Using gravitational wave early warning to pre-point neutron star mergers

GRAN SASSO SCIENCE INSTITUTE

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Collaborators:
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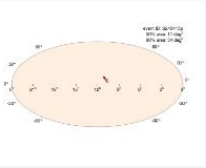
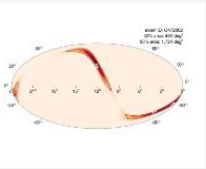
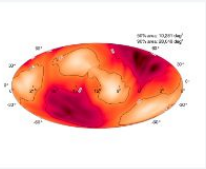
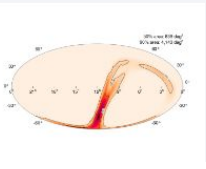
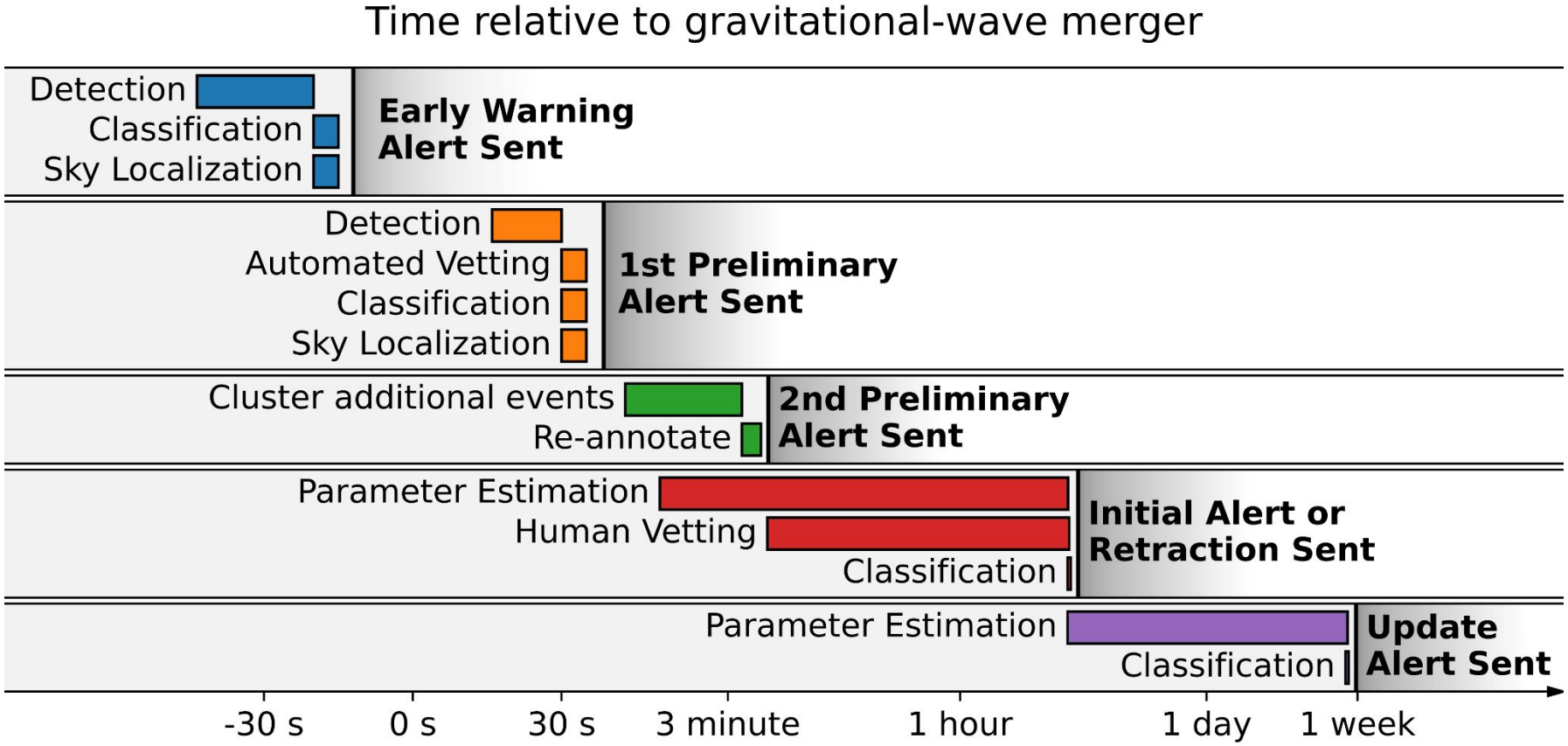
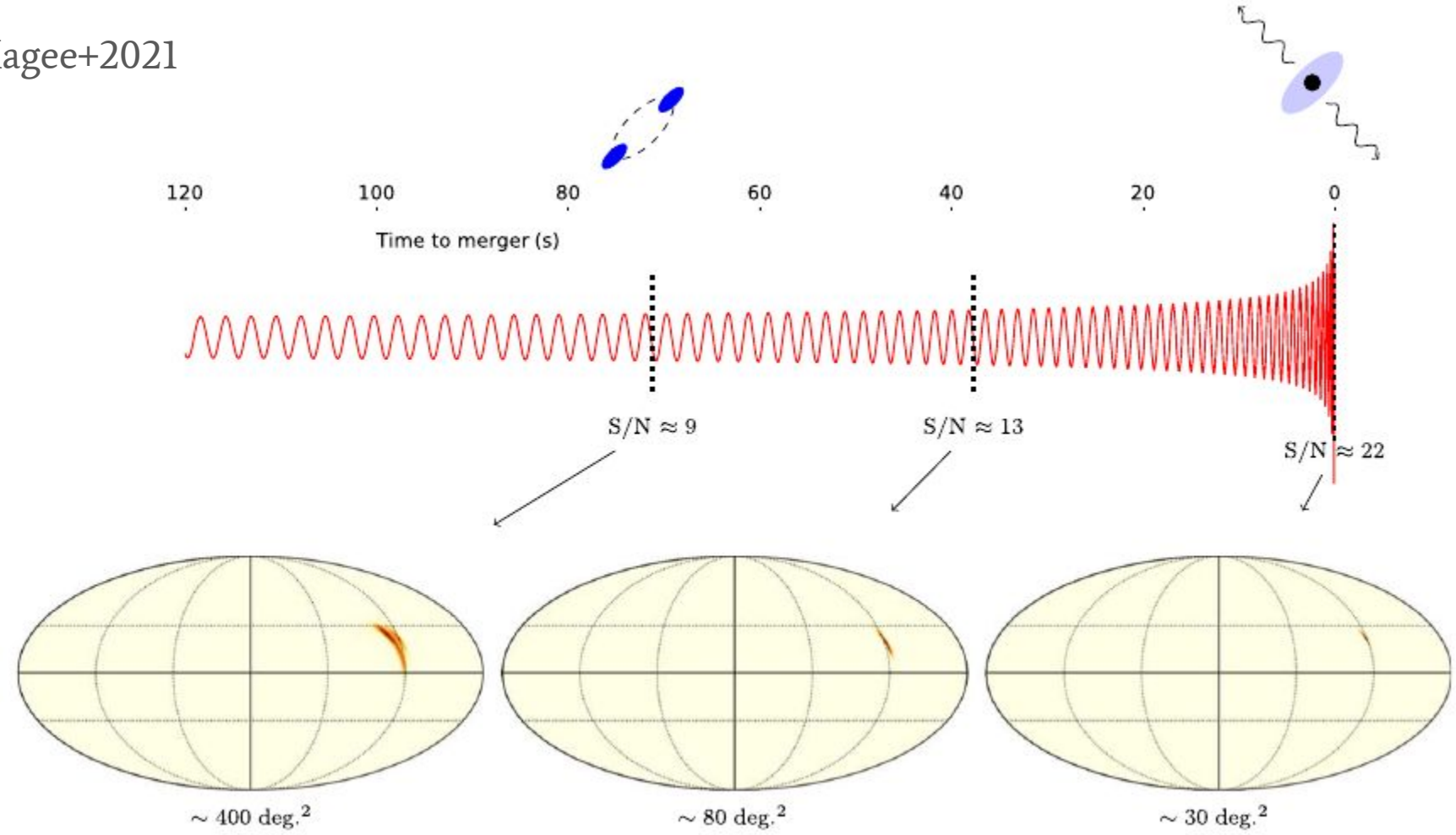
Event ID	Possible Source (Probability)	Significant	UTC	GCN	Location	FAR
S240413p	BBH (98%), Terrestrial (2%)	Yes	April 13, 2024 02:20:19 UTC	GCN Circular Query Notices | VOE		1 per 100.04 years
S240406aj	BBH (>99%)	Yes	April 6, 2024 06:28:47 UTC	GCN Circular Query Notices | VOE		1 per 2.029e+07 years
S240109a	BBH (99%)	Yes	Jan. 9, 2024 05:04:31 UTC	GCN Circular Query Notices | VOE		1 per 4.3136 years
S240107b	BBH (97%), Terrestrial (3%)	Yes	Jan. 7, 2024 01:32:15 UTC	GCN Circular Query Notices | VOE		1.8411 per year

