Status & Prospect of Gamma-ray Astronomy

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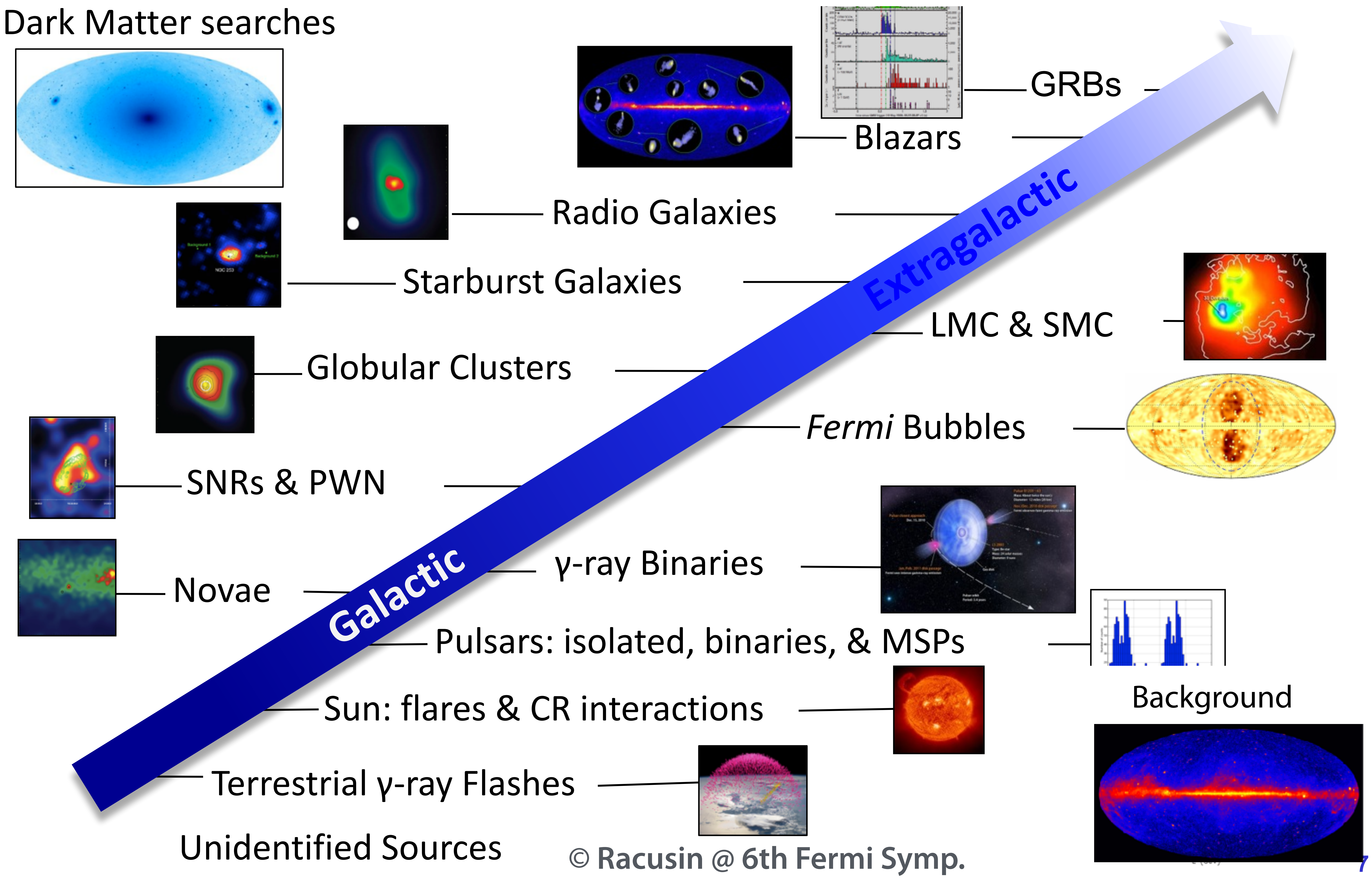
Special thanks to Takahiro Sudoh (Tokyo) & Dmitry Khangulyan (Rikkyo)

CRC Town Meeting @ Online, 2020-09-28

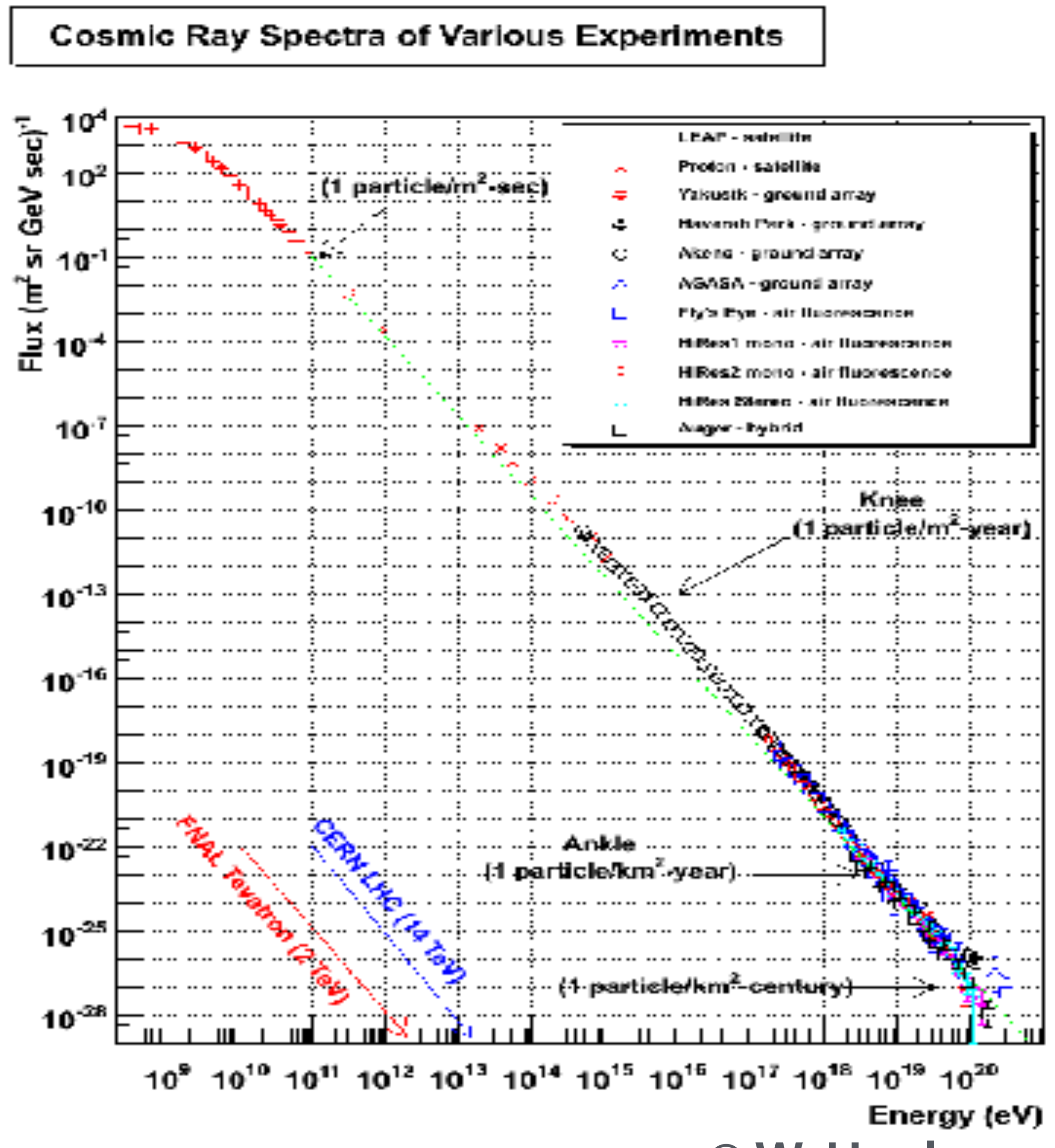
Contents

- Gamma-ray Astronomy
- Recent Interesting Results
  - Jet Power, Cosmic Star Formation History, Spatial Extension
- Future of Gamma-ray Astronomy?
- Summary

Gamma-ray ***Astronomy***



Origin of Cosmic Rays



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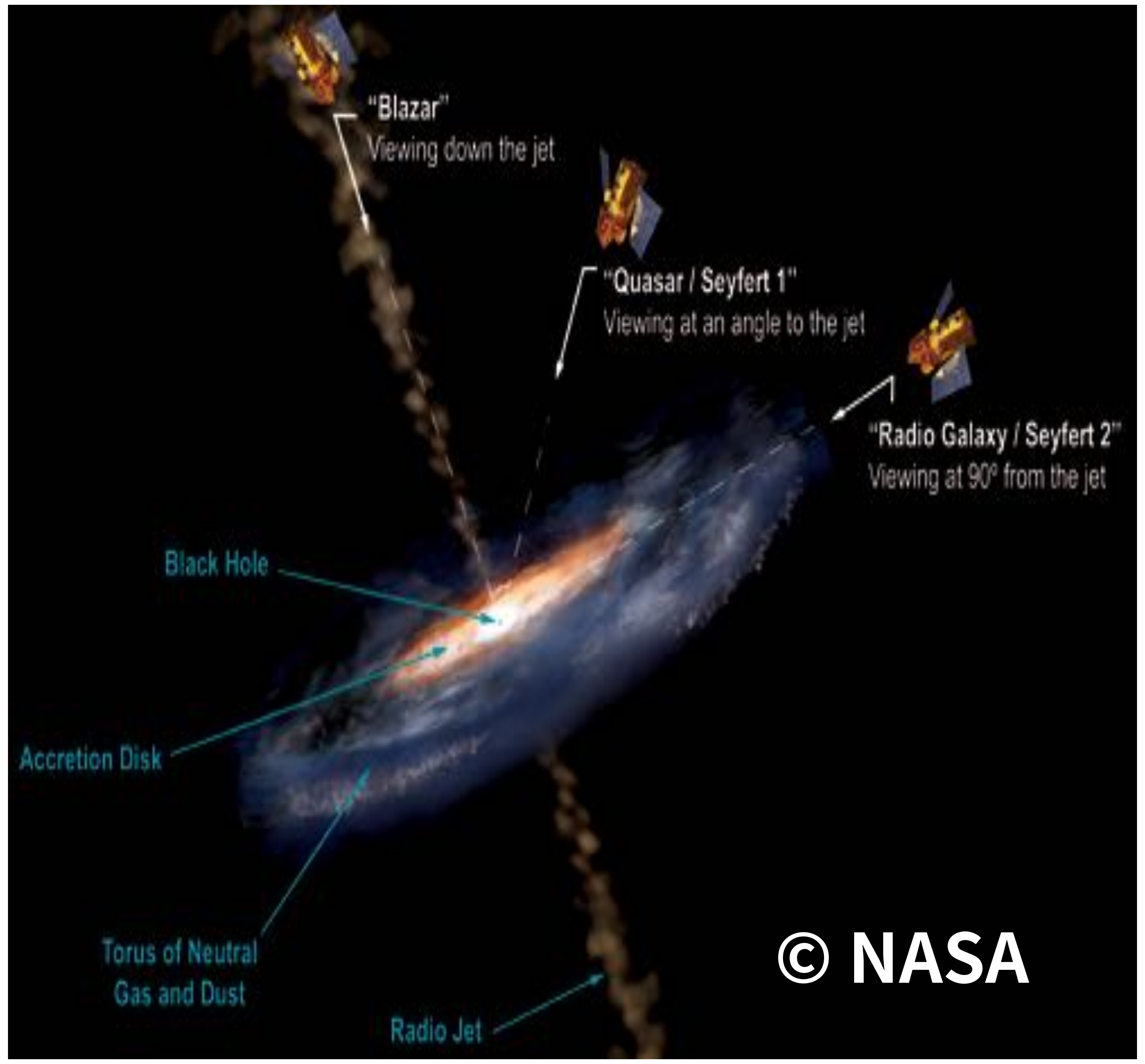
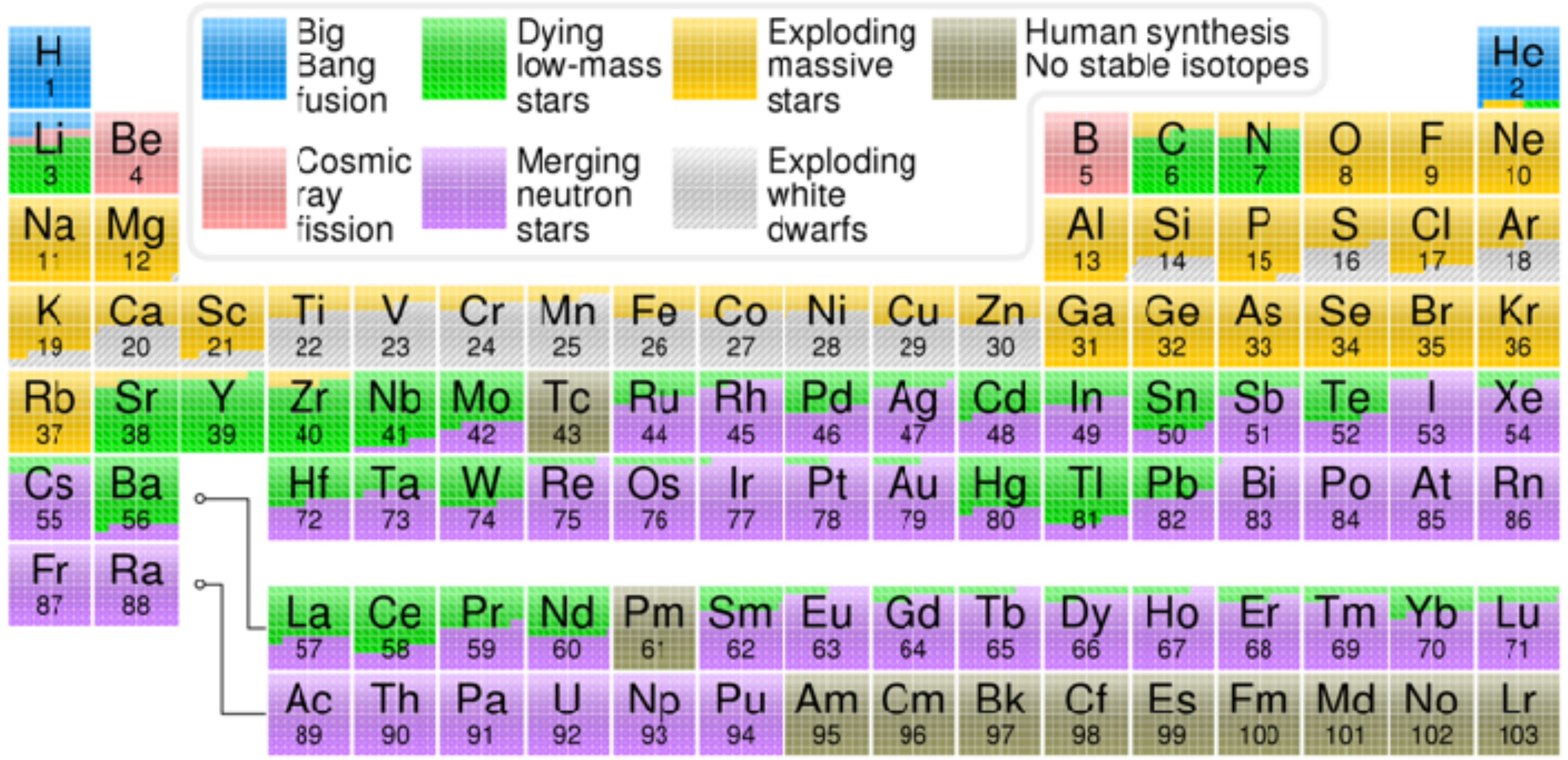
Relativistic Jets

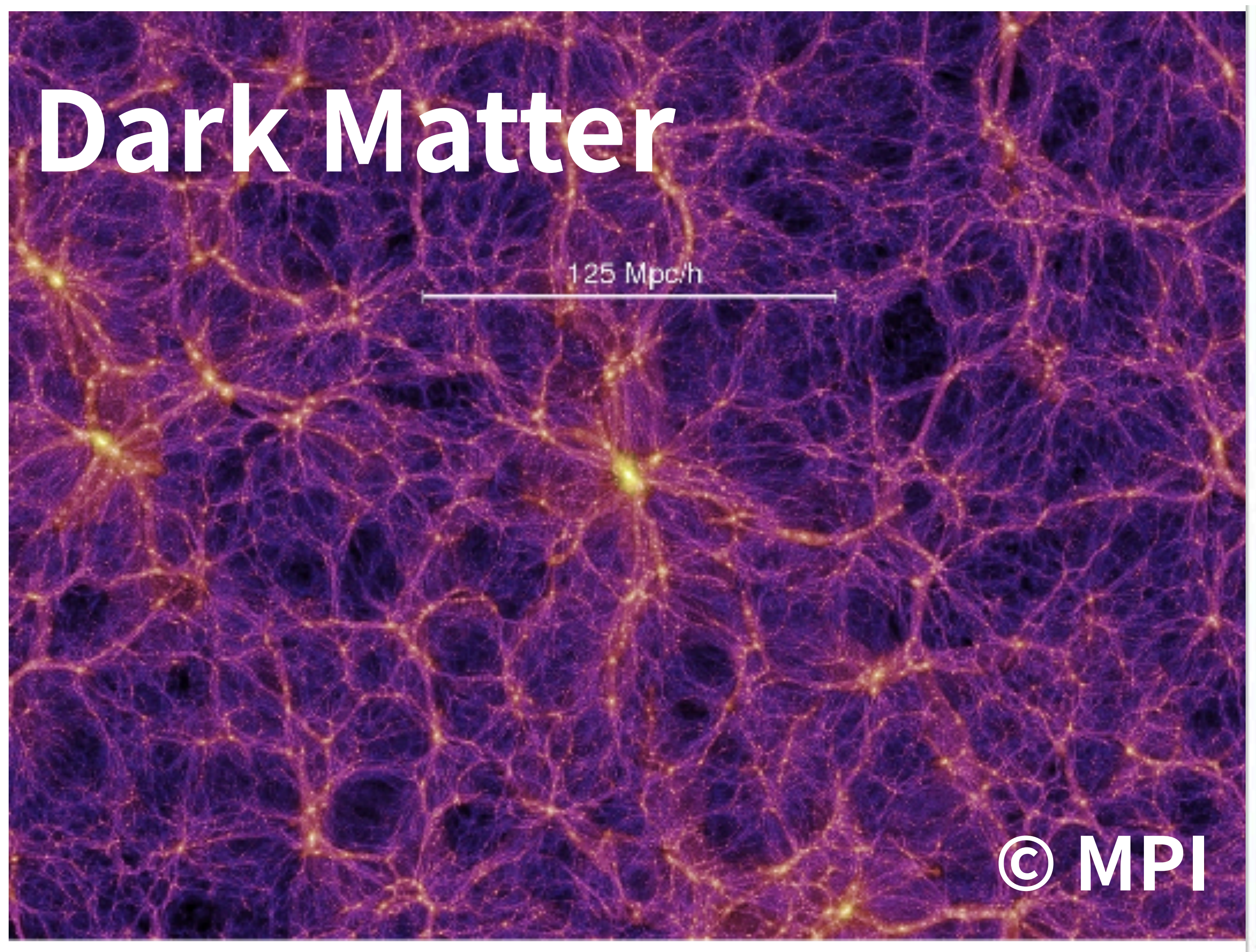


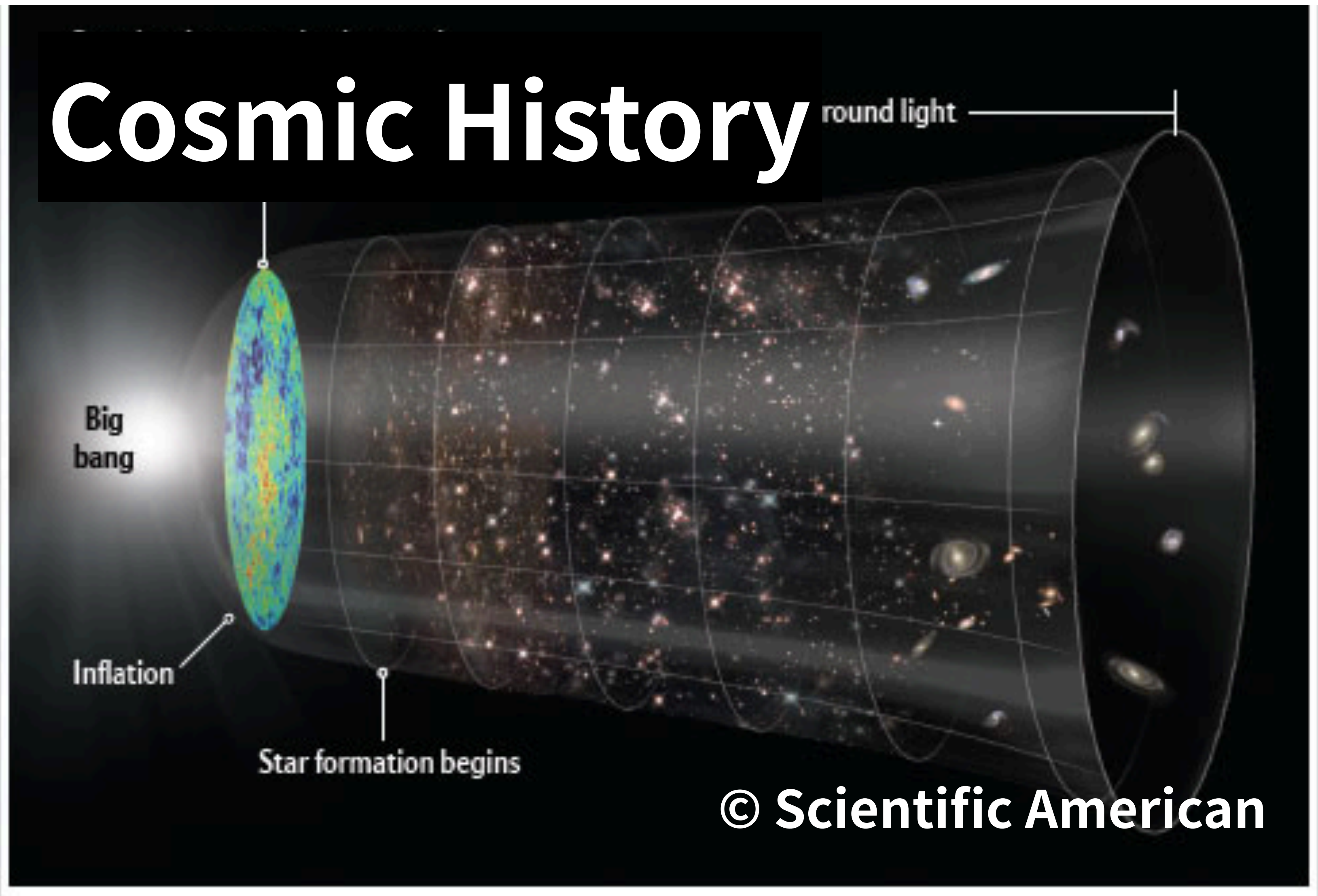
Why Gamma-ray Astronomy?

Gamma-ray : $\gtrsim 0.1\mathrm{MeV}$

Origin of Matter

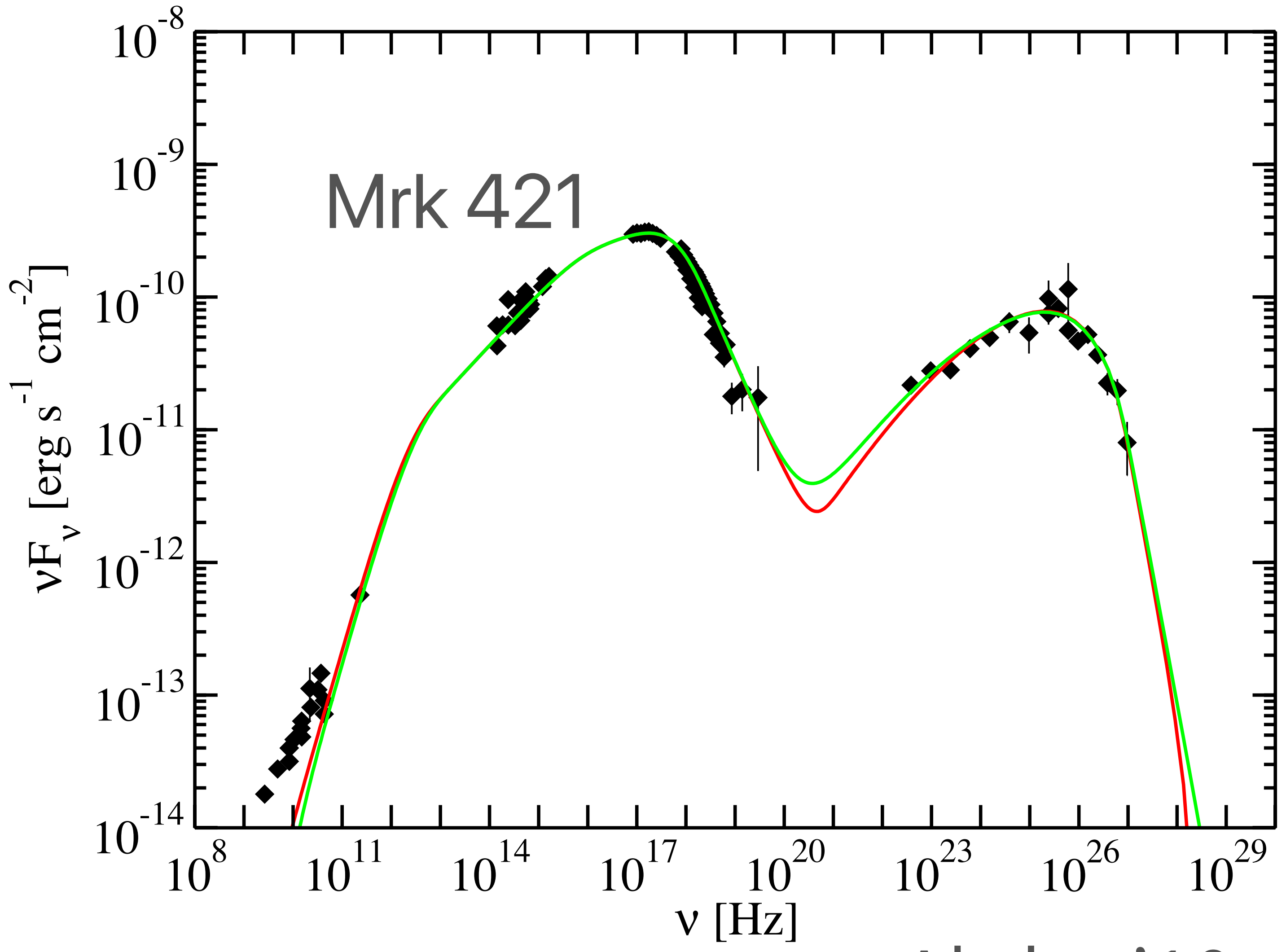




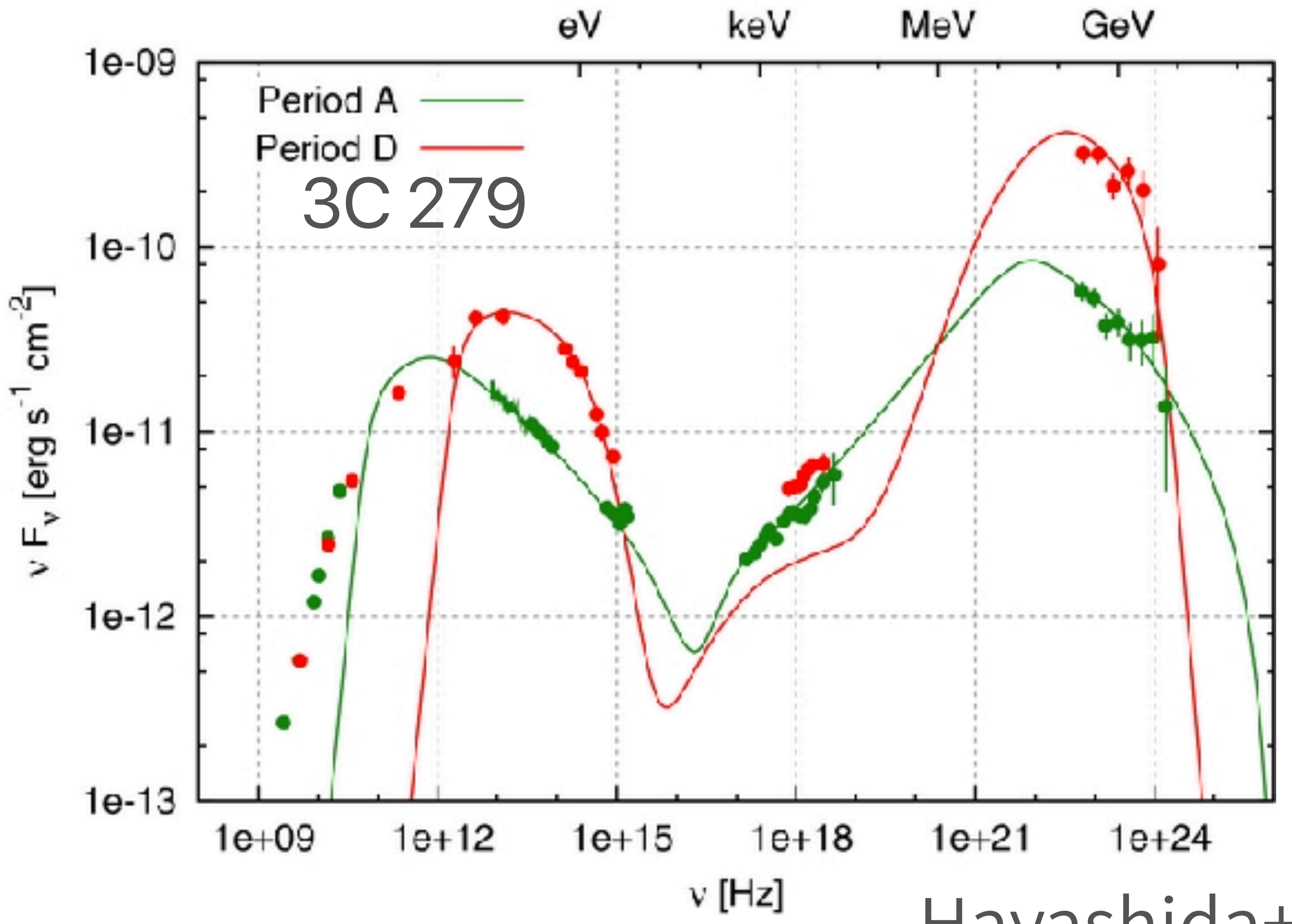


Jet Power > Accretion Power?

