MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES
CSIC Consejo Superior de Investigaciones Científicas
Vniversitat de València
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Multi-Scale Decomposition and Transformers in Compton Image Reconstruction

A novel approach to Compton for space applications

Kiko Albiol,

Gamma imaging sensors

Fast gamma ray location sensor

- 🔬 Directionality is not trivially constructed

No lenses, no mirrors — no easy geometry.

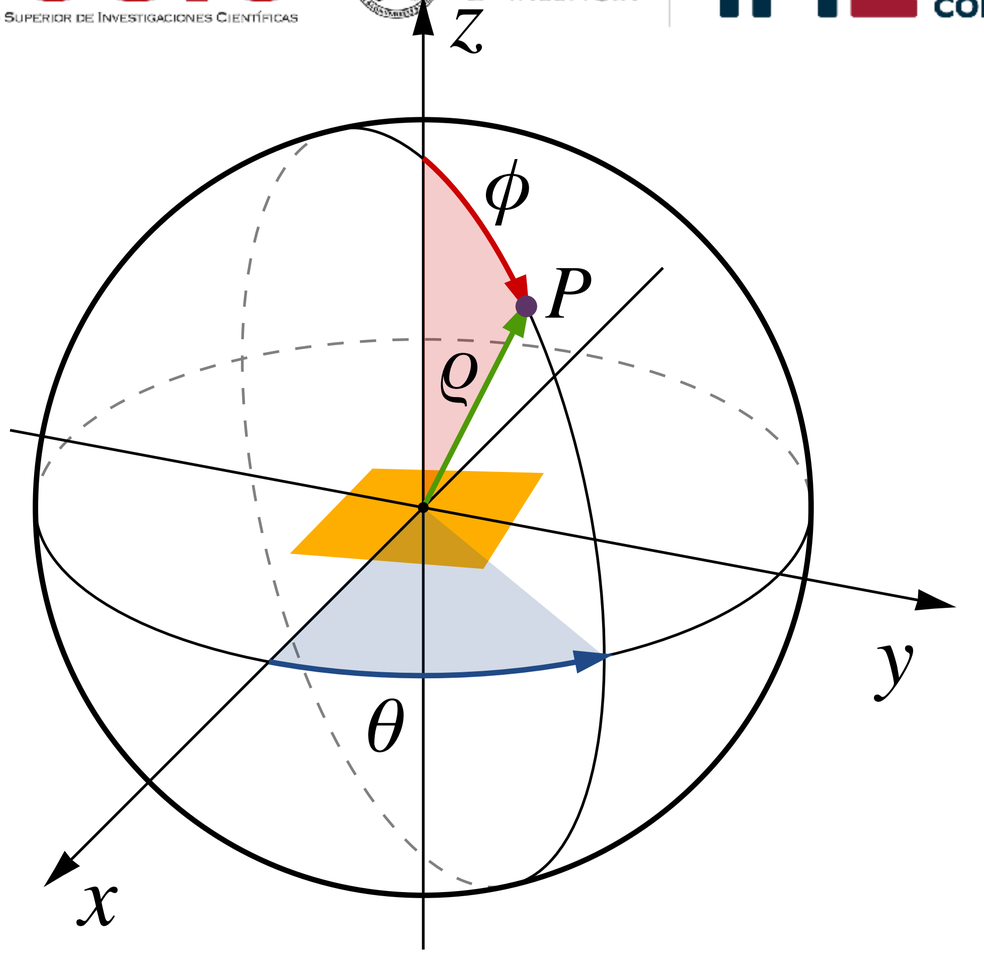
- ⏳ Reconstruction is computationally expensive, and masively data intensive

Large uncertainties and underdetermined models.
Especially challenging in the range **from keV to 100 MeV**.

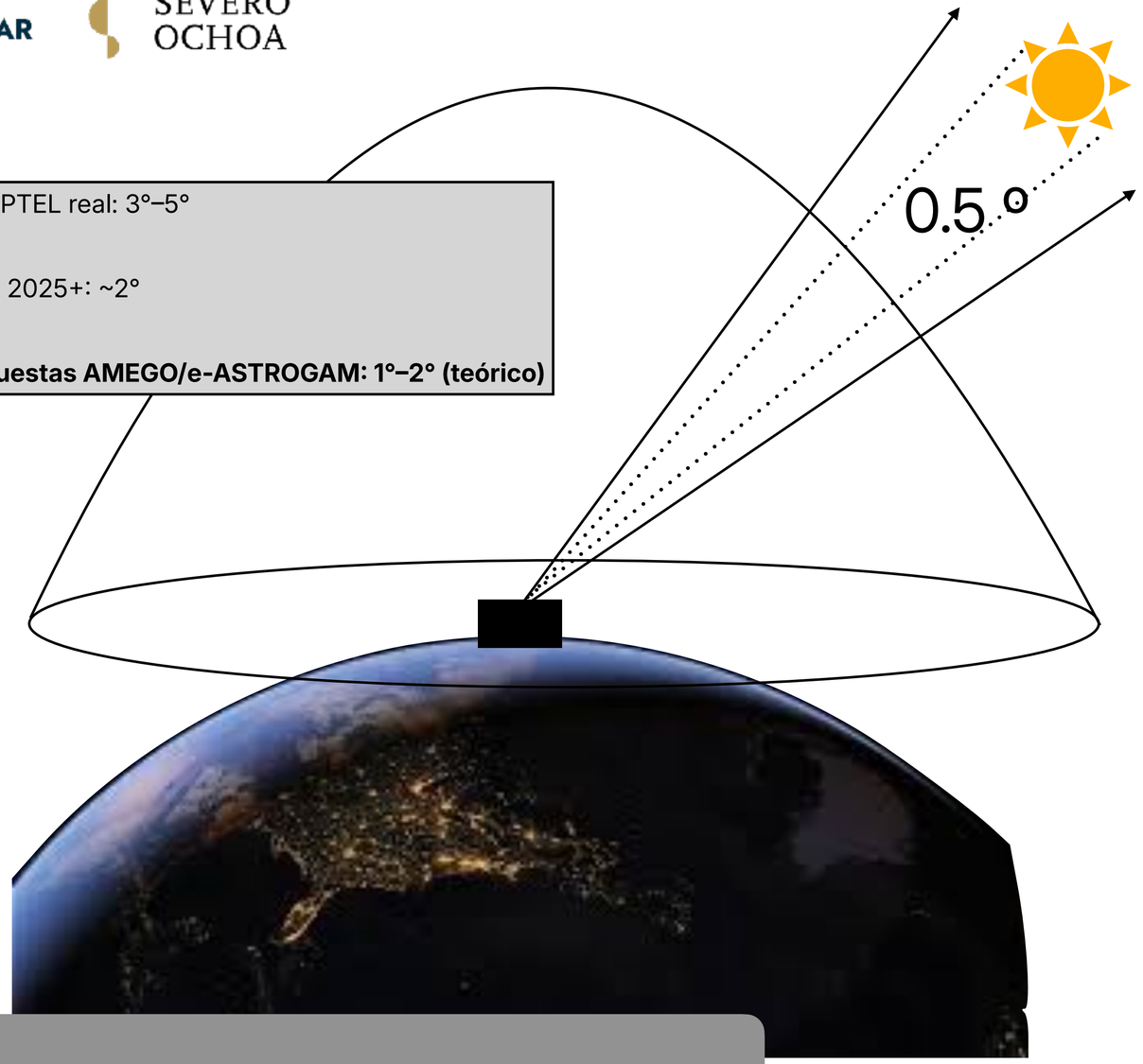
- 🚫 Sensor limitations prevent accurate imaging

Sparse detectors + low photon statistics = poor resolution.

