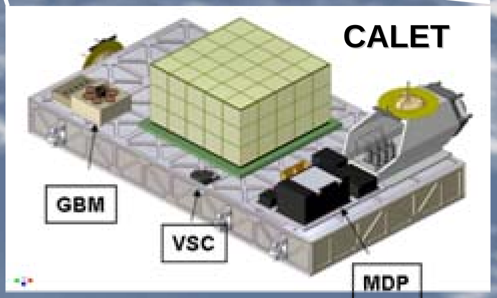
CALORIMETRIC ELECTRON TELESCOPE (CALET) Mission

-Search for Nearby Sources and Dark Matter-



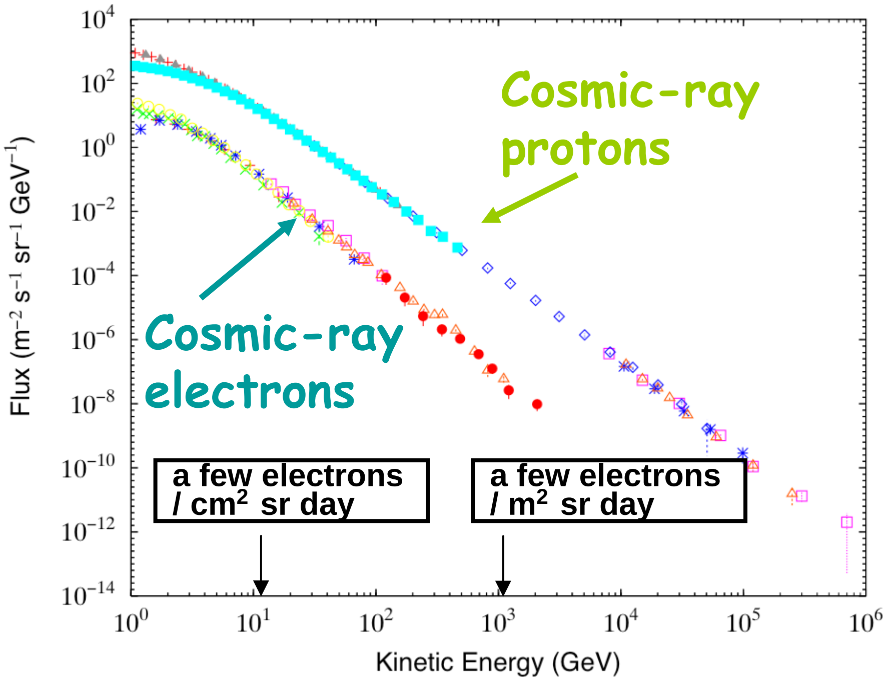
Shoji Torii
Waseda University

Outline

- Introduction – What is Electron Observation?
- General Understanding of Pamela Positron Excess and ATIC/PPB-BETS Anomaly
- Nearby Pulsars or Unknown Astro. Source
- Dark Matter Decay or Annihilation
- What's Next – CALET Project
- Summary

Electron Observation in 1~1000 GeV

Cosmic-ray Energy Spectra



- Flux of electrons:
  ~1% of protons @10GeV
  ~0.1 % @ 1000GeV
- Spectrum of electrons:
  steeper 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

⇒ Long duration balloon flight in 10~1000 GeV
Observation in space for years over 1000 GeV

Cosmic Ray Electron Models

- Where do CR electrons come from?
  - ✓ Discrete Sources (~98% at 100 GeV)
  - ✓ Interactions of CR nuclei with interstellar gas
    - producing $\pi^{+/-}$ or $K^{+/-} \rightarrow \mu^{+/-} \rightarrow e^{+/-}$

- How do they move through the Galaxy?
  - ✓ Diffusion
    - Energy loss by synchrotron and inverse Compton

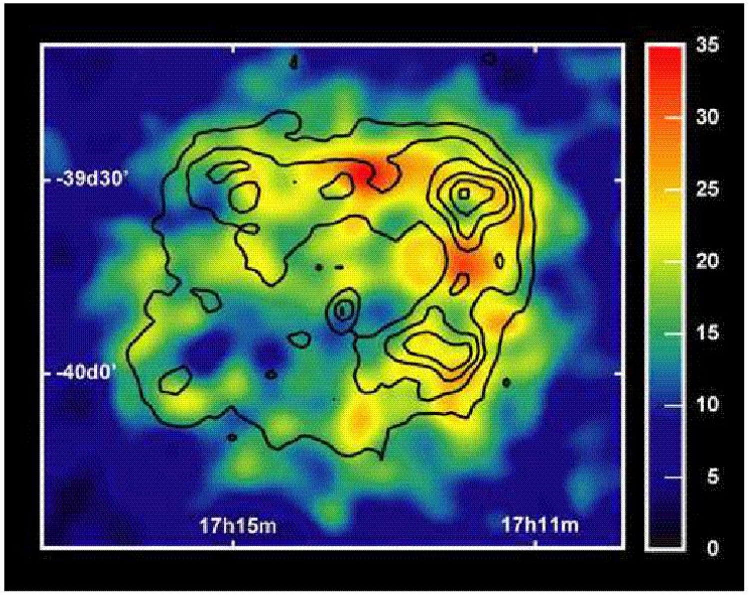
[so, $T = 2.5 \times 10^5 \times (1\ \mathrm{TeV}/E)$ yr and $R = 600 \times (1\ \mathrm{TeV}/E)^{1/2}$ pc]

What are the source candidates?

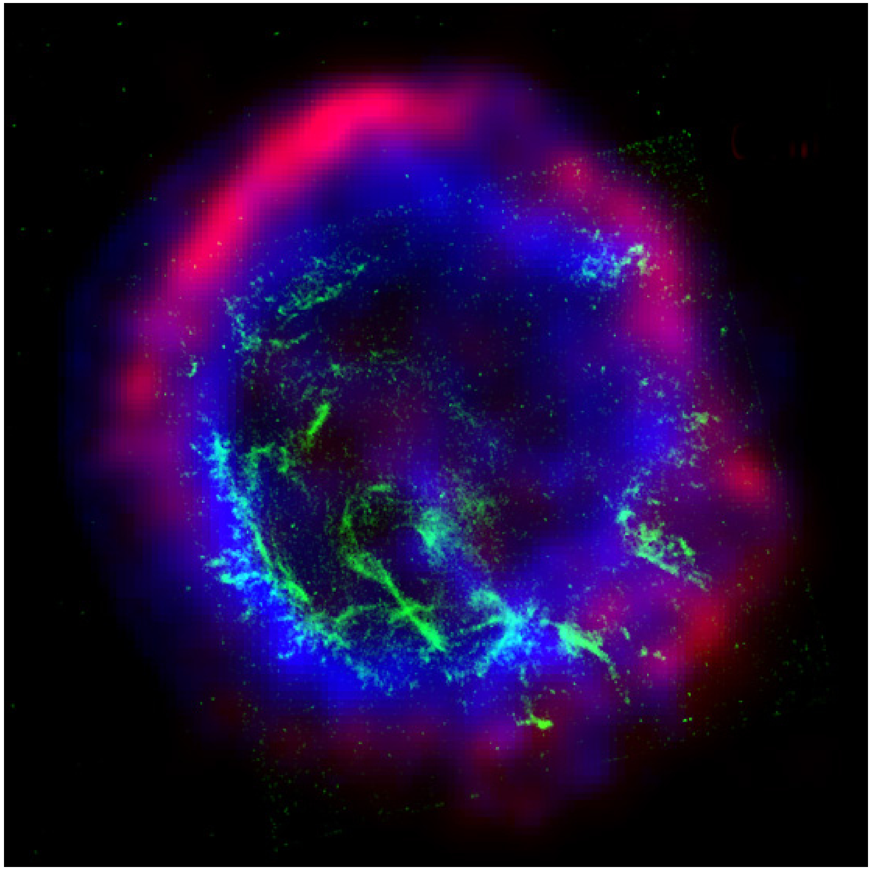
- **Supernova Remnants**
  - Shock acceleration gives a $d\phi/dt \propto E^{-2} exp(-E/E_c)$ spectrum injected into the ISM, where $E_c \sim 10$ TeV.
- **Pulsar Wind Nebulae (PWNe)**
  - Electrons released from the stellar surface in the polar caps pair produce in the magnetic fields producing e^+/e^- pairs
  - The pairs are accelerated at the PWN termination shock, again giving a $d\phi/dt \propto E^{-2} exp(E/E_c)$ injection
- **Microquasars**
  - Relativistic jets sending out beams of mono-energetic electrons in to the ISM

The Case for Supernova Remnants

- Experimental Evidence
  - Radio synchrotron emission observed
  - X-ray synchrotron emission observed
  - TeV gamma ray emission predicted and observed



HESS image of RX J1713.7-3946



Color-composite image of E0102-72.3: Radio from ATCA; X-ray from Chandra and Visible from HST.

Nearby Sources of Cosmic-Ray Electrons

Electron Energy Loss by

- **Inverse Compton Scattering**
- **Synchrotron Radiation**

Electron Propagation in the Galaxy

- **Diffusion Process**

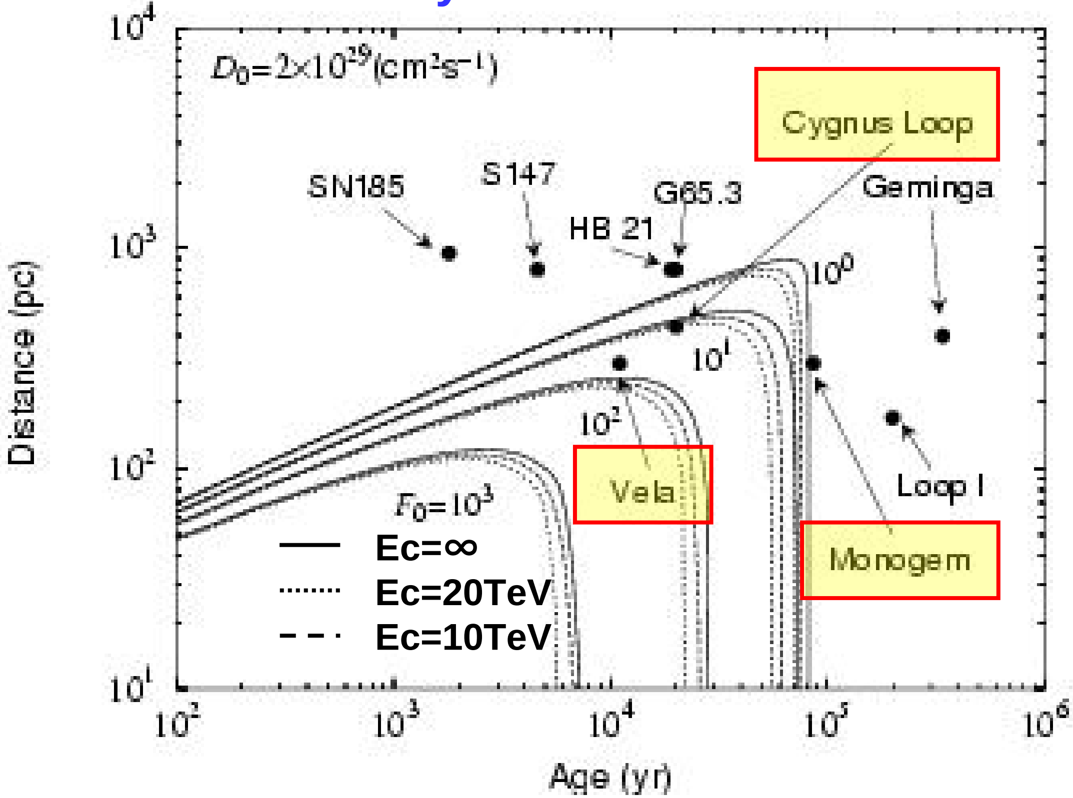
Electron Density Equation

$$\frac{dNe}{dt} - \nabla(D\nabla Ne) - \frac{\partial}{\partial E}(bE^2 Ne) = Q$$

Anisotropy

$$\Delta_i = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} = \frac{3D}{c}\frac{\nabla N_i}{N_i} = \frac{3R_i}{2ct_i}$$

Nearby Source Candidates



Energy Loss Rate
dE/dt = -bE²

T*(Age) = *1/bE
***R*(Distance)=(*2DT*)$^{1/2}$**

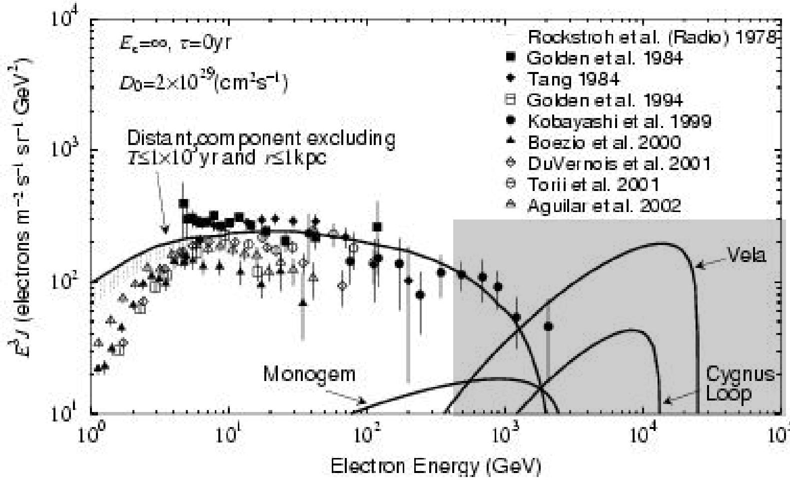
1 TeV Electron Source:

- **Age < 10^5 years**
- **Distance < 1 kpc**

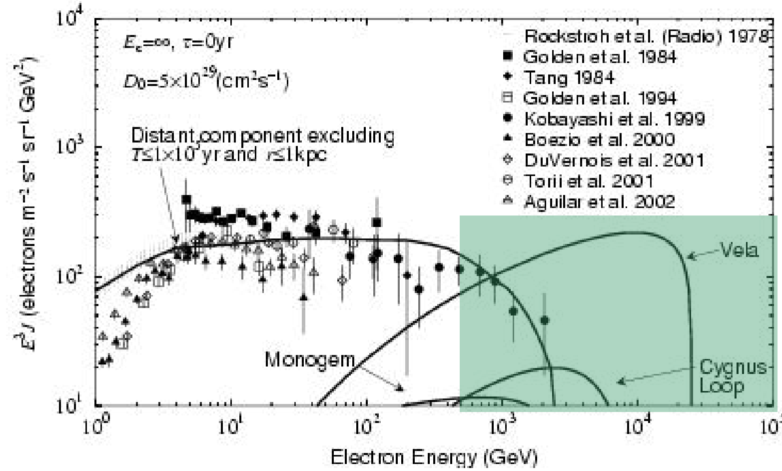
Vela
Cygnus Loop
Monogem
or
Unobserved Sources?

