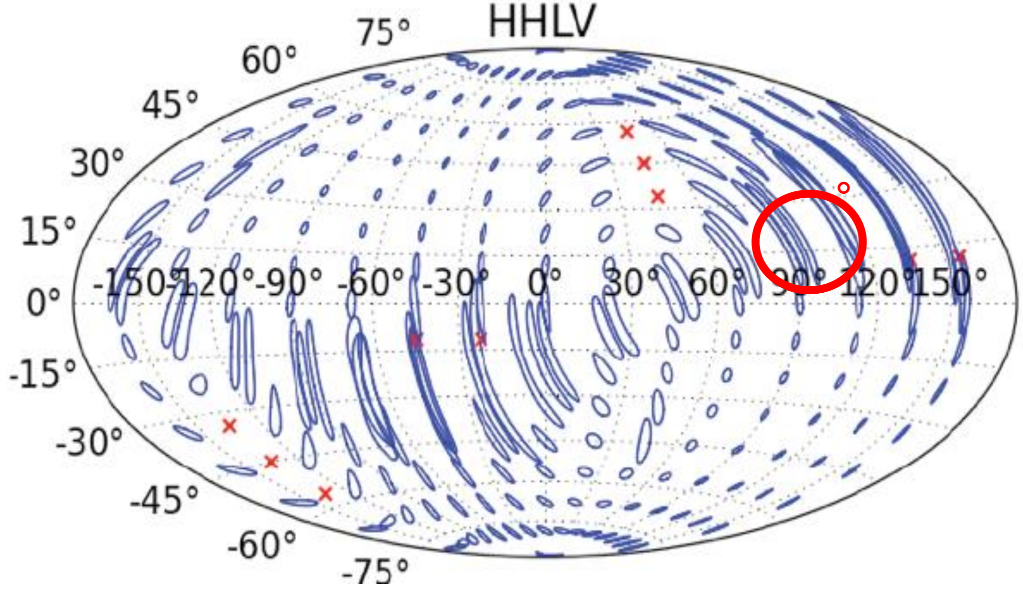
Fermi/GBM localizations of γ-ray bursts



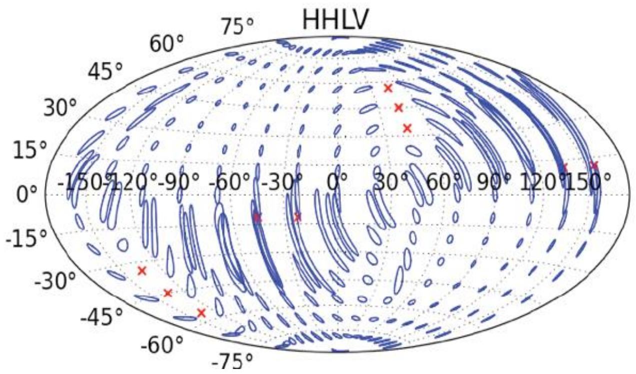
Jochen Greiner
Max-Planck Institut für extraterrestrische Physik, Garching

Collaborators:
Francesco Berlato, J. Michael Burgess, Björn Biltzinger, Felix Kunzweiler

