National Science Challenge Initiatives
Center for the Gravitational-Wave Universe

Observing Strategy for Electromagnetic Follow-up of Gravitational-Wave Events

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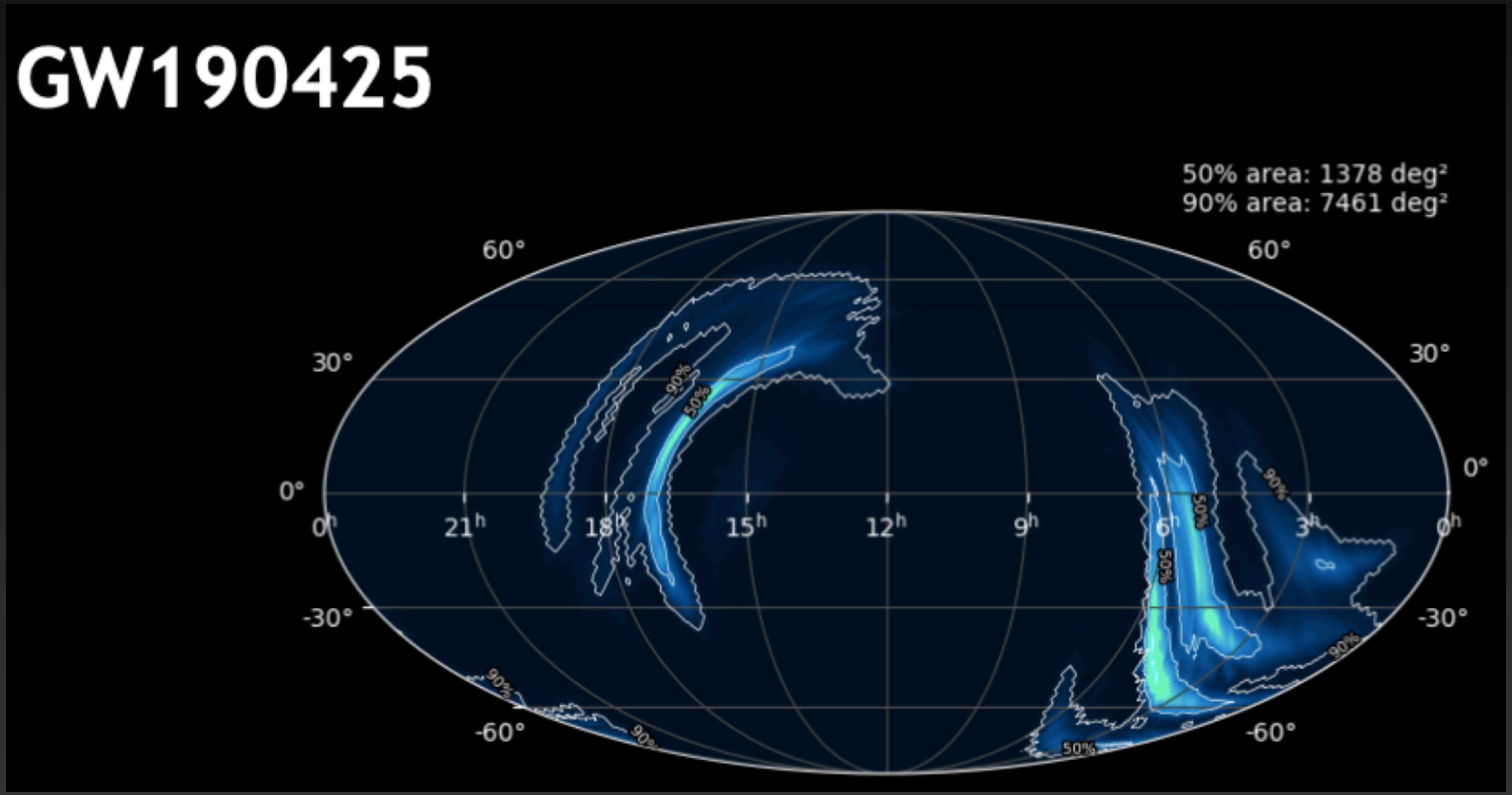
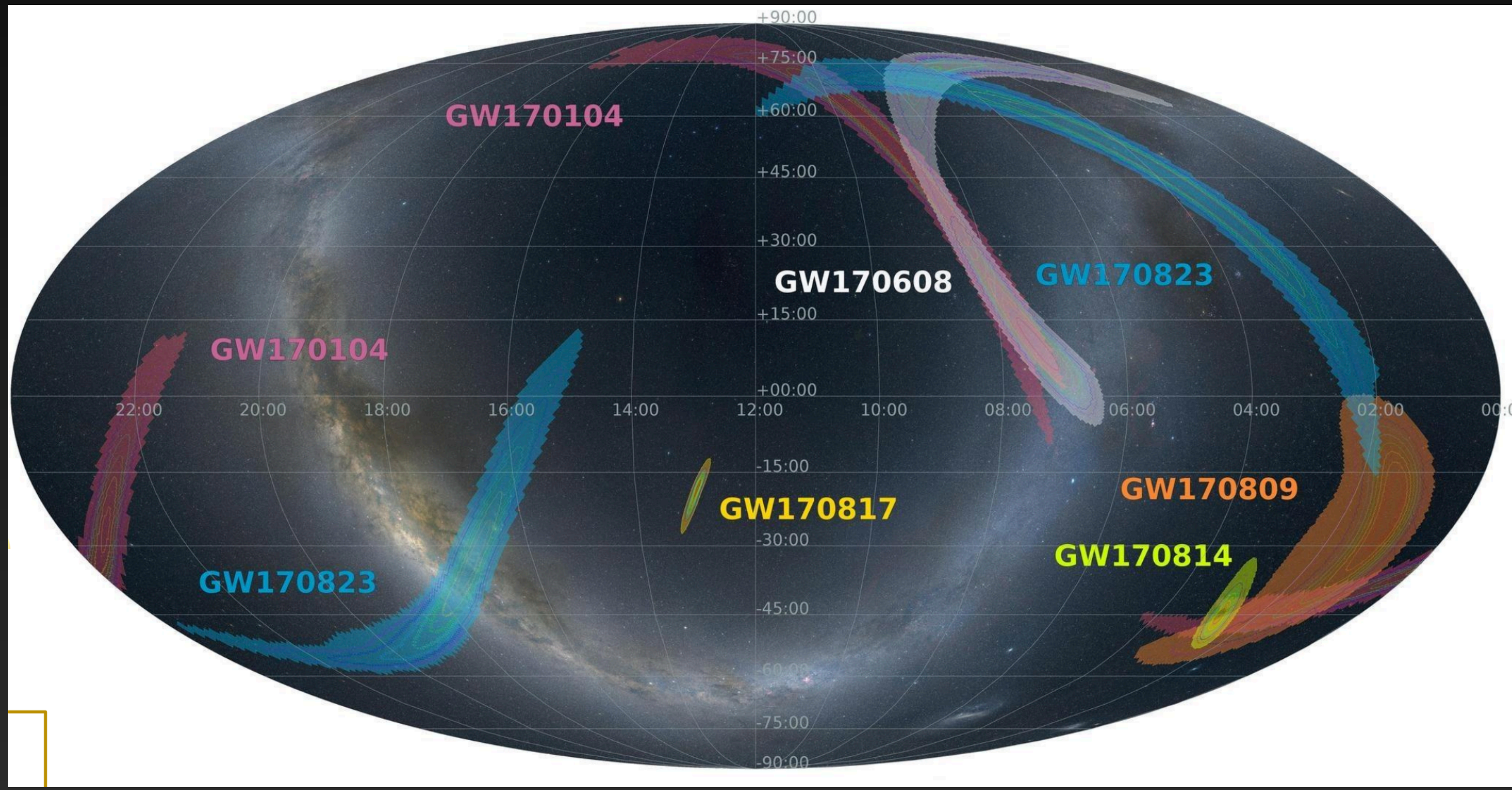
Challenges to EM Observation:

1- Large GW sky localization for some GW events: We should survey a wide region of sky to catch the EM counterparts

Typically, there is a large sky localization uncertainty



The localization of GW190425. Credit: Ben Farr/LIGO.



GW170817 located at 40 Mpc with 2D sky localization(90%) 28 deg^2

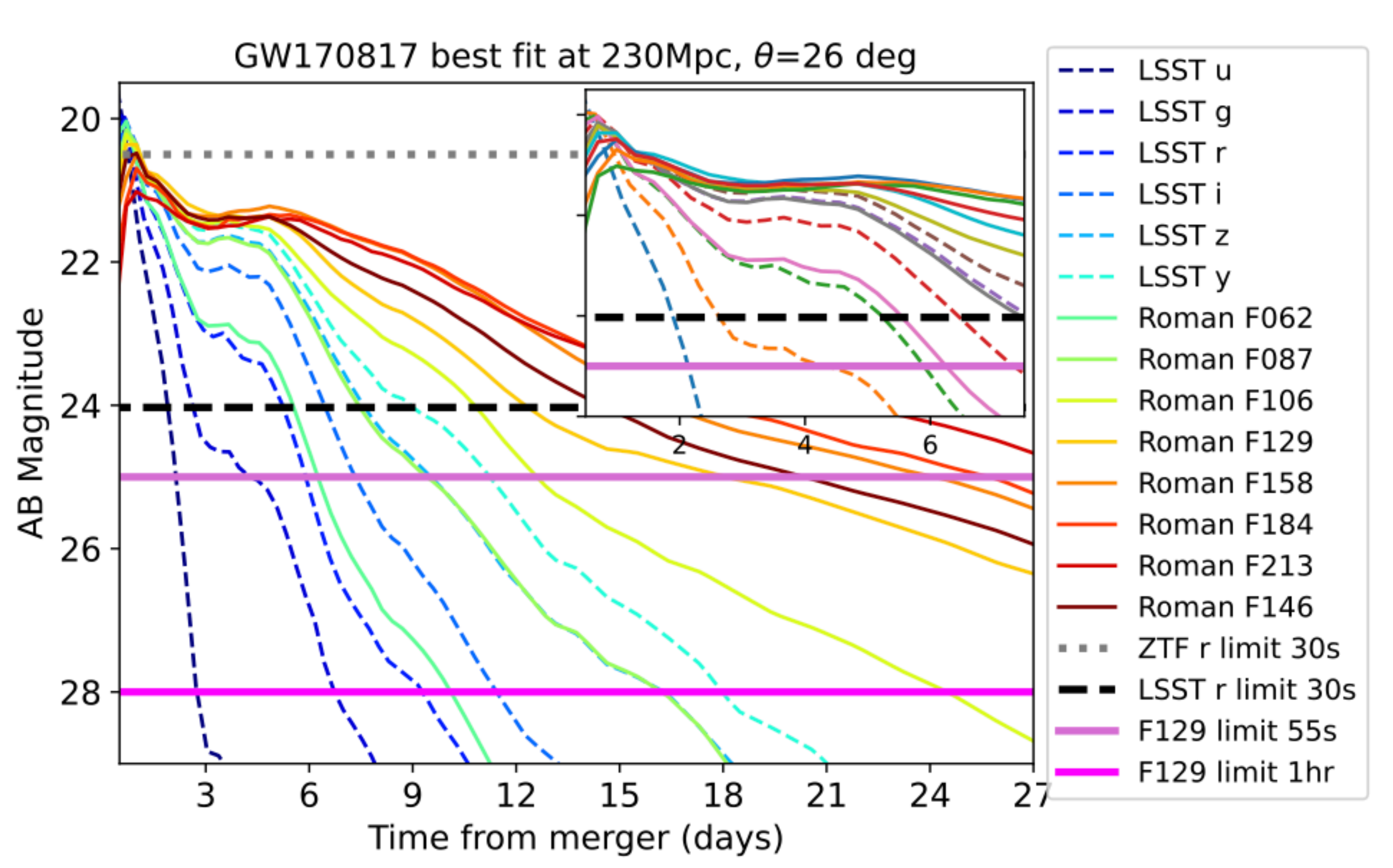
https://multi-messenger.asterics2020.eu/Documents/presentations/Greco_Giuseppe.pdf

