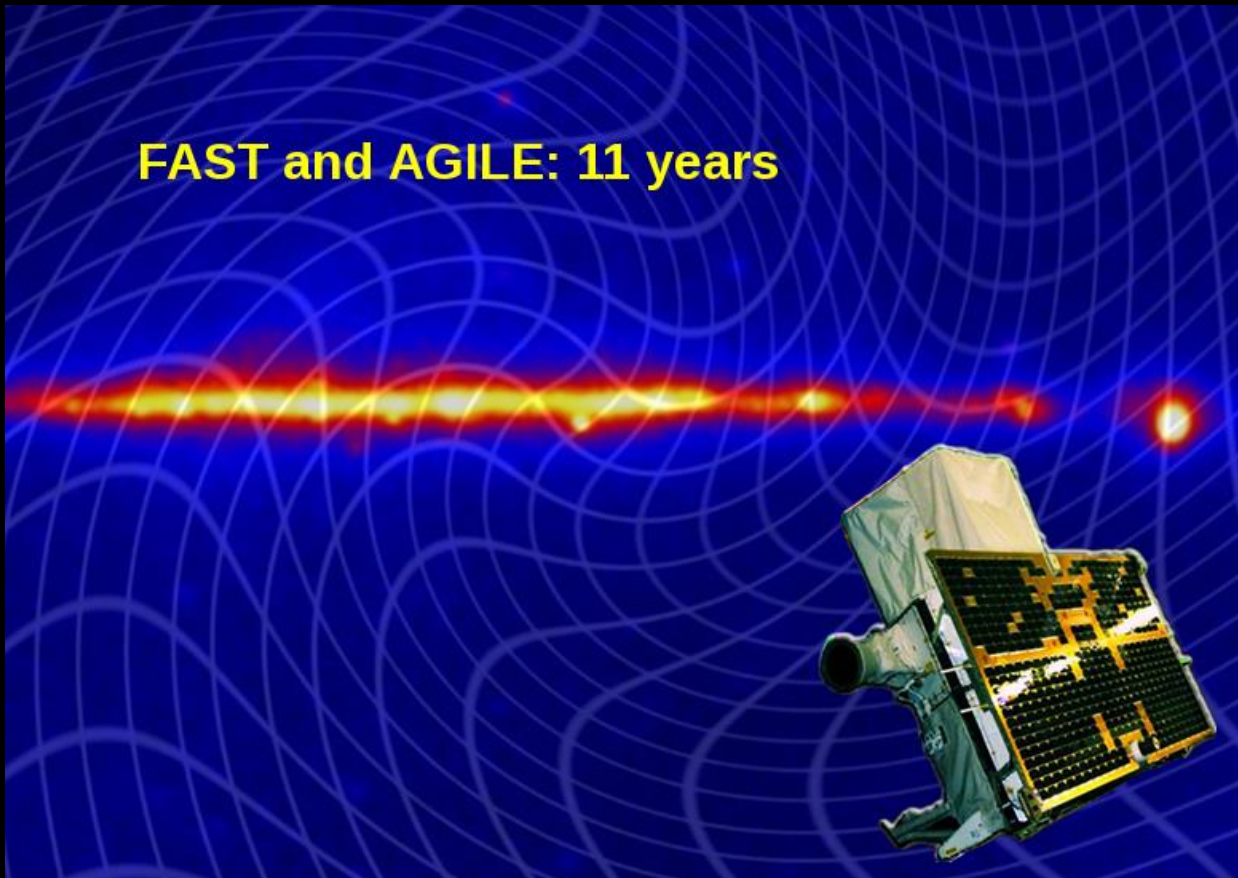
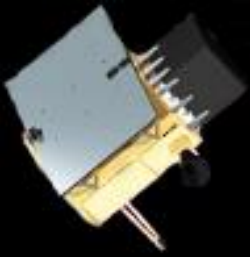


AGILE activity for the GW e.m. counterpart search

Francesco Verrecchia, on behalf of the AGILE Team

16th AGILE Workshop, ASI-HQ, Roma, May 18, 2018





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



ANTICOINCIDENCE

**HARD X-RAY IMAGER
SUPER-AGILE (SA)**

Energy Range: 18–60 keV

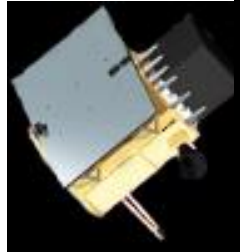
SILICON TRACKER

GAMMA-RAY IMAGER (GRID)

Energy Range: 30 MeV – 30GeV

(MINI) CALORIMETER

Energy Range: 0.3–100 MeV



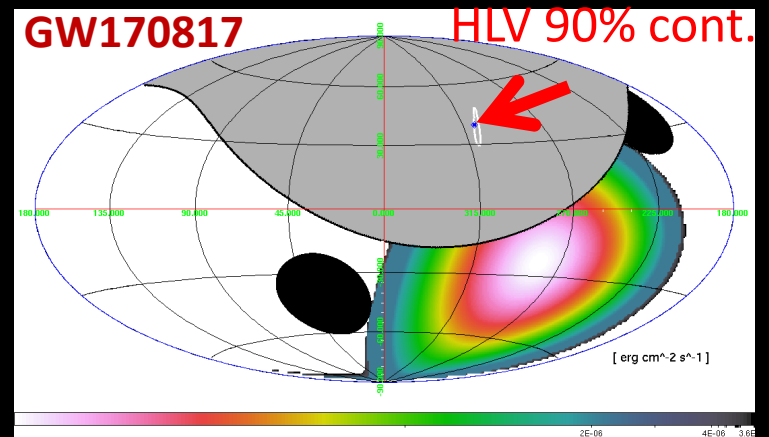
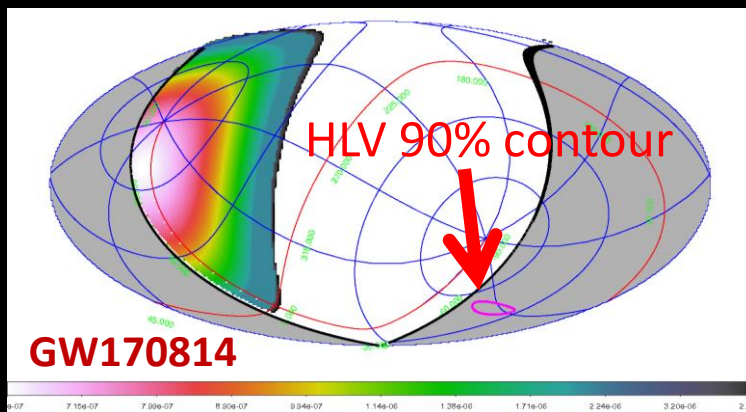
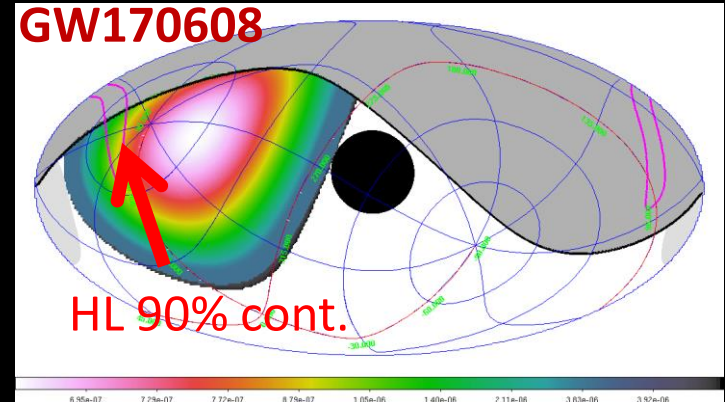
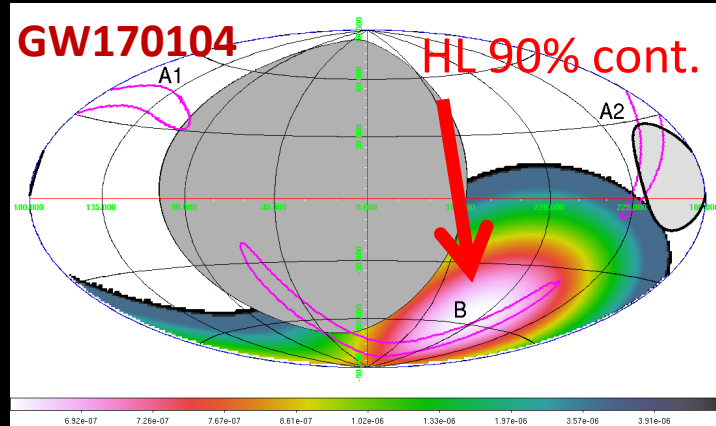
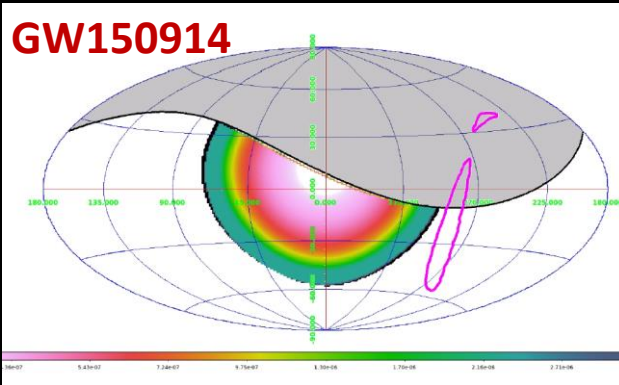
AGILE characteristics

- Furtherly improved performance
- MCAL upgraded configuration and automatic Alert issue
- Hard X-ray Super-AGILE continuous coverage
- **Bright future for O3: reaction to Open Public alerts**

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 (1 st with Virgo data); ---
170817	21525,21526, 21562, 21785	0 %	+ 930	OT NOT covered; Verrecchia et al. 2017b

