Very High-Energy Gamma-Ray Astrophysics

David A. Williams

daw@ucsc.edu

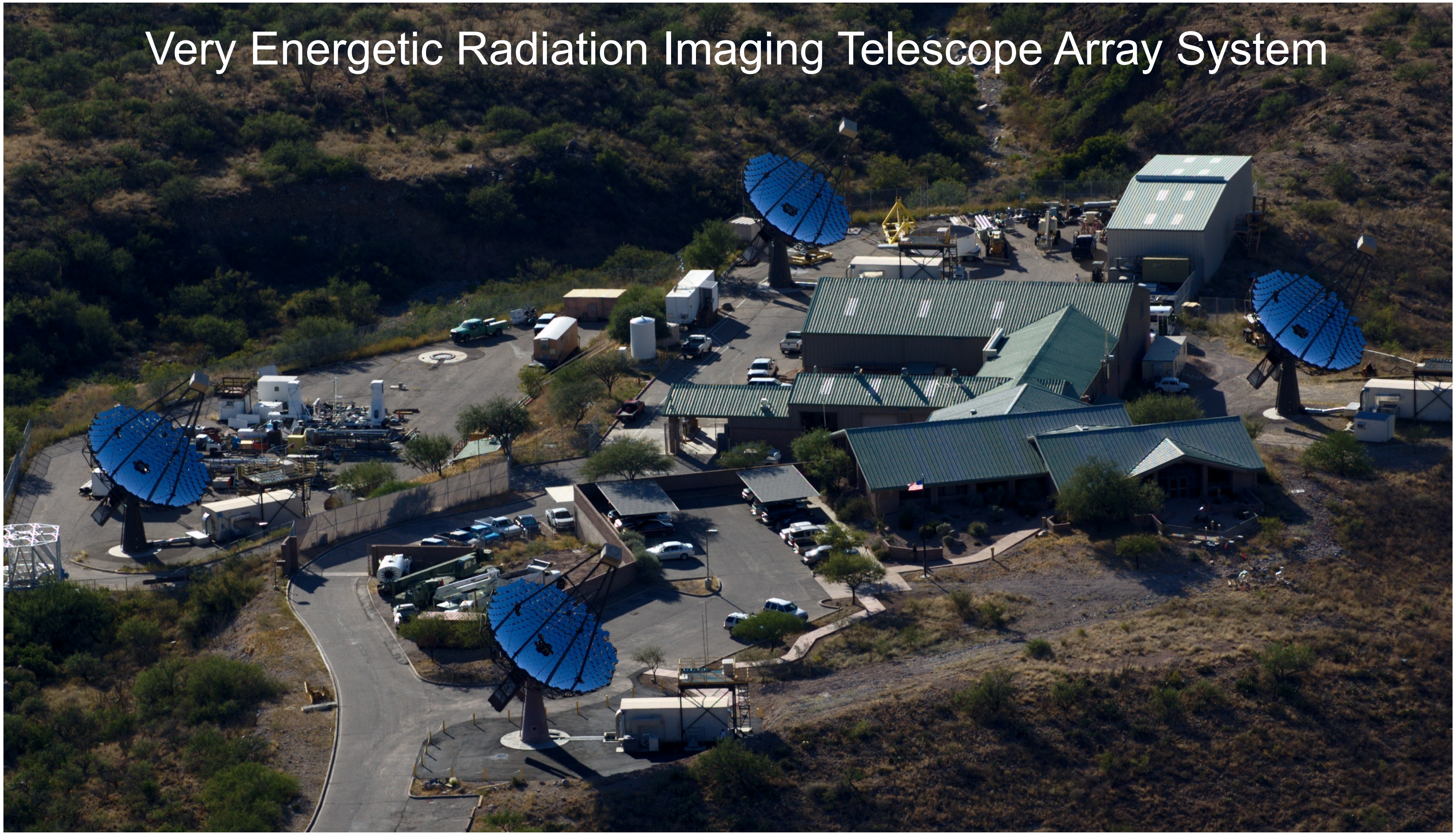
Natural Sciences 2, 319
459-3032

February 3, 2014

Main Research Interests

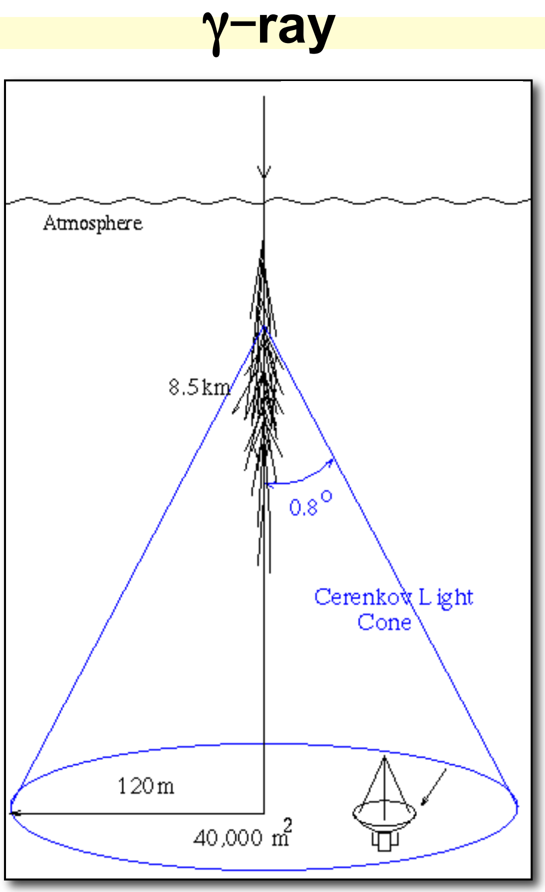
- How are high energy particles accelerated in the jets of AGN? Are they primarily electrons or protons?
- Do gamma-ray bursts produce very high-energy gamma-rays, either in the prompt or afterglow phase? What does that tell us about GRBs if they do/don't?
- What can we learn about the evolution of the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

