# AstroMeV

# Towards a sensitive survey of the γ-ray sky between 100 keV and 100 MeV

- **What is AstroMeV?**

  An initiative started in France in the context of the CNES prospective (2012 - 2014), with two workshops held in APC (Paris)

  Scientific perspectives in the MeV domain (January 15 - 16, 2013)

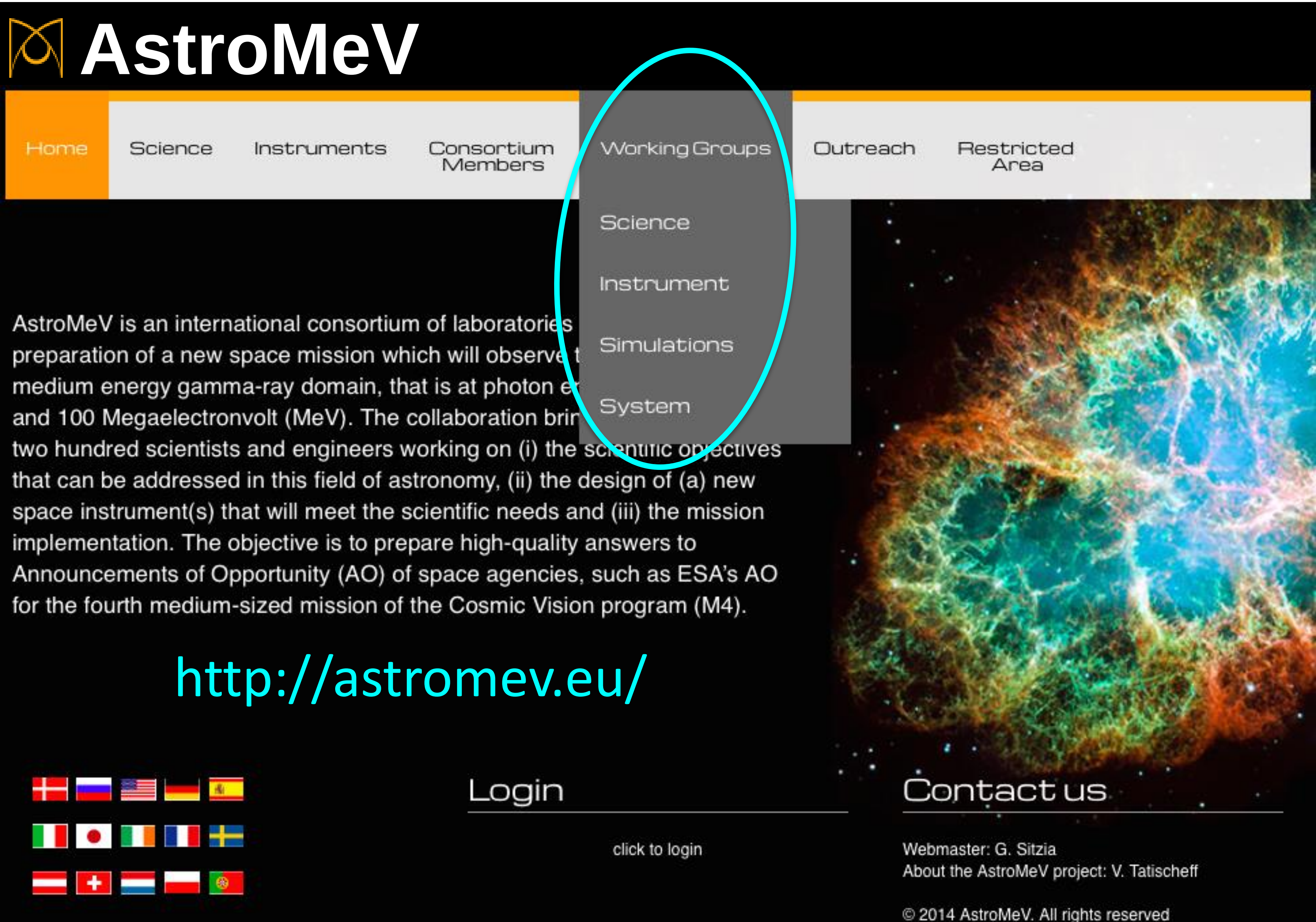
  Instrumental concepts in the MeV domain (November 6 - 8, 2013)

- **What is it for?**

  **-** Coordinate global efforts for the preparation of a new space mission in the medium energy γ-ray domain

  - Immediate objective is to prepare a high-quality answer to ESA's M4 Call

- Already nearly **200 scientists from 18 countries** have signed up to be part of the AstroMeV consortium (Co-PIs: P. von Ballmoos and V. Tatischeff)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AstroMeV is an international consortium of laboratories
preparation of a new space mission which will observe t
medium energy gamma-ray domain, that is at photon e
and 100 Megaelectronvolt (MeV). The collaboration brin
two hundred scientists and engineers working on (i) the scientific objectives
that can be addressed in this field of astronomy, (ii) the design of (a) new
space instrument(s) that will meet the scientific needs and (iii) the mission
implementation. The objective is to prepare high-quality answers to
Announcements of Opportunity (AO) of space agencies, such as ESA's AO
for the fourth medium-sized mission of the Cosmic Vision program (M4).
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# AstroMeV Scientific objectives

**Theme 1**: Radioactivity and antimatter

Radioactive emission from type Ia supernovae
Core-collapse supernovae and radioactivity
44-Ti line emission from young supernova remnants
Gamma-ray lines from long-lived radioactive isotopes
Radioactive emission from classical novae
511 keV emission from positron annihilation

Results of the workshop “Scientific perspectives in the MeV domain” (APC, Paris, 15 - 16 January 2013)
$\Rightarrow$ **an inventory “à la Prévert”**
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**Theme 2**: Cosmic-ray physics

MeV astronomy of the high-energy interstellar medium
Nuclear gamma-ray lines from low-energy cosmic rays
Gamma-ray emission from particle acceleration in supernova remnants and superbubbles
Continuum emission from particle acceleration in novae
Cosmic rays in star-forming galaxies
The Galactic center in the MeV range