Review of main public events prompt maps



Spinning mode: GW150914 exposure animation

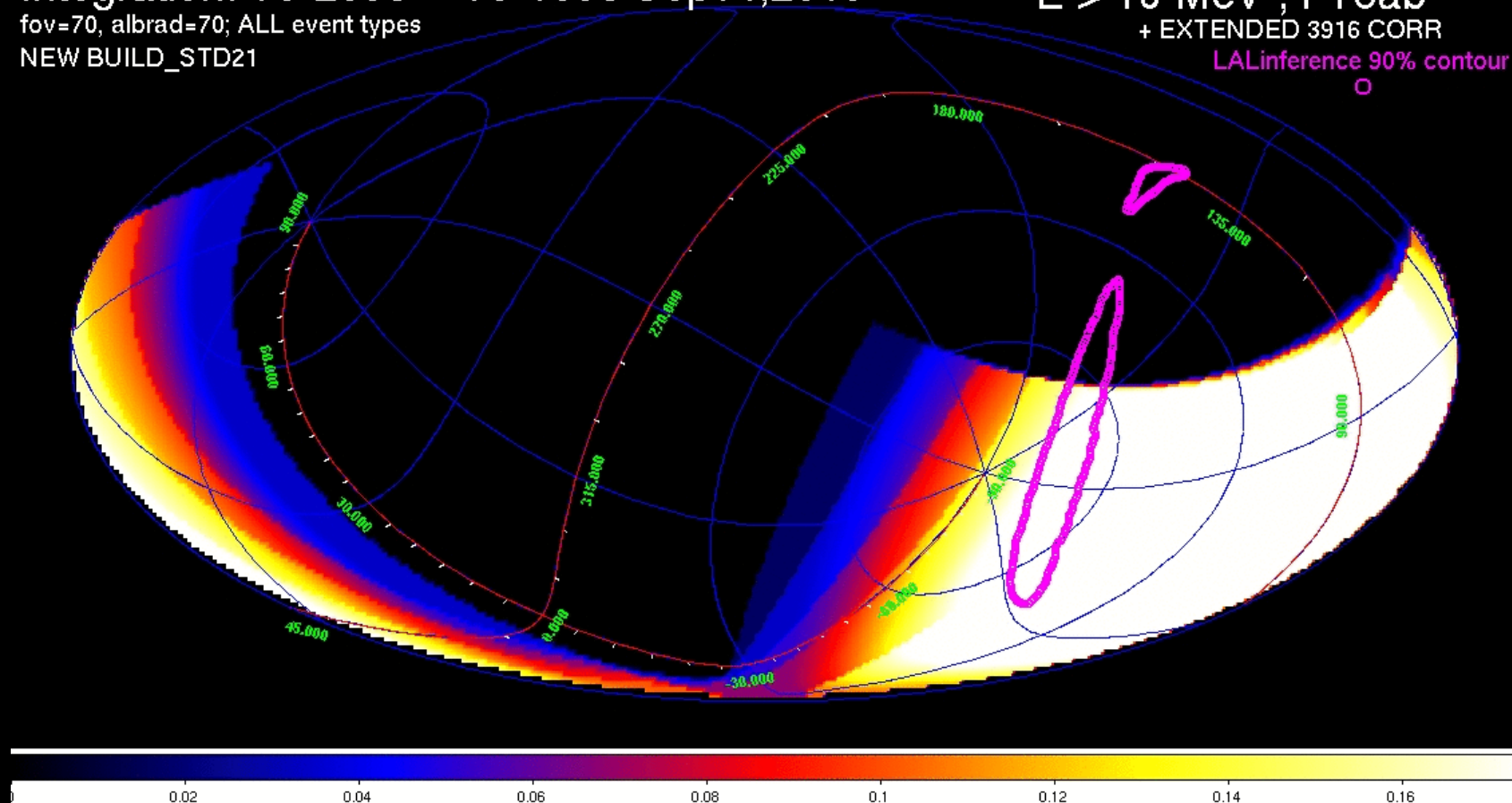
Integration: T0-205s -- T0-105s Sep14,2015

