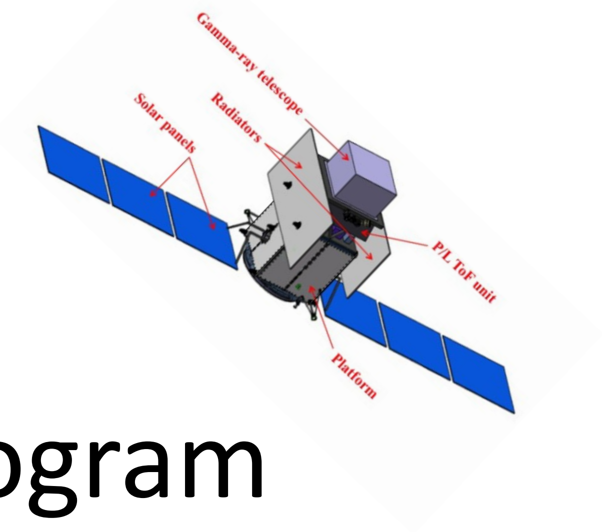


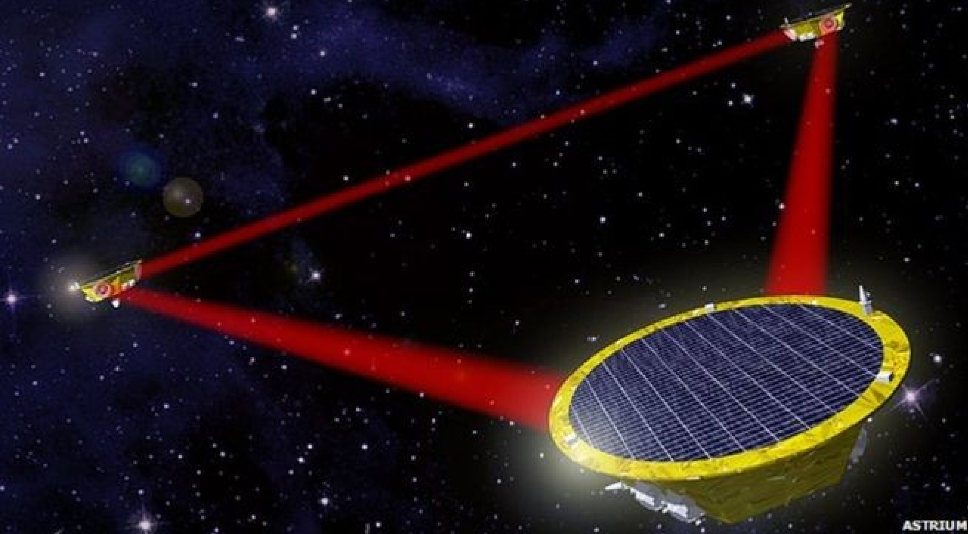
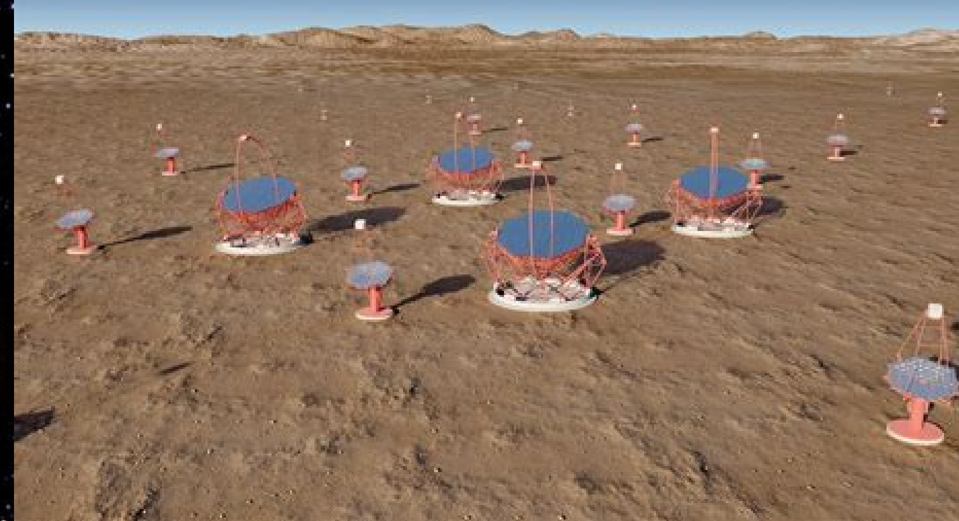
The eASTROGAM program

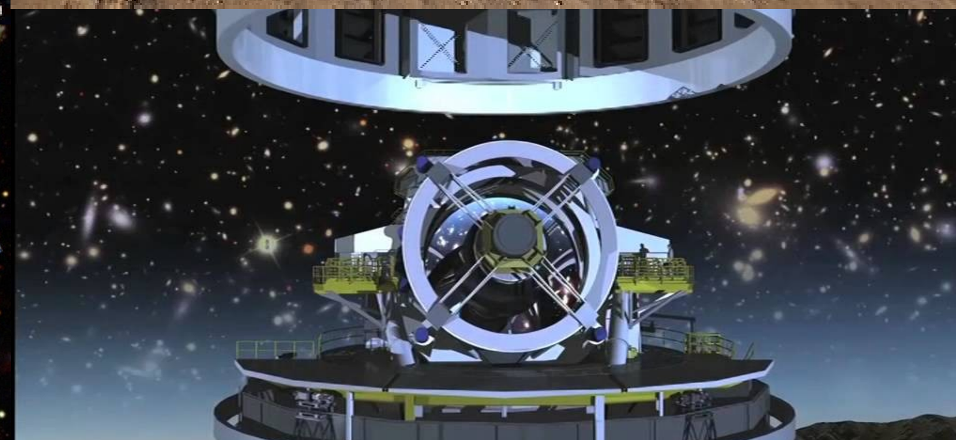
Acknowledgement: The e-ASTROGAM Collaboration
lead by Alessandro De Angelis and Victor Tatischeff

arXiv:1711.01265v1

Karl Mannheim

Julius-Maximilians-Universität
Würzburg, Germany


ASTRIUM




A program for gamma-ray astronomy in the MeV-GeV regime

- Cos-B, CGRO-EGRET, Fermi-LAT
- MeV: CGRO-COMPTEL, INTEGRAL
- Next?
- Science case?

Technical considerations

> GeV energies

- Above 10s of GeV: → CTA
- Spaceborne instruments:
  - Background rejection already close to optimum
  - Photon detection efficiency already almost maximal

→ Going beyond Fermi-LAT sensitivity means putting a 10x larger effective area in place

MeV - GeV energies

- INTEGRAL sensitivity much worse than Fermi-LAT sensitivity
- Poor effective area, poor background rejection

→ Faster read-out electronics and photo-sensors imply huge room for improvements

MEGA (Kanbach et al.)

GRIPS (Greiner et al.)

CH + US-lead concepts

Fundamental energy scales in the MeV regime:

thermal

$e^+ + e^- \rightarrow \gamma + \gamma$ — Plasma maximum temperature $T \sim m_e$

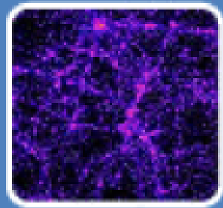
$A^* \rightarrow A$ — Thermonuclear nucleosynthesis

Spallation

$\pi^0 \rightarrow \gamma + \gamma$ — Cosmic rays

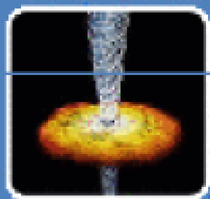
non-thermal

Highest redshifts



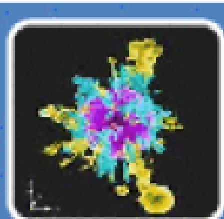
- Find first massive stars through GRBs
- Pinpoint first massive DM halos with MeV blazars

Beyond the thermal regime



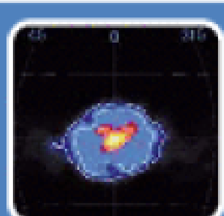
- Study accretion and jets near spinning black holes
- Injection of cosmic rays from the thermal pool

Extreme explosions



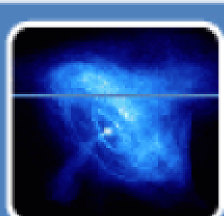
- Decipher the explosion mechanisms of SNe and GRBs
- Formation of elements and isotopes

Antimatter



- Trace the sources of positrons
- Identify signatures of elusive dark matter

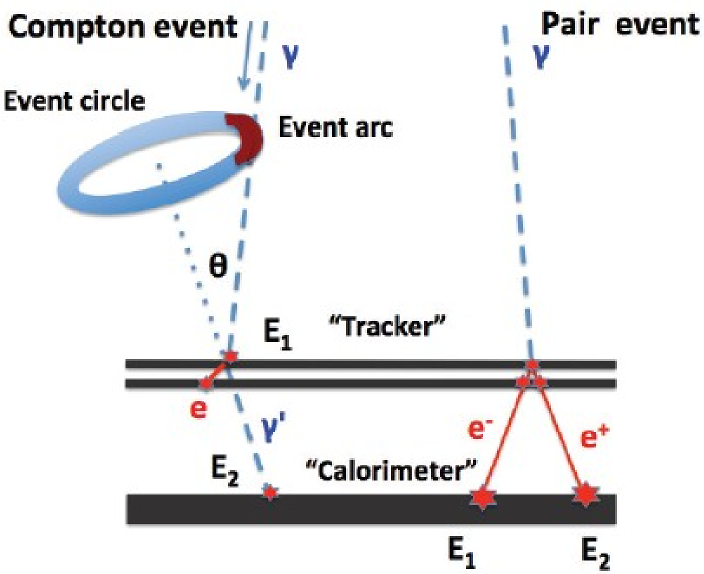
Strongest magnetic fields

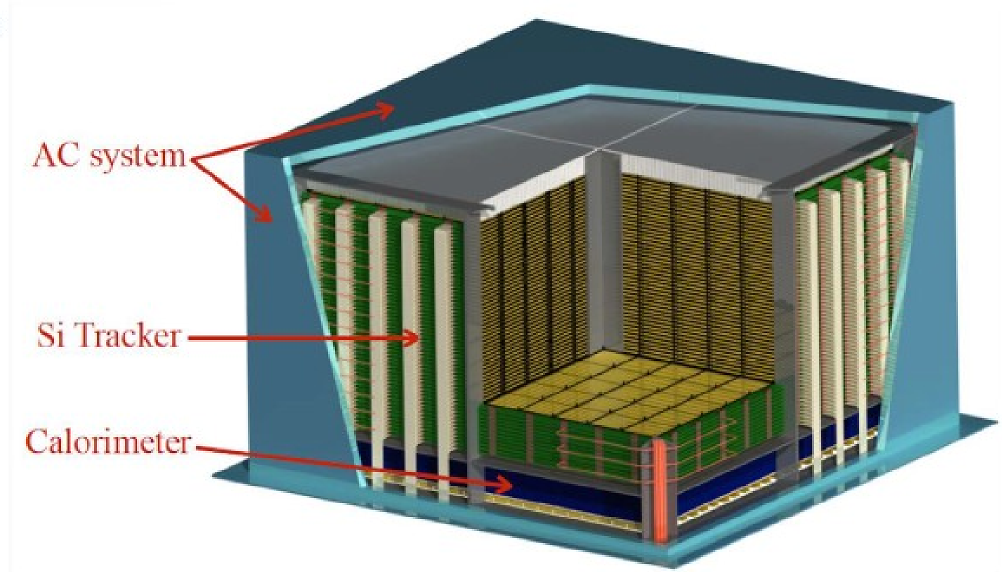


- Discriminate radiation mechanisms in pulsars
- Understand supercritical fields in magnetars

eASTROGAM – LEO mission concept

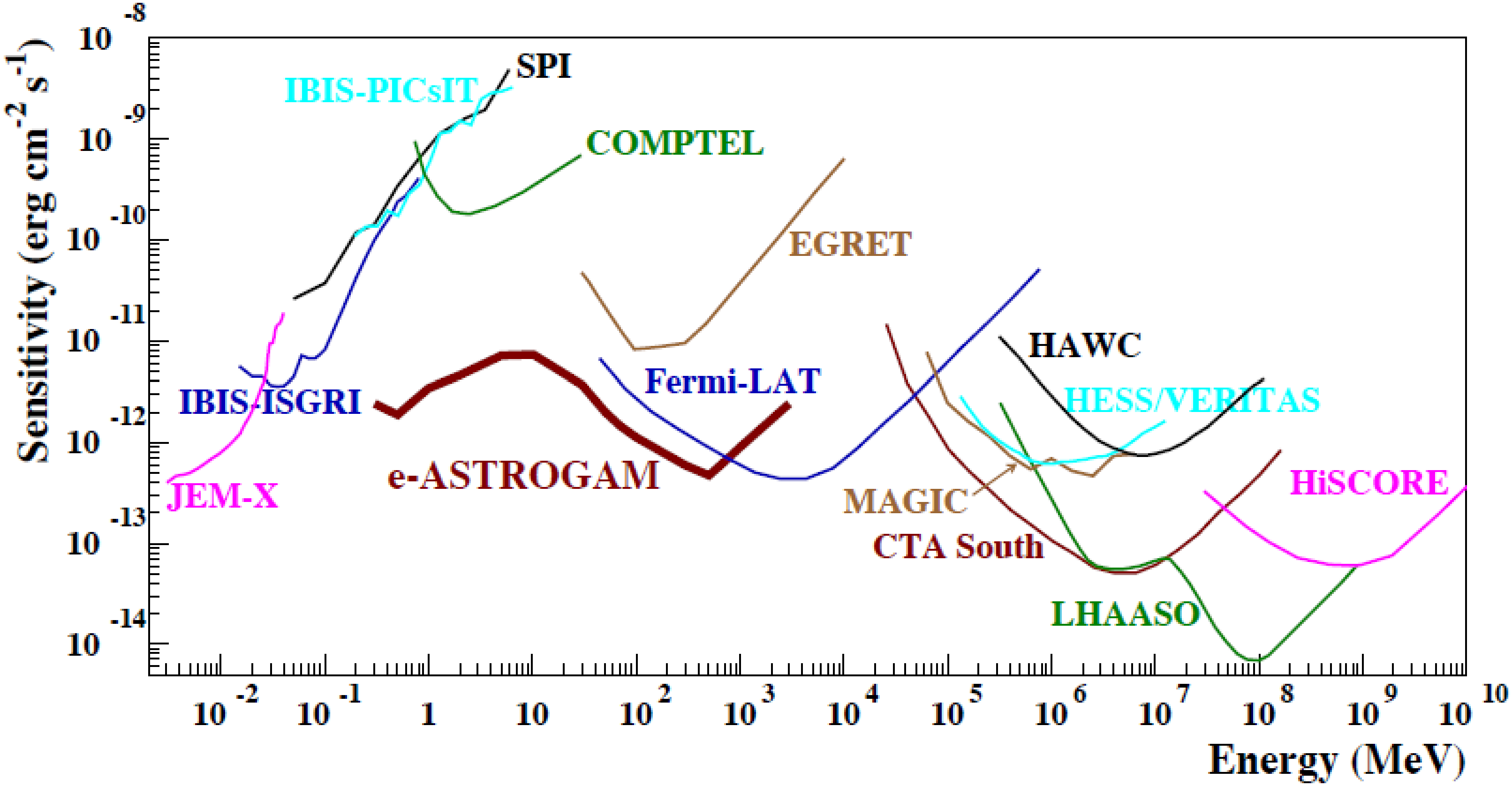
Proposal submitted to ESA in response to the M5 call

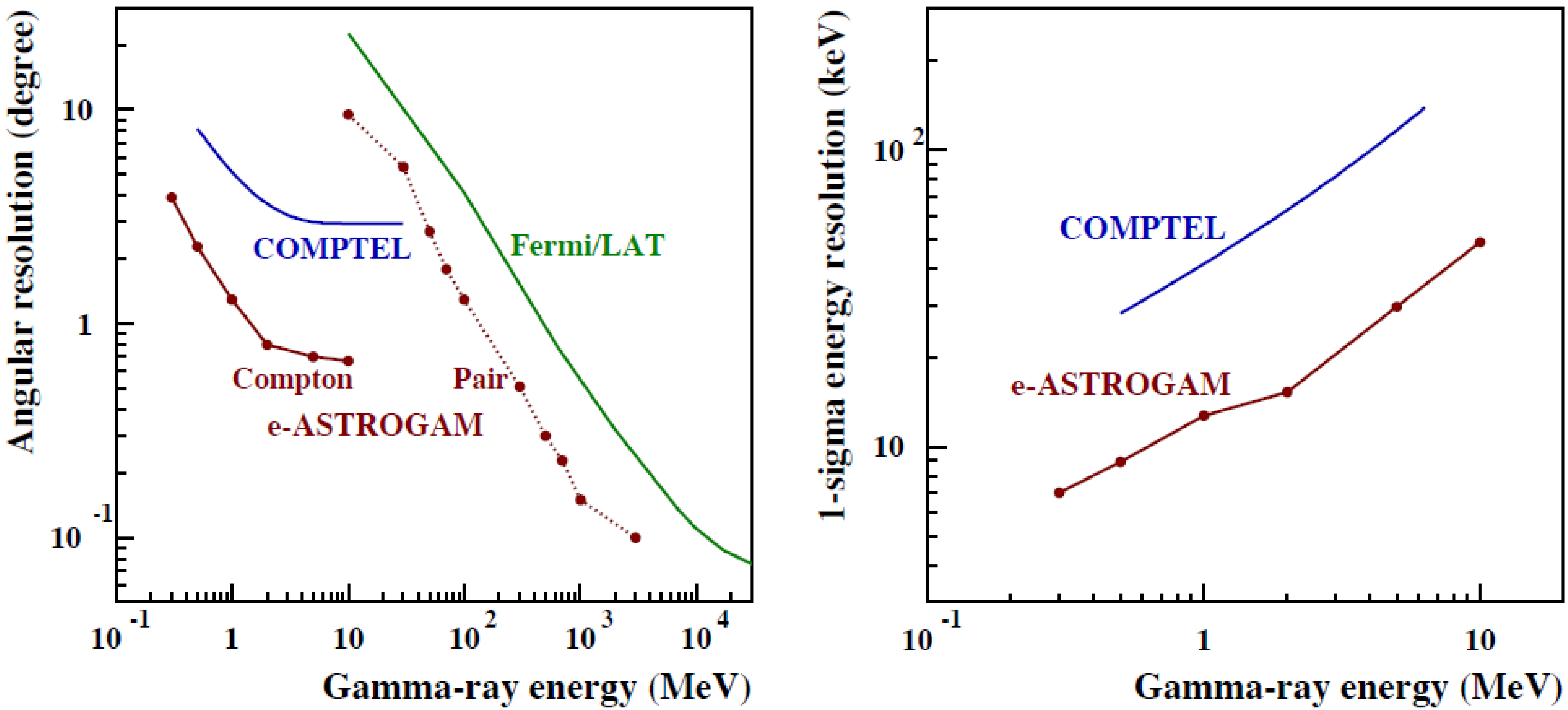




- A **Tracker** in which the cosmic γ-rays can undergo a Compton scattering or a pair conversion, based on 56 planes of double-sided Si strip detectors, each plane with total area of $\sim$1 m^2;
- A **Calorimeter** to measure the energy of the secondary particles, made of an array of CsI (Tl) bars of $5\times5\times80$ mm^3 each, with relative energy resolution of 4.5% at 662 keV;
- An **Anticoincidence system** (AC), composed of a standard plastic scintillator AC shielding and a Time of Flight, to veto the charged particle background.