**Theme 4**: Fundamental physics and cosmology

Dark matter annihilation and decay
Explore the limits of modern physics

**Theme 3**: Black holes, neutron stars and pulsar wind nebulae

Active galactic nuclei in the MeV domain
Gamma-ray binaries
Gamma-ray line emission from X-ray binaries
MeV emission of black hole binaries
Gamma-ray emission from magnetars and rotation-powered pulsars
Pulsar wind nebulae in the MeV domain
Gamma-ray bursts

**Theme 5**: Sun and Earth science

The sun in the MeV domain
Terrestrial gamma-ray flashes

# AstroMeV Possible main science drivers

❖ Some science drivers can provide key contributions to ESA's Cosmic Vision

- **Explosive nucleosynthesis -** MeV gamma-ray astronomy gives a unique vision of core-collapse and thermonuclear supernovae, see SN 2014J

  *<u>Cosmic Vision §4.3</u>: "Understand in detail the history of supernovae in our Galaxy and in the Local Group of galaxies"*

- **Active Galactic nuclei -** Study the formation and evolution of AGNs, as well as the origin of the extragalactic gamma-ray background

  *<u>Cosmic Vision §4.3</u>: "Trace the formation and evolution of the supermassive black holes at galactic centres – in relation to galaxy and star formation – and trace the life cycles of chemical elements through cosmic history "*

- **511 keV emission from the GC region -** Still a mystery!

  *<u>Cosmic Vision §5.4.3</u>: "Sources of explosive nucleosynthesis and electron-positron annihilation are also of major interest"*

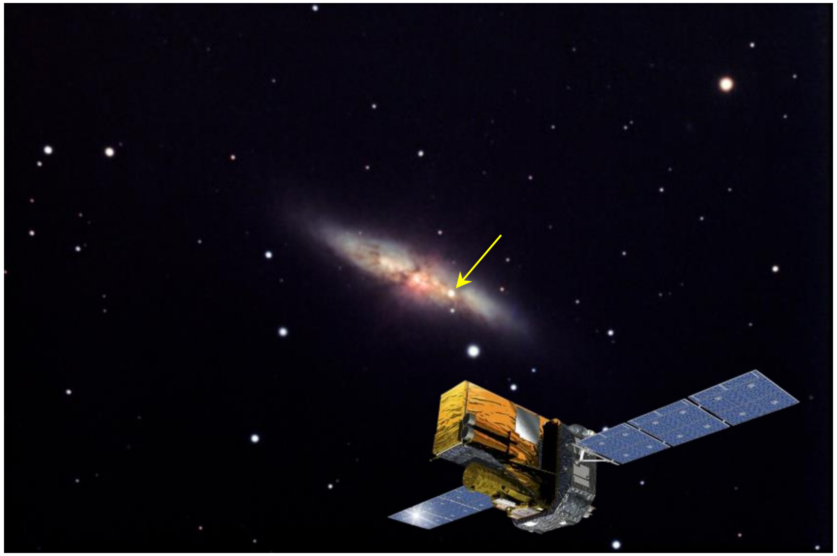
- **Gamma-ray bursts -** Of course! But SVOM ($\sim 2021 \rightarrow 2026+$)

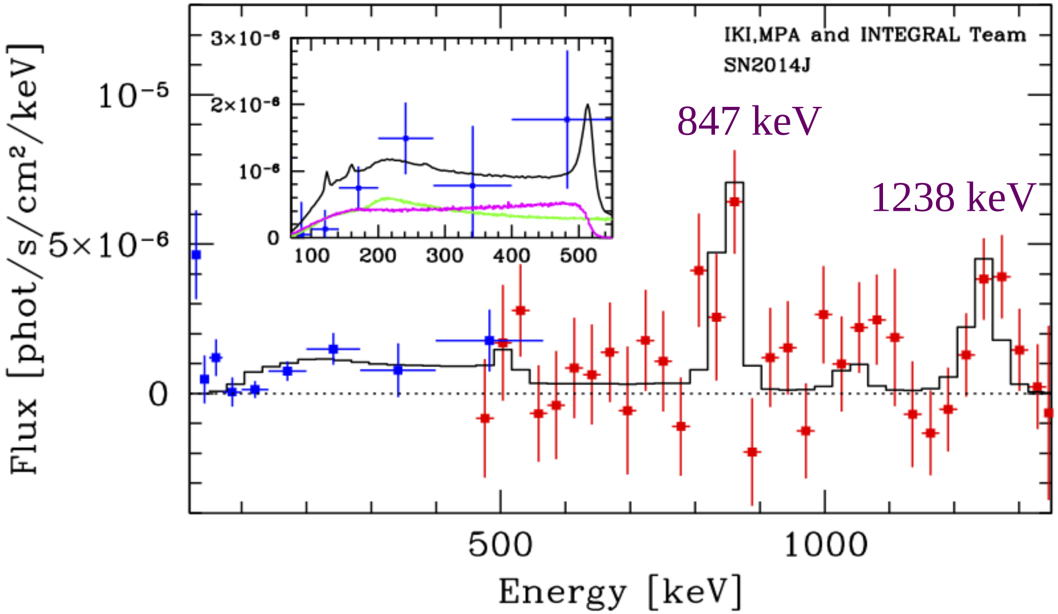
- **Dark matter …?**

# AstroMeV SN 2014J

- Type Ia supernova exploded on 2014 Jan 14 in the starburst galaxy M82 at $D \approx 3.5$ Mpc $\Rightarrow$ nearest SN Ia in more than 40 years
- Detection with INTEGRAL of gamma-ray lines from $^{56}$Co decay ($T_{1/2}$=77 d) $\Rightarrow$ synthesis of $0.6 \pm 0.1\ M_{\odot}$ of $^{56}$Ni (Churazov et al. 2014, *Nature, 28 Aug*) and from $^{56}$Ni decay ($T_{1/2}$=6,1 d) ~20 d after explosion (Diehl et al. 2014, *Science, 5 Sep*); $^{56}$Ni lines are broad and redshifted (!) (Isern et al., in prep.)

