

Towards ARCTIS: The All-sky Recoil-electron and Compton-photon Tracking Imager and Spectrometer

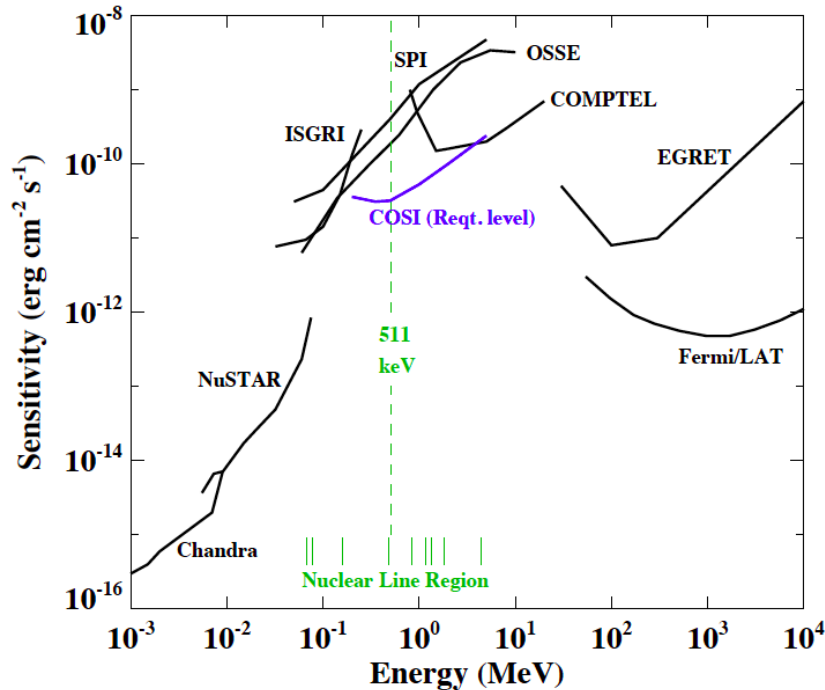


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Science Goal

Fill the MeV sensitivity gap



A future large gamma-ray mission should improve sensitivities by at least a factor of 10 over COSI to look at:

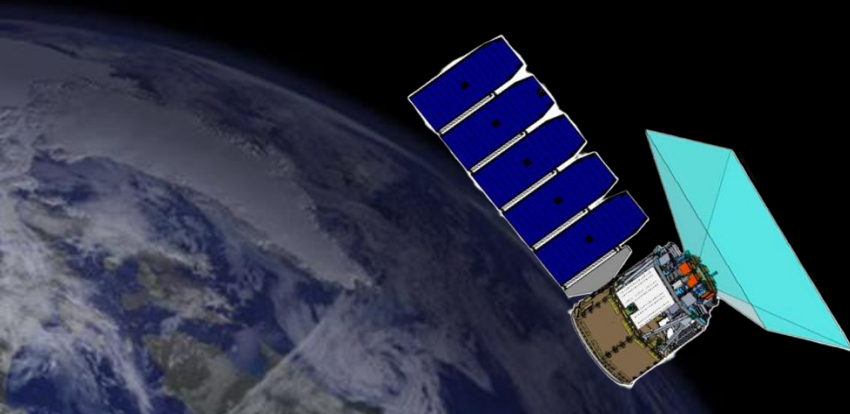
- Nucleosynthesis & chemical evolution
- Origin of galactic positrons
- Multi-messenger transients
- Dark matter search
- Strong-field QED & jets
- and many, many more

Let's build a SUPER-COSI

Orbit, shield, and boom

COSI

- Low-earth equatorial
- Heavy BGO shield on bottom to block atmospheric gamma-rays
- Field-of-view: 25% of sky



