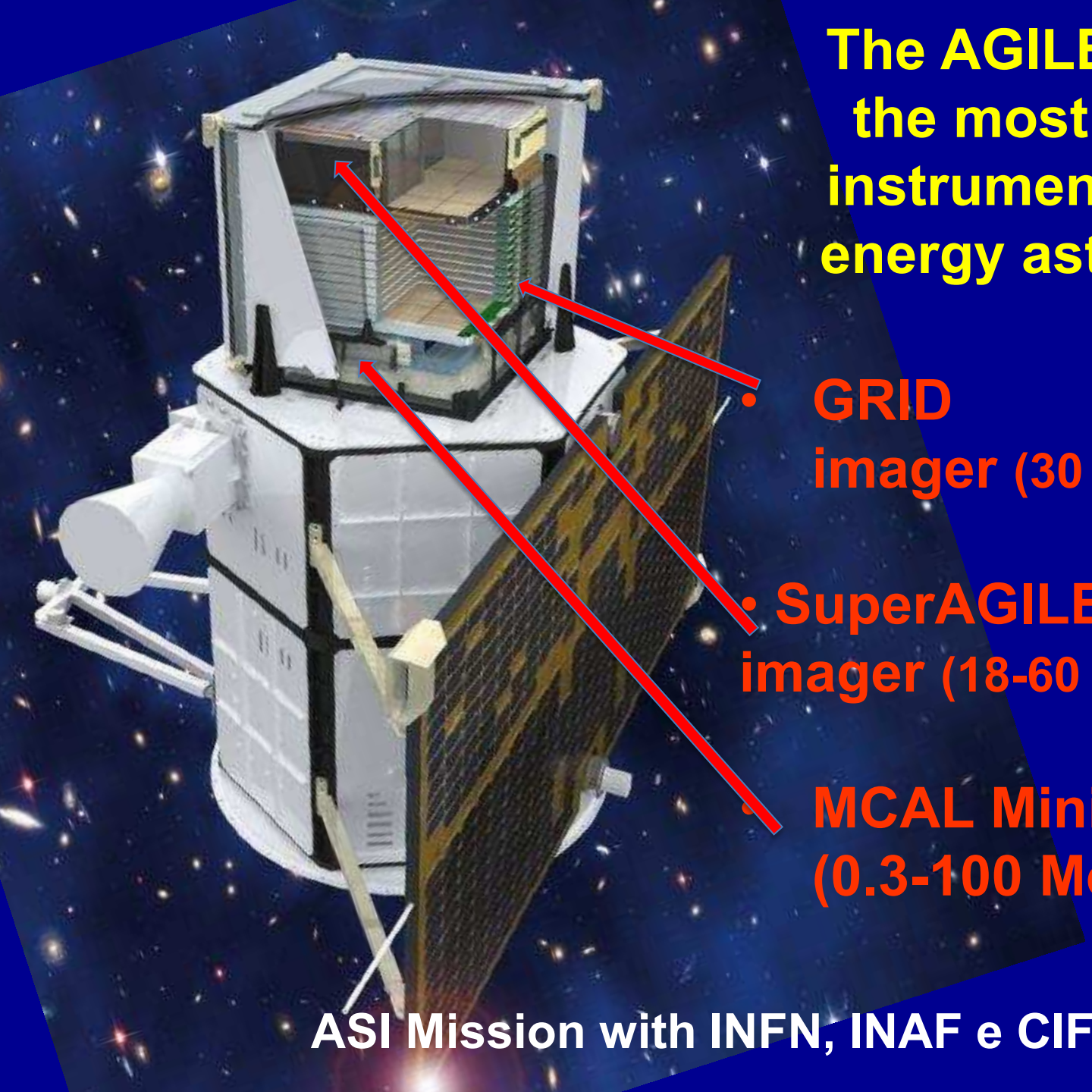
Status of AGILE
(and gravitational wave source search)

C. Pittori & M. Tavani

Vulcano, May 2016



The AGILE Payload: the most compact instrument for high-energy astrophysics

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

ASI Mission with INFN, INAF e CIFS participation

RECENT DETECTIONS

AGILE confirms the enhanced gamma-ray emission from Cygnus X-3
ATel # 8597

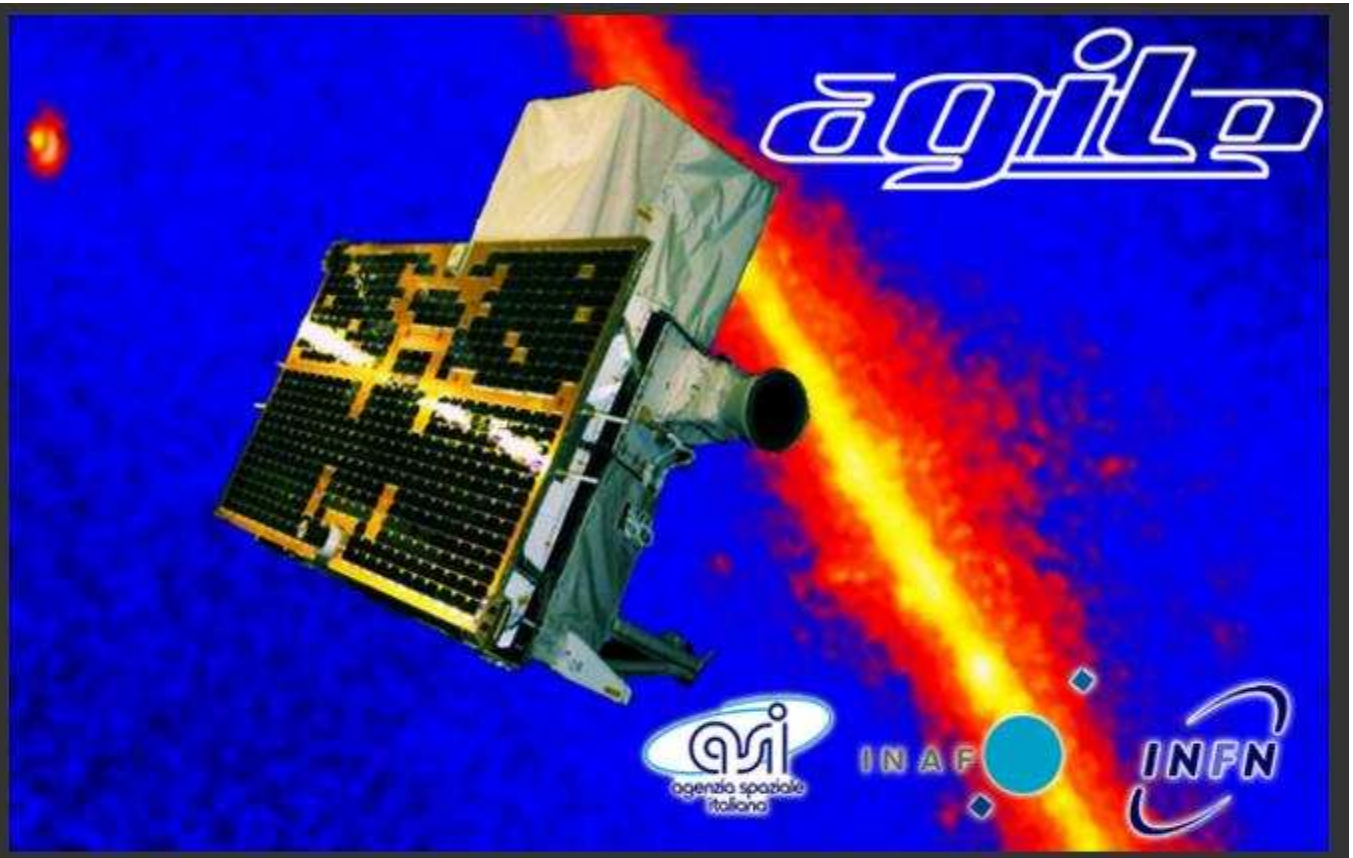
AGILE detection of renewed gamma-ray activity from the blazar PKS 1502+106
ATel # 8593

AGILE detection of increased gamma-ray emission from the FSRQ PKS 1313-333
ATel # 8536

AGILE detection of enhanced gamma-ray activity from the CTA 102 region
ATel # 8476

Increasing gamma-ray activity from the FSRQ 4C +40.25
ATel # 8344

Swift follow-up observations of the renewed gamma-ray activity of the quasar S5 0836+710 (4C 71.07) detected by AGILE
ATel # 8271



Home | AGILE Team | AGILE in ASI | AGILE Data Center | Contacts | AT reserved

Time elapsed since the AGILE launch on April 23, 2007 at 10:00 GMT

Days	Hours	Mins	Secs
3258	04	40	32

AGILE Launch

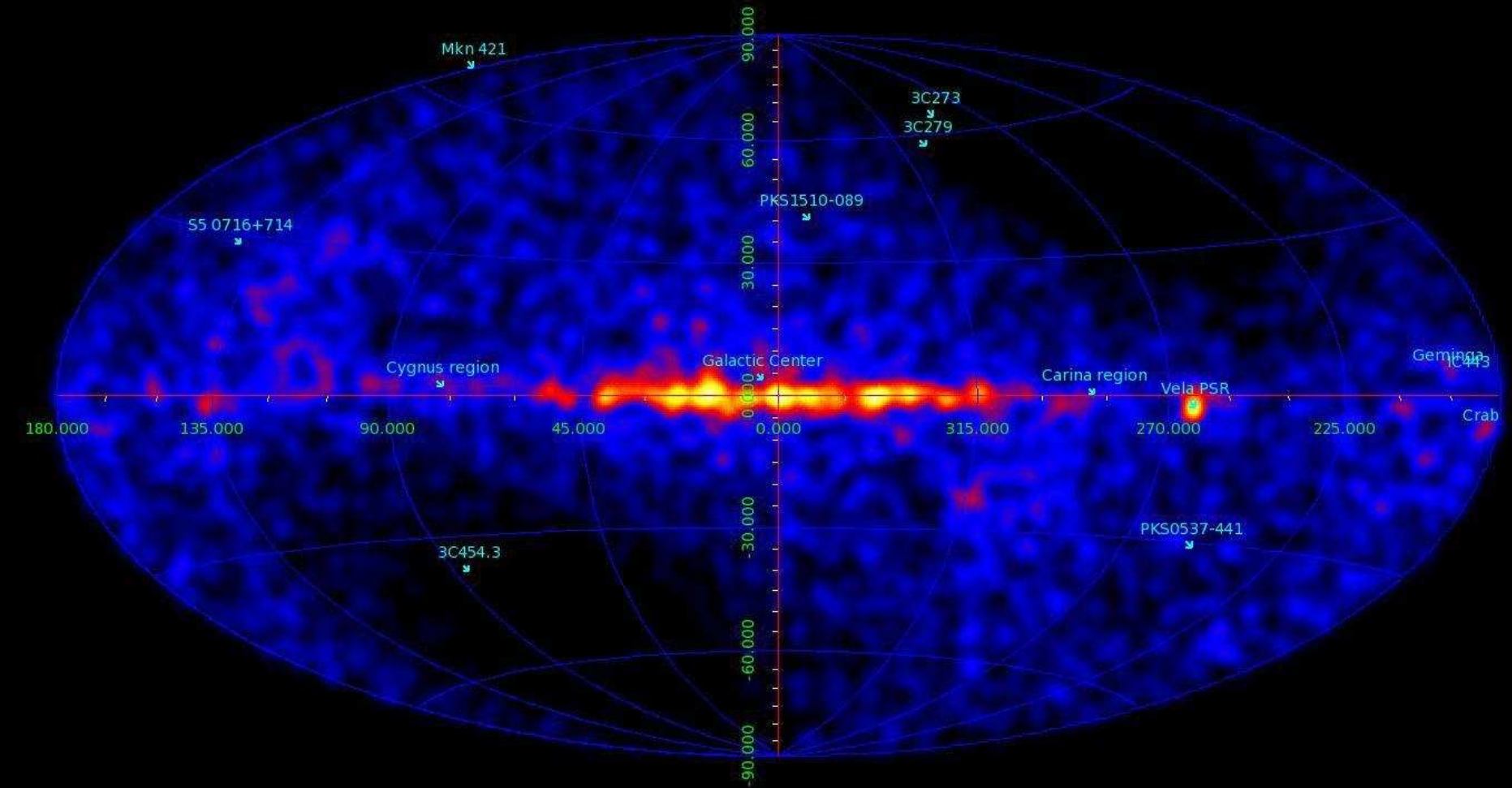
AGILE Principal Investigator and ASI Directors

Mission status, scientific activity

- **Nominal operations of the Payload**
- **AC, Tracker e MCAL fully functional**
- **Super-AGILE: ratemeters only (for TM limitation)**
- **7 orbit/day downlink, > 90% efficiency.**

- **Nominal gamma-ray astrophysics**
- **Terrestrial physics,**
  - **TGF (much improved efficiency, very interesting results)**

AGILE: gamma-ray sky, 8 March, 2016, 00:30 UT



- **APP (iPhone, Android)**

AGILEScience

- **AGILE completed its NINTH YEAR in orbit on April 23, 2016 !**

- **14th Science Workshop: June 20-21, 2016**

- **idea of a MEGA-Workshop for the 10th year in orbit.**

- **AGILE has the shortest reaction time to bright gamma-ray transients**
  - **blazars,**
  - **Galactic transients (recently Cyg X-3)**

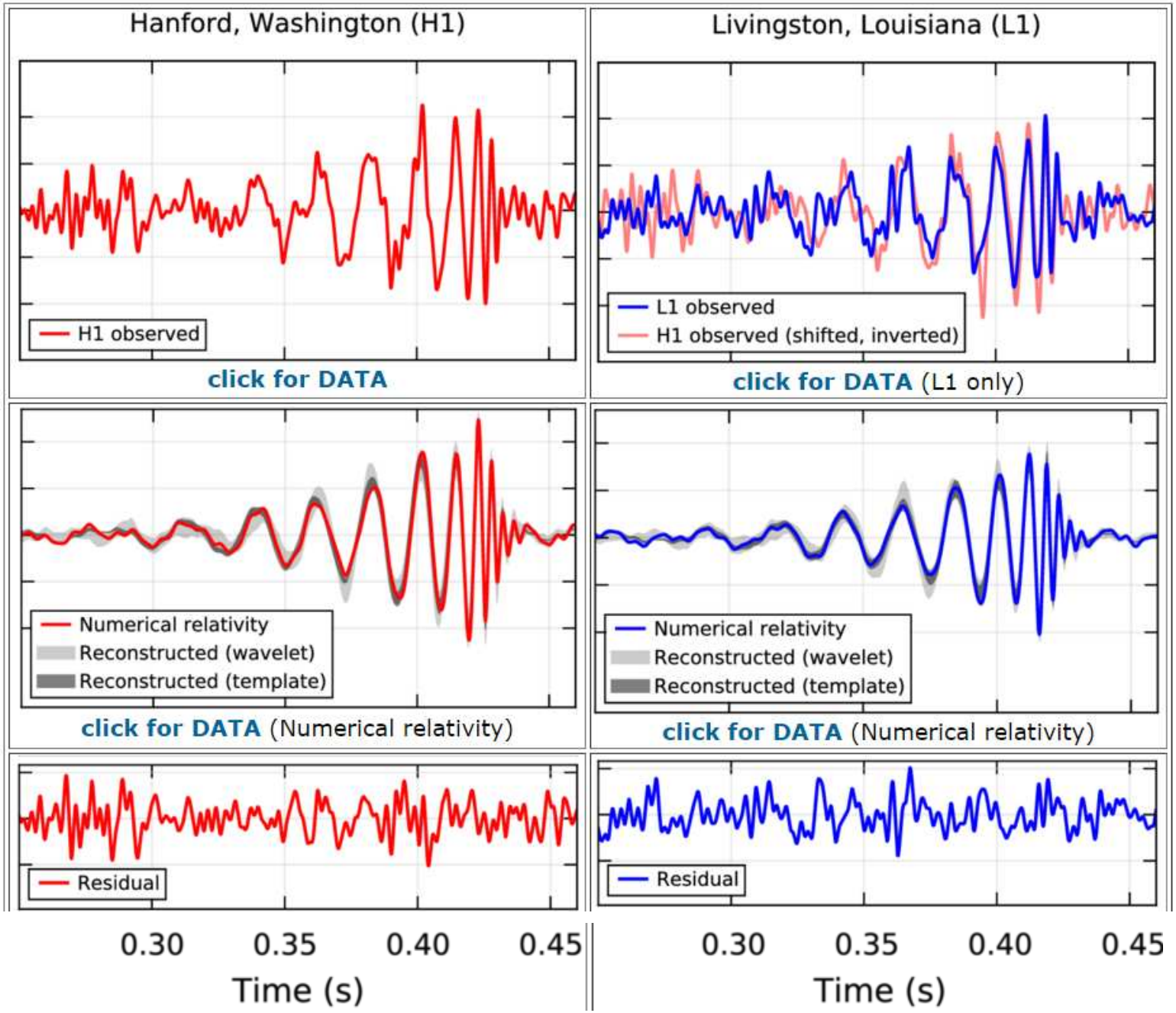
- **excellent for GW source searches**
  - **Large field of view (2.5 sr)**
  - **200 passes/day over more than 80% of the sky**

