Status of CTA and Crab Flare

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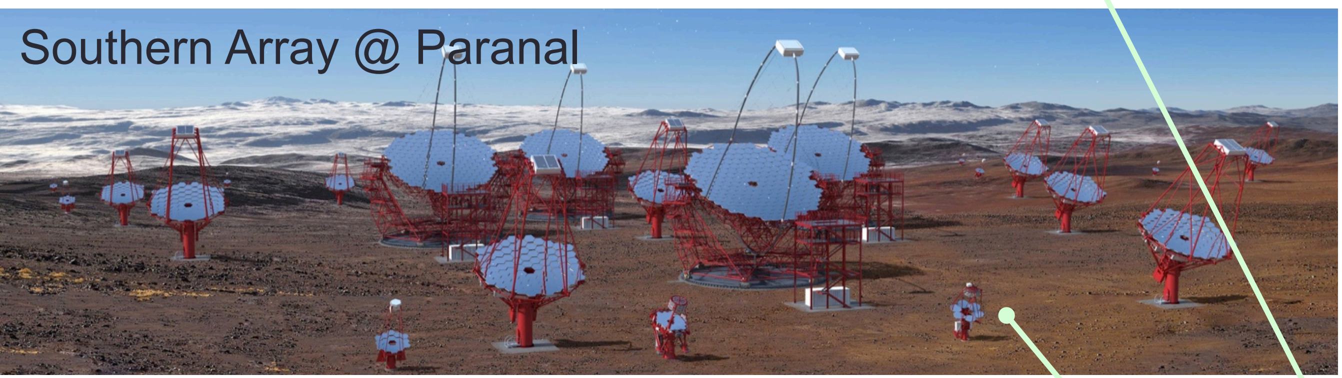
for the CTA consortium

Outline

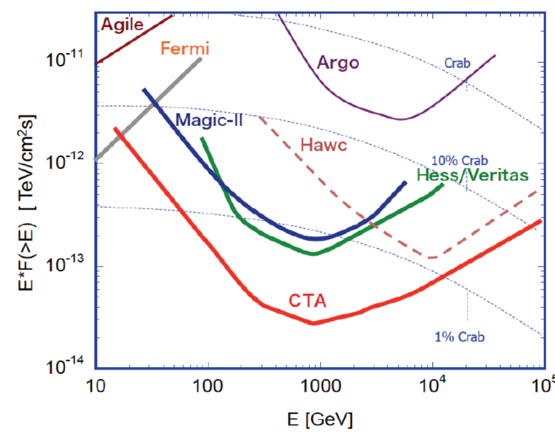
- Status of CTA
  - Introduction
  - Configuration of array and telescopes
  - Sensitivity
  - Some examples of expected physics

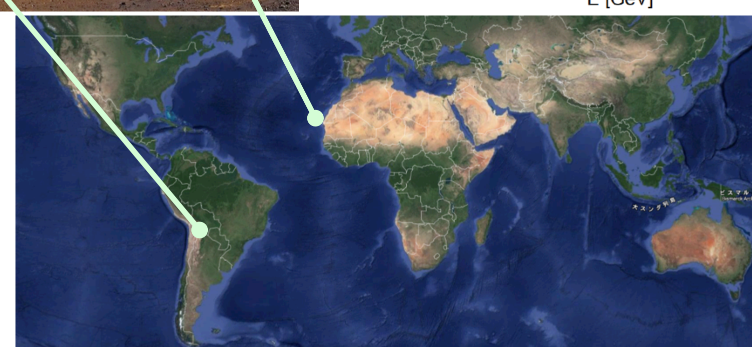
- Simulation Study for Crab Flare for CTA
  - GeV Flare in April 2011
  - Moving blob model
  - Prospects with CTA

Cherenkov Telescope Array



- New Generation VHE Gamma-ray Observatory
- North and South
- >30 countries
- > 1200 scientists
- x10 sensitivity
- above 20 GeV





CTA Scientific Cases

Understanding the Origin and Role of Relativistic Cosmic Particles

- Acceleration site & mechanism
- Feedback of accelerated particles on star formation and galaxy evolution

Probing Extreme Environments

- Physical process at vicinity of neutron stars and black holes
- Characteristics of Relativistic jets, winds and explosions

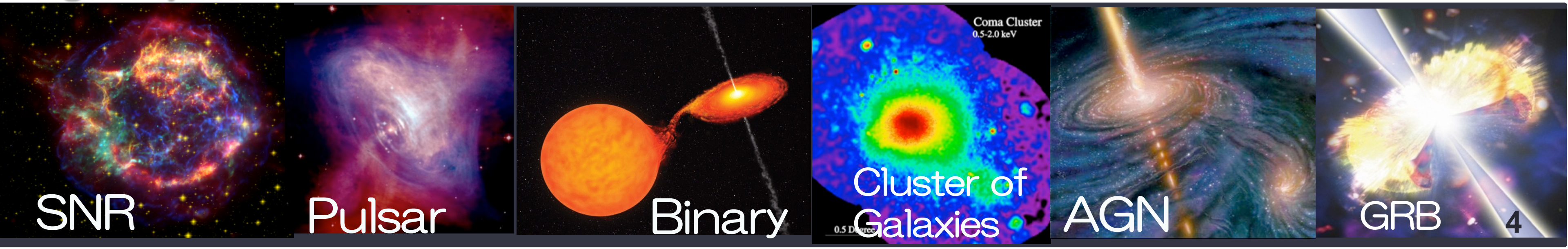
Exploring Frontiers in Physics

- Nature of Dark Matter
- Effect of Quantum Gravity on photon propagation
- Existence of Axion-like particles