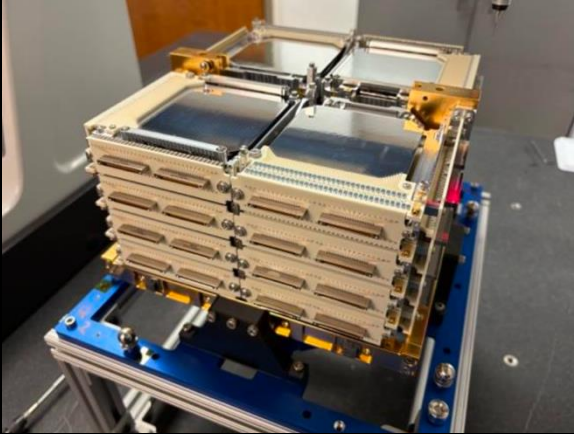
SUPER-COSI

- L1 or cis-lunar orbit
- Only charged particle shield and instrument on boom to avoid satellite activation
 - Field-of-view: 75%+ of the sky

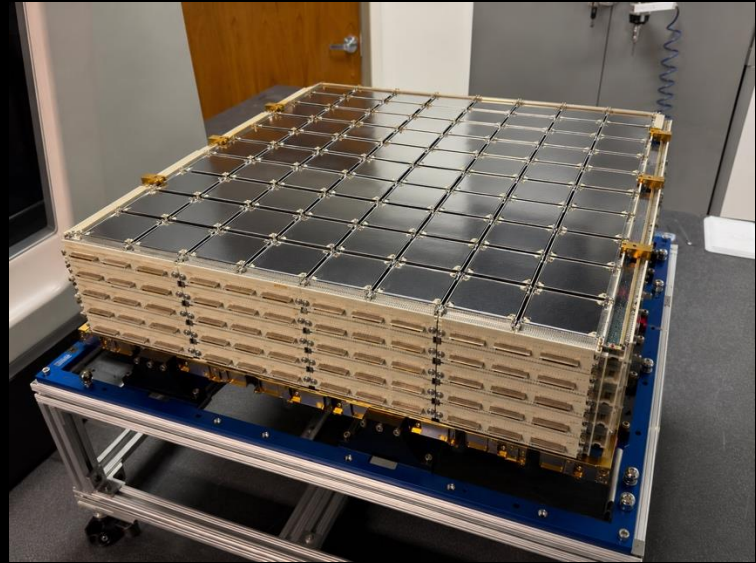


Let's build a SUPER-COSI

Let's make it **LARGE!**



Real COSI flight detectors
(2x2x4 stack)

