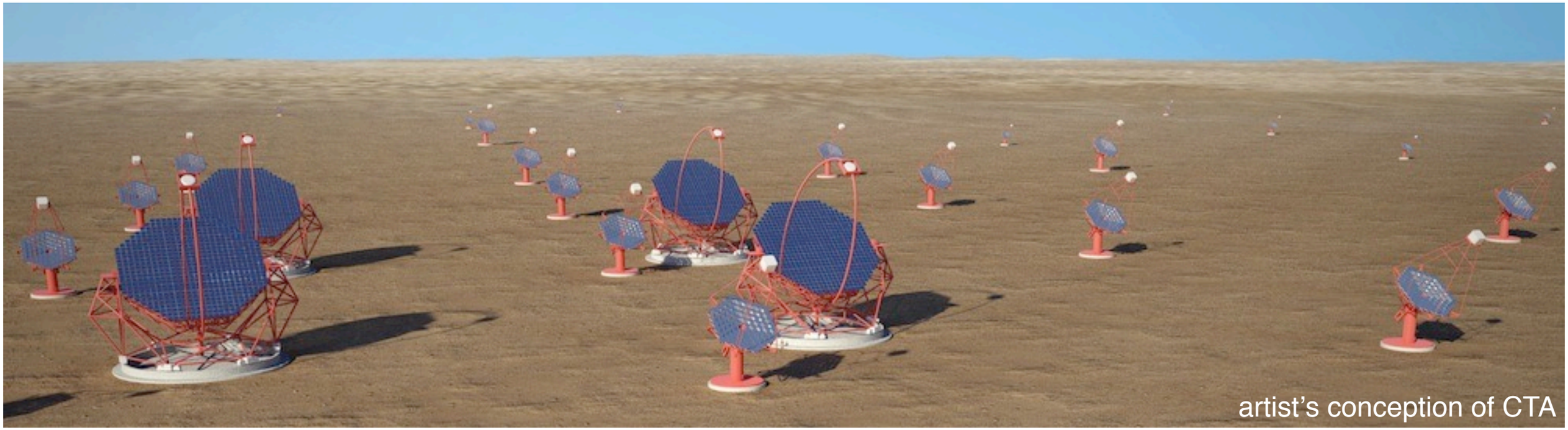
Science with the Cherenkov Telescope Array (CTA)


artist's conception of CTA

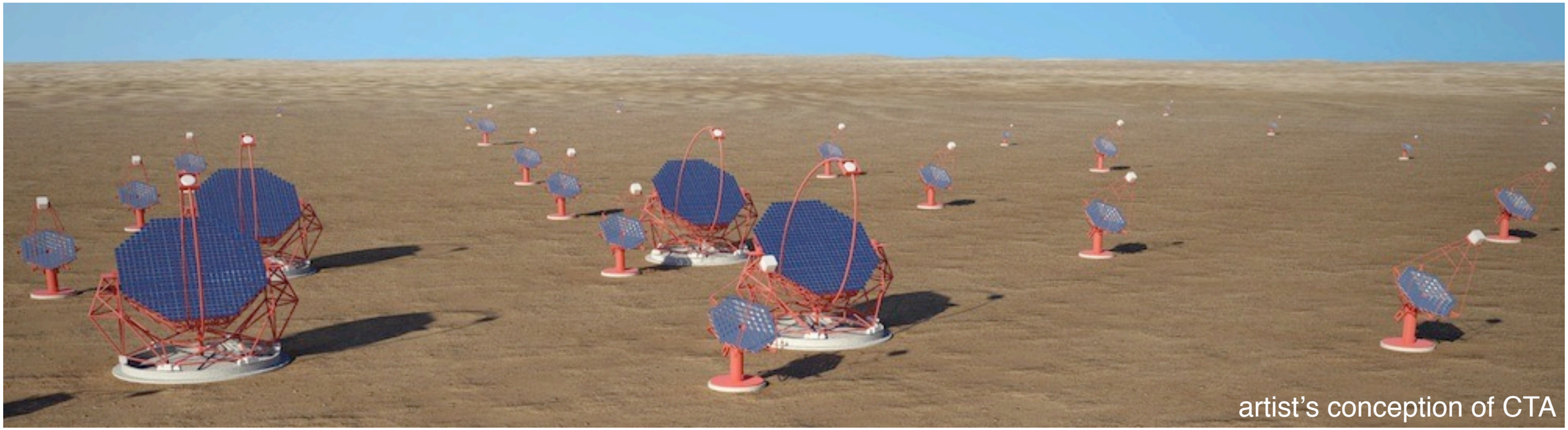
Jeff Grube

on behalf of the CTA Consortium

www.cta-observatory.org

Imaging the Extreme Universe
Solid-state Cameras for Astroparticle Physics
KICP, University of Chicago
May 9, 2013

Science with the Cherenkov Telescope Array (CTA)


artist's conception of CTA

CTA design goals:

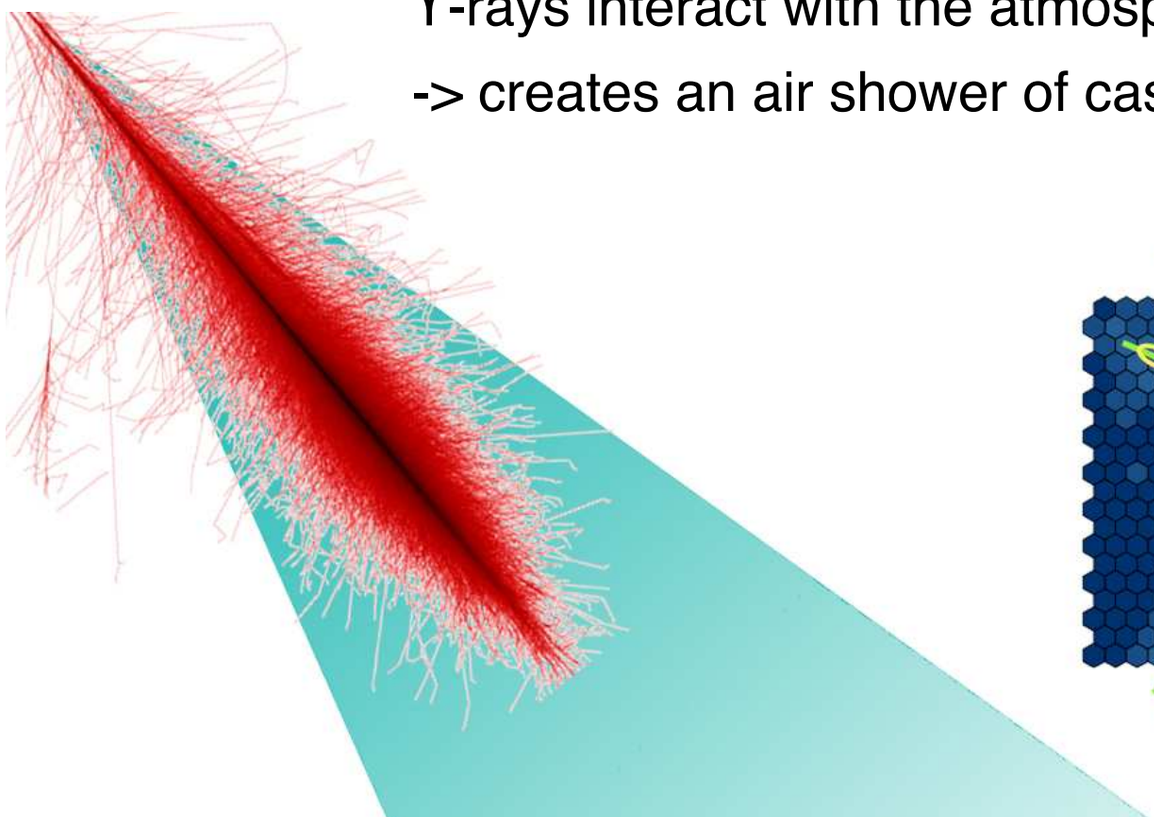
- 10-fold increase in sensitivity over current VHE ϒ-ray instruments
- energy range of ~30 GeV - 100 TeV
- large (~8°) field of view for surveys
- improved angular and energy resolution
- operate as an open observatory

CTA science goals:

- understanding where and how the bulk of CR particles are accelerated
- what makes black holes of all sizes such efficient particle accelerators
- the nature of dark matter
- ϒ-ray probe for the fundamental laws of physics

www.cta-observatory.org
B.S. Acharya et al. 2013, APh, 43, 3

Imaging Atmospheric Cherenkov Technique



ϒ-rays interact with the atmosphere at a height of 15-30 km above ground

-> creates an air shower of cascading interactions over 10 km in length

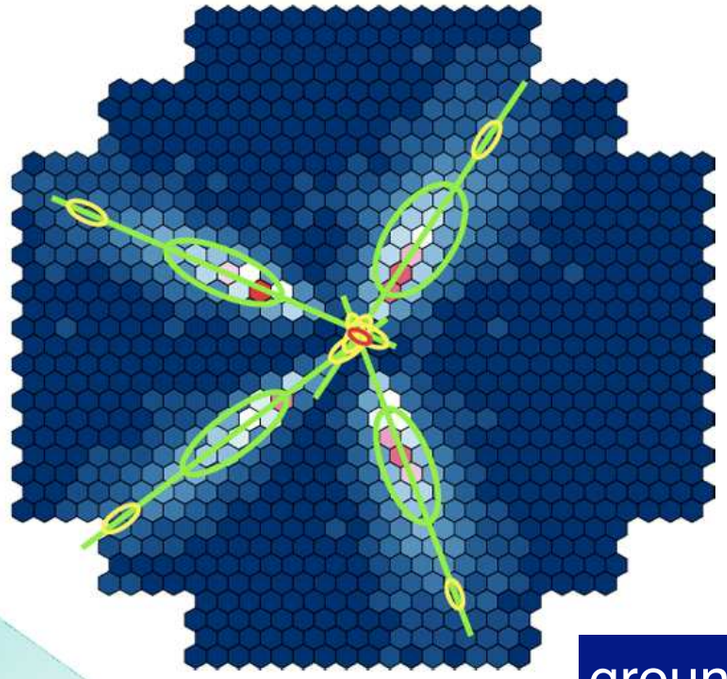
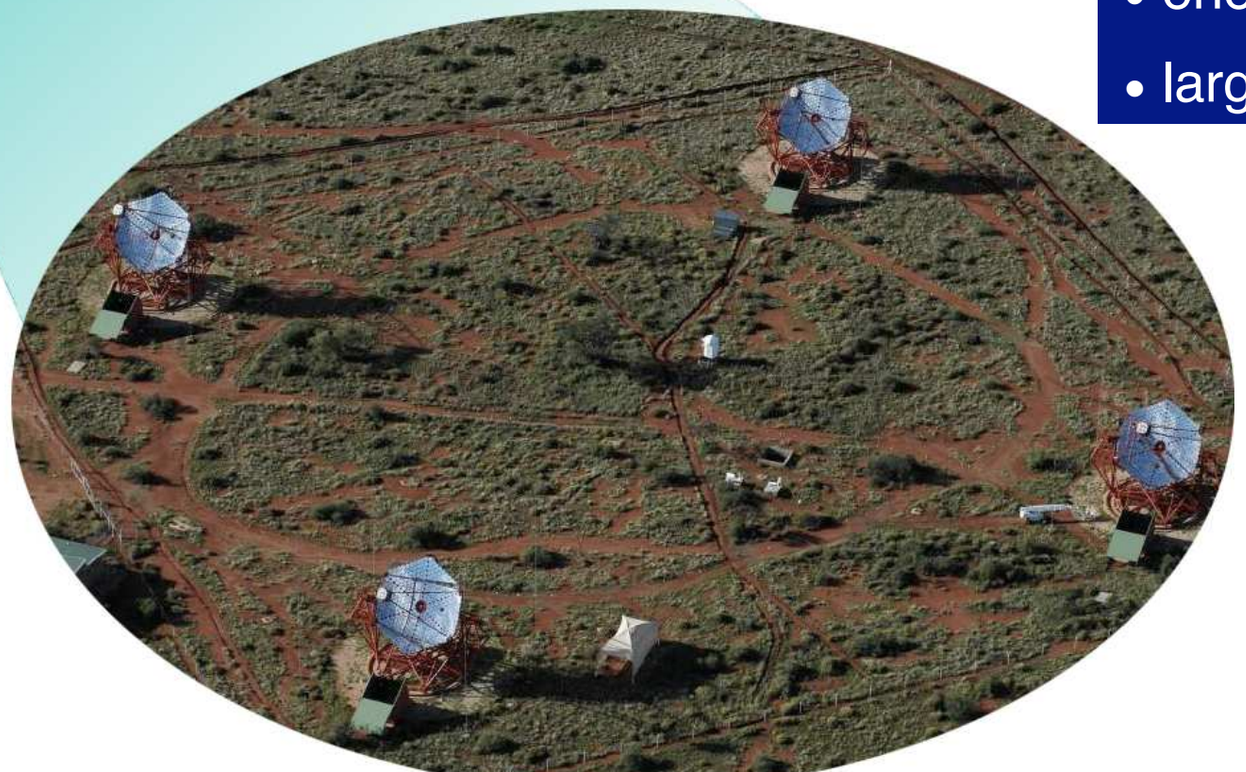


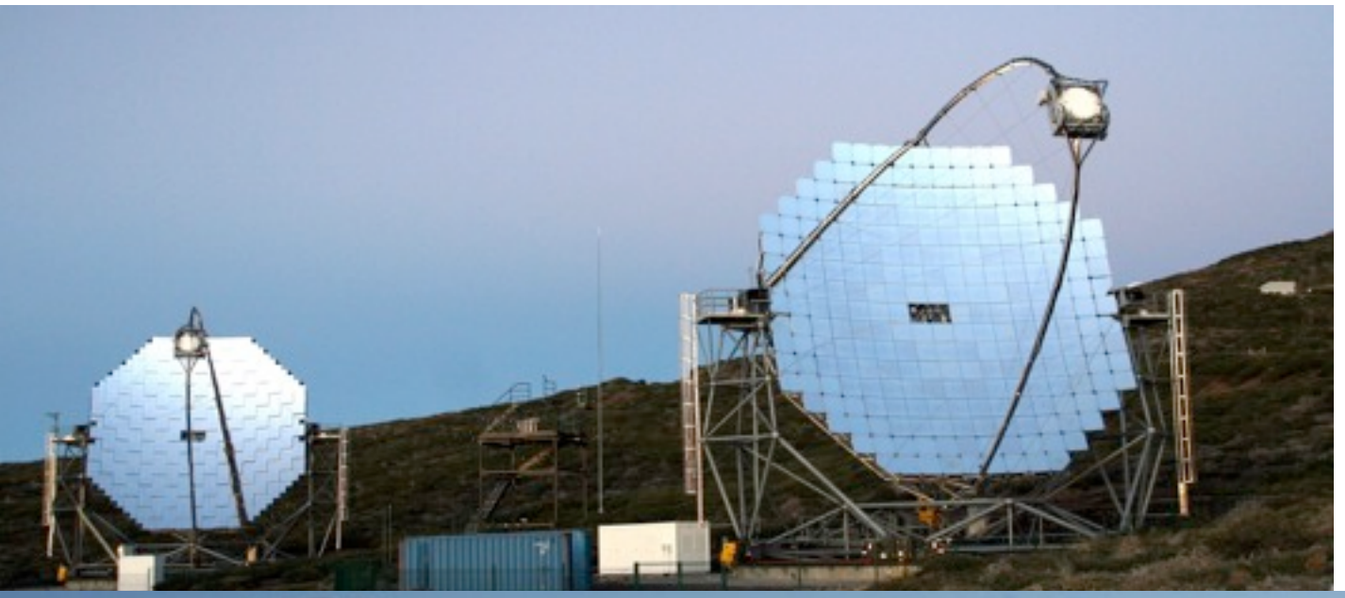
image the air shower
with multiple telescopes
to determine the direction
and energy of the ϒ-ray

ground-based detection

- energy range ~30 GeV - 100 TeV
- large effective area of ~10^5 m^2



Currently Operating VHE ϒ-ray Instruments

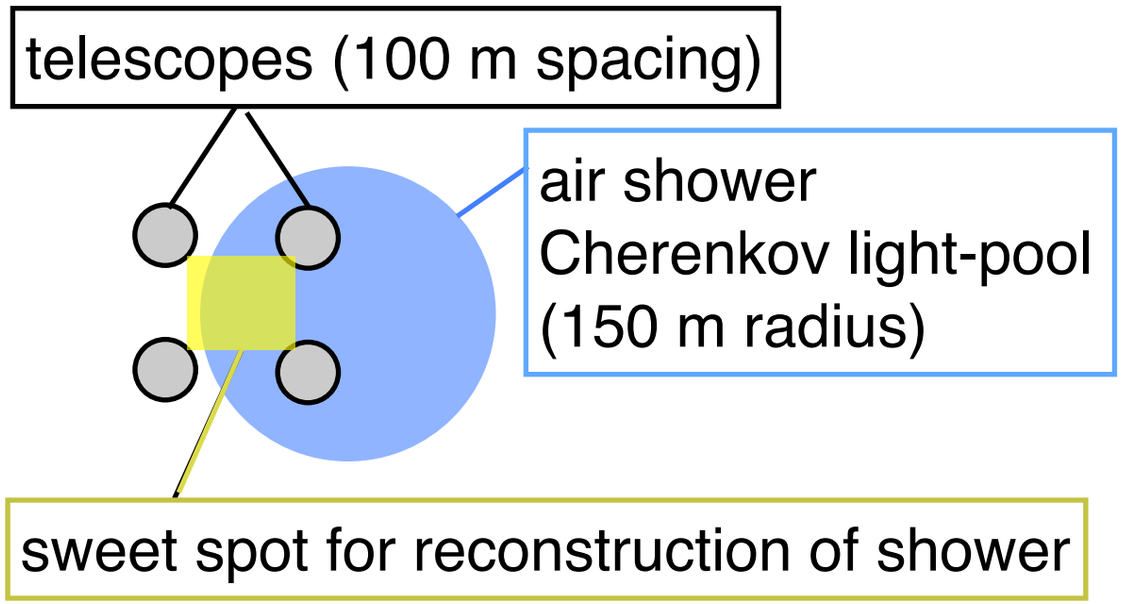


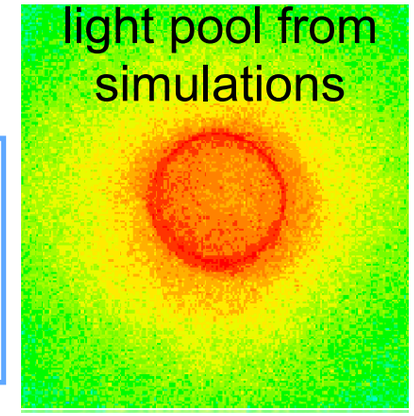
MAGIC: located in La Palma, Spain
since 2004: single 17m telescope
since 2009: system of two 17m telescopes

VERITAS: located in Mt Hopkins, Arizona
since 2007: four 12m telescope
since 2012: upgraded PMTs in all telescopes