The MeV-gap in sensitivity





Angular resolution (degree)
10
1
10 -1
COMPTEL
Fermi/LAT
Compton
Pair
e-ASTROGAM
10 -1
1
10
10 2
10 3
10 4
Gamma-ray energy (MeV)
1-sigma energy resolution (keV)
10 2
10
COMPTEL
e-ASTROGAM
10 -1
1
10
Gamma-ray energy (MeV)

Polarization measurements from azimuthal distribution of scattering plane made possible by 3d-resolution of tracker and calorimeter

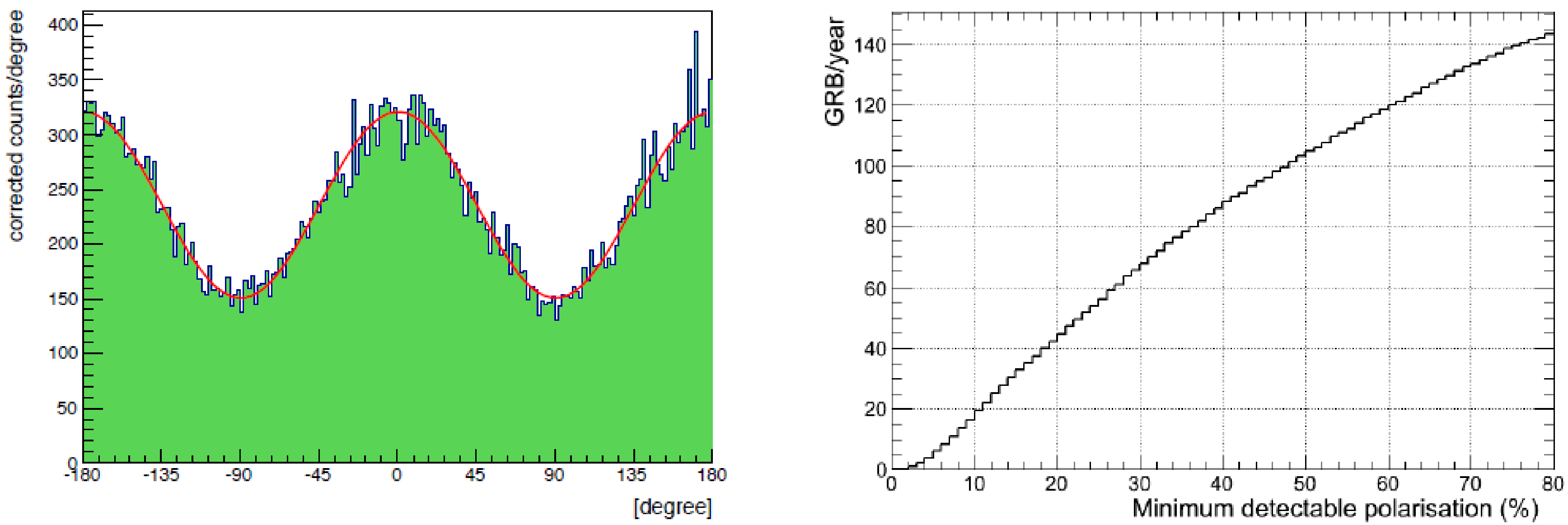
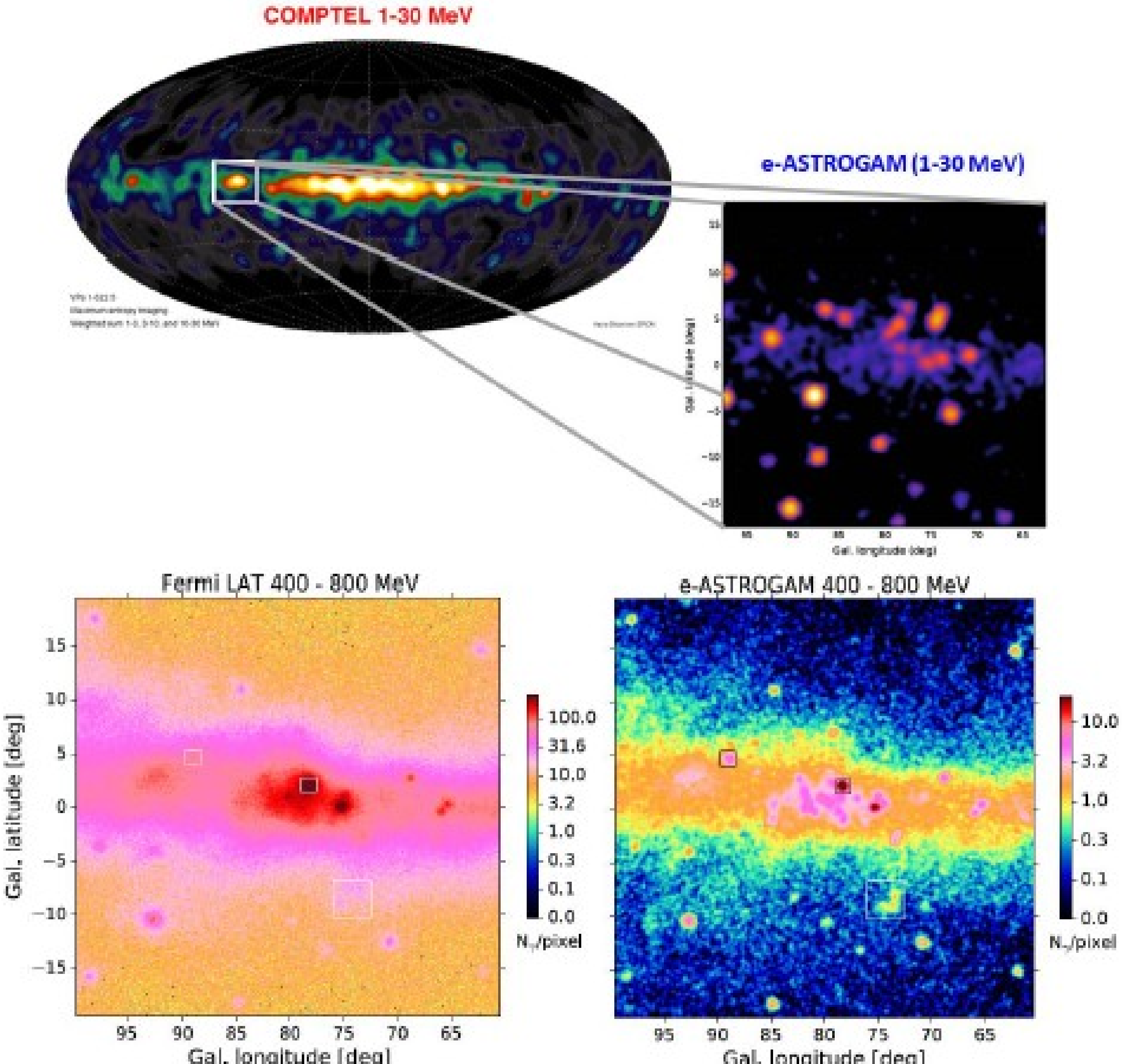


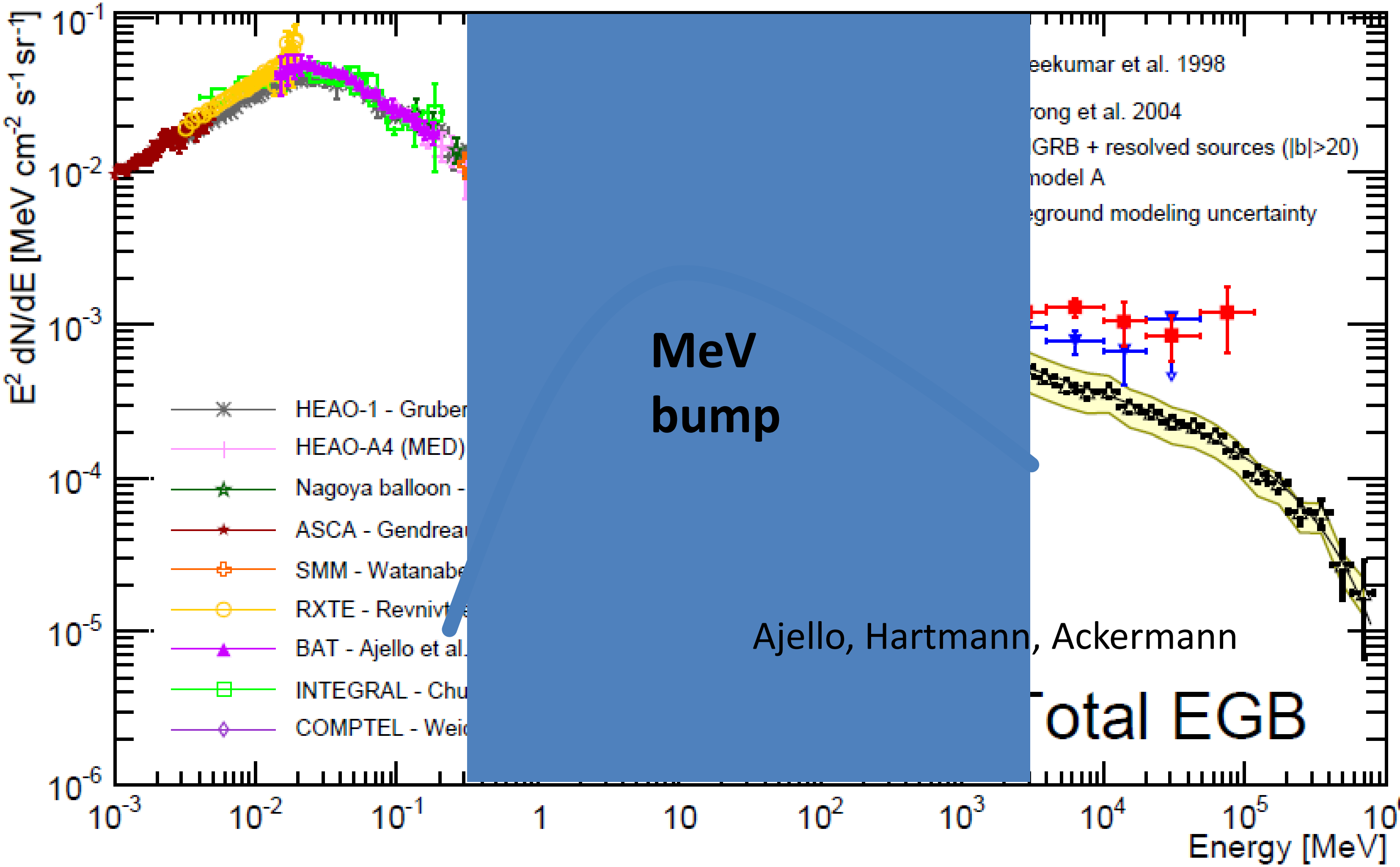
Figure 7: *Left panel* – e-ASTROGAM polarization response (polarigramme) in the 0.2 – 2 MeV range for a 100% polarized, 10 mCrab-like source observed on axis for 10^6 s. The corresponding modulation is $\mu_{100} = 0.36$. *Right panel* – Cumulative number of GRBs to be detected by e-ASTROGAM as a function of the minimum detectable polarization at the 99% confidence level.

8 years



1 year

Resolving the MeV background



Harvest expectations for a MeV survey with eASTROGAM sensitivity

Type	3 yr	New sources
Total	3000 – 4000	~1800 (including GRBs)
Galactic	~ 1000	~400
MeV blazars	~ 350	~ 350
GeV blazars	1000 – 1500	~ 350
Other AGN (<10 MeV)	70 – 100	35 – 50
Supernovae	10 – 15	10 – 15
Novae	4 – 6	4 – 6
GRBs	~600	~600

Follow-up:

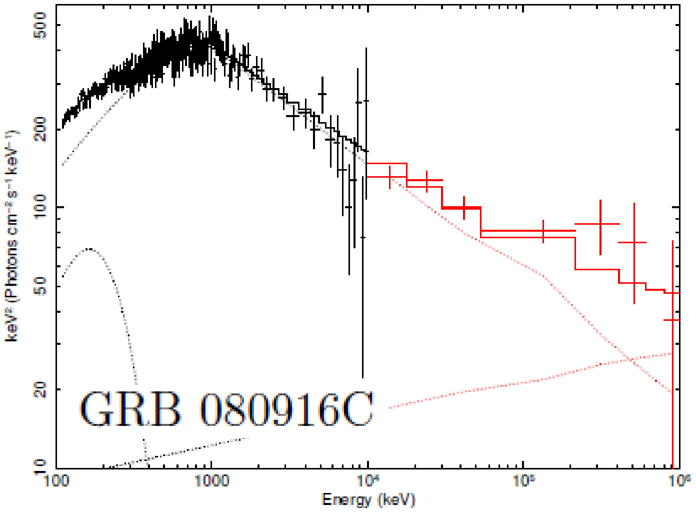
Gravitational wave events (Abott et al. 2017, GW170817)

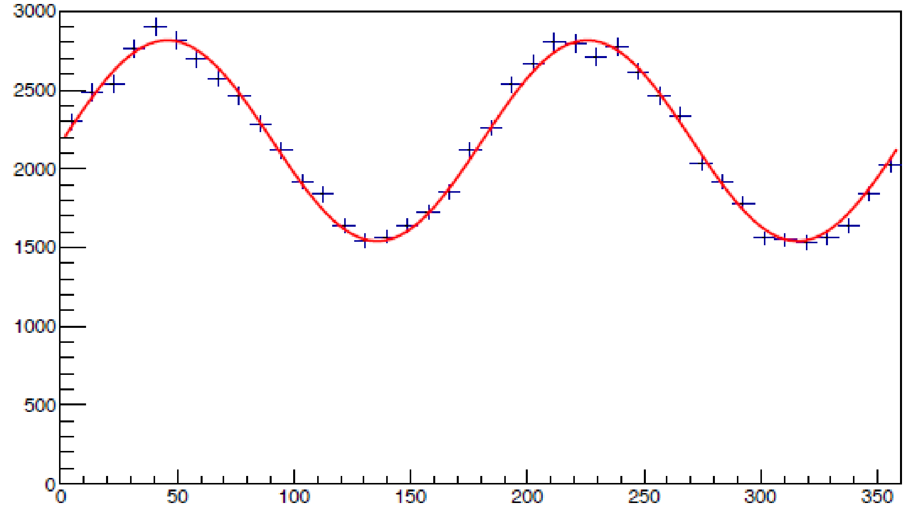
High-energy neutrinos (Bernardini et al., eg. TXS 0506+56)

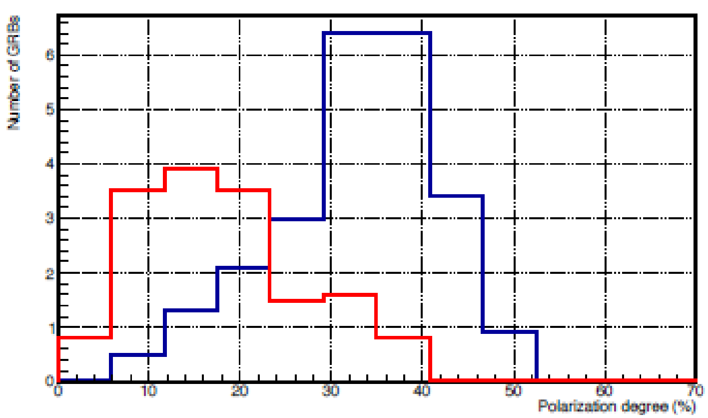
Gravitational lensing events in blazars (Ciprini et al.)

GRB polarimetry

Bernasconi et al.



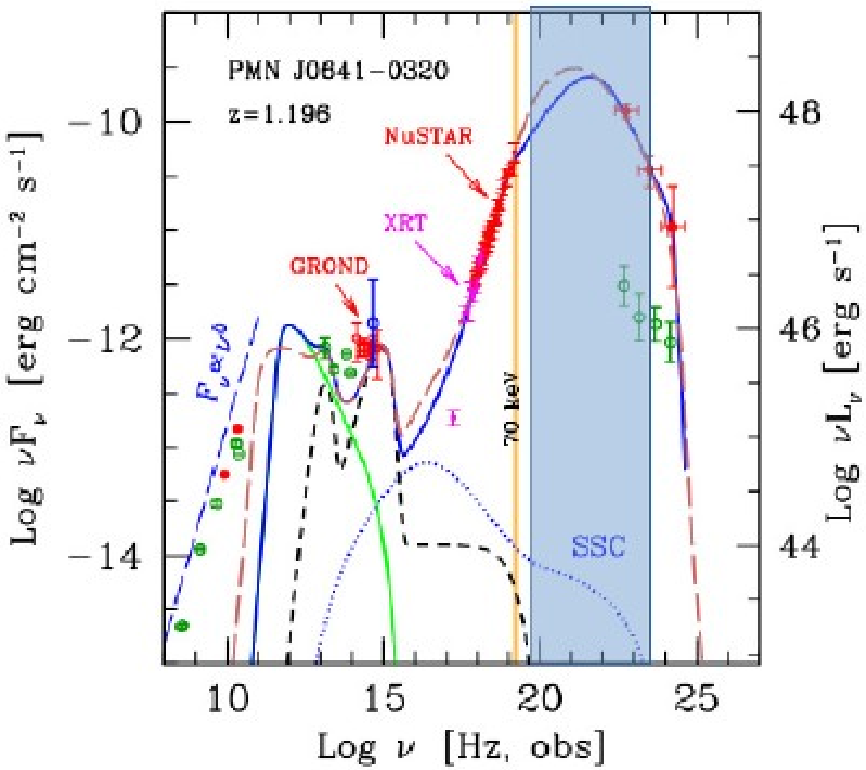


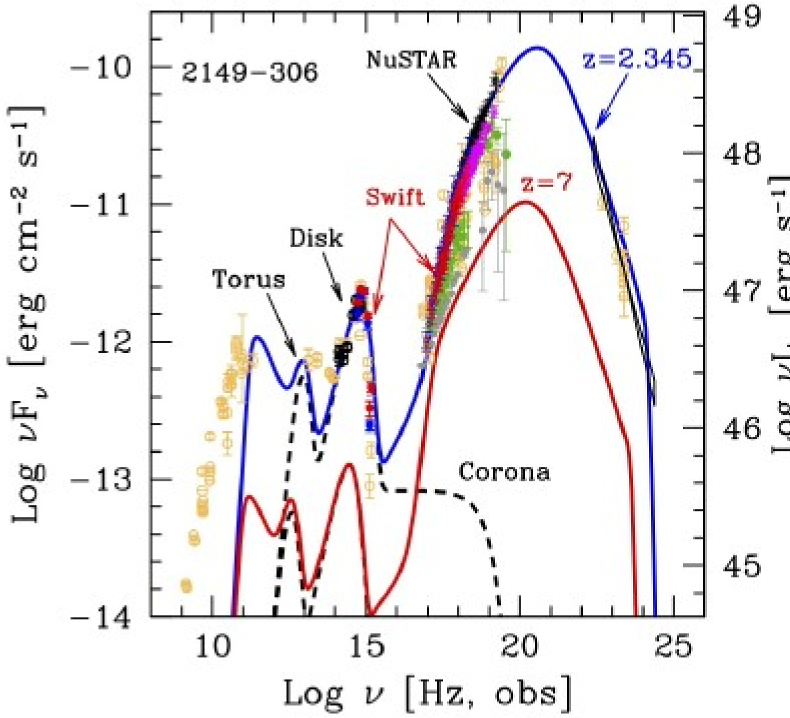


eASTROGAM can discriminate photospheric from synchrotron (ordered field) models for GRBs

MeV Blazars

Kaufmann et al.

