Future mission CAMELOT for localisation of gamma-ray transients by fleet of cubesats

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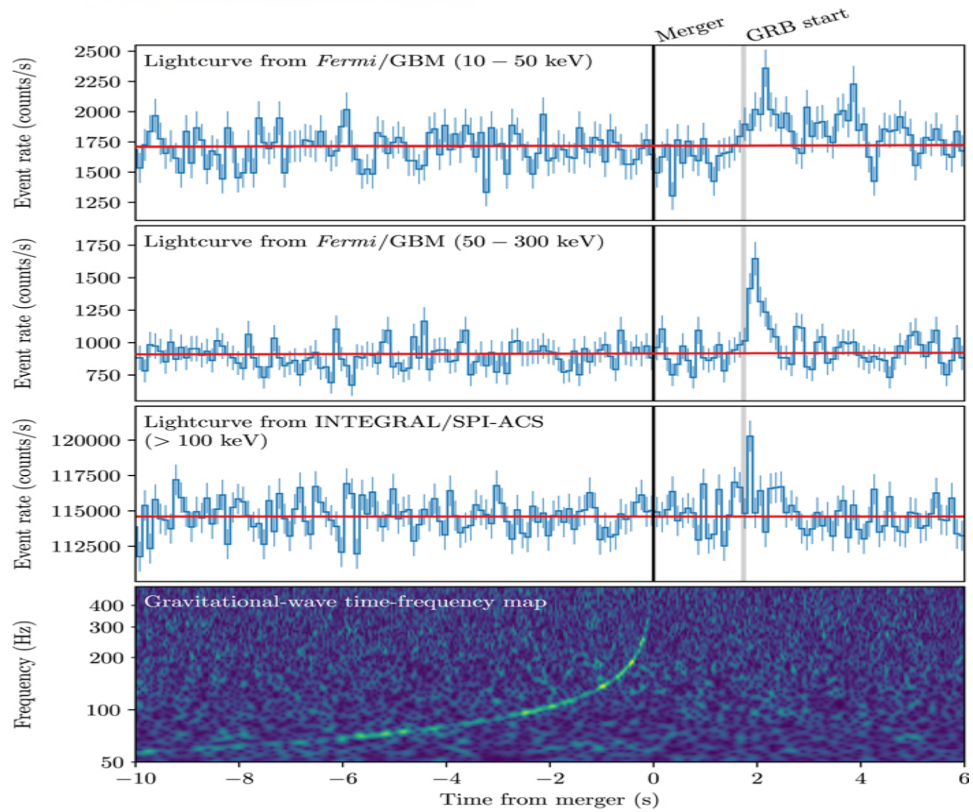
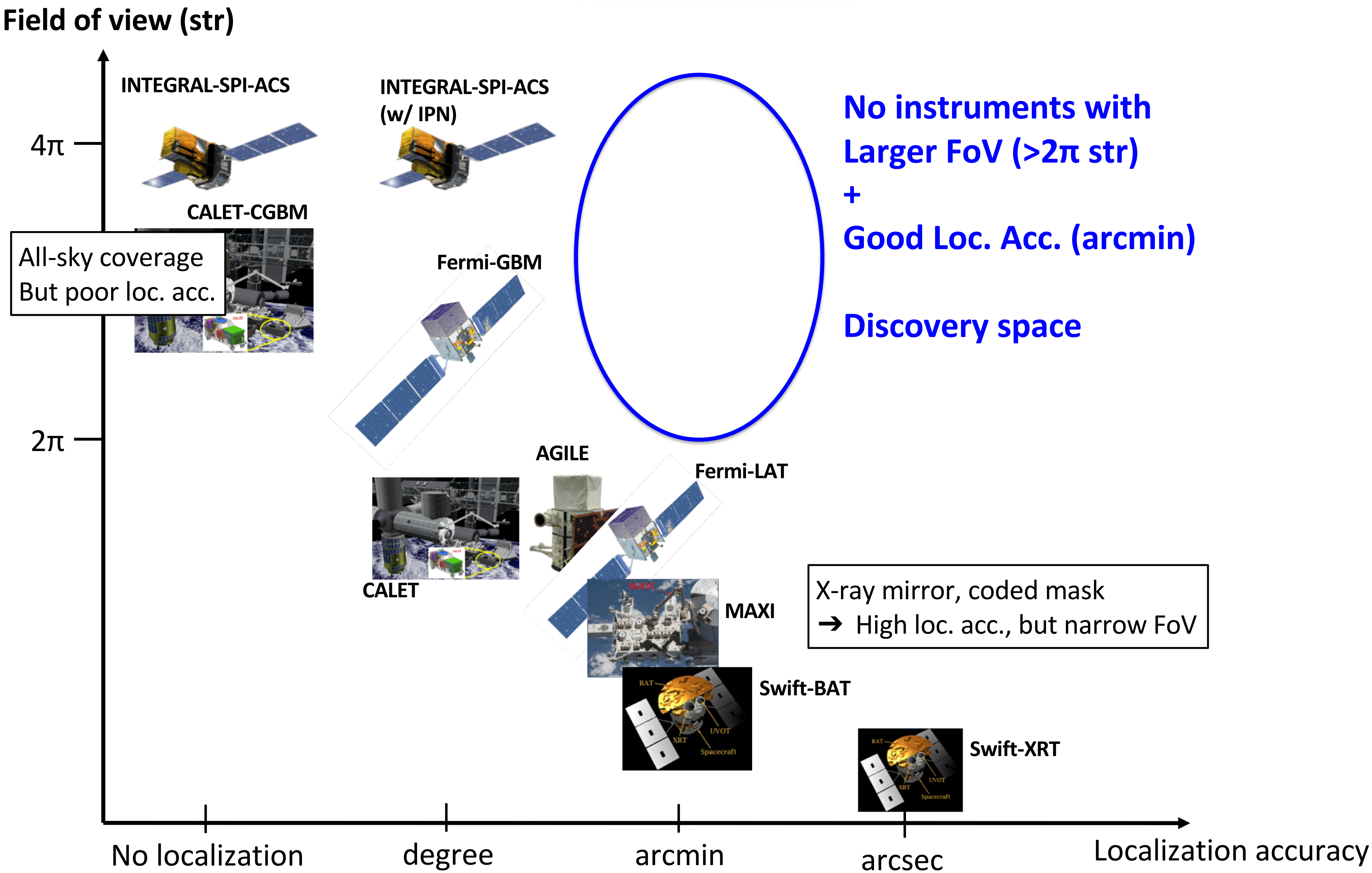
17. 08. 2017
BEGINNING OF MULTI-MESSENGER ASTROPHYSICS OF GRBs

