AGIS Project
(Advanced Gamma-ray Imaging System)

Hiro Tajima on behalf of AGIS collaboration
SLAC National Accelerator Laboratory
Kavli Institute for Particle Astrophysics and Cosmology

Outline

- Project concepts
- Science drivers
- Technology development
- Summary and Prospects

January 9, 2010
CTA Japan Workshop
ICRR, Japan

Current/Past Gamma-Ray Telescopes

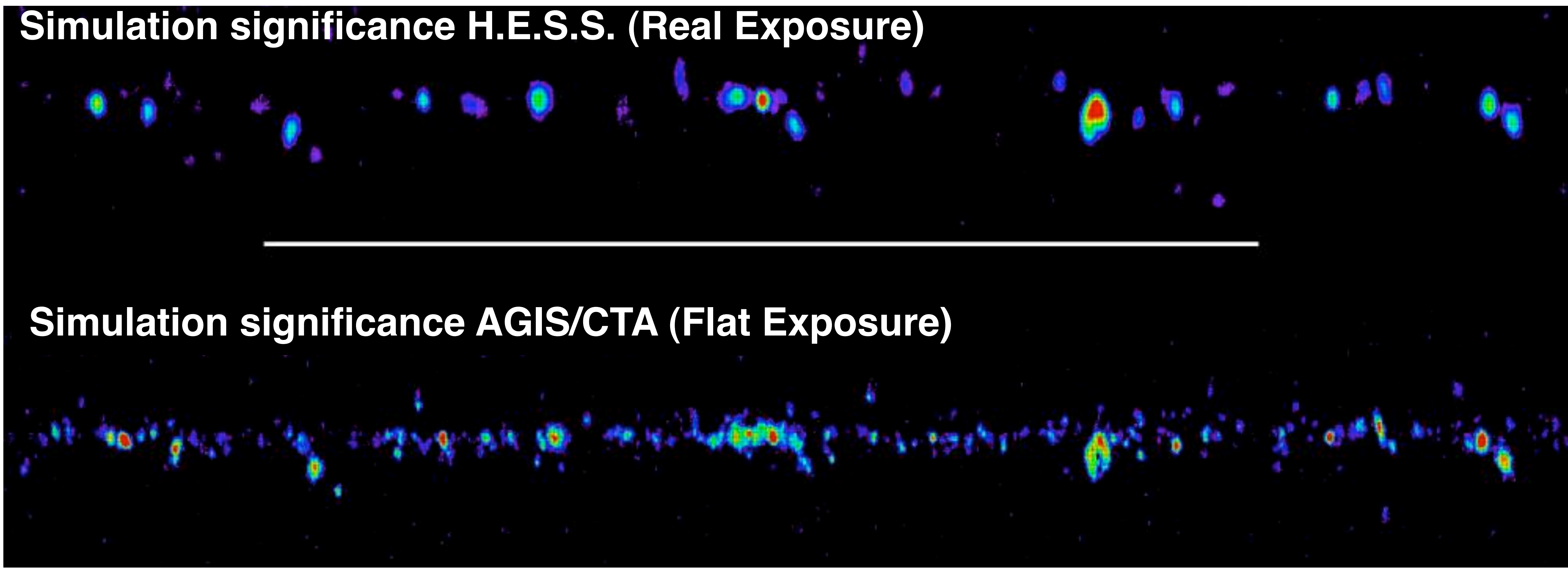
- ❖ **MeV region (Compton, photo absorption)**
  - ✤ **INTEGRAL, Swift? (not really MeV instrument)**
  - ✤ **COMPTEL**
    - ✦ **State of art “ACT” in study, however, no clear future path**
    - ✦ **SGD (sub-MeV) onboard JAXA ASTRO-H to be launched in 2014**
- ❖ **GeV region (pair conversion)**
  - ✤ **EGRET, AGILE**
  - ✤ **Fermi (GLAST)**
    - ✦ **~ $700M/mission, state of art instrumentation**
    - ✦ **Constraints on volume, mass and power**
- ❖ **TeV region (air shower)**
  - ✤ **HESS, CANGAROO, MAGIC, VERITAS**
    - ✦ **~$15M/site (2–4 telescopes)**
    - ✦ **Room for technology development**
  - ✤ **Milagro (large FOV, limited sensitivity)**

Future TeV Gamma-Ray Telescopes

- HAWC
  - Larger active area and better background rejection by rearrangement of PMTs
    - Lessons learned from Milagro
  - Further increase of effective area is not easy
- Future IACT (Imaging Atmospheric Cherenkov Telescope)
  - x~10 better sensitivity
  - CTA (European effort)
    - Majority of members from HESS/MAGIC + new members
    - Tends to be conservative on technology choices
    - ~150M€ (100/50M€ for southern/northern sites)
  - AGIS (US effort)
    - Open to new technologies (optics, photon detectors, ASICs)
      - Submit joint R&D proposals to NSF/DOE
    - Aiming $~200M level project
      - New technologies required to reduce cost

AGIS Science Drivers

- **Origin of Comic rays**
  - **High-energy cut-offs in cosmic-ray accelerators in the Milky Way**
  - **Extragalactic sources?**
    - **AGN (Active galactic nuclei) and GRB (Gamma-ray burst)**
    - **Extragalactic background light**
- **Dark matter search**
- **Dark TeV sources**
- **Complementary to Fermi LAT (higher energy band)**



Digel & Funk

INSTITUTIONS:

Adler
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Barnard
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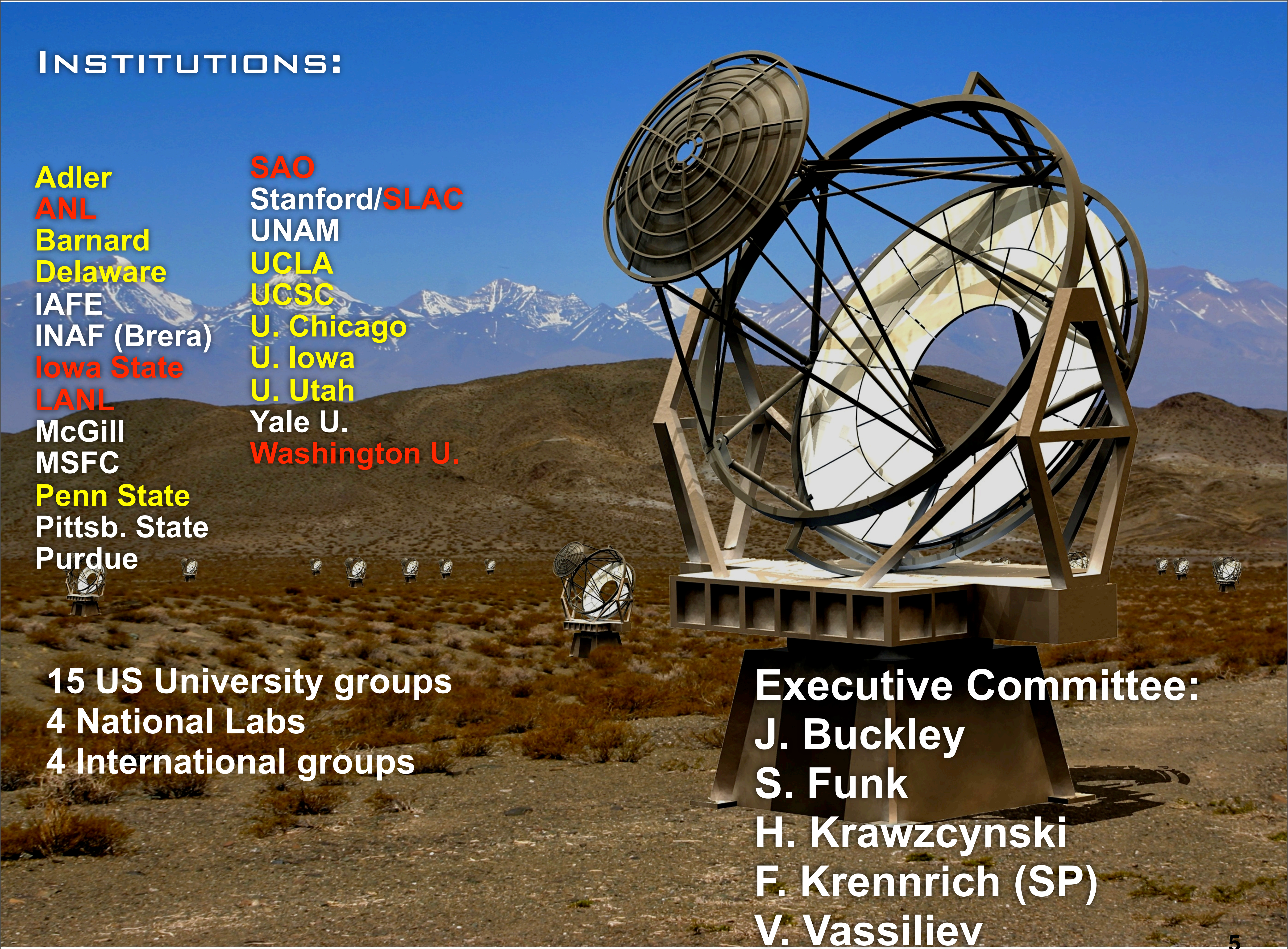
15 US University groups
4 National Labs
4 International groups



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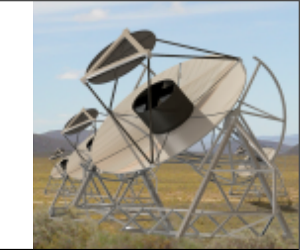
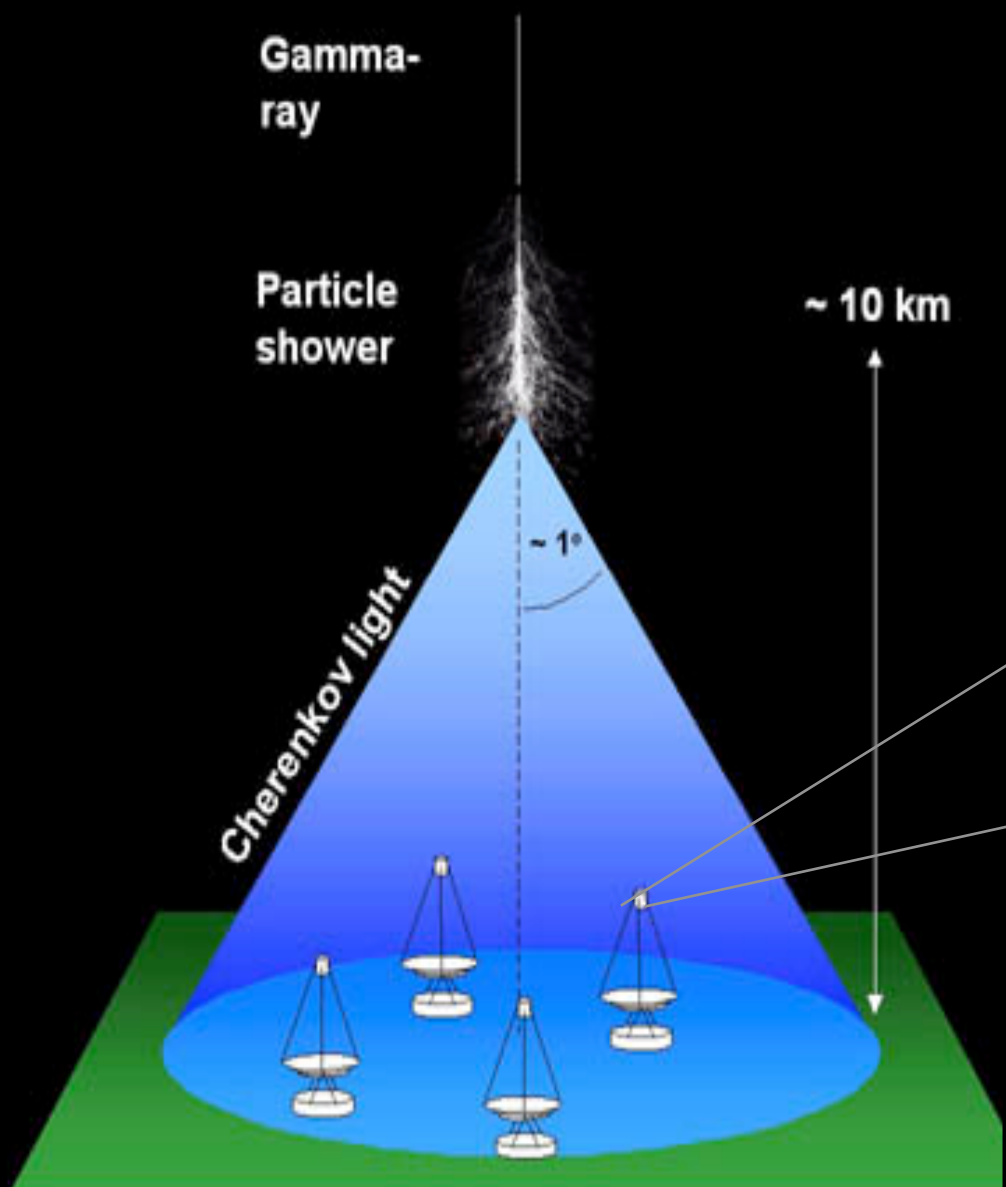
Executive Committee:
J. Buckley
S. Funk
H. Krawzcynski
F. Krennrich (SP)
V. Vassiliev



IACT Technique



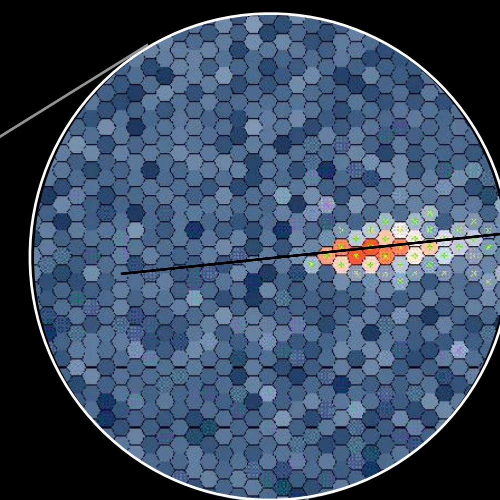


Image analysis yields:

- Shower direction
- Primary energy
- background rejection

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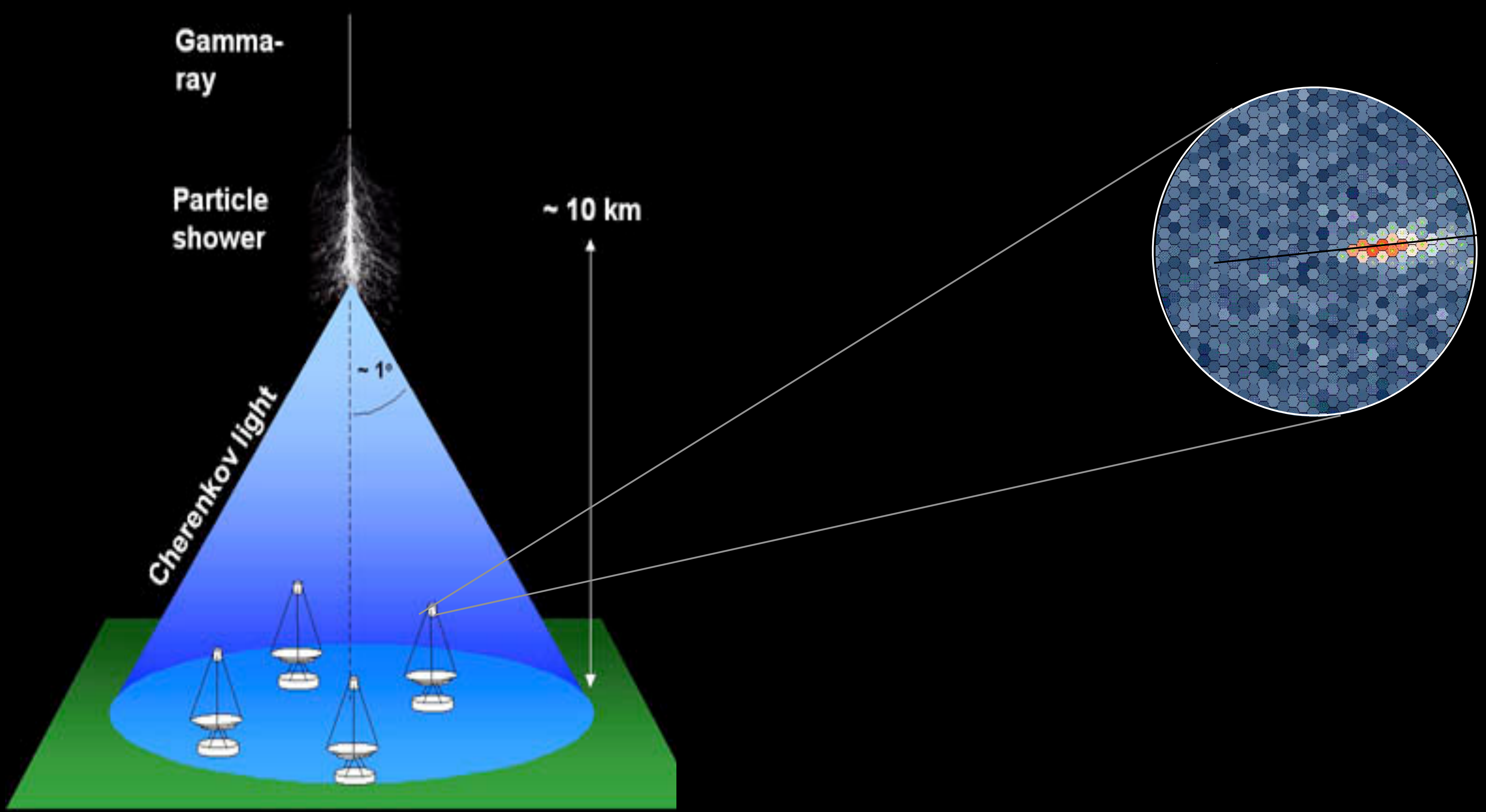

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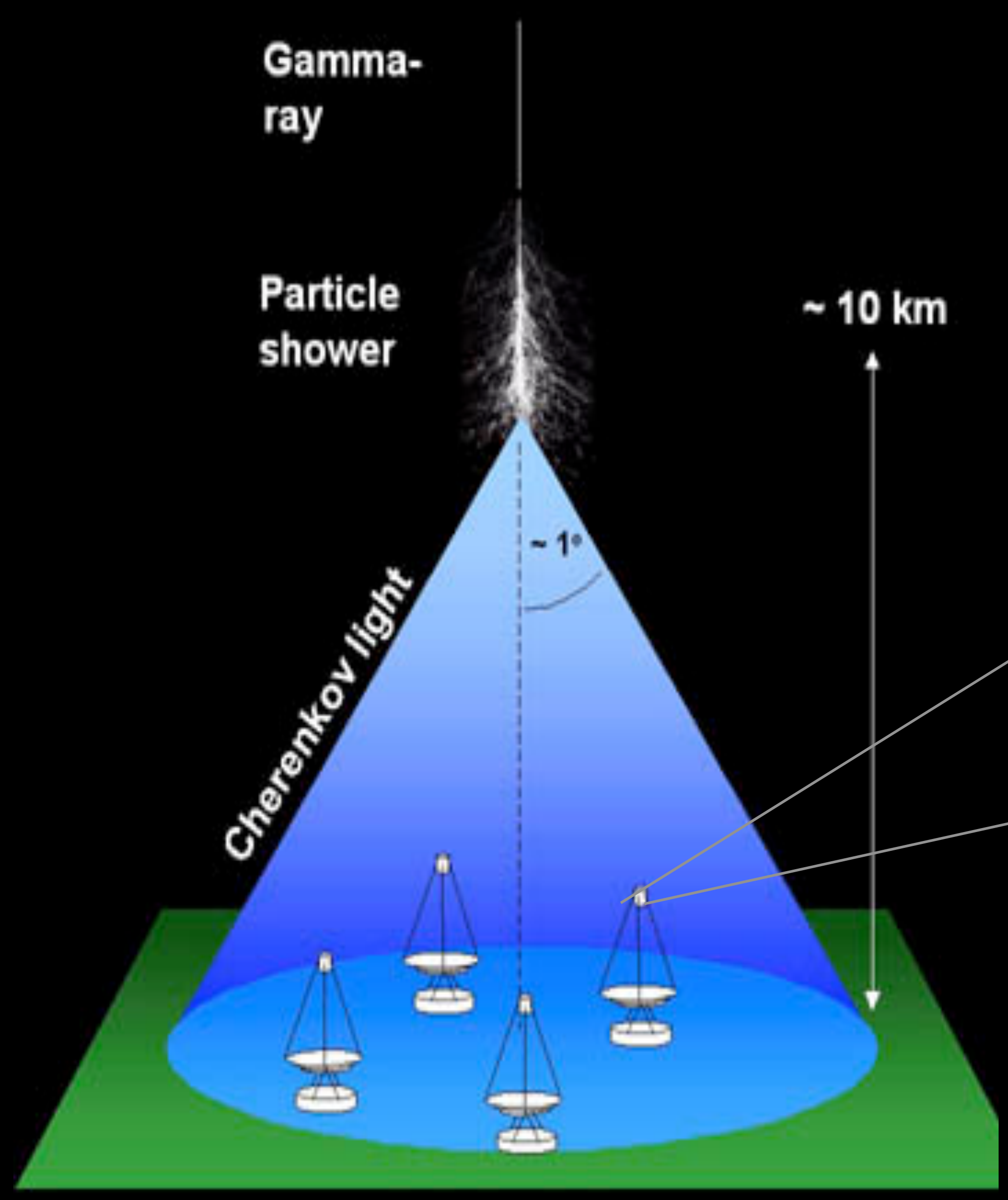
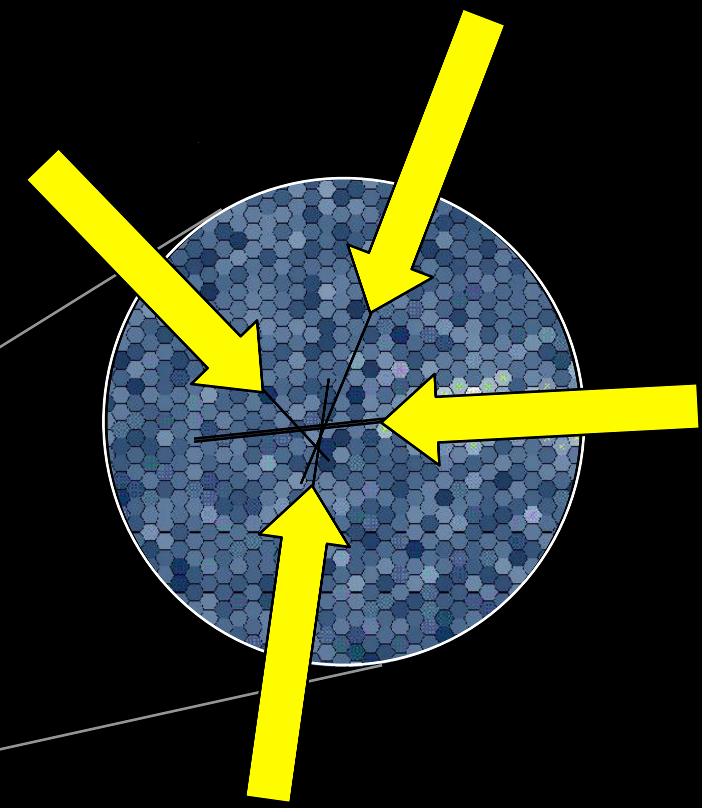


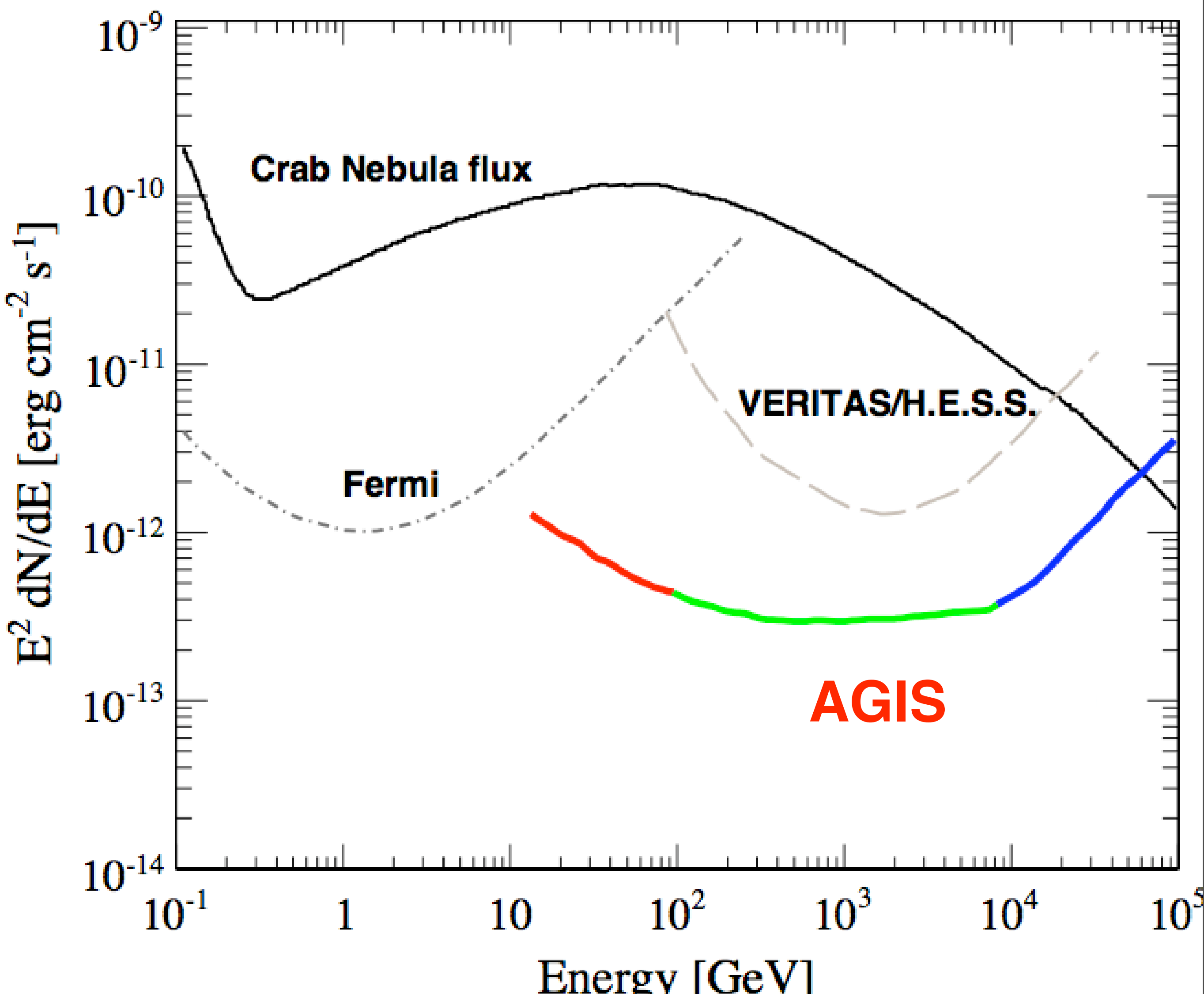


Stereo image analysis improves:

- background rejection
- angular resolution
- geometry over-constrained

AGIS Instrument Concept

- ❖ Improve sensitivity by a factor of ~10 in 0.1–10 TeV
  - ✤ 4 telescope → 36 telescope array
  - ✤ Wide FOV (3–5° → 8°), large telescope spacing
- ❖ High resolution imaging (0.1° → 0.05°)
  - ✤ Sharper image
  - ✤ Better BG rejection
  - ✤ Better sensitivity
- ❖ Similar improvement in # of sources like EGRET ➡ Fermi
- ❖ 220 M$ project (includes construction, operation for 10 years)
  - ✤ Large collaboration (> 20 institutes) supporting AGIS



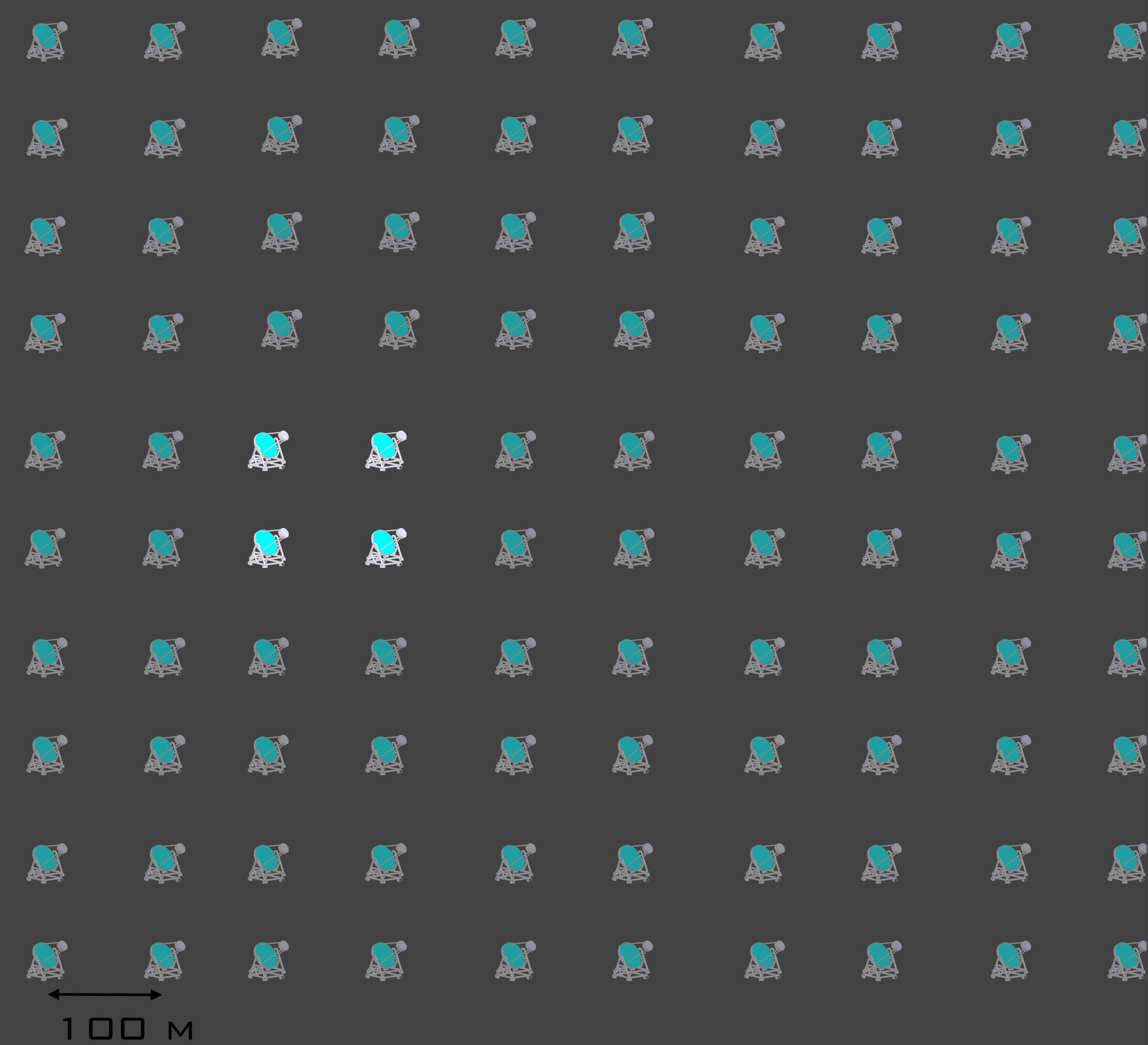
Large Array Concept

❖ Event containment:

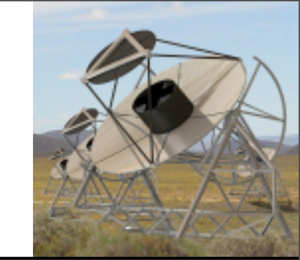
- ✤ angular resolution x 3
- ✤ background rejection x 2
- ✤ collection area x 10
- ✤ FOV x 4

Photon statistics!

$$S \propto \Theta \times \sqrt{back} \times \sqrt{area} \times \sqrt{\Omega}$$



Event containment only works for minimum size of array, so that combination of collection area and angular resolution are achieved!



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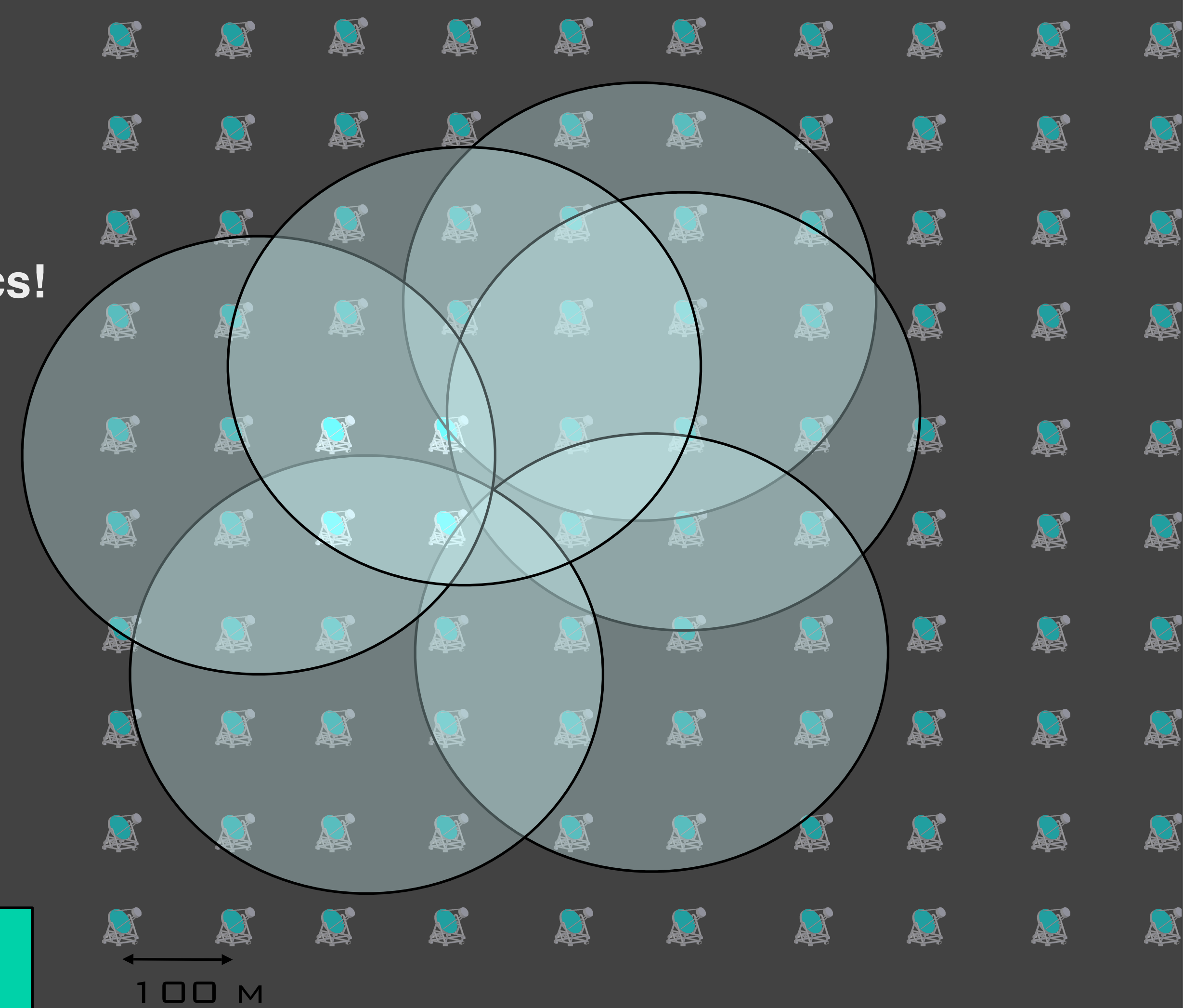

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AGIS Specifications

Specification of the AGIS-36 Array	Target
Telescope Spacing	120 - 150 m
Effective Mirror Area per Tel.	100 m^2
Field of View (FOV)	8 deg
Pixelation	0.05 - 0.10 deg
Effective Collection Area	1 km^2
Energy Threshold	100 GeV
Angular Resolution	0.02 - 0.05 deg

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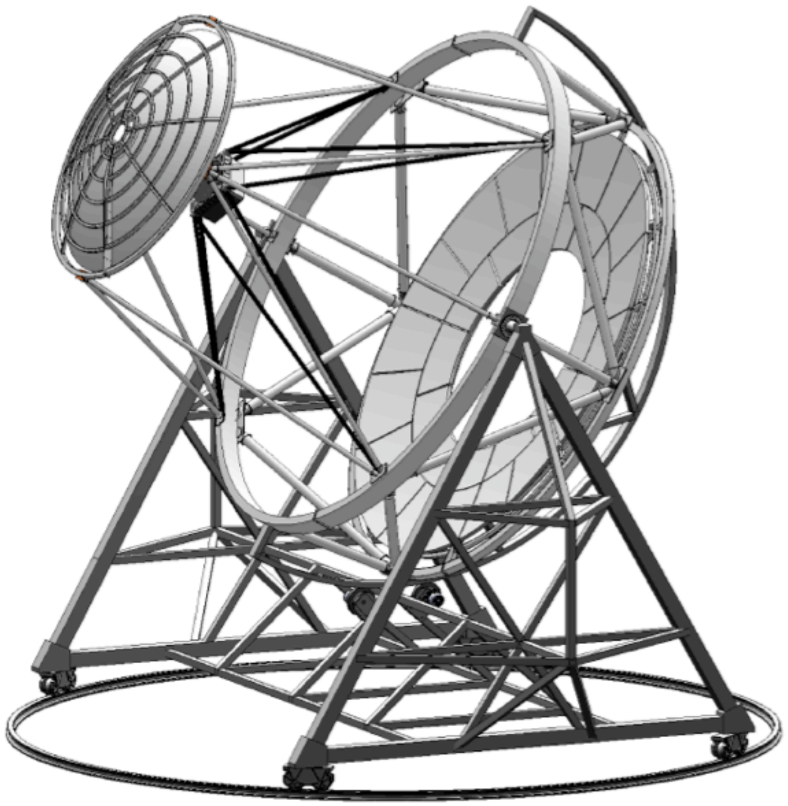
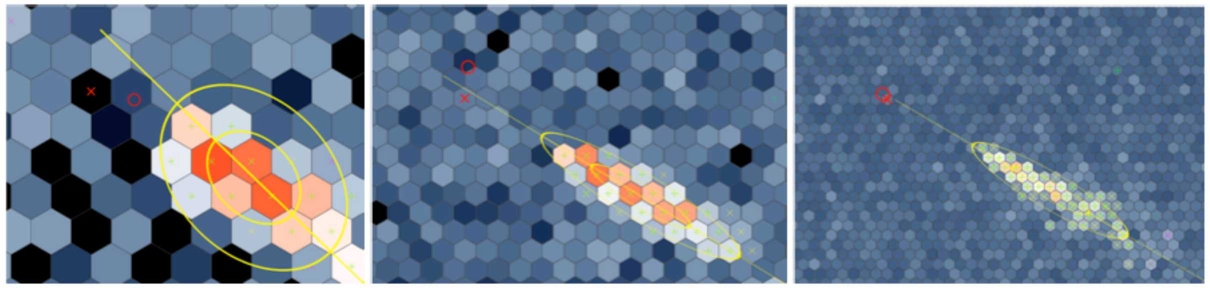
Key attributes of AGIS

AGIS Telescope Concept

- ❖ **AGIS Element:**
  - ✤ **Schwarzschild-Couder optics**
    - ✦ Secondary optics
    - ✦ Short F/D
    - ✦ Compact
    - ✦ High resolution
    - ✦ Wide FOV

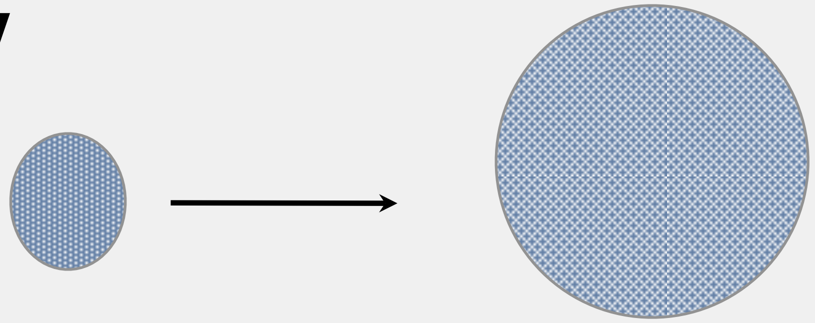


Pixelation



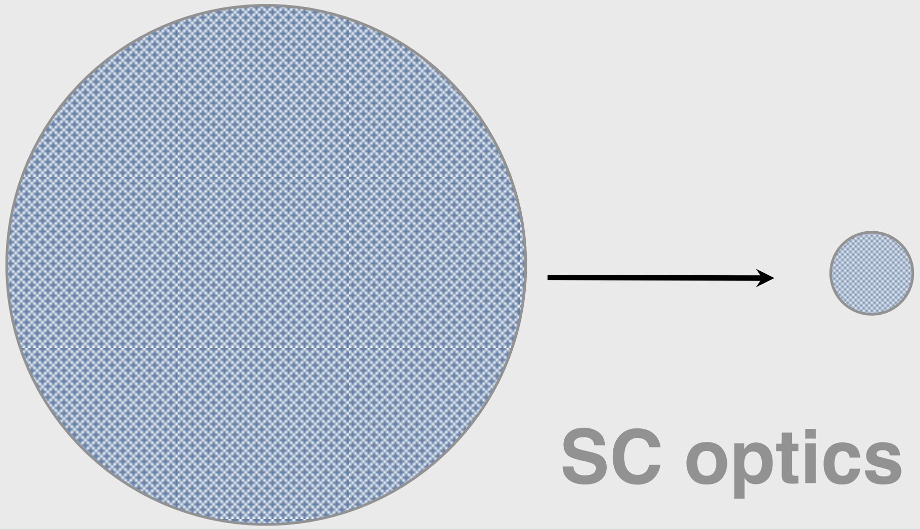
0.28° 0.20° 0.07°

FOV



3.5 deg. 8 deg.

Actual Size



DC optics SC optics

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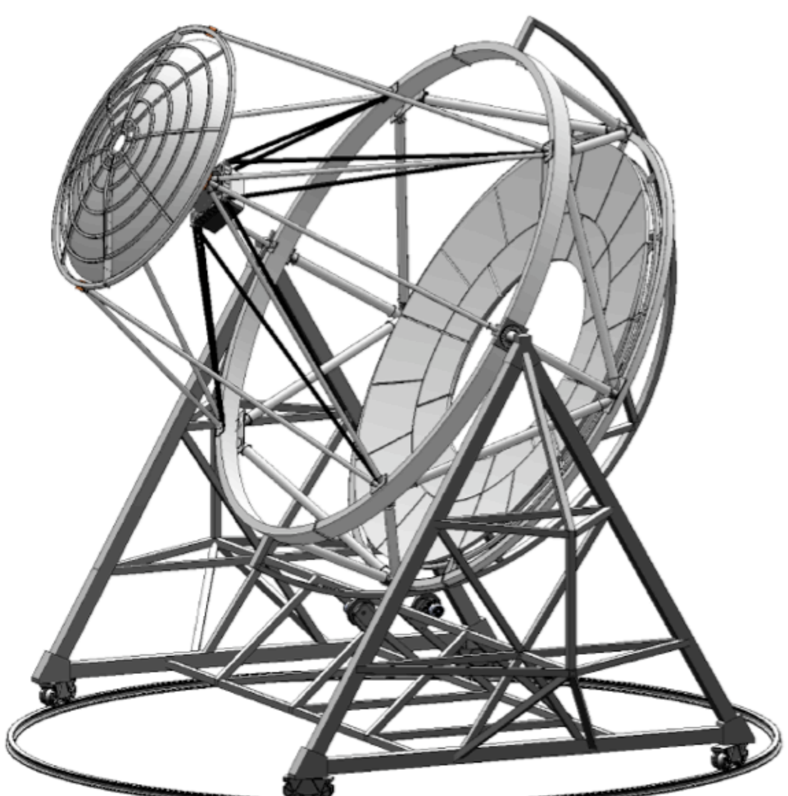

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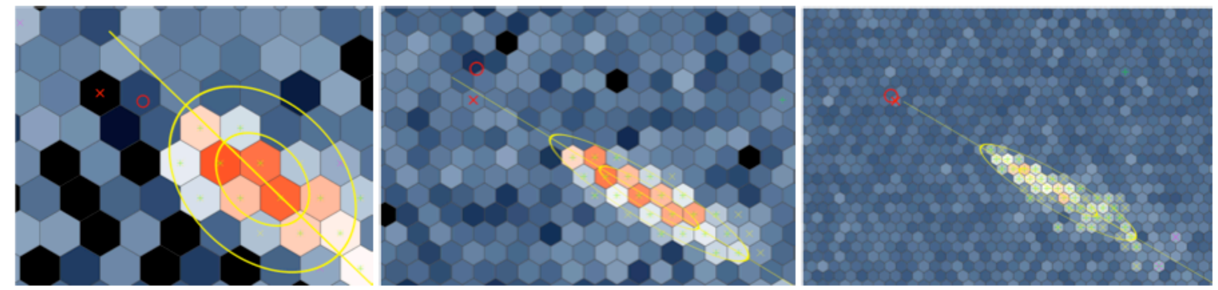

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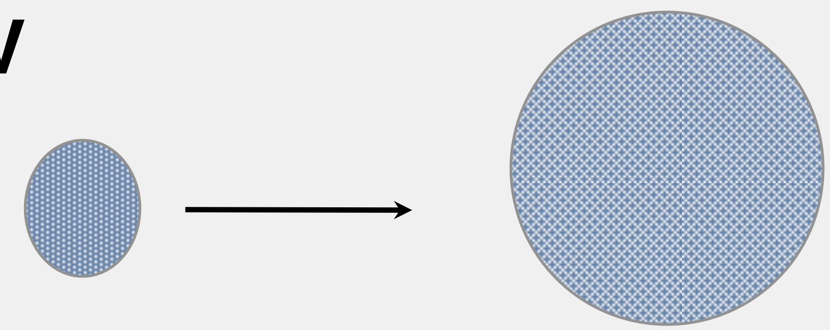

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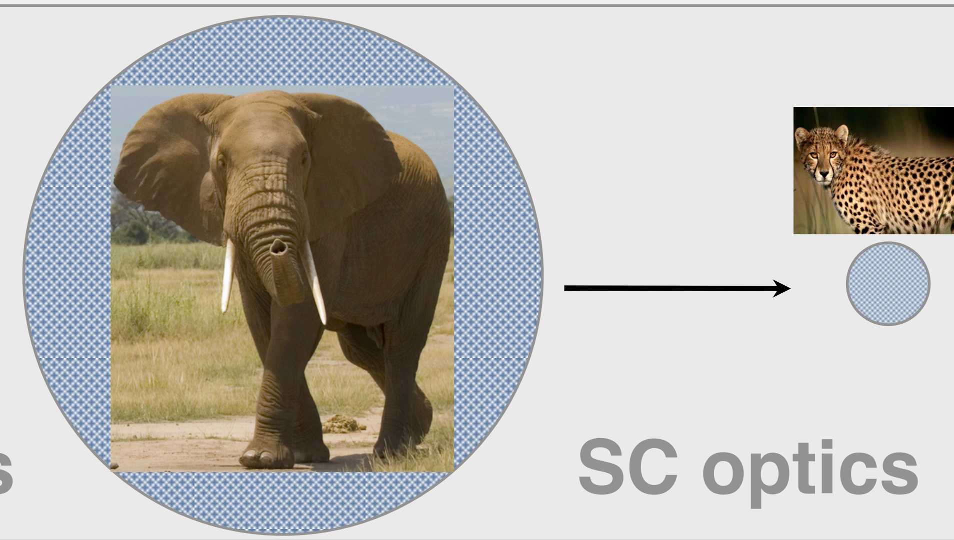
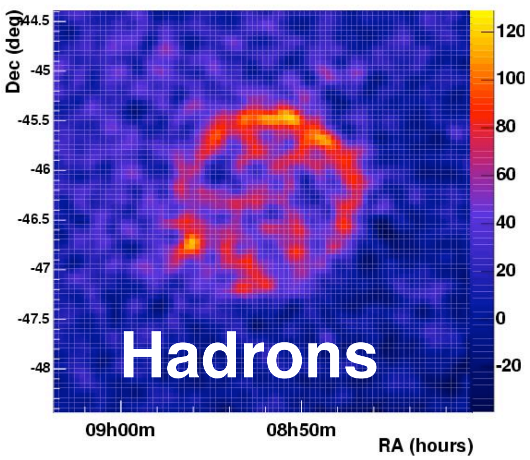
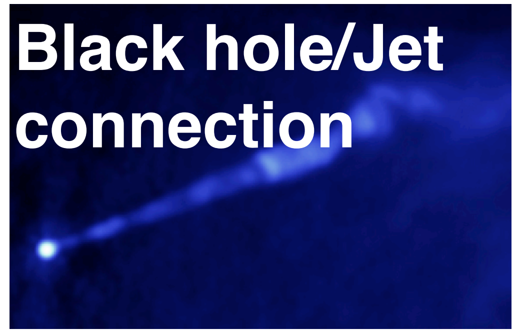
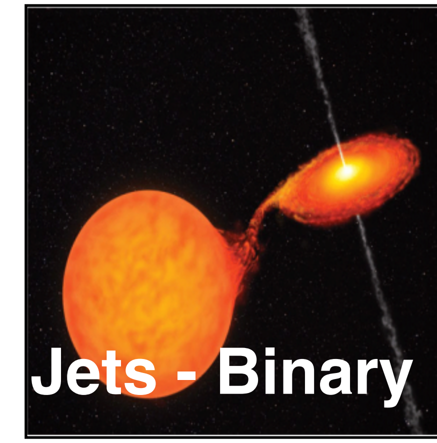


