Centre for
Space Research
NWU

History of Gamma-ray Astronomy in South Africa

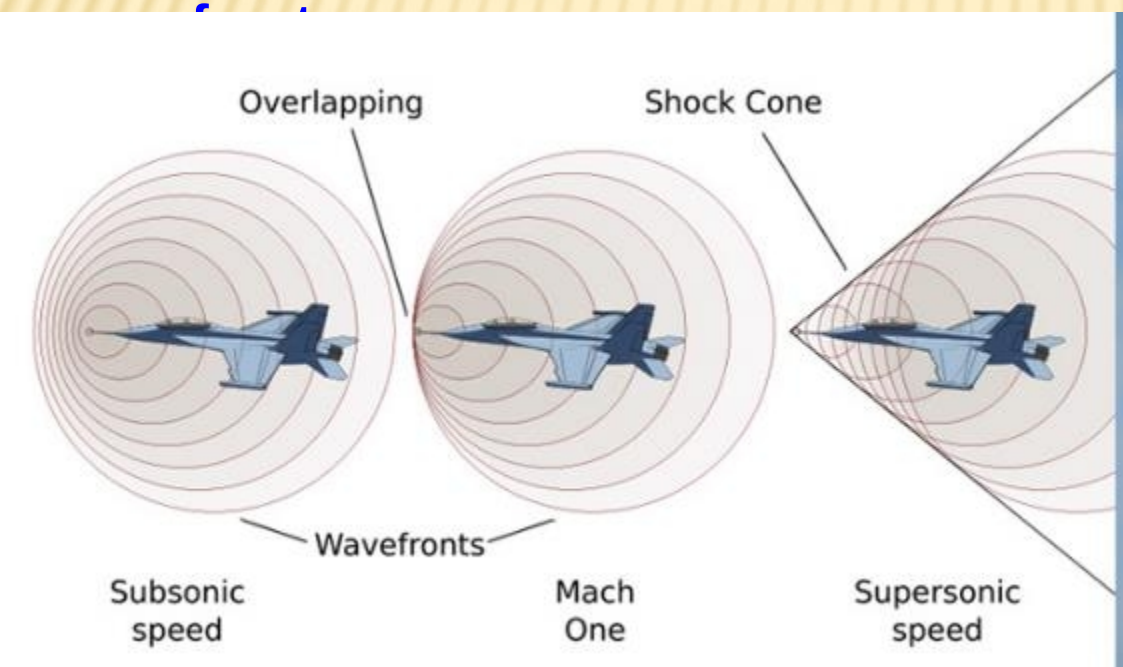
C. Venter (on behalf of many)

History Symposium 2018

7 – 8 March 2018, Cape Town, South Africa

CHERENKOV RADIATION

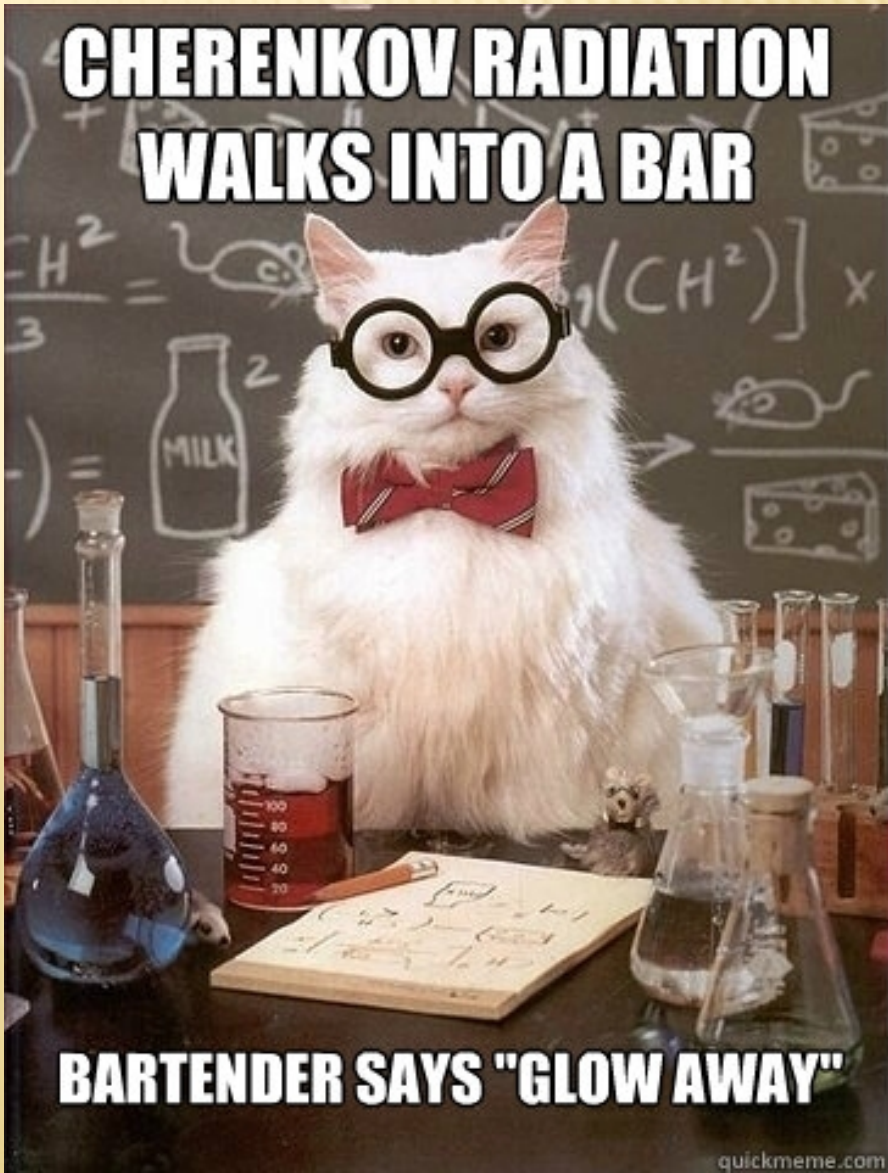
- **Visible light produced by relativistic particles moving in a medium at a speed exceeding the phase velocity of light in that medium (insulator).**
- **Coherent shockwave, short-duration (ns), emitted in narrow cone (~1.3^{o}) parallel to direction of motion of incoming particle.**
- **Analogy: Sonic boom of supersonic aircraft. Sound waves propagate slower than speeding object, forming a shock**



http://jinavie.tumblr.com/post/76353752941/sonic-boom

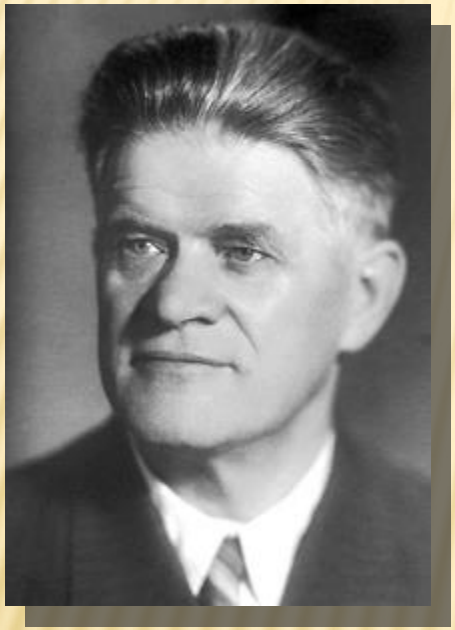
CHERENKOV RADIATION

- VHE (≥100 GeV) photons or gamma rays enter atmosphere, collides with atmospheric nuclei (~12 km), produces shower of relativistic electrons; light cone with ~ 100 m diameter.
- Cosmic-ray "background" signal; discrimination using periodicity at first; later images of showers.
- First VHE telescope in 1967 on Mt Hopkins, USA.

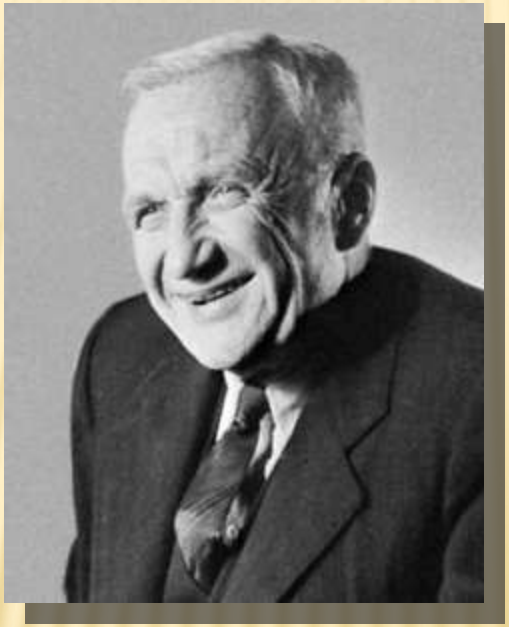


CHERENKOV RADIATION

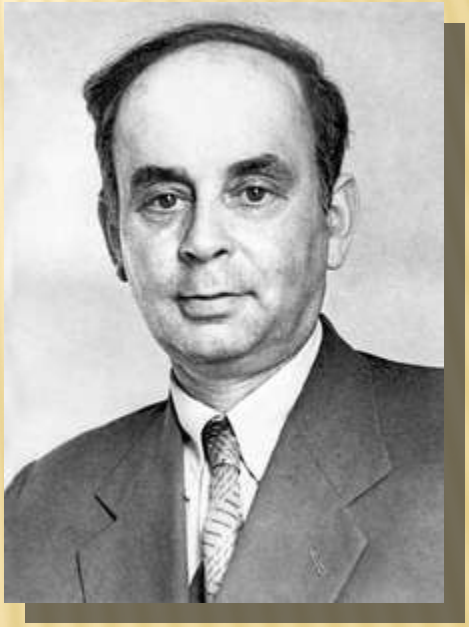
1958 Nobel Prize in Physics for explaining the phenomenon of Cherenkov radiation



Pavel Cherenkov



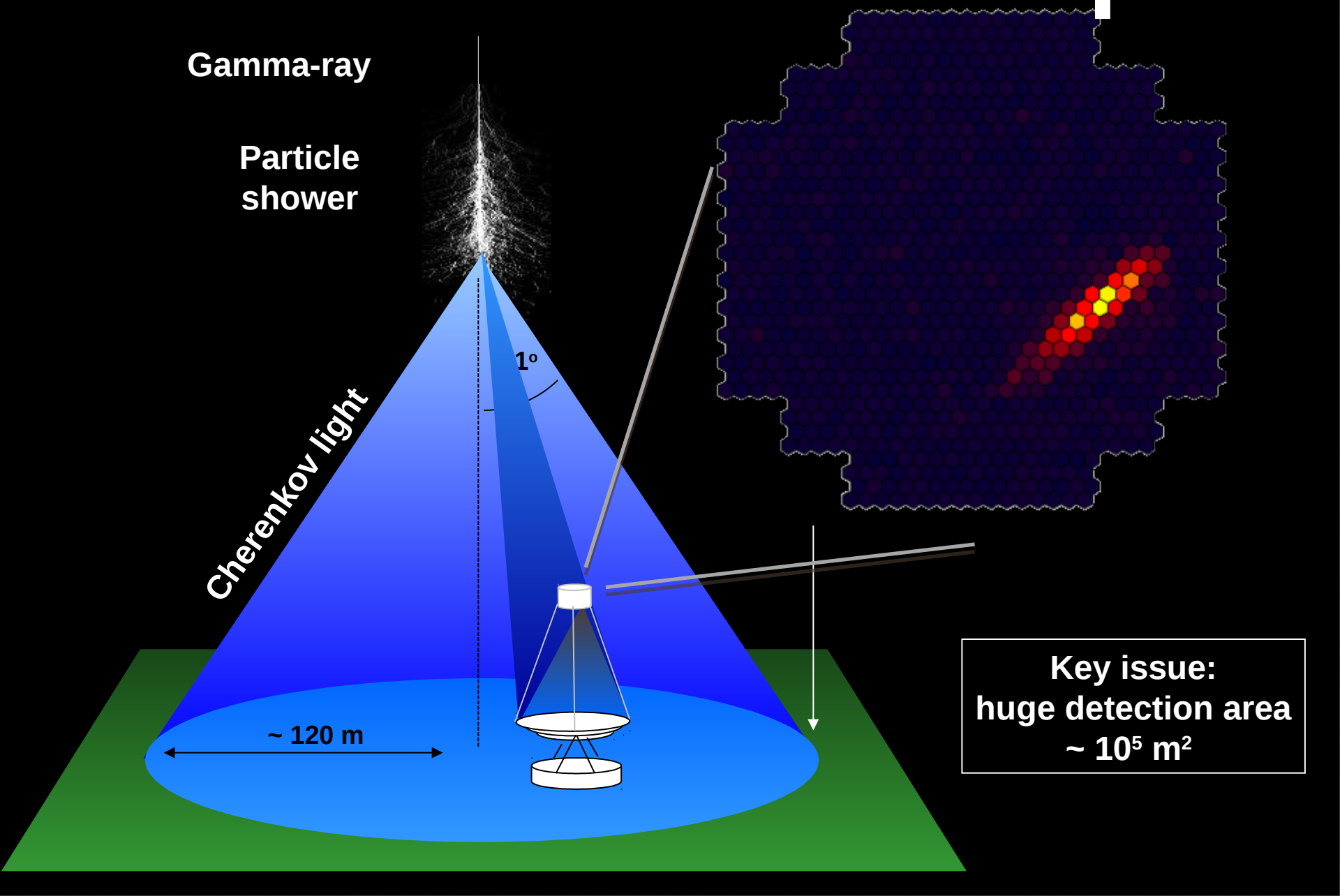
Igor Tamm



Ilya Frank

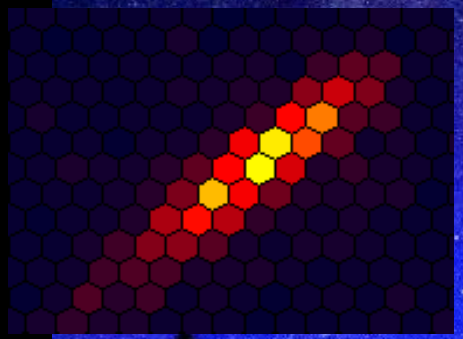
http://en.wikipedia.org/wiki/File:Cerenkov.jpg
https://www.britannica.com/science/Cherenkov-radiation

Cherenkov Technique



Key issue:
huge detection area
~ 10^5 m^2

Air Showers Resemble Meteors



(from Sky & Telescope)

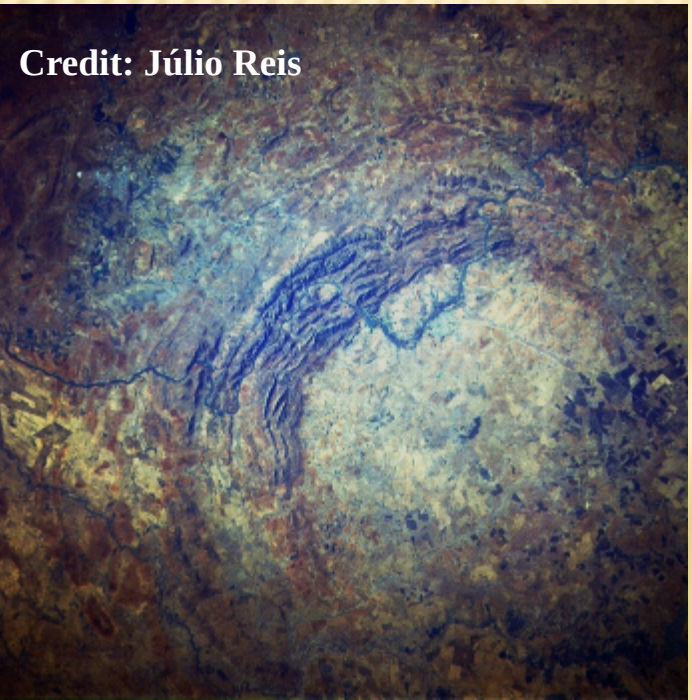
LOCAL HISTORY

- **Department of Physics at the Potchefstroom University for Christian Higher Education became involved in experiments involving Extensive Air Showers in the 60s.**

Pierre Auger Observatory
http://www.ung.si/en/research/cac/projects/auger/

LOCAL HISTORY

- **Scintillation counters: photomultiplier tubes and ns-technology in 70s.**
- **Raubenheimer (1983) proposed to build an Atmospheric Cherenkov Telescope given the good climate, clear skies, and tech know-how.**
- **Farm Nooitgedacht, 35 km from Potchefstroom in the Vredefort Dome (26.9°S, 27.2°E, 1438 masl).**
- **MK I telescope became operational in 1985 – first in S. Hemisphere.**
- **Good site with Galactic Centre passing near zenith during winter.**



THE MK I TELESCOPE

- Commissioning of Mk I in April 1985.
- 4 mini-telescopes (MTs), distributed 55 m from each other on the corners of a triangle and one the middle.
- Compactness of array allowed multiple sampling of single shower: pin-point shower direction.
- Each MT consisted of 12 search light mirrors from WWII (d = 1.5 m) used as reflectors.
- Each MT contained three light detectors.
- To maximise light flux detected by the XP2020Q photomultiplier, a custom collimator system was designed and built (cf. MSc thesis of HI Nel on optimalisation of system).
- Low reflection coefficient (~0.7 at 400 nm); f-value ~ 0.43 (maximum incident angle 61°); hyperbolic form (focus planes instead of single focus).

Data log: Nooitgedacht Mk I

Source type	Total number	Exposure (h)
Isolated radio pulsars	21	1070
X-ray binaries	14	672
Cataclysmic variables	8	578
Binary radio pulsars	9	574
Miscellaneous	6	690

THE MK I TELESCOPE

- Low-tech: no imaging possible. Identied a gamma-ray event using coincidence techniques (and locally-produced electronics).
- Cosmic-ray event rate of 1 Hz, threshold energy of 1 TeV at zenith.
- 9 years in operation; 3 600 hours of observations.
- Only 5 statistically significant VHE sources detected at the time: Crab pulsar @ 6σ, Cyg X-3, Cen A, Vela Pulsar, and Her X-1.
- Most important: arrival time of the gamma ray. Registering absolute time before the advent of cell phones, GPSs, internet... National time service provided by CSIR (0.1 ms) to calibrate time. Later, acquired an expensive atomic clock.
- Original control room a caravan containing a lot of electronics.
- 40-minute “drift scans”; repositioning to new coordinates took 5 minutes!
- All coordinates for the night were pre-calculated and printed out in tables.

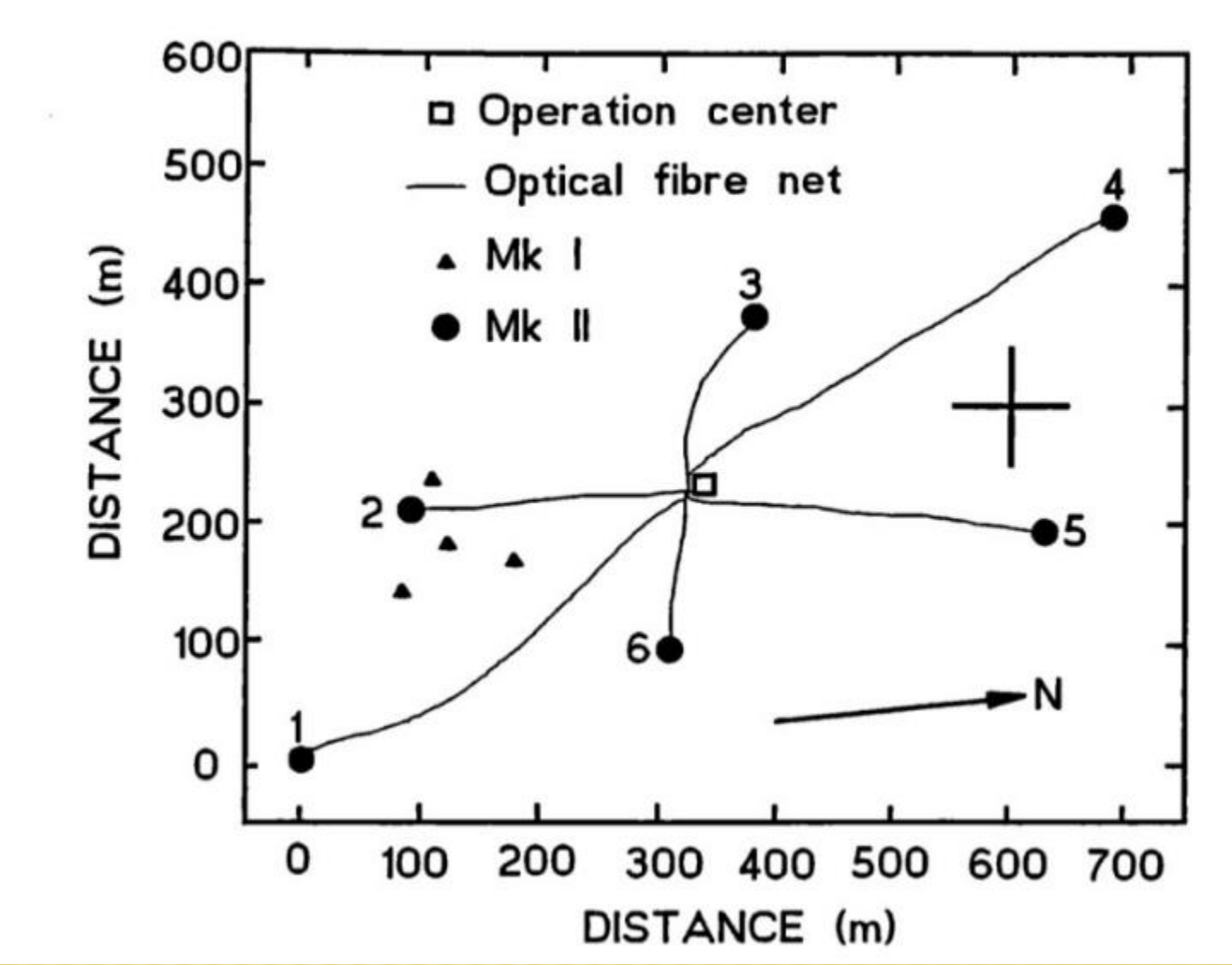
THE MK I TELESCOPE

- One night's data filled an entire box of 5.25" floppy discs.
- Transferal to the NWU's IBM mainframe took half a day (captured on Apple PC, transferred to IBM PC, then mainframe).
- Barycentric corrections to arrival times via programme that throttled the mainframe – no student and financial systems could function! Special permission from IT department.
- Big problems with bird droppings on mirrors.
- Basic temporary buildings, no running water, basic ablution facilities.
- Decommissioned: October 1993. Mirror reflectivity deteriorated, resulting in 0.4 Hz event rate; huge thunderstorm.