VERITAS: Imaging Atmospheric Cherenkov Telescope

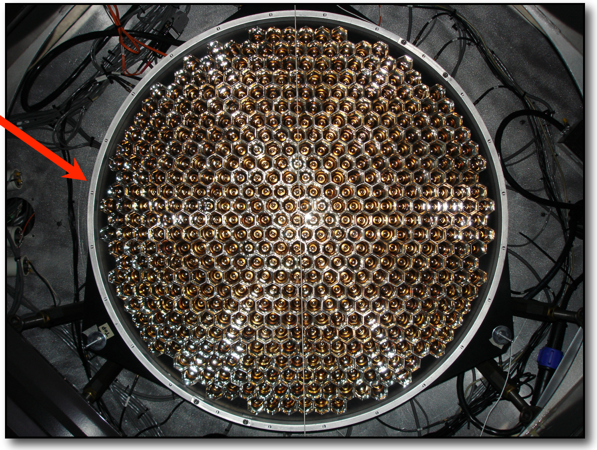


Whipple Observatory Basecamp (el. 1275 m) at foot of Mt. Hopkins

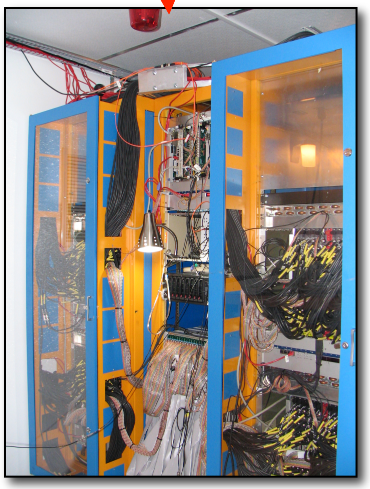
Atmospheric Imaging Technique



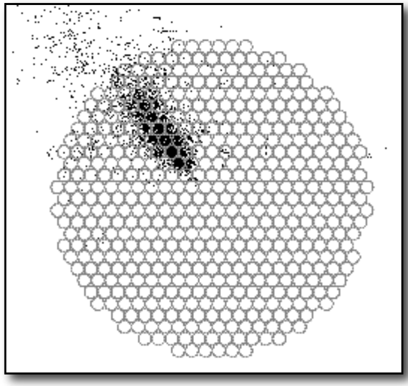
12 m Mirror



499-PMT camera



500-MHz FADC electronics



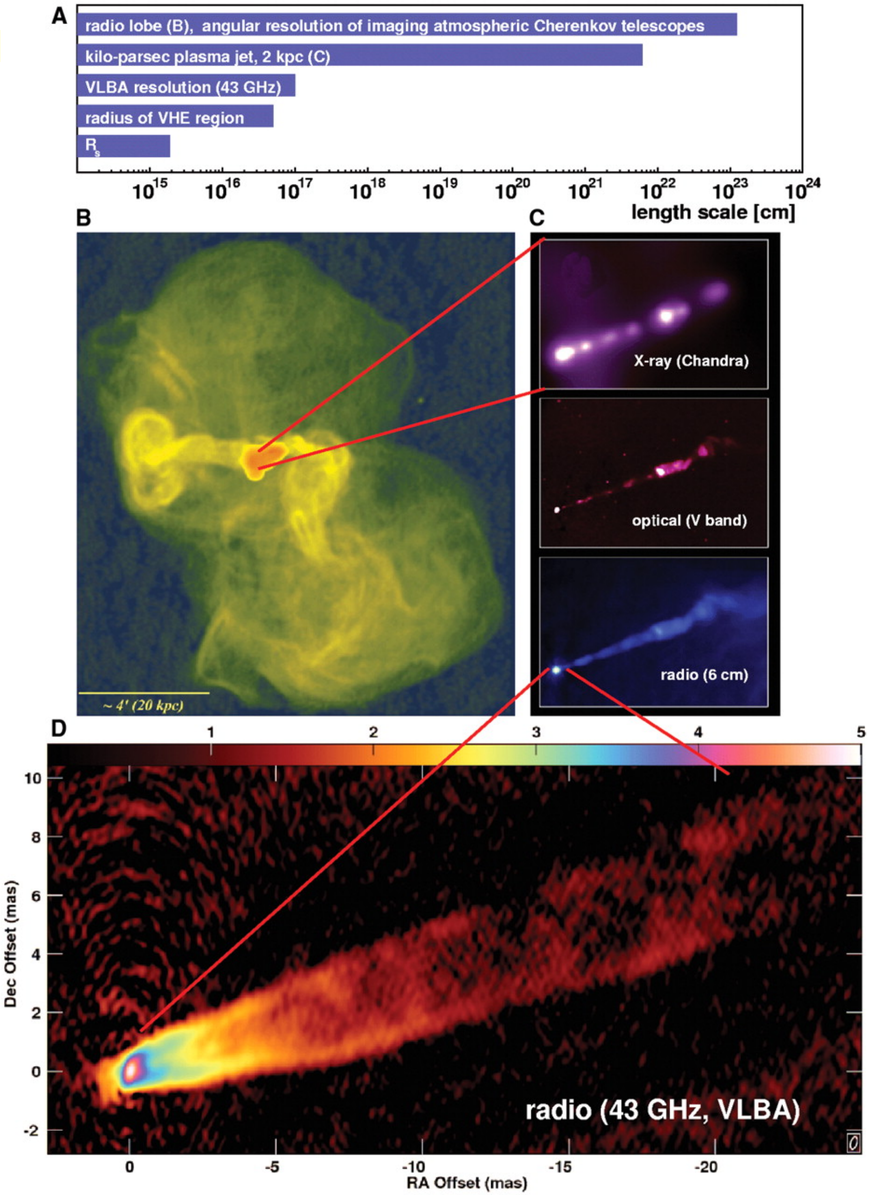
Cherenkov image

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

γ-rays above ~100 GeV

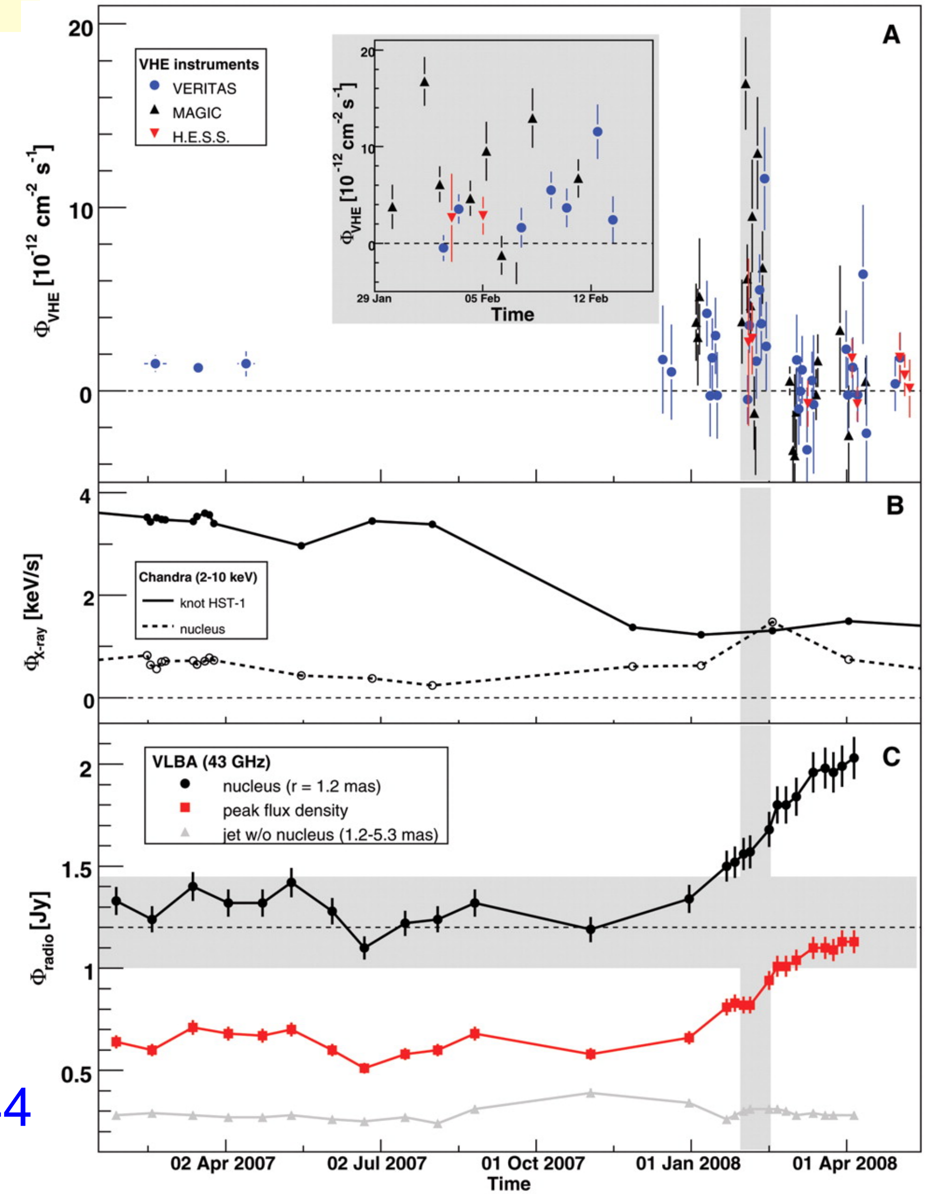
Radio Galaxy: M 87

- 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



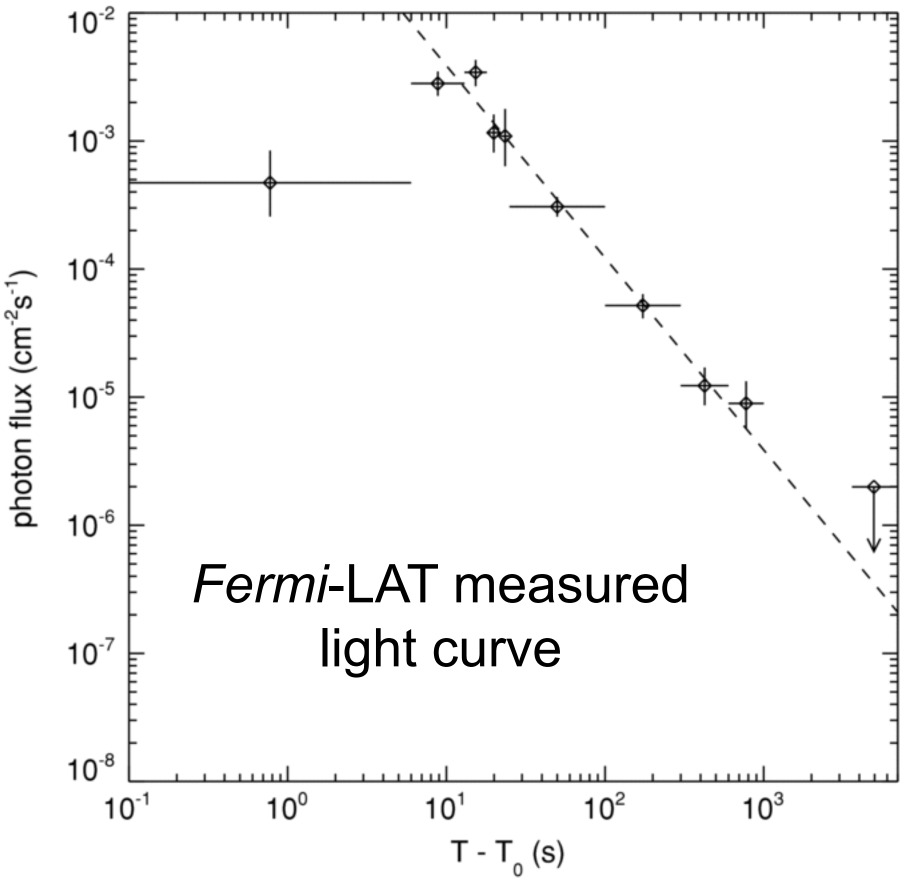
M 87 – Radio and TeV flares

- 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

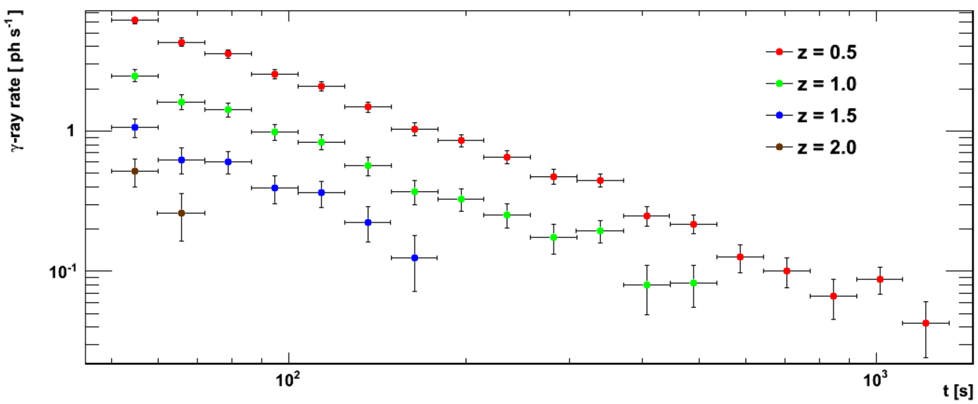


V. Acciari *et al*. 2009, Science 325, 444

GRB 090902B

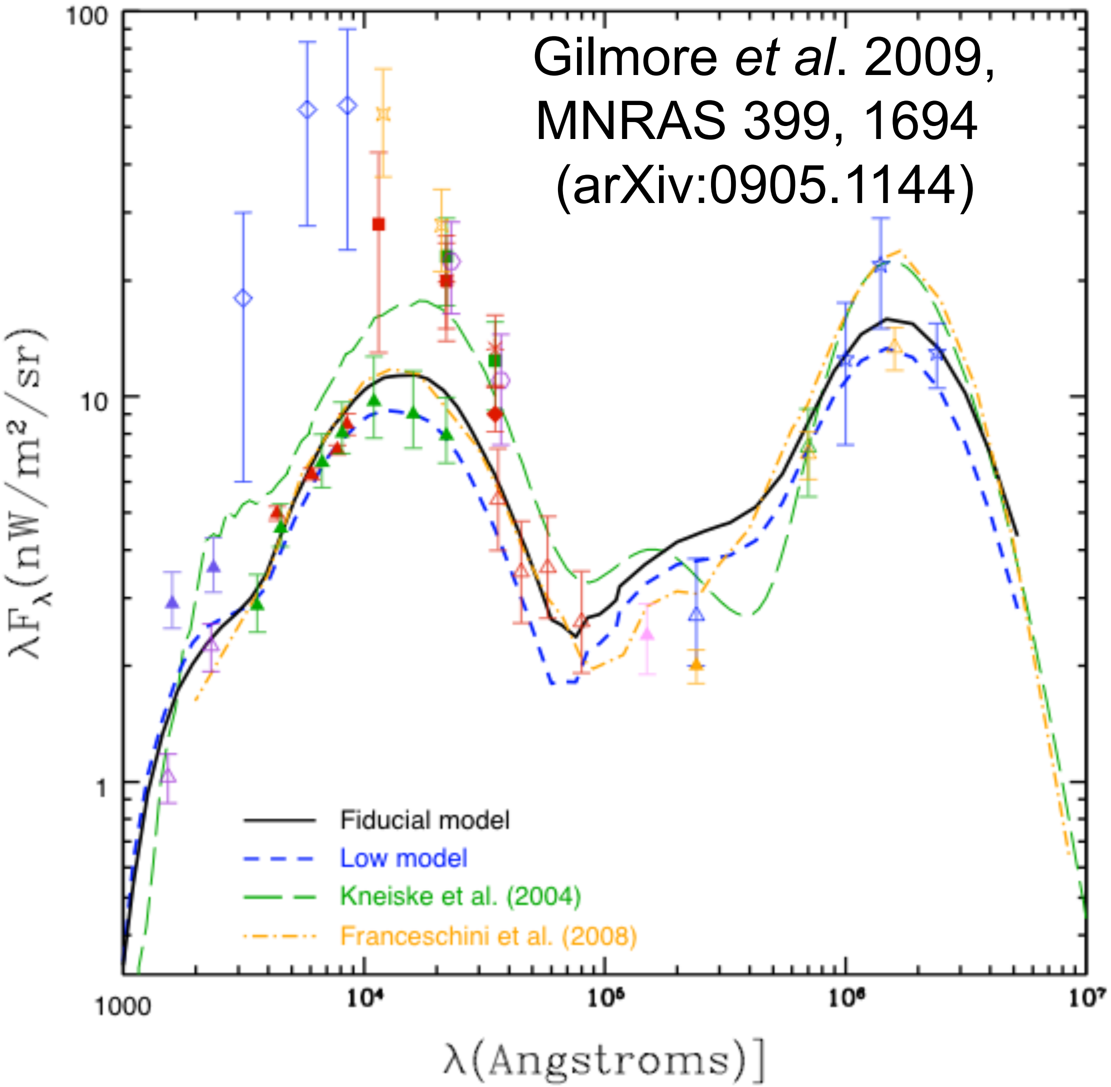


