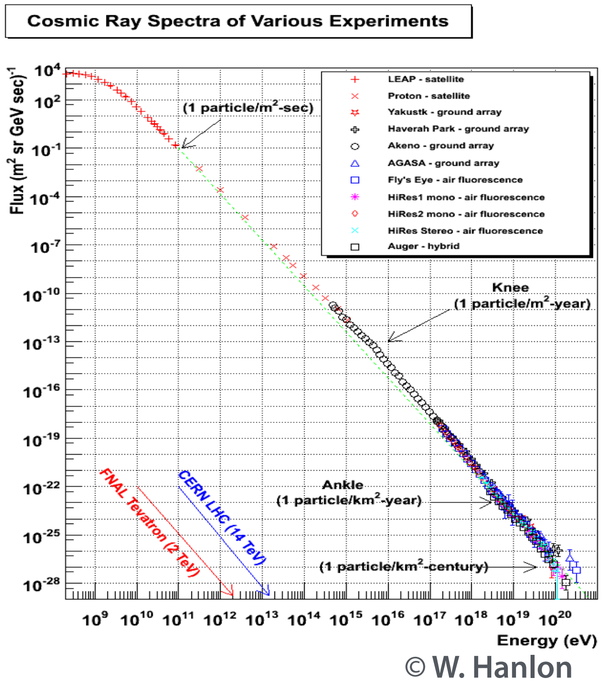
Future Prospects of MeV Gamma-ray Astronomy

Yoshiyuki Inoue

Connecting high-energy astroparticle physics for origins of cosmic rays and future perspectives
@ Online, 2020-12-09

Particle Acceleration



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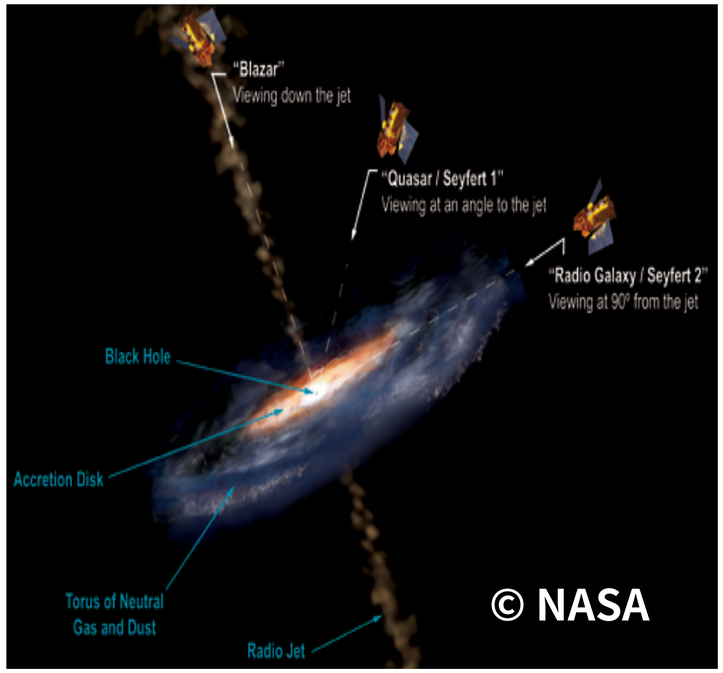
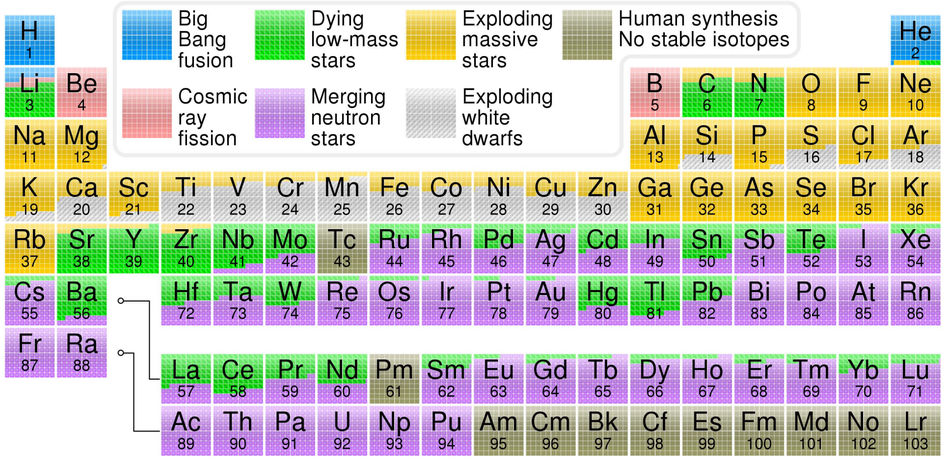
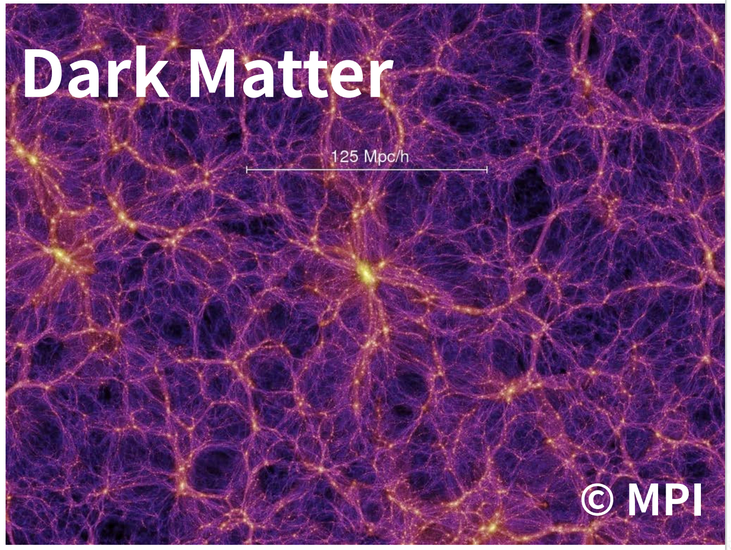
Relativistic Jets

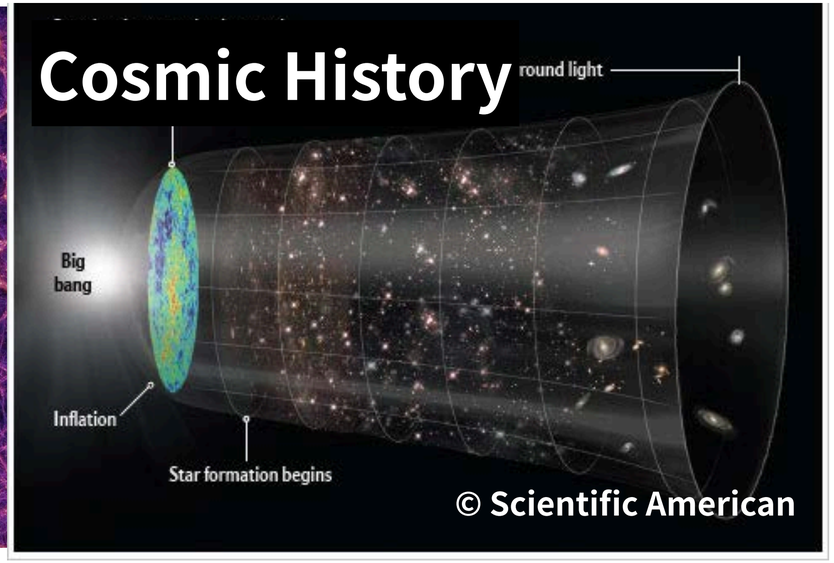


Why MeV Gamma-ray Astrophysics?

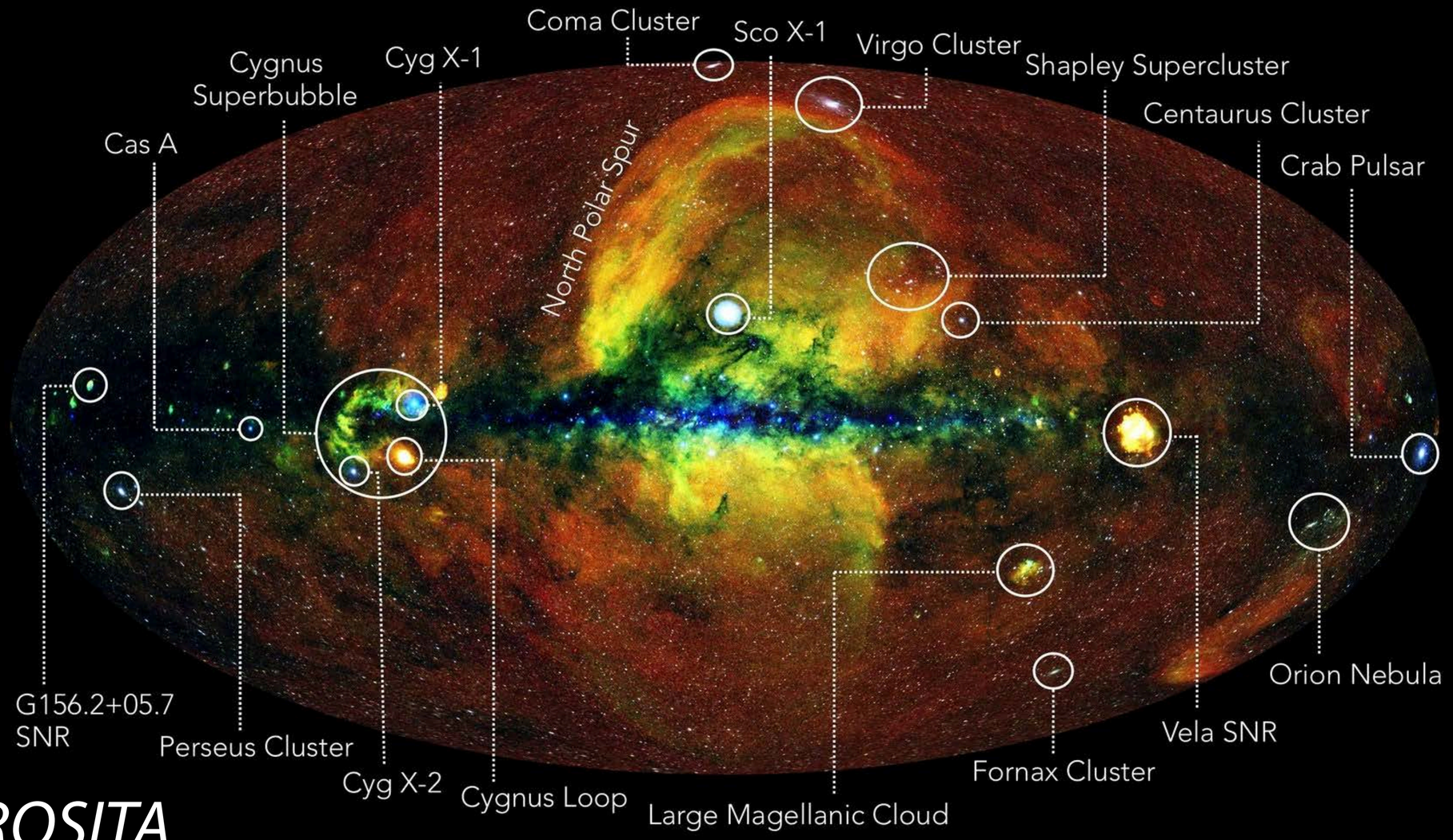
Origin of Matter







Soft X-ray Sky (0.3-2.3 keV)

