The future of Ground-based Gamma-ray Astronomy

Luke Drury <ld@cp.dias.ie>

Bottom line

- The future is bright!
- Two proven (not promising!) and complementary approaches (IACT/EAS, or Whipple/Milagro)
- Excellent synergies with GLAST, Agile, SKA, LOFAR, etc....
- Problems are political, financial and organisational, not technical....

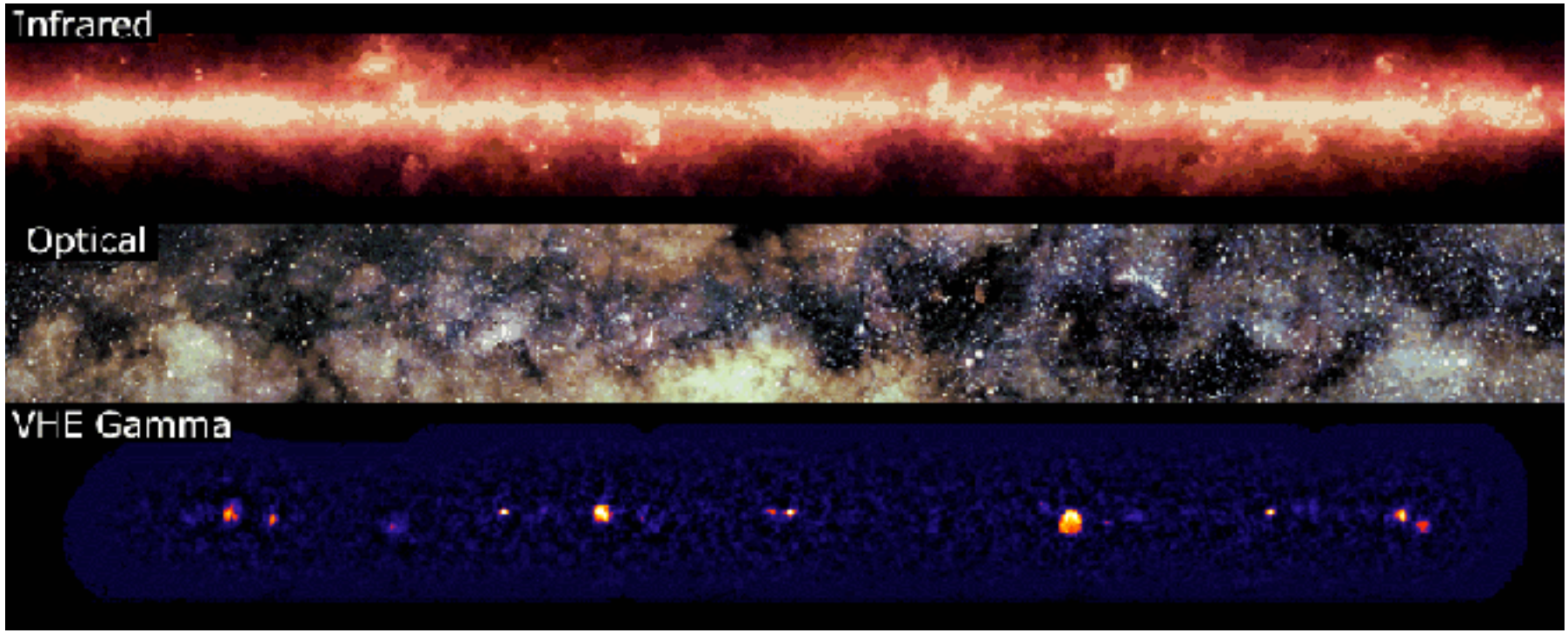
Up to a few years ago had techniques, but not an Astronomy...

- Statistics!
- Theta-squared plots
- Hillas parameters
- Alpha distributions

Now REAL Astronomy at TeV energies!

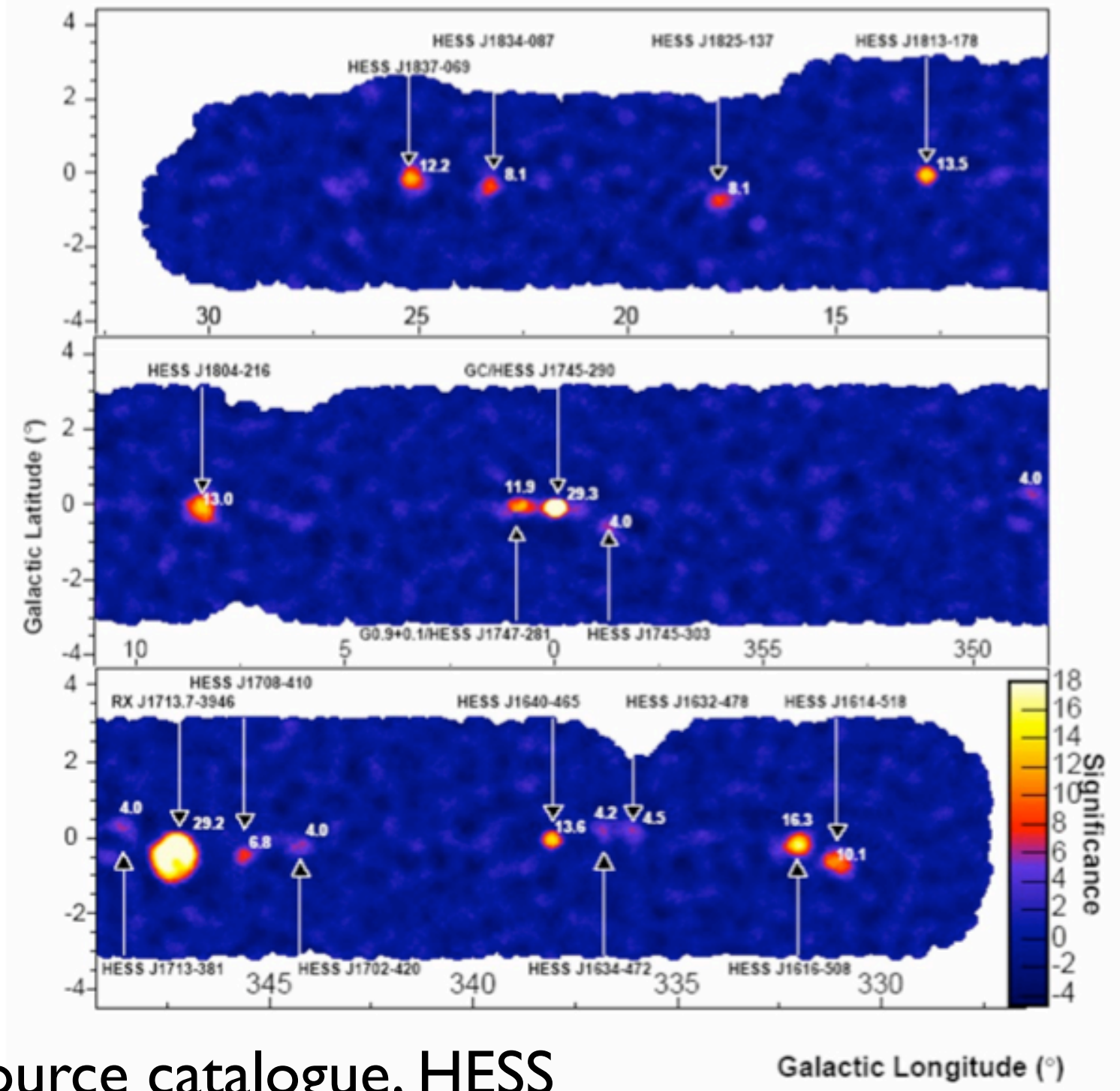
- Surveys and catalogues
- Images and maps
- Light curves
- Spectra