Simulated VERITAS
light curves for
different redshifts



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

Extragalactic Background Light



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

Difficult to measure EBL because of foreground sources

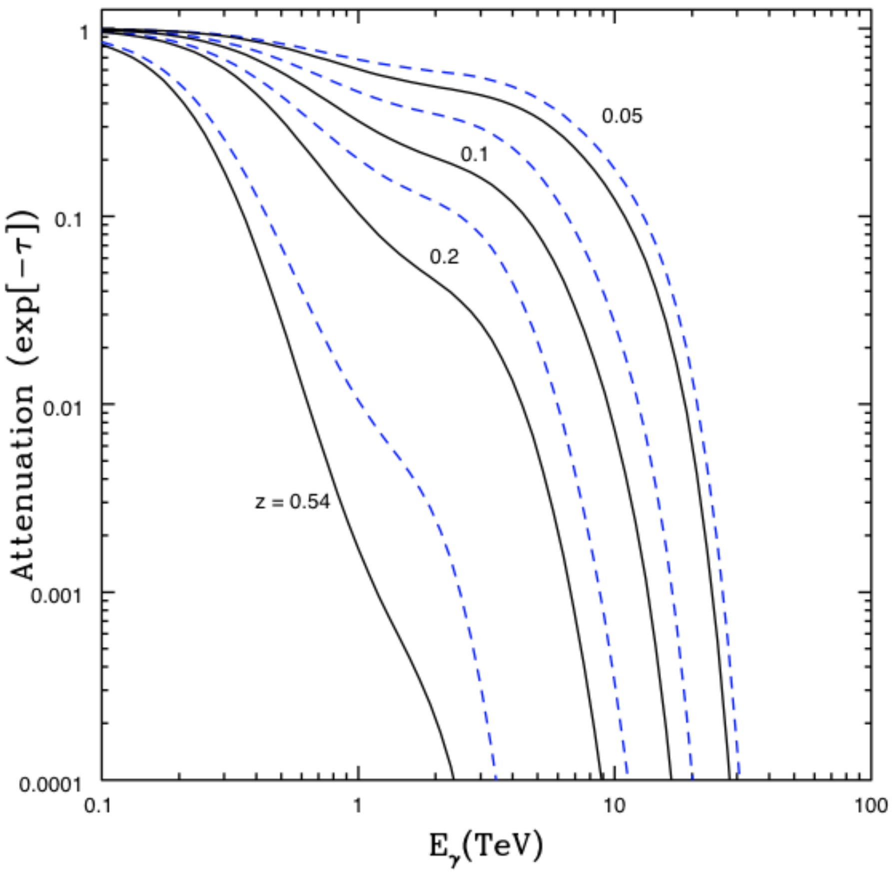
Test of cosmology

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

Recent modeling consistent with the published experimental results

Understanding the EBL

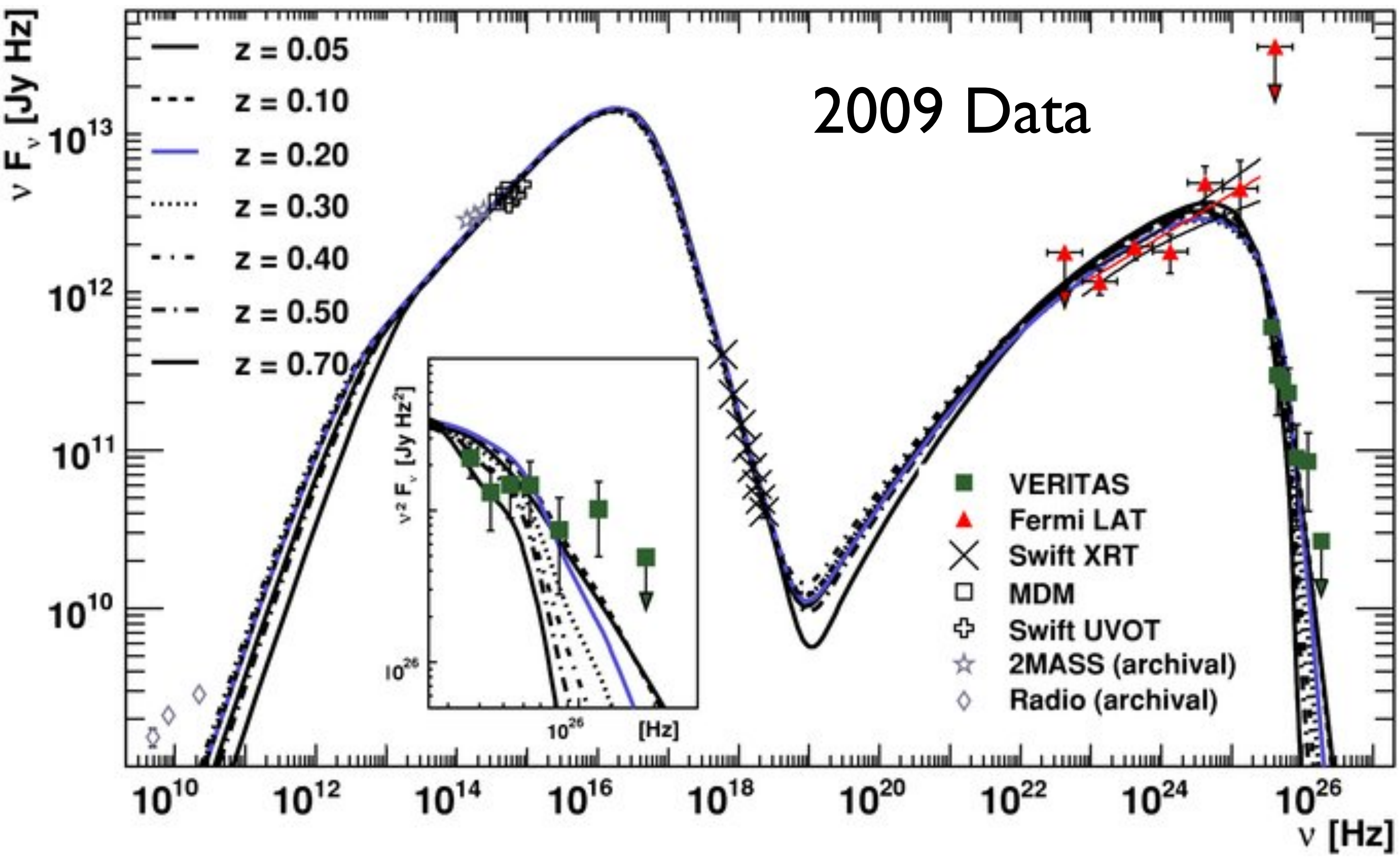
- Search for new, more distant blazars (e.g. 4C +55.17)
- More precise spectral measurements of known blazars (e.g. Mrk 421, PKS 1424+240)
- Obtain data at other wavelengths to help model intrinsic spectra (*Fermi*, *Swift*)
- Obtain redshifts for detected blazars (w/ Prochaska, Fumagalli)
- Theoretical modeling of the EBL (w/ Primack, Madau, Gilmore)



