Very High-Energy Gamma-Ray Astrophysics

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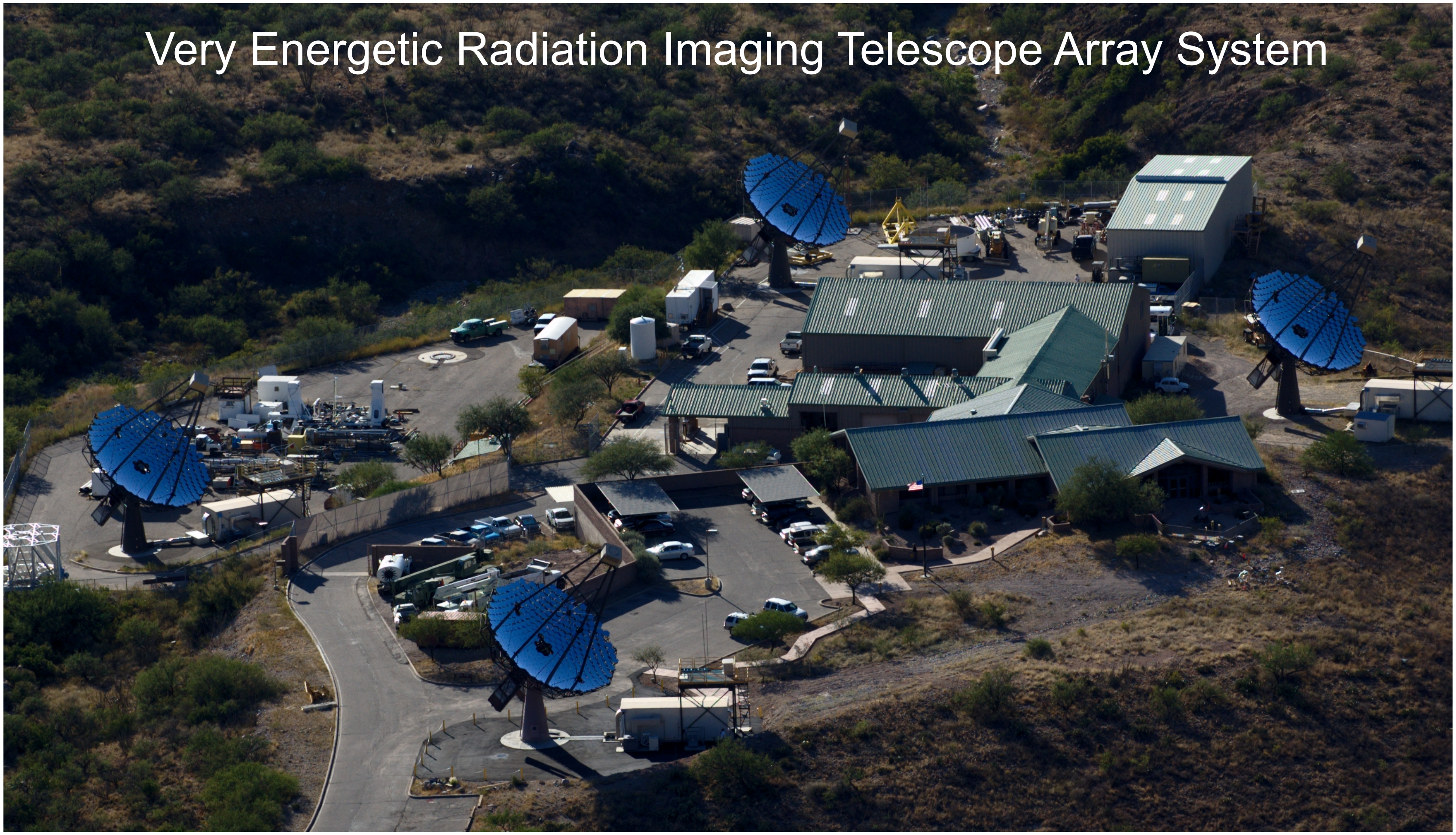
Main Research Interests

- How are high energy particles accelerated in the jets of AGN? Are they primarily electrons or protons?
- Do gamma-ray bursts produce very high-energy gamma-rays, either in the prompt or afterglow phase? What does that tell us about GRBs if they do/don’t?
- What can we learn about the evolution of the Universe from the extragalactic background light?
- How can we build more sensitive instruments to address these – and other – questions?
  - VERITAS upgrade
  - CTA, the Cherenkov Telescope Array

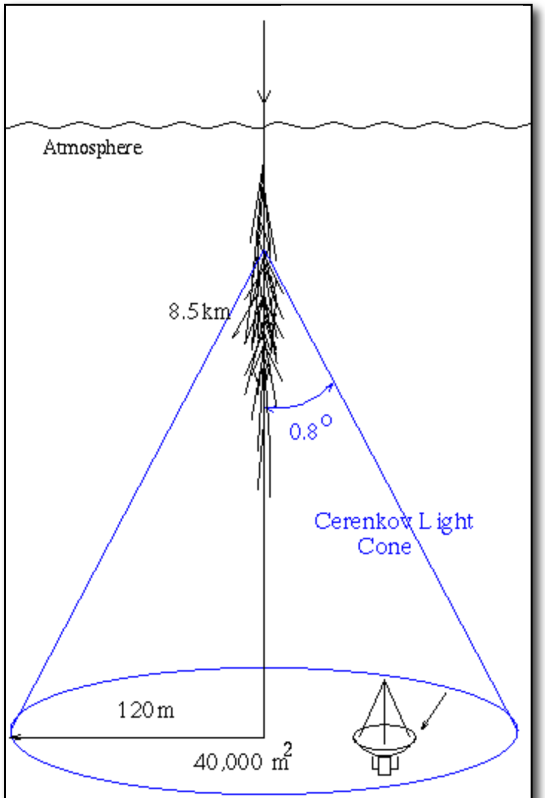
VERITAS: Imaging Atmospheric Cherenkov Telescope



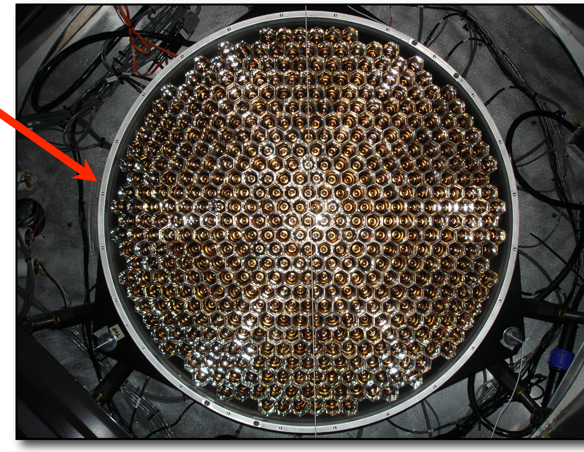
Whipple Observatory Basecamp (el. 1275 m) at foot of Mt. Hopkins

