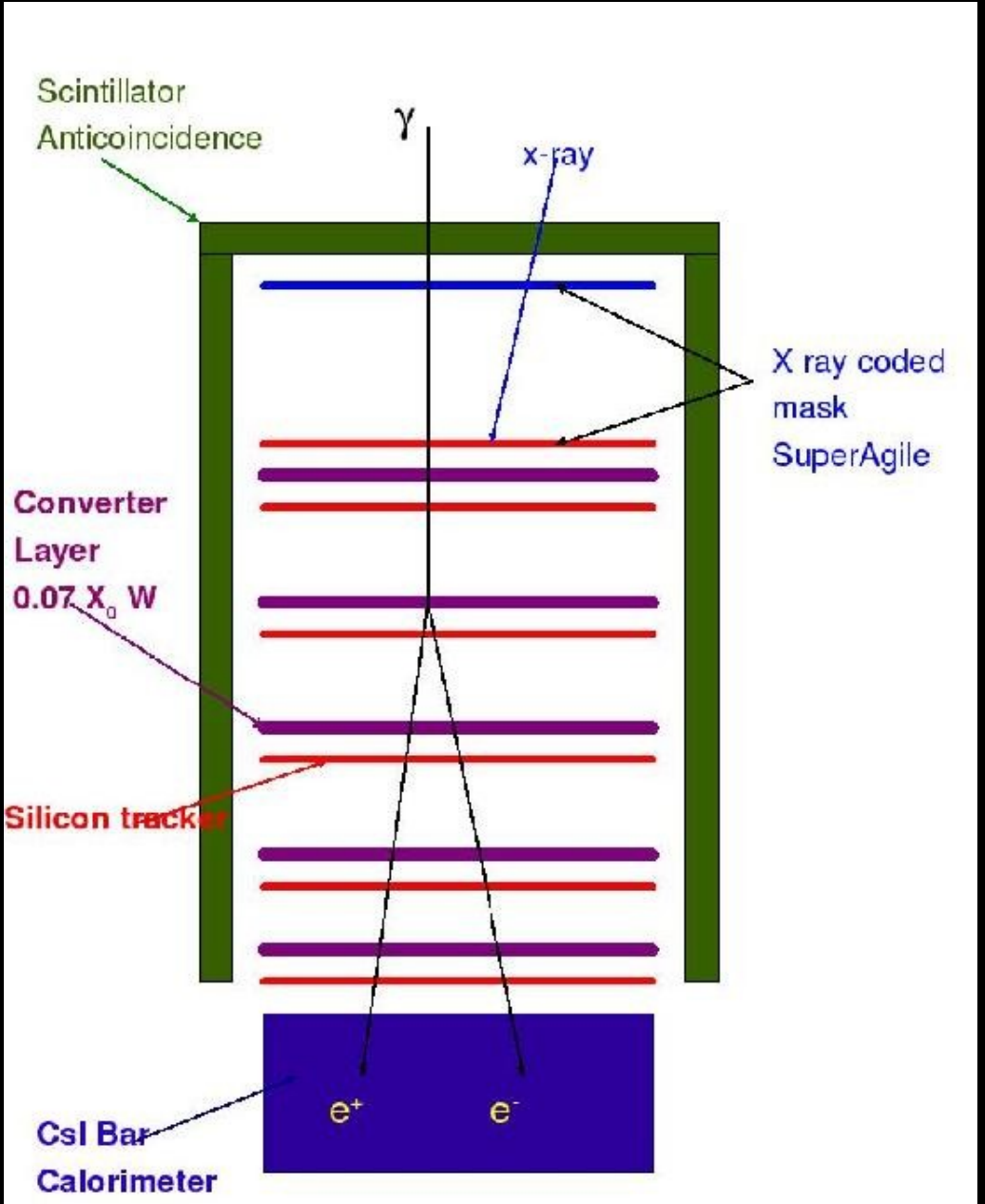


The AGILE Payload: the most compact instrument for HE astrophysics

only ~100 kg (~ 60 × 60 cm)

- GRID gamma-ray imager (30 MeV - 30 GeV)
- SuperAGILE hard X-ray imager (18 - 60 keV)
- MCAL Minicalorimeter (0.3 - 100 MeV)

Italian Space Agency (ASI) Mission with INFN, INAF participation



γ-rays detected through pair conversion (e^+e^-) then measured in the Silicon Tracker

Hard X-ray detected with Coded mask followed by silicon plane

MiniCALorimeter of CsI Bar (1.5 X_0). Acting standalone as GRB, TGF detector.

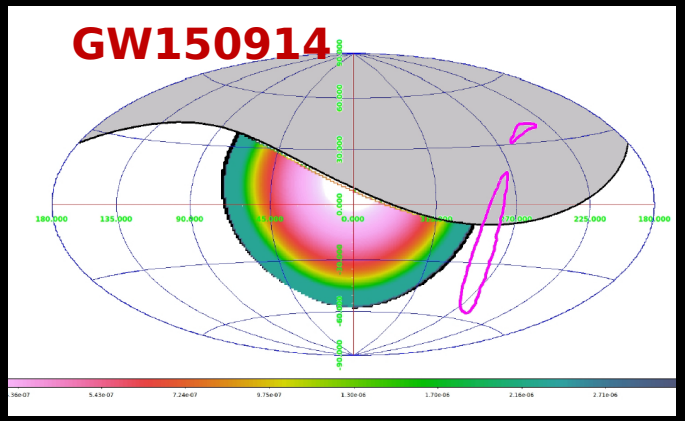
AGILE and GW astrophysics

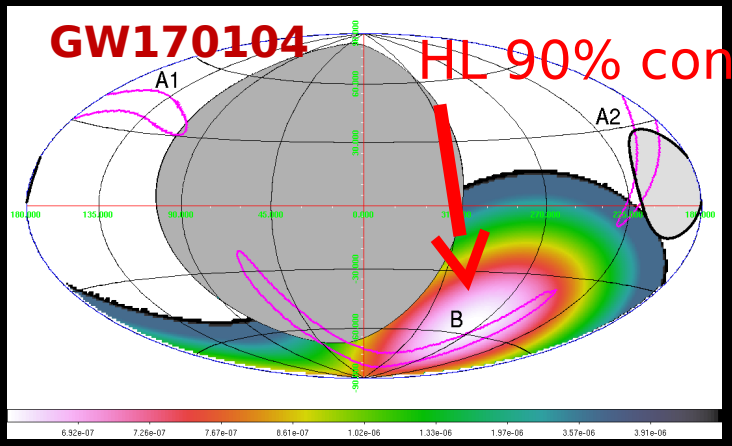
- very fast reaction to external GW trigger
- new processing pipelines
- great potential for fast discovery of gamma-ray transients associated with NS-NS, NS-BH and BH-BH (if any) coalescences
- AGILE GW-Team monitoring shifts (24/7) during the O2 GW LIGO-Virgo observing run.

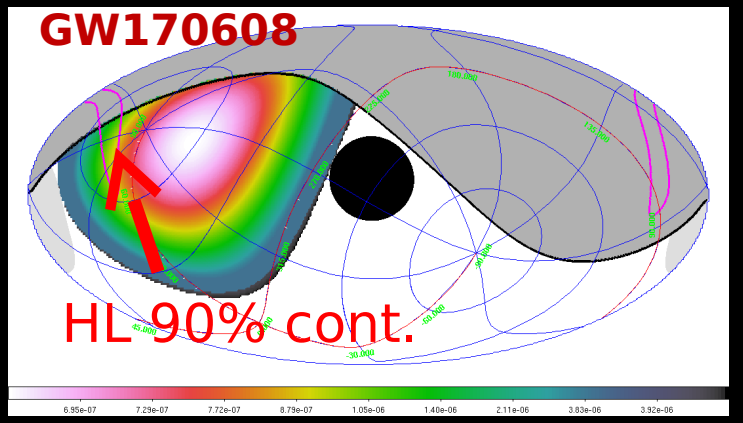
AGILE search for gamma-ray counterparts of GW events

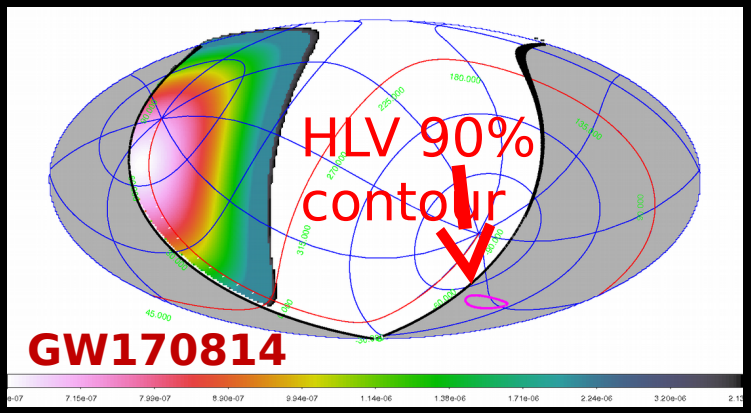
GW ID	AGILE GCN #s	% coverage of 90% c.l. contour	NEAREST EXP.	Comments on Prompt and papers
150914	----	0 %	+330	**Prompt just missed;** Tavani et al. 2016
151226	**----**	**30 %**	**0**	**Partially covered;** ---
170104	**20375,20395**	**36 %**	**0**	**Partially covered GRID, covered by MCAL**; Verrecchia et al.2017a
170608	**21224,21228**	**40 %**	**0**	**Partially covered GRID, covered by MCAL for a few tens of ms;** ---
170814	21477, 21482	0 %	+ 500	**Not covered (1st with Virgo data)**;
170817	**21525,21526, 21562, 21785**	**0 %**	**+ 930**	**OT NOT covered; Verrecchia et al. 2017b**

