GRB localization by timing in LEO

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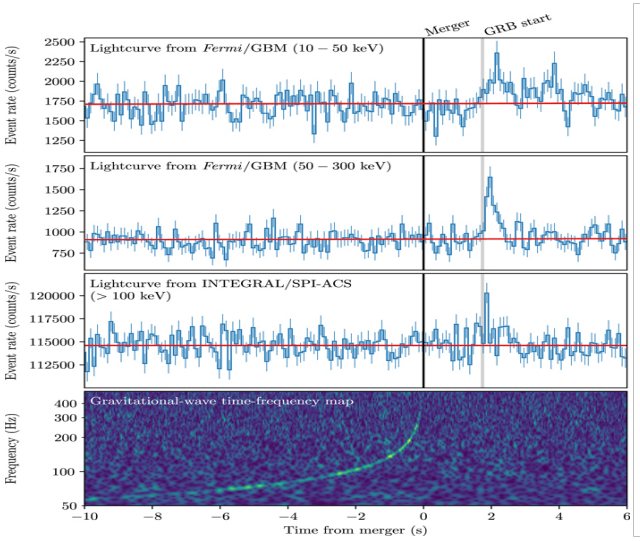
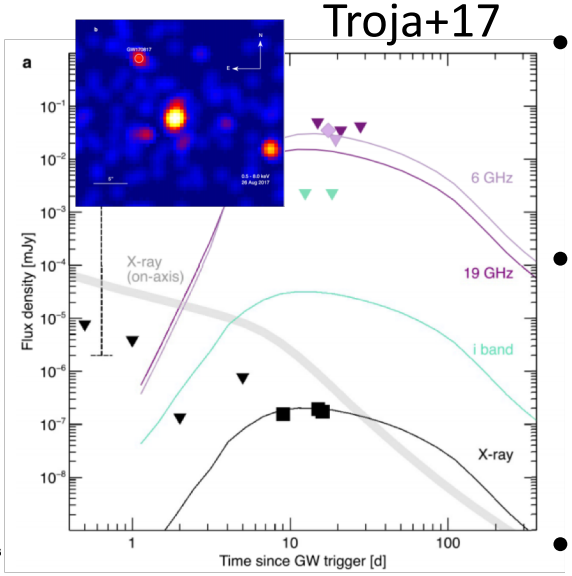
Localization of GRBs : a key for the future MM astronomy

広島大学

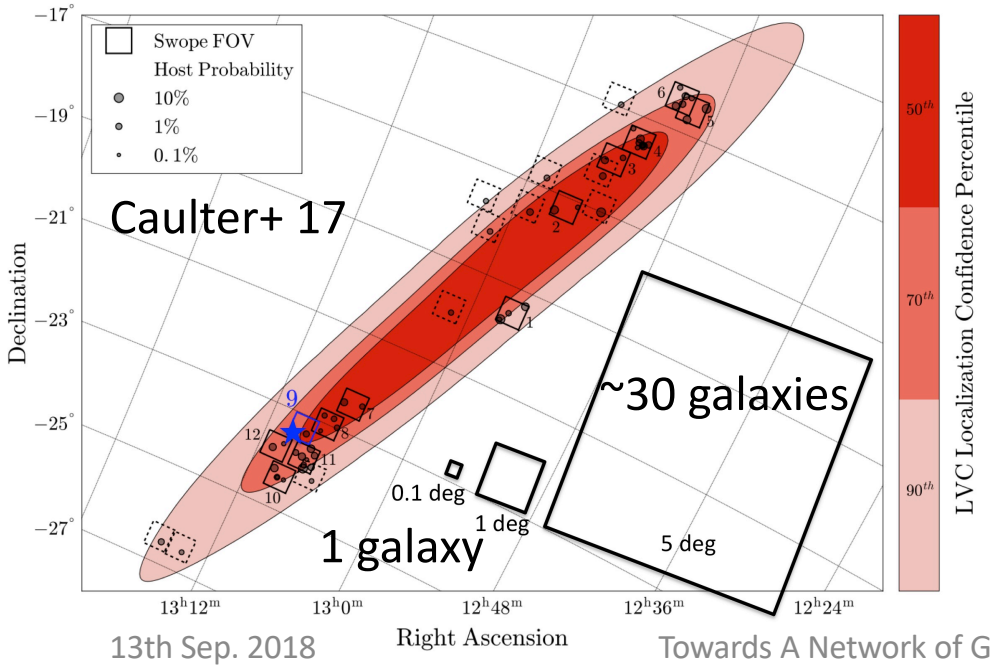
Abbott+17



Troja+17



- **EM counterpart from NS-NS merger event GW170817/GRB170817A**
- **Gigantic campaign of follow-up observation in many EM wavelengths successfully carried out**
- **short GRB association is still unbigious**



Large FoV (all-sky)