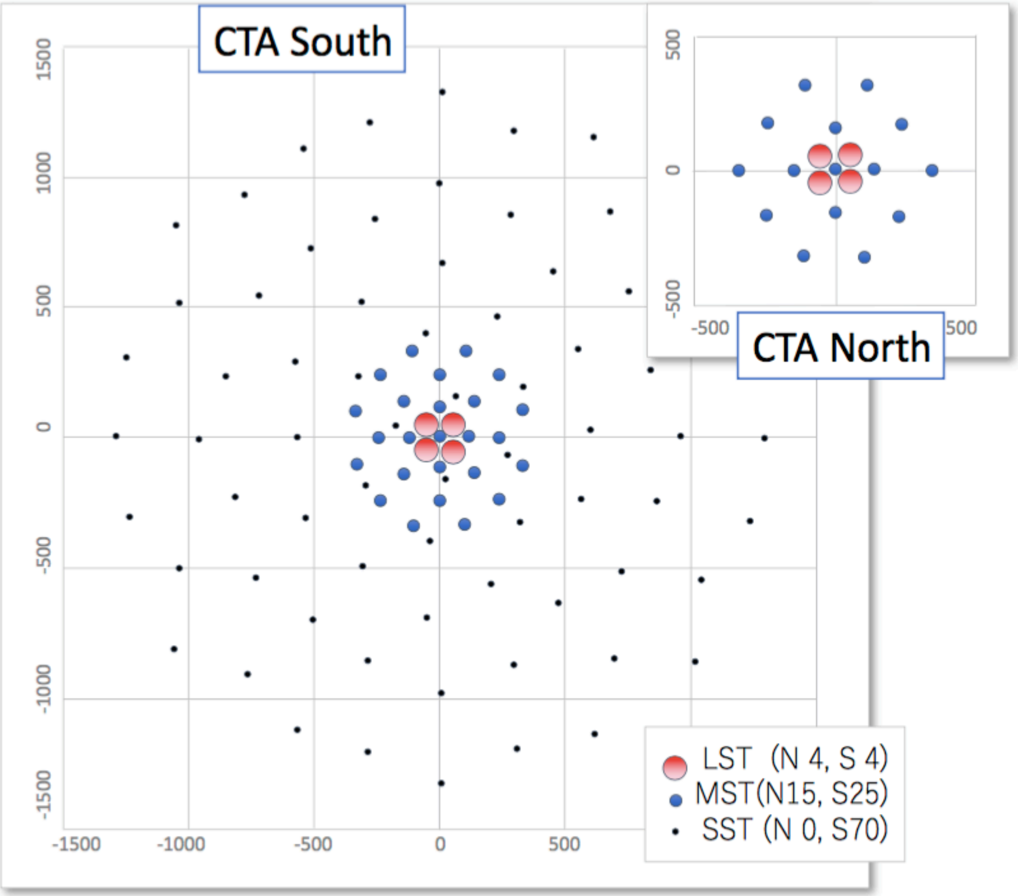
Key Science Project

- Galactic Plane Survey
- Galactic Center
- Extreme Particle Accelerators
- Star Forming System
- Active Galaxies
- Galaxy clusters
- Transients
- Extragalactic Survey
- Dark Matter
- Cygnus
- LMC

Target Objects

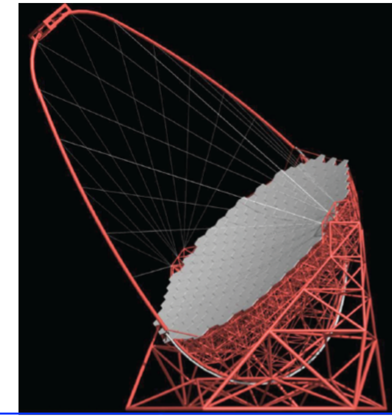


Array Configuration



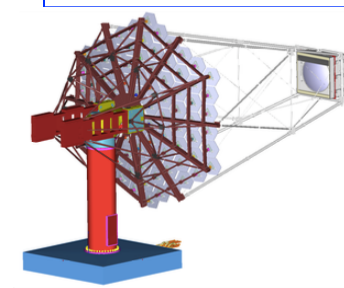
#Tel	Site	LST	MST	SST	SCT
	South	4	25	70	Option (24)
	North	4	15		

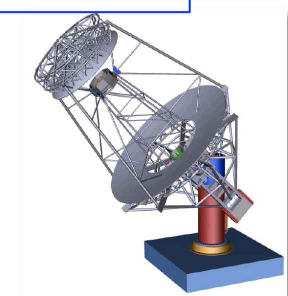
- Observatory operations 2021 ～
- Full array operations 2024 ～



