Joint Localization between gamma-rays & gravitational waves, new IPN

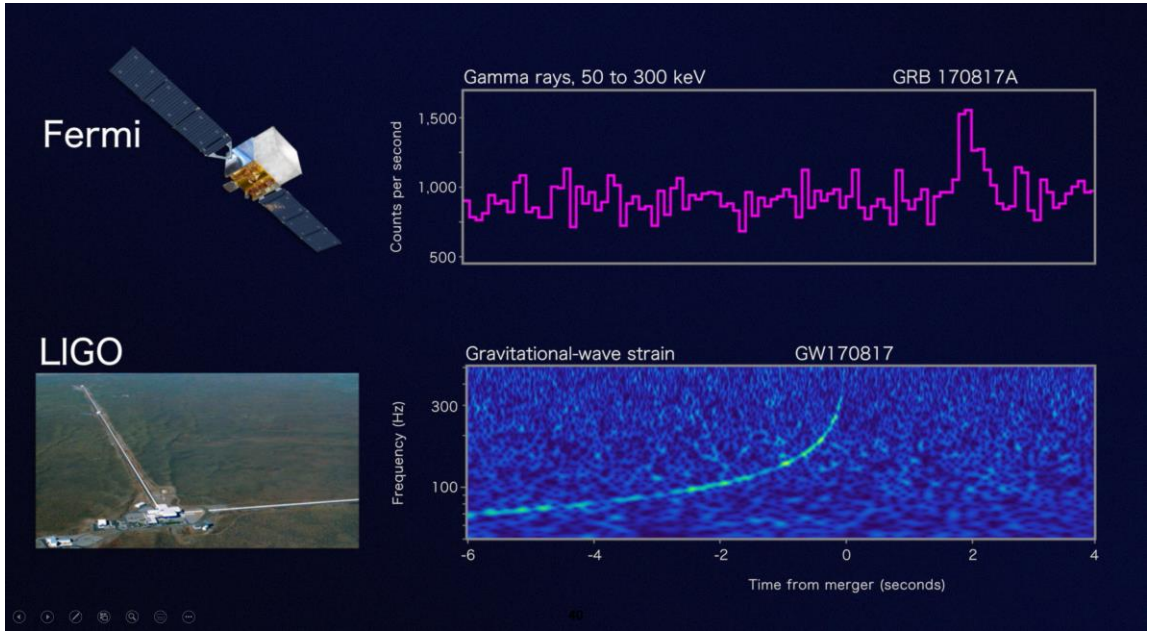
Eric Burns (Louisiana State University)

On behalf of a lot of people, including ~20% of this conference Elisabetta Bissaldi, Michael Briggs, Rachel Dunwoody, Adam Goldstein, Michelle Hui, Daniel Kocevski, Israel Martinez-Castellanos, Joseph Manga, Sheila McBreen, Pi Nuessle, Jeremy Perkins, Judith Racusin, Oliver Roberts, Leo Singer, Aaron Tohuvavohu, Anastasia Tsvetkova

