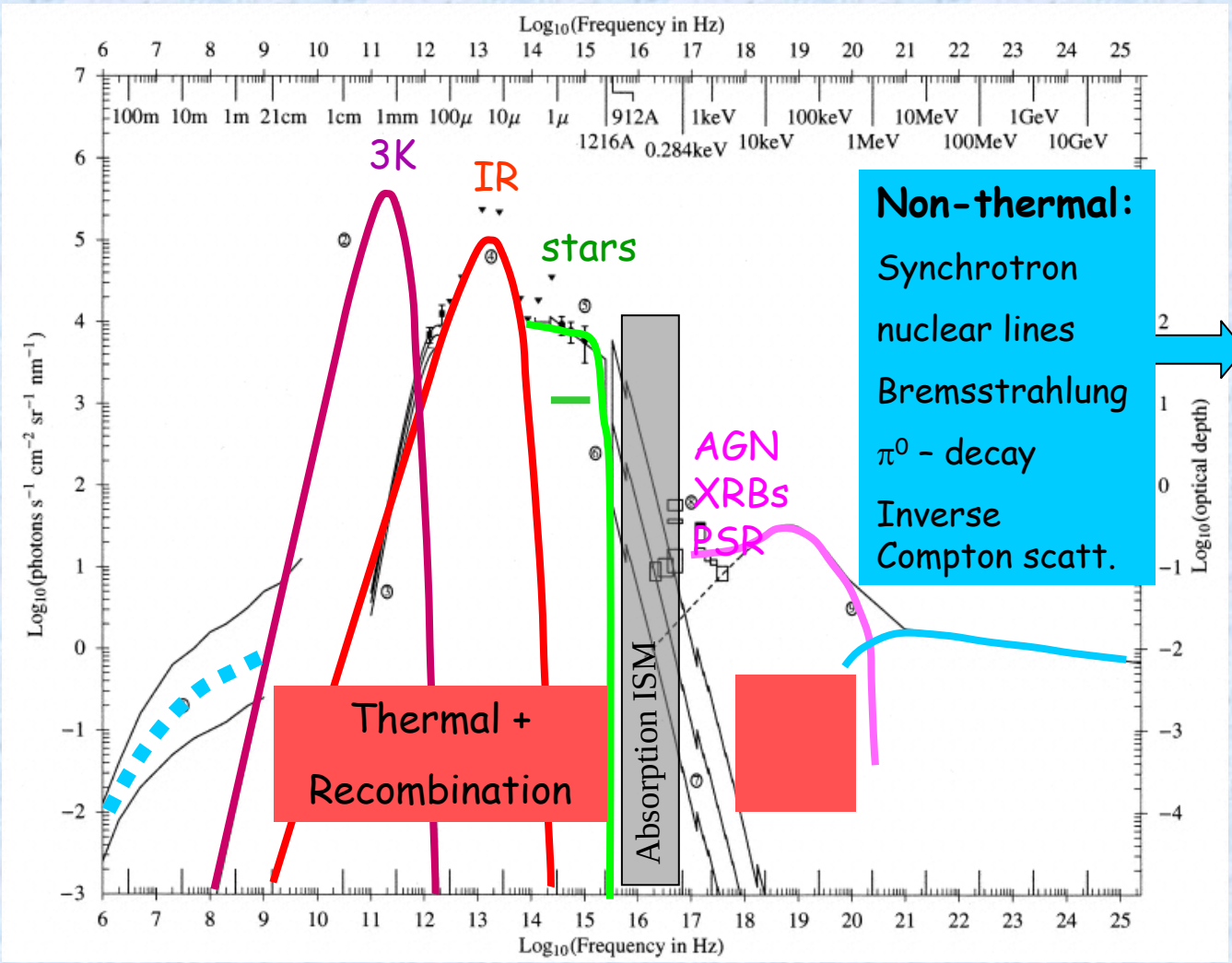
Low to Medium Energy Gamma-Ray Astronomy: Status and Perspectives

Gottfried Kanbach, MPE, Garching

- From the thermal to the non-thermal Universe: a spectral roadmap
- Pioneering experiments at MeV energies:
  SMM (1980-1989, solar); COMPTEL (CGRO, 1991-2000);
  current: INTEGRAL (>2002); RHESSI(>2002, solar)
- Highlights of present MeV astronomy / achieved sensititivity
- Experimental aspects and strategies
- Science goals for the next generation instruments
- the forseeable and visionary future ...

Cosmic Frontiers, Berlin, May 2004

Cosmic Background Radiation



Non-thermal:

Synchrotron

nuclear lines

Bremsstrahlung

π^0 - decay

Inverse Compton scatt.

Astrophysics:

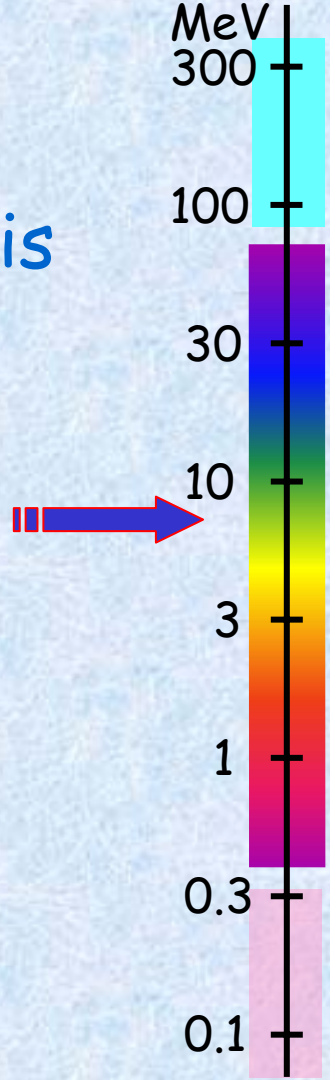
Cosmic Accelerators

Nuclear Reactions

SUSY particles

(Henry, *ApJ*, **516**, L49, 1999)

Astrophysics in the ‚MeV' region



High energy γ-ray range

Nucleosynthesis

nuclear γ-lines

nuclear energy levels

✂ 8 MeV

cosmic accelerators

non-thermal continuum
(Bremsstrahlung,
synchro-cyclotron radiation,
inverse Compton,...)

„the starting line of acceleration..."

restmass of the electron 0.511 MeV

Hard X-ray range

Overview of MeV Astronomy

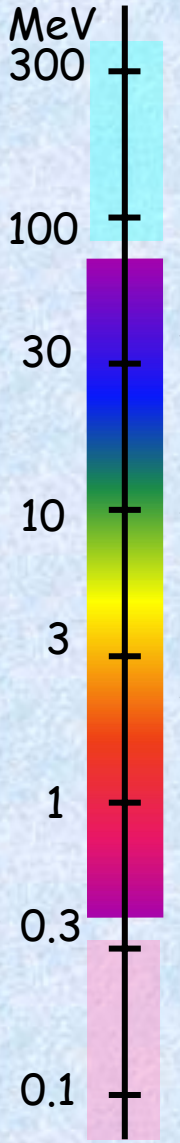
Nucleosynthesis

SN/massive stars:
nuclear reactions/isotopes

galactic radioactivity ^{26}Al; ^{60}Fe

young SNRs ^{44}Ti

511 keV: novae; solar flares
decay of DM neutralinos



cosmic accelerators

Unidentified EGRET/COMPTEL Sources

Galactic and extragalactic diffuse background

Luminosity maxima of SED in EGRET/COMPTEL Blazars

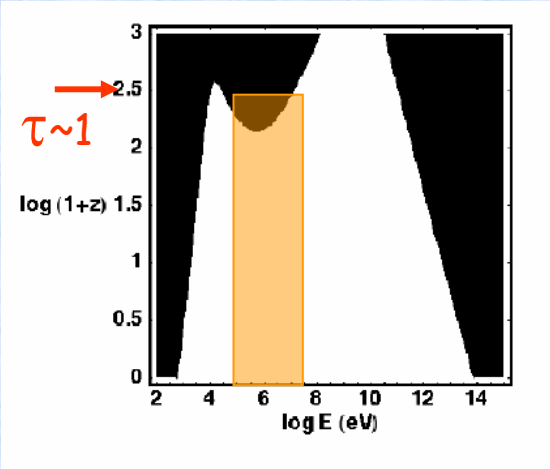
non-thermal spectra in black-hole binaries, micro-quasars

GRB spectra polarization

The dilemma of MeV astronomy

Astrophysics

The Universe is transparent to z ~ several 100



Detection

Low X-section for MeV photons; long range secondaries

Low efficiency!

MeV photons are plentiful from interactions of energetic particles with matter and fields; Natural radioactivity in nucleosynthesis abundant