LST
23m
dish

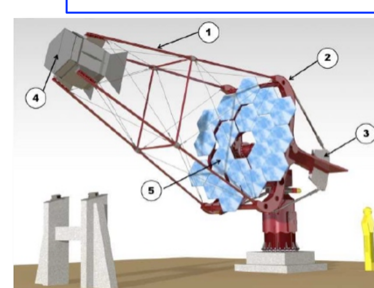
20 GeV—200 GeV

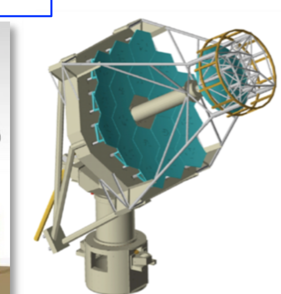




MST 12m SCT 10m

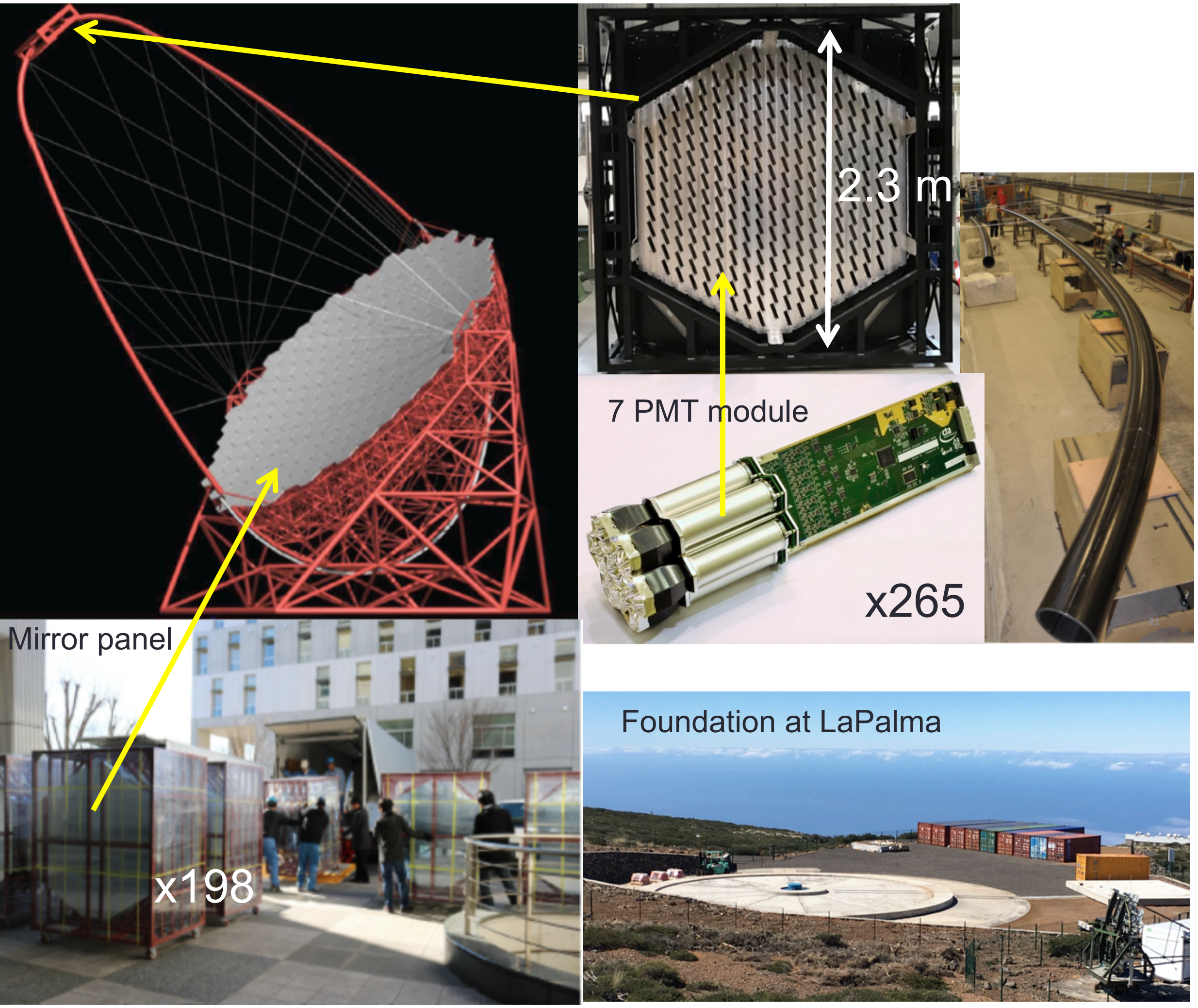
0.1—10 TeV





SST ～4m 5—300 TeV

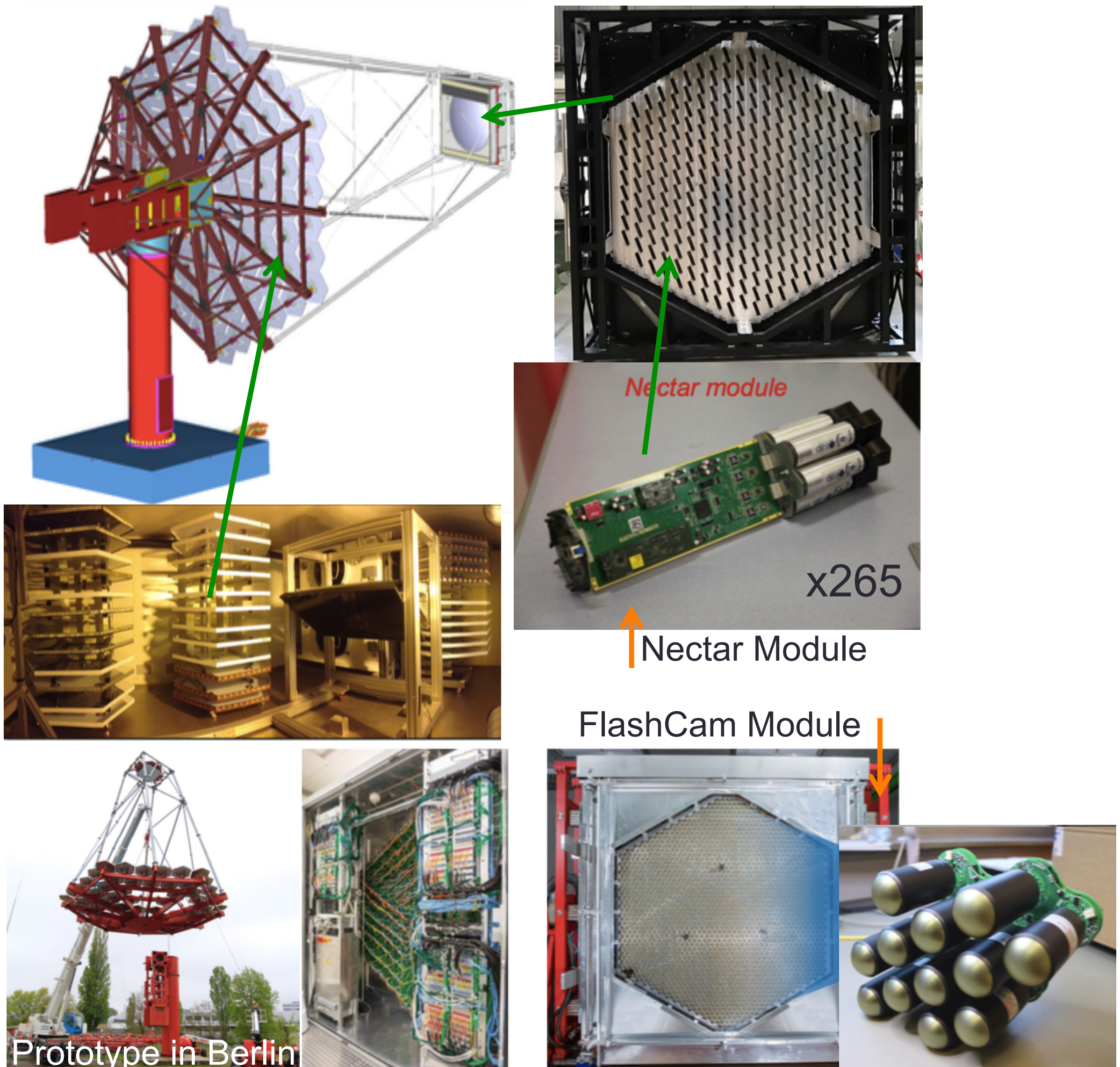
Large–Sized Telescope (N: 4, S: 4)



Dish Size	23 m
Dish Shape	Parabola
Focal Length	28 m
Camera Size	2.3 m 4.5 deg
Pixel Size	5 cm 0.1 deg
Photo Sensor	1855 PMTs
DAQ	1 GHz sampling.
Energy Coverage	20 – 200 GeV

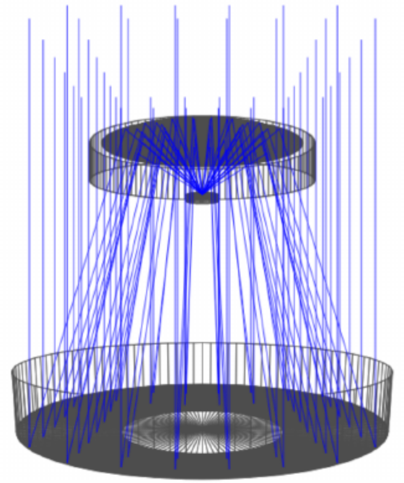
1^{st} Telescope at LaPalma is being build.

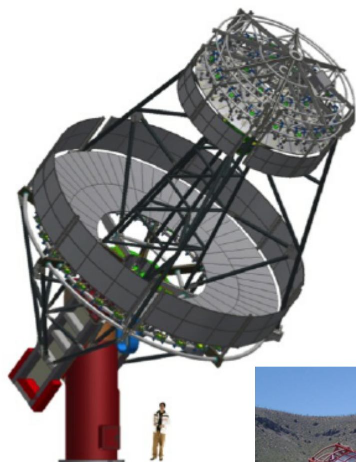
Mid–Sized Telescope (N: 15, S: 25)

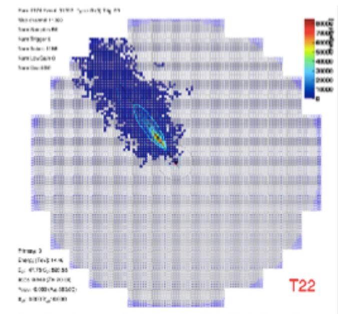


Dish Size	12 m
Dish Shape	Davies-Cotton
Focal Length	16 m
Camera Size	2.3 m 8.2 deg
Pixel Size	5 cm 0.18 deg
Photo Sensor	1855 PMTs
DAQ	1 GHz/ 250MHz digtization
Energy Coverage	0.1 – 10 TeV

SC-Mid-Sized Telescope (N: 0, S: 24)

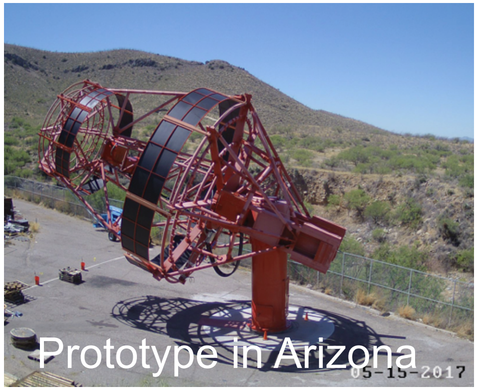




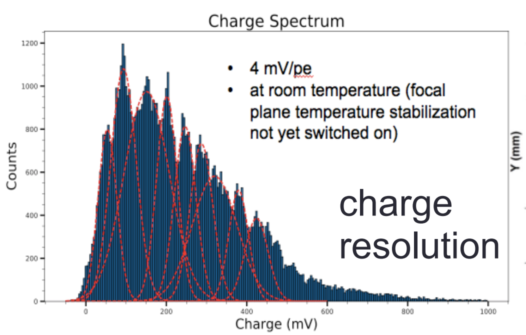


Dish Size	9.7 m
Dish Shape	Schwarzschild-Couder
Focal Length	5.6 m
Camera Size	8 deg
Photo Sensor	11328 SiPM
DAQ	1 GHz digitization
Energy Coverage	0.2 – 10 TeV

