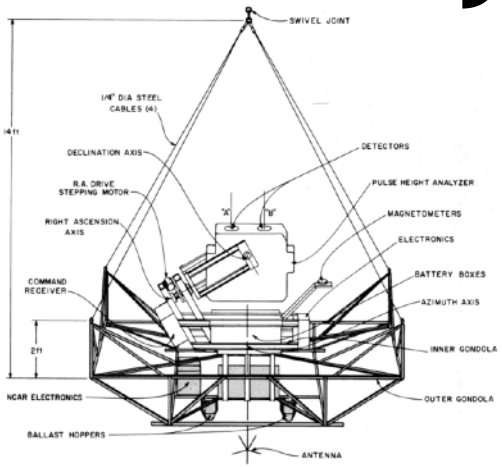
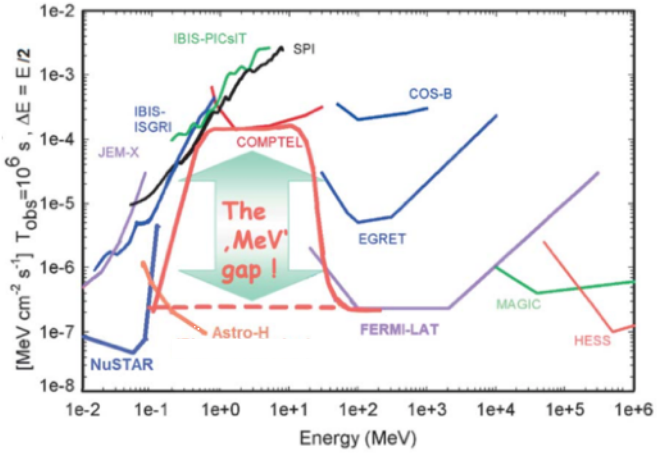
Gamma-Ray Line Astrophysics:

Yesterday,



Now,

and Then?

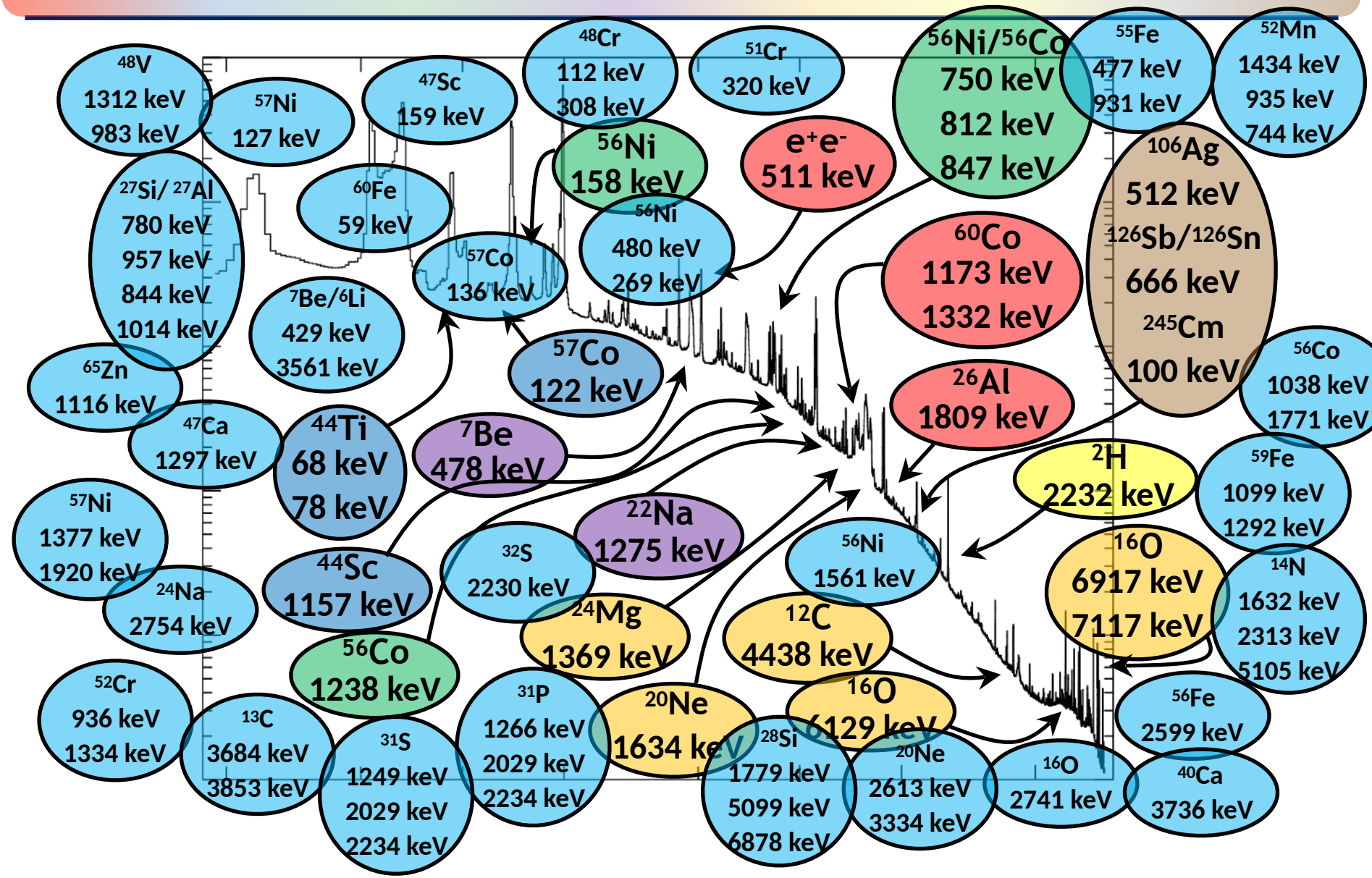


Thomas Siegert

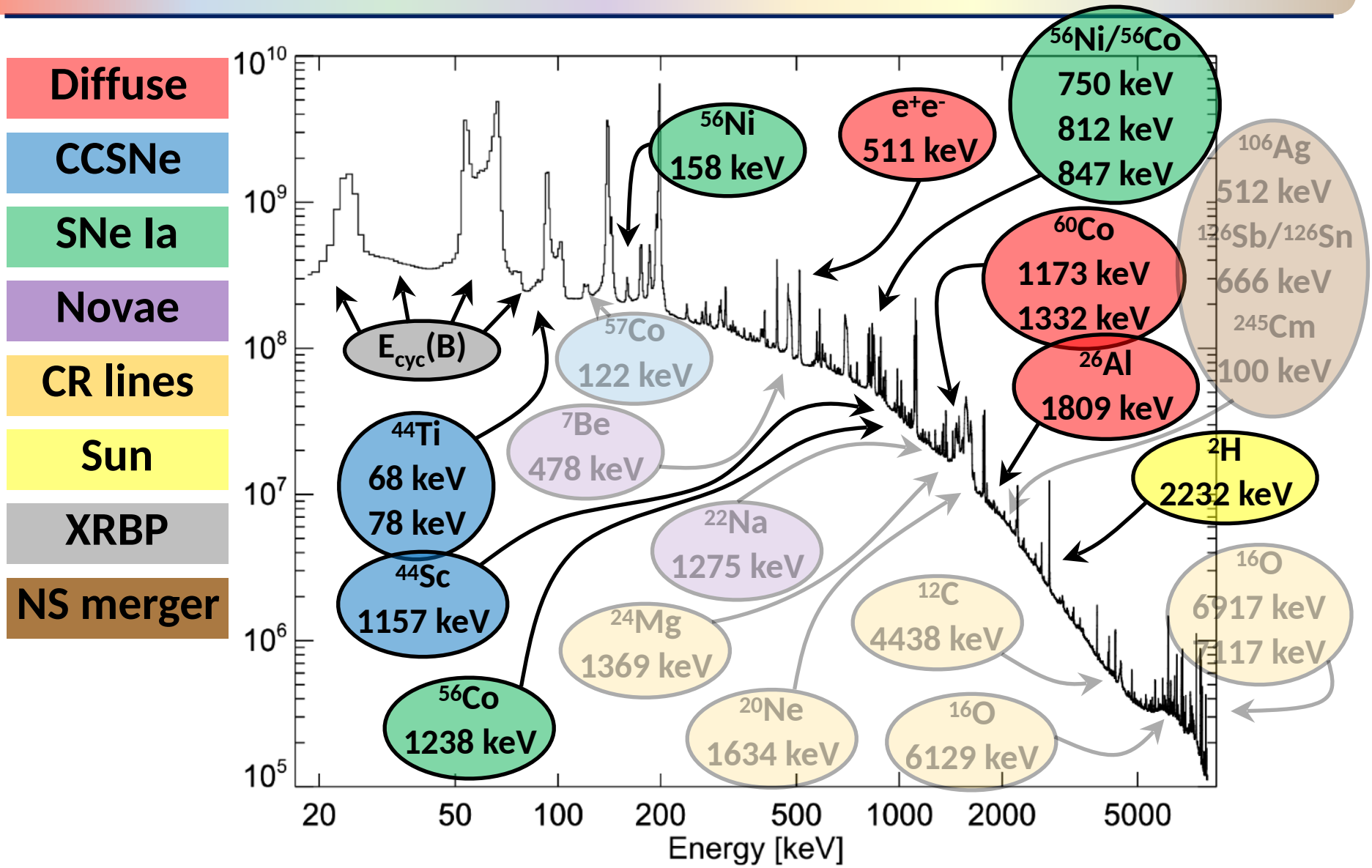
Center for Astrophysics and Space Sciences, UC San Diego