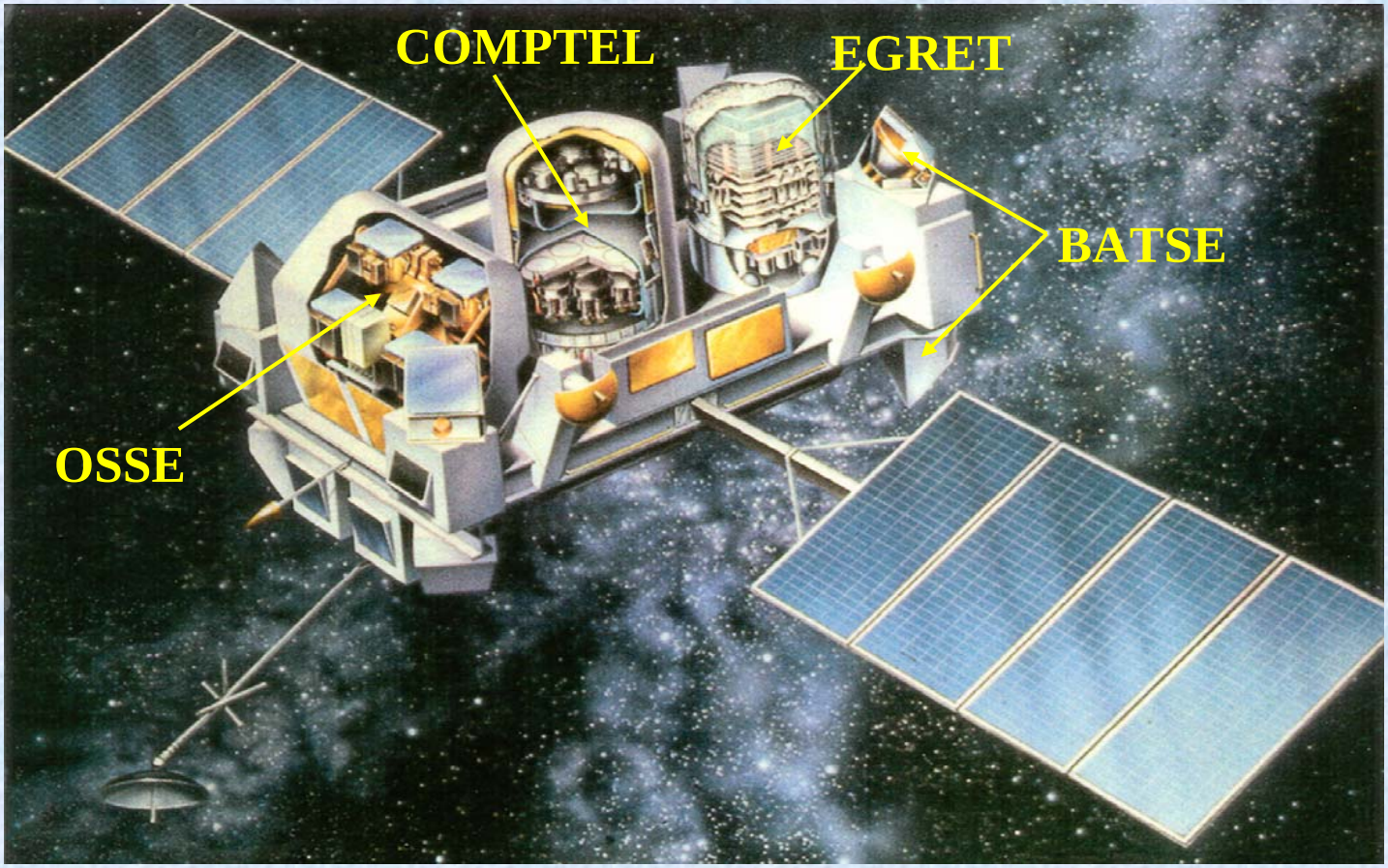
High levels of instrumental background from CR interayctions and activations

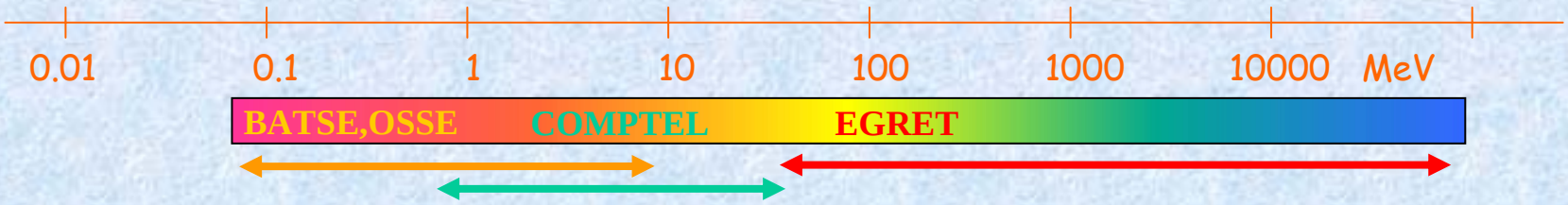
High background!

Exciting astrophysics and a multitude of compact and diffuse sources

Low sensitivity with massive telescopes

Compton Gamma-Ray Observatory (1991-2000)

