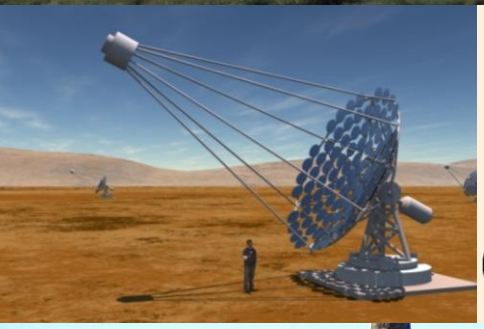
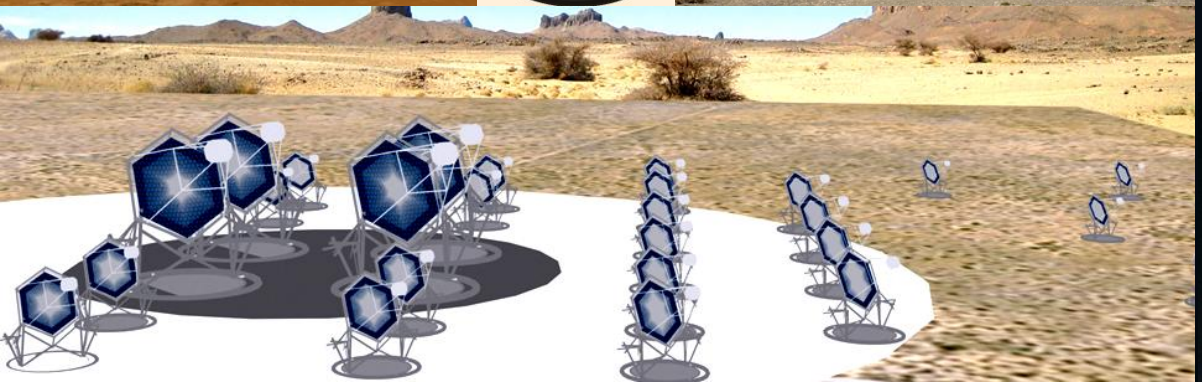




Present and Future ACTs

Jim Hinton

University of Leicester

TeV Particle Astrophysics 2010

19-23 July

Institut d'Astrophysique de Paris
& Cité Universitaire de Paris
France

2 Contents

University of Leicester

- ACT results/potential discussed in many talks
  - T. Bringmann, W. Benbow, M. Kachelriess, Y. Gallant, S. Casanova, D. Giannios, M. Dalton, M. Vivier, R. Mukherjee, S. Sarkar, G. Morlino, S. Vincent, Q. Weitzel, R. Gilmore, C. Medina, D. Caprioli, I. Vovk, F. Aharonian, I. Puerto (Poster)...

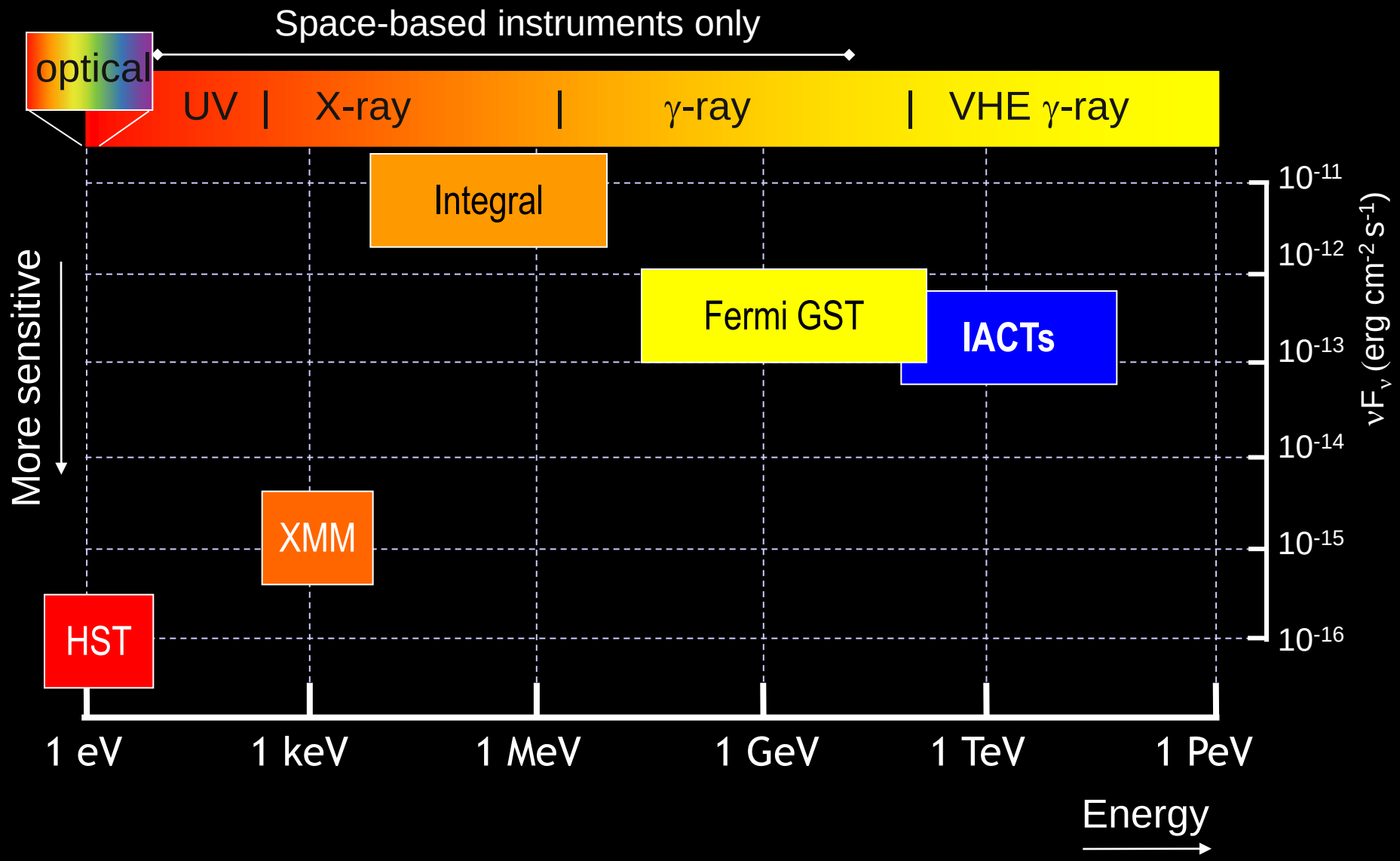
  → ACTs are a central part of TeV Particle Astrophysics

  → too many results/too much potential for 40 minutes!

- I will try not to cover too much of the same ground again – I will focus on the experimental status, capabilities and plans for future ACTs

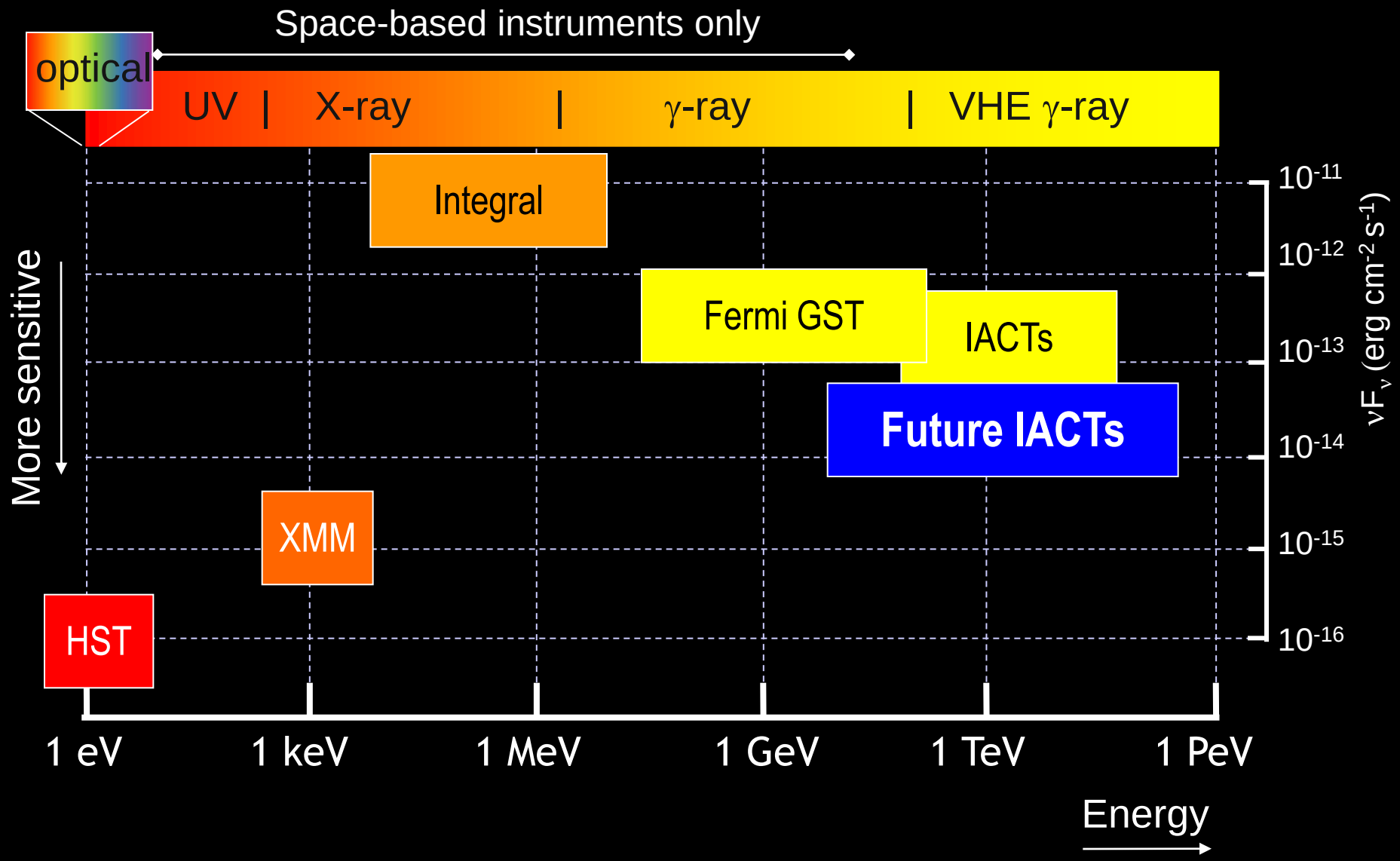
3 High Energy Sensitivity

University of Leicester



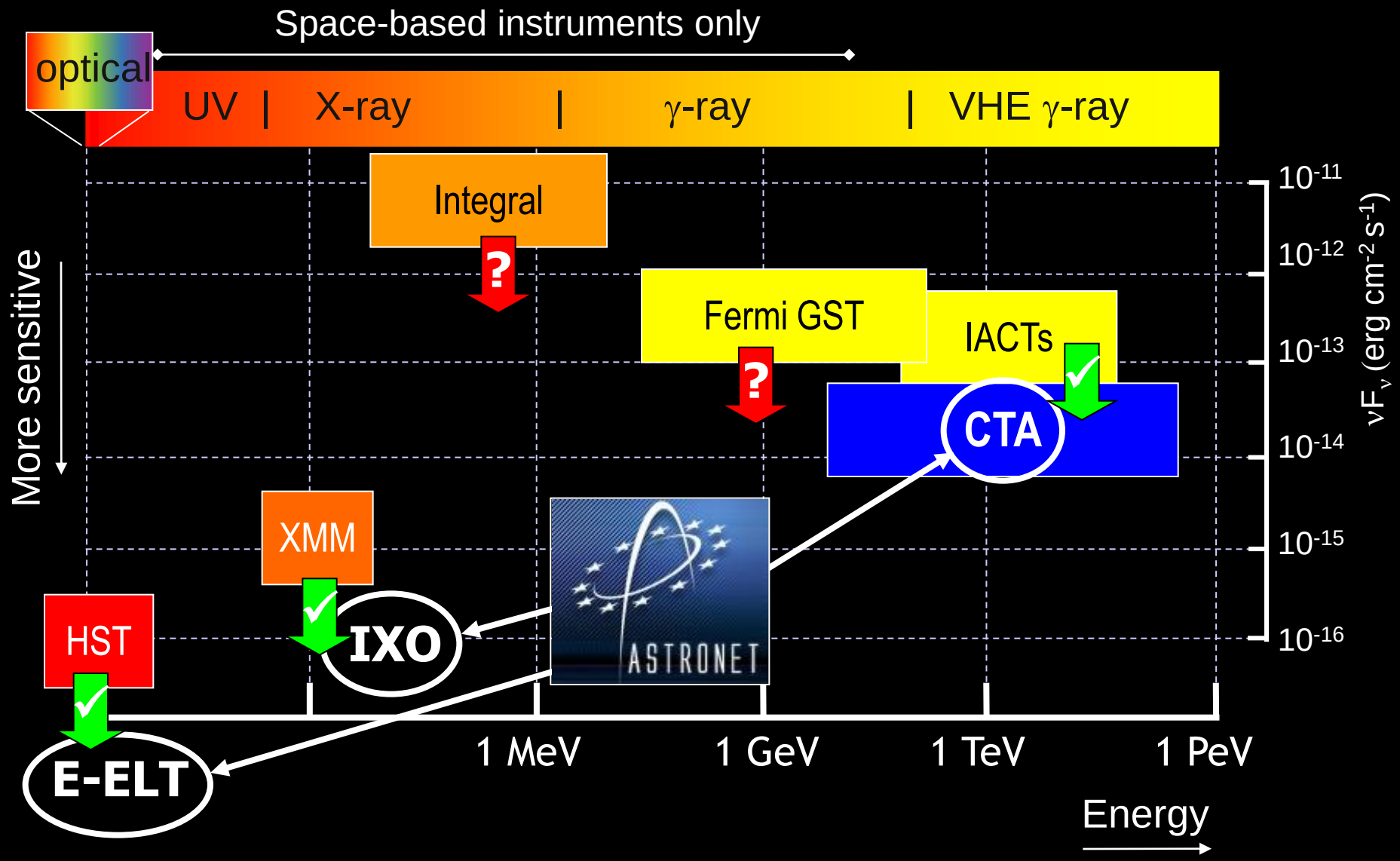
4 High Energy Sensitivity

University of Leicester



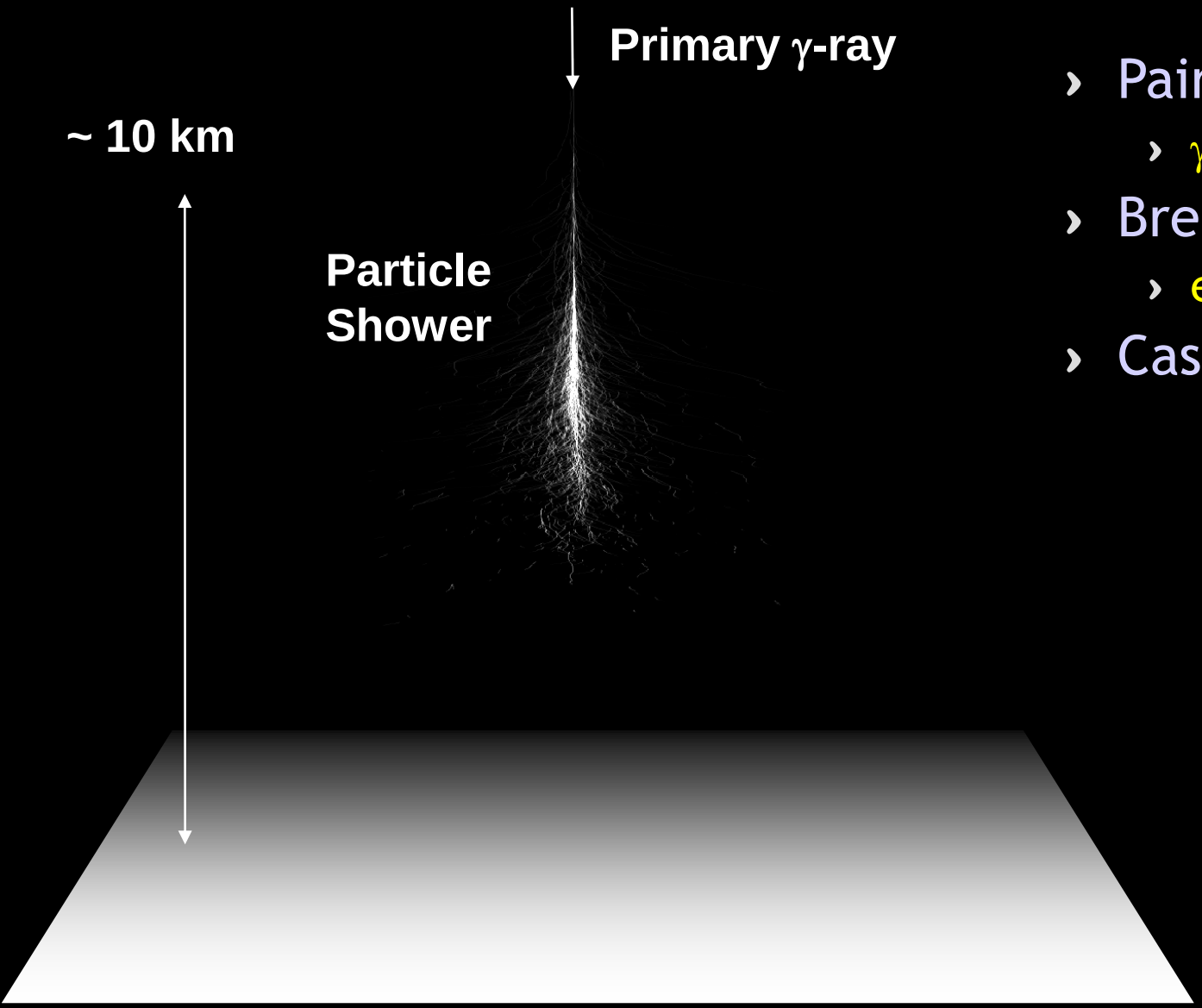
5 High Energy Sensitivity

University of Leicester



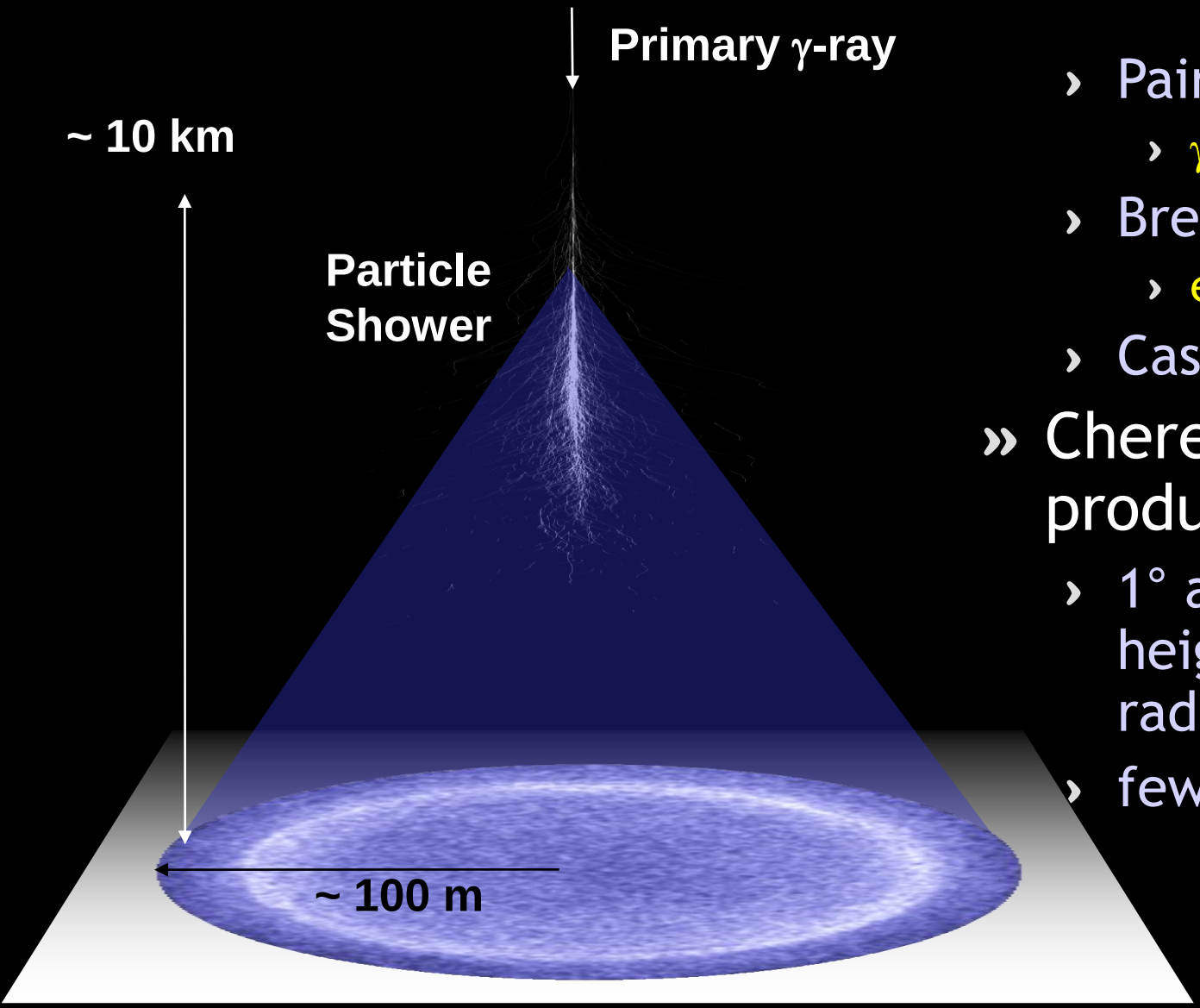
6 Technique

University of Leicester



- Pair production
  - $\gamma \rightarrow e^+ e^-$
- Bremsstrahlung
  - $e^- + (\gamma) \rightarrow e^- + \gamma$
- Cascade develops

