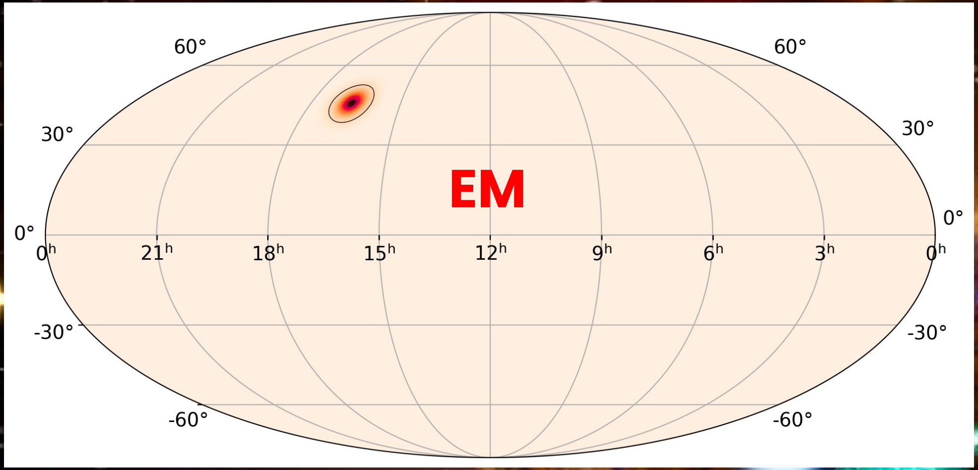
Istituto Nazionale di Fisica Nucleare
Sezione di Trieste

Alternative tiling strategies for transient events

Alessandro Armando Vigliano[1,2]

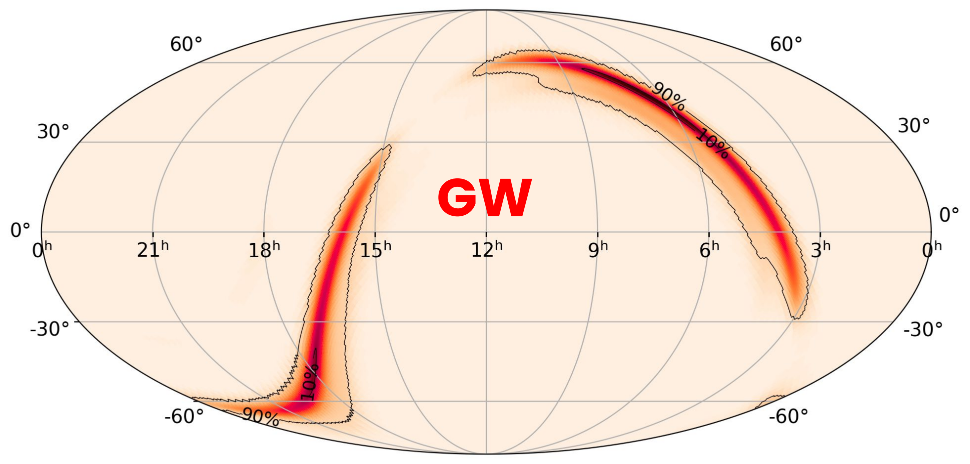
1st VHEGAM meeting, Bologna
15-17 January 2024

[1]Department of Mathematical, Computer and Physical Sciences, University of Udine, Udine, Italy
[2]Istituto Nazionale di Fisica Nucleare (INFN), sezione di Trieste, Trieste, Italy



E.G.:

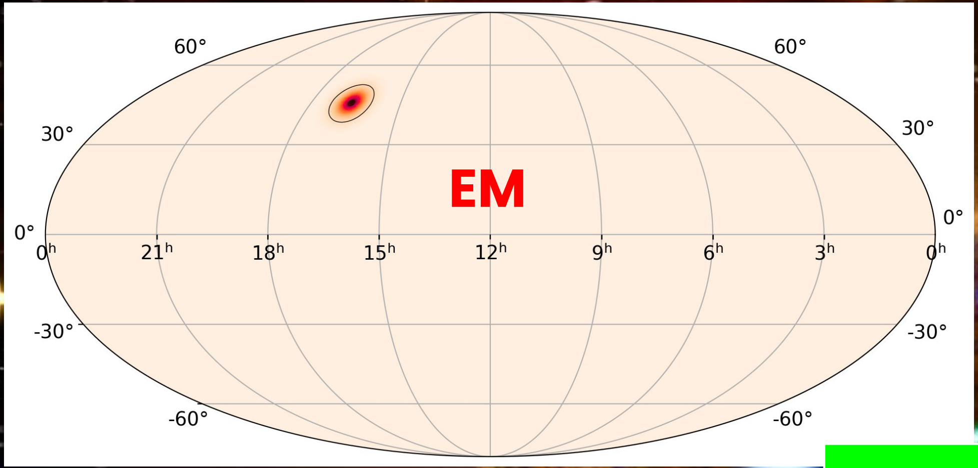
Fermi
Gamma-ray Space Telescope

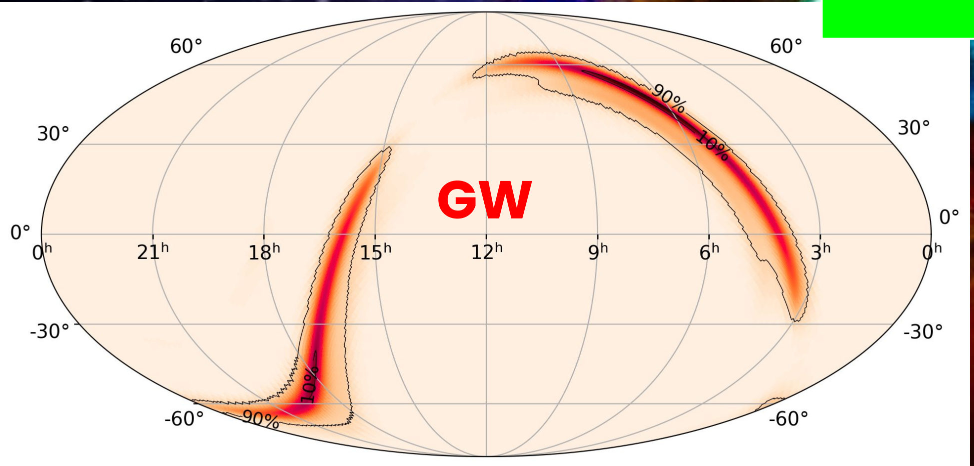


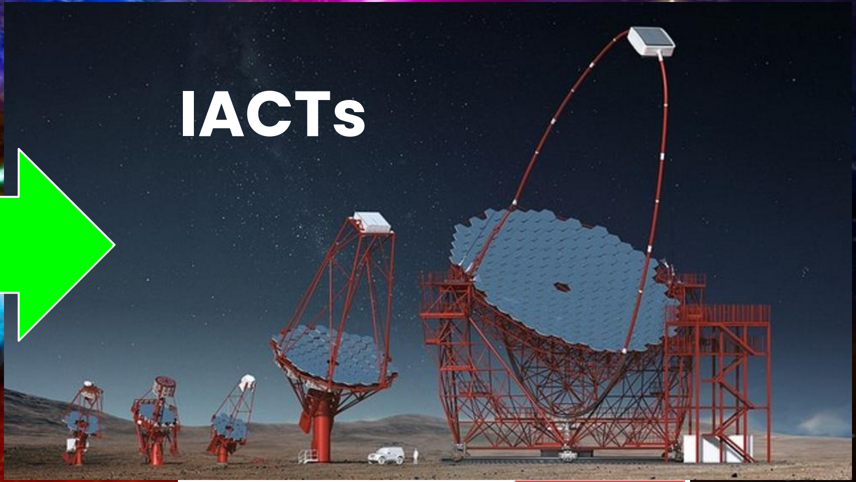
E.G.:

LIGO
VIRGO
KAGRA

Triggers

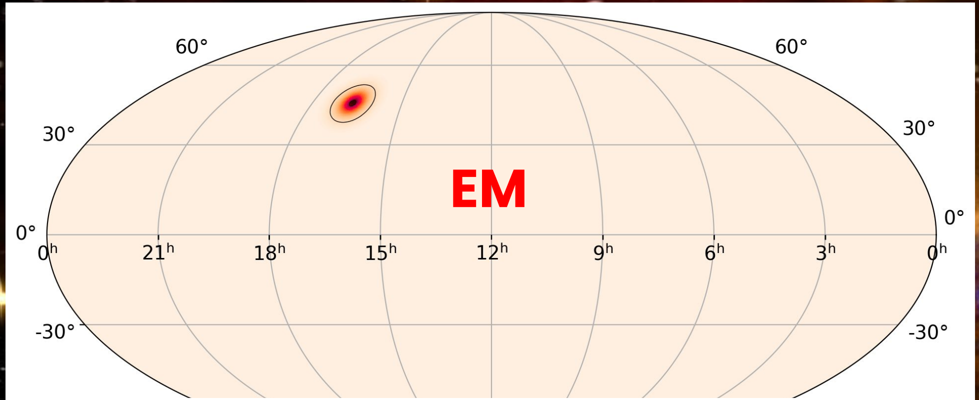




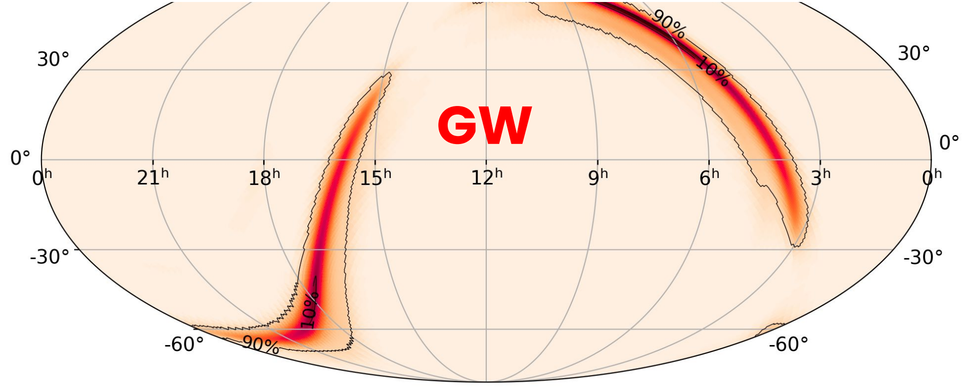


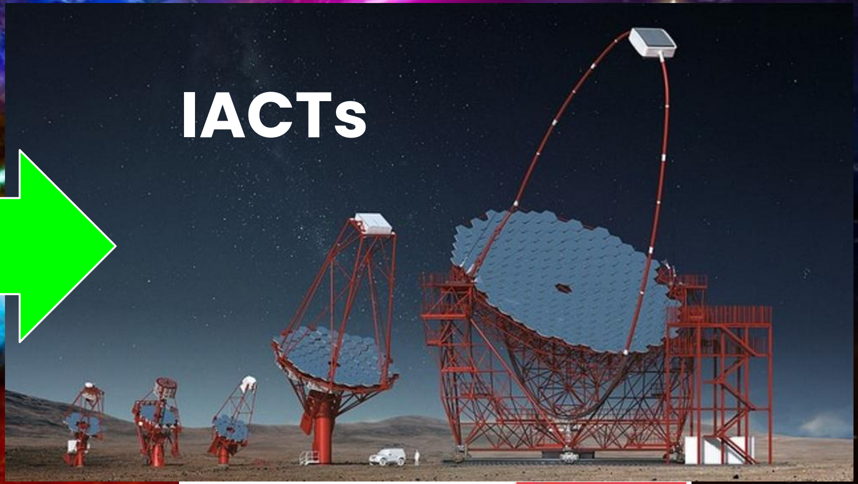
cta cherenkov telescope array

Triggers



From ~10 to >>1000 deg^2!

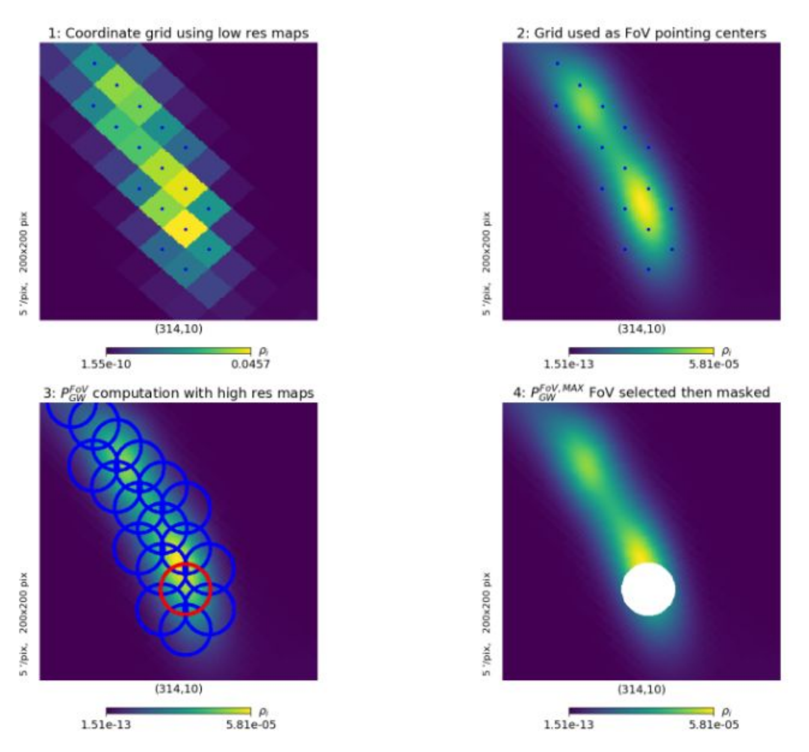


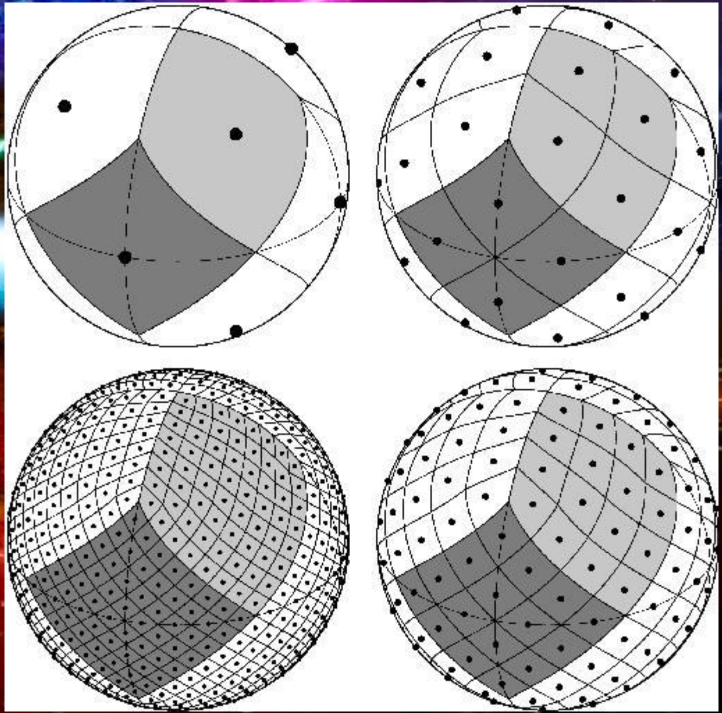


cta cherenkov telescope array

Current tiling strategies for IACTs:

Ashkar et al., ArXiv:2010.16172

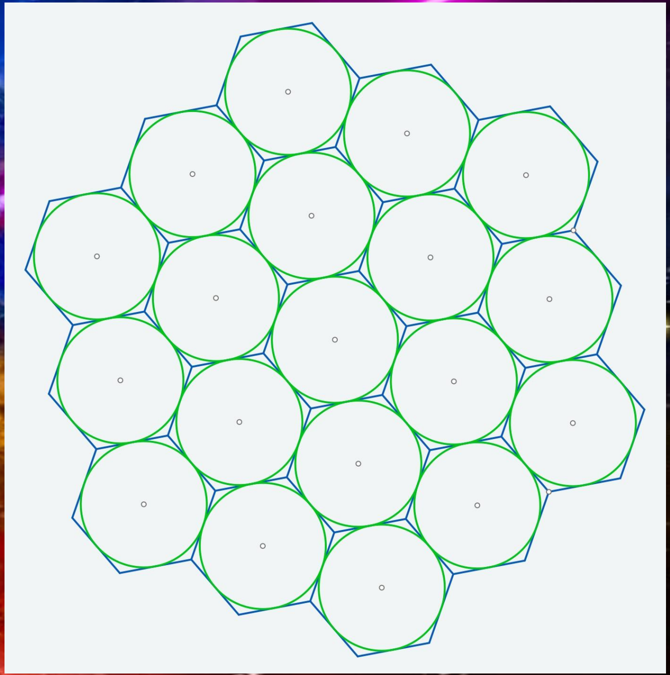





HEXAGONAL TILING

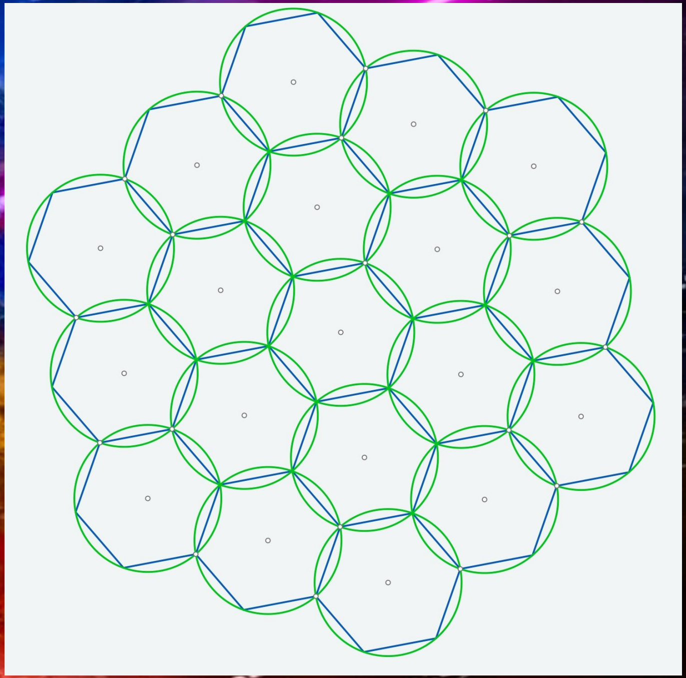
Why hexagons?

- Tightly packed circles make a hexagonal grid



Why hexagons?

- Tightly packed circles make a hexagonal grid
- This minimize the superposed area when there are no holes between different FoV
- Hexagons tessellate the plane optimally (Hales, T. The Honeycomb Conjecture. *Discrete Comput Geom* 25, 1–22 (2001))
- A hexagonal cell that has the same diagonal (FoV diameter) to other regular tiling cells has a larger area that better approximates the FoV area

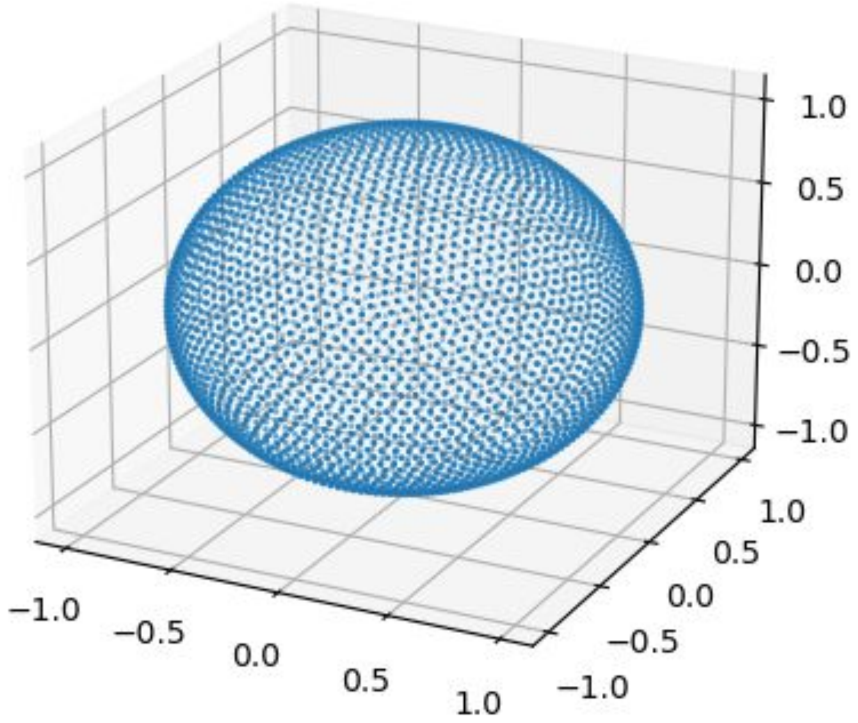


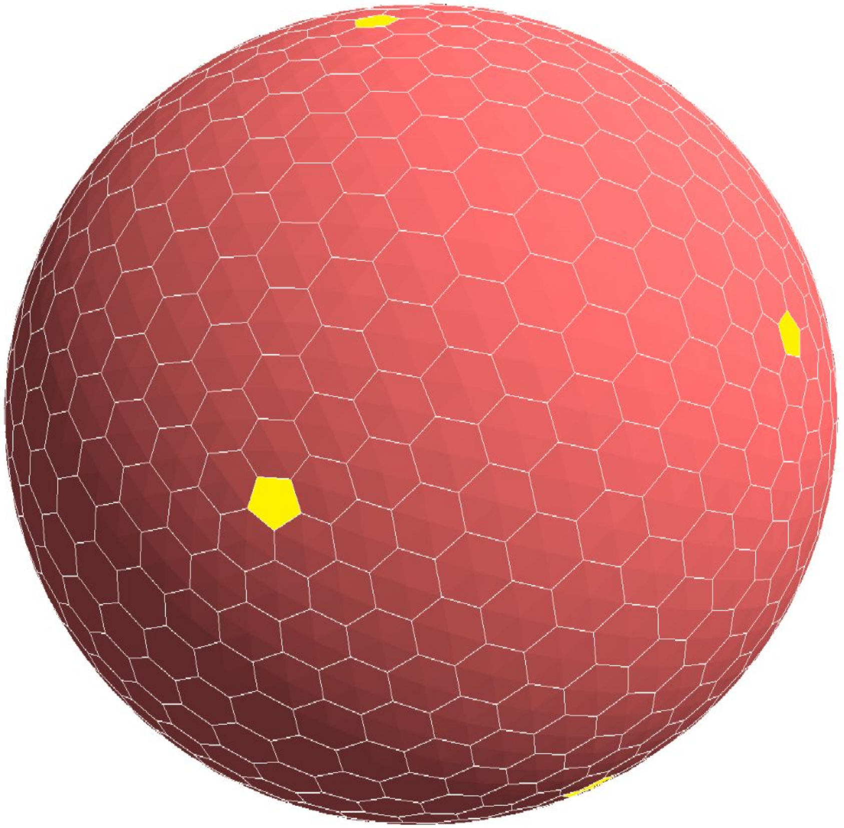
Hexagons on a sphere

- **No easy way to tile the sphere with regular tiles**
- (Not so) large distances -> non-negligible curvature
  - e.g. HEALPix has distorted tiles (not true square/regular pixels)
- Hexagons tessellate the plane optimally (Hales, T. The Honeycomb Conjecture. *Discrete Comput Geom* 25, 1–22 (2001)), but adjustments need to be made for curvature