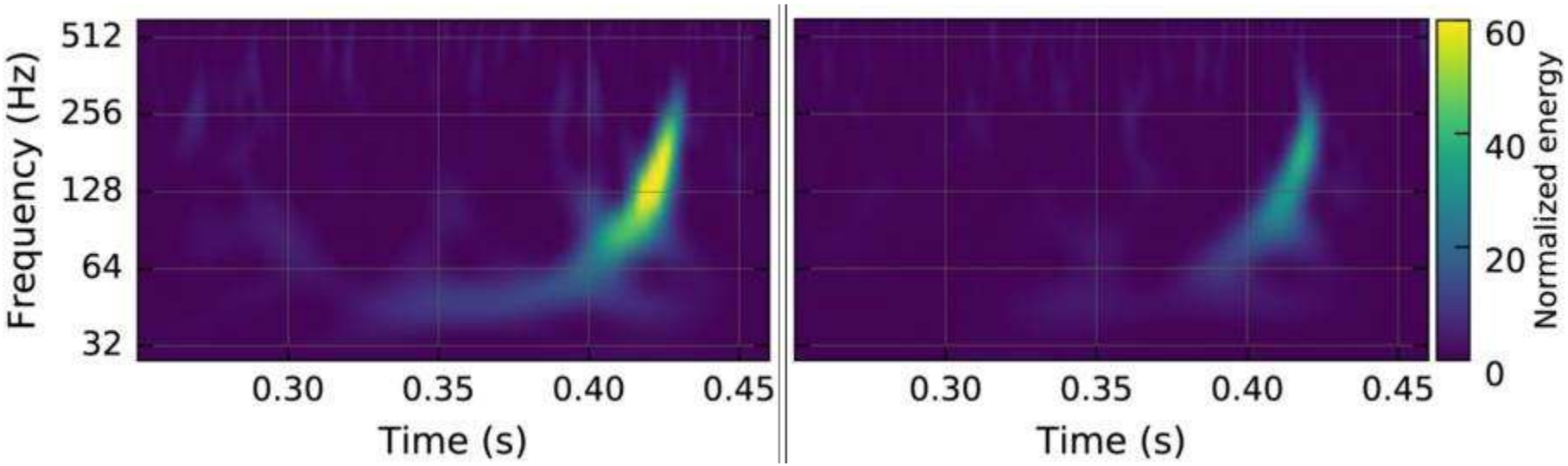
AGILE's main results

- discovery of super-acceleration in the *Crab Nebula*
- first detections of hadronic cosmic ray acceleration in the SNRs *W44* and *IC433*
- transient gamma-ray emission from *Cyg X-3*
- the "Crazy Diamond" (*3C 454.3*, since August 2007) and other bright gamma-ray blazars
- transient and subsequent discovery of the "hidden black hole" MCW 656 in a Be star binary
- detection of the remarkable short GRB 090510
- hundreds of gamma-ray sources, optimized in the range 100 MeV-10 GeV

AGILE and Gravitational Waves

- **AGILE can play a crucial role in the search of GW source counterparts.**
- **AGILE and GW150914 (and December GW event still under embargo)**
- **Prospects for a first detection of prompt gamma-ray emission counterpart of GW events**


Hanford, Washington (H1)
H1 observed
click for DATA
Livingston, Louisiana (L1)
L1 observed
H1 observed (shifted, inverted)
click for DATA (L1 only)
Numerical relativity
Reconstructed (wavelet)
Reconstructed (template)
click for DATA (Numerical relativity)
Numerical relativity
Reconstructed (wavelet)
Reconstructed (template)
click for DATA (Numerical relativity)
Residual
Residual
0.30
0.35
0.40
0.45
Time (s)
0.30
0.35
0.40
0.45
Time (s)


Frequency (Hz)
512
256
128
64
32
0.30
0.35
0.40
0.45
Time (s)
0.30
0.35
0.40
0.45
Time (s)
60
40
20
0
Normalized energy

AGILE and GW astrophysics

- new operational mode for AGILE
- very fast reaction to external GW trigger
- new processing pipeline
- great potential for fast discovery of gamma-ray transients associated with NS-NS, NS-BH, and BH-BH coalescences.

AGILE and GW astrophysics

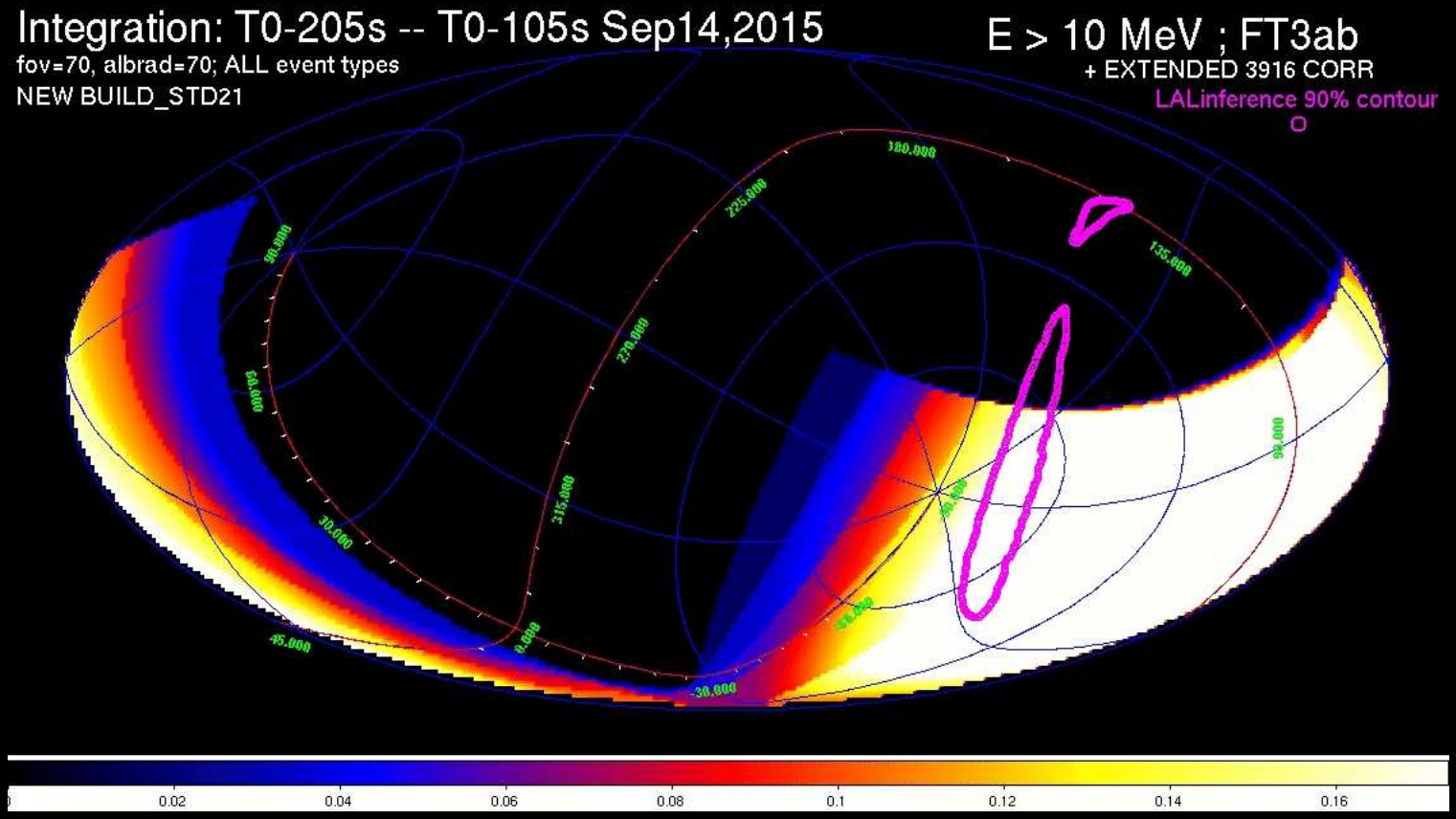
- new operational mode for AGILE
- very fast reaction to external GW trigger
- new processing pipeline
- great potential for fast discovery of gamma-ray transients associated with NS-NS, NS-BH, and BH-BH coalescences
- AGILE-GW new Key Project: AGILE can play a key role in the study of GW waves

- **AGILE in equatorial orbit, LEO, 500 km**

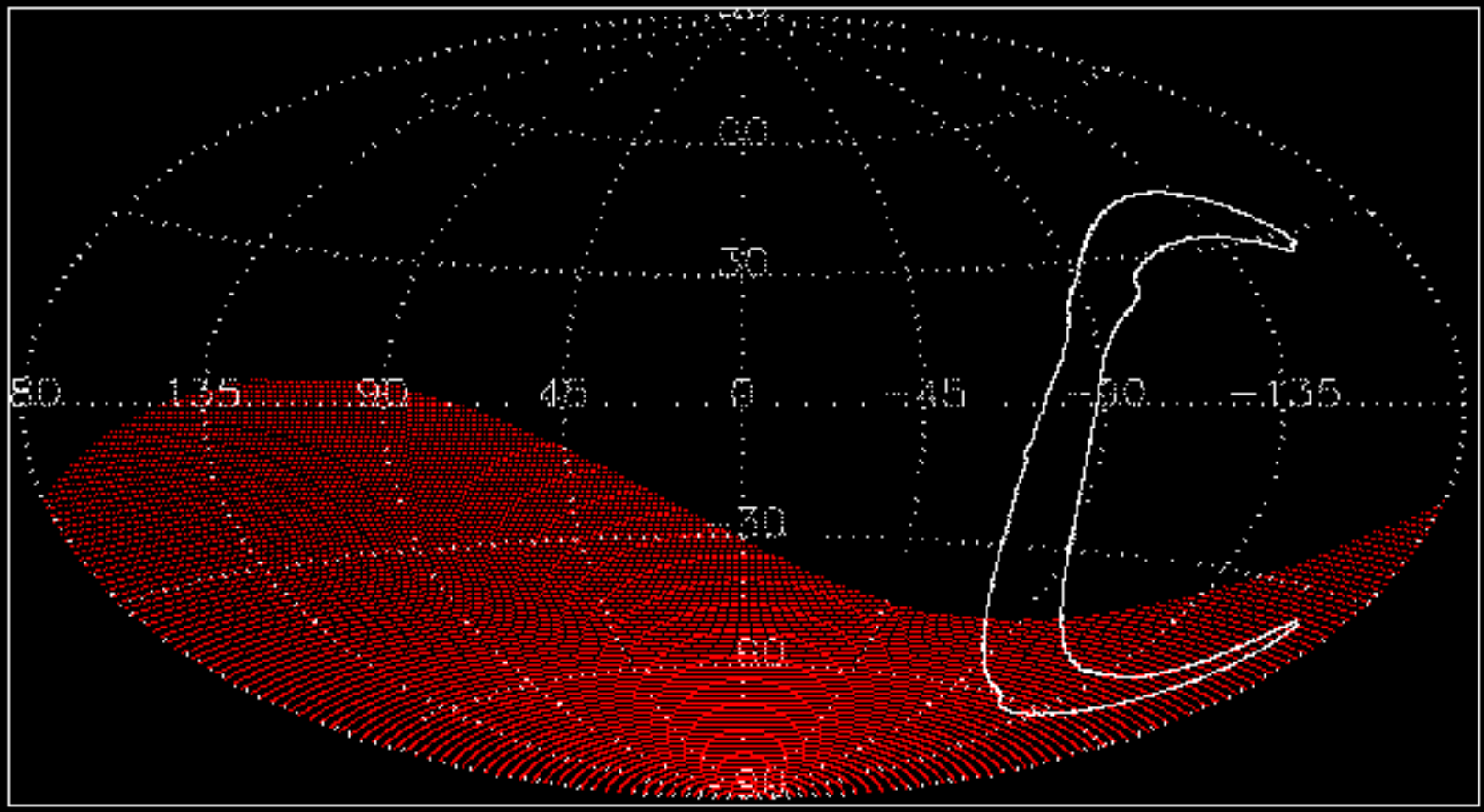
- **imaging gamma-ray detector (FoV = 2.5 sr)**
  - energy range: 30 MeV – 30 GeV
  - optimal PSF
  - **sensitivity ~10^{-8} erg cm^{-2} s^{-1} in 100 sec.**

- **non-imaging detectors (4 π):**
  - **MCAL (0.4 – 100 MeV)**
  - **AC (50 keV – 10 MeV)**

AGILE in spinning: revolution including T_0 of GW150914



Earth occultation during one orbit (95 min)



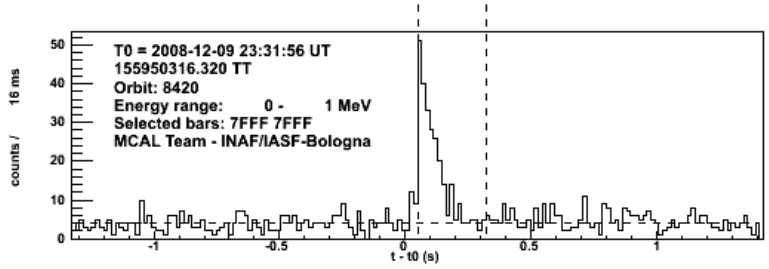
Search for gamma-ray transients

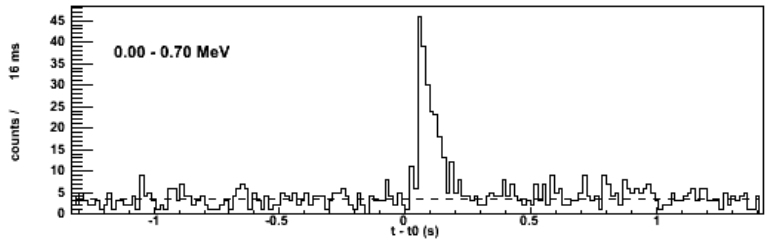
- gamma-ray imager: covers 80% of the sky
- 200 revolutions / day
- (Earth occultations, SAA) - > **100 useful passes**
- passes of 150 sec duration
- **sensitivity ~ (1-2) 10^{-8} erg cm^{-2} s^{-1} in 100 sec.**
- GRB – like searches, MCAL, AC

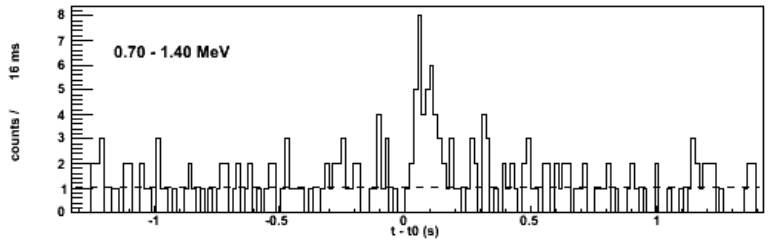
- **Unique features**
  - **> 100 useful passes/day over 80% of the sky**
  - optimal PSF
  - optimal sensitivity above 30 MeV
  - **very fast processing and alert**
    (it could be 2-3 hrs after the event if 100% of the 14 orbits/day are transmitted)