Model Dependence of Nearby Source Effect

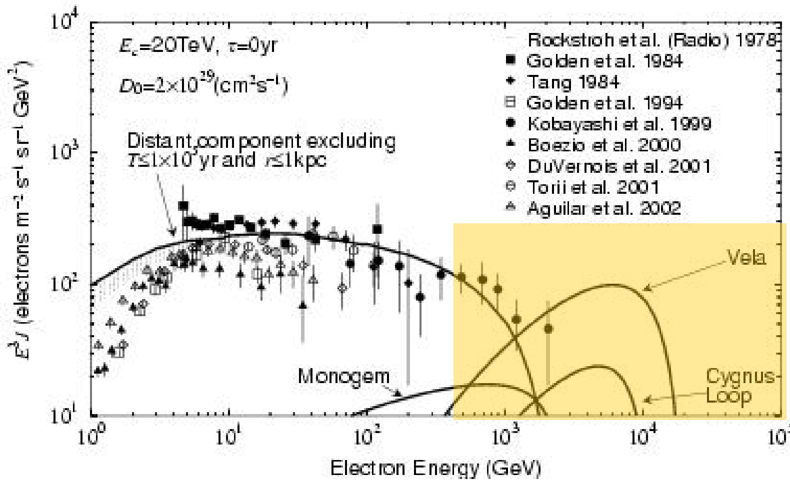
Ec=∞、ΔT=0 yr, Do=2x10^{29} cm^{2}/s



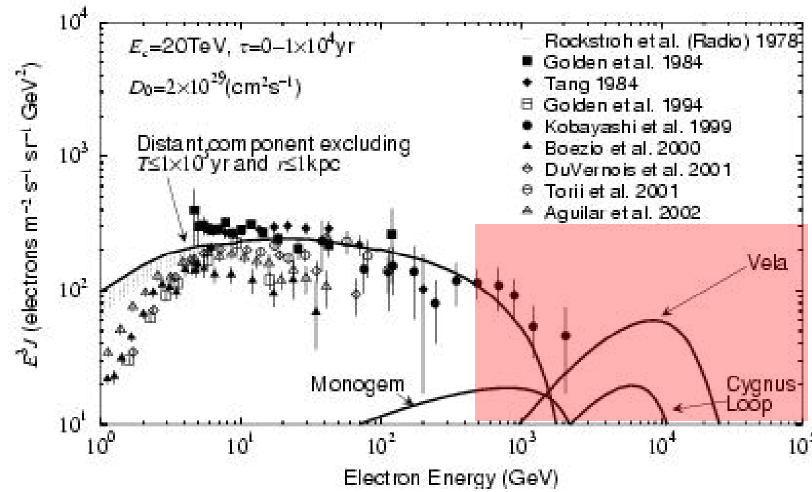
Do=5 x 10^{29} cm^{2}/s



Ec= 20 TeV

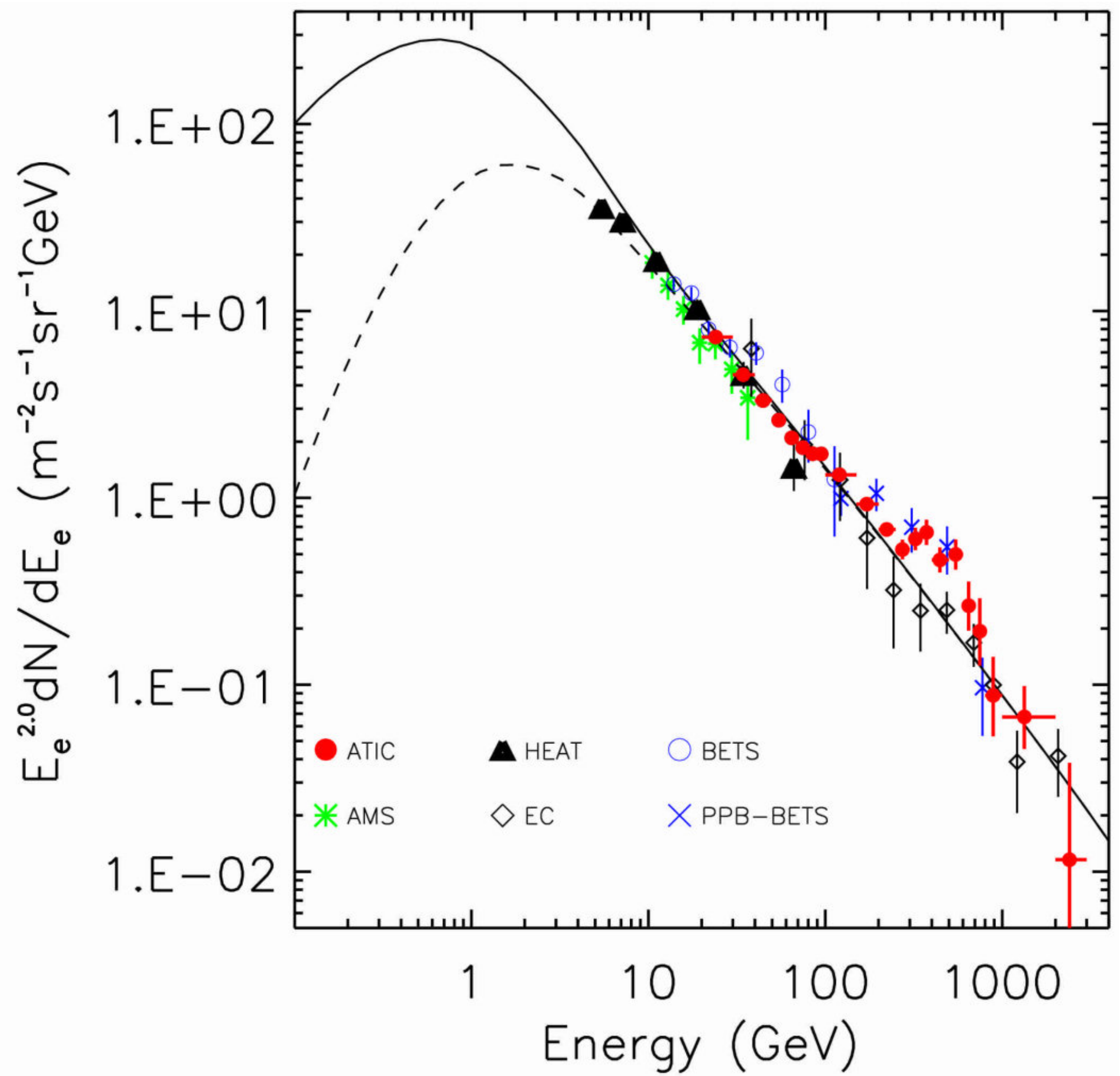


Ec=20 TeV、ΔT=1-10^{4} yr



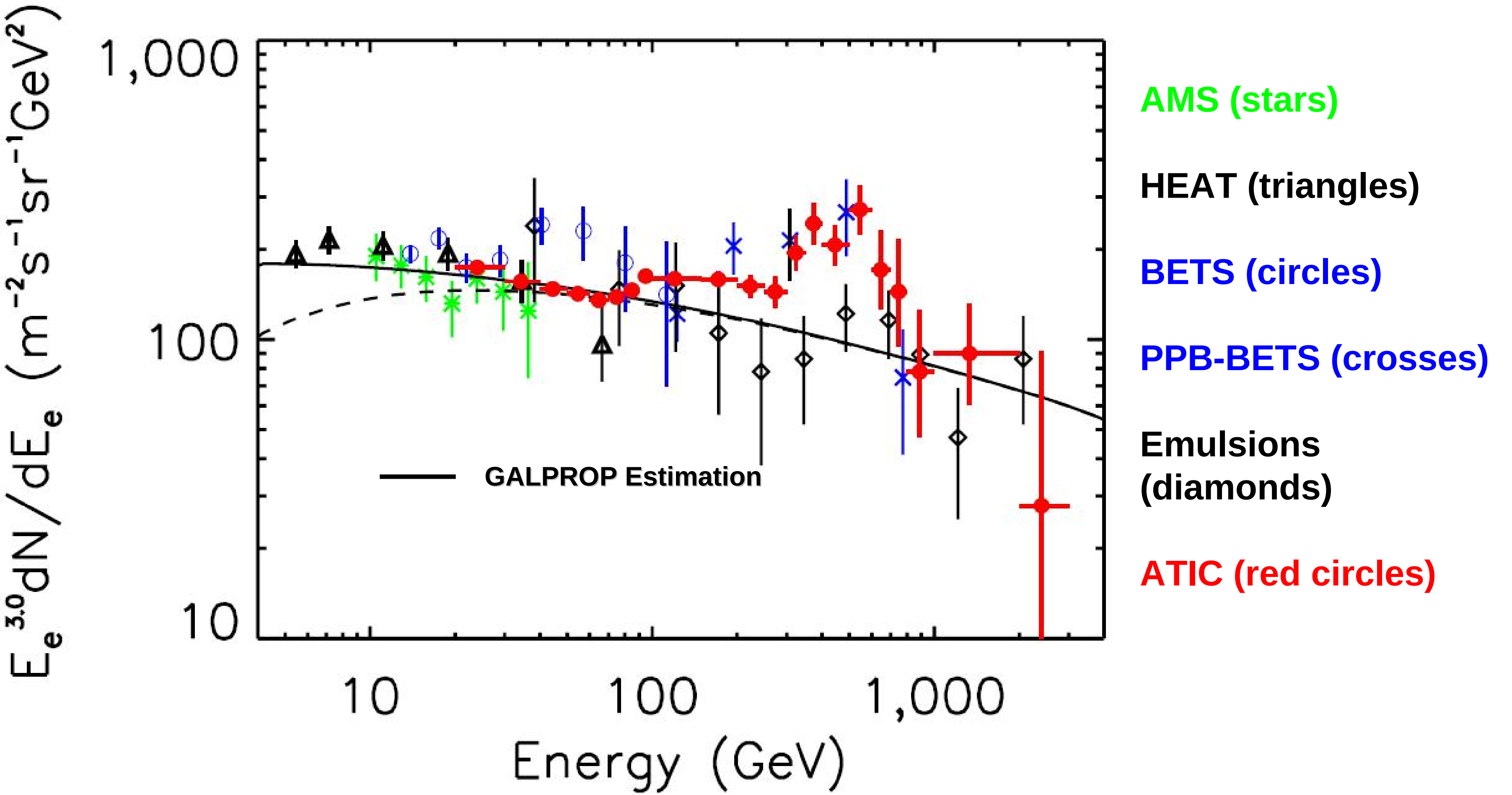
Kobayashi et al. ApJ 2003

Balloon Observations of Electrons



Measured Electron Spectrum

Chang el al. Nature



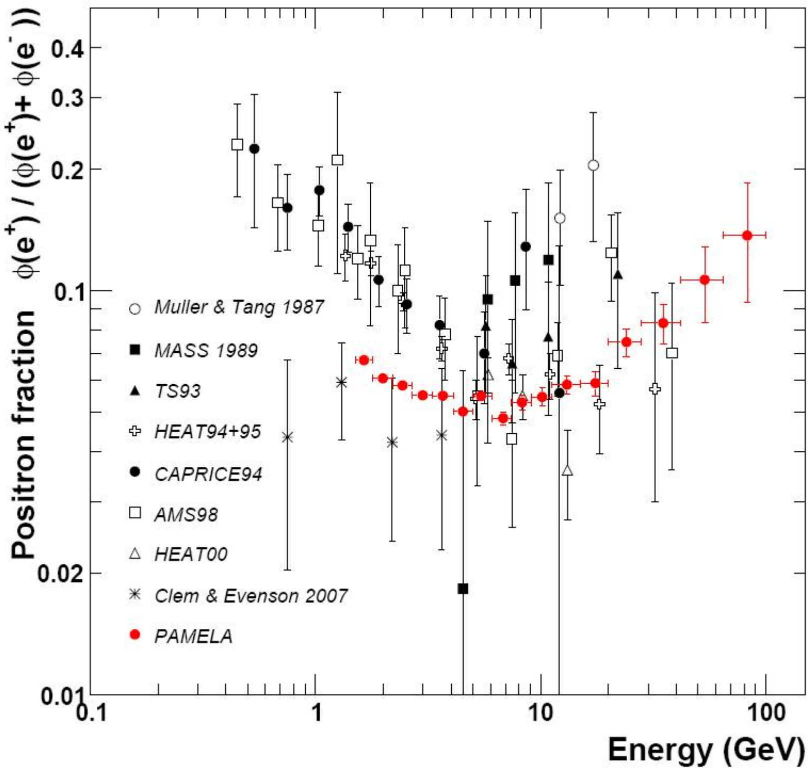
PAMELA Results

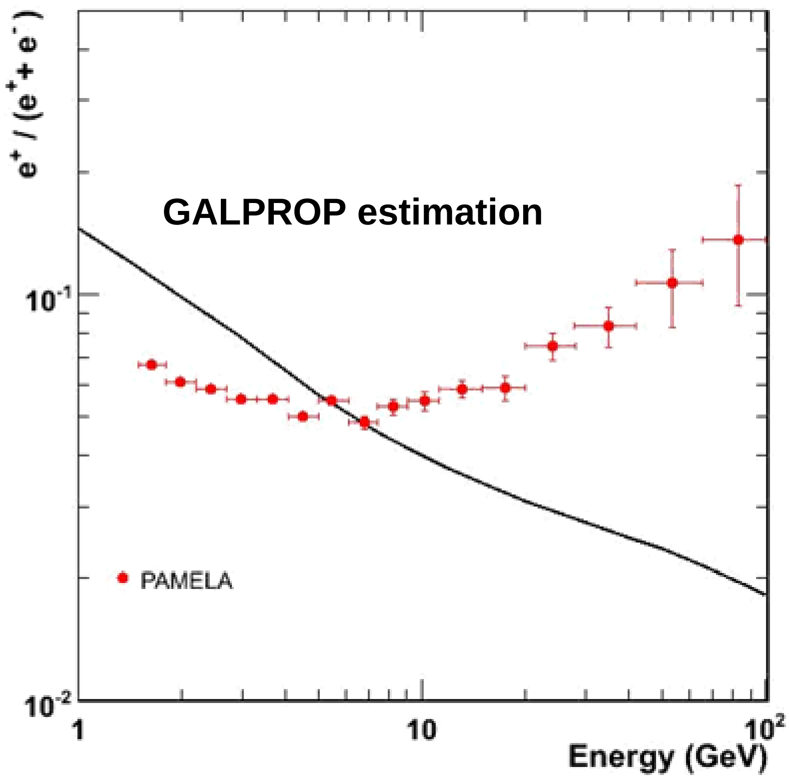
Adriani et al. (2008)