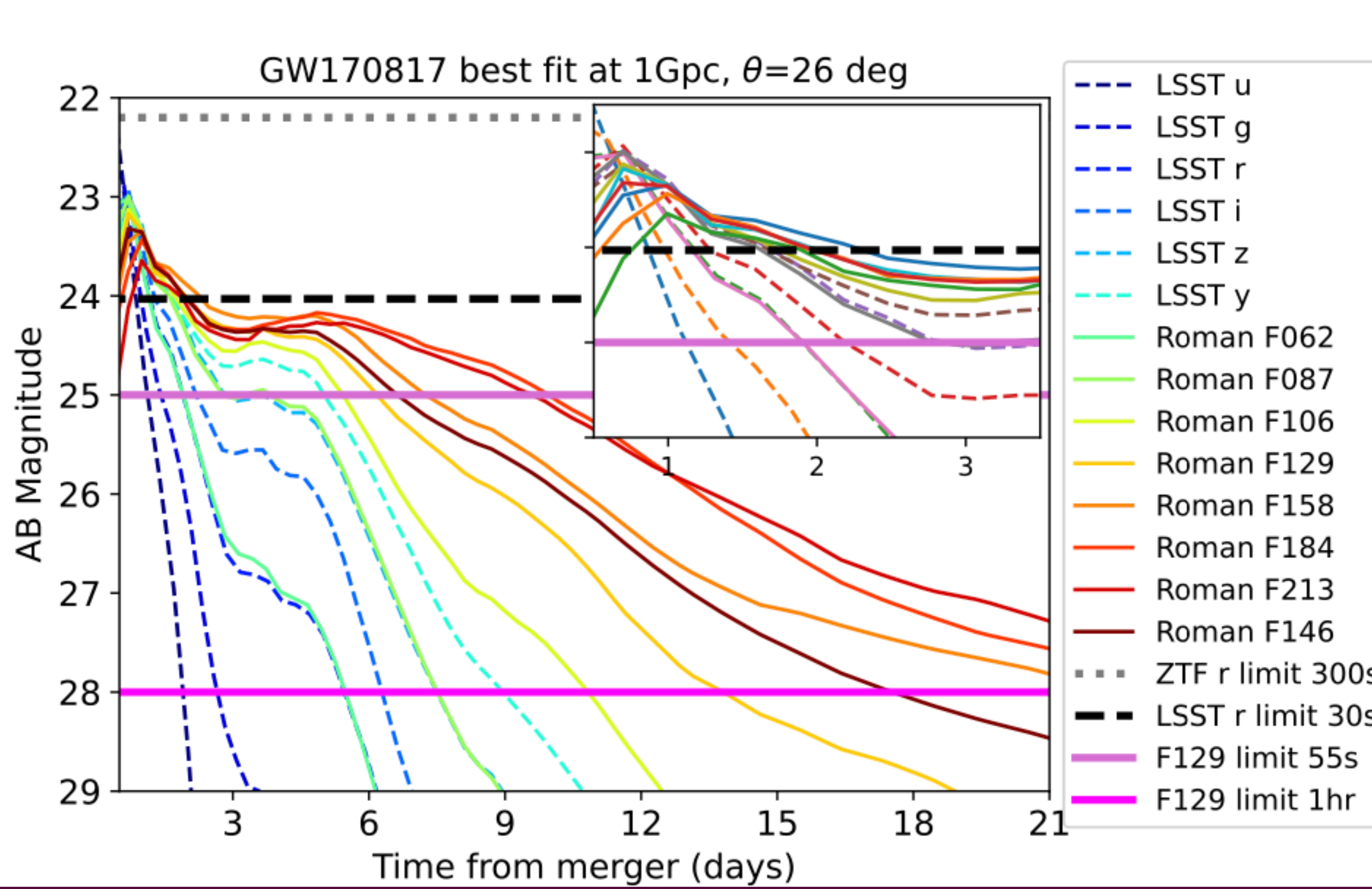
We were lucky for GW170817

Challenges to EM Observation:

2- The EM signals are faint and become fainter fast

AT2017gfo is bright kilonova peaked at the magnitude of 17 in the I band



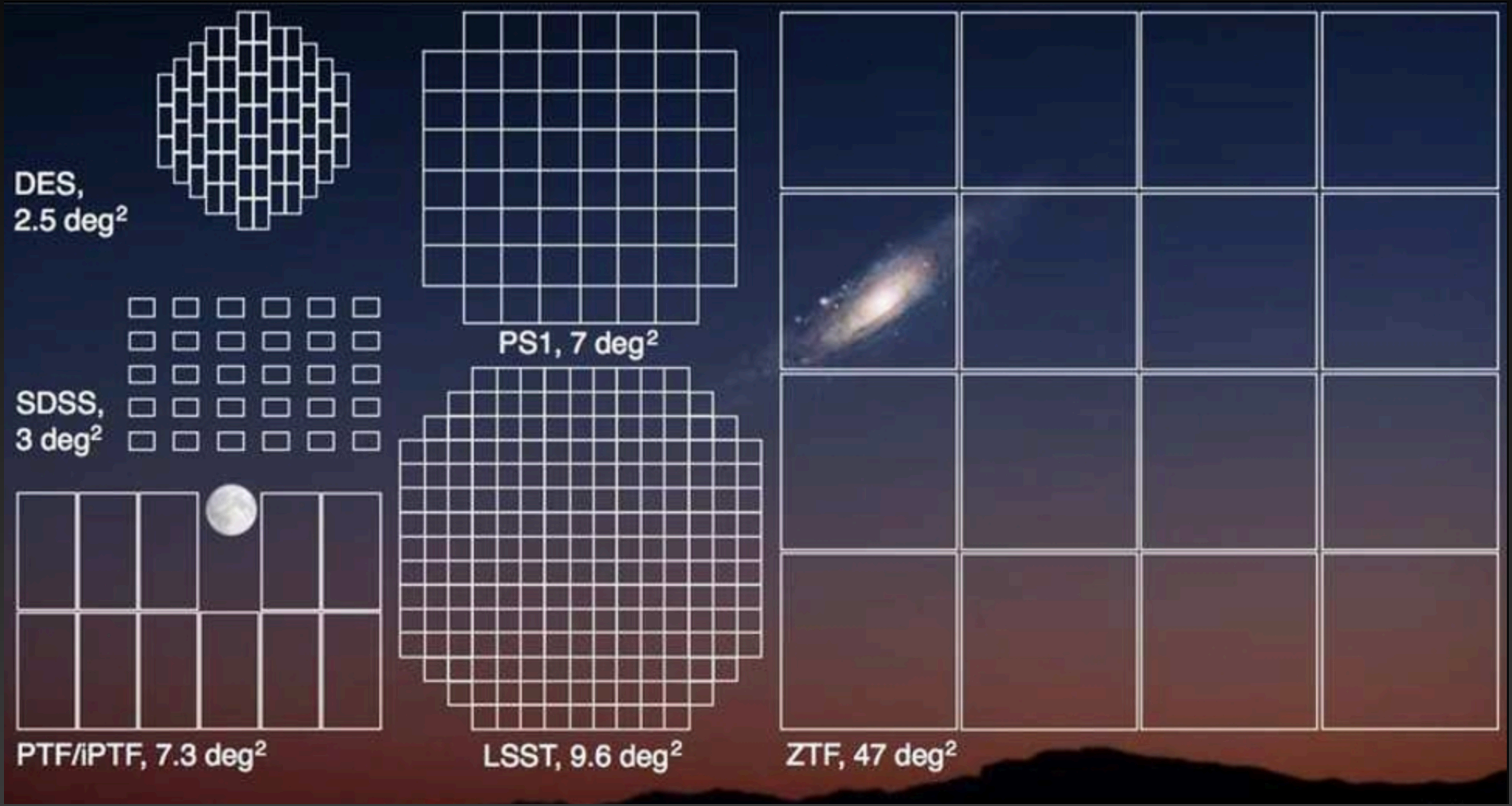


it is 1⁄10 to 1⁄100 the brightness of a typical supernova

https://arxiv.org/pdf/2307.09511.pdf

To overcome this challenge, we propose optimal observing strategies for GW follow-up observation

We classify the telescopes in two categories based on the size of FOV.



Observing Strategy

Galaxy-Targeting Strategy:

NARROW FIELD TELESCOPES (FOV<1 deg^2).

Single galaxy per pointing

Tiling Strategy:

WIDE FIELD TELESCOPES (FOV>= 1 deg^2)