7 Technique

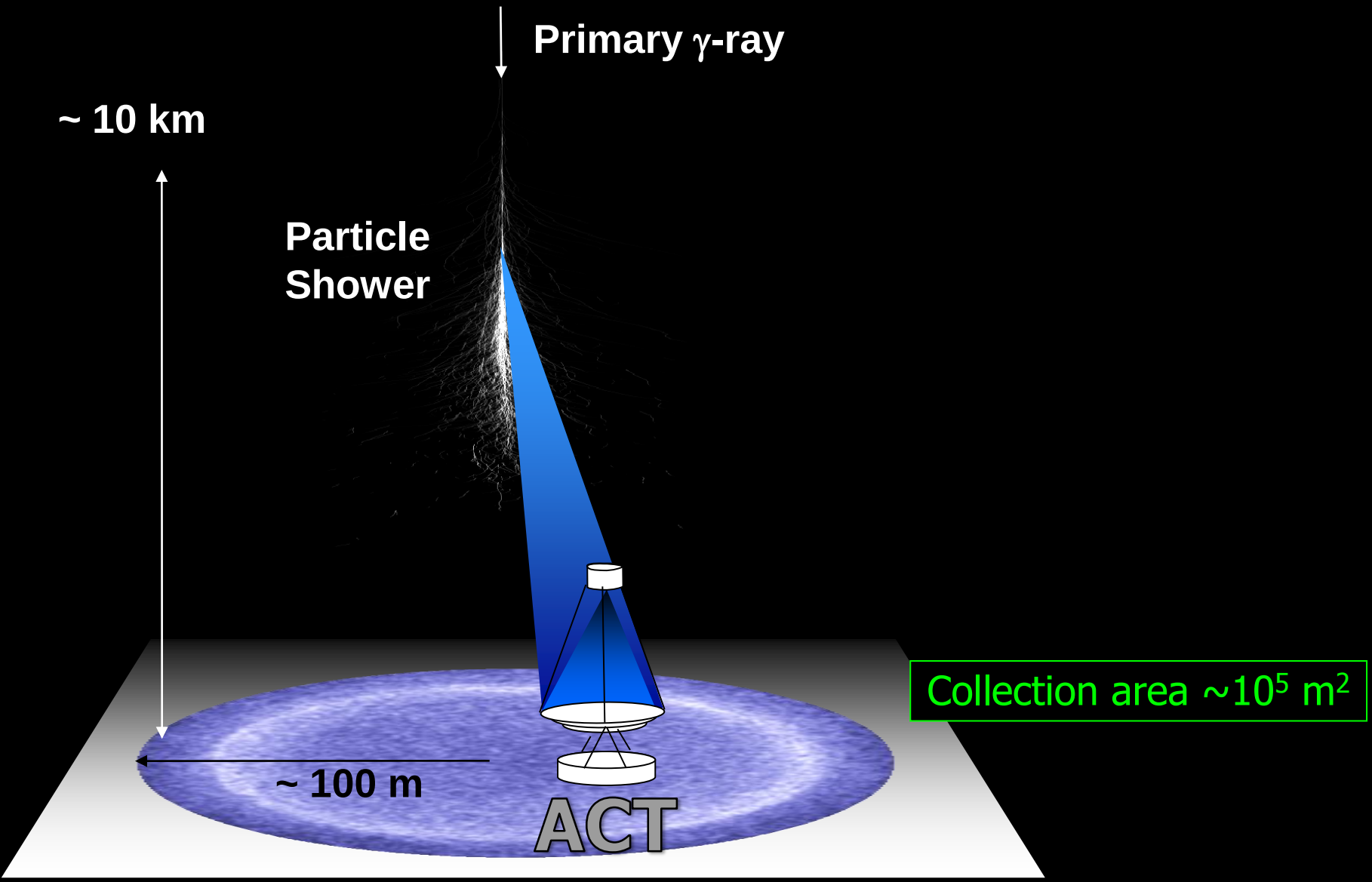


- Pair production
  - $\gamma \rightarrow e^+ e^-$
- Bremsstrahlung
  - $e^- + (\gamma) \rightarrow e^- + \gamma$
- Cascade develops

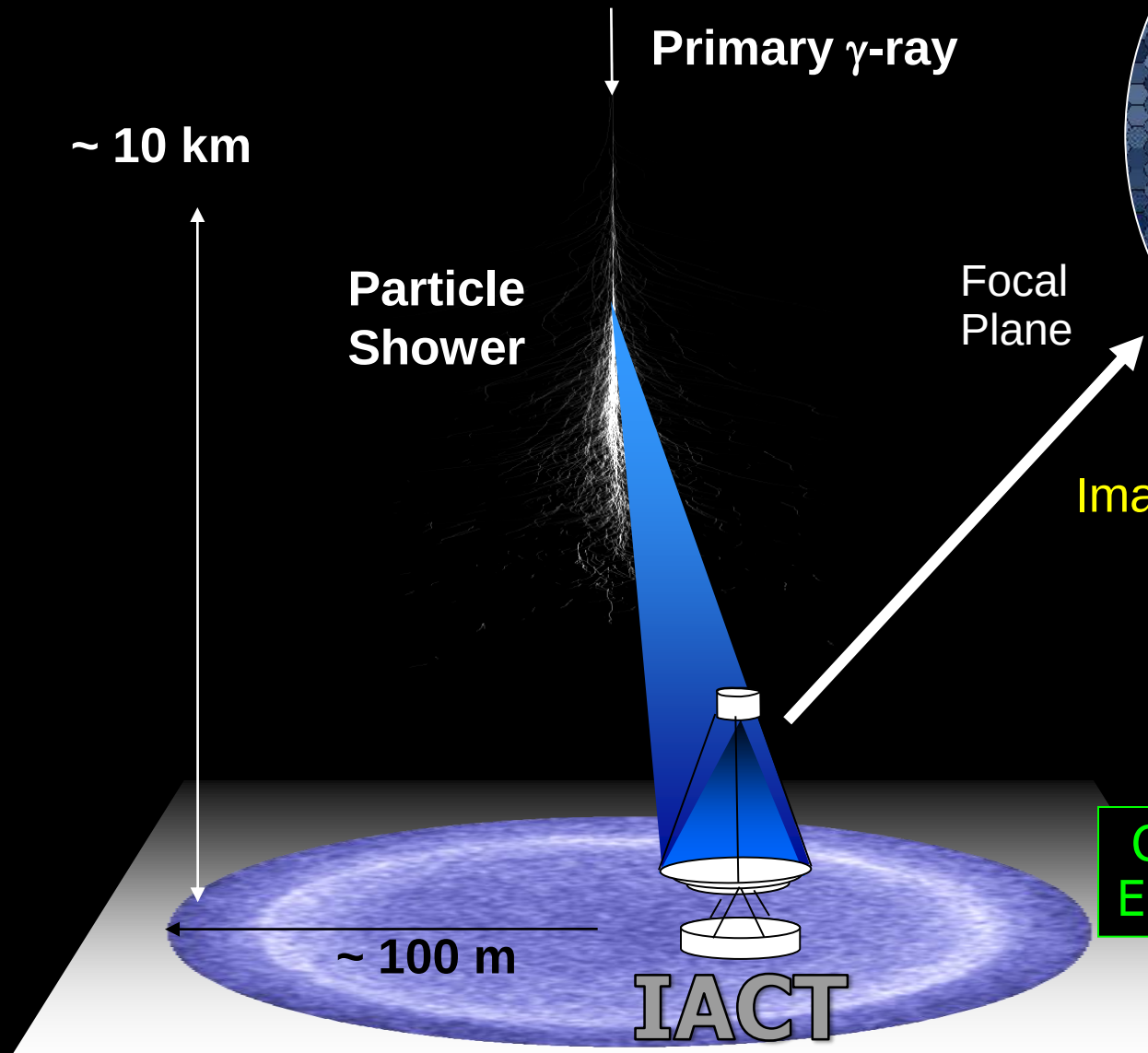
» Cherenkov light produced

- 1° angle at 10 km height → 100 m radius ‘light-pool’
- few ns light ‘flash’

Technique


Primary γ-ray
~ 10 km
Particle Shower
~ 100 m
ACT
Collection area ~10^5 m^2

9 Technique



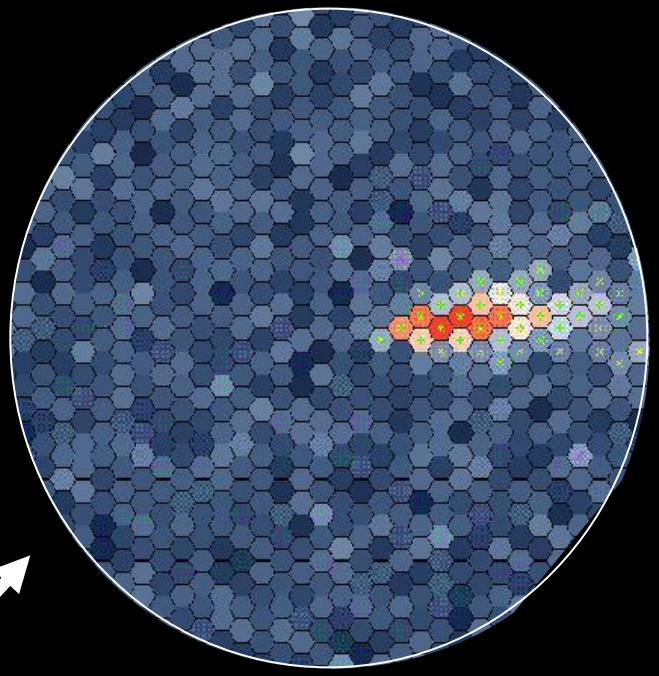
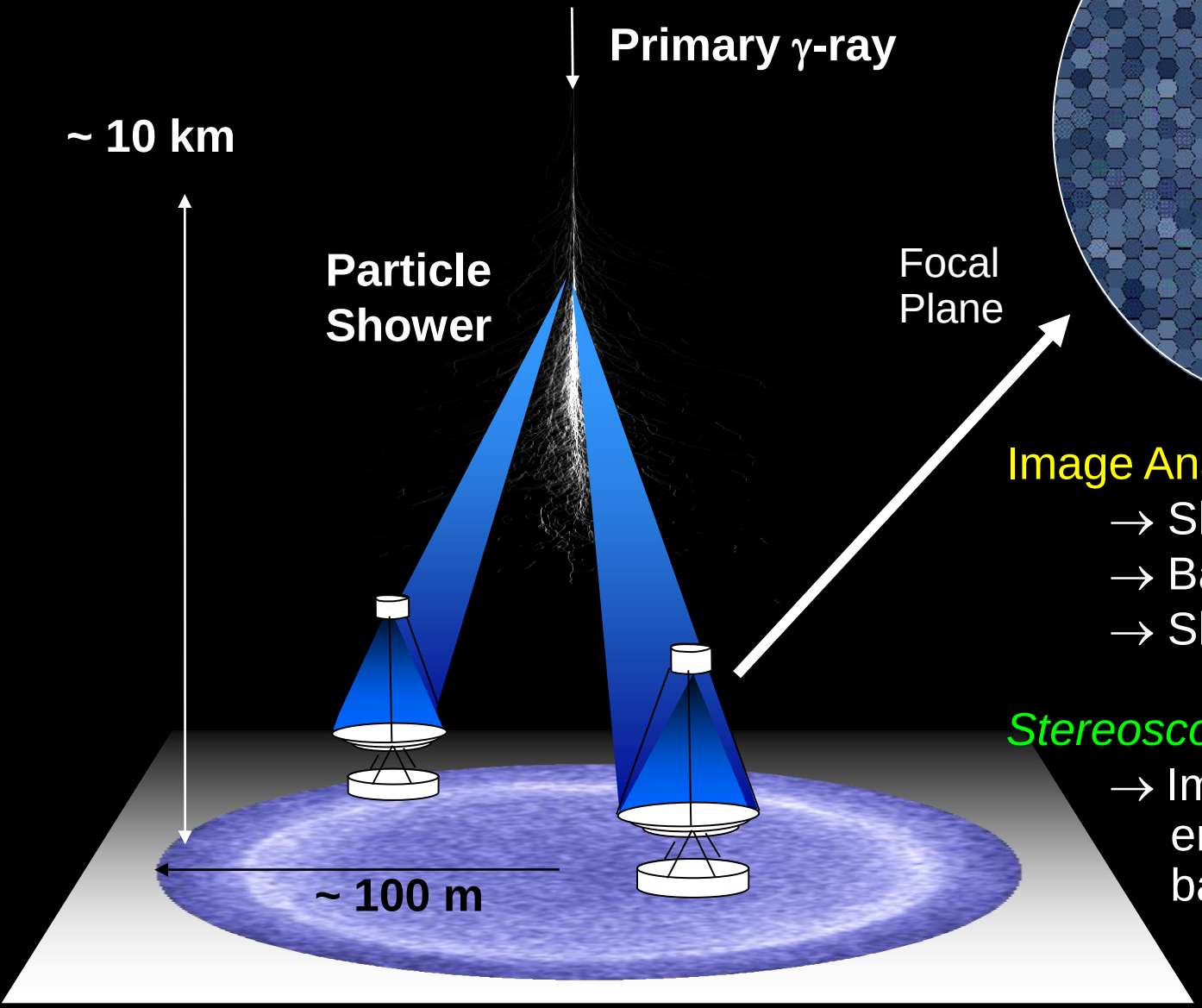


Image Analysis gives
- → Shower Energy
- → Background rejection
- → Shower Direction

Collection area ~10^5 m^2
Energy resolution ~ 20%

10 Technique



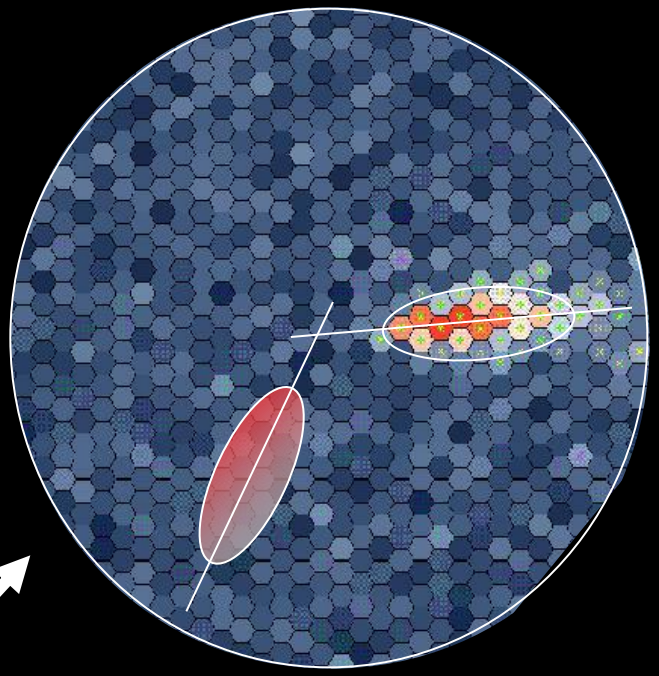


Image Analysis gives
- → Shower Energy
- → Background rejection
- → Shower Direction

Stereoscopic views
- → Improved angular / energy resolution & background rejection

11 Current ACTs

University of Leicester

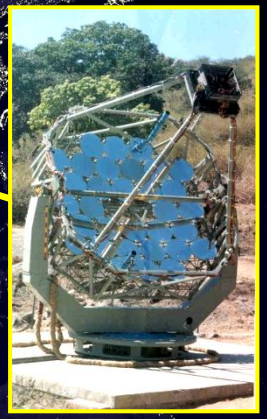
VERITAS

HAGAR

Whipple 10m

MAGIC

TACTIC



HESS

CANGAROO-III

Apologies if you have a currently operating ACT that I have missed!

12 Current ACTs

University of Leicester

- HAGAR
  - Non-imaging array 7×7×1 m
  - Altitude 4300 m
  - Sensitivity ~35% Crab
- TACTIC
  - 3.5 m imaging telescope
  - Altitude 1300m
  - Sensitivity ~70% Crab
- Whipple 10m
  - Sensitivity ~15% Crab
- CANGAROO-III
  - Operating with 2 telescopes
  - Sensitivity ~15% Crab.

(note that reanalysis of CANGAROO-I data clears up many old disagreements on southern sources ApJ 702, 631 (2009)

HAGAR

Whipple 10m

TACTIC

CANGAROO-III

13 Current ACTs

University of Leicester

VERITAS

MAGIC

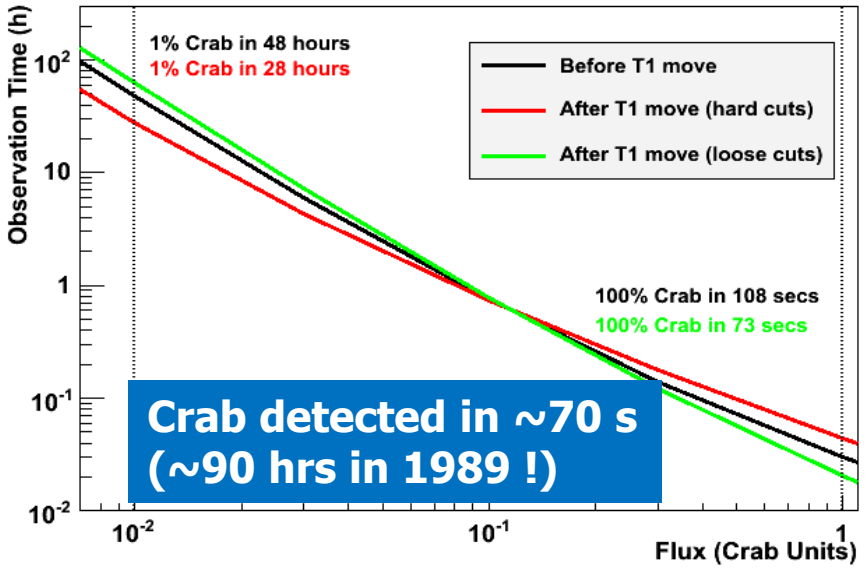
HESS

"The Big Three"

14 VERITAS

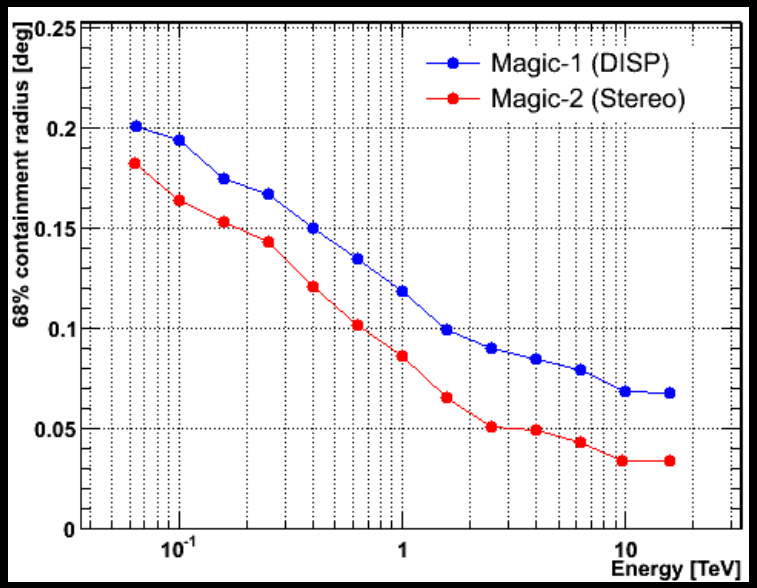
University of Leicester

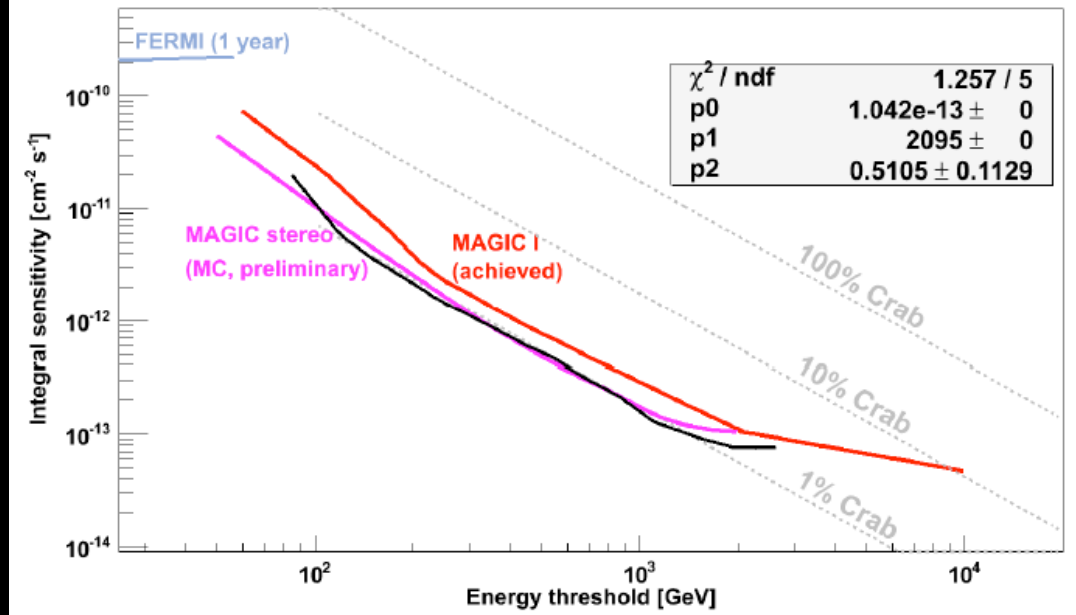
- 4× 12 m telescopes
  - 3.5° Field of View
- 2009 Upgrade
  - Moved 1 telescope
  - Improved alignment
  - 1% → 0.7% Crab sen.
- Planned upgrade
  - Higher QE PMs (35% more light)
  - Improved trigger
  - Funded – complete mid-2012



15 MAGIC

- Two 17m telescope system operational, gives improved:
  - Energy & Angular res
    - ~30% better: <0.1° above 600 GeV
  - Sensitivity →1% Crab





Preliminary integral sensitivity achieved with MAGIC Stereo system

H.E.S.S.

