Status of the CTA project: Science Case

The Future of Very High Energy Gamma-ray Astronomy
Chicago, May 14, 2007

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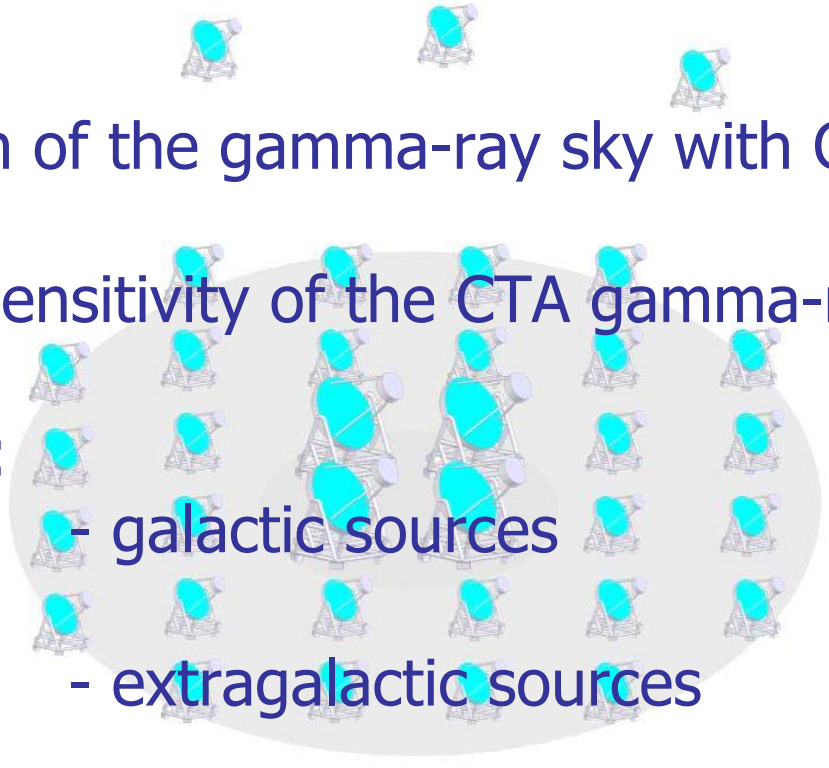
on behalf of CTA:

Armenia, Czech Republic, France, Germany, Italy, Ireland, Namibia, Netherlands, Poland, South Africa, Spain, Sweden, Switzerland, UK, ...

Outline

An advanced facility for ground-based high-energy gamma ray astronomy



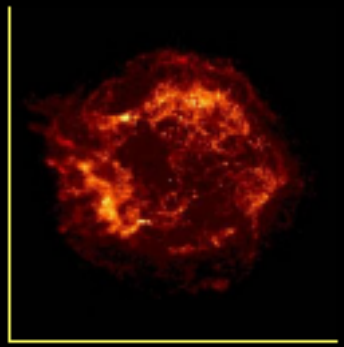
- Exploration of the gamma-ray sky with CTA
- Expected sensitivity of the CTA gamma-ray telescope
- CTA reach:
  - galactic sources
  - extragalactic sources

Summary

Science topics

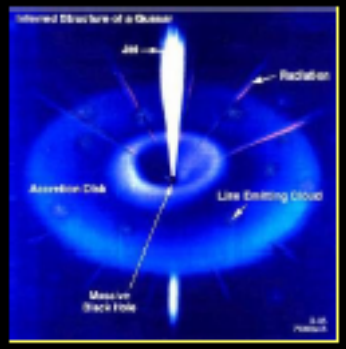
CTA

An advanced facility for ground-based high-energy gamma ray astronomy

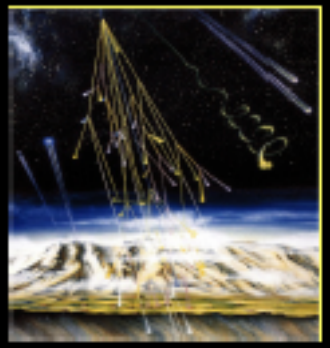


SNRs

Pulsars and PWN

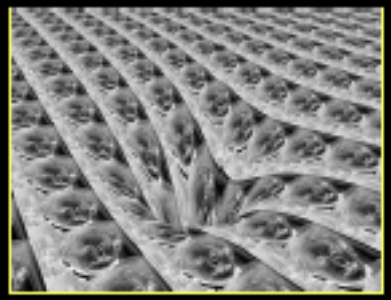


AGNs

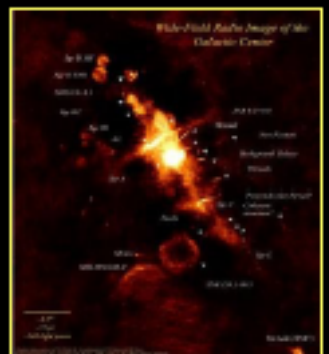


Origin of cosmic rays

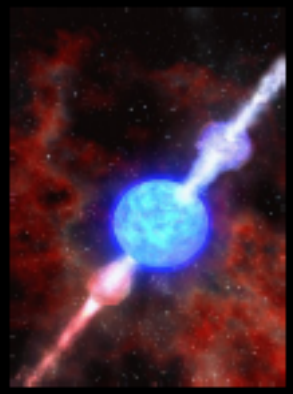
Space-time & relativity

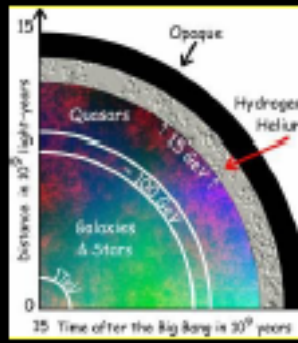


Dark matter



GRBs





Cosmology

Science potential

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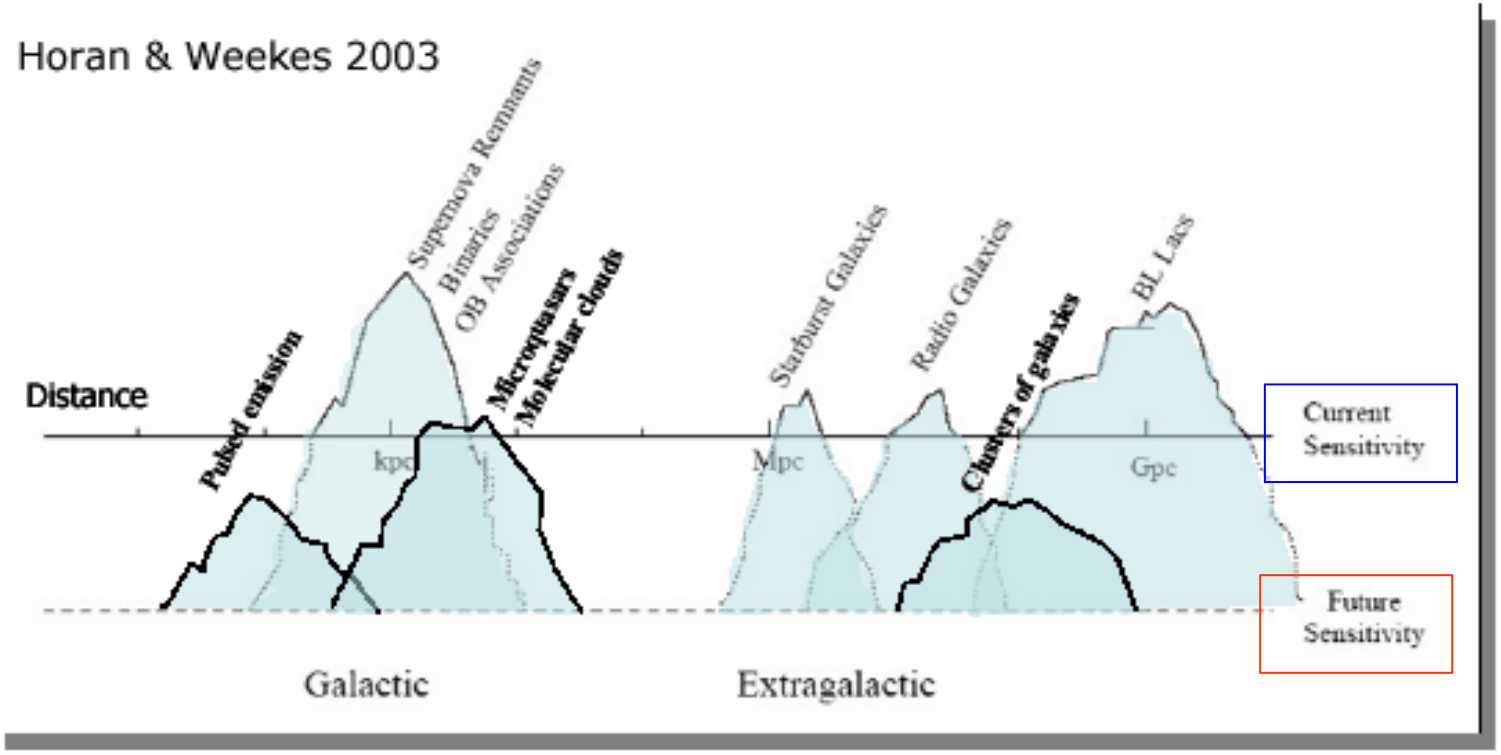