computermuseum.wiwi.hu-berlin.de

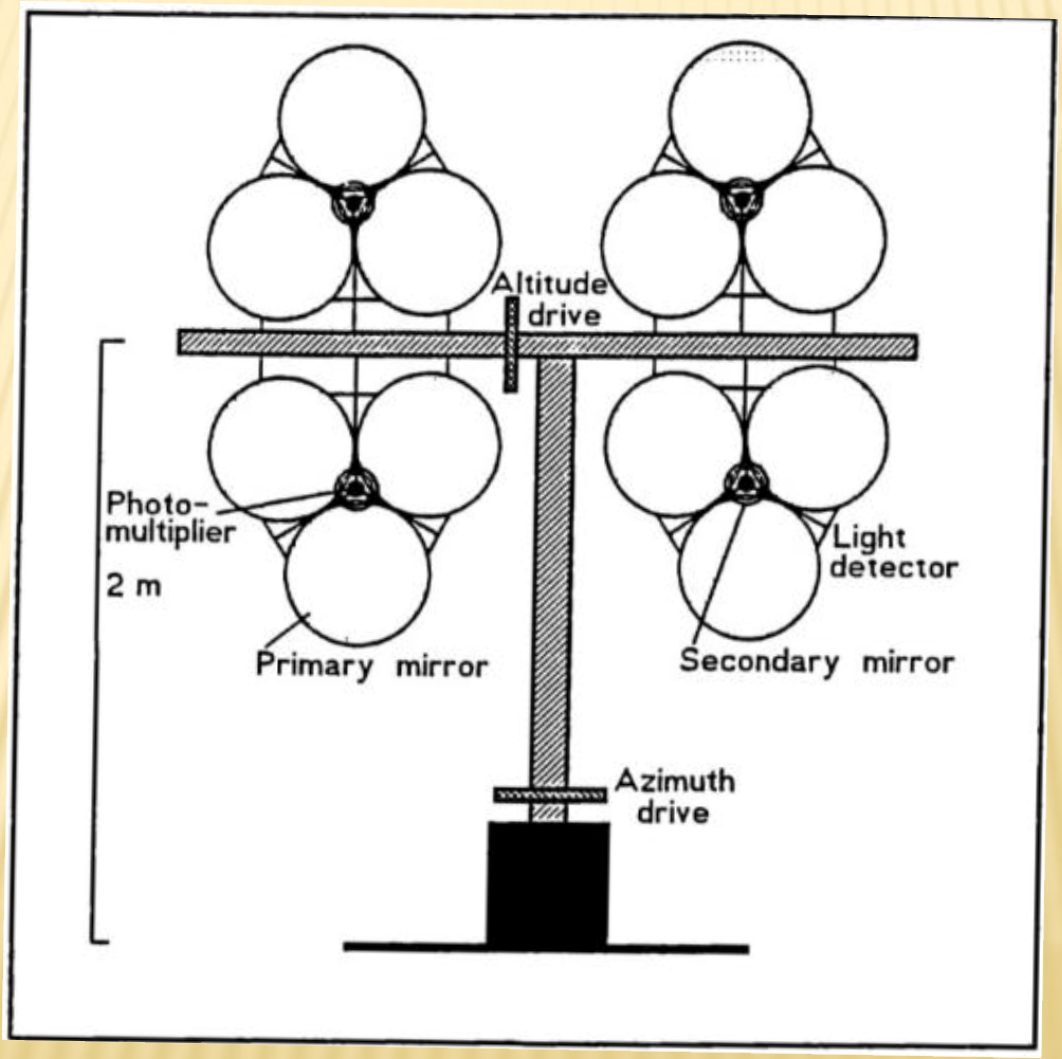
www.automotive-fleet.com

MK I & II TELESCOPE LAYOUT



Raubenheimer (1995)

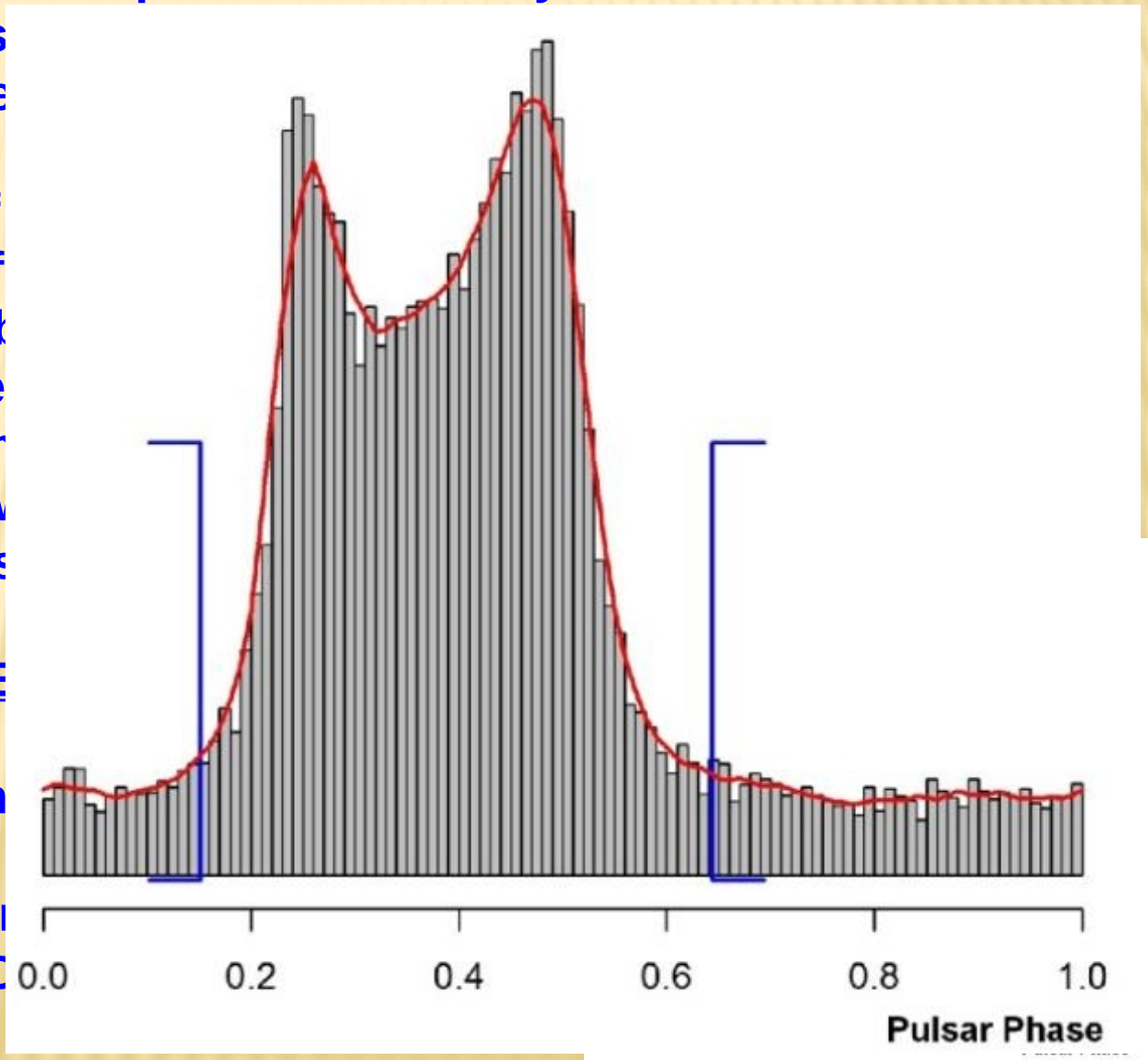
MK II TELESCOPE SCHEMATIC DIAGRAM



Raubenheimer (1995)

MK II TELESCOPE

- Building of the Mk 2 Telescope involved nearly the whole Department of Physics
- 9 units, distributed ove spacing).
- Each unit consisted of d = 50 cm segments of
- Each unit had a small b control electronics. Ce
- Cabling, mirrors, optim
- Long hours, extreme w optimise mirror images



EARLY THEORETICAL RE

- KDE method to obtain plus errors, overcomin binning (De Jager et al
- H-test to search for per unknown light curve (D

MK II TELESCOPE

- **Local wild life: warthogs damaged water pipes, snakes in warm buildings, cattle, ants, spiders...**
- **MK 2 operational for ± 2 years. Shut down due to finances, person power, competition from new international imaging telescopes.**
- **Electronics: Barend Visser and Gerrit van Urk.**
- **Building, cleaning, observations, data analysis: Paul van Wyk, Estie en Okkie de Jager, Piet Meintjies, Adrian North, Neels Brink and Isabel (du Plessis) North et al. under leadership of prof. Christo Raubenheimer.**
- **Christo Raubenheimer intitiated the project after having spent a year at MPI (Garching).**
- **NWU became involved in H.E.S.S. in late 1990s.**

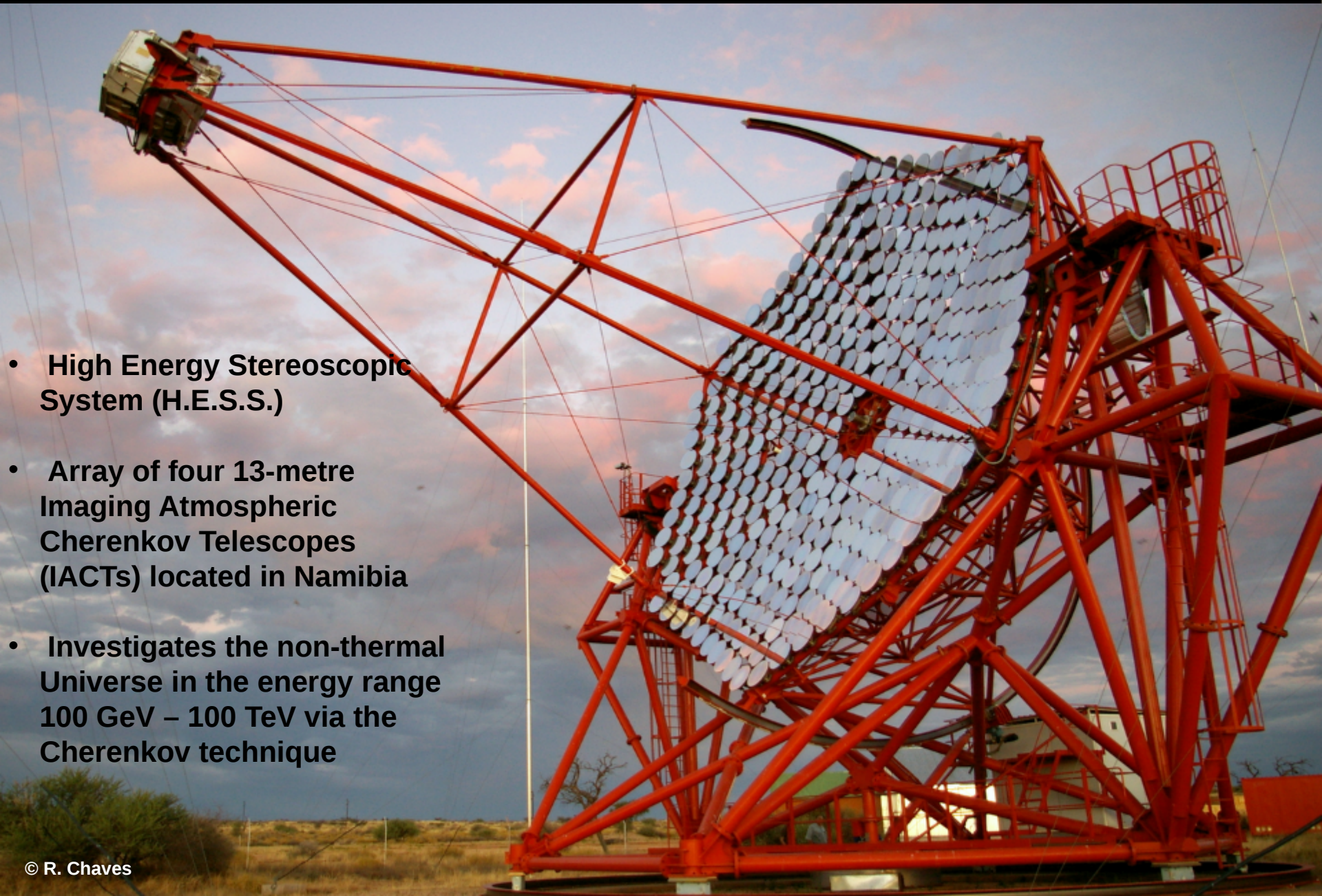
Prof. Christo Raubenheimer

Credit: HI Nel de Jager

Credit: HI Nel de Jager

Credit: HI Nel de Jager

What is H.E.S.S. I?



- High Energy Stereoscopic System (H.E.S.S.)
- Array of four 13-metre Imaging Atmospheric Cherenkov Telescopes (IACTs) located in Namibia
- Investigates the non-thermal Universe in the energy range 100 GeV – 100 TeV via the Cherenkov technique


25

NWU H.E.S.S. GROUP IN 2006

**Christo Venter, Mathew Holleran,
Ingo Büsching, Christo Raubenheimer,
Okkie de Jager [Isak Davids]**

The Name

High Energy Stereoscopic System

1883 –1964

Discovery of Cosmic Rays
Victor Hess 1912
(Nobel Prize 1936)

The H.E.S.S. Collaboration

Multinational Team:
260 scientists
40 institutes
13 countries













Why γ-rays?

Indirectly “seeing” cosmic particle accelerators

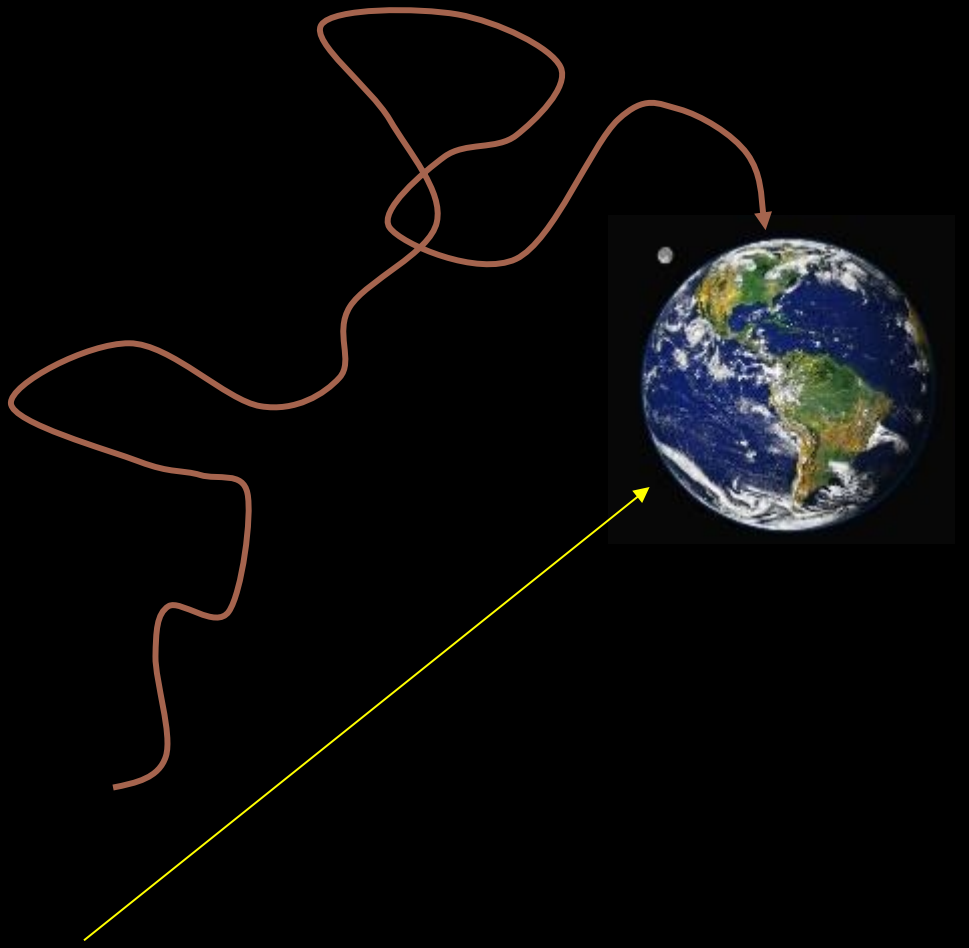
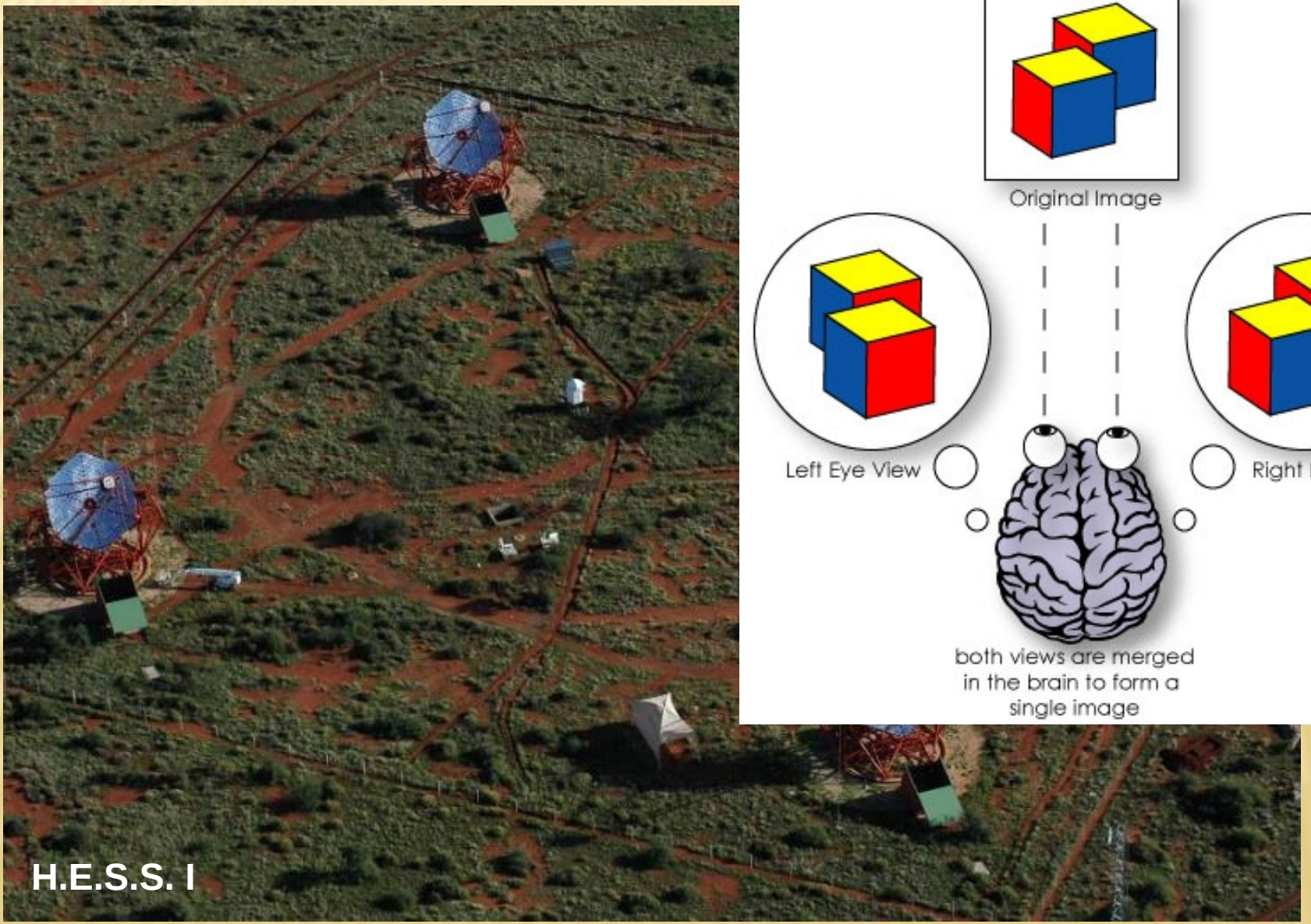


Image accelerators with neutral secondaries
Gamma-ray and Neutrino Astronomy

$$p + \text{nucleus} \rightarrow \pi + X$$

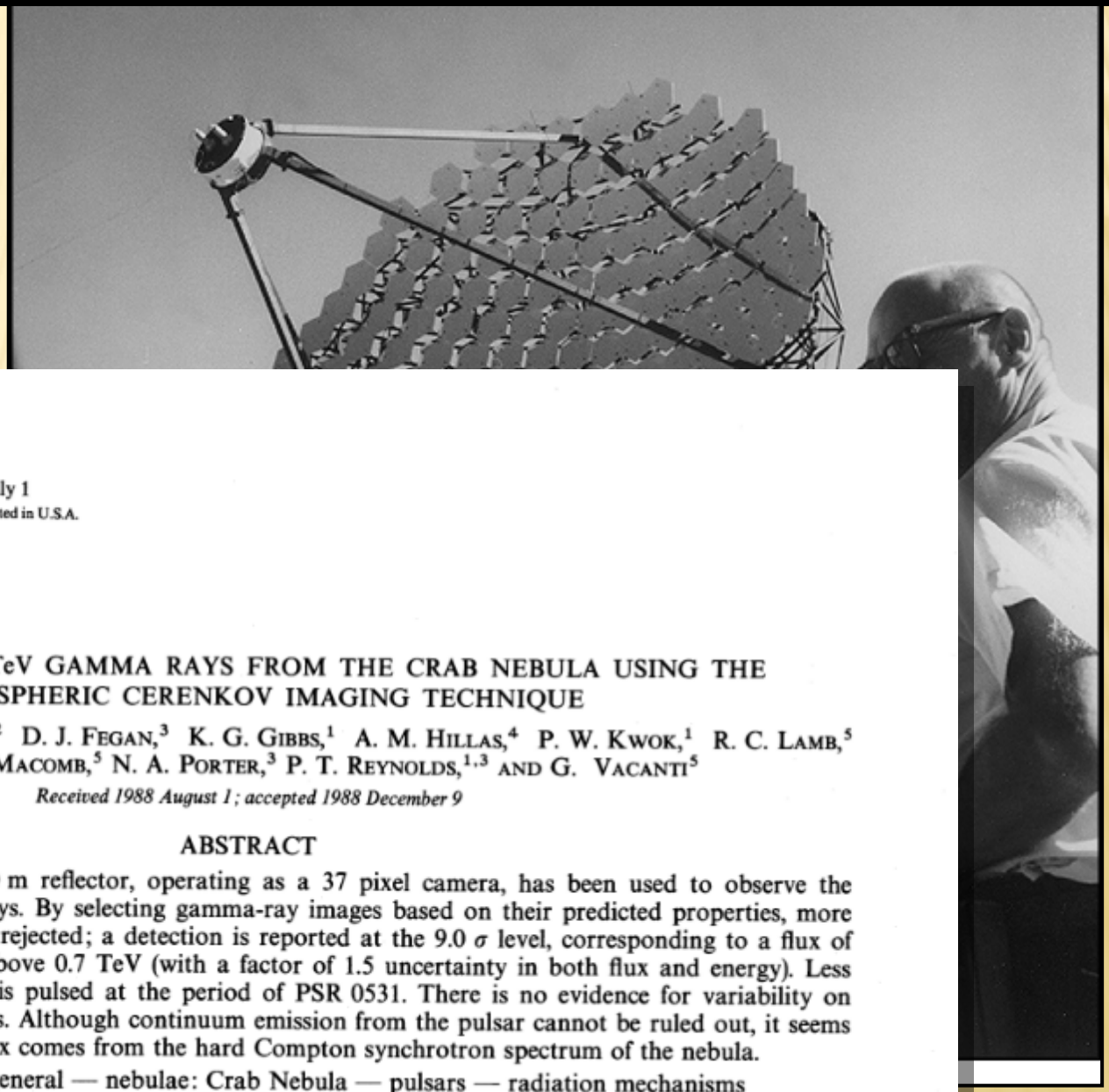
$$\pi^{o} \rightarrow \gamma\gamma$$
$$\pi^{\pm} \rightarrow \mu^{\pm} \nu$$

Four “Eyes”: Stereoscopic Vision



“Standing on the Shoulders of Giants”

WHIPPLE



THE ASTROPHYSICAL JOURNAL, 342:379–395, 1989 July 1

OBSERVATION OF TeV GAMMA RAYS FROM THE CRAB NEBULA USING THE ATMOSPHERIC CERENKOV IMAGING TECHNIQUE

T. C. WEEKES,[1] M. F. CAWLEY,[2] D. J. FEGAN,[3] K. G. GIBBS,[1] A. M. HILLAS,[4] P. W. KWOK,[1] R. C. LAMB,[5] D. A. LEWIS,[5] D. MACOMB,[5] N. A. PORTER,[3] P. T. REYNOLDS,[1,3] AND G. VACANTI[5]

Received 1988 August 1; accepted 1988 December 9

ABSTRACT

The Whipple Observatory 10 m reflector, operating as a 37 pixel camera, has been used to observe the Crab Nebula in TeV gamma rays. By selecting gamma-ray images based on their predicted properties, more than 98% of the background is rejected; a detection is reported at the 9.0 σ level, corresponding to a flux of 1.8×10^{-11} photons cm^2 s^{-1} above 0.7 TeV (with a factor of 1.5 uncertainty in both flux and energy). Less than 25% of the observed flux is pulsed at the period of PSR 0531. There is no evidence for variability on time scales from months to years. Although continuum emission from the pulsar cannot be ruled out, it seems more likely that the observed flux comes from the hard Compton synchrotron spectrum of the nebula.

Subject headings: gamma rays: general — nebulae: Crab Nebula — pulsars — radiation mechanisms

H.E.S.S. Family Tree

Whipple

Imaging principle
Dish size

HEGRA:

Stereoscopy

CAT:

Small pixels

H.E.S.S.

(& VERITAS)

H.E.S.S. I Characteristics

- 960-pixel camera
- 380 mirror segments
- 107 m^2 mirror area per telescope
- Measure fluxes up to a few thousands of that of the Crab Nebula
- Angular resolution: < 0.1 deg
- Spectral resolution: 10% – 15%
- Field of view (5 deg)
- Good pointing accuracy (< 10”)
- Energy threshold > 100 GeV (zenith) up to 0.7 TeV

Drivers for Success of H.E.S.S.

