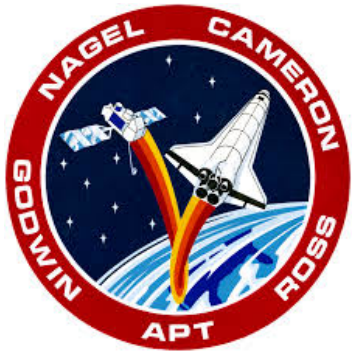


Goddard
SPACE FLIGHT CENTER

GSFC June 23, 2016
- CGRO celebration -

Dieter H. Hartmann
Clemson University

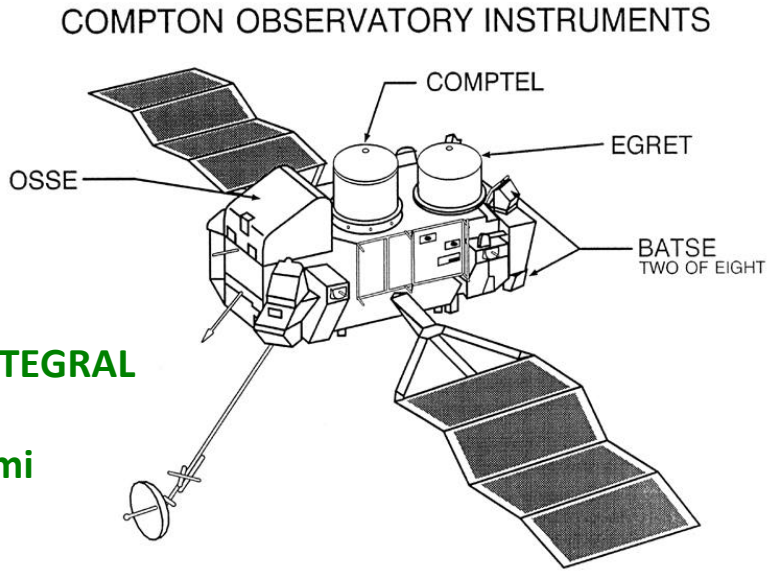
Second of NASA's great observatories:
Study the sky in the 30 keV to 30 GeV.

- Launched aboard Space Shuttle Atlantis (STS-37) on April 5, 1991.

- Deorbited and re-entered the Earth's atmosphere on June 4, 2000.

The 9 year CGRO science harvest:
back to the future of gamma-ray astronomy

A 17 ton discovery machine: the heaviest scientific payload flown.

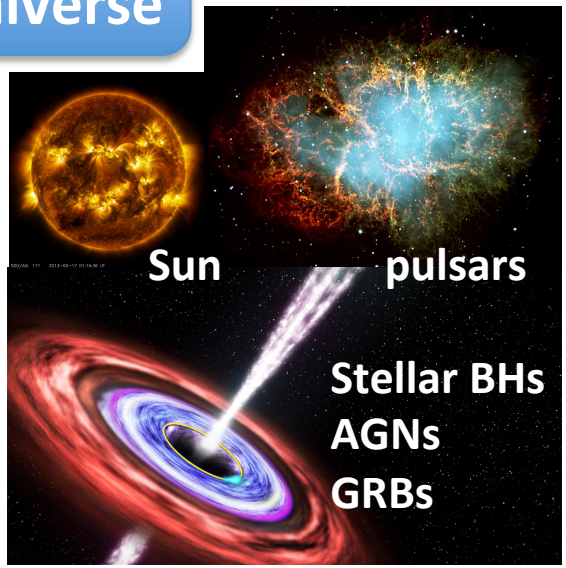


Burst And Transient Source Experiment (**BATSE**) ***Swift***
Oriented Scintillation Spectrometer Experiment (**OSSE**) **INTEGRAL**
Imaging Compton Telescope (**COMPTE**L) **INTEGRAL**
Energetic Gamma Ray Experiment Telescope **(EGRET**) **Fermi**

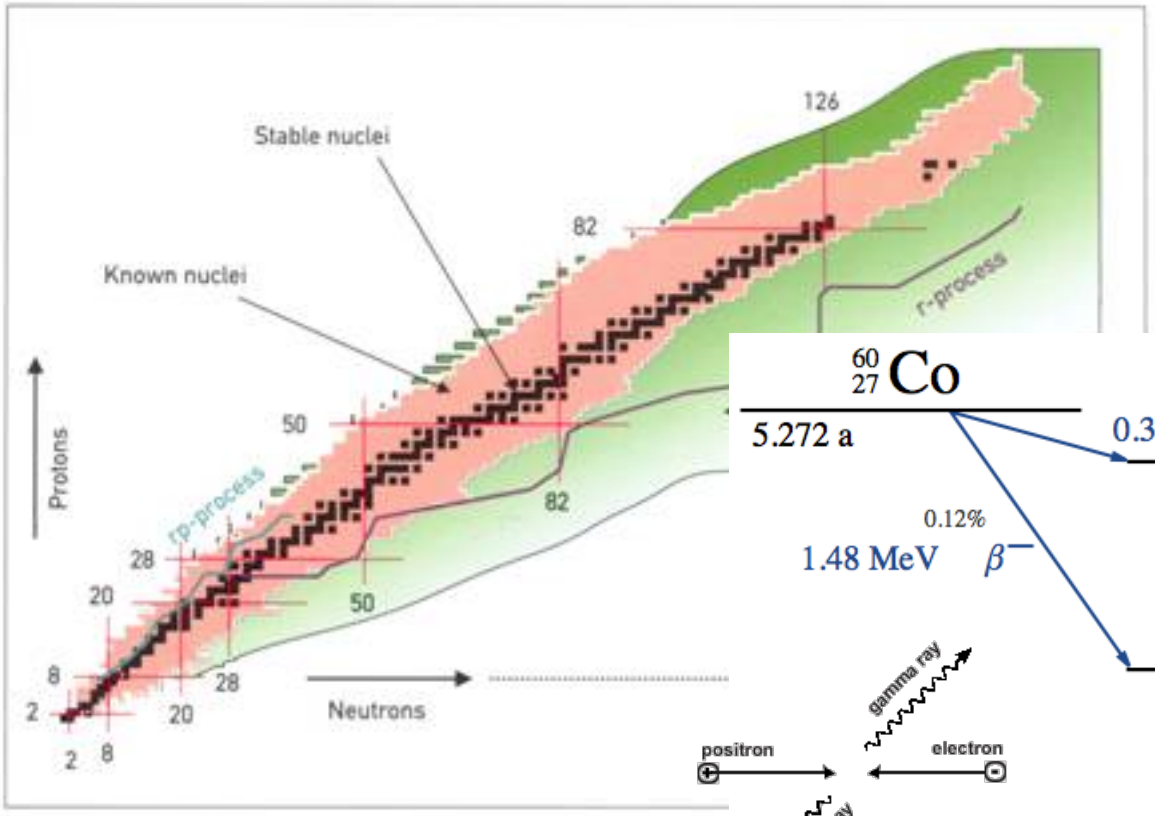
Each instrument sensitivity better by X 10

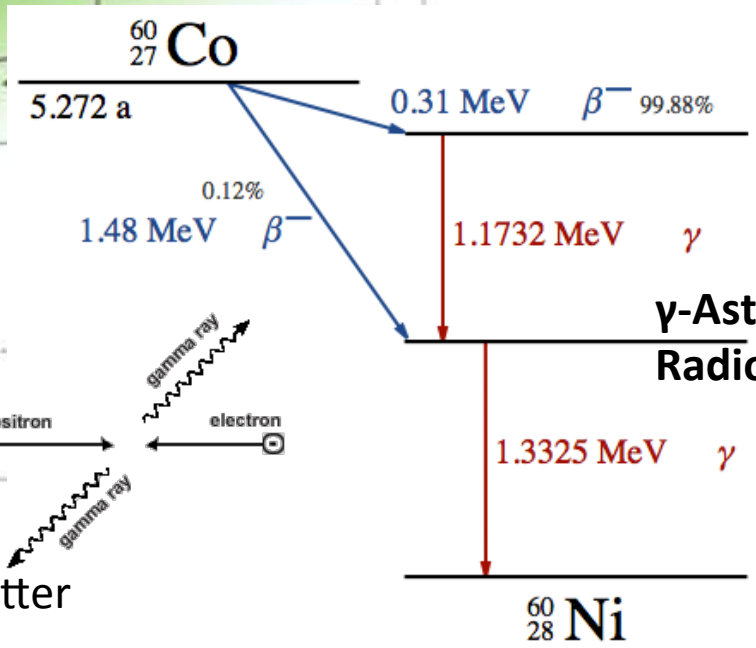
Gamma-Ray Astronomy:
E = kT = MeV implies 10^{10} K

The non-thermal, variable & violent universe



Molecular – atomic – **nuclear** & **particle** **astrophysics**
meV eV keV MeV GeV TeV

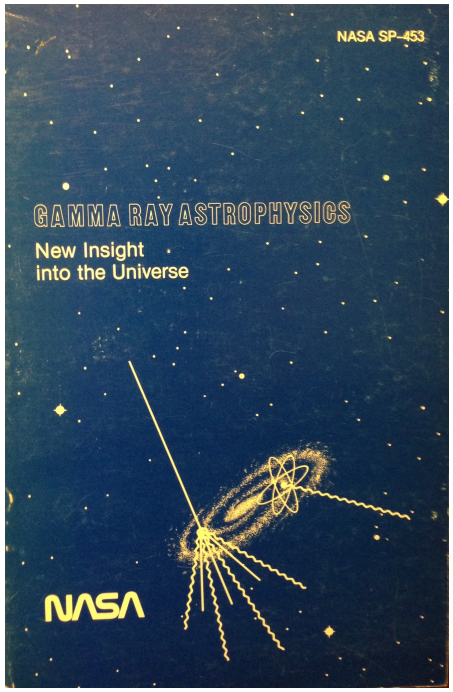




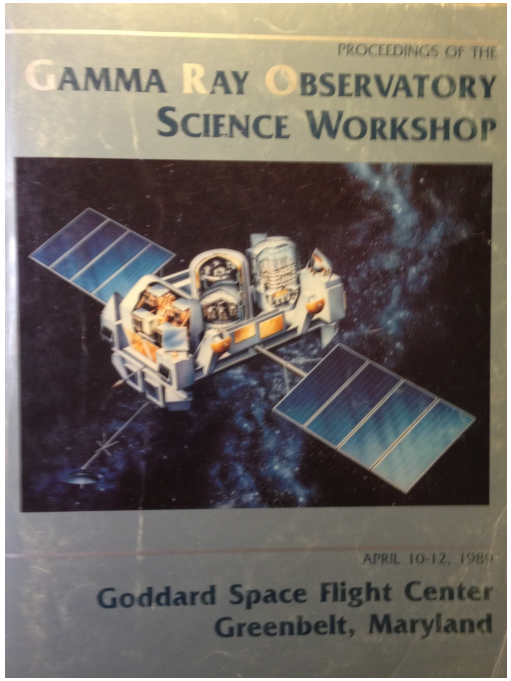
γ-Astronomy with Radioactivities

Annihilation
Incl. Dark Matter

All you need to know?



Fichtel & Trombka 1981



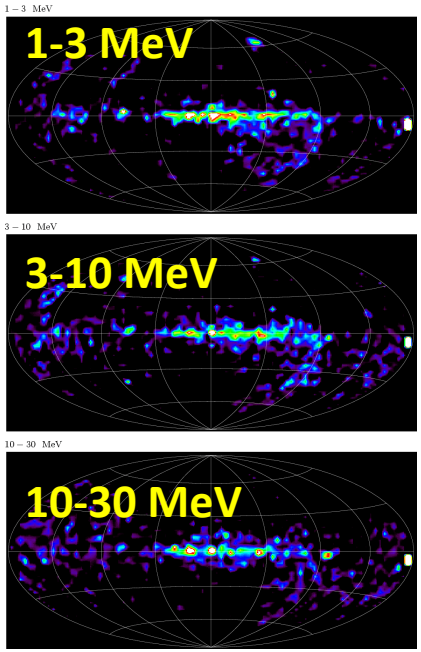
1989 Workshop at GSFC

Atlantis (STS-37) launch April 5, 91

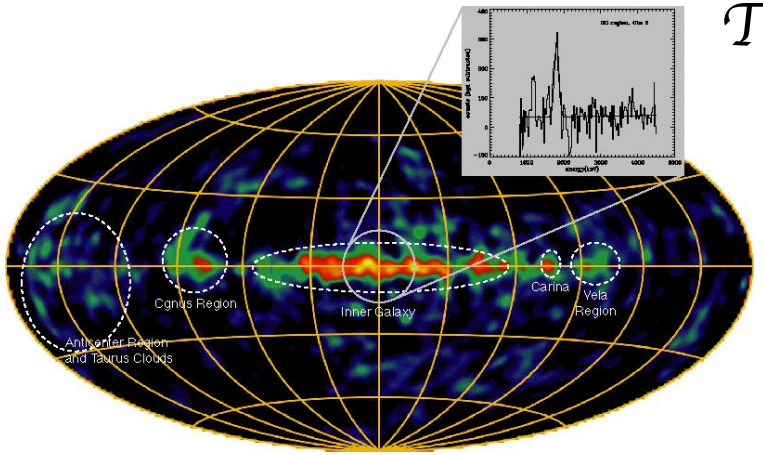
1973 GRBs SN 1987A

1983 UCSC 1989 PhD on GRBs 1991 Clemson

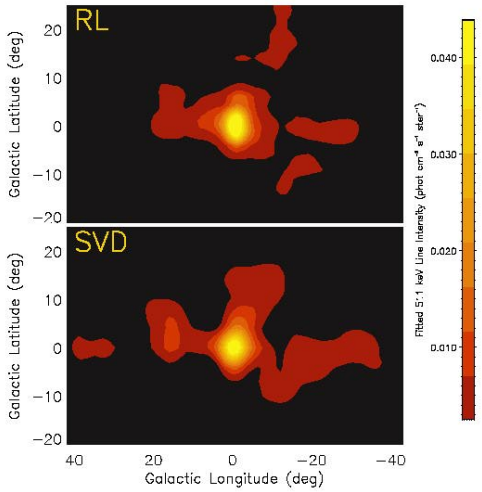
The Compton Harvest:



COMPTEL: 32 steady sources Schönfelder 2000

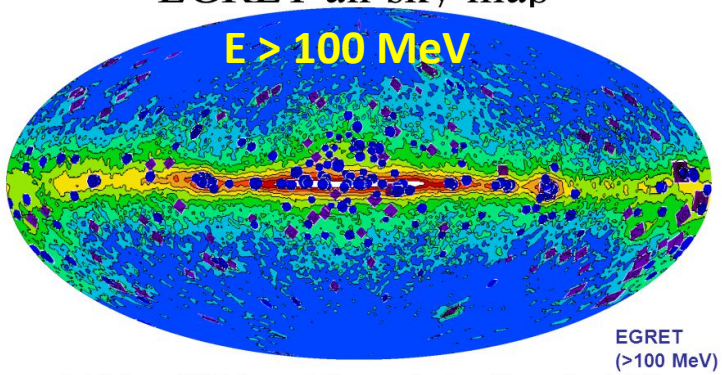


COMPTEL ^{26}Al 1.809 MeV



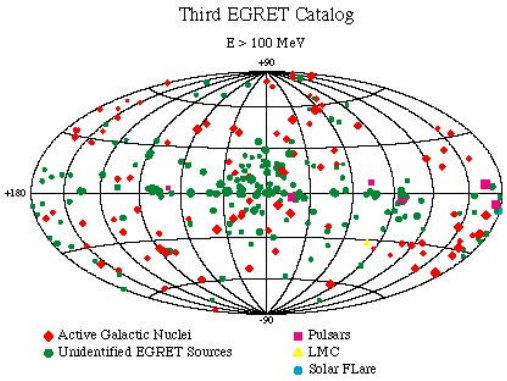
OSSE gc 511 map

EGRET all-sky map

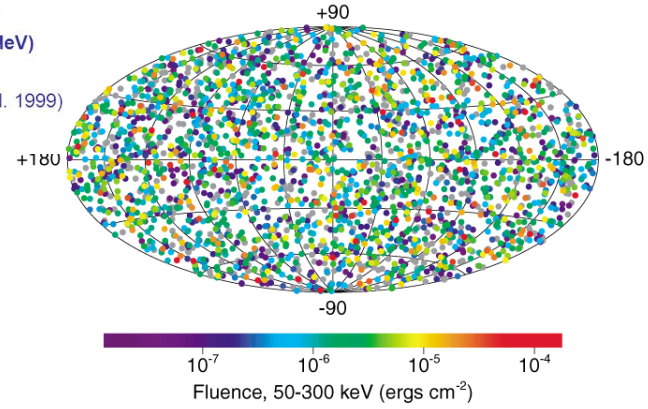


- ~1.4 Mγ, ~60% interstellar emission from the MW
- ~10% are cataloged (3EG) point sources

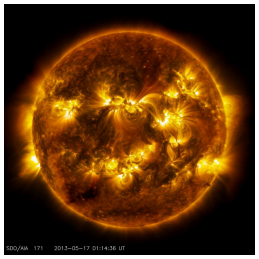
3EG catalog (Hartman et al. 1999)