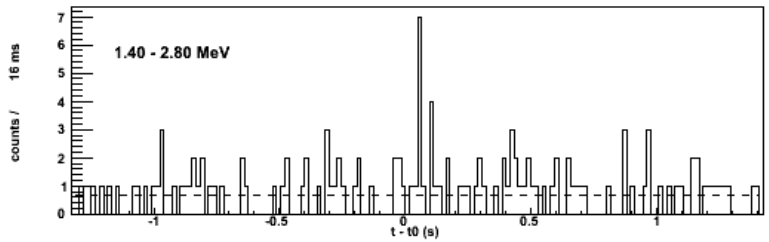
AGILE detection of short GRBs

GRB 081209

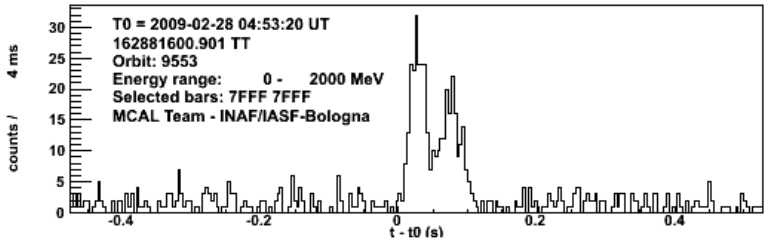


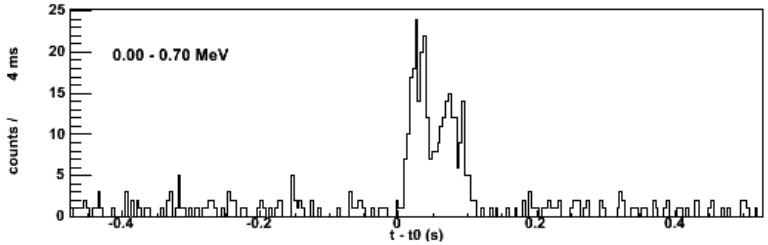


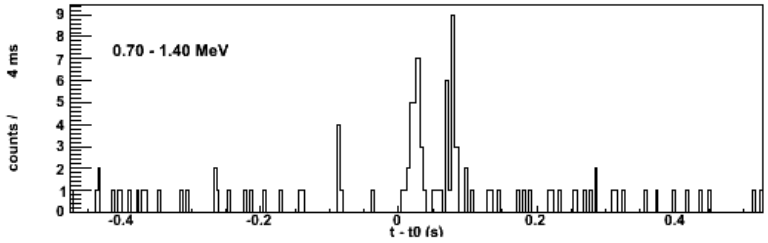


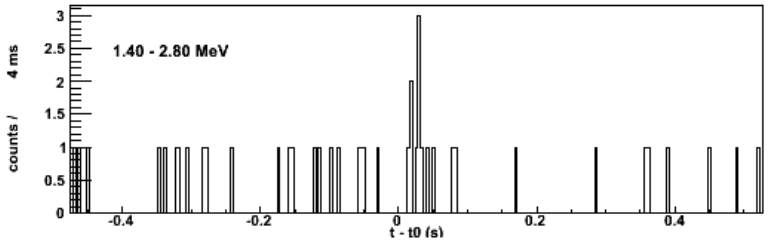


GRB 090228

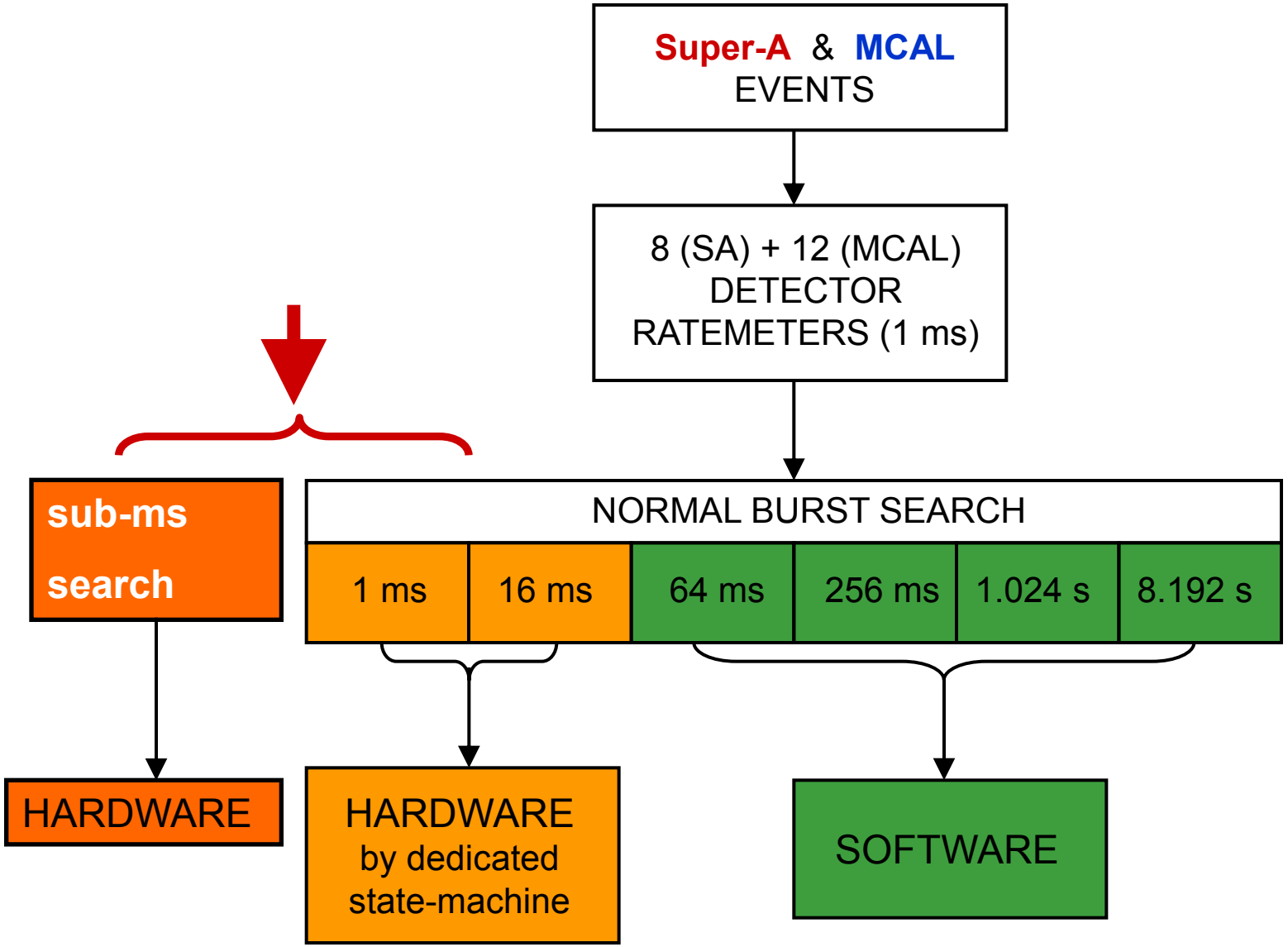




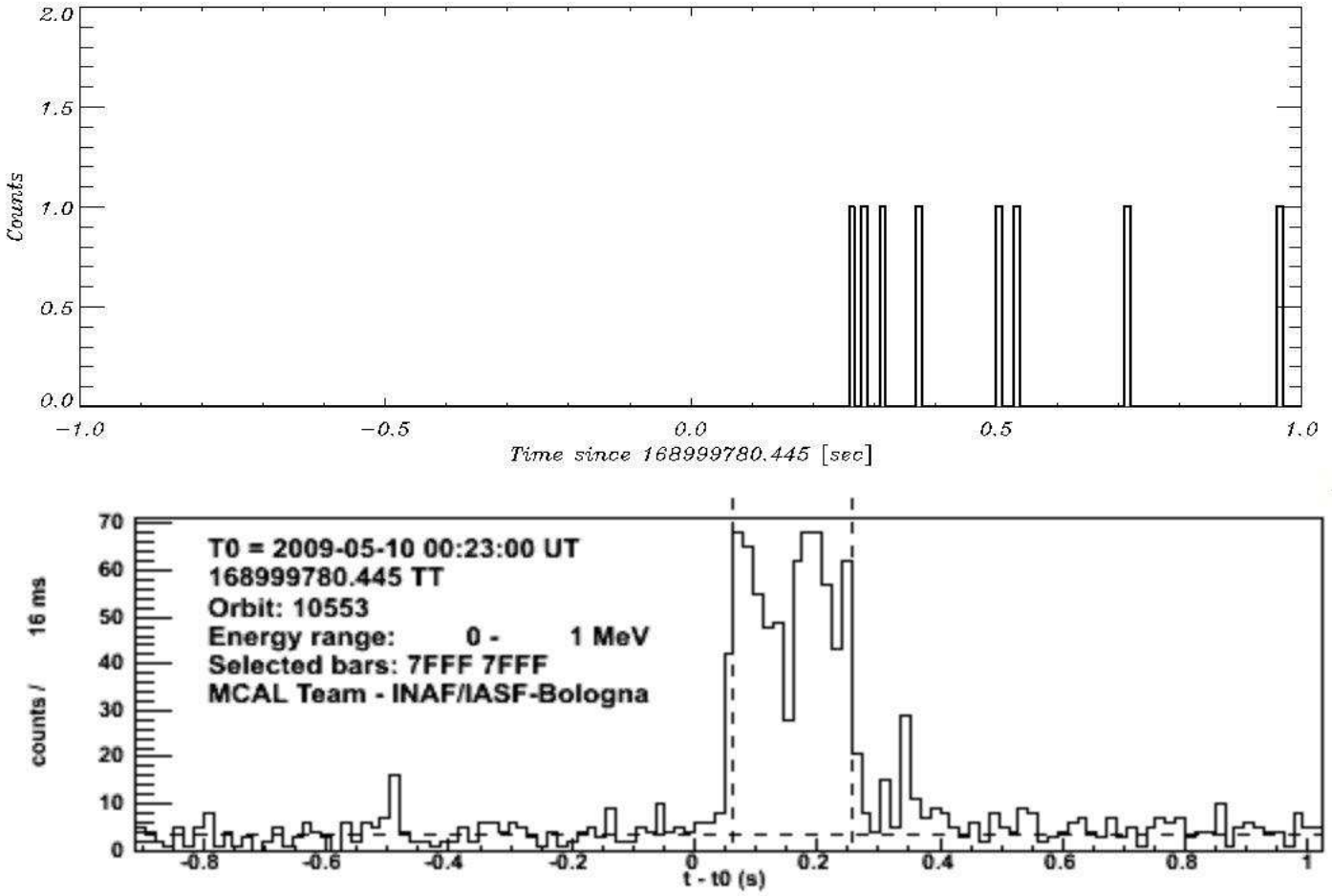




AGILE GRB ON-BOARD SEARCH PROCEDURE



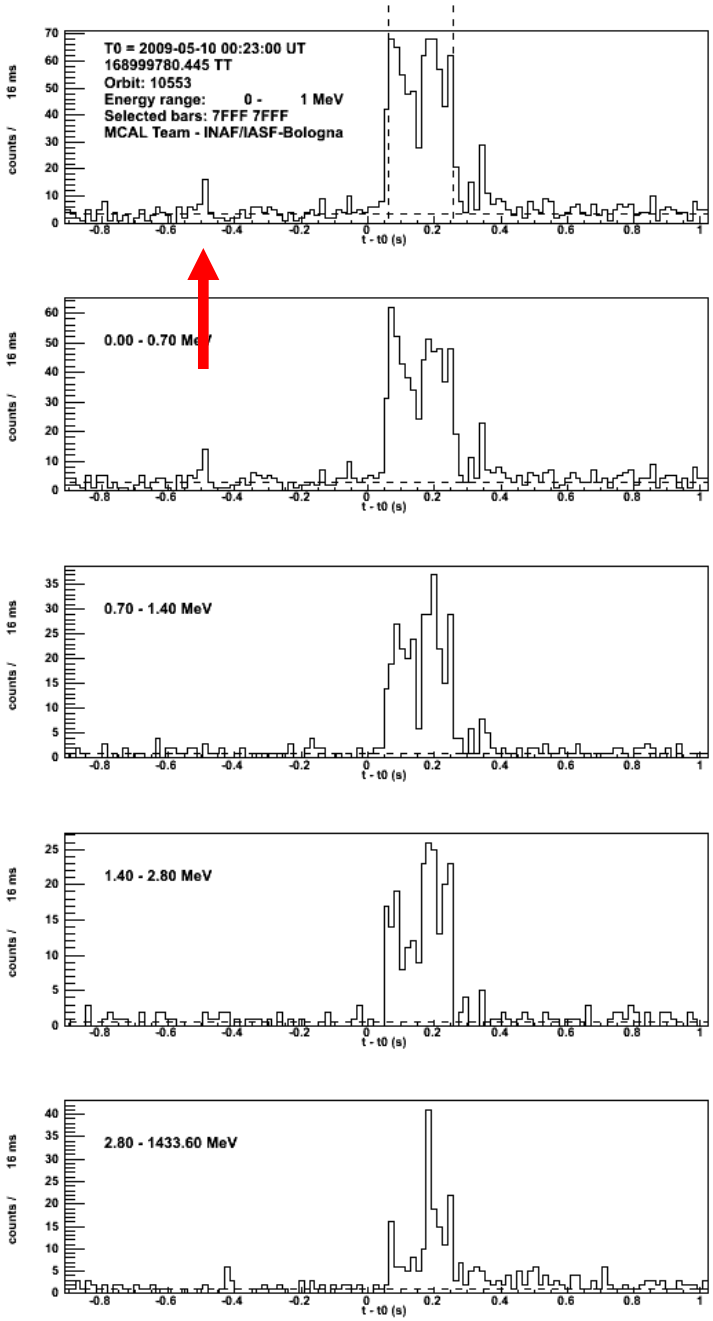
The short GRB 090510 (61 degree off-axis)

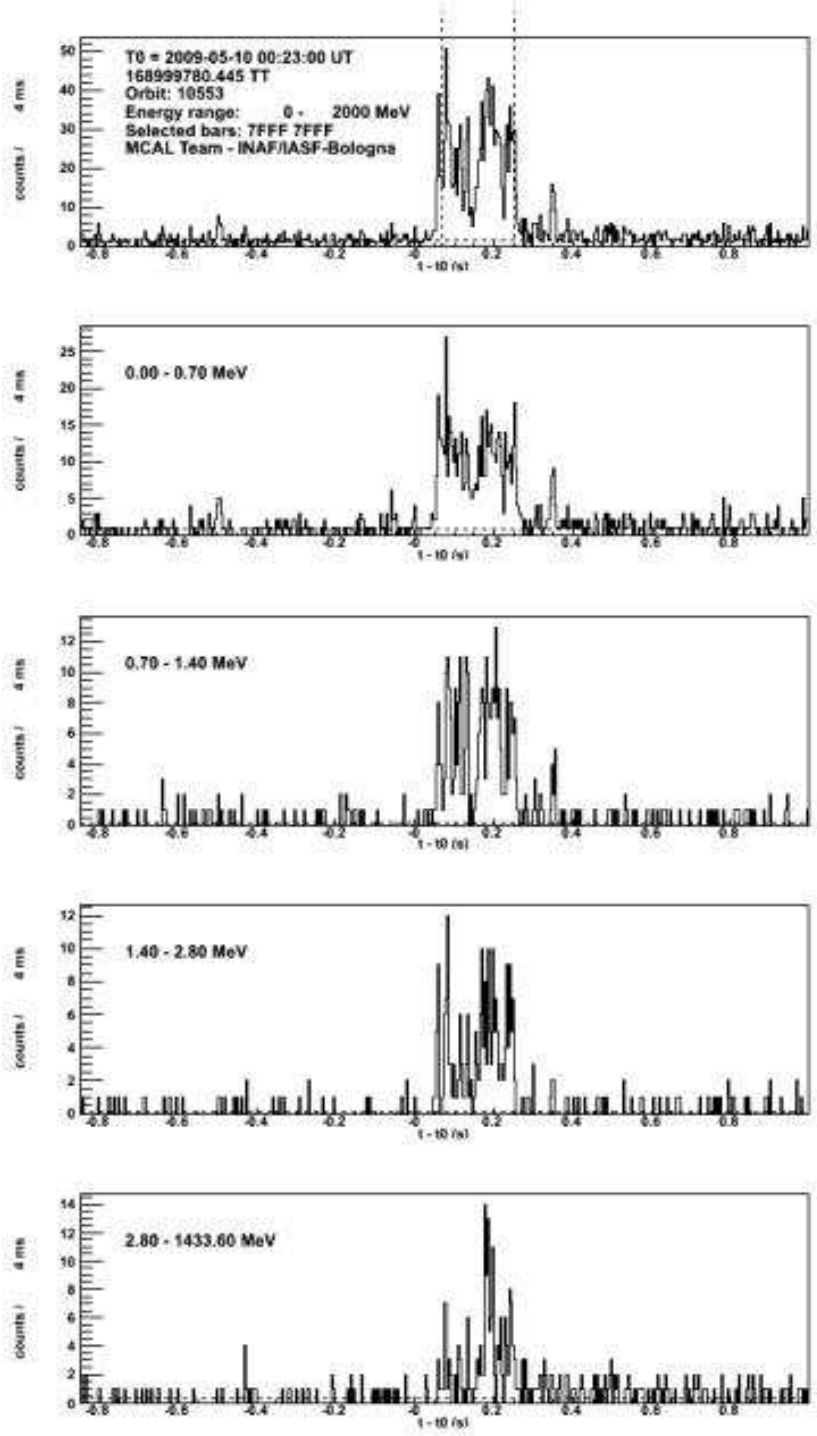


AGILE
and
the “short”
GRB 090510

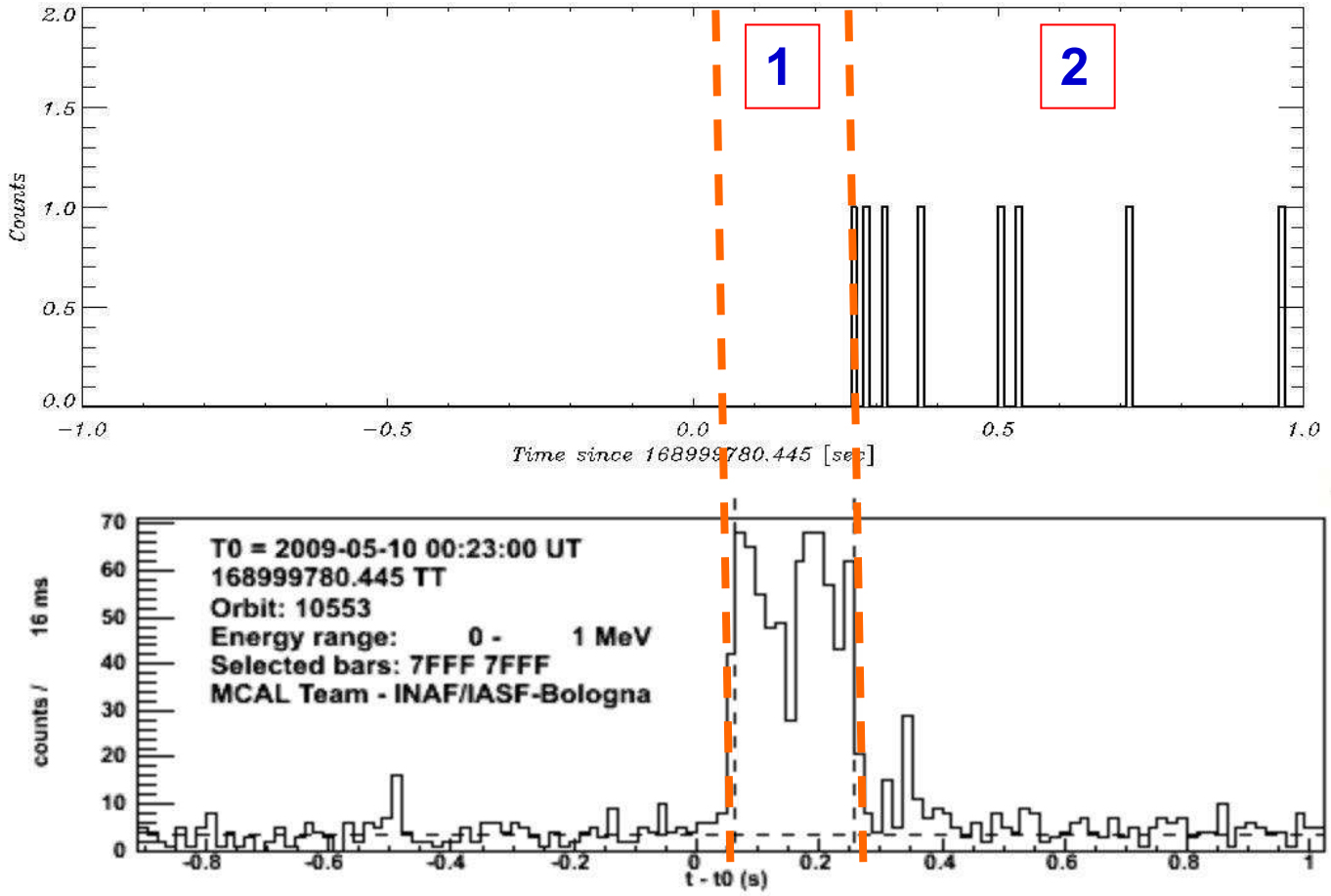
(Giuliani et al. 2010)

z = 0.9


T0 = 2009-05-10 00:23:00 UT
168999780.445 TT
Orbit: 10553
Energy range: 0 - 1 MeV
Selected bars: 7FFF 7FFF
MCAL Team - INAF/IASF-Bologna
0.00 - 0.70 MeV
0.70 - 1.40 MeV
1.40 - 2.80 MeV
2.80 - 1433.60 MeV
counts / 16 ms
t - t0 (s)