And two complementary methods!

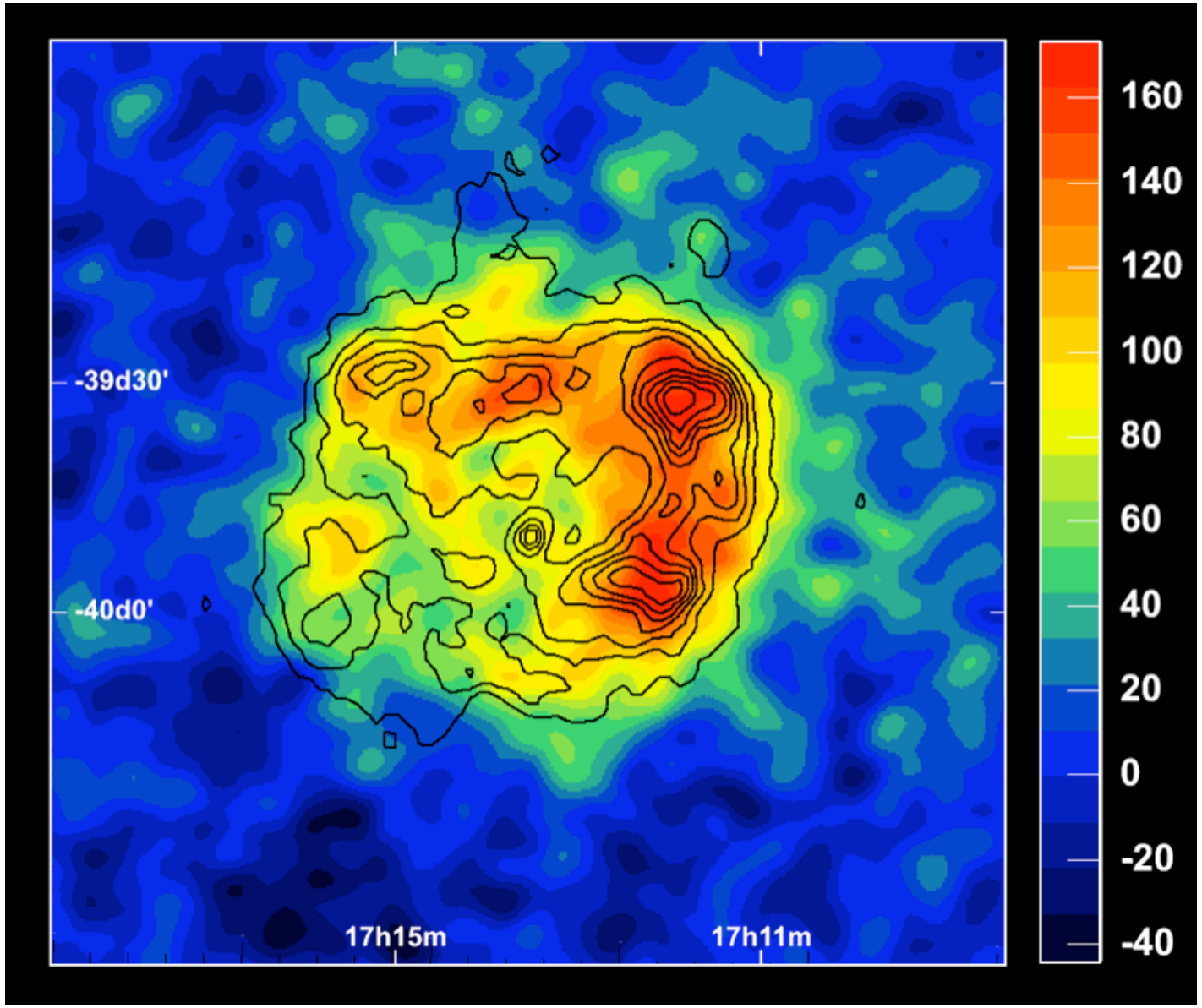


HESS Galactic plane survey

Astro-ph/0510397



Source catalogue, HESS J1234-567 etc

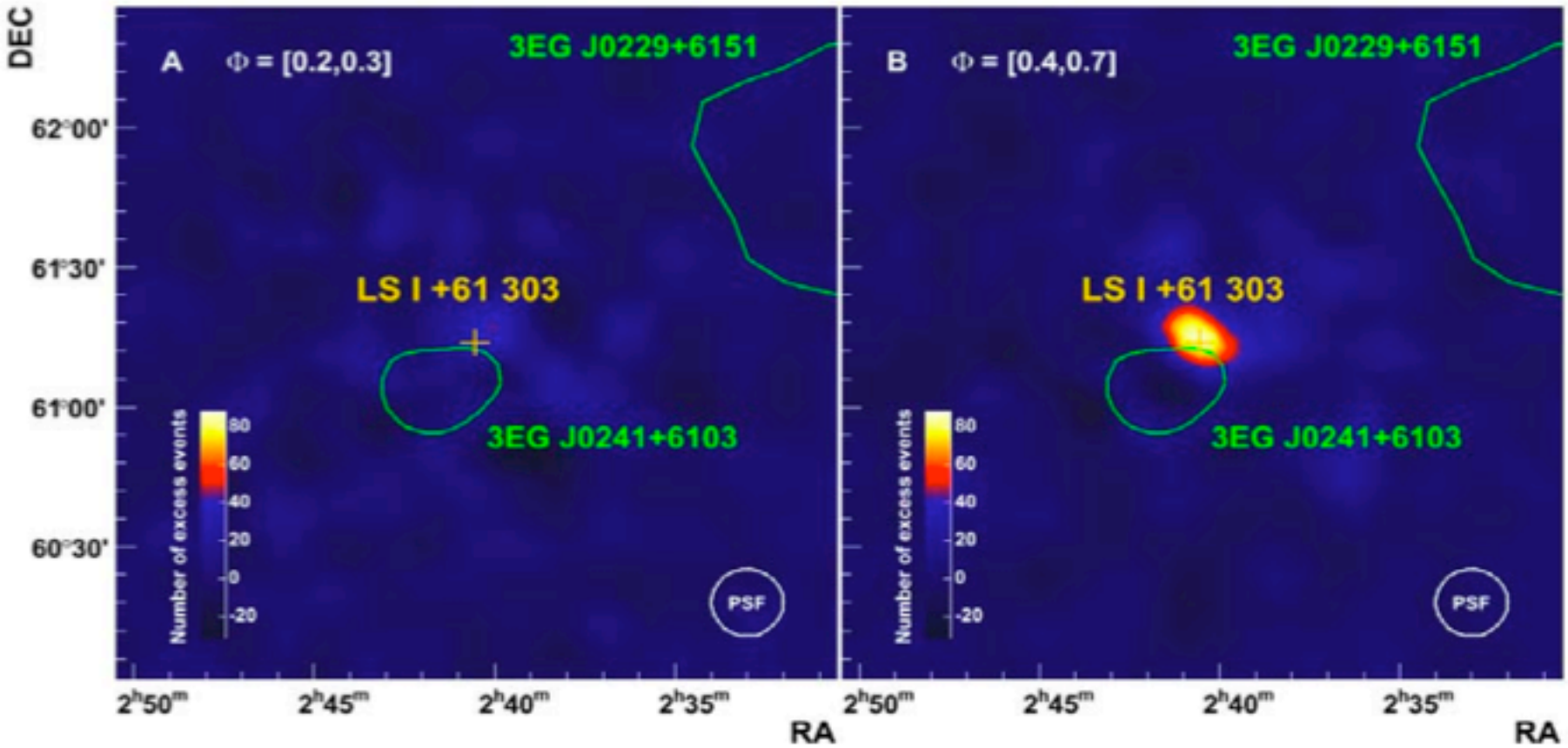


TeV Image of RX J 1713-3946 showing comparison with X-ray morphology

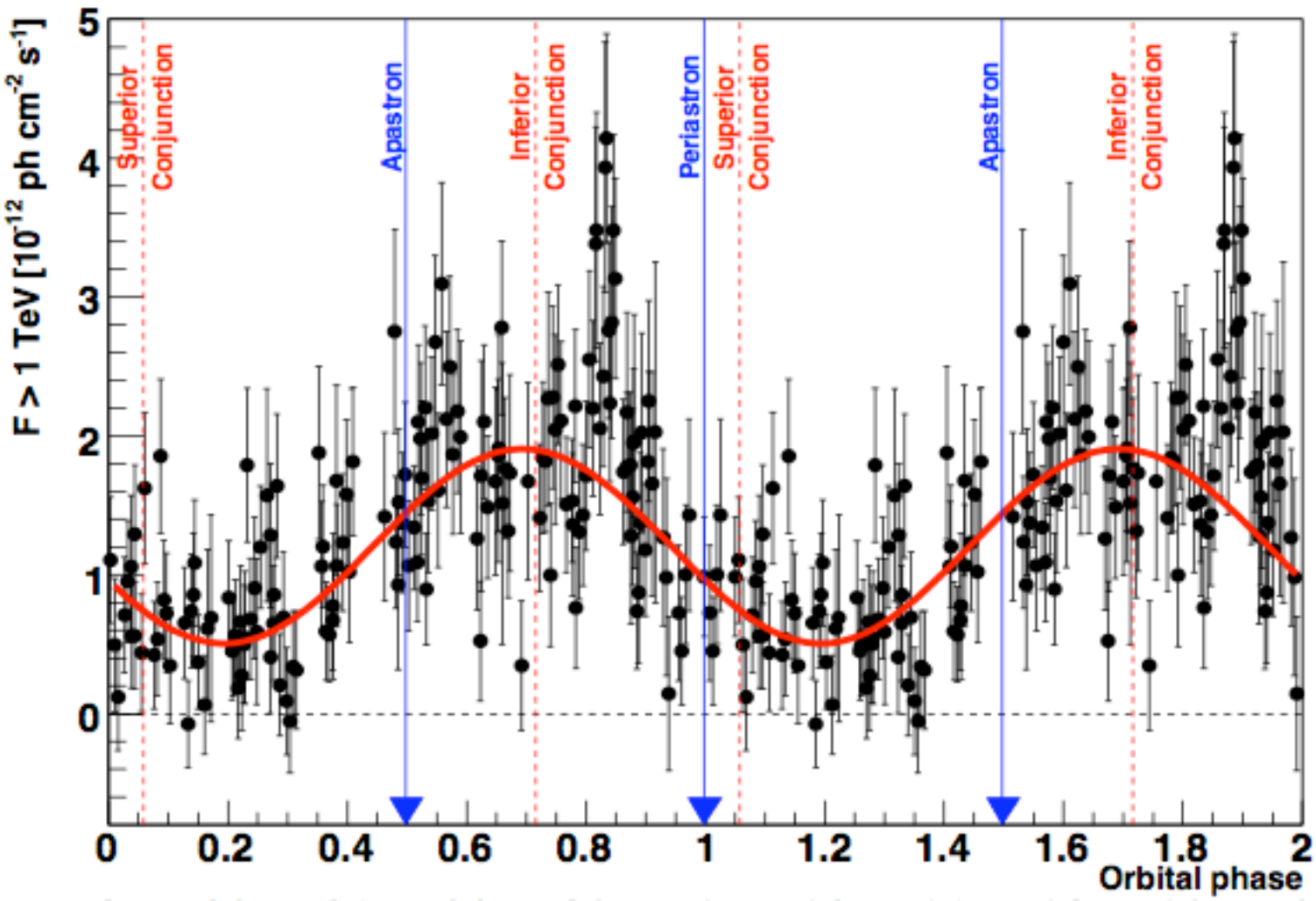
Nature 432 (2004) 75-77

Periastron

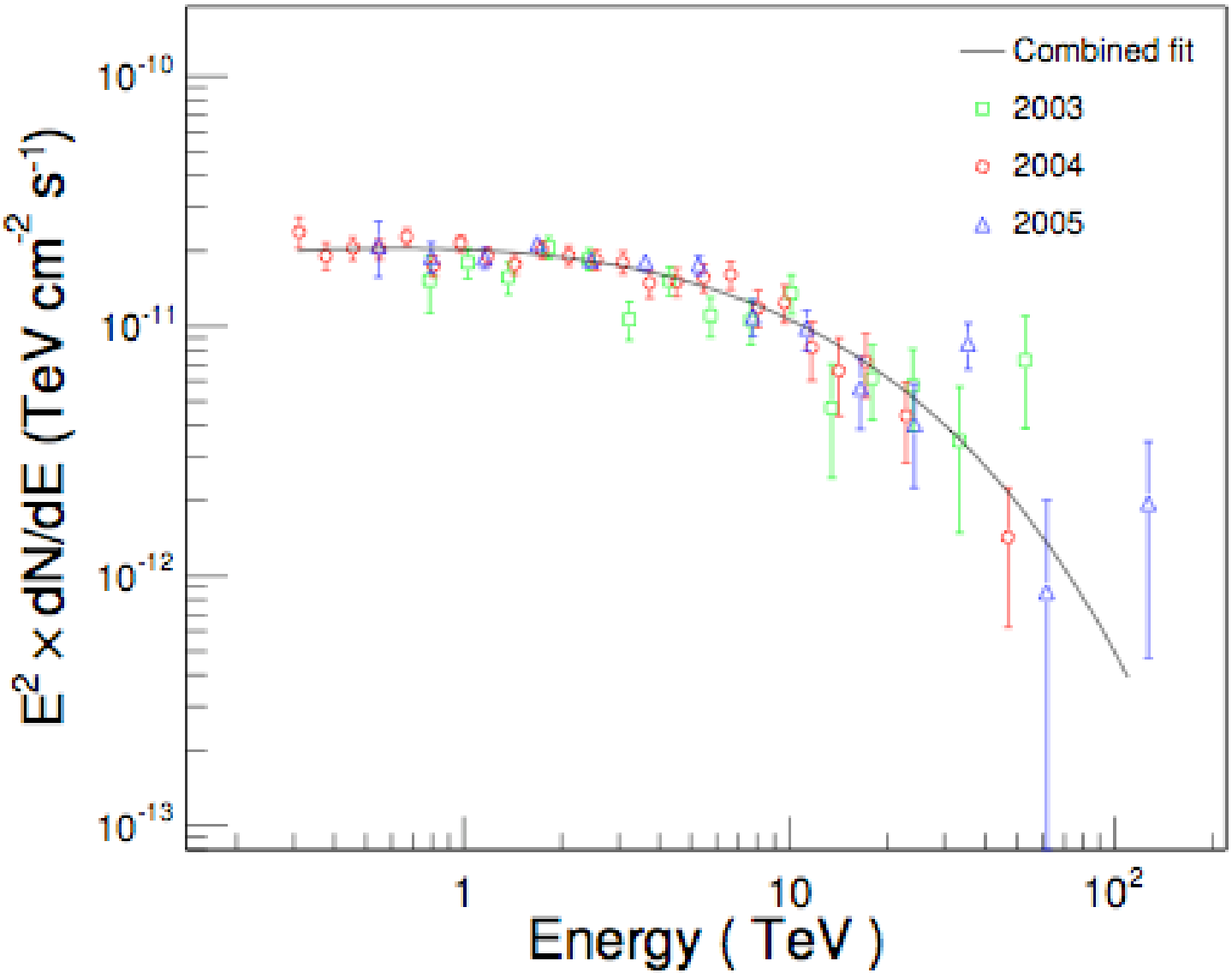
Apastron



