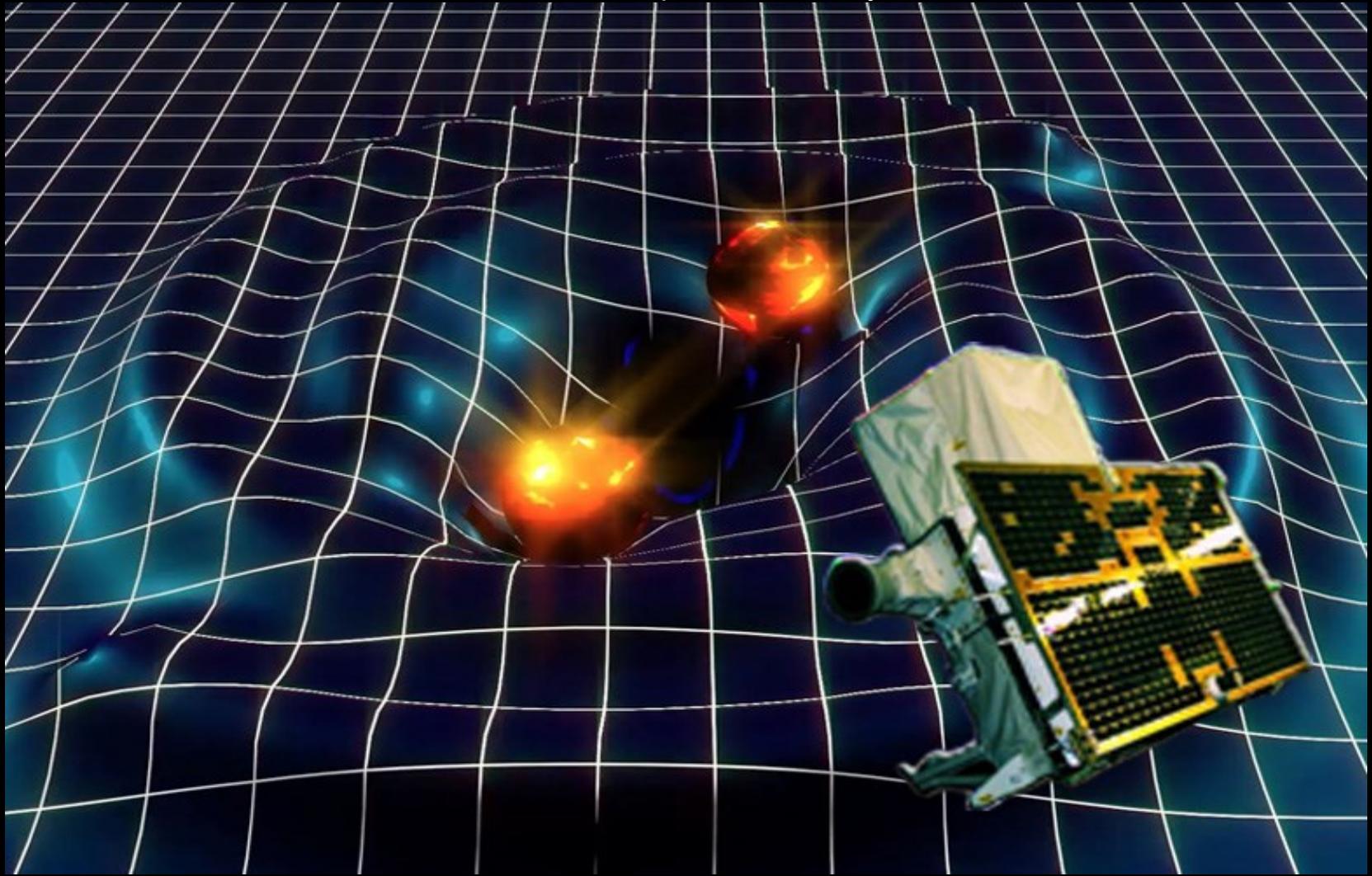


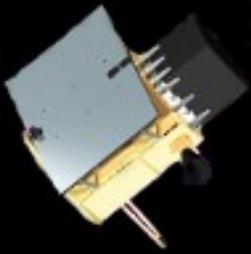


AGILE observations of GW events

Francesco Verrecchia, on behalf of the AGILE Team

15th AGILE Science Workshop, ASI HQ, May 23-24, 2017





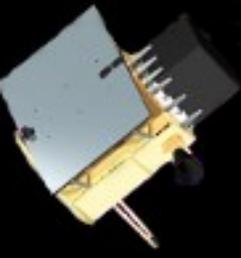
AGILE crucial role in the search of GW source counterparts

1° part

- AGILE spinning mode: sky scanning + shortest reaction time
- AGILE-LIGO MoU: O2 run, AGILE and GW150914 -> lesson learned
- AGILE upgraded configuration for LIGO O2 run,
- AGW pipeline & FA Team -> GW & γ -ray transients

2° part (if ever!)

- Recent results: GRB 170115B and GRB170127C



AGILE Search for gamma-ray transients

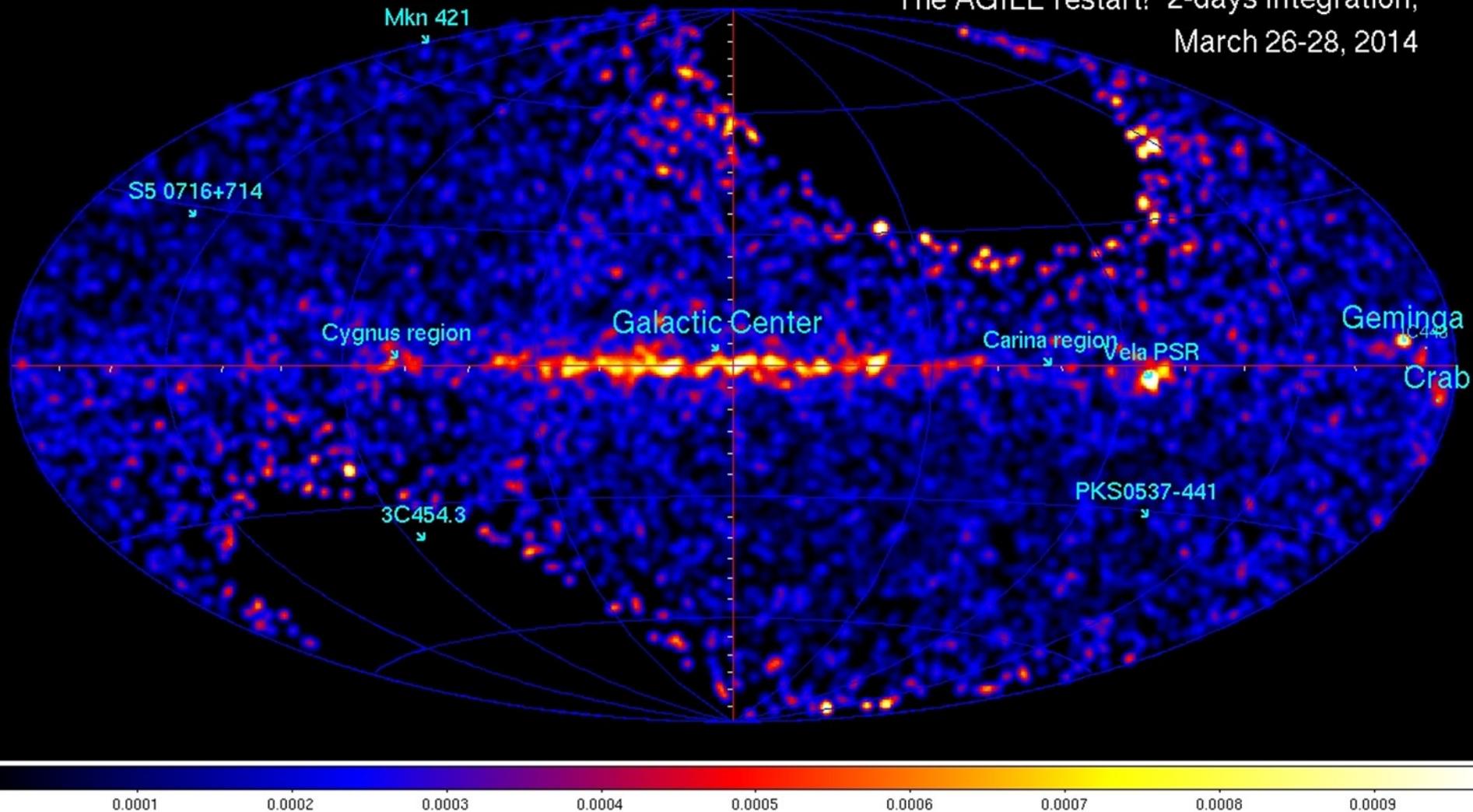
Science Data Center

- 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.**
- **good probability of prompt event coverage**
- GRB – like searches, MCAL, AC
- **AGILE efficient in detecting short GRBs**
- **AGILE has the shortest reaction time to bright gamma-ray transients ->a lot of Atels&GCNs**

Spinning example: AGILE data acquisition restart, 26 Mar 2014

(2d)

