# Finding Fermi GBM Counterparts to LIGO/Virgo Gravitational-Wave Candidates

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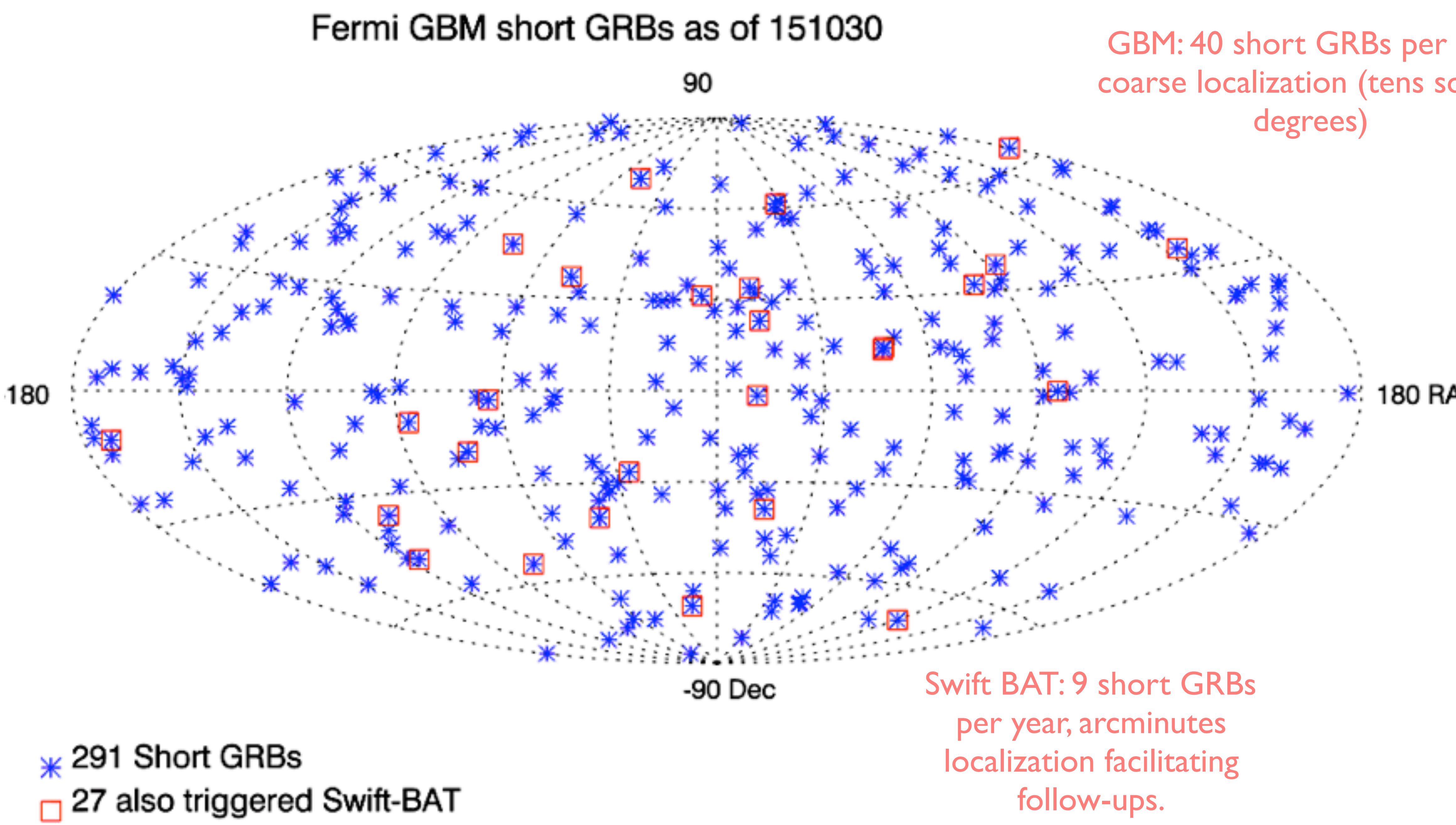
# Owing to all-sky coverage, Fermi GBM detects and localizes more short GRBs than other GRB detectors.



