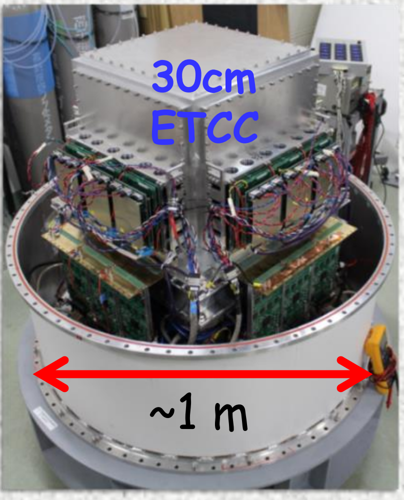
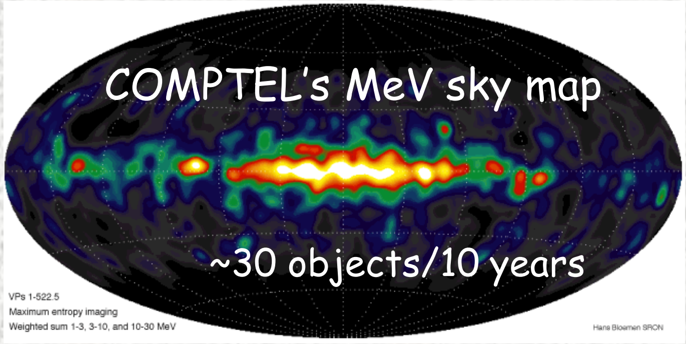
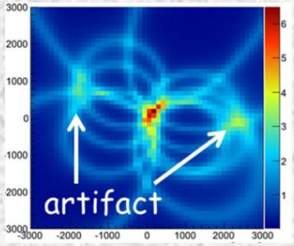
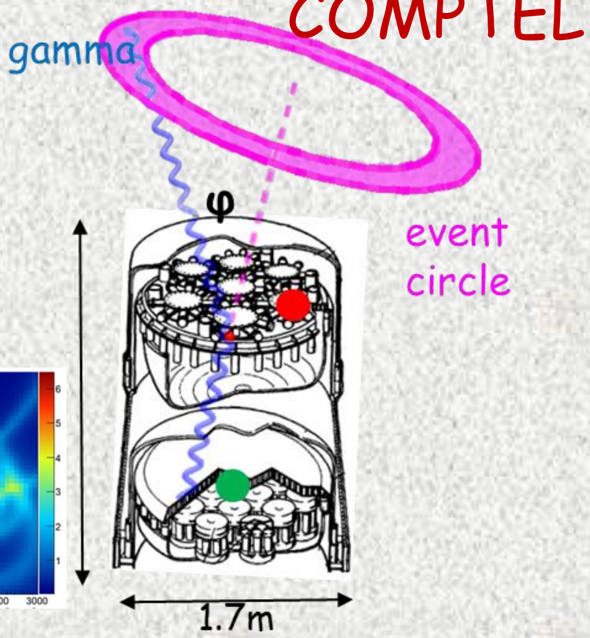
Establishment of Imaging Spectroscopy in MeV gammas & its application to GRB detections





V. Schönfelder+ (A&AS, 2000)





CONTENTS

1. Point Spread Function in MeV region
2. Imaging Spectroscopy by ETCC
3. Imaging Observations for GRBs +Kilonova
1. Summary

Two big problems in MeV Astro.

1. Imaging is very difficult
2. Huge background

03/Mar./2017 @ Chiba Univ.

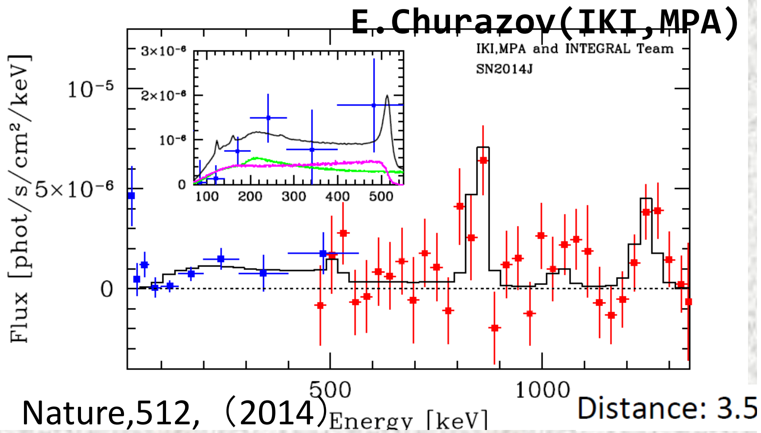
T. Tanimori on behalf of SMILE-Project,
Cosmic-ray group, Physics-II Division, Kyoto Universty, Japan

Line gammas from SN Ia SN2014J (INTEGRAL-SPI)

Broad band SN2014J spectrum and the model (day 75)

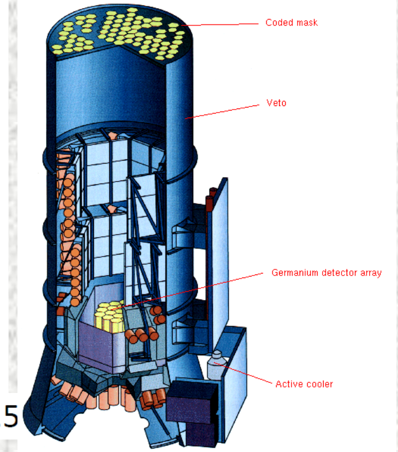
Fluxes of 847 and 1238 keV lines + continuum below 511 keV

E.Churazov(IKI,MPA)



Nature,512, (2014)   Distance: 3.5

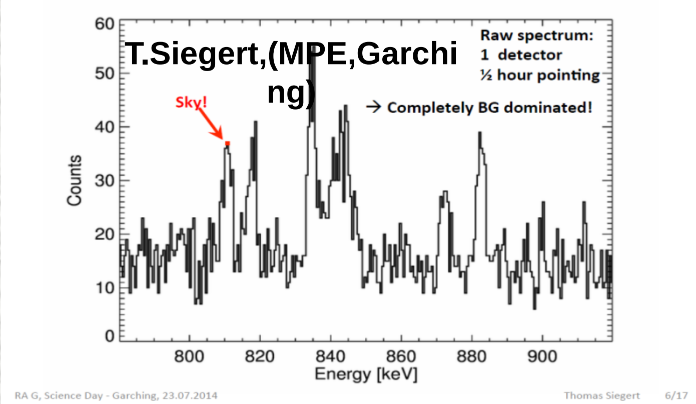
SPI: Codded Mask 19 xGe FoV ~1 str

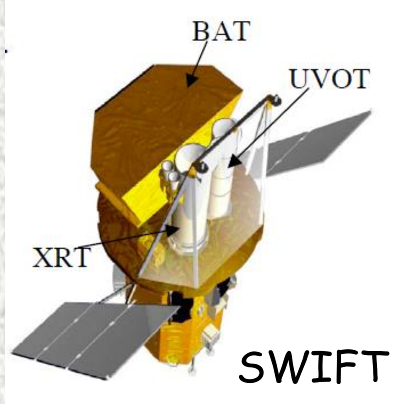


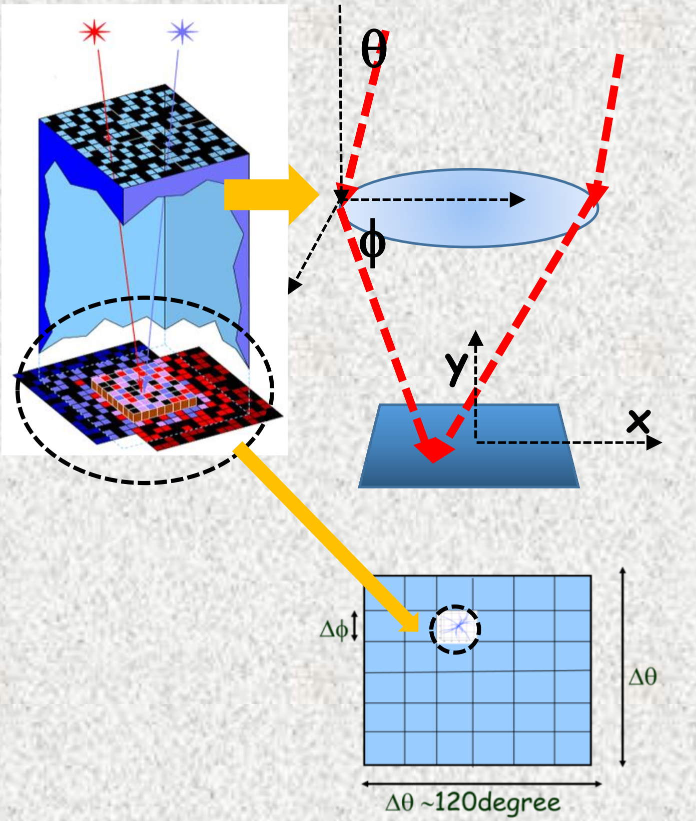
SN2014J

Tanimori et al., ApJ (2015), 810, 28

How to discriminate between sky and BG?