The AGILE restart! 2-days integration,
March 26-28, 2014



Spinning example: GW150914 counts/expo animation

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

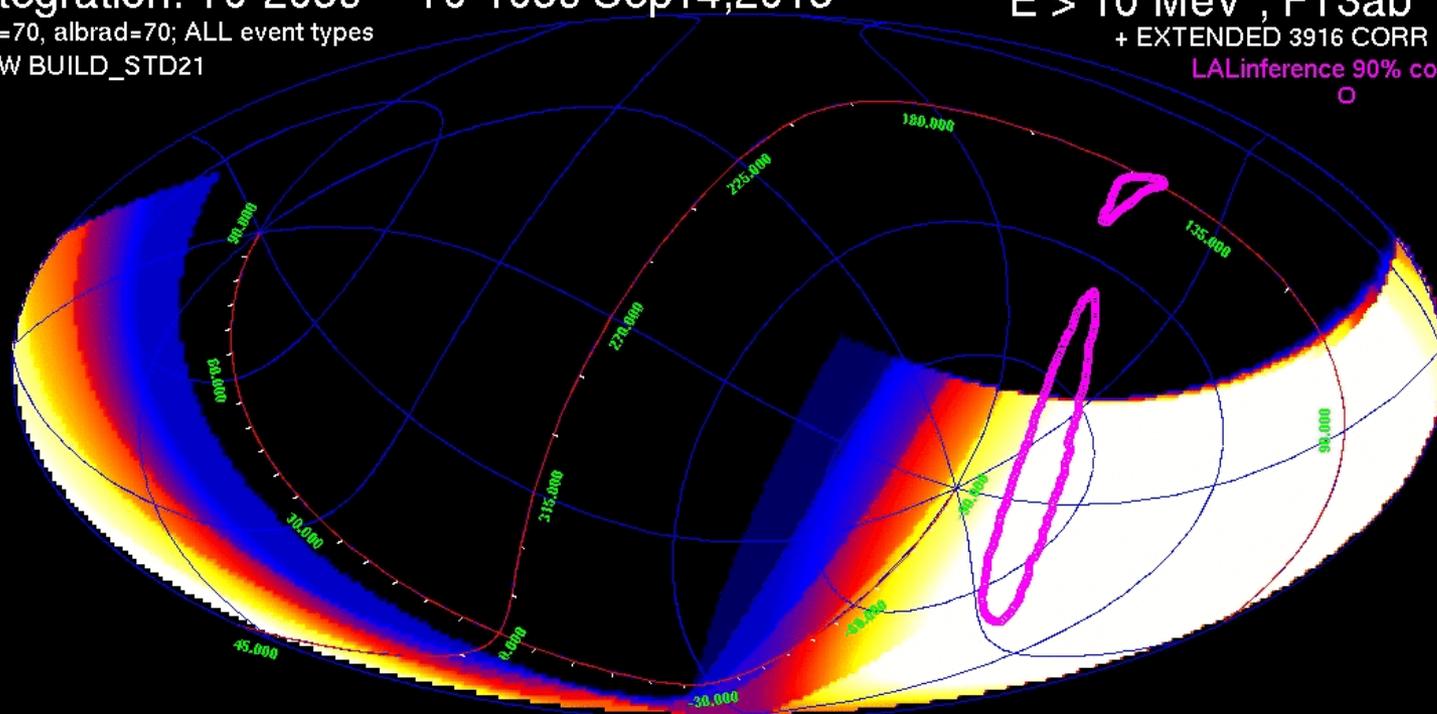
fov=70, albrad=70; ALL event types

NEW BUILD_STD21

$E > 10$ MeV ; FT3ab

+ EXTENDED 3916 CORR

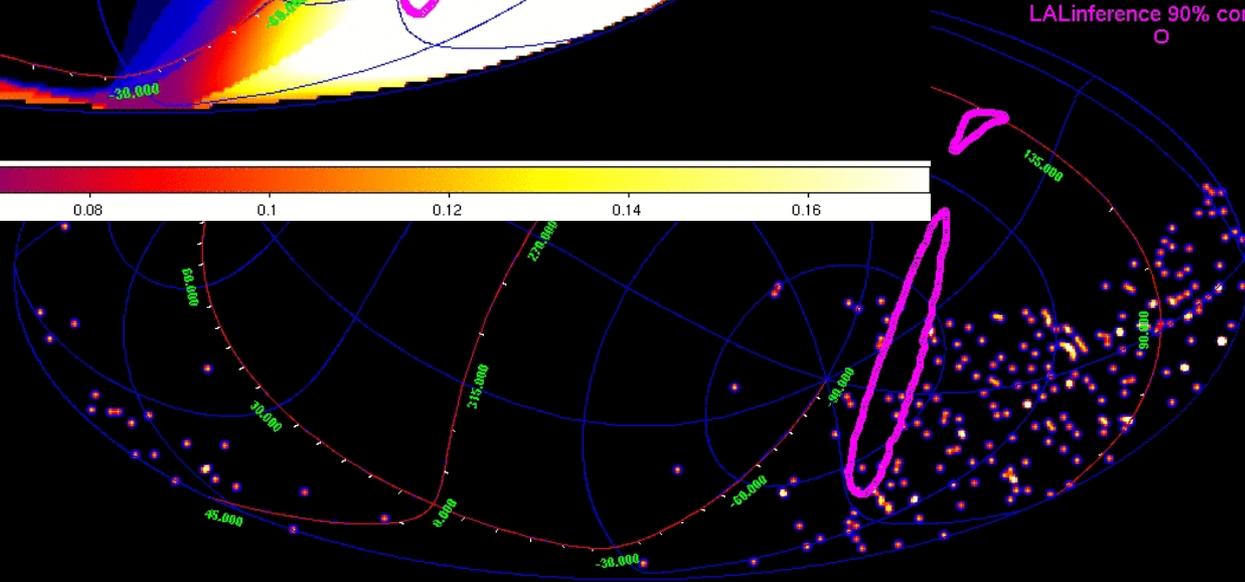
LALInference 90% contour



10 MeV ; FT3ab

+ EXTENDED 3916 CORR

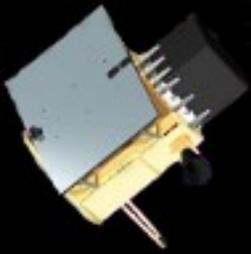
LALInference 90% contour



LIGO-VIRGO planning (O2)

LIGO-VIRGO MoU with AGILE signed and now fully operative.

- **commissioning in August-November 2016**
- **O2a run: December/end-December**
- **intermission**
- **O2b run: January-August 2017**



AGILE

Science Data Center

AGILE and GWs



AGILE is excellent for GW source searches

**First AGILE publication on GW150914
observation analysis (Tavani et al. 2016)
published on ApJ**

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 T₀

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

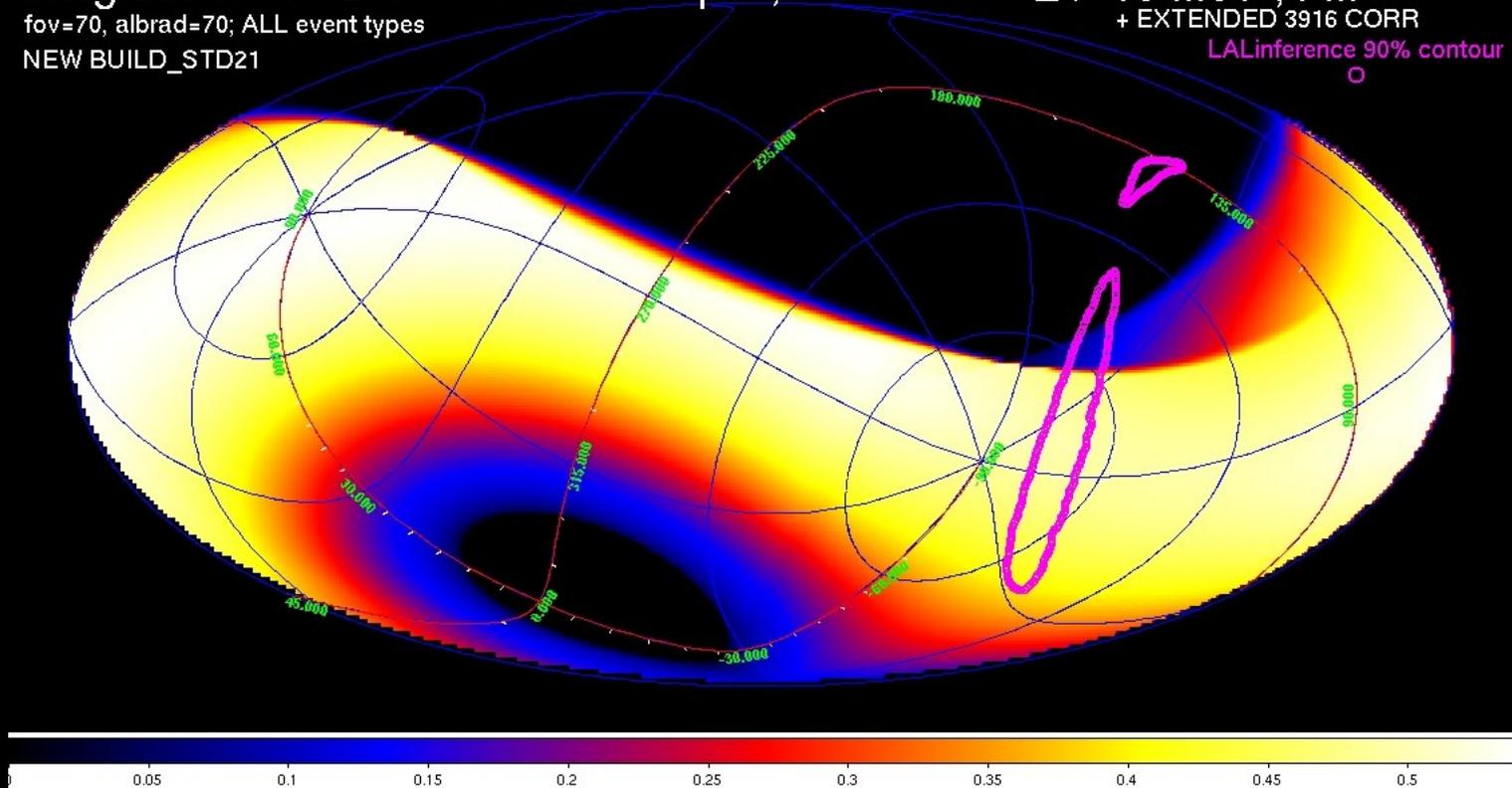
fov=70, albrad=70; ALL event types

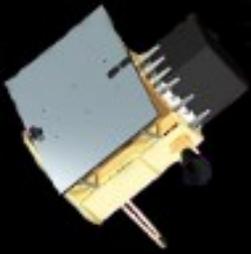
NEW BUILD_STD21

E > 10 MeV ; FM

+ EXTENDED 3916 CORR

LALInference 90% contour





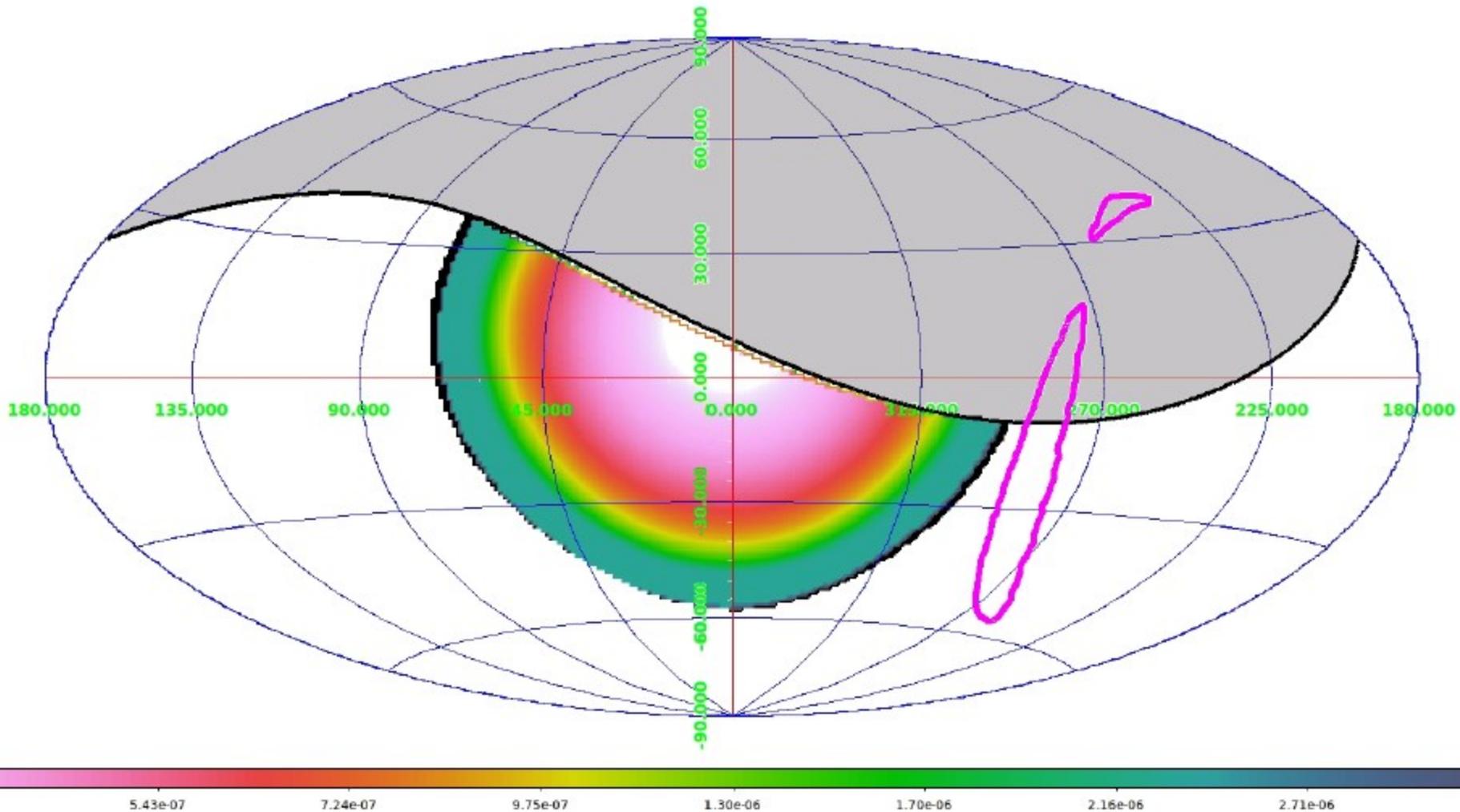
AGILE

Science Data Center



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

just missed it (-2 / +2 sec)