- Current instruments have passed the critical sensitivity threshold and reveal a rich panorama, but this is clearly only the tip of the iceberg
- Broad and diverse program ahead, combining guaranteed astrophysics with significant discovery potential

VHE Log(S)-Log(N) plot

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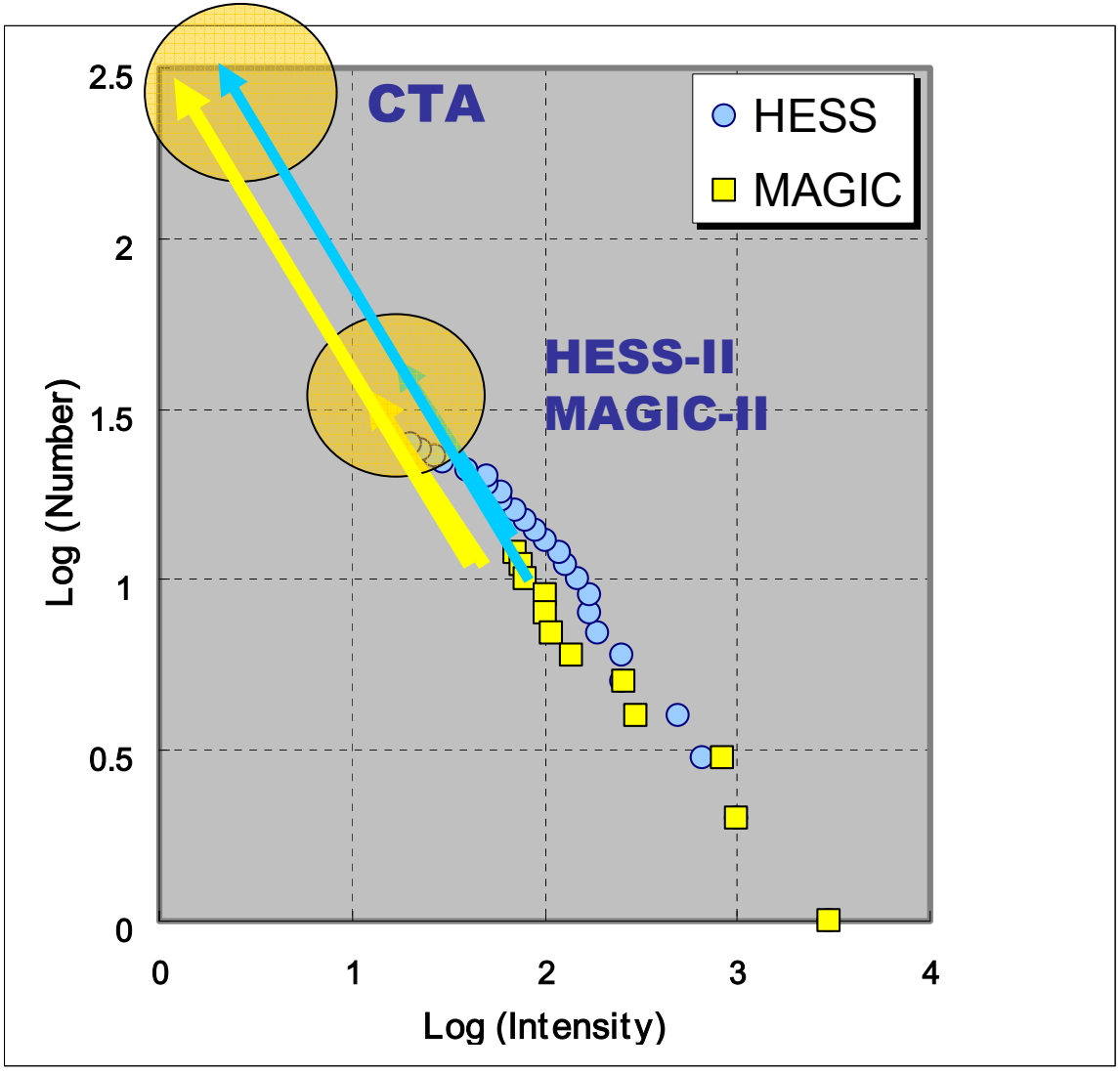


HESS-I ~60 sources
MAGIC-I ~20 sources

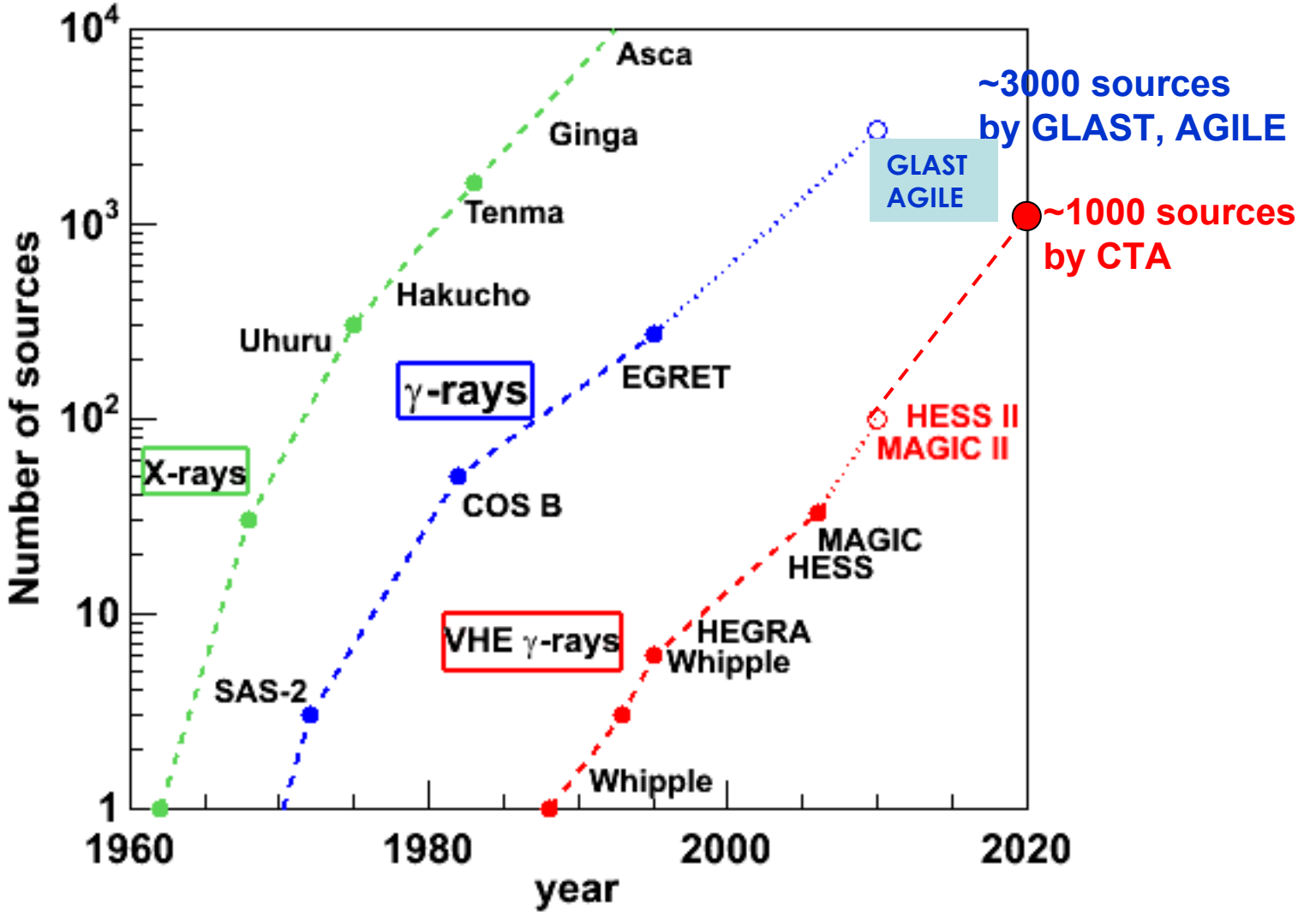
Log(N) ~ -1.0 Log(S) ???