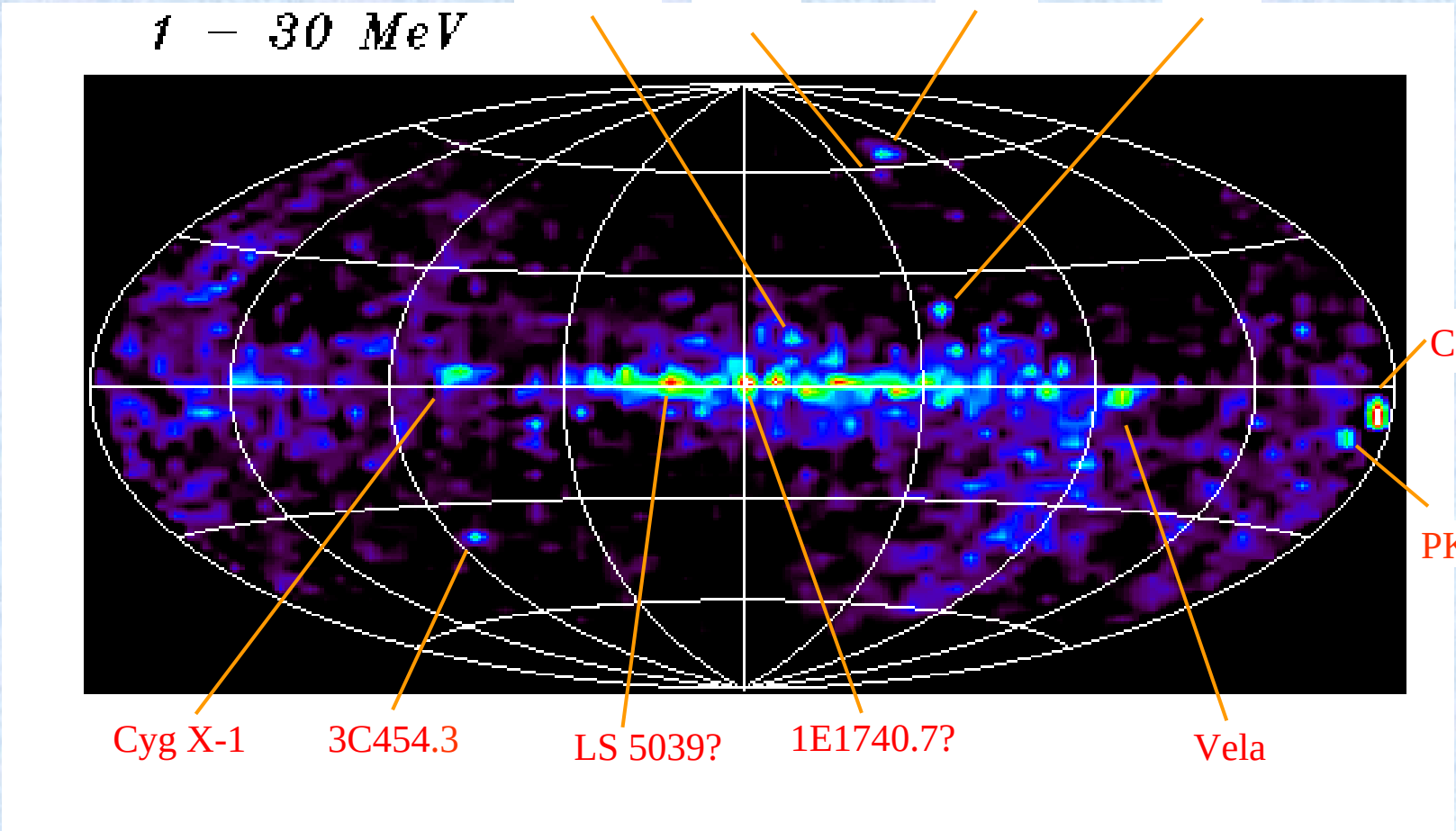




CGRO

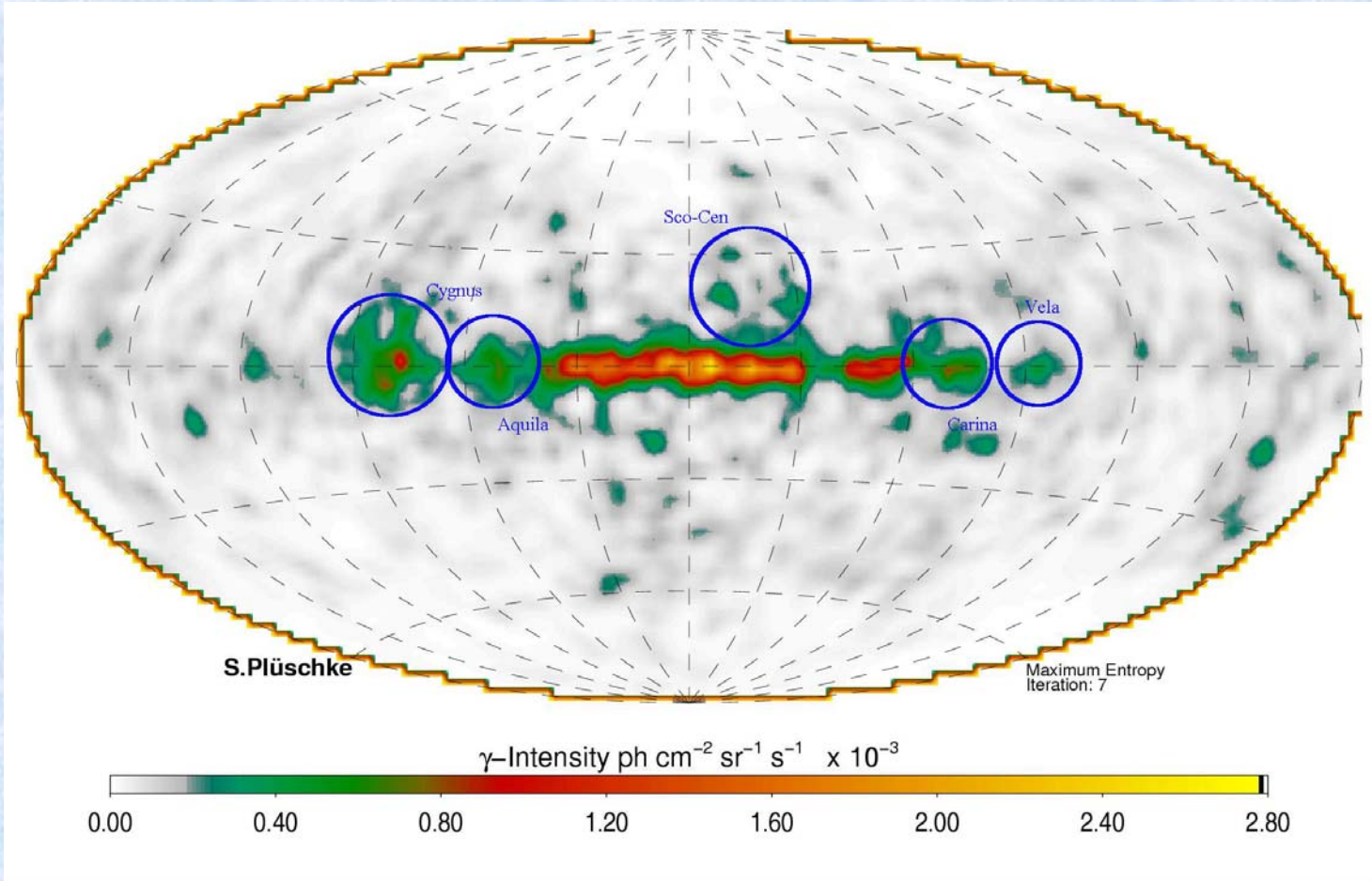
Sky Survey

COMPTEL

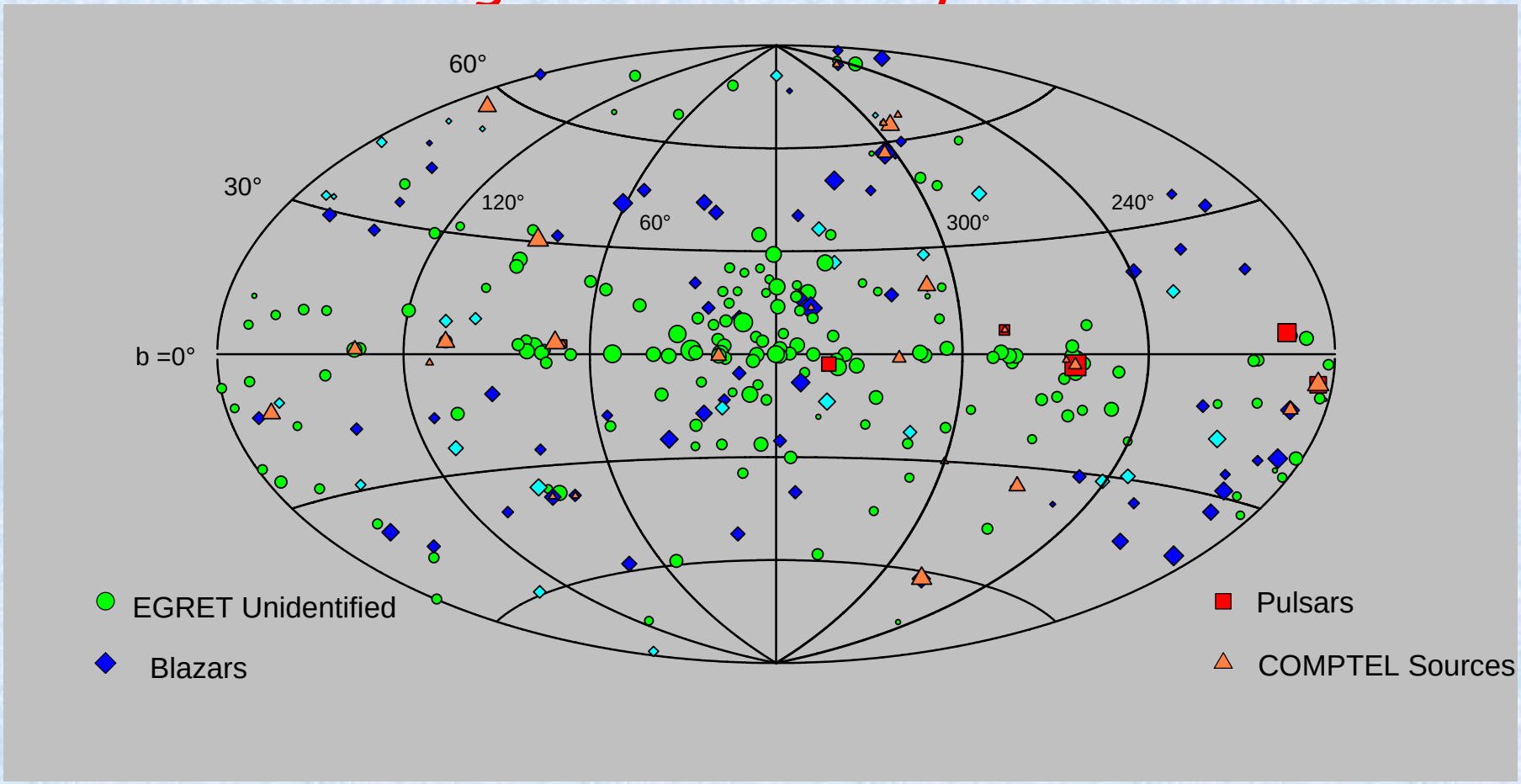


Radioactivity Sky Survey

COMPTEL ^{26}Al Map of the Galaxy (1.809 MeV)



Catalog of Gamma-Ray-Sources



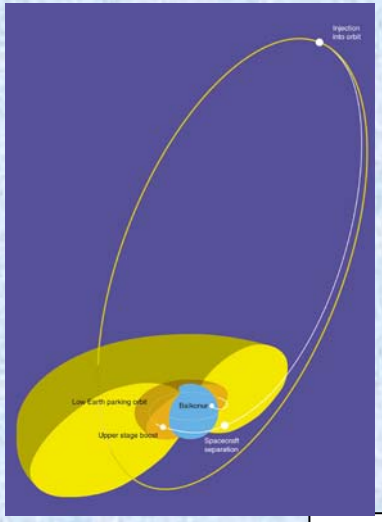
3. EGRET Catalog:
(3EG)
Hartman et al, 1999
ApJS, 123, 79

271 Sources
80-90 AGN
6-8 PSR
~170 Unid..

1. COMPTEL Catalog:
Schönfelder et al., 2000
A&AS, 143, 145

32 constant Srces.
39 transient
11 AGN
3 PSR
4 EGRET Unid.

INTEGRAL



Satellite:

4100 kg, (5x4x3) m,

16 m wingspan

2000 kg payload

Launch: 17 Oct 2002

Orbit: 72h, 9-153 Mm

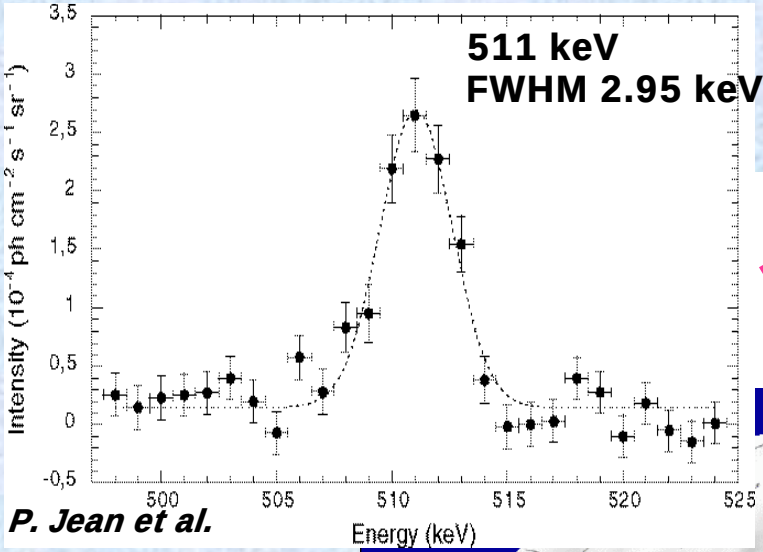
Jem-X – X-ray Monitor (3-35 keV)

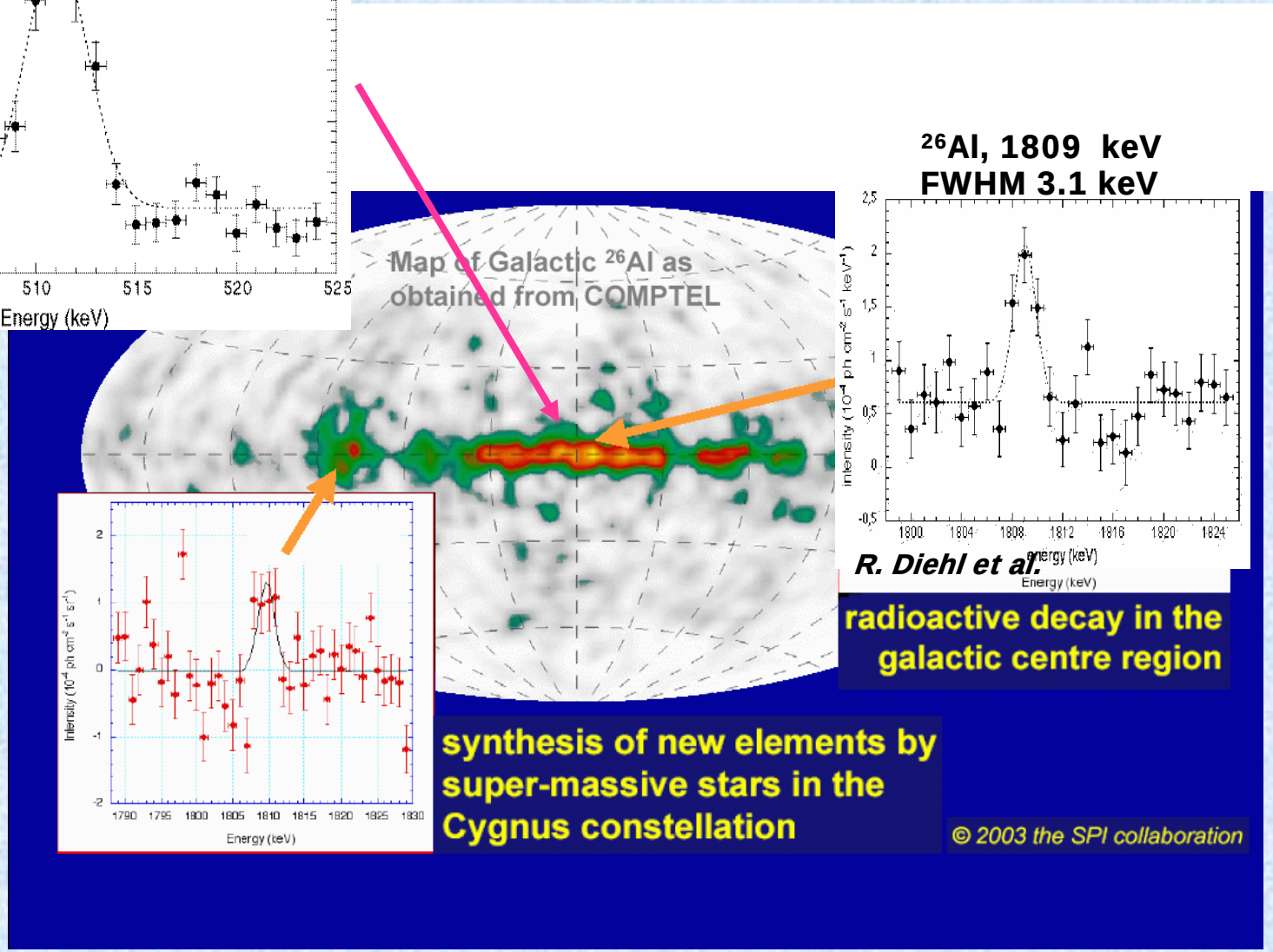
IBIS – Imager (15 keV – 10 MeV) Pointsources, Spectra

SPI –Spectrometer (20 keV – 8 MeV) High-resolution spectroscopy Imaging of sources and diffuse emission

OMC – Optical Monitor (500 nm).