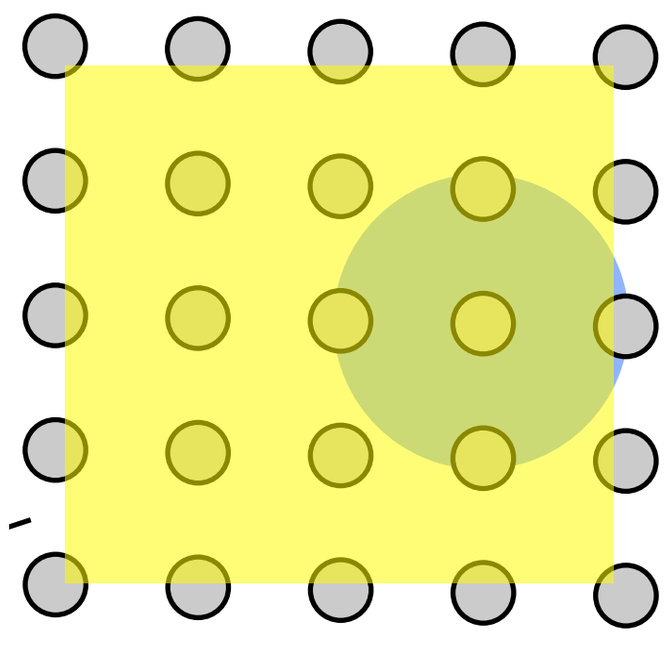
HESS: located in Khomas Highlands, Namibia
since 2002: four 12m telescopes
since 2012: added 32m by 24m telescope

Maximizing the Sensitivity, Resolution, and Energy Range



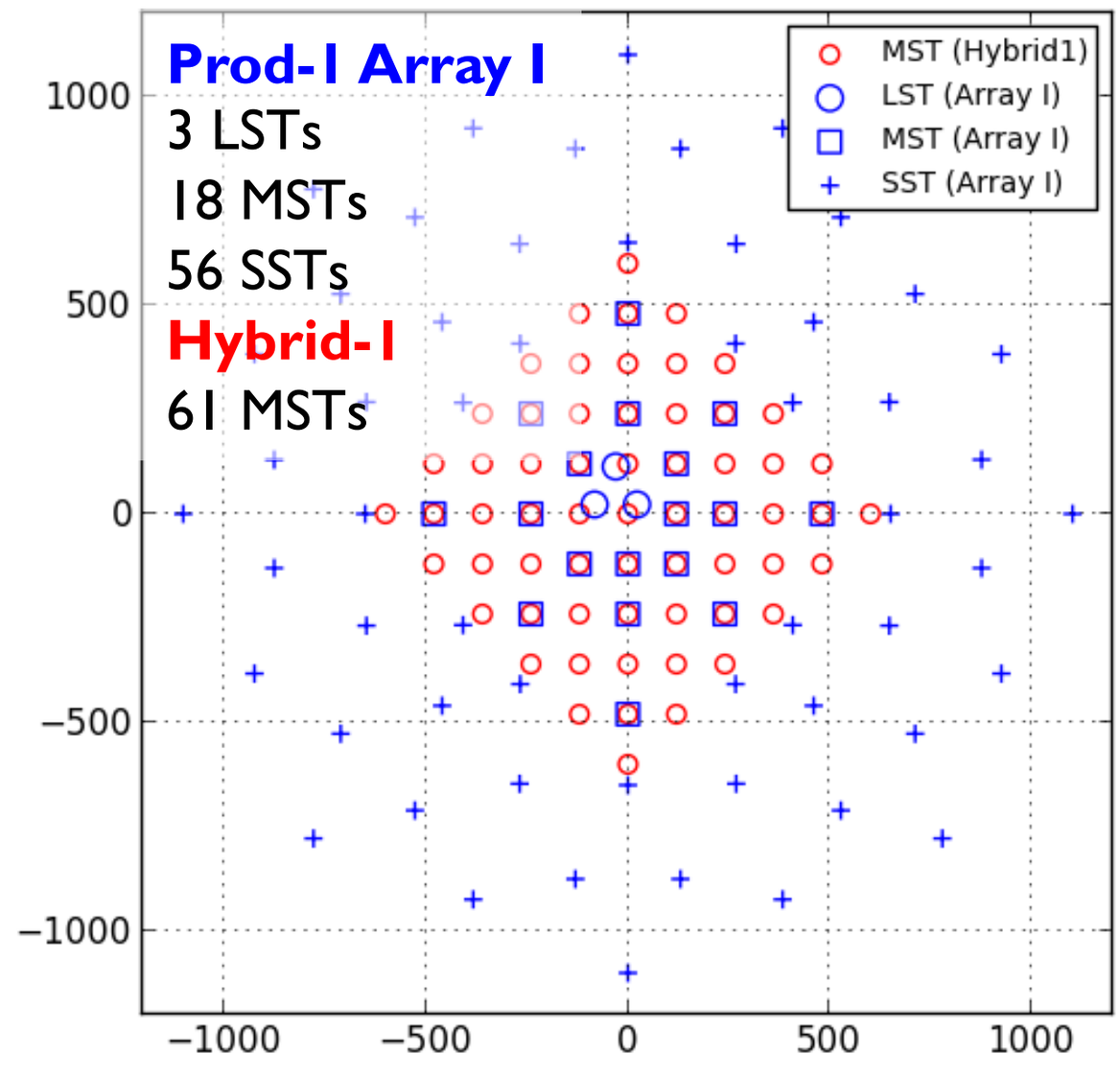


large array of telescopes:
more recorded images of air shower



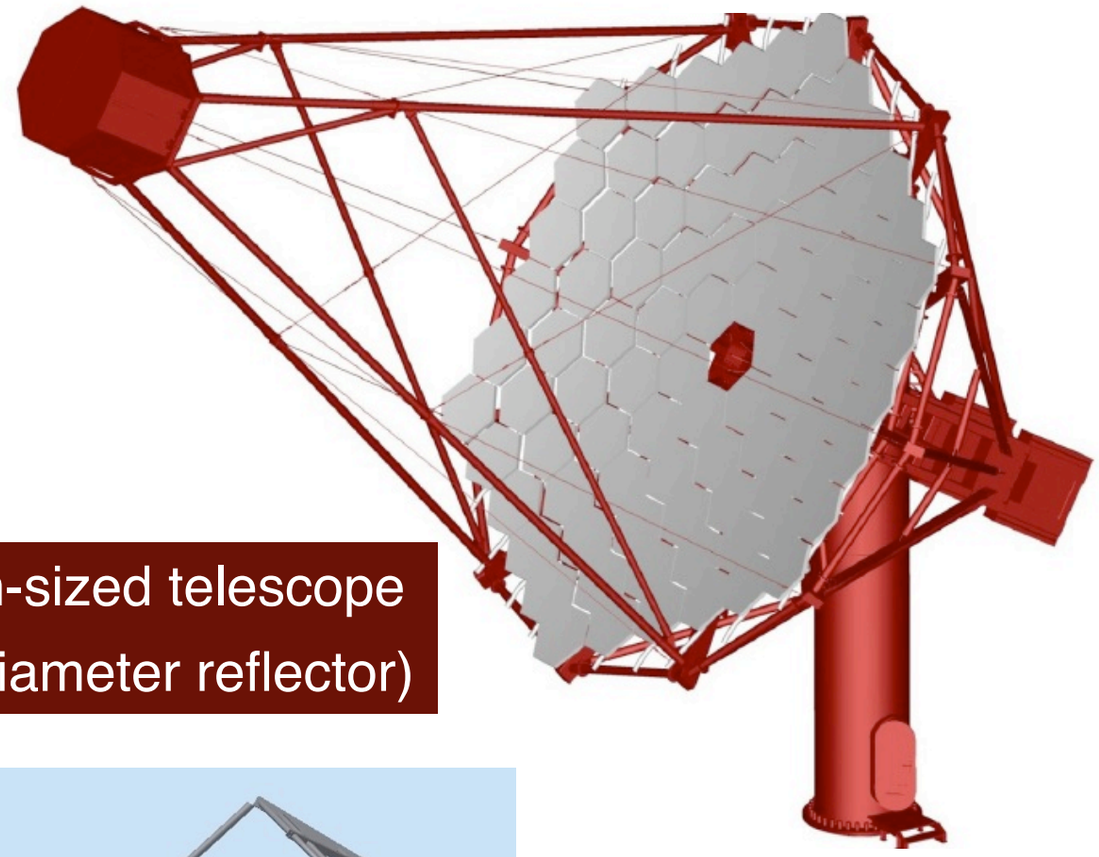
potential array configuration
(from simulation study)

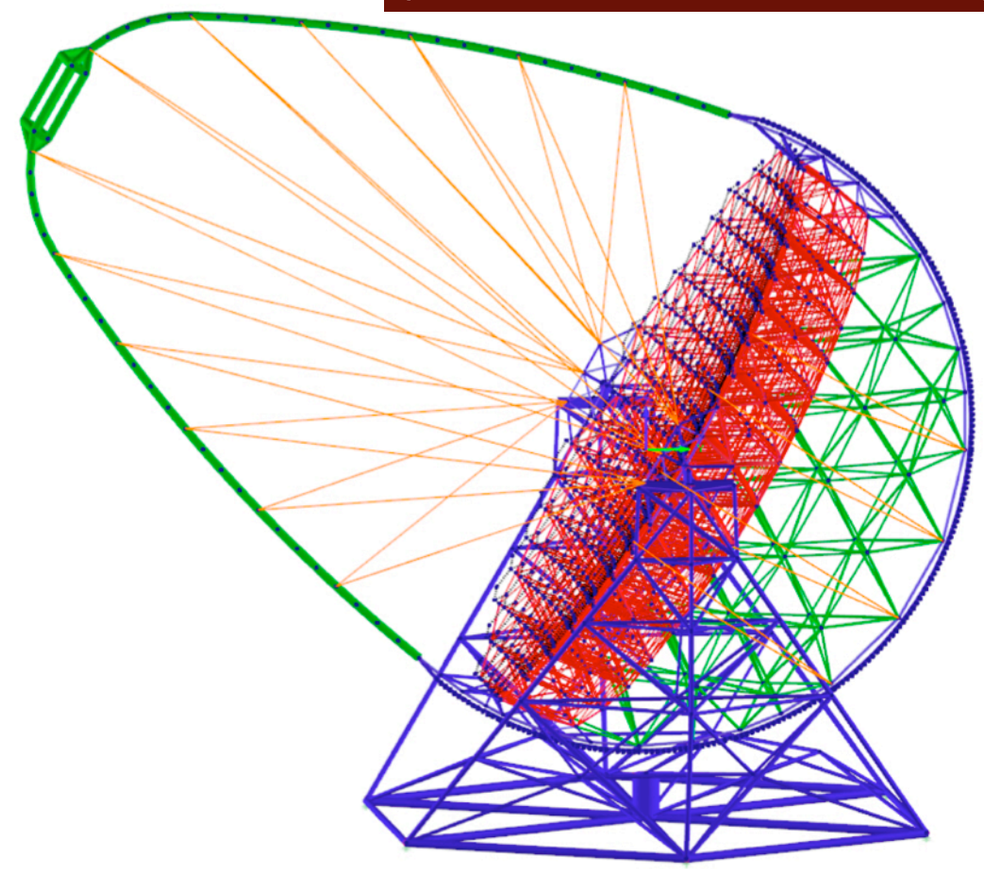
telescope size: large, medium, small



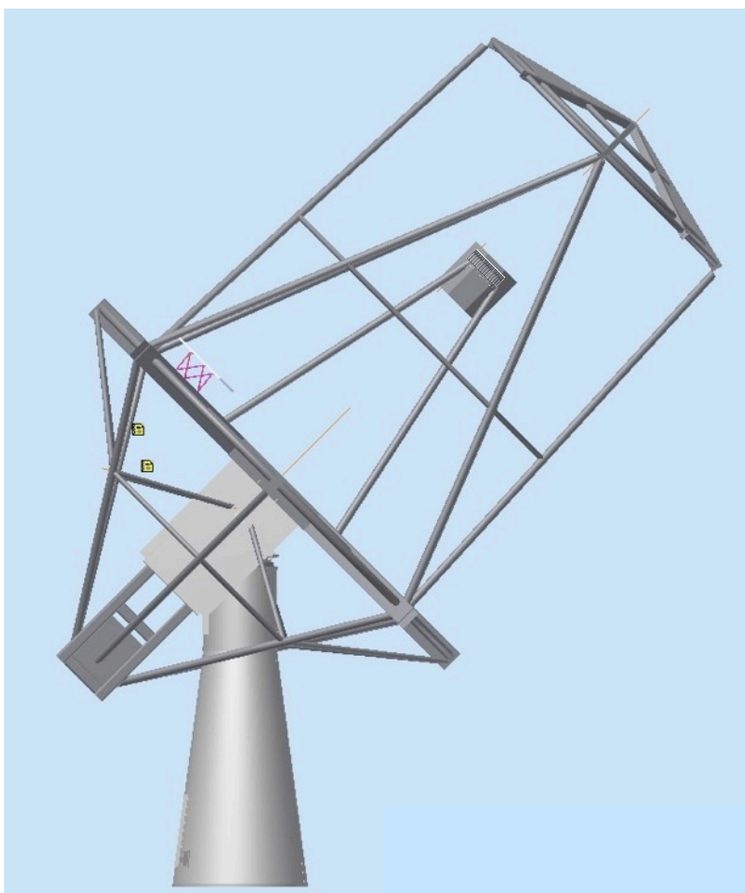
CTA Telescope Designs

large-sized telescope
(28 m diameter reflector)



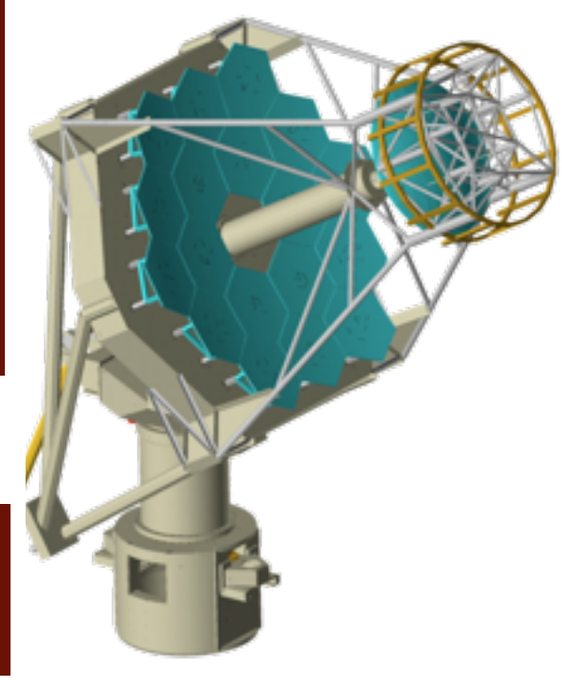


medium-sized telescope
(12 m diameter reflector)



medium-sized telescope (SC)
(10 m primary, 5 m secondary)

- new design led by US groups
- provides wide field of view
- MRI funded prototype

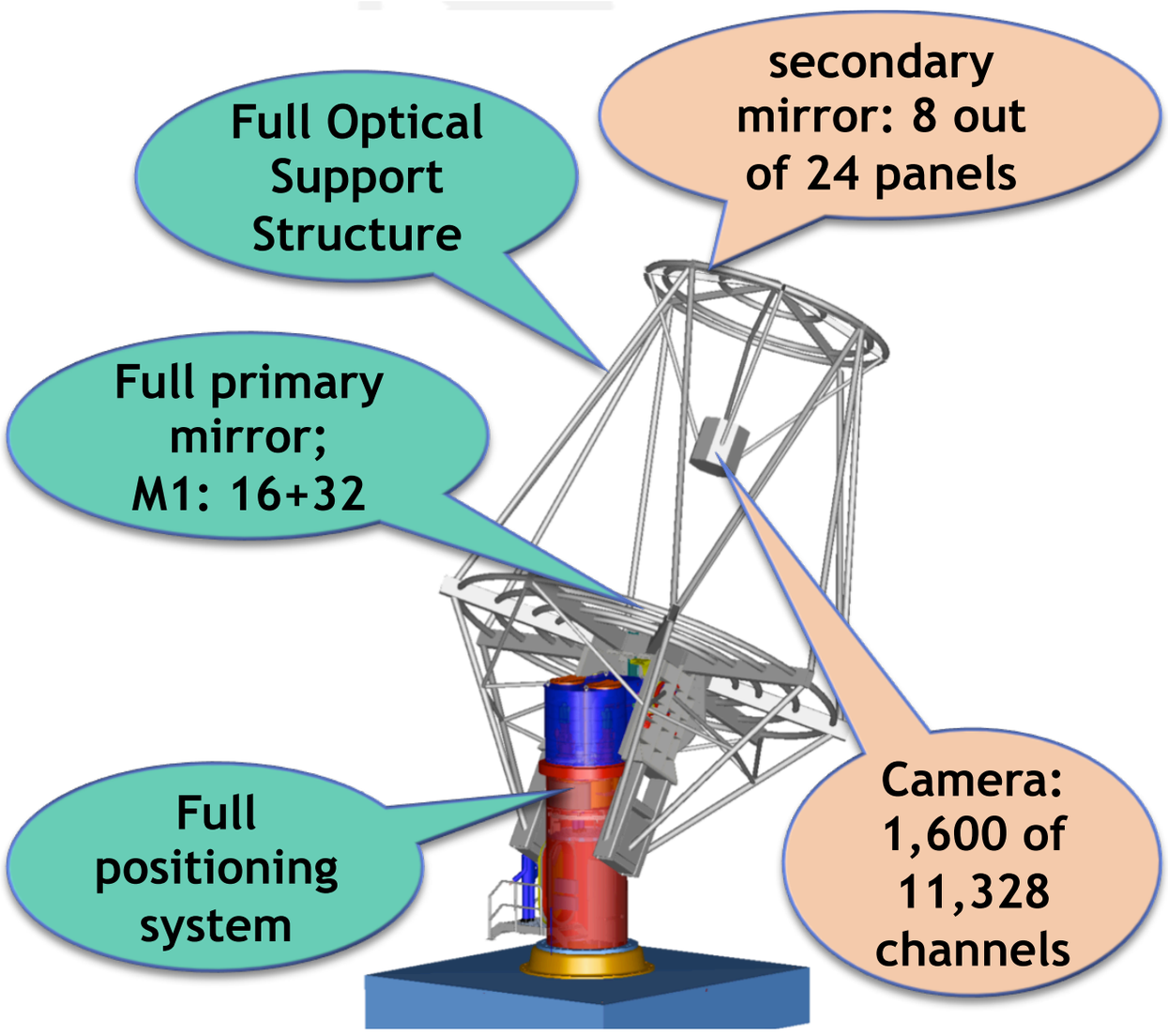


small-sized telescope
(4 m diameter primary)

Schwarzschild-Couder Telescopes

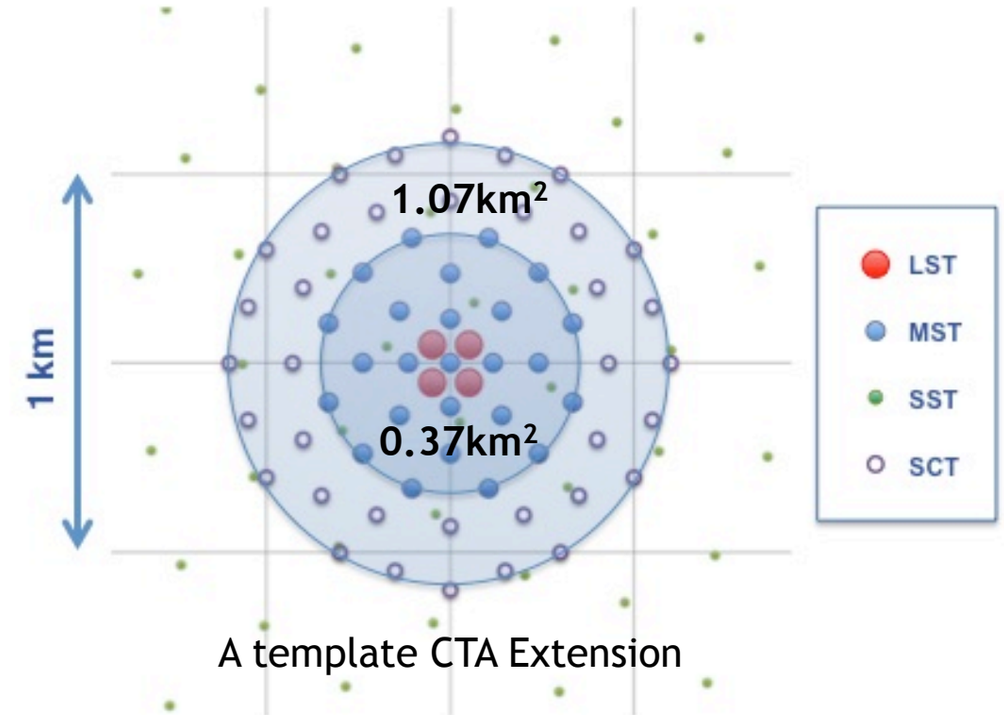
by design provides large field of view (8-9°)
and compact camera (SiPM detectors)
>11,000 pixels (0.07°) and good QE

primary mirror: 9.7 m diameter
secondary mirror: 5.4 m diameter



SC prototype with reduced secondary mirror and camera -> begin construction in 2014