HESS-I+II ~100 sources
MAGIC-I+II ~60 sources

CTA ~1000 sources

CTA

Kifune Plot



Possible CTA sensitivity

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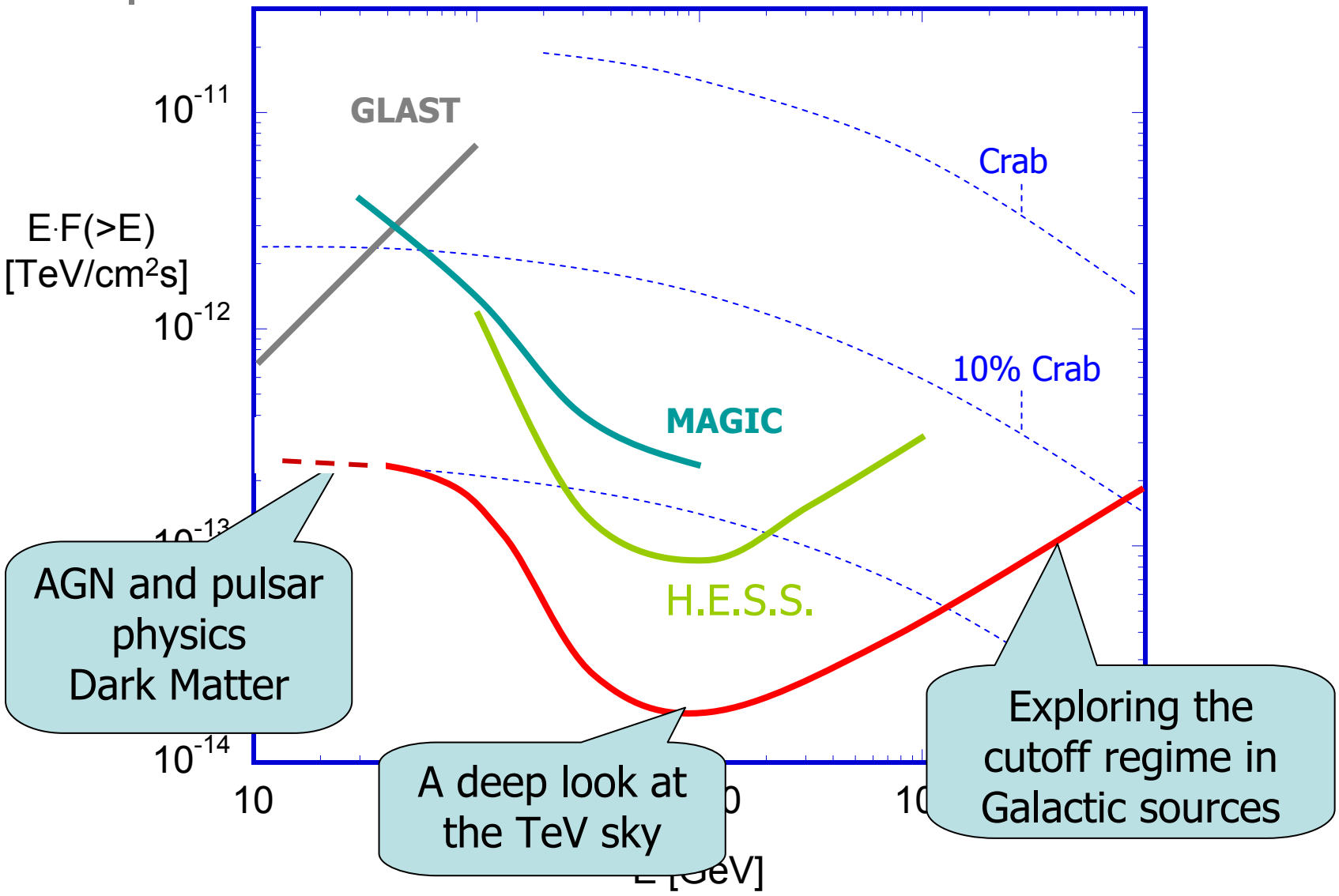


10-100 GeV:

low energy region for CTA, currently yet unexplored. New EM window.
GLAST to cover it, decreasing sensitivity with energy.
Reminder: GLAST sensitivity curve is 1-year observation.
Question: what does CTA specifically brings beyond GLAST?

100 GeV - 10 TeV:

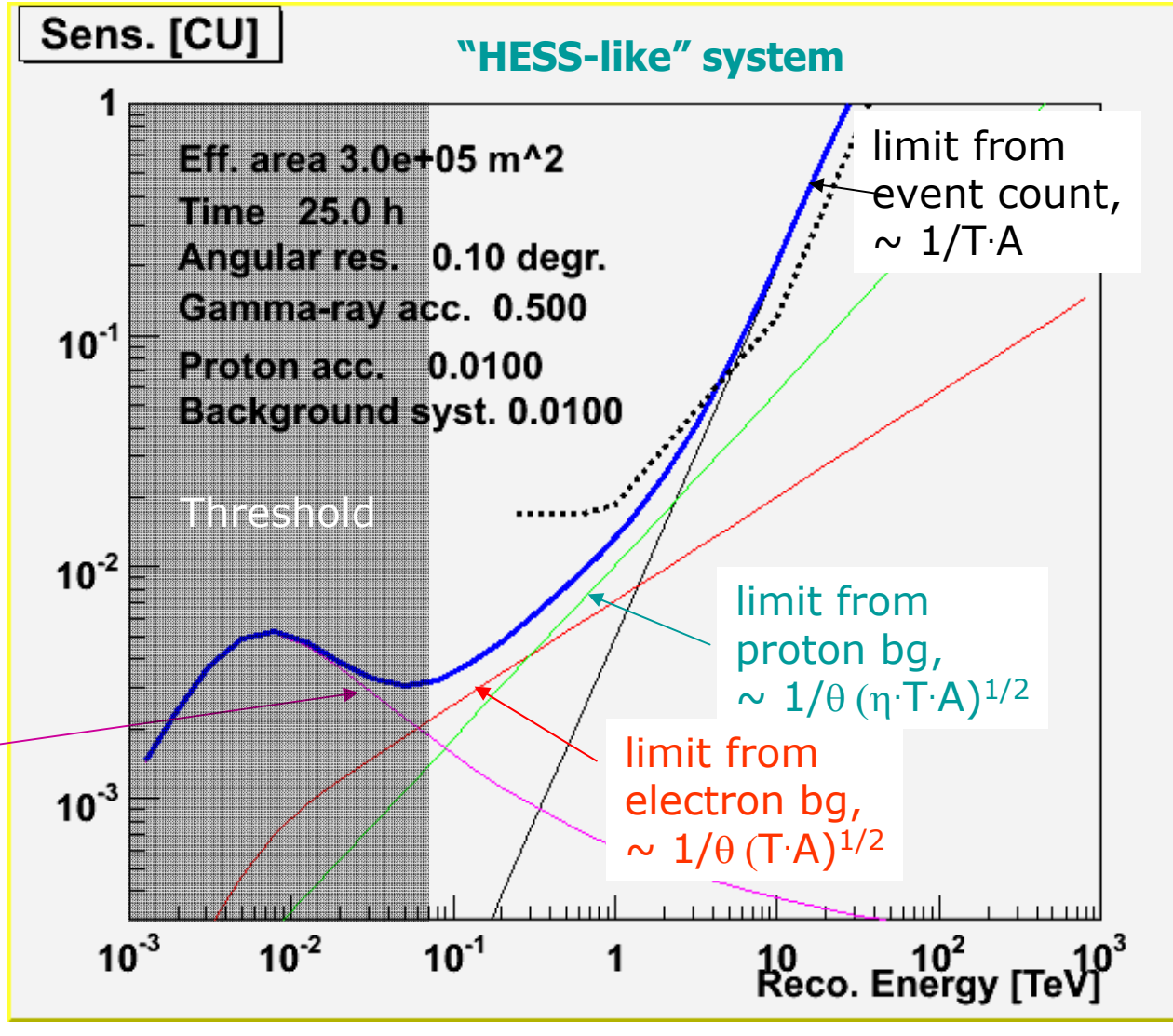
HESS and MAGIC success to be seen as pathfinder telescopes in this regime, with secure astrophysics and feedback to detailed theory modeling

>10 TeV:

Predictably few new sources, but direct appeal to cosmic ray acceleration sites, possibilities for unexpected breakthrough, again mostly unexplored part of the EM, exotic phenomena ?

