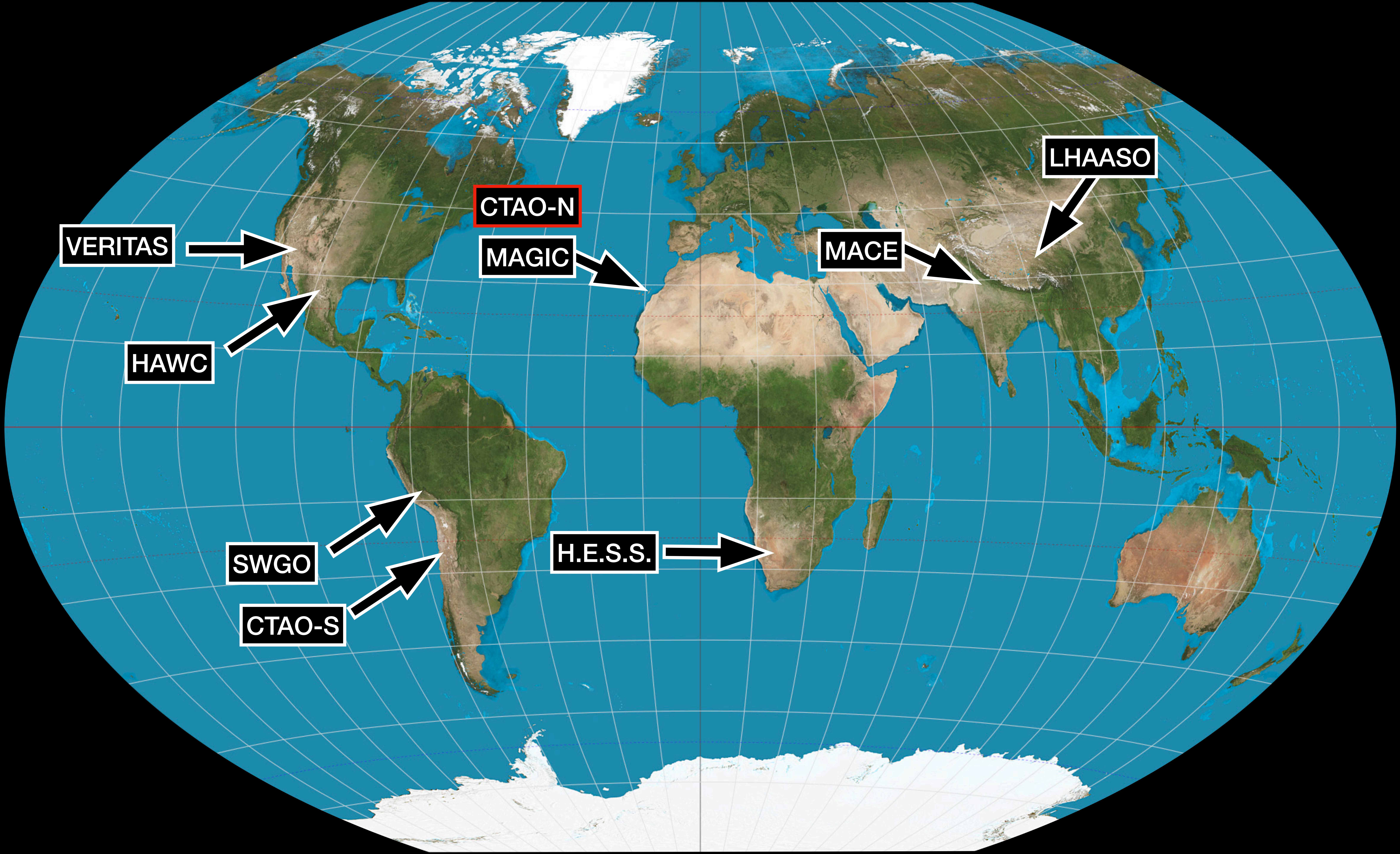
What do I need for a proposal?

David Green, CTAO Deputy Project Scientist, June 15th, 2025

What do we need?

- Over the next few days we will focus on the following sections:
    - Observability -> When is the target observable and under what conditions?
    - Instrument Performance -> how to estimate observation time
    - Observation Strategy -> Determine Telescope Pointing Positions
    - Putting all together into a proposal
- I am assuming you already have a scientific justification and a target
- Please be aware that your target may not be a good fit for your telescope


VERITAS
CTAO-N
MAGIC
HAWC
MACE
LHAASO
SWGO
CTAO-S
H.E.S.S.

Setting Things Up

- You can see the MAGIC+LST Proposal Form at the following link:
  - https://www.overleaf.com/read/kmsvyyvxdsrs#5a1618
  - Just copy it or download it
- We are going to focus on the technical justification

3. Technical description of the MAGIC and/or LST-1 observations:

Describe how the observations will be performed, so the feasibility of the project becomes clear. Describe (in this or the next section) also the S/N ratio calculations you have used to justify the number of hours you request (no correction for expected weather conditions should be applied).

If Time Category was set to a value higher than 0 (in the web form) the PI should give here the justification of this choice, which will be later on evaluated by the TAC and the schedulers.

The Time Category defines the time criticality of the observations, i.e. how necessary is to perform the observations of this source on a particular day and time. It can take five values [0, 1, 2, 3, 4], which have the following meanings:

- [0] No time critical
- [1] Critical on timescales of days (e.g. MWL contemporaneous observations or ToO on slow transients)
- [2] Critical on timescales of hours (e.g. MWL simultaneous observations or ToO on fast transients)
- [3] MWL simultaneous observations with major astronomical facilities (ALMA, EHT, NuSTAR)
- [4] Critical on timescales of minutes/seconds (e.g. automatic follow up of fast transients)

For each target, the PI can select more than one time category because a source can be observed under different time priorities on different days.

In case a monitoring is requested, please, give the cadence you would like to have for your observations, with a short justification. E.g. 'every X days', 'X times per week', 'X times per period', 'custom requirements will be sent to the schedulers before the period' and please indicate how strict this cadence needs to be kept: 'strict', '+-1d', '+-2d', '+-3d', 'custom'

If needed justify the minimum/maximum allowed sky brightness set for your source. For MAGIC a dedicated script (https://magic.pic.es/moon-level-performance-calculation/) is available to compute the energy threshold as a function of the sky-brightness and zenith angle.

If a special dedicated analysis needs to be developed for this proposal, explain if the proposers have appropriate expertise for developing it.

Setting Things Up

- For this session you need:
  - Gammapy 1.3
  - Notebooks
  - CTA prod5 IRFs https://doi.org/10.5281/zenodo.5499840 (fits files for the LST sub-array)
  - Your favorite source & an idea for a proposal

- IRFs = Instrument Response Functions
  - describe how the reconstructed event distribution corresponds to the incoming true photon distribution
  - Response is (in general) a function of direction, energy and time.