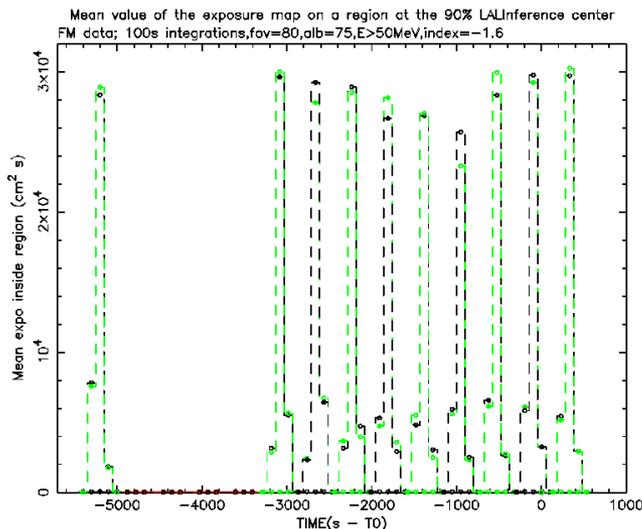
Central LIGO contour exposure scan: from $T_0 - 300s$ to $T_0 + 500s$

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

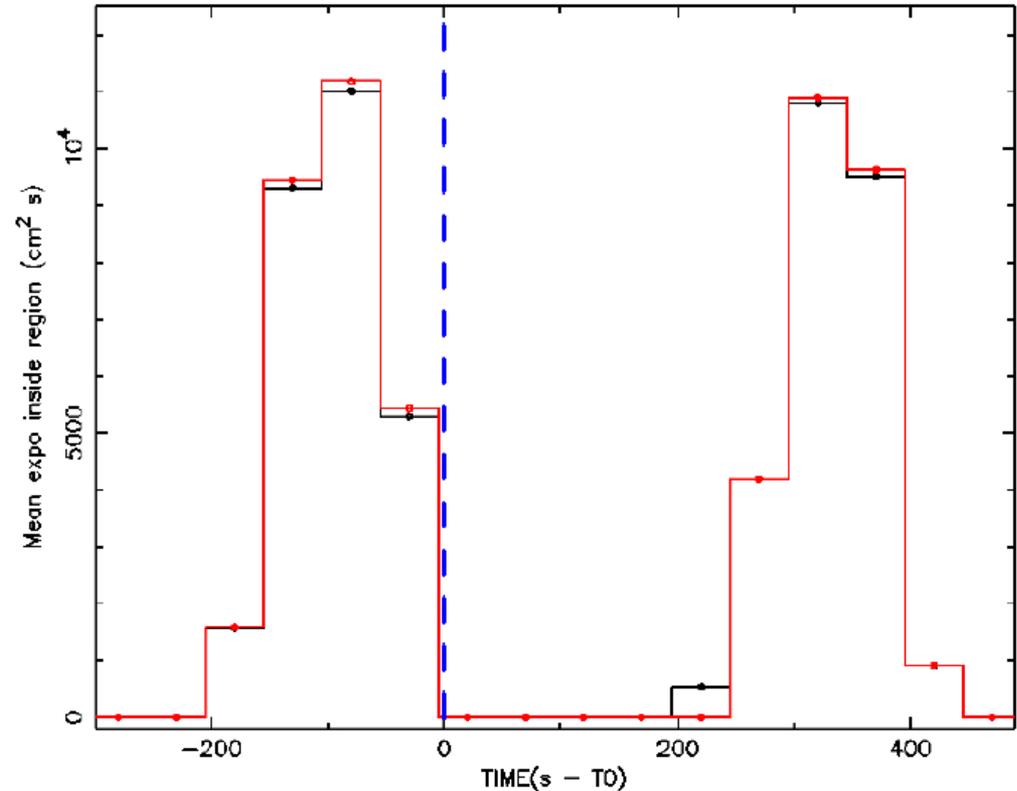
100s exposure scan

65% of LIGO contour

covered $\sim 10-60s$ before T_0



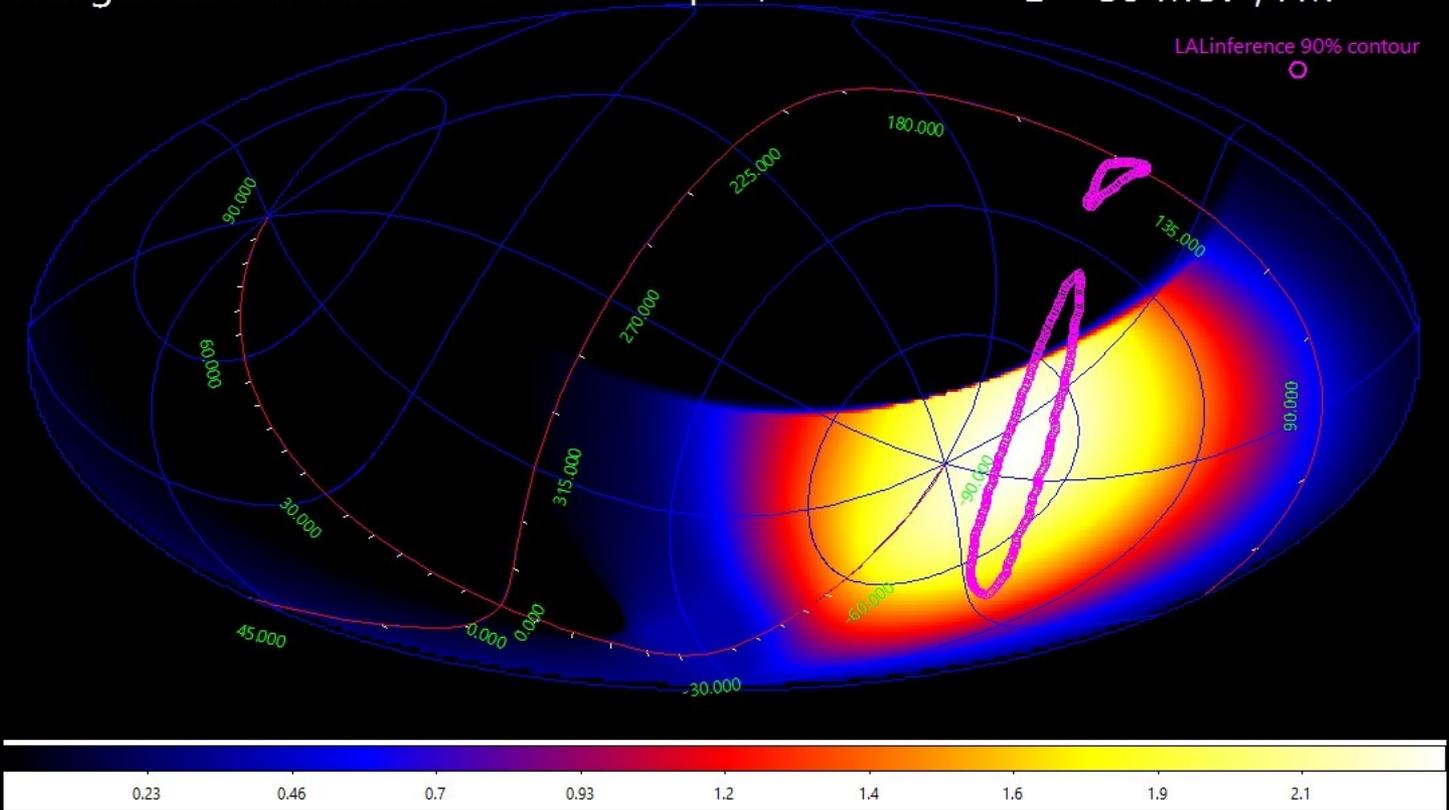
Mean value of the exposure map in region at the 90% LALInference contour center



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

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

$E > 50$ MeV ; FM

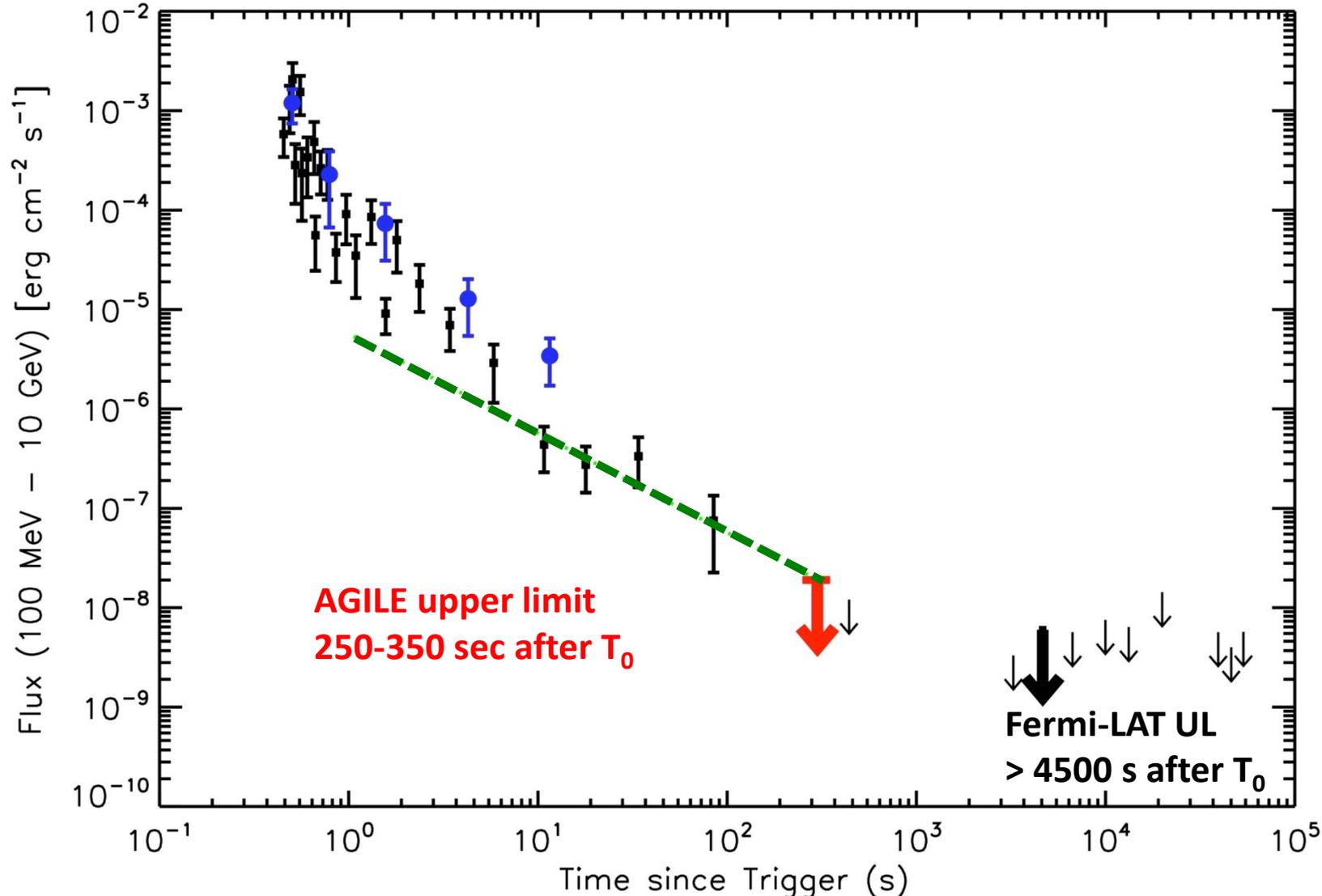


2-sigma upper limit ($E > 50$ MeV) = $1.9 \times 10^{-8} \text{ erg cm}^{-2} \text{ s}^{-1}$