- HESS phase-I (since 2004)
  - 4× 12m telescopes In Namibia, 5° FoV
  - 0.7% Crab sens. (NB NGC 253, 0.3% Crab in 120 h)
  - recoating underway to restore original reflectivity (1 tel. done, others finished by end of next year)
- HESS phase-II
  - A single giant (30 m) telescope under construction in the centre array → ~20 GeV threshold
  - Construction on hold – changing contractor

17 What are ACTs good for?

University of Leicester

- Short-timescale variability (better lower E)
- Imaging (better higher E)
- Spectroscopy (better higher E)

**Current IACT arrays have factor ~2 better E-res and ang-res at 1 TeV than at 100 GeV*

- NOT
  - Long-timescale variability/monitoring
    - Sparsely sampled light-curves (moon, sun, weather)
  - Very extended emission (>> 1°, limited FoV)
  - Precision measurements at <<100 GeV (shower fluc.)

  - Fermi can do these things better <100 GeV
  - HAWC will (hopefully) do them > a few TeV

18 Angular resolution

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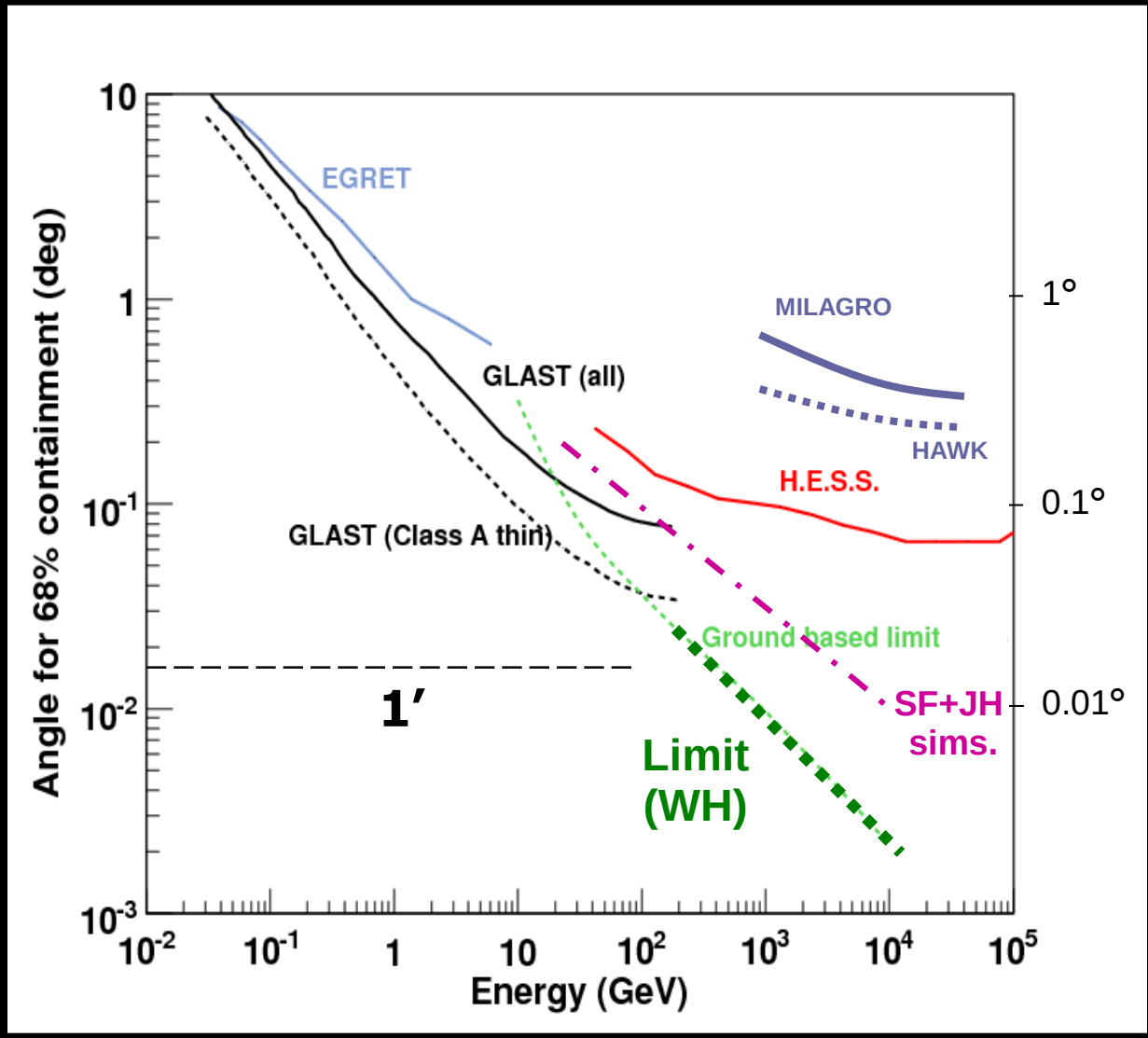
- ~1’ resolution achievable with next generation IACT arrays
- Fundamental limit is ~10” above a few TeV



19 Source Numbers

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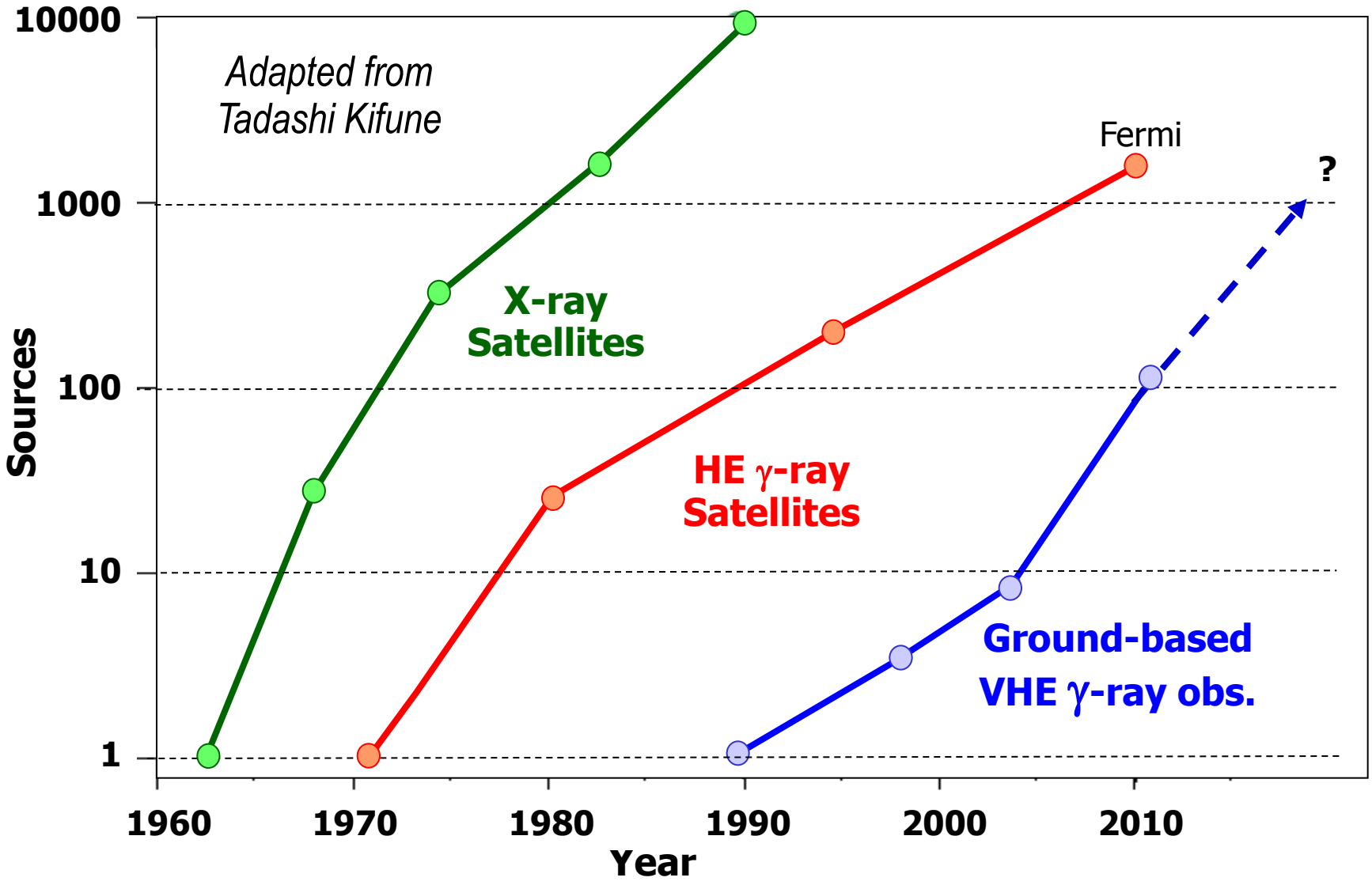
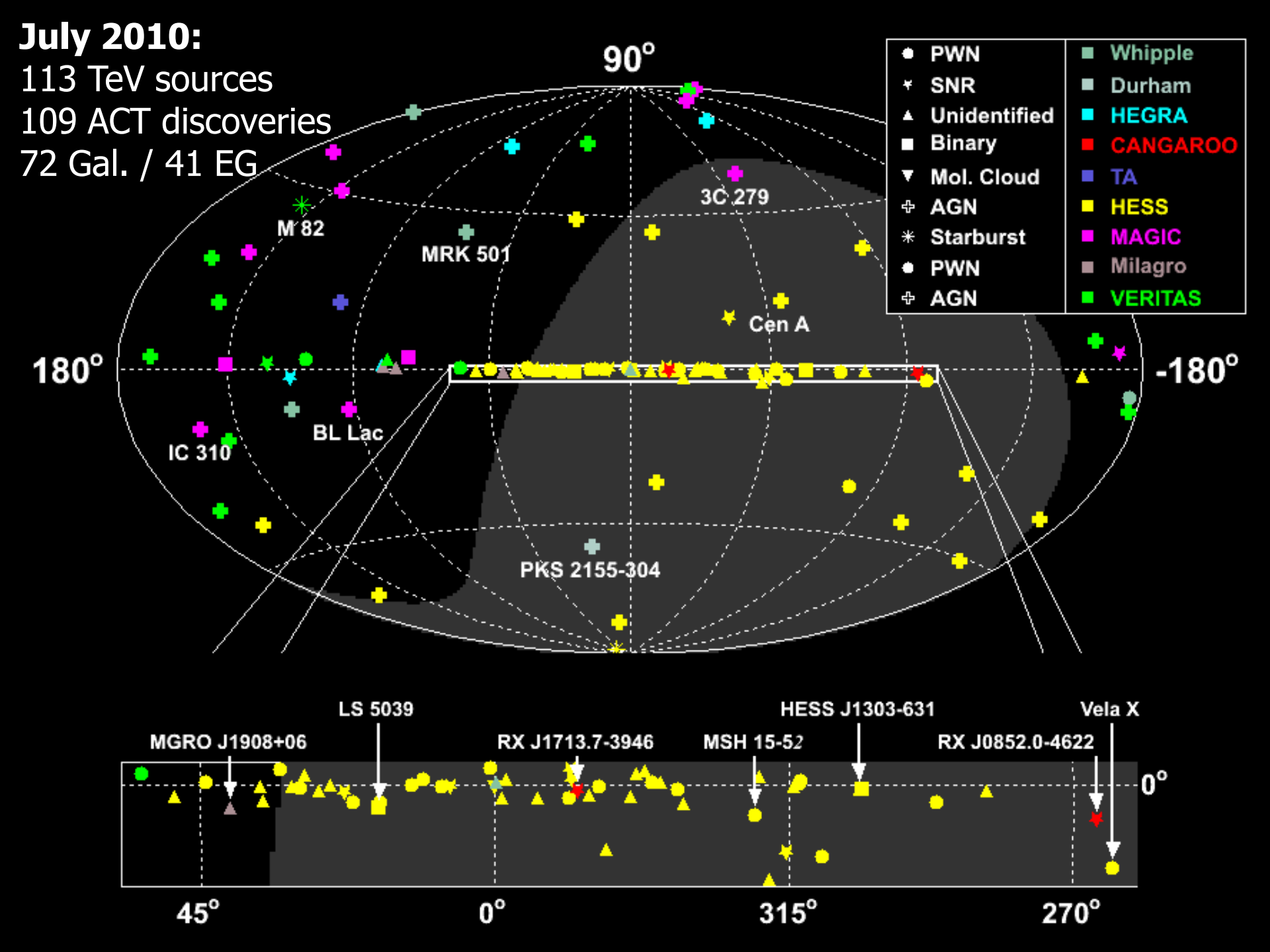
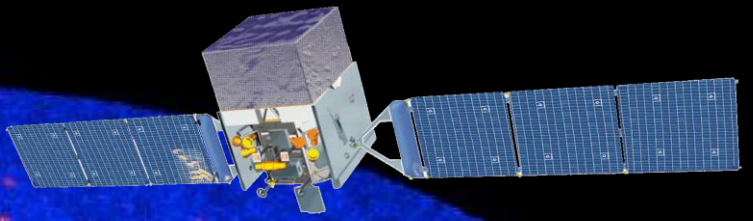



July 2010:
113 TeV sources
109 ACT discoveries
72 Gal. / 41 EG
90°
180°
-180°
0°
45°
315°
270°
PWN
SNR
Unidentified
Binary
Mol. Cloud
AGN
Starburst
PWN
AGN
Whipple
Durham
HEGRA
CANGAROO
TA
HESS
MAGIC
Milagro
VERITAS
M 82
MRK 501
3C 279
Cen A
BL Lac
IC 310
PKS 2155-304
MGRO J1908+06
LS 5039
RX J1713.7-3946
MSH 15-52
HESS J1303-631
RX J0852.0-4622
Vela X

21 The High Energy Sky

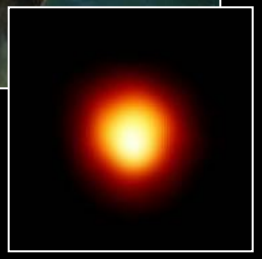
University of Leicester

- >1 GeV (Fermi)



- >5 GeV (Fermi) cf >200 GeV (HESS)

Molecular cloud

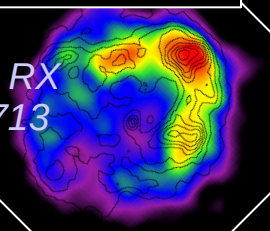


Massive star

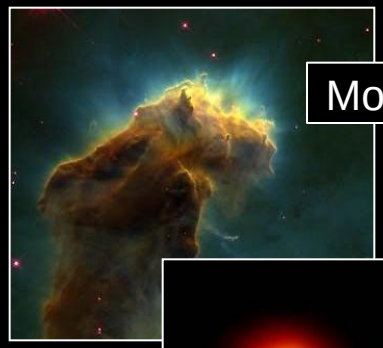
No acceleration expected until…

Supernova

SNR shell



e.g. RX J1713

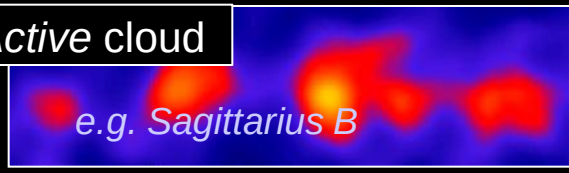


Molecular cloud

Nearby accelerator?

Yes

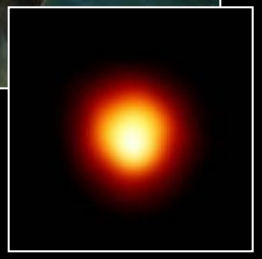
Active cloud



No

Passive cloud

(e.g. EGRET galactic clouds)



Massive star

In cluster?

Yes

Collective wind interactions

No

Binary?

No

No acceleration expected until…

Yes

Compact companion?

No

Massive companion?

Yes

Yes

Neutron star companion?

Yes

Binary PWN

No

Radio jets?

Yes

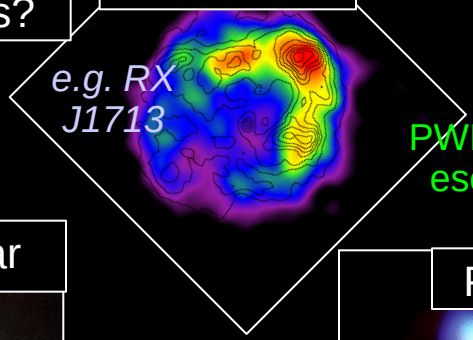
Microquasar

Supernova

Neutron star remains?

No

SNR shell

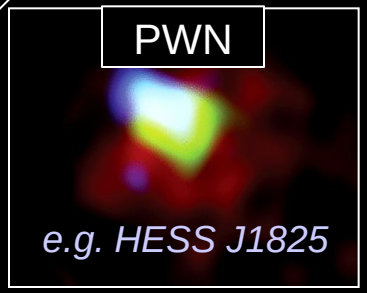


Yes

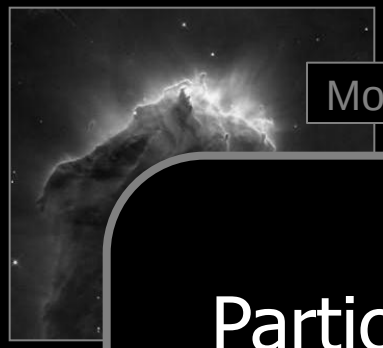
Composite SNR

PWN outlasts or escapes SNR

PWN



Colliding wind sys.

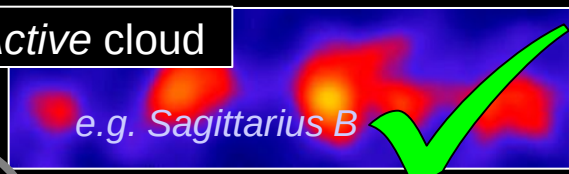


Molecular cloud

Nearby accelerator?

Yes

Active cloud



ssive cloud

(e.g. EGRET galactic clouds)

Particle Acceleration is common in nature and TeV emission can be used to probe a wide range of astrophysical systems!

Collective wind interactions

ova

companion?

Yes

No

Yes

Binary PWN

Radio jets?