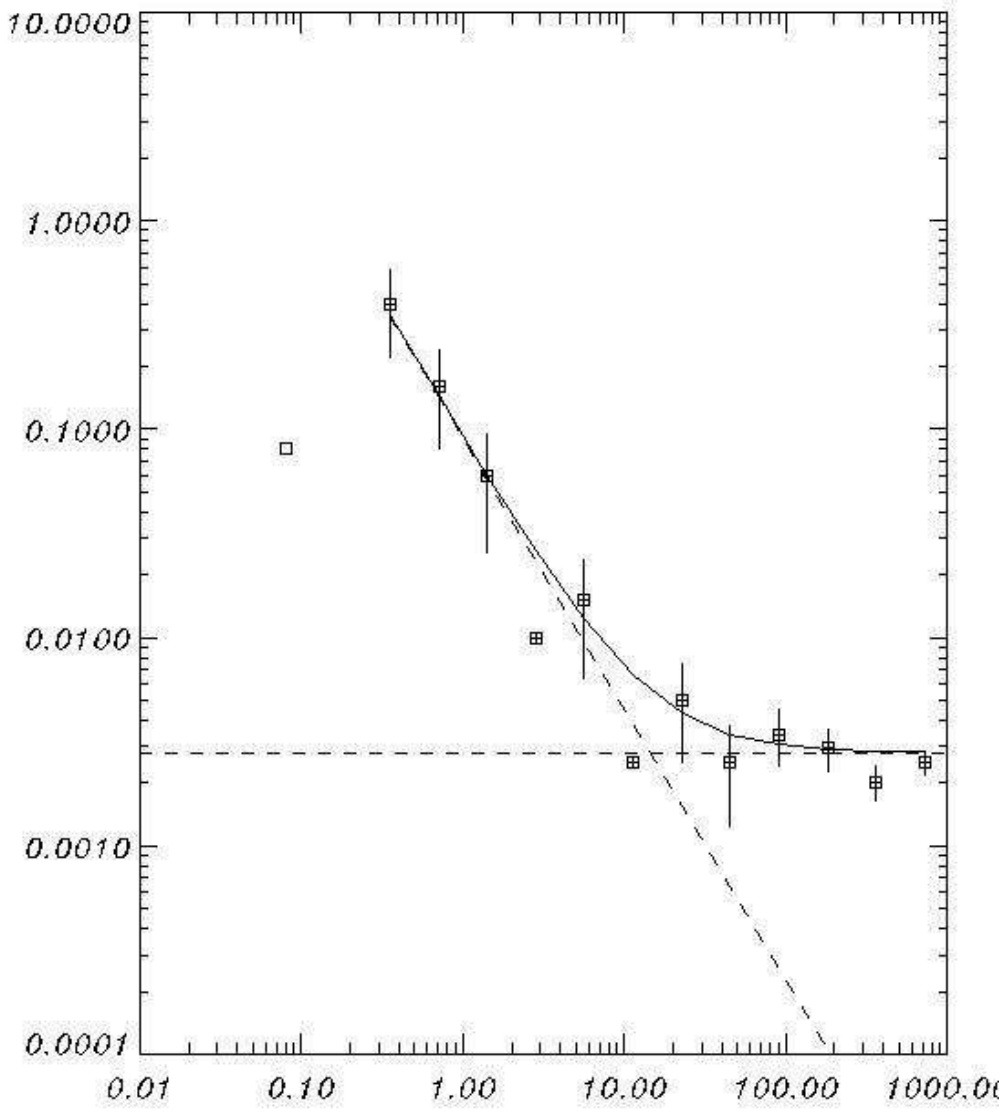

T0 = 2009-05-10 00:23:00 UT
168999780.445 TT
Orbit: 10553
Energy range: 0 - 2000 MeV
Selected bars: 7FFF 7FFF
MCAL Team - INAF/IASF-Bologna
0.00 - 0.70 MeV
0.70 - 1.40 MeV
1.40 - 2.80 MeV
2.80 - 1433.60 MeV
counts / 4 ms
T - t0 (s)

AGILE: GRB 090510

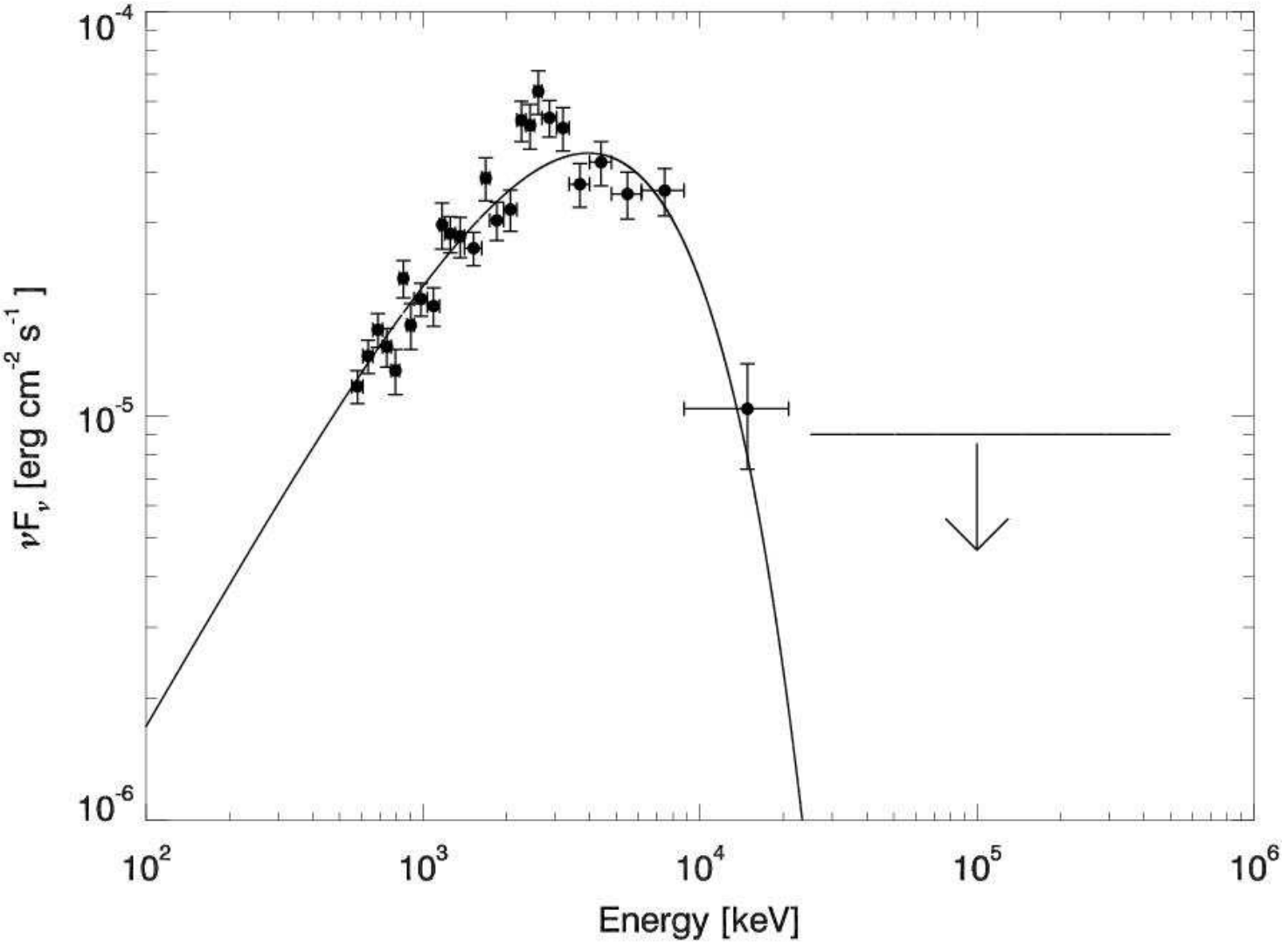


Gamma-ray tail (delayed emission)

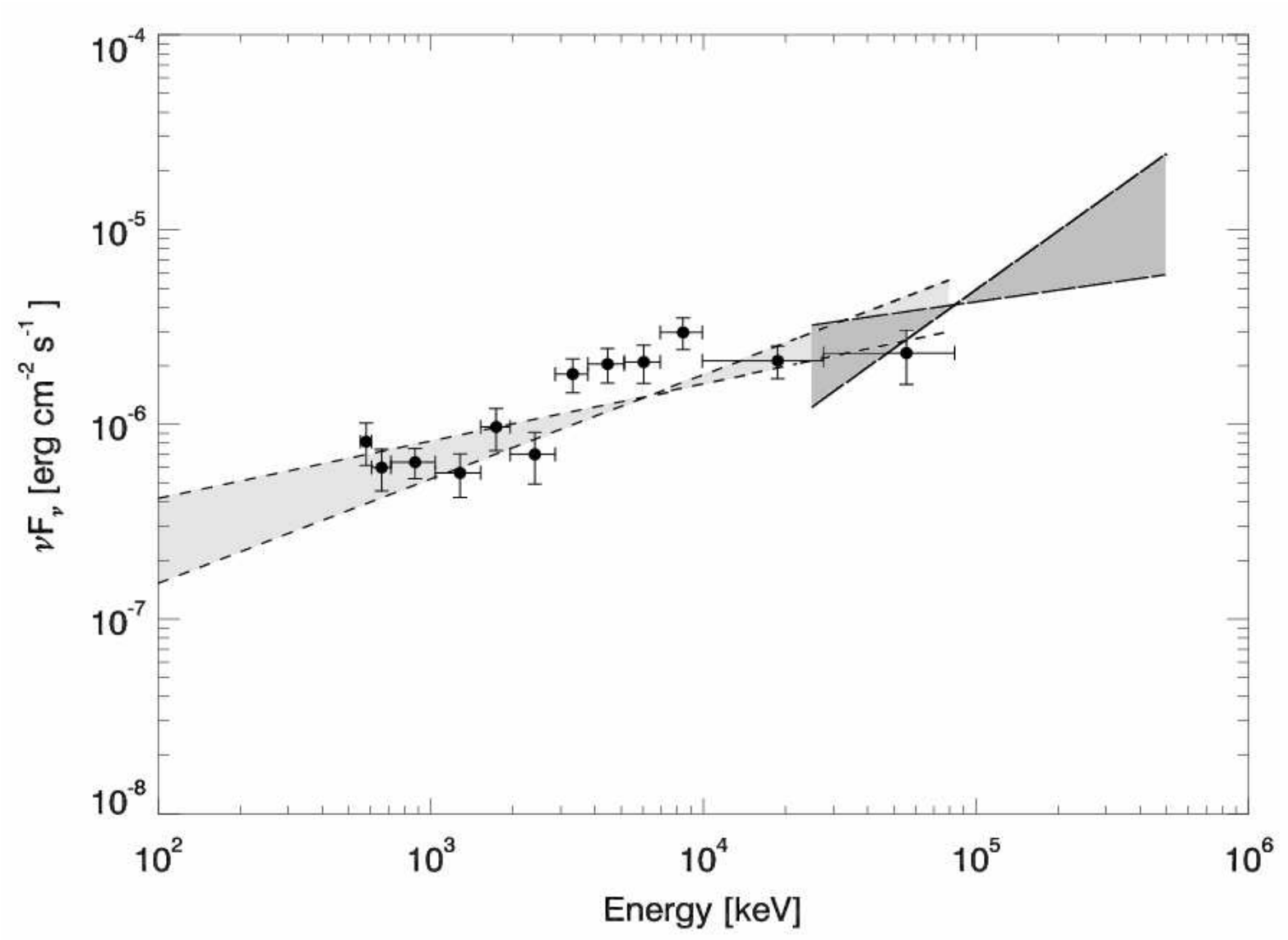
$F = t^{-1.32}$



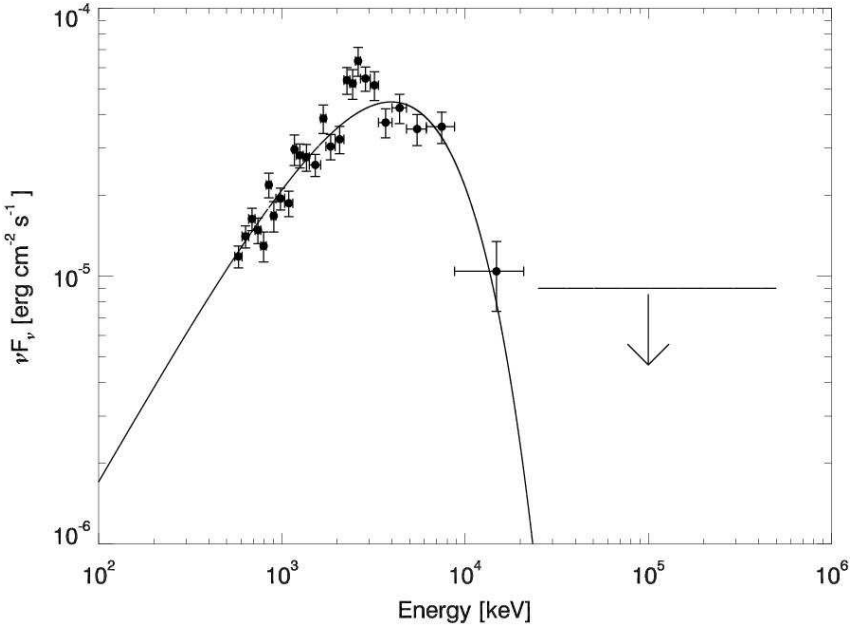
AGILE – GRB 090510: interval: 1



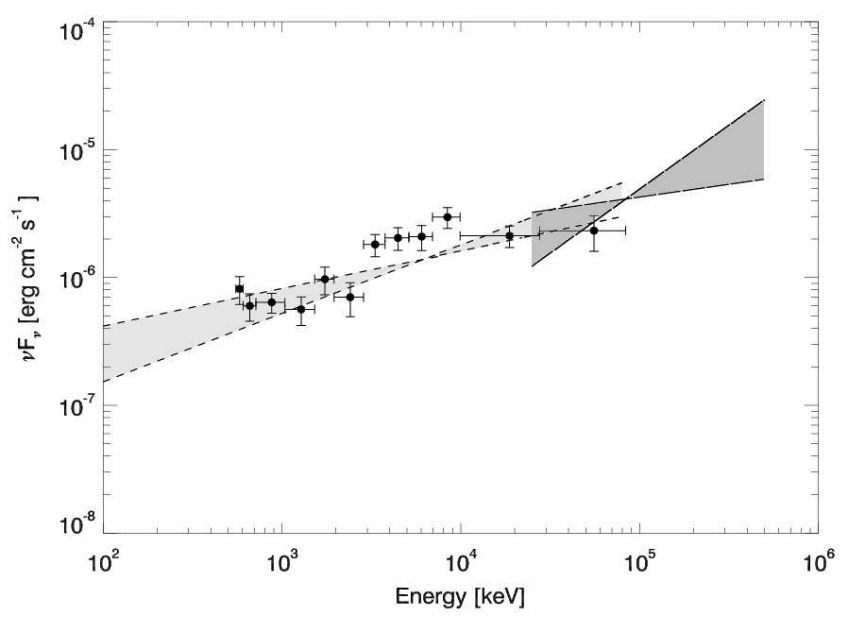
AGILE – GRB 090510: interval: 2



Interval 1



Interval 2



on the “short” GRB 090510…

- one of the shortest events with remarkable high-energy emission
- For a z~0.9, E(iso) = 10^{52} ergs
- MeV and gamma-ray emission above 100 MeV
  - Interval 1: E(peak) ~ 3 MeV
  - Interval 2: E(peak) > 50 MeV
    - » **$F = t^{-1.3}$**

Submitted to the *Astrophysical Journal Letters*, April 1, 2016.