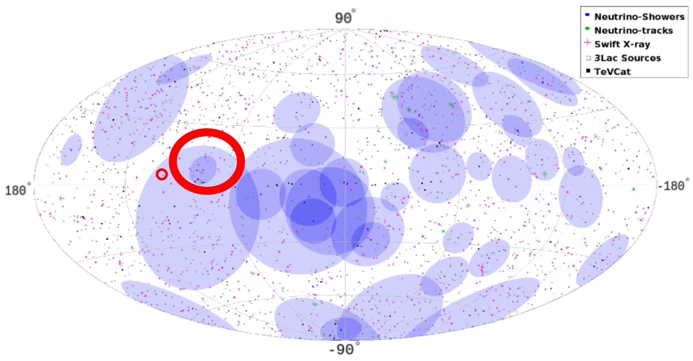
Neutrino or GW Counterpart Search

what matters is: location, location, location…

Abbott+2016, Living Rev. Relativity, 19, 1



Error ellipses with 2 US sites + Virgo

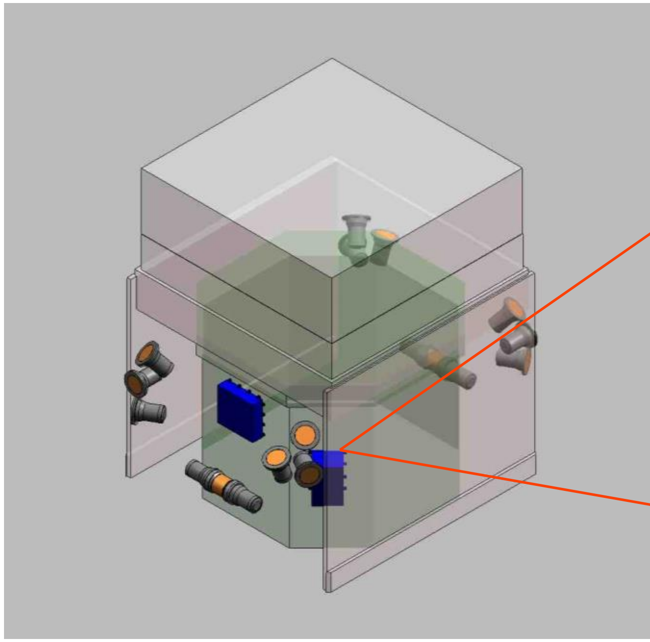


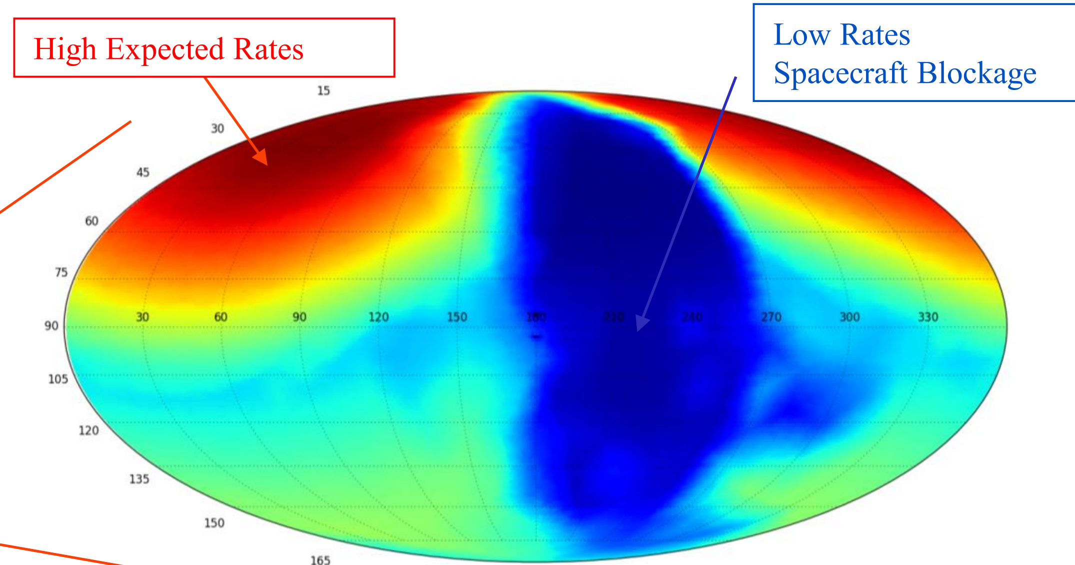
IceCube tracks (1°) vs. showers (~15°)