Atmospheric Imaging Technique

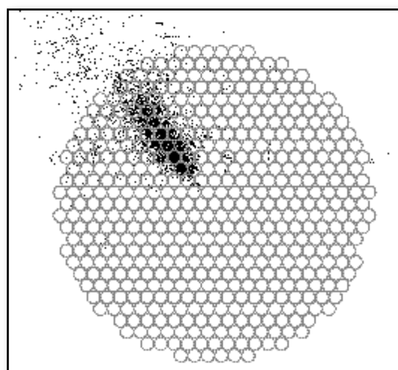
g–ray



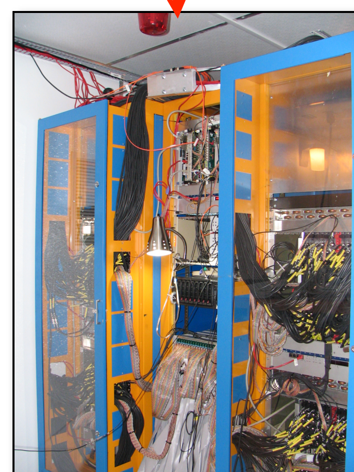
12 m Mirror



499-PMT camera



Cherenkov image

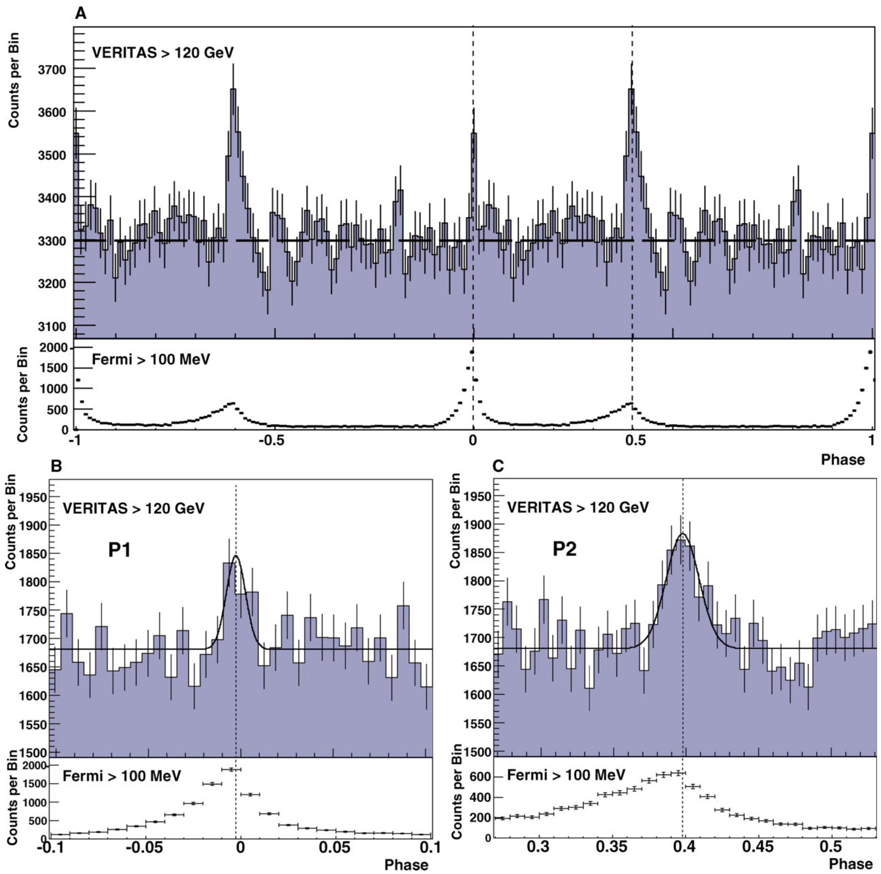


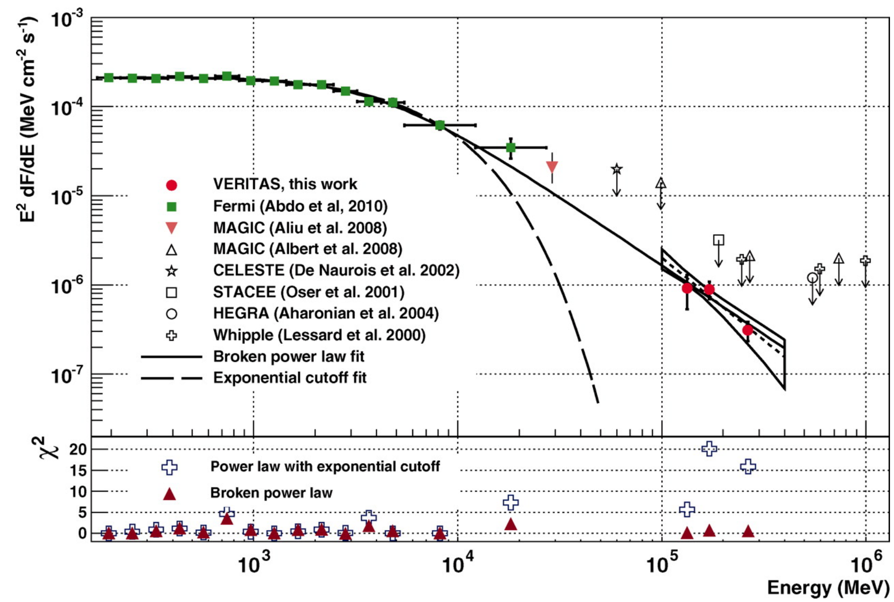
500-MHz FADC electronics

Area = $10^4 – 10^5$ m^2
~60 optical photons/m^2/TeV

[illegible]-rays above ~100 GeV

Discovery of VHE Crab Pulsar





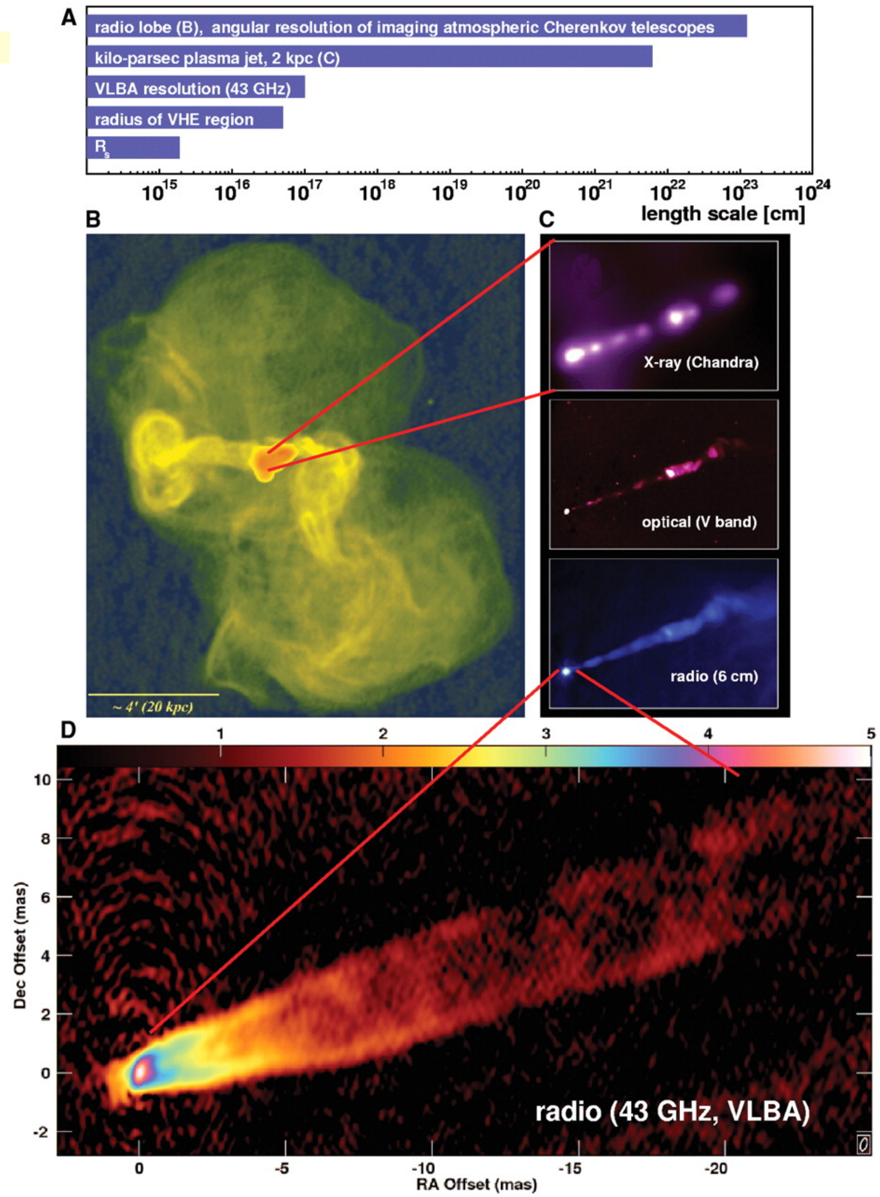
E. Aliu et al. 2011, *Science* 334, 69–72