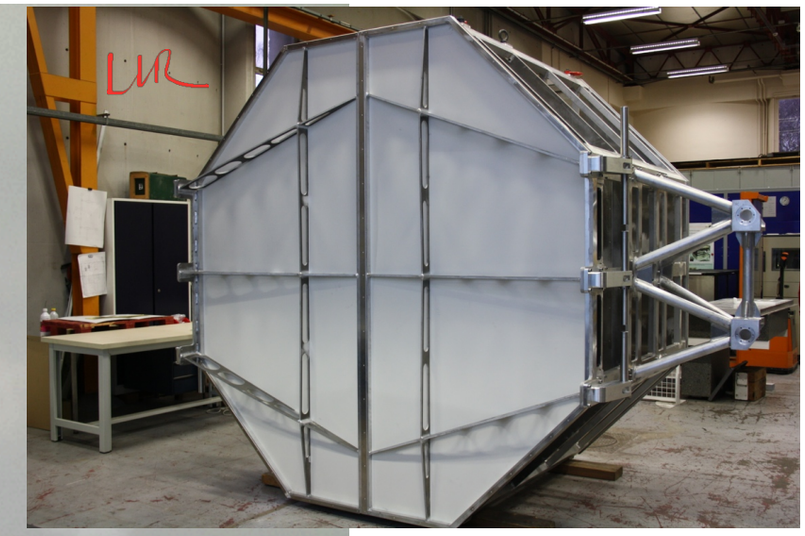
propose: 36 SC telescopes at Southern CTA site



A template CTA Extension

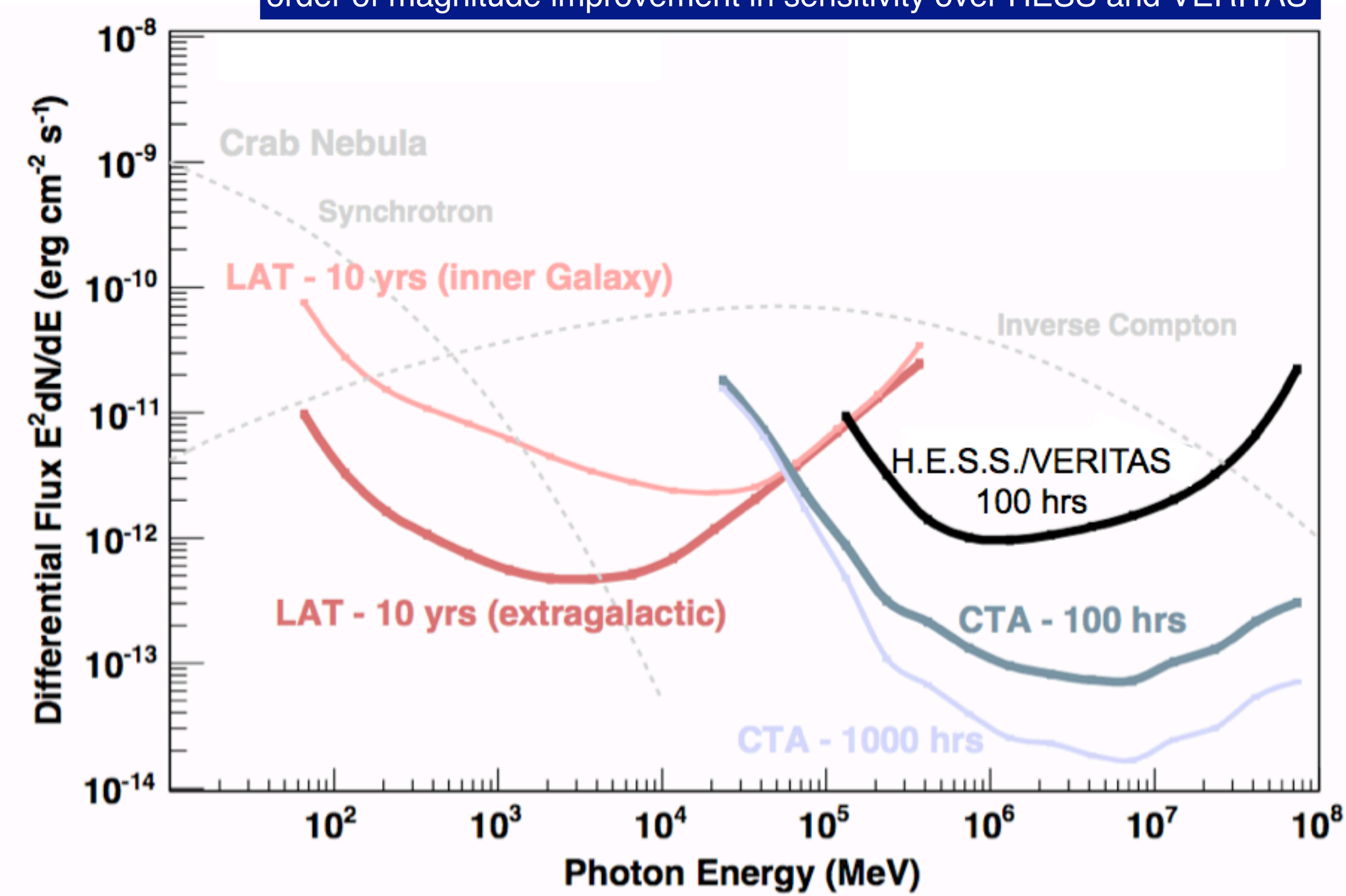
location of prototype SC telescope:
VERITAS site at Mt Hopkins, AZ

Medium-Size Telescope (MST-DC) Prototype near Berlin



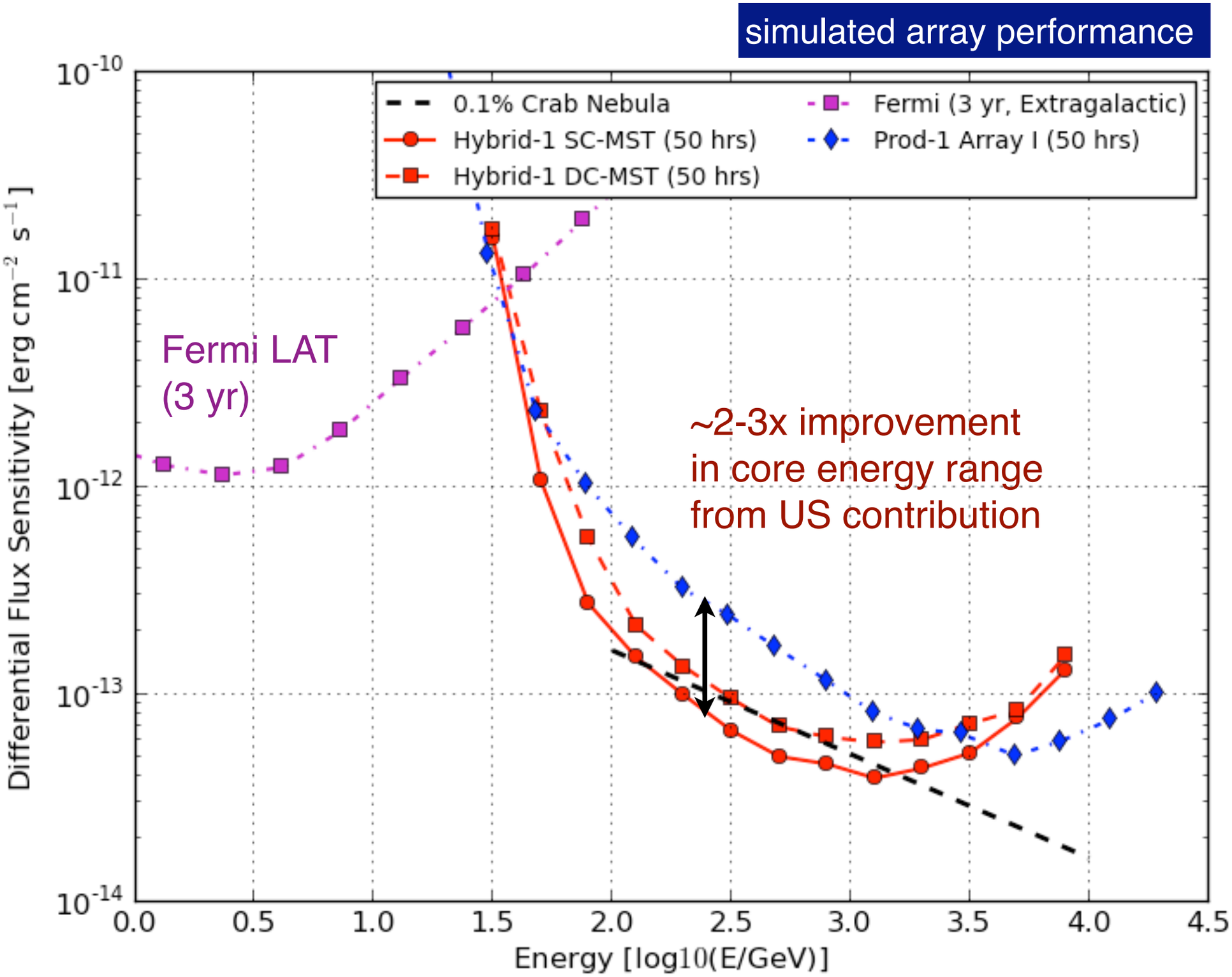
Sensitivity of CTA

order of magnitude improvement in sensitivity over HESS and VERITAS



S. Funk et al. 2013, APh, 43, 348

Sensitivity of CTA

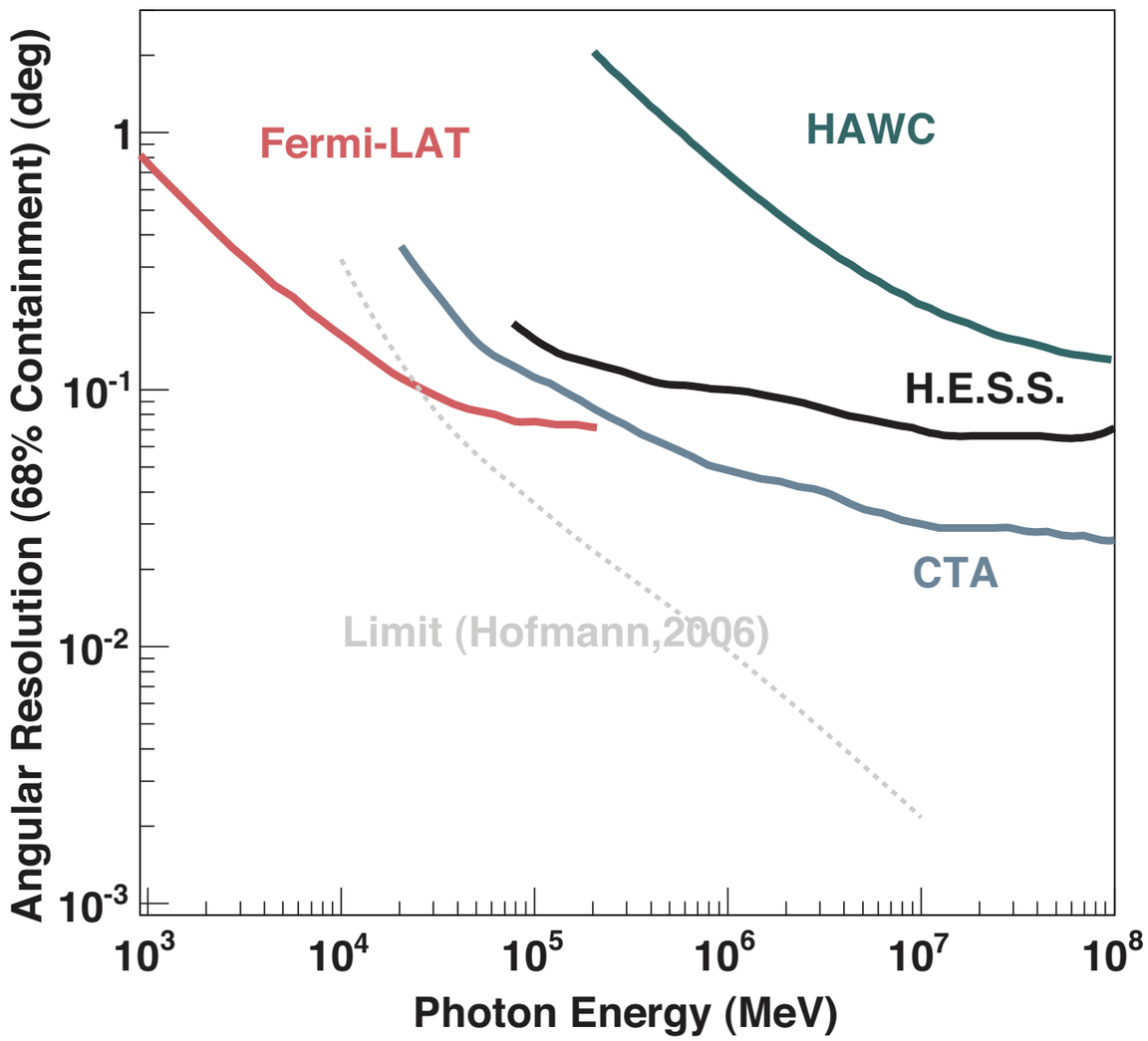


T. Jogler et al. 2012, proceedings of Gamma2012, Heidelberg (arXiv: 1211.3181)

Angular and Energy Resolution of CTA

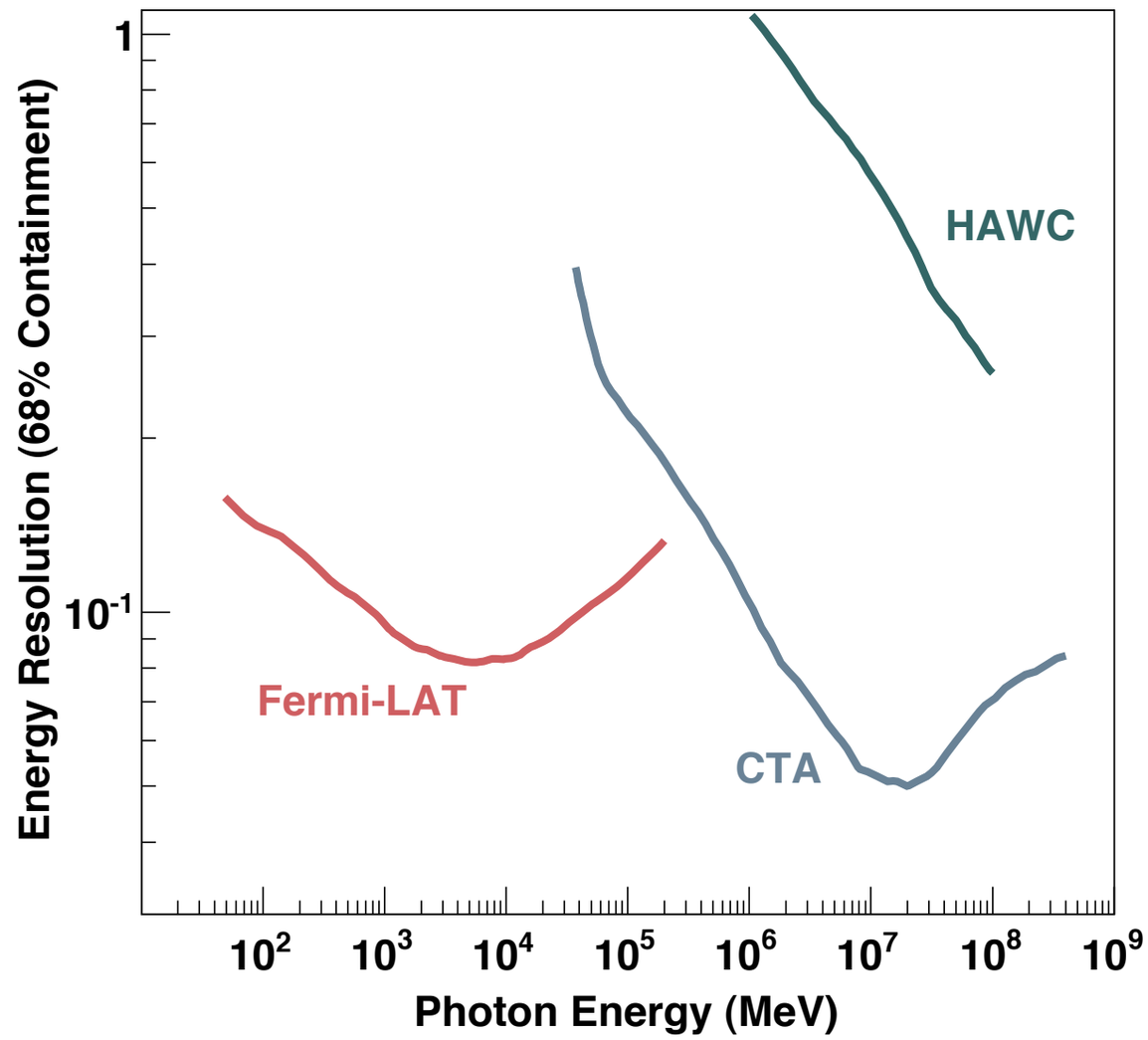
angular resolution: 1-2 arcmin

localization of point-sources: < 5 arcsec



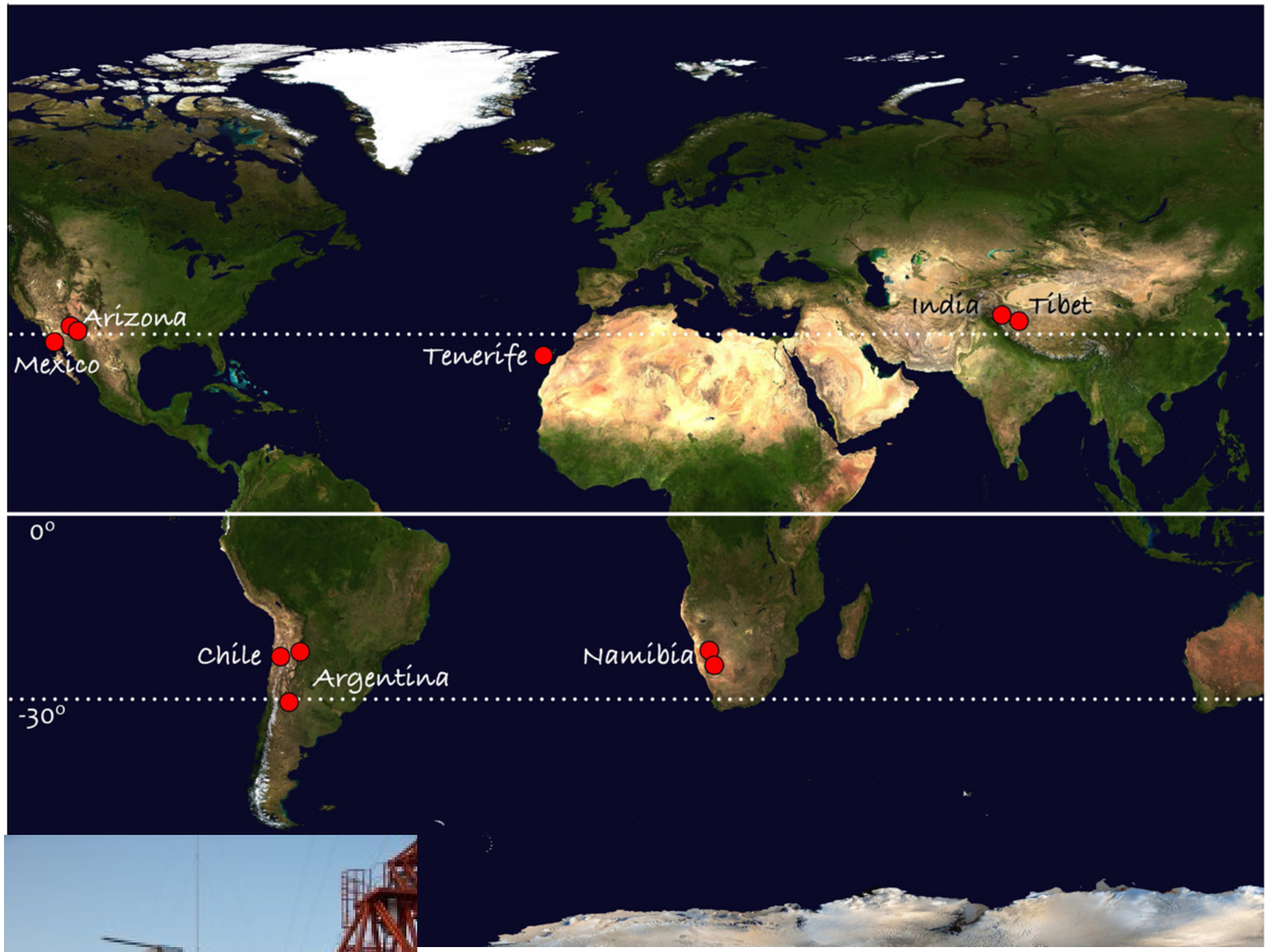
energy resolution:

systematic uncertainty < 10-15%



S. Funk et al. 2013, APh, 43, 348

CTA Site Selection



Northern sites under investigation:

- Meteor Crater, Arizona, USA
- San Pedro Martir, Mexico
- Tenerife, Spain

Souther sites under investigation:

- Aar, Namibia
- San Antonio, Argentina
- near Paranal, Chile

site evaluation (scientific)

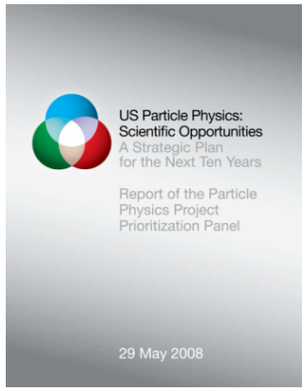
- annual observing time (clear skies)
- best instrument sensitivity (dark, steady, high-transmission skies)
  - atmoscopes for weather monitoring
  - remote (satellite) data comparisons

site evaluation (costs and risks)

- construction costs
- operations costs
- facility / personal risks

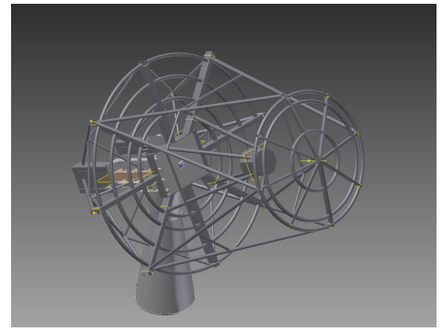
Site decision by early 2014

CTA Projected Timeline

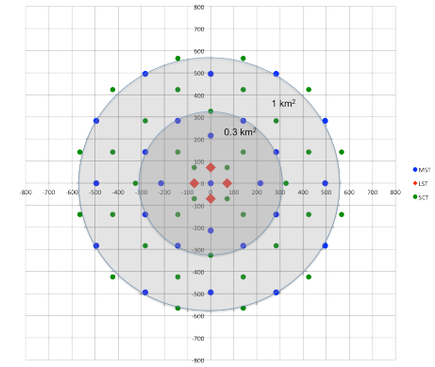


P5 Report
"The Cosmic Frontier"
2008

HEPAP
PA SAG Report
2009



First projected opportunity for initial CTA Extension construction funds in the US (NSF/DOE)



Hybrid MST-SCT installation

SCT roadmap

pSCT design Completed

pSCT Verified and Commissioned

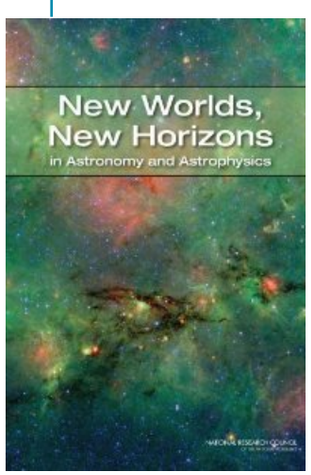
2005 …. 2012 2013 2014 2015 2016 2017 2018

Ideas of large IACT arrays originated

SCT and AGIS ideas formulated

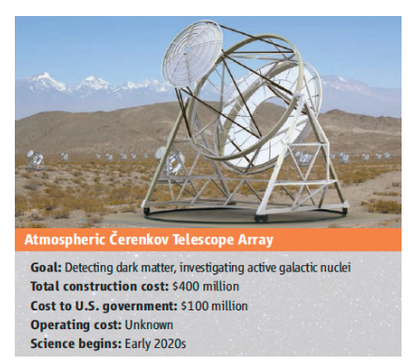
SCT MRI funded

National Science Foundation
WHERE DISCOVERIES BEGIN



AADS 2010 Report
"New Worlds, New Horizons in Astronomy and Astrophysics "
2010

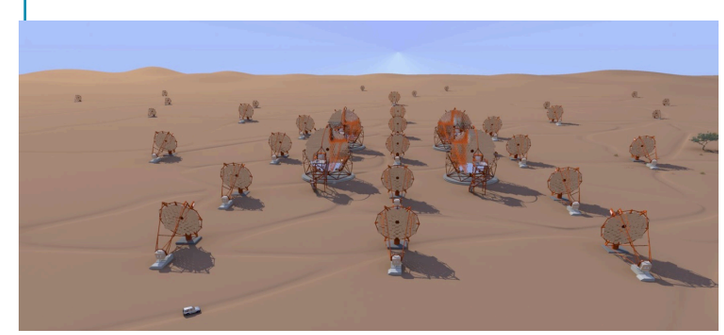
pSCT constructed



Science, August 2010

US CTA construction proposal to be submitted

Projected CTA construction



CTA Science Goals

1. produce the deepest surveys of the sky at ϒ-ray energies with unprecedented angular and energy resolution
2. test SNR-origin of comic-rays; lepto-hadronic production & propagation
3. assess cosmic-ray population in galaxies/starbursts and clusters

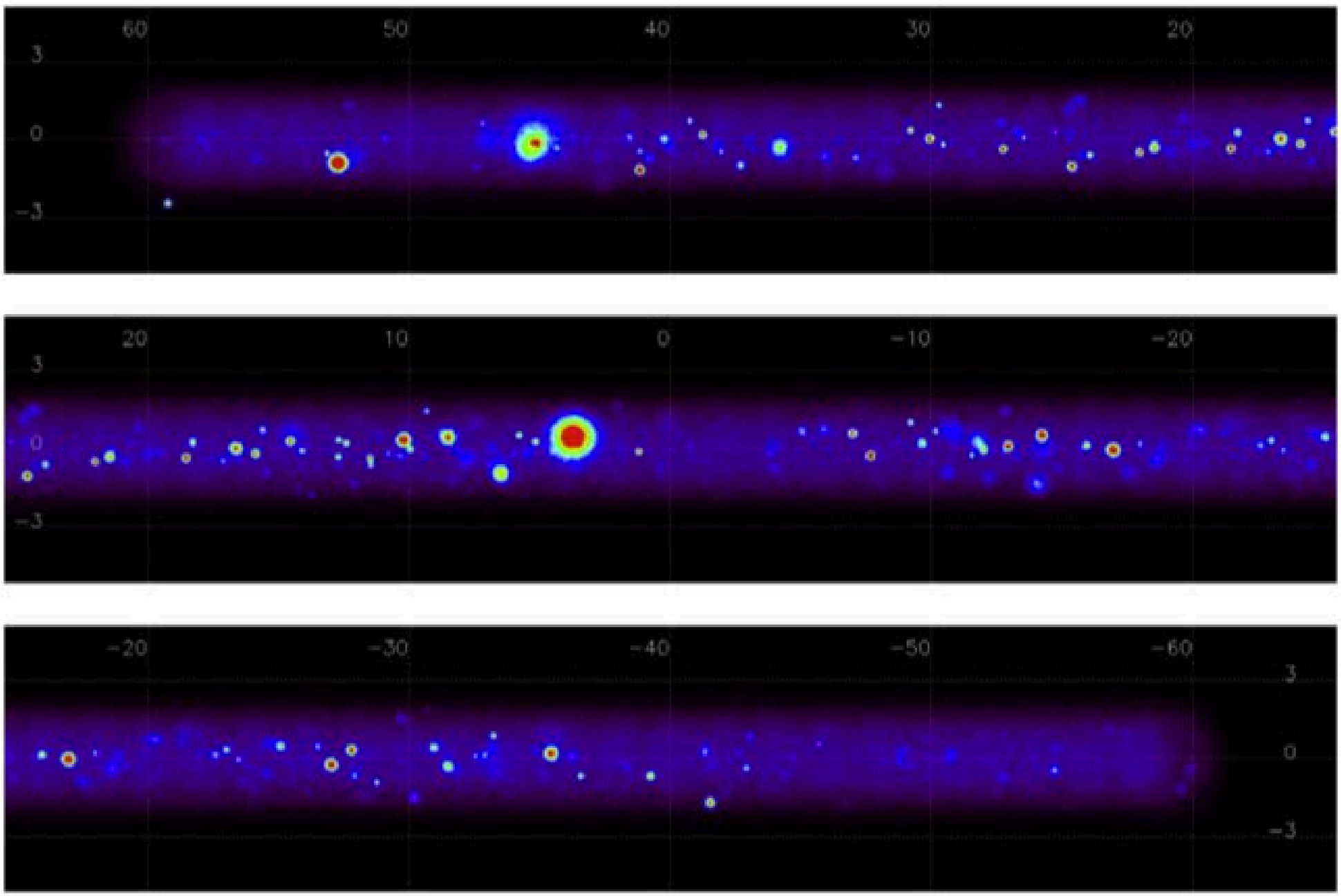
4. perform the most sensitive ϒ-ray observations on short timescales
5. expand the population of ϒ-ray emitting AGN (in flaring and steady-states) to study unification schemes, evolution, and gamma-ray origin
6. strong constraints on the EBL and IGMF

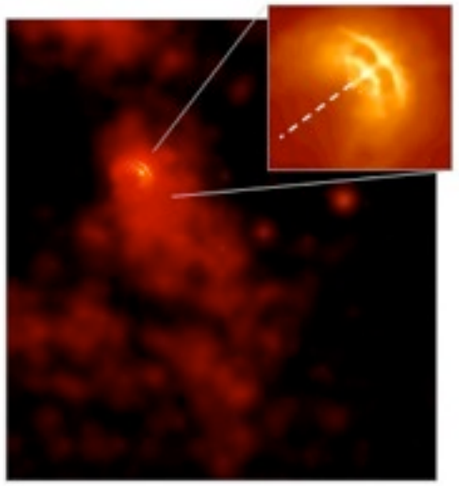
7. sensitivity to probe canonical WIMP DM models
8. precision tests of Lorenz Invariance Violation

CTA Science: (1) Surveys

- highly sensitive surveys provides strong discovery potential
- aim for uniform sensitivity of ~3 mCrab along Galactic Plane
- complementary extragalactic coverage to HAWC

simulation of 500 Pulsar Wind Nebula in the CTA Galactic Survey

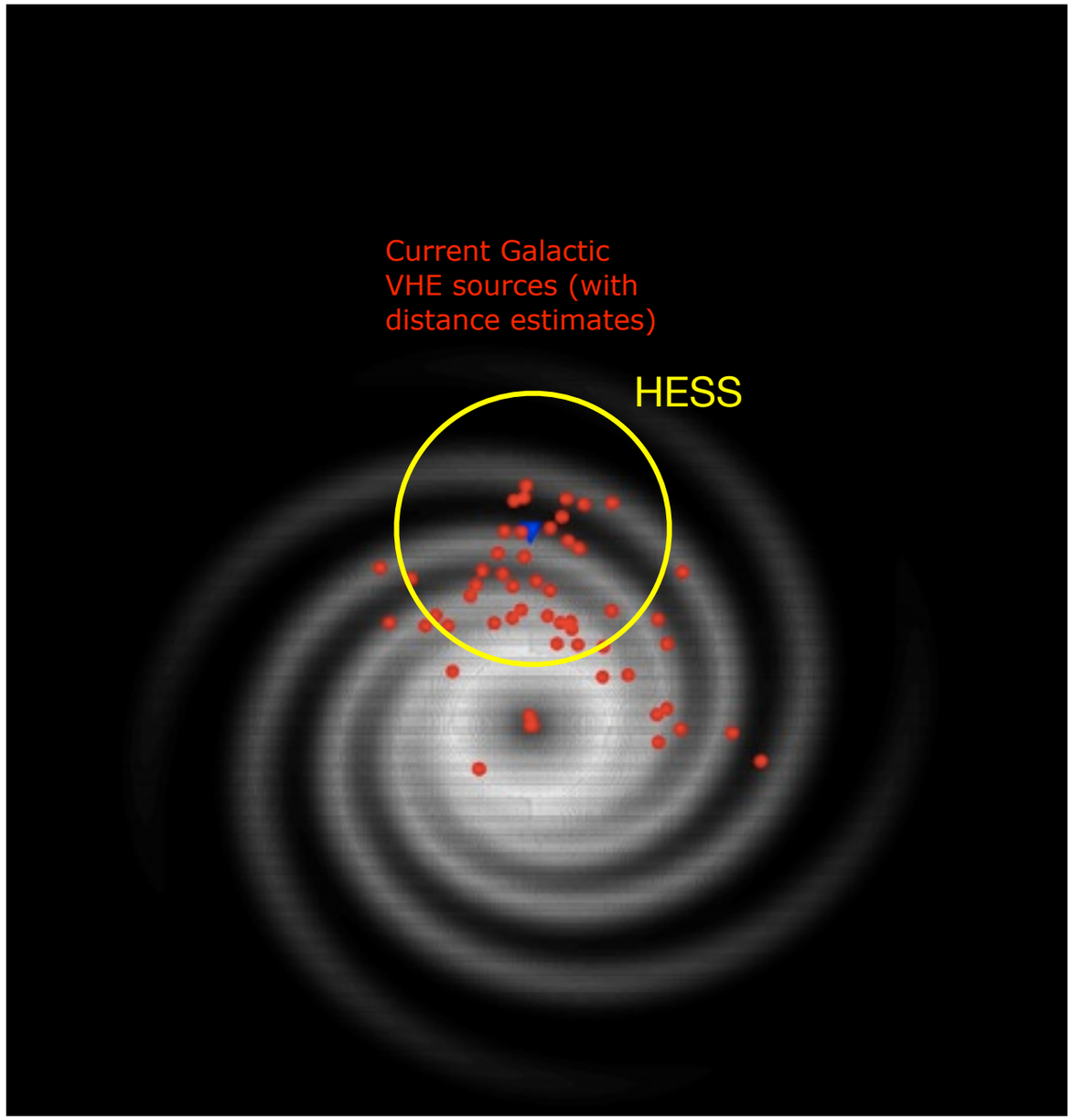


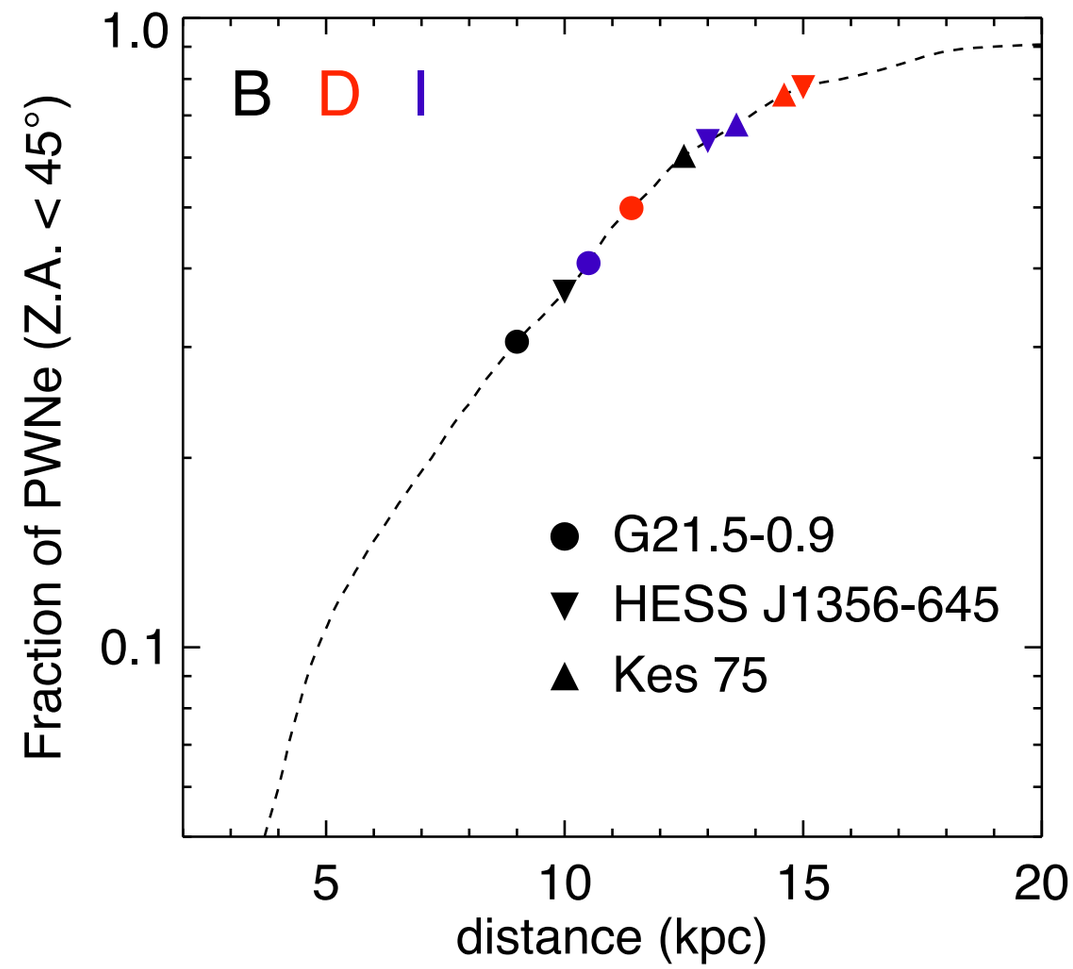


Dubus et al. 2013, APh, 43, 317

CTA Science: (1) Surveys

Horizons of detectability:
CTA sensitivity will greatly expand distances
at which VHE sources are detected in the Galaxy





estimated fraction of PWN detected by CTA
as a function of distance from Earth
assuming 20 hr, faint sources (2% Crab flux)

