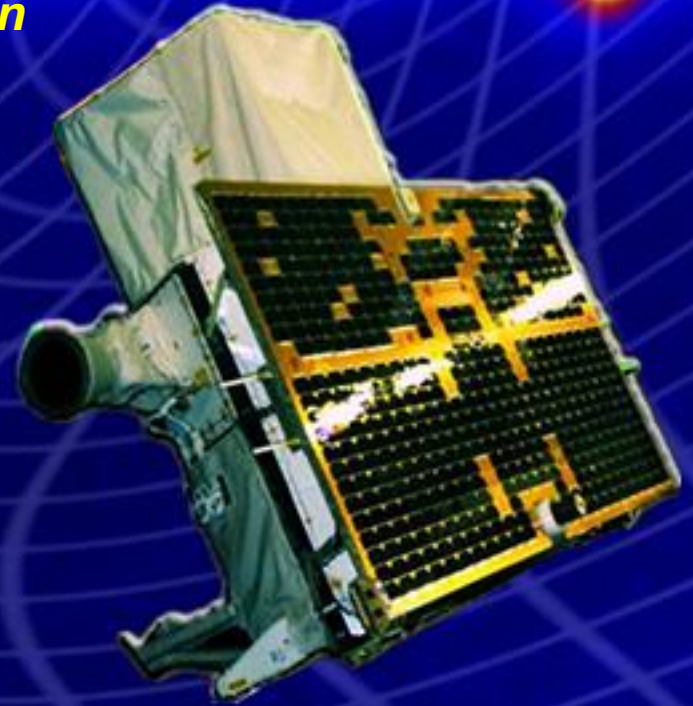


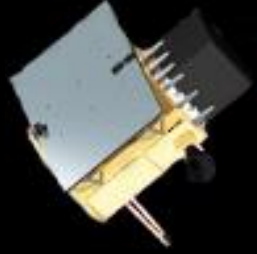
Update on AGILE search for GW counterparts

on behalf of the AGILE Collaboration

First Perugia Gravi-Gamma Wave

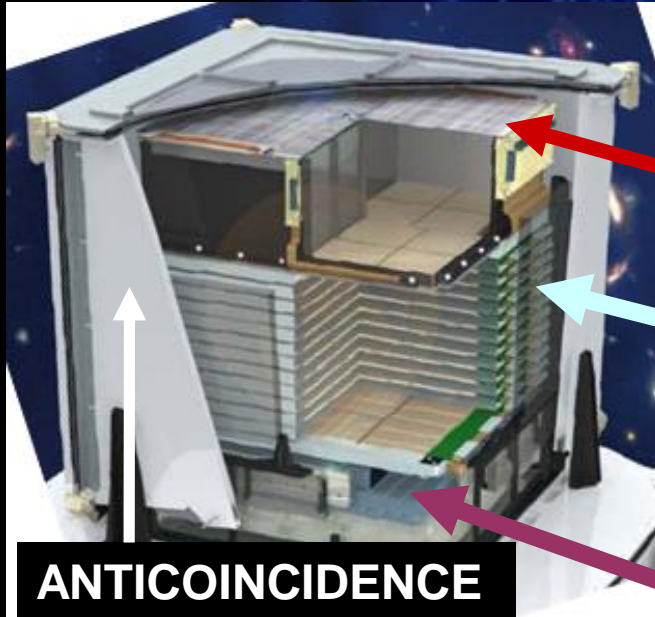


F. Verrecchia, INAF-OAR and SSDC
Rocca S.Apollinare, Perugia, May 17, 2019



AGILE payload

Science Data Center



**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 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 gamma (30 MeV-10GeV; GRID) + MCAL (0.4-100 MeV)

AGILE in spinning mode

3

Single revolution including T_0 of GW150914

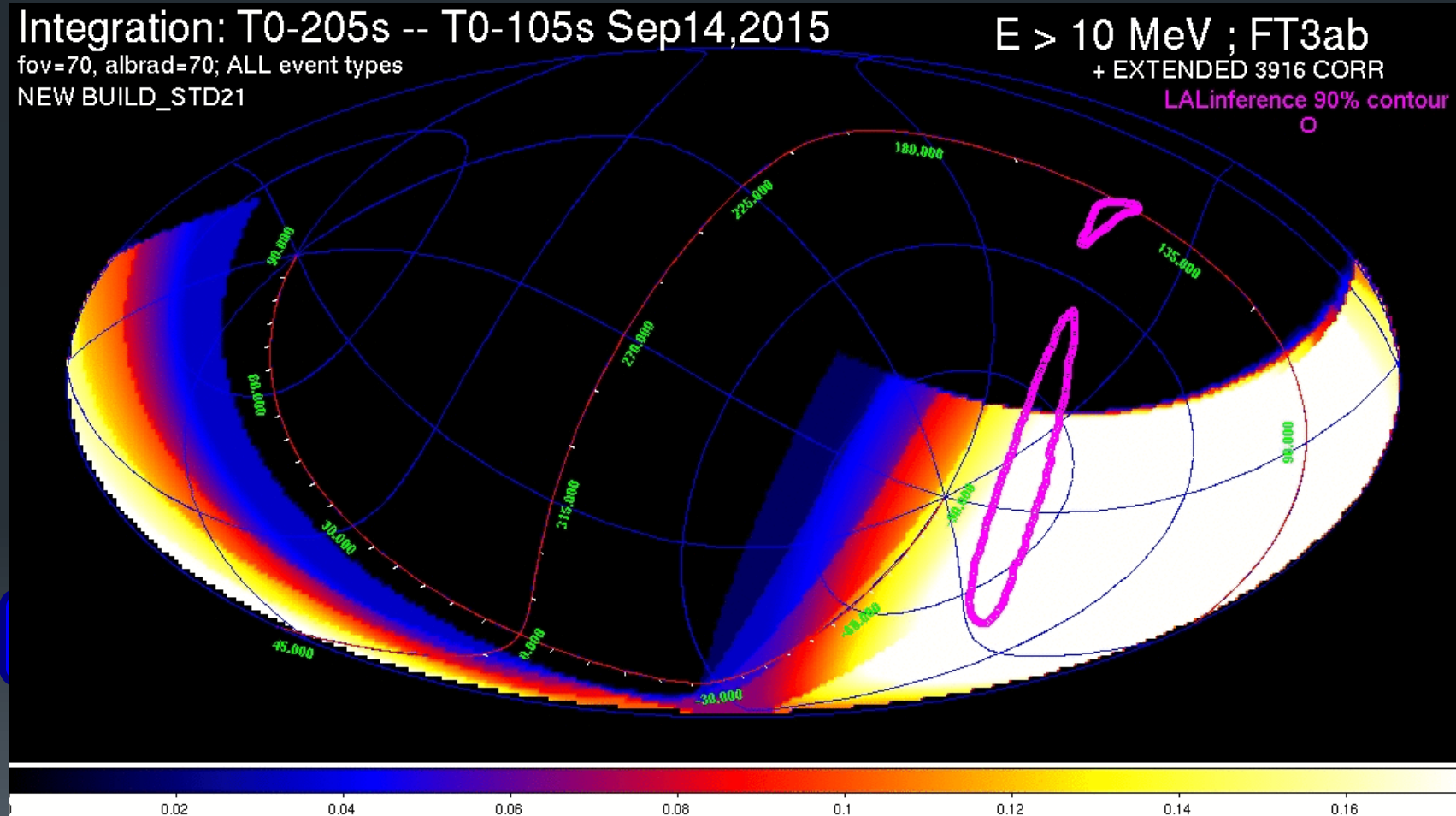
- Very large field of view (~ 2.5 sr).
- Coverage of 70% -- 80% of the whole sky every day.
- Very fast ground segment: first *Quick Look* analysis (on *contact* basis) available **~ 30 min** after telemetry download.