Blazars

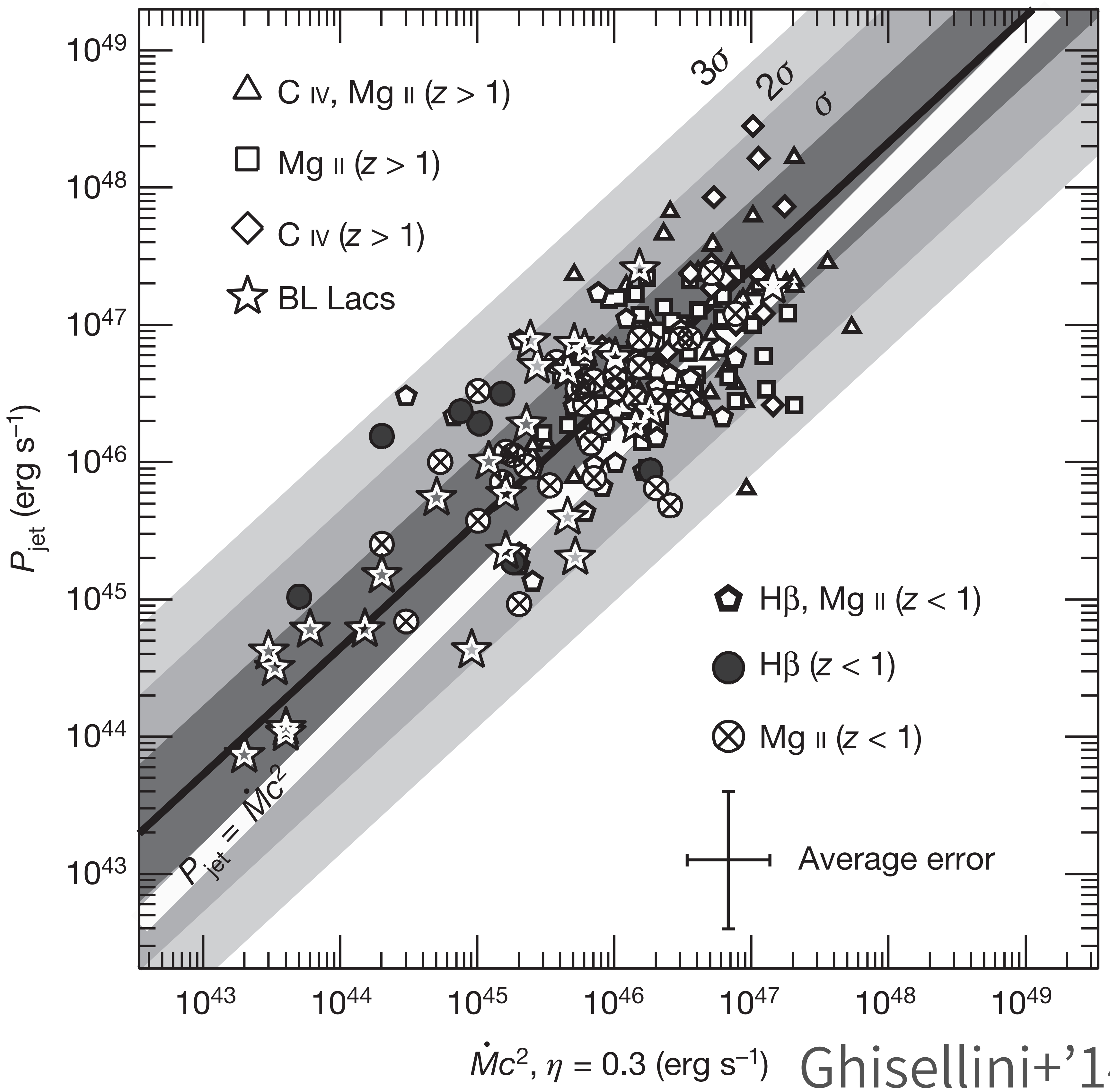


Abdo+’10



Hayashida+’12

Jet Power



Ghisellini+’14

Accretion Rate

- Spectral fitting can tell the particle energy distribution.

  ➡ Jet power estimation

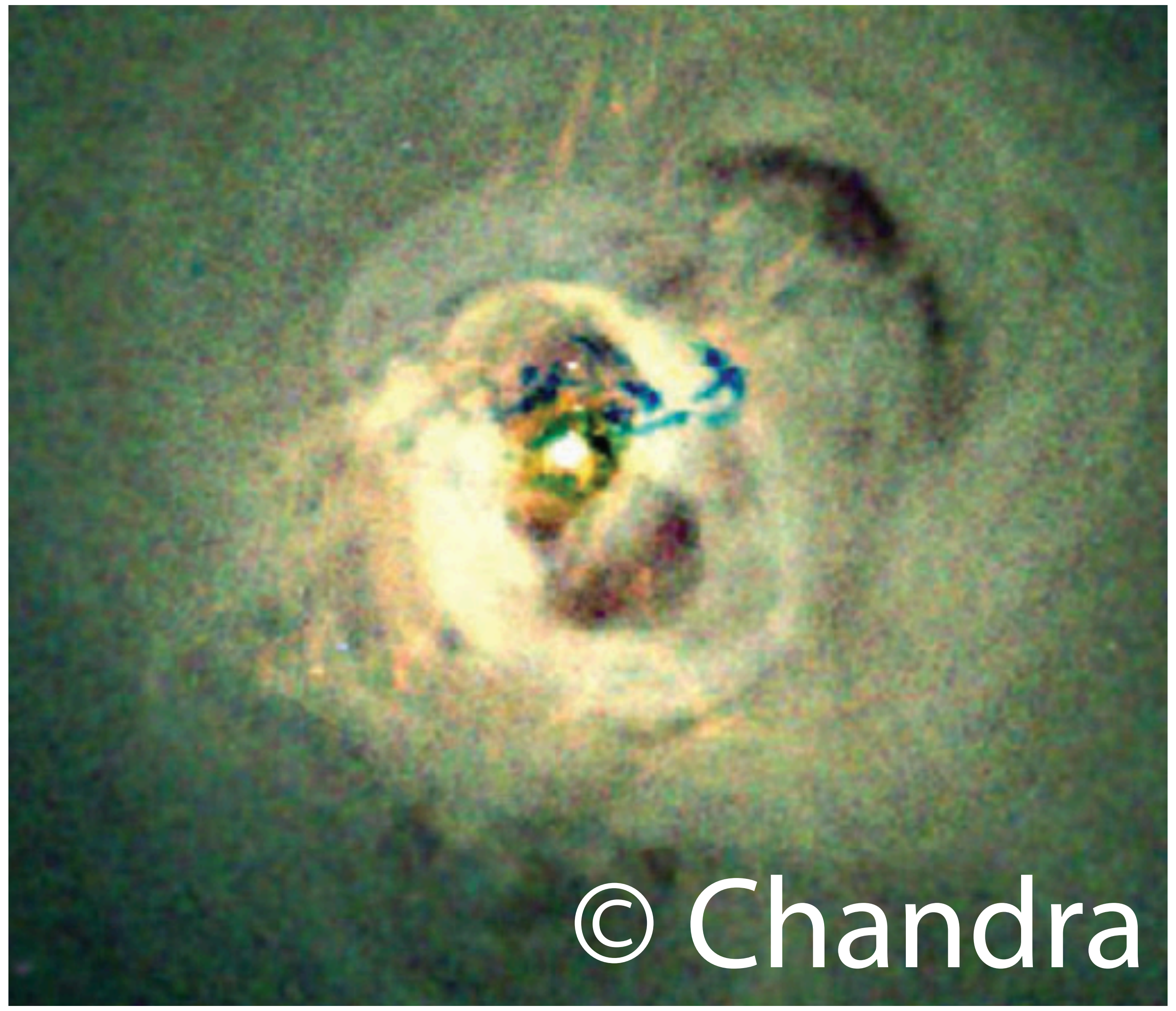
- Accretion rate from emission lines

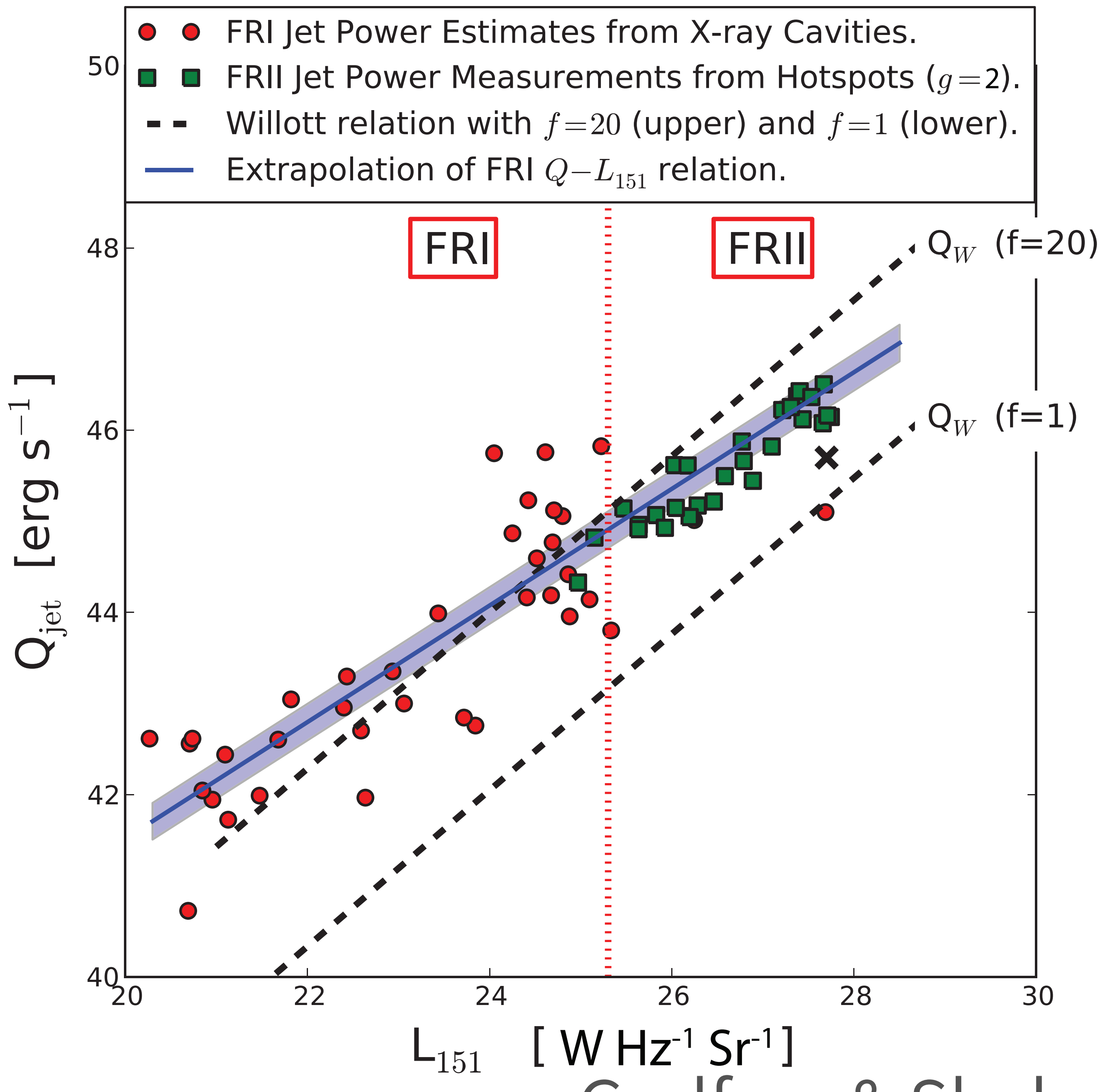
- Correlation between jet power and accretion rate (Ghisellini+’14; YI & Tanaka ’16)

- $P_{\rm jet} \gtrsim \dot{M}_{\rm in} c^2$

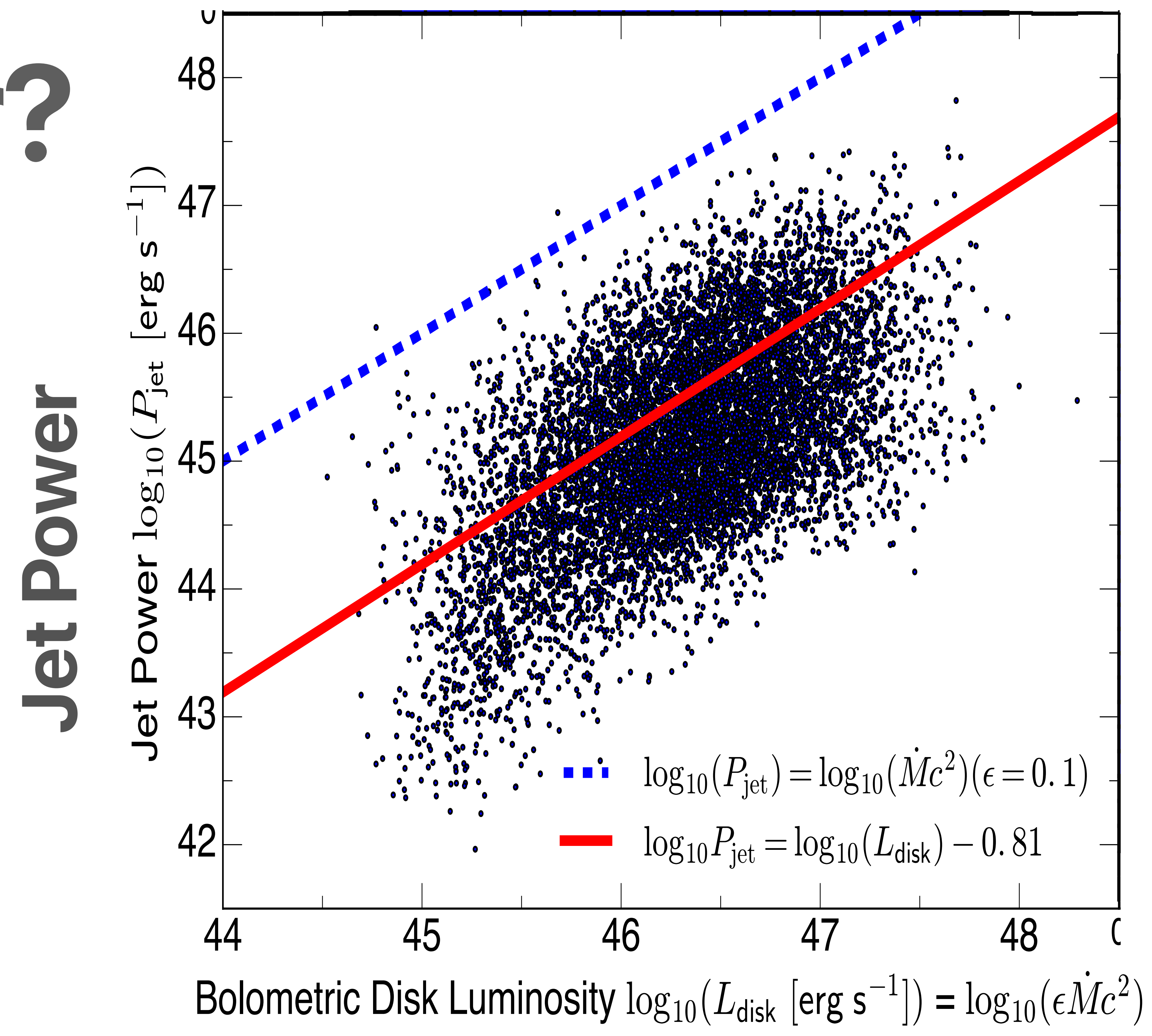
Jet Power < Accretion Power?

Radio Galaxies





Godfrey & Shabala '13



Accretion Rate YI+'17

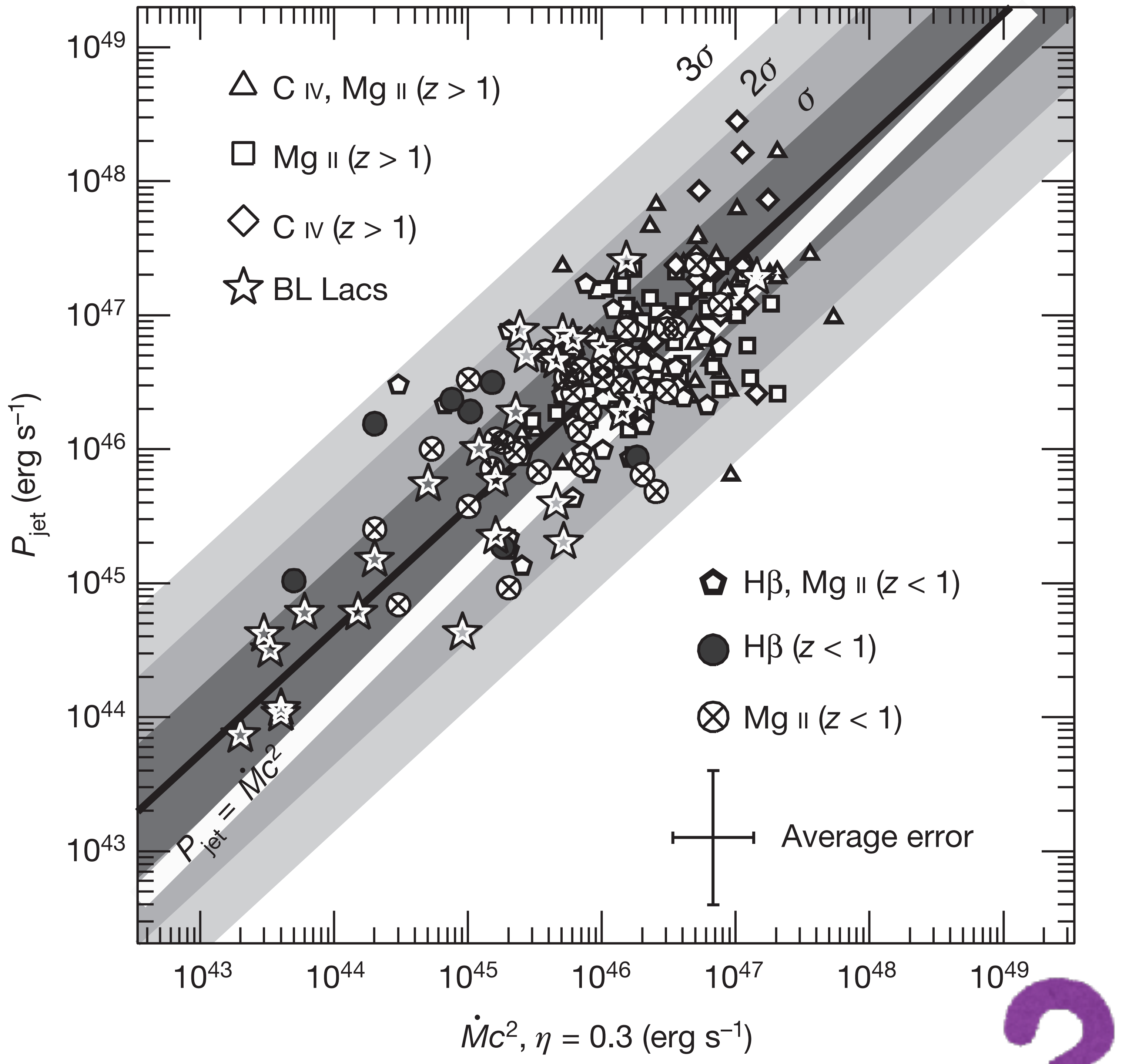
- Jet power can be estimated from X-ray cavity and hot spot (Godfrey & Shabala '13)
  - A well-known empirical relation between radio and jet power (Willott+'99)

- With ~8000 radio galaxies (off-axis blazars),

$$P_{\rm jet} \sim 10^{-2} \dot{M}_{\rm in} c^2$$ (YI+'17)

Current Situation of AGN Jet Power

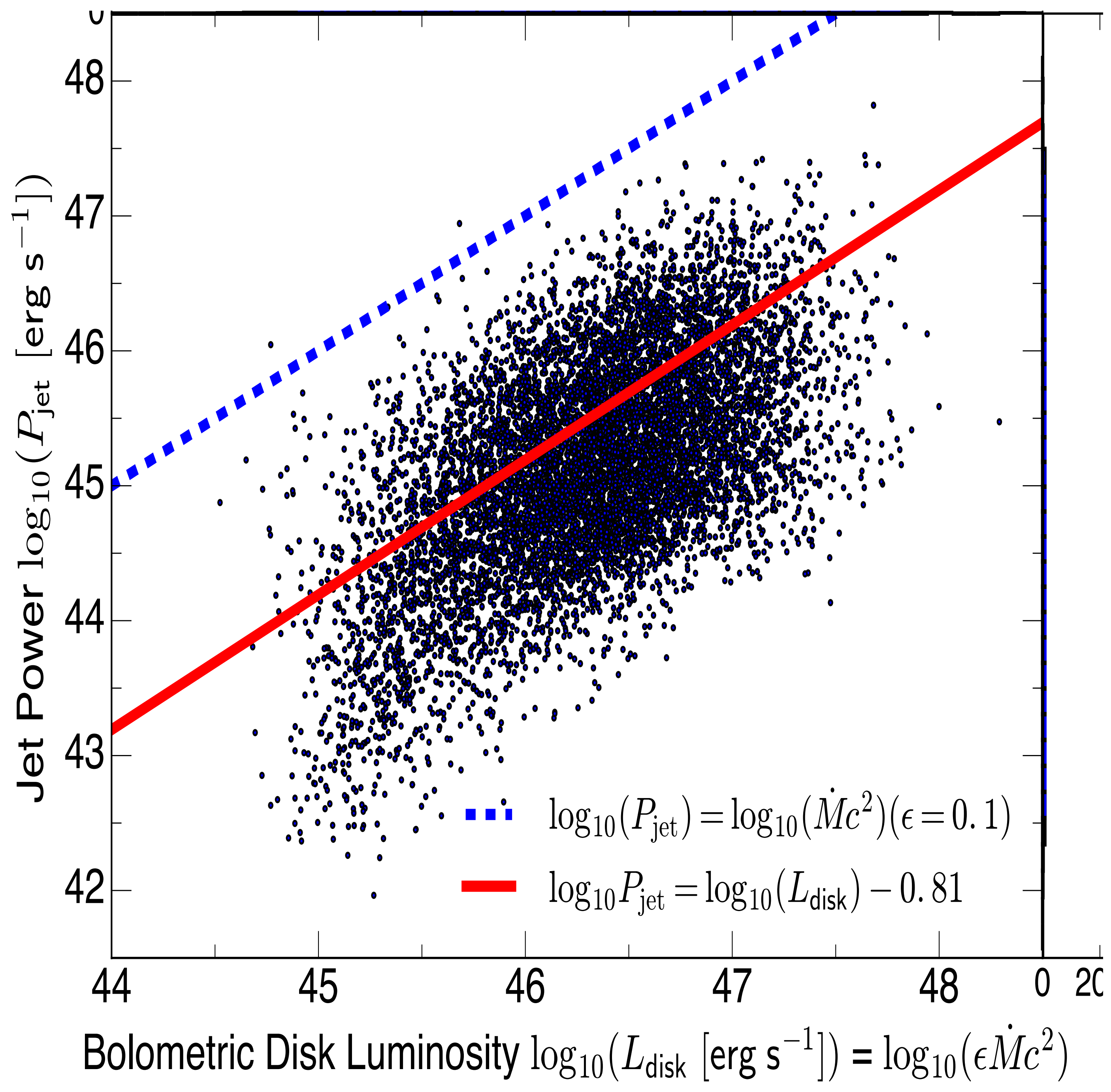
Blazar SED Fitting



Ghisellini+'14

$$P_{\rm jet} \gtrsim \dot{M}_{\rm in} c^2$$

Large-scale Jet



YI+'17

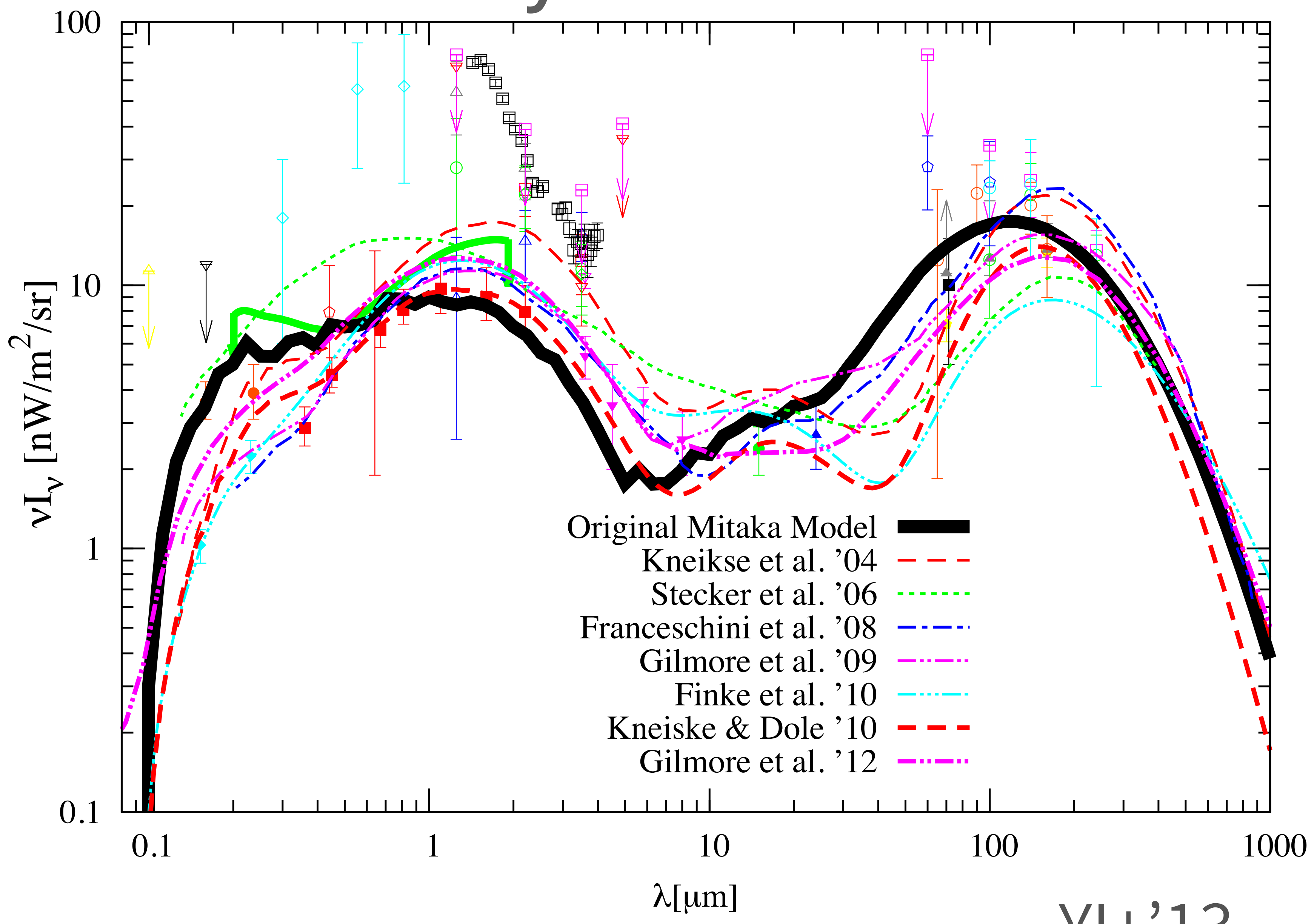
$$P_{\rm jet} \sim 10^{-2}\dot{M}_{\rm in} c^2$$

- Blazar Method
  - Minimum electron Lorentz factor $\gamma_{\rm min}$ ~1
  - Composition
- Large-scale Jet Method
  - Different Timescale
- We need to understand this discrepancy.
  - e.g., important for neutrinos.

