GLAST and beyond GLAST: TeV Astrophysics

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Outline:

• Recent excitement of GLAST and plans for the immediate future: how to best take advantage of the data

• Longer-range scientific prospects for gamma-ray astrophysics and plans for SLAC involvement
GLAST is in orbit!

**Schematic principle of operation of the GLAST Large Area Telescope**

* $\gamma$-rays interact with the hi-z material in the foils, pair-produce, and are tracked with silicon strip detectors

* The instrument “looks” simultaneously into $\sim 2$ steradians of the sky

* Energy range is $\sim 0.03-300$ GeV, with the peak effective area of $\sim 12,000$ cm$^2$ - allows an overlap with TeV observatories

**Clear synergy with particle physics:**
- particle-detector-like tracker/calorimeter
- potential of discovery of dark matter particle
GLAST LAT has much higher sensitivity to weak sources, with much better angular resolution.
Cosmology and GLAST: dark matter

1E 0657–56

Offset between gas and mass peaks → Dark Matter exists!
(Clowe et al. 2004)

Can’t explain all this just via “tweaks” to gravitational laws…
New Particle Physics and Cosmology with GLAST: Observable signatures of dark matter

Extensions to Standard Model of particle physics provide postulated dark matter candidates

If true, there may be observable dark matter particle annihilations producing gamma-ray emission

This is just an example of what may await us!

Multi-pronged approach: Direct searches (CDMS), LHC, and indirect searches (GLAST) is likely to be most fruitful
Galactic γ-ray sources and the origin of cosmic rays

* Among the most prominent Galactic γ-ray sources (besides pulsars!) are shell-type supernova remnants - accelerators of the Galactic cosmic rays?
* Example: RX J1713.7-3946
* First object resolved in γ-rays (H.E.S.S., Aharonian et al. 2004)
* Emission mechanism: up to the X-ray band – synchrotron process
* Gamma-ray emission mechanisms - ambiguity between leptonic (inverse Compton) vs. hadronic (π⁰-decay) processes
GLAST and SNR as sources of cosmic rays

X-rays to the rescue!

• Chandra imaging data reveal relatively rapid (time scale of years) X-ray variability of large-scale knots (Uchiyama et al. 2008) ->
  • This indicates strong (milliGauss!) B field
  • Strong B-field -> weaker emission via the inverse Compton process -> hadronic models favored
  • Hadronic models -> extremely energetic protons (VHE cosmic ray range)

-> MULTI-BAND STUDIES (GLAST!) ESSENTIAL
The most prominent extragalactic γ-ray sources are jets associated with active galaxies.

Jets are common in AGN – and clearly seen in radio, optical and X-ray images.

When the jet points close to the our line of sight, its emission can dominate the observed spectrum, often extending to the highest observable energy (TeV!) γ-rays – this requires very energetic particles to produce the radiation.

Another remarkable example of “cosmic accelerators”

Prominent jet in the local active galaxy M87

All-sky EGRET map in Galactic coordinates
Extragalactic sources are jet-dominated AGN
Extragalactic jets and their \(\gamma\)-ray emission

- Jets are powered by accretion onto a massive black hole – but the details of the energy conversion process are still poorly known but \(\gamma\)-rays often energetically dominant
- All inferences hinge on the current "standard model" – broad-band emission is due to synchrotron & inverse Compton processes
- We gradually are developing a better picture of the jet (content, location of the energy dissipation region), but how are the particles accelerated?
- Variability (simultaneous broad-band monitoring) can provide crucial information about the structure/content of the innermost jet, relative power as compared to that dissipated via accretion, …

SLAC/KIPAC scientists play leading role in securing / interpreting multi-band data
BL Lac Reveals its Inner Jet (Marscher et al. 2008, Nature, 24/04/08)

Late 2005: Double optical/X-ray flare, detection at TeV energies, rotation of optical polarization vector during first flare, radio outburst starts during 2nd flare