Sensitivity: background suppression

Minimal detectable flux per band $\Delta\log_{10}E=0.2$, relative to a power-law Crab spectrum



CTA: galactic sources

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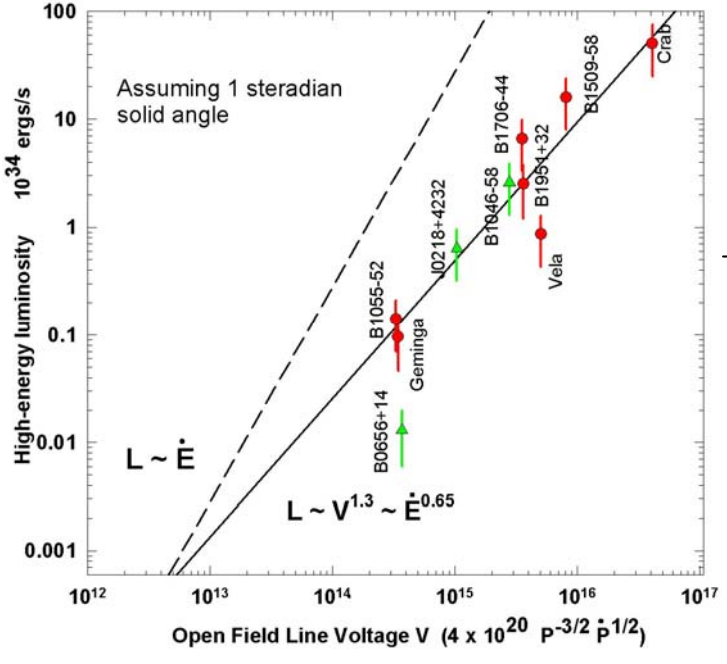
- **Pulsars**
- **SNRs/PWNe/cosmic-ray related**
- **X-ray binaries and microquasars**
- **clusters/stellar systems**
- **Galactic Center (excluding Dark Matter studies)**

Pulsars: populations

- **Essentially, to first order pulsed detection is limited by photon statistics**
  - GLAST/LAT is more than 100 times more sensitive than EGRET above 10 GeV
- **Extrapolate to CTA:**
  - **expected a factor of 10 (more?) better than LAT at ~50 GeV**
  - difference at higher energy even larger, follow up of pulsar cutoffs @ HE
  - improvement in population studies, and feedback to theory



Example of questions requiring a larger sample:

- What happens as the observed luminosity approaches the total available spin-down luminosity?
- How much does the assumption of a 1 sr beaming solid angle distort the picture?
- How does this correlation looks like above 10 GeV?

Pulsars: cut-offs with large statistics

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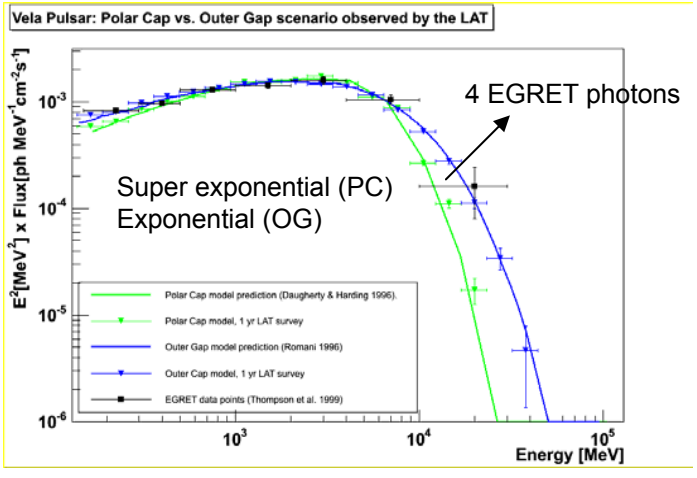

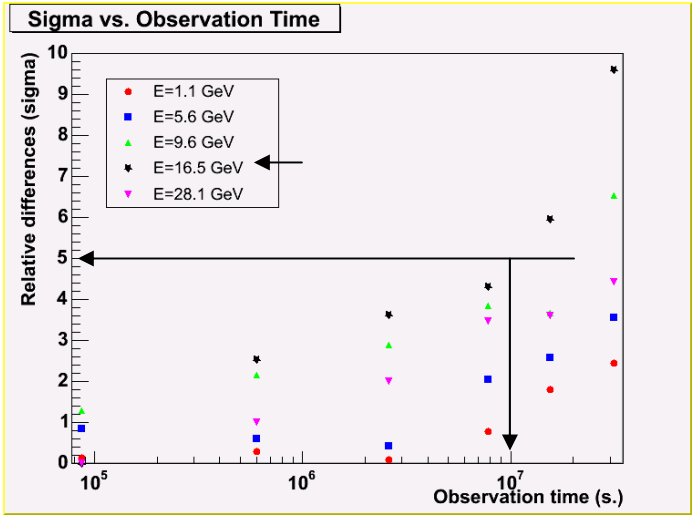

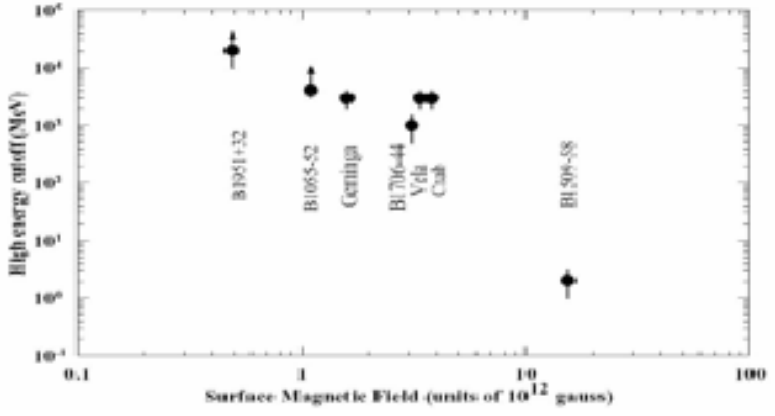

Example of question requiring a large sample:
correlation between Ec and surface magnetic field?

- Vela is an especial case for the LAT (brightest source above 100 MeV).

- **The differentiation between models is best at E>10 GeV and requires 1 year statistics.**

- It will be hard to achieve for many (a handful?) pulsars at this level of confidence.

→ **CTA can do this with a large sample**

Pulsars: open questions

CTA

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- **How and where are particles accelerated in the pulsar magnetosphere? What are the high-energy radiation mechanisms:**
  CTA: study of pulsar profiles (geometry), and cutoffs (acceleration)

- **Are processes the same for all pulsars:**
  CTA: broad band spectra with high number statistics

- **Are there gamma-ray millisecond pulsars? Are there gamma-ray magnetars:**
  CTA: accessibility to large number of 'in principle' observable ms pulsars, large sensitivity above 10 GeV

- **What are the population trends: Spectrum index vs age, L(gamma) vs L(SP), Ec vs B0, limit to gamma-ray radiation efficiency as function of E, radio-loud to radio-quiet fraction:**
  CTA: almost all radio pulsars in the P-Pdot diagram accessible, large number for population studies, answers directly measured, blind searches

- **Serendipity:**
  CTA: high confidence detection in seconds timescales may open the window for new high energy phenomena (e.g., timing noise? Glitches?)