Very suitable instrument to perform all-sky searches for short transient γ -ray sources and γ -ray counterparts to multi-messenger transients (GW and neutrinos).

AGILE in spinning mode

4

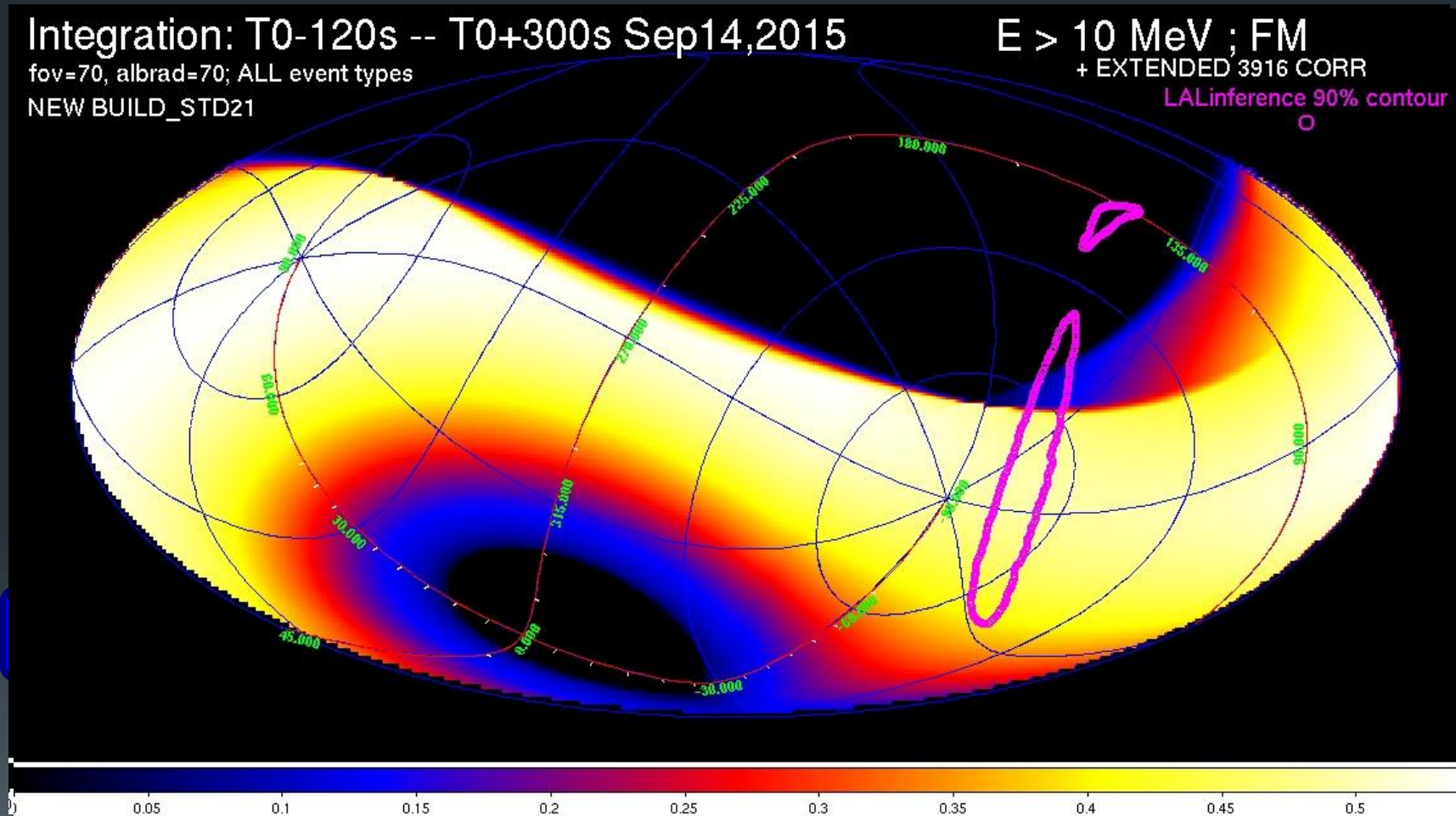
Single revolution including T_0 of GW150914