New VHE Window on the Universe

- **High sensitivity**

  3 orders of magnitude dynamic range in flux between strongest and faintest sources

- **Wide spectral range**

  > 2 orders of magnitude coverage in energy, up to 10s of TeV

  10% – 15% energy resolution

- **Resolved source morphology**

  ~5’ angular resolution

  10” – 20” source localization

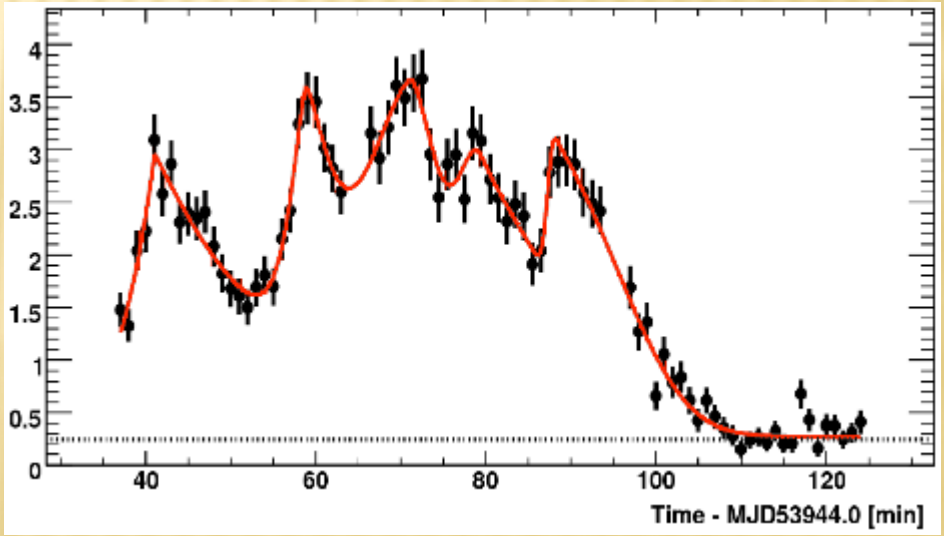
- **Survey capability**

  H.E.S.S. Galactic Plane Survey:

  2% Crab sensitivity

- **Well-resolved light curves**

  Minute-scale variability of AGN



Accolades

EU Descartes Prize for Research 2006

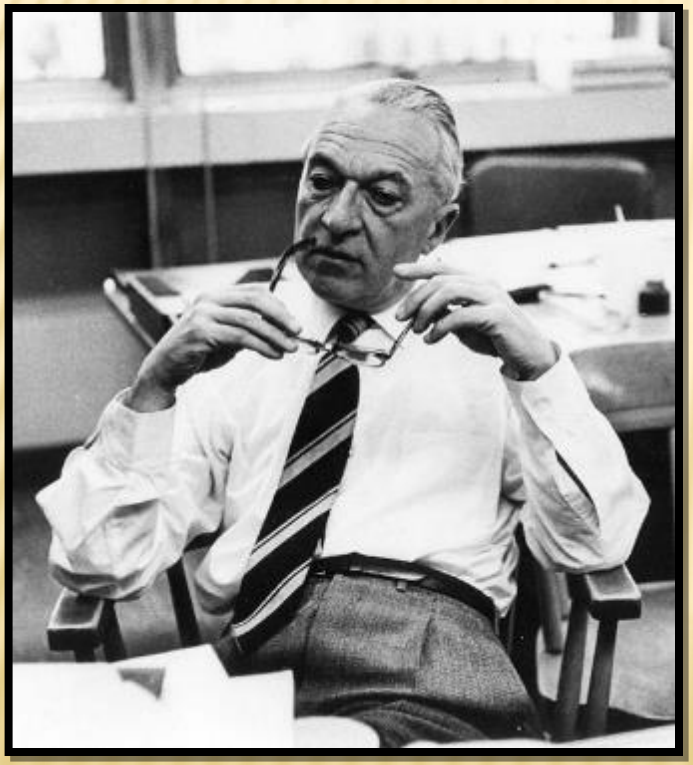
H.E.S.S. shares €1 million Prize

"[H.E.S.S.] has revolutionised existing astronomical observation techniques and increased our knowledge and understanding of the Milky Way and beyond."

Accolades

HEAD Bruno Rossi Prize 2010

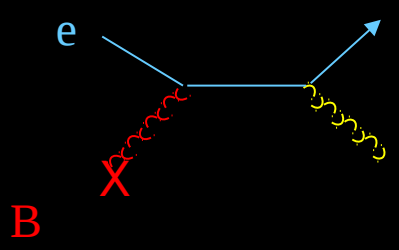
Awarded annually for a significant contribution to High Energy Astrophysics, with particular emphasis on recent, original work.



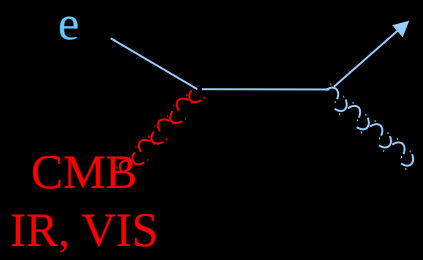
Bruno Rossi (1905 –1993)

"…awarded or their outstanding contributions to imaging of very high-energy (TeV) gamma rays with H.E.S.S. Their work addressed fundamental questions related to particle acceleration and the origin of cosmic rays through the study of supernova remnants, pulsar wind nebulae and nearby active galactic nuclei.

Basic γ-ray Generation Processes

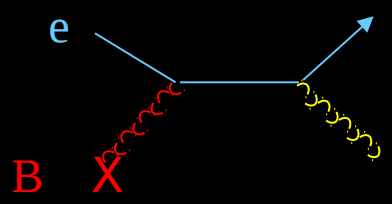


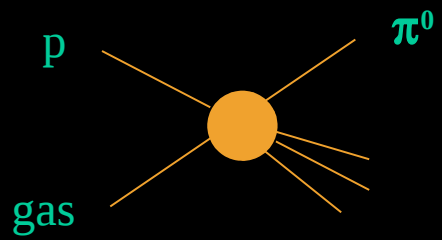
Synchrotron
Radiation
(eV … GeV)



Inverse Compton
Upscattering
(GeV … TeV)

Basic γ-ray Generation Processes





SED
E^2 F(E)

Radio

Infrared

Visible light

X-rays

VHE
gamma rays

Leptonic
Scenario

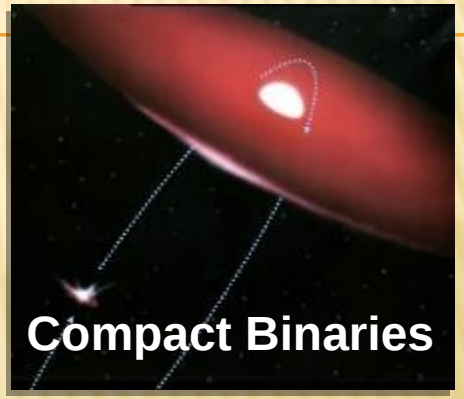
Hadronic
scenario

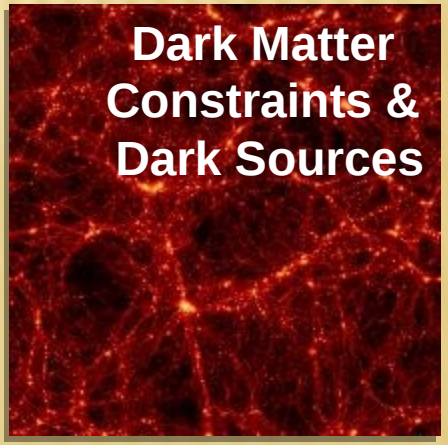
Synchrotron
radiation

Inverse
Compton
upscattering

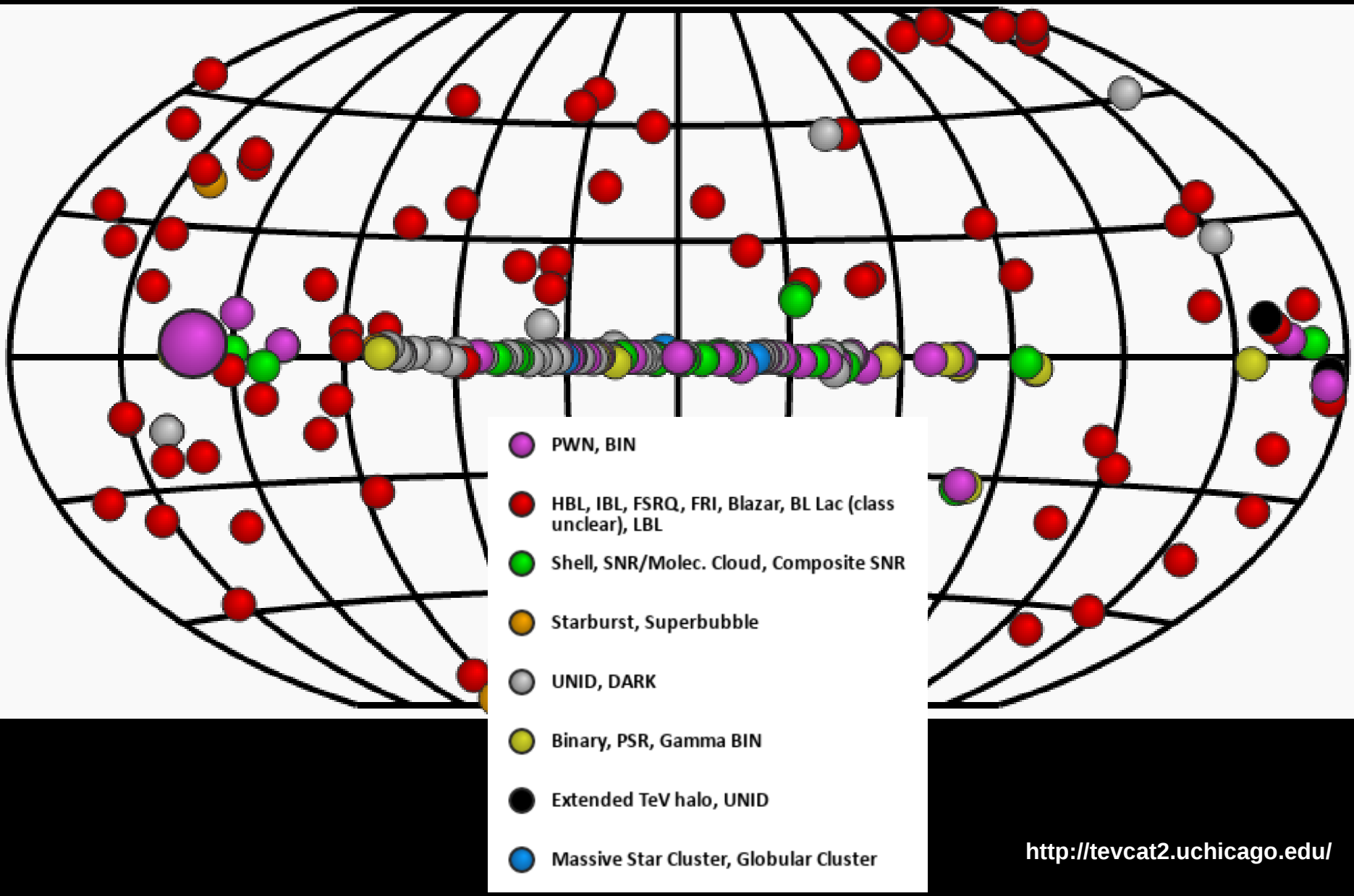
E

Source Classes





TeV γ-ray Sky: > 200 sources



http://tevcat2.uchicago.edu/

KNP Conference 2012

Overview

- Home
- Abstract submission
- Accommodation
- Circulars
- Conference Proceedings
- Contribution List
- Gallery
- Health Issues
- Important dates
- In and around Kruger
- Invited Speakers
- List of Registrants
- Local Organising Committee
- Posters
- Science Program
- Registration
- Scientific Organising Committee
- Skukuza
- Social Events and Game Drives
- Speaker Index
- Travel

As the title suggests, the meeting will focus on the high-energy astrophysics topics that were strongly influenced by Okkie's work. These topics will include high-energy aspects of pulsars, pulsar wind nebulae, supernova remnants, and absorption by extragalactic background light, with emphasis on their multi-wavelength properties, as well as new VHE detection and detector concepts. The exciting new results from Fermi, H.E.S.S., MAGIC, and VERITAS are creating a fast-evolving landscape yielding as many new puzzles as answers to old questions.

We aim to celebrate the science that was dear to Okkie, in one of his favourite places, Kruger National Park, South Africa.

Dates: From 13 August 2012 to 17 August 20
Welcoming reception on Sunday, 12 A

Time zone: Africa / Johannesburg

Location: Kruger National Park - Skukuza Rest C
Latitude: -24.9898, Longitude: 31.592

Additional info: Skukuza is the Kruger National Par headquarters. It is situated on the sou is well foliaged and there are some l and facilities are diverse, as are the camp and in the surrounding areas internet cafe, restaurant, library, fuel st

Registration: The Registration fee will be R3550 (R4 (dollar amount may vary). This include
1. Welcoming Reception,

Okkie de Jager
14 December 2010

KNP Conference SOC

KNP Conference Photo

Front (f.l.t.r.): Peter den Hartog, Yang Chen, Mallory Roberts, Isak Davids, Anna Barnacka, Anna Zajczyk, Arache Djannati-Ataï, Christo Venter, Wlodek Bednarek, Pieter Meintjes, Vanessa Mangano, Johan van der Walt, Ping Zhou, Bing Jiang, Eduardo de la Fuente, ***Second row:*** Petro Siebenhagen, Alice Harding, Stefan Funk, Wim Hermsen, Nepomuk Otte, Elsa Giacani, Eveline Helder, John Hewitt, Brian Williams, Gloria Dubner, Yosi Gelfand, Michael Vorster, Tomek Bulik, Jacek Niemiec, Yves Gallant, Nukri Komin, Marco Micell, Stefano Gabici, Omar Tibolla, Eric Gotthelf, Takalani Enos Marubini, Jonatan Martin, ***Back (f.l.t.r.):*** Bronek Rudak, Elanie van Rooyen, Monica Breed, Estie de Jager, Reinhard Schlickeiser, Markus Böttcher, Stephen C.-Y. Ng, Tea Temim, Sarah Buchner, Parviz Ghavamian, Kristoffer Eriksen, Matthew Kerr, Rino Bandiera, Roger Blandford, Pat Slane, Augusts van der Schyff, Bertie Seyffert, Jacco Vink, David Buckley, Sjors Broersen, Paulus Krüger, Klara Schure, Brian van Soelen, Patrizia Caraveo, Oliver Porth, Lorenzo Sironi, Igor Telezhinsky, Roger Chevalier, Brian Humensky, Heather Matheson, Gilles Ferrand, Anne Lemière, ***Absent:*** Jon Arons, Matthew Baring, Ingo Buesching, Daniel Castro, Pete Gonthier, Isabelle Grenier, Mathew Holleran, Marcos Lopez-Moya, Claire Max, Paul Ray, Agnieszka Slowikowska

SA-GAMMA CONSORTIUM

- The South African Gamma-Ray Astronomy Programme (SA-GAMMA)
- Consortium of South African Universities and research institutions which engage in research in the fields of gamma-ray astronomy and high-energy astrophysics.
- Co-ordinates the SA involvement in H.E.S.S. and the Cherenkov Telescope Array (CTA)
- Current members: NWU, Wits, UFS, UJ, and SAAO.
- Sponsored by South African Department of Science and Technology (DST).
- Annual conference series: High Energy Astrophysics in Southern Africa (HEASA) – 6th event in 2018.

Prof. Markus Boettcher

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT

UNIVERSITY OF THE WITWATERSRAND
JOHANNESBURG

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA
UFS
UV

UNIVERSITY OF JOHANNESBURG

NRF
National Research Foundation

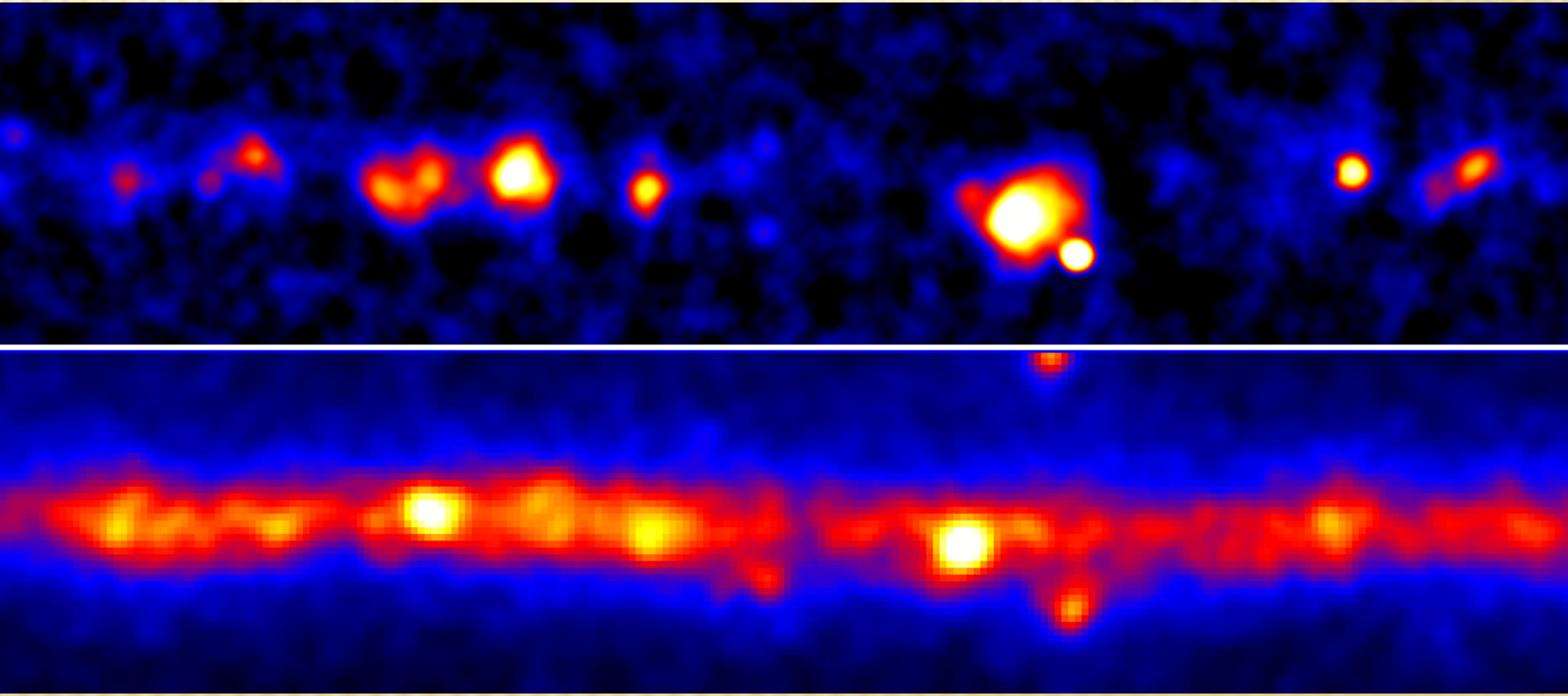
SAAO
South African Astronomical Observatory

The Milky Way at GeV and TeV Energies

Galactic Plane Survey

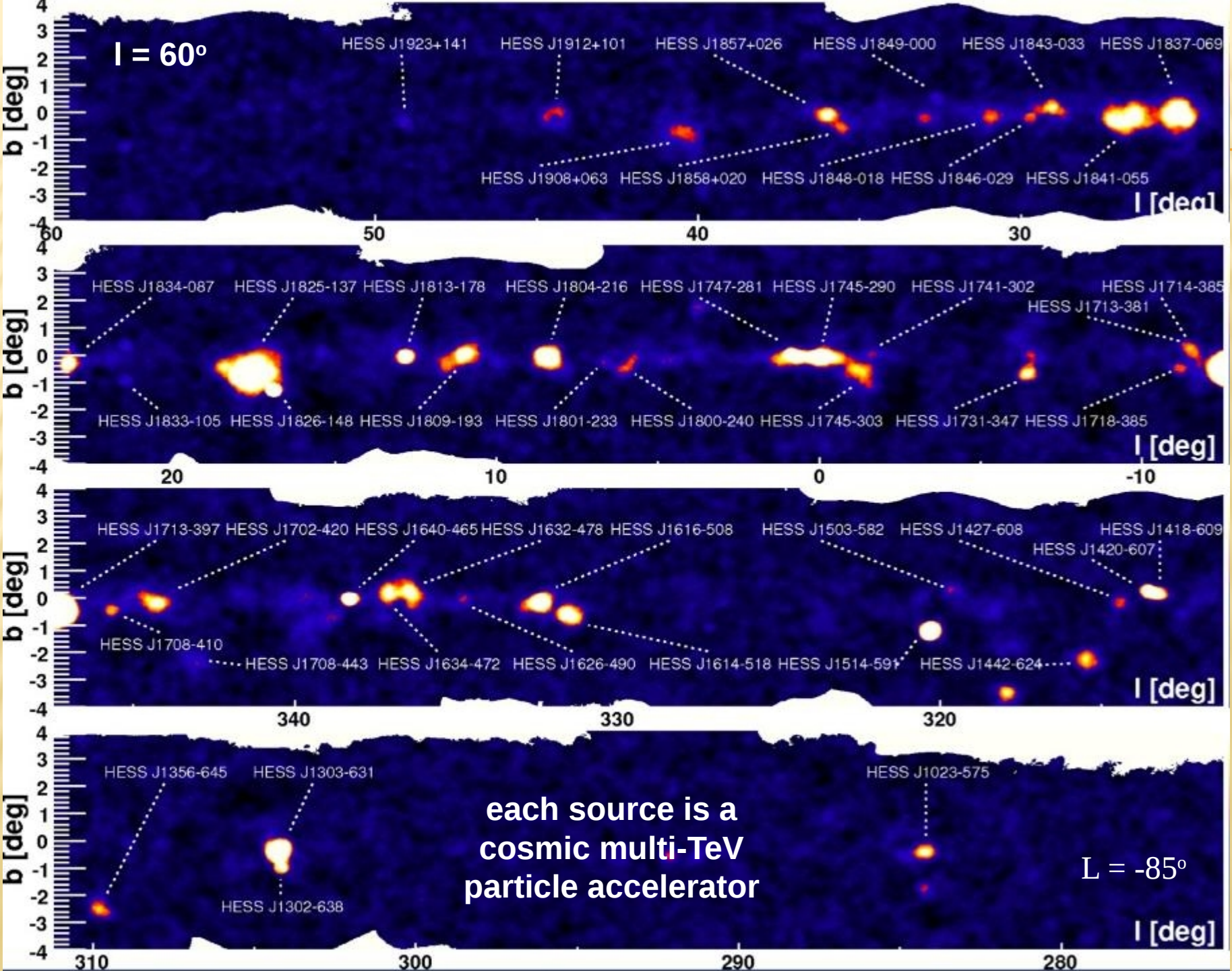
Extended sources, size typically few 0.1° (few 10 pc)

H.E.S.S. (~ 1 TeV)