MAGIC images of LS I +61 303 showing time variability, astro-ph/0605549



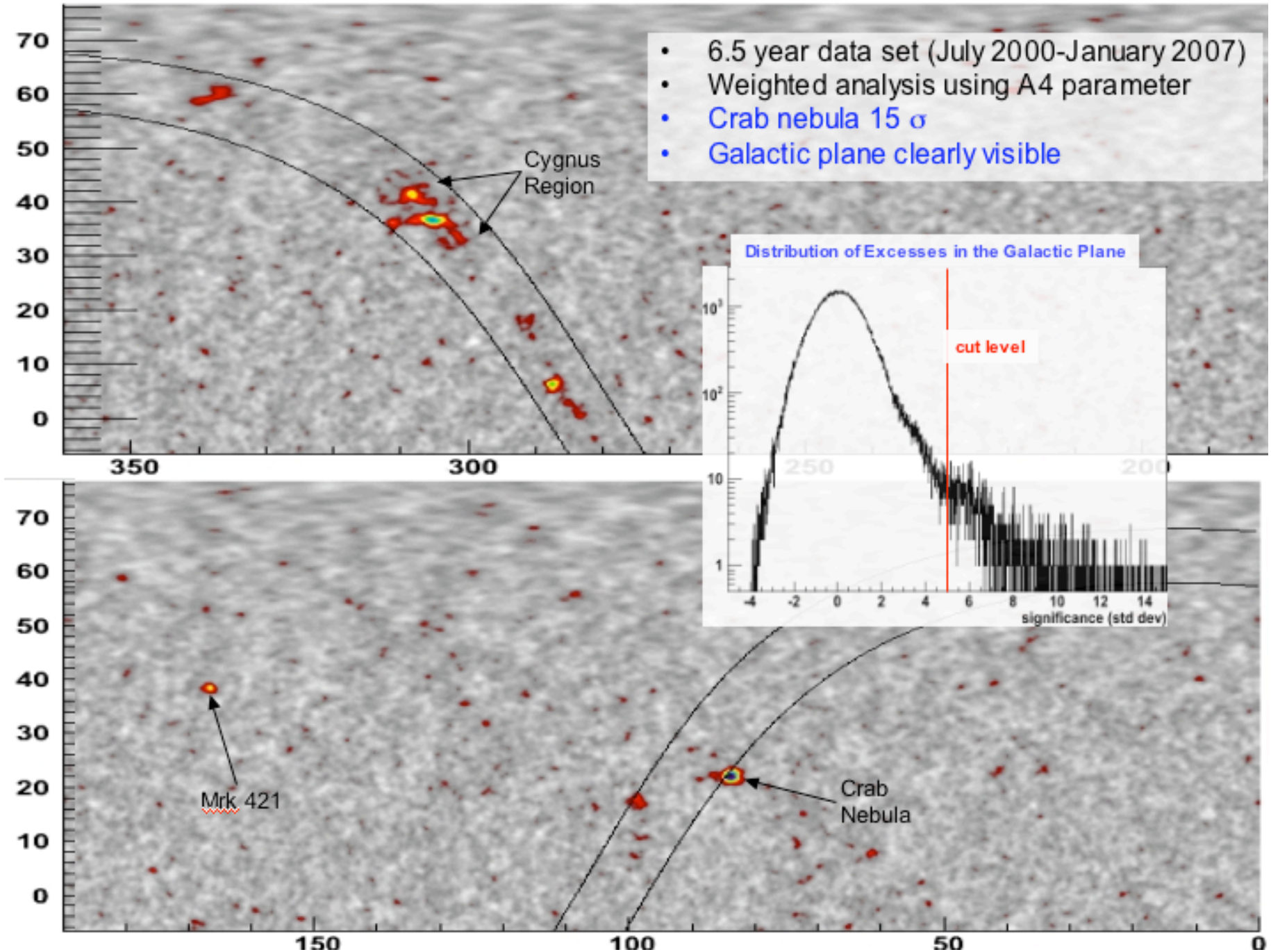
HESS TeV lightcurve of LS5039 showing orbital modulation - astro-ph/0607192



Energy spectrum of RX J1713-3946 showing hard spectrum with high-energy cut-off, astro-ph/0611813

New development

- Milagro technique now clearly works!
- Have all-sky monitoring and survey capabilities at TeV energies.