Jan 11 2021, AAS 237, MeV Splinter Session, Online

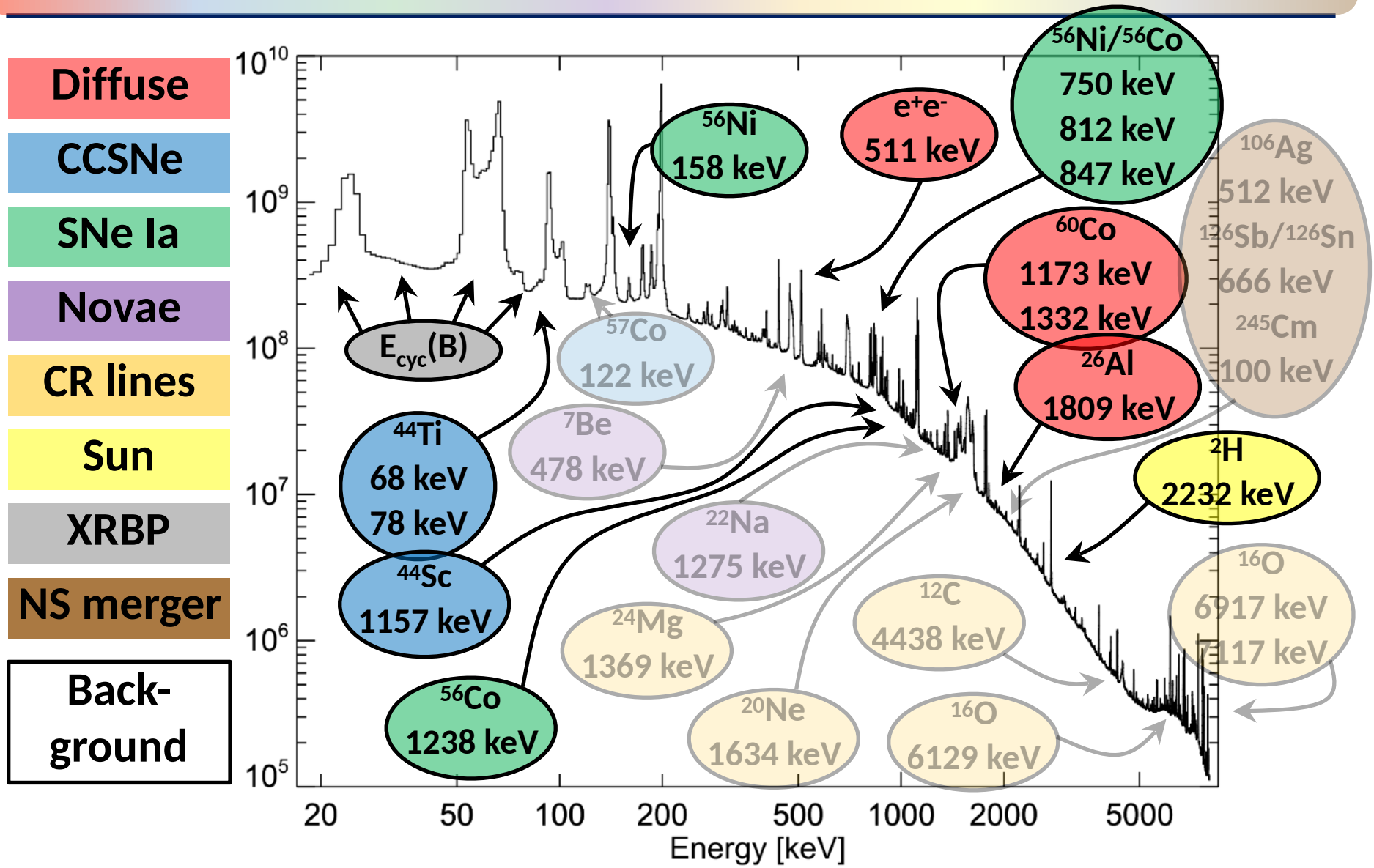
MeV Gamma-Ray Line Diagnostics



A Messenger for Everything



A Messenger for Everything

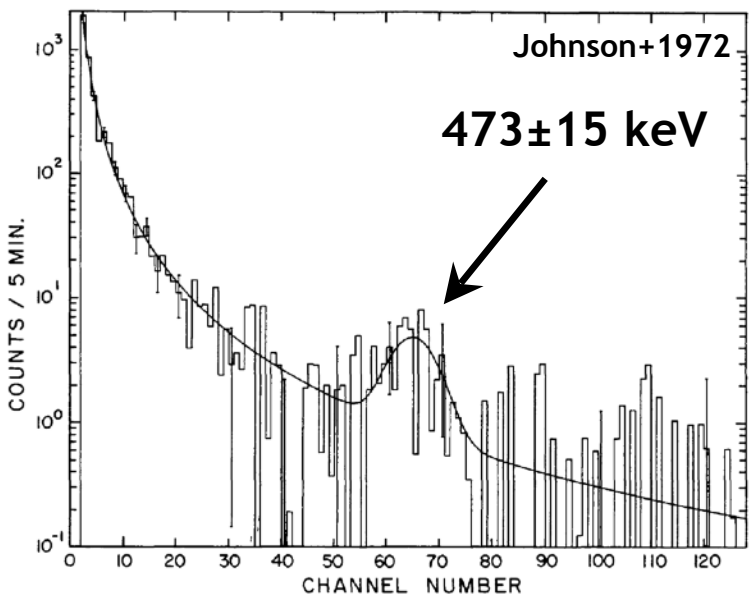


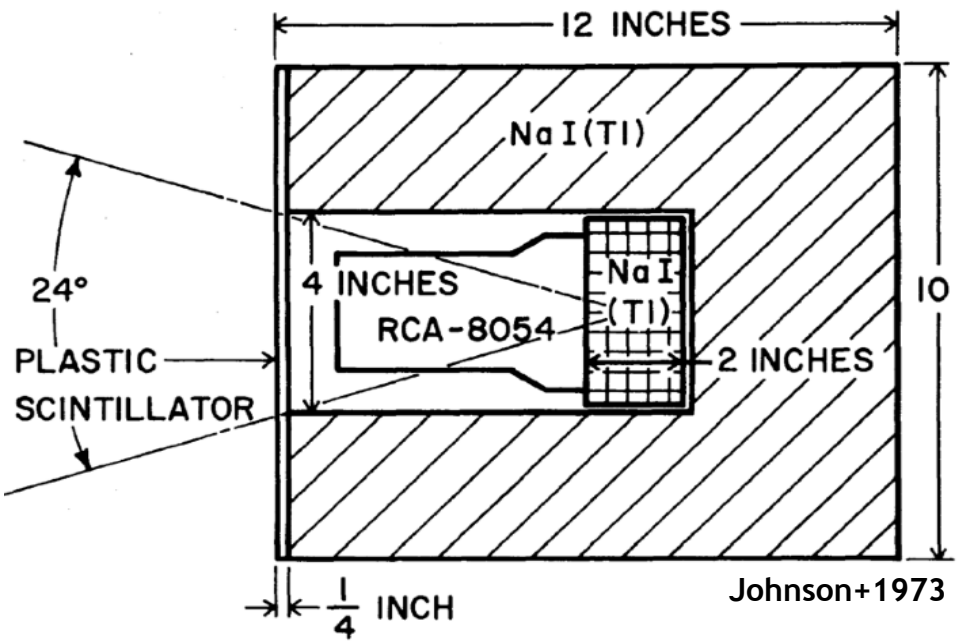
The Early Years — The Persistent Problems

- **Atmosphere:** Late 60s, early 70s: Balloon-borne experiments
- **Instrumental BG:** Collimator apertures with on-off-measurements
- **Data analysis:** First "evidence of a spectral feature at 0.5 MeV"

➡ **Shoot it into space, avoid/veto cosmic rays, forward-fold models**

➡ **Use better detectors / find more informative apertures?**

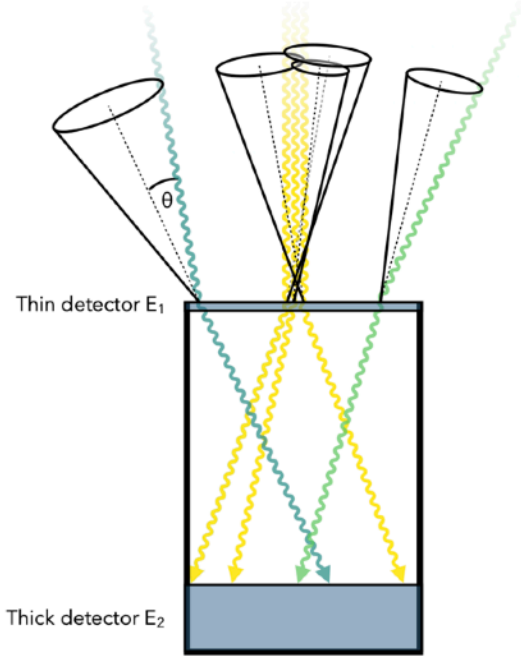




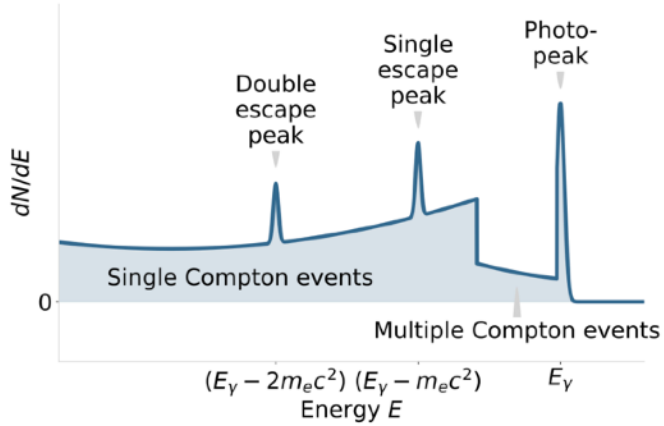
Now — Advanced MeV Telescopes

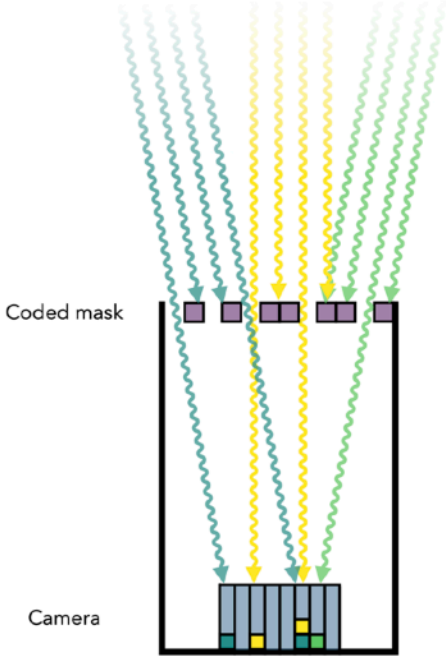
Compton Telescopes:
COMPTEL, COSI, SMILE, …

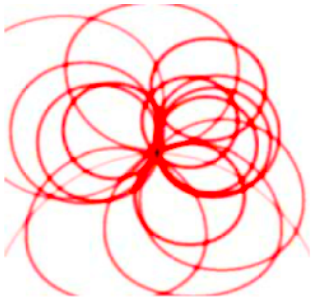
Coded-Mask Telescopes:
SPI, ISGRI, BAT, …

