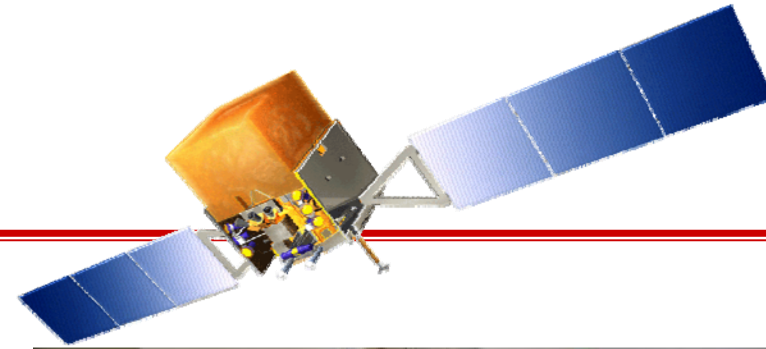
GLAST and beyond GLAST: TeV Astrophysics

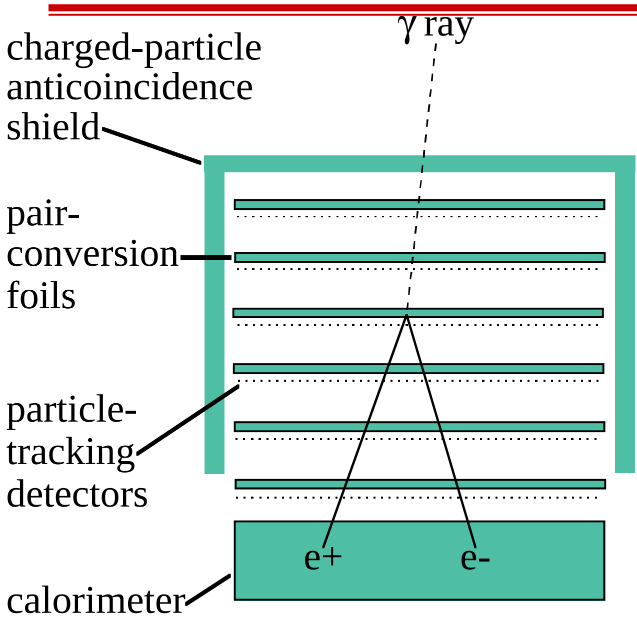
Greg Madejski
Assistant Director for Scientific Programs,
SLAC / Kavli Institute for Astrophysics and Cosmology

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!



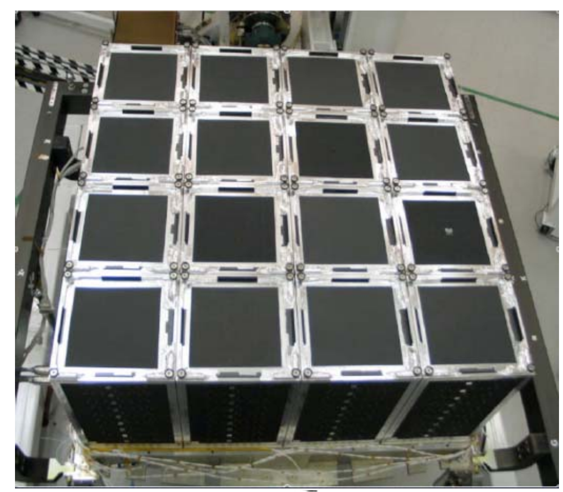


Schematic principle of operation of the GLAST Large Area Telescope

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

* The instrument "looks" simultaneously into ~ 2 steradians of the sky

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

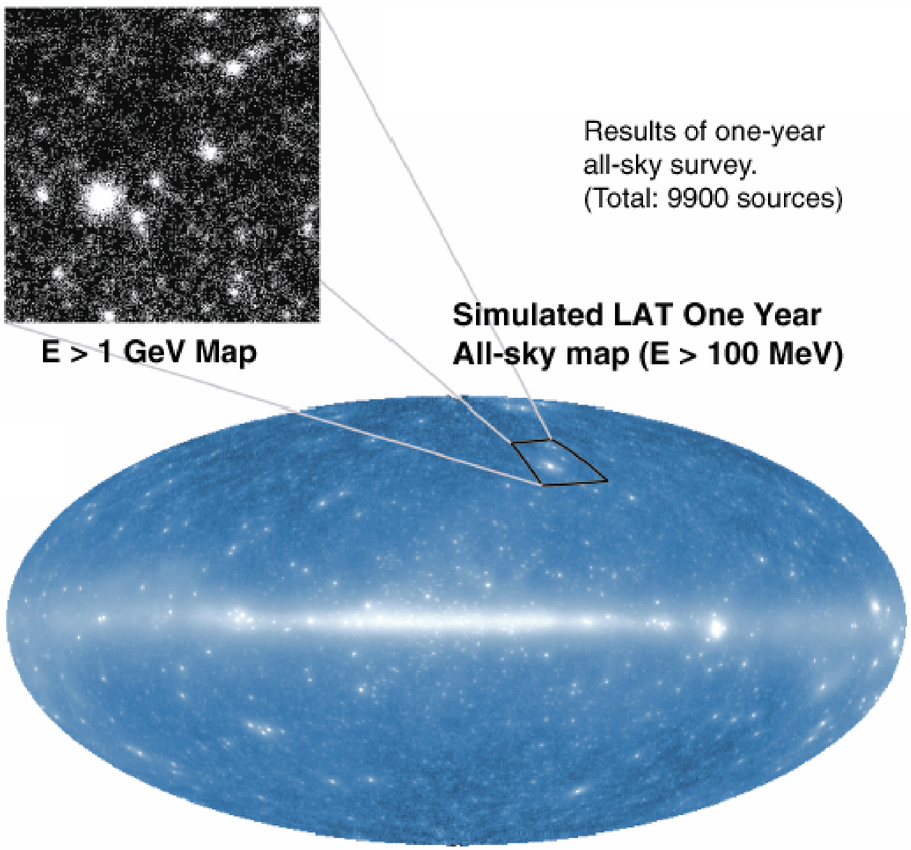


SLAC

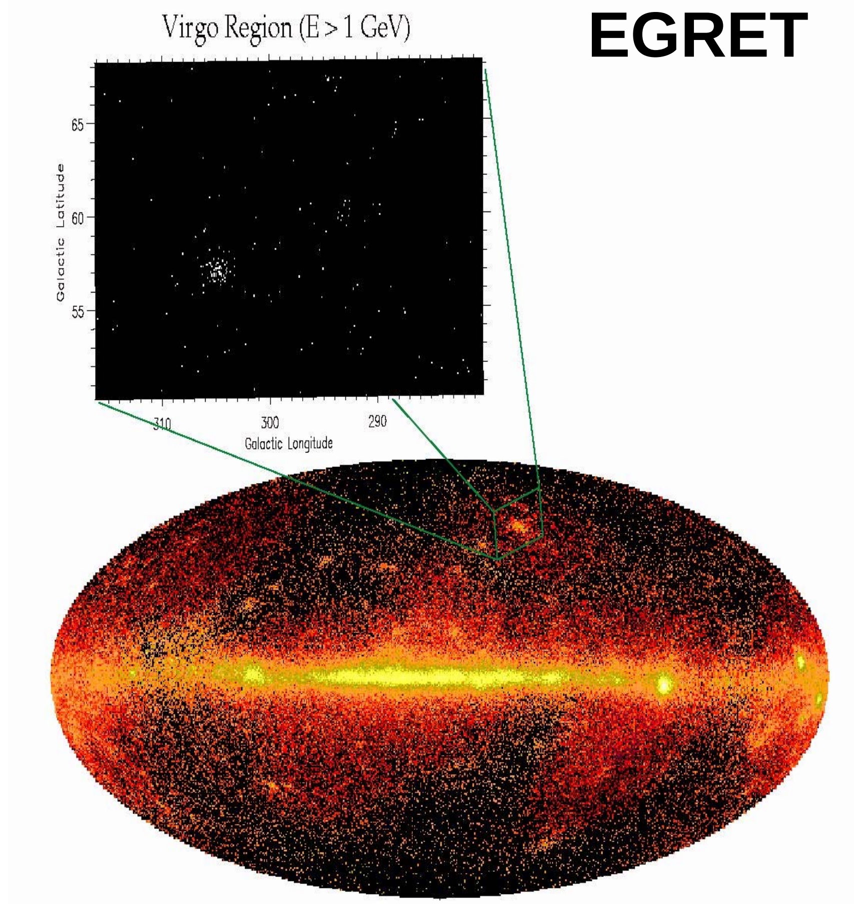
Clear synergy with particle physics:
- particle-detector-like tracker/calorimeter
- potential of discovery of dark matter particle