This talk is about how to improve Detector complex reconstruction system using novel computing methods which involves GPU and new algorithms



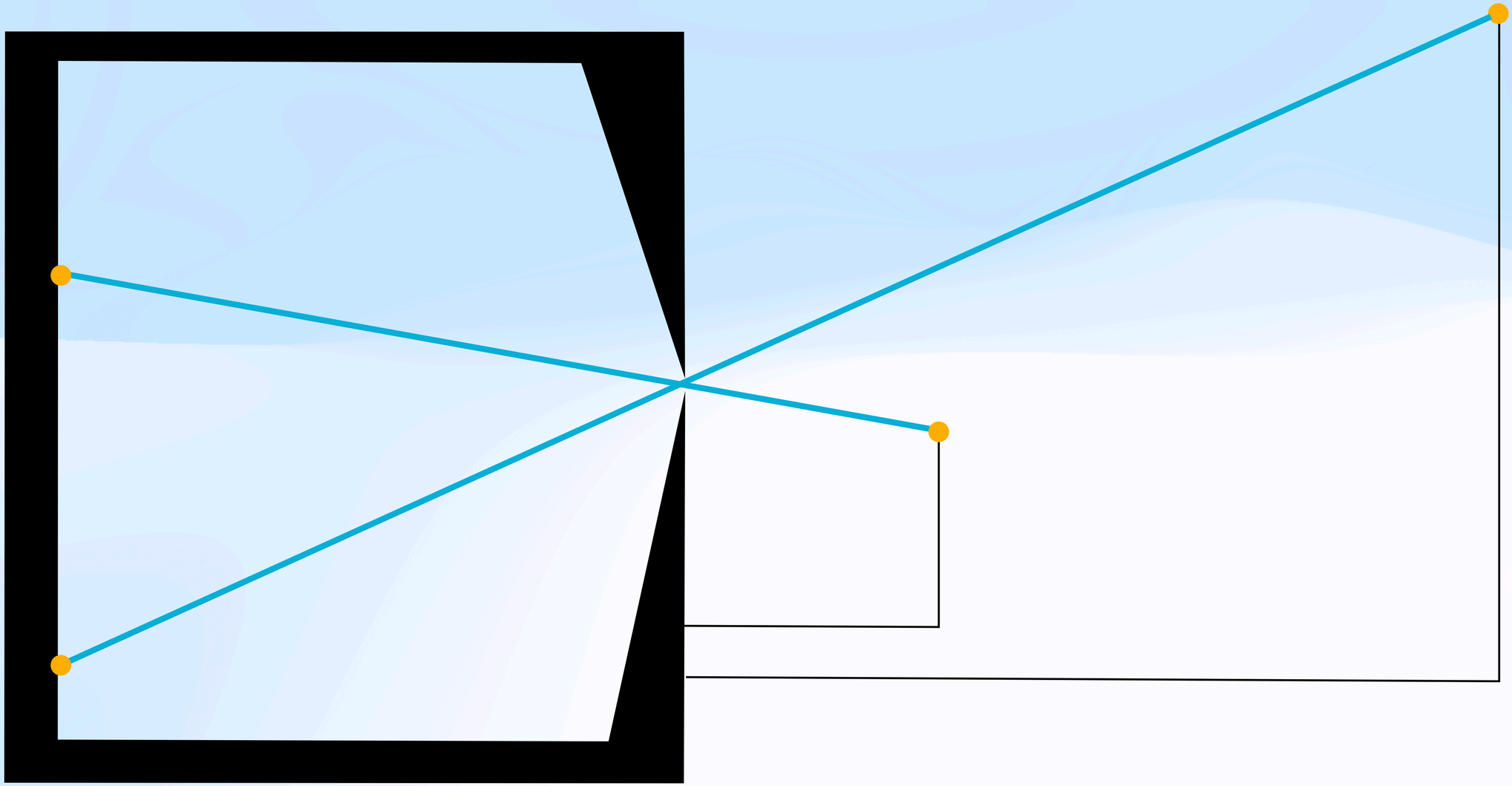
- COMPTEL real: 3°–5°
- COSI 2025+: ~2°
- **Propuestas AMEGO/e-ASTROGAM: 1°–2° (teórico)**



Increase resolution using numerical algorithms, will make feasible long term mission based on current state of the technology

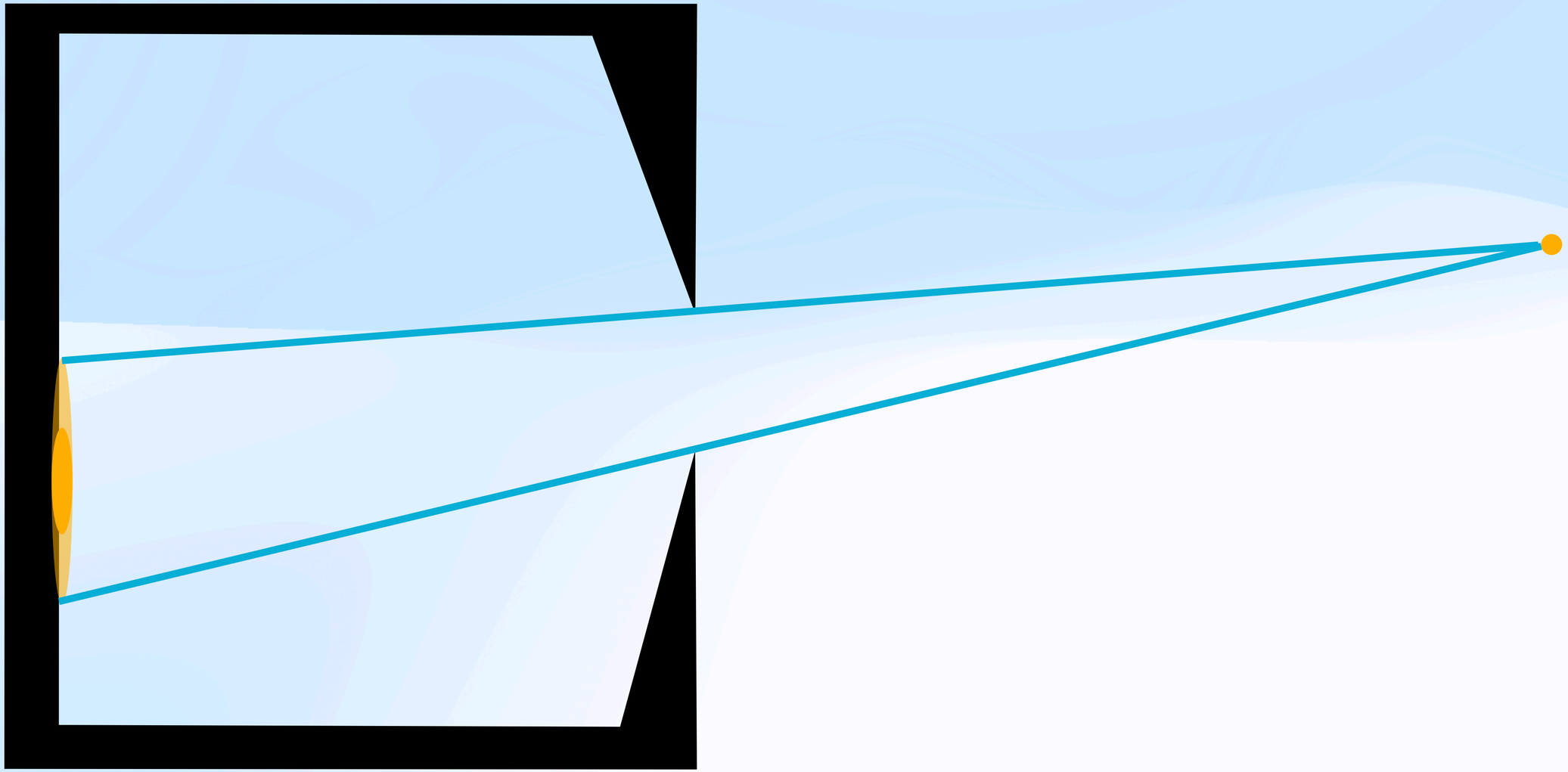
Pinhole detector: A line is the unambiquity

High resolution at the cost of limiting the field of view and reduce statistics.