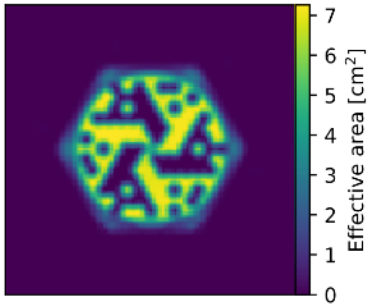


High-resolution detectors:
Solid state: Ge, CZT, …
Scintillator: LaBr, SrI, …

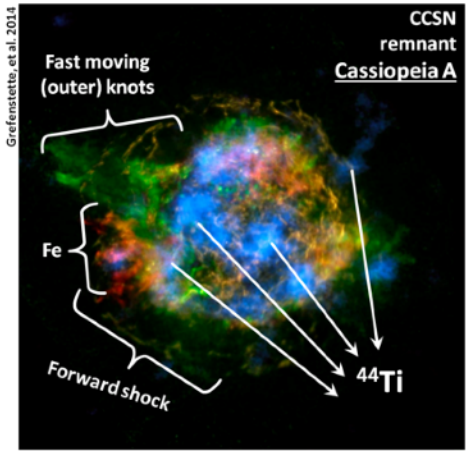






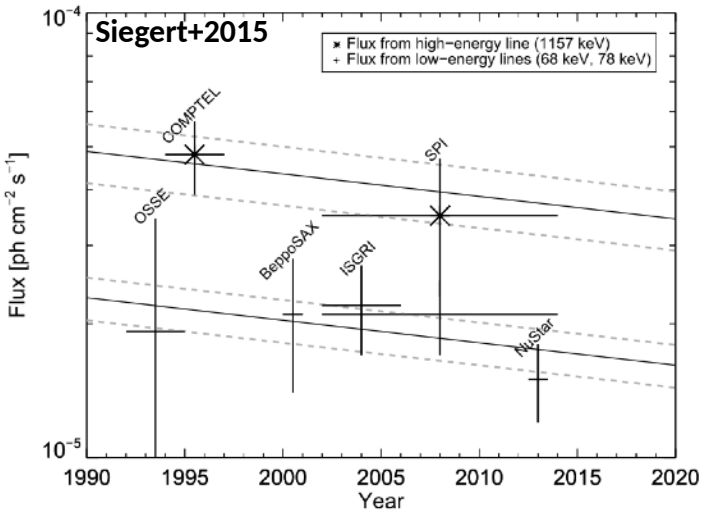


CCSNe: ^{44}Ti in Supernova Remnants



Grefenstette+2014,2017

Cassiopeia A (360 yr)



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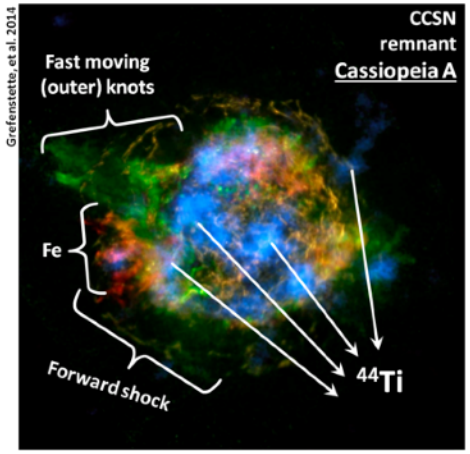
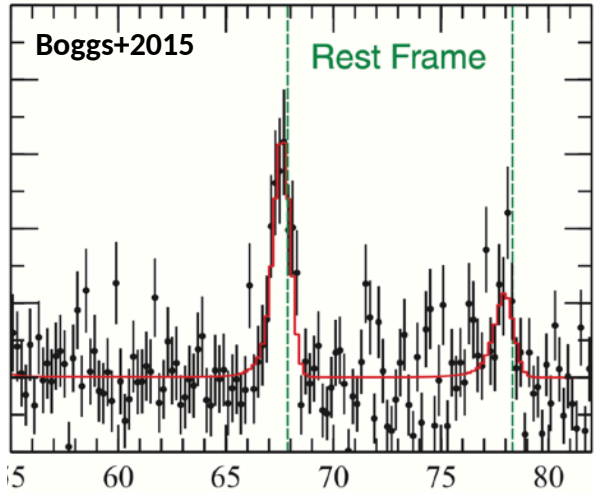
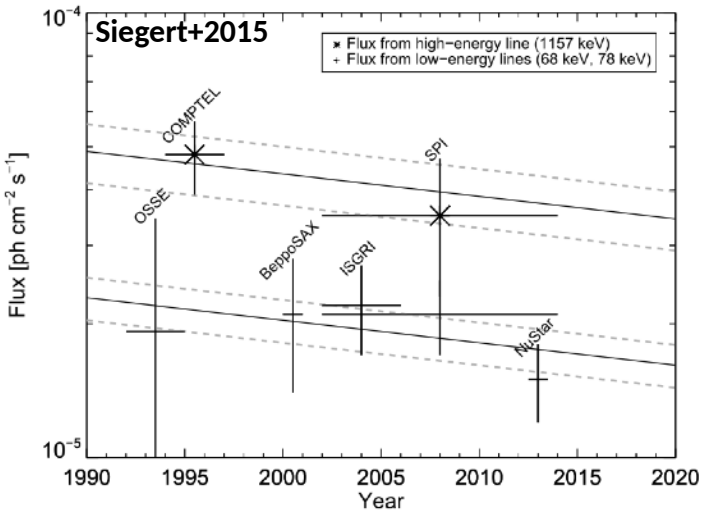


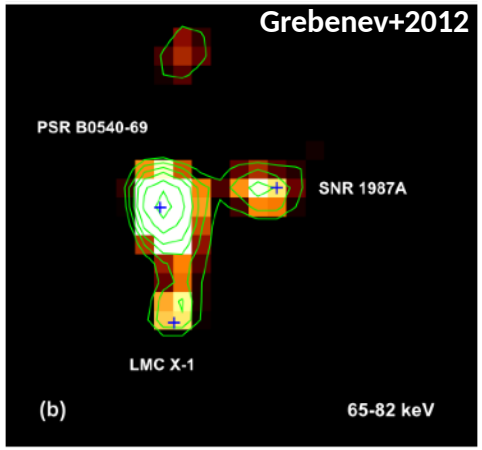
Grefenstette+2014,2017



Cassiopeia A (360 yr)

SN 1987A (33 yr)





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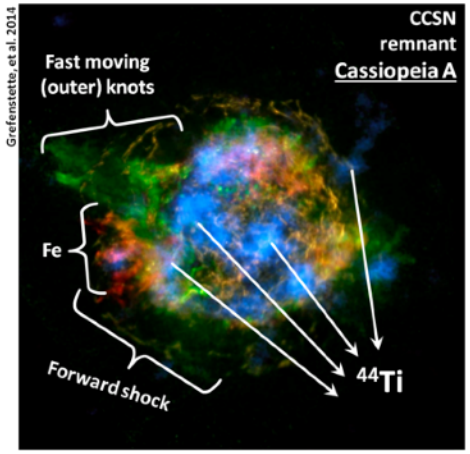
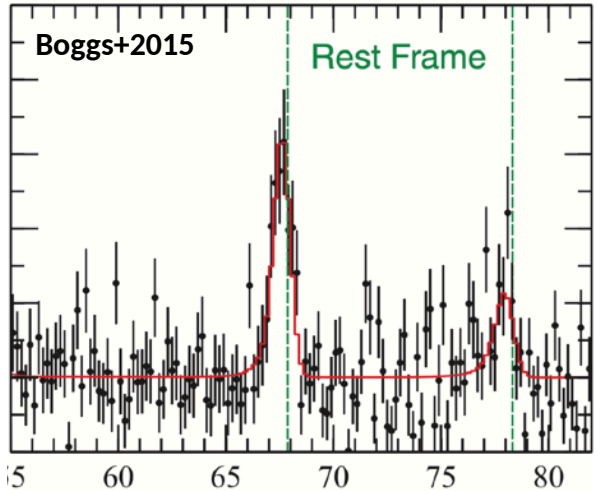
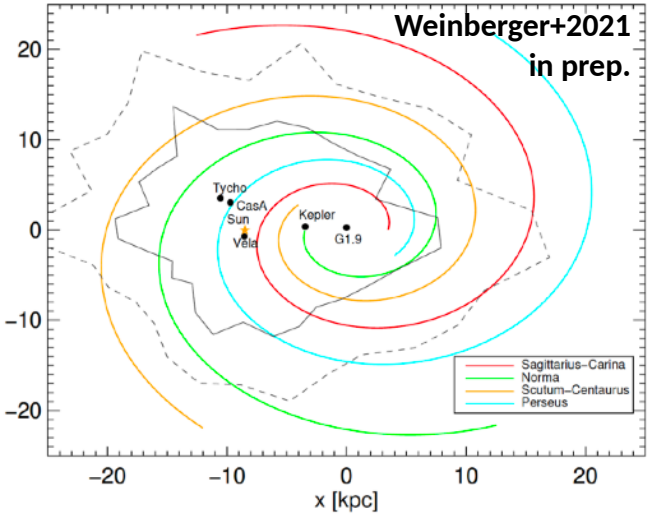