SPI Effective Area 65cm²@1MeV

#of Photons ; $5\times10^{-6}\times65\text{cm}^2\times30\text{keV}\times5\times10^6\text{s}$ $\sim4\times10^4\gamma$

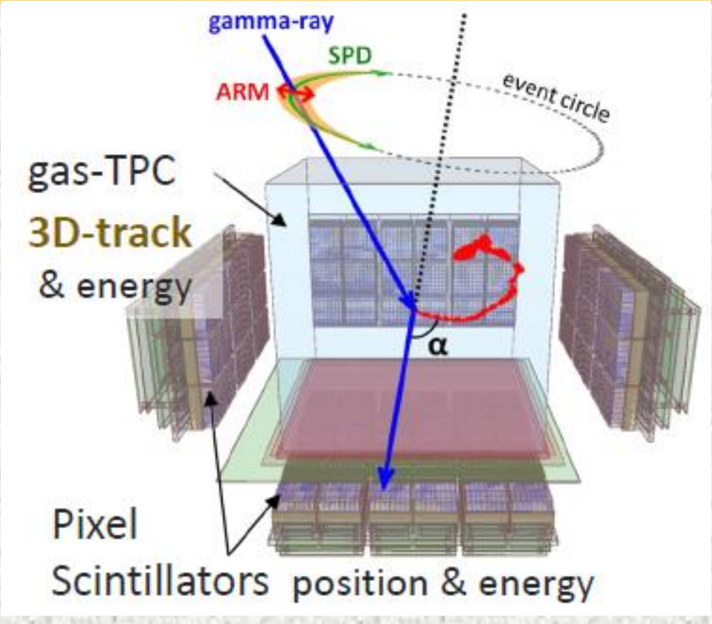
From ~4σ detection BG Estimation ->$\sim10^8\gamma$ at 60keV band

If BG were reduced by 3 orders

BG $\sim10^5$ => $4\times10^4/\sqrt{(10^5)}$ > 100σ

PSF (radius=2°) -> $\sim10^{-3}$ of π sr

Electron Tracking Compton Camera



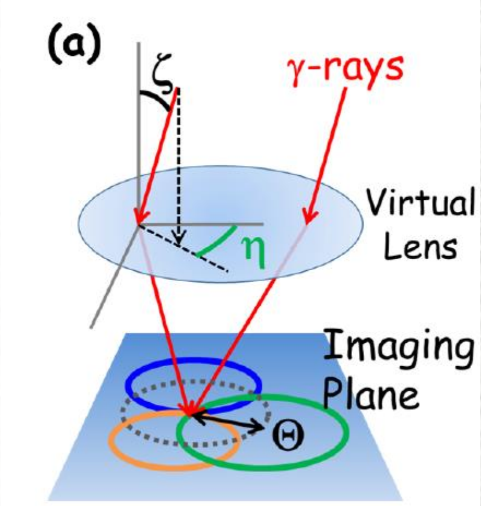
30cm-cubic Gas Time Projection Chamber

--- tracking of recoil electron ---

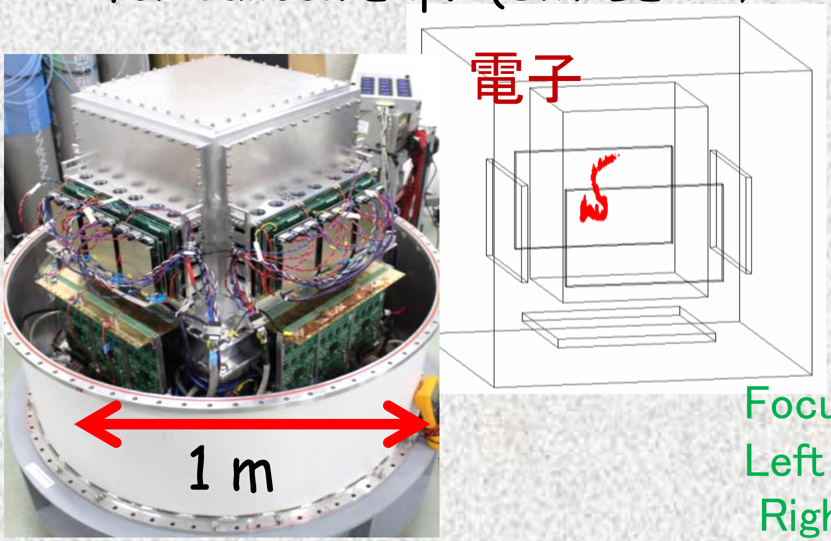
well-defined PSF based ARM & SPD

dE/dx + kinematical test using α

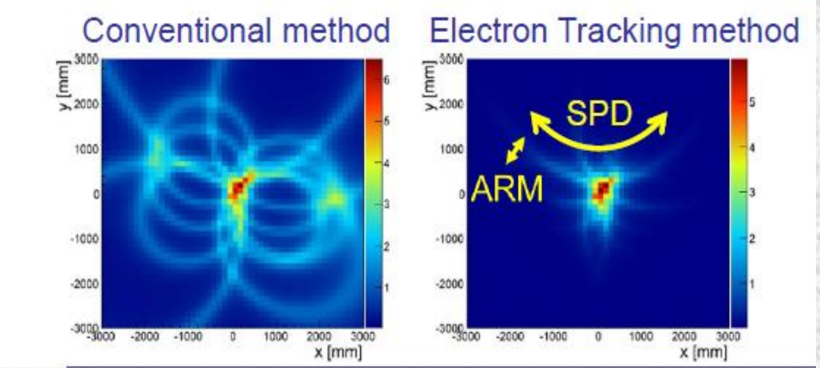
Scintillator Array for scattered γ



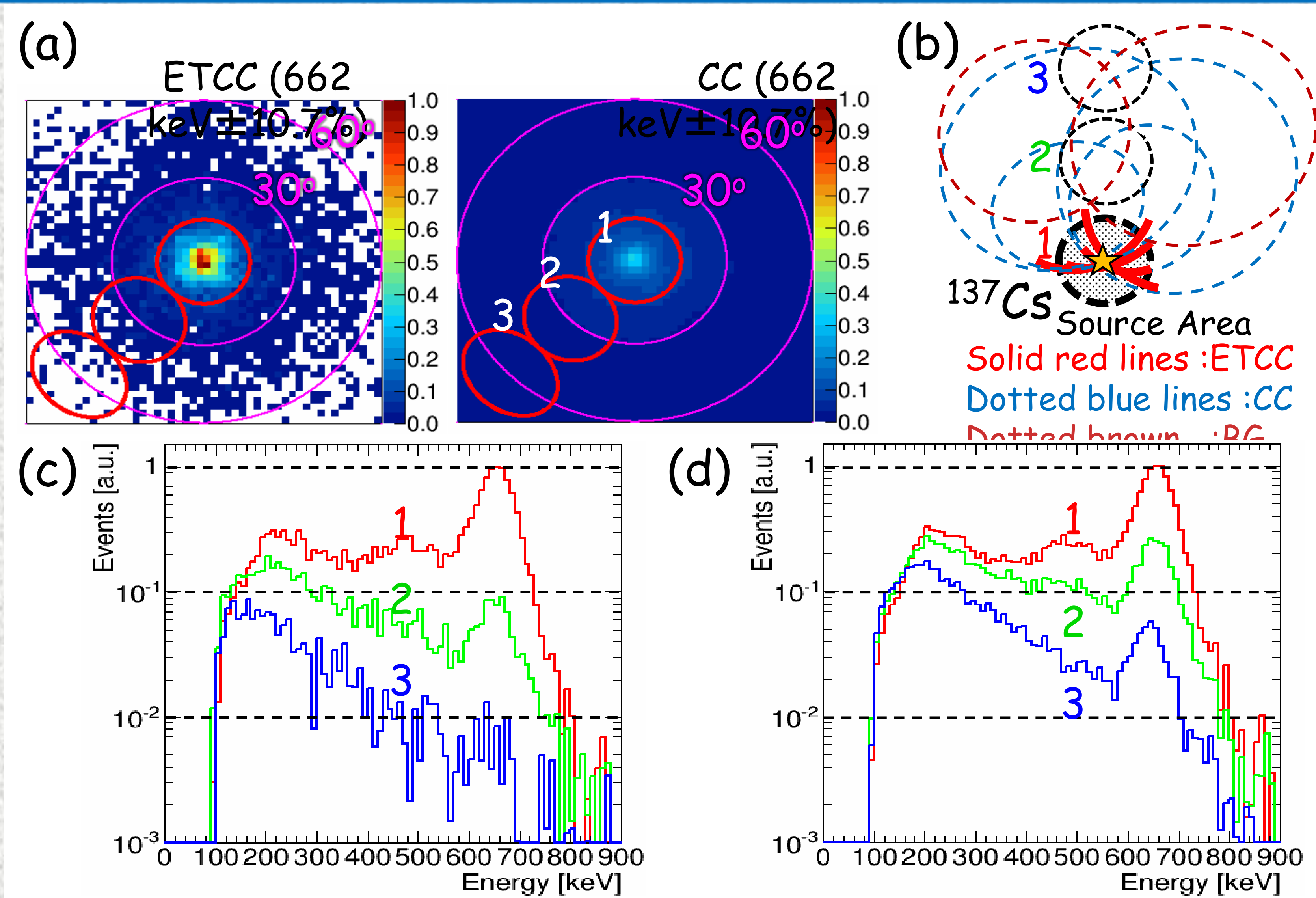
ETCC for balloon Exp. (SMILE-II)



Focus image
Left CC
Right ETCC

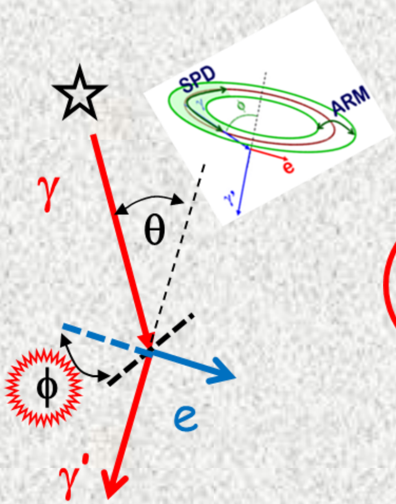


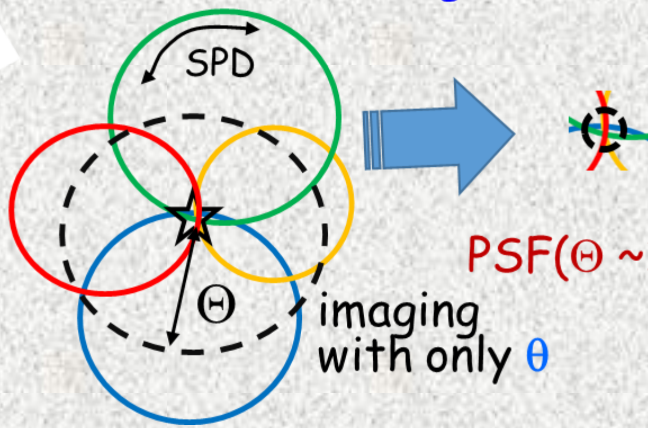
Well-defined PSF in ETCC and leakage in CC