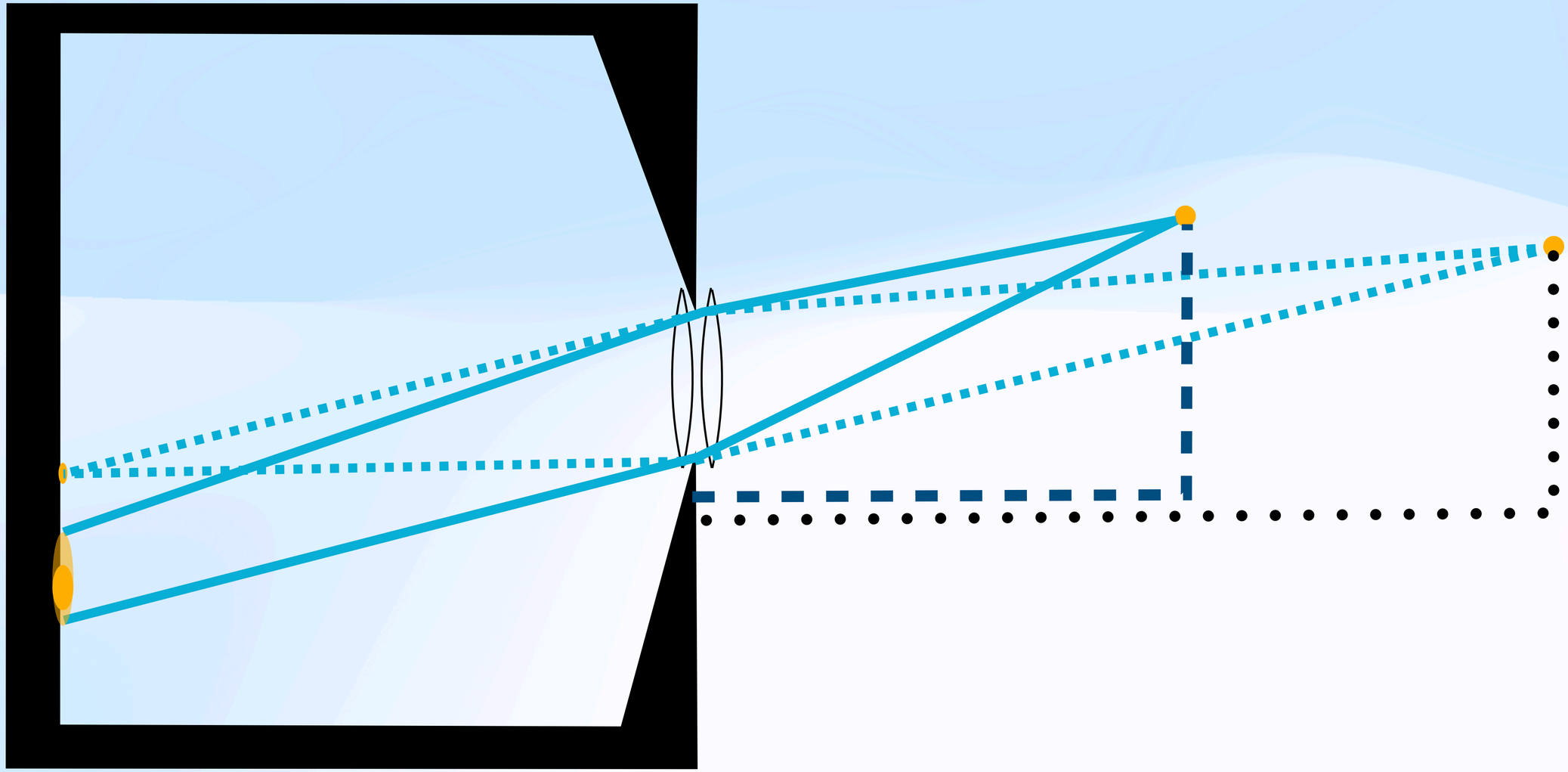
Large aceptance detector: A cone is the unambiquity