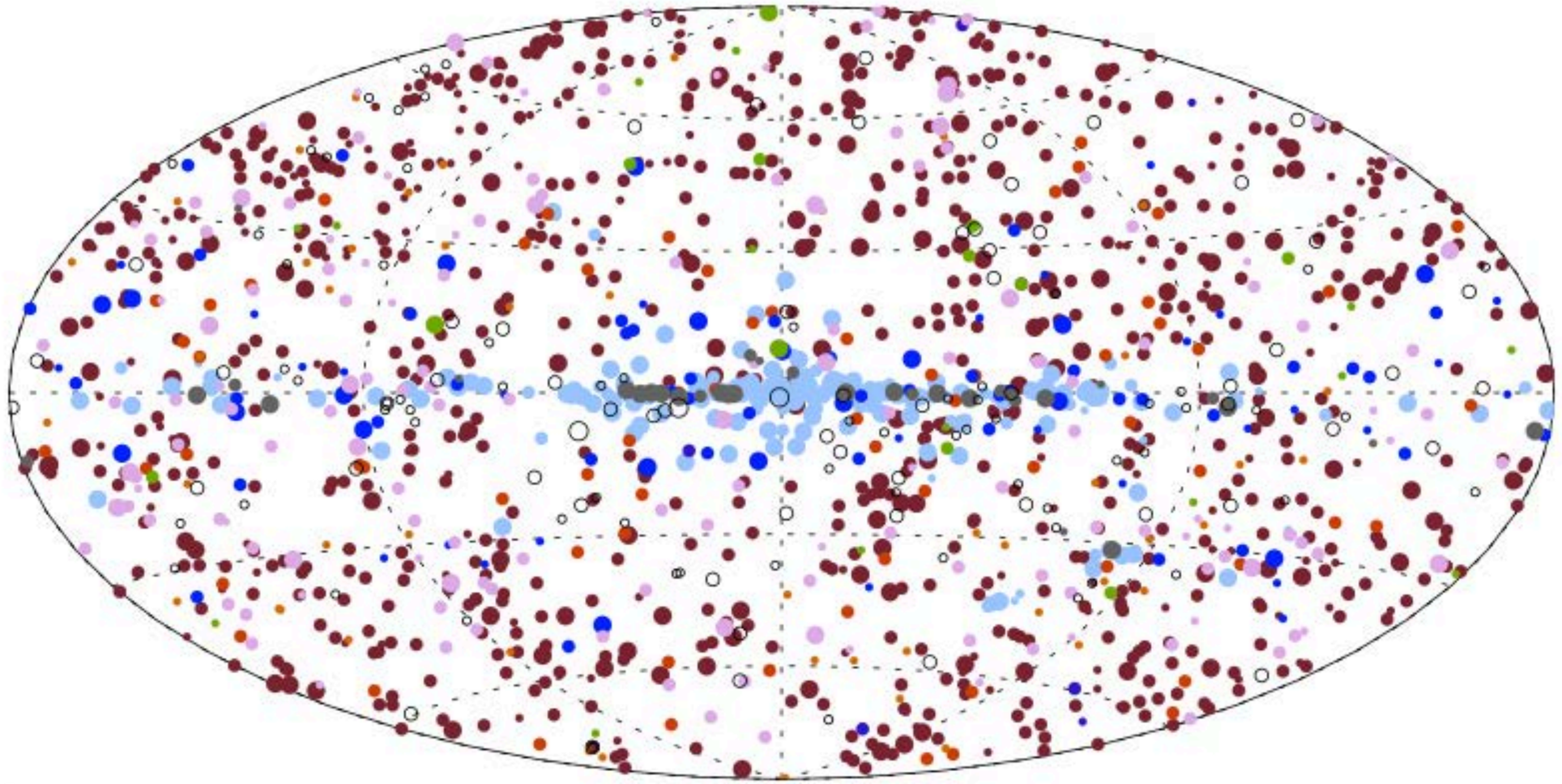


SRG/e-ROSITA
6-month survey

$> 1 \times 10^{-14}$ erg/cm²/s

~10⁶ objects

Hard X-ray Sky (14-195 keV)

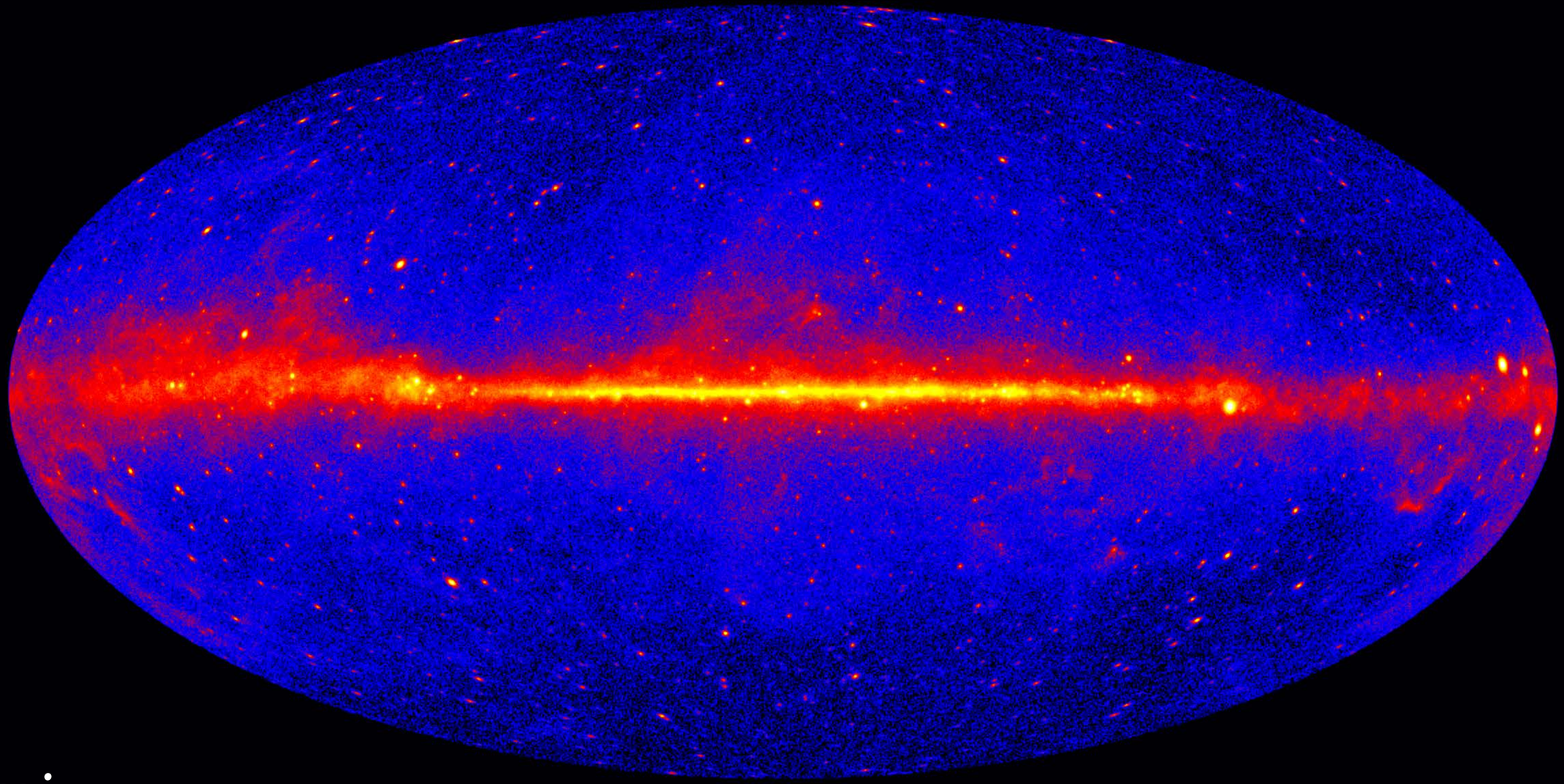


Swift/BAT
105-month survey

$> 7 \times 10^{-12}$ erg/cm^2/s

~1600 objects

GeV Gamma-ray Sky (0.1-100 GeV)