Grefenstette+2014,2017

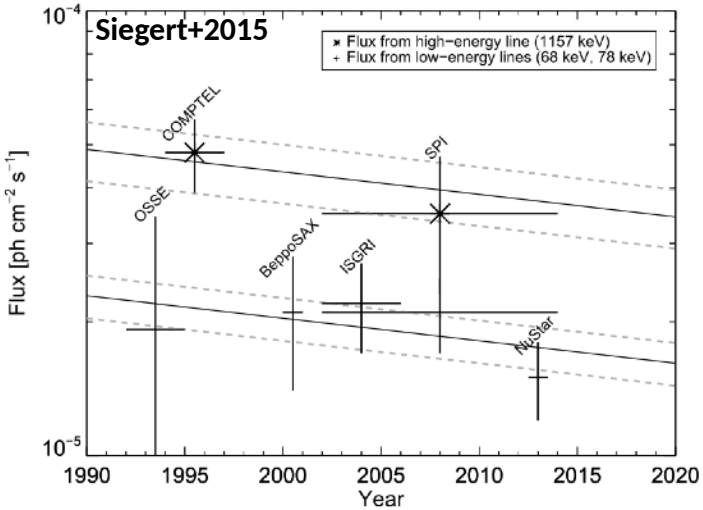


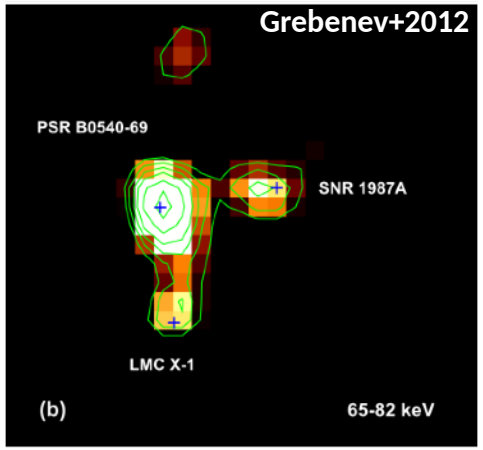


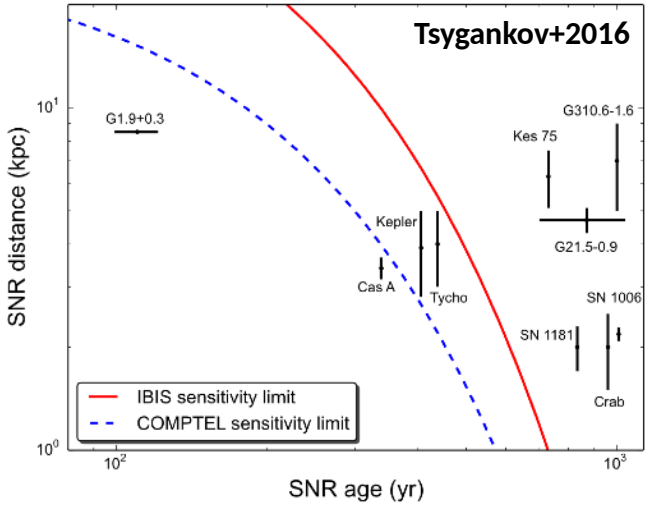
Cassiopeia A (360 yr)

SN 1987A (33 yr)