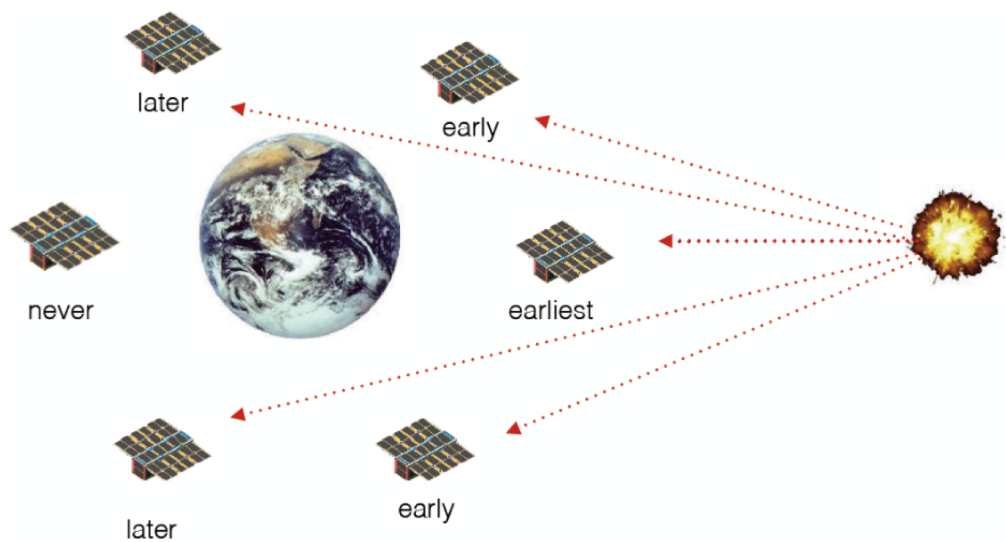


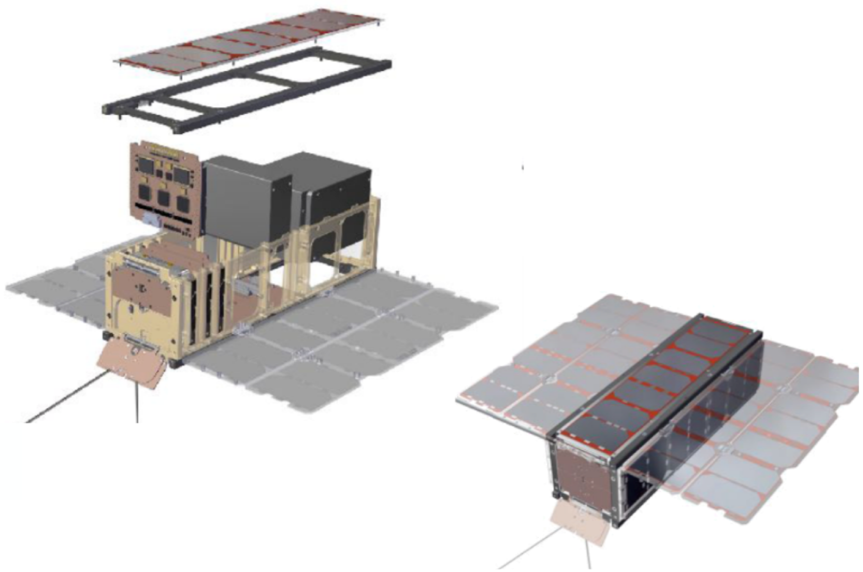
- 5 gravitational wave detections from BH-BH merger
- EM counterpart from NS-NS merger event GW170817/GRB170817A
- Large campaign of follow-up observations identified a kilonova
- The gamma-ray counterpart is unusual
- **Regular detections/follow-up observations are needed to make progress**

AN EMPTY REGION IN PARAMETER SPACE



CAMELOT: Cubesats Applied for MEasuring and LOcalising Transients



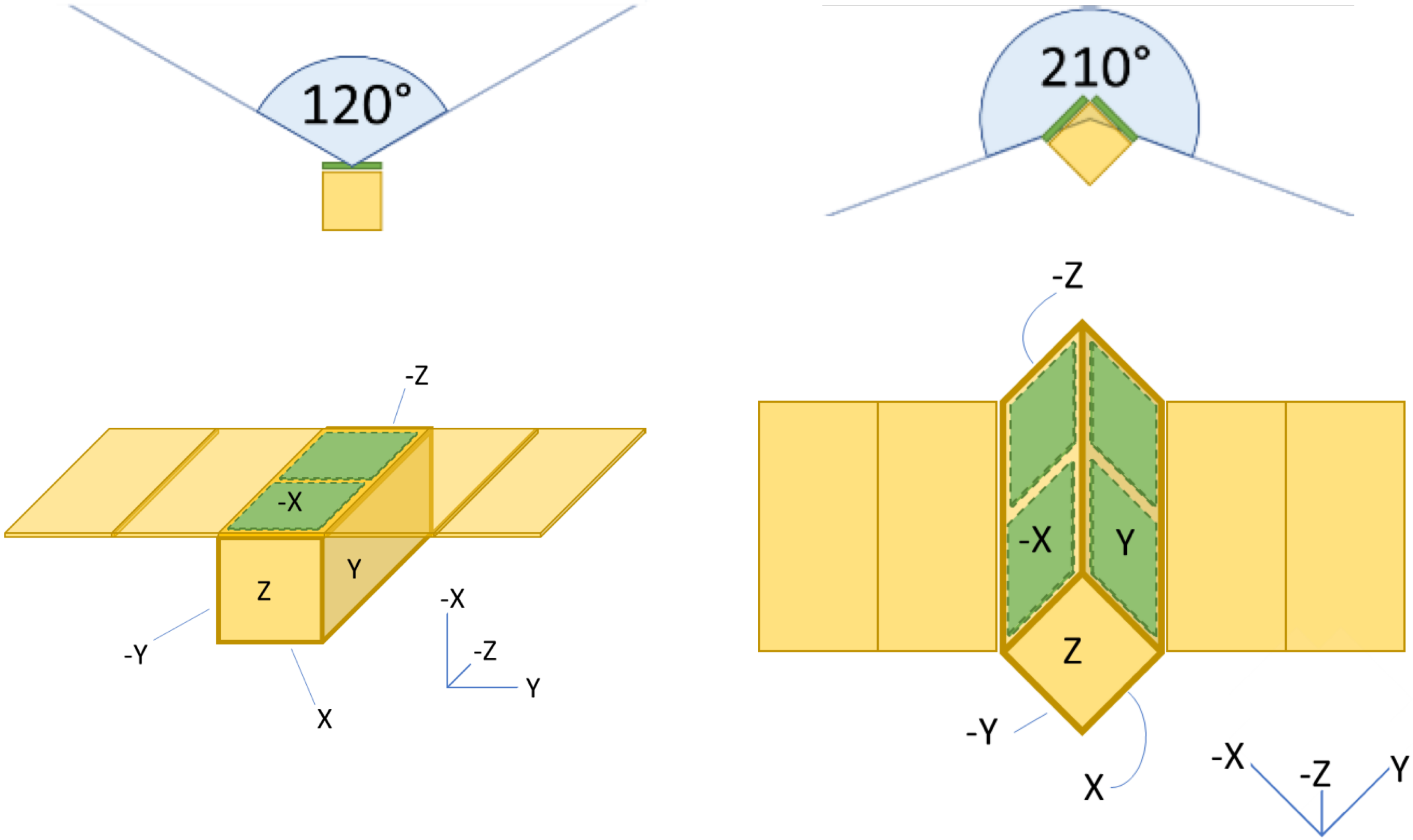


A constellation of at least 9 satellites can provide:

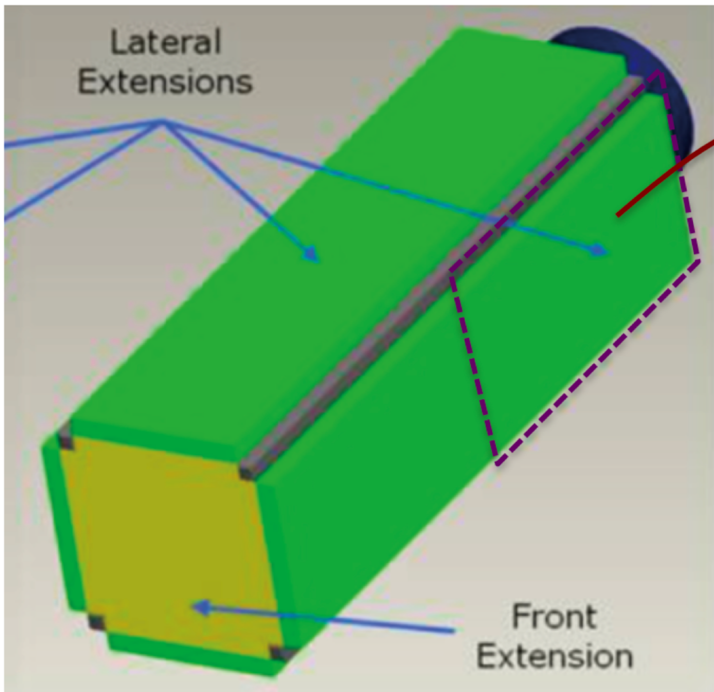
- all sky coverage with a large effective area
- Better than 0.1 millisecond timing accuracy
- ~10 arcmin localisation accuracy using triangulation

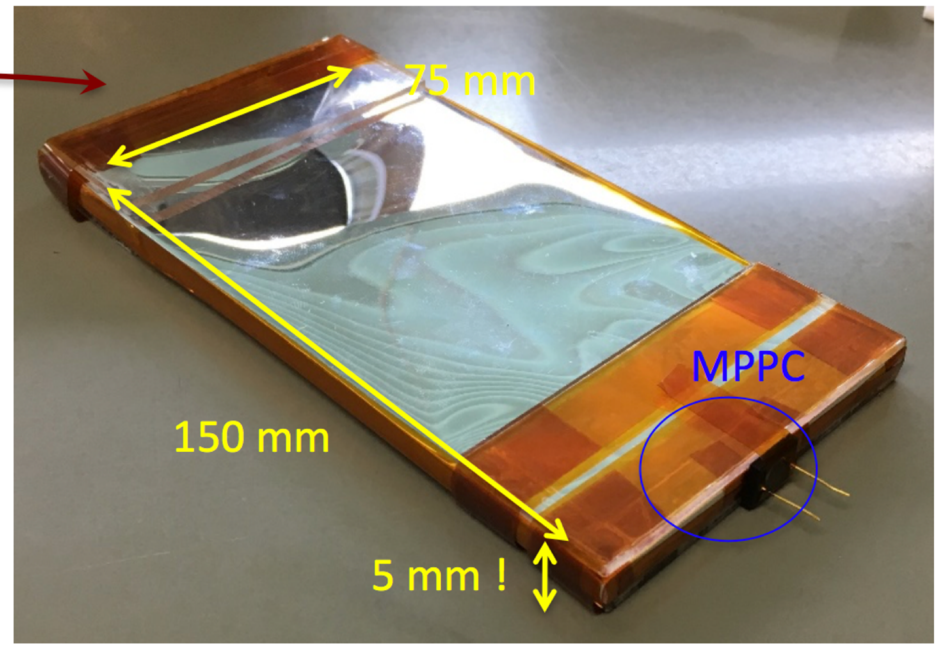
Each satellite will use a standard 3U cubesat platform developed by C3S LLC for the ESA sponsored RadCube mission. The cubsesats will be equipped with a *GPS receiver for precise time synchronisation* and *inter-satellite* (Iridium NEXT) *communication* equipment for *rapid data download*

