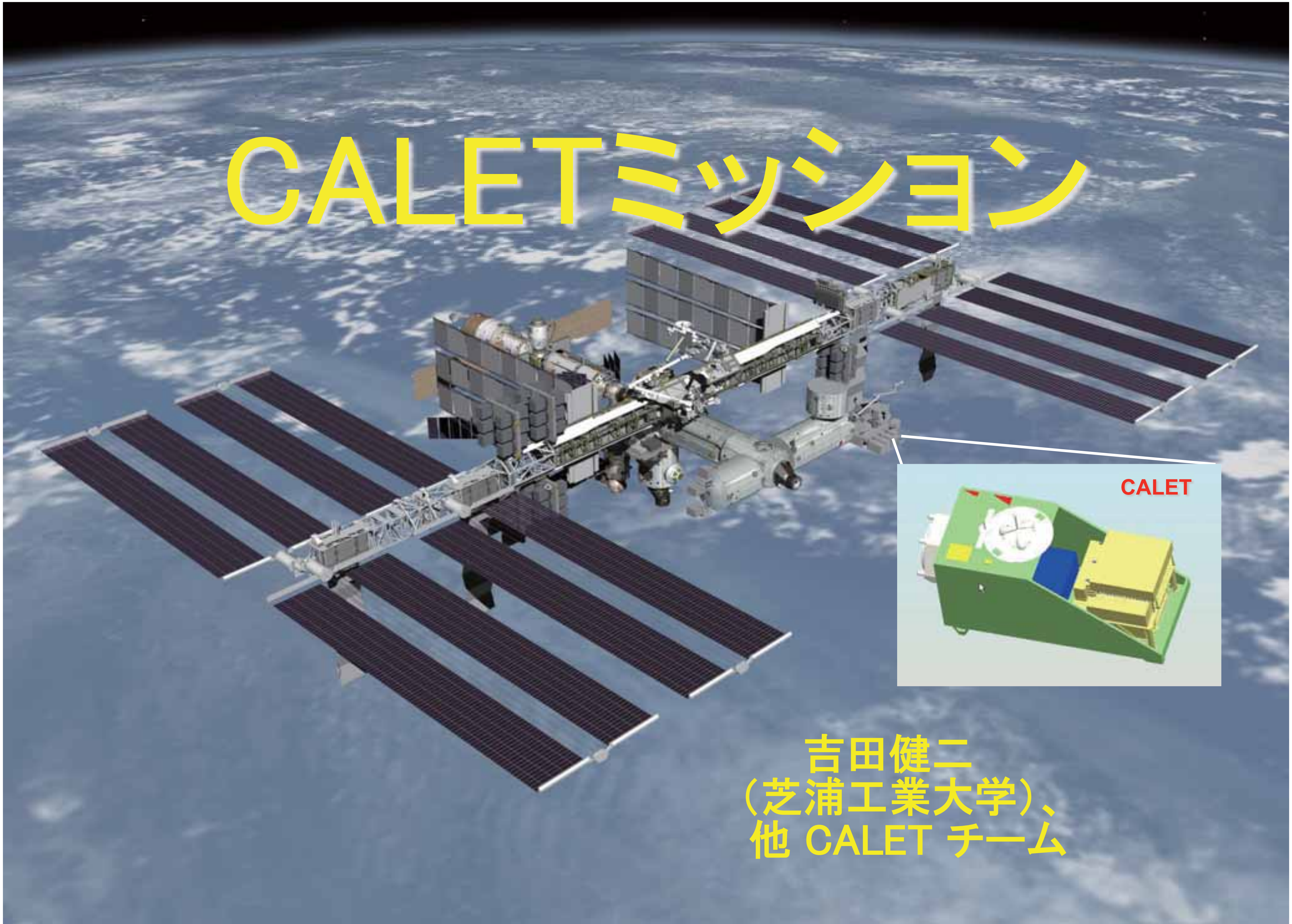
CALETミッション



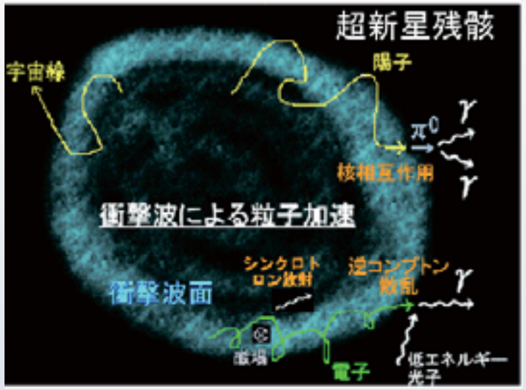
吉田健二
（芝浦工業大学）、
他 CALET チーム

電子・陽電子観測

高エネルギー**宇宙線電子・陽電子**の観測により、宇宙物理学における
最大の謎である**暗黒物質**及び**宇宙線加速源**の解明

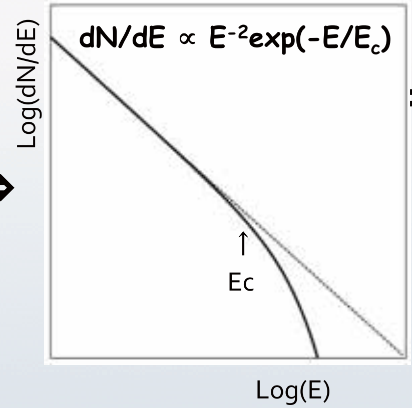
宇宙物理的起源

超新星残骸における衝撃波加速　　パルサー風星雲における加速



⇒

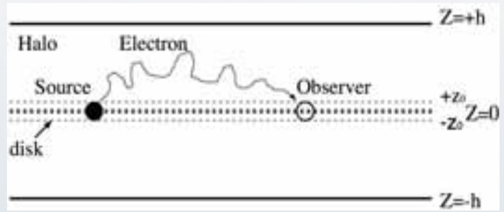
生成スペクトル
（冪型関数＋カットオフ）



⇒

銀河内伝播機構

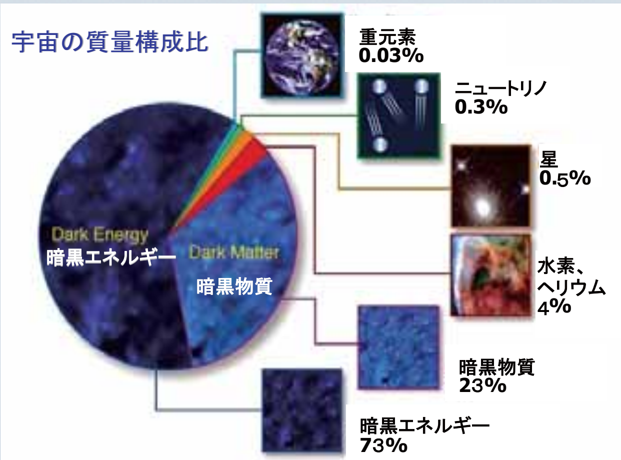
- 拡散過程
- エネルギー損失
  $dE/dt = -bE^2$
  （シンクロトロン放射
  ＋逆コンプトン散乱）
- π+/- or K+/- → μ+/- → e+/-



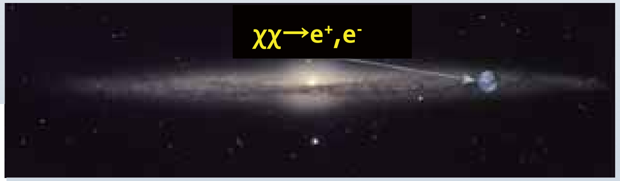
⇑

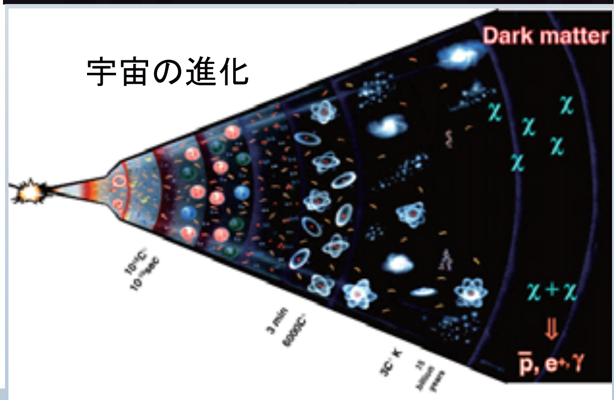
素粒子物理的起源

宇宙論観測による暗黒物質の割合

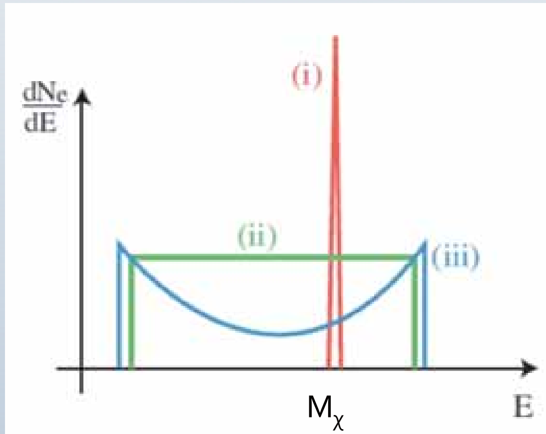


暗黒物質（WIMP)の対消滅





⇒



生成スペクトル（WIMPの種類に依存）

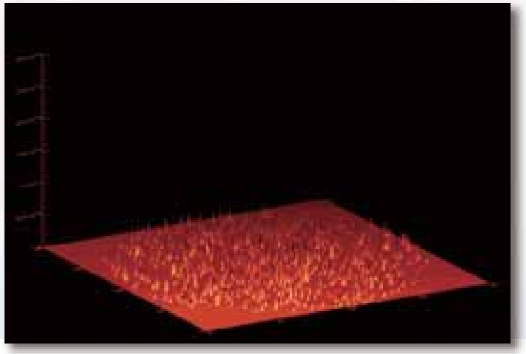
（ｉ） 単一エネルギー：電子・陽電子対直接生成(LKP)
（ii） 一様分布：一様分布で崩壊する中間粒子を経由
（iii） ダブルピーク：双極的分布で崩壊する中間粒子を経由(SUSY)

A Naïve Result from Propagation

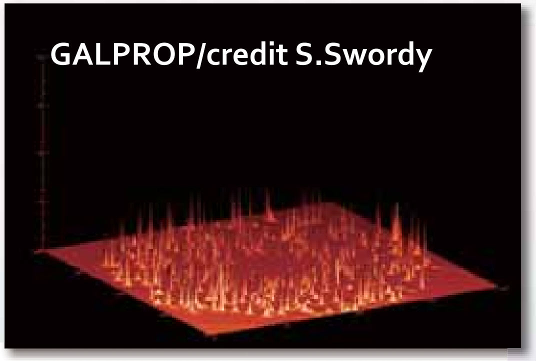
T (age) = 2.5 X 10^5 X (1 TeV/E) yr

R (distance) = 600 X (1 TeV/E)$^{1/2}$ pc

1 GeV Electrons



100 TeV Electrons

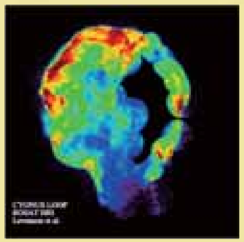


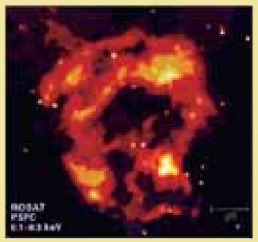
1 TeV Electron Source:

- Age < a few10^5 years
  very young comparing
  to ~10^7 year at low energies
- Distance < 1 kpc
  nearby source

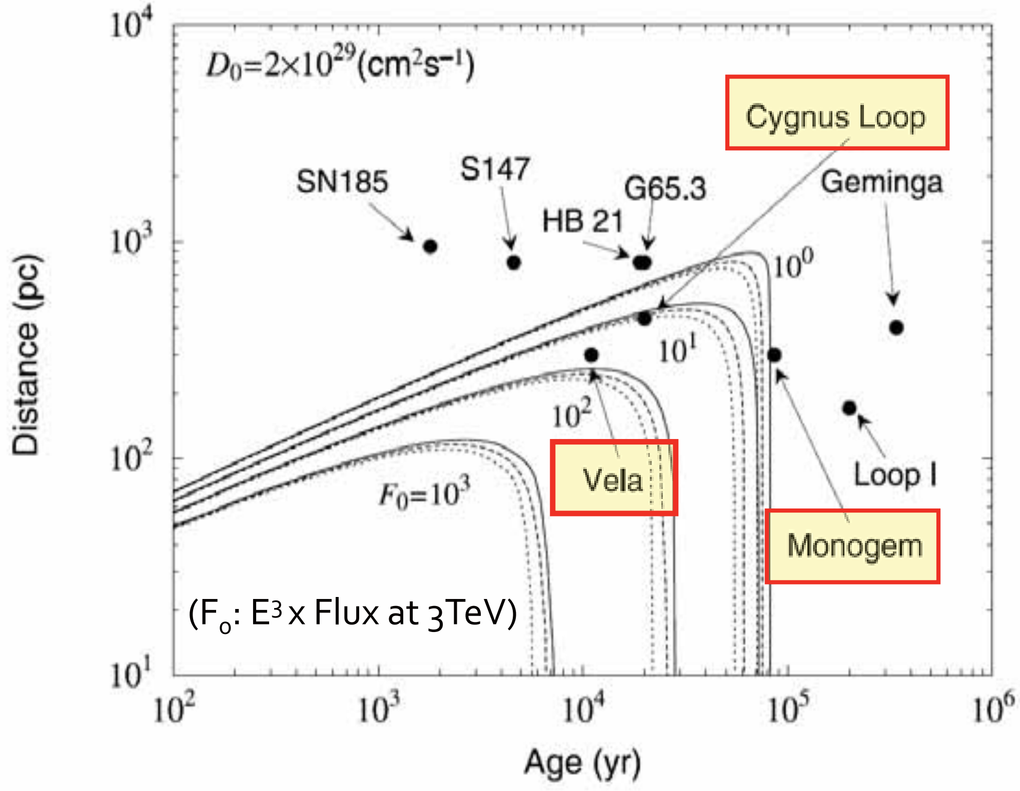
Source (SNR) Candidates :