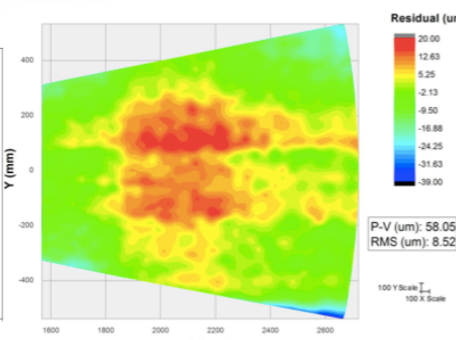
TARGET 7 module

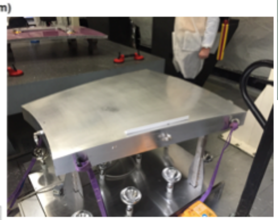


Prototype in Arizona



charge resolution

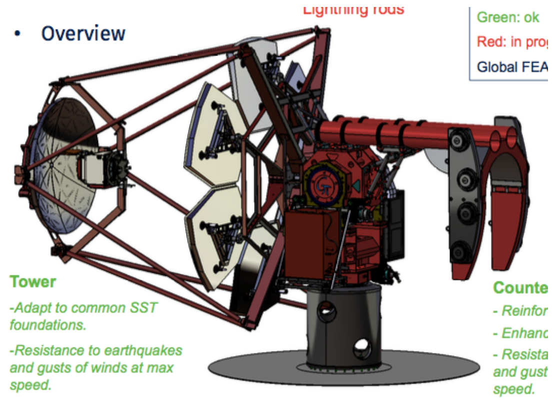




Mirror Panel

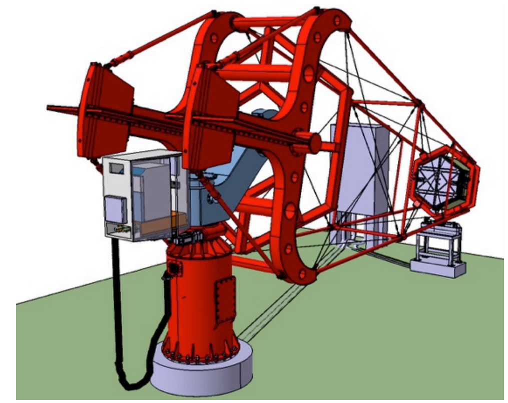
Small-Sized Telescope (N: 0, S: 70)

GCT



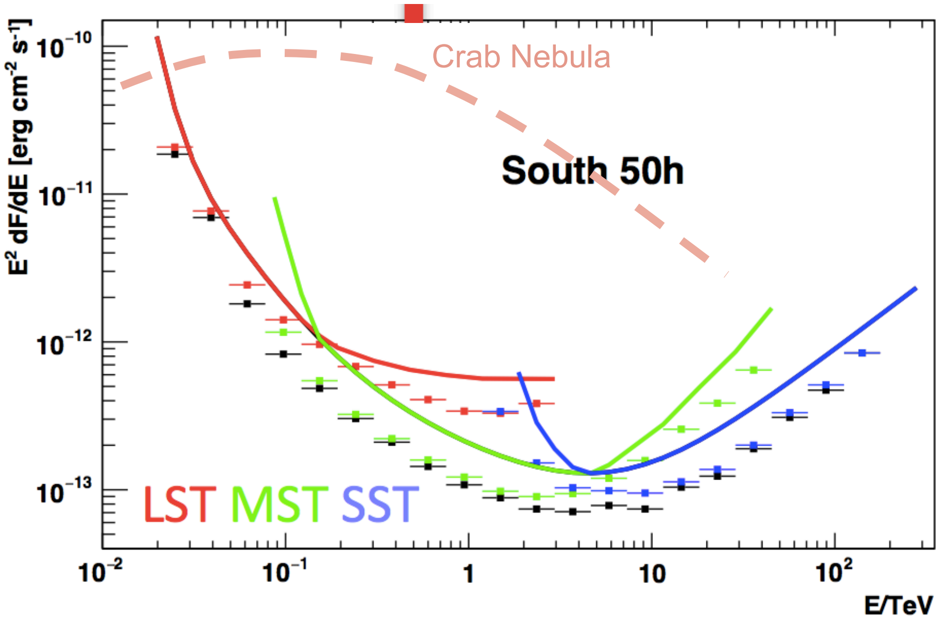
ASTRI

SST-1M

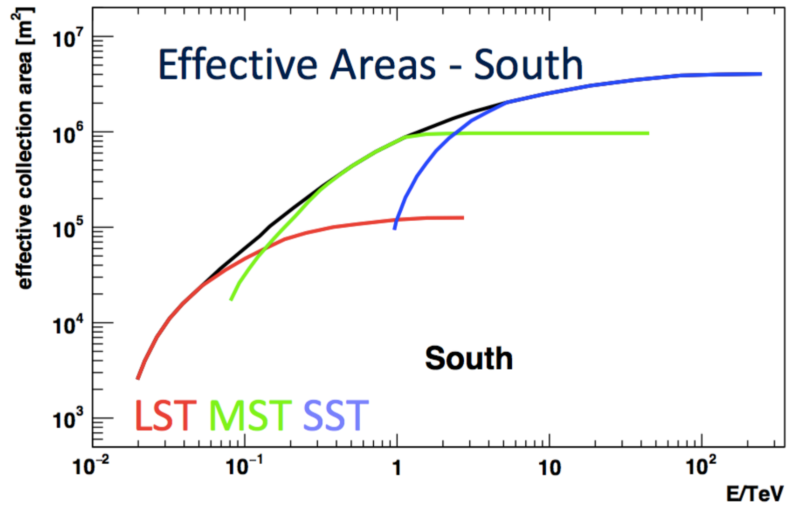


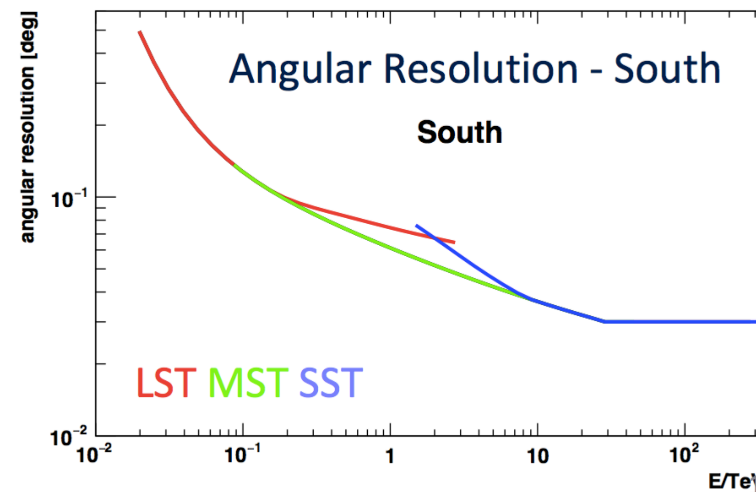
	GCT	ASTRI	SST-1M
Dish Size	4 m	4 m	4 m
Dish Shape	Schwarzschild - Couder	Schwarzschild - Couder	Davies-Cotton
Focal Length	2.3 m	2.15 m	5.6 m
FoV	8.6 deg	9.6 deg	9 deg
Photo Sensor	2048 SiPM	1984 SiPM	1296 SiPM
Energy Coverage	5 – 300 TeV	5 – 300 TeV	5 – 300 TeV