Secondary Production Models

$CR + ISM \rightarrow \pi^{\pm} + \ldots \rightarrow \mu^{\pm} + \ldots \rightarrow e^{\pm} + \ldots$

$CR + ISM \rightarrow \pi^{0} + \ldots \rightarrow \gamma\gamma \rightarrow e^{\pm}$





These are difficult experiments. Positrons and protons must be separated

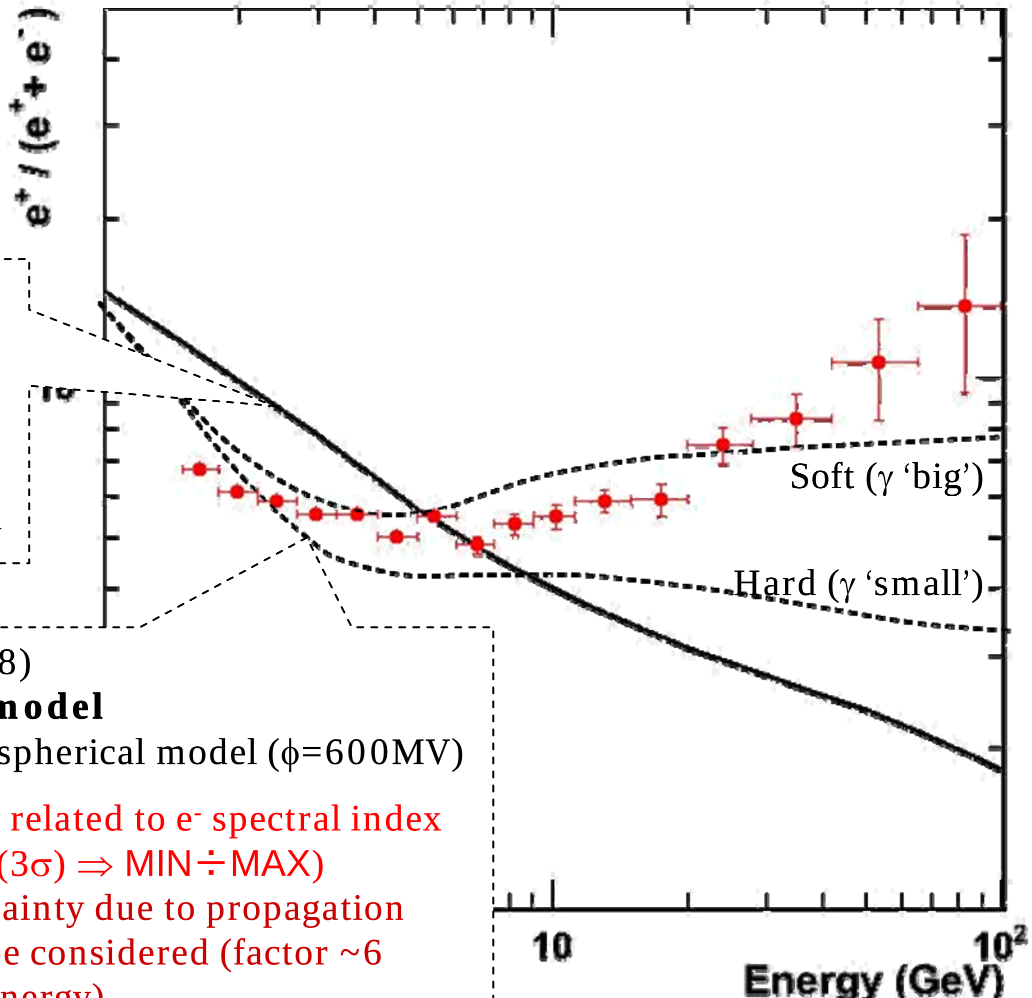
The positron excess exceeds the prediction of Moskalenko and Strong (1998) above 10 GeV (*solid curve*)

Positron fraction

Secondary Production Models

CR + ISM → $\pi^{\pm}$ + … → $\mu^{\pm}$ + … → $e^{\pm}$ + …

CR + ISM → π^{0} + … → $\gamma\gamma$ → $e^{\pm}$



(Moskalenko & Strong 1998)
GALPROP code
- **Plain diffusion model**
- Interstellar spectra

(Delahaye et al. 2008)
- **Plain diffusion model**
- Solar modulation: spherical model (ϕ=600MV)

→ Uncertainty band related to e- spectral index (γ_e = **3.44±0.1** (3σ) ⇒ MIN÷MAX)

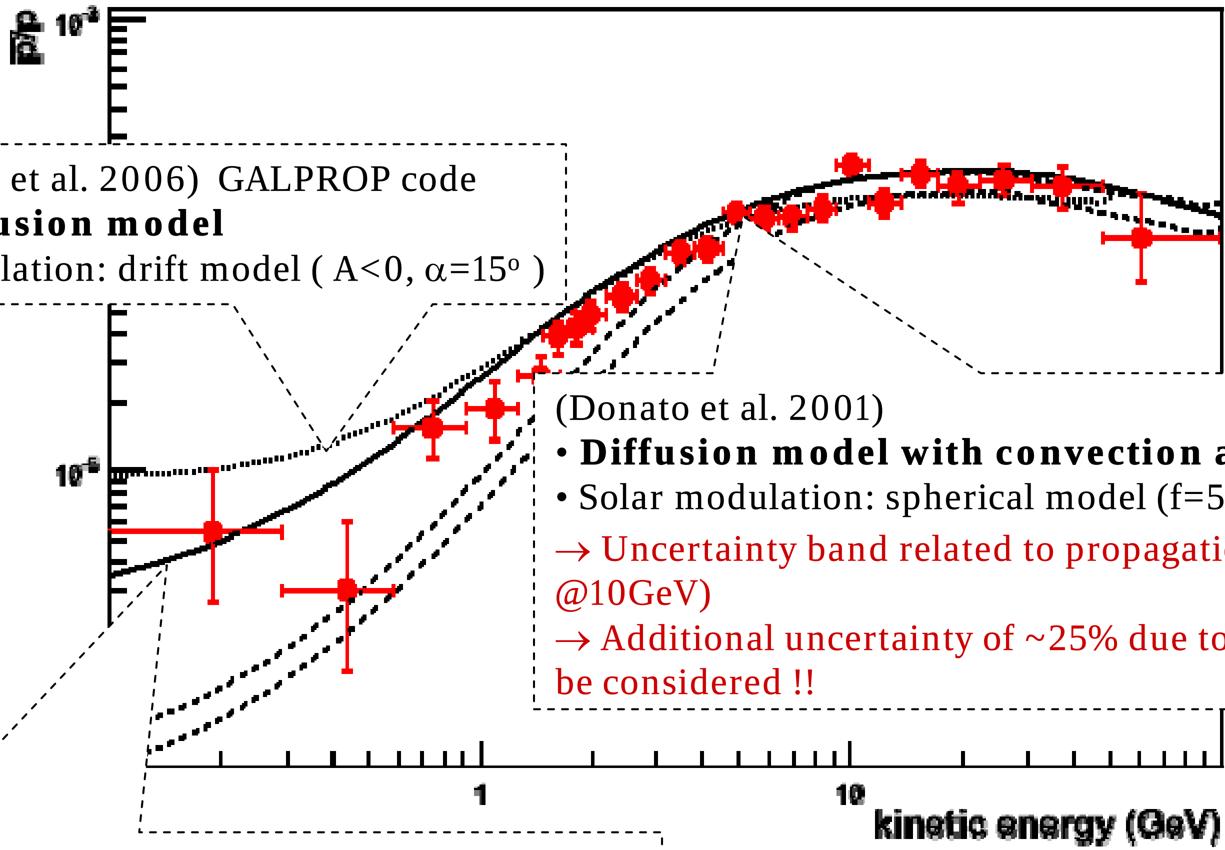
→ Additional uncertainty due to propagation parameters should be considered (factor ~6 @1GeV ~4 @high-energy)

Quite robust evidence for a positron excess

O.Adriani

Antiproton-to-proton ratio by PAMELA

Secondary Production Models CR + ISM → p-bar + …



(Moskalenko et al. 2006) GALPROP code

- **Plain diffusion model**
- Solar modulation: drift model (A<0, α=15^{o})

(Donato et al. 2001)

- **Diffusion model with convection and reacceleration**
- Solar modulation: spherical model (f=500MV)

→ Uncertainty band related to propagation parameters (~10% @10GeV)

→ Additional uncertainty of ~25% due to production cs should be considered !!

(Ptuskin et al. 2006) GALPROP code

- **Plain diffusion model**
- Solar modulation: spherical model (f=550MV)

No evidence for any antiproton excess

O.Adriani

General Understand of PAMELA and ATIC/PPB-BETS results

- The PAMELA data suggests that there is a local primary source for positrons.
- The positron source spectrum needs to be hard.
- Then, we should expect that the electron spectrum may be also significantly modified at > 100 GeV.

Perhaps, the PAMELA and ATIC/PPB-BETS excesses arise from the same origin.

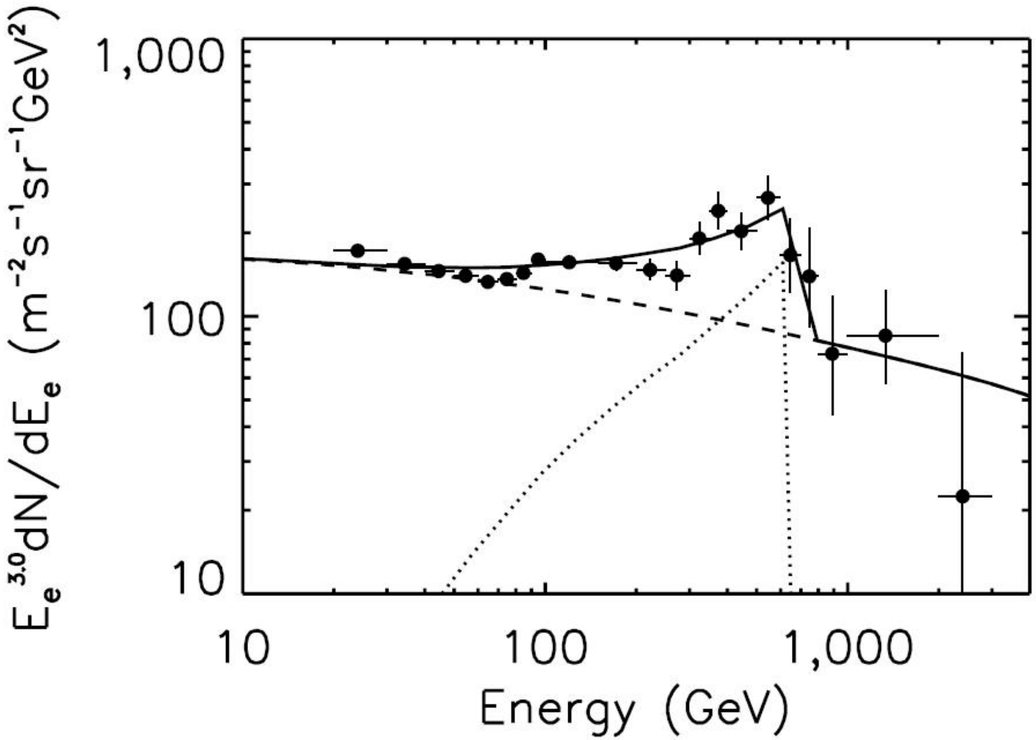
Possible Candidates

- Dark Matter decay or annihilation
- Nearby pulsars or unknown astronomical source (Gamma-ray burst remnant?)

Difficult to explain the observed flux with a sharp edge seen by ATIC/PPB-BETS ??