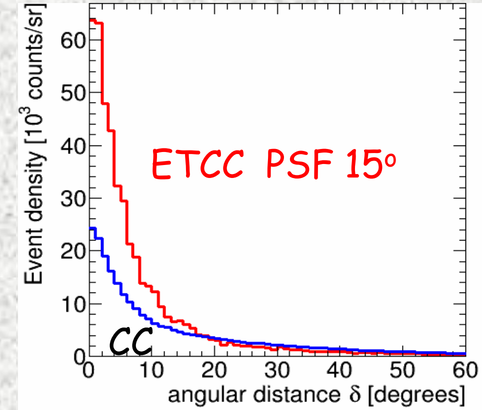


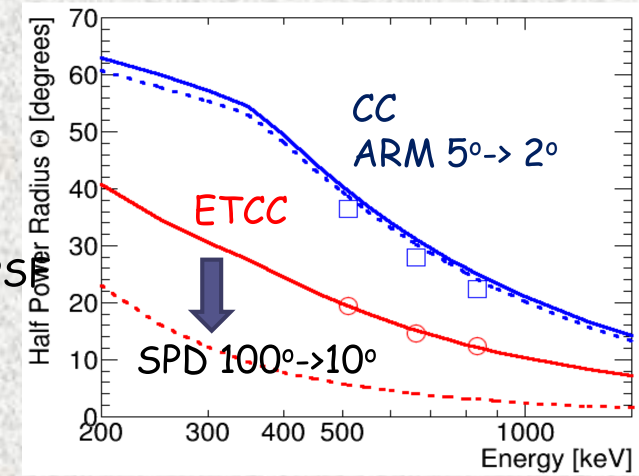
Case S/N ~1 : a peak density of CC increases by ~3 times due to the leakage of background to the source position

ETCCのPSF(15°)　CCのPSF(35°)

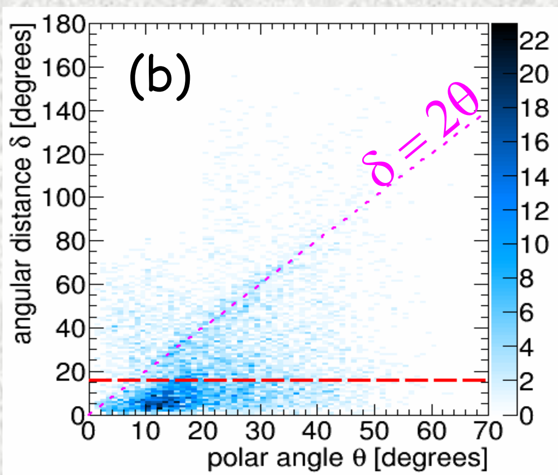




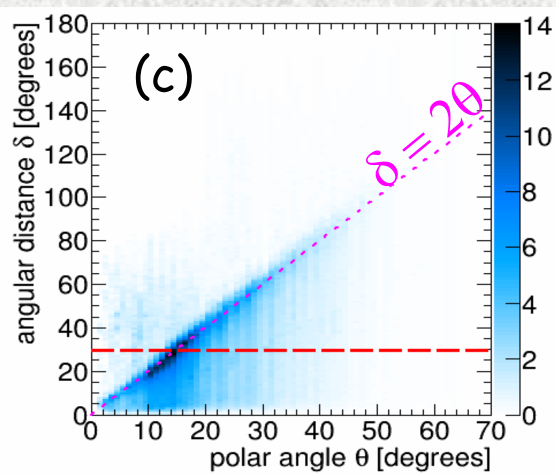


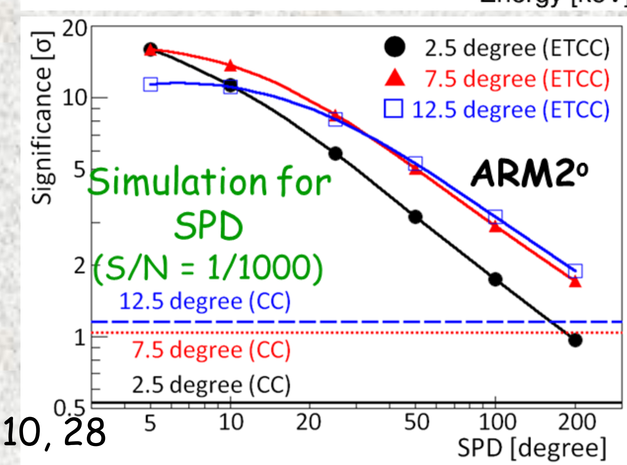


ETCC PSF(15°) 実測値



CC PSF(35°)　実測値



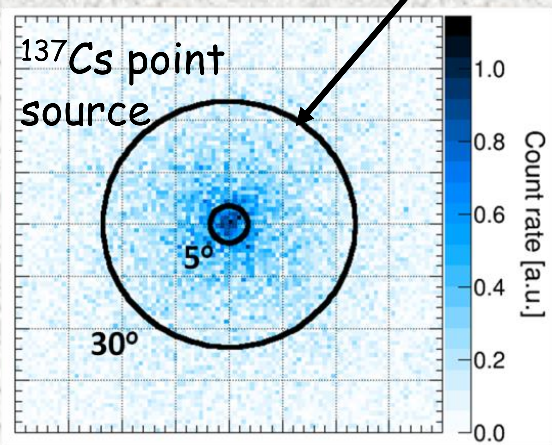


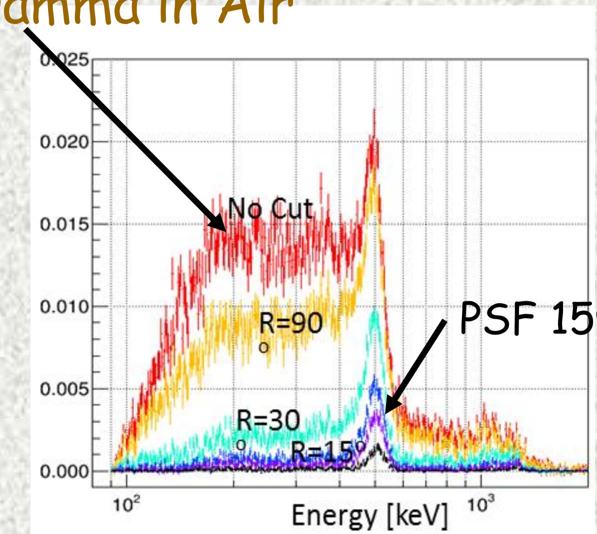
Tanimori et al., ApJ (2015), 810, 28

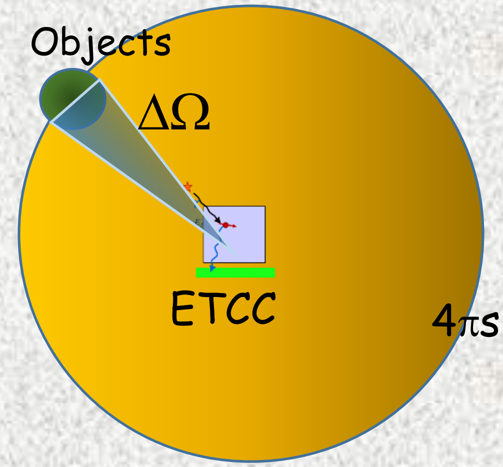
Noise Reduction by Imaging Spec.

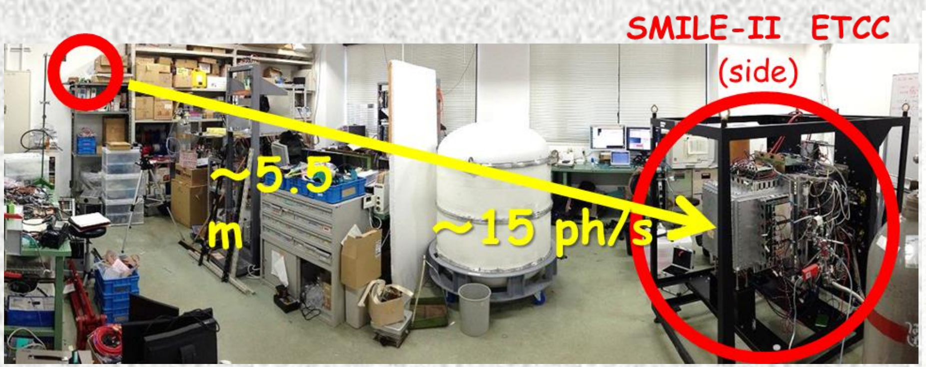
FoV 4 sr (~60° Radius) PSF 5° FoV 0.02sr BG~1/150