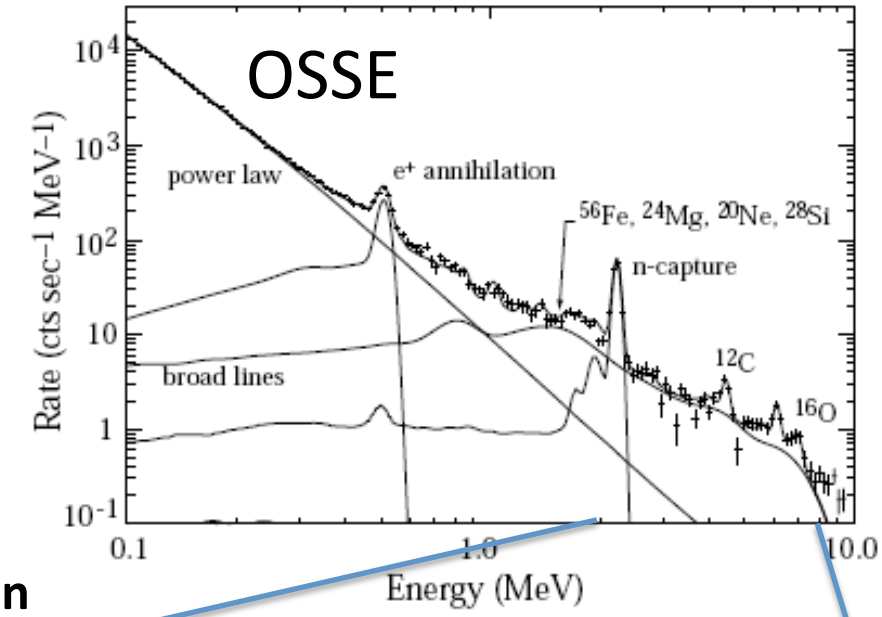


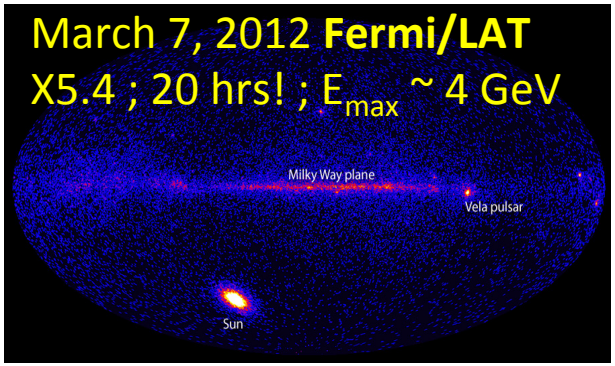
2704 BATSE Gamma-Ray Bursts



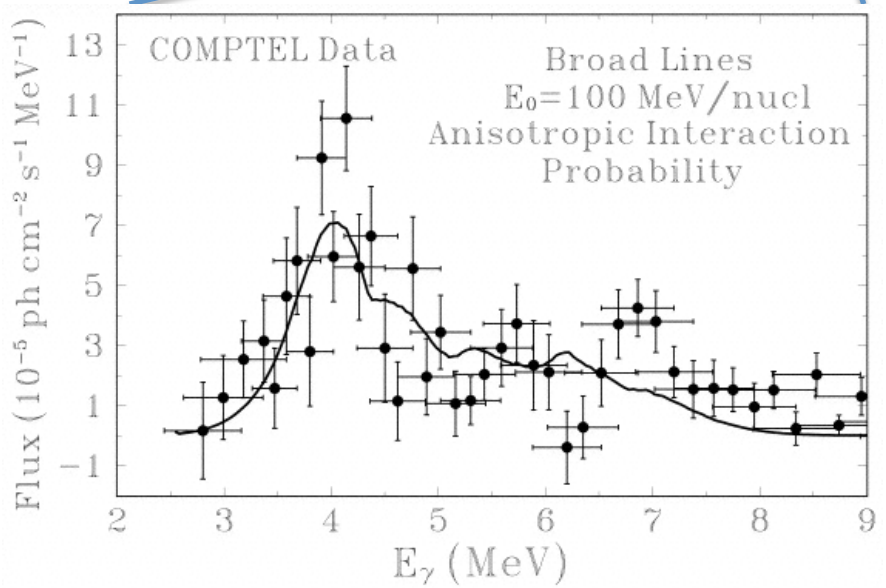
Diffuse galactic emission due to CR propagation: GALPROP

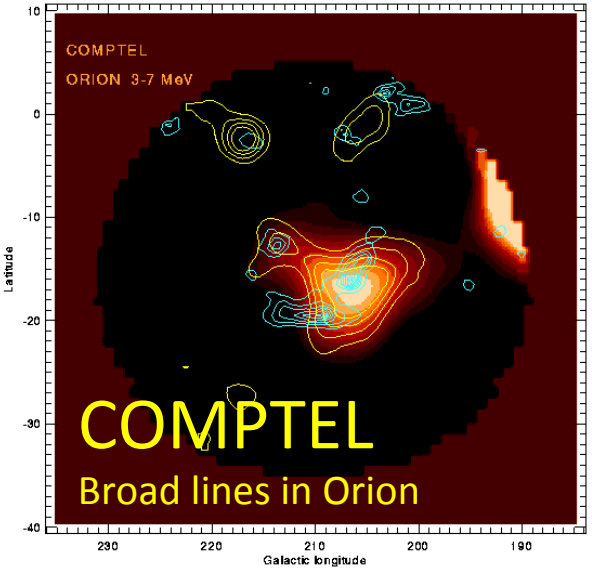




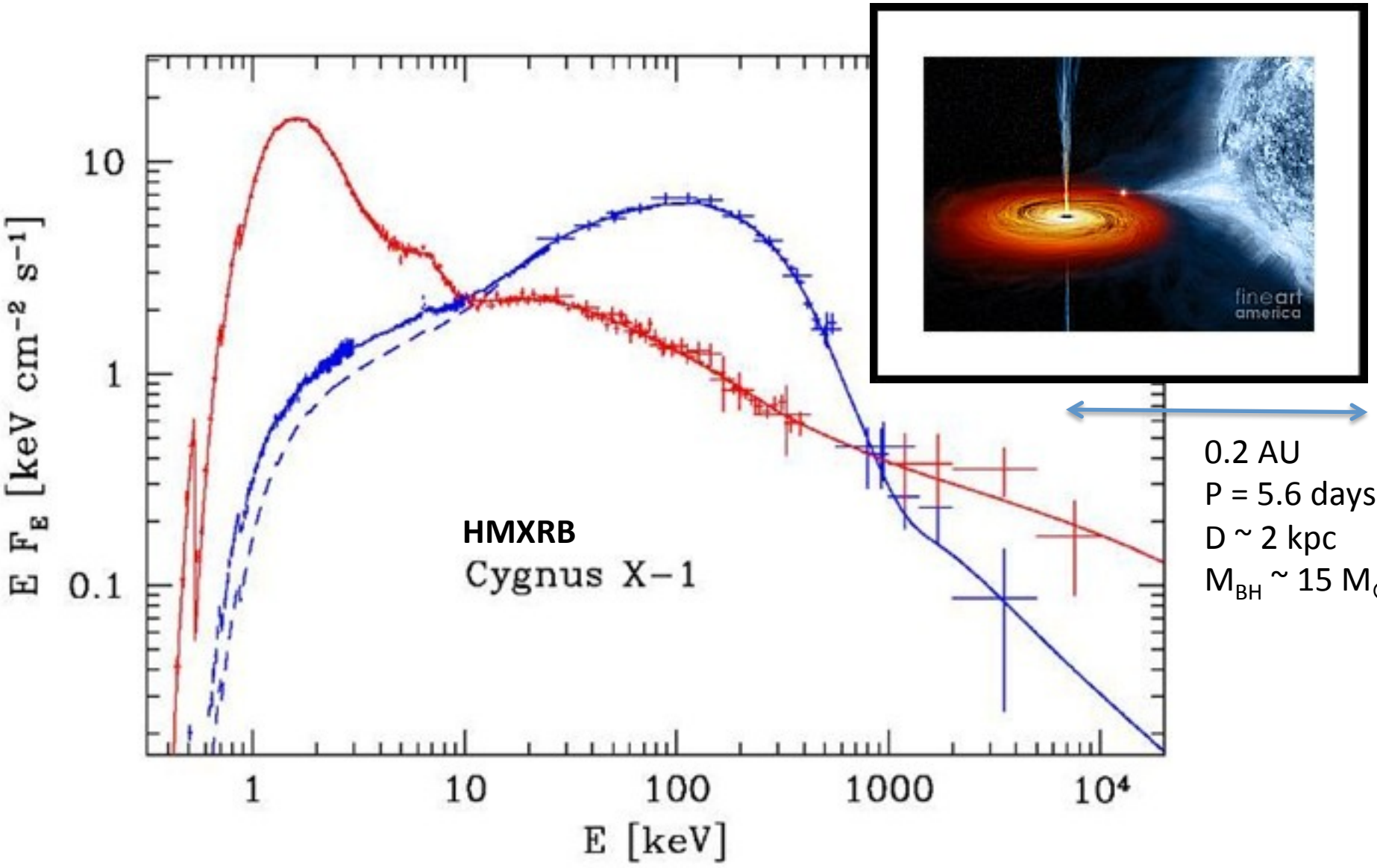


Nuclear Deexcitation in the ISM





Bloemen+ 94,97: Accelerated C, O on stationary H, He
Ramaty, Kozlovsky, Lingenfelter 97

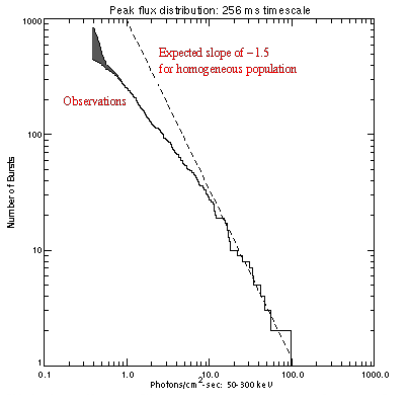


X- and gamma-ray spectra of Cyg X-1 in soft ("high") and hard ("low") spectral states as measured by COMPTEL (MeV), OSSE (sub-MeV) and BeppoSAX (X-ray) instruments. Spectral fits : hybrid thermal/nonthermal Comtonization model.

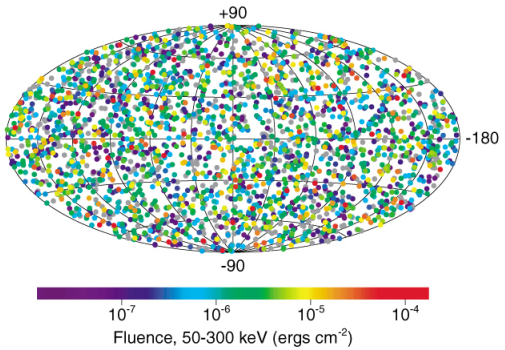
The GRB Debate (95)