Large statistis low resolution

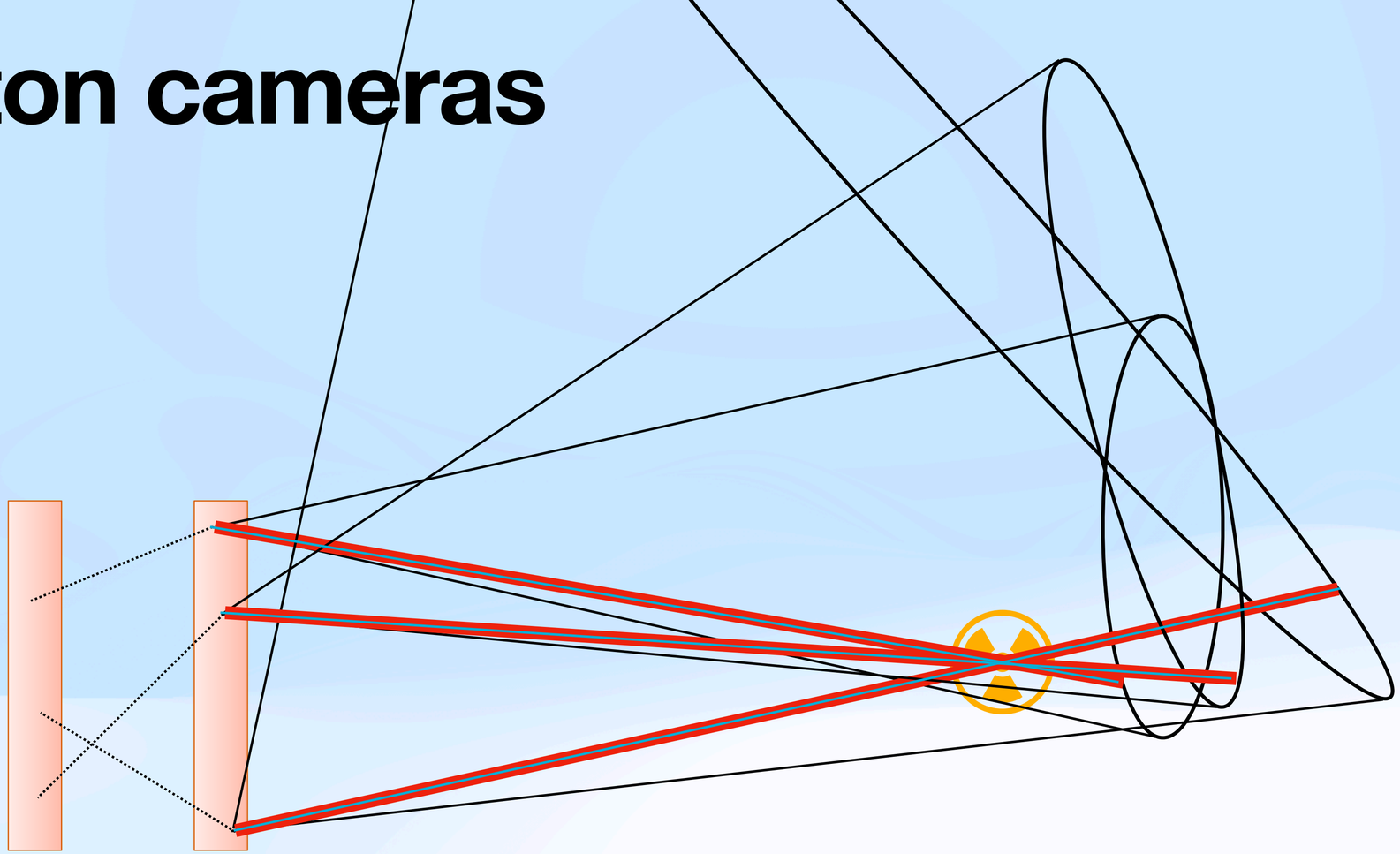


No lenses availables in radiation detector

Lenses are not an option in photons



Compton cameras

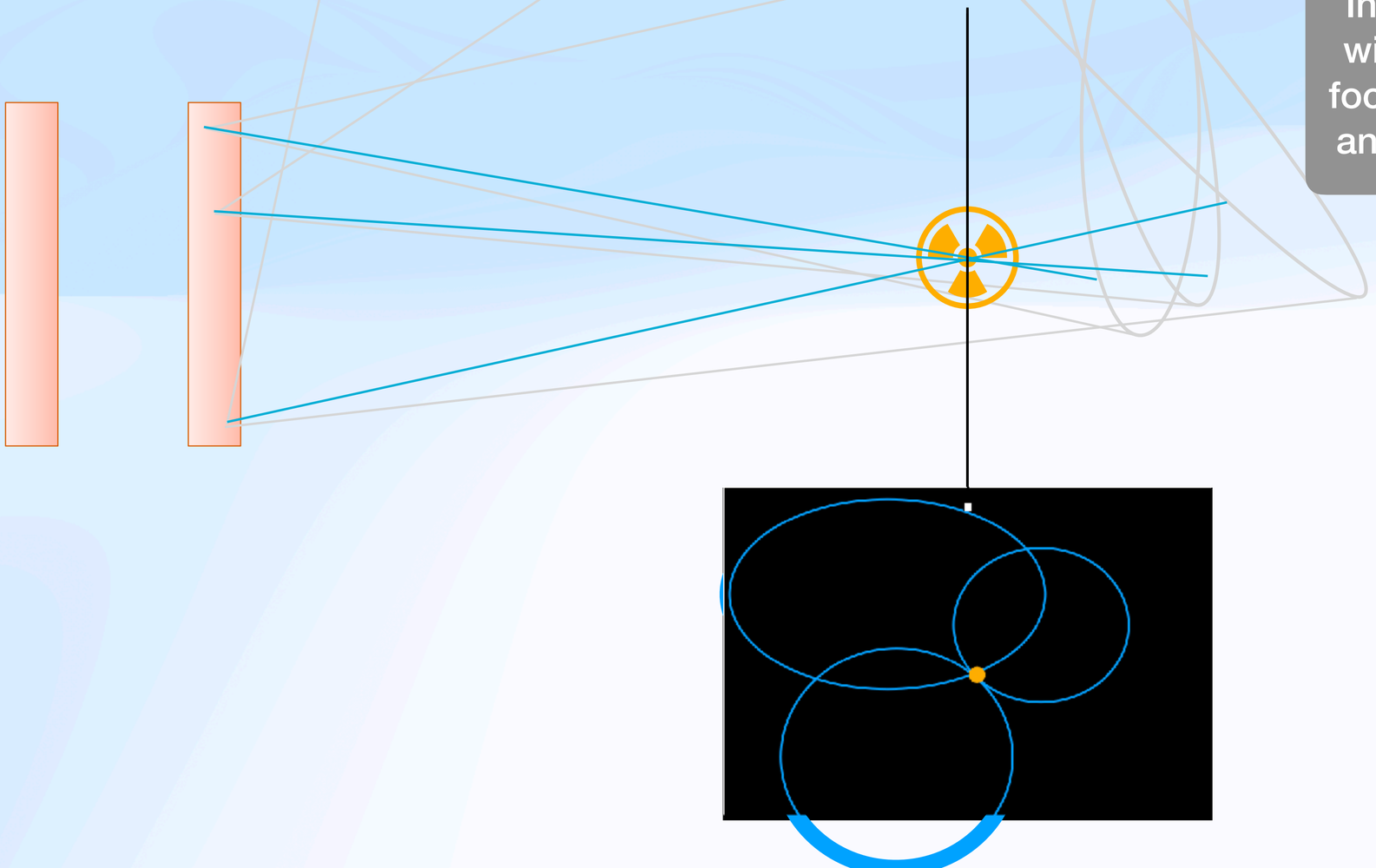


Compton Cameras

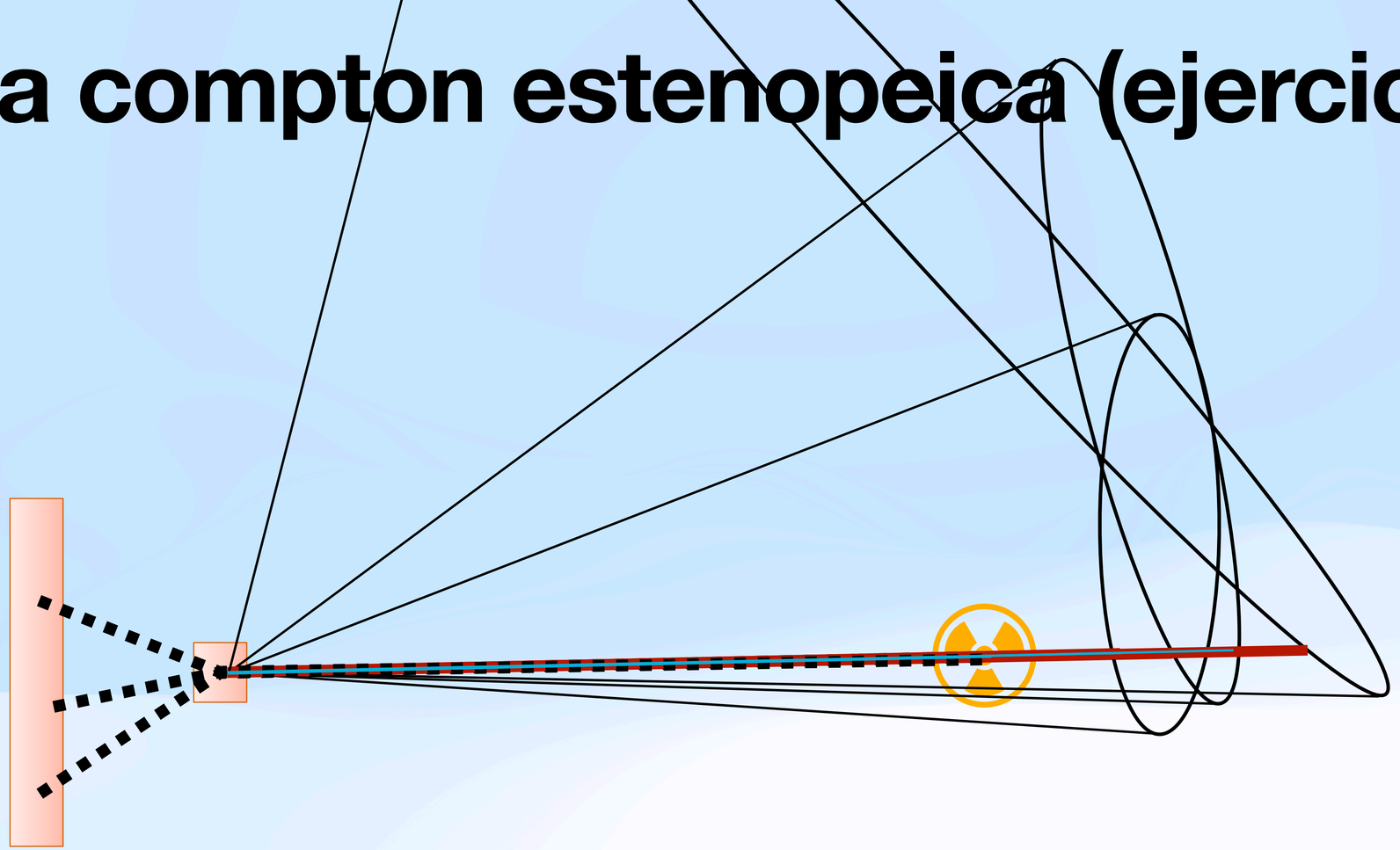
Focalization efect

- Needs to know focal plane