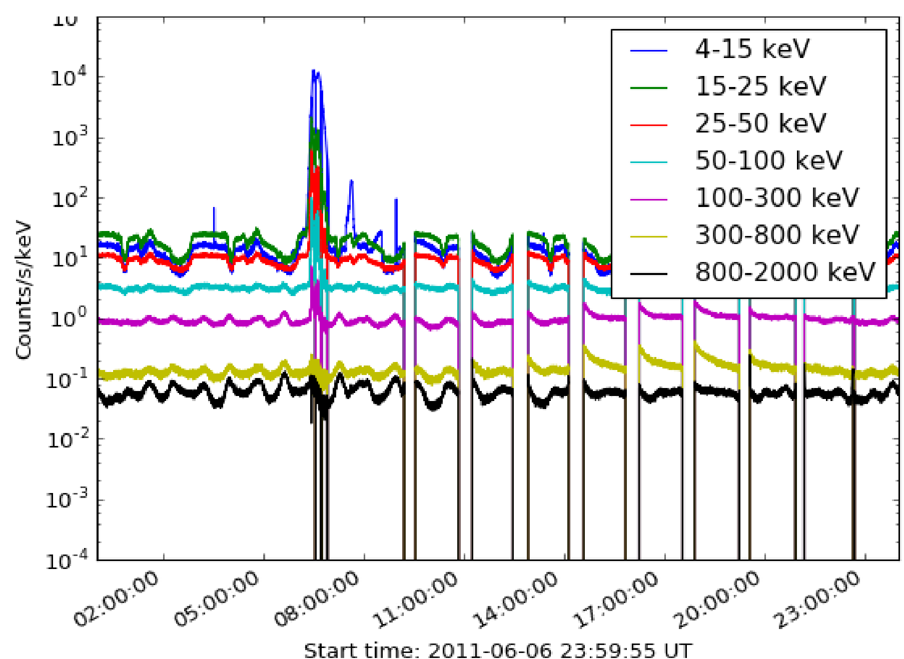
Moharana+2016, PoS ICRC2015, 1122

Previous Fermi/GBM locations do not provide improvements, …but this can be cured

GBM Detection: Sky + Bkg + Earth + Sun





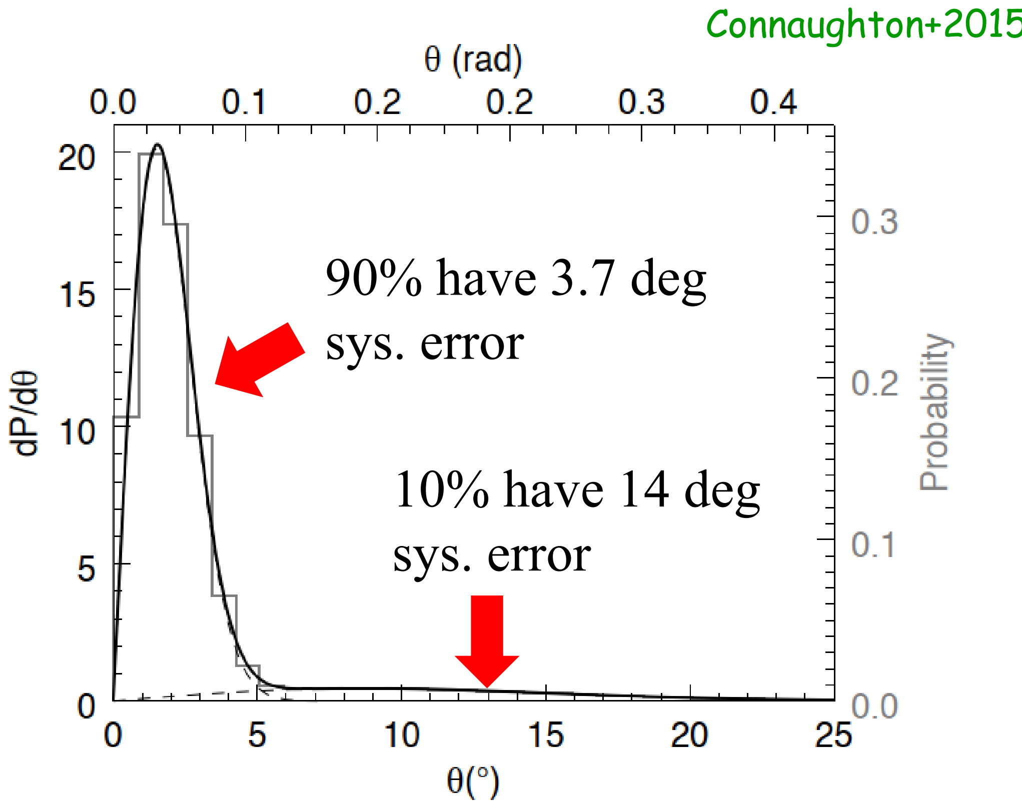


Each detector sees a certain relative fraction of sky (bkg and sources), Earth albedo or blockage, etc

This relative fraction changes with time

At a given time, this fraction is different for each detector

Previous GBM localization performance

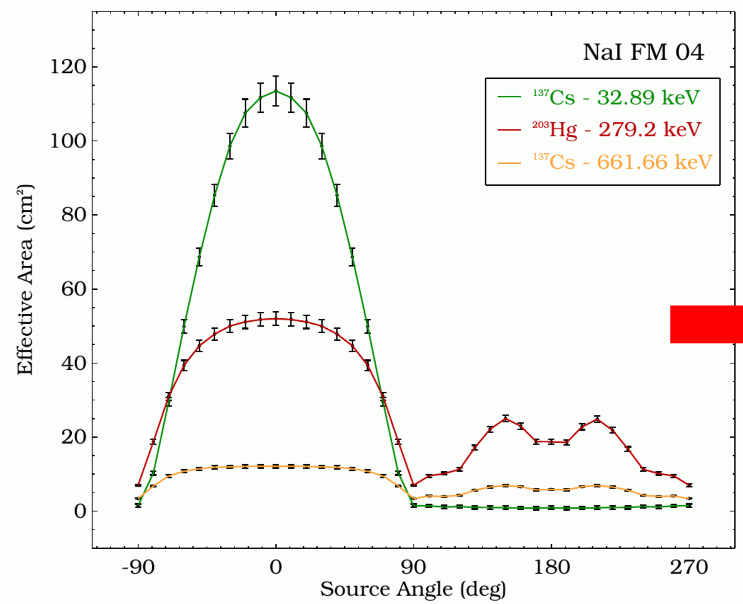


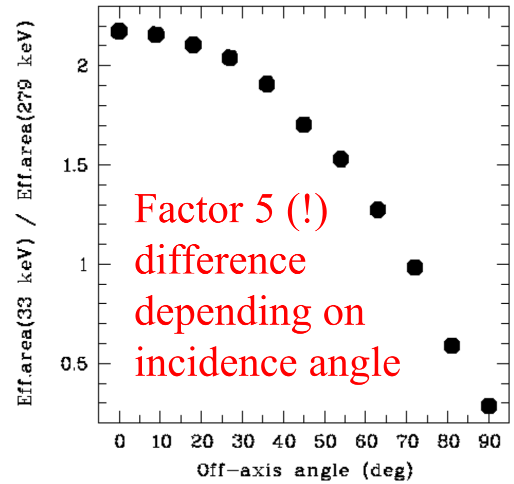
- integrating this function to 95% containment implies $2\sigma_{sys} \sim 16^o$
- only GRBs with statistical error »16^o are not affected by systematics (=4%)

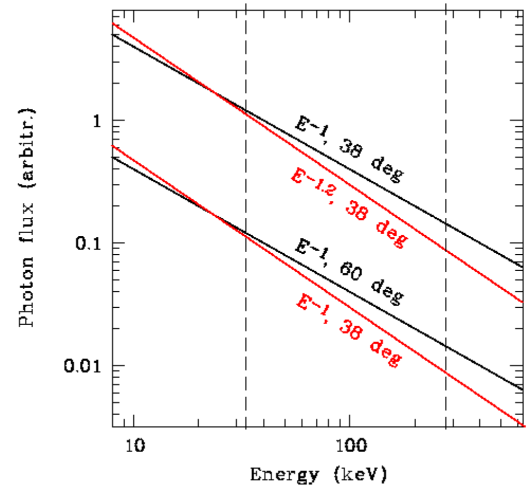
The problem: for a given GRB, we don't know to which of these two components it belongs?

