The InterPlanetary Network

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On behalf of the IPN:

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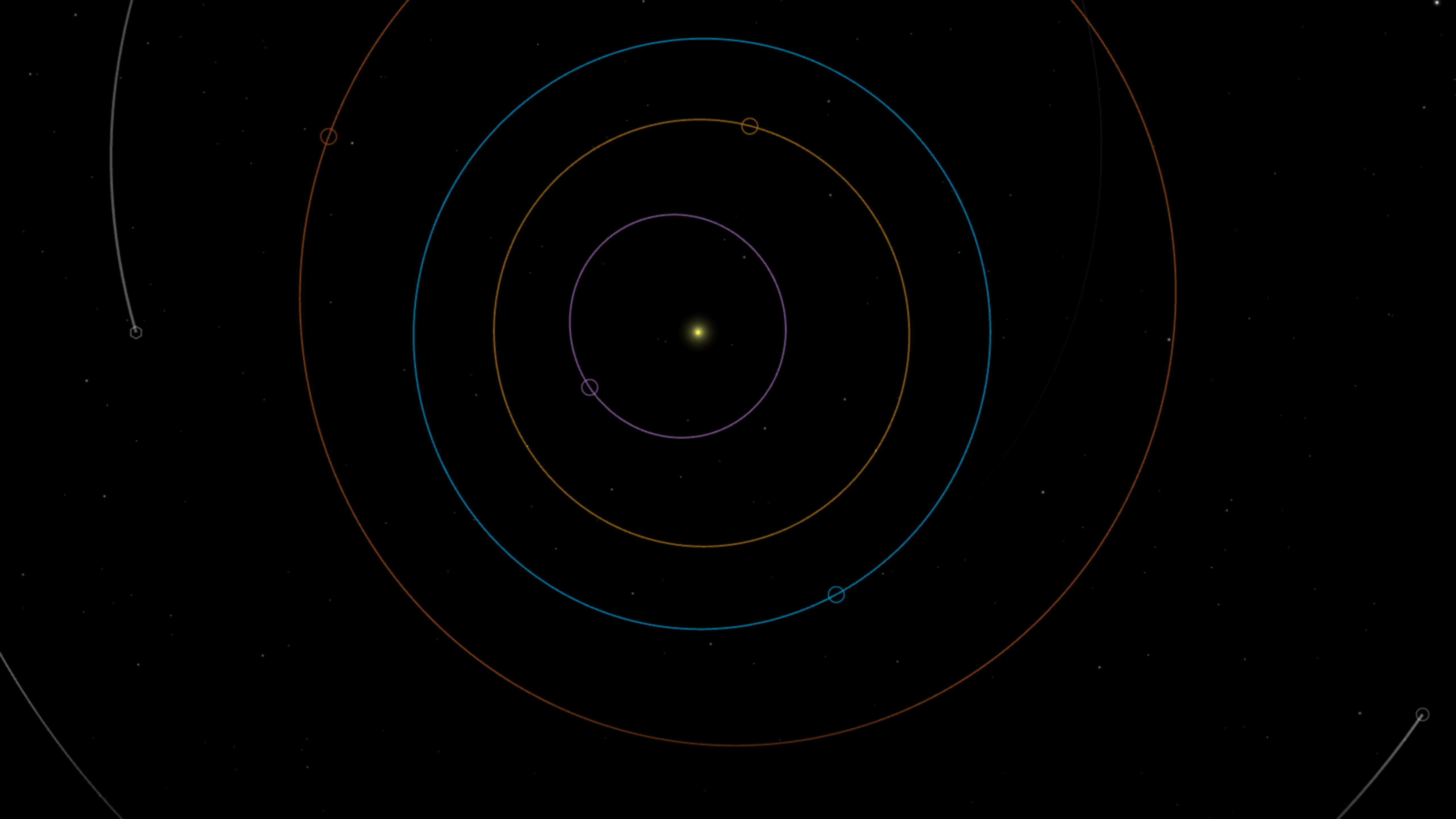
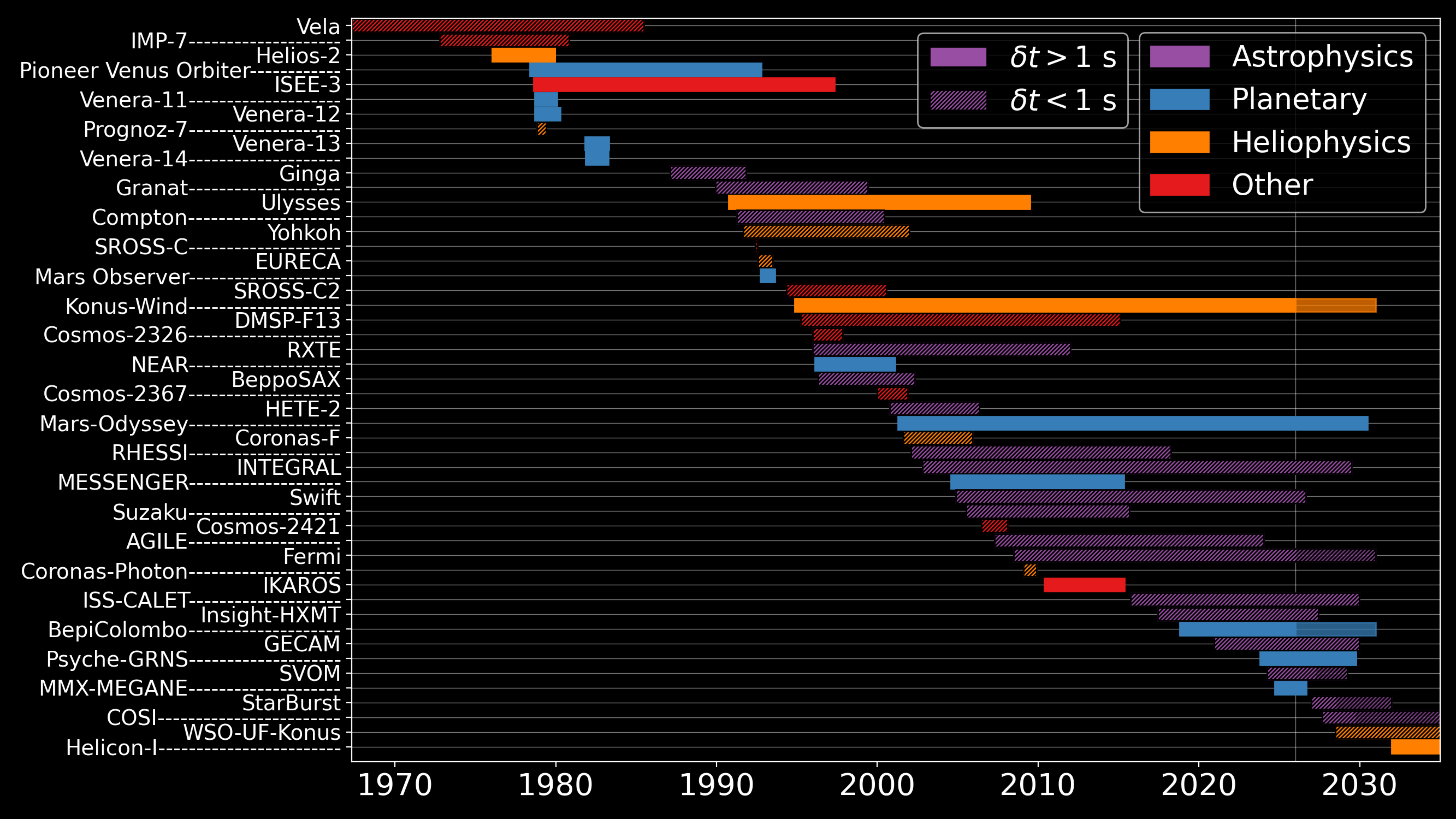
Dmitry Frederiks, Alexandra Lysenko, Anna Ridnaia (Ioffe), Courey Elliott, Emily Reilly (LSU),
Suman Bala, Cori Fletcher, Adam Goldstein, Rachel Hamburg (USRA)

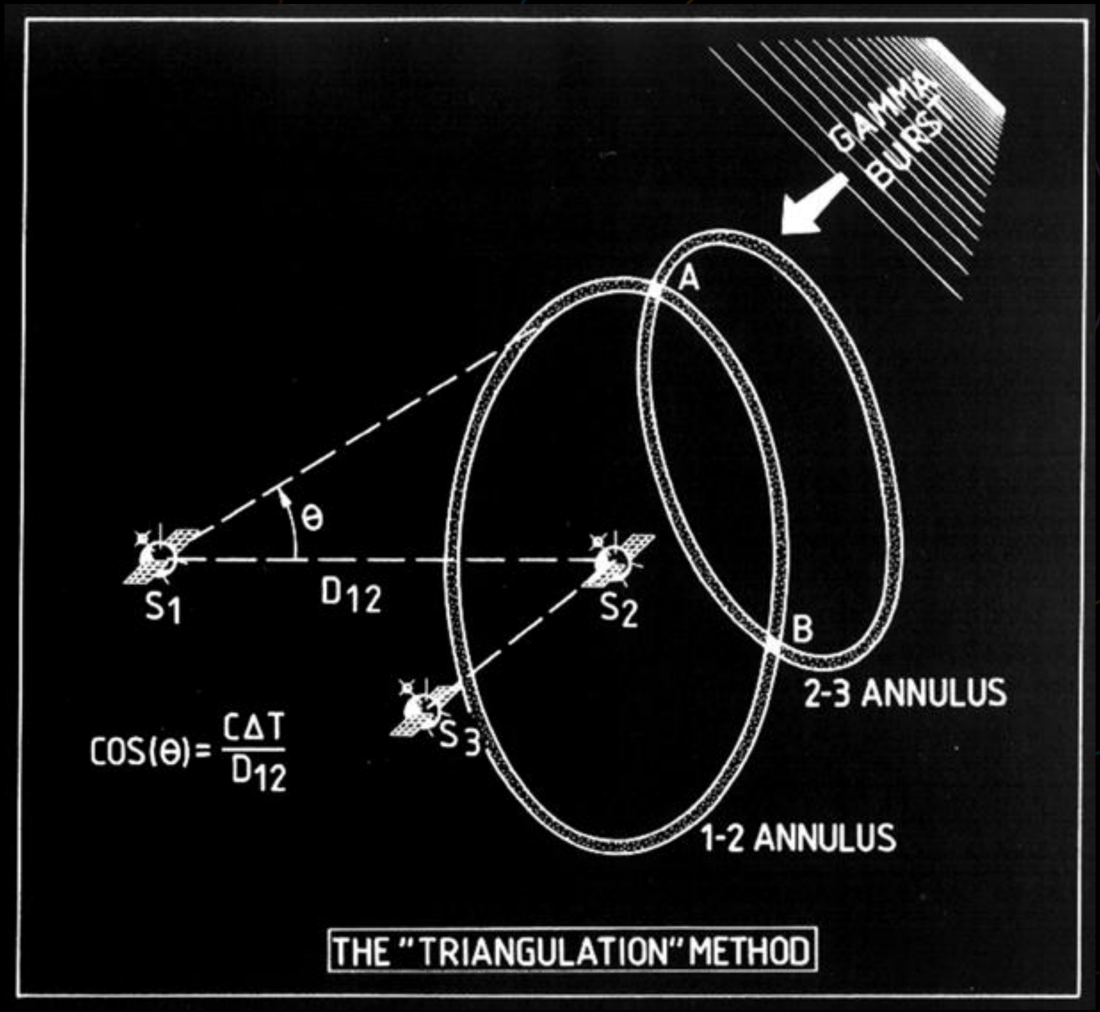
And BepiColombo-MGNS, COSI, Fermi-GBM, GECAM, INTEGRAL SPI-ACS, ISS-CALET, Konus-Wind, Mars Odyssey-HEND, MMX-MEGANE, Psyche-GRNS, StarBurst, Swift-BAT