Built new full sky tessellation

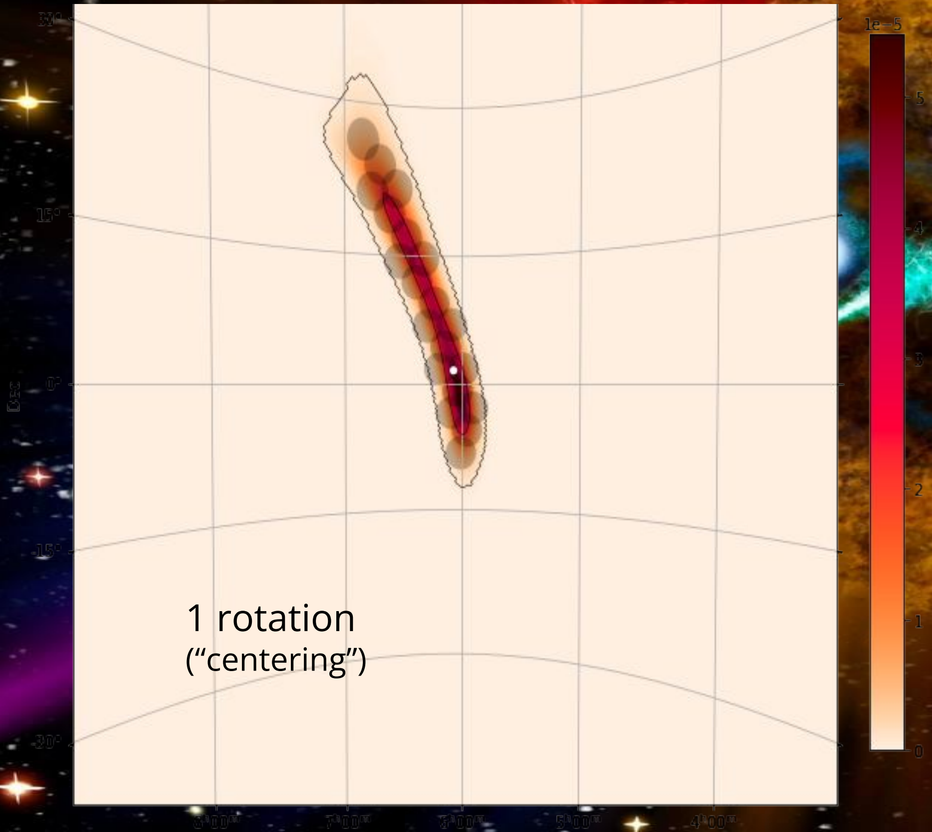
Hexagonal Sky Grid

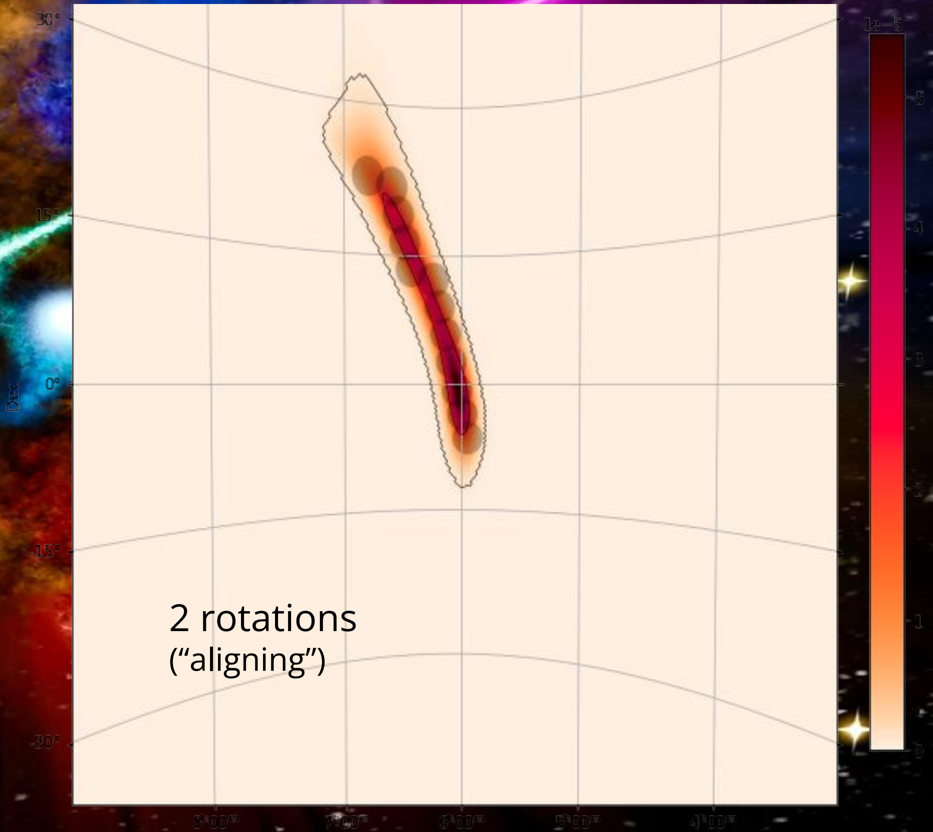




Goldberg, Michael (1937). "A class of multi-symmetric polyhedra". *Tohoku Mathematical Journal*. **43**: 104–108.

Pointing Optimization



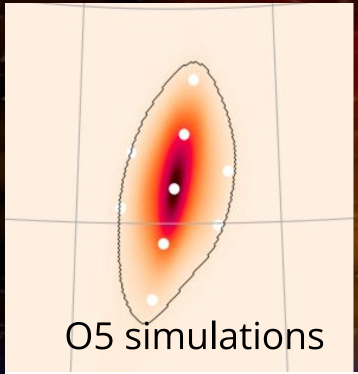


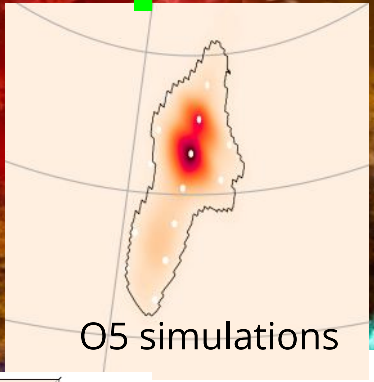
Advantages:

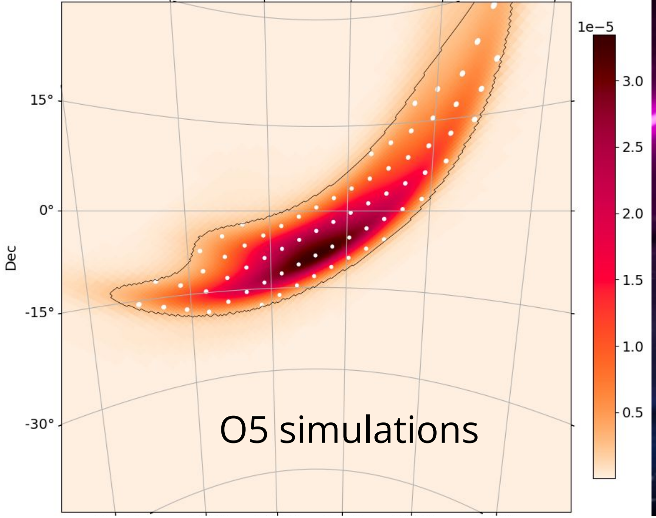
- Homogeneity on the whole sky (no issues/deformations for |dec| > 30°)
- Geometrical optimization: most compact symmetrical tessellation of the sphere
- Pre built grid for full sky tessellation -> fast!
- Just geometry -> Can be used in combination with other strategies/information

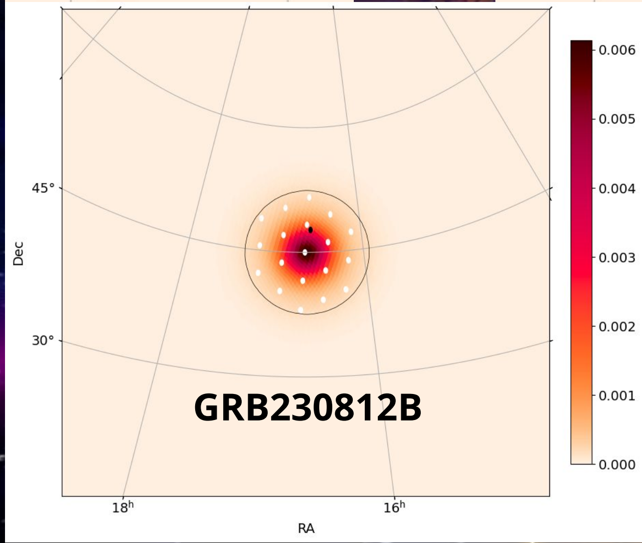
⇨ Combination with exposure time calculator to get full scheduler