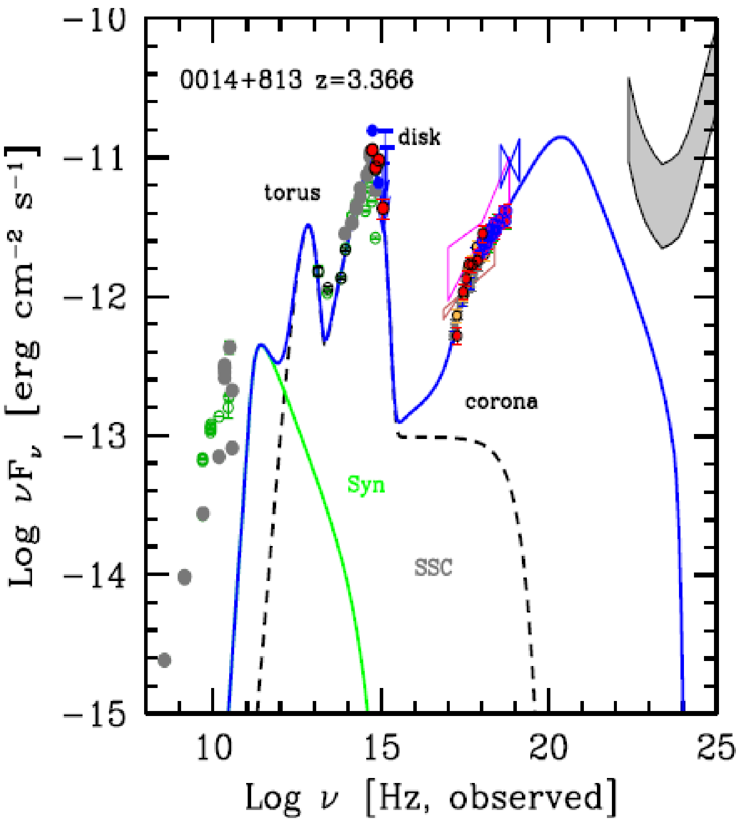


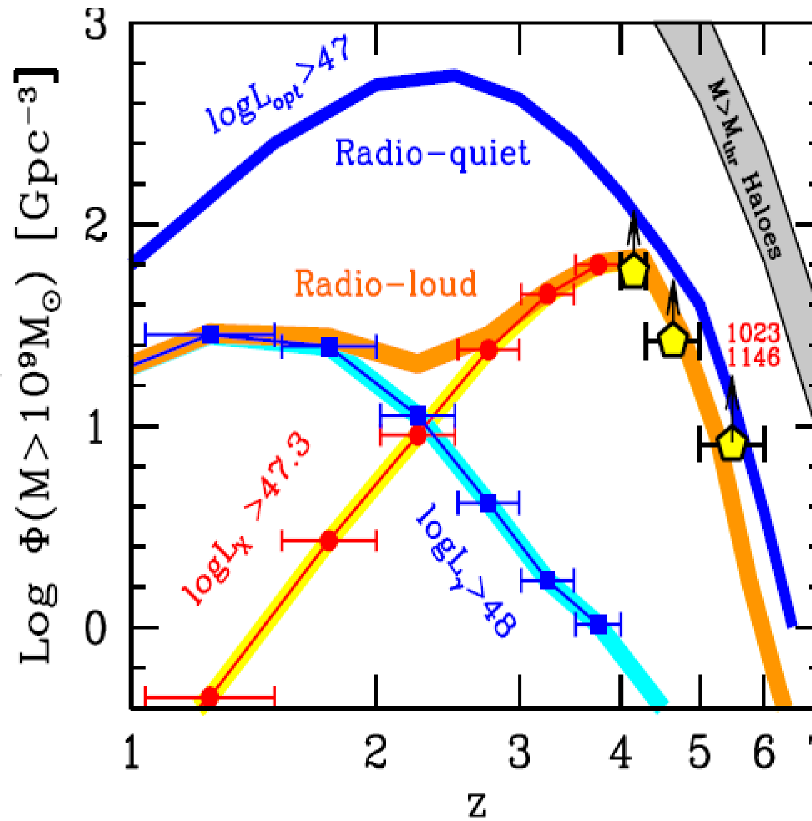


Note also the detections from a reanalysis of COMPTEL data by Collmar (priv. comm.)

Black hole formation at high redshifts

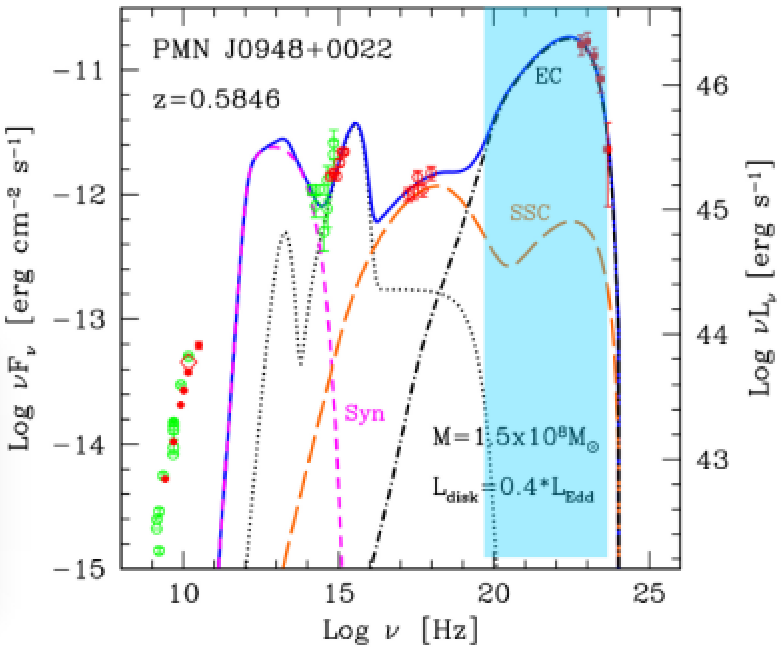
Ghisellini , Tavecchio, Sbarrato, Kaufmann, Tibolla

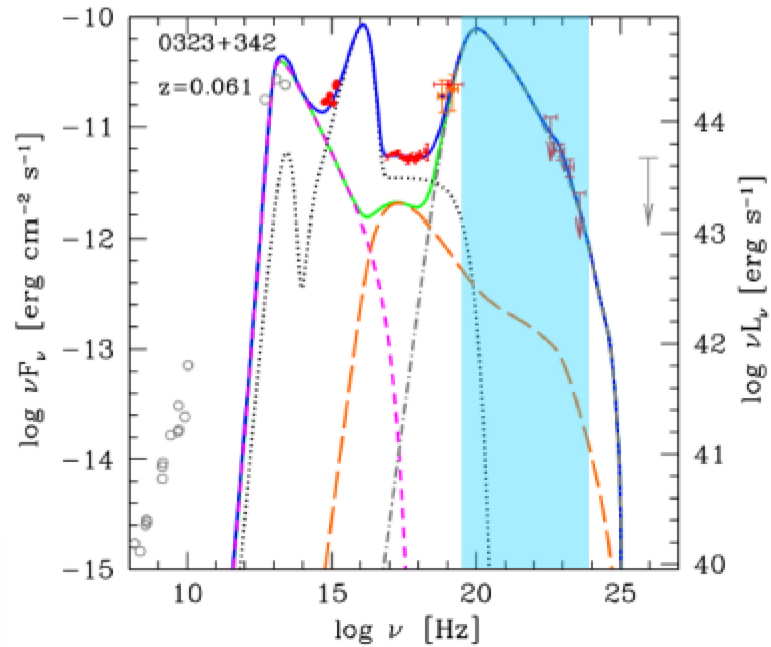




Jetted Narrow-line Seyfert galaxies

Kaufmann et al.

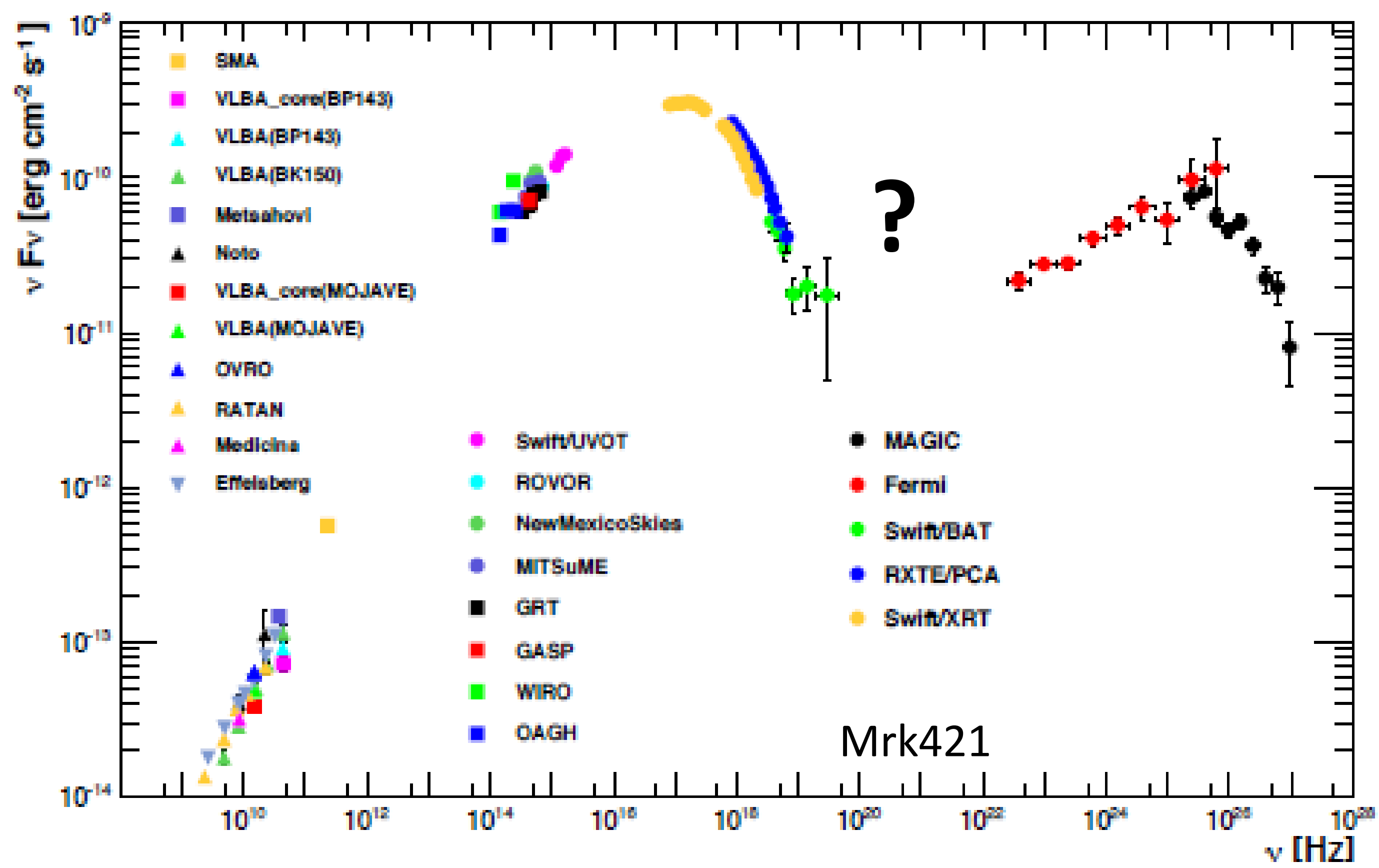


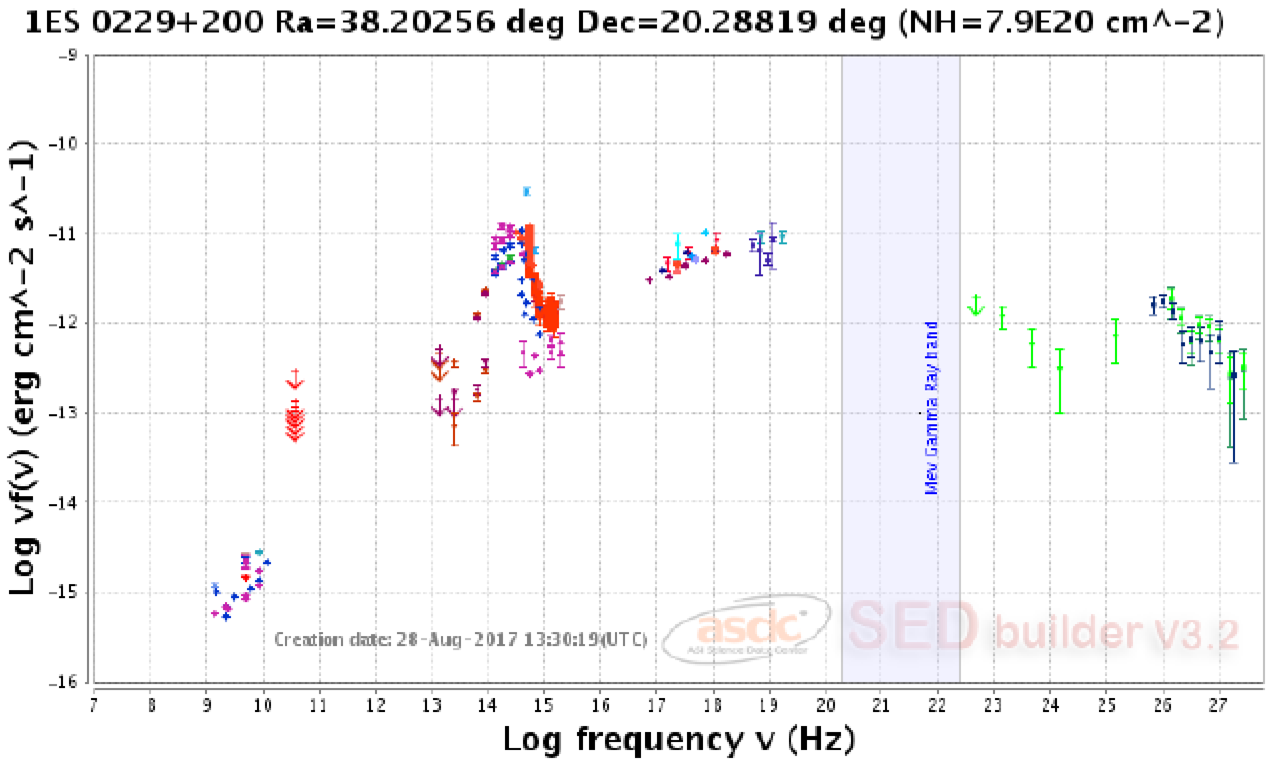


Small fraction of NLS1s are radio-loud.
SKA will detect >1000 radio-loud NLSy1 (Berton et al. 2015).
Gamma-rays from young jets in MeV regime?

Extreme blazars

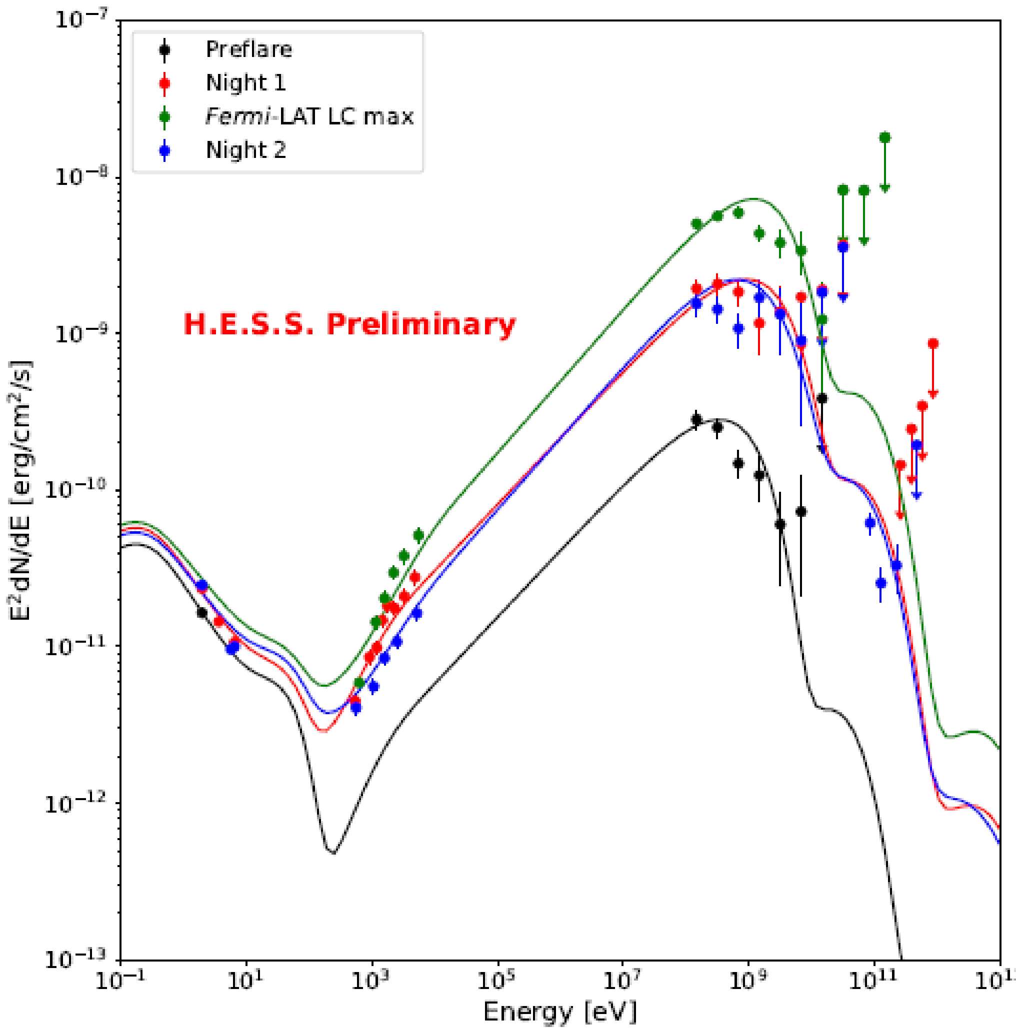
Prandini et al.