GLAST LAT has much higher sensitivity to weak sources, with much better angular resolution

GLAST

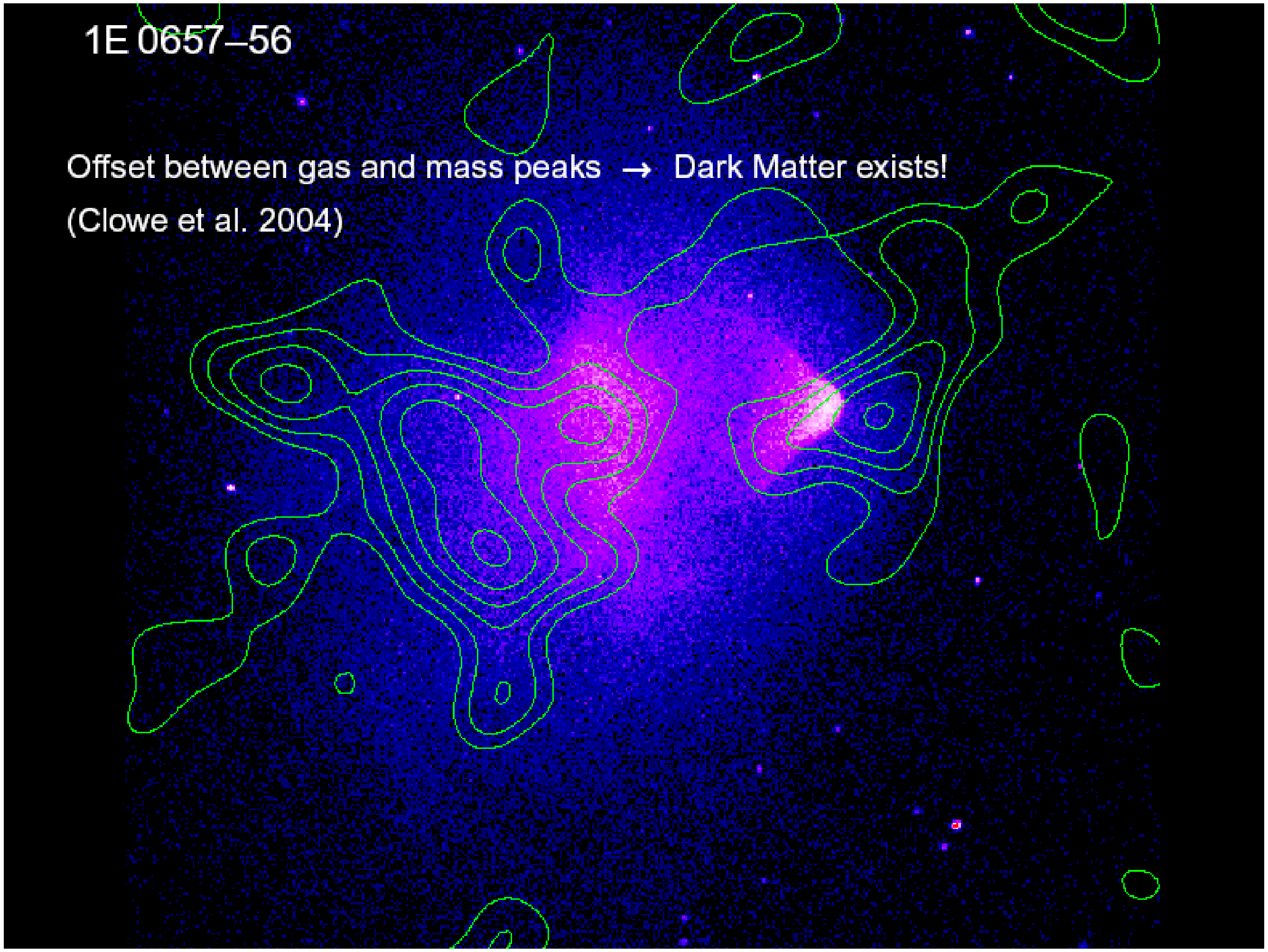


EGRET



EGRET One-Year All-Sky Survey (E > 100 MeV)

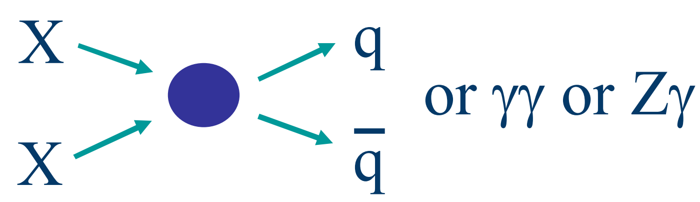
Cosmology and GLAST: dark matter



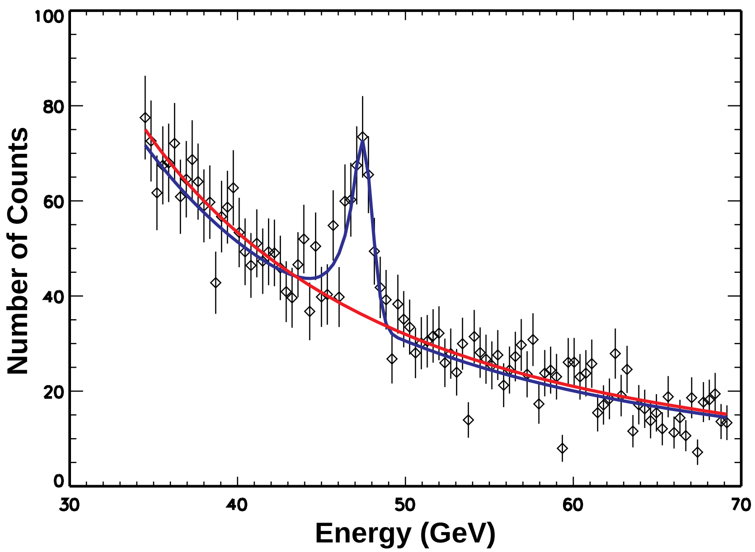
Can't explain all this just via "tweaks" to gravitational laws…

New Particle Physics and Cosmology with GLAST: Observable signatures of dark matter

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



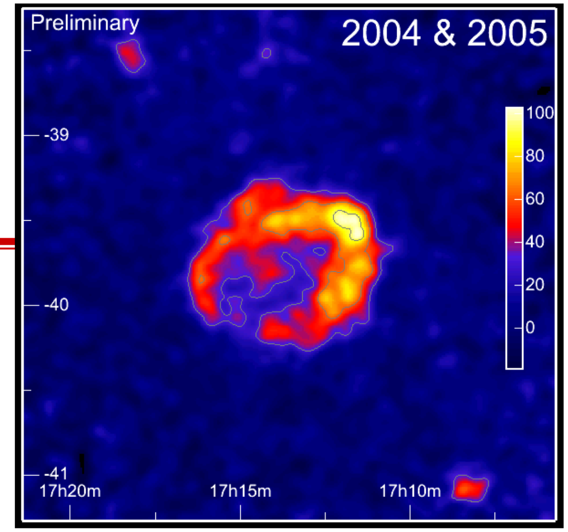
If true, there may be observable dark matter particle annihilations producing gamma-ray emission



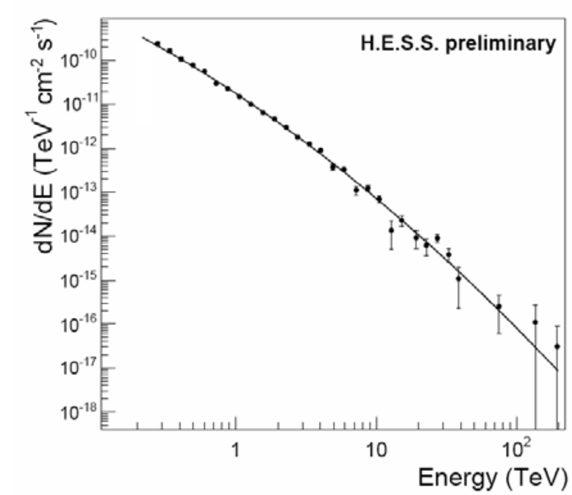
This is just an example of what may await us!