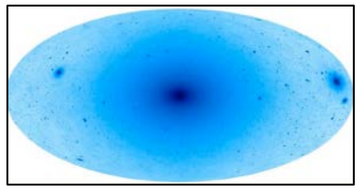


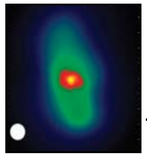
Fermi
5-year survey

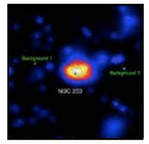
$> 2 \times 10^{-12}$ erg/cm^2/s

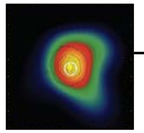
~5000 objects

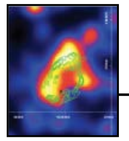
GeV Gamma-ray Objects

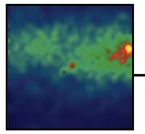

Dark Matter searches

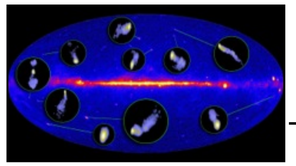

Radio Galaxies

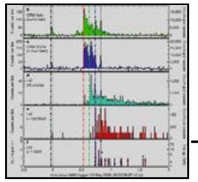

Starburst Galaxies


Globular Clusters

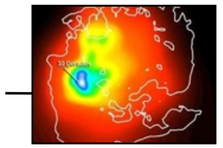

SNRs & PWN

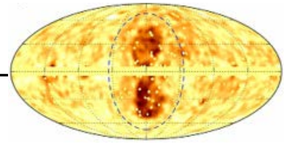

Novae


Blazars

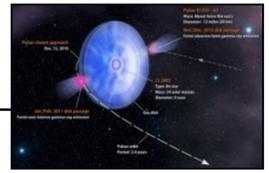

GRBs

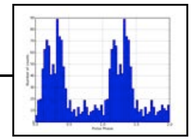
Extragalactic

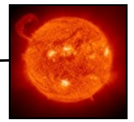

LMC & SMC


Fermi Bubbles

Galactic


γ-ray Binaries

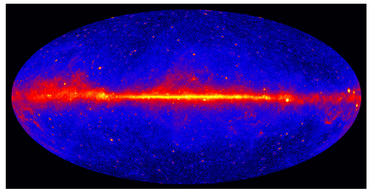

Pulsars: isolated, binaries, & MSPs


Sun: flares & CR interactions

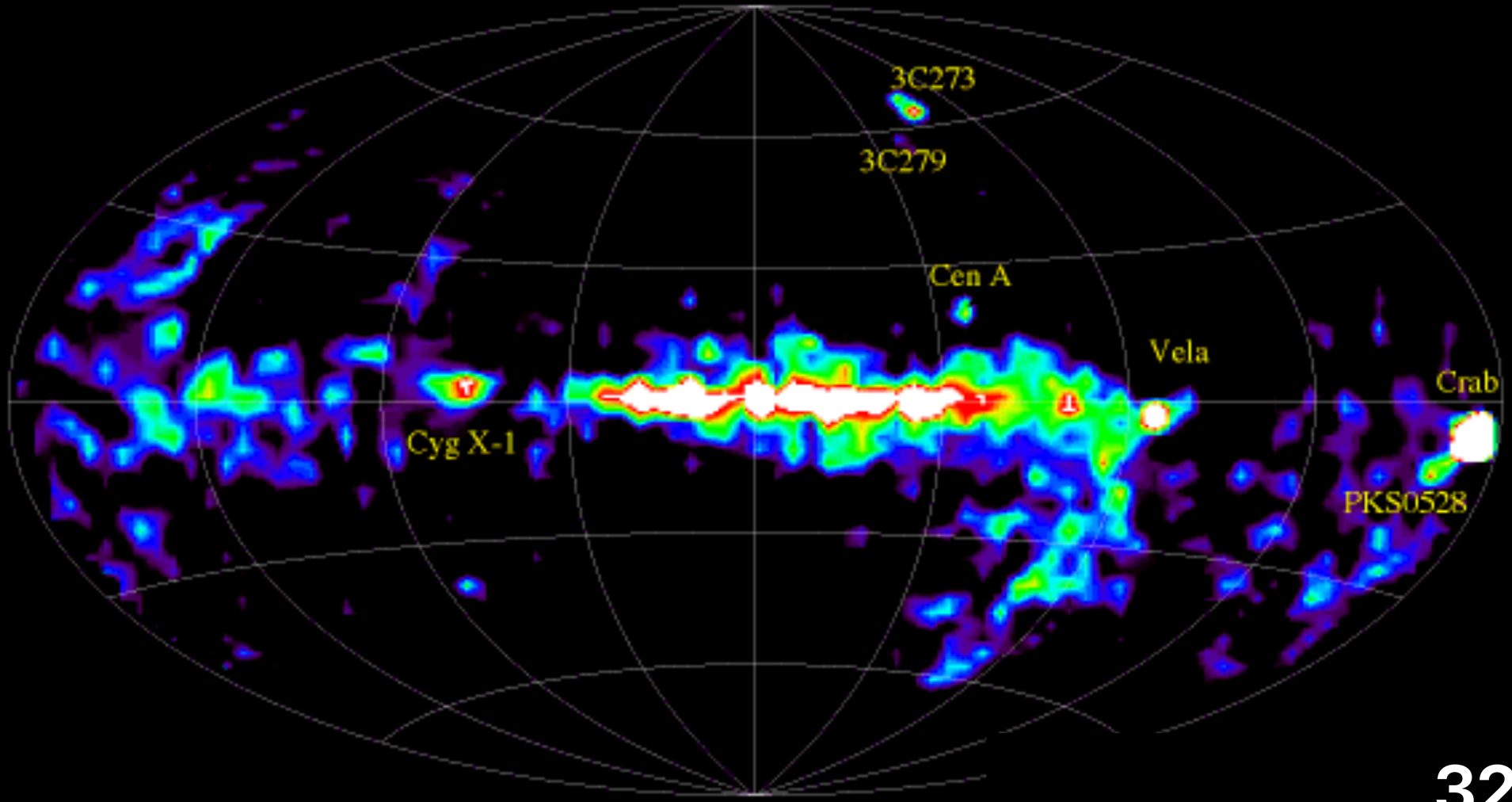

Terrestrial γ-ray Flashes

Unidentified Sources

Background



MeV Gamma-ray Sky



COMPTEL

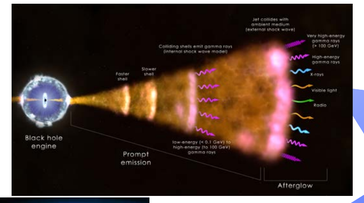
$> 1 \times 10^{-10}$ erg/cm^2/s

32 objects

Note: >50 Candidates in GW now

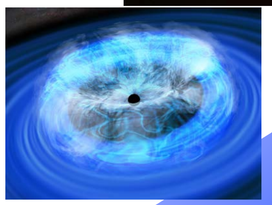
MeV Gamma-ray Science

Gamma-ray bursts

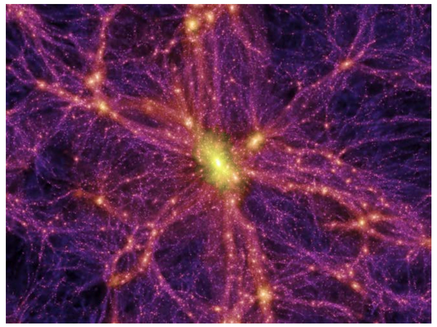


Blazars

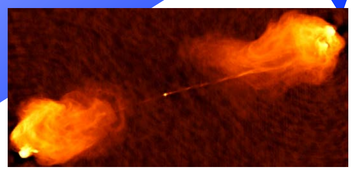
Seyferts



Dark Matter

