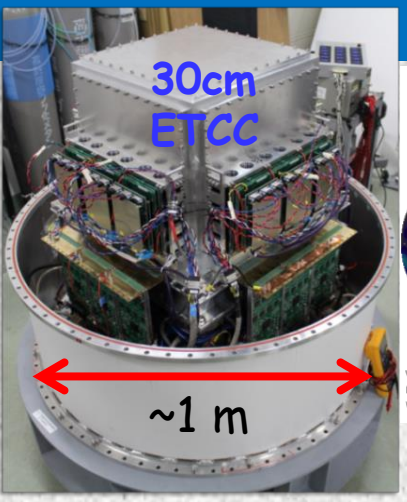
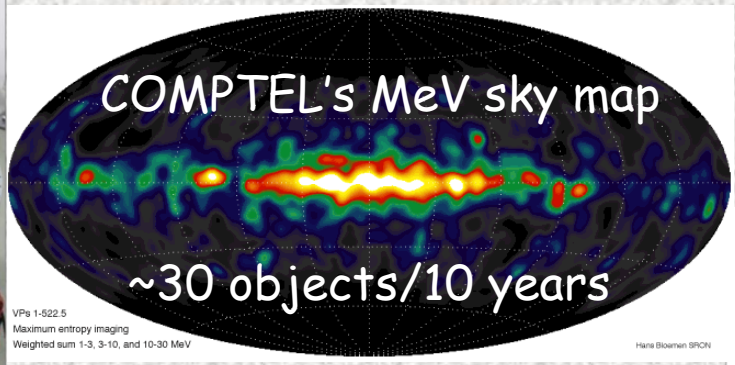
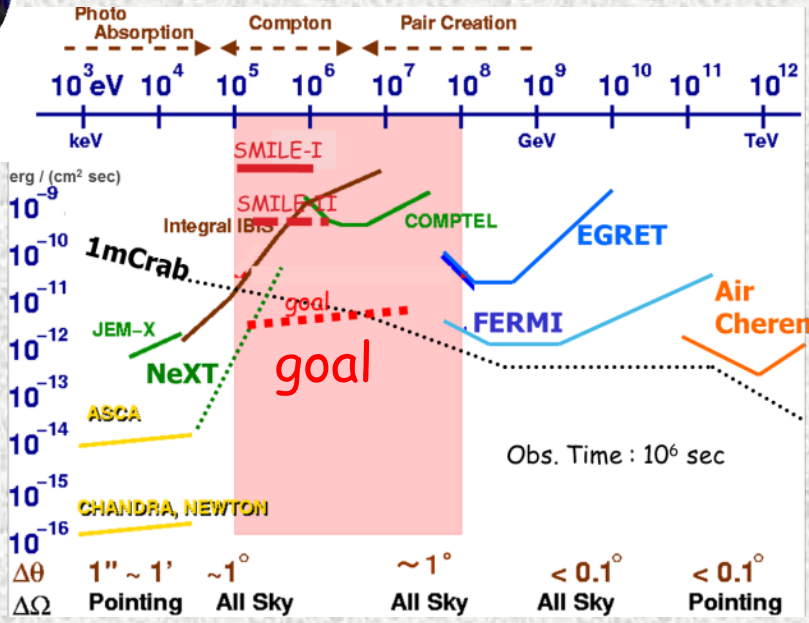
True Imaging trigger for GRBs by Electron-Tracking Compton Camera (ETCC) with an well-defined PSF





V. Schönfelder+ (A&AS, 2000)

2/Sep./2015 GRB-ws2015@Riken



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2. MeV gamma-ray imaging by ETCC
3. Fluence trigger for GRBs
4. Future plan & Summary

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How to reach 1 mCrab

- Target in the next generation MeV γ observatory
  Requested Sensitivity ~10^{-12} erg cm^{-2} s^{-1} (1 mCrab)@10^6 s

$$\text{Significance} \propto \frac{EA \bullet S}{\sqrt{EA \bullet \left(S + BG \bullet \theta^2\right)}}$$

S: γ-ray flux from object

- Effective Area (EA) >2x100 cm^2
  Possible !
- Good BG rejection --> BG(/str) ~ Cosmic diffuse gamma
  Possible (only ETCC) !
- Point Spread Function (PSF) radius θ ~1°
  PSF in Compton Camera is very ambiguous !

Solution is **Fine Electron Tracking**

Imaging and Point Spread Function (PSF)

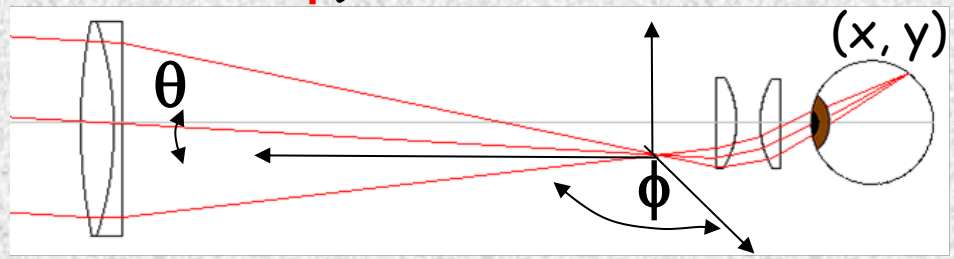
◆General Imaging (measures θ and ϕ)