$\Rightarrow$ INTEGRAL and NuSTAR observations can not be explained by current SN Ia explosion models (Burrows et al., in prep.)





# AstroMeV Type Ia supernovae

**SN 2014J**

D = 3.5 Mpc

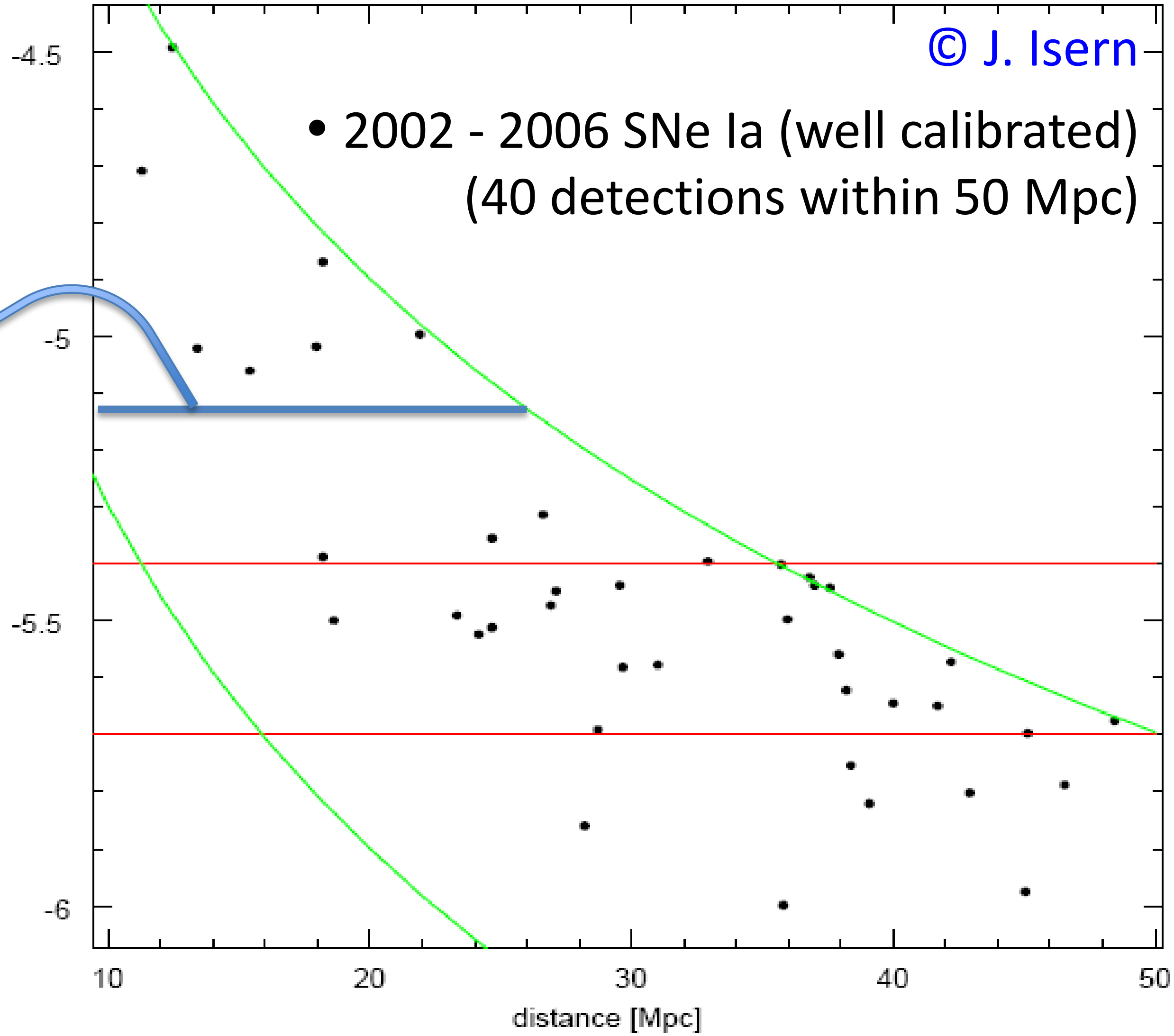
$F_{847} \sim 2.3\times10^{-4}$ cm$^{-2}$ s$^{-1}$

($\Rightarrow$ Log Flux = -3.6)

(Churazov et al. 2014)

With a sensitivity ~30 times better than SPI
$\Rightarrow$ **~ 7 SNe Ia in 5 yr**
$\Rightarrow$ Is SN 2014J the rule or the exception?