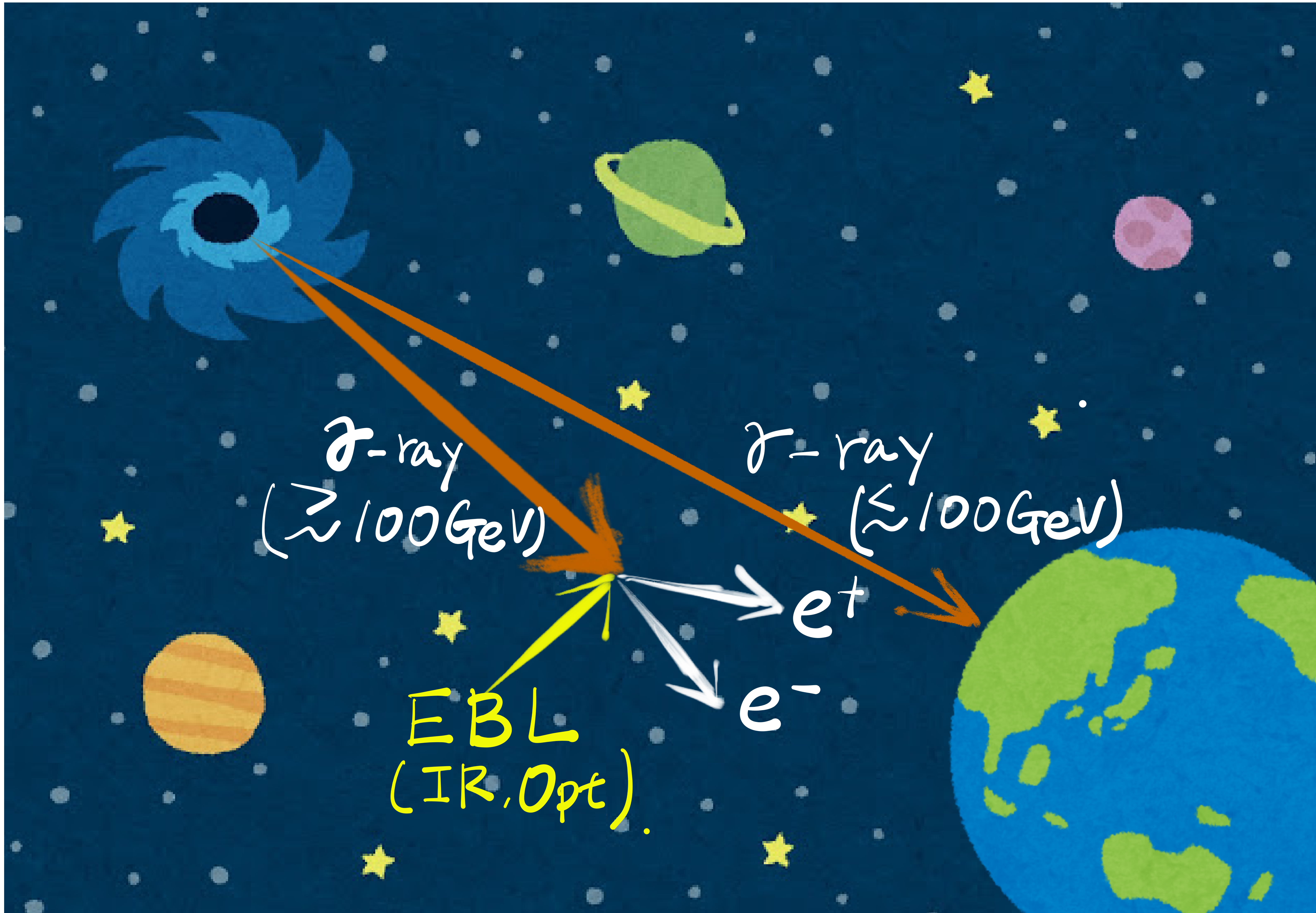
Gamma-ray Astrophysics with Cosmic History

$\gamma_{\gtrsim 100\ \mathrm{GeV}} + \gamma_{\mathrm{EBL}} \to e^+ + e^-$

- Extragalactic Background Light (EBL)
  - Integrated history of cosmic star formation activity.

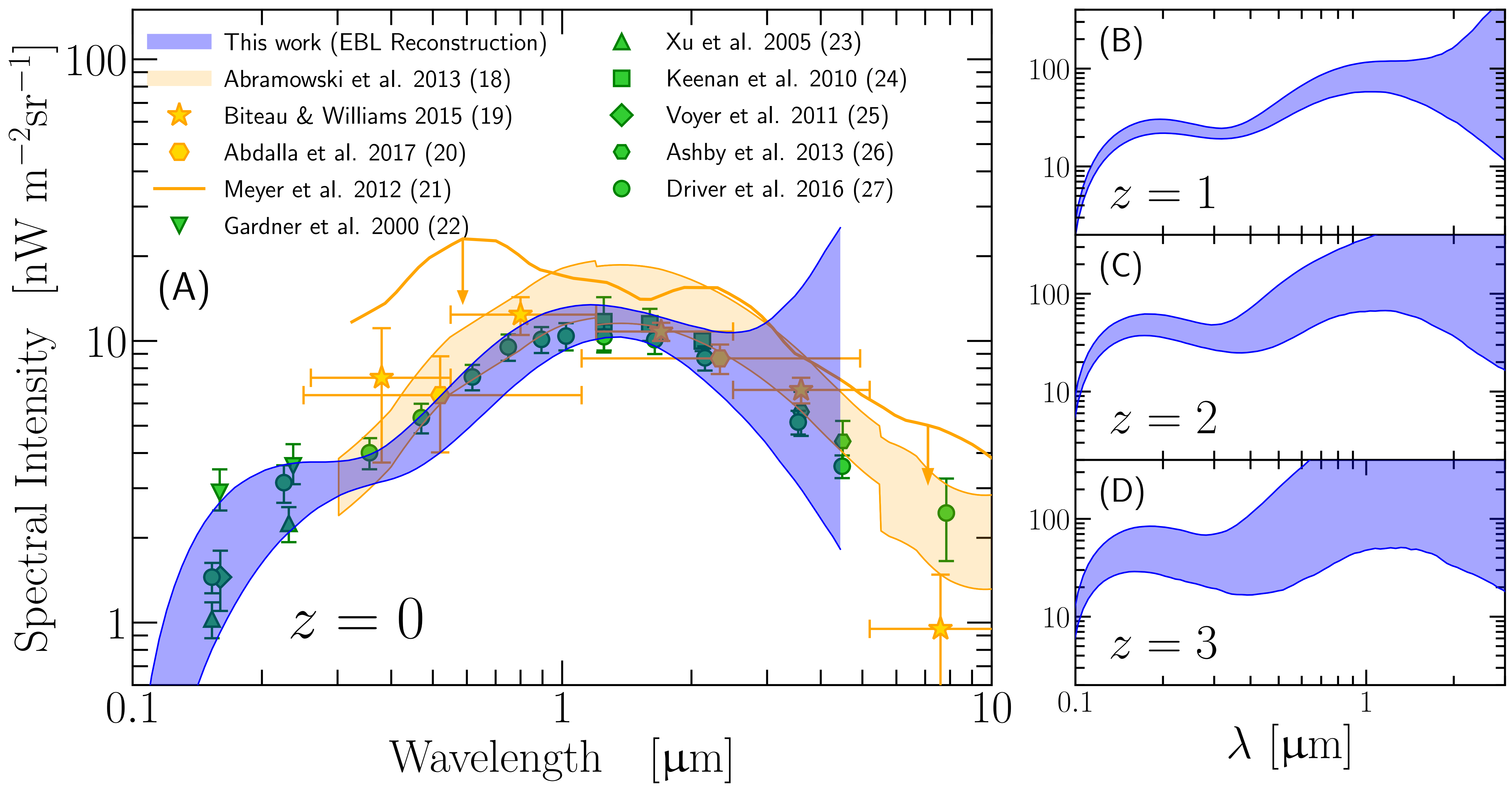


YI+'13

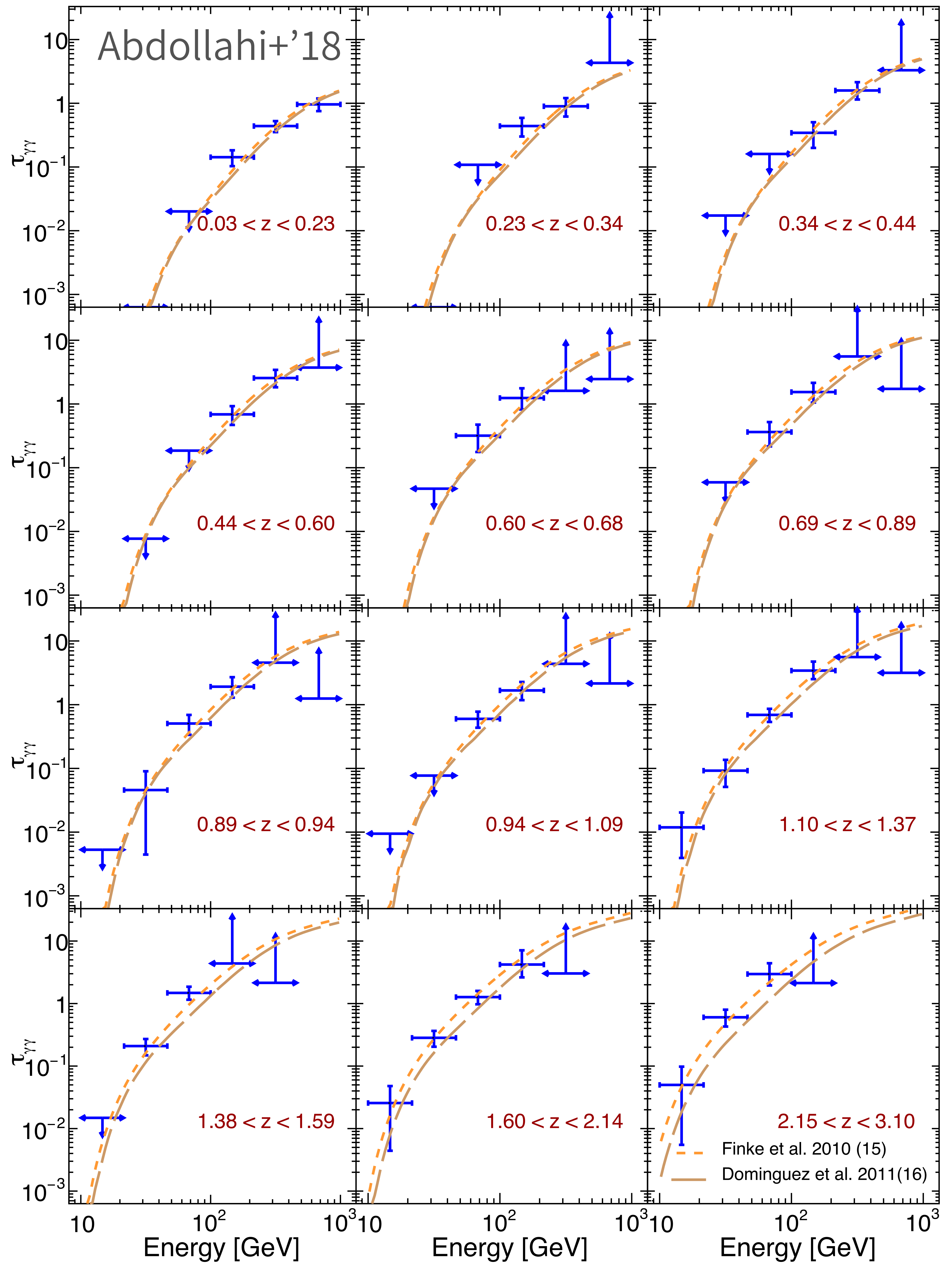


EBL and its Evolution

Gamma-ray Determination



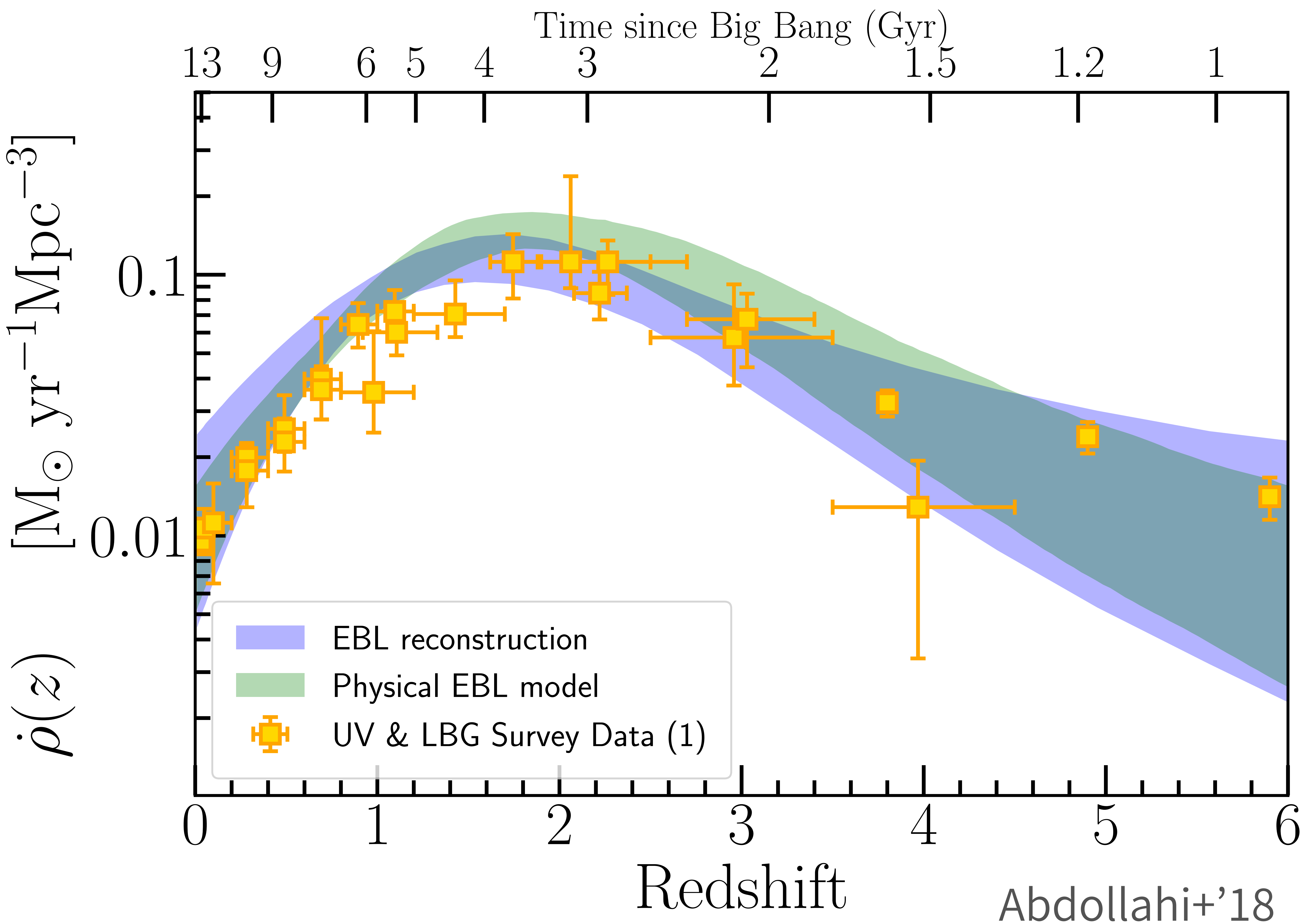
Abdollahi+'18



- By assuming intrinsic spectrum, we can determine the EBL.
  - Log-parabola fitting to low-energy data.

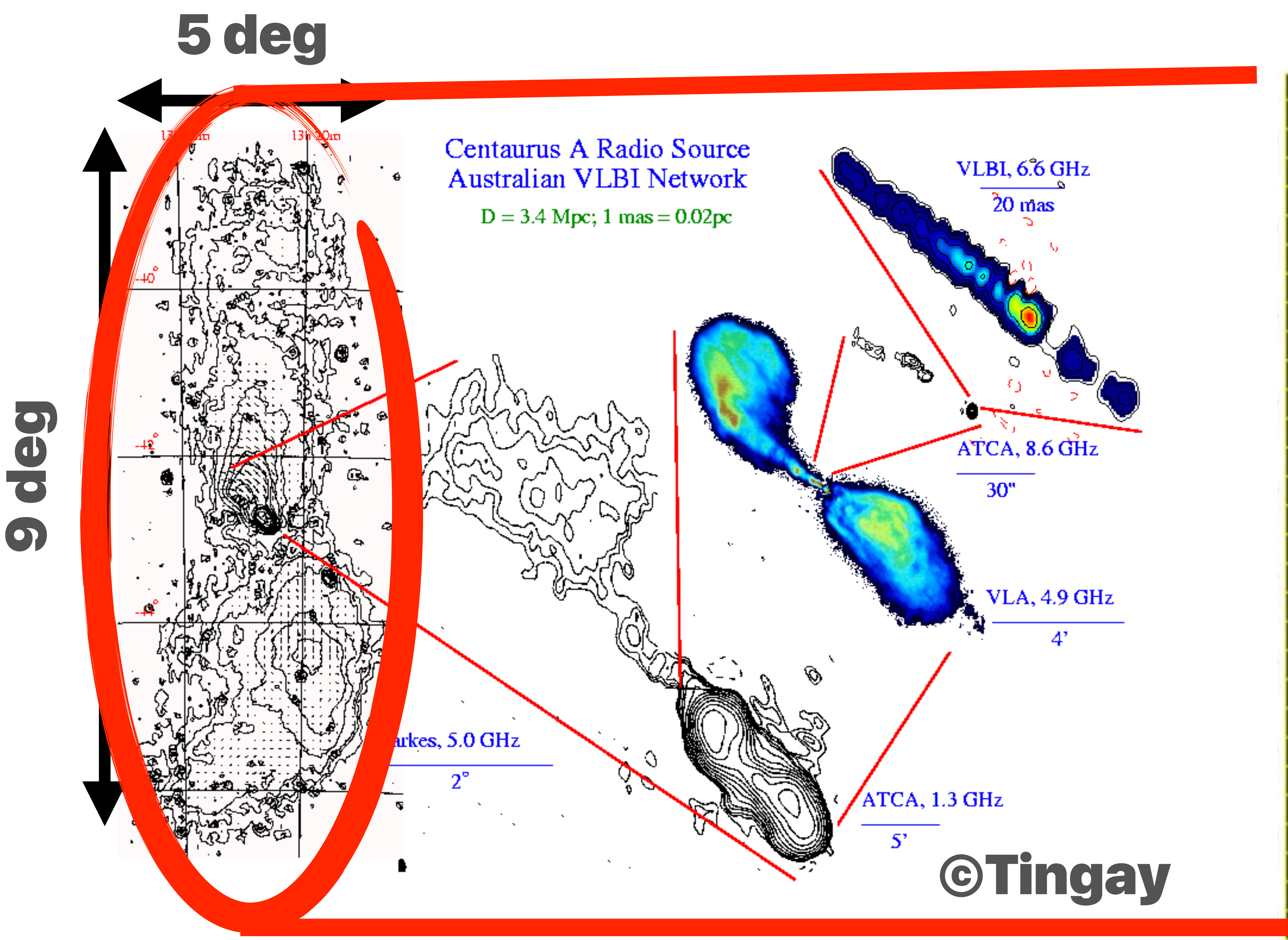
Determination of the Cosmic Star Formation History

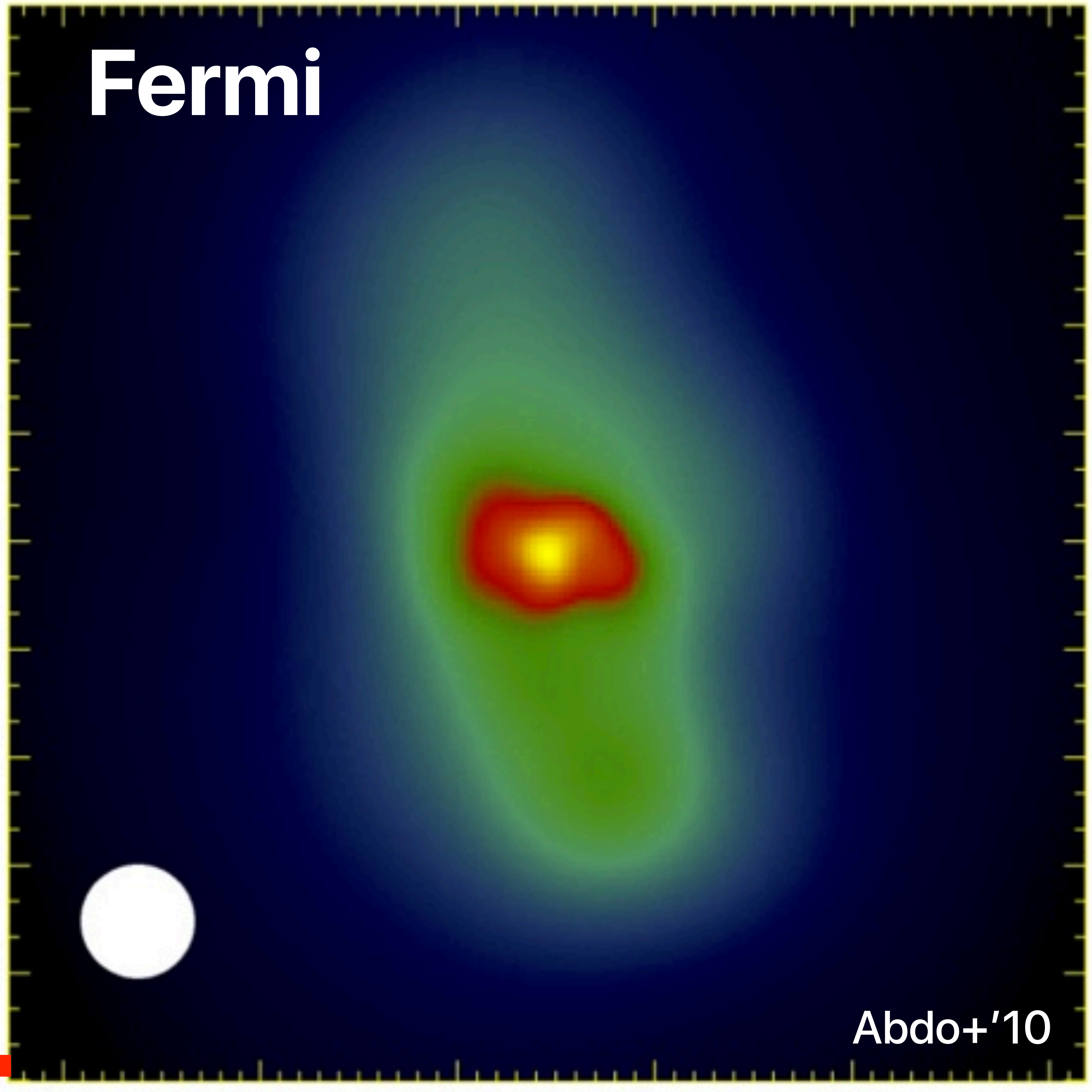
- Consistent with galaxy survey data.
- Need to assume the EBL shape.
    - sum of log-normal (Blue)
    - stellar population synthesis (Green)



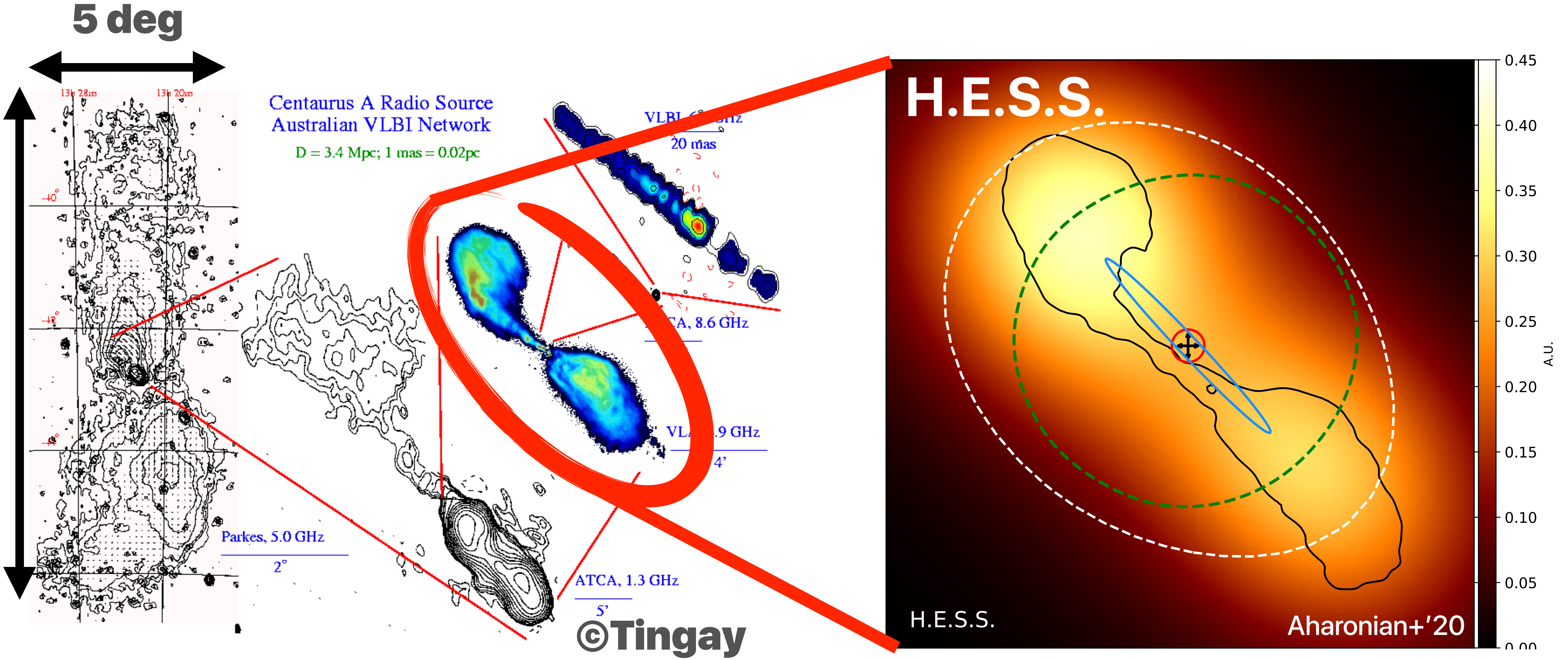
Abdollahi+'18

Spatial Extension of Cen A Seen by Fermi and H.E.S.S.