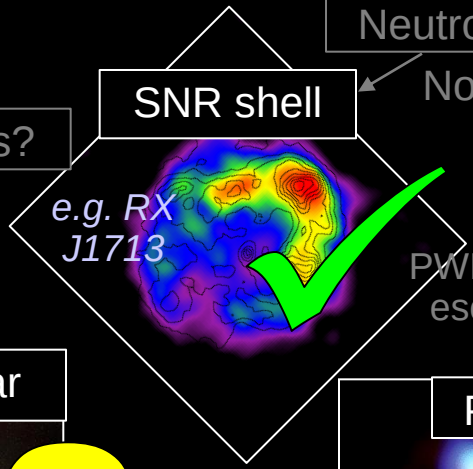
Yes

Neutron star remains?

No

Yes

SNR shell

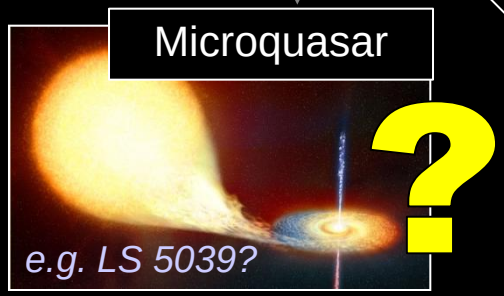


Composite SNR

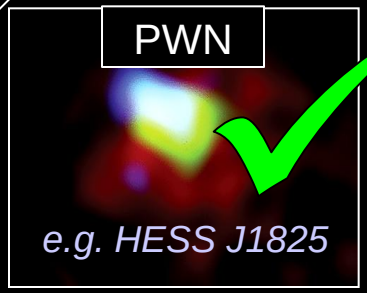
PWN outlasts or escapes SNR

Colliding wind sys.

Microquasar



PWN



25 Supernova Remnants

University of Leicester

- SNRs
  - Tycho (VERITAS)
  - HESS J1731-347A
    - New shell-like TeV SNR (1st VHE Discovery)
  - New SNR/cloud interaction candidates
    - G22.7-0.2 (HESS)
    - γ-Cygni (VERITAS)
- Expect many ACT + Fermi results in the near future for gal. sources

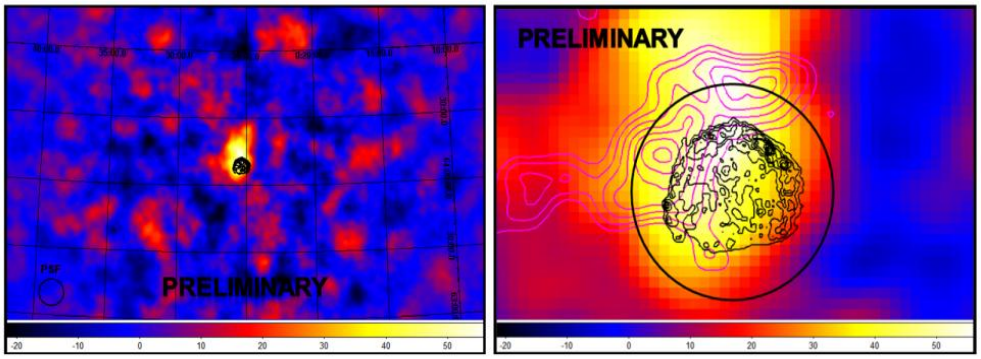
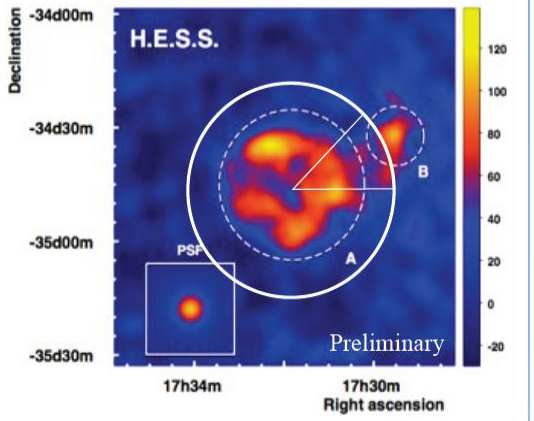


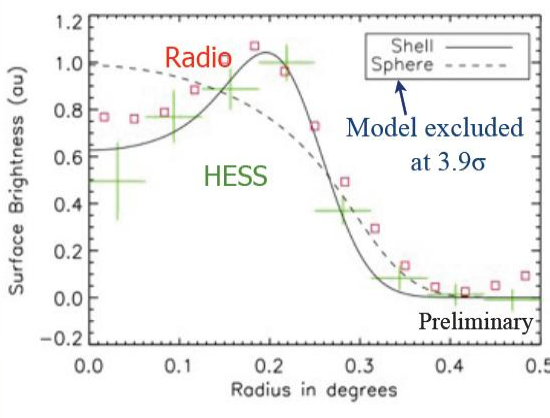
Figure 3: Preliminary VERITAS excess maps of TeV gamma-rays from the direction of Tycho. Left: Wide view of the remnant with superimposed X-ray contours from the Chandra ACIS[39]. Right: Zoomed image of the center of the remnant, again with black contours from the Chandra ACIS. The magenta contours are ^{12}CO data from the FCRAO Survey[33], centered on -64 km/s[42]. On both plots, the color scale shows the (smoothed) excess number of TeV gamma rays and the black circles represent the point spread function of VERITAS for the cuts used.

HESS J1731-347A : Profiles

Gamma-ray excess smoothed with gaussian (σ=0.05°)



Radial profiles



26 Starburst Galaxies

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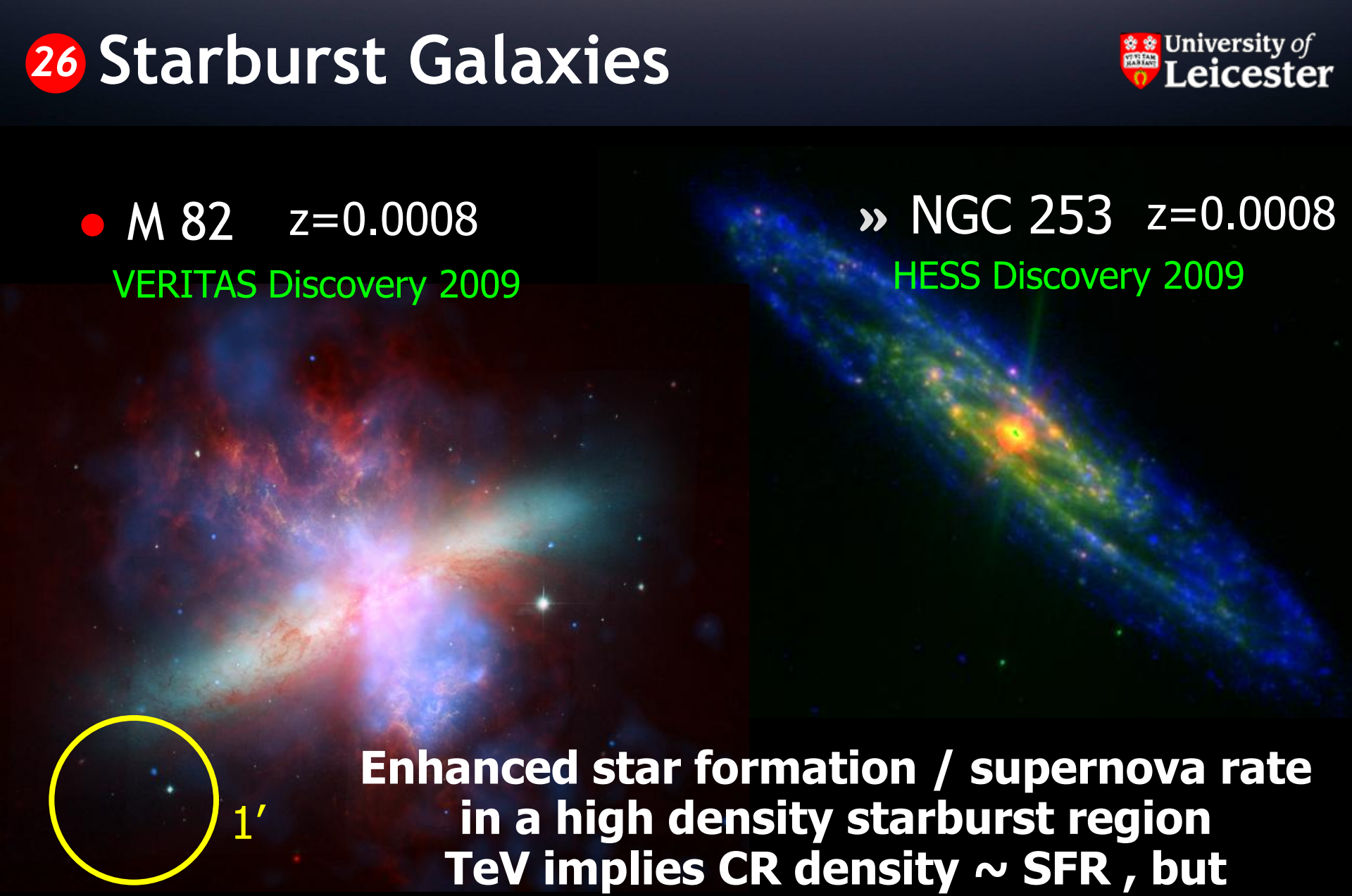
- M 82 z=0.0008
  VERITAS Discovery 2009

» NGC 253 z=0.0008
HESS Discovery 2009

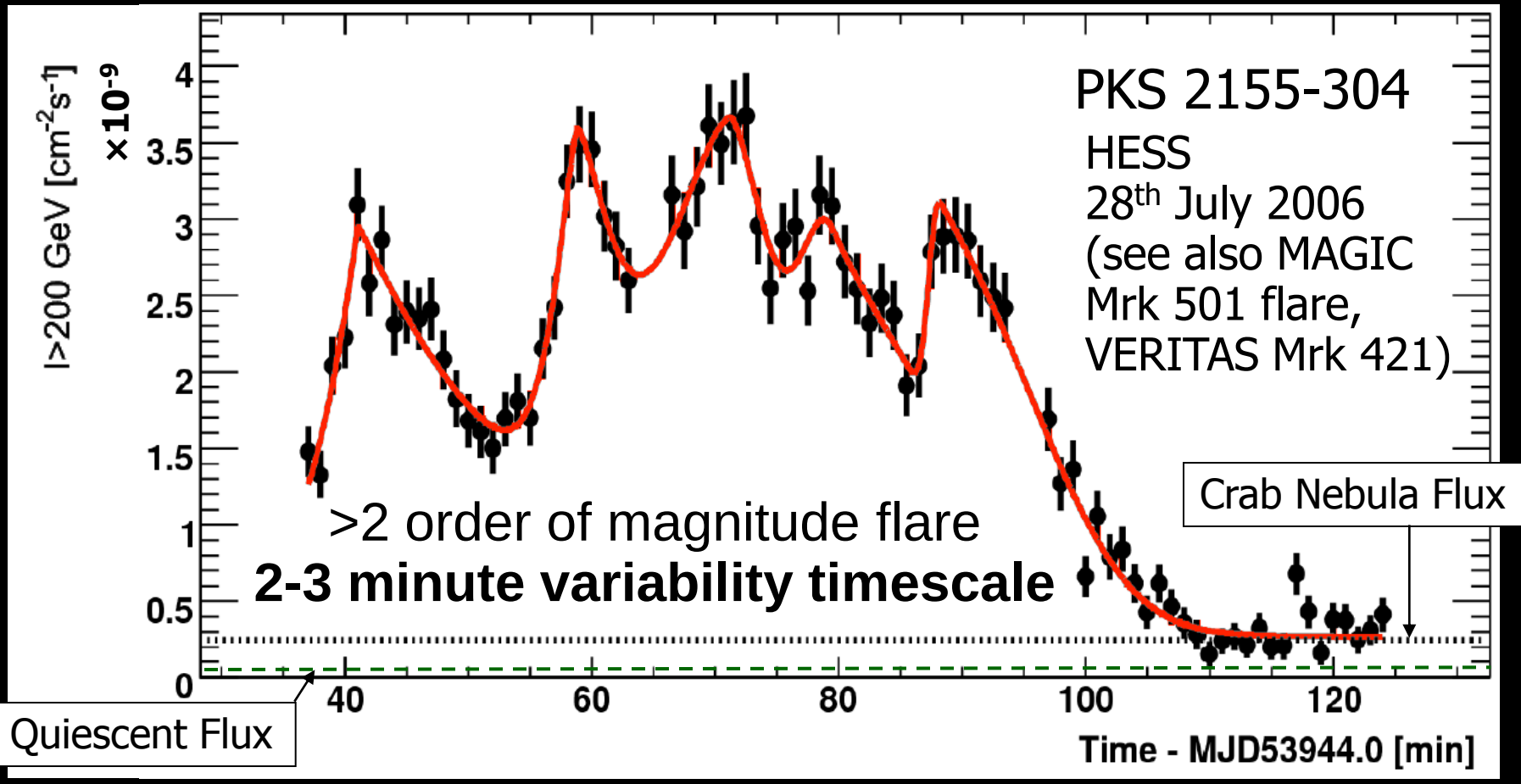


1′

Enhanced star formation / supernova rate in a high density starburst region
TeV implies CR density ~ SFR , but
TeV emission from π_0 inside starburst
or IC in superwind, …

27 Blazars

University of Leicester



- *Variability timescale is ~1% R_S c*
  - Can be used to constrain Lorenz Invariance Violation – but not quite as good as Fermi GRBs (need more distant/faster objects)

28 A flood of new VHE AGN

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Present Time: 16 Jul 2010; 14:41 UT

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MAGIC detects a VHE flare from 4C +21.35 (PKS 1222+21)

ATel #2684; *Mose Mariotti (INFN and Univ. of Padova) on behalf of the MAGIC Collaboration*
on 19 Jun 2010; 1:19 UT
Password Certification: Mosè Mariotti (mariotti@pd.infn.it)

Subjects: Gamma Ray, >GeV, TeV, AGN, Quasars
Referred to by ATel #: 2686, 2687, 2693

The MAGIC collaboration reports the detection of a very high gamma ray flare from the Flat Spectrum Radio Quasar 4C +21.35 (PKS 1222+21, z=0.432, RA: 12h24m54.4s DEC: +21d22m46s, J2000) at energies above 100 GeV. The observation was performed in stereoscopic mode during low intensity moon light using the two 17m diameter imaging Cherenkov telescopes on La Palma, Canary Islands, Spain, during 0.5 hours on MJD 55364 (June 17th 2010). The preliminary results indicate a significant gamma-ray signal of ~120 excess events corresponding to >8 sigma level above the background. The integral flux for gamma-rays with energies above 100 GeV is estimated to be at >=30% of the Crab nebula flux. 4C +21.35 has been recently found to be a very high energy (VHE)


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Present Time: 16 Jul 2010; 14:49 UT

[Previous | Next | ADS]

H.E.S.S. discovers VHE emission from the Fermi LAT source PKS 0447-439

ATel #2350; *M. Raue, B. Behera, A. Charbonnier, B. Giebels, M. Hauser, K. Kosack, M. Punch, H.-S. Zechlin for the H.E.S.S. collaboration*
on 16 Dec 2009; 20:35 UT
Distributed as an Instant Email Notice (Request for Observations)
Password Certification: Martin Raue (martin.raue@mpi-hd.mpg.de)

Subjects: Gamma Ray, >GeV, Request for Observations, AGN, Variables

The High Energy Stereoscopic System (H.E.S.S.) collaboration reports the discovery of very-high energy (VHE; E>100 GeV) gamma-ray emission from the source 0FGL J0449.7-4348, one of the brightest extragalactic source from the Fermi bright source list (Abdo et al. 2009, ApJ 700, 597). 0FGL J0449.7-4348 has been associated with PKS 0447-439 (RA: 04h49m24.7s DEC: -43d50'09", J2000), which has been associated with a BL Lac object located at a redshift of z ~ 0.2 (Perlman et al. 1998, ApJ 115, 1253). Note that PKS 0447-439 has also been associated with a Seyfert 1 galaxy located at a redshift of z=0.107 (Craig & Fruscione 1997, AJ, 114, 4). VHE emission from this source has been detected in 12h of observations recorded with the H.E.S.S. imaging atmospheric


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Present Time: 16 Jul 2010; 14:47 UT

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VERITAS Discovery of Very High-Energy Gamma-Ray Emission from 1FGL J0648.8+1516

ATel #2486; *Rene A Ong (UCLA) for the VERITAS Collaboration; David Paneque (SLAC/KIPAC) on behalf of the Fermi Large Area Telescope (LAT) Collaboration*
on 17 Mar 2010; 17:27 UT
Distributed as an Instant Email Notice (Request for Observations)
Password Certification: Rene Ong (rene@astro.ucla.edu)

Subjects: Gamma Ray, >GeV, Request for Observations, AGN

The VERITAS Collaboration reports the discovery of very high energy (VHE; E>100 GeV) gamma-ray emission from the source VER J0648+152. This source is consistent with the Fermi-LAT gamma-ray source 1FGL J0648.8+1516 (RA 06 48 49.7, dec +15 16 22, J2000) and the radio and X-ray source RGB J0648+152 (RA 06 48 47.6, dec +15 16 25, J2000), of unknown redshift. The new source was identified as a promising candidate for VHE emission based upon an analysis of >10 GeV photons detected by Fermi-LAT. The Fermi-LAT source is reported in the


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Present Time: 16 Jul 2010; 14:47 UT

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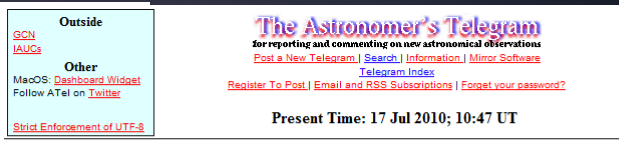
MAGIC detects VHE gamma-ray emission from IC 310

ATel #2510; *Mose Mariotti, on behalf of the MAGIC collaboration*
on 25 Mar 2010; 15:10 UT
Password Certification: Mosè Mariotti (mariotti@pd.infn.it)

Subjects: Gamma Ray, >GeV, AGN

The MAGIC Collaboration reports the discovery of VHE (E >100 GeV) emission from the new source MAGIC J0317+413. The source was in the field of view of the MAGIC telescopes between October 2009 and February 2010. The emission position is consistent with the head-tail radio galaxy IC310 (z=0.0189, RA: 03 16 43.0 Dec: +41 19 29, J2000) located in the outer region of the Perseus cluster of galaxies (Abell 426). A gamma-ray signal with a significance corresponding to >6 standard deviations was obtained from 20 hours taken in stereoscopic observation mode. An analysis of 38 hours of single telescope observations performed from 2008 to 2010 has confirmed the detection at ~6 sigma significance. Preliminary analysis indicates emission at the level of ~2.5% of the Crab Nebula flux above 300 GeV. The source was also recently detected in the Fermi/LAT data (A. Neronov, D. Semikoz, Ie.Vovk arXiv:1003.4615). The MAGIC Telescope system consists of two 17m diameter Imaging Atmospheric Cherenkov Telescopes observing gamma-rays at energies above 50 GeV. Both telescopes are operating together in the stereoscopic mode since the end of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Present Time: 17 Jul 2010; 10:47 UT

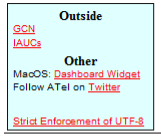
[Previous]

Very High Energy gamma-ray emission from AP Lib detected by H.E.S.S.