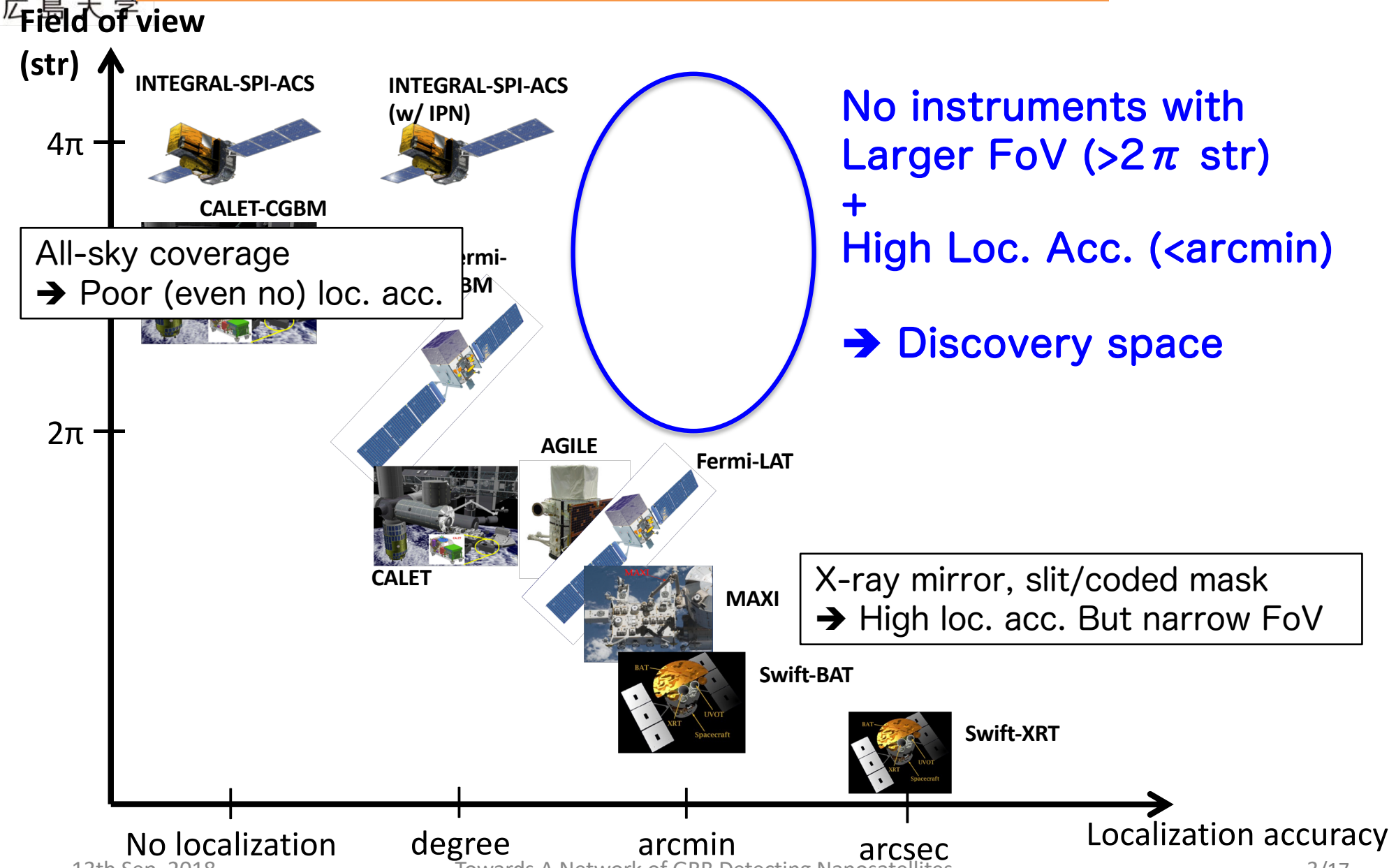
+

good localization

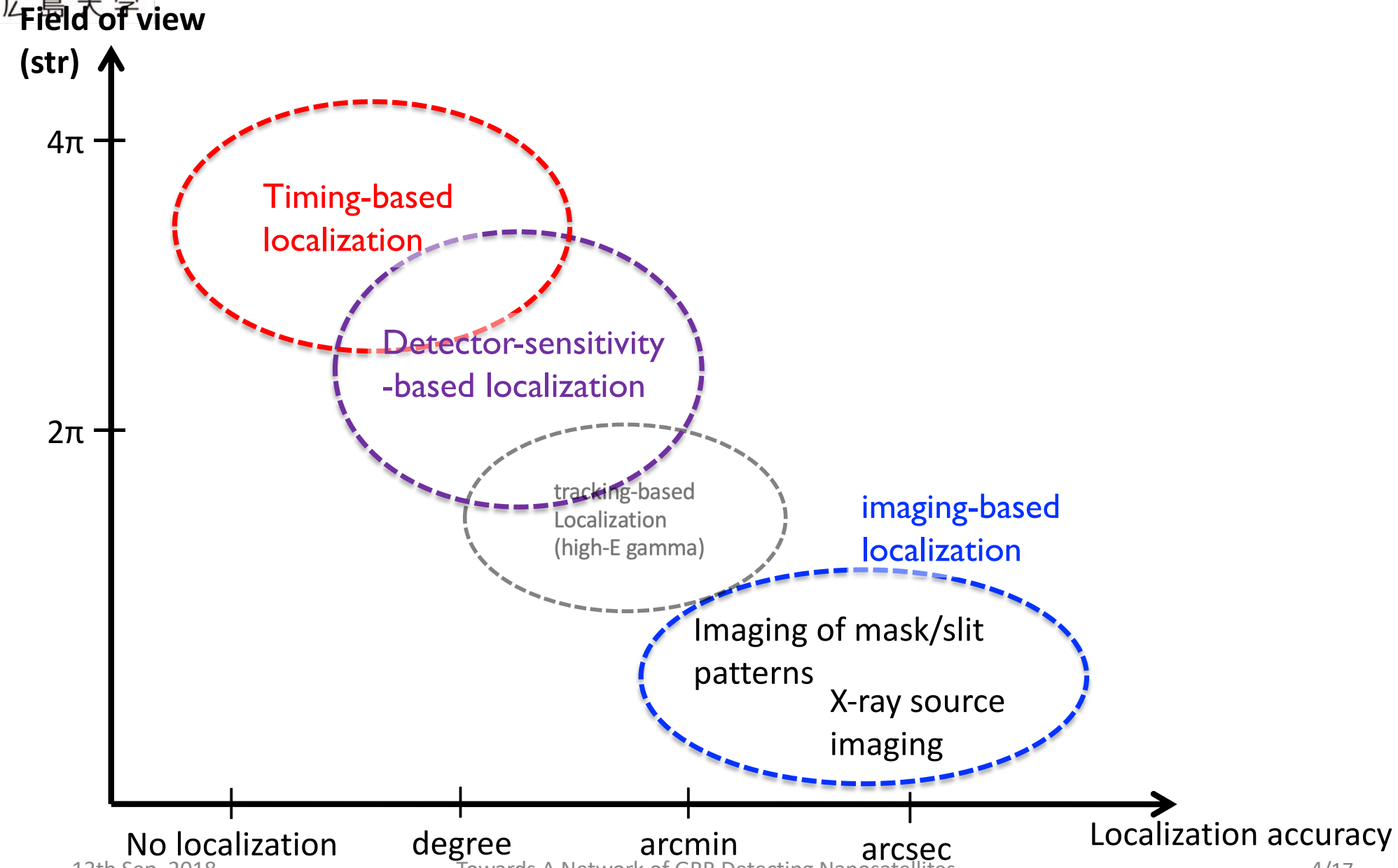
(tens arcmin : FoV of future opt. telescopes

~arcsec : unique candidate constraint)

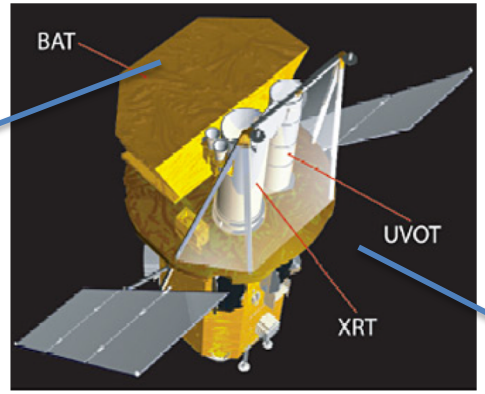
What do we need ?