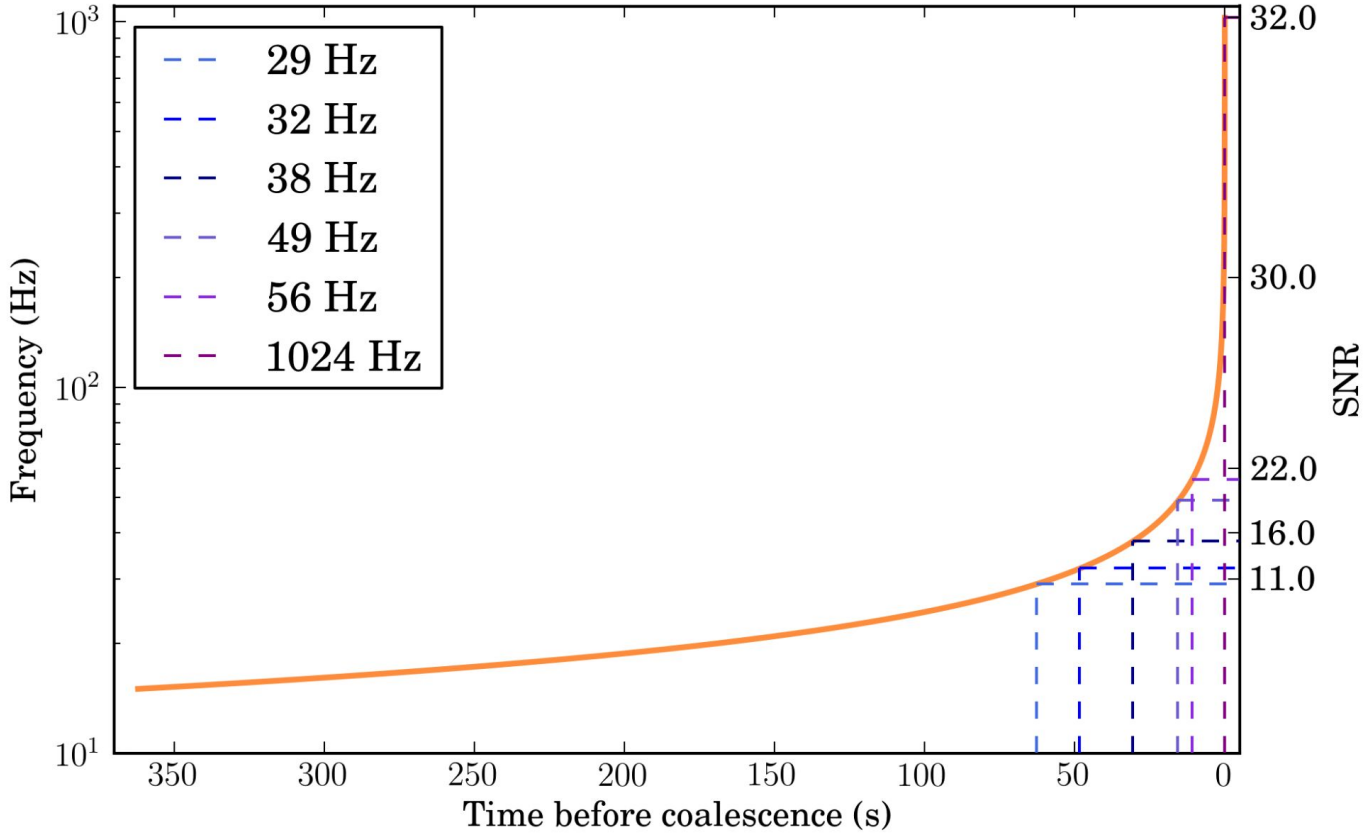
GraceDB (gracedb.ligo.org)



EMFollow userguide (emfollow.docs.ligo.org)

Magee+2021


120
100
80
60
40
20
0
Time to merger (s)
S/N ≈ 9
S/N ≈ 13
S/N ≈ 22
~ 400 deg.²
~ 80 deg.²
~ 30 deg.²



EMFollow userguide (emfollow.docs.ligo.org)

Latest as of 23 March 2024 17:41:34 UTC

Test and MDC events and superevents are not included in the search results by default; see the query help for information on how to search for events and superevents in those categories.

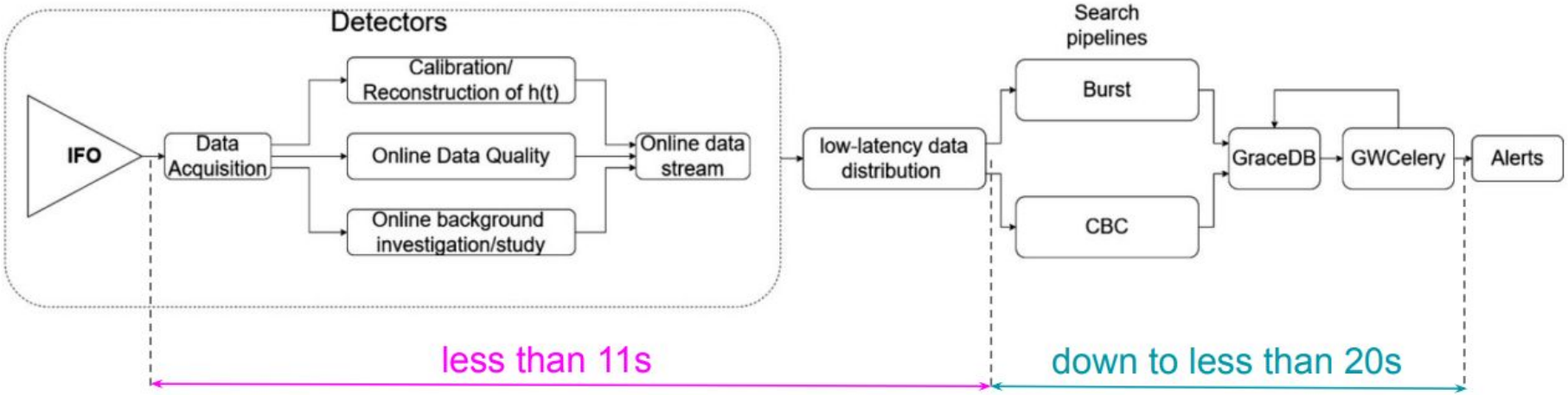
Query: EARLY_WARNING

Search for: Superevent

Search

Tap on entry for detailed information

UID	Labels	FAR (Hz)	Created
S231030av	EARLY_WARNING EM_READY LOW_SIGNIF_LOCKED PASTRO_READY EMBRIGHT_READY SKYMAP_READY ADVNO PE_READY	4.215e-08	2023-10-30 12:51:20 UTC
S230918aq	EARLY_WARNING EM_READY LOW_SIGNIF_LOCKED EMBRIGHT_READY PASTRO_READY SKYMAP_READY ADVNO	5.418e-08	2023-09-18 11:19:28 UTC
S230810af	EM_READY EARLY_WARNING LOW_SIGNIF_LOCKED PASTRO_READY EMBRIGHT_READY SKYMAP_READY PE_READY ADVNO	2.905e-08	2023-08-10 10:00:53 UTC
S230524x	EM_READY EARLY_WARNING LOW_SIGNIF_LOCKED PASTRO_READY EMBRIGHT_READY SKYMAP_READY HIGH_PROFILE ADVNO PE_READY	7.224e-08	2023-05-24 20:22:27 UTC



De Pietri, Vallero 2023

GW instruments

- **O5 LIGO-Virgo-KAGRA**
(~2027, ~100 BNS)
- Einstein Telescope, Cosmic Explorer
(~2035, ~100 000 BNS)