Vela Cygnus Loop Monogem





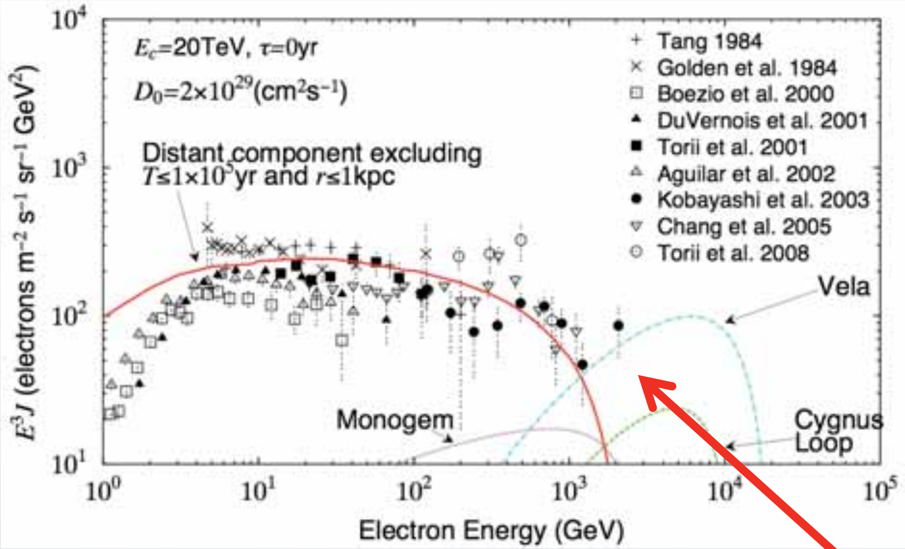
Unobserved Sources?



Astrophysical Origin

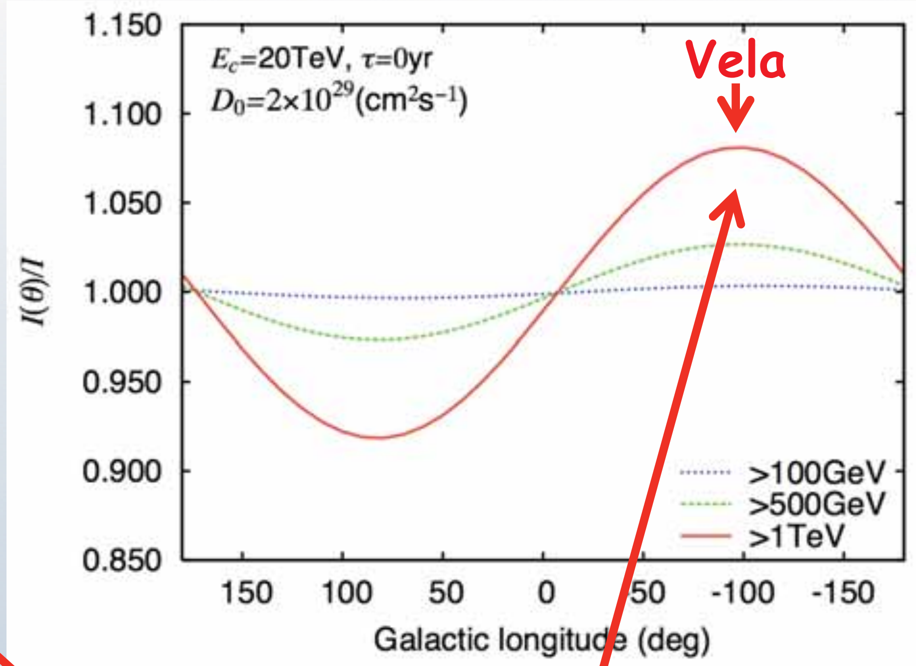
- Search for nearby SNRs -

Calculated electron spectrum



Kobayashi et al. (2004)

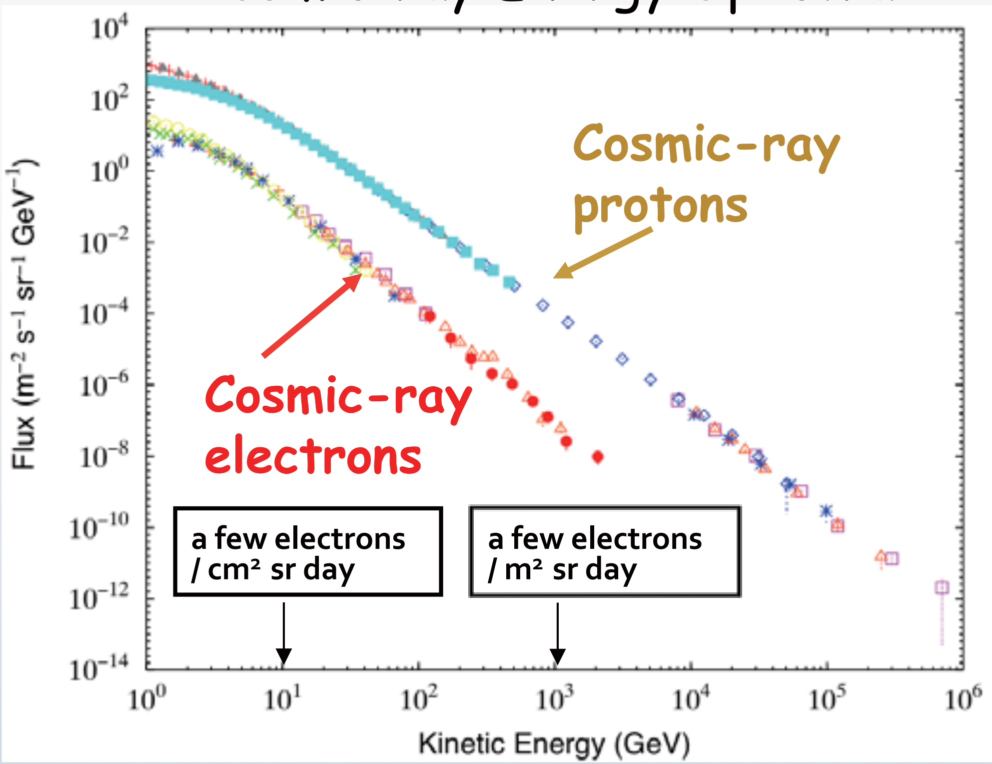
Anisotropy distribution



Spectral signature and anisotropy by nearby sources
=> Identification of cosmic-ray sources by TeV electron observations

Electron and Positron Observations

Cosmic-ray Energy Spectra



- Flux of electrons and positrons:
  ~1 % of protons @10GeV
  ~0.1 % @ 1000GeV
  ~0.1 % @ 10 GeV

- Spectrum of electrons:
- softer than protons
- power-law index:
  e:~-3.0, p:-2.7

=> As higher energies,
✓ Lower electron flux
✓ Lager proton backgrounds

Large amount of exposures
with a detector of high proton rejection power (+ charge separation)

➡ Long duration balloon flight in 10~1000 GeV (~10 m^2srday)
Observation in space for years over 1000 GeV (> 100 m^2srday)

Efforts by the new experiments for deriving the positron and electron spectra are really appreciated to open a door to new era in astroparticle physics.

We are waiting for much more study by ATIC, PAMELA, Fermi-LAT, HESS and a forthcoming experiment in space, AMS-02.

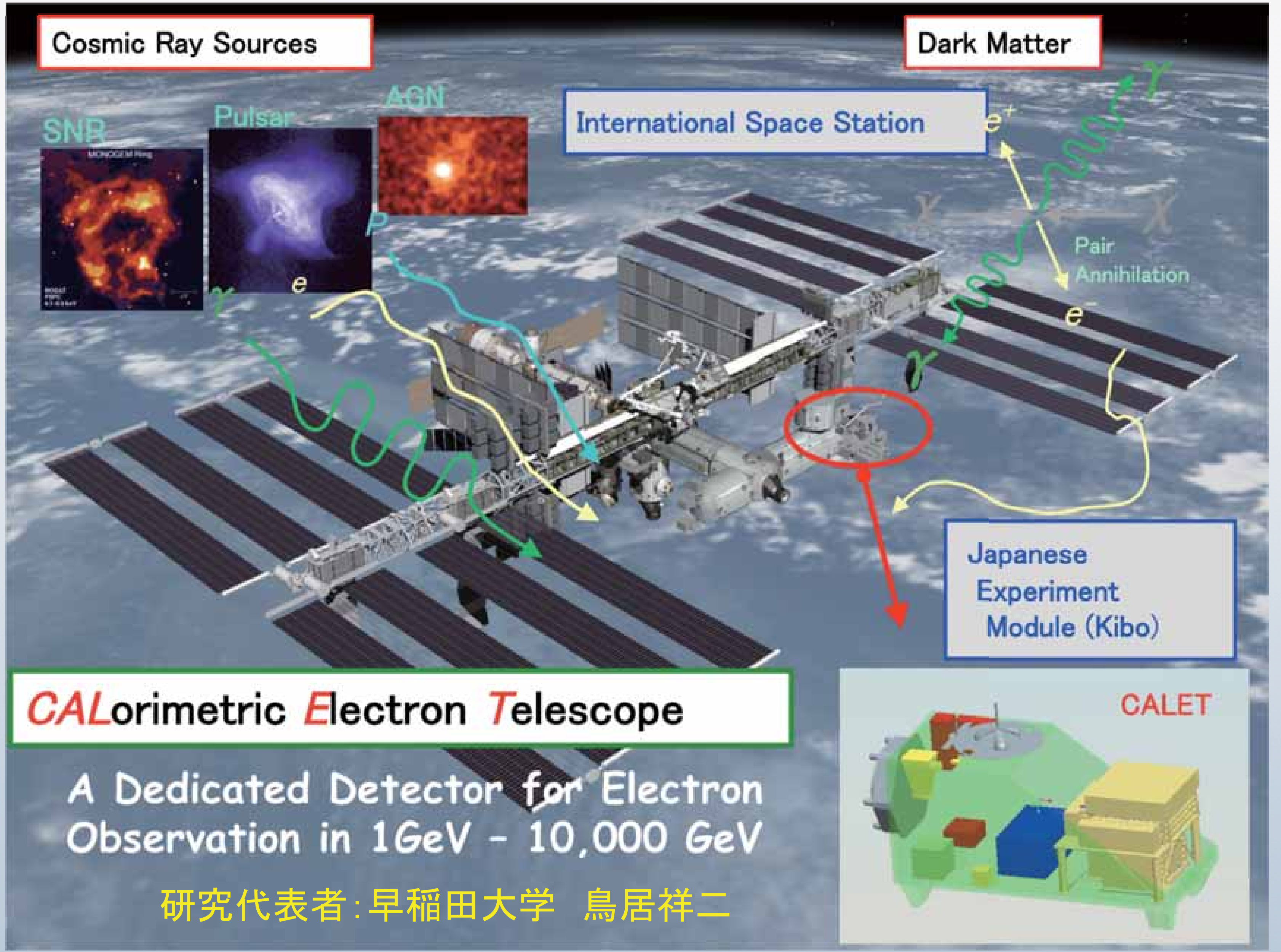
Moreover,
We need an accurate and very-high-statistics observation for searching Dark Matter and/or Nearby Pulsars in the sub-TeV to the trans-TeV region with a detector which has following performance:

- The systematic errors including GF is less than a few %.
- The absolute energy resolution is as small as a few % (~ATIC).
- The exposure factor is as large as more than 100 m^2srday (~ FERMI-LAT).
- The proton rejection power is comparable to 10^5 , and does not depend largely on energies .

It should be a dedicated detector for electron observation in space.