AGILE in spinning mode

5

Single revolution including T_0 of GW150914





AGILE and GW astrophysics

- Furtherly improved performance
- MCAL upgraded configuration with SuperAGILE....
- very fast reaction to external GW trigger: AGILE real-time analysis «GW» pipeline @OAS Bologna and SSDC
- **new MCAL processing pipelines for “sub-threshold events” -->automatic alerts**
- **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 & O3 GW LIGO-Virgo observing runs.**

AGILE search for gamma-ray counterparts of GW events: till O2

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; ---
170729	----	0 %	+150	Prompt just missed;
170814	21477, 21482	0 %	+ 500	Not covered (1 st with Virgo data); ---
170817	21525,21526, 21562, 21785	0 %	+ 930	OT NOT covered; Verrecchia et al. 2017b

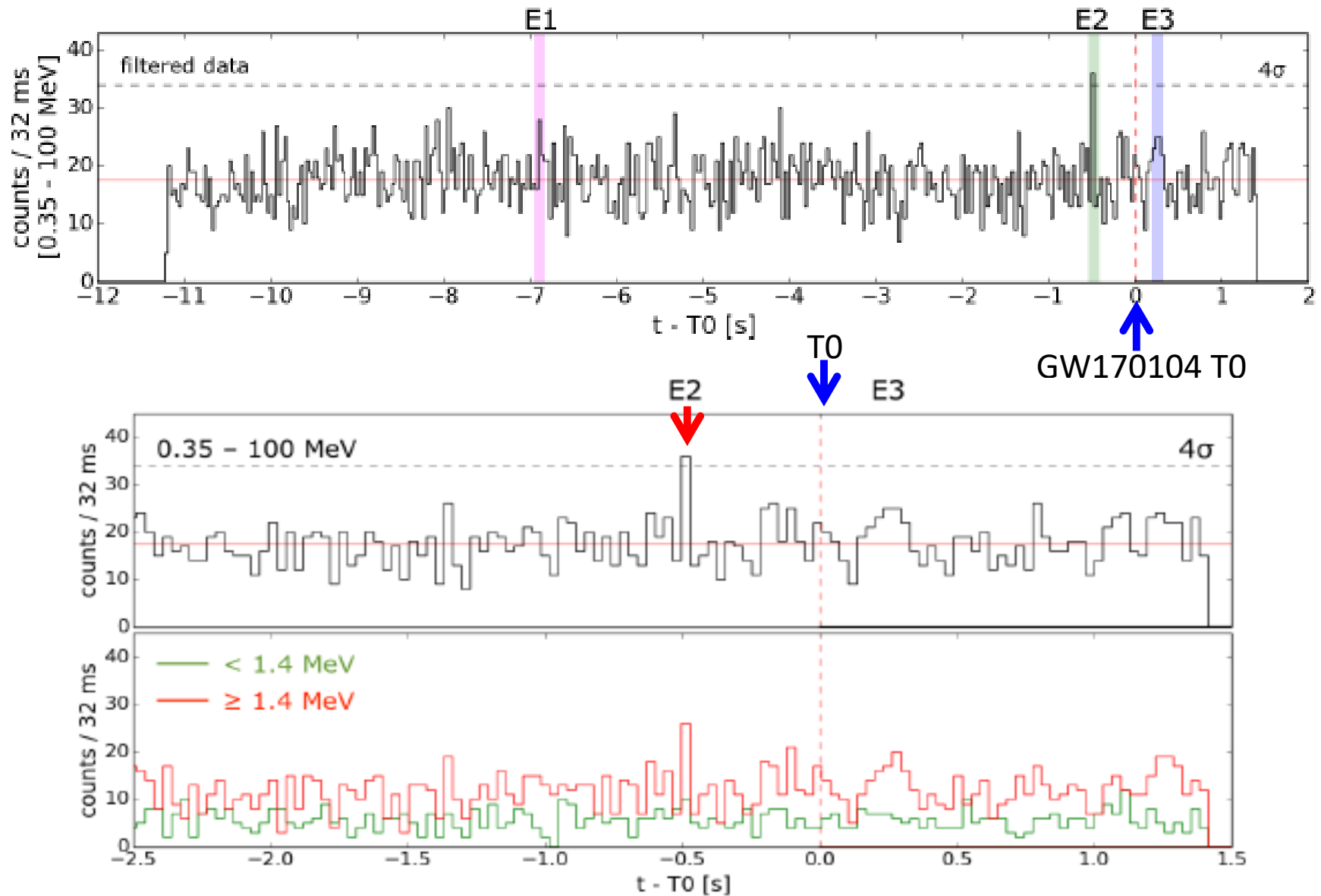
BLUE: Binary NS merger ; **RED:** prompt covered



Summary 2016-2017:

- Preparation to O2: commissioning activity on summer=> **Improvement of MCAL burst detection: goal GRB090519 pre-cursor like events**
- 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 $\sim T_0 + 930s$ (Verrecchia et al., ApJL 850,2017)**
- AGILE observations provided the fastest response and the most significant upper limits above 50 MeV **to all GW events detected up to now!**