TWO POSSIBLE DETECTOR CONFIGURATIONS



THE DETECTOR DESIGN



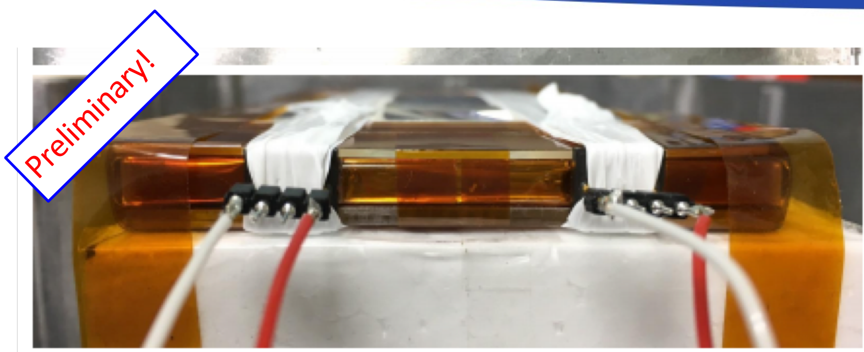


To maximise the effective area, the detectors based on CsI scintillators and Multi-Pixel Photon Counters (MPPC) will occupy two lateral extensions (8.3 cm x 15 cm x 0.9 cm x 4)

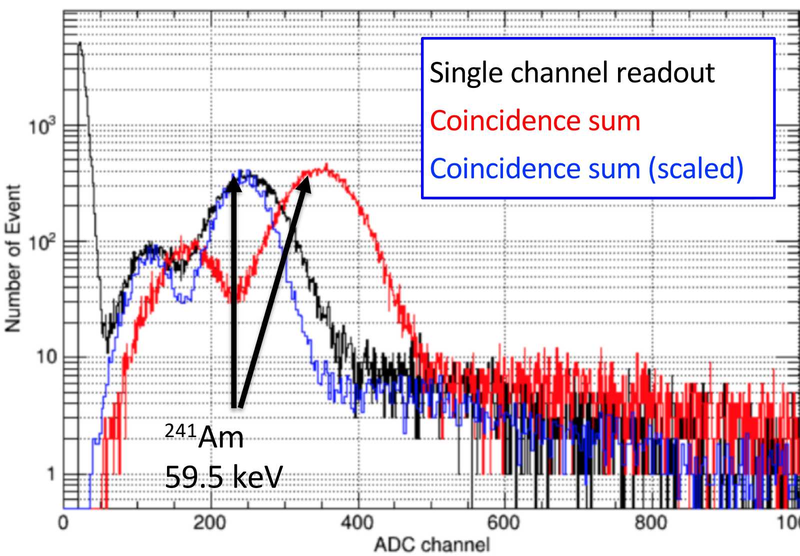
The large and thin detectors with small readout area are challenging

The read out of the CsI detectors with MPPC is currently being evaluated in the lab as part of our feasibility study. The system provides a large light yield, compact readout area and relatively low operational voltage.

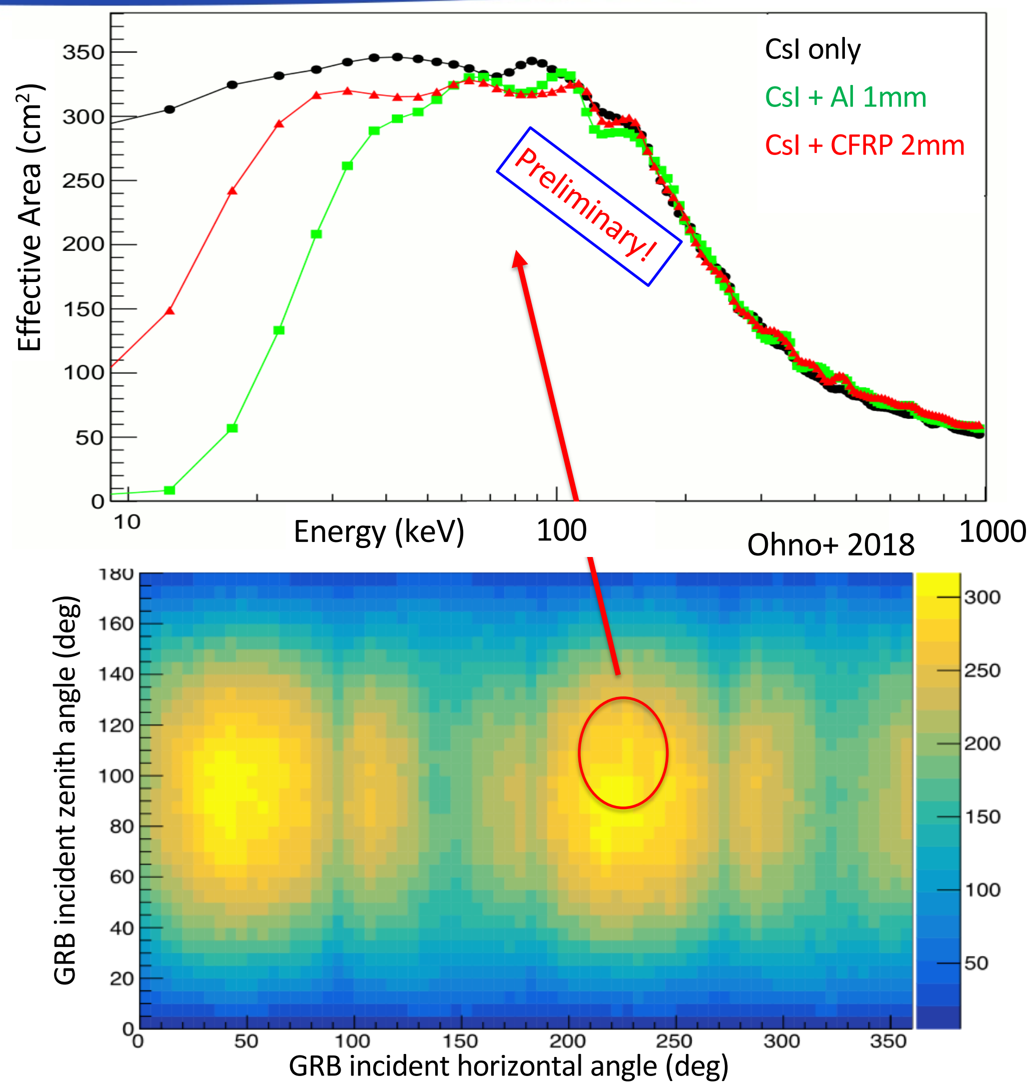
SPECTRAL FEASIBILITY



Torigoe+ 2018



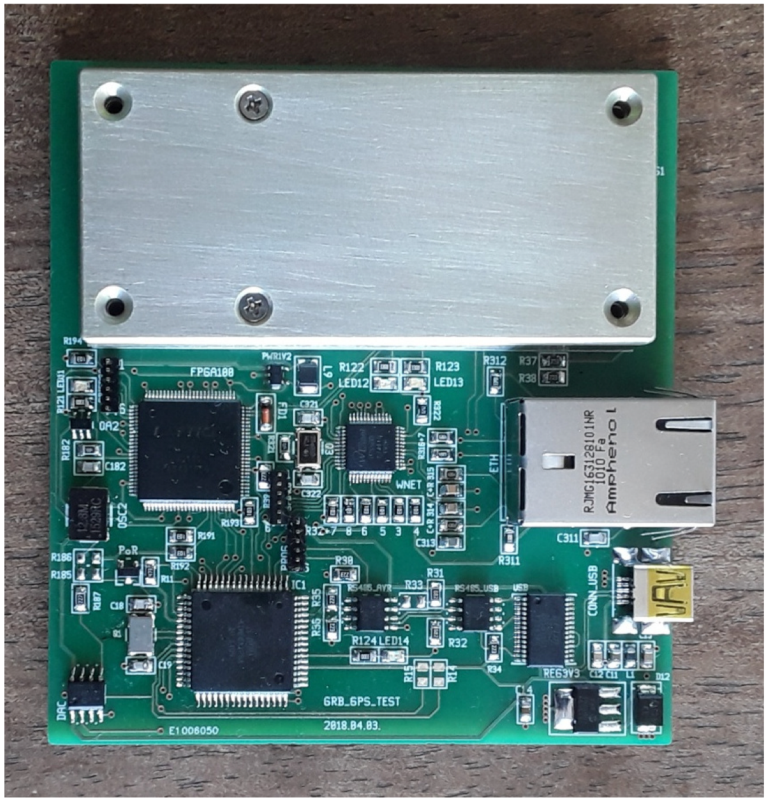
Energy threshold of ~10 keV is achieved for both single/multi channel readout
Energy range: 10-1000 keV (TBD)