Work led by, A. Nepomuk Otte

UCSC postdoc, now asst. prof. at Georgia Tech

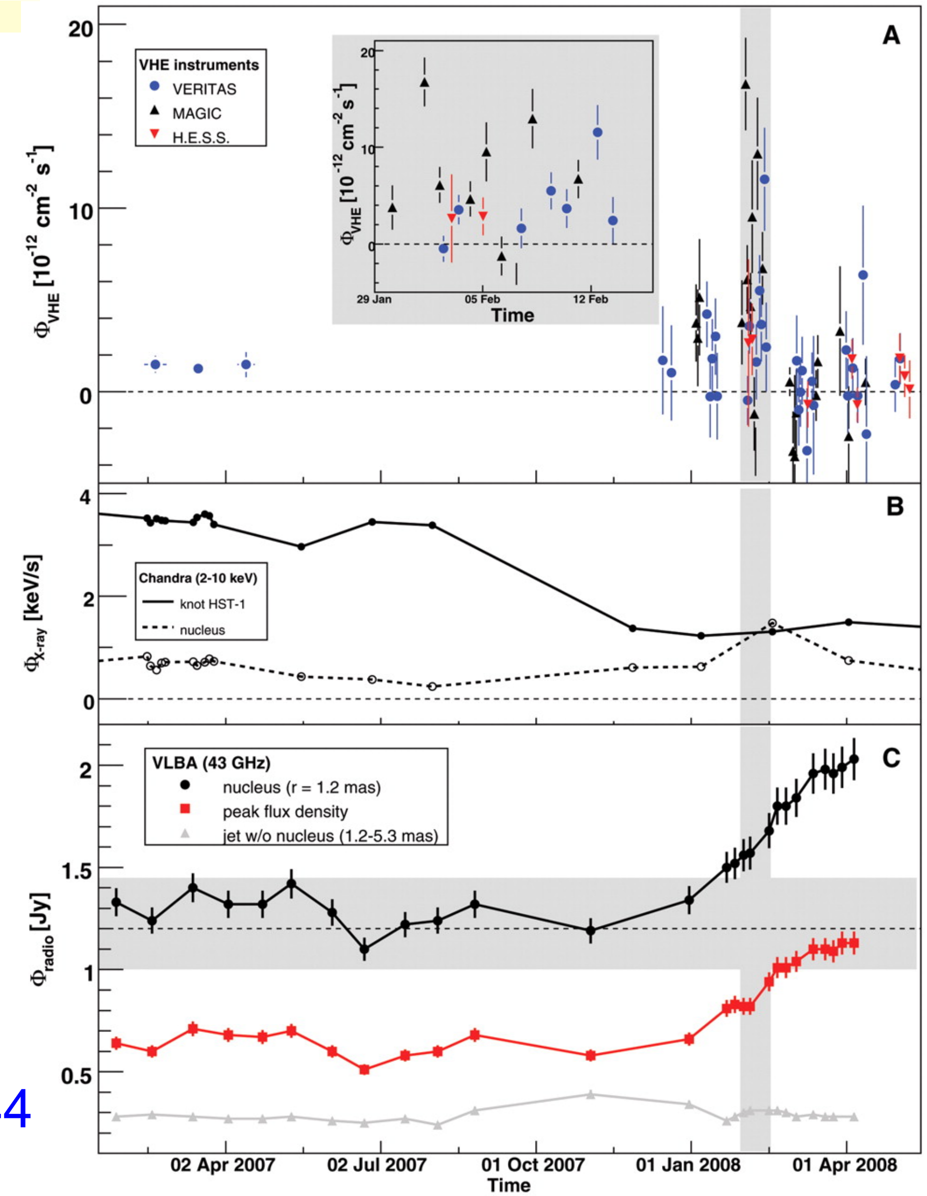
Radio Galaxy: M 87

- Giant radio galaxy (class of AGN)
- Distance ~16 Mpc, redshift 0.004
- Central black hole ~6 x 10^9 M_{sun}
- Jet angle 15°–30°
- Knots resolved in the jet
- Jet is variable in all wavebands



M 87 – Radio and TeV flares

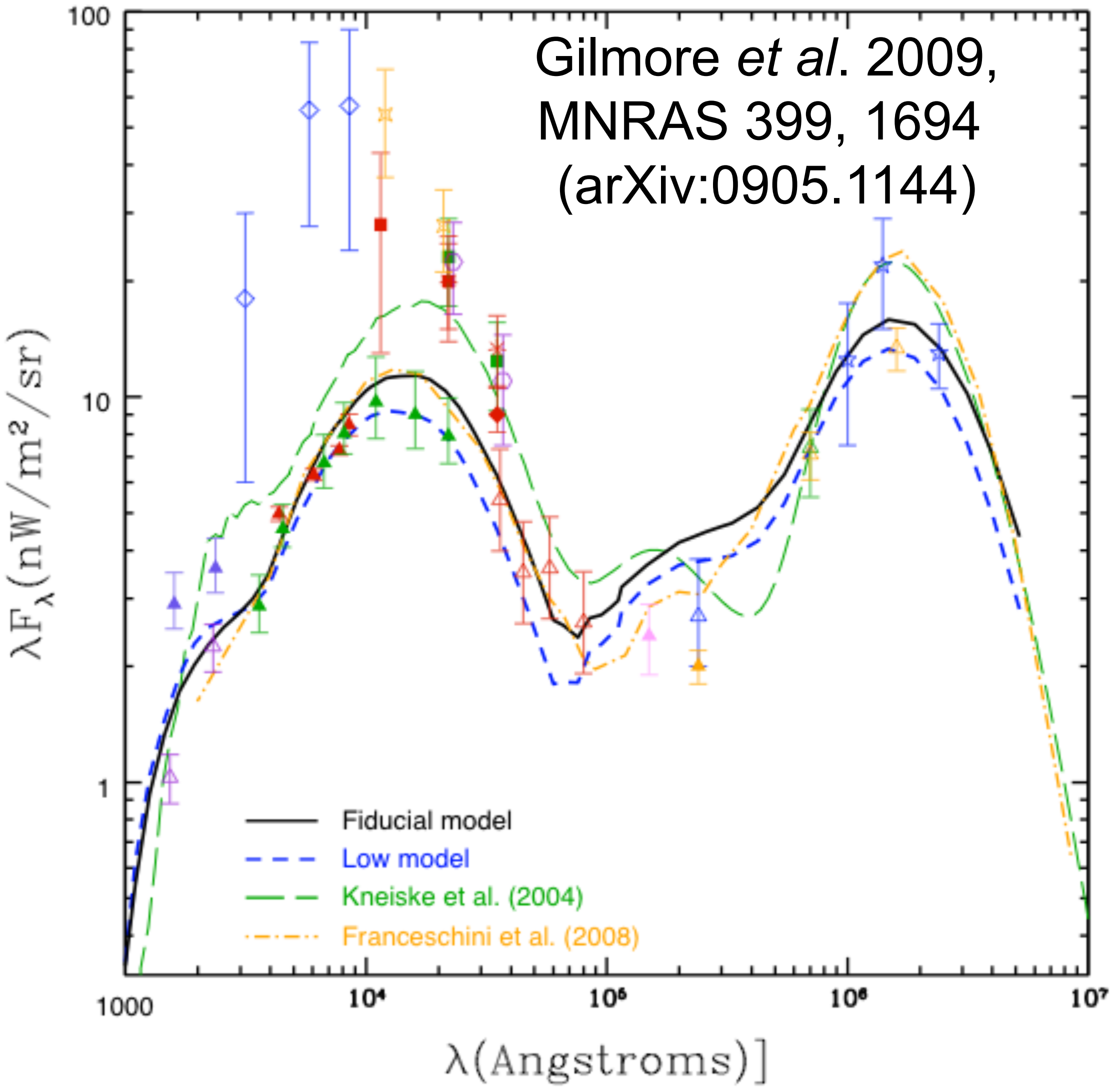
- Rapid TeV flares coincident with the core brightening
- TeV particles accelerated within ~100 R_s of BH
- Best determination so far of location of particle acceleration



V. Acciari *et al*. 2009, Science 325, 444

Extragalactic Background Light

$\square_{\text{High Energy}} + \square_{\text{EBL}} \rightarrow e^+ e^-$



Difficult to measure EBL because of foreground sources

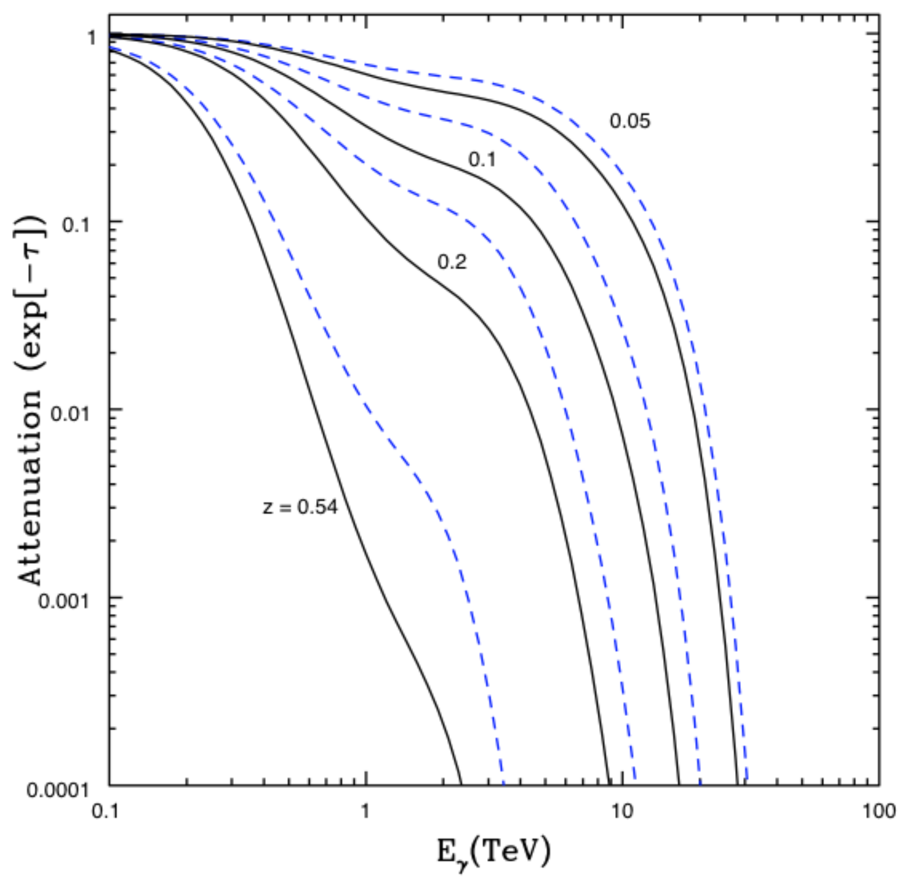
Test of cosmology

Attenuation by 1/e
(*i.e.* $e^{-\square}$ with $\square\square = 1$)
for
z ~ 1.2 at 100 GeV
z ~ 0.1 at 1 TeV