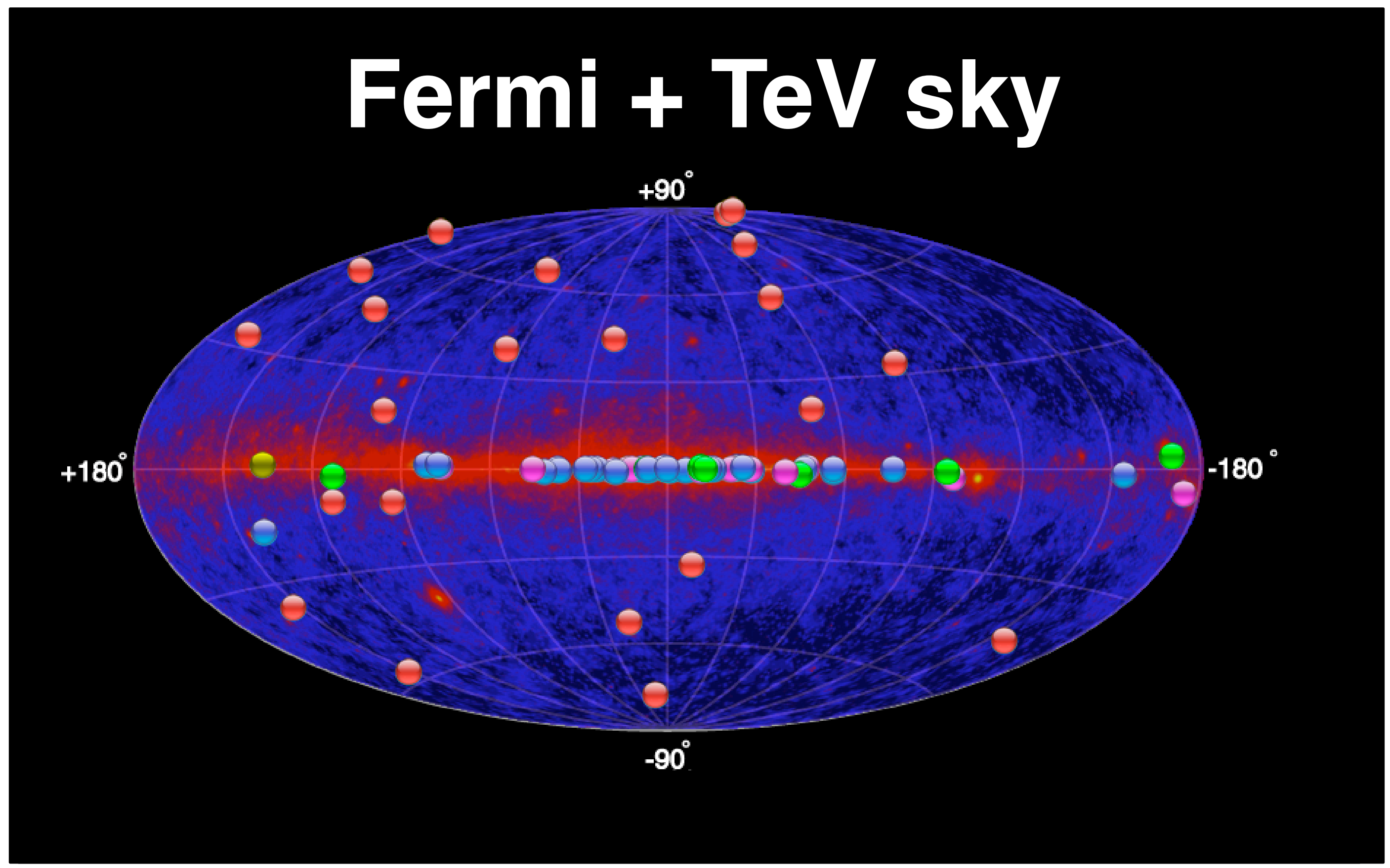
DC optics SC optics

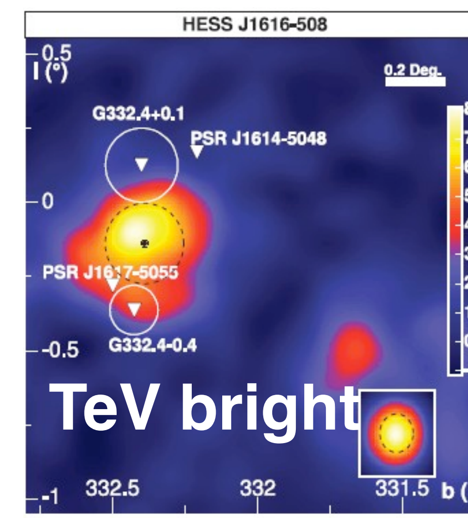
Science Drivers

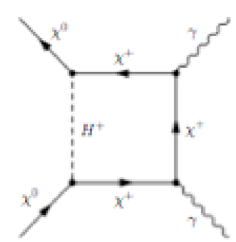


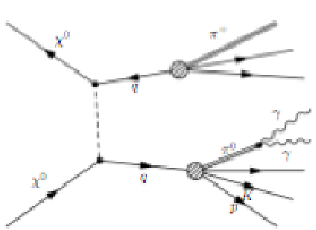












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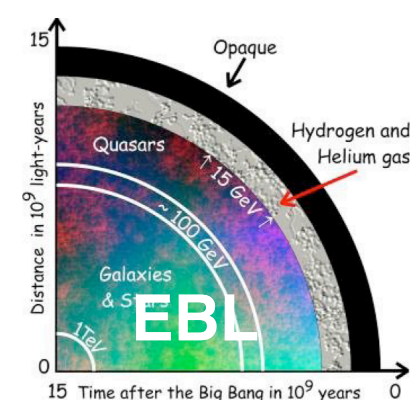
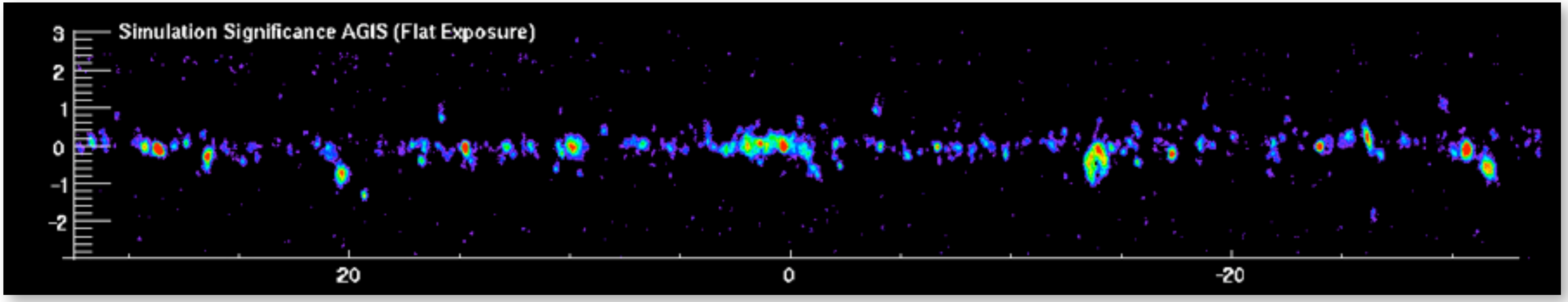


Galactic Cosmic Accelerators

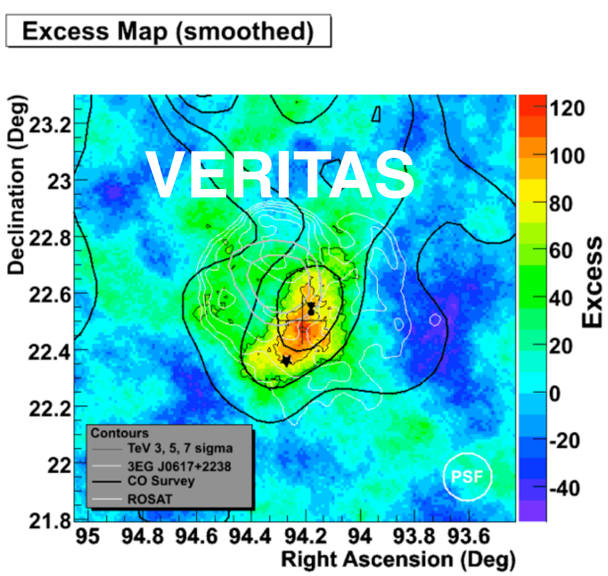
- **AGIS will provide precision measurements:**
  - **detect 200 - 300 SNRs (population studies)**
  - **image with arcmin resolution: radio - X-ray - TeV (hadrons?)**
  - **spectroscopy: 30 GeV - 100 TeV (hadrons vs. leptons)**
  - **role of SNRs, X-ray binaries, PWNe & dark accelerators**
  - **resolve point sources from diffuse emission**
  - **discovery potential for dark matter self-annihilation**

Sky survey: Angular Resolution, FoV, Sensitivity (5 mCrab in 1 year)

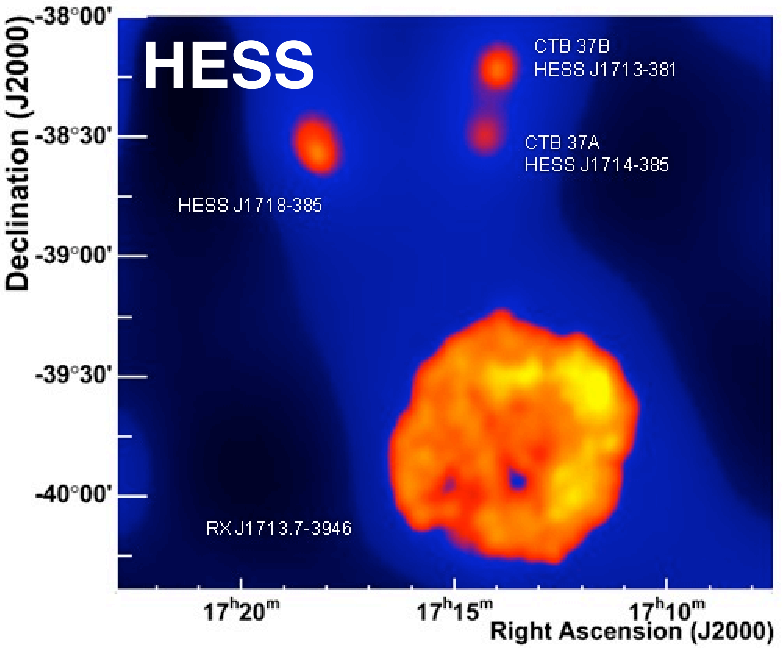


Physics: Supernova Shocks

AGIS:
Wide Field of
View Imaging



IC443



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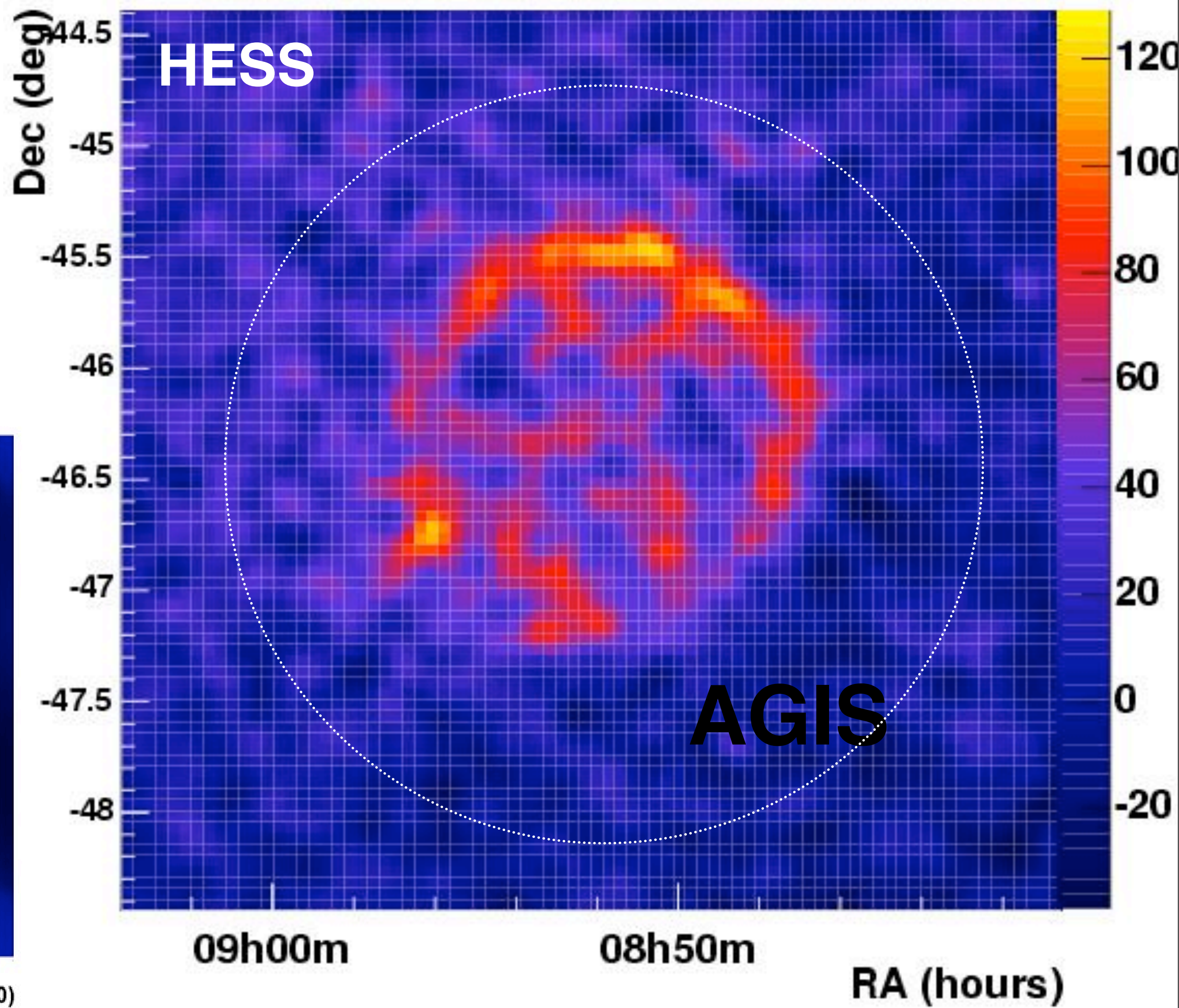
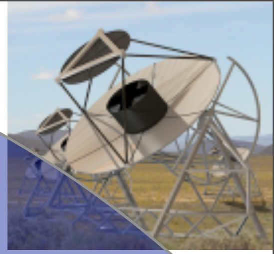


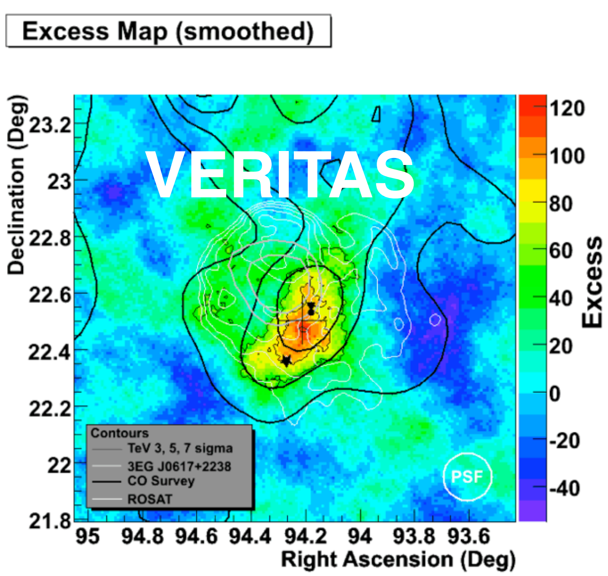
Vela Junior

Physics: Supernova Shocks



AGIS:
Wide Field of View Imaging

8°



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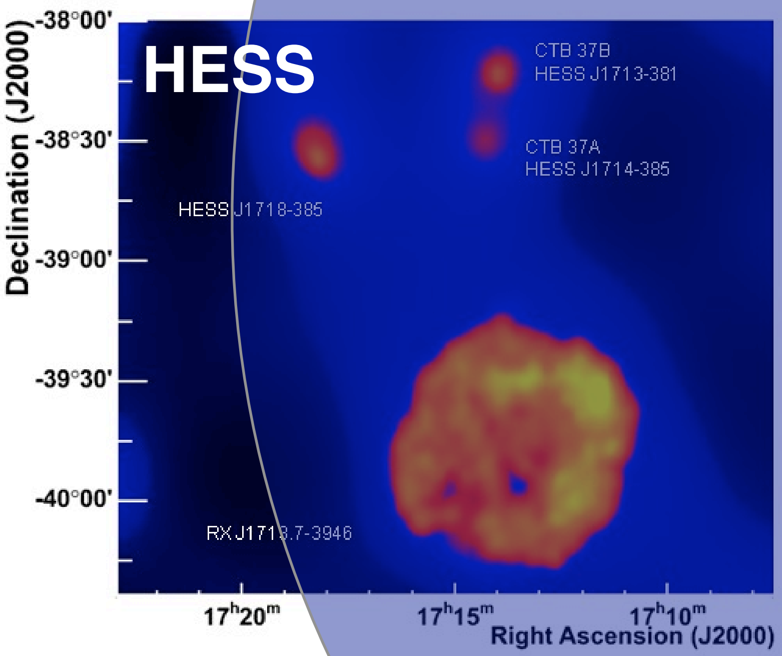

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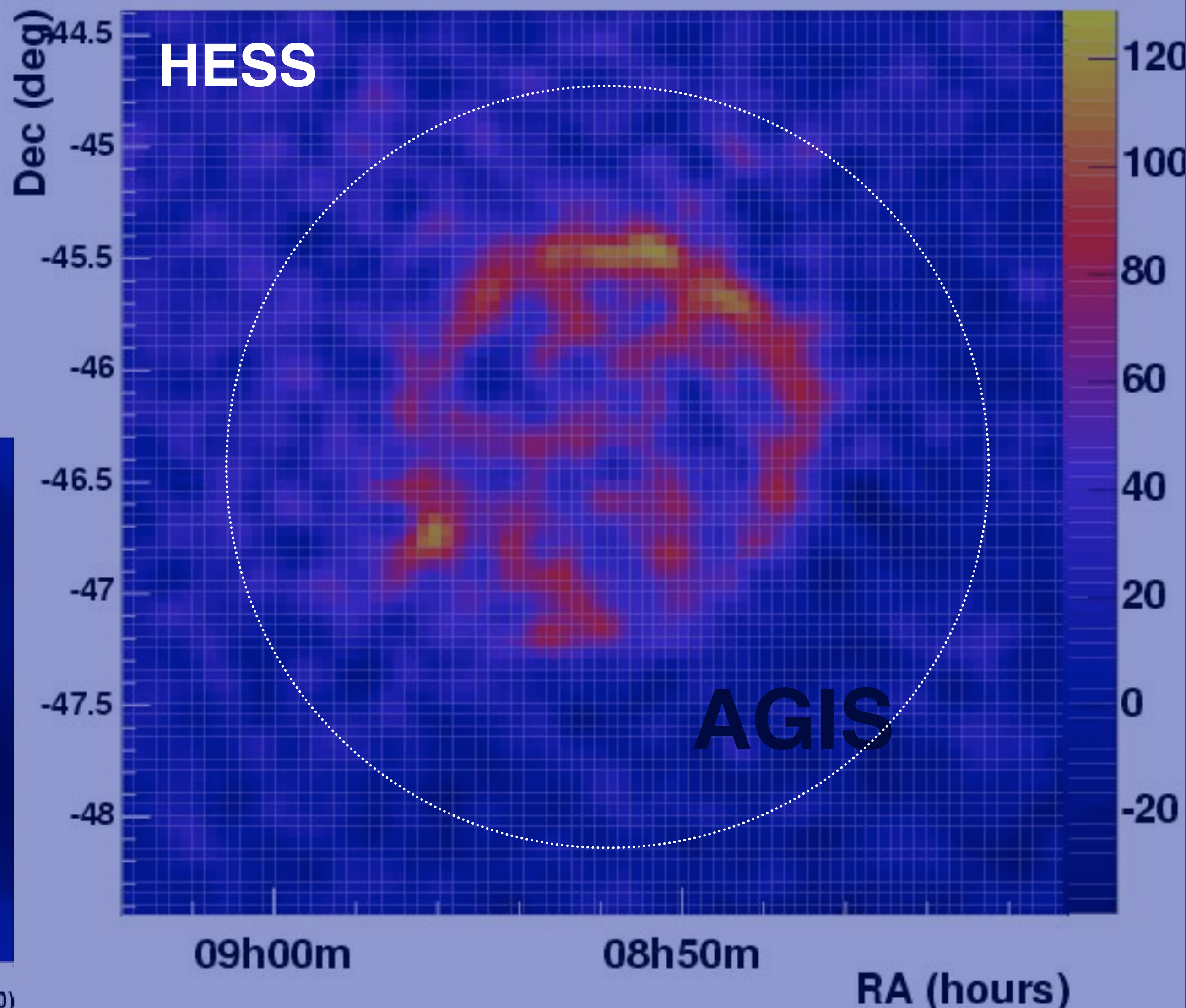

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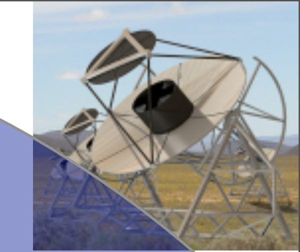

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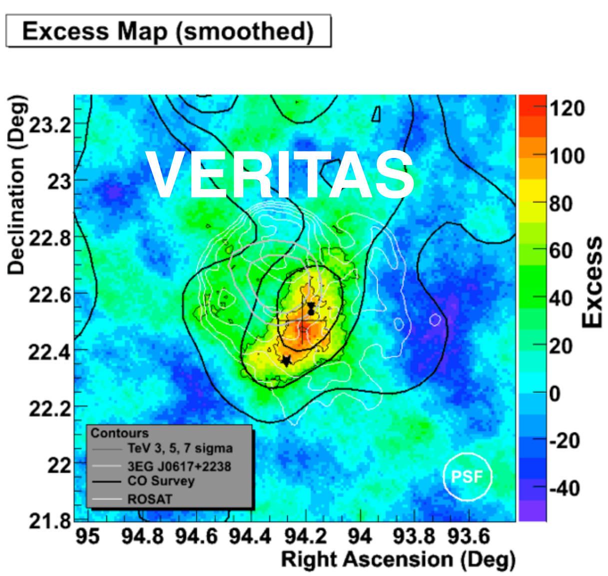

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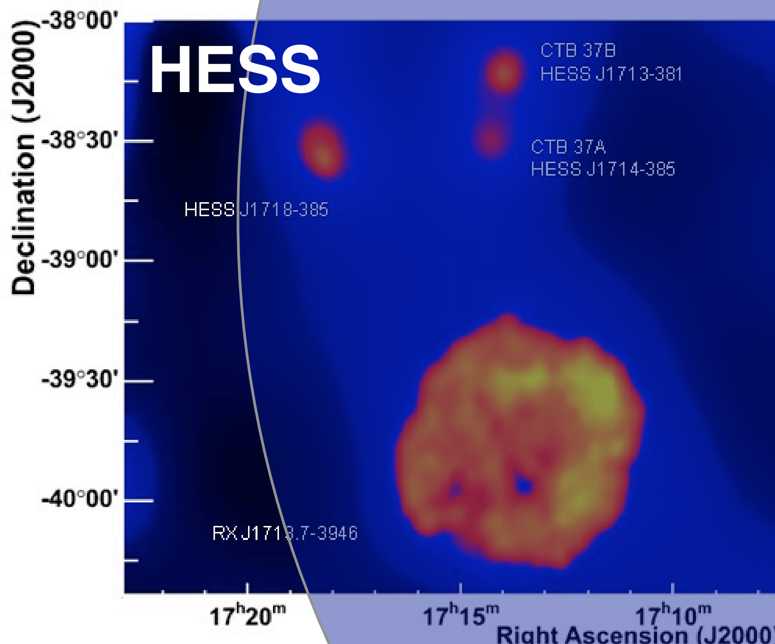

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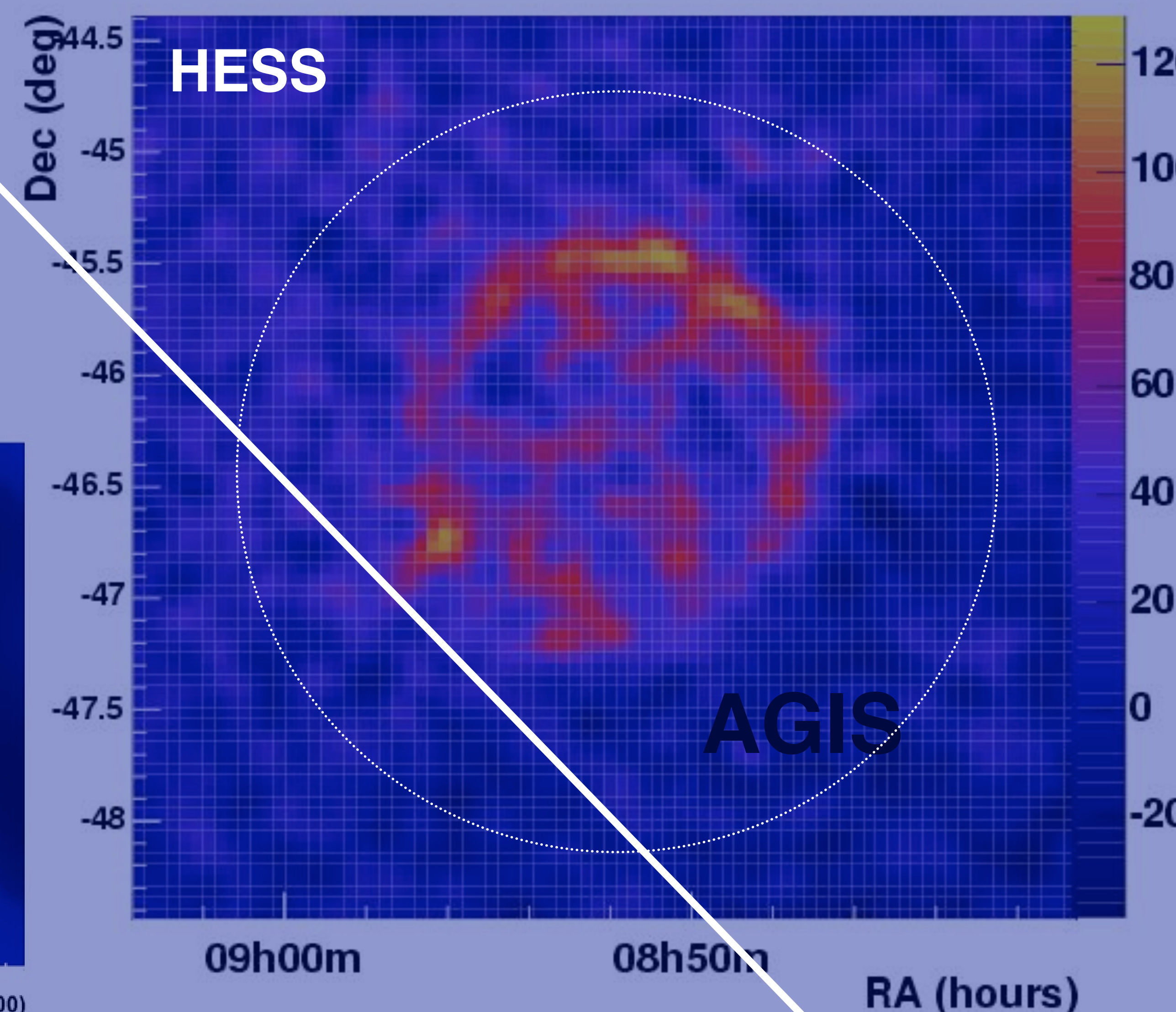