Kiendrebeogo+2023, Branchesi+2023

IACTs

Name	Field of View	Energy Band	Slew speed
MAGIC	~ 3.5 deg	≳ 100 GeV	6 deg/s
ASTRI	**~ 10 deg**	**≳ 1 TeV**	**2 deg/s**
CTA-LST	~ 4 deg	≳ 100 GeV	6 deg/s

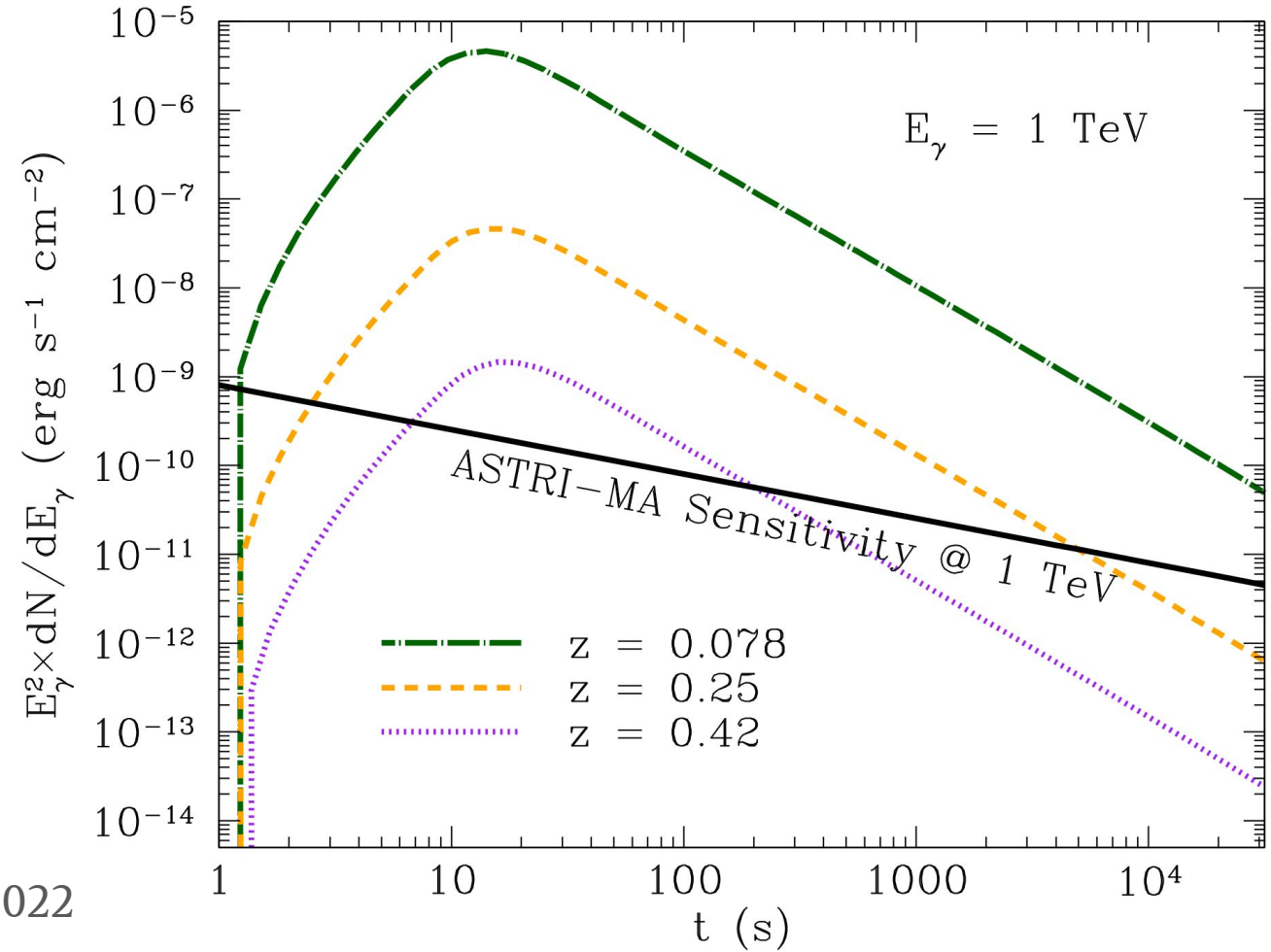
MAGIC started observing GRB 160821B within **24s** of the GCN arriving!