➔ So we have to adopt the large uncertainty for every GRB in order to be on the safe side (in terms of counterpart search)

GBM localization algorithm







➔ being 0.1 off in slope ≡ 10° off

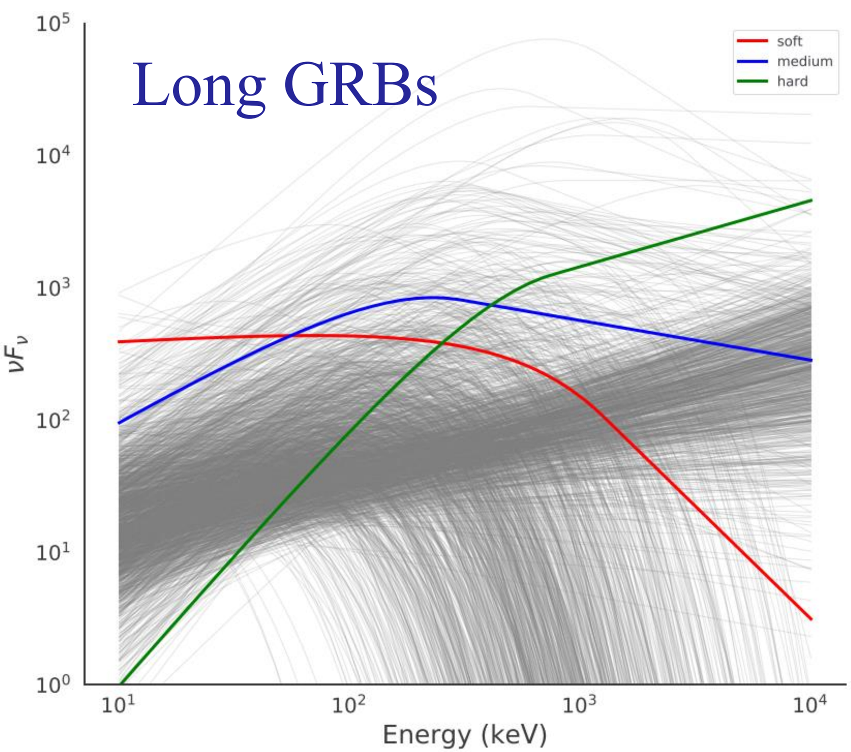
- Principle: Relative response at different energies varies with off-axis angle
- So far: same spectral template spectrum is assumed for all (long/short) GRBs to compute model rates, and a position is derived via comparison to the relative observed rates in each detector on a 1° grid on the sky

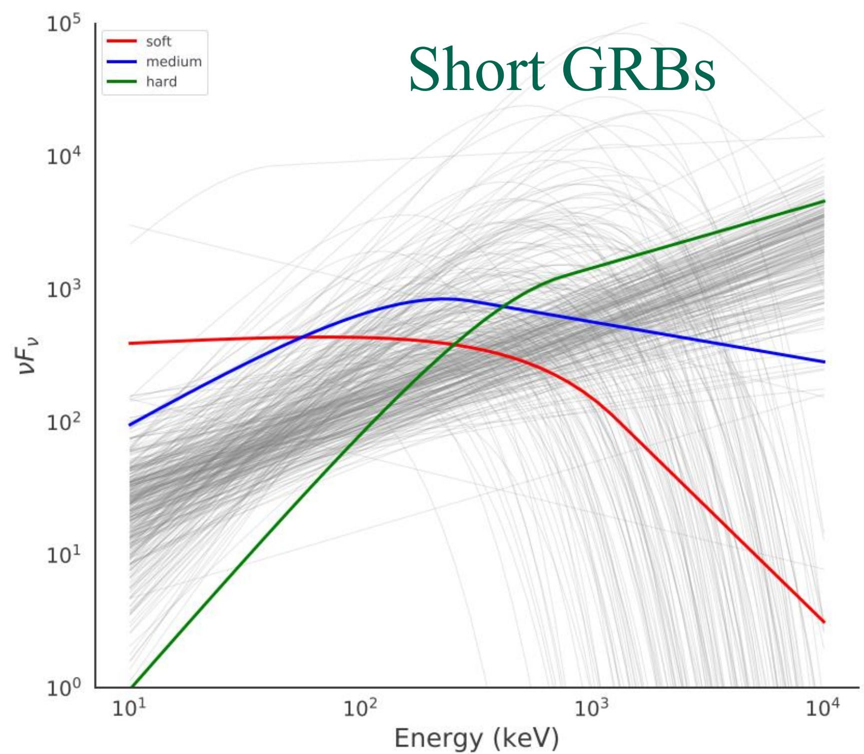
Connaughton+2015

- Previous Fermi/GBM (and CGRO/BATSE) method has large systematic error:
- Correct way: fit spectrum and position at the same time ➔ BALROG