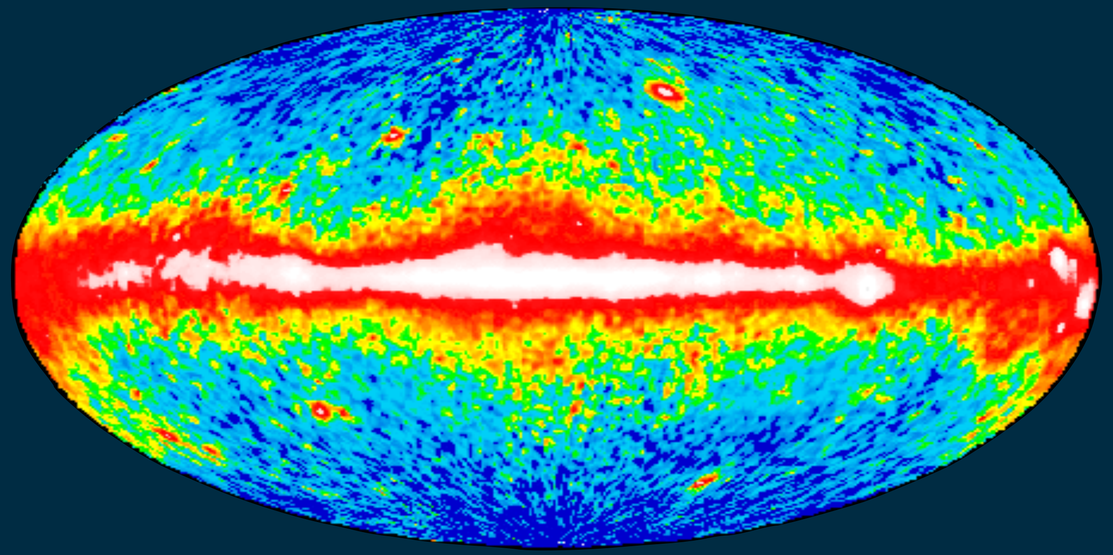
Increase the statistics comes with a cost, need to know the focus of the system. This is not an issue when observing stars



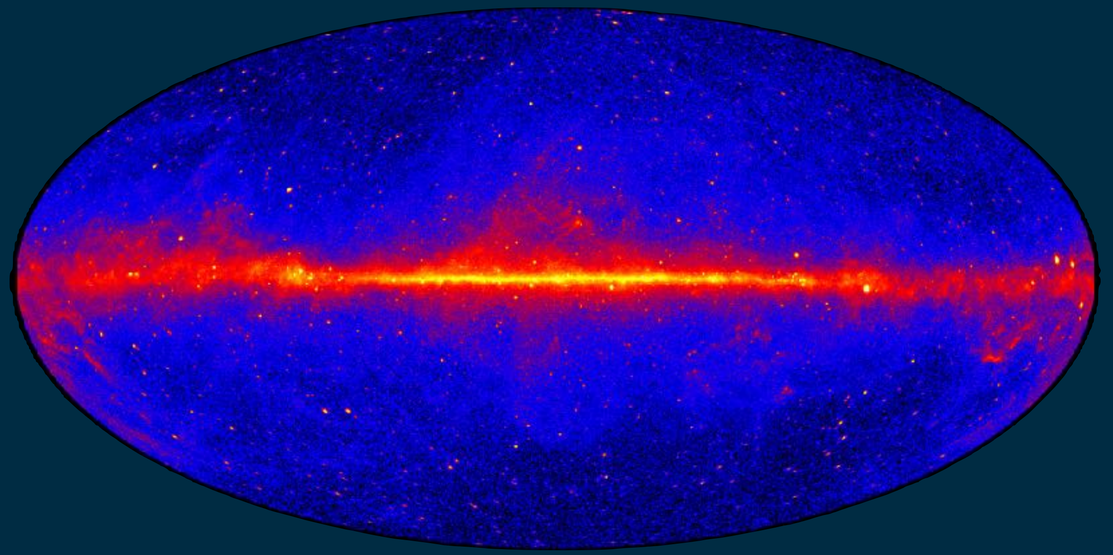
Cámara compton estenopeica (ejercicio mental)



As an exercise this problems allows to explore more refined segmentation devices based in numeric methods