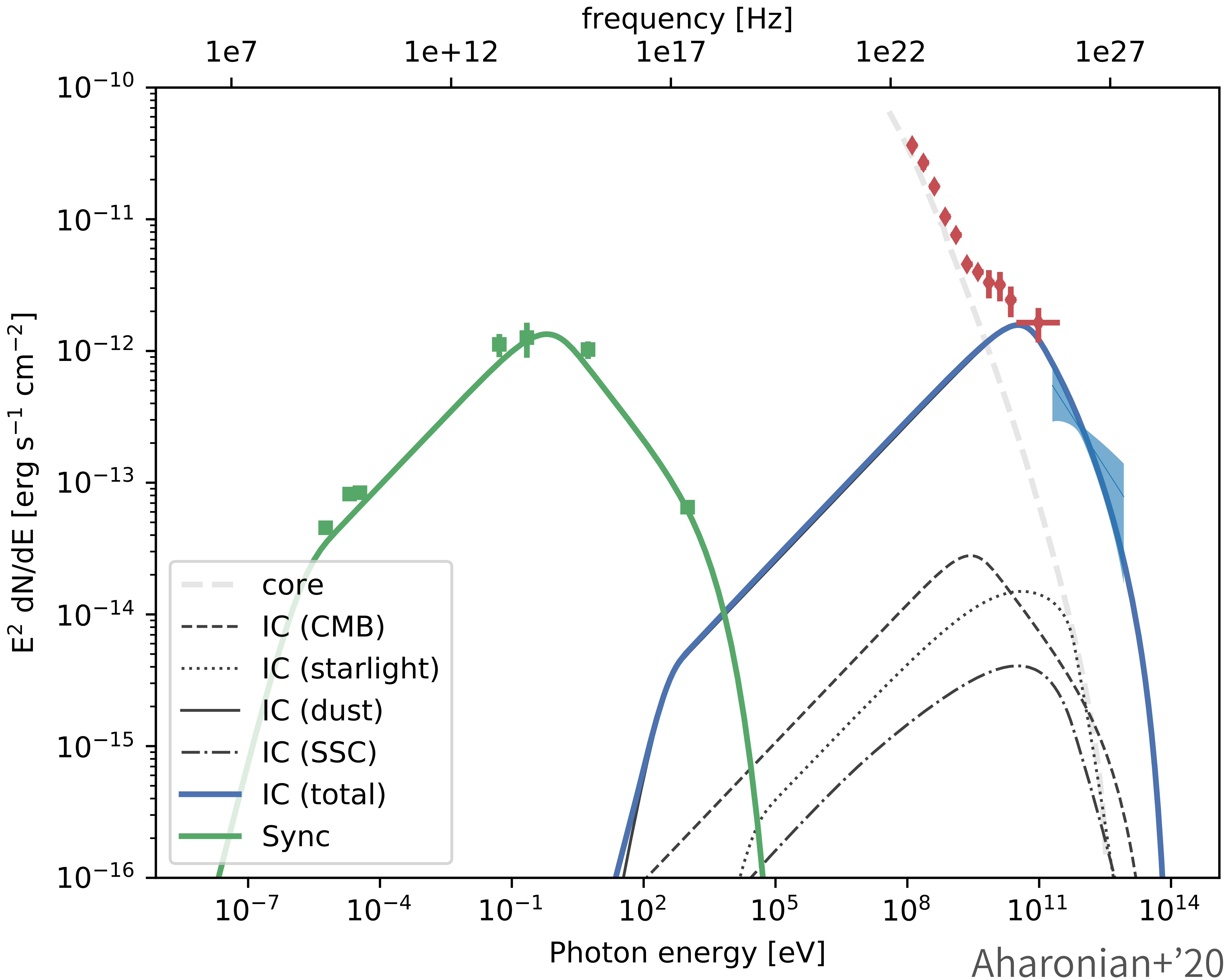


Spatial Extension of Cen A Seen by Fermi and H.E.S.S.

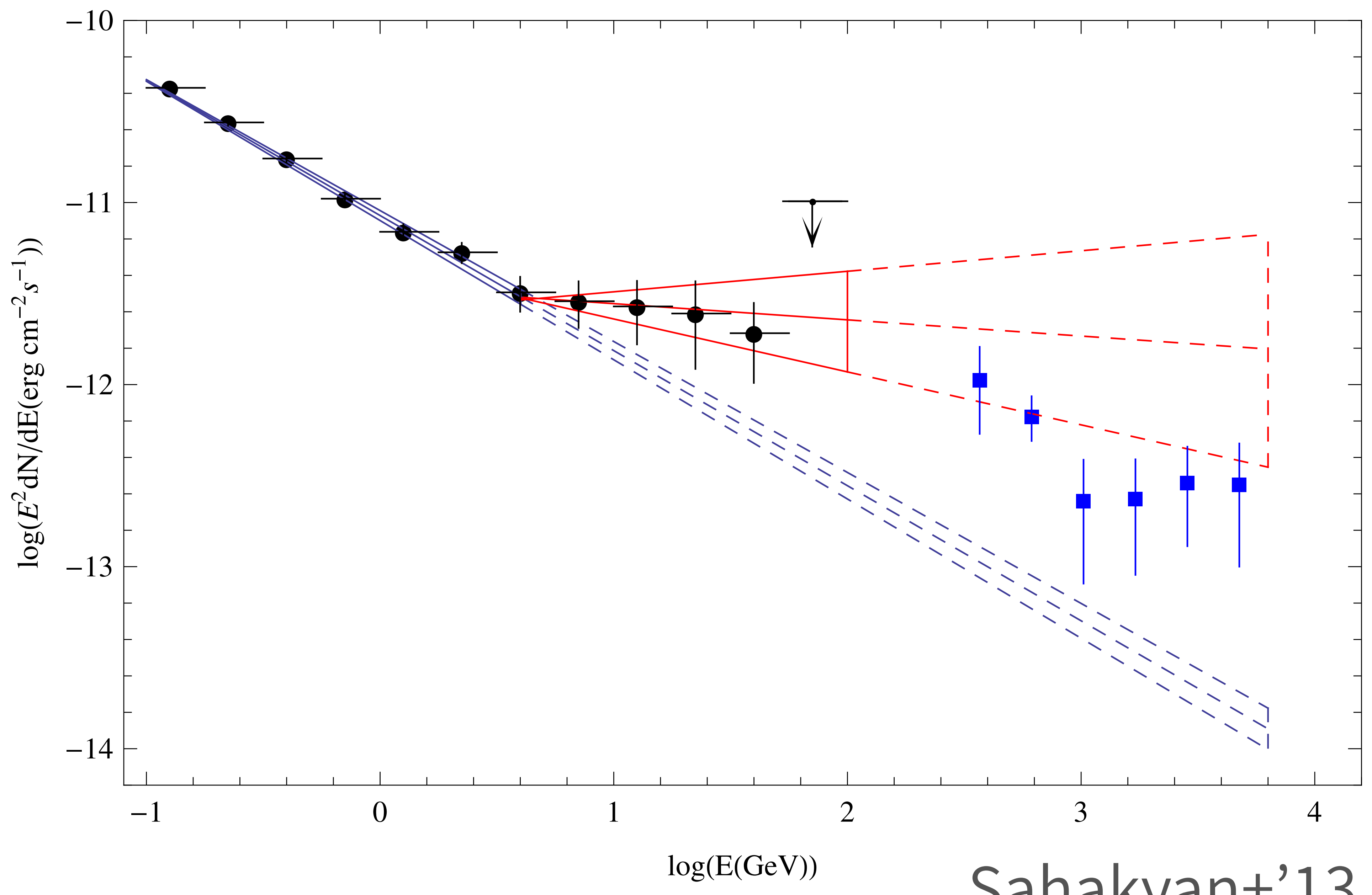


NOTE: Color scale is radio!
HESS region is WHITE circle.

Unusual Spectral Hardening in the Cen A Spectrum



Aharonian+’20

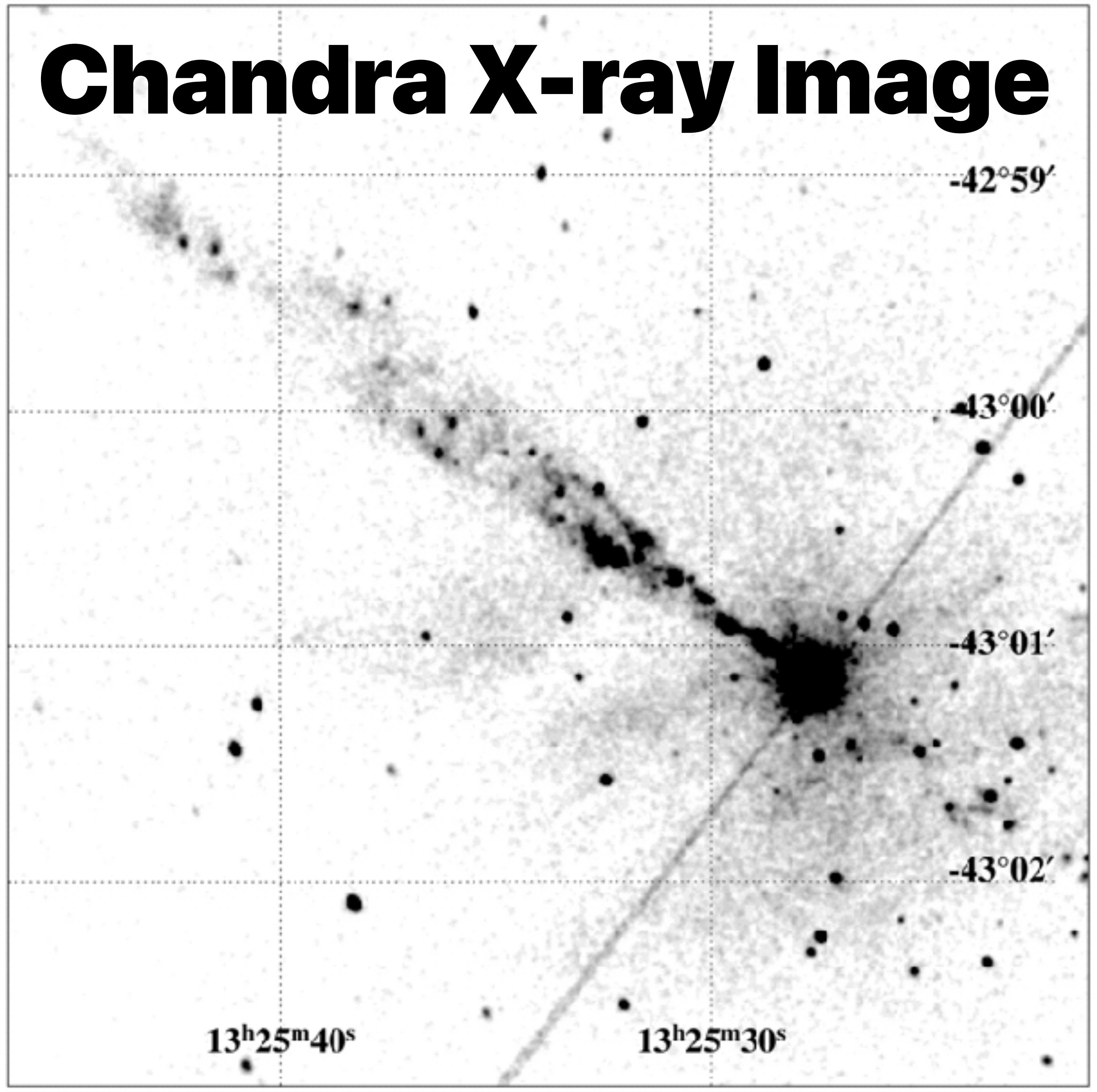


Sahakyan+’13

- Cen A MWL spectrum shows an unusual spectral hardening at 4 GeV.
  - H.E.S.S. spatial decomposition revealed it from the kpc scale.

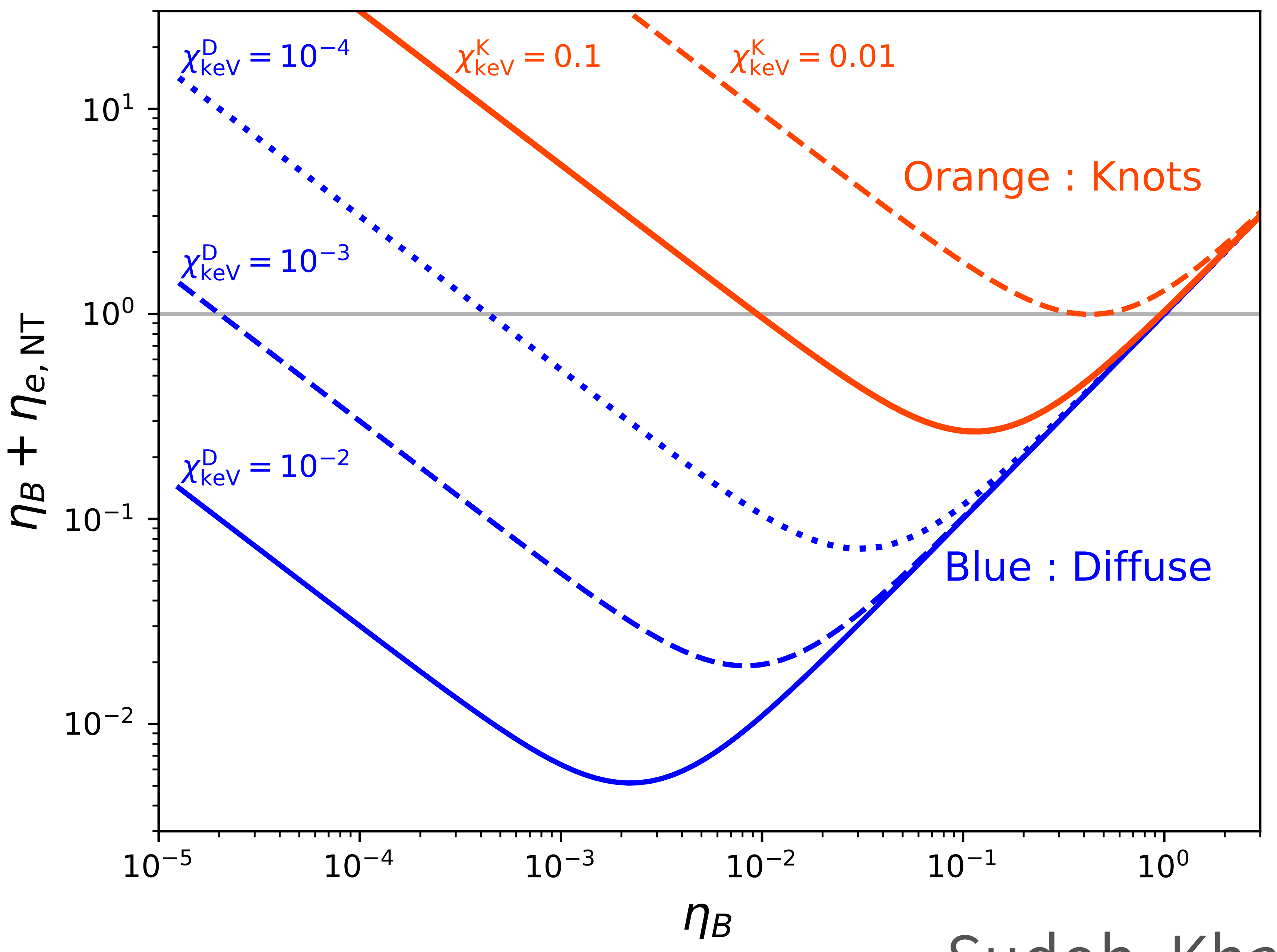
Physical Properties of the kpc Jet (Diffuse + Knots)

Sudoh, Khangulyan, & YI '20

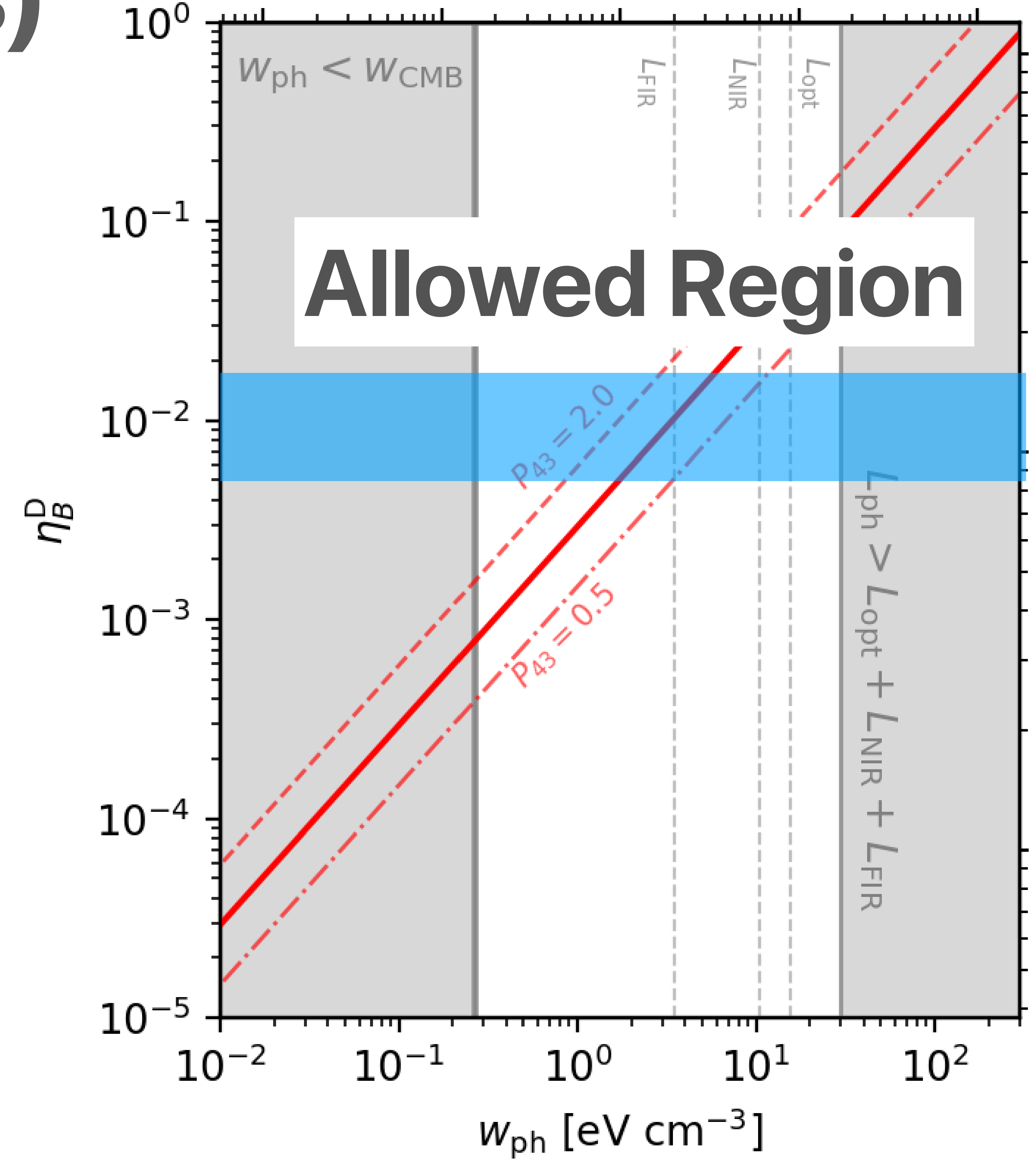


Kataoka+'06; Goodger+'10

Radio + X-ray Constraints



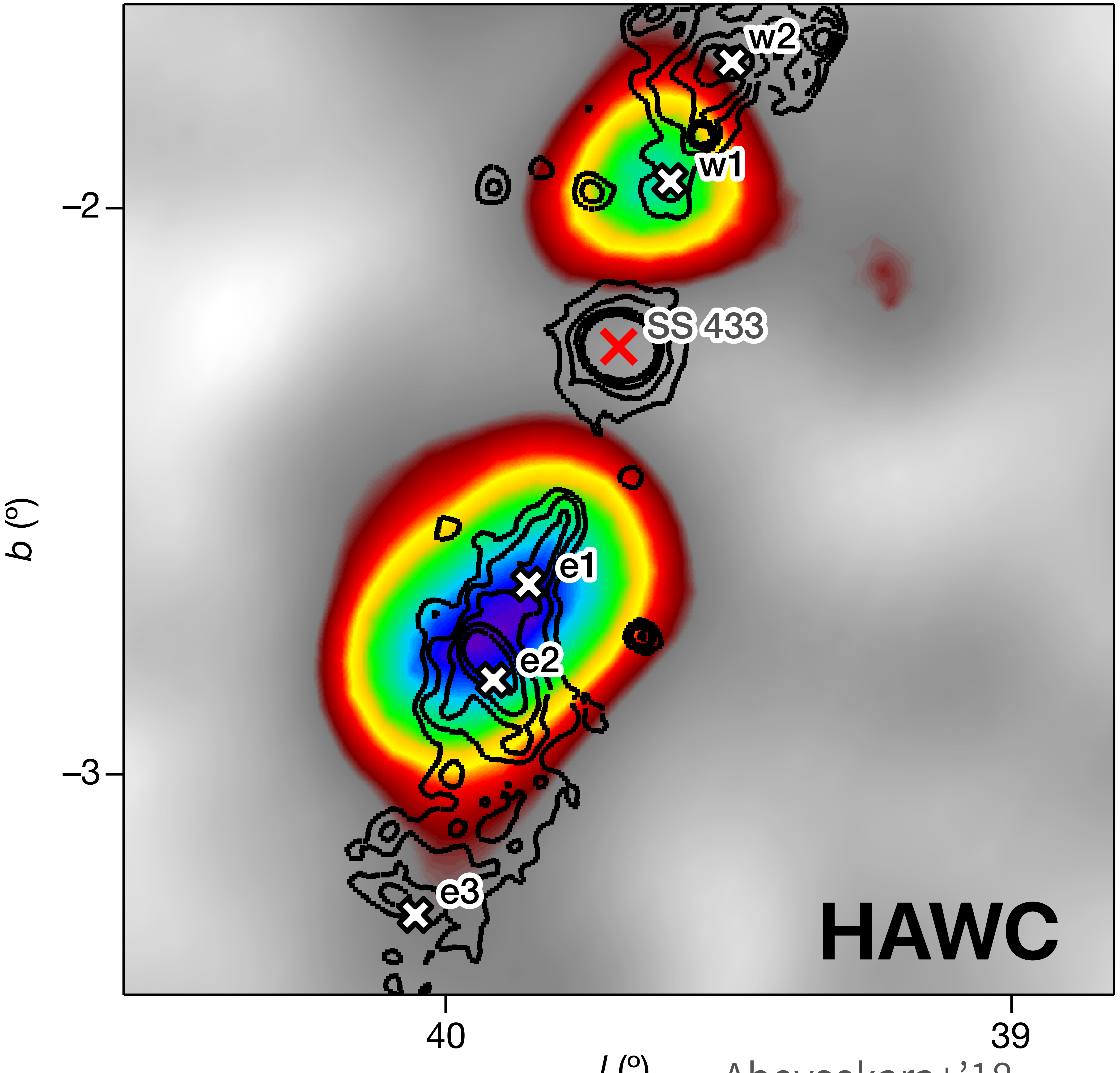
+ VHE Constraints



Sudoh, Khangulyan, & YI '20

- kpc jets are observed in radio, X-ray, and γ-ray.
- Diffuse jet: $\eta_B \sim 10^{-2}$
  - consistent with a general analysis of FR-II galaxies (Sikora+'20)
- Knots : $\eta_B \sim \eta_e \sim 0.1$

>20 TeV Gamma-ray from SS 433 Knots by HAWC



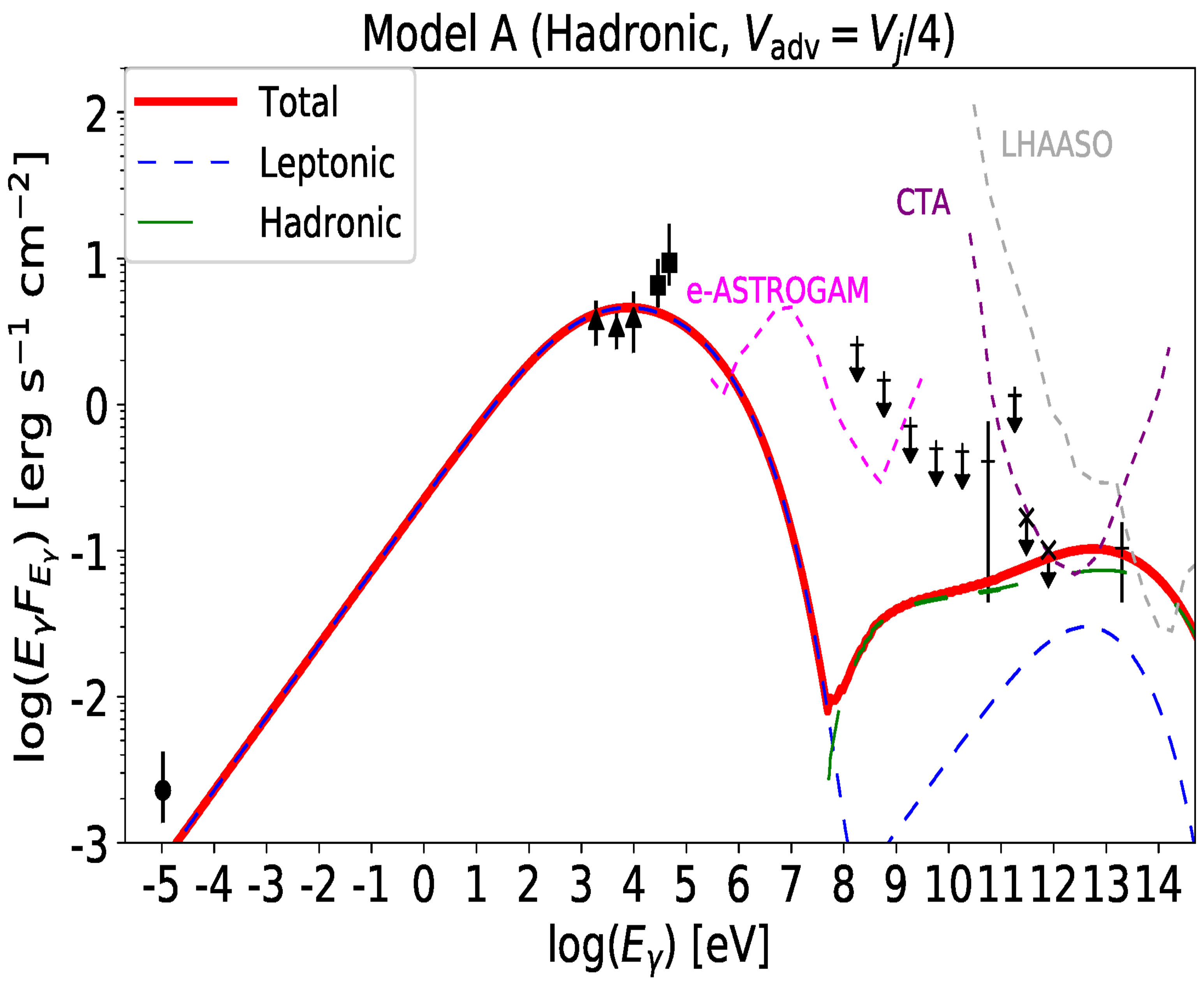
Abeysekara+'18

- SS 433 is a Galactic microquasar.
- Twin jets
- $v_{\rm jet} \sim 0.26c$
- $L_{\rm jet} \sim 10^{39}$ erg/s