SNR, PWN: extending energy coverage

CTA
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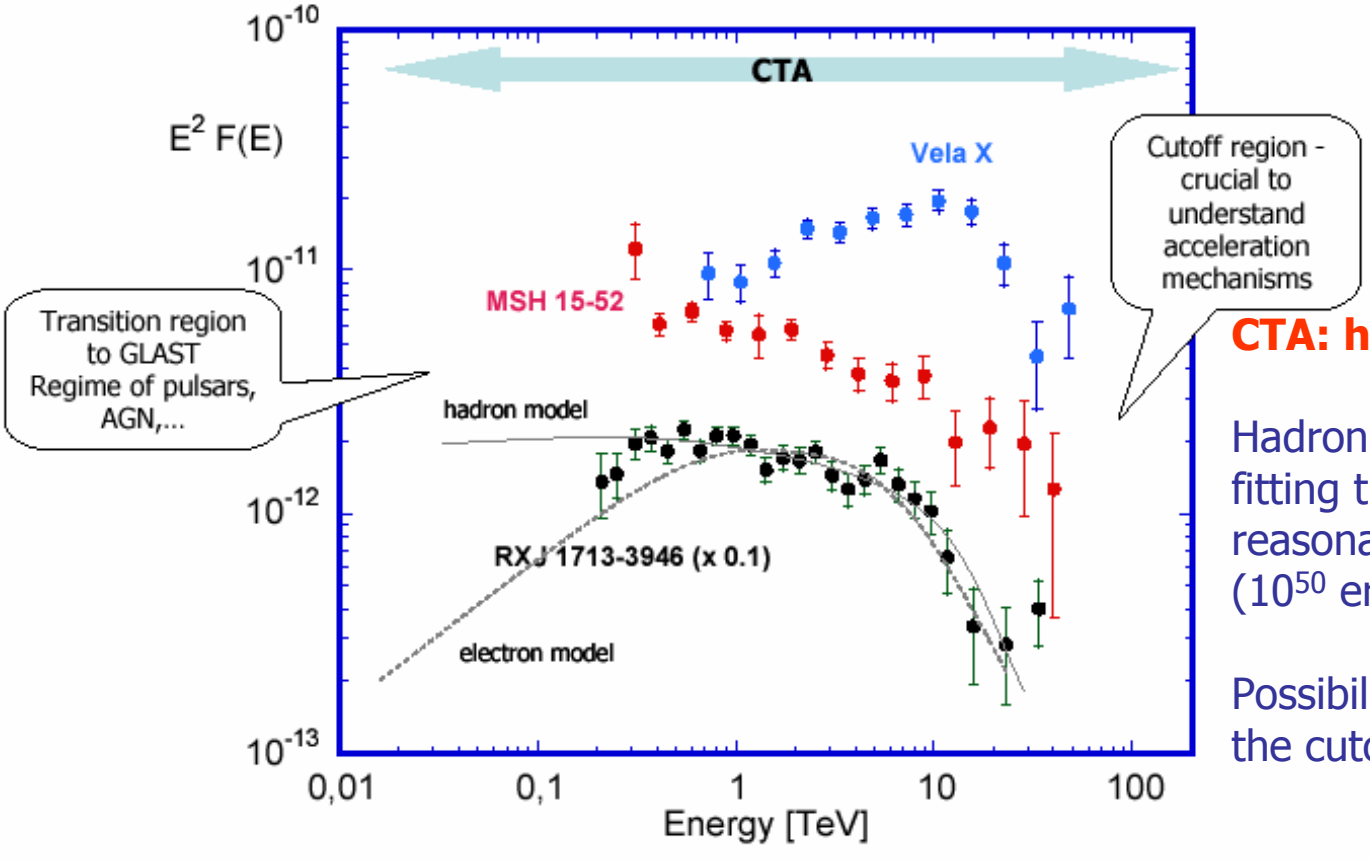


CTA: hadronic or leptonic ?

Hadronic models comfortably fitting the spectrum, with reasonably energetics (10^{50} erg in n=1 cm^{-3} medium)

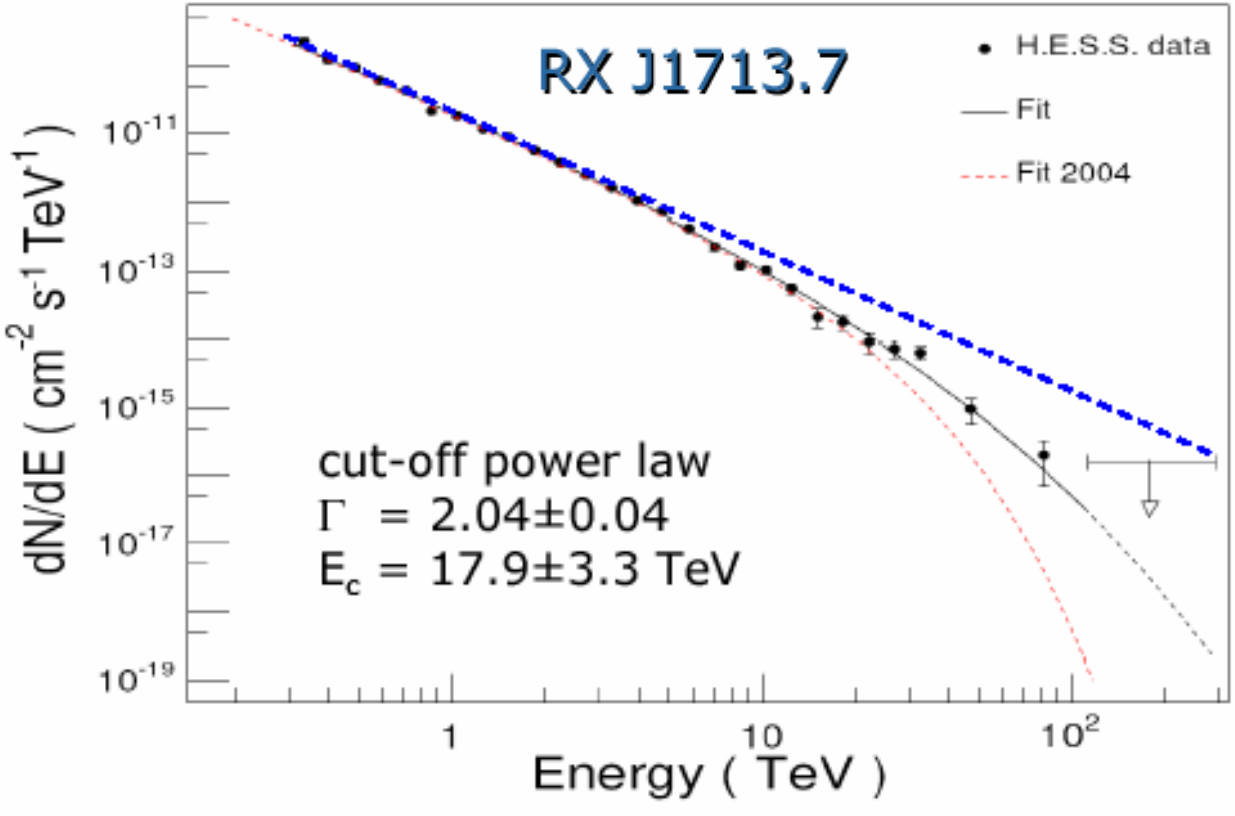
Possibility of differentiating the cutoff energy.