➡ **Calorimetric Electron Telescope (CALET) is proposed.**

CALETミッション


Cosmic Ray Sources
Dark Matter
SNR
Pulsar
AGN
International Space Station
Pair Annihilation
Japanese Experiment Module (Kibo)
CALorimetric Electron Telescope
A Dedicated Detector for Electron Observation in 1GeV - 10,000 GeV
研究代表者:早稲田大学　鳥居祥二
CALET

CALET International Collaboration Team

O. Adriani[20] , F. Angelini[21] , C. Avanzini[21], M.G. Bagliesi[23], A. Basti[21], K. Batkov[23], G. Bigongiari[23], W.R. Binns[25], L. Bonechi[20], S. Bonechi[23], S. Bottai[20], M. Calamai[20], G. Castellini[20], R. Cesshi[23], J. Chang[13], G. Chen[4], M.L. Cherry[9], G. Collazuol[21], K. Ebisawa[5], A. J. Ericson[10], H. Fuke[5], W. Gan[13], T.G. Guzik[9], T. Hams[10], N. Hasebe[24], M. Hareyama[5], K. Hibino[7], M. Ichimura[2], K. Ioka[8], M. H. Israel[25], E. Kamioka[16], K. Kasahara[24], Y. Katayose[26],J. Kataoka[24], R.Kataoka [18],N. Kawanaka[8], M.Y. Kim[23], H. Kitamura[11], Y. Komori[6], T. Kotani[1], H.S. Krawzczynski[25], J.F. Krizmanic[10], A. Kubota[16], S. Kuramata[2], Y. Ma[4], P. Maestro[23], V. Malvezzi[22], L. Marcelli[22], P. S. Marrocchesi[23], V. Millucci[23], J.W. Mitchell[10], K. Mizutani[15], A.A. Moissev[10], M. Mori[14], F. Morsani[21], K. Munekata[17], H. Murakami[24], J. Nishimura[5], S. Okuno[7], J.F. Ormes[19], S. Ozawa[24], F. Palma[22], P. Papini[20], Y. Saito[5], C. De Santis[22], M. Sasaki[10], M. Shibata[26], Y. Shimizu[24], A. Shiomi[12], R. Spalvoli[22], P. Spillantini[20], M. Takayanagi[5], M. Takita[3], T. Tamura[7], N. Tateyama[7], T. Terasawa[3], H. Tomida[5], S. Torii[24], Y. Tunesada[18], Y. Uchihori[11], S. Ueno[5], E. Vannuccini[20], H. Wang[4], J.P. Wefel[9], K.Yamaoka[1], J. Yang[13], A. Yoshida[1], K. Yoshida[16], T. Yuda[7], R. Zei[23]

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7) Kanagawa University, Japan
8) KEK, Japan
9) Louisiana State University, USA
10) NASA/GSFC, USA
11) National Inst. of Radiological Sciences, Japan
12) Nihon University, Japan
13) Purple Mountain Observatory, China
14) Ritsumeikan University, Japan
15) Saitama University, Japan
16) Shibaura Institute of Technology, Japan
17) Shinshu University, Japan
18) Tokyo Technology Inst., Japan
19) University of Denver, USA
20) University of Florence and INFN, Italy
21) University of Pisa and INFN, Italy
22) University of Rome Tor Vergata and INFN, Italy
23) University of Siena, Italy
24) Waseda University, Japan
25) Washington University in St Louis, USA
26) Yokohama National University, Japan

CALETミッションの経緯

2006年11月　：JAXAによるJEM曝露部第2期利用の募集

2007年5月　：JAXAで概念設計を行うポート占有ミッションとしてCALET選定
（ポート共有：8ミッション　ポート占有：3ミッション）

2007年8月　：JAXAはミッション定義審査（MDR)を実施後、提案機関である早稲田大学と概念設計の共同研究を開始

2009年10月　：ISS「きぼう」利用推進委員会でCALETをポート占有利用ミッション候補として選定
標準（500kg級）ペイロードとして2013年打ち上げ（目標）

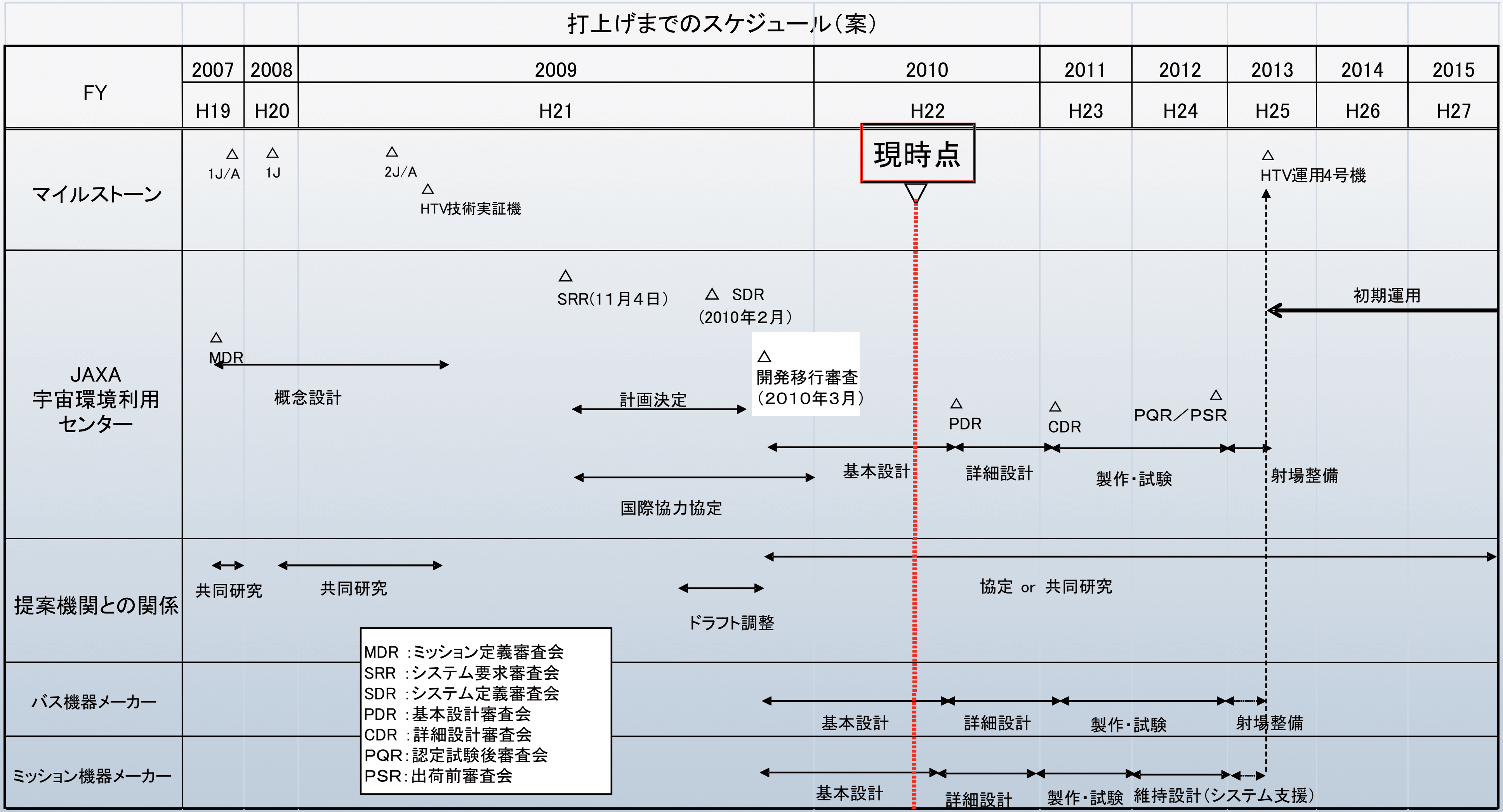
2009年11月　：システム要求審査会（SRR)を実施
JAXAによる開発メーカ公募　（RFP)の開示

2010年2月　：システム定義審査会（SDR)を実施
JAXAは「IHIエアロスペース」をCALET開発メーカとして選定

2010年3月5日：開発移行審査

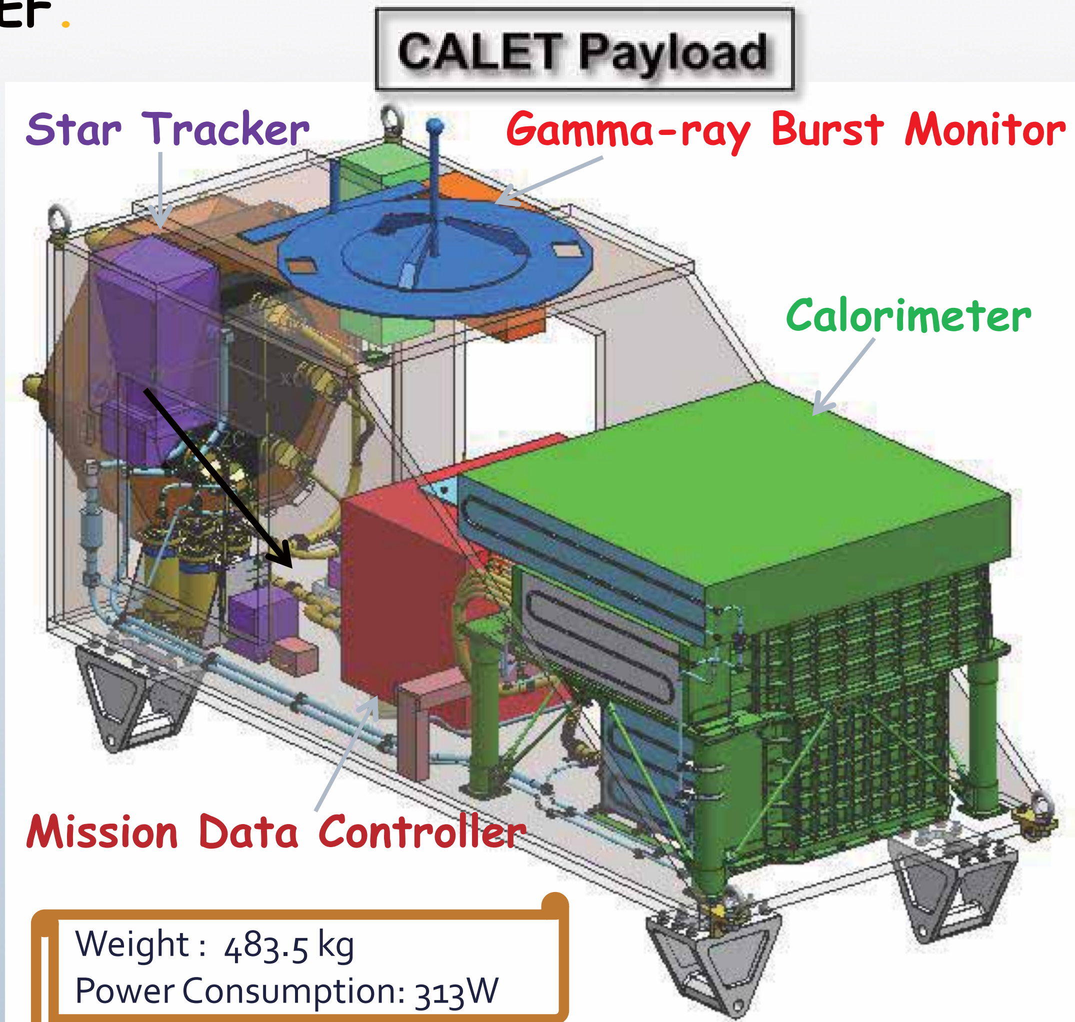
2010年4月1日：　開発以降に伴い、JAXA宇宙環境利用センター内にCALETプロジェクトチーム設置

開発スケジュール(案)

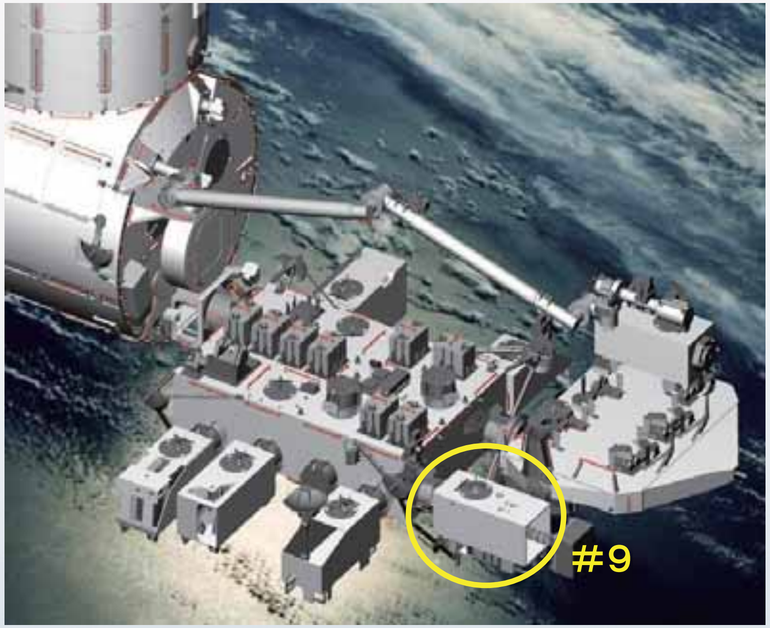

打上げまでのスケジュール（案）
FY
2007
2008
2009
2010
2011
2012
2013
2014
2015
H19
H20
H21
H22
H23
H24
H25
H26
H27
マイルストーン
1J/A
1J
2J/A
HTV技術実証機
現時点
HTV運用4号機
JAXA
宇宙環境利用
センター
SRR(11月4日）
SDR
（2010年2月）
MDR
概念設計
開発移行審査
（2010年3月）
計画決定
PDR
CDR
PQR／PSR
初期運用
基本設計
詳細設計
製作・試験
射場整備
国際協力協定
提案機関との関係
共同研究
共同研究
ドラフト調整
協定 or 共同研究
バス機器メーカー
基本設計
詳細設計
製作・試験
射場整備
ミッション機器メーカー
基本設計
詳細設計
製作・試験
維持設計（システム支援）
MDR ：ミッション定義審査会
SRR ：システム要求審査会
SDR ：システム定義審査会
PDR ：基本設計審査会
CDR ：詳細設計審査会
PQR：認定試験後審査会
PSR：出荷前審査会