2.2 IRF factorisation

Equation 2.2 implies 7-dimensional instrument response functions that in general are computationally unmanageable. Simplifications can be achieved by making further assumptions, and in existing Imaging Air Cherenkov Telescope (IACT) experiments the IRF is generally factorised as follows:

$$R_i(\hat{\alpha}, \hat{\delta}, \hat{E}|\alpha, \delta, E, t) = \mathrm{A}_i(\alpha, \delta, E, t) \times \mathrm{PSF}_i(\hat{\alpha}, \hat{\delta}|\alpha, \delta, E, t) \times \mathrm{D}_i(\hat{E}|\alpha, \delta, E, t) \tag{2.3}$$

where $\mathrm{A}_i(\alpha, \delta, E, t)$ is the effective area in units of cm^2, $\mathrm{PSF}_i(\hat{\alpha}, \hat{\delta}|\alpha, \delta, E, t)$ is the point spread function in units of sr^{-1}, with

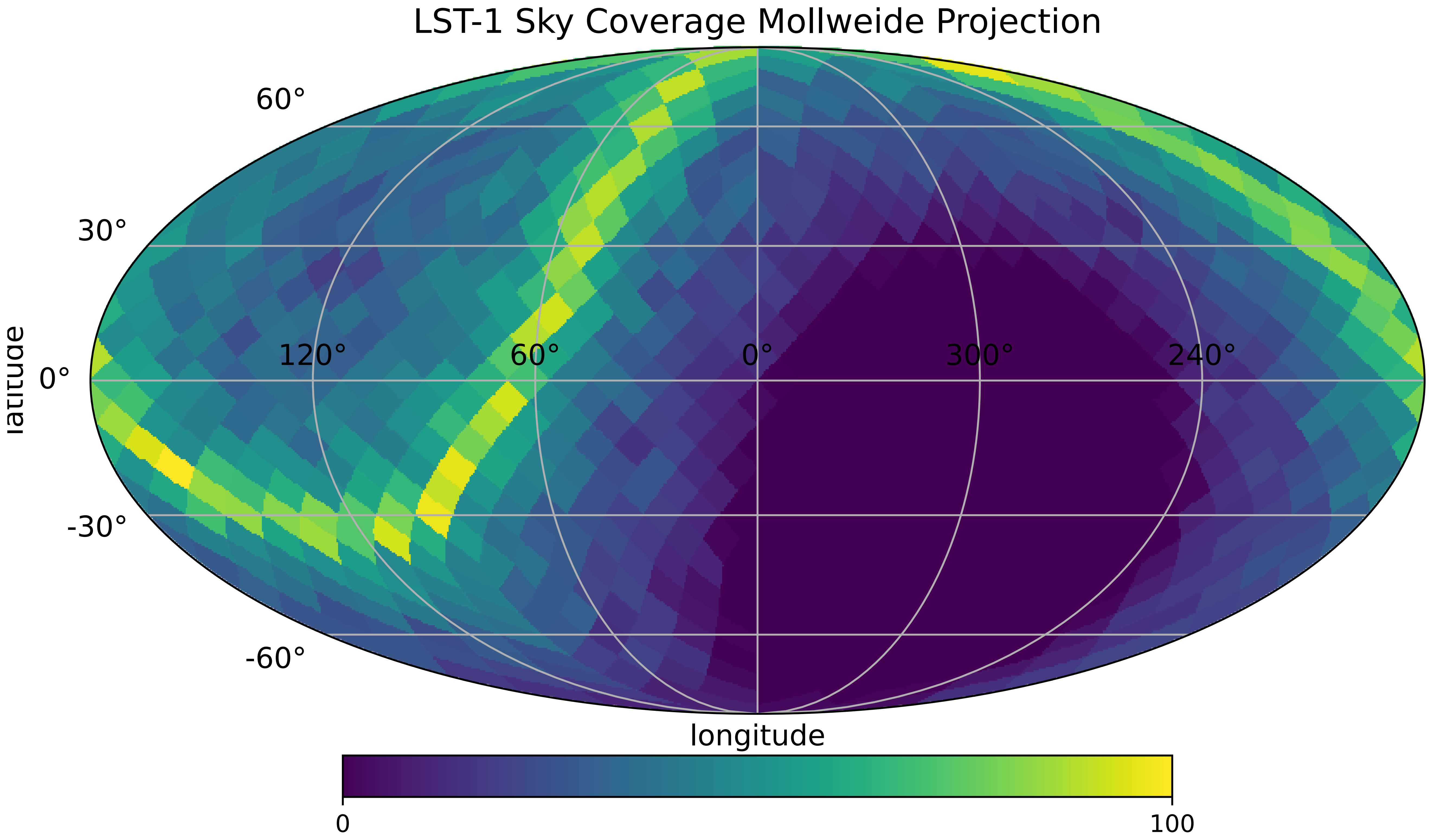
$$\int d\hat{\Omega}\ \mathrm{PSF}_i(\hat{\alpha}, \hat{\delta}|\alpha, \delta, E, t) = 1 \tag{2.4}$$

and $\mathrm{D}_i(\hat{E}|\alpha, \delta, E, t)$ is the energy dispersion in units of TeV^{-1}, with

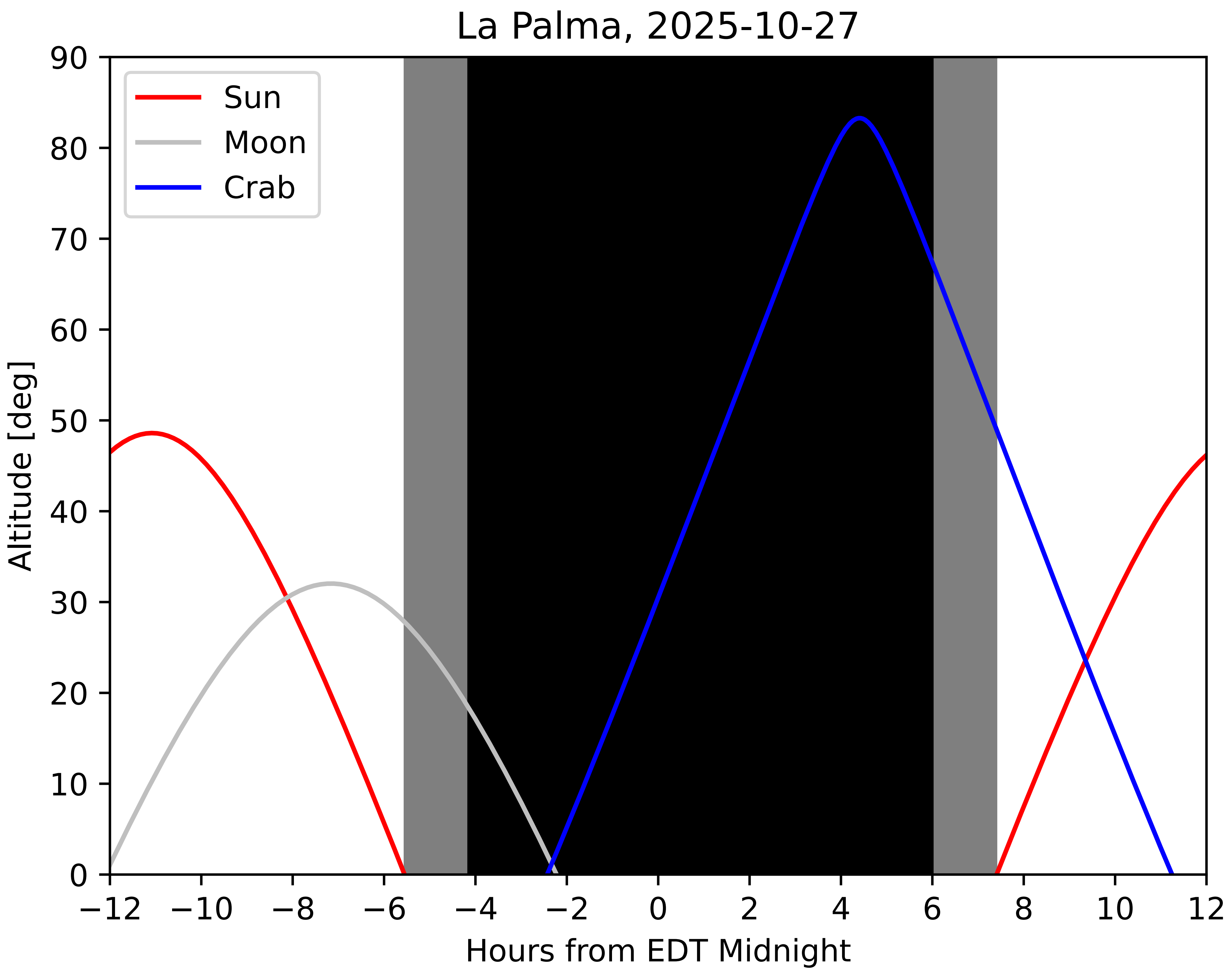
$$\int d\hat{E}\,\mathrm{D}_i(\hat{E}|\alpha, \delta, E, t) = 1 \tag{2.5}$$