Scale: 1 mas = 1.2 pc

TeV data: Albert et al. 2007 ApJL

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Gamma-ray astrophysics beyond GLAST

* Two basic approaches to detect $\gamma$-rays
  - Satellite-based space observations (GLAST)
    • Directly detect primary $\gamma$-rays
    • Small detection area (only works at lower energies)
  - Measure particle shower from interaction with atmosphere
    • Cherenkov light from particles (Whipple, H.E.S.S., Veritas, MAGIC)
      - Need enough light over night sky background
      - Can provide huge detection areas (high-energy end)
Current major VHE $\gamma$-ray facilities

[Map showing locations of various gamma-ray observatories around the world.

- VERITAS
- Milagro
- MAGIC
- H.E.S.S.
- Cangaroo
- Tibet
- EAS
- IACT]
Prospects for the near future of γ-ray astrophysics

* Now-and for the next few years:
  - GLAST – of course!
  - Extensions of H.E.S.S. and MAGIC coming on line and will be ready soon …
    • Improve sensitivity and threshold energy
γ-ray astrophysics - more distant future

* SLAC/KIPAC members are thinking now about future γ-ray instruments

* Atmospheric instruments:
  – Still quite cheap (4 M$ / Tel)
  – Need ~ 50 telescopes to
    • Improve sensitivity by x10
    • Angular resolution down to arcmin
    • Energy threshold from 100 to 10 GeV
    • Measure up to PeV gamma-rays?
  – Two on-going collaborations
    US: AGIS; Europe - CTA; KIPAC involved in both (mainly via S. Funk)
  – Currently doing design (MC) study on optimization of parameters and develop low-cost detectors (Hiro Tajima’s talk)
First steps in R&D for future TeV γ-ray astrophysics projects

* Instrumentation:
  - Advanced photo-detectors (currently PMTs) such as Si-PMTs, ...
  - Secondary optics for larger FoV and smaller cameras
  - ... later: site studies etc.
  - All driven by need to establish a cheap and reliable technology to detect Cherenkov photons ... (synergies with SLAC particle physics needs)
Simulations of the Galactic plane studied in the TeV band with the future instruments

* Successful GLAST launch and turn-on provides strong motivation for planning for the future of $\gamma$-ray astrophysics
Backup slides
TeV $\gamma$-ray astrophysics – recent highlights

* Extended (up to ~2°) emission to 100 TeV from shell-type SNRs and PWN (e.g. Nature 432, 77; A&A 449, 223, A&A 448, L43)

* $\gamma$–ray emission from GC (e.g. A&A 425, L13)

* Survey of the inner 30° of the Galaxy (Science 307, 1938; ApJ 636, 777) and serendipitous discovery of unidentified Galactic VHE $\gamma$–ray sources

* Periodic $\gamma$–ray emission from binary system LS 5039 (A&A 460, 743)

* Giant flare of PKS 2155 + Mkr501 with flux doubling time-scales of 2-3 min.

* Limits on the Extra-Galactic Background light, Dark Matter in the Galactic Center, Quantum Gravity, ...
NuSTAR Payload Description

* NASA’s Small Explorer program led by Caltech with KIPAC involvement
* Approved for launch in 2011/2012
* Two identical coaligned grazing incidence hard X-ray telescopes
  - Multilayer coated segmented glass optics
  - Actively shielded solid state CdZnTe pixel detectors
* Extendable mast provides 10-m focal length
* Resulting tremendous improvement of the hard X-ray (10-80 keV) sensitivity: AGN & CXB, SNR, blazars, …
Time variability of TeV blazar 1H1218+304

- Large flare detected by Suzaku on a timescale of ~1 day (Sato et al. 2008)
- Flare amplitude becomes larger as the photon energy increases
- Hard X-ray peak lags behind that in the soft X-ray by ~ 20 ks
- Need good TeV data to establish the TeV – X-ray connection