Two directional angles

↓ Transformation

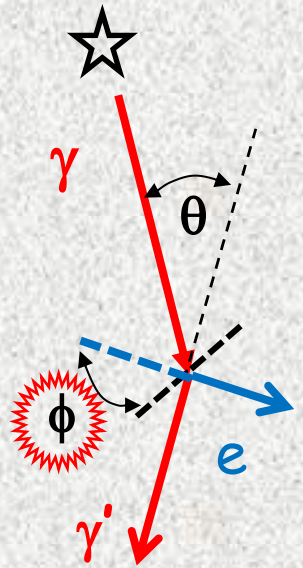
2D position

$$\begin{cases} f(\theta, \phi) = x \\ g(\theta, \phi) = y \end{cases}$$



◆Compton Imaging (measures only θ / both of θ and ϕ)

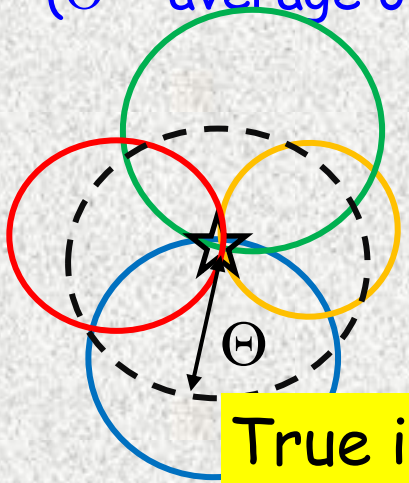
direction (θ, ϕ)



imaging with only θ

PSF(Θ ~20-40°)

(Θ ~ average of θ)



Fine 3D-electron tracking

imaging with θ and ϕ

(Fine 3D-electron tracking gives ϕ)

PSF(Θ ~1°)

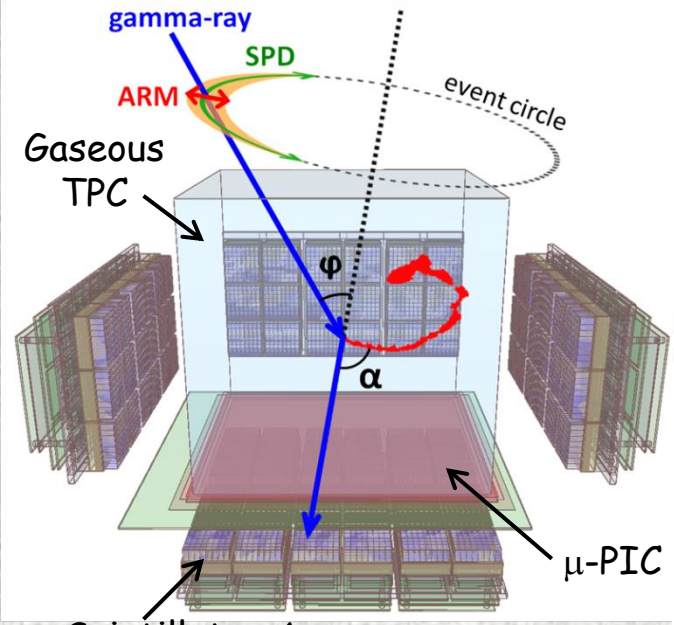
If accuracies of θ and ϕ are similar to a few degree

↓

well-defined PSF with ~1°

True imaging (PSF(~1°)) + wide FoV (>4str) enables us a fluence trigger for GRB search