- Complements classical ICT method very nicely.



Courtesy of Gus Sinnis

Physics

- Above about 10 GeV a gamma-ray deposits enough energy in the atmosphere to trigger ground-based detectors
- Problem is the charged cosmic ray background
- Key is gamma/hadron separation

Key realisation

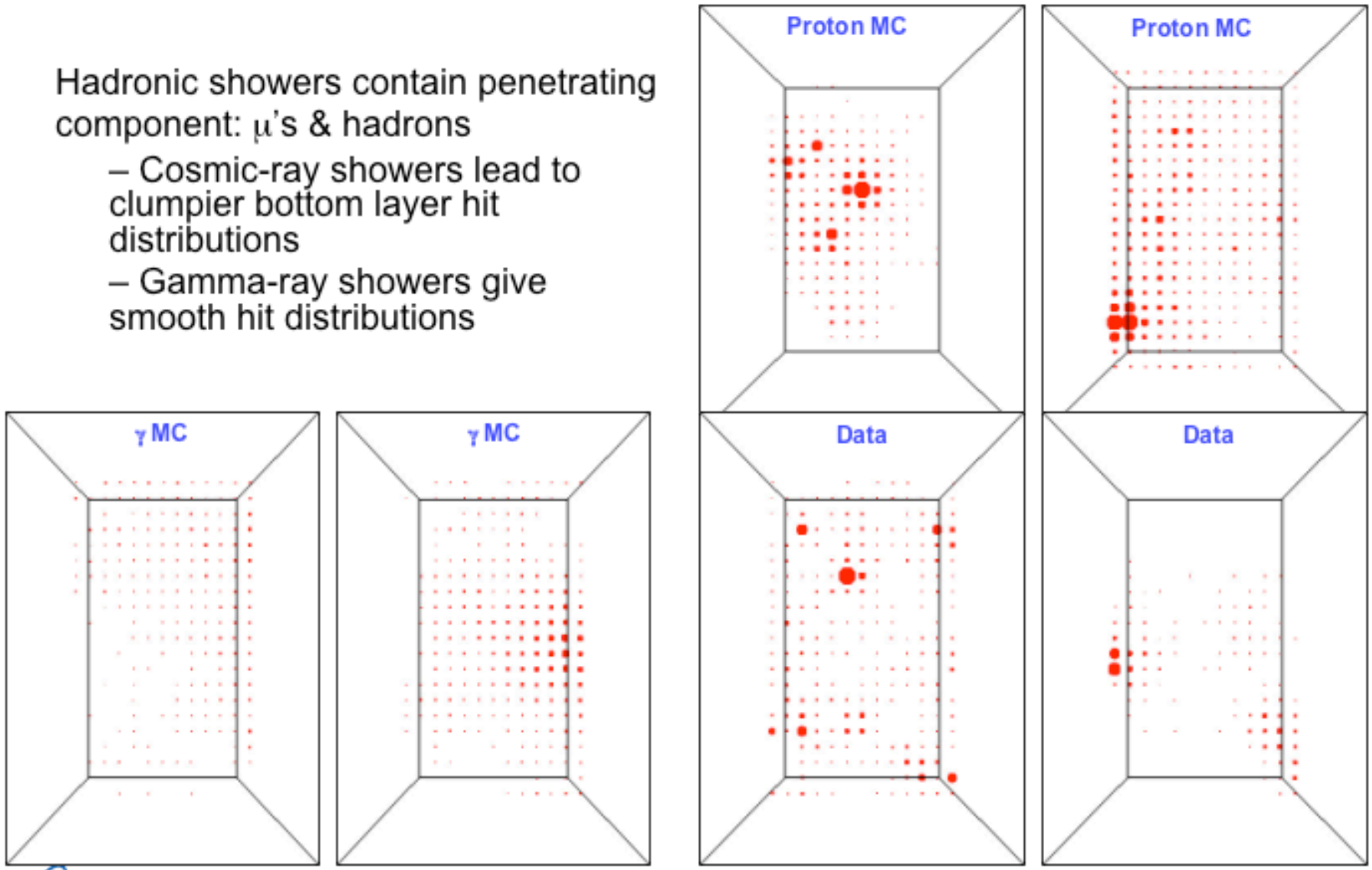
- Hadronic showers have a lot of sub-structure (particles with high transverse momenta, jets etc)
- Electromagnetic showers are much more uniform
- Exploited by both ICT and Milagro-type detectors for gamma/hadron separation

- Need to either
  - Image Cherenkov light of shower well (good angular resolution, several stereo views)
  - Sample ionisation of shower as close to shower maximum as possible and with dense sampling
- Then can improve gamma/hadon ratio by two to three decades....