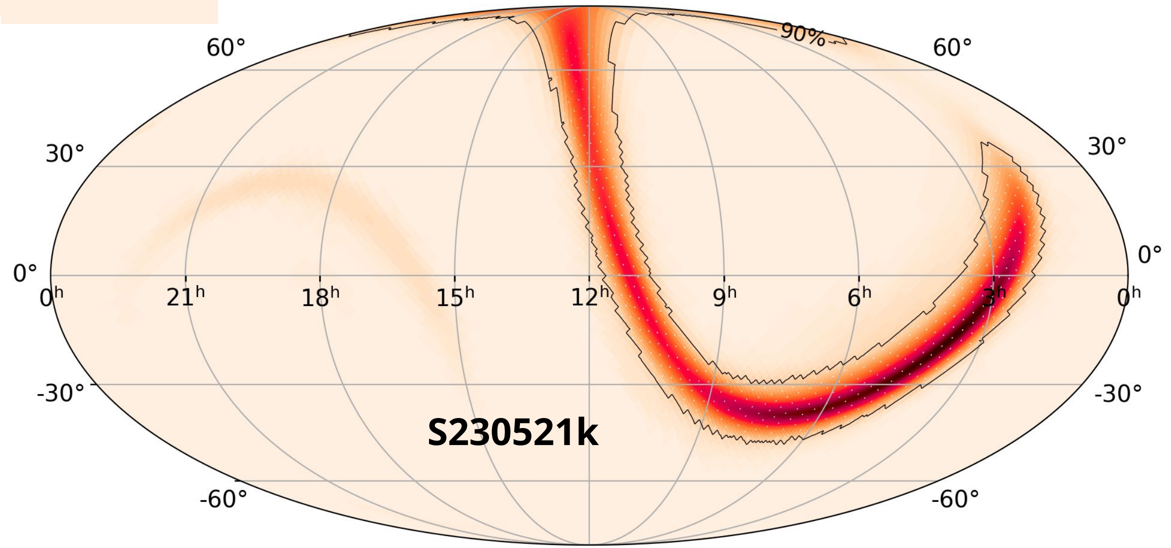
Some examples







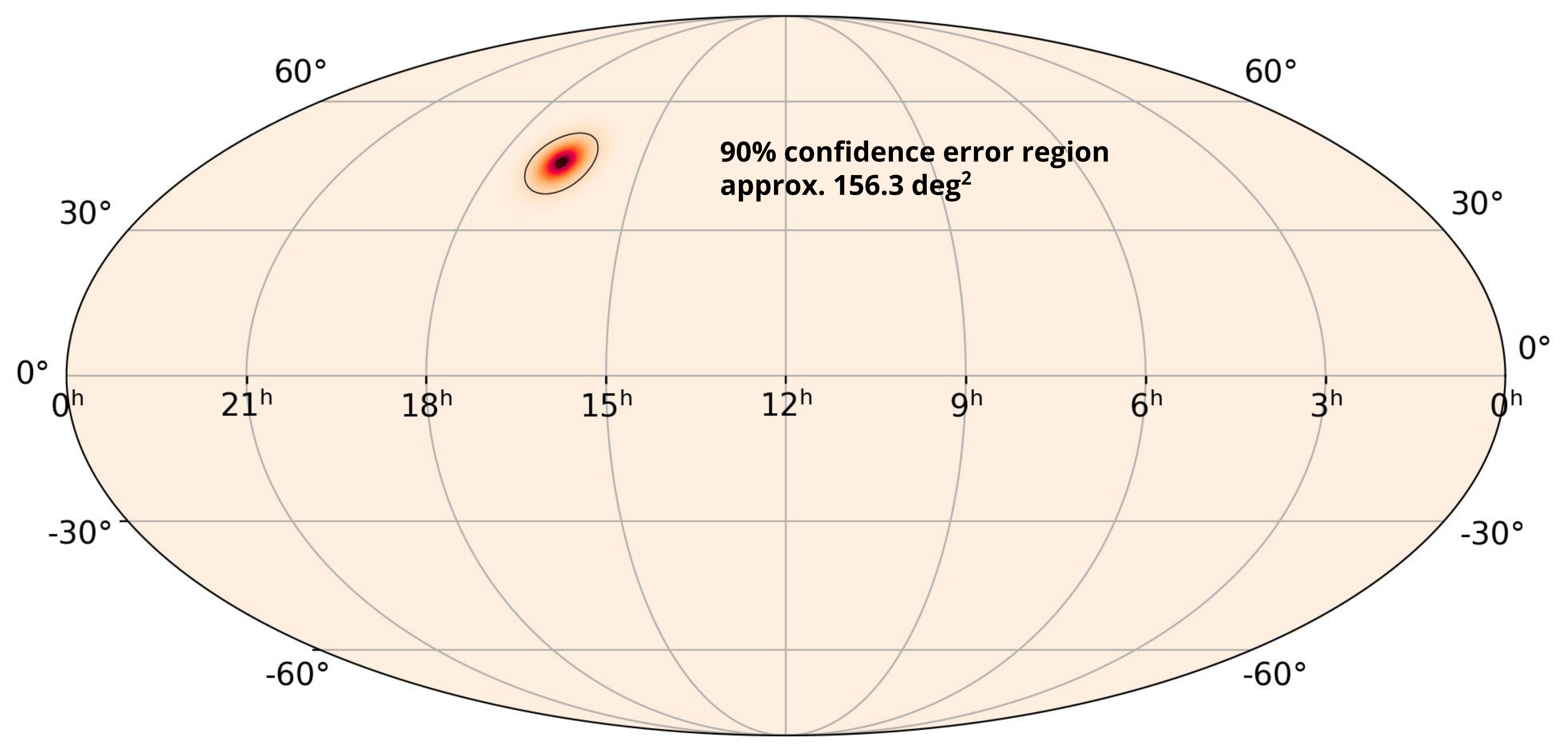




First LST1 test of tiling strategies for GRB follow up

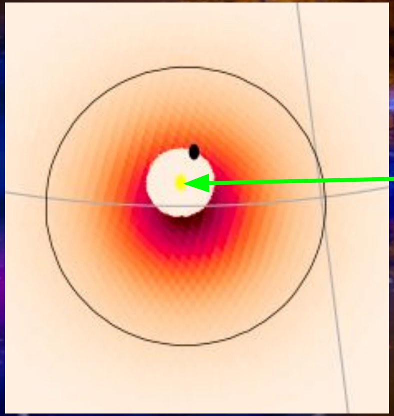
Follow up of Fermi GBM alert 12/08/2023 i.e. GRB230812B

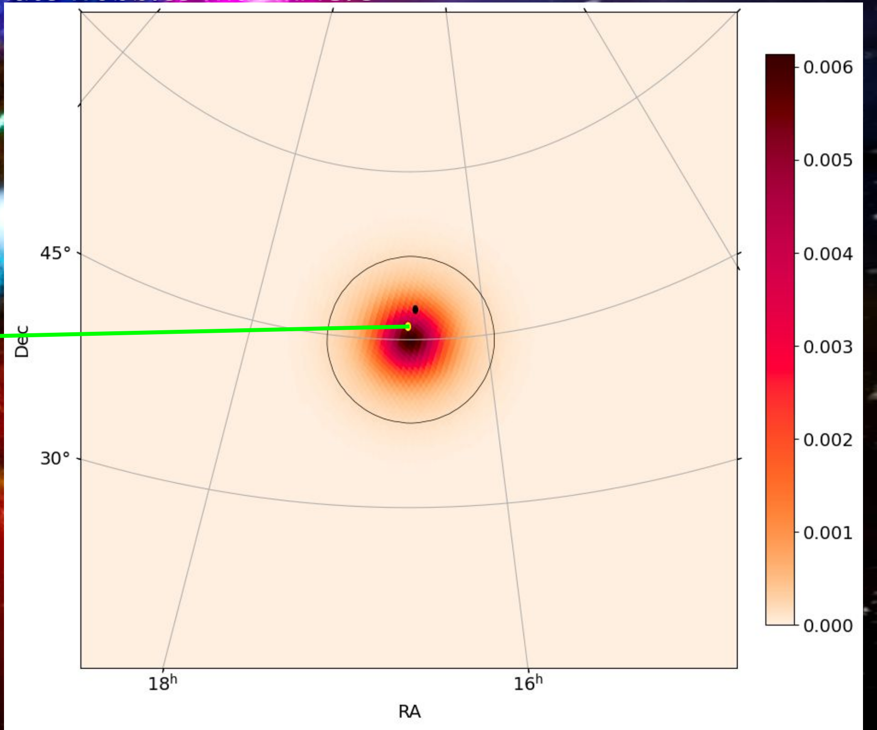
GRB230812b GBM alert



LST1 schedule

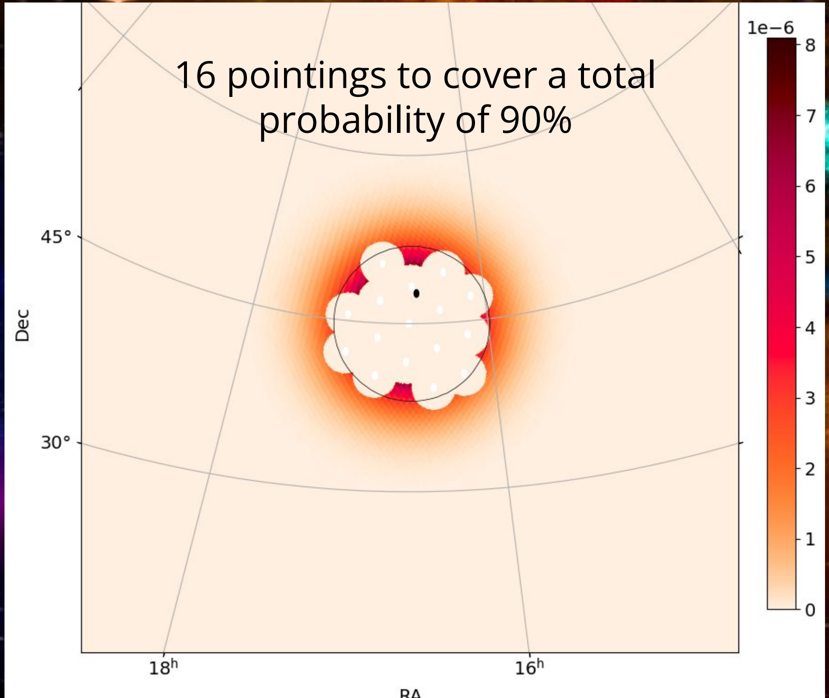
1. 21:46 -> 22:59 Joint observation with MAGIC
   a. RA: 250.1, DEC: 46.20, standard wobbles, coordinate wobbles with MAGIC
   b. LAT position (arrived later, in black) immediately outside the FoV of this observation (yellow)