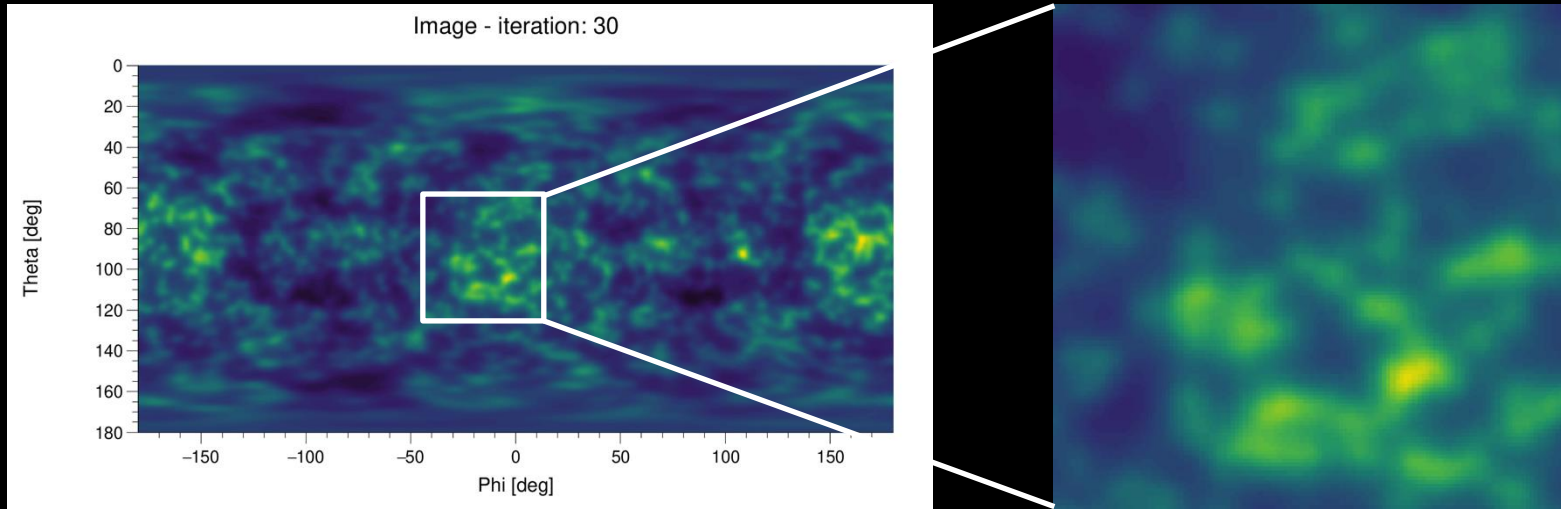


AI generated 8x8x5 stack of SUPER-COSI
(please ignore the missing cold fingers and
unreasonable electronics)

Let's image with SUPER-COSI

Let's check what we will see

Let's assume we are 10x as sensitive as COSI and thus see $\sim x20$ more sources (~ 1000)

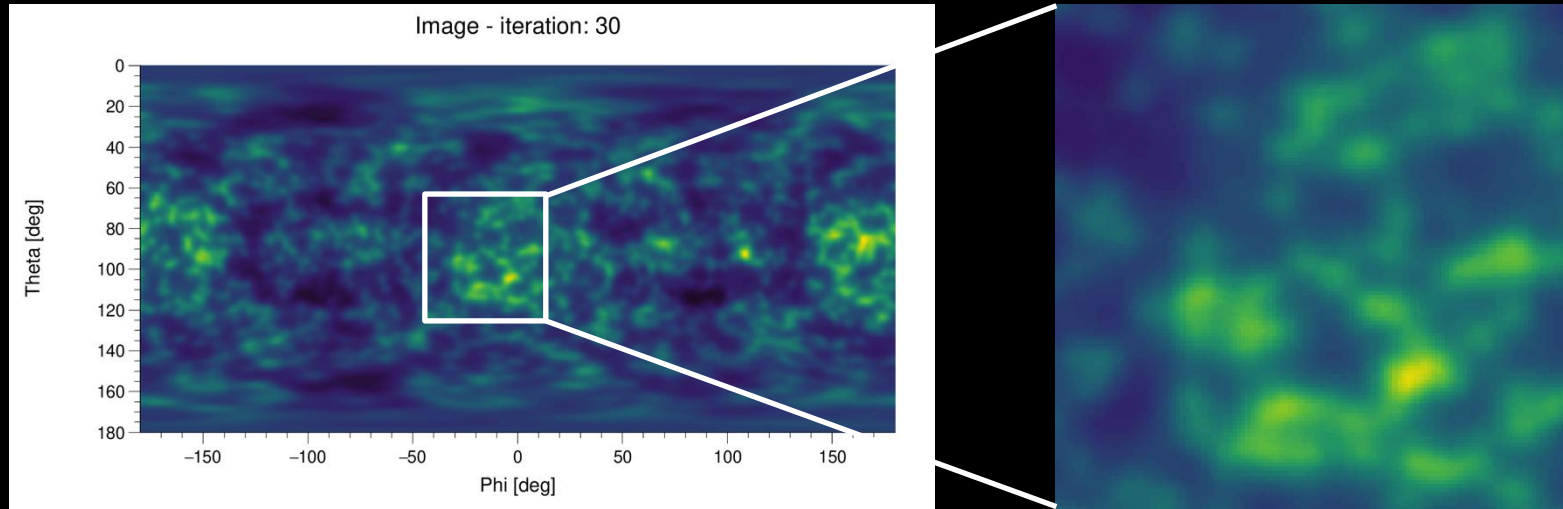


Simplified simulations: 1000 equally strong sources
without background

Let's image with SUPER-COSI

Let's check what we will see

Let's assume we are 10x as sensitive as COSI and thus see ~ 20 more sources (~ 1000)