Efficient Particle Acceleration in the SS 433 jet

Sudoh, YI, & Khangulyan ’20; Kimura, Murase, & Meszaros ‘20

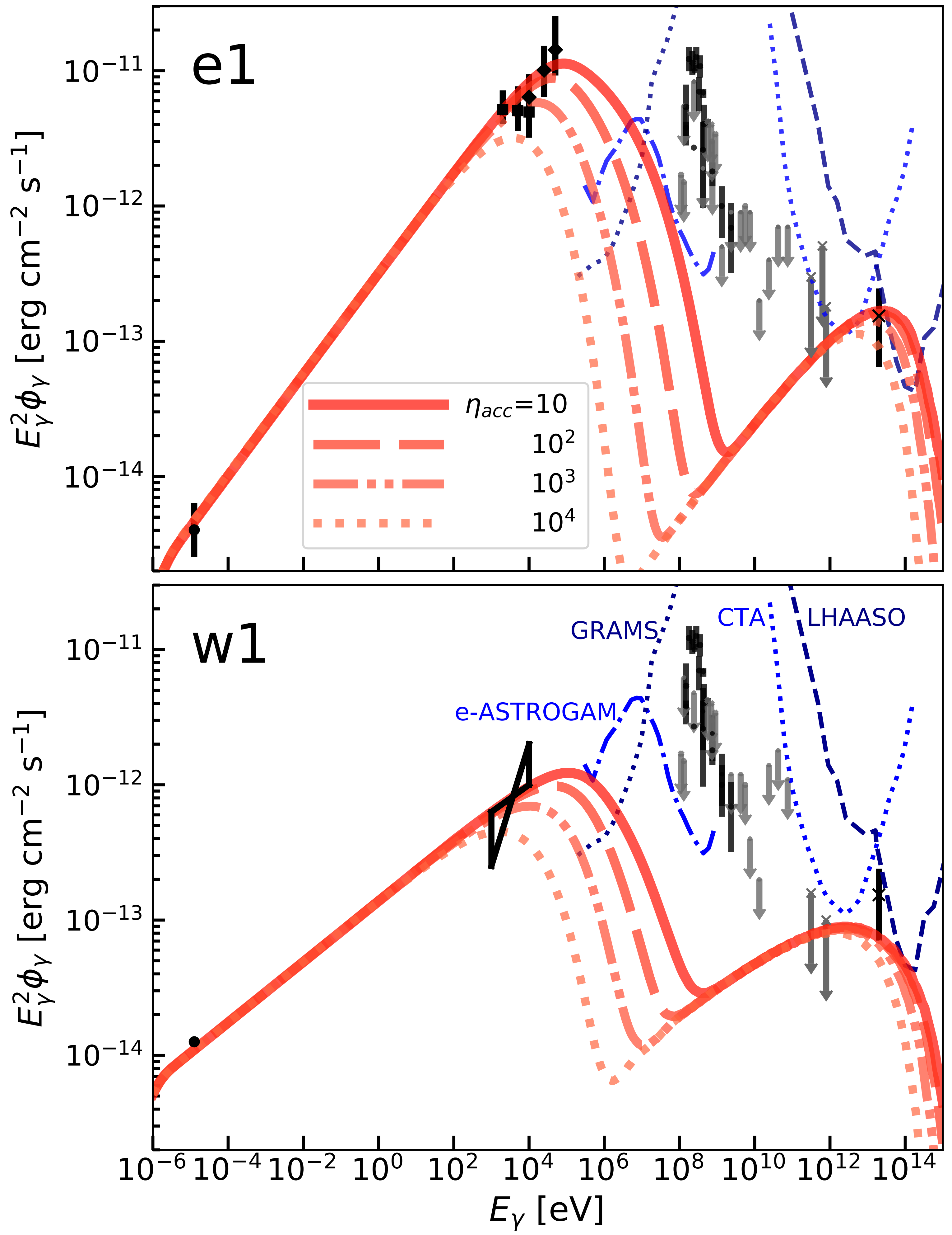
Hadronic



Kimura+’20

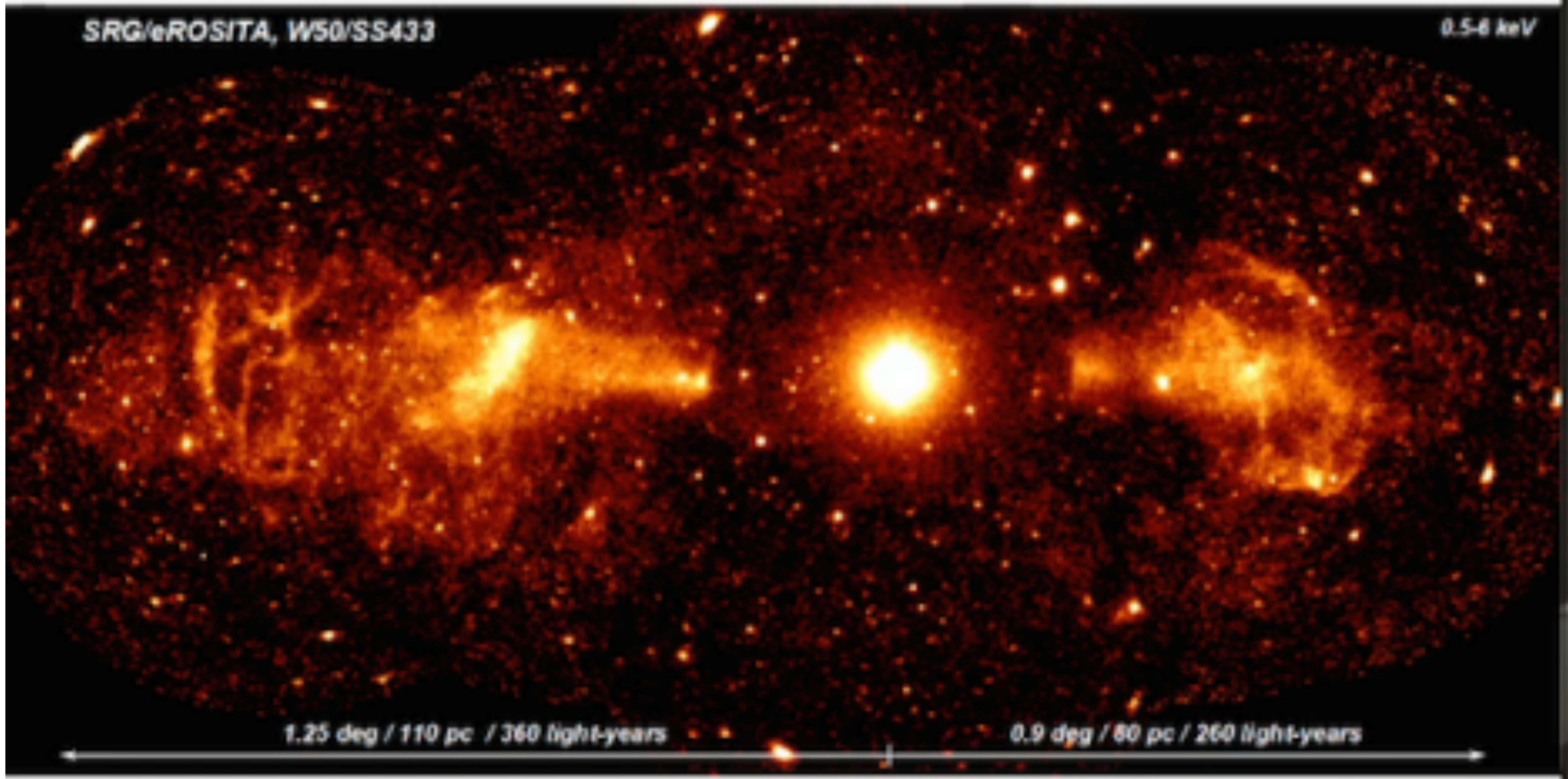
- Both OK.
  - Both require efficient acceleration
  - Different from blazars (Inoue & Takahara ’96; Finke+’08; YI & Tanaka ’16)
- Confirmation by CTA & LHAASO is needed.
- X-ray and GeV data are keys.

Leptonic



Sudoh, YI, & Khangulyan ‘20

SS 433 Seen by e-ROSITA

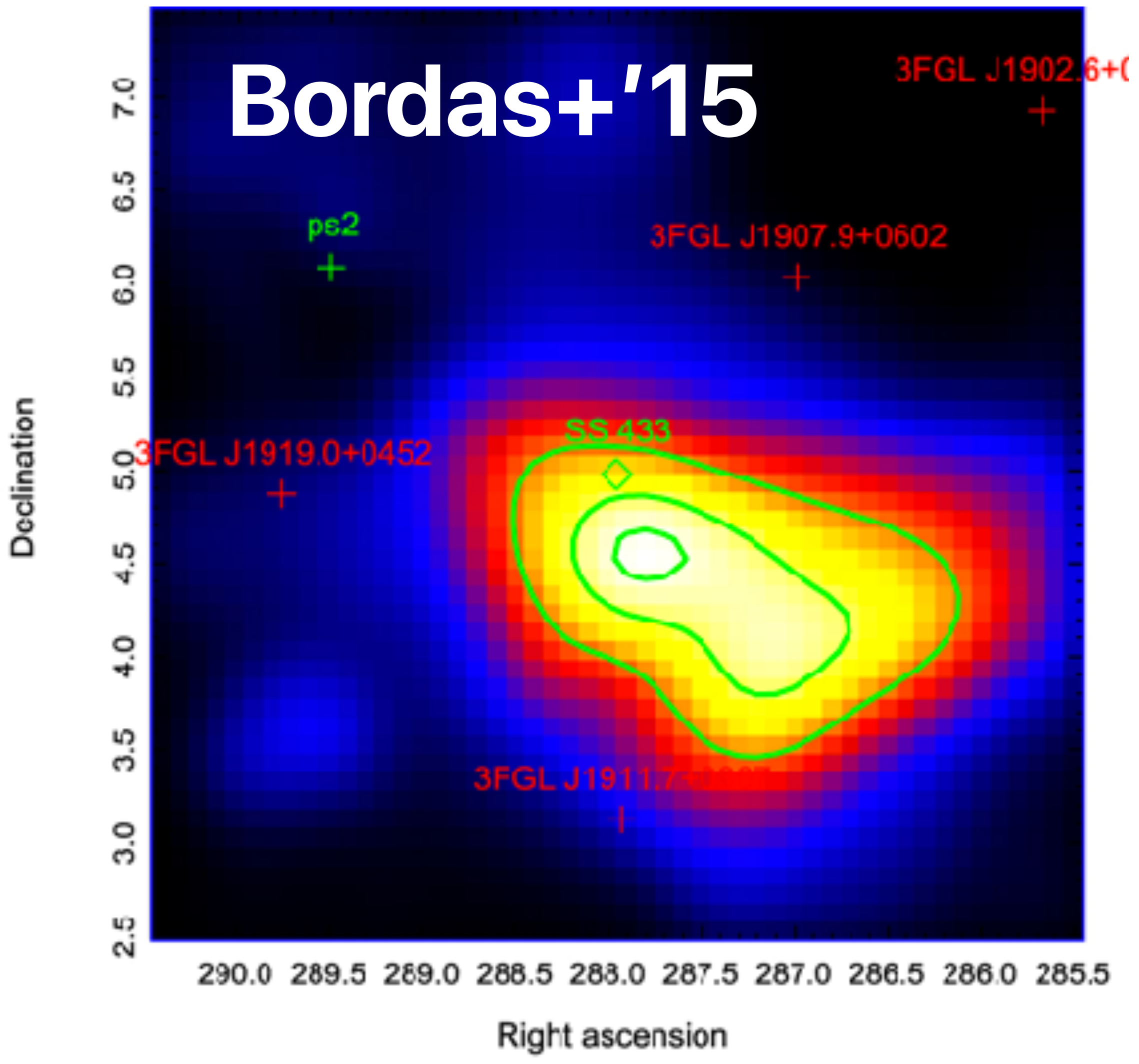


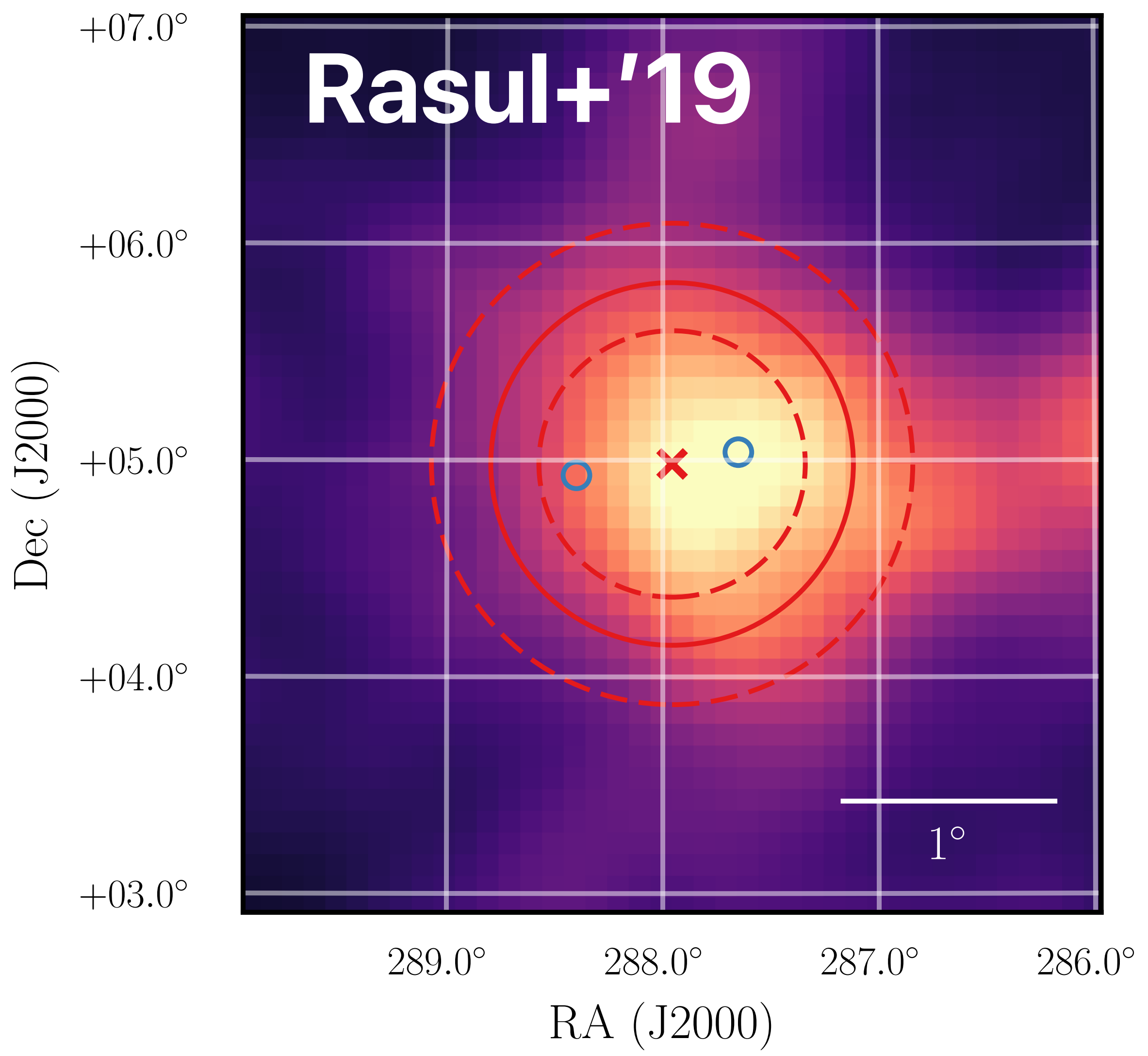
SS433

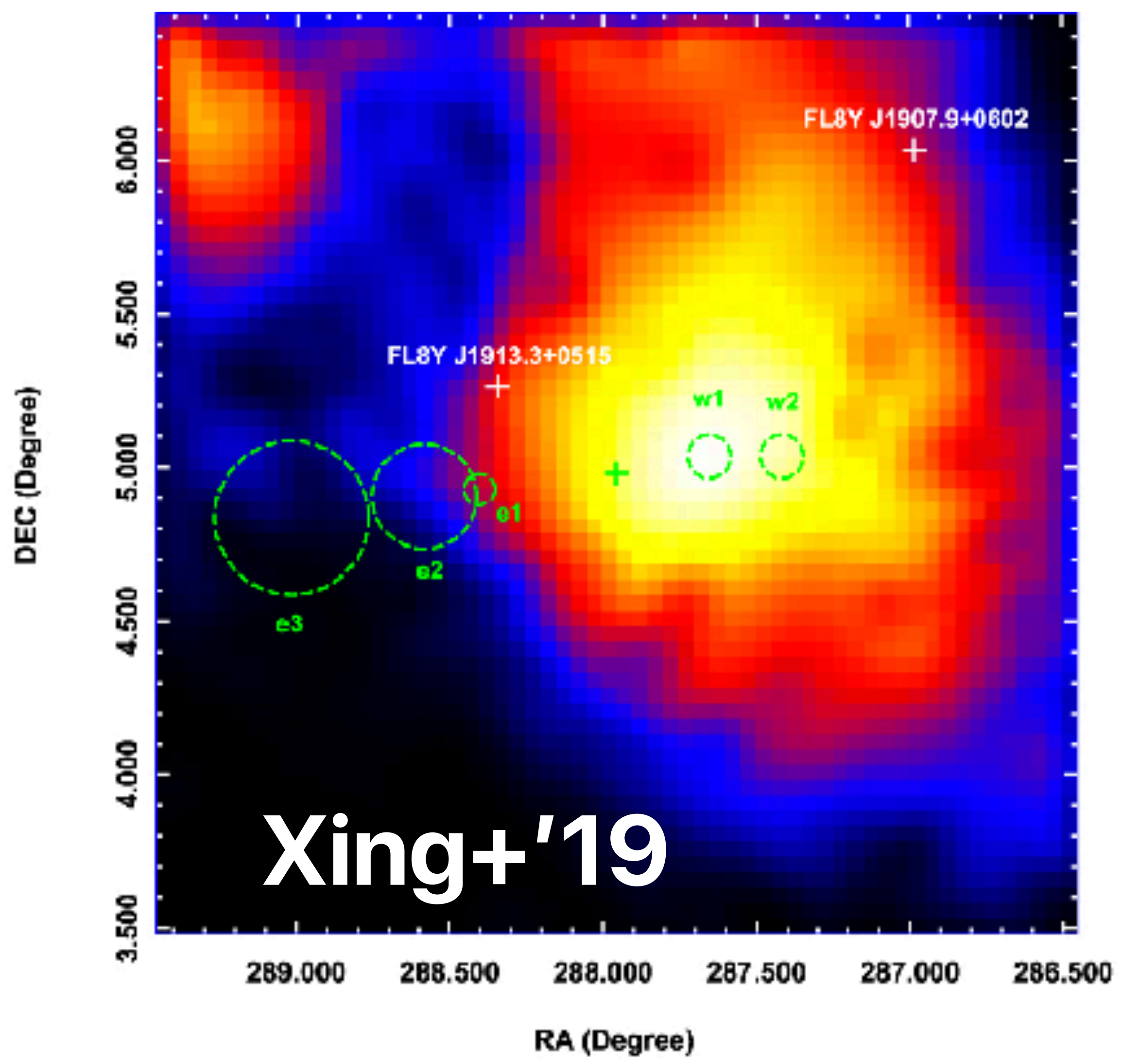
http://novostinauki.ru/news/162232/

Where is the GeV emitting region?

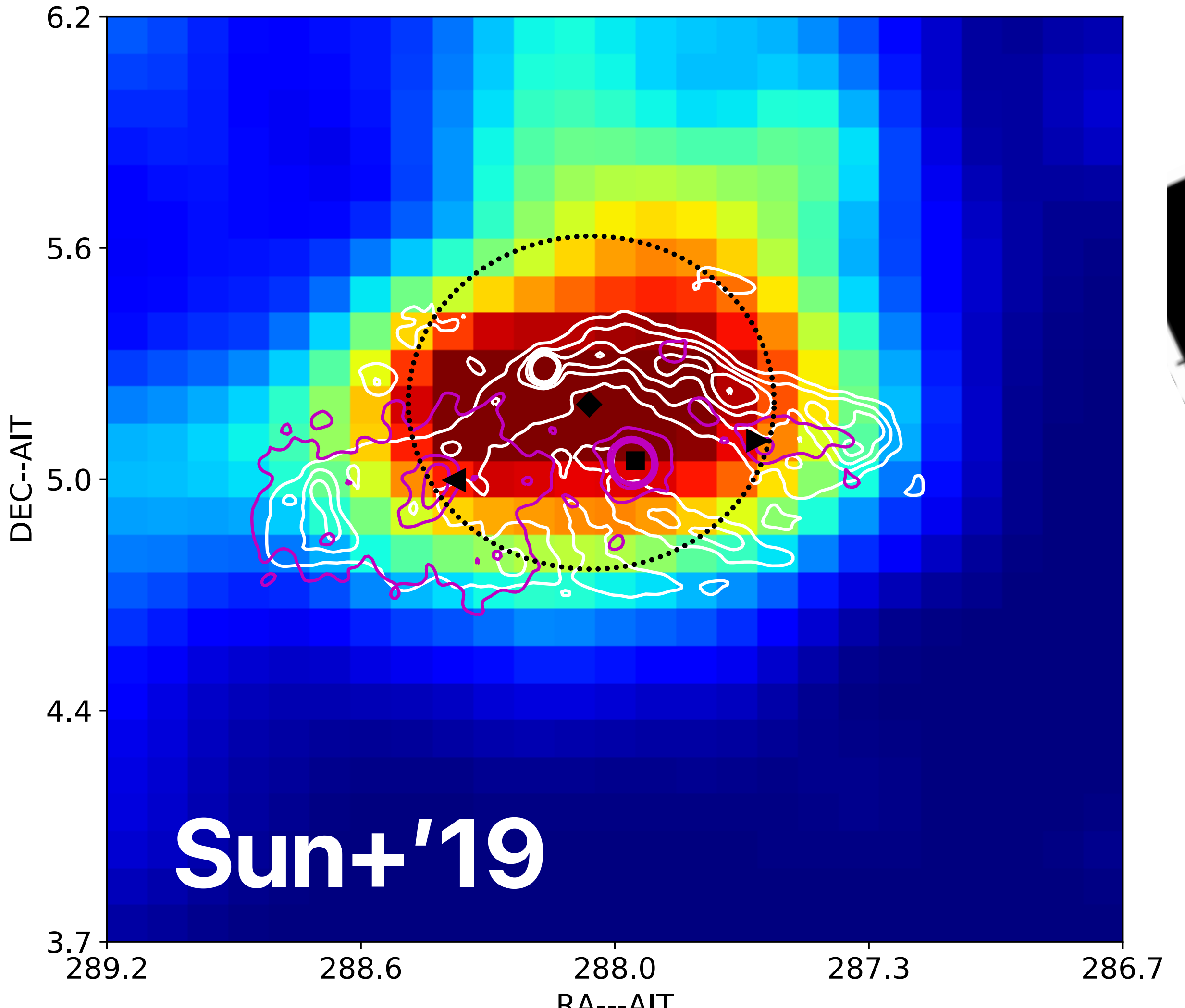
Different people report different places...