Sensitivity



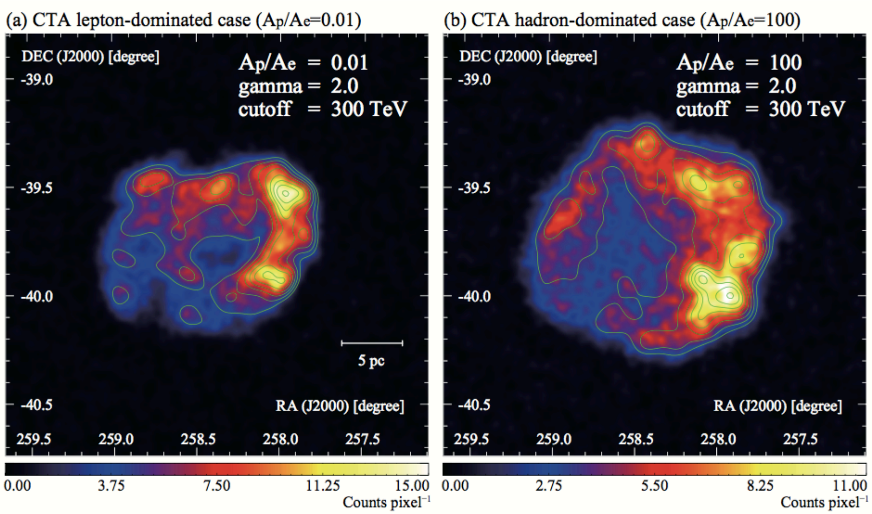
- a few – 10 mCrab above 100 GeV
- 10000 times larger effective area than Fermi LAT@ 30 GeV
- 3 km^2 > 10 TeV
- Angular resolution 0.1 deg @ 100 GeV
- Angular resolution 0.3 deg above 10 TeV



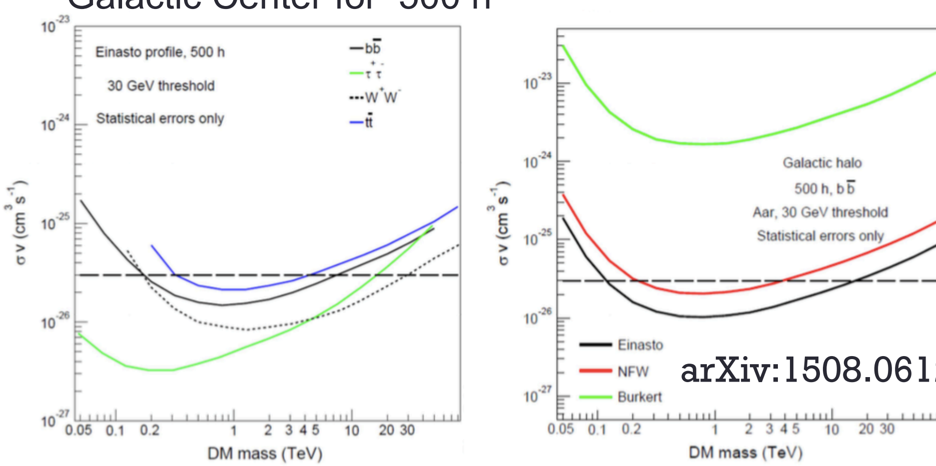


Some examples of expected physics

<RX J1713 Morphology >
Leptonic vs Haaronic



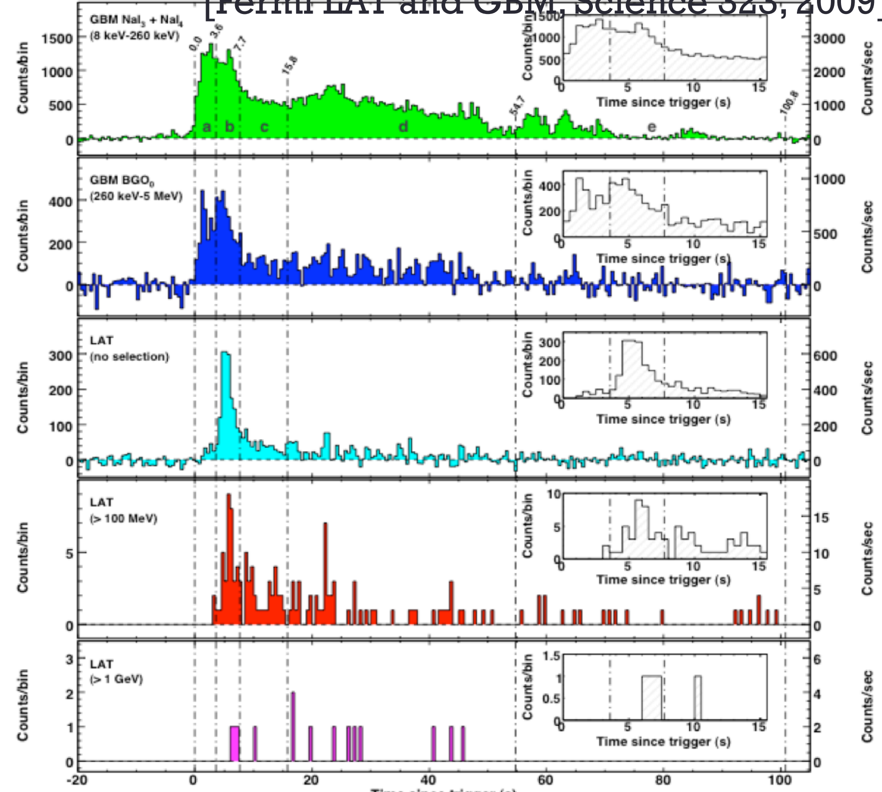
<Limits to DM anninilation Cross Section>
Galactic Center for 500 h



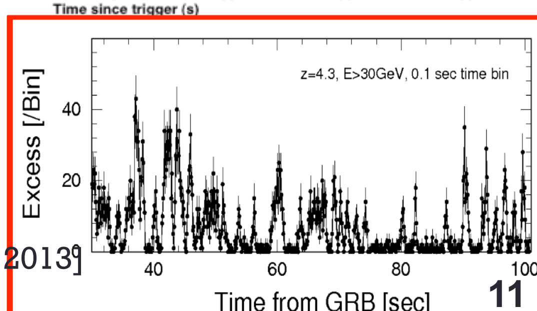
arXiv:1508.06128

< GRB 080916C (Z=4.3) >

[Fermi LAT and GBM, Science 323, 2009]



CTA Simulation
>30 GeV



[Inoue et al.,
Astropart. Phys. 43, 2013]

Crab Flare

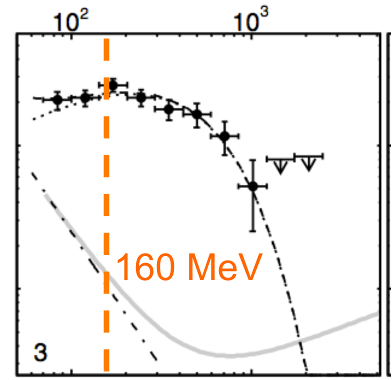
- Crab Nebula exhibit Flaring activity at GeV range.
  - Time scale of Variation (hours ~ days) << nebula size scale (months ~ years)
  - Peak Energy > the Synchrotron limit (160 MeV)

    (acceleration rate = energy loss rate)

$$\eta e B c = 2\sigma_T c \gamma^2 U_B$$

$$E_{sync} = \frac{3}{2}\hbar\varpi_B\gamma^2 \le \frac{9}{4}\frac{mc^2}{\alpha} \cong 160\,MeV$$

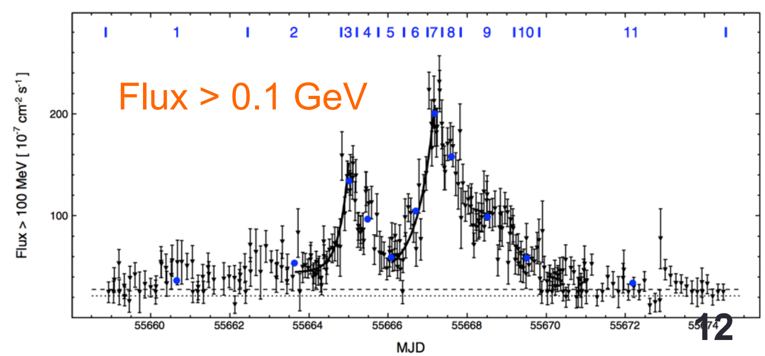
(e.g. de. Jager et al. 1996)



- In order to explain this phenomena,
  - Moving Blob models (Doppler boost)
  - Magnetic reconnection models
  - others..