**Predicted flux in the 847 keV line vs distance**



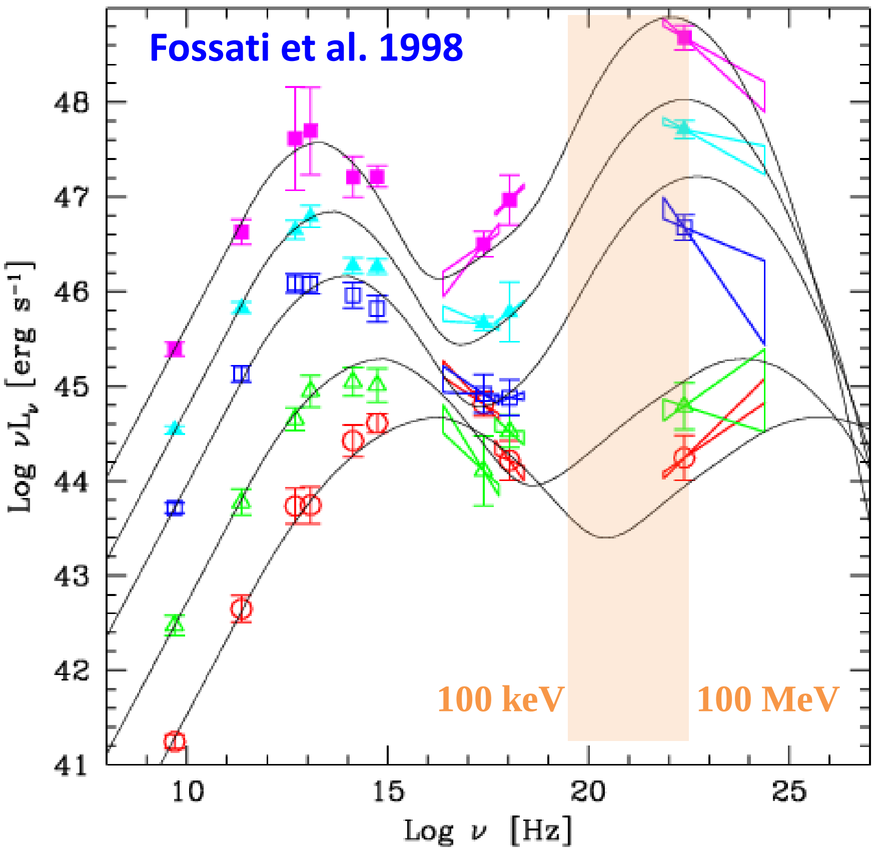
# AstroMeV Active galactic nuclei

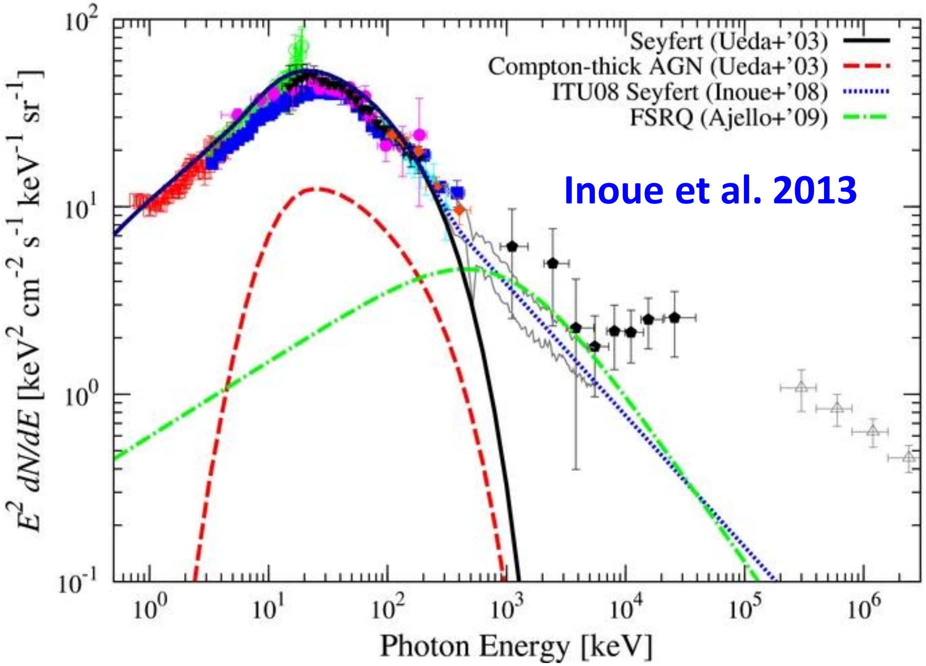
- The SEDs of many blazars (FSRQs) and non-blazar AGNs detected in $\gamma$-rays peak in the "MeV range"

⇒ **Total energy output ⇒ feedback**

- Obs. below 100 MeV are useful to distinguish leptonic and hadronic models

⇒ **Origin of UHECRs and HE neutrinos**



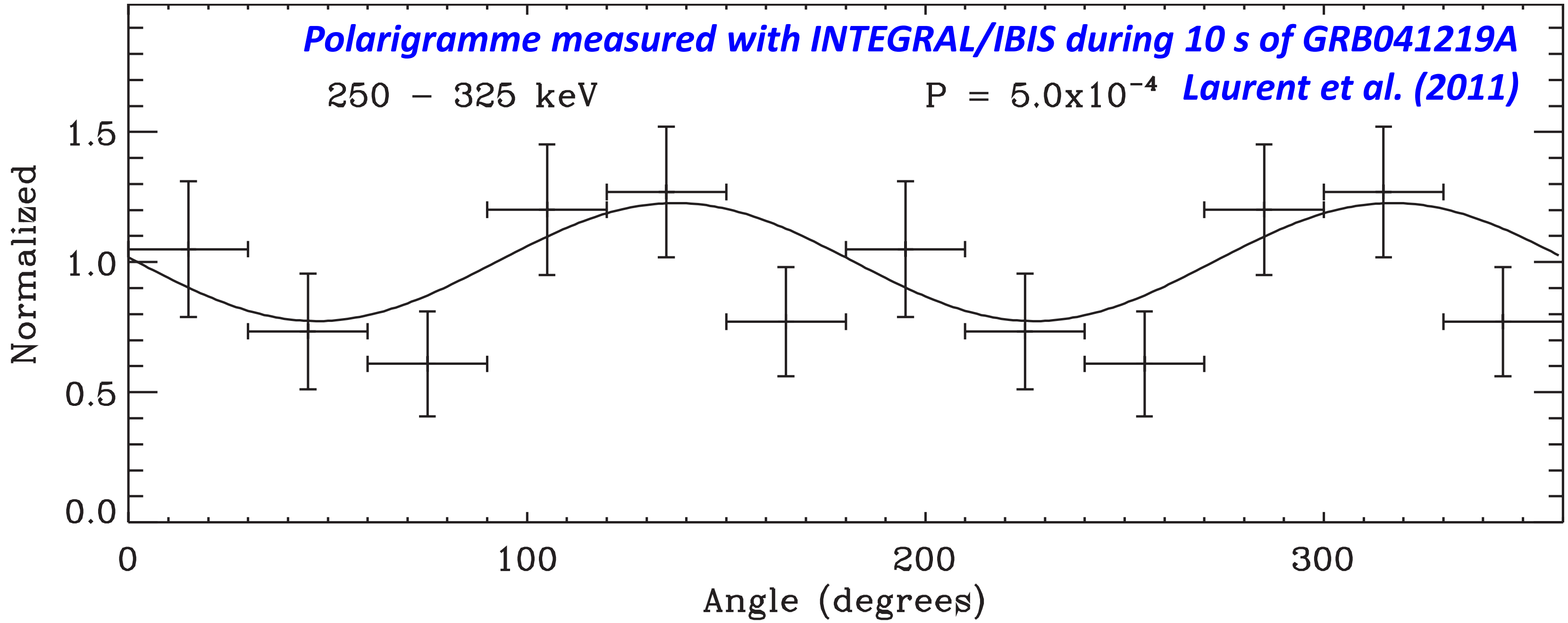

- AstroMeV will detect more than 1000 AGNs (mostly FSRQs)