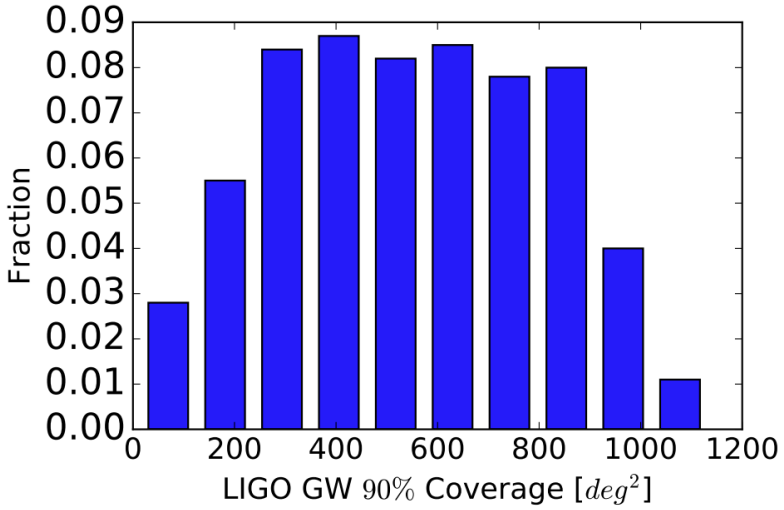
And a lot of teams and collaborations

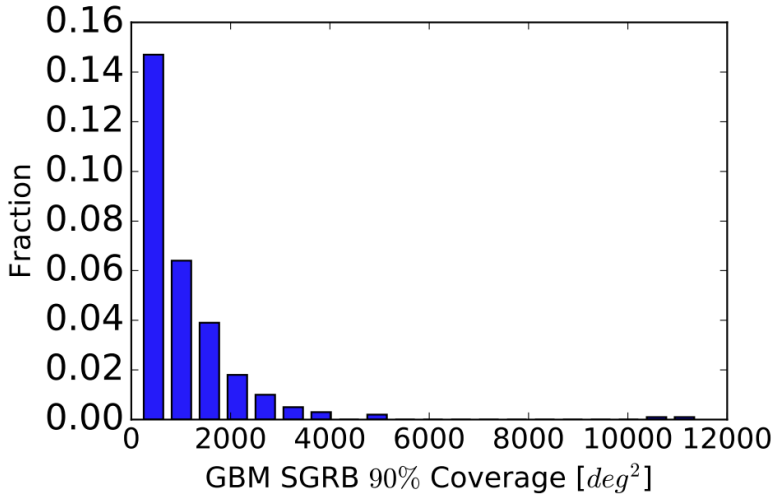
The GW-GRB Working Group

- 1 decade old; ~40 active members
  - 2012 – 2017; Organizers: Valerie Connaughton, Jordan Camp
    - Members: LIGO, Fermi-GBM
  - 2017 – 2022; Organizers: Eric Burns, Nelson Christensen
    - Members: LIGO, Virgo, Fermi-GBM, Swift-BAT/GUANO
  - 2022 – ; Organizers: Rachel Hamburg, Tito dal Canton
    - Members: LIGO, Virgo, KAGRA, Fermi-GBM, Swift-BAT/GUANO, BurstCube
    - Future members: GlowBug, StarBurst, COSI, MoonBEAM?
- Outputs:
  - >6500 citations
  - 10 lead papers, contributions to several more
  - Multiple papers in development
  - Combined prompt alert streams
  - Multimessenger association formalisms
  - Successful predictions proven with GRB 170817A