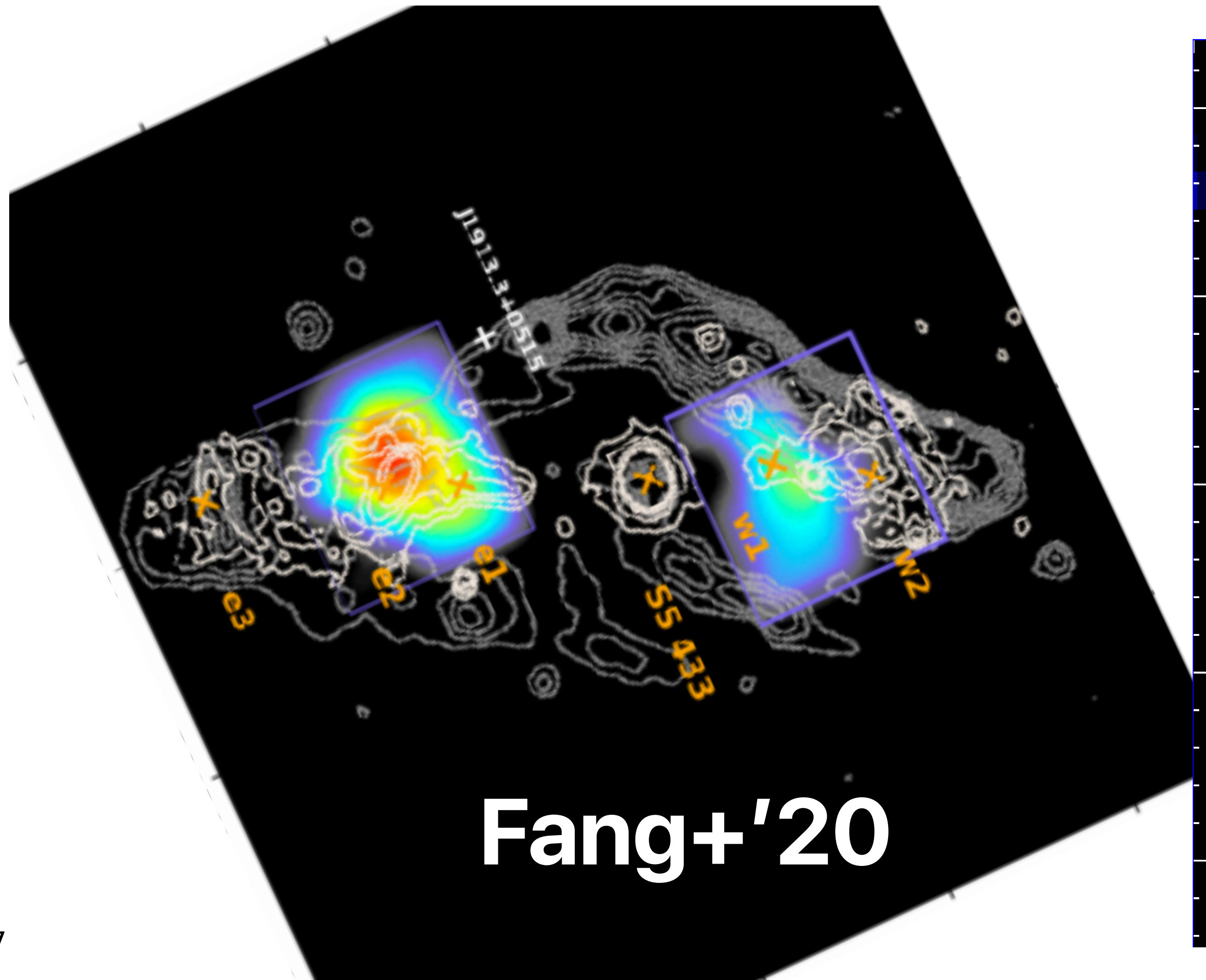


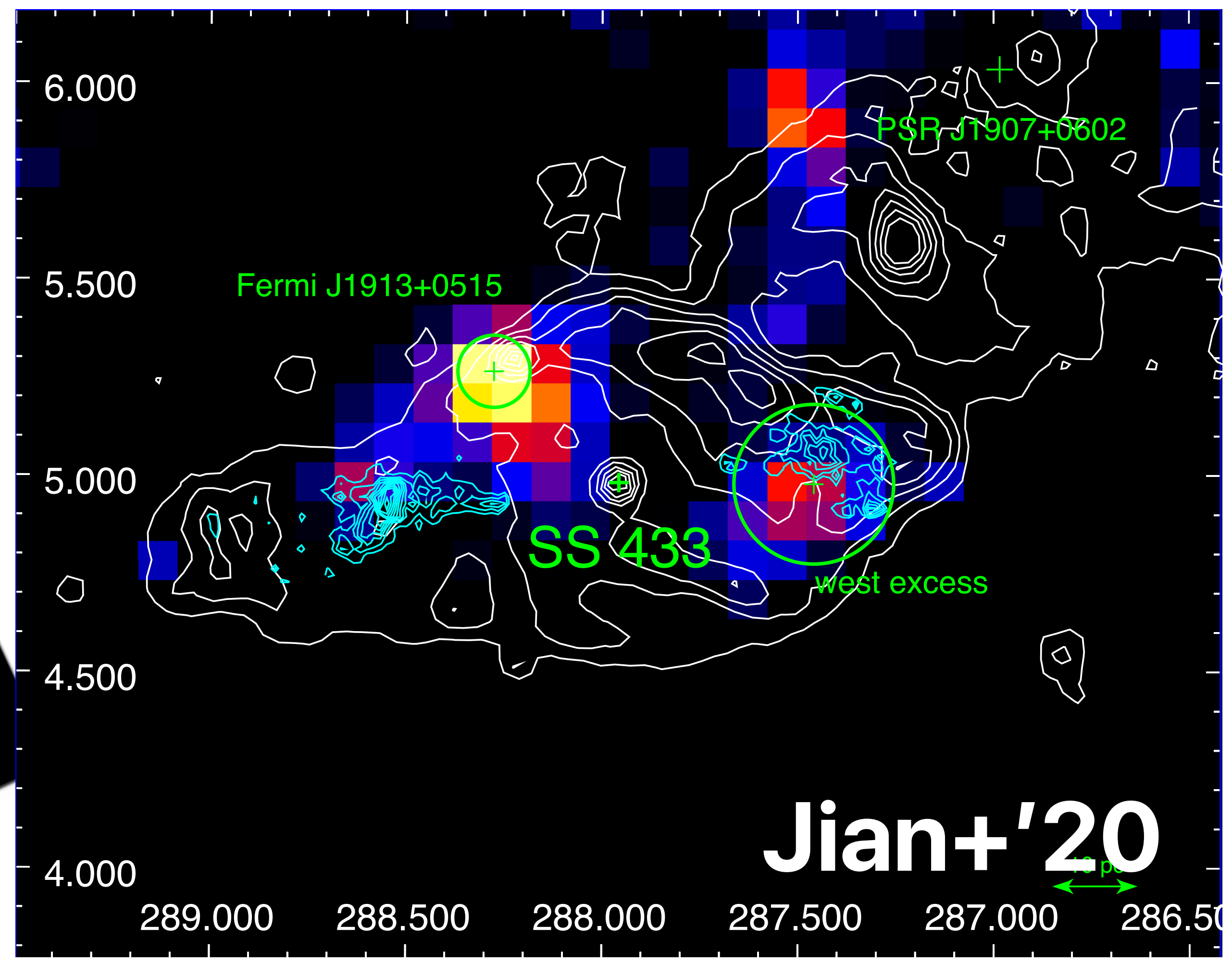




- 6 papers
- 6 different images
- 6 different GeV spectra
- Some report periodicity, some not.







Request for (Young) CRC Members

What will you do in the next 20-30 years?

タウンミーティングについて

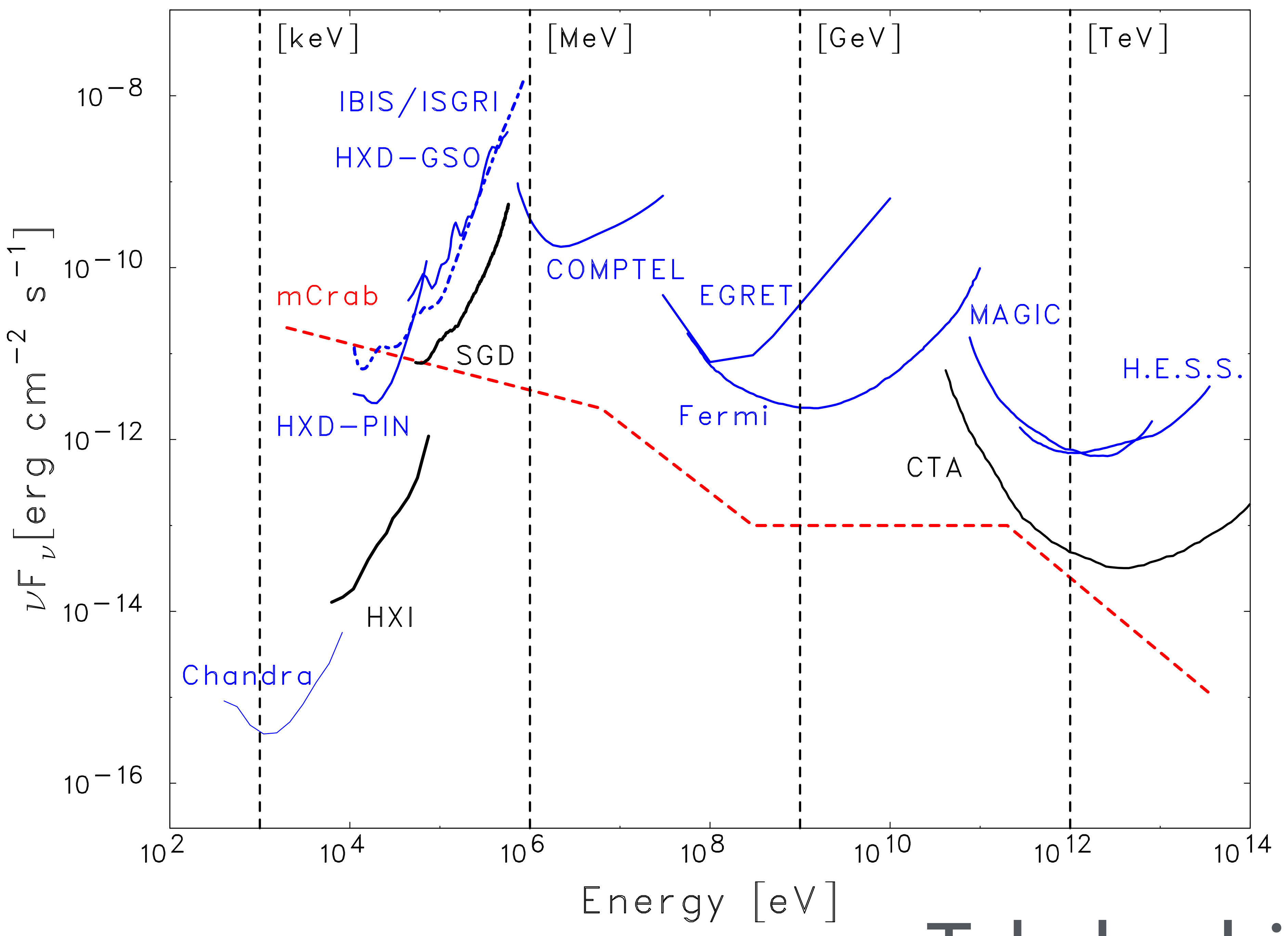
CRCでは、現在検討中の将来計画についての検討を行い、研究者のコンセンサスを形成するためにタウンミーティングを開催してゆきます。

9/28(月)
「地上ガンマ線観測」

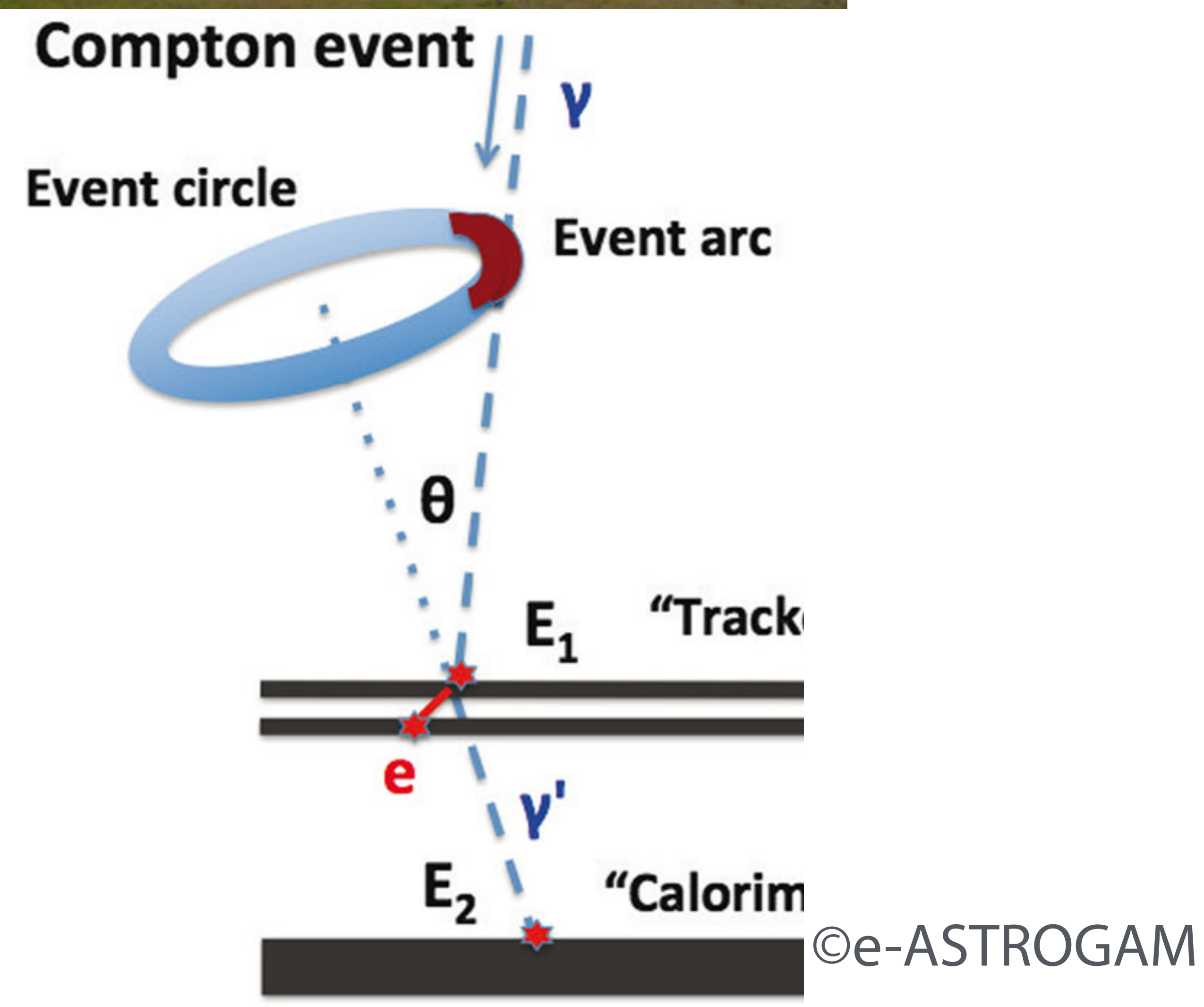
9:00-9:40	理論レビュー	井上芳幸(理研)
9:40-10:10	CTA全体状況	手嶋政廣(東大ICRR)
10:10-10:30	CTA-LST-N の建設状況	窪秀利(京大)
10:30-11:50	CTA-Sへ向けてのSiPM 開発	田島宏康(名大ISEE)
11:50-11:10	ALPACA	さこ隆志(東大ICRR)
11:10-11:40	議論	

- Senior people only.
- Now the time scale of astrophysics projects can be >15 years from the idea to realization.
- What’s next? When I become 60 years old, what kind of projects we have in Japan?

Open the MeV Gamma-ray Astronomy



Takahashi+'13

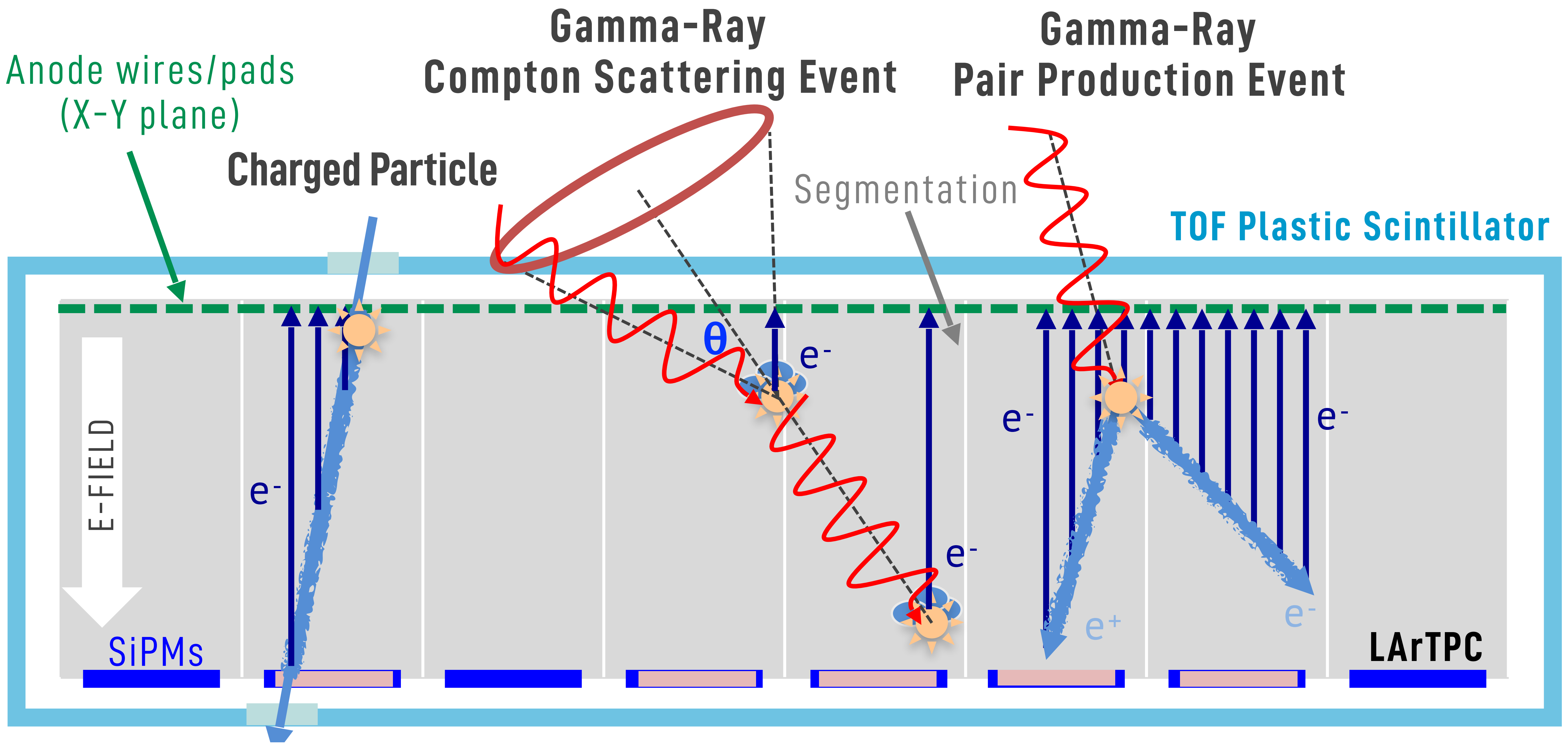


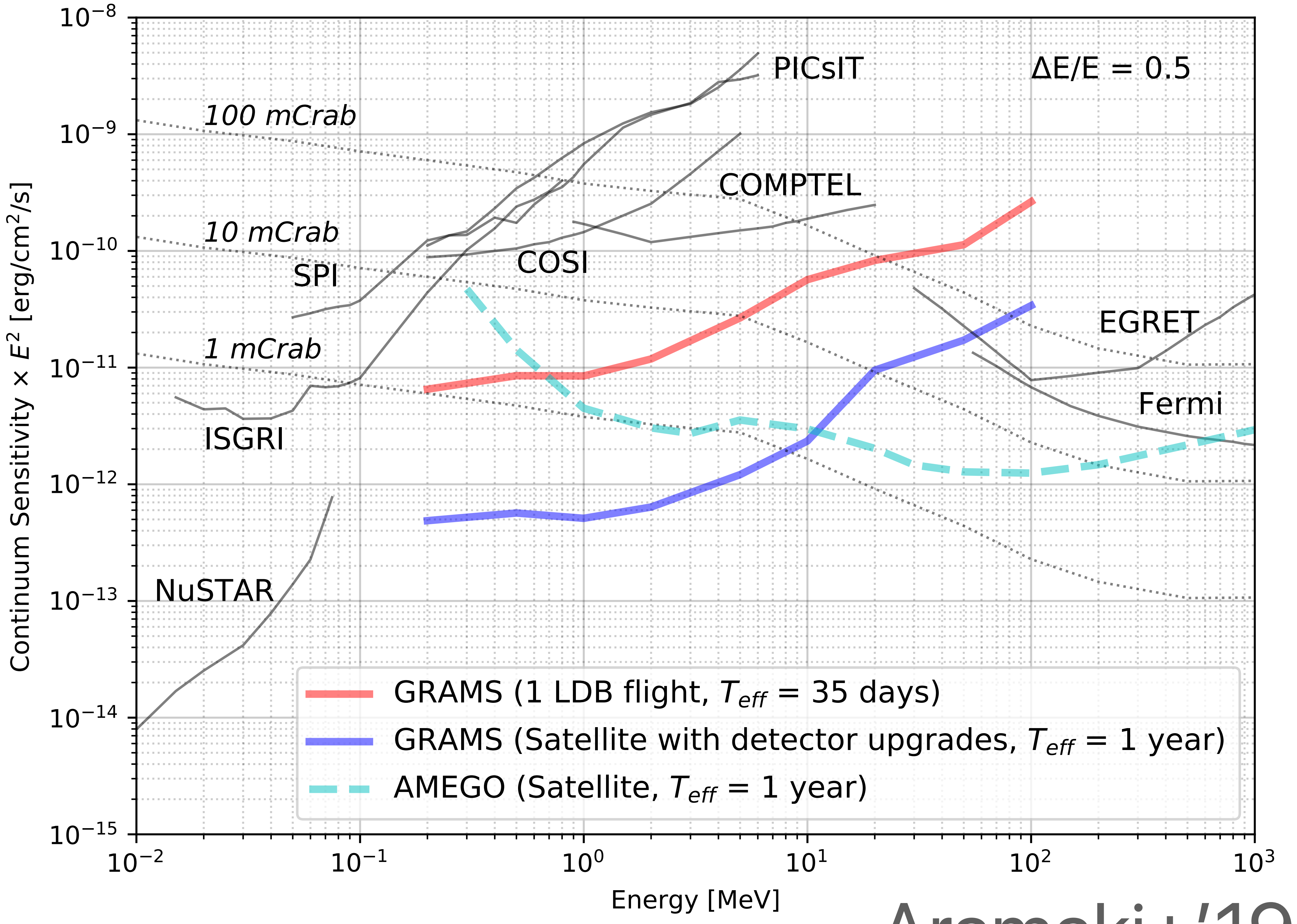
- **<u>MeV is still Challenging & Exploratory Research</u>**
- Various proposals: AMEGO, COSI-X, GRAINE, SGD, SMILE,,,

➡ Our plan: First, go to balloon missions. Then, to the space.

Gamma-Ray and AntiMatter Survey (GRAMS)

Liquid Argon Time Projection Chamber (LArTPC) surrounded by Plastic scintillators

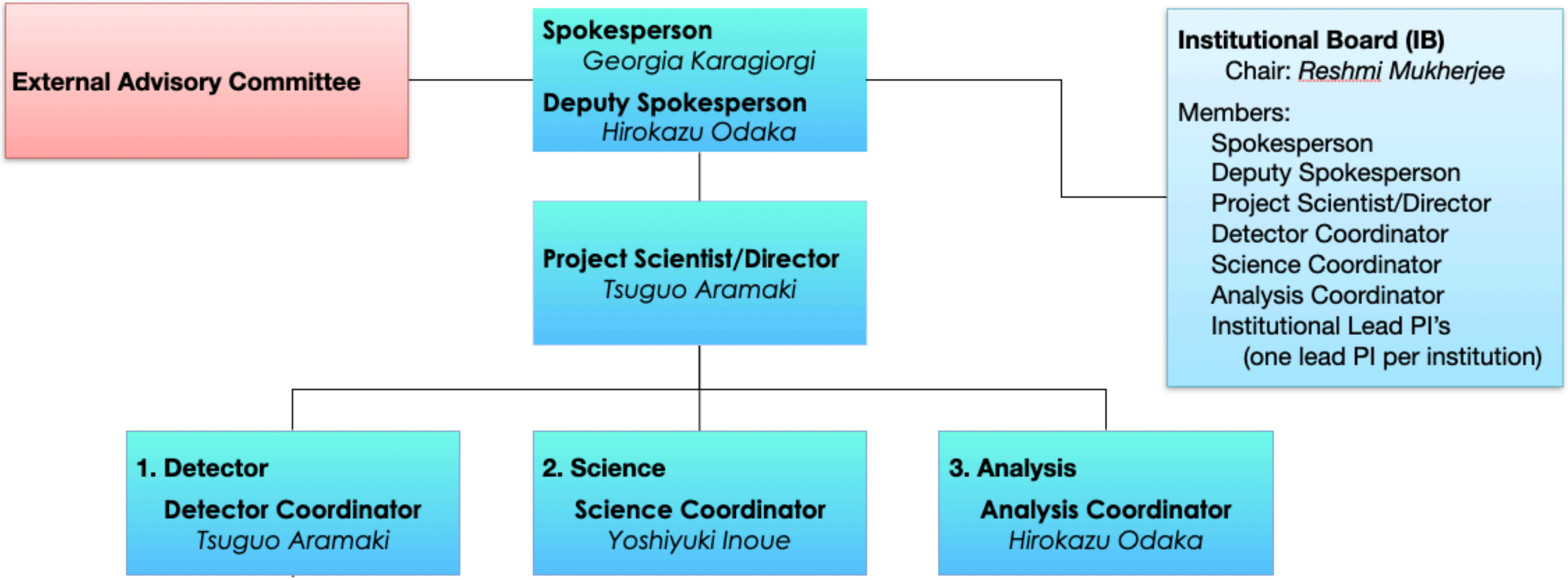




Aramaki+'19

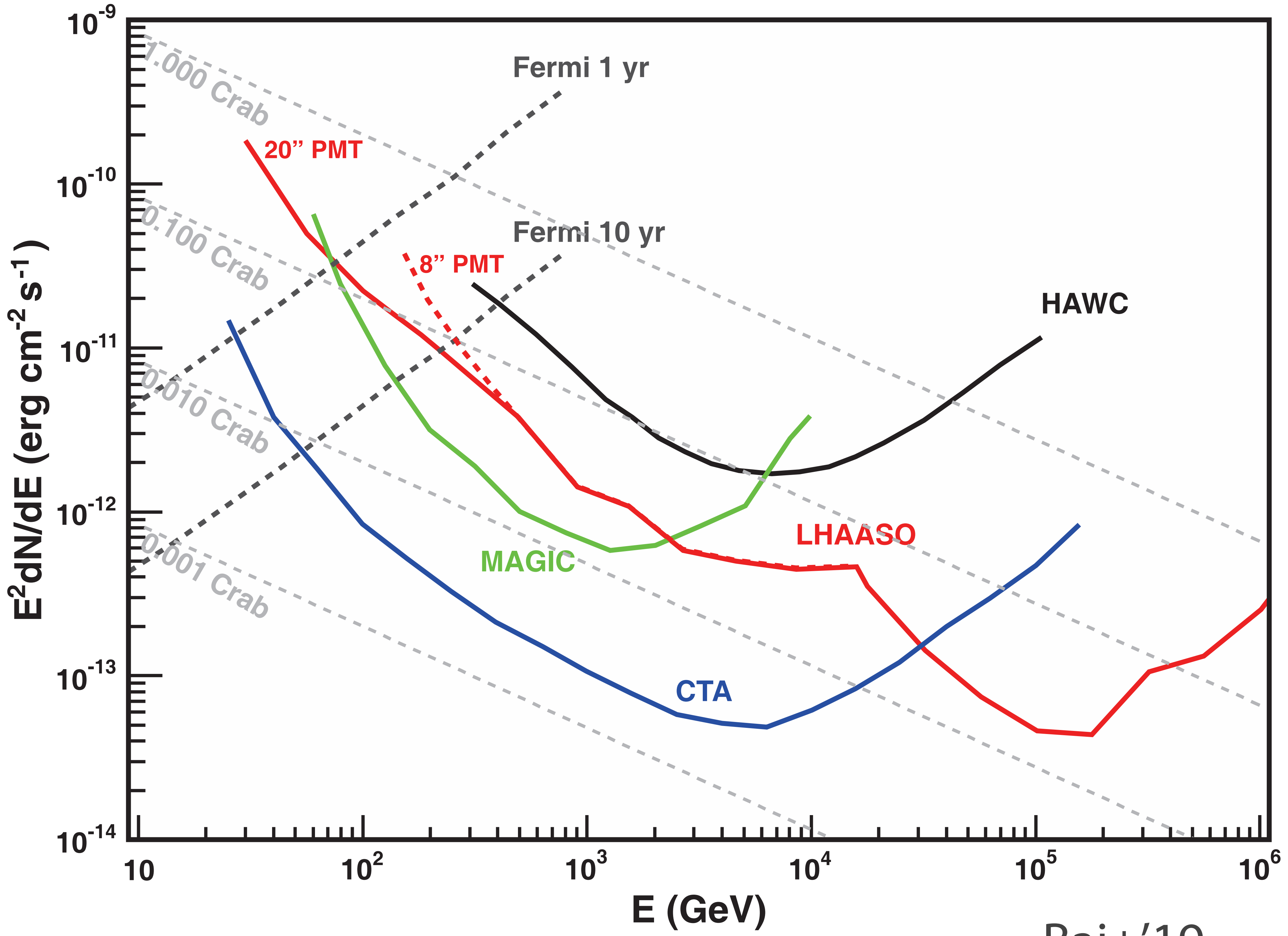
- Plastic Scintillators: Veto
- LArTPC: Compton camera and calorimeter
- LArTPC is more cost-effective and more easily expandable, much less channels/ electronics required, almost no dead volume