Electron-Tracking Compton Camera (ETCC) in SMILE-II

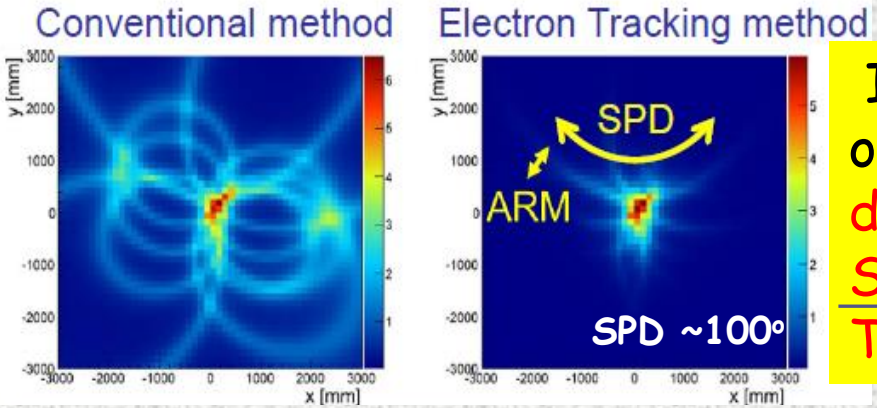


30cm-cubic Gaseous Time Projection Chamber

--- tracking of recoil electron ---

SPD (Scatter Plane Deviation) + dE/dx + α

Scintillator Array for scattered γ

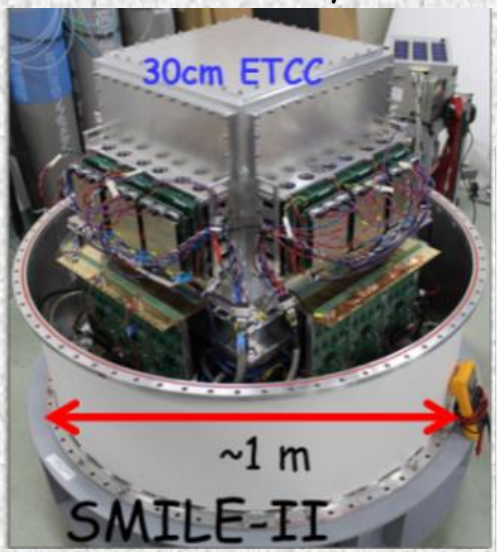


Improvement of Sensitivity

dE/dx x3

SPD x3~4

Total x5~10



30cm cubic ETCC

Eff. Area of 1-20cm²

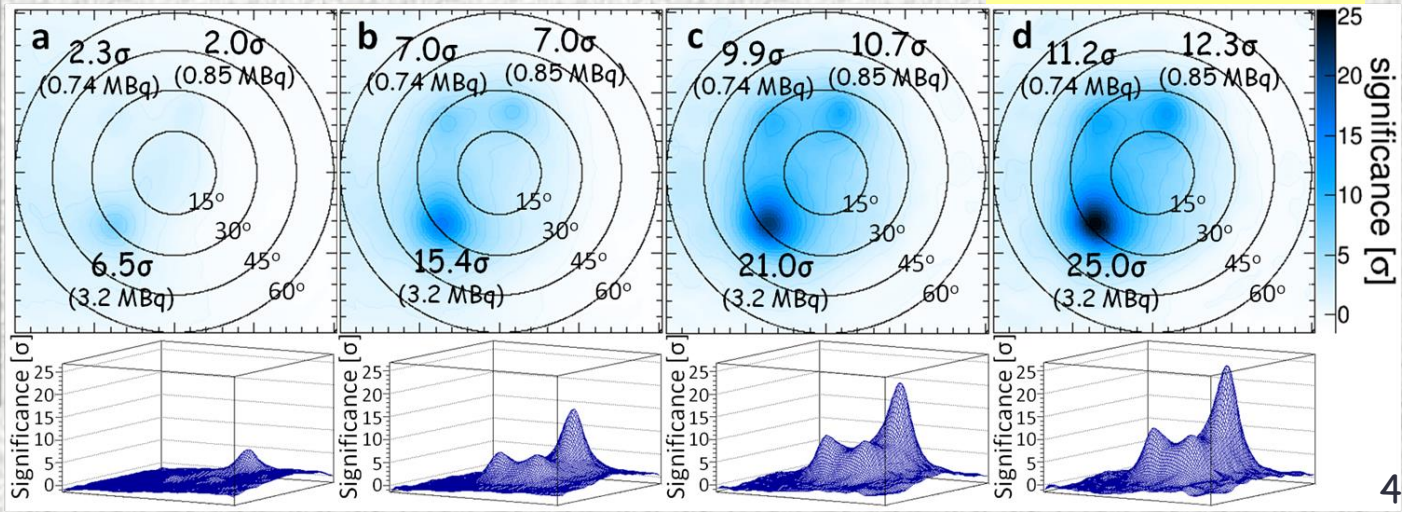
no use of SPD

SPD ~200°

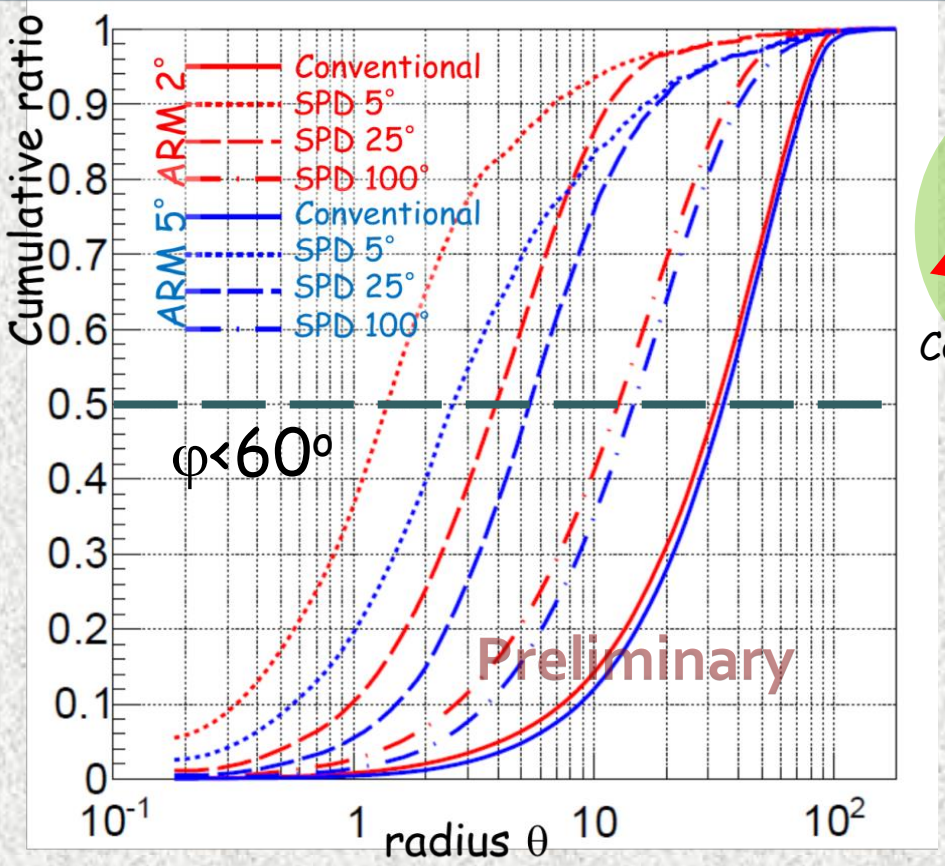
SPD ~100°

SPD 90° (<80keV)