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

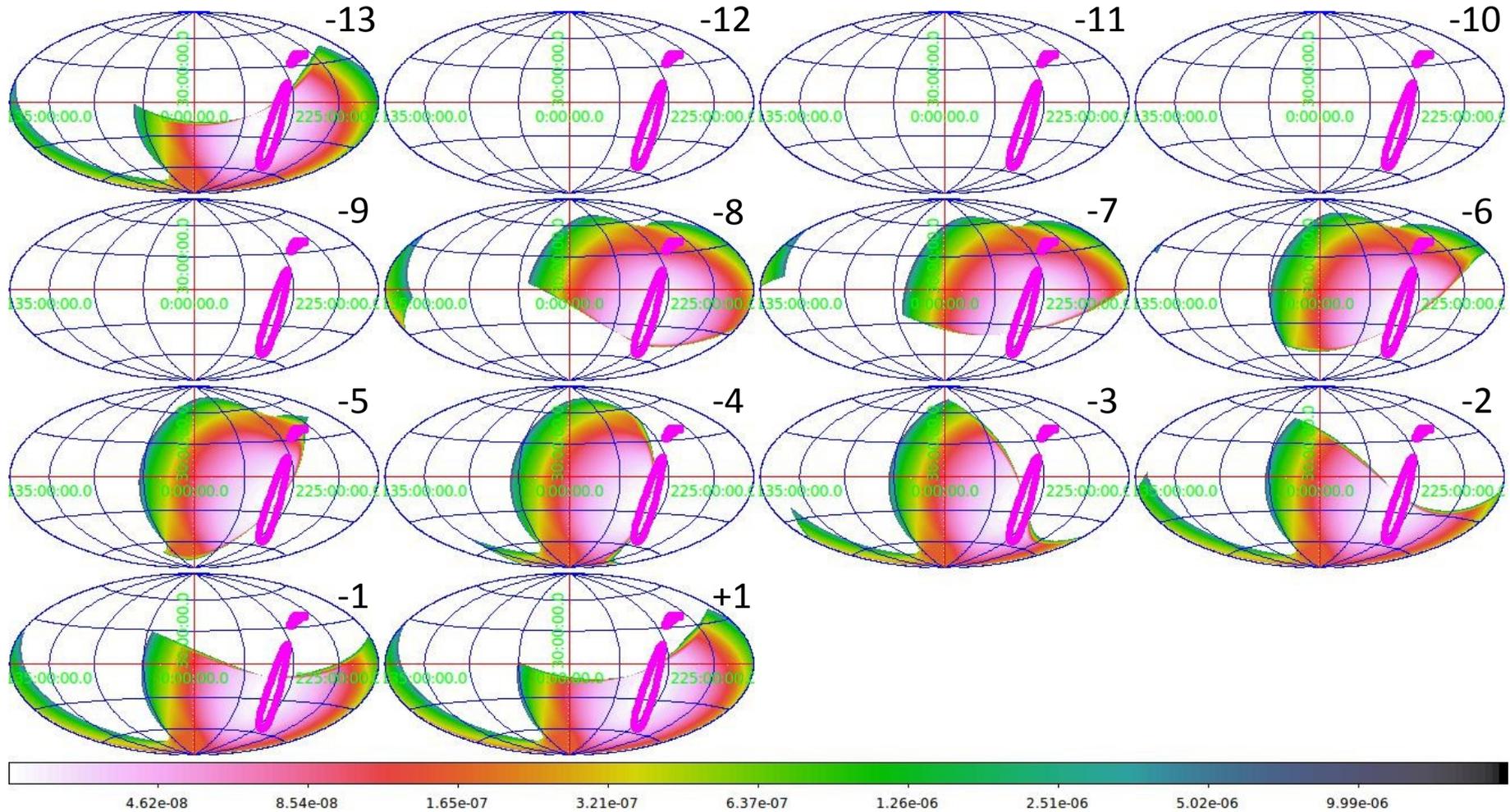


- precursor search

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 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**

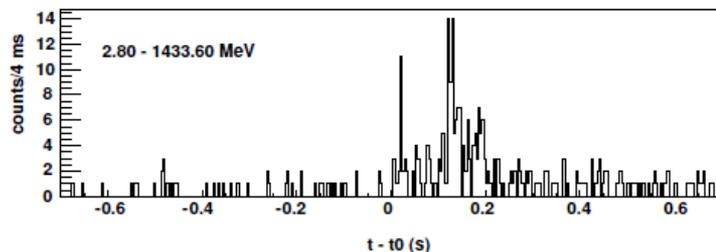
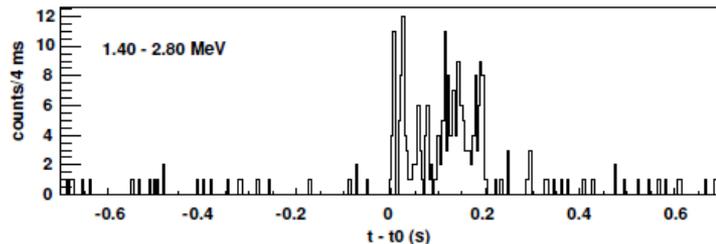
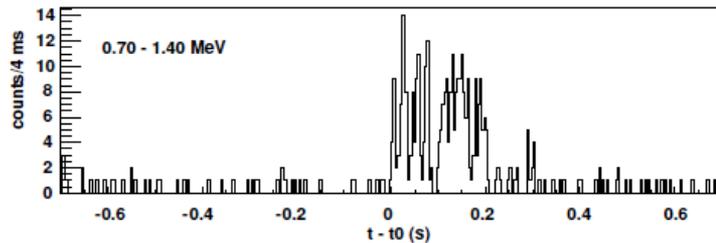
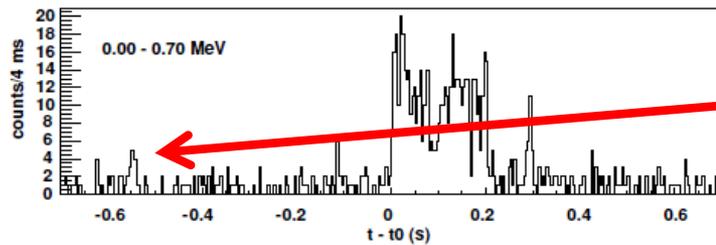
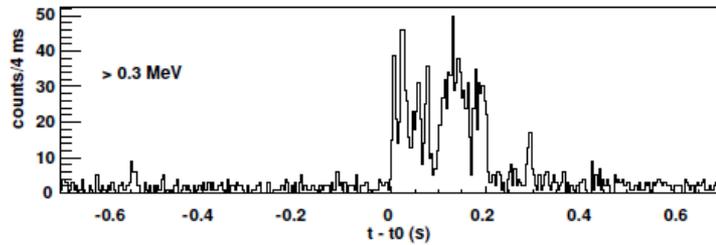
Lesson learned: we need

- **complete data coverage, ~ 100% efficiency**
- **orbit-by-orbit transmission (14 orbits/days)**
(not only no data losses!)
- **fast & automatic data processing in the GW error box region (a special pipeline linked to the GW alert),**
- **step 1: internal alert**
- **human intervention for quality check**
- **step 2: alert to the outside world (GCN or Atel)**

AGILE preparation in 2016

- 25-26 August, AGILE commissioning activity
- Review of the on-board performance and of the quicklook transient SW
- Improvement of MCAL burst detection
- Decision on TM allocation, GRID, MCAL, Super-A in full configuration (end of Oct.)
- Tests (November 2016)
- December 2016: start LIGO O2

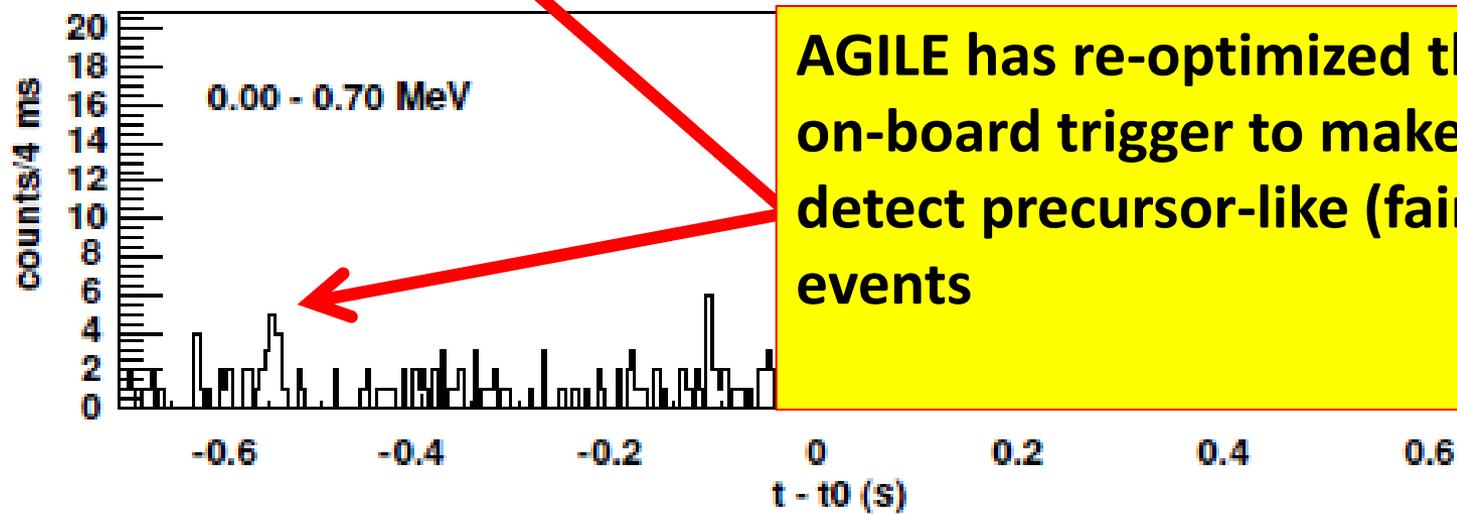
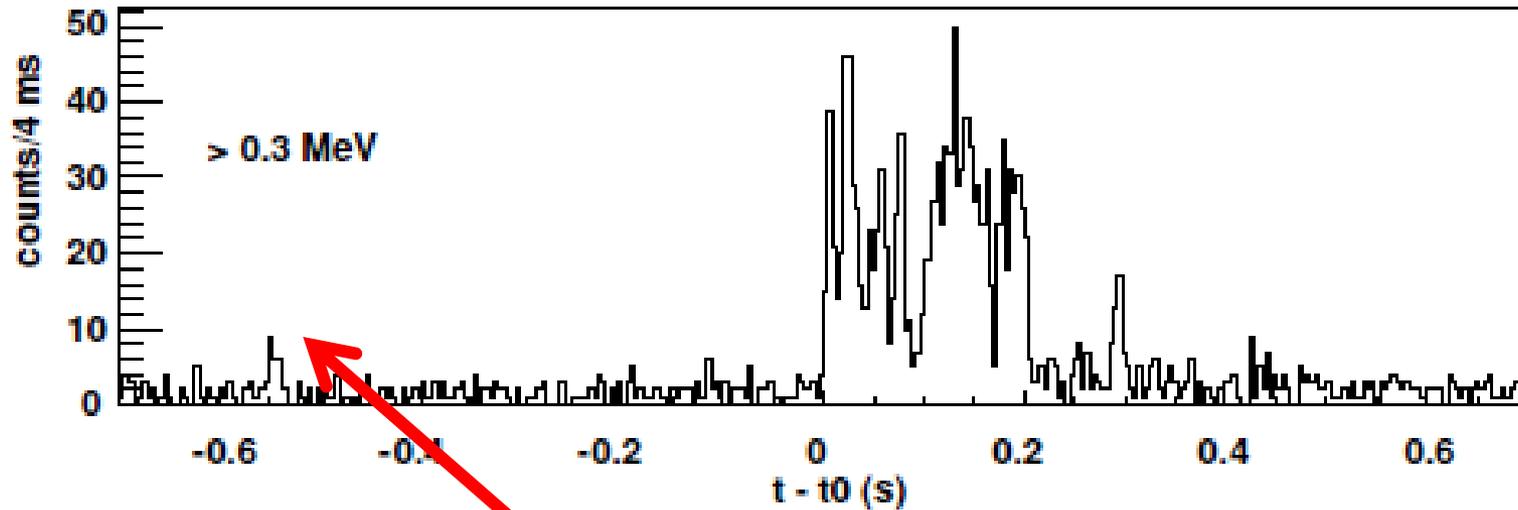
AGILE-MCAL GRB090510 light curve



GRB090510 light curve as detected by AGILE-MCAL (4ms bin), Giuliani + 2010
->15ms soft precursor at $T=T_0 - 0.55s$ ($E < 0.7MeV$)

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

AGILE-MCAL GRB090510 light curve



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

bright perspectives for AGILE

- **LIGO-VIRGO MoU with AGILE signed in November 2016 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.**

operational improvements (mid-2016)

- **increase the orbit downlink up to the maximum of 14 downlinks/day (ASI, Malindi)**
- **processing delay up to 20min-2 hours**
- **implement automatic processing pipeline for GW alert ->AGW pipeline**
- **a dedicated team to fast GW follow-up**

AGILE-GW GROUP

**ACTIVE ROUND-THE-CLOCK,
24HR/DAY**

**LIGO-VIRGO NOTICES ()
& Circulars!**

AGILE GW GROUP:

- **QUICK RESPONSE TO GW EVENTS**
- **CHECK MCAL, GRID, SUPER-AGILE**
- **FIRST ISSUING OF GCN CIRCULARS**
- **REFINED ANALYSIS**
- But applied ALSO to: standard transients, GRB!