fov=70, albrad=70; ALL event types
NEW BUILD STD21

$E > 10 \text{ MeV}$: FT3ab

+ EXTENDED 3916 CORR

LAInference 90% contour



Spinning mode: one single rotation

Integration: T0-120s -- T0+300s Sep14,2015

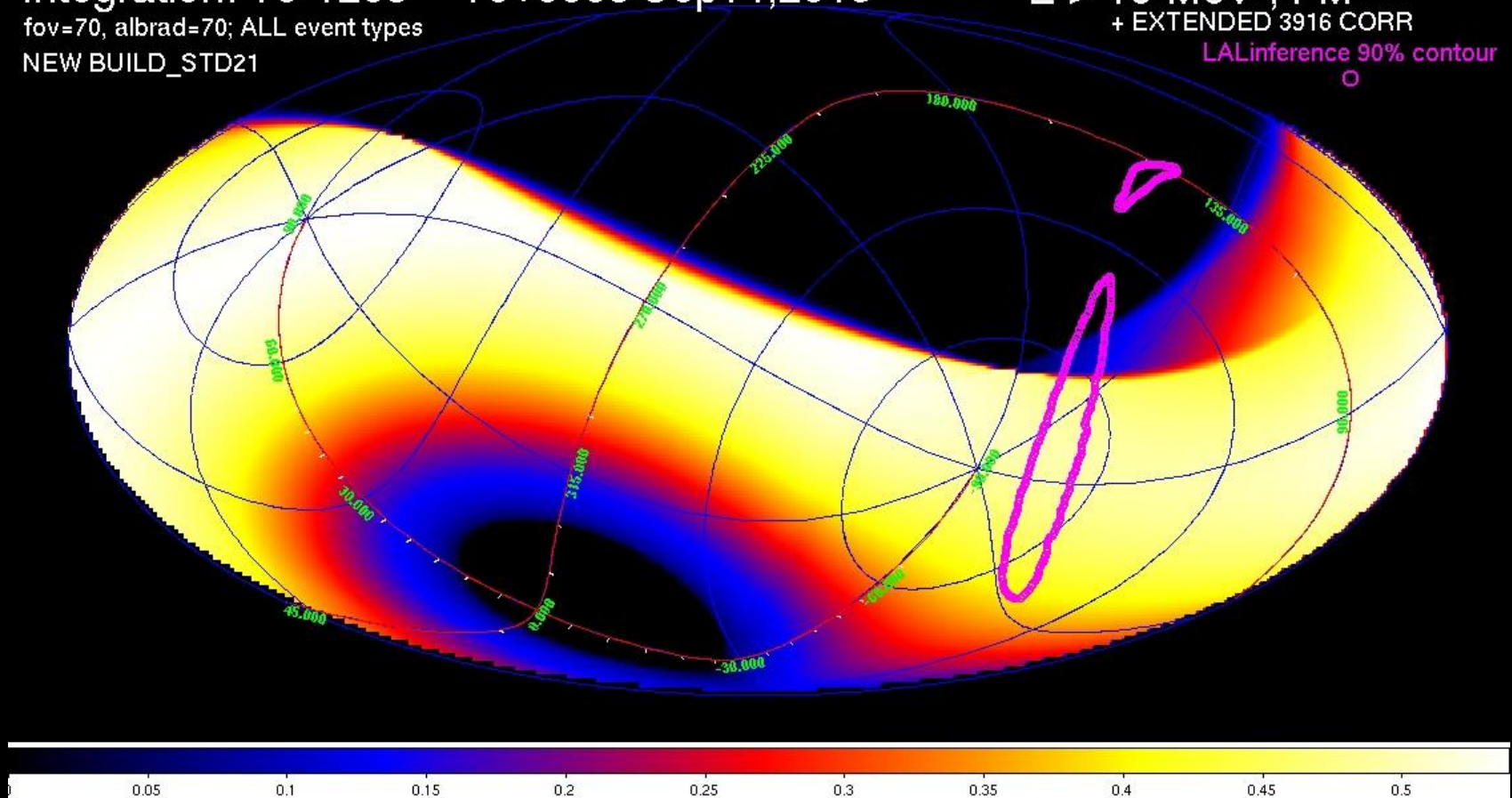
fov=70, albrad=70; ALL event types

NEW BUILD_STD21

$E > 10$ MeV ; FM

+ EXTENDED 3916 CORR

LALInference 90% contour

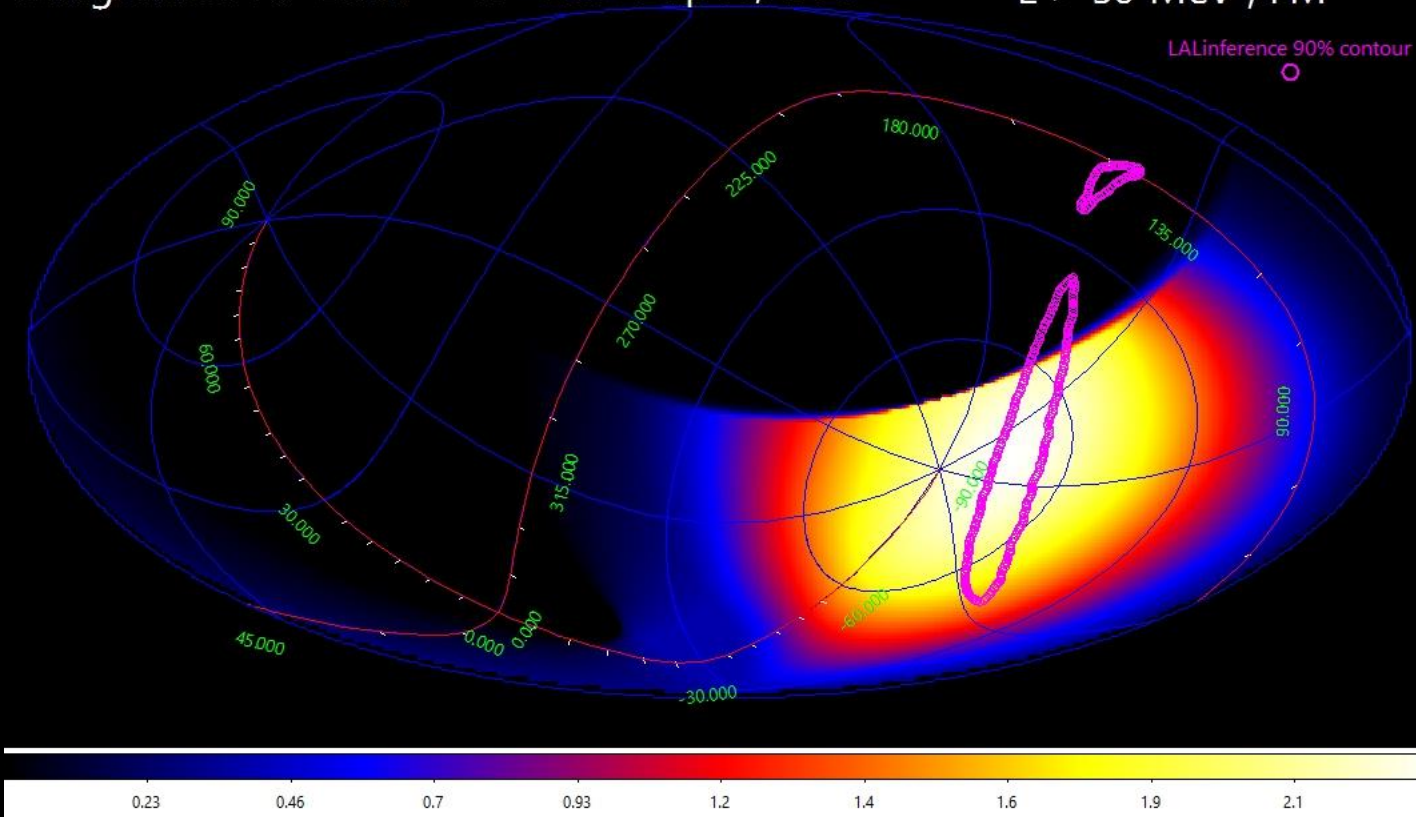


GW150914 analysis (No MoU)

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) = 1.9×10^{-8} erg cm $^{-2}$ s $^{-1}$

GW150914 as test case for dedicated AGILE GW analyses

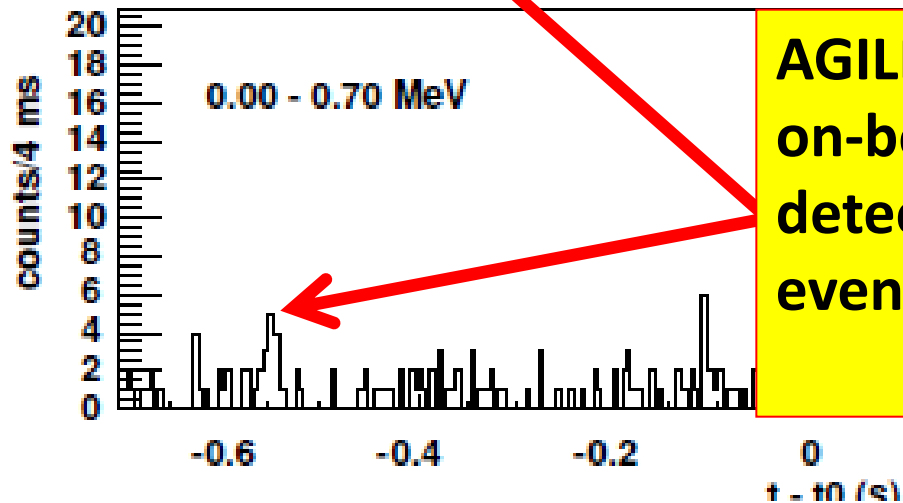
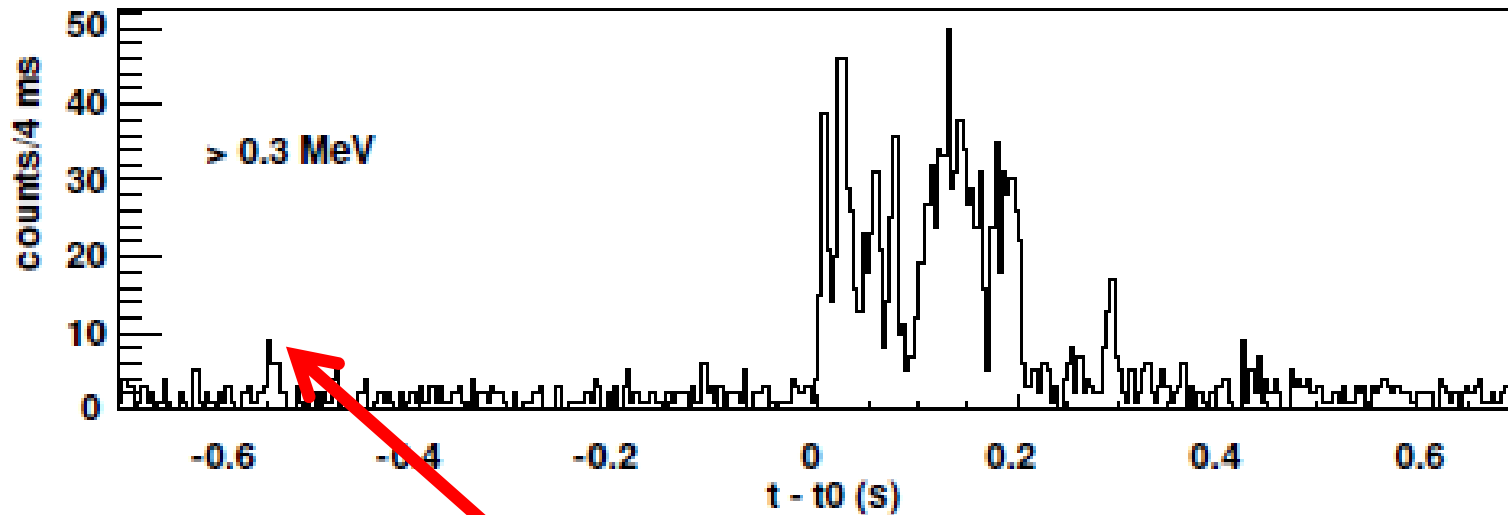
- **Developed dedicated MCAL&GRID data analysis tasks**
- **Tested on archival search**
- **Pre-cursor/delayed GRID event search on short (100s) up to long (days) time scales: «grb-mode», maximum likelihood**
- **MCAL&GRID automatic data analysis reaction pipeline on-trigger**
- **Improvement of the on-board triggering capabilities: need for larger time coverage**

AGILE reconfiguration in 2016

- AGILE commissioning activity on summer
- Improvement of MCAL burst detection: goal GRB090519 pre-cursor like events
- TM allocation revision, GRID, MCAL, Super-A in full configuration but not uniformly (data gaps)
- Tests (November 2016)

MoU signed in Nov. 2016, real-time participation to the counterpart search during the O2 run

AGILE-MCAL GRB090510 light curve



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

AGILE-GW GROUP

LIGO/Virgo Notices & Circulars:

=>AGILE-GW pipeline on LVC triggers

AGILE GW GROUP:

- QUICK RESPONSE TO GW EVENTS
- CHECK MCAL, GRID, SUPER-AGILE
- FIRST ISSUING OF GCN CIRCULARS
- REFINED ANALYSIS
- ALSO standard transients, i.e. GRBs