1ES 0229+200 Ra=38.20256 deg Dec=20.28819 deg (NH=7.9E20 cm^-2)
Log νf(ν) (erg cm^-2 s^-1)
Log frequency ν (Hz)
Mev Gamma Ray band
Creation date: 28-Aug-2017 13:30:19(UTC)
asdc
SED builder v3.2

Time-domain studies of blazars

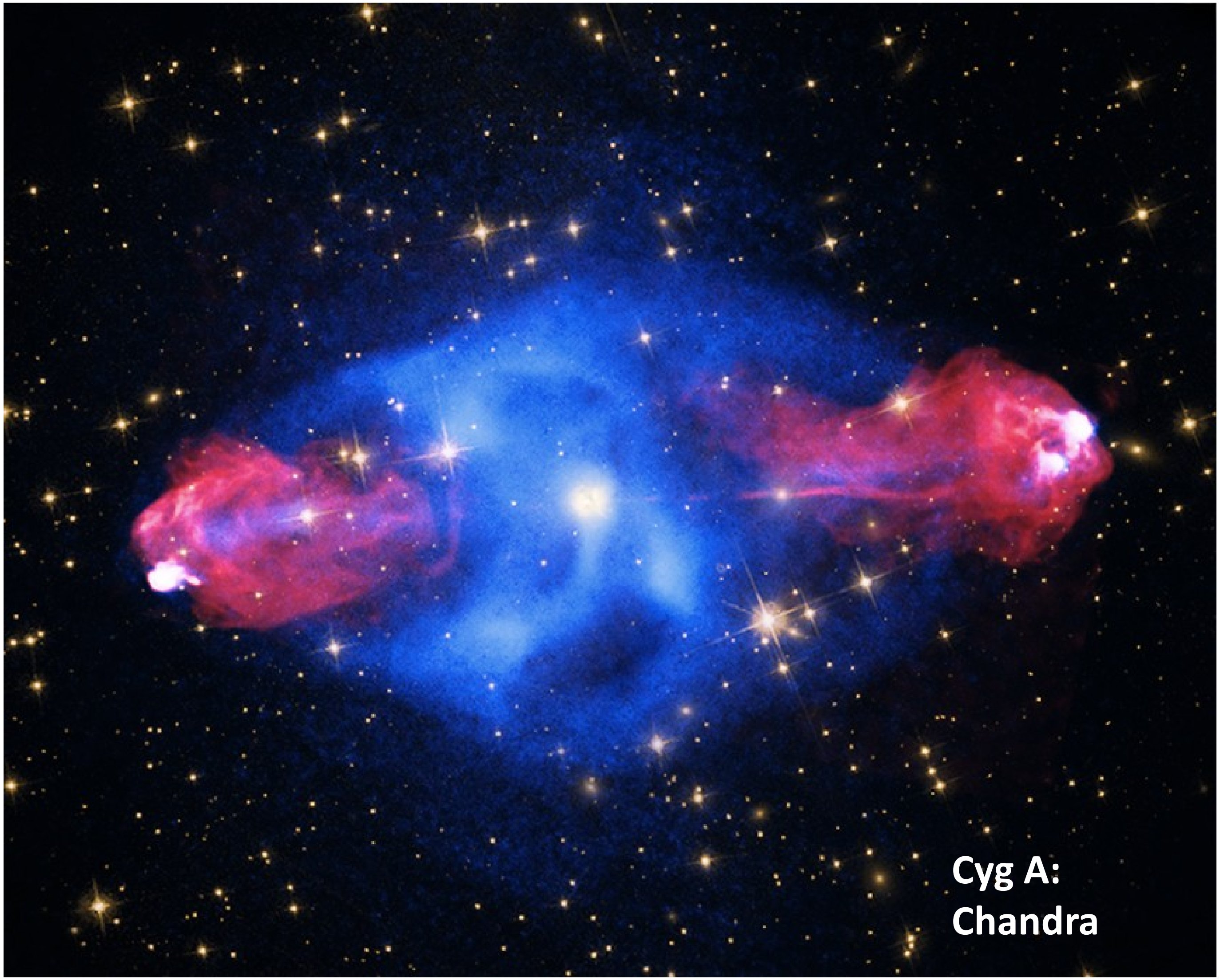
Dorner & Bretz

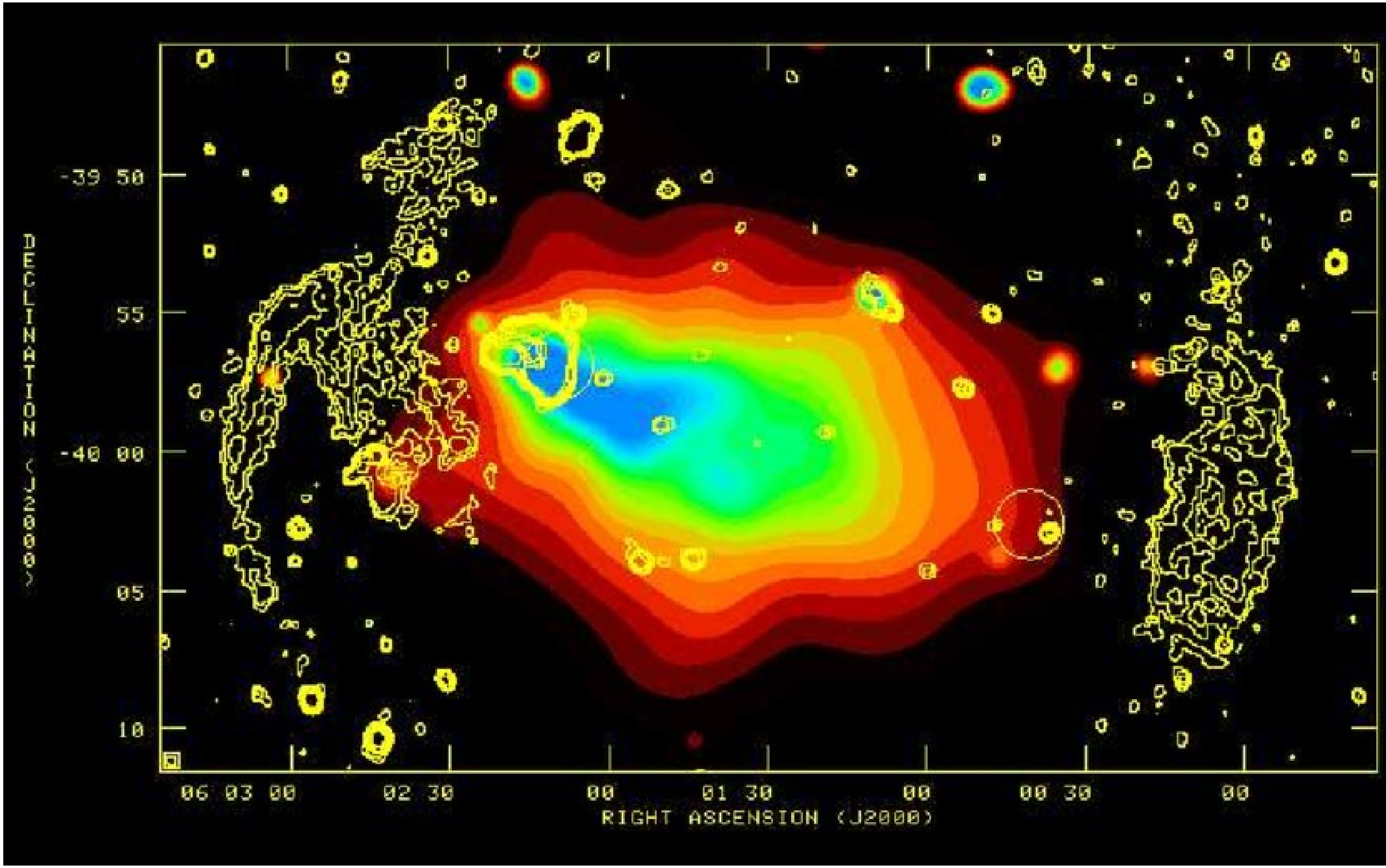


Hadronic model fits to time-variable SED of 3C279

Link statistical properties of flux variations with central machine

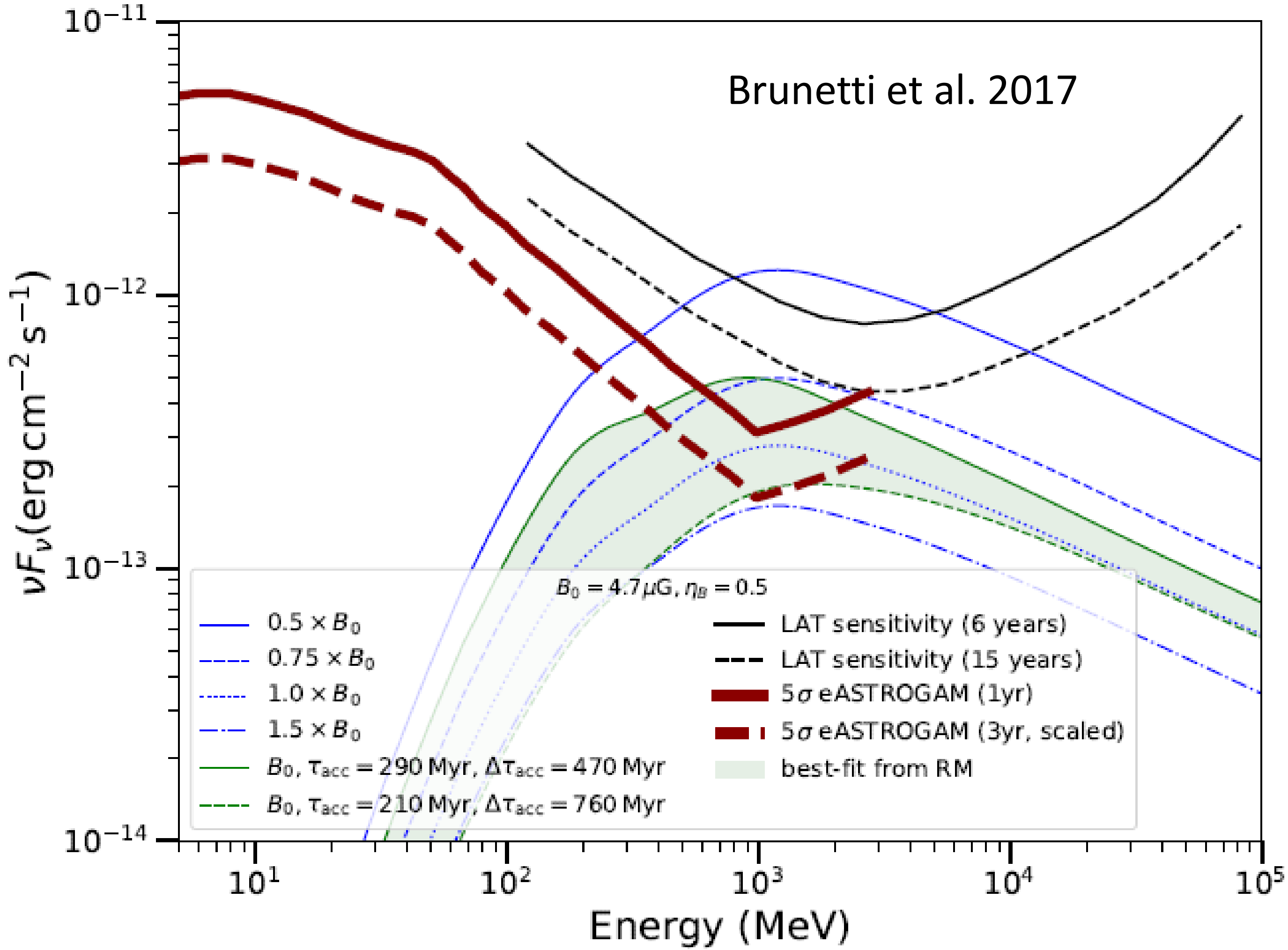
Indications for periodic modulation in PG 1553+113 (Fermi-LAT, MAGIC)

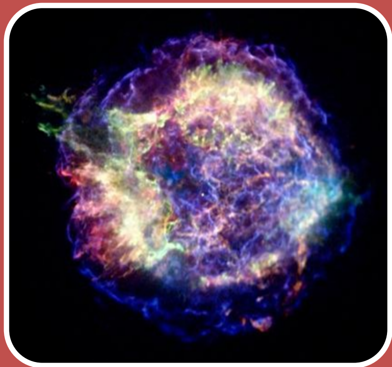

Cyg A:
Chandra



A3376: Bagchi et al. (2002)

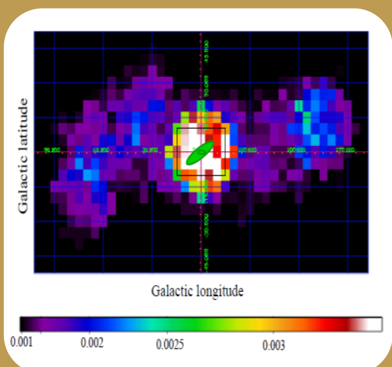
Cosmic rays in clusters of galaxies





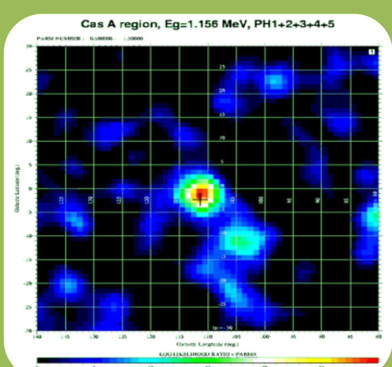
Explosive Nucleosynthesis

- Radioactive isotopes



Positronium Annihilation

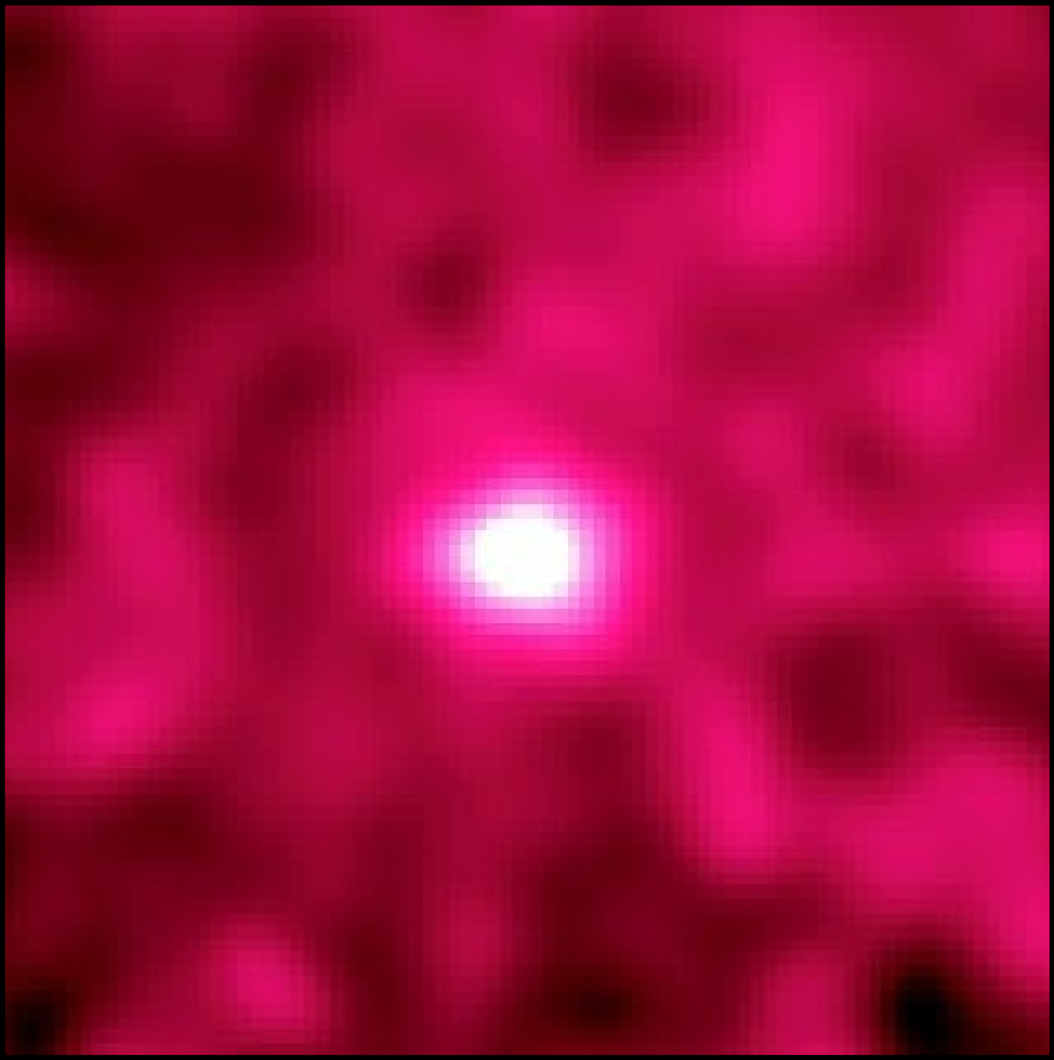
- Vacuum breakdown in pulsars
- Secondary positrons