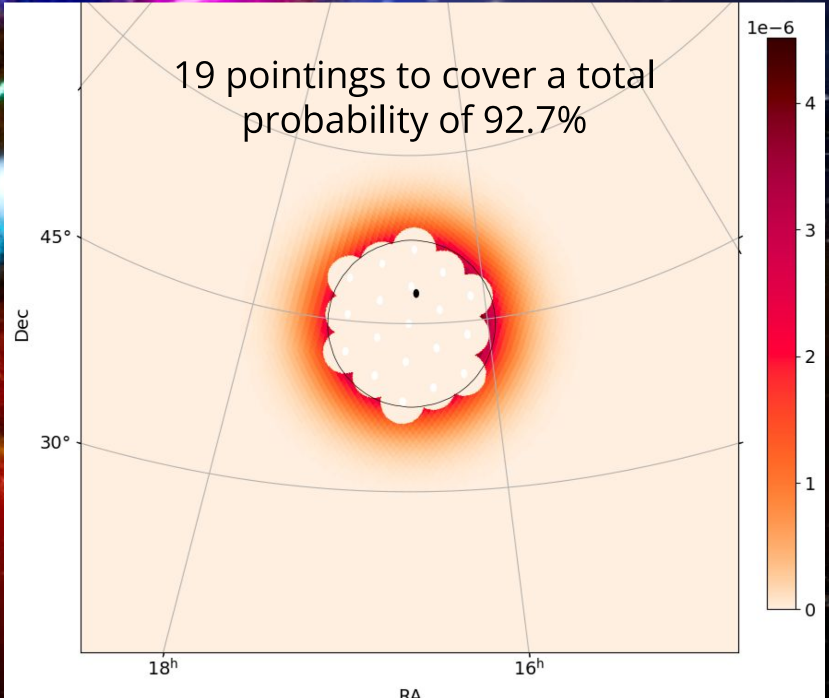




LST1 schedule

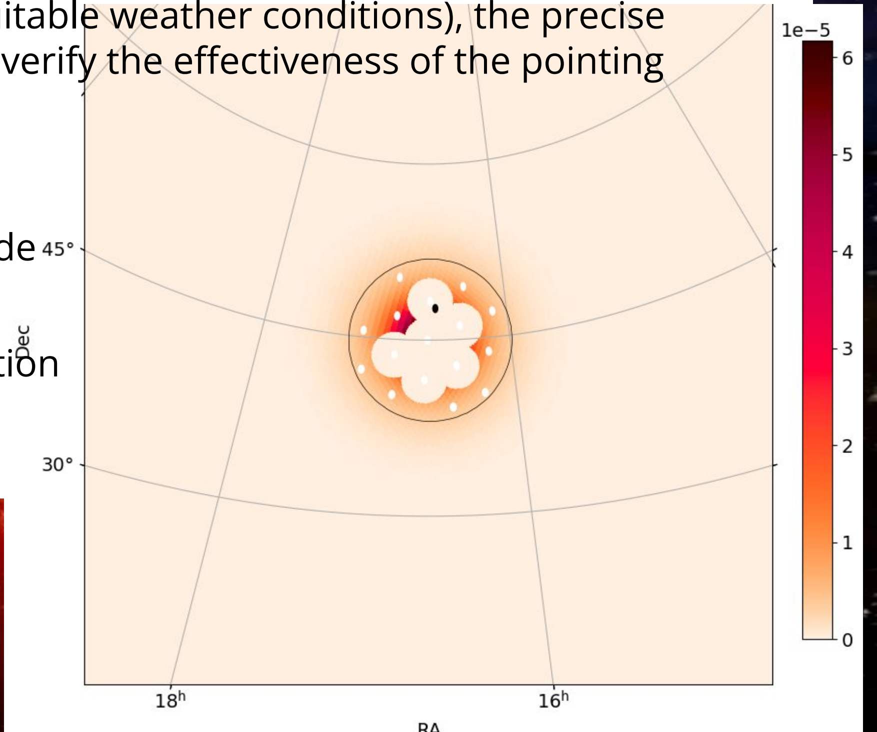
1. 21:46 -> 22:59 Joint observation with MAGIC
2. 23:03 -> 00:47 LST1 only: **tiling observations**





LST1 observation of GRB230812B

1. First ever use of tiling strategies for the follow-up of a GRB alert with LST1
2. Although we did not observe the signal (unsuitable weather conditions), the precise localization by Fermi-LAT made it possible to verify the effectiveness of the pointing strategy:
   a. **SUCCESS!**
   b. The Fermi-LAT localization fell right inside the 6th FoV that was being observed
   c. LST1 was observing the correct localization at least 15/20 min before the LAT alert

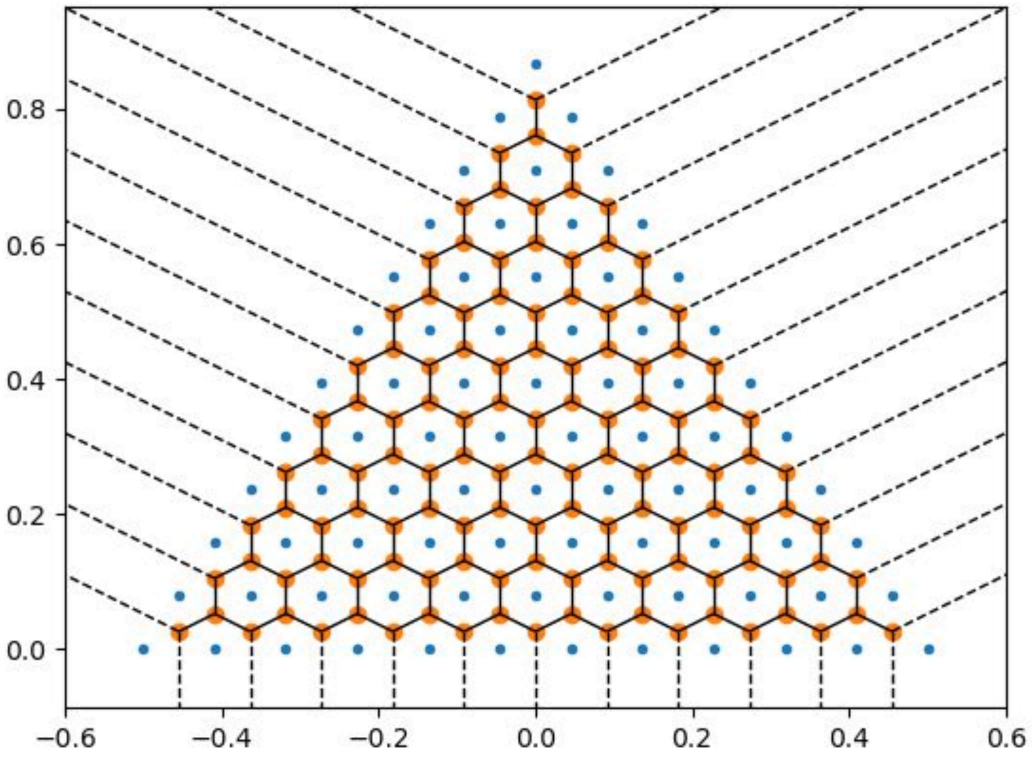


Conclusions:

- Tessellation strategies are the way forward to increase the number of observations of transient events with IACTs.
- The hexagonal grid proposed here is, once applied with the necessary rotations, excellent for minimizing the number of pointings required to cover the GRB and GW localization error areas.
- The hexagonal grid proposed here is optimal for tessellation of the sphere -> possible use for (extra galactic) surveys!
- The integration of the exposure times shows how the number of possible repointings to observe GRB at TeV is probably very limited (about 23 pointings in 3h for an initial exposure of 25s, about 4 pointings in 3h for an initial exposure of 10min)