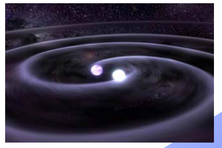


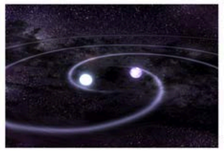
Starburst Galaxies

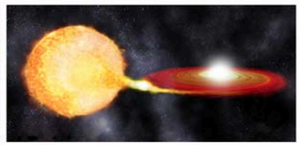


Radio Galaxies

NS merger

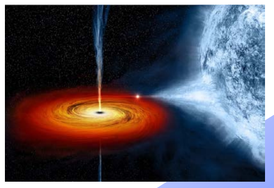




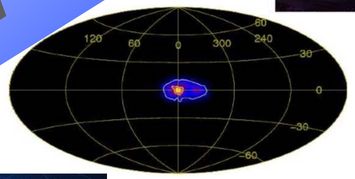


Type-Ia SNe

X-ray/γ-ray Binaries

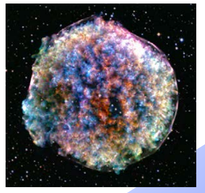


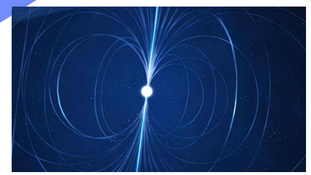
DISTANCE



Galactic Center

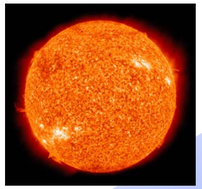
SNRs & PWN



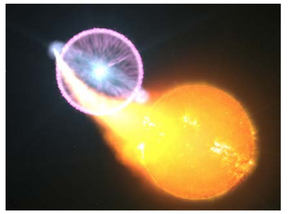


Pulsars & Magnetars

Sun

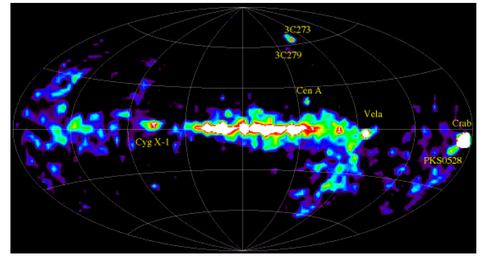


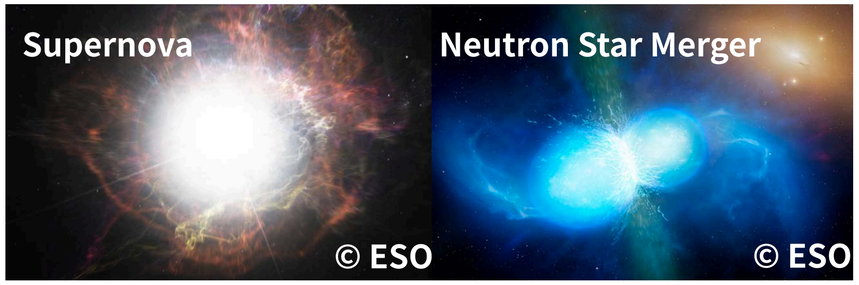
Novae



Terrestrial Flashes

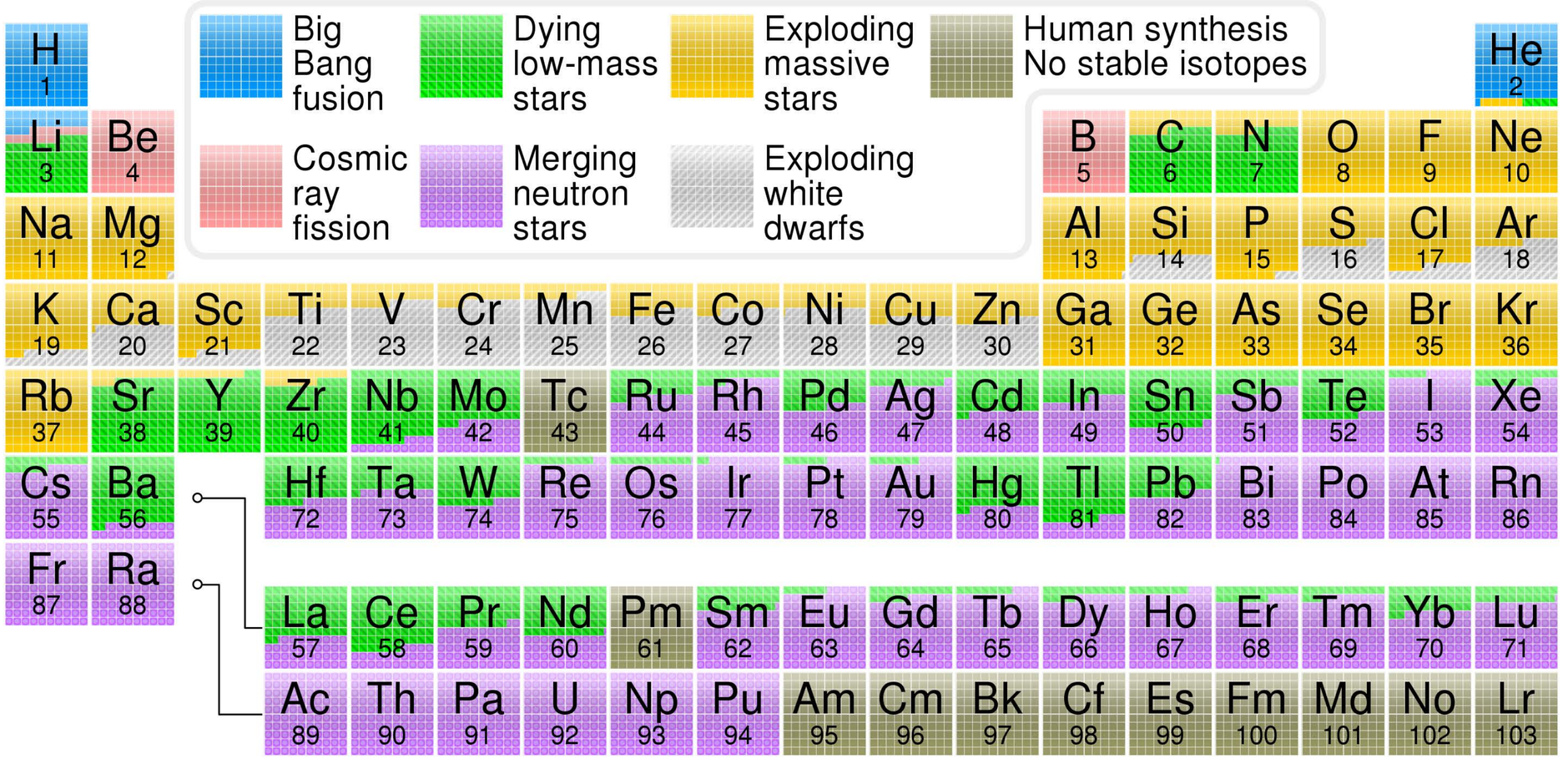
Background





Nuclear processes: Gamma-ray Lines

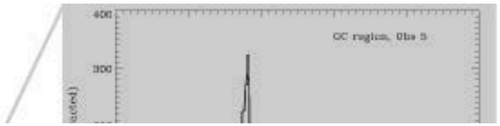
Transitions between nuclear energy levels



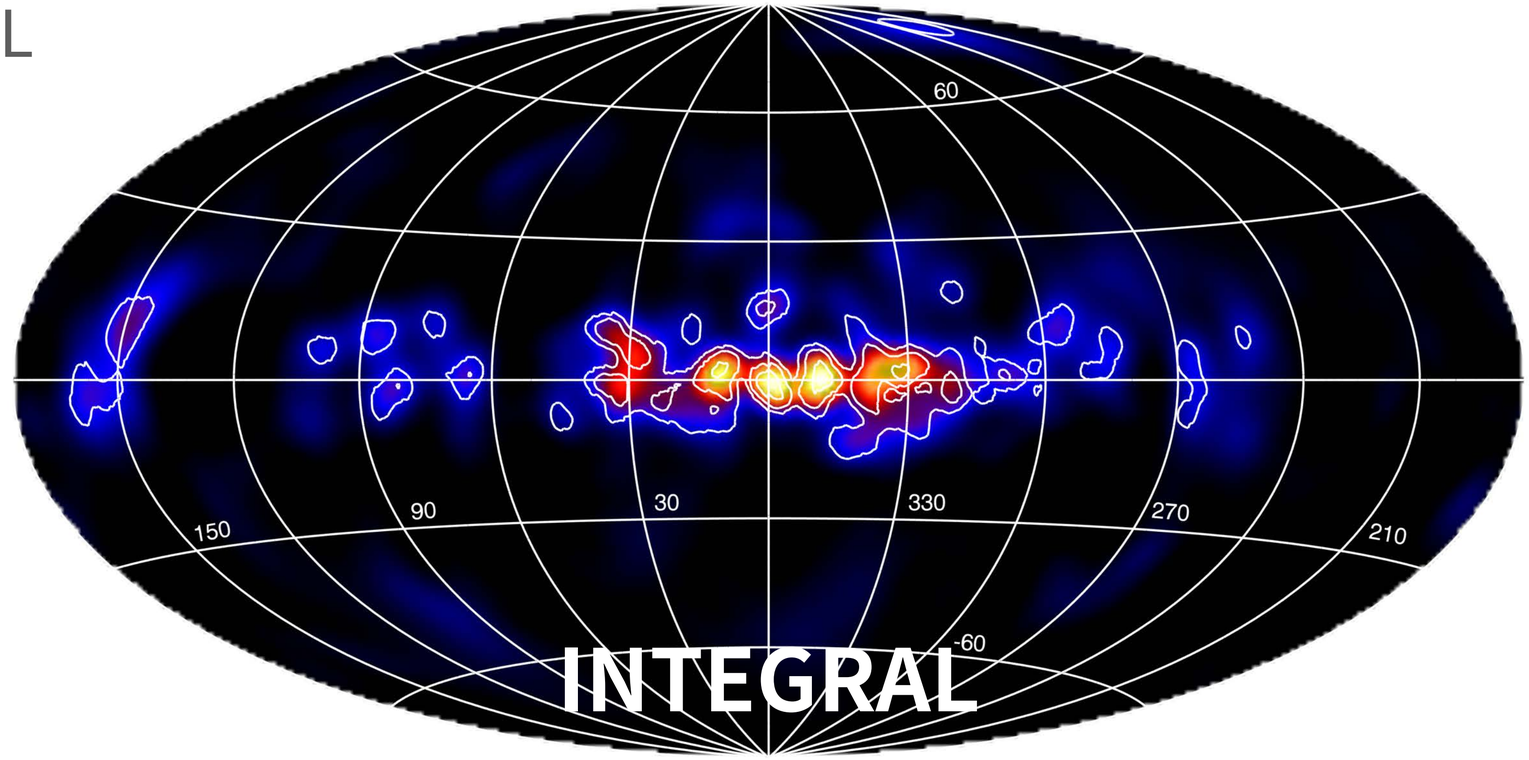
© Wikipedia

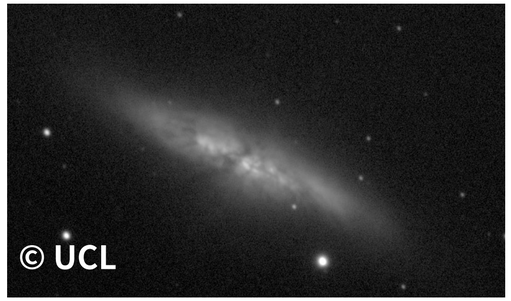
All-sky image of 1.8 MeV ^{26}Al gamma-ray line

Tracing massive young star formation activity



- INTEGRAL confirms COMPTEL
  - confined in the galaxy.
- scale height: ~800 pc (Pleintinger+’19; Wang+’20)
  - ~50 pc for young stars
- Foreground local structure? (Fujimoto+’20)

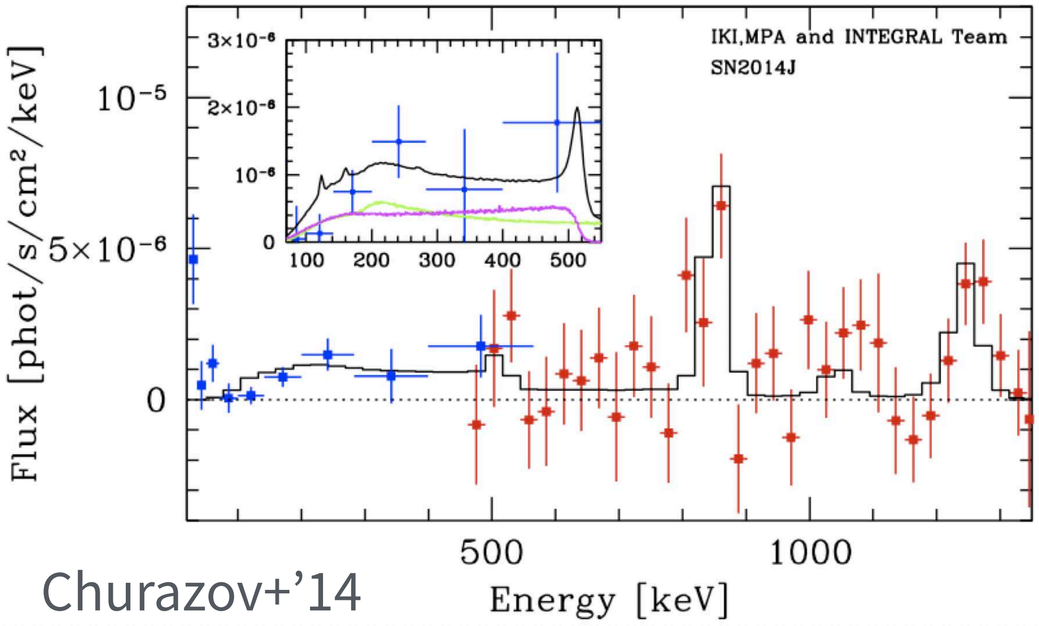




SN 2014J in M 82

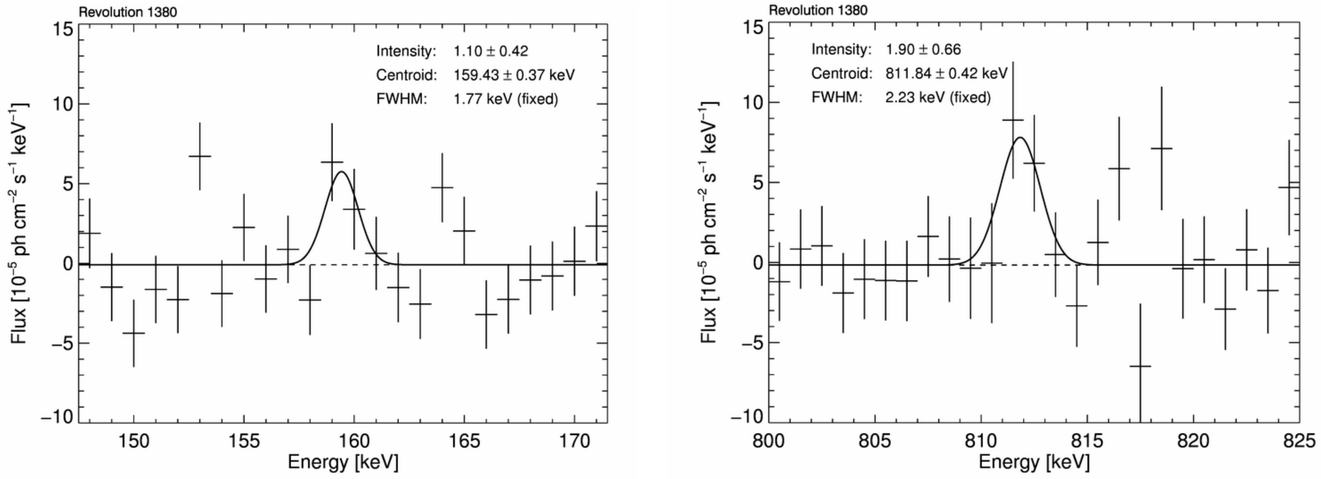
Type Ia SN: Thermonuclear explosion ^{56}Ni → ^{56}Co → ^{56}Fe