Nuclear De-Excitation Lines

- Cosmic ray bombardment
- Ultrahot accretion disks

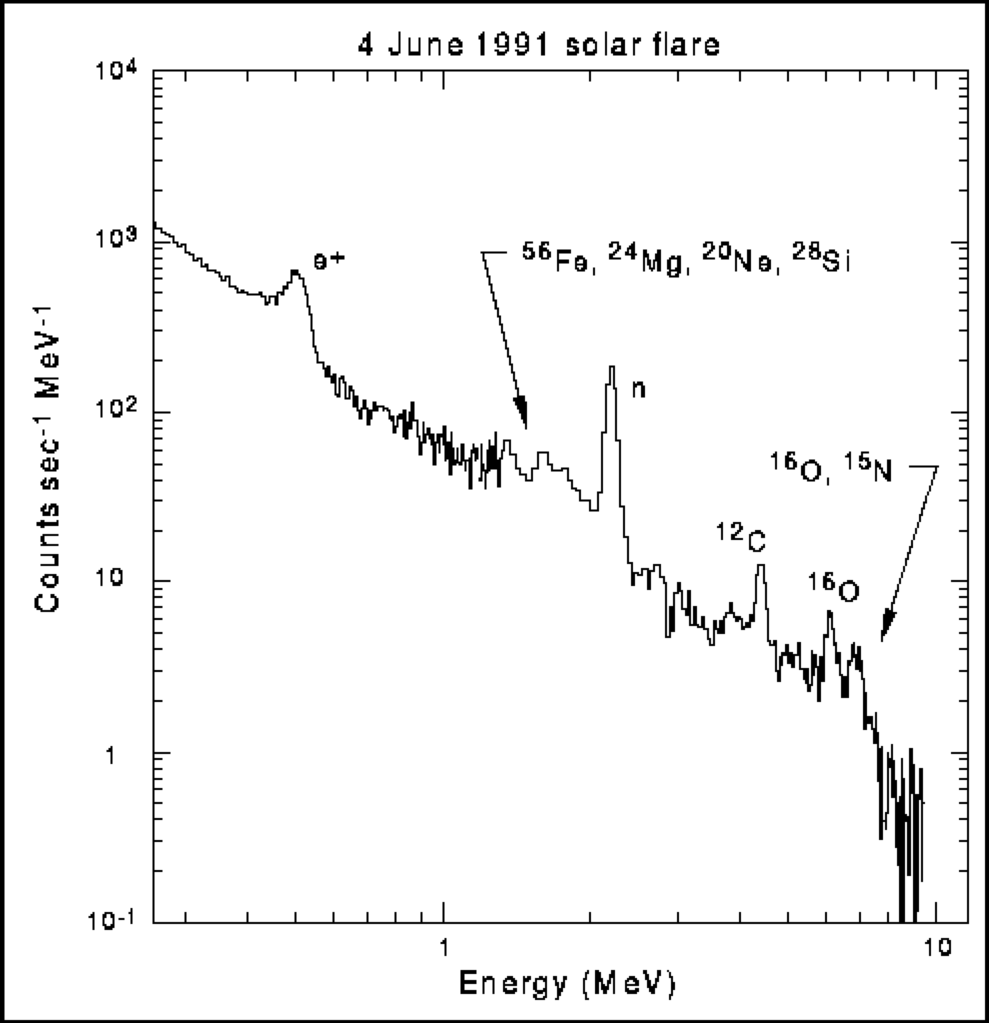
The Moon



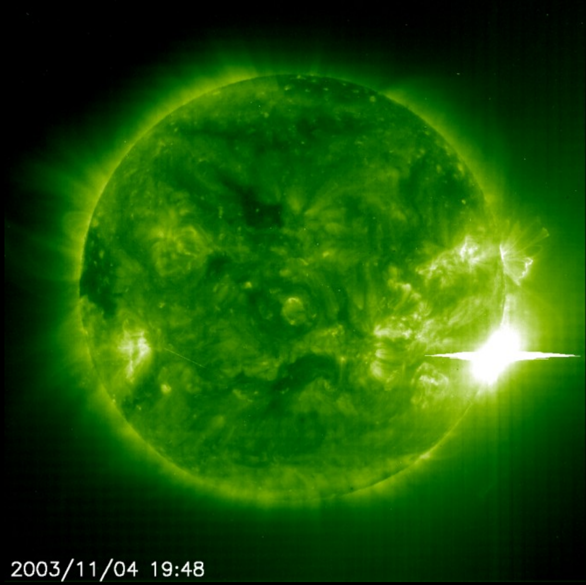
Thomson et al., JGR 1997

...as seen by the Compton GRO at >20 MeV

The Sun

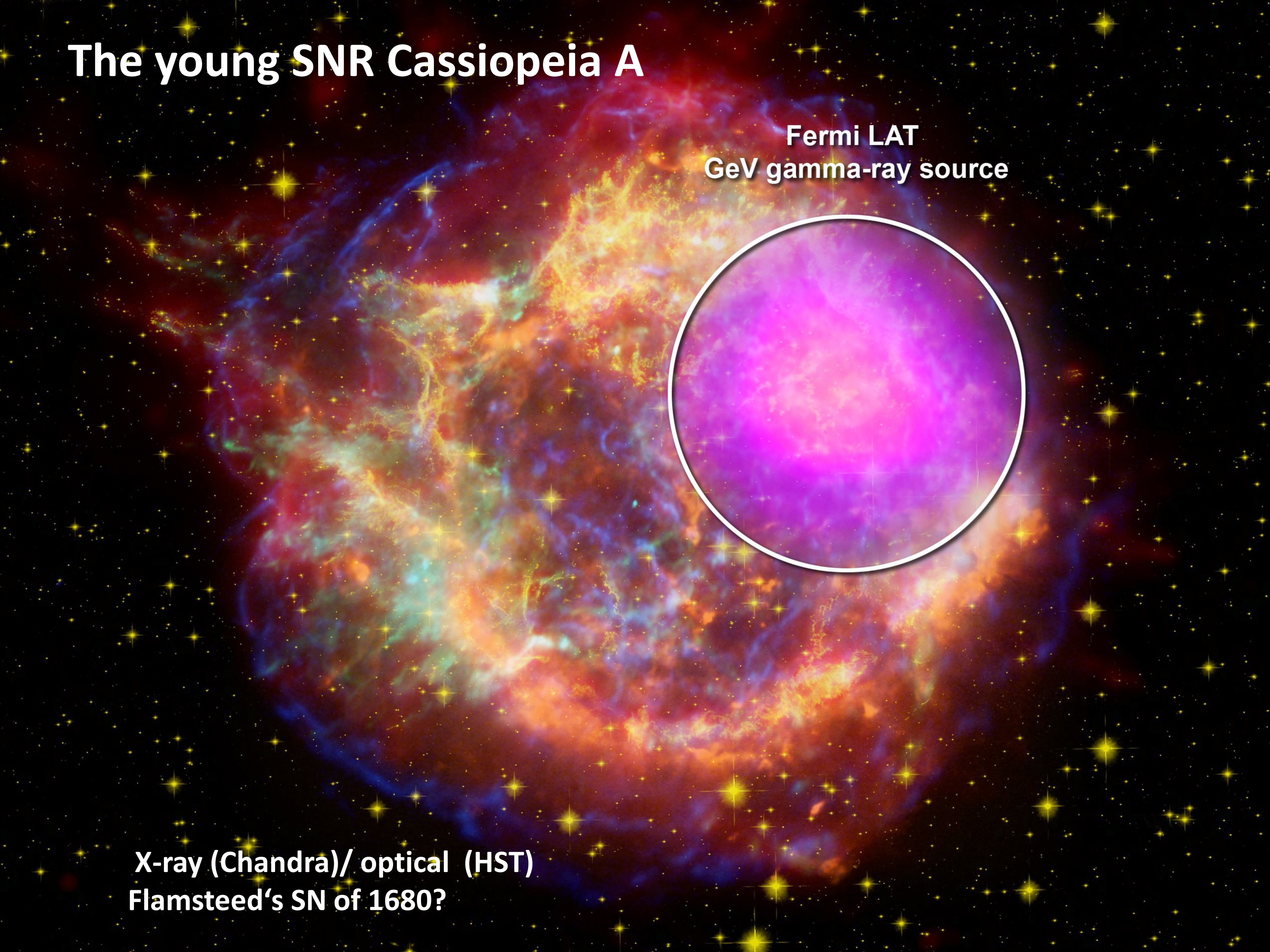


Murphy et al., ApJ 1997

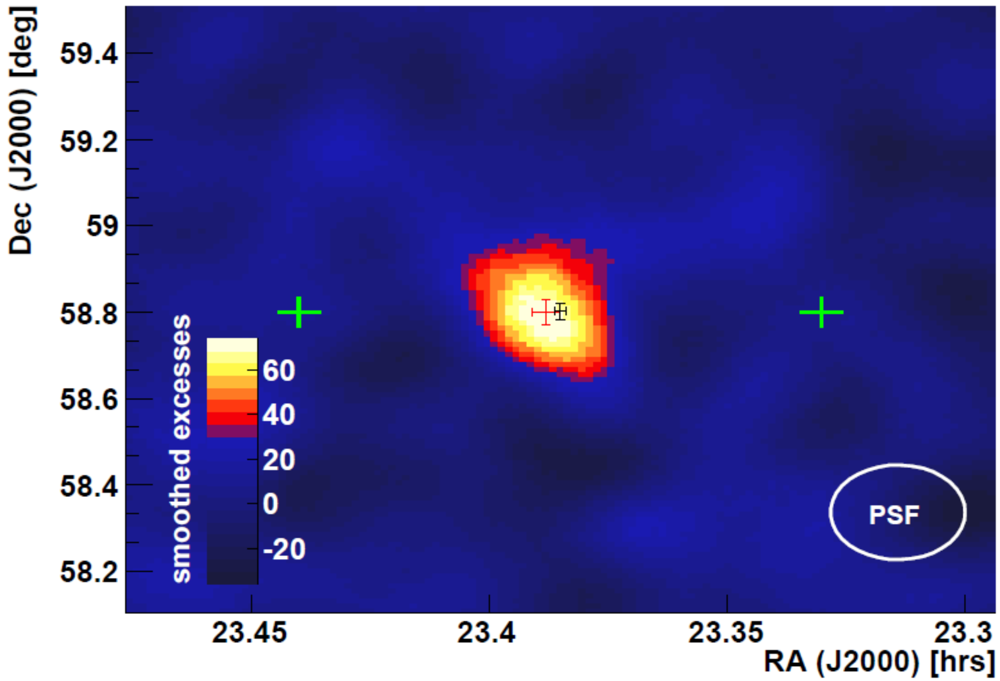


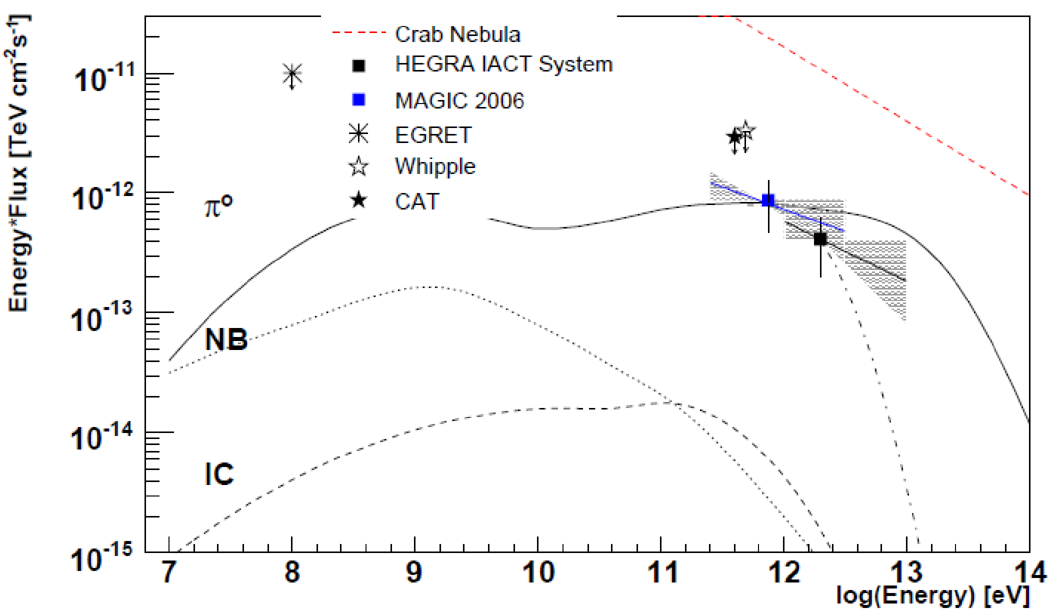
... as seen by OSSE at MeV energies

The young SNR Cassiopeia A



X-ray (Chandra)/ optical (HST)
Flamsteed‘s SN of 1680?





Wolf-Rayet Supernova Remnant

Cas A

(Albert et al. 2007)

Evidence for cosmic ray acceleration from pion production spectrum

(Berezkho al. 2003)

Target abundances from X-ray and optical spectroscopy: Heavy-element enriched Wolf-Rayet wind mixed with supernova ejecta

Table 1. Mean measured abundance mass ratios and rms scatter resp. upper limits according to the results of Willingale et al. (2002), Docenko & Sunyaev (2010) and Chevalier & Kirshner (1979).

ratio	mean	rms
H/Si	$< 2.29 \times 10^{-5}$	-
He/Si	$< 4.93 \times 10^{-3}$	-
C/Si	1.76	0.88
O/Si	1.69	1.37
Ne/Si	0.24	0.37
Mg/Si	0.16	0.15
S/Si	1.25	0.24
Ar/Si	1.38	0.48
Ca/Si	1.46	0.68
FeL/Si	0.19	0.65
FeK/Si	0.60	0.51
Ni/Si	1.67	5.52

Cosmic Ray spectrum
(Berezhko et al. 2003)

+

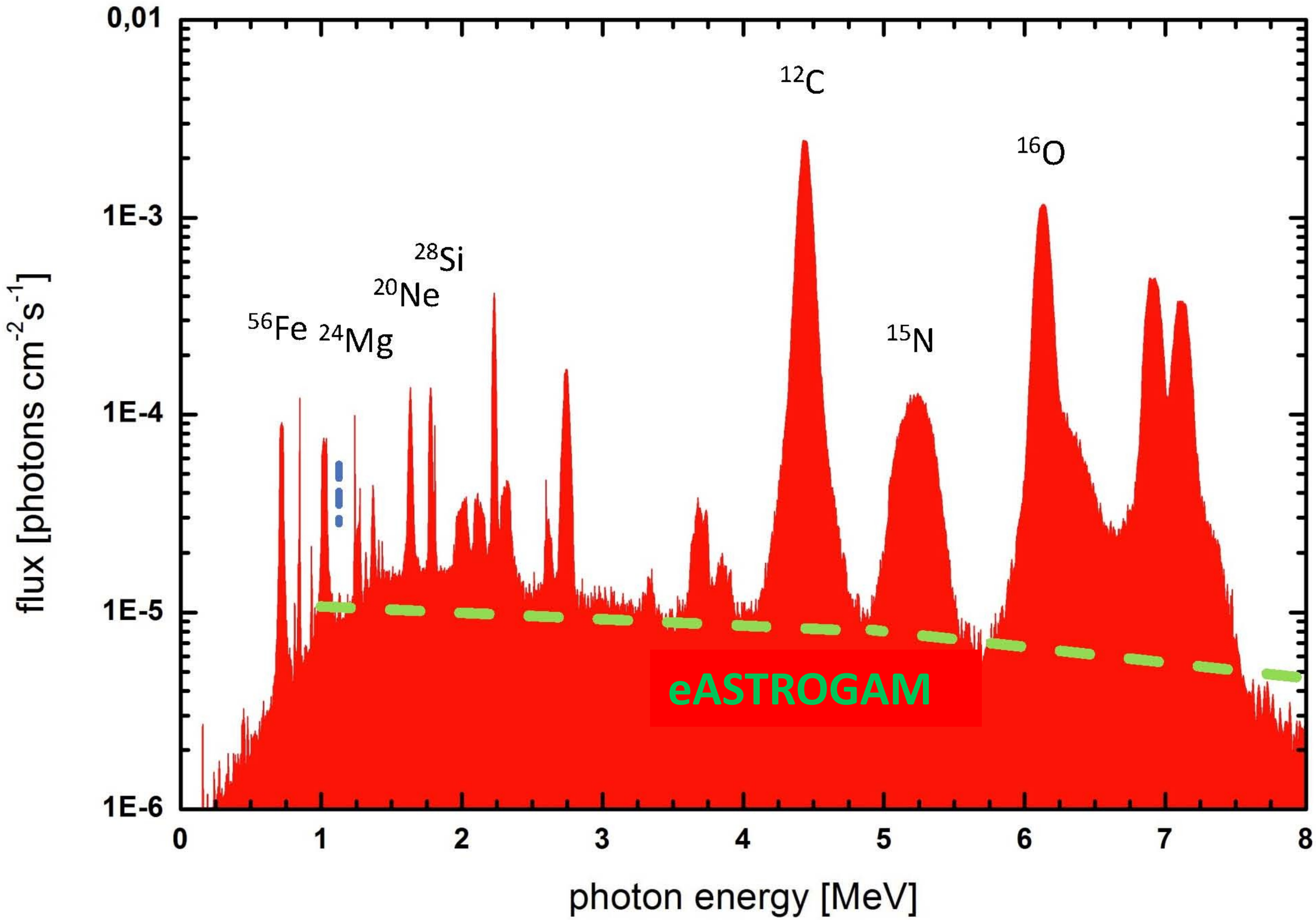
Target abundances

+

Nuclear excitation cross sections
(Kozhlovski & Ramaty 2002)

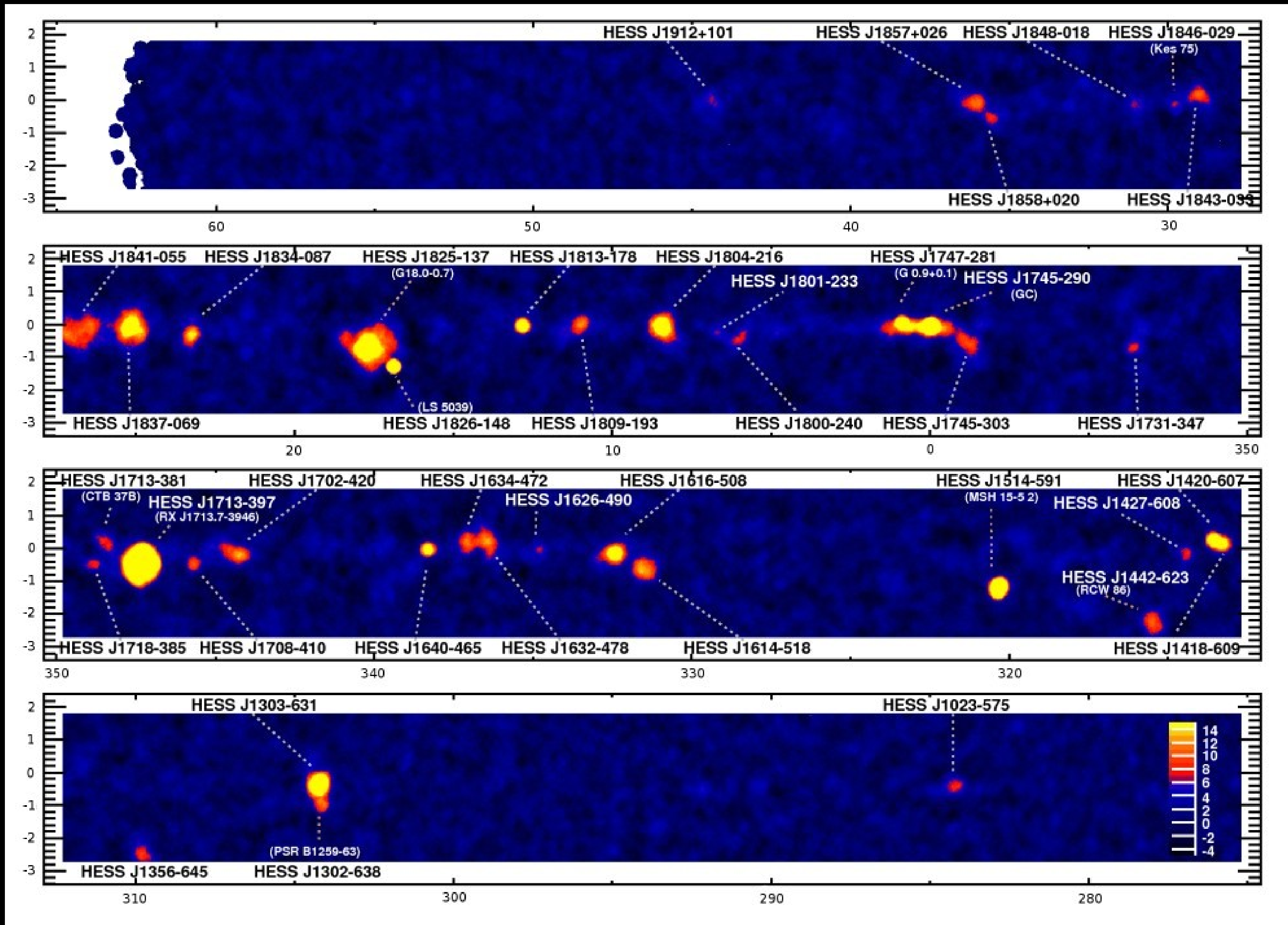
→

Prediction of nuclear de-excitation lines based on high-energy spectrum observed from Cas A