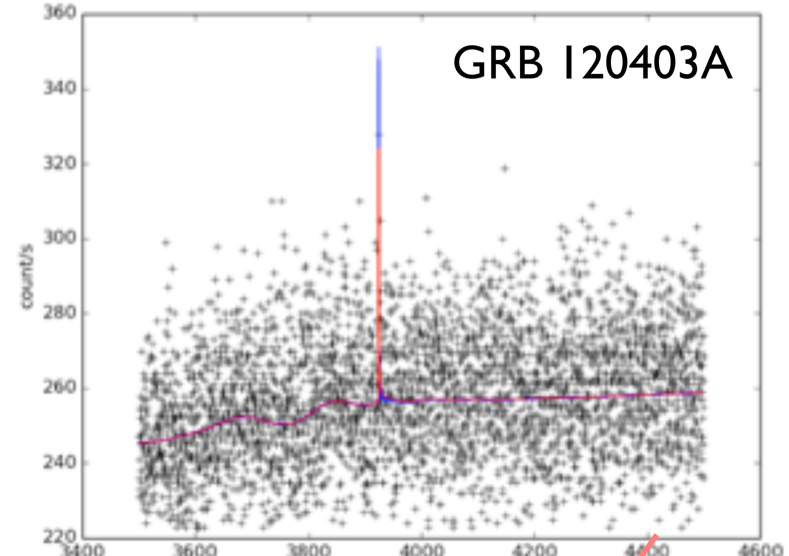

GBM: 40 short GRBs per year, coarse localization (tens square degrees)

Swift BAT: 9 short GRBs per year, arcminutes localization facilitating follow-ups.

Fermi GBM and Swift BAT detect the same population of short GRBs: we shall assume they all come from mergers of binary neutron star systems (could also be neutron star - black hole).

- Swift BAT does not see a separate class of collapsar short GRBs that dominate the long-duration end of the short GRB population.
- Swift BAT sees some weaker GRBs than GBM close to its fully-coded center but its sensitivity drops off faster towards the edge than it does for long GRBs.
- Fermi GBM short GRB sensitivity is more even over its field-of-view.
- These effects are a wash and GBM and BAT have short GRB detection rates that reflect their fields-of-view.
- See poster by Eric Burns for study of short GRBs detected/not detected by Swift BAT/GBM, and arXiv.xxxx

# Most of the Swift BAT short GRBS that did not trigger GBM are found in a ground search of the Continuous Time-Tagged Event (CTTE) data for untriggered bursts.




Missed GRBs are either weak (detected close to BAT's boresight) or at large offset to Fermi boresight.

Missed GRBs are not systematically long i.e. collapsars masquerading as mergers

| | BAT | | | | | GBM | | |
|---|---|---|---|---|---|---|---|---|
| GRB (Name) | $T_{90}$ (sec) | Fluence (%ile) | Peak Flux (%ile) | PL Index | Partial Coding | LAT offset (degrees) | # of NaI detectors | Ground (signal) |
| 140606A | 0.34 | 34.1 | 6.7 | 0.53 | 86 | 91 | 3 (18, 49) | Strong |
| 120403A | 1.25 | 61.0 | 40.0 | 1.64 | 50 | 71 | 3 (32, 33) | Strong |
| 140516A | 0.19 | 8.5 | 6.7 | 1.87 | 75 | 31 | 3 (18, 31) | Weak |
| 090305A | 0.40 | 52.4 | 64.0 | 0.86 | 50 | 97 | 1 (39, 69) | Weak |
| 140129B | 1.36 | 47.6 | 28.0 | 2.23 | 100 | 14 | 3 (33, 53) | None |
| 110112A | 0.50 | 14.6 | 6.7 | 2.14 | 87 | 135 | 1 (45, 66) | None |
| 090815C | 0.60 | 28.0 | 16.0 | 0.90 | 76 | 116 | 1 (43, 86) | None |