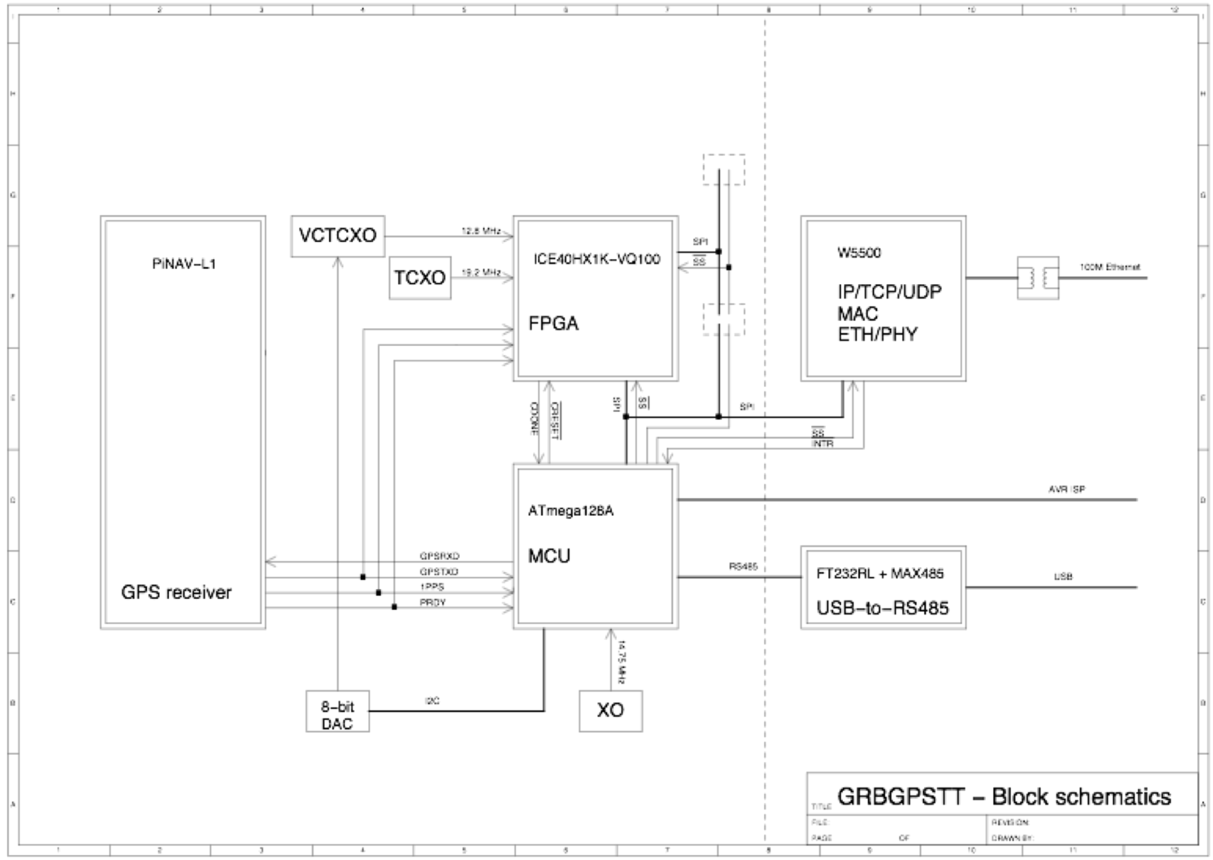


Effective area for best incident angle is estimated by the Monte-Carlo simulation, ~300 cm² (@100 keV)