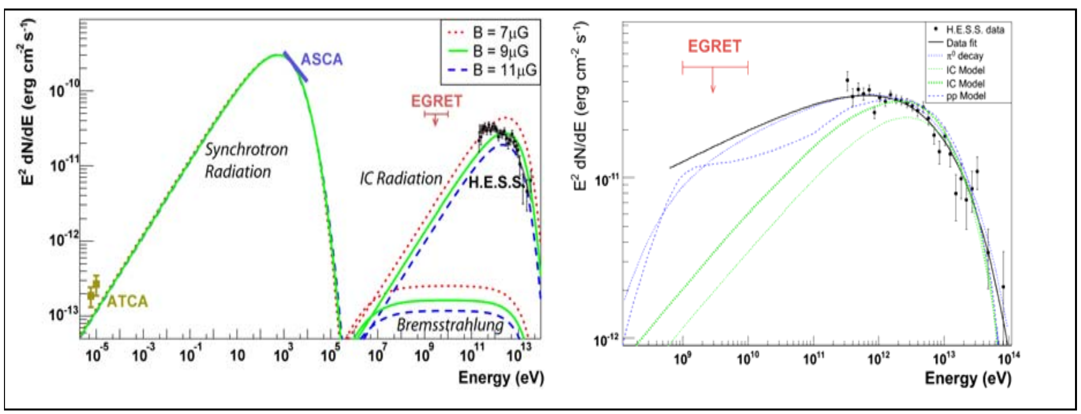
Multi-pronged approach: Direct searches (CDMS), LHC, and indirect searches (GLAST) is likely to be most fruitful

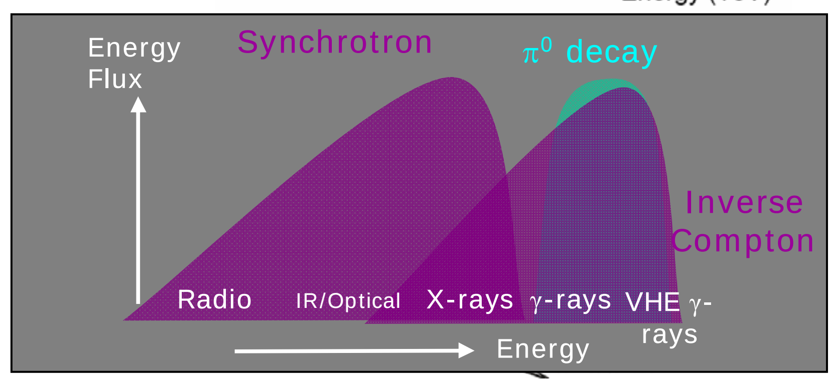
Galactic γ-ray sources and the origin of cosmic rays



- 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 (π^0-decay) processes







GLAST and SNR as sources of cosmic rays

X-rays to the rescue!

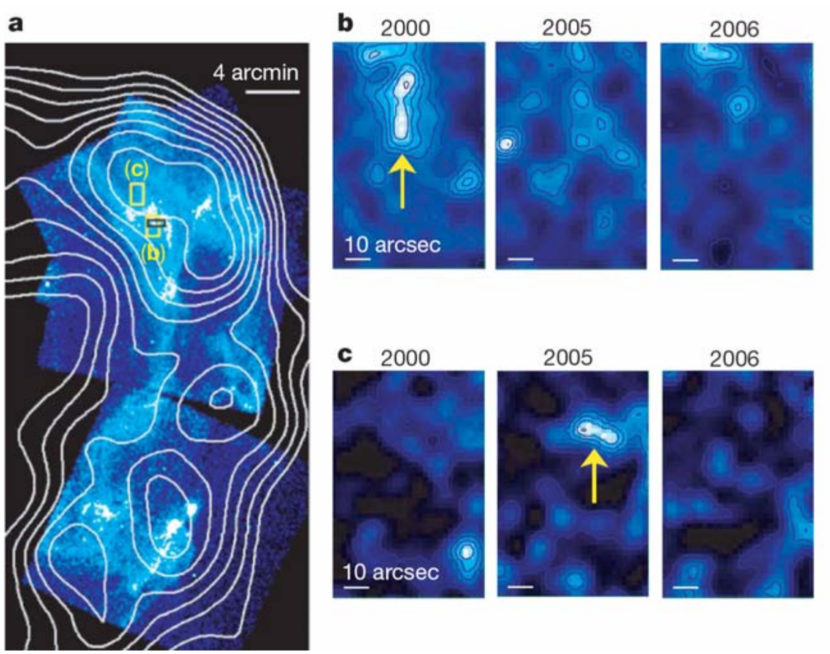
•Chandra imaging data reveal relatively rapid (time scale of years) X-ray variability of large-scale knots (Uchiyama et al. 2008) ->

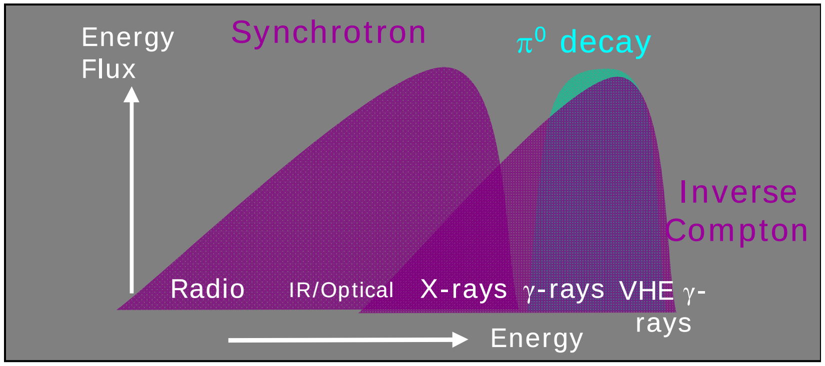
•This indicates strong (milliGauss!) B field

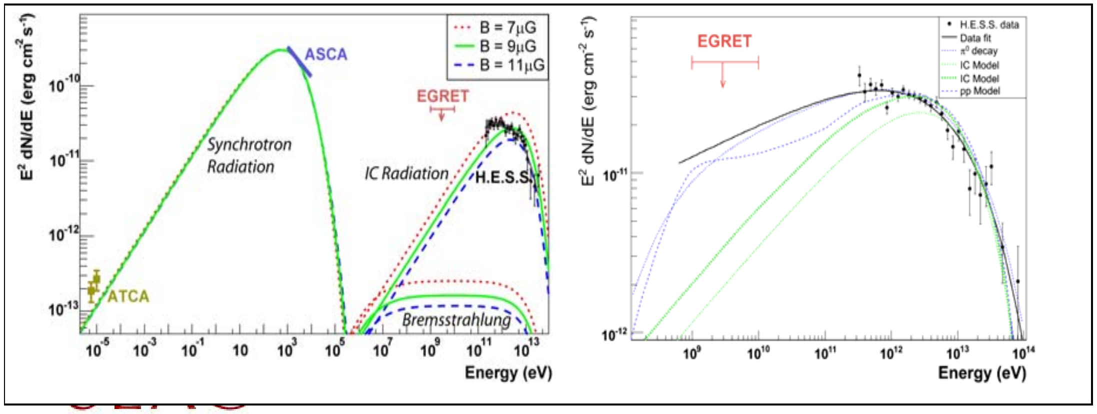
• Strong B-field -> weaker emission via the inverse Compton process -> hadronic models favored