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

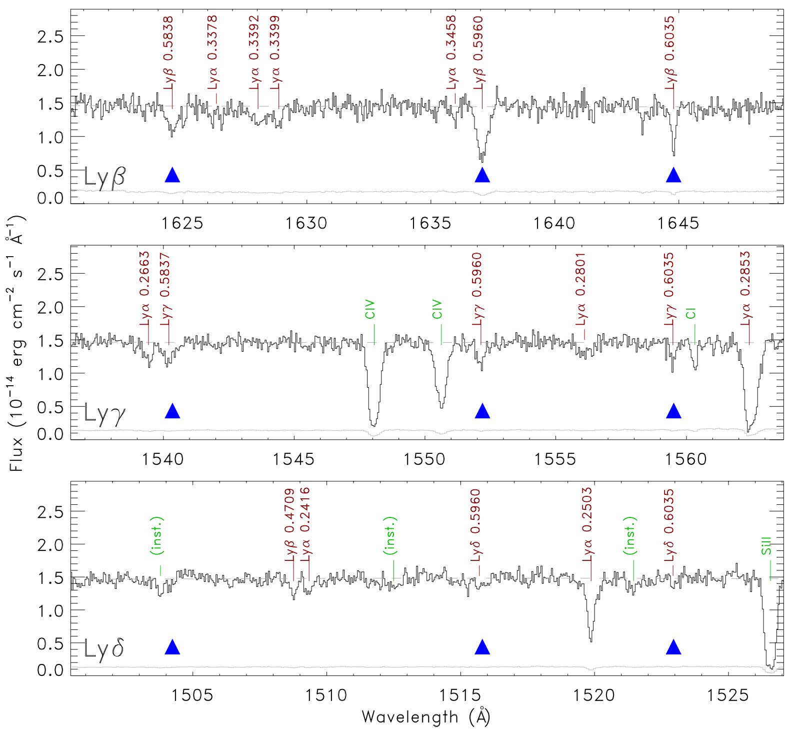
First VHE blazar found using Fermi-LAT observations

- No redshift information
- On the ISP/HSP cusp
- Soft X-ray spectrum
- Used MWL data to show likely z<0.67
- Used SSC SED modeling to show likely z<0.2



Redshift Lower Limit of PKS 1424+240 from Far UV Observations

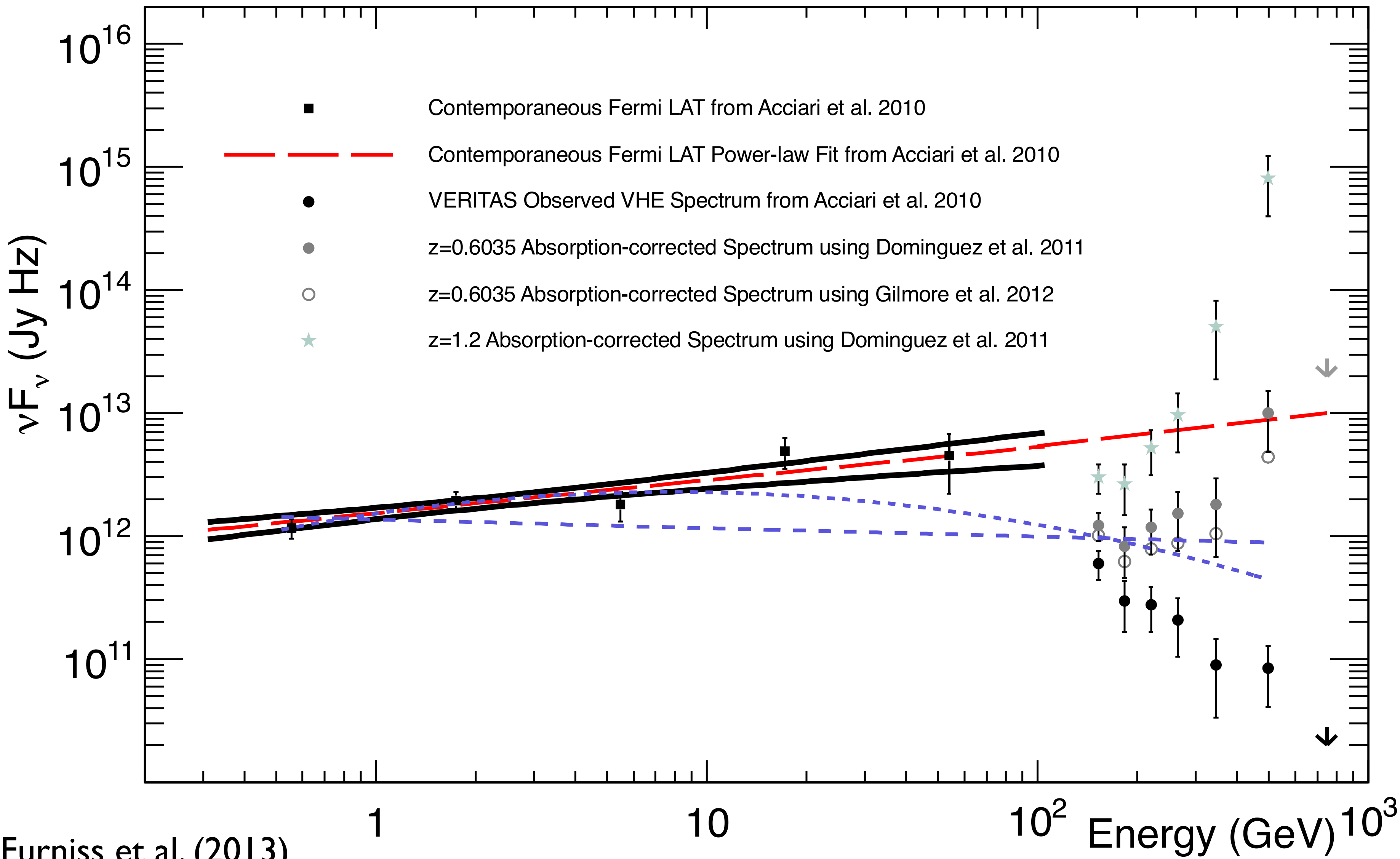
- Bright, featureless blazars are also used as background sources to study the intergalactic medium
- Lower limit of blazar distance can be derived from observation of intervening Lyman absorption with HST/COS
- Observations of PKS 1424+240 on April 19, 2012 show higher-order Lyman absorption at z=0.6035



Furniss et al. (2013)

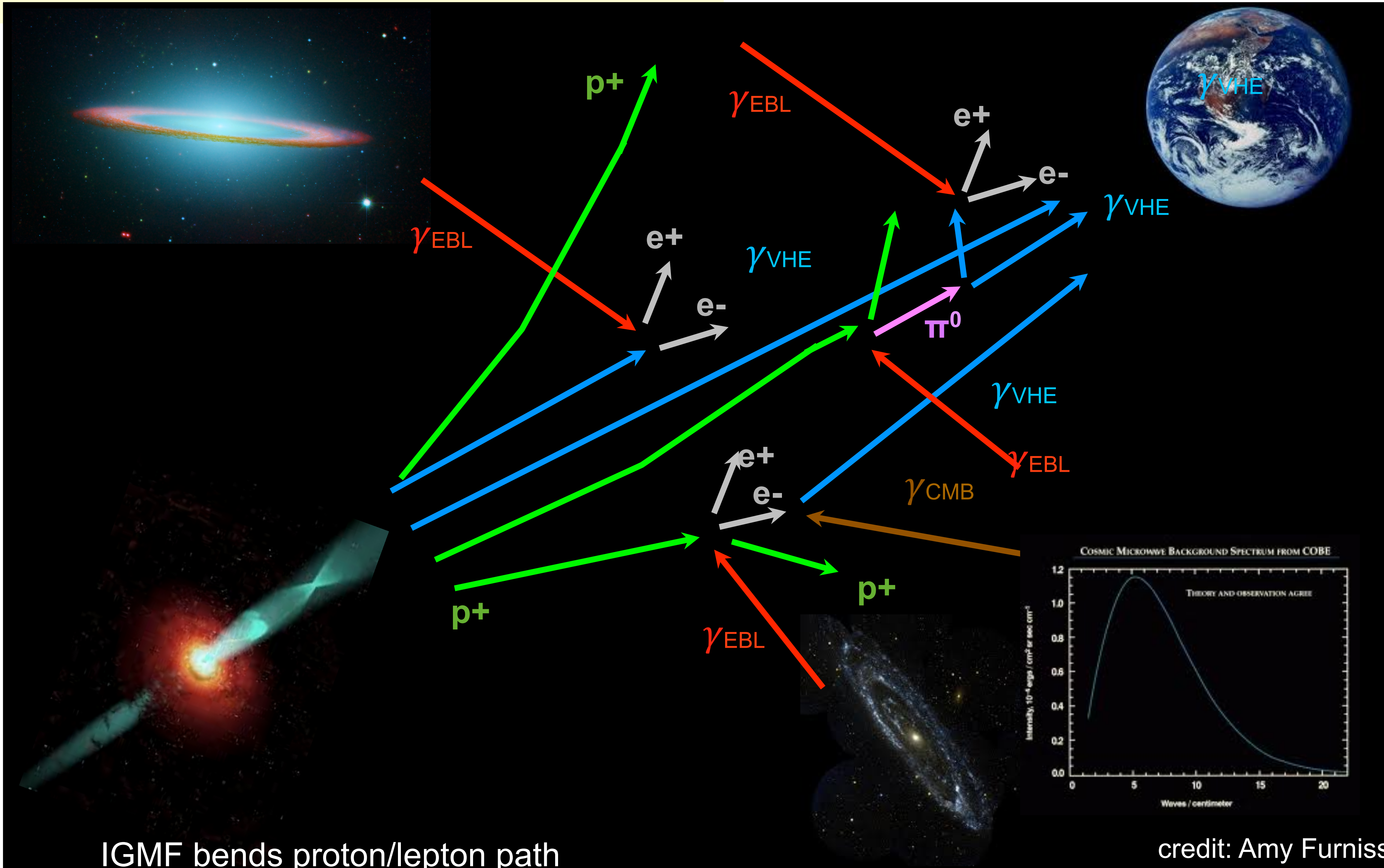
Absorption-corrected Gamma-ray Emission

A First Look...