AGILE-GW pipeline

On LIGO-VIRGO NOTICES:

On Public GCN ->Swift , Fermi

- Automatic processing & manual analysis AGW FA personnel
- twin ASDC machine for manual analysis, and in the future also automatic processing

Other Notices

Instrument Name	Notice Time (UTC)	Trigger Time (UTC)	Trigger ID	Seqnum	Pages
Fermi-GBM	2017-03-28T13:25:22	2017-03-27T22:43:54.800	512347439	1	Prompt analysis results Full analysis results
ICECUBE	2017-03-22T14:57:00	2017-03-21T07:32:20.000	80305071	1	Prompt analysis results Full analysis results
Fermi-GBM	2017-01-15T17:49:39	2017-01-15T17:49:14.030	506195359	0	Prompt analysis results Full analysis results
Fermi-GBM	2017-01-15T15:53:10	2017-01-15T15:52:36.930	506188361	1	Prompt analysis results Full analysis results
Fermi-GBM	2017-01-14T22:01:43	2017-01-14T22:01:09.500	506124074	1	Prompt analysis results Full analysis results
Fermi-GBM	2017-01-14T19:59:47	2017-01-14T19:59:12.490	506116757	1	Prompt analysis results Full analysis results
Fermi-GBM	2017-01-13T10:04:37	2017-01-13T10:04:10.110	505994655	0	Prompt analysis results Full analysis results

Recent GCN CIRCULARS

Numero	Data	Primo Autore	Titolo
20545	27/01/17	A. Ursi	GRB 170127C (Fermi/GBM trigger 507173752): AGILE analysis
20525	25/01/17	Y. Evangelista	GRB 170115B : AGILE/SuperAGILE localization
20474	16/01/17	F. Verrecchia	GRB 170115B : AGILE detection

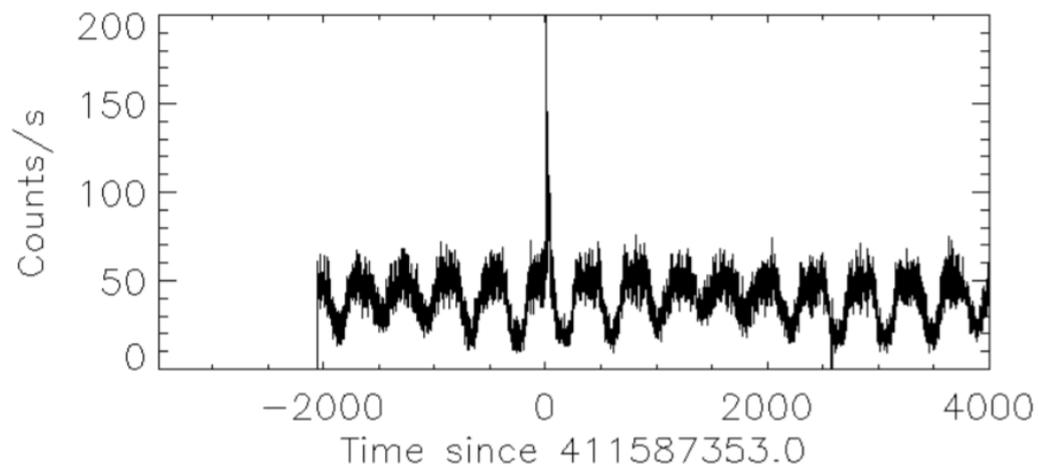
Recent results: non-GW!

GRB 170115B

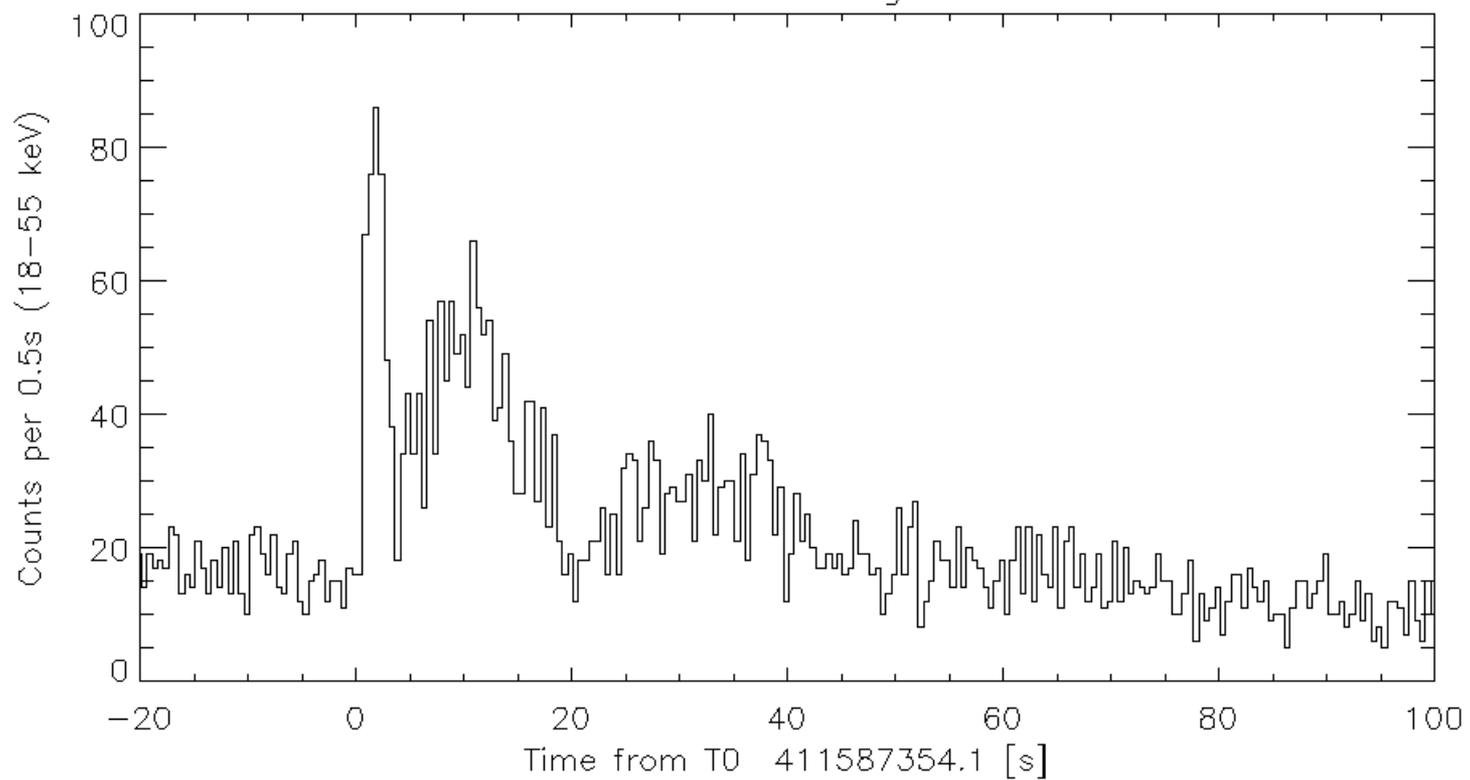
GRB 170115B

- **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!**
- **AGILE published two GCN Circulars on
MCAL/SA data analysis on Jan 16, at 23:00
and Jan 25**

20 keV - 60 keV LIGHT CURVE



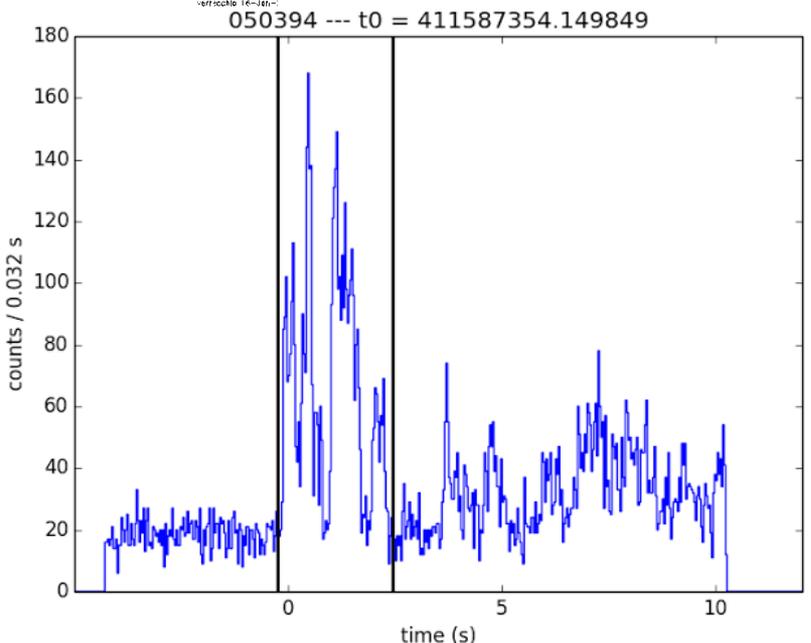
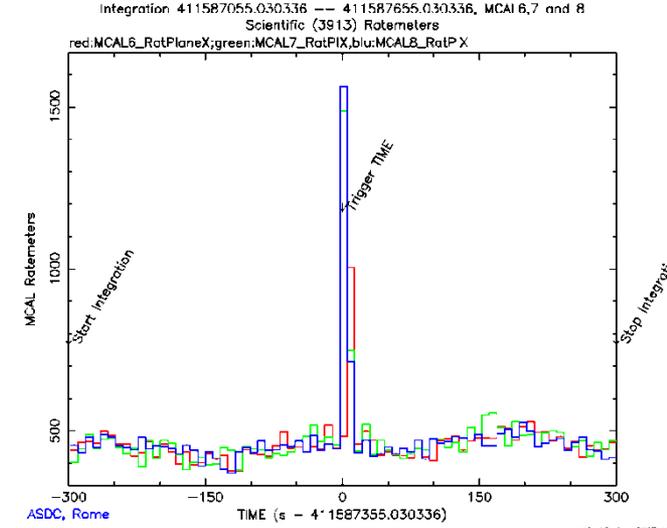
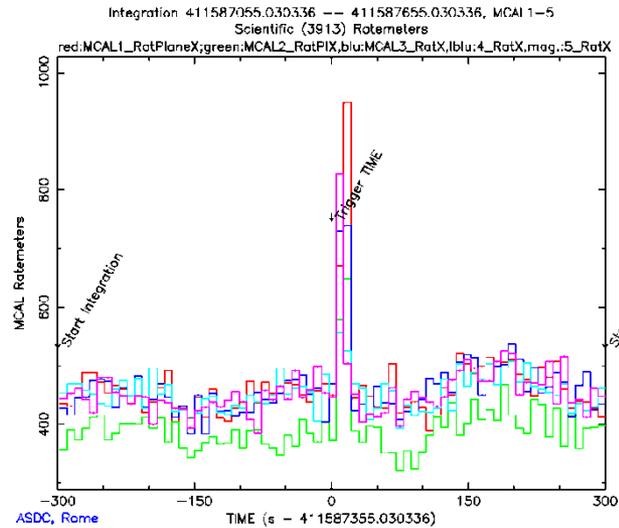
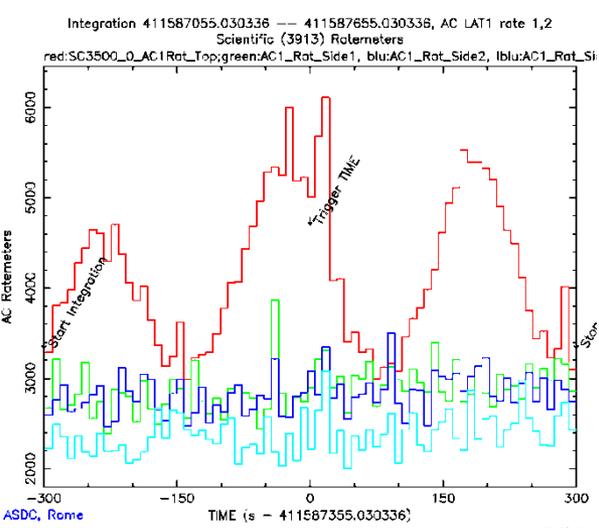
GRB170115B SA Light Curve



First reaction: Scientific Ratemeters & MCAL coverage

- AC, MCAL and GRID «ST-only» scientific ratemeters: integration T0 +/- 300s

=>evident BRIGHT peak in MCAL plots!