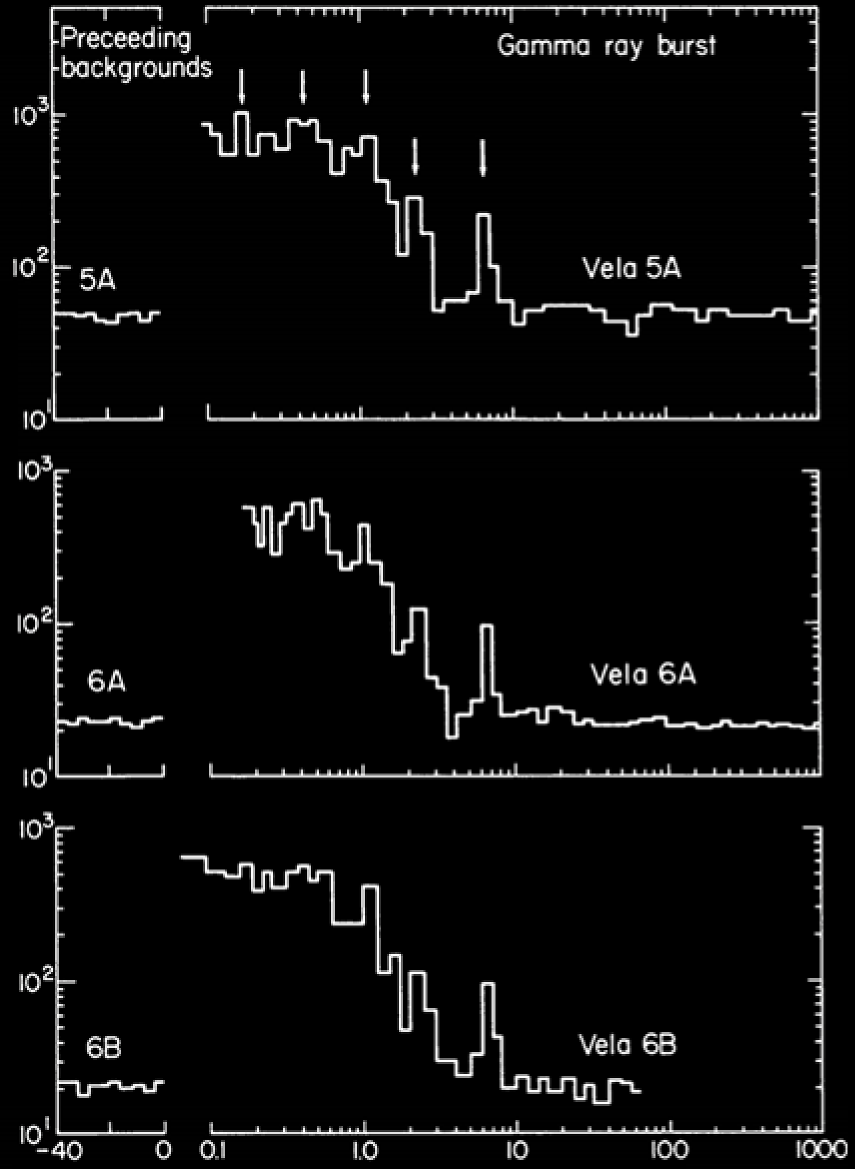



Vela
IMP-7
Helios-2
Pioneer Venus Orbiter
ISEE-3
Venera-11
Venera-12
Prognoz-7
Venera-13
Venera-14
Ginga
Granat
Ulysses
Compton
Yohkoh
SROSS-C
EURECA
Mars Observer
SROSS-C2
Konus-Wind
DMSP-F13
Cosmos-2326
RXTE
NEAR
BeppoSAX
Cosmos-2367
HETE-2
Mars-Odyssey
Coronas-F
RHESSI
INTEGRAL
MESSENGER
Swift
Suzaku
Cosmos-2421
AGILE
Fermi
Coronas-Photon
IKAROS
ISS-CALET
Insight-HXMT
BepiColombo
GECAM
Psyche-GRNS
SVOM
MMX-MEGANE
StarBurst
COSI
WSO-UF-Konus
Helicon-I
$\delta t > 1$ s
$\delta t < 1$ s
Astrophysics
Planetary
Heliophysics
Other
1970
1980
1990
2000
2010
2020
2030

How IPN works

http://www.ssl.berkeley.edu/ipn3/index.html

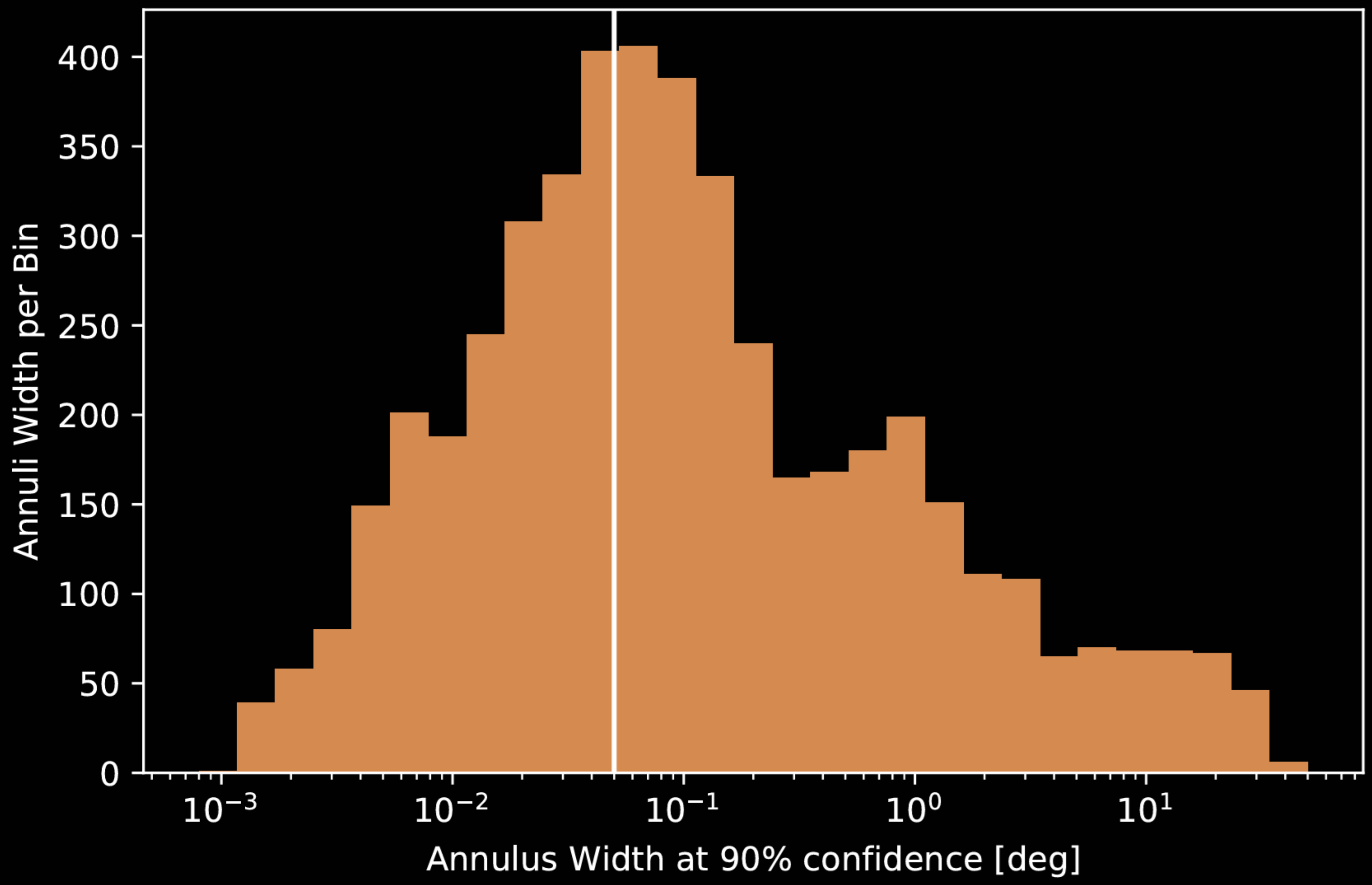




Log Count Rate

Log Time (s)