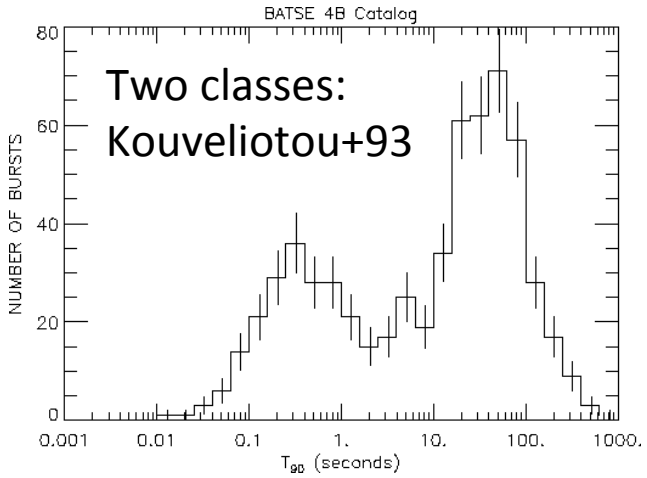
- Shapley-Curtis 1920 -

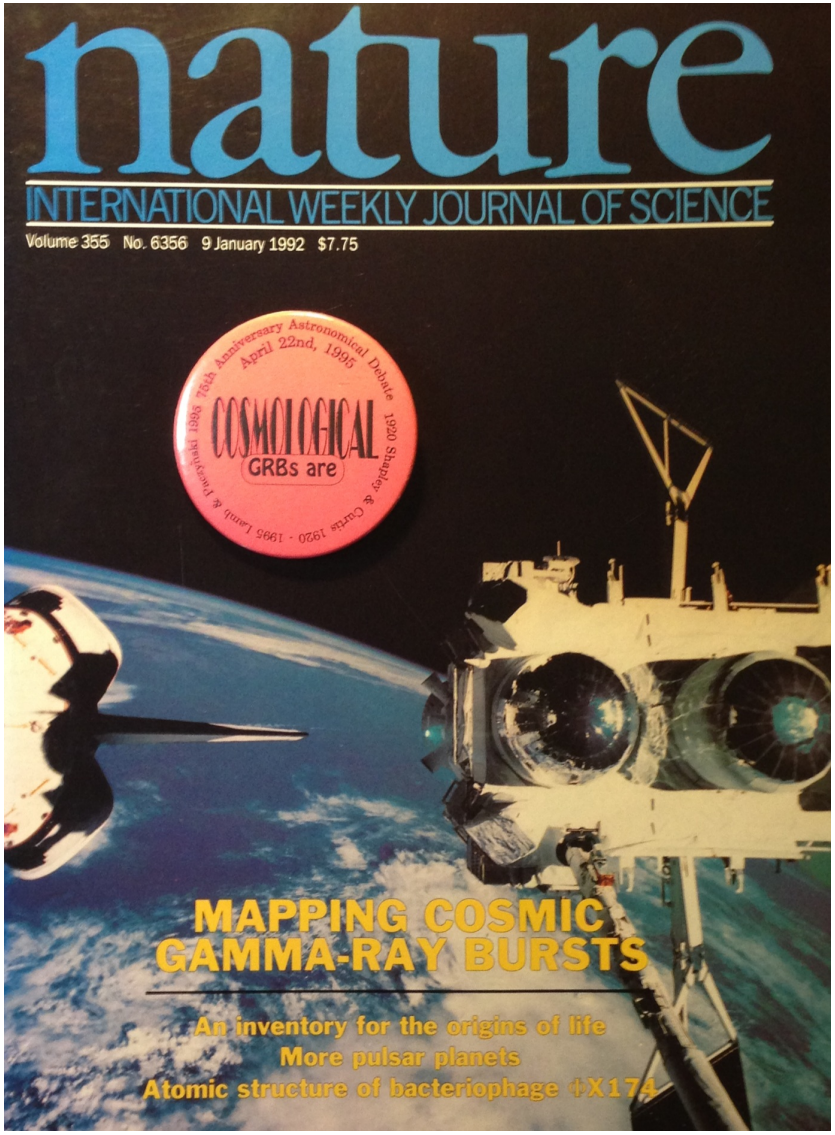
D. Lamb,
B. Paczynski
M. Rees



2704 BATSE Gamma-Ray Bursts



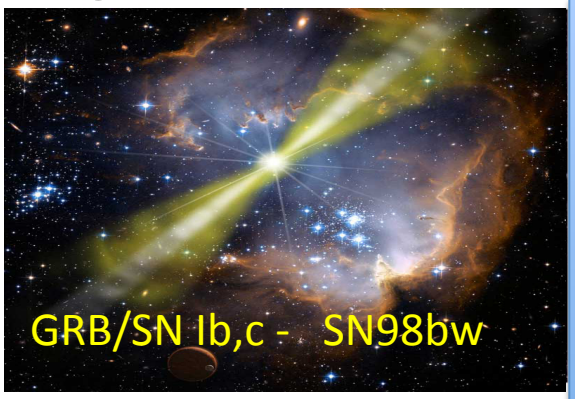




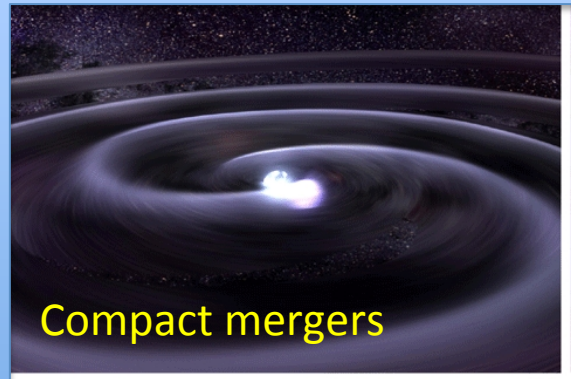
Meegan et al. 1992, Nature 355, 143

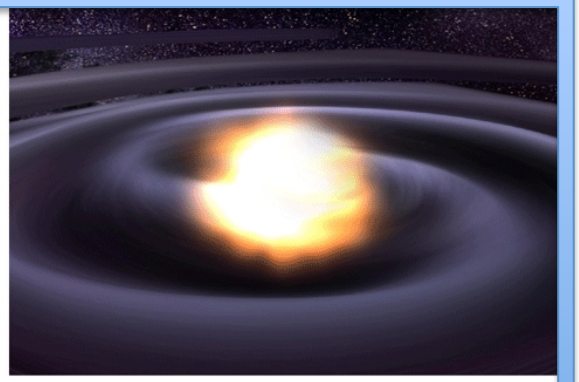
153 bursts

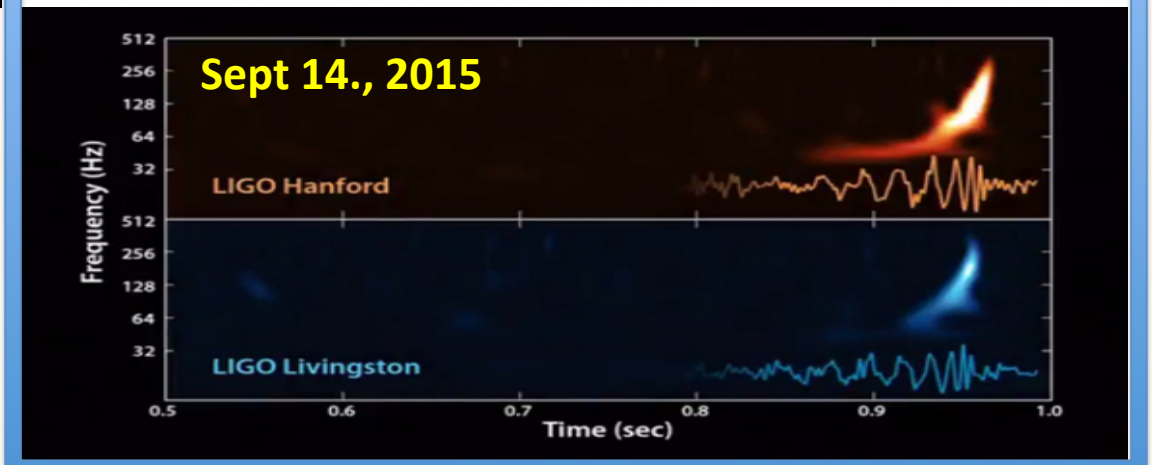
Long Duration GRBs

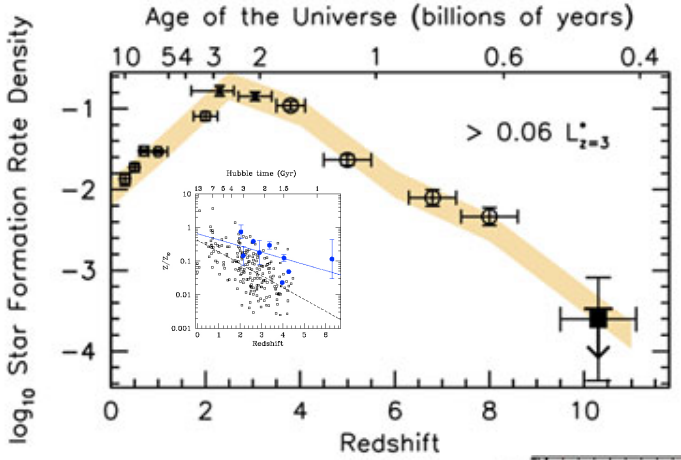


Short Duration GRBs

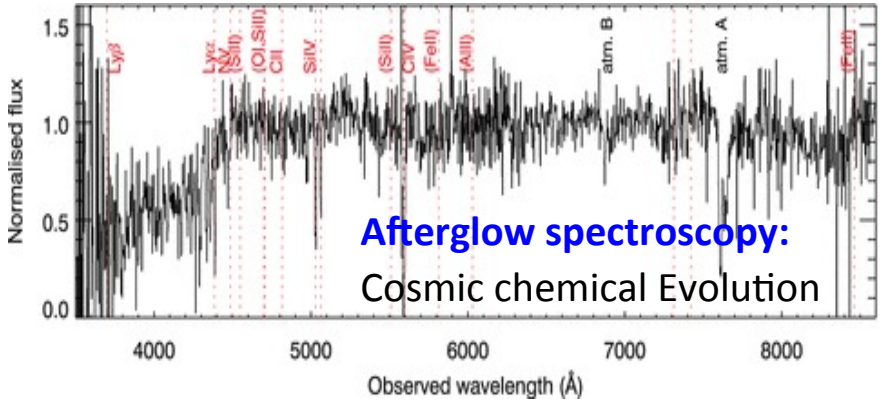




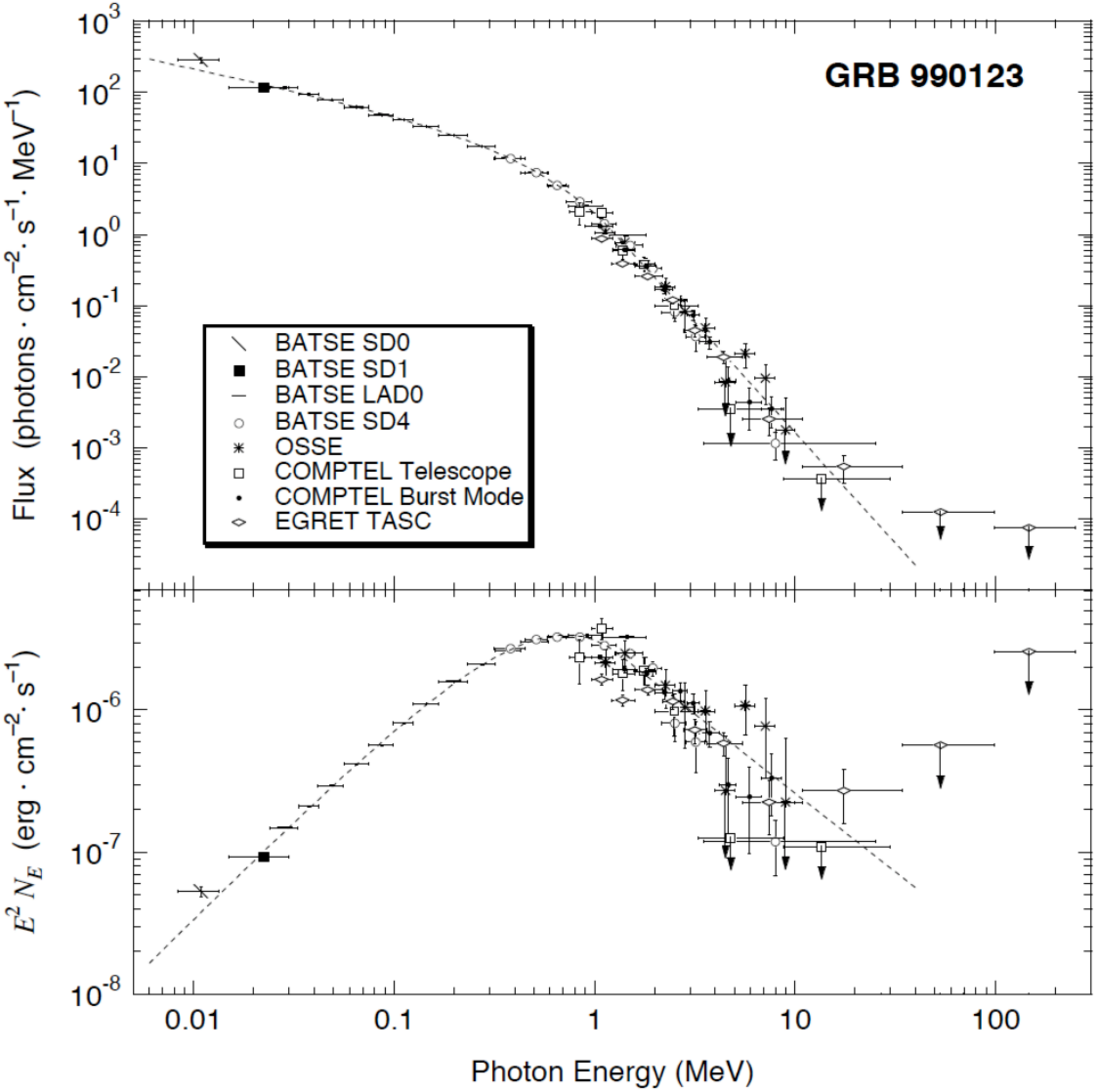


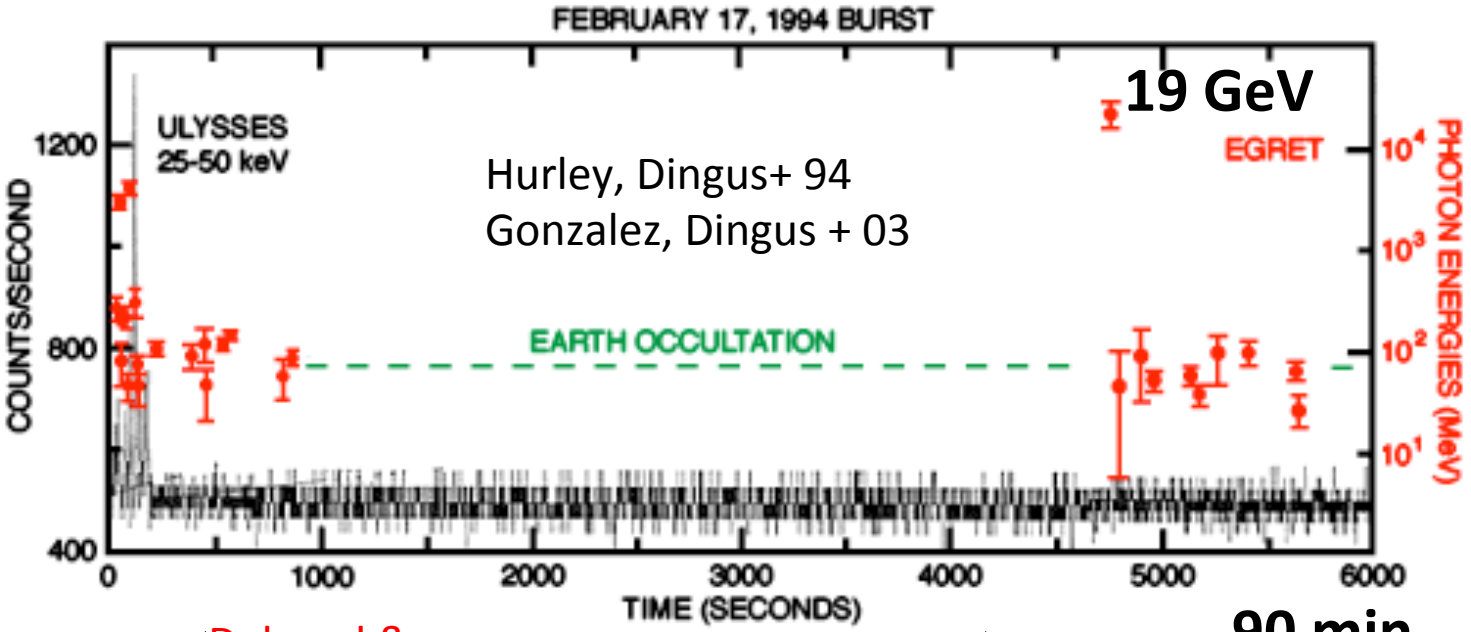


11/2004

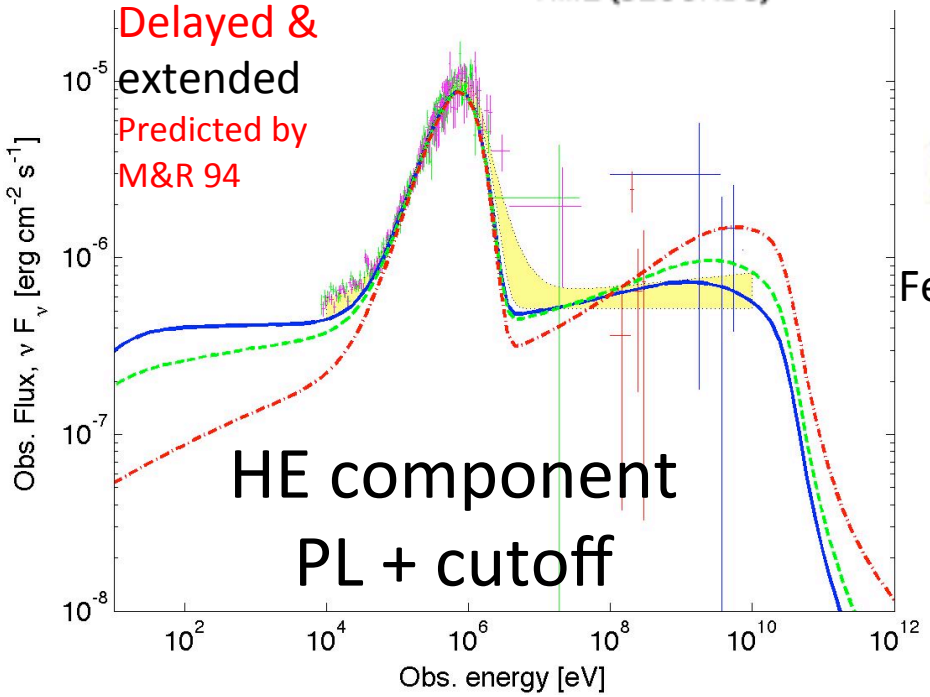


Prompt emission





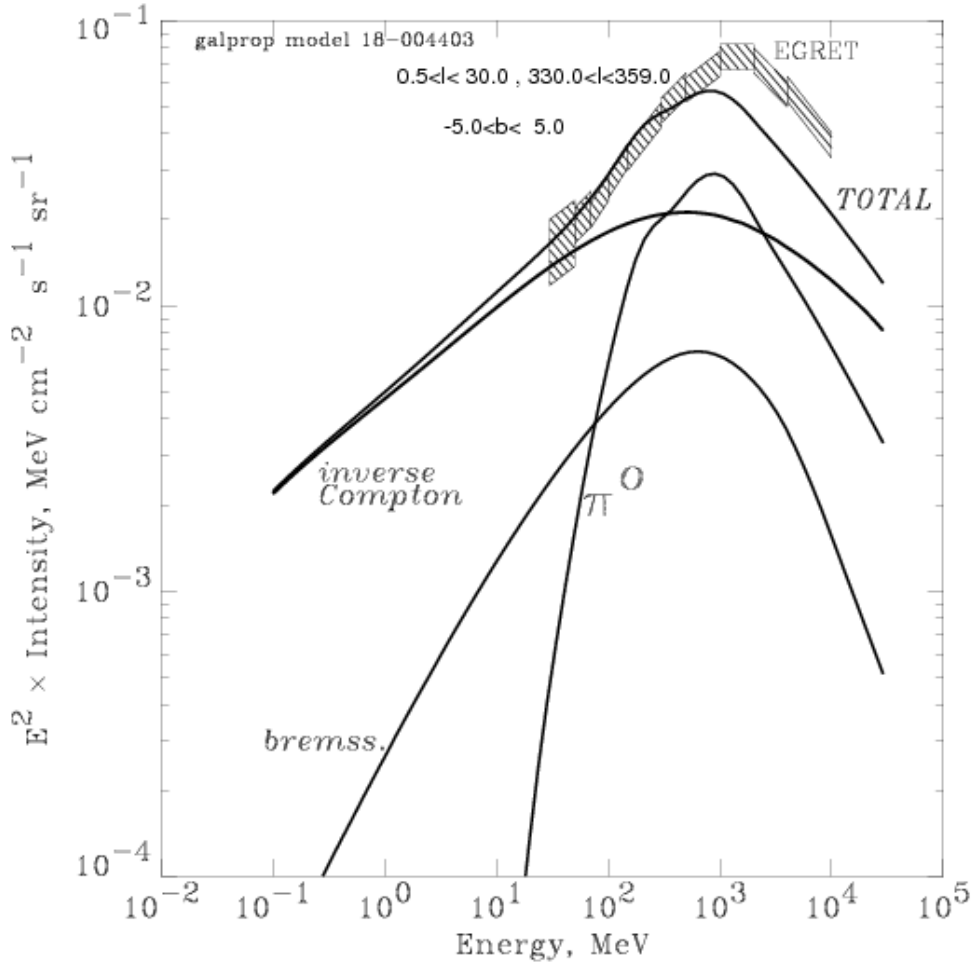
90 min



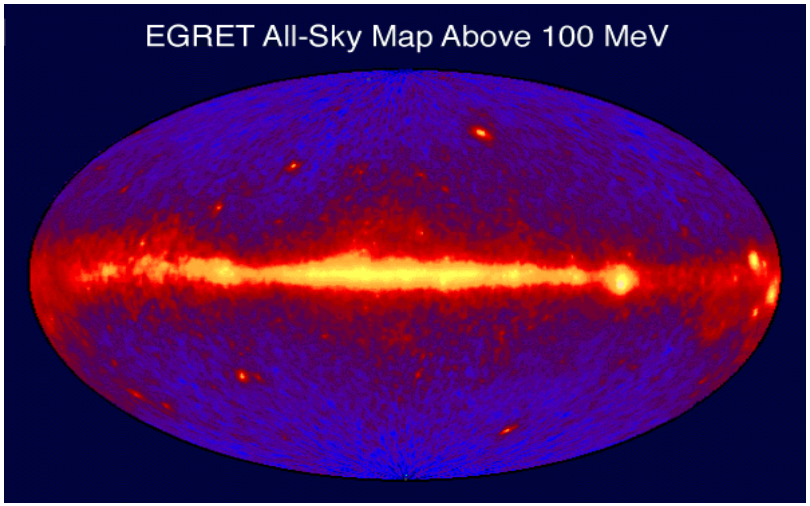
Fermi: 2008

The era of physical models for prompt emission, begun it has

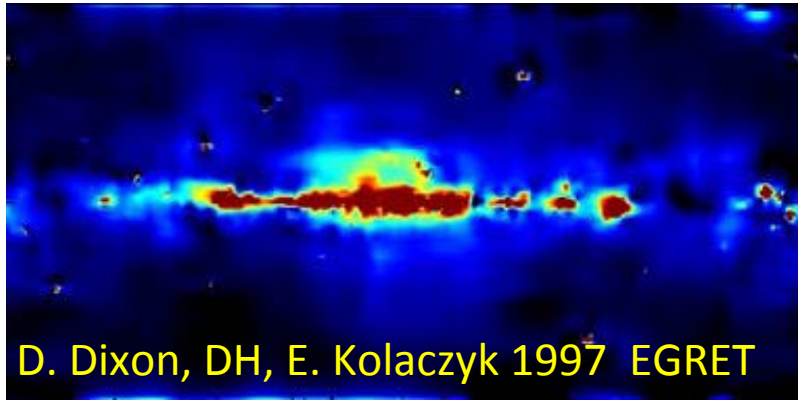
high energy emission in GRBs A. Pe'er et al.