⇒ **Evolution ("Blazar sequence")**

⇒ **MeV gamma-ray background**

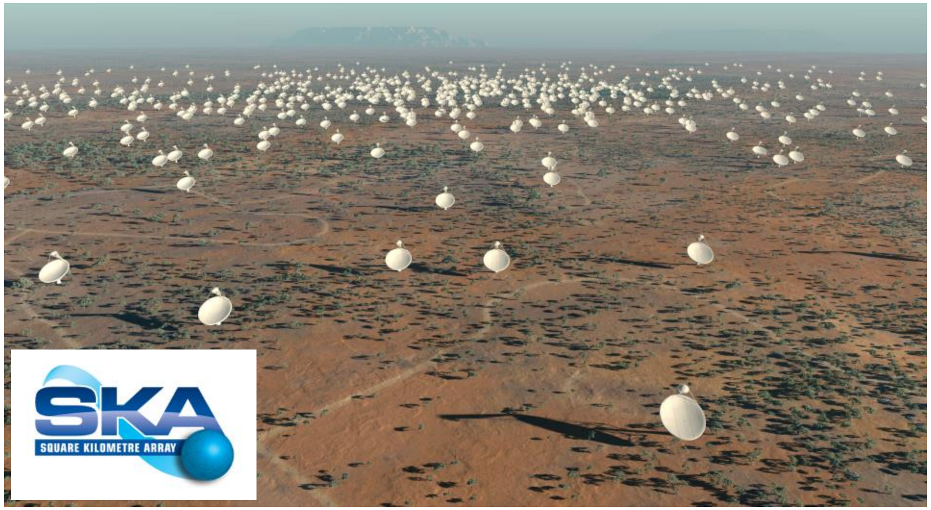
# AstroMeV Gamma-ray polarization

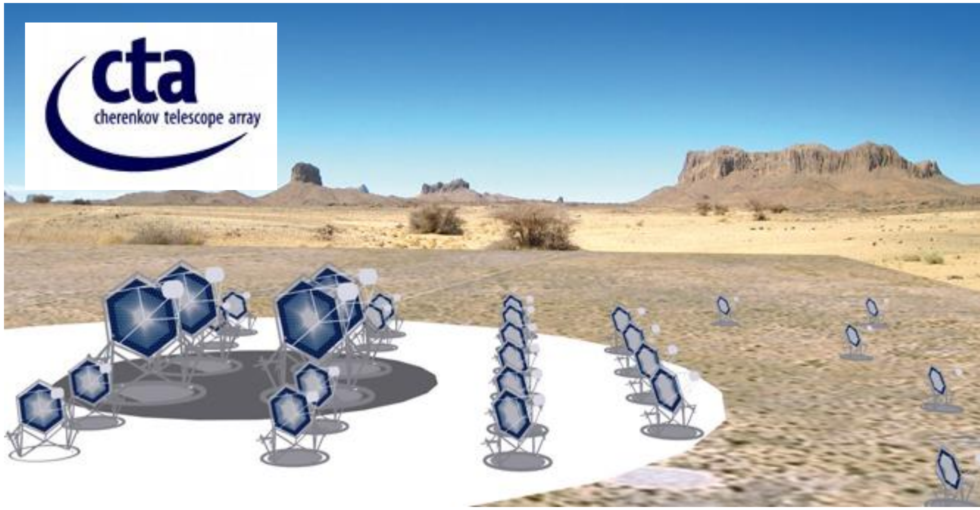
- γ-ray polarization in **objects emitting jets** (Blazars, GRBs, X-ray binaries) or with **strong magnetic field** (pulsars, magnetars) poses strong constraints on the magnetic field structure and the nature of the γ-ray emission process
- **10 – 100 MeV γ-ray polarization** will be a key observation to prove (or disprove) that hadrons are accelerated in blazar jets (Zhang & Böttcher 2013)
- Polarization from **cosmological sources** (Blazars, GRBs) can provide strong constraints on a form of Lorentz Invariance Violation (vacuum birefringence)



# AstroMeV    Time domain astronomy

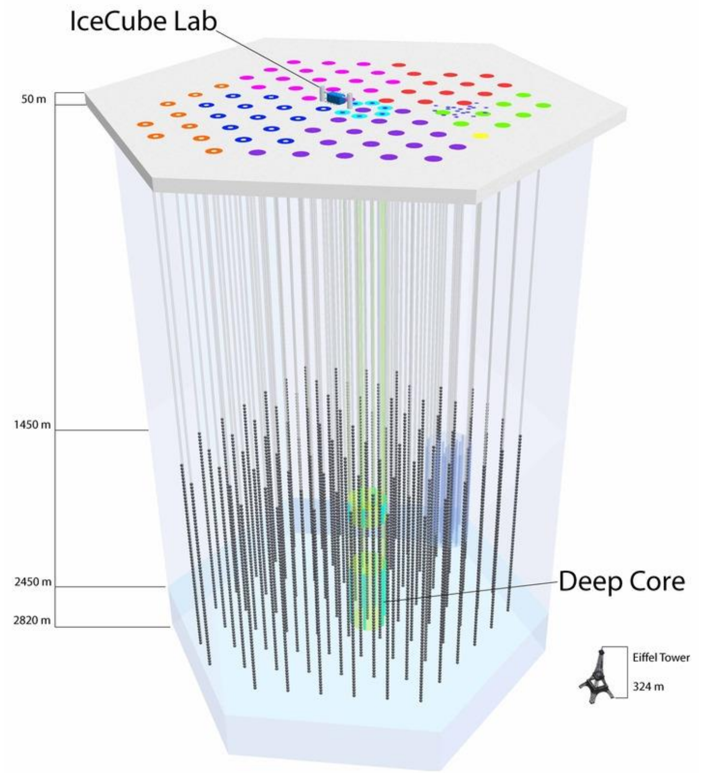
- Uniform coverage of the sky (as Fermi and Swift do) provides access to phenomena evolving on time scales ranging from milliseconds to years
- The **transient sky** will be an important topic of study in the coming decades with the development of observatories like LSST and SKA
- A wide-field γ-ray observatory operating at the same time would give a more coherent picture of the transient sky
- CTA science related to variable sources will need a coverage of the γ-ray sky at lower energies to trigger Target-of-Opportunity observations