Low resolution low energy gamma map



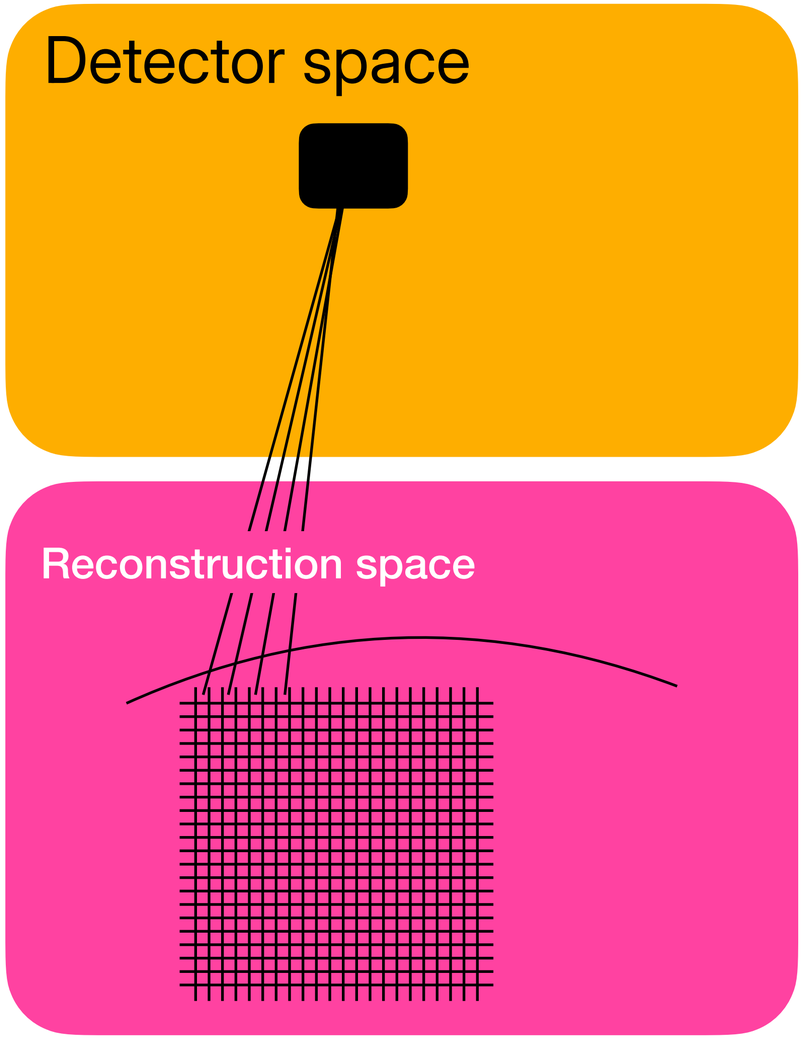
High resolution energy gamma map

Background, difusion, spots, are not accesible in low energy range

Time series (rare events) and directionality are other goals

Signal/data processing is the key of the innovation

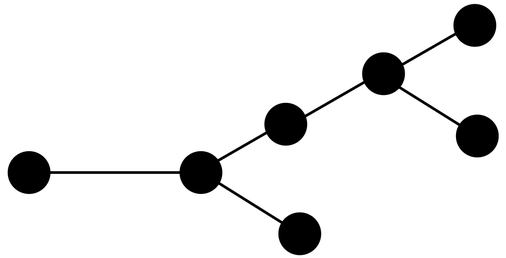
Signal processing in traditional sensors looks for cartesian grids, angles are not preserved due to the nature of the sensors itself



Traditional approaches:

- Rely on Cartesian geometry to reconstruct **signal** trajectories.
- Struggle with angular uncertainty and sparse data.
- Sensitive to translations and rotations, especially in airborne or space platforms.
- Good for high spatial resolution sensors (small angles limited range).
- Does not scale for large angular field of view

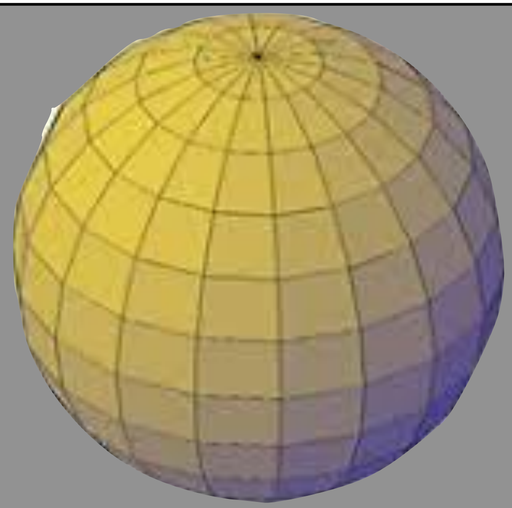
Graphs as a data relation



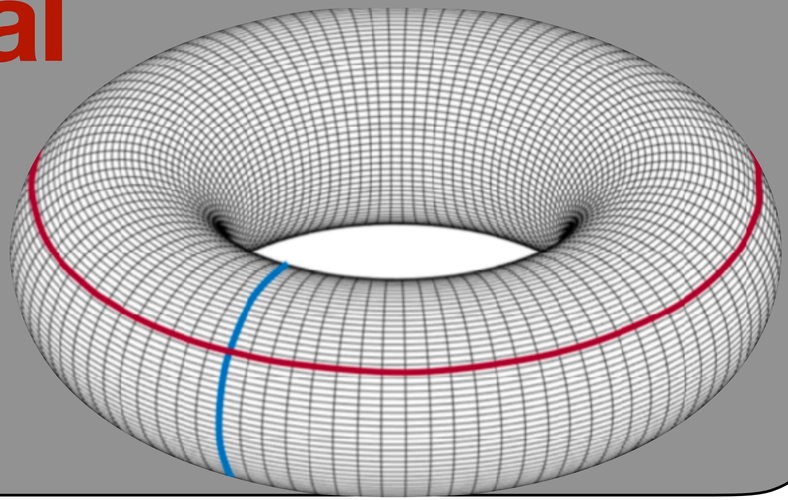
- *Points*
- *Coordinates*
- *Information (usually scalar)*

We model the detector space as a geometric graph, associating points with scalar responses. This geometry-as-graph view is particularly well suited for Transformer-based architectures.

Spherical



Thoroidal



Graphs as a data relation

Armonical Decomposition

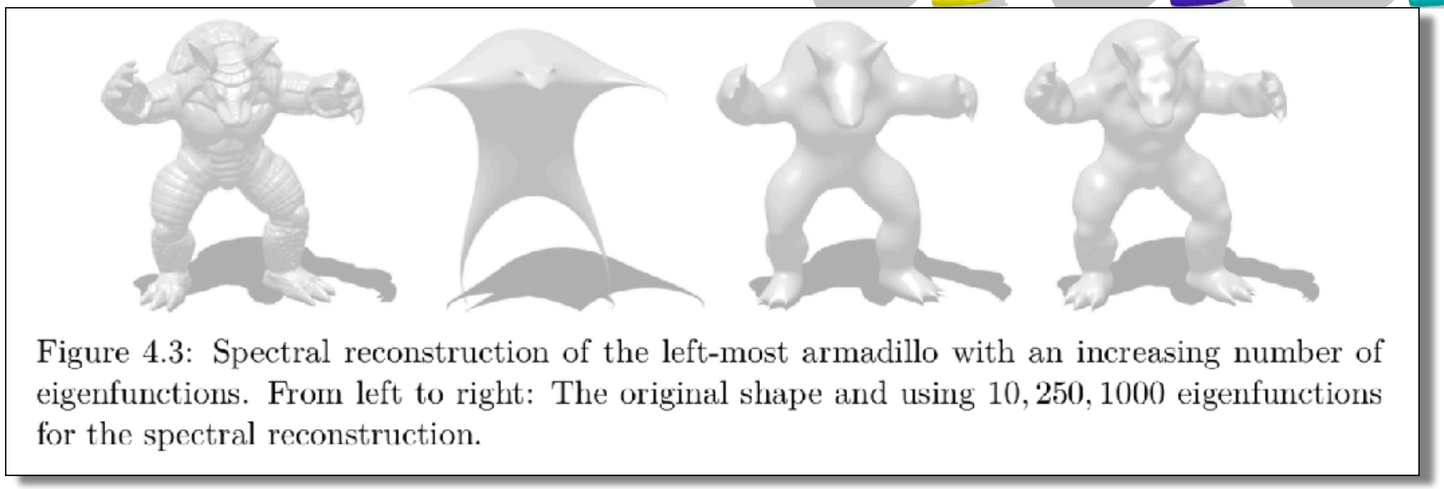
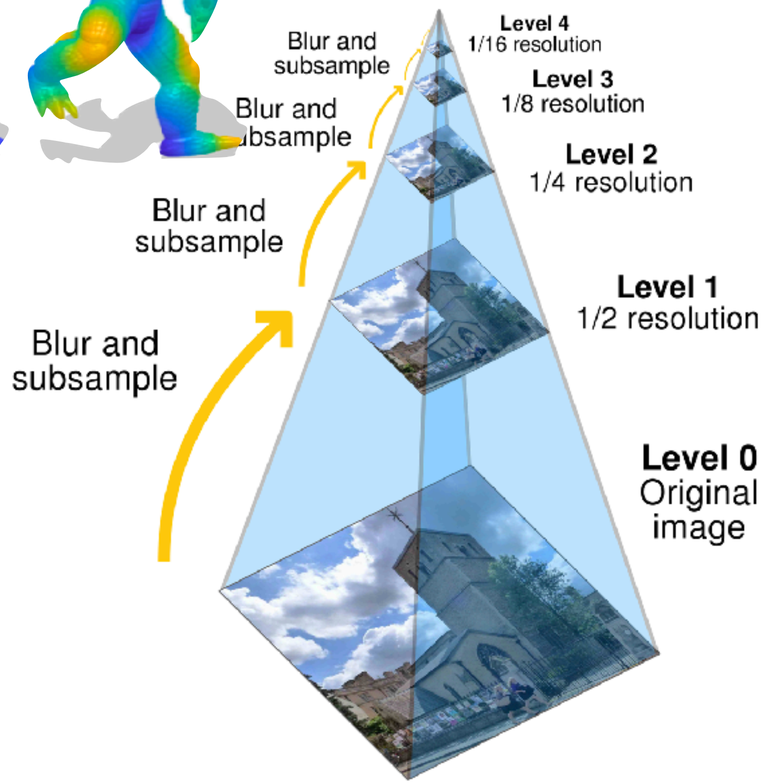