Galactic γ-ray line emission





The galactic 511 keV halo

Positron injection rate ~ 10^{43} s^{-1}

possible e+ origins:

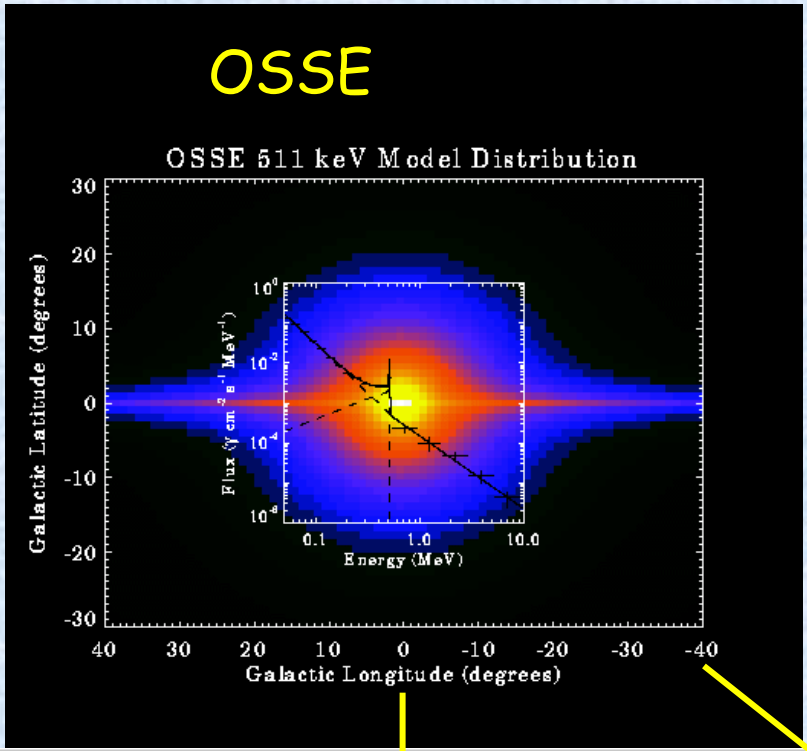
$^{56}Ni \rightarrow ^{56}Co \rightarrow ^{56}Fe + e+$

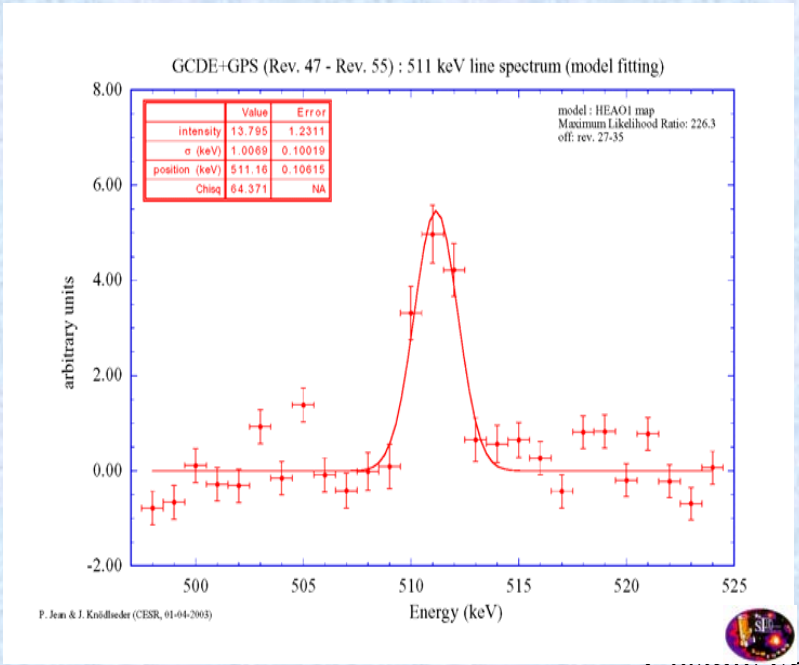
GRB/Hypernovae (Casse et al. 2003)

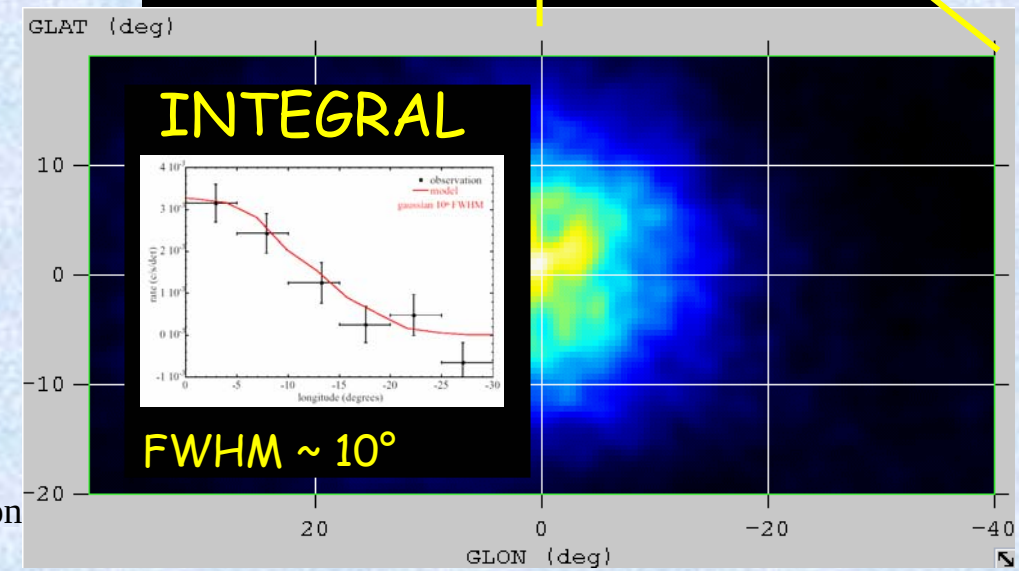
or:

$XX \rightarrow e^+e^-$; m_X ~ 4-10 MeV *(Boehm et al. 2004)*

Dark-Matter Annihilation



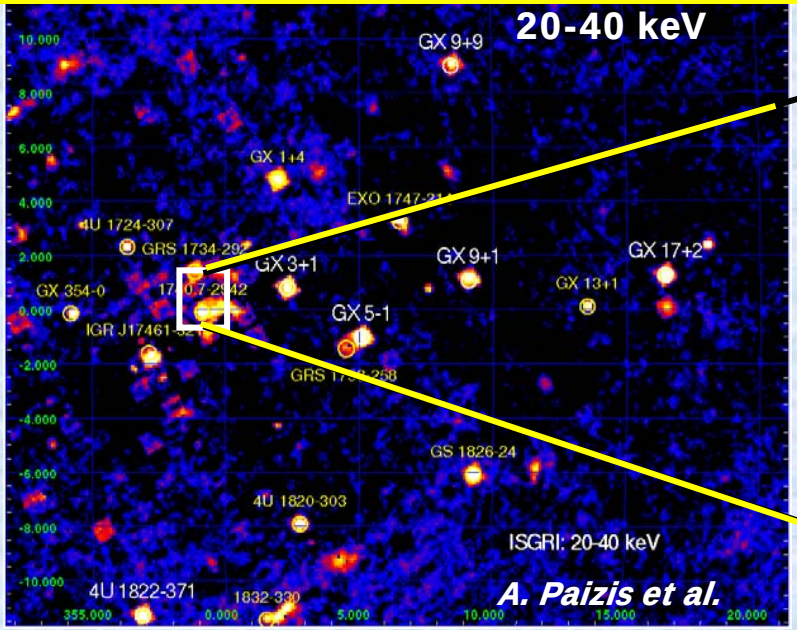




INTEGRAL – Pointsource Surveys

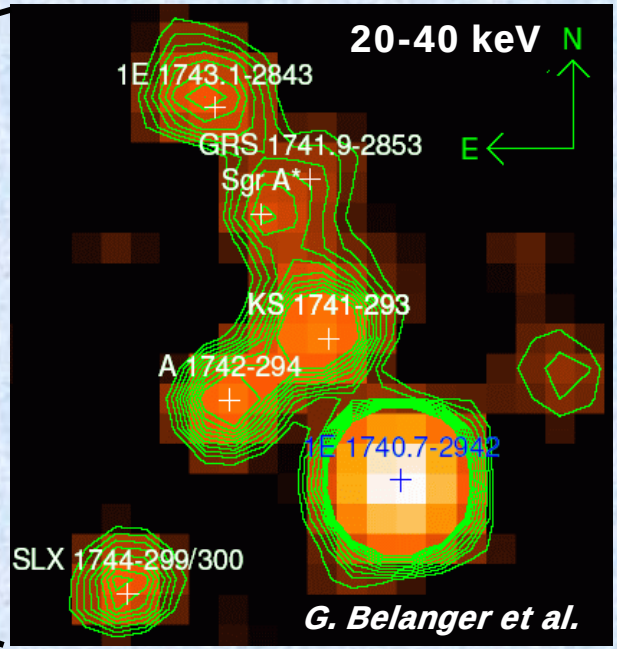
- Inner Galaxy (IBIS)
- Neutronstars, Black Holes, Binary Systems
- Discovery and Identification of new sources