•Hadronic models -> extremely energetic protons (VHE cosmic ray range)

-> MULTI-BAND STUDIES (GLAST!) ESSENTIAL

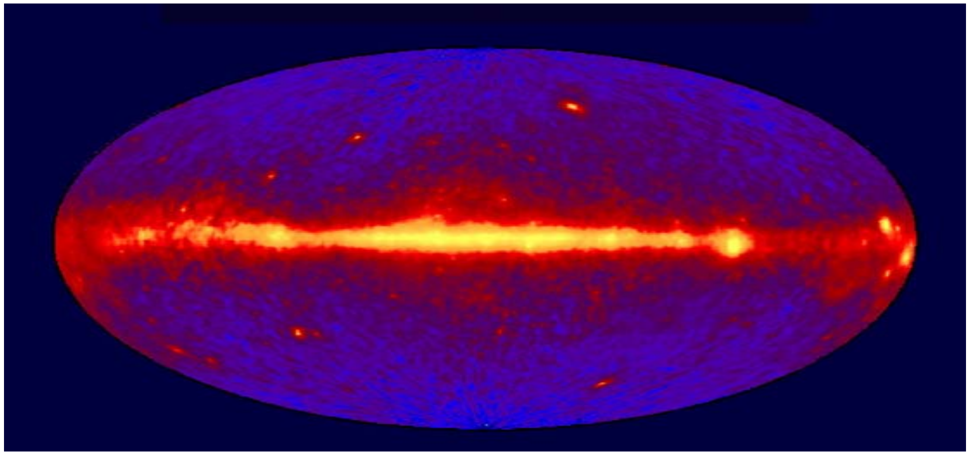




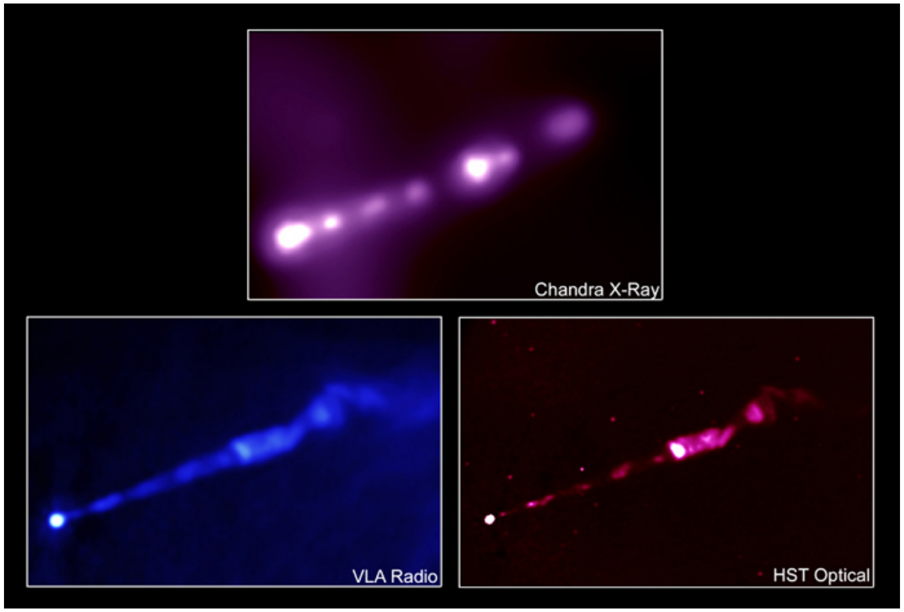


GLAST and relativistic jets

* 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 dominates 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”

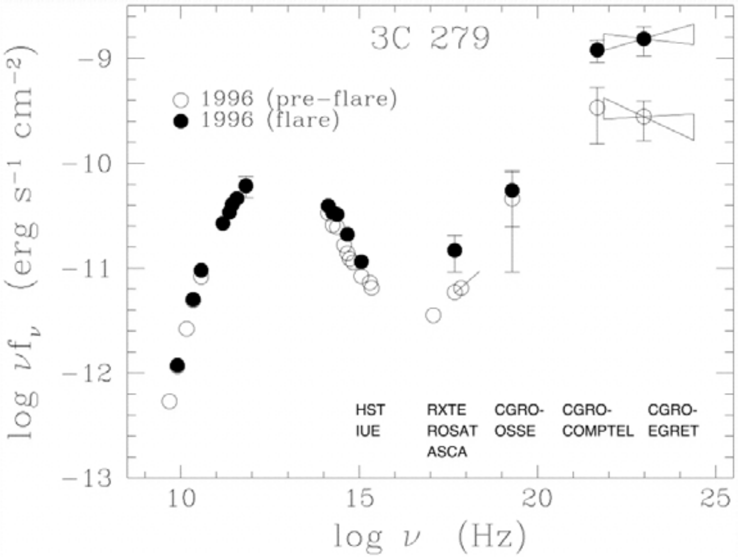


All-sky EGRET map in Galactic coordinates
Extragalactic sources are jet-dominated AGN

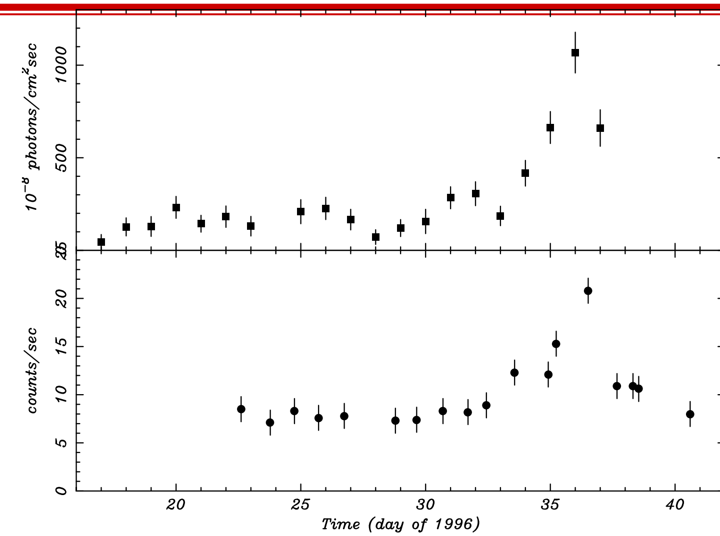


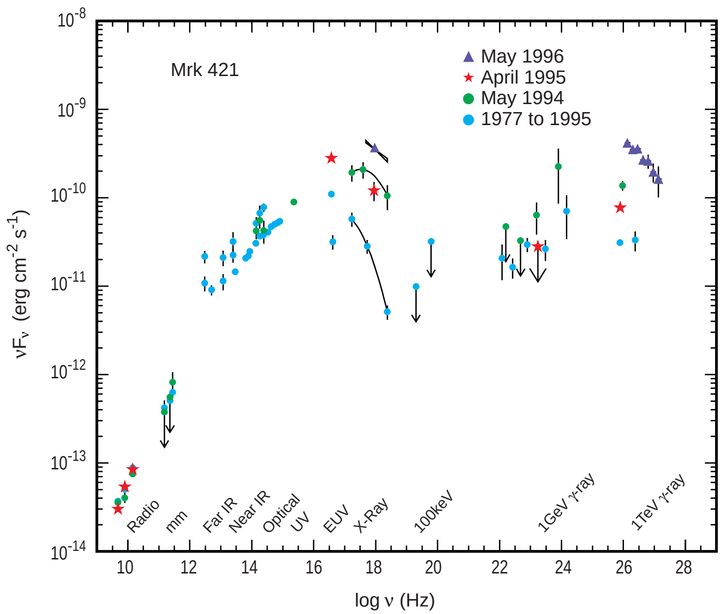
Prominent jet in the local active galaxy M87