Localization Accuracy



IPN Discoveries

- Pre-BeppoSAX
  - Discovery of gamma-ray bursts (pre IPN formalization)
  - Astrophysical origin of gamma-ray bursts
  - Isotropy of gamma-ray bursts, from no known objects
  - Two origins of gamma-ray bursts
  - Ultra-long gamma-ray bursts
  - Discovery of giant flares
  - Separation of soft gamma-ray repeater flares
  - Discovery of magnetars
- Post-Swift
  - Identified every Galactic magnetar giant flare
  - Proof of extragalactic magnetar giant flares
  - Localization for most direct proof of r-process nucleosynthesis
  - Characterization of the most direct proof of r-process nucleosynthesis
  - Ultra-long gamma-ray bursts require a new progenitor

Gamma-ray Transient Network Science Analysis Group Report

Eric Burns, Michael Coughlin, Kendall Ackley, Igor Andreoni, Marie-Anne Bizouard, Floor Broekgaarden, Nelson L. Christensen, Filippo D'Ammando, James DeLaunay, Henrike Fleischhack, Raymond Frey, Chris L. Fryer, Adam Goldstein, Bruce Grossan, Rachel Hamburg, Dieter H. Hartmann, Anna Y. Q. Ho, Eric J. Howell, C. Michelle Hui, Leah Jenks, Alyson Joens, Stephen Lesage, Andrew J. Levan, Amy Lien, Athina Meli, Michela Negro, Tyler Parsotan, Oliver J. Roberts, Marcos Santander, Jacob R. Smith, Aaron Tohuvavohu, John A. Tomsick, Zorawar Wadiasingh, Peter Veres, Ashley V. Villar, Haocheng Zhang, Sylvia J. Zhu

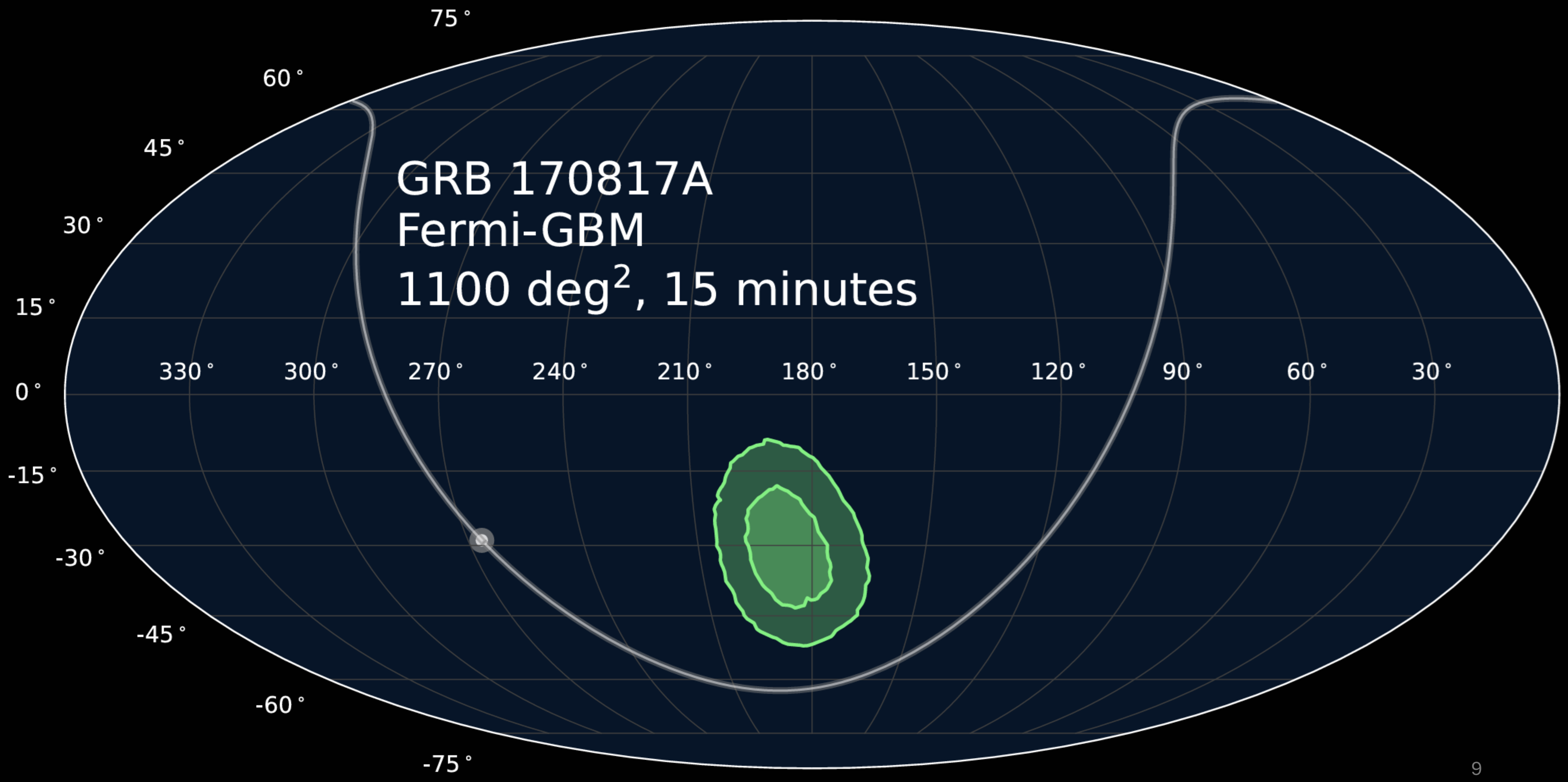
- Is the IPN still needed? If so, what needs to be done?
- Endorsements from CMB S-4, ngVLA, LSC and LIGO Lab, WVU FRB Group, Chime, CTAC, HAWC, IceCube, Fermi-GBM, Veritas, Rubin, Swift, COSI

Why the IPN

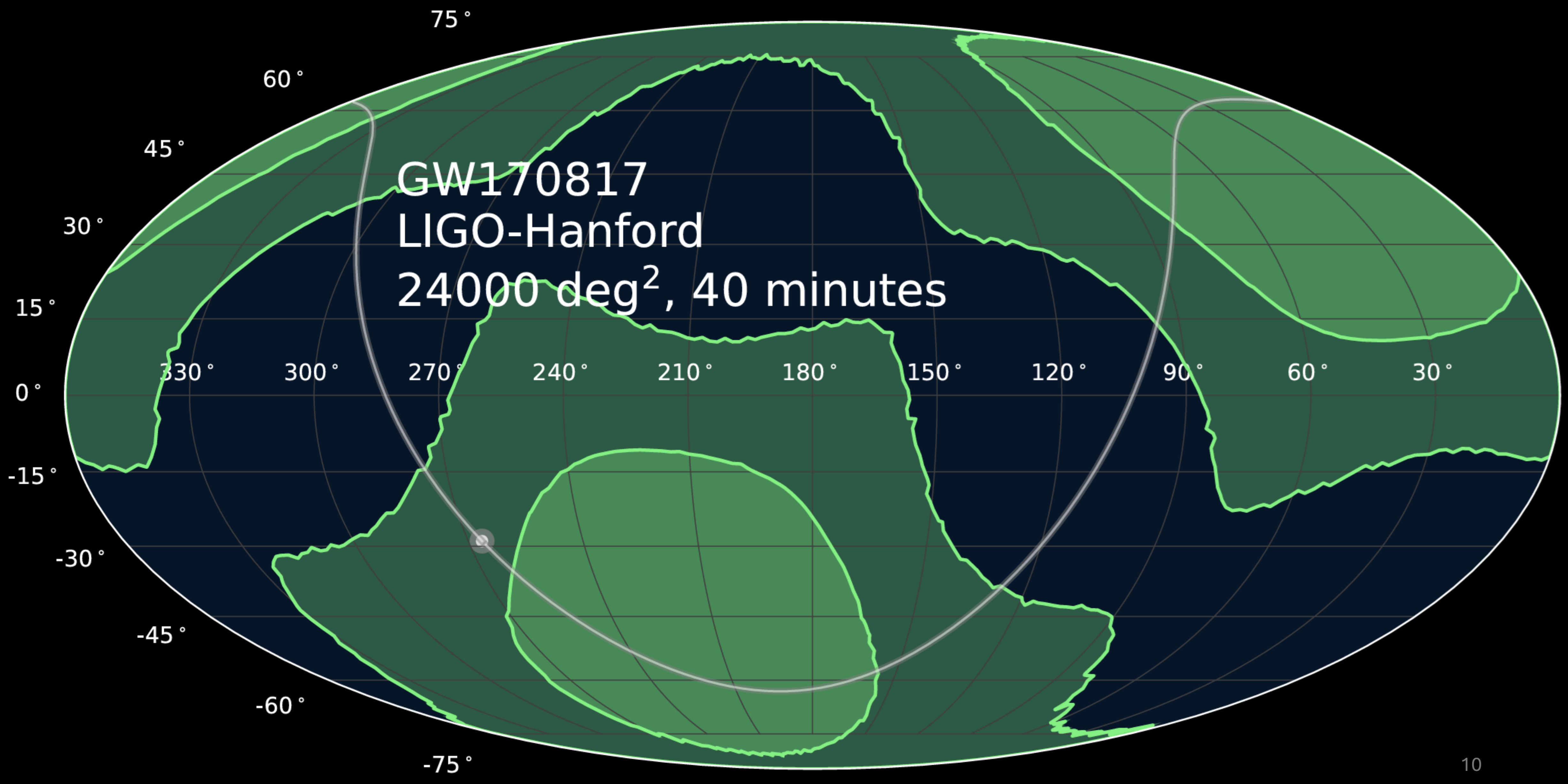
- IPN and the 4th TDAMM Workshop
  - Crucial for gamma-ray bursts, compact mergers, magnetars
  - Useful tidal disruption events, neutrinos, rare supernovae
  - Not so helpful otherwise (sorry X-ray binary, nova people)

- The next decade
  - Possible end of Swift
  - Rare transients are best found with all-sky coverage
  - The continued advancement of other surveys