- Galactic Centre
- Hard X-rays from the vicinity of SgrA* (0.9')
- 2004: INTEGRAL + XMM

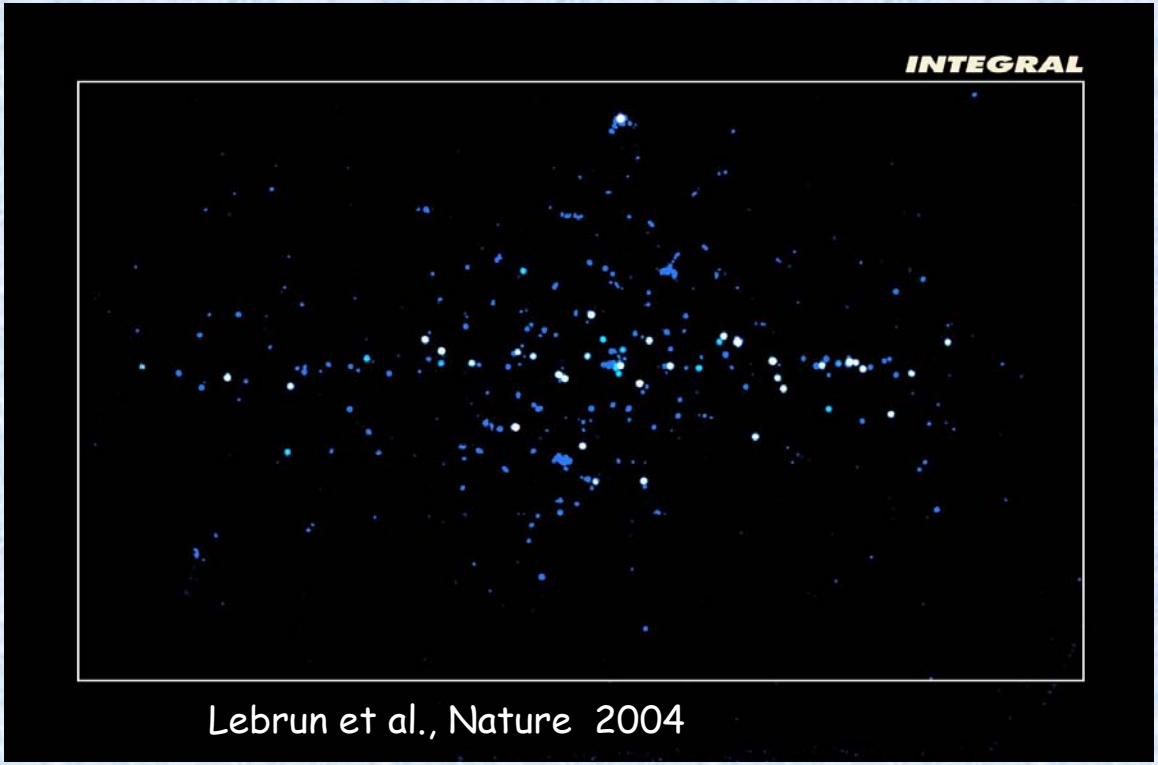


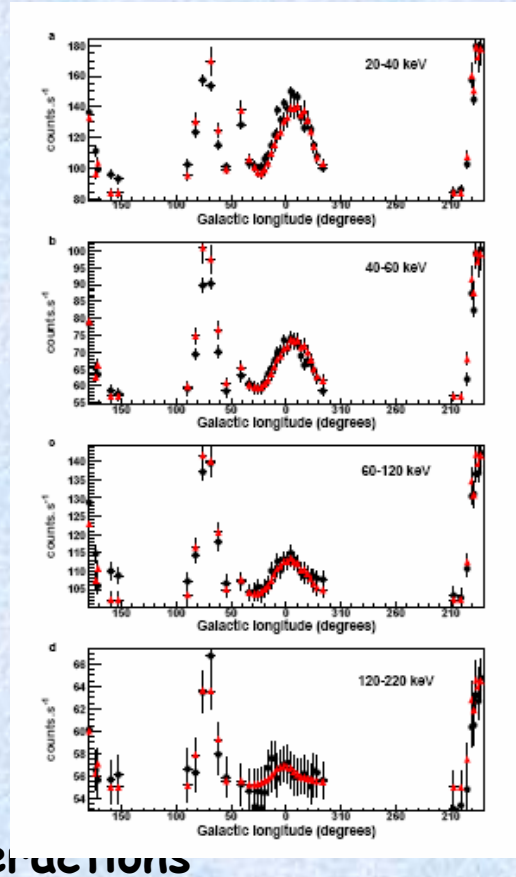
20°

2°



Point Sources (20-200 keV) in the inner Galaxy





Ansatz: Sources and diffuse cosmic ray/ISM interactions

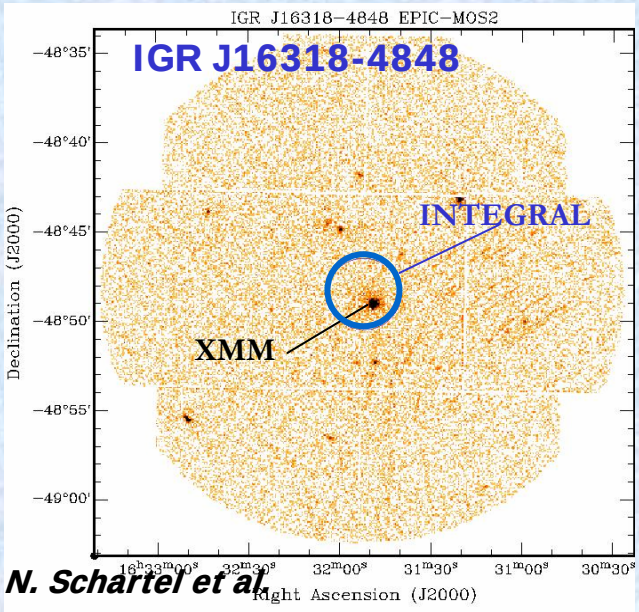
Question: relative contributions?

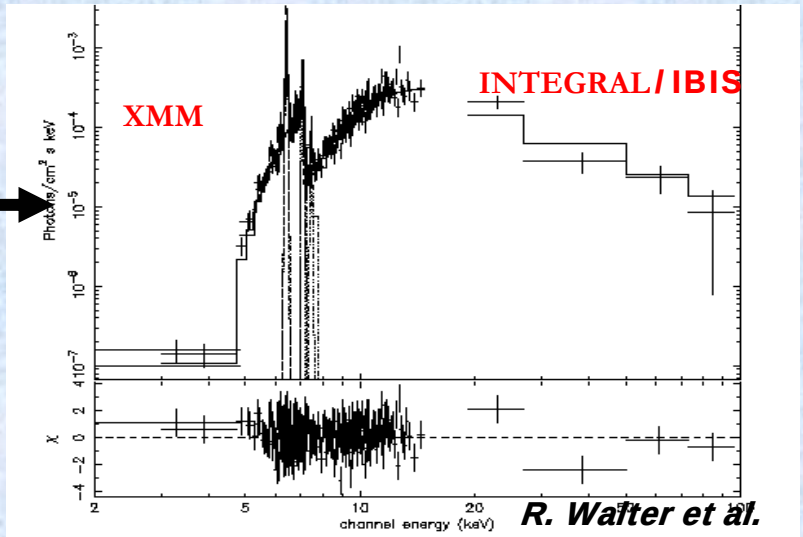
Result: ~ 90% explained by sum of discrete point sources

~ 10% still 'diffuse' ... but what is it really?