- predict a total of 300 - 600 PWN in our Galaxy

E. de Ona-Wilhelmi et al. 2013, APh, 43, 287

CTA Science: (1) Surveys

Horizons of detectability:
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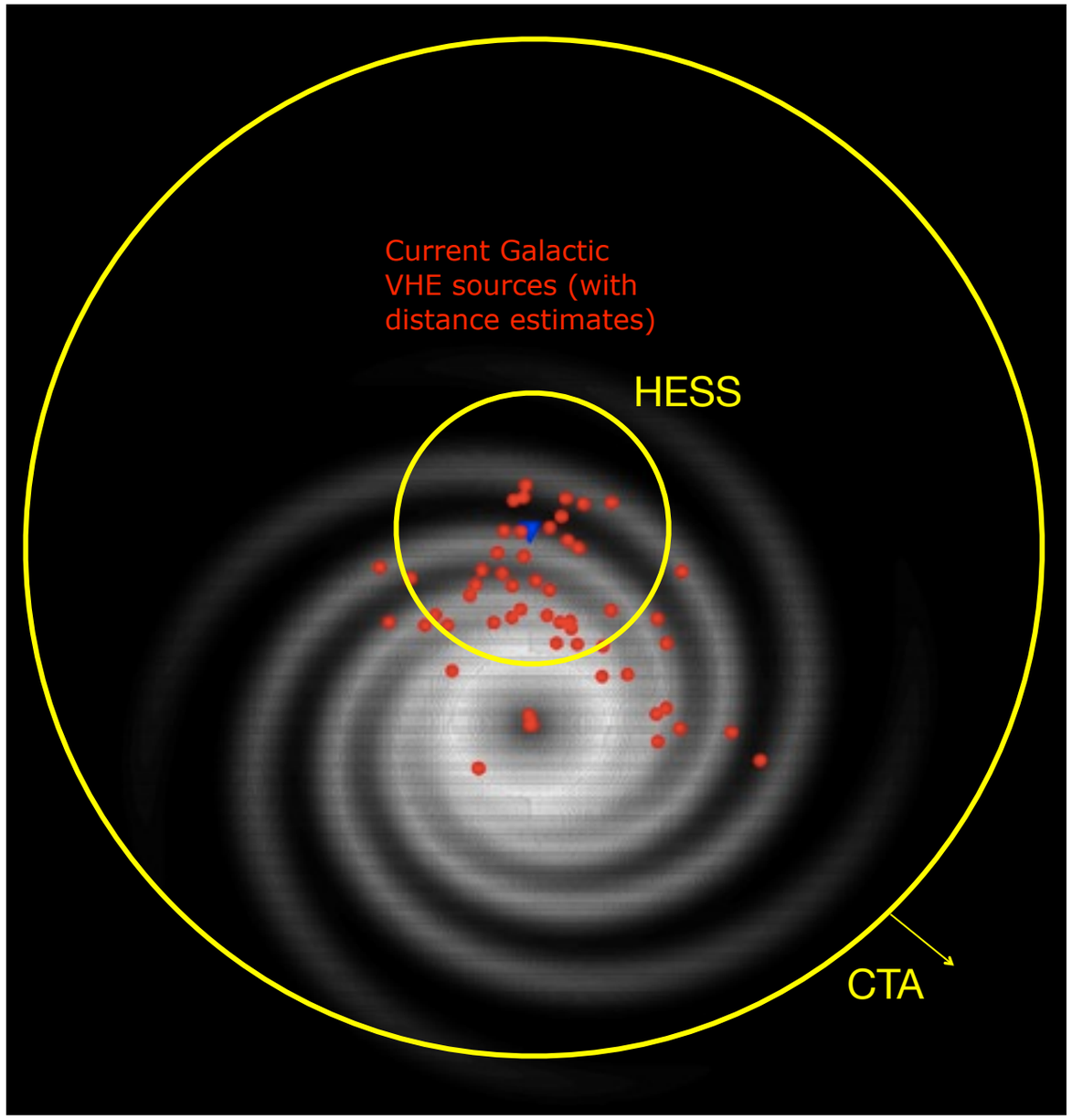

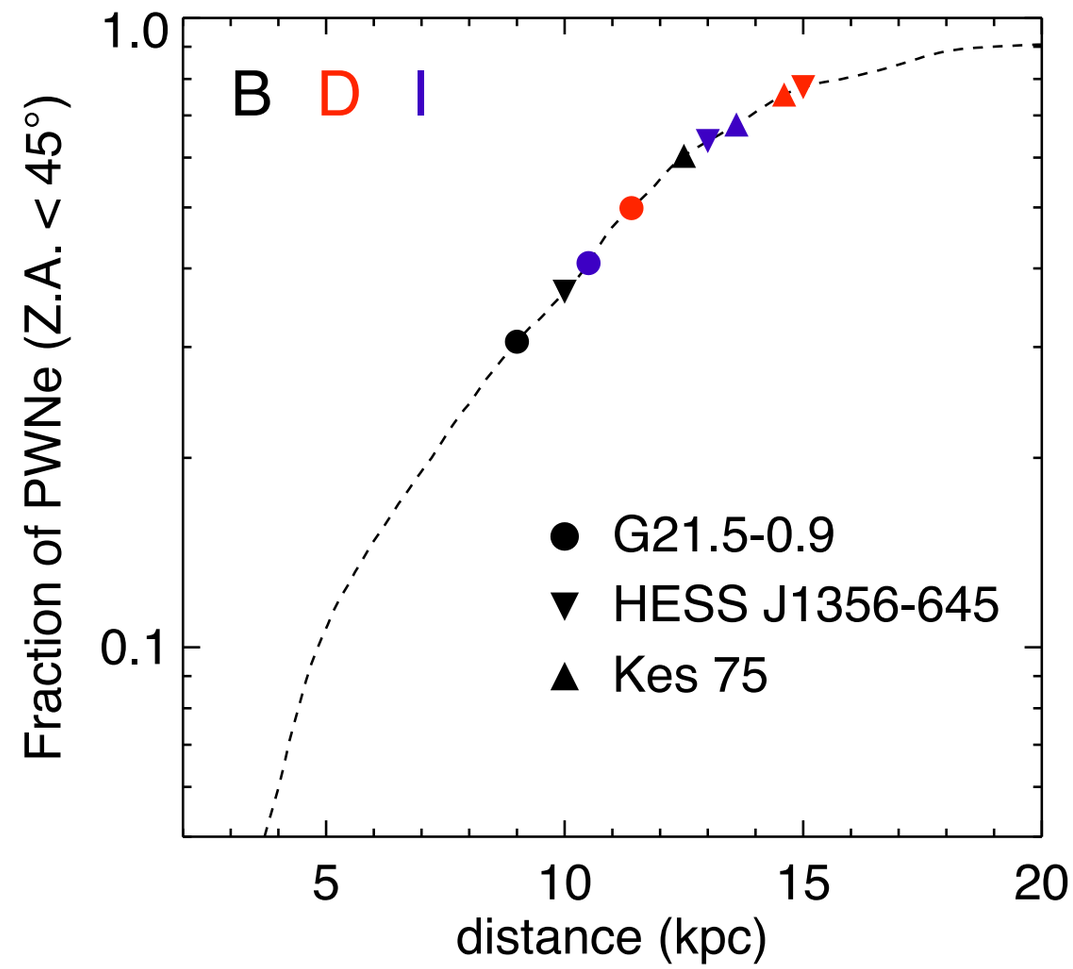

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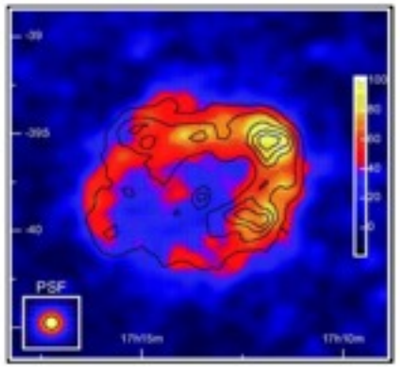
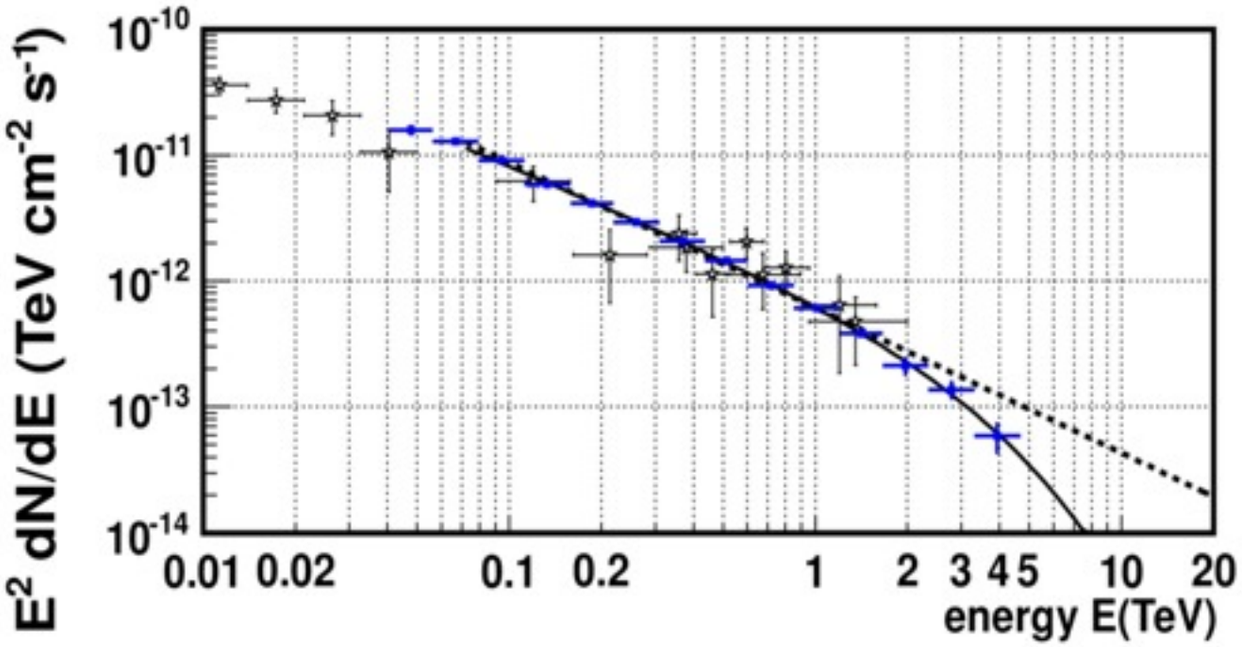
- predict a total of 300 - 600 PWN in our Galaxy

E. de Ona-Wilhelmi et al. 2013, APh, 43, 287

CTA Science: (2) SNR, PWN, Galactic Cosmic Rays



IC 443: CTA simulated spectra (blue points)



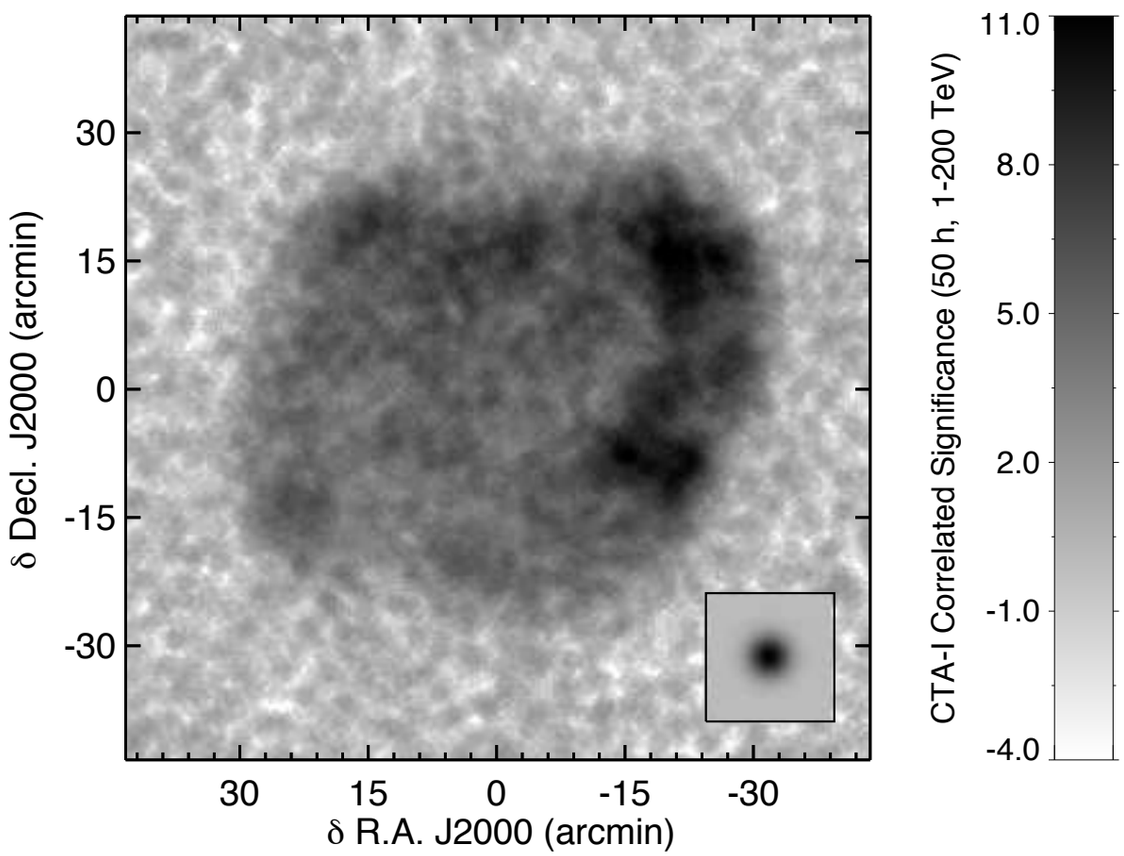
Morphology studies:

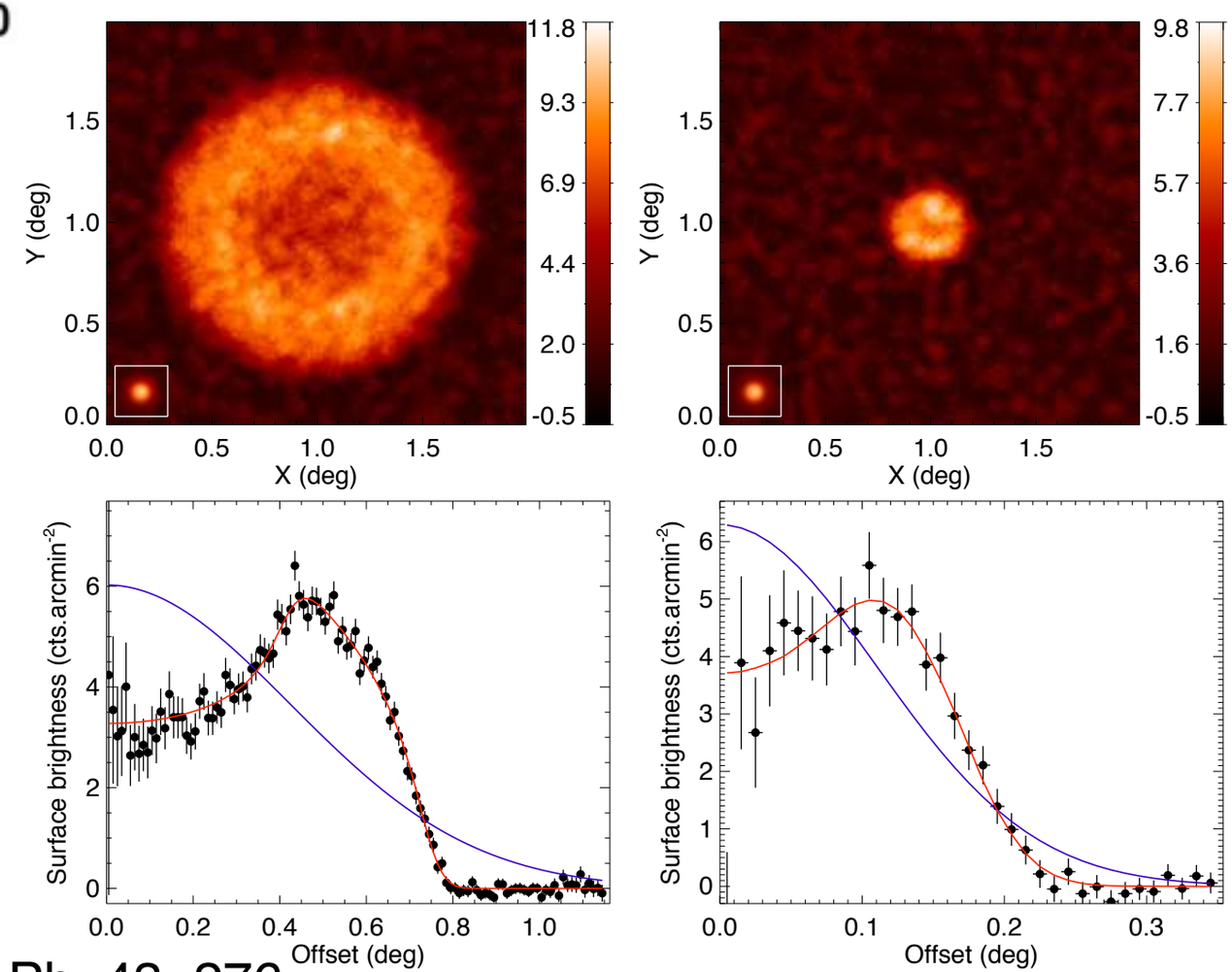
simulated CTA image of RX J1713.7-3946

from 50 hr data

(bottom left) RX J1713 actual distance (1 kpc)