Spectral templates for position determination

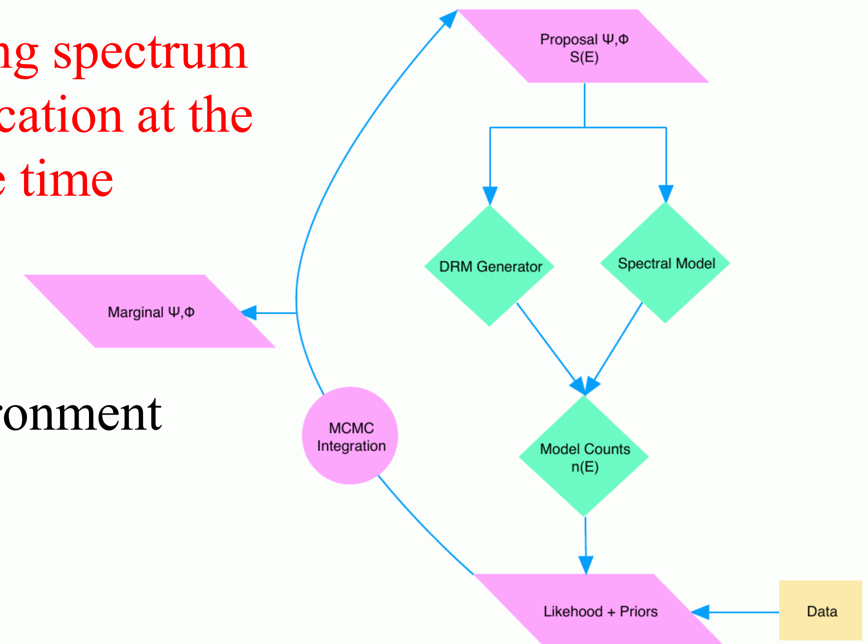
	alpha	beta	Epeak	application
Soft	-1.9	-3.7	70 keV	sol flares, SGR
Moderate	-1.0	-2.3	230 keV	long GRBs
Hard	0.0	-1.5	1 MeV	short GRBs





BALROG

Fitting spectrum & location at the same time



- "corrects" systematics in GBM location
- easily implemented on desktop/cluster environment with a built-in Pythonic user interface
- dramatic effect on spectral parameters

Burgess, Yu, Greiner (2016)

Likelihood Model

$$-2\log L = 2\sum_{i=1}^{N} \underline{M_i(\vec{\phi},\vec{p})} + t_s f_i - D_i \log(\underline{M_i(\vec{\phi},\vec{p})} t_s f_i) + \frac{1}{2\sigma_{B,i}^2}(B_i - t_s f_i)^2 - D_i(1-\log D_i)$$