GRAMS Collaboration

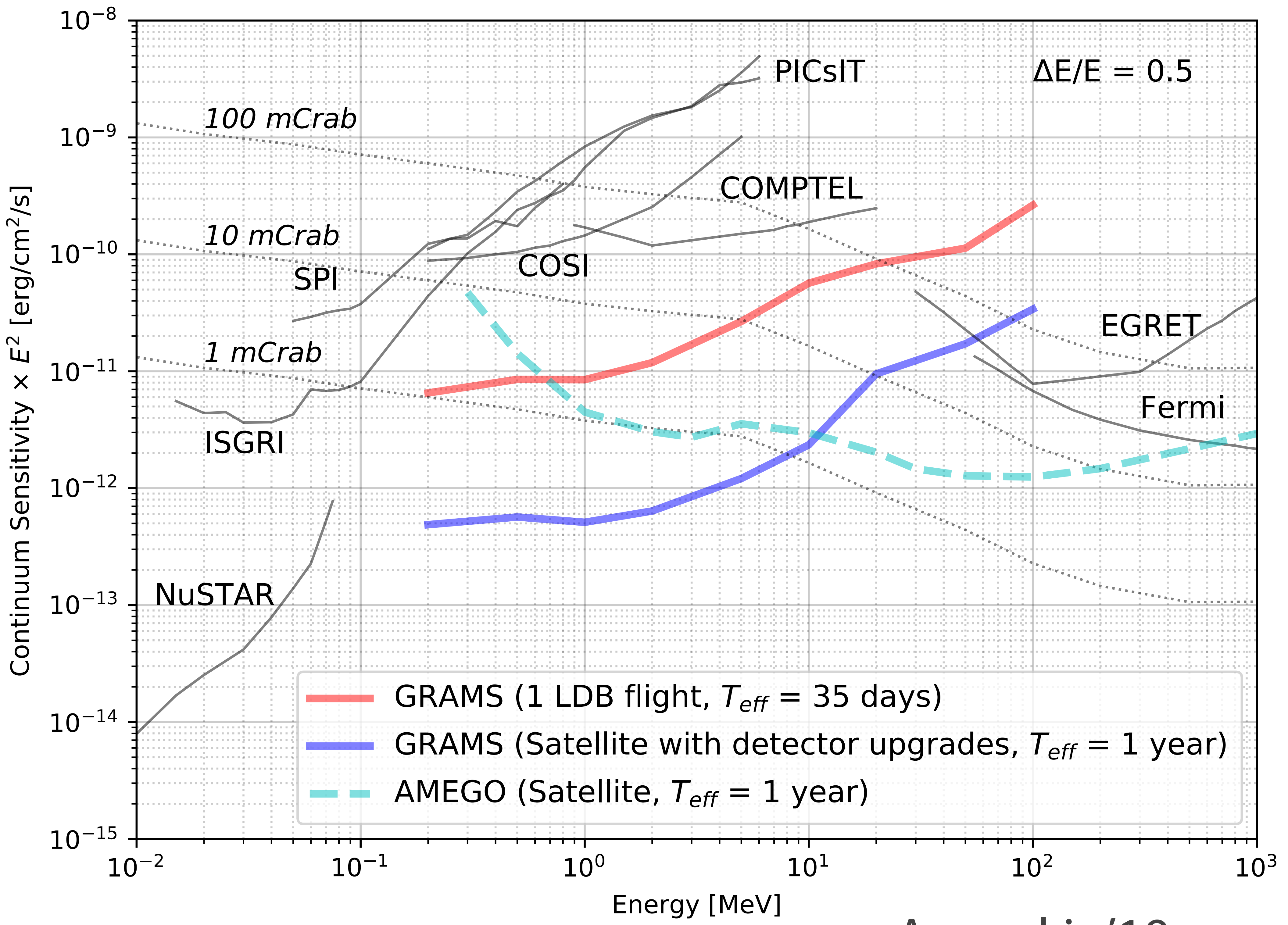


- ~20 members from US and Japan
  - We are expecting to have the first ballon flight in 5-7 years.

Gamma-ray Astronomy in 2020s



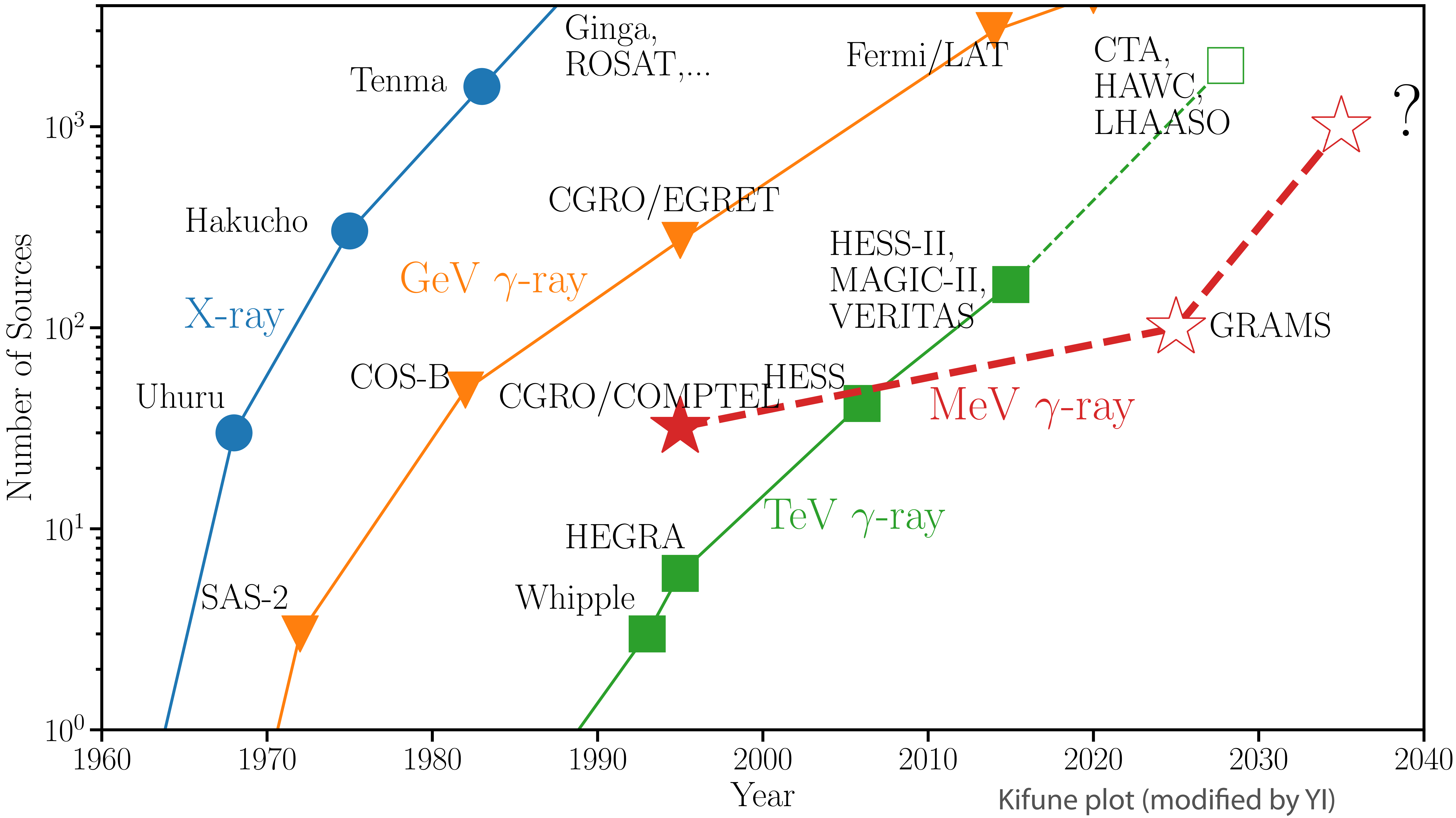
Bai+'19



Aramaki+'19

- At >20 GeV, CTA and LHAASO will enable us to observe >10 times fainter sources.
- In the MeV band, GRAMS will enable us to observe >10 times fainter sources.

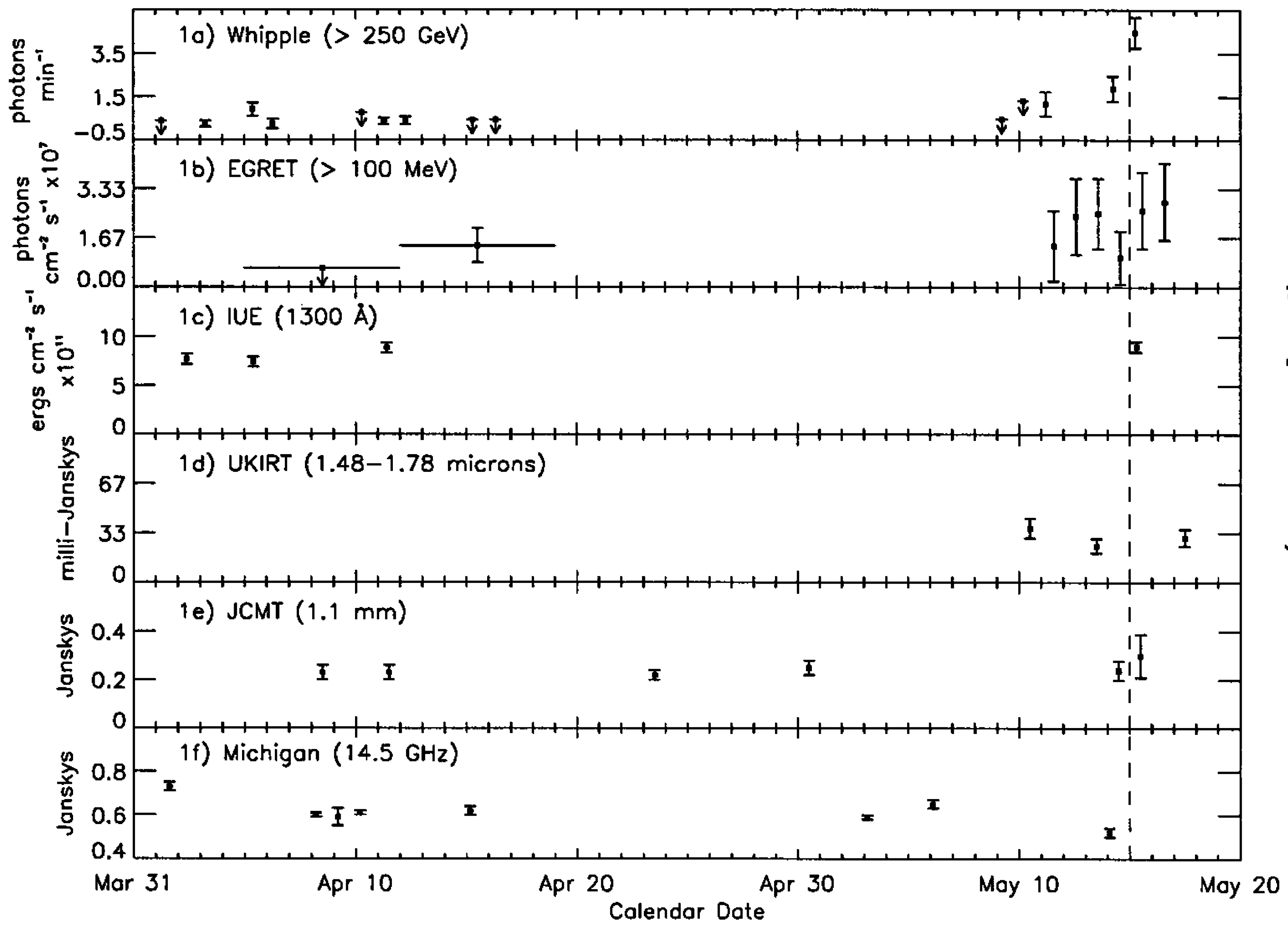
Number of Gamma-ray Objects

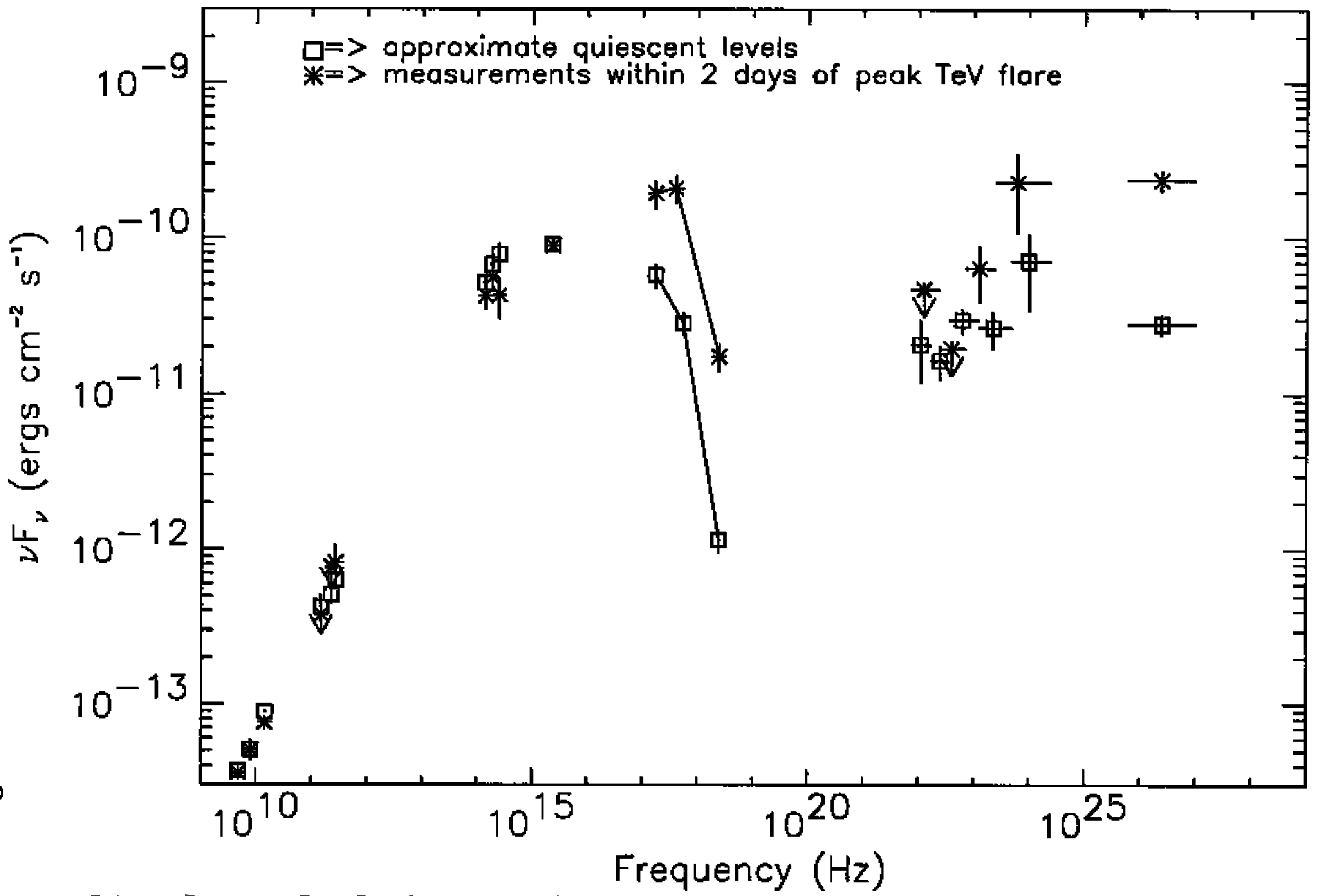


Kifune plot (modified by YI)

Multi-wavelength/Multi-messenger Astronomy?

Already Long History,,,

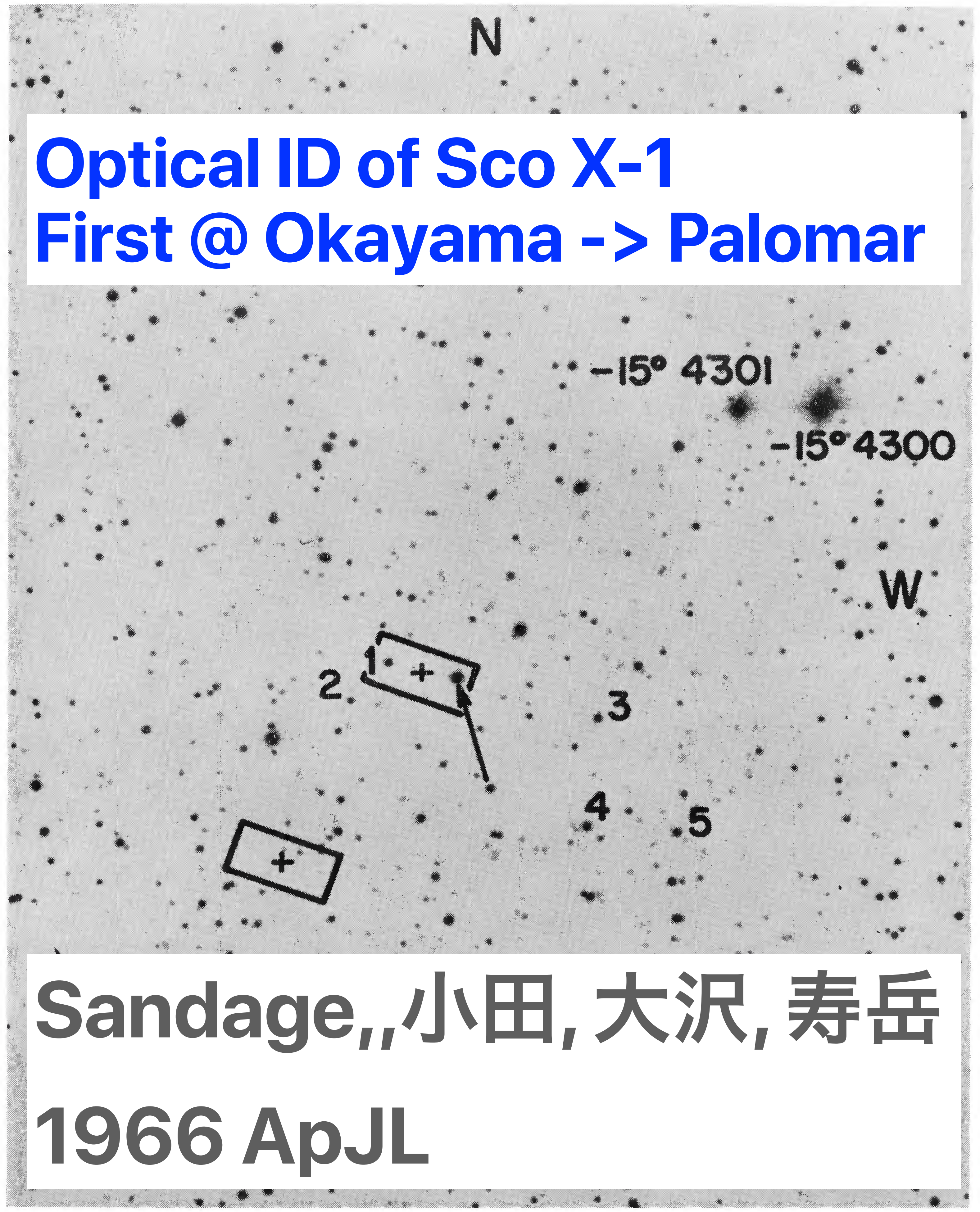




Macomb,,, 近藤, 窪, 牧野, 牧島, 高橋, 田代 1995 ApJL;

See also Takahashi+'1996

- Multi-wavelength astronomy has already started in 1995 (or 1966). **NOT in 2010s,,,,**
- How will you do in 2020s?



Optical ID of Sco X-1
First @ Okayama -> Palomar

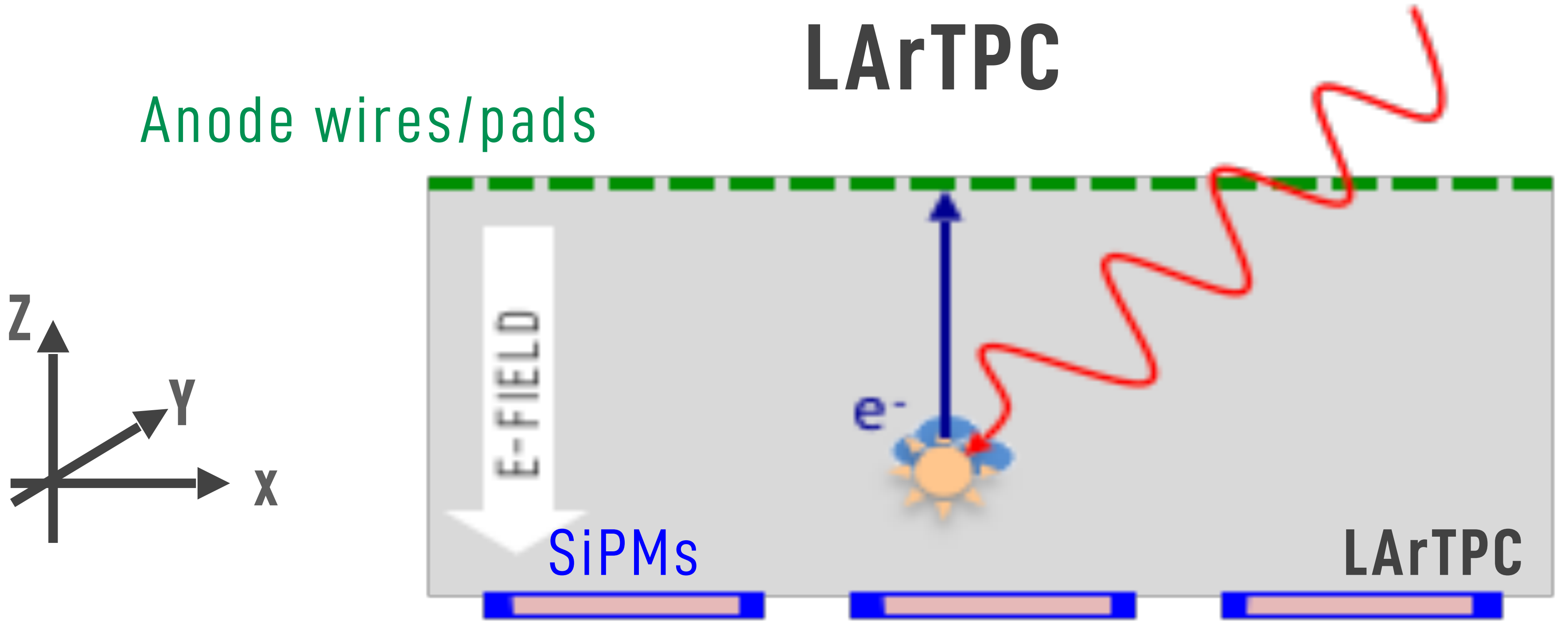
Sandage,,小田, 大沢, 寿岳
1966 ApJL

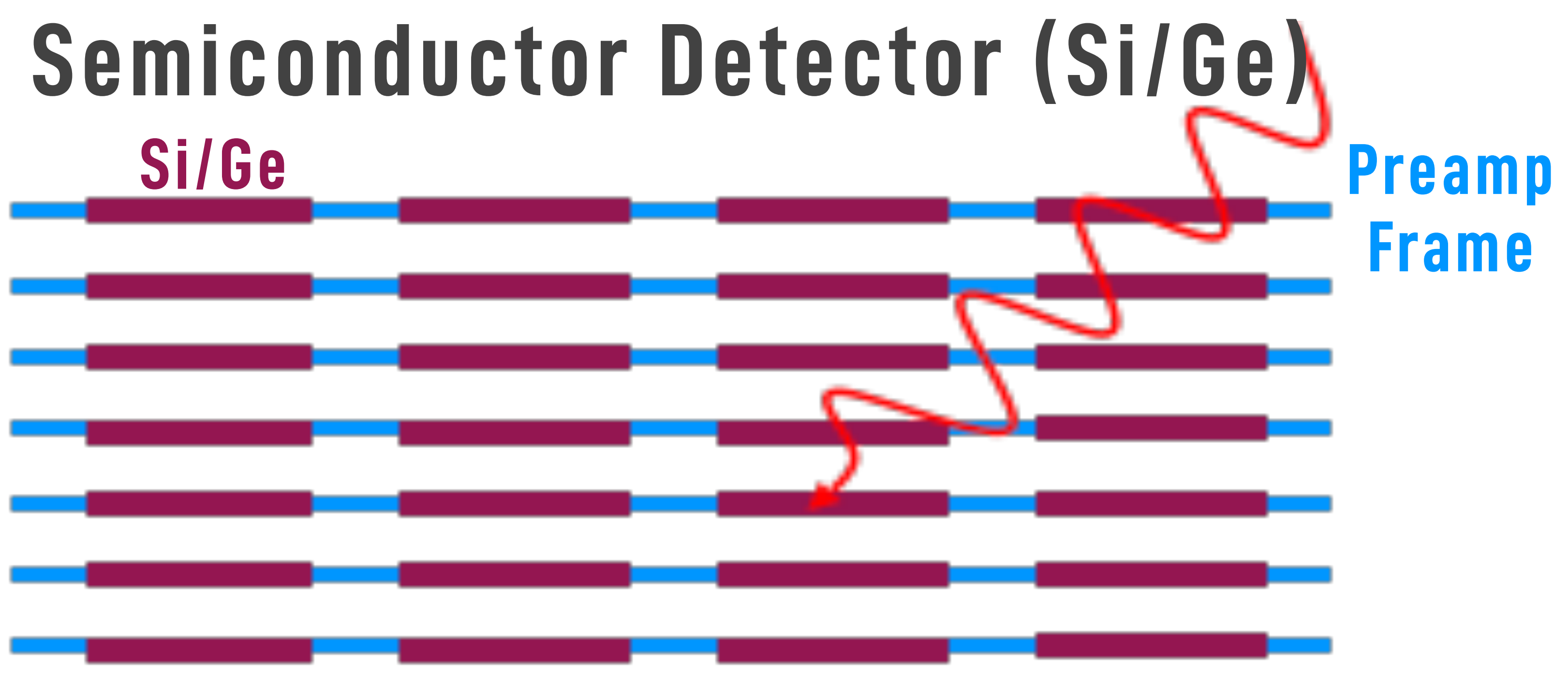
FIG. 1.—Photograph of the region containing the new X-ray position of Sco X-1, reproduced from the Palomar Sky Survey prints. The two equally probable X-ray positions are marked by crosses surrounded by a rectangle of 1 by 2 arc min. The object described in the text is marked with an arrow. The identifications of other stars for which photoelectric photometry exists are also marked.

Summary

- Jet power argument should be solved.
- Now gamma-ray observations start to measure the cosmic star formation history.
- New extended gamma-ray objects are emerging. CTA should study the detailed structure.
- What is your plan for the gamma-ray missions in the next 20, 30 years?

WHY LARTPC?