CALET System Design

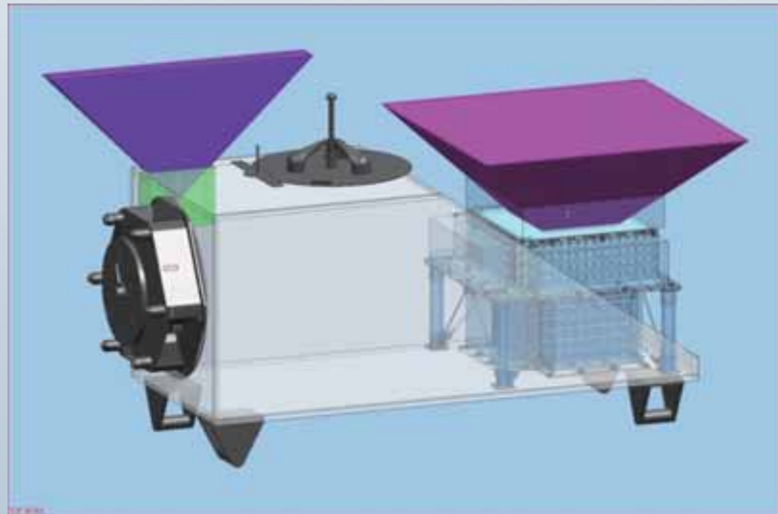
The CALET mission instrument can satisfy the requirements as a standard payload in size, weight, power, telemetry etc. for launching by HTV and observation at JEM/EF.



JEM/EF & the CALET Port



Field of View (45 degrees from the zenith)



CALET Overview

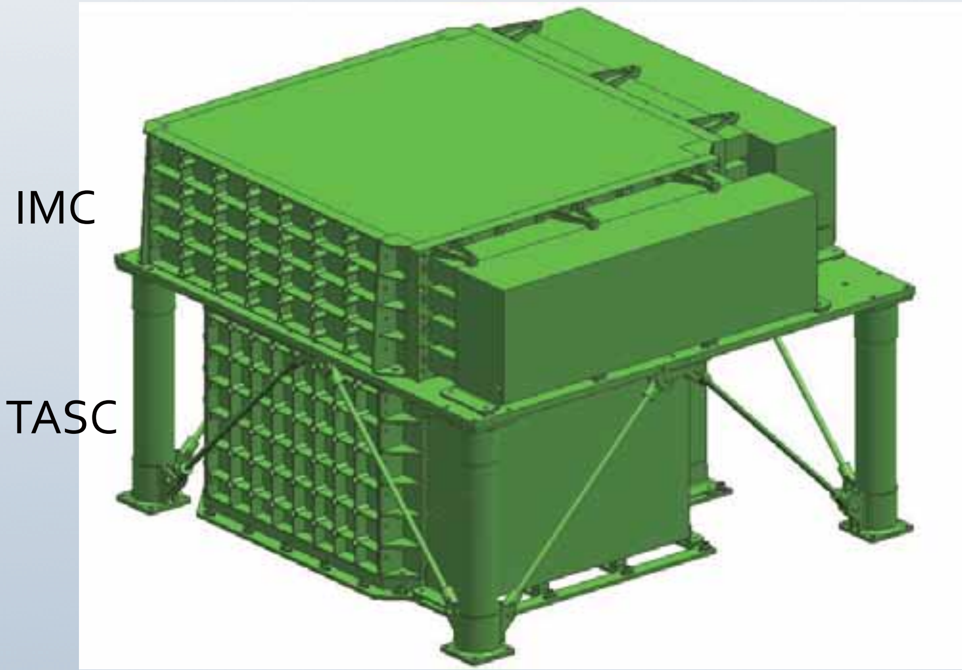
☐ Observation:

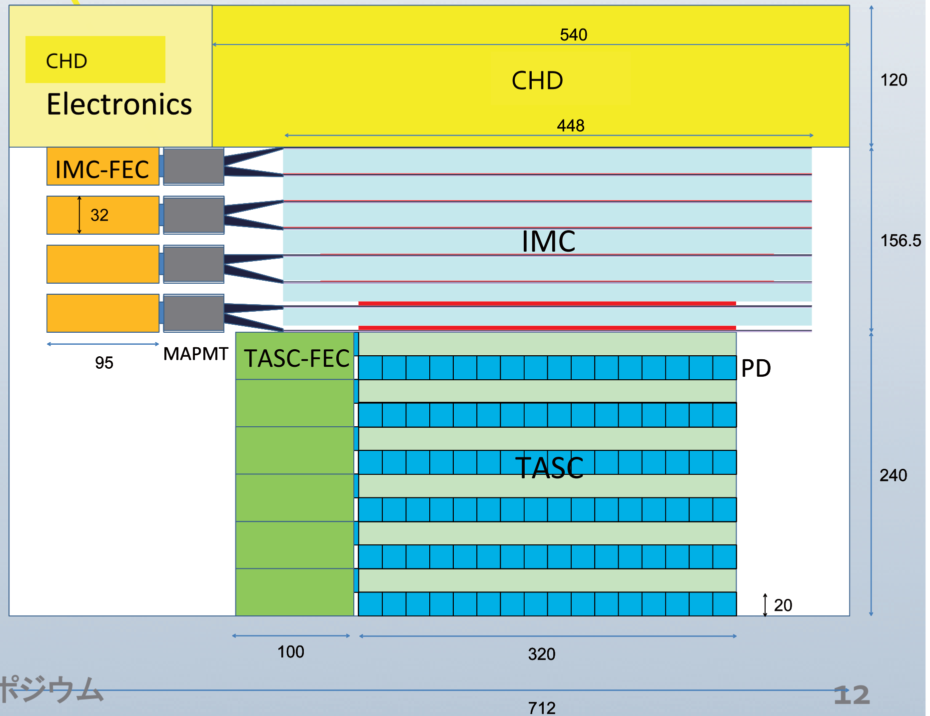
- **Electrons** : 1-10,000 GeV
- **Gamma-rays** : 10-10,000 GeV (GRB >100MeV)
  + Gamma-ray Bursts : 7 keV-20 MeV
- **Protons, Heavy Nuclei:**
  several 10 GeV- 1000 TeV (per particle)
- **Solar Particles and Modulated Particles in Solar System**: 1-10 GeV (Electrons)

☐ Instrument:

High Energy Electron and Gamma- Ray Telescope Consisted of :

- **Imaging Calorimeter (Particle ID, Direction)**
  Total Thickness of Tungsten (W) : 3 X_0
  Layer Number of Scifi Belts: 8 Layers ×2(X,Y)
- **Total Absorption Calorimeter (Energy Measurement, Particle ID)**
  PWO 20mmx20mmx320mm
  Total Depth of PWO: 27 X_0 (24cm)
- Charge **Detector (Charge Measurement up in Z=1-35)**
  Cherenkov Detector
  2 Layers with a coverage of 45.0x45.0 cm^2





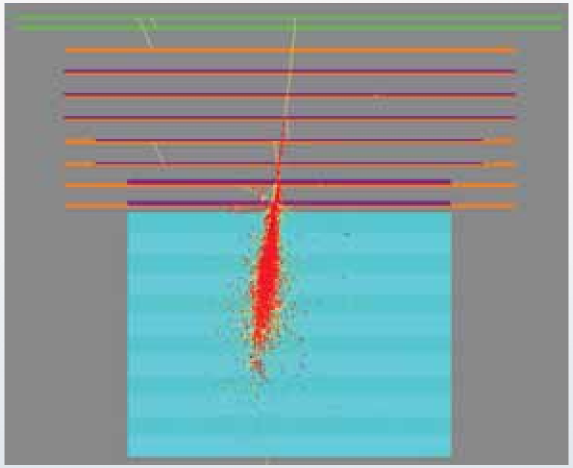
CALET Performance for Electron Observation (1)

Electron 100 GeV

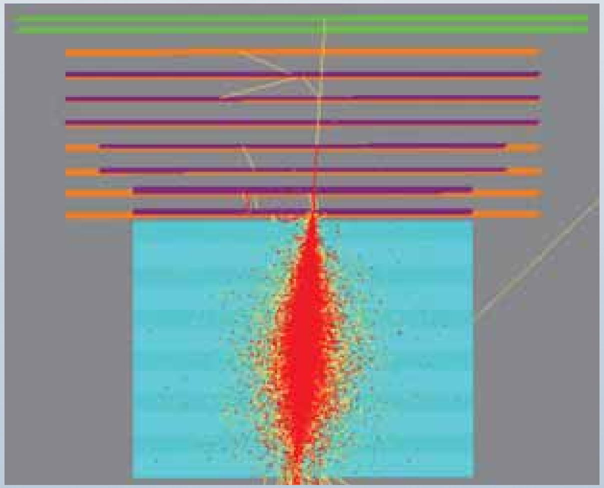
SIA

IMC

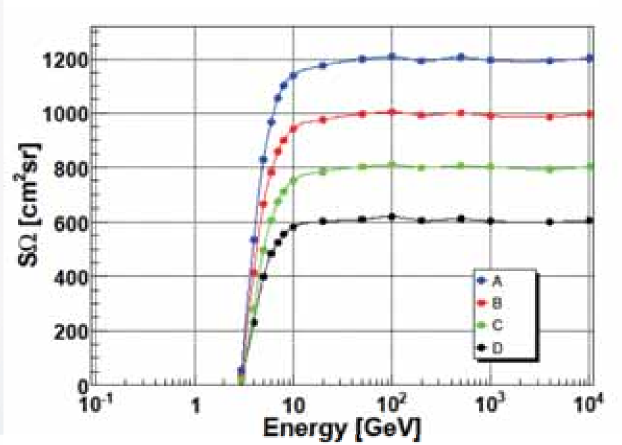
TASC



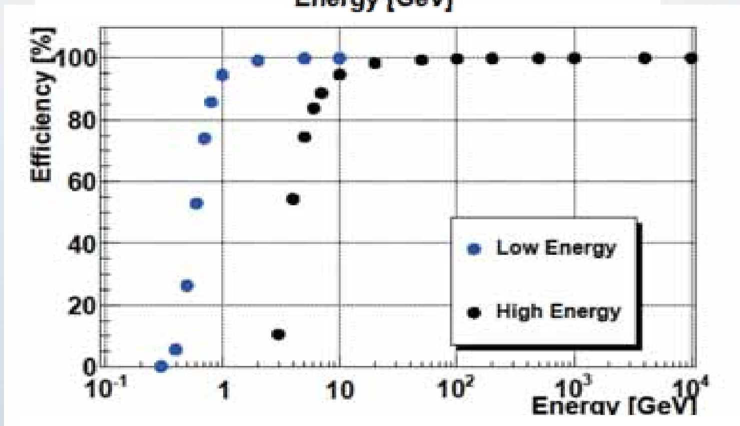
Electron 1 TeV



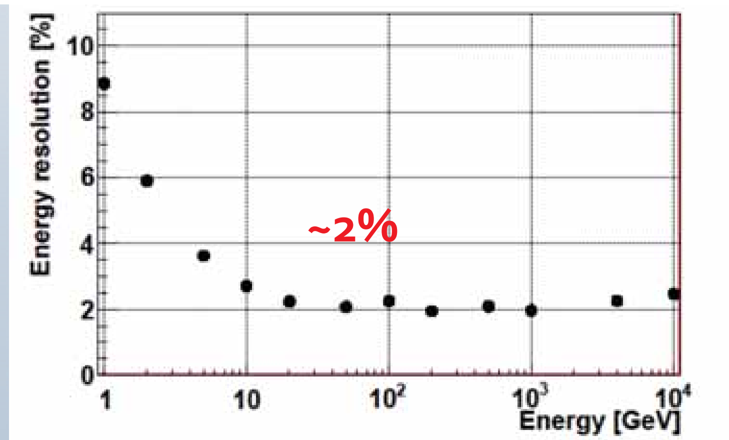
Geometrical Factor (Blue Marks)



