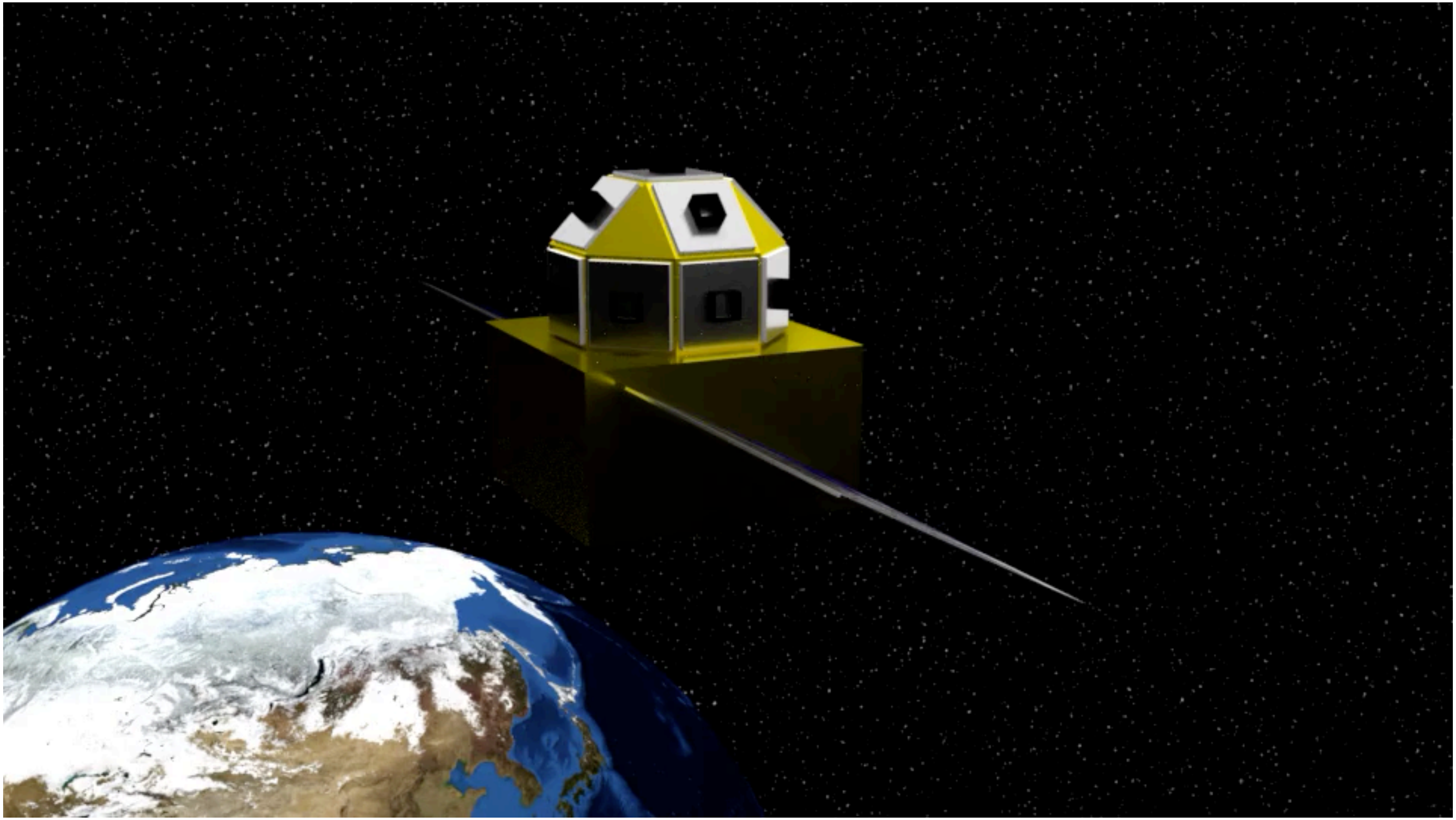
Daksha

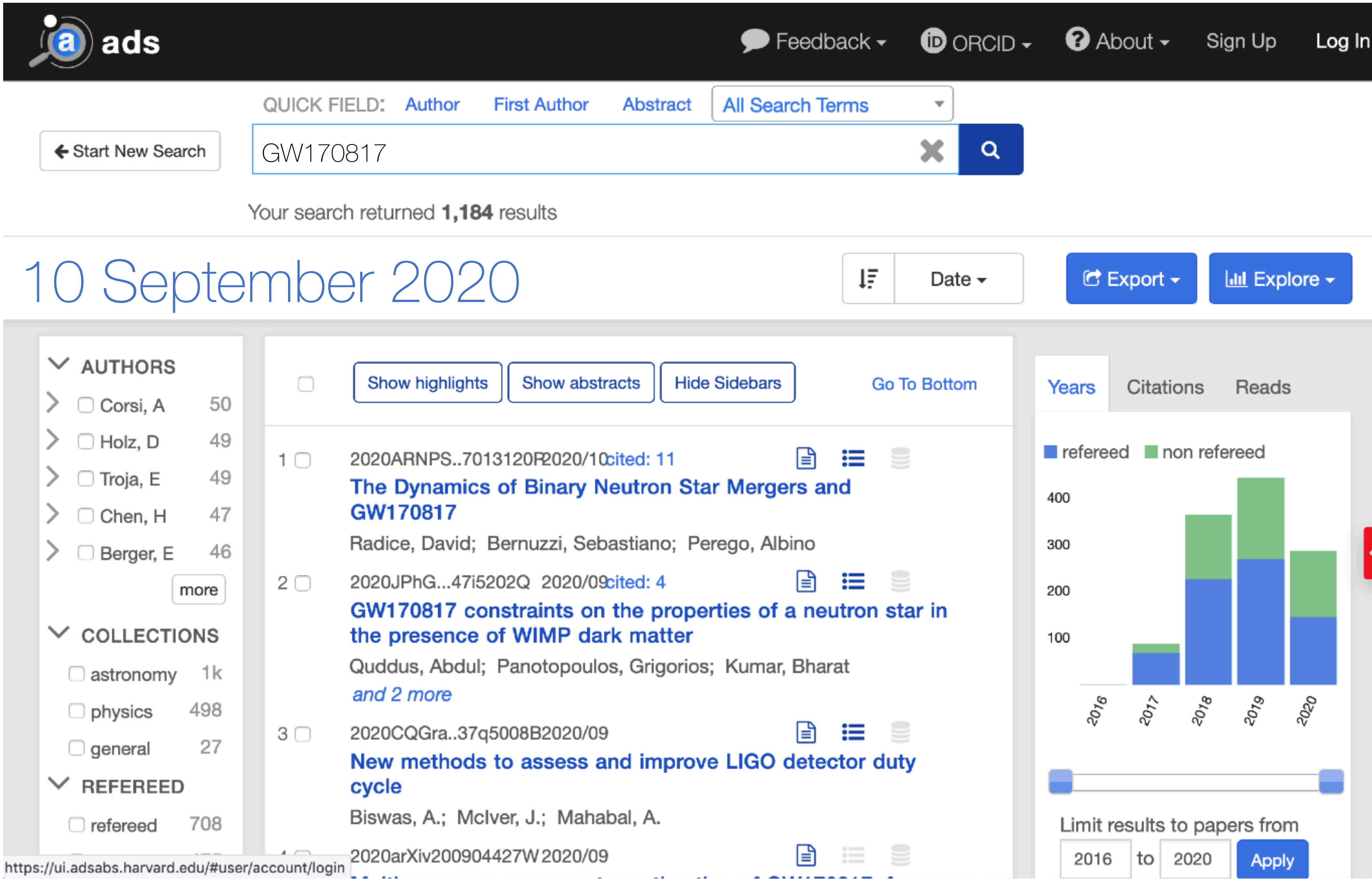


On alert for high energy transients

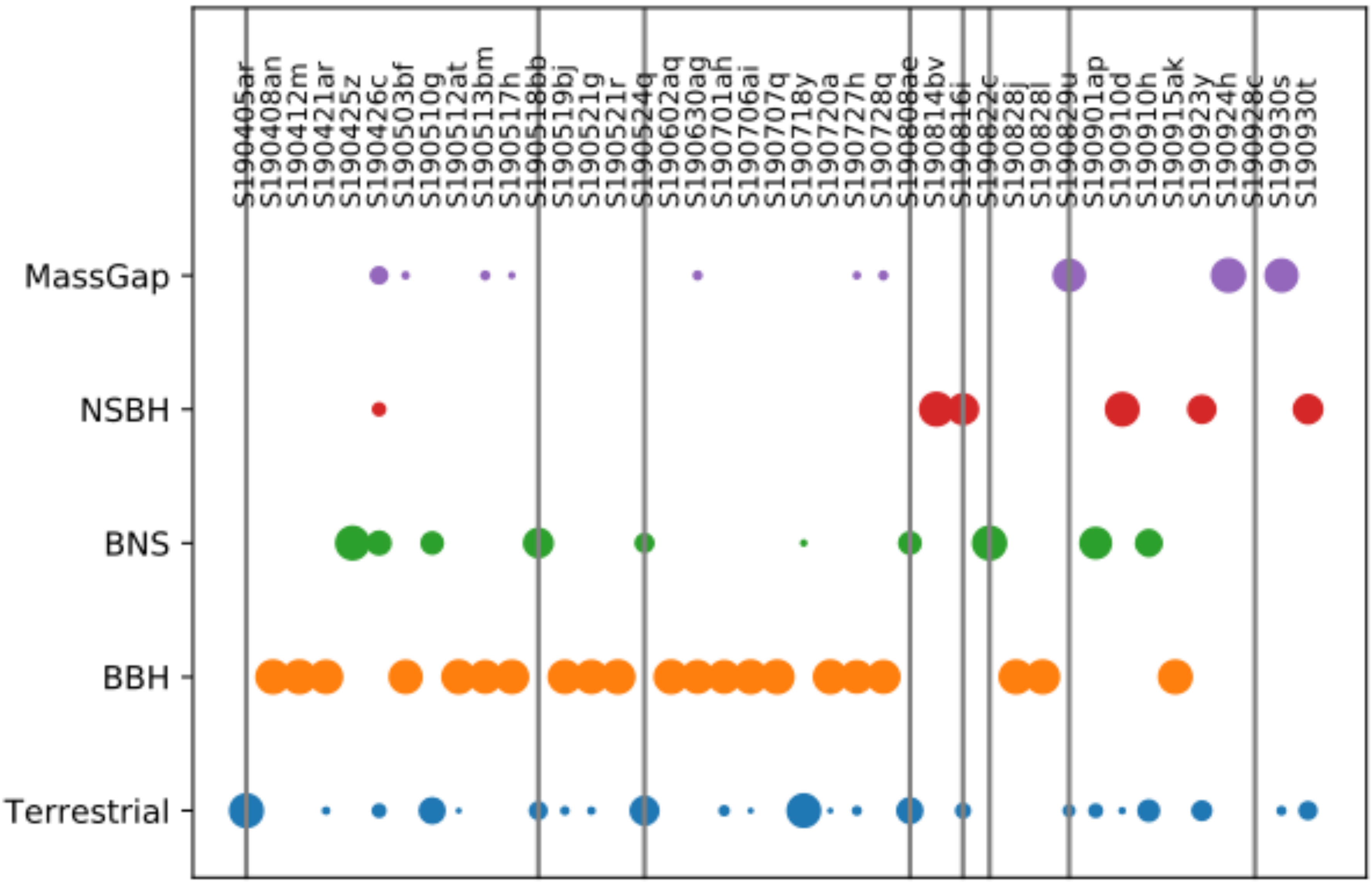
Background

- A mission to find high energy counterparts to GW sources

1120 days, 1184 papers…



O3a candidates



https://gracedb.ligo.org/superevents/public/O3/

O3a NS candidates

Name	Type	Distance (Mpc)	90% area (sq deg)	Counterpart
S190425z	99% BNS	156 ± 41	7461	No
S190426c	49% BNS, 13% NSBH, 24% Gap, 14% Terrestrial	377 ± 100	1131	No
S190510g	42% BNS, 58% Terrestrial	227 ± 92	1166	No
S190718y	2% BNS, 98% Terrestrial	227 ± 165	7246	No
S190814bv	100% NSBH	267 ± 52	23	No
GW170817	100% BNS	41	31	Yes

GW170817-like scaling

Name	Type	Distance (Mpc)	90% area (sq deg)	X-ray (10 keV-1000 keV)
S190425z	99% BNS	156 ± 41	7461	5e-8
S190426c	49% BNS	377 ± 100	1131	9e-9
S190510g	42% BNS	227 ± 92	1166	2e-8
S190718y	2% BNS, 98% Terrestrial	227 ± 165	7246	2e-8
S190814bv	100% NSBH	267 ± 52	23	2e-8
Fake event	100% BNS	500	–	5e-9
GW170817	100% BNS	41	31	7e-7

Scaling from Abott et al 2017 (Fermi + Integral +LVC)

Typical X-ray / Gamma ray sensitivity ~ few e-7 ergs/cm^2/sec

GW170817-like scaling

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Scaling from Abott et al 2017 (Fermi + Integral +LVC)

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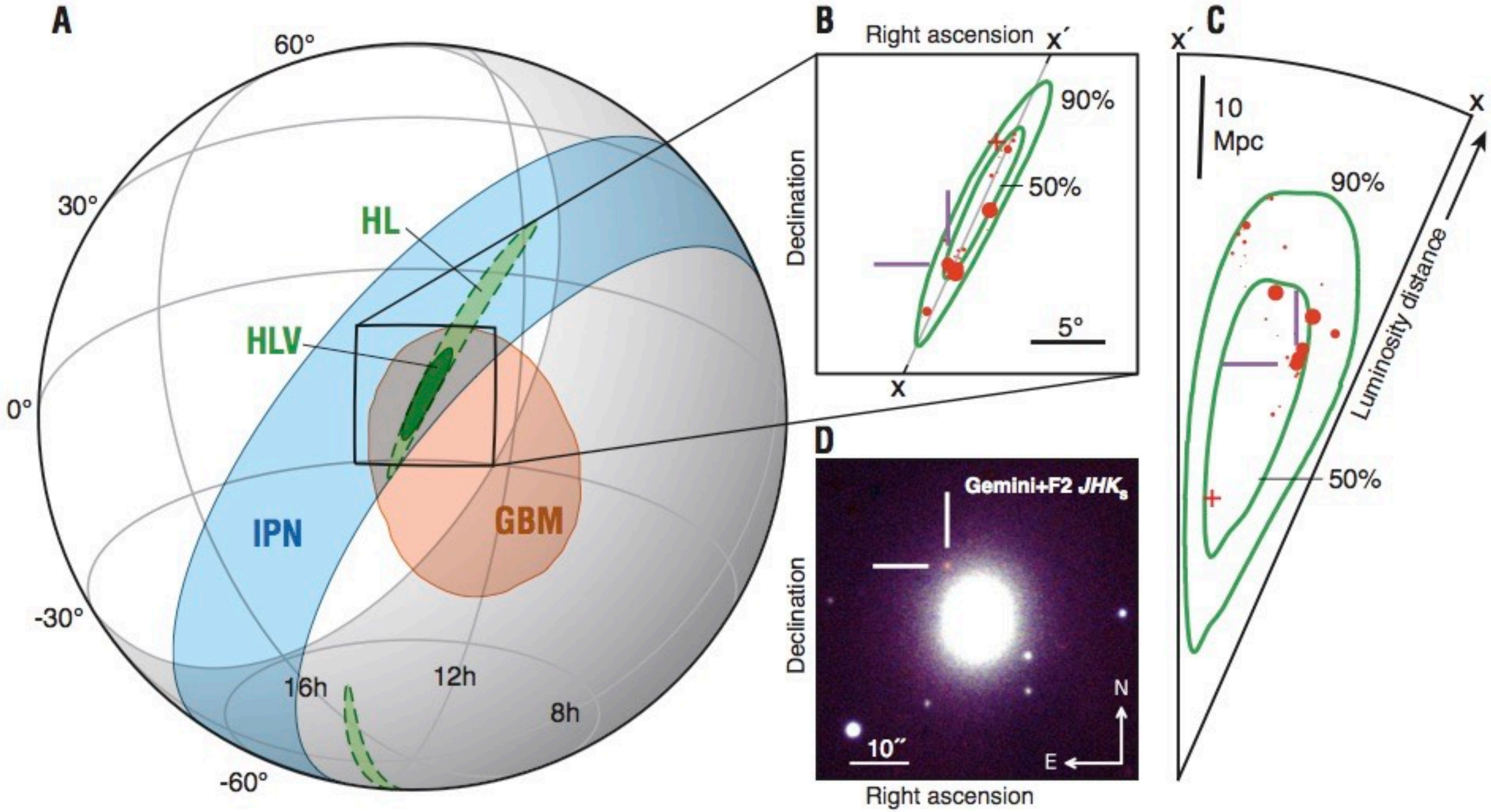
What's next?

Lessons from GW170817 + O3

GW170817: AstroSat

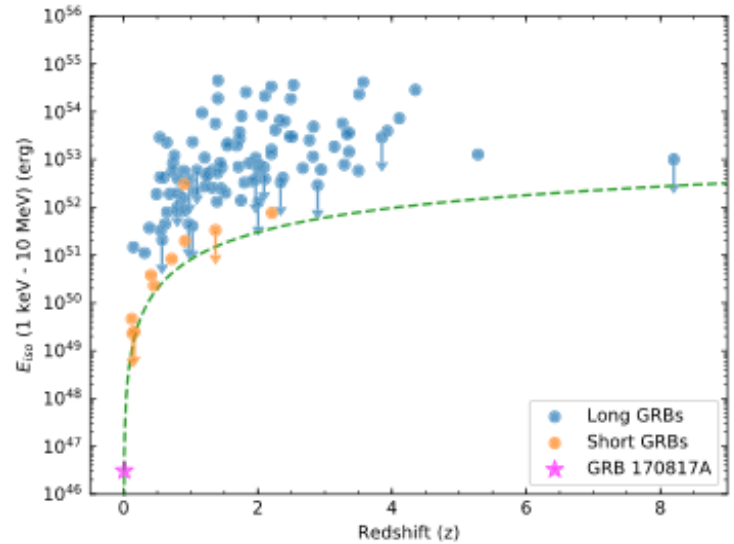


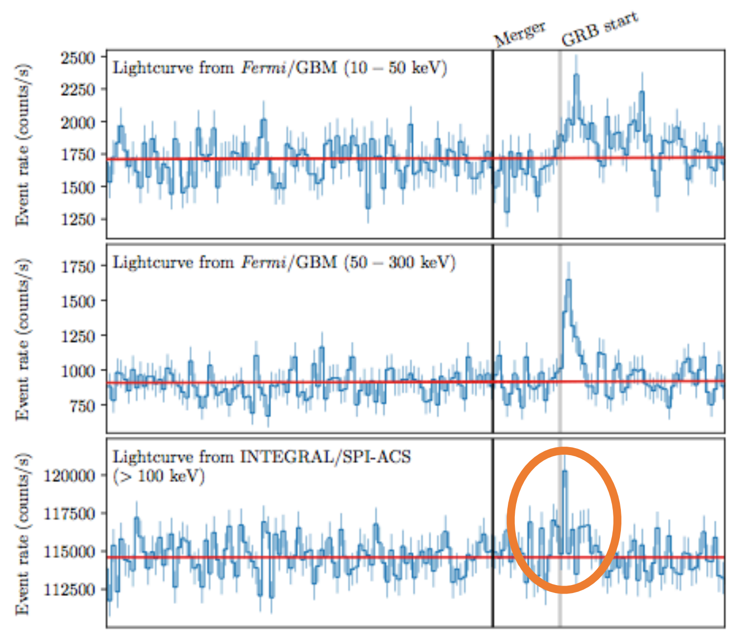
Lesson 1

Look at the entire sky at all times

New class of bursts !

- GRB was very faint: 3-4 orders of magnitude lower than SGRBs
  next will be fainter!
- Broadband: seen from few keV to hundreds of keV
- Missed by Swift, AstroSat, CALET…





Lesson 2

Need 10x higher sensitivity
as compared to current missions

Saw it. So what?

- Any thermal components?
- Primary emission mechanism?
- Spectral evolution?

Lesson 3

Wide spectral band

Requirements

Order of magnitude higher sensitivity

(Large area, lower noise, background rejection)

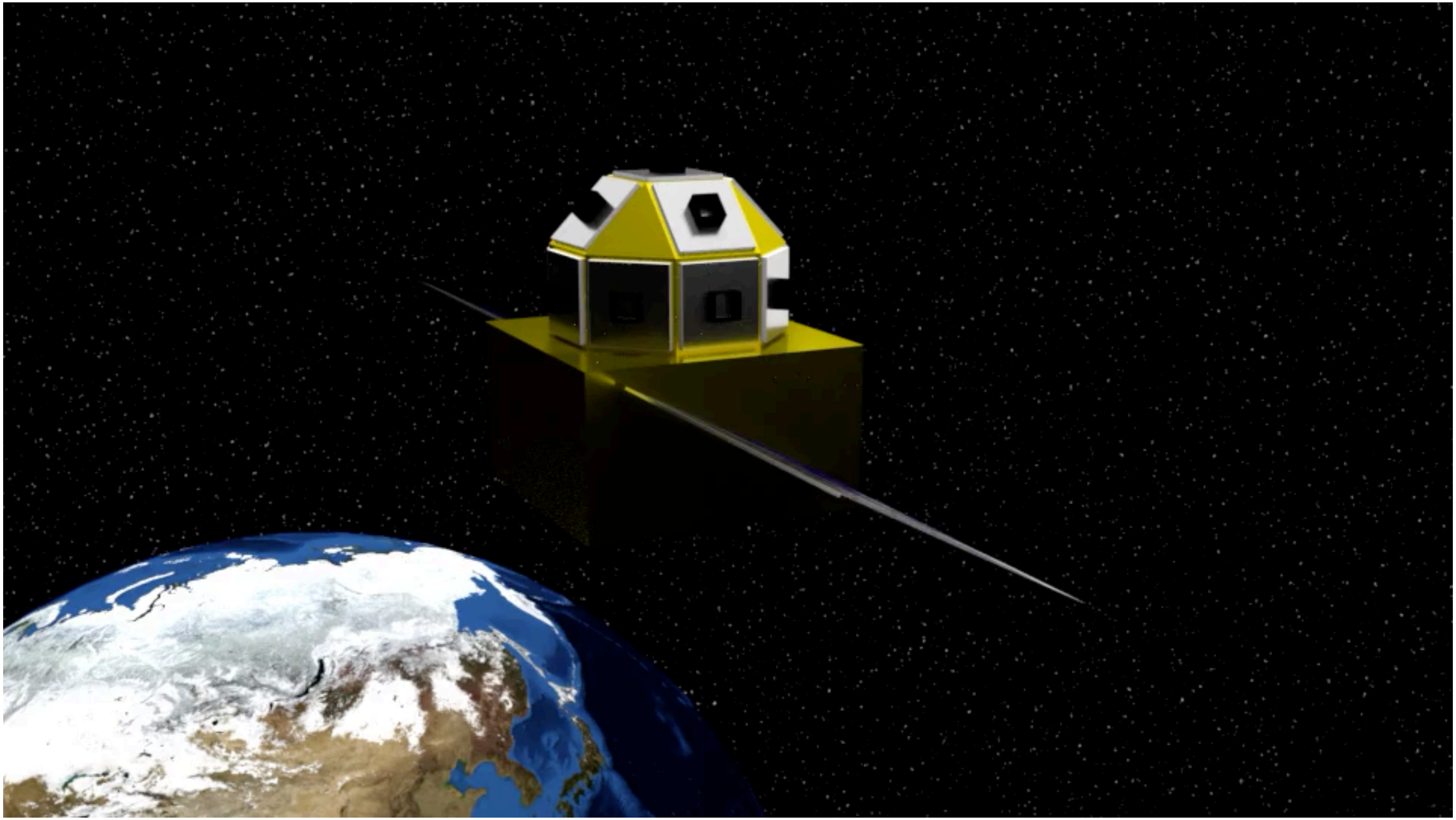
Wide spectral band

(1 keV to >1 MeV)

Continuous all-sky coverage

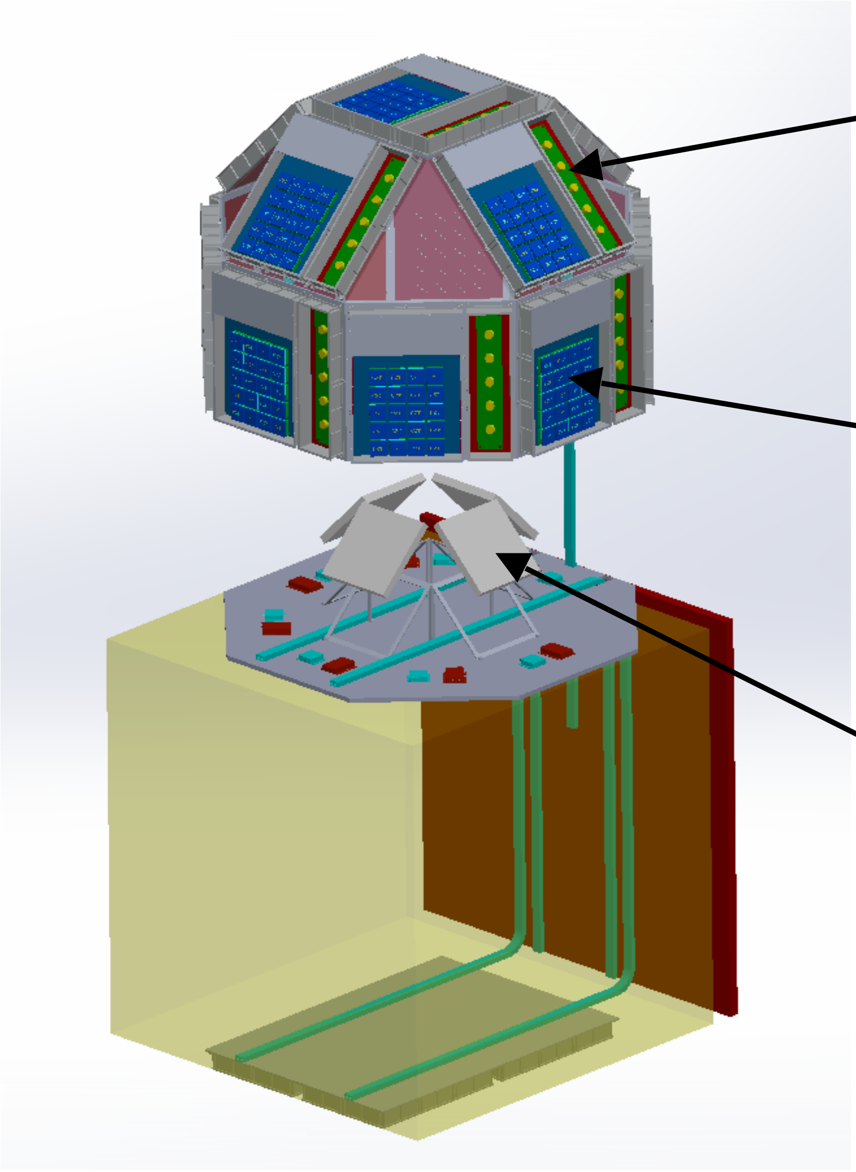
(Two satellites)

Introducing Daksha



On alert for high energy transients

Daksha



Low Energy: SDDs
1-25 keV

Medium Energy: CZT
20-200 keV

High Energy: Scintillator
100-1000 keV

Two satellites

BLUF

Bottom Line Up First

Advantage Daksha

- Effective area (2 satellites): 1700 cm^2
  - » Fermi: ~100 cm^2 individual, ~300 cm^2 total
- Sky coverage:
  - » 71% individual, ~100% two satellites
  - » BAT: ~11%
- Energy range: 1 keV to > 1 MeV
  - » BAT 15 – 150 keV, Fermi GBM > 8 keV

Daksha results – 1

- Detect dozens of BNS mergers per year
  - » Also ~1000 on-axis GRBs per year
- Localisation:
  - » ~10 degrees on board
  - » ~5 degrees ground processing
- Broadband prompt spectra
  - » Only mission to give prompt soft spectra
- Hard X-ray polarimetry

Daksha results – 2

Daksha results – 2

- Provide time and direction of burst
  - » Lower FAR for GW searches
  - » Lower detection statistic!