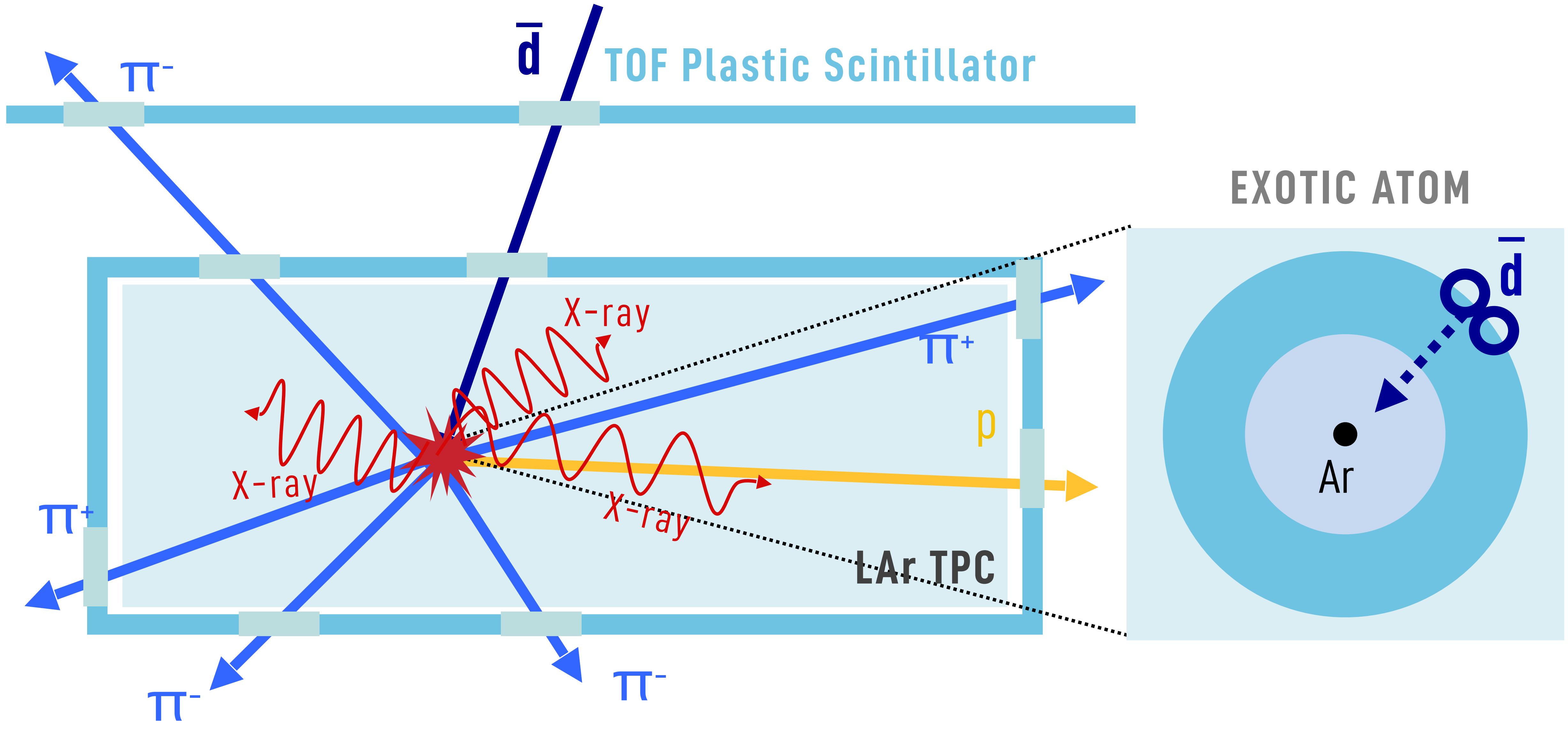


	LArTPC	Semiconductor (Si/Ge)
ρ (g/cm³)	1.4	2.3/5.3
$T_{operation}$	~80K	~240K/~80K
Cost	$	$$$
Signal	scintillation light + Ionization electrons	electrons, holes
X, Y Positions	wires on anode plane (X-Y)	double-sided strips
Z position	from drift time	from layer #
# of Layers	1 layer	multi-layers
# of Electronics	#	###
Dead Volume	almost no dead volume	detector frame, preamps
Neutron bkg	Identified with pulse shape	No rejection capability

LARTPC IS COST-EFFECTIVE AND EASILY EXPANDABLE TO A LARGER-SCALE, MUCH LESS CHANNELS/ELECTRONICS REQUIRED, ALMOST NO DEAD VOLUME

GRAMS ANTIMATTER DETECTION CONCEPT

MEASURE ATOMIC X-RAYS AND ANNIHILATION PRODUCTS



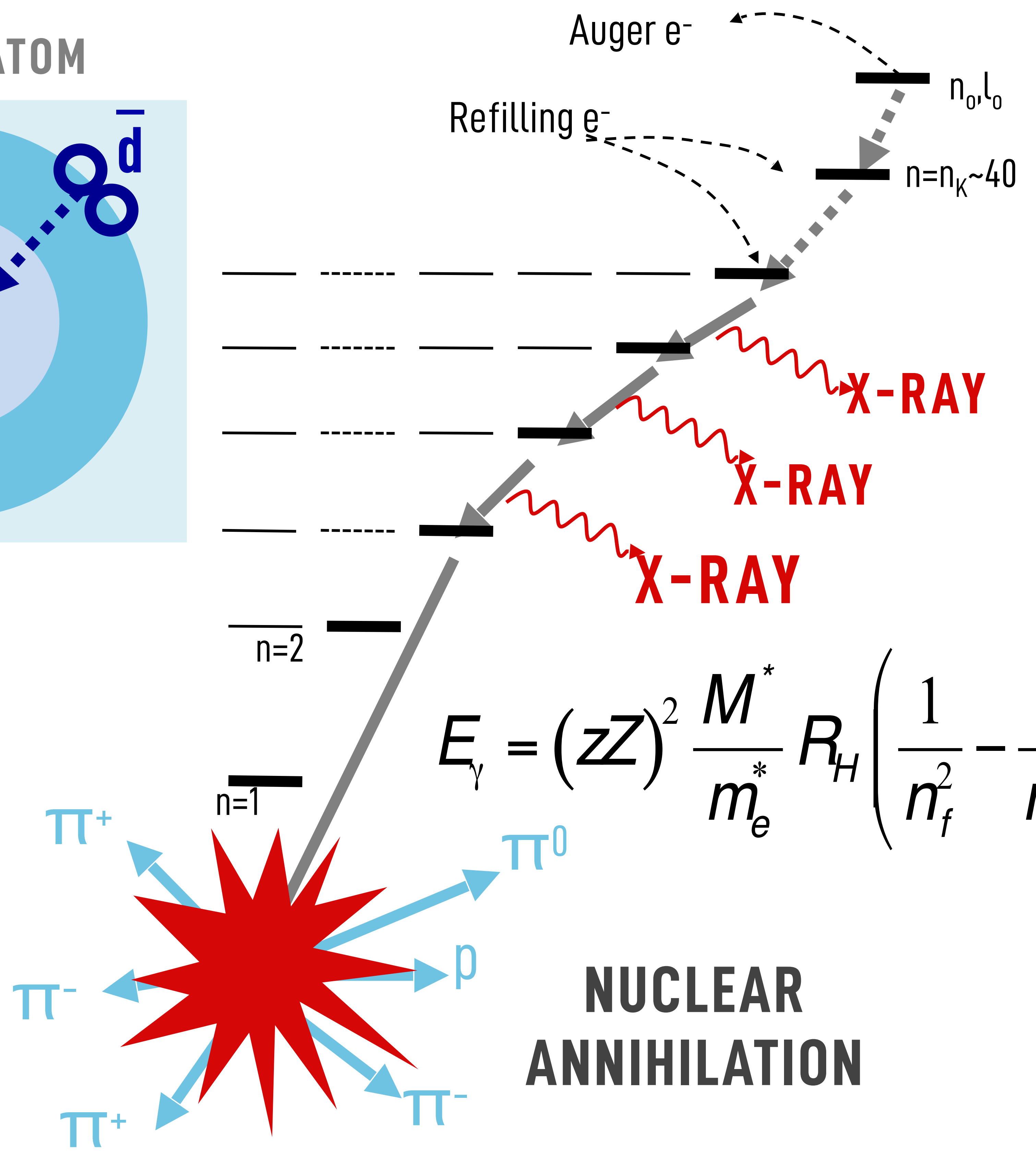
A time of flight (TOF) system tags candidate events and records velocity

The antiparticle slows down & stops, forming an excited exotic atom

De-excitation X-rays provide signature

Annihilation products provide additional background suppression

ATOMIC TRANSITIONS



$$E_\gamma = (zZ)^2 \frac{M^*}{m_e^*} R_H \left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

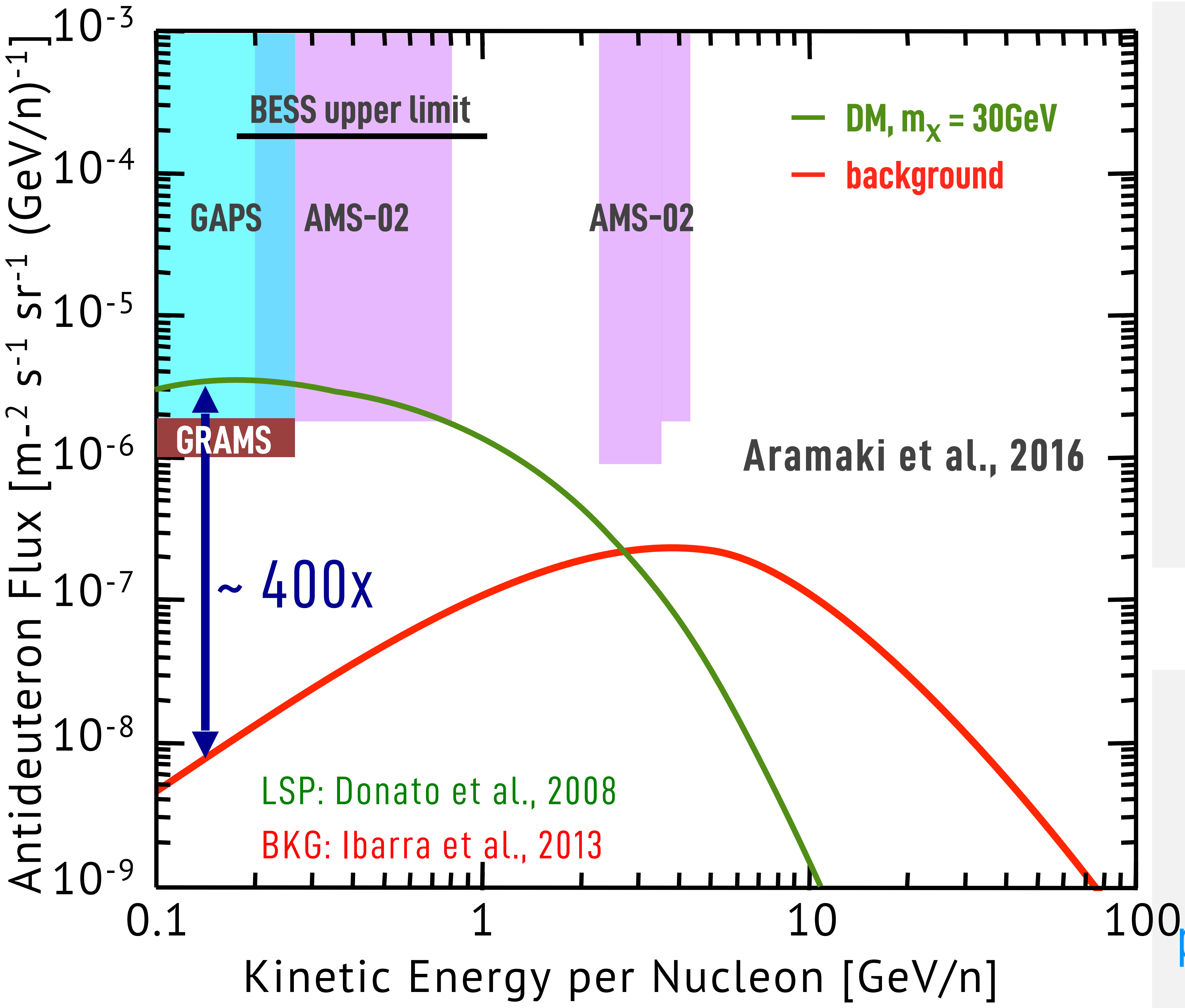
Aramaki et al., 2013

Concept proven with accelerator beam test

Cascade model developed for X-ray yields

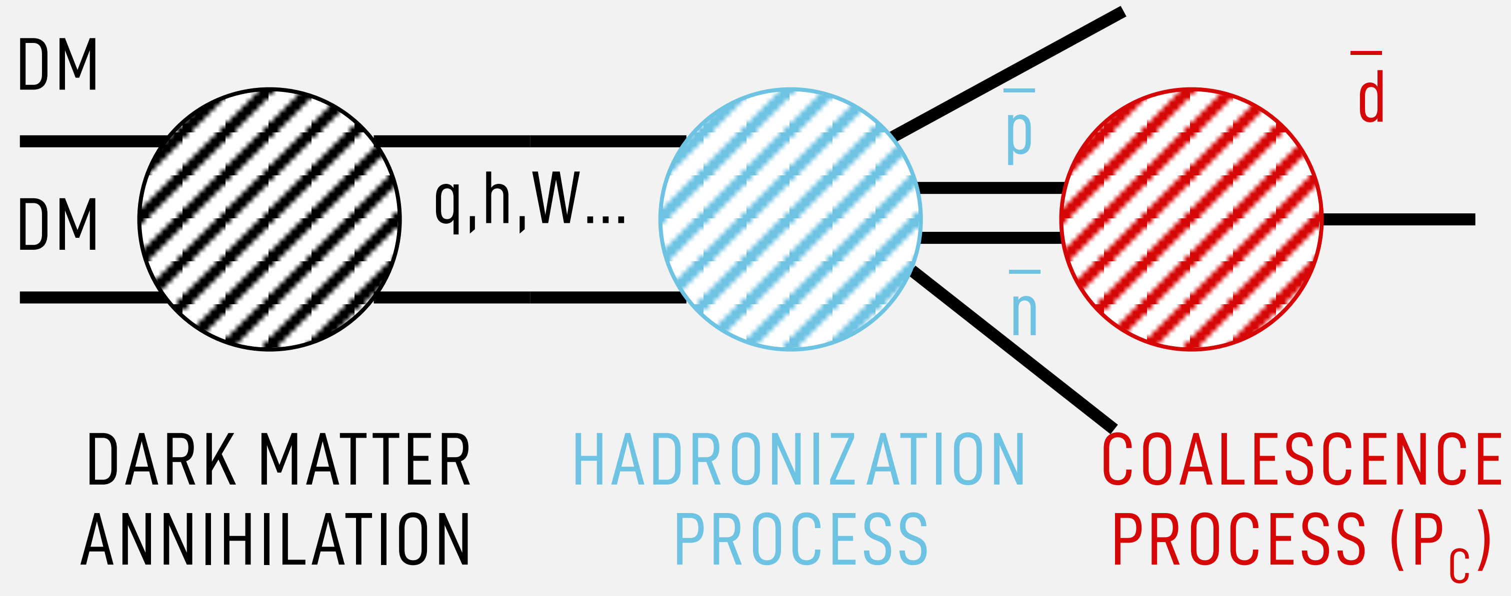
WHY ANTIDEUTERONS?

BACKGROUND-FREE DM SEARCH AT LOW-ENERGY



PRIMARY FLUX

DM ANNIHILATION/DECAY



SECONDARY FLUX

COSMIC RAY INTERACTION

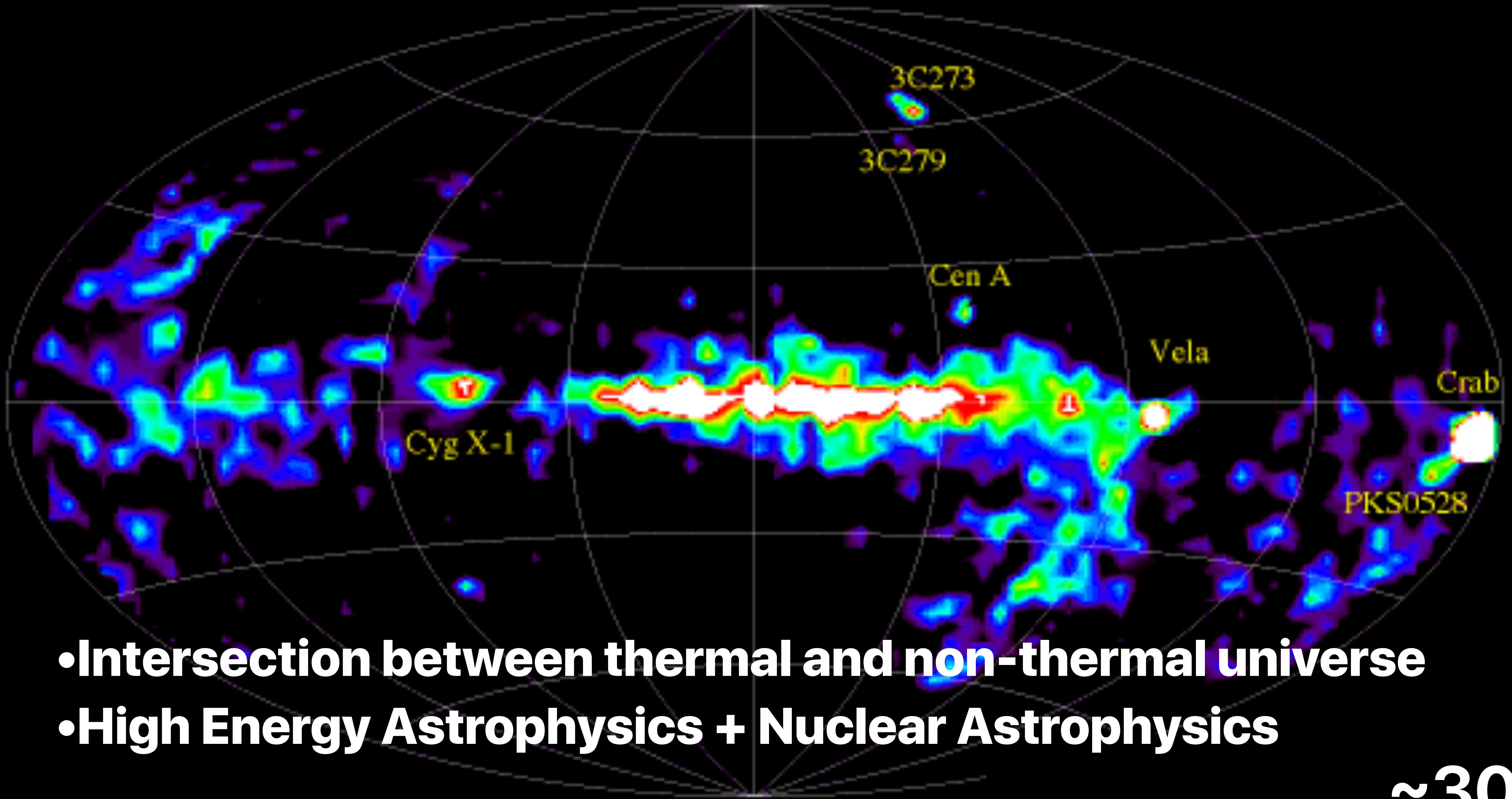
$\bar{d}$

p (CR) +H (ISM) $\rightarrow$ p + H + p + n + $\bar{p}$ + $\bar{n}$

GAPS FIRST SCIENCE FLIGHT IS SCHEDULED FROM ANTARCTIC IN 2021

GRAMS: NEXT-GENERATION EXPERIMENT

MeV Gamma-ray Sky



- Intersection between thermal and non-thermal universe
- High Energy Astrophysics + Nuclear Astrophysics

~30 objects

Note: 56 Candidates in GW now

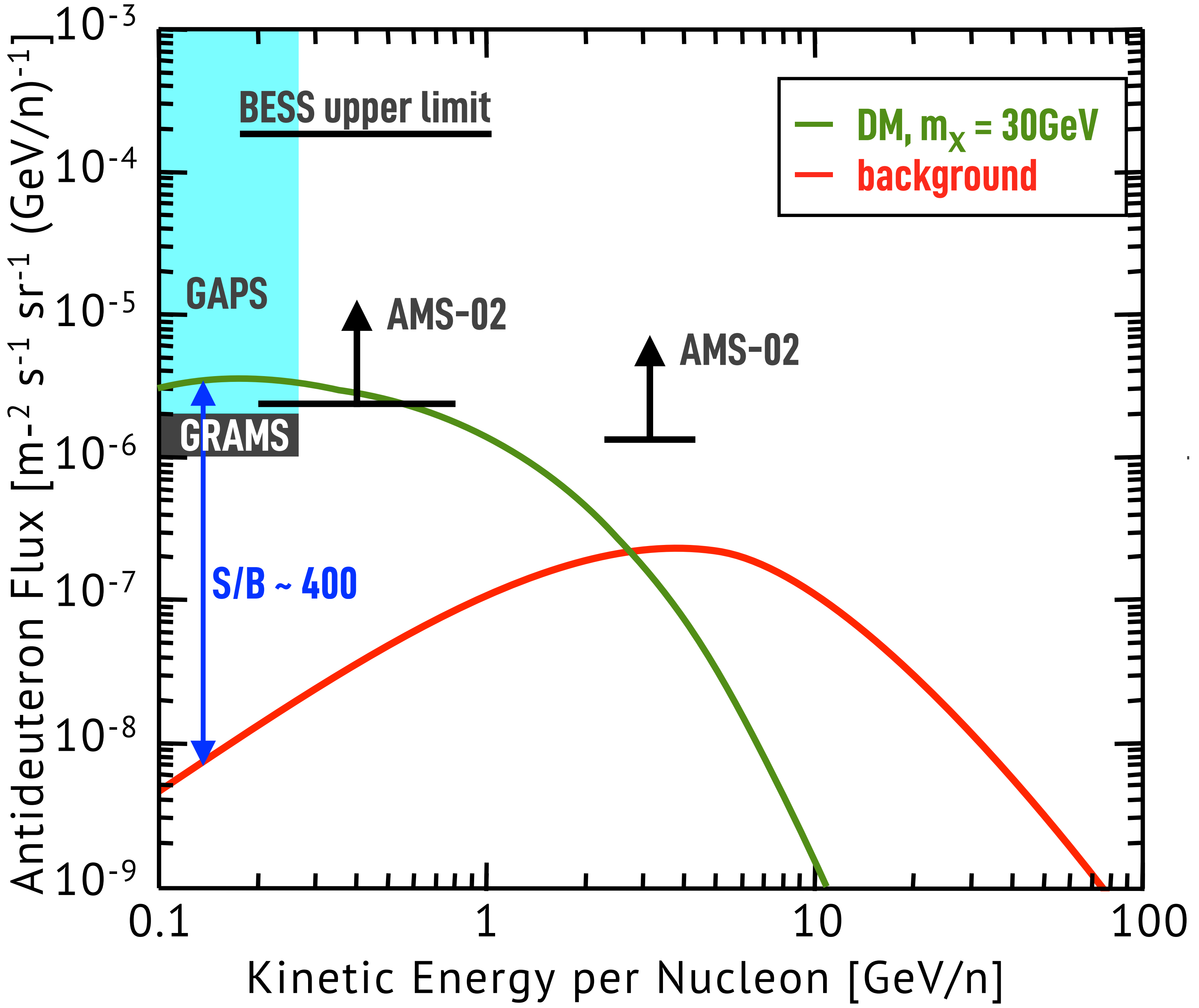
COMPTEL

$> 1 \times 10^{-10}$ erg/cm²/s

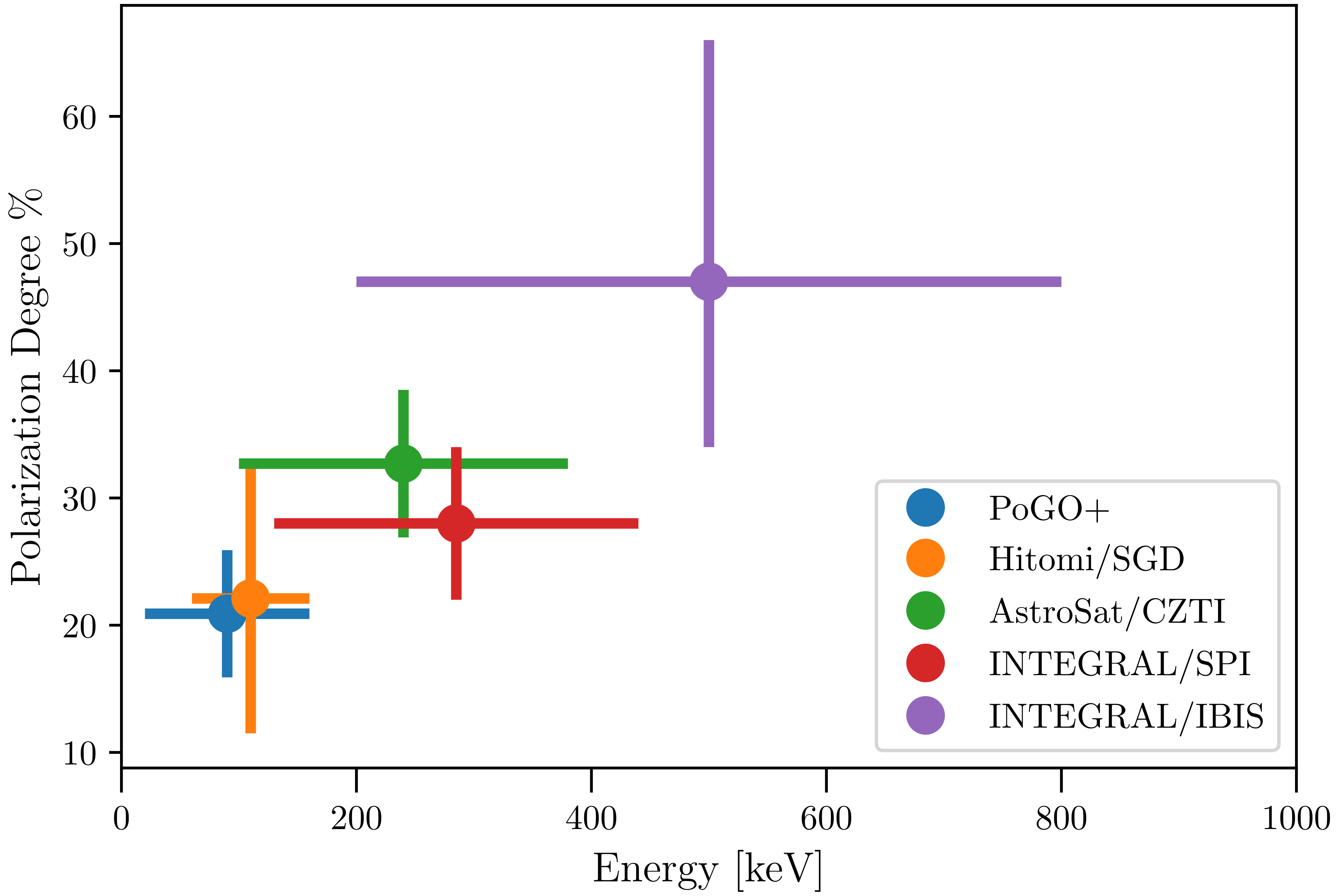

MeV Gamma-ray Science
Dark Matter
X-ray/γ-ray Binaries
➡ Hiroki Yoneda's talk
SNRs & PWN
Sun
Terrestrial
Flashes
Novae
NS merger
Starburst Galaxies
Seyferts
Gamma-ray bursts
Blazars
Radio
Galaxies
Type-Ia
SNe
Galactic Center
Pulsars & Magnetars
DISTANCE
Background
Further details
➡ Reshmi Mukherjee's talk

More Consideration Needed For

Antideutron Searches



Polarization of the Crab nebula



- Dark Matter Search from Anti-matter
  - Unique point of GRAMS

➡*Kerstin Perez's Talk*

- Polarization at MeV band
  - Unique point of Compton camera