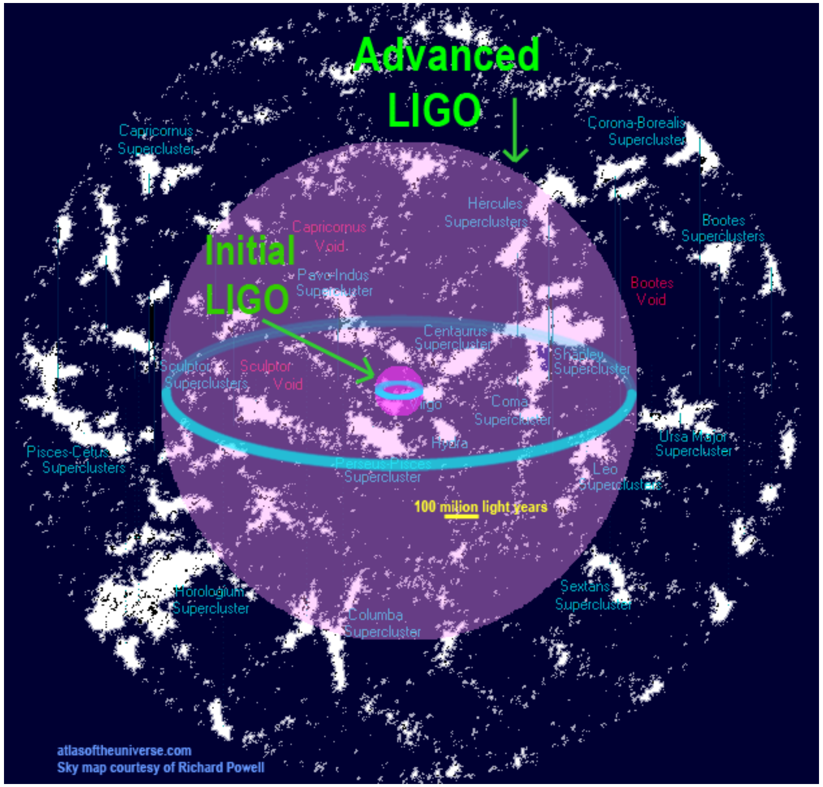


# AstroMeV Astronomy of new messengers

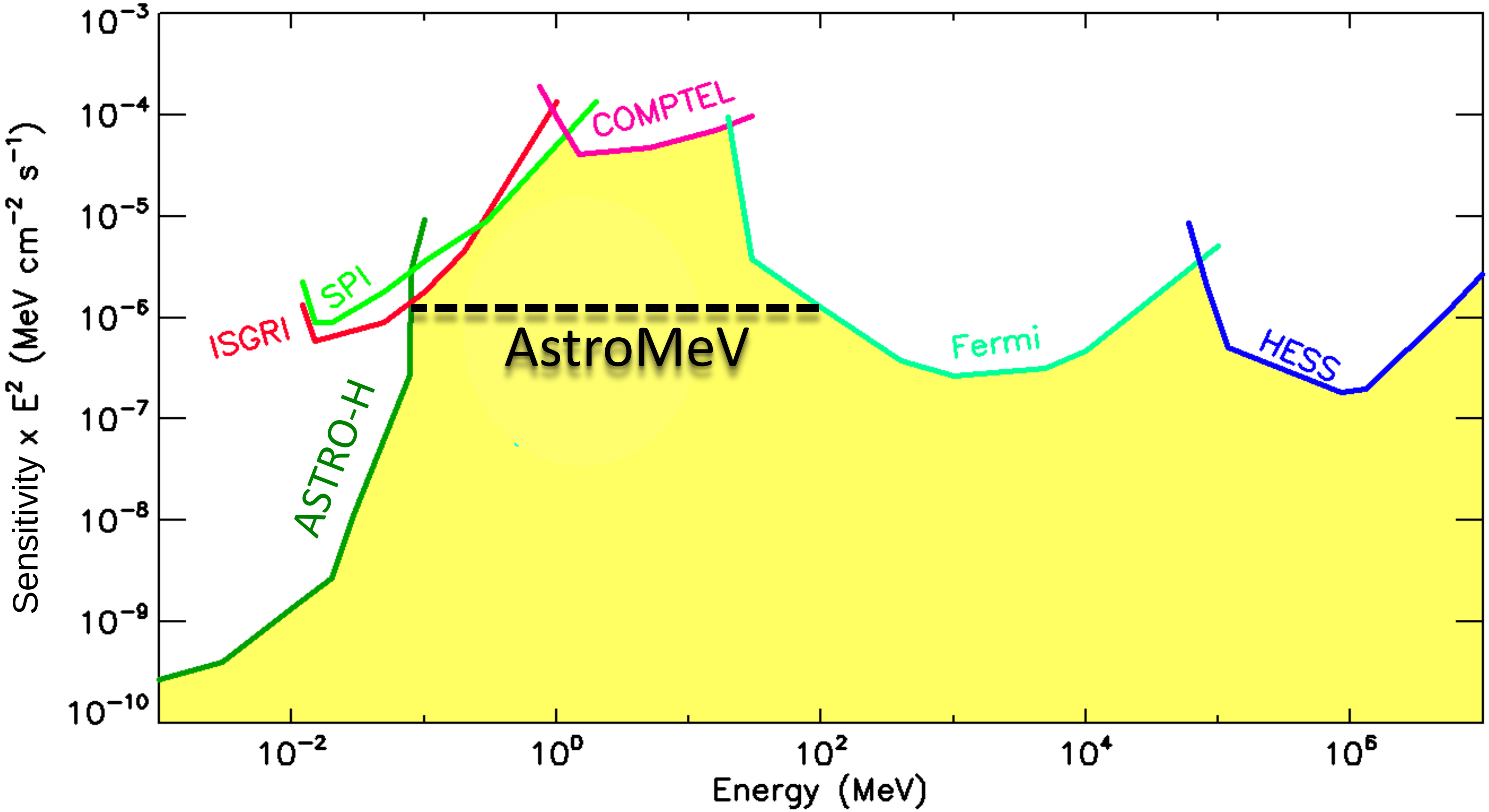
- The next decade should see the development of more sensitive neutrino detectors and gravitational wave observatories
- An imaging gamma-ray observatory monitoring the sky at the same time will be essential to identify the high-energy sources of neutrino and gravitational wave emission (collapsing compact objects, supernovae…).