- **Increase LIGO detections by 2x – 3x !**

Huge discovery space

Building Daksha

- Lead institute: IIT Bombay
- Jointly with PRL, TIFR, IUCAA, RRI, ISRO

- Currently active sub-teams:
  - » Science
  - » Detectors and electronics
  - » Design and fabrication

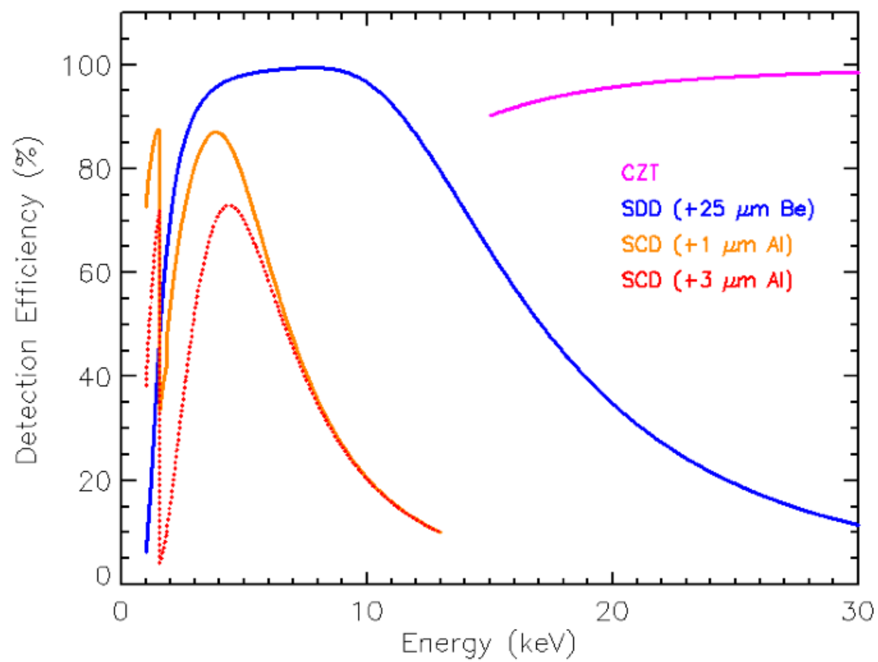
- Current status: *Seed funding has been provided to demonstrate a proof-of-concept!*

Digging Deeper

Detectors

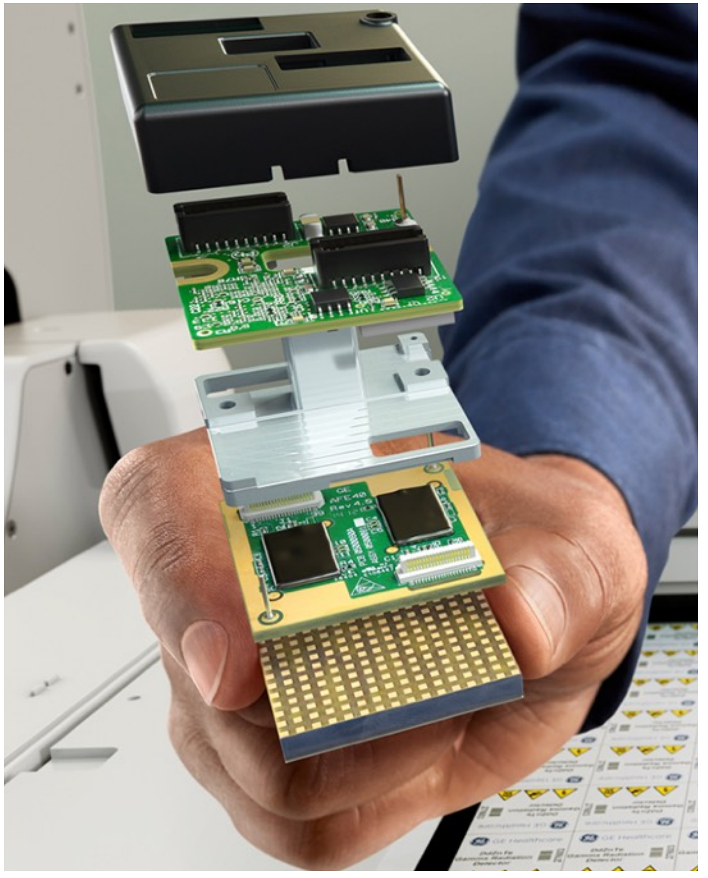
Low Energy: SDDs

- Silicon Drift Detectors
- 450μm thickness, 1 – 25 keV coverage
- 10μs timing
- Chandrayaan 2 legacy



Medium Energy: CZT

- Cadmium Zinc Telluride detectors
- 5 mm thickness, 4×4 cm^2 area
- 20 – 200 keV range
- AstroSat CZTI, RT2 legacy
- Microsecond timing
- 340 detectors / satellite!

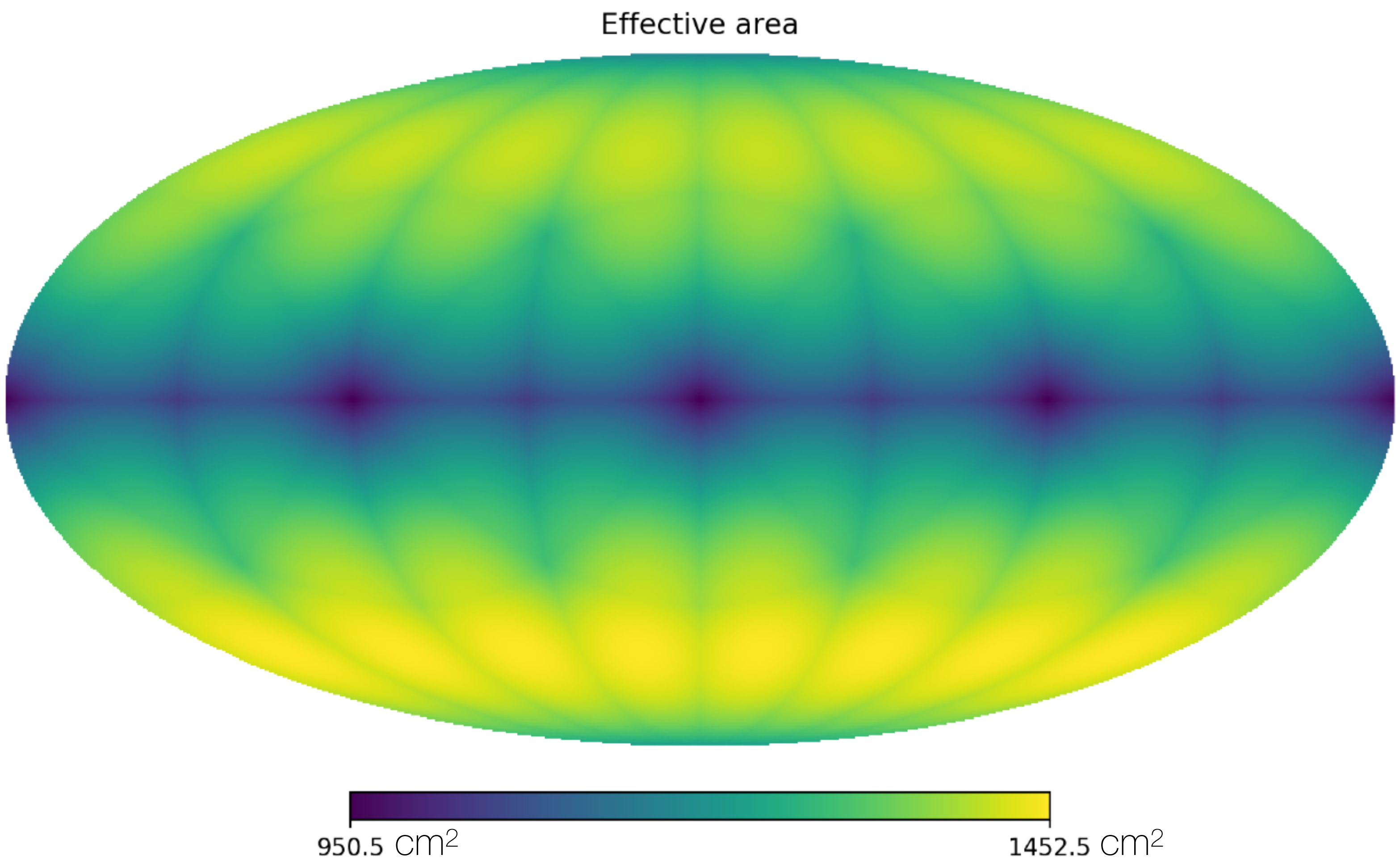


High Energy: NaI (Tl)

- Thallium activated Sodium Iodide detectors
- 400 cm^2, 2 cm thickness
- 100 keV – >1 MeV sensitivity
- Silicon Photomultipliers for compact, low voltage setup
- Position sensitive (Anger camera)

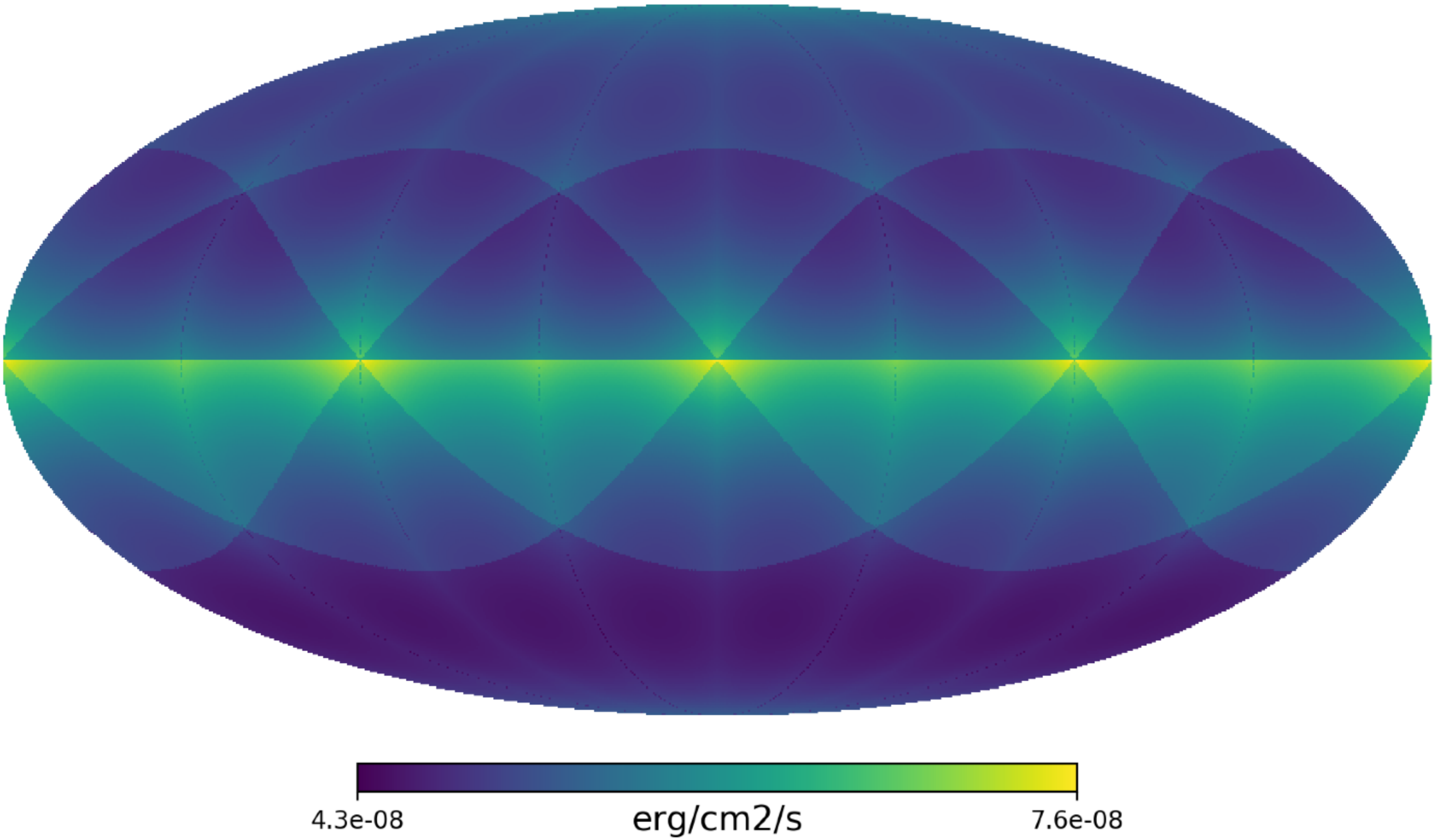
Sensitivity

Single satellite effective area



Median: 1230 cm^2 for single satellite

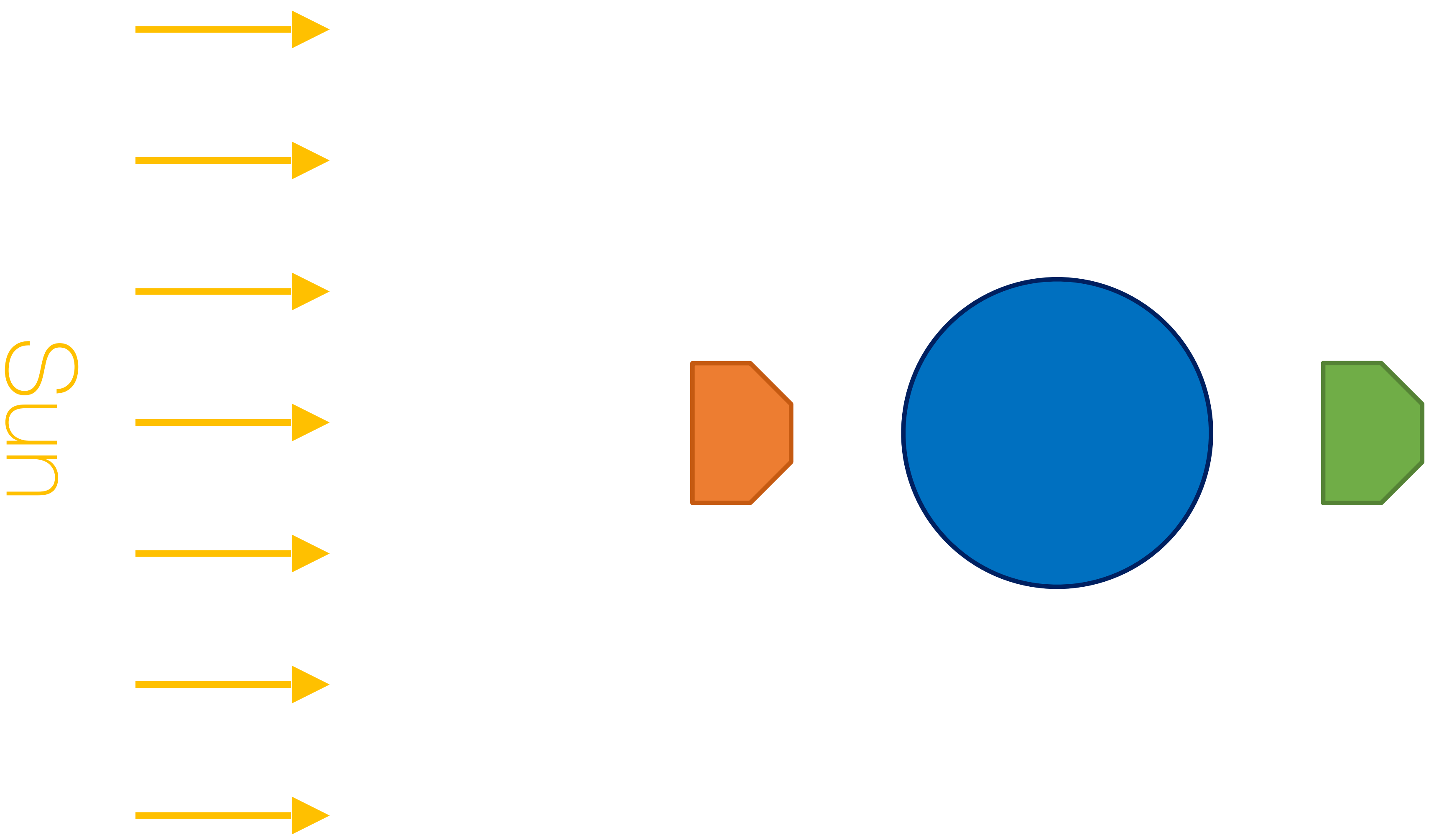
Single-satellite sensitivity



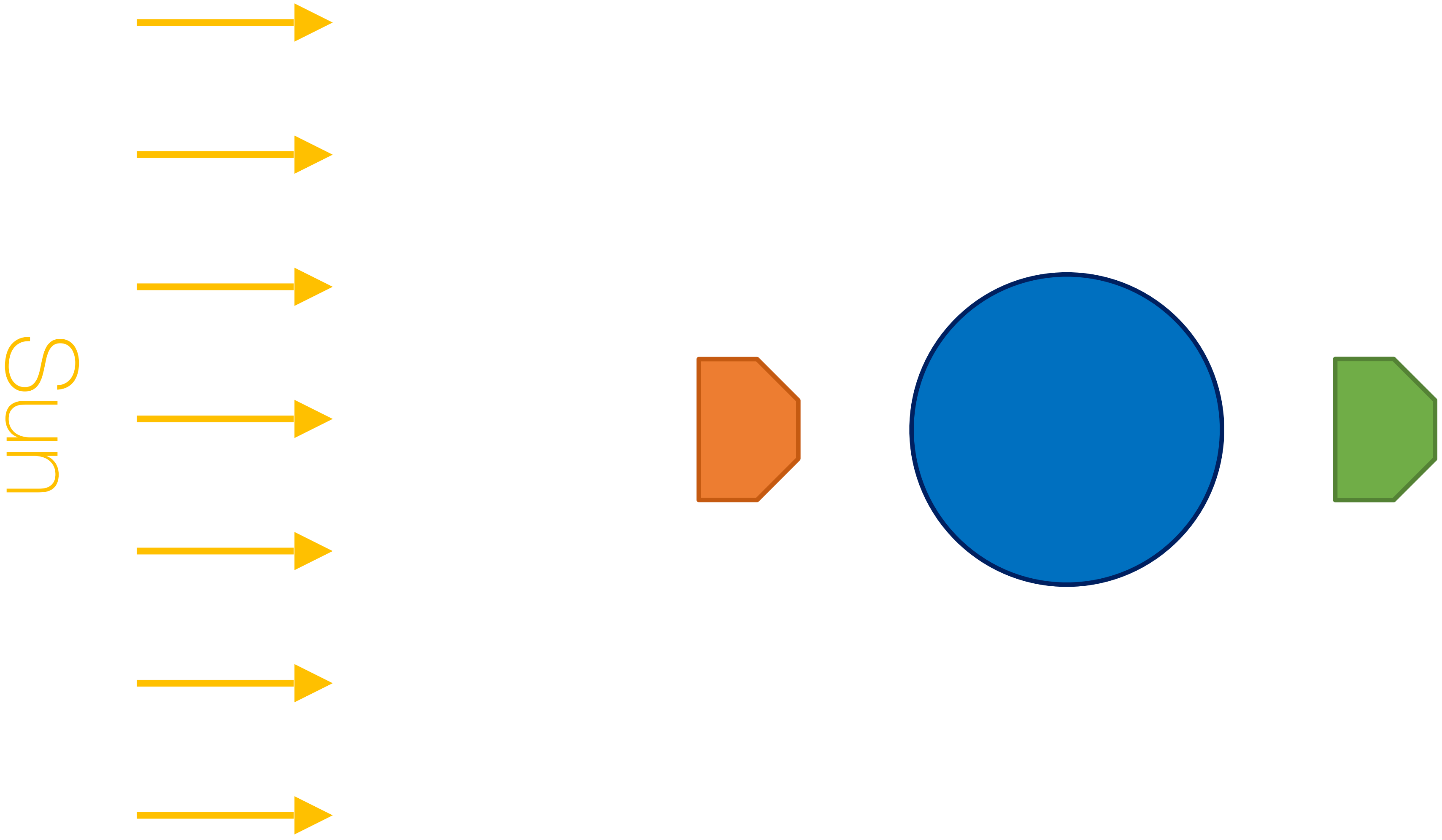
Crude 3-sigma estimate, actual sensitivity will be better

Coverage

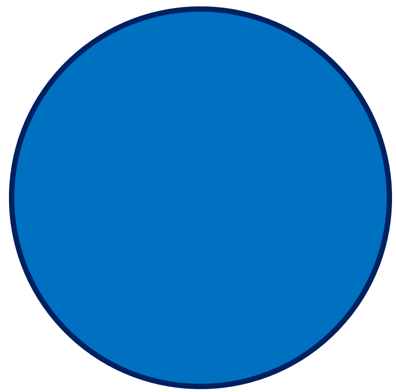
Pointing



Pointing



Number of satellites



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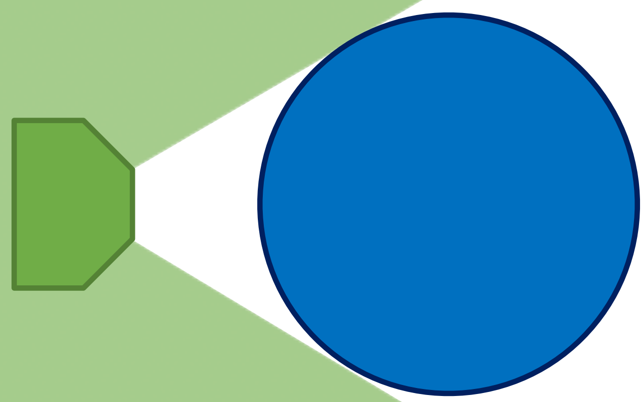
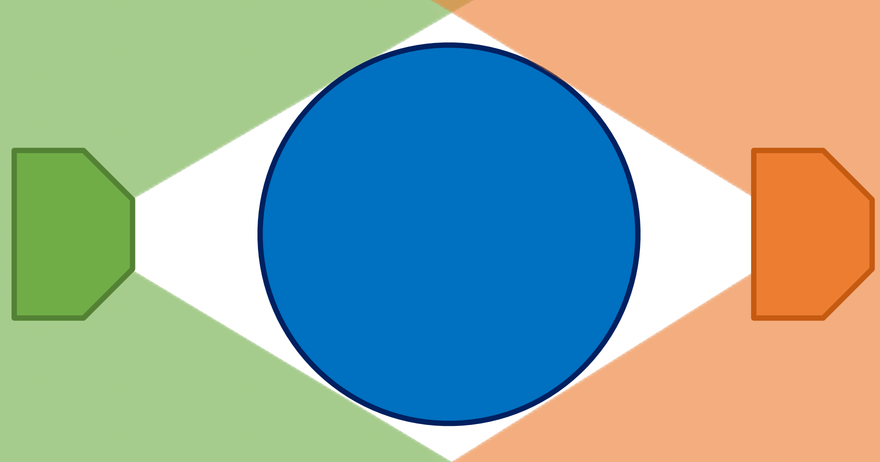