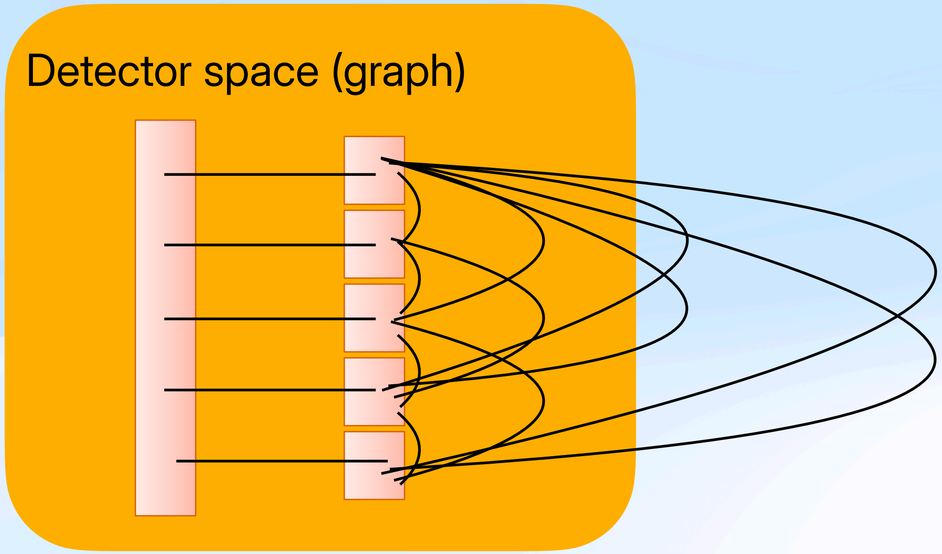
Figure 4.3: Spectral reconstruction of the left-most armadillo with an increasing number of eigenfunctions. From left to right: The original shape and using $10, 250, 1000$ eigenfunctions for the spectral reconstruction.

Continuous Correspondence of Non-Rigid 3D Shapes

Zorah Lähner



Multi-pinhole approach
Information is stored as an HOLOGRAM



Noise reduction

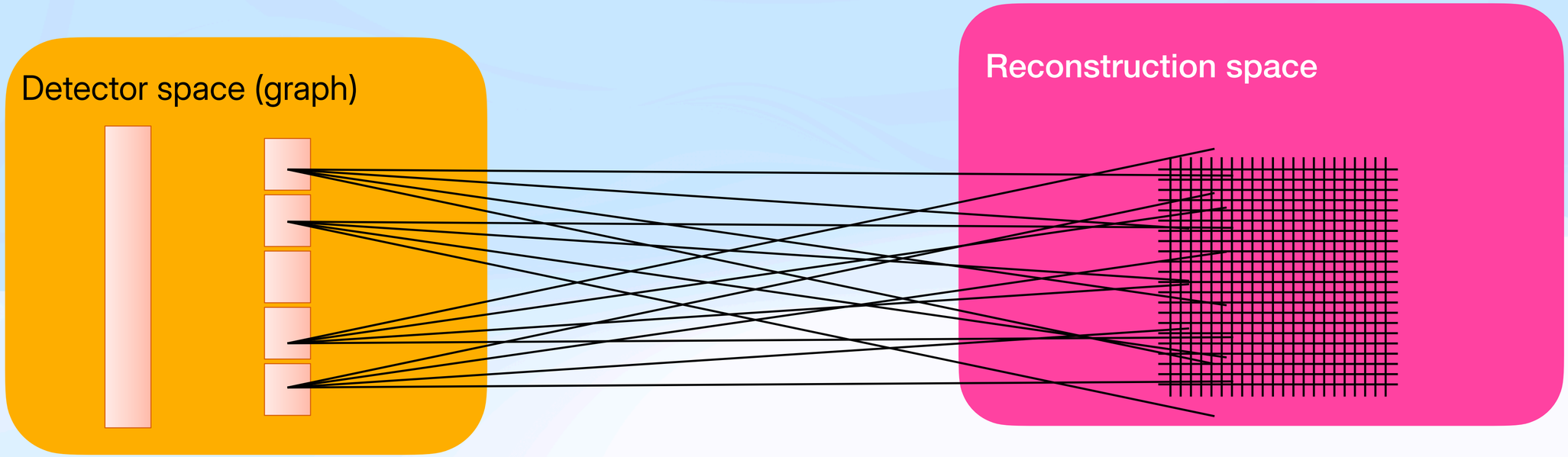
Signal correction (tunning)

Reduce compton correlation

Number of connections grows as N!, so decimation and lowering order the problem is part of the issues to be able to get results