Summa et al. (2011)

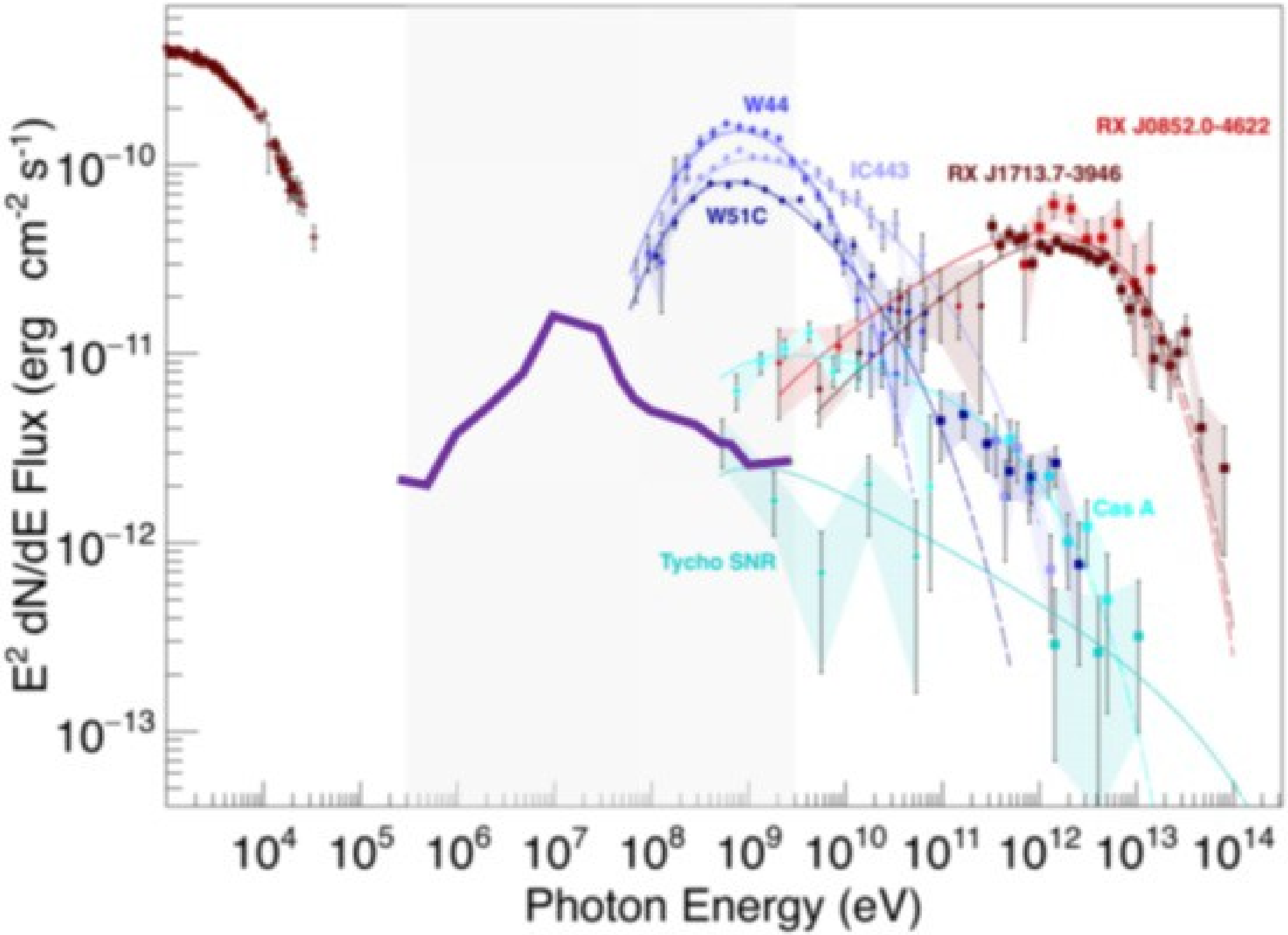
The Milky Way Galaxy: Cosmic accelerators



Aharonian et al. 2005

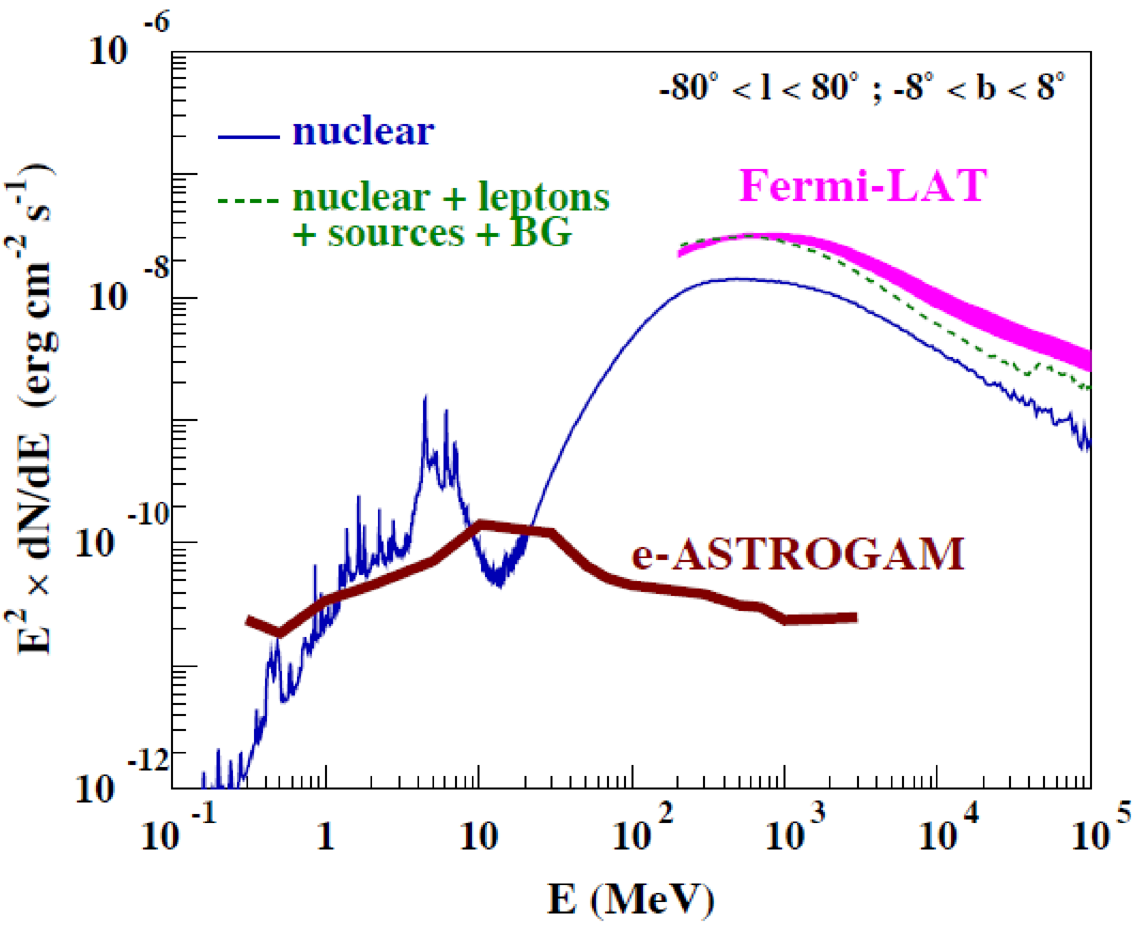
eASTROGAM view on cosmic ray interactions in young SNR

Cardillio, Pohl, et al.



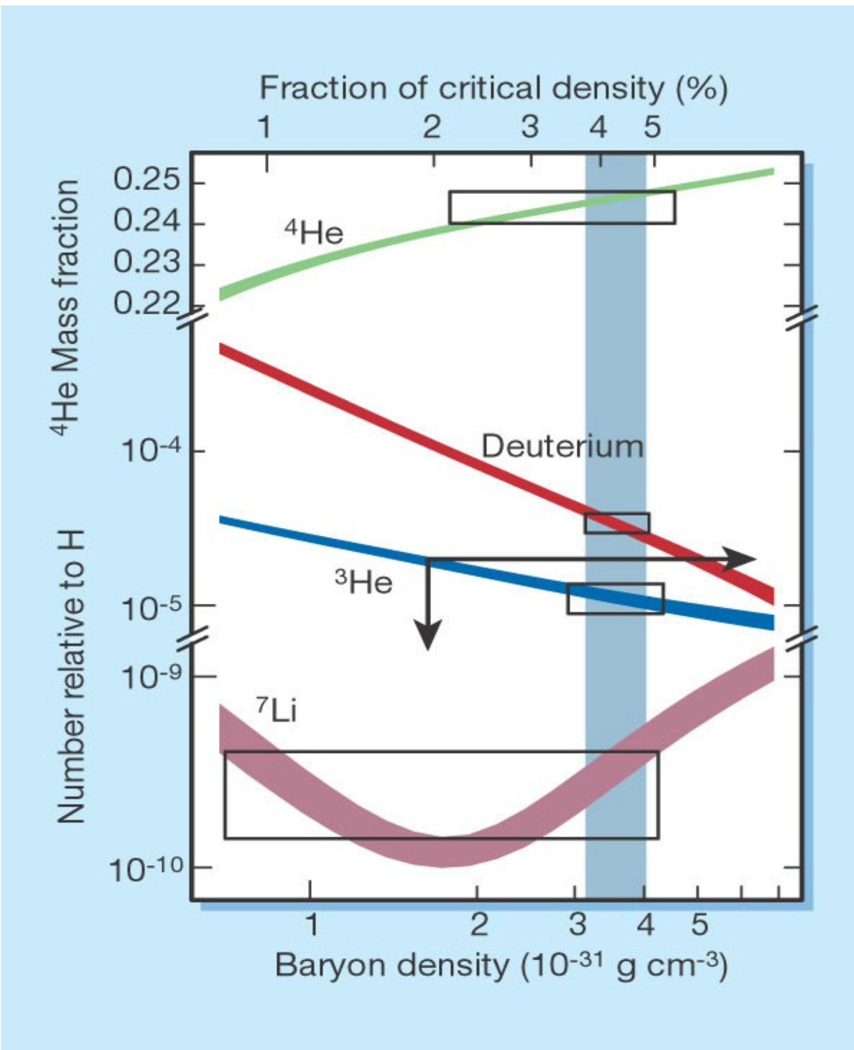
Inner Galaxy diffuse emission

Strong et al.

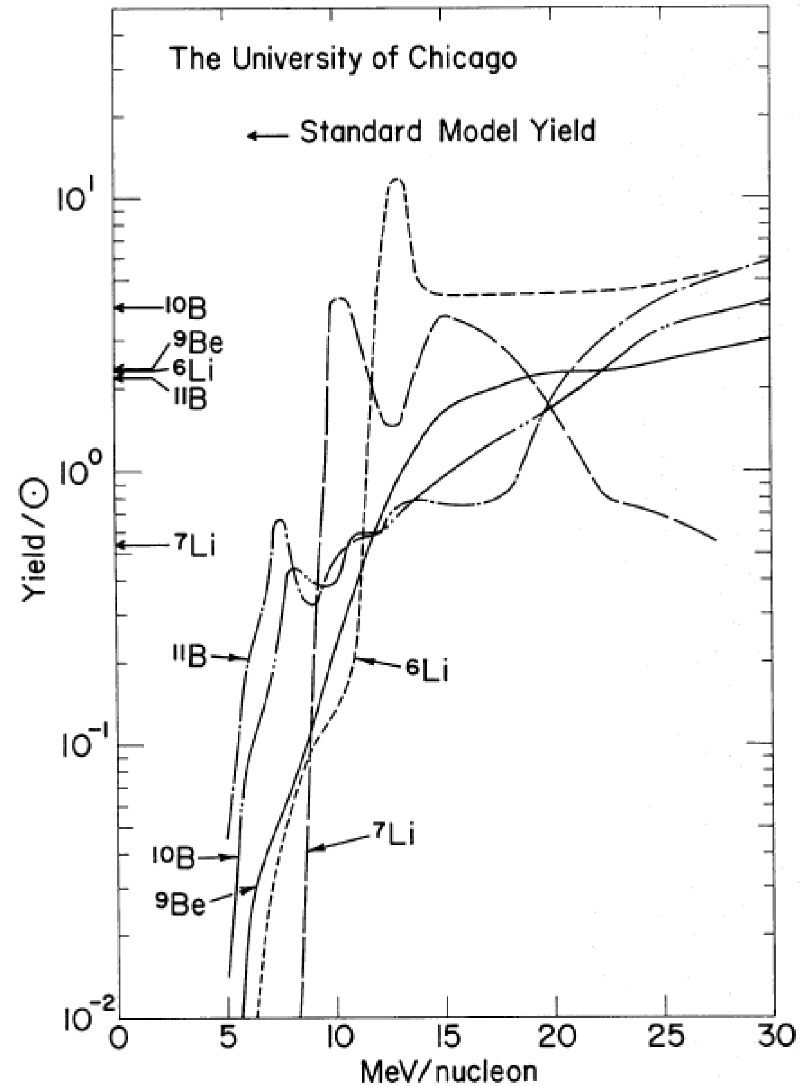


Big Bang Nucleosynthesis

element	theory	Observation
D/H	$2.75^{+0.24}_{-0.19} \times 10^{-5}$	$2.78 \pm 0.29 \times 10^{-5}$
^{4}He	$0.2484^{+0.0004}_{-0.0005}$	$0.238 \pm 0.002 \pm 0.005$
^{7}Li	$3.82^{+0.73}_{-0.60} \times 10^{-10}$	$1.23^{+0.34}_{-0.16} \times 10^{-10}$



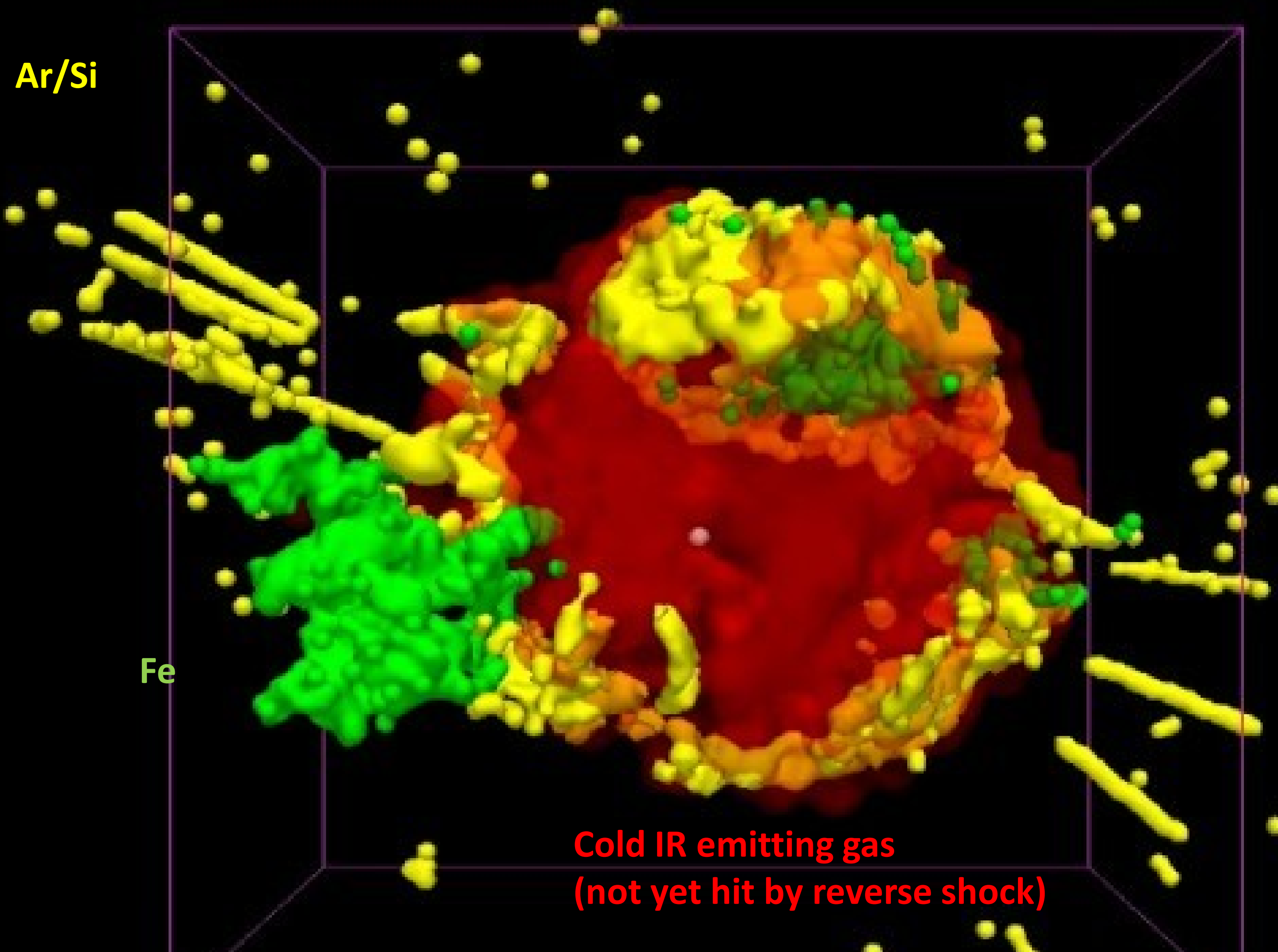
Spallation in cosmic ray sources sharpens Li-problem



Nuclear de-excitation line measurements essential for our understanding of cosmic chemical abundances

