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)

J. Greiner for the AstroMeV consortium, Ioffe Workshop on GRBs, St. Petersburg, 22 - 26 Sep 2014
AstroMeV is an international consortium of laboratories preparing for the development of a new space mission which will observe medium energy gamma-ray domain, that is at photon energies between 10 and 100 Megaelectronvolt (MeV). The collaboration brings together 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).

http://astromev.eu/
Results of the workshop “Scientific perspectives in the MeV domain” (APC, Paris, 15 - 16 January 2013)
⇒ an inventory “à la Prévert”
http://astromev.eu/

**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

**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 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 4: Fundamental physics and cosmology**
- Dark matter annihilation and decay
- Explore the limits of modern physics

**Theme 5: Sun and Earth science**
- The sun in the MeV domain
- Terrestrial gamma-ray flashes

J. Greiner for the AstroMeV consortium, Ioffe Workshop on GRBs, St. Petersburg, 22 - 26 Sep 2014
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
  
  *Cosmic Vision §4.3:* “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
  
  *Cosmic Vision §4.3:* “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!
  
  *Cosmic Vision §5.4.3:* “Sources of explosive nucleosynthesis and electron-positron annihilation are also of major interest”

- **Gamma-ray bursts** - Of course! But SVOM (~ 2021 → 2026+)

- **Dark matter ...?**

J. Greiner for the AstroMeV consortium, Ioffe Workshop on GRBs, St. Petersburg, 22 - 26 Sep 2014
• Type Ia supernova exploded on 2014 Jan 14 in the starburst galaxy M82 at $D \approx 3.5$ Mpc ⇒ nearest SN Ia in more than 40 years

• Detection with INTEGRAL of gamma-ray lines from $^{56}$Co decay ($T_{1/2}=77$ d) ⇒ 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.)

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

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AstroMeV

Type Ia supernovae

**SN 2014J**

- **D = 3.5 Mpc**
- **$F_{847} \sim 2.3 \times 10^{-4} \text{ cm}^{-2} \text{ s}^{-1}$**
- ($\Rightarrow \text{Log Flux} = -3.6$)

(Churazov et al. 2014)

Predicted flux in the 847 keV line vs distance

- 2002 - 2006 SNe Ia (well calibrated)
- (40 detections within 50 Mpc)

With a sensitivity $\sim 30$ times better than SPI

$\Rightarrow \sim 7$ SNe Ia in 5 yr

$\Rightarrow$ Is SN 2014J the rule or the exception?

J. Greiner for the AstroMeV consortium, Ioffe Workshop on GRBs, St. Petersburg, 22 - 26 Sep 2014
• The SEDs of many blazars (FSRQs) and non-blazar AGNs detected in γ-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

J. Greiner for the AstroMeV consortium, Ioffe Workshop on GRBs, St. Petersburg, 22 - 26 Sep 2014
• 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).
• 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
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...).
• 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

J. Greiner for the AstroMeV consortium, Ioffe Workshop on GRBs, St. Petersburg, 22 - 26 Sep 2014
• 1 Ms on-axis sensitivity of asCi and PACT for the 847 keV $^{56}$Co line (SN Ia): $3.7 \times 10^{-5}$ and $2.2 \times 10^{-6}$ photons cm$^{-2}$ s$^{-1}$ (PACT is 100 times better than SPI)

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

J. Greiner for the AstroMeV consortium, Ioffe Workshop on GRBs, St. Petersburg, 22 - 26 Sep 2014
• 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).**

<table>
<thead>
<tr>
<th>Element</th>
<th>Recommended values</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spacecraft dry mass (including</td>
<td>&lt; ~ 800 kg</td>
<td>Upper limit, excluding the launcher adapter. Applies to both Vega and Soyuz launchers. A lower mass figure may be needed for fitting</td>
</tr>
<tr>
<td>payload and propulsion system(s)</td>
<td></td>
<td>launcher capability (see below).</td>
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<tr>
<td>Payload mass</td>
<td>&lt; ~ 300 kg</td>
<td>Also to be interpreted as an upper limit. For planetary missions, it is recommended to limit the science instrumentation mass to 80</td>
</tr>
<tr>
<td></td>
<td></td>
<td>kg.</td>
</tr>
<tr>
<td>Technology Readiness</td>
<td>TRL &gt; 5-6 (ISO scale)</td>
<td>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)</td>
</tr>
<tr>
<td>In-orbit operations</td>
<td>&lt; 3-3.5 years</td>
<td>Nominal lifetime, excluding possible extensions.</td>
</tr>
<tr>
<td>Launcher</td>
<td>Vega or Soyuz</td>
<td>See Section 0 for possible mission profiles.</td>
</tr>
</tbody>
</table>
• **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/](http://astromev.eu/)