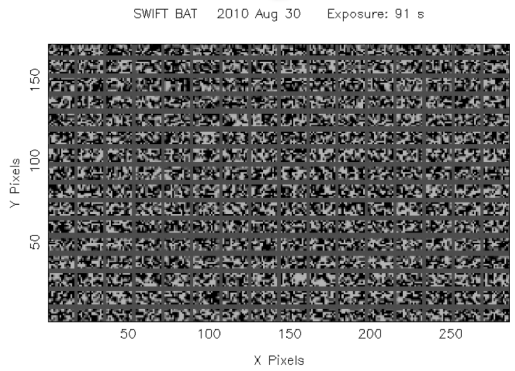


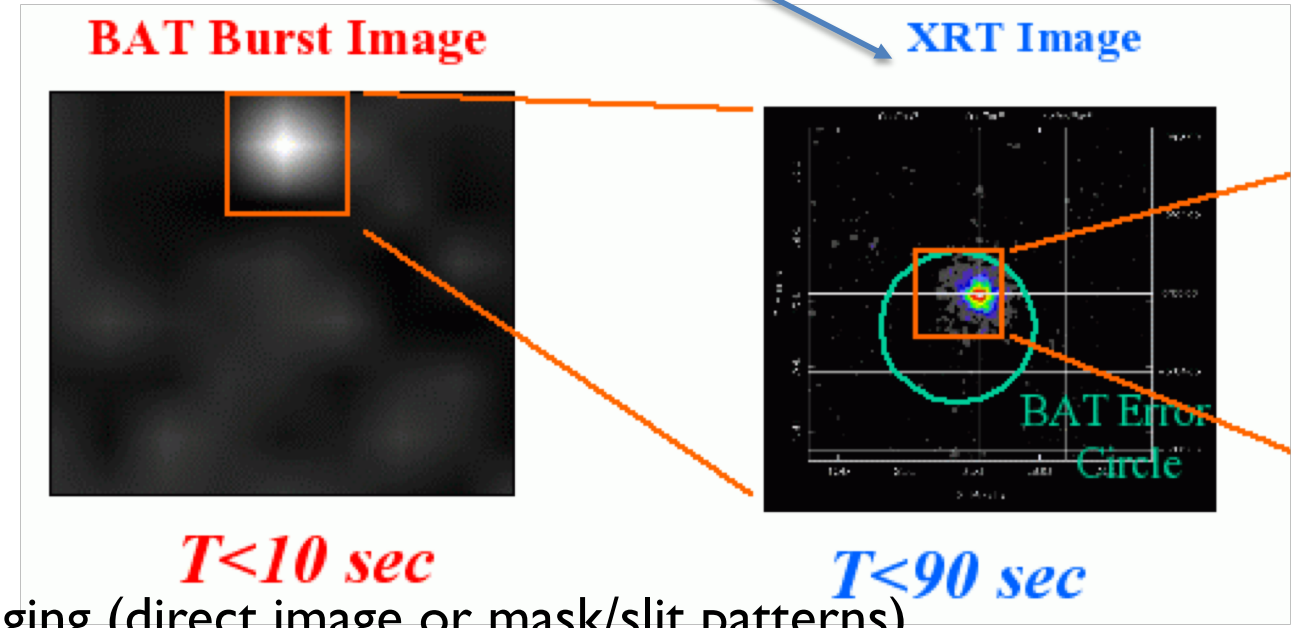
A localization method view



Imaging-based localization





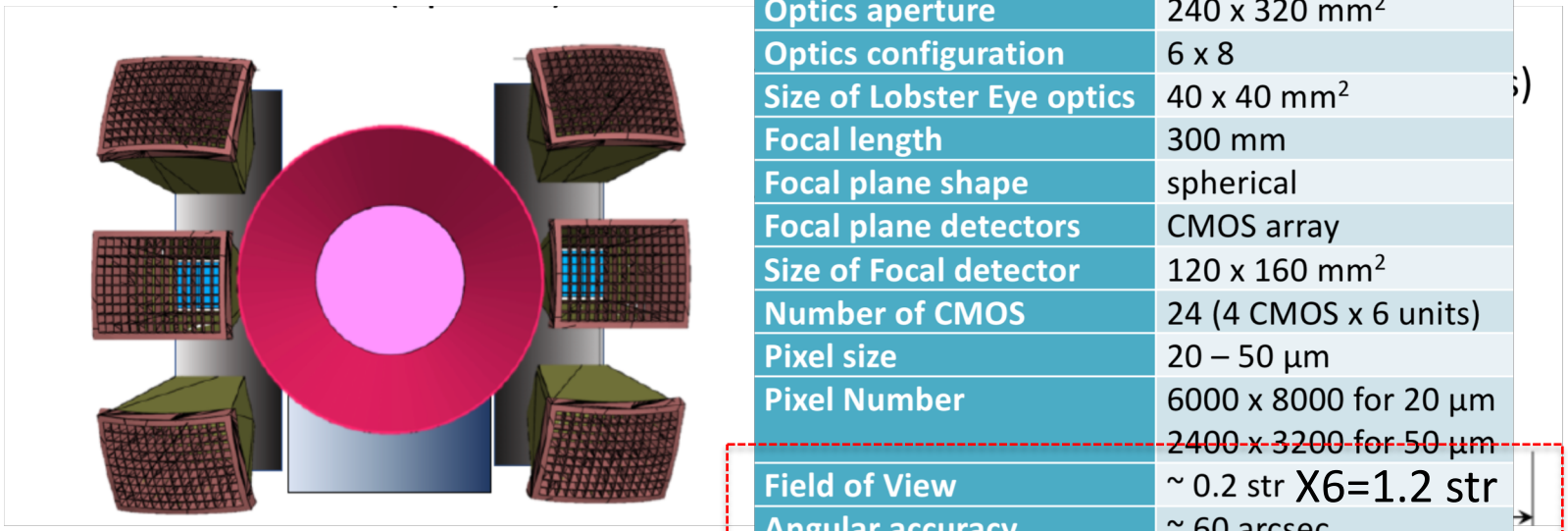


- Simple localization by imaging (direct image or mask/slit patterns)
- Excellent positional accuracy (arcsec-arcmin), but a limited field of view (<~1str)

Lobster-eye optics : imaging+large FoV

Future missions for realizing the good (arcmin) imaging localization with larger FoV are proposing

High-Z Gamma-ray bursts for UNraveling the Dark Ages (HiZ-GUNDAM) : Japan

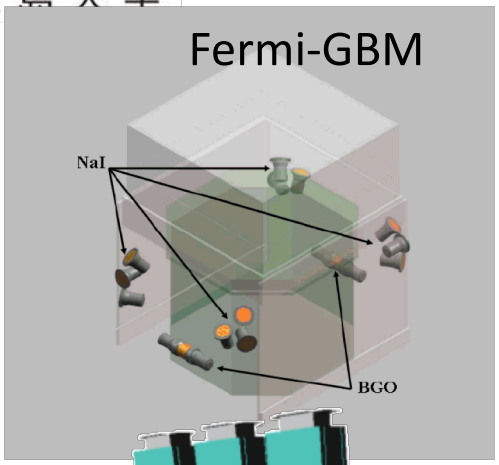


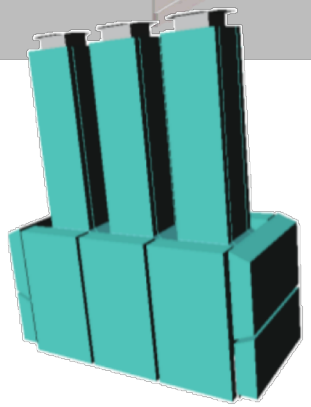
Energy band (keV)	0.5 – 4 keV
Telescope type:	Lobster Eye Optics
Optics aperture	240 x 320 mm^2
Optics configuration	6 x 8
Size of Lobster Eye optics	40 x 40 mm^2
Focal length	300 mm
Focal plane shape	spherical
Focal plane detectors	CMOS array
Size of Focal detector	120 x 160 mm^2
Number of CMOS	24 (4 CMOS x 6 units)
Pixel size	20 – 50 μm
Pixel Number	6000 x 8000 for 20 μm 2400 x 3200 for 50 μm
Field of View	~ 0.2 str X6=1.2 str
Angular accuracy	~ 60 arcsec

