Astrophysics Challenges in MeV Astronomy

What are the questions and how do we answer them?

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What are our goals in γ-ray astronomy?

- Always evolving.
- Prior to CGRO we were willing to claim success in simply finding sources, regardless of what science they possessed.
- Now our goals are higher demanding greater instrumental power.
COMPTEL Sky maps

1–3 MeV

3–10 MeV

10–30 MeV

Continuum total
1–30 MeV

Continuum sources
1–30 MeV
We would like something like this at 1 MeV

But now, we’d like lots of other things too, now that we know what is out there.
### What science are we studying?

<table>
<thead>
<tr>
<th>Object</th>
<th>Spatial Extent</th>
<th>Spectral Feature</th>
<th>Ancillary Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galactic BH</td>
<td>unresolvable</td>
<td>hi-E tail continuum</td>
<td>critical &amp; contemporaneous</td>
</tr>
<tr>
<td>Pulsars</td>
<td>unresolvable</td>
<td>continuum</td>
<td>critical</td>
</tr>
<tr>
<td>Galactic Diffuse Emission</td>
<td>Extended with unresolved</td>
<td>multi-component continuum</td>
<td>critical but archival</td>
</tr>
<tr>
<td>EG Diffuse</td>
<td>Isotropic and unresolved</td>
<td>multi-component</td>
<td>critical but archival</td>
</tr>
<tr>
<td>Solar</td>
<td>Extended and time variable</td>
<td>Sharp &amp; Broad lines, continuumÑ all variable</td>
<td>time critical</td>
</tr>
<tr>
<td>Supernovae</td>
<td>unresolvable</td>
<td>time-variable line shapes and intensities</td>
<td></td>
</tr>
<tr>
<td>Galactic RA</td>
<td>extended and point</td>
<td>broadened line shapes</td>
<td></td>
</tr>
</tbody>
</table>

### Can we measure all these quantities?

**In one instrument?**
Brief Aside

• MeV (or GeV or keV) astronomy is its most productive when one knows what is happening in other wavelengths.

• Preaching to the choir: we note the progress made by the Compton Gamma Ray Observatory.
The Compton Gamma Ray Observatory

Space Shuttle Atlantis
STS-37
April 5, 1991
The Instruments on CGRO Cover Six Orders of Magnitude in Photon Energy

- BATSE
- OSSE
- COMPTEL
- EGRET
GRB 990123 Energy Spectrum
Cyg X-1 Broadband, Variable Spectrum
Active Galactic Nuclei - Blazars

![Graph showing energy density vs frequency for 3C 273 and various observatories.]

- IUE
- Lowell Observatory
- Blue Mesa
- La Silla
- Rosemary Hill
- IRAS
- Mauna Kea
- Swiss telescope
- Pico Veleta
- Kitt Peak
- Metsaehovi
- Effelsberg

3C 273

Energy Density [erg/(cm² s Dekade)]

Frequency [Hz]

G. Lichti
Contemporaneous Measurements a Standard Practice in Solar Physics

The full extent of the energy domain reveals the various sources of the radiation, in turn revealing the relative contributions of particle acceleration and their efficiency.
The Next Step

• We should probably not hold our breaths waiting for another comprehensive observatory.

• So, given our current understanding of the physics of MeV astronomy, what are the burning issues, and then, how do we go about addressing them?
Best instruments for the job

• Coded-mask and collimated detectors
• Focusing and concentrators
• Compton telescopes
• Other ideas?
Coded Masks and other collimators

- Some improvement is possible over INTEGRAL in a coded mask instrument (Skinner later today), but
  - Not optimum for extended objects (little modulation)
  - Background becomes big problem (> 500 keV)
  - Probably restricted to narrow line studies

- They excel in transient studies if the target is predetermined or large FoV, e.g., RHESSI, SWIFT.
Focusing and “concentrators”

• **Large improvement in S/N**
  - $\propto (\text{aperture/size of detector})^2$: $\geq 10^3$ for Fresnel lens design
  - Fixed by Bragg scattering: $\sim 50$ for Claire

• **FoV $\propto$ detector size/focal length**
  - Makes Fresnel lens ideal for Crab pulsar, but not nebula (too big). ($\sim 20$ mas, $f/10^8$)
  - Claire: $\sim 1'$

• Perhaps the chromatic aberration of the lens can be used to widen the energy range (multiple sensors). (SN line shapes will be difficult.)
Compton Telescopes

- Wide FoV, good background rejection due to coincidence req.
- Key to success is much more background reduction with larger area.
- COMPTEL was background, not photon, limited. Increasing area will gain some sensitivity but not as much as reducing background.
Image construction by simple superposition of Compton event circles

Method works for large S/N data. Fails with background superimposed.

1. Shrink radius of event annuli.
2. Shrink width of annuli.
3. Contract annuli into arcs.
4. Minimize background.
5. Increase photopeak fraction.
Increasing Effective Area

- Make designs more compact, thereby increasing the internal solid angle advantage.
- Factor of $10 \times$ over COMPTEL.
- Perform full energy measurement.
  - Partial E absorption events in double scatter instruments add to background.
Reducing Background

- Additional coincidence req.
- Time-of-flight (powerful tool, but difficult to implement in compact instruments).
- Tracking recoil electrons.
- High $E$ resolution detectors (small $\Delta \phi$).
- Fine spatial resolution.
- Shielding (less benefit than for collimated instruments)
The Curse of Background

Compton telescope backgrounds are low but not zero.

- If the background can be isolated to certain volumes of multi-d data space, those volumes of data space can be avoided in the analysis.
- The Orion result can be traced to the data volume heavily populated by $^{24}\text{Na}$ activation.
Sources of Background

Event Types A, B: Internally-generated
e.g., $^1\text{H}(n,\gamma)\text{D}$ (2.2 MeV),
$^{40}\text{K}$ (1.46 MeV)

Event Type C: Two photons spatially and
temporally correlated, cascade events.
e.g., $^{27}\text{Al}(n,\alpha)^{24}\text{Na}$, $^{27}\text{Al}(n;\gamma\gamma\gamma\gamma...)^{27}\text{Al}$

Event Type D: Two photons spatially and
temporally uncorrelated.
“random coincidences”

Event Type E: Two photons which are spatially
uncorrelated, but temporally correlated.
Trap doors, land mines and booby traps!

1. Event ambiguity.
   A. Forward vs. backward
   B. Neutron vs. $\gamma$

2. Accidental coincidences with high count rate from large area.

3. Multiple photon, neutron induced, background.

4. Activation of passive material.

5. Doppler broadening effect.

• COMPTEL suffered from all but 1A and 5.
Precautions

• Avoid all neutron producing matter, including spacecraft.

• Minimize passive material in instrument.

• Measure as many things as possible for each photon.

• Assume all your data are background until you know how background populates your multi-d dataspace.

Naked detectors

Give background space and time to reveal itself.
Good luck!

MeV astronomy is not for WIMPS!