Observability

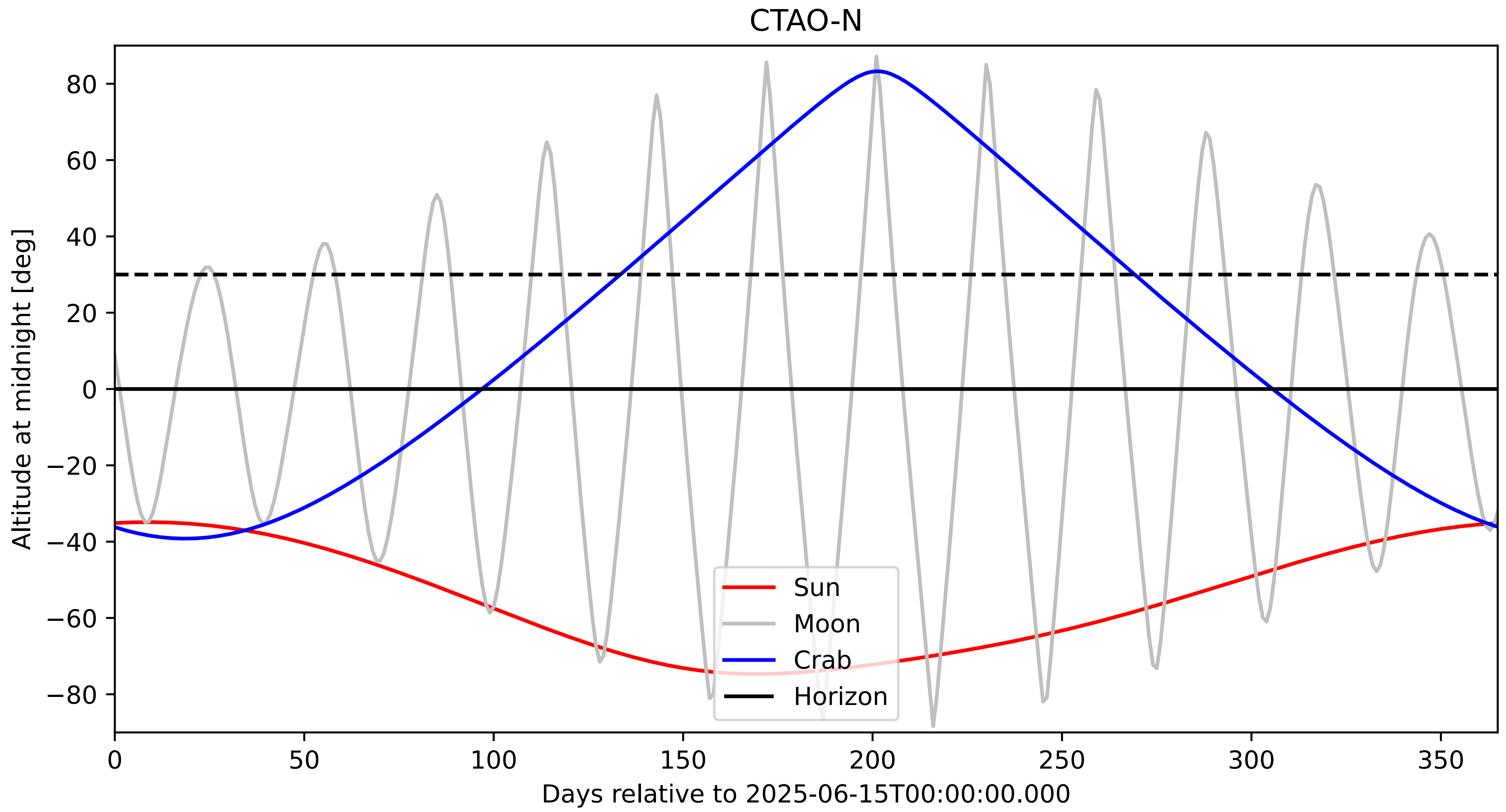
- Not all the sky is accessible to all ground based telescopes
- Different parts of the sky can be observed at different times during a year, or throughout
- First check whether your telescopes can observe your target



Observability



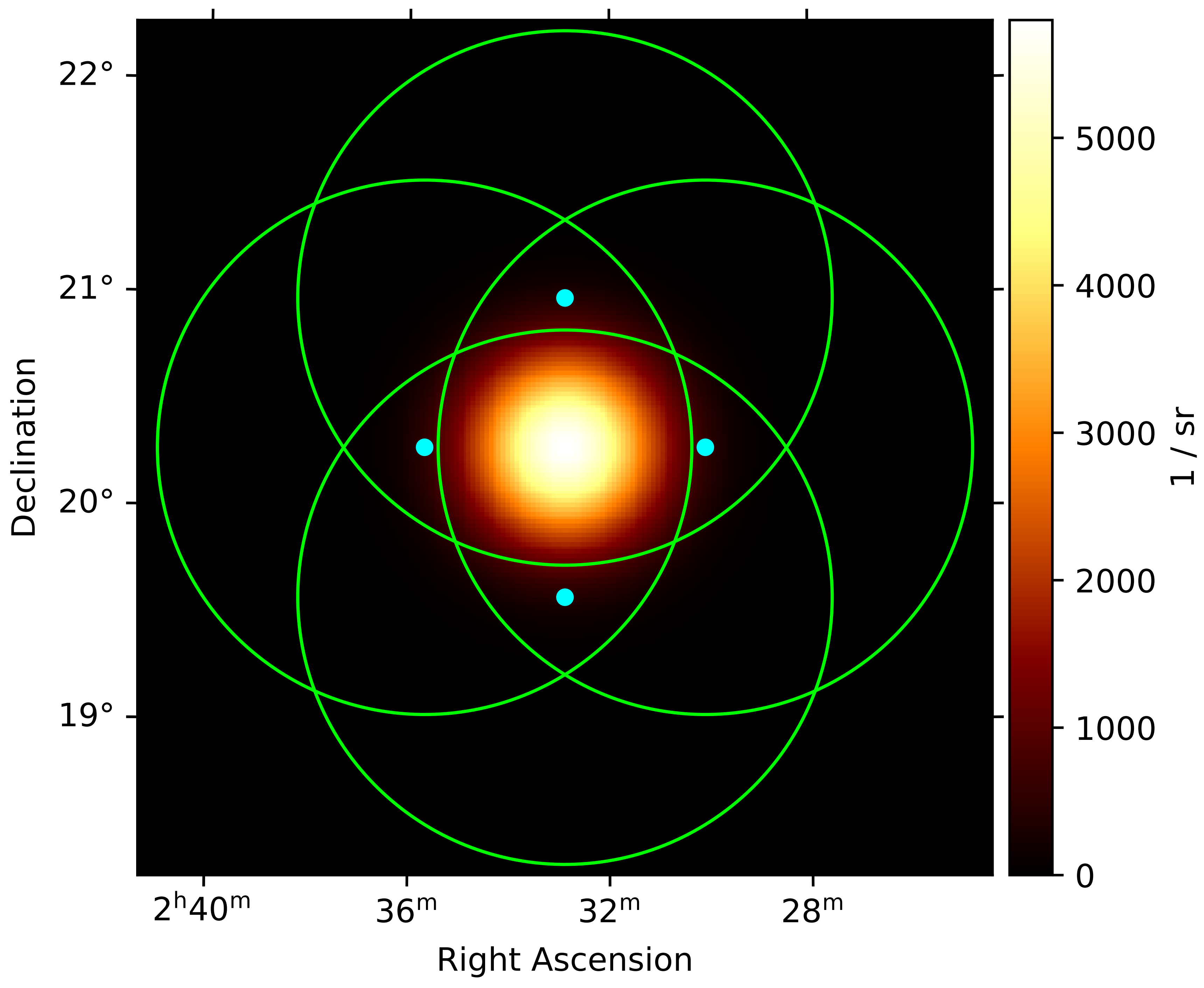
- Consider a year:
  - Altitudes at midnight plotted
  - Can identify moon cycles and seasons (sun elevation)
  - Sky region observability depends on time of year