Extragalactic jets and their γ-ray emission



Plot showing the lightcurves of 3C 279 from EGRET (top) and XTE (bottom) during the flare in early 1996





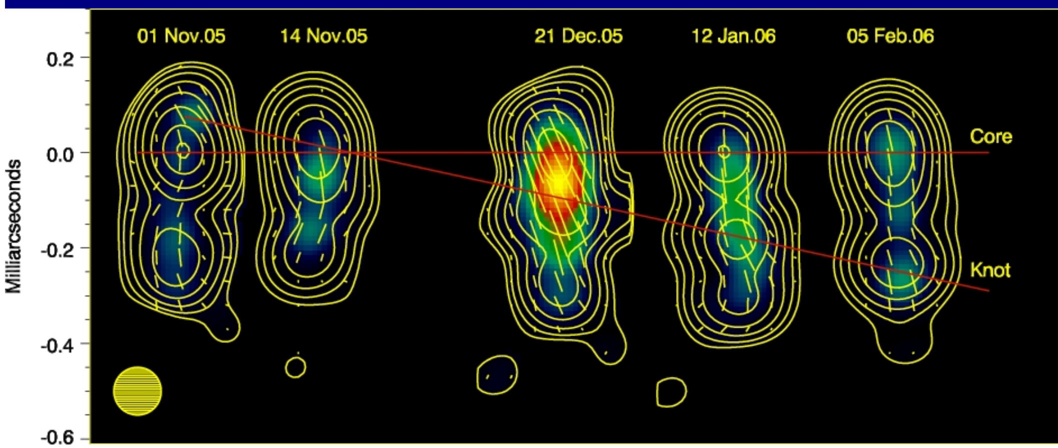
data from Wehrle et al. 1998, Macomb et al. 1995

- Jets are powered by accretion onto a massive black hole – but the details of the energy conversion process are still poorly known but γ-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

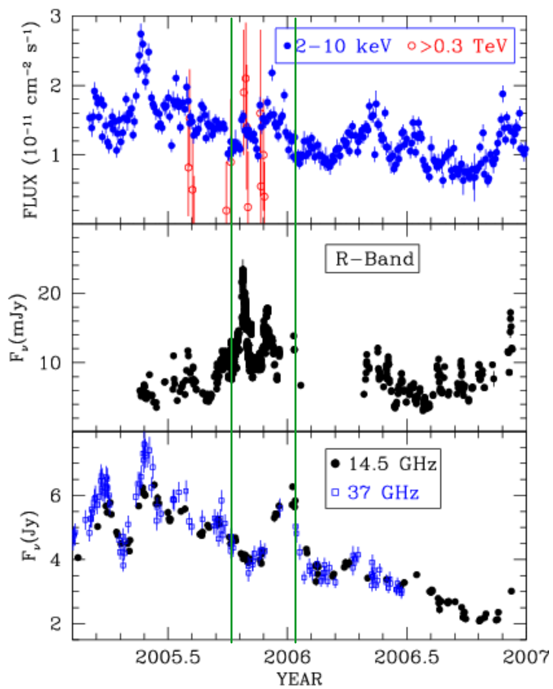
BL Lac Reveals its Inner Jet (Marscher et al. 2008, *Nature*, 24/04/08)

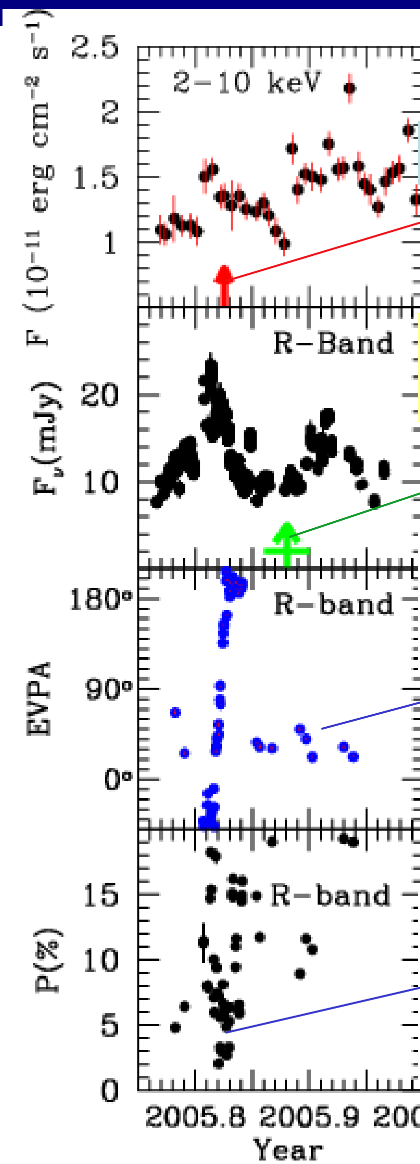
Late 2005: Double optical/X-ray flare, detection at TeV energies, rotation of optical polarization vector during first flare, radio outburst starts during 2nd flare



Scale:
1 mas = 1.2 pc

TeV data: Albert et al. 2007 ApJL





Strong TeV detection

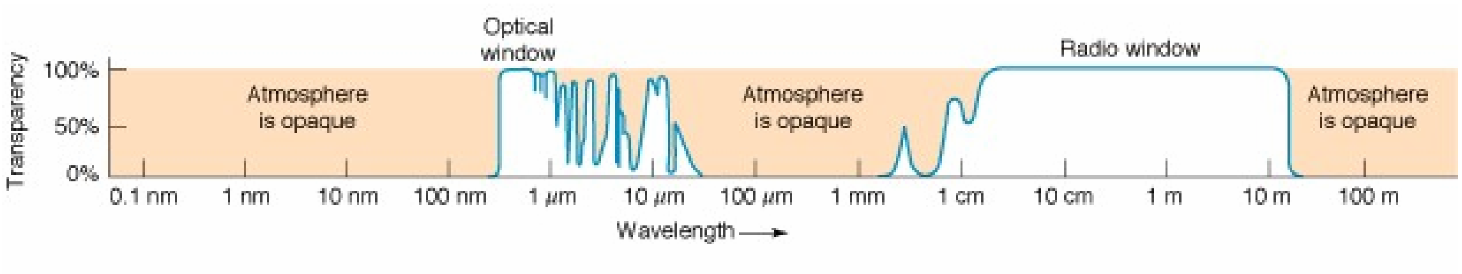
Superluminal knot coincident with core

Optical EVPA matches that of knot during 2nd flare

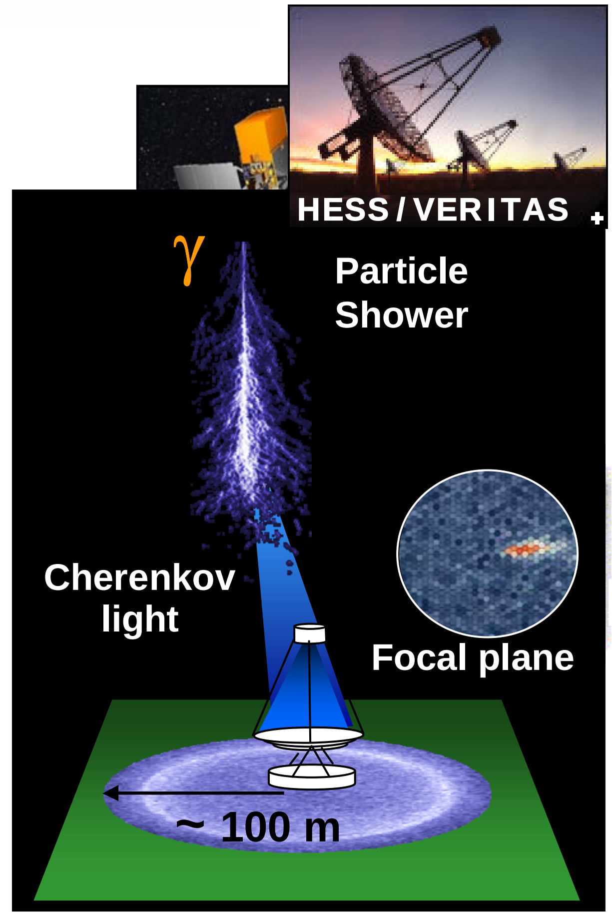
P decreases during rotation → **B** is nearly circularly symmetric