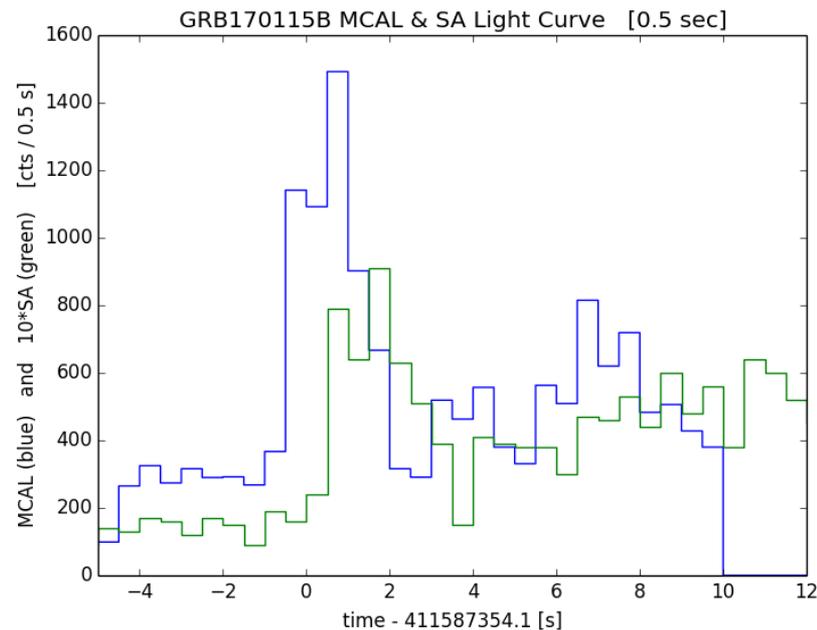
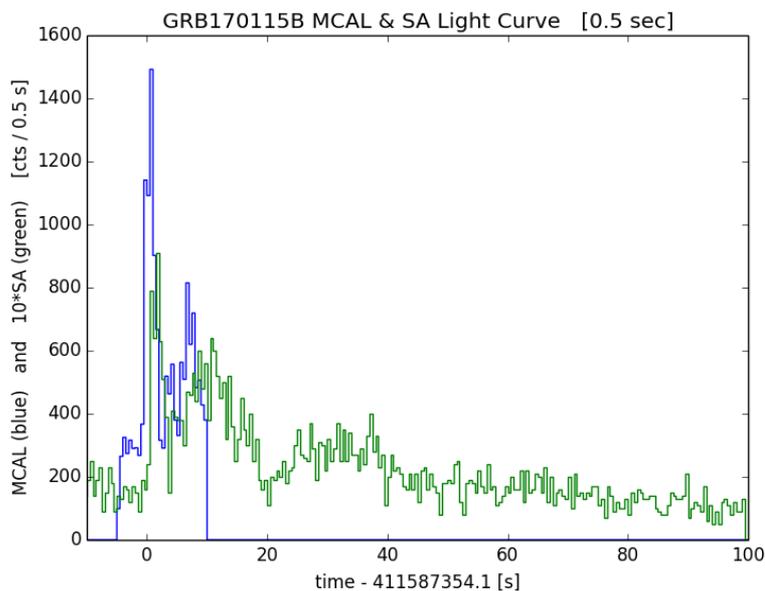
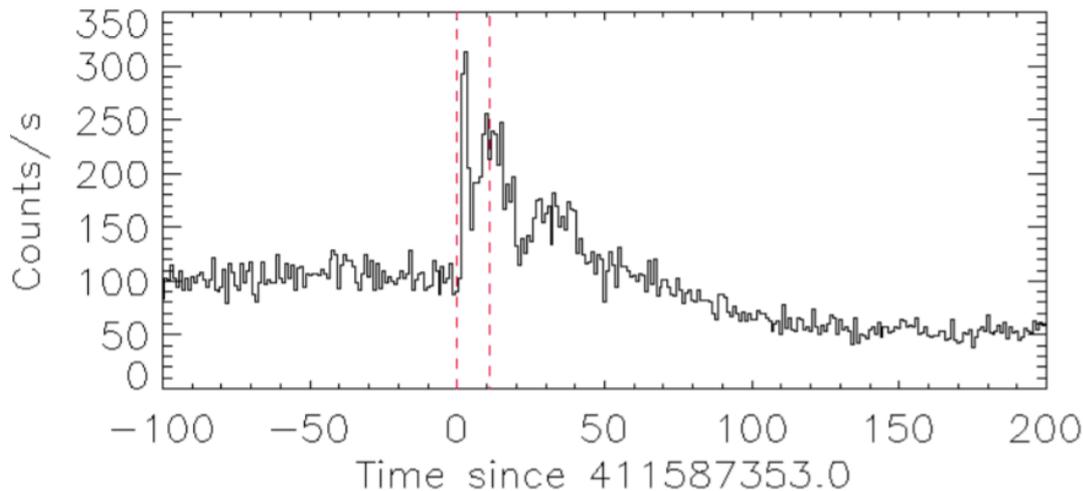


<- MCAL high resolution
(photon-by-photon data)
light curve with the “main
GRB active phase”, with
three peaks;

Super-Agile LC compared with MCAL!

- Super-Agile data covered the burst and the preliminary light curve in T0-20s; T0+100s was compared with the MCAL one which was truncated at T0+10s

17 keV - 60 keV LIGHT CURVE



MCAL high resolution light curve compared with SA 0.5s bin LC: in SA is evident the longer duration of the event with respect to the MCAL trigger 10s acquisition window

GCN 20474: GRB 170115B – AGILE GRID, MCAL & Super-A

TITLE: GCN CIRCULAR

NUMBER: 20474

SUBJECT: GRB 170115B: AGILE detection

DATE: 17/01/16 22:48:39 GMT

FROM: Francesco Verrecchia at ASDC <francesco.verrecchia@asdc.asi.it>

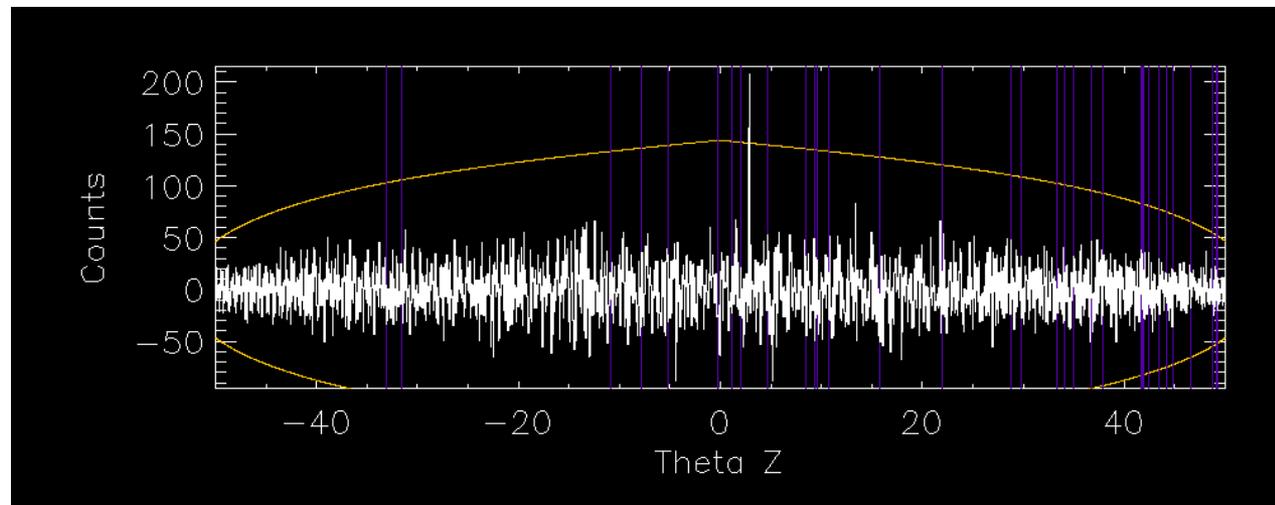
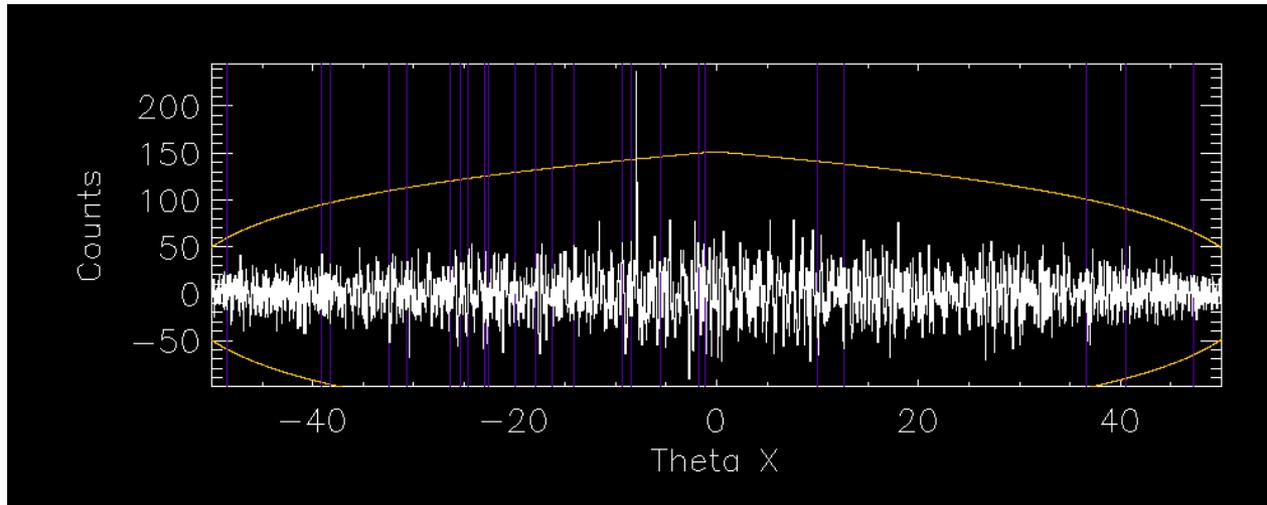
F. Verrecchia (ASDC and INAF/OAR), A. Ursi (INAF/IAPS), F. Lucarelli (ASDC and INAF/OAR), F. Longo (Univ. Trieste and INFN Trieste), M. Tavani (INAF/IAPS, and Univ. Roma Tor Vergata) report:

AGILE detected the long GRB 170115B, reported by Fermi-GBM (Hamburg et al. GCN #20463) and Fermi-LAT (McEnery et al. GCN #20464), at favourable off-axis angles between 0 and 30 deg. The AGILE-GRID detected the burst at about 4-sigma above 30 MeV with an extended gamma-ray emission lasting about 60 sec.

The AGILE MiniCaLorimeter (MCAL), sensitive in the energy range from 400 keV to 100 MeV, detected this burst that triggered the on-board sub-millisecond timescale logic. The MCAL light curve shows multiple peaks, from T0 until the end of the acquisition at T0 + 10.5 s. Three main peaks are evident during the first 2.5 sec following T0. During this time interval, the total number of counts is ~5500 for a background rate of 580 counts/s.

This measurement was obtained with AGILE observing a large portion of the sky in spinning mode.

GRB 170115B: SA localisation!



GRB 170115B: SA localisation!