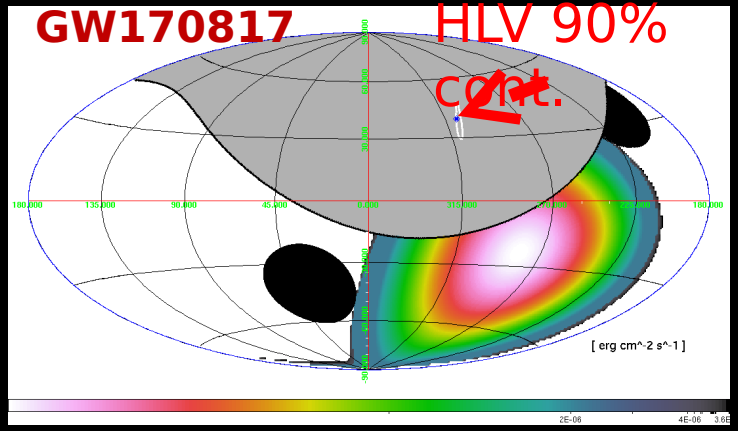
AGILE prompt maps of main GW events







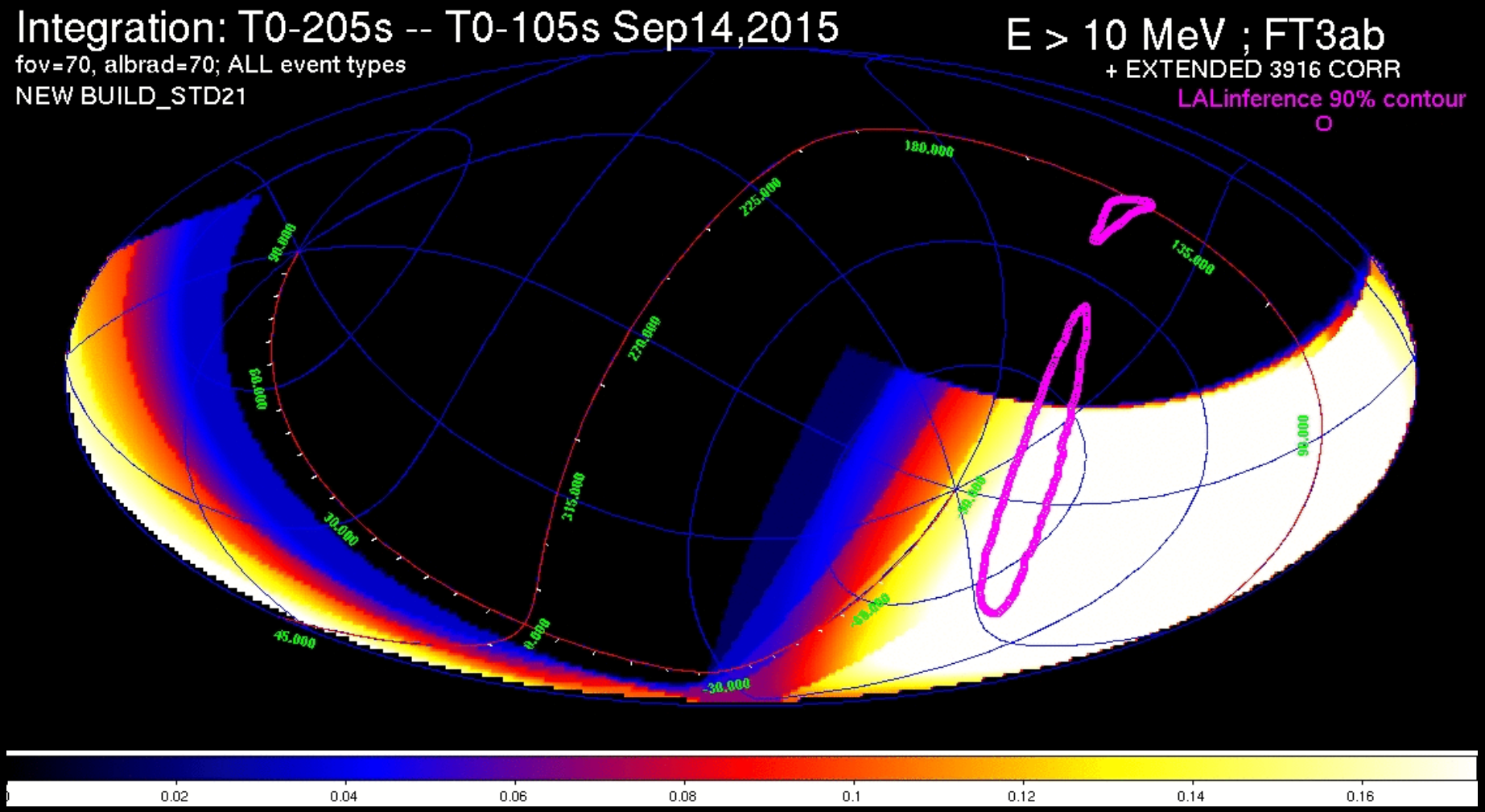




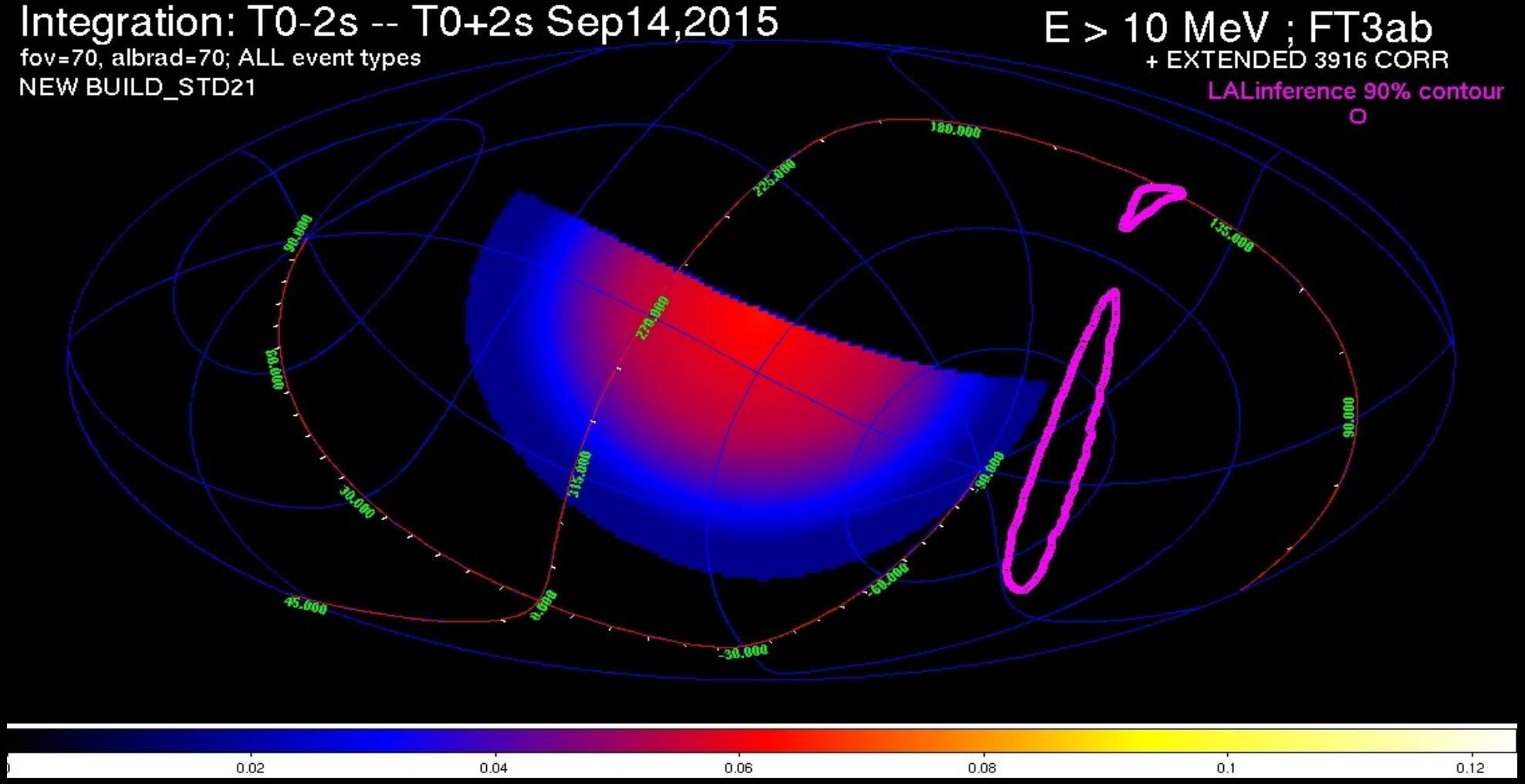
First gravitational wave event: GW150914

- T_0 = 9:50:45 UT, 14 September, 2015
- Announced by LIGO/Virgo on Feb. 11, 2016
- We learned about the event on Feb. 11, 2016 (no MoU active yet): archival search
- AGILE publication on the first GW event: Tavani et al., ApJ. 825, L4 (2016)