ASTRI

Pictured here:
ASTRI prototype,
Mount Etna, Italy

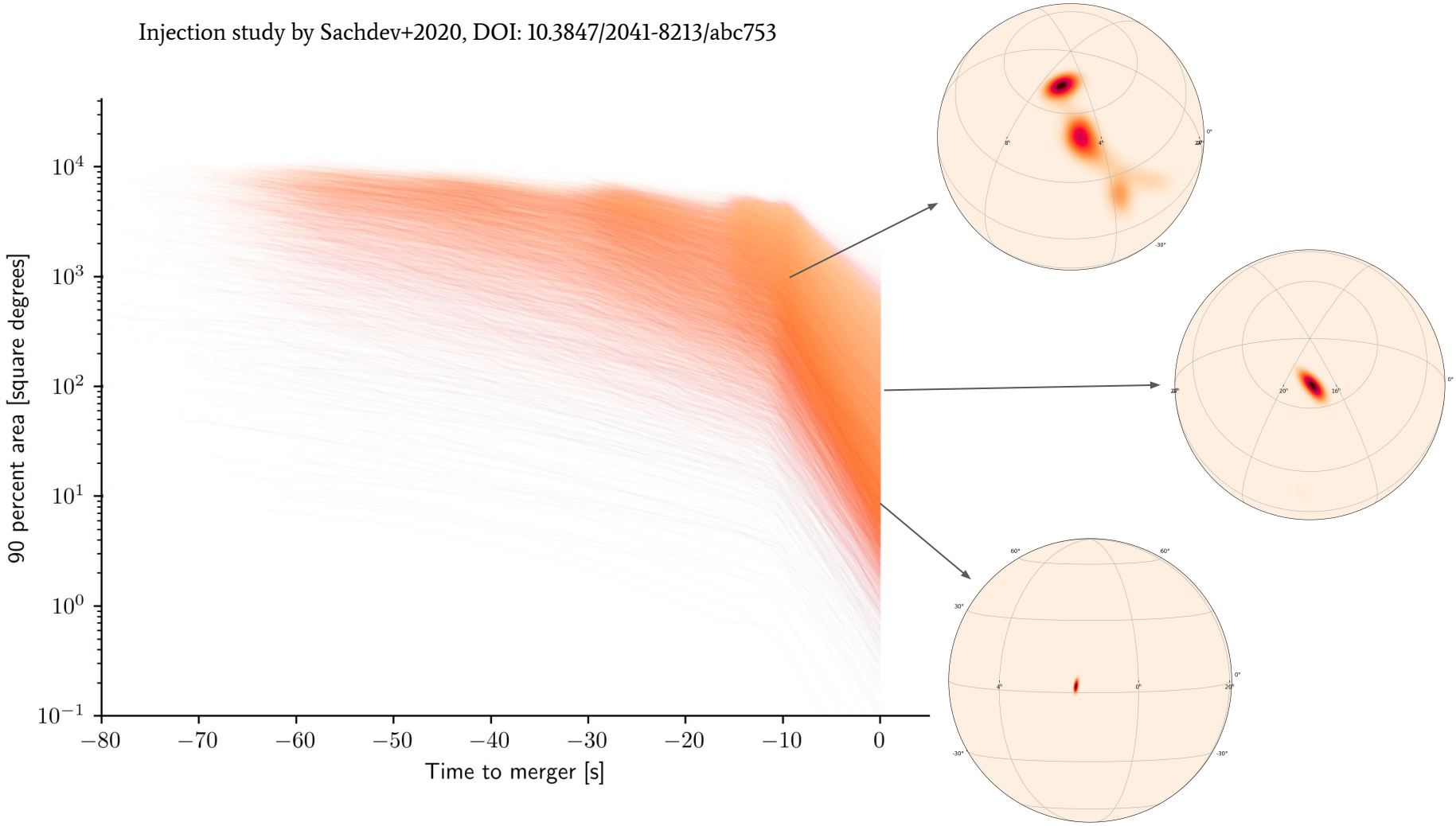
Strategy

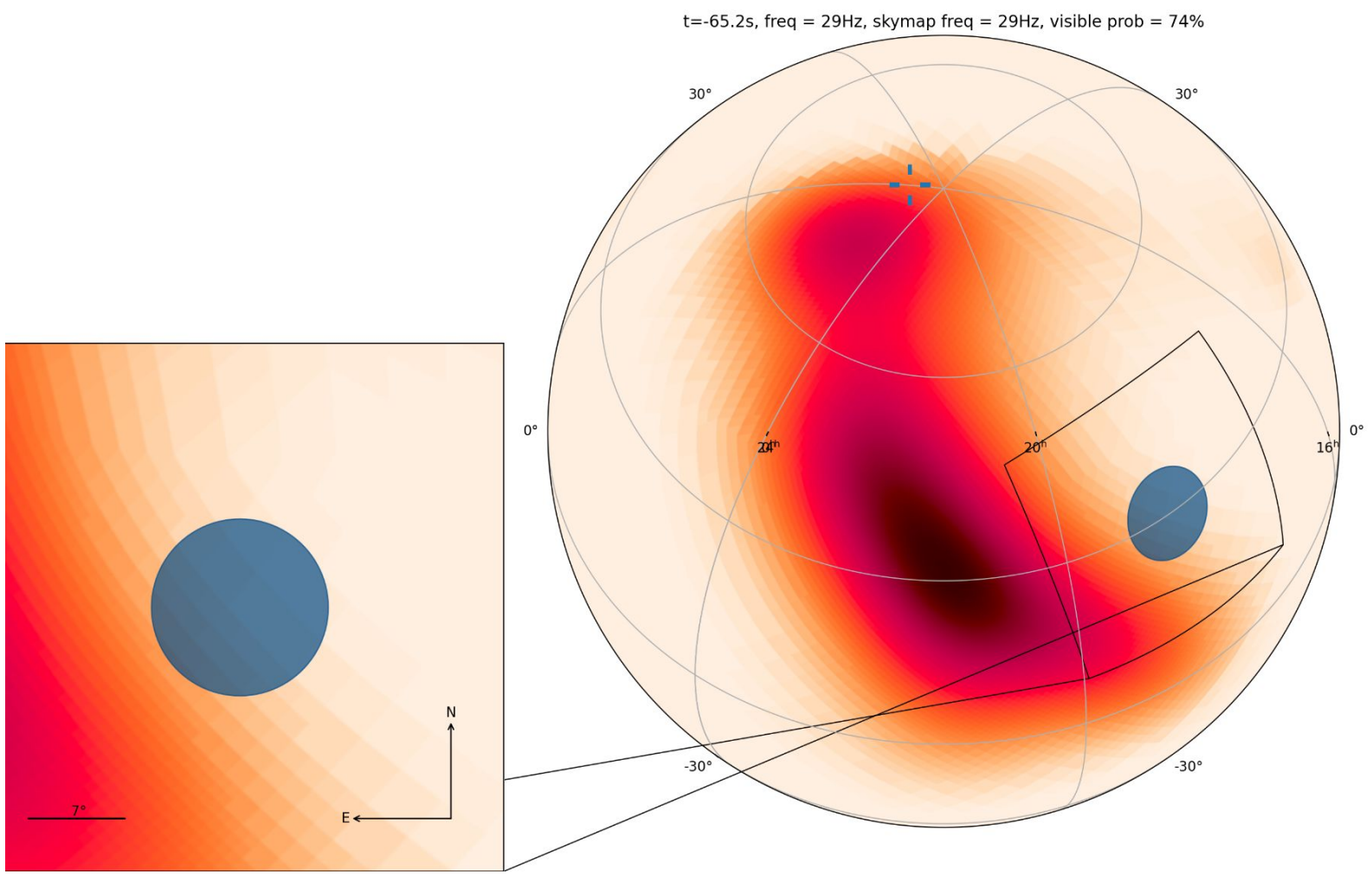
- **Mosaic** for non well-localized events
  - Afterglow
- **One-shot** for well-localized events
  - Maybe prompt? (cf. Samanta Macera's talk)