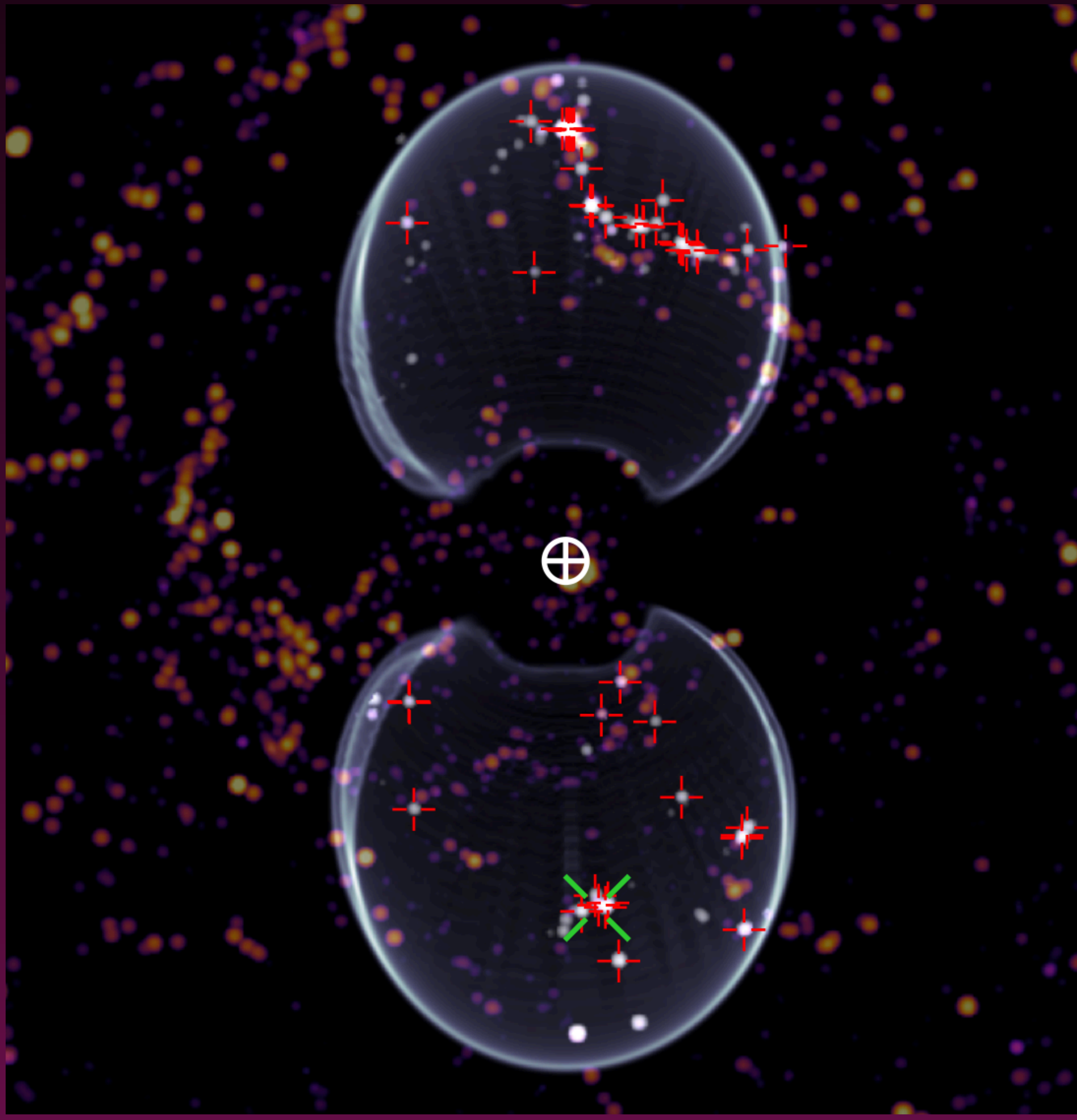
A few galaxies per single pointing

Credit: ChatGPT4

Search strategy for narrow field telescopes

Galaxy-Targeting Method: Galaxy cross-matching within volume:

- We find the galaxies that locate in the 90% GW (within volume).
- We used the GLADE+ Galaxy Catalog.



Singer L. P., et al., 2016b, Astrophys. J. Lett., 829, L15

We ranked the host galaxy candidates based on the:

Mass (Assumption: BNS merger rate ~ M*)

Probability of GW source at the position of each galaxy in the 3D GW sky map

Credit: ChatGPT4

Singer L. P., et al., 2016b, Astrophys. J. Lett., 829, L15
Arcavi I., et al., 2017b, Astrophys. J. Lett., 848, L33

Search strategy for wide field telescopes

Tiling Strategy

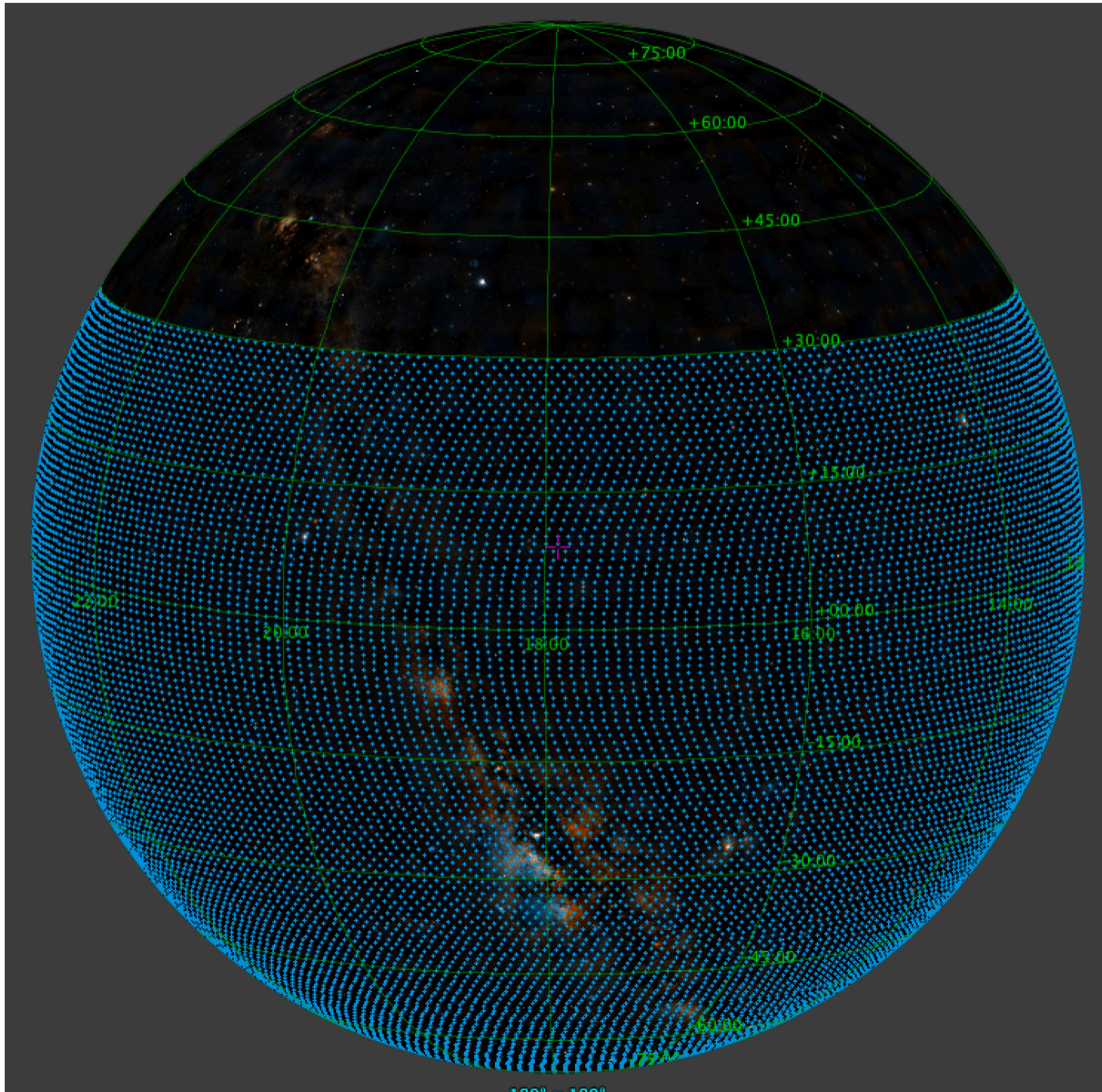
Process to generate the tiling patterns for a telescope:

•Step 1: Create sky grid

Generate Points on a unit sphere in an optimum way.

NOTE:

The points show the center of a telescope FOV for portions of the sky that are observable with the telescope.



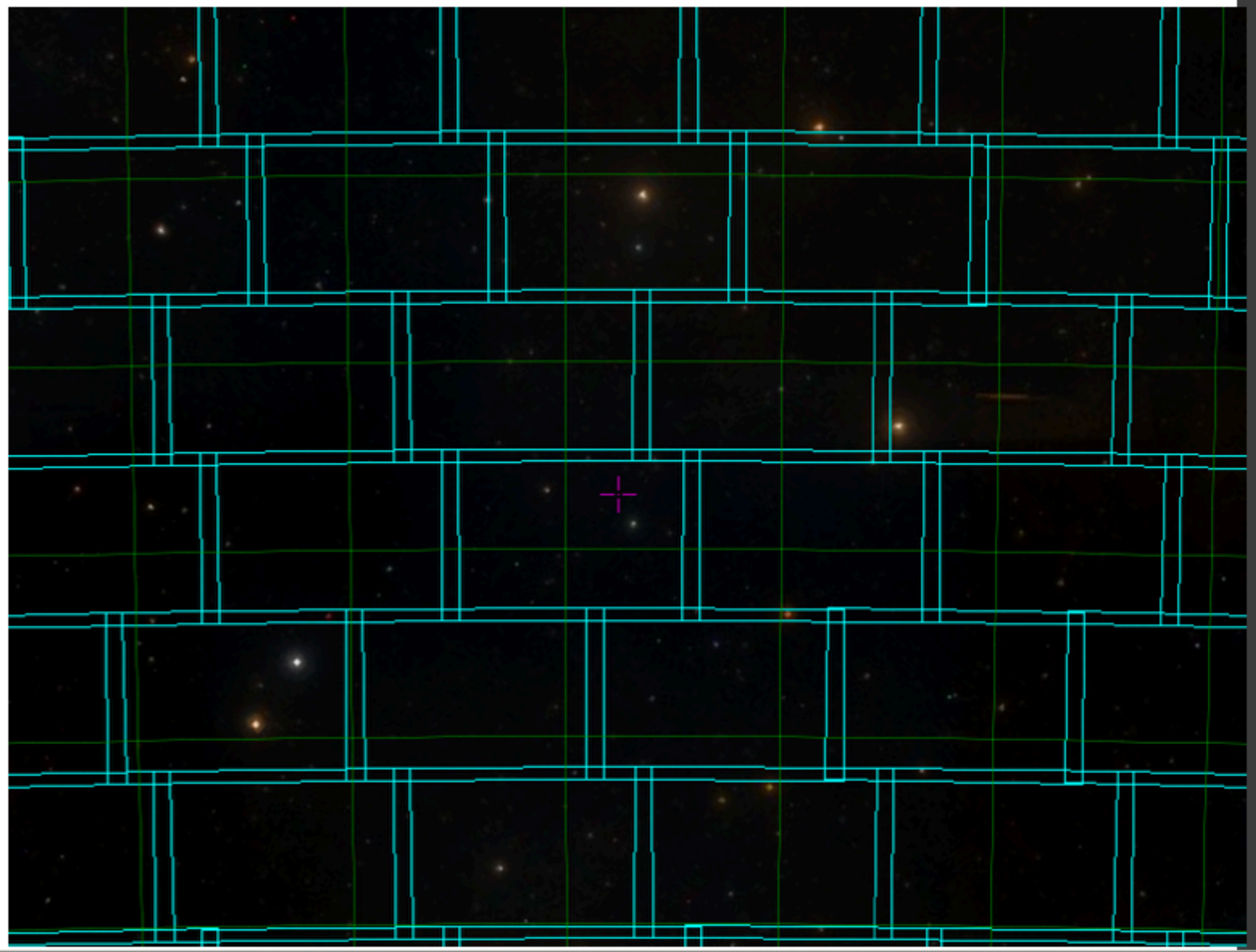
https://aladin.cds.unistra.fr/
https://dorado-scheduling.readthedocs.io/en/latest/background.html