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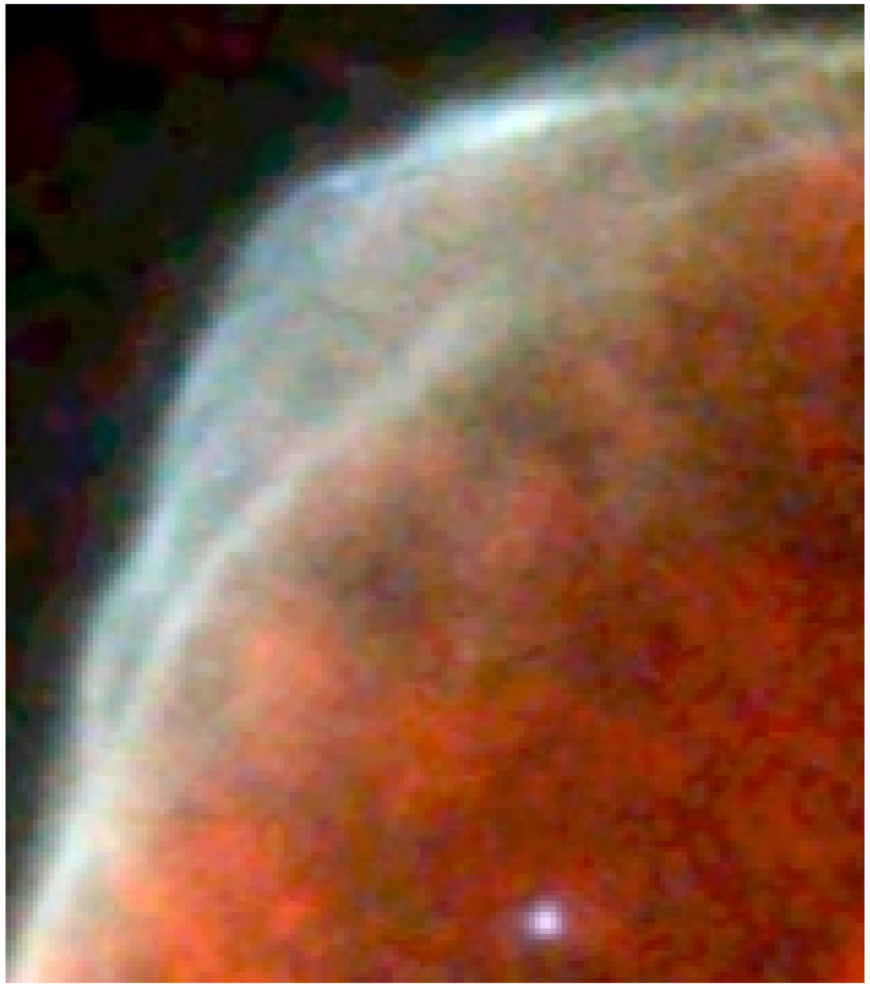
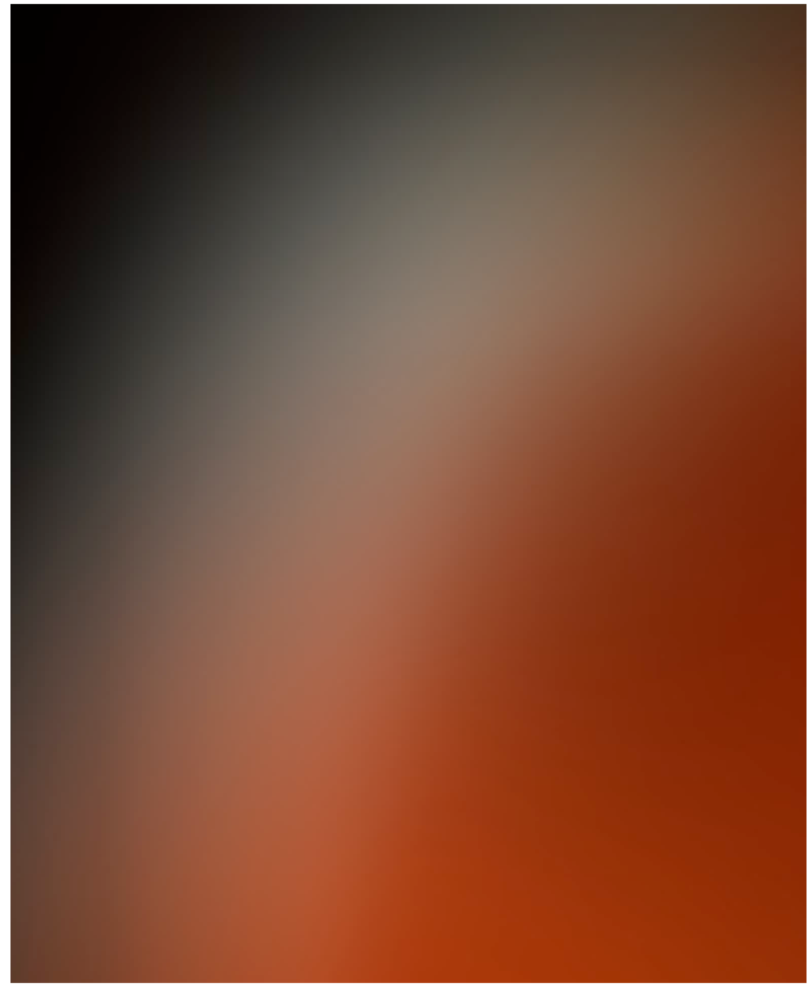


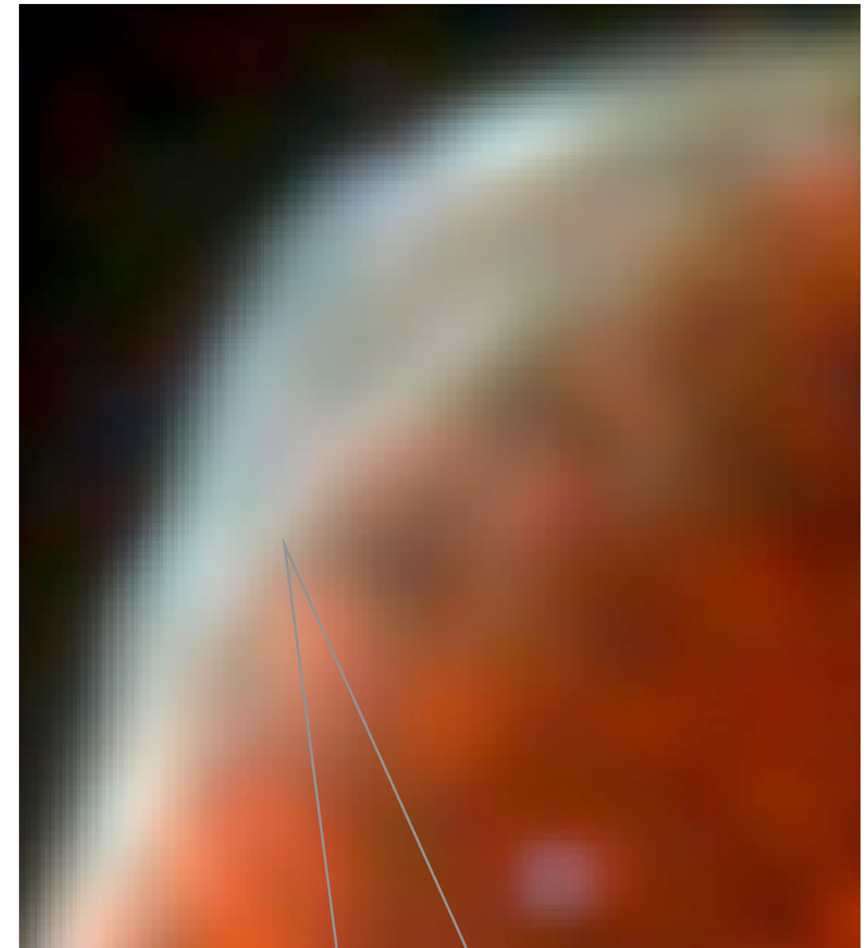
0.004°

XMM 10 keV



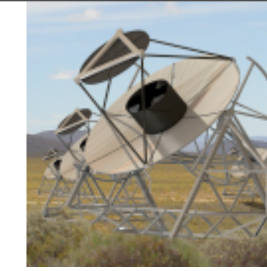
0.1°

With current generation IACT



0.02°

With AGIS @ few TeV



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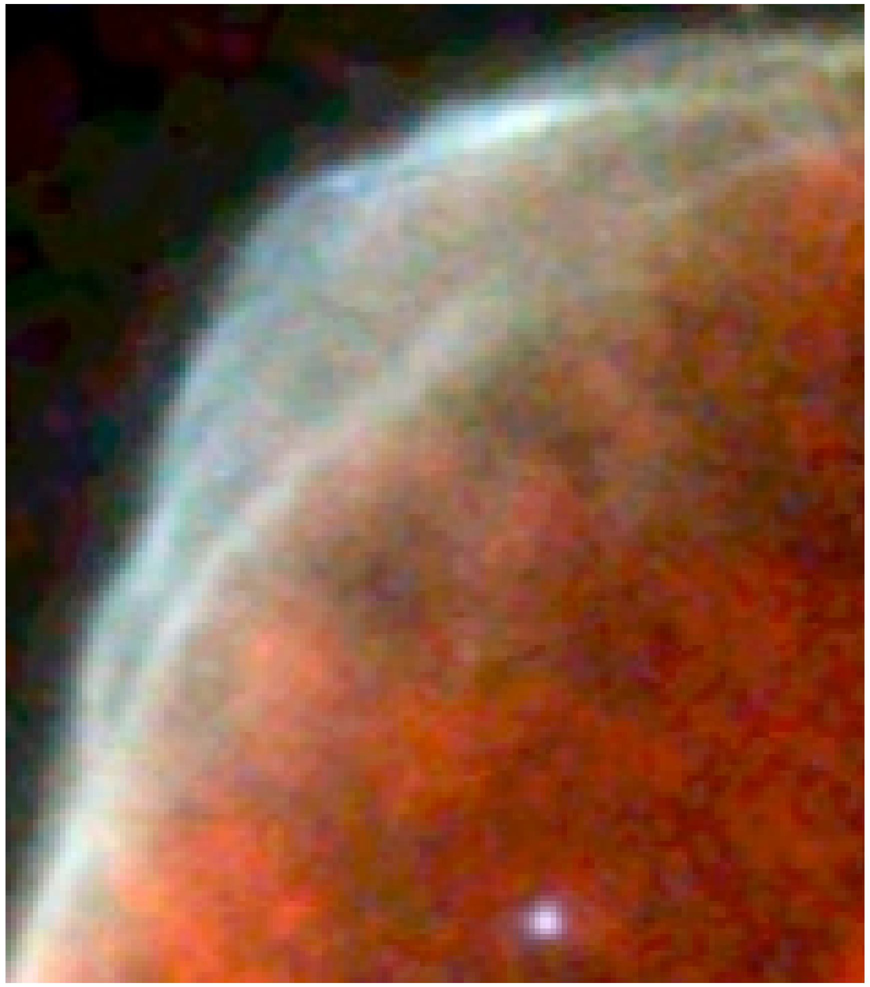

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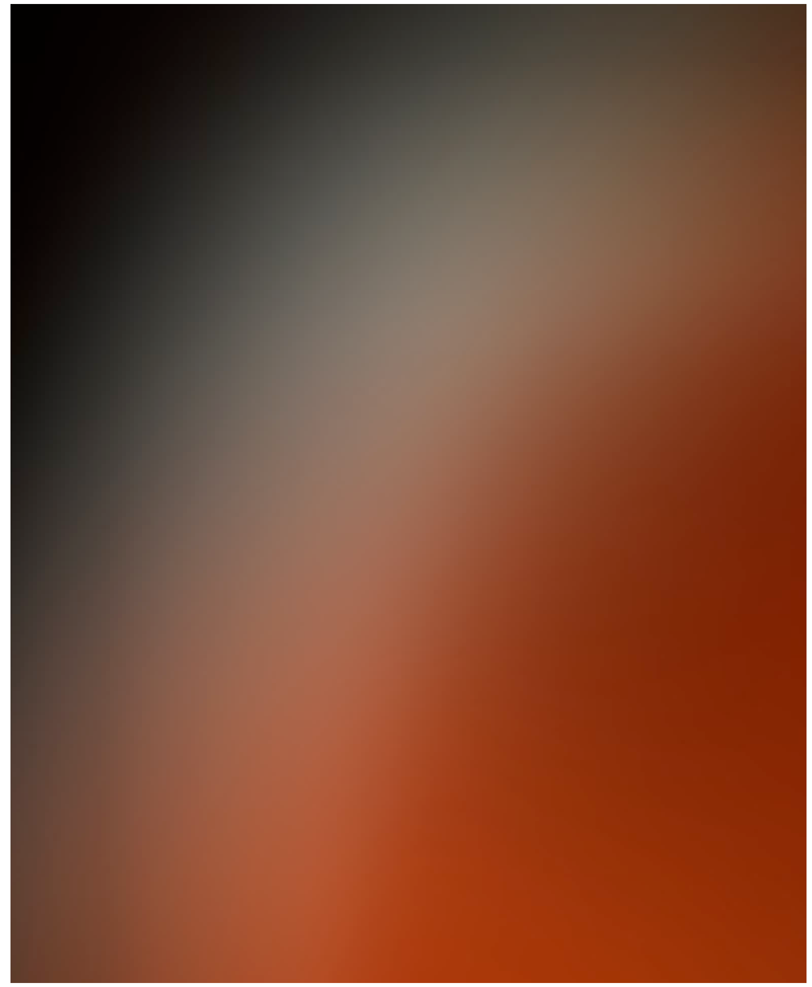

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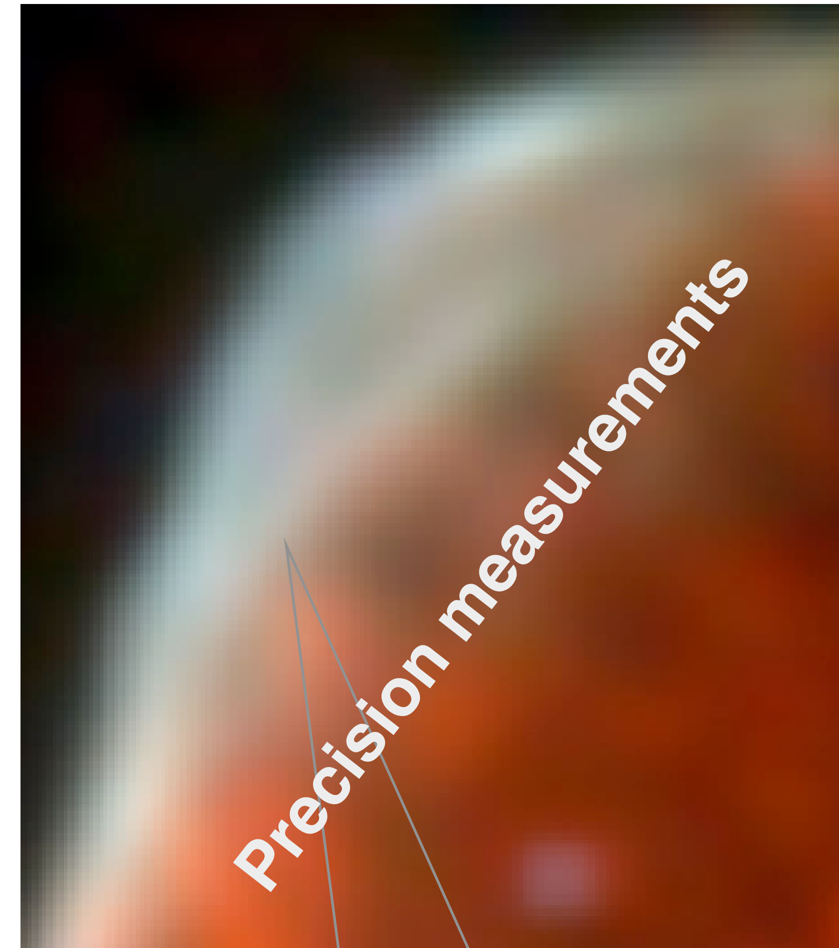

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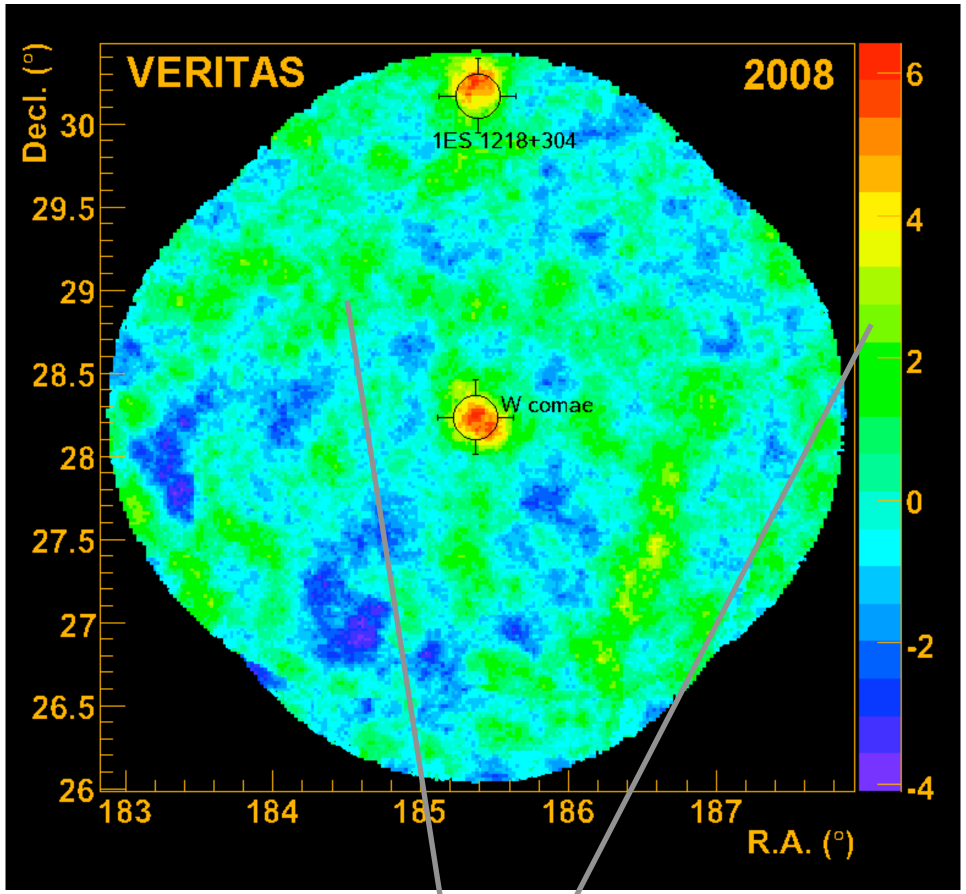
With AGIS @ few TeV

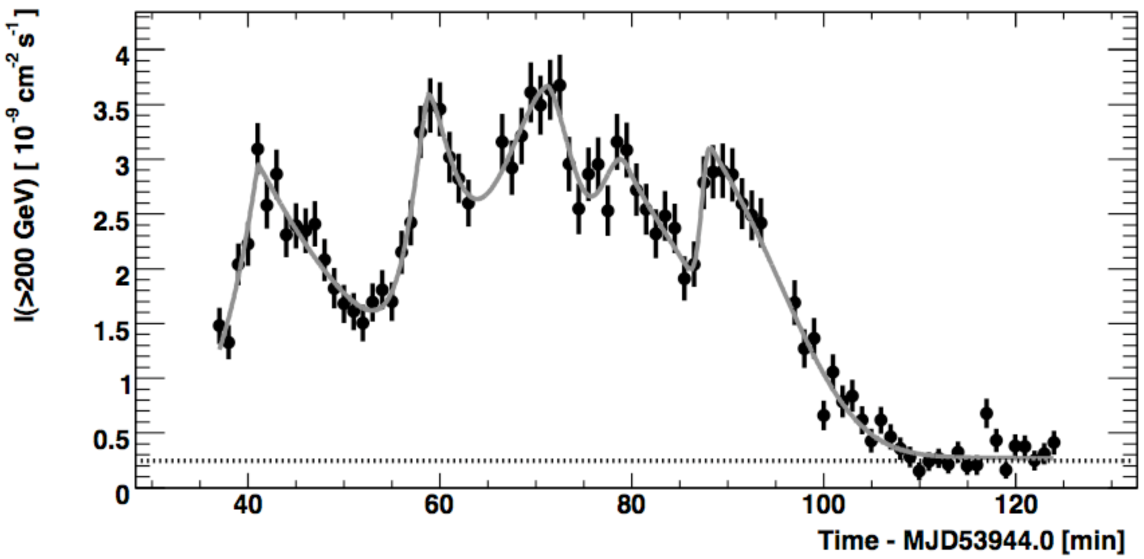
Physics: Galaxies/AGNs

- **AGIS will:**
  - **detect 100's of AGN**
  - **probe space time & intergal. medium**

  - **probe SMBH - Jet connection**
  - **e, p, n in relativistic jet**
  - **always > 1 γ-ray AGN in FOV**
  - **flux variability on ~ 1 sec.**

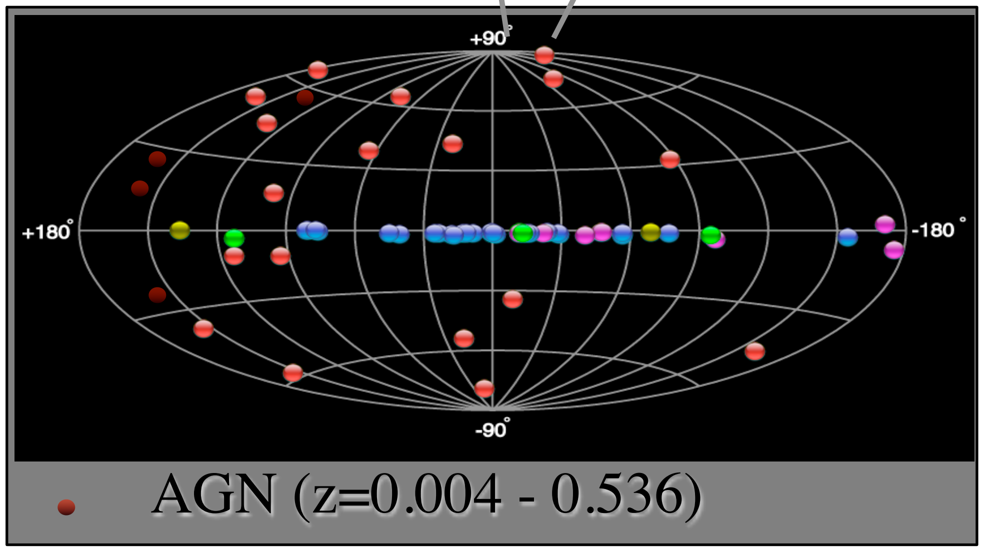


VERITAS: Acciari et al. 2009, ApJL, 684, L73



HESS: Aharonian et al., arXiv:0706.0797v2 (2007))