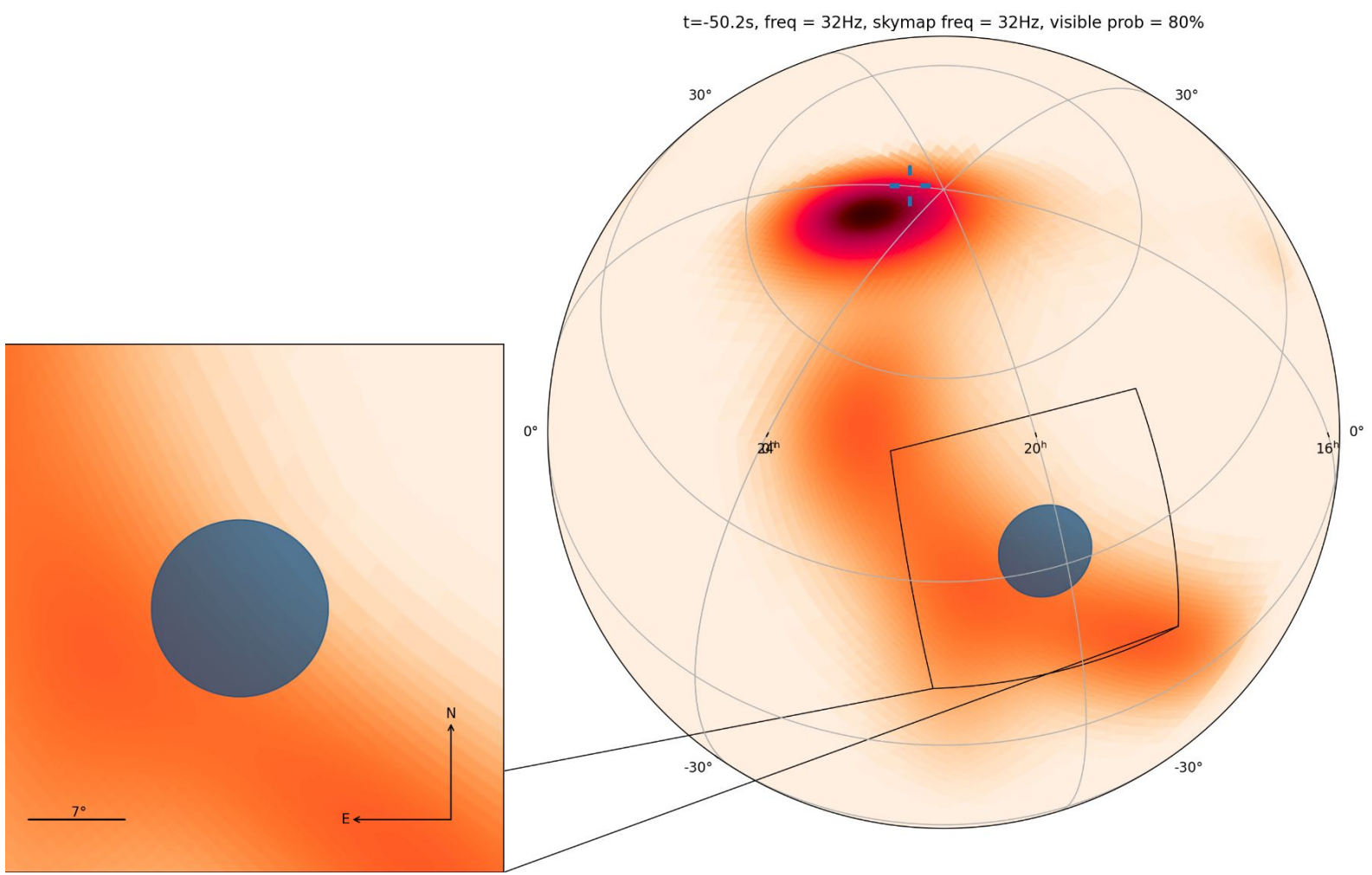


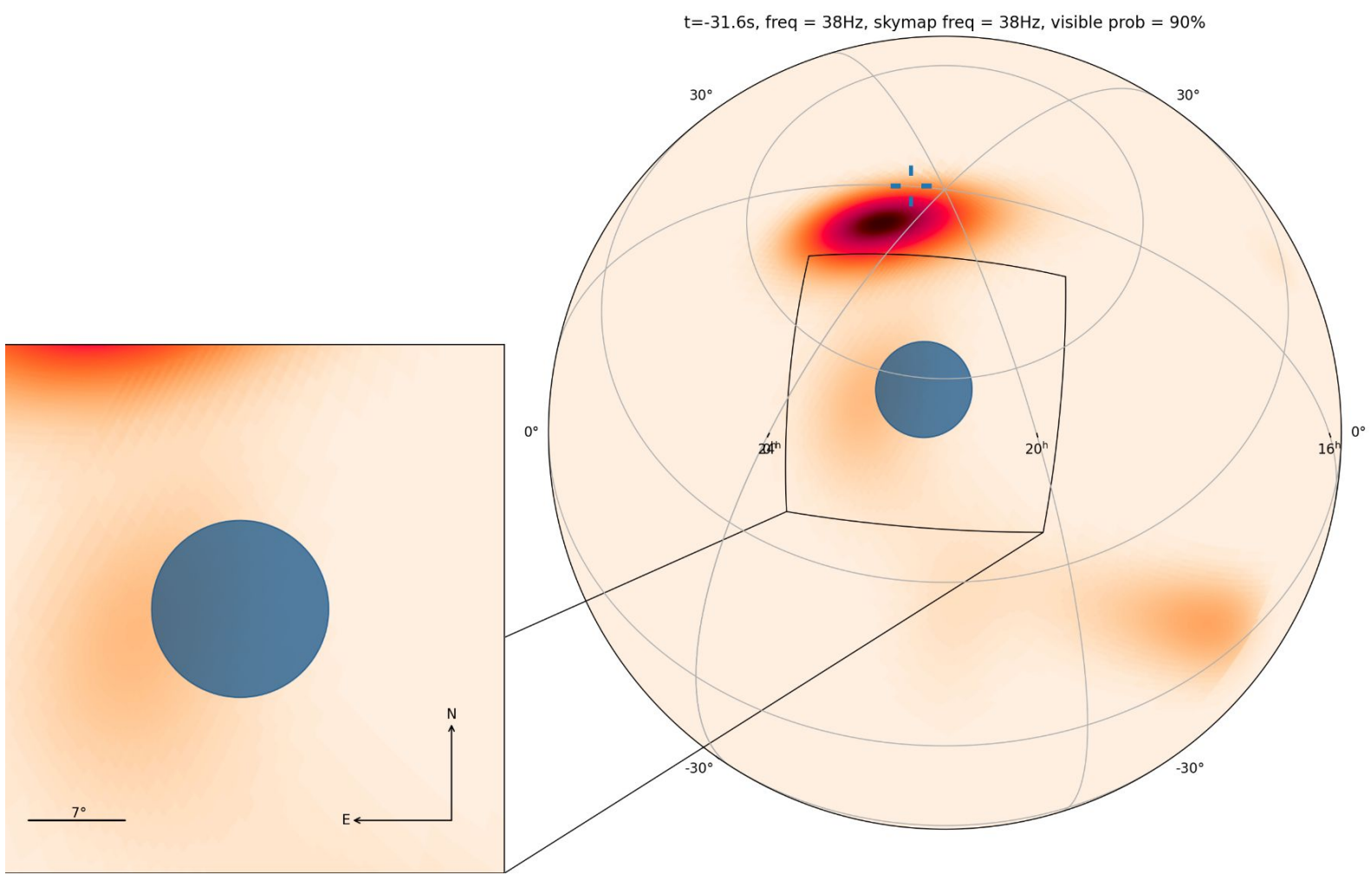
Vercellone+2022

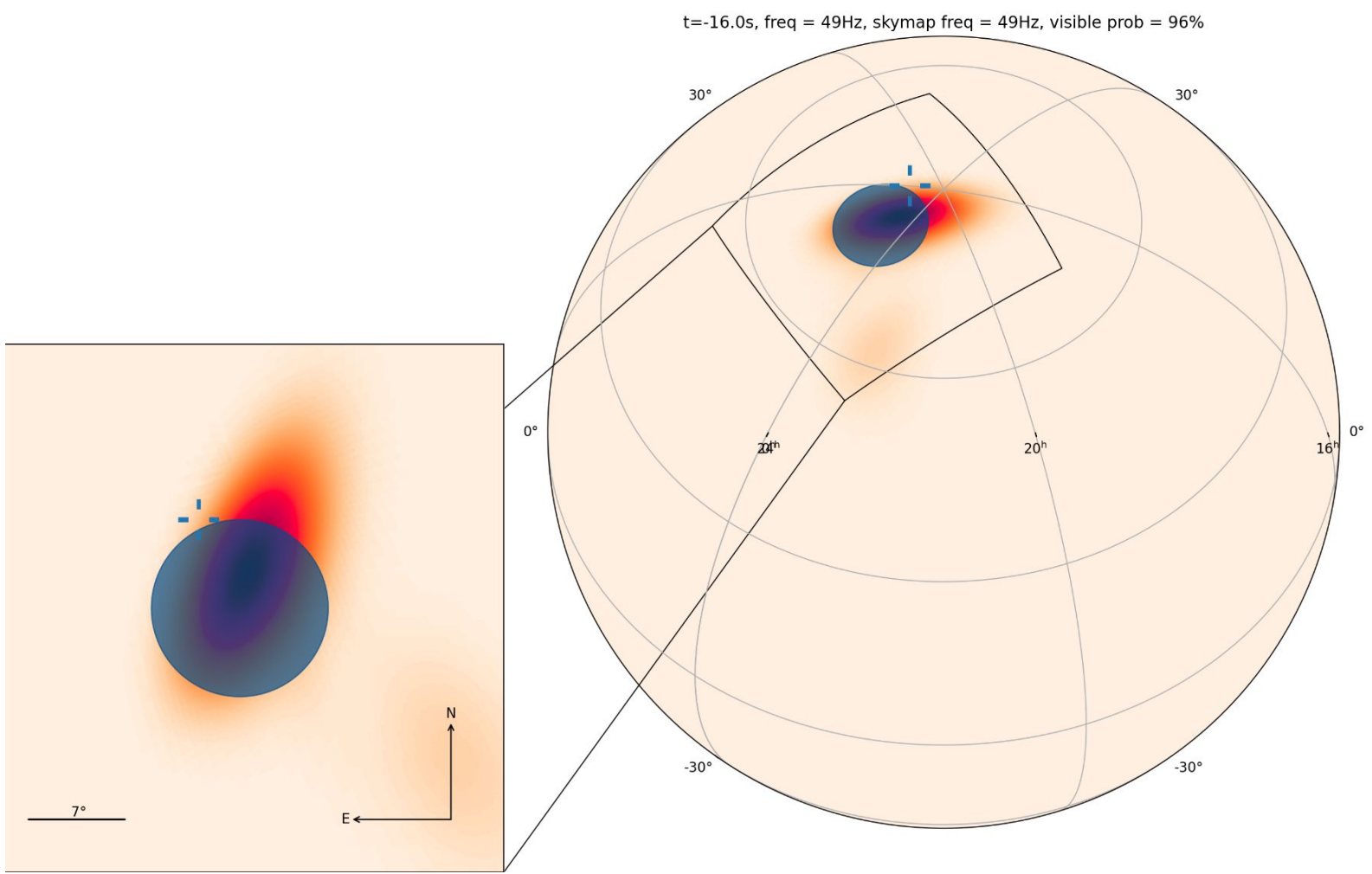
Injection study by Sachdev+2020, DOI: 10.3847/2041-8213/abc753