Effective area of one satellite is comparable to two Fermi-GBM detector modules

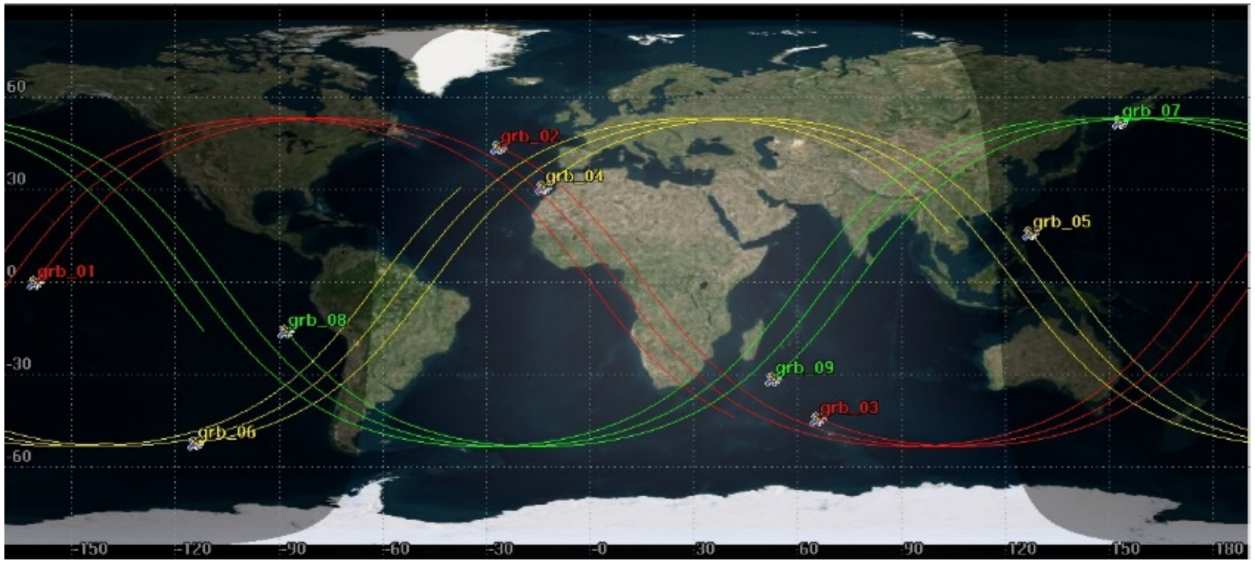
CAMELOT GPS TIME-STAMPING TEST BOARD

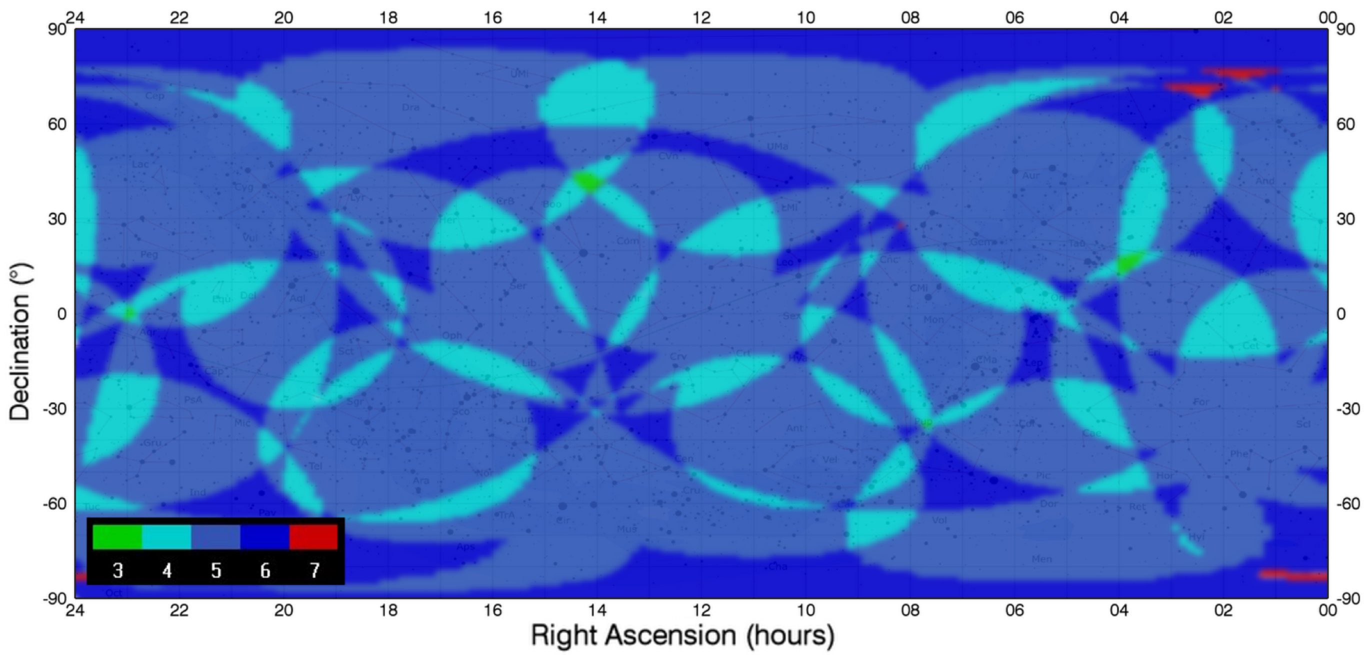




Pál et al. 2018

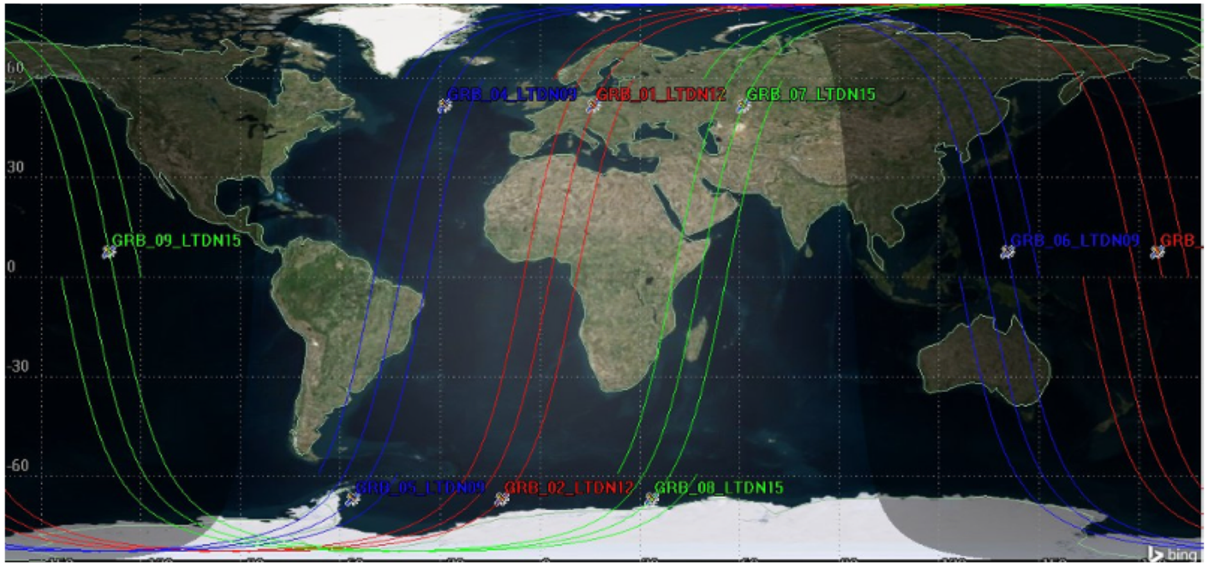
SKY VISIBILITY ON 53 DEG WALKER ORBITS

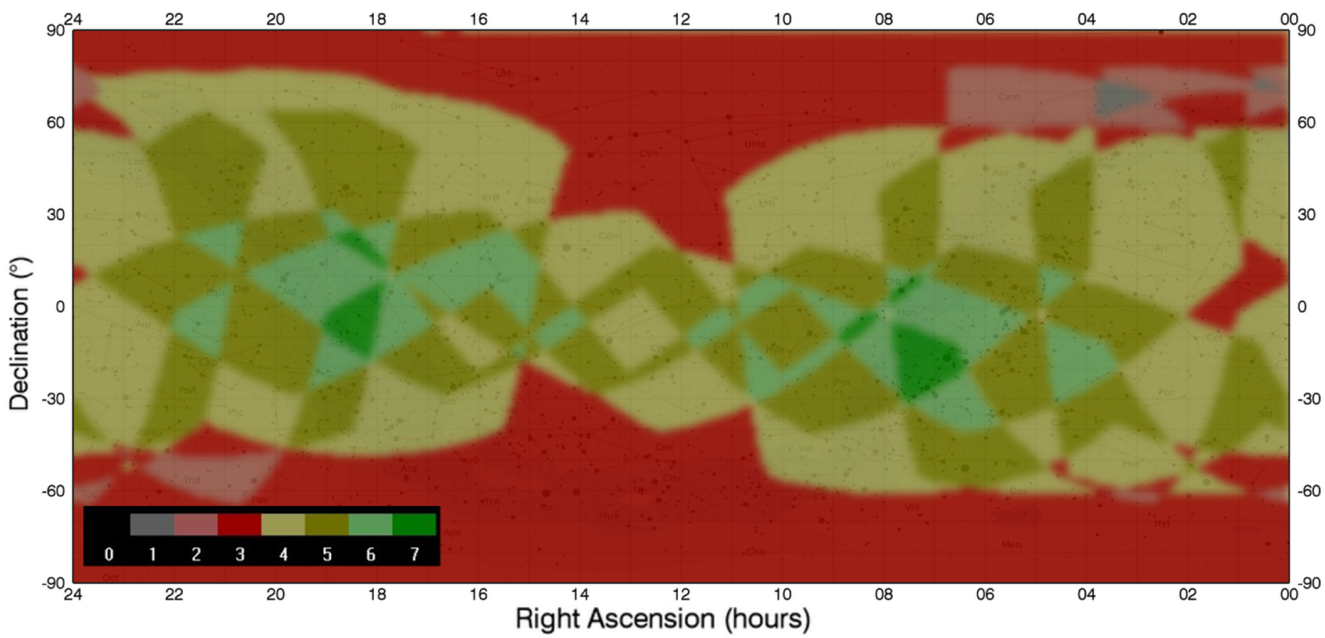




95% of the sky will be simultaneously covered by at least 5 satellites.

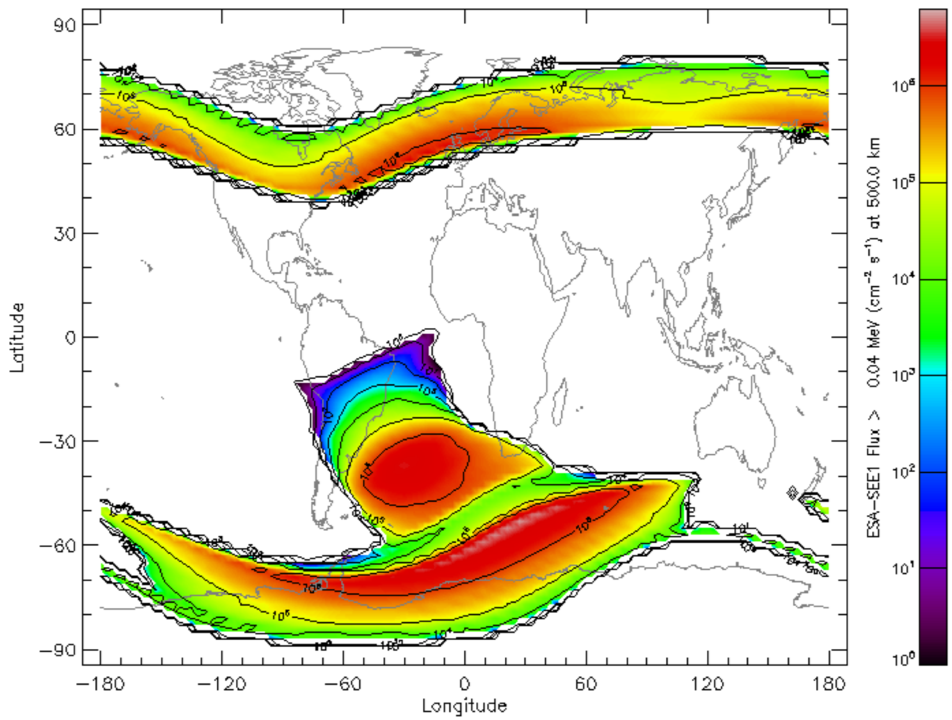
SKY VISIBILITY ON SUN-SYNCHRONOUS POLAR ORBITS