AGIS: Effective Area



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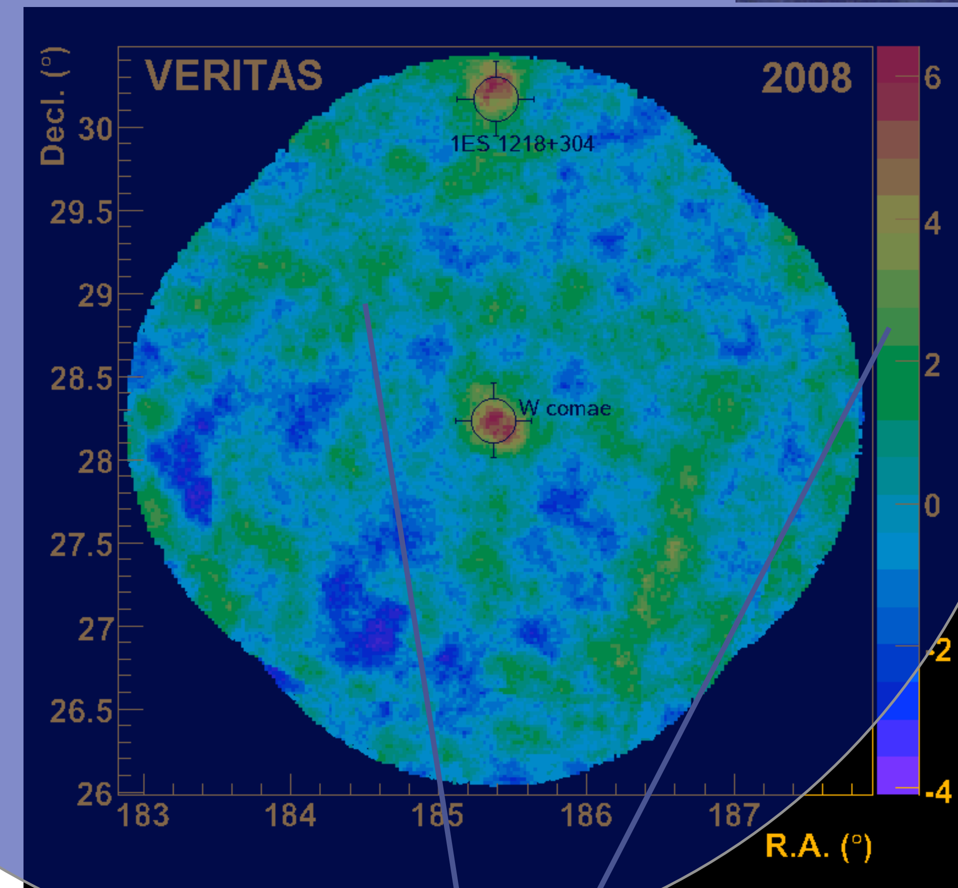

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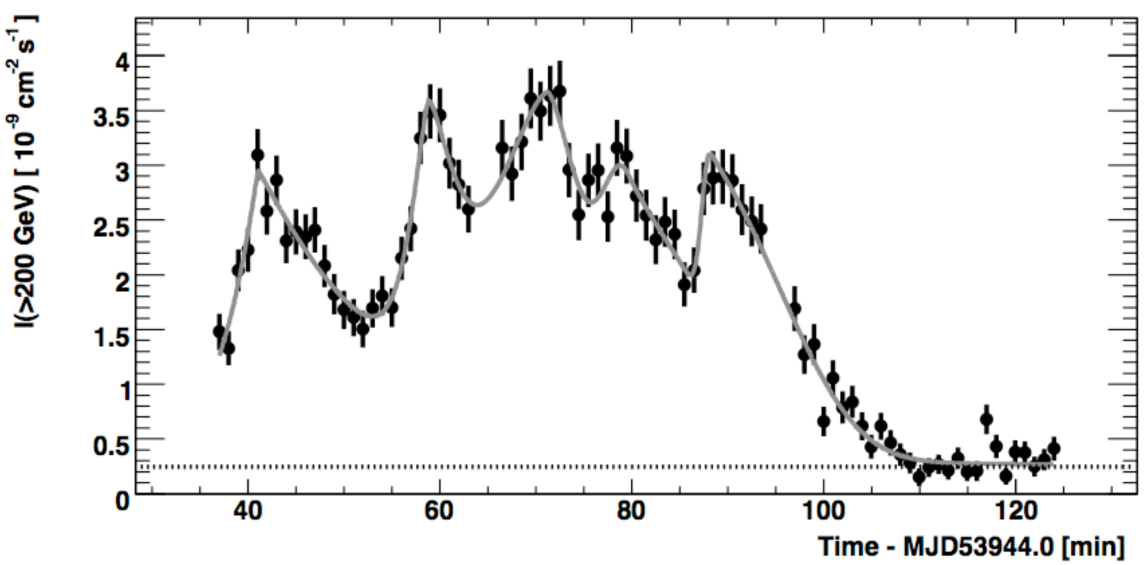

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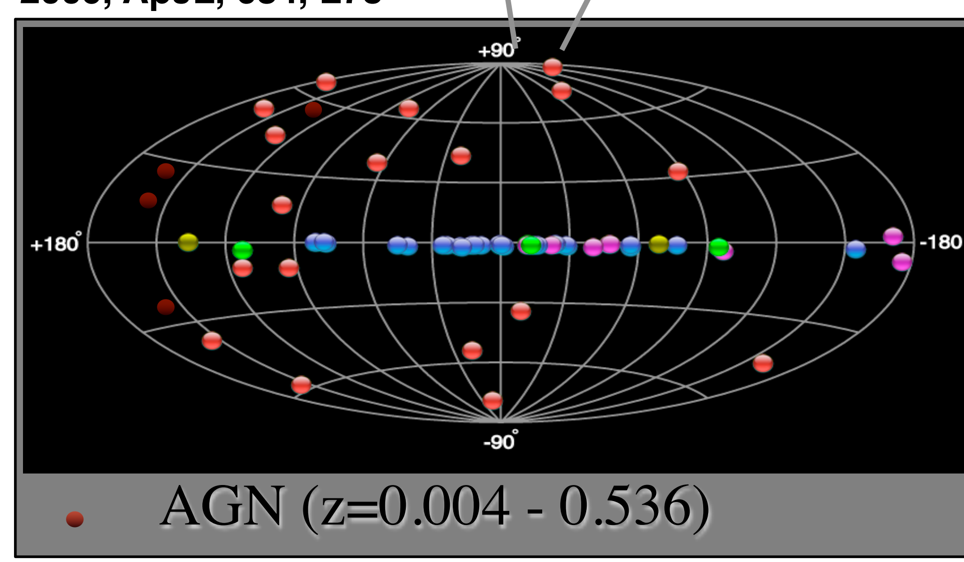
AGIS: Effective Area

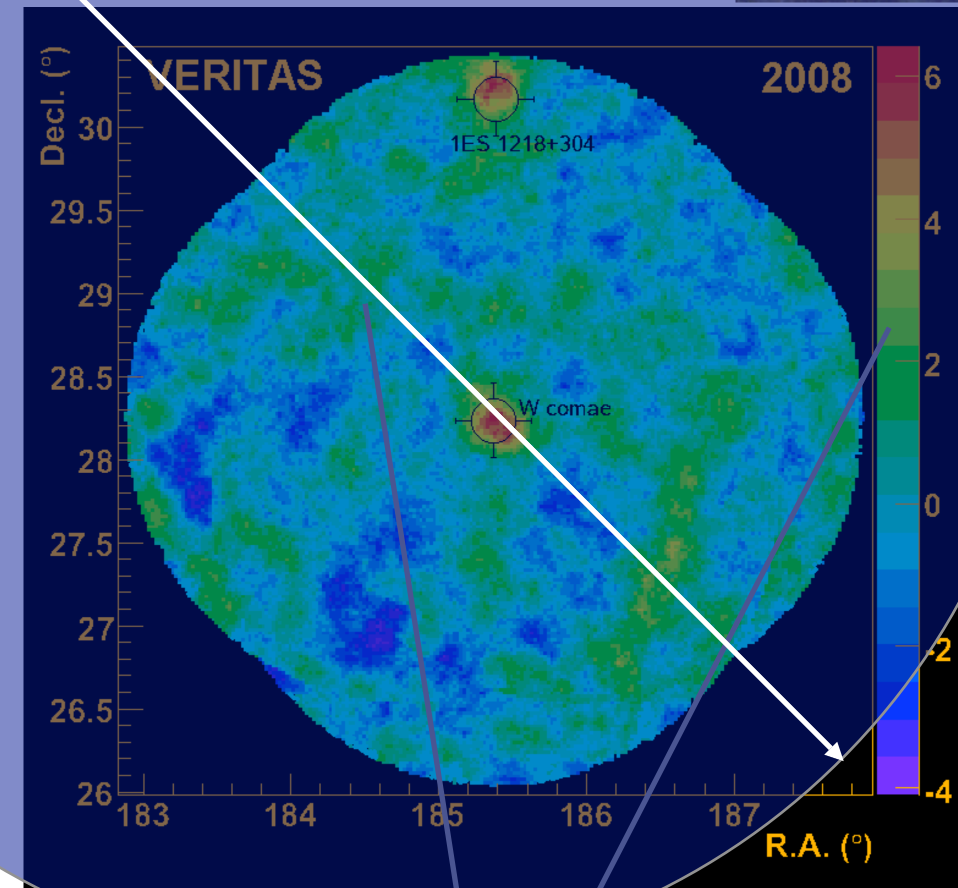


Physics: Galaxies/AGNs

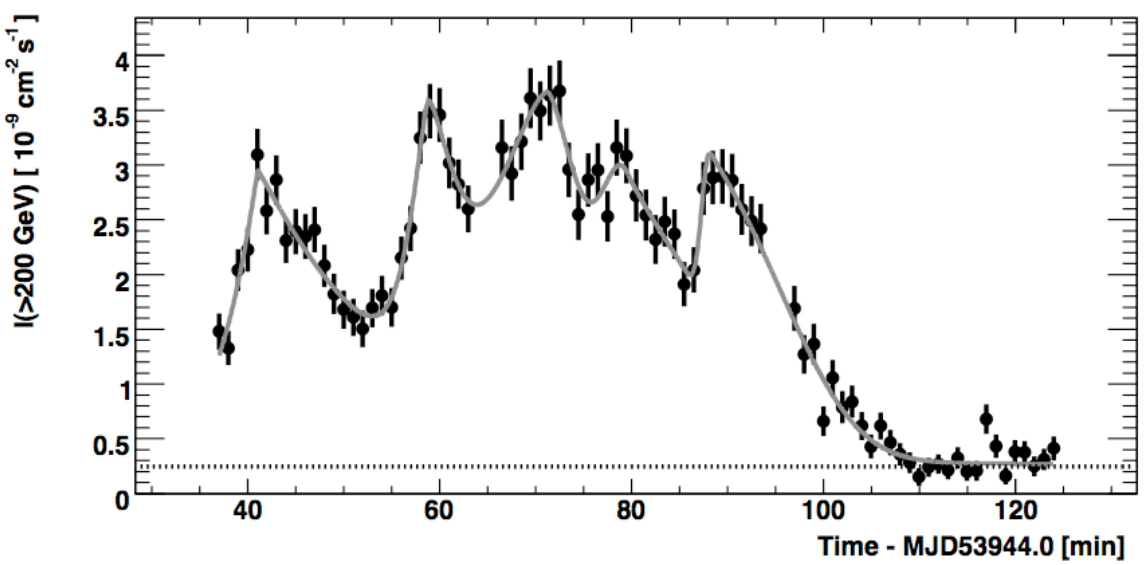
- **AGIS will:**
  - detect 100's of AGN
  - probe space time & intergal. medium

  - probe SMBH - Jet connection
  - e, p, n in relativistic jet
  - always > 1 γ-ray AGN in FOV
  - flux variability on ~ 1 sec.

8°



VERITAS: Acciari et al. 2009, ApJL, 684, L73



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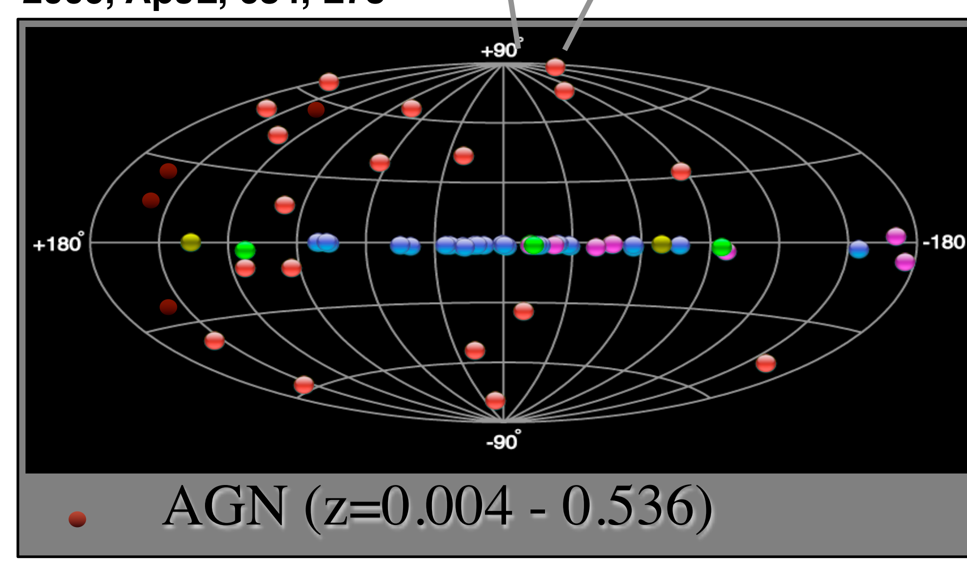

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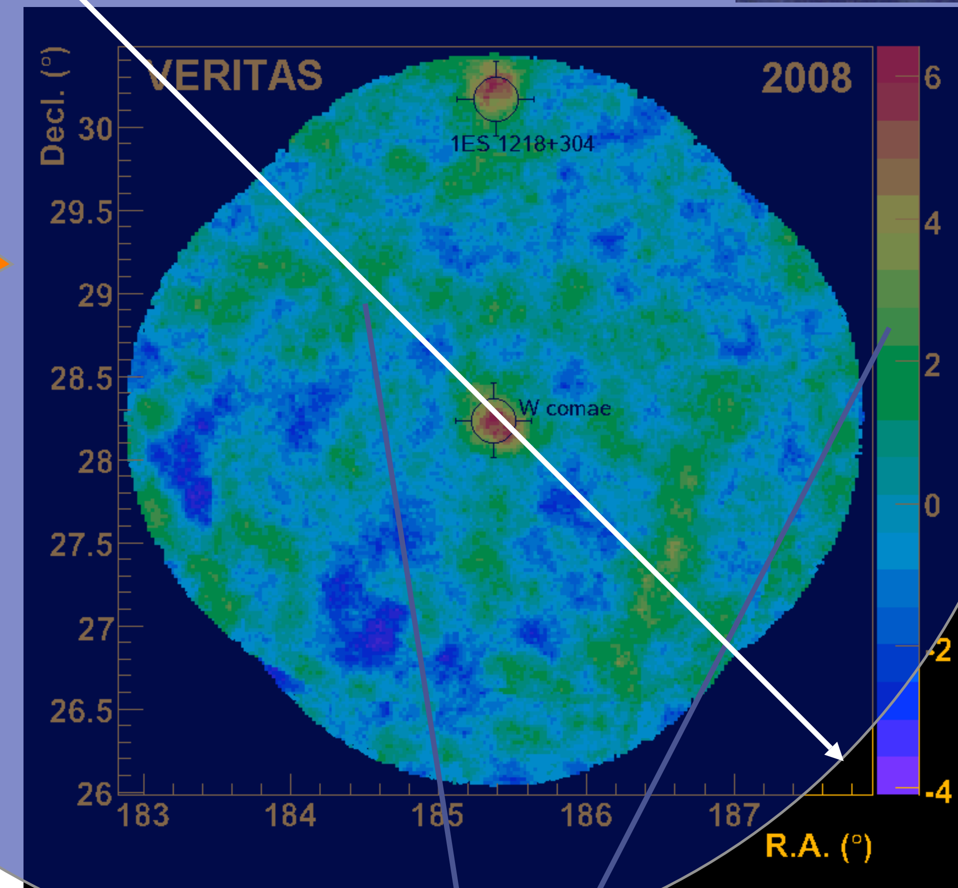

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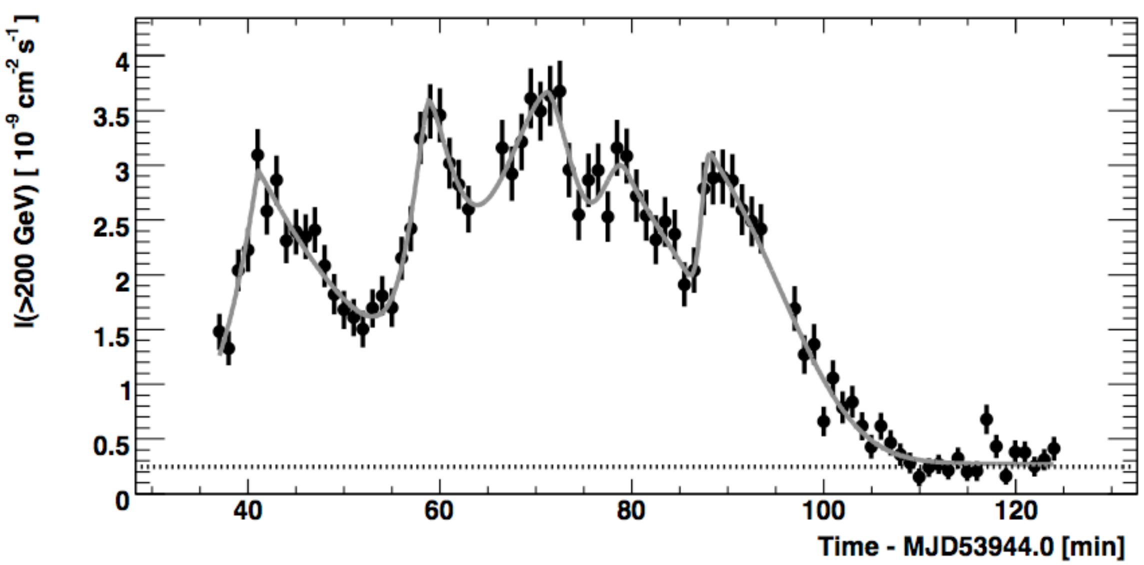

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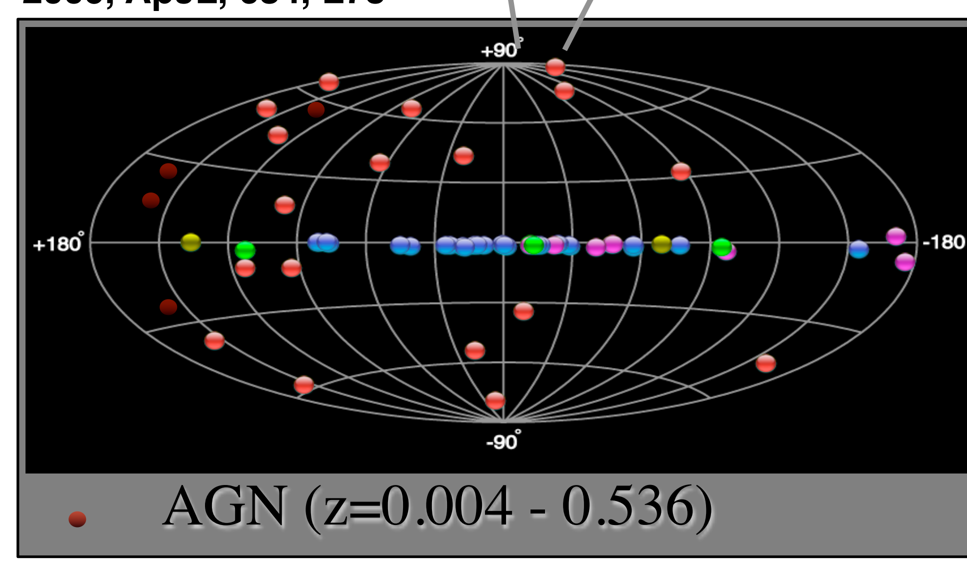

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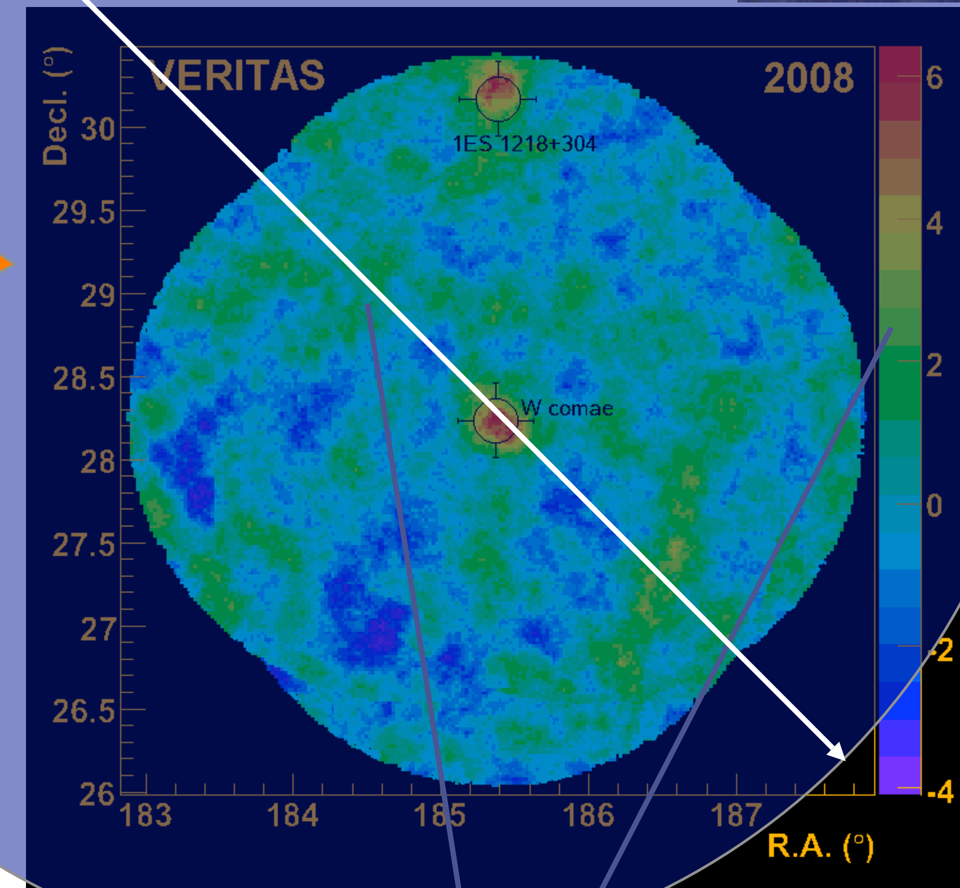
AGIS: Wide Field of View Imaging

8o



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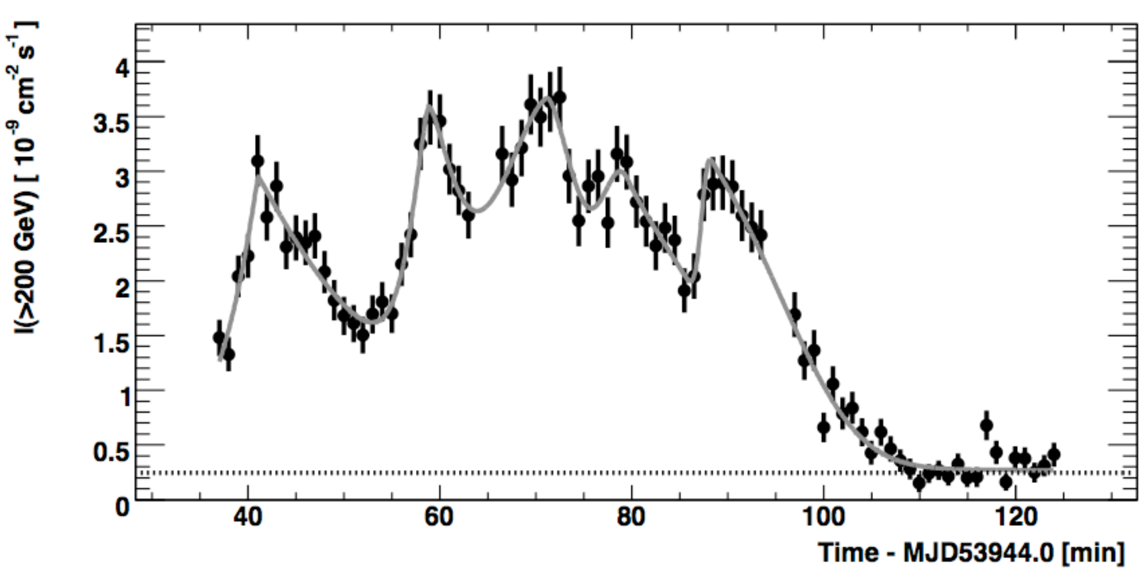

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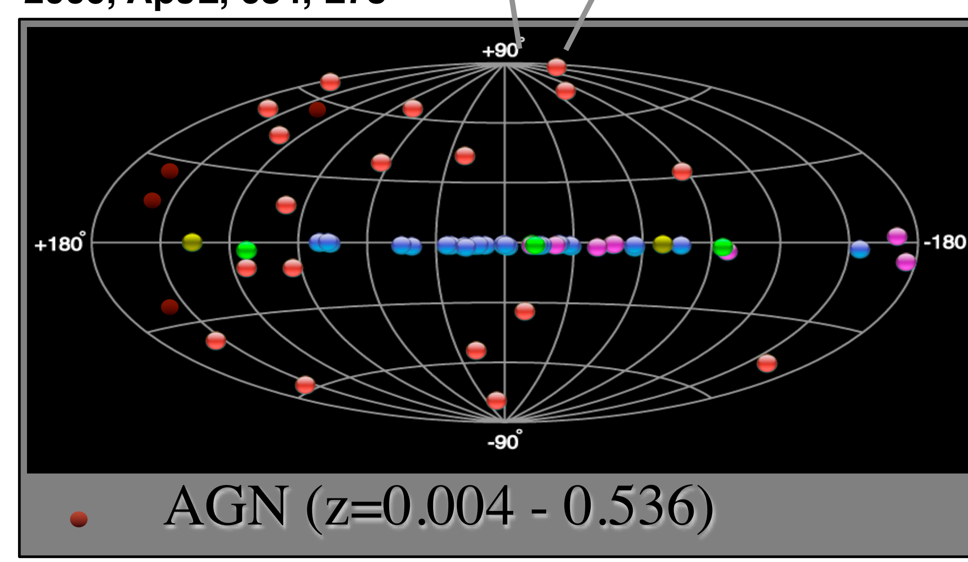

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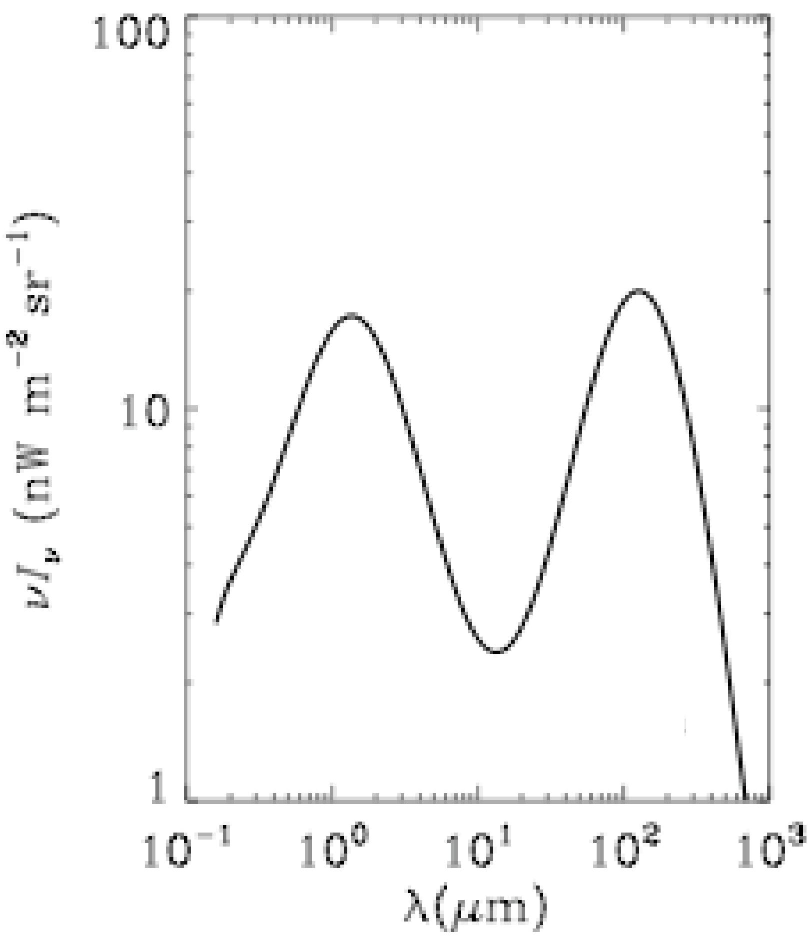
  - **EBL poorly understood: near - mid IR**
  - **TeV beam: $\gamma + \gamma \rightarrow e^{+} + e^{-}$ interaction**
  - **measure CIRB: absorption(z)**

Star/galaxy Formation z<5

AGNs z<5

Pop III z ~ 7 - 30



Relics?