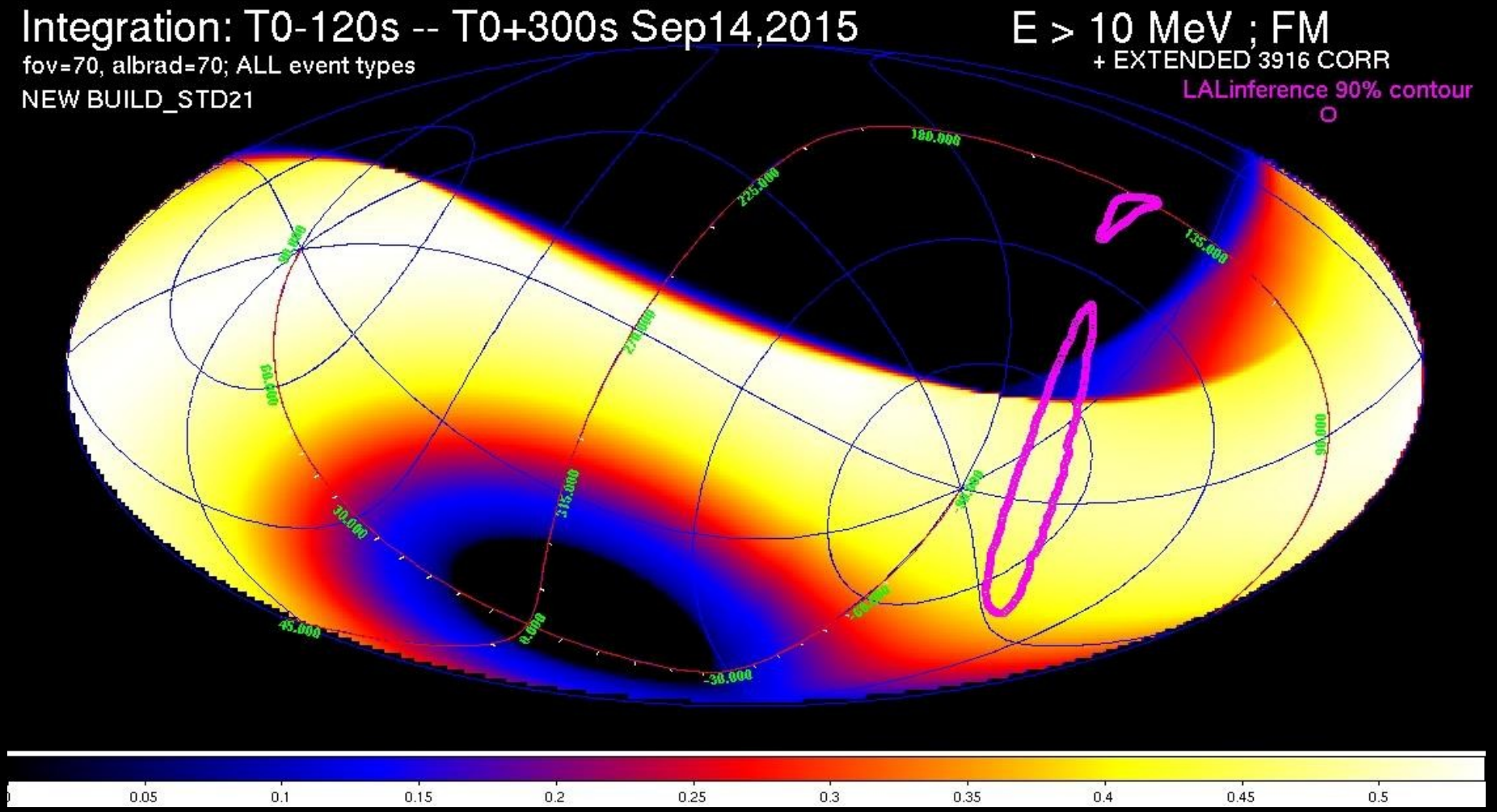
Spinning mode: GW150914 exposure



AGILE just missed the T0 !

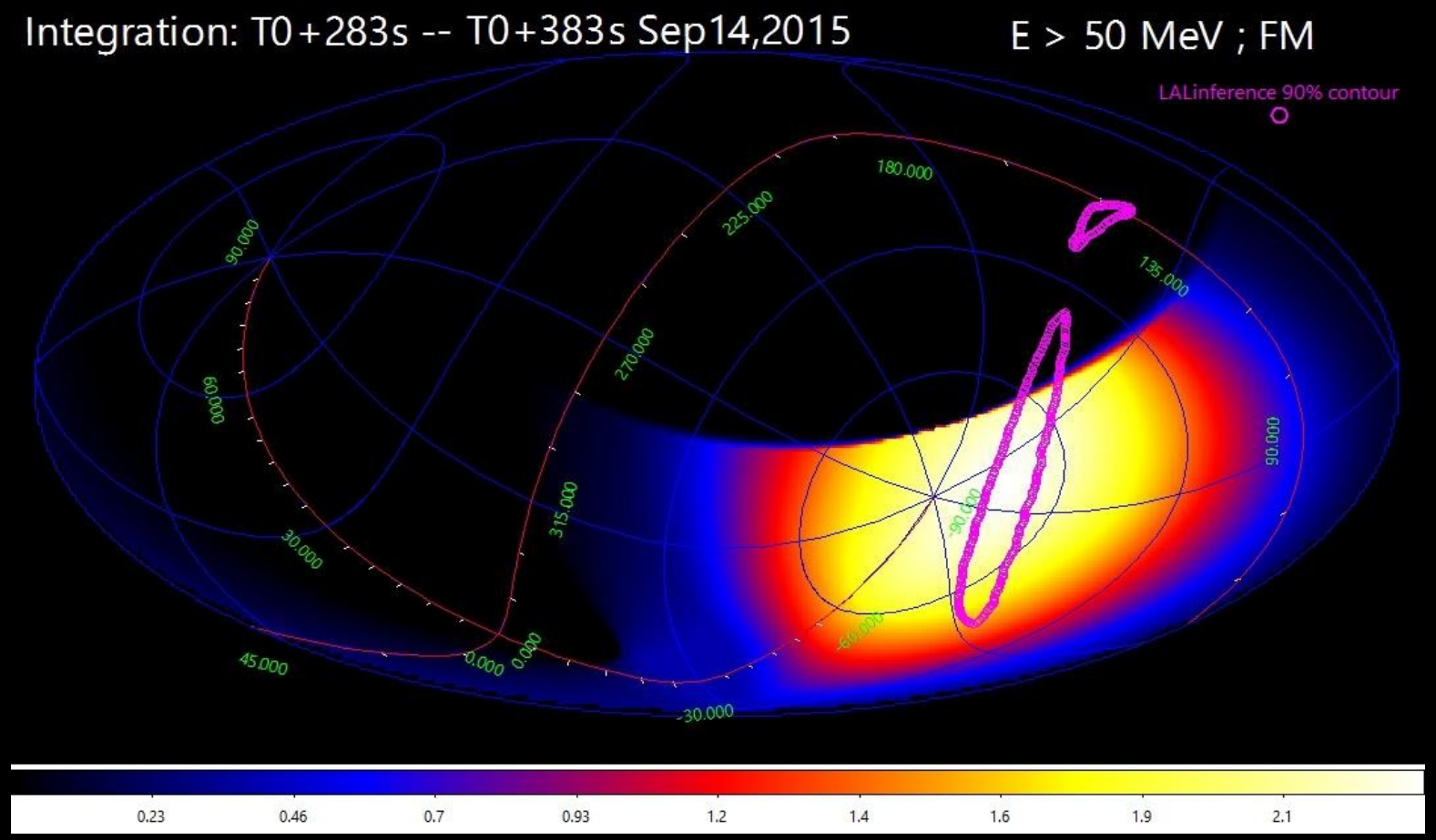


Spinning mode: one single rotation



GW150914 analysis (No MoU)

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



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

GW150914 as test case for dedicated AGILE GW analyses

- **Developed dedicated MCAL&GRID data analysis tasks**
- **Tested on archival search**

- **Pre-cursor/delayed GRID event search on short (100s) up to long (days) time scales: «grb-mode», maximum likelihood**

- **MCAL&GRID automatic data analysis reaction pipeline on-trigger**
  - **Improvement of the on-board triggering capabilities: need for larger time coverage**