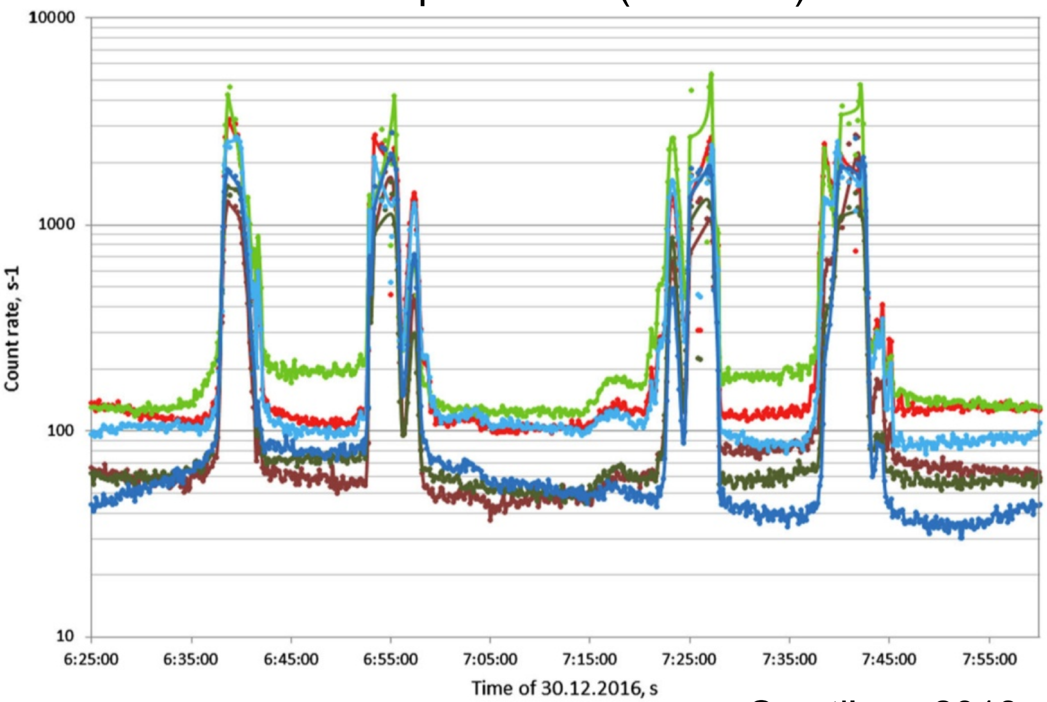


HIGH BACKGROUND ON POLAR ORBITS

Electron flux by ESA-SEE1 model at 500 km



Lomonosov / BDRG count rate in scintillator-based GRB detector on polar orbit (~500 km).



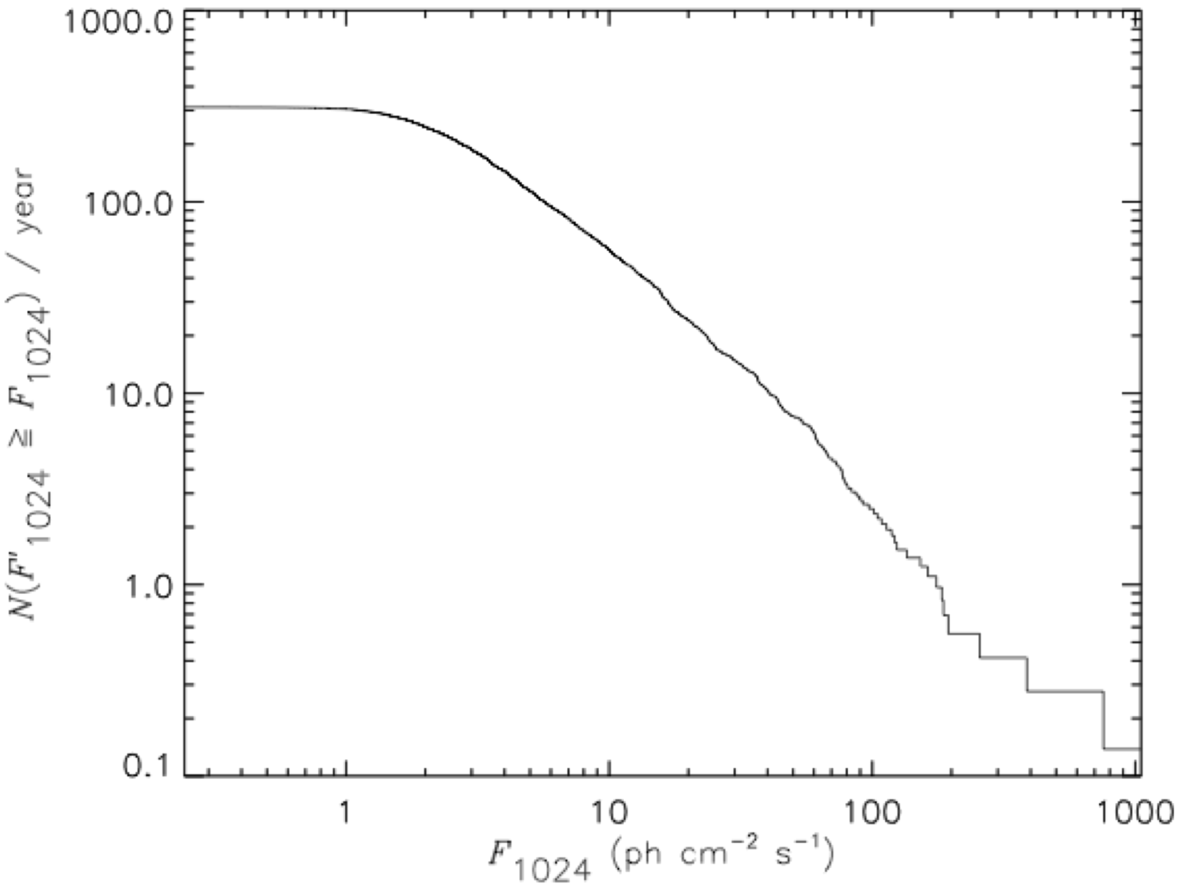
Svertilov+ 2018

On **polar** orbit, each satellite will **loose >30-40%** of observing time.

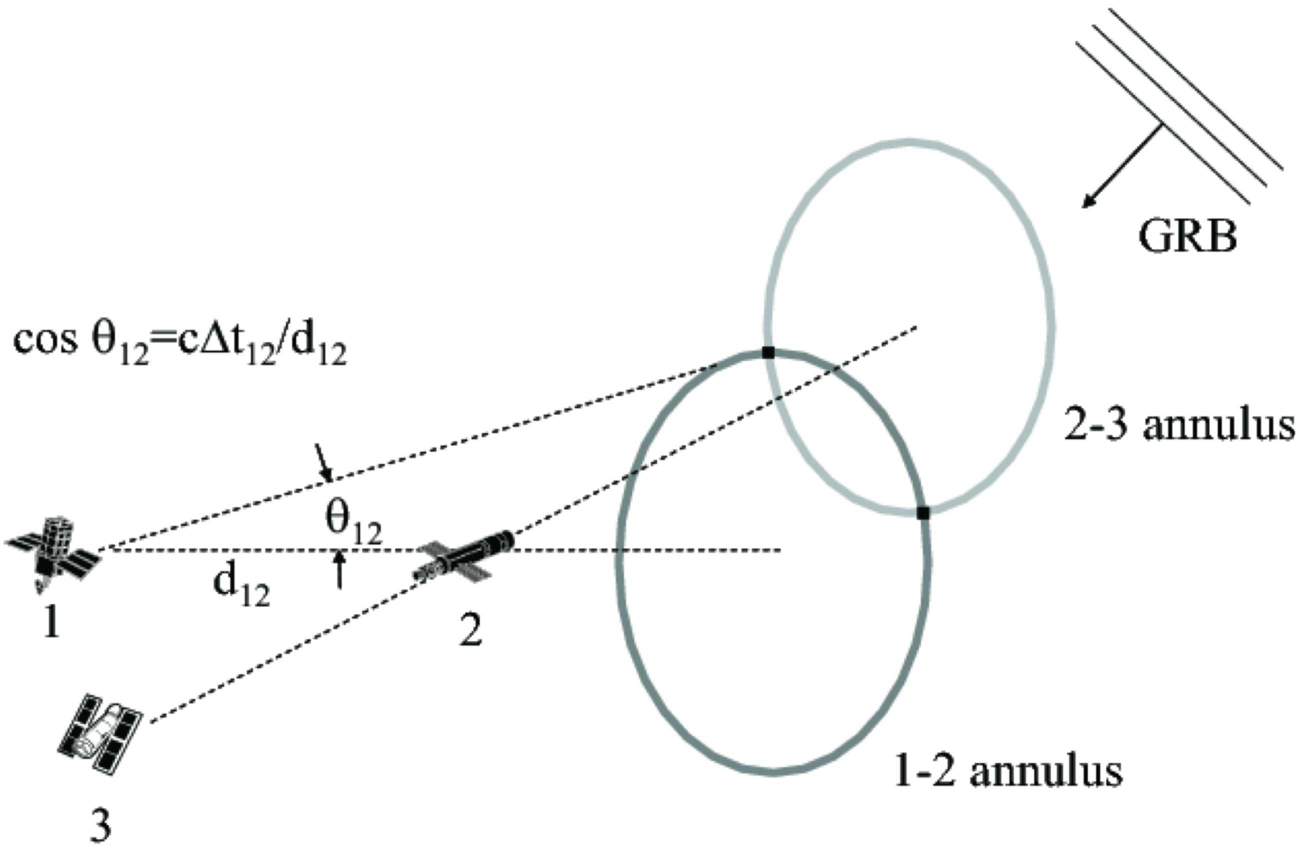
On **53° inclination** orbit, each satellite will **loose >20%** of observing time.