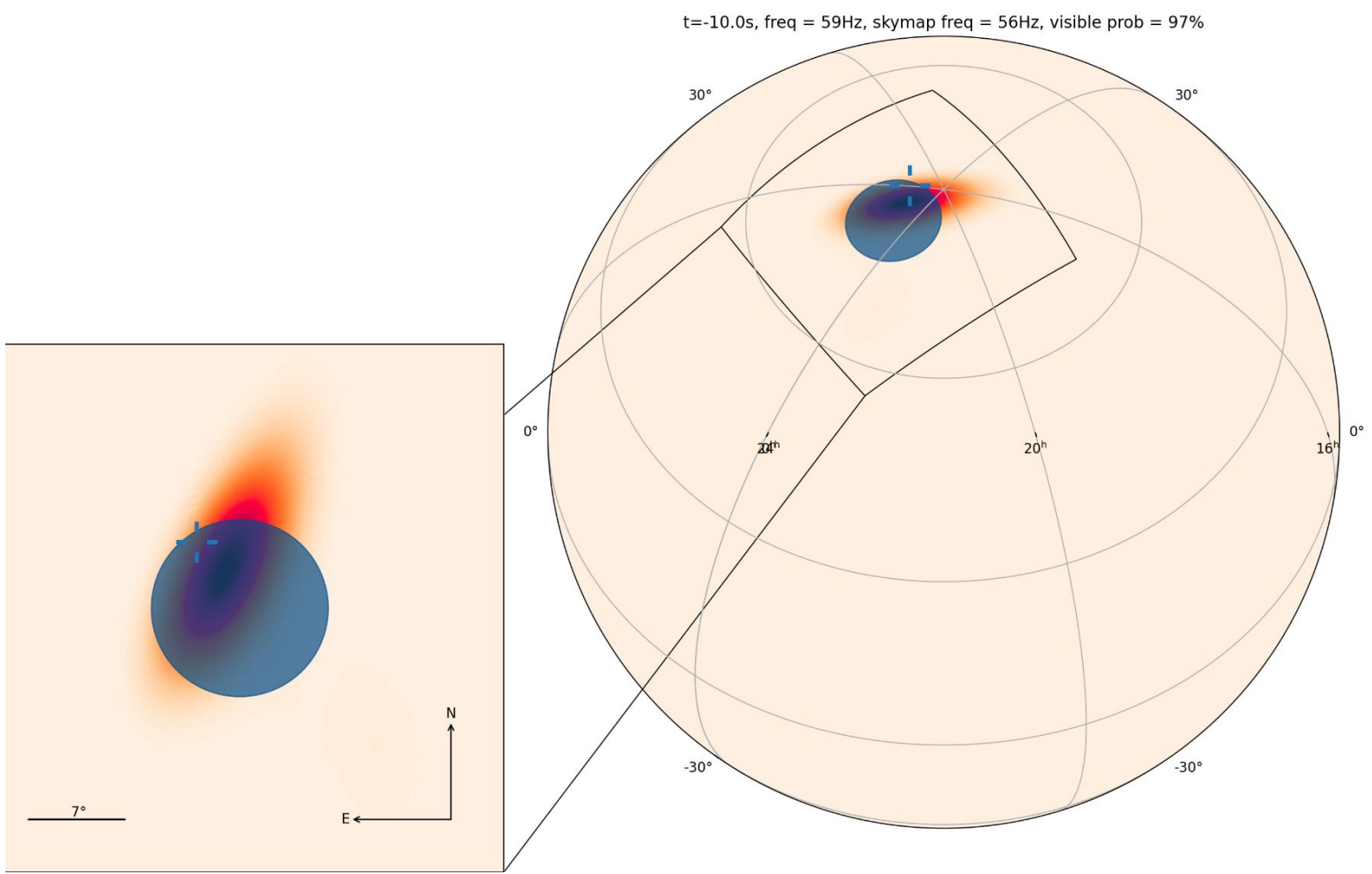


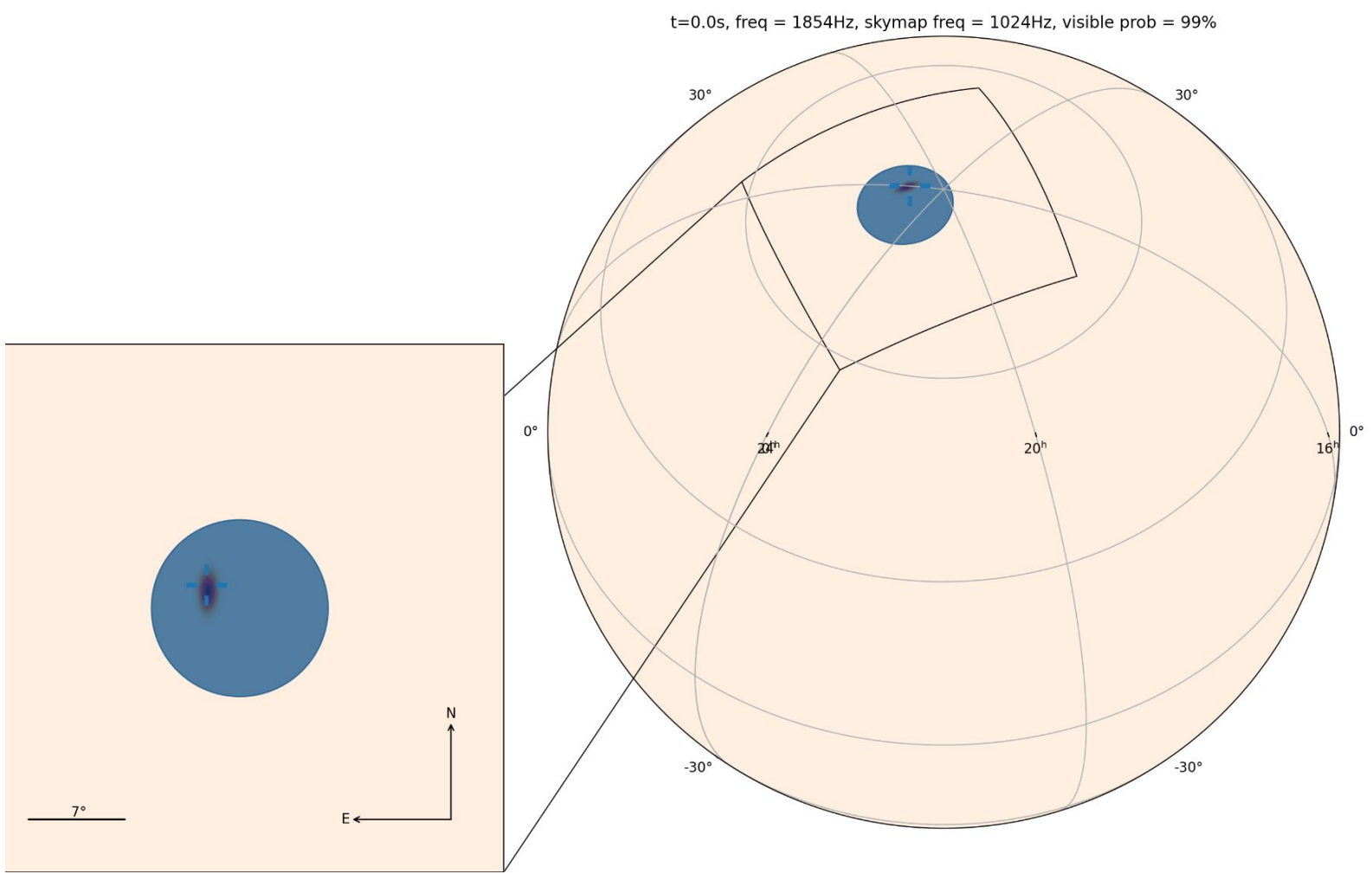

t=-65.2s, freq = 29Hz, skymap freq = 29Hz, visible prob = 74%
30°
30°
0°
0°
-30°
-30°
20h
16h
N
E
7°