Recovered in untriggered search

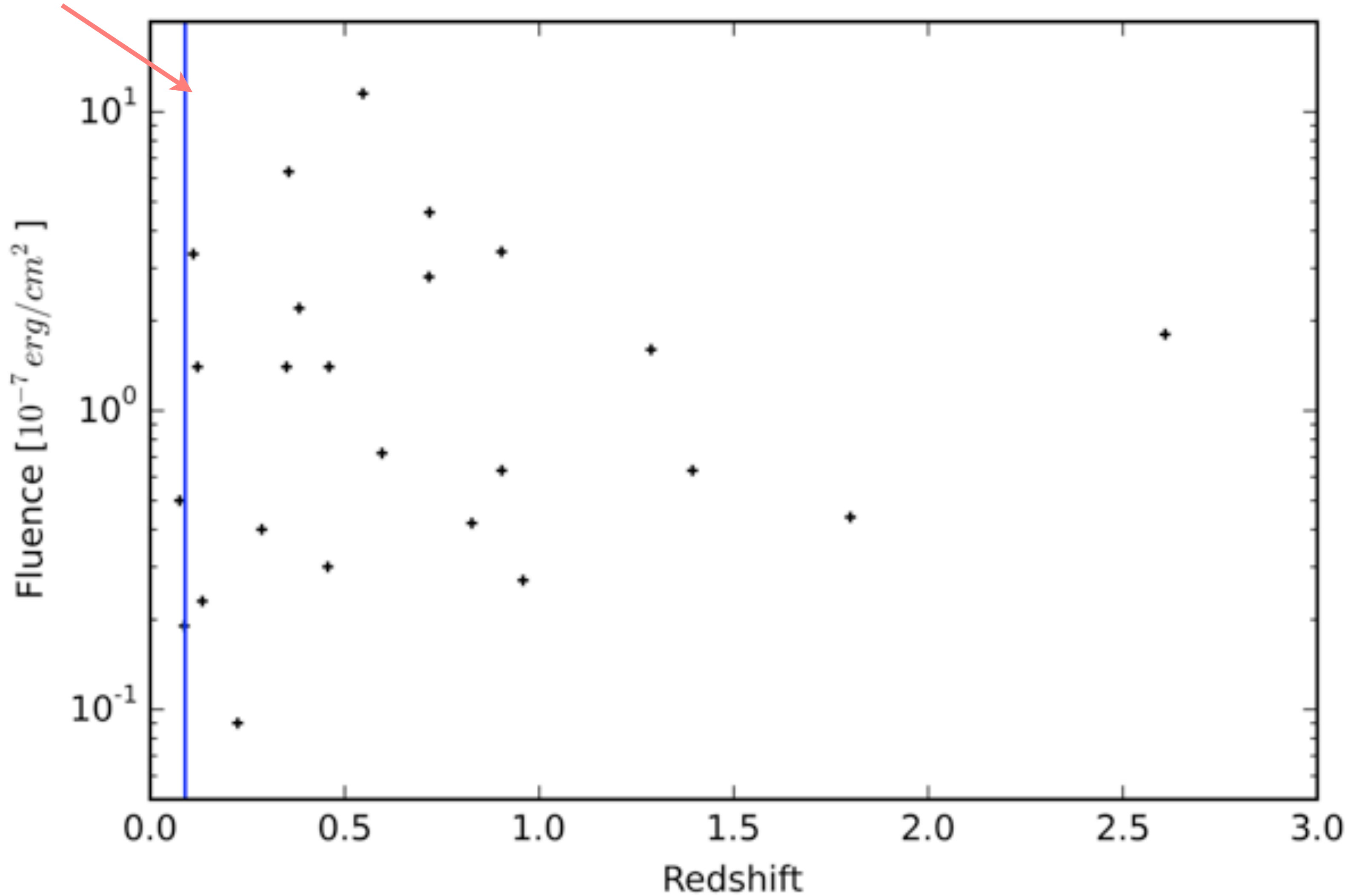
Oddbod - can be found in <50 keV data, v. soft, not like GRB

Pre-date availability of CTTE

- GBM GRBs Swift BAT misses can also generally be found in ground search.
- Finding weaker short GRBs when search seeded by other instrument motivate blind search
- We expect 2x more short GRBs through this untriggered search: quality control in progress.