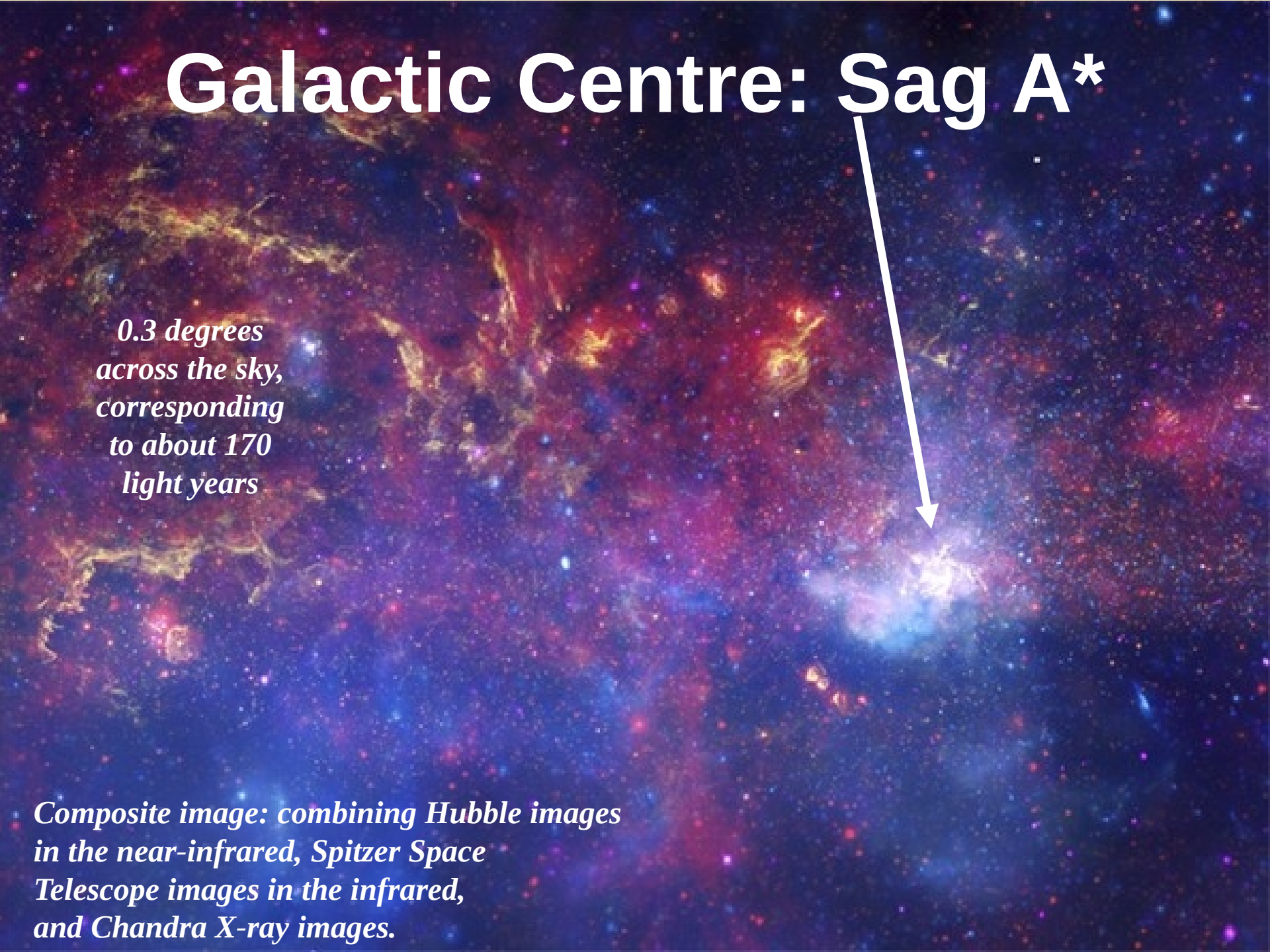


***Fermi*-LAT (>1 GeV)**

“Background” due to propagating Galactic cosmic rays

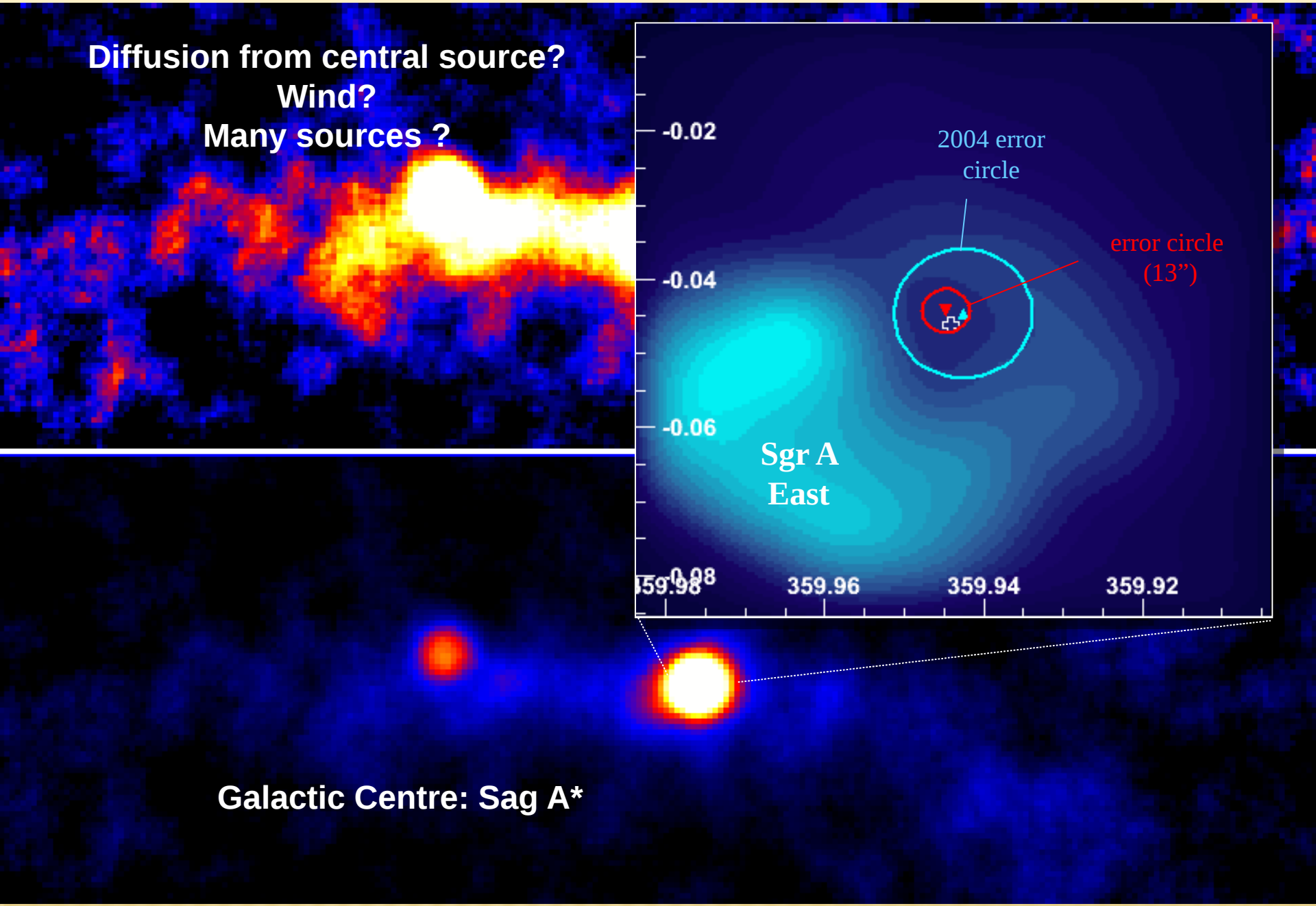

l = 60°
HESS J1923+141
HESS J1912+101
HESS J1857+026
HESS J1849-000
HESS J1843-033
HESS J1837-069
HESS J1908+063
HESS J1858+020
HESS J1848-018
HESS J1846-029
HESS J1841-055
HESS J1834-087
HESS J1825-137
HESS J1813-178
HESS J1804-216
HESS J1747-281
HESS J1745-290
HESS J1741-302
HESS J1714-385
HESS J1713-381
HESS J1833-105
HESS J1826-148
HESS J1809-193
HESS J1801-233
HESS J1800-240
HESS J1745-303
HESS J1731-347
HESS J1718-385
HESS J1713-397
HESS J1702-420
HESS J1640-465
HESS J1632-478
HESS J1616-508
HESS J1503-582
HESS J1427-608
HESS J1418-609
HESS J1420-607
HESS J1708-410
HESS J1708-443
HESS J1634-472
HESS J1626-490
HESS J1614-518
HESS J1514-591
HESS J1442-624
HESS J1356-645
HESS J1303-631
HESS J1023-575
HESS J1302-638
each source is a cosmic multi-TeV particle accelerator
L = -85°
b [deg]
l [deg]

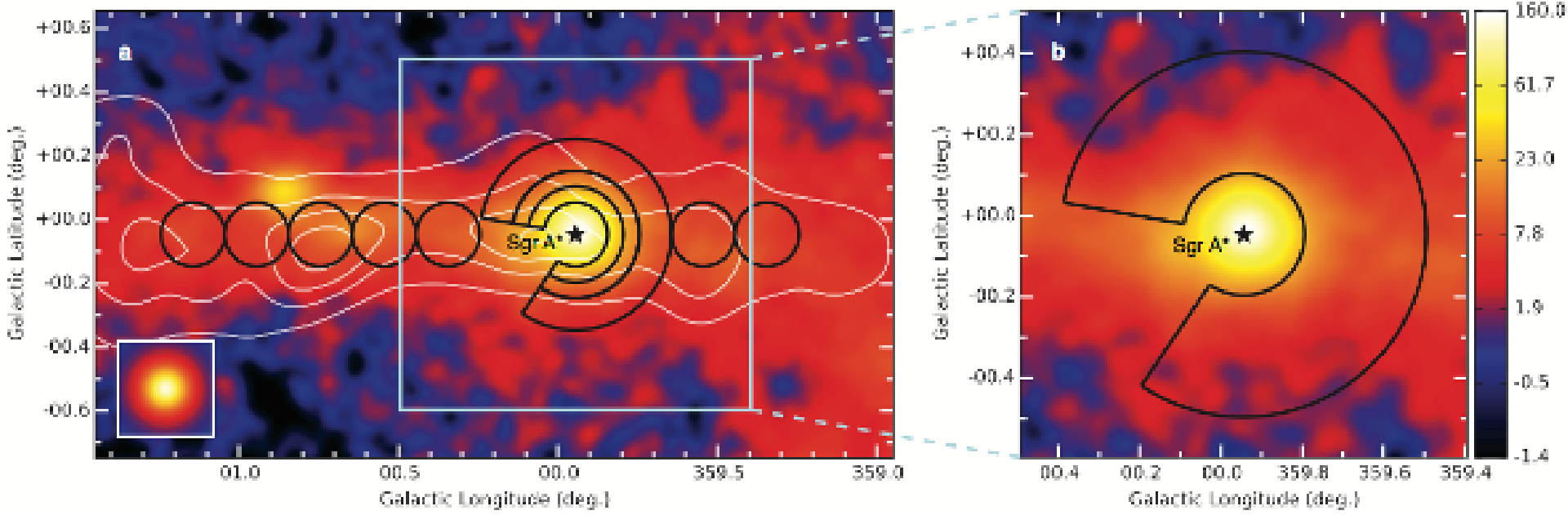
Galactic Centre: Sag A*

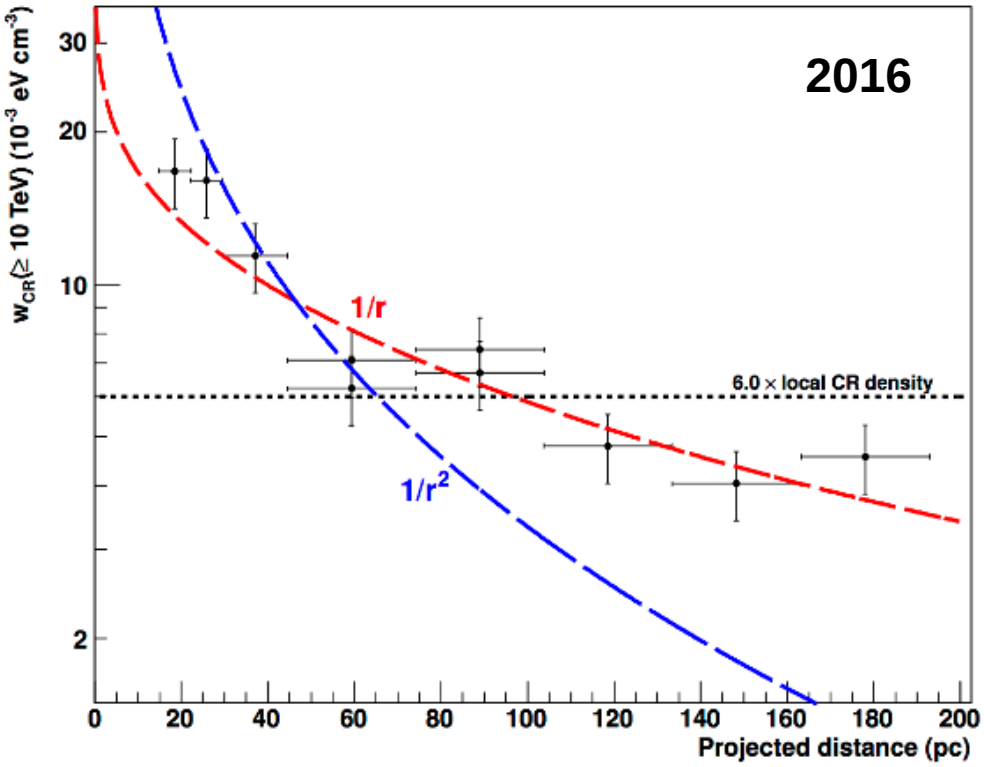


0.3 degrees across the sky, corresponding to about 170 light years

Composite image: combining Hubble images in the near-infrared, Spitzer Space Telescope images in the infrared, and Chandra X-ray images.

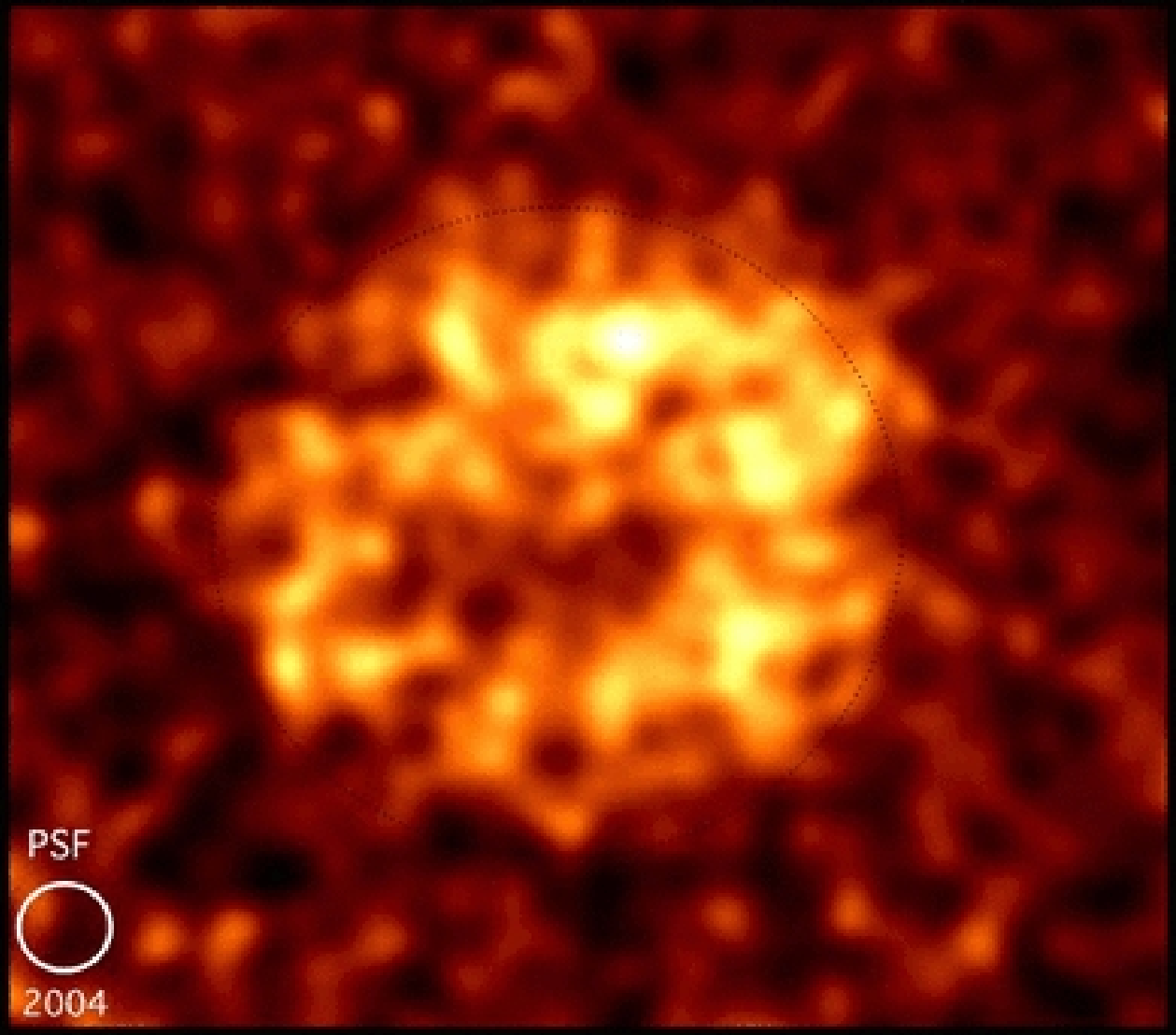

Diffusion from central source?
Wind?
Many sources ?
-0.02
-0.04
-0.06
-0.08
2004 error
circle
error circle
(13”)
Sgr A
East
359.96
359.94
359.92
Galactic Centre: Sag A*





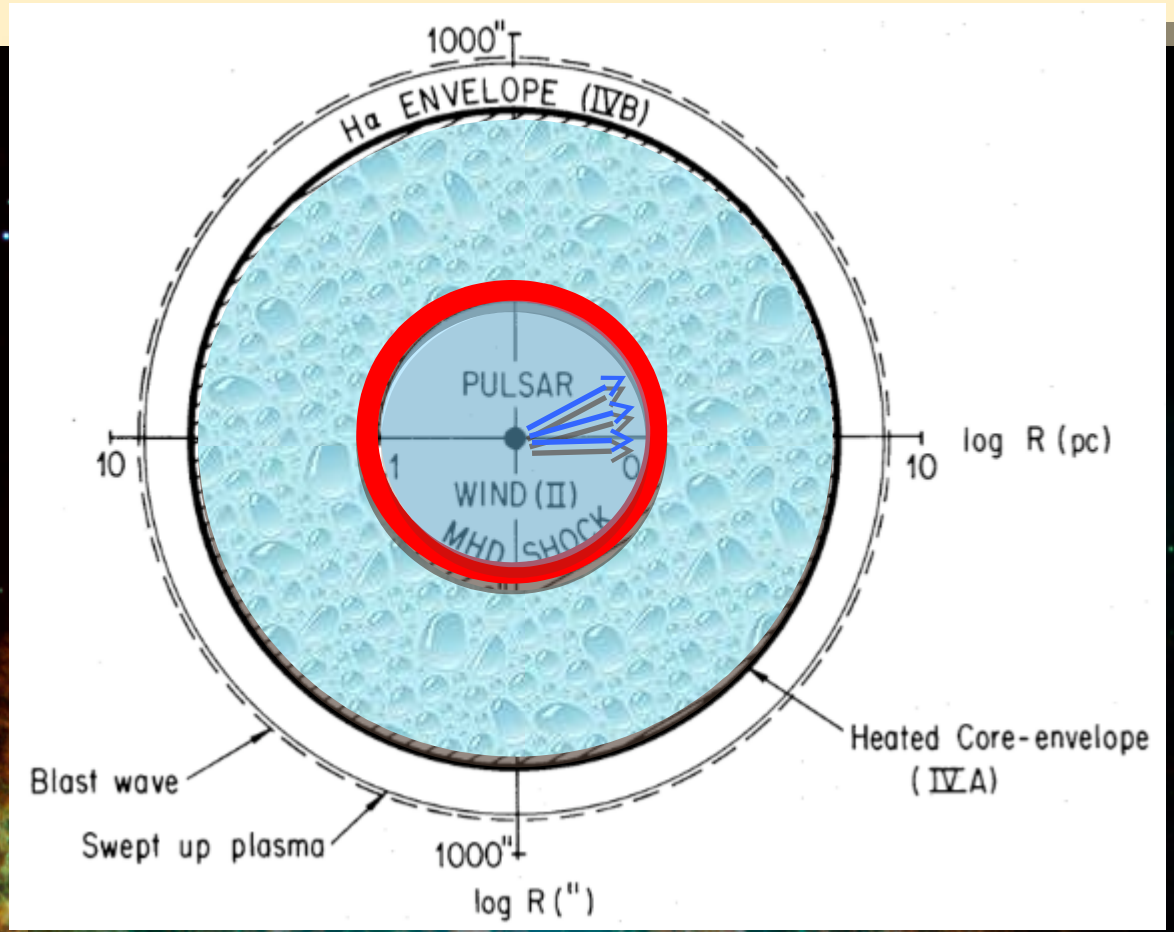
- **Profile characteristic of central source (within 10 pc of Galactic Centre)**
- **Continuous injection of accelerated protons (1 000 to 10 000 year timescales).**
- **Diffusive propagation**
- **Interacting with the central molecular zone (CMZ) gas, producing neutral pions, which then decay producing γ-rays and other sub-products.**

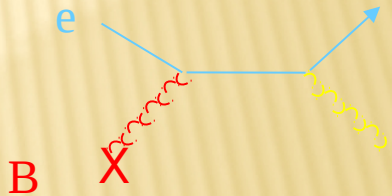
H.E.S.S. RX J1713.7-3946



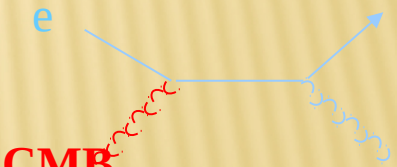
Year	2004
Live-time	18h
Energy	> 1 TeV
PSF (R_{68})	4.8 arcmin
γ's	1,430

Pulsar Wind Nebulae



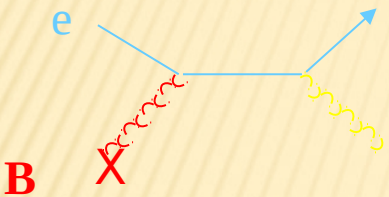


Synchrotron Radiation (eV … GeV)

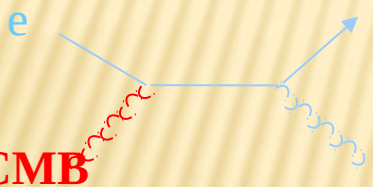


CMB IR, VIS

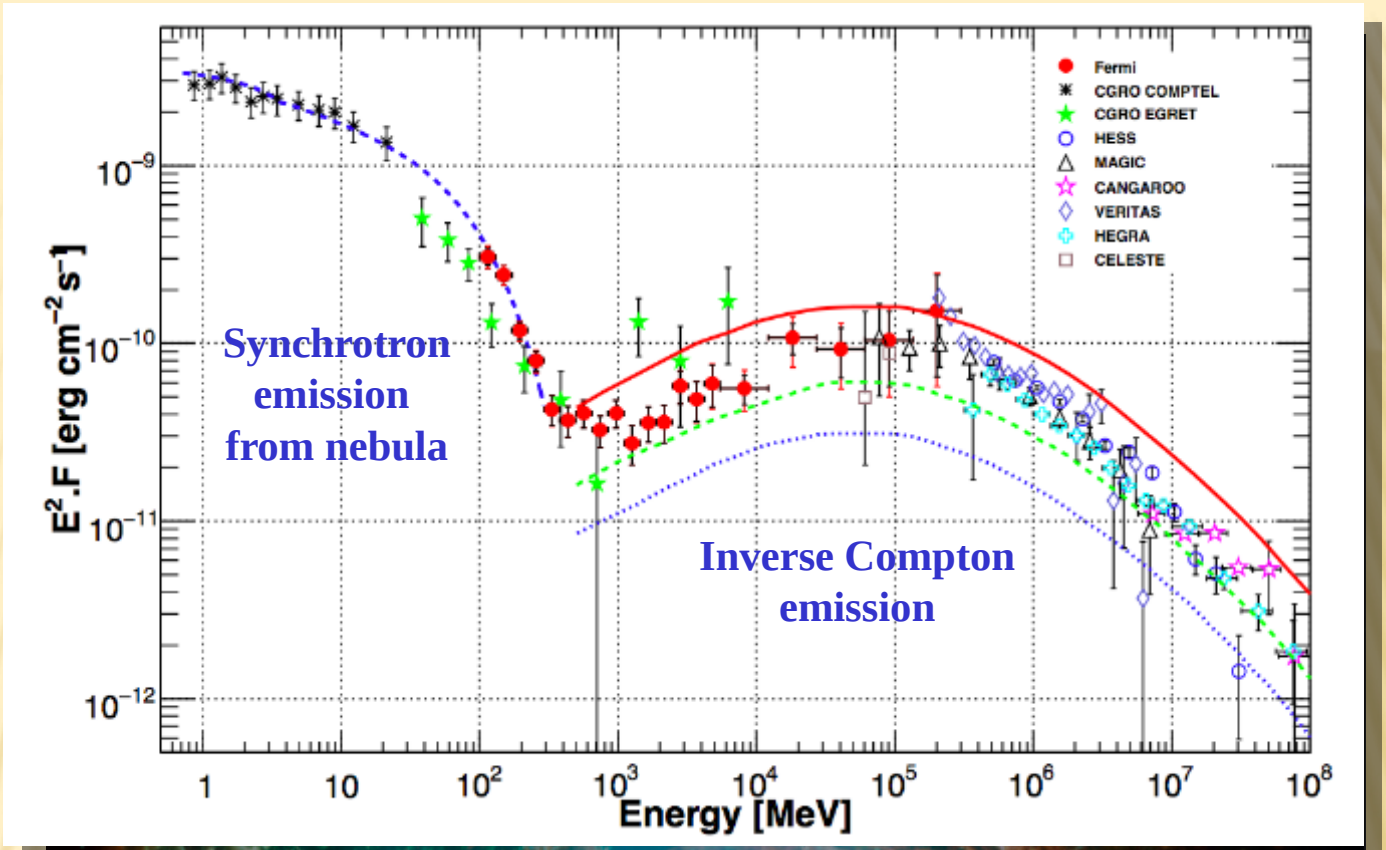
Inverse Compton Upscattering (GeV … TeV)