Truly diffuse Component?

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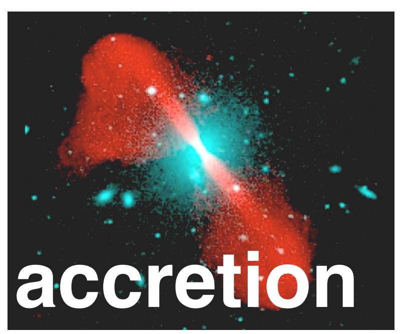

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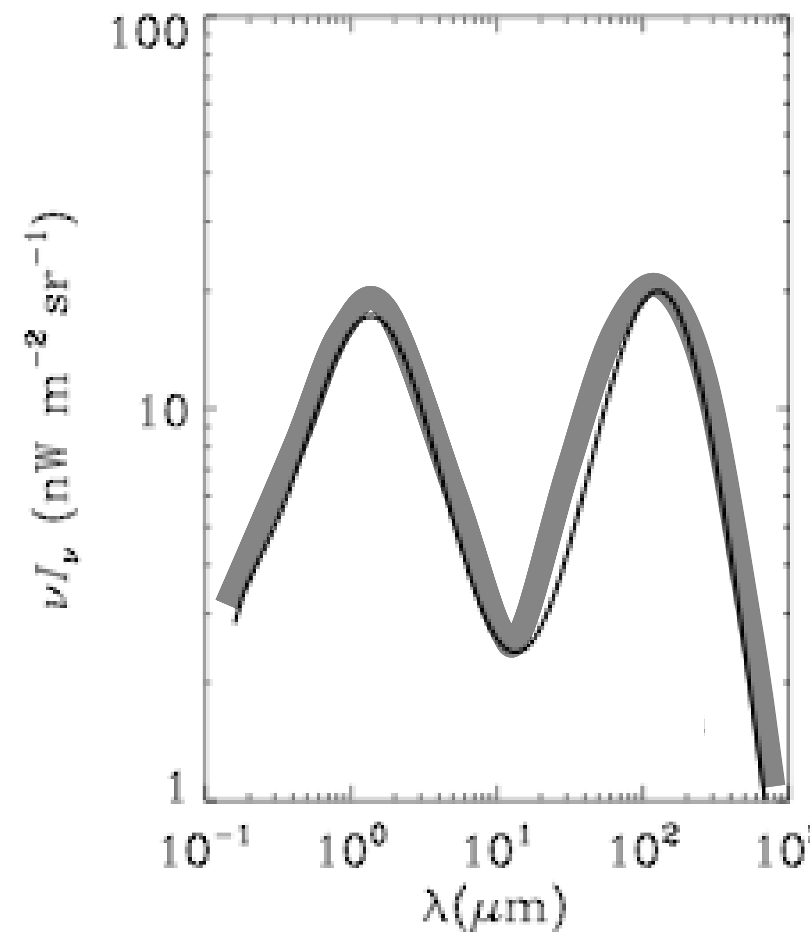

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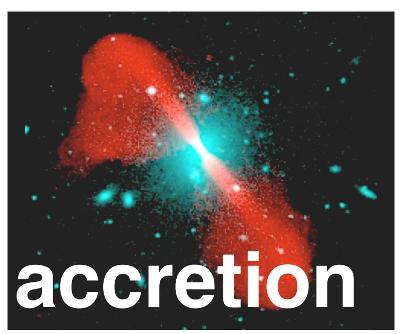

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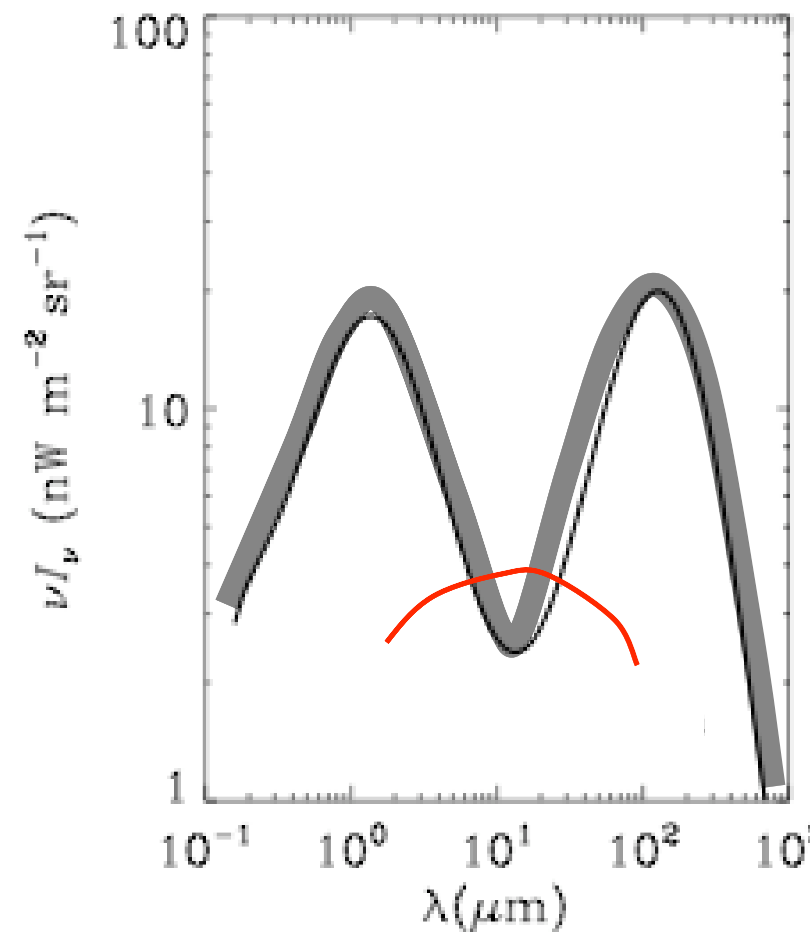

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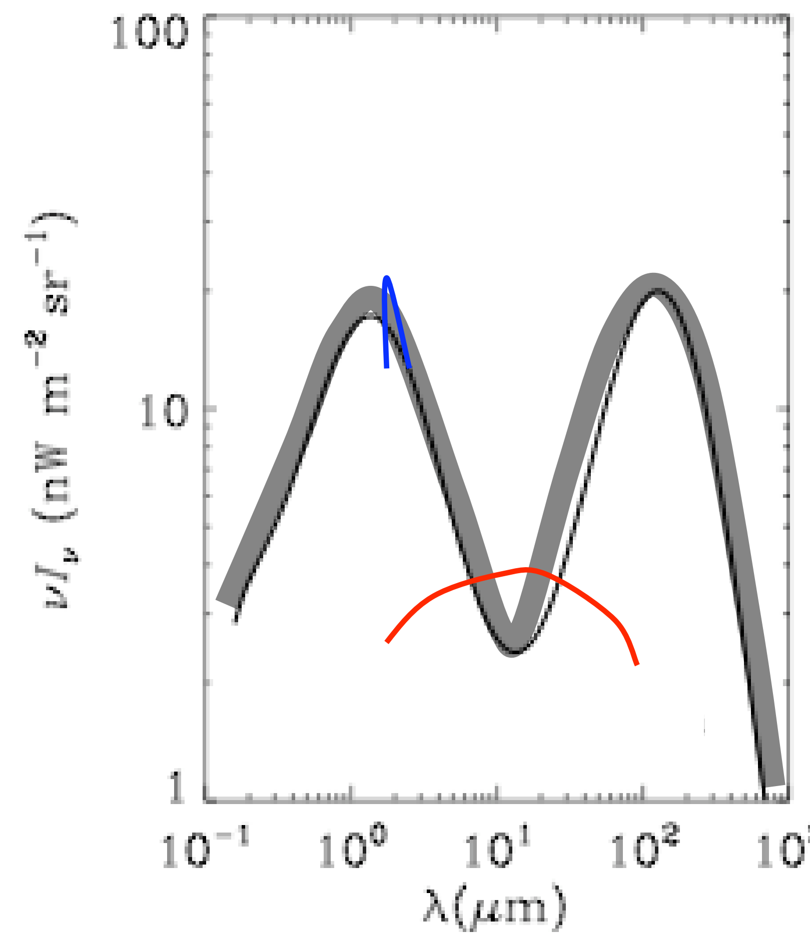

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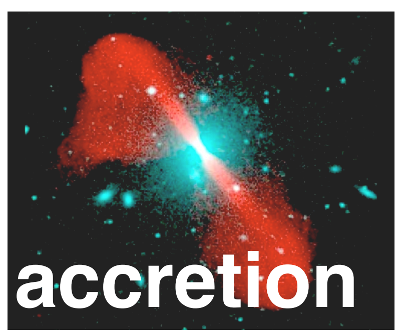

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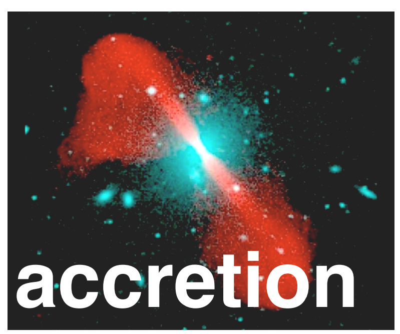

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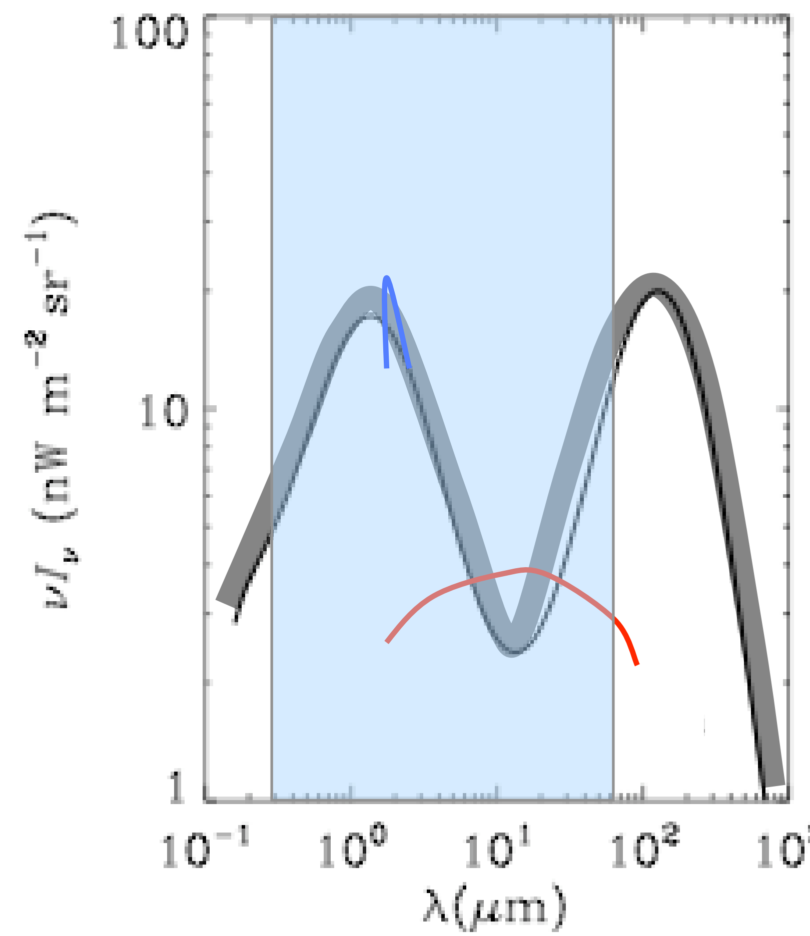

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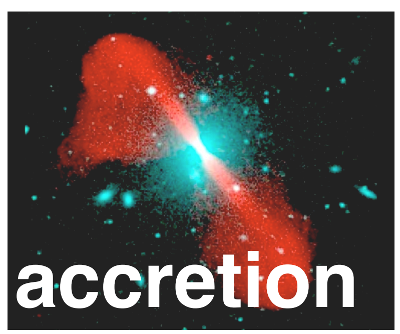

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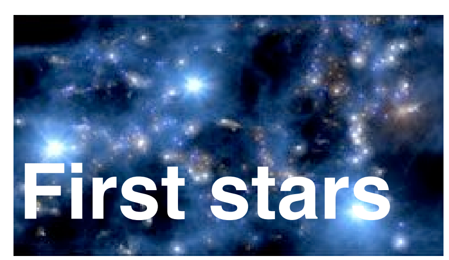

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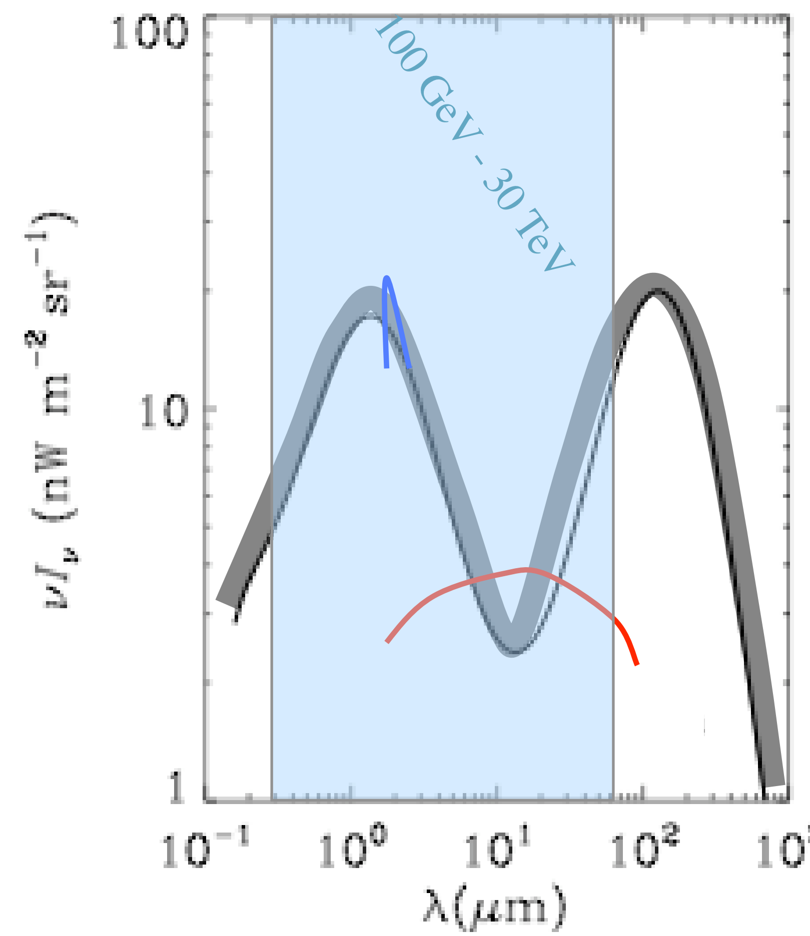

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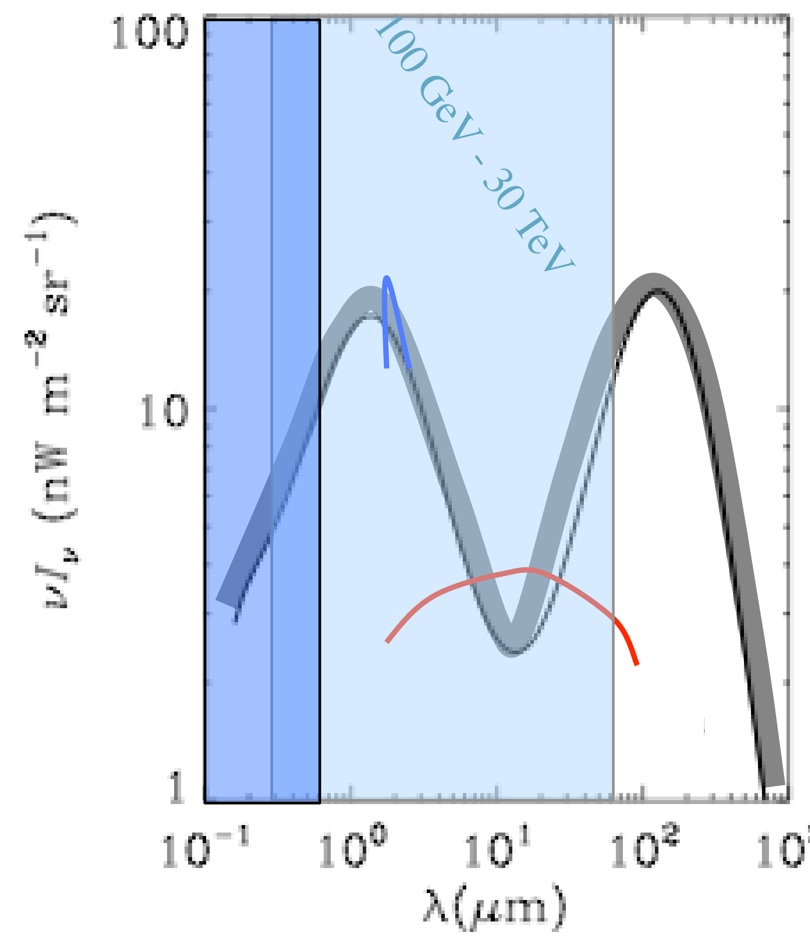

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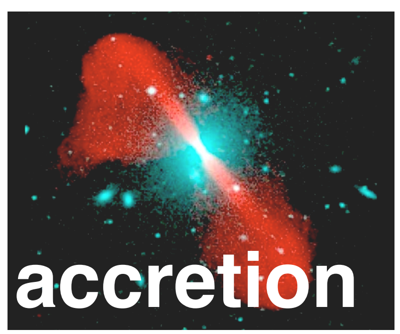

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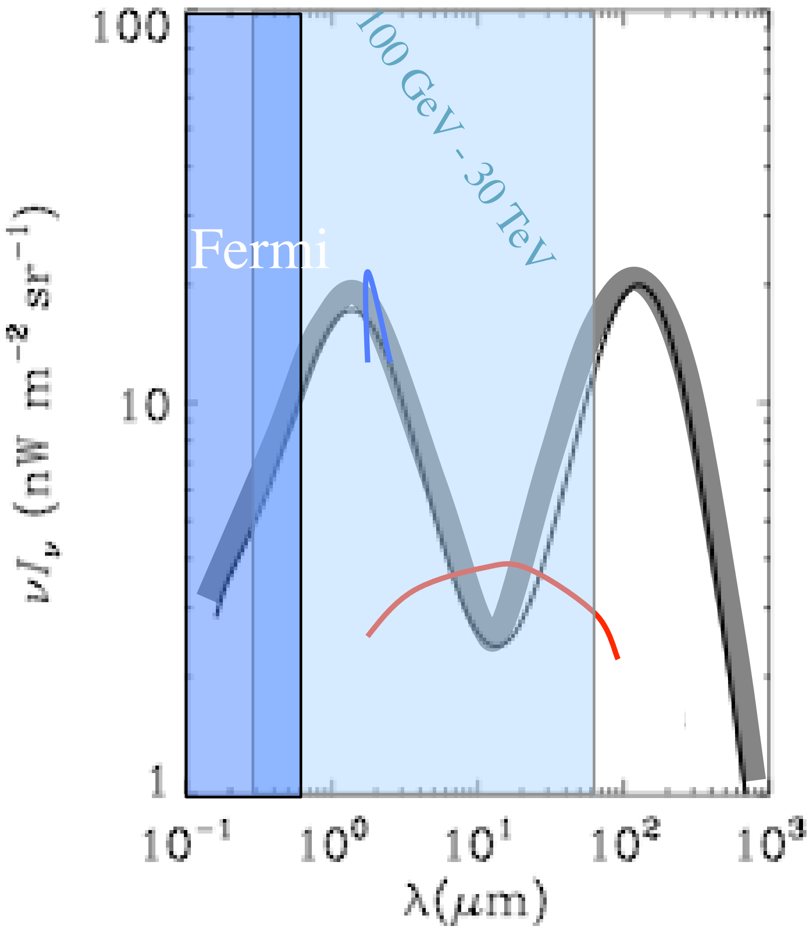

Relics?

Truly diffuse Component?