All Sky, all ages

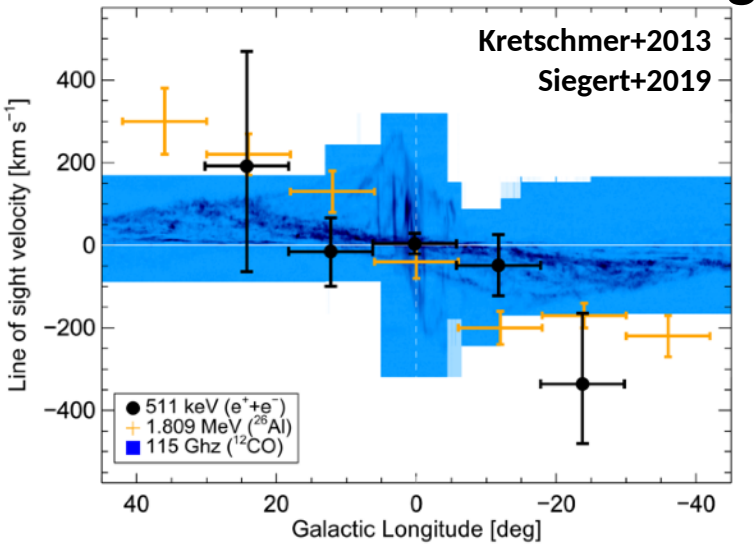




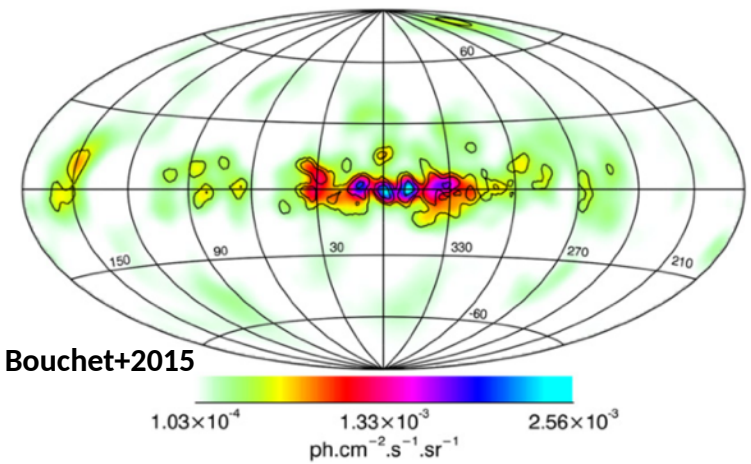


Diffuse: 1809 keV Kinematics / Morphology

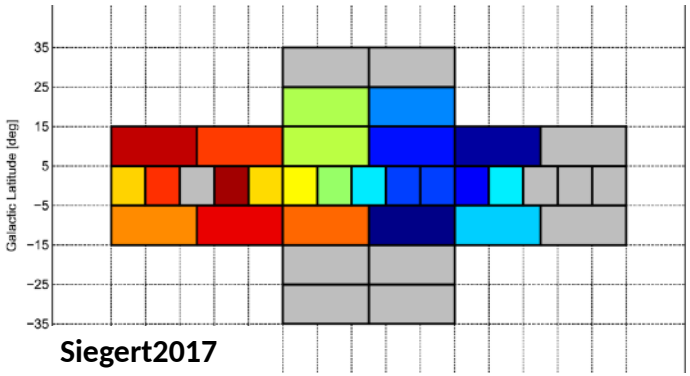
^{26}Al / 511 keV Lon.-Velo.-Diagram



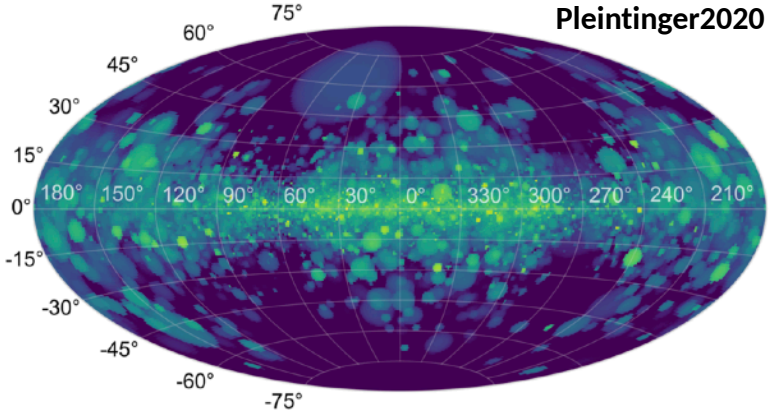
SPI ^{26}Al Map



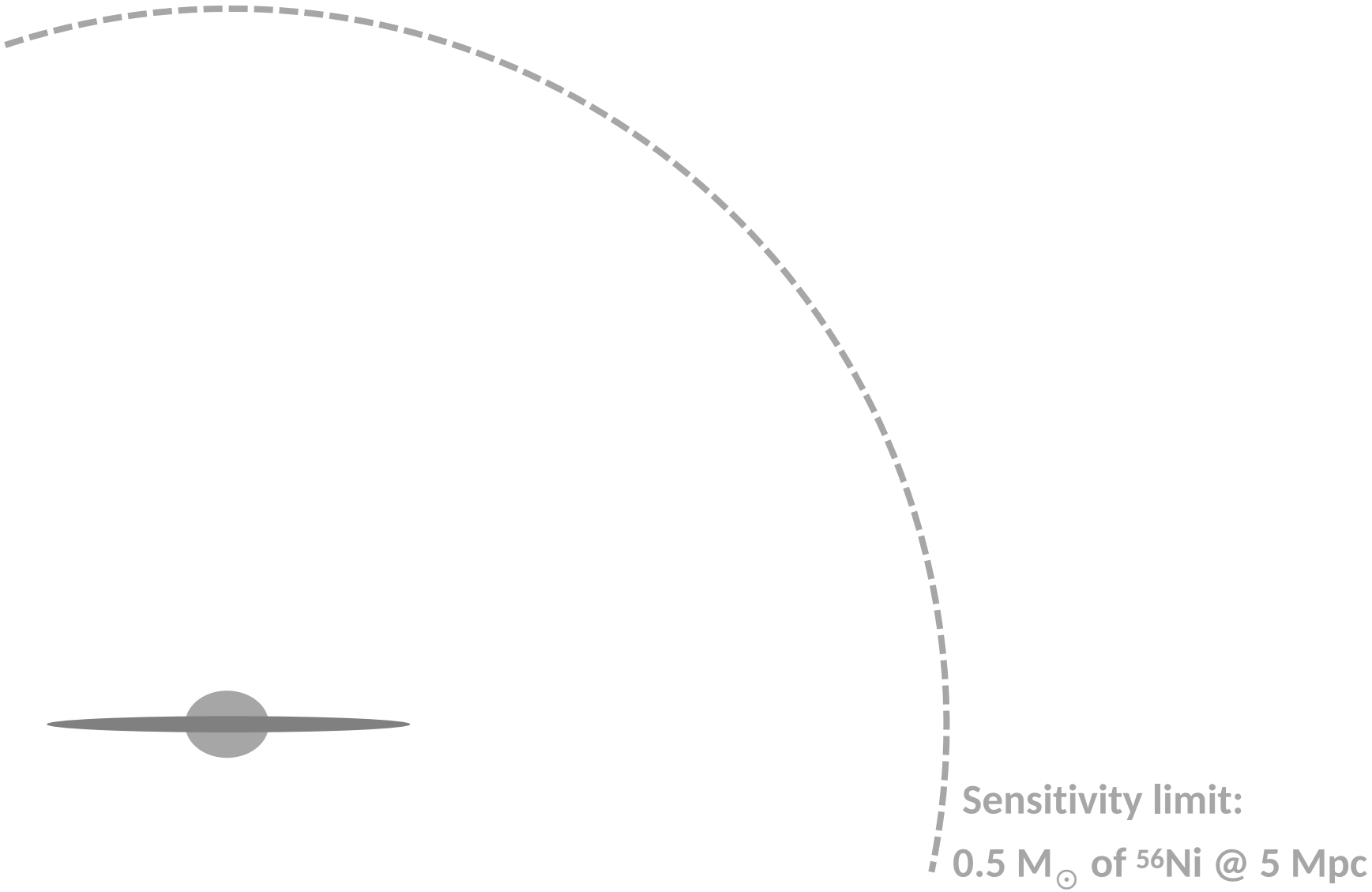
^{26}Al Lon.-Lat.-Velo.-Diagram



Modelling 1809 keV Emission



SNe Ia: Production and Decay of ^{56}Ni



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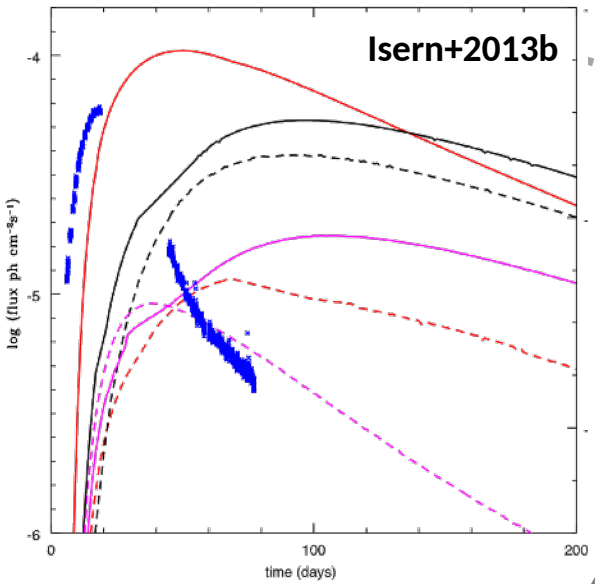
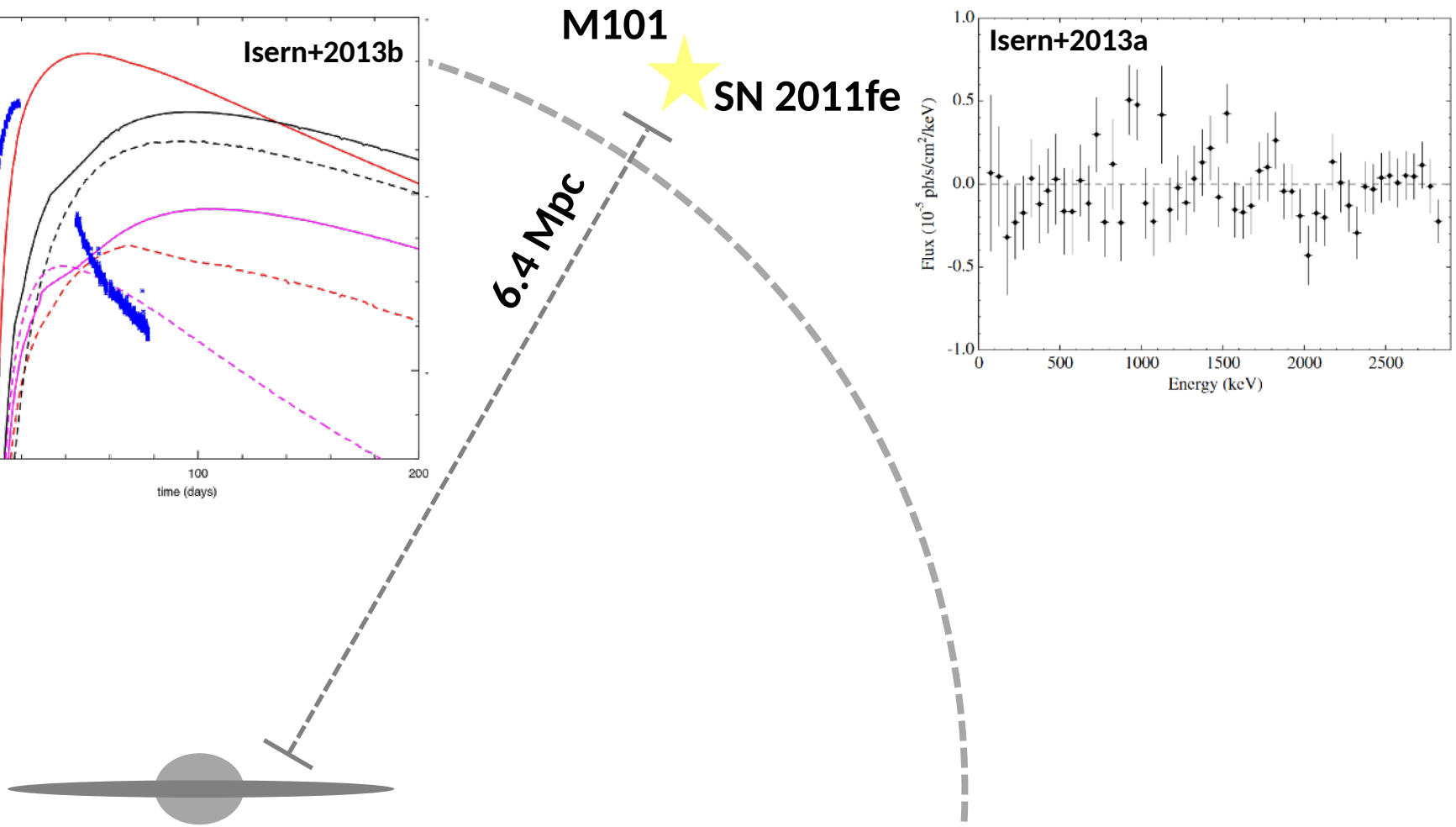
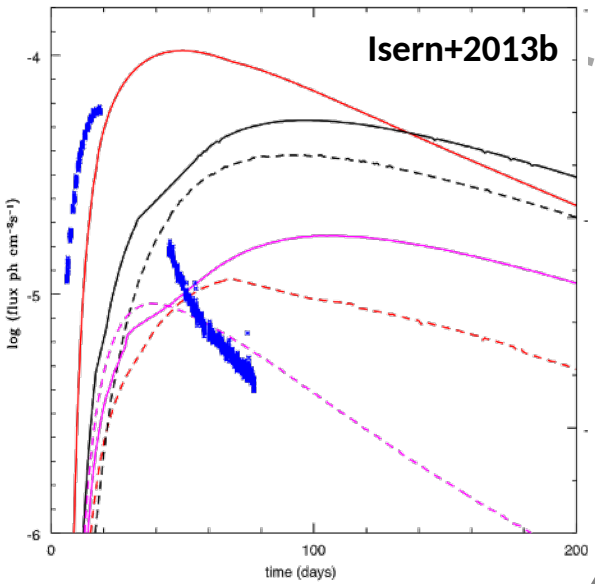




Sensitivity limit:

0.5 $M_\odot$ of ^{56}Ni @ 5 Mpc

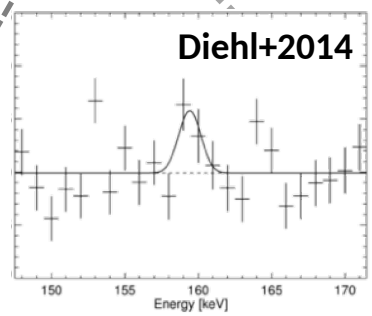
SNe Ia: Production and Decay of ^{56}Ni

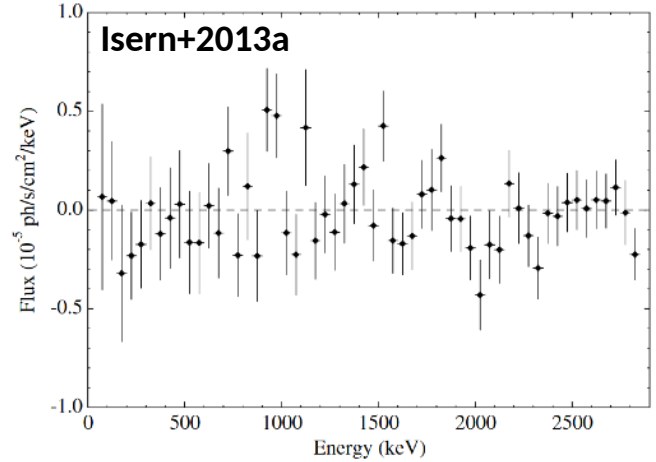


M101

SN 2011fe

6.4 Mpc

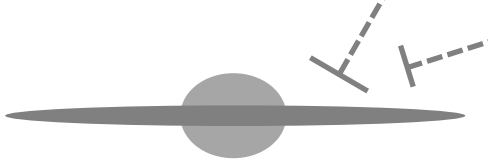


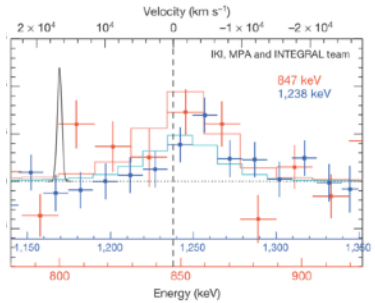


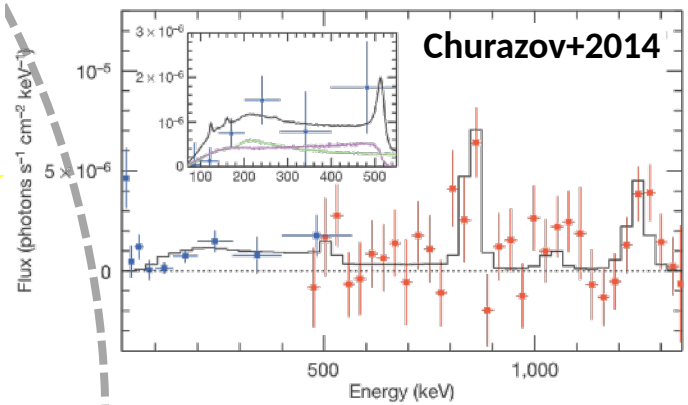
M82

SN 2014J

3.5 Mpc





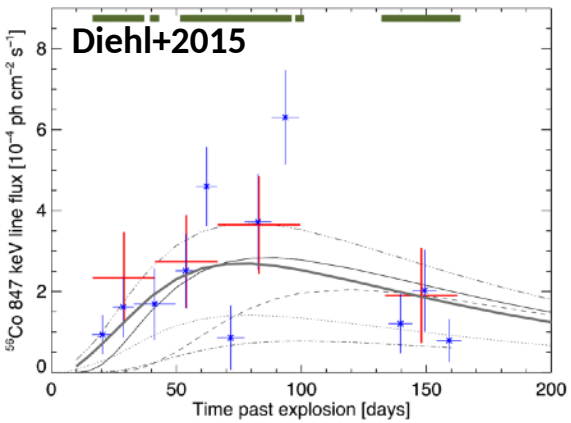


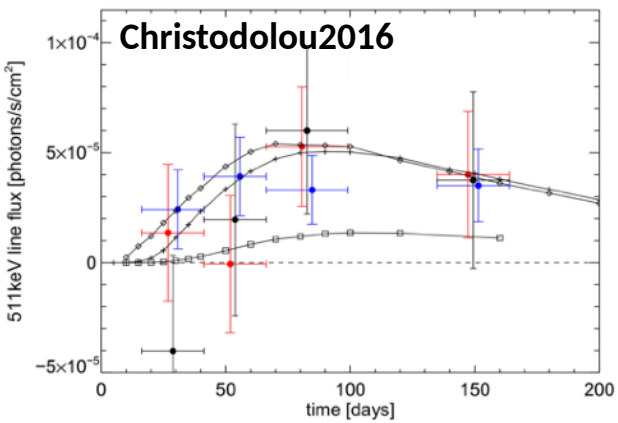
Sensitivity limit:

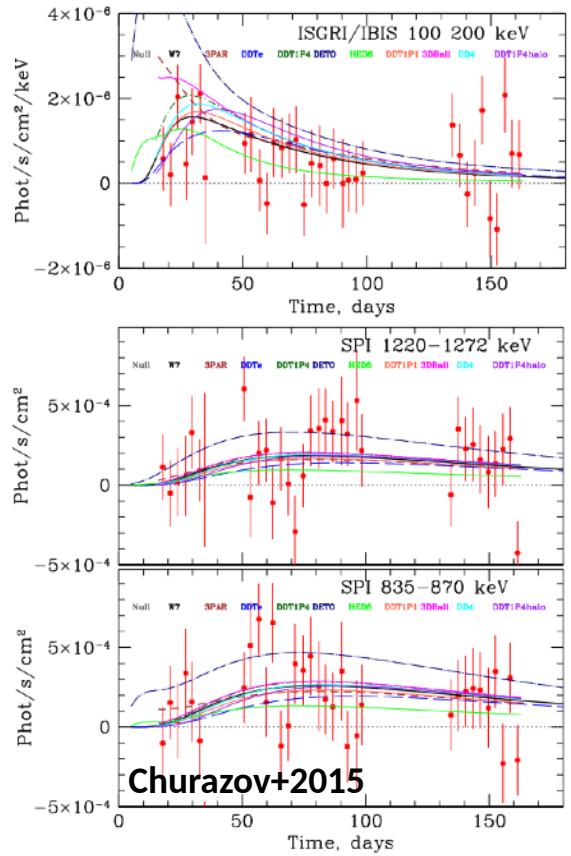
0.5 $M_\odot$ of ^{56}Ni @ 5 Mpc

SNe Ia: Gamma-Ray Line Studies in SN 2014 J

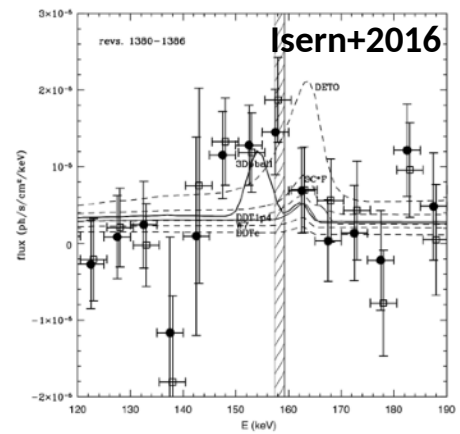
Light Curve Analysis (158, 847, 1238, 511)

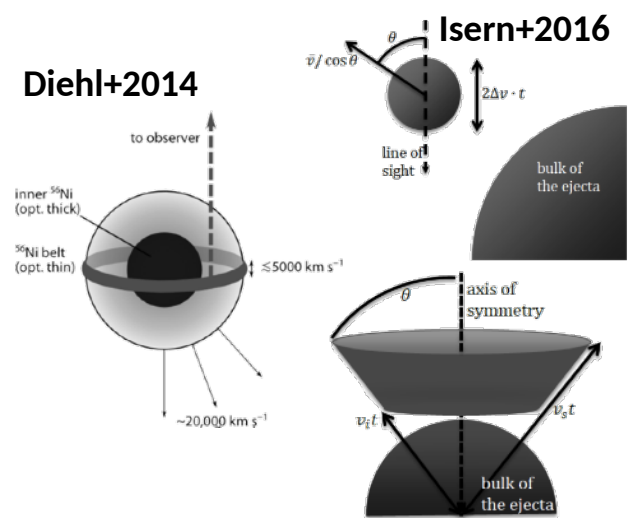






Early ^{56}Ni





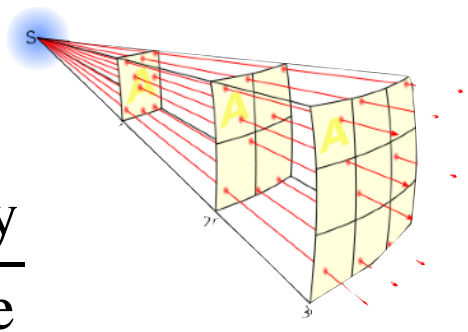
! ^{56}Ni on the surface! 0.03 – 0.09 $M_\odot$!

Gamma-Ray Mass Measurements

Exponential decay wins over increased exposure

1 nucleus decayed per 1 photon detected

Mass(!) $\xleftarrow{\text{+ geometry}}$ Flux (measured)



$$\text{Flux} = \frac{\text{Luminosity}}{\text{Area}} = \frac{\text{Specific activity}}{\text{Distance sphere}}$$

$$F = \frac{-\dot{N}(t)}{A} = \frac{\lambda N_0 \exp(-\lambda \Delta t)}{4\pi d^2} = \frac{M_{ej}}{4\pi d^2 \tau m_A} \exp(-\Delta t/\tau)$$

What to do?

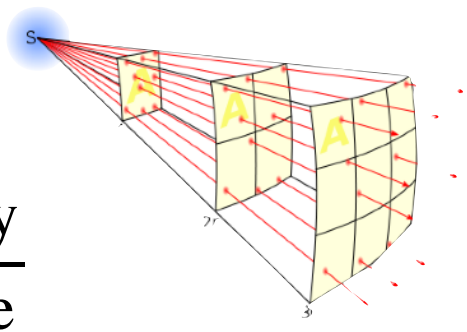
Gamma-Ray Mass Measurements

Exponential decay wins over increased exposure

1 nucleus decayed per 1 photon detected

+ geometry

Mass(!) ← Flux (measured)



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What to do?

➡ **Produce at high rate:**

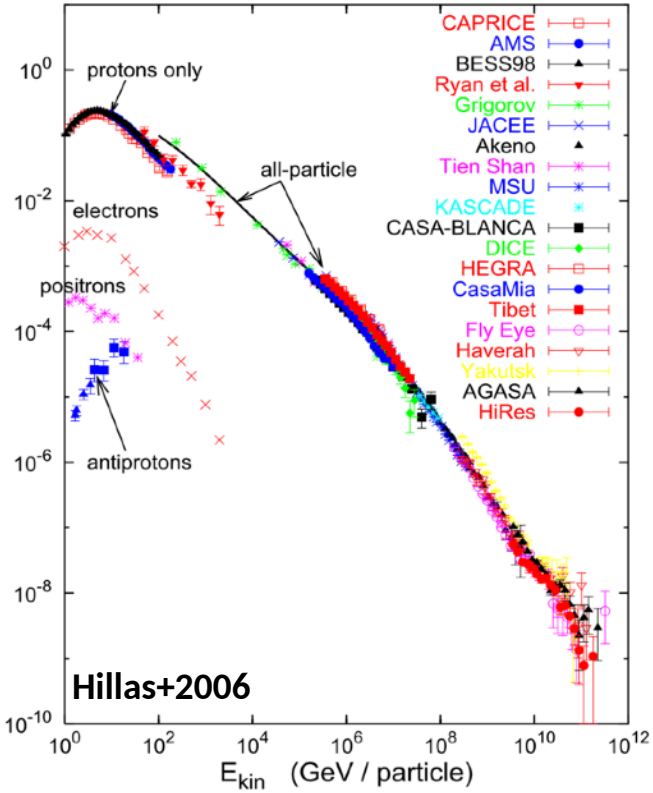
R > λ (^{26}Al, ^{22}Na, …)

➡ **Excite the products:**

^{26}Mg, ^{22}Ne, …, ^{12}C, ^{16}O, ^{56}Fe, ^{28}Si, …

Soon — Cosmic-Ray De-Excitation Lines

Questions: 1) How does particle acceleration work?
2) What are the abundances in the ISM / SNR / CSM?
3) What is the low-energy cosmic-ray spectrum?



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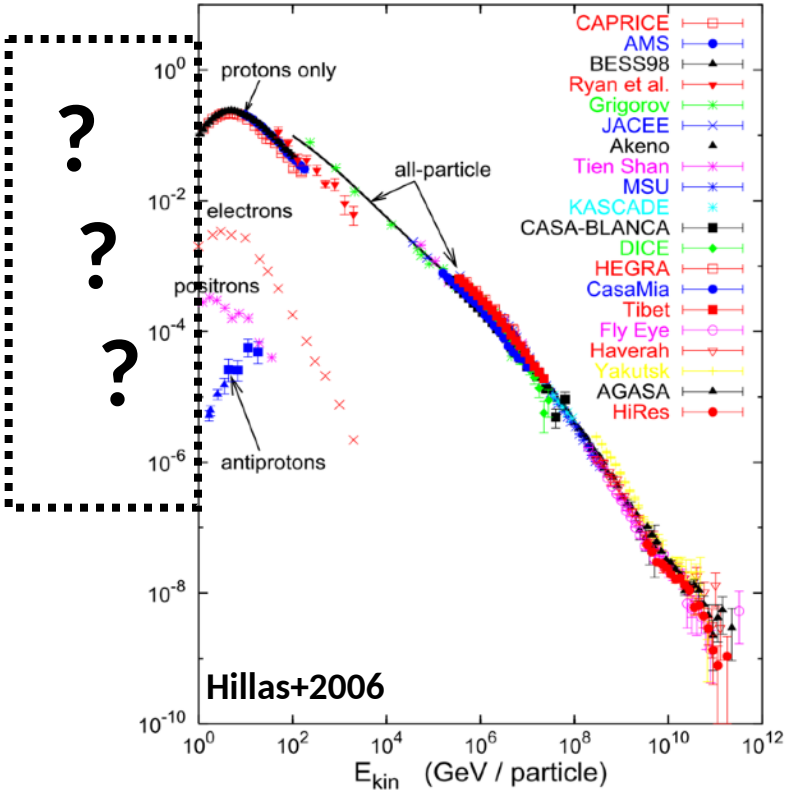