# AstroMeV Required performances

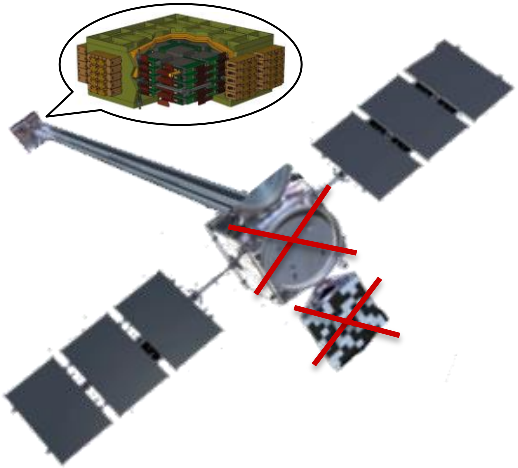
- The next gamma-ray space observatory should (i) cover a wide energy band (~ 100 keV to 100 MeV), (ii) have a wide field of view, (iii) be a sensitive polarimeter, and (iv) reach a **sensitivity** significantly better than those of CGRO/COMPTEL and INTEGRAL



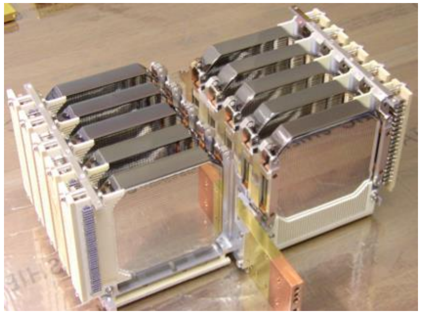
# AstroMeV Instrument concepts

- 3 concepts discussed in detail at the 2nd AstroMeV workshop in Nov. 2013

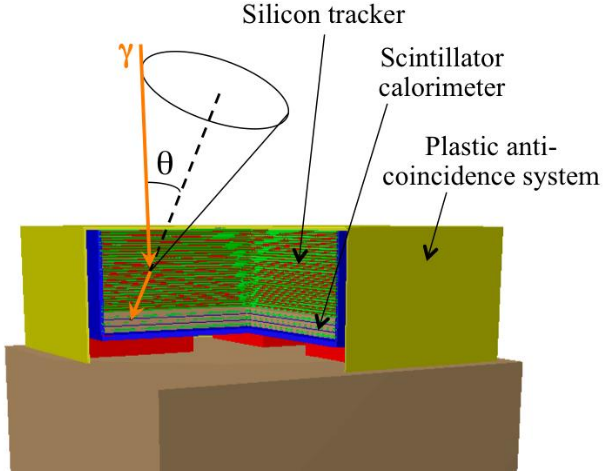
**asCi** (*all sky Compton imager*; von Ballmoos et al.)



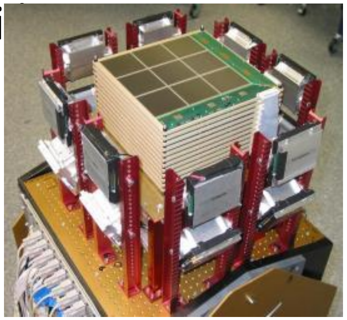
Ge-strip detectors
Heritage: NCT/COSI (UC Berkeley), DUAL M3



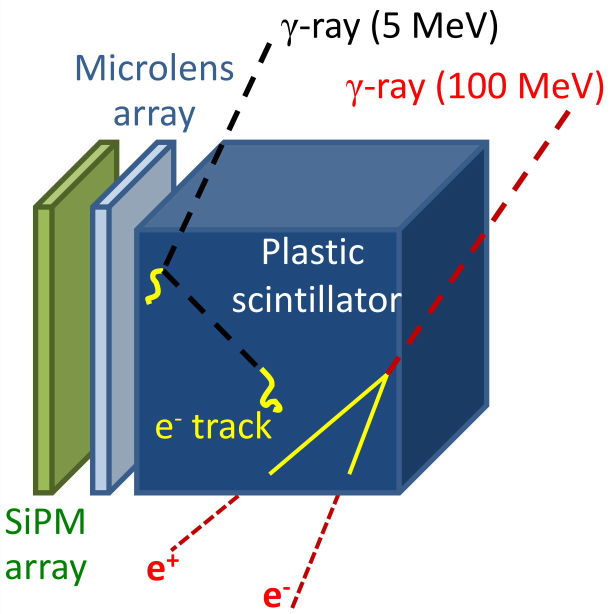
**PACT** (*Pair and Compton Telescope*; Tatischeff et al.)