I. Moskalenko, A. Strong, +



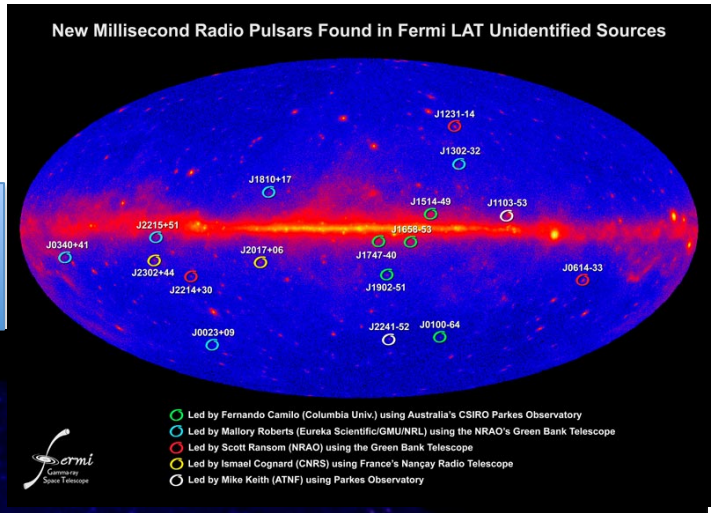
Is the inner galaxy GeV excess due to DM annihilation?

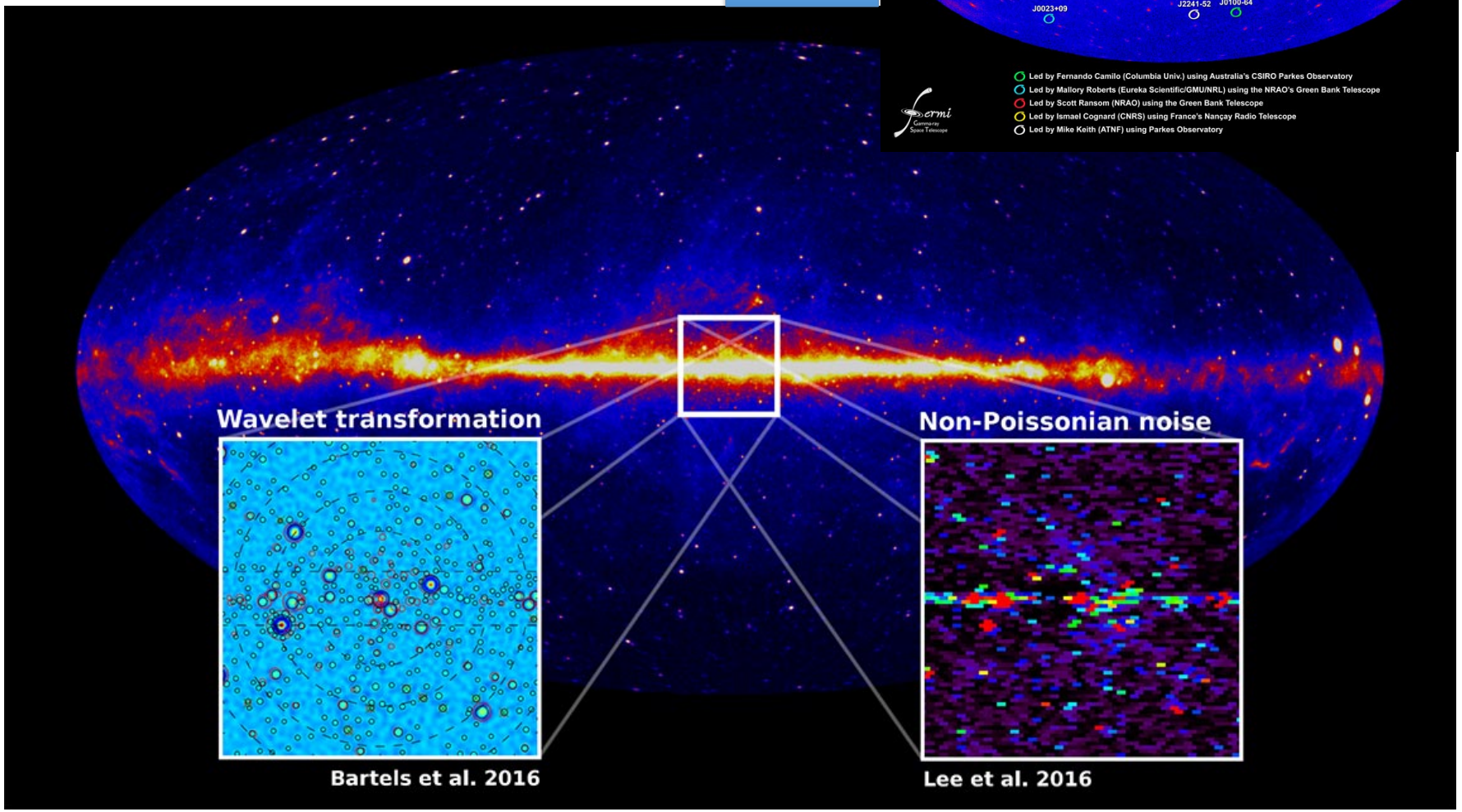


DM annihilation in the central Milky Way?

Unresolved MSPs can explain the FermiGeV excess data !

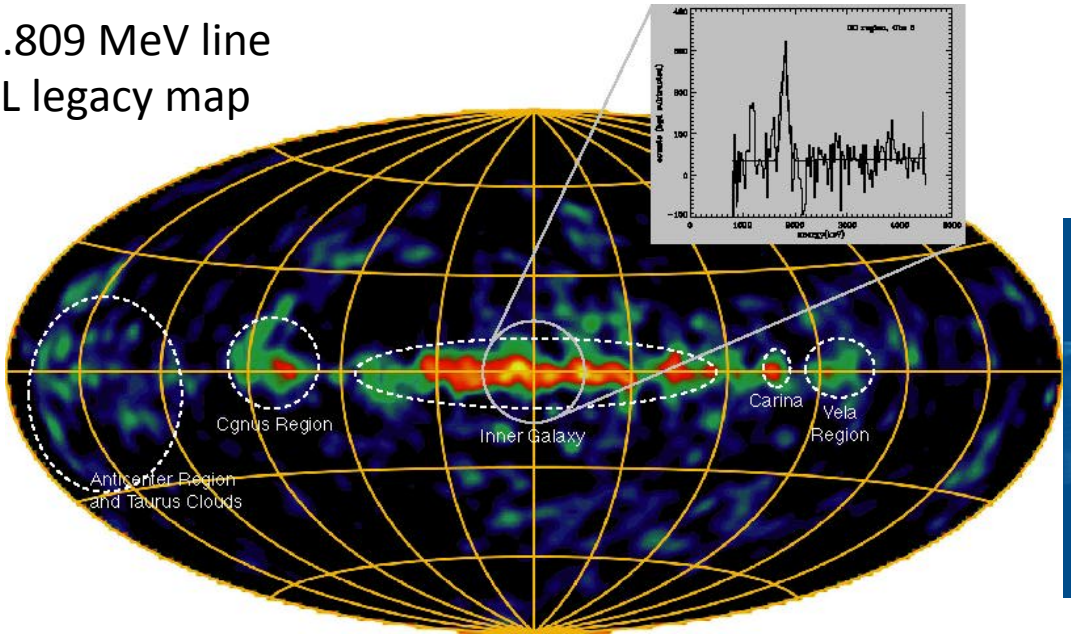
PTAs



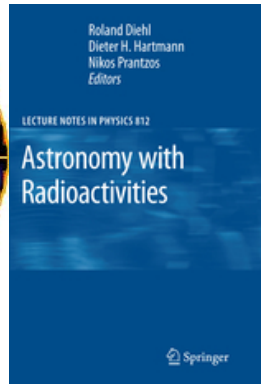


Diffuse 1.809 MeV line
COMPTEL legacy map

^{26}Al



Predicted 1977
Ramaty & Lingenfelter
Discovered 1984
Mahoney+ HEAO-3



Steady state: $M_{26,ISM} = SNR * M_{ej} * \tau$

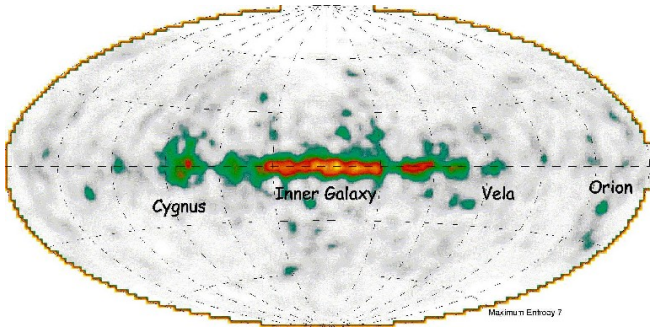
~ $10^{-2}\ 10^{-4}\ M_\odot\ 10^6$

Best indicator of mean galaxy wide SFR: few $M_\odot$/year

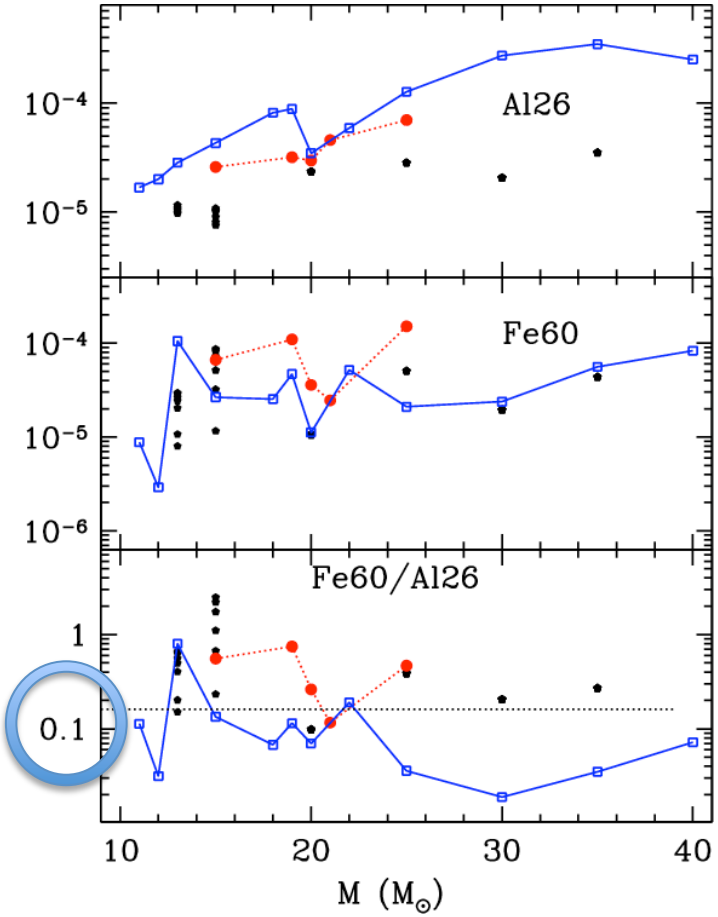
Static H/He-shell .b
➔WR winds
& explosive Ne/C b.
<Yield> ~ $10^{-4}\ M_\odot$

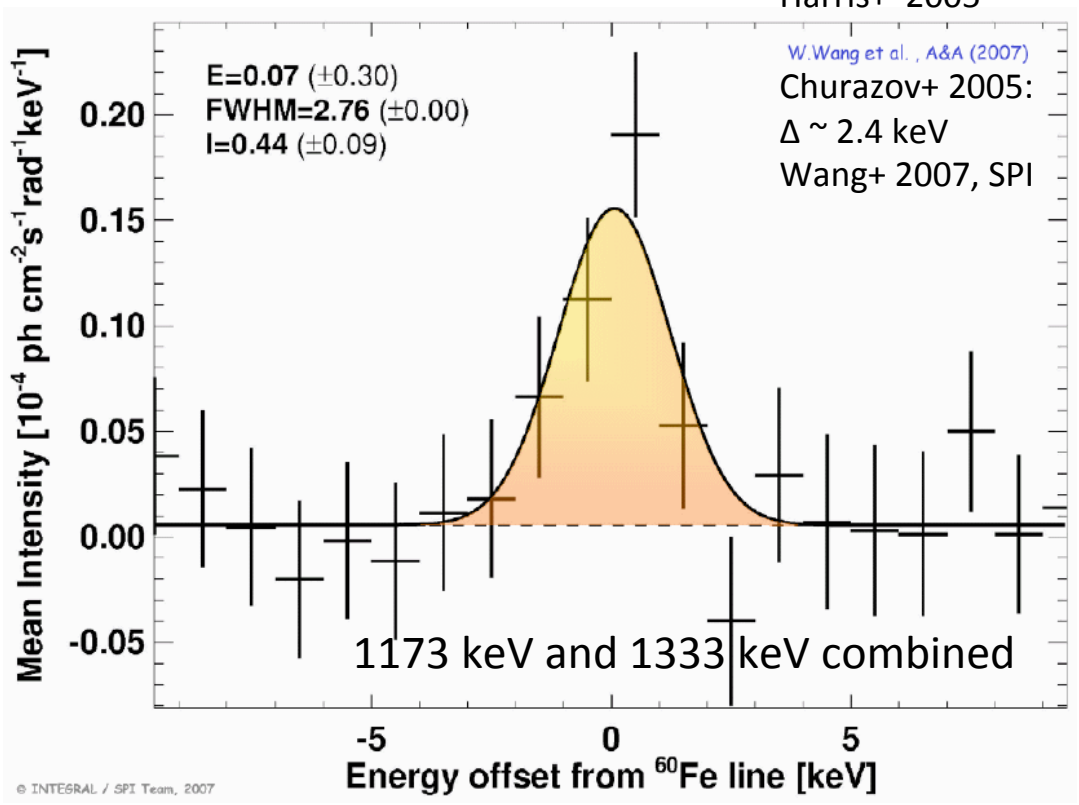
^{26}Al & ^{60}Fe map needed

Coproduced in massive stars:
Static He-shell b. s-process
(explosion only ejects!)