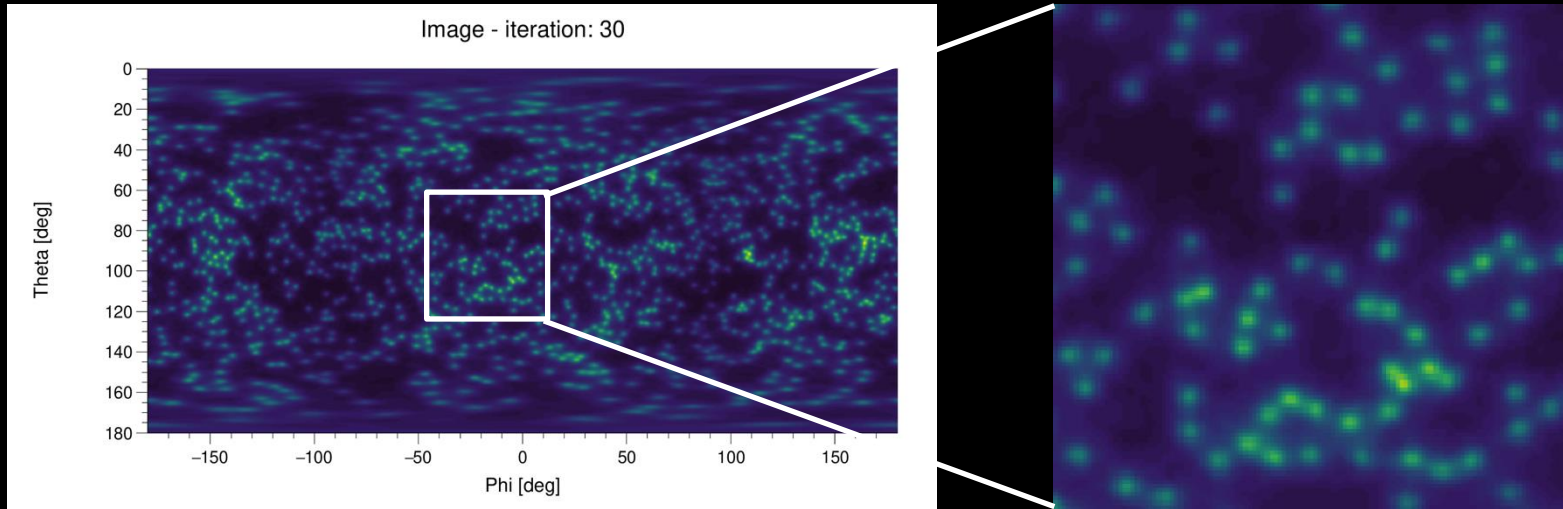


This is not a factor of 10 sensitivity improvement!

We hit the source confusion sensitivity limit before we reached the statistics sensitivity limit!

Let's image with something better (ARCTIS)

Same simulation with 1000 sources at same position
using next-generation (ARCTIS) detectors resulting in better response



That would be a factor of 10!

What happened earlier?