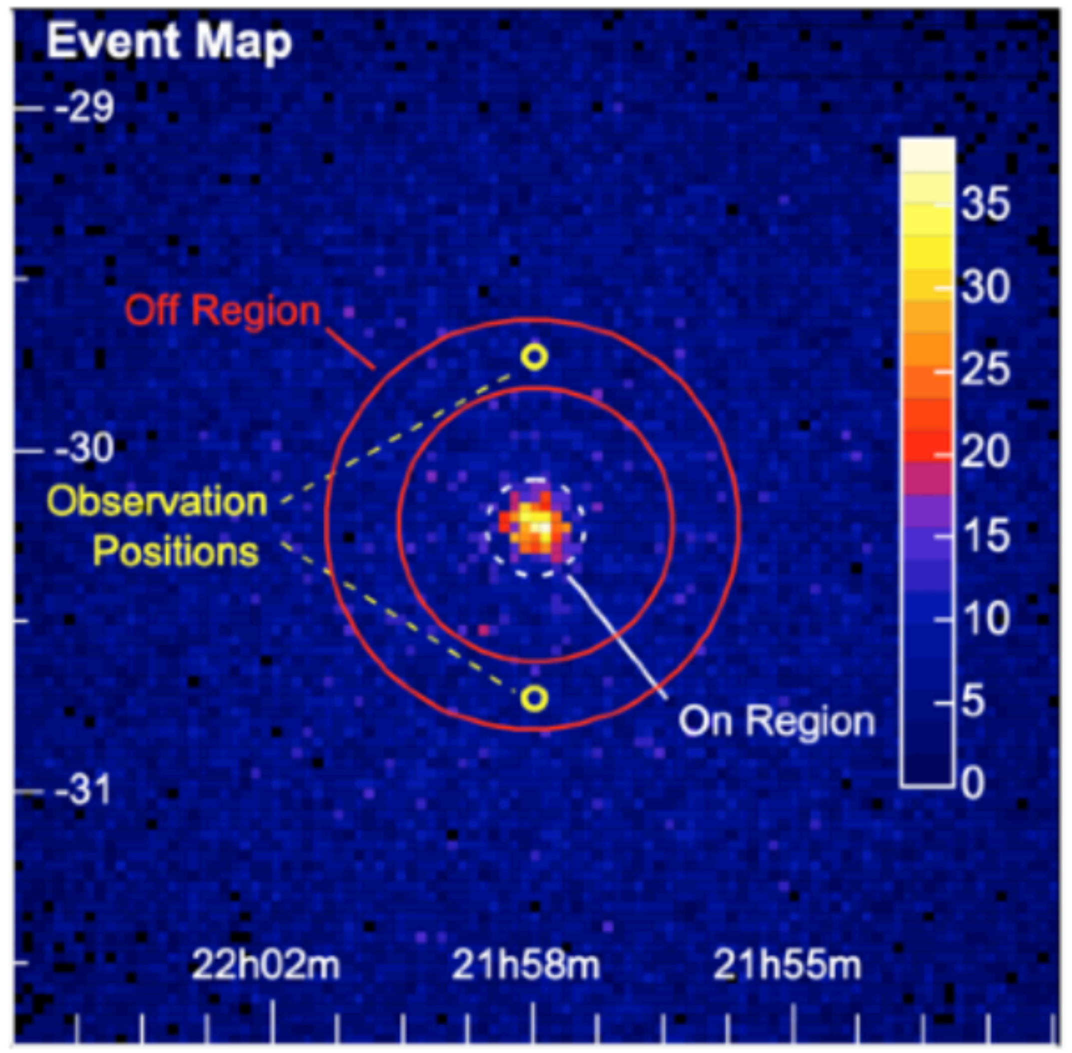


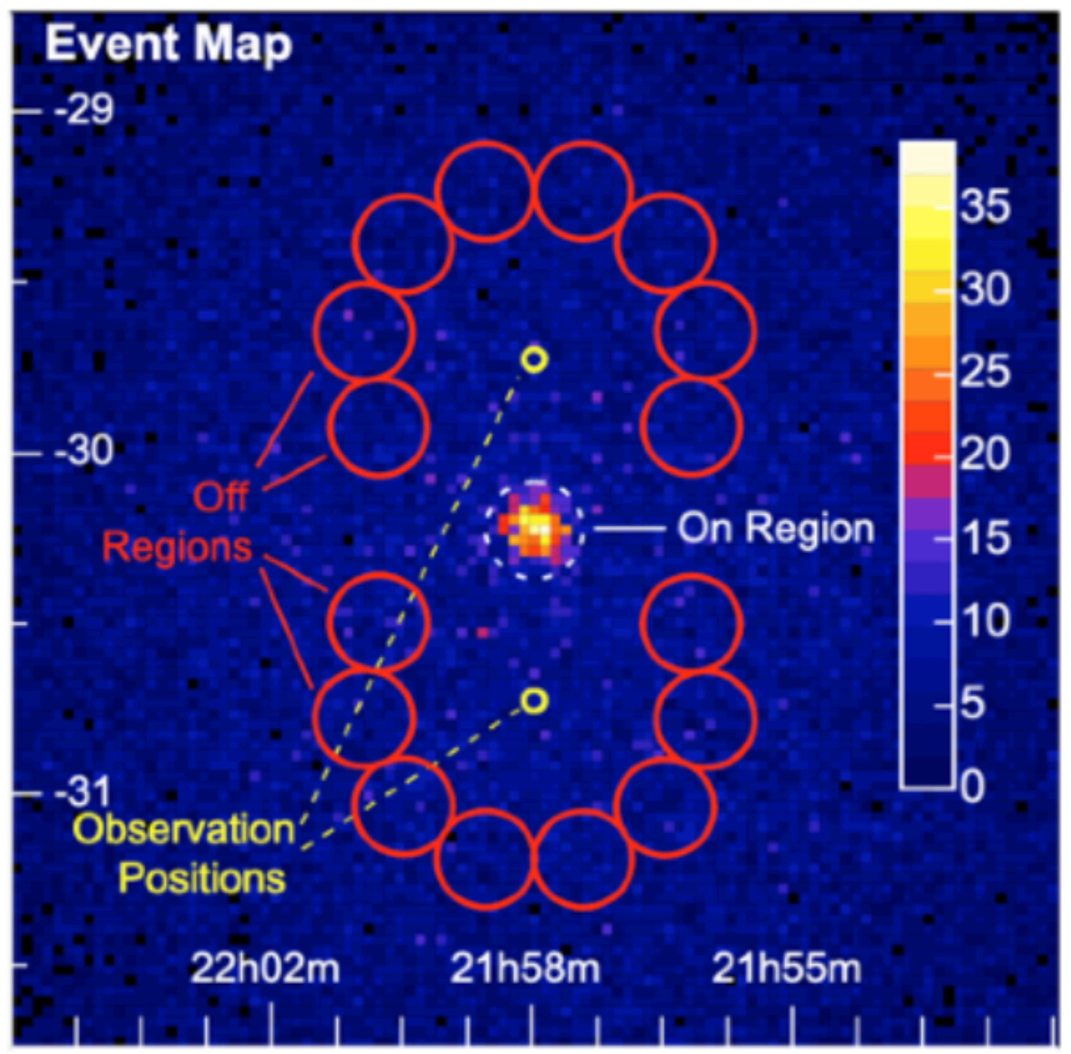
- Consider a single night:
  - Altitude above horizon for objects of interest
  - White = daylight, sun above horizon; grey = twilight, sun below
  - horizon; dark = astronomical darkness, sun < -18°

Pointing Strategy

- How should the observations be conducted?
- Depends on the nature of the source being observed and the intended strategy for background estimation.
- Most common case: point source or mildly extended source.
    - (Here we simulate a source in order to check the pointing positions.)
- Most common strategy: “wobble” pointings.
    - The telescopes point alternately at ~four positions at equal offsets by a wobble offset
    - The optimal wobble offset depends on the source and and region
    - e.g. LST / MAGIC typically values ~0.4° whereas HESS uses ~0.7°
- Wobble strategy is ideal for e.g. Ring and Reflected background methods