RHESSI: Smith 2005
INTEGRAL/SPI
Harris+ 2005

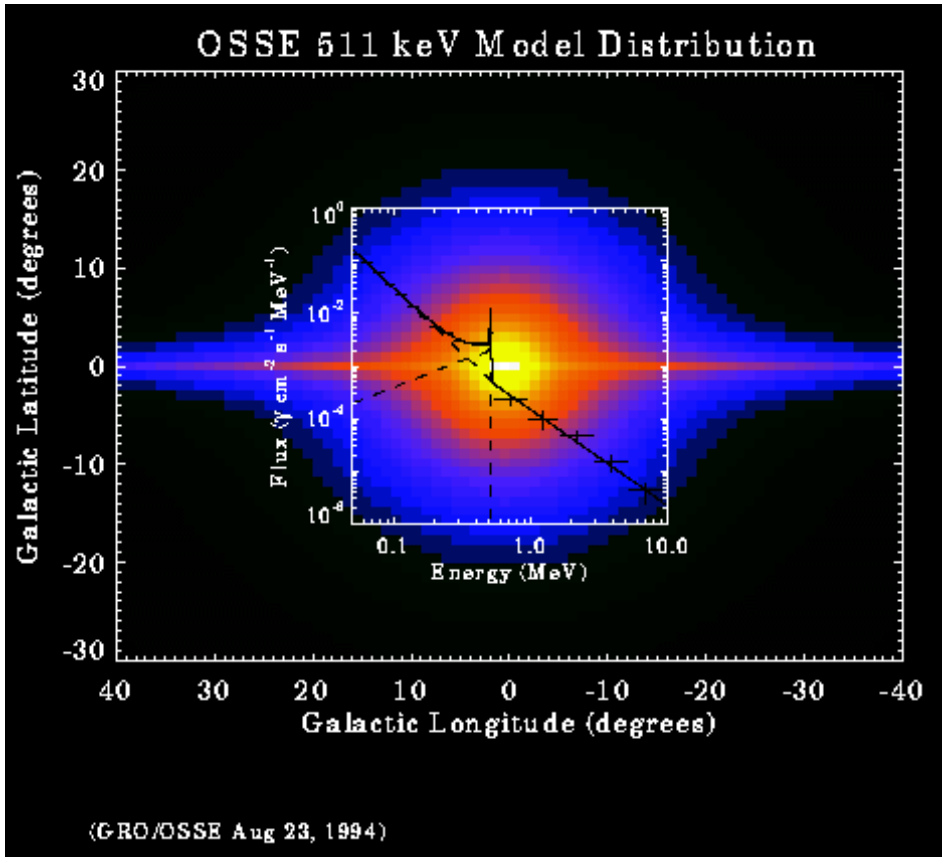


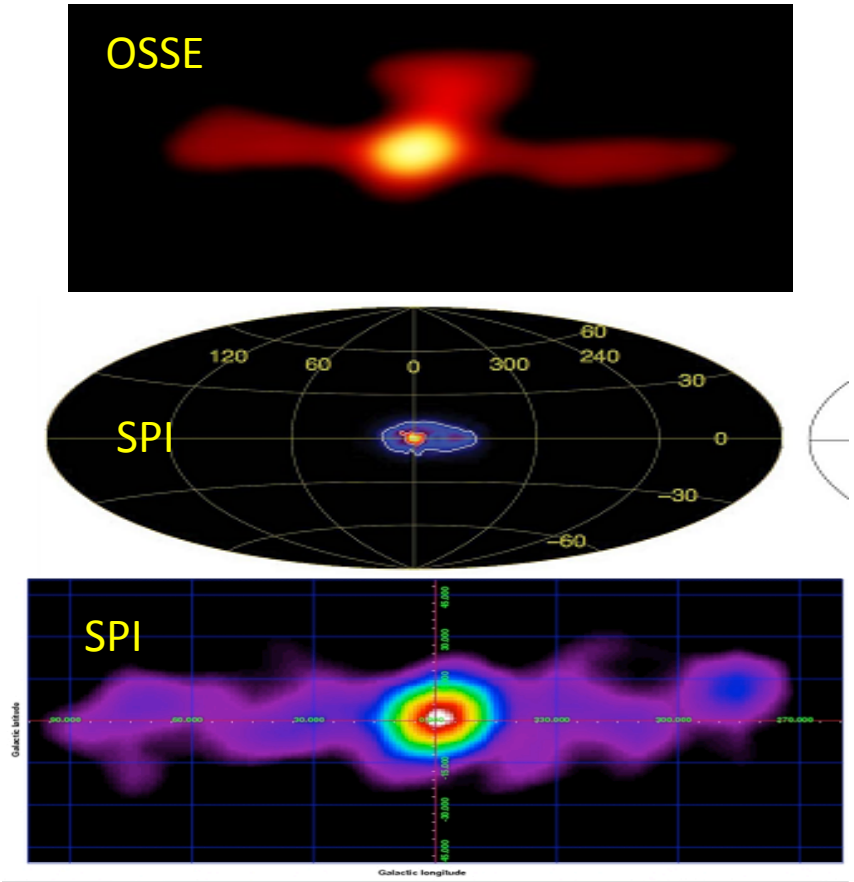


Churazov+ 2005:
Δ ~ 2.4 keV
Wang+ 2007, SPI

1173 keV and 1333 keV combined

^{59}Fe(n,γ)^{60}Fe(n,γ)^{61}Fe Rate uncertainties ➔ yield uncertainties





Johnson, 72; Leventhal 78 – balloons

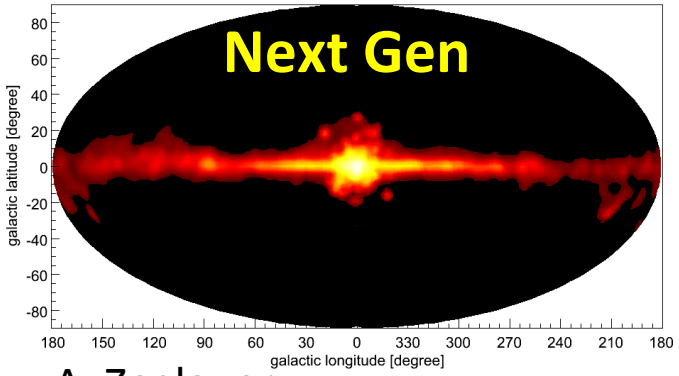
OSSE Purcell 93…: Constant emission
marginal disk detection, north jet

INTEGRAL/SPI: B/D ~ 0.6

Positron production rate 5 10^{43} s^{-1}

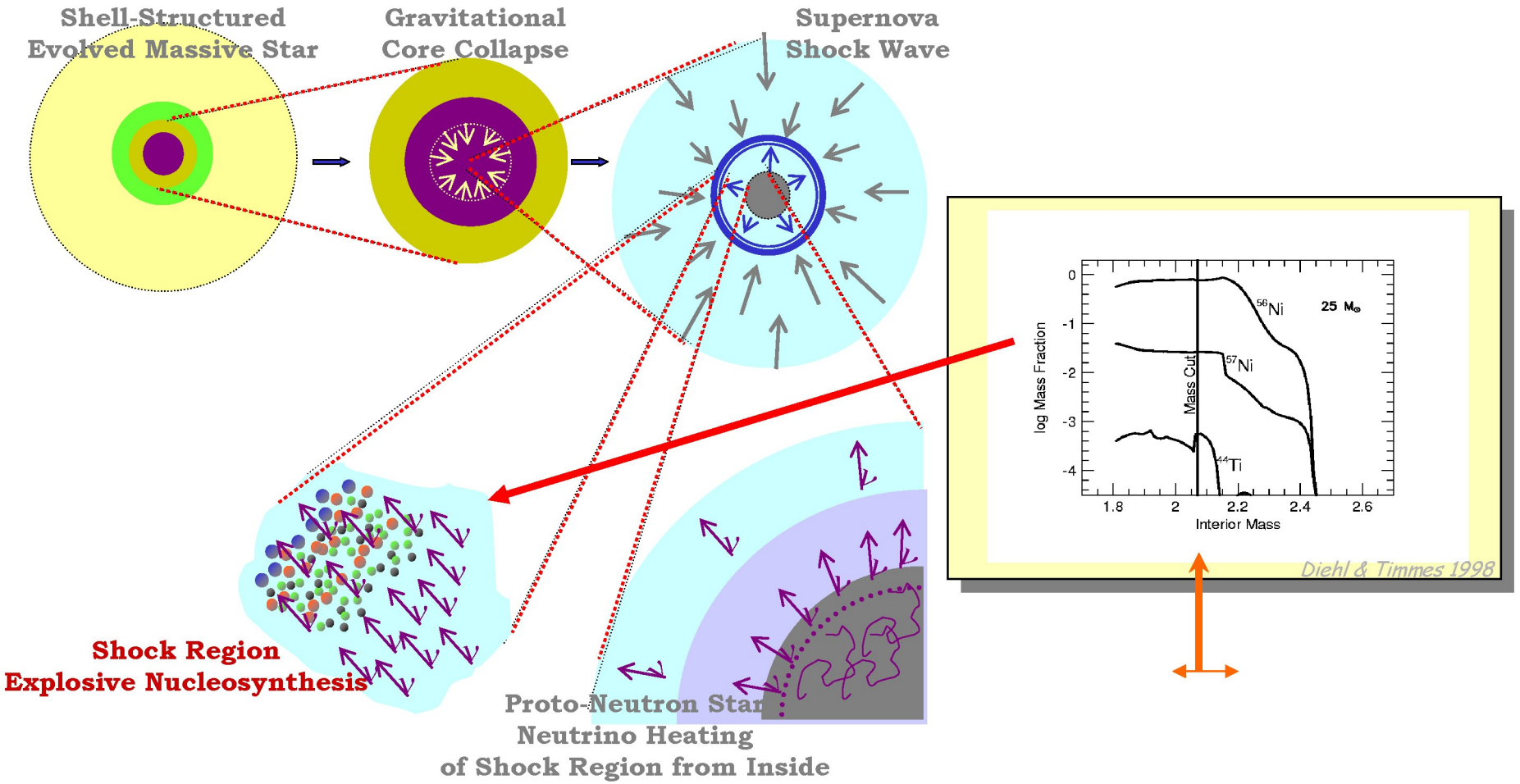
^{26}Al, ^{44}Ti, SNIa, V404 Cyg micro-quasar, MSPs,…

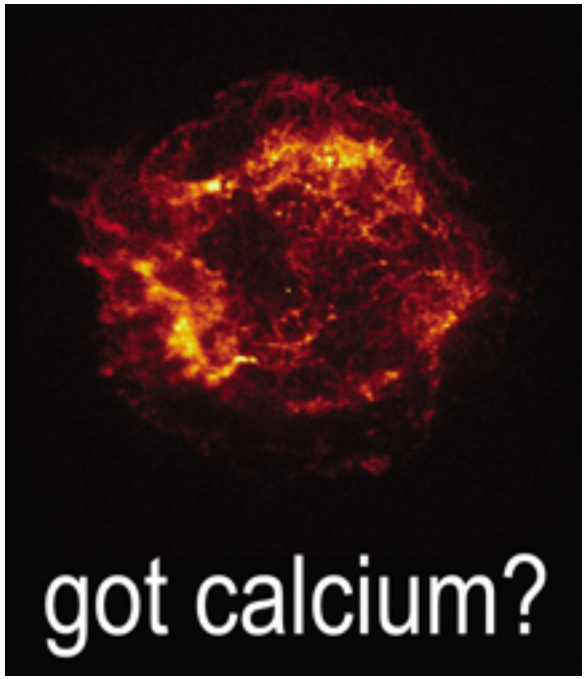
All-sky image in the 511 keV line after 5 years



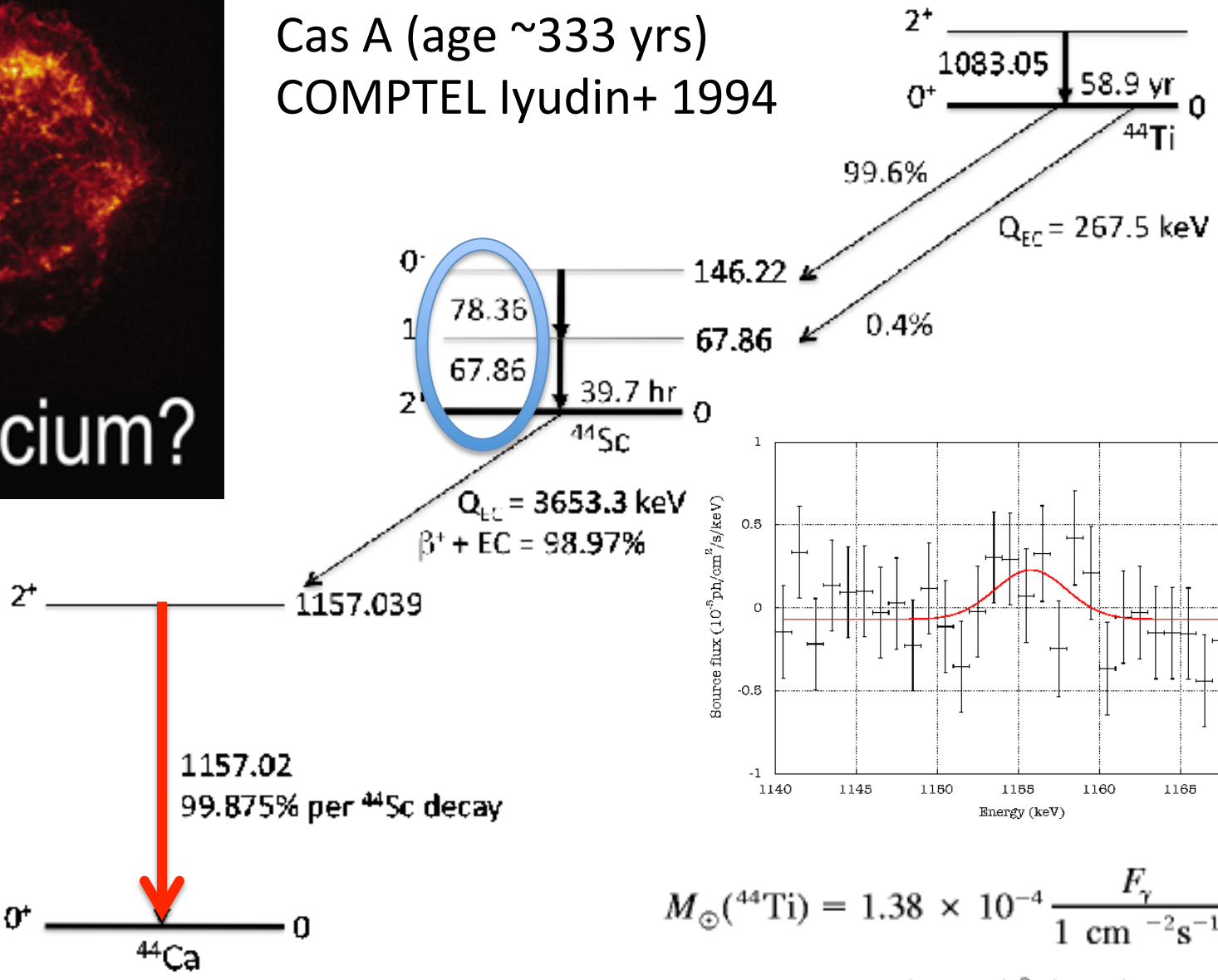
A. Zoglauer

Explosive Si burning: Looking deep into a dying massive star





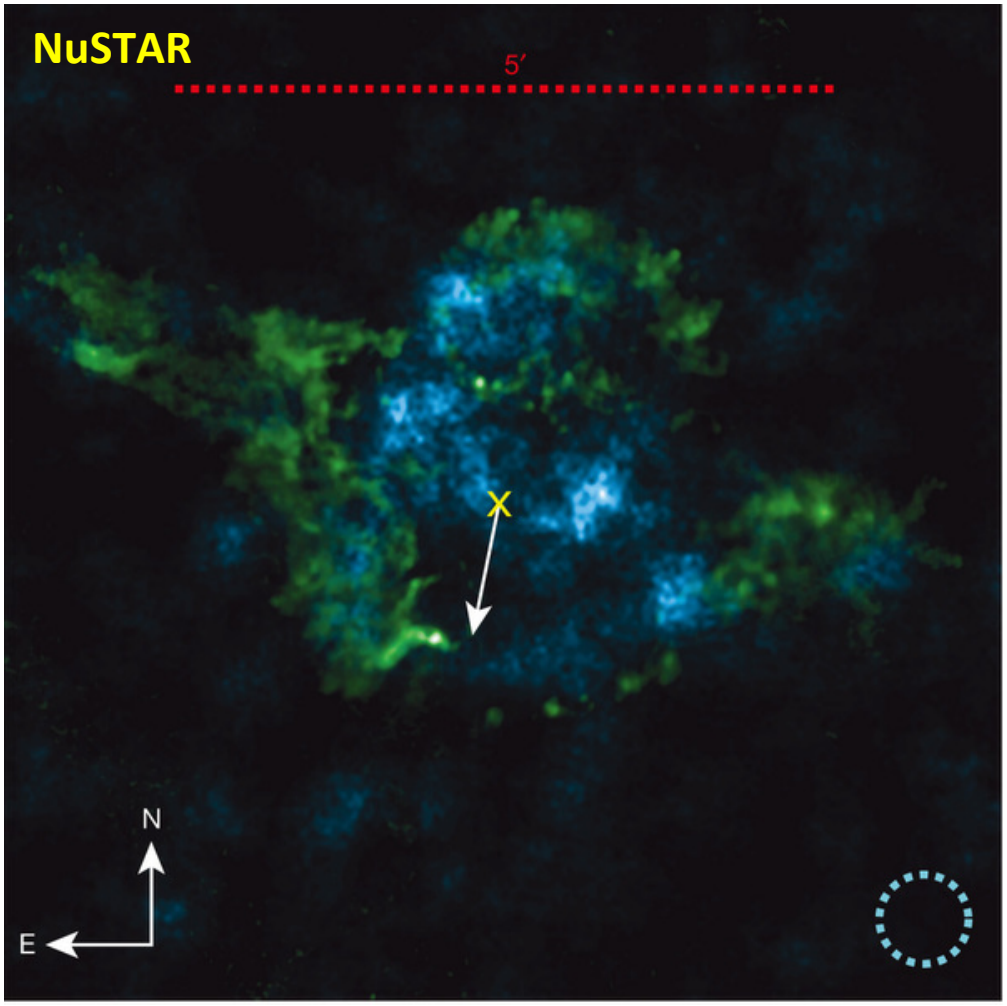
Cas A (age ~333 yrs)
COMPTEL Iyudin+ 1994



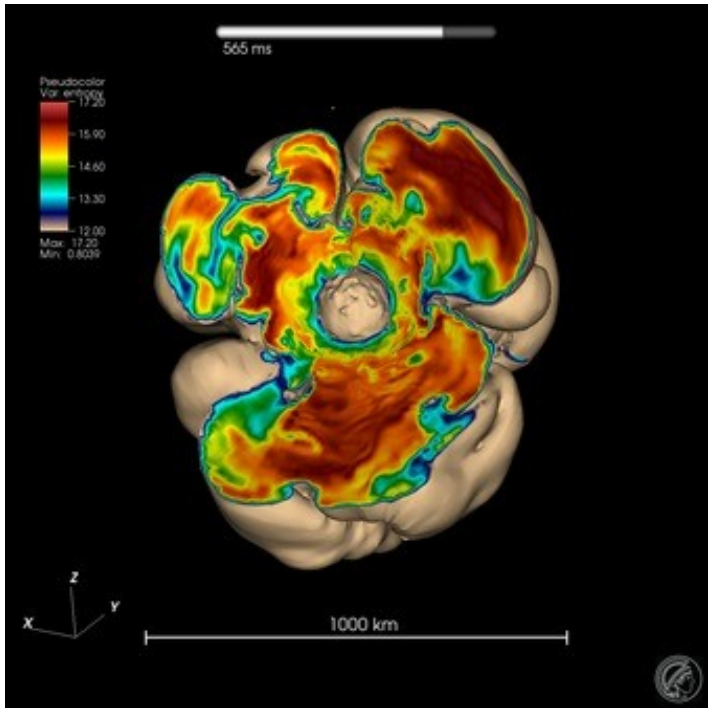
$$M_{\odot}(^{44}\mathrm{Ti}) = 1.38 \times 10^{-4} \frac{F_{\gamma}}{1\ \mathrm{cm}^{-2}\mathrm{s}^{-1}} \times \left(\frac{d}{1\ \mathrm{kpc}}\right)^{2} \left(\frac{\tau}{1\ \mathrm{yr}}\right) \exp(t/\tau),$$