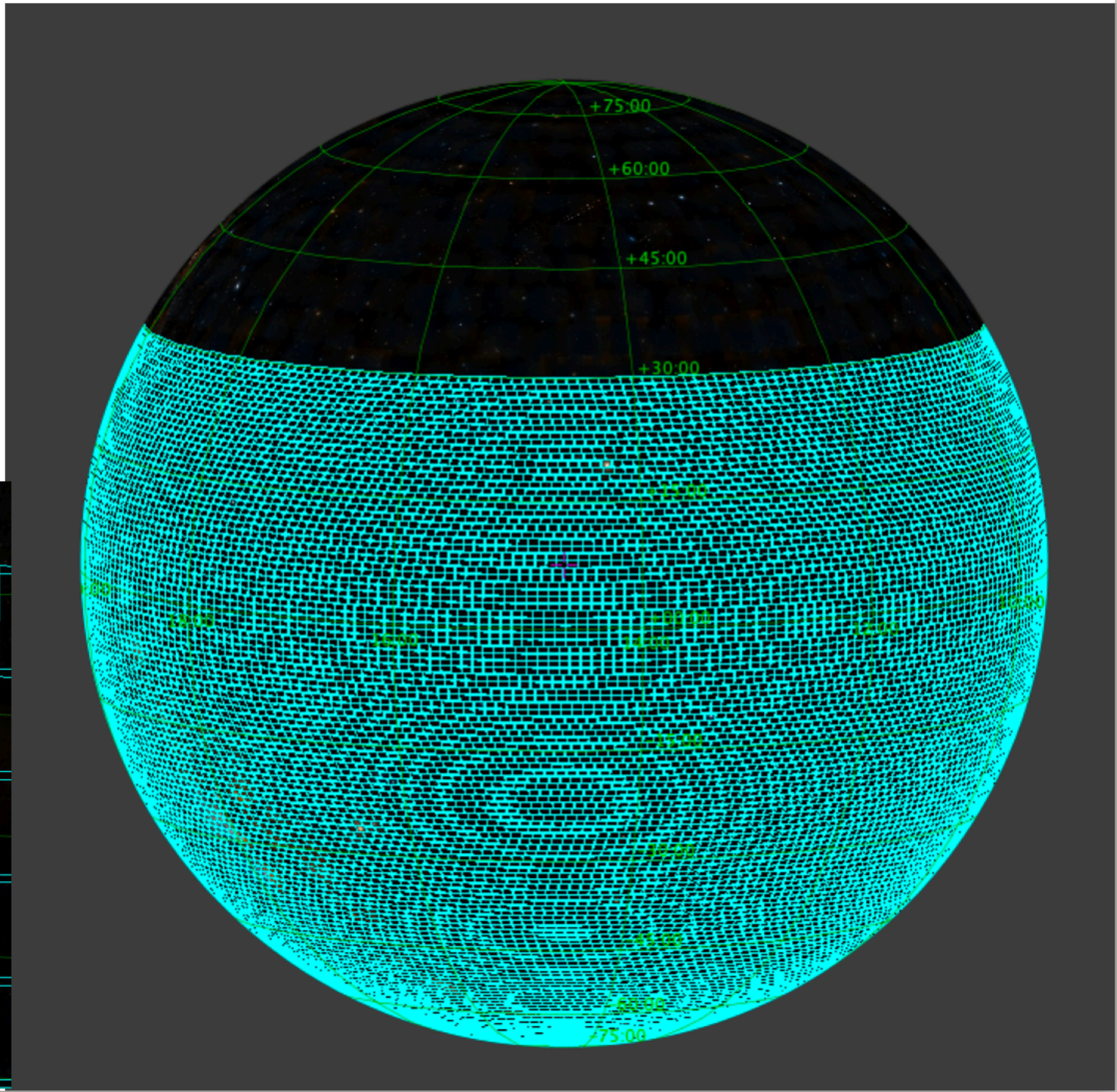
Tiling Strategy

Process to generate the tiling patterns for a telescope:

- **Step 2: Create tiling patterns**

Based on the shape and size of telescope FOV, we generate tiles at the position of generated sky grids.



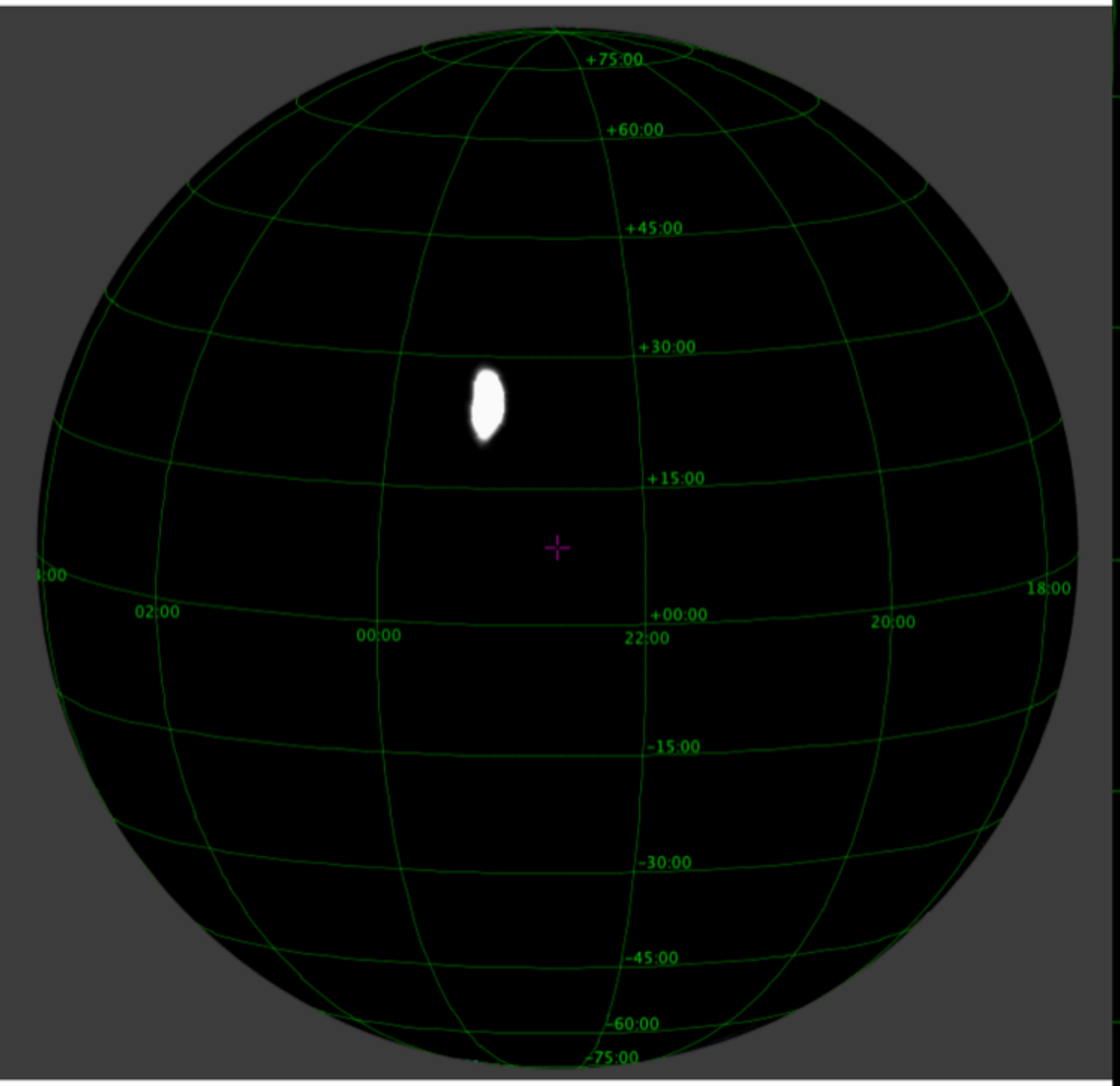


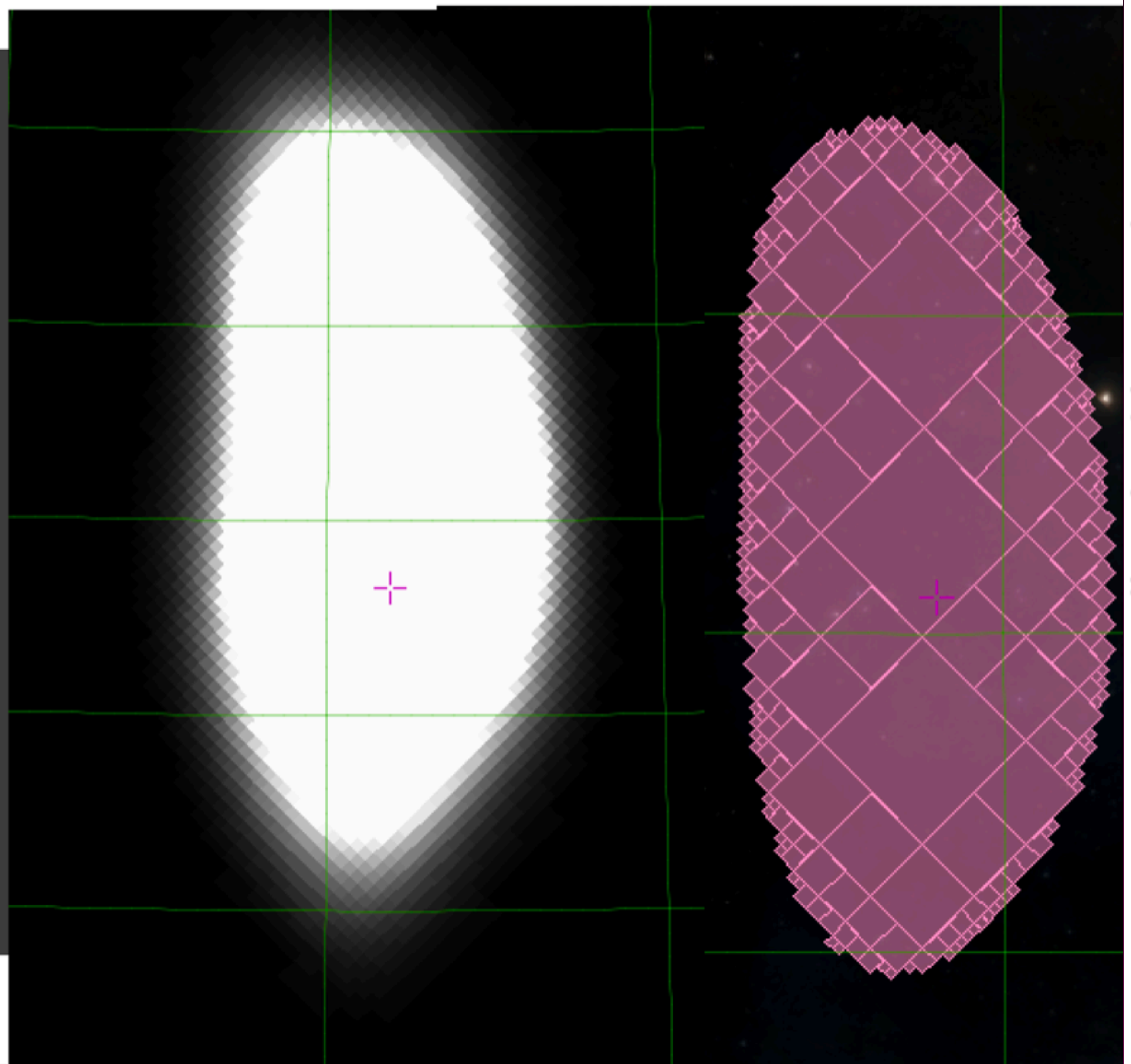
- To determine the telescope pointings for observation, we create patterns of tiles that span the two-dimensional sky localization of gravitational waves (GW) and potential host galaxies identified through a galaxy-targeting method. Then we ranked the tiles based on the:

1- 2-D GW sky localization at each tile

2- Characteristic of host galaxy candidates such as mass, 3D sky localization of GW at position of each galaxy