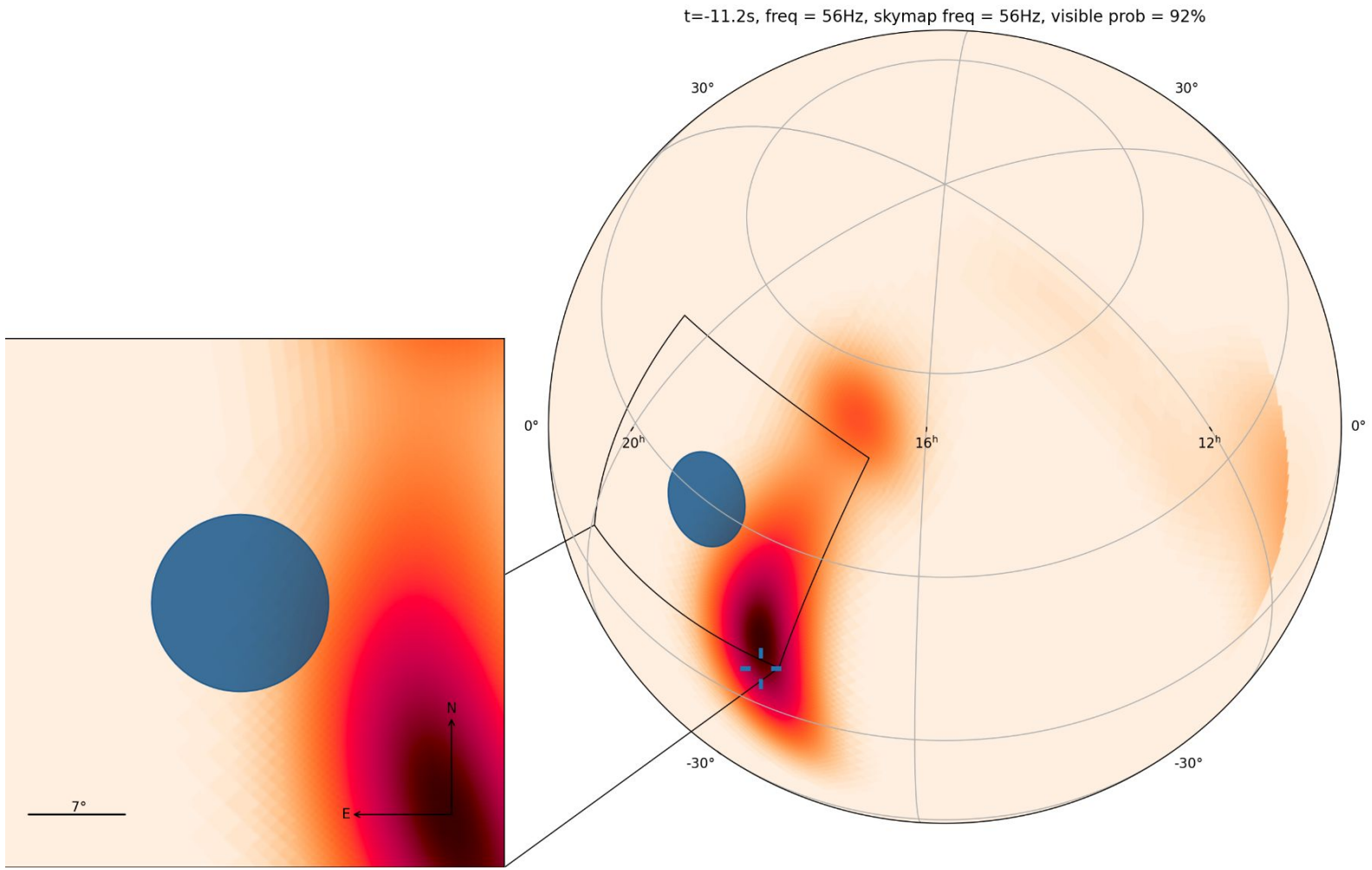

t=-50.2s, freq = 32Hz, skymap freq = 32Hz, visible prob = 80%
30°
30°
0°
0°
-30°
-30°
20h
16h
N
E
7°

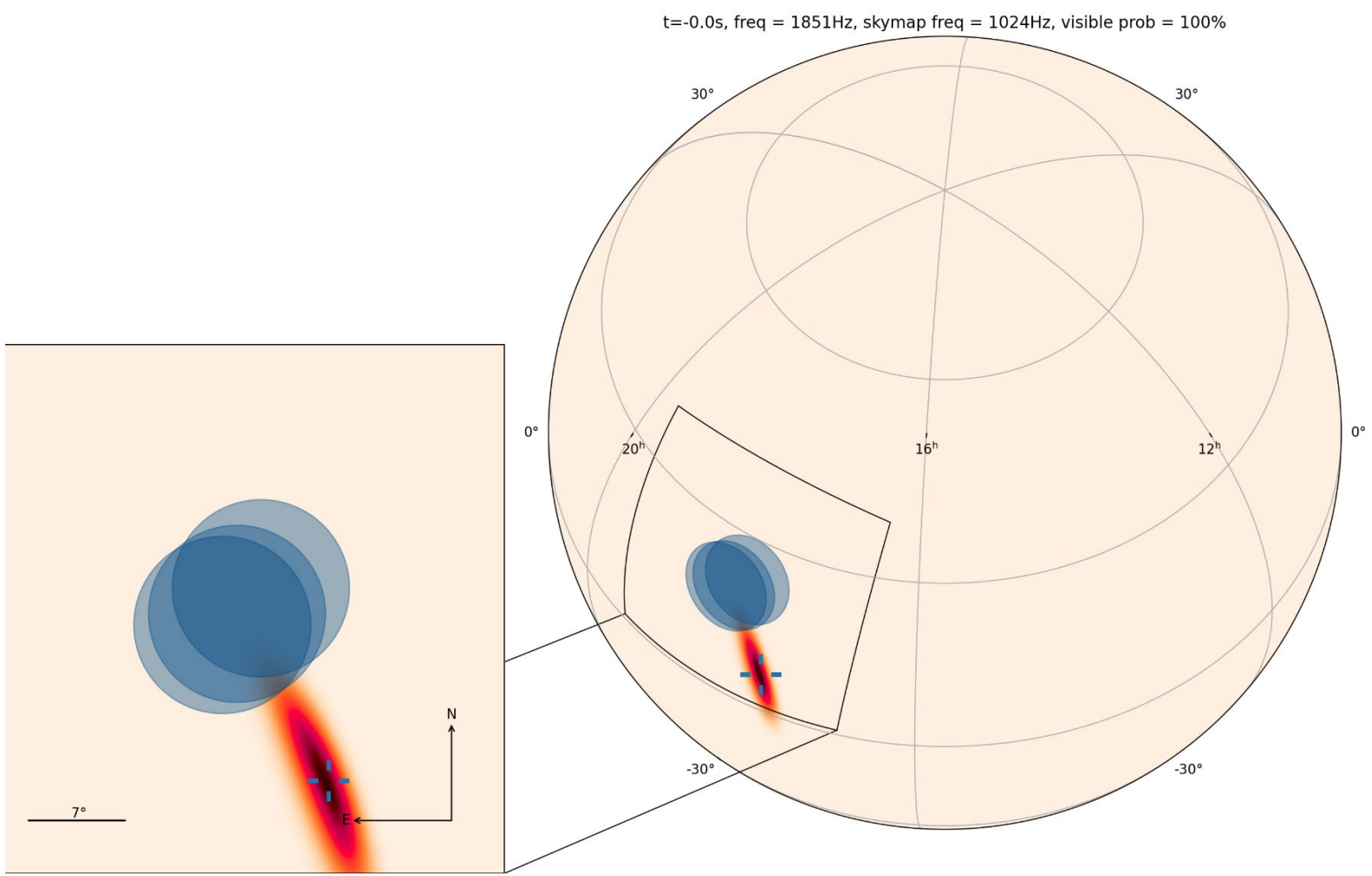

t=-31.6s, freq = 38Hz, skymap freq = 38Hz, visible prob = 90%
30°
30°
0°
0°
-30°
-30°
24h
20h
16h
7°
N
E