Similar concept is proposed by ESA :Transient High-Energy Sky and Early Universe Surveyor (Theseus)

Expect to improve the FoV of imaging localization, but still not cover the "all-sky"

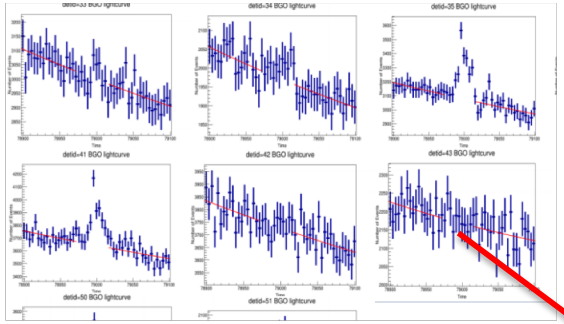
Detector-sensitivity-based localization



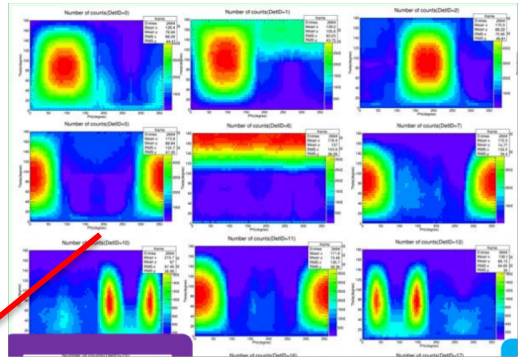


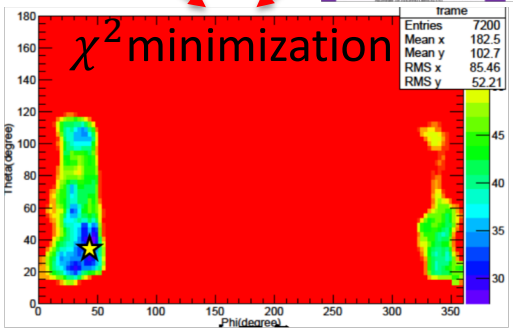
Hitomi-SGD-shields

Observed counts for
Each detector



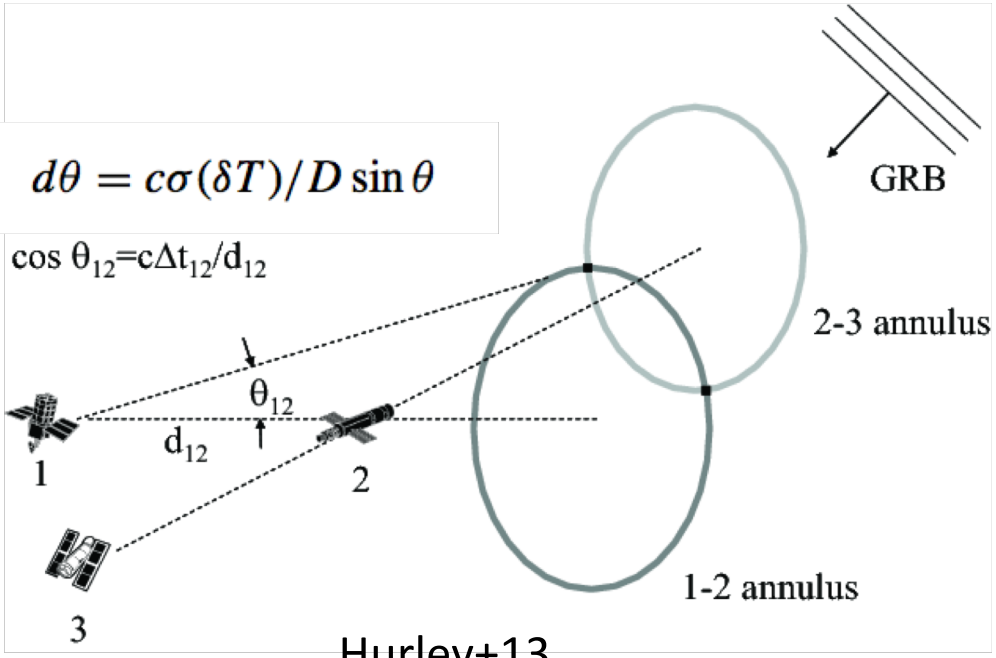
Predicted counts from
various incident direcitions



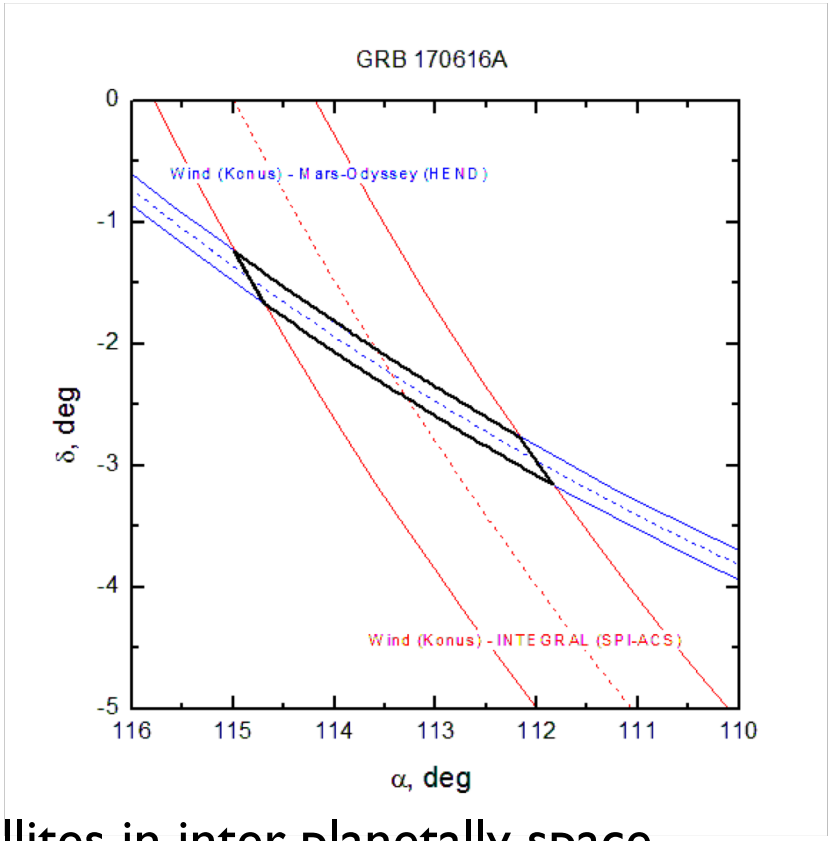


- Comparison of detected counts and the modeling for detectors with various orientations
- Nice FoV (almost all-sky), and moderate localization (several degs)
- Systematic uncertainty (modeling of background, detector response ..etc.) is a limiting factor