^{56}Co Lines: 50-100 days after the explosion



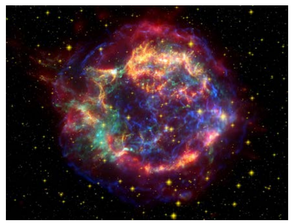
Churazov+'14

^{56}Ni Lines: ~17.5 days after the explosion



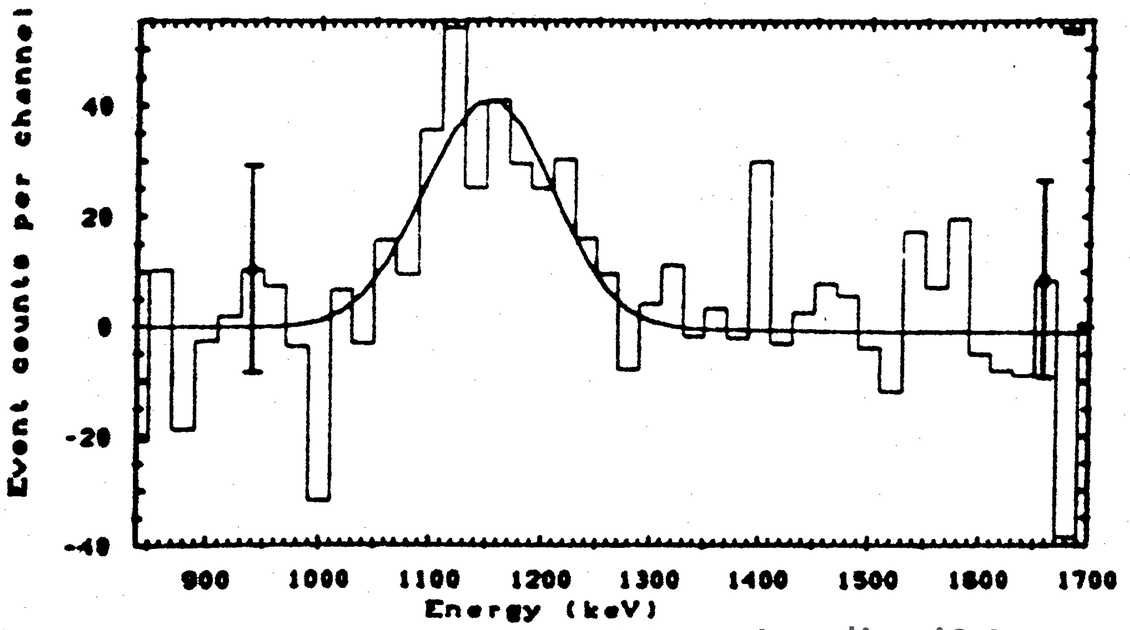
Diehl+'14

- 158 & 812 keV lines from ^{56}Ni ($\tau \sim 8.8$ days)
- 847 & 1238 keV lines from ^{56}CO ($\tau \sim 77$ days)
- $\sim 0.6 M_{\odot}$ of ^{56}Ni

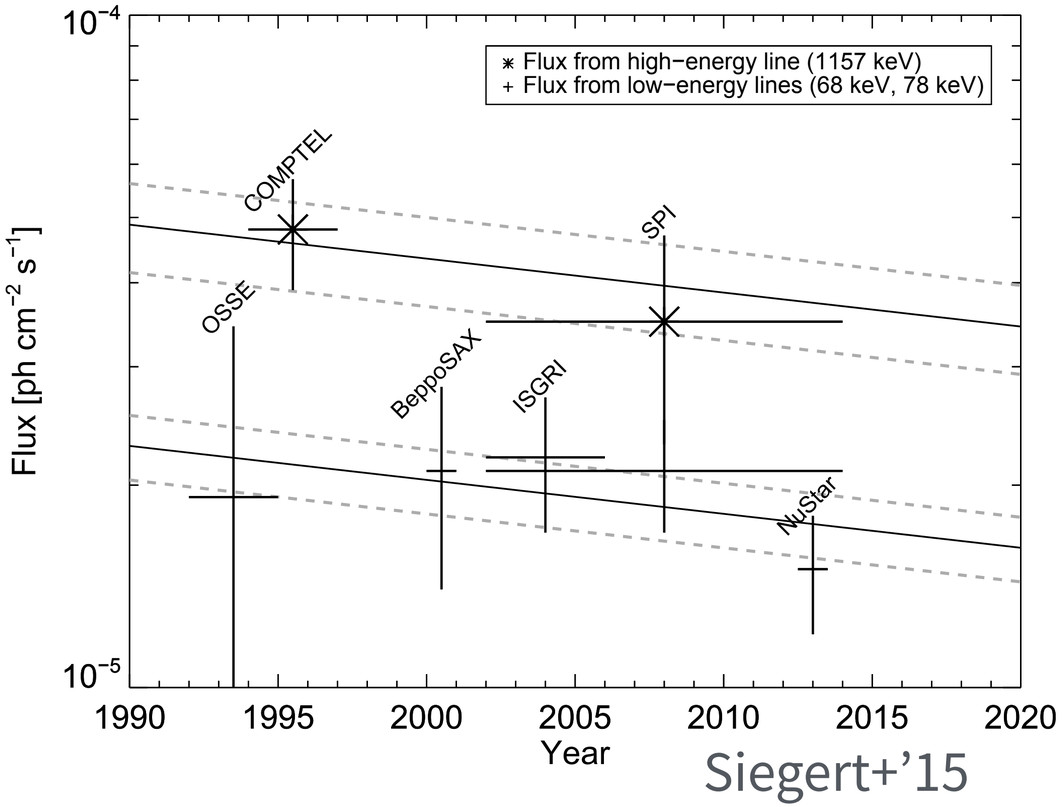


COMPTEL/INTEGRAL observation of Cas A

^{44}Ti line @ 1.16 MeV

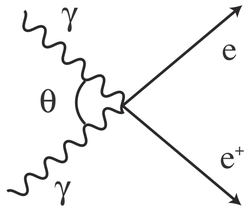


Iyudin+'94



Siegert+'15

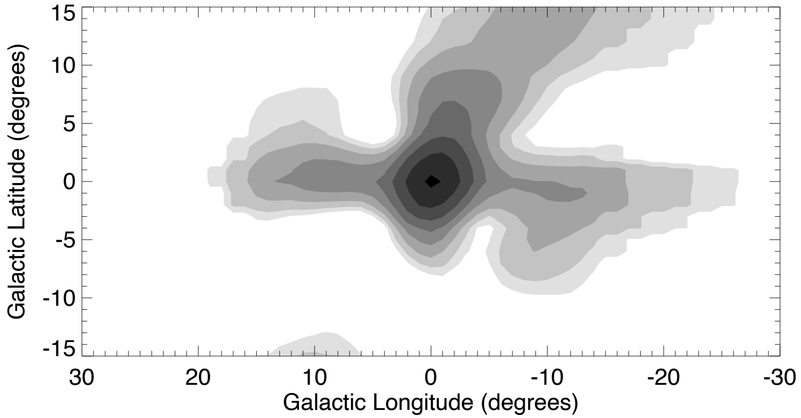
- 1.16 MeV ^{44}Ti line from Cas A is detected
- Flux should change with time.



Particle physics processes: Gamma-ray Lines

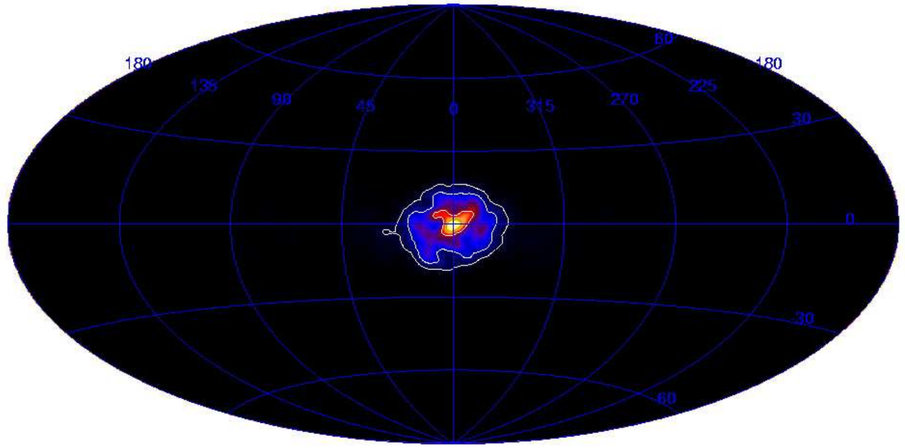
511 keV e^+e^- annihilation line from Galactic Center