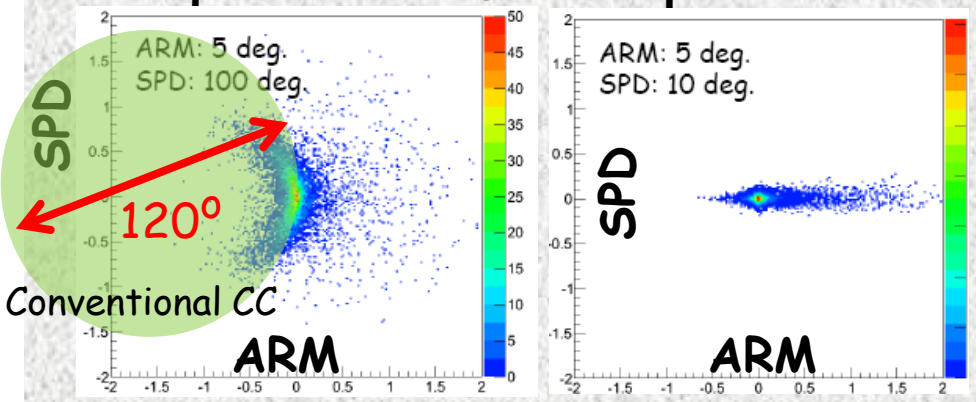
SPD 45° (>80keV)

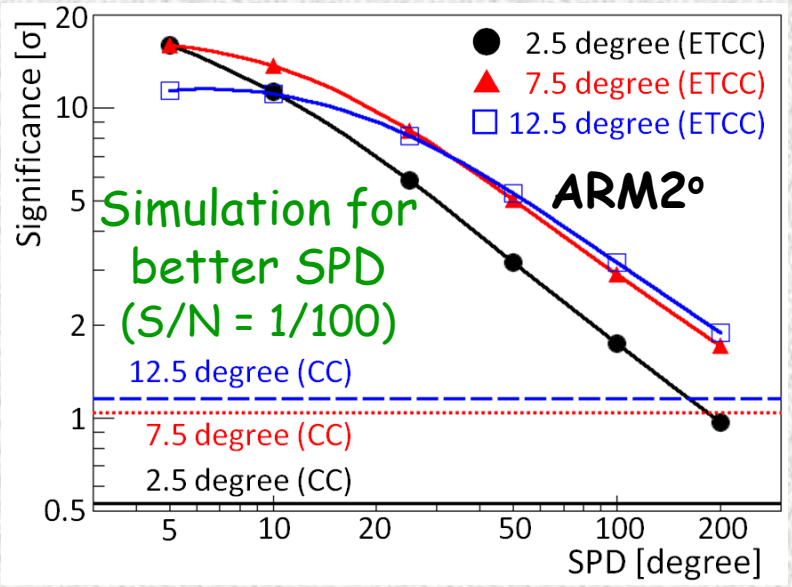


Point Spread Function in Compton Camera



Spread on SPD-ARM plane





PSF(θ) = ½ gammas in the radius of θ

Conventional CC PSF(35°)

SPD 50° ARM 5° PSF(7°)

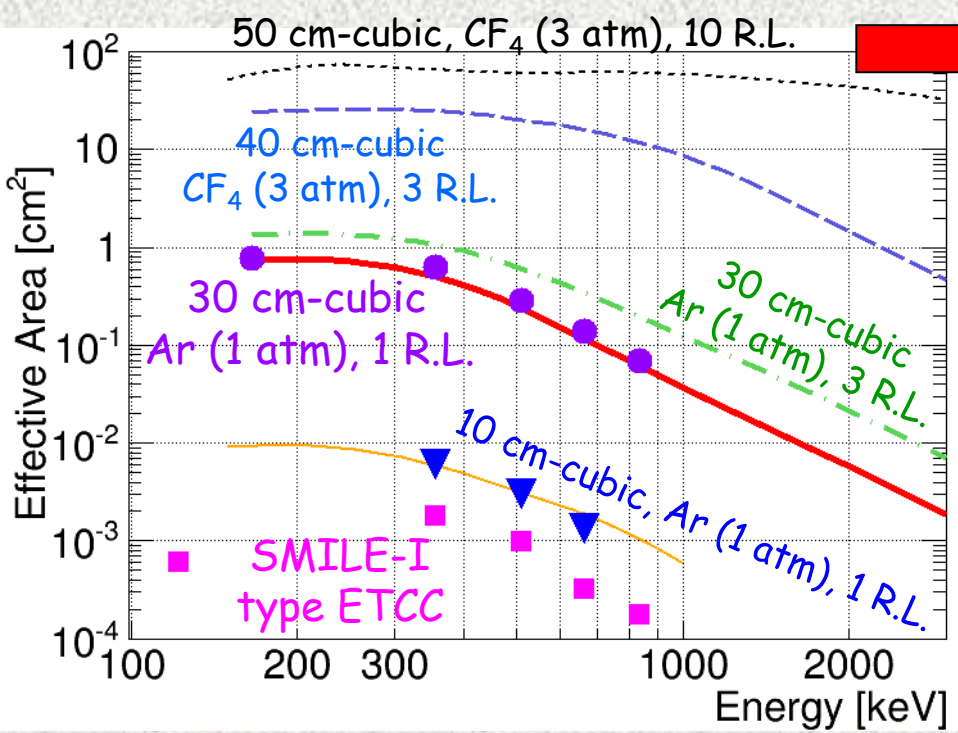
SPD 25° ARM 5° PSF(5°)