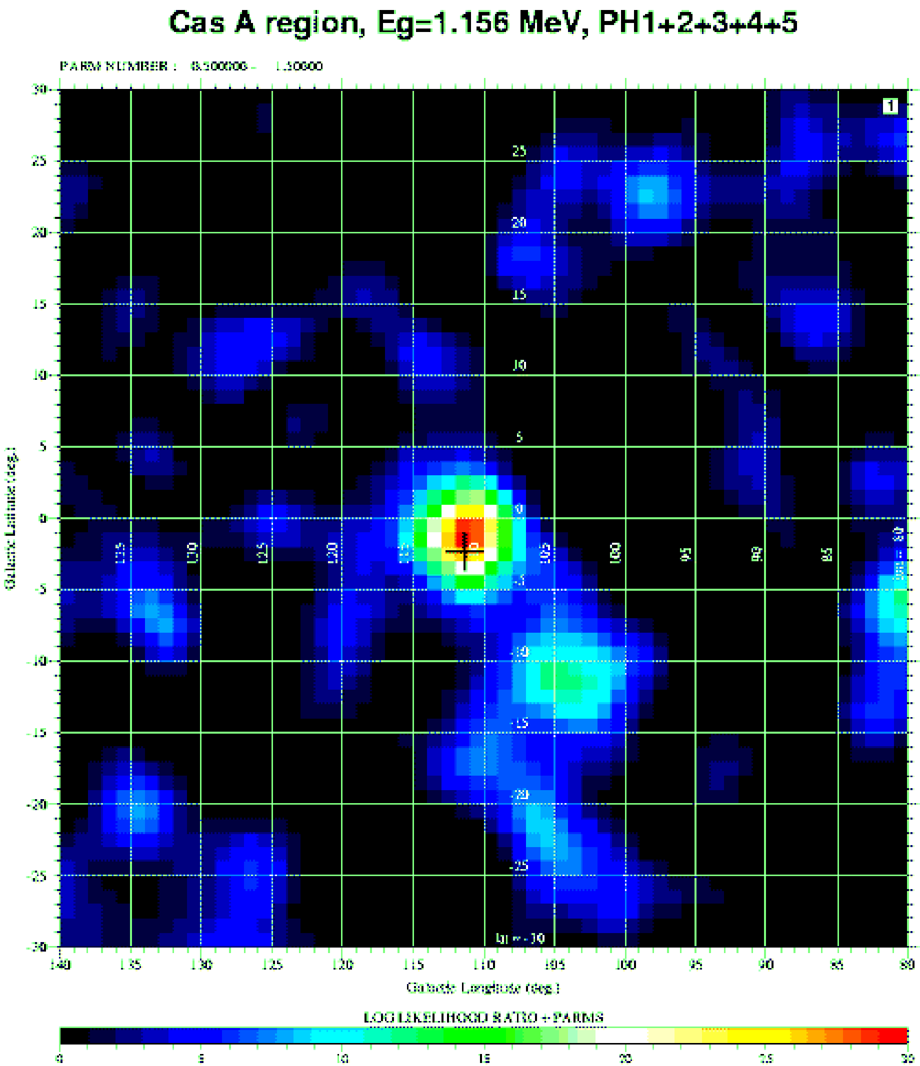
- Unambiguous spectroscopic fingerprint of cosmic ray proton and ion acceleration
- Chemical composition of cosmic rays and supernova ejecta
- Spallation production of
  - Rare odd-odd nuclei (e.g., ^{138}La, ^{50}V, ^{180}Ta)
  - Isotopes of light elements Li, Be, B
- Cosmic ray heating of interstellar medium
- Activation of molecular bindings/breakups

3D-model from Doppler imaging (Delaney et al.)

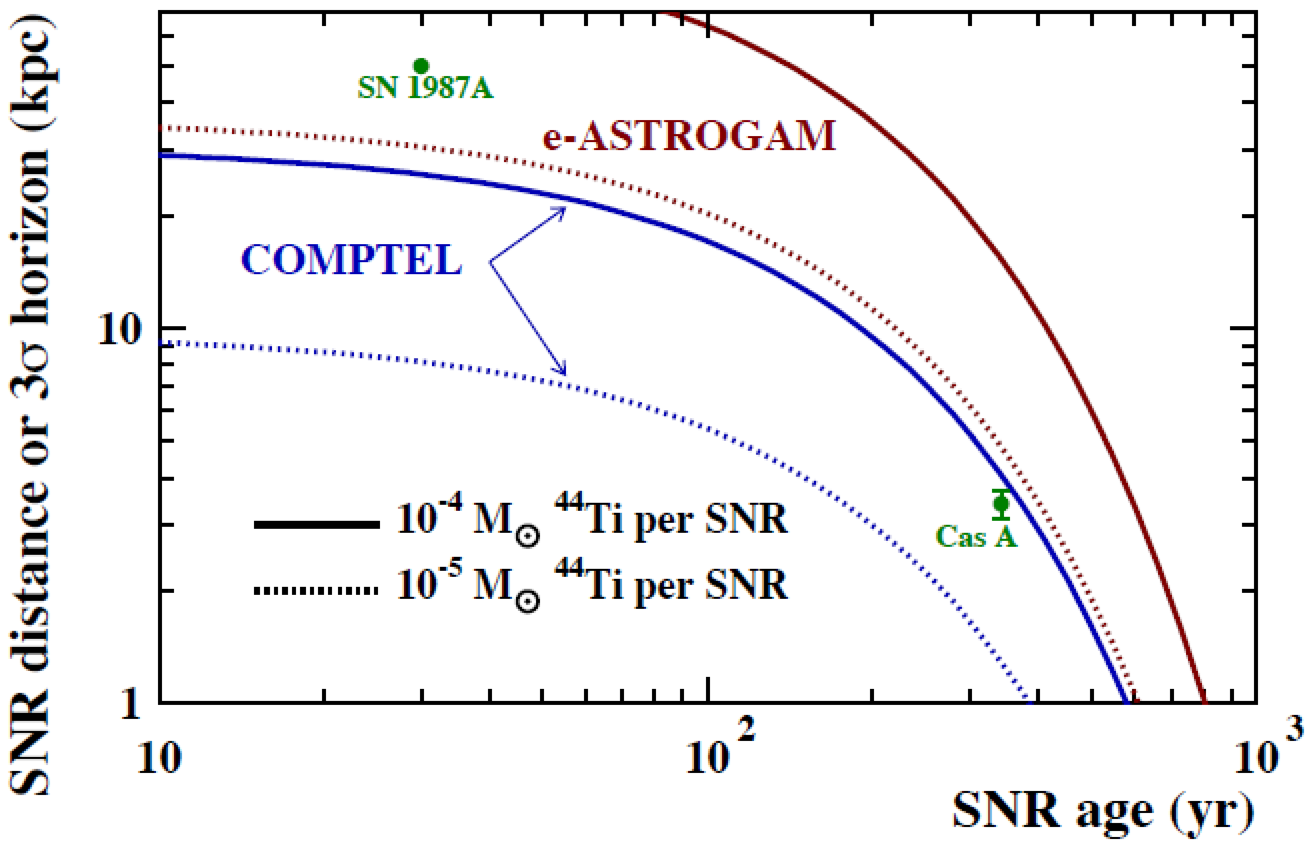


Outer shock not shown since Doppler imaging does not work with synchrotron emission

Ti-44 line detected with COMPTEL (Iyudin et al. 1994)



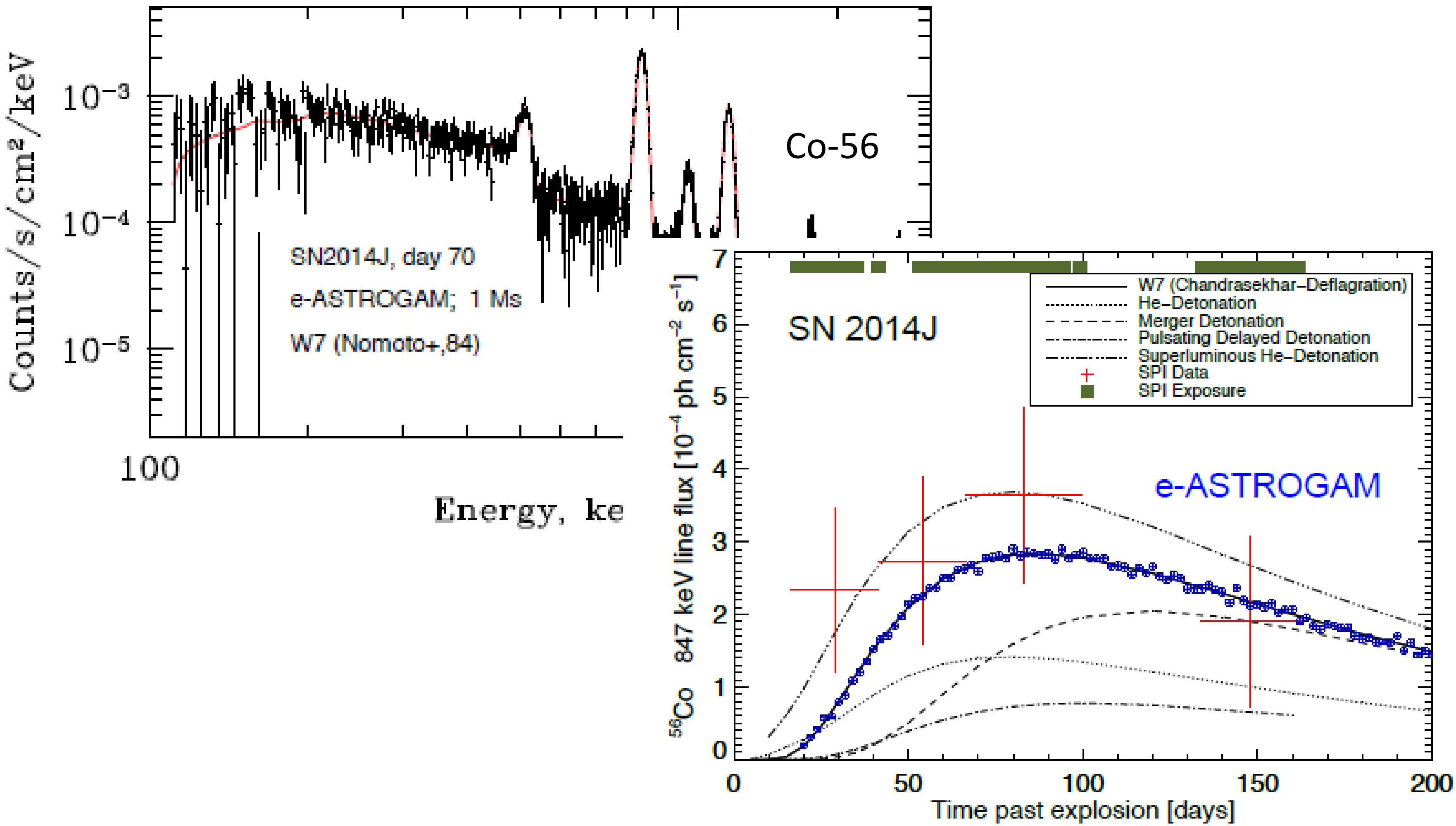
- ^{44}Ti nucleosynthesis (by-product of ^{56}Ni)
- Half-life of 86 yrs
- Comptel flux $(4.8 \pm 0.9)\times 10^{-5}$ cm^{-2} sec^{-1}
- ^{44}Ti mass of $(1.62 \pm 0.31)\times 10^{-4}$ M_O
- Mass is highly sensitive to NS models
- High value may be hint of asymmetry
- ^{44}Ti → ^{44}Sc → ^{44}Ca
- X-ray lines at 68 keV and 78 keV
- Confirmed by BeppoSax



SN 1987A
e-ASTROGAM
COMPTEL
Cas A
10^{-4} M$_\odot$ ^{44}Ti per SNR
10^{-5} M$_\odot$ ^{44}Ti per SNR
SNR distance or 3σ horizon (kpc)
SNR age (yr)
10
1
10
10^2
10^3

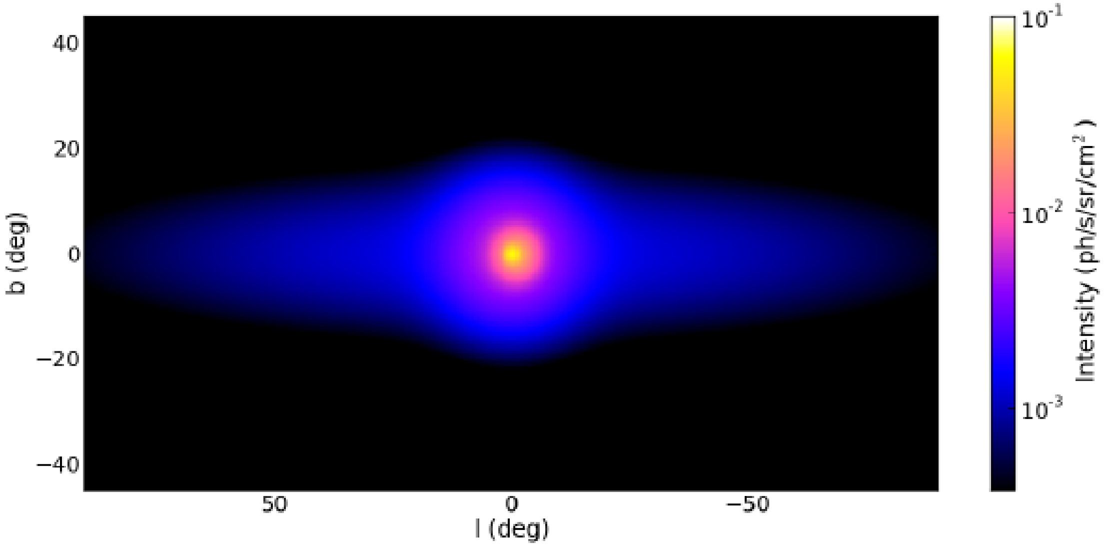
Thermonuclear explosions SNIa

Churazov et al.

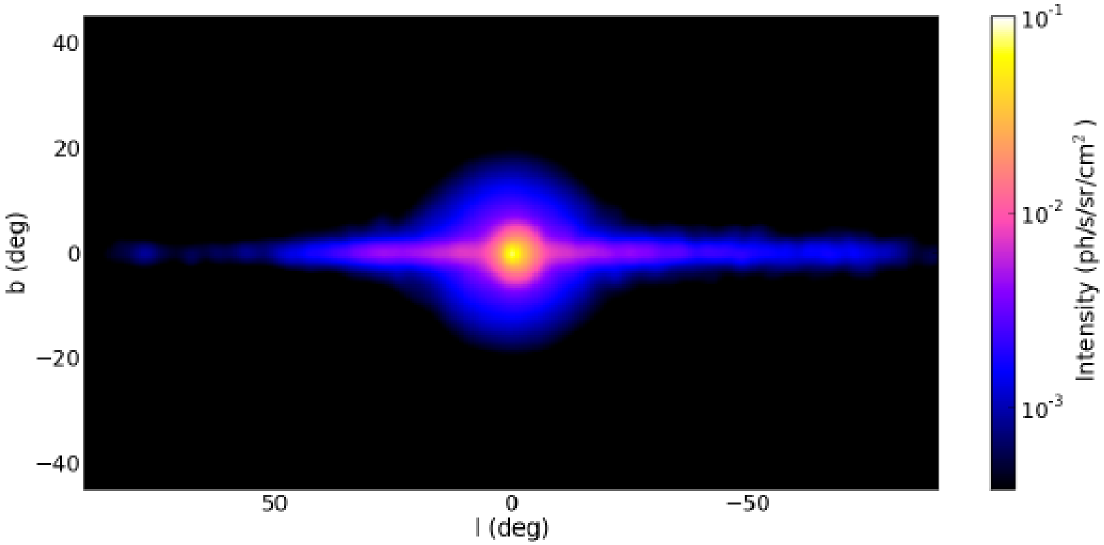


Riddle of positronium annihilation

1-year of eASTROGAM



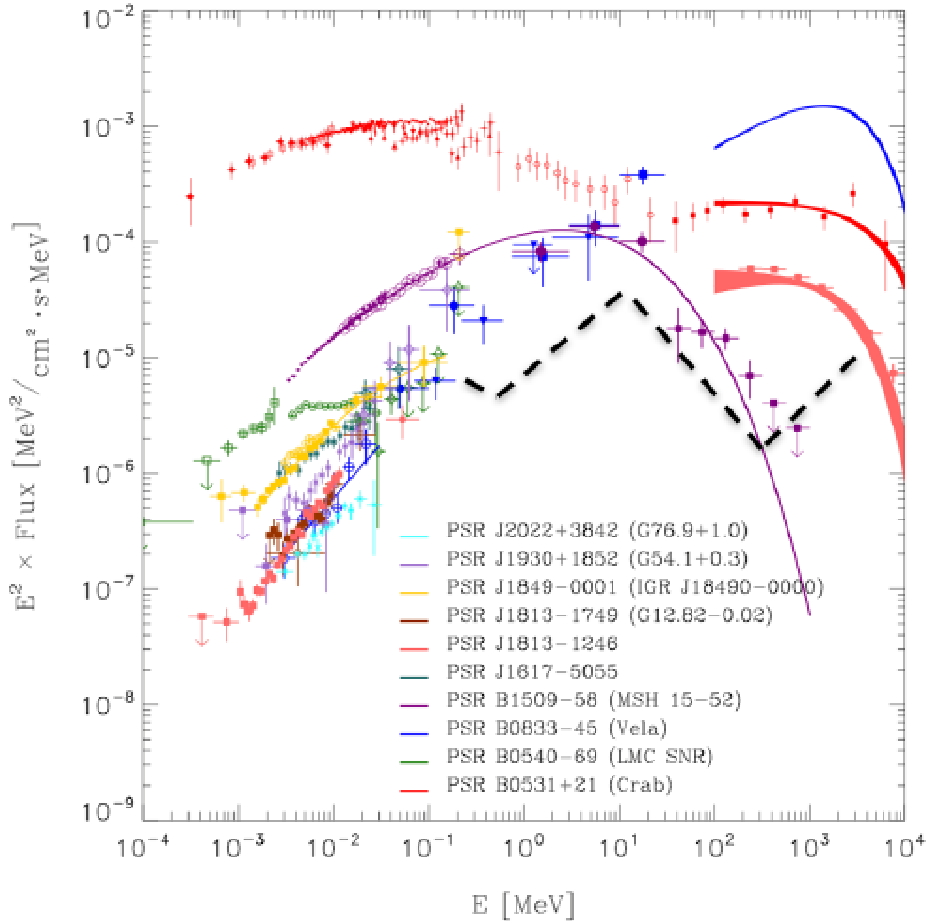
Thick disk
(Siegert et al. 2016)



Disk + Point source + Bulge
(Skinner et al. 2014)