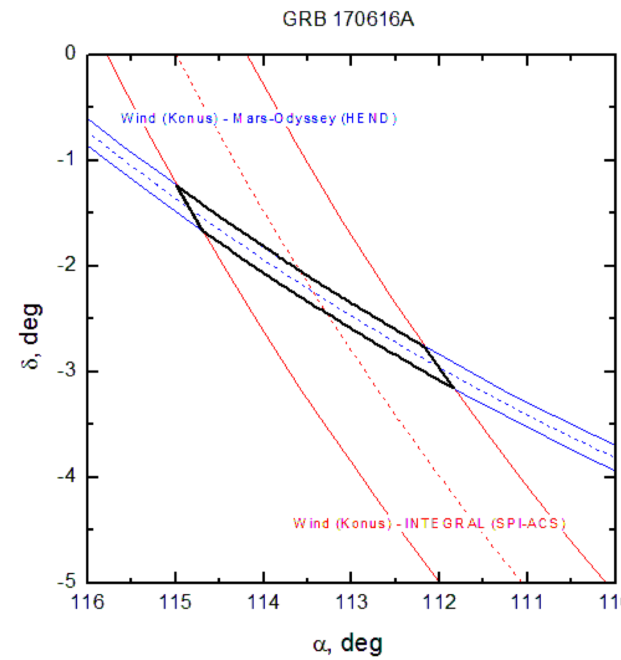
WHAT DO WE EXPECT TO SEE?

- Over **300 GRBs** detected per **year**
- Many **terrestrial gamma ray flashes**, solar flares, soft gamma ray repeaters, X-ray binaries, etc.



TIMING BASED LOCALISATION



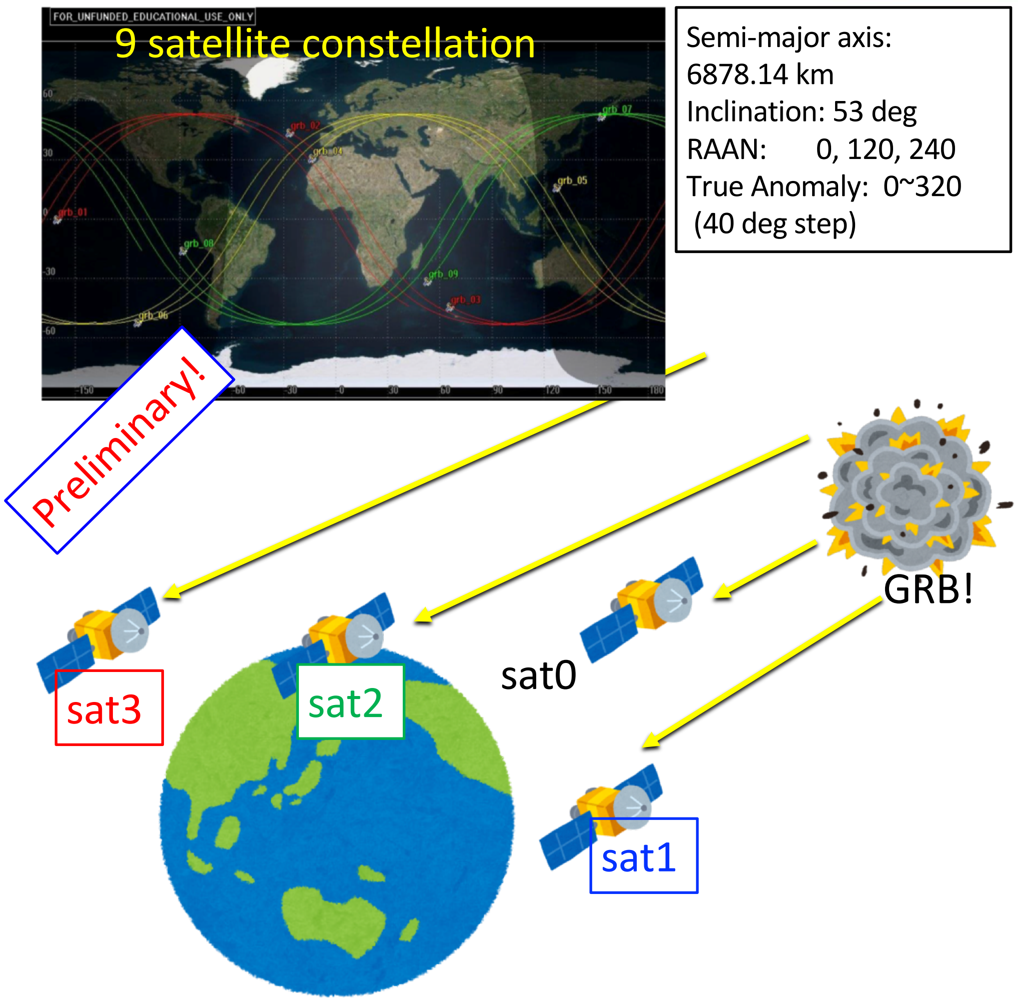


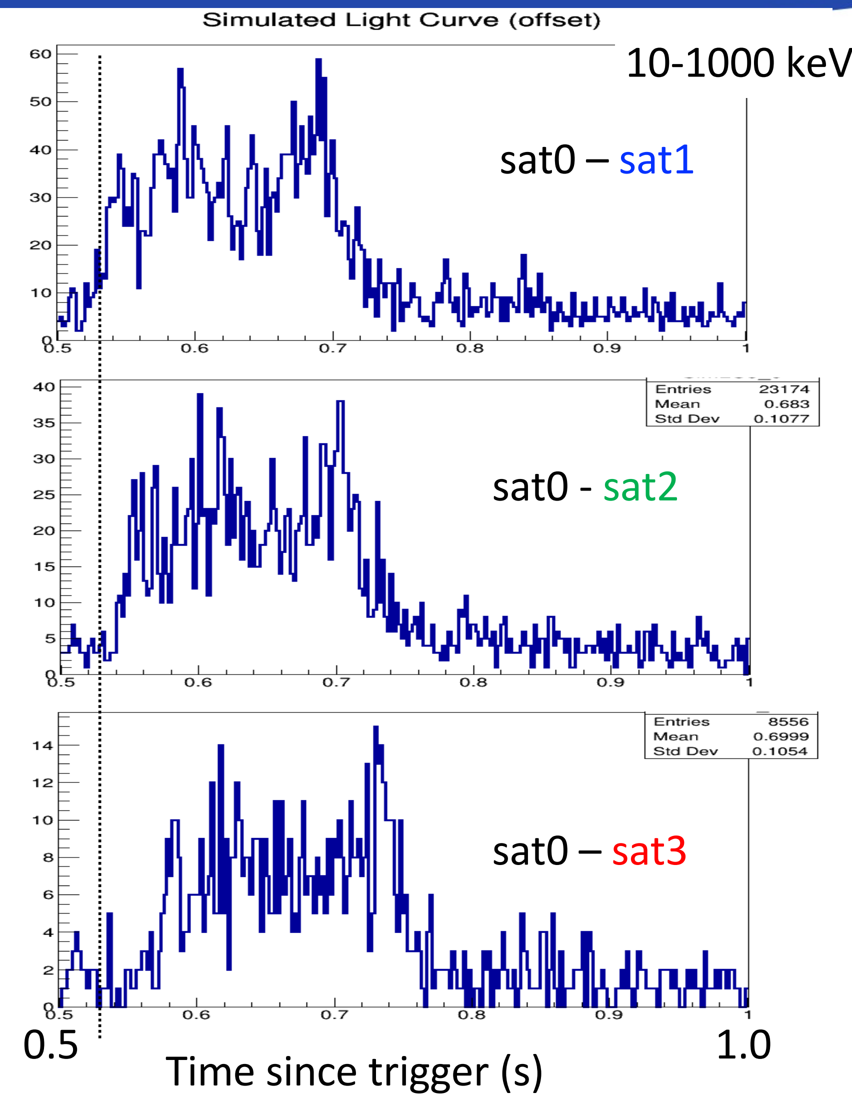
- <u>localisation by photon arrival time</u>

High timing synchronization by GPS + 10µ-sec timing accuracy results several arcmin localisation accuracy ?

Hurley+13

LOCALISATION FEASIBILITY





Satellite attitude, GRB position, predicted photon count/arrival time estimated using orbit and detector simulations.