TITLE: GCN CIRCULAR

NUMBER: 20525

SUBJECT: GRB 170115B: AGILE/SuperAGILE localisation

DATE: 17/01/25 15:51:18 GMT

FROM: Ettore Del Monte at IASF/INAF <sa.grb@iaps.inaf.it>

Y. Evangelista, L. Pacciani, E. Del Monte and I. Donnarumma (INAF/IAPS), A. Trois (INAF/OAC) on behalf of the AGILE Team, report:

SuperAGILE localised the long-duration GRB 170115B (Hamburg et al., GCN 20463; McEney et al., GCN 20464; Sharma et al., GCN 20466; Xiao et al., GCN 20469; Verrecchia et al., GCN 20474; Frederiks et al., GCN 20476, Shimizu et al., GCN 20483) on 15 January 2017, at 17:49:14 UT.

The event had a duration of about 50.0 s in the 18-60 keV energy range, with a multi-peaked structure. The burst position was reconstructed as:

RA(J2000): 189.011 deg (12h 36m 02.64s)

DEC(J2000): -46.796 deg (-46d 47' 45.58")

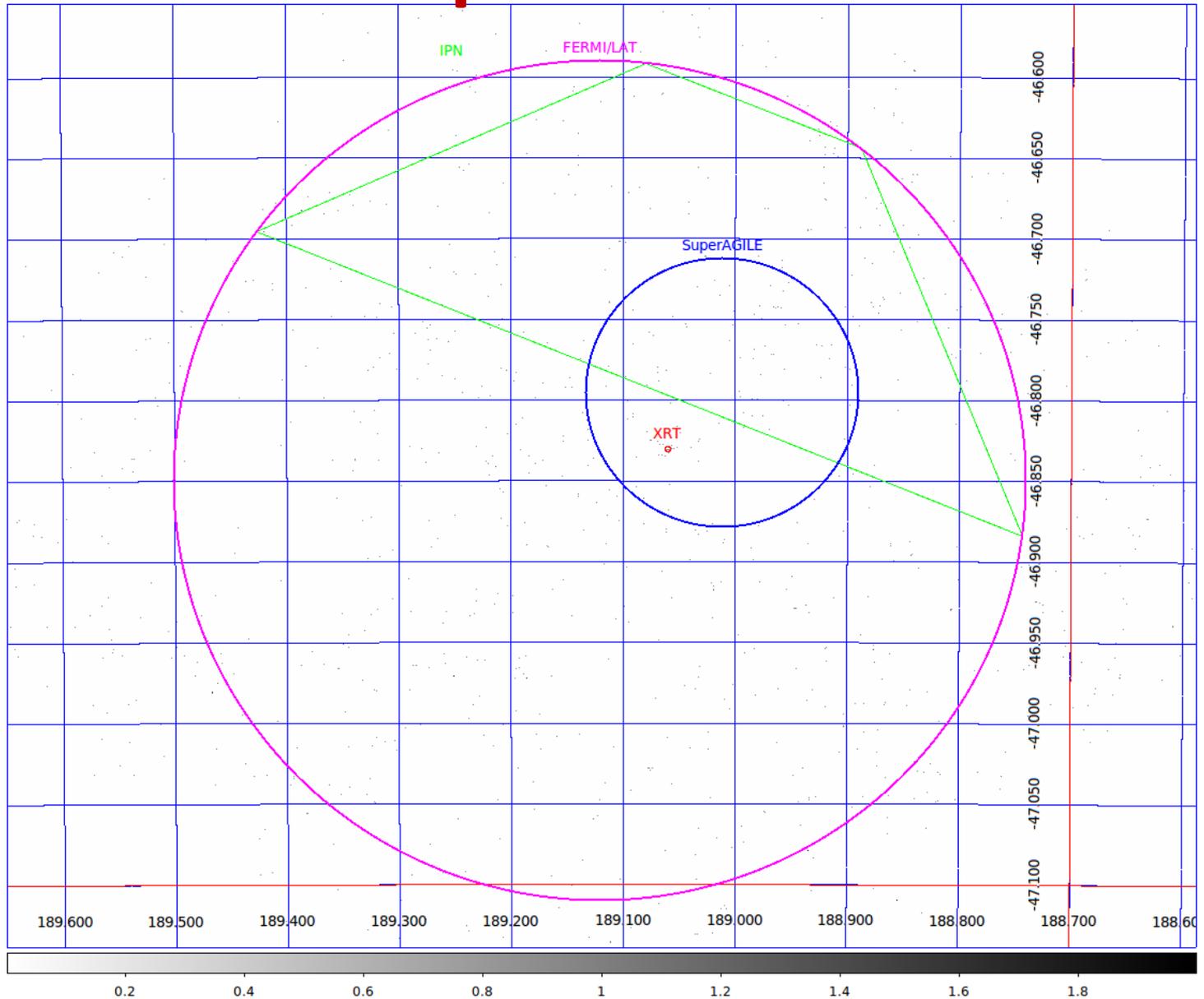
with an uncertainty of 5' (radius). The uncertainty accounts for both the statistical and systematic errors.

The SuperAGILE error box is completely contained in the FERMI-LAT error box (McEney et al., GCN 20464) and partially intersects the IPN annulus (Hurley et al., GCN 20475). The Swift-XRT afterglow candidate (D'Avanzo et al., GNC 20477) is also contained in the SuperAGILE error box.

Due to telemetry downlink restrictions, the SuperAGILE experiment has been kept on but with no telemetry download since late 2012. The full telemetry link for the AGILE mission has now been restored and the data of SuperAGILE are again routinely downloaded.

This message may be cited.

..need for Super-AGILE detection!

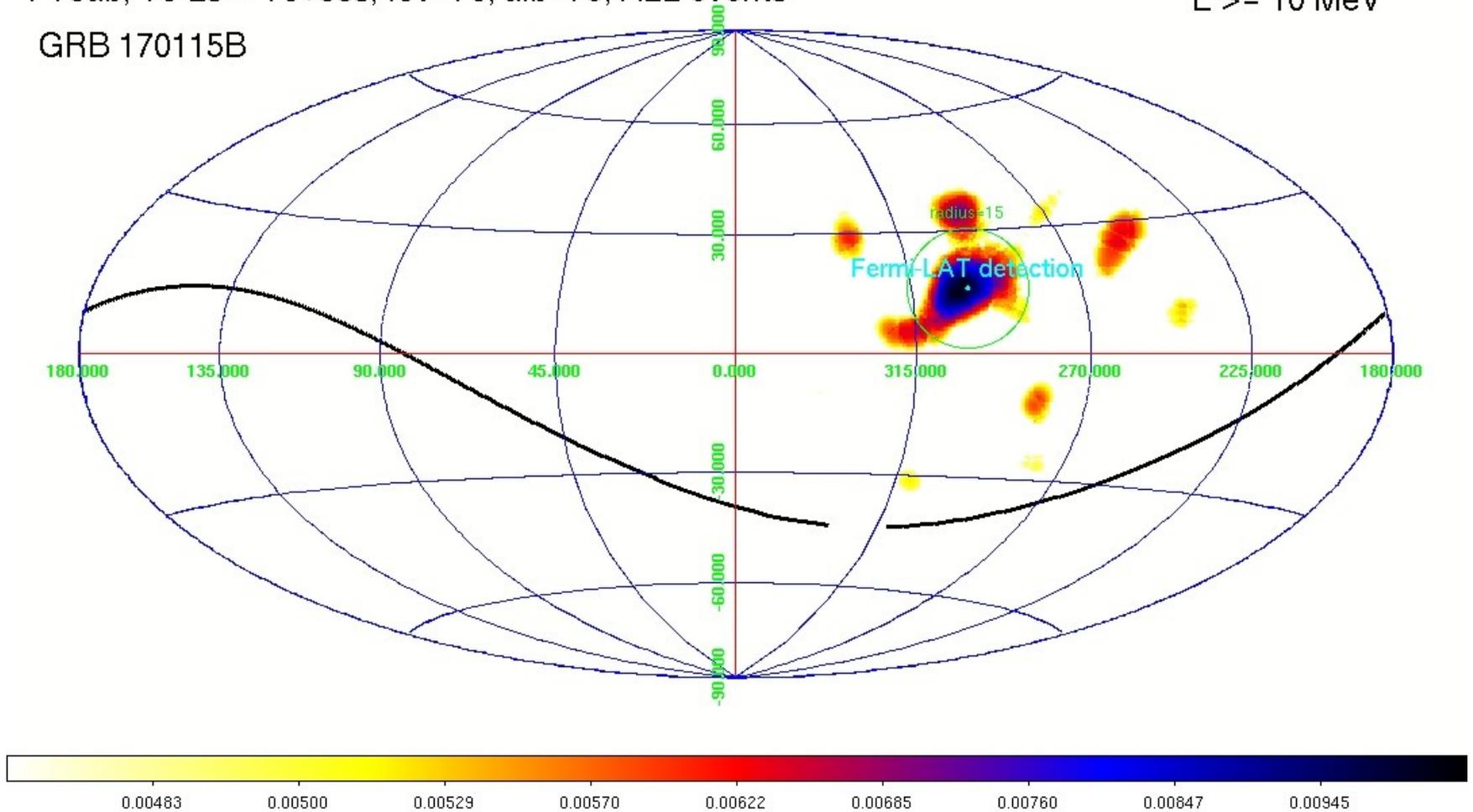


A low-significance detection in GRID

FT3ab, T0-2s -- T0+38s, fov=70, alb=75, ALL events

E \geq 10 MeV

GRB 170115B



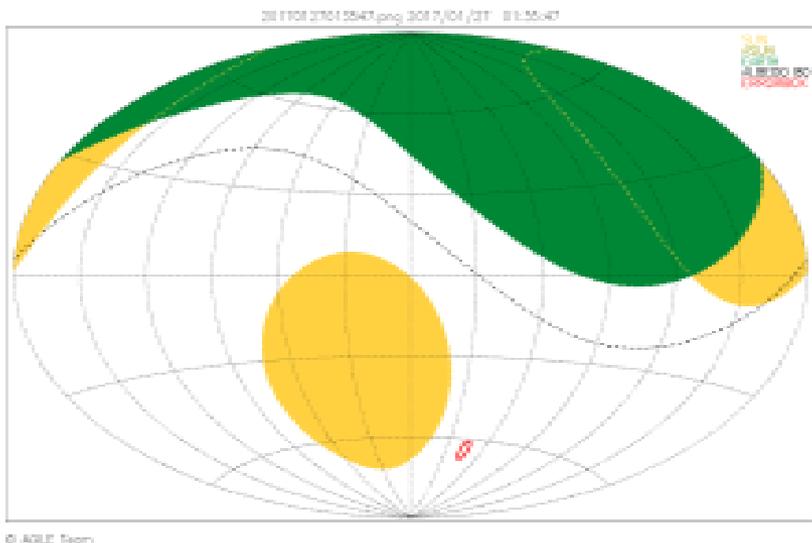
the short GRB 170127C

- **T0 = 01:35:47.79 UT, 27 January, 2017**

also by Fermi GBM (two GCN Notices + one of LAT), with on-ground location, (R.A., Dec = 332.39, -70.96, error radius= 4.96d).

- **In real-time: three notifications triggered GW pipeline**
- **Check automatic results: after some checks, automatic visibility with localisation good => SHORT burst! Duration 0.1 sec.**
- **Published a GCN circular on MCAL/SA data analysis on Jan 5, at 22:00**

First reaction: Visibility, Scientific Ratemet. & MCAL coverage

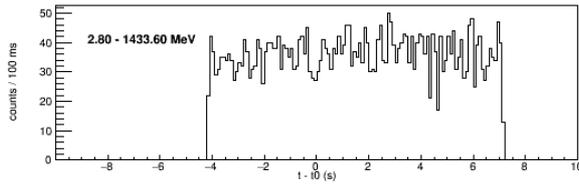
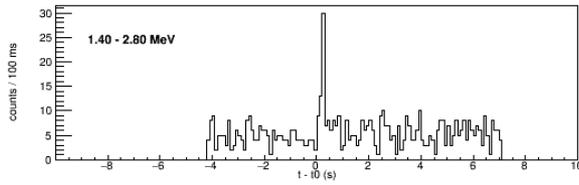
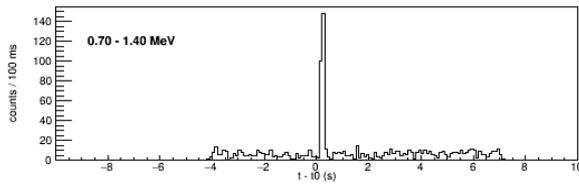
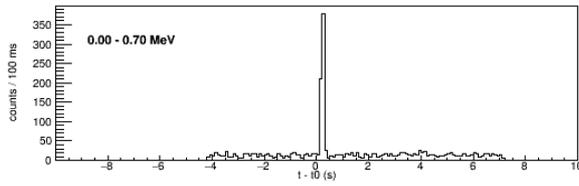
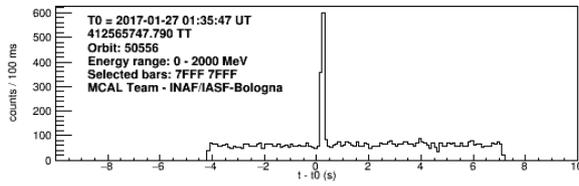


- Automatic GW pipeline: FoV prevision with GBM localisation contour than also the LAT one

Manual check of real data FoV

- MCAL trigger data automatic light curve: Bright PEAK!