Why “just make it larger” does not always work

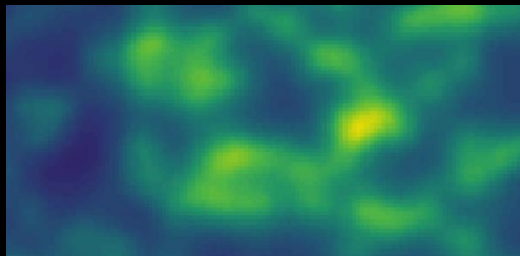
Sensitivity is limited by

Statistics

$$S = \frac{z^2 + z\sqrt{z^2 + 4N_B}}{2A_{eff} T_{eff}}$$

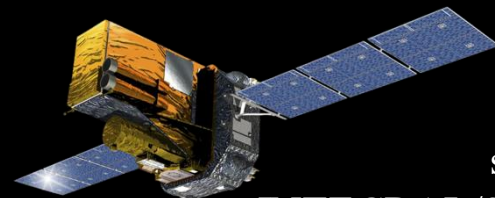
- Standard formula to estimate sensitivity,
- Implies sensitivity improves with size = effective area

Source confusion



- Compton telescope response is complex
- This limit needs full imaging to see its effect

Systematics

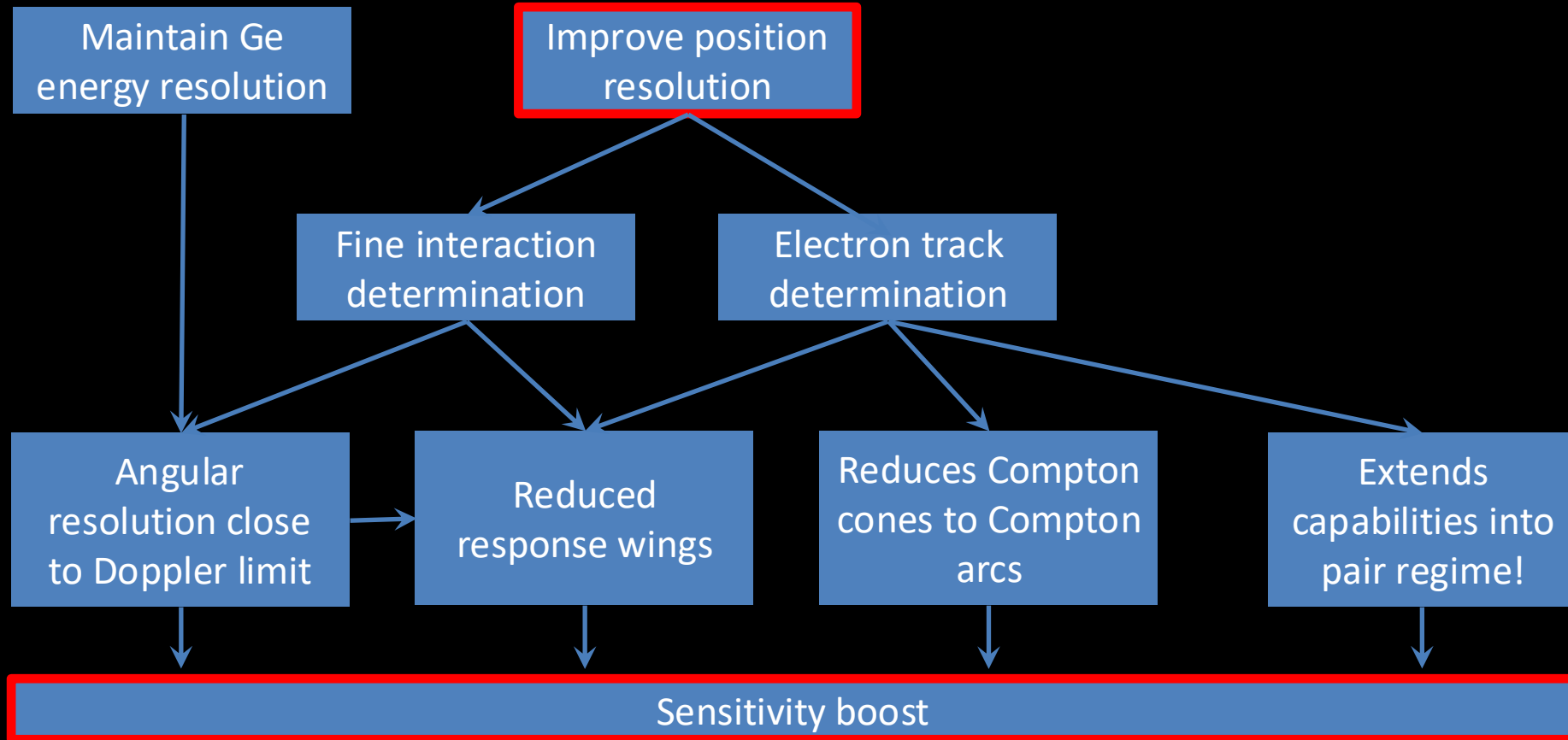


see
INTEGRAL/SPI

- Sensitivity limited by complexity to determine a model which covers full variability of response & background