Recent modeling consistent with the published experimental results

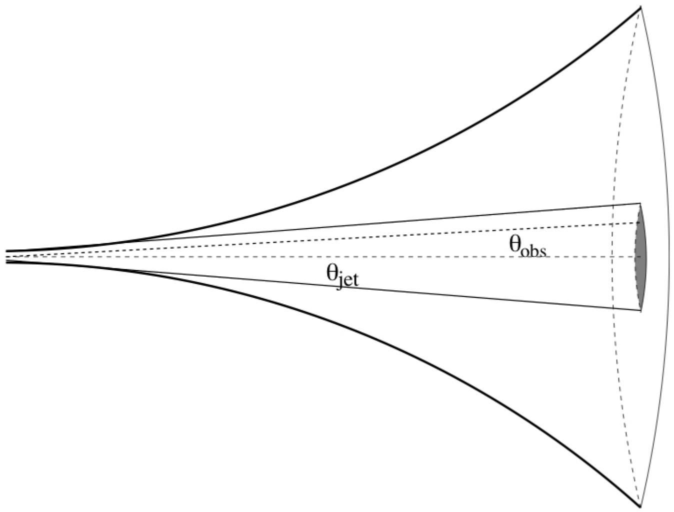
Understanding the EBL

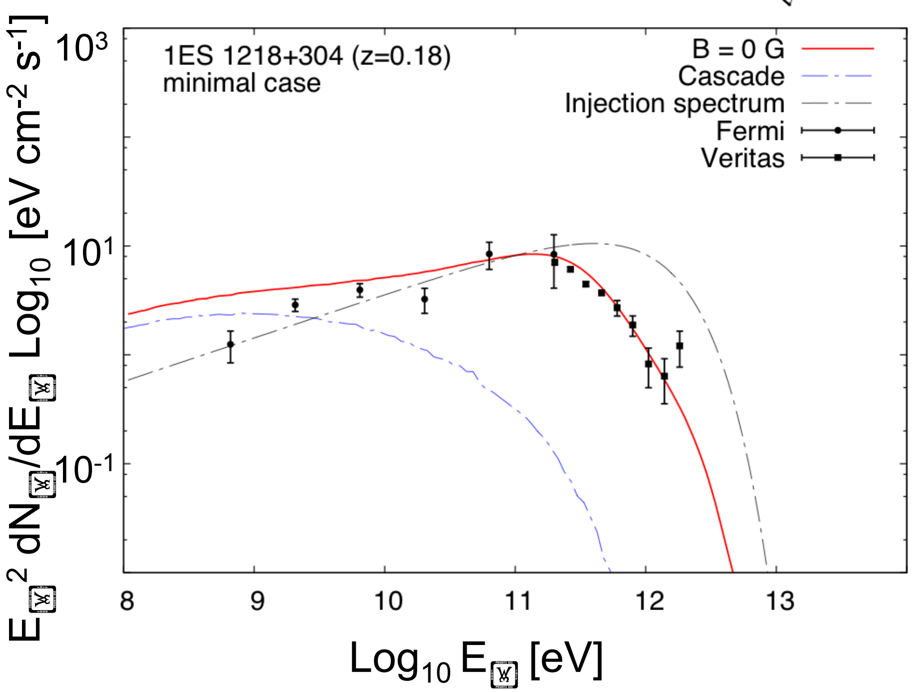
- Search for new, more distant blazars (e.g. 4C +55.17)
- More precise spectral measurements of known blazars (e.g. Mrk 421)
- Obtain data at other wavelengths to help model intrinsic spectra (*Fermi*, *Swift*)
- Obtain redshifts for detected blazars (w/ Prochaska, Fumagalli)
- Theoretical modeling of the EBL (w/ Primack, Madau, Gilmore)



Primack *et al*. 2008, AIPC 1075, 71 (arXiv:0811.3230)

The EBL and Intergalactic B Fields





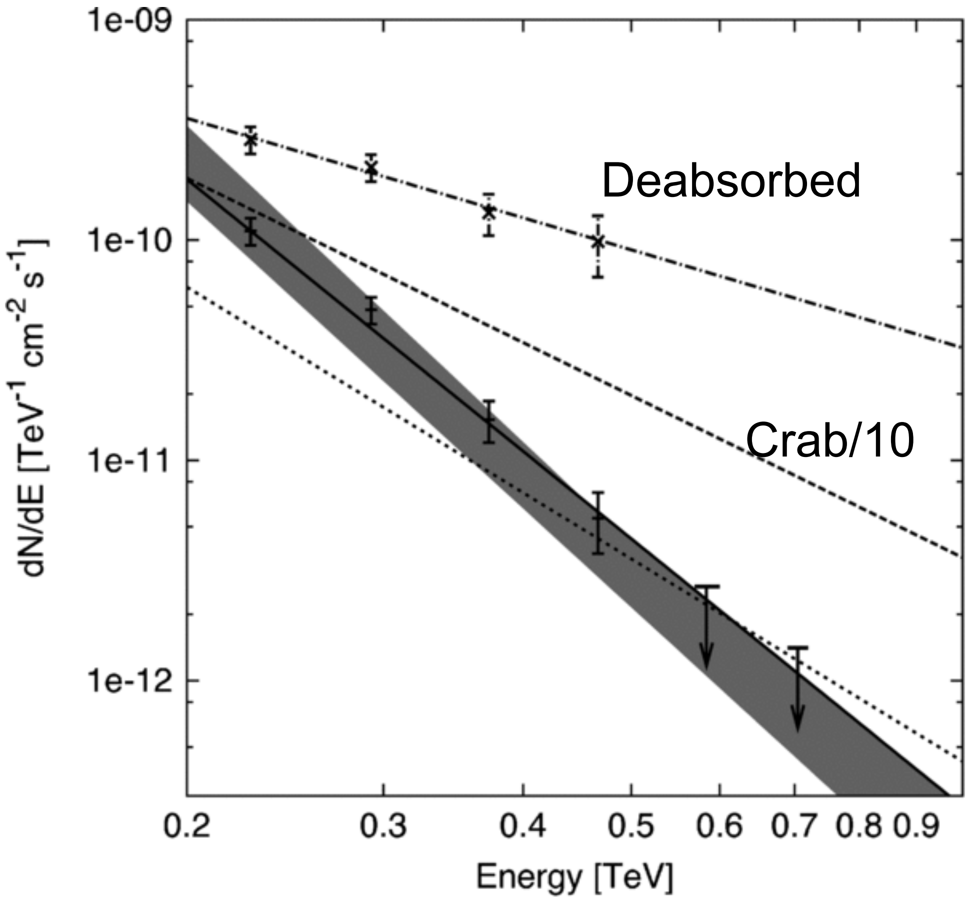
- Electrons produced by

  $\gamma_{\text{High Energy}} + \gamma_{\text{EBL}} \rightarrow e^+ e^-$

  Compton scatter off EBL to produce more photons
- Amount that the cascade fans out depends on intergalactic magnetic field (IGMF) strength
- Observable effects:
  - Pair halo
  - Spectral distortion
  - Time delays between prompt and reprocessed photons