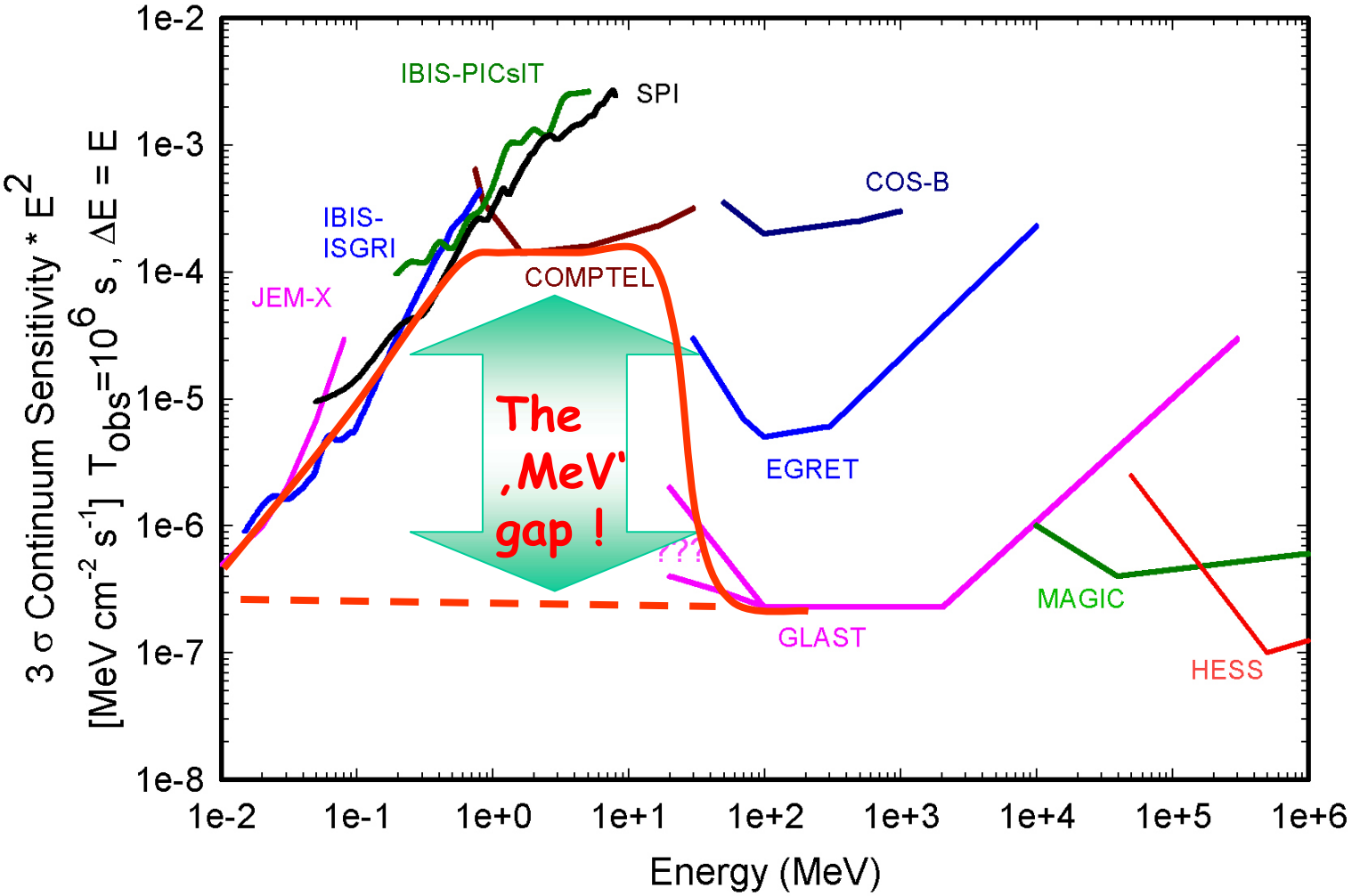
New INTEGRAL Pointsources

- INTEGRAL has discovered many new pointsources (>15)
- "Follow-up" observations with XMM
- some sources exhibit previously unknown spectra → massively "shrouded" binary systems with NS or BH ?

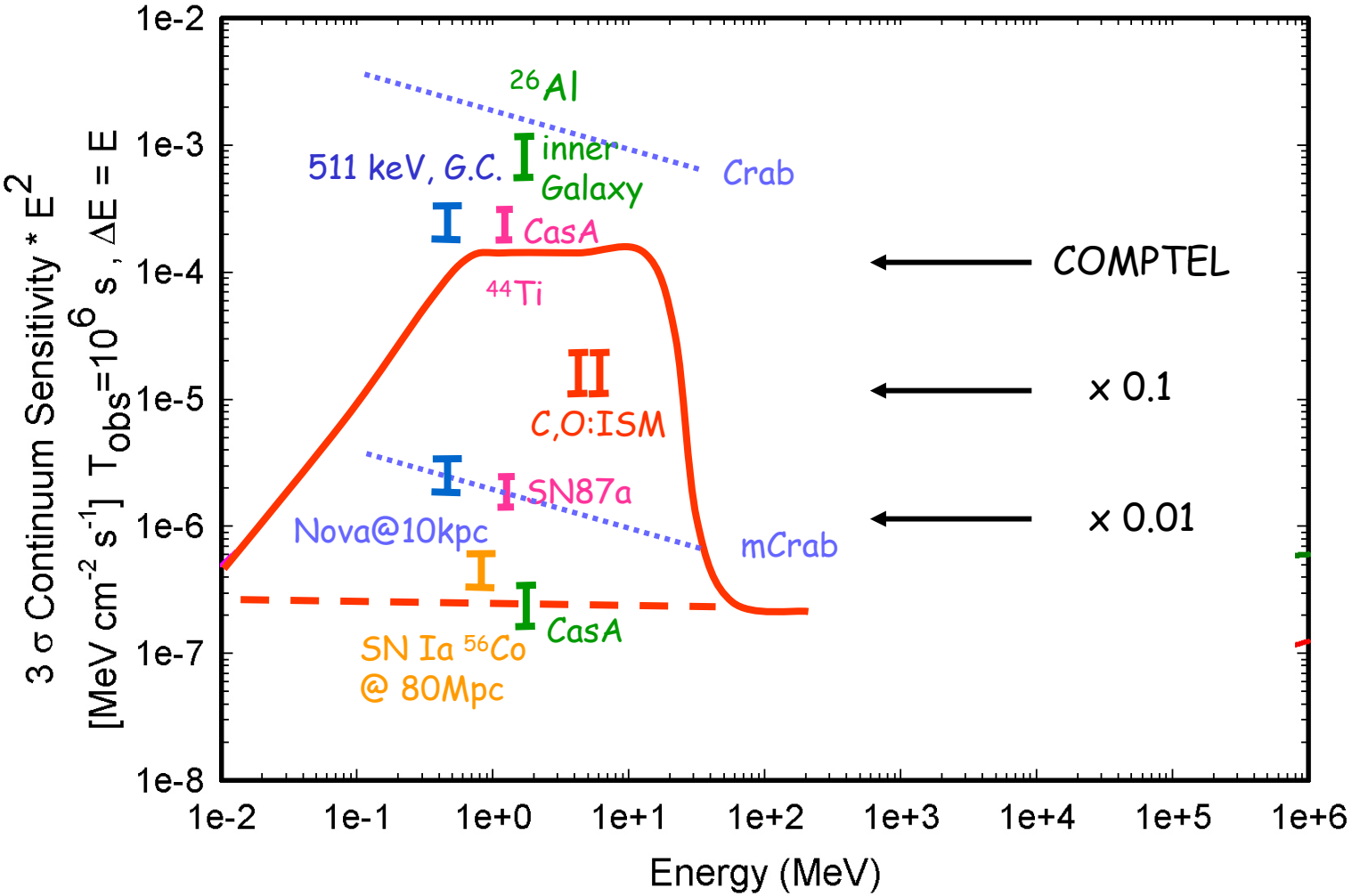




Sensitivity of current missions



Potential Sources in the MeV gap



Summary: Major Science Topics for γ-ray astronomy at ~MeV energies

Cosmic Accelerators

Physics and Energetics of the most dynamic and powerful sites in the Universe

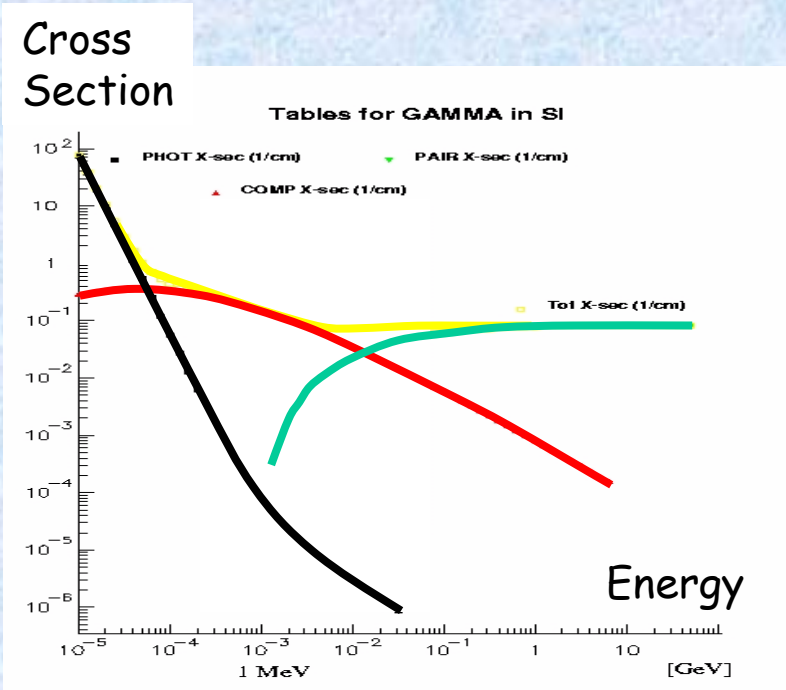
Nucleosynthesis

Production and Dispersion of radioactive Isotopes in the Galaxy
Massive stars, Novae, Supernovae physics

Cosmic Rays/Interstellar Medium in the Galaxy and beyond

Cosmic Background and primordial relic particle decays

Detection of Gamma Radiation



Photoeffect(< 100 keV)

Photons effectively blocked and stopped

Telescopes:

Collimators
Coded Mask Systems

Pair Creation (> 10 MeV)
Photons completely converted to e^+e^-

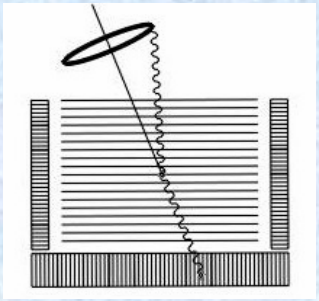
Telescope:
Tracking chambers to visualize the pairs

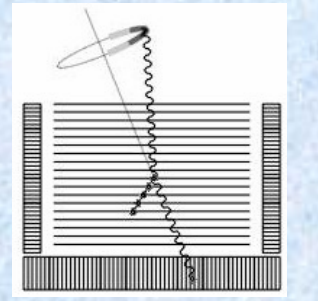
Compton Scattering (0.2-10 MeV)
Photon Crossection Minimum
Scattered photons with long range
Telescope:
Compton Camera Coincidence System

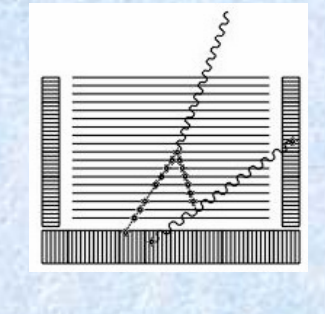
Telescope Schematics

Detectors using Compton Scaattering and Pair Creation

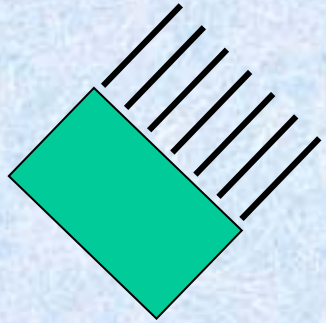
Classical Compton Event Circles (no electron tracking)	Compton arcs for events with electron track or 3rd interaction	Direct imaging of pair-creation events