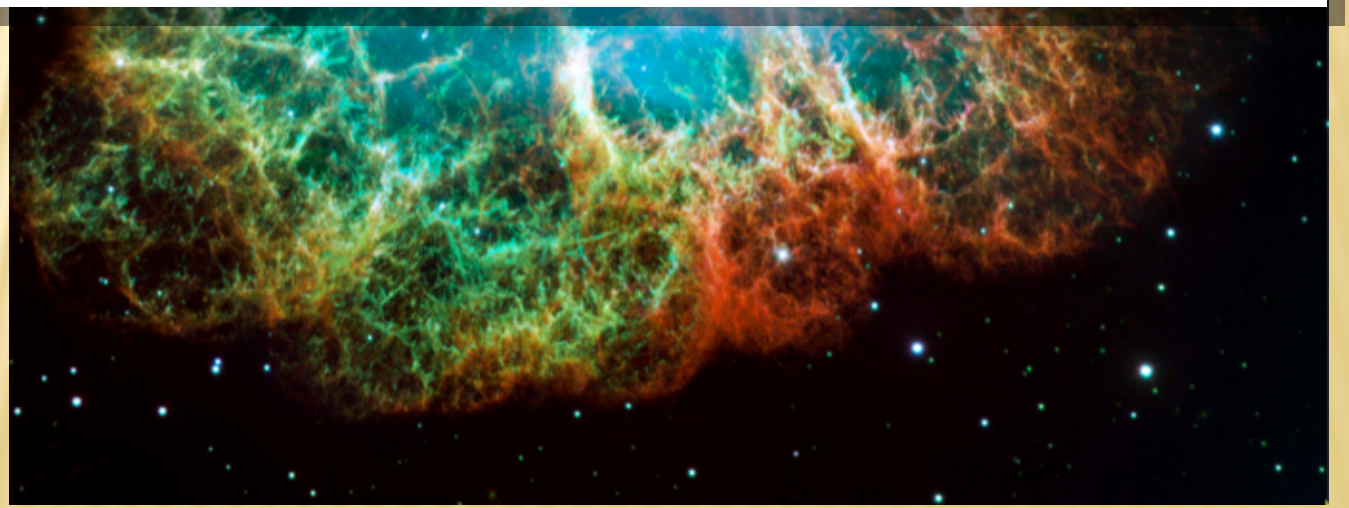


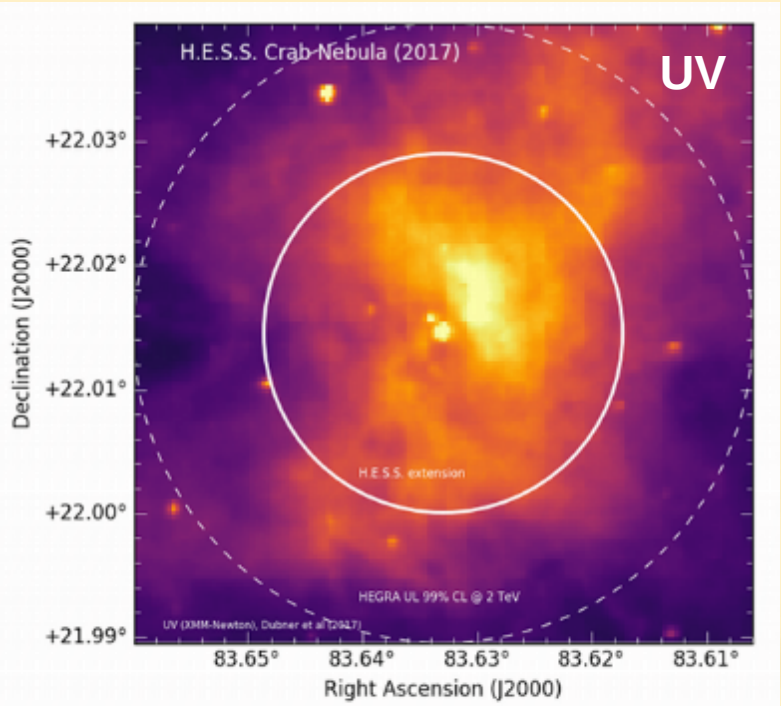
Synchrotron Radiation (X-rays)

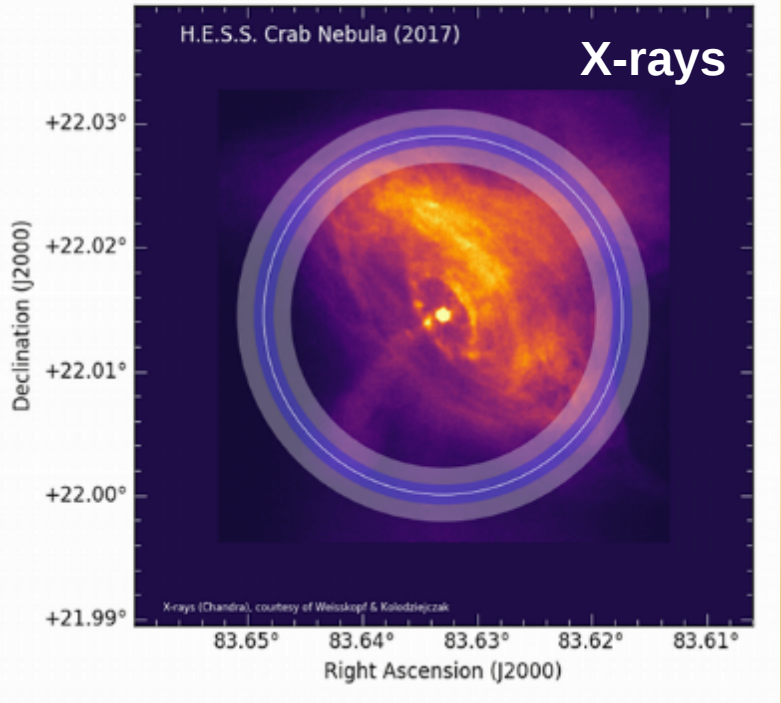


Inverse Compton Upscattering (γ-rays)









Crab Nebula Extension

- **Morphology** of Crab Nebula has only been resolved with radio, optical, and X-ray telescopes (<80 keV).
- No extension at higher energies (worse **angular resolution**)
- Improved PSF description.
- New level of resolving source sizes in VHE gamma-ray astronomy.
- σ_{Crab} = 52.2'' ± 2.9'' ± 7.8''sys.


10°

H.E.S.S. PHASE II

H.E.S.S. II

H.E.S.S. Phase II
Aims & Approach

- **Aims:**
  - **Extending the energy threshold to ~10-20 GeV**
  - **Achieve overlap in energy (and time) with *Fermi* LAT**
  - **Improving the sensitivity at 100 GeV**

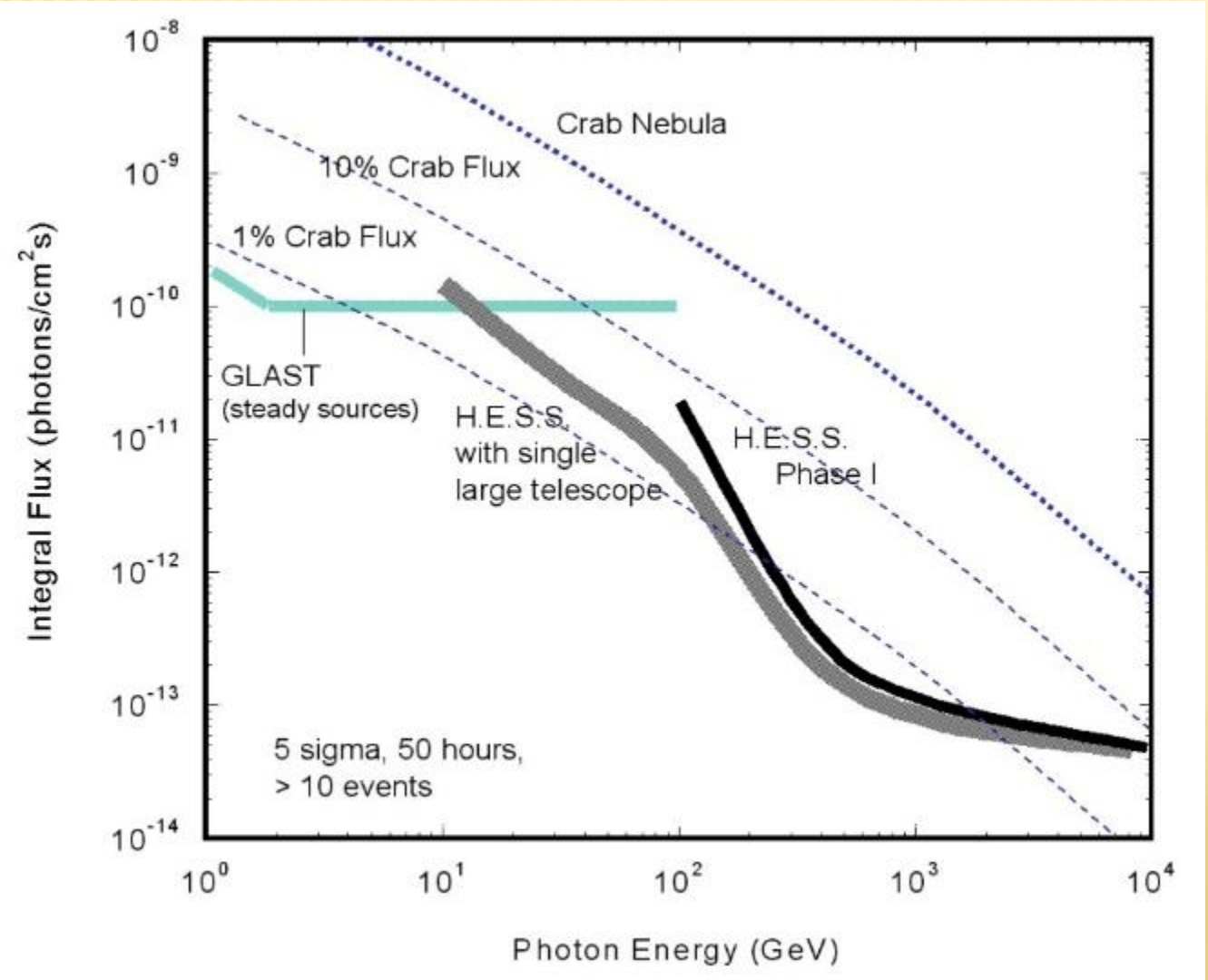
Approach

- **Increased mirror size to 600 m^2 (equiv. 28 m⊘, 560 t steel frame)**
- **Increased focal length to 36 m**
- **Decreased pixel size to 0.07^o (FoV = 3.17^o, >2 t camera)**
- **Used well-established H.E.S.S. Phase I type electronics**
- **Combine a single telescope with the 4 Phase I telescopes**

(G. Hermann)

H.E.S.S. Phase II
Expected Performance

Based on simulations verified with H.E.S.S. Phase I



Punch et al. (2006)

H.E.S.S. Phase II
Physics

- Study gamma-ray emission from pulsar magnetosphere
- Gamma-ray emission from XRBs
- Explore the high-redshift universe: AGNs, Radio-Galaxies, GRBs
- Indirect Dark matter search

THE FUTURE OF GAMMA-RAY ASTRONOMY: CTA

H.E.S.S. has been highly successful, but…

Some key object classes still elusive, e.g.

- **Galaxy clusters as cosmological storehouses of CRs**
- **Very-high-energy emission from GRBs**
- **Dark Matter annihilation signatures**

Some key mechanisms remain to be understood, e.g.

- **Supernovae as sources of cosmic rays: do they provide sufficient peak energy & energy output? Morphology?**
- **Cosmic-ray escape from accelerators and propagation**
- **Energy conversion in pulsars**

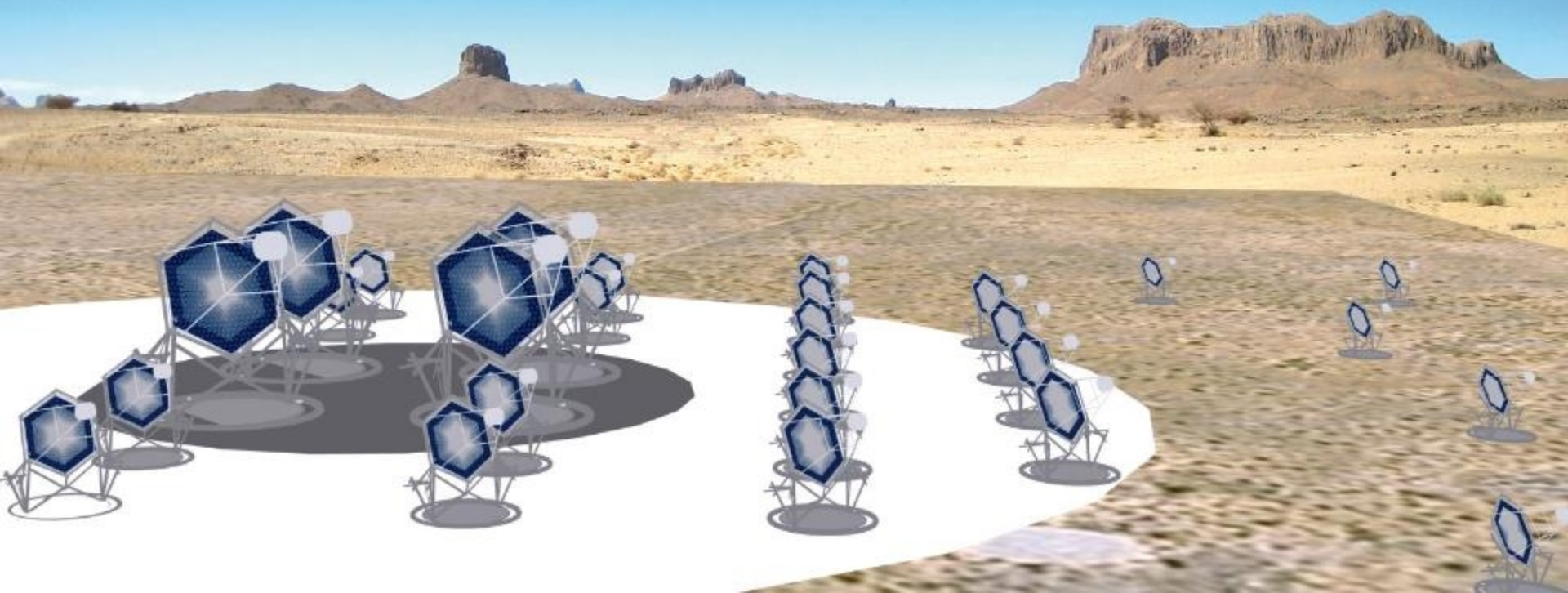
Energy range & angular resolution of current instruments insufficient to probe details

- 10-fold sensitivity increase above that of current instruments
- Extended energy range
- Improved angular resolution
- Operation as open observatory
- Two sites for full-sky coverage

The future in VHE gamma ray astronomy:

CTA

Partners from almost all European countries
+ US, South America, India, Japan, South Africa



Low-energy section:
4 x 23 m tel. (LST)
- Parabolic reflector
- FOV: 4-5 degrees
- f/D: ~1.2

energy threshold
of some 10 GeV

(one) possible configuration

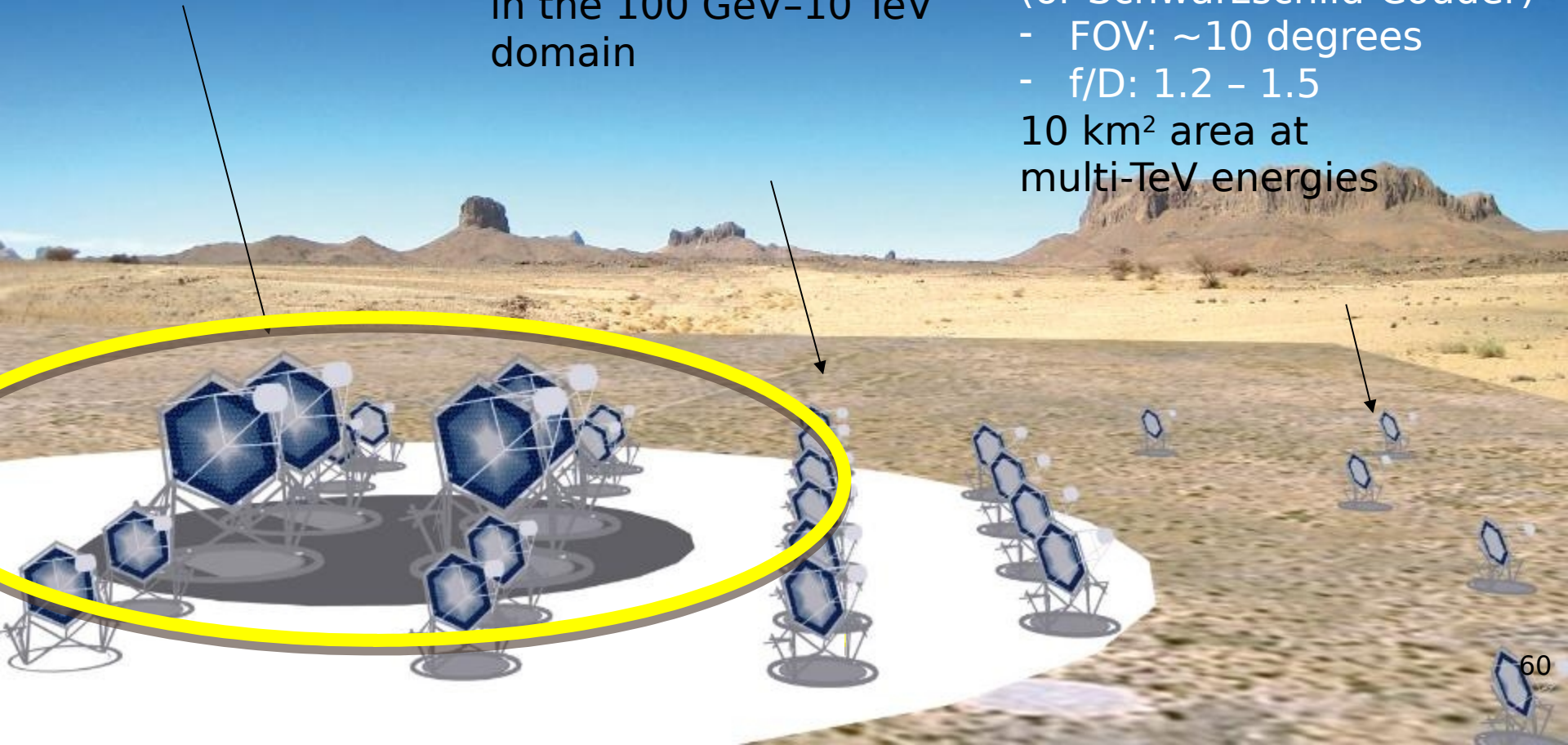
100 M€ (2006 costs)

Core-energy array:
23 x 12 m tel. (MST)
Davies-Cotton reflector
- FOV: 7-8 degrees
- f/D: ~1.4

mCrab sensitivity
in the 100 GeV–10 TeV
domain

High-energy section:
32 x 5-6 m tel. (SST)
Davies-Cotton reflector
(or Schwarzschild-Couder)
- FOV: ~10 degrees
- f/D: 1.2 – 1.5

10 km^2 area at
multi-TeV energies



SA-GAMMA TIMELINE

- NWU involved in H.E.S.S. since late 1990s
- 2012: Wits joins the H.E.S.S. Collaboration
- 2012 - 2016: SA and Namibia CTA members work closely to foster the bid for the Aar site in southern Namibia for CTA South
- 2013: UFS joins the H.E.S.S. Collaboration
- 2013: SA-GAMMA is founded, with NWU, Wits, UFS as founding members.
- 2013: 1st HEASA meeting in Potchefstroom (NWU)
- ~2014 UJ joins the CTA Consortium and SA-GAMMA
- 2014: 2nd HEASA meeting in Bloemfontein (UFS)
- 2015: Namibian and Chilean sites short-listed as leading sites for hosting CTA South
- 2015: SAAO joins SA-GAMMA.
- 2015: 3rd HEASA meeting in Johannesburg (UJ)
- 2016: CTA Council decides to focus CTA South negotiations on Chile as preferred site.
- 2016: 4th HEASA in Cape Town (SAAO)
- 2017: 5th HEASA in Johannesburg (Wits)
- 2018: 6th HEASA near Parys (NWU)

6TH HEASA ANNUAL CONFERENCE

1 – 3 August 2018
Stonehenge in Africa, near Parys

https://fskbhe1.puk.ac.za/people/mboett/SAGAMMA/HEASA2018/HEASA2018.html

Abstract submission by 20 July 2018.

Outlook

- Gamma-ray Astronomy is a lively, growing field
- Lots of exciting discoveries!
- South Africa has a long and proud history of pioneering contributions
- Current involvement in H.E.S.S. and CTA
- Multi-wavelength Astronomy – regional links
- World-class opportunities for SA students
- The promise of unravelling the inner workings of the most energetic and violent phenomena in the Universe!

THANKS!

"'Do I not fill heaven and earth?' says the LORD" (Jer. 23:24b)

ENKOV

ATION

ivistic particles moving in

the phase velocity of ligh

When something moves through the air, it pushes the air in front and creates a sound. This sound spreads as a wave at the speed of **340m/s** (1225km/h). As the object moves, it makes a series of pressure waves, which is why the *Doppler effect* happens. These pressure waves look like rings that are squashed to the side the object is moving towards. As the object moves faster, the more compressed these rings become. When the object moves at the speed of sound (340m/s), the pressure waves all overlap as the object makes a pressure wave on the same place as where the last wave reached. This is the **sound barrier**.

uration (ns), emitted in na

on of motion of incoming

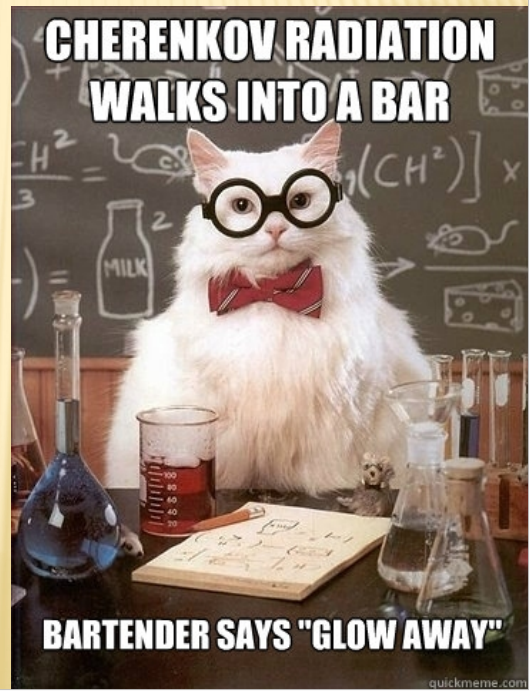
rsonic aircraft. Sound wa

ng object, forming a shoc

At this point, there is a huge build up of energy and that a shockwave is formed. This shockwave - made of compressed air - travels at the speed of

CHERENKOV RADIATION

- VHE (≥100 GeV) photons or gamma rays enter atmosphere, collides with atmospheric nuclei (~12 km), produces shower of relativistic electrons; light cone with ~ 100 m diameter.
- Cosmic-ray "background" signal; discrimination using periodicity at first; later images of showers.
- First VHE telescope in 1967 on Mt Hopkins, USA.