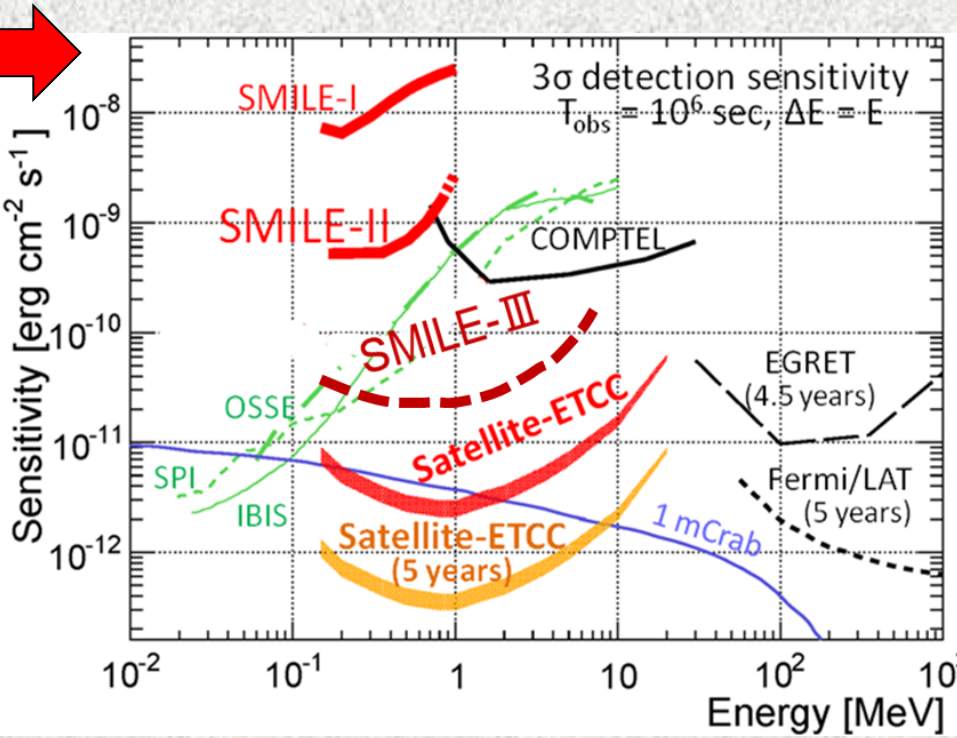
SPD 5° ARM 2° PSF(1.2°)

- PSF of Compton Camera is determined by φ (NOT by ARM).
- PSF of ETCC is determined by Max{ARM, SPD}

Future Sensitivities by ETCC

Sensitivities are calculated simply from effective area and PSF with no use of MLEM





- **SMILE-II (Balloon, in USA)**
  (30 cm)^3 ETCC with ~1-4 cm^2
  Crab, Cyg X-1 at >5σ, +Polarization

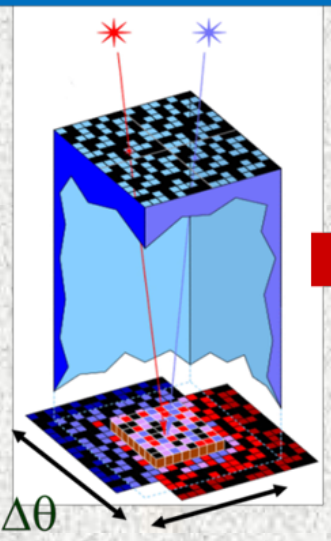
- **SMILE-III (Balloon, in polars)**
  (40 cm)^3 ETCC x2 = ~80cm^2
  Deep Survey, GRB

- **SMILE-Satellite: (50 cm)^3 ETCC x 4**

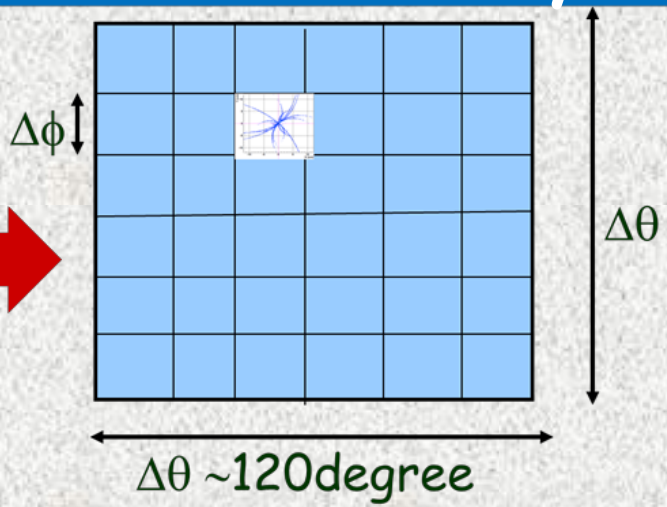
  SMILE-II, III PSF(7°)
  SMILE-Satellite PSF(1.2°)

Assumed BG flux:
SMILE-II, III: observed flux by SMILE-I
SMILE-Satellite: 2x (Cosmic diffuse gamma)

Detection of GRB by "True Imaging"



Noise area = Δθ x Δθ



Noise area = (Δϕ x Δϕ)

Δϕ/Δθ =10 Noise reduction -> 1/100

Sensitivity for GRBs

Satellite-ETCC 250cm^2

Trigger FoV = 4x4°

$T_{obs.}$ ~ 10 sec

BG (4x4°) 2γ --> 12γ >8σ

Δθ <0.5° (position accuracy)