GW-GRB Joint Localizations

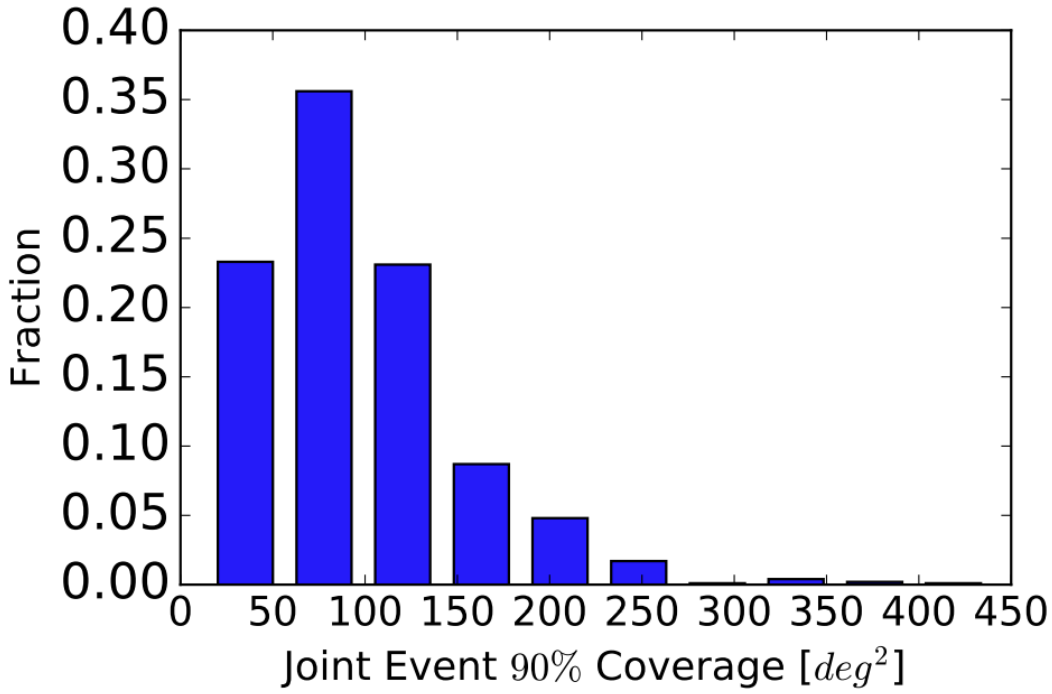




GW

GW+GBM

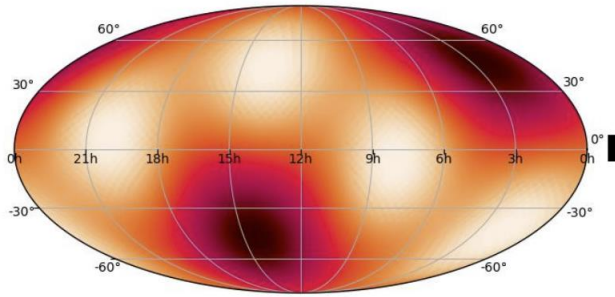
GBM



2015

GW-GRB Joint Localizations

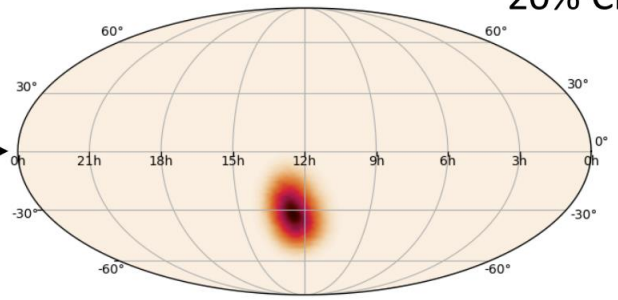
Single Interferometer
GW Detection



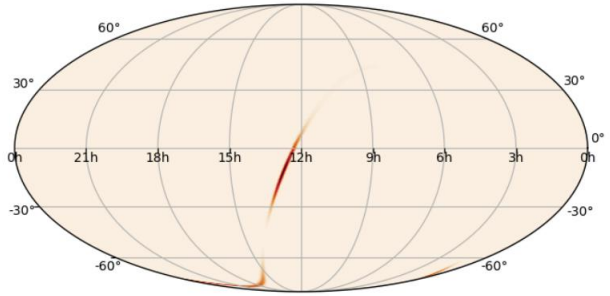
90%
Reduction

Single GW +
GBM Detection

~20% Chance



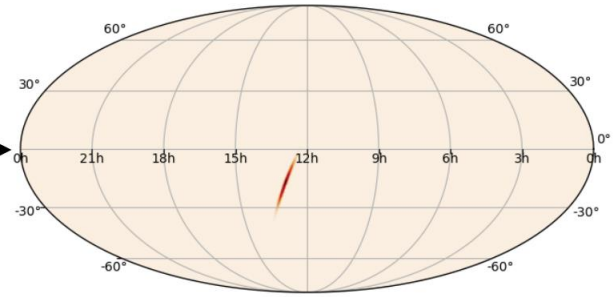