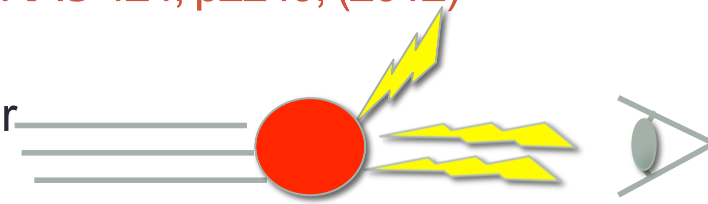
  have been proposed.

- In this talk, a moving blob model is adopted and discuss how CTA would see IC component.



Moving Blob Model (Kohri et al., MNRAS 424, p2249, (2012)

- Radiative Blob moves relativistically toward observer



- Variation time scale (Δt) ～ the size of blob (R) / Doppler factor (δ).
- Larmor radius of electron in the blob < R
- Then, maximum energy of electron in the blob is

$$E'_{\rm max,e} = 790\,{\rm TeV}\left(\frac{B'}{3\,{\rm mG}}\right)\left(\frac{\delta}{10}\right)\left(\frac{\Delta t_{\rm obs}}{8\,{\rm h}}\right) \quad (1)$$

- Snchrotron Energy is

$$E_{\rm syn} = 95\,{\rm MeV}\left(\frac{\delta}{10}\right)\left(\frac{E'_{\rm max,e}}{500\,{\rm TeV}}\right)^2\left(\frac{B'}{3\,{\rm mG}}\right) \quad (2)$$

Observable: Δt, E_{syn}

Unknown: δ, B'

- From (1) and (2)

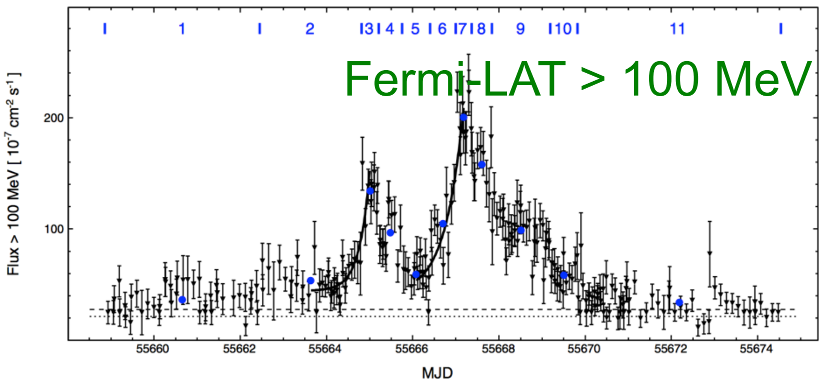
$$E'_{\rm max,e} = 480\,{\rm TeV}\left(\frac{E_{\rm syn}}{10^2\,{\rm MeV}}\right)^{1/2}\left(\frac{\Delta t_{\rm obs}}{8\,{\rm h}}\right)^{1/3}$$

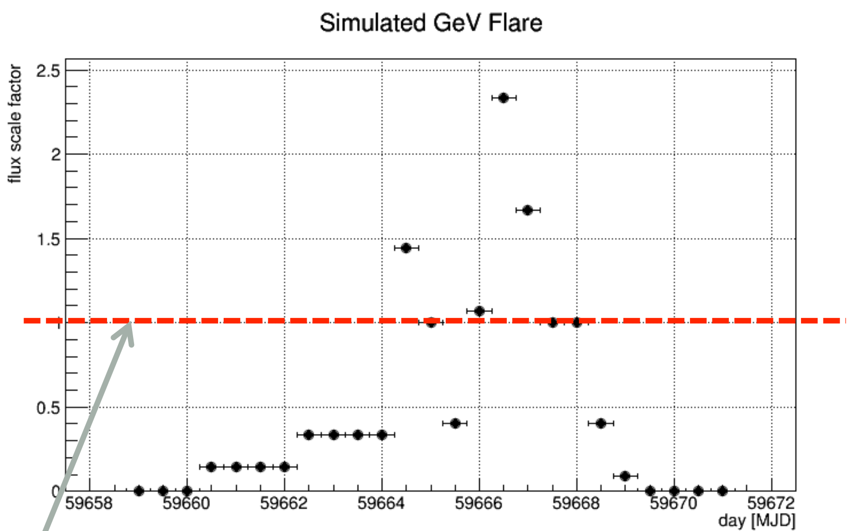
Unknowns cancel out.

- $E_{max,\,e}$ can be inferred from E_{syn} and Δt.
- The same electron causes IC on CMB and Synch photons producing TeV-PeV photons.

- δ and B' can be determined only with IC componet measurement.

How would CTA have seen the Crab Flare in April 2011?