Any mission claiming a big significance jump needs to look into all 3

How to improve COSI's response



The enabling technology: ARCTIS detectors

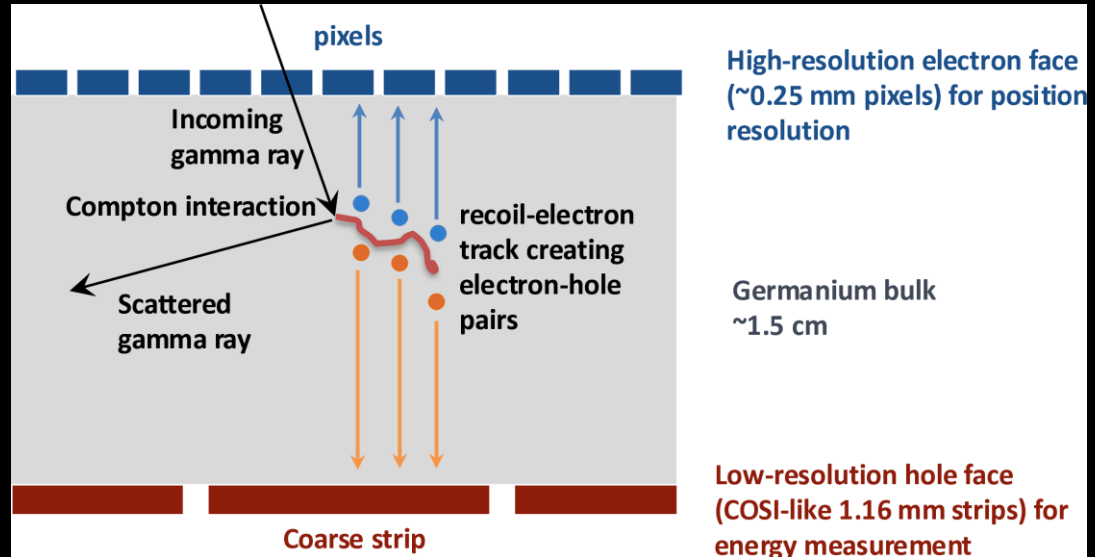
The challenge:

We cannot just make COSI's strips finer:

- Would result in many small energy deposits
- Deterioration of energy resolution, scales with $\sim\sqrt{N}$
- Energy lost below thresholds

Solution: Dual-face Ge detector

- High-resolution side measures localization
- Low-resolution side measures energy including waveform sampling to resolve multiple interactions



The ARCTIS concept

Sensitivity gain (full mission,
background limited)