Detection Efficiency

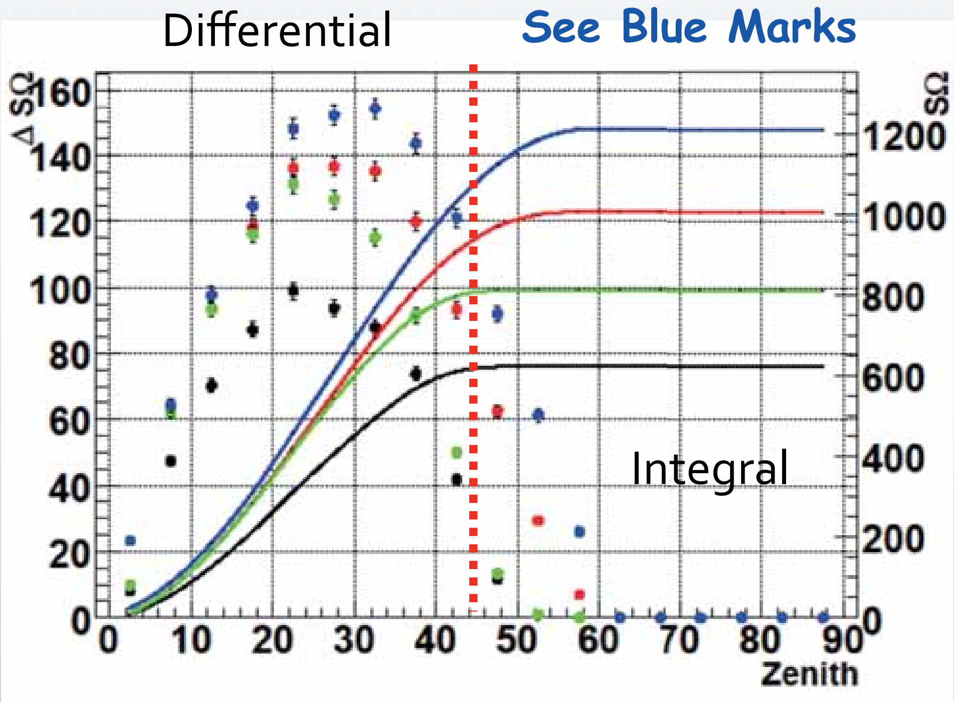


Energy Resolution

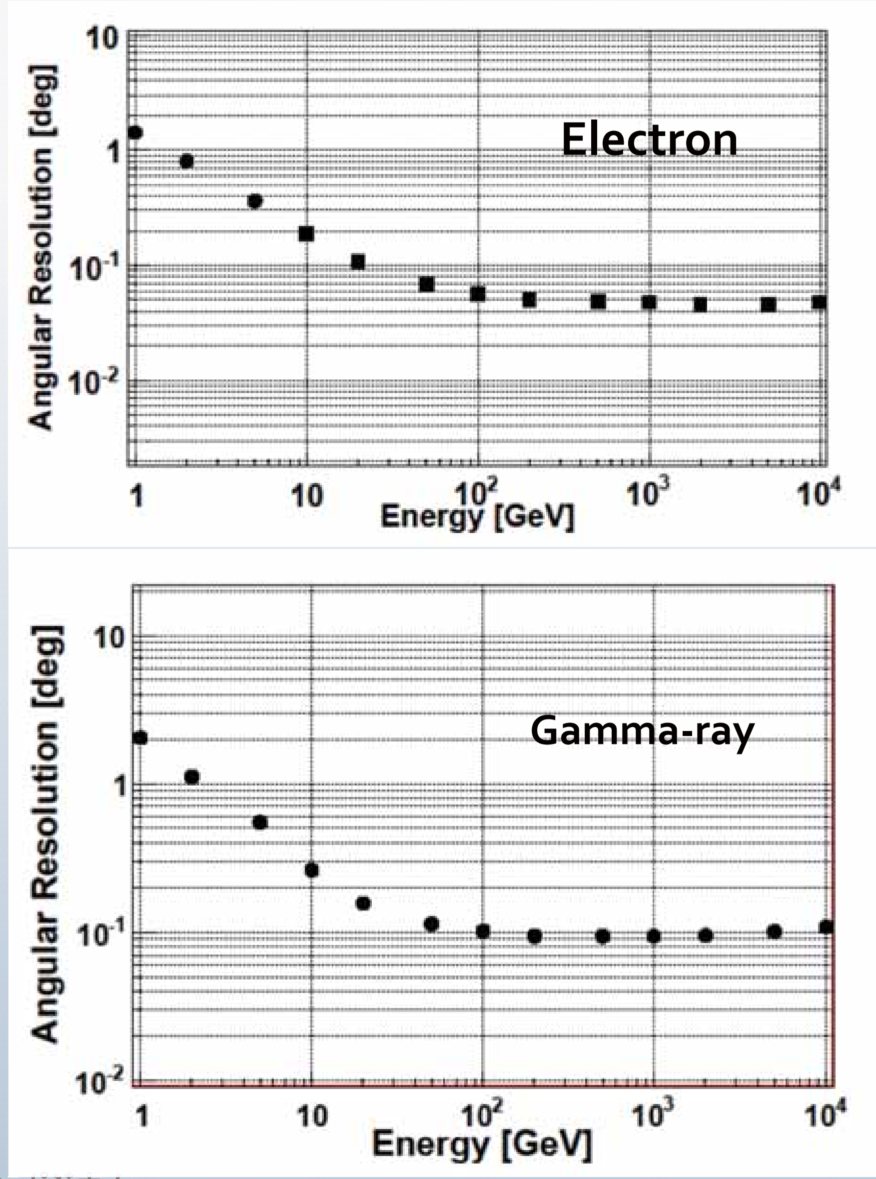


CALET Performance for Electron Observation (2)

SΩ (for electrons) vs. Incident Angle

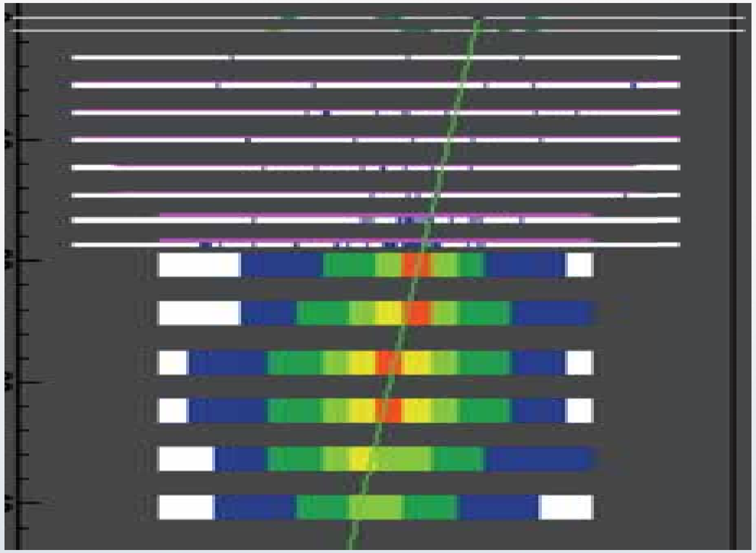


Angular Resolution

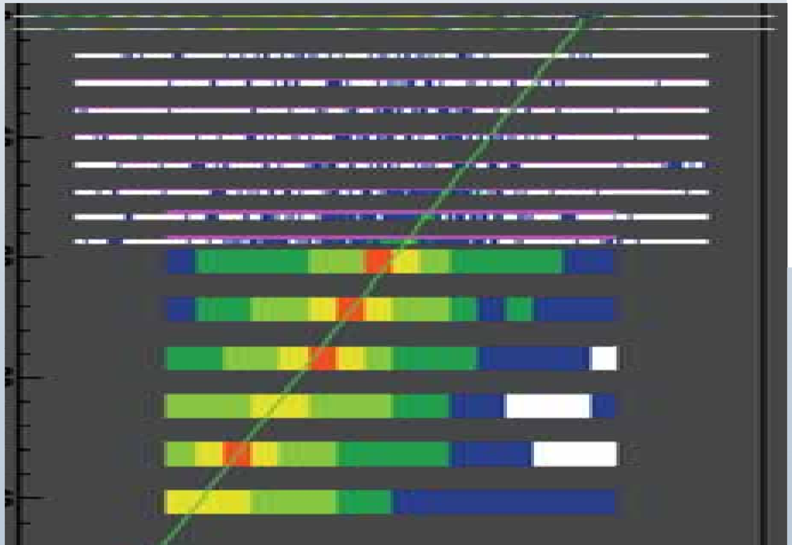


Proton Rejection Power for 1 TeV Electron

Electron 1 TeV



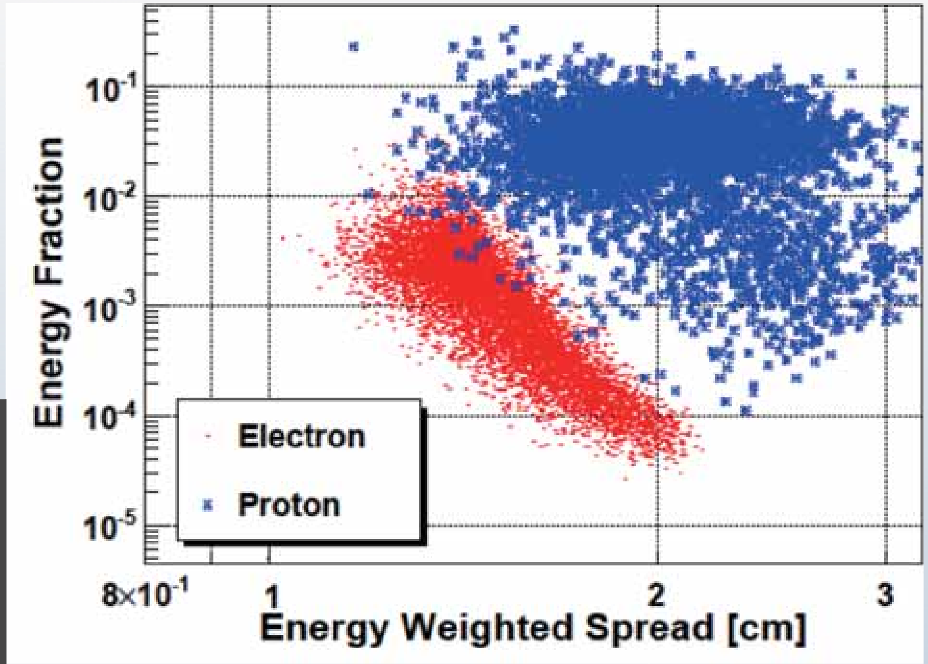
Proton 2.9 TeV



Generated Events

Protons: 1.6×10^6 events with energy spectrum $E^{-2.7}$ in 1-1000TeV

Electrons: 1 TeV



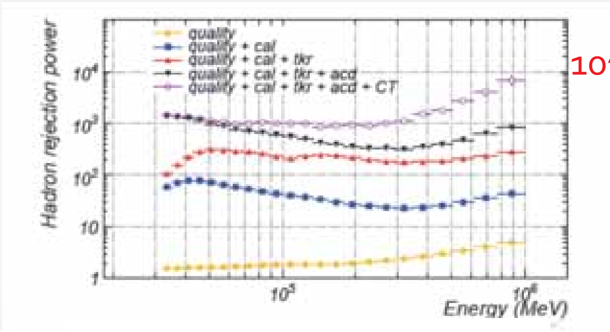
4 proton events are contaminated in electron region (95 % electron retained)
⇒ Proton rejection power: $\sim2\times10^5$ (90% C.L.)

Why we need CALET ?