ACTIVE ROUND-THE-CLOCK, 24HR/DAY

Participation to the O2 run

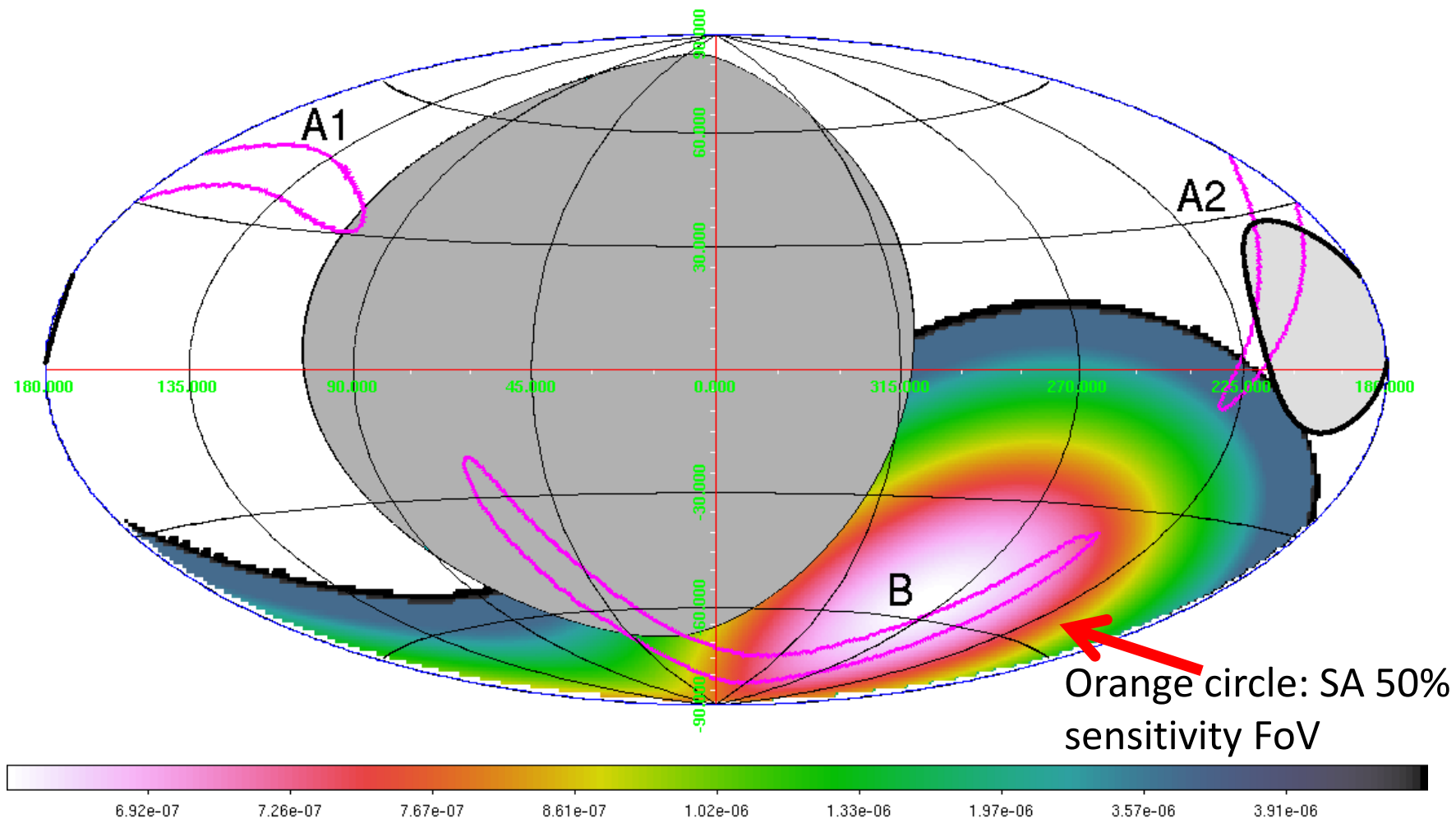
- AGILE observed all the GW events
- **Main scientific results:**
 - the 1st O2 event, **GW170104** : prompt partial spatial coverage in gamma-rays ($E > 30$ MeV), U.L.; MCAL light curve covering of the T_0
 - the famous **GW170817** event, the first with an identified e.m. counterpart : prompt occulted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

GW170104

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

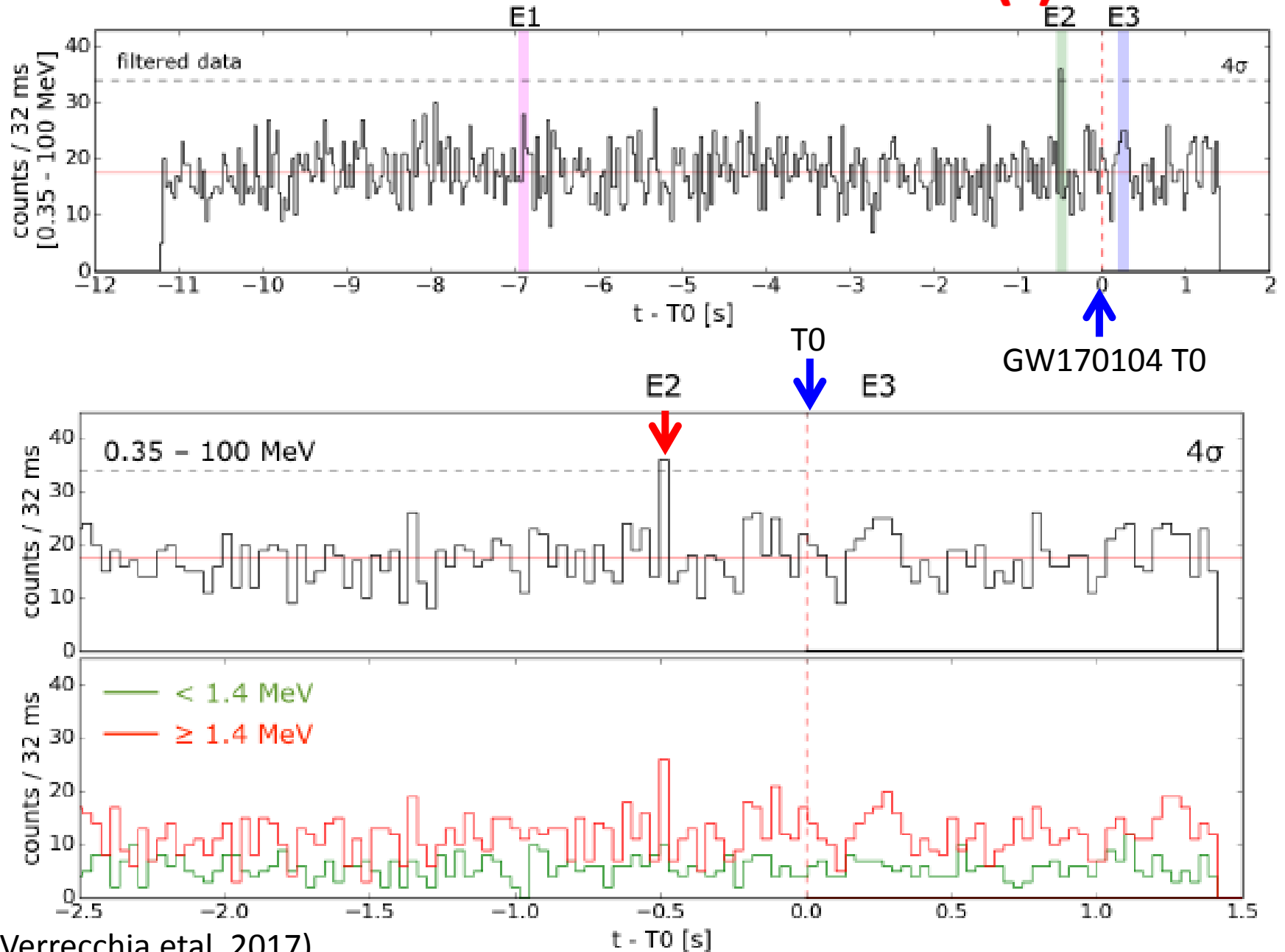
- **90% c.l. contour covered for 36% at event time**
- **Two LVC-GCN, by MCAL and GRID published**

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



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

an MCAL candidate event (!)



Lesson learned: MCAL data analysis revision

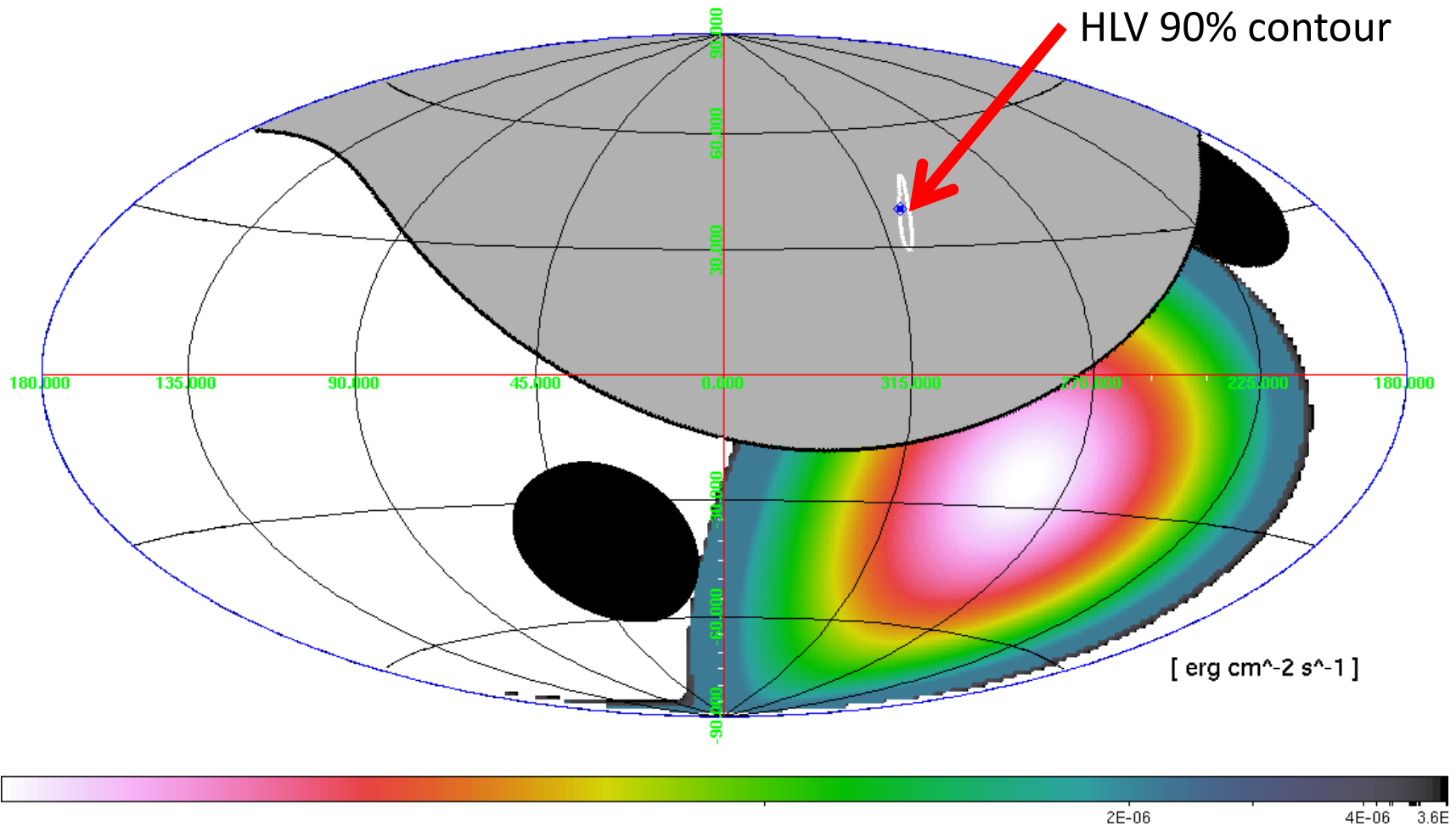
- ✓ **MCAL data are now processed with a focus on short & weak events**
- ✓ **Statistically characterized FAR and post-trial probability**
- ✓ **similar to the precursor and GBM/Integral signal of GW170817**
- ✓ **Prospect for O3: improved multi-binning automatic detection**

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.