ATel #2743; *W. Hofmann for the H.E.S.S. Collaboration*
on 17 Jul 2010; 9:44 UT
Password Certification: Martin Raue (martin.raue@mpi-hd.mpg.de)

Subjects: Gamma Ray, >GeV, TeV, VHE, AGN, Blazars

The BL Lac type object AP Lib has been targeted for ~8h of observations with the High Energy Stereoscopic System (H.E.S.S.) in June and July 2010. The Fermi source 1FGL J1517.8-2423, associated with AP Lib (Abdo et al., 2010, ApJS, 188, 405), has a hard gamma-ray photon index of 2.1+/-0.1. This, combined with its proximity (z=0.049), makes AP Lib an excellent candidate for very high energy (E>100 GeV; VHE) gamma-ray emission. Initial analysis of the H.E.S.S. data-set, using published advanced analysis methods, results in a detection of AP Lib with a statistical significance exceeding 6 standard deviations above 300 GeV, corresponding to ~2% of the flux of the Crab nebula (note that the mirror reflectivity of the system is currently being upgraded and this preliminary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Present Time: 16 Jul 2010; 14:57 UT

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Discovery of VHE Gamma-Ray Emission from the Fermi-LAT Source 1ES 0502+675

ATel #2301; *Rene A. Ong (UCLA) for the VERITAS Collaboration*
on 17 Nov 2009; 20:19 UT
Distributed as an Instant Email Notice (Request for Observations)
Password Certification: Rene Ong (rene@astro.ucla.edu)

Subjects: Gamma Ray, >GeV, Request for Observations, AGN

The VERITAS Collaboration reports the discovery of very high energy (VHE; E>100 GeV) gamma-ray emission from the high-frequency-peaked BL Lac object 1ES 0502+675. The redshift is z = 0.341 (E. Perlman, private communication, 2009), which makes this the most distant BL Lac with a secure redshift detected at VHE. This new VHE source was observed with the VERITAS atmospheric-Cherenkov telescope array at relatively low elevation angles for ~13 hours of good-quality live time between 23 September 2009 and 16 November 2009 (UT). The observations were motivated by the flux and spectrum reported in the Fermi-LAT Bright Source List for 0FGL J0507.9+6739 (Abdo et al. 2009, ApJS 183, 46; Abdo et al. 2009, ApJ 700, 597). Analysis of the

» Mostly Fermi triggered/motivated

29 ACTs + Fermi

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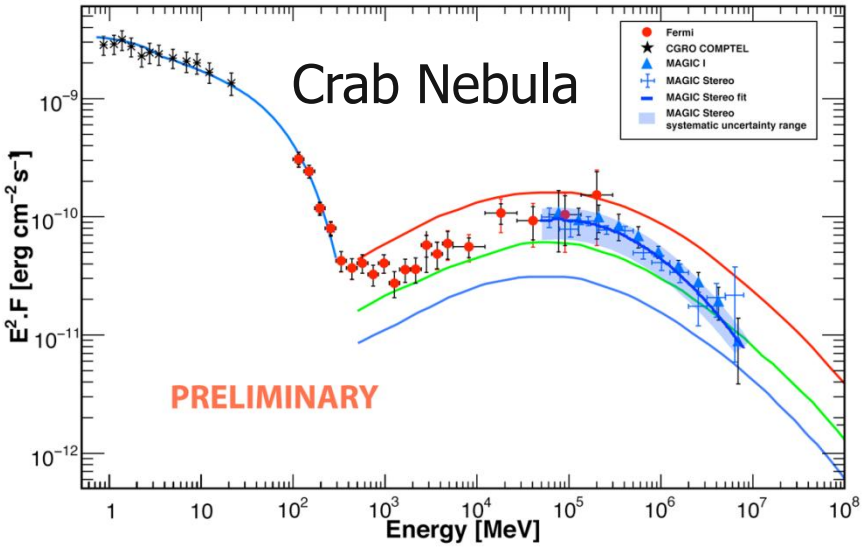
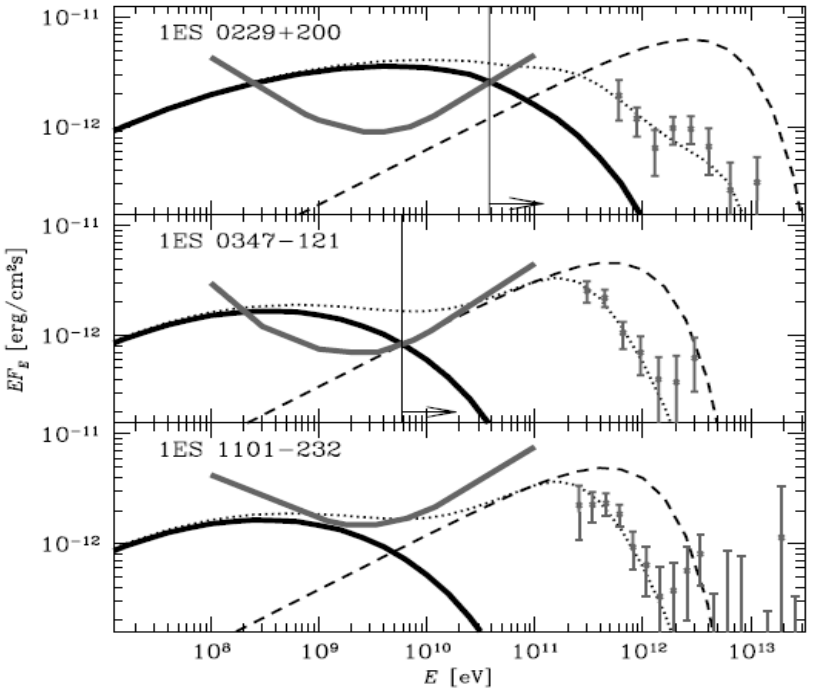
- Better sensitivity match
  - w.r.t EGRET
- No more "10-100 GeV gap"
  - For strong TeV sources
- Lots of science potential e.g.
  - B_{EG} lower limit
    - Neronov & Vovk (2010)
  - Blazars
    - PKS 2155-302, PG 1553+113
      - MAGIC/HESS/VERITAS +Fermi collaborations
  - Binaries, PWN, SNR
    - LS I +61303
    - Vela X
    - RX J1713-3946





30 TeV Astronomy: Highlights

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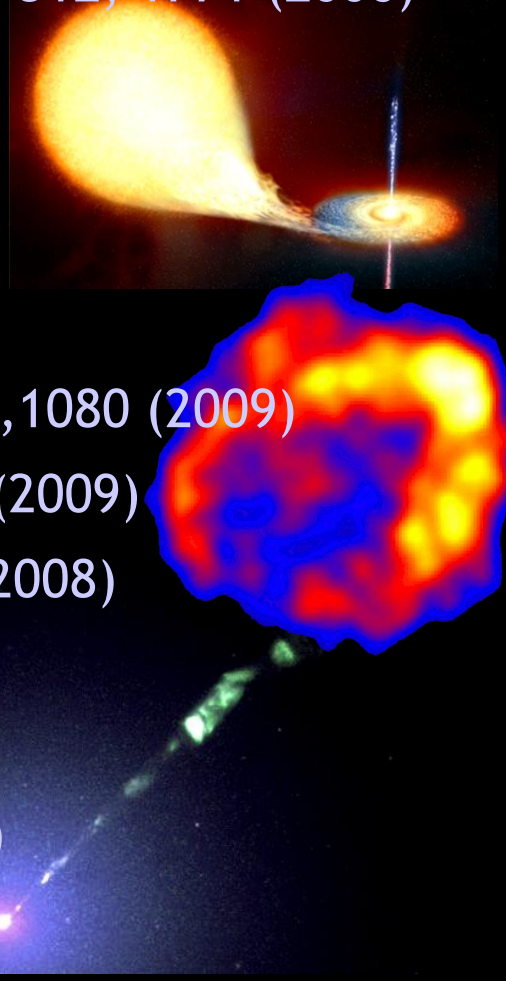
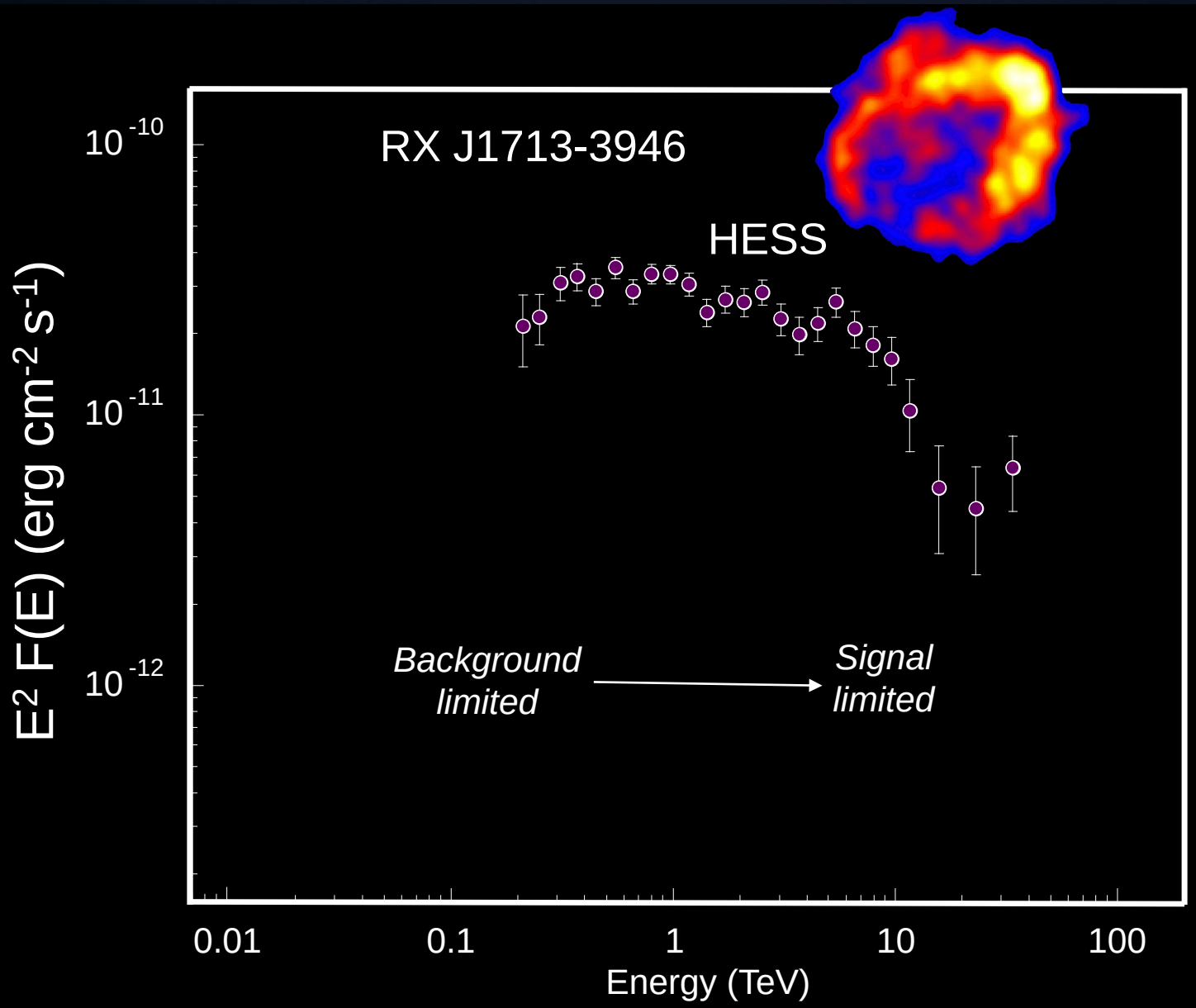
- *Microquasars*: Science 309, 746 (2005), Science 312, 1771 (2006)
- *Pulsars*: Science 322, 1221 (2008)
- *Supernova remnants*: Nature 432, 75 (2004)
- *Galactic Centre*: Nature 439, 695 (2006)
- *Galactic Survey*: Science 307, 1839 (2005)
- *Starbursts*: Nature 462, 770 (2009), Science 326,1080 (2009)
- *AGN*: Science 314,1424 (2006), Science 325, 444 (2009)
- *EBL*: Nature 440, 1018 (2006), Science 320, 752 (2008)
- *DM*: Phys Rev Letters 96, 221102 (2006)
- *LIV*: Phys Rev Letters 101, 170402 (2008)
- *Cosmic Ray Electrons*: Phys Rev Letters (2009)



Results from HESS, MAGIC and VERITAS

Photon Statistics



32 Photon Statistics

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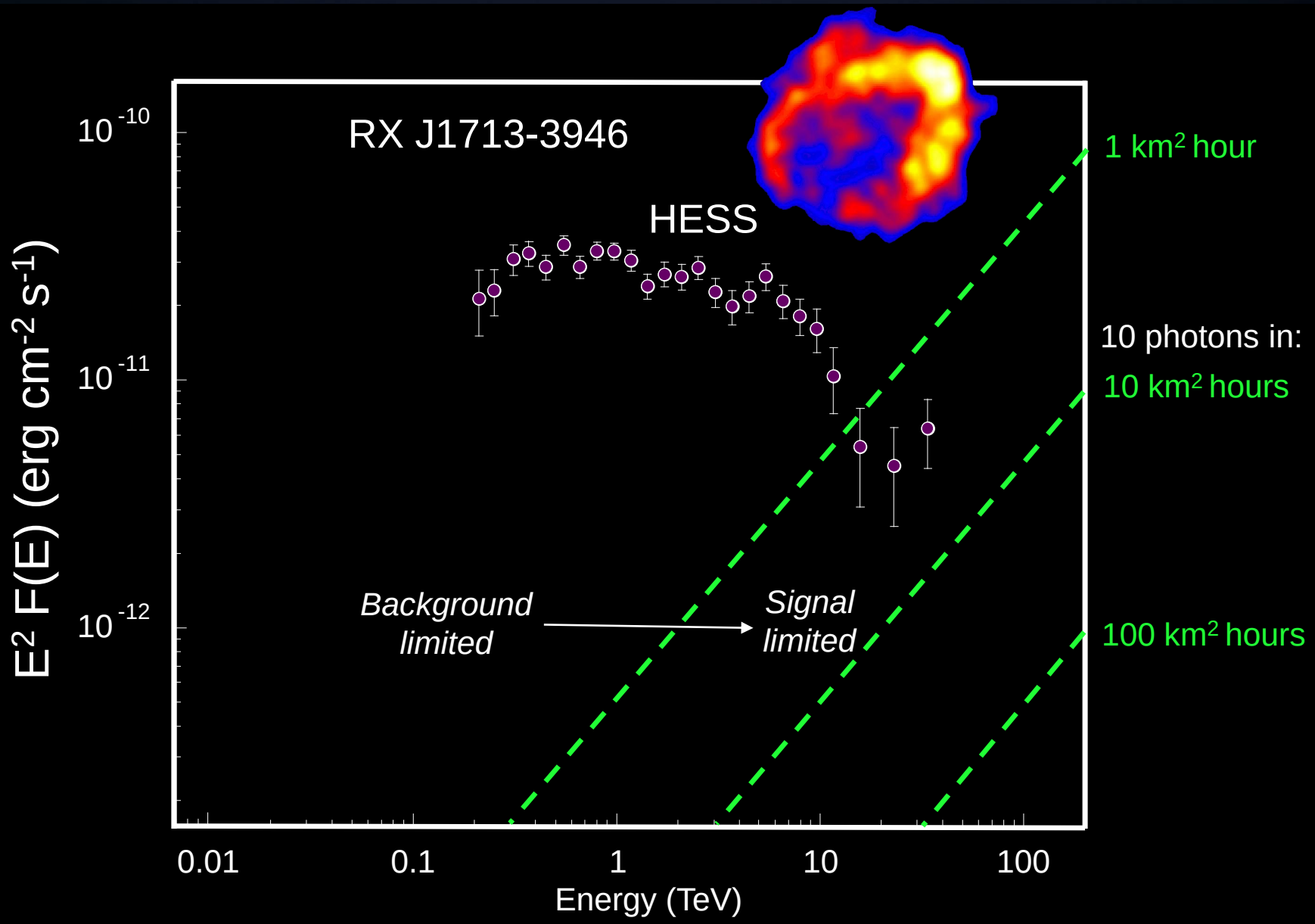

33 Photon Statistics

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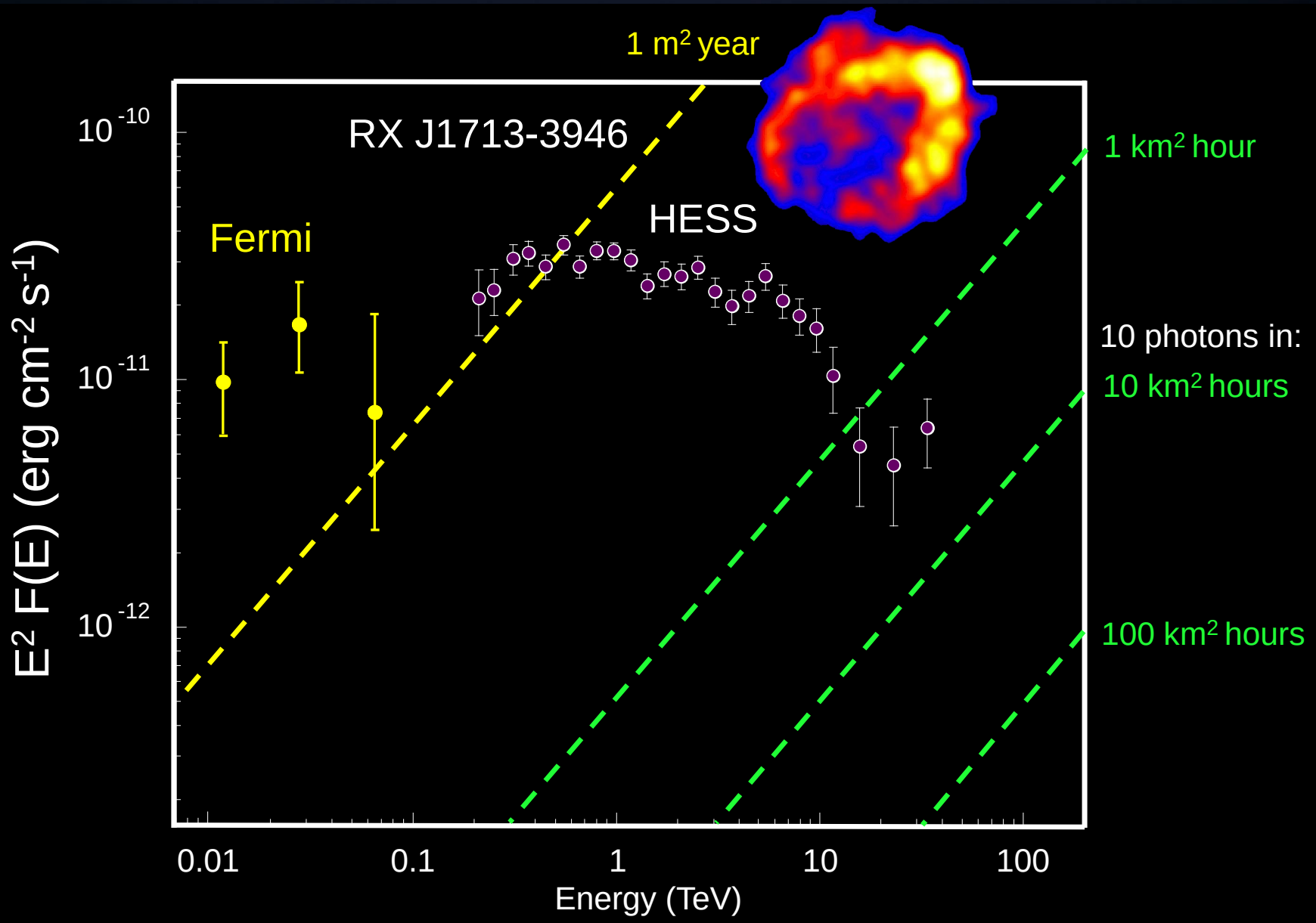
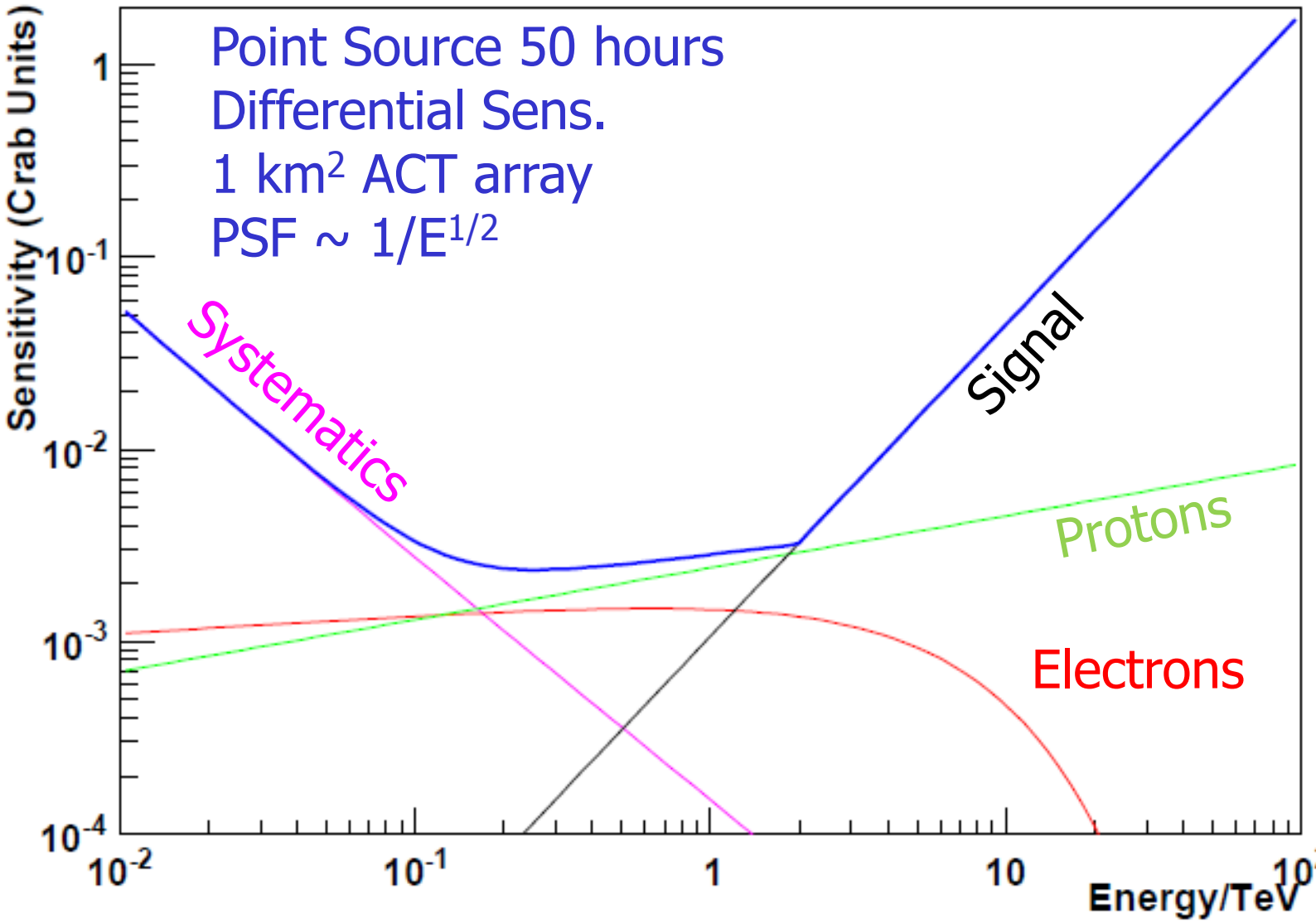
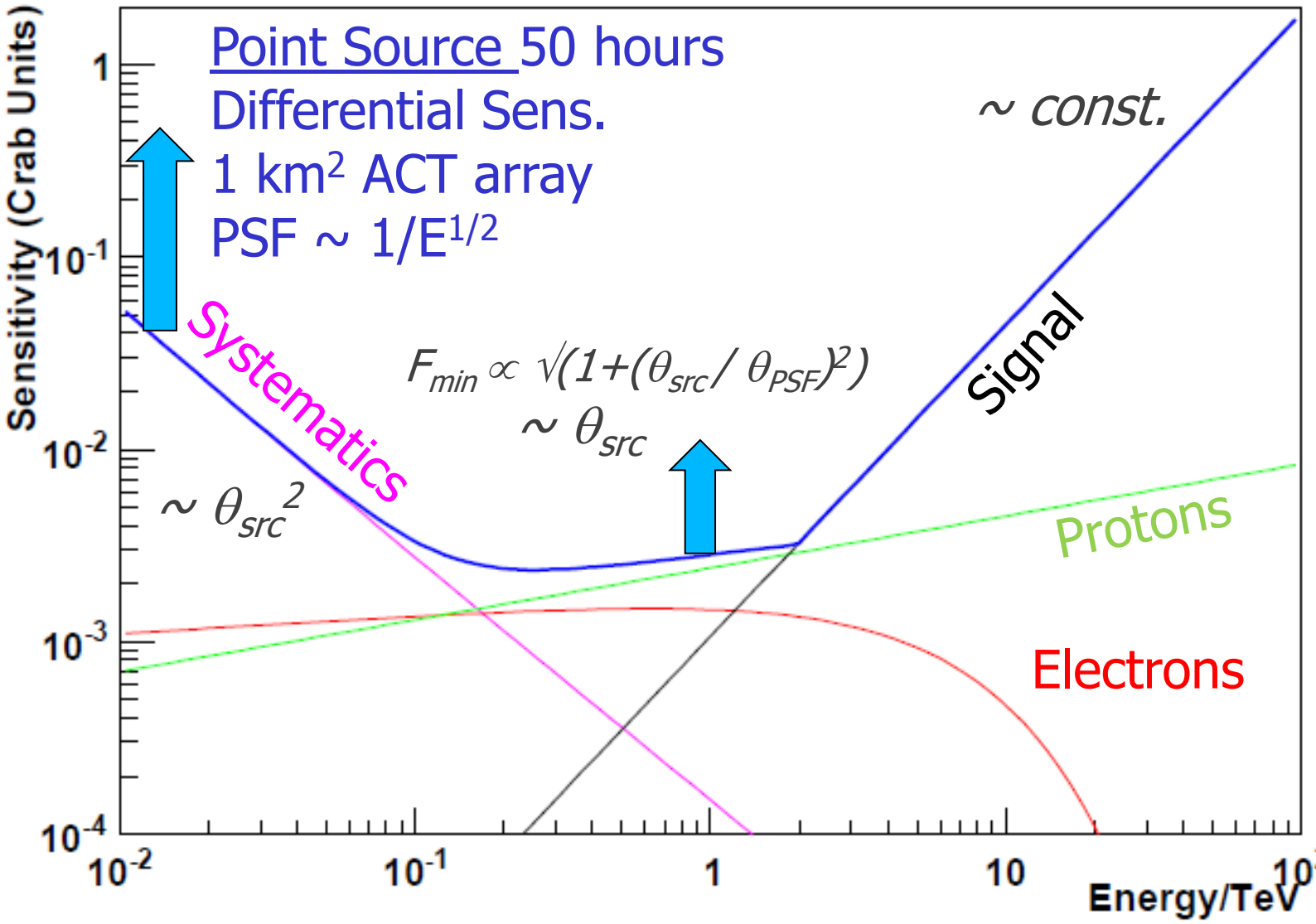