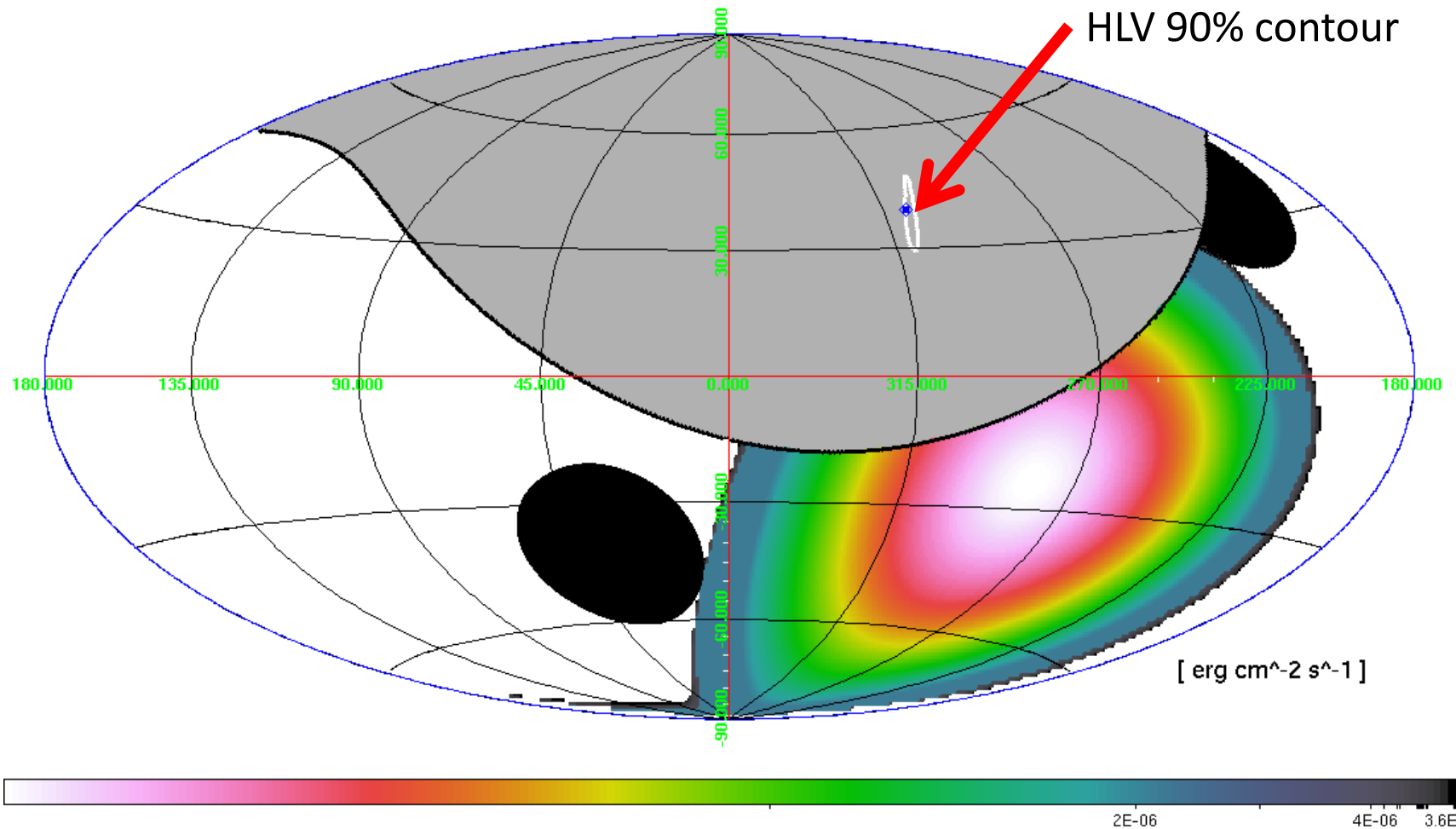
GW170104: an MCAL candidate event



Careful FAR estimation, only E2 is a good candidate but post-trial Prob. resulted to be below 3σ (Verrecchia et al. 2017a)