Double Interferometer
GW Detection



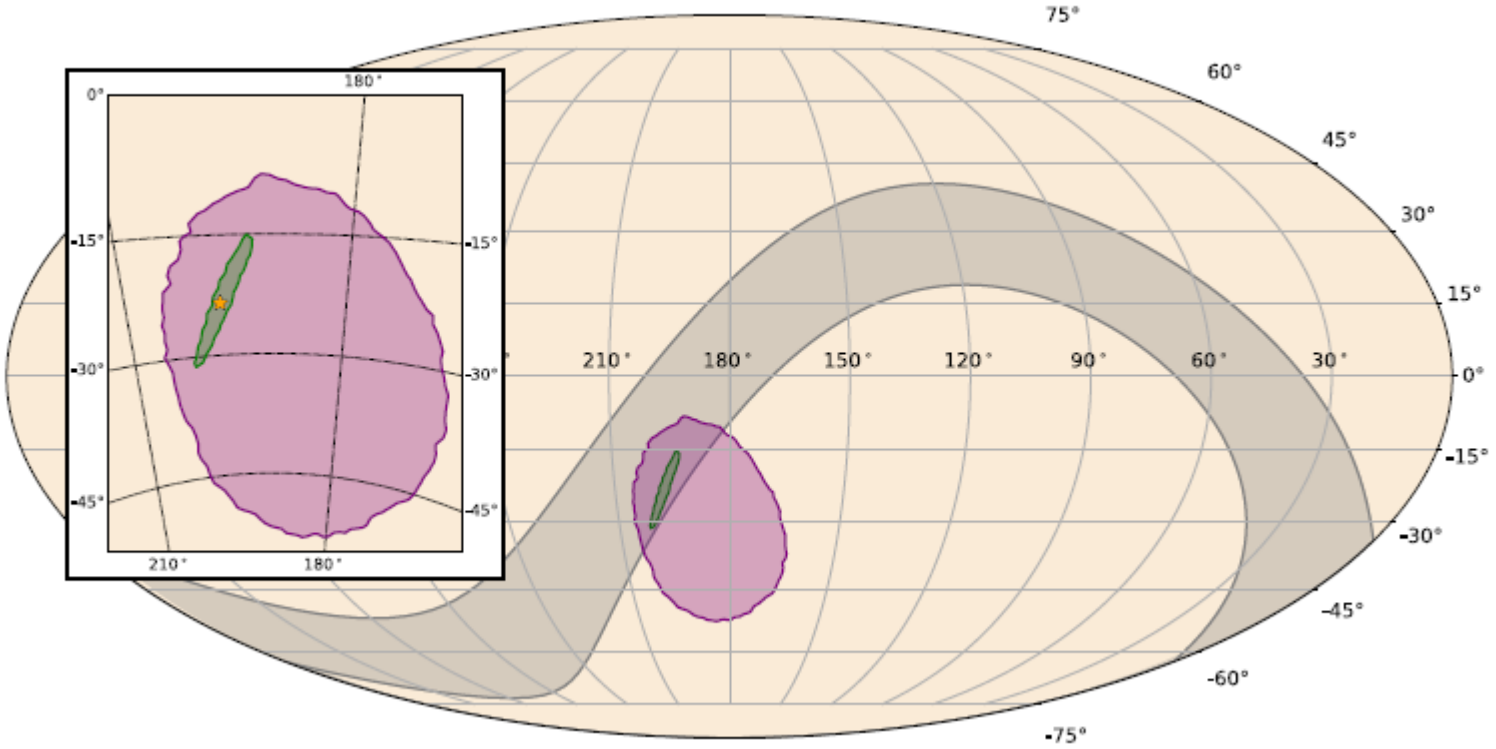
80%
Reduction

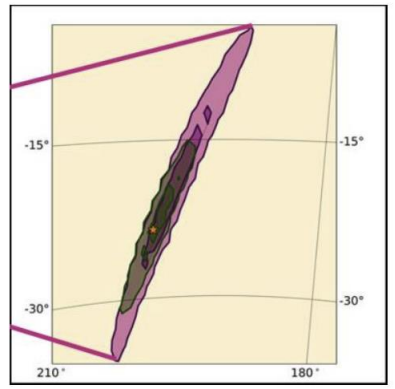
Double GW +
GBM Detection

~45% Chance



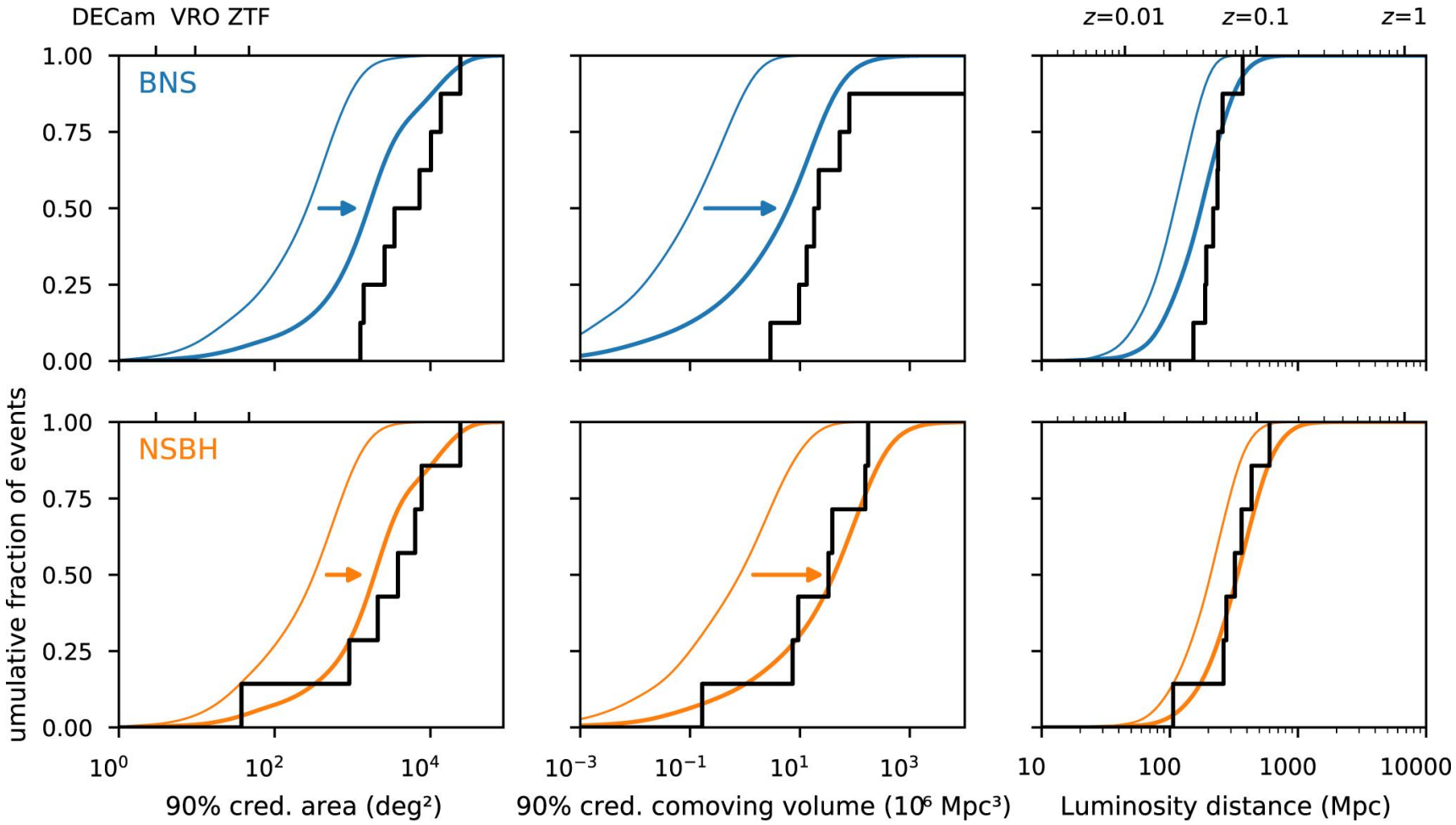
GW-GRB Joint Localizations





LIGO GW170817 +
GBM GRB 170817A
LIGO+Virgo GW170817

GW-GRB Joint Localizations