Dark Matter Search

- **Detection of dark matter signal from Space is complementary**
  - **Accelerator production**
    - **Precise measurements of DM properties: mass, cross section**
    - **UED (KK) vs SUSY**
  - **Direct detection**
    - **Good sensitivity to dark matter**
    - **Measurement of local dark matter density**
  - **Indirect detection**
    - **Distribution of WIMP in the Universe**

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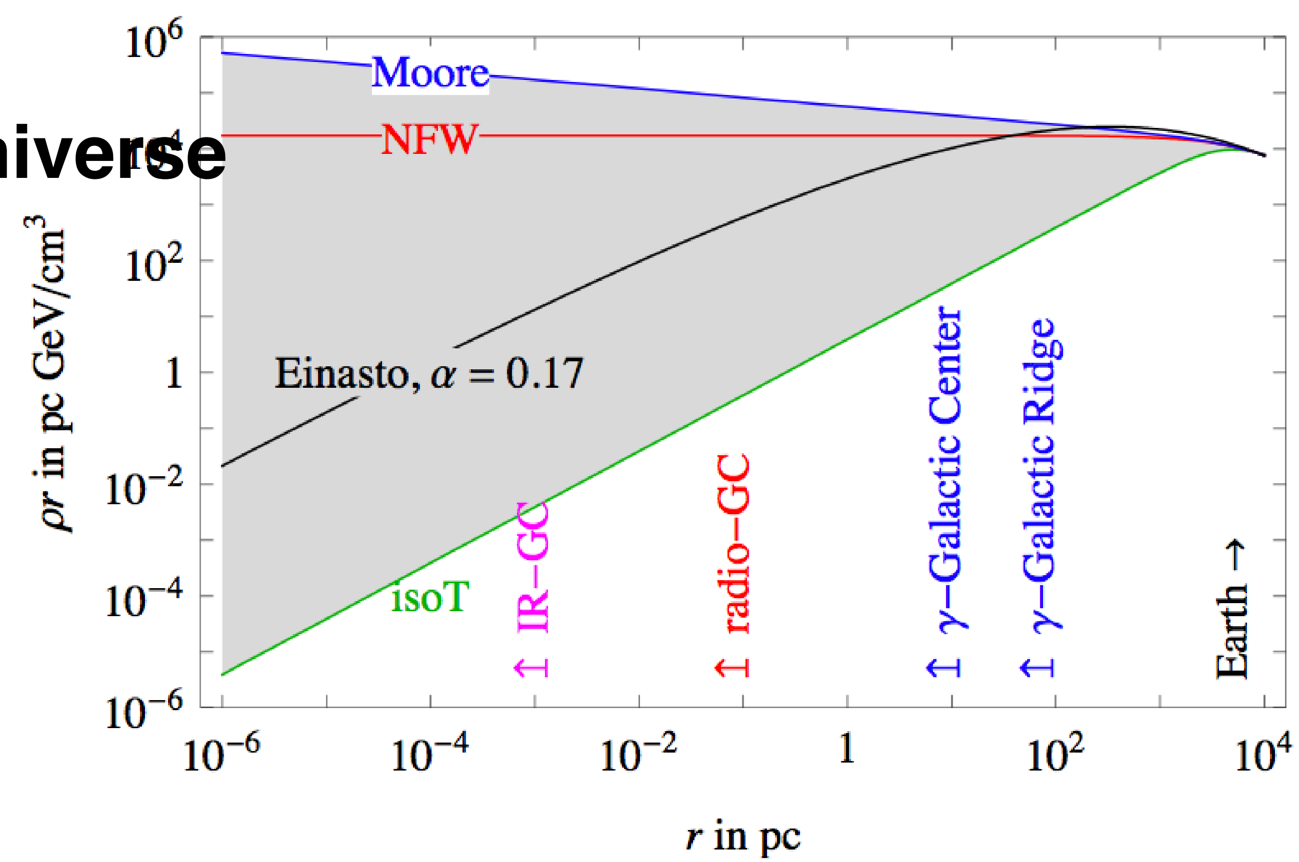
$$\frac{d\Phi_\gamma}{dE_\gamma}(E_\gamma,\varphi,\theta) = \boxed{\frac{1}{4\pi}\frac{< \sigma_{ann} v >}{2m^2_{WIMP}}\sum_f \frac{dN^f_\gamma}{dE_\gamma}B_f} \times \boxed{\int_{\Delta\Omega\ (\varphi,\theta)} d\Omega' \int_{los} \rho^2(r(l,\varphi'))\, dl(r,\varphi')}$$

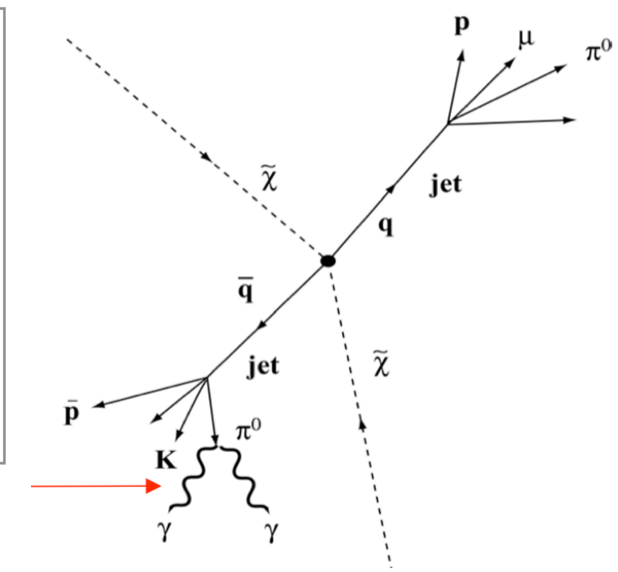
$'-.,"'/.'*)



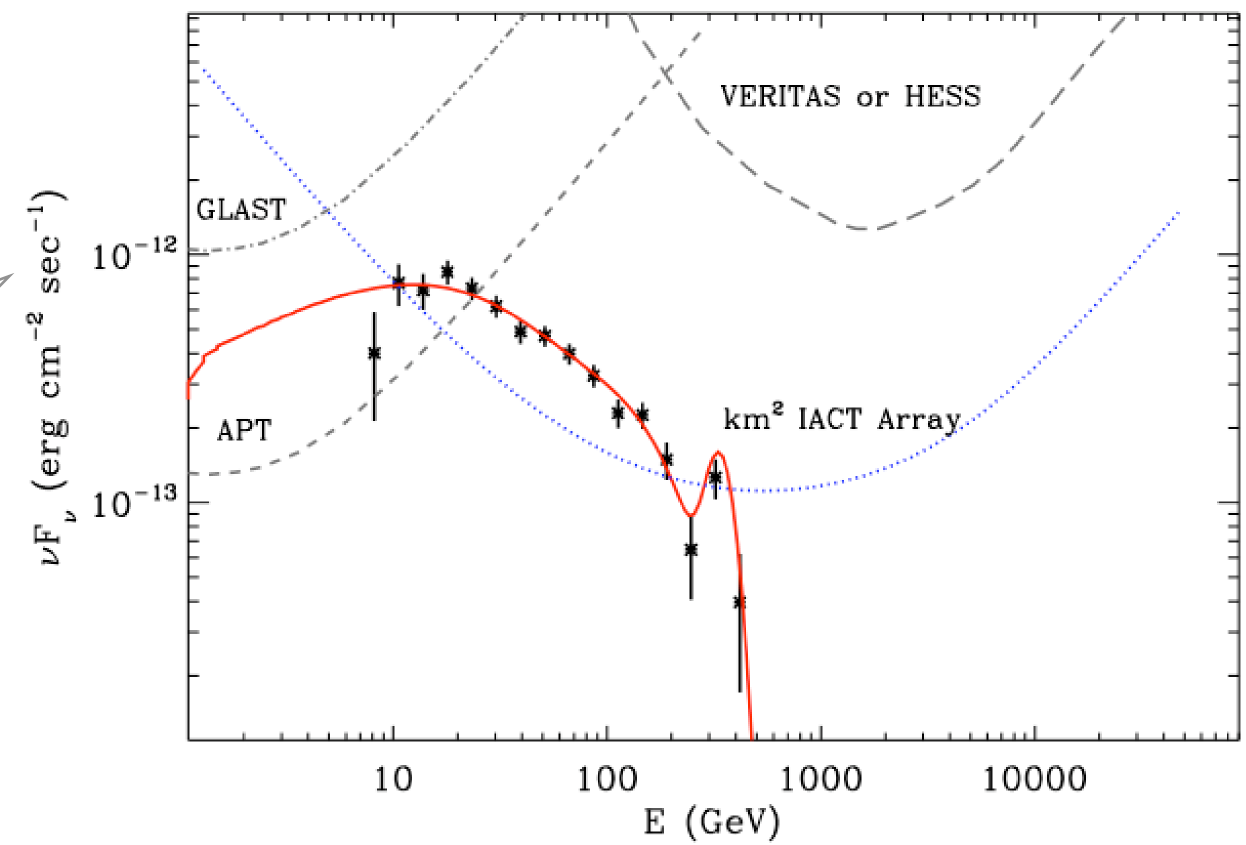
Dark Matter Search

- ❖ **AGIS:**
  - probe the annihilation cross-section
  - measure the WIMP mass
  - usher the era of "dark matter astronomy"
  - Complimentary to Fermi
    - ✦ Deeper observation of Fermi sources
    - ✦ Wider mass coverage (in VHE)

AGIS: Effective Area



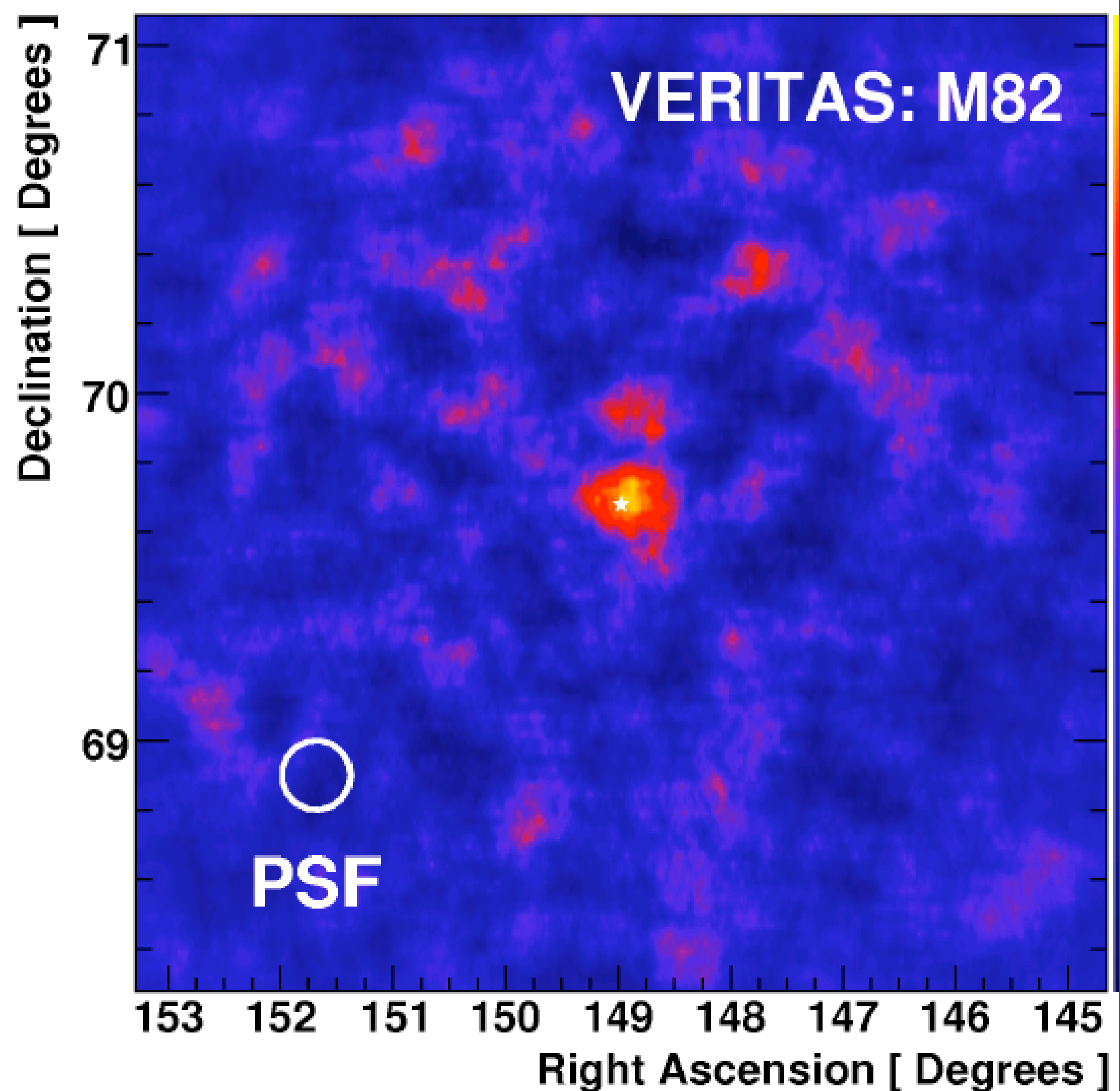
AGIS: sensitivity



Discovery Potential

- Discovery of TeV γ-rays from starburst galaxy M82
  - Probing cosmic-rays from outside our galaxy
  - Dark Matter component possible in SB-galaxies
  - flux ~ 9 mCrab, at the limit of VERITAS, HESS (139 hour exposure)

- VERITAS/Fermi are pathfinders for AGIS:
  - sensitivity < 1 mCrab
  - probe angular extent



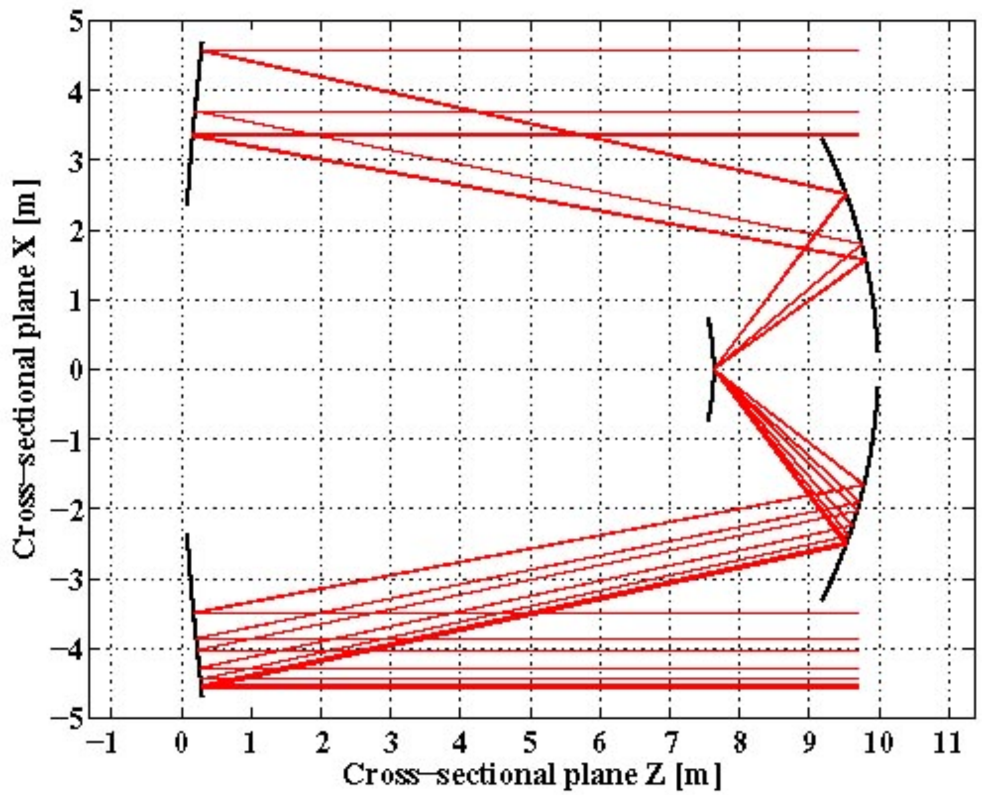
VERITAS: Acciari et al. 2009, submitted to Nature

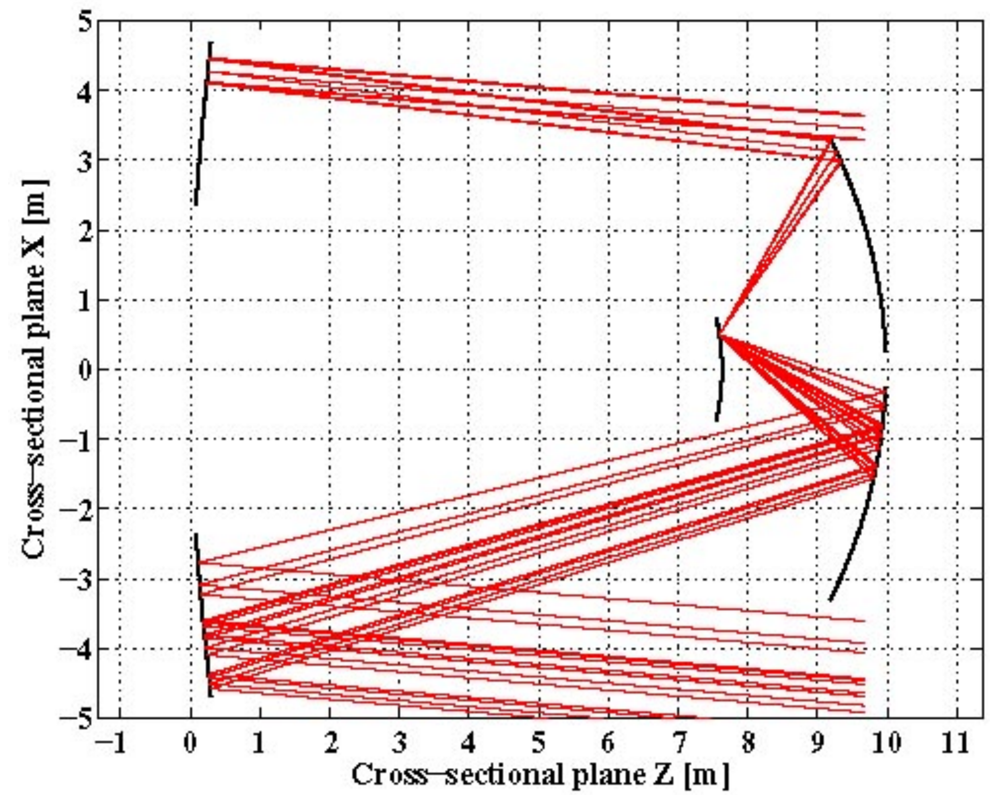
Technology Development Directions

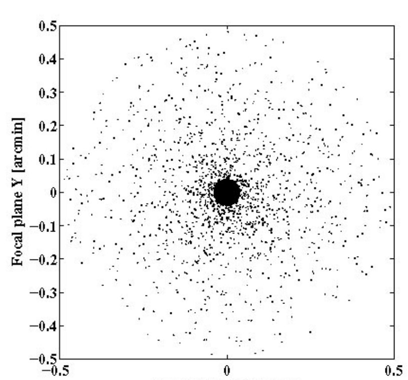
- Two mirror optics
  - Wide FOV ~8°
    - Better survey capability and larger collection area
  - Reduced plate scale: ~30 cm/deg → ~3 cm/deg
  - Shorter focus arms: fast slew (or less cost)
- Large number (~50) of telescopes and camera
  - Reliability of components
  - Modular design: easy to replace and maintain
  - Low power
  - Cost reduction
    - Currently $~1M each for telescope and camera
    - Optimization of mirror size, FOV, # of telescopes
      - Depends on component cost
  - More efficient trigger to reduce dead time

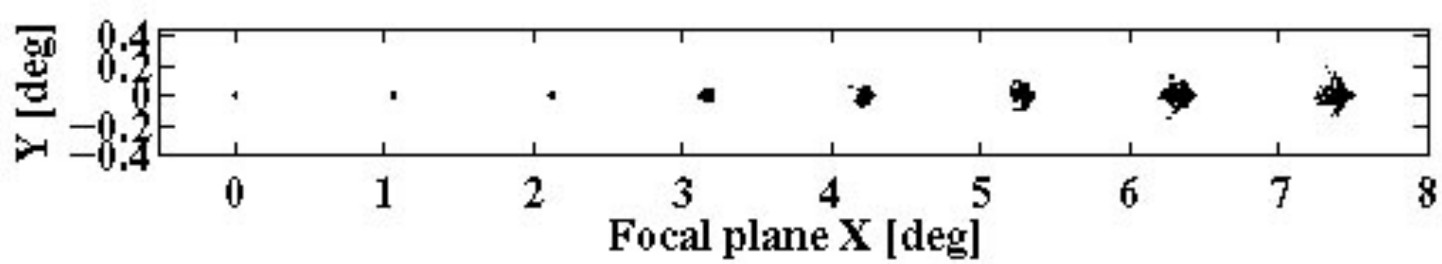
Optics Design

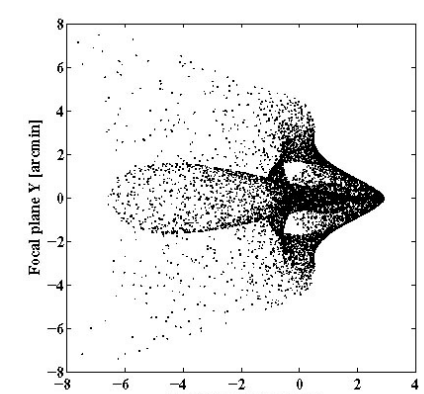
❖ **Two-mirror system required for wide FOV and/or small plate scale**









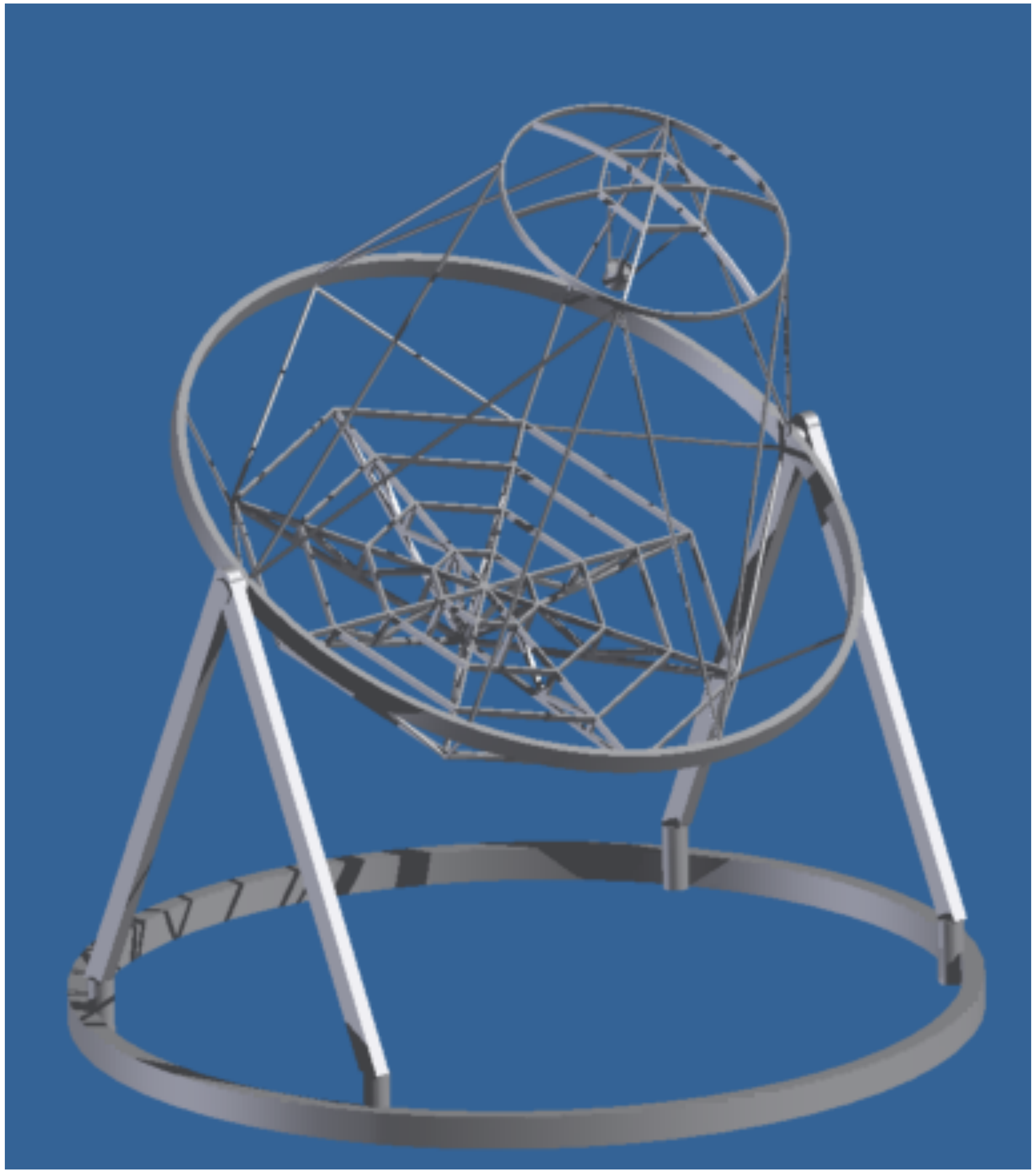


2RMS < 3’ over full 15 deg FoV can be achieved

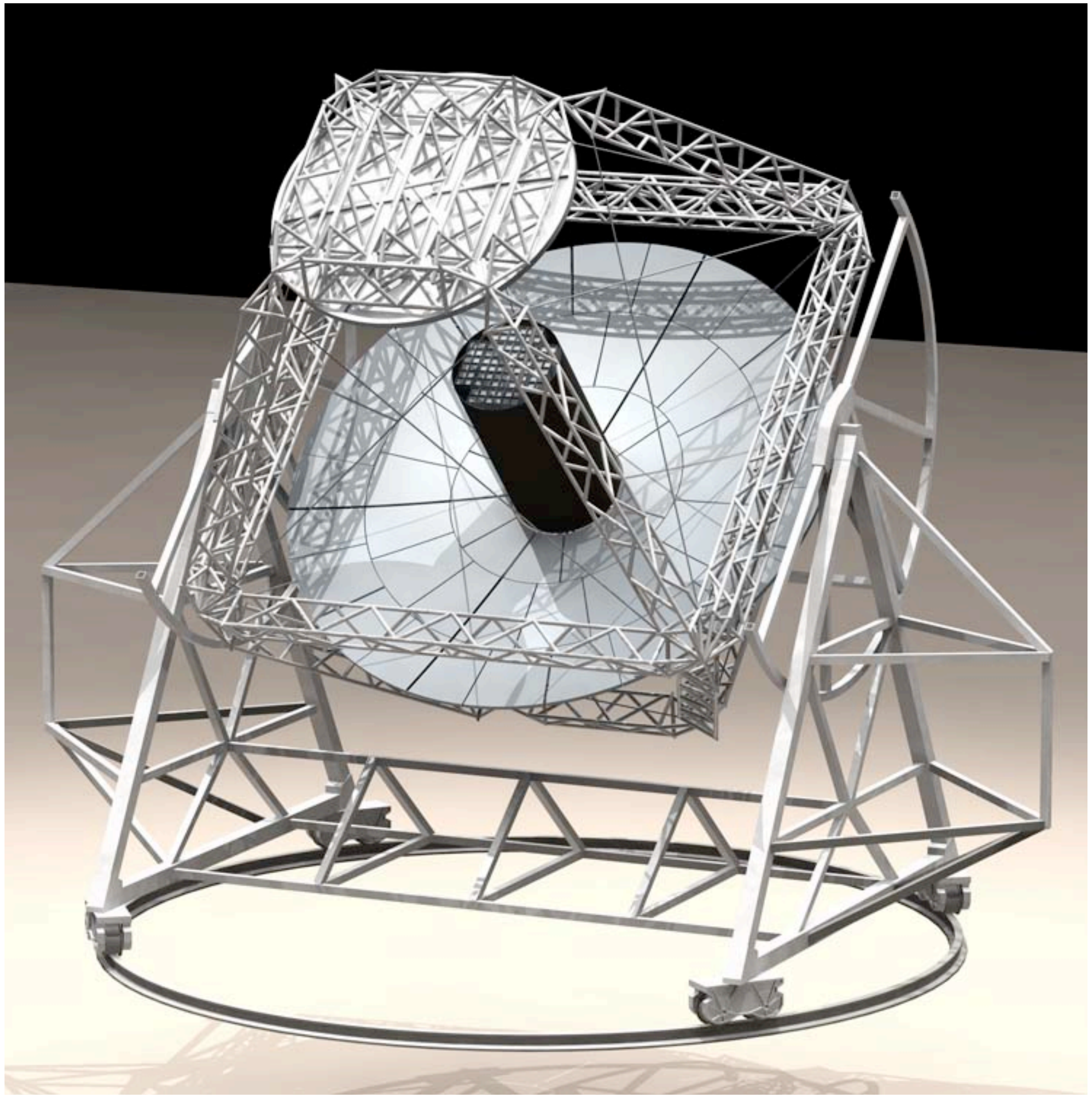
(V. Vassiliev, S. Fegan, astro-ph/0612718)