Background Rejection in Milagro

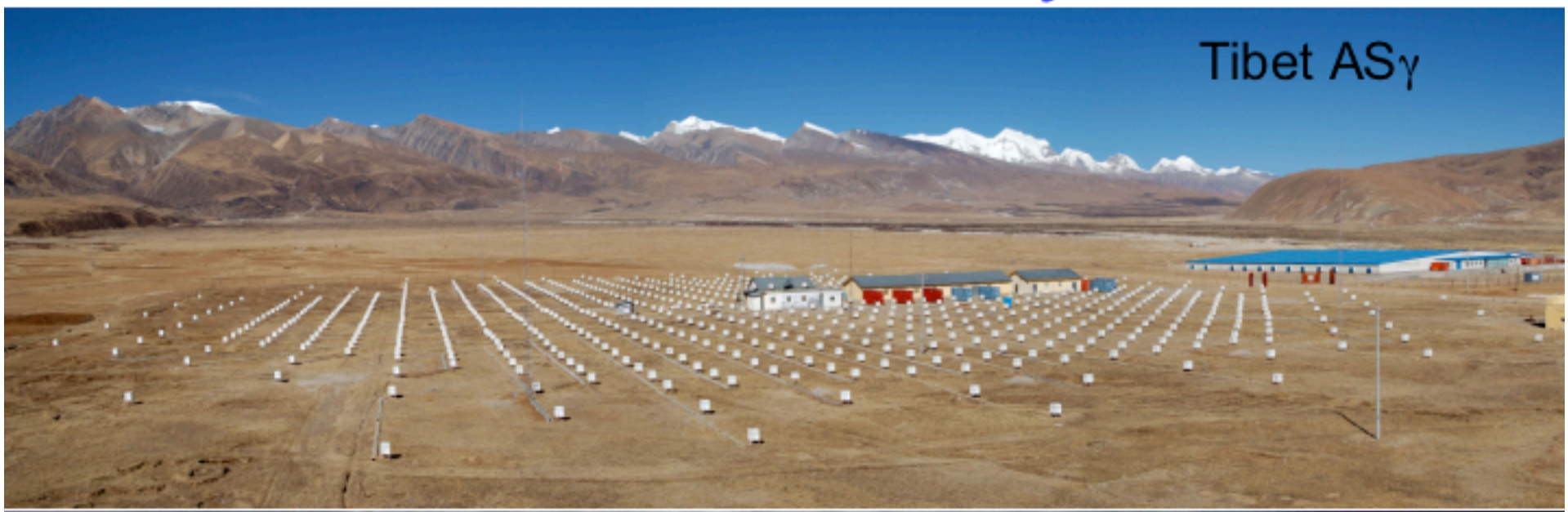
Hadronic showers contain penetrating component: μ's & hadrons

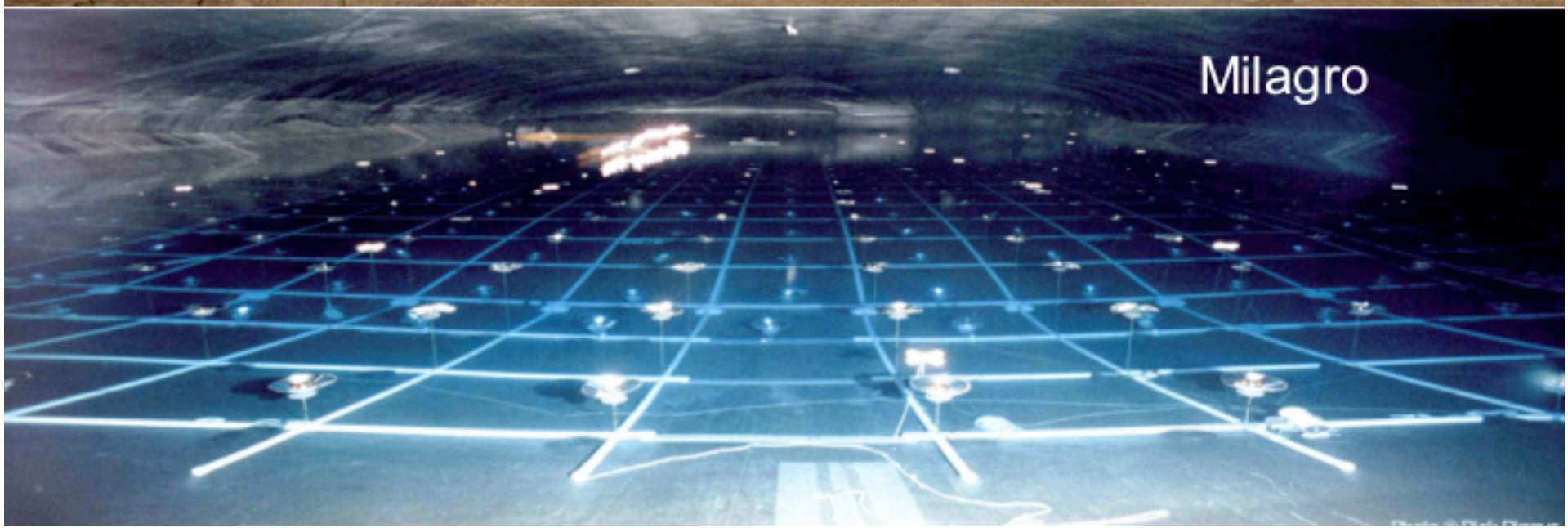
- Cosmic-ray showers lead to clumpier bottom layer hit distributions
- Gamma-ray showers give smooth hit distributions



Los Alamos NATIONAL LABORATORY EST.1943

Current Generation EAS Arrays





Courtesy of Gus Sinnis

- Synoptic EAS arrays and pointed IACT arrays both clearly work and have opened up a new astronomical window at TeV energies.
- Need to make astronomers aware of this!
- Need to develop "roadmaps" for the field and plan for the future - CTA, AGIS etc....