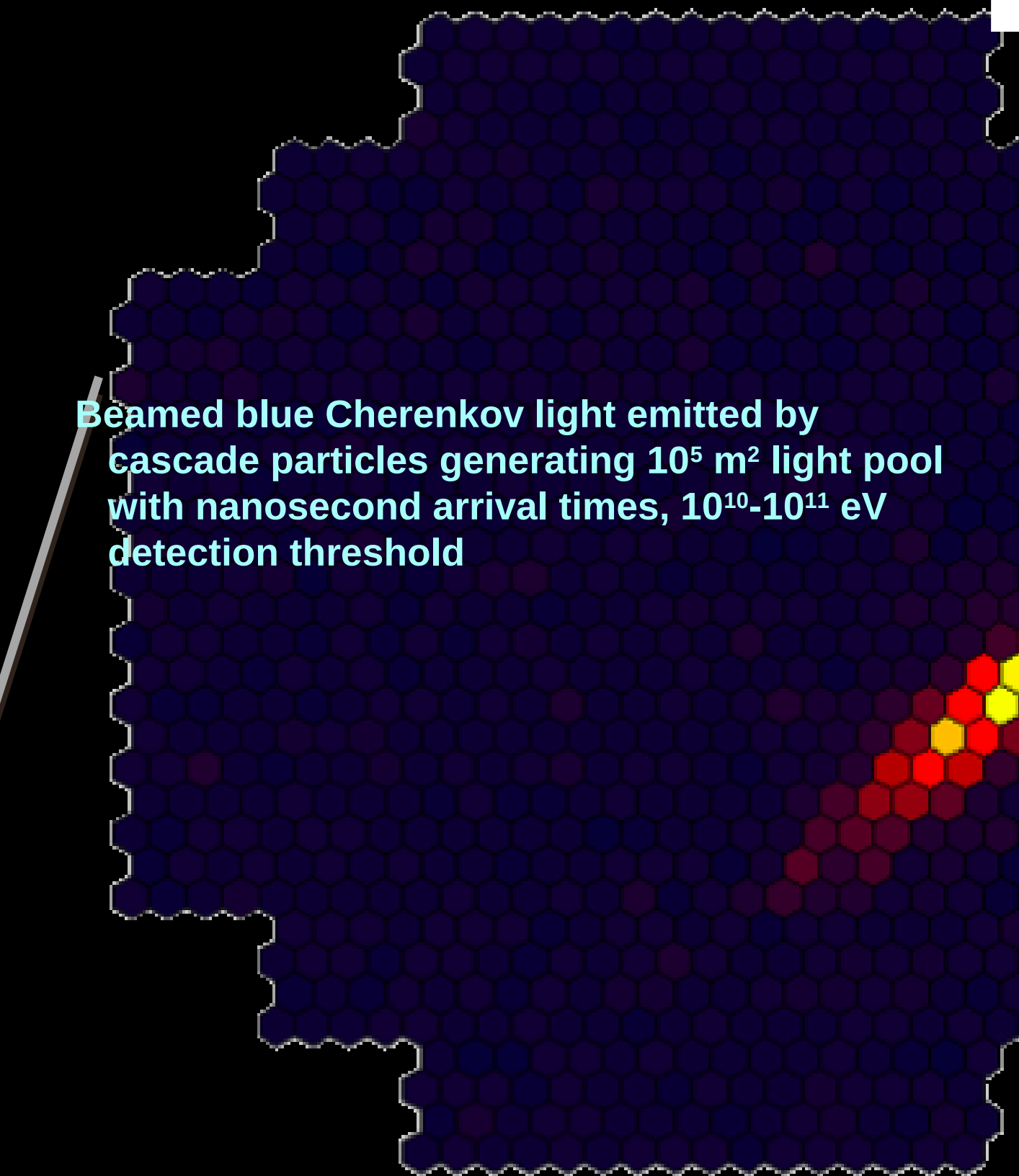
ENKOV

ATION

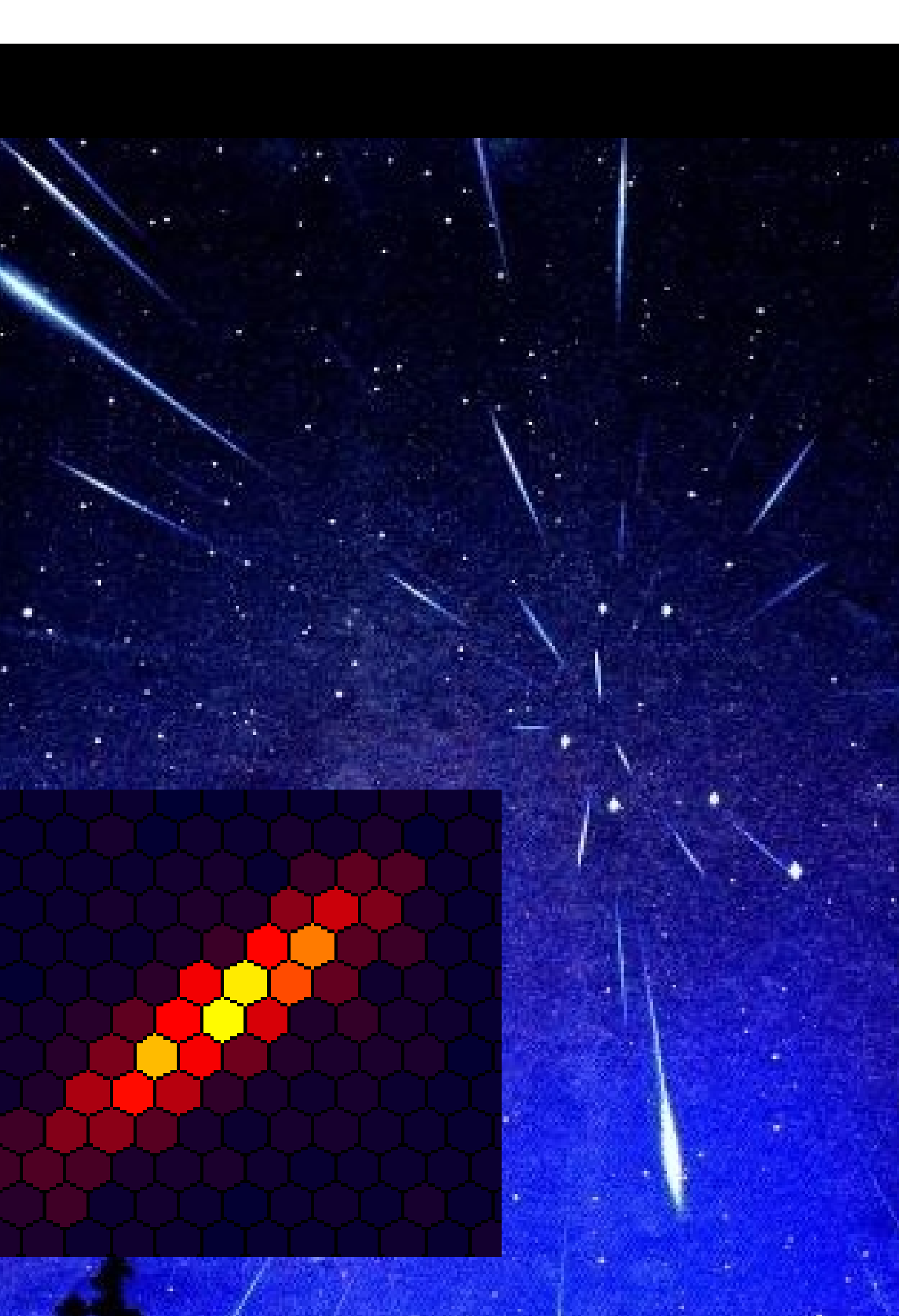
hysics for explaini

Cherenkov radiatio

Technique

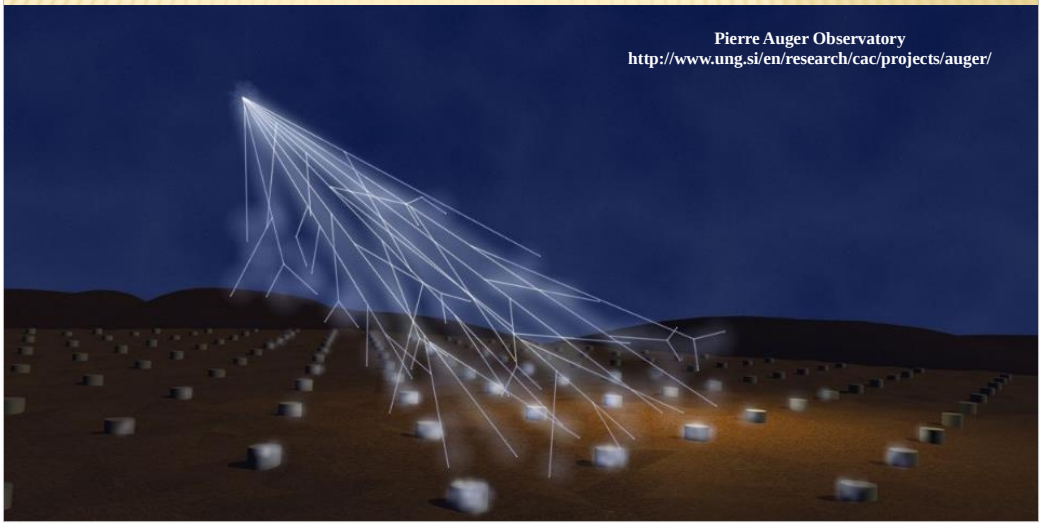


Beamed blue Cherenkov light emitted by cascade particles generating 10^5 m^2 light pool with nanosecond arrival times, 10^{10}-10^{11} eV detection threshold



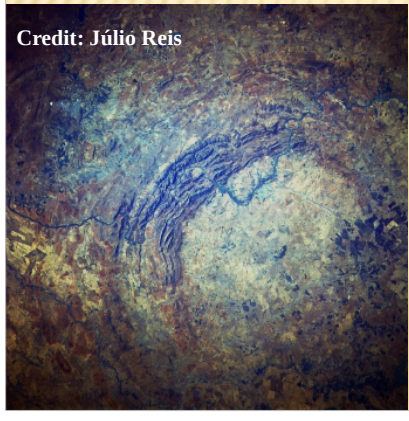
LOCAL HISTORY

- **Department of Physics at the Potchefstroom University for Christian Higher Education became involved in experiments involving Extensive Air Showers in the 60s.**



LOCAL HISTORY

- **Scintillation counters: photomultiplier tubes and ns-technology in 70s.**
- **Raubenheimer (1983) proposed to build an Atmospheric Cherenkov Telescope given the good climate, clear skies, and tech know-how.**
- **Farm Nooitgedacht, 35 km from Potchefstroom in the Vredefort Dome (26.9°S, 27.2°E, 1438 masl).**
- **MK I telescope became operational in 1985 – first in S. Hemisphere.**
- **Good site with Galactic Centre passing near zenith during winter.**



THE MK I TELESCOPE

- Commissioning of Mk I in April 1985.
- 4 mini-telescopes (MTs), distributed 55 m from each other on the corners of a triangle and one the middle.
- Compactness of array allowed multiple sampling of single shower: pin-point shower direction.
- Each MT consisted of 12 search light mirrors from WWII (d = 1.5 m) used as reflectors.
- Each MT contained three light detectors.
- To maximise light flux detected by the XP2020Q photomultiplier, a custom collimator system was designed and built (cf. MSc thesis of HI Nel on optimalisation of system).
- Low reflection coefficient (~0.7 at 400 nm); f-value ~ 0.43 (maximum incident angle 61°); hyperbolic form (focus planes instead of single focus).

Data log: Nooitgedacht Mk I

Source type	Total number	Exposure (h)
Isolated radio pulsars	21	1070
X-ray binaries	14	672
Cataclysmic variables	8	578
Binary radio pulsars	9	574
Miscellaneous	6	690

THE MK I TELESCOPE

- Low-tech: no imaging possible. Identied a gamma-ray event using coincidence techniques (and locally-produced electronics).
- Cosmic-ray event rate of 1 Hz, threshold energy of 1 TeV at zenith.
- 9 years in operation; 3 600 hours of observations.
- Only 5 statistically significant VHE sources detected at the time: Crab pulsar @ 6σ, Cyg X-3, Cen A, Vela Pulsar, and Her X-1.
- Most important: arrival time of the gamma ray. Registering absolute time before the advent of cell phones, GPSs, internet... National time service provided by CSIR (0.1 ms) to calibrate time. Later, acquired an expensive atomic clock.
- Original control room a caravan containing a lot of electronics.
- 40-minute “drift scans”; repositioning to new coordinates took 5 minutes!
- All coordinates for the night were pre-calculated and printed out in tables.

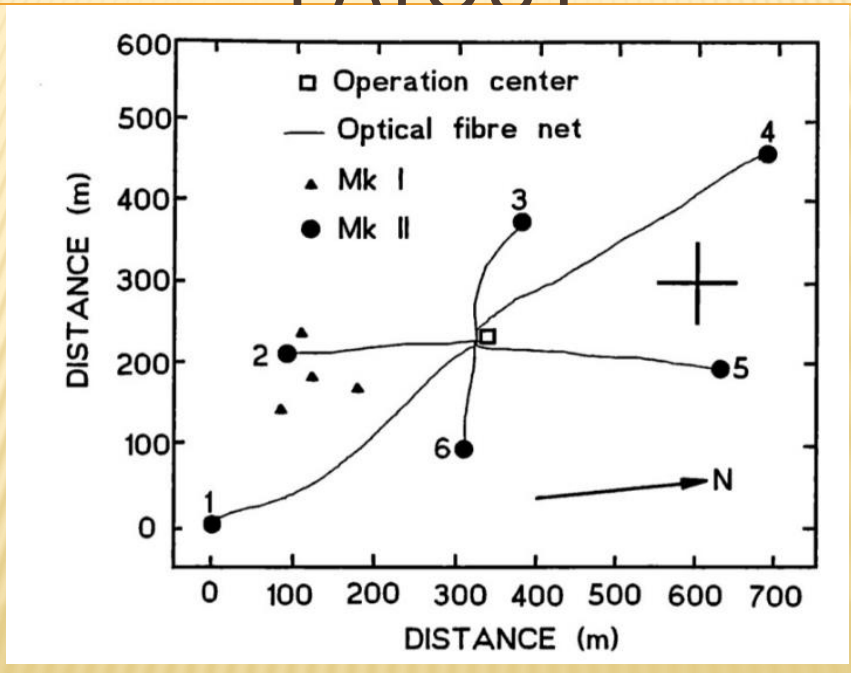
THE MK I TELESCOPE

- One night's data filled an entire box of 5.25" floppy discs.
- Transferal to the NWU's IBM mainframe took half a day (captured on Apple PC, transferred to IBM PC, then mainframe).
- Barycentric corrections to arrival times via programme that throttled the mainframe – no student and financial systems could function! Special permission from IT department.
- Big problems with bird droppings on mirrors.
- Basic temporary buildings, no running water, basic ablution facilities.
- Decommissioned: October 1993. Mirror reflectivity deteriorated, resulting in 0.4 Hz event rate; huge thunderstorm.

computermuseum.wiwi.hu-berlin.de

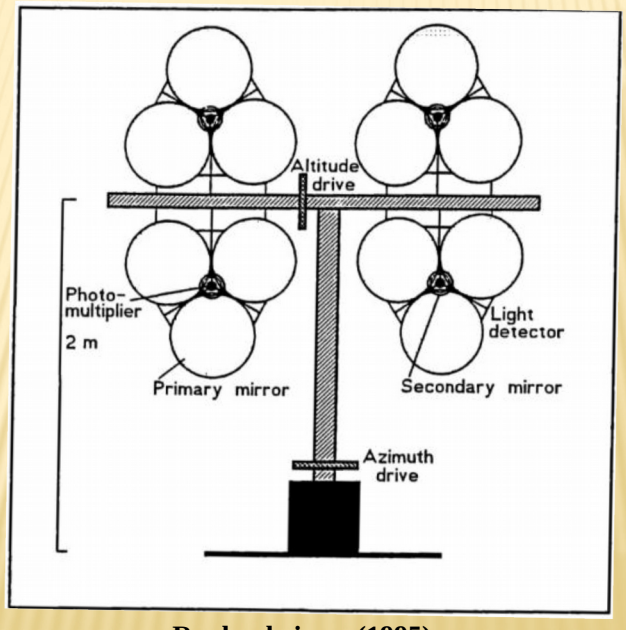
www.automotive-fleet.com

MK I & II TELESCOPE LAYOUT



Raubenheimer (1995)

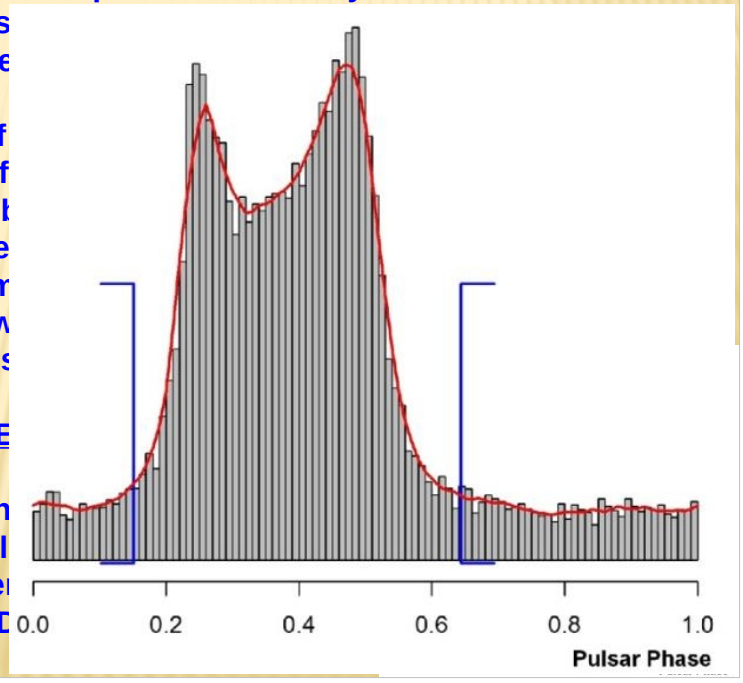
MK II TELESCOPE SCHEMATIC DIAGRAM



Raubenheimer (1995)

MK II TELESCOPE

- Building of the Mk 2 Telescope involved nearly the whole Department of Physics
- 9 units, distributed ove spacing).
- Each unit consisted of d = 50 cm segments of
- Each unit had a small b control electronics. Ce
- Cabling, mirrors, optim
- Long hours, extreme w optimise mirror images



EARLY THEORETICAL RE

- KDE method to obtain plus errors, overcomin binning (De Jager et al
- H-test to search for pe unknown light curve (D

MK II TELESCOPE

- **Local wild life: warthogs damaged water pipes, snakes in warm buildings, cattle, ants, spiders...**
- **MK 2 operational for ± 2 years. Shut down due to finances, person power, competition from new international imaging telescopes.**
- **Electronics: Barend Visser and Gerrit van Urk.**
- **Building, cleaning, observations, data analysis: Paul van Wyk, Estie en Okkie de Jager, Piet Meintjies, Adrian North, Neels Brink and Isabel (du Plessis) North et al. under leadership of prof. Christo Raubenheimer.**
- **Christo Raubenheimer intitiated the project after having spent a year at MPI (Garching).**
- **NWU became involved in H.E.S.S. in late 1990s.**

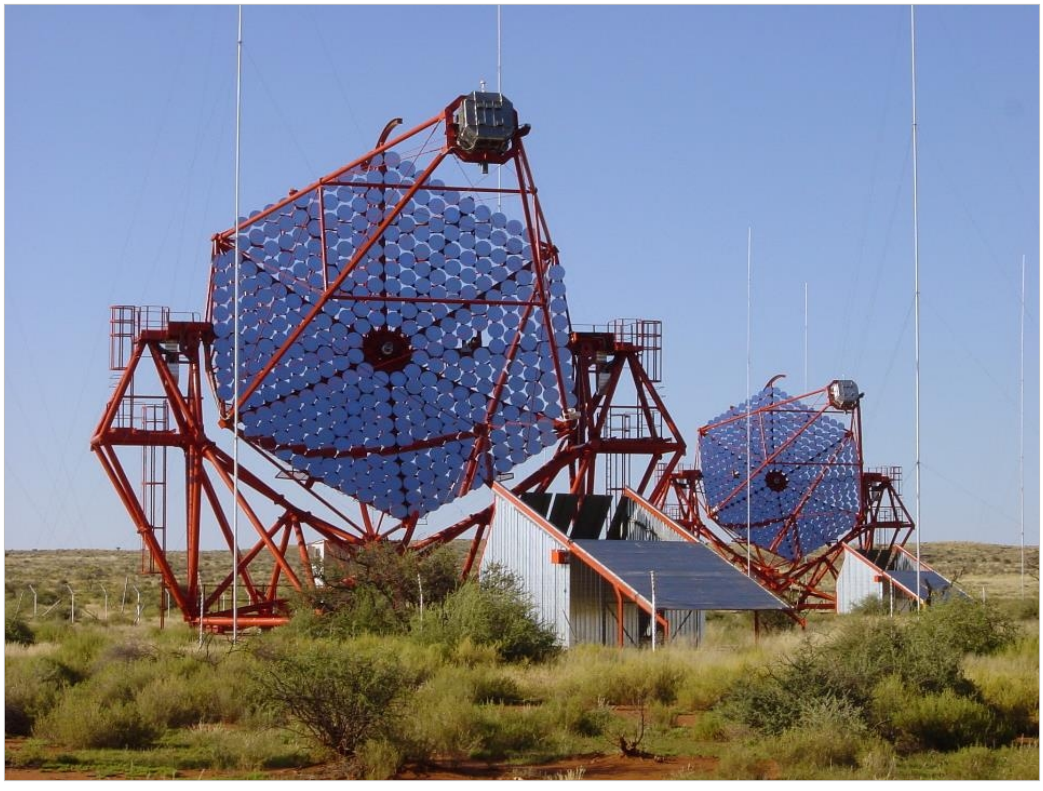
Prof. Christo Raubenheimer


Credit: HI Nel de Jager

Credit: HI Nel de Jager


Credit: HI Nel de Jager

I.E.S.S. I?




25

NWU H.E.S.S. GROUP IN 2006

Christo Venter, Mathew Holleran,
Ingo Büsching, Christo Raubenheimer,
Okkie de Jager [Isak Davids]

The Name

High Energy Stereoscopic System

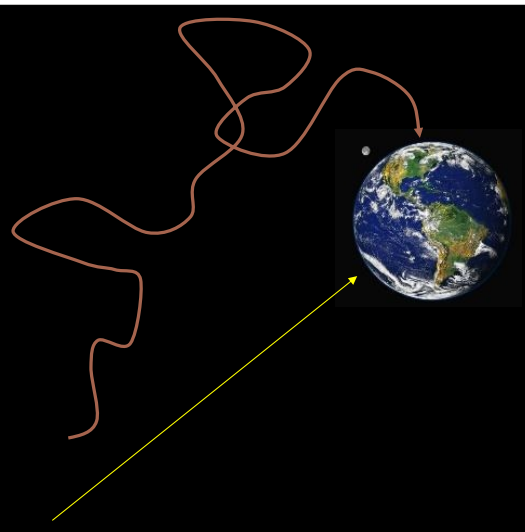
1883 –1964

Discovery of Cosmic Rays
Victor Hess 1912
(Nobel Prize 1936)

Collaboratio

Why γ-rays?