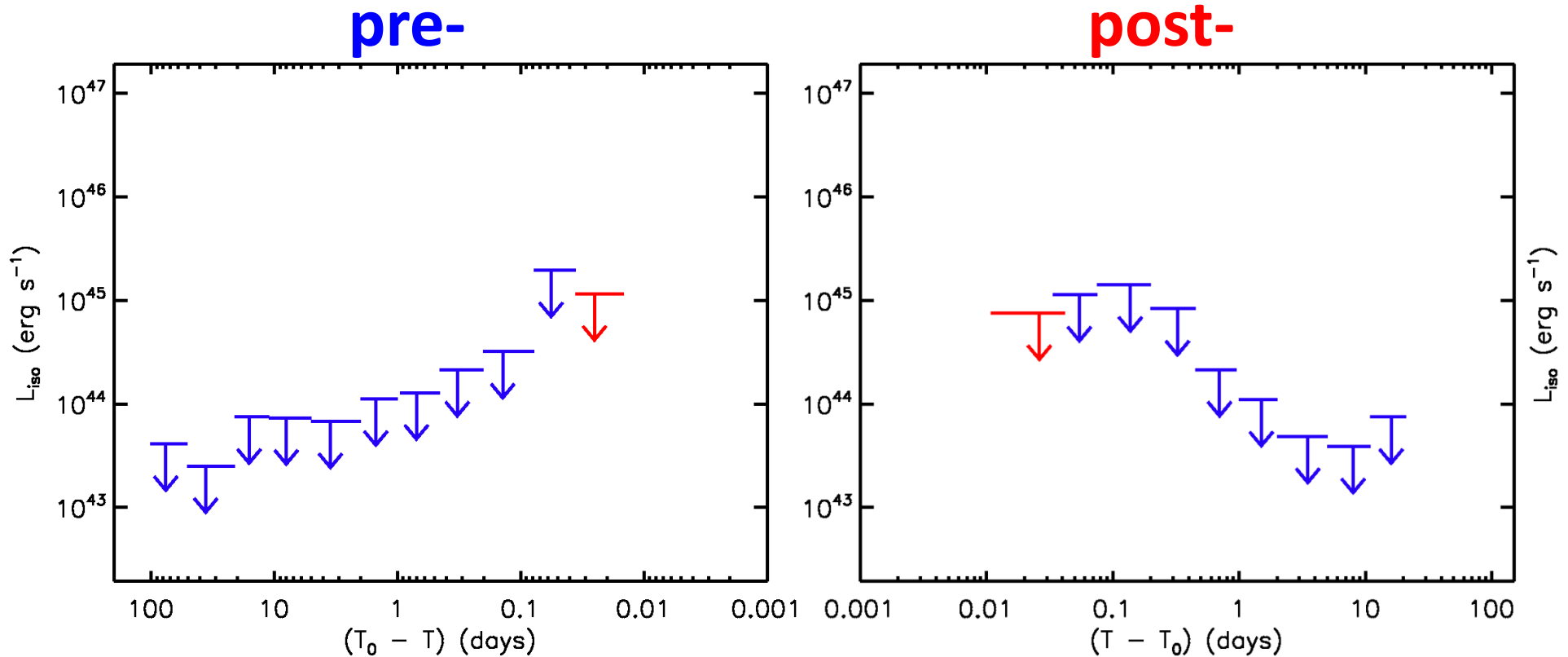
GW170817

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



In E > 30 MeV energy band

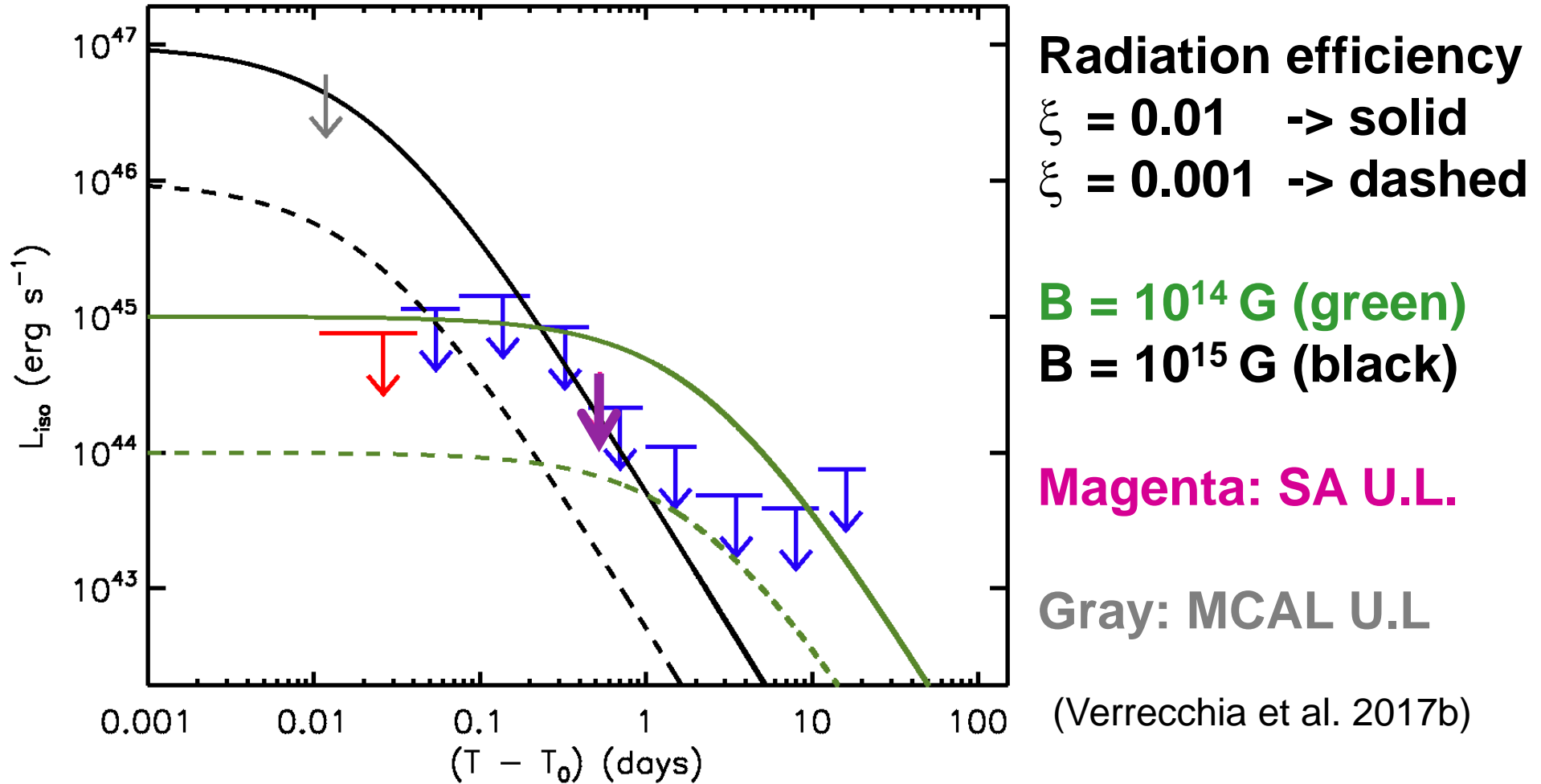
AGILE-GRID precursor/delayed emission search: medium/long time scales (-/+1 , -101/+21 days)



Reference for future GRID data analyses

GW170817: AGILE crucial limits on magnetar emission:

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



(GBM GRB170817A spectrum cutoff **out** of MCAL band)

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**



Preparation for O3 GW hunt:

- **AGILE fast and unique hard X/ γ -ray coverage (good TM budget)**
- **Improved performance with NEW MCAL pipeline developed for “sub-threshold events” btw 5 \div 6 sigma pre-trial significance**
- **GW pipeline also upgraded: revised products/functionalities**
- **Can play an important role in the new astronomy of gravitational waves. Contributing to LIGO-Virgo O3 run!**