INTEGRAL finds no additional sources

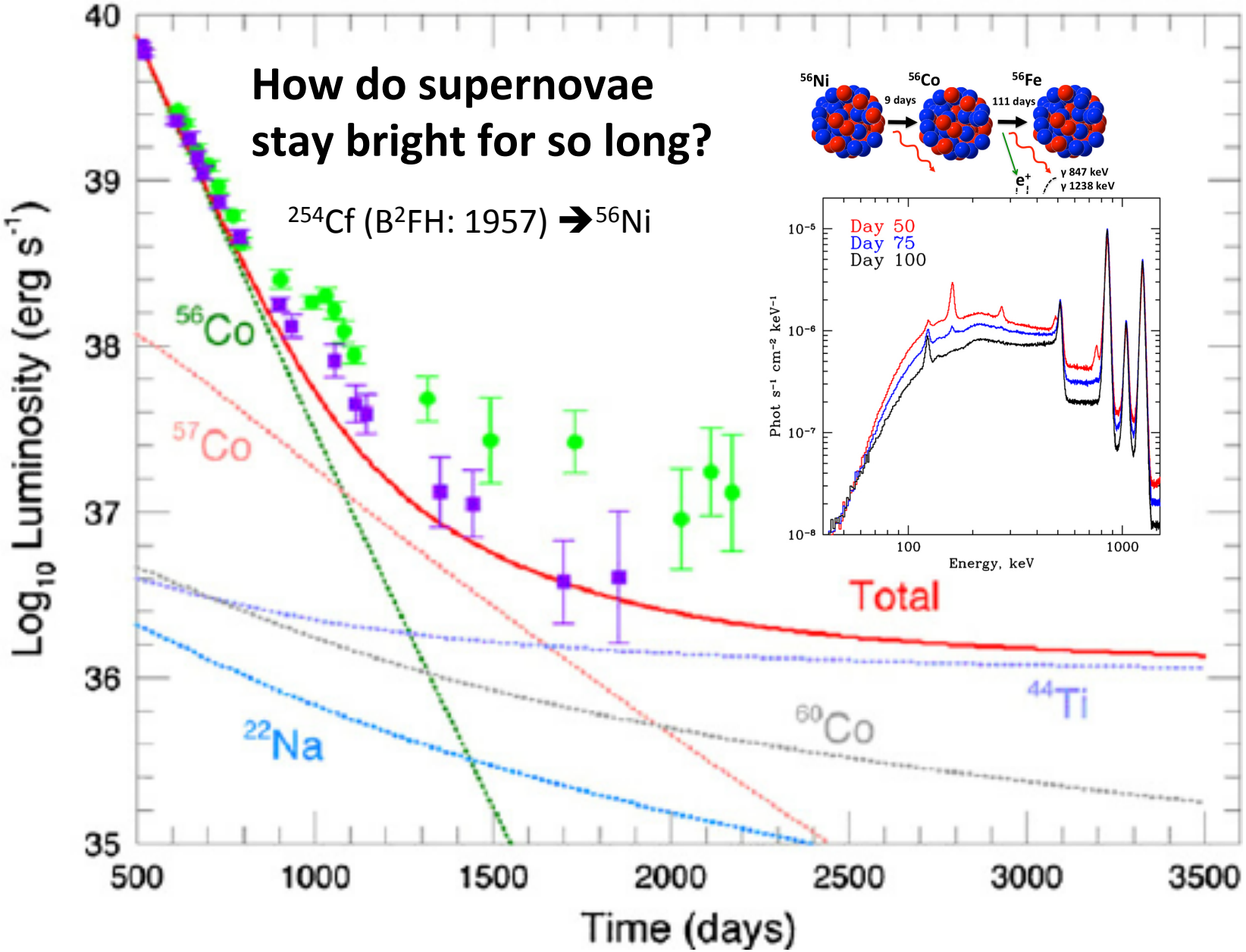
Grefenstette+ 2014, Nature



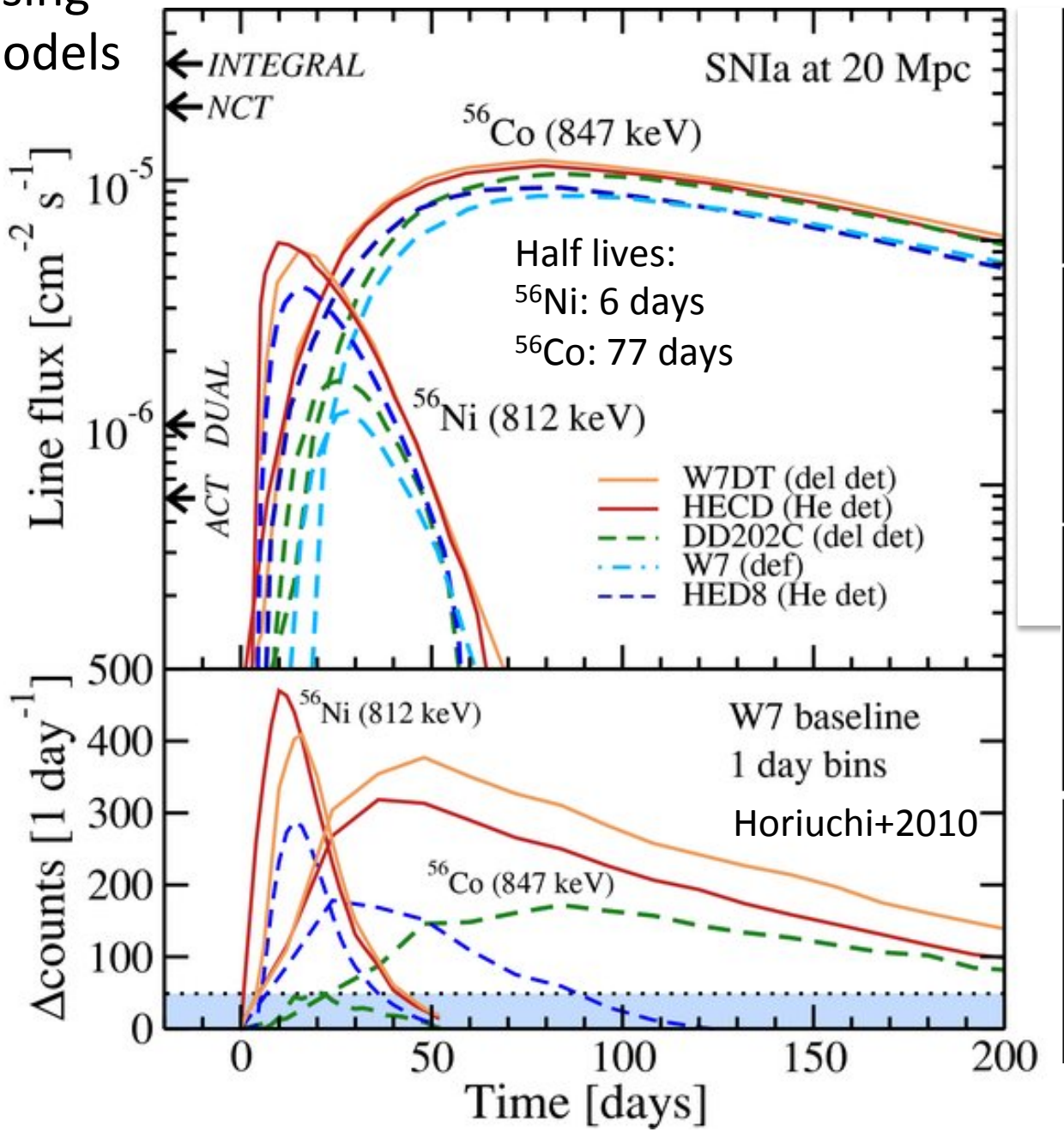
Asymmetric ejecta flows – constraints on explosion mechanisms

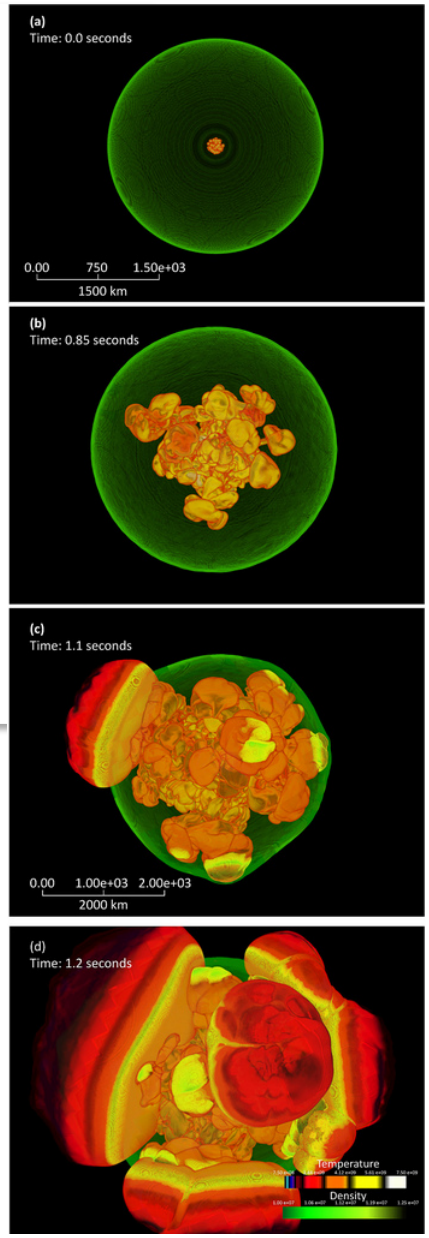


Neutrino driven ccSN: MPA team

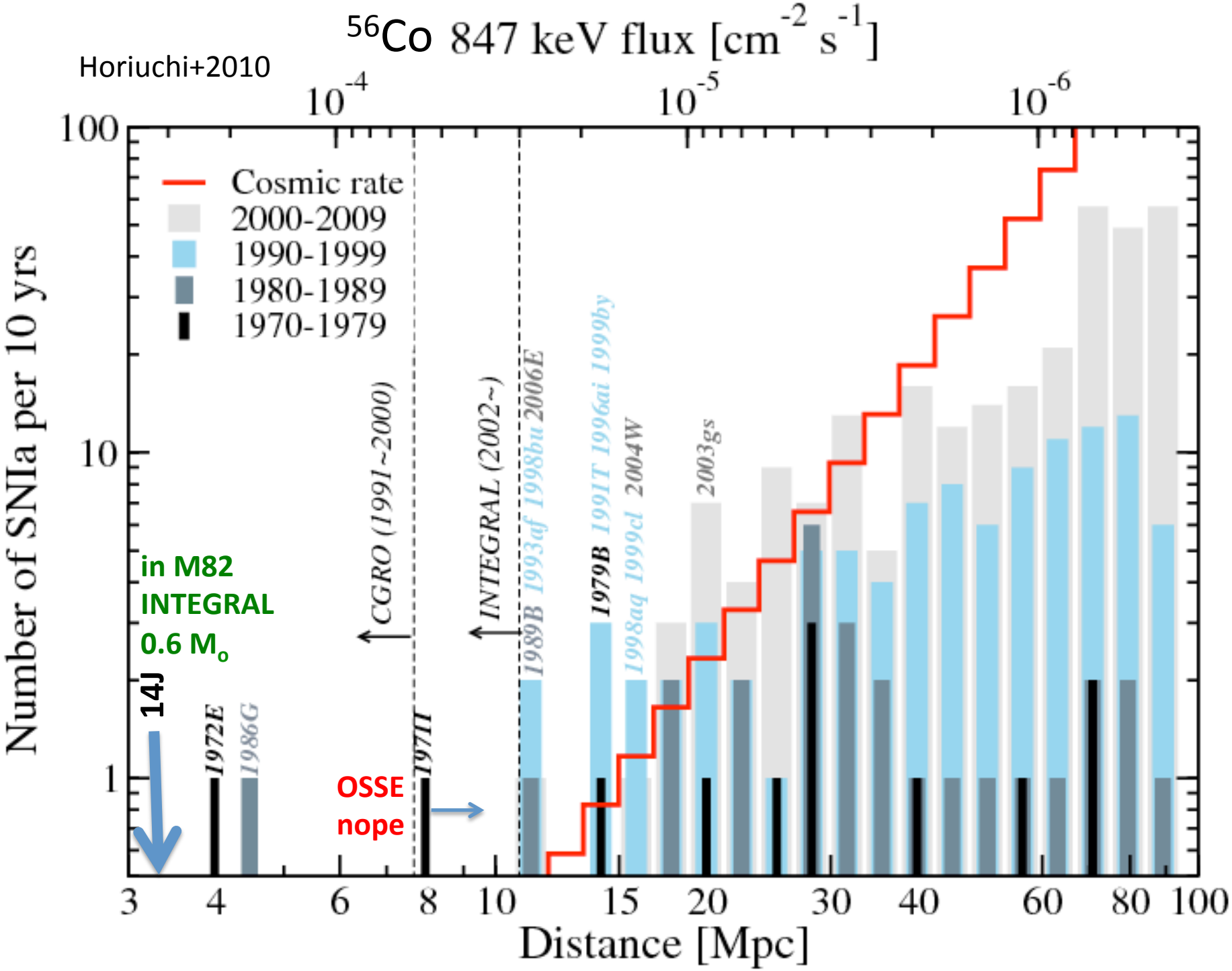

How do supernovae stay bright for so long?
254Cf (B2FH: 1957) ➔56Ni
56Ni
56Co
56Fe
9 days
111 days
e+
γ 847 keV
γ 1238 keV
Day 50
Day 75
Day 100
Phot s⁻¹ cm⁻² keV⁻¹
Energy, keV
Total
56Co
57Co
44Ti
60Co
22Na
Log10 Luminosity (erg s-1)
Time (days)

Diagnosing SNIa models

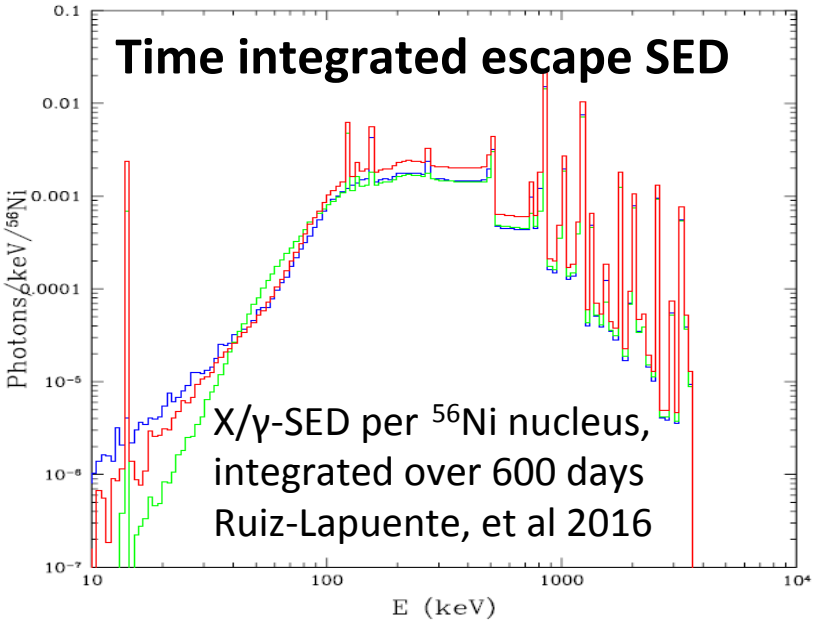




D. Lamb+ 2010: DDT

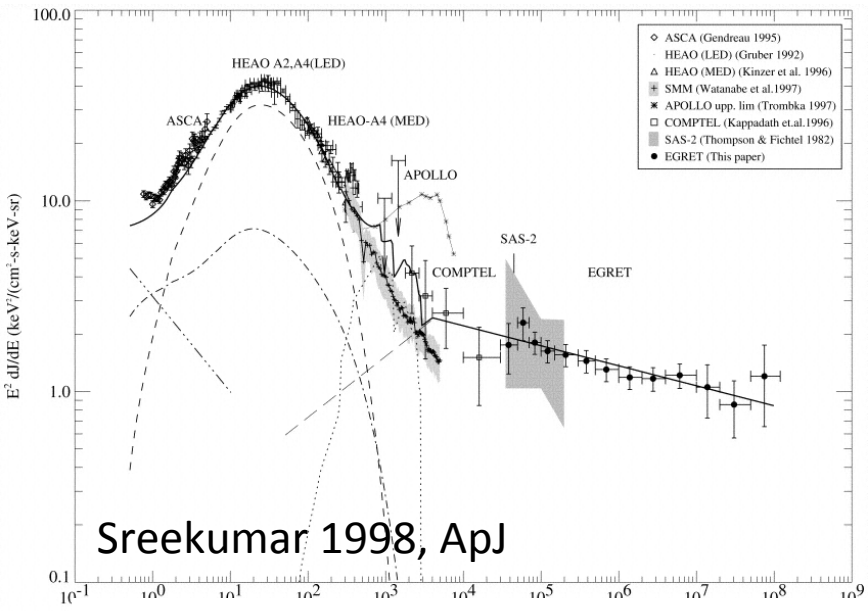

Horiuchi+2010
^{56}Co 847 keV flux [cm^{-2} s^{-1}]
10^{-4}
10^{-5}
10^{-6}
Number of SNIa per 10 yrs
100
10
1
Cosmic rate
2000-2009
1990-1999
1980-1989
1970-1979
CGRO (1991~2000)
INTEGRAL (2002~)
1989B 1993af 1998bu 2006E
1979B 1991T 1996ai 1999by
1998aq 1999cl 2004W
2003gs
1972E
1986G
1971I
in M82
INTEGRAL
0.6 M$_o$
14J
OSSE
nope
3
4
6
8
10
15
20
30
40
60
80
100
Distance [Mpc]