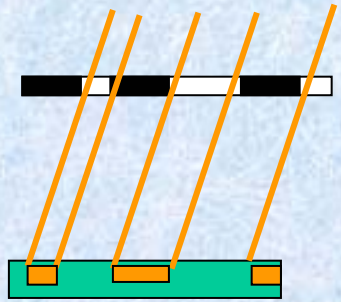




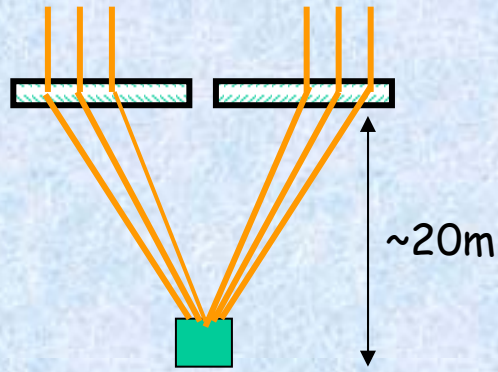
Collimated Detectors



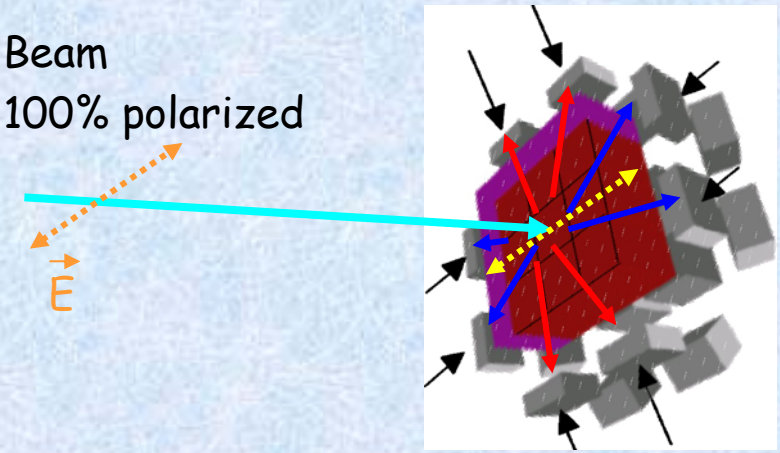
Coded Mask Systems



Laue Lens Telescope

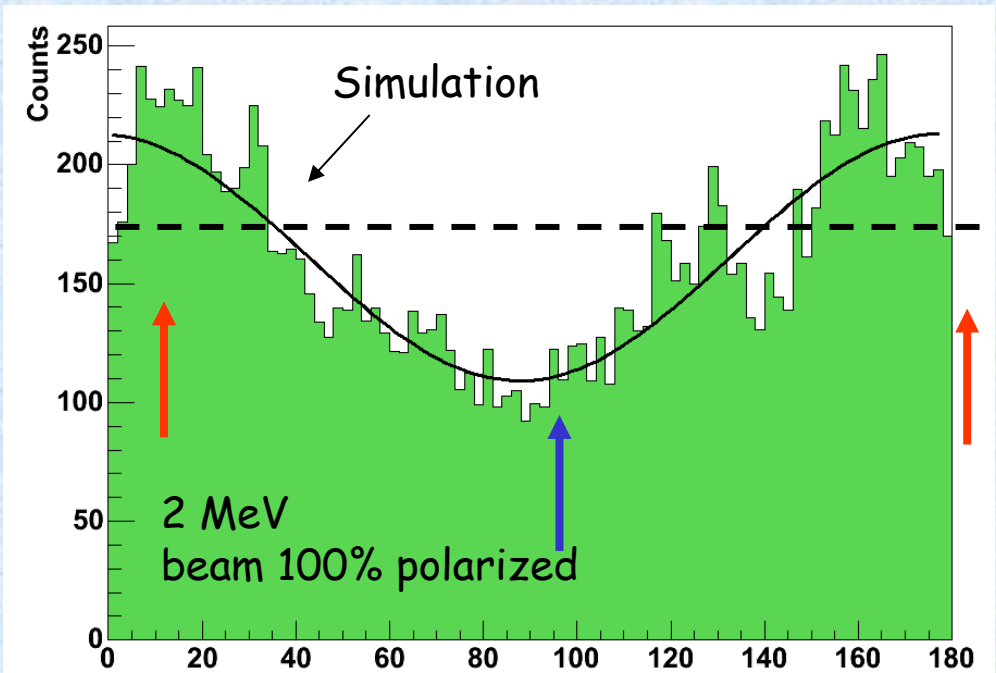


Polarization: Measurement & Simulation



$$\frac{\partial\sigma}{\partial\Omega} = \frac{r_e^2}{2}\left(\frac{E_g}{E_i}\right)^2\left(\frac{E_g}{E_i} + \frac{E_i}{E_g} - 2\sin^2\varphi\cos^2\chi\right)$$

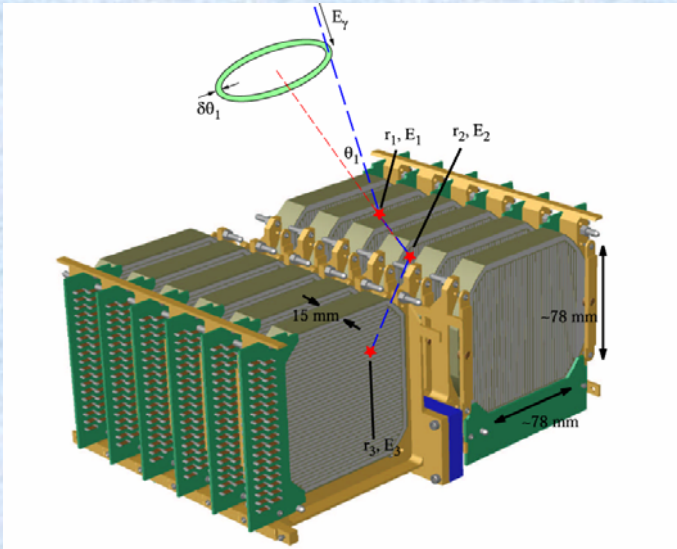
Azimuthal distribution: a*cos(2(χ+χ$_0$))+c



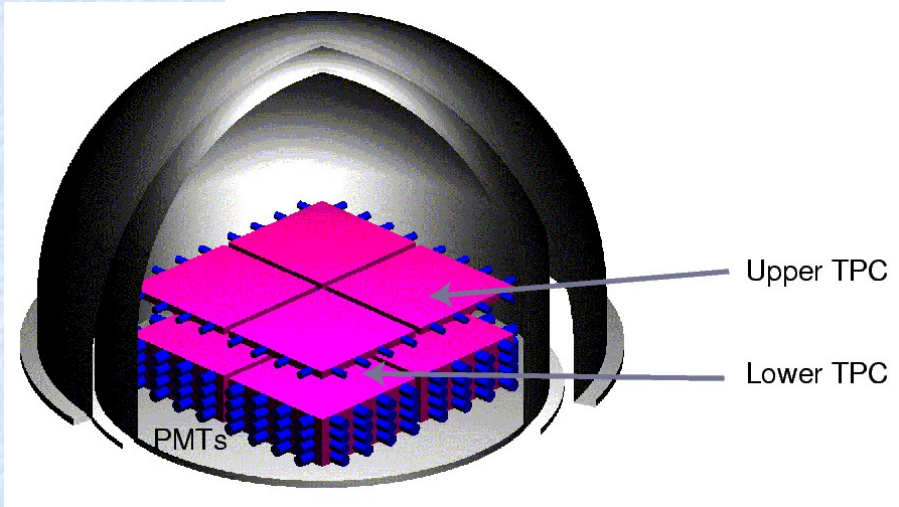
MeV Instrument Concepts (1)

<u>High spectral resolution:</u>
$\Delta E/E \sim 1\%$
E: 0.2-2MeV

- Compton telescope with position sensitive Ge detectors (Boggs et al, UCB)

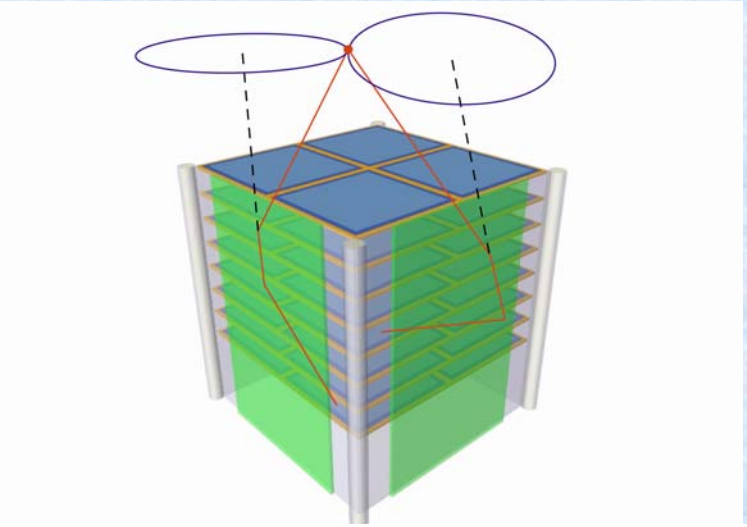


- Liquid Xe detector: time projection chamber to resolve interactions (Aprile et al., Columbia U.)