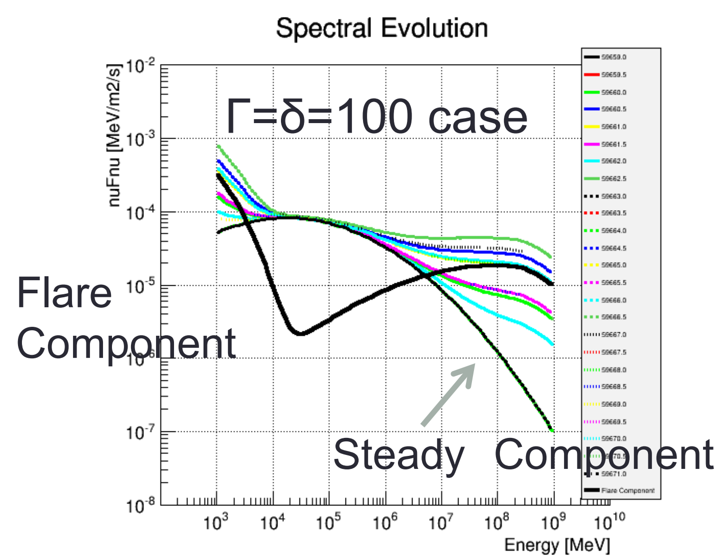


Average flux level

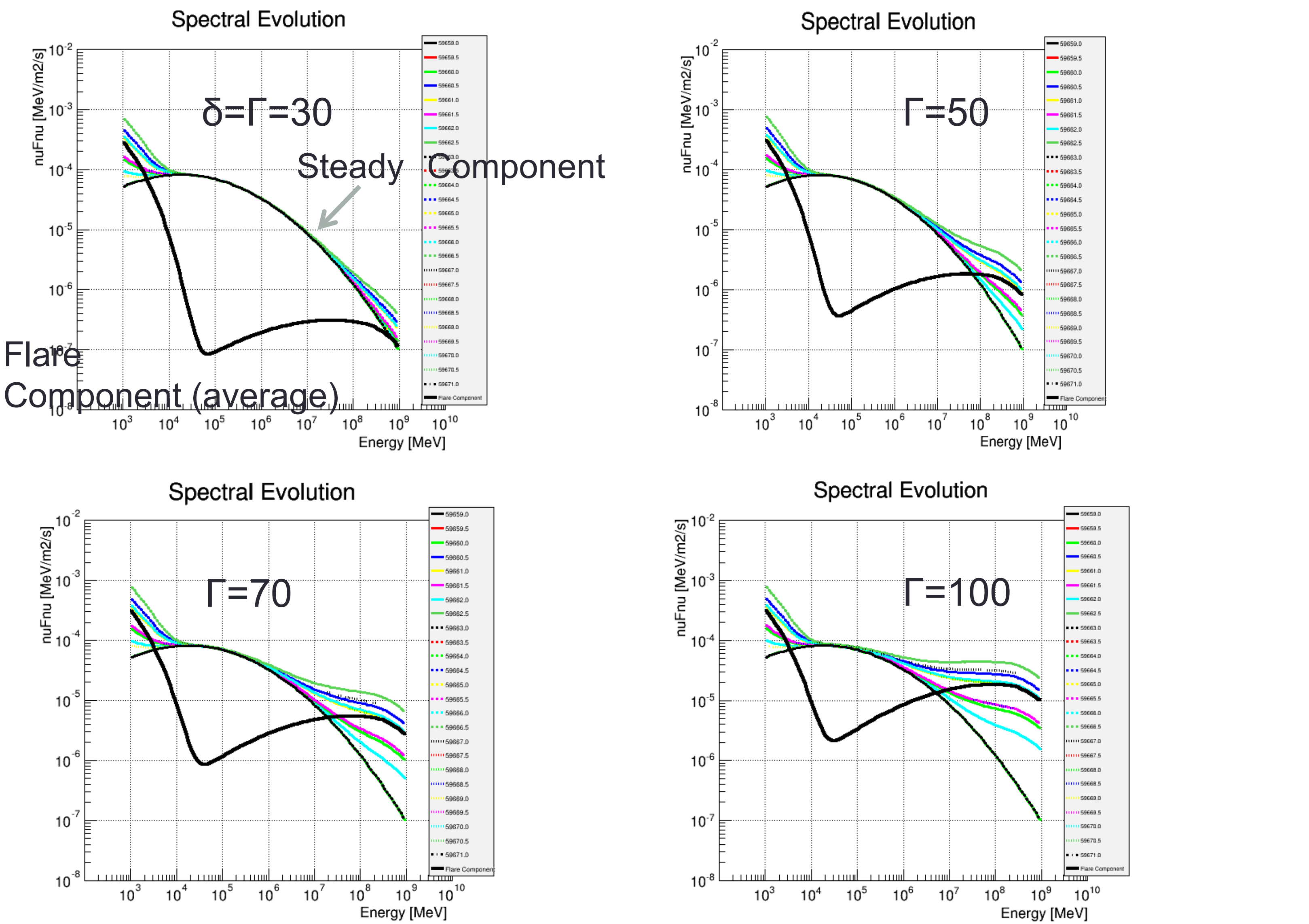
Using “CTOOL”, http://cta.irap.omp.eu/ctools/admin/download.html study how TeV-PeV emission would have been with CTA.

Assumptions:

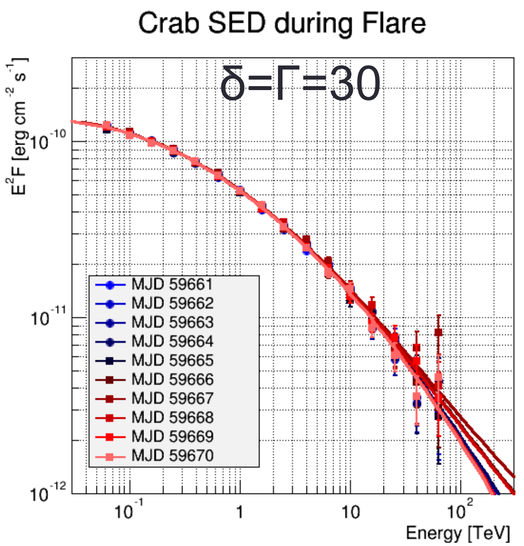
- Flaring component changes every half day.
- Flaring component has the same spectral shape and only normalization changes.
- CTA observe Crab 3 hours every day.
- Lorentz factor Γ = Doppler factor δ