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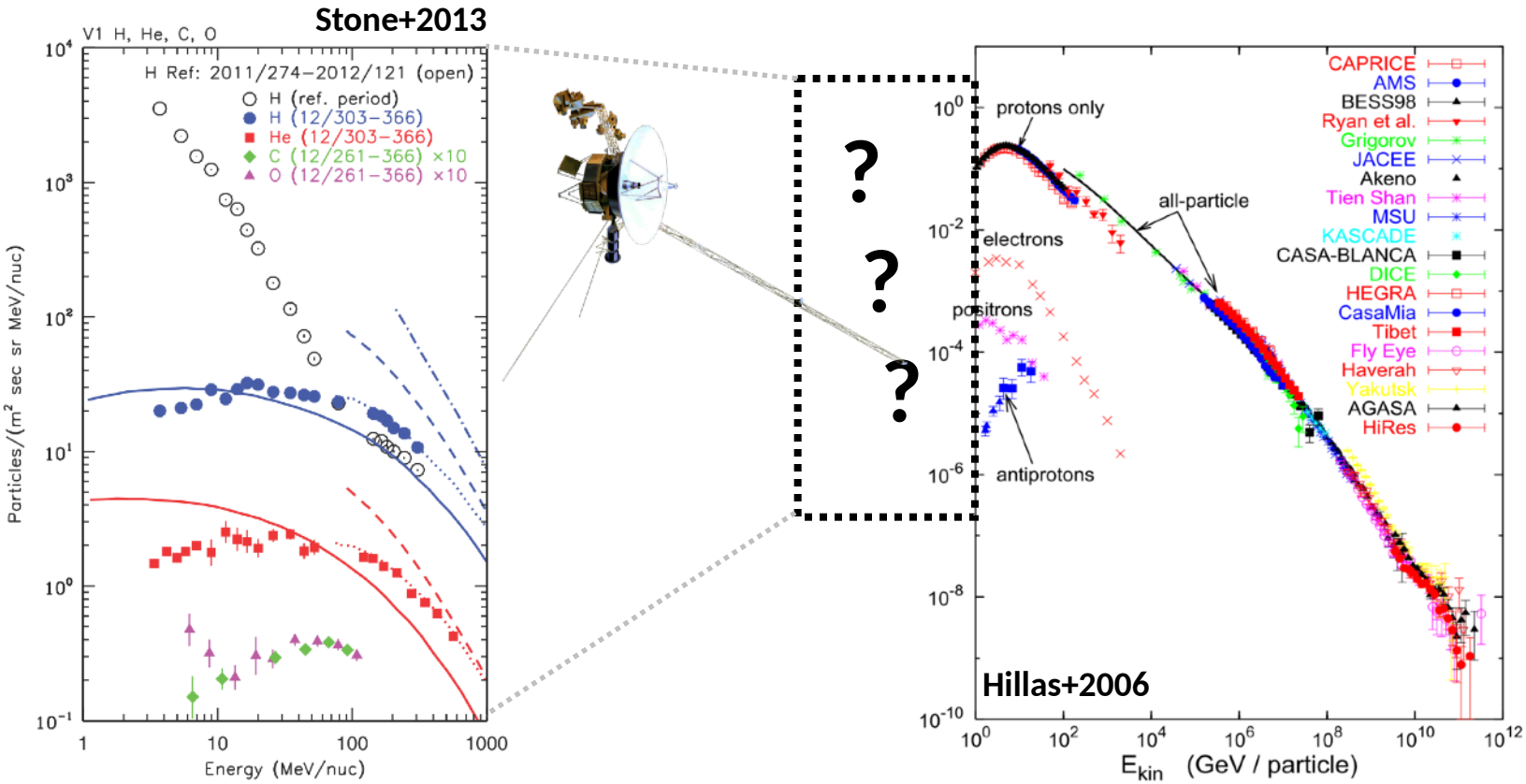

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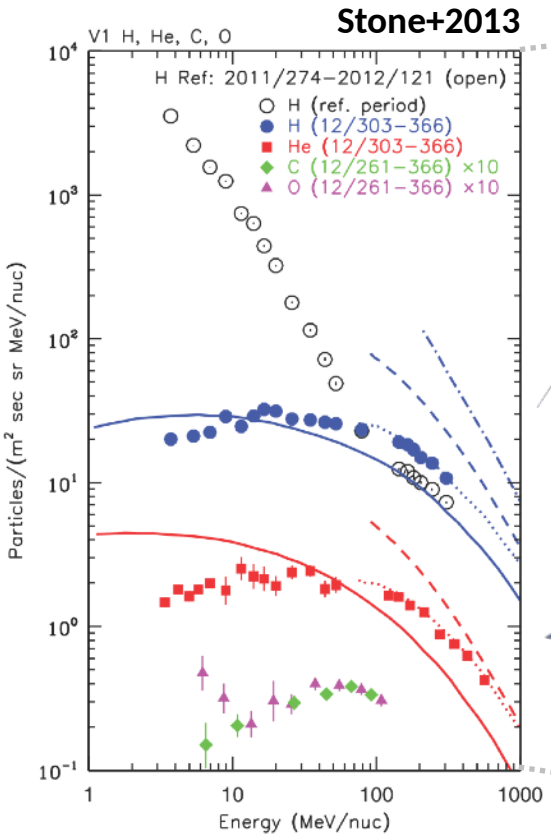
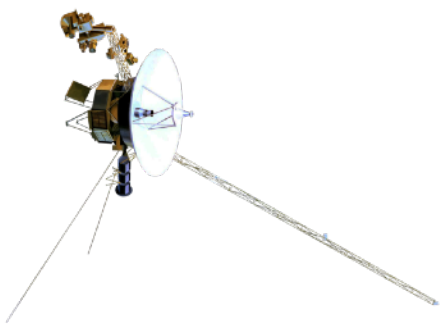
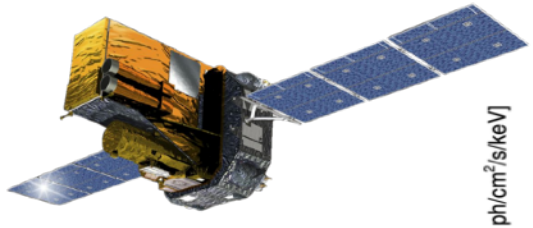
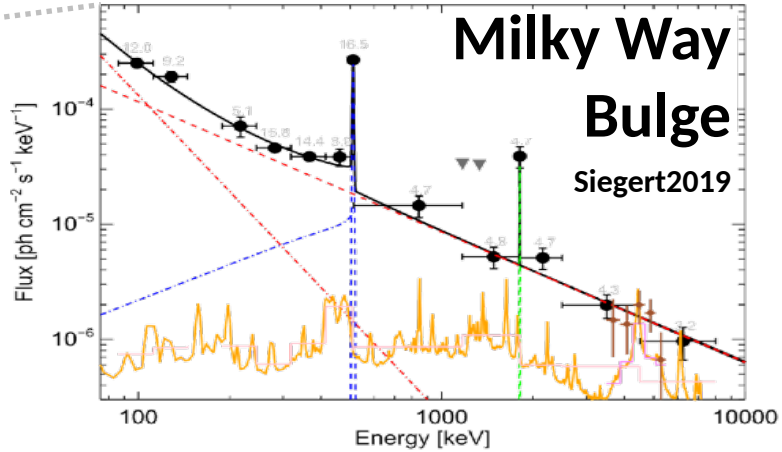
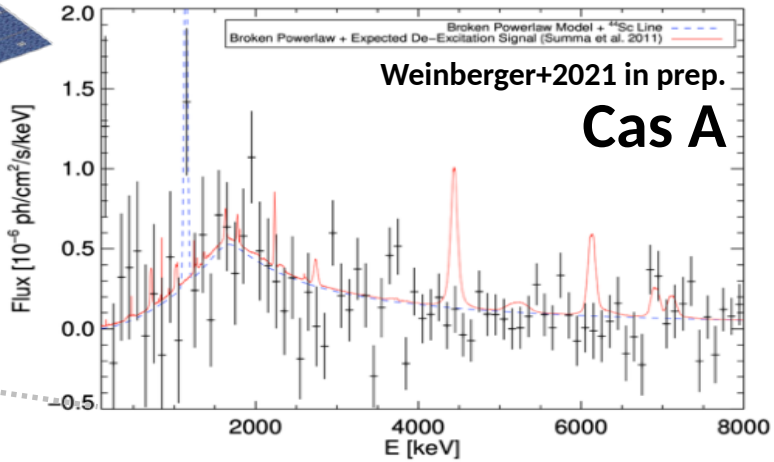
3) What is the low-energy cosmic-ray spectrum?