(bottom left) RX J1713 at a distance of 4 kpc

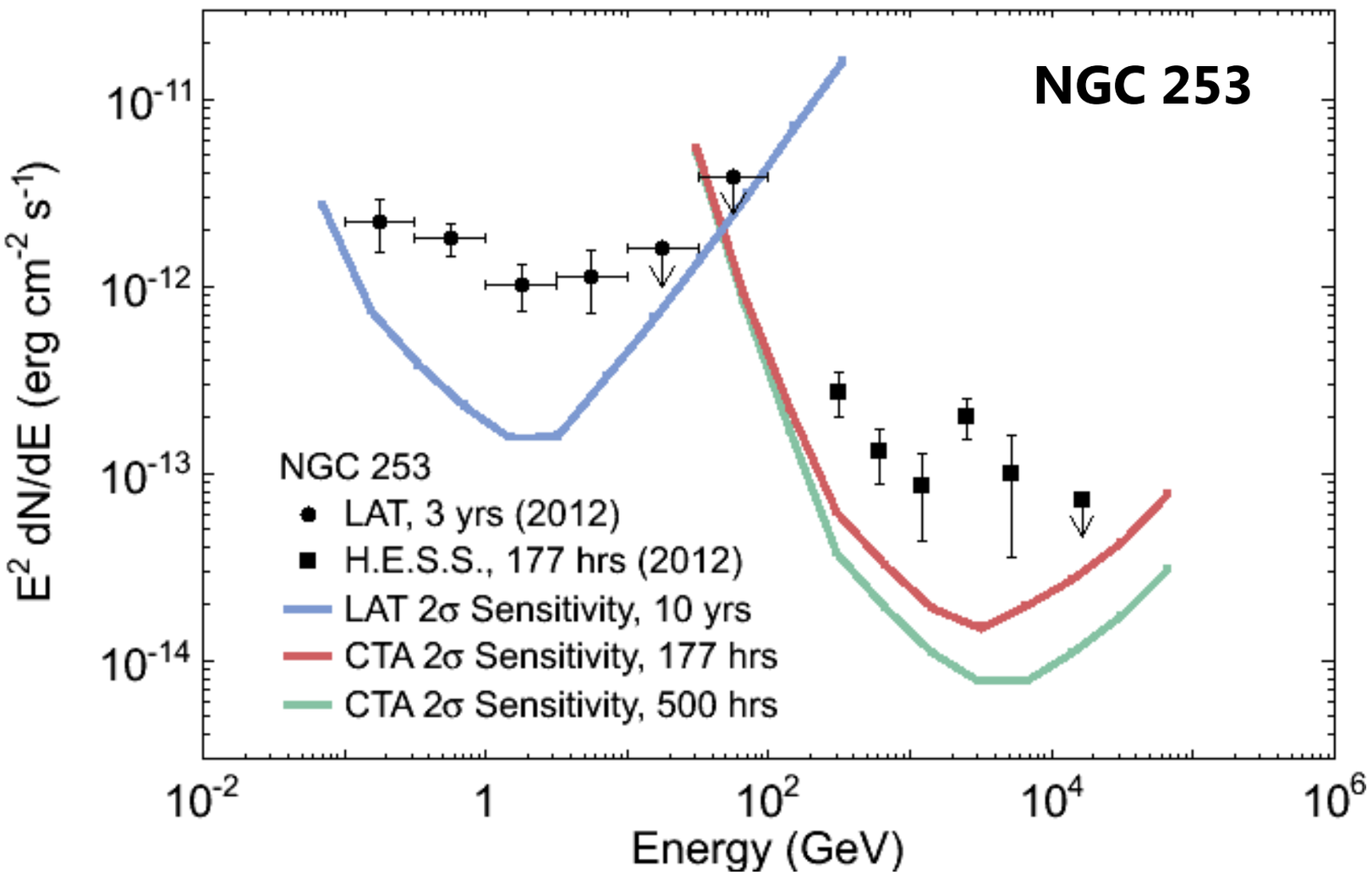


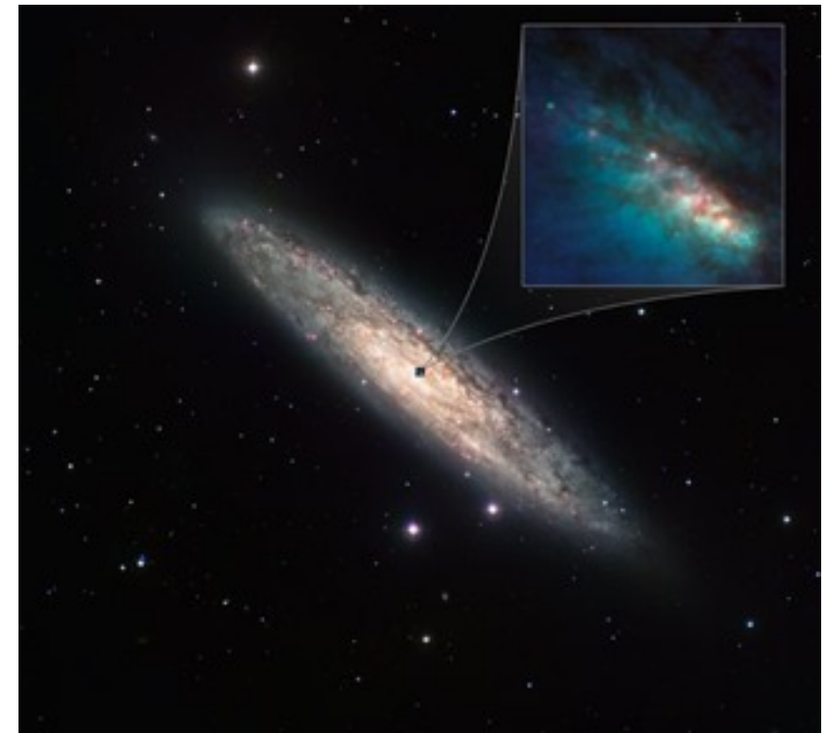


Acero et al. 2013, APh, 43, 276

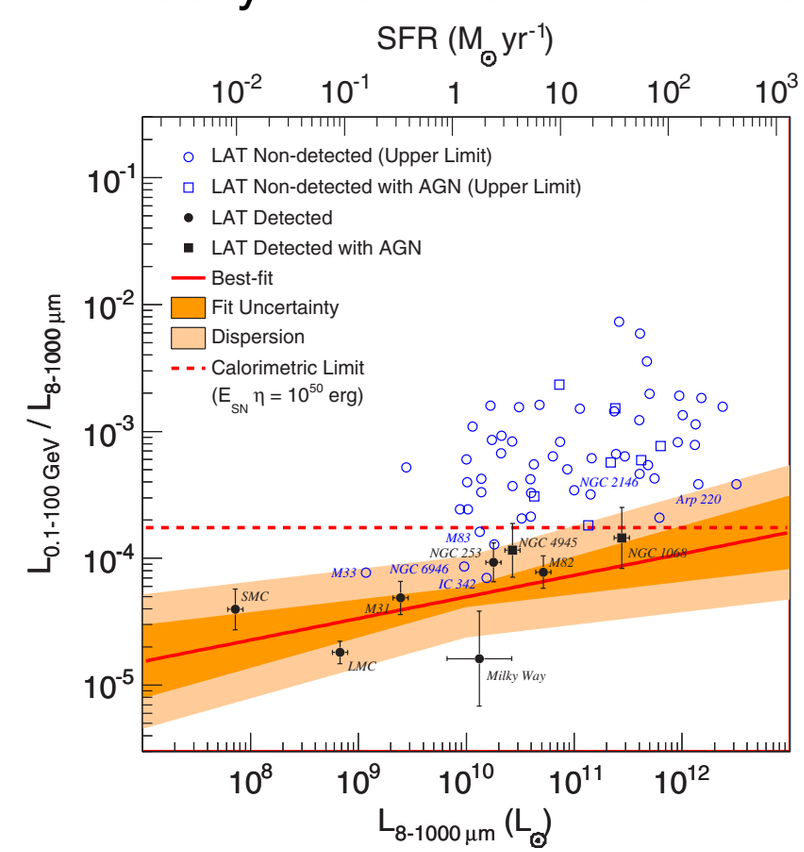
CTA Science: (3) Cosmic Rays in Star-forming Galaxies

- CTA sensitivity to star-forming galaxies provides insight to cosmic ray acceleration and interaction efficiencies
- test gamma-ray luminosity scaling with star formation rate



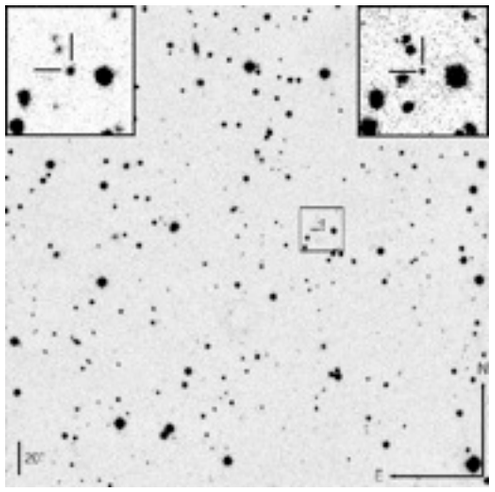


Fermi LAT luminosity / total IR luminosity vs star-formation rate



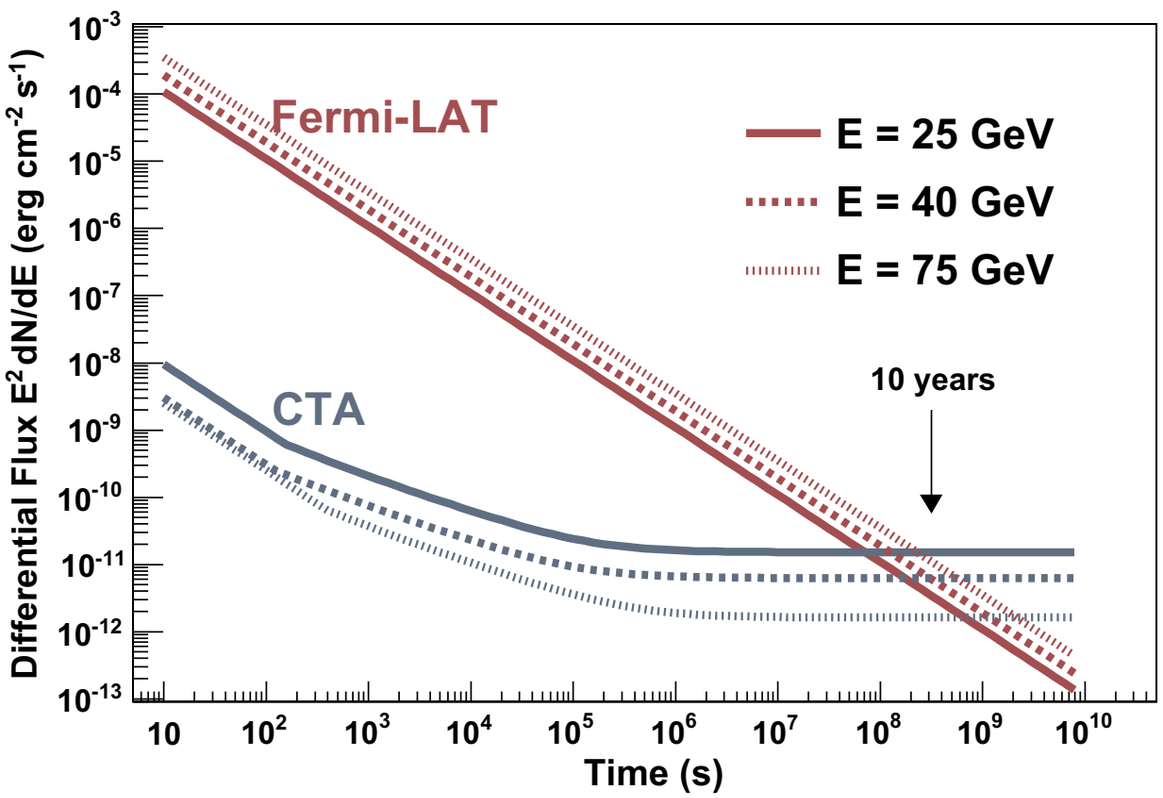
K. Bechtol et al. 2012, 4th Fermi Symposium

CTA Science: (4) Short timescales: GRBs, flares

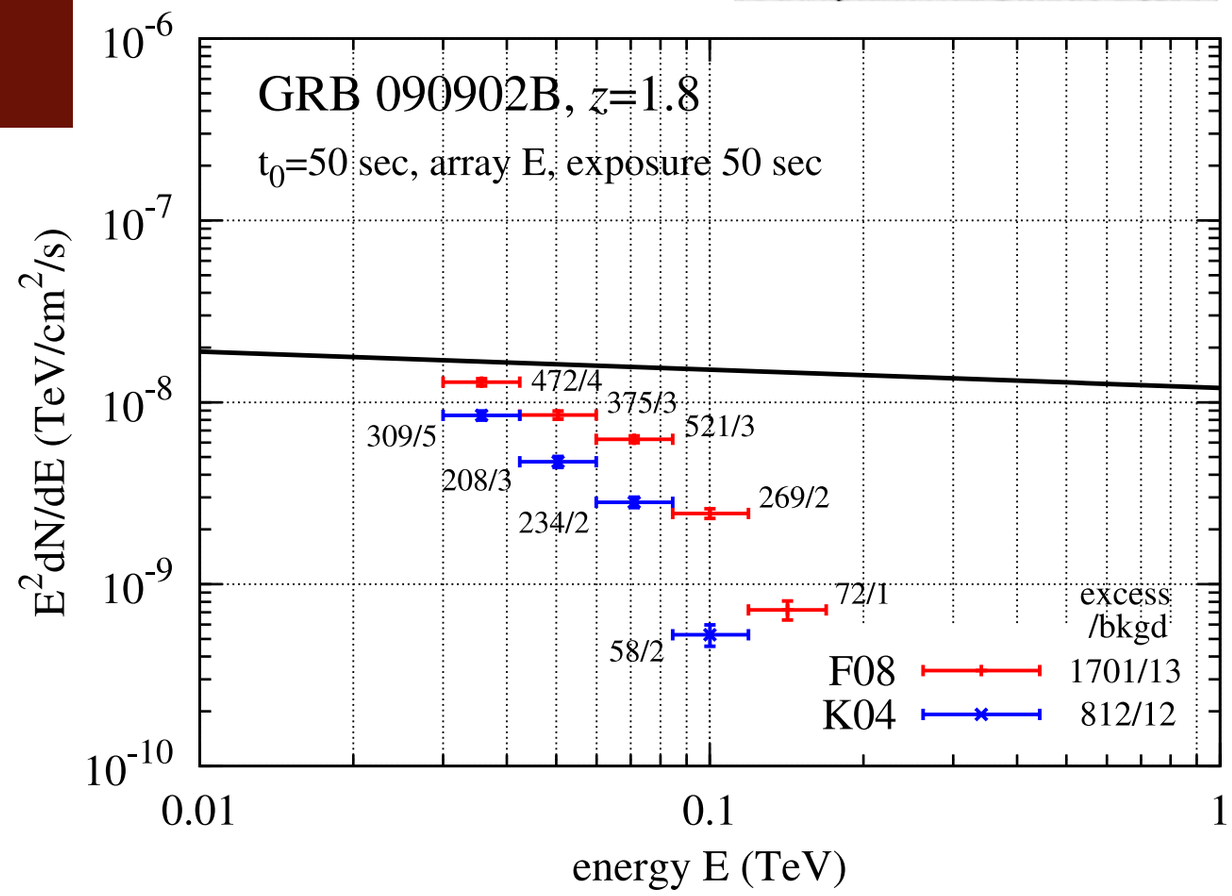


wide range of exciting science topics with ϒ-ray flares:

- CTA offers detailed VHE ϒ-ray study of GRBs
- constraints on black hole and jet physics in AGN
- formation of relativistic outflows in binaries
- precision tests of Lorentz Invariance from flares



sensitivity as a function of observation time

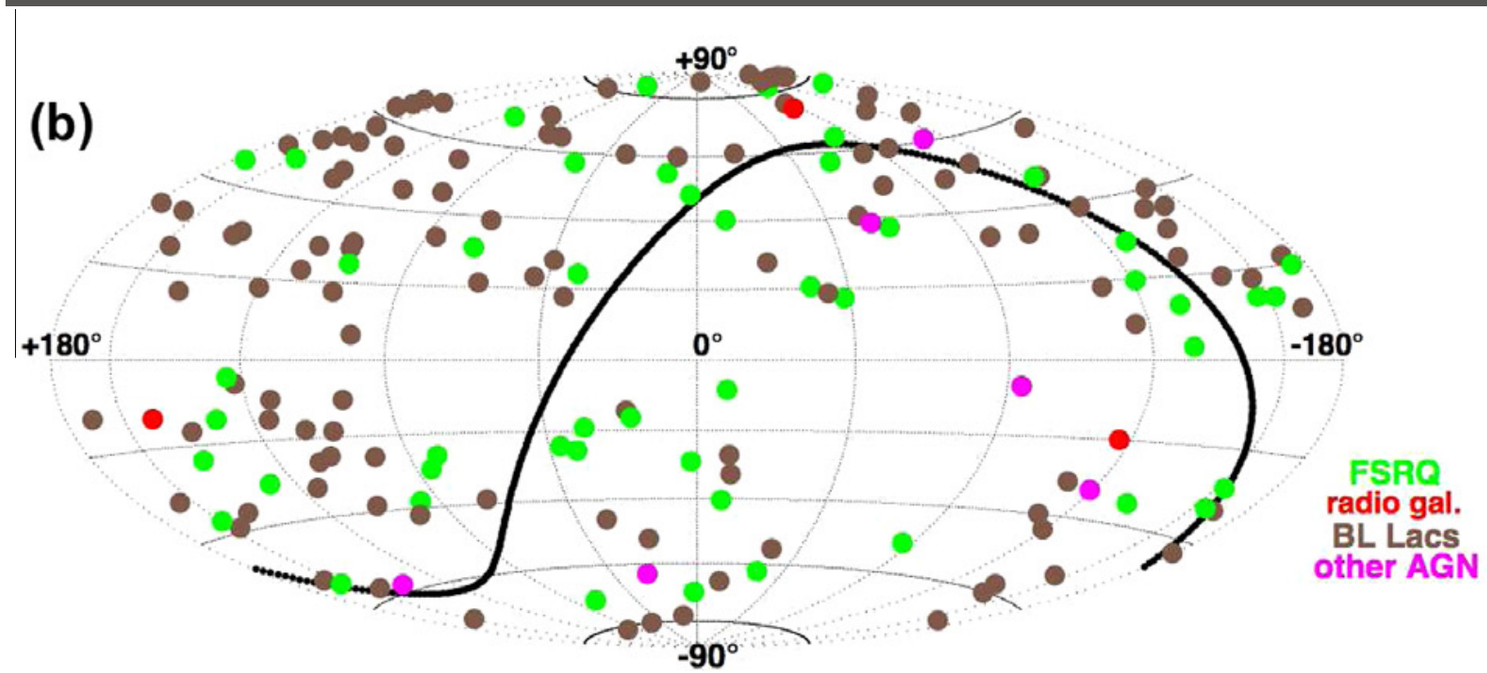


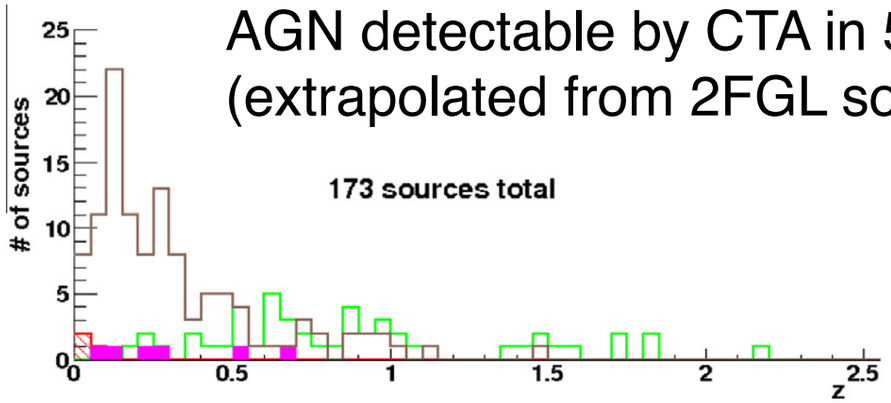
CTA simulation of GRB 090902B based on an extrapolation of the Fermi LAT spectrum at 50 sec after the trigger

S. Funk et al. 2013, APh, 43, 348

Acero et al. 2013, APh, 43, 276

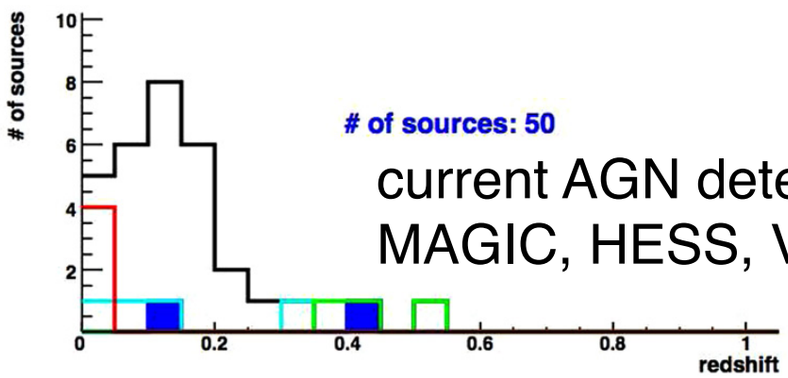
CTA Science: (5) AGN population and flaring