OSSE



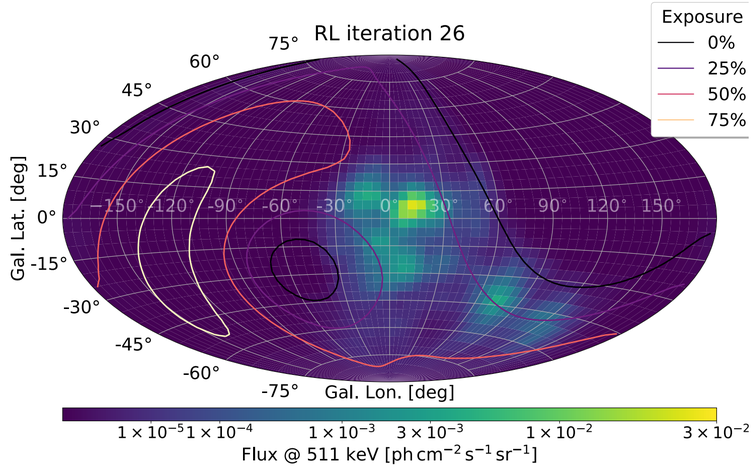
Purcell+'97

INTEGRAL



Knödlseder+'05

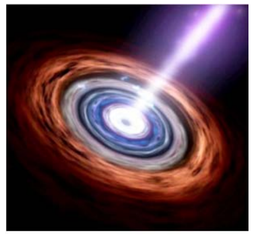
COSI



Siegert+'20

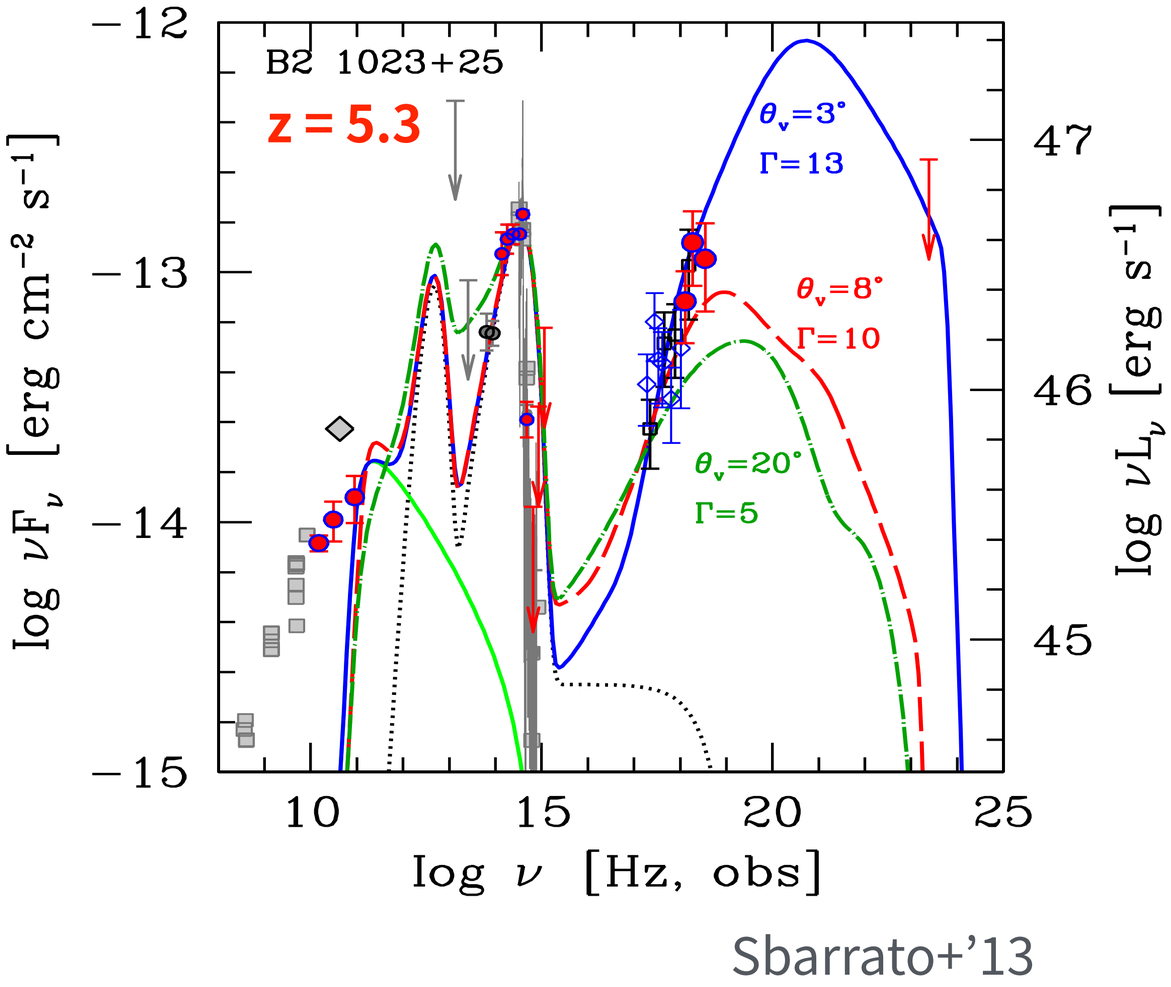
- Clear excess toward the direction of the Galactic Center
- Detailed morphology is still not clear

- Various origins are proposed
  - SNe Ia, LXMBs, Microquasars, RIAF,,,, (e.g., Prantzos '06; Guessoum+'06; Totani '06)

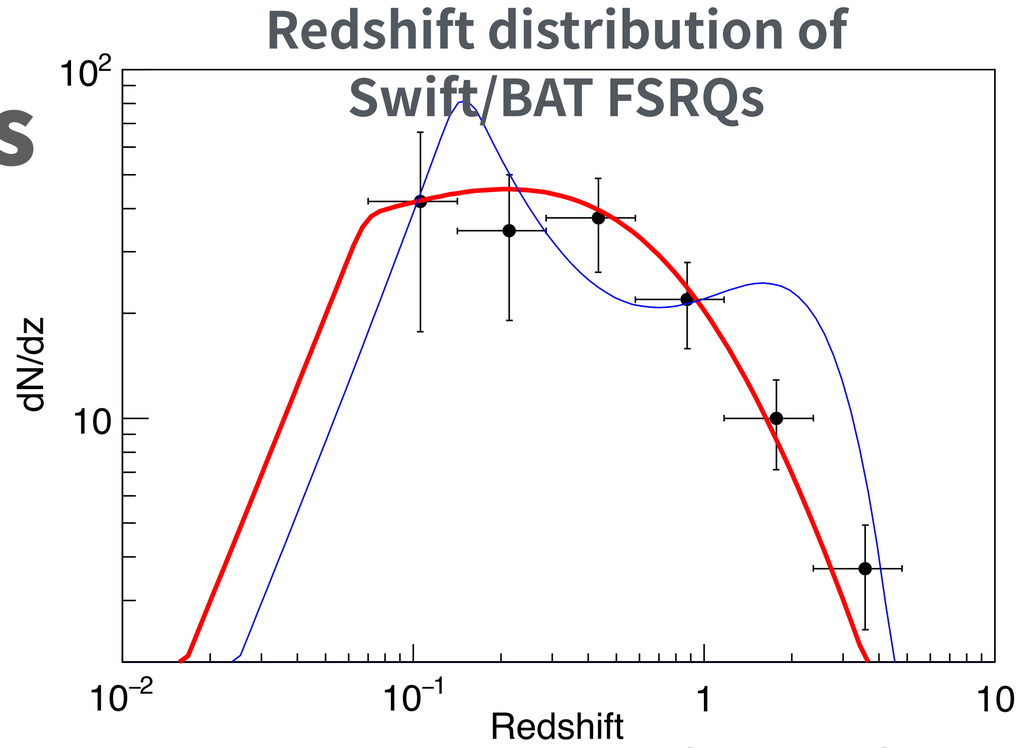


High Redshift Blazars

Probing the distant universe

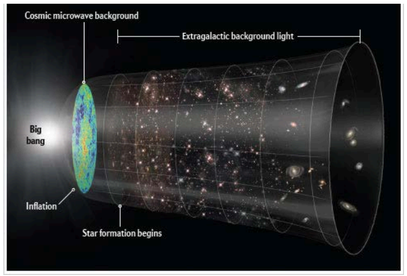


Sbarrato+'13



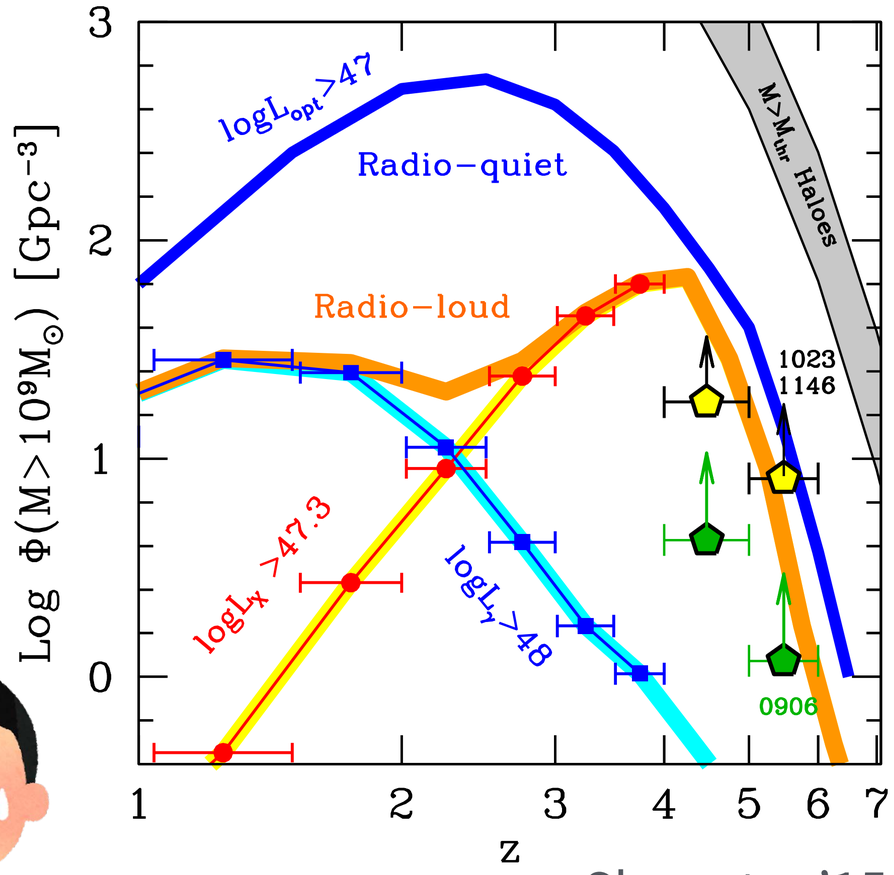
Toda, YI, Fukazawa+'20

- Swift/BAT & NuSTAR report high redshift blazars, likely peaking at MeV
  - negative k-correction
- MeV gamma-ray can study high redshift universe.



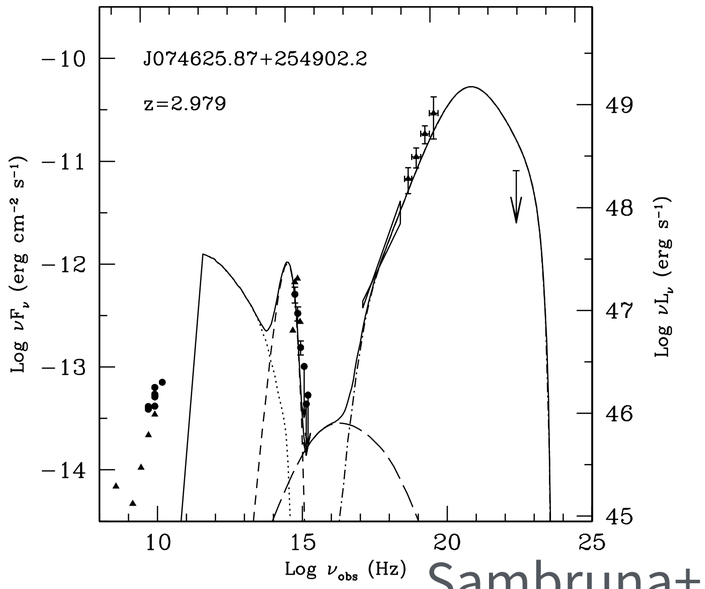
Evolution of Blazars

Inconsistency in X-ray and Gamma-ray?