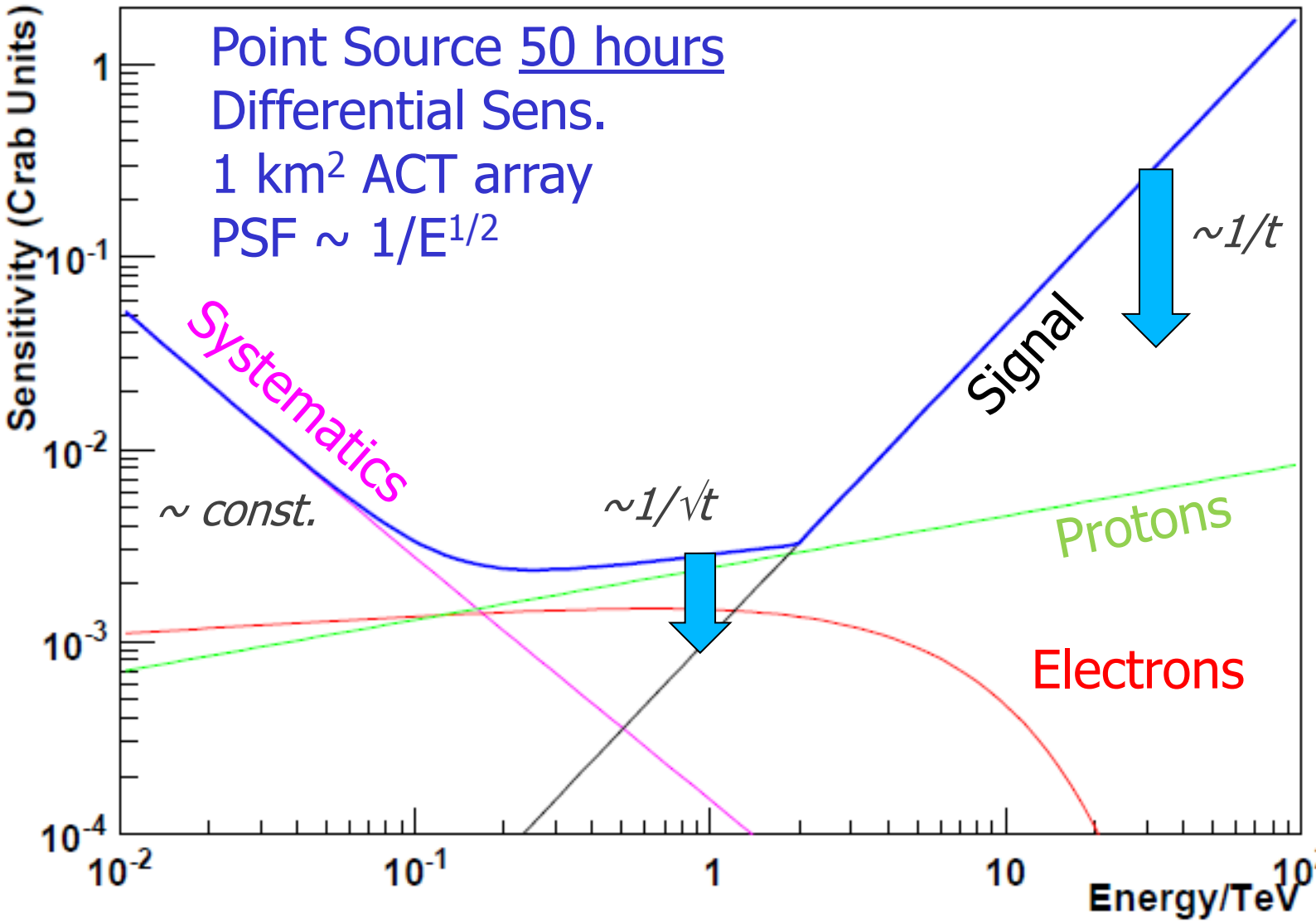
34 Toy Model Sensitivity



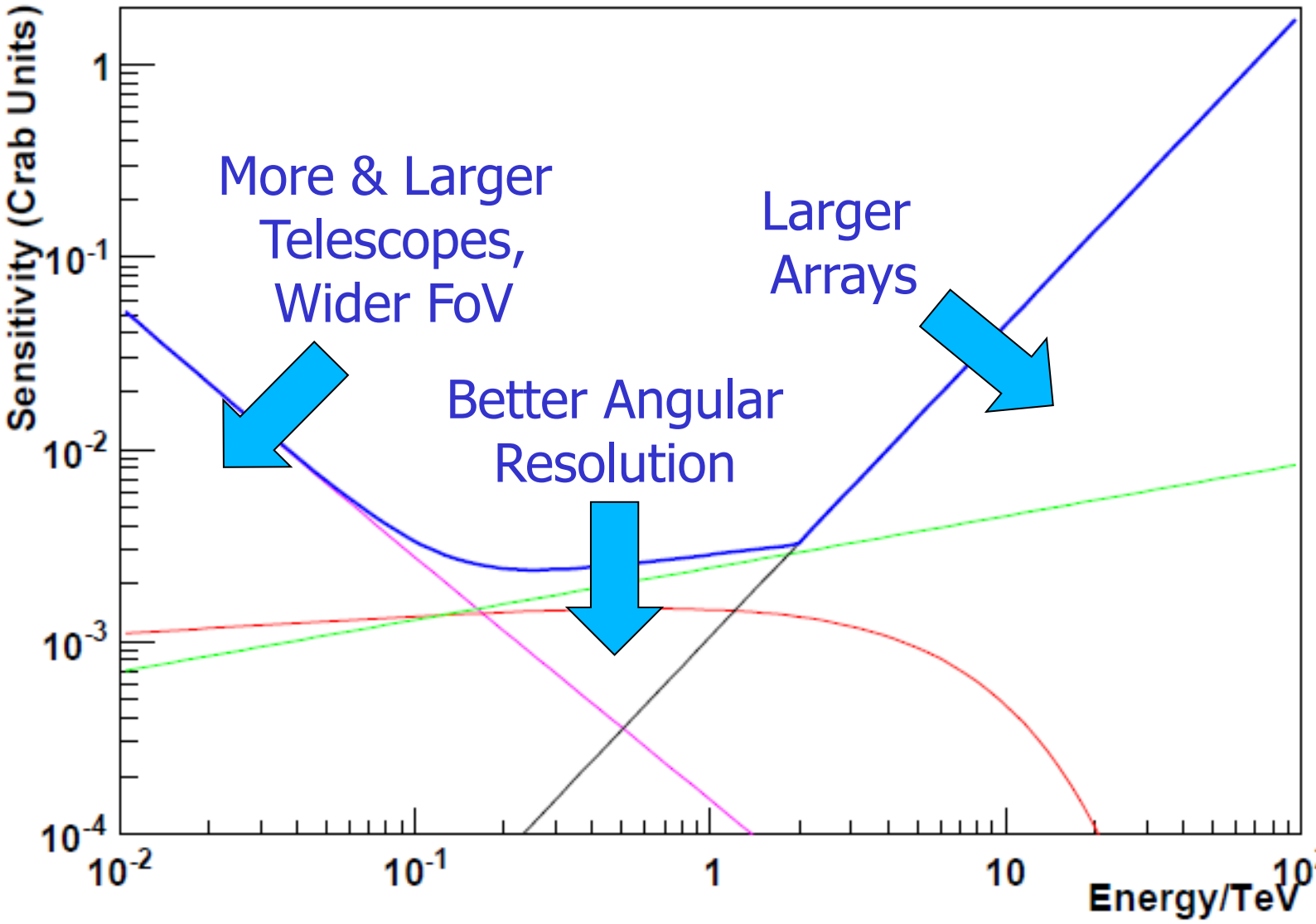
35 Toy Model Sensitivity



36 Toy Model Sensitivity



37 Toy Model Sensitivity



38 The Gamma-ray Horizon

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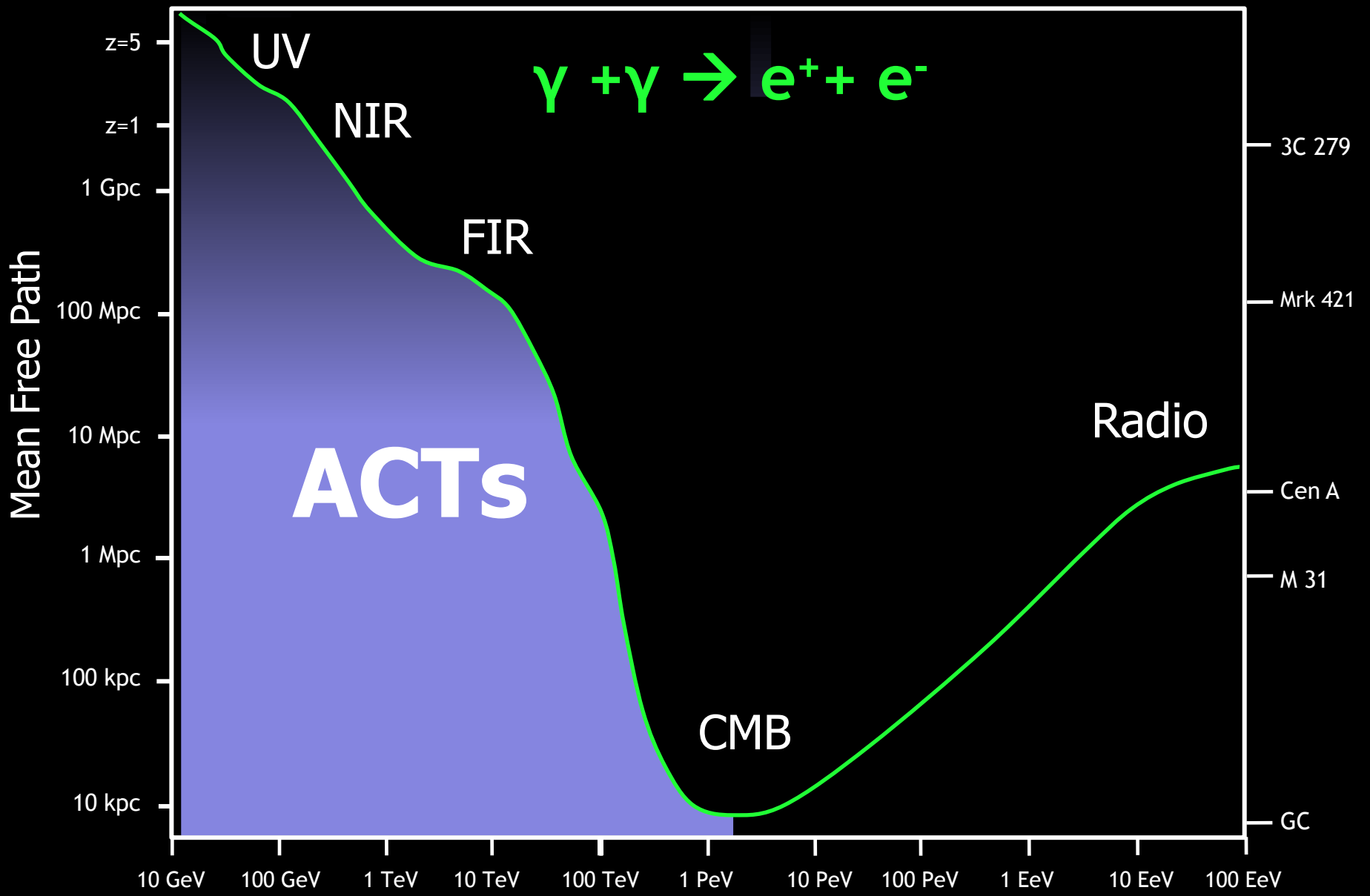

39 The Gamma-ray Horizon

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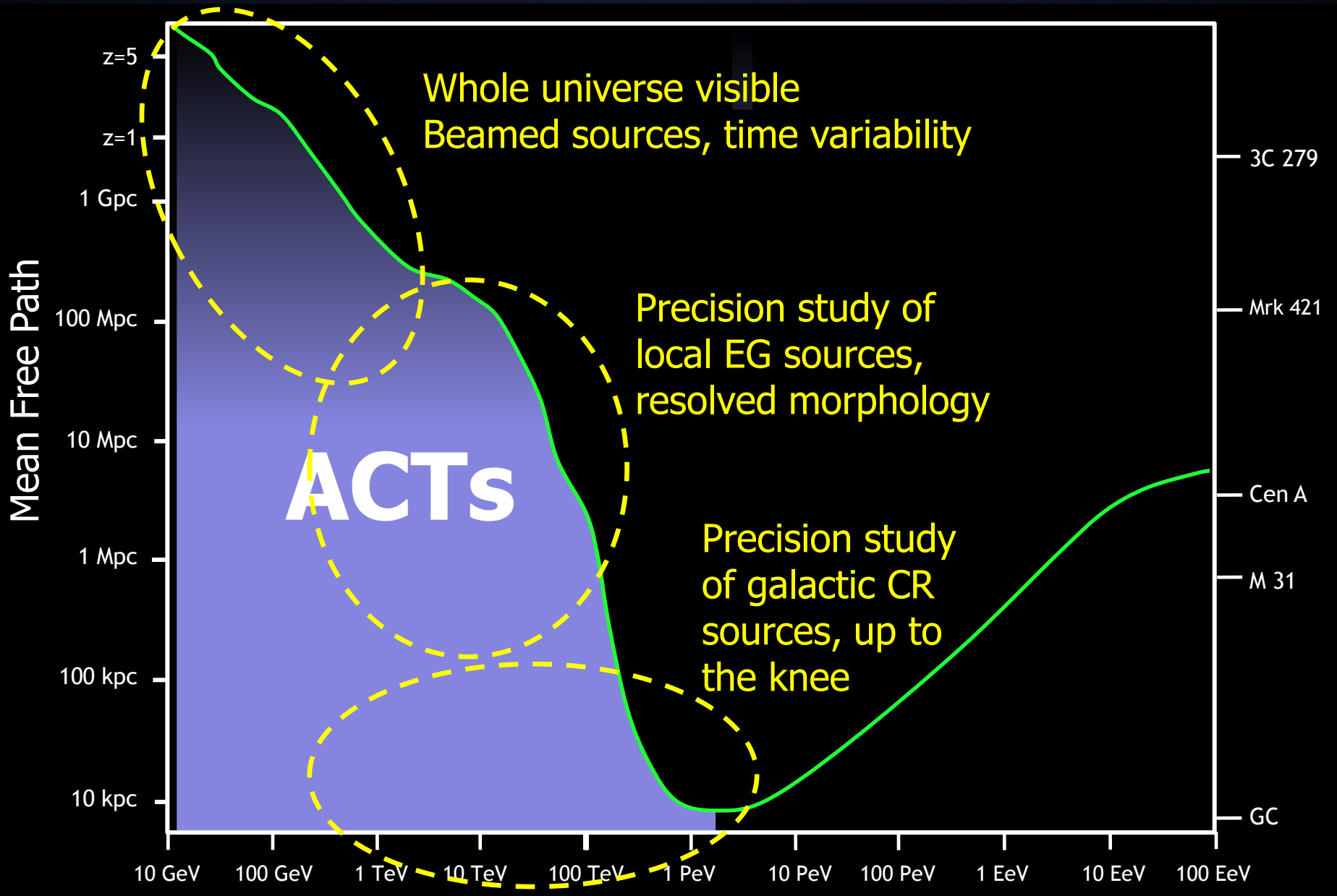

Future ACTs

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- Low Energies
  - 5@5 (Large telescopes at high alt. - 5 GeV @ 5 km alt.), MACE, HESS-2

(Timing explorers – systematics limited for long exposures)