Participation to the O2 run

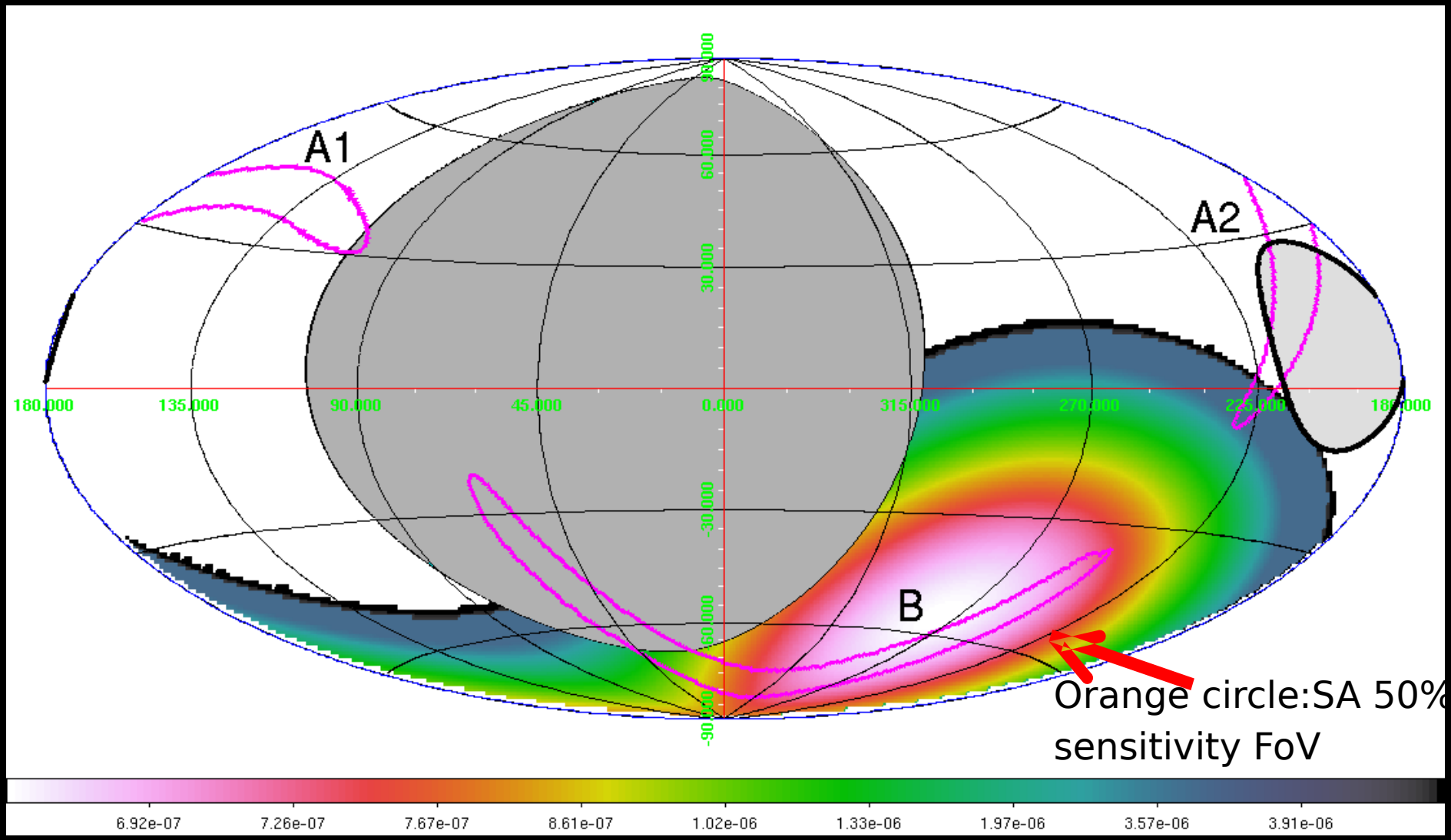
- AGILE observed all the GW events
- Main scientific results:
  - the 1st O2 event, GW170104 : prompt partial spatial coverage in γ-rays (E > 30 MeV), U.L.; MCAL light curve covering of the T_0.
  - the famous GW170817 event,first with an identified e.m. counterpart: prompt occulted by Earth; nearest in time gamma-ray U.L.; precursor/delayed emission scan.

GW170104

T_0 = 10:11:58:59 UT, 4 January, 2017

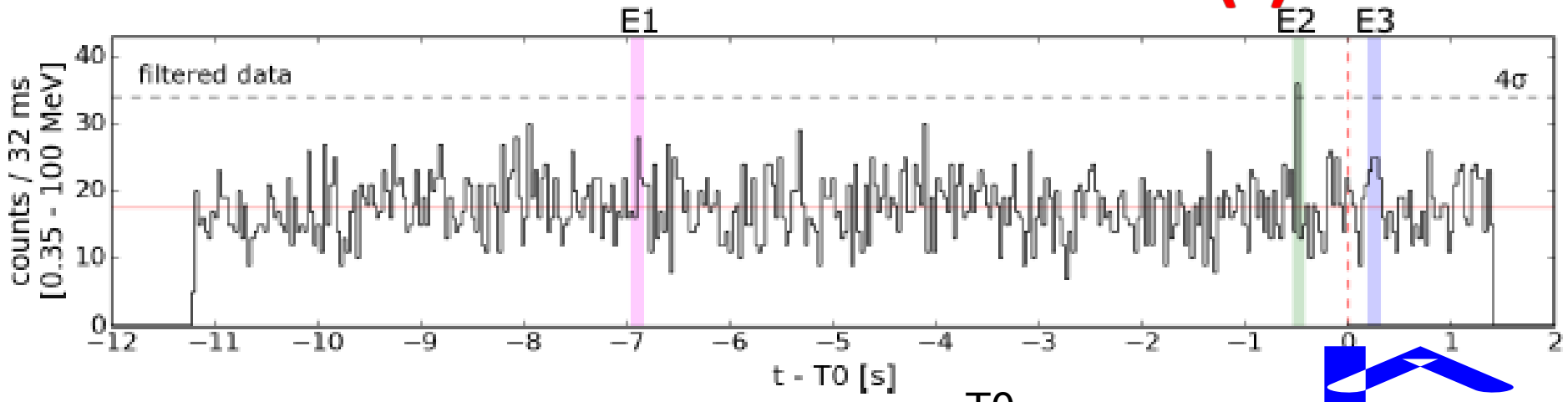
- **90% c.l. contour covered for 36% at event time**
- **Two LVC-GCN, by MCAL and GRID published**

AGILE gamma-ray exposure at trigger time (-2 / +2 sec)

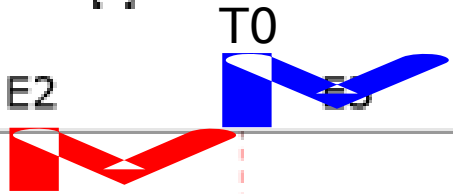


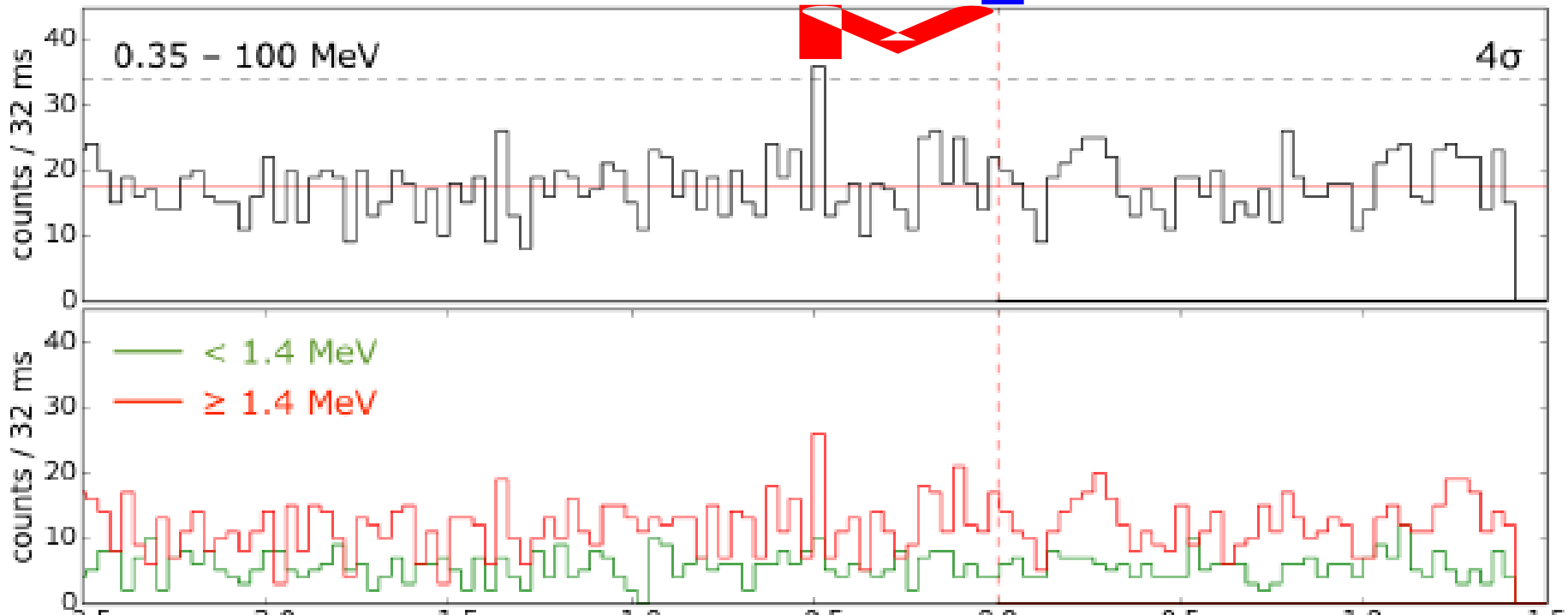
3-sigma upper limit (E > 50 MeV) = 2.9 x 10^{-8} erg cm^{-2} s^{-1}

an MCAL candidate event (!)