KK Dark Matter

Chang et al. Nature(2008)



Dashed curve: The electron spectrum predicted by the GALPROP model (Strong and Moskalenko, 2001)

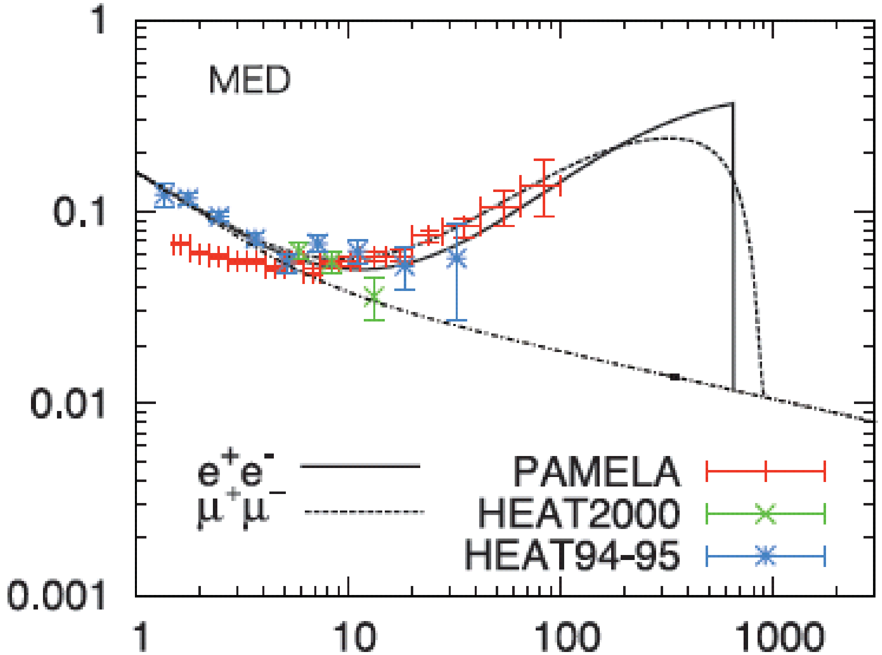
Dotted curve: 620 GeV Kaluza-Klein particle directly annihilating to e^+/e^- pairs and propagated using GALPROP

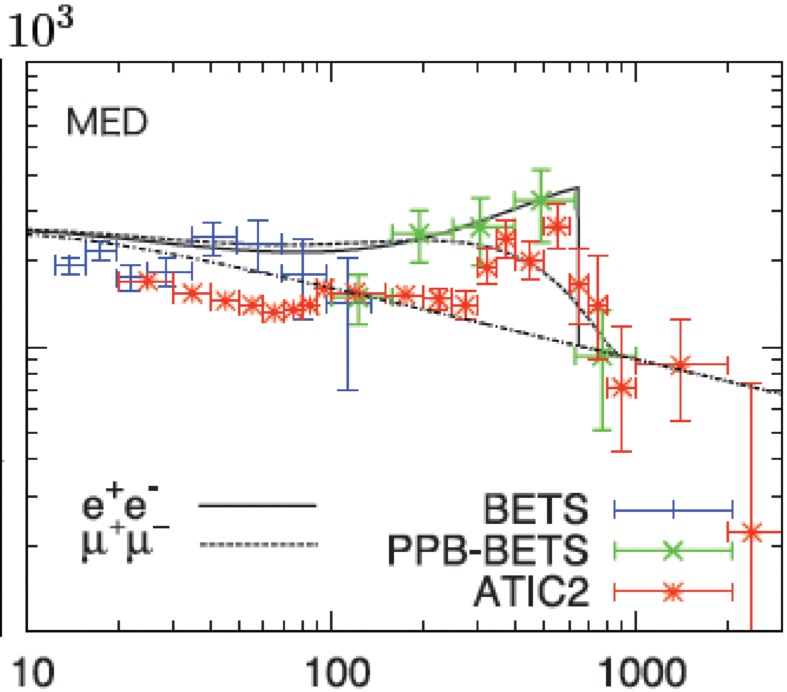
Solid curve: Sum of background electron spectrum and KK annihilation spectrum

KK annihilation does fit the excess well but it requires a local clump of dark matter that is ~200 times the average density in the Galaxy

Positron fraction

Total flux $[\mathrm{GeV^2 m^{-2} s^{-1} sr^{-1}}]$

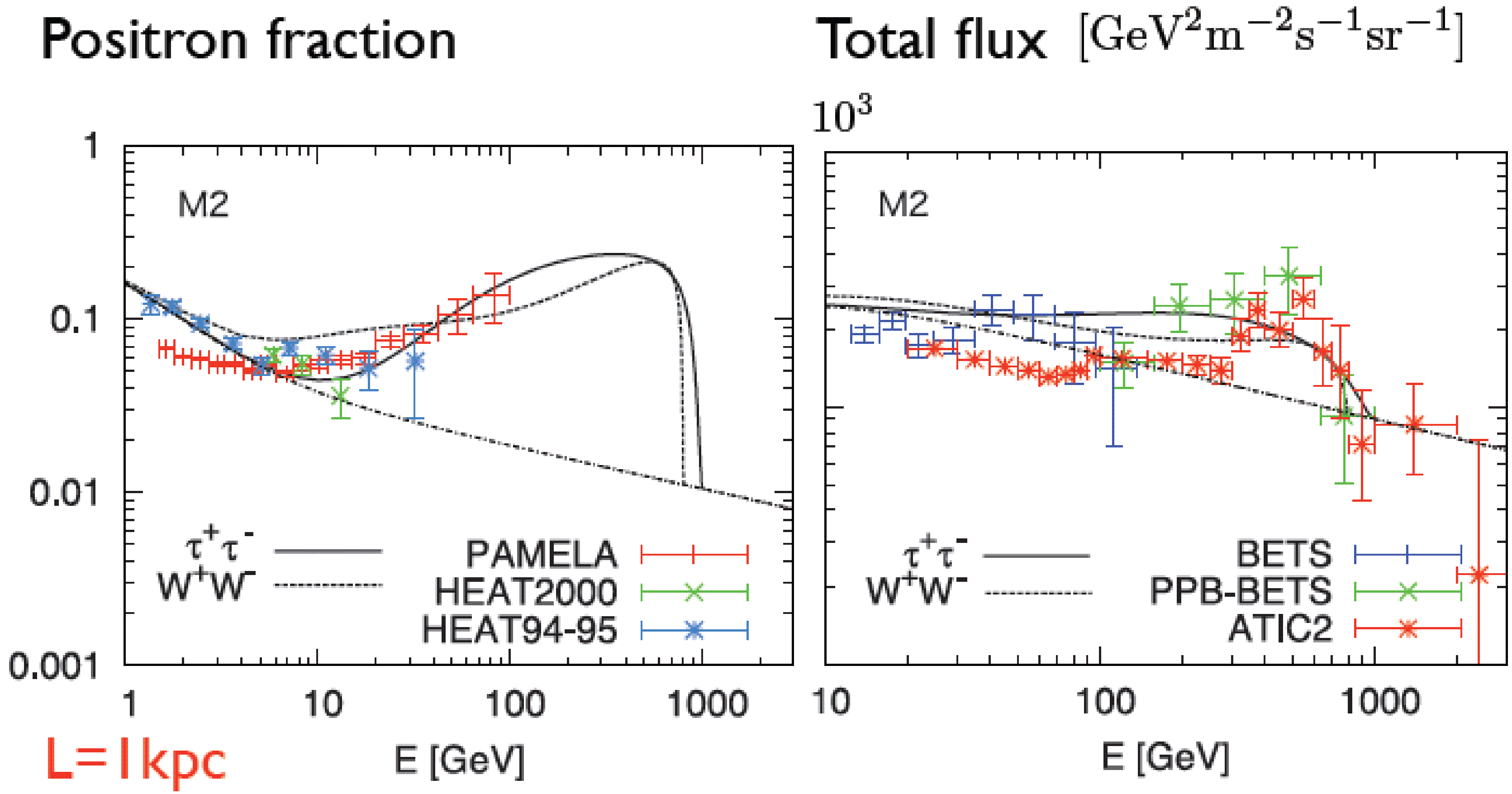




L=4kpc

- $\chi\chi \to e^+e^- \,: m_\chi = 650\mathrm{GeV}, \langle\sigma v\rangle = 5\times 10^{-24}\mathrm{cm^3 s^{-1}}$
- $\chi\chi \to \mu^+\mu^- \,: m_\chi = 900\mathrm{GeV}, \langle\sigma v\rangle = 15\times 10^{-24}\mathrm{cm^3 s^{-1}}$

J.Hisano et al. arXiv:0901.3852 [hep-ph]



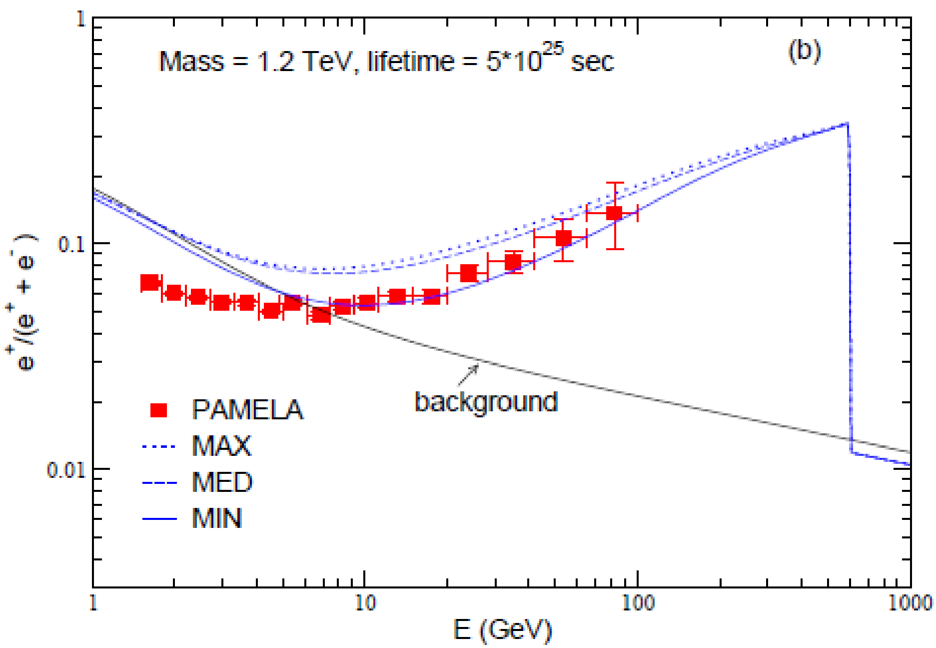
- $\chi\chi \to \tau^+\tau^- : m_\chi = 1\mathrm{TeV}, \langle\sigma v\rangle = 4\times 10^{-23}\mathrm{cm^3 s^{-1}}$
- $\chi\chi \to W^+W^- : m_\chi = 800\mathrm{GeV}, \langle\sigma v\rangle = 3\times 10^{-23}\mathrm{cm^3 s^{-1}}$

J.Hisano et al. arXiv:0901.3852 [hep-ph]

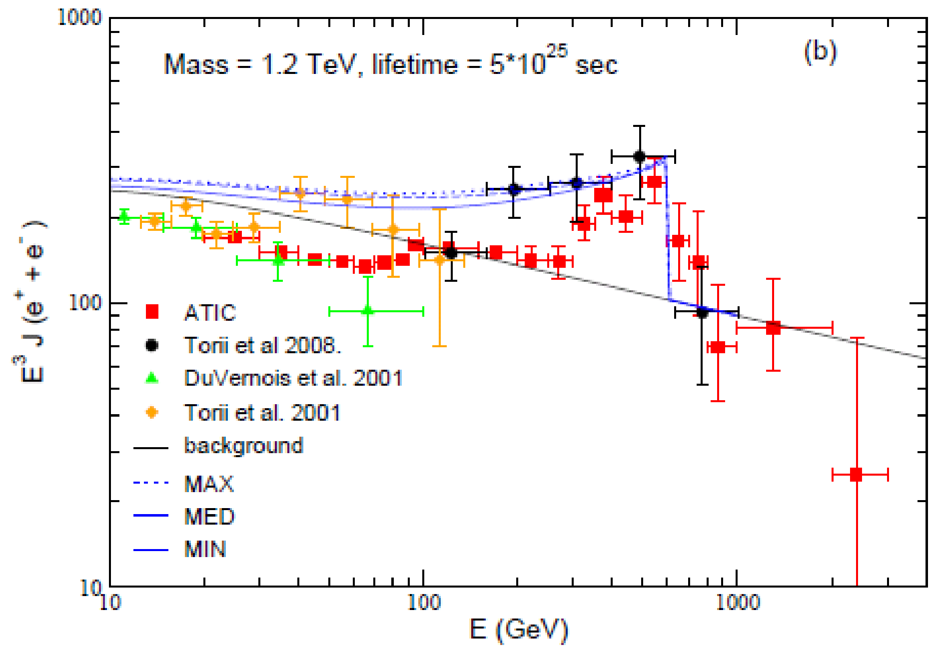
Decaying DM (Hidden Gauge Boson) with Lifetime of $O(10^{26})$ Seconds

Large boost factor is not necessary.

Positron Faction



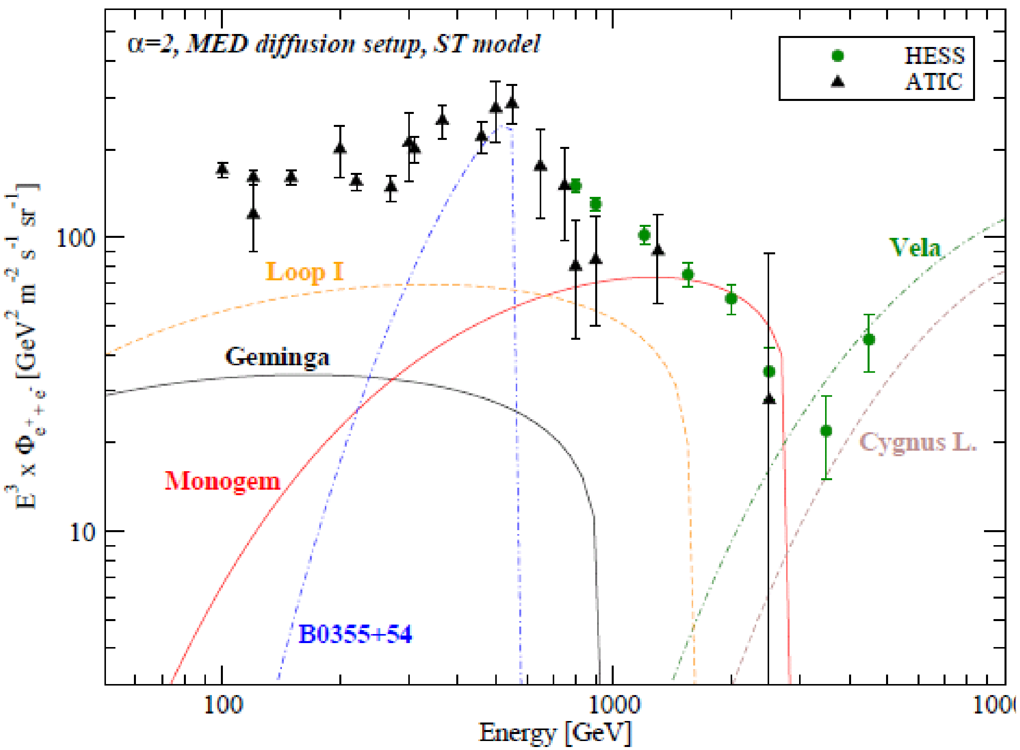
Electron & Positron Spectrum



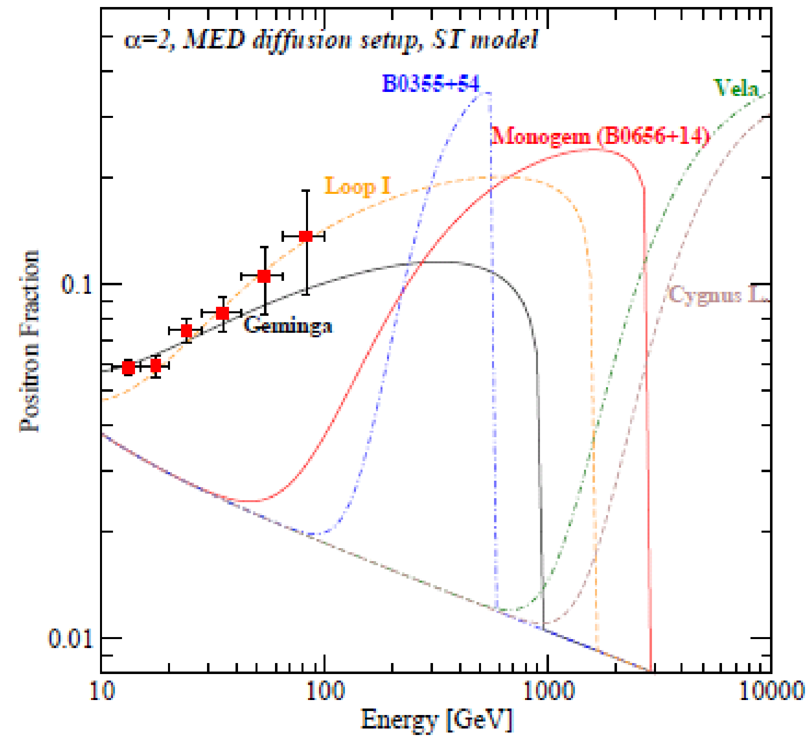
Chen, Nojiri, Takahashi, Yanagida arXiv:0811.3357