Weak short GRBs are not necessarily more distant than bright short GRBs and may lie within the detection horizon of LIGO/Virgo.

LIGO/Virgo detection horizon for on-axis events with favorable sky position




- Extrapolating from sGRBs with known redshift gives <0.5 - 5 per year sGRB for GBM within LIGO/Virgo horizon (nearby z uncertain).
- This number is doubled with unseeded search for GRBs that do not trigger on-board.

# The significance of sub-threshold LIGO/Virgo candidates is strengthened with a coincident gamma-ray signal

- Joint GBM-subthreshold search developed for LIGO/Virgo S6 science runs in 2009-2010 (L. Blackburn et al. ApJS 2015, 217, 8) - GBM background characterized and likelihood-based search finds known short GRBs in GBM data.

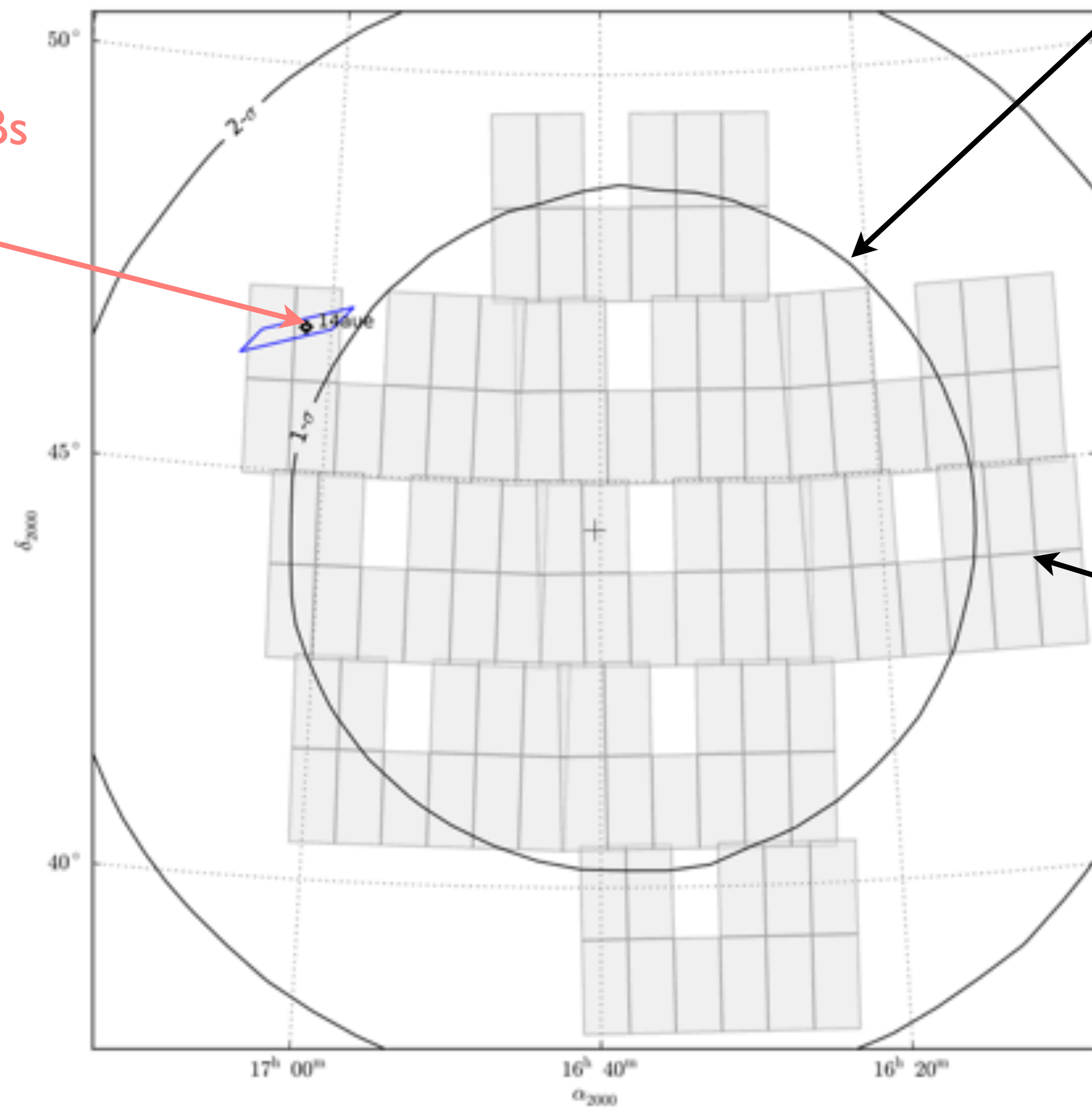
- Sensitivity of LIGO/Virgo search can be improved by ~15 - 20 % relative to LIGO/Virgo alone (Blackburn et al. ibid; Kelley, Mandel & Ramirez-Ruiz 2013, PhRevD 87, 123004).