Orbit close to Earth but beyond the radiation belts (e.g. L1 or cis-lunar orbit): no Earth occultation, no SAA, no BGO just plastic shield, instrument on boom: FoV > 75% sky	x1.7
Increase effective area (4x4x5 detectors = Probe mission, 8x8x5 = Flagship) compared to COSI	x2-x4
Dual-face Germanium pixel / strip detectors:	
(1) Strip-side: Maintain or slightly improve COSI's energy resolution: 2-3 keV FWHM per Compton interaction	x1
(2) Pixel-side: Enable high-resolution interaction localization	
- Enable close to Doppler-limit angular resolution (down to below 1 degree @ 2 MeV)	x2
- Enables electron tracking starting around 0.5 MeV	x2-x3

x10-40 improvement



The Technology Development Plan

Phase 1	Prototype with small pixel patches (5x6 pixels) readout with COSI electronics
↑ submitted as APRA	Prove we can build a dual-face detector, read it out, proof angular resolution scales with position resolution / pixel size, measure electron tracks
Phase 2	Full single-detector prototype with triple ASIC readout: 1 cold & 1 warm ASIC for pixel side, 1 hot ASIC with waveform-sampling for strip side
	Prove bump bonding of ASICs on Germanium, ASIC themselves, get full detector working
Phase 3	Iteration on the above plus build a full flight-ready 5-stack prototype
	Prove we can scale and package, and survive environmental testing
Phase 4	Iteration on the above plus balloon-flight, pioneer-mission, etc.
	Test a small instrument on a space or near-space mission
Phase 5	Probe or Flagship mission to achieve 10-40 sensitivity improvement

Key Challenges for the Future

Challenges:

- Make the first working dual-face Germanium detector
 - Partnered with MIRION to deliver first detector if APRA is selected
- Custom 80-K low-noise, low-power readout ASIC across the roughly 100,000 fine-face channels
- Power extraction from the cold mass
- Ge/Si bond survival through thermal cycling
- Modularization & minimizing passive material

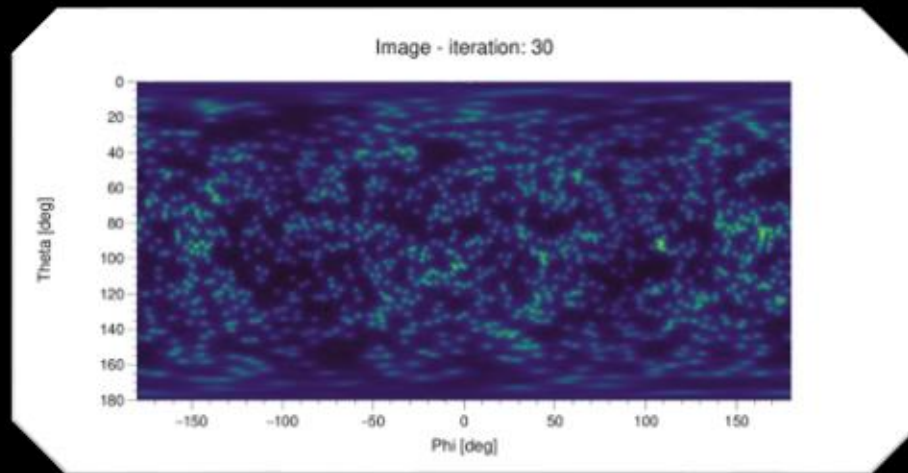
Other applications

- Single stack: Focal plane detector for a focusing gamma-ray mission (solar mission to look at solar flares or astrophysics mission to look at known point sources – both including polarization measurements)
 - Single or few stacks: High-resolution radioactive-element-mapper (including water via 2.2 MeV line) for a solar system body mission (from moon to far away)
 - Several 1-2 detector deep stacks with a coded mask: low-energy GRB detector measuring also polarization
- **COSI detectors can be applied similarly, just with a factor of 2-3 lower resolution**

Thank You!

ARCTIS:

FoV:	> 75% sky
Grasp:	up to x50 COSI
Energy resolution:	2-3 keV per interaction
Angular resolution:	down to < 1 degree
2-year sensitivity:	x10 or more than COSI



Just a resolution demonstration – a full sky simulations needs a supercomputer...