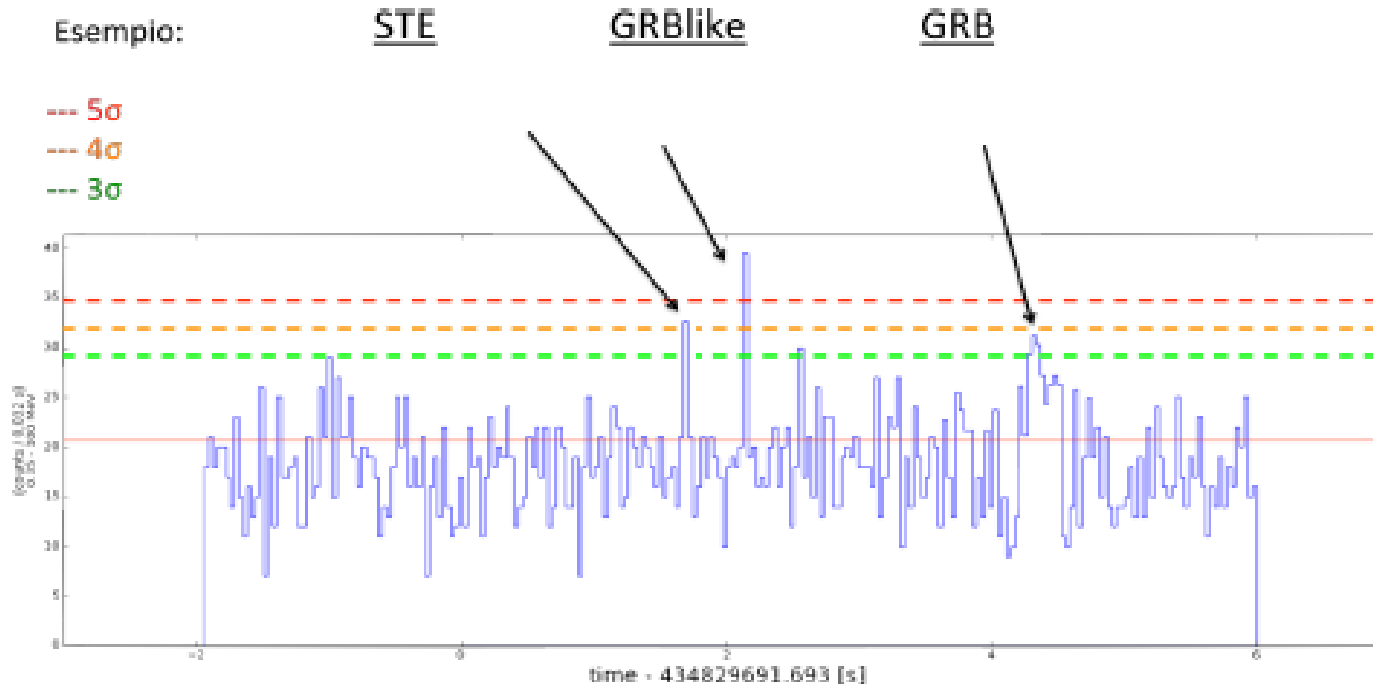
Preparation to O3: AGILE-MCAL, new detection pipeline

MCAL automatic detection pipeline: 4 binning timescales (16, 32, 64, 128 ms), 4 phase shifts.

Three event classes: **revised** (see archival analysis in Ursi et al. 2019)

- 1) standard GRBs (short & long),
- 2) GRB-like (single+S/N >6 σ),
- 3) Sub-Threshold Events (STEs, single+S/N \geq 5 σ).

differences among the three classes



(Ursi et al. 2019)

AGILE status for GW

- Optimal overall configuration of the instrument
 - **Not yet full telemetry (14 orbits/day), but no data gaps =>SuperAGILE discontinuous coverage**
- Sensitivity to weak (“sub-threshold”) events: possible correlation with other missions events from, **IPN, GBM (started) ->off-line**
- O3: reduced human vetting of detections
- MCAL automatic **detection** and notification to community with notices ->operative!
- GW pipe: separated notice creation! Soon ready

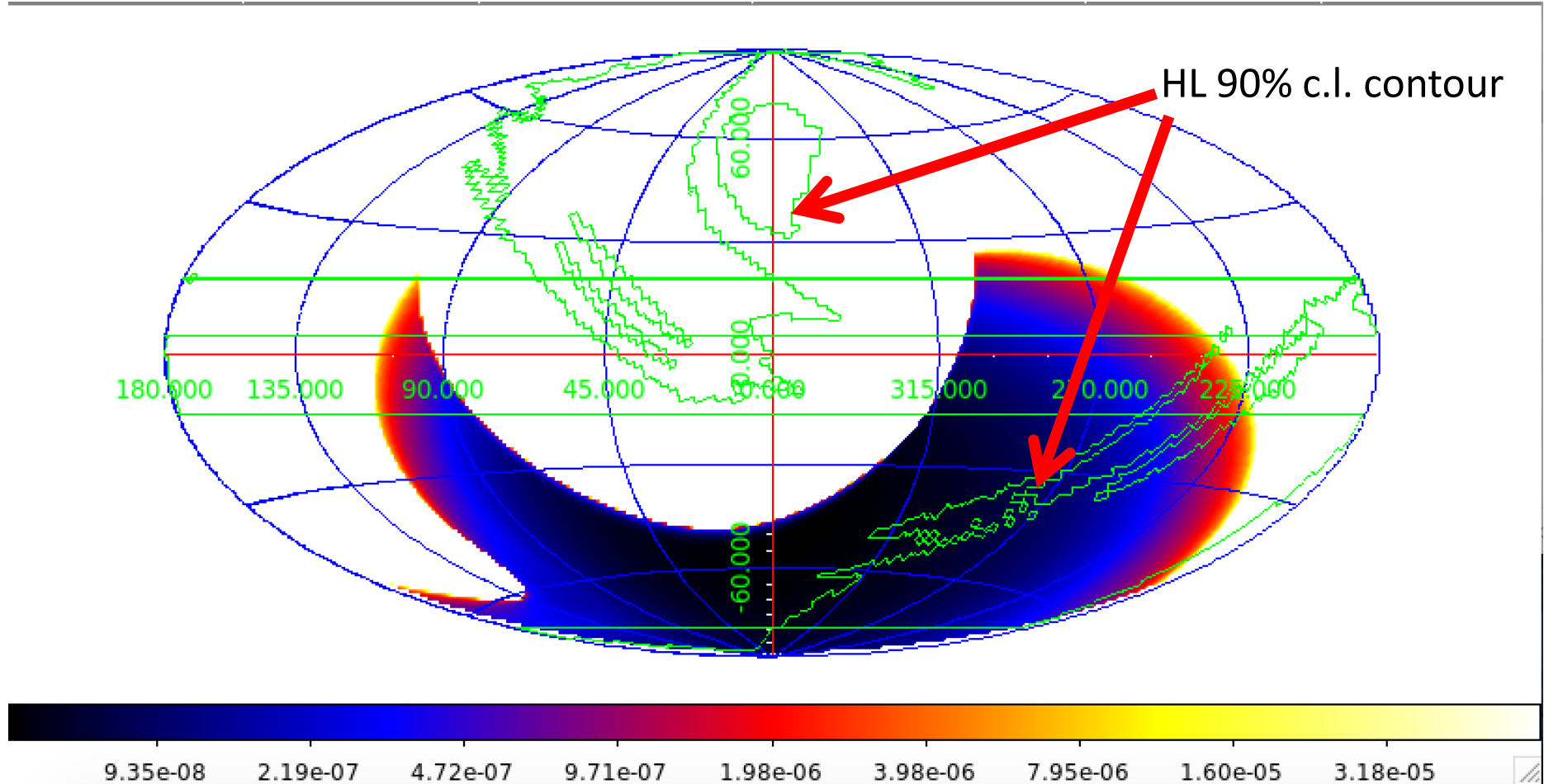
AGILE search for gamma-ray counterparts of GW events in O3