1 Satellite: ~70%

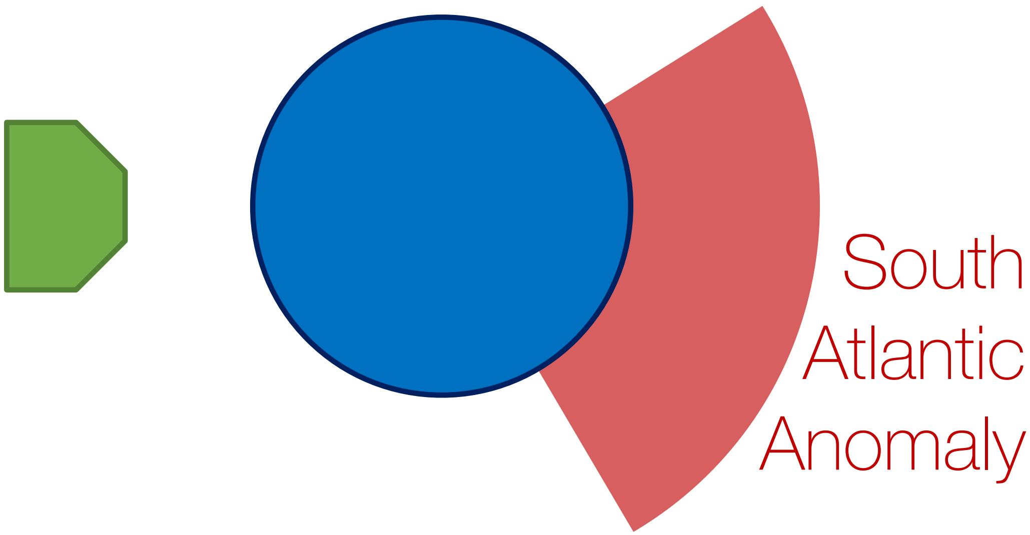
Number of satellites



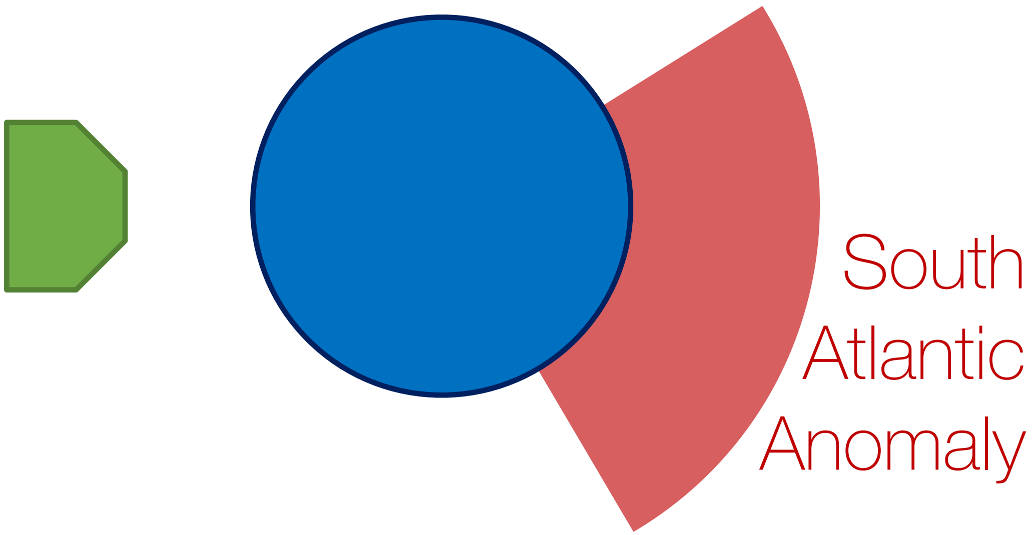
1 Satellite: ~70%

2 Satellites: 100%

Number of satellites

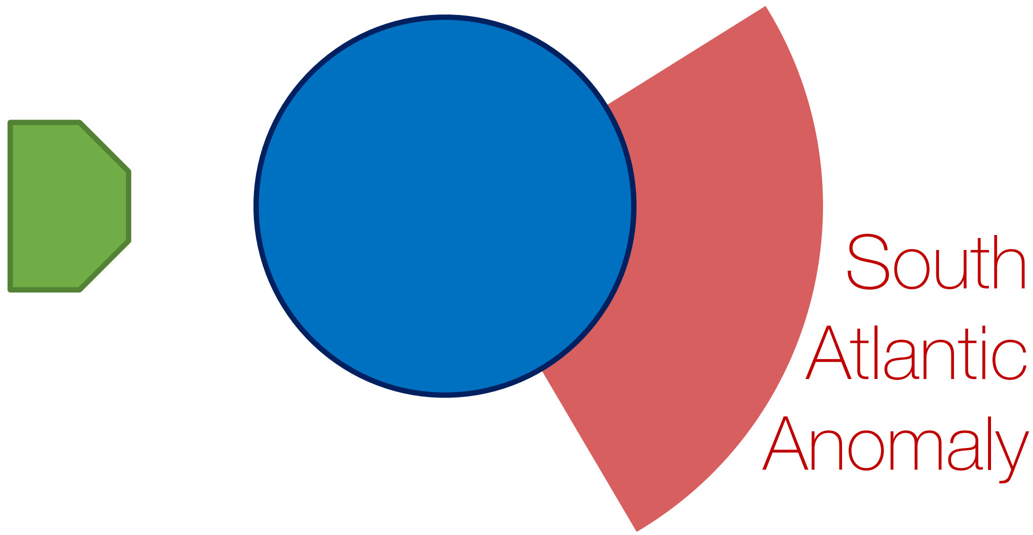


Number of satellites



- 1 satellite: ~70% for ~75% of the time
  - » Average: ~52% coverage

Number of satellites

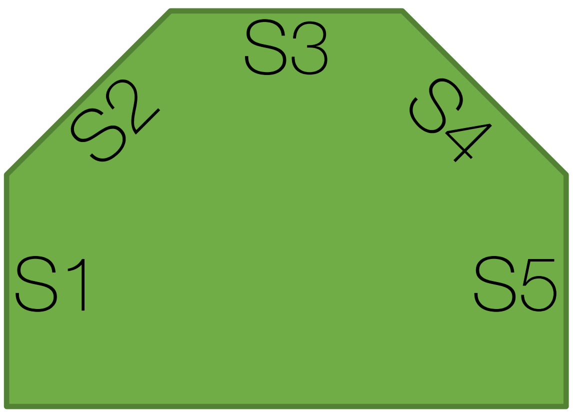


- 1 satellite: ~70% for ~75% of the time
  » Average: ~52% coverage
- 2 satellites: 100% for 50% time, 70% for rest
  » Average: ~85%

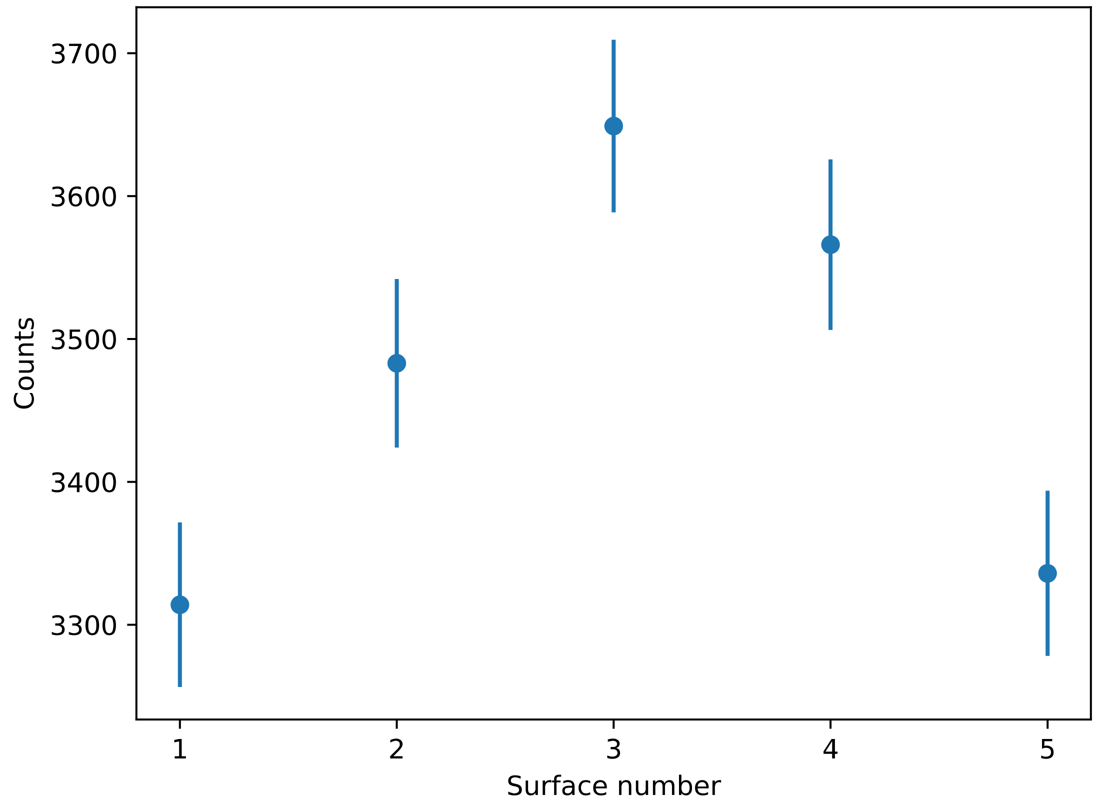
Angular Resolution

How localisation works

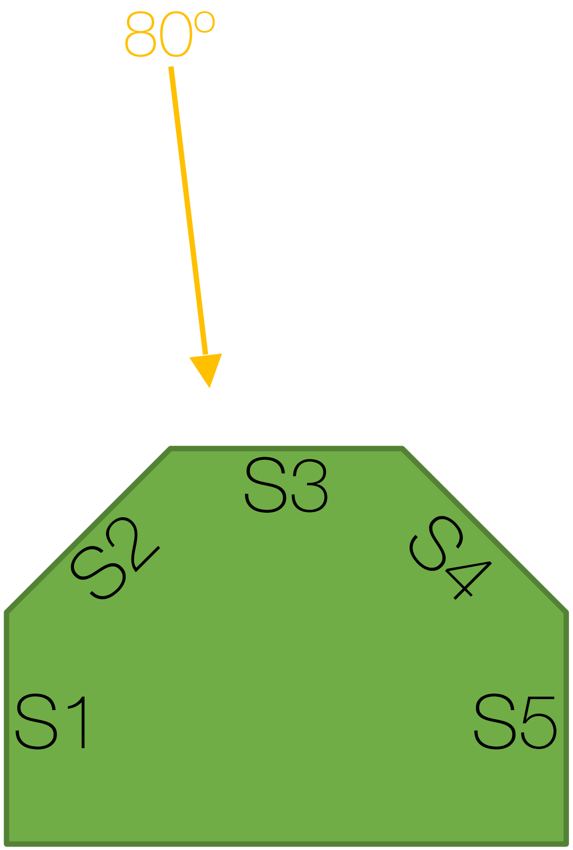
Where is the burst from?

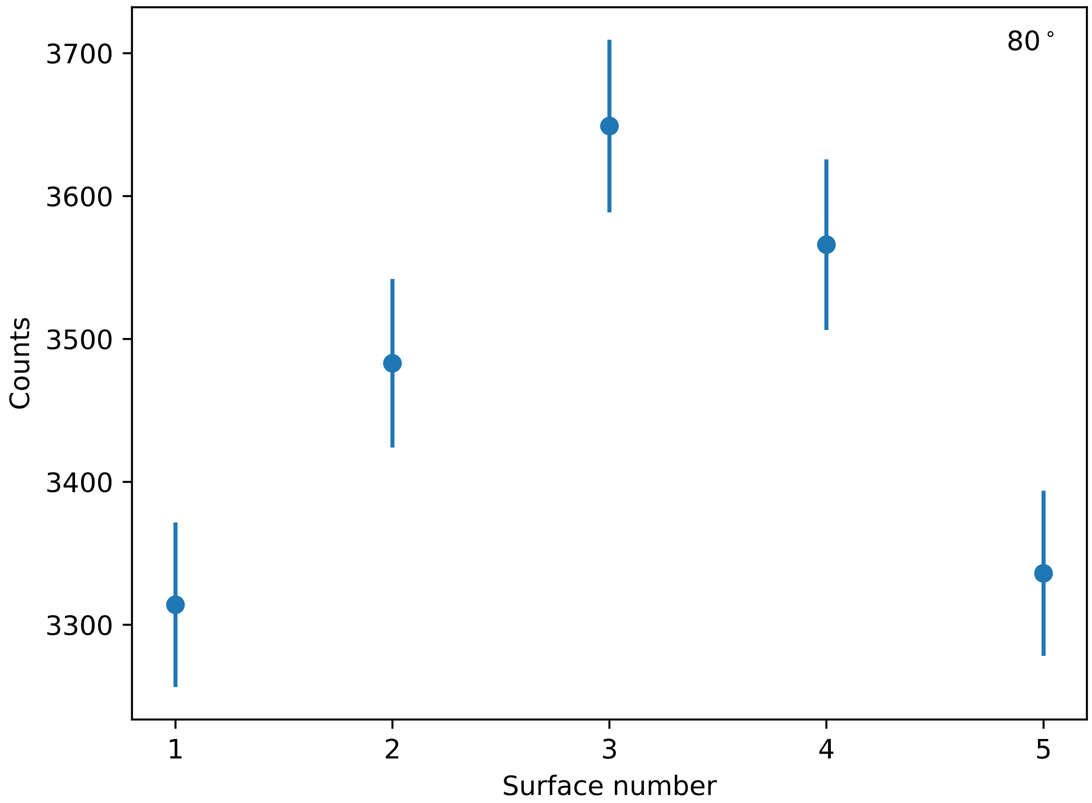


Observed counts



How localisation works





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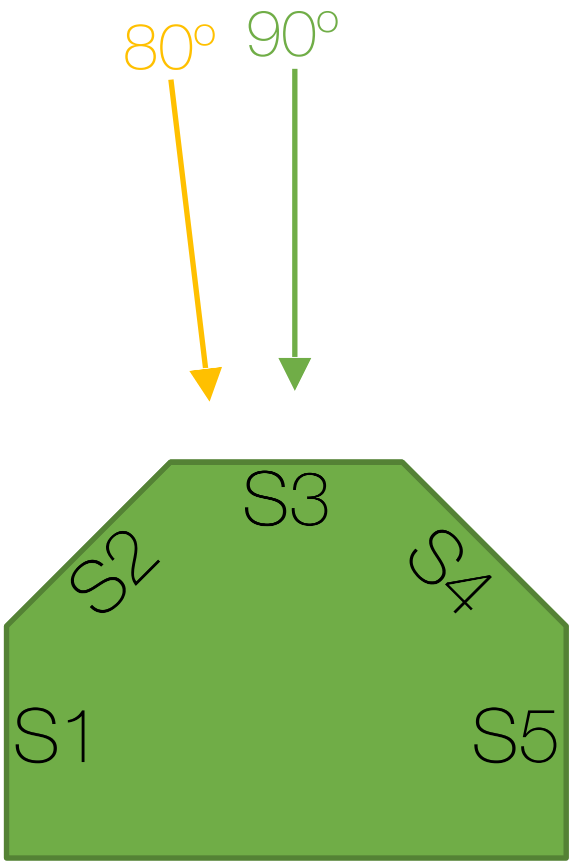

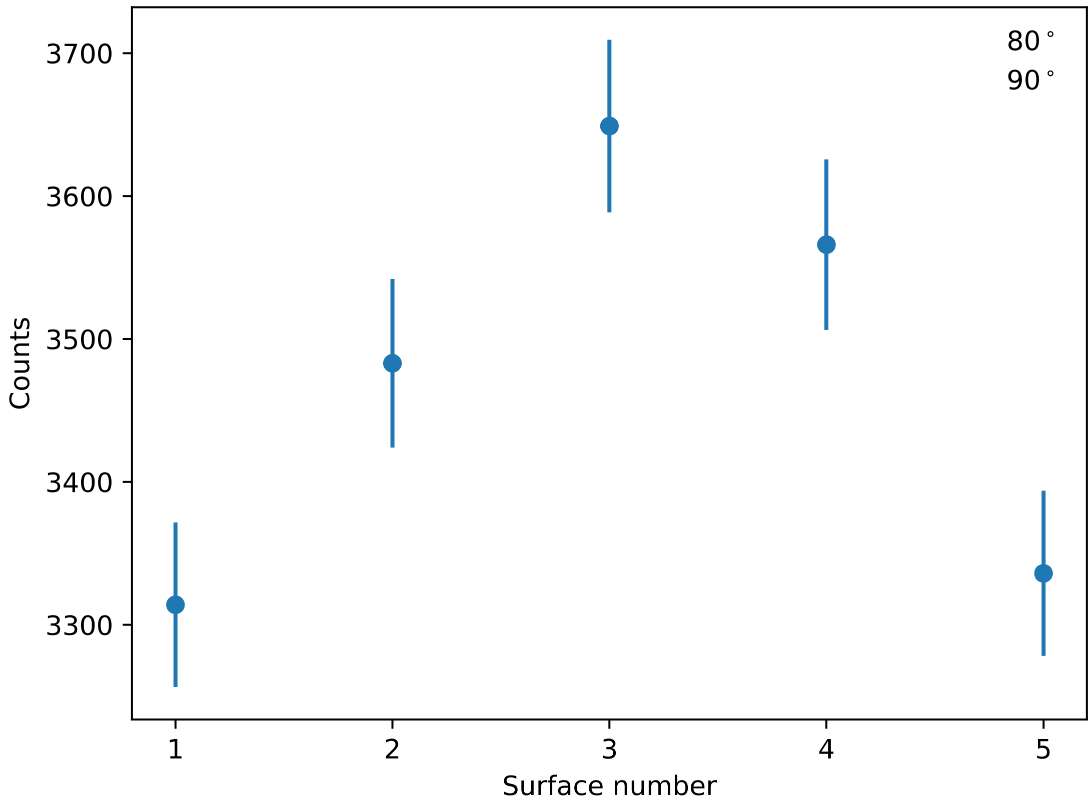

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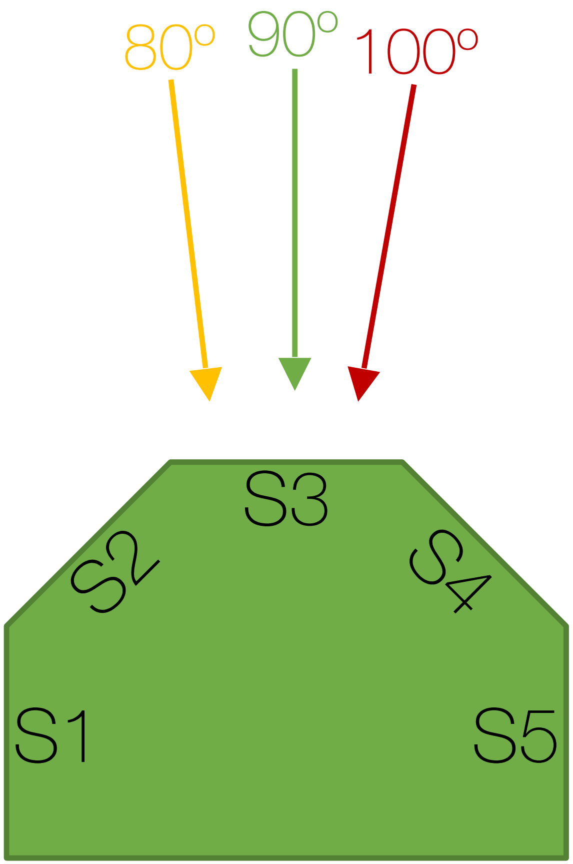
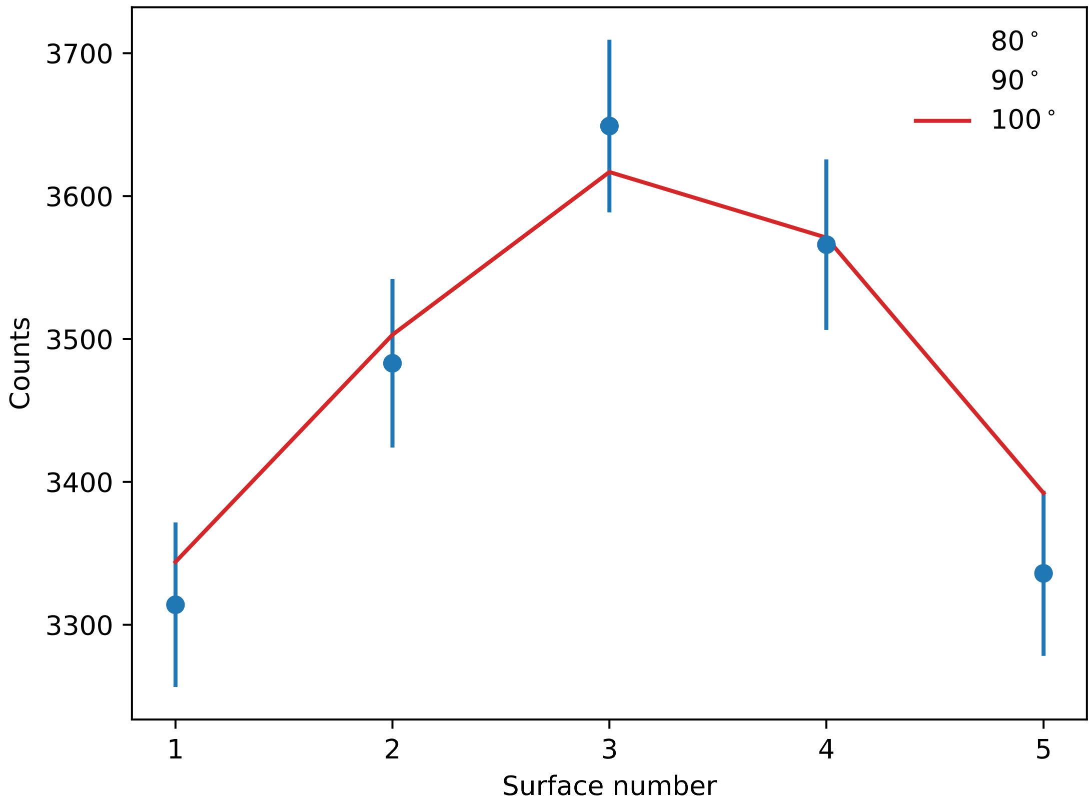
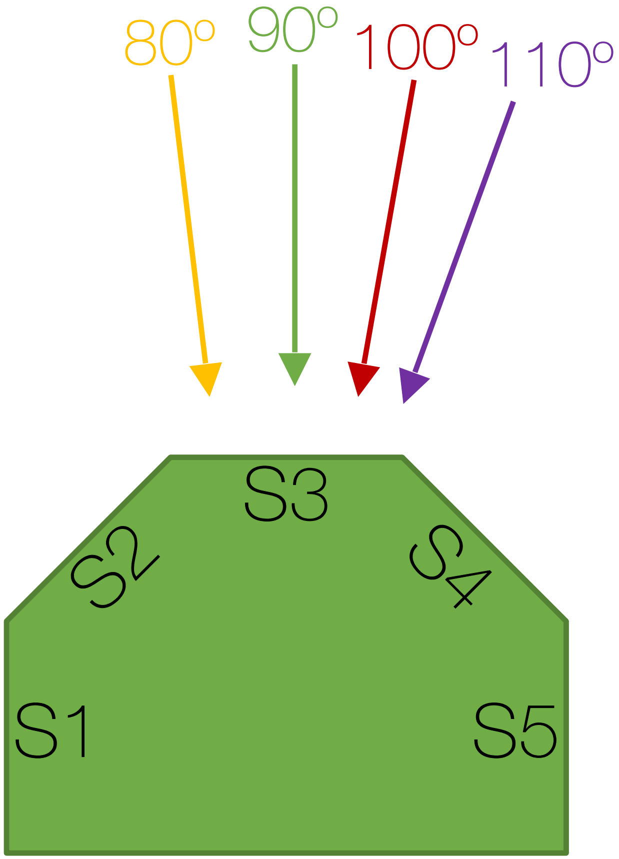
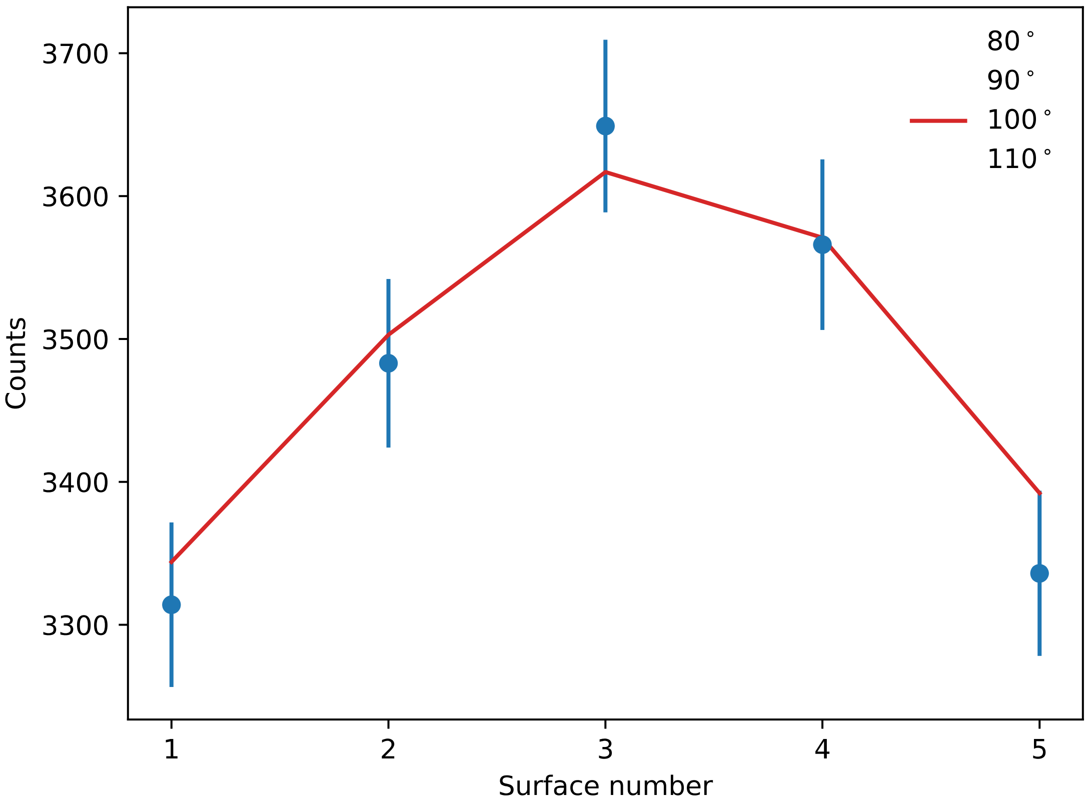