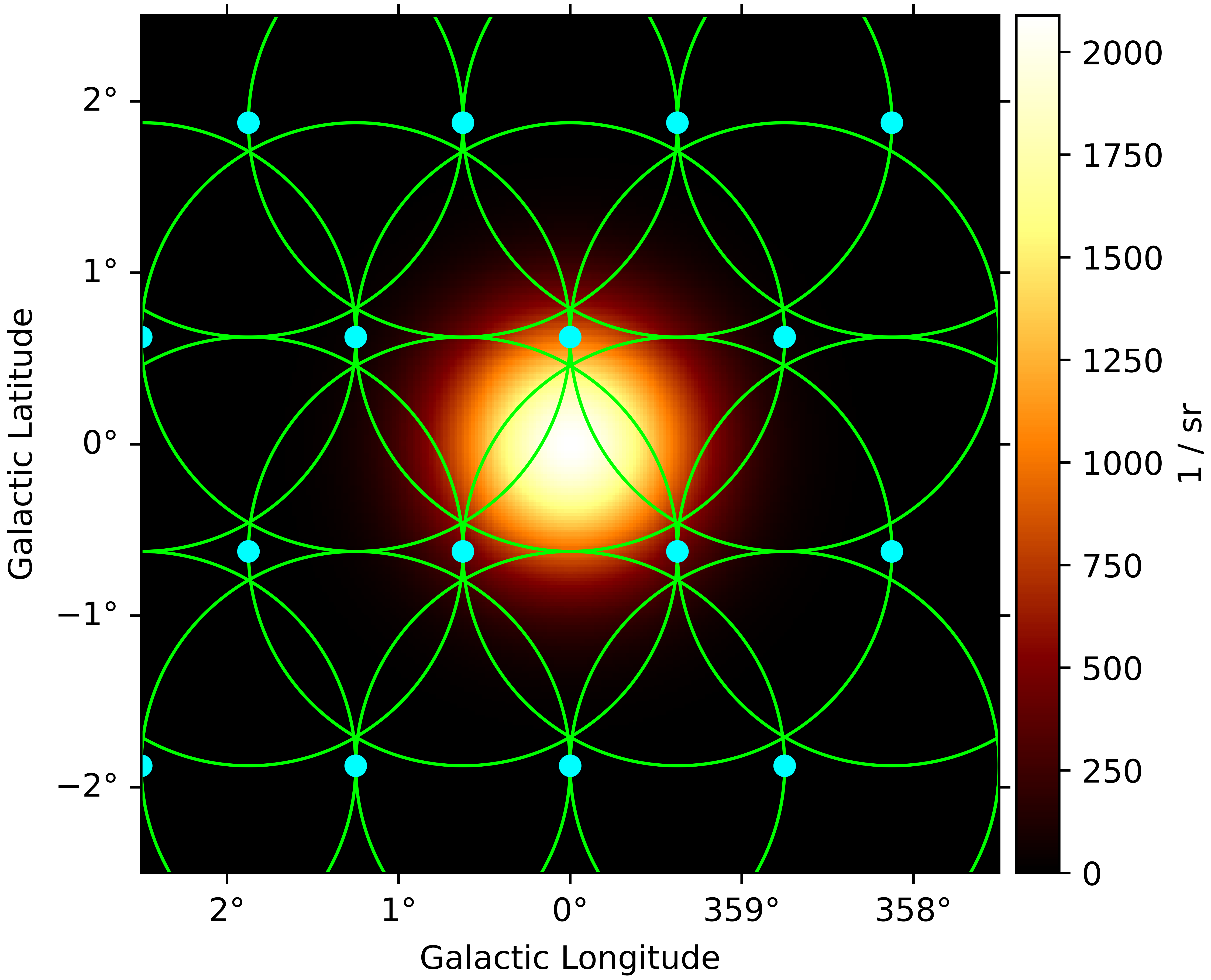






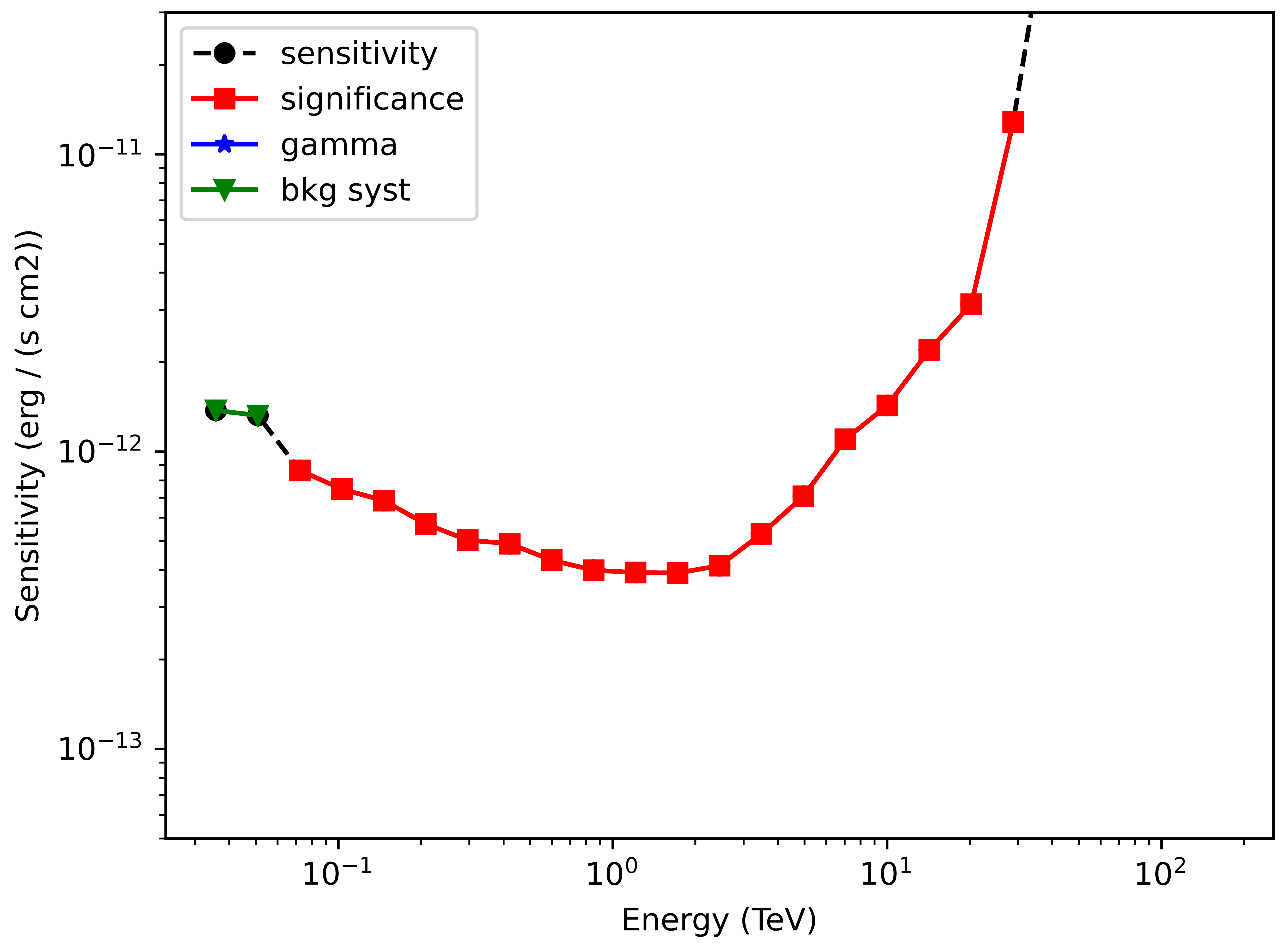
Pointing Strategy

- If, however, we want to cover a larger region of the sky, a grid strategy might be more appropriate.
- Here, the grid spacings should be chosen similarly to the wobble offsets: based (primarily) on the acceptance of the telescopes and their FoV.
- Suitable background methods could be Field-of-View or template background approaches.
- An “On-Off” strategy, e.g. where a source fills a field of view, would require dedicated observations of an ON