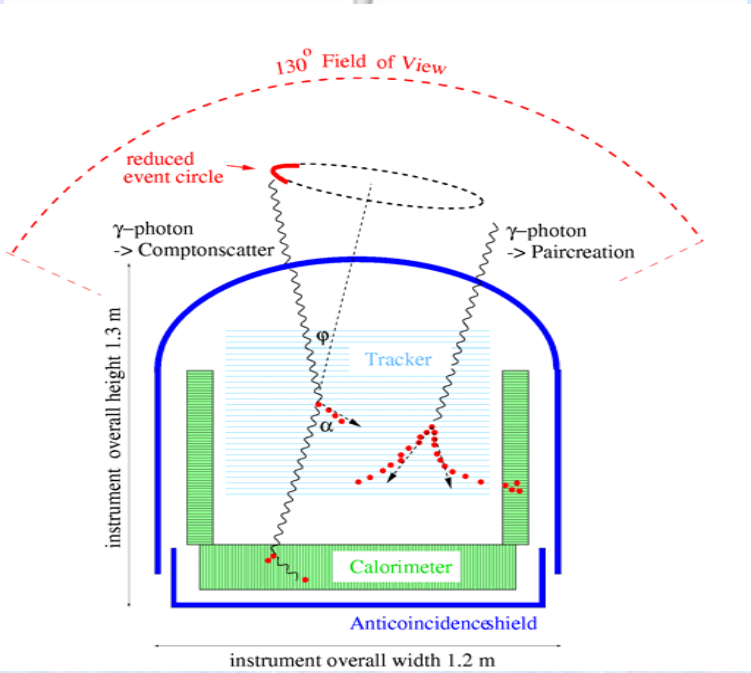


MeV Instrument Concepts (2)

- thick Si(Li) doublesided strip detectors -> record multiple Compton scatterings (Kurfess et al., NRL)

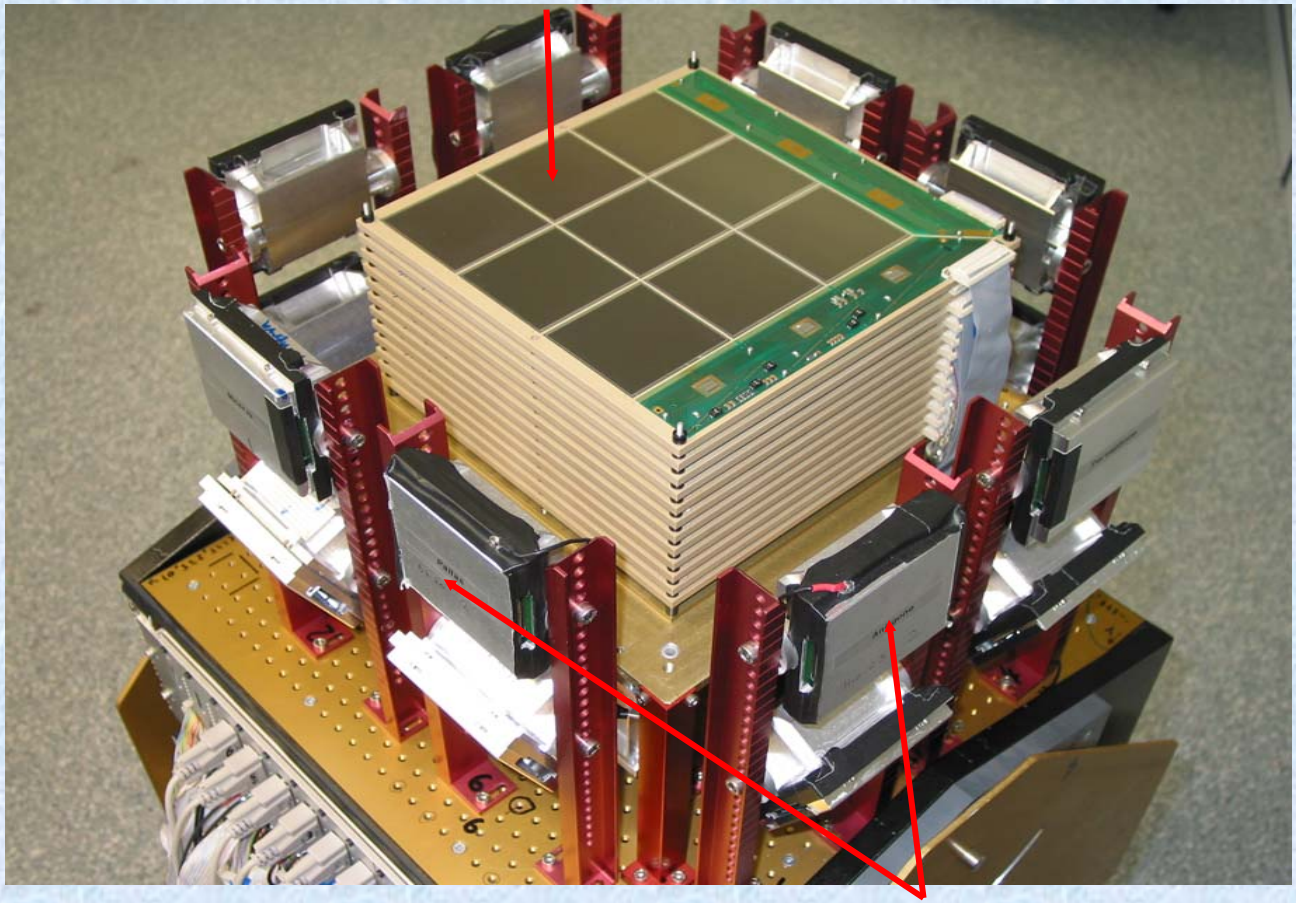


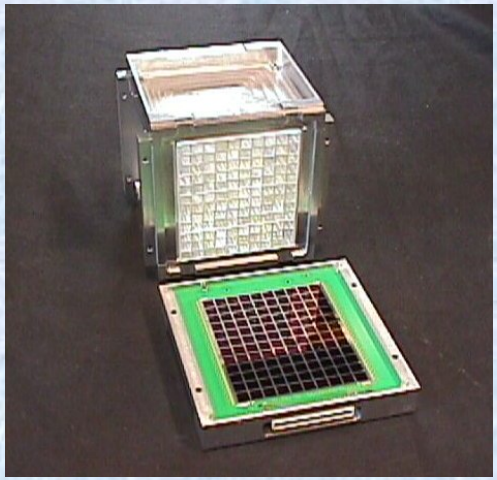
- Electron tracking – Calorimeter detectors (MEGA, TIGRE) MPE, Garching; UCR: Energy range from 0.4 to 50 MeV Background suppression by tracking



MEGA Prototype

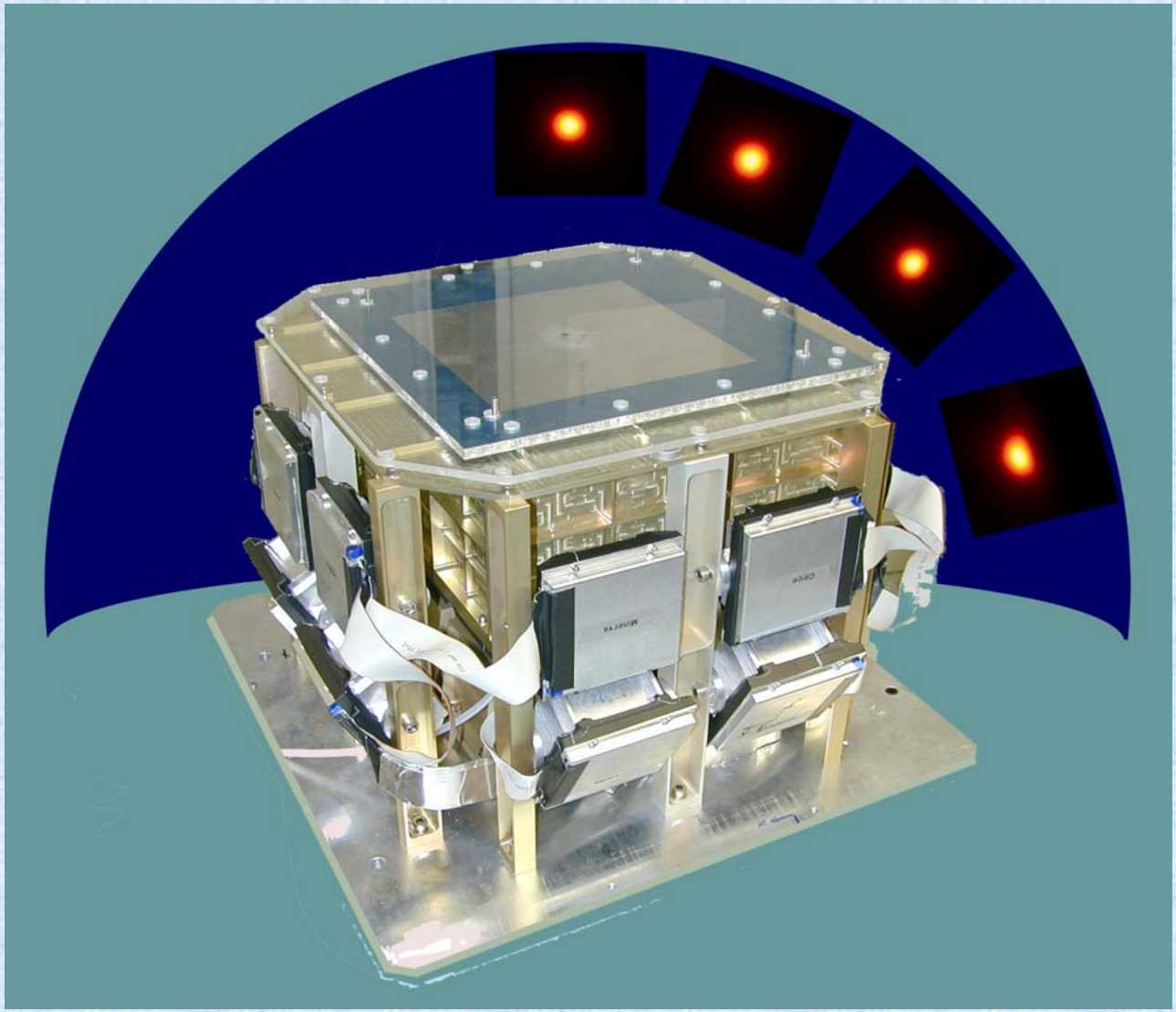
Tracker:
10 (+1) layers of Silicon stripdetectors (wafers 6x6cm^2)





Calorimeter: 20 modules of pixellated CsI(Tl) Scintillators
Fill factor lower hemisphere ~ 40%

MEGA Prototype & 50 MeV calibration beams



Visions for MeV telescopes for the 21st Century

INTEGRAL will operate at least to the end of 2008
SWIFT: coded mask GRB telescope with wide f.o.v.; E<150 keV
launch planned for September 2004
GLAST: Pair creation telescope; E>20 MeV; Sensitivity ~ 30 x EGRET
launch planned for 2007

Presently no missions are planned to follow up on INTEGRAL or CGRO-COMPTEL!

NASA studies an `Advanced Compton Telescope´ (**ACT**) as a "Vision Mission" circa 2013-2025: focussed on nuclear line studies of SNe type Ia (0.2 – 3 MeV; $E/\Delta E \sim 100$)

The wider MeV range from several 100 keV to about 100 MeV presents a unique `window of opportunity´ for fundamental astrophysics !
A new, highly sensitive telescope based on innovative but realistic technology is feasible and could now be developed for space application!

... a little explored wavelength range

+ new detector technology
+ improved background suppression

Guarantee for many unexpected discoveries!

(cit. Ron Ekers, this meeting)