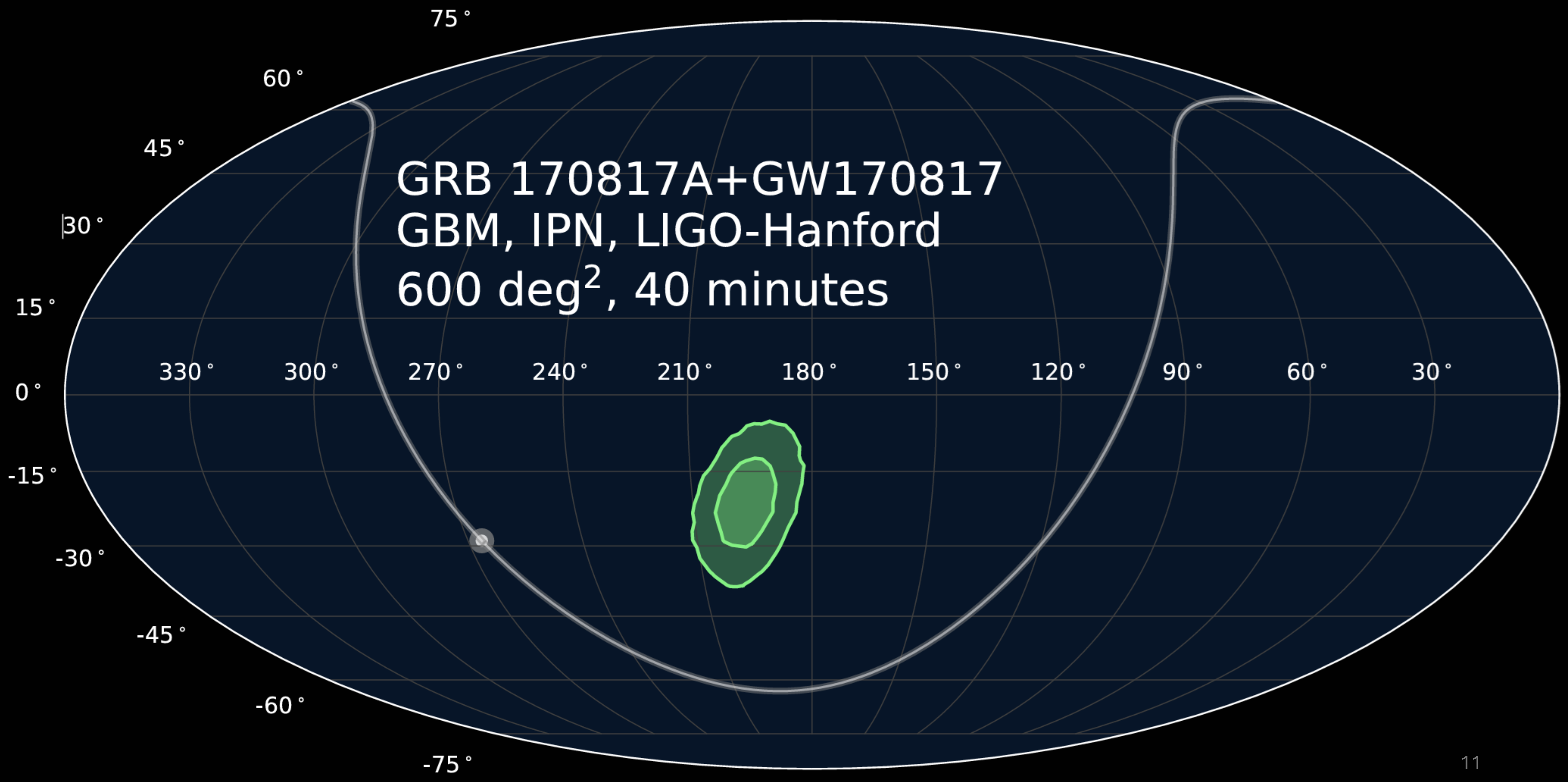
Localization of Transients



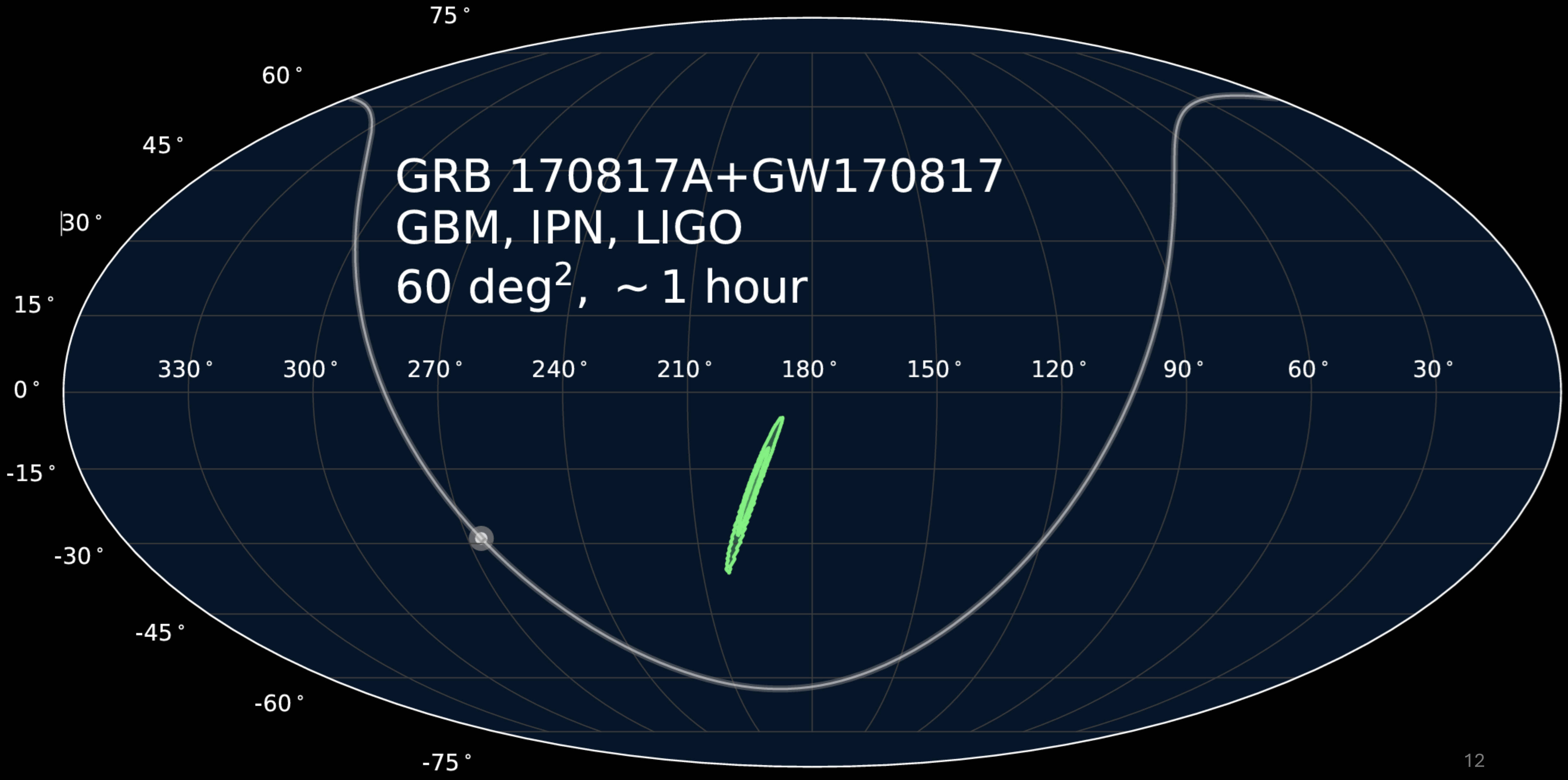
Localization of Transients



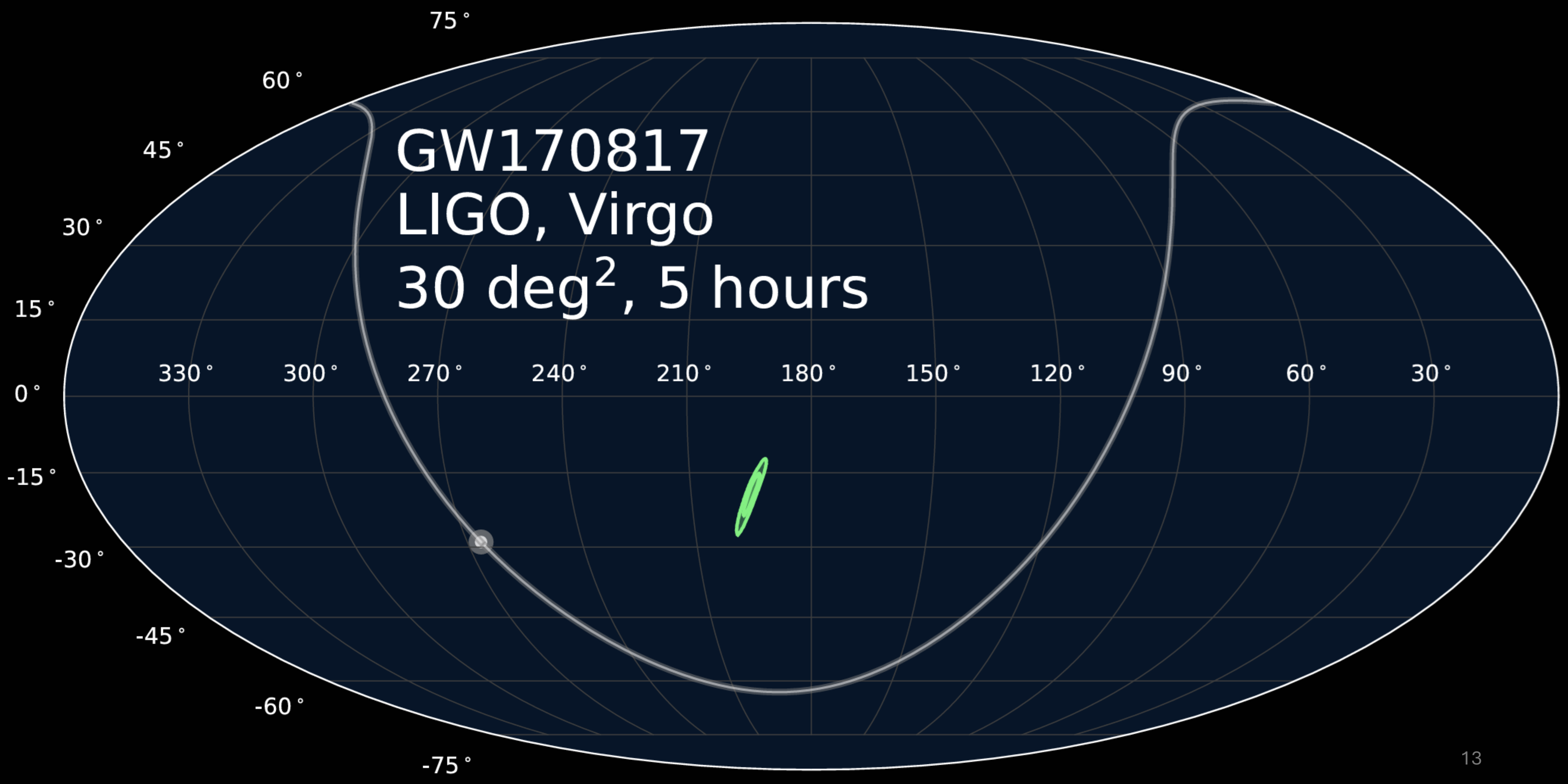
Localization of Transients



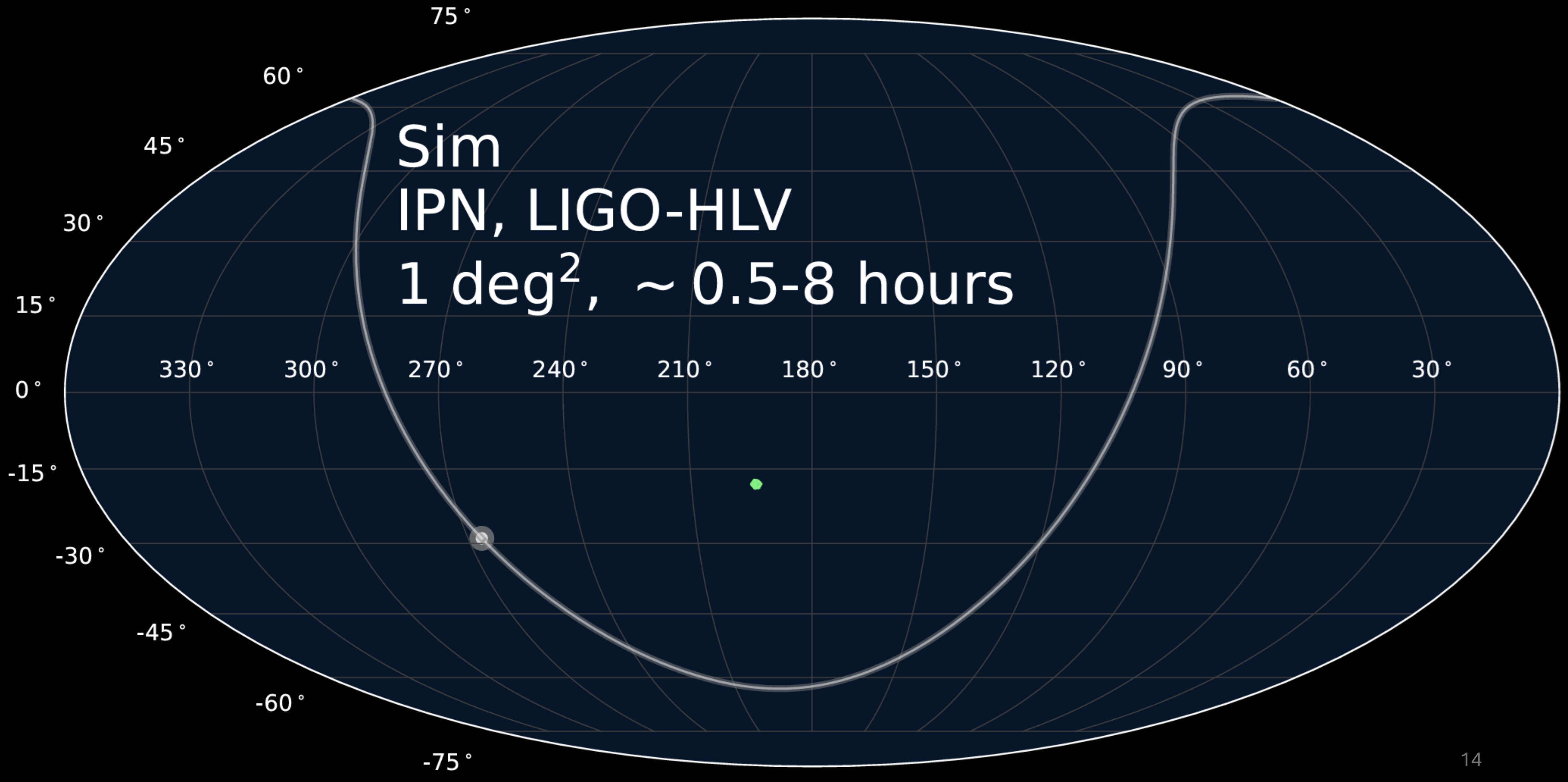