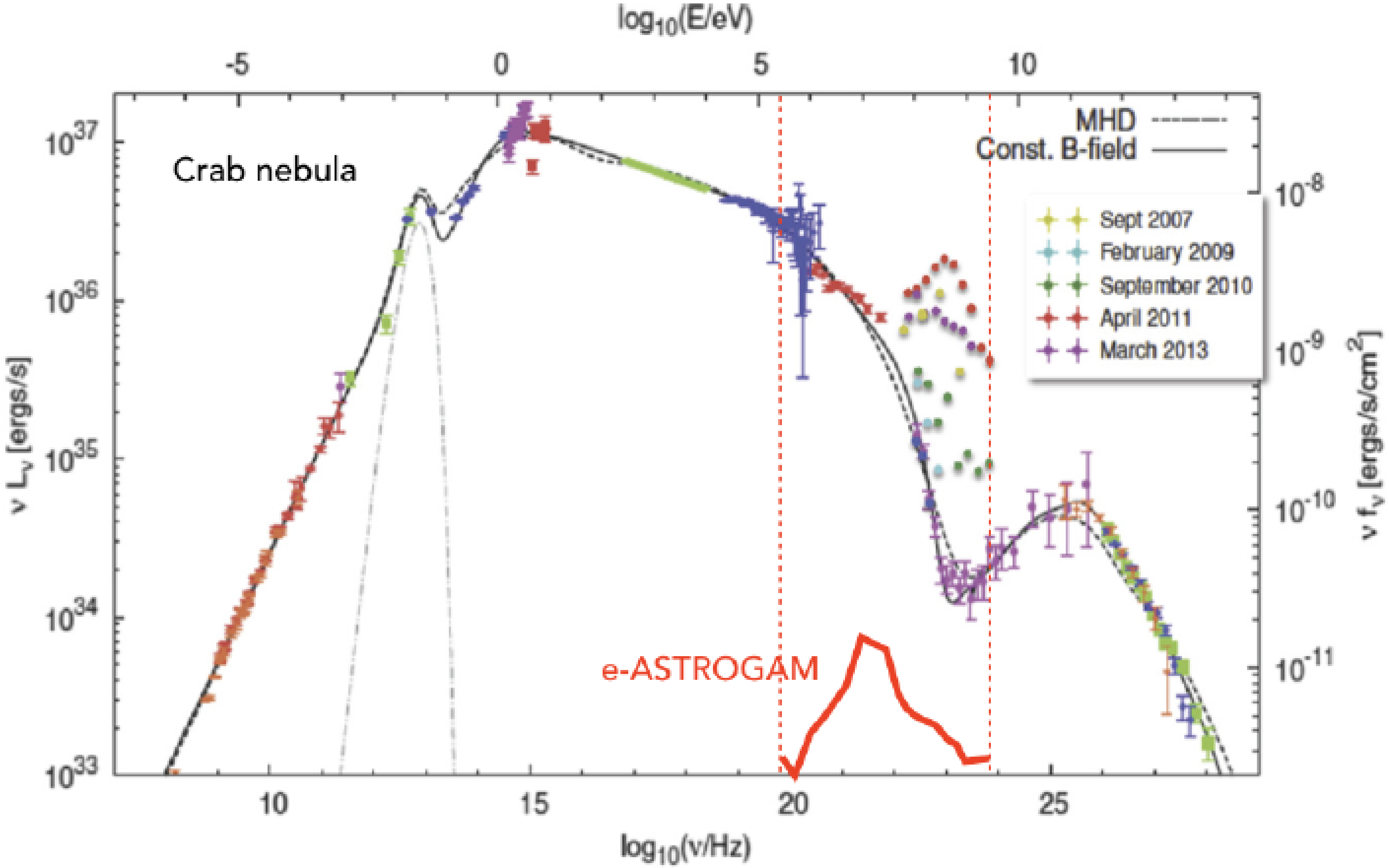
Pulsars

Harding et al.



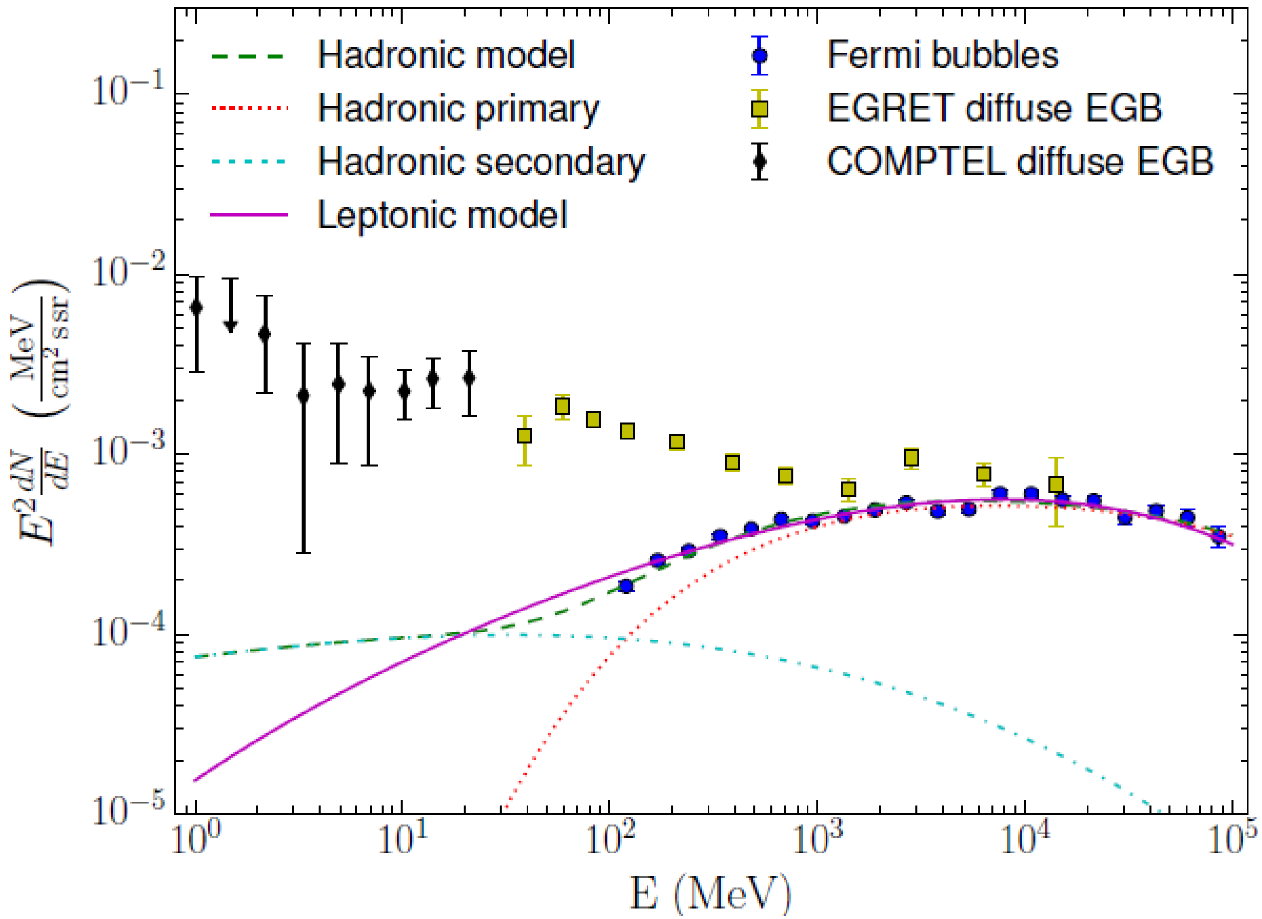
SEDs from Kuiper & Hermsen

PWN



log10(E/eV)
-5
0
5
10
MHD
Const. B-field
Crab nebula
Sept 2007
February 2009
September 2010
April 2011
March 2013
e-ASTROGAM
ν Lν [ergs/s]
ν fν [ergs/s/cm2]
10^37
10^36
10^35
10^34
10^33
10^-8
10^-9
10^-10
10^-11
10
15
20
25
log10(ν/Hz)

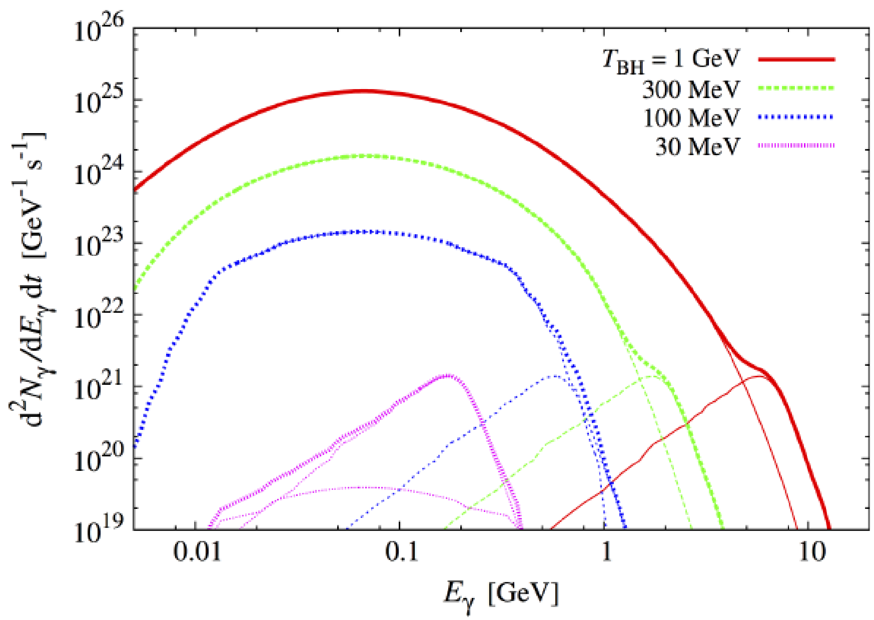
Fermi-bubbles radiation process



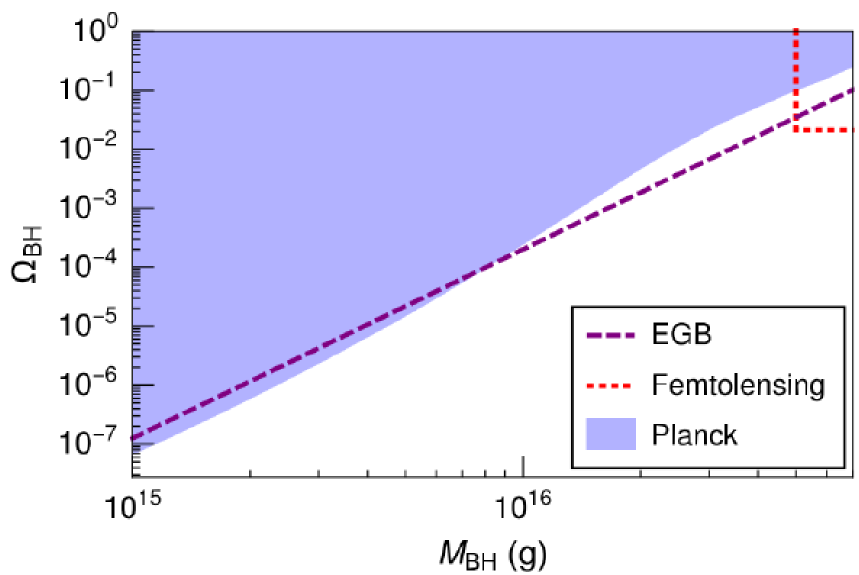
Malyshev & Franckowiak

Primordial black holes

Doro et al.



Carr et al. 2010

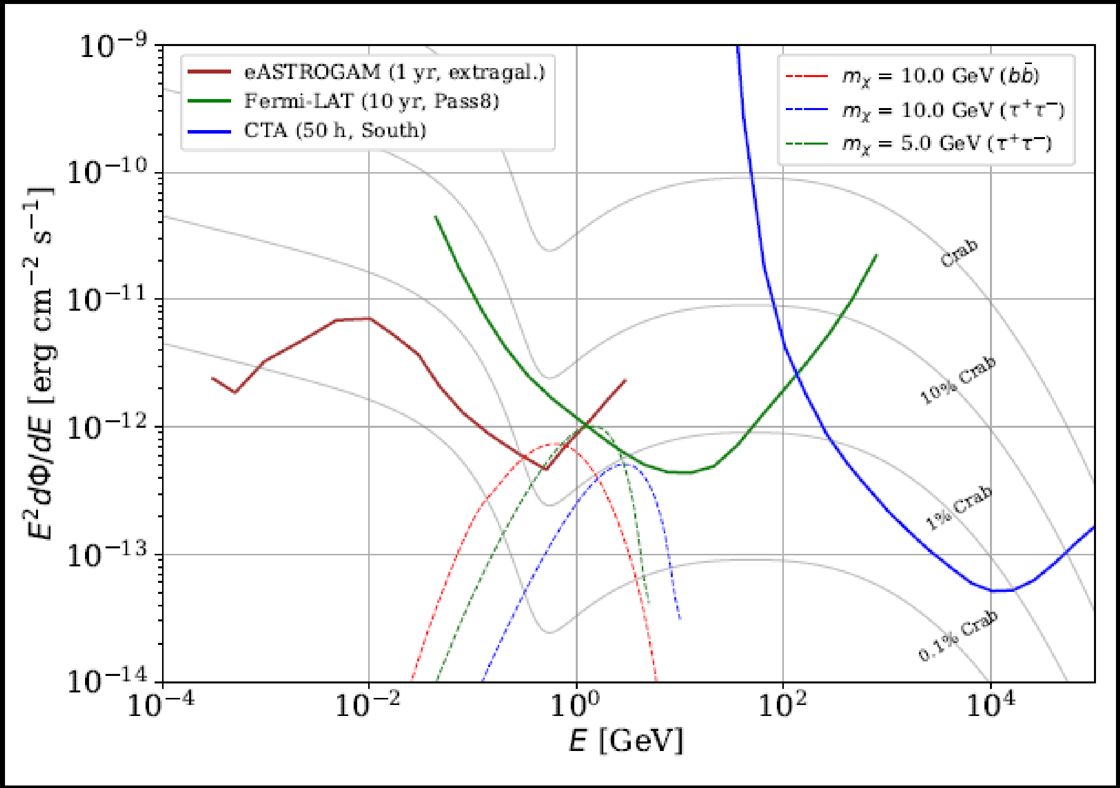


Clark et al. 2017

Dark Matter

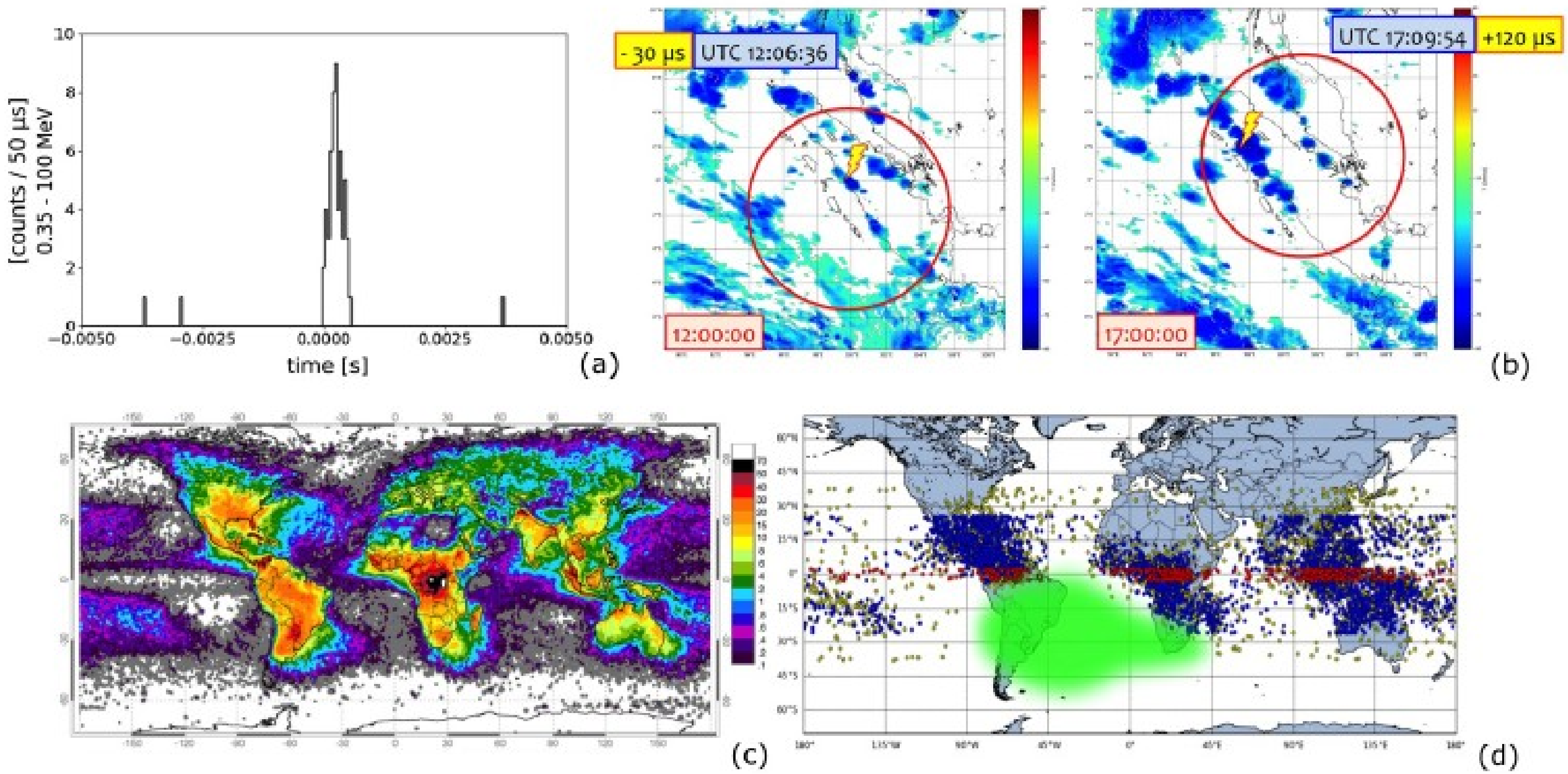
Konrad et al.

- Light WIMPs, majorons, dark photons
- Non-thermal CDM (out-of-equilibrium freeze-out in the early Universe)
- Decays or annihilations for indirect detection with gamma rays: huge parameter space for phenomenology
- Energies too low for direct measurements (recoil)



Terrestrial Gamma-ray Flashes

Ursi et al.



eASTROGAM imaging calorimeter capabilities will show high-energy shape of the spectrum in ca. 1000 TGFs per year

eASTROGAM will be looking at…

Compact objects

- Clusters of galaxies
- GRBs
- Blazars
- GW or neutrino counterparts
- Nucleosynthesis in Supernovae
- Neutron stars, pulsars, magnetars, etc.
- Stellar binaries
- Globular clusters
- Primordial BHs

Extended and diffuse emissions

- Cosmic ray interactions in SNR, OB associations, Fermi lobes, MCs, ISM
- Diffuse isotropic background
- Light DM
- Positronium enigma
- Axion-like particles
- Matter-antimatter annihilation at high z
- Terrestrial gamma-ray flashes
- SETI

… great prospects for high-energy astrophysics

Global Survey Era

- Multi-wavelength
- Multi-messenger

→ Prepare for massive data streams and ML-augmented analysis