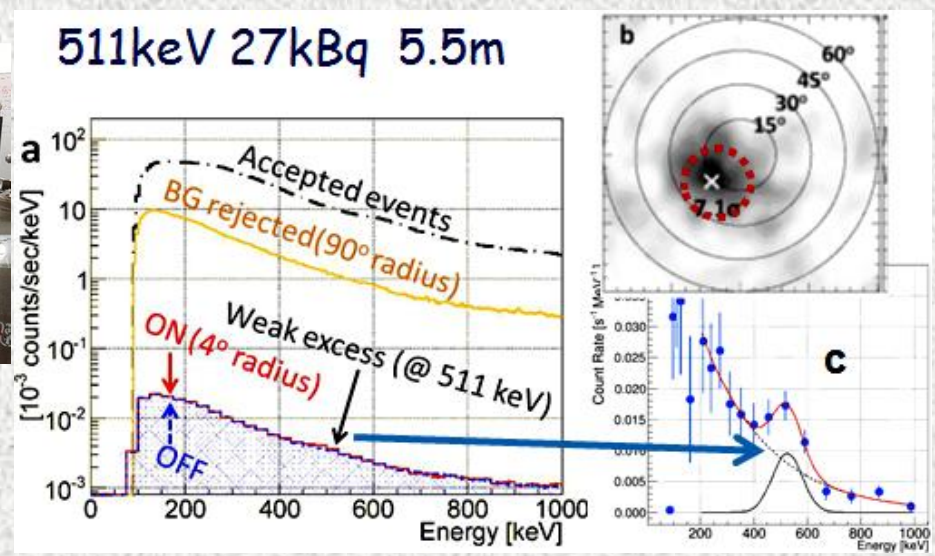
Scattered gamma in Air







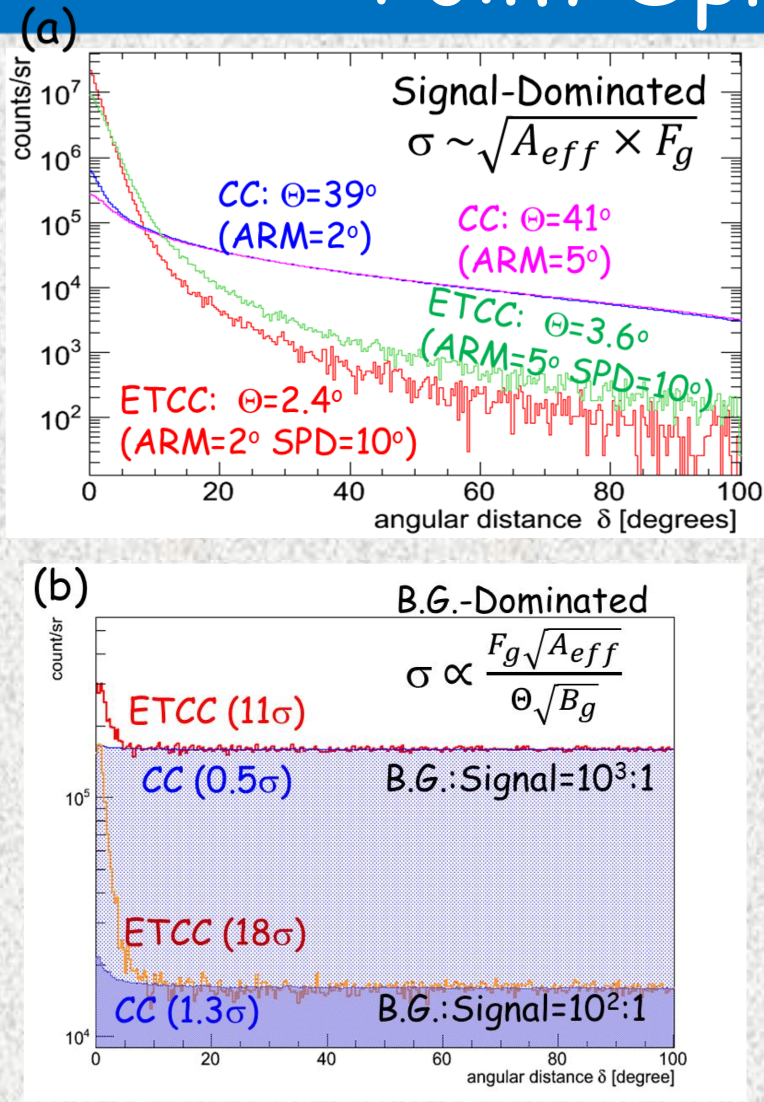


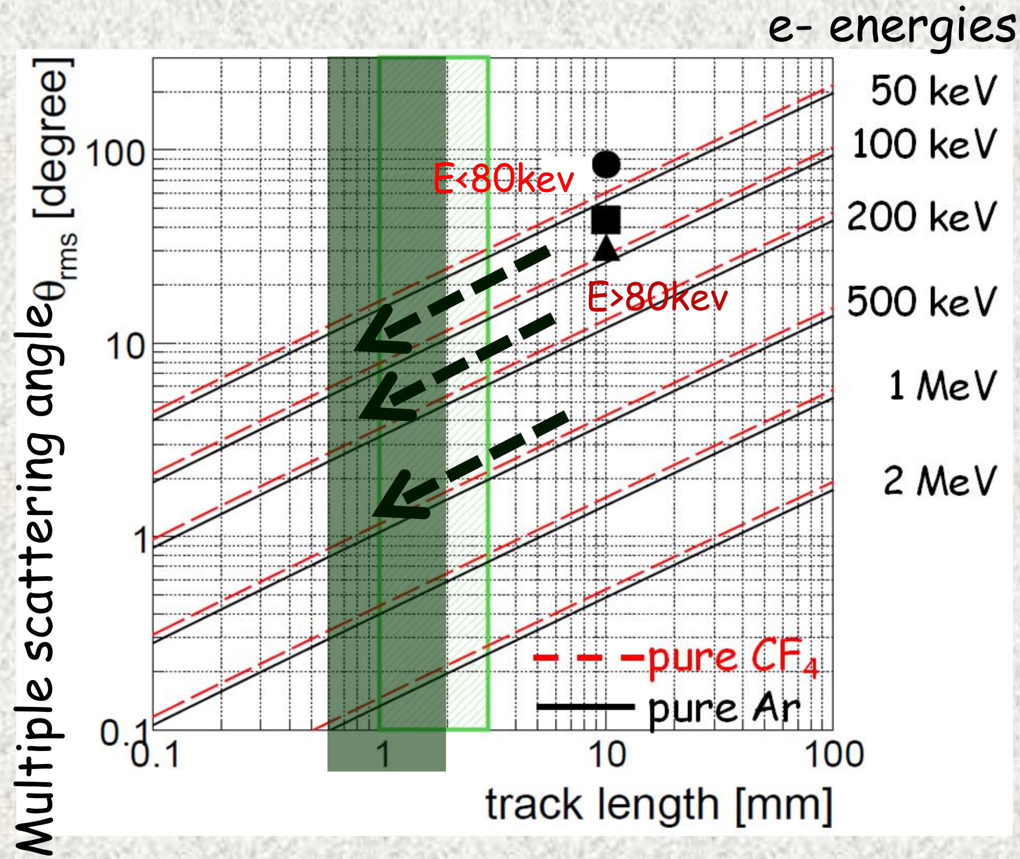


^{22}Na (27 kBq, 511 keV) 5.5m
8x10^{-5}μSv/h
(1/1000 of Environmental radiation)

Tanimori et al., ApJ (2015)

Point Spread Function in





PSF(7°) SPD 50° ARM 5°
PSF(5°) SPD 25° ARM 5°
PSF(1.2°) SPD 5° ARM 2°

- For good PSF of ~1°

3D-tracking with 1mm in Gas or
3D 1μm sampling in Solid State is inevitable !
Already GAS is possible !!!

Possibility of <1m Crab

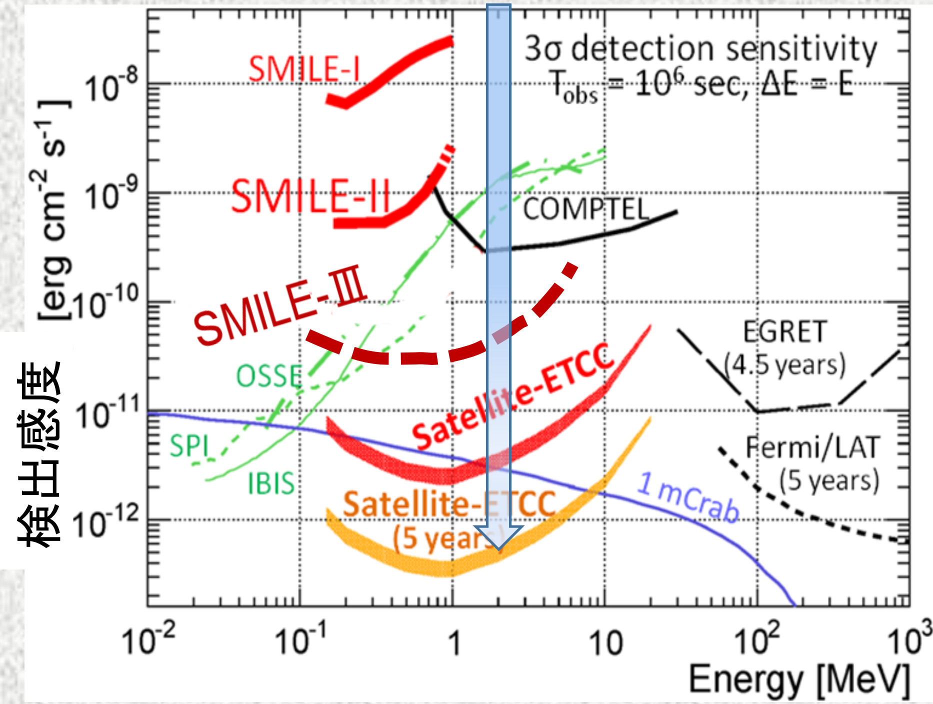
- For Next MeV Astronomy, significance ~10^{-13} erg cm^{-2} s^{-1}

S: signal
θ: PSF

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

BG dominated

2. $\mathrm{Significance} \propto \dfrac{EA \bullet S}{\theta\sqrt{(EA \bullet BG)}}$



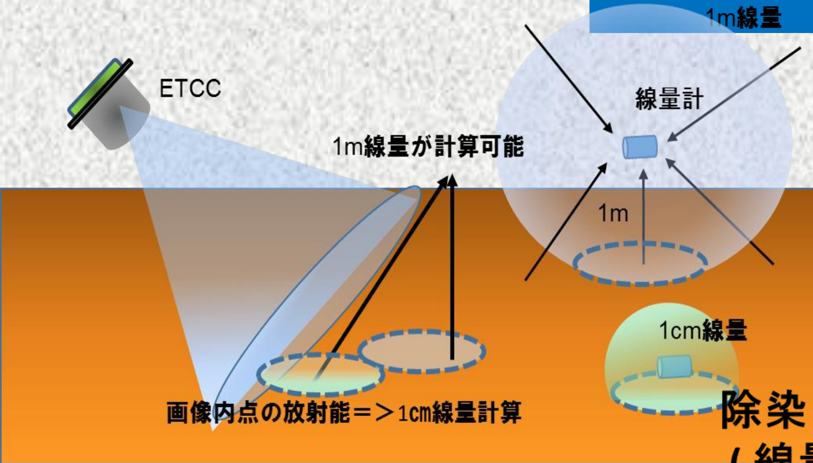
1. Effective Area ~200 cm² Possible!
2. BG. Cosmic MeV background
   (PSF, dE/dx, kinematical test) Possible!