Extra slides

Hexagonal Sky Grid



Hexagons on a sphere

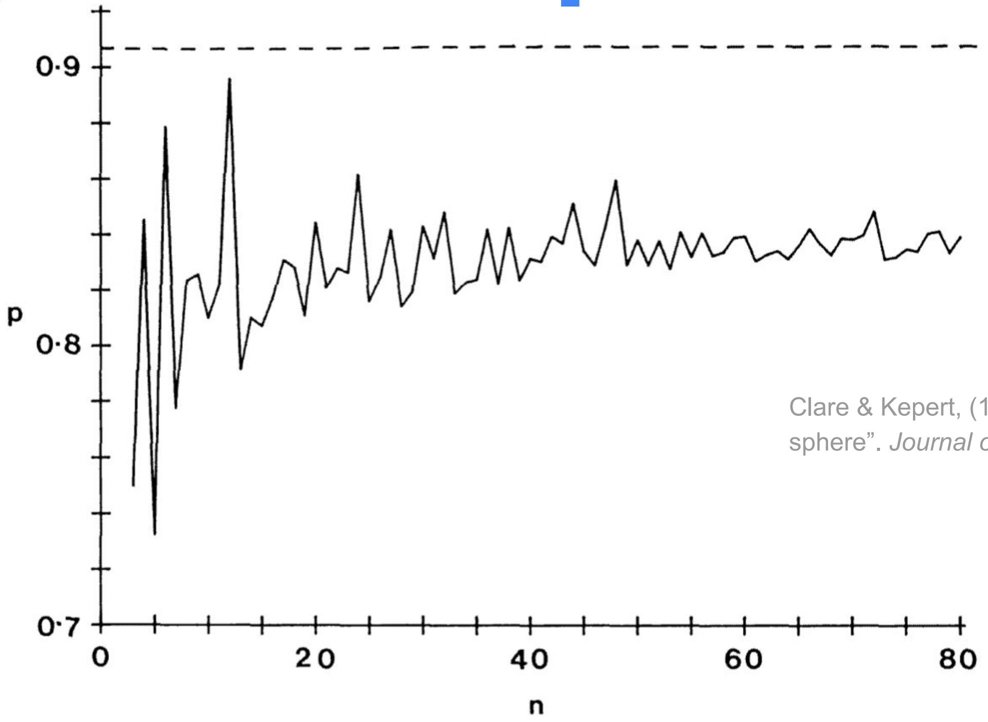


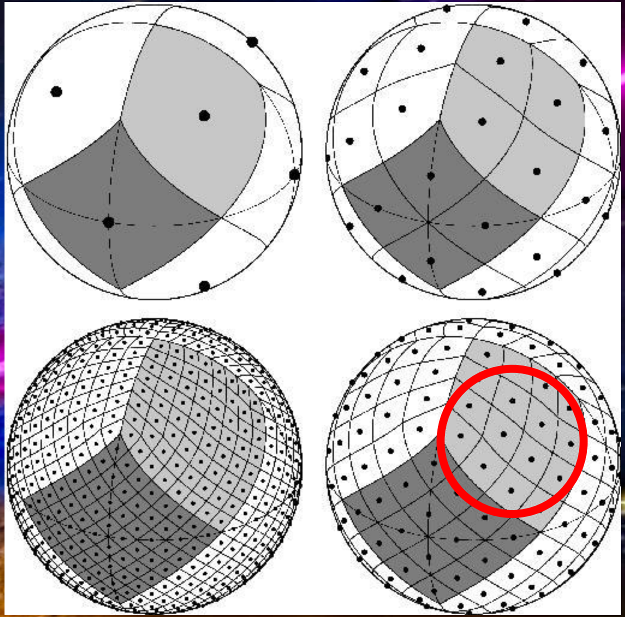
Fig. 21. Packing density p as a function of the number of circles x, for the best closest packings of circles on the surface of a sphere. The broken line indicates the value for an infinite number of circles, p = 0.906900.

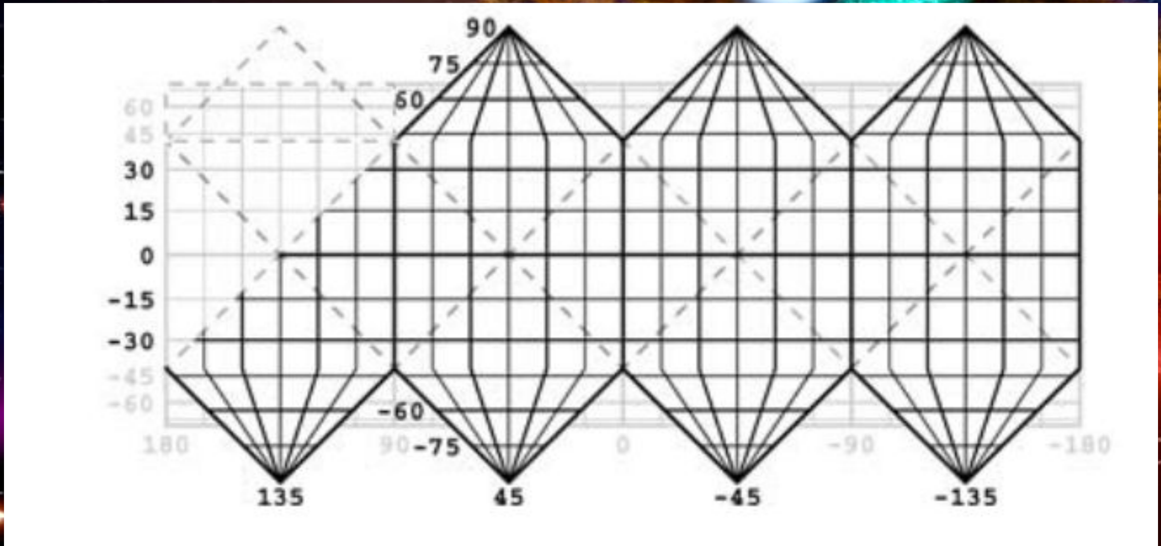
Clare & Kepert, (1991). "The optimal packing of circles on a sphere". *Journal of Mathematical Chemistry.* **6**: 325-349

HEALPix map

Issues:

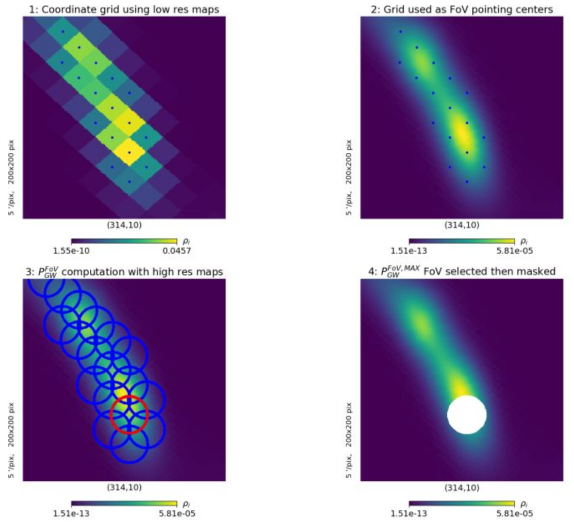
- Deformations
- Does not guarantee "without holes" coverage
- It goes to the ideal case only in the limit for high resolutions, calculation intensive!!