region followed by dedicated observations of an OFF (empty) sky region taken under similar conditions (zenith angle etc.)



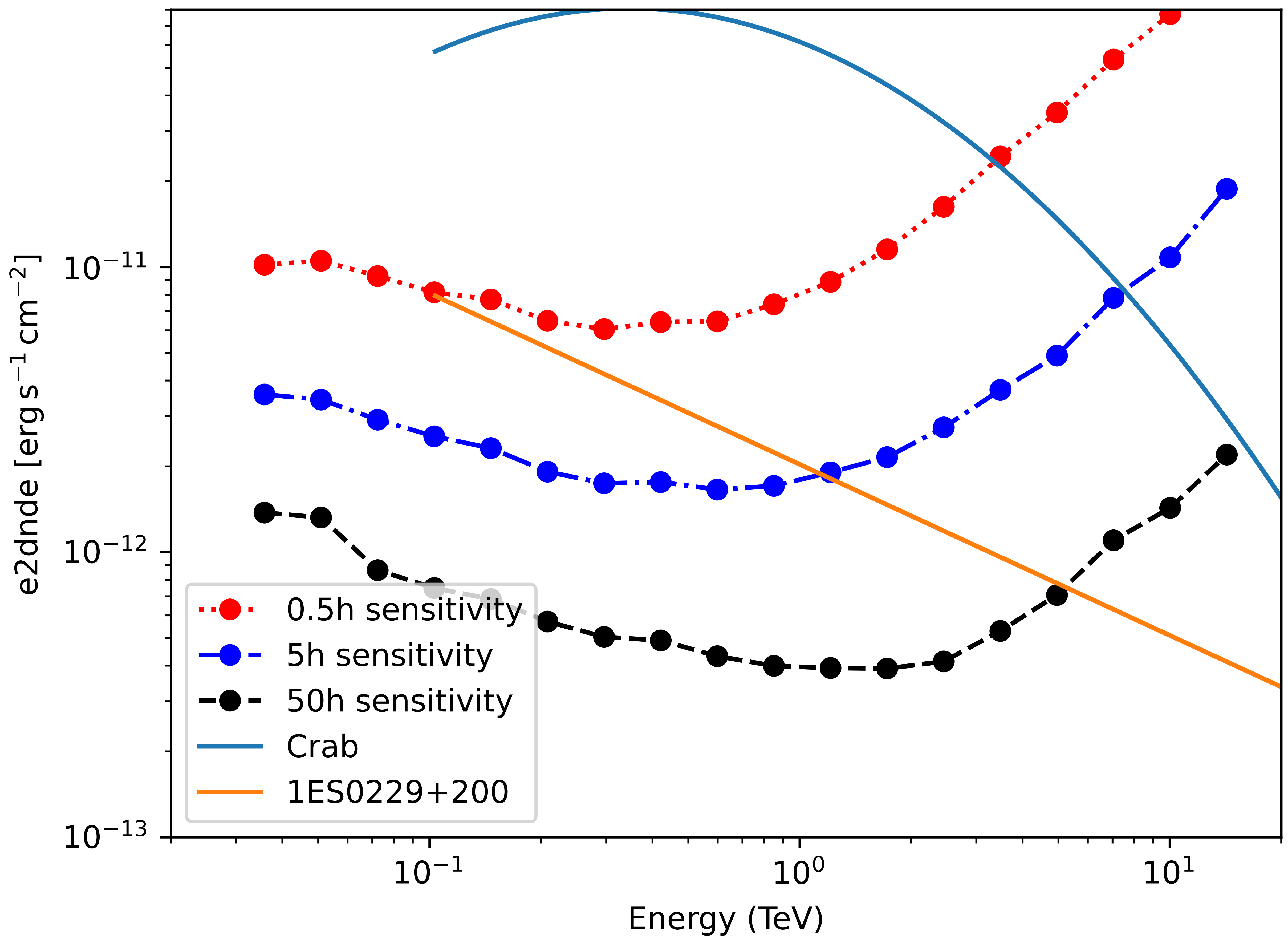
Sensitivity

- CTAO-N full array prod5 IRFs 50 hour
- Criteria per energy bin include:
    - a minimum of 10 gamma-ray events
    - a minimum significance of 5 sigma
    - a maximum background systematic of 10%
- Which criterion dominates at which energy is indicated on the curve
- Background systematics tend to dominate at lower energies
- Gamma-ray counts tend to dominate at high energies