- The GBM-LIGO/Virgo team has grown, Lindy Blackburn, Michael S. Briggs, Eric Burns, Jordan Camp, Nelson Christensen, Valerie Connaughton, Tito del Canto, Adam Goldstein, Peter Jenke, Tyson Littenberg, Judith Racusin, Peter Shawhan, Leo Singer, Colleen Wilson-Hodge, Binbin Zhang, pipelines have evolved and the search is up and running for LIGO O1:

- Details of LIGO/Virgo-seeded search of GBM data in poster by Lindy Blackburn

# Tiling of GBM localization error regions can be done and afterglows can be found!

GRB 140508A




One of 8 confirmed afterglows of GBM GRBs by iPTF

The GBM team has characterized localization uncertainties (VC+ ApJS 2015, 216, 32) + Poster by Rachel Hamburg)

We distribute probability maps to aid follow-up observers

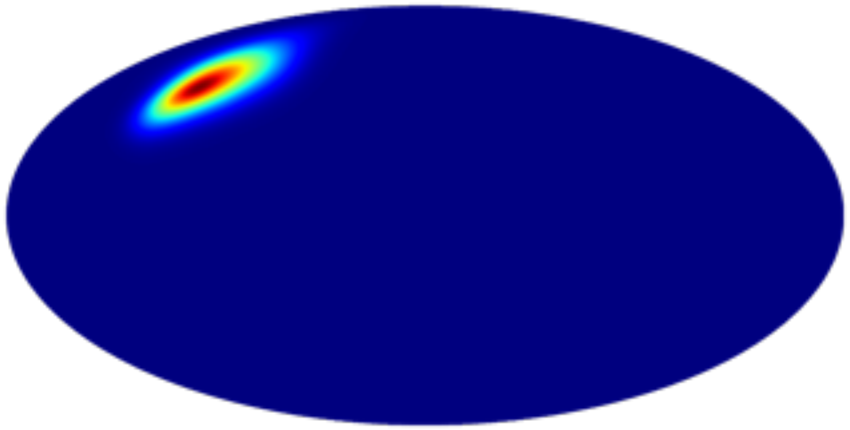
iPTF tiles as much of uncertainty region as possible. 8/40 successes, reported in L. Singer et al. ApJ 2015, 806, 52

No success with short GRBs - upgrade iPTF to ZTF goes from 1 to 8 deg FoV

- RECENT! Improved ground-automated localization using more data/smarter algorithm
- NEW! Short/Long flag in GCN notice
- IMMINENT! Probability contours with automated ground locations within seconds
- VERY SOON! Replacement of human-in-loop ~1 hr post-trigger with automated, 10 min after trigger

# Even a large banana and a large orange can help: using joint GBM-LIGO/Virgo detections and GBM non-detection to guide follow-up observers