GW170104 T0



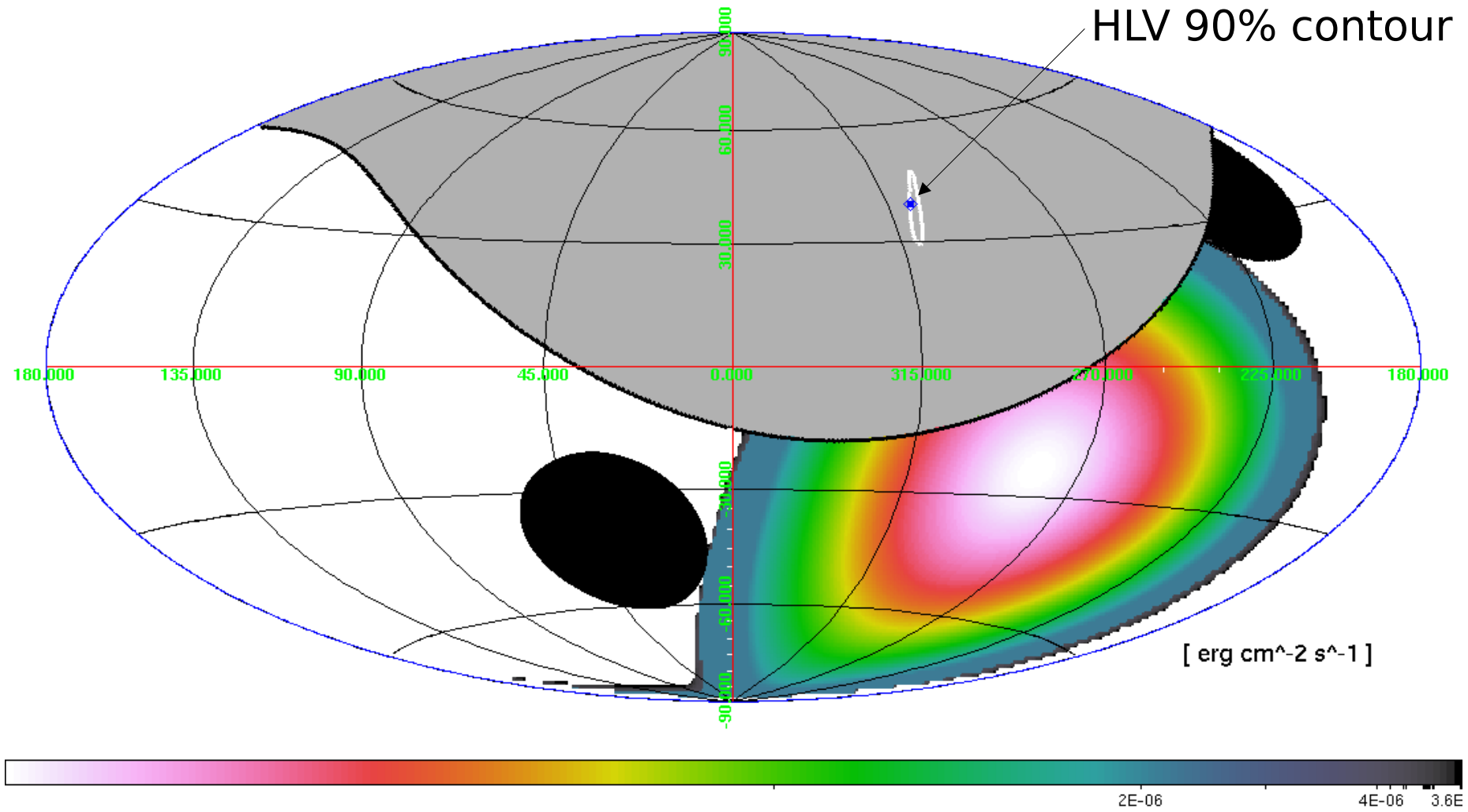


The event: GW170817

T_0 = 12:41:06 UT, 17 August, 2017

- **LVC error region OCCULTED by the Earth at T_0**
- **first γ-ray instrument with exposure starting at $\sim T_0 + 930s$**
- **Four LVC-GCN published, 1 on MCAL data analysis and 3 on GRID data, regarding the prompt data analysis and OT follow-up.**

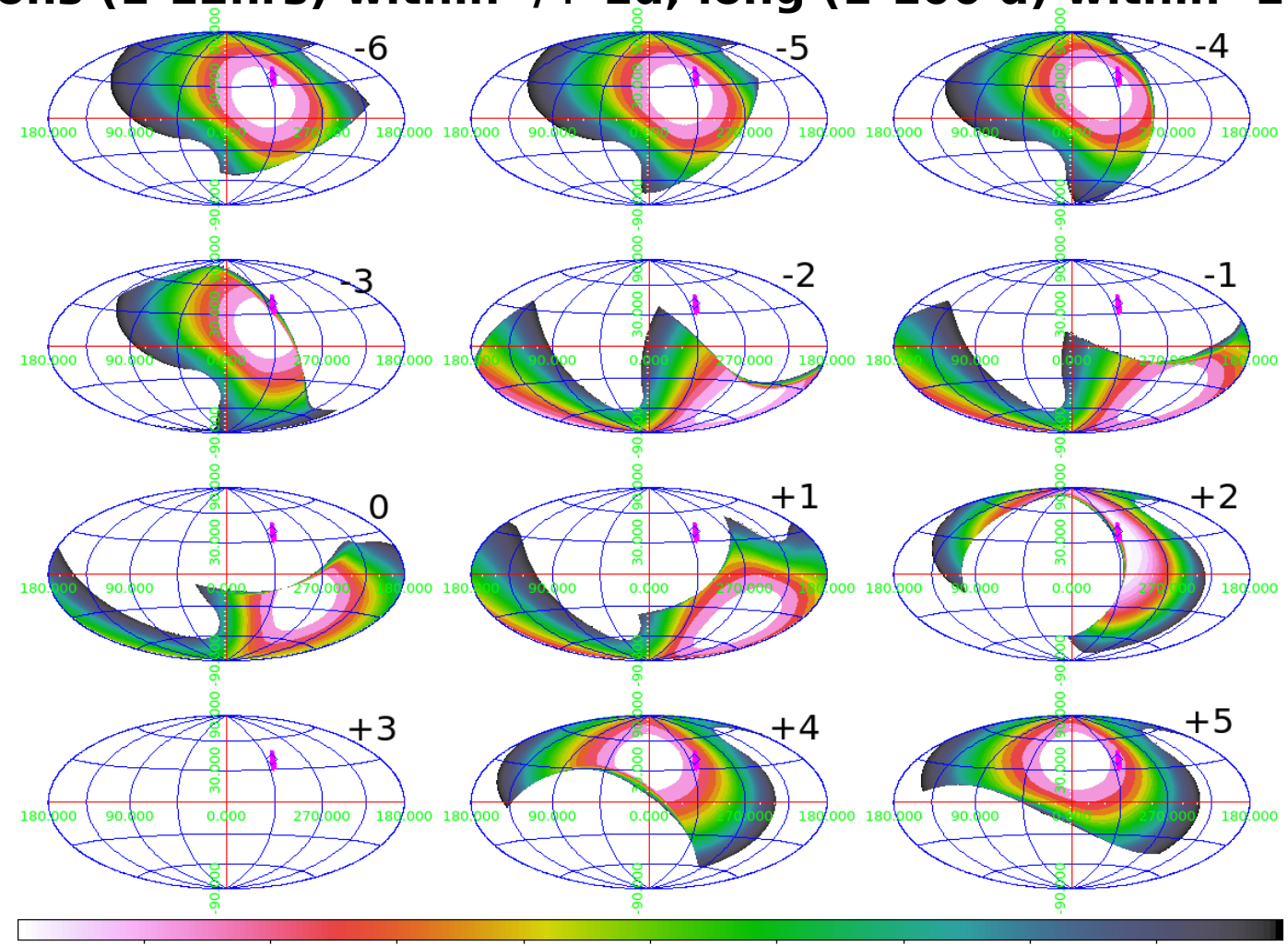
AGILE exposure at trigger time (-2 / +2 sec) occulted!



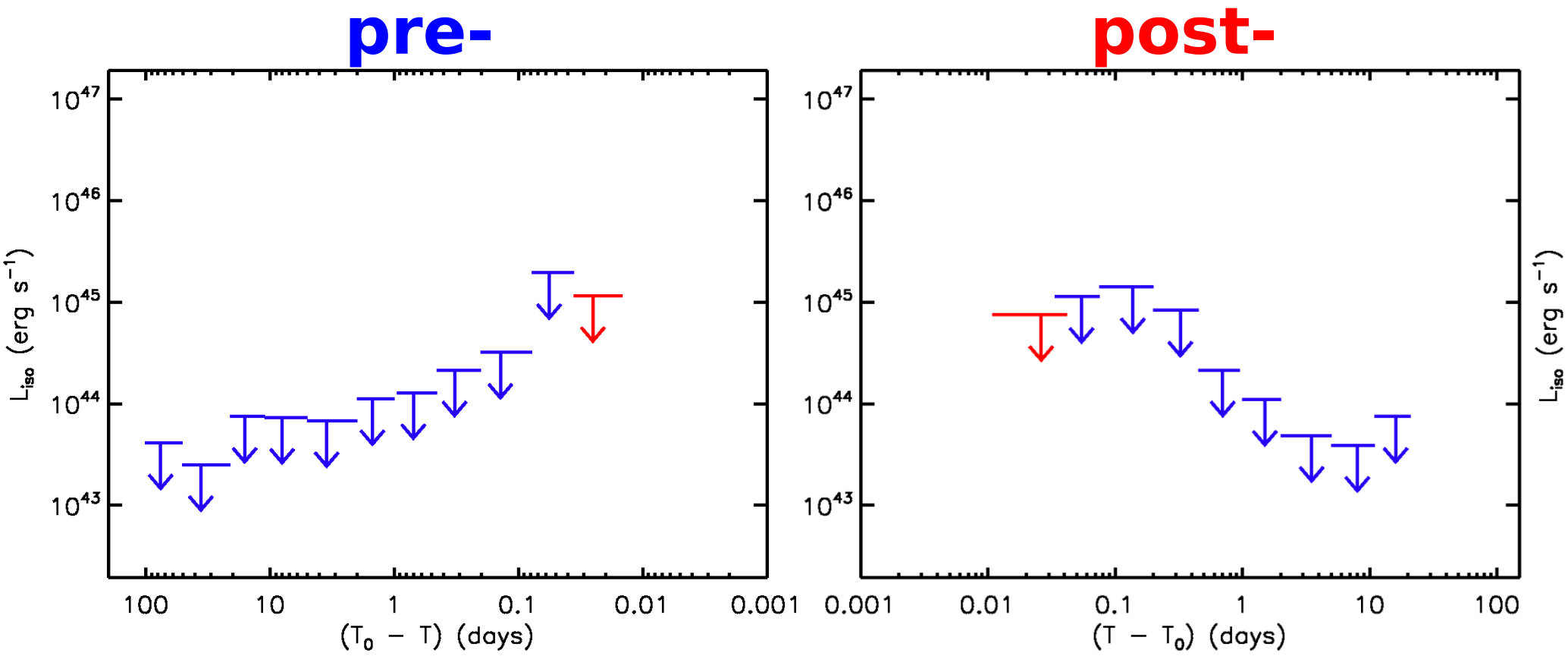
In E > 30 MeV energy band

AGILE-GRID precursor/delayed emission search: short time scales (-/+1 hr)