GW ID	AGILE GCN #	% coverage of 90% c.l. contour	NEAREST EXP.	Comments on Prompt
190408an	24063, 24071,24080	0 %	+100	Prompt just missed;
190412m	24100, 24110	0 %	-700	Occulted;
190421ar	24140, 24143	0 %	+450	Not covered, SAA;
190425z	24180, 24186	0 %	+100	Prompt just missed by GRID;
190426c	24245, 24246	70 %	0	Partially covered;
190503bf	24379,24382	4 %	0	Prompt partially covered, occultation;
190510g	24437,24457	60 %	0	Not covered;
190512at	24507, 24519	0%	+840	SAA+ occultation + Sun constraints;
190513bm	24526, 24528	0%	-100	Prompt just missed
190517h	24572	0%	-100	Prompt just missed

example: S190425z

$T_0 = 08:18:05$ UT, 25 April, 2019

Integration (+100 / +200 sec)



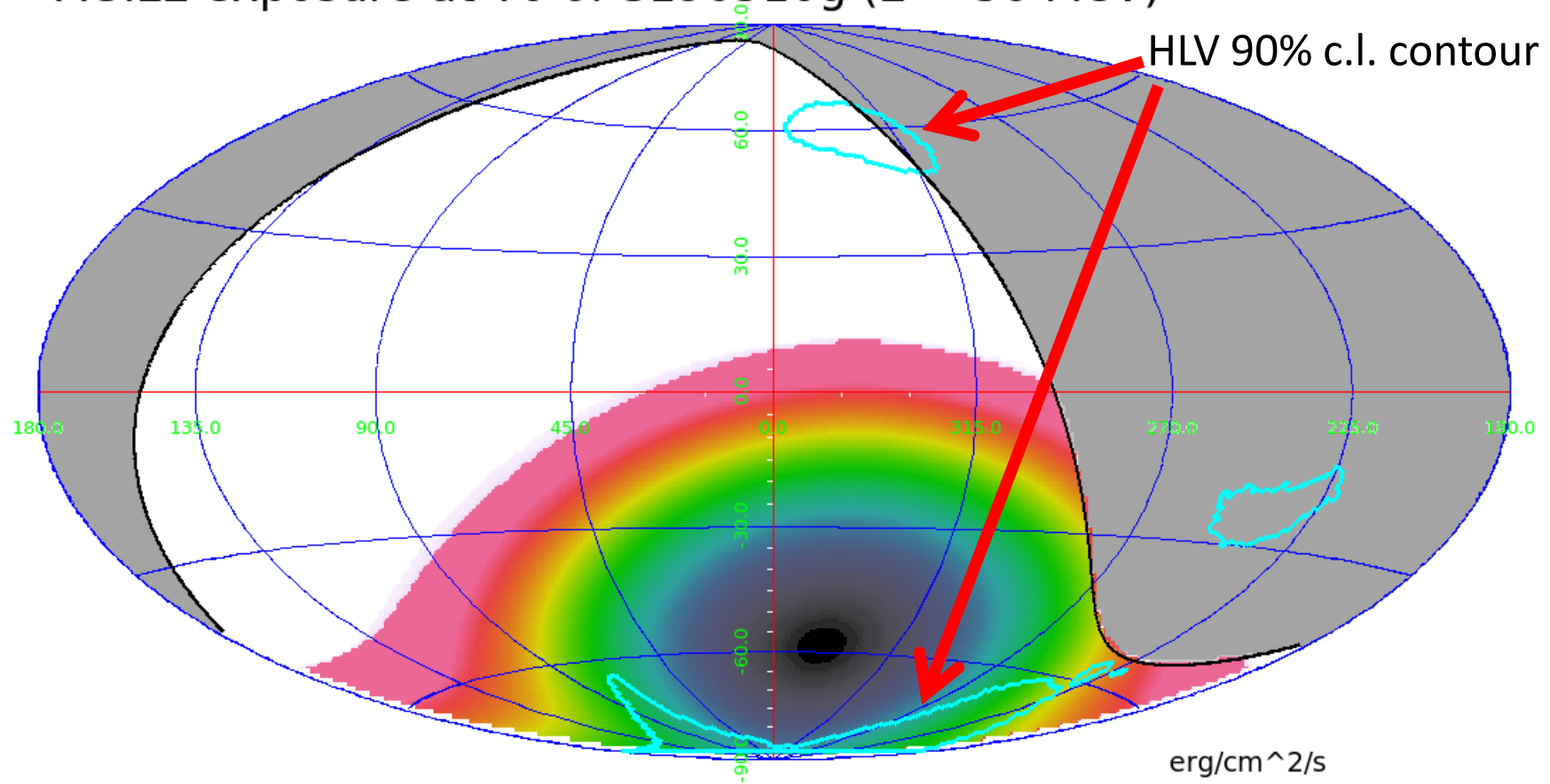
3-sigma upper limit ($E > 50$ MeV) $\sim 5.0 \times 10^{-8}$ erg cm $^{-2}$ s $^{-1}$