Figures from Taylor *et al*. 2011, arXiv: 1101.0932

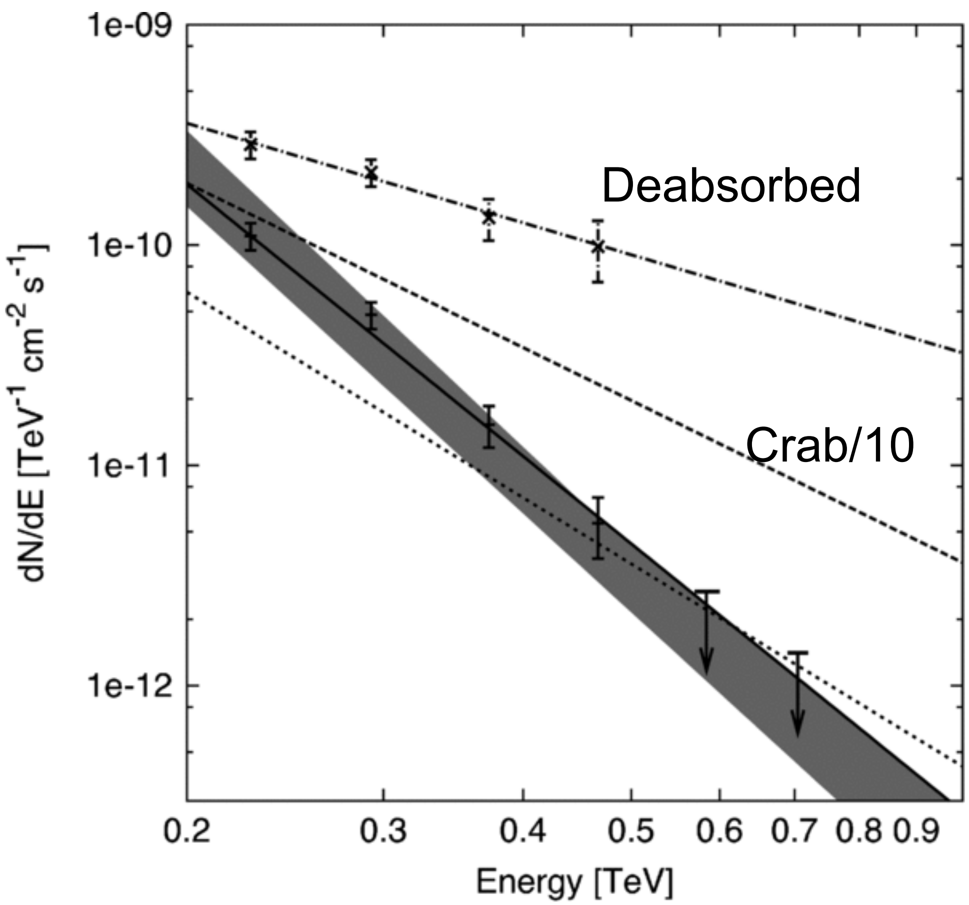
Blazar: 3C 66A



V. Acciari *et al*. 2009, ApJL 693, L104; erratum ApJL 721, L203

- AGN with jet oriented along line of sight – BL Lac object
- redshift 0.44?
- Observed spectral index
  $\Gamma = 4.1 \pm 0.4_{stat} \pm 0.6_{sys}$
- Deabsorbed spectrum using Franceschini et al 2008 model gives
  $\Gamma = 1.5 \pm 0.4$
- At the limit the models can tolerate
- Need firm redshift & more VERITAS data

Blazar: 3C 66A

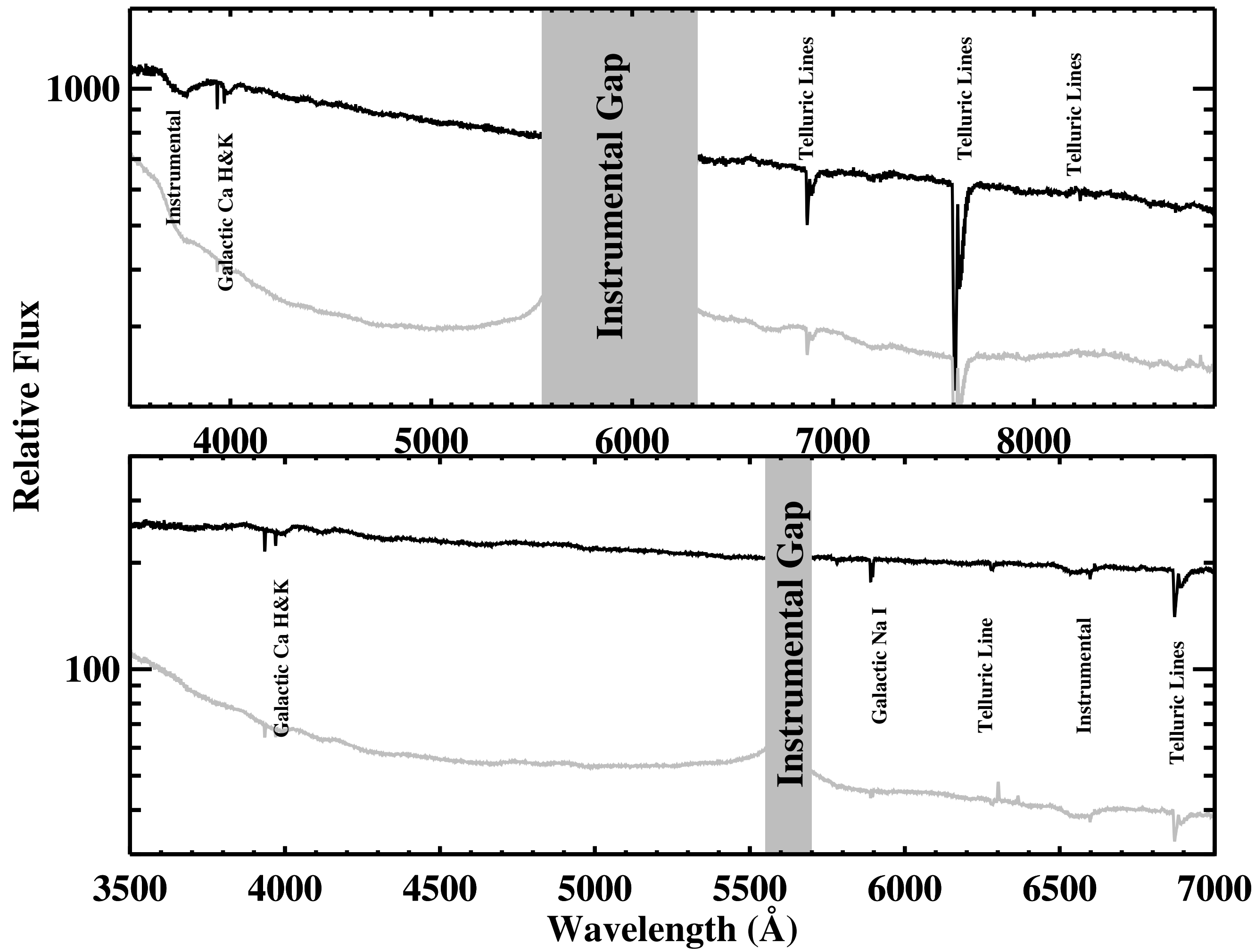


V. Acciari *et al*. 2009, ApJL 693, L104; erratum ApJL 721, L203

- AGN with jet oriented along line of sight – BL Lac object
- redshift ~~0.44~~? 0.335–0.41
- Observed spectral index $\Gamma = 4.1 \pm 0.4_{stat} \pm 0.6_{sys}$
- Deabsorbed spectrum using Franceschini et al 2008 model gives