Timing-based localization

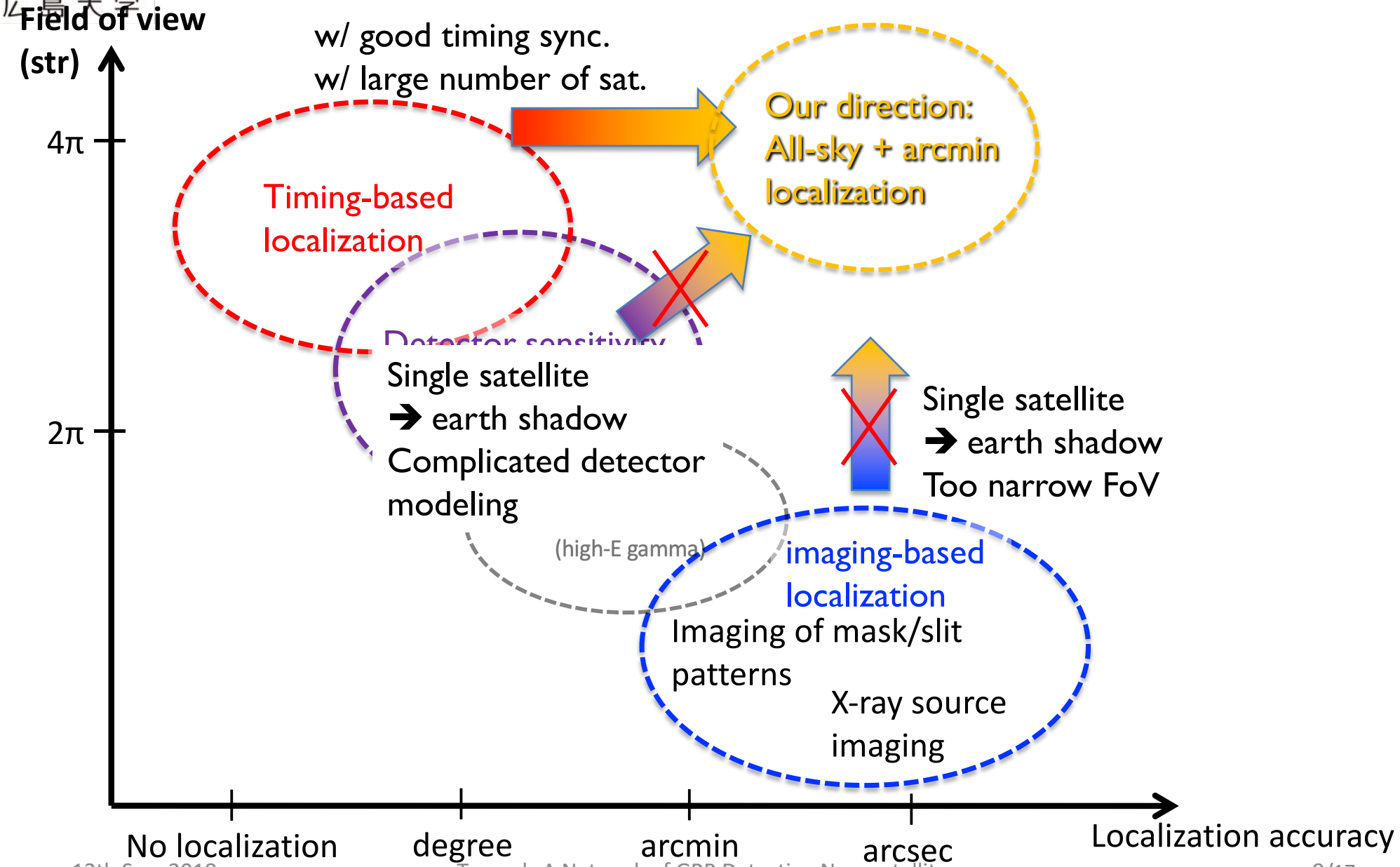


Hurley+13

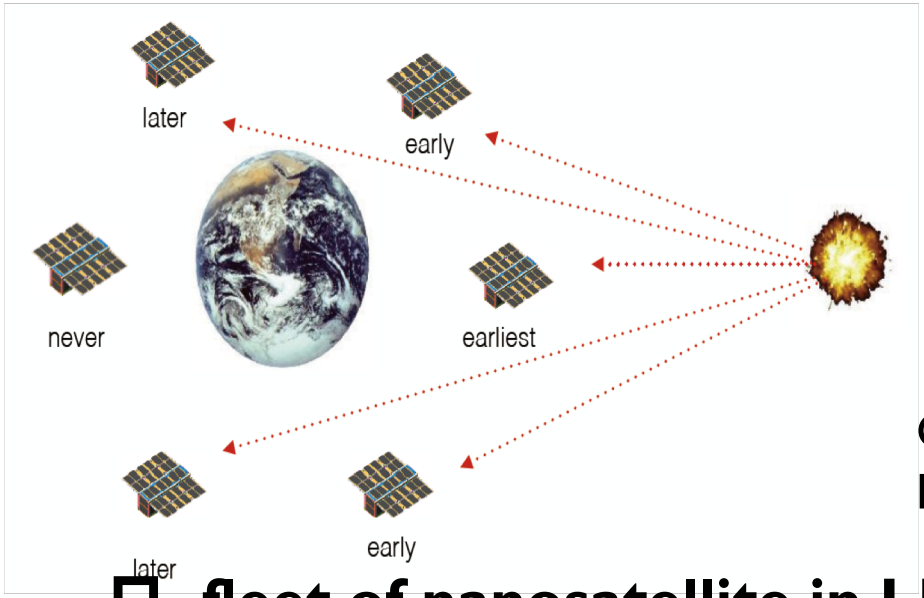


- "Triangulation" by several long-distant satellites in inter-planetally space
- Since 1976 and ongoing
- Long baseline gives a good localization (arcmin~deg) but difficult to synchronize the timing between different satellites.
- Very long data acquisition latency (>days)

How to achieve the all-sky+arcmin localization ?



timing-based localization + Fleet of nanosatellite in LEO



- **timing-based localization with high timing synchronization accuracy**

$$d\theta = c\sigma(\delta T)/D\sin\theta$$ Hurley+13

GPS <100 us sync. accuracy (Pal+18) ➔ arcmin Localization accuracy

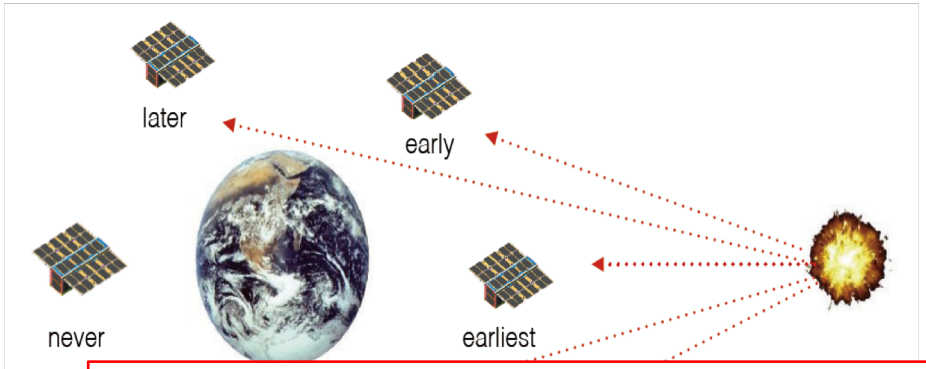
- **fleet of nanosatellite in LEO**
  - **all-sky coverage (no earth shadow)**
  - **large satellite number gives a better localization accuracy**
    - ➔ **good to think about data sharing for each smallsat project**
  - **better latency than IPN**

$$\sigma_{Pos} = \sigma_{CCF} \times c / \langle B \rangle / (N - 1 - 2)^{1/2}$$

Taken from F. Fiore's slide

100 satellites collaboration
➔ Arcsec localization !?

timing-based localization + Fleet of nanosatellite in LEO



- **timing-based localization with high timing synchronization accuracy**

$$d\theta = c\sigma(\delta T)/D\sin\theta$$ Hurley+13

Can we really realize such a good localization even if we take into account the realistic photon statistics and detector response for the nanosatellite ?