Multi-pinhole approach

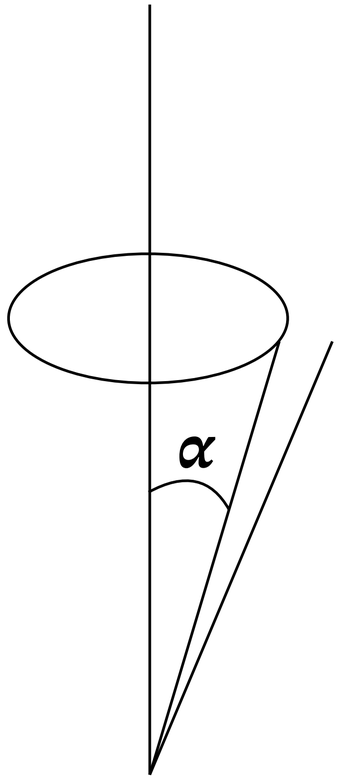
Information is delivered as an HOLOGRAM



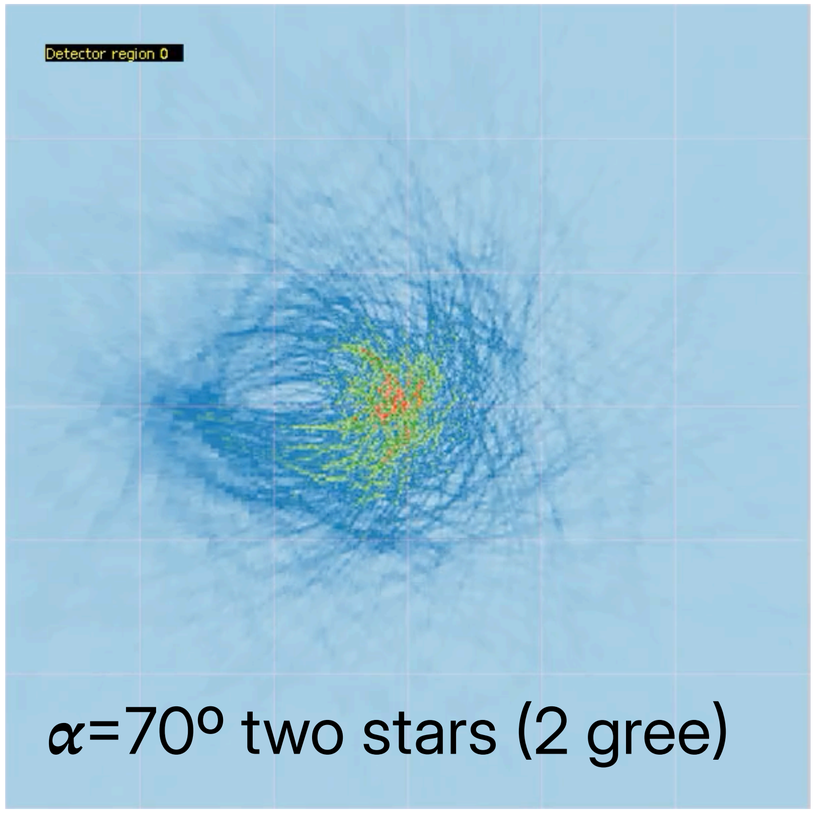
Number of connections grows as N!, so decimation and lowering order the problem is part of the issues to be able to get results

Noise signal reduction

Increase resolution



α=70º two stars (2 gree)



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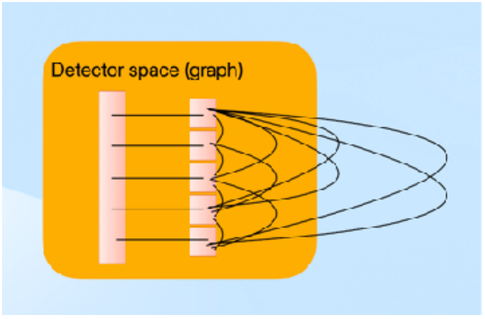
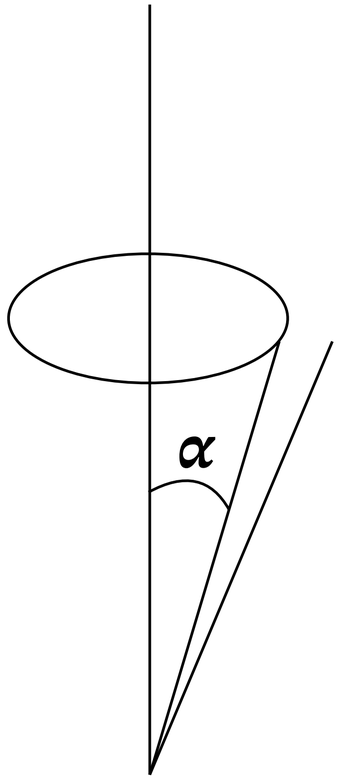
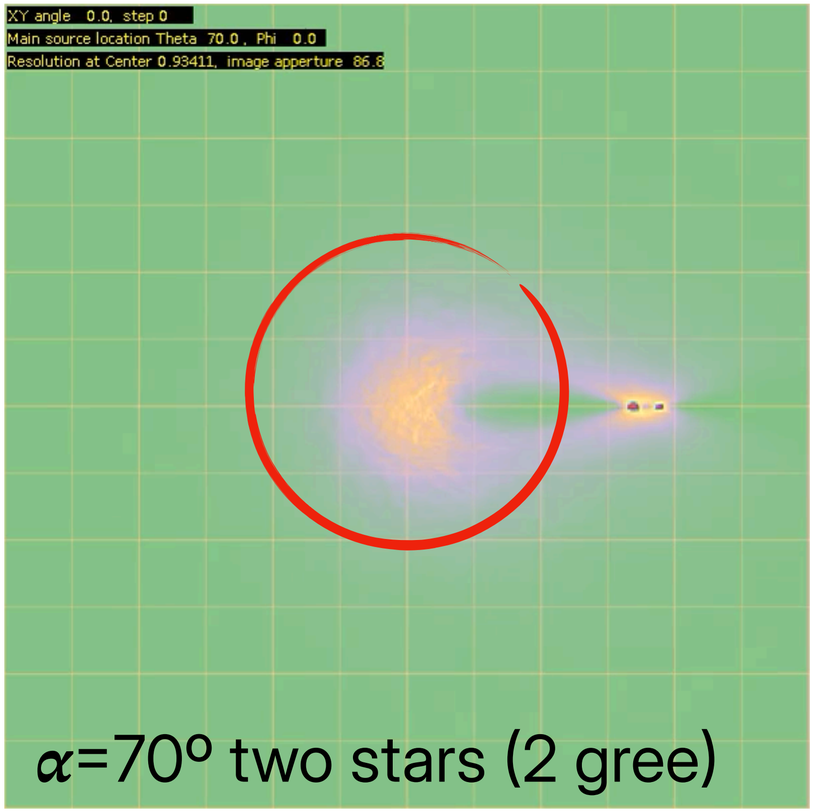
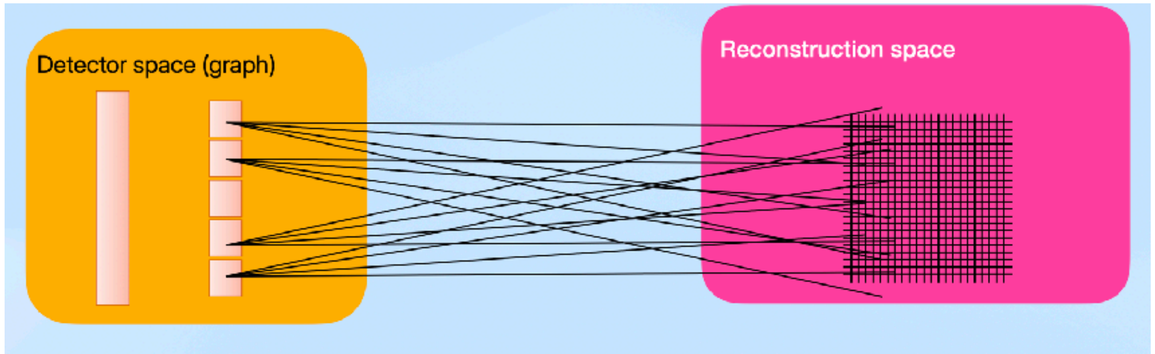




α=45º two stars (2 gree)



α=70º two stars (2 gree)

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Summary

Novel approach of particle detectors using transformers

- Preliminary results shows noise reductions about 20%
- Projection algorithms are conducted by transformers Increase of a factor 3-4 in the resolution (as a 2D proble this could achieve to a factor 10)
- Generative noise reduction based on the full scene.
- Combined noise reduction with transforemer projection is the current task, and the optimistic values could achieve another factor 3-4 in resolution
- Outgoing temporary series.