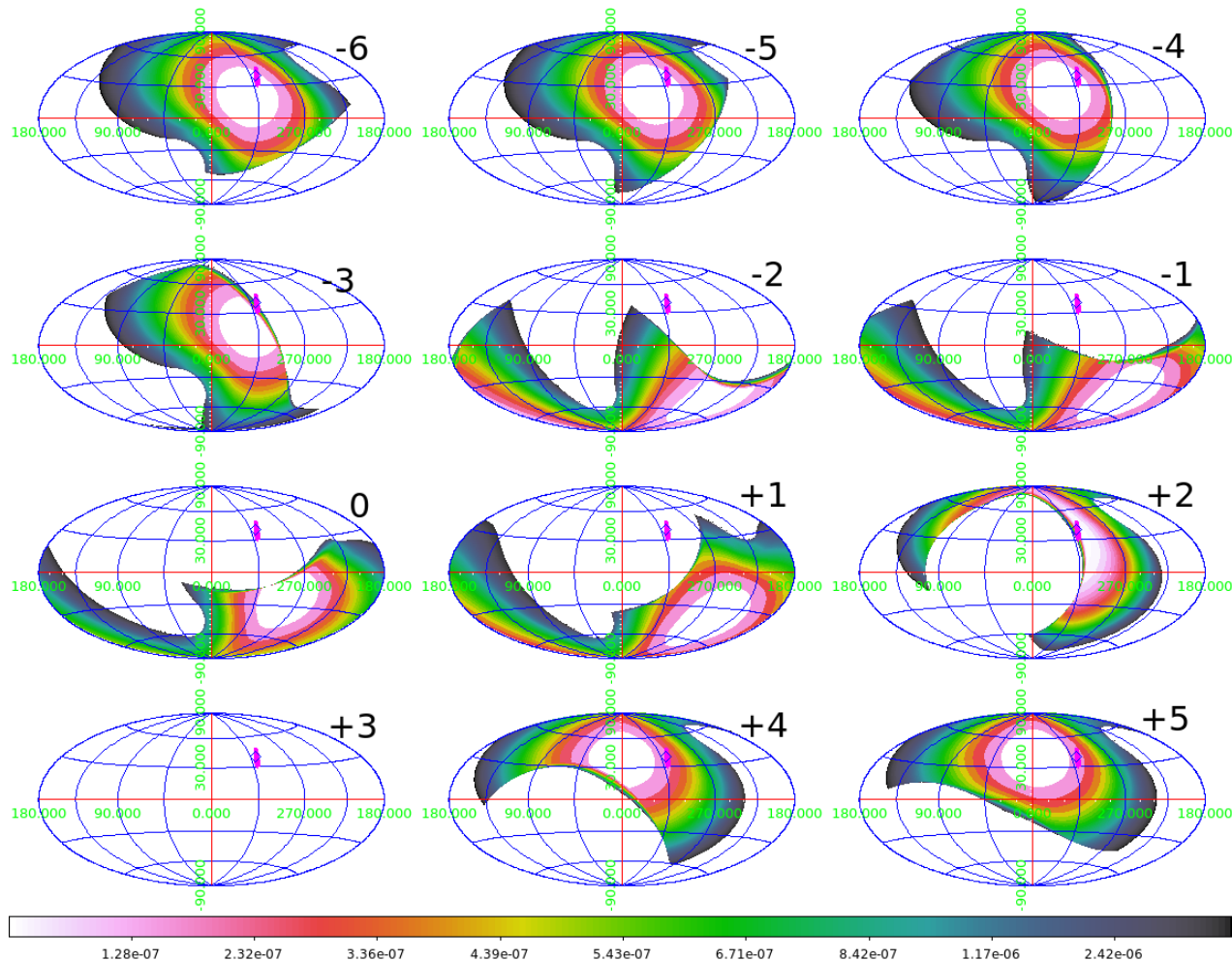
AGILE exposure at trigger time (-2 / +2 sec) occulted!



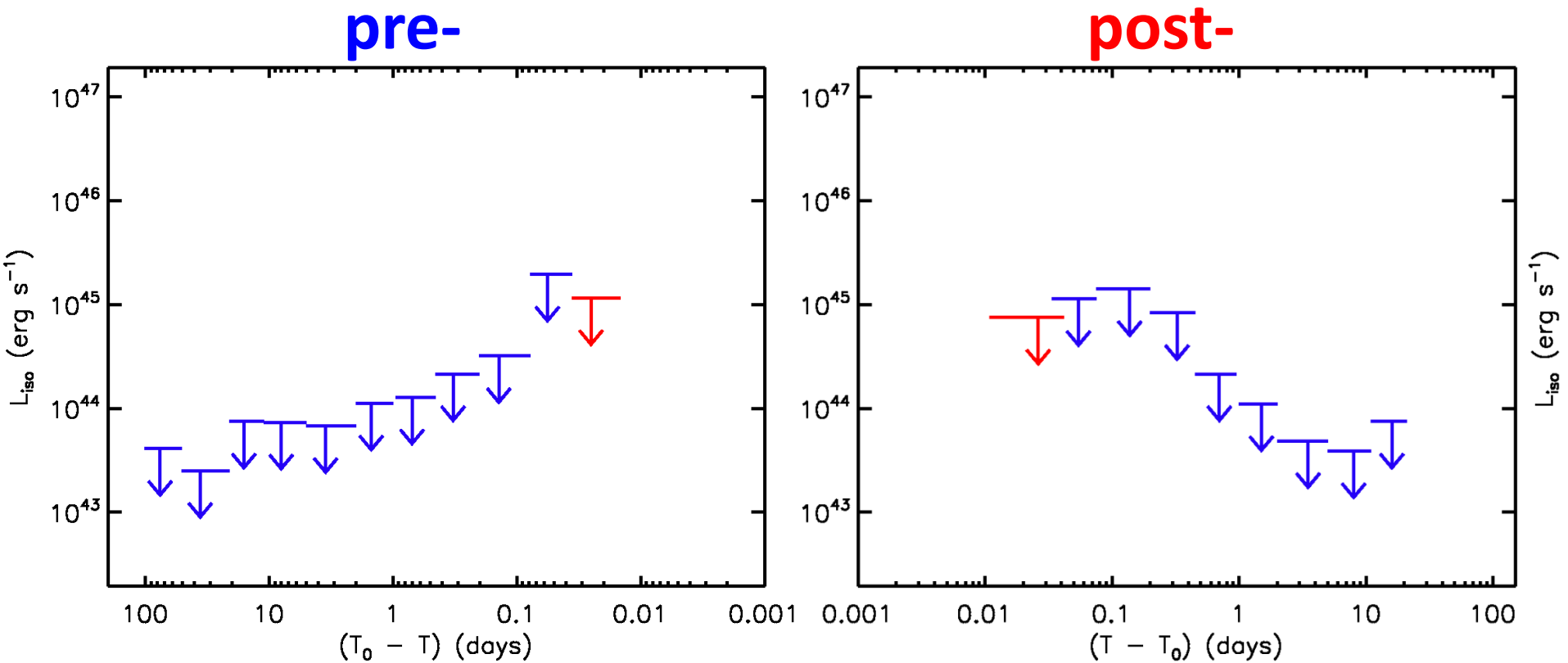
In $E > 30 \text{ MeV}$ energy band

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

Evaluation of GRID 2- σ upper limit Pre-/Post - T_0 @OT position, in three 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.