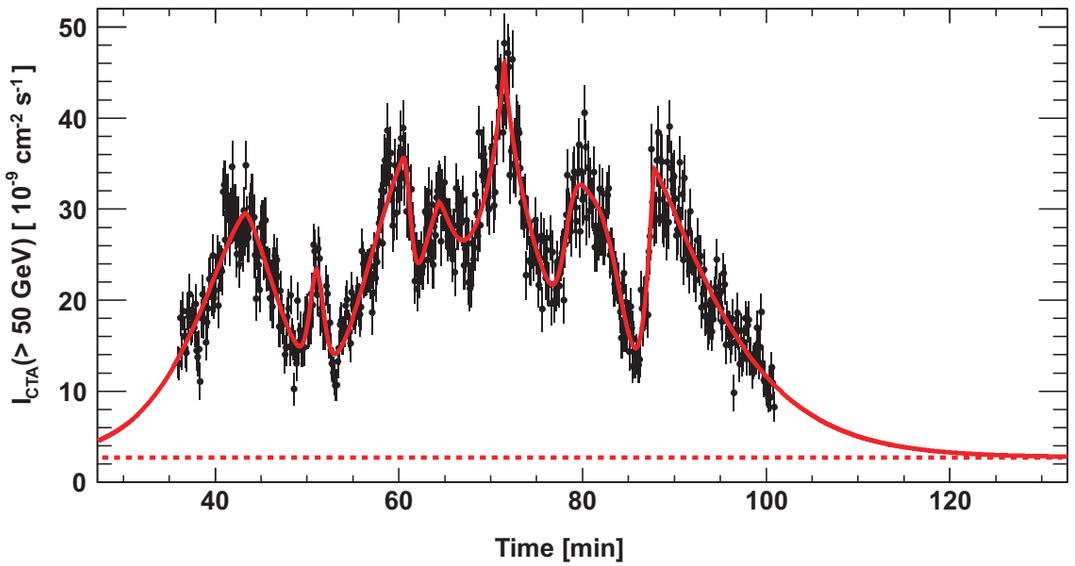
AGN detectable by CTA in 50 hr (extrapolated from 2FGL sources)

- greatly expand the catalog of VHE ϒ-ray AGN
- study missing link between supermassive black hole environment and the formation of relativistic jets



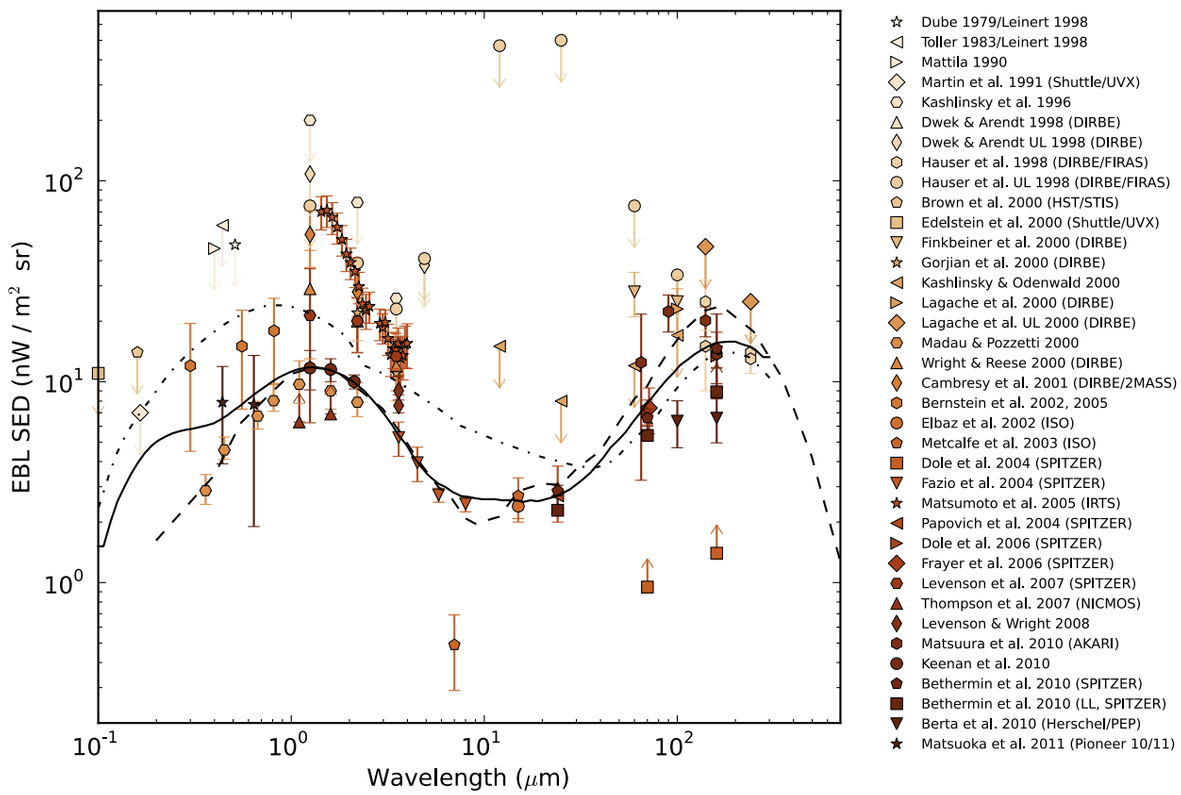
current AGN detected by MAGIC, HESS, VERITAS

simulated CTA lightcurve of PKS 2155-304 (flux >50 GeV in 7.5 sec bins)

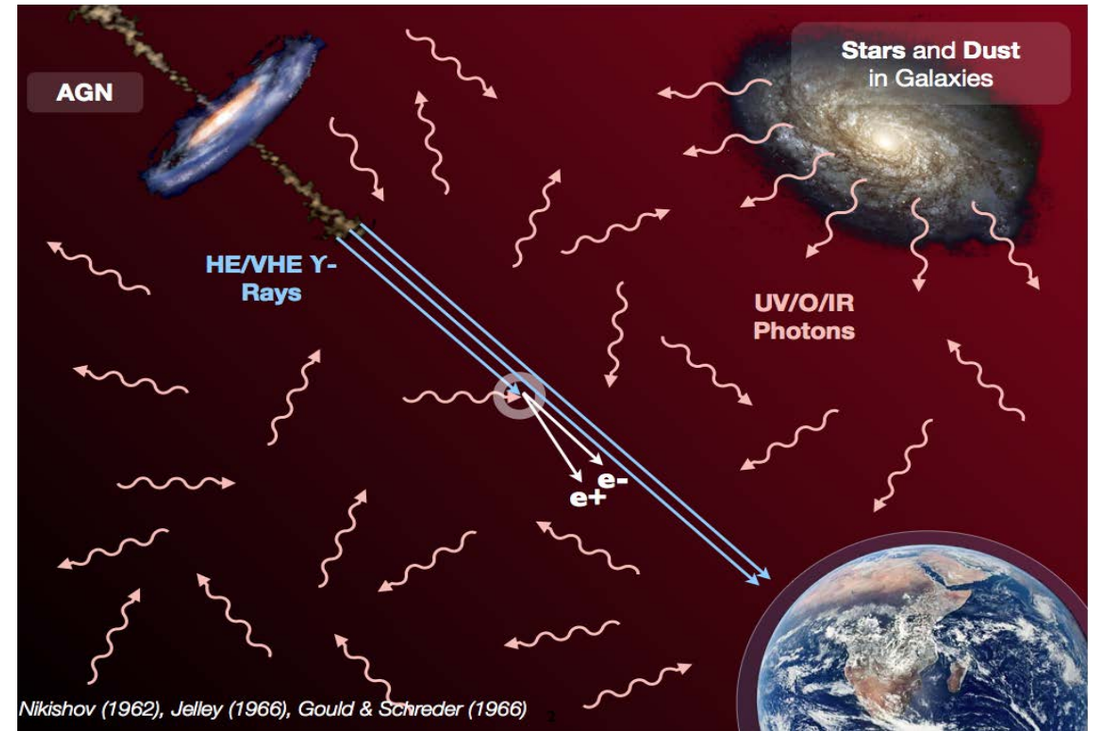


H. Sol et al. 2013, APh, 43, 215

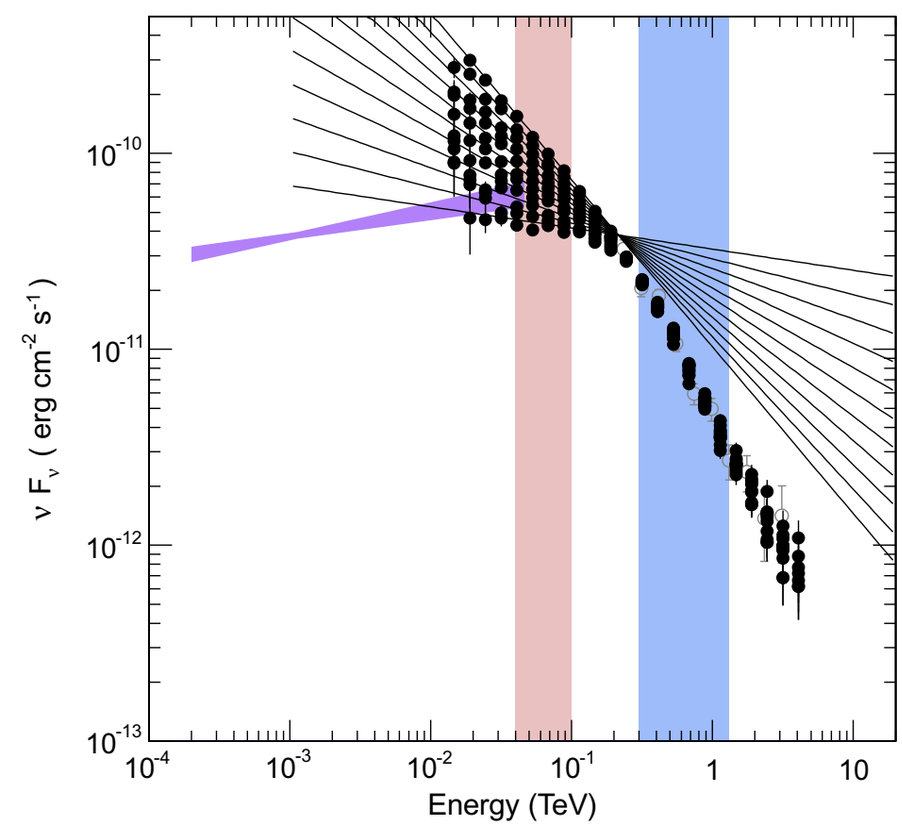
CTA Science: (6) Constraints on the Extragalactic Background Light (EBL)



measurements and limits on the EBL density



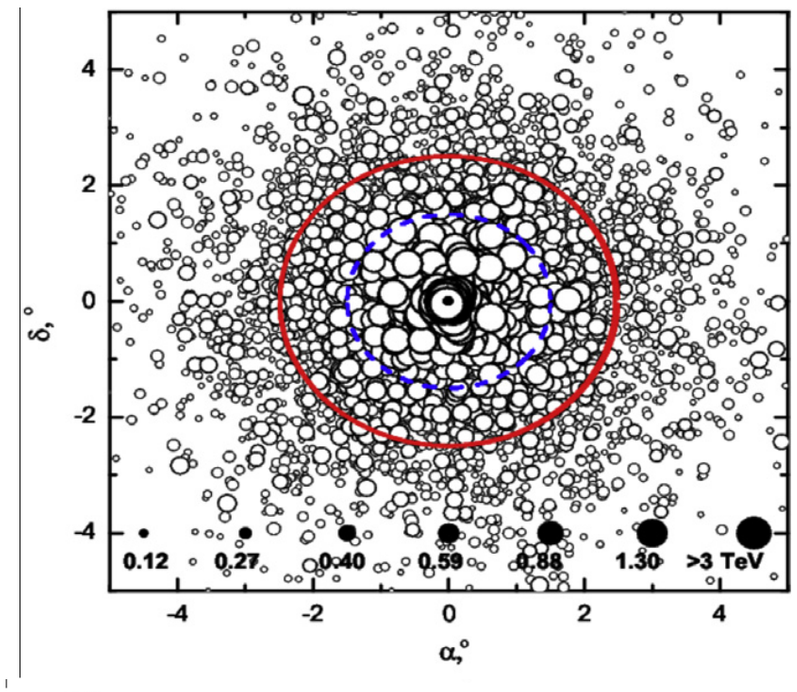
- CTA spectra of AGN will place strong limits on the EBL density, which is difficult to measure directly
- evolution of the EBL density offers new insights into structure formation and galaxy evolution

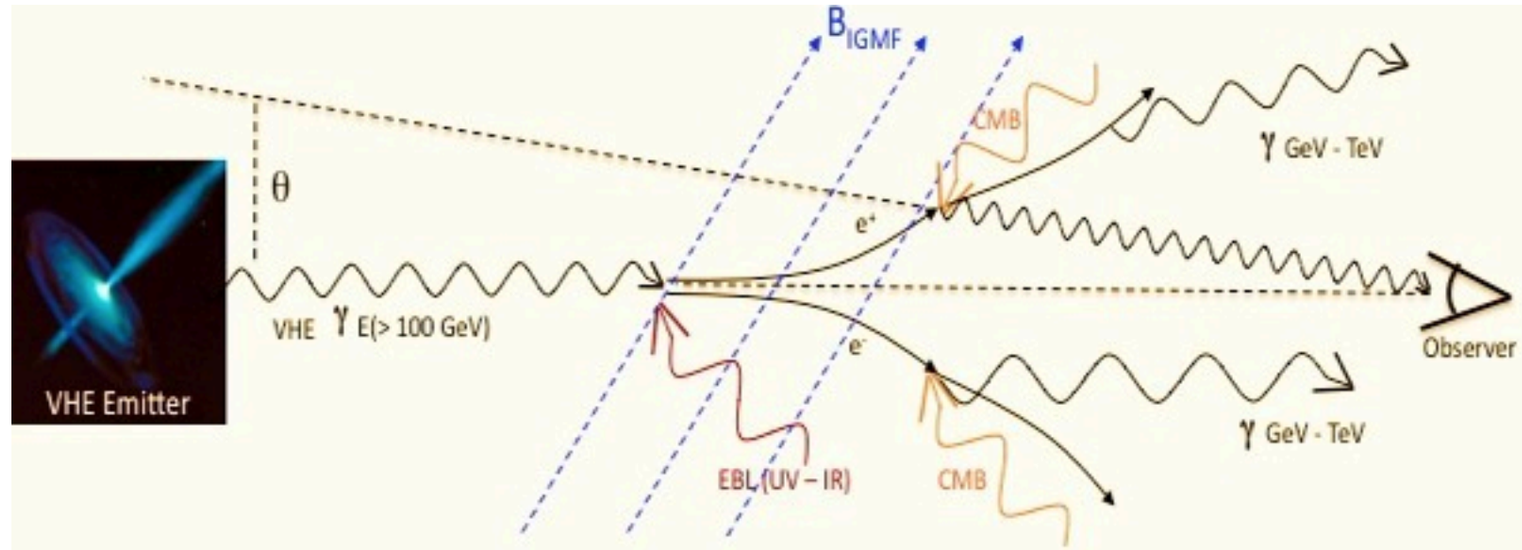


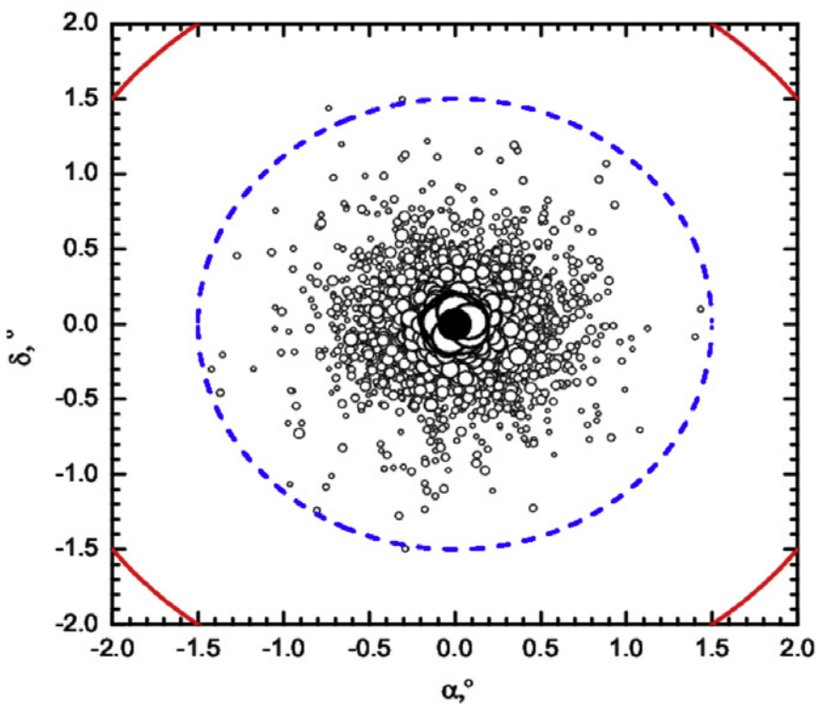
simulated CTA spectra for PKS 2155-304 (z=0.116) for different EBL densities

D. Mazin et al. 2013, APh, 43, 241

CTA Science: (6) Probe to Intergalactic Magnetic Fields (IGMFs)







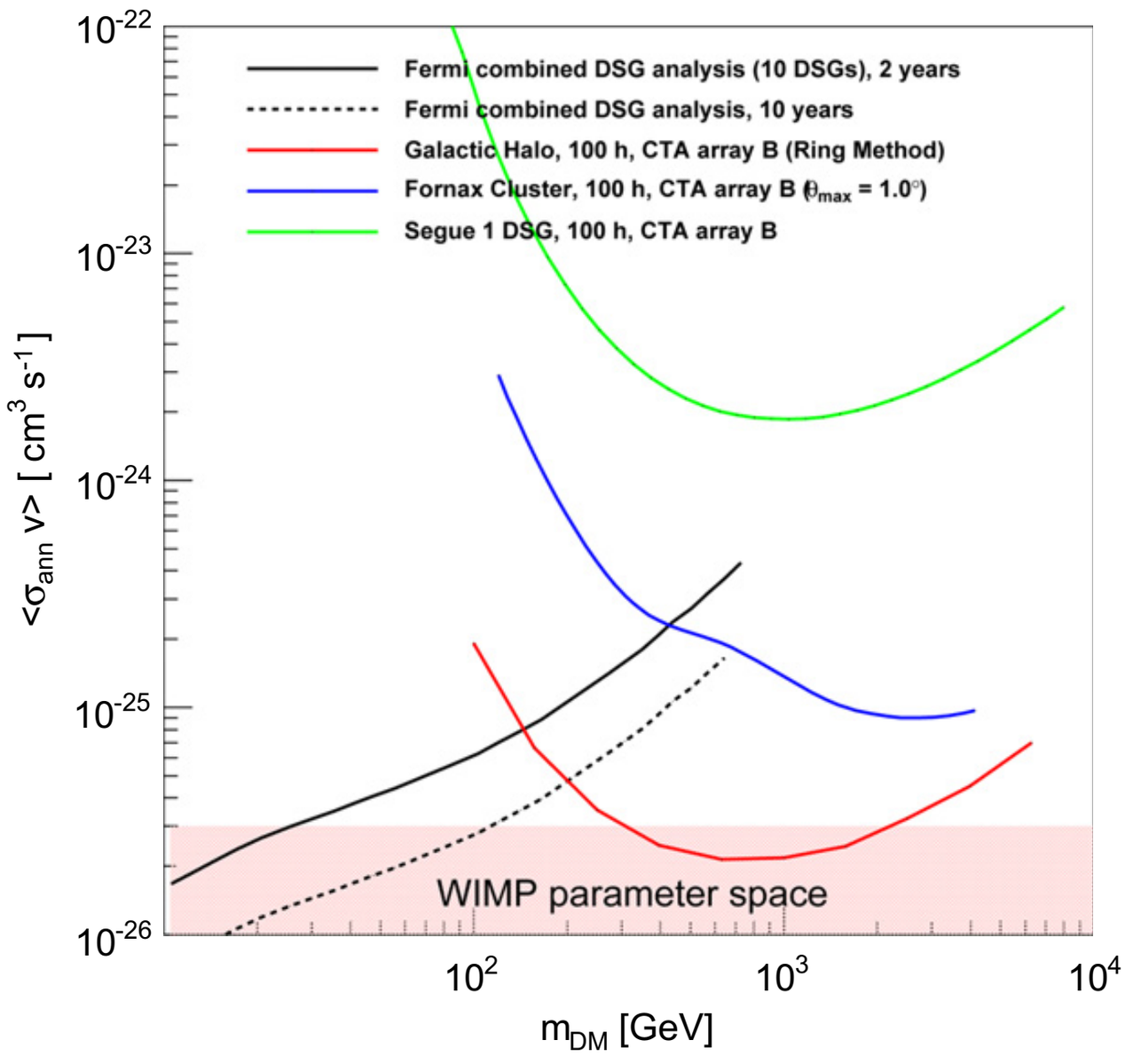
primary and secondary ϒ-rays from a distance of 120 Mpc
(top) IMGF strength ~10^{14} G
(bot) IMGF strength ~10^{15} G