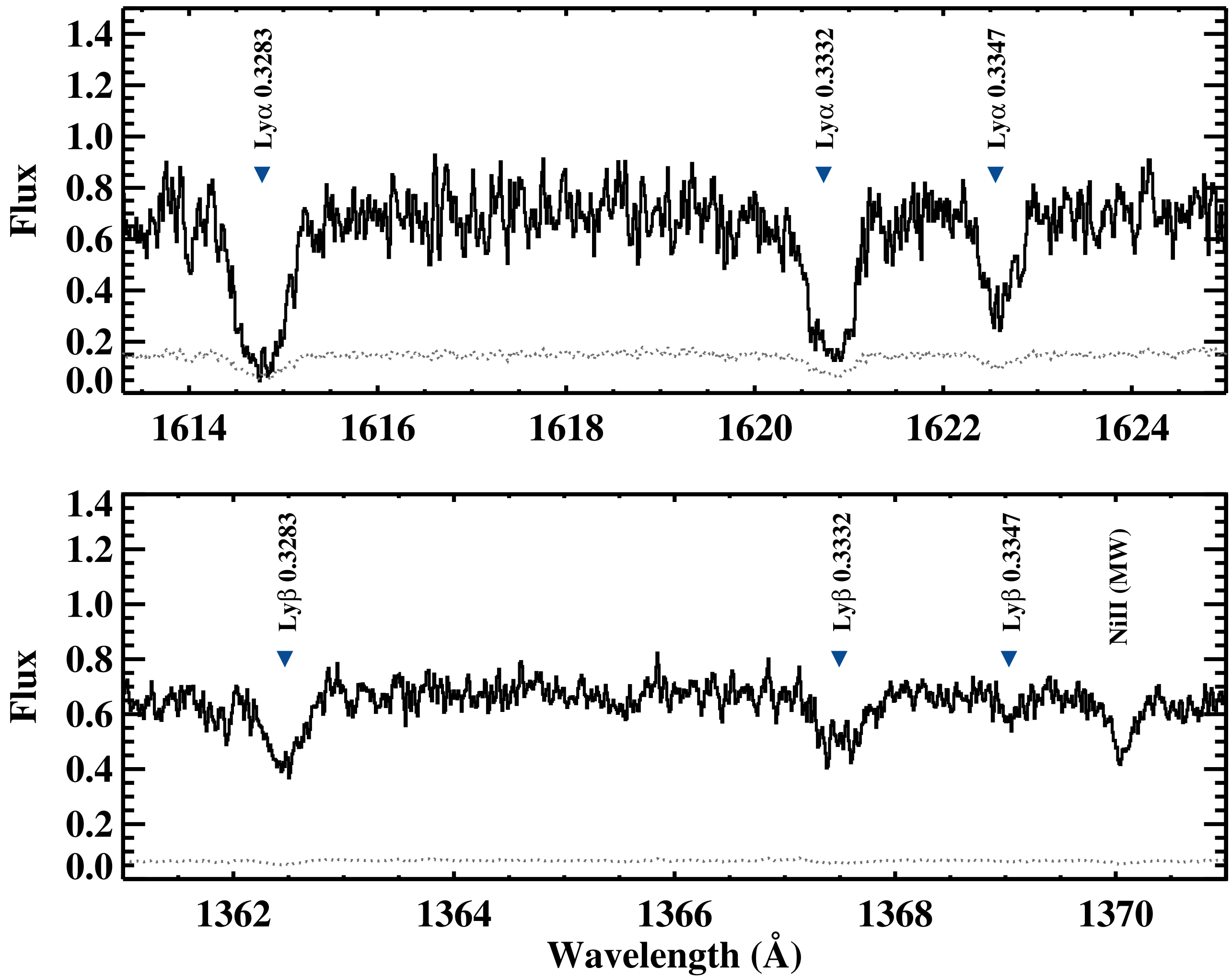
  $\Gamma = 1.5 \pm 0.4$
- At the limit the models can tolerate
- Need firm redshift & more VERITAS data

3C 66A Spectra — Keck



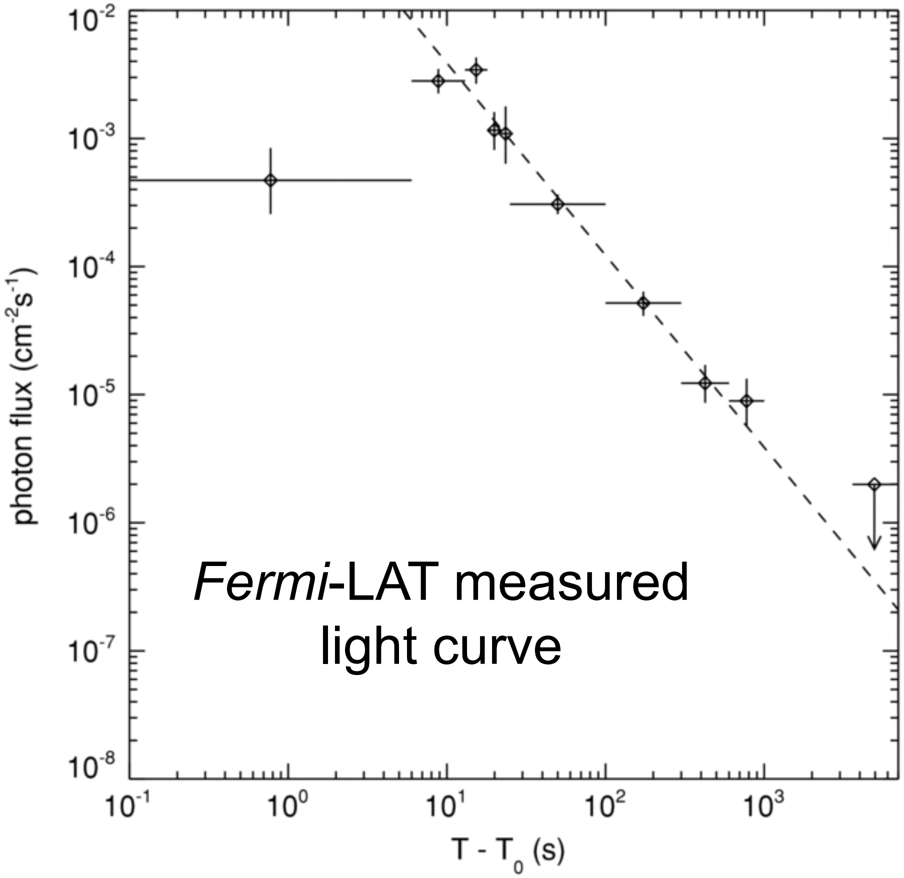
A. Furniss *et al*. 2013, submitted to ApJ