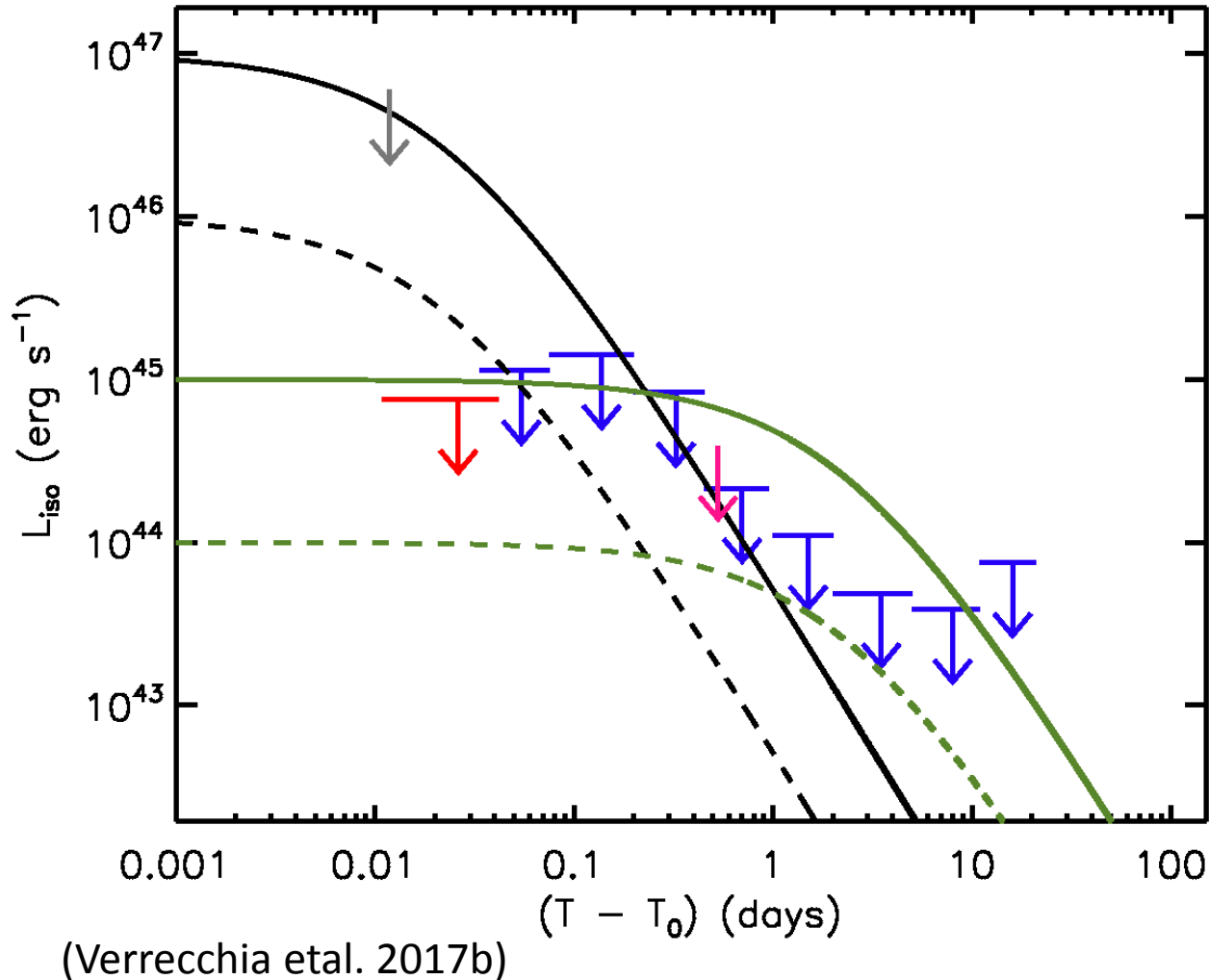


AGILE-GRID precursor/delayed emission search: medium/long time scales (-/+1 , -101/+21 days)



AGILE limits on magnetar emission:

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



Radiation efficiency

$\xi = 0.01$ -> solid

$\xi = 0.001$ -> dashed

$B = 10^{14}$ G (green)

$B = 10^{15}$ G (black)

Magenta: SA U.L., no
data earlier

If prompt data
available, 170817A
significant SA
detection possible

Gray: MCAL U.L., GBM spectrum mostly out of MCAL band

AGILE limits on magnetar emission:

AGILE results important in the early phases to exclude a highly magnetized magnetar for the remnant of GW170817.

Further possible models for different short-GRB detection; pre-cursor or delayed emission



Lesson learned: MCAL data analysis revision

- ✓ GBM/INTEGRAL signal of GRB170817A/
GW170817: **dedicated scientific MoU** with
LVC regarding e.m. signal triggering LVC and
sub-threshold event search
- ✓ MCAL statistically validated sub-threshold
(STE) events;
- ✓ comparison with events from other
missions, before and during O3

))) Prospects for LIGO-Virgo O3 run

- Open Public Alerts!
 - **Automatic LVC public alerts issued within minutes w/o human vetting. Retraction managing**
 - **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: Could detect one or more during O3, but uncertain.**
- Timeline: joint LIGO-Virgo 1-month engineering run on ~Nov; **O3 Start: Dec 2018-Jan 2019??**

AGILE Work in progress

- Optimal overall configuration of the instrument
 - **full telemetry (14 orbits/day), no data gaps**
- Sensitivity to weak (“sub-threshold”) events: possible correlation with events from other missions, **IPN (almost done), GBM (started)**
- O3: reduced human vetting of detections
- MCAL automatic detection and notification to community
- Super-AGILE operative, continuously

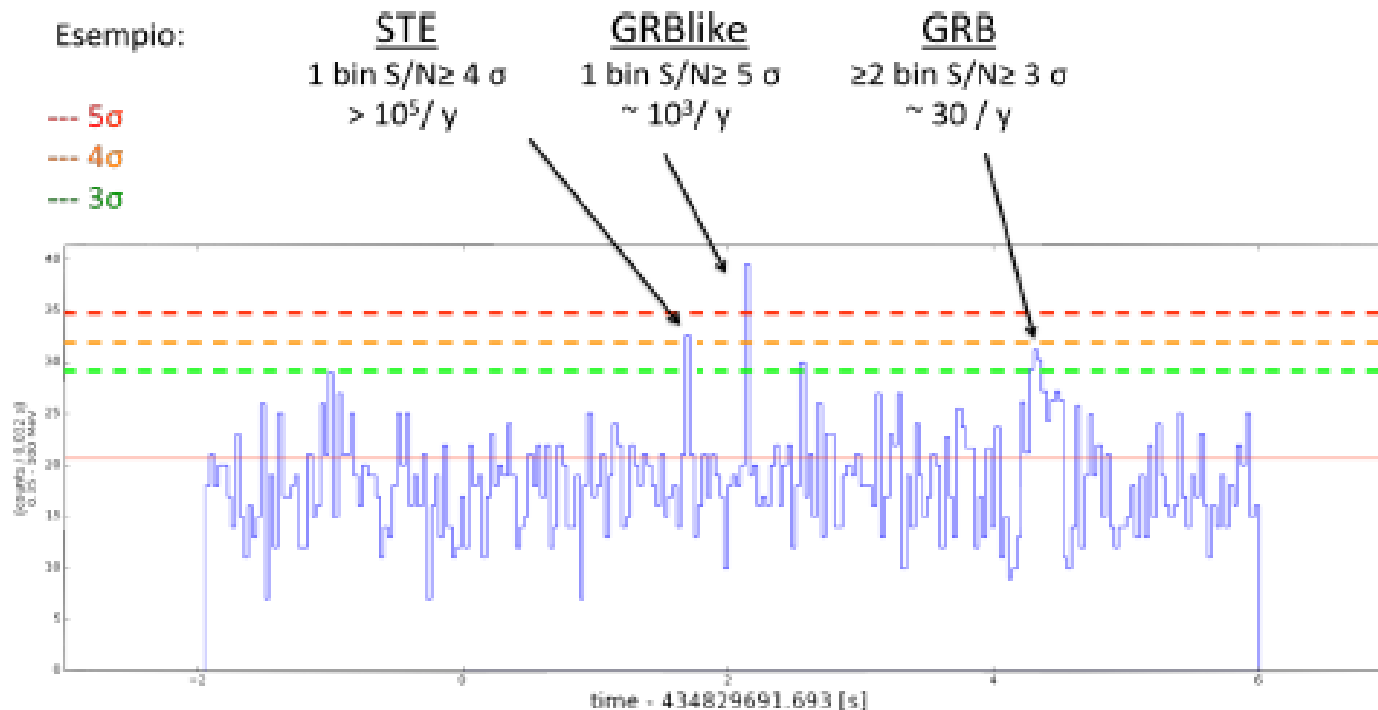
AGILE-MCAL: new detection pipeline

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

Three event classes: **preliminary, under revision**

- 1) standard GRBs (short & long),
- 2) GRB-like (single+S/N > 5 σ),
- 3) Sub-Threshold Events (STEs, single+S/N $\geq 4 \sigma$).

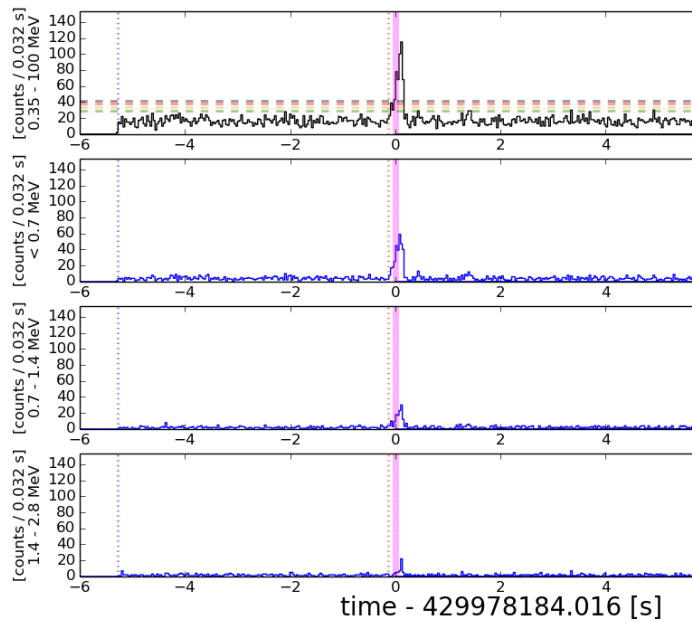
differences among the three classes



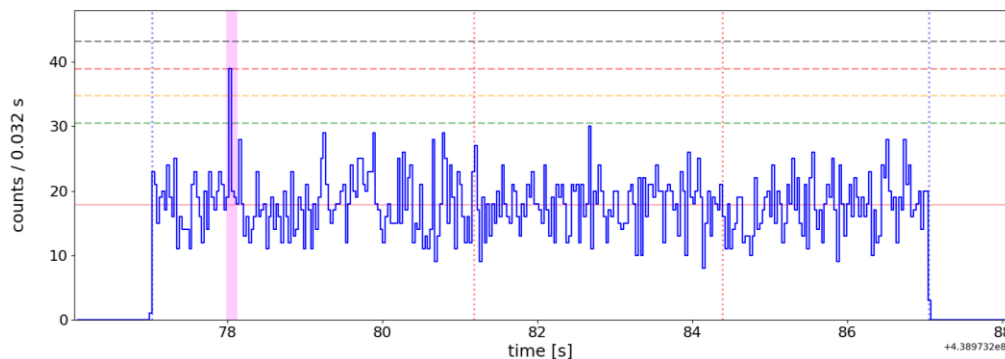
AGILE-MCAL: new detection pipeline

Example of GRB detection: **short 170816A**,
on 32 ms binning (33σ)