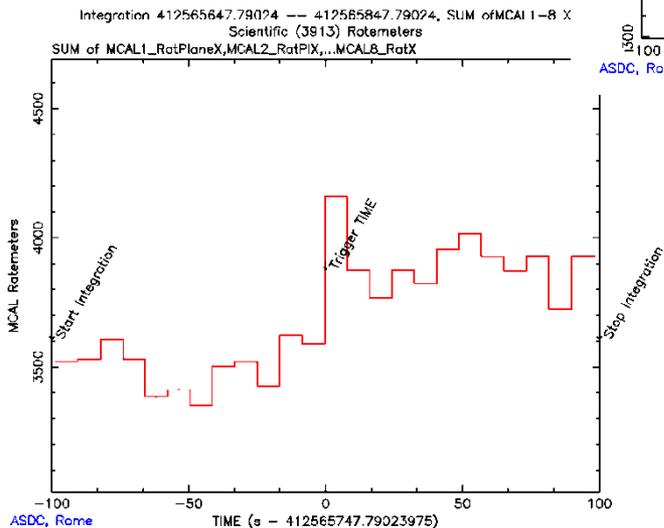
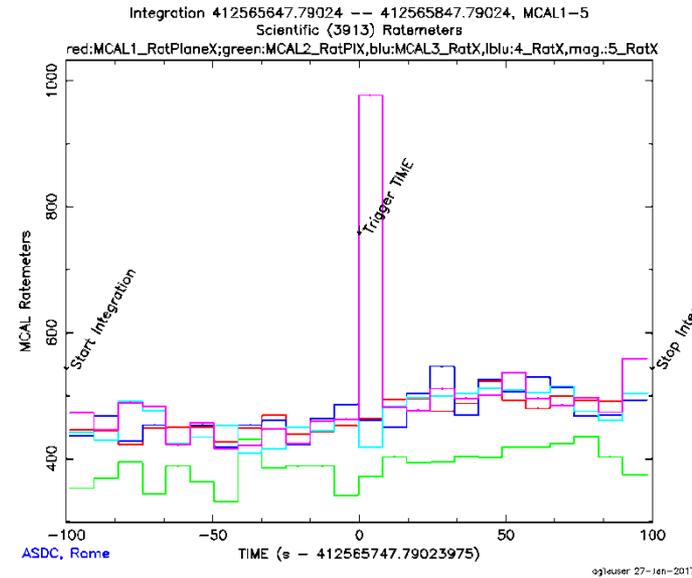
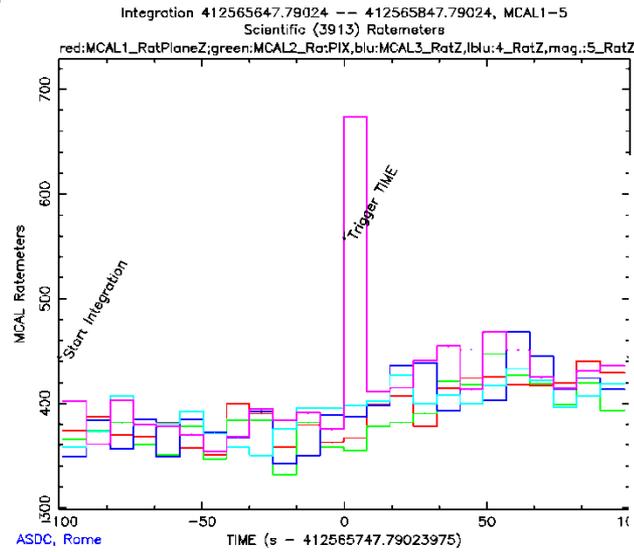
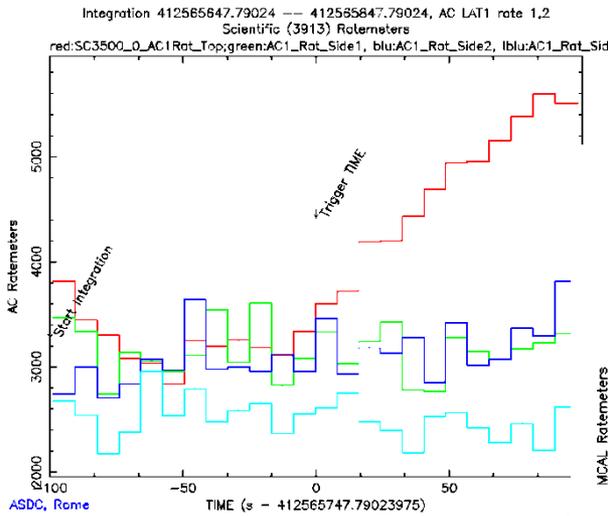
MCAL detection of the short GRB 170127C



First reaction: Scientific Ratemeters

- AC, MCAL and GRID «ST-only» scientific ratemeters: integration T0 +/- 100s

Manually generated => EVIDENT PEAK in MCAL!

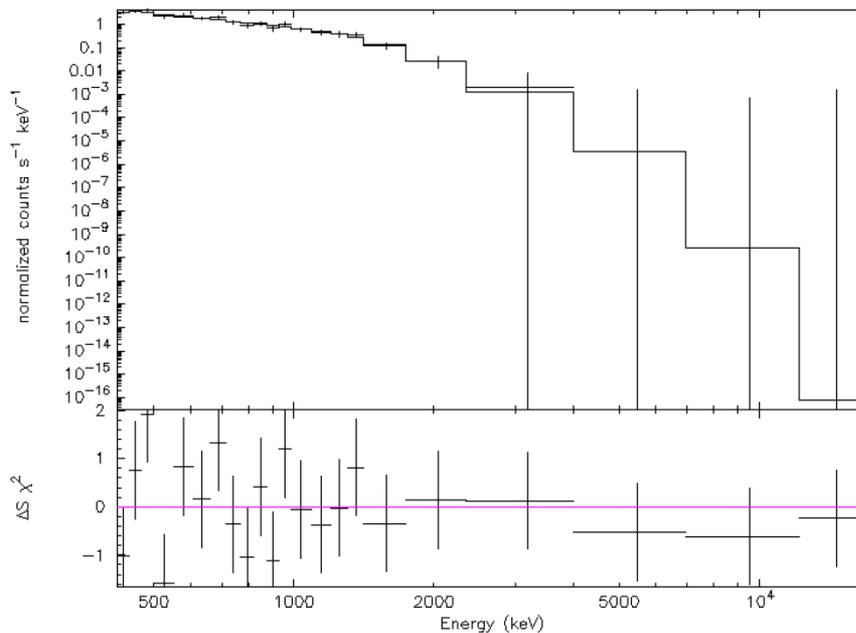
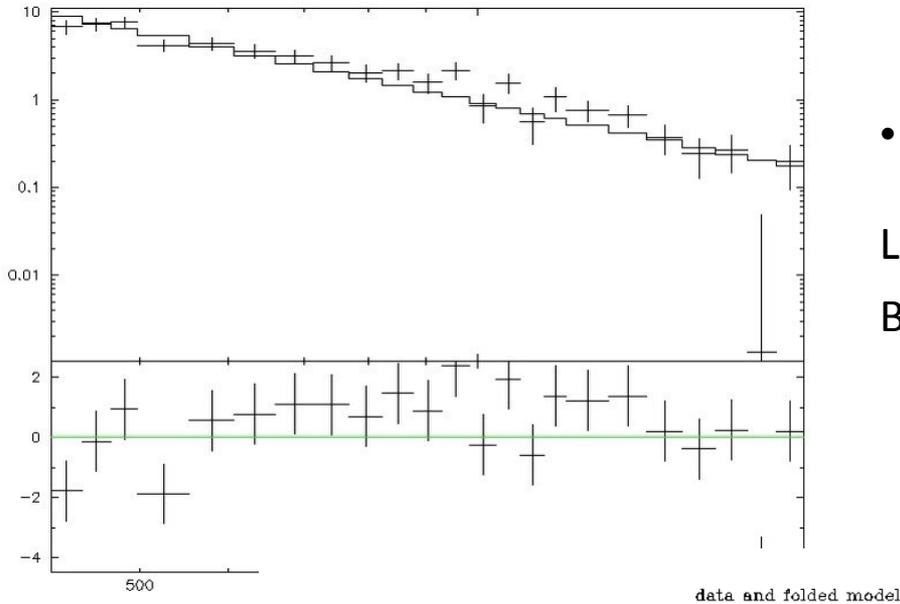


MCAL analysis: spectral fit

- MCAL high resolution spectral analysis on the GRB peak

Left: power law model

Best fit below: power law + exponential cut-off



<- MCAL high resolution spectrum on T0;T0+0.13s integration: energy range 0.5 - 20 MeV, power law with exponential cut-off at 1.63 MeV, with photon index -1.64 ± 0.19

GRB 170127C: MCAL&SA

TITLE: GCN CIRCULAR

NUMBER: 20545

SUBJECT: GRB 170127C (Fermi/GBM trigger 507173752): AGILE analysis

DATE: 17/01/27 17:15:24 GMT

FROM: Francesco Verrecchia at ASDC <francesco.verrecchia@asdc.asi.it>

A. Ursi (INAF/IAPS), P. Munar-Adrover (INAF/IAPS), F. Verrecchia (ASDC and INAF/OAR), M. Tavani (INAF/IAPS, and Univ. Roma Tor Vergata), Y. Evangelista (INAF/IAPS), F. Lucarelli (ASDC and INAF/OAR), F. Fuschino (INAF/IASF-Bo), I. Donnarumma (INAF/IAPS), ..., report on behalf of the AGILE Team:

We performed an analysis of AGILE data of the GRB 170127C (Fermi/GBM trigger num 507173752; GCN #20543), which occurred at 2017-01-27 01:35:47.79 UTC.

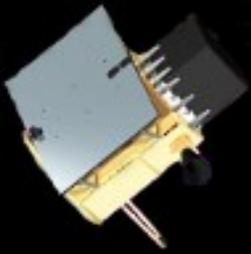
The Mini-CALorimeter (MCAL), sensitive in the energy range from 400 keV to 100 MeV, detected a short burst at $T_0 = 2017-01-27 01:35:47.9294$ UTC, that triggered both the on-board 16 ms and 64 ms timescale hardware logic system. The MCAL light curve shows a sharp single peak, that lasted about 0.13 s and released a total number of ~ 980 counts above 400 keV in the detector, above an average background rate of 590 counts/s.

The time-integrated spectrum measured between T_0 and $T_0+0.13$ s can be fit in the energy range 0.5 - 20 MeV with a power law with high-energy cut-off at 1.63 MeV, with photon index -1.64 ± 0.19 and reduced chi-squared 1.08 (18 d.o.f.). As observed by MCAL, the burst fluence in the same energy range and time interval is $1.20 \pm 0.01 e^{-6}$ erg cm^{-2} . All quoted errors are at 90% confidence levels.

SuperAGILE, sensitive in the energy range 18 to 60 keV, also clearly detected the burst with its ratemeters.

AGW Team (front line)

- A. Bulgarelli
- M. Cardillo
- F. Longo
- F. Lucarelli
- G. Minervini
- A. Morselli
- P. Munar
- G. Piano
- M. Pilia
- C. Pittori
- M. Tavani
- E. Striani
- A. Ursi
- F. Verrecchia



AGILE

Science Data Center

Thank you and
happy ...surfing
birthday AGILE!