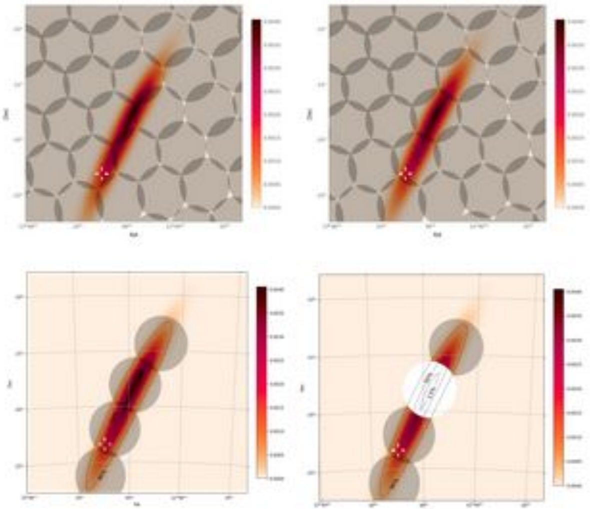




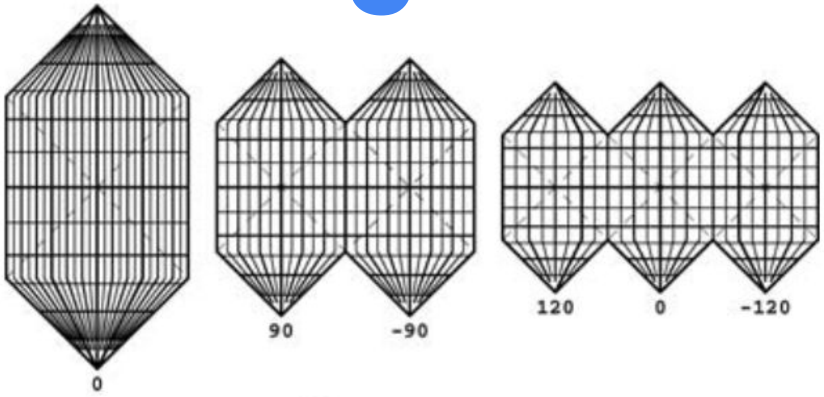
Main differences

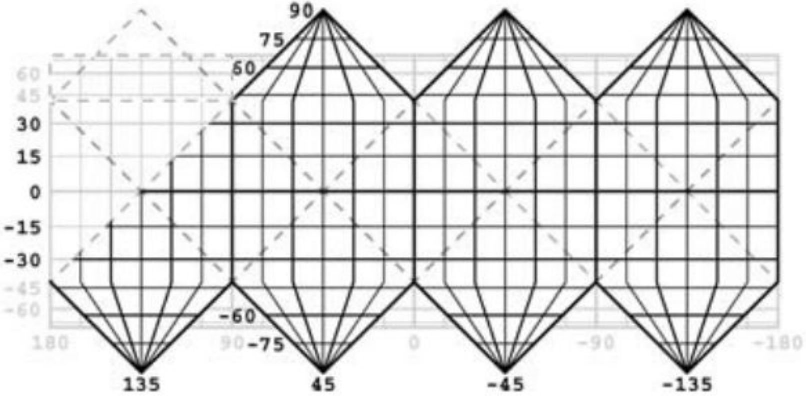
1. Upload vs build the grid:
    a. Once the FoV is fixed the grid is always the same:
        i. Numpy array (N,2)
        ii. N = number of cells of given radius to tile the entire sky
    b. Low memory usage
    c. Faster (modulo rotations)
2. Geometrical optimization:
    a. Homogeneity on the whole sky
    b. Full sky tessellation -> good for big error areas
    c. Hexagonal vs Square tiling
    d. Lower # of pointings
3. Longer exposures with time





Hexagonal HEALPix

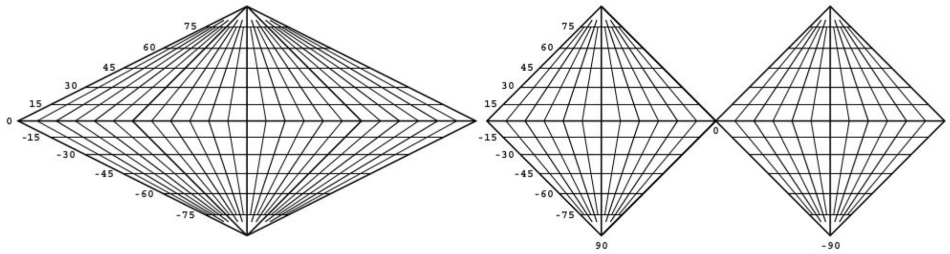




(H=1-4, K=3)

(H=1-2, K=1)

- Class of HEALPix projections
- (H, K) with H,K=1,2,3,4….
- “Regular” HEALPix is defined by (4,3)
- “Hexagonal” HEALPix can be constructed by (3,3)



Hexagonal HEALPix

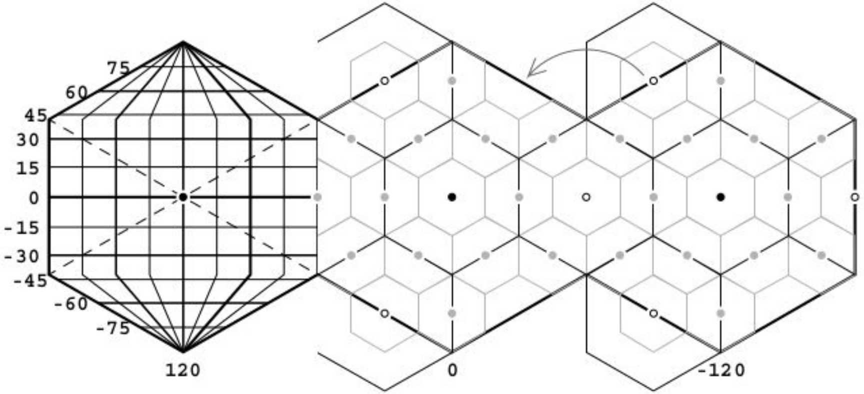
Calabretta & Roukema, Mon. Not. R. Astron. Soc. 381, 865–872 (2007)

Good:

- Similar to the grids we are already using
- All the benefits of regular HEALPix
- Hexagonal cells/pixels

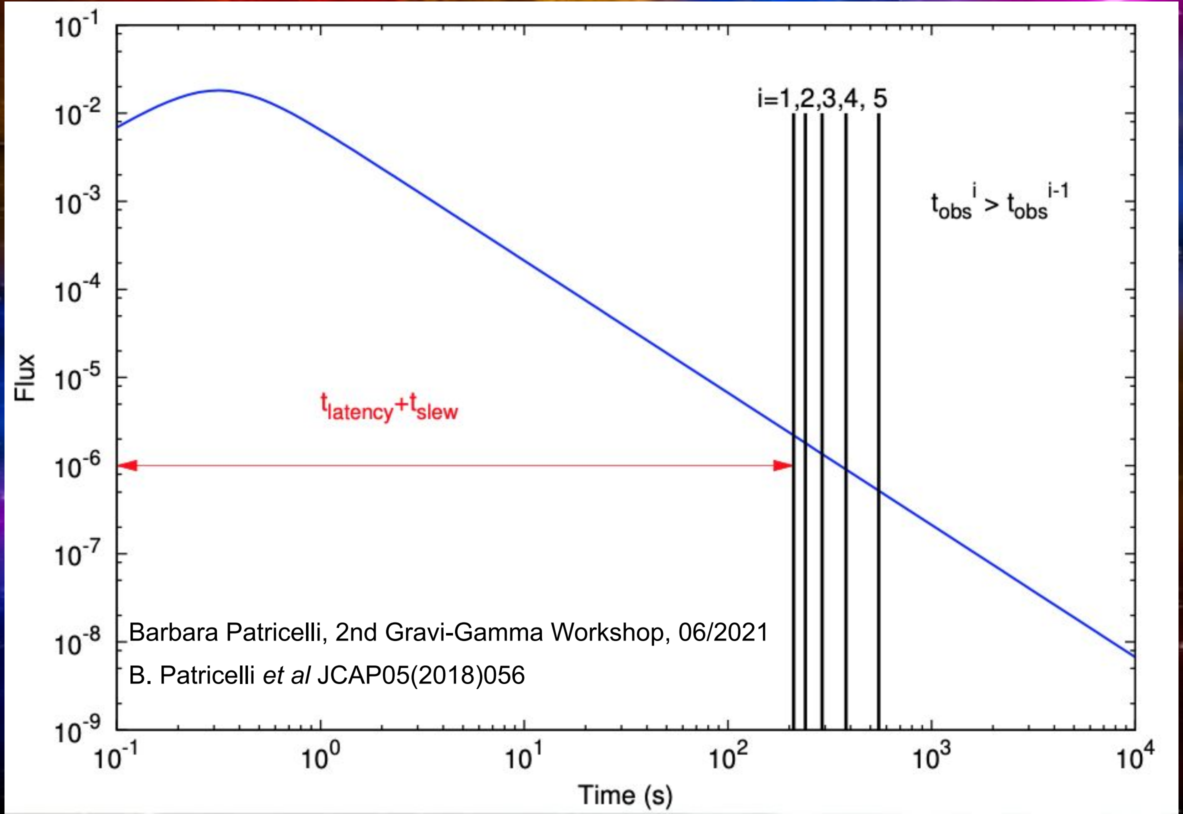
Bad:

- Even more deformations than the regular case
- Possible, but not easy hierarchical pixelization



(H=3, K=3)

Recent developments: exposure times



Lightcurves