SLAC

Gamma-ray astrophysics beyond GLAST

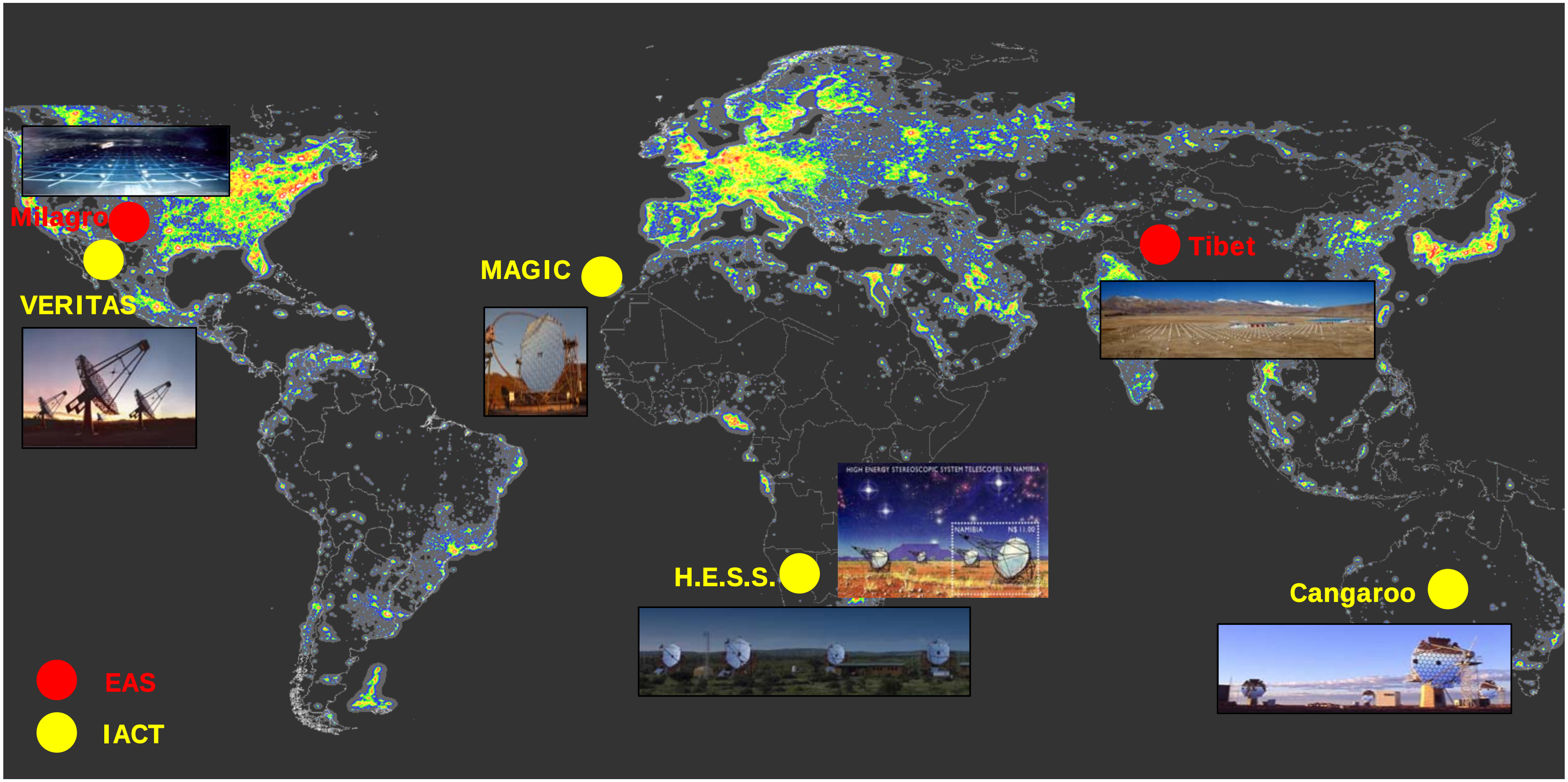


* Two basic approaches to detect γ-rays
  – Satellite-based space observations (GLAST)
    • Directly detect primary γ-rays
    • Small detection area (only works at lower energies)
  – Measure particle shower from interaction with atmosphere
    • Cherenkov light from particles (Whipple, H.E.S.S., Veritas,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