- CTA offers a powerful probe to the predicted weak IMGF
- detection of extended ϒ-ray emission or a pair halo could provide highly valuable information on the IMGF, exploring the potential origin of magnetic fields in galaxies

H. Sol et al. 2013, APh, 43, 215

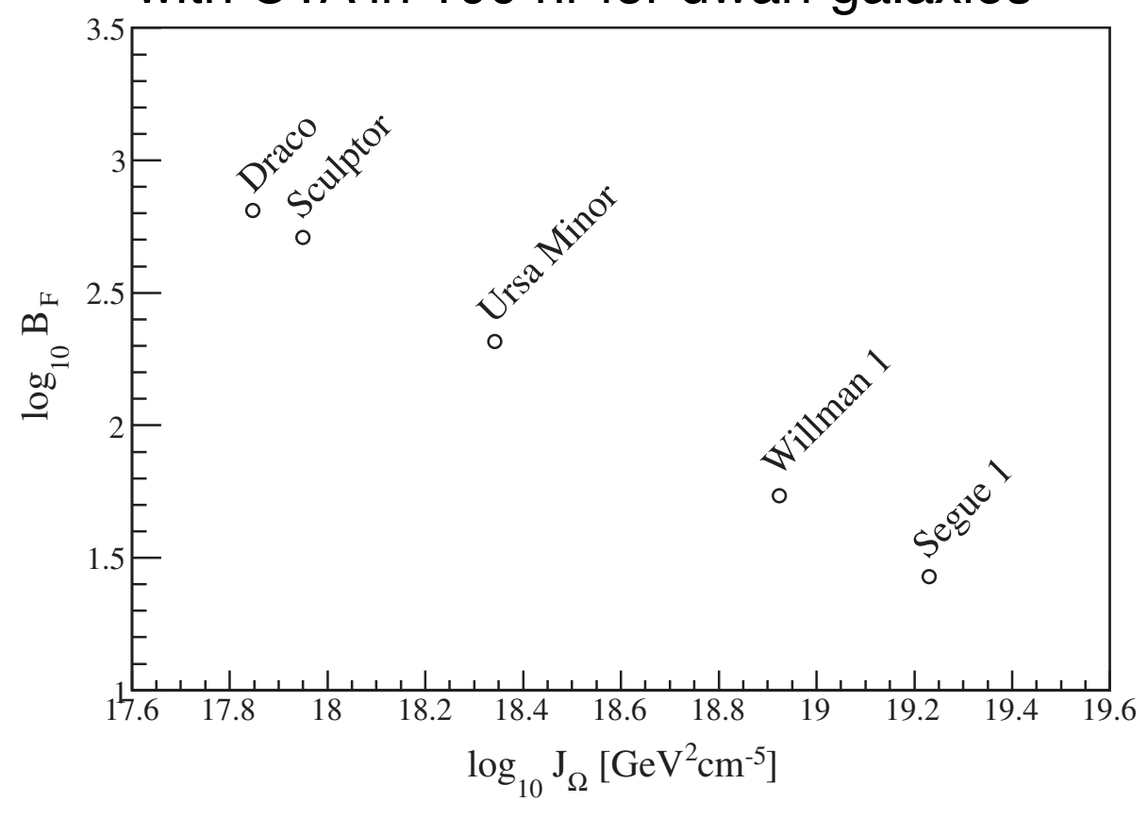
CTA Science: (7) Search Indirect Detection of Dark Matter

- CTA will have sufficient sensitivity to probe an annihilation cross-section of ~3 x10^{-26} cm^3 s^{-1} for the Galactic Center Halo in 100 hr for WIMP masses above 300 GeV
- good energy resolution to search for DM spectral features



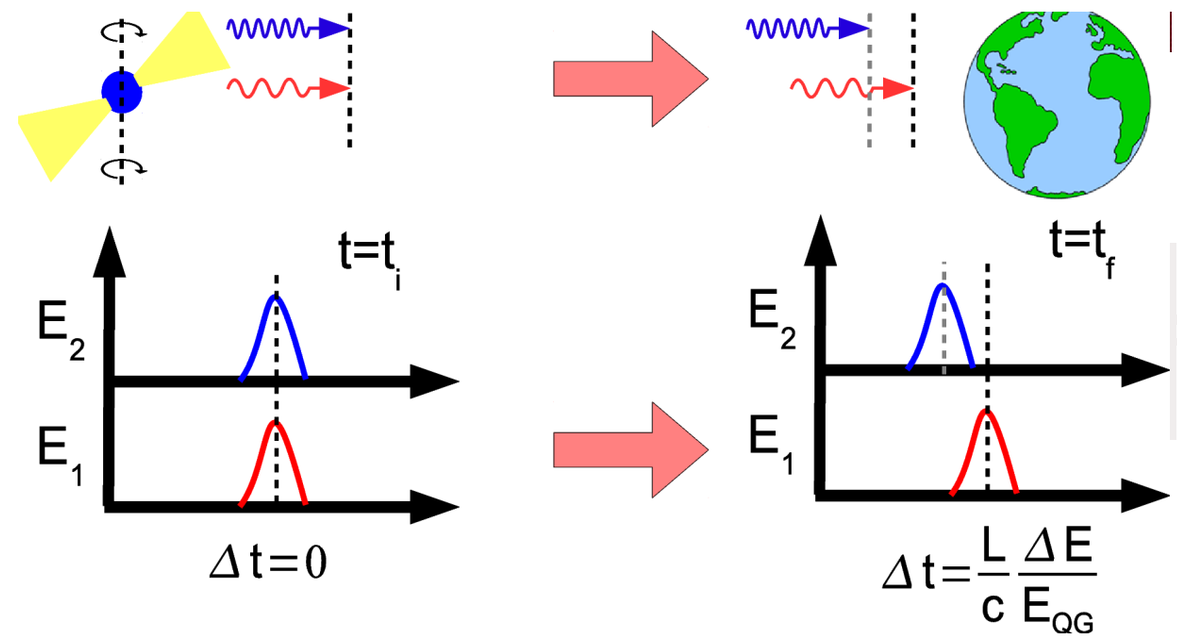
M. Doro et al. 2013, APh, 43, 189

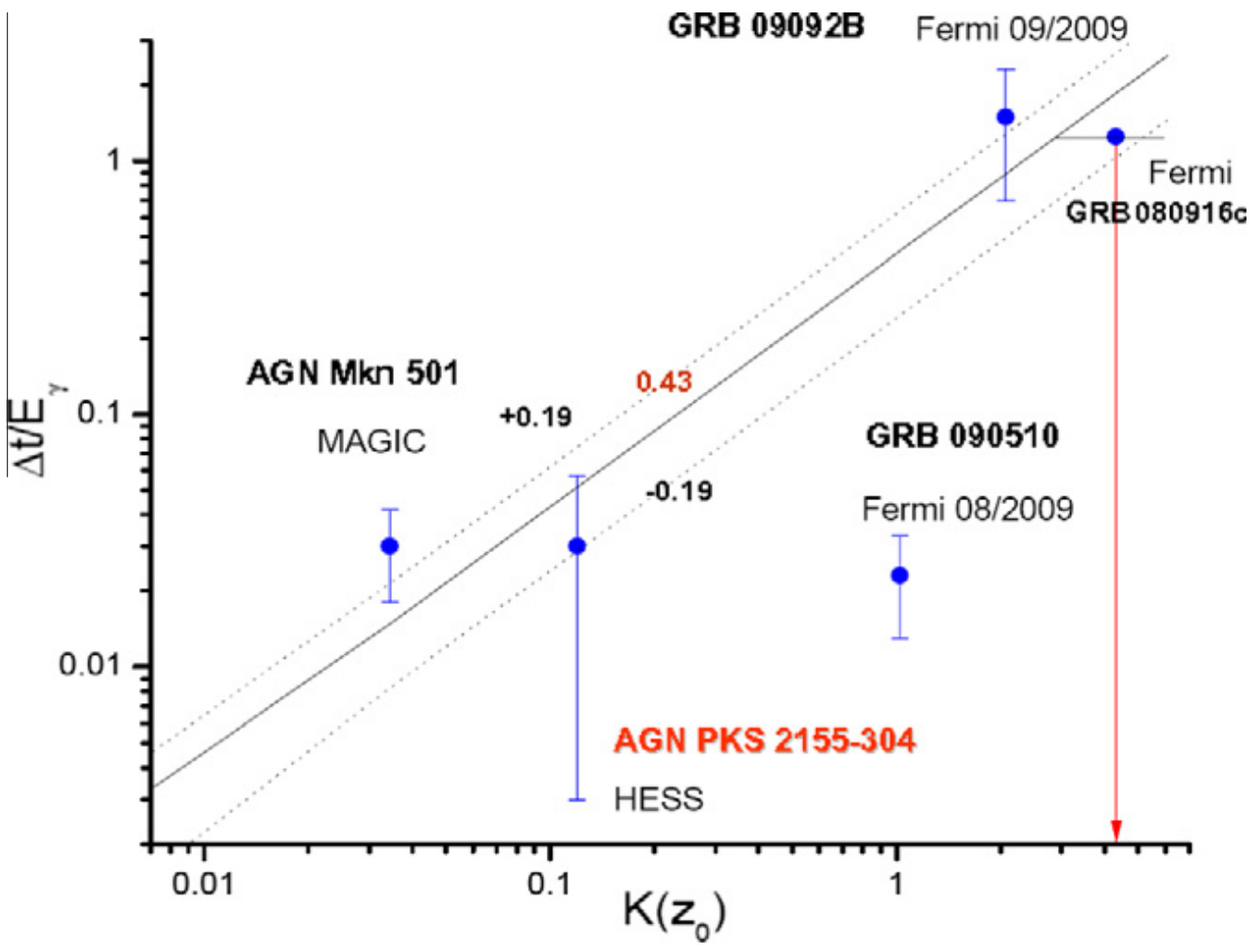
minimum boost factor for 5σ detection with CTA in 100 hr for dwarf galaxies



CTA Science: (8) Probes of Lorenz Violation

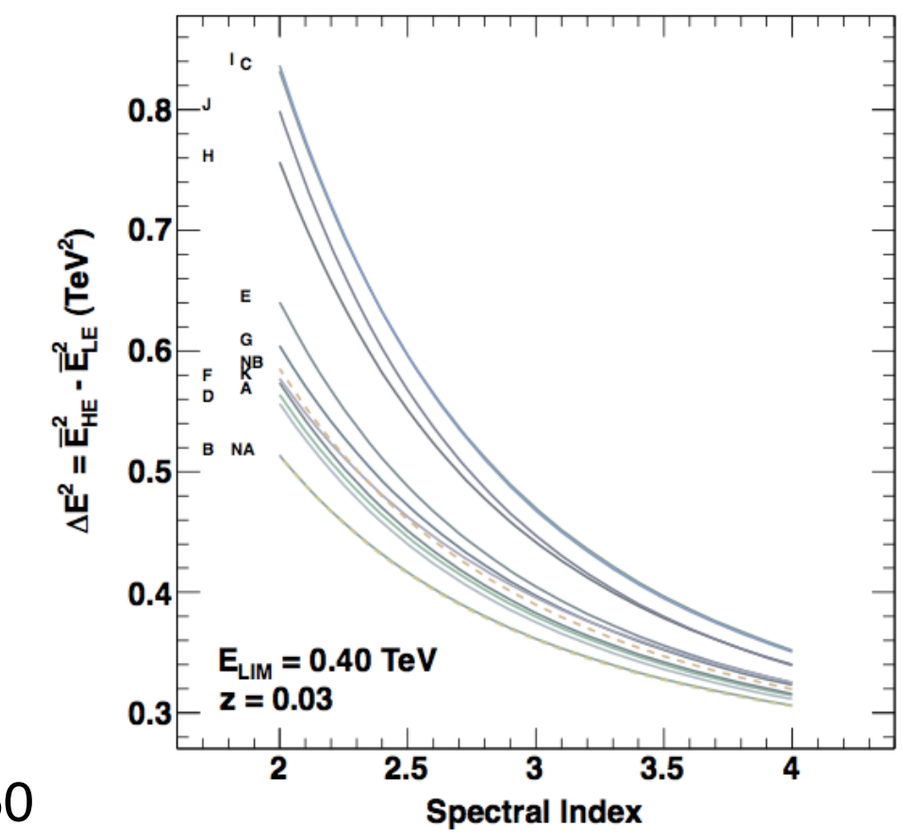
CTA observations of distant ϒ-ray sources (GRB and AGN) offers a far more sensitive probe to Lorenz violation than accelerators and astrophysical neutrino measurements





delay in arrival time of ϒ-ray per energy vs redshift

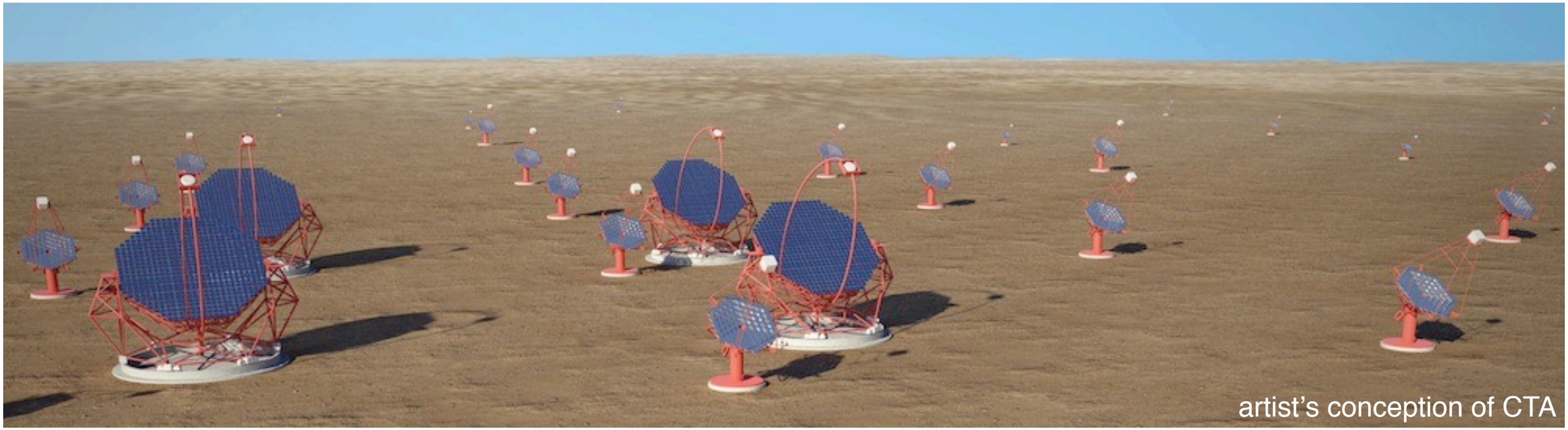
- line shows model where the velocity of light is reduced by an amount linear in photon energy



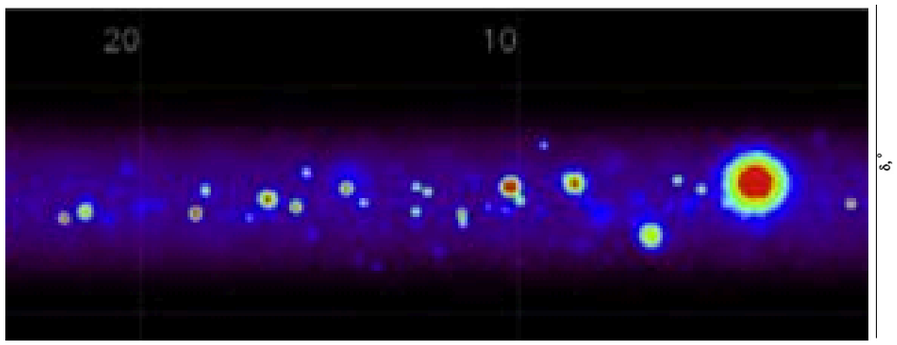
J. Ellis & N. Mavromatos 2013, APh, 43, 50

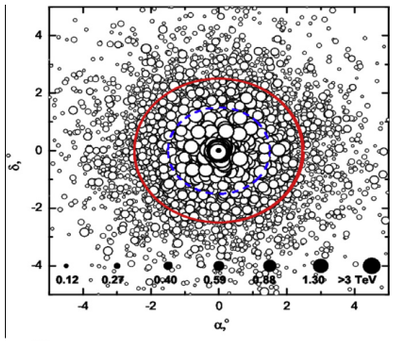
M. Doro et al. 2013, APh, 43, 189

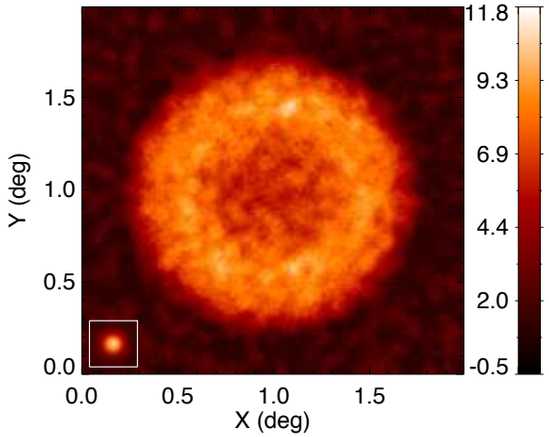
Conclusions

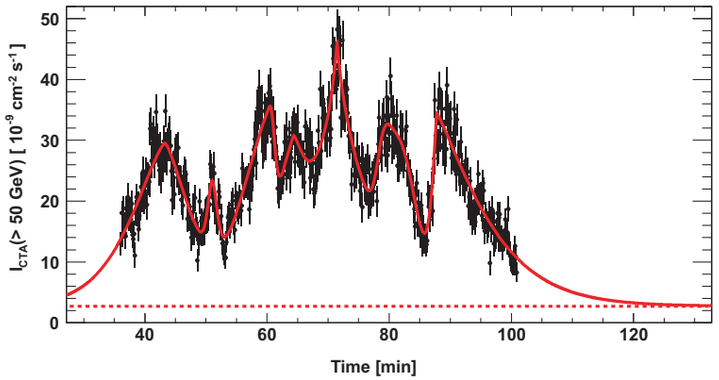


Legacy of CTA:
physics impact of a high-sensitivity VHE ϒ-ray observatory will cover a wide range of modern astrophysics topics









www.cta-observatory.org