- **all-sky coverage (no earth shadow)**
- **large satellite number gives a better localization accuracy**
  - ➔ **good to think about data sharing for each smallsat project**
- **better latency than IPN**

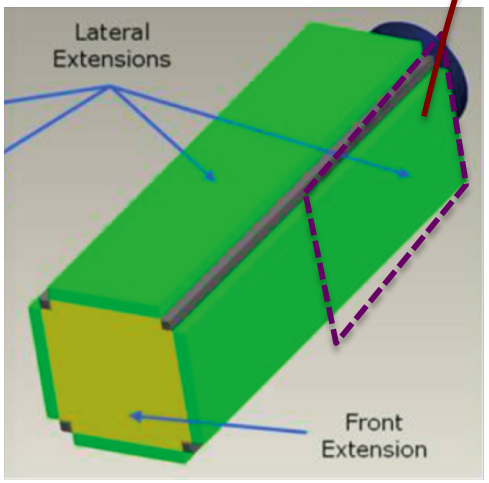
$$\sigma_{Pos} = \sigma_{CCF} \times c / \langle B \rangle / (N - 1 - 2)^{1/2}$$

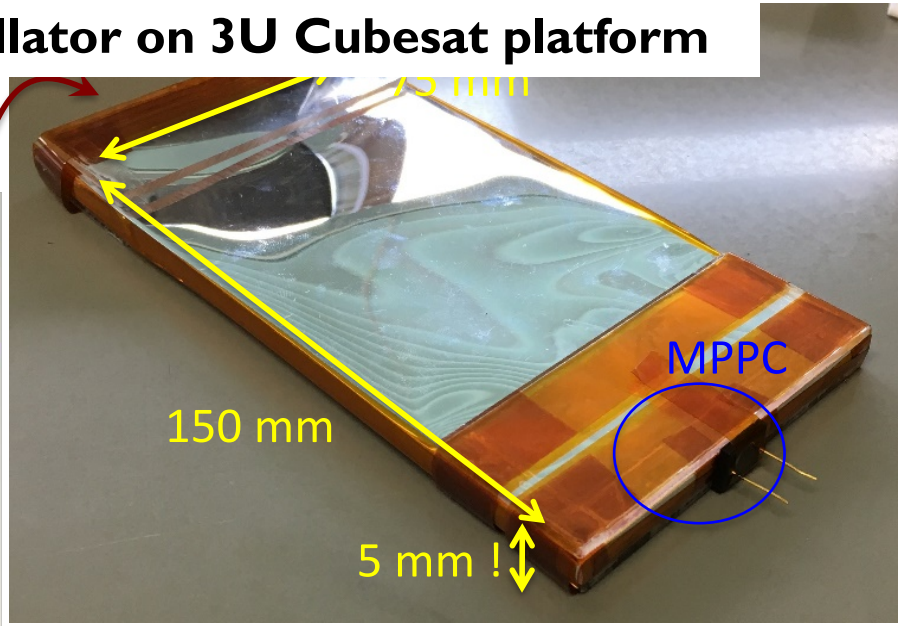
Taken from F. Fiore's slide

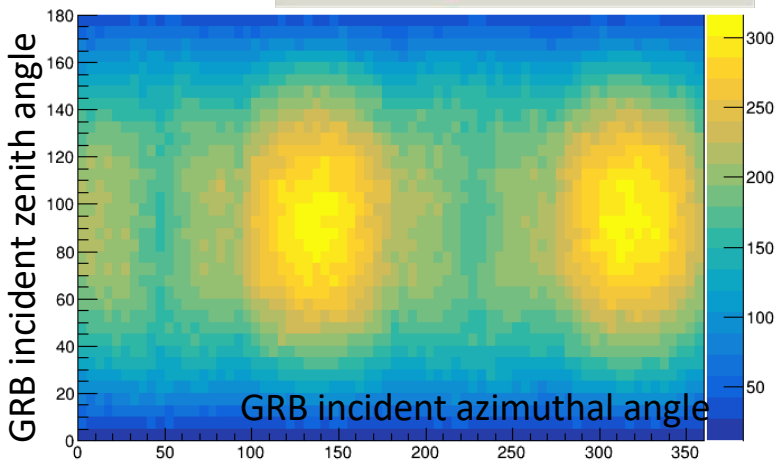
100 satellites collaboration
➔ Arcsec localization !?

Timing-based localization w/ nanosats : feasibility ?

Assumed Detector design:
4 large-thin plates of CsI scintillator on 3U Cubesat platform