Nearby Pulsars

Electron + Positron Spectrum

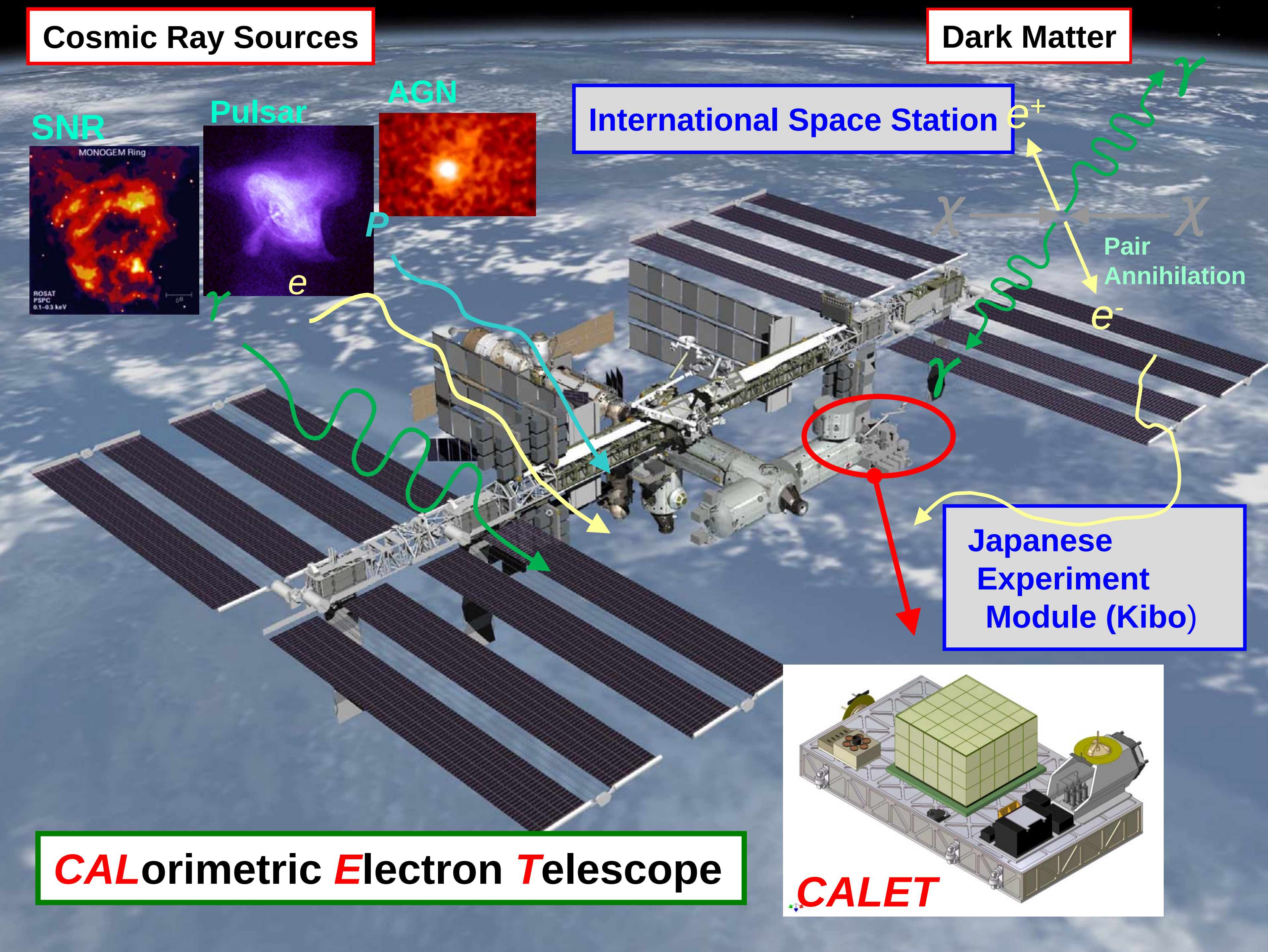


Positron Fraction



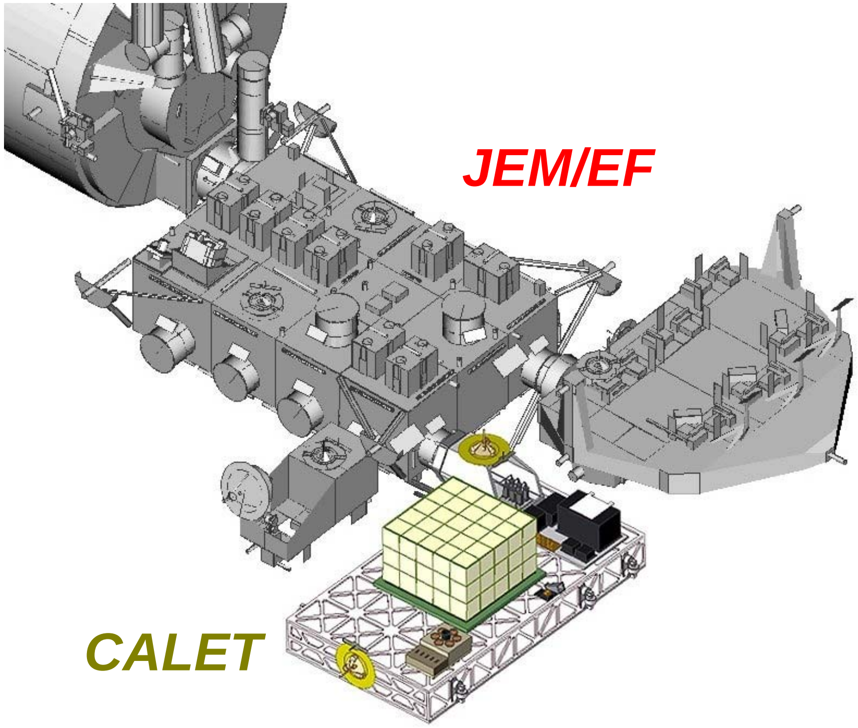
Name	Distance [kpc]	Age [yr]	$\dot{E}$ [ergs/s]	E_{out} [ST]	E_{out} [CCY]	E_{out} [HR]	E_{out} [ZC]	$f_{e\pm}$	g
Geminga [J0633+1746]	0.16	3.42×10^5	3.2×10^{34}	0.360	0.344	0.013	0.053	0.005	0.70
Monogem [B0656+14]	0.29	1.11×10^5	3.8×10^{34}	0.084	0.456	0.004	0.372	0.015	0.14
Vela [B0833-45]	0.29	1.13×10^4	6.9×10^{36}	0.044	0.133	0.133	0.005	0.020	0.70
B0355+54	1.10	5.64×10^5	4.5×10^{34}	1.366	0.677	0.022	0.121	0.2	0.61
Loop I [SNR]	0.17	2×10^5		*0.3*				0.006	
Cygnus Loop [SNR]	0.44	2×10^4		*0.03*				0.01	

arXiv:0812.4457[astro-ph] S.Profumo



Cosmic Ray Sources
Dark Matter
SNR
MONOGEM Ring
ROSAT
PSPC
0.1–0.3 keV
Pulsar
AGN
International Space Station
e+
γ
χ
χ
Pair Annihilation
e-
P
e
γ
γ
Japanese Experiment Module (Kibo)
CALET
CALorimetric Electron Telescope

CALET Overview



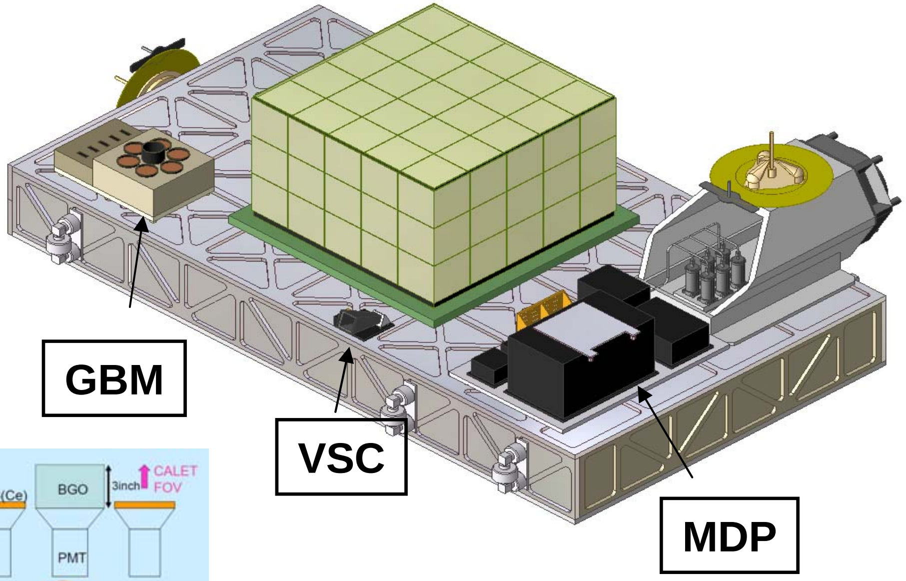
CALET Mission Concept

- **Observation:**
  - Electrons in 1GeV - 20 TeV
  - Gamma-rays in 20 MeV - 10TeV
  - \+ Gamma-ray Bursts in 7 keV - 20MeV
  - P-Fe in several 10GeV - 1000 TeV
- **Launch:**
  HTV: H-IIA Transfer Vehicle
- **Attach Point on the ISS:**
  Exposed Facility of Japanese Experiment Module (JEM-EF)
- **Life Time:**
  3(min.) - 5 years
- **Mission Status**
  Phase A Study
  Launch around 2013 in Plan

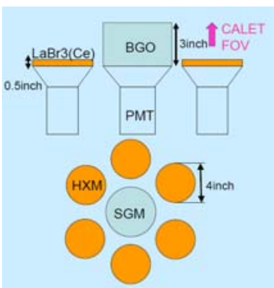
CALET Payload

- High Energy Electron and Gamma- Ray Telescope Consisted of
  - Imaging Calorimeter
  - Total Absorption Calorimeter
- Weight: 1500 kg
- Geometrical Factor: ~0.7 m^2sr
- Power Consumption: 640 W
- Data Rate: 300 kbps

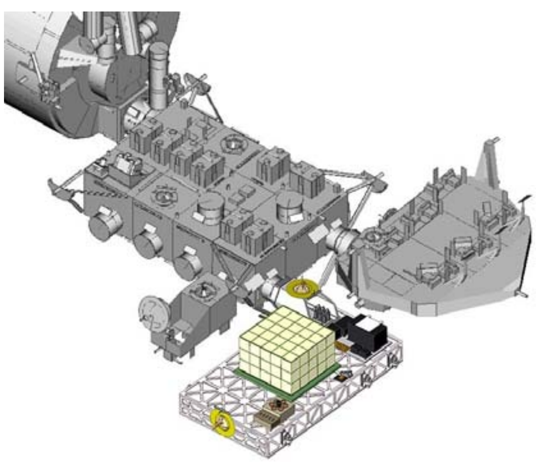
Schematic Structure of the CALET Payload