How localisation works





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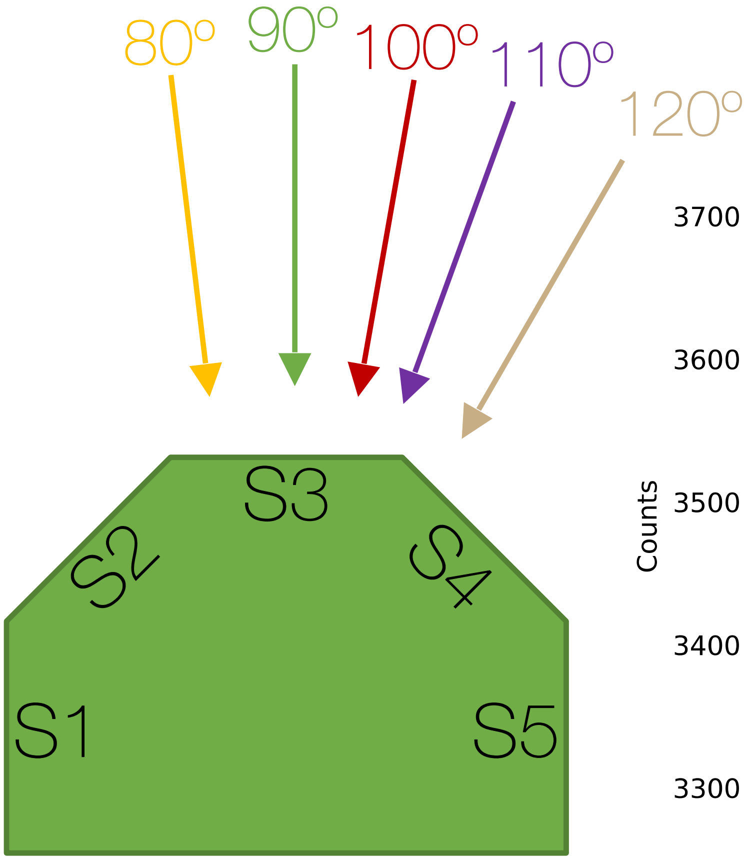
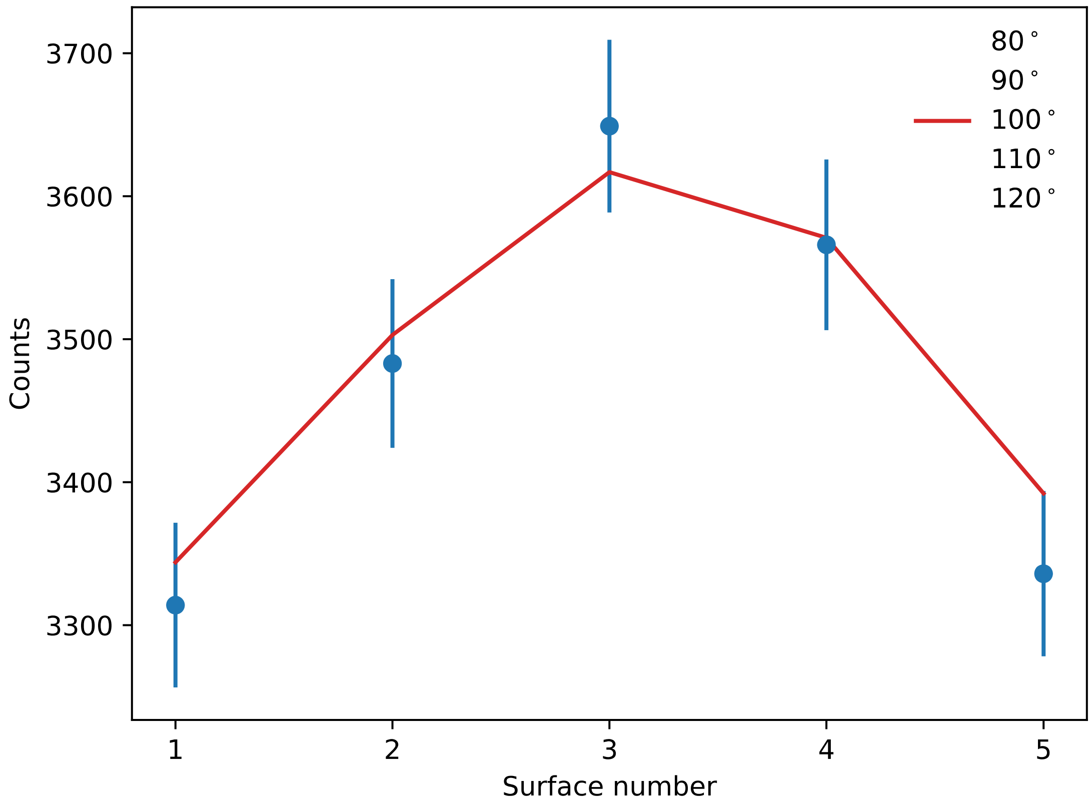
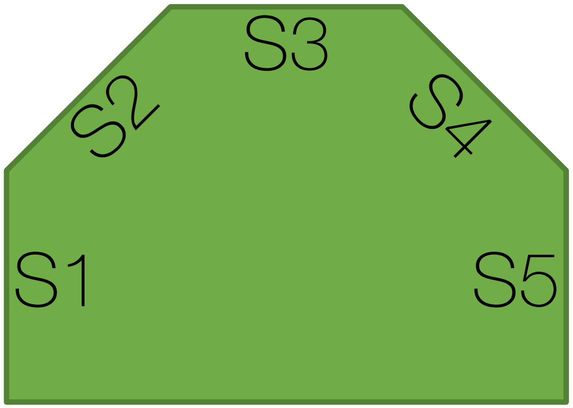




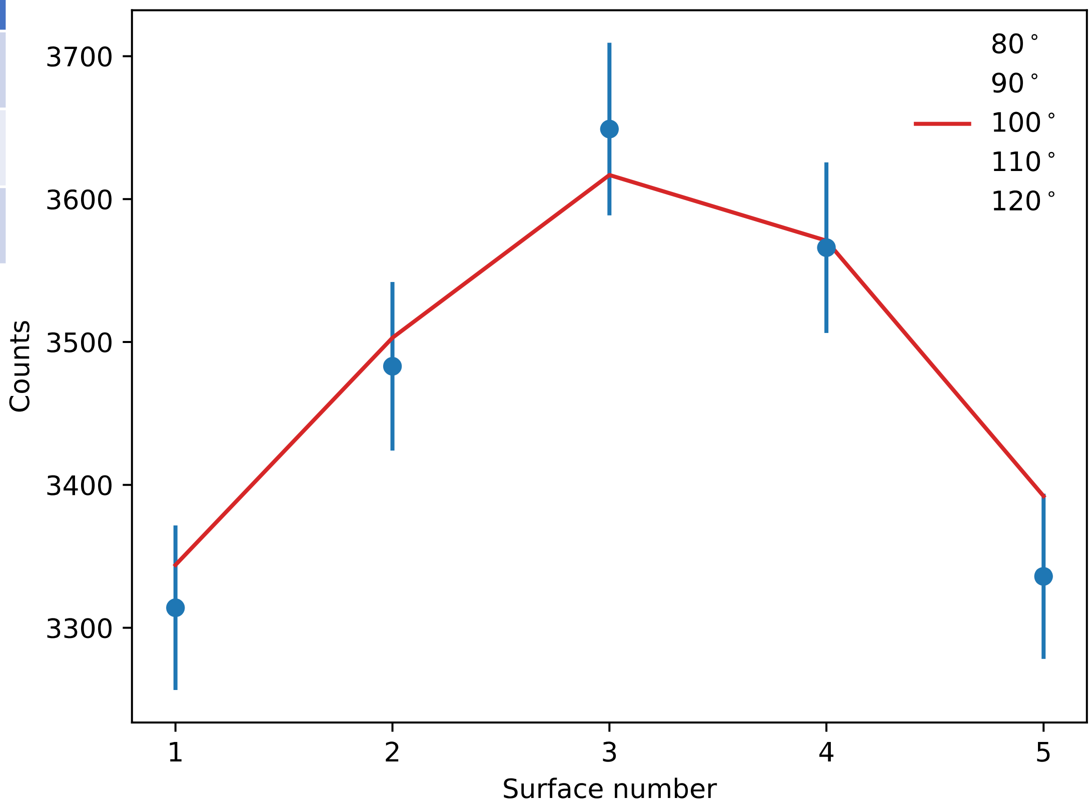
How localisation works

Final answer:

Param	Injected	Fit	Sigma
θ	100	98.1	2.8
Src	277	338	27
Bkg	3344	3298	17



(Note: Very simplistic fit used here)



Results

- Bright GRB (10^{-6} erg/cm^2/s): 1°
- Moderate GRB (10^{-7} erg/cm^2/s): 10°

- Resolution inversely proportional to flux

- Two-satellite detection: IPN-like triangulation

Rates

BNS

- BNS merger rate: 250 – 2810 Gpc^{-1} yr $^{-1}$
  - » Assume nominal rate 1000 Gpc^{-1} yr $^{-1}$
  - » Abbott et al 2020, ApJL, 892, L3

- Daksha rates: 19 yr $^{-1}$ (5 – 54)
- GW (5-det network): 62 yr $^{-1}$ (15 – 174)
- EM + GW: 15 yr $^{-1}$ (4 – 42)

Classical GRBs

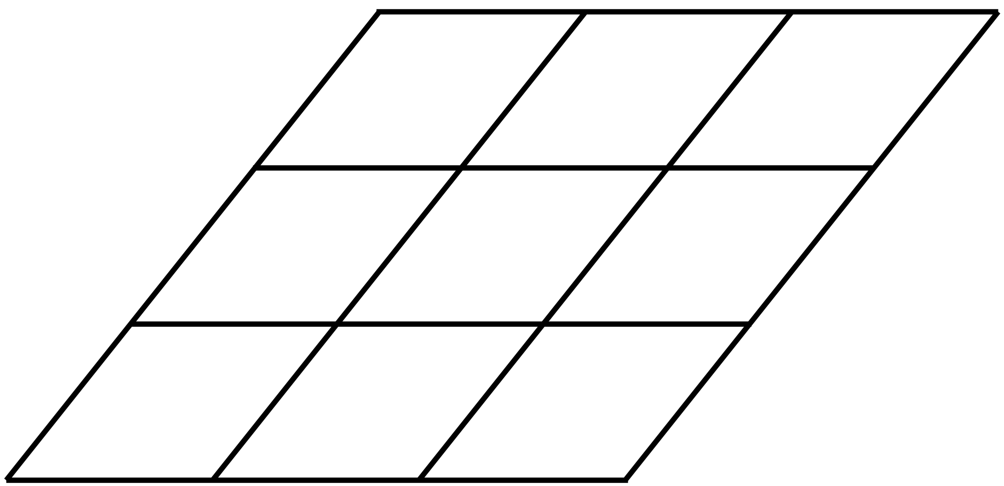
- Rate computation tough: we're too sensitive!
- Long GRBs: ~850 yr^{-1}
- Short GRBs: ~250 yr^{-1}

- Thresholds:
  - » Daksha: 0.36 ph cm^{-2} s^{-1}
  - » Fermi: 7 ph cm^{-2} s^{-1}

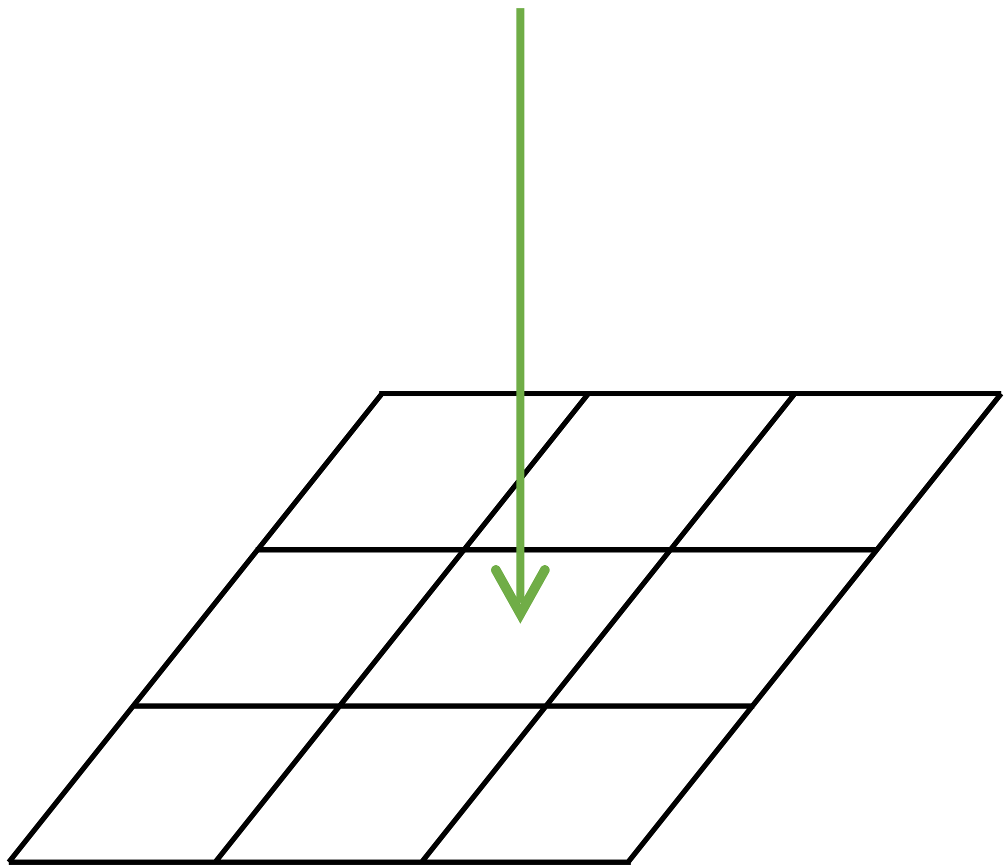
Secondary Science Goals

Polarisation

Polarisation & Scattering



Polarisation & Scattering



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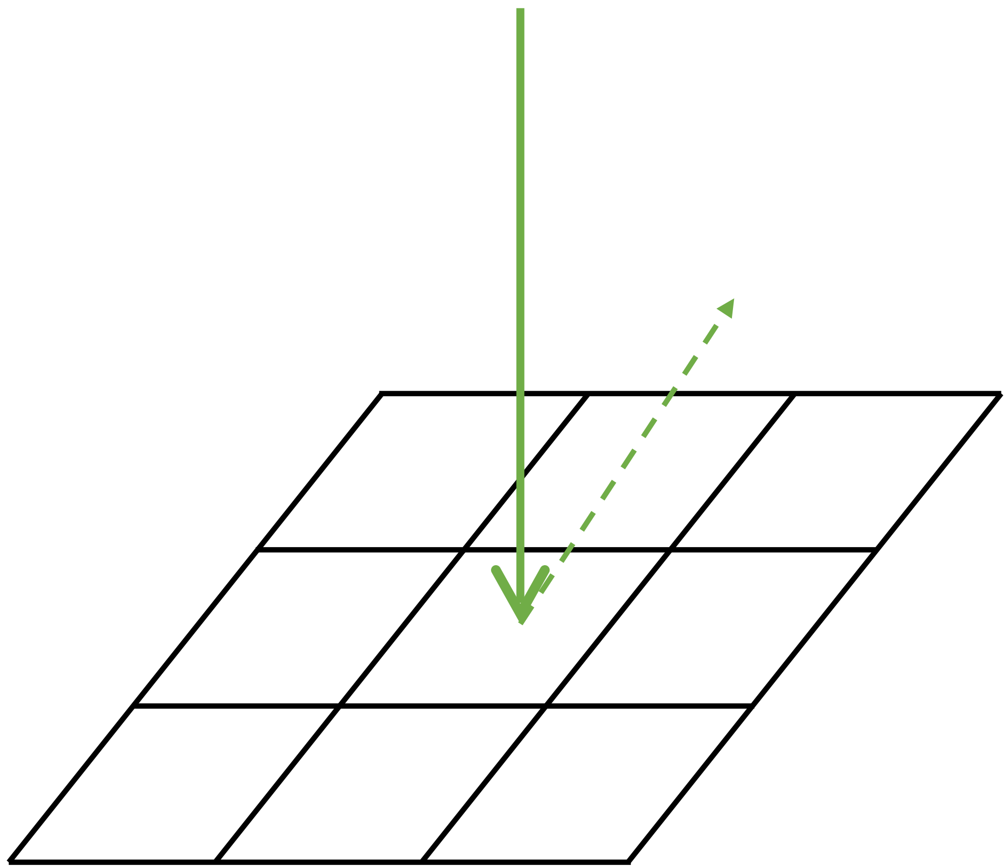

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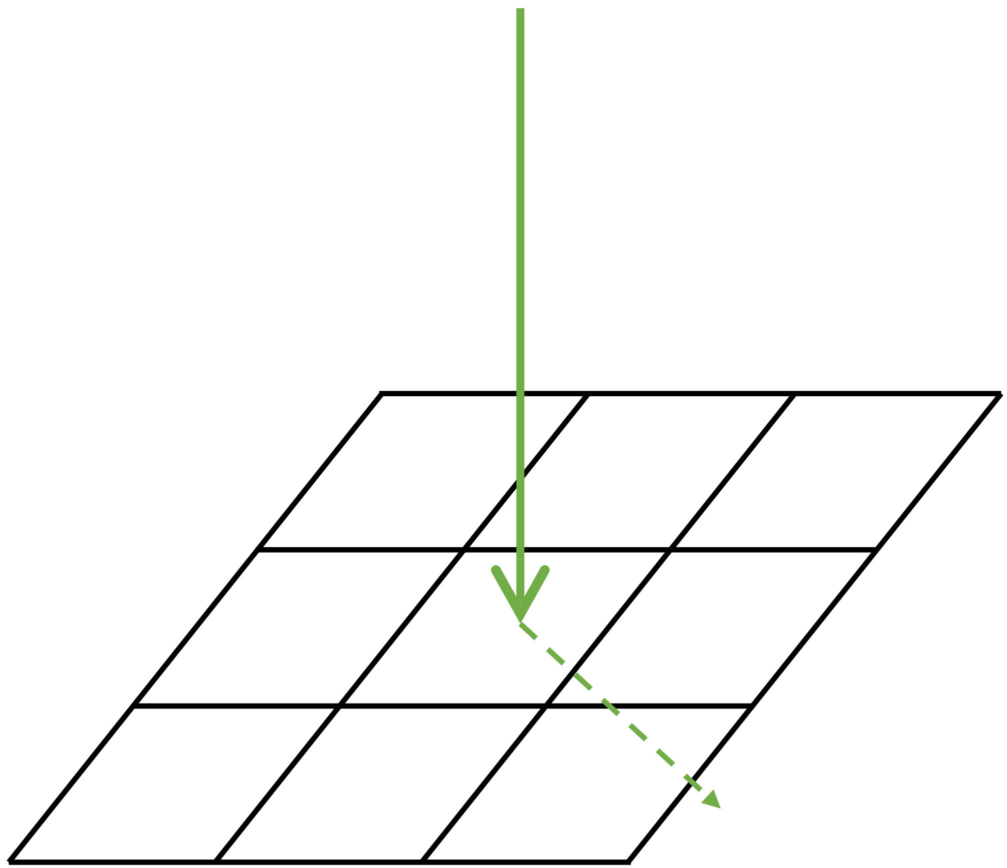

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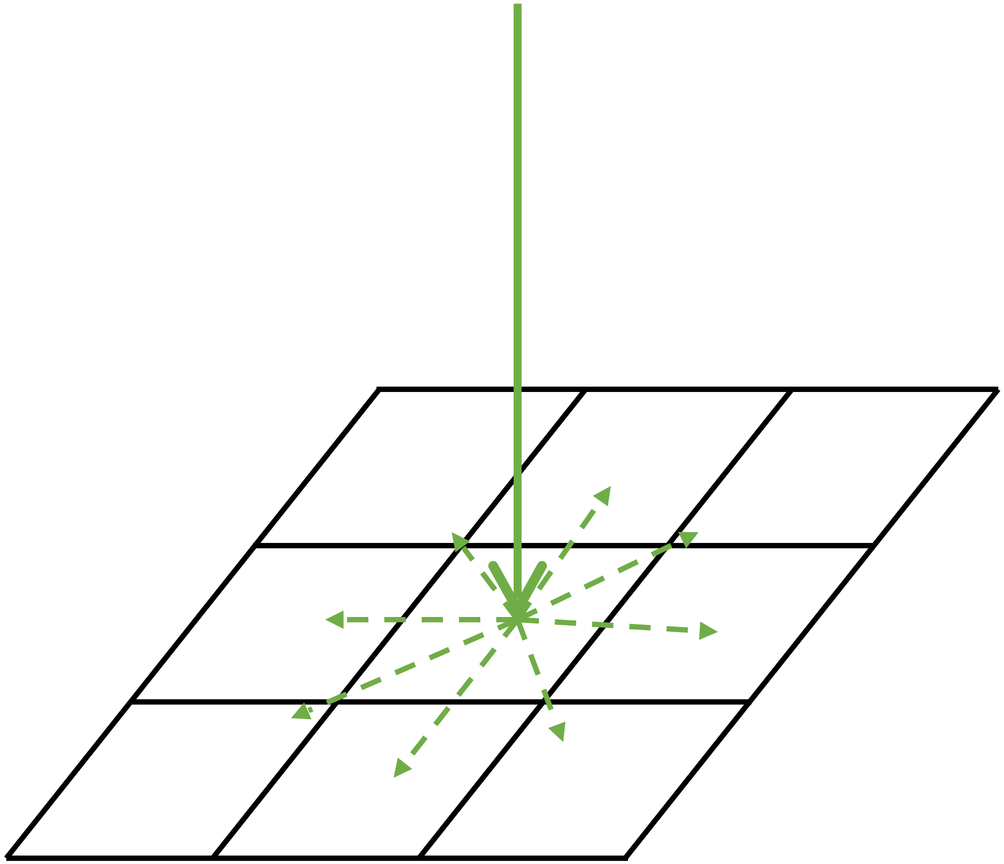

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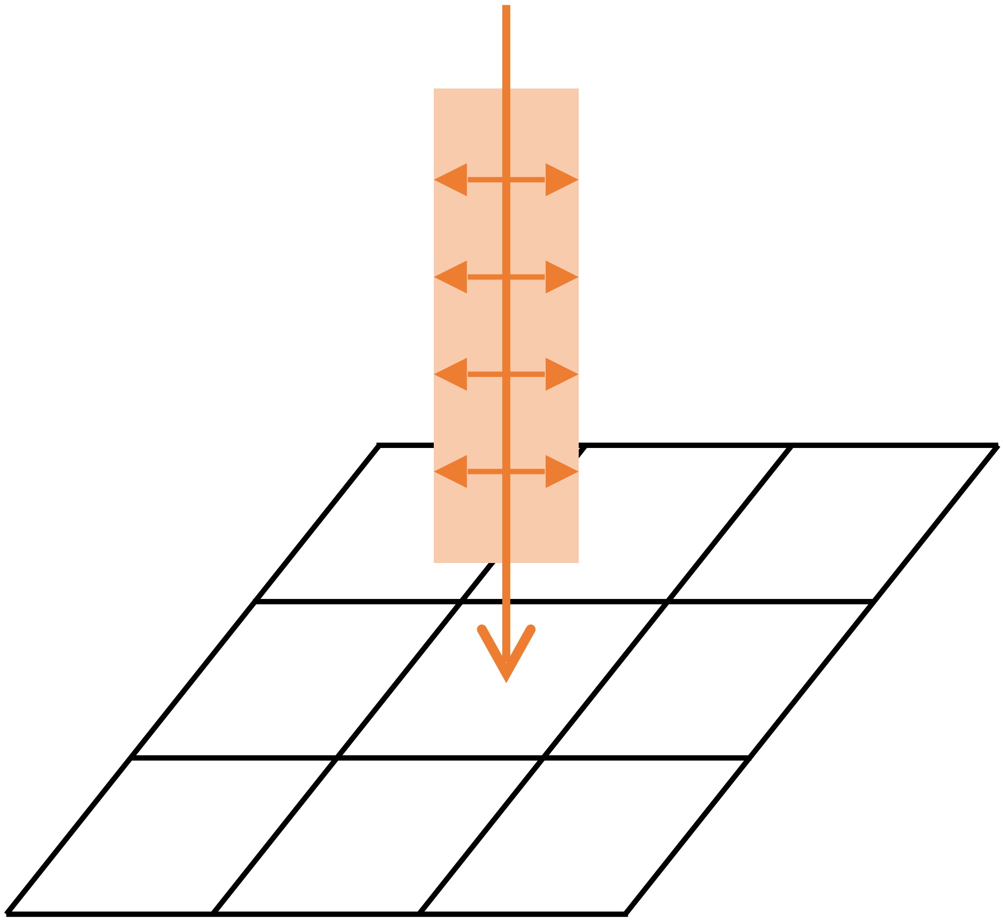