Currently operating

- IACTs
  - CANGAROO, HESS, MAGIC, VERITAS
- EASAs
  - Milagro, Tibet
- All run as experimental consortia

- At least for IACTs need to move to "Observatory" mode of operation for next generation.
- Need to integrate with virtual observatories.
- Need standardised data products and user-friendly reduction and analysis software tools.
- Less critical for EASAs...

European proposal - CTA
Cherenkov Telescope Array

- What characteristics should CTA have to optimise the science return?
- What synergies are there with other planned instruments and projects?
- Why now?
- 25 page report produced by WG.....

Context

- Can certainly built systems with
  - 0.1 km^2 @ 100GeV
  - 10 km^2 @ 10 TeV
- 50 GeV possible, 30 GeV maybe....
- 100 TeV possible, but expensive...
- Angular resolution could be improved to 0.02 degrees above 1 TeV

The usual suspects...

- SNRs and origin of CRs
- PWNe
- Binary systems
- OB associations, starburst galaxies
- Galactic Centre
- Blazars
- Other AGNs

and some long shots...

- Pulsars
- GRBs
- Clusters of galaxies
- UHECR sources
- Dark matter

and some other uses...

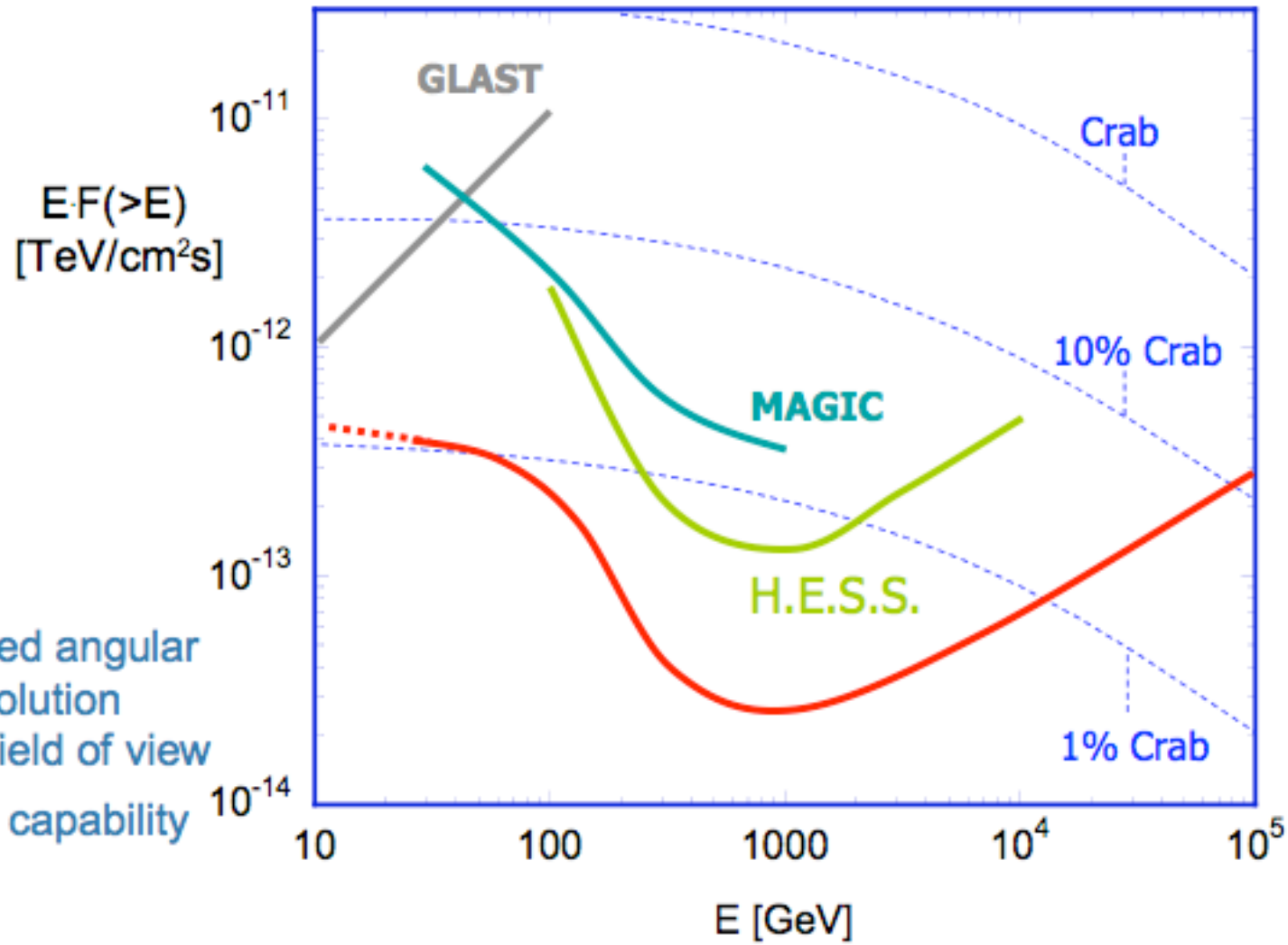
- Ultra-fast optical astronomy
- Optical intensity interferometry (Hanbury Brown method)
- CR studies (composition, electrons etc)

Drivers

- Sensitivity is most important issue - need to push into the milli-Crab regime for almost all proposed areas of study.
- Improved angular resolution and large FOV is highly desirable for many studies.
- Extended energy coverage is important, but to higher as well as to lower energies and is not a critical driver.
- Must be designed and operated as an open observatory.