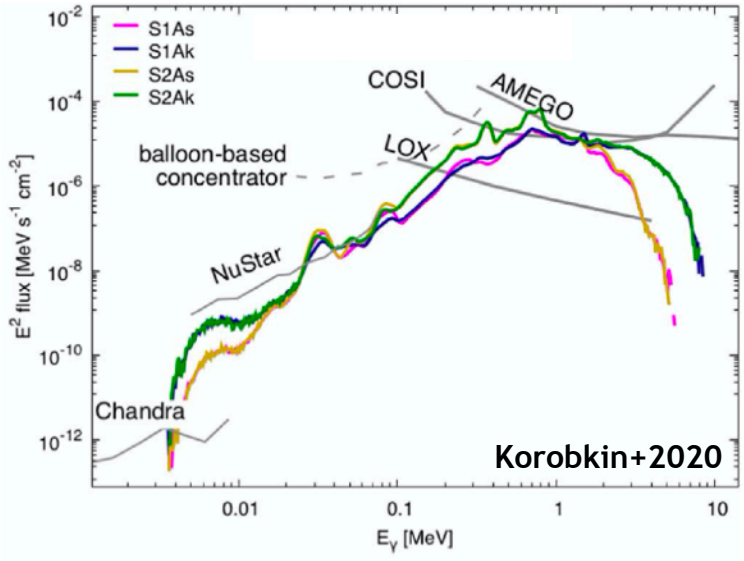






Soon? — Neutron Star Mergers

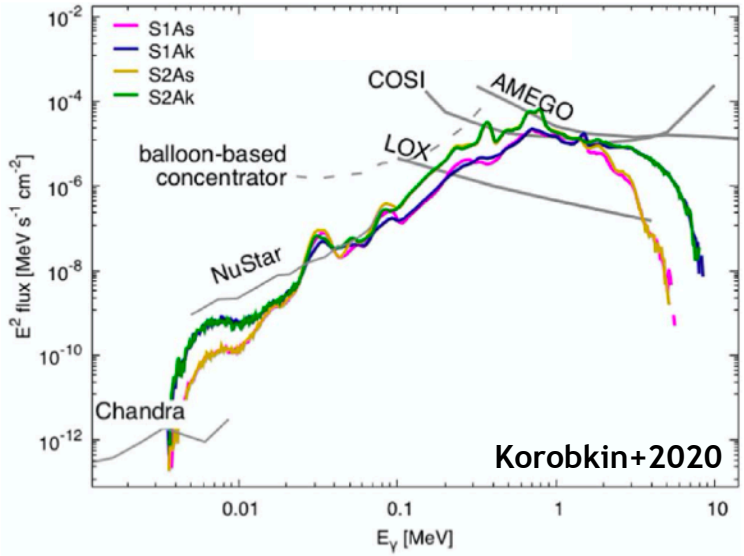
“Distant” NS merger



3 Mpc, 11.6 Ms after prompt

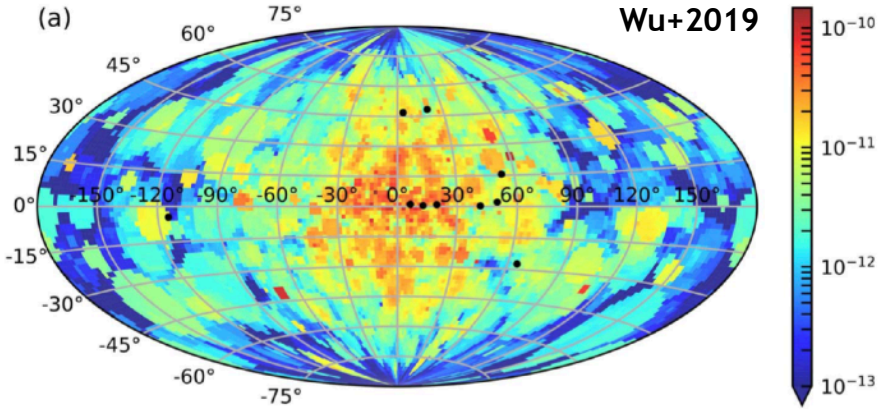
Soon? — Neutron Star Mergers

"Distant" NS merger



3 Mpc, 11.6 Ms after prompt

Find recent r-process activity



MC realisation of ^{182}Hf γ-rays (1121 keV), assuming NS kicks

Far Future? — (Exo)planet Spectroscopy

Cosmic rays + anything = shows what "anything" is

An atmosphere

$^{14}N(n, n'\gamma(1635))^{14}N$

$^{14}N(n, n'\gamma(2313))^{14}N$

$^{14}N(n, x\gamma(3684))^{13}C$

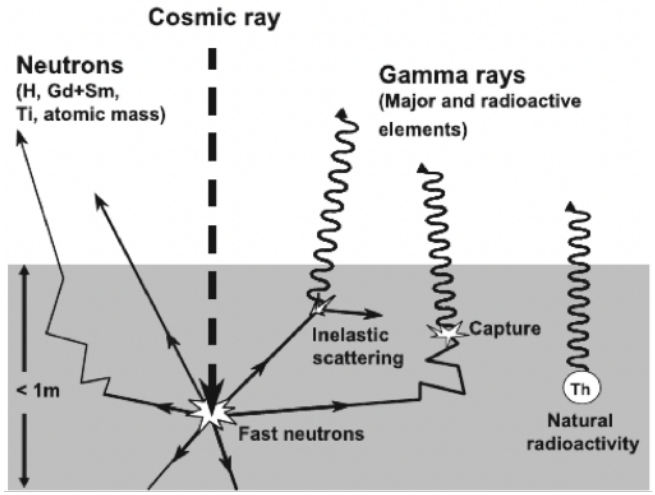
$^{16}O(n, \alpha\gamma(3684))^{13}C$

$^{14}N(n, t\gamma(4438))^{12}C$

$^{14}N(n, \alpha\gamma(4444))^{11}B$

$^{16}O(n, n'\gamma(6129))^{16}O$

$^{16}O(n, n'\gamma(6915))^{16}O$



A solid

Far Future? — (Exo)planet Spectroscopy

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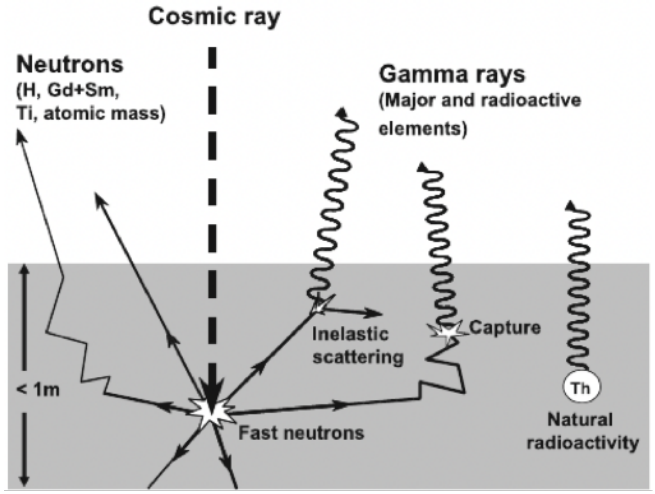
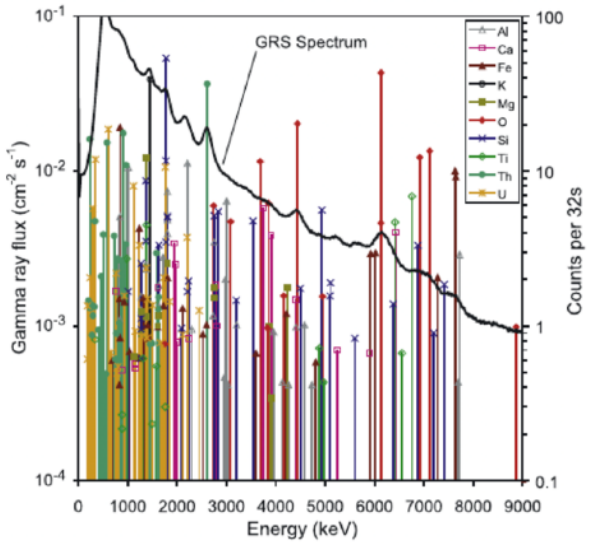
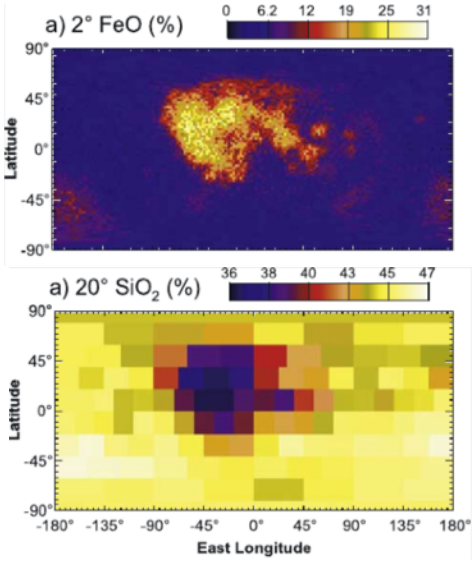


A solid

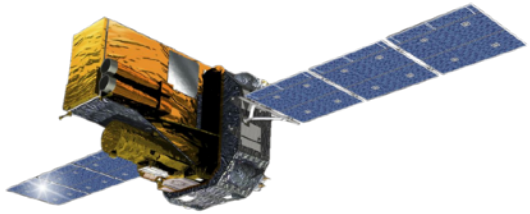


Measurements (!) by Lunar Prospector

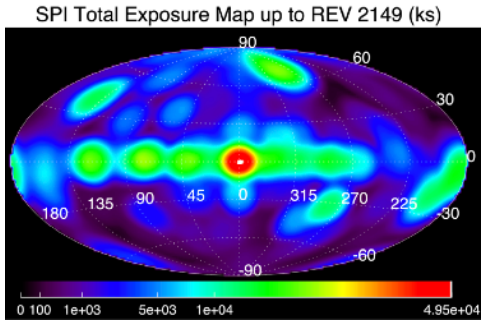
Prettyman+2006



MeV Astrophysics Projects — Which Way to go?

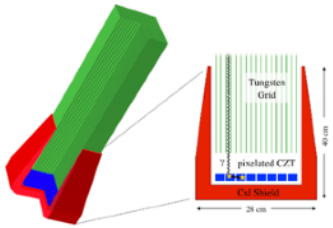


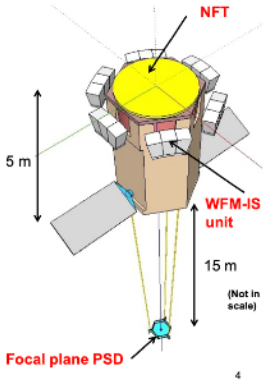
INTEGRAL: 2002-2029



Which way to go?

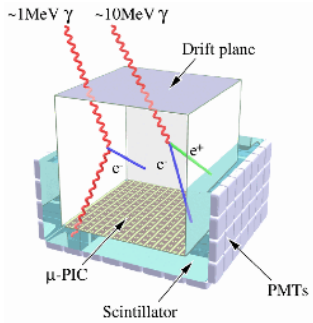
ASAPP: concept
1x1 deg^2 collimator
Mapping 511 keV
Polarisation
AGN, MeV background

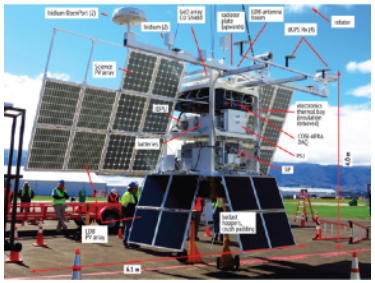




SMILE: already flown
Electron Tracking
Compton Camera
High BG rejection
Polarisation
Low spectral resolution

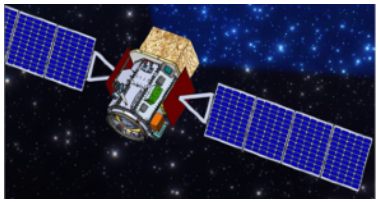
ASTENA: concept
Laue lens principle
(sub)-arcmin resolution:
Extragalactic sources
Imaging in MeV

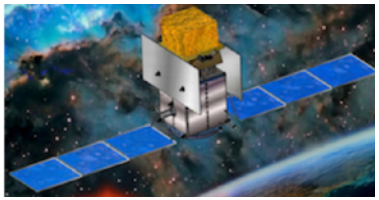




COSI: already flown
Excellent for:
Nuclear lines
GRBs (polarisation)
XRBs, AGN,
Large FoV (CGB)

Flagships:
AMEGO — Astrogam





Great, but great enough?