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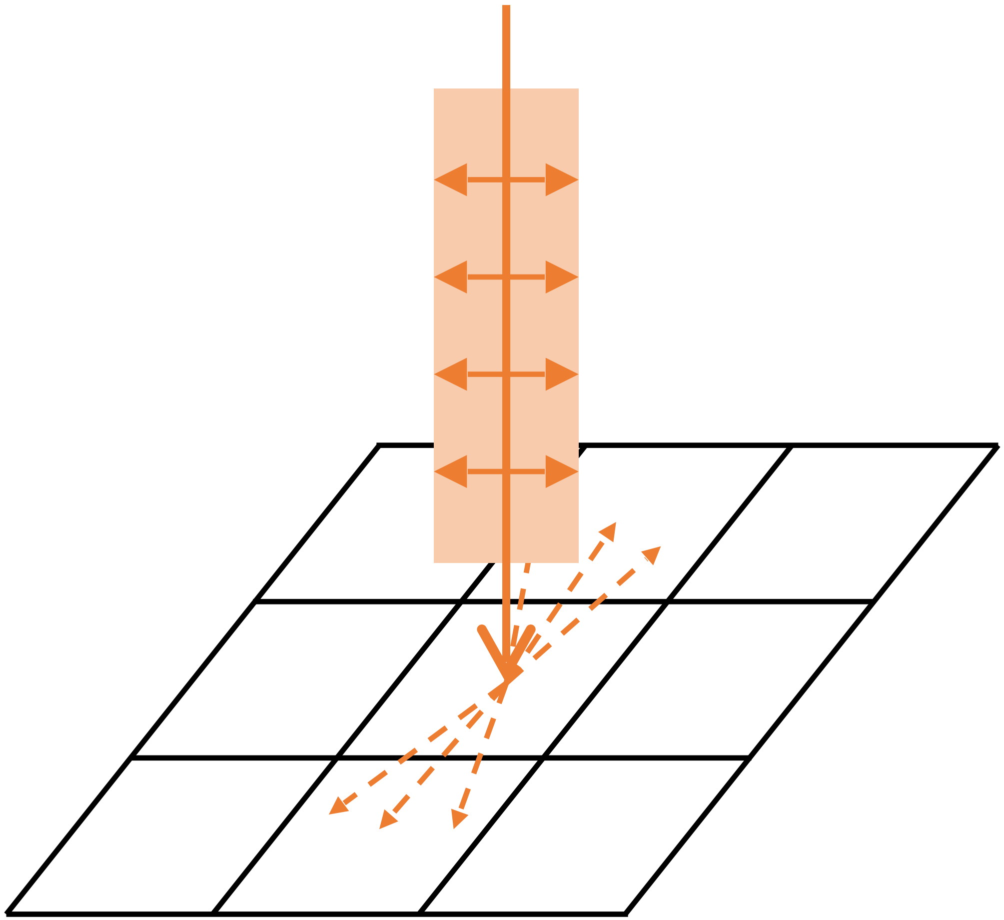

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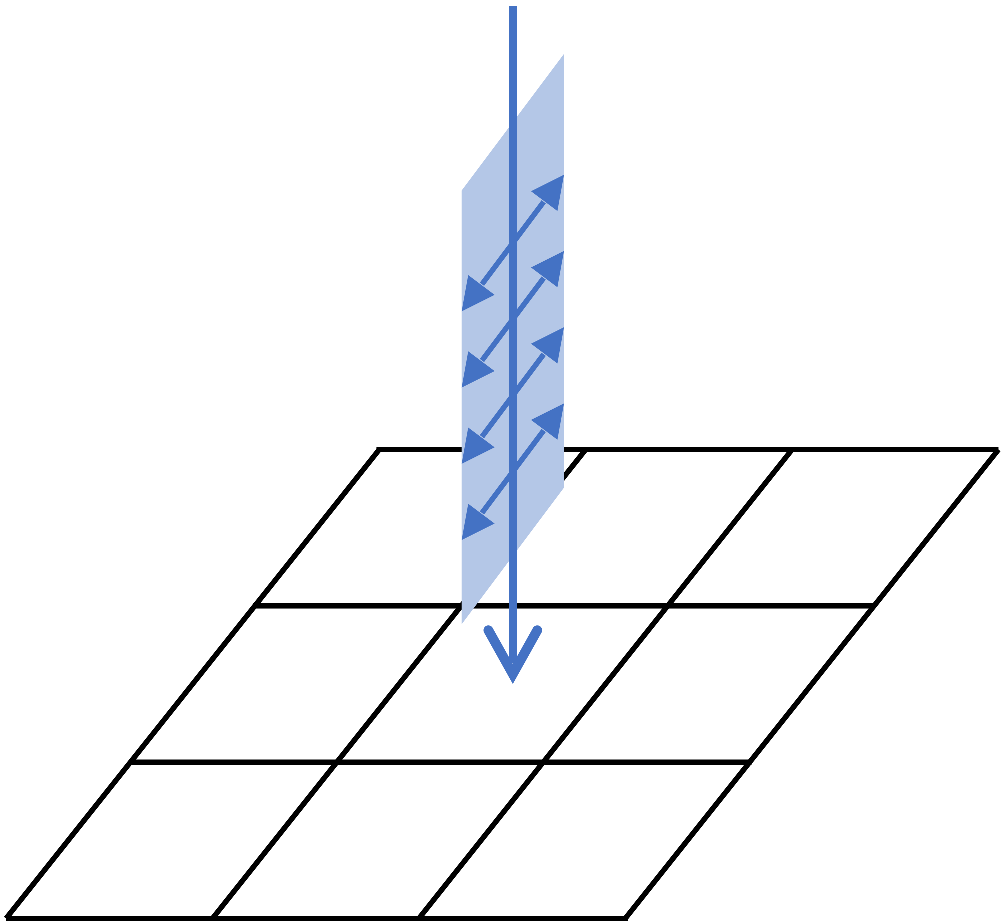

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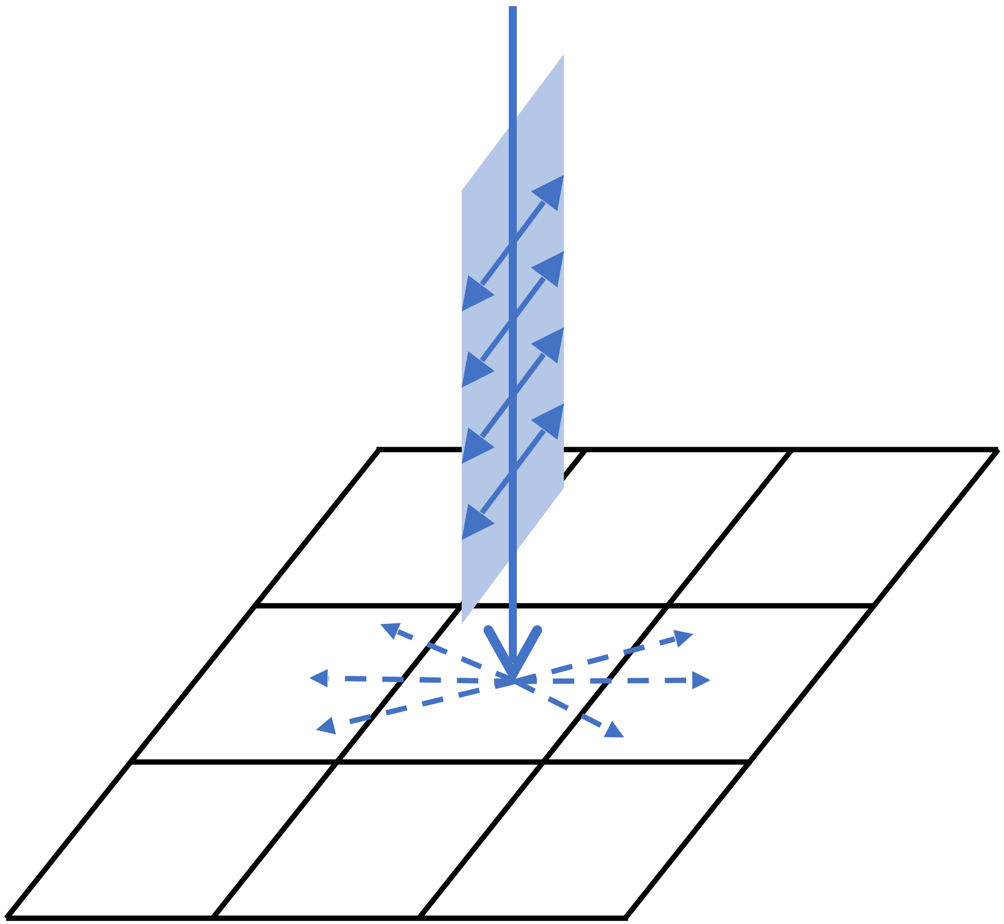
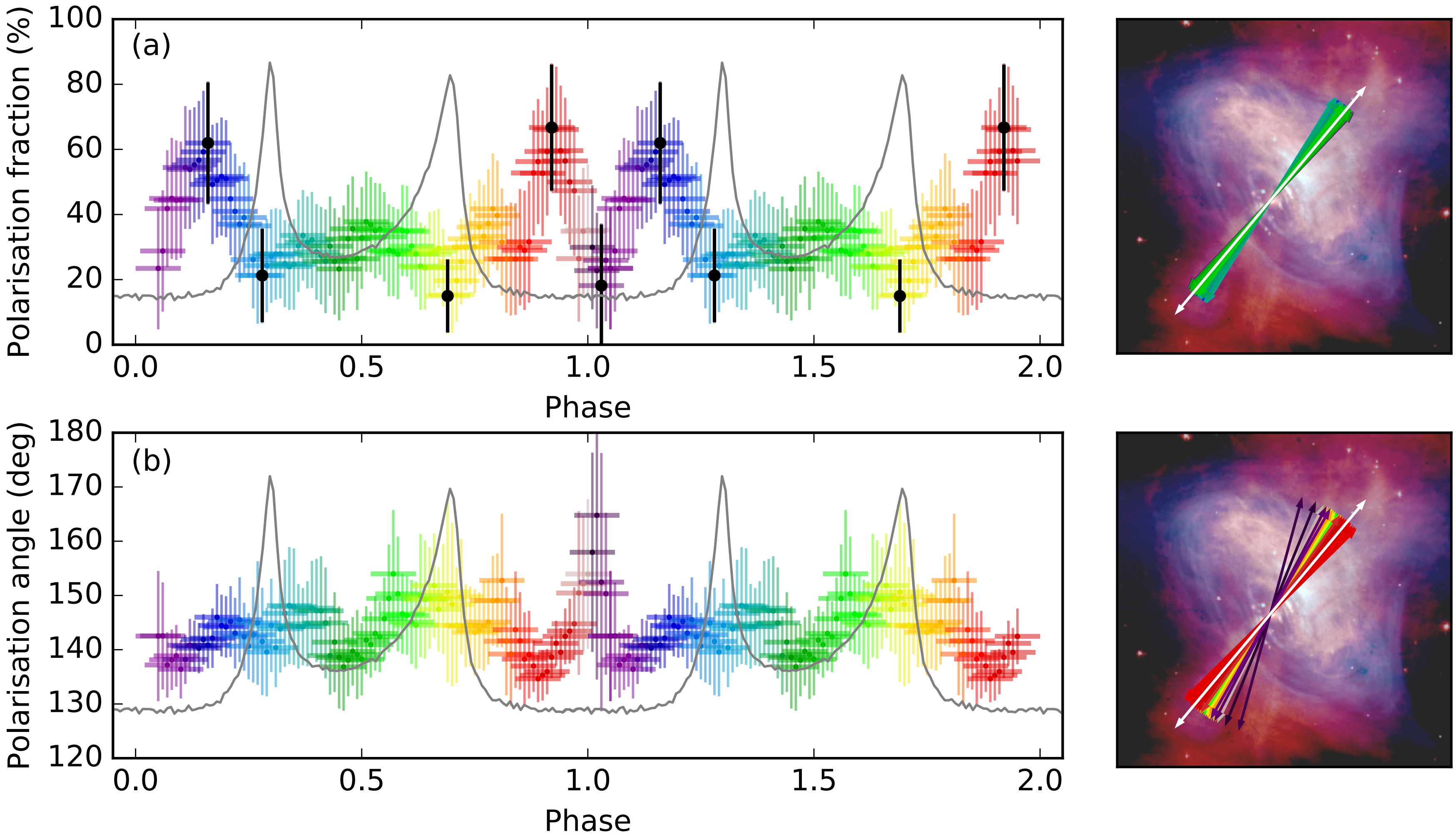
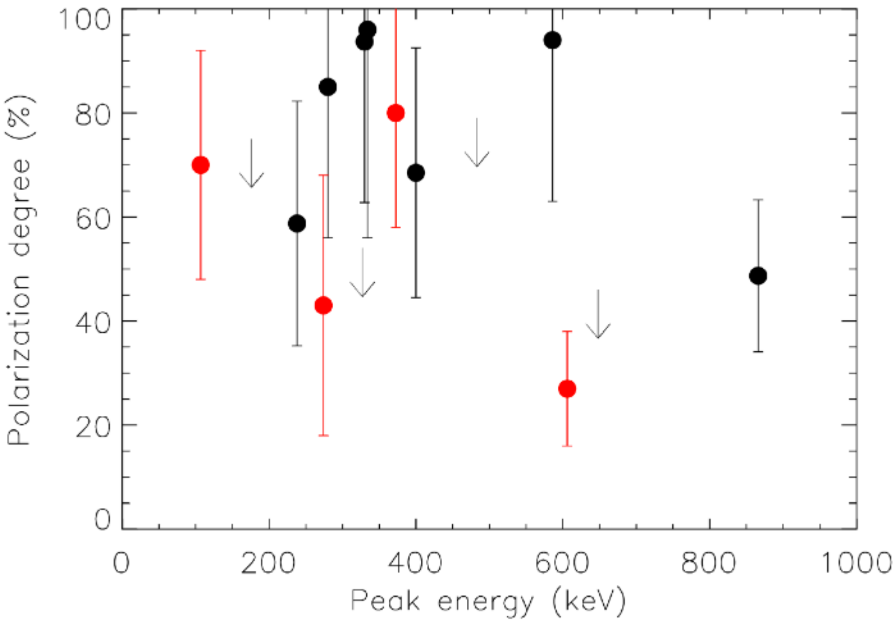


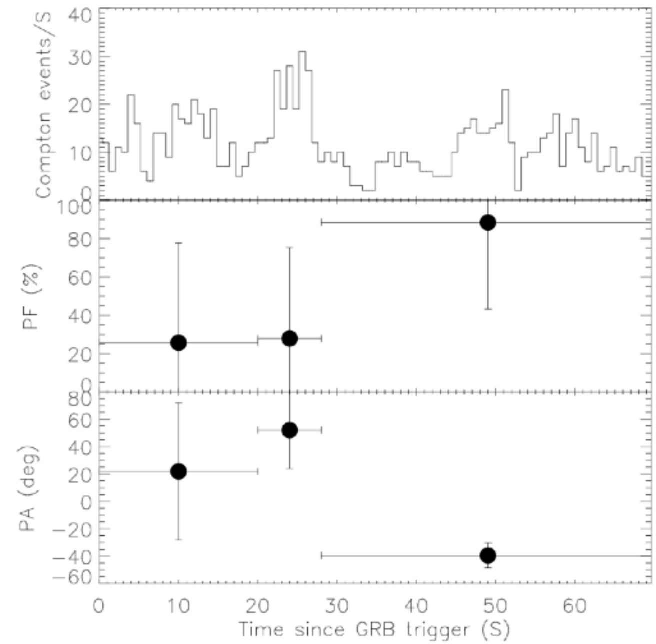
Polarisation measurements: CZTI



Vadawale et al, Nature Astronomy, 2017

GRB polarisation measurements





Prompt emission polarimetry for 11 GRBs
Chattopadhyay et al., 2019 ApJ 884 123

Variable pol in GRB171010A
Chand et al., 2019 ApJ 874 70

Limitations due to angle of incidence, effective area

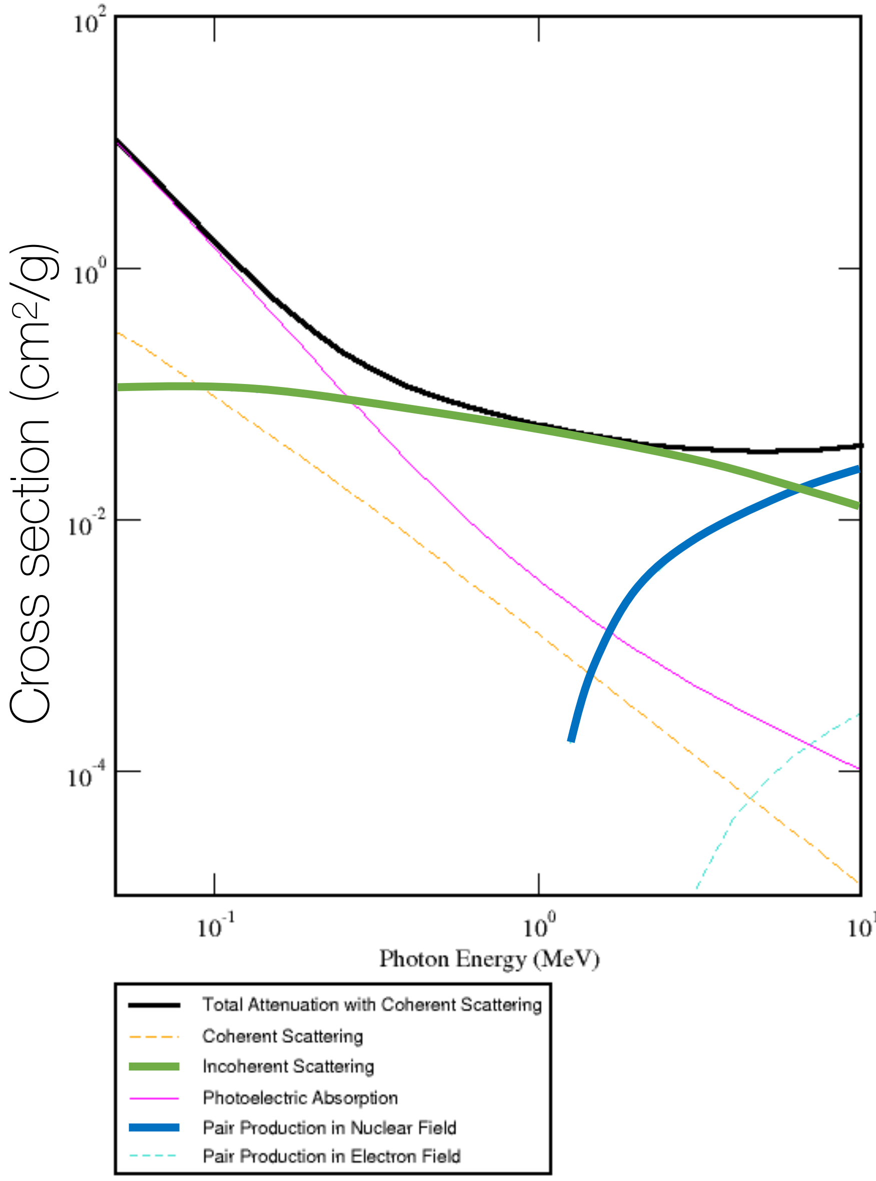
CZTI → Daksha

- CZTI total effective area ~ Daksha per-surface effective area
- Less “superstructure” for interfering with incident photons
- Many different incident angles
  - » Better control over systematics
  - » Consistency check – validate with bright GRBs

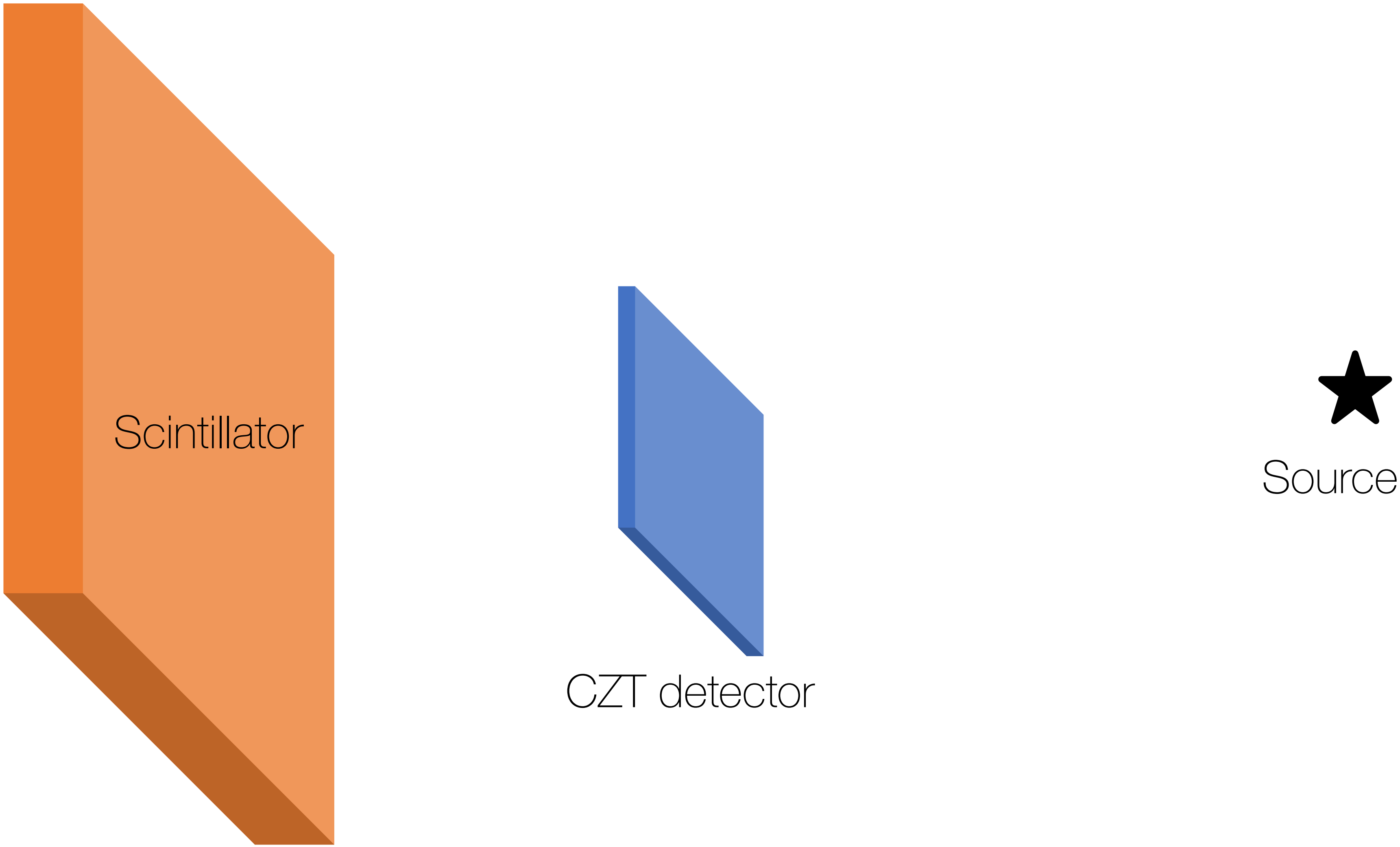
Compton Imaging

Compton energy range

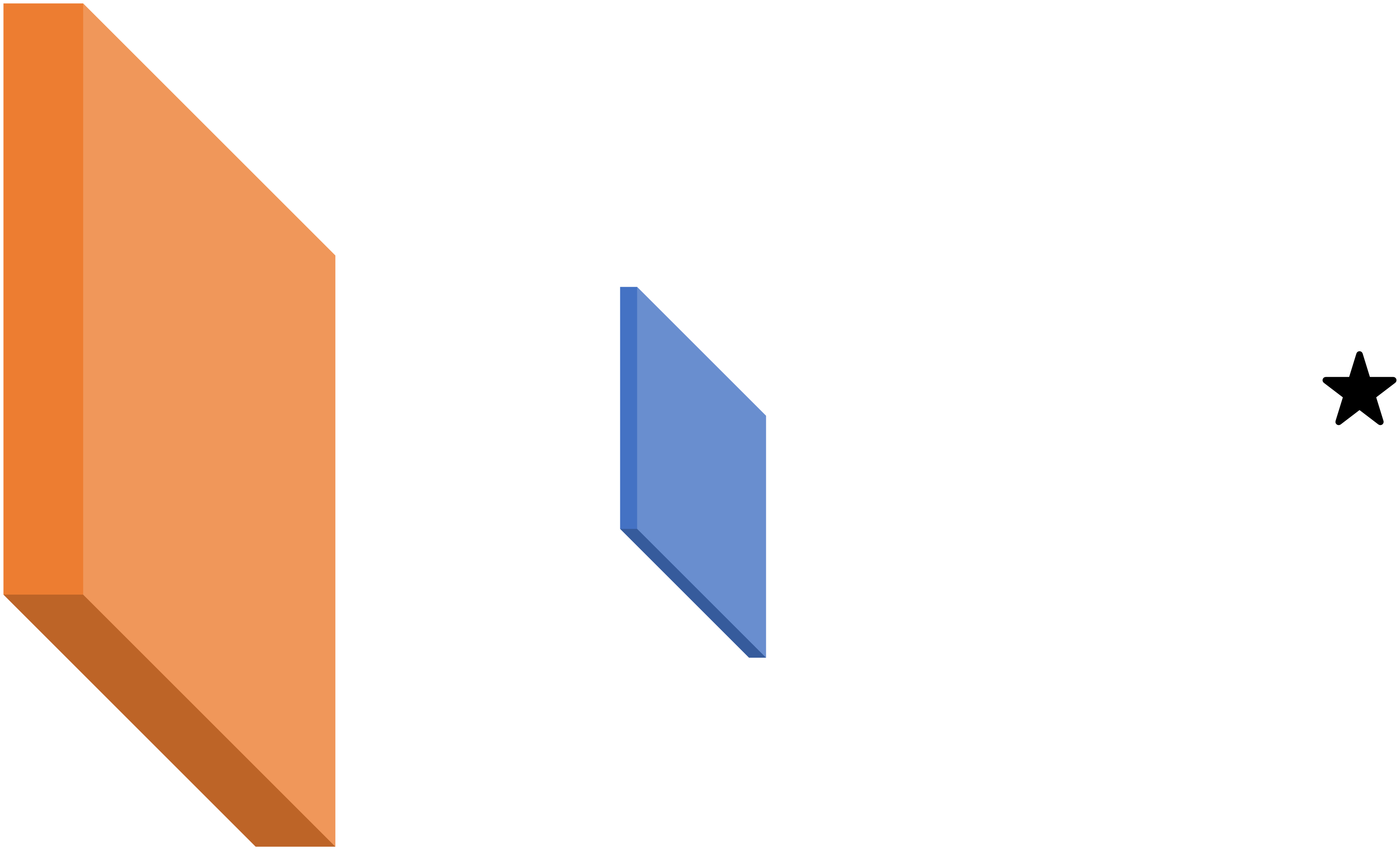
- Photoelectric effect dominates at soft X-ray energies (tens of keV)
- Compton effect dominates ~ MeV energies
- Our target range: 100s of keV