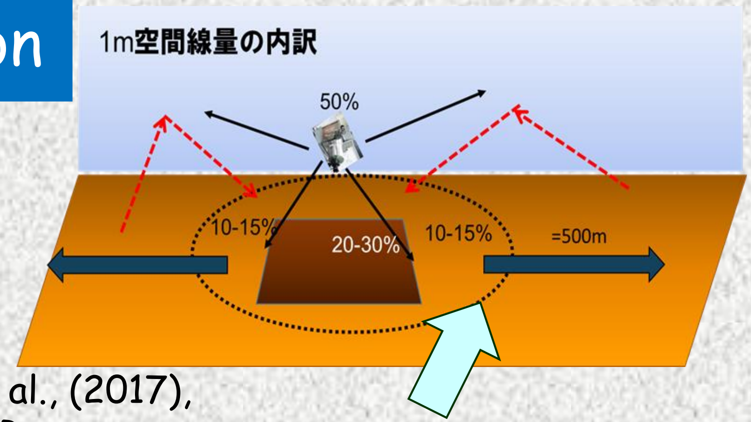
=>PSF $\theta = 1\sim2^\circ$ inevitable !!

Gas electron tracking may be a unique solution

- "An Electron-Tracking Compton Telescope for a Survey of the Deep Universe by MeV gamma-rays" T.Tanimori et al. ApJ 810 (2015)
- "Establishment of Imaging Spectroscopy of Nuclear Gamma-Rays based on Geometrical Optics" T.Tanimori et al. Scientific Reports 7, (2017).
- "First On-Site True Gamma-Ray Imaging-Spectroscopy of Contamination near Fukushima Plant", D.Tomono et al.Scientific Reports 7, (2017).

Decontamination

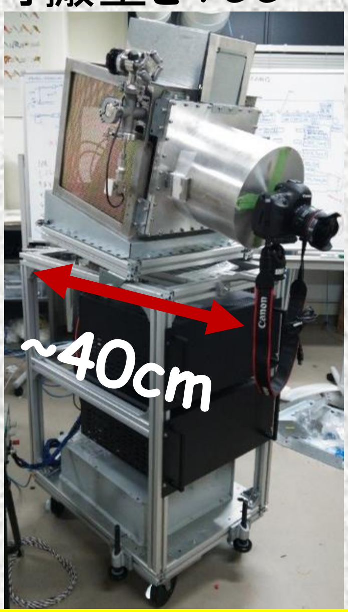




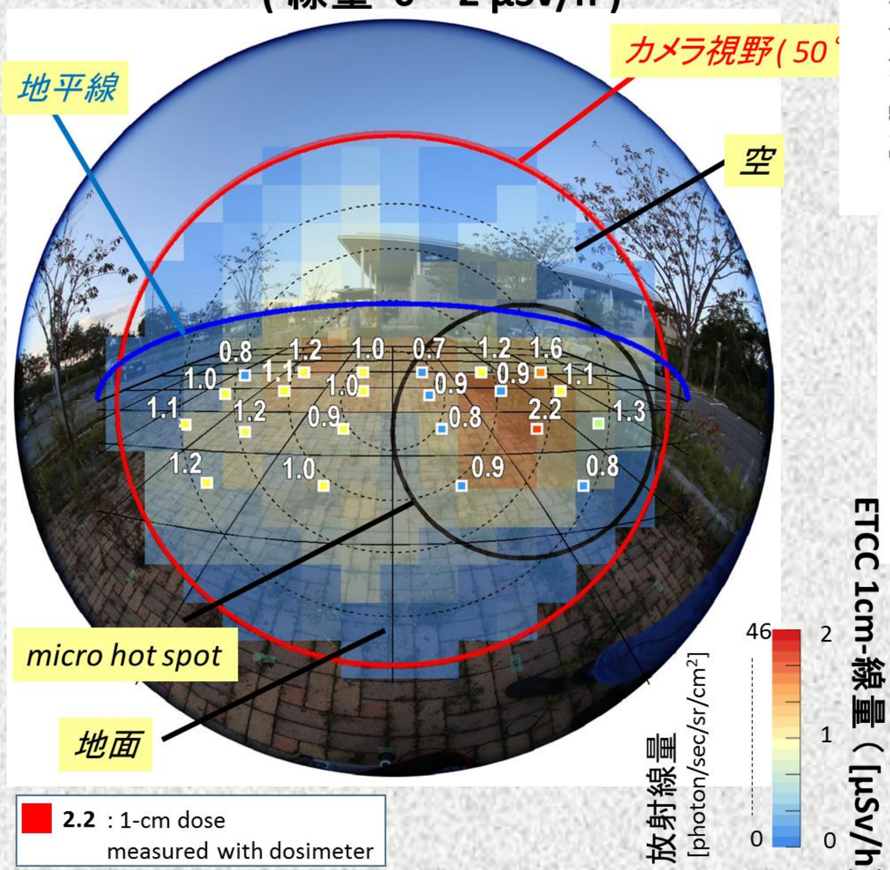
Tomono et al., (2017), Scientific Reports

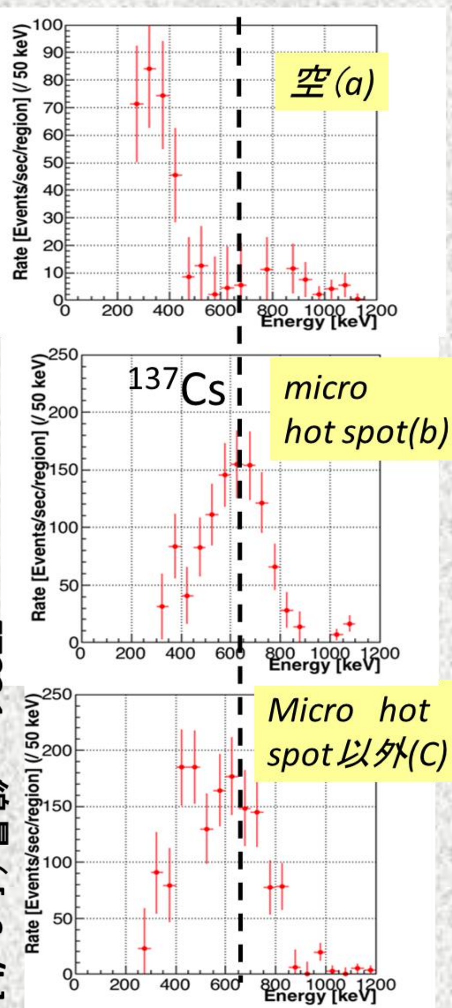
除染区域 （駐車場）
(線量 0 ~ 2 μSv/h)

可搬型ETCC

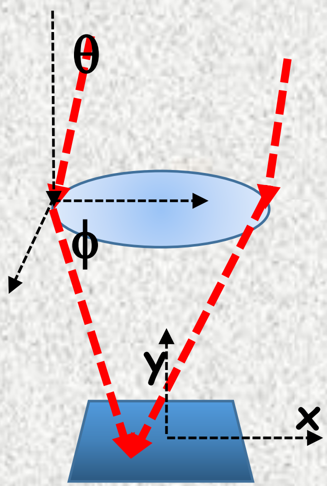


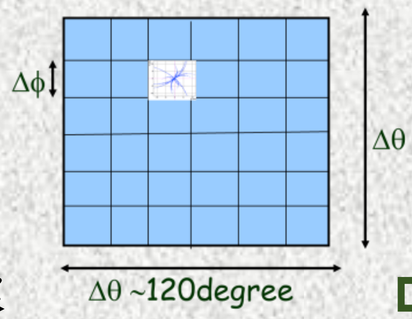
検出面積 数mm^2
PSF ~15^o





Fluence (Real Imaging) Triggers





$$S \propto \frac{EA \bullet Cs}{\sqrt{EA \bullet \left(Cs + BG\Delta\phi^2\right)}} \sim \frac{EA \bullet Cs}{\sqrt{EA \bullet Cs}}$$

Noise area = ($\Delta\phi \times \Delta\phi$)

$\Delta\phi/\Delta\theta = 10$ Noise reduction -> $1/10^2 \sim 1/10^3$

- Very Low BG and Large Field of View (>4str)
- Wide band trigger in νFν (70keV ~>10MeV)
- Wide range of accumulation time $0.1\text{-}10^6$s