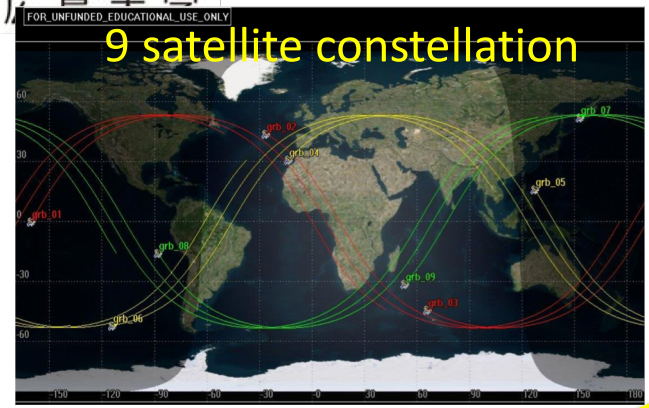




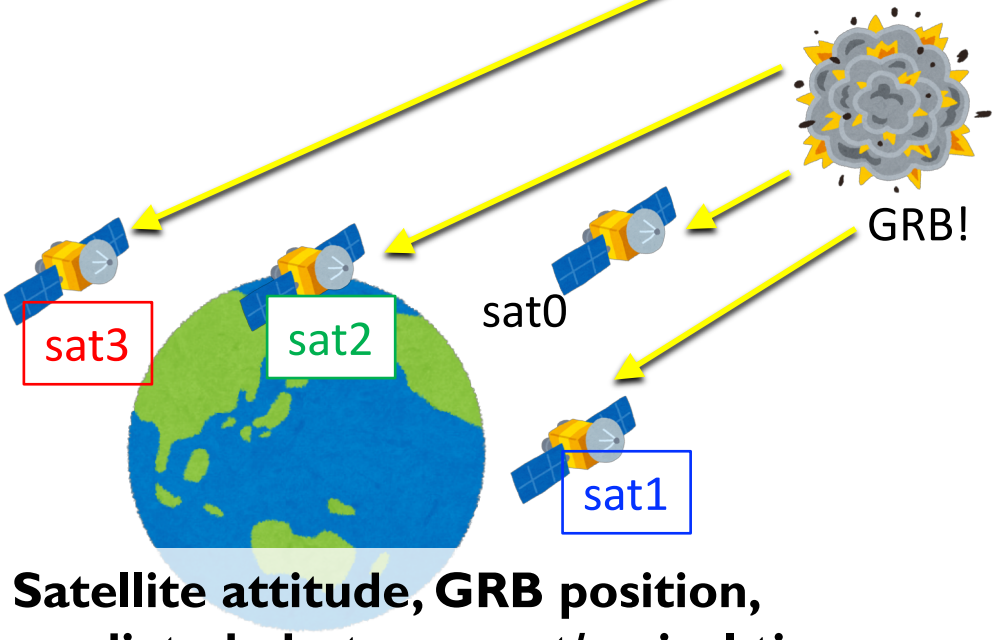


A simple single cubesat design realizes a comparable effective area to Fermi-GBM (~300cm^2 at good incident angles) with an energy range of 10 to 1000 keV

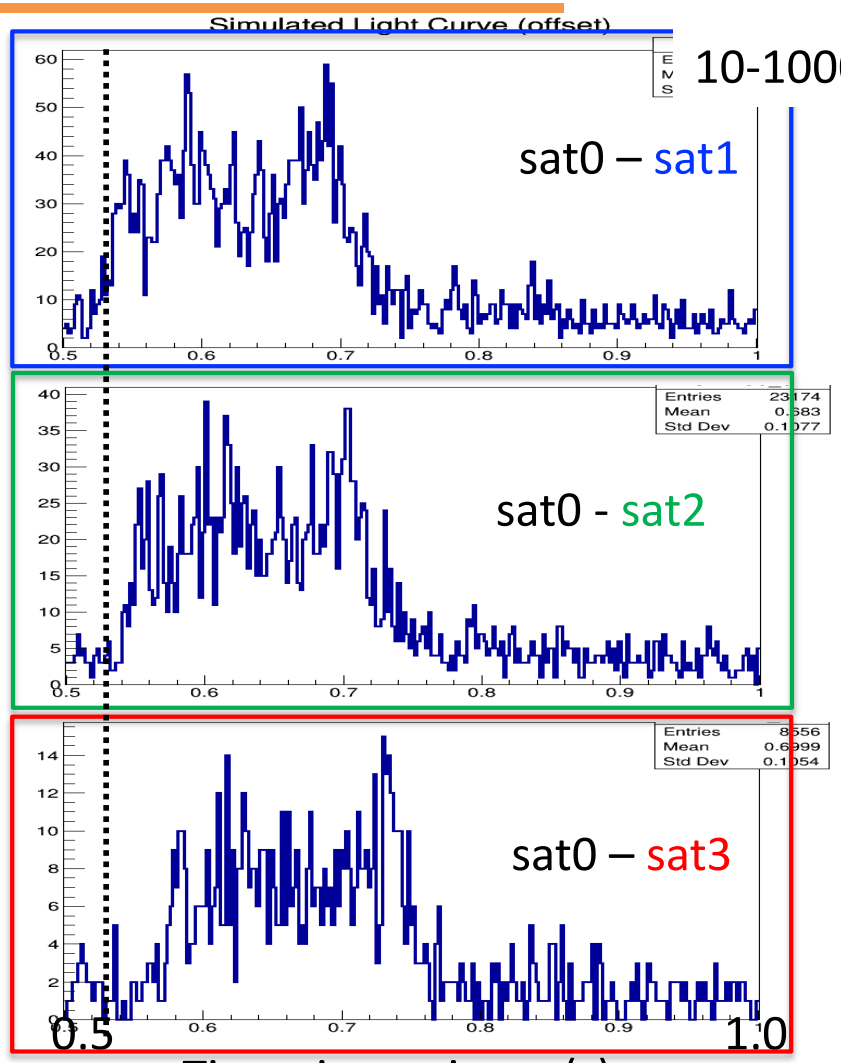
Localization feasibility



Semi-major axis:
6878.14 km
Inclination:
53 degree
RAAN:
0, 120, 240
True Anomaly:
0~320
(40 deg step)



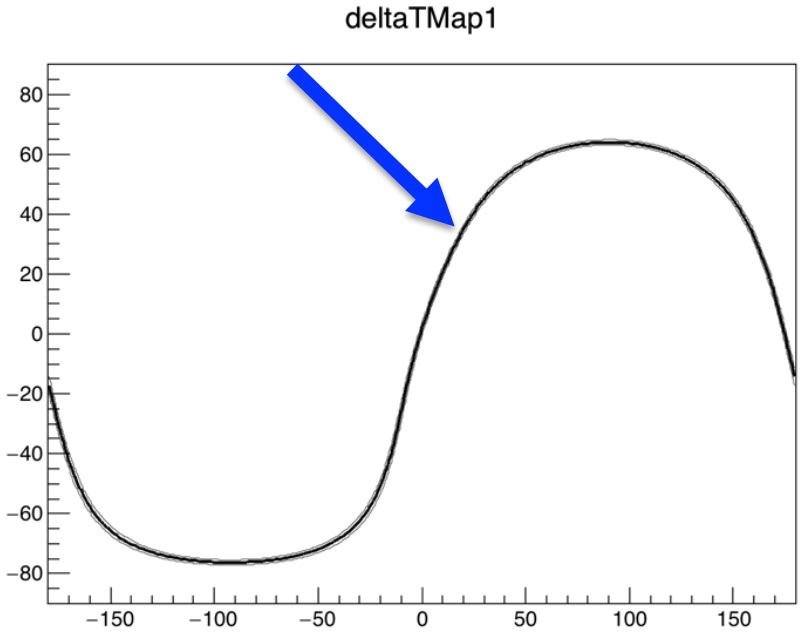
Satellite attitude, GRB position, predicted photon count/arrival time can be estimated by orbital and detector simulations.