Compton Imaging



Compton Imaging



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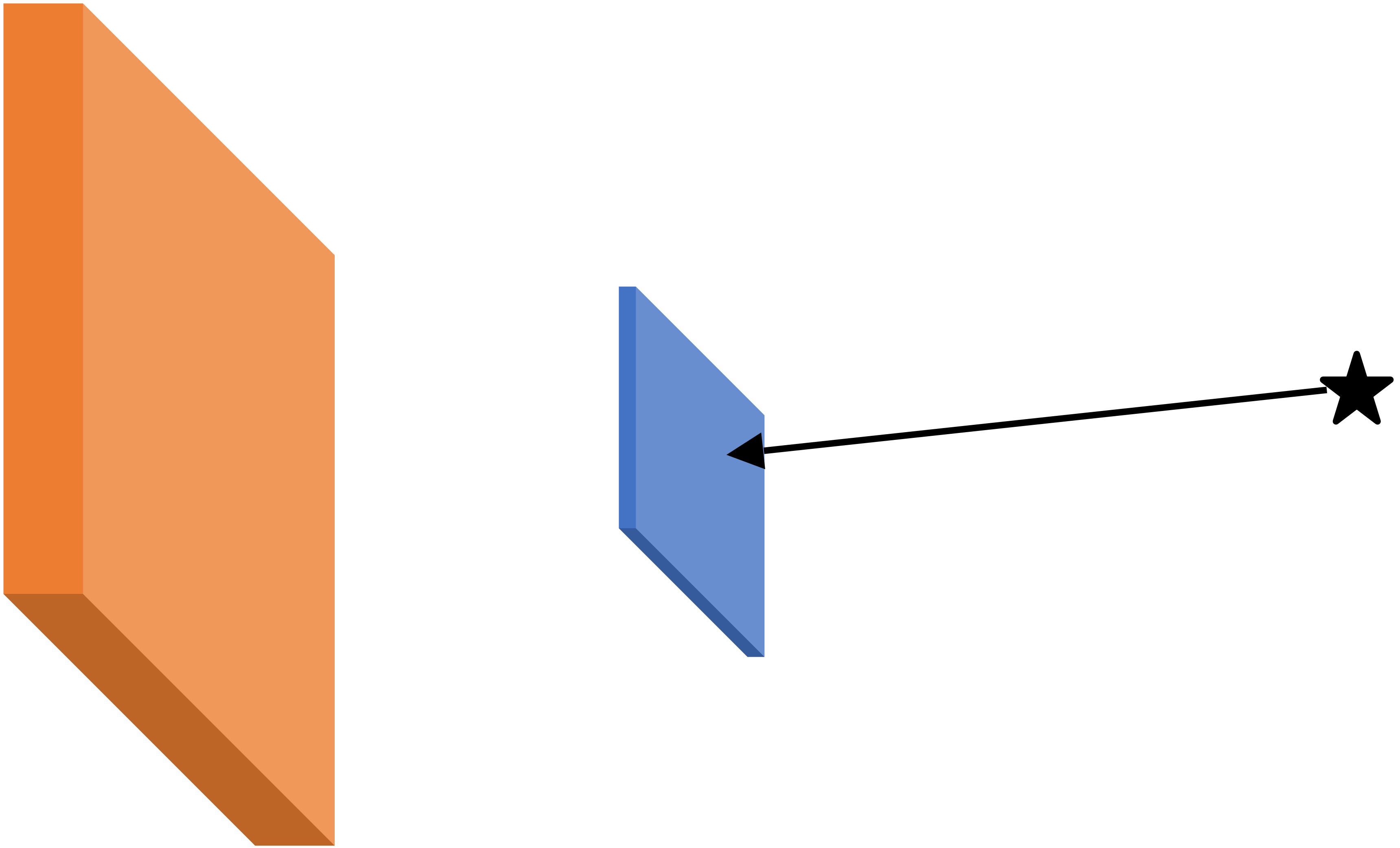

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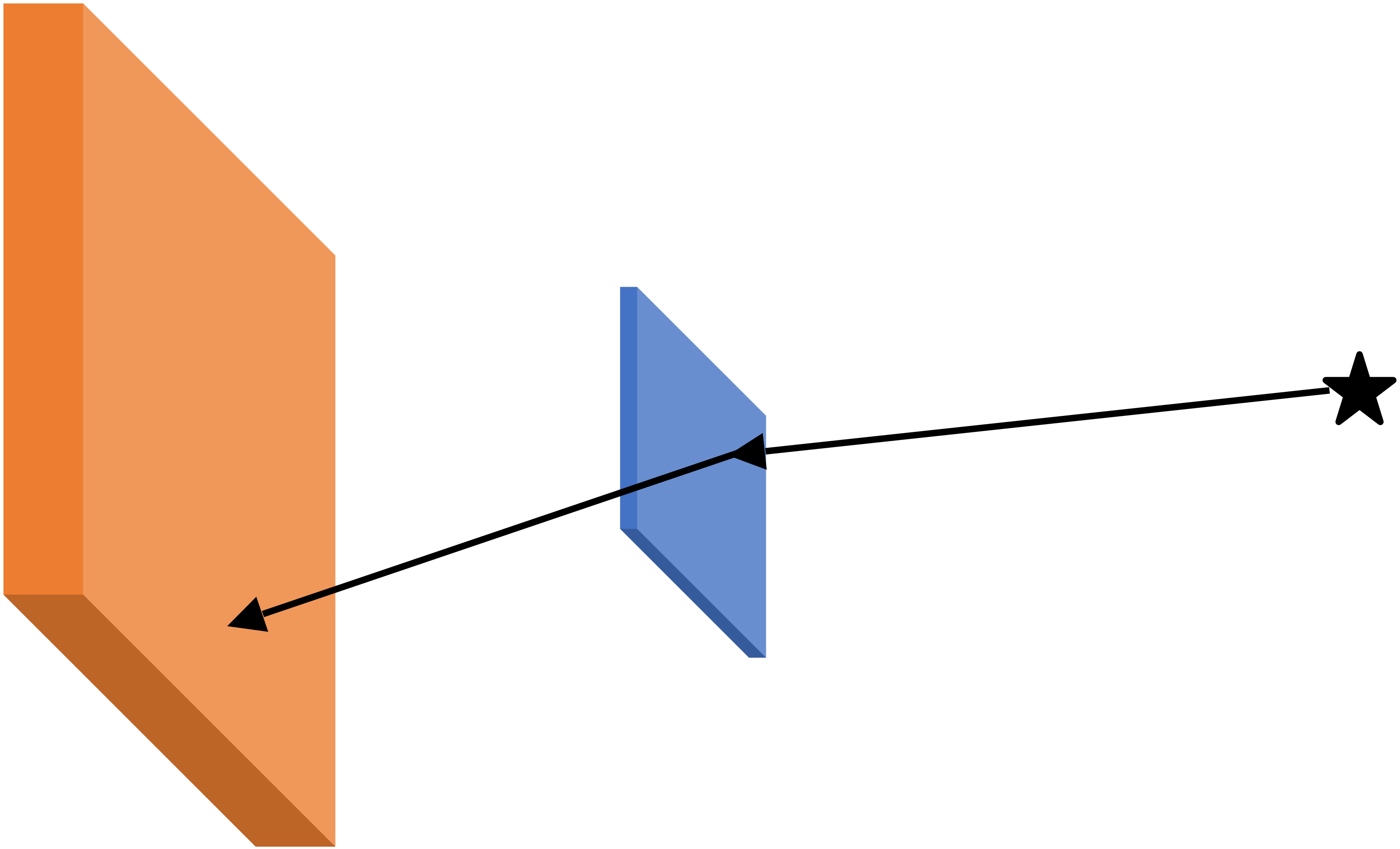

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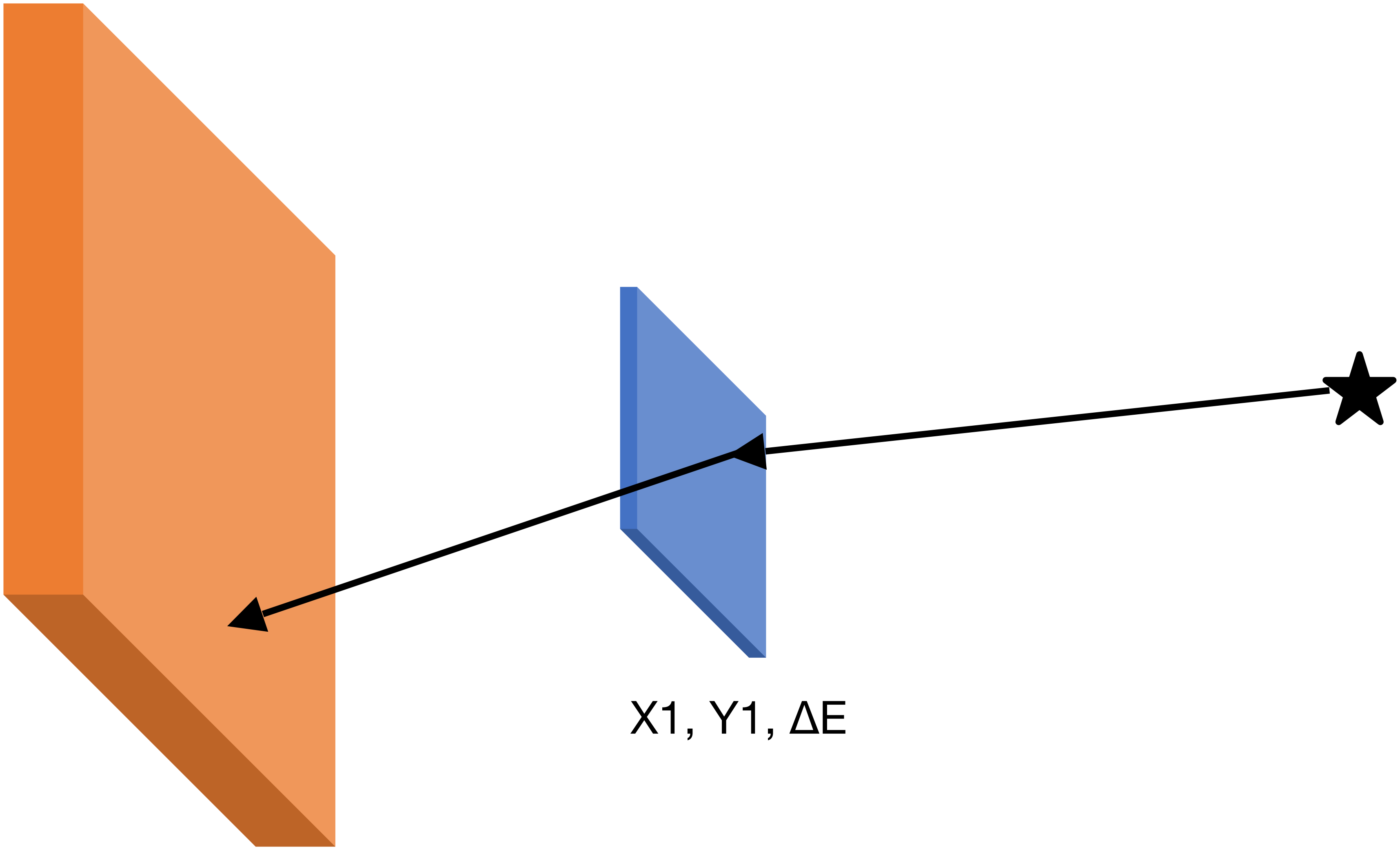

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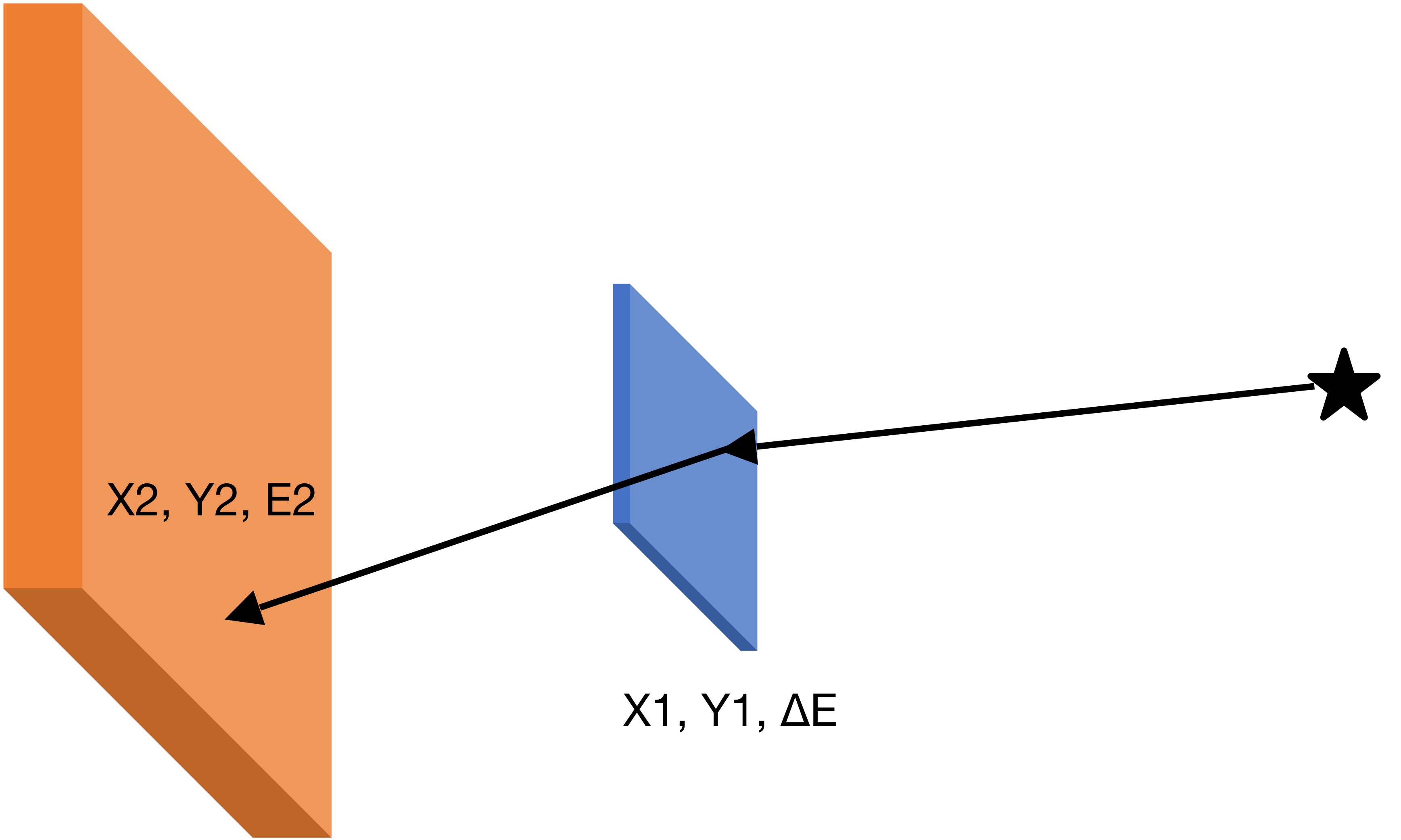

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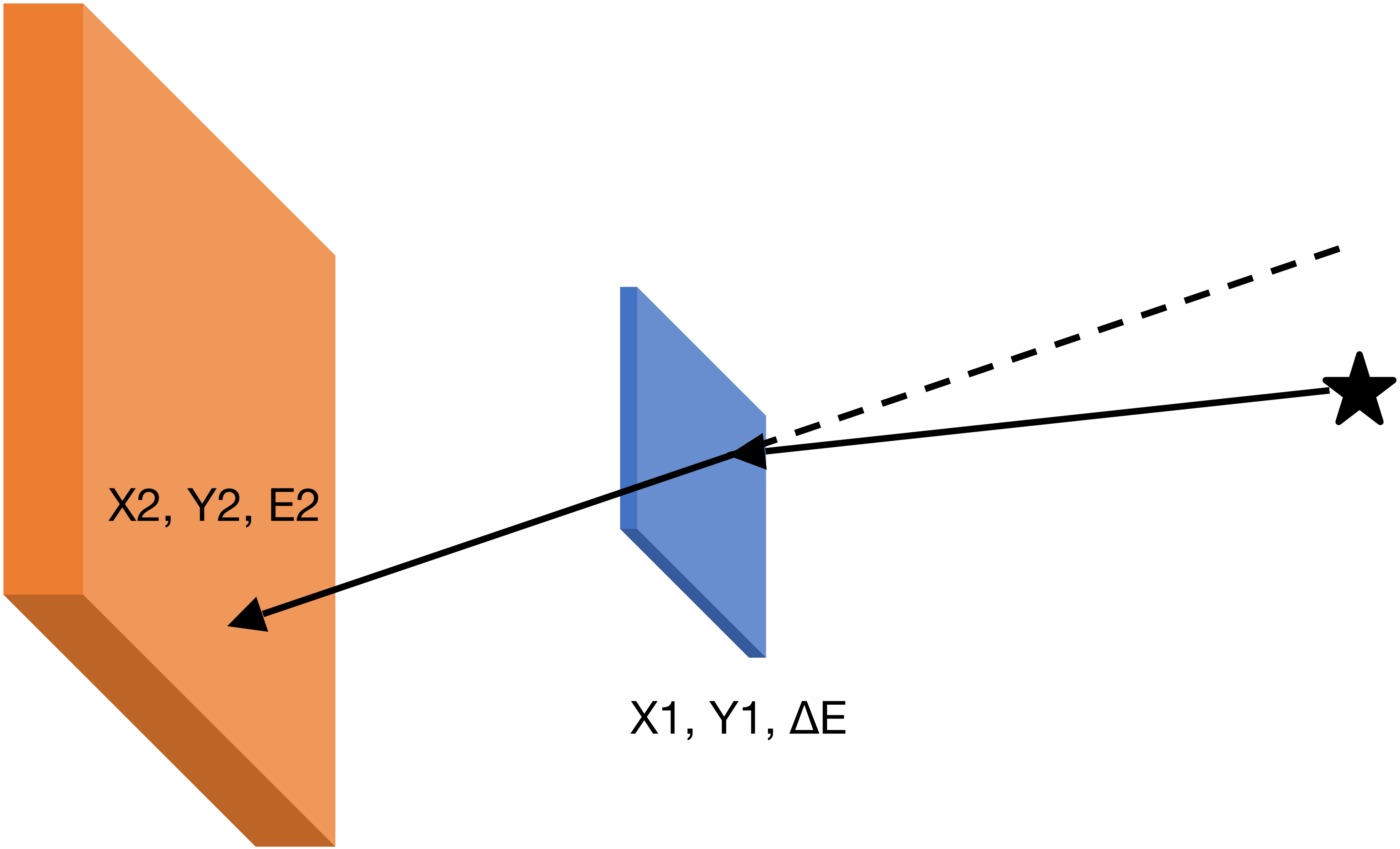
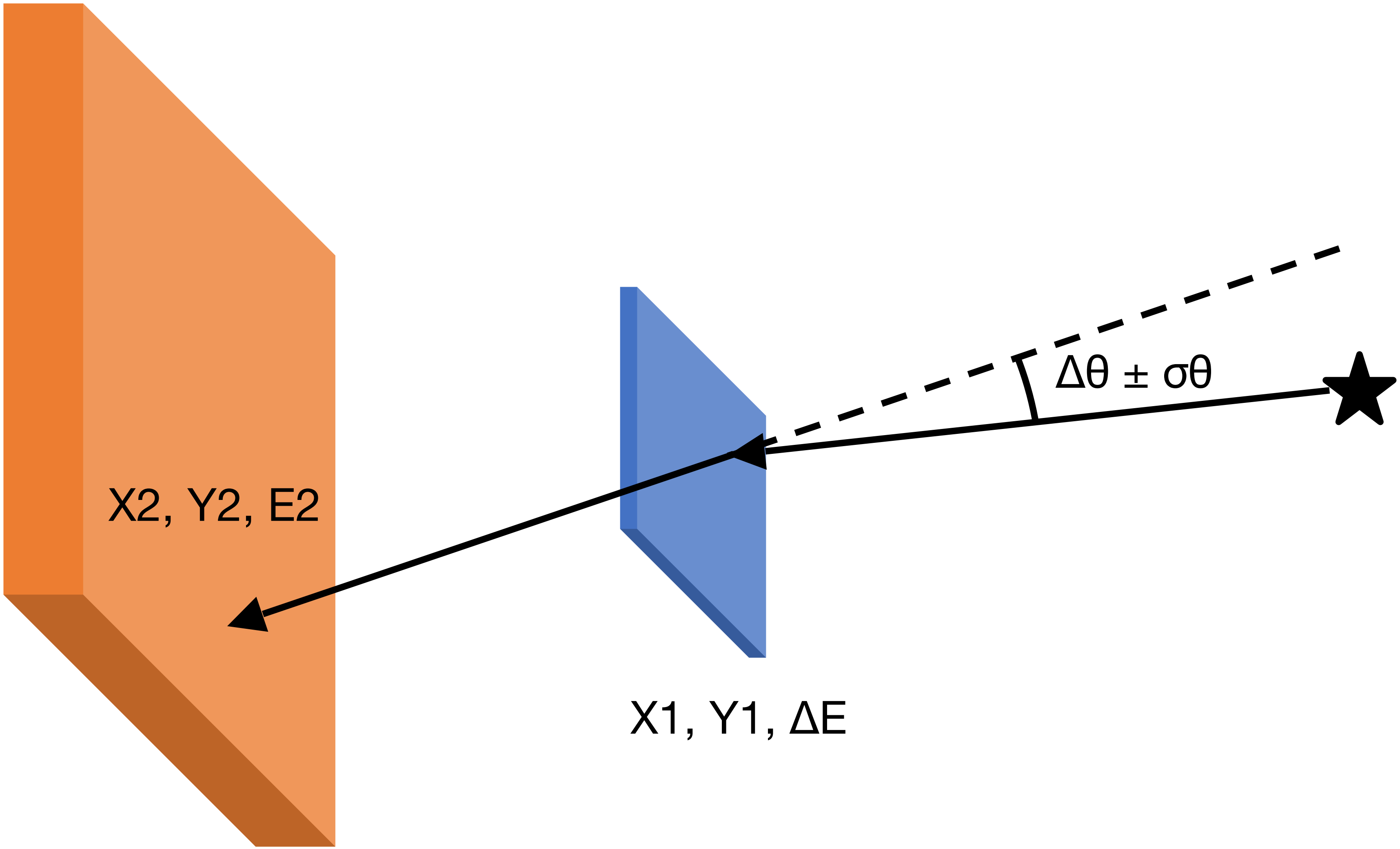


Compton Imaging



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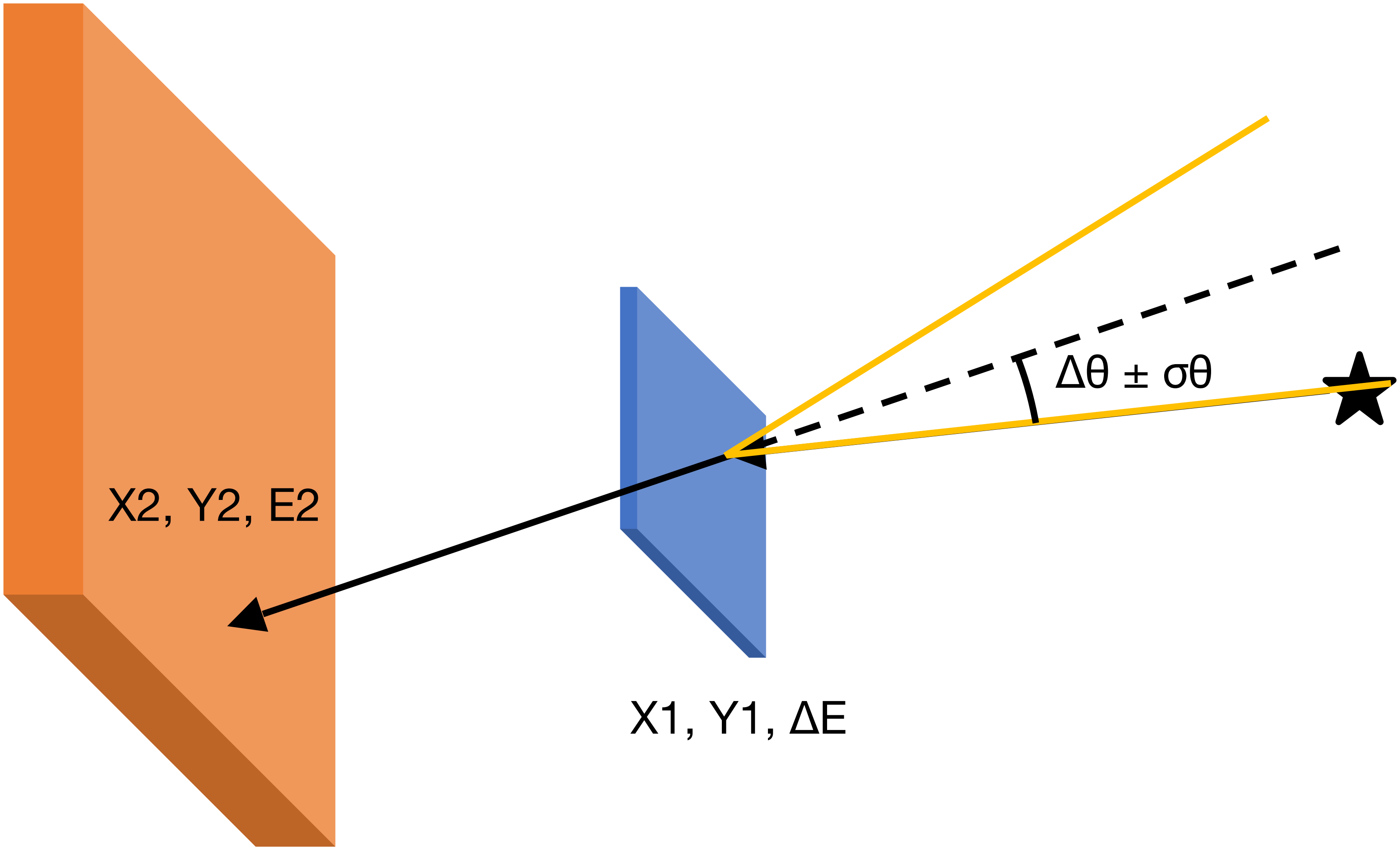