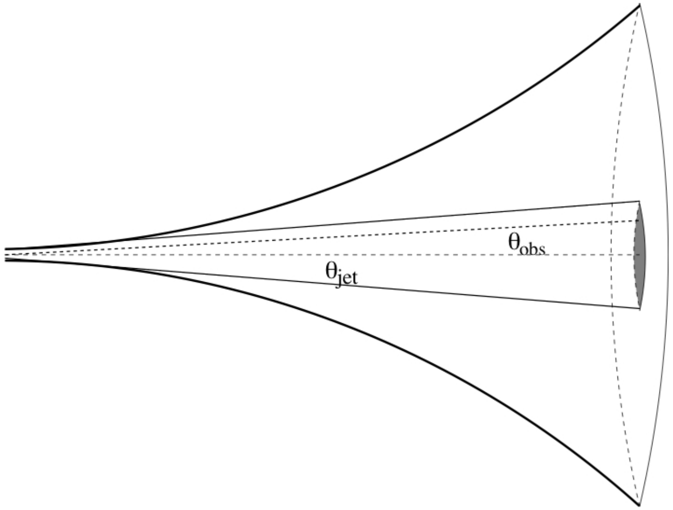


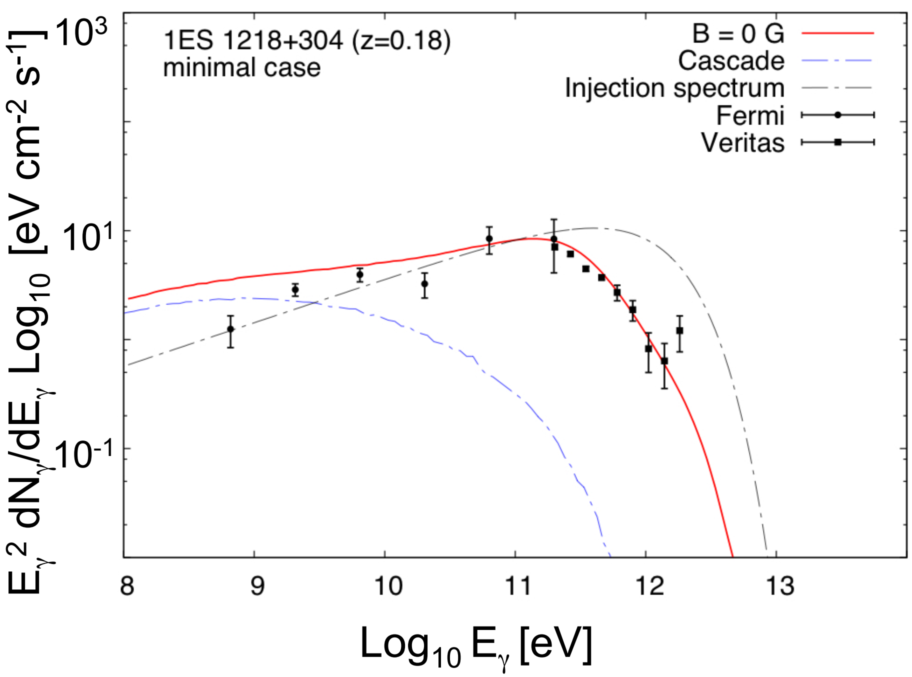
Furniss et al. (2013)

Cosmic-ray Contribution?



The EBL and Intergalactic B Fields





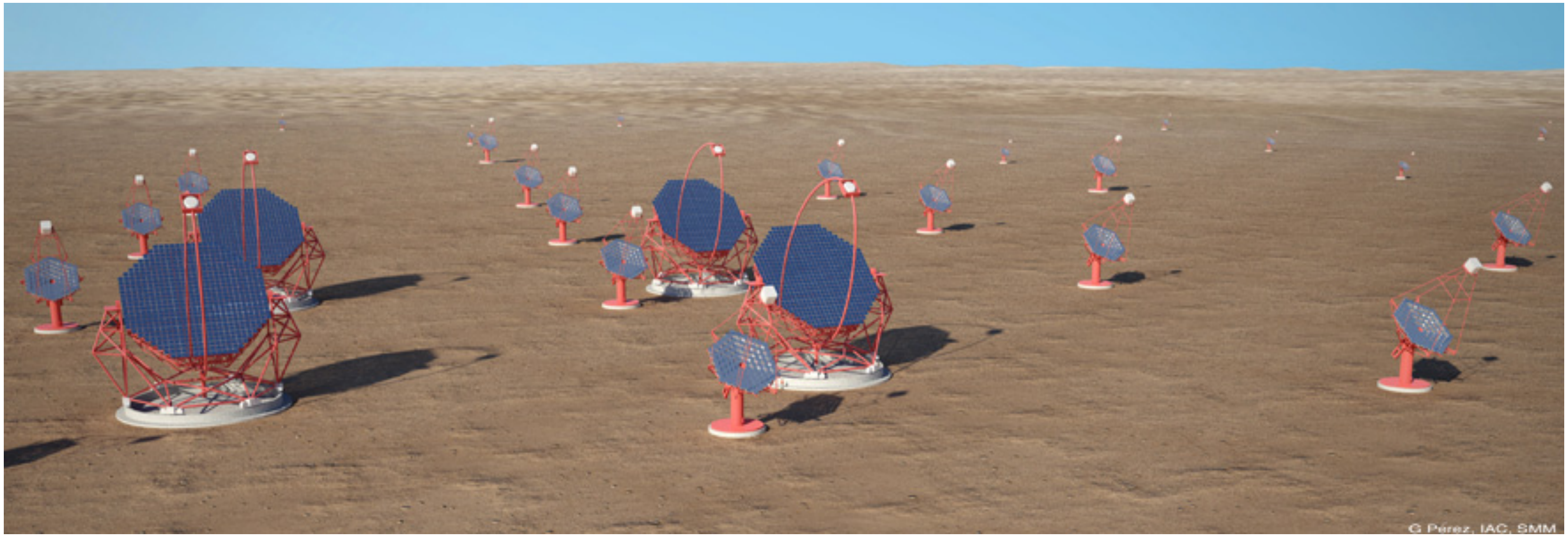
- Electrons produced by

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

  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

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

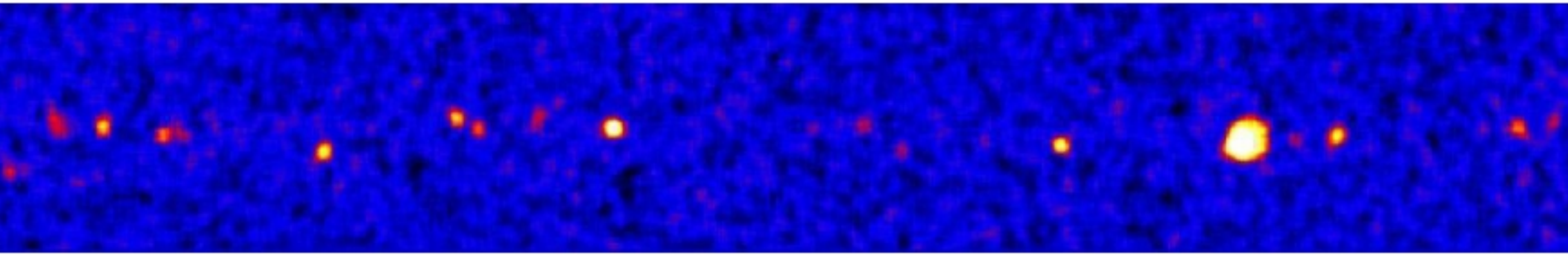
Small telescopes (SSTs) covering >3 km^2 in south

- >10 TeV observations of Galactic sources

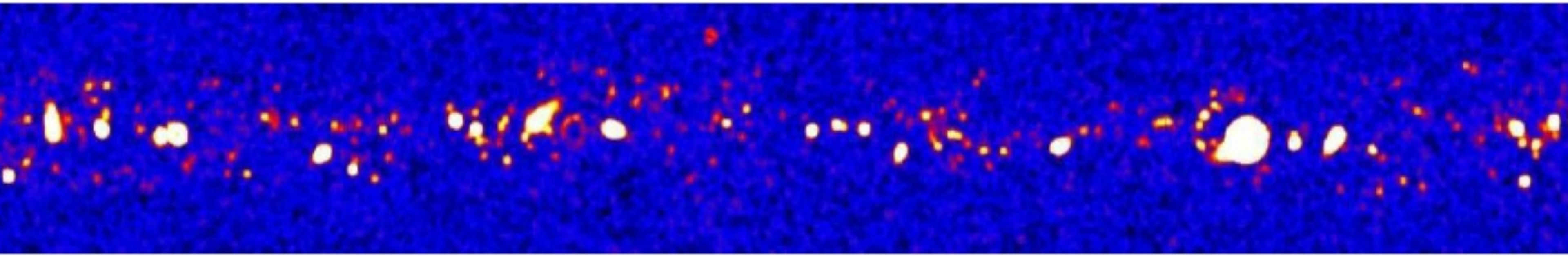
Construction begins in ~2015

Simulated Galactic Plane surveys

H.E.S.S.