A large ZOO of PWNs is awaiting for CTA (building upon the results from HESS):

less powerful pulsar --> weaker magnetic field --> higher gamma-ray efficiency

SNR, PWN: extending energy coverage

Particle acceleration to beyond 100 TeV



H.E.S.S., astroph 0611813

SNR, PWN: morphology

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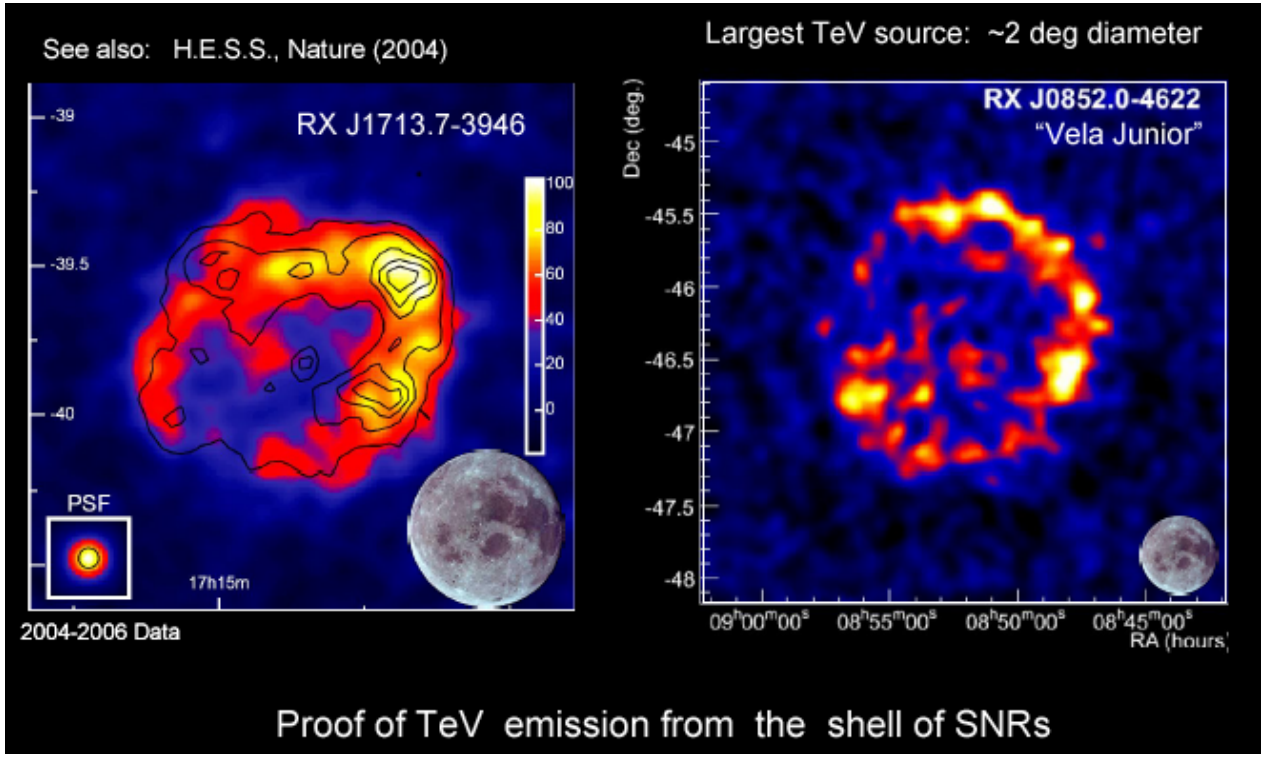

Study of energy dependent morphology of the extended sources:

- large field –of-view
- excellent angular resolution
- good sensitivity
- low energy - high energy domains

CTA should provide these conditions

X/Gamma-ray binaries

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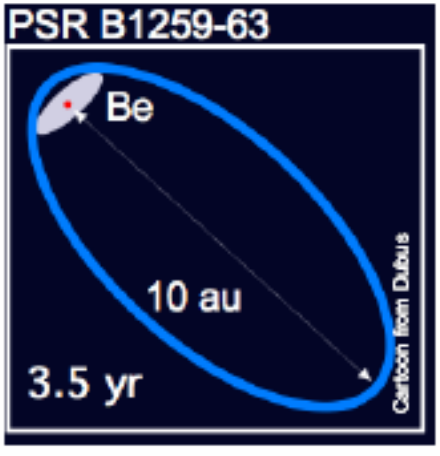

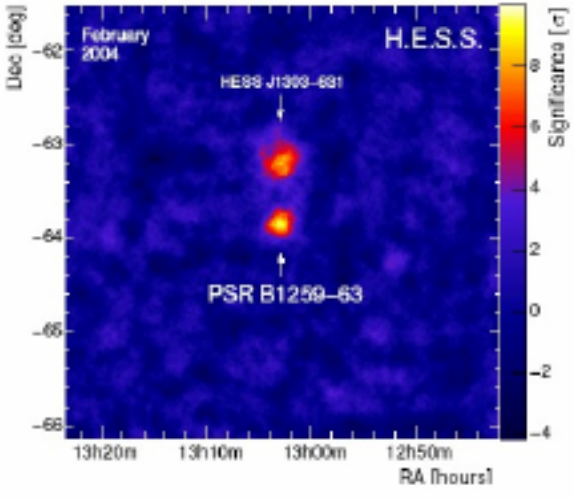

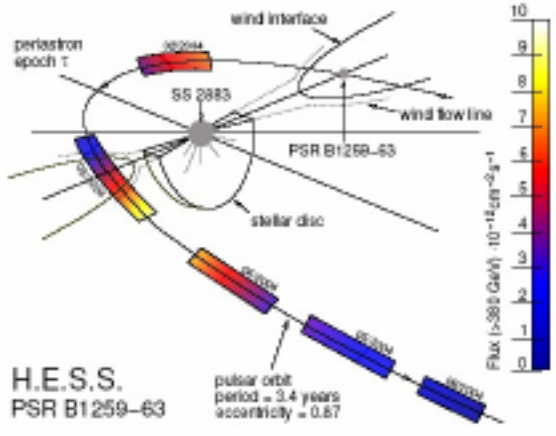

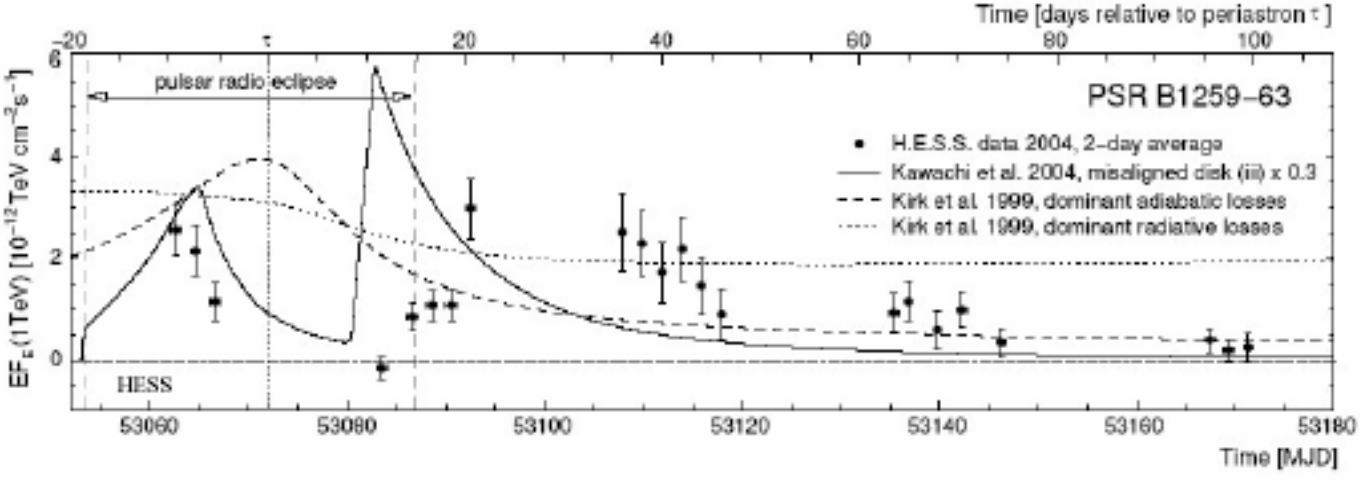

X/Gamma-ray binaries

- **Significantly enlarge the population of XRBs/MQs observed**

  CTA :
  understand dichotomy between pulsar/star interactions and jets, detailed log N - log S

- **Feedback to models**

  CTA :
  understand the emission process, the emitting region, absorption/cascading, magnetic fields, composition, primaries

- **Short term variability**

  CTA :
  follow up radio and/or X-ray flares
  GeV to TeV emission in state changes?
  Radio - X - Gamma correlation?