Accepted by ApJL

AGILE Observations of the Gravitational Wave Event GW150914

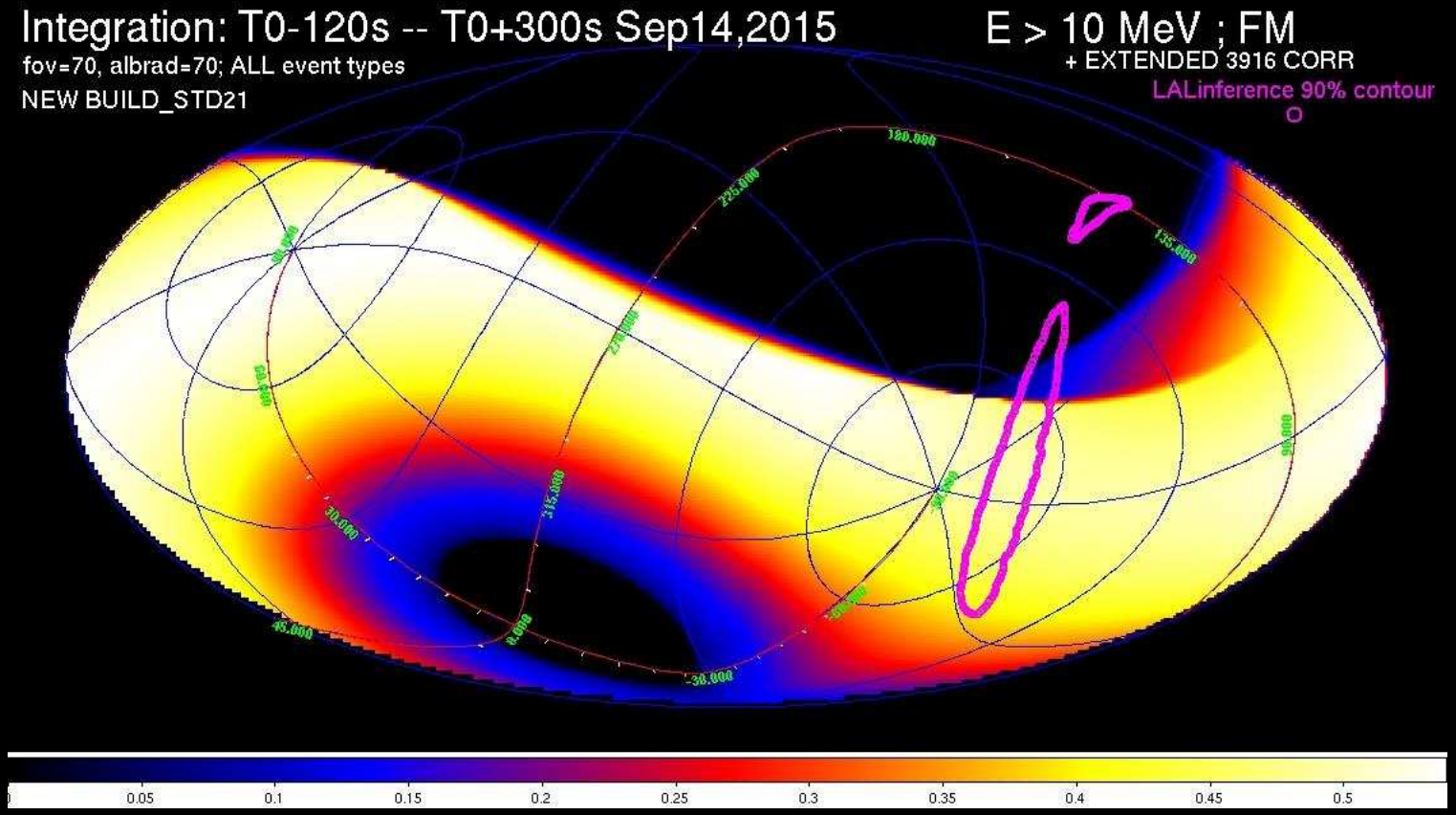
M. Tavani[1,2,3], C. Pittori[4,5], F. Verrecchia[4,5], A. Bulgarelli[6], A. Giuliani[7], I. Donnarumma[1], A. Argan[1], A. Trois[8], F. Lucarelli[4,5], M. Marisaldi[6], E. Del Monte[1], Y. Evangelista[1], V. Fioretti[6], A. Zoli[6], G. Piano[1], P. Munar-Adrover[1], L.A. Antonelli[4,5], G. Barbiellini[9], P. Caraveo[7], P.W. Cattaneo[10], E. Costa[1], M. Feroci[1], A. Ferrari[11], F. Longo[9], S. Mereghetti[7], G. Minervini[12], A. Morselli[13], L. Pacciani[1], A. Pellizzoni[8], P. Picozza[13], M. Pilia [8], A. Rappoldi[10], S. Sabatini[1], S. Vercellone[14], V. Vittorini[1], P. Giommi[4], S. Colafrancesco[15], M. Cardillo[16].