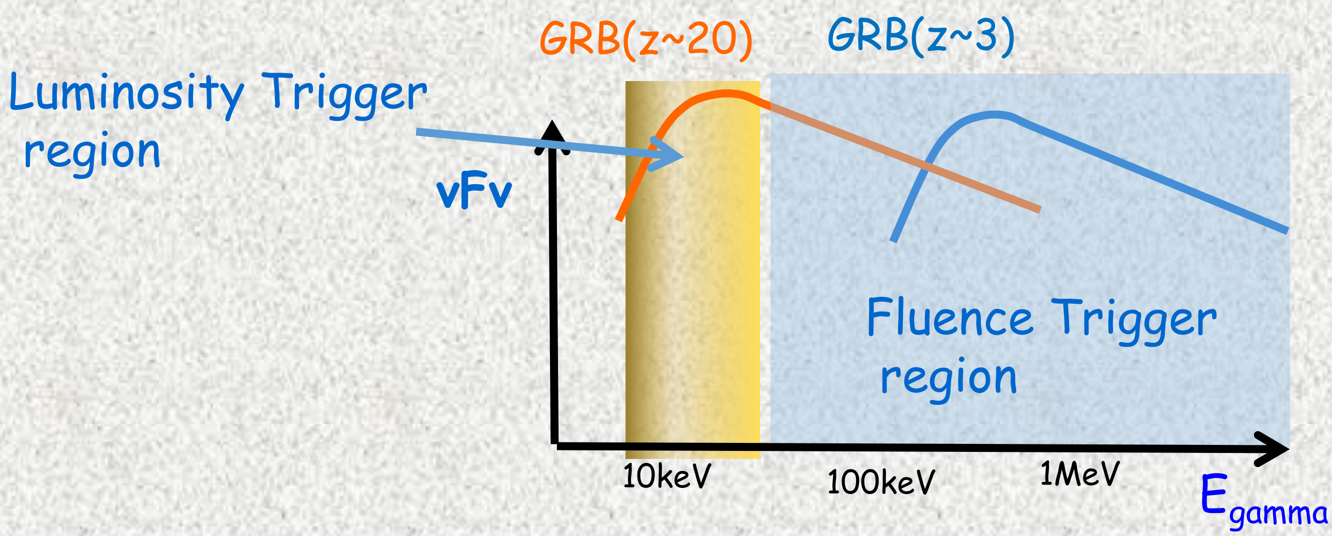
little bias for any type of GRBs

insensitive for dilation factor

little Sensitive for E_{peak} and Redshift

Position Accuracy

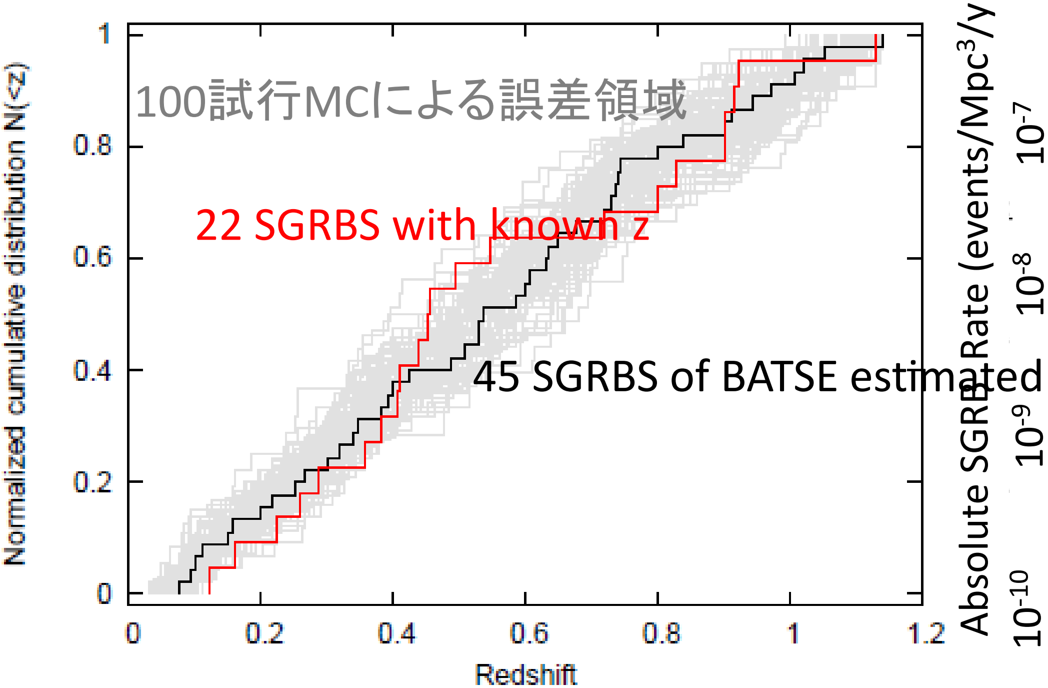
~20gammas <0.5°



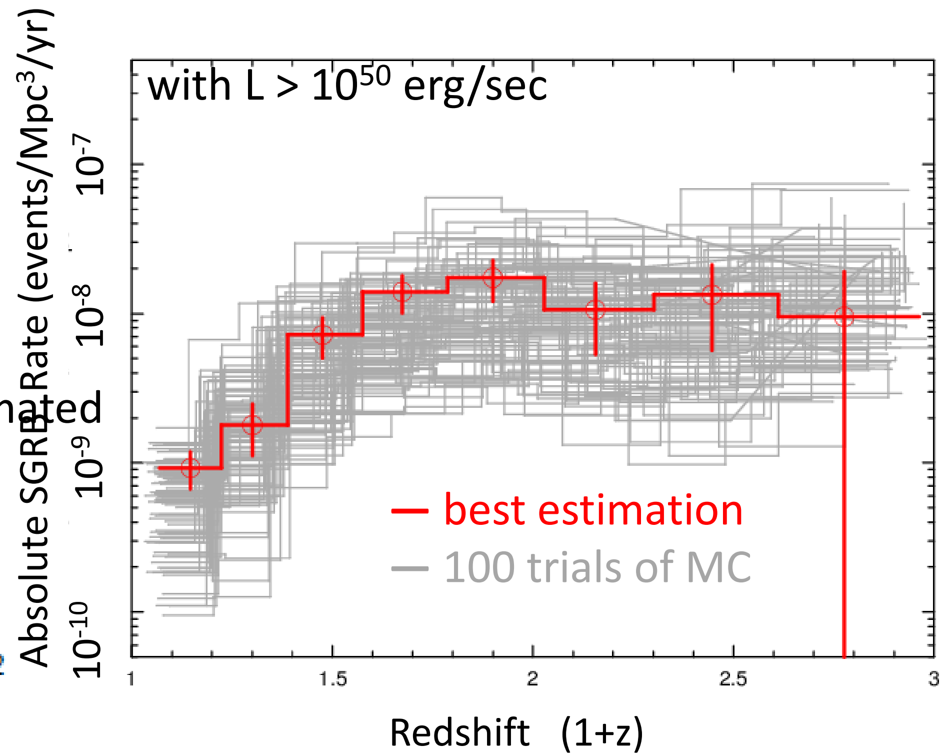
Short GRB formation rate

D. Yonetoku, T. Nakamura, **T. Sawano** et al. 2014

Cumulative redshift distribution



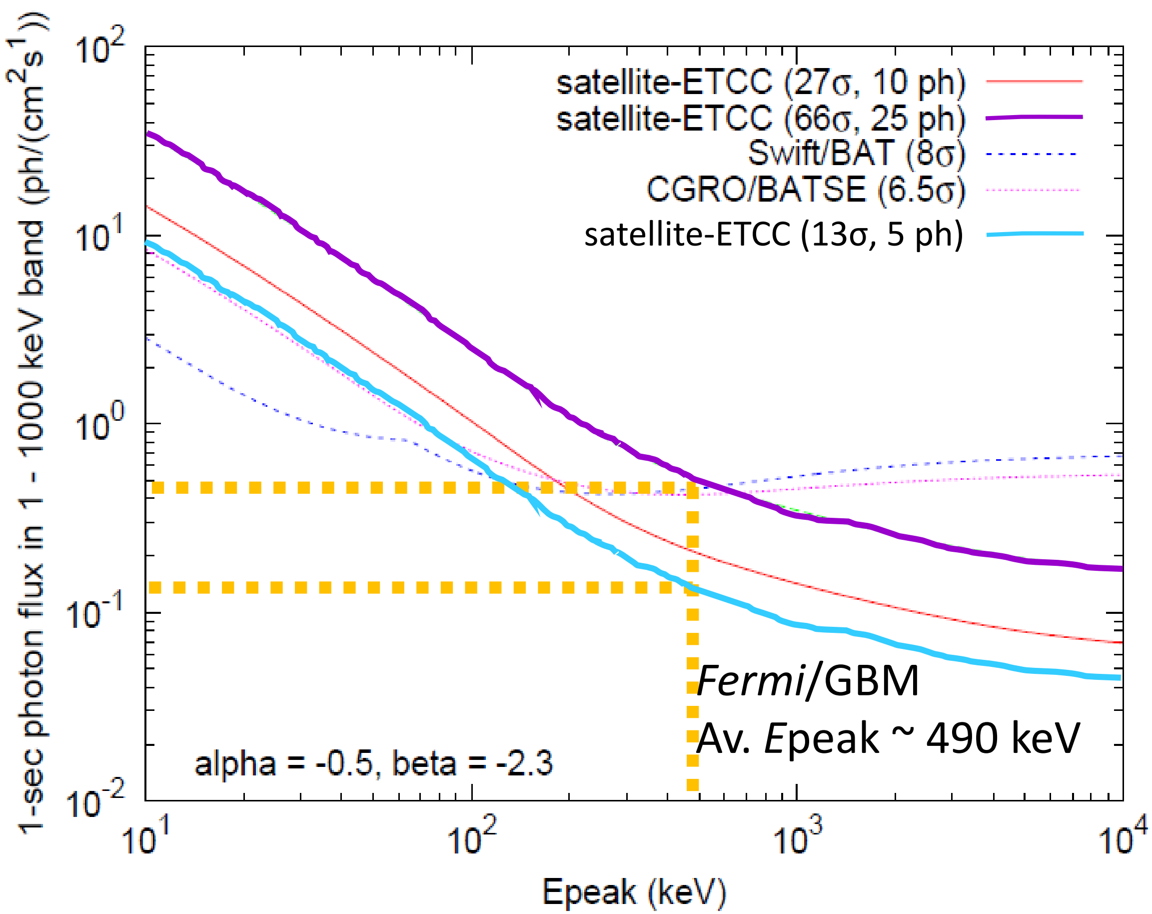
Short GRB Formation Rate



Rate of SGRBs with Luminosity > 10^{50} erg/s based on BATSE data

~ 0.02 events/year in (200 Mpc)^3

ETCC sensitivity for short GRBs



Sensitivity of ETCC for SGRBs

Case 1; 25ph, 66σ

0.5 ph/cm^2/s (1-1000 keV)

⇒1.3 × 10^{-7} erg/cm^2/s, ~ 0.4°

Case II 5 ph, 13σ

⇒2.6 × 10^{-8} erg/cm^2/s, ~ 0.9°

+ X-ray Telescope -> <0.1°

BATSE flux limit

~ 1 × 10^{-6} erg/cm^2/s

(Yonetoku et al. 2014)

ETCC 10 times better

Brightness fuction ∝ L^{-1}

Sensitivity x10 ⇒ # Det. x10

0.02 x10 ~ 0.2 events/year within 200Mpc

In 5years Observation. ~1 coincidence event with GW is expected !