Sbarrato+'15

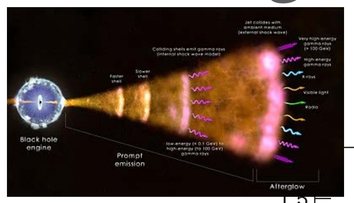
- Gamma-ray blazars show evolutionary peak at z~1-2 (e.g., YI & Totani'09; Ajello,YI+'15)
  - But, it is at z~3-4 for X-ray blazars (Ajello+'09, see also Toda, Fukazawa, YI'20).
- More MeV blazars are needed (e.g., Blom+'96; Sambruna+'06).



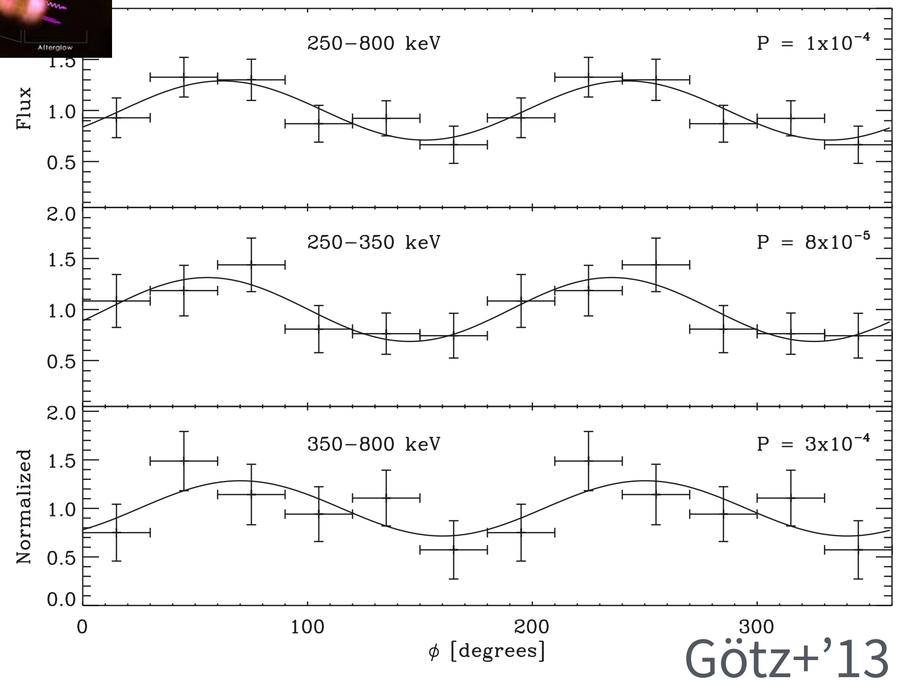
Sambruna+'06

Gamma-ray Polzarization

Probing the structure using Compton kinematics



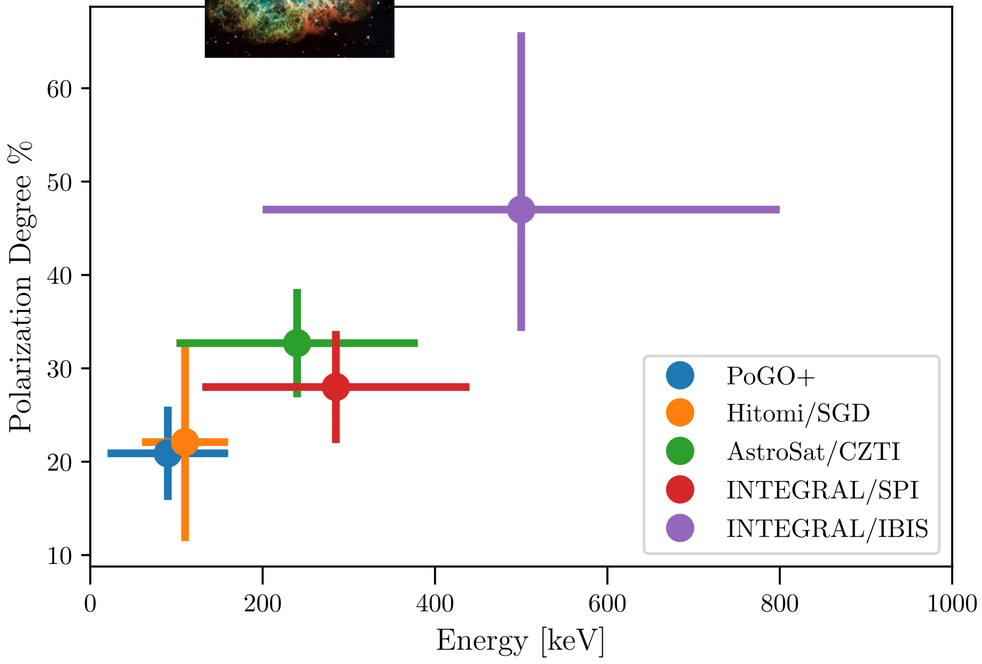
GRB 061122



Götz+'13

- Linear polarization measurement of GRB prompt emission in 250-800 keV by INTEGRAL (Götz+'13)

Crab

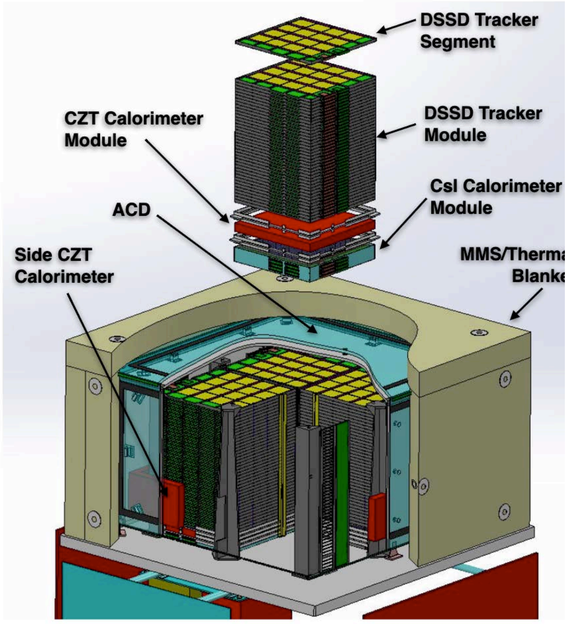


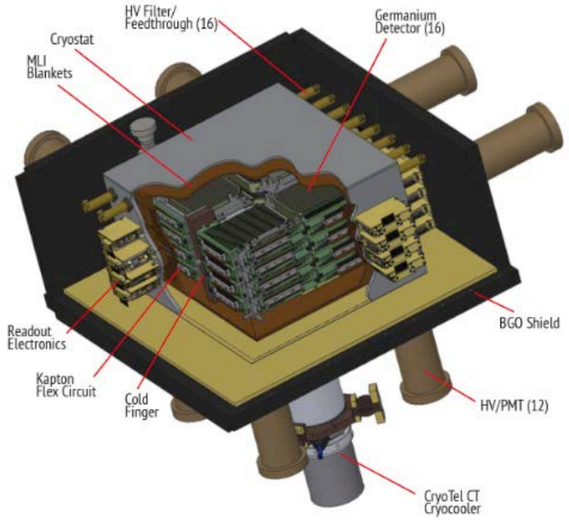
- Increase of polarization degree in Crab nebula (PoGo+, Hitomi, AstroSat, INTEGRAL)?