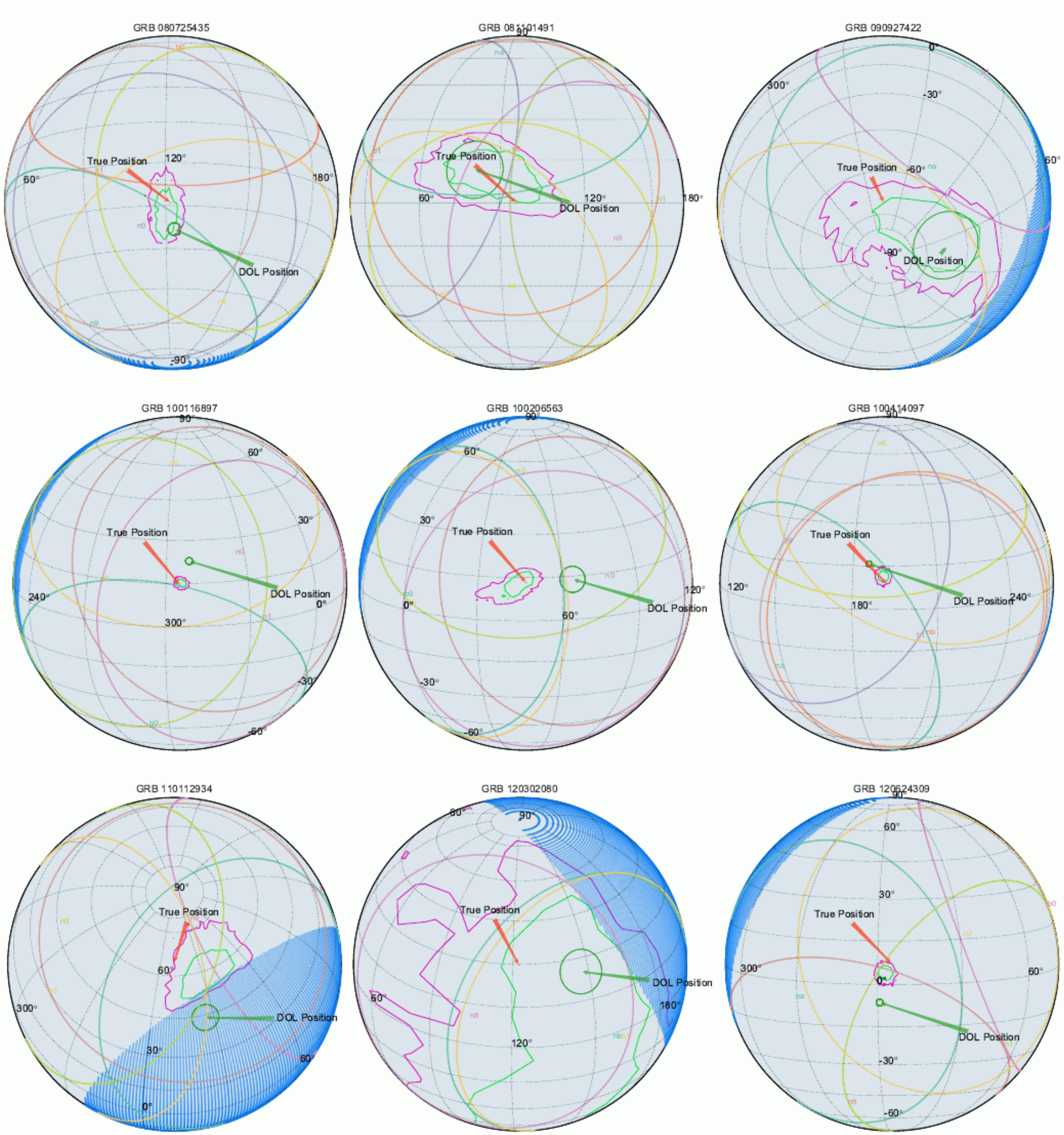
Position-dependent

p=position, Φ=spectral par.

B_i=bkg cts, $\sigma_{B,i}$=Gaussian error in ith channel

D_i=observed total data cts

BALROG results on GBM/Swift GRBs



- Statistical errors about 30% larger, as they incorporate the location uncertainty
- Proof of concept against 115 Swift localized GRBs (2008-2018): For all the statistical 3σ + systematic error contour includes the true position when $\sigma_{sys} \sim 1^{o}$ (2^{o}) (s/c dep.)
- Paradigm shift: problems since 1991 (CGRO/BATSE)

Berlato+2019

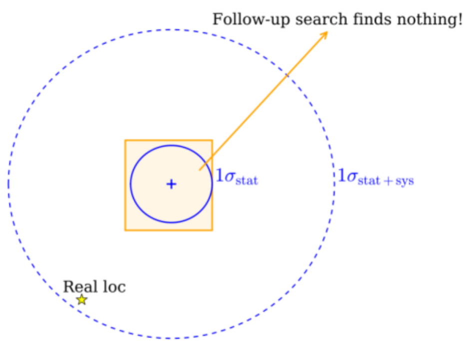
Fermi/GBM Localizations

- Previous Fermi/GBM (and CGRO/BATSE) method has large systematic error:

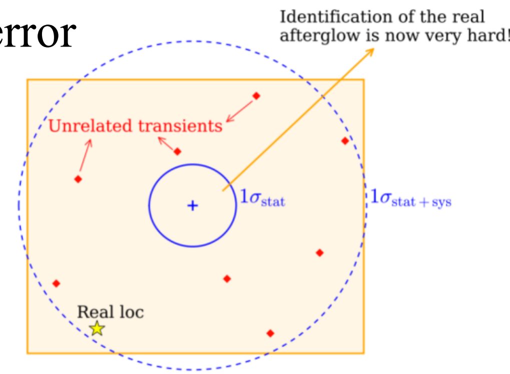
Connaughton+2015

Connaughton+2015

Last 30 years until present ("official" GBM team)