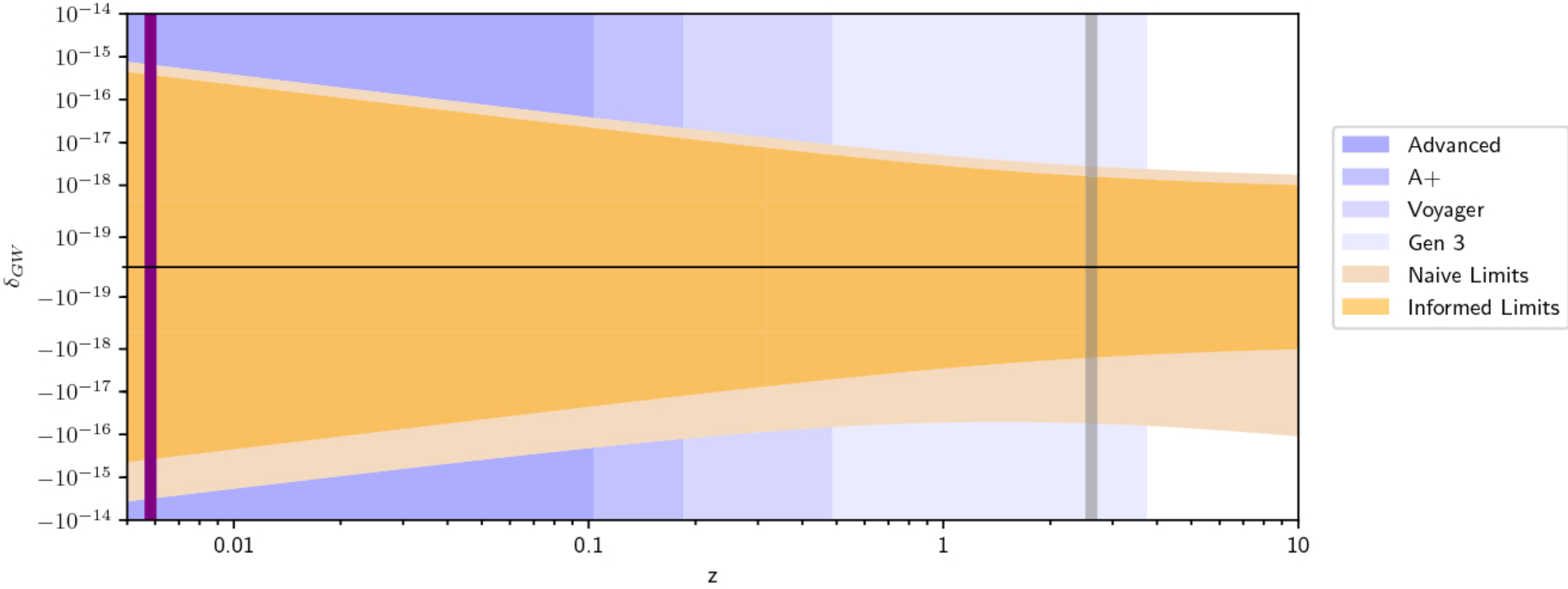


Petrov et al., ApJ 924 2 (2022)

RAVEN and O4 Joint Localizations

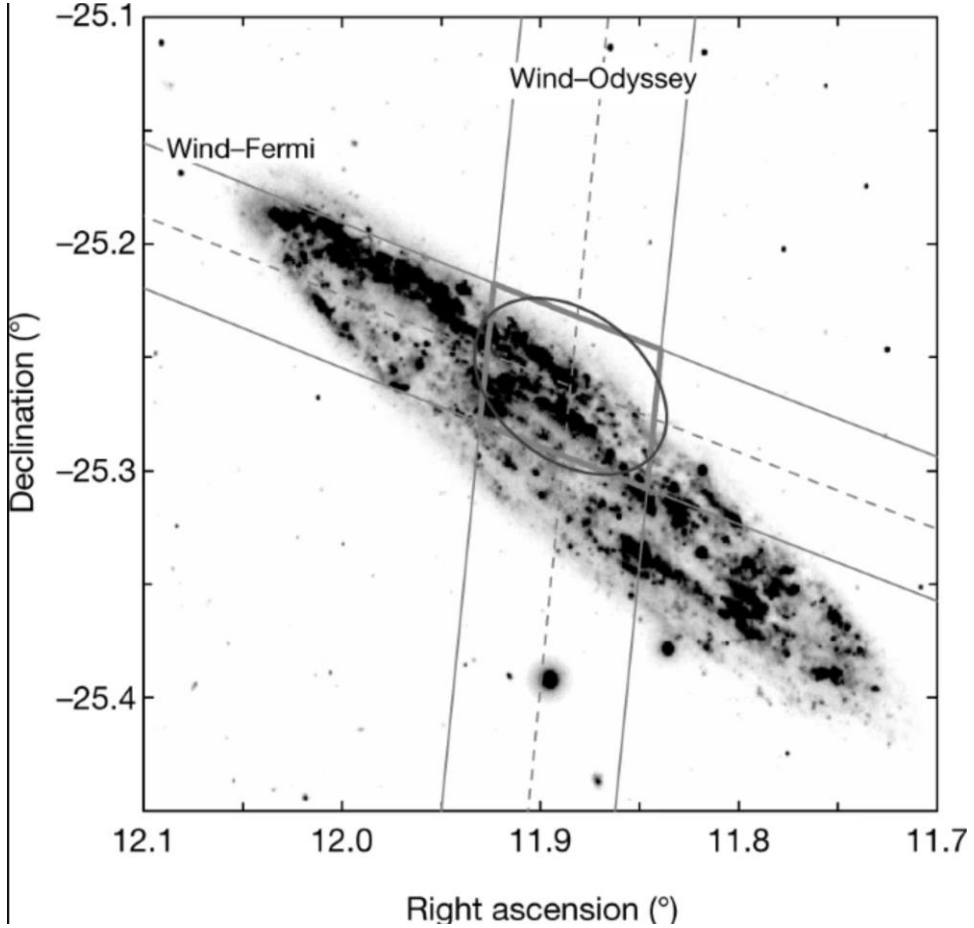
- RAVEN is an LVK pipeline that listens for external alerts
  - Listens to Fermi-GBM, Swift-BAT, BurstCube, etc on-board triggers **and sub-threshold search results from GBM and BAT**, communicated through GCN
  - Correlates these results with LVK GW triggers (including sub-threshold)
  - Determines joint significance
- If joint detection:
  - Automatic joint localization
    - w/ Fermi-GBM (or similar) often an 80-90% reduction in area
    - w/ Swift-BAT localization to a few arcminute
  - Automatic distribution to the entire GW follow-up community through the existing LVK alert streams