--> S ~20γ ->10^{-9} erg cm^{-2} s^{-1}

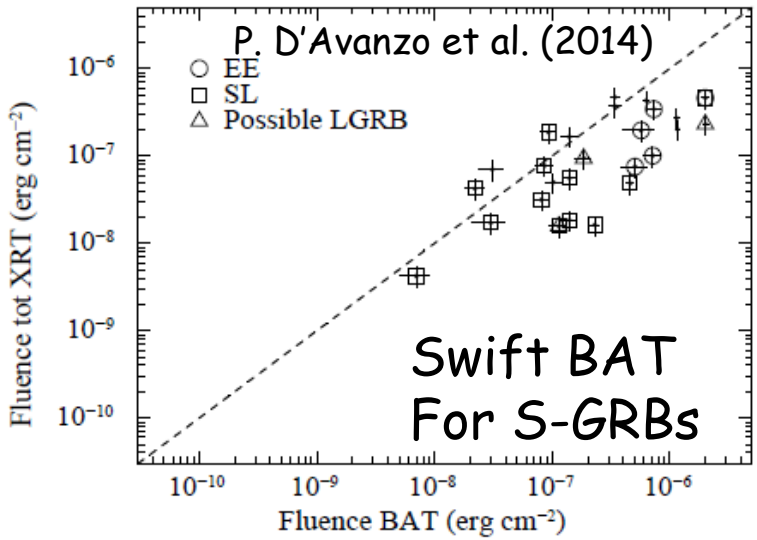
Fluence ~10^{-8} erg cm^{-2}

Short GRBs (E_{peak} > ~300 keV)

Swift less efficient for short GRB than BATSE due to its low sensitivity >100 keV

	15-150 keV (Swift band)	0.5-5 MeV (ETCC band)
Swift threshold [erg cm^{-2}]	~5x10^{-7} →	3-5x10^{-6}
ETCC threshold [erg cm^{-2}]	1-5x10^{-9} ←	~1x10^{-8}

ETCC improves fluence threshold about 10-100 times in Swift-band



Fluence Trigger for standard long GRB

(G. Ghirlanda et al. MNRAS 448, (2015))

1. Time dilation

   Photon flux trigger is affected strongly by time dilation.

   Fluence trigger is NOT affected.

2. Redshift

   Broad band SED (keV to 10 MeV) very little effect on fluence.

Satellite-ETCC (T_{90}: 10-100 sec)

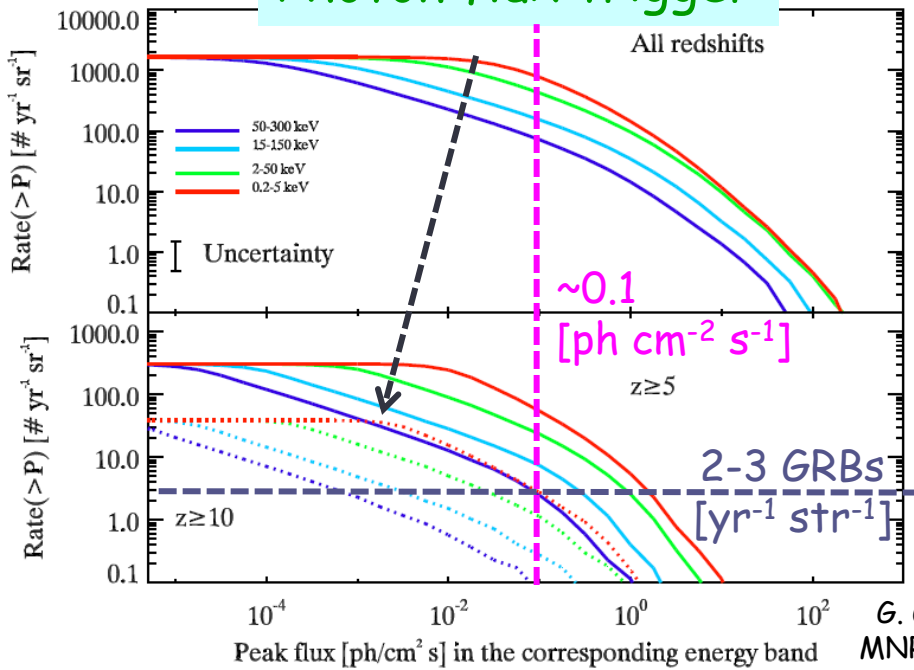
--> Fluence ~10^{-8} erg cm^{-2}
(2-3 GRBs/year/str (z>10))
+ wide FoV >4 str

--> ~10 GRBs/year (z >10)
200 GRBs/year (z > 5)

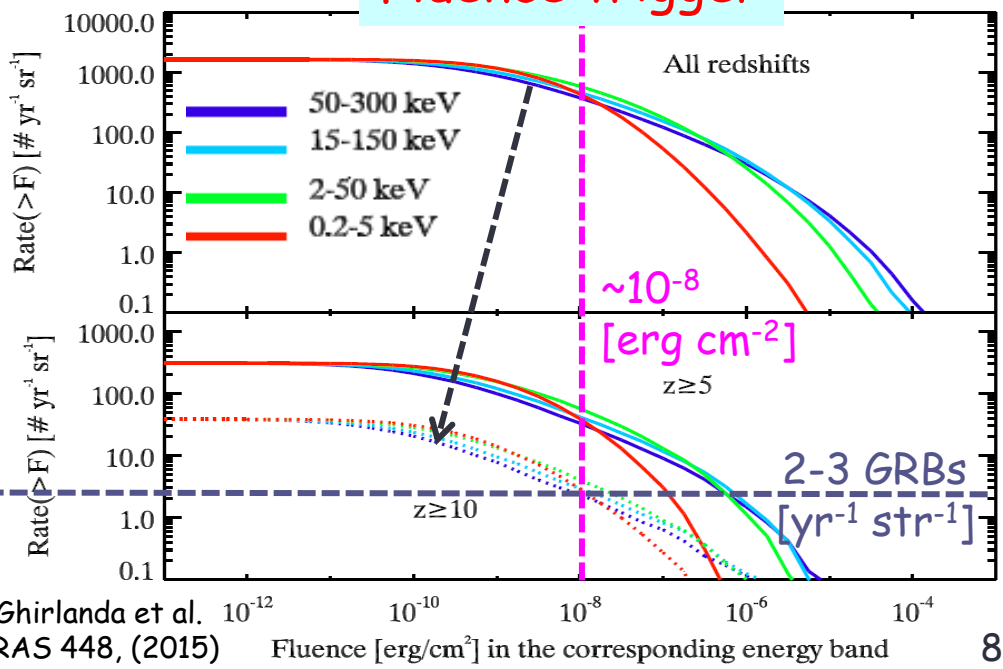
Energy band

50-300 keV --> 50 keV-10 MeV
more GRBs will be detected.