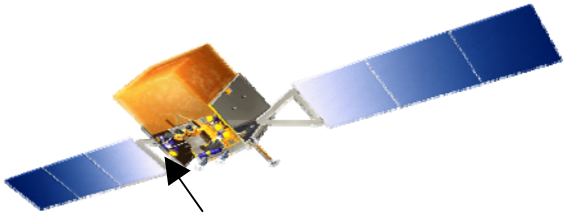
SLAC

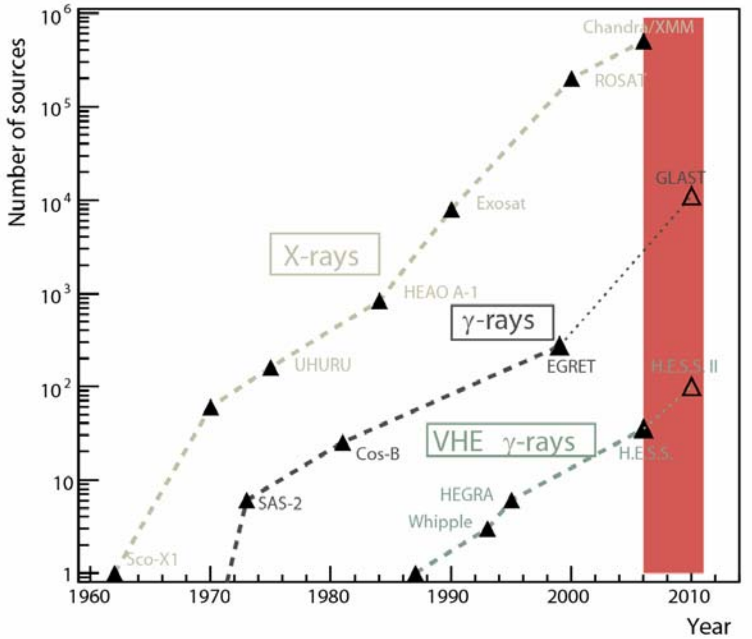
Current major VHE γ-ray facilities



Prospects for the near future of γ-ray astrophysics

* Now-and for the next 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

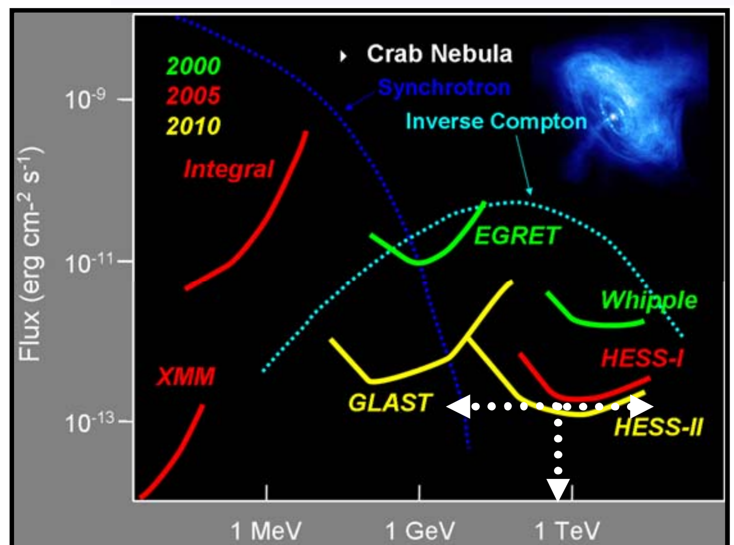




γ-ray astrophysics – more distant future

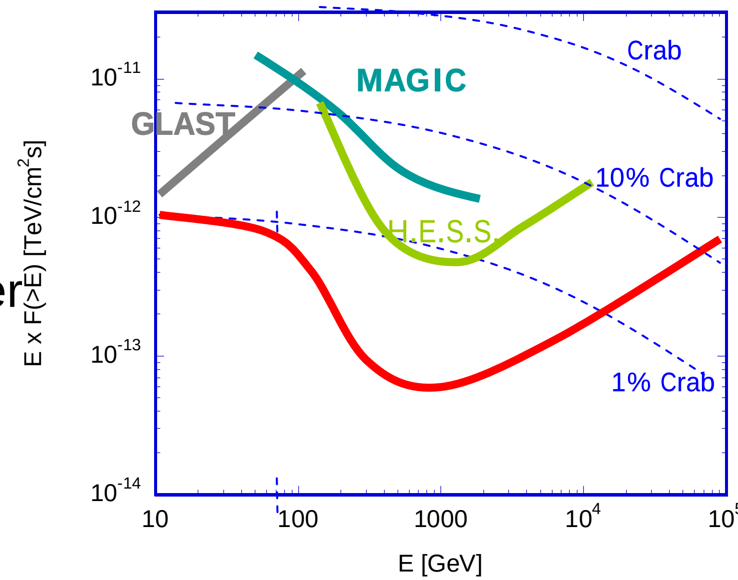
* SLAC/KIPAC members are thinking now about future γ-ray instruments

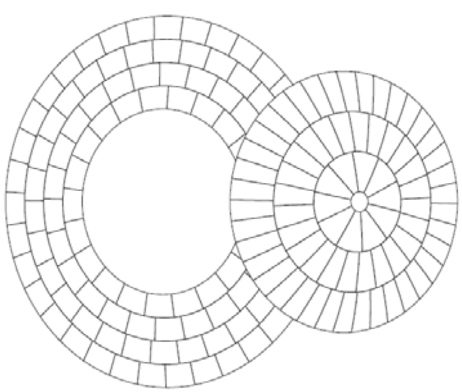
* Atmospheric instruments:
  – Still quite cheap (4 M$ / Tel)
  – Need ~ 50 telescopes to
    • Improve sensitivity by x10
    • Angular resolution down to arcmin
    • Energy threshold from 100 to 10 GeV
    • Measure up to PeV gamma-rays?
  – Two on-going collaborations
    US: AGIS; Europe - CTA; 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)

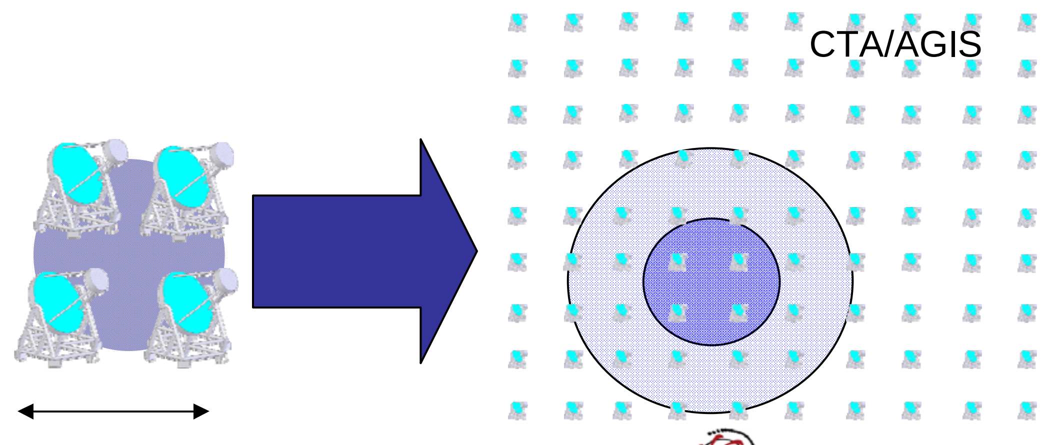


First steps in R&D for future TeV γ-ray astrophysics projects

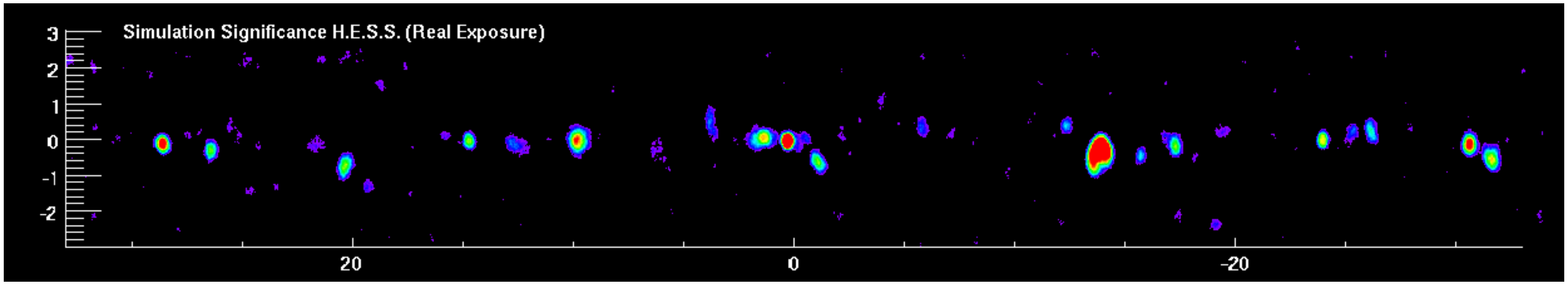
* Instrumentation:
  - Advanced photo-detectors (currently PMTs) such as Si-PMTs, ...
  - Secondary optics for larger FoV and smaller cameras
  - ... later: site studies etc.
  - All driven by need to establish a cheap and reliable technology to detect Cherenkov photons ... (synergies with SLAC particle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

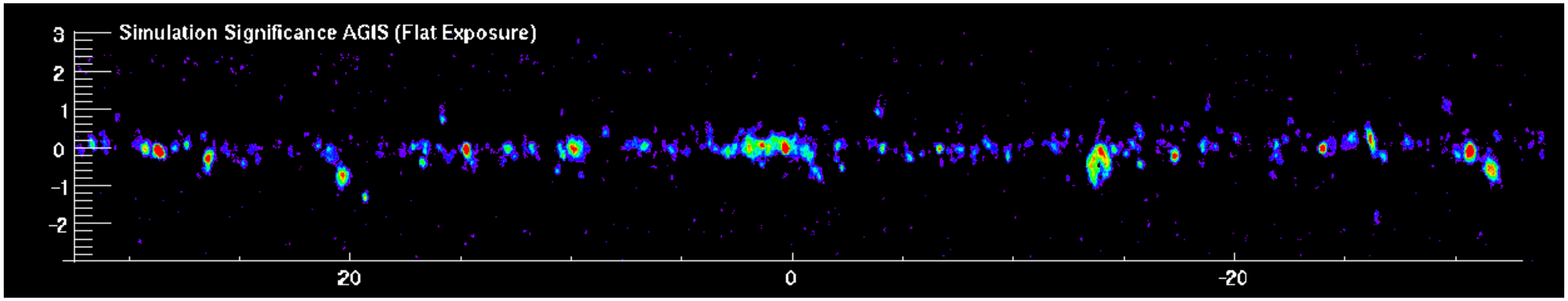






Simulations of the Galactic plane studied in the TeV band with the future instruments

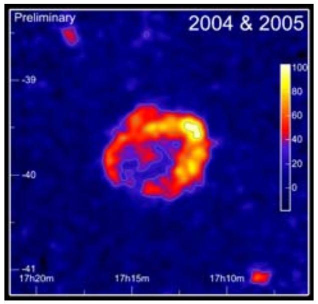




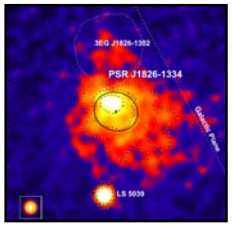
* Successful GLAST launch and turn-on provides strong motivation for planning for the future of γ-ray astrophysics