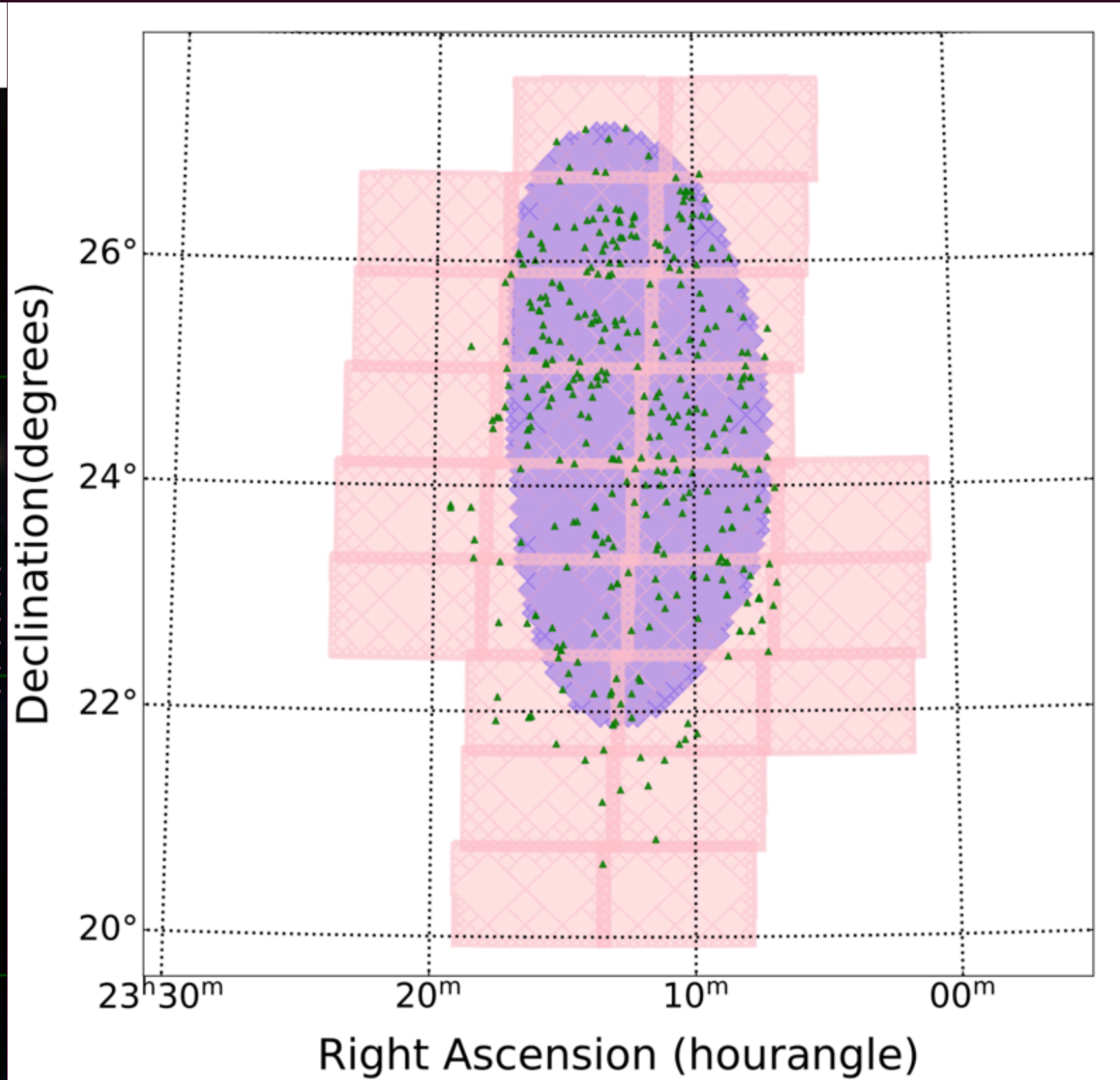
•Multi-Resolution representation of GW sky localization(90%)

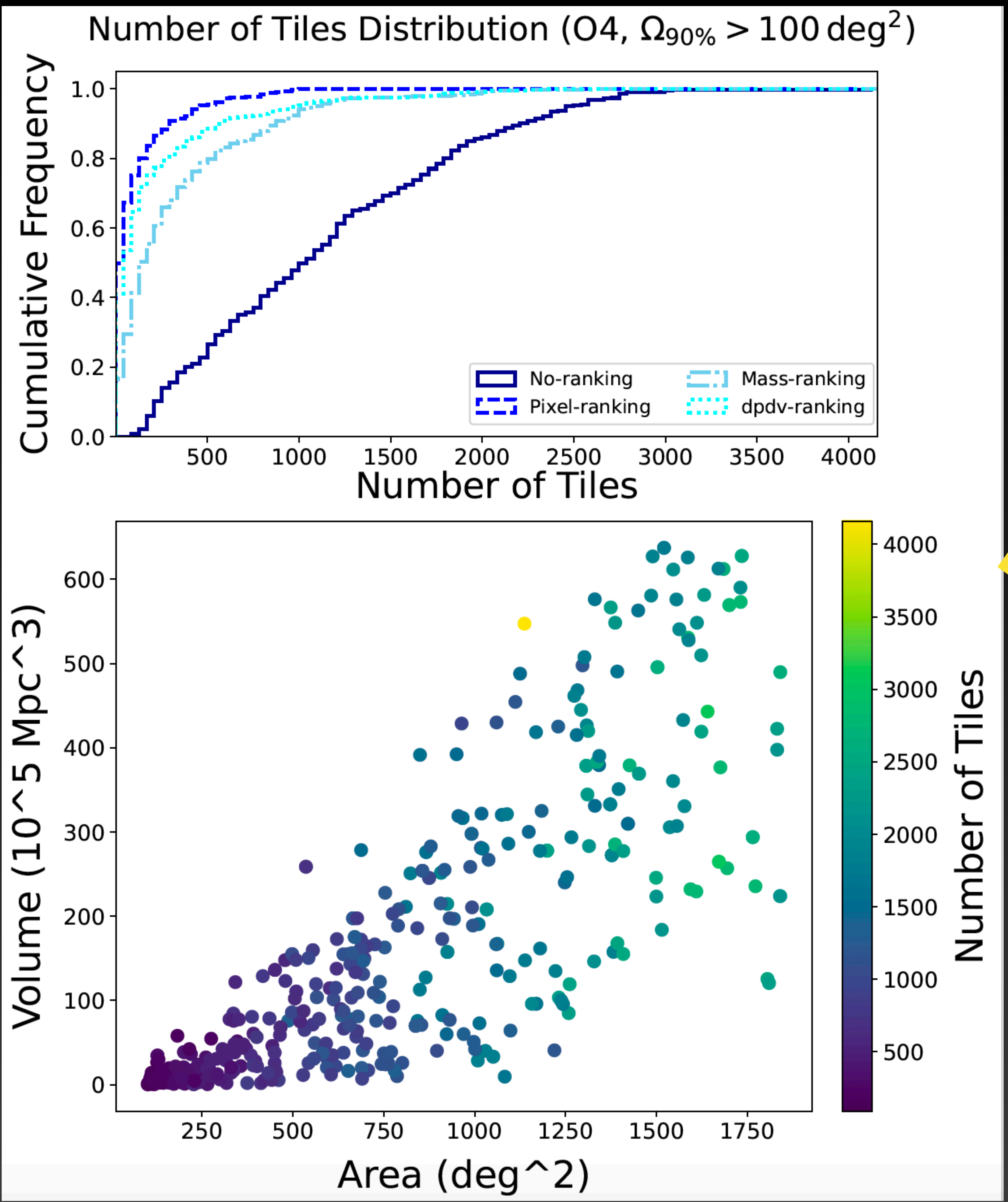




https://cds-astro.github.io/mocpy/

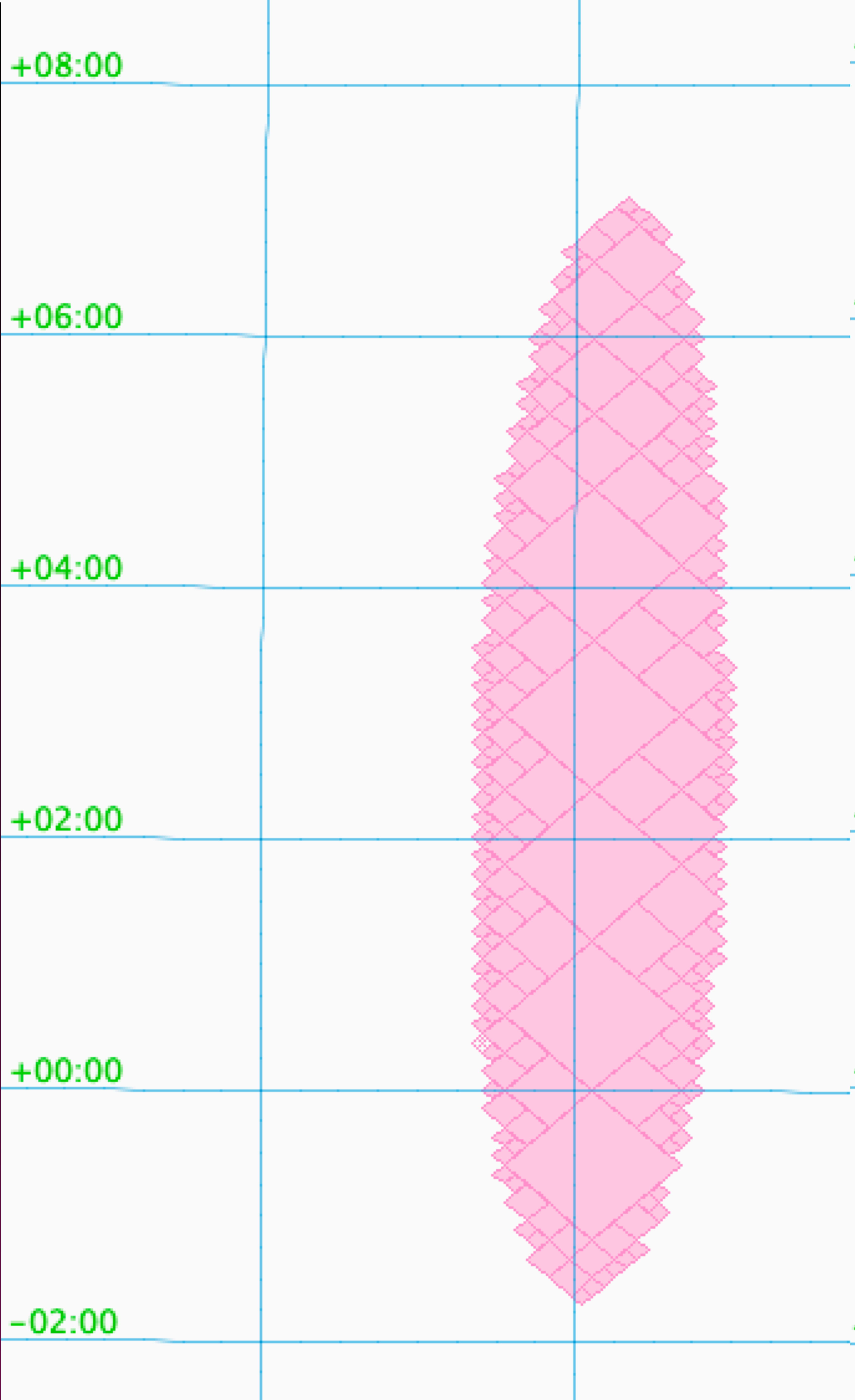
Greco G., et al., 2022, Astronomy and Computing, 39, 100547