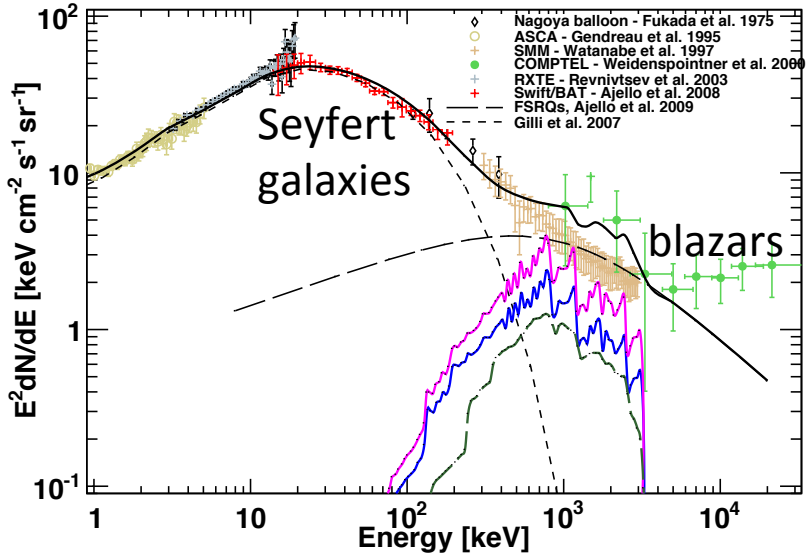
Time integrated escape SED



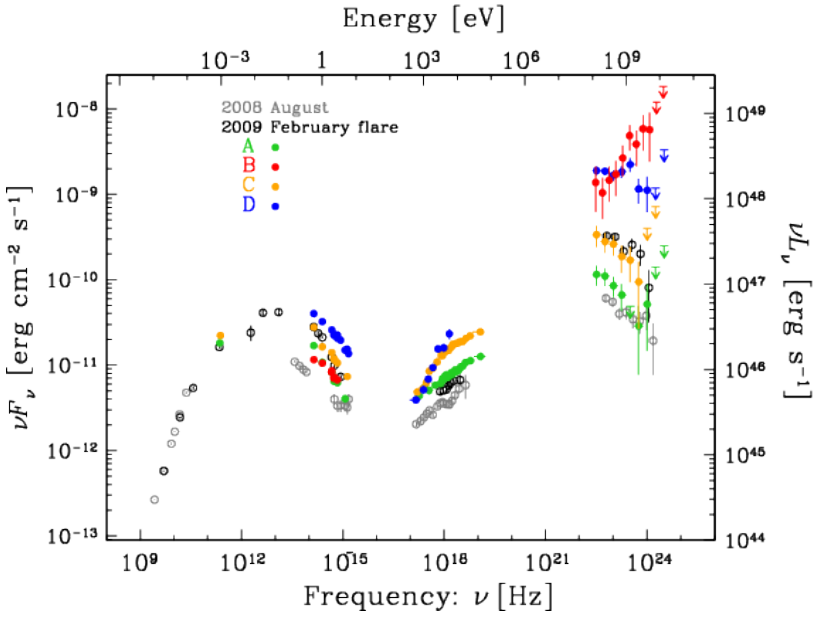
SNIa/SNII >> 1
Rates comparable but ^{56}Ni yield ~ 0.5/01
Also: extinction in SNII ejecta

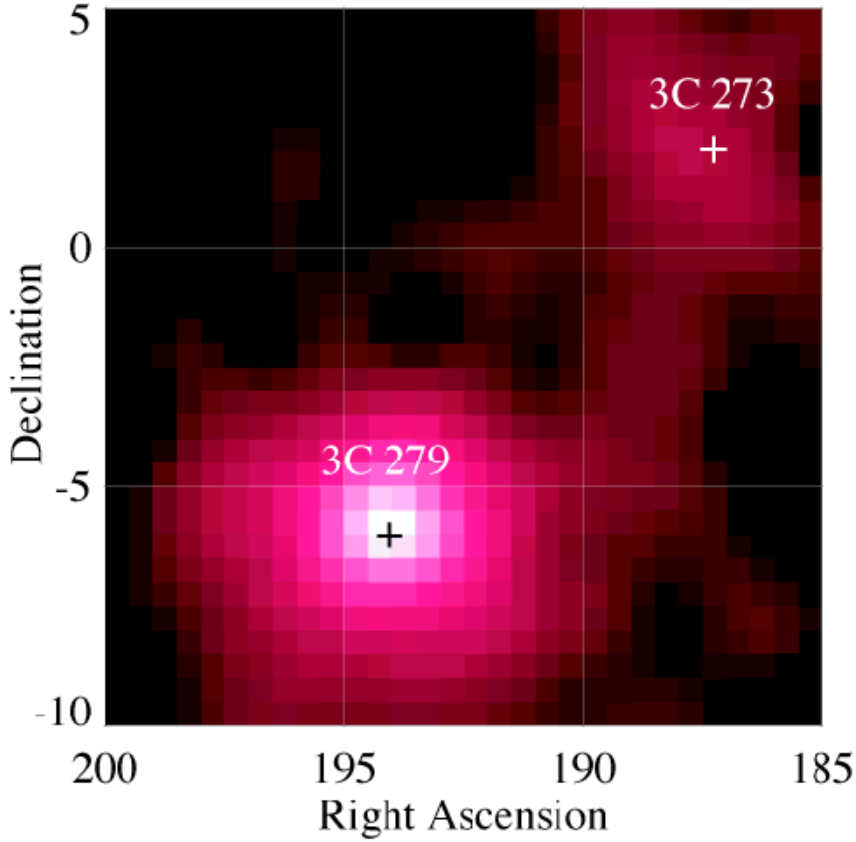
The Cosmic Gamma-Ray Background

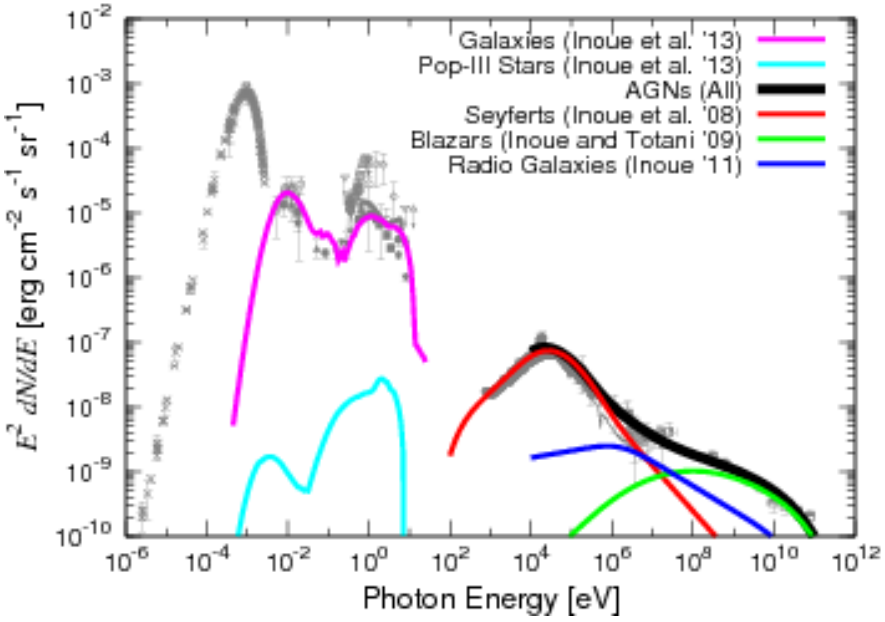


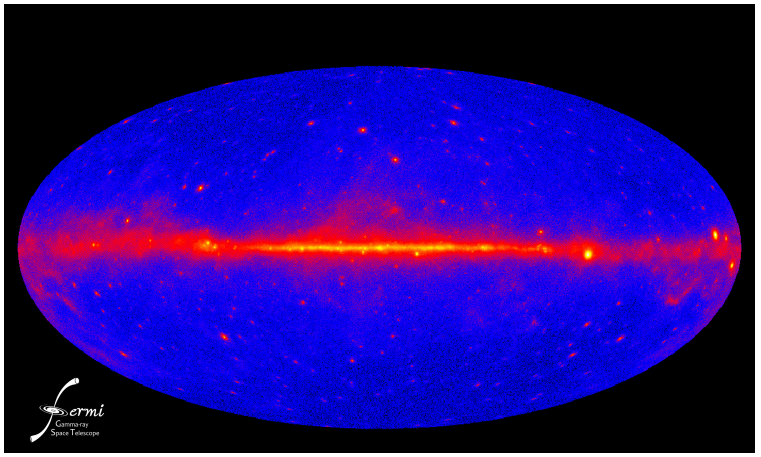


1991 EGRET (R. Hartman) discovery of the first blazar: 3C 279

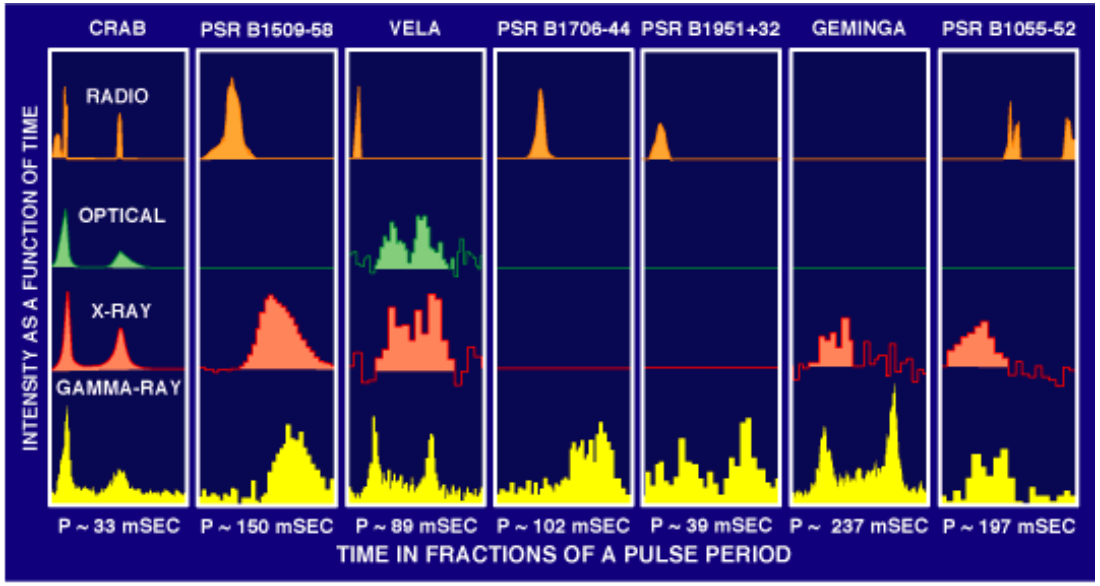


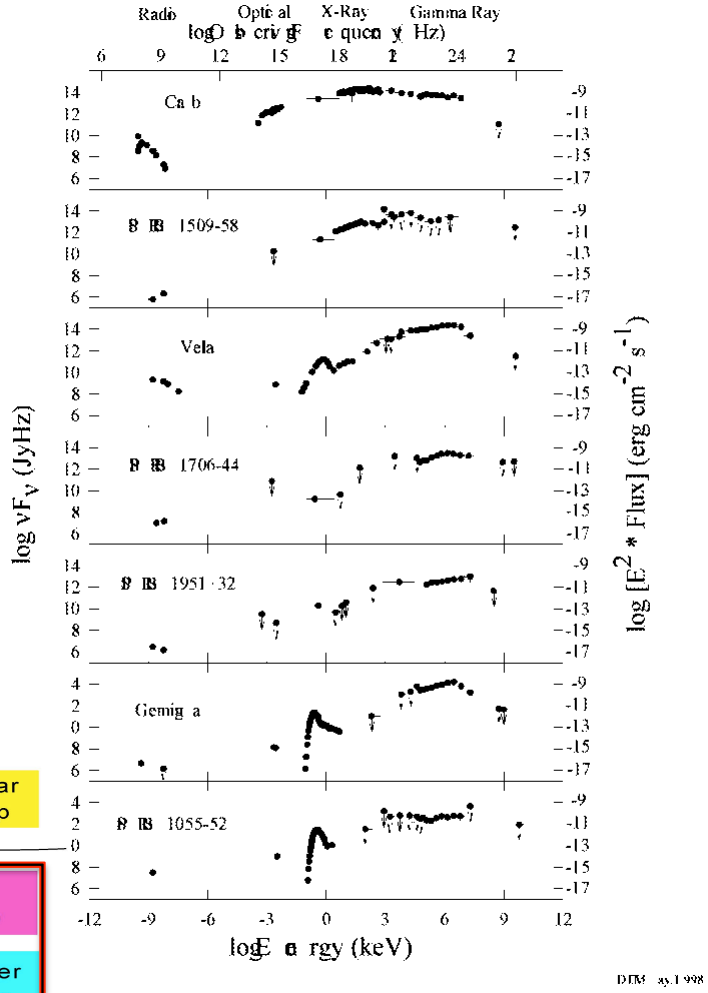






EGRET/COMPTEL gave us 7 (10) gamma-ray pulsars





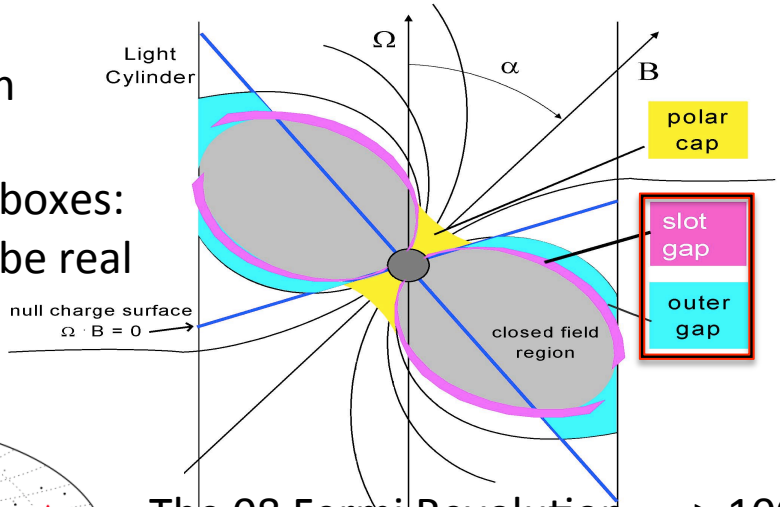
Tip of the Iceberg

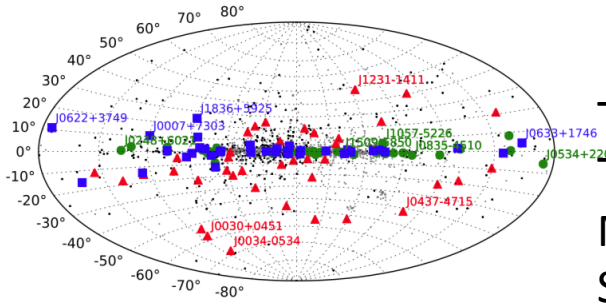
Low angular resolution

Low photon fluxes

Many pulsars in error boxes:

10-25 (of 1300) could be real





The 08 Fermi Revolution …. > 100

Time-resolved spectroscopy

Model discrimination >10 GeV

SR, GR, high-B, QED: γ-transport

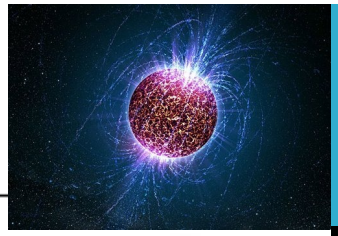
D. Thompson+ 99

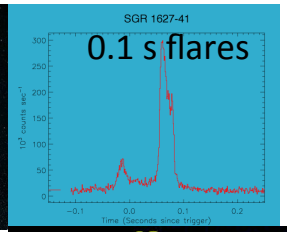
PL SED with exp-cutoffs;