2nd example: S190510g

$T_0 = 02:59:39$ UT, 10 May, 2019

Integration (-2 / +2 sec)

AGILE exposure at T_0 of S190510g ($E > 50$ MeV)



7.39e-07 8.47e-07 9.52e-07 1.06e-06 1.20e-06 1.41e-06 1.72e-06 2.22e-06 3.08e-06

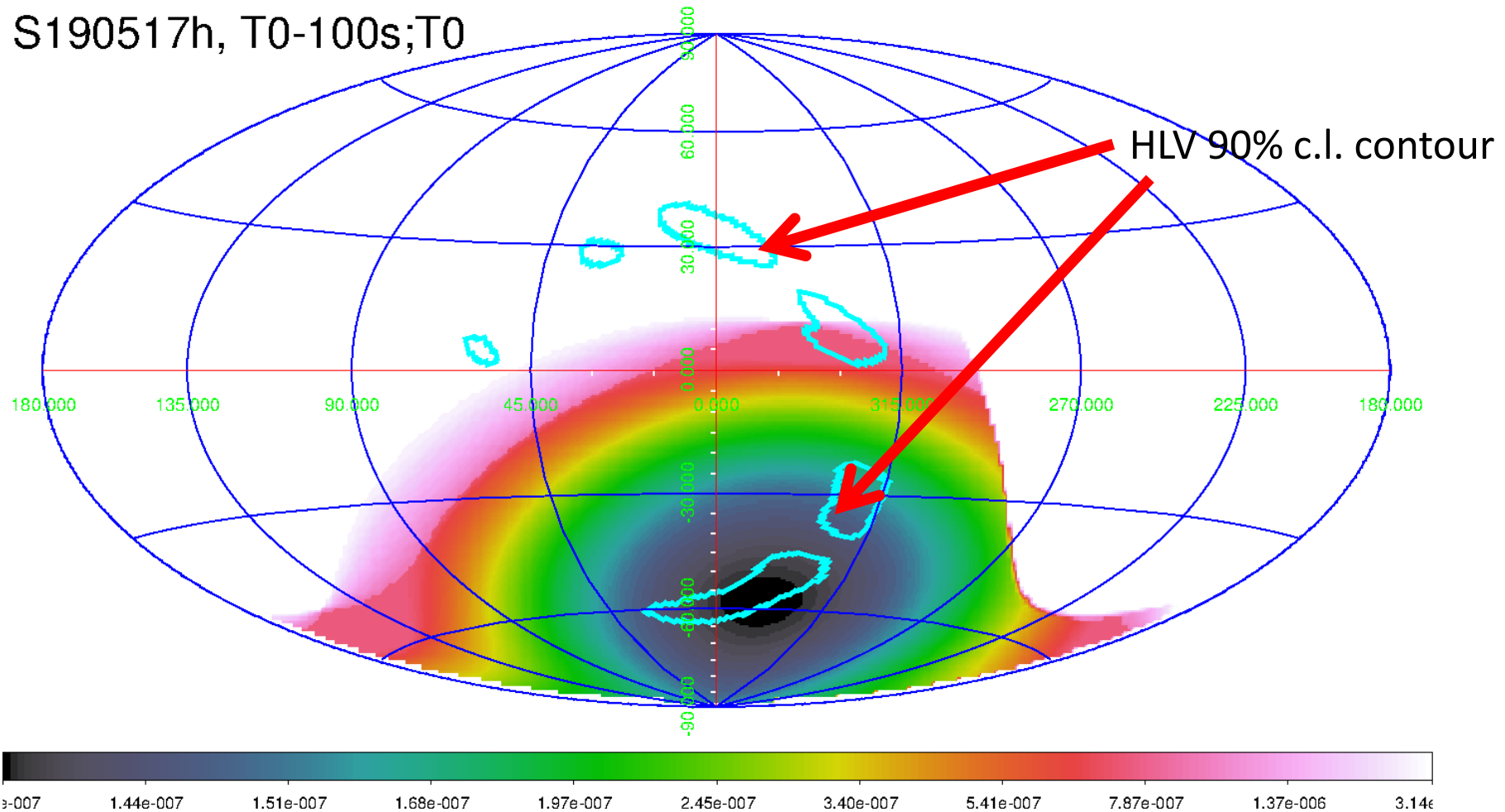
3-sigma upper limit ($E > 50$ MeV) $\sim 8.0 \times 10^{-7}$ erg cm⁻² s⁻¹

3rd example(real time): S190517h

$T_0 = 05:51:01$ UT, 17 May, 2019

Integration (-100s / +0 sec)

S190517h, T0-100s;T0



AGILE is still...scanning...

- **AGILE continues its journey...**
- **fully integrated in a network of multi-frequency observers from ground and space.**
- **enhanced detection capabilities of short (and long) transients, especially for GW events (and neutrinos), also GRB!.**
- **Contributing to LV O3 run! 3 BNS**
- **check also the AGILE APP (“AGILEScience”)!**

AGILE is still...scanning...

Bin central time: -1000s
Time bin: 410608468.6 -- 410608568.6

Trigger date: 2017-01-04