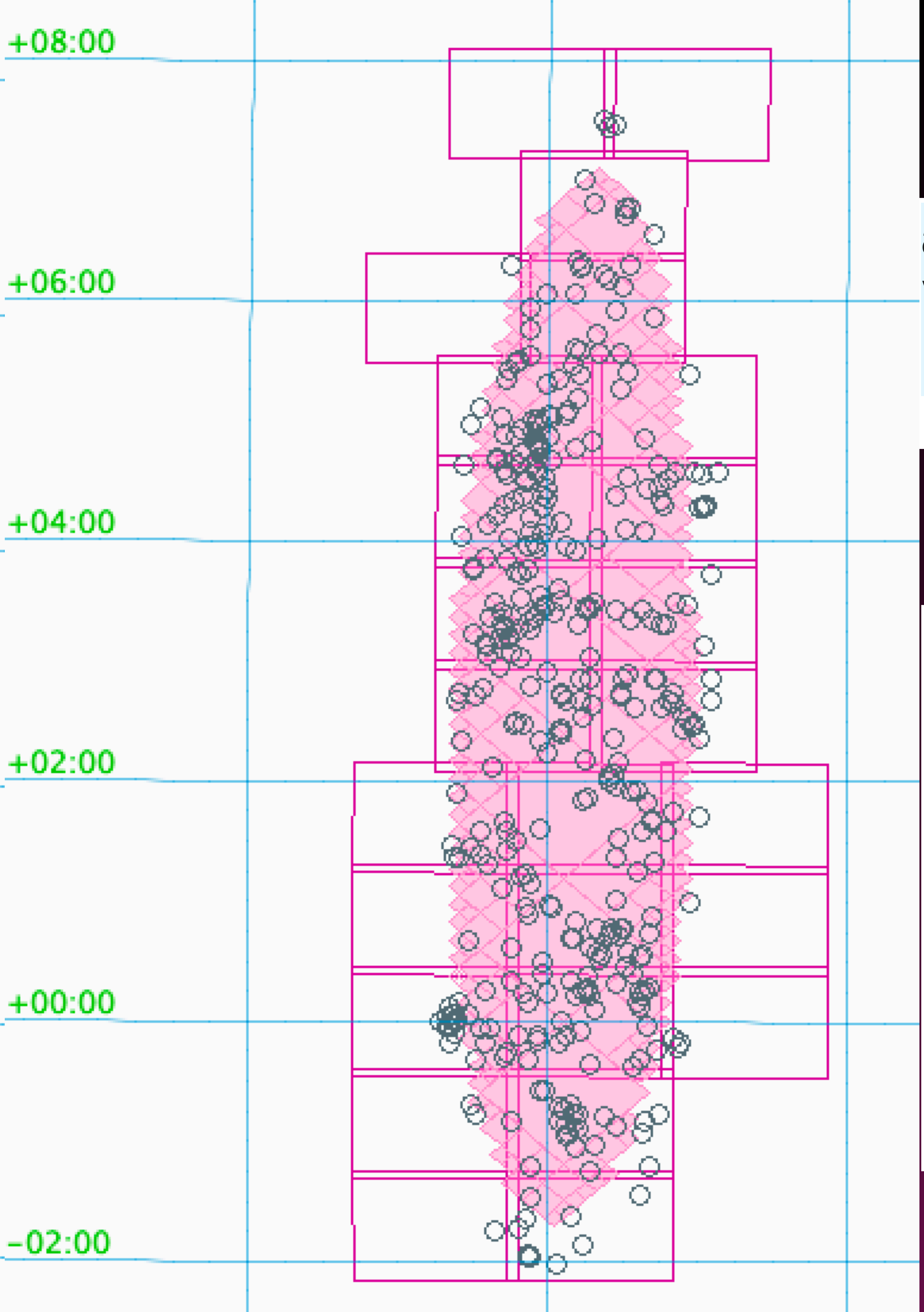




By observing 125 pixel-ranked tiles, we can identify the tile that contains the source of the gravitational waves (GW) with an 80% confidence level.
By observing 541 and 292 tiles, which are prioritized respectively based on the mass and probability density of host galaxy candidates, with an 80% confidence level, we can successfully pinpoint the tile that contains the source of the gravitational waves (GW).

Example1: Well-Localized Event





area(90)=13.7
Volume(90)=0.15* 10^5 Mpc^3

Num_tiles=26

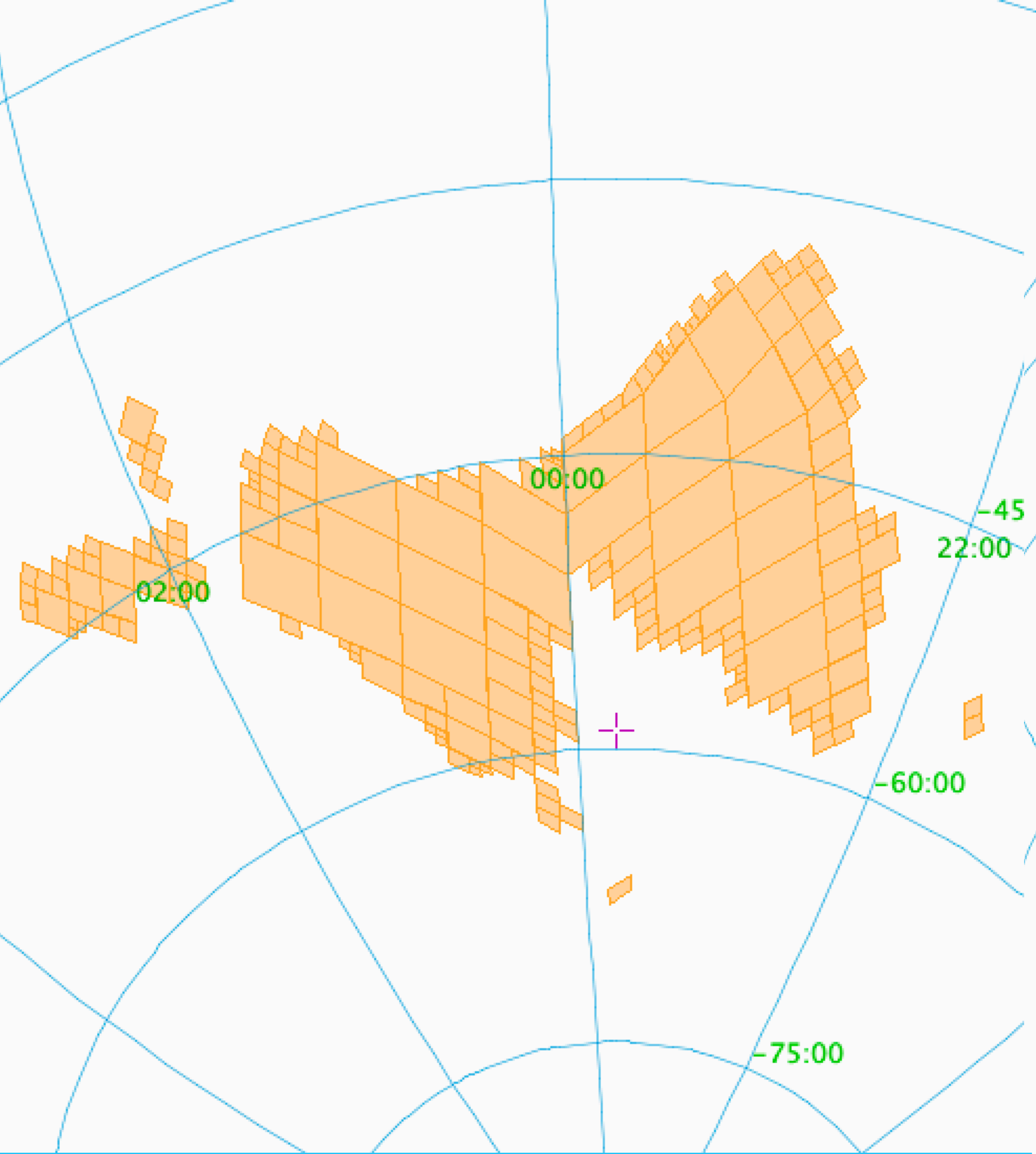
Ranked_2D GW localization= 10

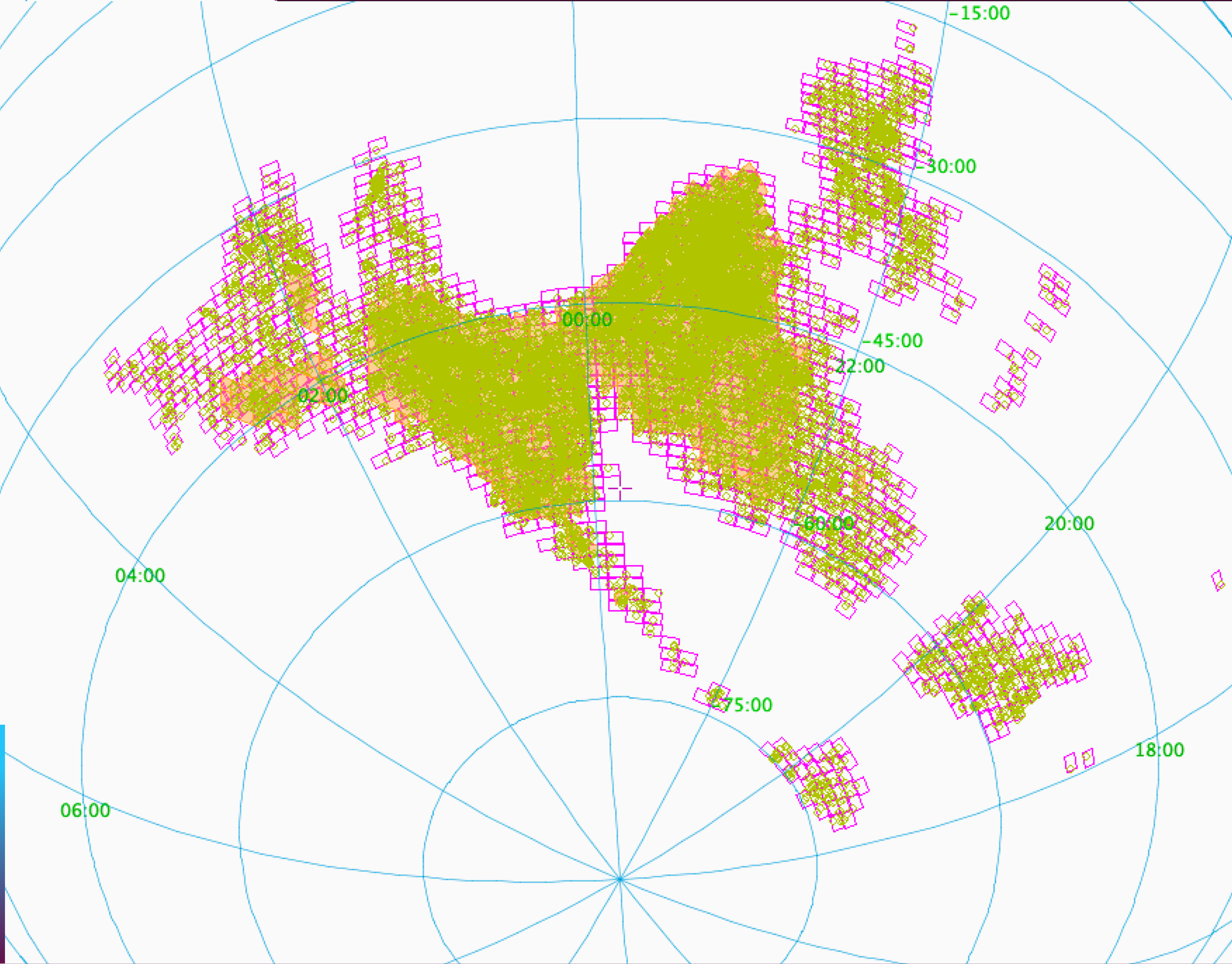
Ranked based on the characteristic of host galaxy candidates:

Mass= 13
Probability density=12

Example 2: Wide-Localized Event

The number of tiles is in order of 1000





Using ranking method:
Mass of host galaxy candidates: 1
Probability density of GW: 1
2D gravitational wave localization probability: 6

Case Study for an Electromagnetic Observing Strategy Using a Ground-Based Network Telescope (7-DT)

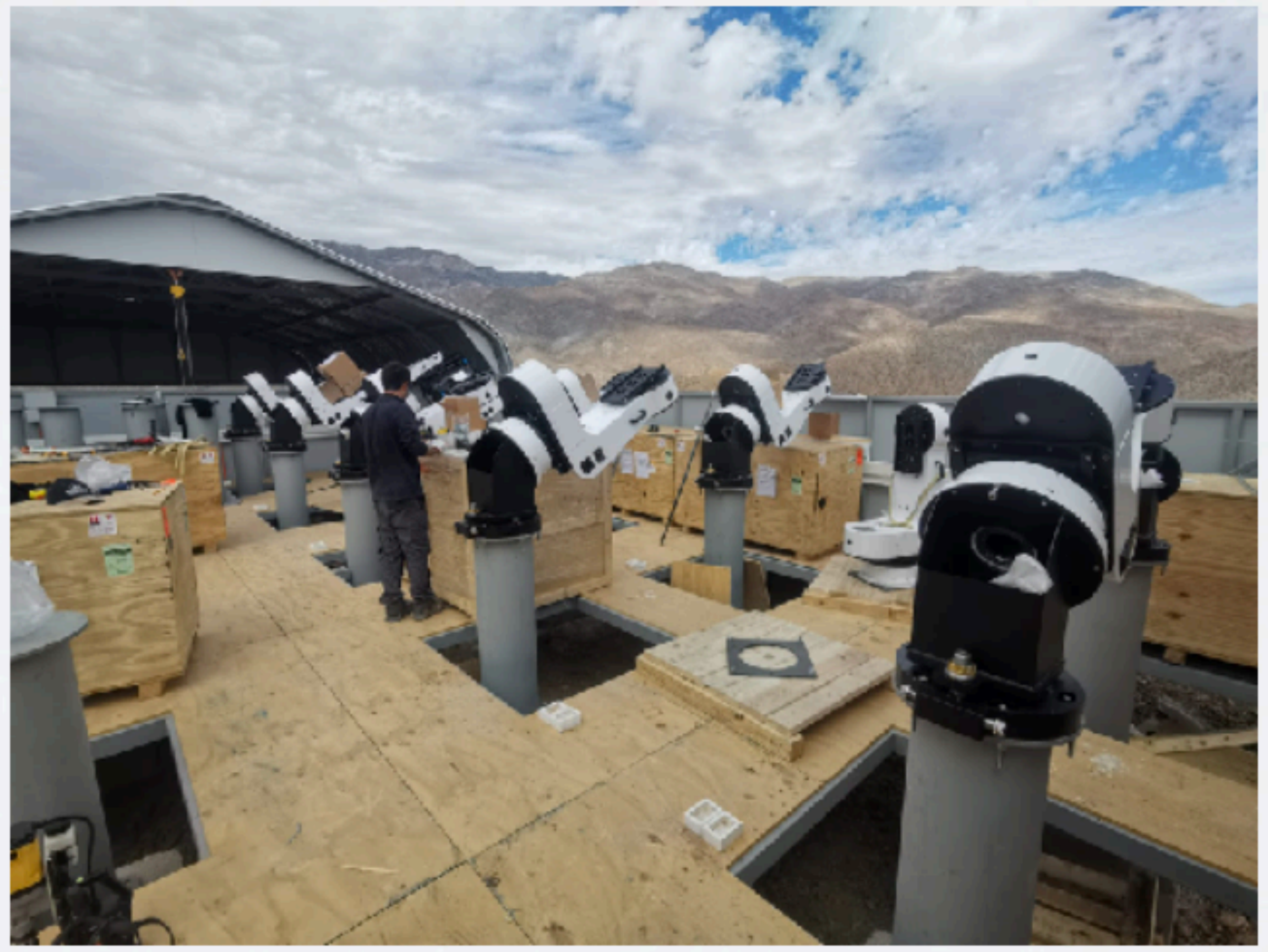
Optimal Observing Method using Ranking Method

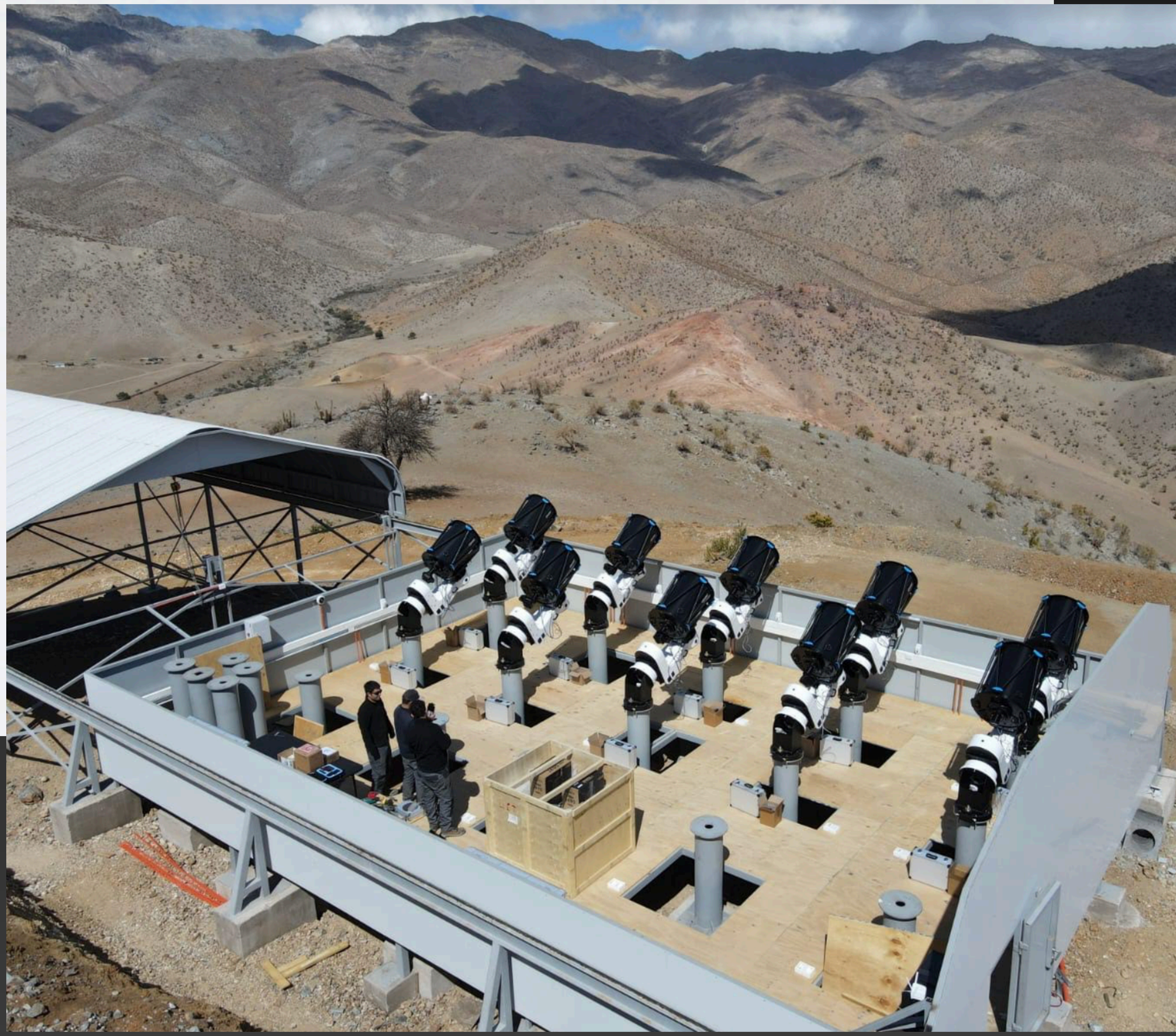
7-DIMENSIONAL TELESCOPE

- 7DT = x (RA) + y (Dec) + z (distance) + flux + v (radial vel.) + λ (wavelength) + t (time)
- FOV: 1.2 – 24 deg^2
- Limiting mag: ~21 AB at 3 min (5-σ, point source)
- 40-medium-band (25nm width, from 400 nm to 900 nm) →low res spectra
- Sloan Broad-band u-, g-, r-, i-, and z-bands

A conceptual view of 7DT (Image Credit : Mankeun Jeong & Minhee Hyun)

Site: Current Status





Credit: Ji Hoon Kim

Different Search modes for 7DT

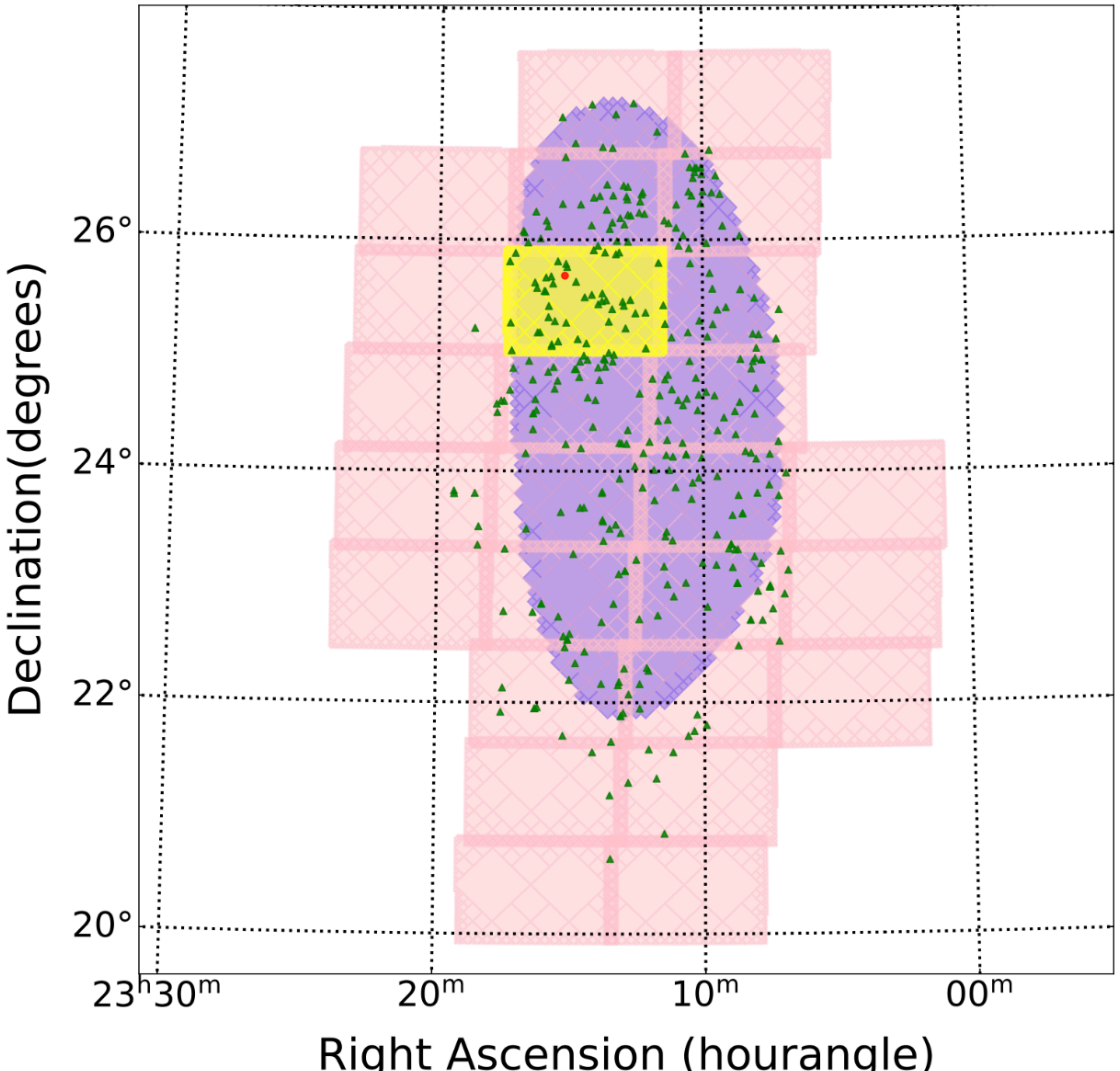
- **Deep Observing Mode : FOV: 1.2 deg^2**
- **Wide Observing Mode: FOV: 24 deg^2**