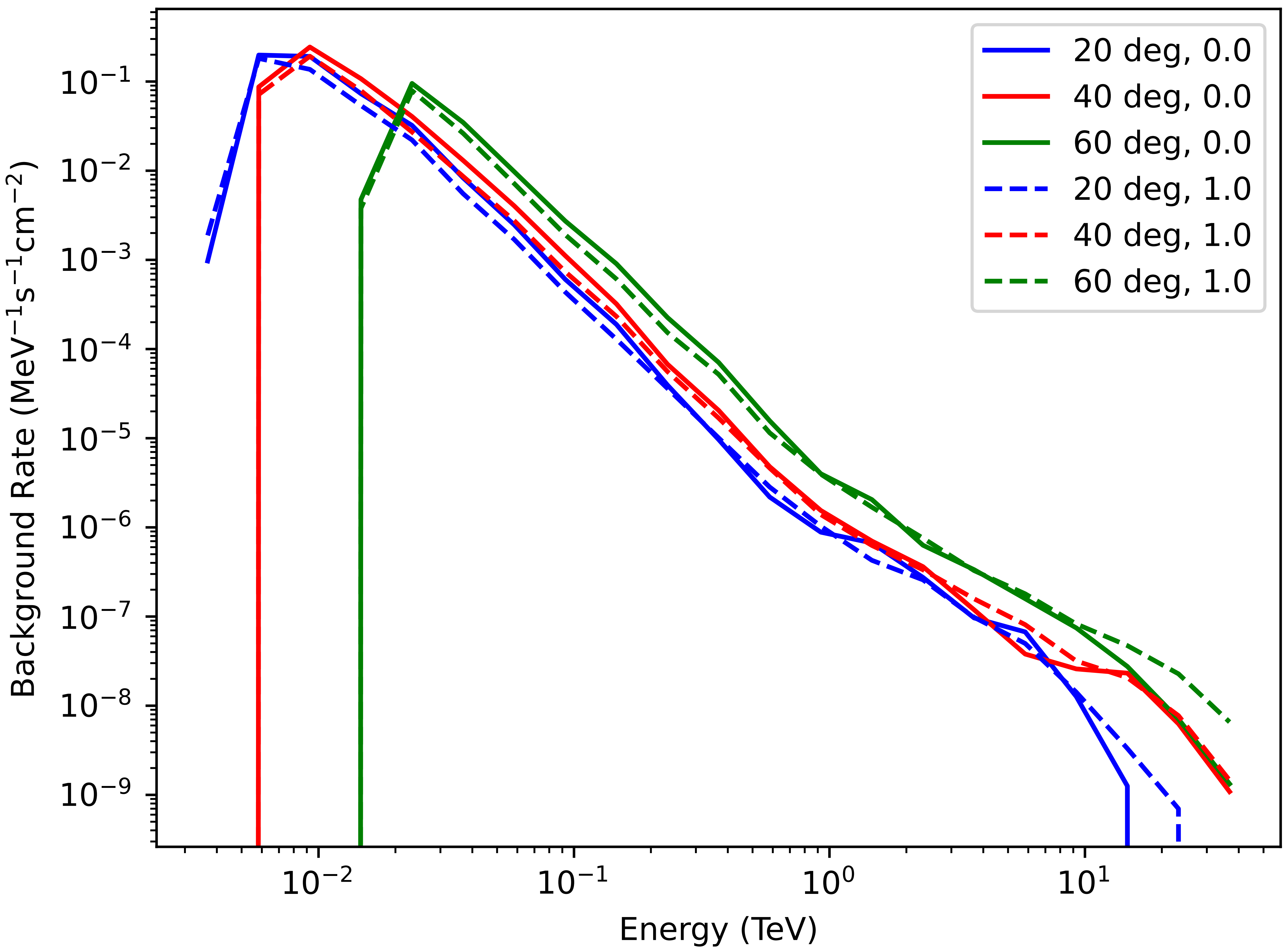
Sensitivity with time

- Sensitivity improves over time, but not linearly.
- Two approaches will be shown:
    - 1 the *rough* approach guesstimating based on different sensitivity curves generated from Monte Carlo
    - 2) using a python tool developed to do the full calculation
    - interpolate between curves of different times at a given energy
    - find where the **predicted source spectrum** intersects with the fitted function
- linking the sensitivity curves for different times
    - This provides the time required for a 5 sigma detection of a point source
- Scaling arguments can be used to go further:
    - Sensitivity improves with time as $\propto \sqrt{t}$
    - sensitivity degrades with increasing source size as $\propto \sqrt{\sigma_{PSF}^2 + \sigma_r^2}$