Backup slides

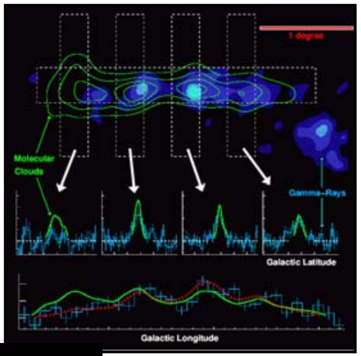
TeV γ-ray astrophysics – recent highlights

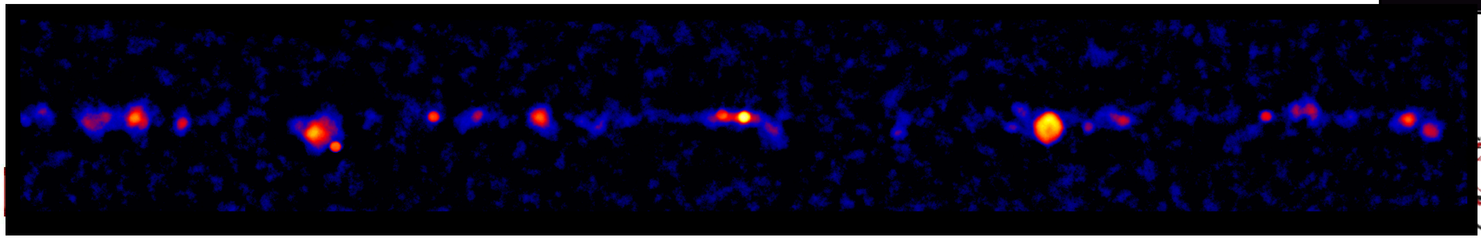


- Extended (up to ~2°) emission to 100 TeV from shell-type SNRs and PWN (e.g. Nature 432, 77; A&A 449, 223, A&A 448, L43)
- γ–ray emission from GC (e.g. A&A 425, L13)
- Survey of the inner 30° of the Galaxy (Science 307, 1938; ApJ 636, 777) and serendipitous discovery of unidentified Galactic VHE γ–ray sources



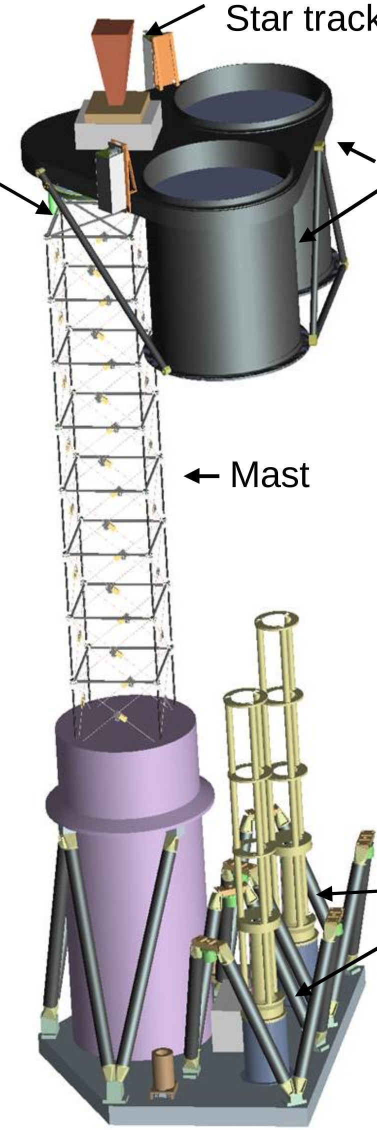
- Periodic γ–ray emission from binary system LS 5039 (A&A 460, 743)
- Giant flare of PKS 2155 + Mkr501 with flux doubling time-scales of 2-3 min.
- Limits on the Extra-Galactic Background light, Dark Matter in the Galactic Center, Quantum Gravity, ...



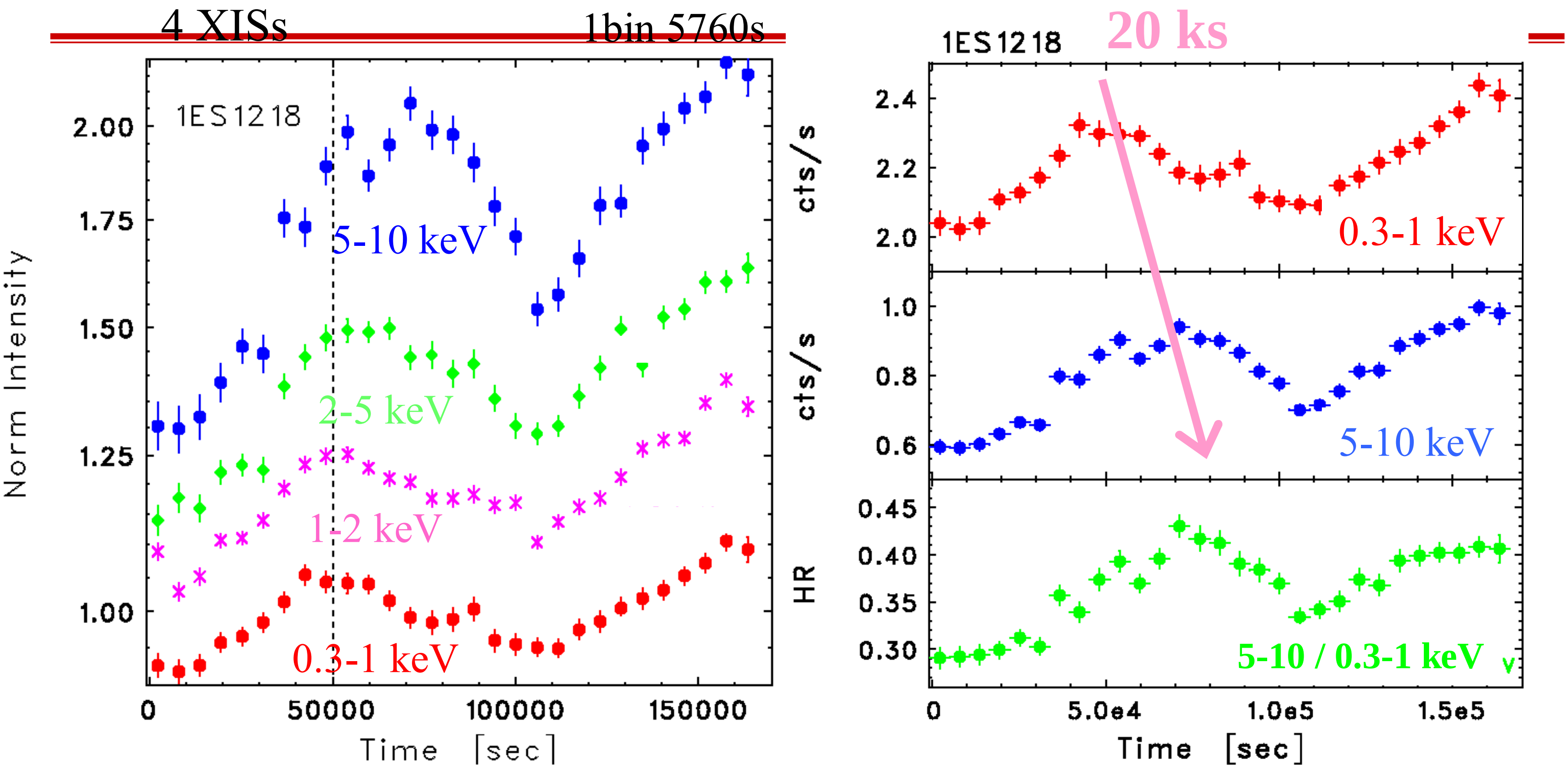


NuSTAR Payload Description

* 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