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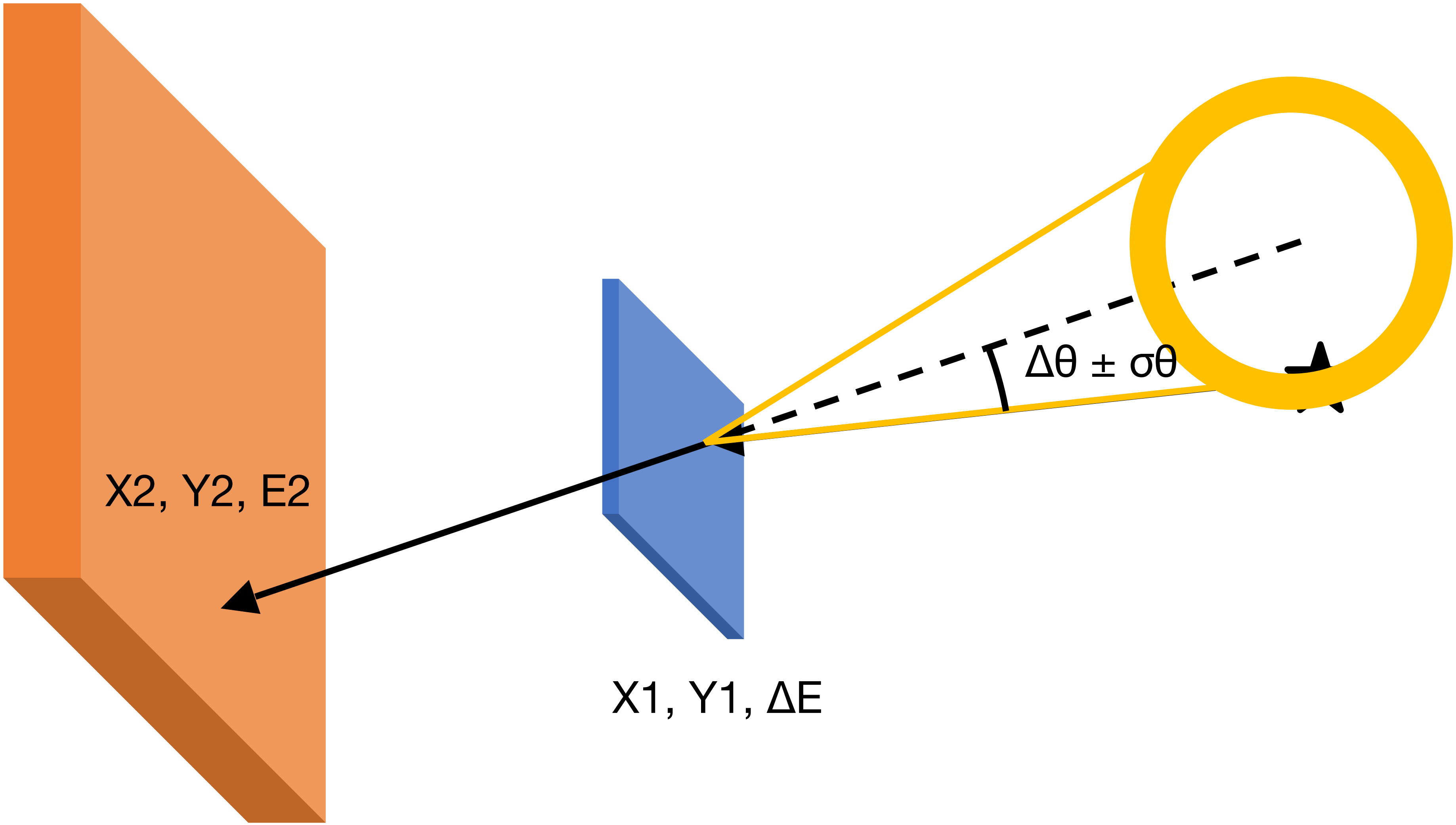

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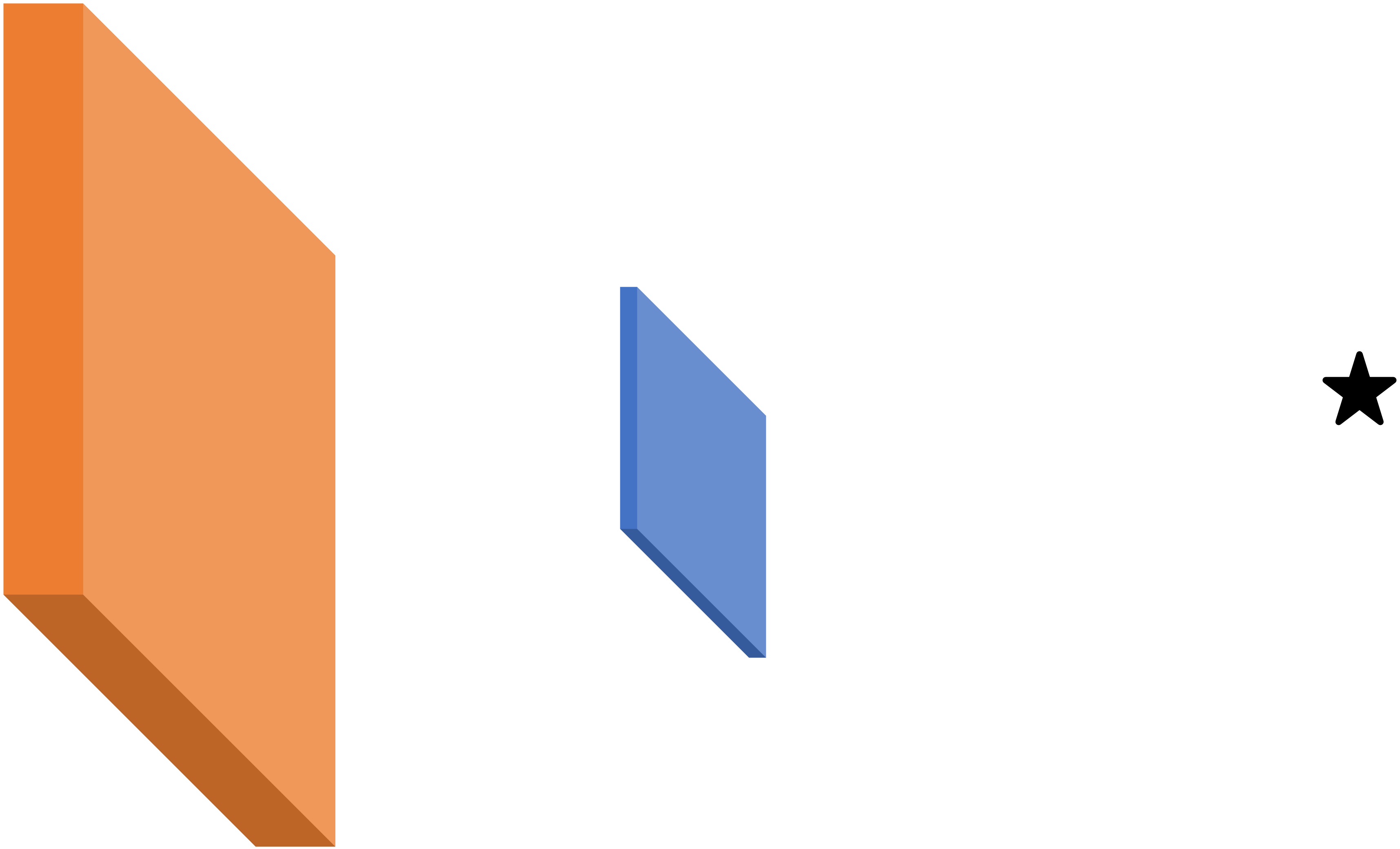

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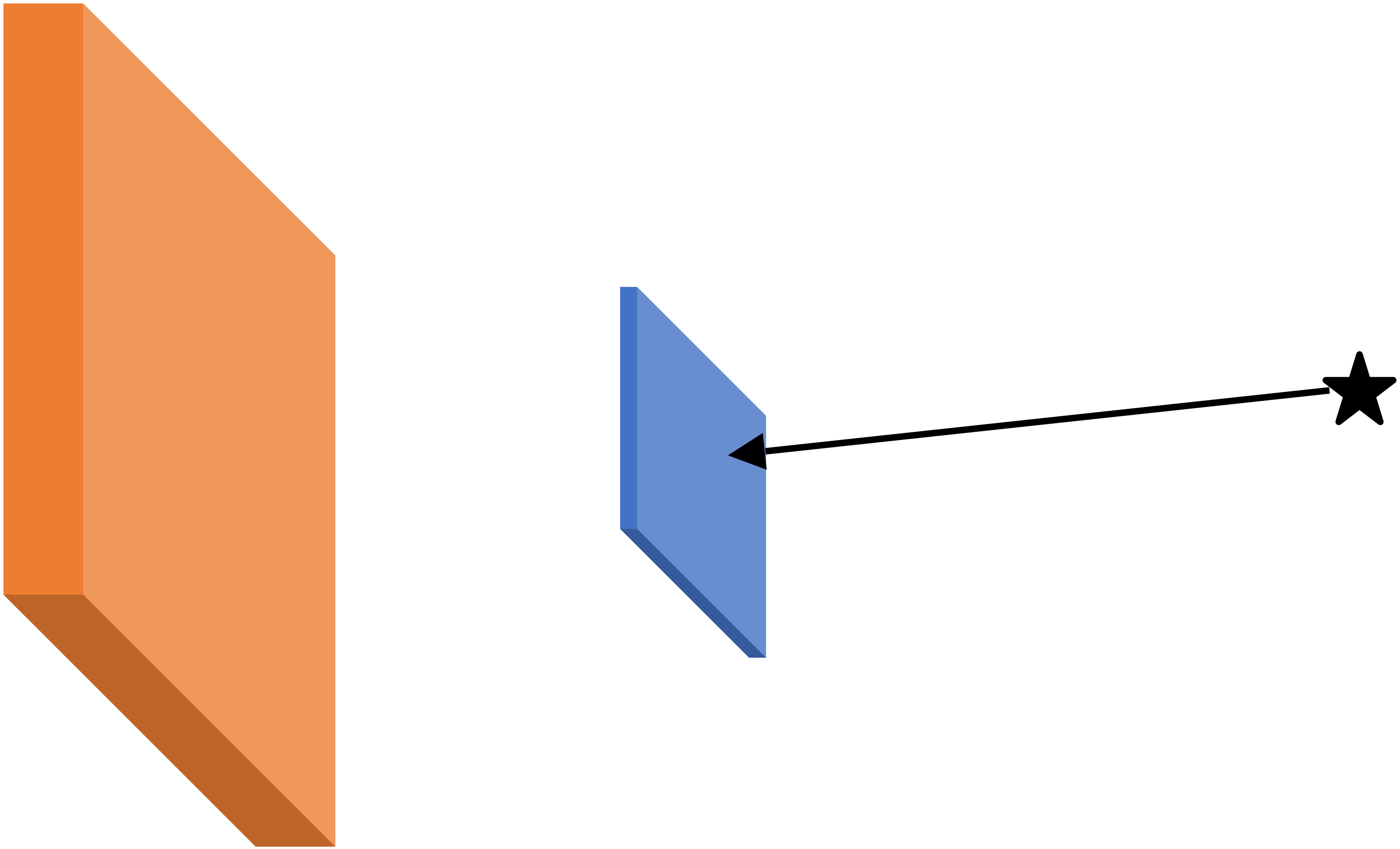

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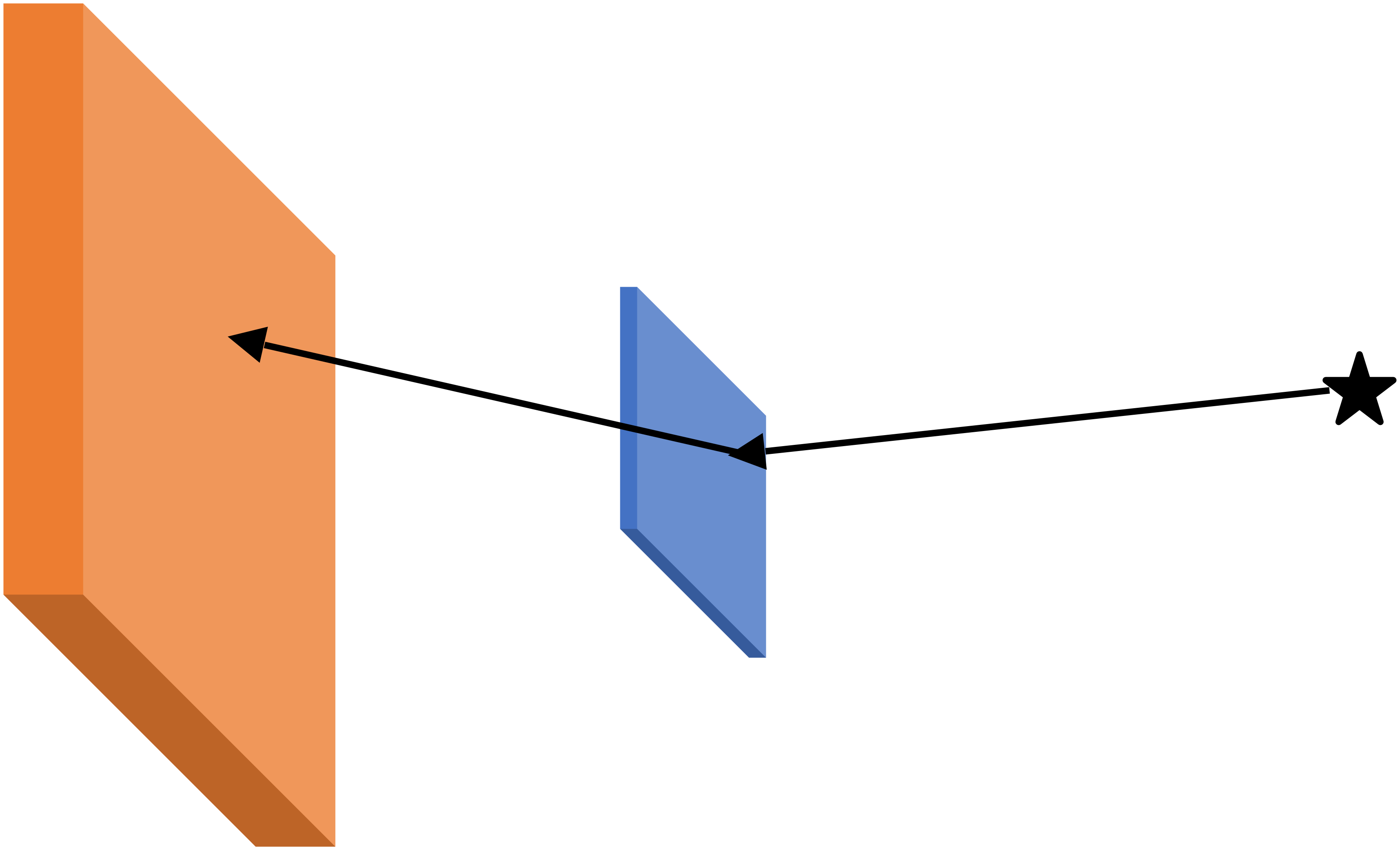

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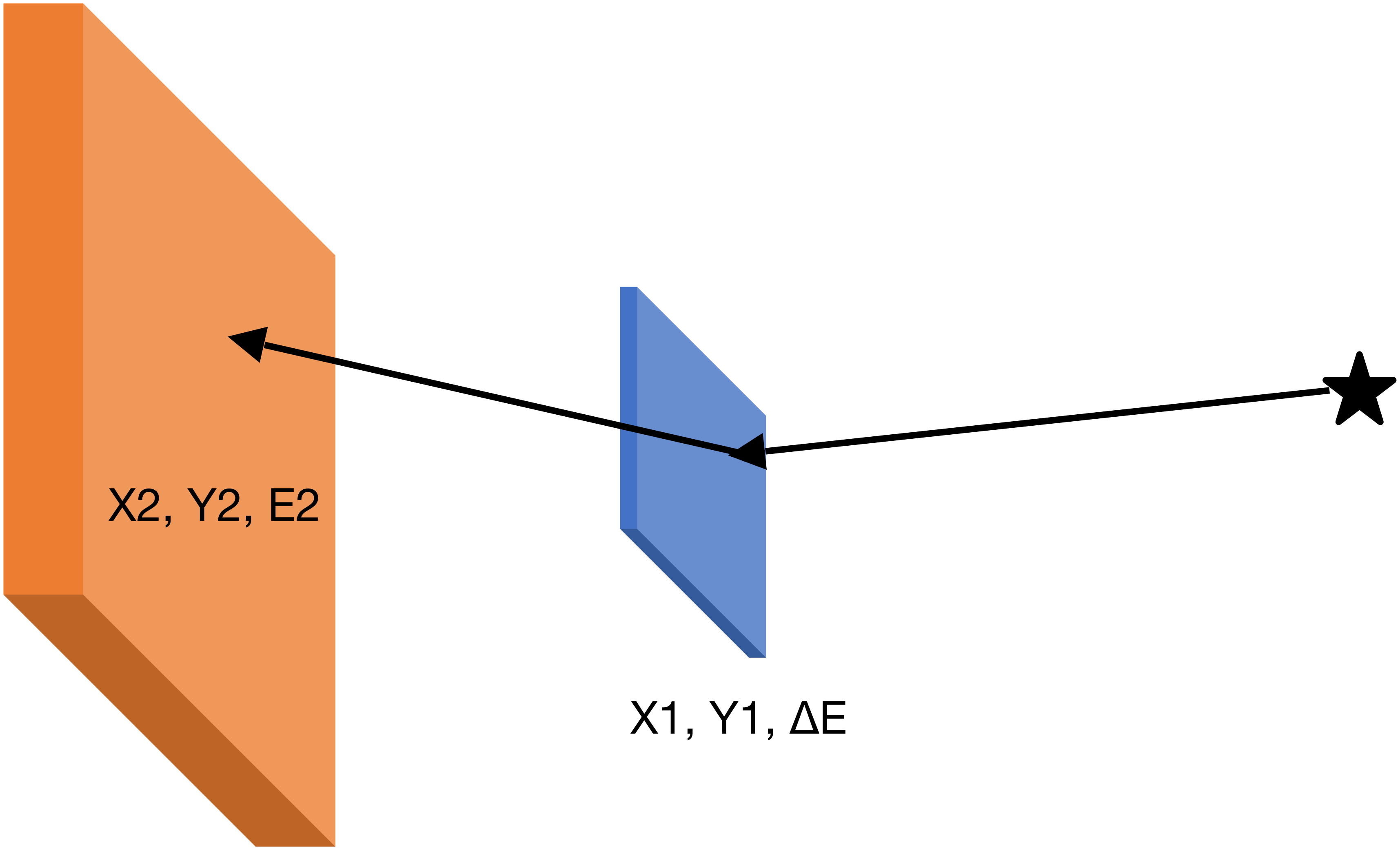

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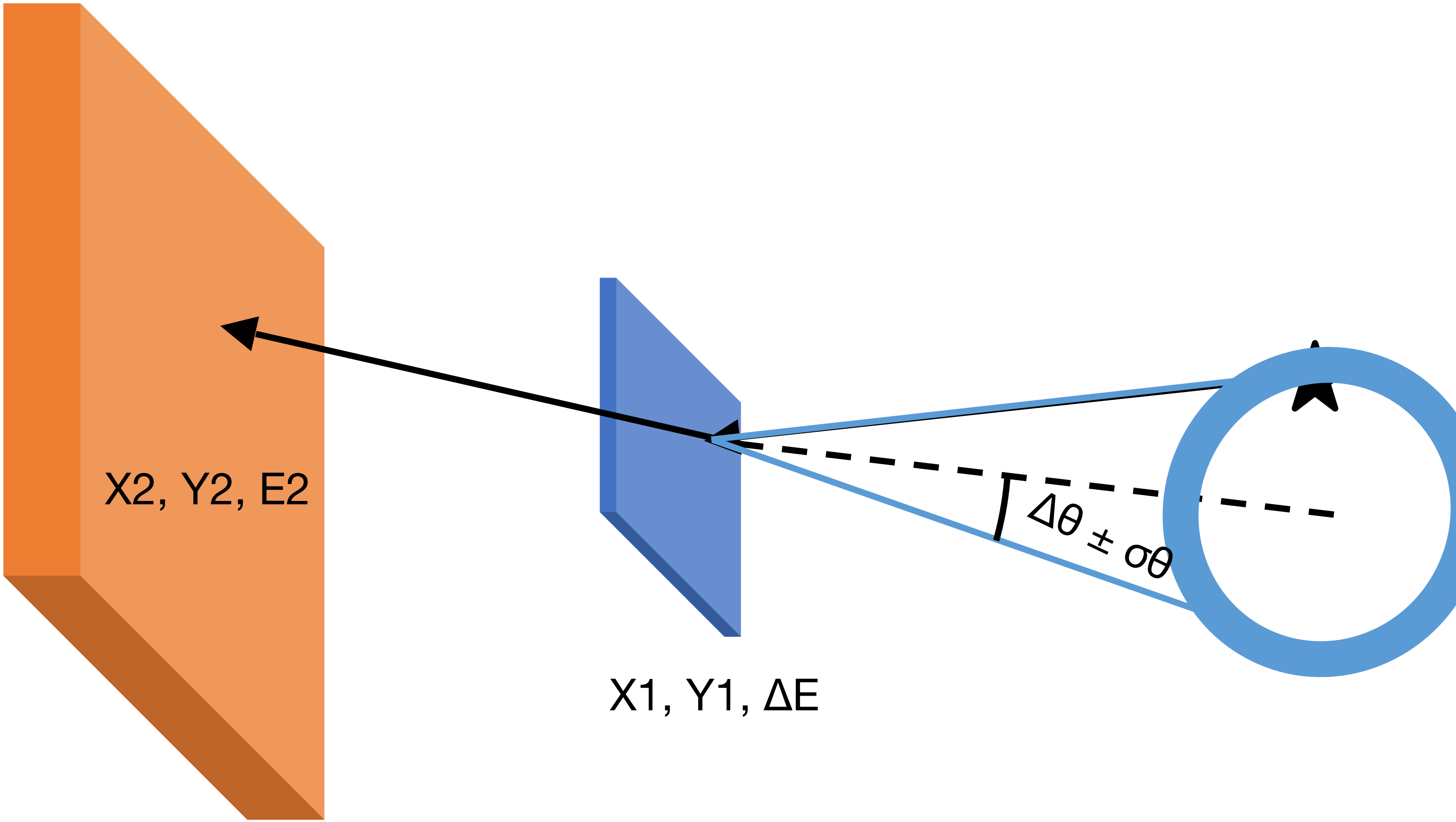