Localization of Transients



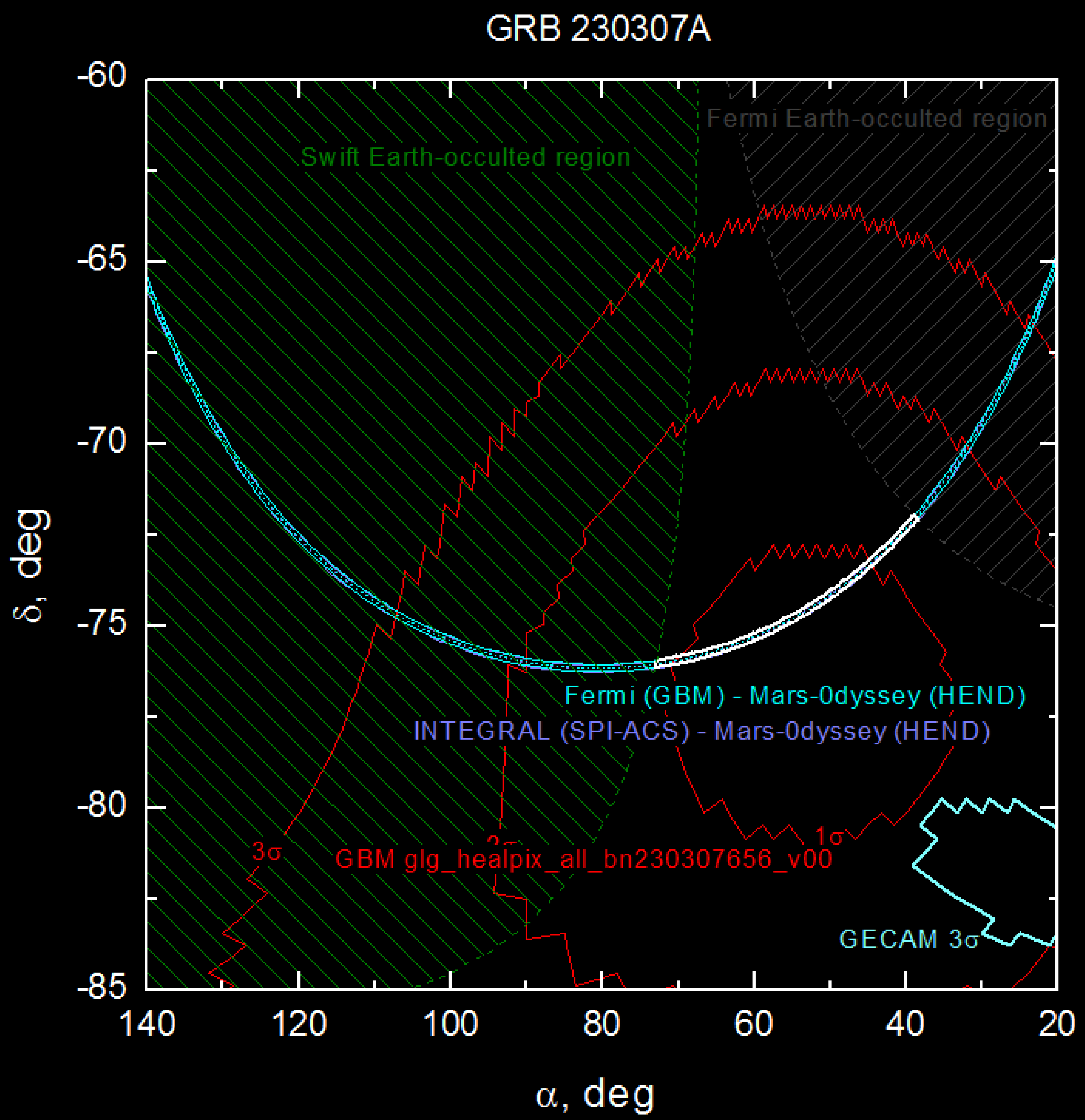
Localization of Transients



Localization of Transients

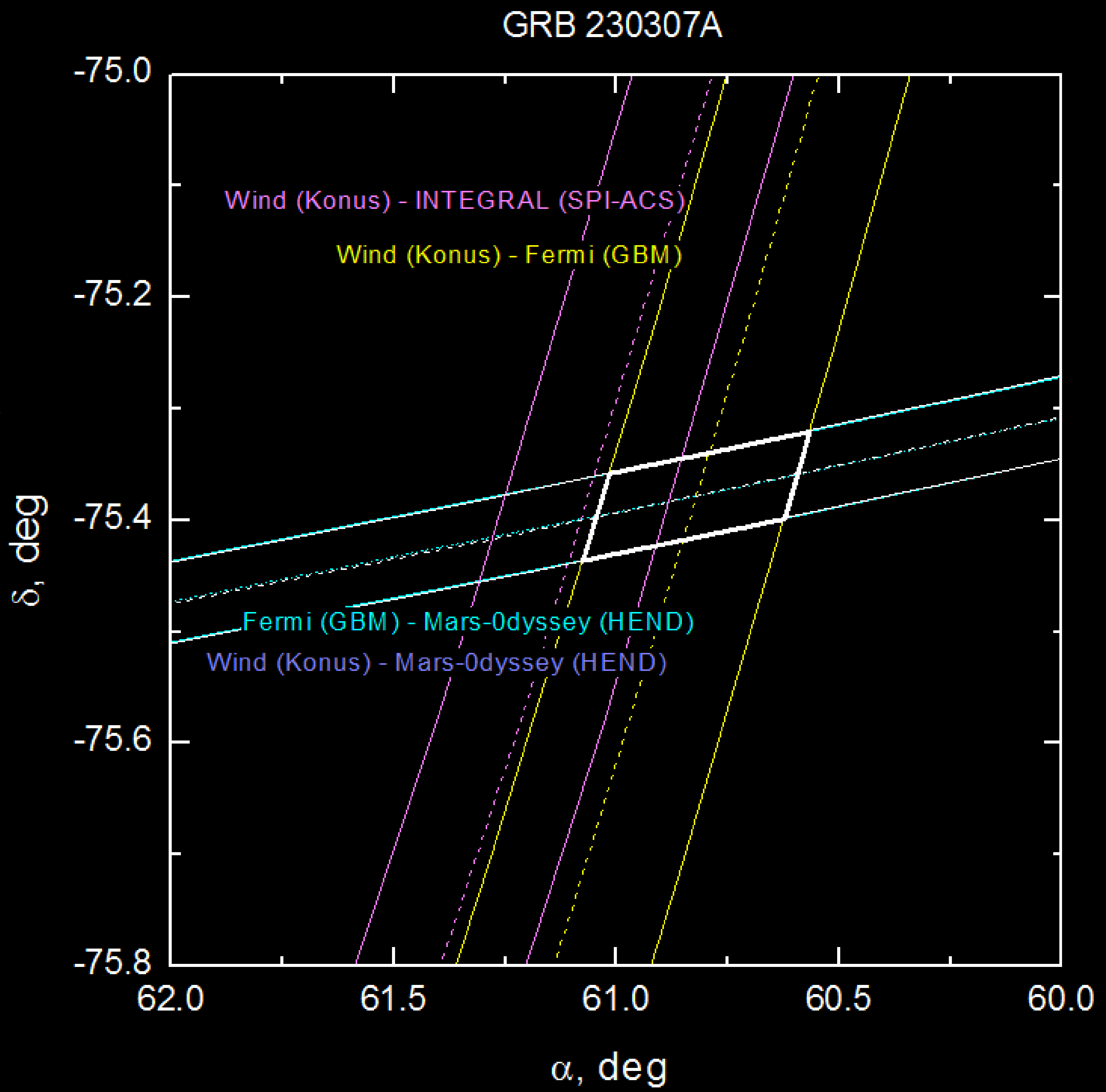


Localization of Transients



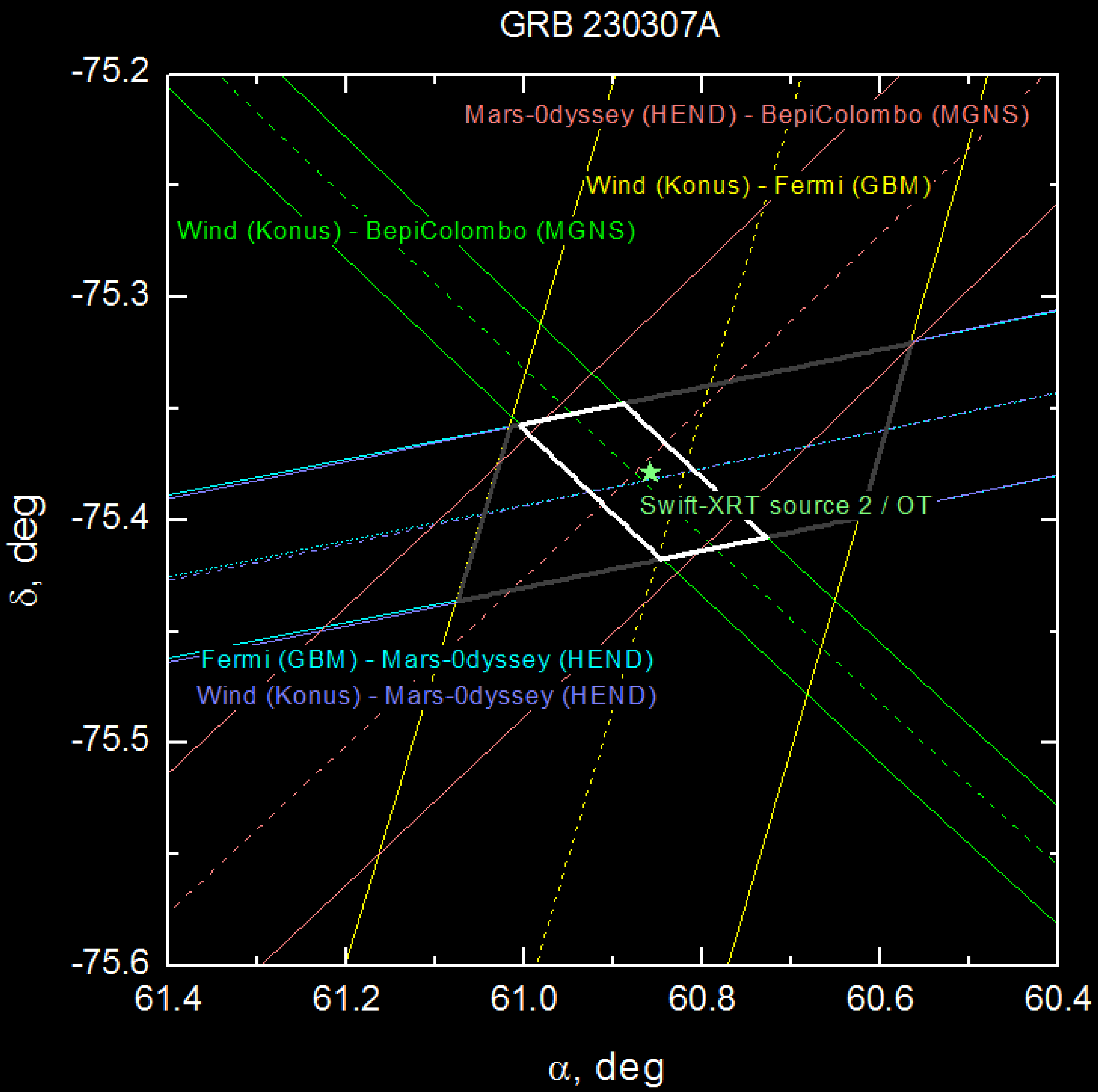