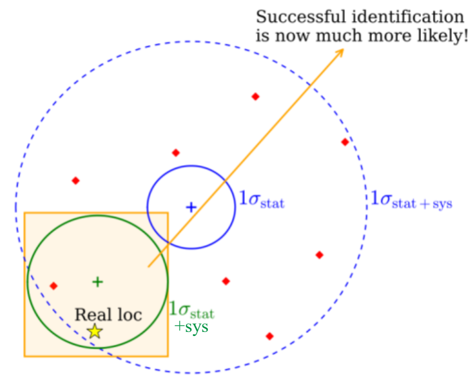


This would be the correct way with the previous systematic error

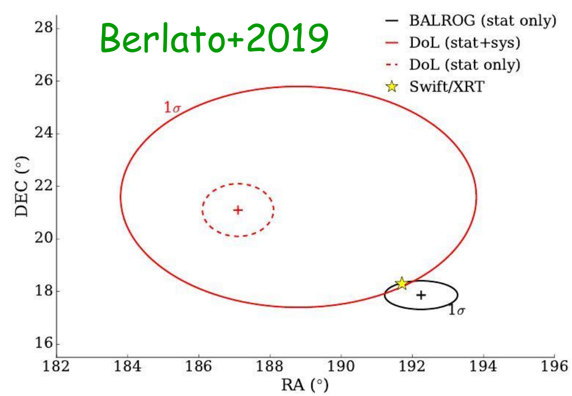


Berlato+2019

Our improved method (BALROG) since 2017

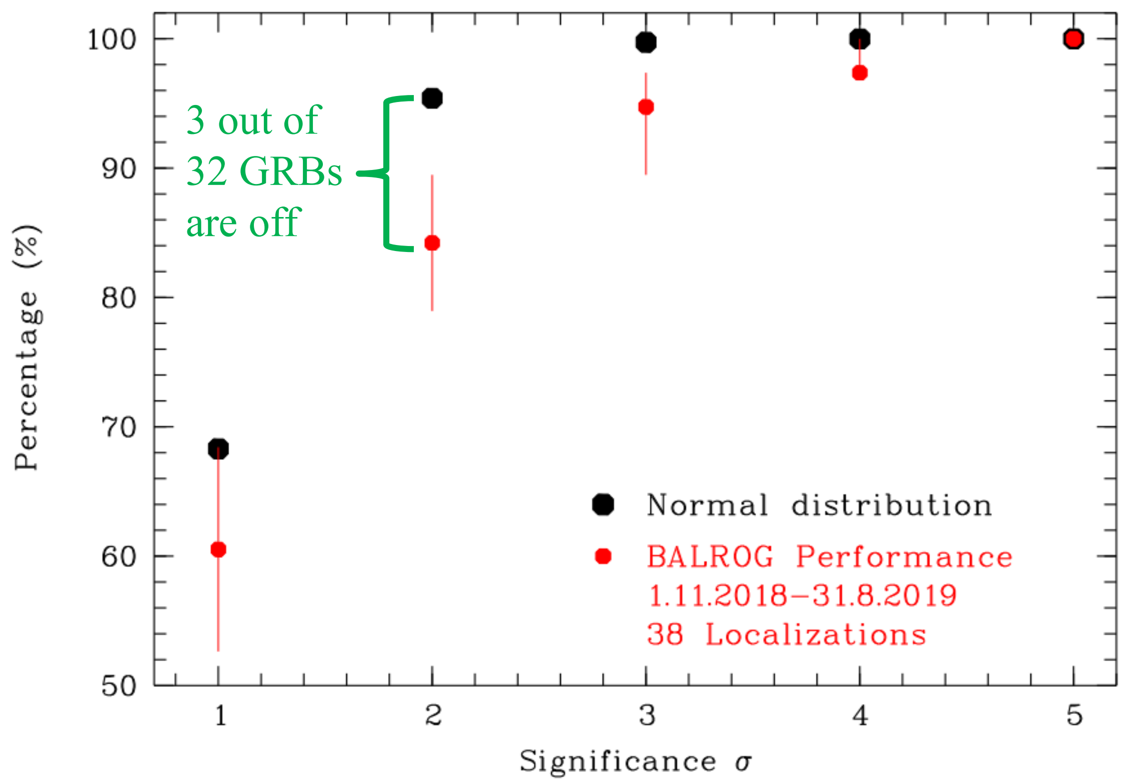


Example from real life: GRB 170705.115



Performance of the Automatic BALROG

- 225 localizations computed in real-time since Nov. 1, 2018
- 38 have accurate localizations from Swift/MAXI/INTEGRAL/IPN
- Percentage of GRBs, containing the accurate position within their 1σ, 2σ or 3σ error region:



Consequences for follow-up

Berlato+2019

- Size of sky area reduces by substantial fraction:
  - for 96% of GRBs where 2σ stat. < syst.…
  - …the search regions would have to be inflated by 800 deg^2 (DoL) vs. 50 deg^2 (BALROG's systematics)
  - …96% of all DoL-localized GRBs come with inflated error region (only 4% have a statistical error larger than the DoL systematics)
- Smaller size also implies much less tiling by small(er)-FOV instruments
- Smaller size has substantially smaller number of false positives: ZTF finds roughly 3 variables per deg^2 per night!

Future: multi-λ instruments

Wavelength	# src / □°	FOV	Sensitivity	instruments
γ-rays	0	++	-	Fermi/GBM, INTEGRAL/ACS, IPN
X-rays	2	+	--	Swift (tiling), MAXI
UV	10	--	-	-
Optical/NIR	1000	+	-	many
IR	50	--	--	-
Radio	2	-	-	LOFAR

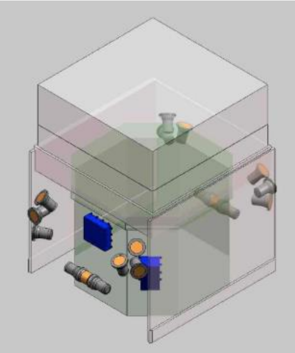
➔ Largest progress possible: with new, more sensitive γ-ray detector(s)

Four Different Localization Methods

Relative rates in different detectors

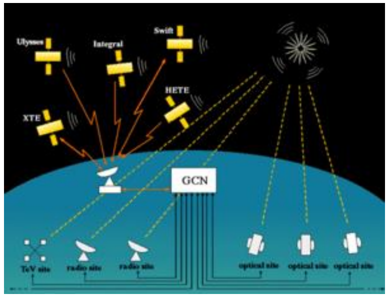
cheap, but localization accuracy ≥1°

Fermi/GBM



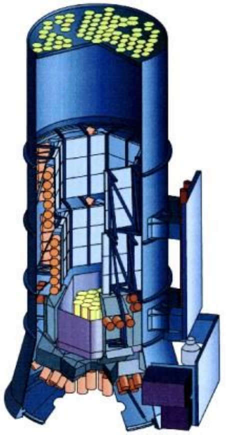
Relative arrival times at different detectors

cheap, localization accuracy depends on detector size, time resolution and satellite distances



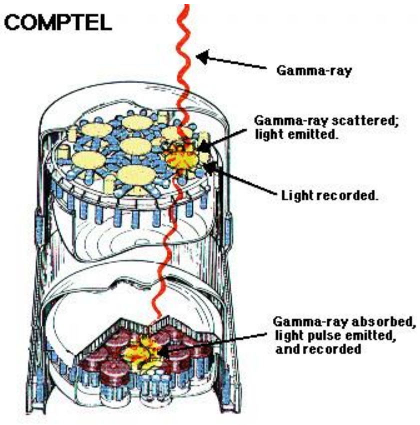
Interplanetary network

INTEGRAL (IBIS/SPI)