3C 66A Spectra — HST

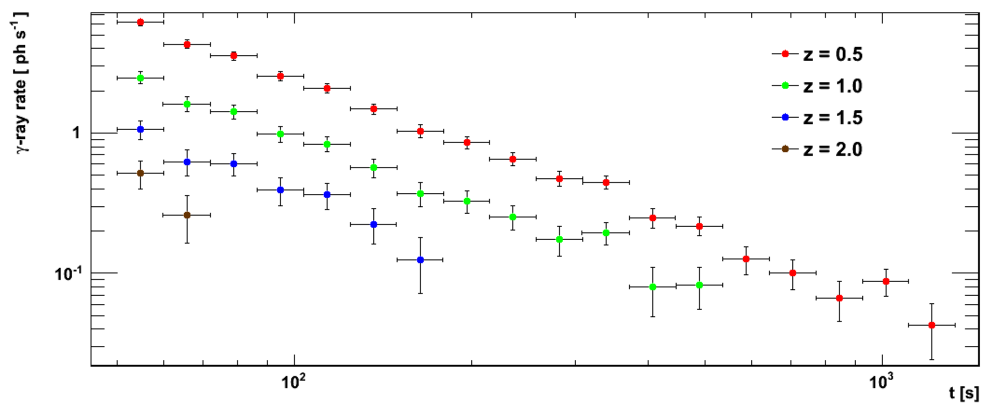


A. Furniss *et al*. 2013, submitted to ApJ

GRB 090902B



Simulated VERITAS
light curves for
different redshifts

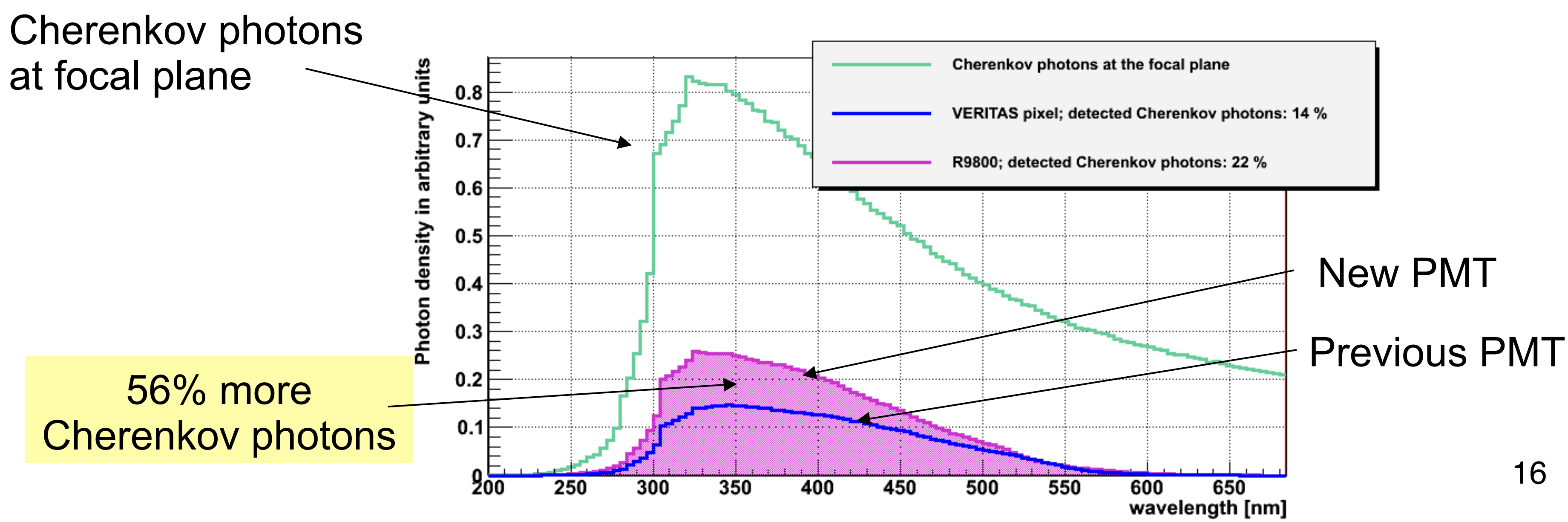


A. Abdo *et al*. 2009, ApJL 706, L138

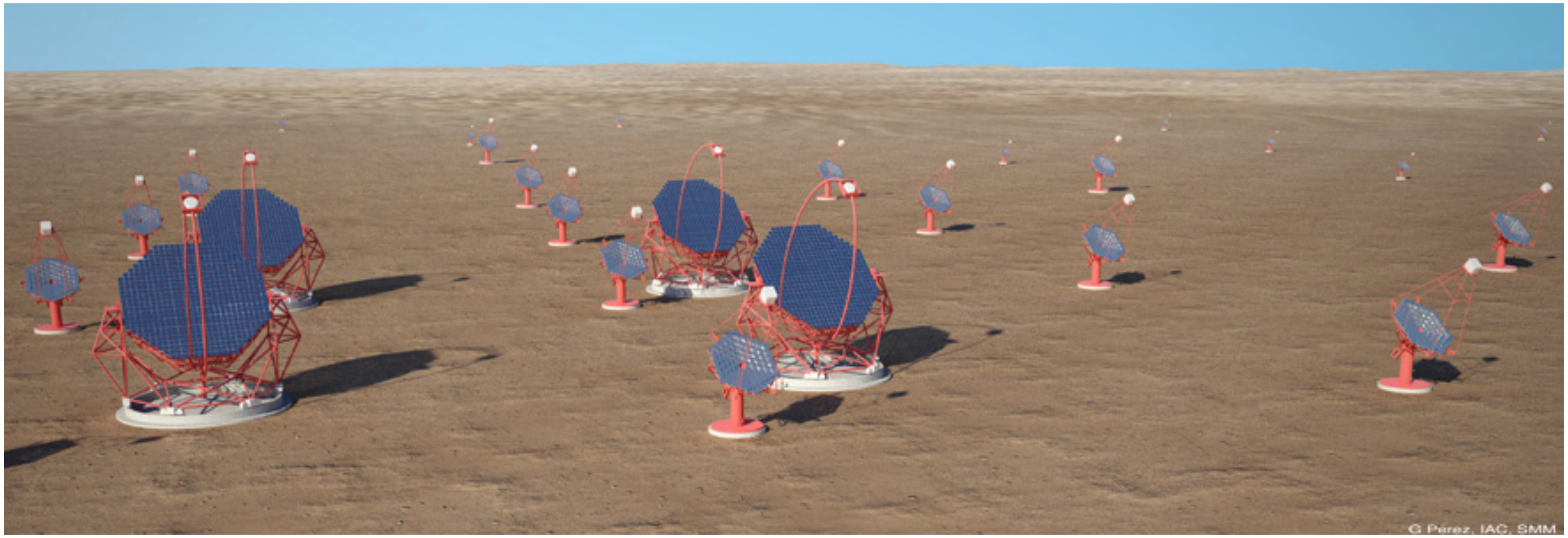
VERITAS Upgrade

– Moved 1 telescope (complete)
– Install improved trigger system (fall 2011)
– Install higher quantum efficiency phototubes (summer 2012)
– Investigating faster telescope slewing

Opportunities to work on the telescope hardware



The CTA Concept



Arrays in northern and southern hemispheres for full sky coverage

4 large telescopes in the center (LSTs)

- Threshold of ~30 GeV

≥25 medium telescopes (MSTs) covering ~1 km^2

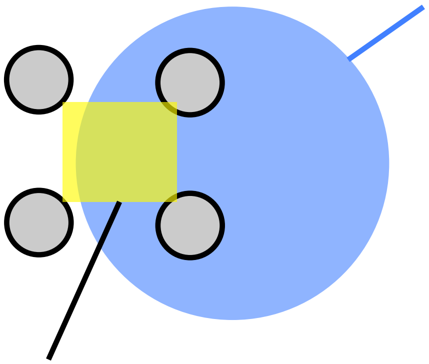
- Order of magnitude improvement in 100 GeV–10 TeV range

Small telescopes (SSTs) covering >3 km^2 in south

- >10 TeV observations of Galactic sources

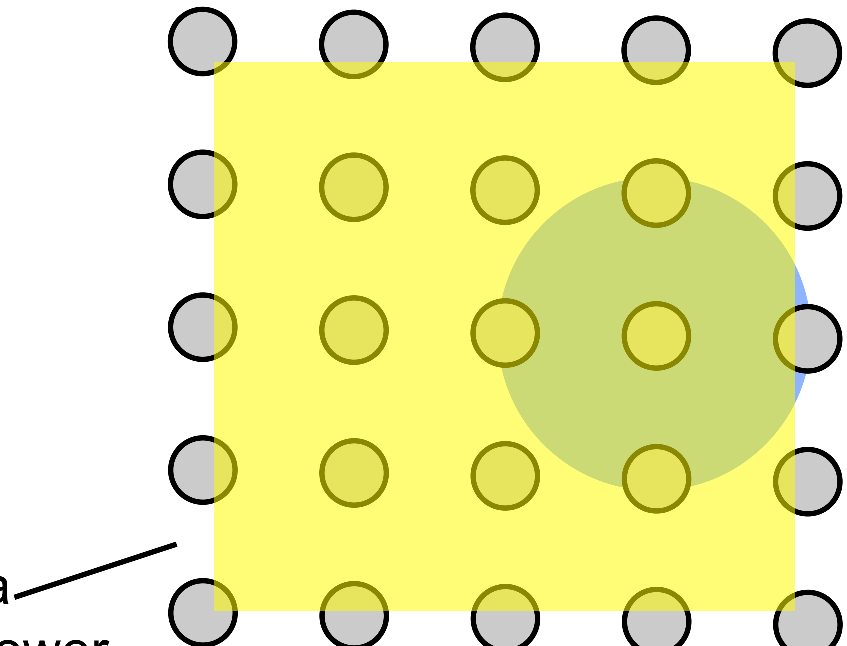
Construction begins in ~2015

From current arrays to CTA



Light pool radius
R ≈100-150 m
≈ typical telescope spacing

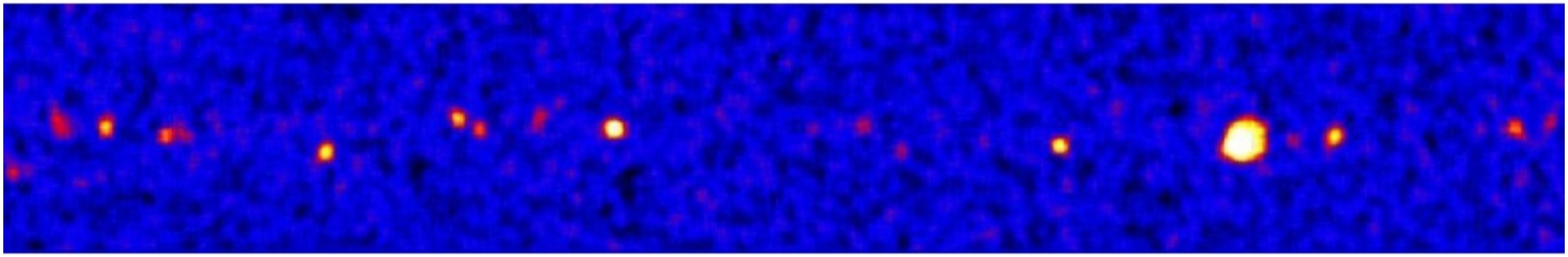
Sweet spot for
best triggering
and reconstruction:
Most showers miss it!