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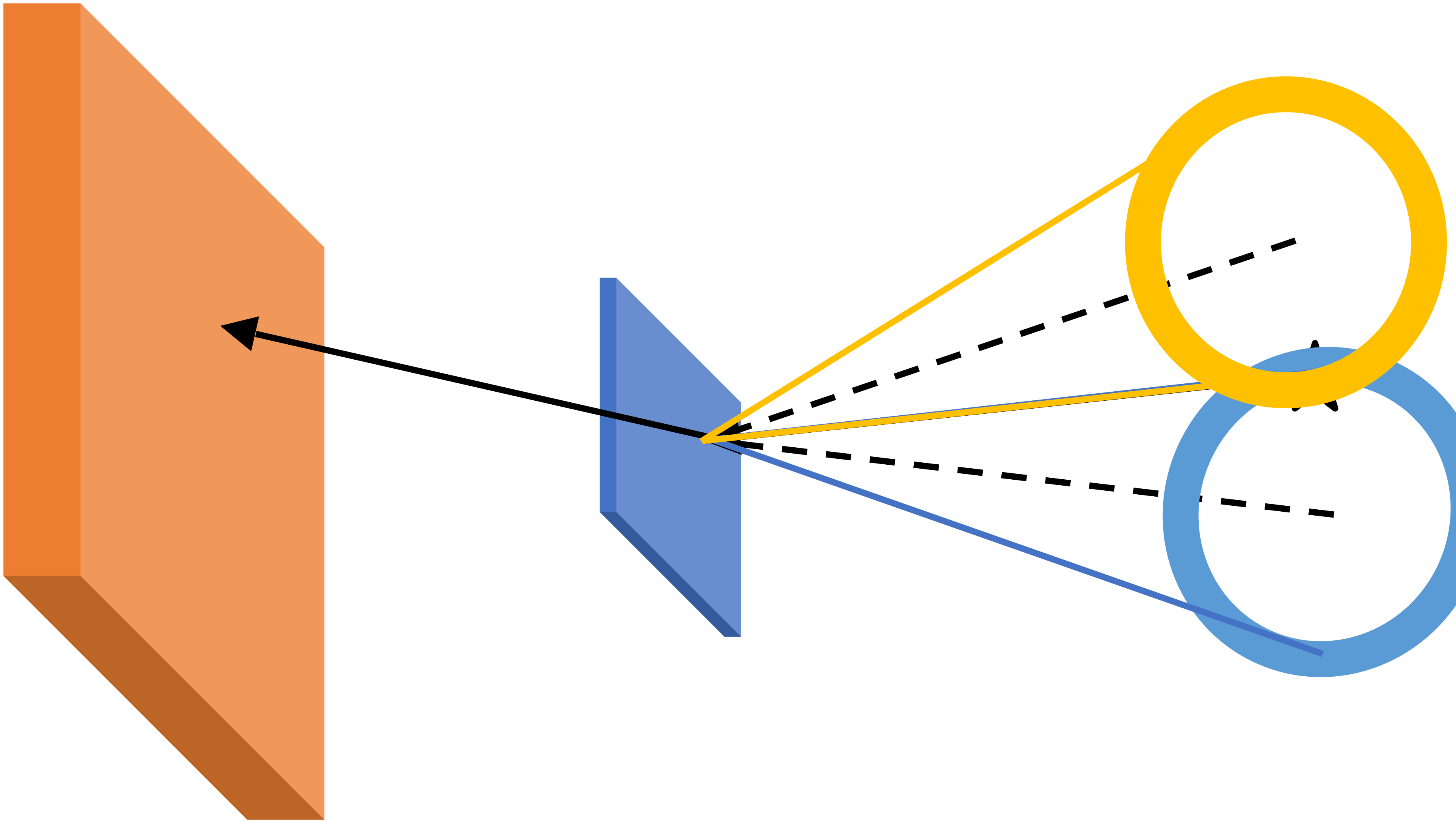

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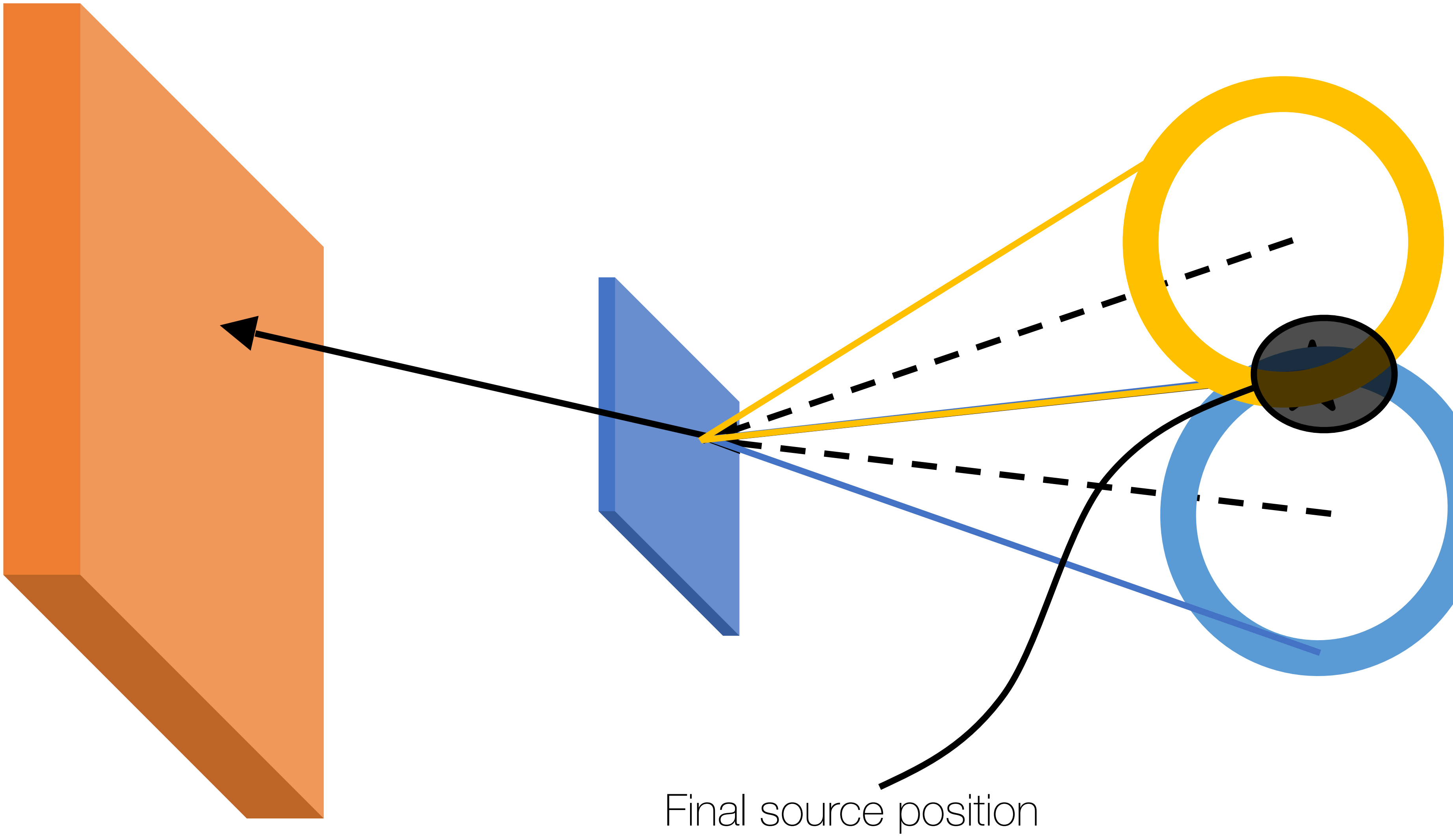
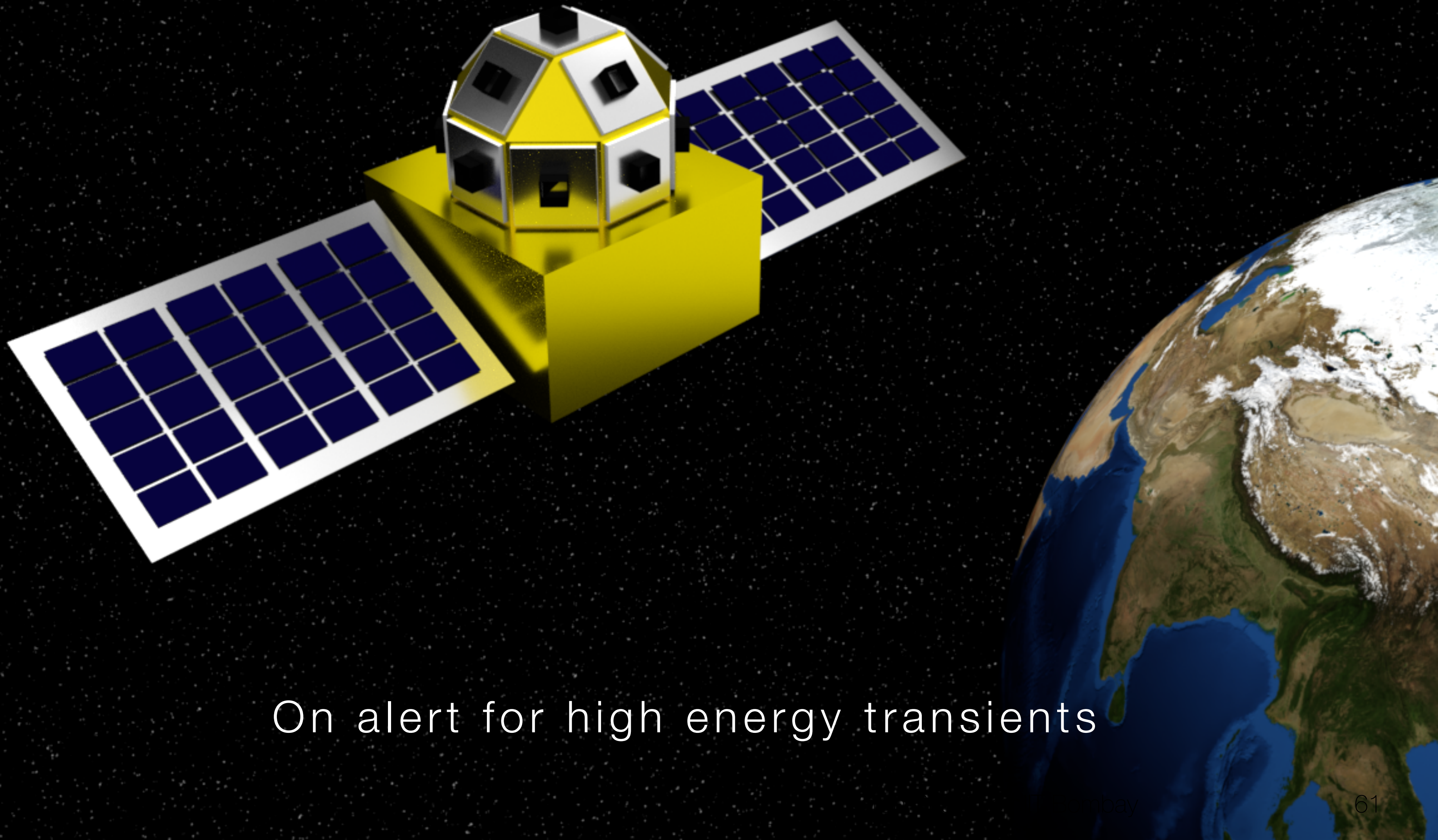


Daksha summary

- 2 satellites, average 86% coverage
- High sensitivity
- Broadband: 1 keV – 1 MeV
  - » Only all-sky soft X-ray monitor

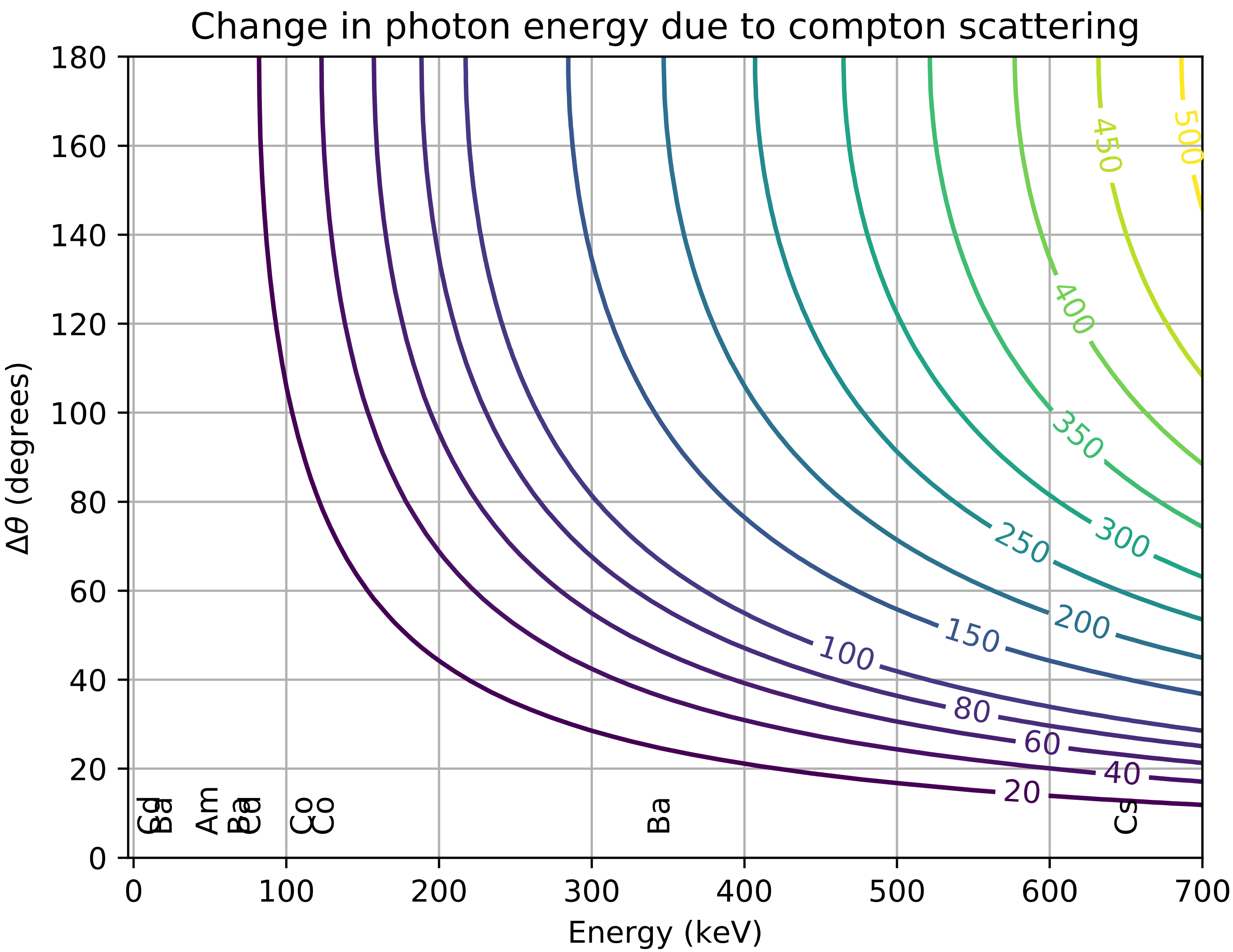
- Annual haul: ~19 BNS, (15 EM + GW), 850 LGRB, 250 SGRB
- GRB polarisation
- All-sky Compton map

Daksha

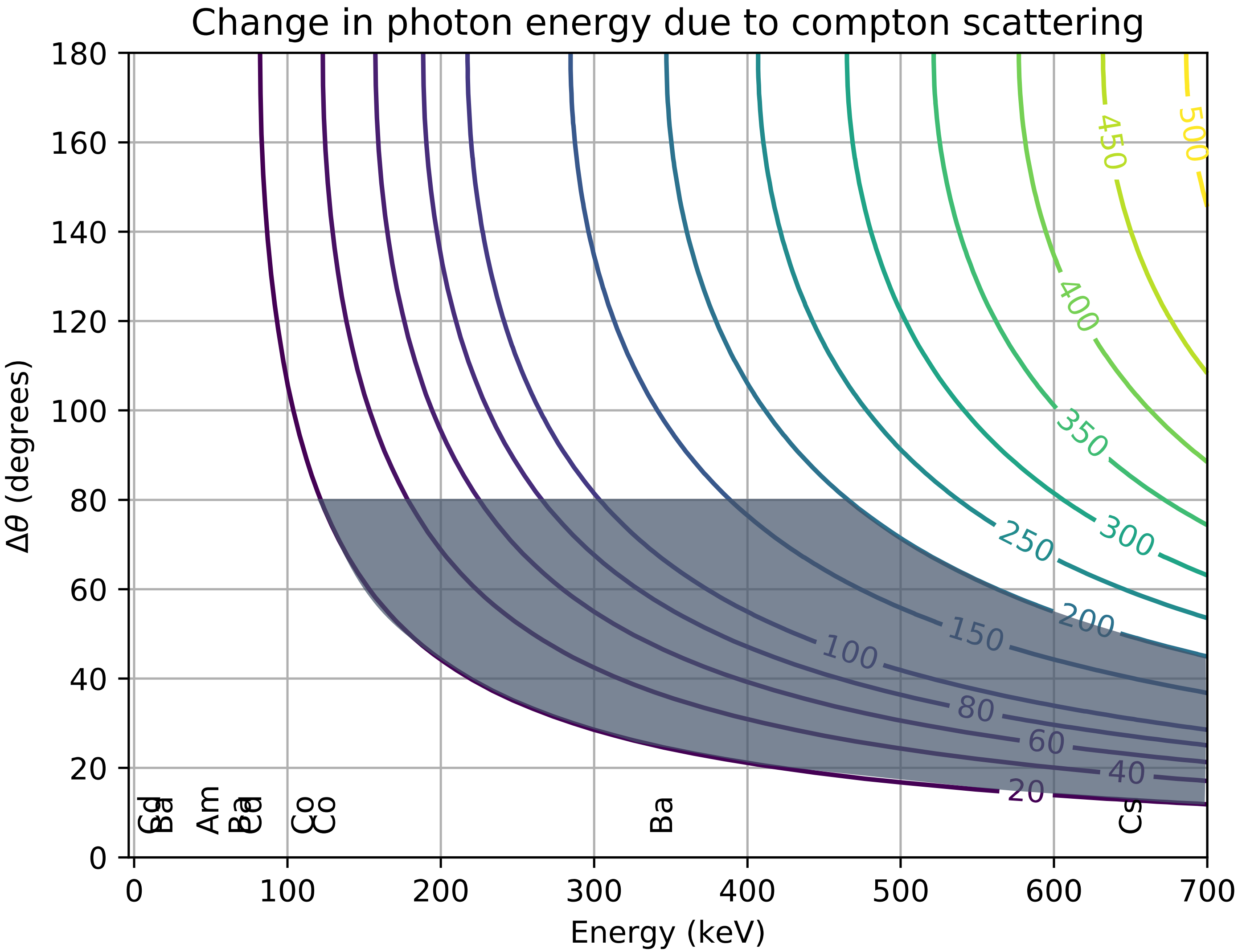


On alert for high energy transients

Compton Sensitive region



Compton Sensitive region



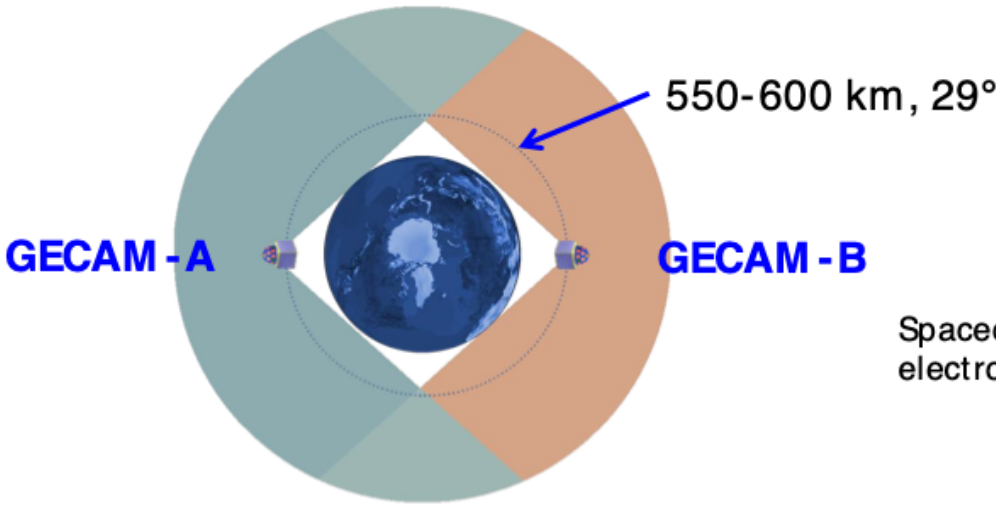
Other Future Missions

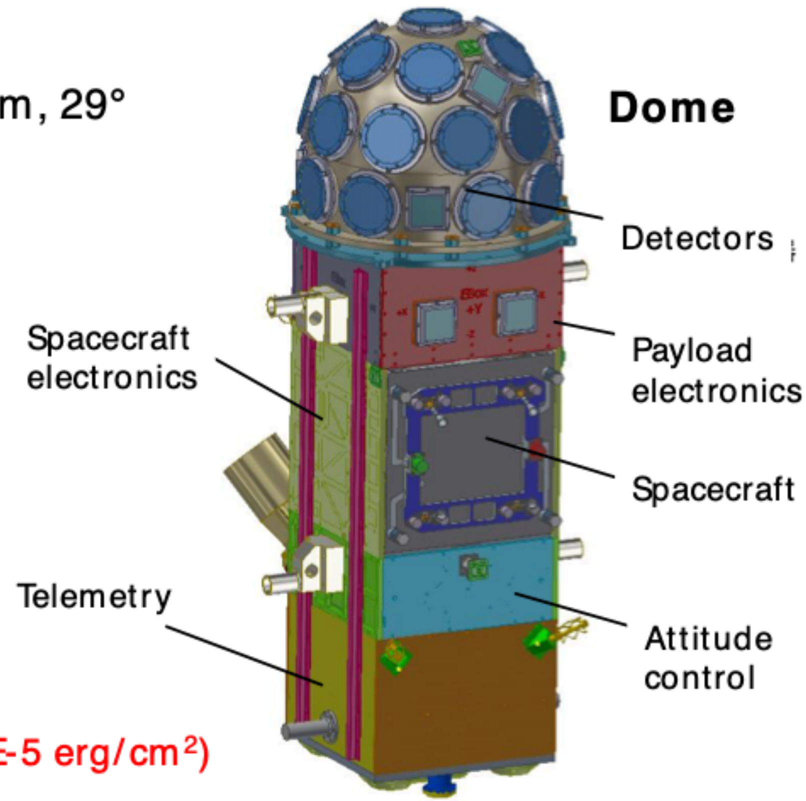
Small satellites and survey missions

- BurstCube (NASA GSFC ++)
  - » 1/20 collecting area (52 cm^2)
  - » CsI: 10 keV – 1 MeV
  - » Launch: 2022/23
- HERMES (Italy)
  - » 1/20 collecting area (50 cm^2)
  - » CsI / LaBr3: 3 keV – 50 MeV
  - » Unfunded
- Few lobster-eye concepts (ISS-TAO, China, Theseus)

GECAM

Gravitational wave high-energy Electromagnetic Counterpart All-sky Monitor





GECAM satellite (~140 kg for each)

- **Characteristics**
  - **FOV:** 100% all-sky
  - **Sensitivity:** ~2E-8 erg/cm²/s
  - **Localization:** ~1 deg (1-σ stat., 1E-5 erg/cm²)
  - **Energy band:** 6 keV – 5 MeV
- **Planned to launch by the end of 2020**
  - since LIGO will reach the design sensitivity around 2020 to 2021

Slide from Shaolin XIONG, Institute of High Energy Physics (IHEP), Chinese Academy of Sciences (CAS)

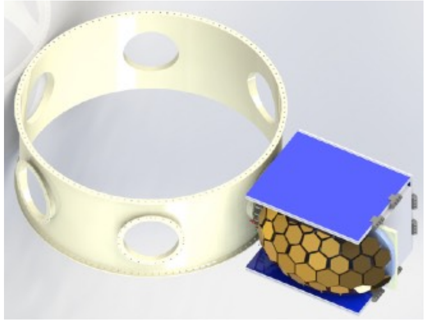
U.S. NAVAL RESEARCH LABORATORY

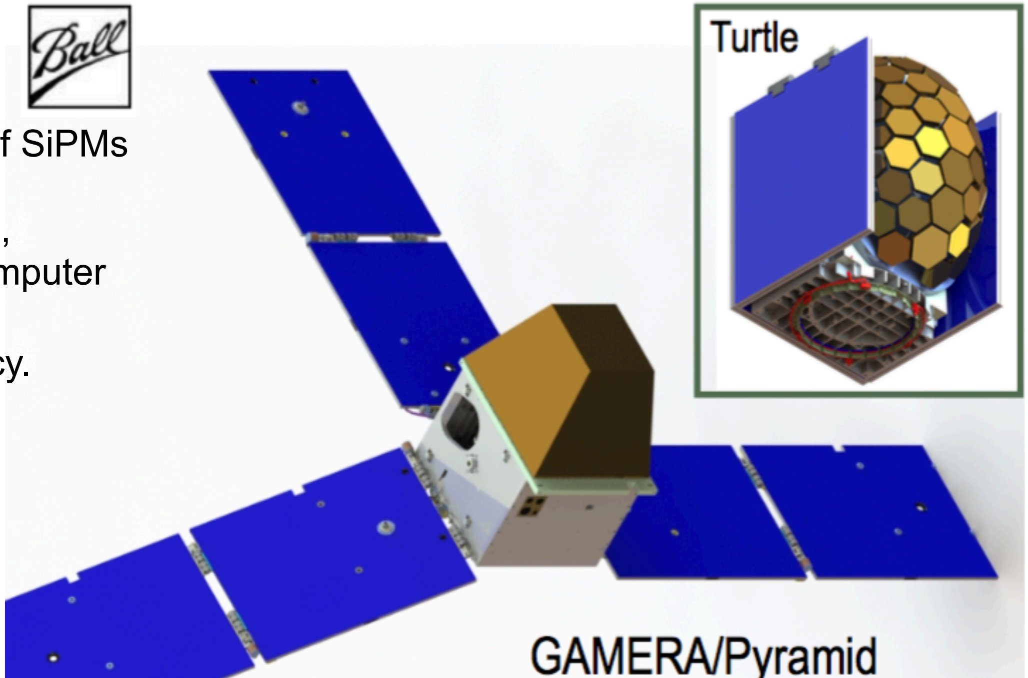
GAMERA Mission Concept – Instrument

GAMERA/Pyramid truncated pyramid CsI array (base 60x50 cm, height 40 cm). Dimensions fill ESPA volume and mass limit and are compatible with a standard SmallSat bus. Total instrument masses are ~70 kg.

GAMERA/Turtle ellipsoidal dome array spanning the longer ~90x60 cm dimensions of the ESPA volume. More efficiently exposes detector area to the sky, but requires a modified spacecraft bus layout.

- Scintillator modules read out with an array of SiPMs digitized by a multichannel analyzer.
- Time-tagged pulse-height data are collected, processed, and stored by a single-board computer that interfaces with the spacecraft bus.
- GPS provides absolute time with μs accuracy.





GAMERA concepts on BCP-100 (Pyramid) / custom (Turtle) spacecraft.