Proposed MeV Gamma-ray Missions

Not complete,,,,

Solid



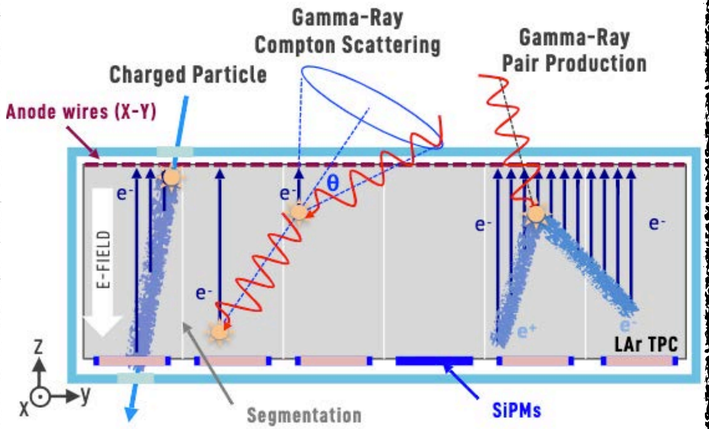


AMEGO

COSI

See talk by Zoglauer

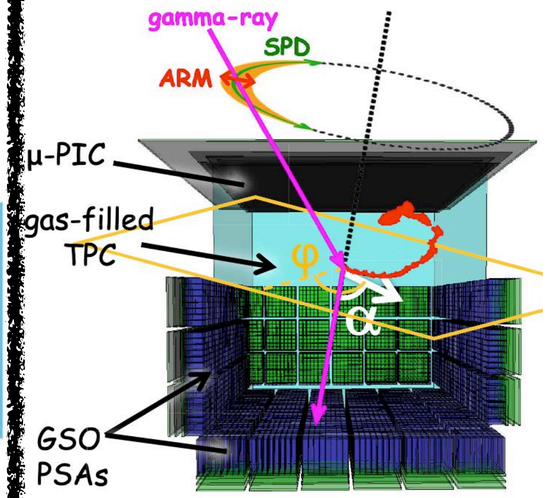
Liquid



GRAMS

See Poster by Takashima

Gas

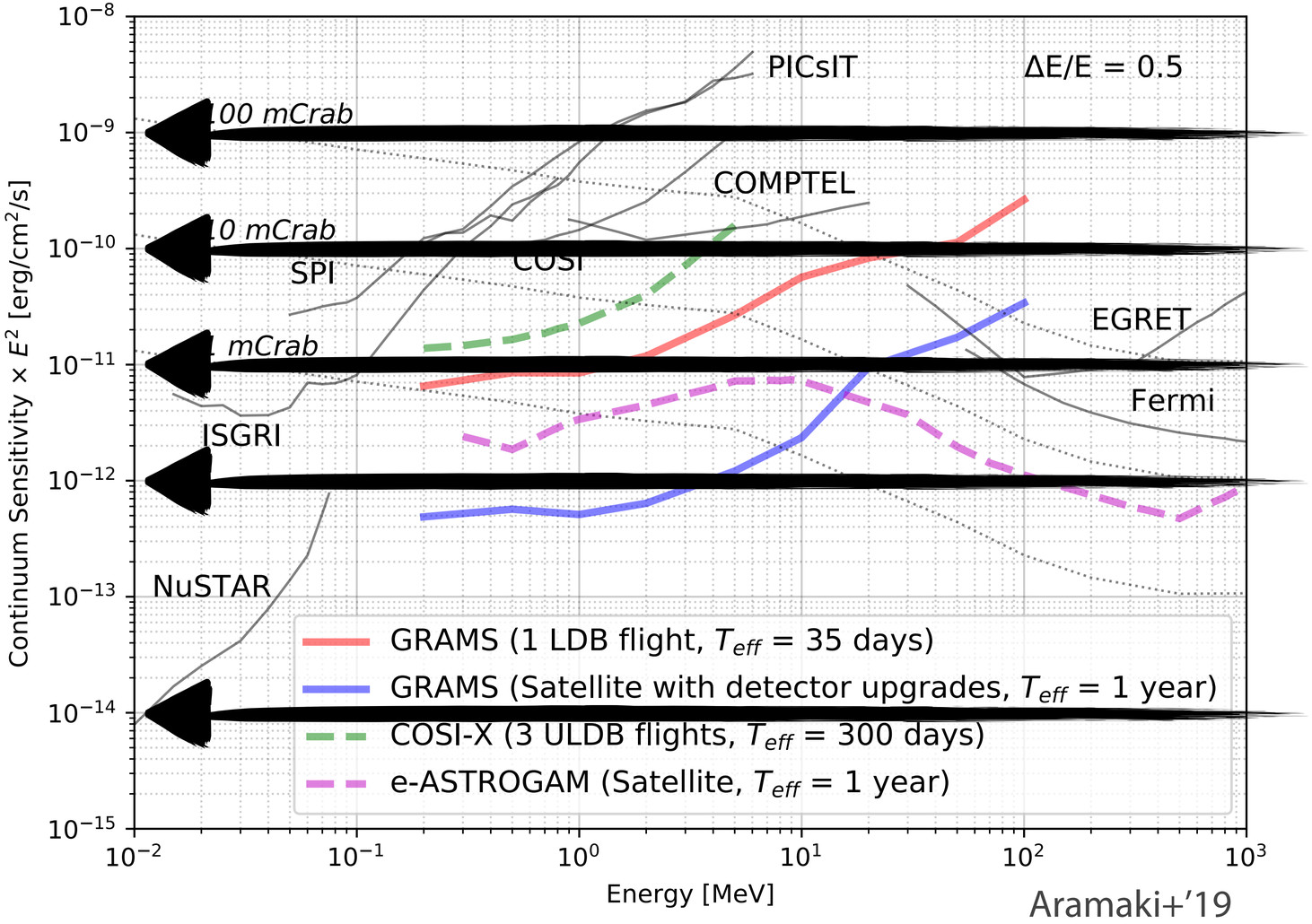


SMILE

See talk by Takada

Crude Estimates for MeV Science

What kind of sources can we see?



Aramaki+'19

Centaurus A

MeV Background Anisotropy

Type-Ia SNe

NS merger (3 Mpc!!!)

NS merger (30 Mpc)

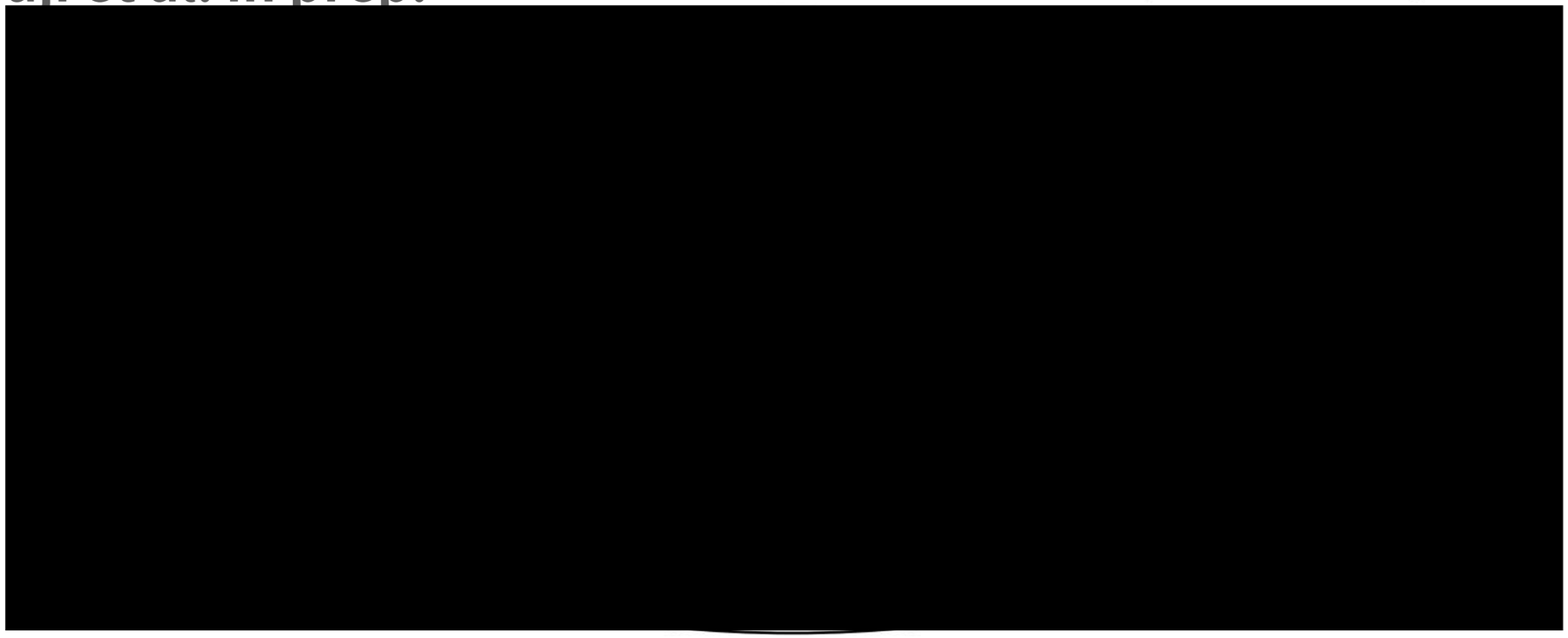
Expectation from Swift/BAT & Fermi/LAT

Realistic estimation for MeV Gamma-ray Astronomy in the next decade

- Spatially matching Swift/BAT 105-month catalog and 4FGL-DR2 (10 year) catalog.
  - 0.05° (5% contamination)
- 135 matched objects
- Dominated by blazars: 89
  - Bimodal distribution in Photon index

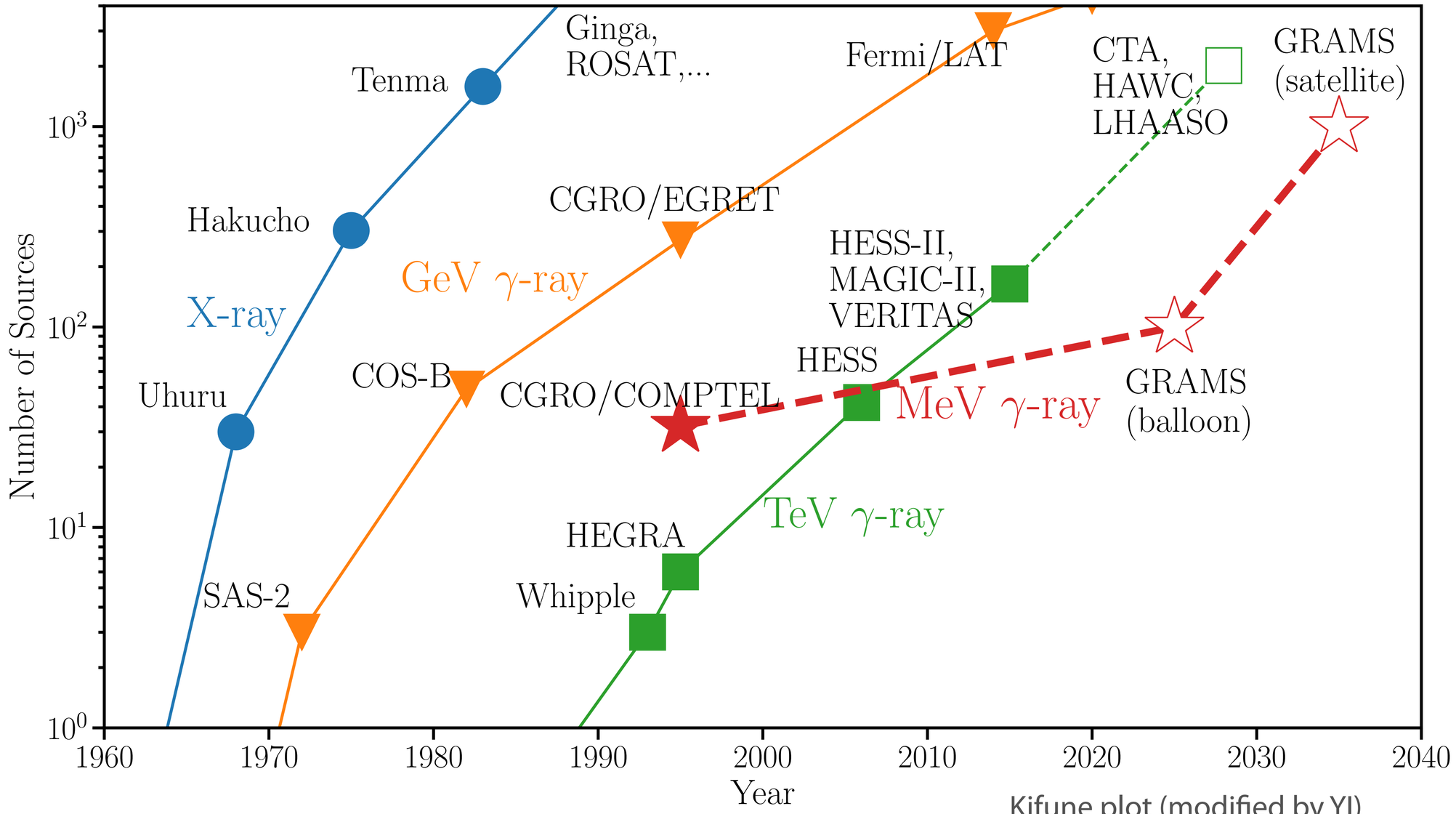
BAT-LAT MeV objects sky distribution

Naomi Tsuji et al. in prep.



- Toward the future observation plan.
- Interpolate MeV gamma-ray spectra of the Tsuji catalog
- Number of objects having MeV flux of
  - $> 10^{-10}$ erg/cm^2/s **: 23 sources**
  - $> 10^{-11}$ erg/cm^2/s **: 67 sources**

Number of Gamma-ray Objects



Kifune plot (modified by YI)

Summary

What's we need to accomplish? A: Operation of MeV balloons/satellites.

- A MeV gamma-ray observatory can bring various discoveries to us
  - nuclear astrophysics, cosmic evolution, high energy phenomena, dark matter particles
- Variety of Compton Cameras are proposed
  - Solid (AMEGO, COSI), Liquid (GRAMS), & Gas (SMILE)
- Latest Swift/BAT & Fermi/LAT catalogs tell us
  - @ $> 10^{-10}$ erg/cm^2/s : 23 sources
  - @ $> 10^{-11}$ erg/cm^2/s : 67 sources (Mostly blazars)