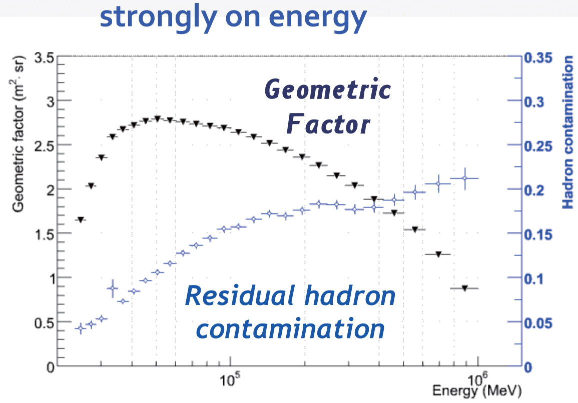
CALET is a dedicated detector for electrons and has a superior performance in the trans-TeV region as well as at the lower energies by using IMC and TASC

FERMI Electron Analysis

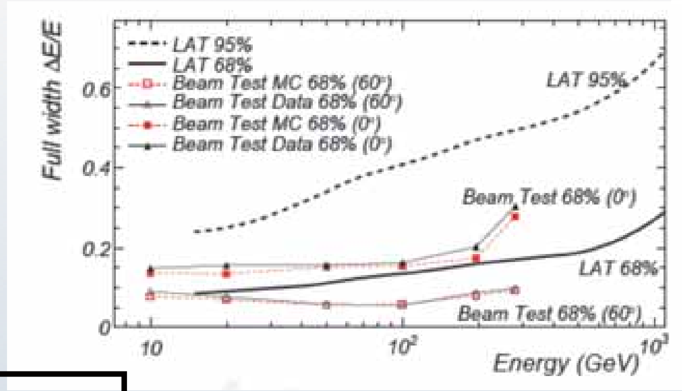
Proton rejection power depends fully on simulation by using different parameters

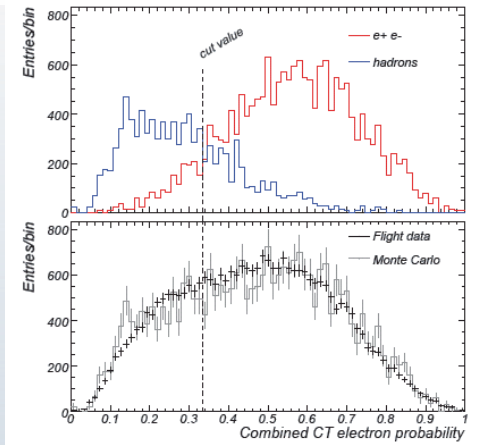


Geometric Factor depends strongly on energy



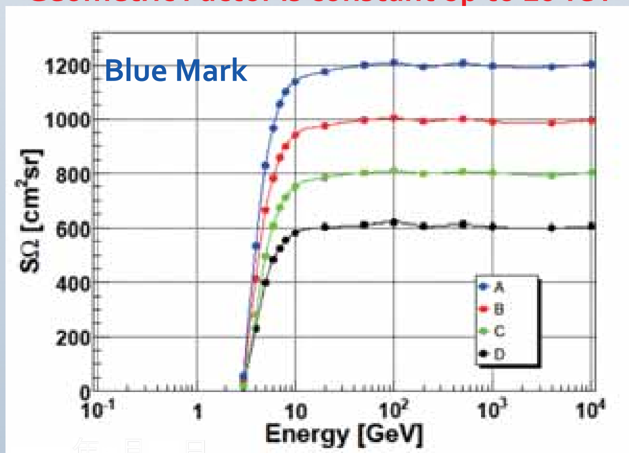
Energy resolution becomes worse at high energies(~30 %@ 1 TeV)



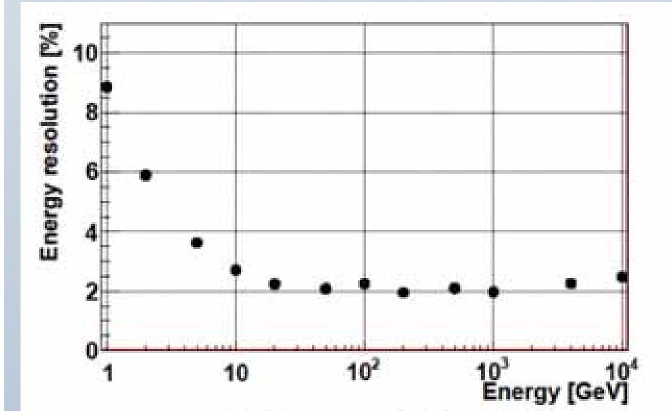


Expected CALET Performance

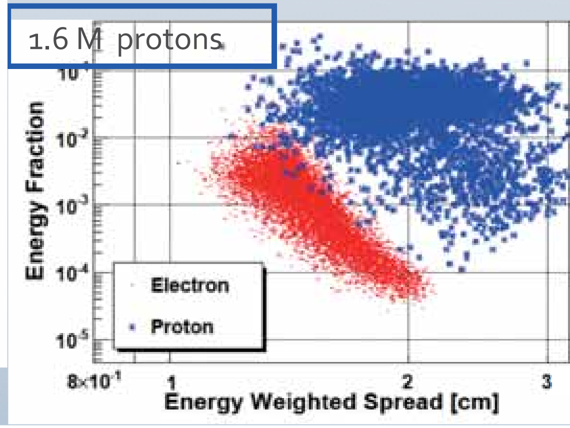
Geometric Factor is constant up to 10 TeV



Energy resolution is nearly 2 %, and constant over 10 GeV



Proton rejection power at 4 TeV is better than 10^5 with 95 % electron retained



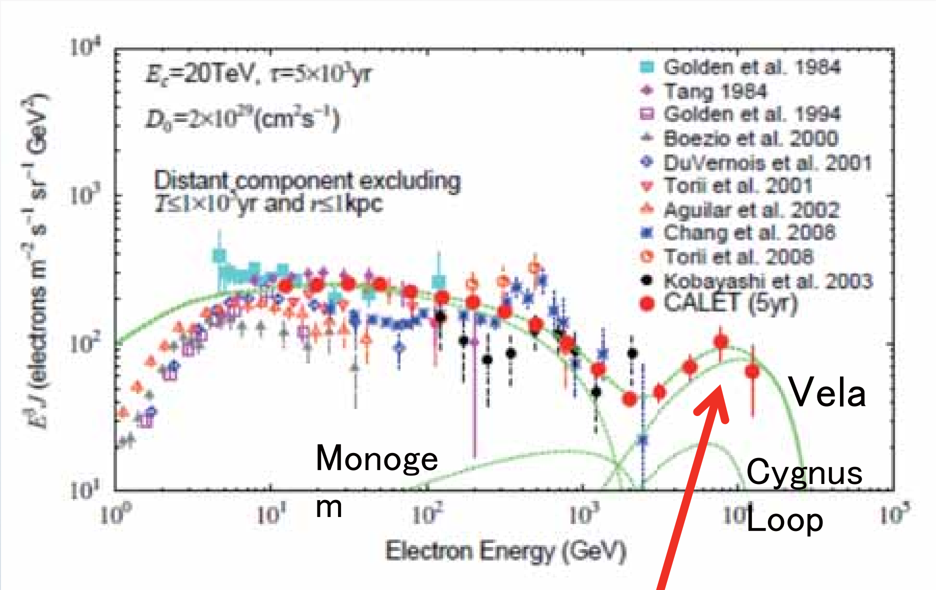
Comparison of Detector Performance for Electrons

CALET is optimized for the electron observation in the tran-TeV region, and the performance is best also in 10-1000 GeV.

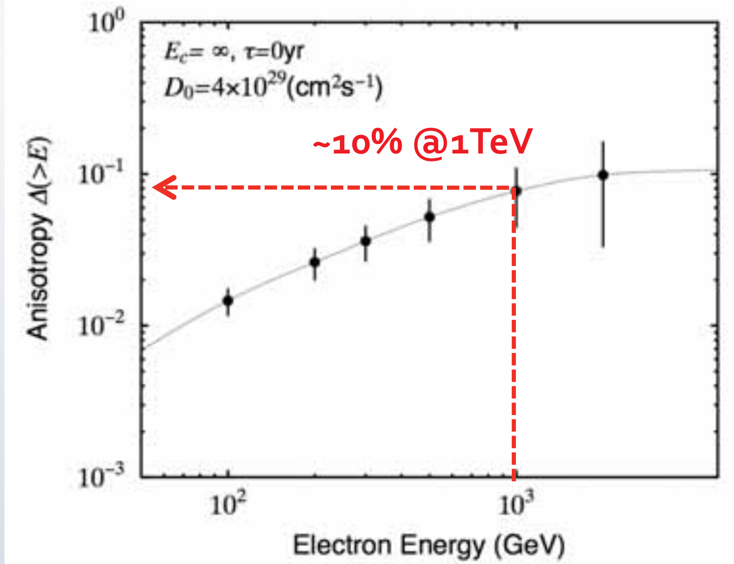
Detector	Energy Range (GeV)	Energy Resolution	e/p Selection Power	Key Instrument (Thickness of CAL)	SΩT (m²srday)
PPB-BETS (+BETS)	10 -1000	13% @100 GeV	4000 (> 10 GeV)	IMC : (Lead: 9 X_0)	~0.42
ATIC1+2 (+ ATIC4)	10 - a few 1000	<3% (>100 GeV)	~10,000	Thick Seg. CAL (BGO: 22 X_0) + **C Targets**	3.08
PAMELA	1-700	5% @200 GeV	10^5	Magnet+IMC (W:16 X_0)	~1.4 (2 years)
FERMI-LAT	20-1,000	5-20 % (20-1000 GeV)	10^3-10^4 (20-1000GeV) Energy dep. GF	Tracker+ACD + **Thin Seg. CAL** (W:1.5X_0+CsI:8.6X_0)	300@TeV (1 year)
AMS **(less capability in PM model)**	1-1,000 (Due to Magnet)	~2.5% @100 GeV	10^4 (x 10^2 by TRD)	Magnet+IMC +TRD+RICH (Lead: 17X_o)	~100(?) (1year)
CALET	**1-10,000**	**~2% (>100 GeV)**	**~10^5**	**IMC+Thick Seg. CAL (W: 3 X_o+ PWO : 27 X_o)**	**220 (5 years)**

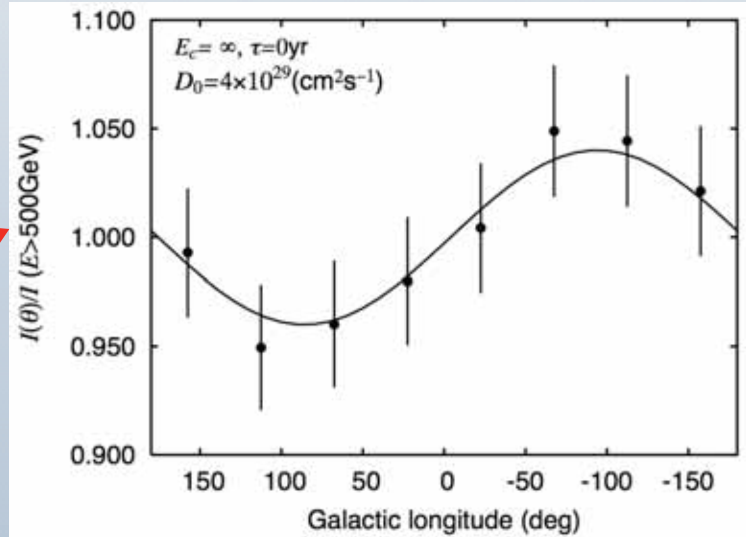
CALETによる宇宙線加速源の同定

期待される電子スペクトル



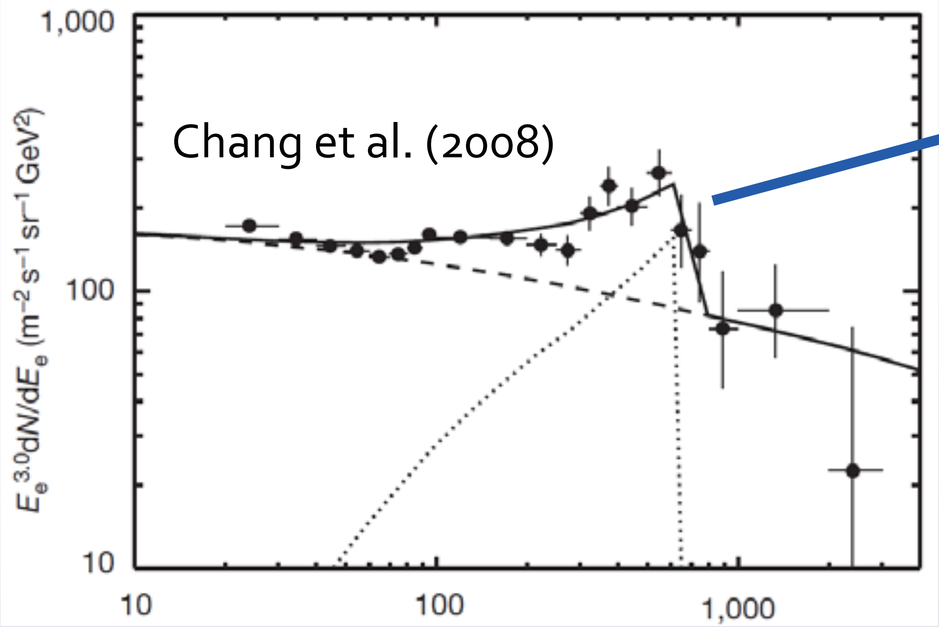
$$\Delta \equiv \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}} = \frac{\sum_i I_i (\mathbf{r}_i / r_i) \cdot \mathbf{n}_{\max} \delta_i}{\sum_i I_i}, \left(\delta_i = \frac{3 r_i}{2 c t_i}\right)$$