CONT 053441 - BIN 0.032 s - T0 429978

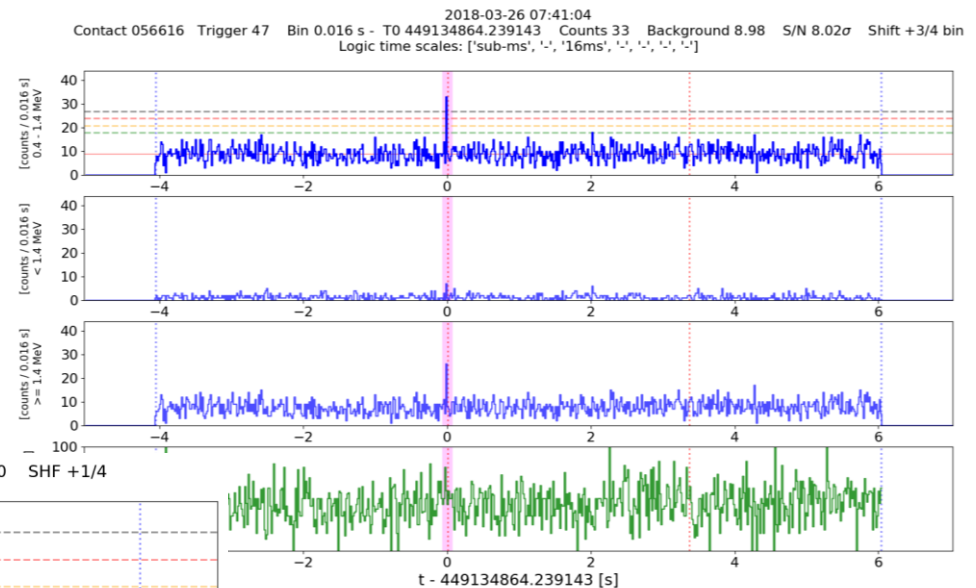


CONT 054932 T0 438973278.053516 CTS 39 BKG 17.87 S/N 5.00 SHF +1/4



cross-check with IPN data is about
completed;
cross-check with GBM STE sample started

Example of GRB-like detection: 8σ on 16ms binning



Example of STE detection: 5σ on 32ms
binning

Recent results:

- Automatic detection testing and calibration, for shorter events but..
- prototypes active in last months, detecting also some confirmed **new GRB** events:

180111A (GCN), 180305A , 180325A

180326A, 189329B (**GRB-like**)?

180404C ->IPN notified

all long burst

- «Spin-off», next scientific result: **new MCAL GRB catalog!**

Recent results: GRB 180111A

- **180111A T0 = 16:43:34.1 UT, 11 January, 2018**
by Swift (Lien, GCN #22318), with optical location.
=>LONG burst
- **AGILE published a GCN Circular on MCAL data analysis on Jan 12**

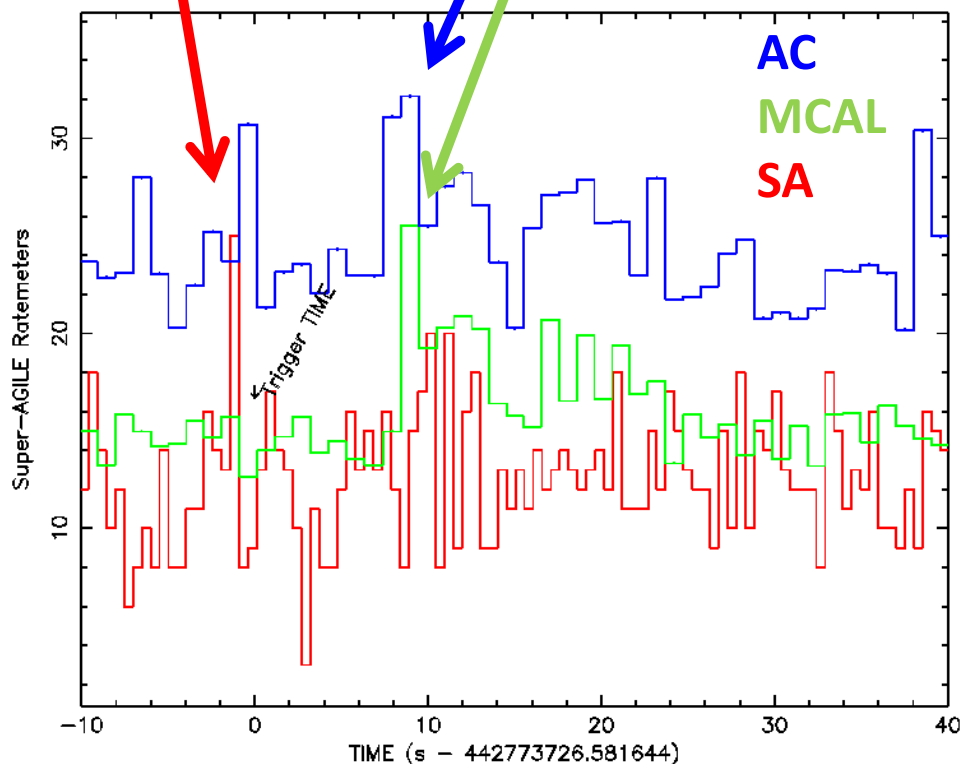
GRB 180111A

Real-time comparison among three detector ratemeters

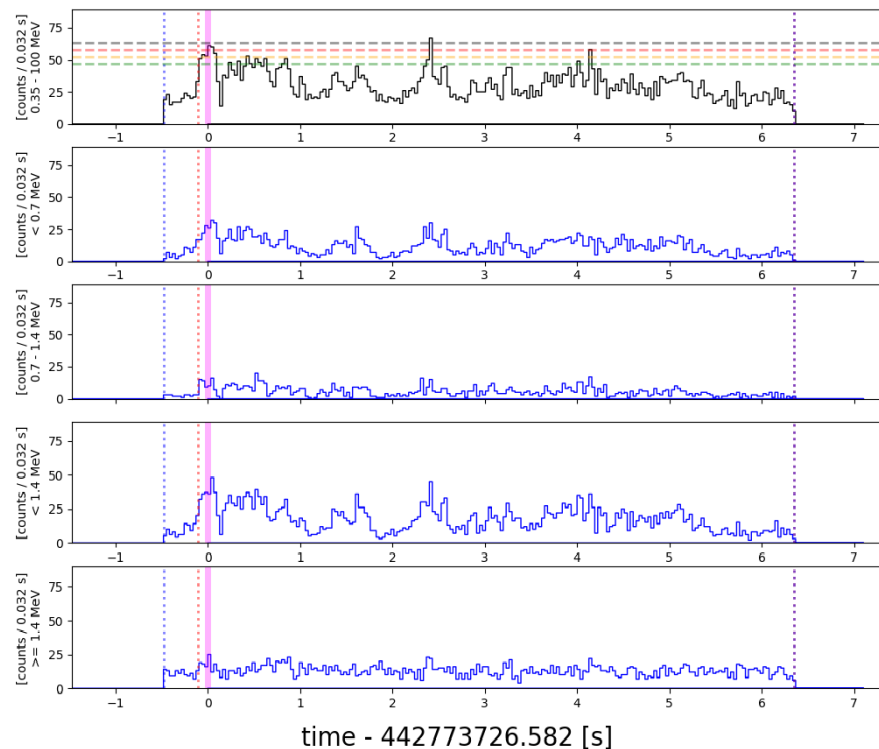
1st peak, softer component

2nd peak, harder component

Integration 442773426.581644 --- 442774026.581644, SA egr.DetDet1 --- Scientific (3915) Ratemeters



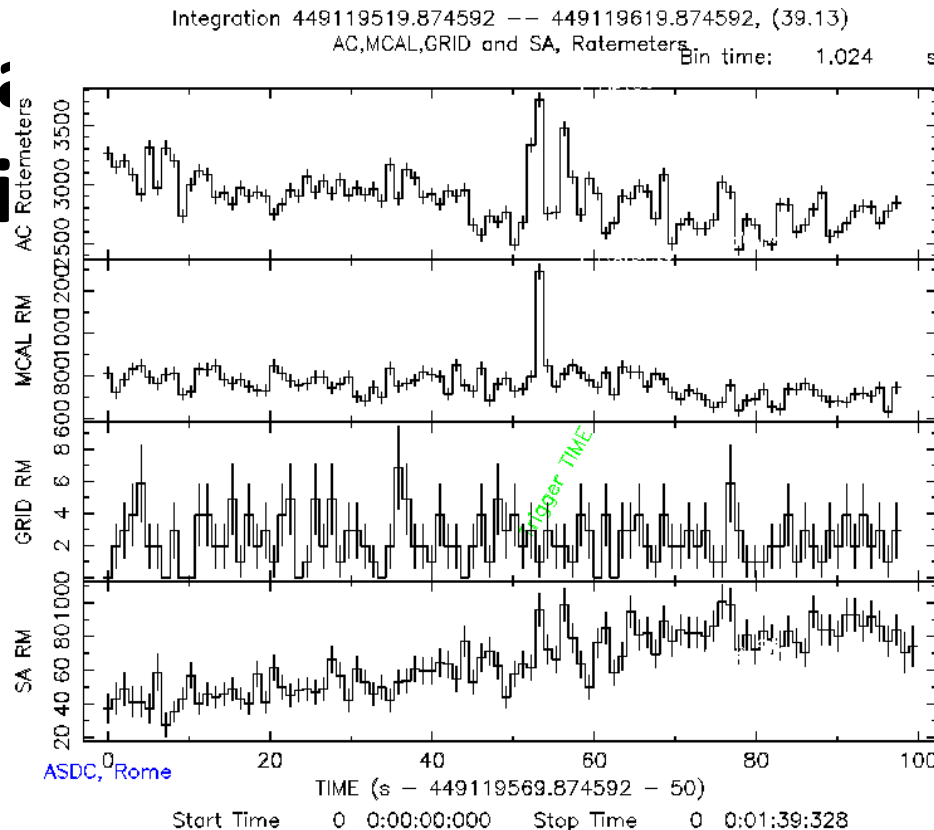
CONT 055562 - BIN 0.032 s - T0 442773726.581644



and GRB 180326A

- **180326A T0 = 03:26:07.1 UT, 26 January, 2018**
by Konus-Wind (Hurley, GCN #22550), with IPN
triangulation. =>**LONG burst**