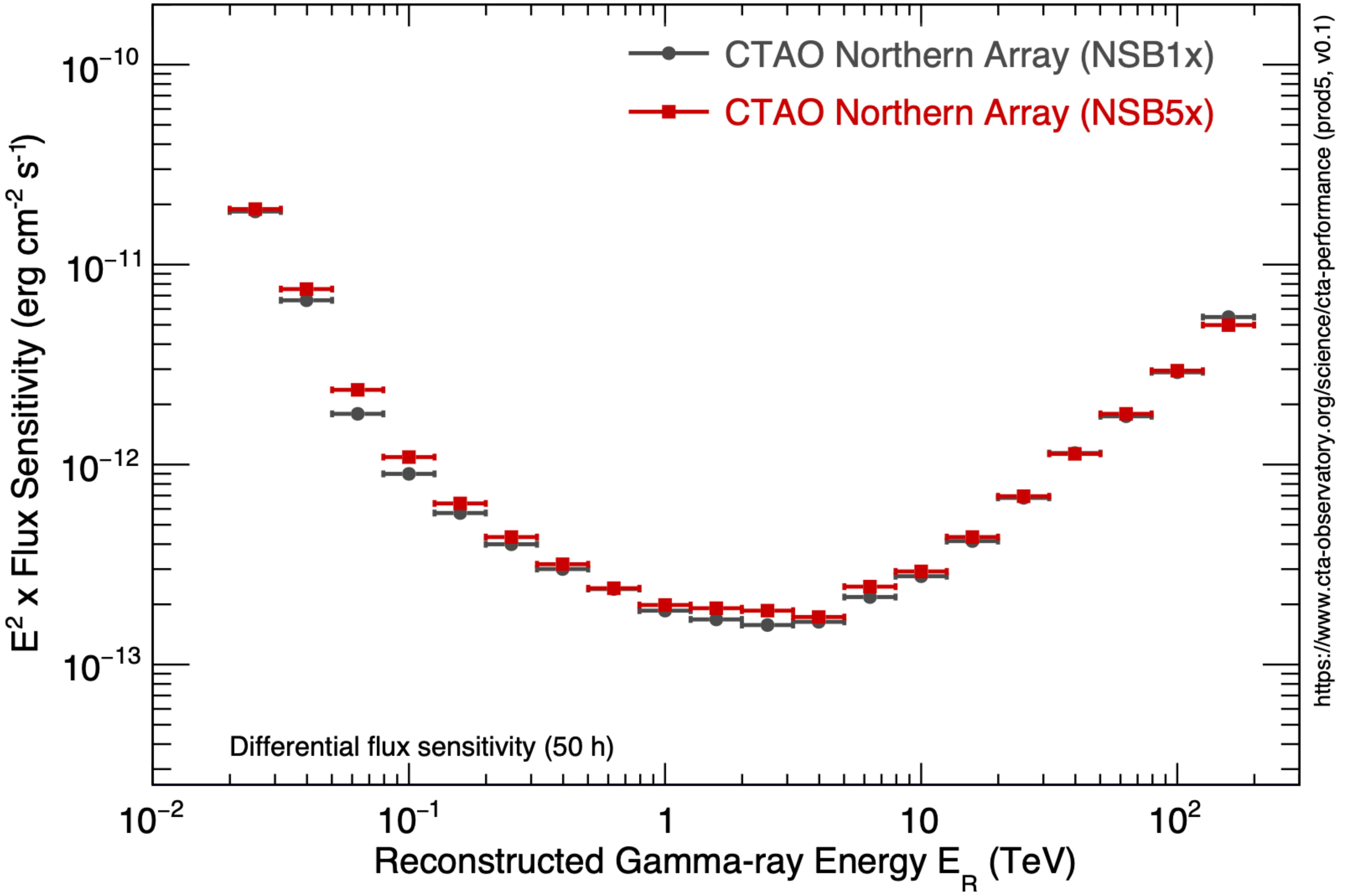
Zenith Dependence

- Not all sources can be observed at the same zenith angle.
- With increasing zenith angle of observations (decreasing altitude / elevation) the air showers must pass through more atmosphere prior to reaching the telescope
- Therefore, low energy events are more absorbed, and the energy threshold increases.
- The overall rate of events at higher energies, however, also increases, as the effective area increases with zenith angle.
    - The offset angle starts to have an influence at ≥1°



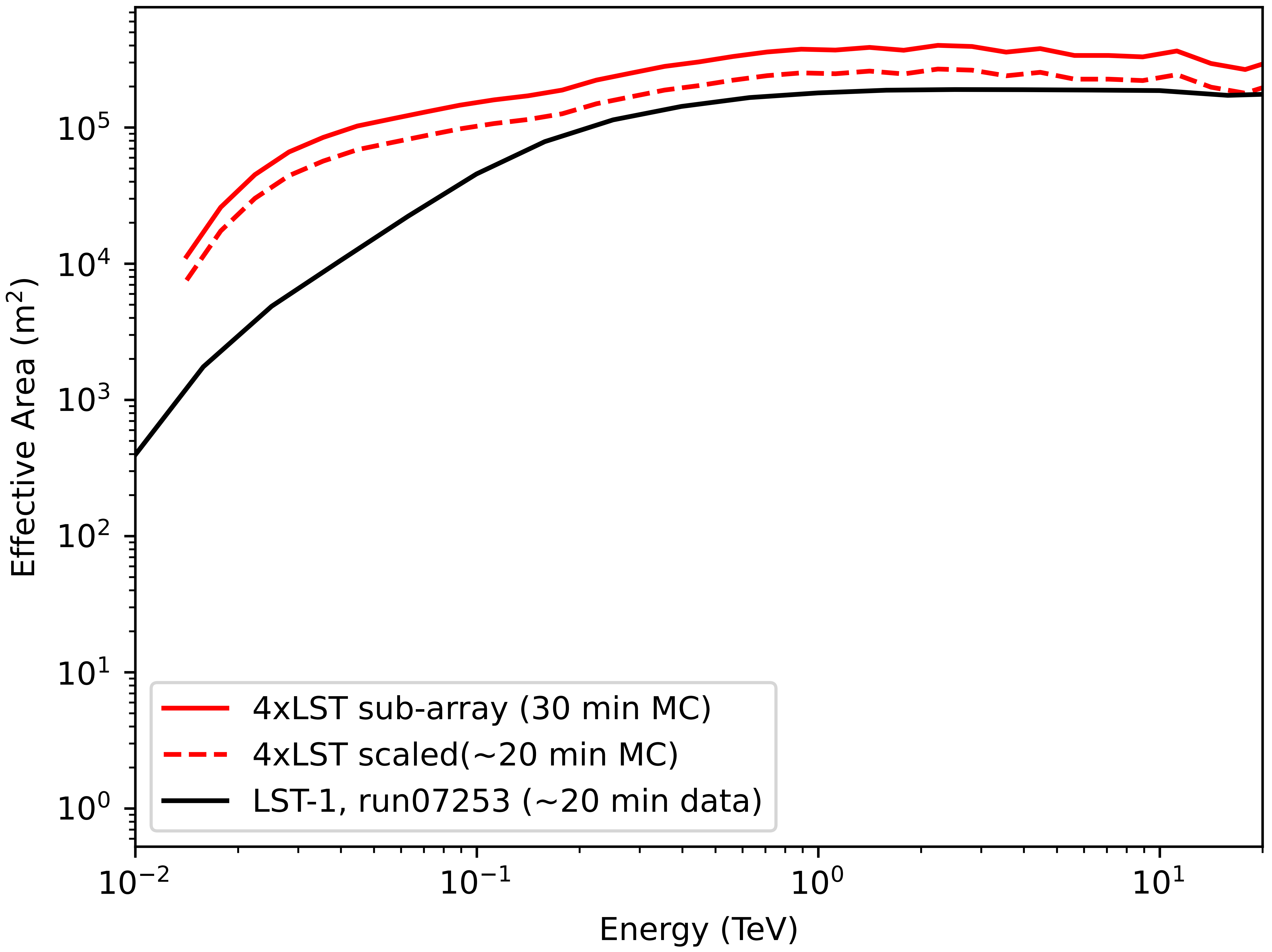
Influence of Night Sky Background

- Sources of night sky background include bright stars, diffuse air glow and moonlight.
- LSTs and MSTs are required by CTA to continue data taking under NSB up to 5x the nominal dark level.
- SSTs are required to continue data taking under NSB conditions up to 30x the nominal dark level.
- This increases the available observing time, at the cost of sensitivity.



Focusing in LSTs

- You should have already noticed a major issue:
    - the IRFs from MC are for a 4 telescope sub-array, but we want to estimate the observing time required by LST-1 as a single telescope. How to approximate this?
- Simple scaling the effective area and accounting for changes in background rate. This is a quick approximation



General Tips

- You know your science case best!
- Don’t propose data that won’t be useful (e.g. too high energy threshold / too low sensitivity)
    - Proposal should be convincing enough for a review committee:
        - that you understand the caveats and how to analyze the data
        - well-motivated science case and the context of previous observations taken into account
- Common sense: don’t propose targets that are not visible from CTAO-N!!
- In general, will need an approximate spectrum / flux level to estimate the required time.
    - Use previous gamma-ray data if available
    - Use MWL data (e.g. Fermi-LAT?) and extrapolate under reasonable models
    - Use comparable sources to estimate a reasonable range of fluxes
- Pointing strategy: wobble for point-sources
    - wobble should always be larger than the source size for extended sources
    - double-check the positions; avoid pointing directly at a source, e.g. in crowded regions such as the Galactic plane
      (Remember, there could be a neighboring source!)