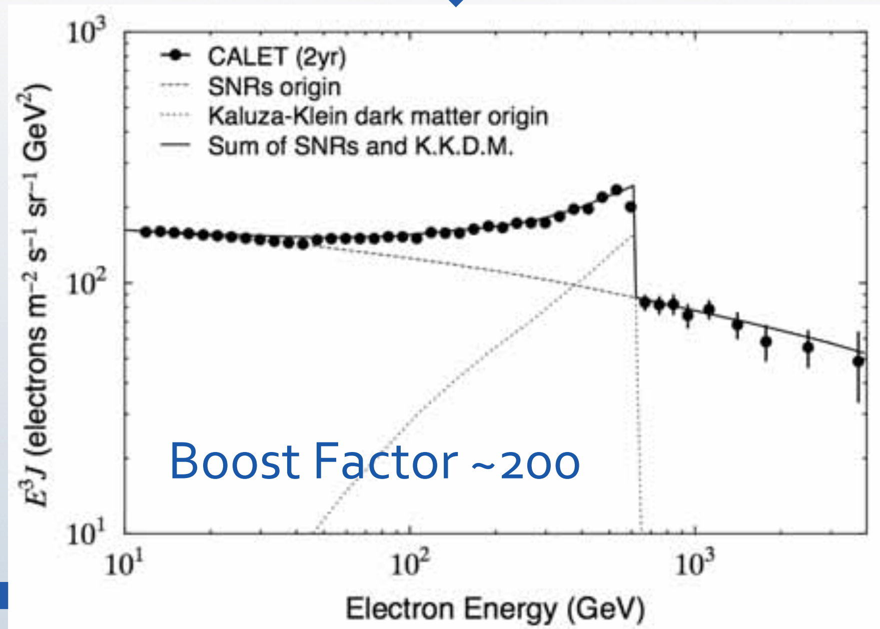


近傍のSNRsによるスペクトル構造、
非等方性の検出
=> 宇宙線加速源の同定

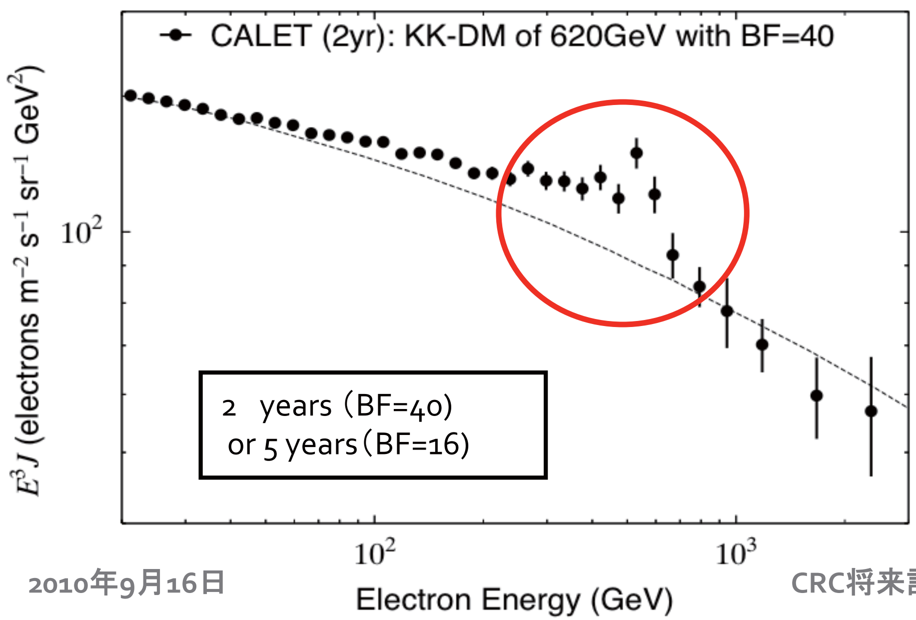
Electron (+ Positron) from Dark Matter Annihilation



Expected energy spectrum from Kaluza-Klein Dark Matter (m=620GeV)



Expected e^-+e^+ energy spectrum by CALET in case of the ATIC observation

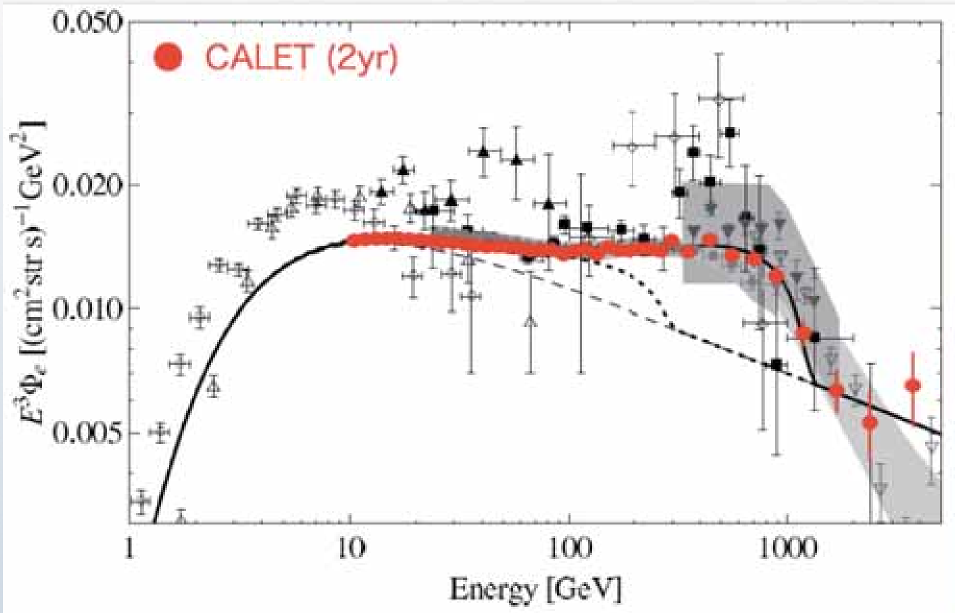


Dark Matter detection capability by CALET

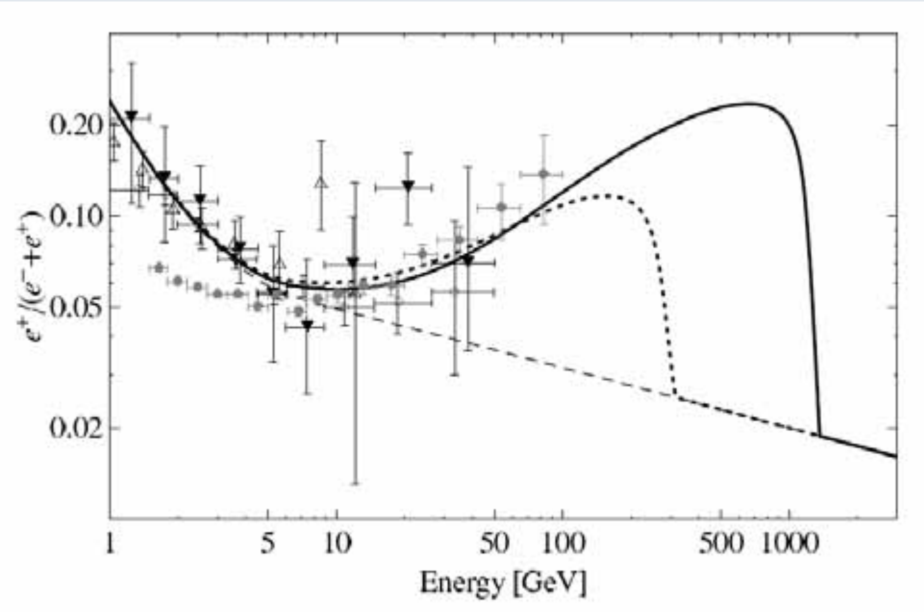
Electron and Positron from Dark Matter Decay

Decay Mode: D.M. -> $l^+l^-\nu$
Mass: $M_{D.M.}$=2.5TeV
Decay Time: $\tau_{D.M.}$ = 2.1×10^{26} s

Expected e^-+e^+ energy spectrum by CALET observation



Expected $e^+/(e^-+e^+)$ ratio by a theory and the observed data



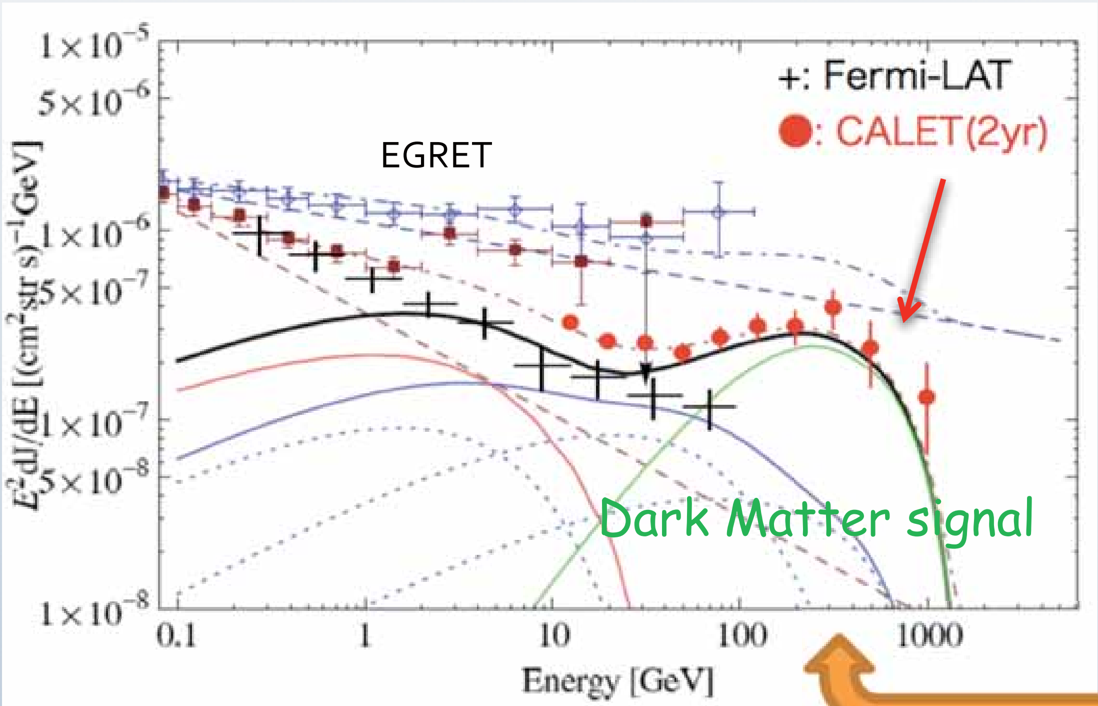
Ibarra et al. (2010)

Observation in the trans-TeV region

→ Dark Matter signal

Extragalactic Diffuse Gamma-rays from Dark Matter Decay

Decay Mode: D.M. -> $l^{+}l^{-}\nu$
Mass: $M_{D.M.}$=2.5TeV
Decay Time: $\tau_{D.M.}$ = 2.1×10^{26} s



Ibarra et al. (2010)

Extra-galactic diffuse gamma-rays

Extragalactic background

\+

Gamma-rays by inverse Compton scattering of the electrons and positrons from DM decay with the inter-stellar and extragalactic photons

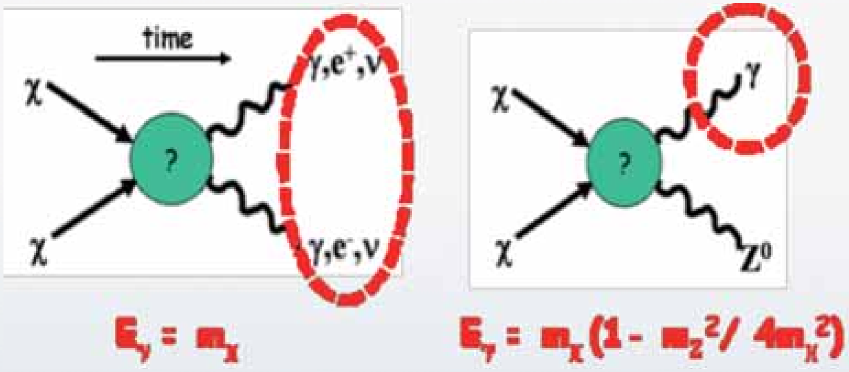
\+

Gamma-rays from DM

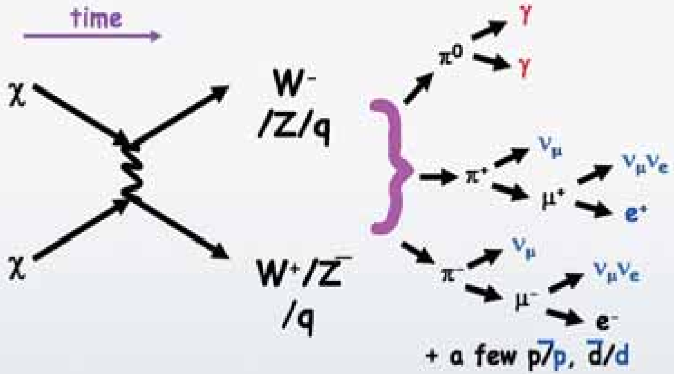
Observation in the sub-TeV region

Gamma-ray line from Dark Matter

(1) WIMP line annihilation

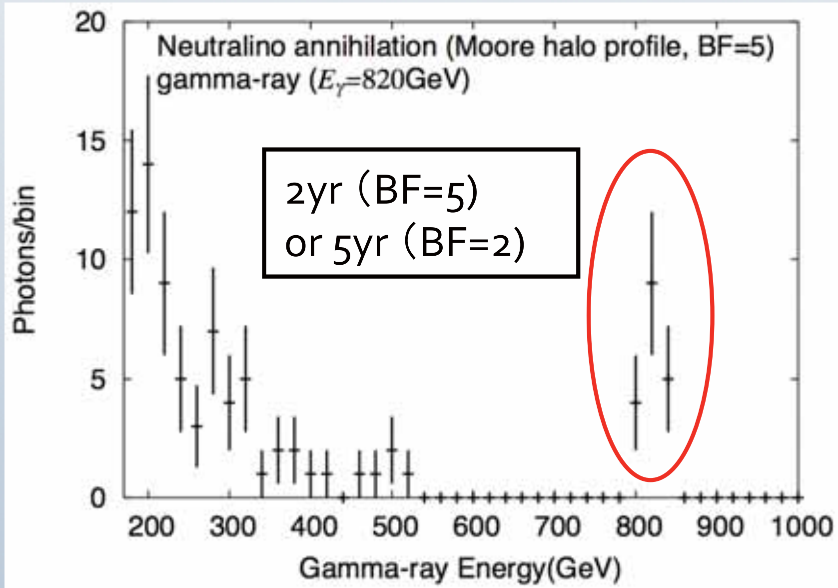


(2) WIMP continuum emission



Excellent energy resolution with CALET
(~2%:10GeV~10TeV)