Indirectly "seeing" cosmic particle accelerators

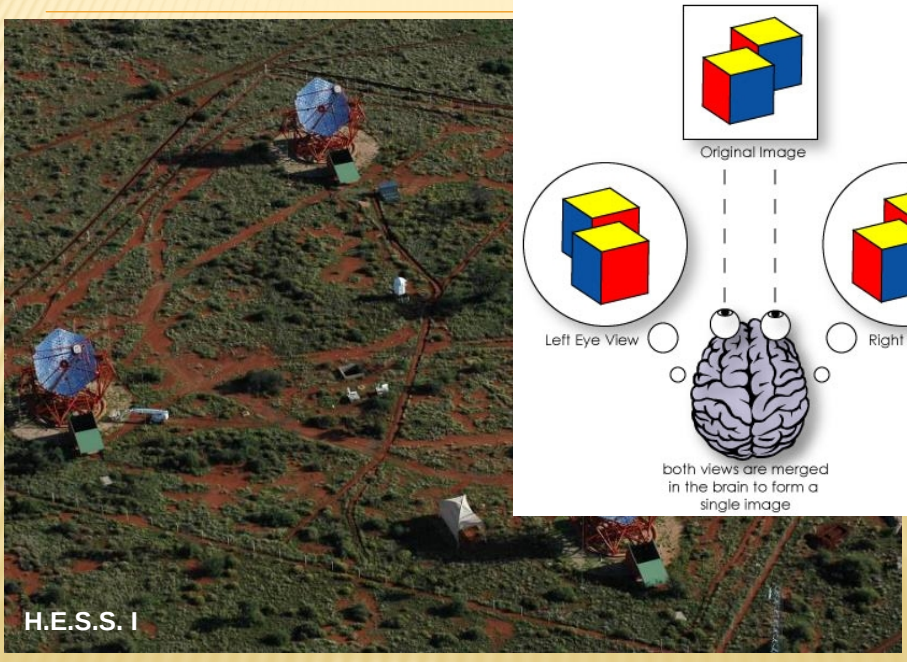


→ Image accelerators with neutral secondaries
→ Gamma-ray and Neutrino Astronomy

$$p + \text{nucleus} \rightarrow \pi + X$$

$$\pi^{o} \rightarrow \gamma\gamma$$
$$\pi^{\pm} \rightarrow \mu^{\pm} \nu$$

Four “Eyes”: Stereoscopic Vision



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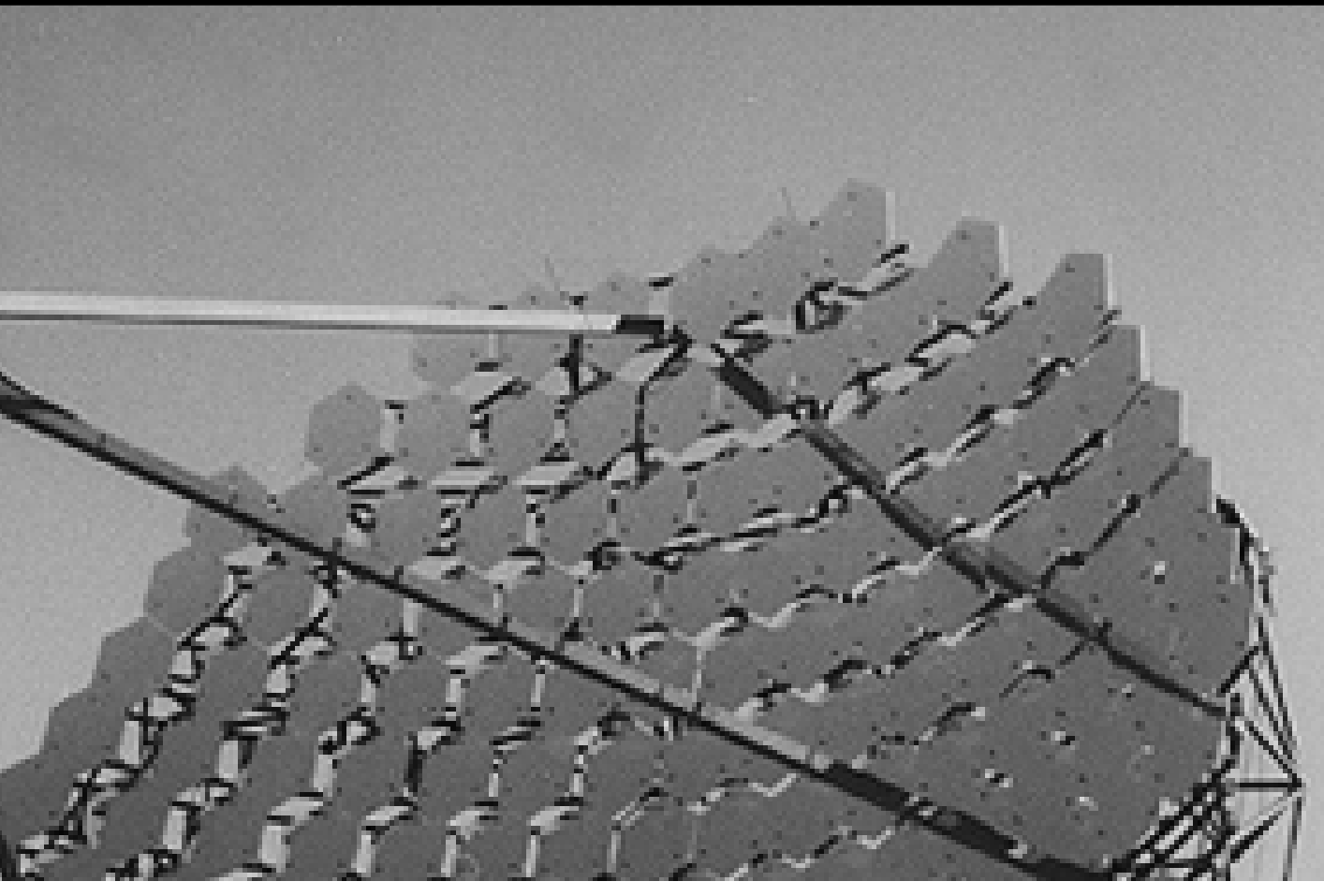
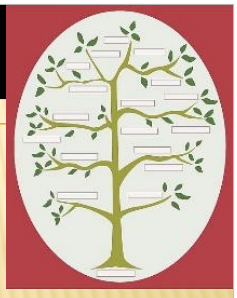


H.E.S.S. Family Tree



Whipple

HEGRA:
Stereoscopy

Imaging principle
Dish size

CAT:
Small pixels

H.E.S.S.

(& VERITAS)

aracteristic

960-pixel camera

380 mirror segment

107 m² mirror area

elescope

Measure fluxes up t

housands of that of

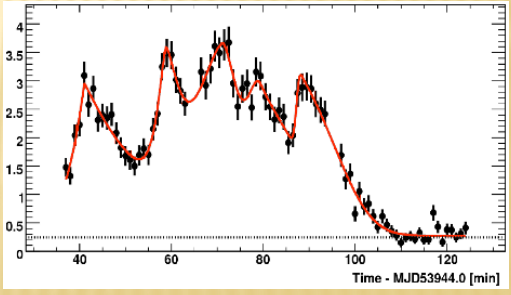
Crab Nebula

Angular resolution:

Drivers for Success of H.E.S.S.

New VHE Window on the Universe

- **High sensitivity**
  - 3 orders of magnitude dynamic range in flux between strongest and faintest sources
- **Wide spectral range**
  - > 2 orders of magnitude coverage in energy, up to 10s of TeV
  - 10% – 15% energy resolution
- **Resolved source morphology**
  - ~5' angular resolution
  - 10" – 20" source localization
- **Survey capability**
  - H.E.S.S. Galactic Plane Survey:
  - 2% Crab sensitivity
- **Well-resolved light curves**
  - Minute-scale variability of AGN



lades

e for Research 2

€1 million Pr

HEAD High Energy Astrophysics Division of
the American Astronomical Society (AAS)

"[H.E.S
revolu
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o Rossi Prize 20

ignificant contribu

, with particular e

riginal work.

HEAD: High Energy Astrophysics Division of the American Astronomical Society (AAS)

"...awarded or thei

outstanding contributio

imaging of very high-e

(TeV) gamma rays w

ration Proc

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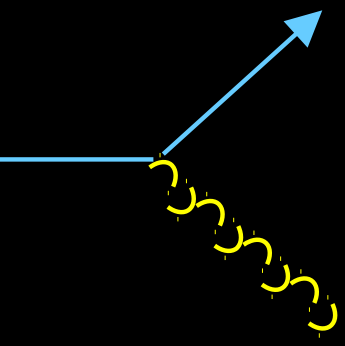


p

gas

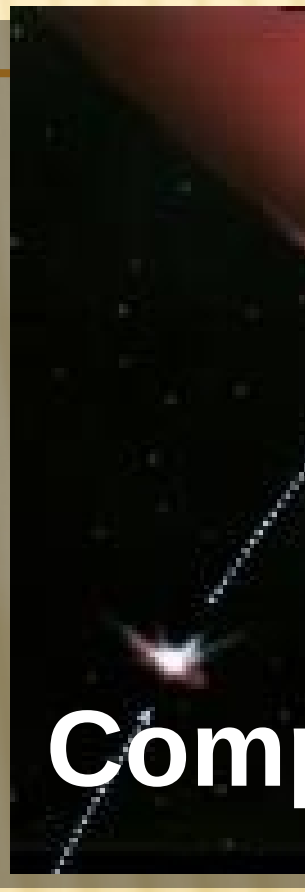
ble light

X-rays

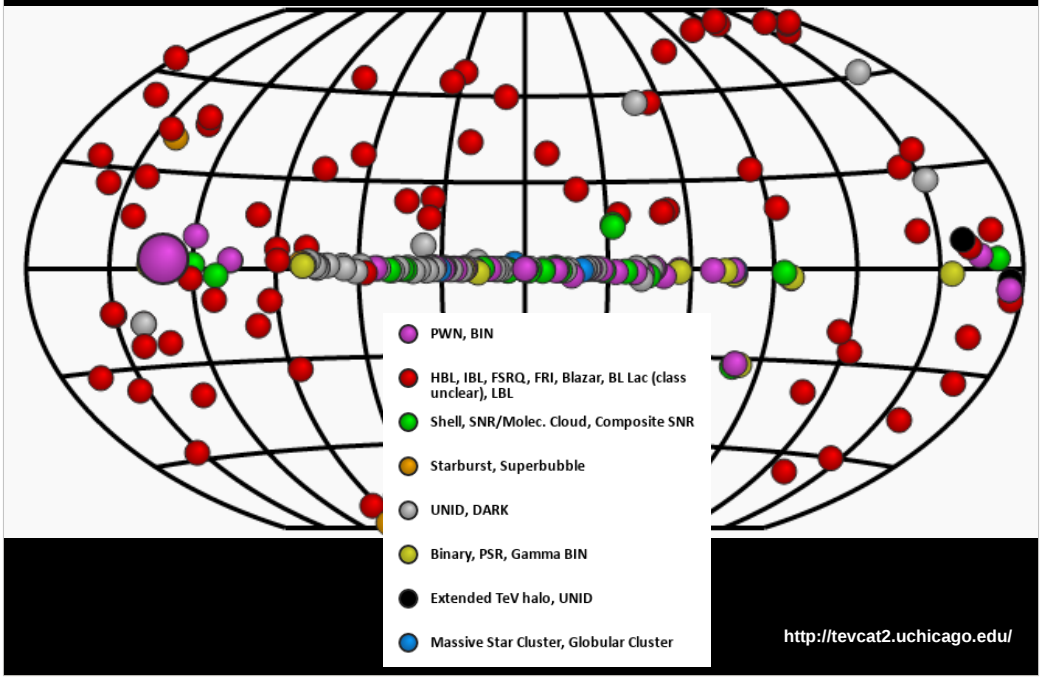
g

H

Classes

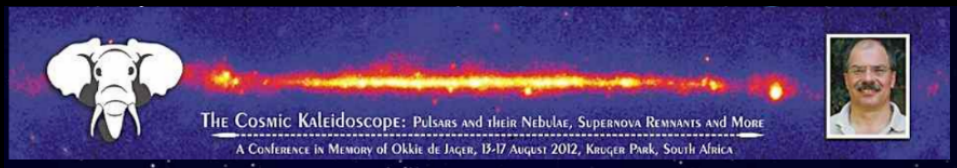


TeV γ-ray Sky: > 200 sources



http://tevcat2.uchicago.edu/

KNP Conference 2012



Overview

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In and around Kruger
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Local Organising Committee
Posters
Science Program
Registration
Scientific Organising Committee
Skukuza
Social Events and Game Drives
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Travel

As the title suggests, the meeting will focus on the high-energy astrophysics topics that were strongly influenced by Okkie's work. These topics will include high-energy aspects of pulsars, pulsar wind nebulae, supernova remnants, and absorption by extragalactic background light, with emphasis on their multi-wavelength properties, as well as new VHE detection and detector concepts. The exciting new results from Fermi, H.E.S.S., MAGIC, and VERITAS are creating a fast-evolving landscape yielding as many new puzzles as answers to old questions.

We aim to celebrate the science that was dear to Okkie, in one of his favourite places, Kruger National Park, South Africa.

Dates: From 13 August 2012 to 17 August 20
Welcoming reception on Sunday, 12-A

Time zone: Africa / Johannesburg

Location: Kruger National Park - Skukuza Rest
Latitude: -24.9898, Longitude: 31.592

Additional info: Skukuza is the Kruger National Par
headquarters. It is situated on the sou
is well foliaged and there are some l
and facilities are diverse, as are the
camp and in the surrounding areas
internet cafe, restaurant, library, fuel st

Registration: The Registration fee will be R3550 (R
(dollar amount may vary). This include
1. Welcoming Reception,

Okkie de Jager
14 December 2010

KNP Conference SOC

KNP Conference Photo

Front (f.l.t.r.): Peter den Hartog, Yang Chen, Mallory Roberts, Isak Davids, Anna Barnacka, Anna Zajczyk, Arache Djannati-Atai, Christo Venter, Wlodek Bednarek, Pieter Meintjes, Vanessa Mangano, Johan van der Walt, Ping Zhou, Bing Jiang, Eduardo de la Fuente, ***Second row:*** Petro Siebenhagen, Alice Harding, Stefan Funk, Wim Hermsen, Nepomuk Otte, Elsa Giacani, Eveline Helder, John Hewitt, Brian Williams, Gloria Dubner, Yosi Gelfand, Michael Vorster, Tomek Bulik, Jacek Niemiec, Yves Gallant, Nukri Komin, Marco Micel, Stefano Gabici, Omar Tibolla, Eric Gotthelf, Takalani Enos Manubini, Jonatan Martin, ***Back (f.l.t.r.):*** Bronek Rudak, Elanie van Rooyen, Monica Breed, Estie de Jager, Reinhard Schlickeiser, Markus Böttcher, Stephen C.-Y. Ng, Tea Temim, Sarah Buchner, Parviz Ghavamian, Kristoffer Eriksen, Matthew Kerr, Rino Bandiera, Roger Blandford, Pat Slane, Augusts van der Schyff, Bertie Seyffert, Jacco Vink, David Buckley, Sjors Broersen, Paulus Krüger, Klara Schure, Brian van Soelen, Patrizia Caraveo, Oliver Porth, Lorenzo Sironi, Igor Telezhinsky, Roger Chevalier, Brian Humensky, Heather Matheson, Gilles Ferrand, Anne Lemière, ***Absent:*** Jon Arons, Matthew Baring, Ingo Buesching, Daniel Castro, Pete Gonthier, Isabelle Grenier, Mathew Holleran, Marcos Lopez-Moya, Claire Max, Paul Ray, Agnieszka Slowikowska

SA-GAMMA CONSORTIUM

- The South African Gamma-Ray Astronomy Programme (SA-GAMMA)
- Consortium of South African Universities and research institutions which engage in research in the fields of gamma-ray astronomy and high-energy astrophysics.
- Co-ordinates the SA involvement in H.E.S.S. and the Cherenkov Telescope Array (CTA)
- Current members: NWU, Wits, UFS, UJ, and SAAO.
- Sponsored by South African Department of Science and Technology (DST).
- Annual conference series: High Energy Astrophysics in Southern Africa (HEASA) – 6th event in 2018.

Prof. Markus Boettcher

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT

UNIVERSITY OF THE WITWATERSRAND
JOHANNESBURG

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA
UFS UV

UNIVERSITY OF JOHANNESBURG

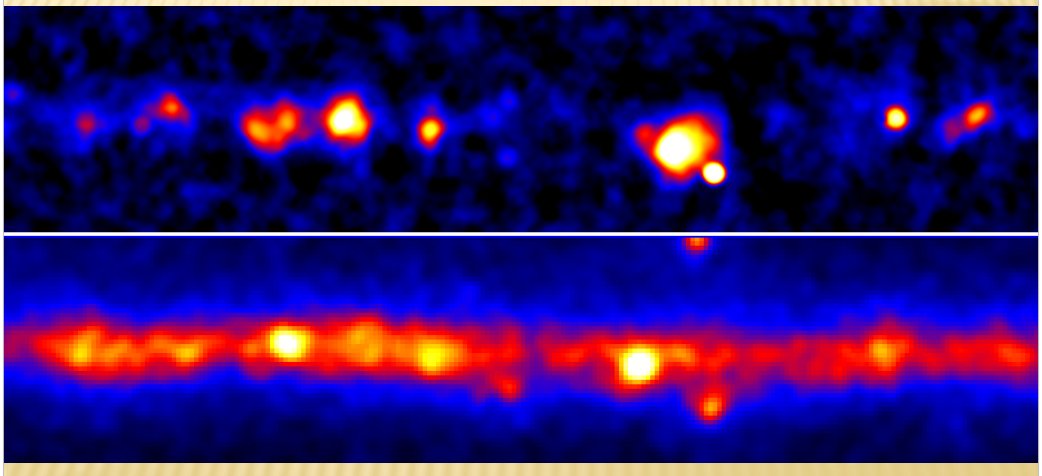
NRF National Research Foundation
SAAO South African Astronomical Observatory

The Milky Way at GeV and TeV Energies

Galactic Plane Survey

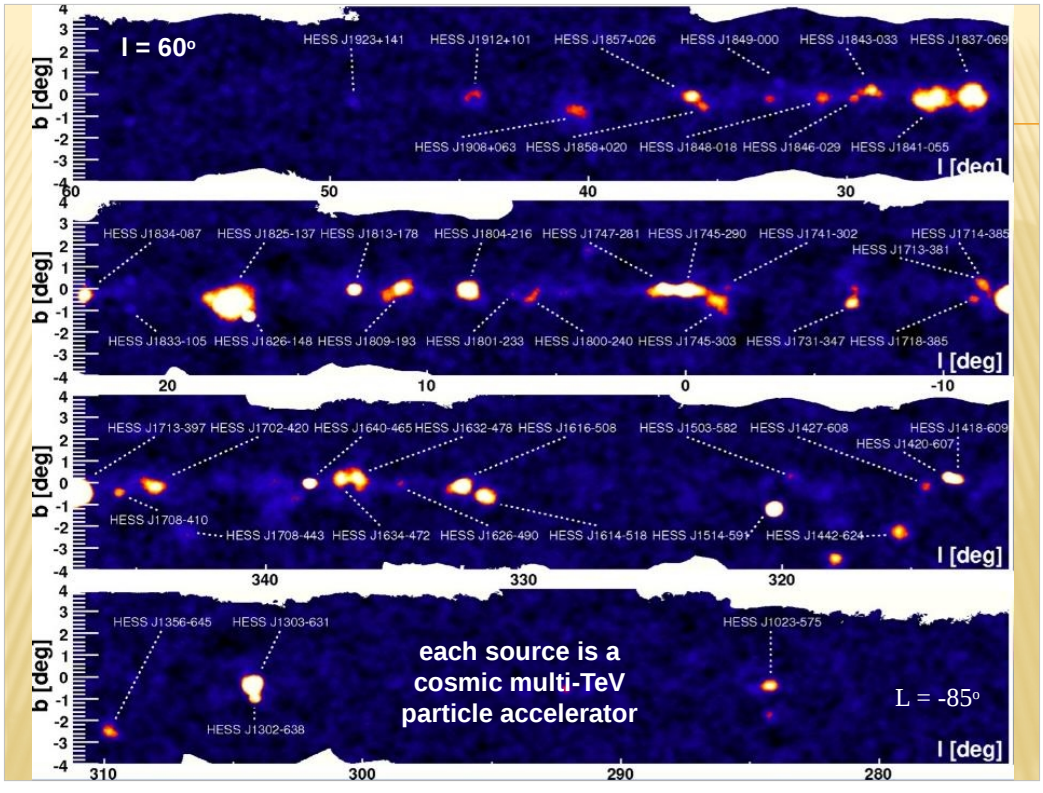
Extended sources, size typically few 0.1° (few 10 pc)

H.E.S.S. (~ 1 TeV)