GW150914

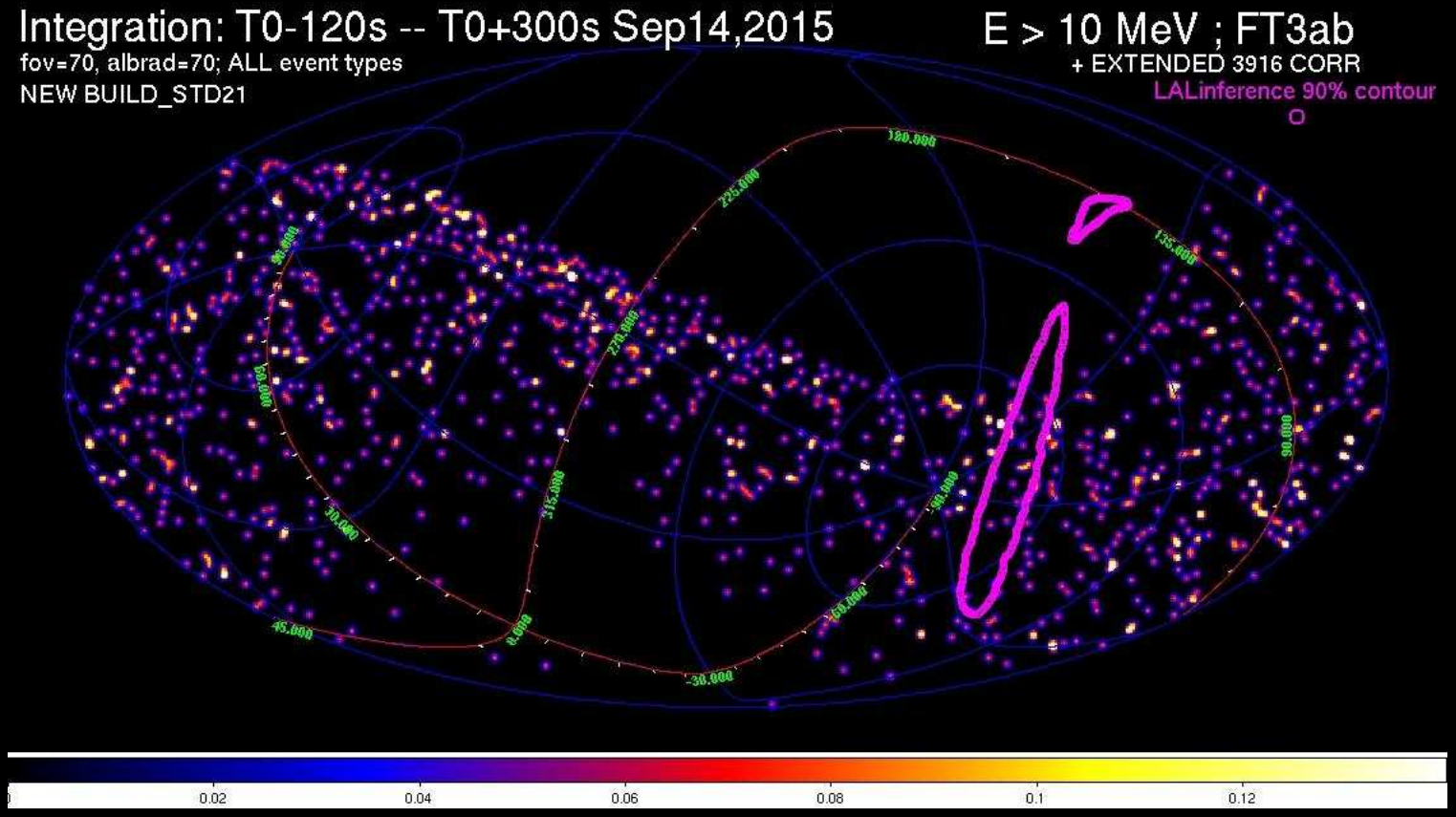
- T_0 = 9:50:45 UT, 14 September, 2015

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

exposure: revolution -120/+300 sec from T_0

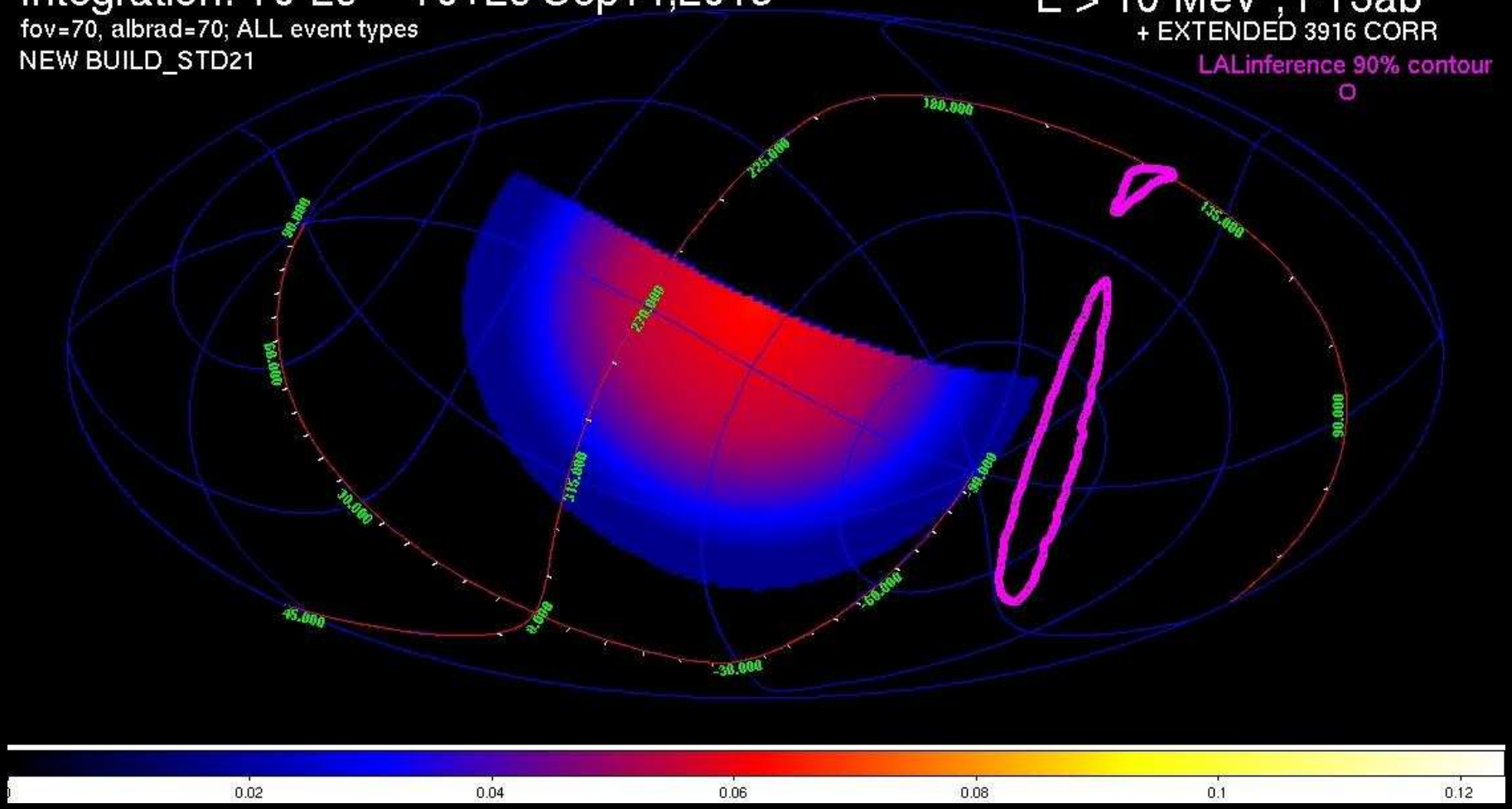


exposure: revolution -120/+300 sec from T_0

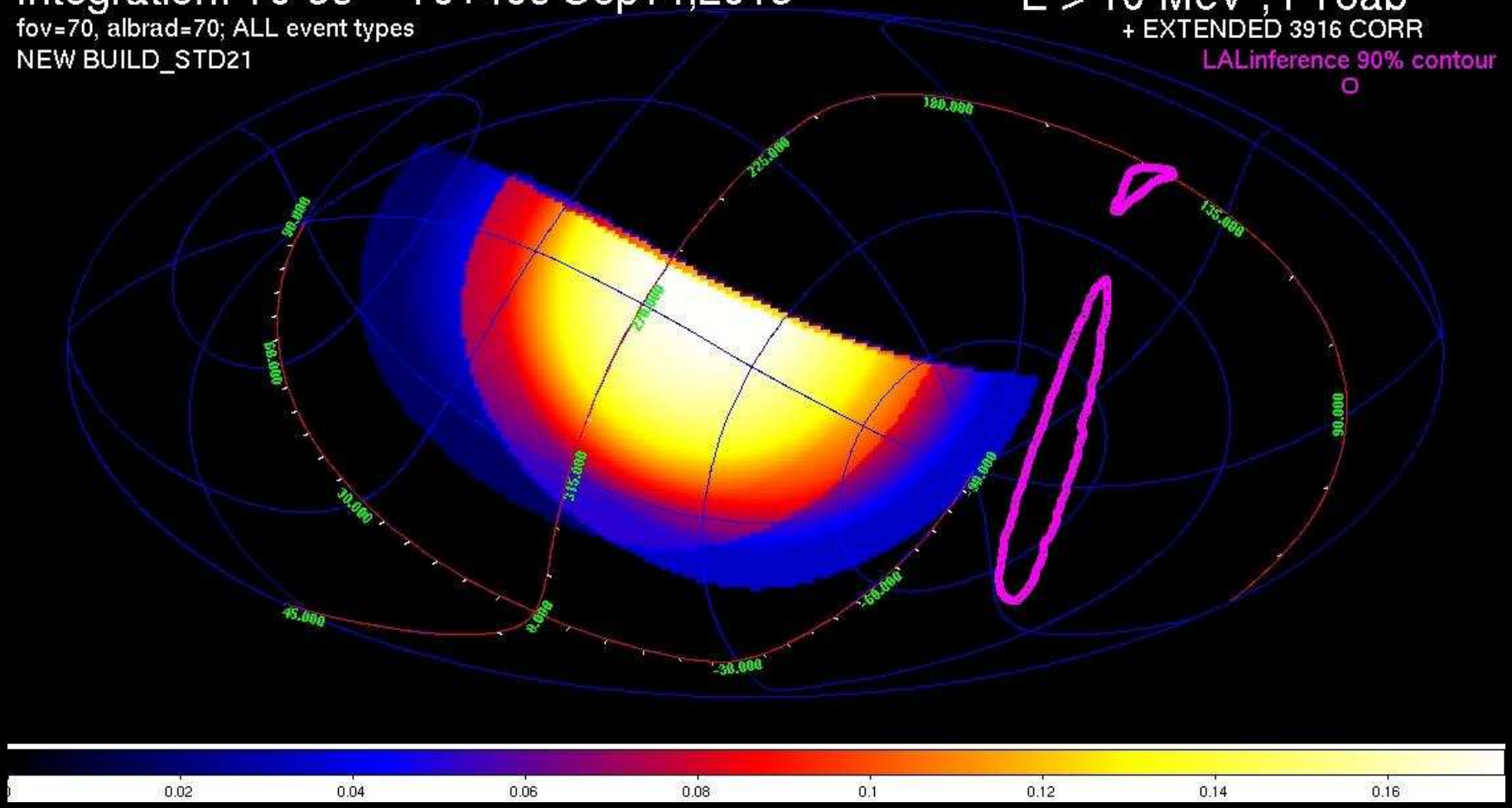


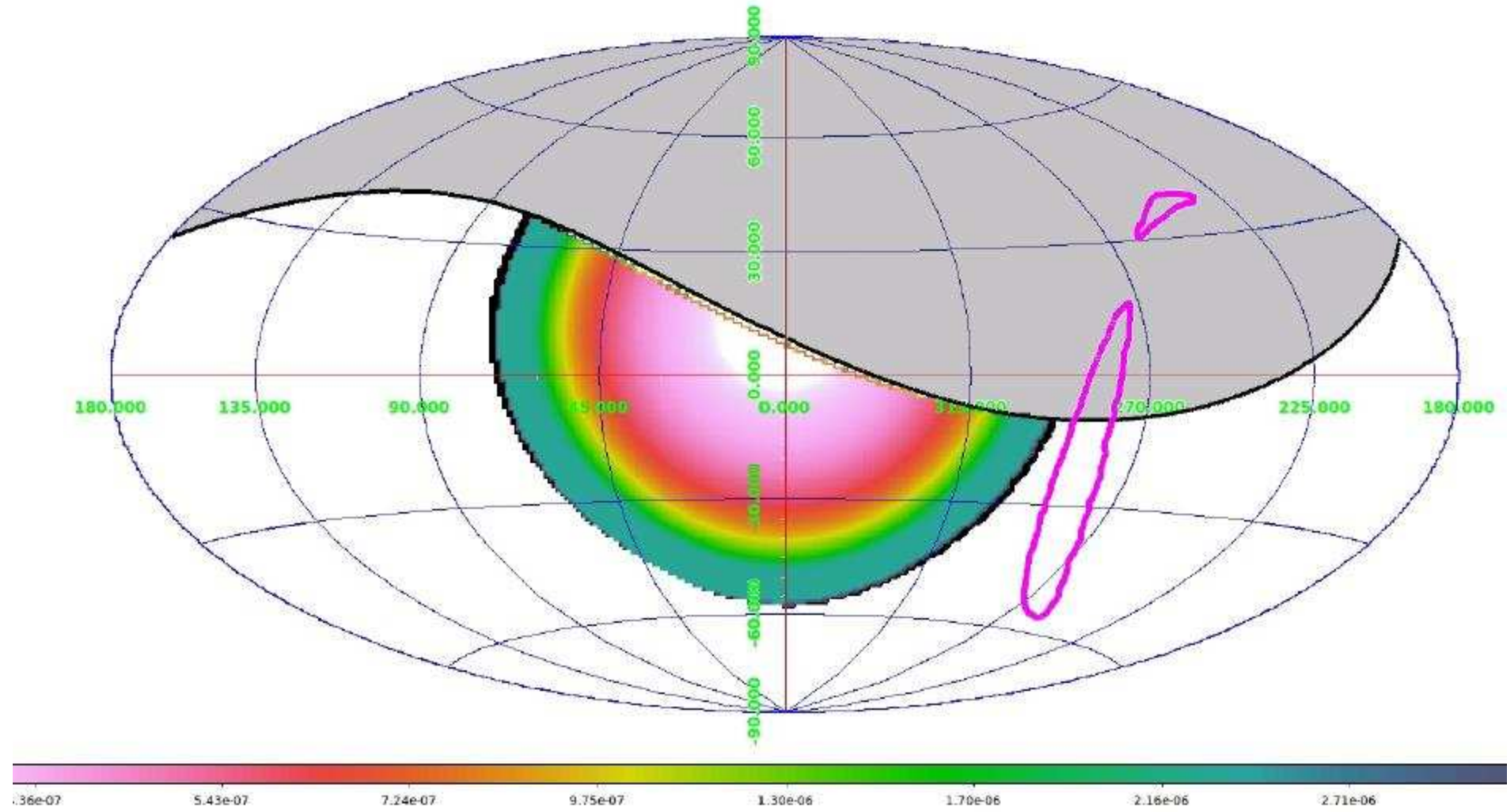
AGILE field at T_0 = 09:50:45 UT

just missed it !



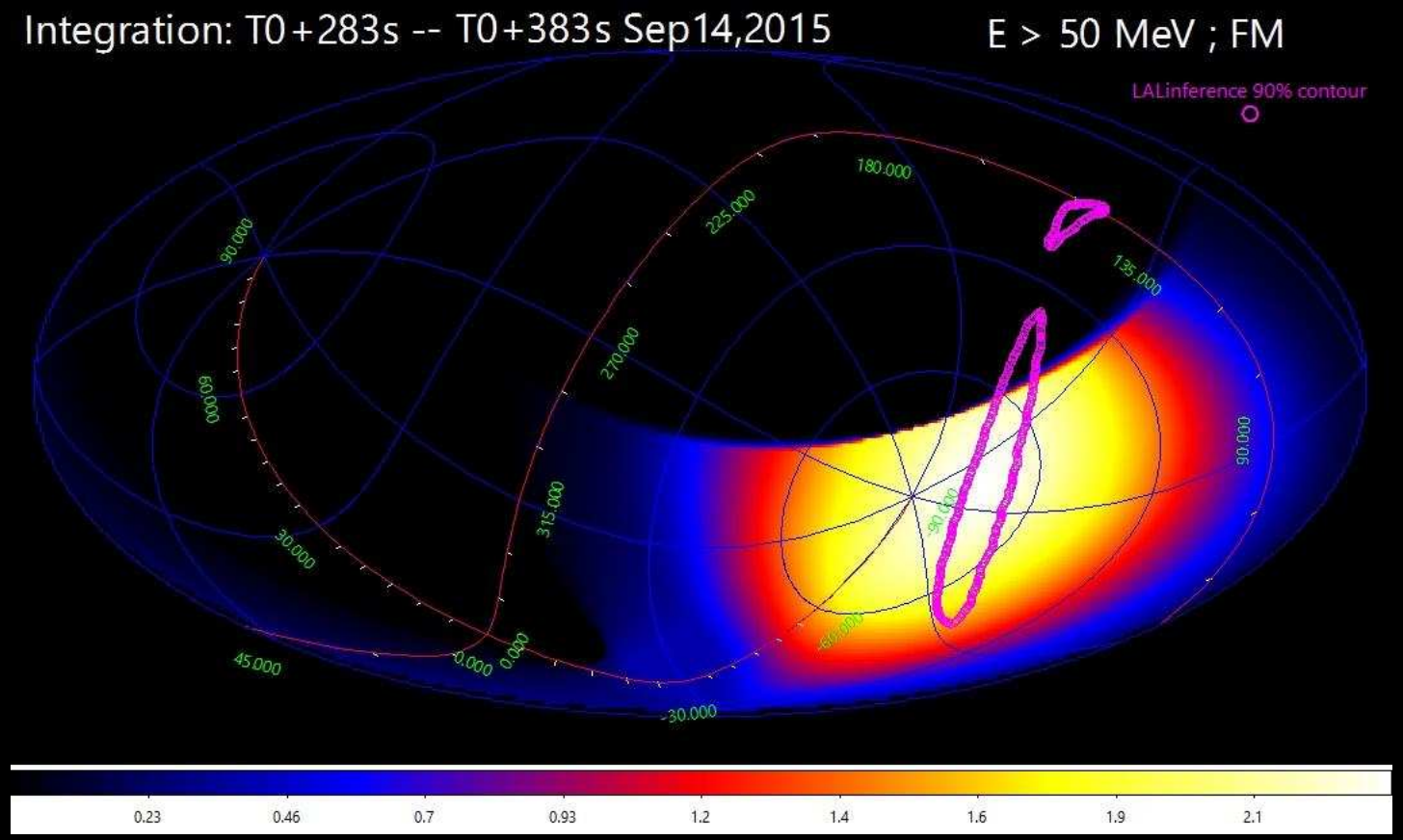
just missed it (-5 / +40 sec)



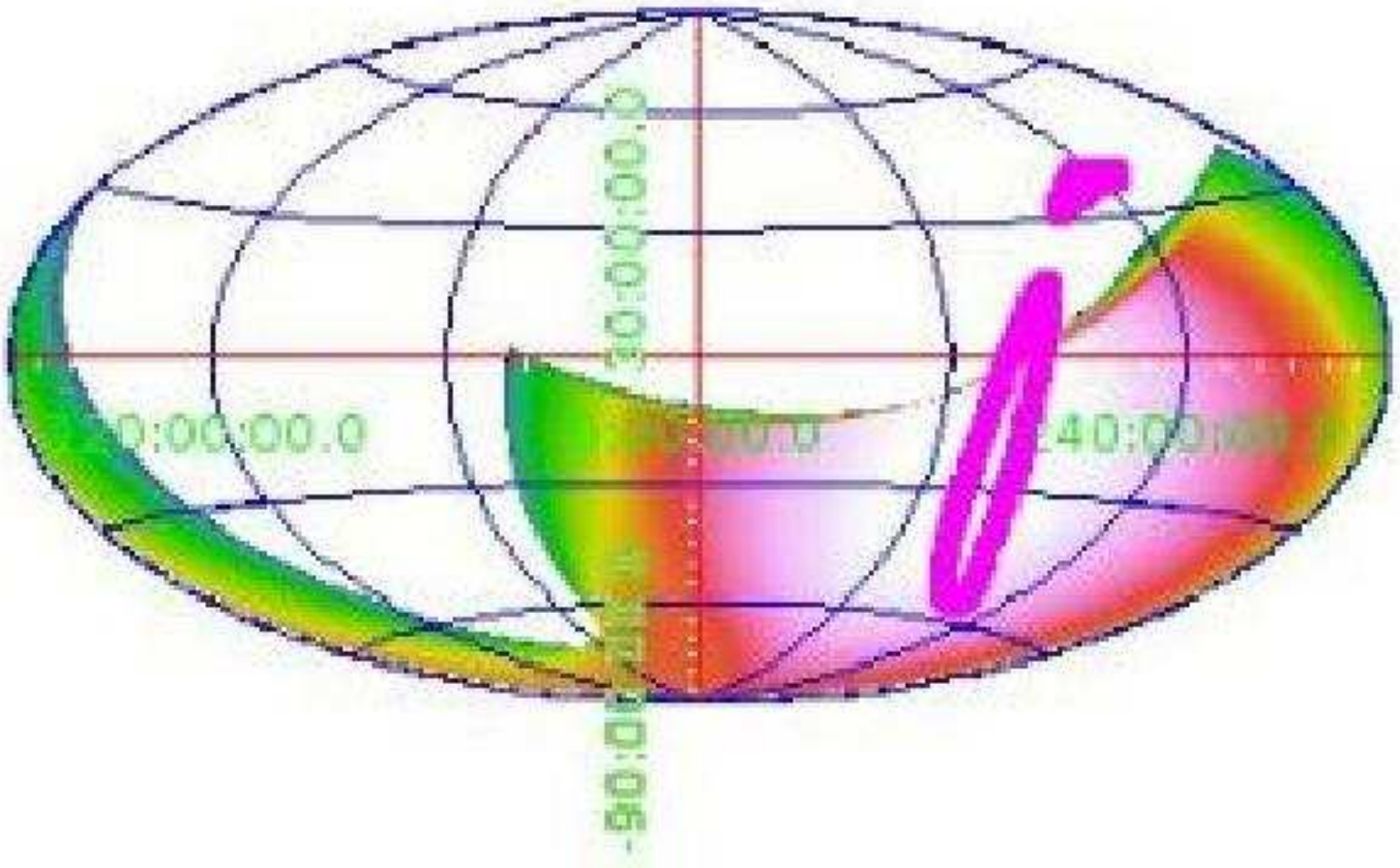

90.000
60.000
30.000
0.000
-30.000
-60.000
-90.000
180.000
135.000
90.000
0.000
225.000
180.000
.36e-07
5.43e-07
7.24e-07
9.75e-07
1.30e-06
1.70e-06
2.16e-06
2.71e-06

300 sec later…

AGILE exposure 330 sec (+/- 50 sec)

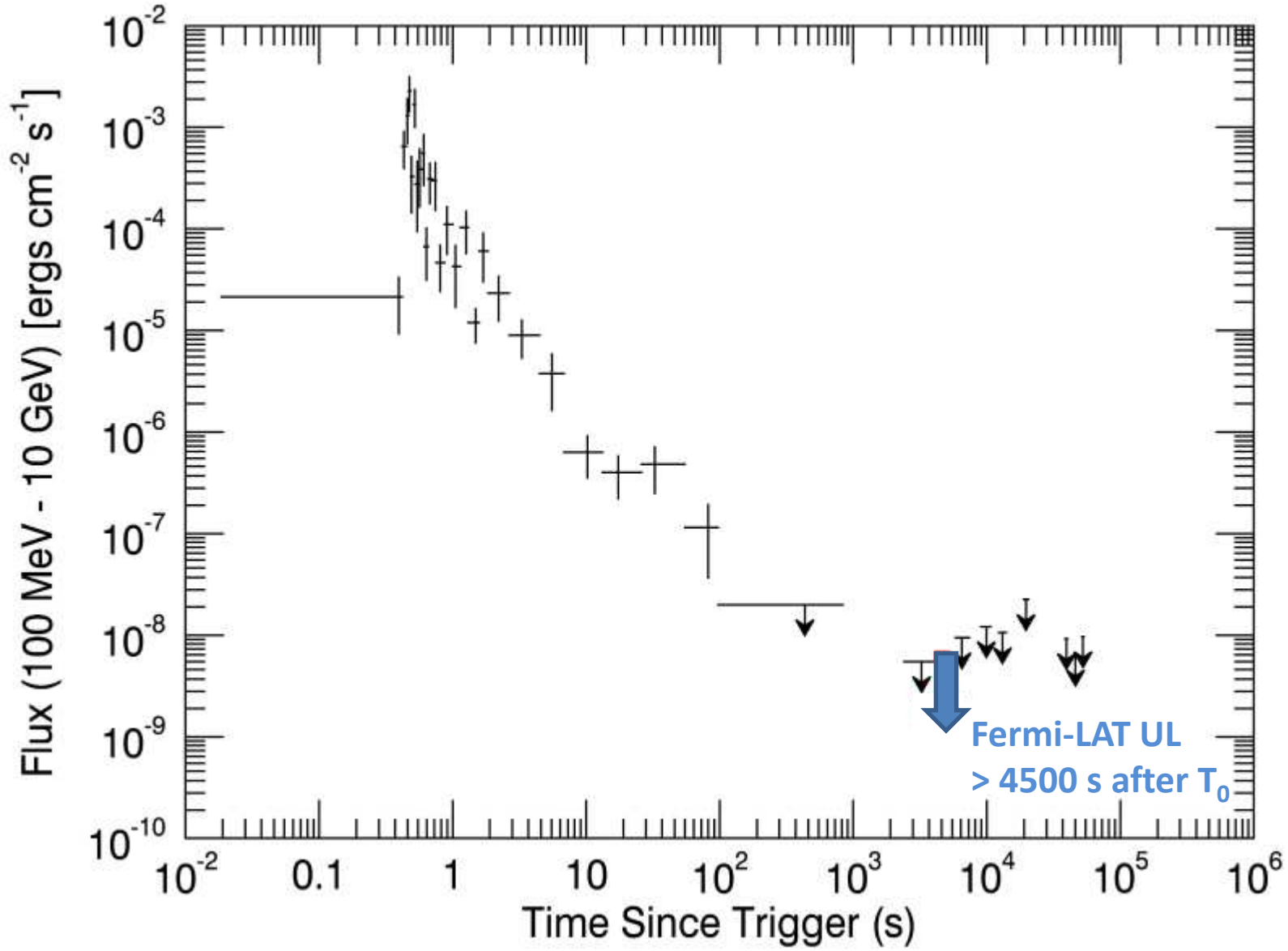


2-sigma upper limit (E > 50 MeV) = 1.5 x 10^{-8} erg cm^{-2} s^{-1}



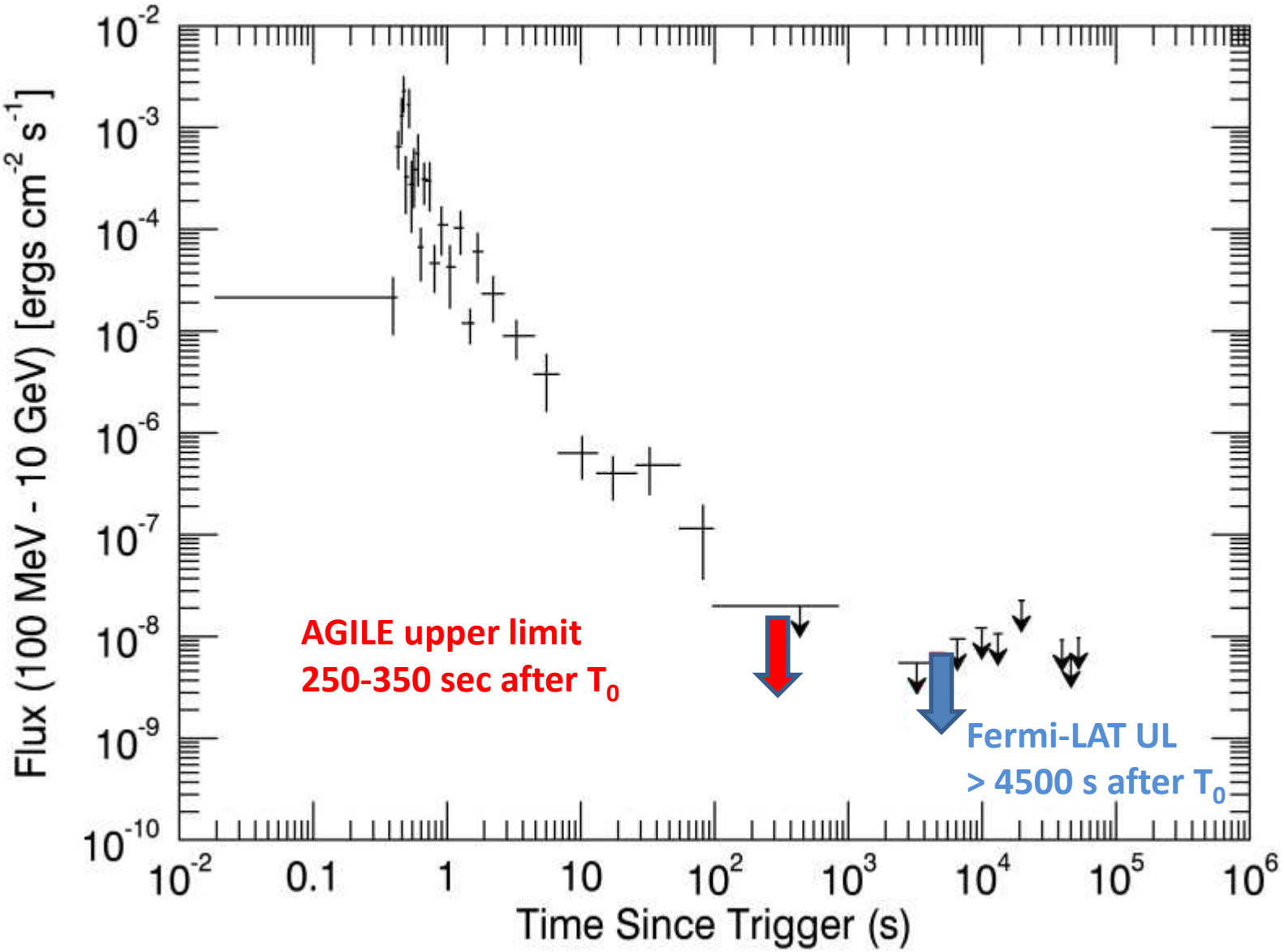
AGILE and Fermi-LAT upper limits in the GRB090510 lightcurve