Typical GBM GRB localization region for weak GRB



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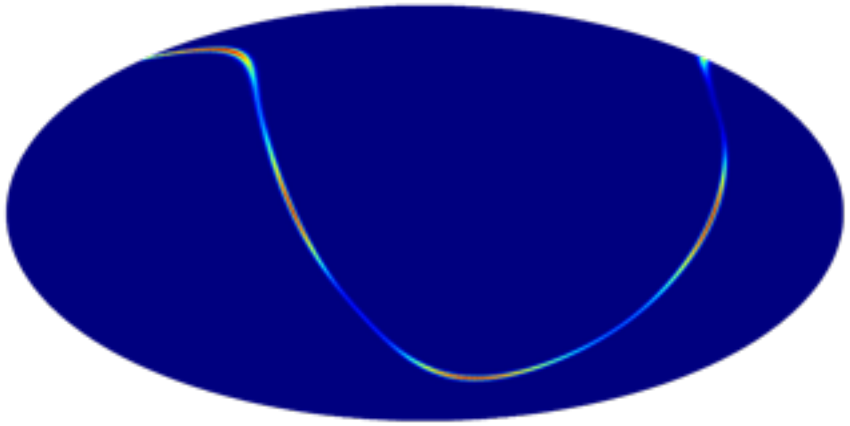
Typical LIGO localization region from http://www.ligo.org/scientists/first2years/: changes in 2016 with addition of Virgo



18 +/- 5 nearby galaxies (N. Gehrels et al. 2015, arXiv:1508.03608)

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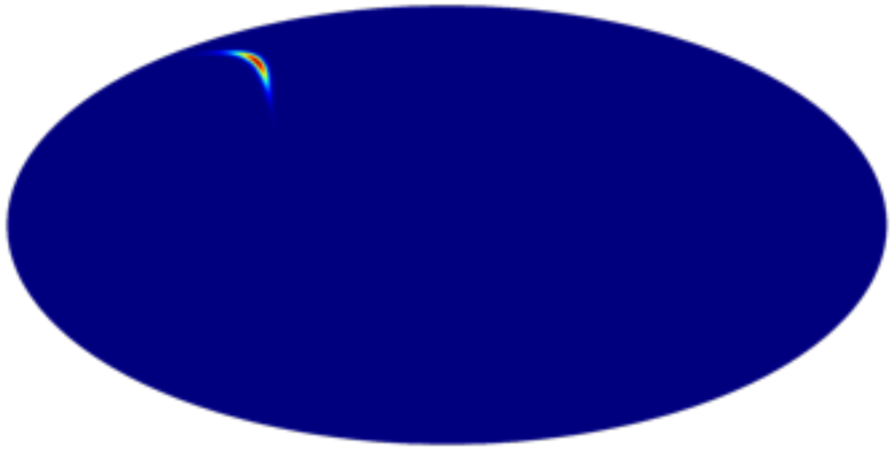

Typical reduction of 80% in sky region:

4 nearby galaxies: easier to follow up with XRT or optical telescopes.

- Using the non-detection of a GRB (triggered or untriggered) by GBM or Swift: limiting the sky region to that not viewed by either instrument reduces LIGO sky region by about 50%, assuming on-axis GW candidate with sGRB above detection threshold.
- Taken from E. Burns at Swift meeting (and in prep) http://www.clemson.edu/ces/physics-astro/conferences/Swift2015

# GBM can contribute in many ways to the breakthrough observations of gravitational wave radiation

- A detection by GBM of a short GRB in coincidence with LIGO/Virgo strengthens the significance of the GW detection
- Sub-threshold searches of GBM data for short GRBs may yield twice as many short GRBs within the LIGO/Virgo horizon
- Swift BAT can find and localize on the ground GBM GRBs, facilitating follow ups.
- Observing GBM localization regions of 10s sq degs has been successful!
- Joint GBM-LIGO/Virgo sub-threshold searches can find candidates that would otherwise go undetected
- GBM localization regions can greatly reduce (by 80%) the region of sky to be observed at lower energies
- The non-detection of GBM short GRBs can similarly limit the follow-up region for on-axis merger afterglows.

- Next Huntsville GRB workshop: 24 - 28 October 2016, in Huntsville AL. Organizers: VC, Neil Gehrels, Adam Goldstein. Details soon!