Swift begins tiling

Localization of Transients



Tiling with 3.6m New Technology Telescope

Localization of Transients



X-ray and optical recovery of afterglow

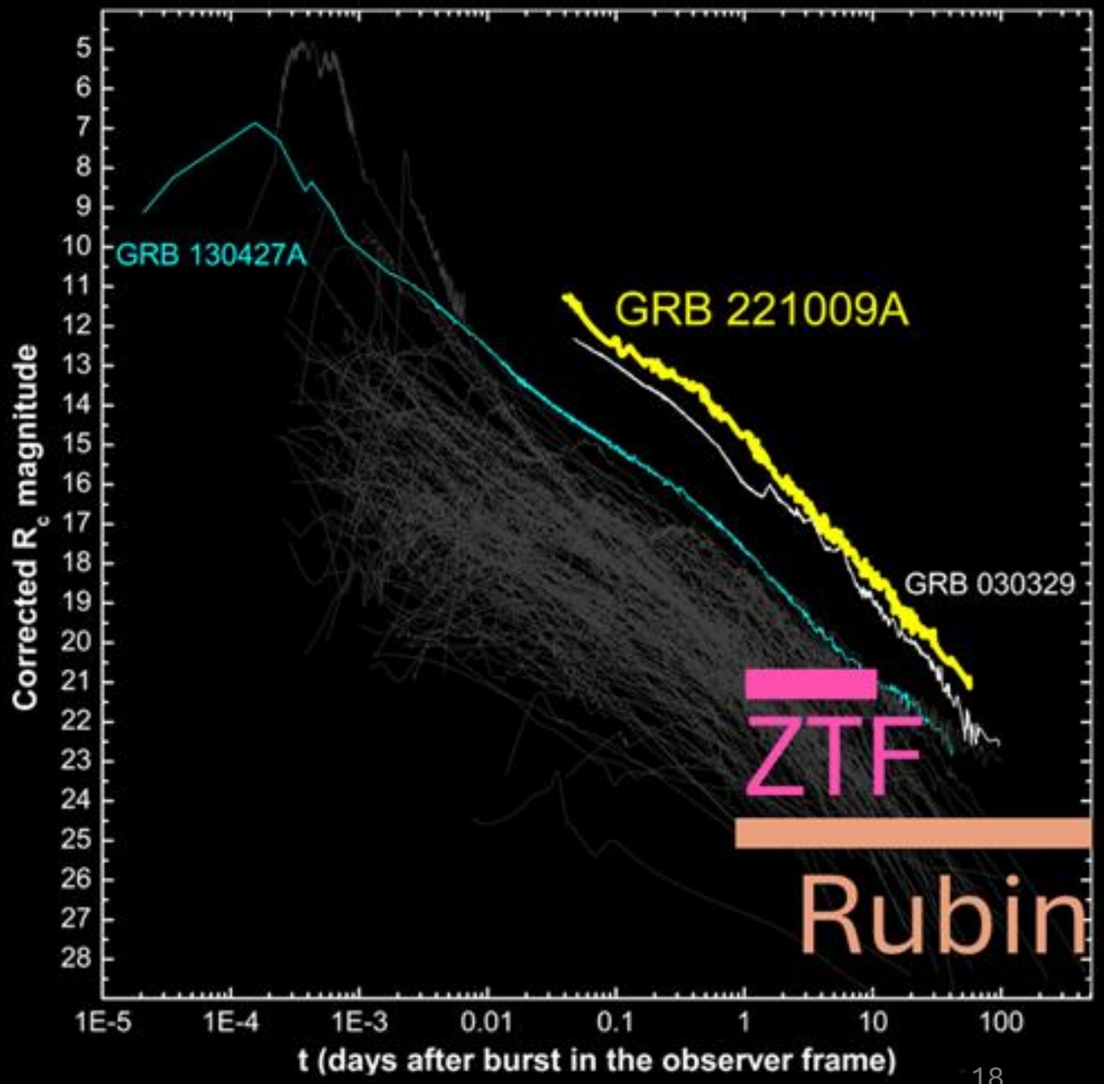
First late-time infrared spectrum of a kilonova