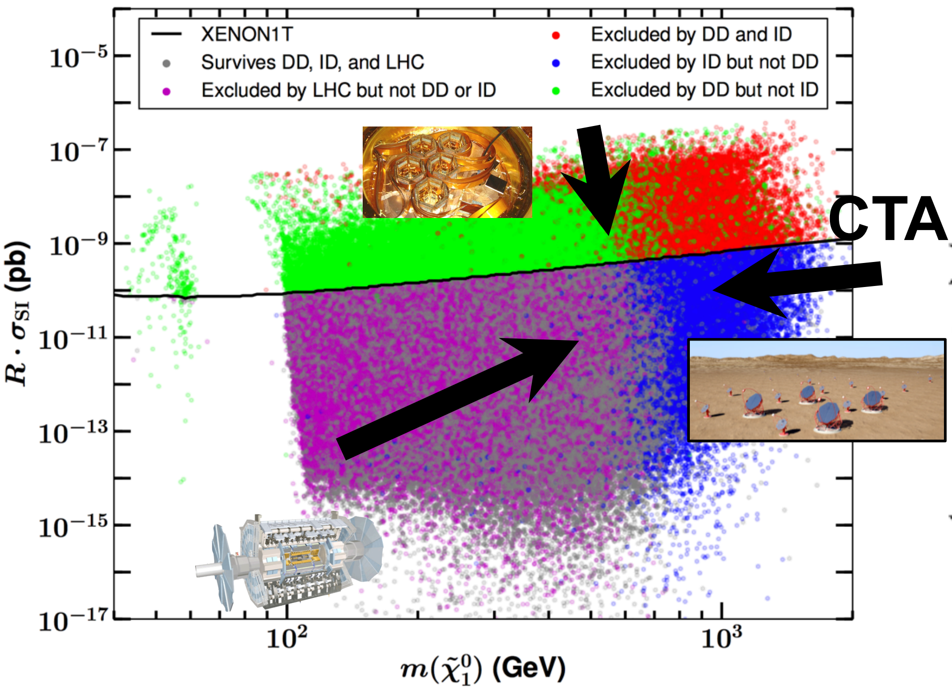


CTA, for same exposure



Expect ~1000 detected sources over the whole sky

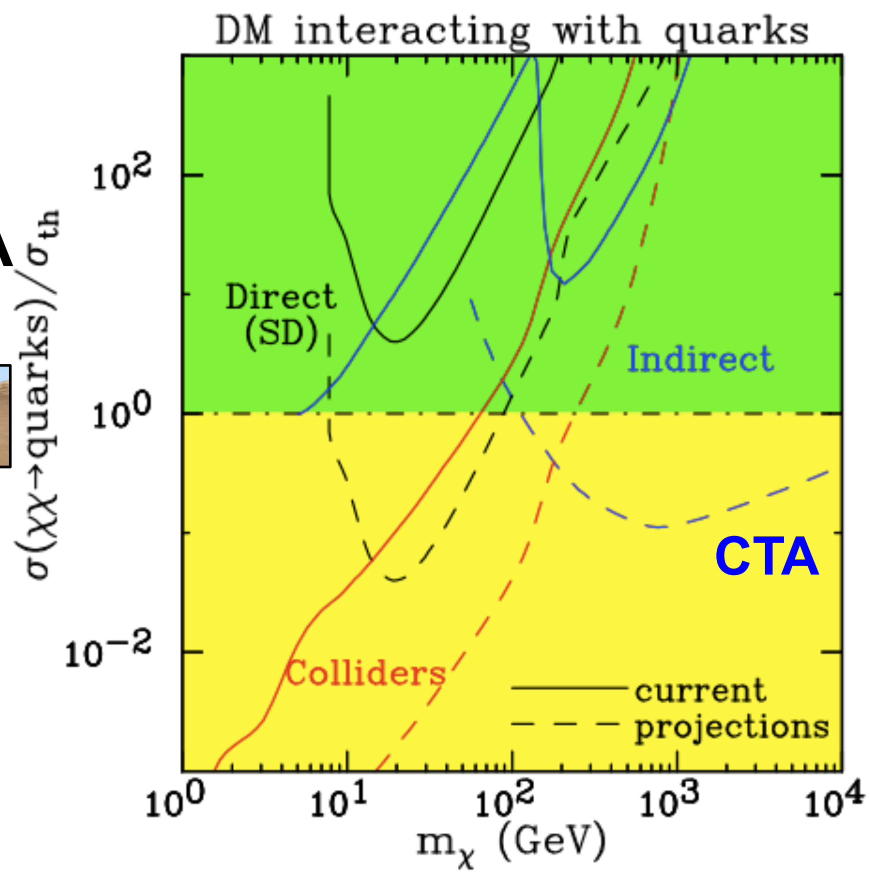
Unique Dark Matter Results with CTA



Constraints:
$\Omega_{DM}h^2$ > 0.1, XENON100 (2011), CMS+ATLAS (2012)