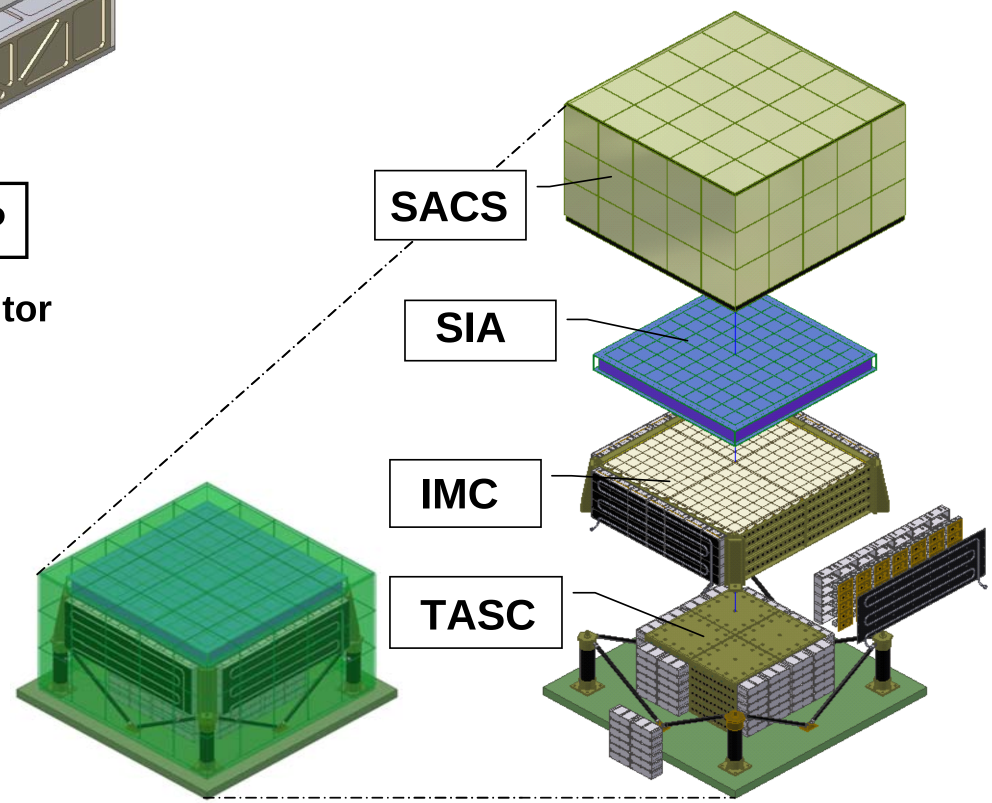


SACS:Scitillator Anti-Coincidence System
SIA: Silicon Pixel Array
IMC: Imaging Calorimeter
TASC: Total Absorption Calorimeter



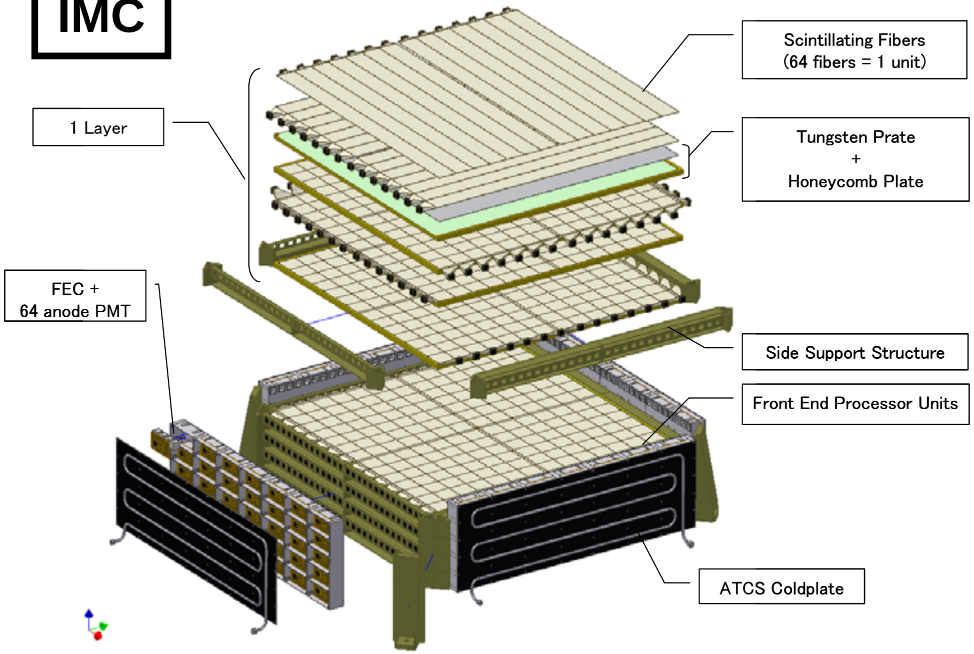
GBM: Gamma-Ray Burst Monitor
VSC: Visual Sky Camera
MDP: Mission Data Processor



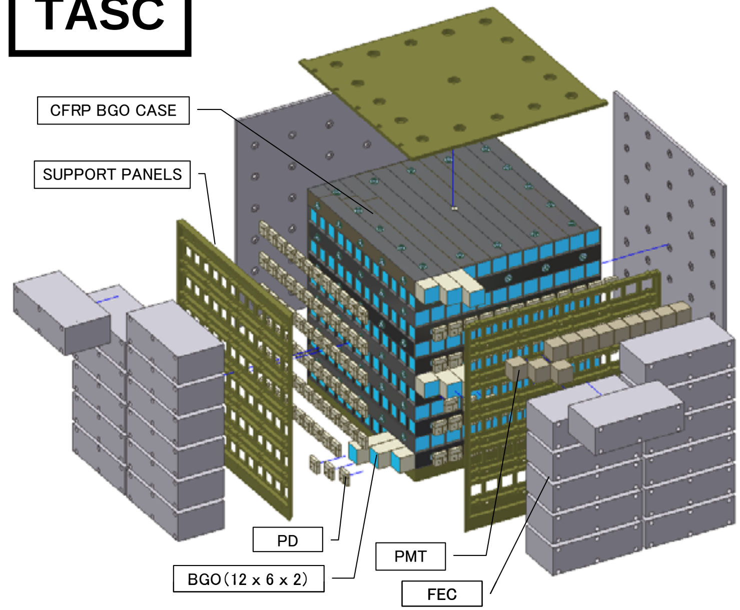


Details of Each Component

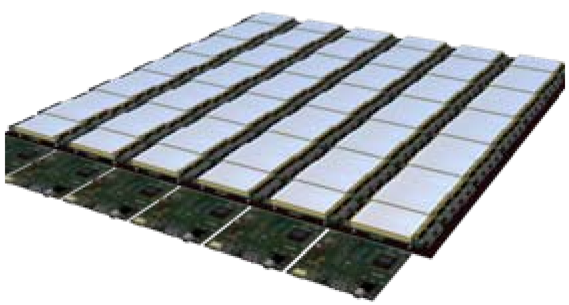
IMC



TASC

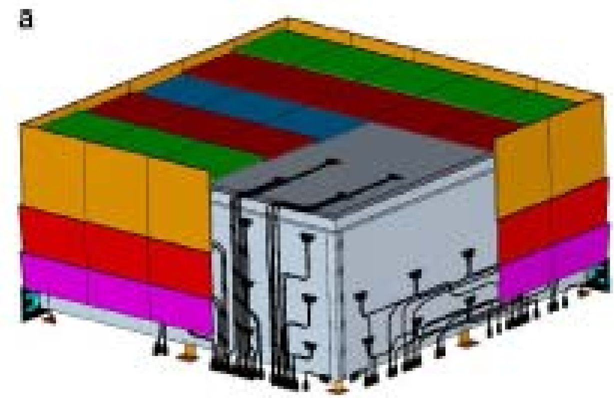


SIA



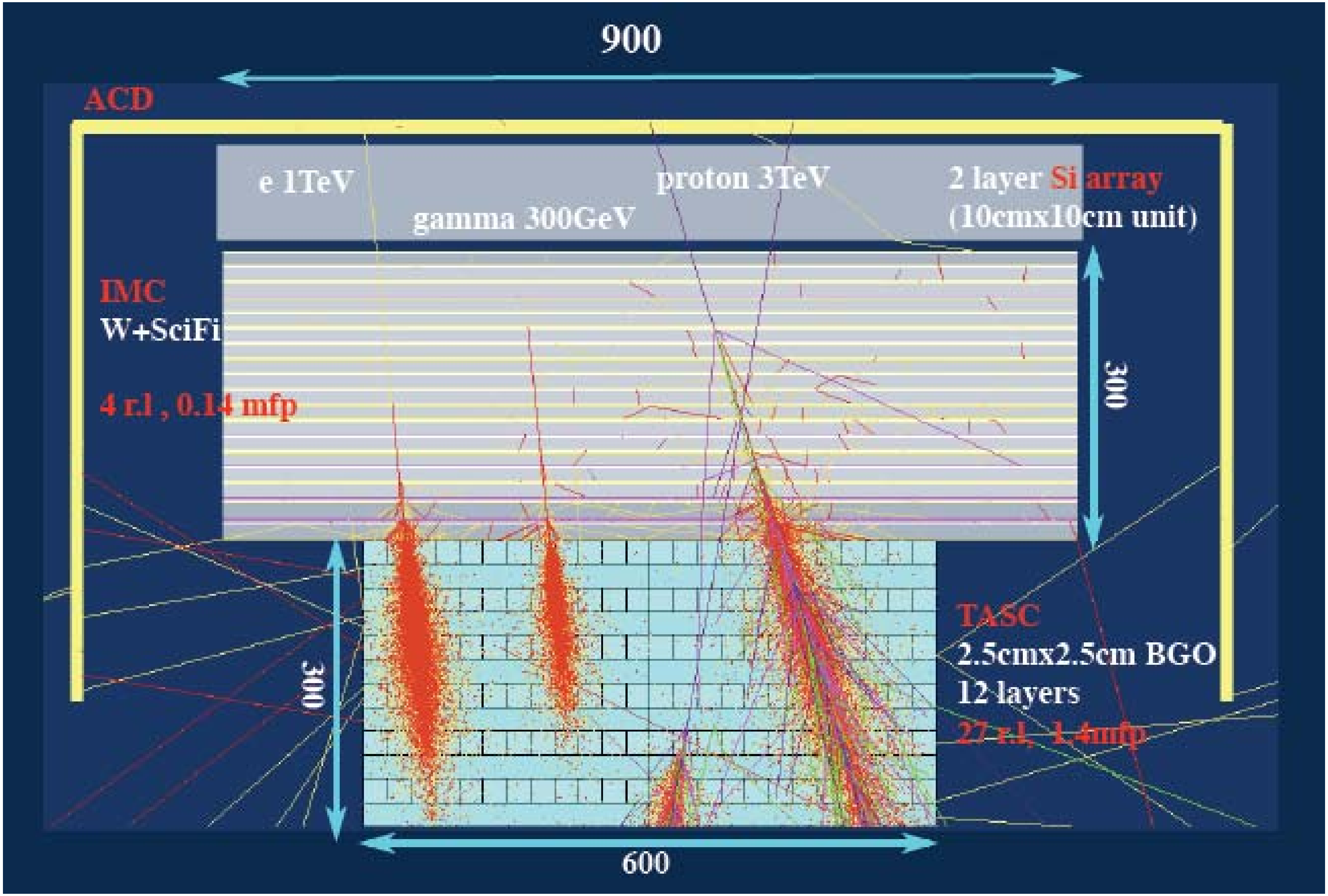
- Silicon Pixel Array x 2 layers (Pixel ~1cmx 1cm)
- Charge resolution: 0.1e for p, 0.35e for Fe

SACS(ACD)



- Segmented Plastic Scintillators for Anti-Coincidence

Examples of Simulation Events



Purposes of Electron Observation

Possible Nearby Sources
- $T < 10^5$ years
- $L < 1$ kpc

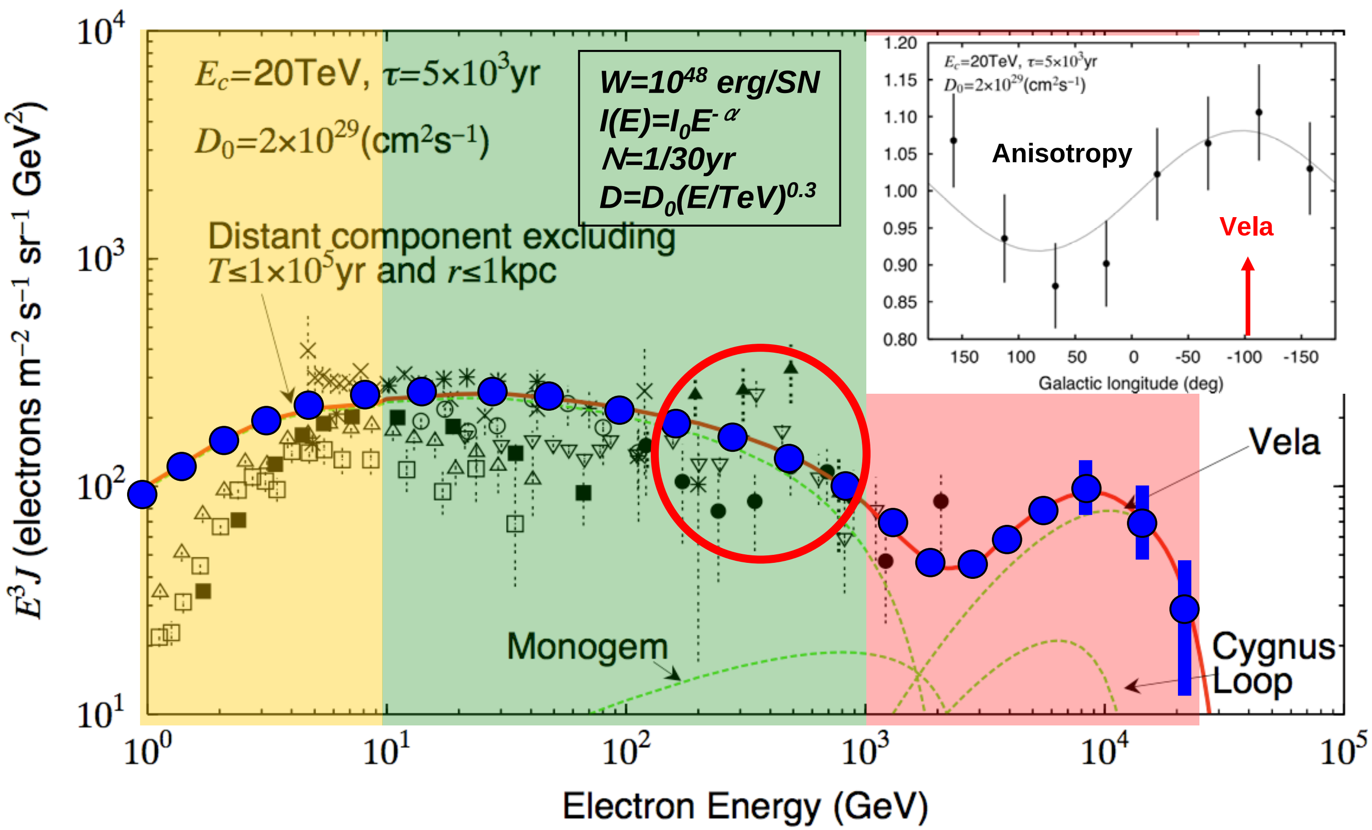
Observation of electron spectrum in 1~10 GeV for study of solar modulation

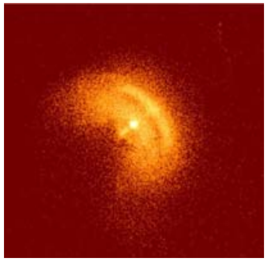
Precise measurement of electron spectrum above 10 GeV to define a model of acceleration and propagation.