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



AGILE and Fermi-LAT upper limits in the GRB090510 lightcurve

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

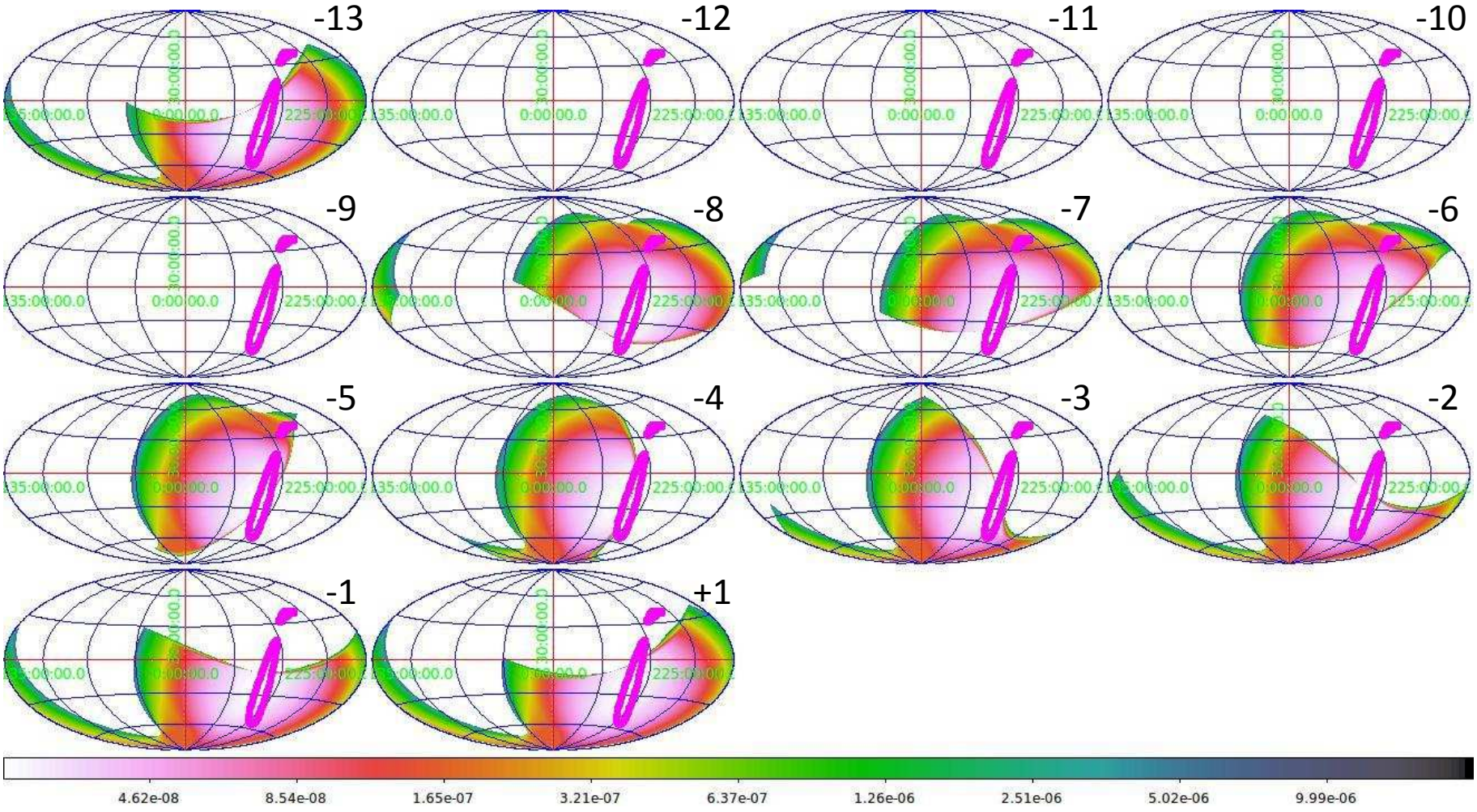


- **precursor search**

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)



- **search for delayed emission**

Table 2: Long-integration time analysis of the GW150914 error box

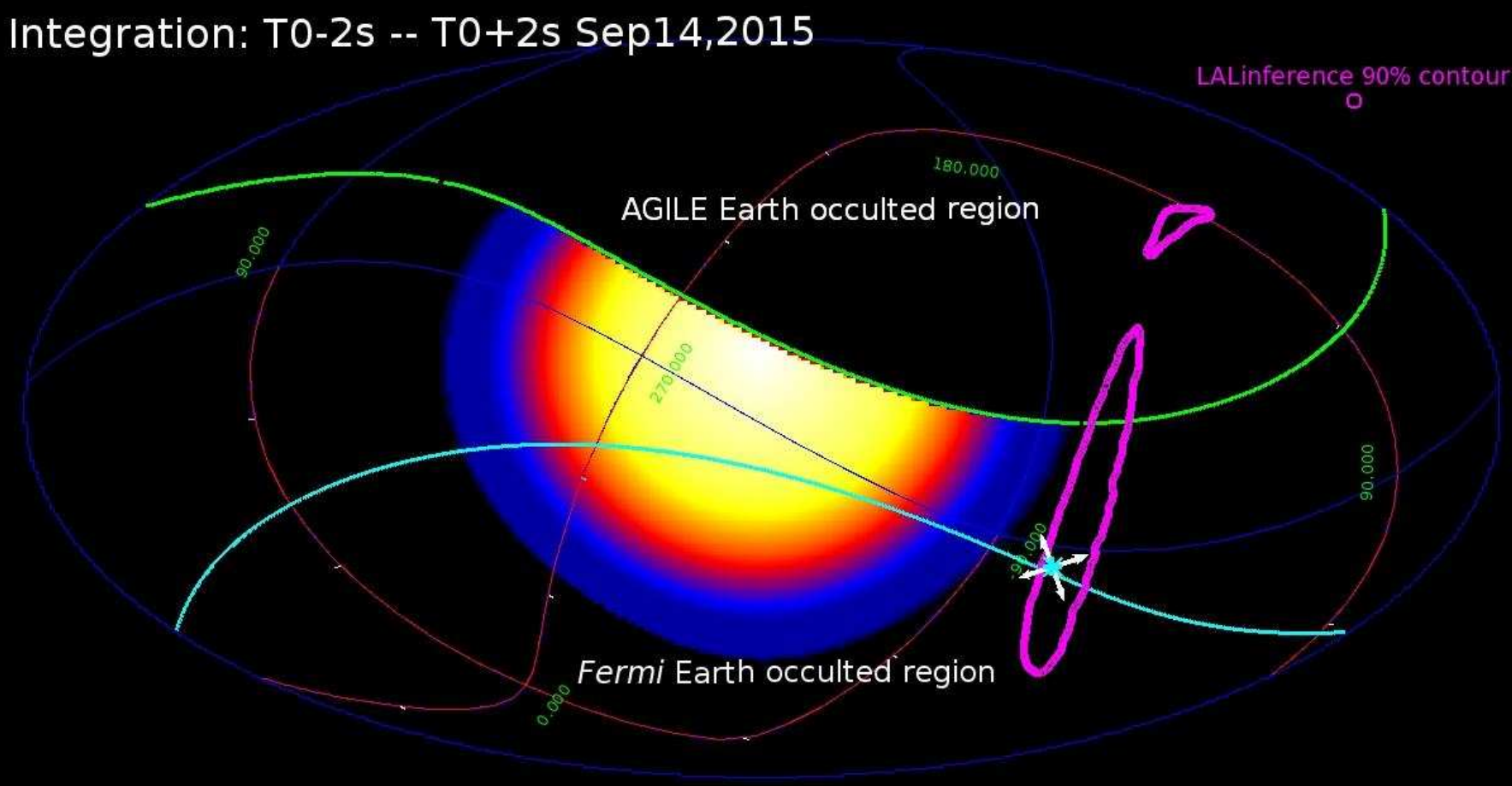
Interval name	Duration	2σ UL (*) (10^{-9} erg cm^{-2} s^{-1})	Comments
-3d	3 days	0.3	
-2d	2 days	0.5	
-1d	1 day	0.7	
-12h	12 hours	0.8	
-6h	6 hours	2.5	
-3h	3 hours	3.5	
+3h	3 hours	–	telemetry interruption (**)
+6h	6 hours	3.5	with telemetry interruption (**)
+12h	12 hours	1.8	with telemetry interruption (**)
+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 (**)

AGILE does not detect the Fermi-GBM transient

- at the GW150914 prompt time, best GBM position region at about 90° off-axis for AGILE GRID and MCAL
- limited exposure of MCAL
- **AGILE 5-sigma MCAL upper limit**
  $F_{GBM} = 2 \times 10^{-6}$ erg cm^{-2} (0.45 – 100 MeV),

- 2.5 times larger than GBM event extrapolation at 1 MeV
  $F_{GBM} = (2 \pm 1) \times 10^{-7}$ erg cm^{-2} (10 keV – 1 MeV),
  photon index 1.4