From Doctor thesis of T.Sawano

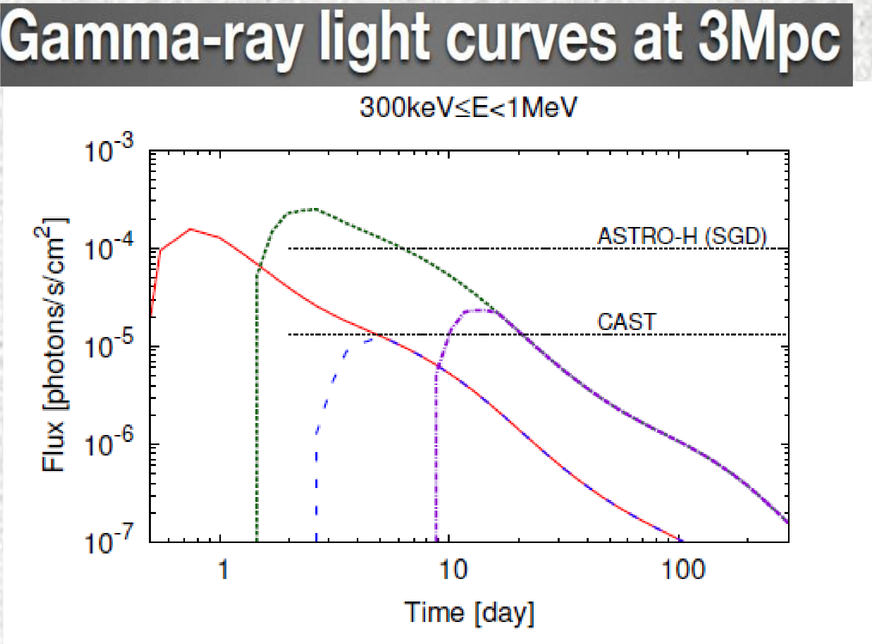
Another Approach to GW

Kilo nova or micro nova -> Neutron Star merger

Dominant emission MeV gamma $10^{41\text{-}42}$erg/s

1-10days bright

~10days 10^{-4} gammas /cm^2s at 3Mpc kilo nova



Hotokezaka 2017

Satellite-ETCC

10days ~10^4 gammas detection

20Mpc ~300 gammas >300keV

√BG ~100 >3σ

N-N GW ~10^3year within 200Mpc

~1 year within 20Mpc

Most efficient method ??

And Proof of R-process

Fluence Trigger for long GRB

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

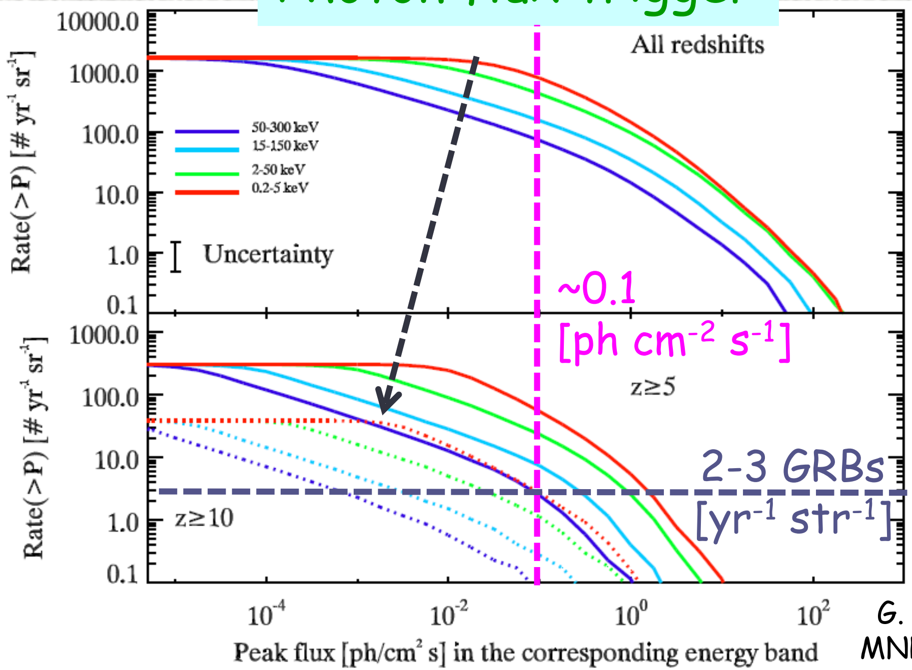
1. Time dilation
   Fluence trigger is NOT affected.

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

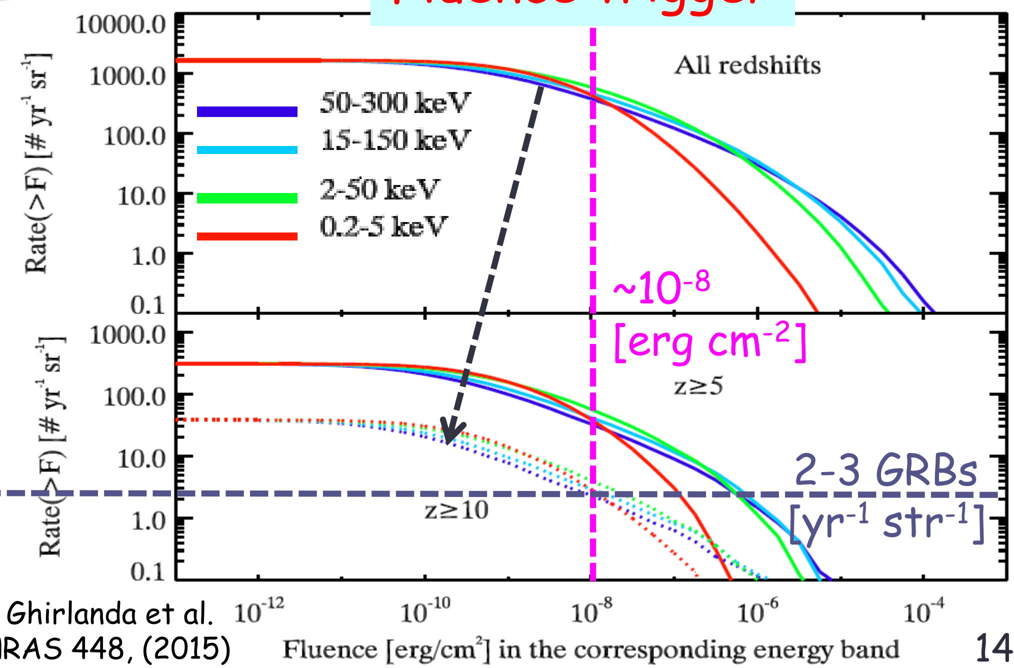
Satellite-ETCC (T_{90}: 10-100 sec)
--> Fluence ~10^{-8} erg cm^{-2}
(2-3 GRBs/year/str (z>10))
+ wide FoV >4 str
--> Several GRBs/year (z >10)
200 GRBs/year (z > 5)

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)

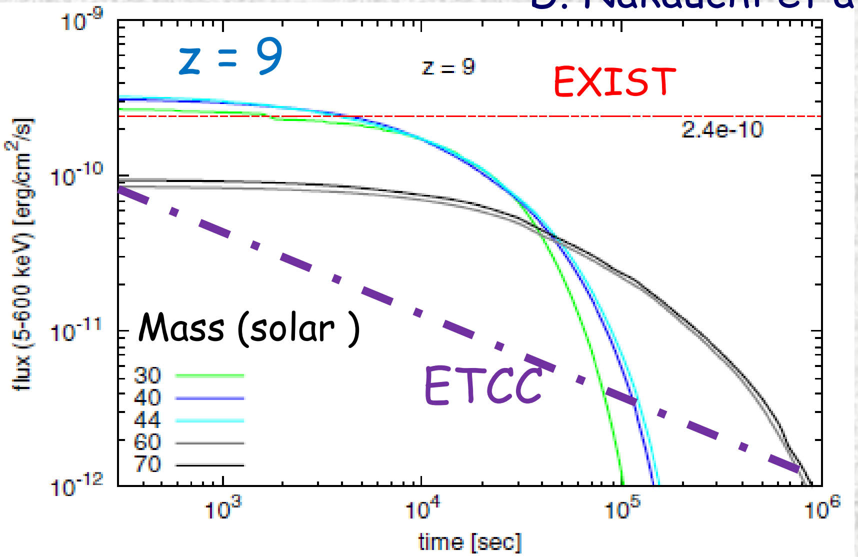


Figure 6. Same as Figure 5, but for the *EXIST* (5–600 keV) case. The red dashed line represents the *EXIST* sensitivity $f_{sen} \sim 2.4 \times 10^{-10}$ erg cm^{-2} s^{-1} (5–600 keV, 5σ) in the longest exposure timescale at the on-board process ($\Delta t \sim 512$ s; Hong et al. 2009). Note that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

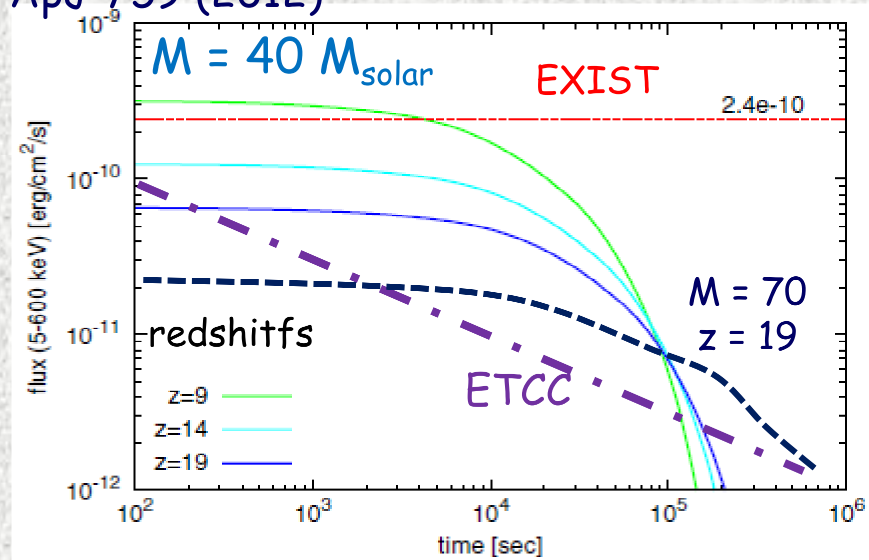


Figure 3. Same as Figure 2 but for the *EXIST* case. *EXIST* will have the limited energy range of 5–600 keV. The red dashed line represents the *EXIST* sensitivity $f_{sen} \sim 2.4 \times 10^{-10}$ erg cm^{-2} s^{-1} (5–600 keV, 5σ) in the longest exposure timescale at the on-board process ($\Delta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