Total Coverage of All Transients

- IPN has complete coverage of all transients

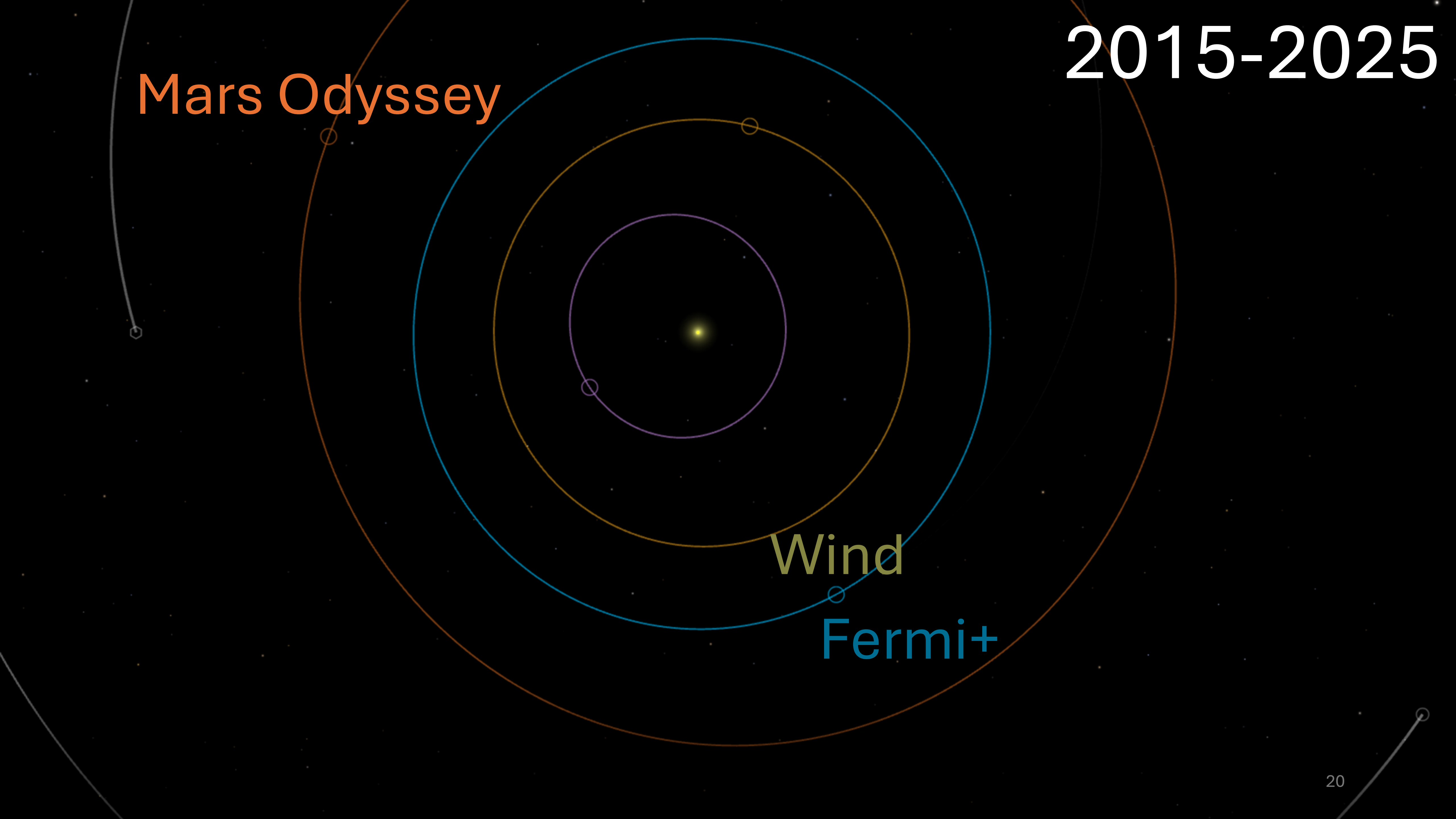
- IPN and Rubin will detect and precise localize numerous GRBs

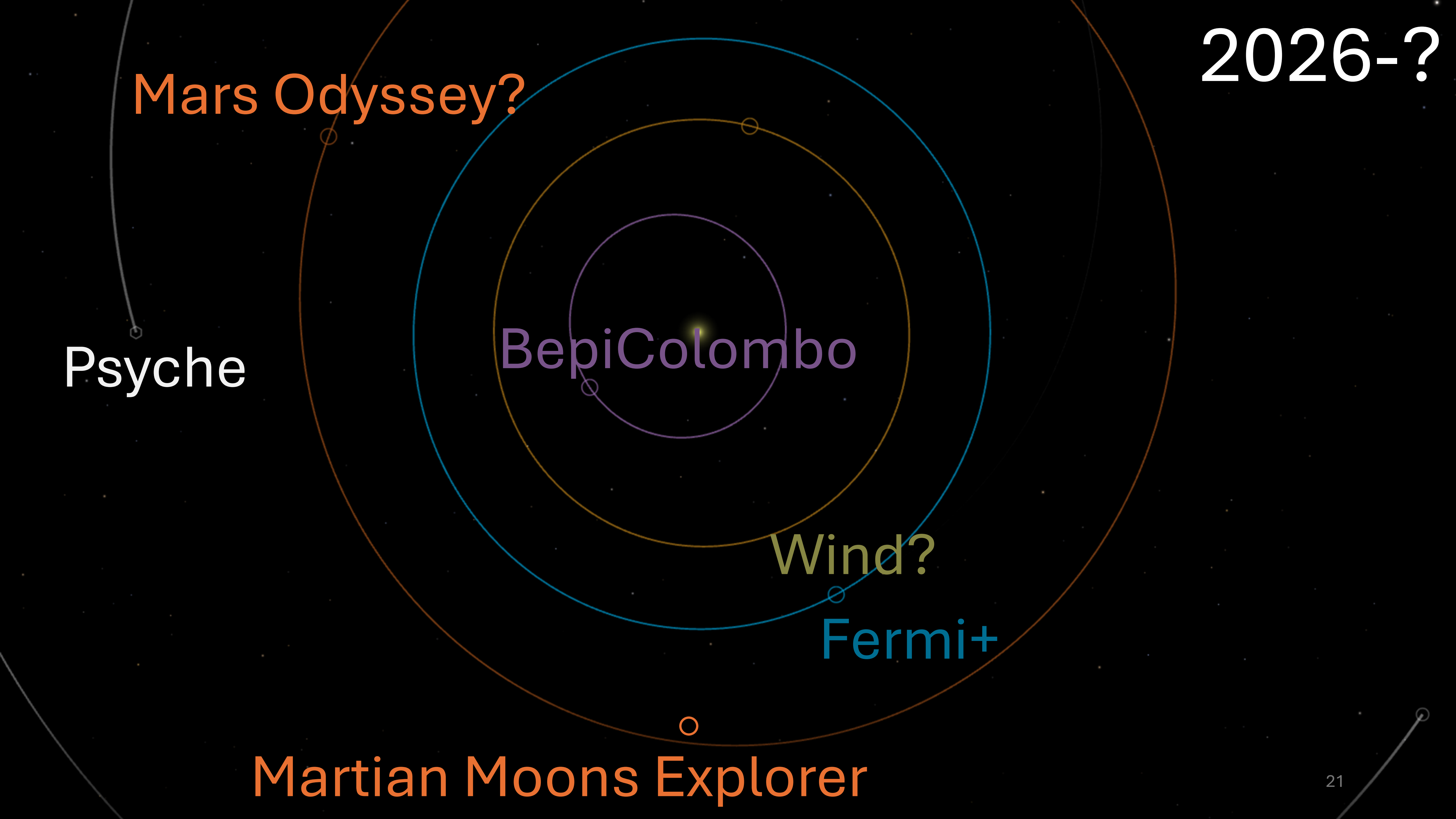
- Detections or upper limits useful for classification, confirmation