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



AGILE observations of GW150914: minutes, hours, days

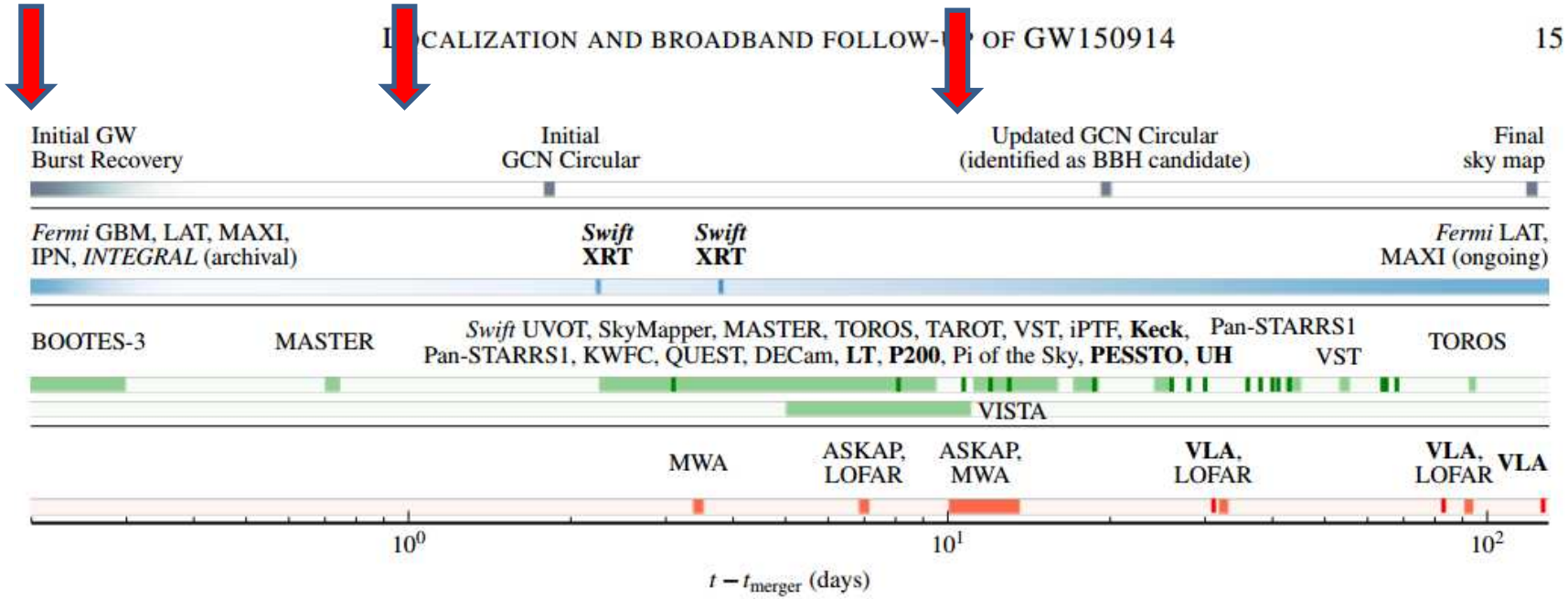


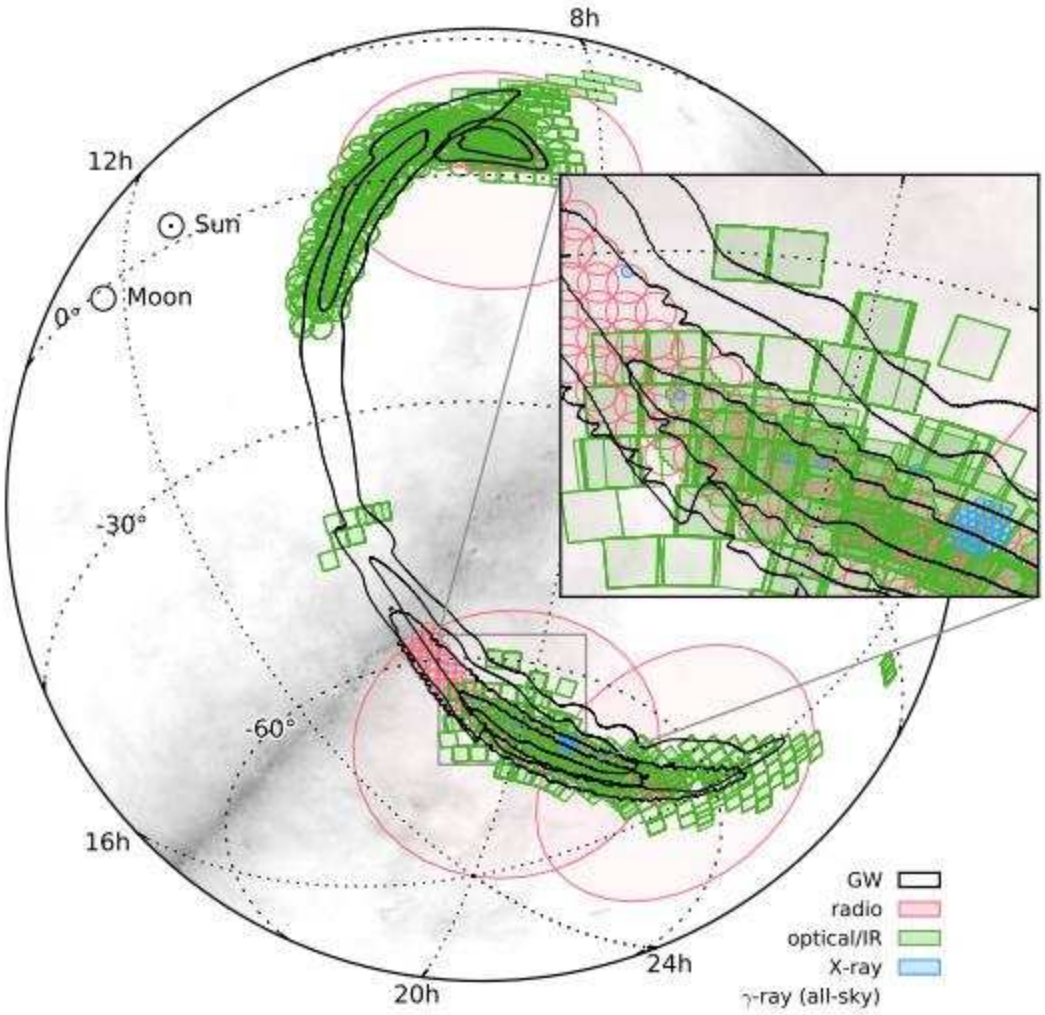
Table 2. Summary of Tiled Observations

Instrument	Band[a]	Depth[b]	Time[c]	Area (deg^2)	Contained probability (%) cWB	LIB	BSTR.	LALInf.	GCN
			Gamma-ray						
Fermi LAT	20 MeV–300 GeV	1.7×10^{-9}	(every 3 hr)	—	100	100	100	100	18709
Fermi GBM	8 keV–40 MeV	$0.7–5 \times 10^{-7}$ (0.1–1 MeV)	(archival)	—	100	100	100	100	18339
INTEGRAL	75 keV–1 MeV	1.3×10^{-7}	(archival)	—	100	100	100	100	18354
IPN	15 keV–10 MeV	1×10^{-9}	(archival)	—	100	100	100	100	—
			X-ray						
MAXI/GSC	2–20 keV	1×10^{-9}	(archival)	17900	95	89	92	84	19013
Swift XRT	0.3–10 keV	5×10^{-13} (gal.)	2.3, 1, 1	0.6	0.03	0.18	0.04	0.05	18331
		$2–4 \times 10^{-12}$ (LMC)	3.4, 1, 1	4.1	1.2	1.9	0.16	0.26	18346
			Optical						
DECam	i, z	$i < 22.5, z < 21.5$	3.9, 5, 22	100	38	14	14	11	18344, 18350
iPTF	R	$R < 20.4$	3.1, 3, 1	140	3.1	2.9	0.0	0.2	18337
KWFC	i	$i < 18.8$	3.4, 1, 1	24	0.0	1.2	0.0	0.1	18361
MASTER	C	< 19.9	-1.1, 7, 7	590	56	35	55	49	18333, 18390, 18903, 19021
Pan-STARRS1	i	$i < 19.2 – 20.8$	3.2, 21, 42	430	28	29	2.0	4.2	18335, 18343, 18362, 18394
La Silla–QUEST	g, r	$r < 21$	3.8, 5, 0.1	80	23	16	6.2	5.7	18347
SkyMapper	i, v	$i < 19.1, v < 17.1$	2.4, 2, 3	30	9.1	7.9	1.5	1.9	18349
Swift UVOT	u	$u < 19.8$ (gal.)	2.3, 1, 1	3	0.7	1.0	0.1	0.1	18331
	u	$u < 18.8$ (LMC)	3.4, 1, 1						18346
TAROT	C	$R < 18$	2.8, 5, 14	30	15	3.5	1.6	1.9	18332, 18348
TOROS	C	$r < 21$	2.5, 7, 90	0.6	0.03	0.0	0.0	0.0	18338
VST	r	$r < 22.4$	2.9, 6, 50	90	29	10	14	10	18336, 18397
			Near Infrared						
VISTA	Y, J, K_S	$J < 20.7$	4.8, 1, 7	70	15	6.4	10	8.0	18353
			Radio						
ASKAP	863.5 MHz	5–15 mJy	7.5, 2, 6	270	82	28	44	27	18363, 18655
LOFAR	145 MHz	12.5 mJy	6.8, 3, 90	100	27	1.3	0.0	0.1	18364, 18424, 18690
MWA	118 MHz	200 mJy	3.5, 2, 8	2800	97	72	86	86	18345

[a] Band: photon energy, optical or near-infrared filter (or C for clear, unfiltered light), wavelength range, or central frequency

[b] Depth: gamma/X-ray limiting flux in erg cm^{-2} s^{-1}; 5σ optical/IR limiting magnitude (AB); and 5σ radio limiting spectral flux density in mJy. The reported values correspond to the faintest flux/magnitude of detectable sources in the images.

[c] Elapsed time in days between start of observations and the time of GW150914 (2015 September 14 09:50:45), number of repeated observations of the same area, total observation period in days


8h
12h
Sun
Moon
0°
-30°
-60°
16h
20h
24h
GW
radio
optical/IR
X-ray
γ-ray (all-sky)

AGILE-GRID provided the most stringent constraint to any delayed emission above 50 MeV shortly after the GW150914 event

AGILE-MCAL did not detect the transient reported by the Fermi GBM team

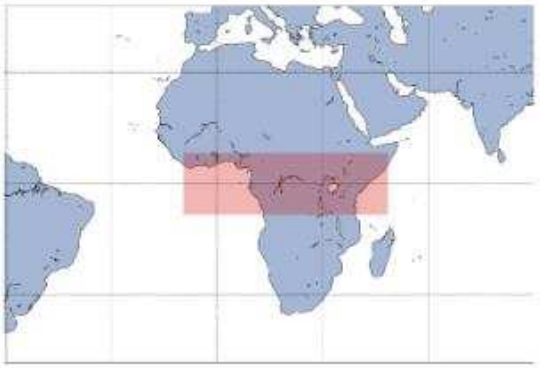
Great potential for AGILE observations of GW error boxes: prompt, minutes, hours, days

(see also December GW event, still under embargo)

- **probability of covering with the imaging GRID-FoV the region (error box) of the prompt GW event: ~ 10% (½ x 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 and TGFs

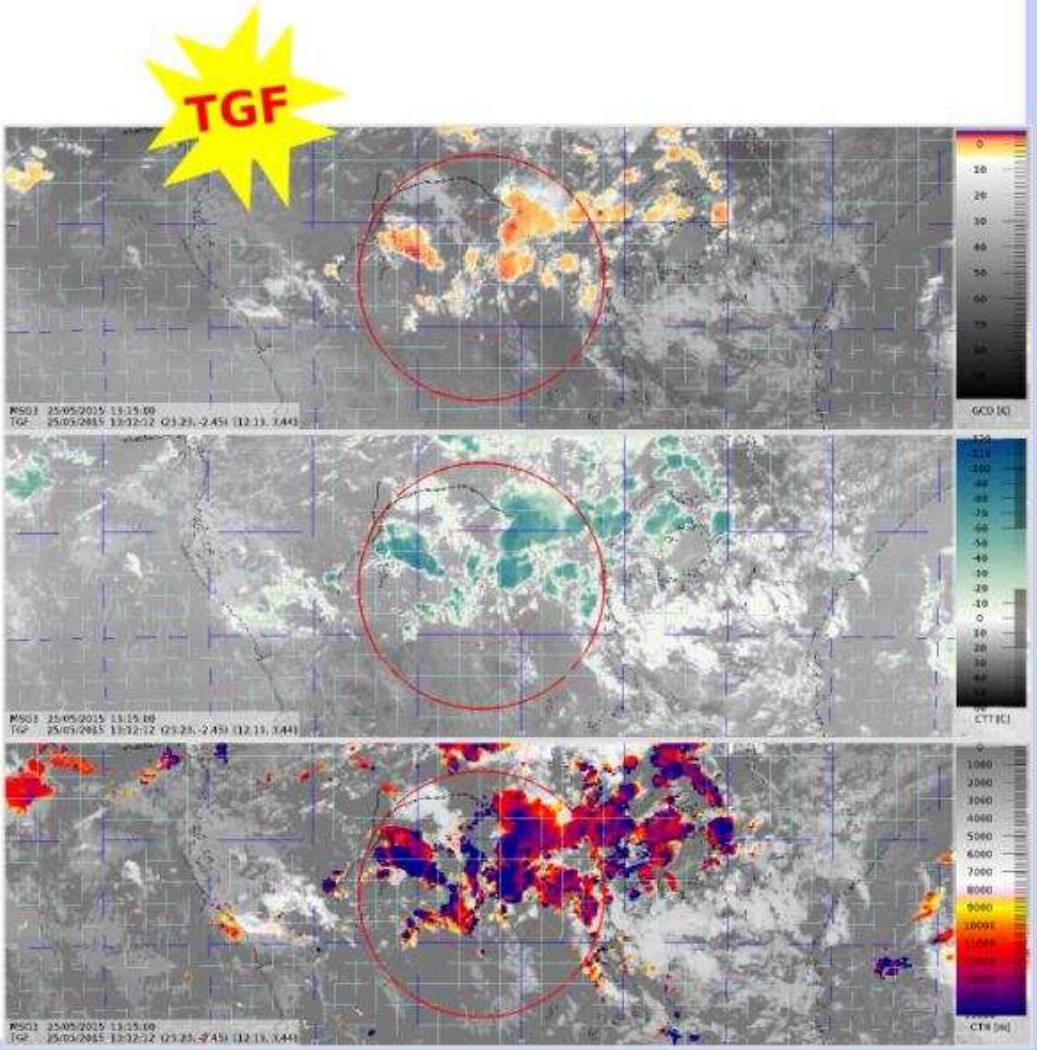
METEO characterization of TGFs



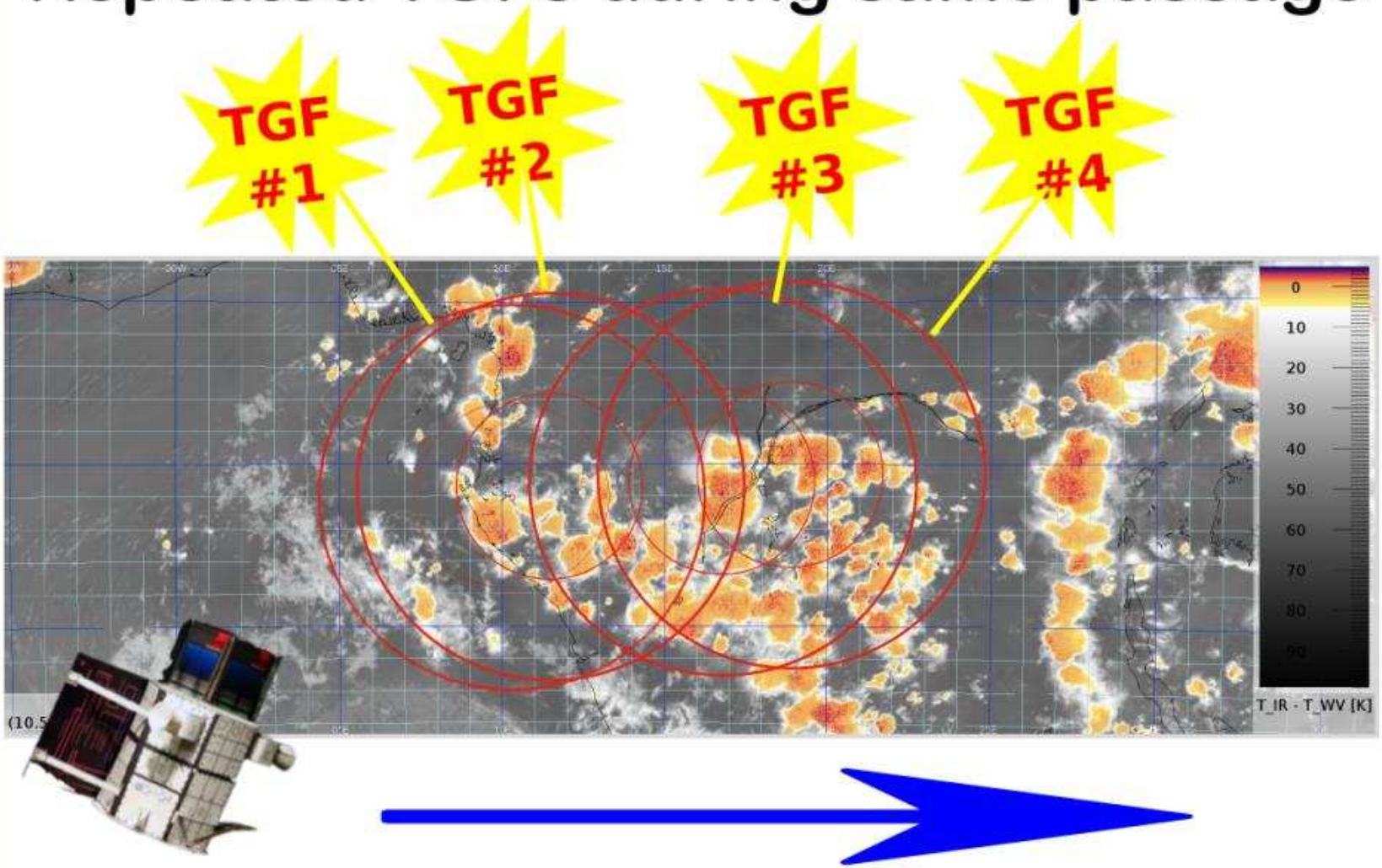
presence of convection

cloud top temperature

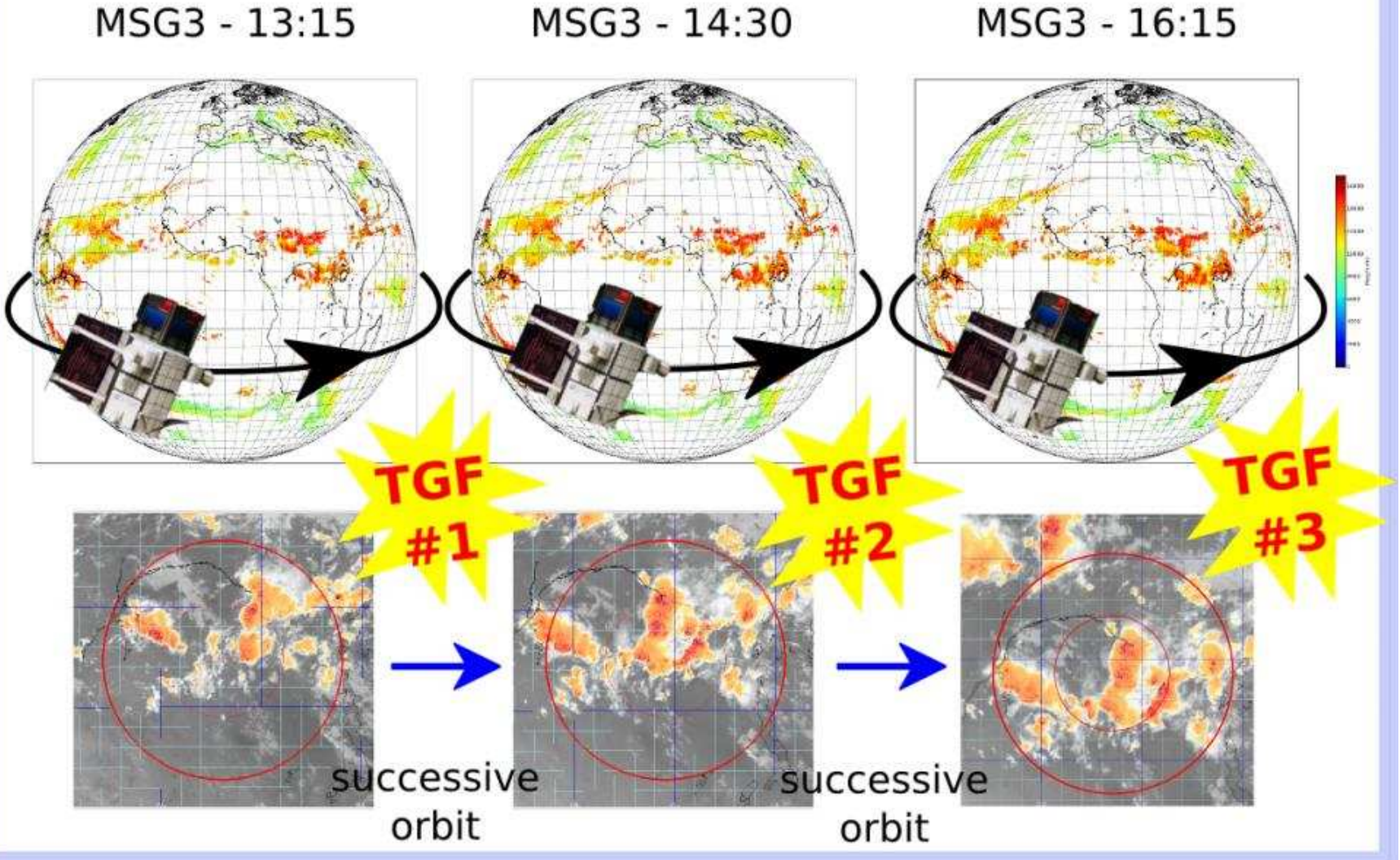
cloud top height



Repeated TGFs during same passage



Repeated TGFs at successive passages



ONLY AGILE

HAS	CAN
WIDE ENERGY RANGE	→ detect hard-spectrum TGFs (up to 100 MeV and more...)
EXTREMELY LOW-INCLINATION ORBIT	→ monitor the same thunderstorm system
HIGH DETECTION SENSITIVITY	→ detect up to 100 events / month
LINK WITH METEO INFORMATION	→ perform detailed studies on the associated meteorology

asdc ASI Science Data Center

agenzia spaziale italiana

INFN Istituto Nazionale di Fisica Nucleare

INAF ISTITUTO NAZIONALE DI ASTROFISICA NATIONAL INSTITUTE FOR ASTROPHYSICS

Consiglio Nazionale delle Ricerche

AGILE 14th Science Workshop
"AGILE on the wave"
June 20 and 21, 2016
ASI Headquarters, Via del Politecnico, Rome

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