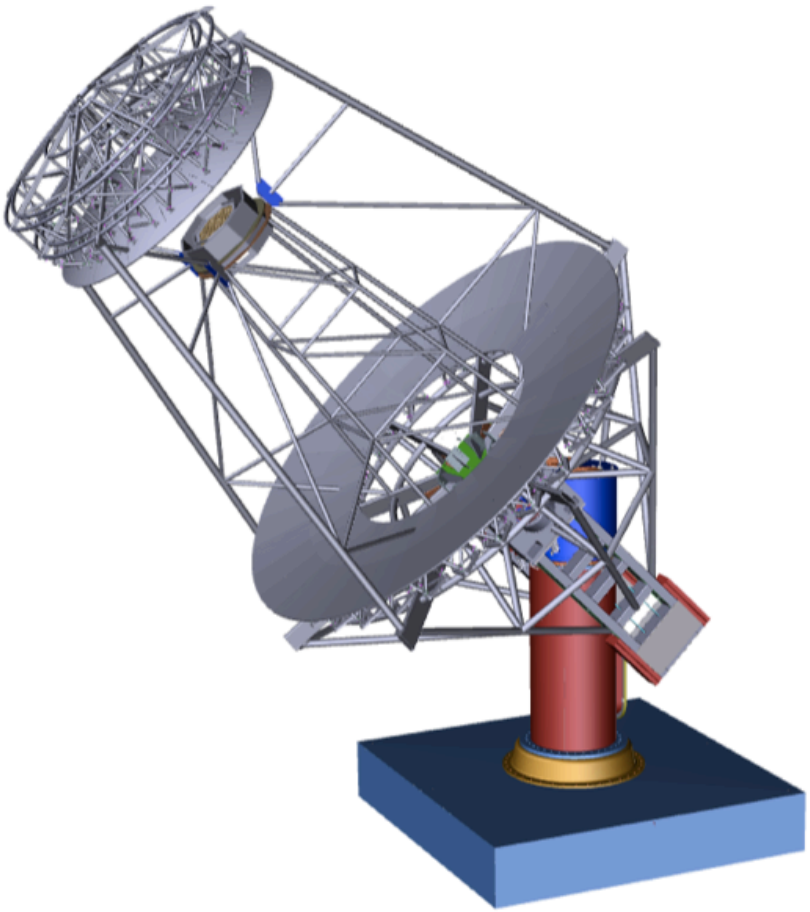
CTA results include U.S. contribution

M. Cahill-Rowley et al. – Snowmass white paper, arXiv:1305.6921

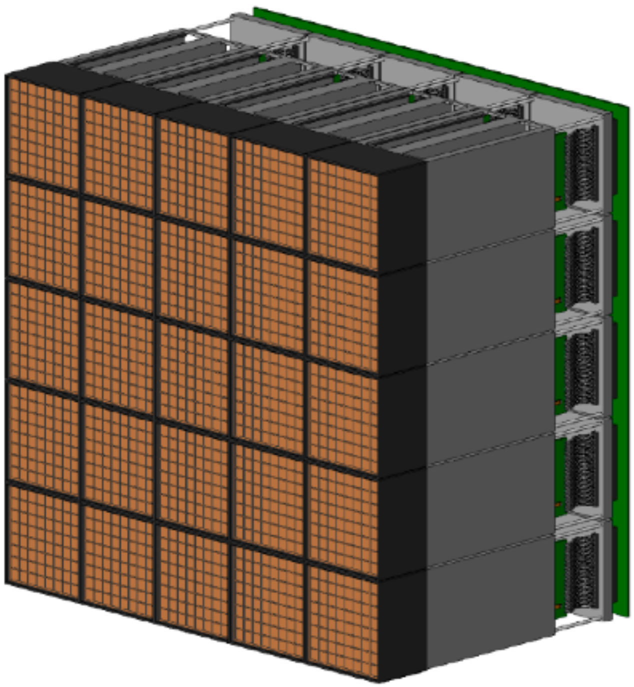


D. Bauer et al. – Snowmass complementarity report, arXiv:1305.1605

A Novel Telescope for CTA

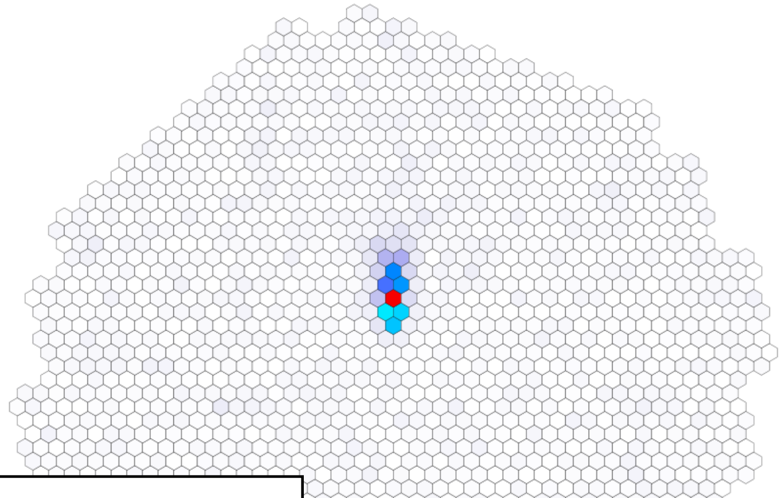


Schwarzschild-Couder optics

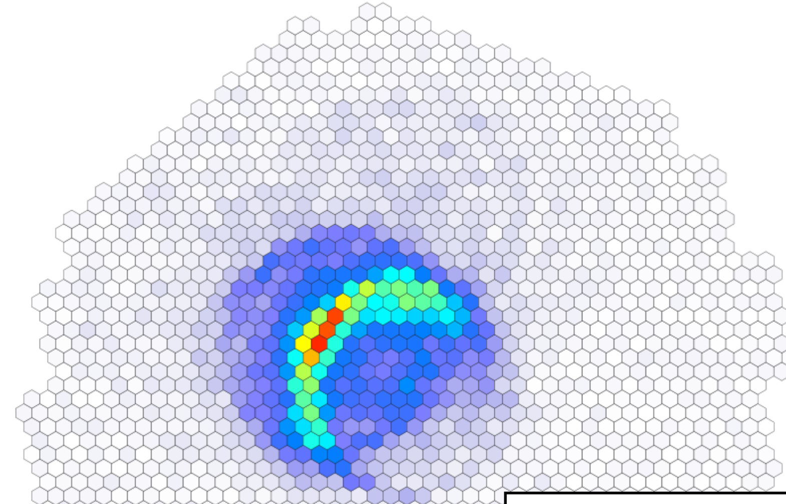


Camera using silicon photomultipliers with integrated electronics

Adding Two-mirror Telescopes: More Showers, Measured Better

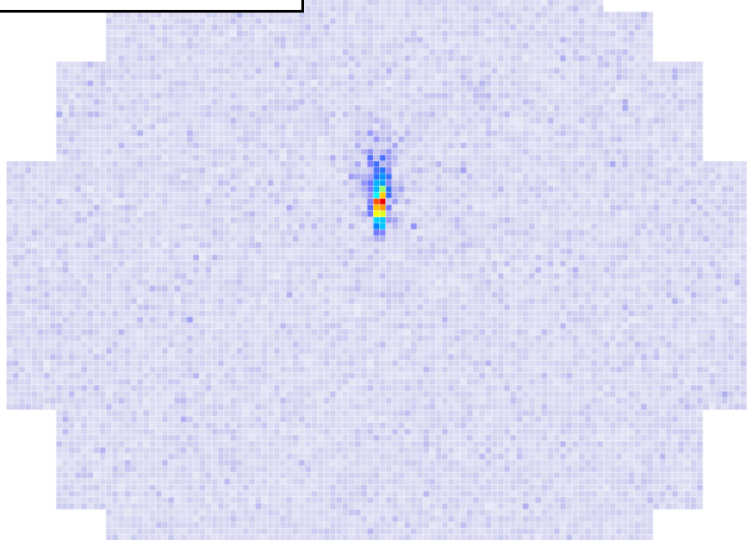


Baseline
Single-Mirror
Telescope
Images
8° field of view
0.18° pixels
1,570 channels

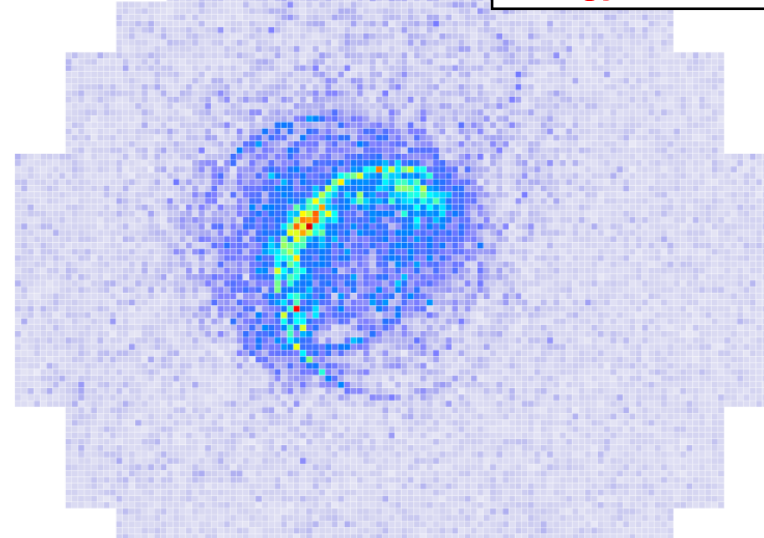


Signal:
γ-ray Shower
Energy: 1 TeV

Background:
Proton Shower
Energy: 3.2 TeV



U.S. Design
Two-Mirror
Telescope
Images
8° field of view
0.067° pixels
11,328 channels



Opportunities

- Data analysis with VERITAS – unsurpassed 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

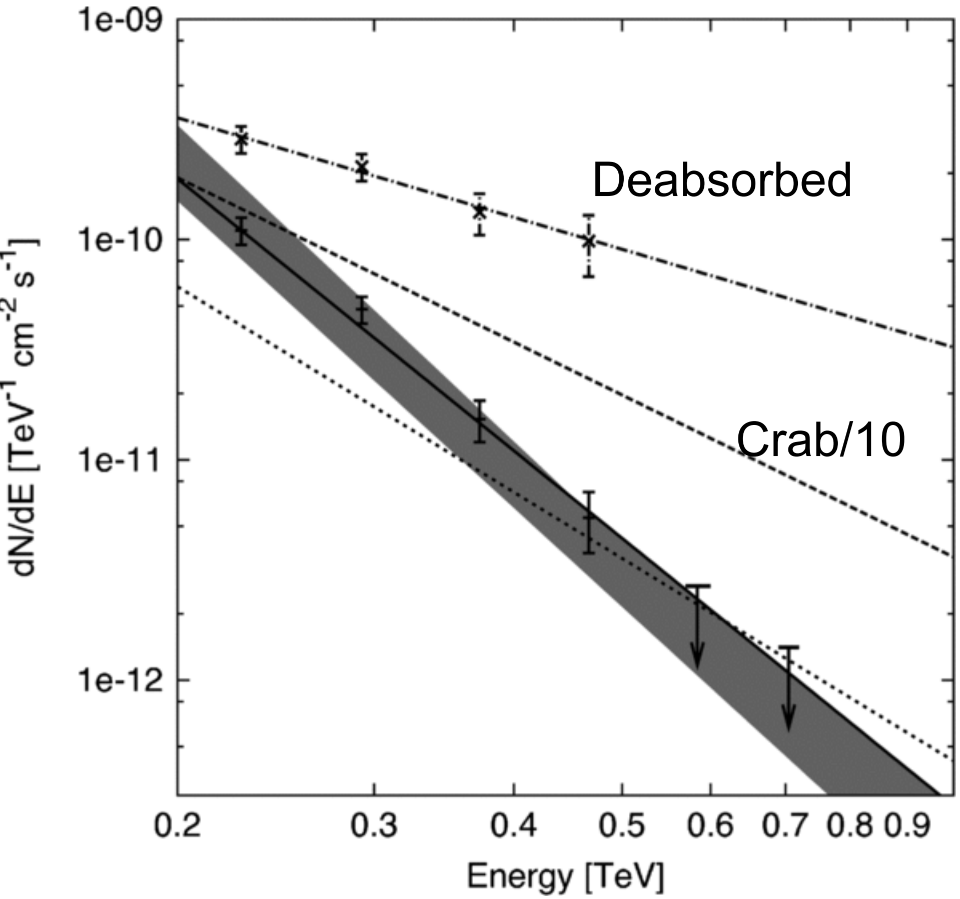
Postdoc: Jonathan Biteau

Visiting postdoc: Amy Furniss (Stanford)

Graduate student: Caitlin Johnson, your name here!