- Intermediate Energies
  - AGIS
- High Energies
  - TenTen
- *All* energies
  - CTA

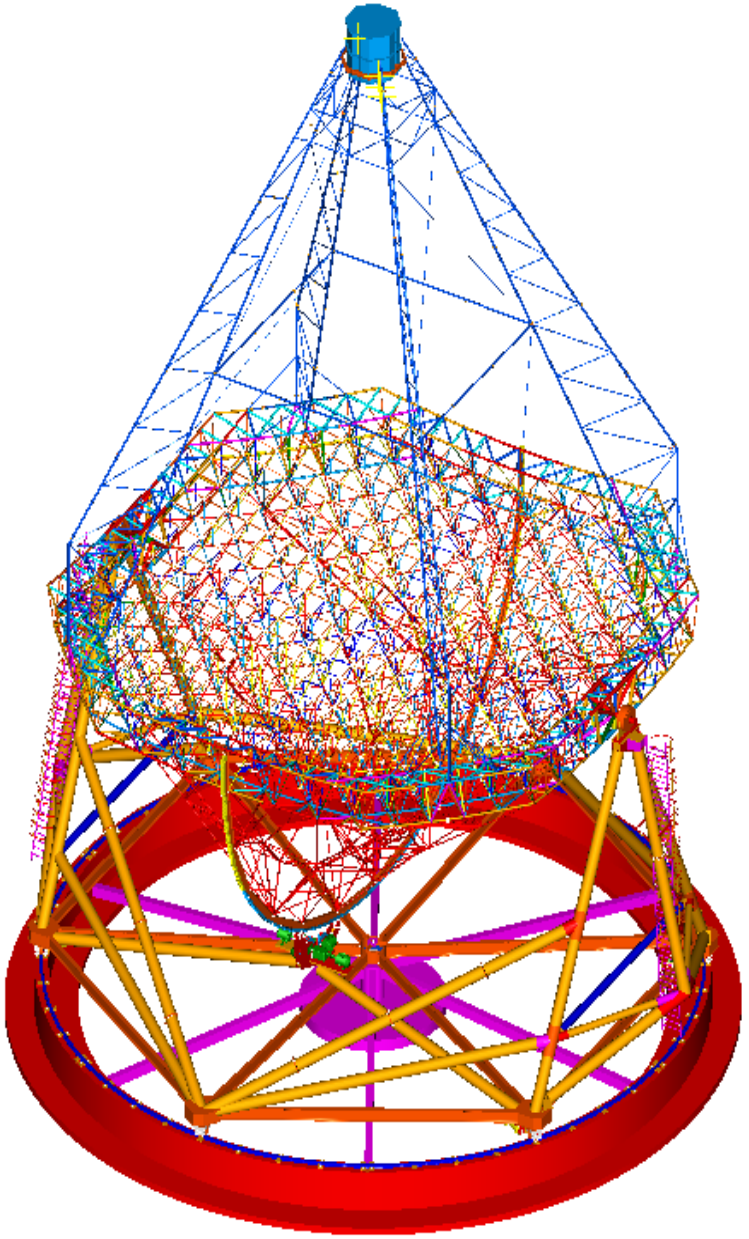
5 GeV 50 GeV 0.5 TeV 5 TeV 50 TeV 0.5 PeV

MACE

University of Leicester

- At Hanle, India, 4200m
- 360 m^2 (21 m ∅) mirror
- Threshold ~20 GeV
- 1088 pixel – 4° FoV
- First work on site begun
- Expect 1st results 2013

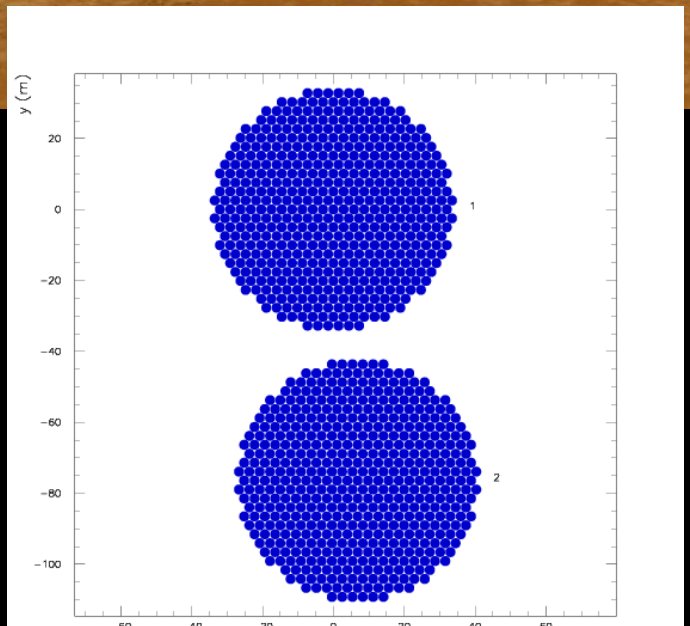
- Add 3 more tels ~2016



42 TenTen

University of Leicester

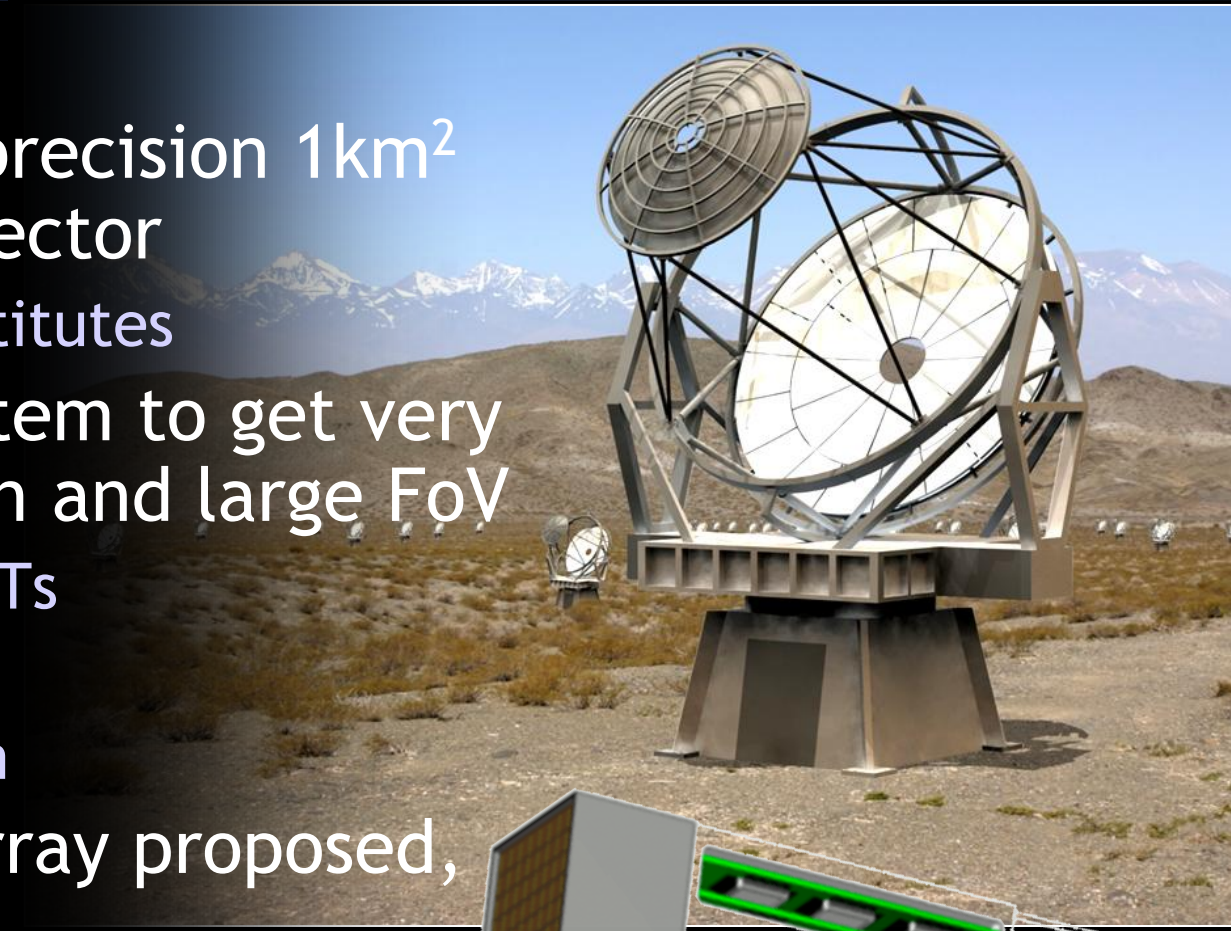
- Goal: 10 km^2 at 10 TeV
- Low altitude site
  - 220 m a.s.l. (Australia)
- Baseline elements
  - 6m telescopes
  - 8° FoV
  - 0.24° pixels
  - 500 m squares + central
- Use of timing info in reco.
  - E.g. VERITAS movie →
  - 0.05-0.1° res. above 10 TeV
- Led by University of Adelaide

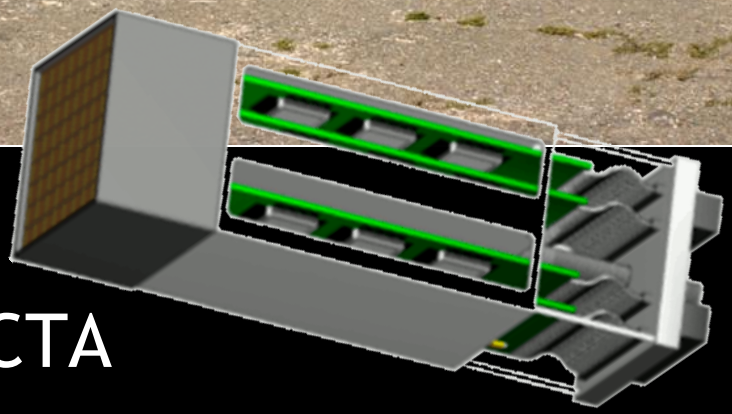


AGIS

University of Leicester

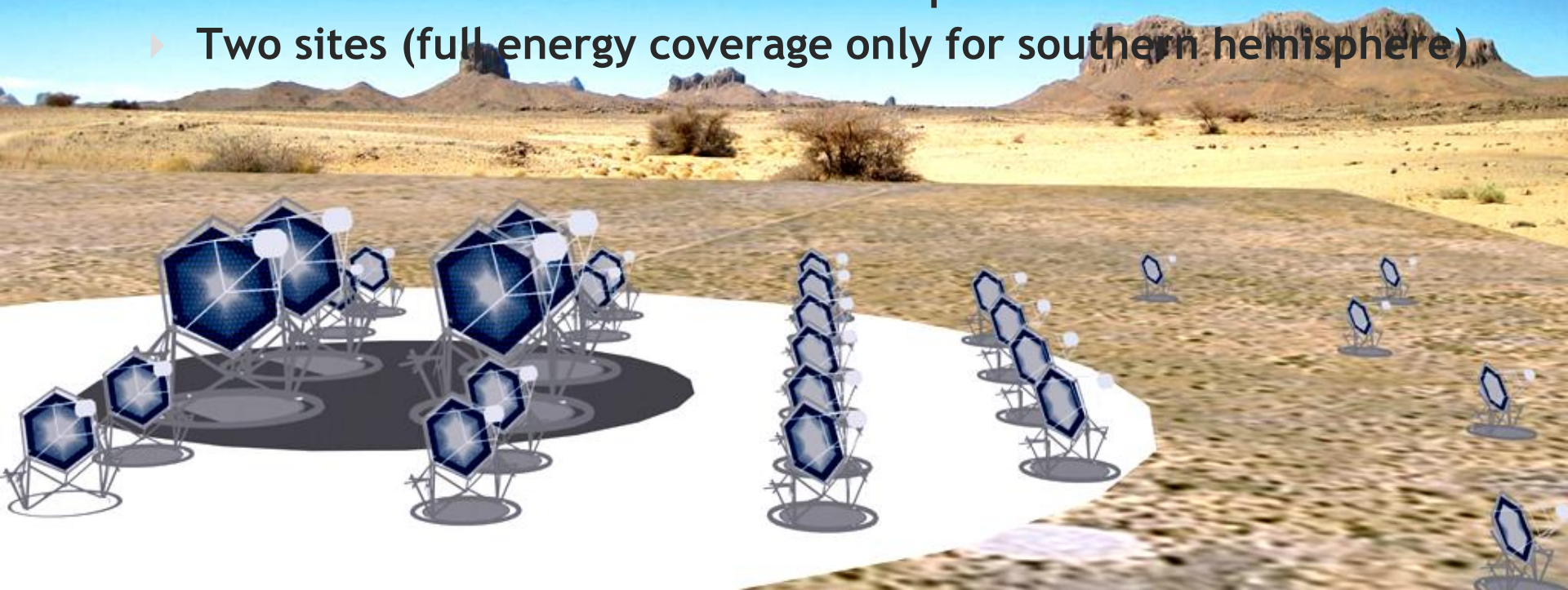
- Concept for a precision 1km^2 0.1-10 TeV detector
  - US led – 22 institutes
- Two mirror system to get very fine pixelisation and large FoV
  - Use e.g. MAPMTs
  - ~6mm $\rightarrow$ 0.05°
  - 8° FoV is <1 m
- 36 telescope array proposed, but...
- Groups have applied to join CTA





The Cherenkov Telescope Array

- A factor 10 more sensitive than current instruments
  - Plus - much wider energy coverage, substantially better angular and energy resolution & wider field of view
- A ~€150M European led project
  - 100 institutes in 22 countries signed MoU
  - Design 2008-2011, Prototyping 2011-13, Construction 2013-18
  - Baseline: 50-100 Cherenkov telescopes
  - Two sites (full energy coverage only for southern hemisphere)



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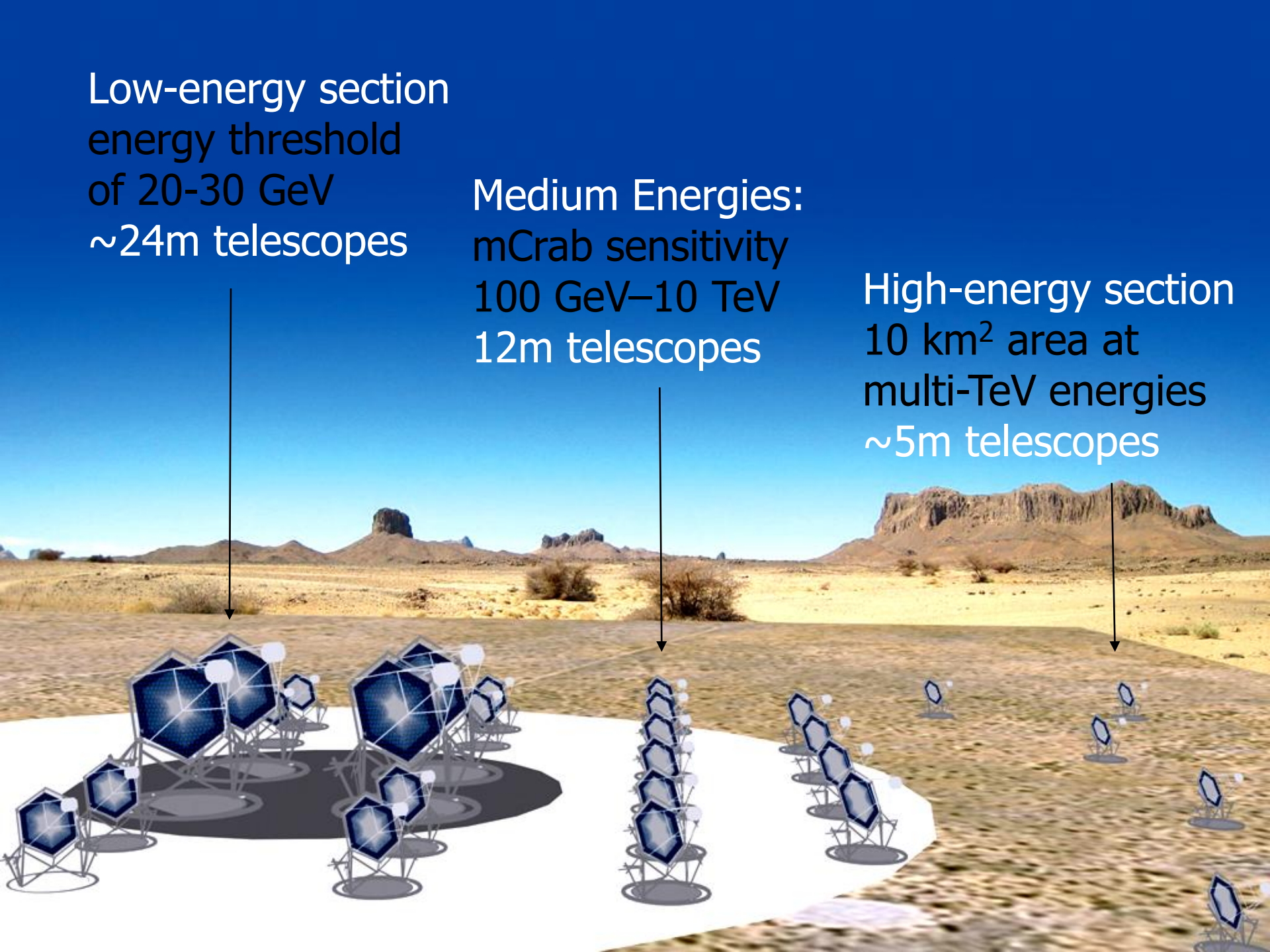
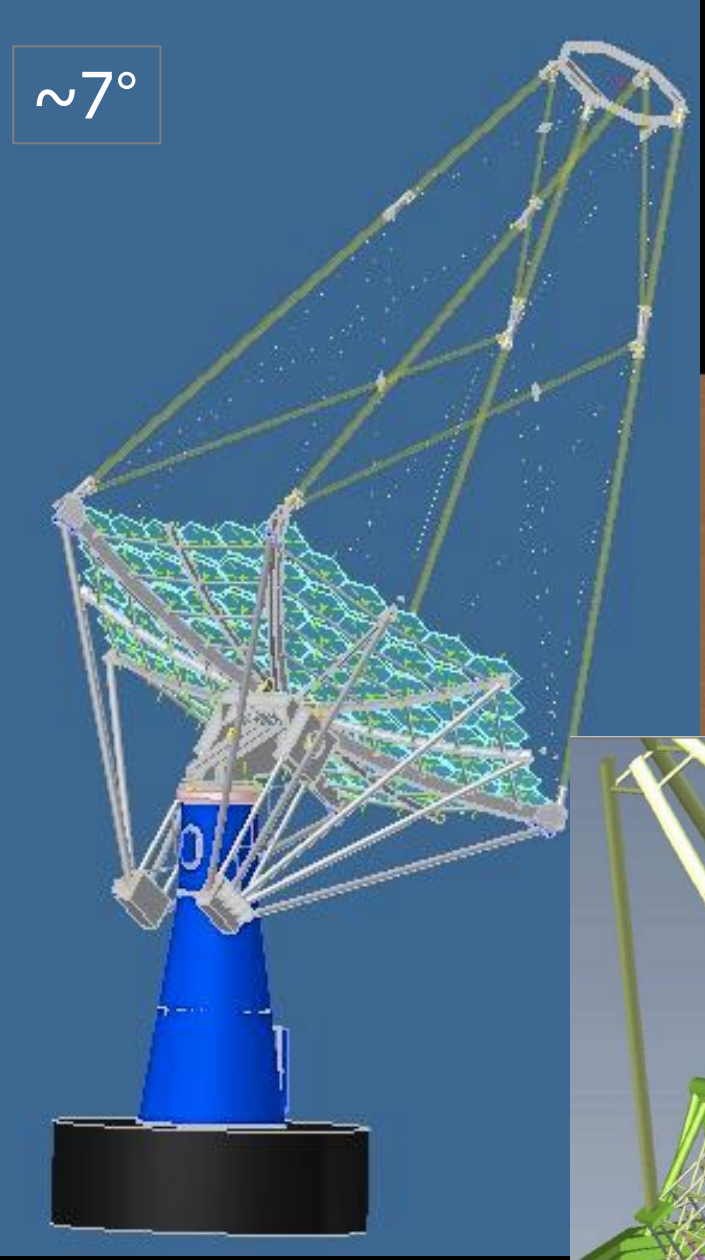
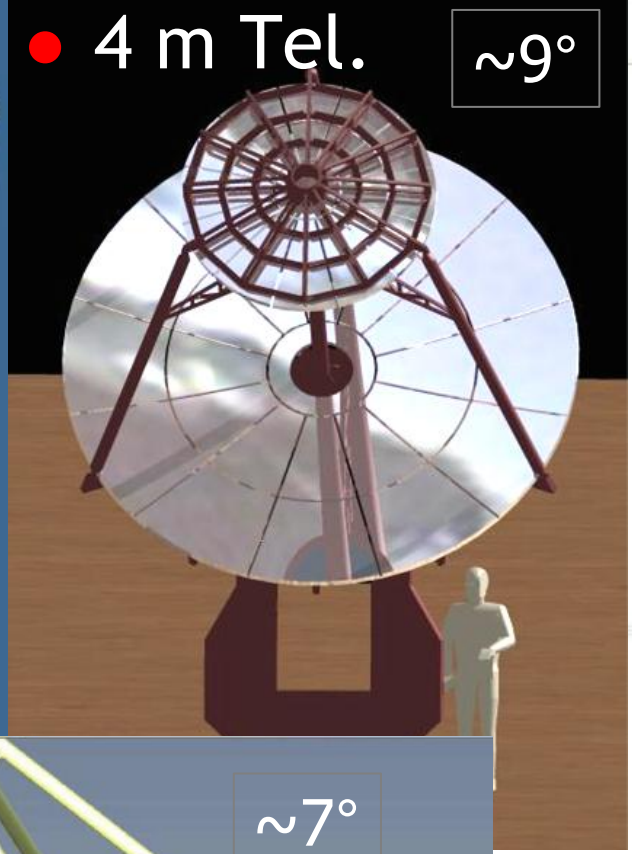
EU funded - €5.2M
Preparatory Phase 7/2010 – 7/2013