Building on automated GW-GRB associations: The speed of gravity



Burns *Living Reviews in Relativity* 23 4 (2020)

The InterPlanetary Network

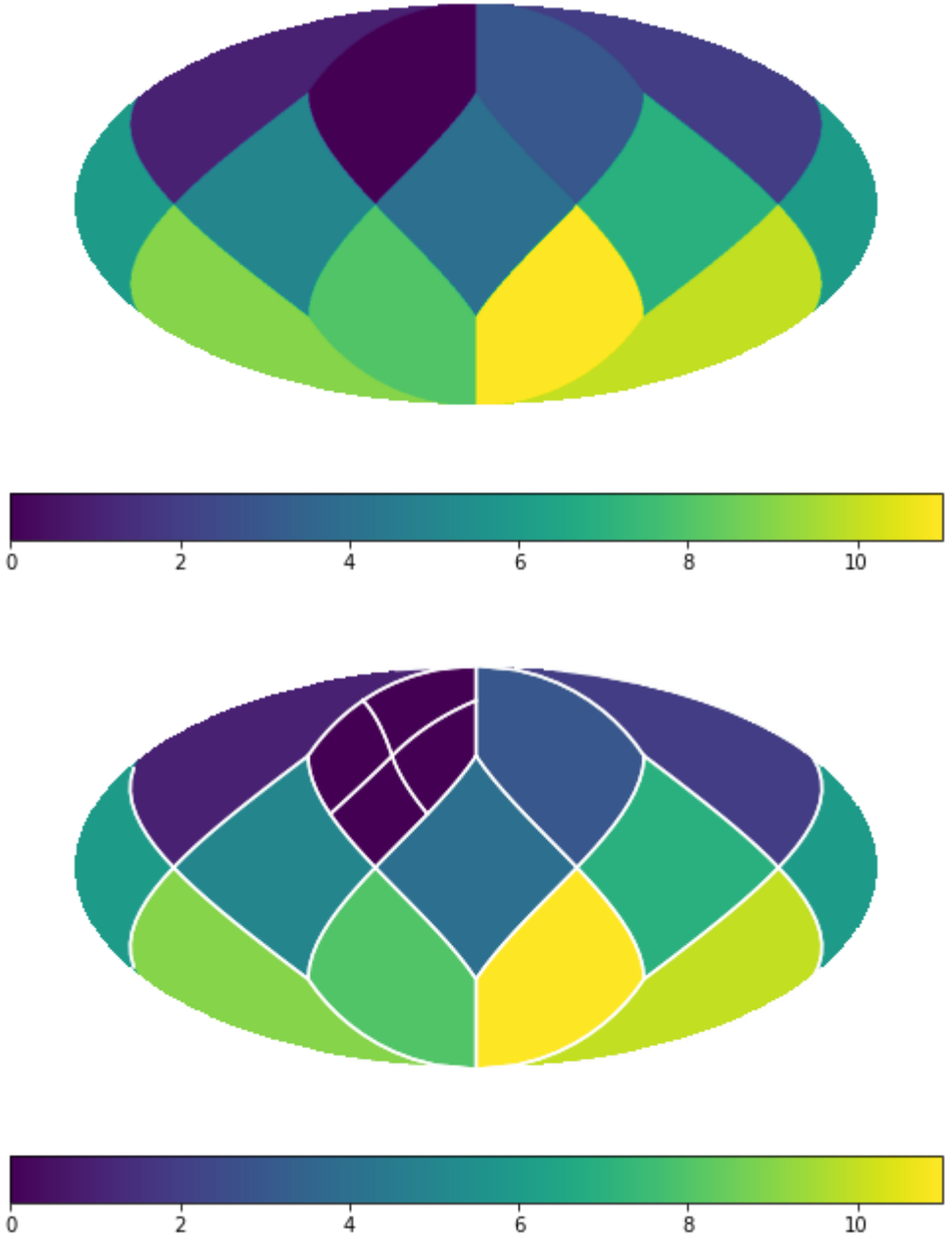


- 5 decades old
  - 1967 – Vela triangulation
  - 1978 – 1980 First IPN; Kevin Hurley
  - 1981 – 1984 Second IPN; Kevin Hurley
  - 1990 – Now Third IPN
    - Kevin Hurley until 2021; Eric Burns, Adam Goldstein, Judith Racusin
    - Dmitry Svinkin and several Konus team members
    - Current instruments: Konus-Wind, INTEGRAL SPI-ACS, Fermi-GBM, Swift-BAT, Mars Odyssey-HEND, Odyssey-GRS, **BepiColombo-MGNS**
    - Future instruments: StarBurst, COSI, **Psyche, MEGANE**
- Discoveries
  - Magnetars and soft gamma-ray repeaters
  - Spatial isotropy and homogeneity of GRBs
  - Anisotropy of SGRs
  - Extragalactic MGFs

HEALPix localizations

- **Everybody should distribute HEALPix**
  - Easier to automatically combine skymaps
  - A shared development base
  - Multi-Order maps are becoming standard

- Groups that have or will adopt HEALPix
  - LIGO, Virgo, KAGRA
  - **InterPlanetary Network**
  - GW-GRB Working Group
  - Fermi-GBM, BurstCube, GlowBug, StarBurst, COSI, MoonBEAM(?)



One option: mhealpy

Martinez-Castellanos et al., Astronomical Journal 163.6 (2022)

TITLE: GCN CIRCULAR
NUMBER: 32373
SUBJECT: IPN triangulation of GRB 220711C (short)
DATE: 22/07/12 15:50:56 GMT
FROM: Dmitry Svinkin at Ioffe Institute <svinkin@mail.ioffe.ru>

D. Svinkin, D. Frederiks, A. Ridnaia, A. Lysenko,
and T. Cline on behalf of the Konus-Wind team,

A. Goldstein, M. S. Briggs, and C. Wilson-Hodge
on behalf of the Fermi GBM team,

E. Bozzo and C. Ferrigno, on behalf of the INTEGRAL SPI-ACS GRB team,

and

S. Barthelmy, J. Cummings, H. Krimm, D. Palmer, and A. Tohuvavohu
on behalf of the Swift-BAT team, report:

The short-duration GRB 220711C
was detected by Fermi (GBM trigger 679248723),
INTEGRAL (SPI-ACS), Konus-Wind, and Swift (BAT)
at about 58318 s UT (16:11:58).
The burst was outside the coded field of view of the BAT.

We have triangulated it to a preliminary, 3 sigma error box
whose coordinates are:

RA(2000), deg	Dec(2000), deg
Center:	
79.625	-47.309
Corners:	
64.292	-35.777
64.270	-36.123
94.188	-53.124
93.862	-52.805

The error box area is 5.5 sq. deg, and its maximum
dimension is 27 deg (the minimum one is 12 arcmin).
The Sun distance was 72 deg.

This box may be improved.

The IPN localization is consistent with, but reduces the area of, the
Fermi-GBM final localization (glg_healpix_all_bn220711675_v00).