Photon flux trigger



Fluence trigger



G. Ghirlanda et al. MNRAS 448, (2015)

Ultra Long duration GRBs (POP-III)

D. Nakauchi et al. ApJ 759 (2012)

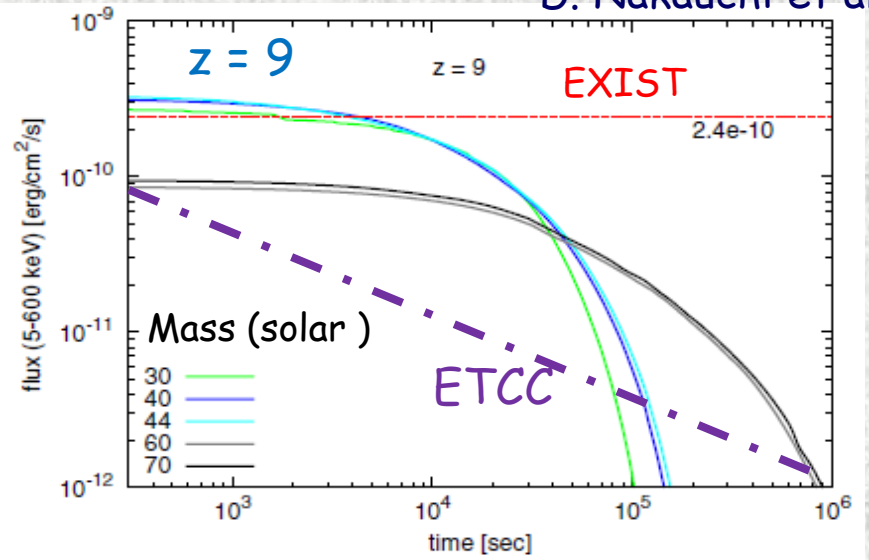


Figure 6. Same as Figure 5, but for the *EXIST* (5–600 keV) case. The red dashed line represents the *EXIST* sensitivity $f_{sen} \sim 2.4 \times 10^{-10}$ erg cm^{-2} s^{-1} (5–600 keV, 5σ) in the longest exposure timescale at the on-board process ($\Delta t \sim 512$ s; Hong et al. 2009). Note that we focus on Pop III GRBs at $z = 9$ in this figure.

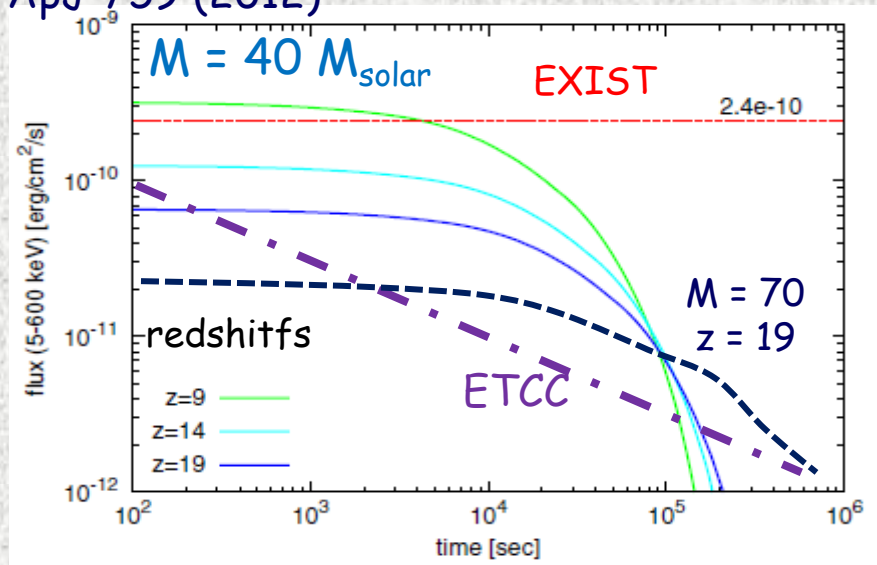


Figure 3. Same as Figure 2 but for the *EXIST* case. *EXIST* will have the limited energy range of 5–600 keV. The red dashed line represents the *EXIST* sensitivity $f_{sen} \sim 2.4 \times 10^{-10}$ erg cm^{-2} s^{-1} (5–600 keV, 5σ) in the longest exposure timescale at the on-board process ($\Delta t \sim 512$ s; Hong et al. 2009).