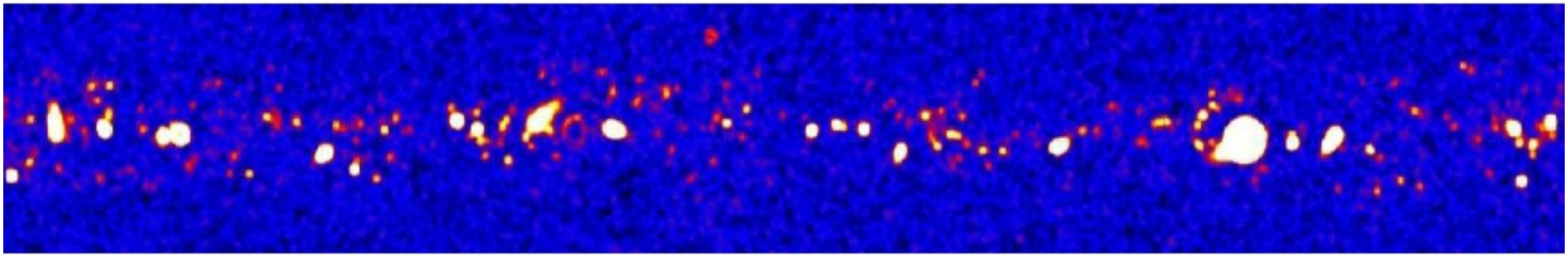
Large detection area
More images per shower
Lower trigger threshold

Simulated Galactic Plane surveys

H.E.S.S.



CTA, for same exposure



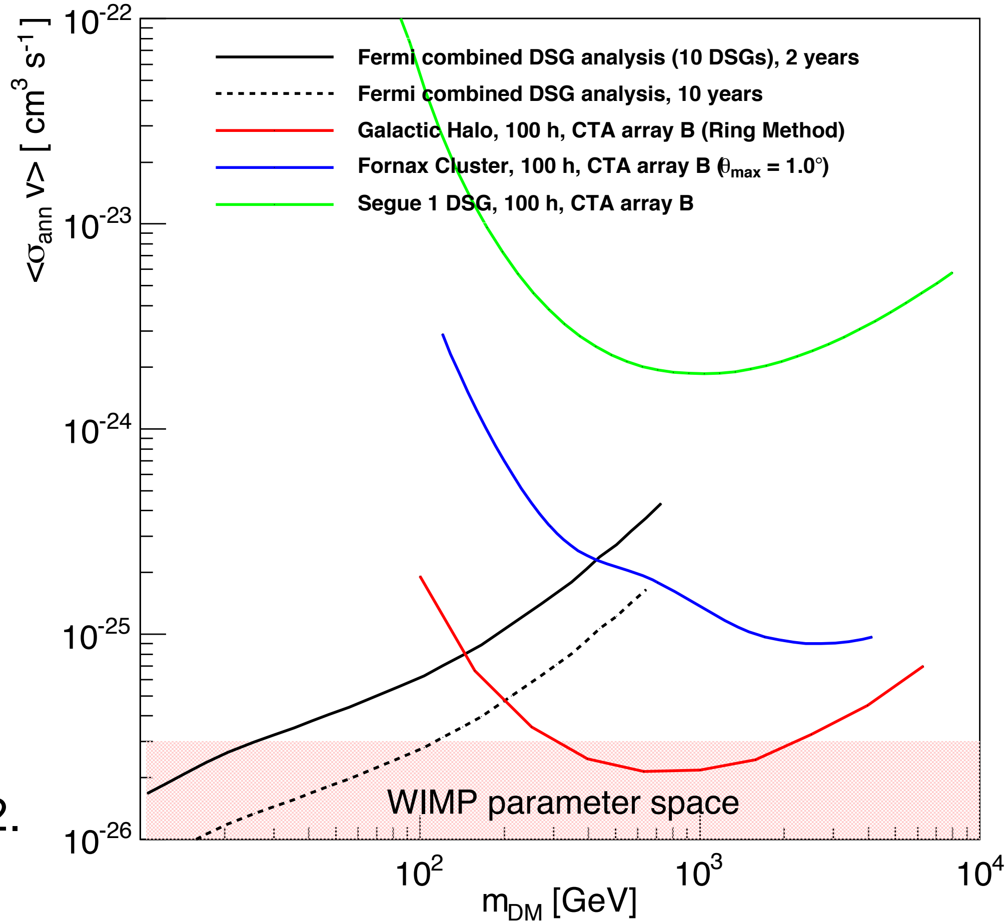
Expect ~1000 detected sources over the whole sky

Dark matter searches with Fermi & CTA

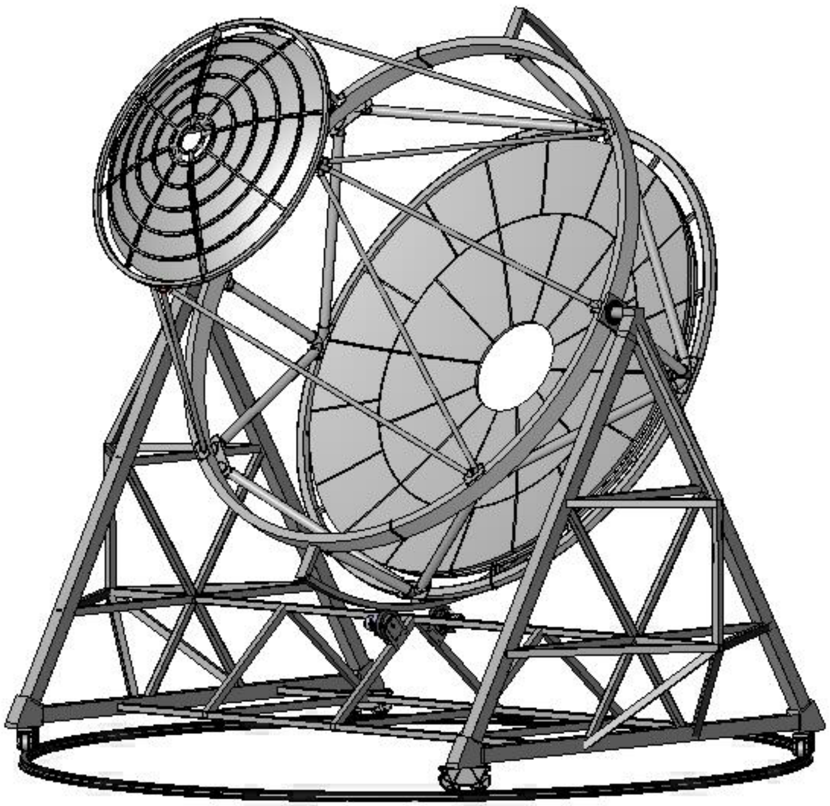
Fermi dwarf spheroidal and CTA Galactic Center searches are complementary

Assuming b b-bar decay channel

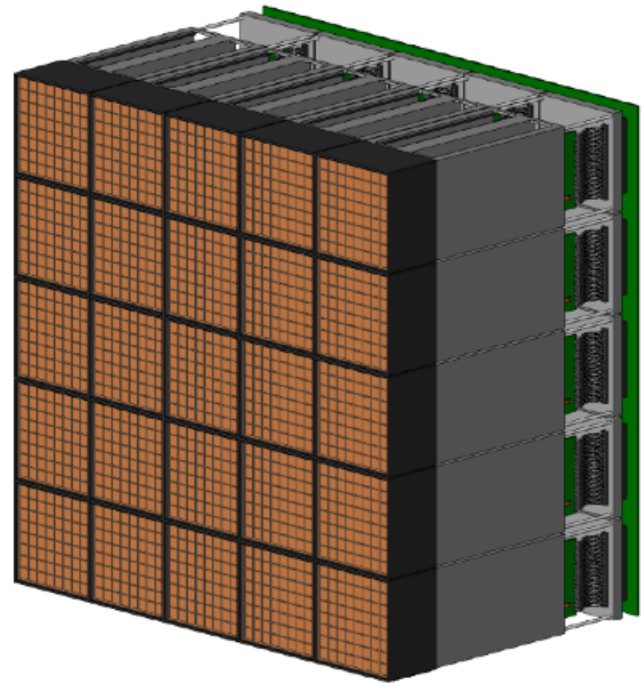
LAT 2-year result from Ackermann et al. 2011, *Phys. Rev. Lett.* **107**, 241302.



A Novel Telescope for CTA



Schwarzschild-Couder optics



Camera using multianode photomultiplier tubes or Geiger-APDs with integrated electronics

Opportunities

- Data analysis with VERITAS – most sensitive instrument in the world >100 GeV
- Synergy with *Fermi*, X-ray satellites, *e.g. Swift*
- Optical program for redshifts and source monitoring
- CTA development
  - Studies of new, more efficient photosensors
  - Design and construction of the prototype telescope
  - Optimization of full CTA telescope and array

Postdocs: Aurelien Bouvier

Graduate students: Amy Furniss, Caitlin Johnson

Undergraduate students: Lloyd Gebremedhin, Zach Hughes, Andrey Kuznetsov