Sensitivity aimed for

An advanced Facility for ground-based gamma-ray Astronomy



+ Improved angular resolution
+ Large field of view
+ all-sky capability

TenTen: A new IACT Array for Multi-TeV Gamma-Ray Astronomy

Gavin Rowell, Victor Stamatescu, Roger Clay, Bruce Dawson, Ray Protheroe, Andrew Smith, Greg Thornton, Neville Wild

(University of Adelaide, Australia)

- Instead of a general purpose IACT system focus on high energy region.
  - Know there are sources at >10TeV.
  - Intrinsic interest for CR origin (where are the "knee" particles accelerated?)
  - Technically easier - more light, better separation, lower backgrounds.
  - But very low fluxes!

Why Consider multi-TeV energies?

- Growing number of Galactic TeV sources, most with hard spectra,
  some reaching >20 TeV –> there are definitely E>10 TeV sources
  Present instruments limited to few x 10 TeV
  E>0.1 TeV telescope programmes are packed

- Need to search for and understand Particle PeVatrons
  PeV Acceleration not well understood - Major mystery in astrophysics...
- E>10 TeV: Easier to separate hadronic & leptonic components
  (synchrotron 'cooling' of electrons & reduced IC cross-section)
  --> better chance to determine origin of parent particles in sources

.....

- *E>10 TeV detection technically simple with small Cherenkov imaging telescopes*
  & low evt rates per telescope
  need >=10 km ^{2} collection area for sufficient statistics (few% Crab fluxes)
  There is great potential for Gamma Ray telescopes dedicated to
  multi-TeV studies

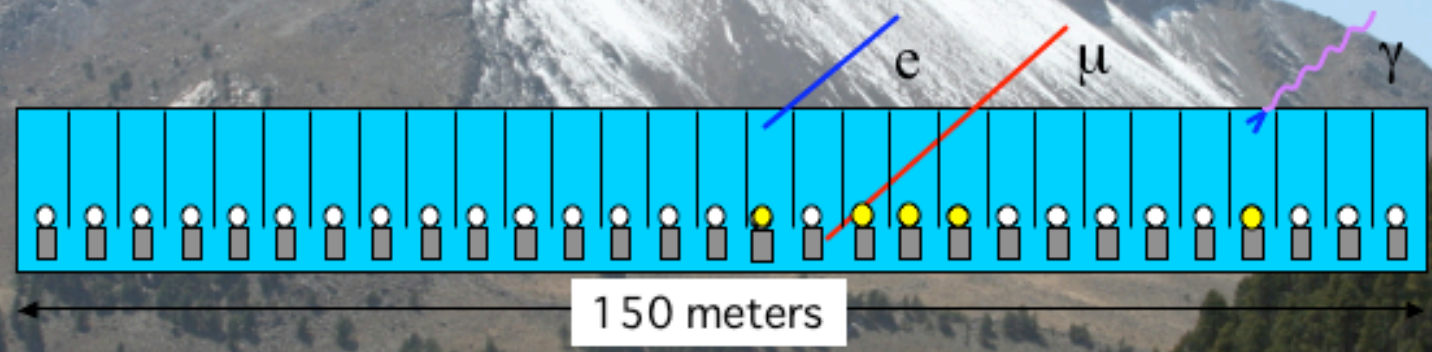
Courtesy of Gavin Rowell

Synoptic EASAs

- Concept proven by Milagro, Tibet
- All-sky monitors, survey instruments
- Proposals for HAWC, sHAWC...

HAWC: High Altitude Water Cherenkov

- Build pond at extreme altitude
  - Sierra Negra, Mexico 4100m
- Incorporate new design
  - Optical isolation between PMTs
  - Larger PMT spacing
  - Single PMT layer (4m deep)
- Reuse Milagro PMTs and electronics
- 22,500 m^2 sensitive area



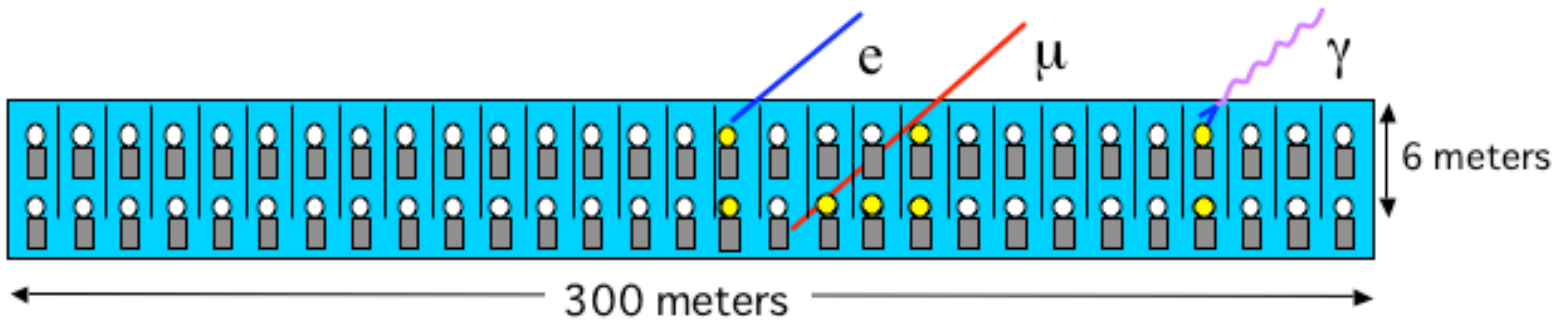
~$6M for complete detector
~10-15x sensitivity of Milagro
Crab Nebula in 1 day (4 hours) [Milagro 3-4 months]
4x Crab flux in 15 minutes
GRBs to z < 0.8 (now 0.4)

Courtesy of Gus Sinnis

And even....

superHAWC

- Build pond at extreme altitude (Tibet 4300m, Bolivia 5200m, Mexico 4030m)
- Incorporate new design
  - Optical isolation between PMTs
  - Much larger area (90,000 m^2)
  - Two layer design (2 m and 6 m below water surface)
- Advanced electronics and DAQ (~200MBytes/sec)



~$50M for complete detector

~60-100x sensitivity of Milagro

Crab Nebula in 30 minutes

4x Crab flare in 2 minutes

GRBs to z >1 (now 0.4)

Repeat Bottom line

- The future is very bright.
- Two proven and complementary approaches - need to develop both.
- Excellent synergies with satellite instruments, SKA, LOFAR, etc....
- Problems are political and organisational, not technical....