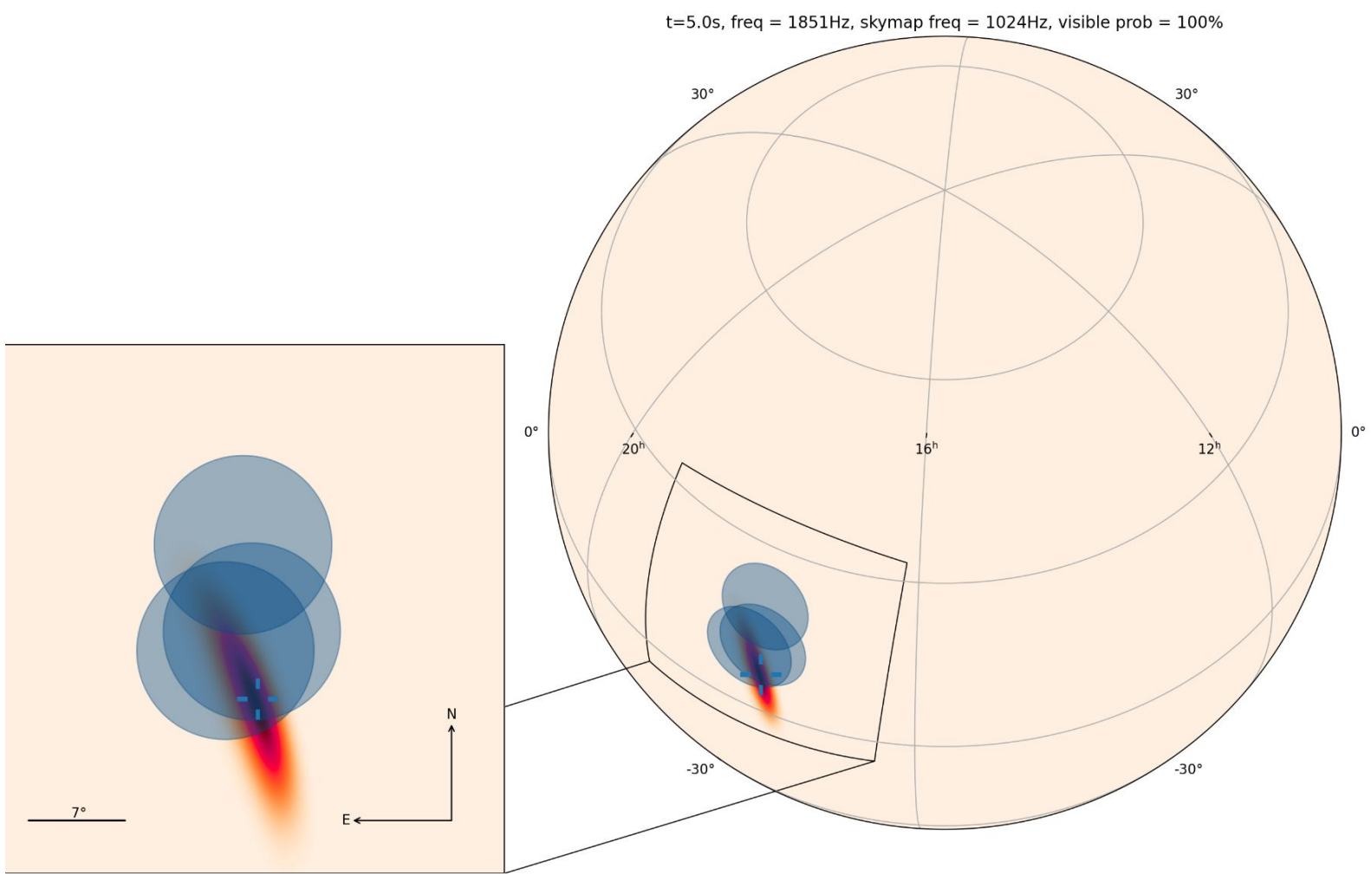

t=-16.0s, freq = 49Hz, skymap freq = 49Hz, visible prob = 96%
30°
30°
0°
0°
-30°
-30°
20h
20h
16h
7°
N
E

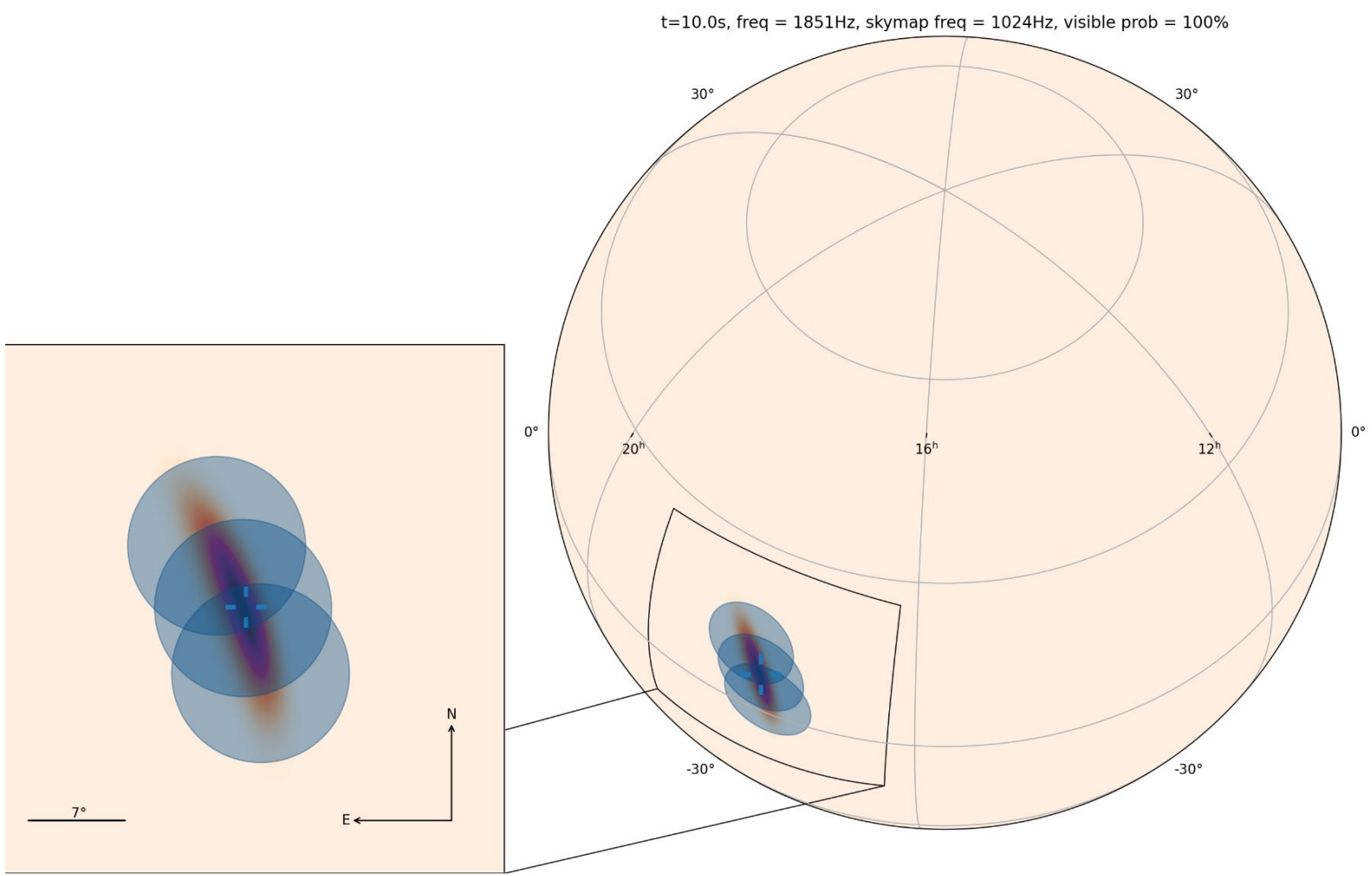

t=-10.0s, freq = 59Hz, skymap freq = 56Hz, visible prob = 97%
30°
30°
0°
0°
-30°
-30°
20h
20h
16h
7°
N
E


t=0.0s, freq = 1854Hz, skymap freq = 1024Hz, visible prob = 99%
30°
30°
0°
0°
-30°
-30°
20h
20h
16h
N
E
7°


t=-11.2s, freq = 56Hz, skymap freq = 56Hz, visible prob = 92%
30°
30°
0°
0°
20h
16h
12h
-30°
-30°
N
E
7°


t=-0.0s, freq = 1851Hz, skymap freq = 1024Hz, visible prob = 100%
30°
30°
0°
0°
20h
16h
12h
-30°
-30°
N
E
7°


t=5.0s, freq = 1851Hz, skymap freq = 1024Hz, visible prob = 100%
30°
30°
0°
0°
20h
16h
12h
-30°
-30°
N
E
7°


t=10.0s, freq = 1851Hz, skymap freq = 1024Hz, visible prob = 100%
30°
30°
0°
0°
20h
16h
12h
-30°
-30°
N
E
7°

Backup

Is there detectable VHE prompt emission?

It's plausible: the assumptions are

- There is a **HE component**, with a spectrum that's flat or harder
  - Specifically, the **spectrum** does not decay faster than **dN/dE ~ E^-3**
- The prompt emission is at least **as bright as the afterglow**: see Nava+2014, L_iso / E_iso > 0.03 Hz in the first 10 seconds
- Then, for the first 10 seconds we expect a **flux** of

$$F_{1-5\mathrm{TeV}} \gtrsim 10^{-9}\mathrm{erg\ cm^{-2}\ s^{-1}} \left(\frac{E_{\mathrm{iso}}}{10^{51}\mathrm{erg}}\right)\left(\frac{100\mathrm{Mpc}}{d_L}\right)^2\left(\frac{e^{-\tau_{\gamma\gamma}}}{0.5}\right)$$