Evaluation of GRID 2σ-upper limit Pre-/Post -T_0@OT position, in 3 ranges: Short, integrations of 150s, within -/+ 1h: in «GRB detection mode» (E > 30 MeV); medium integrations (1-12hrs) within -/+ 1d; long (1-100 d) within -100/+21d.

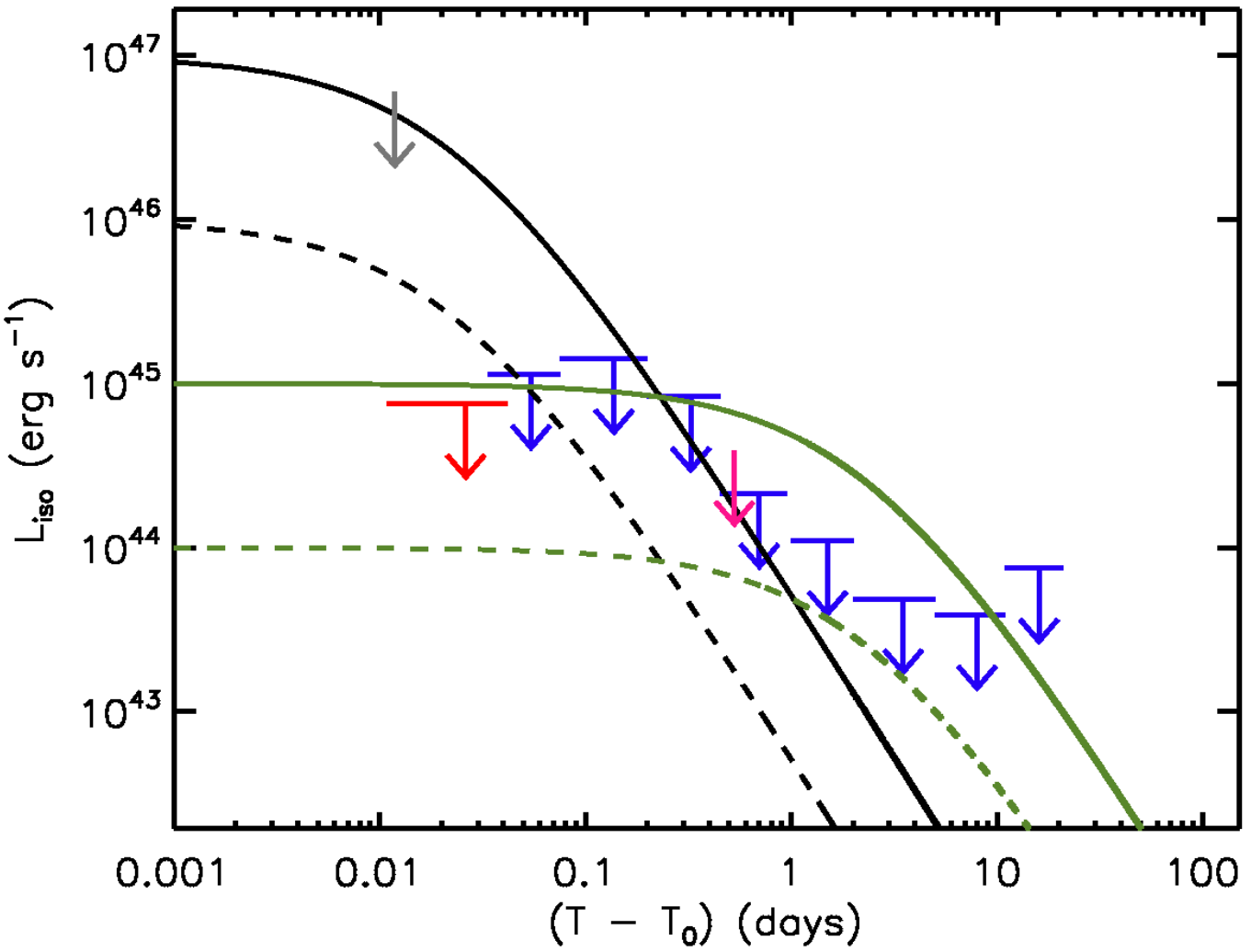


AGILE-GRID precursor/delayed emission search: medium/long time scales (-/+1 , -101/+21 days)



AGILE limits on magnetar emission:

High-energy emission from a magnetar remnant left by NS-NS coalescence model:



Radiation efficiency

ξ = 0.01-> solid

ξ = 0.001-> dashed

B = 10^{14}G (green)

B = 10^{15}G (black)

Magenta: SA U.L.

Gray: MCAL U.L.

If prompt data available, 170817A significant SA detection possible

Summary 2016-2017:

- **AGILE in the MoU since Nov 2016 promptly reacted to all GW candidate events communicated by LIGO-Virgo in O2 with reaction time of 2-3 hrs (including manual refined validation)**

- **1 possible AGILE-MCAL gamma-ray transient candidate found as counterpart of GW170104 (Verrecchia et al., ApJL 847, 2017)**

- **AGILE and GW170817: first γ-ray instrument with exposure on the localization region starting at ~ T_0 + 930s (Verrecchia et al., ApJL 850,2017)**

- **AGILE observations provided among the fastest response and the most significant upper limits above 30 MeV to many GW events detected up to now!!**

))) Prospects for LIGO-Virgo O3 run

- Open Public Alerts!
  - **Automatic LVC public alerts issued within Minutes w/o human vetting.**
  - **Specific «scientific MoU» for particular topics**
- Ranges of likely rates (from LVC):

  > **BBH: at least a few per month, maybe more**

  > **BNS: 1–10, possibly up to ~1 per month**

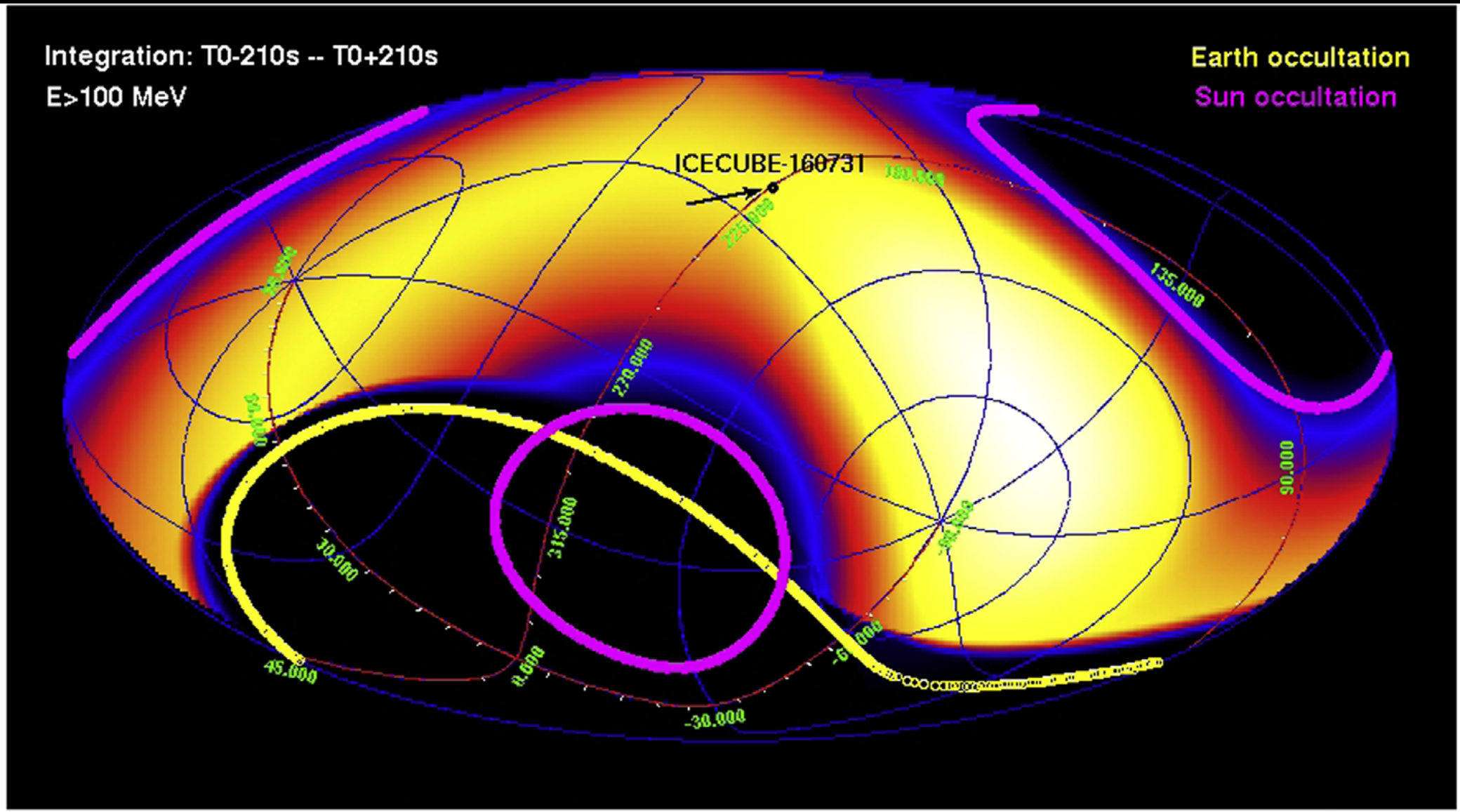
  > **NSBH: ~1 during O3, but uncertain.**