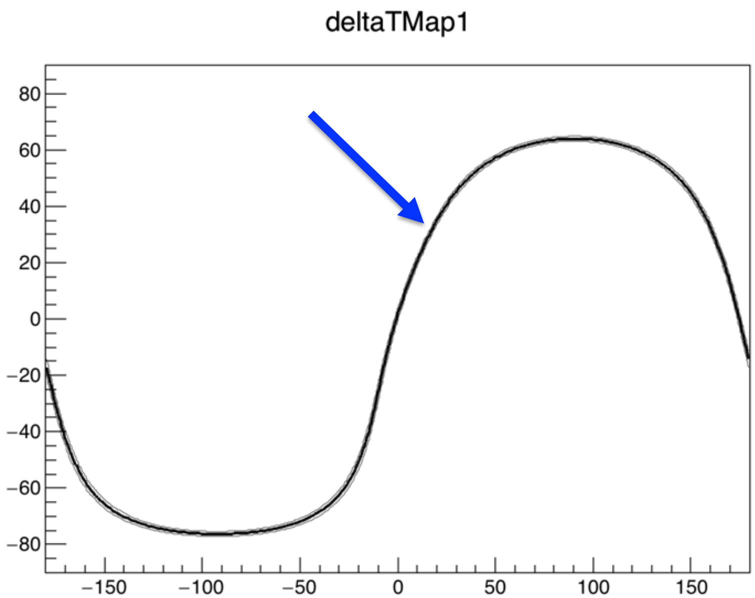
Simulated photon arrival time is estimated by the cross correlation analysis ➔ triangulation annulus

Ohno et al. 2018

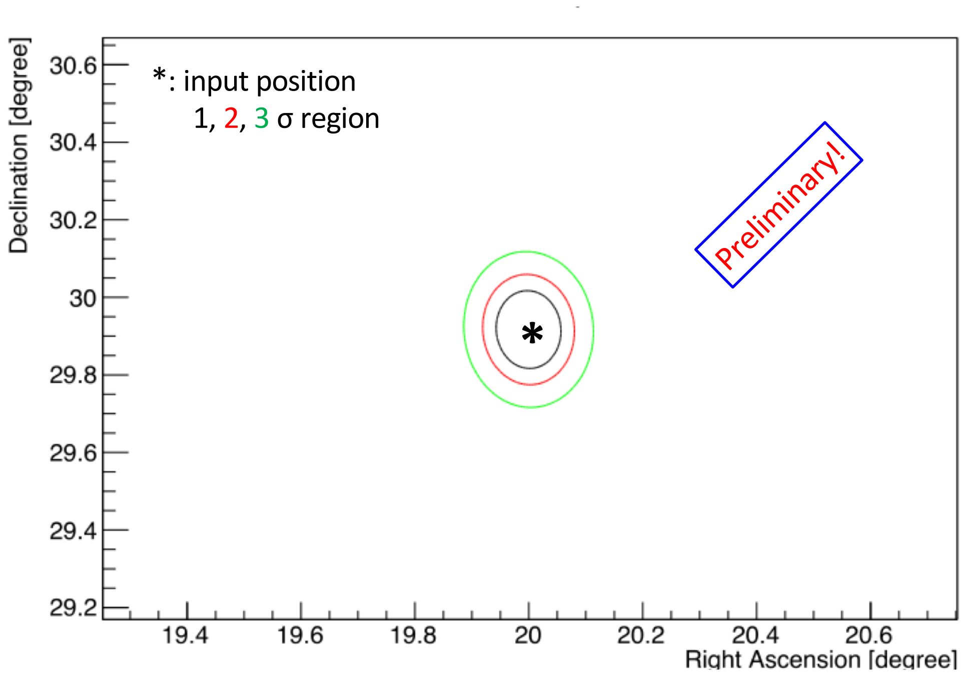
LOCALISATION ALGORITHM

Intersection of annuli

➔ GRB position!



How can we estimate the most probable position and error ?



$$\chi^2 \equiv \sum_{i=0}^{N} \frac{\left\{\delta t_{\rm sim,i} - {\rm Norm} \times \cos\theta_{\rm model,i}({\rm R.A.}, {\rm Dec.}) \times {\rm D/c}\right\}^2}{\sigma^2_{\rm sim,i}},$$

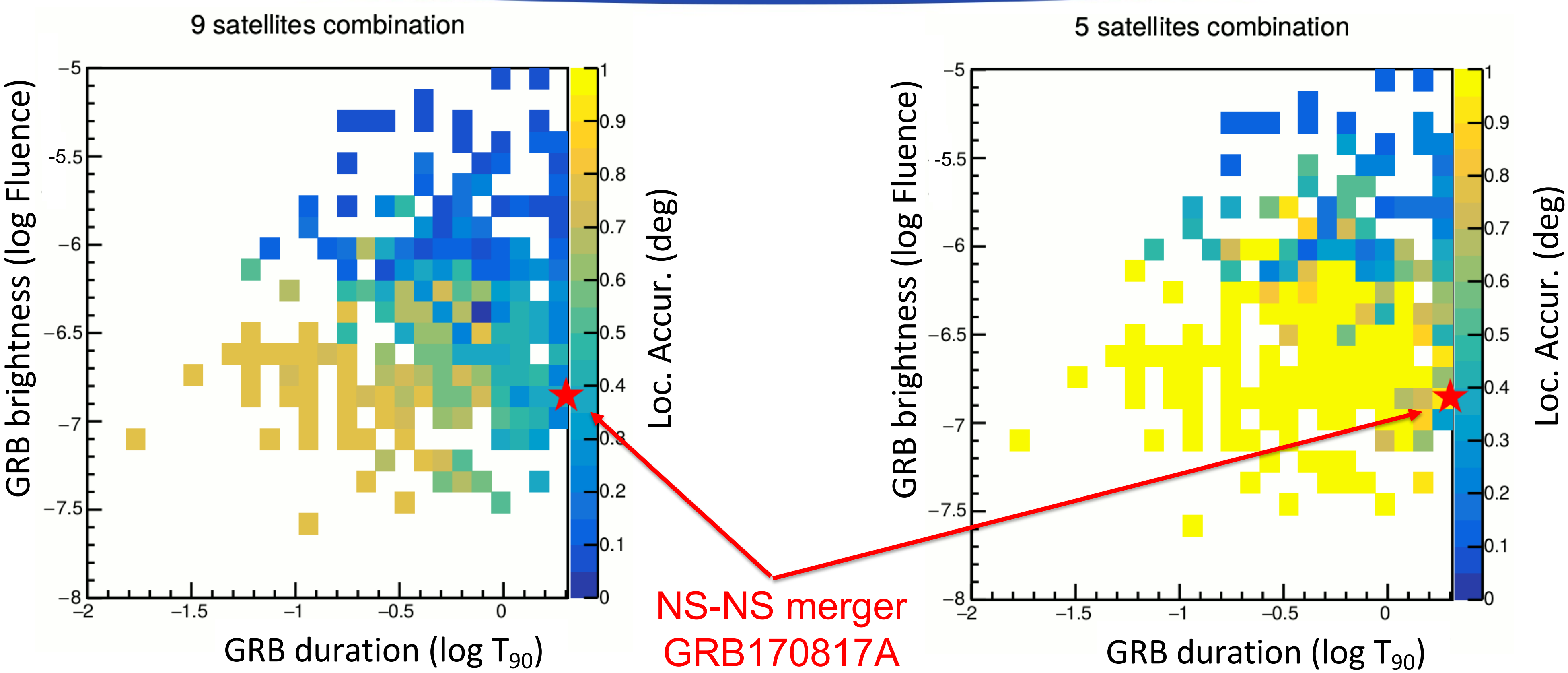
GRB position and error is estimated by simple χ^2 minimization (Tanaka+ 17)

~0.1 $\text{deg}_{1\sigma}$ (~6 arcmin) accuracy is achievable for bright/high-visibility case

Best fit position
R.A. = 20.0 (+/- 0.06) deg
Dec. = 29.9 (+/-0.10) deg

Ohno et al. 2018

LOCALISATION ACCURACY



Localization accuracy of our concept is examined for all short GRBs listed in Fermi 3rd GRB Catalog (Bhar+16 T_{90}<2s: 326 events)

- **High localisation accuracy for good photon statistics (brighter/longer)**
- **5-10 arcmin accuracy in the best case**
- **Ten short GRBs per year localised to within 20 arcmin**

Ohno et al. 2018

SUMMARY

- We are proposing the ***CAMELOT* mission,** a constellation of nine 3U cubesats in three orbital planes on low Earth orbit, to provide an **all-sky coverage** and **~10 arcmin localisation accuracy**
- Each nanosatellite shall be equipped with **four thin**, 9 mm, and relatively **large, 8.3 × 15 cm, CsI(Tl) based detectors** as lateral extensions on its surface read out by MPPCs. The large thin detectors provide **high sensitivity** (comparable with *Fermi*-GBM), while leaving enough room for electronics.
- Timing based localisation demands precise **time synchronization** between the satellites and **accurate time stamping** of detected photons. This will be **achieved by using GPS receivers.**

Rapid localisation by gamma-ray observations is critical for the study of GW sources

- Rapid follow up observations at other wavelengths require the **capability for fast simultaneous downlink of data** for the triggered events from all satellites in the fleet. This can be achieved using **satellite-to-satellite communication networks** such as *Iridium NEXT.*
- *CAMELOT* will also provide **important secondary science**, such as monitoring of outbursts of soft gamma-ray repeaters, gamma-ray flares on the Sun, **terrestrial gamma-ray flashes** (produced in thunderstorms), and space weather phenomena.
- *CAMELOT* provides ample **potential for international cooperation**. Because the proposed **fleet is scalable** and extendable, we envision collaboration with future partners using different satellite designs, **extending the capabilities of the constellation**.

Werner et al. arXiv: 180603681
Ohno et al. arXiv: 180603686
Pal et al. arXiv: 180603685