Low-energy section
energy threshold
of 20-30 GeV
~24m telescopes
Medium Energies:
mCrab sensitivity
100 GeV–10 TeV
12m telescopes
High-energy section
10 km^2 area at
multi-TeV energies
~5m telescopes

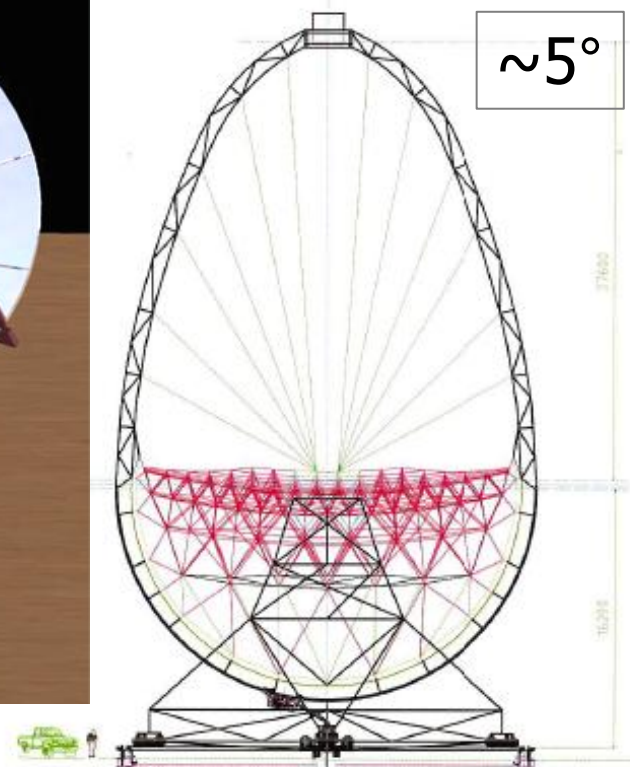


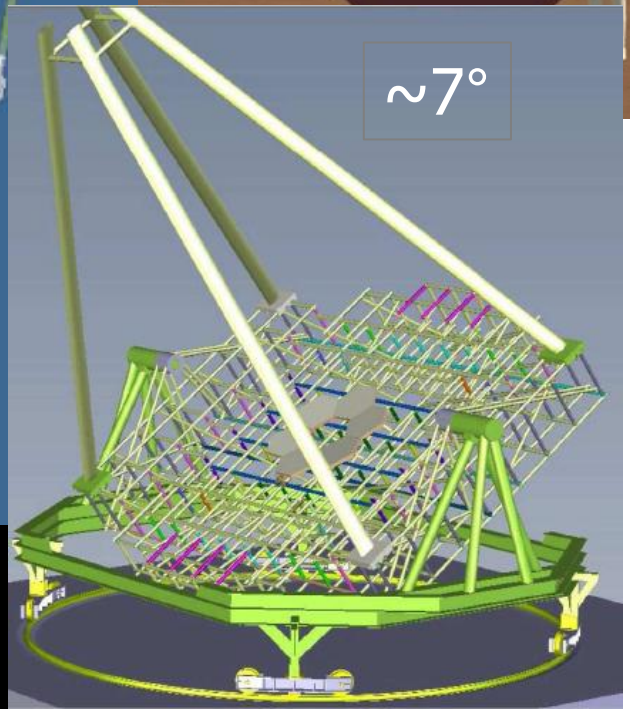
- 12 m Tels.

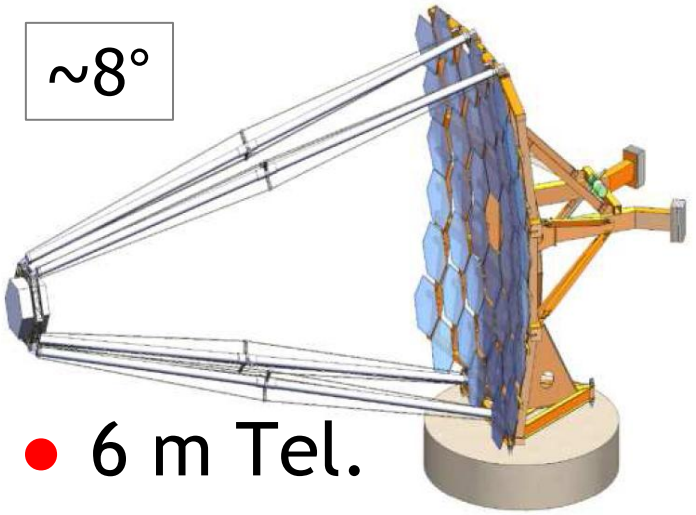
- 4 m Tel.



- 23 m Tel.







- 6 m Tel.

48 Point-source Sensitivity

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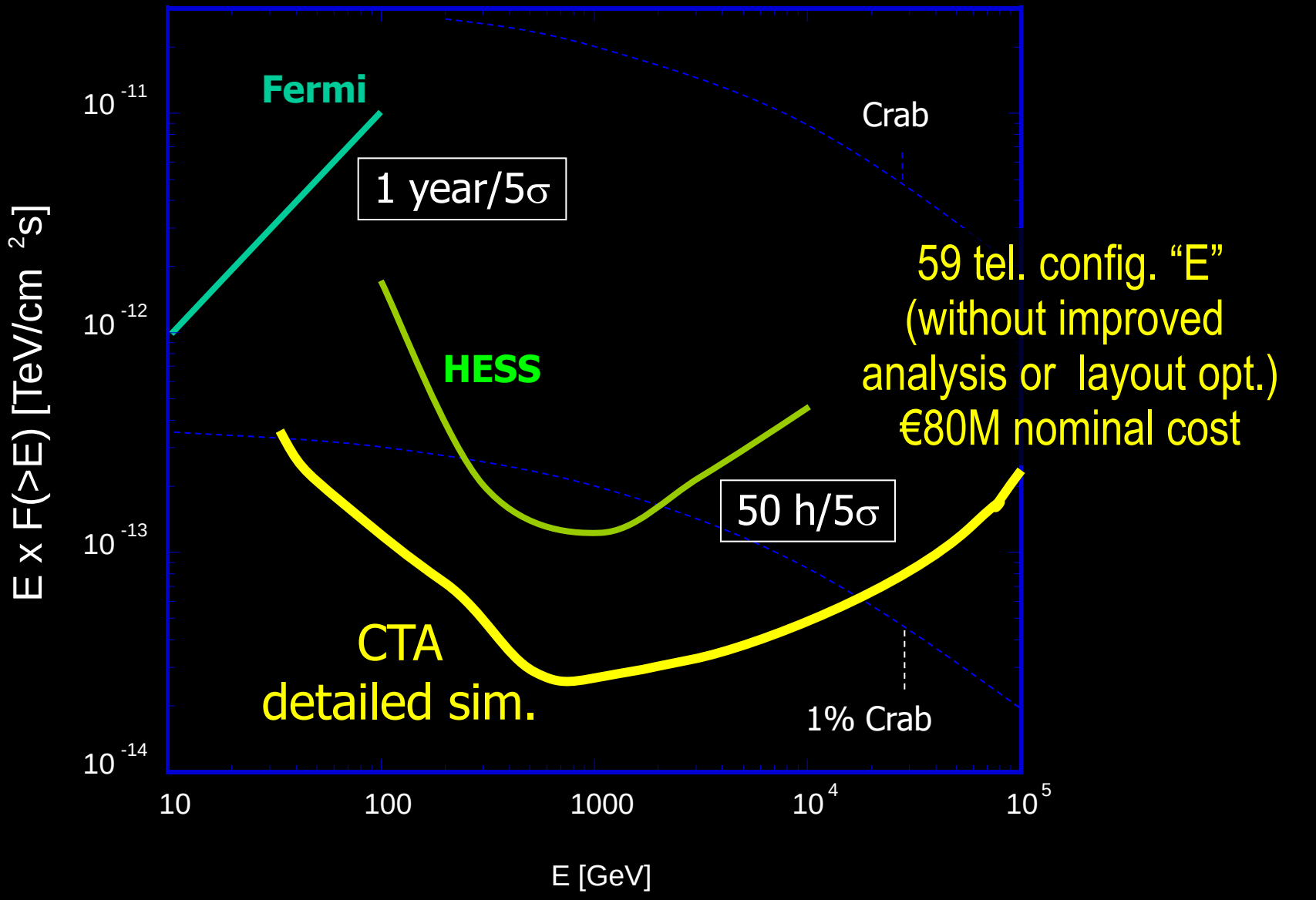

49 Precision

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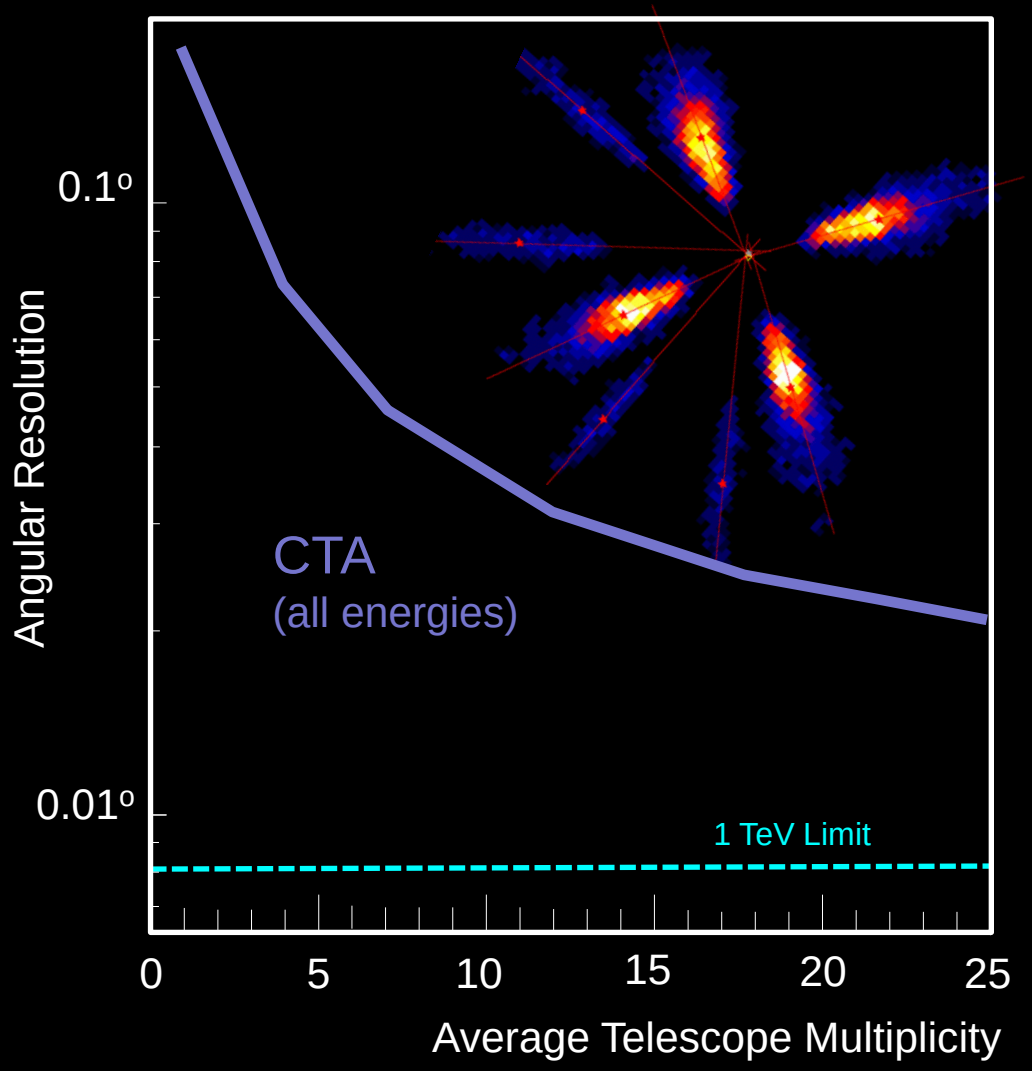
- Increase in the number of Cherenkov images measured in individual telescopes leads to improved angular and energy resolution
- Resolution also improves with energy



50 Science Potential

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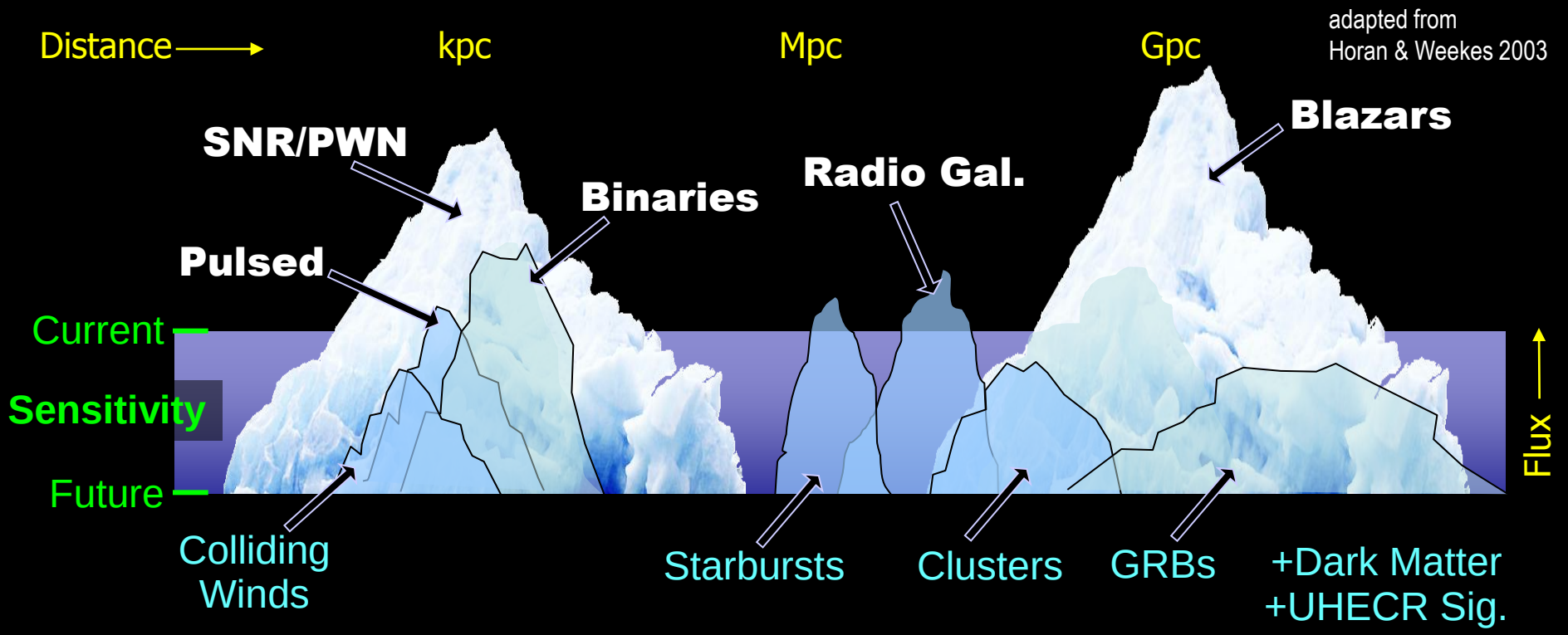
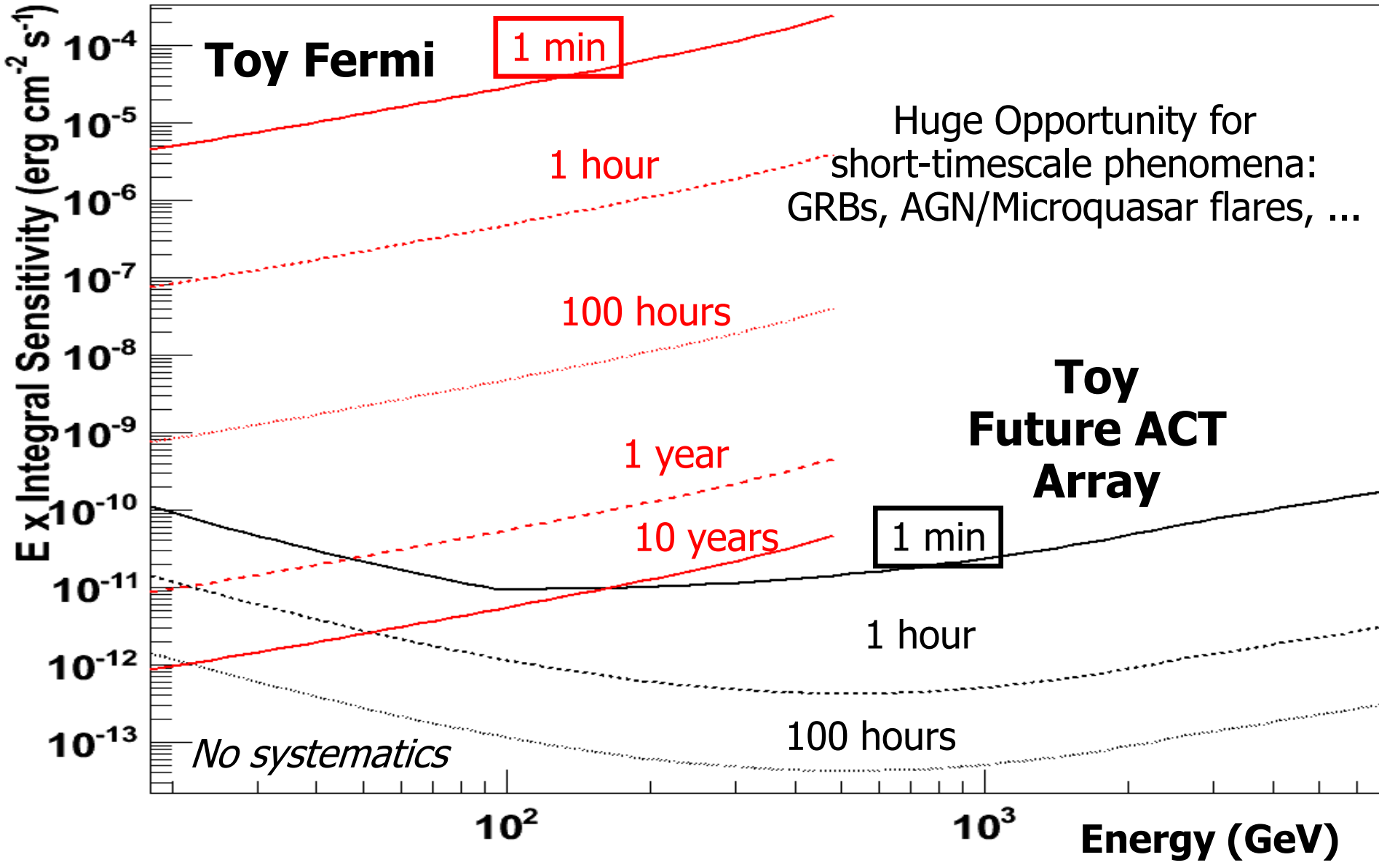


» "Current instruments have passed the critical sensitivity threshold and reveal a rich panorama, but this is clearly only the tip of the iceberg

» Broad and diverse program for future ACTs, combining guaranteed astrophysics with significant discovery potential"

Hofmann 2006

The Variable Universe



Conclusions

- IACT arrays are the precision instruments of high energy (>100 keV) astronomy
- Moving from experiments to observatories
  - Current generation instruments are still going strong – steady stream of significant new results
- Huge potential looks likely to be realised – global convergence on CTA as *the* major project of the next decade
  - *(just ask for more details/plots)*