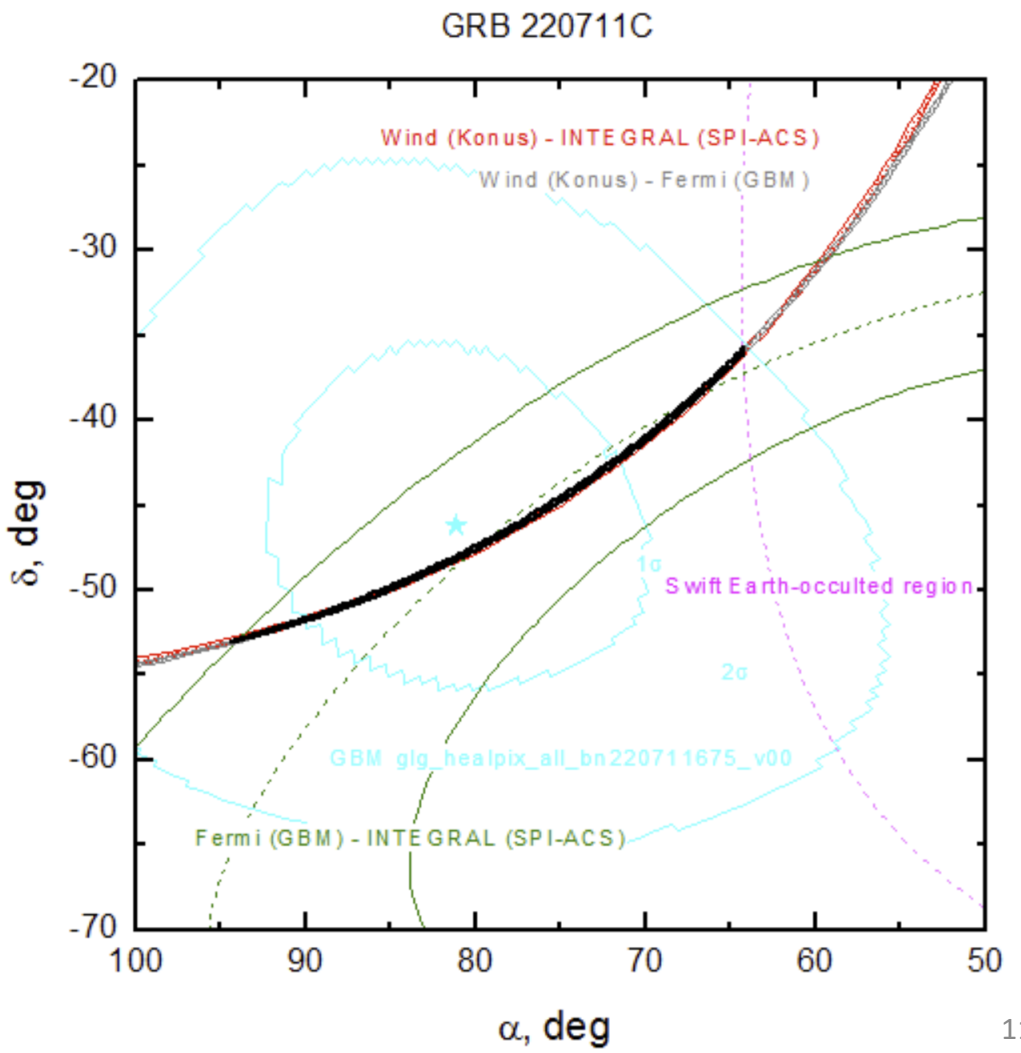
A triangulation map and HEALPix FITS file are posted at
http://www.ioffe.ru/LEA/GRBs/GRB220711_T58317/IPN

The time history and spectrum will be given in forthcoming
GCN Circulars.

GRB 220711C

IPN triangulation map of GRB 220711C

IPN HEALPix triangulation map



IPN – GCN GRB Stream

- A single access stream for prompt GRB information
- Automatic association of GRB triggers reported through notices
  - Fermi-GBM, Swift-BAT, Swift-BAT/GUANO, Fermi-LAT, GECAM, etc
  - Combine localizations and distribute through HEALPix MOC maps
  - **Full tracking of contributing missions, with pointing to appropriate references**
- Push distribution of IPN HEALPix maps
  - Begin with manual distribution of HEALPix maps
  - Move towards automation of IPN over the next few years
    - Fermi-INTEGRAL in ~30 minutes
    - Fermi-MO in ~hours
- Automatic archive (next page) of this information
  - Update ~daily from input catalogs, modeled on the Open Supernova Catalog

IPN – Total (prompt) GRB Archive

- A single repository for every* reported prompt GRB
  - Input catalogs
    - Kevin Hurley's IPN Archive
      - GRBCAT on HEASARC (K. Hurley, N. Gehrels, L. Angellini)
    - Instrument catalogs – GBM (trigger, burst, spectral), BATSE (burst, spectral), Swift (3rd GRB catalog), LAT (GRB catalog), HETE-2, INTEGRAL, Konus (published catalogs, additional info), RHESSI, etc
  - Will be preserved on HEASARC, open source contributions through git
- Content
  - Summary information including geocentric trigger time, durations, spectral parameters, brightness, redshift, associated events, etc
  - HEALPix files for every burst
- Currently >15,000 GRBs

(Prompt) GRB consortiums

- GW-GRB Working Group and IPN
  - Upsides
    - Operation measured in decades
    - Results measured in 1,000s of citations and discovery of multiple objects
  - Cost
    - Long-term investment in international relationships
    - Heavy time investment (i.e. weekly meetings for years, operations for years)
    - Exclusive – politics are a bit of a nightmare
- Steps to be inclusive
  - Contribute to GCN upgrades to enable event-based streams
  - Allow additional teams to contribute to shared GRB GCN stream
  - Inclusion of external authors from contributing instruments
    - E.g. automated Speed of Gravity paper
  - Open source software

Asks and recommendations

- Report through GCN
  - Notices if possible
- Utilize HEALPix
  - Multi-order maps as necessary
- Make catalogs
  - Localizations and broadband spectra from cubesats would be great to archive
- Open source software
  - If systematics are accounted for, can include in GCN GRB stream
    - Only if interested!

- If there are cases where NASA resources (e.g. GCN, GBM software, GW-GRB products, IPN products) would be helpful, please let us know
  - But it takes time to move these large groups