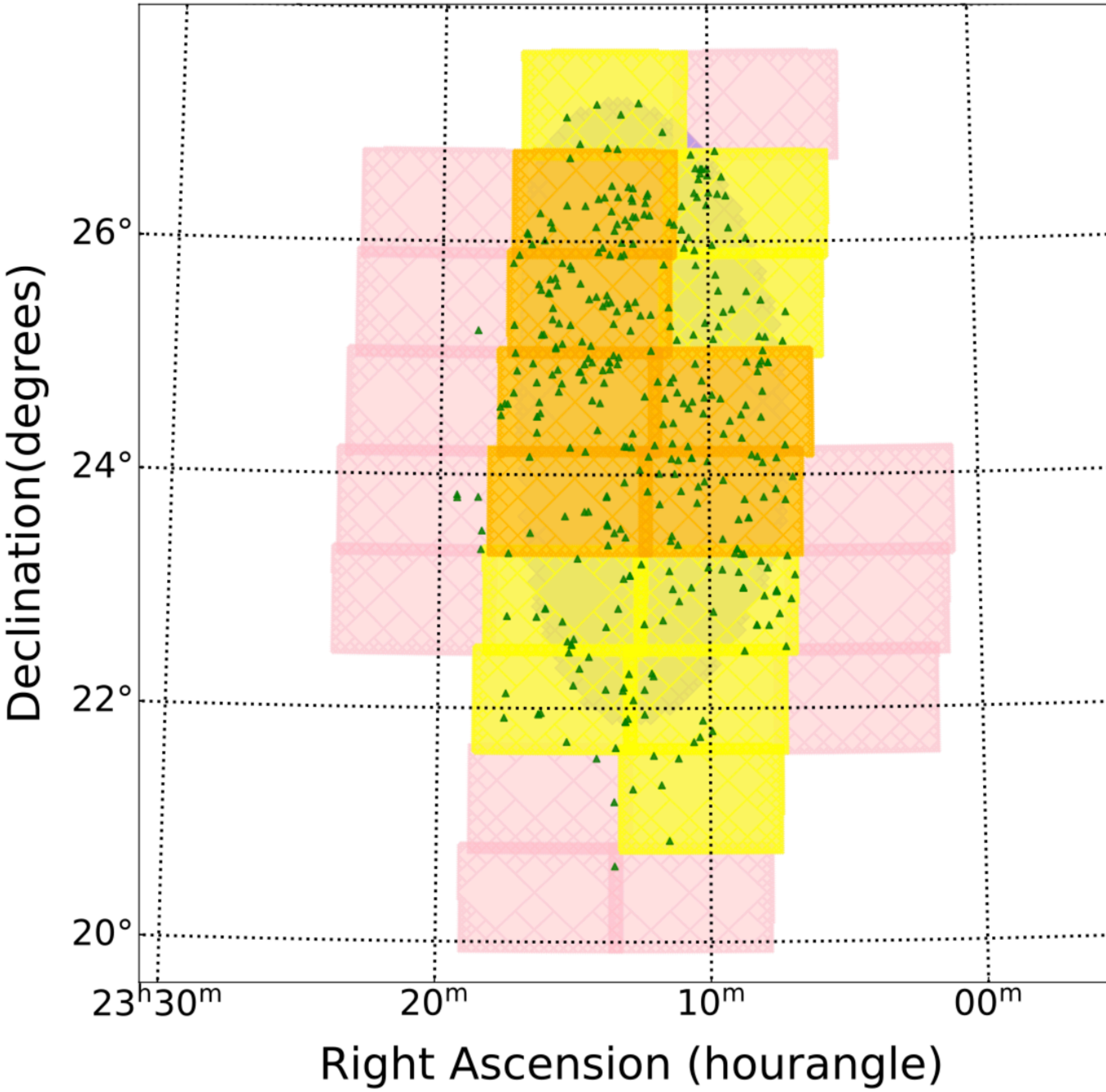
Which observing mode we should Apply?

It is depend on number of tiling that we Should observed.

Credit: ChatGPT4

The total number of tiles for the event is 26.
The host galaxy of binary merger located at the tile with rank 2





Outlook

We review observing strategies for

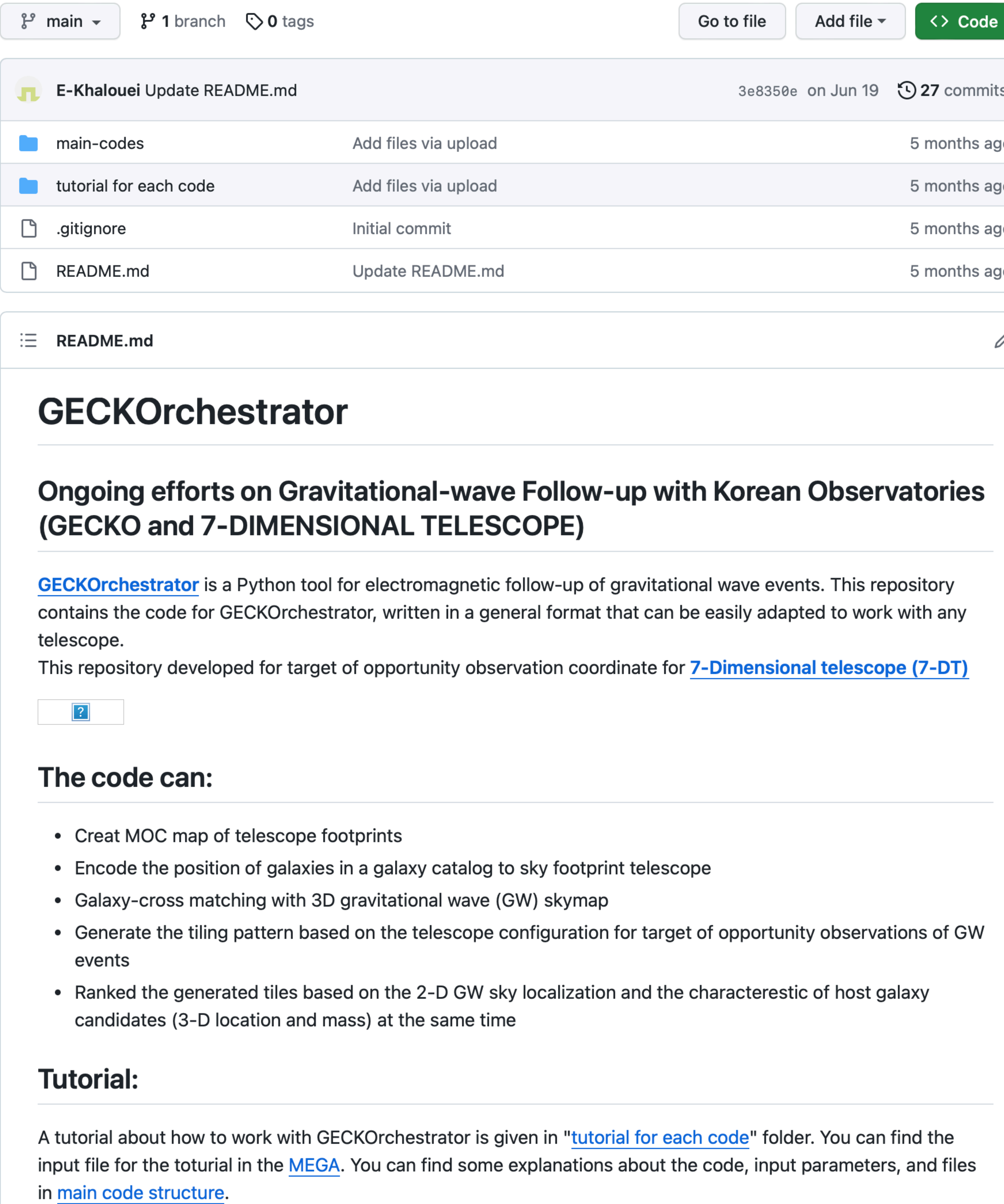
Narrow field telescopes: Galaxy-Targeting Method
Wide field Telescopes: Tiling observation

Implementing the ranking method can expedite the identification of the EM counterpart.

GECKOrchestrator code

- **Thanks!**

Credit: ChatGPT4



main · 1 branch · 0 tags · Go to file · Add file · Code

E-Khalouei Update README.md · 3e8350e on Jun 19 · 27 commits

main-codes	Add files via upload	5 months ag
tutorial for each code	Add files via upload	5 months ag
.gitignore	Initial commit	5 months ag
README.md	Update README.md	5 months ag

README.md

GECKOrchestrator

Ongoing efforts on Gravitational-wave Follow-up with Korean Observatories (GECKO and 7-DIMENSIONAL TELESCOPE)

GECKOrchestrator is a Python tool for electromagnetic follow-up of gravitational wave events. This repository contains the code for GECKOrchestrator, written in a general format that can be easily adapted to work with any telescope.
This repository developed for target of opportunity observation coordinate for 7-Dimensional telescope (7-DT)

The code can:

- Creat MOC map of telescope footprints
- Encode the position of galaxies in a galaxy catalog to sky footprint telescope
- Galaxy-cross matching with 3D gravitational wave (GW) skymap
- Generate the tiling pattern based on the telescope configuration for target of opportunity observations of GW events
- Ranked the generated tiles based on the 2-D GW sky localization and the characterestic of host galaxy candidates (3-D location and mass) at the same time

Tutorial:

A tutorial about how to work with GECKOrchestrator is given in "tutorial for each code" folder. You can find the input file for the toturial in the MEGA. You can find some explanations about the code, input parameters, and files in main code structure.