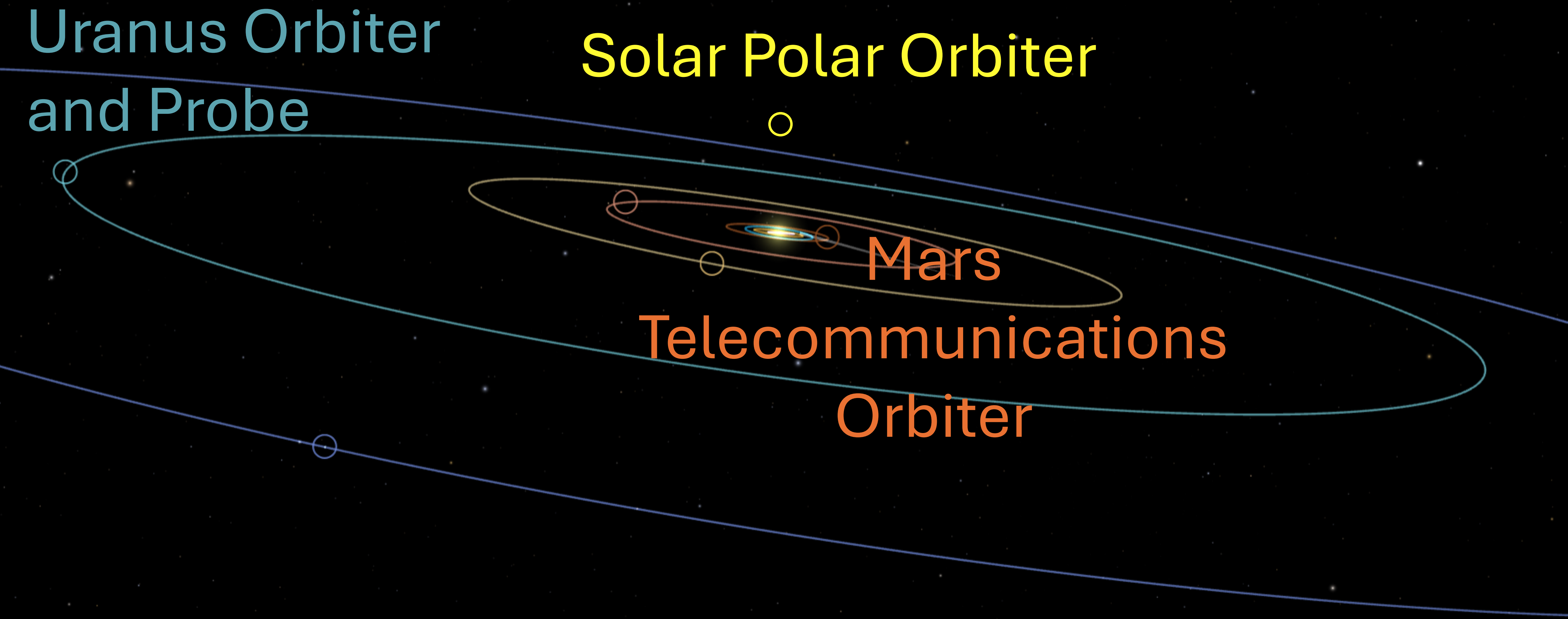
Future of the IPN

- Collated high-energy transient alert stream (2026)
  - Gamma-ray burst stream
  - Magnetar giant flare candidate stream
  - Stream for fast radio burst, magnetar flare associations
- High-energy transient name server (beta 2026)
- Complete prompt gamma-ray burst catalog (2026)
- Preservation of Vela, Pioneer Venus Orbiter, other data (2026)
- Generic high energy transient archive (2027+)
- IPN as a single effective instrument – coherent analysis (~2030)


2015-2025
Mars Odyssey
Wind
Fermi+


2026-?
Mars Odyssey?
Psyche
BepiColombo
Wind?
Fermi+
Martian Moons Explorer

2040+

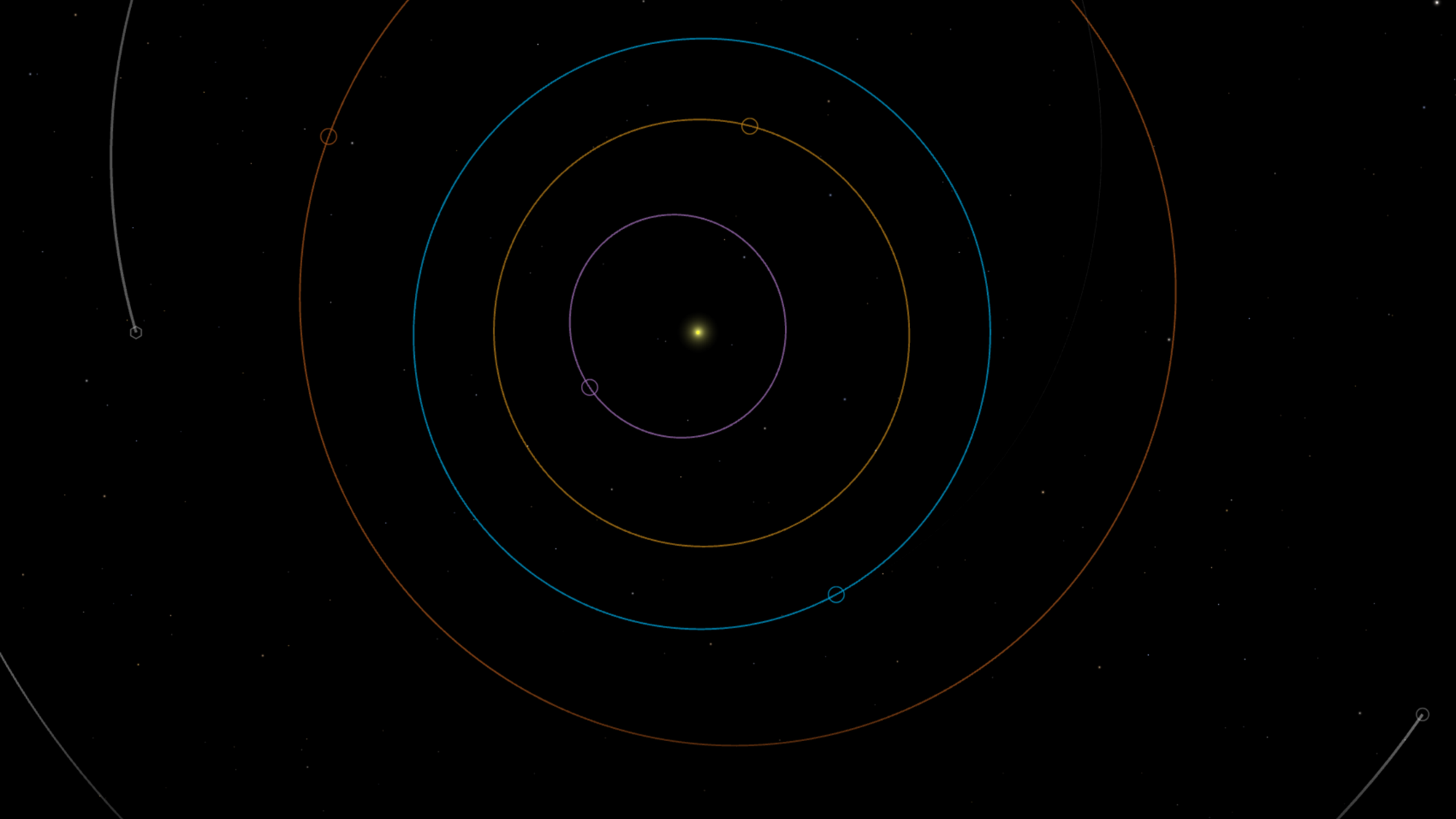

Uranus Orbiter and Probe
Solar Polar Orbiter
Mars Telecommunications Orbiter

The IPN - Conclusions

- The IPN is modernizing. Let us know what you want from us
    - Happy to discuss future IPN instruments (no SiPMs!)

- **Must maintain sensitive, all-sky coverage**
    - Ensure Konus-Wind continues (crucial and cheap TDAMM investment)
    - Begin building a strategic replacement

- What could be done with arcsecond prompt localizations?
    - Cosmology and host galaxies at your leisure
    - Individual magnetars in other galaxies
    - What else?



Science return as a function of capability

Alert Latency	Corresponding Result	Sections
>10,000,000 s	Origin of short GRBs, MGF candidate identification	2.1.1
	Origin and physical mechanisms of FRBs	2.1.4
	MGF QPOs and NS equation of state	2.1.2
	Sources of GWs	2.1.3 2.3.8
	Discovery of new magnetars	2.1.5
	Magnetar formation channels, properties, and burst physics	2.1.6 2.1.7 2.1.8
	Determination of SGRB progenitor fractions	2.2.6
	GRB classification of GW sources	2.2.8
	Speed of gravity measures	2.2.15
	Determination of GRB counterpart to orphan afterglow, dirty fireballs	2.3.1 2.3.2
	Origin of neutrinos, ultra-high energy cosmic rays	2.3.7
1,000,000 s	Guide fast radio burst searches of active Galactic magnetars	2.1.4
	Capture rise of supernova	2.3
100,000 s	Follow-up classification of long GRBs from mergers	2.2.7 2.2.9
	Latest reliable recovery of afterglow, potential redshift determination, cosmology	2.2.10 2.2.11 2.2.13
	Guide follow-up of externally-identified transients based on prompt GRB signal	2.3.1 2.3.2
	Capture rise of red kilonova	2.2.4
10,000	Key diagnostic information on relativistic jets	2.2.14
	X-ray recovery of plateau emission in afterglow	2.2.1
	Tests of gravity parity violation	2.2.15
	Follow-up observations for VHE emission	2.3.6
	Capture rise of blue kilonova	2.2.3
1000 s	X-ray observations of fading tail after Galactic MGFs	2.1
	Discrimination of origin of early UV emission in mergers	2.2.3
	Observation of prompt phase of ultra-long GRBs	2.3.4
	Blandford-Znajek test via afterglow polarization observations	2.3.9
100 s	Multiwavelength characterization of BNS merger classes and associated science	2.2.4
	Critical early observations of EM-bright NSBH mergers	2.2.5
	Prioritized follow-up based on GW merger classification	2.2.8
	X-ray observations of fading tail after extragalactic MGFs	2.1
	X-ray recovery of merger GRB extended emission	2.2.1
	Full tests of dense matter, origin of heavy elements	2.2.12
10 s	Recovery of higher radio frequency (low dispersion measure) precursors	[illegible]

Localization Accuracy	Corresponding Result	Sections
4π sr	Detection of gamma-ray transients by all-sky monitors	
	Chance joint detection of transients with other wide-field monitors	
$\sim$1000 deg^2	Follow-up tiling of GRBs by the widest field UV and optical telescopes	3.1
	Robust association of GWs and GRBs	2.2
$\sim$100 deg^2	Identification of MGF candidates and potential host galaxy	5.3.7
	Follow-up tiling of GRBs by wide-field optical telescopes	2.2.3, 2.3.6
$\sim$30 deg^2	Follow-up tiling of GRBs by wide-field radio, VHE, and IR facilities	3.1
$\sim$10 deg^2	Associate nearby extragalactic MGFs to ideal host galaxies	2.1.1
	Robust association of GRBs to neutrinos	2.3.7
$\sim$1 deg^2	Associate SGR flares to specific magnetars	2.1.3
	Robust association of UVOIR identified transients to GRB	
$\sim$100 arcminute^2	Extragalactic MGF host galaxy association	2.1.1
$\sim$30 arcminute^2	Follow-up observations by the majority of telescopes	
$\sim$1 arcminute^2	Follow-up observations by effectively all telescopes	
$\sim$ 100 arcsecond^2	Follow-up identification of Galactic magnetars	2.1.5
$\sim$ 10 arcsecond^2	Robust associations of cosmological GRBs to host galaxy and measurement of offset	2.3.12