- Timeline: joint LIGO-Virgo 1-month engineering Run on **~Jan 2019**; **O3 Start: Feb 2019.**

Summary

- AGILE has unique capabilities: hard X/γ-ray coverage
- Much improved performance with enhanced MCAL and SA
- Ready for automatic detection of short-weak events
- Capable very soon to issue alerts to LVC for AGILE-detected (new channel)
- Important role in the astronomy of gravitational waves

AGILE and Neutrinos

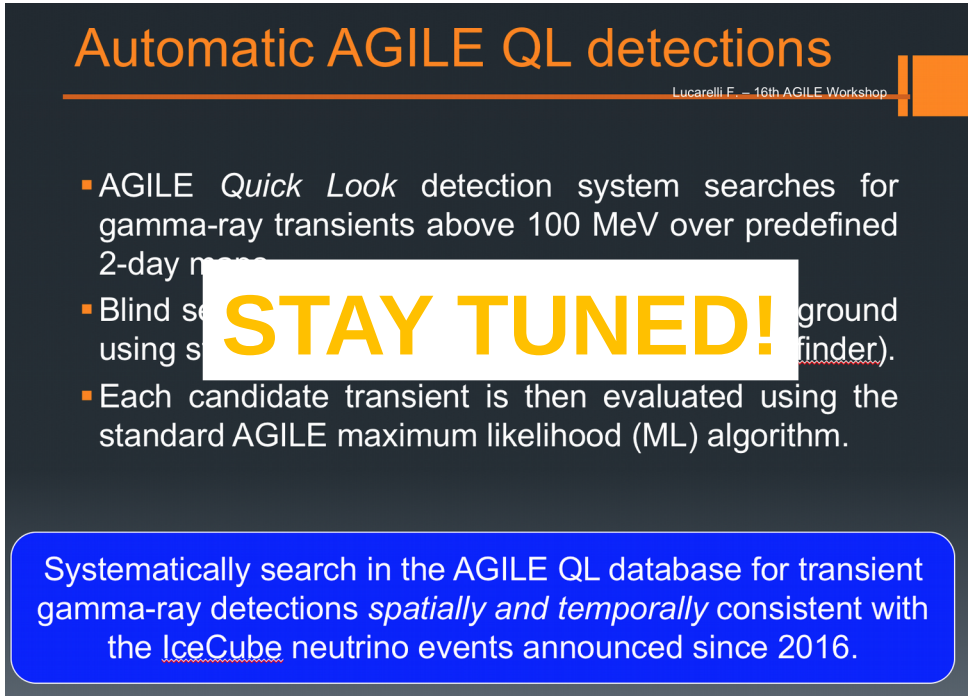


Last (but not least): AGILE and neutrinos

- **AGILE and IC-160731**: Gamma-ray emission ~T_0-1d announced by AGILE in ATel #9265 and further investigated in **ApJ 846 (Lucarelli et al. 2017)**

- **AGILE and IC-170922**: Gamma-ray emission **observed by both Fermi-LAT and AGILE** (ATel #10791 and **ATel #10801**) from the direction of the BL Lac blazar TXS 0506+056

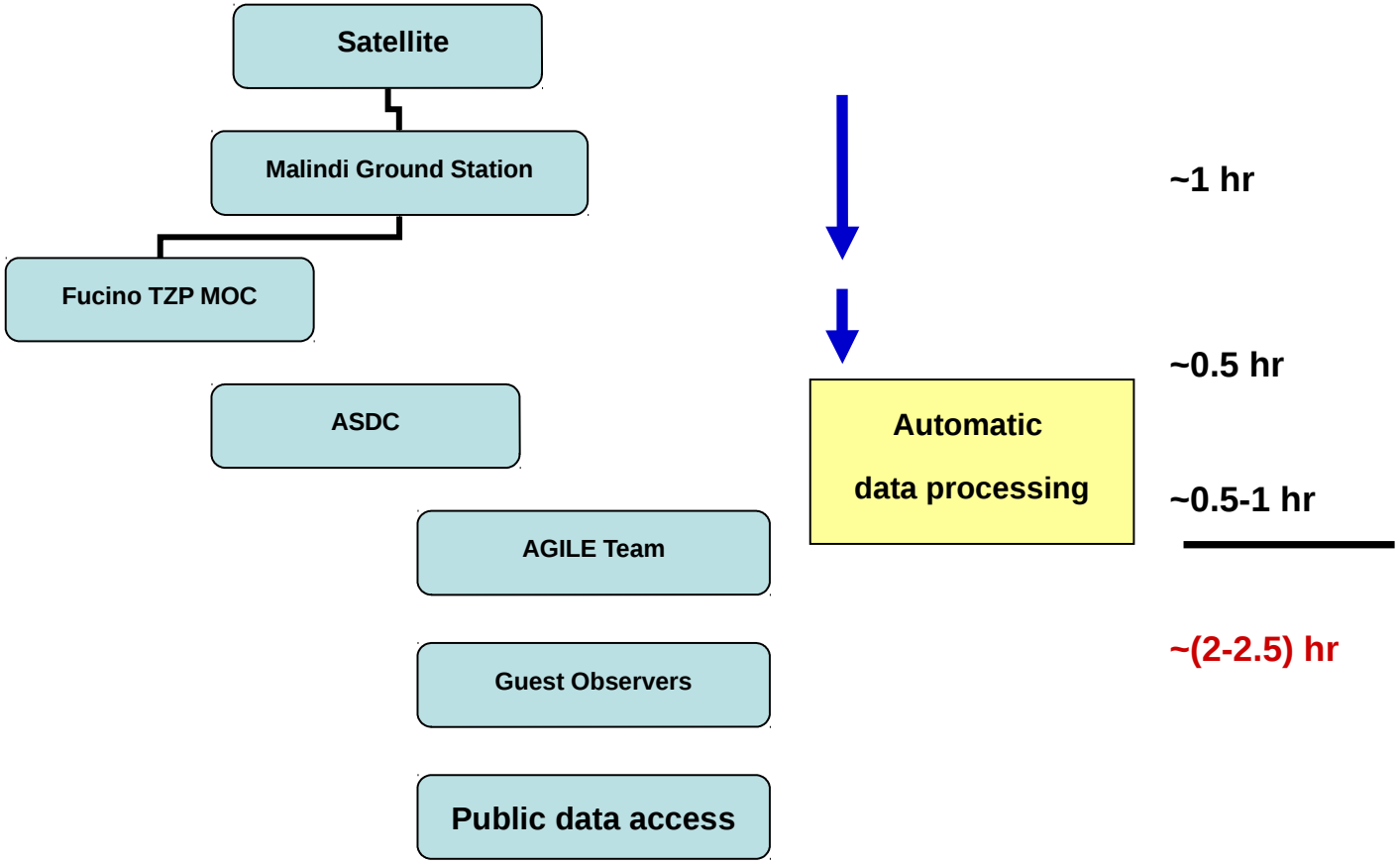
- In progress:



F. Lucarelli talk at the 16th AGILE Workshop

Supplementary Slides

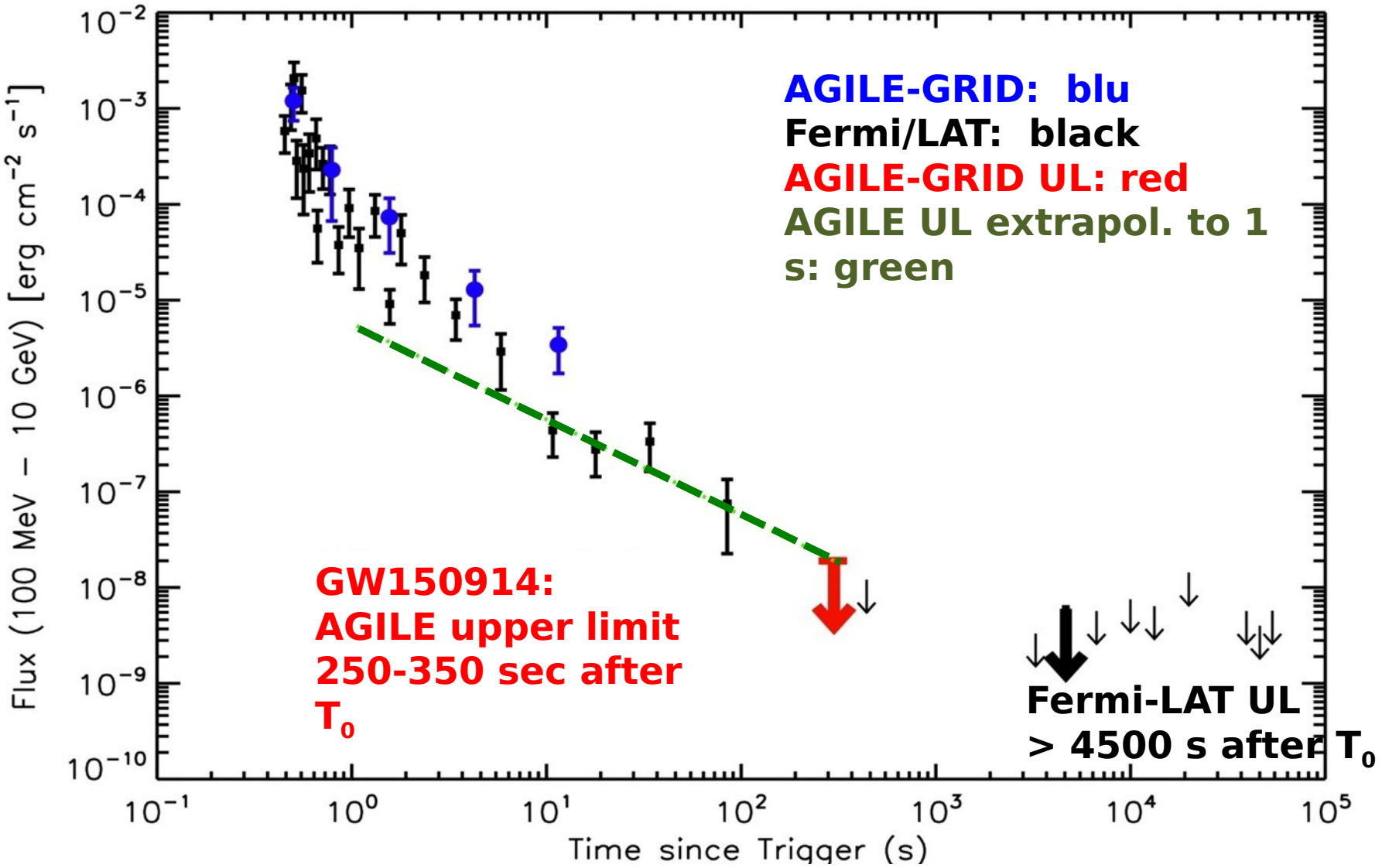
AGILE: “very fast” Ground Segment

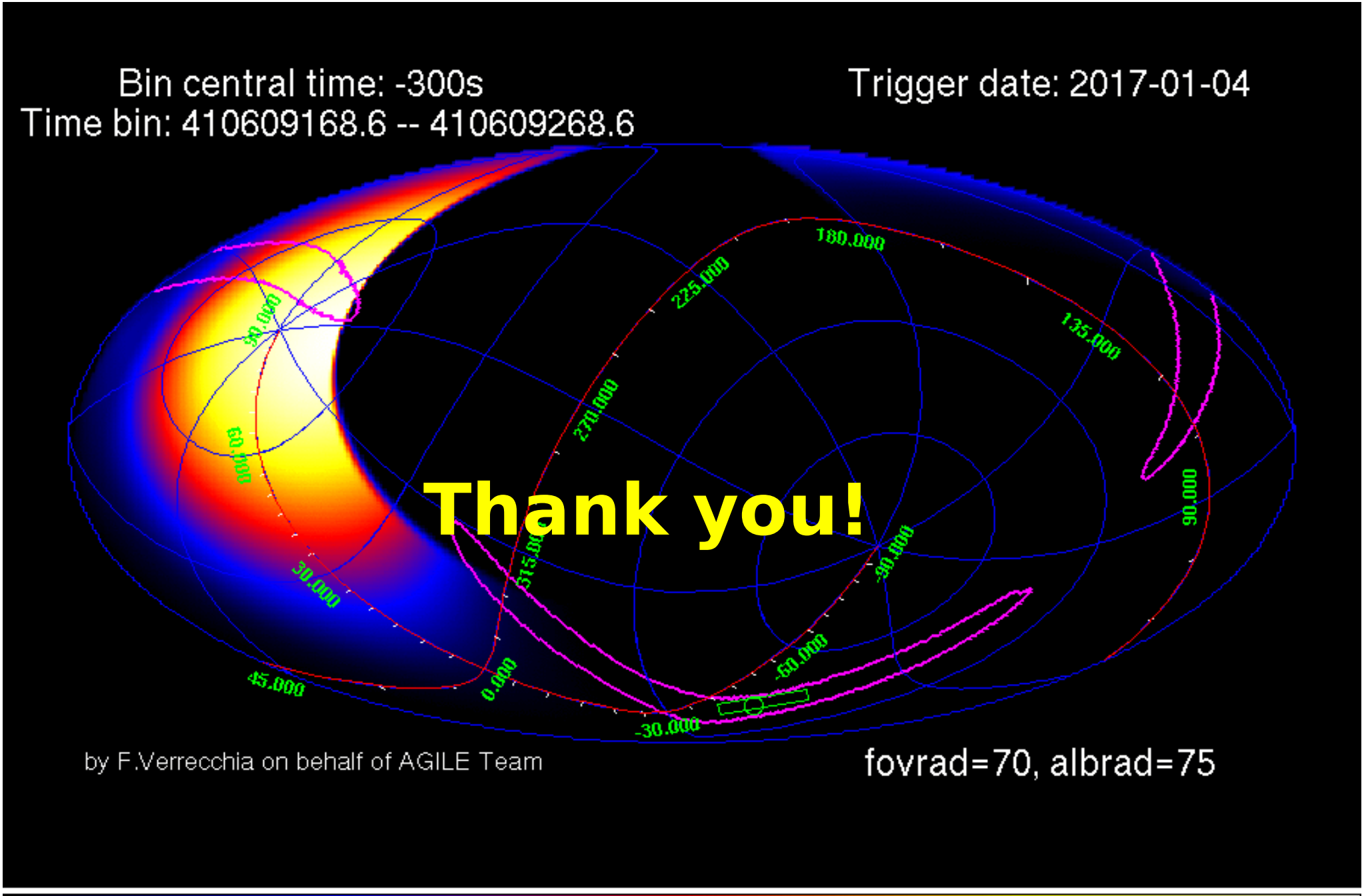


Now even faster: ~25 min latency. Optimized for GW counterpart hunt!

Record for a gamma-ray mission! App AGILEScience for mobile dev

AGILE and Fermi-LAT upper limits in the GRB 090510 light curve used as a template for GW events (scaled at z = 0.1)



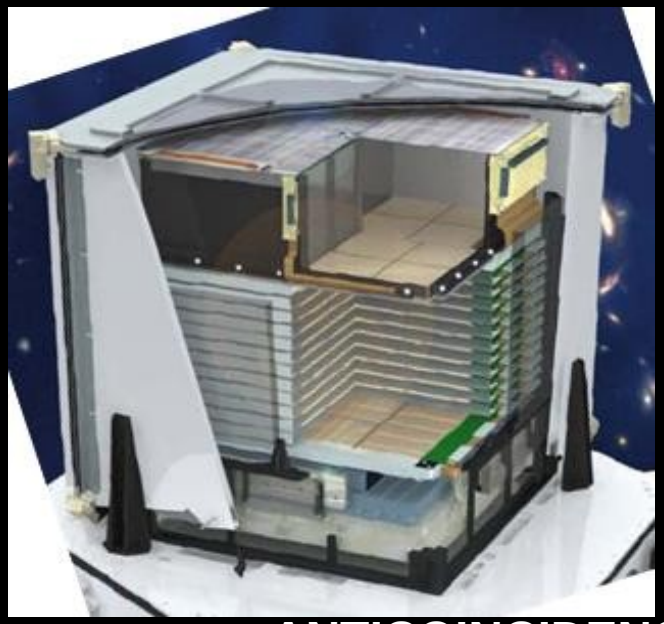

Bin central time: -300s
Time bin: 410609168.6 -- 410609268.6
Trigger date: 2017-01-04
Thank you!
by F.Verrecchia on behalf of AGILE Team
fovrad=70, albrad=75
0.22
0.44
0.66
0.88
1.1
1.3
1.5
1.8
2

AGILE characteristics

Science Data Center

AGILE is unique combination of X-ray and gamma-ray detectors for GW searches

Two co-aligned detectors in hard X-rays (20-60 keV;super-A) and γ–rays (30 MeV-10GeV; GRID) +MCAL (0.4-100 MeV)



ANTICOINCIDENCE

HARD X-RAY IMAGER
SUPER-AGILE (SA)

Energy Range: 18–60 keV

SILICON TRACKER

GAMMA-RAY IMAGER (GRID)

Energy Range: 30 MeV – 30GeV

(MINI) CALORIMETER

Energy Range: 0.3–100 MeV

AGILE limits on magnetar emission:

AGILE UL set important constraints in the early phases to exclude a highly magnetized magnetar for the remnant of GW170817- GRB170817A

Future GW hunt:

- **AGILE fast and unique hard X/γ-ray coverage**
- **Improved performance with NEW MCAL pipeline developed for "sub-threshold events" btw 4 ÷ 5 sigma pre-trial significance**
- **Alerts will be issued to LVC for AGILE-detected events (new channel)**
- **Can play an important role in the new astronomy of gravitational waves. Waiting for Ligo-Virgo O3 run!**