Search for the signature of nearby HE electron sources ... by the CALET observation for 3 years

Nearby Pulsars or Dark Matter

(~1000 m²sr day)

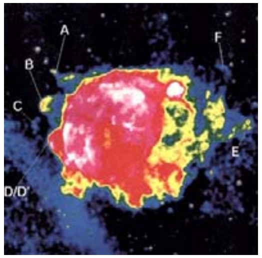


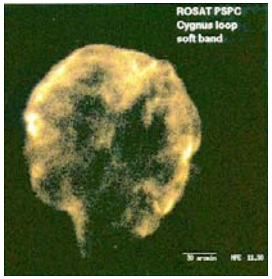


Vela
10,000 years
820 ly

Chandra

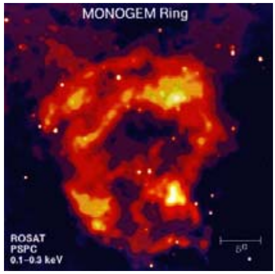
ROSAT





Cygnus Loop
20,000 years
2,500 ly

Monogem
86,000 years
1,000 ly

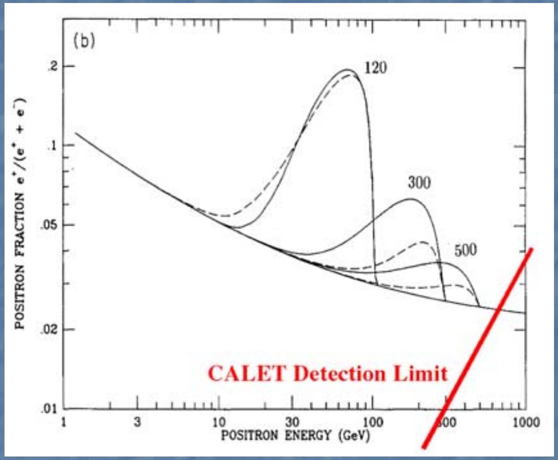


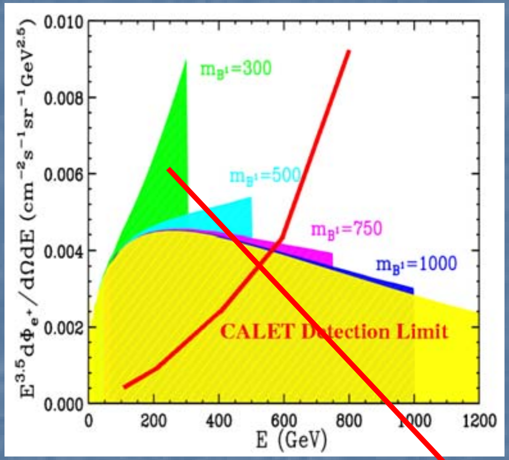
Search for Dark Matter
- electrons+positrons -

Annihilations of WIMP D.M. into mono-energetic e+ e-

SUSY DM

Kamionkowski et al. (1991)

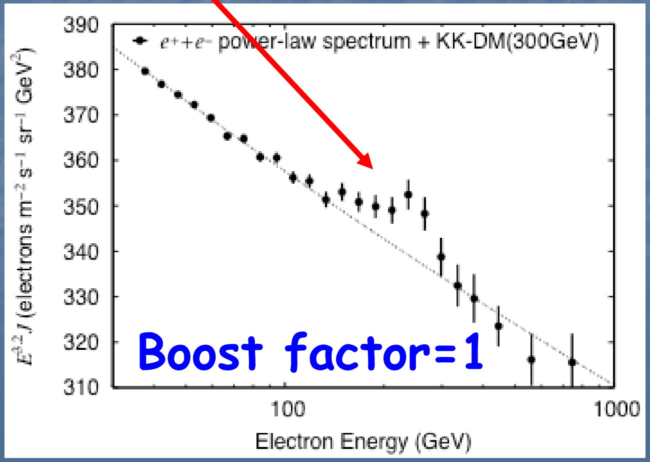




UED (Kaluza-Klein) DM

Cheng et al. (2002)

Simulated electron spectrum with CALET for KK DM of 300GeV mass (3 years observation)



Detection of distinctive electron features from DM annihilations

Gamma-Ray Observation in 20 MeV~several TeV

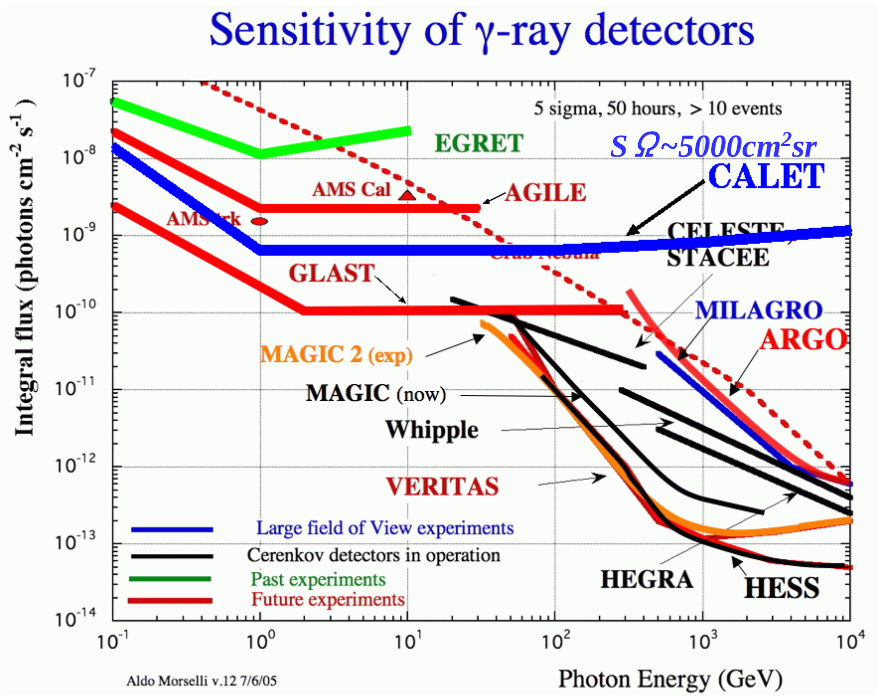
CALET on the ISS orbit without attitude control of the instrument:

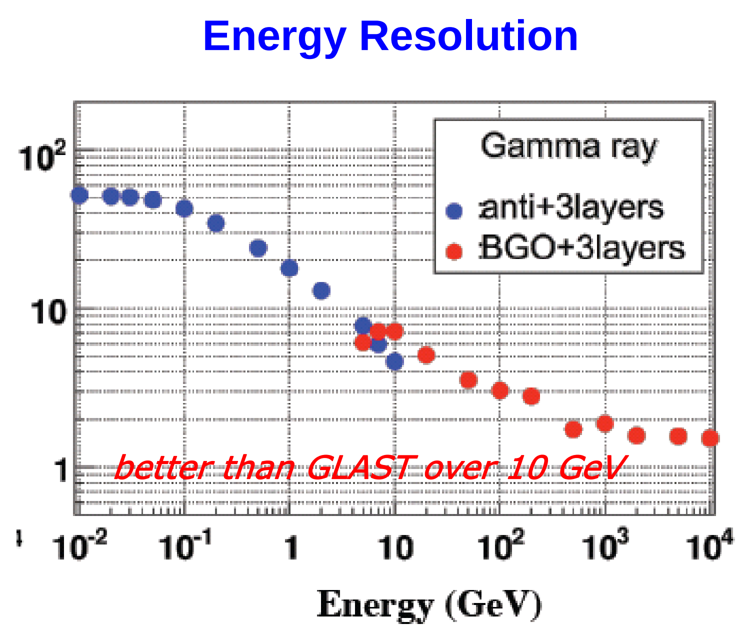
Wide FOV (~45°) and Large Effective Area (~0.5 m^2) in 20 MeV- 10 GeV

⇒
- Sky coverage of 70 % for one day
- All sky coverage in 20 days
- Typical exposure factor of ~50 days in one year for point source

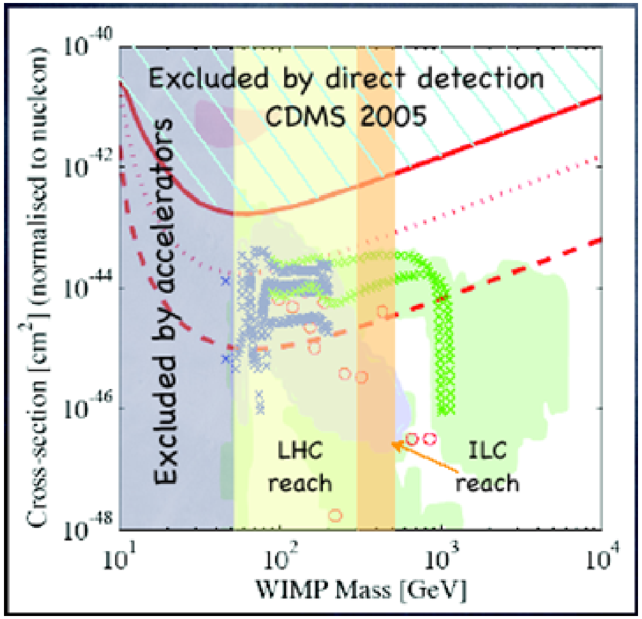
Excellent Energy Resolution (< a few %) over 100 GeV

⇒
- Measurement of change of power-law spectral index
- Possible detection of line gamma-rays from Neutralino annihilation





SUSY Dark Matter Search by Gamma-ray Line



□ WIMP Mass Limit from Direct Observation

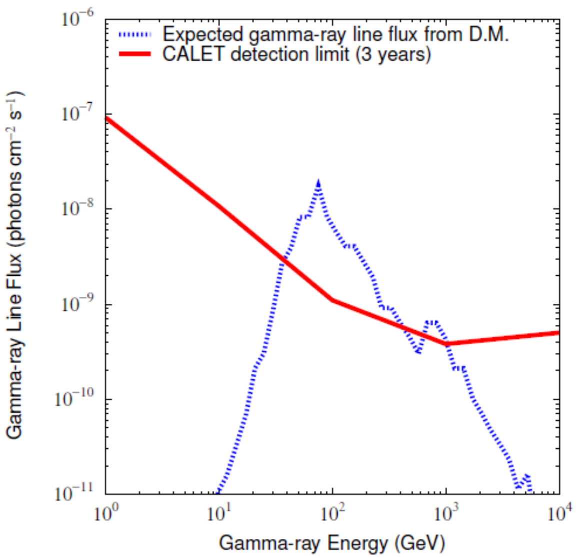
- **WIMP mass is likely heavier than ~100 GeV**
- **Future accelerator experiments will cover the mass range in 100~500 GeV**
- **Indirect observation is very promising to see gamma-ray line according to WIMP mass.**

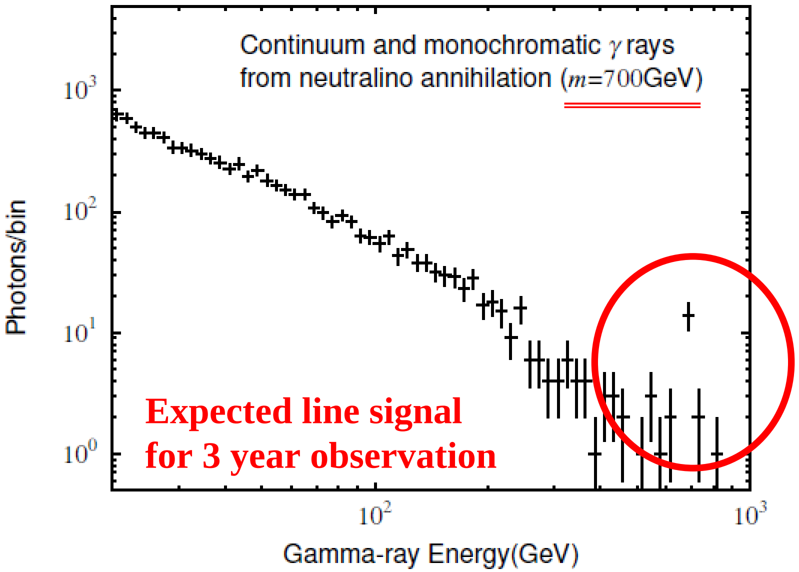
□ CALET Observation of SUSY Dark Matter

- **Neutralino annihilating to $\gamma\gamma$**
- **Maximal annihilation rate of σv in L.Bergstorm et al. PRD (2001)**

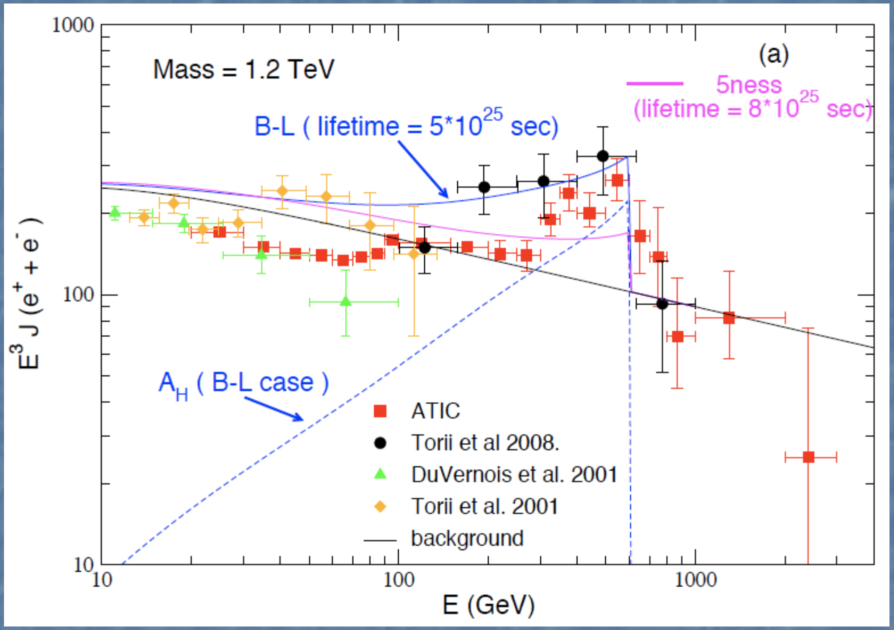
$$\Phi_\gamma = \frac{N_\gamma \sigma v}{m_\chi^2} \frac{1}{4\pi} \int \int_{line\ of\ sight} \rho^2(\ell) d\ell d\Omega$$

Gamma-ray line sensitivity toward the Galactic center (300○<*l*<60○, |*b*|<10○), compared to the gamma-ray line flux from Nutralino annihilation.