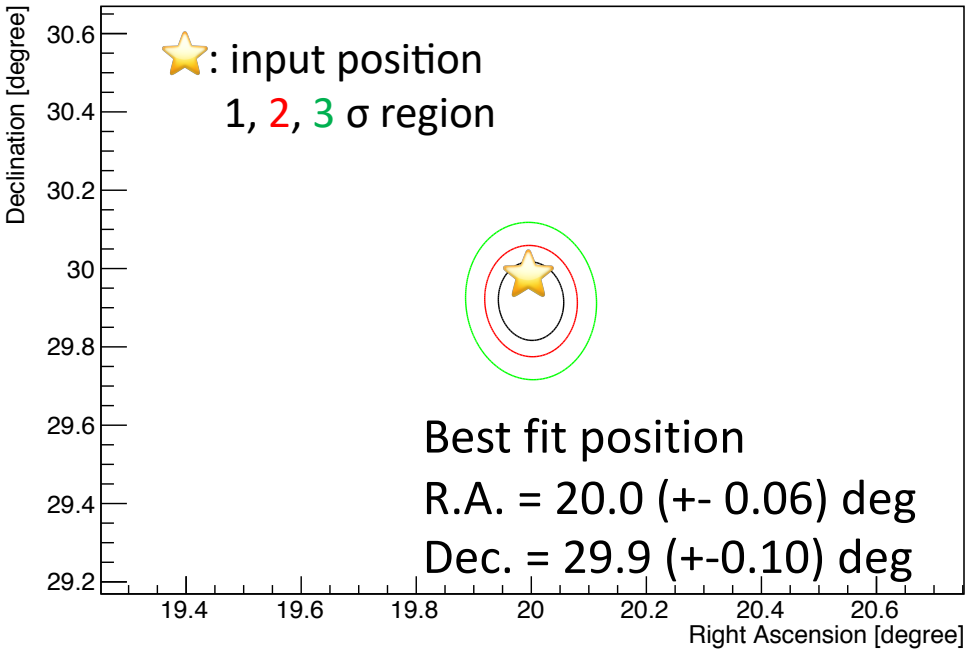


Simulated photon arrival time is estimated by the cross correlation analysis ➔ triangulation annulus

Localization !

Example for a bright (GRB* fluence:** erg cm-2,T90=**s) and good-visibility (detected by 9 satellites) case**





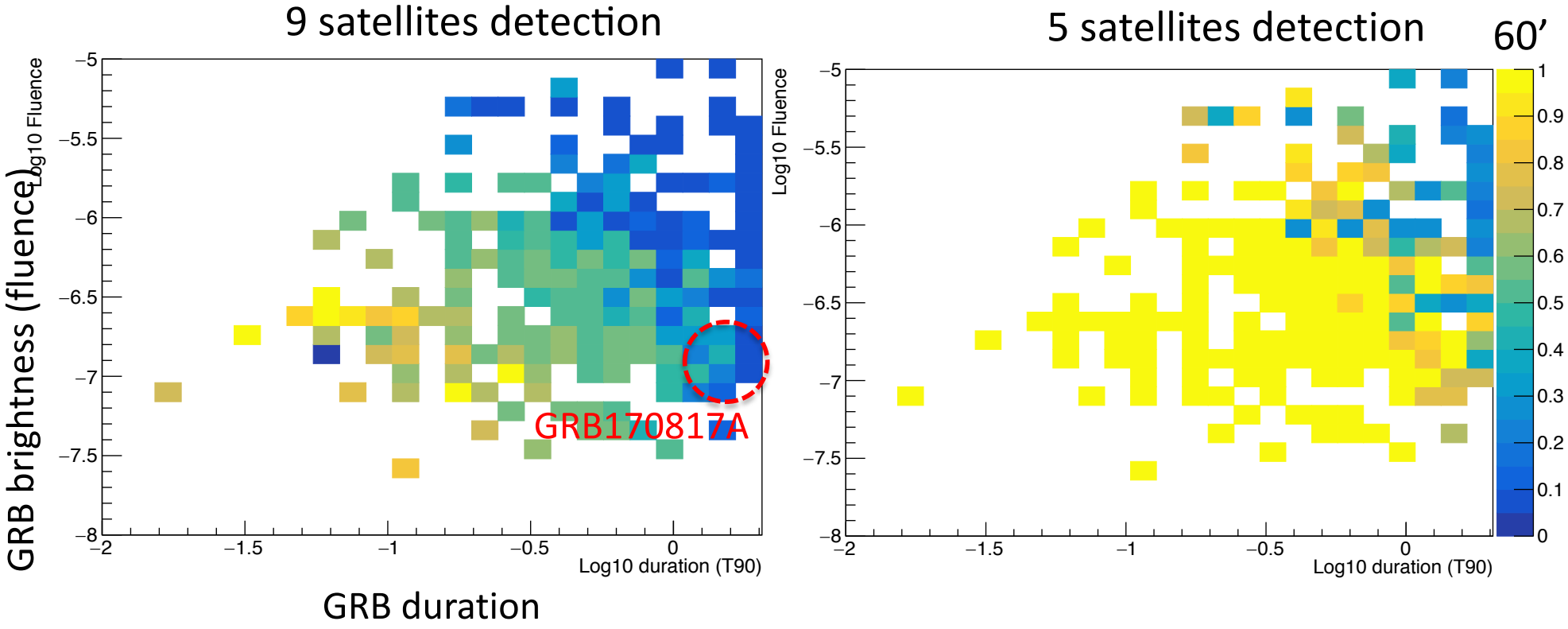
Simple χ^2 minimization

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

~0.1 deg$_{1\sigma}$ (~10 arcmin) accuracy is achievable for bright/good-visibility case

Systematic analysis for Fermi-GBM short GRB

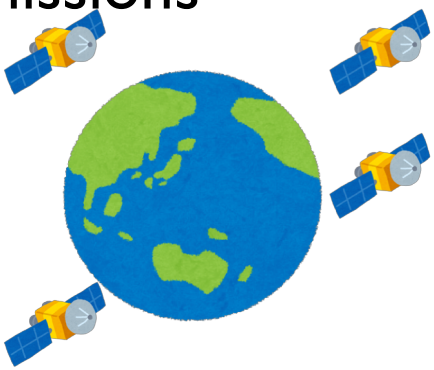
Localization accuracy of this concept is examined for all short GRBs listed in Fermi 3rd GRB Catalog (Bhat+16 T_{90}<2s: 326 samples)



- **High localization accuracy for good photon statistics (brighter/longer)**
- **Larger number of satellite gives a better localization**
- **5-10 arcmin accuracy for good conditions**

Summary

- X-ray/Gamma-ray follow-up of GW counterpart is important for revealing the nature of their sources
- Timing-based localization is a good candidate to realize a arcmin localization with all-sky coverage
- A first stage of the feasibility study shows a nice outlook for this concept
- Increasing the participating satellite would improve the localization accuracy
- Collaboration (data sharing ..etc.) of small satellite missions could be a future direction of GRB localizations



Let's enjoy sharing mission information and discussions !

Event rate and localization

Sat. num.	Visibility prob.	Number ratio of Fermi sGRB for each localization accuracy		
		loc. within <10’	Loc. within <15’	Loc. within <20’
9	1.8%	27%	30%	37%
8	7.6%	26%	29%	33%
7	16%	5%	14%	19%
6	26%	2%	8%	13%
5	25%	1%	3%	8%
4	15%	1%	1%	1%

- ✓ **~12 % of Fermi-GBM sGRB: <20’ localization accuracy**
- ✓ **Fermi GBM sGRB rate: 336 sGRBs/6 years ~ 60 sGRBs/year**
- ✓ **~10 sGRBs/year for <20’ localization accuracy with a timing-localization concept ! (0.5-1° for GRB170817A.. really??)**
- ✓ **Many things should be considered, observation efficiency, systematic uncertainties… etc. etc.**