Telescope Design

❖ **Low cost design for telescope structure**



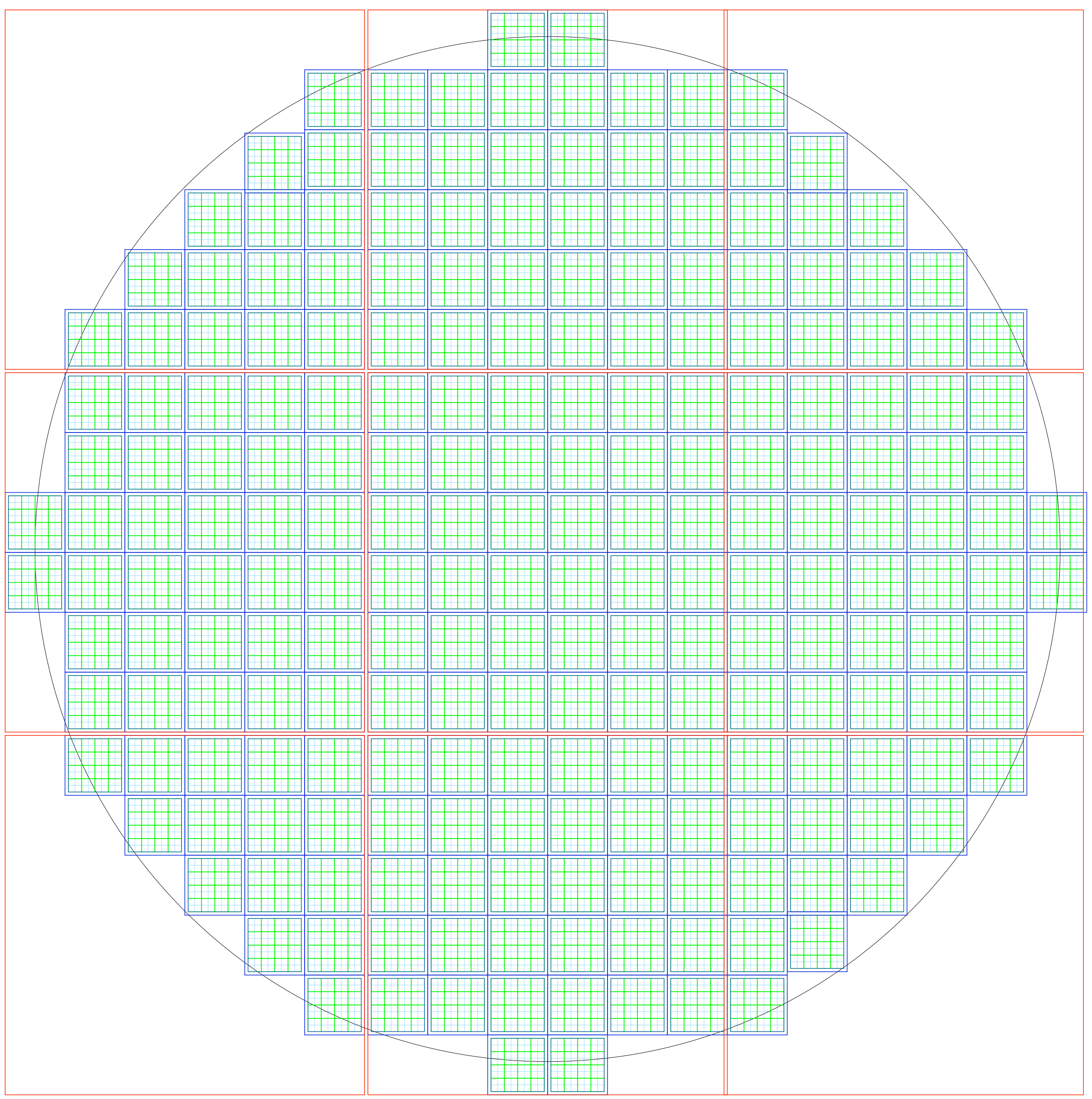
(V. Guarino, ANL)

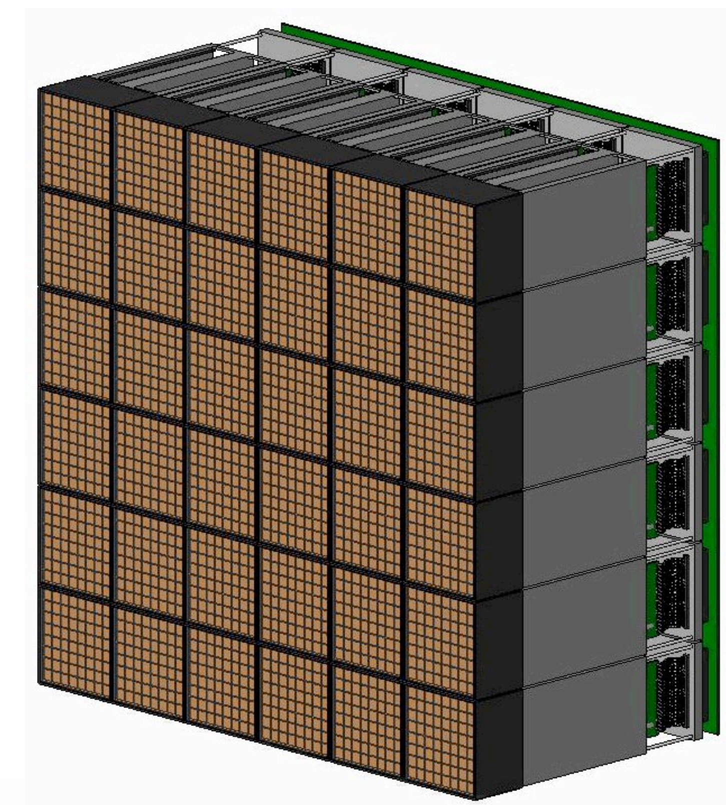


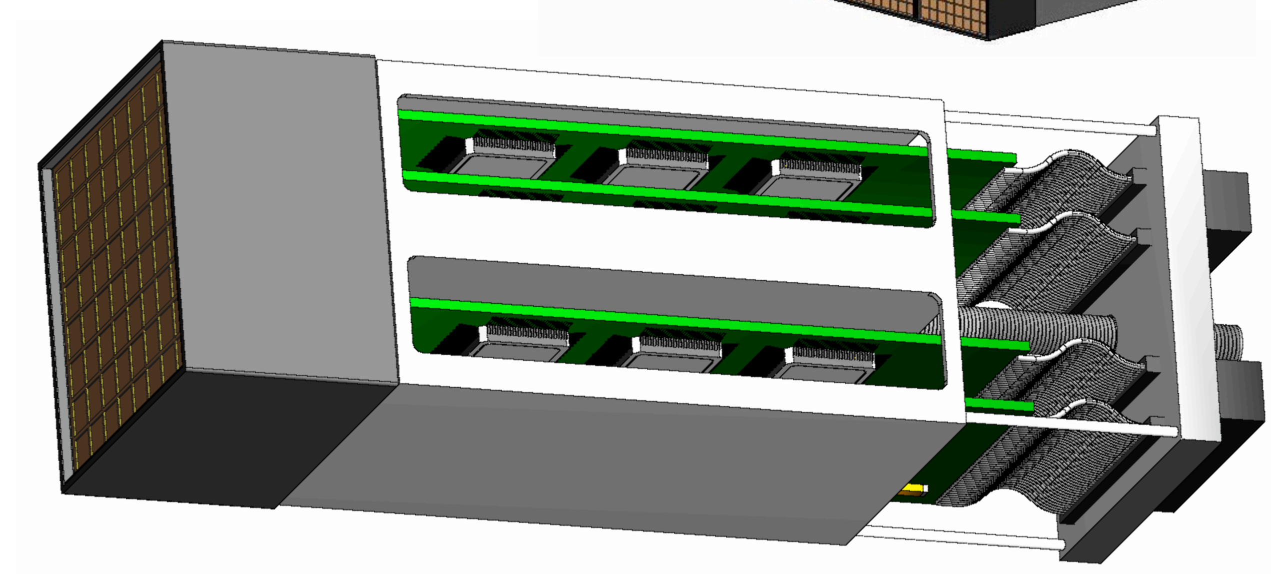
(J. Buckley, WashU)

Camera Design Concept

- ❖ **Modular camera design**
  - ✤ **Divided into subfields**
    - ✦ **Logical unit for trigger generation, easy maintenance**

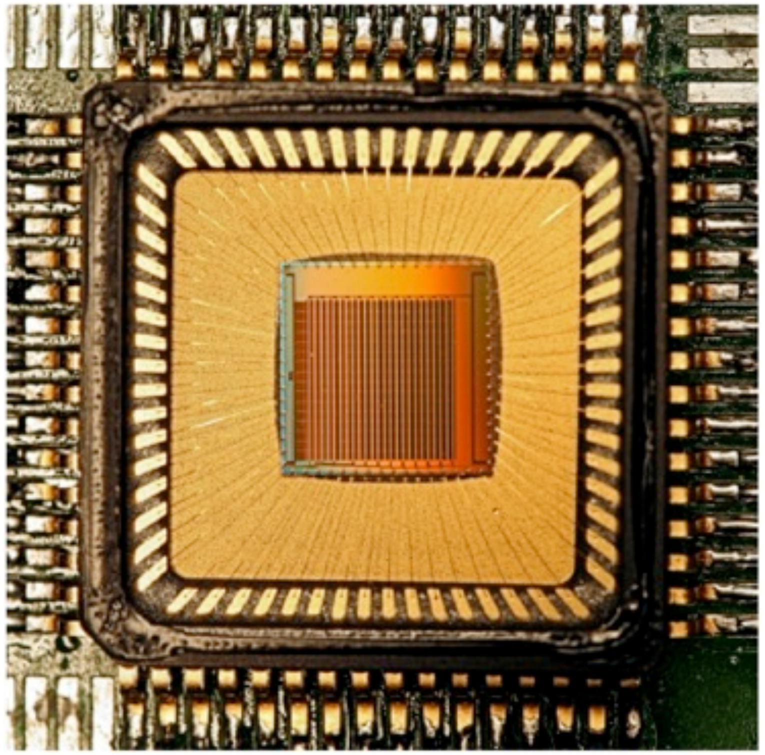






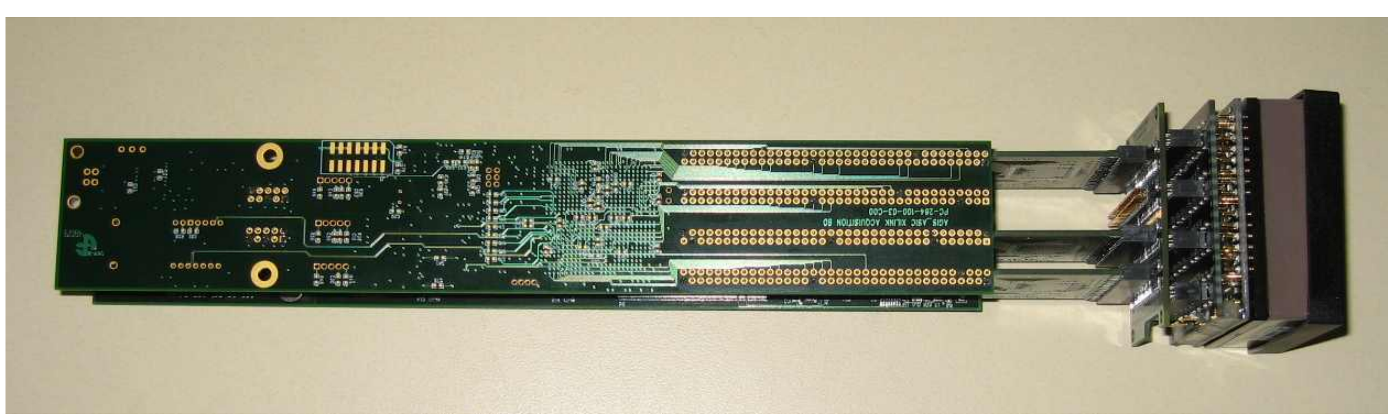
Front-End Electronics R&D

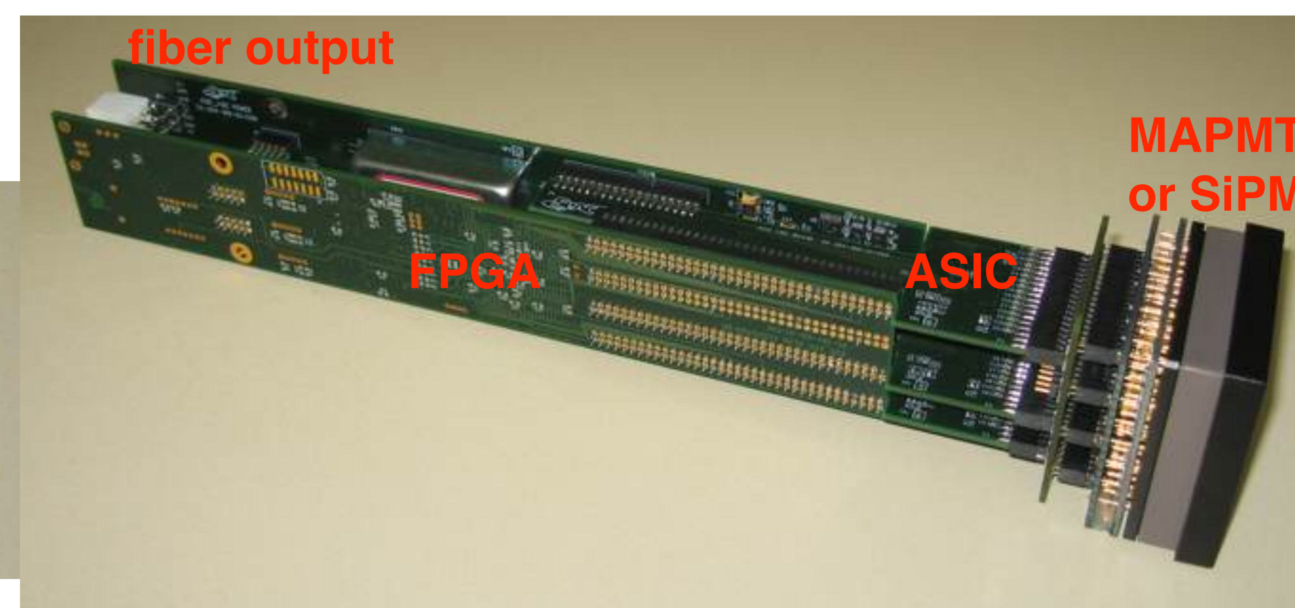
- **Requirements**
  - **Cost reduction**
    - **large # of pixels: 2–4k → 500k**
      - **More telescope, wider FOV, smaller pixels**
    - **Current cost: $1,500 per channel with PMT**
    - **Target cost: $15 per channel with multi-anode PMT**
  - **Reliability**
- **Development of custom waveform sampling ASIC, TARGET**
  - **4098 samples / channel (4 *μ*s look-back time)**
  - **9 bit dynamic range**
  - **16 *μ*s readout time (dead time less option)**
  - **Estimated cost: ~$10 per channel**
    - **16 channel per ASIC**
    - **Partial ADC implemented in ASIC**
  - **2nd generation in planning**
    - **16 *μ*s look-back, shorter dead time (~5 *μ*s)**



Cherenkov Camera Development

- ❖ **Cherenkov camera with large # of pixel**
  - ✤ **Wide FOV (field-of-view)**
  - ✤ **Better angular resolution**
  - ✤ **0.5~1k ch/camera ⇨ ~10k (x ~100 telescopes)**
    - ✦ **Target cost: $15/channel (VERITAS: $1500/channel)**
  - ✤ **Other requirements:**
    - ✦ **Fast timing: ~ ns**
    - ✦ **Readout time: less than 50 *μ*s (trigger rate < 3-5 kHz)**
- ❖ **Low cost, high Q.E. photon detector**
- ❖ **Low cost, low power multi-ch readout ASIC**





Summary and Prospects

- AGIS aims to achieve x10 better sensitivities than current instruments by
  - Larger collection area (wide FOV, large telescope spacing)
  - Better angular resolution
- Technology development
  - SC optics
  - More reliable, less expensive camera electronics
  - Array trigger
- Prospects
  - AIGS received favorable review by PASAG (DOE/NSF)
    - Recommendation for funding for most funding options
    - Under assumption of merger with CTA
  - Under review by Decadal Survey
    - Results in September

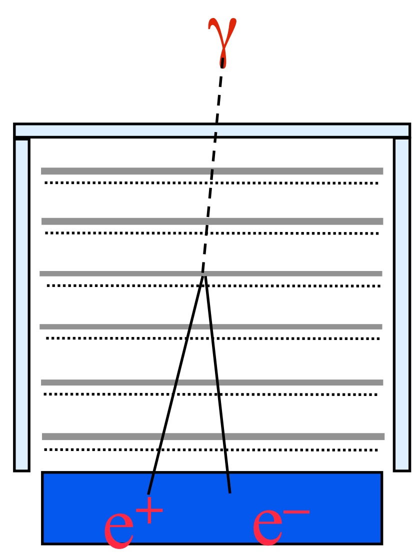
backup slides

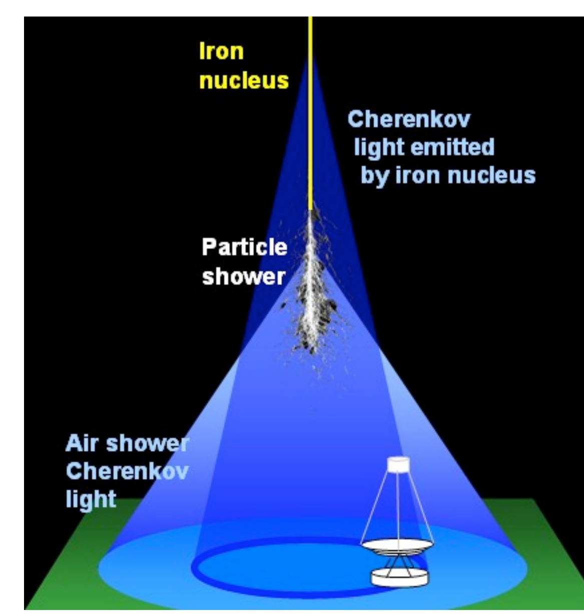
Why SLAC?

- Strong gamma-ray community from Fermi-LAT
- Could play role of a lead national lab in AGIS
  - VERITAS (current US IACT) consists of mostly universities
  - Can benefit from strong involvement of national laboratory to carry out much larger project (if DOE funds AGIS)
  - Collaborative efforts with ANL
- Scope of SLAC involvement
  - Development of AGIS camera electronics
  - Development of DAQ
    - Could be challenging if no level-3 trigger
  - Optimization of array configuration via simulation studies
- Status of project
  - Currently under review by PASAG and Astro2010
  - At that time it could be endorsed by NSF + DOE
  - Aiming to start operation before Fermi LAT cease to operate

Gamma-ray Detectors

	Satellite based pair conversion	Air shower array	Air Cherenkov telescope
Experiments	EGRET, GLAST	Milagro, HAWC	HESS, VERITAS CANGAROO, MAGIC
Energy range	0.02 – 200 GeV	1 – 100 TeV	0.1 – 100 TeV
Angular res.	0.04 – 10 deg	~0.5 deg	~0.1 deg
Collection area	1 m^2	10^3 – 10^4 m^2	10^5 m^2
Field of view	2.4 sr	2 sr	10^{-2} sr
Duty cycle	~95%	>90%	<10%

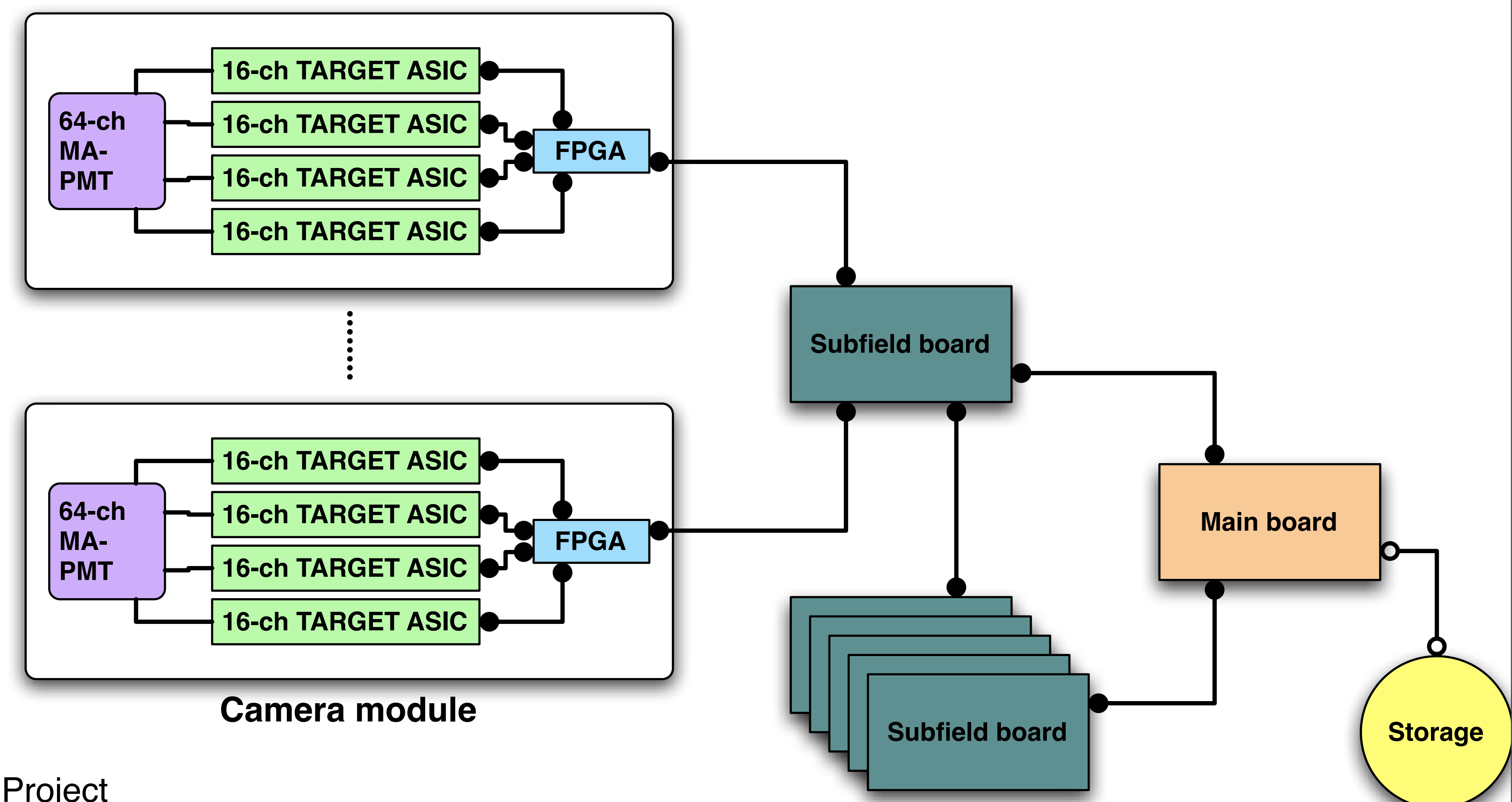




AGIS Project
CTA Japan Workshop, JAN 9, 2010, ICRR. Japan

Camera Electronics Overview

- Camera electronics consists of
  - **Camera modules: ~200/camera (~13k pixels)**
    - Waveform sampling and digitization, 16 triggers
  - **Subfield boards: ~10/camera (~36 modules/field)**
    - Cross-link trigger information
    - Subfield trigger
  - **Main board**
    - Camera trigger
    - Gb ethernet link to outside (or any other commercial solution)



Camera module

Camera Front-end Electronics

- **Board configuration**
  - **Adapter board**
  - **ASIC board**
  - **FPGA board: FPGA, data link connector**
  - **Power supply board: DC/DC converter, HV supply**