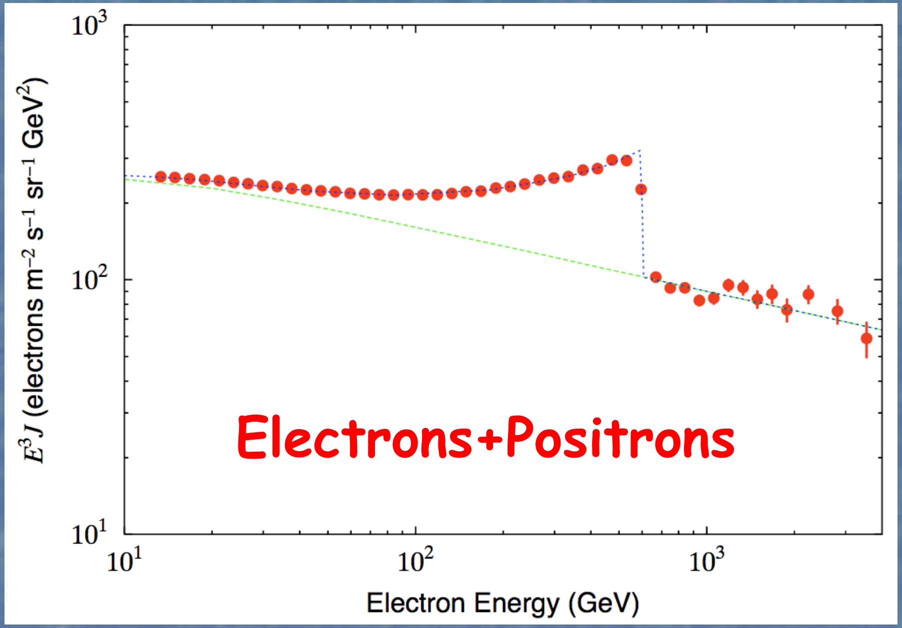




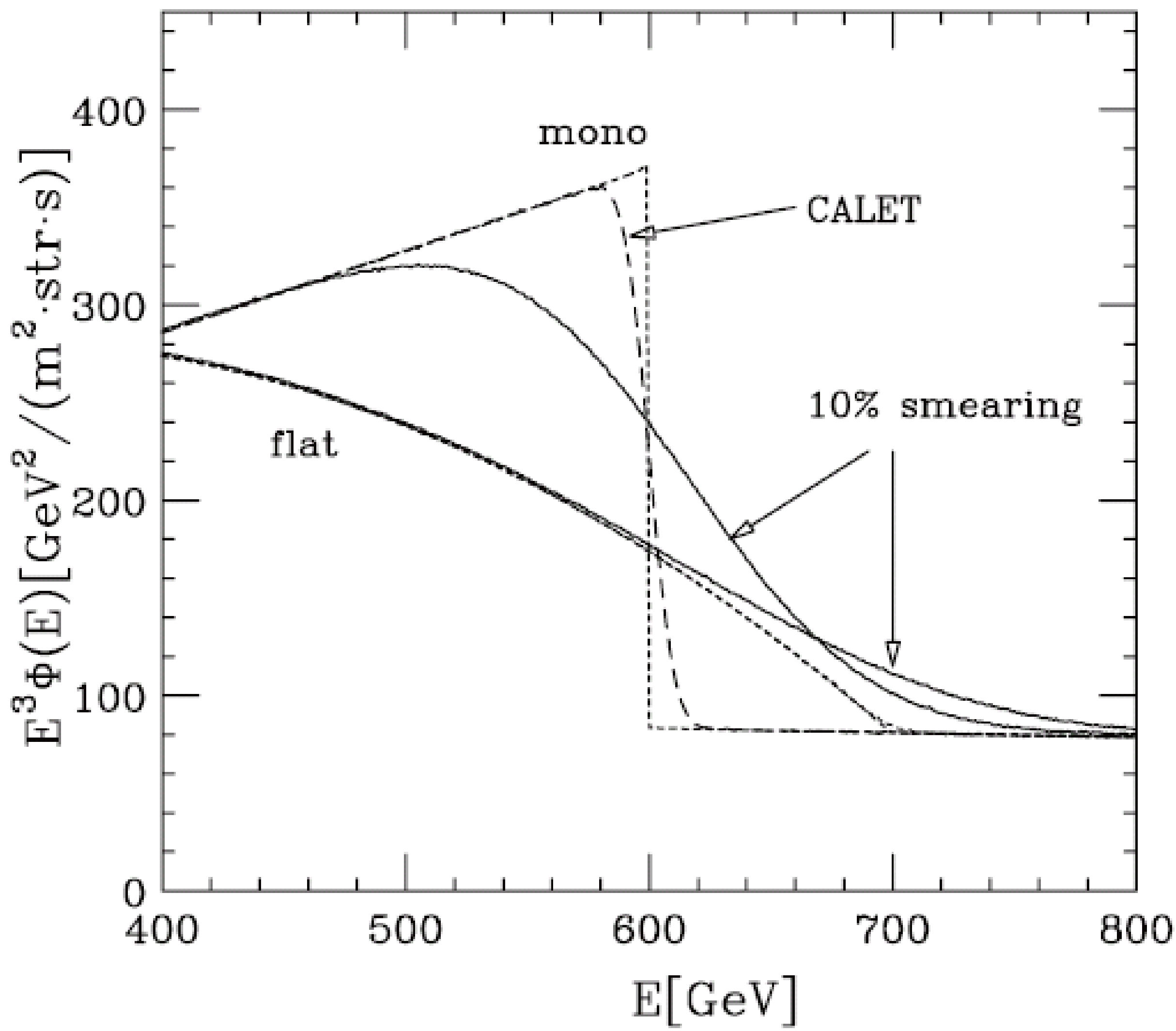
Decaying Hidden Gauge Boson



Chen, Nojiri, Takahashi & Yanagida (2008)

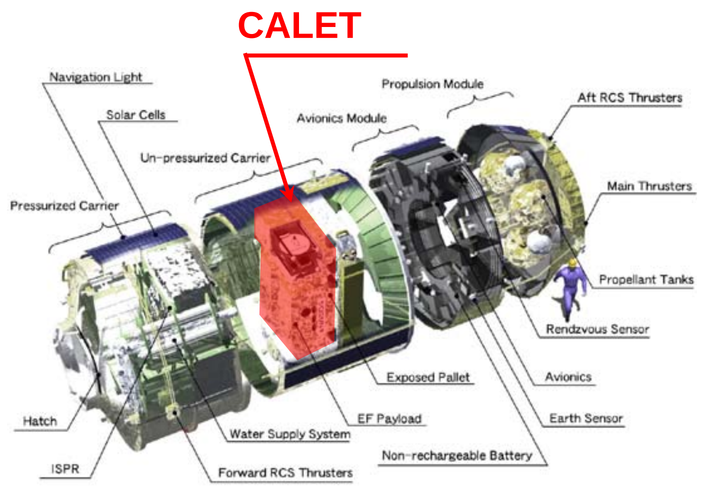


CALET 3yr observations: Simulated spectra



arXiv: 0812.4200[astro-ph] C.R.Chen, K.Hamaguchi, M.M.Nojiri, F.Takahashi, S.Toriii

Launching Procedure of CALET

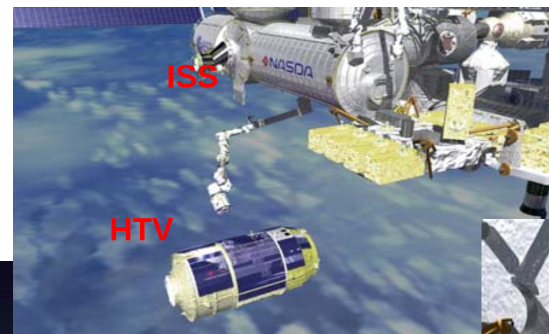


H-IIA Transfer Vehicle (HTV)

CALET launched by HTV

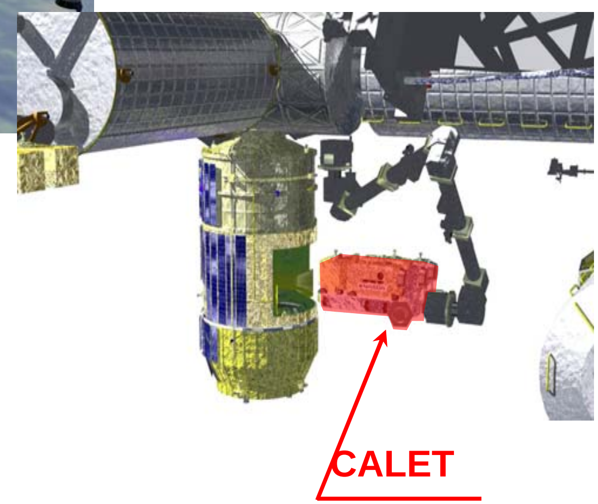
Launching of H-II Rocket

Separation from H-II

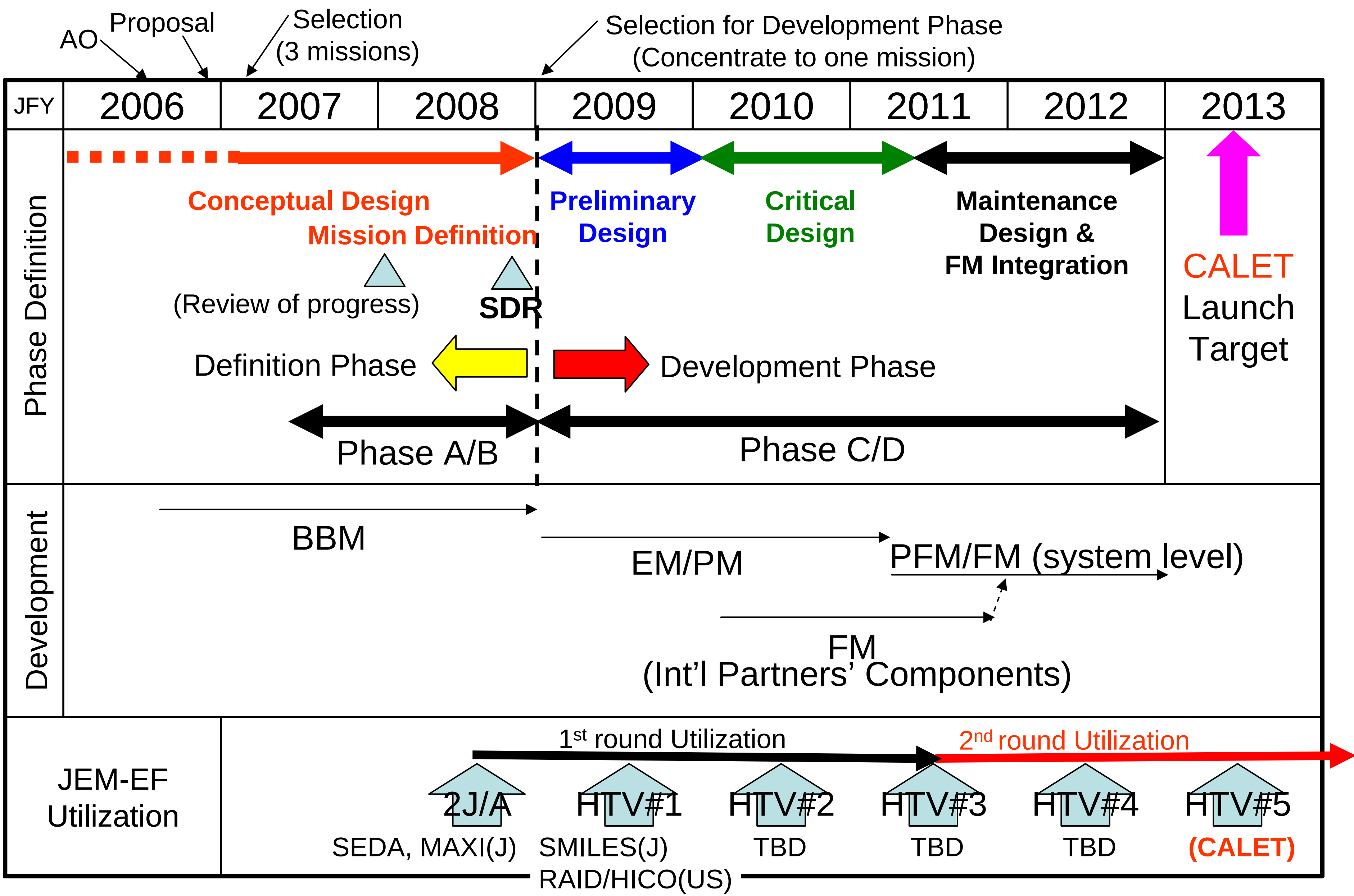


Approach to ISS

Pickup of CALET



CALET Timeline



Summary

- Cosmic-ray electron energy spectrum
  - ~100GeV region: consistent with each other in recent experiments by power-law spectrum of -3.1~3.3
  - 100GeV~1TeV region: excess observed consistently with ATIC and PPB-BETS
  - the PAMELA and ATIC/PPB-BETS excesses arise from the same origin , most likely LKP

- In the near future
  - Investigation of cosmic-ray electron sources from the observed electron energy spectrum with Long Duration Balloon (LDB) flight
  - Final conclusion of Dark Matter and Nearby Sources shall be obtained by the CALET observation
  - New results from PAMELA , FERMI, AMS ……

The CALET project is being carried out in collaboration with JAXA.