Undergraduate students: David Chinn, Zach Hughes, Andrey Kuznetsov

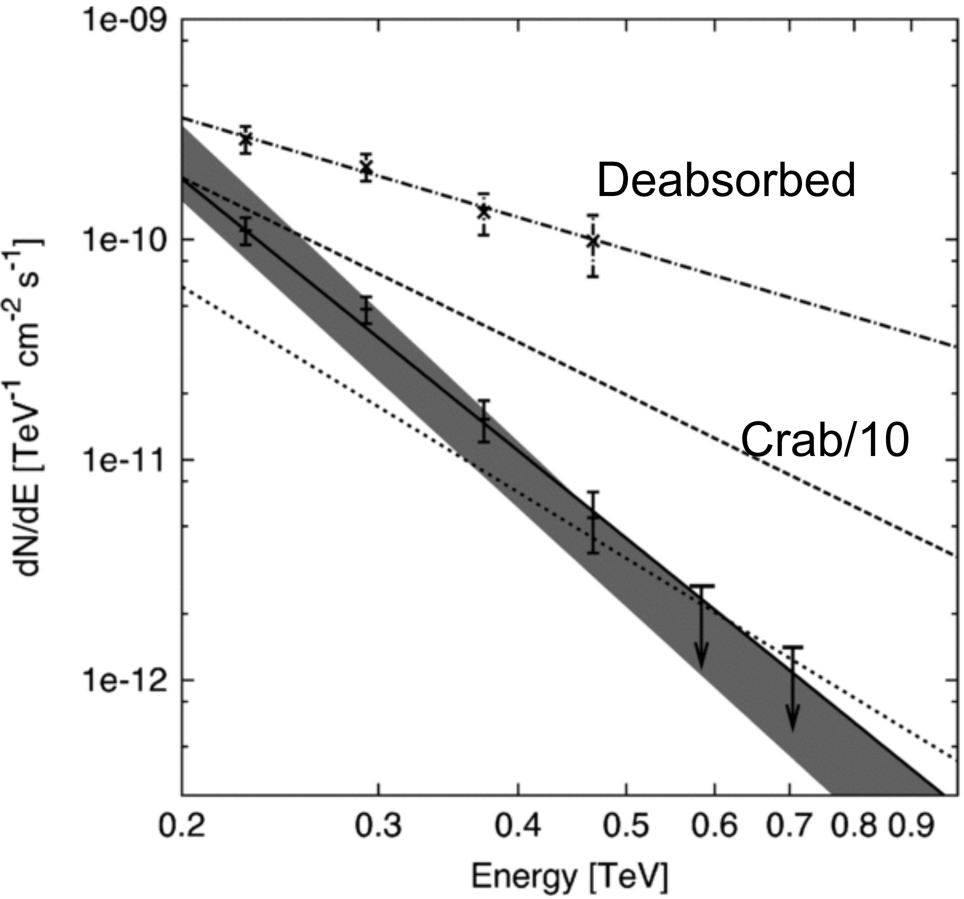
Blazar: 3C 66A



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

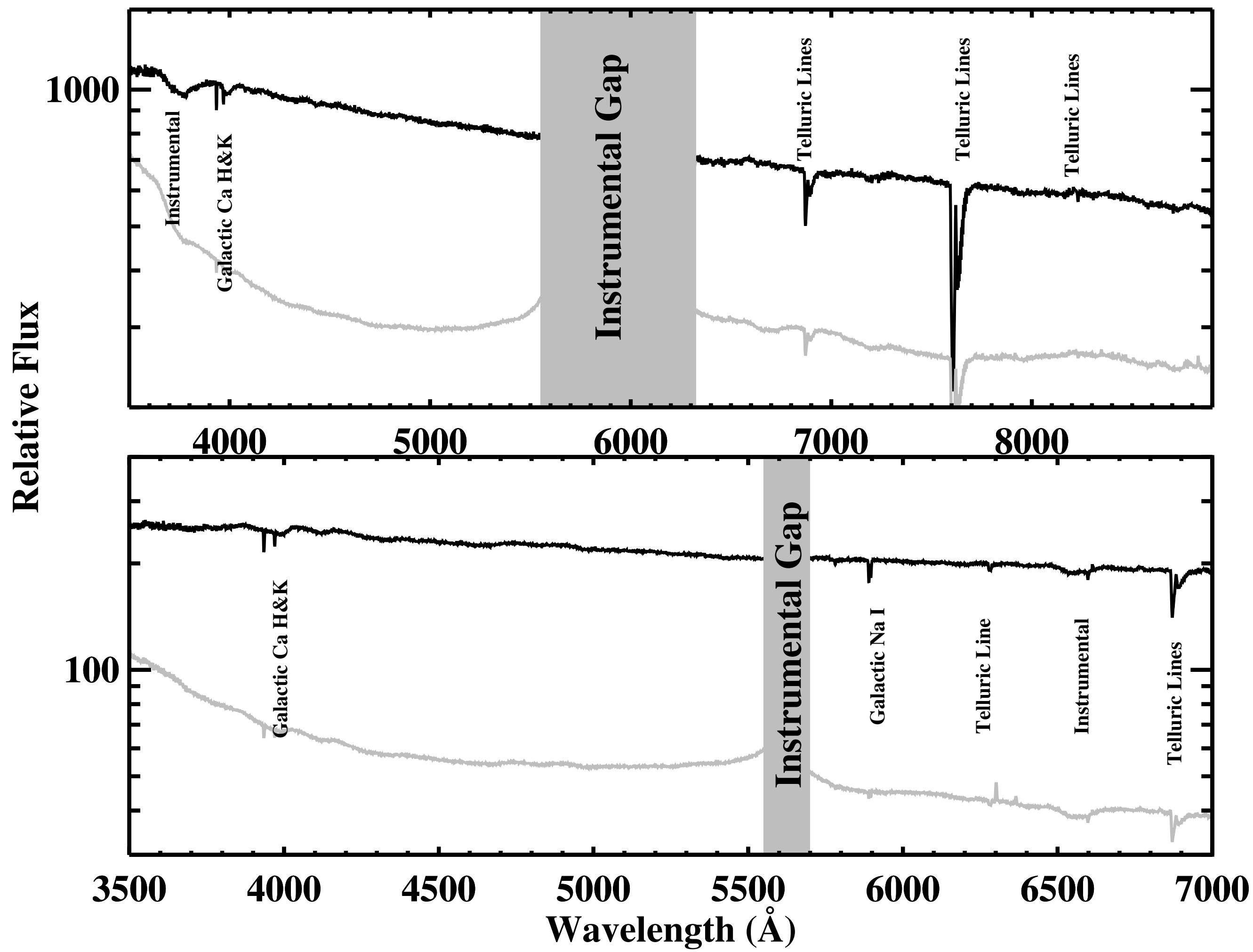
Blazar: 3C 66A



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

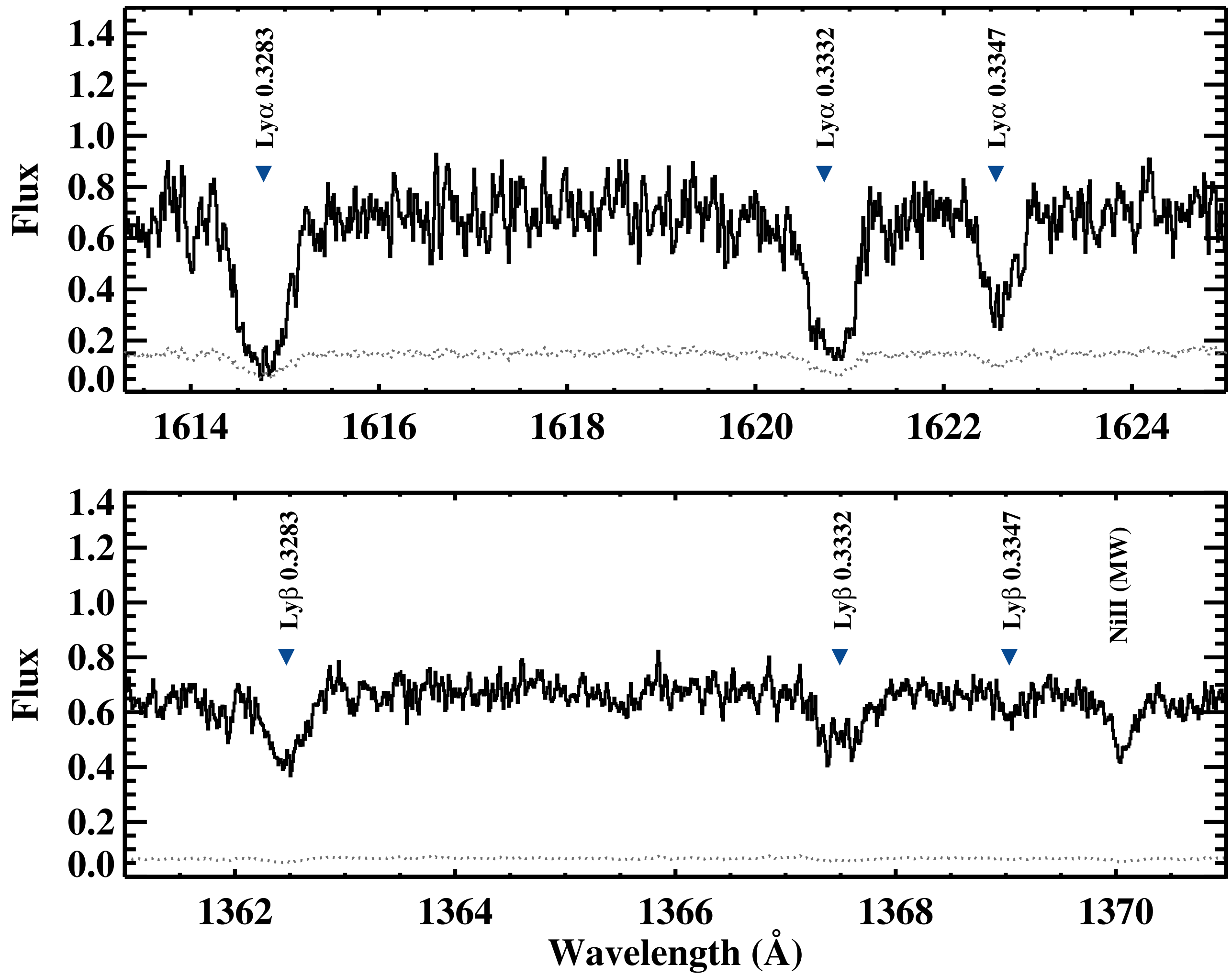
- AGN with jet oriented along line of sight – BL Lac object
- redshift ~~0.44~~? 0.335–0.41
- Observed spectral index
  $\Gamma = 4.1 \pm 0.4_{stat} \pm 0.6_{sys}$
- Deabsorbed spectrum using Franceschini et al 2008 model gives
  $\Gamma = 1.5 \pm 0.4$
- At the limit the models can tolerate
- Need firm 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