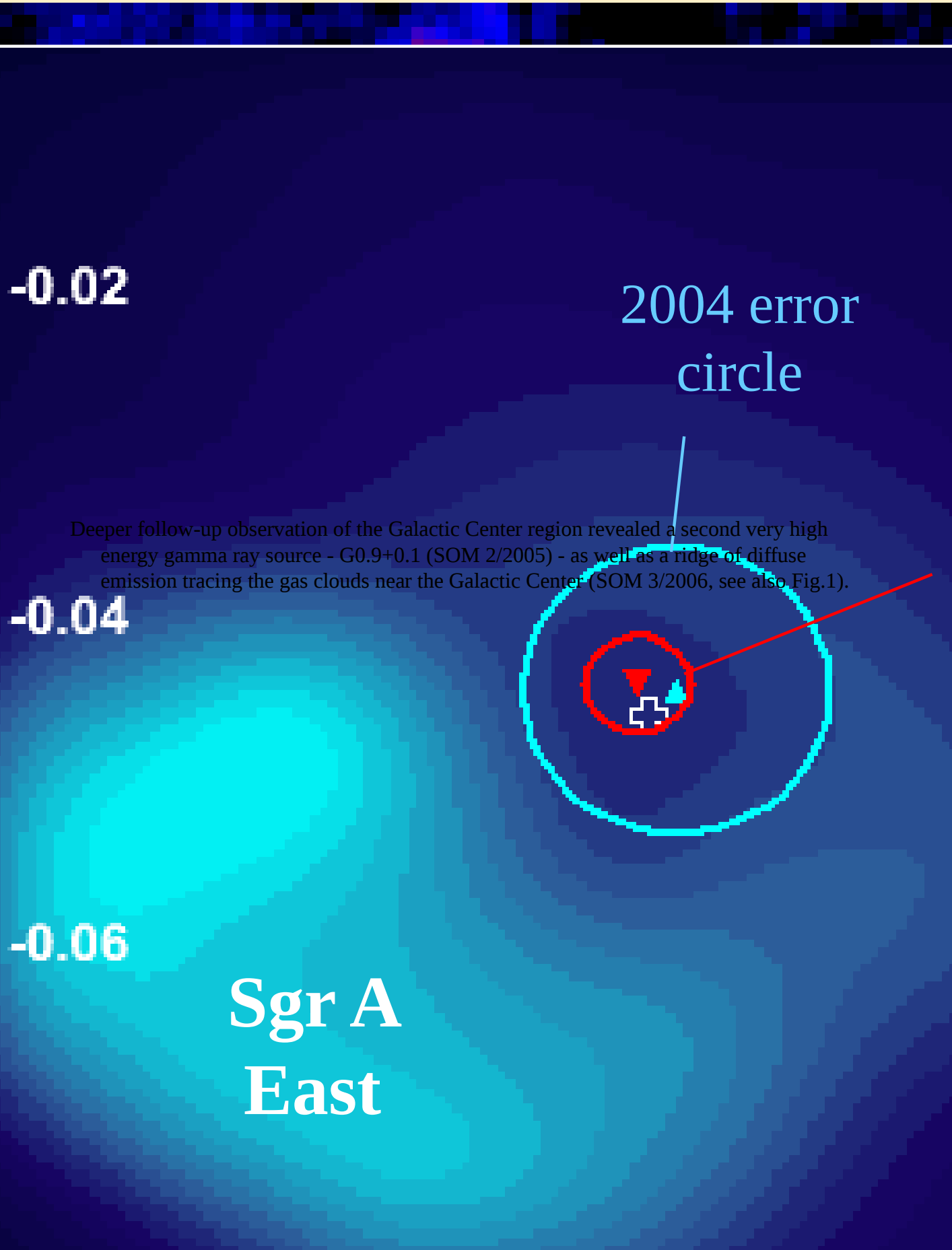
***Fermi*-LAT (>1 GeV)**

“Background” due to propagating Galactic cosmic rays

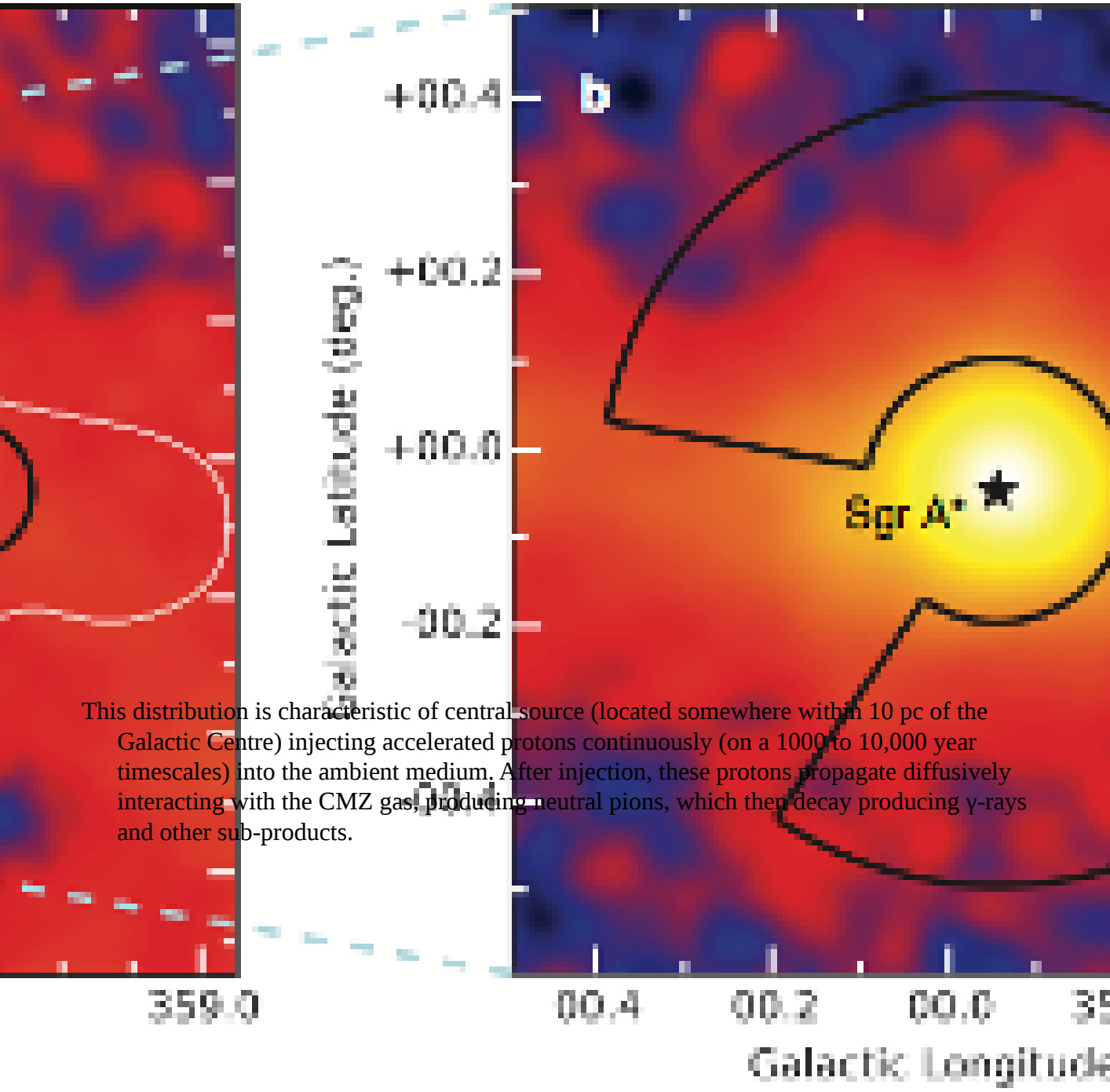

l = 60°
HESS J1923+141
HESS J1912+101
HESS J1857+026
HESS J1849-000
HESS J1843-033
HESS J1837-069
HESS J1908+063
HESS J1858+020
HESS J1848-018
HESS J1846-029
HESS J1841-055
HESS J1834-087
HESS J1825-137
HESS J1813-178
HESS J1804-216
HESS J1747-281
HESS J1745-290
HESS J1741-302
HESS J1714-385
HESS J1713-381
HESS J1833-105
HESS J1826-148
HESS J1809-193
HESS J1801-233
HESS J1800-240
HESS J1745-303
HESS J1731-347
HESS J1718-385
HESS J1713-397
HESS J1702-420
HESS J1640-465
HESS J1632-478
HESS J1616-508
HESS J1503-582
HESS J1427-608
HESS J1418-609
HESS J1420-607
HESS J1708-410
HESS J1708-443
HESS J1634-472
HESS J1626-490
HESS J1614-518
HESS J1514-591
HESS J1442-624
HESS J1356-645
HESS J1303-631
HESS J1023-575
HESS J1302-638
each source is a cosmic multi-TeV particle accelerator
L = -85°
b [deg]
l [deg]

ntre: Sag A

Composite image of the Galactic Center region, combining Hubble images in the near-infrared, Spitzer Space Telescope images in the infrared, and Chandra X-ray images. The bright white region on the bottom right size is Sagittarius A, the Galactic Center. The image spans about 0.3 degr. across the sky, corresponding to about 170 light year at the distance of the Galactic Center. See APOD for details, and for an annotated image. Image credit: NASA, ESA, SSC, CXC, and STScI.



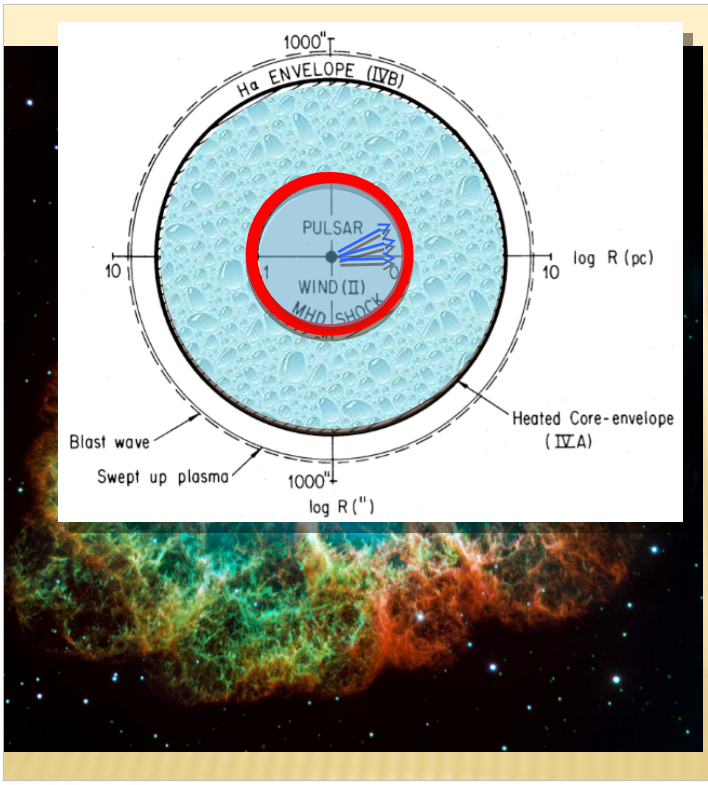
Deeper follow-up observation of the Galactic Center region revealed a second very high energy gamma ray source - G0.9+0.1 (SOM 2/2005) - as well as a ridge of diffuse emission tracing the gas clouds near the Galactic Center (SOM 3/2006, see also Fig.1).



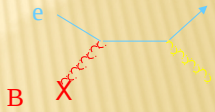
This distribution is characteristic of central source (located somewhere within 10 pc of the Galactic Centre) injecting accelerated protons continuously (on a 1000 to 10,000 year timescales) into the ambient medium. After injection, these protons propagate diffusively interacting with the CMZ gas, producing neutral pions, which then decay producing γ-rays and other sub-products.

- **Profile characterist**
  source (within 10 p
  Galactic Centre)

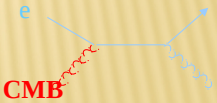
Animation of the H.E.S.S. images of RX J1713.7-3946 produced at three different phases. In 2004, we had barely commissioned the telescope array when one of our first datasets obtained with only two out of the four telescopes revealed this impressive source, which is twice the size of the full moon in the sky! The 2006 image is a deep exposure measurement of the remnant obtained with the full four-telescope array. By then we had developed background modelling and subtraction techniques to produce a real gamma-ray excess image with a good angular resolution of 3.6 arc minutes. [illegible] a much better understanding of the system performance and hence an improved [illegible]. The 2016 image is probably in many respects demonstrating the ultimate performance of [illegible] current-generation instruments like H.E.S.S., MAGIC, or VERITAS. With an angular resolution below 3 arc minutes and superb event statistics from [illegible] hours of deadtime corrected observation time, morphological details at parsec scales can now be investigated and compared in detail to X-ray images. Further improved measurements will likely only become available once CTA [6], our next-generation facility, comes online in the early 2020's.



Pulsar Wind Nebulae

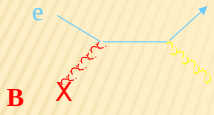


Synchrotron Radiation (eV … GeV)

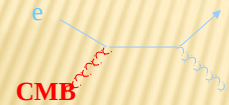


CMB IR, VIS

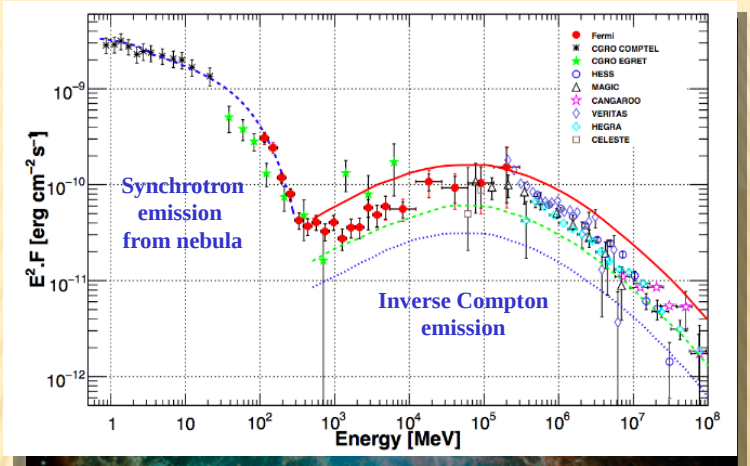
Inverse Compton Upscattering (GeV … TeV)

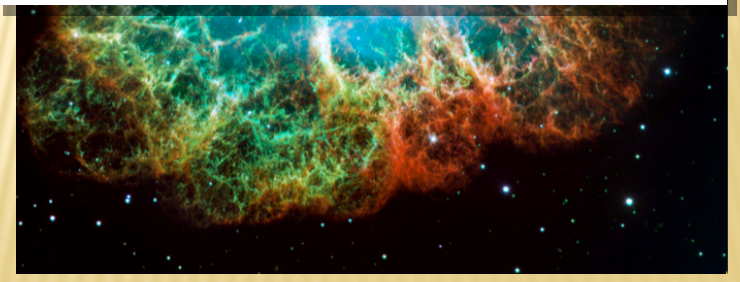


Synchrotron Radiation (X-rays)



Inverse Compton Upscattering (γ-rays)





Crab Nebu

Extensio

Extension of the Crab Nebula as seen with H.E.S.S. (solid white circles, corresponding to Gaussian width), overplotted on the UV (top) and X-ray (bottom) image. The bright dot in the middle corresponds to emission from the Crab Pulsar, whereas the inner ring around the pulsar that is visible in the X-ray image is supposed to be related to the wind termination shock ([5], [6]). For illustration purposes, the VHE extension circle is centered on the pulsar position.

orphology of Crab Ne

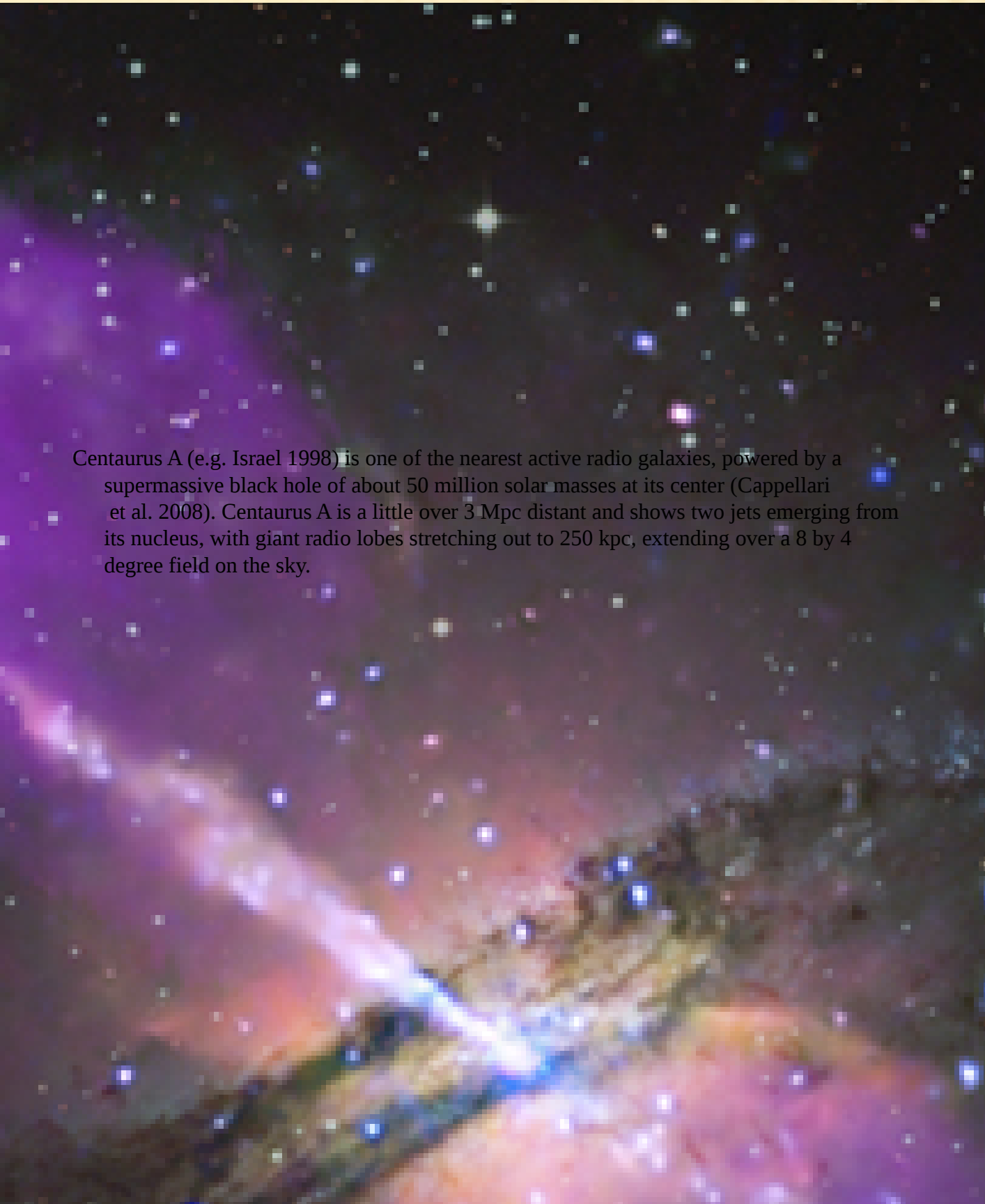
s only been resolved

dio, optical, and X-ray

escopes (<80 keV).

extension at higher

ergies (worse angula



Centaurus A (e.g. Israel 1998) is one of the nearest active radio galaxies, powered by a supermassive black hole of about 50 million solar masses at its center (Cappellari et al. 2008). Centaurus A is a little over 3 Mpc distant and shows two jets emerging from its nucleus, with giant radio lobes stretching out to 250 kpc, extending over a 8 by 4 degree field on the sky.

PHASE II


H.E.S.S. II

Phase II

Approach

reshold to ~10-20 Ge

gy (and time) with *Fe*

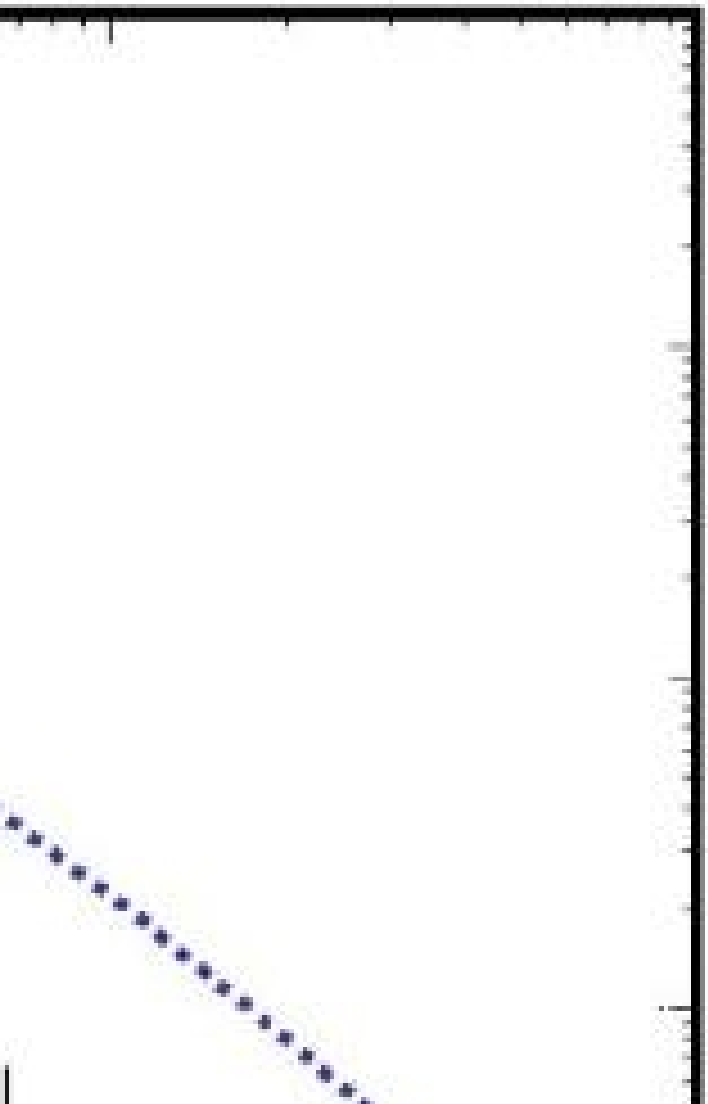
y at 100 GeV

600 m² (equiv. 28 m⌀, 5

Phase II

erformance

H.E.S.S. Phase I



Phase II

sics

emission from
here
sion from XRBs
edshift universe

THE FUTURE OF GAMMA-RAY ASTRONOMY: CTA

H.E.S.S. has been highly successful, but…

Some key object classes still elusive, e.g.

- **Galaxy clusters as cosmological storehouses of CRs**
- **Very-high-energy emission from GRBs**
- **Dark Matter annihilation signatures**

Some key mechanisms remain to be understood, e.g.

- **Supernovae as sources of cosmic rays: do they provide sufficient peak energy & energy output? Morphology?**
- **Cosmic-ray escape from accelerators and propagation**
- **Energy conversion in pulsars**

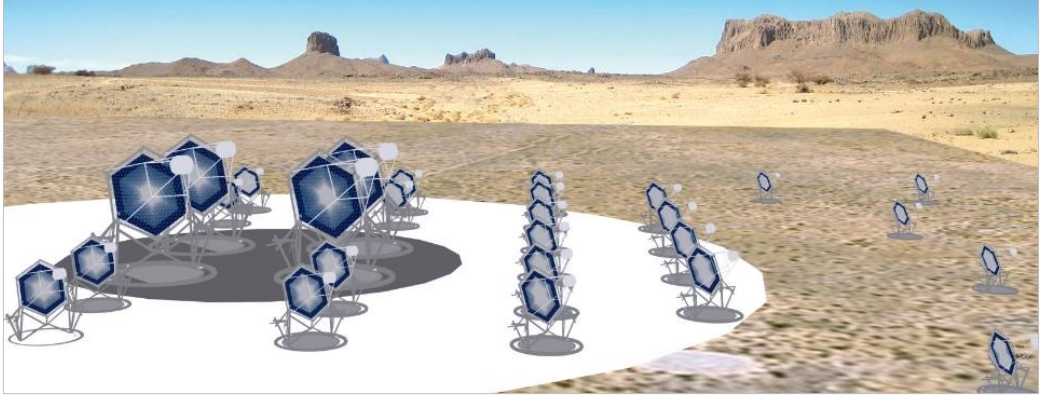
Energy range & angular resolution of current instruments insufficient to probe details

- 10-fold sensitivity increase above that of current instruments
- Extended energy range
- Improved angular resolution
- Operation as open observatory
- Two sites for full-sky coverage

The future in VHE gamma ray astronomy:

CTA

Partners from almost all European countries
+ US, South America, India, Japan, South Africa



Low-energy section:
4 x 23 m tel. (LST)
- Parabolic reflector
- FOV: 4-5 degrees
- f/D: ~1.2

energy threshold
of some 10 GeV

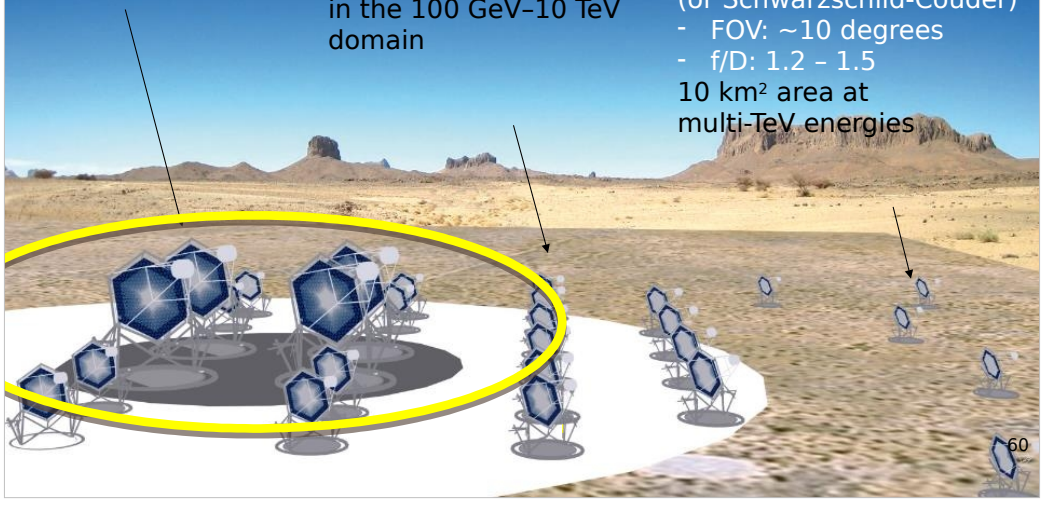
(one) possible configuration
100 M€ (2006 costs)

Core-energy array:
23 x 12 m tel. (MST)
Davies-Cotton reflector
- FOV: 7-8 degrees
- f/D: ~1.4

mCrab sensitivity
in the 100 GeV–10 TeV
domain

High-energy section:
32 x 5-6 m tel. (SST)
Davies-Cotton reflector
(or Schwarzschild-Couder)
- FOV: ~10 degrees
- f/D: 1.2 – 1.5

10 km² area at
multi-TeV energies



SA-GAMMA TIMELINE

- NWU involved in H.E.S.S. since late 1990s
- 2012: Wits joins the H.E.S.S. Collaboration
- 2012 - 2016: SA and Namibia CTA members work closely to foster the bid for the Aar site in southern Namibia for CTA South
- 2013: UFS joins the H.E.S.S. Collaboration
- 2013: SA-GAMMA is founded, with NWU, Wits, UFS as founding members.
- 2013: 1st HEASA meeting in Potchefstroom (NWU)
- ~2014 UJ joins the CTA Consortium and SA-GAMMA
- 2014: 2nd HEASA meeting in Bloemfontein (UFS)
- 2015: Namibian and Chilean sites short-listed as leading sites for hosting CTA South
- 2015: SAAO joins SA-GAMMA.
- 2015: 3rd HEASA meeting in Johannesburg (UJ)
- 2016: CTA Council decides to focus CTA South negotiations on Chile as preferred site.
- 2016: 4th HEASA in Cape Town (SAAO)
- 2017: 5th HEASA in Johannesburg (Wits)
- 2018: 6th HEASA near Parys (NWU)

6TH HEASA ANNUAL CONFERENCE

1 – 3 August 2018
Stonehenge in Africa, near Parys

https://fskbhe1.puk.ac.za/people/mboett/SAGAMMA/HEASA2018/HEASA2018.html

Abstract submission by 20 July 2018.

look

ny is a lively, grow

veries!

ng and proud hist

ons

n H.E.S.S. and C

NKS!