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

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

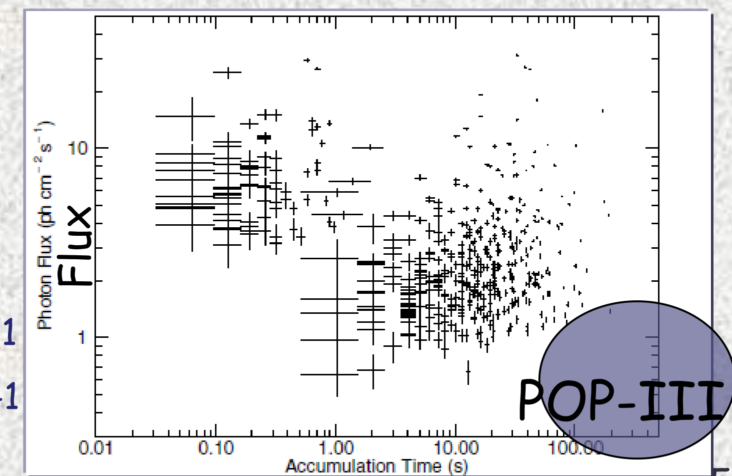
Pop-III Flux <10^{-10} erg cm^{-2} s^{-1} (very faint)

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

Satellite-ETCC; $S/\sqrt{N} > 5\sigma$

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

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



Exploring GRB astronomy by Balloon-SMILE

1. SMILE-II+ one-day flight at Australia in March 2018
2. Next plan, SMILE-III Long-duration flight with larger ETCCs

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

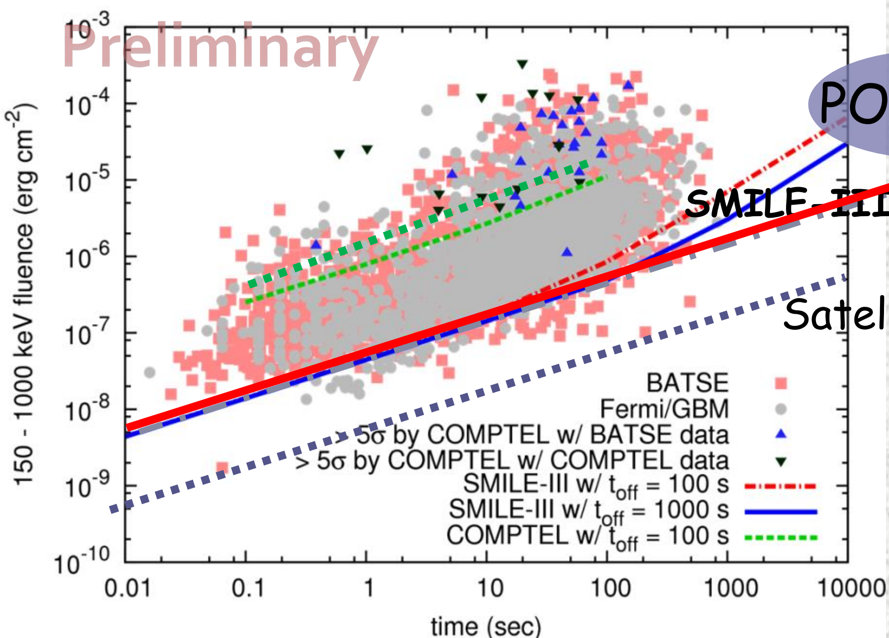
40 cm-cubic ETCC x2 modules (Eff. Area ~80 cm^2)

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

In addition, Polarization Measurements

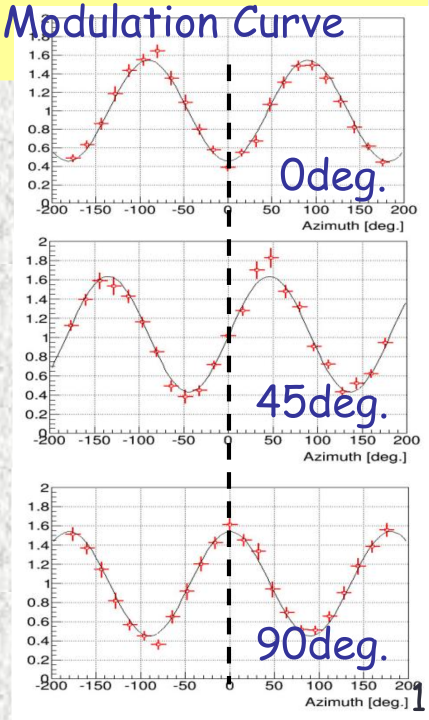
MDP ~ 6% for 10^{-6} erg cm^{-2} s^{-1} (several GRBs/month)

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



GRB detection in SMILE-III Simulated by T. Sawano

Modulation Curve



Primordial Black Holes in Solar System

$$\tau \sim \frac{M^3}{\hbar} \sim 10^{10}\,\mathrm{yr}\left(\frac{M}{10^{15}\,\mathrm{g}}\right)^3 \quad \frac{\mathrm{d}E}{\mathrm{d}t} \sim 10^{20}\,\mathrm{erg\,s^{-1}}\left(\frac{10^{15}\,\mathrm{g}}{M}\right)^2 \quad \hbar\omega \sim 100\,\mathrm{MeV}\left(\frac{10^{15}\,\mathrm{g}}{M}\right)$$

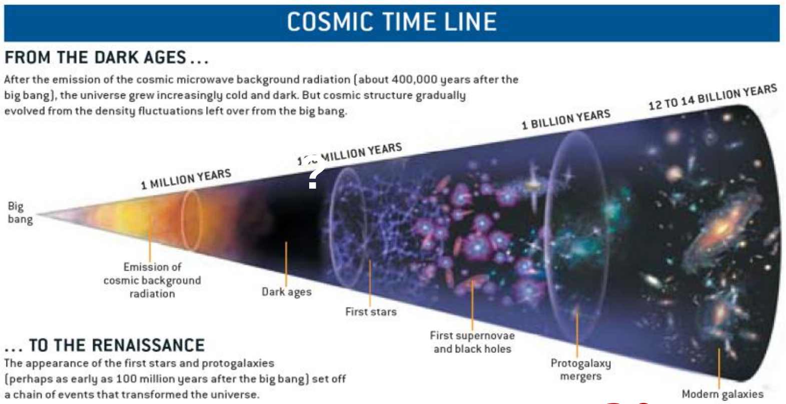
Primordial B.H. still surviving
would emit ~20MeV thermal M~ 10^{15} g , ~ 10^{20} erg/s

Density ~10^4 pc^{-3} (flat 分布で)
10^4 pc^{-3} -> ~10 BH <Oort cloud (10^4AU)
Condensation Factor in Galactic halos x ~10^6
＝＞ 100AU 球に~10BHs

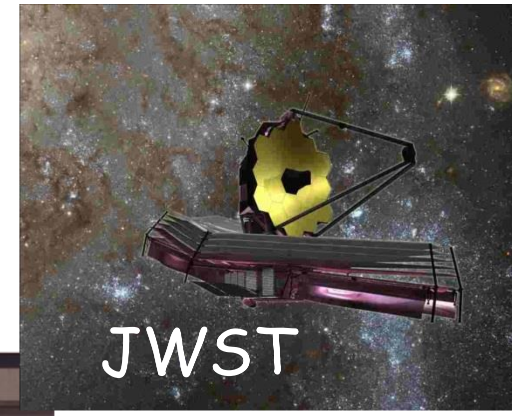
Satellite-ETCC γ線10個 (1MeV)s^{-1} @1AU for 10^{20}erg/s
BHが10^6sの間同じ天球位置として、検出限界100γ@10^6s
この場合、300AUのBHまで観測可能　数10個のBHが見える。
さらに太陽系の増幅効果、ディスク(黄道面)分布、太陽近傍集中
1桁以上の増加、さらにコメット軌道(数日、明るい)、

Deep Universe explored by GRBs

Biggest Explosion in Universe $10^{52\text{-}54}$erg



TMT

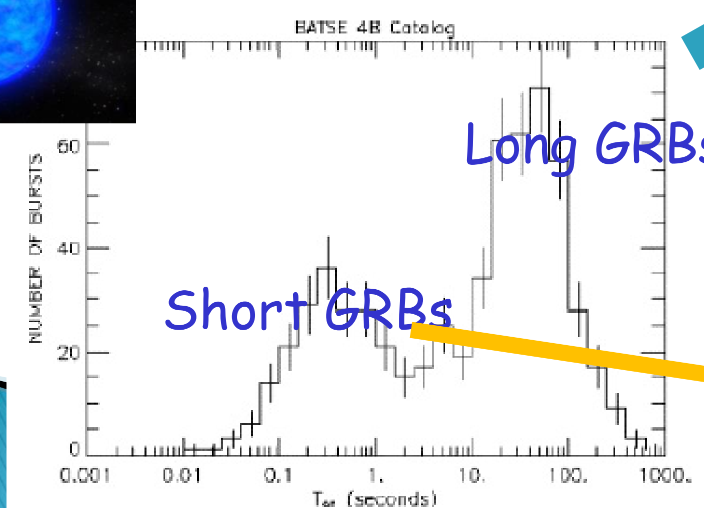


Larson&Bromm 02

GRB z~>20

Galaxy & QSO z~10

First Star & Galaxy



Long GRBs

Short GRBs

Neutron Star Merger

Summary

- ETCC provides Imaging Spectroscopic Observation, and hence reveals the reliable way to reach 1 mCrab sensitivity.

- Clear imaging with well-defined PSF in sub-MeV gives a true Imaging Trigger (Fluence Trigger) and provides a chance to reach most distant GRBs of any type (Short, Long, and Ultra-long). + multi wave observations

- Kilonova（30Mpc） Supernova（100Mpc） Answer for Nucleosynthesis

- 来年　３月に気球上がります。