Assumed E_p-E_{iso} relation (Amati) --> E_p~120 keV @z = 9

EXIST limit: 2.4x10^{-10} erg cm^{-2} s^{-1} (500 s)

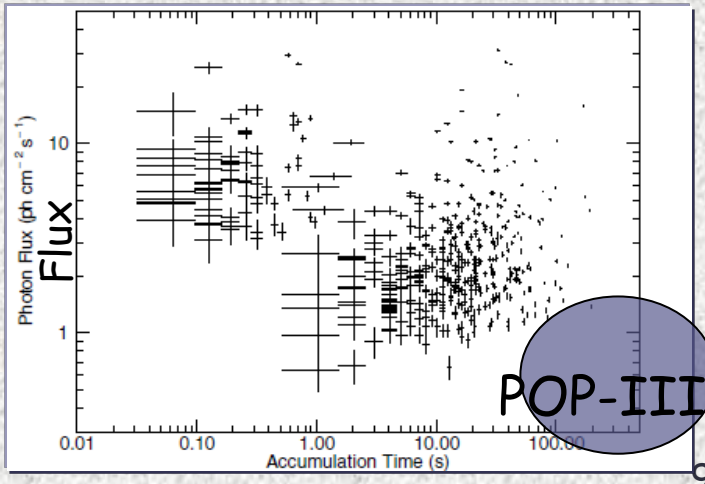
Pop-III Flux <10^{-10} erg cm^{-2} s^{-1} (very faint)

But, Fluence ~10^{-5} erg cm^{-2} (Intense)

Satellite-ETCC; S/√N >5σ

10^{3}s; S ~90γ BG 200γ -> 4x10^{-11} erg cm^{-2} s^{-1}

10^{5}s; S ~800γ BG 2x10^4 γ -> 4x10^{-12} erg cm^{-2} s^{-1}



Exploring GRB astronomy by Balloon-SMILE

1. SMILE-II one-day flight(s) for Crab and Cyg X-1 (Anytime, OK)
2. Next plan, SMILE-III Long-duration flight with larger ETCCs

Polar region 14-50 days (T_{obs} >10^6 sec)

40 cm-cubic ETCC x2 modules (Eff. Area ~80 cm^2)

GRB Search in Long duration flight

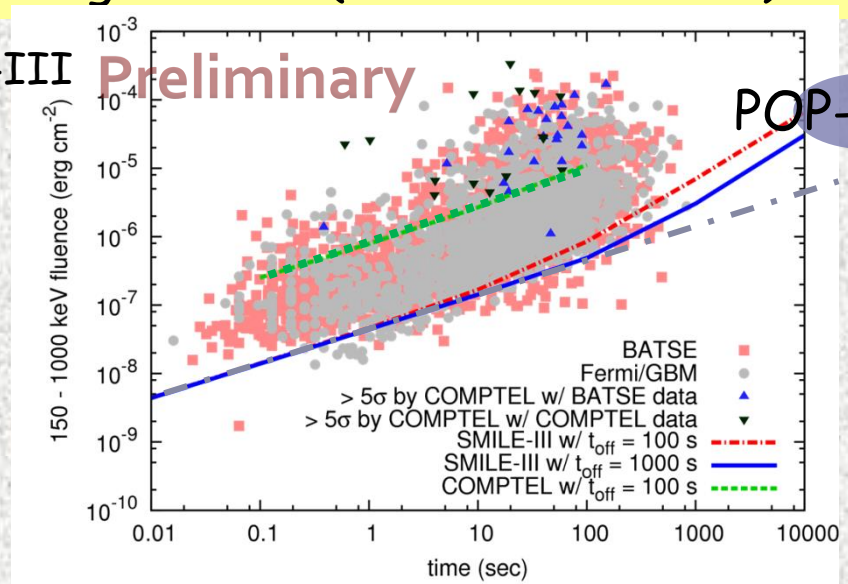
10^6 s --> ~3x10^{-11} erg cm^{-2} s^{-1} (+ FoV of 4 str) --> ~1 GRBs/day

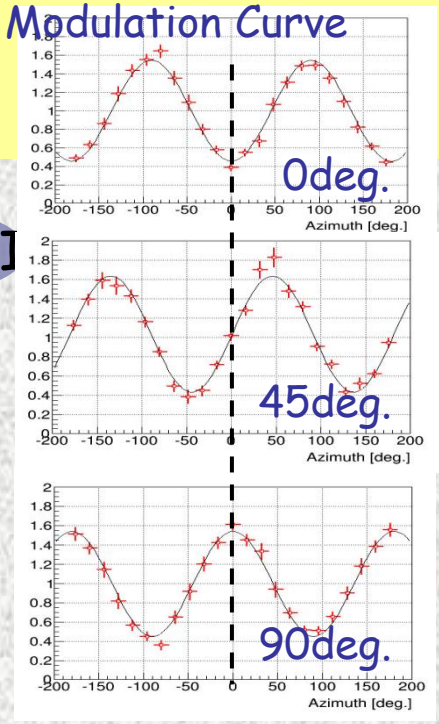
In addition, Polarization Modulation factor 0.6 at 130 keV in SPring-8

MDP ~ 6% for 10^{-6} erg cm^{-2} s^{-1} (2-3 GRBs/month)

~ 20% for 10^{-7} erg cm^{-2} s^{-1} (~10 GRBs/month)

GRB detection in SMILE-III
Simulated by T. Sawano





Summary

- ETCC provides an well-defined PSF which reveals the way to reach 1 mCrab sensitivity without assuming the use of Optimization Algorithm.
- A good PSF gives a >10 times better significance than conventional Compton cameras with efficient BG rejection ability of dE/dx.
- Clear imaging with an well-defined PSF in sub-MeV band would enable a true Imaging Trigger (Fluence Trigger) for GRBs and provide changes to reach most distant GRBs of any type (Short, Long, and Ultra-long).
- SMILE-III (long-duration balloon) will surely certificate above ability of ETCC with measuring polarization of GRBs.

Details of ETCC: **Tanimori et al., ApJ (2015), 810, 28**