- **Explore the jet - ISM interaction**

  CTA : steady + periodic source components, keys to CR acceleration in Galactic jets

Galactic Center & Cosmic rays

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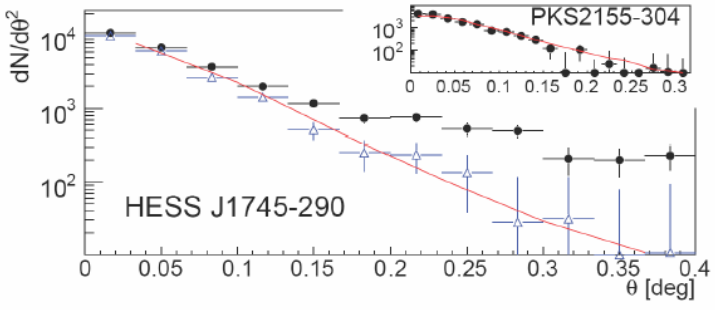
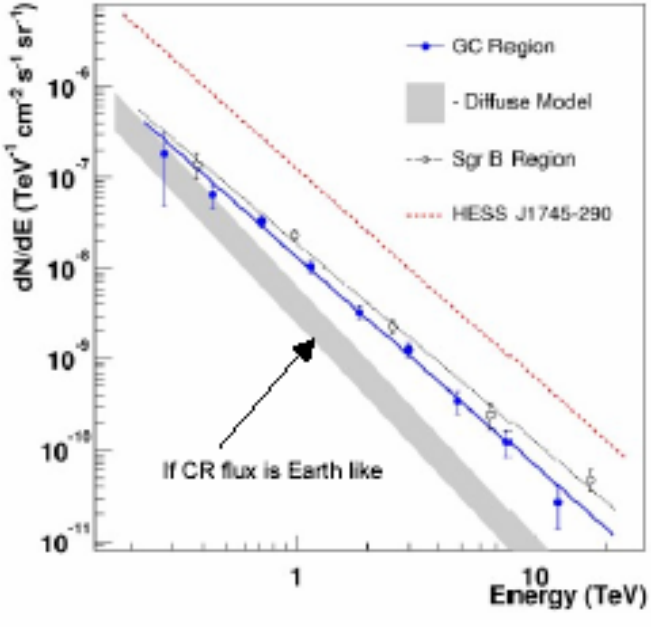
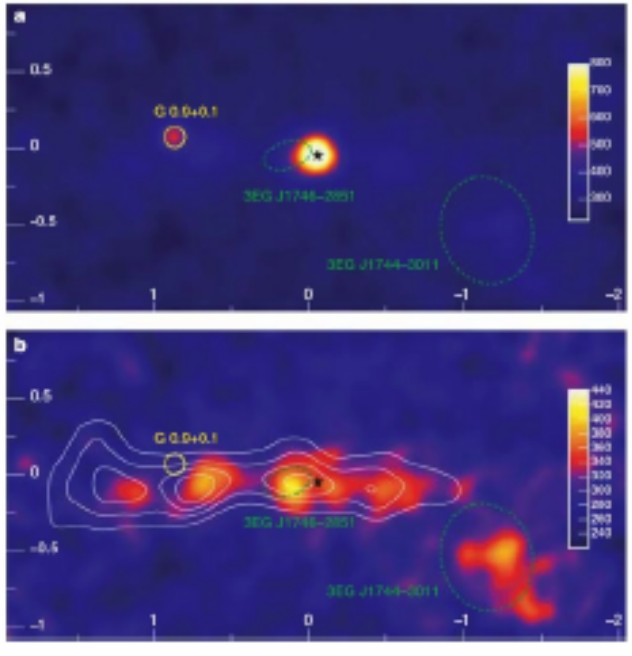
Angular distribution



Well described by H.E.S.S. PSF for point like source

S., PRL 97 (2006)





Galactic Center Region (HESS)

a) sources
b) source subtracted with molecular clouds contours as measured in CS line

Compelling case for CR interaction with target matter.

Dark Matter studies

CTA: large sensitivity and angular resolution

-Analysis of CR diffusion in the region

-Distinguish between one or multiple originators of the primary CR population

-Rule out of the possibility for a number of smaller IC sources to be behind the emission

-Allow for similar studies in other regions, less intense

CTA: extragalactic sources

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- **Starforming regions**
- **Starburst Galaxies**
- **Galaxy Clusters**
- **Extragalactic Dark Accelerators**
- **EBL**
- **Blazars**
- **GRBs**
- **VHE cosmology**

BLAZARS - spectra

CTA:

will study Blazars family with large statistics:
determining hadronic-leptonic model parameters,
jet emission – central engine

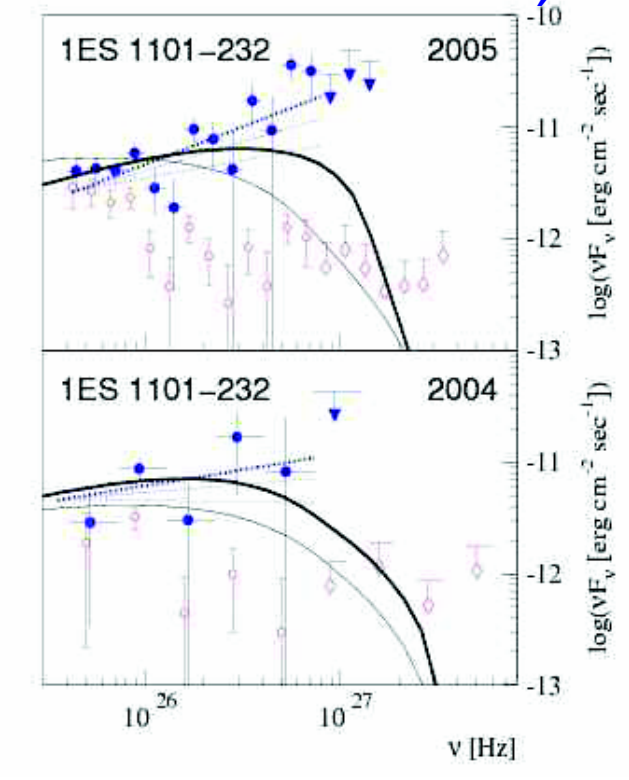
Require a broad coverage in energy
higher sensitivity if quiescent emission
high energies for high cut-offs
long-term light curves and large samples
of sources within z < 0.5

New classes of Blazars may emerge
→ symbiosis with GLAST !

CTA:

will detect more of hard sources such as 1ES1101-232 :
one zone leptonic emission models ruled out,
VHL factors required, single power law ?

HESS: Aharonian et al., 2007



BLAZARS – variability

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Extreme flares - **connection with GRBs**

VHE probes very short time scales

3 observations not triggered by other wavebands

High VHE dominance ?

PKS 2155-304 flares: 10^{50} erg/flare

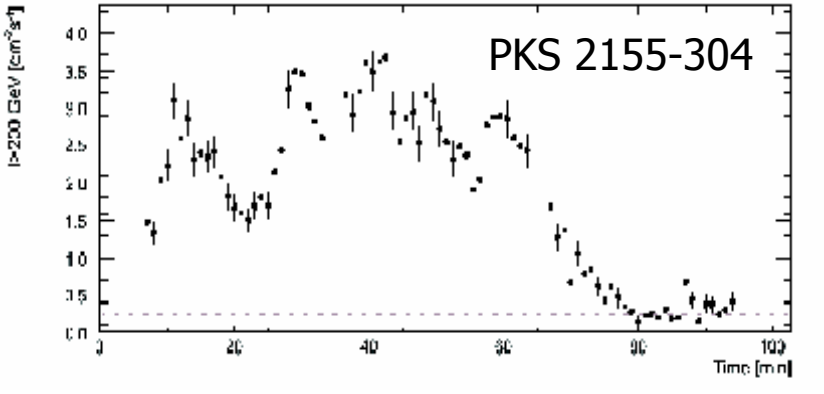
CTA:

increased sensitivity → a second scale

increased wave band → spectral evolution

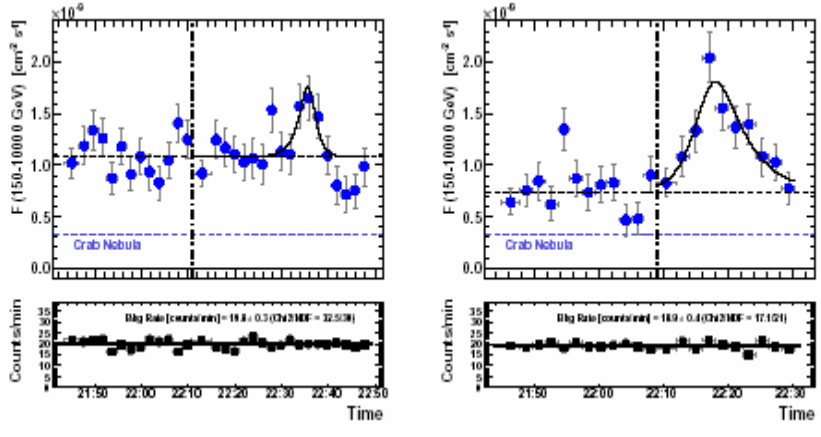
trigger telescope ?