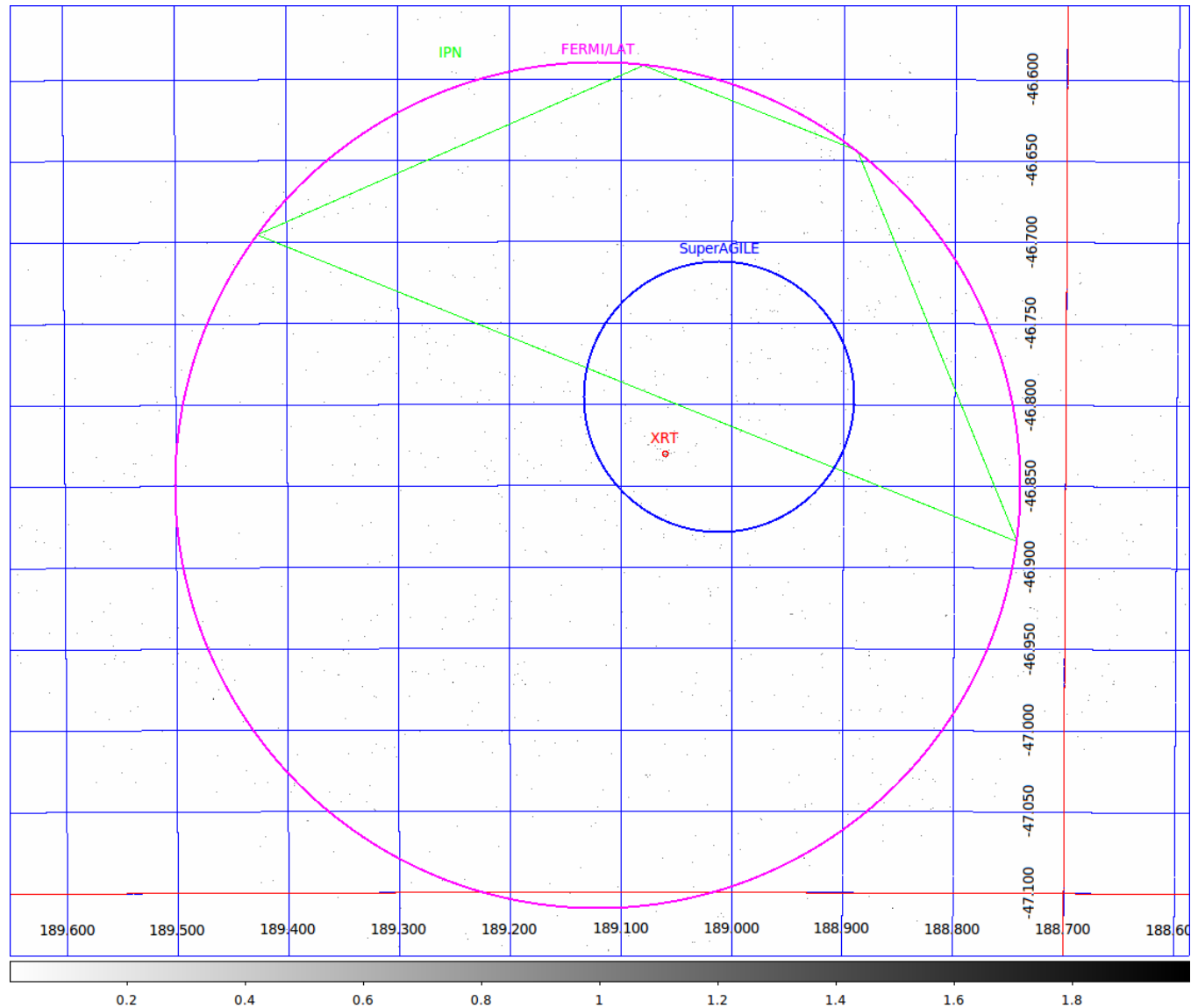
And what
compari



About Super-AGILE detections: GRB 170115B

- **T0 = 17:49:14.03 UT, 15 January, 2017**
by Fermi GBM (Hamburg & Meegan, GCN #20463),
with on-ground location, (R.A., Dec = 189.03, -
51.55, error radius= 1.43 d).
- **=>LONG burst**
- **SA detection: localisation!**
- **AGILE published two GCN Circulars on
MCAL/SA data analysis on Jan 16, at 23:00
and Jan 25**

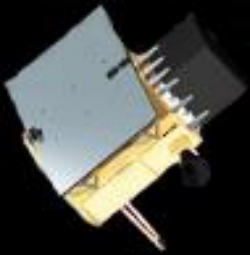
SA localisation example



GCN #20525: GRB 170115B: AGILE/SuperAGILE localisation

Summary

- **AGILE has unique capabilities: hard X/gamma-ray coverage**
- **much improved performance with enhanced MCAL and full Super-A**
- **Ready for automatic detection of short-weak events**
- **capable very soon to issue alerts to LVC for AGILE-detected events (new channel)**
- **Can play an important role in the New Astronomy of gravitational waves**



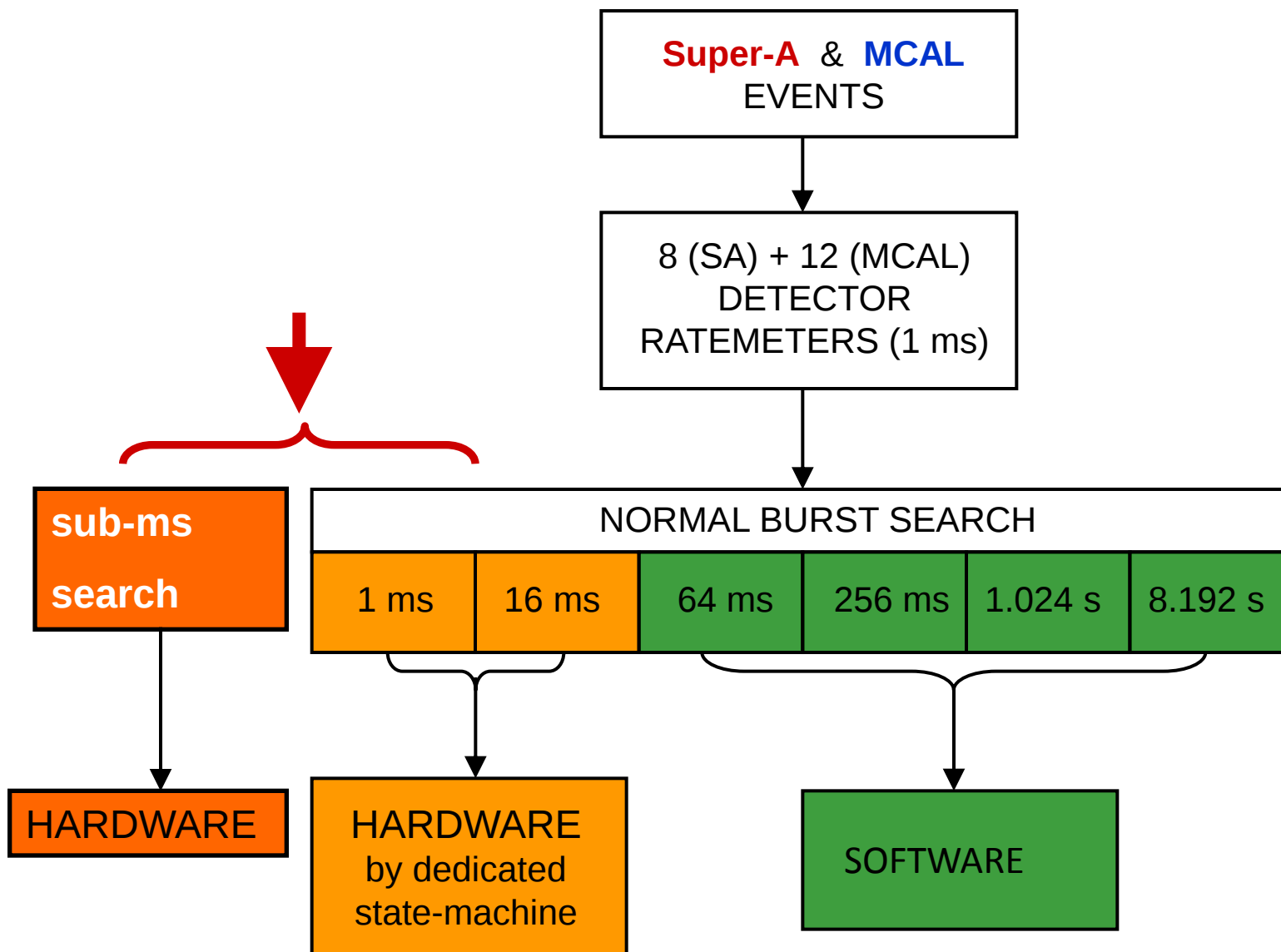
AGILE AGILE characteristics

Science Data Center



by F.Verrecchia on behalf of AGILE Team

AGILE GRB ON-BOARD SEARCH PROCEDURE



GRB 170115B: SA localisation