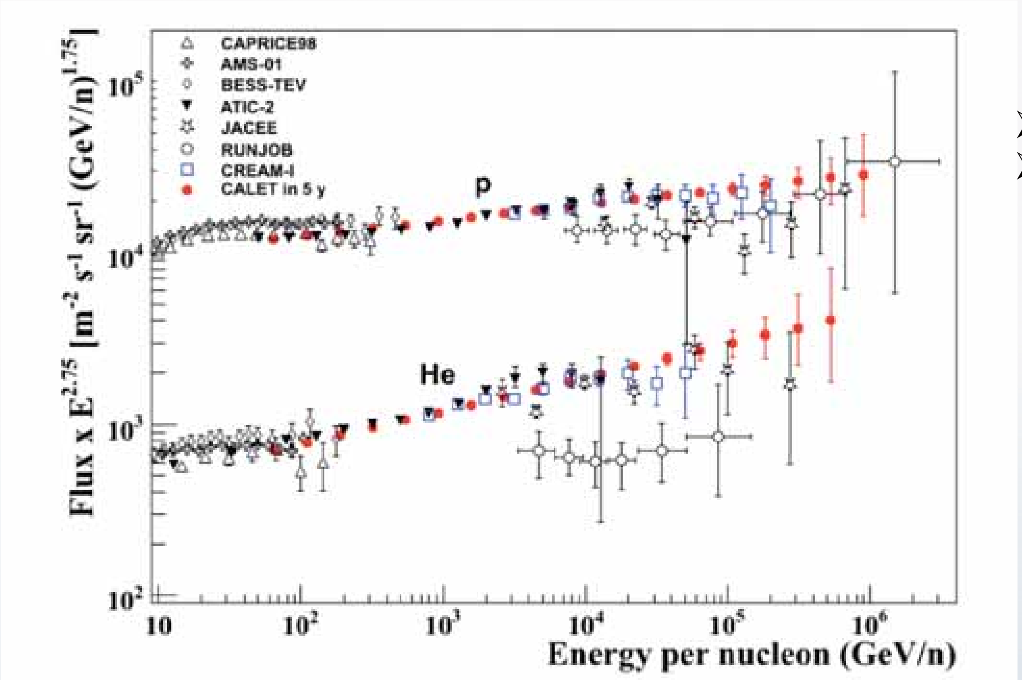
Detection capability of gamma-ray line due to DM annihilation



Expected gamma-ray line for DM (m=820 GeV) annihilation by CALET observation

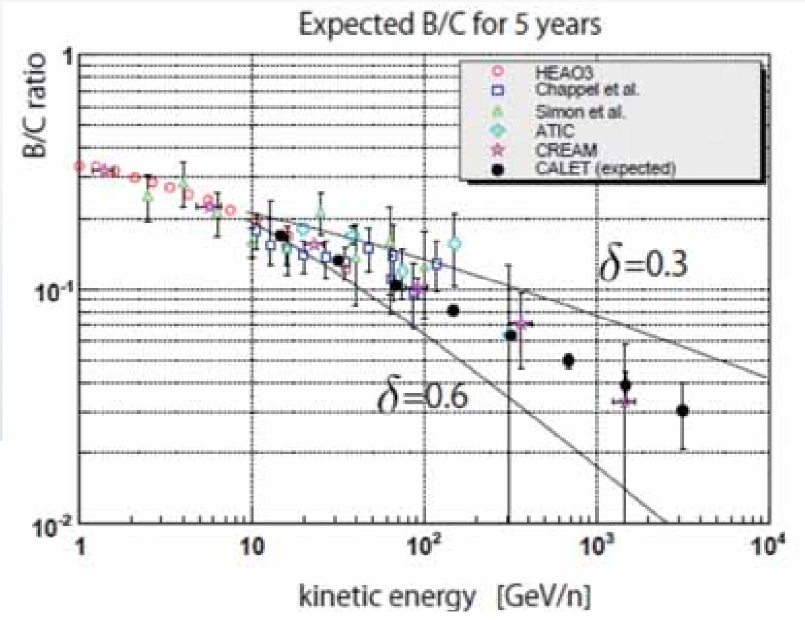
(ref. Bergstrom et al. 2001)

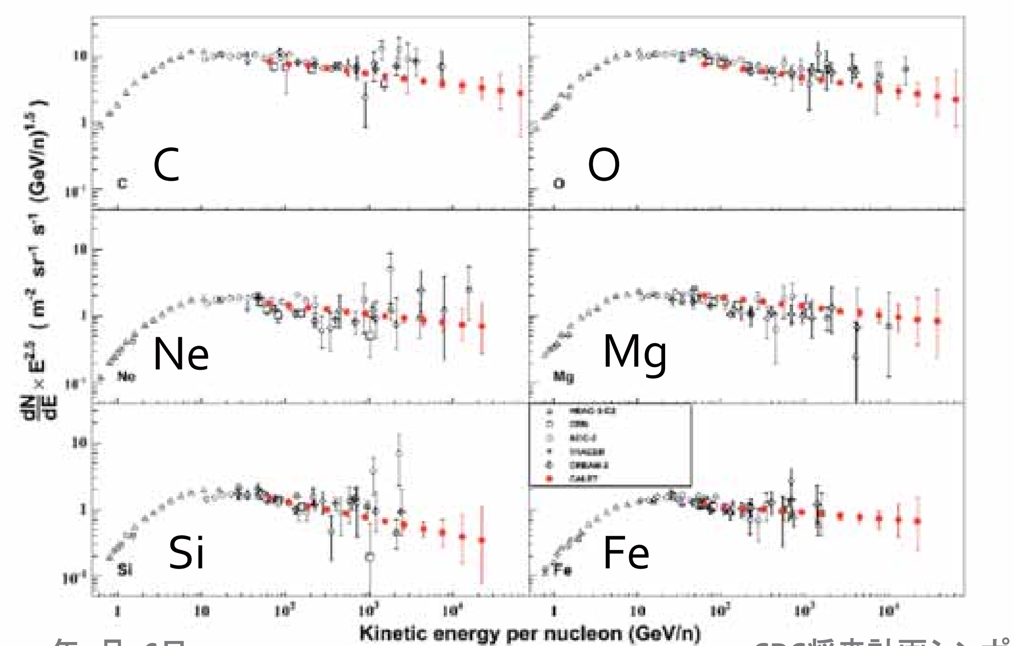
Proton and Nucleus Observation (5years)

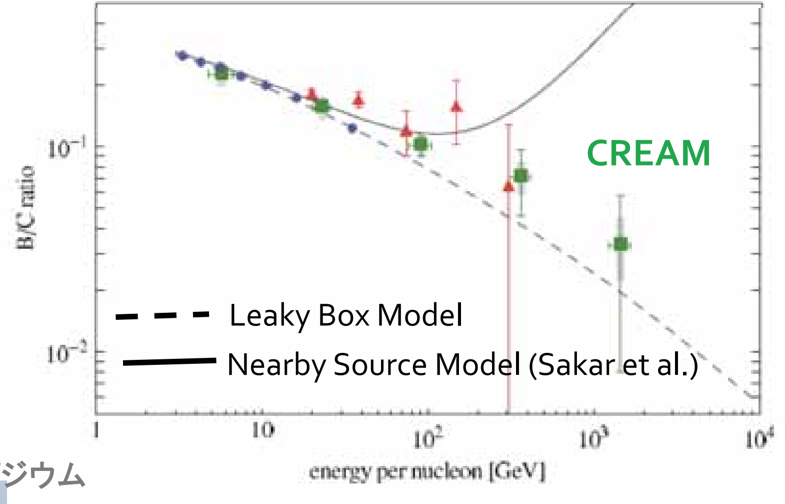


2ry/ 1ry ratio (B/C)

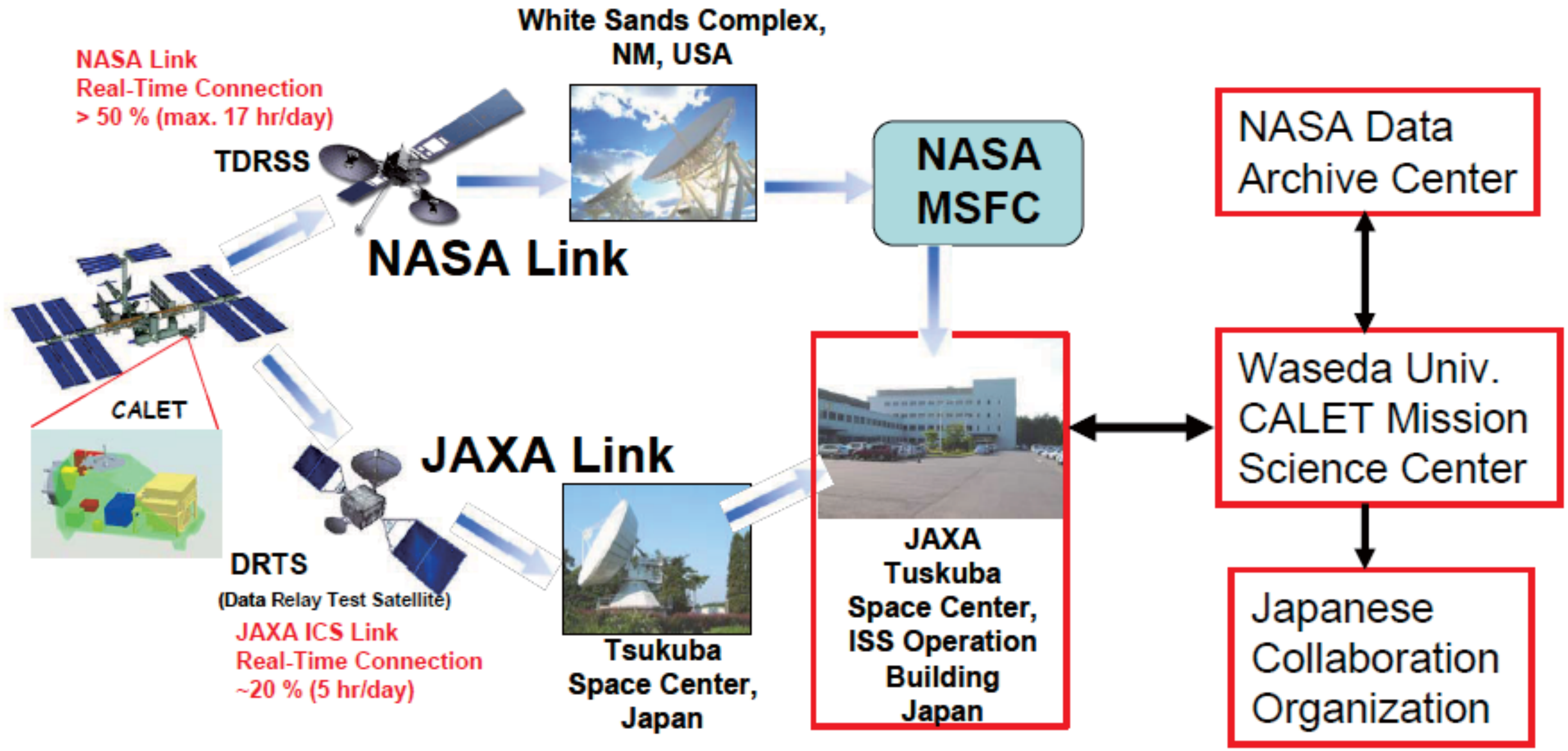
- Energy dependence of diffusion constant: $D \sim E^{\delta}$
- Observation free from the atmospheric effect up to several TeV/n







CALET データダウンリンク 概念図



観測及びHKデータはリレー衛星によって米国経由または直接に筑波宇宙センターISSオペレーションルームにダウンロードされる

早稲田大学ミッションサイエンスセンターから国内外の共同研究機関にデータ配布

まとめ

- CALETのTeV領域の電子・ガンマ線観測により近傍加速源と暗黒物質の探索を行う他、陽子. 原子核の観測を1000TeV領域まで行い、宇宙線の加速・伝播機構を解明
  - さらに、太陽変動やガンマ線バーストのモニター観測を実施
- CALETは日本で初めての宇宙空間における本格的宇宙線観測プロジェクト
  - 2013年度の打ち上げを目指し、2010年4月より開発段階
- CAELTはJAXA有人宇宙環境利用ミッション本部宇宙環境利用センターと早稲田大学の共同ミッション
  - 宇宙科学研究所の支援
- 米国NASAからISSにおける協力としてCALETミッション支援予算の承認