HESS: Aharonian et al., 2007



MAGIC: Albert et al, Astro-ph/0702008

Mrk 501



VHE cosmology

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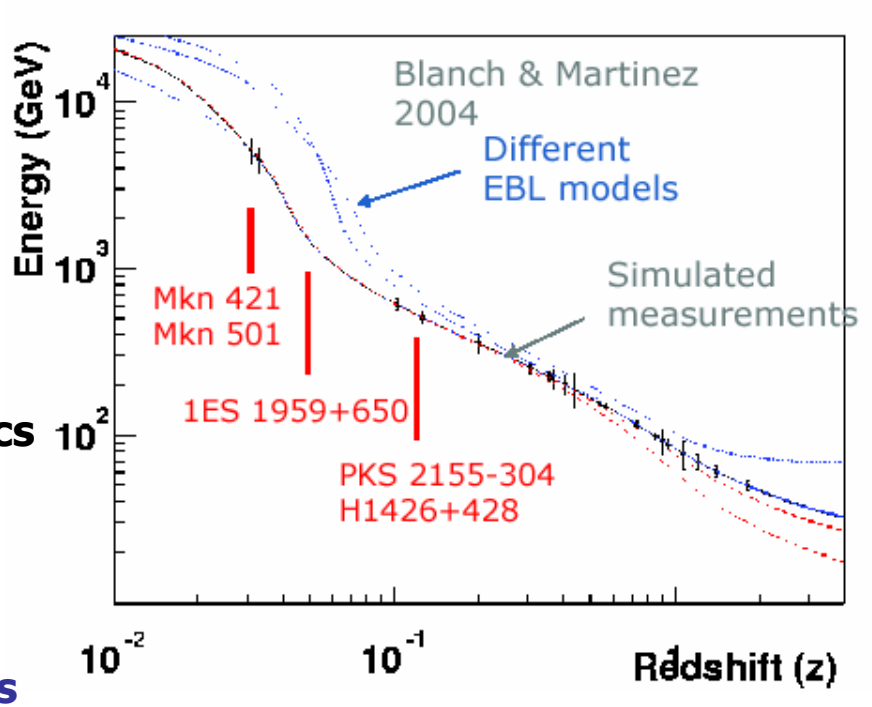
Measuring cosmological parameters:
absolute distances using absorption on EBL and pair halos

CTA:
more statistics, increase in the redshift lever-arm

Variability:
Constraints on Quantum gravity

Fast flares and lensing characteristics

Dark Matter:
extragalactic search cannot ignore the high M/L ratio (clusters)
→ relevance for astroparticle physics and classical astrophysics



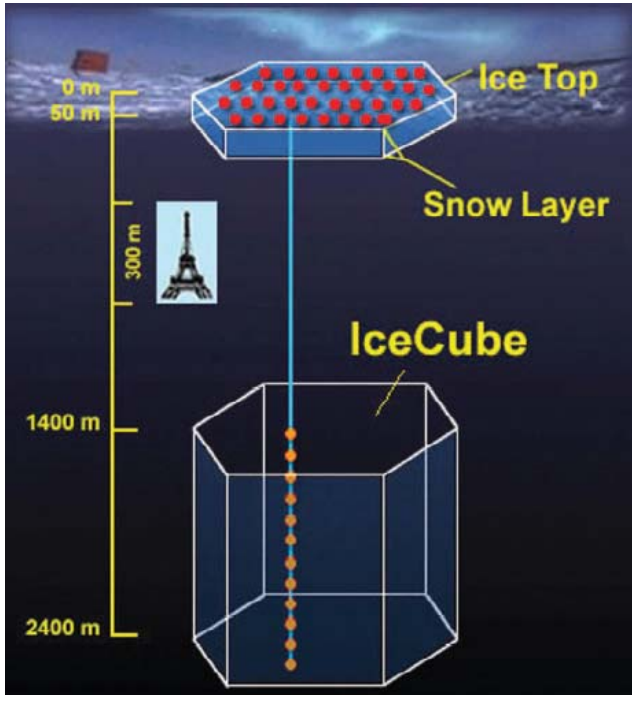
Multi-Messengers observation

All sky observatory (North, South stations)

Gamma Rays

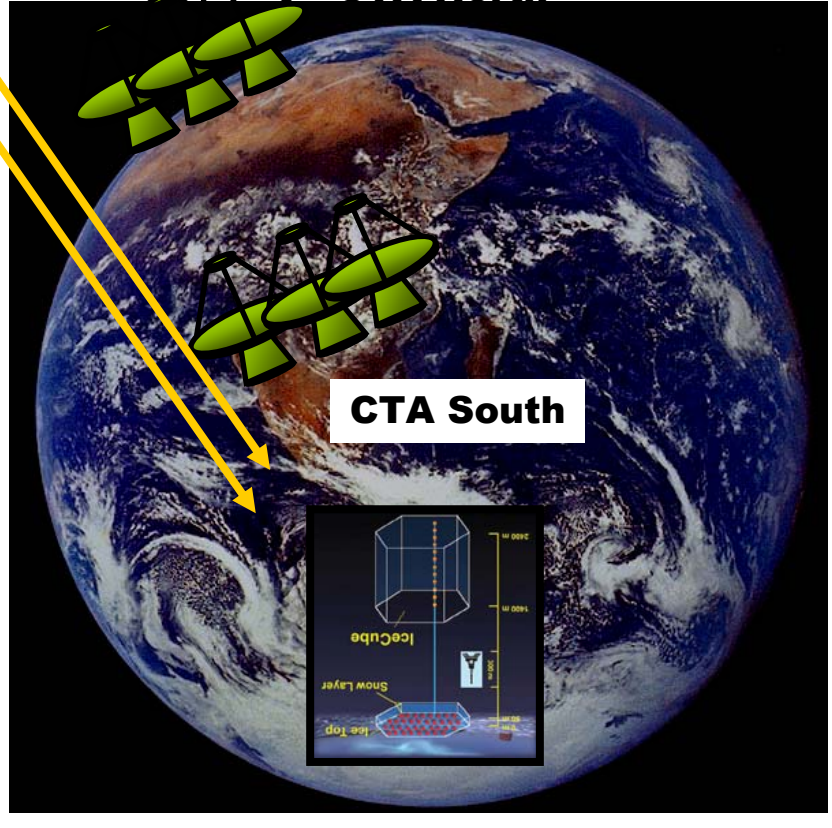
Gamma Ray & X-Ray Satellites

Neutrinos



CTA North

CTA South



IceCube: 2010 Completion of the construction

Summary

CTA

An advanced facility for ground-based high-energy gamma ray astronomy

- Now we know about 50 sources at TeV in the sky. The physics in TeV gamma-ray astronomy is very rich and there are still many open questions
- We definitely need CTA for the development of TeV gamma-ray astronomy after HESS, MAGIC, VERITAS and CANGAROO
- A sample of ~1000 sources will be observed in 10-20 years by CTA in a few*10 GeV – 100 TeV range, with improved sensitivity by a factor of 10 and unprecedented angular resolution (0.02-0.2°)
  the challenge will be the background discrimination at low energy
- Multi-wavelength and multi-messenger observation will contribute to understanding of the nature of high energy sources
  - GLAST, IceCube, KM3, Auger, etc..