Si DSSDs + $CeBr_3$ scintillators
Heritage: MEGA, GRIPS M2/M3 (MPE), AGILE, Fermi



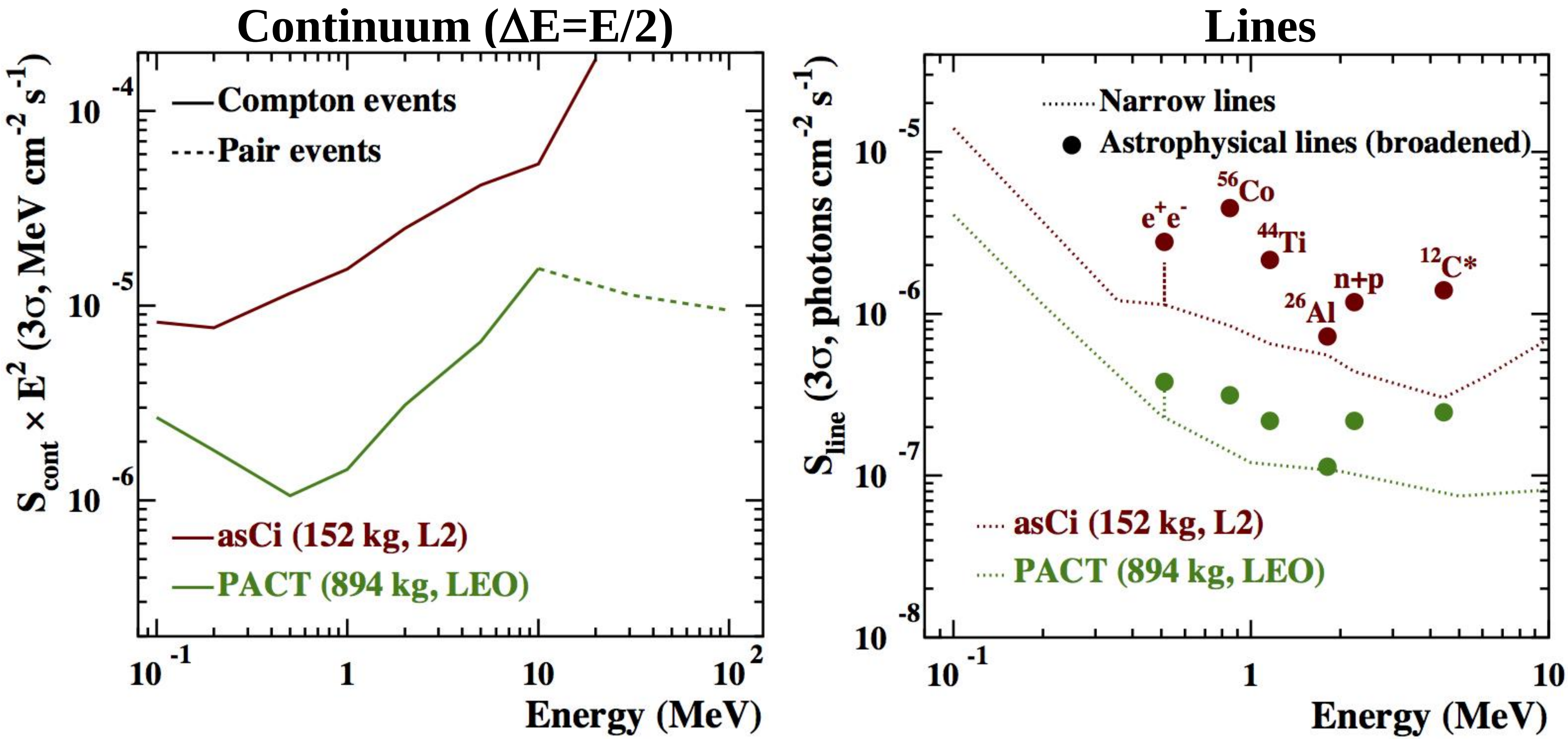
**Gamma Cube** (Lebrun et al.)




Novel concept: imaging ionization traces in a plastic scintillator
Very interesting! But not mature enough for M4

# AstroMeV Performance comparison

## 3σ survey sensitivity after 5 years★




- 1 Ms on-axis sensitivity of asCi and PACT for the 847 keV $^{56}$Co line (SN Ia): $3.7\times10^{-5}$ and $2.2\times10^{-6}$ photons cm$^{-2}$ s$^{-1}$ (PACT is 100 times better than SPI)

★ From MEGAlib simulations - see http://megalibtoolkit.com/

# AstroMeV ESA's M4 Call

- Call for the 4th Medium-size (450 M€) mission of ESA's Cosmic Vision program, for a launch in 2025 (definition and preparation phase until 2018)
- Proposal submission deadline: **January 15, 2015**

**Table 1: Parameter envelope suggested for the M4 mission (see main text for details).**

| Element | Recommended values | Comment |
|---|---|---|
| Spacecraft dry mass (including payload and propulsion system(s)) | < ~ 800 kg | Upper limit, excluding the launcher adapter. Applies to both Vega and Soyuz launchers. A lower mass figure may be needed for fitting launcher capability (see below). |
| Payload mass | < ~ 300 kg | Also to be interpreted as an upper limit. For planetary missions, it is recommended to limit the science instrumentation mass to 80 kg. |
| Technology Readiness | TRL > 5-6<br>(ISO scale)<br>For all the spacecraft elements (including the payload). | See Appendix A for TRL definition. The payload can be a new development but must rely on available technologies for all the instrument elements. Some limited delta-developments or verifications can be envisaged prior to the mission adoption (must be achievable in 2-2.5 years) |
| In-orbit operations | < 3-3.5 years | Nominal lifetime, excluding possible extensions. |
| Launcher | Vega or Soyuz | See Section 0 for possible mission profiles. |

# AstroMeV Conclusion

- M4 proposal: a sensitive (?) sky survey in the medium-energy $\gamma$-ray band (100 keV – 100 MeV), LOI sent to ESA on Sep. 16
- Two concepts to be studied in parallel in the coming months by the Instrument and Simulations WGs:
  - **a light Pair and Compton Telescope (PACT)**
  - **two even lighter instruments**, a Compton telescope for the range 0.1 - 10 MeV and a pair telescope above 10 MeV (e.g. asCi + GAMMA-LIGHT)

- AstroMeV does not end on January 15, 2015

- You are welcome to join! http://astromev.eu/