High fraction of $\dot{E}$ ➔ L_γ

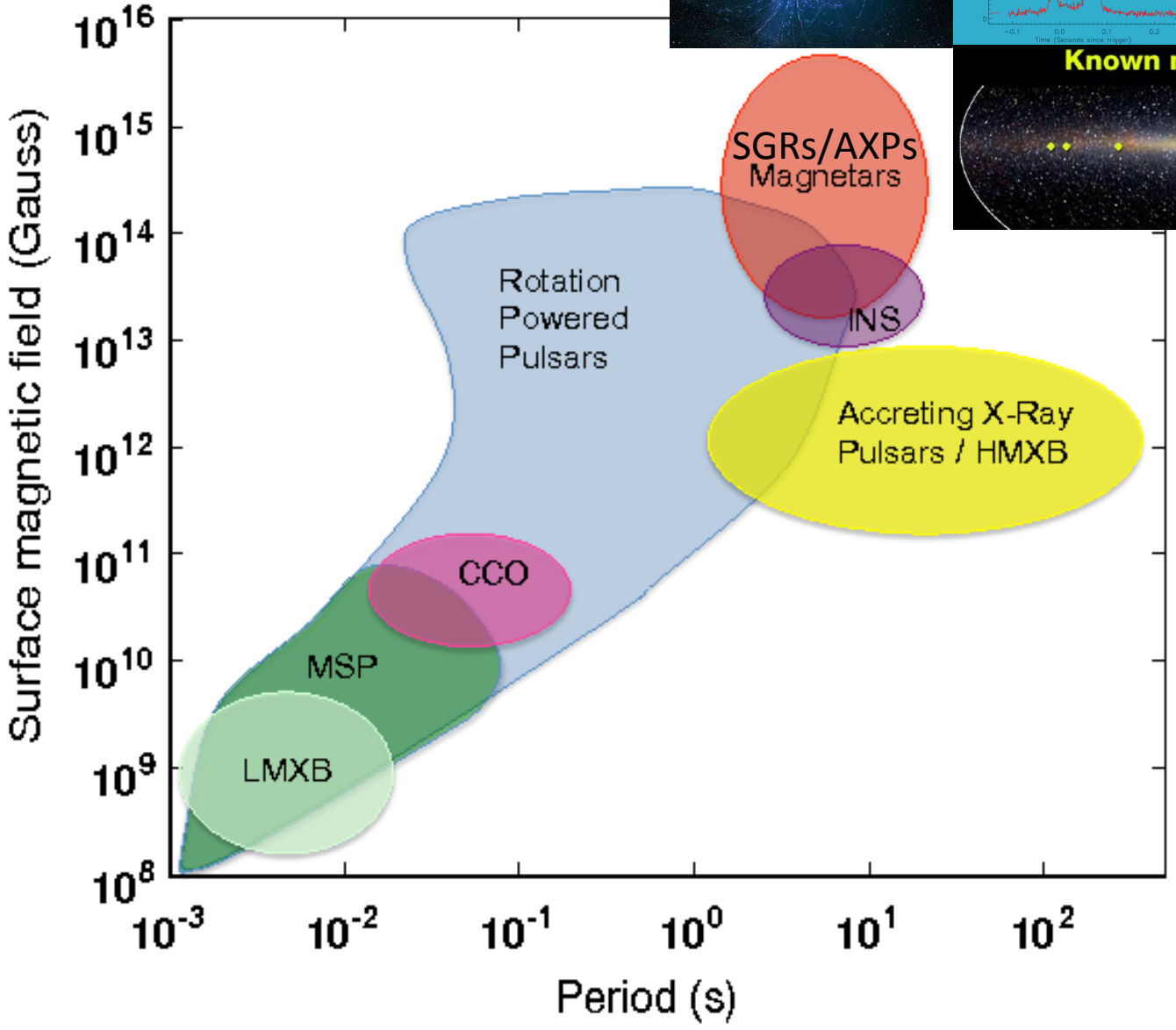
Non-aligned Radio/γ

High altitude emission

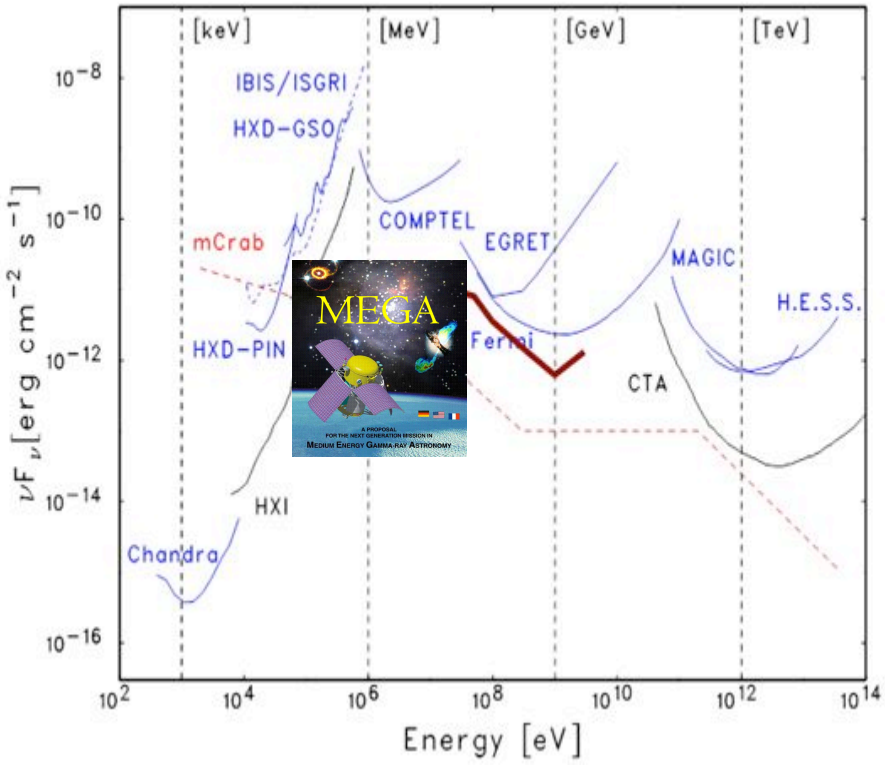


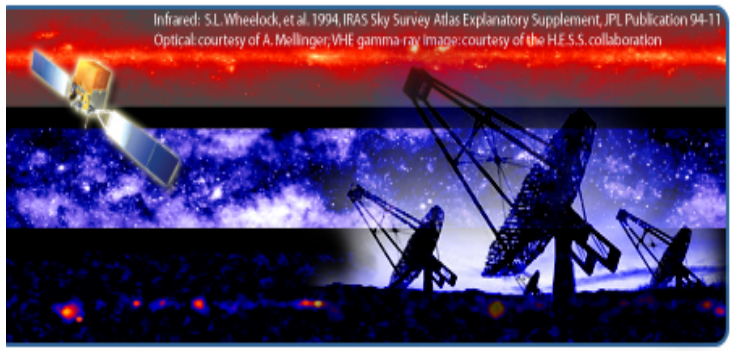


BATSE light curve
June 15, 1998
100 flares in 6 weeks
SGR 1627-41

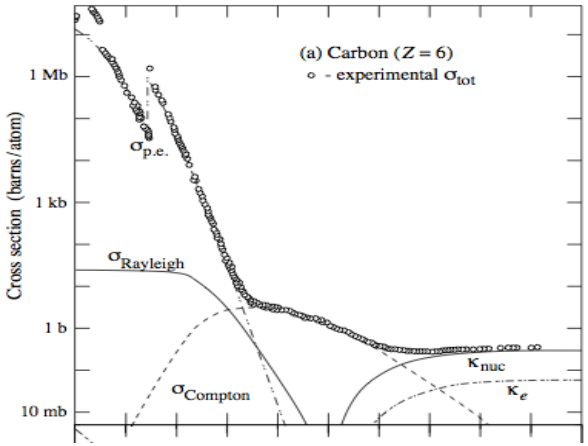


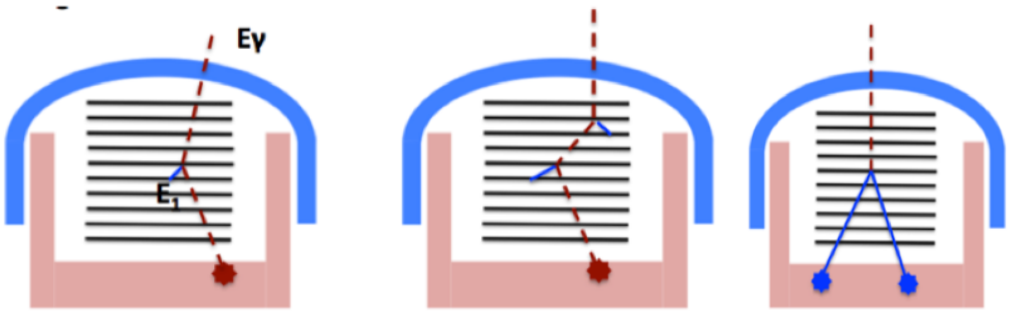
The Future of MeV Time Domain Astrophysics





Toward The Future of Very High Energy Gamma-ray Astronomy





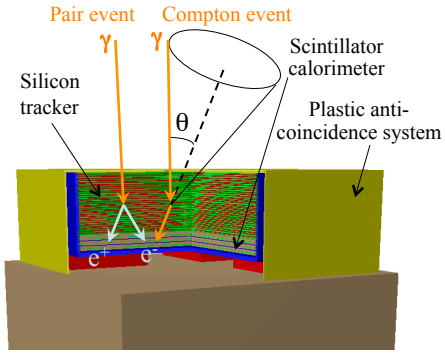
b) Compton event, 1 hit in Tracker

c) Compton event, 2 hits in Tracker

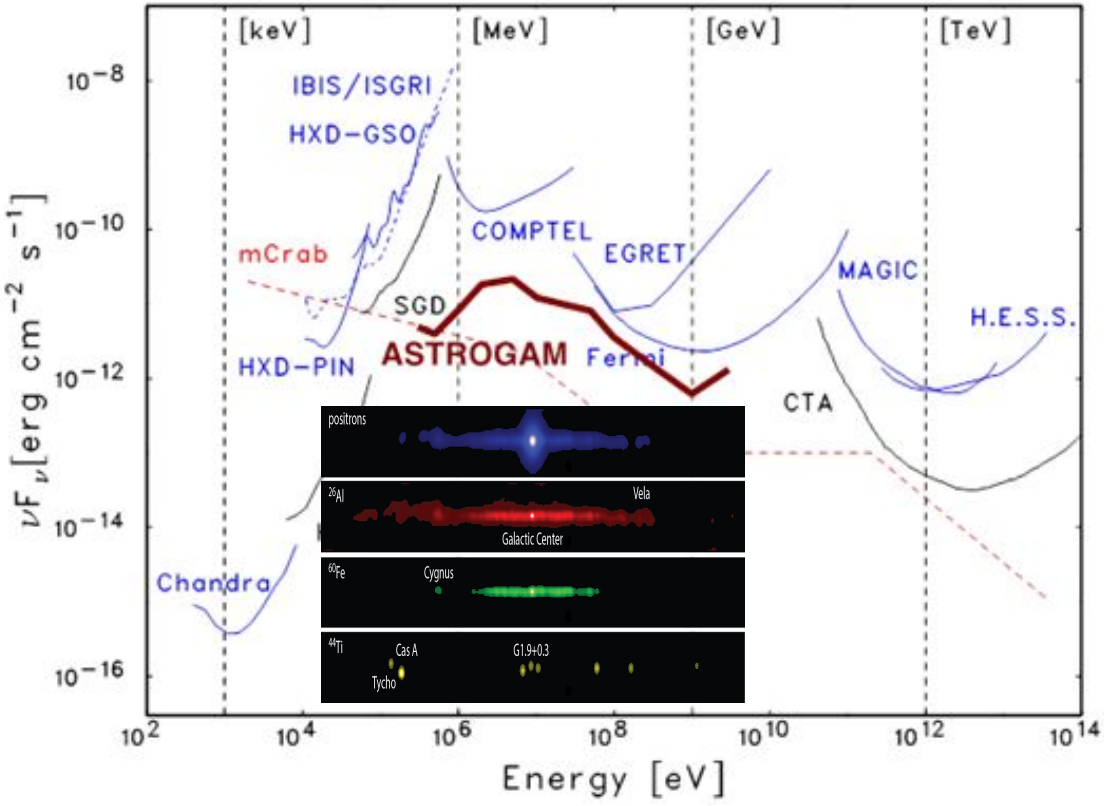
a) Pair production event

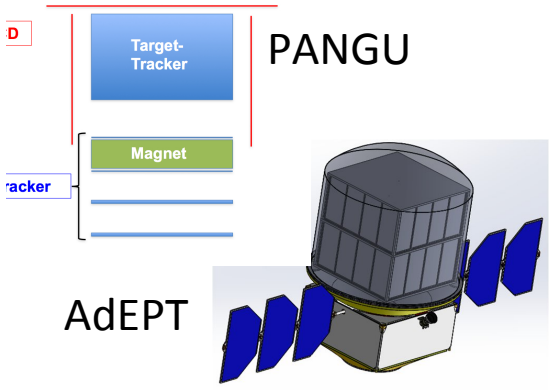
Close the MeV band gap

ComPair



eASTROGAM

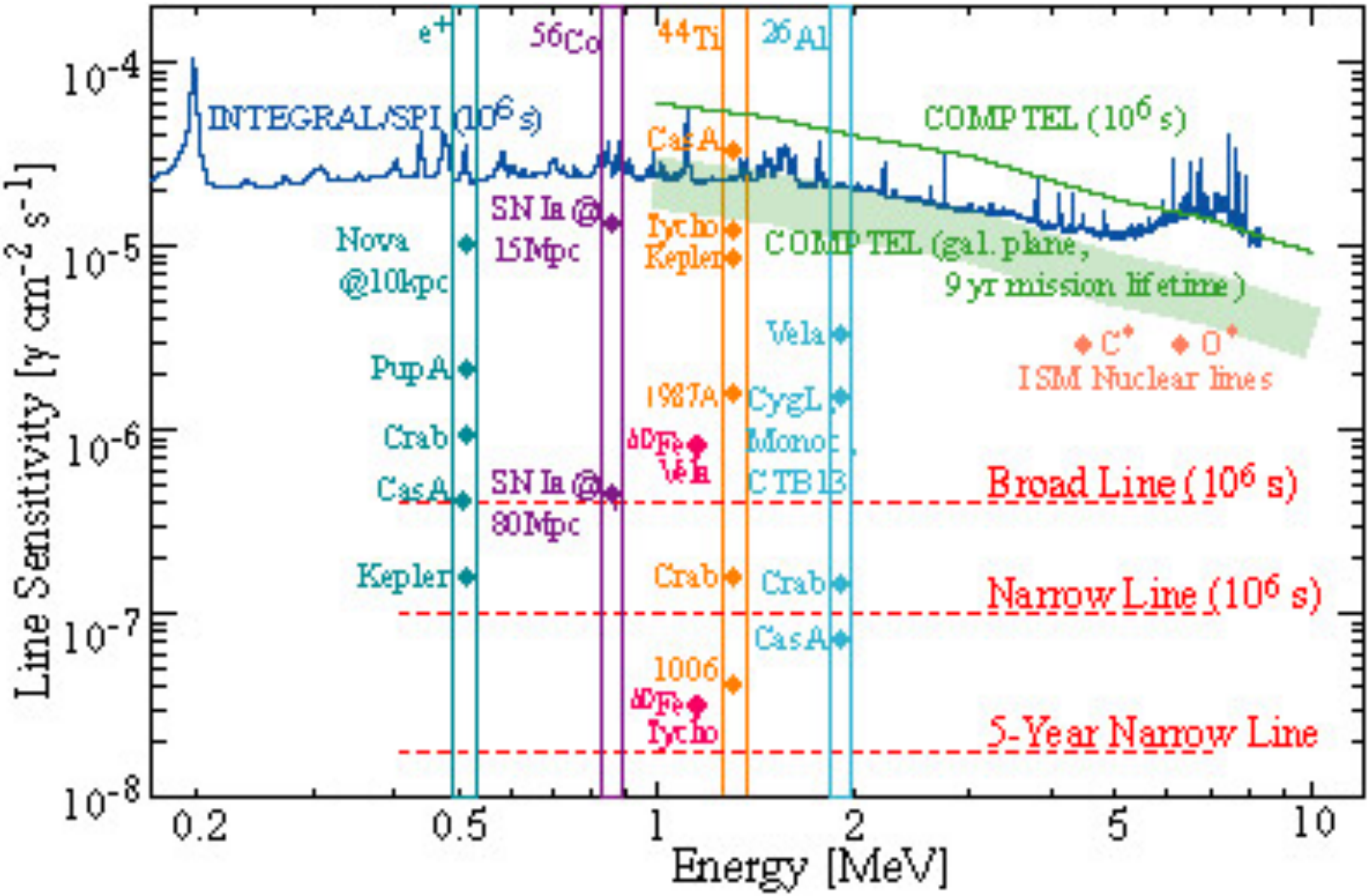




PANGU

AdEPT

… ACT, GRIPS, MEGA, GRX, PANGU, AdEPT, ComPair, eASTROGAM, …


e+
56Co
44Ti
26Al
INTEGRAL/SPI (10^6 s)
COMPTEL (10^6 s)
Cas A
SN Ia @ 15Mpc
Tycho
Kepler
Nova @10kpc
COMPTEL (gal. plane, 9 yr mission lifetime)
Vela
C*
O*
ISM Nuclear lines
Pup A
1987A
Cyg L
Crab
Mono
60Fe
Vela
CTB1
Cas A
SN Ia @ 80Mpc
Broad Line (10^6 s)
Kepler
Crab
Crab
Narrow Line (10^6 s)
Cas A
1006
60Fe
Tycho
5-Year Narrow Line
Line Sensitivity [γ cm^-2 s^-1]
Energy [MeV]
10^-4
10^-5
10^-6
10^-7
10^-8
0.2
0.5
1
2
5
10