Coded mask

large size, small field-of-view

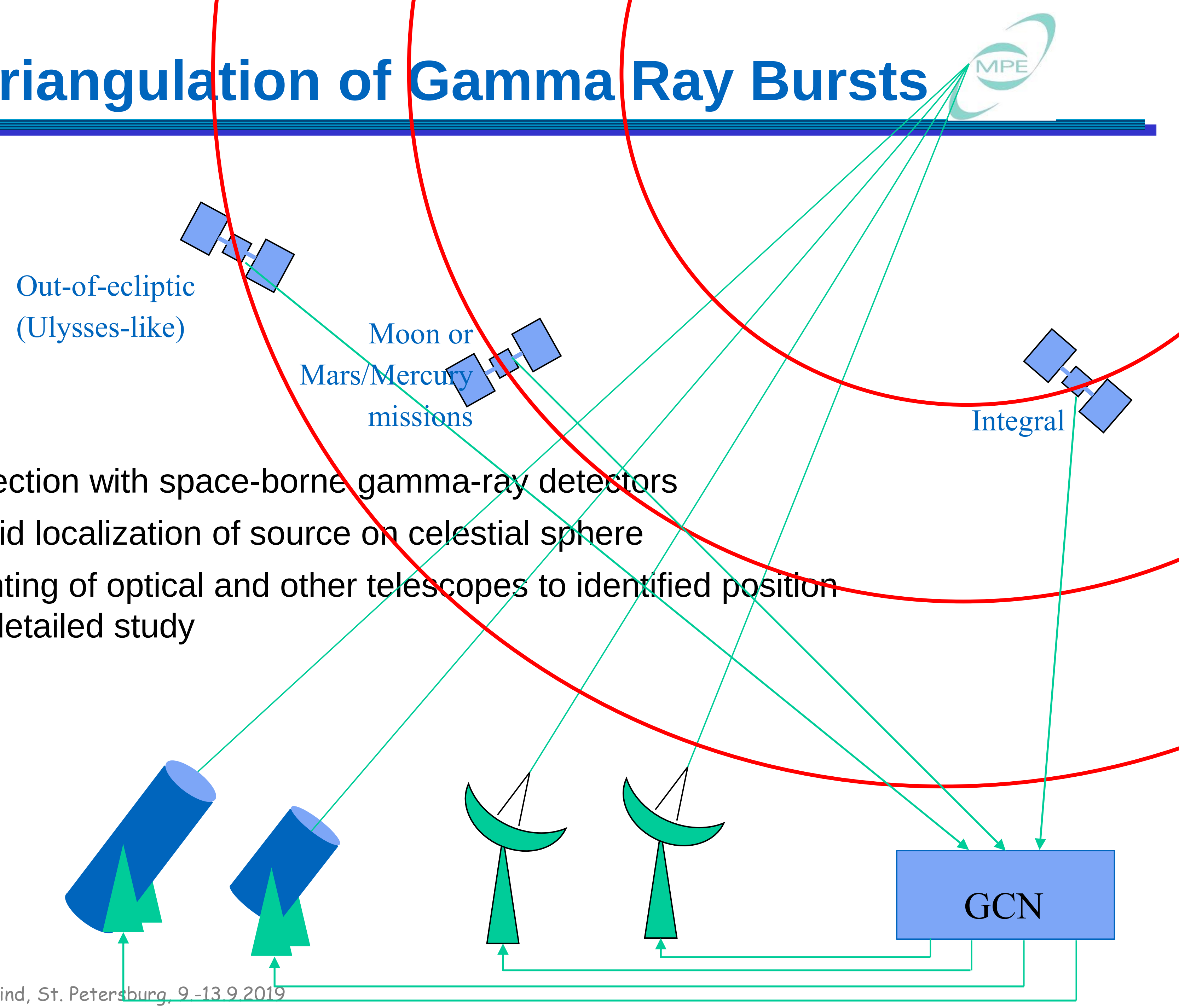


Compton camera

heavy and expensive

COMPTEL
eAstrogam

Triangulation of Gamma Ray Bursts



- Detection with space-borne gamma-ray detectors
- Rapid localization of source on celestial sphere
- Pointing of optical and other telescopes to identified position for detailed study

Summary

- BALROG provides accurate localizations with ~10x smaller (systematic) error, primarily for strong GRBs
- …within ~30 min
- …via GCN,
  or automatically after sign up at https://grb.mpe.mpg.de
- …updated with TTE data after ~1-6 hrs (data availability) (just on Web-page; no GCNs)
- Most promising rapid (few years) route to better localizations: detectors somewhat bigger than Konus on interplanetary s/c

Reply to M. Briggs / arXiv:1909.03006

- It is nice to see that 3 years after we suggested BALROG, the Huntsville team has finally recognized that their templates are a big problem, and now have changed them
- It is hard to understand why they still don't do the final step of fitting position and spectrum together
- It is nice to see that our publicly available BALROG code is used! Fairness implies that they make their code public as well.
- It is irritating to see that upon problems in using that code they don't dare to ask about clarifications, but submit a paper draft to arXiv with lots of strange (if not to say wrong) statements
- The plot shown by M. Briggs is irrelevant – it is not the offset what counts, but its ratio to the quoted error! A GBM position should come with its appropriate statistical and systematic error, which has not been the case, and is still not the case for Huntsville-issued GCNs!