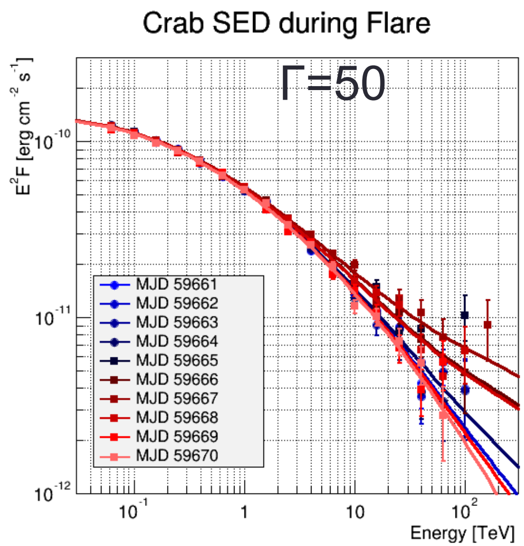


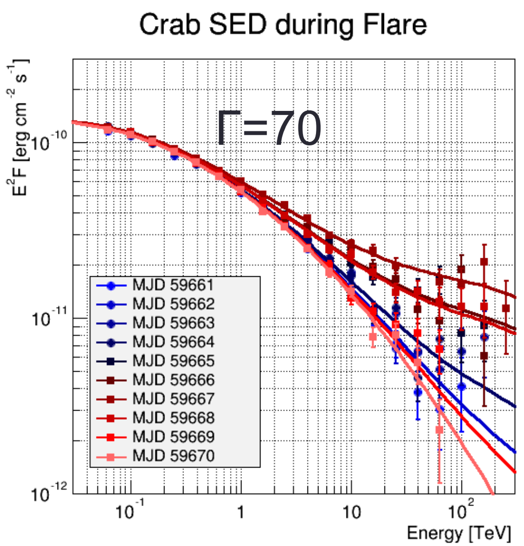
Input Spectrum

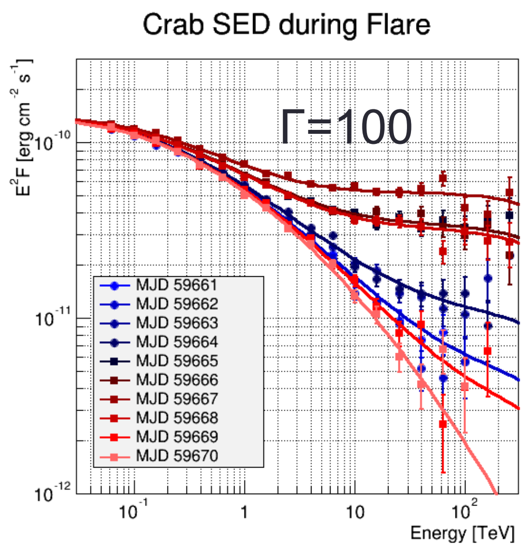


Spectra Observed by CTA

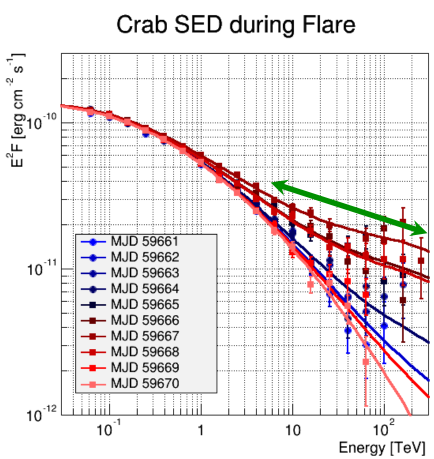


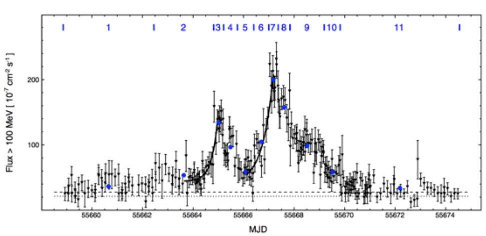


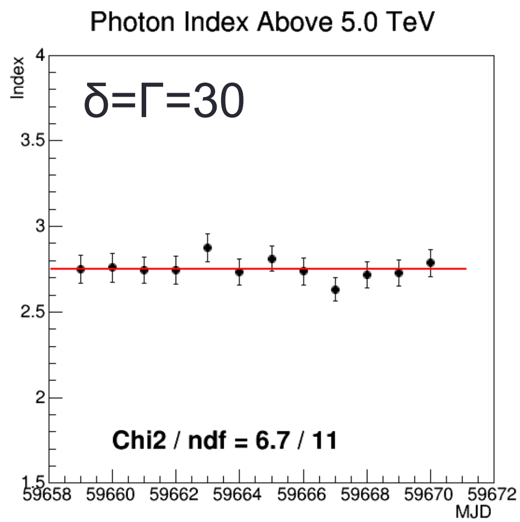


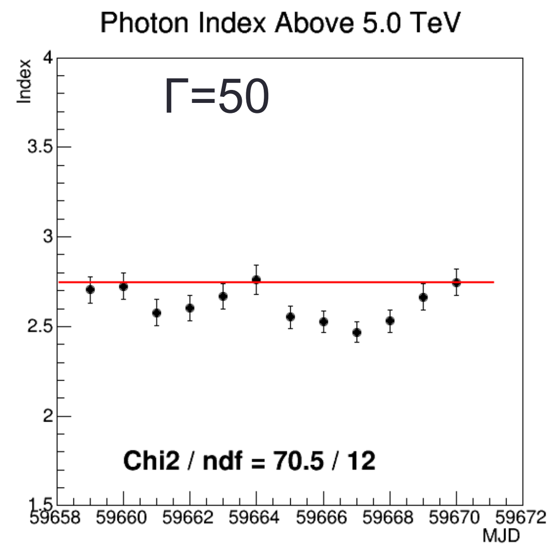


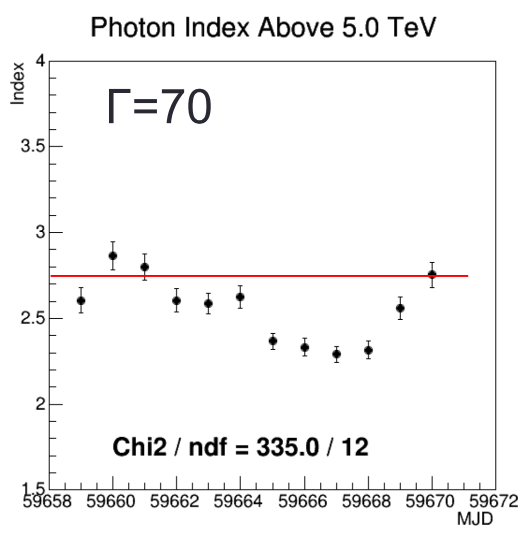
Spectral Index Variation above 5 TeV

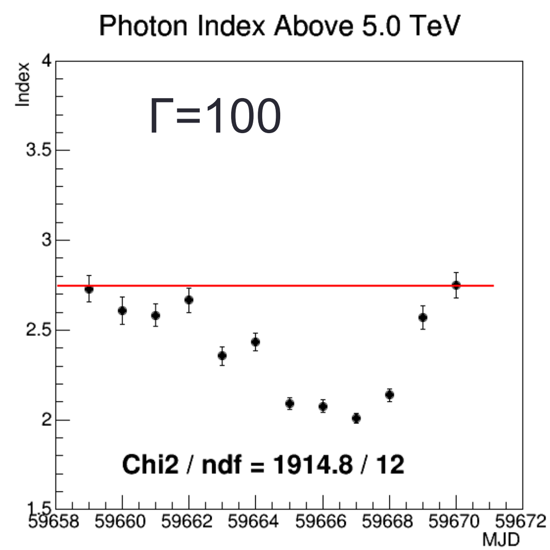




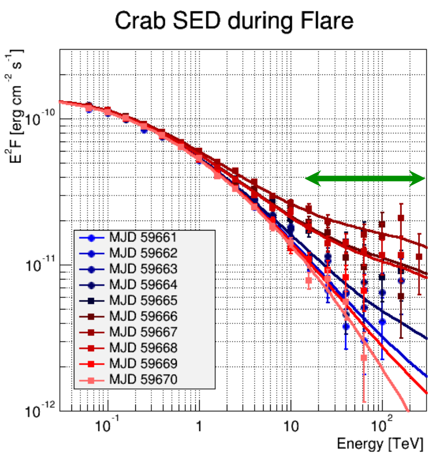


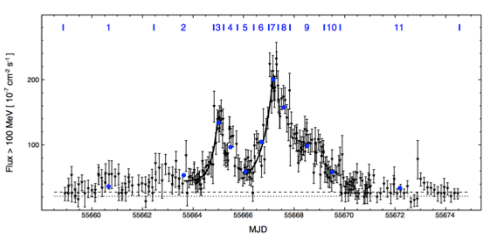


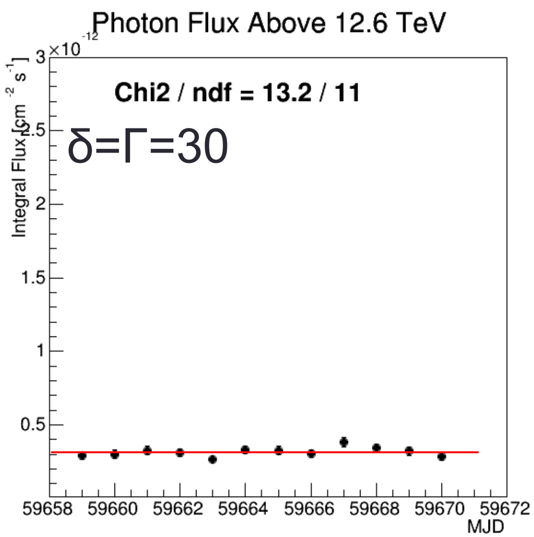


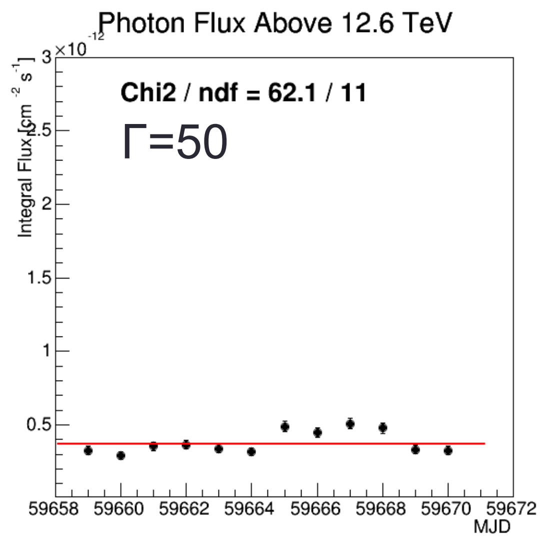


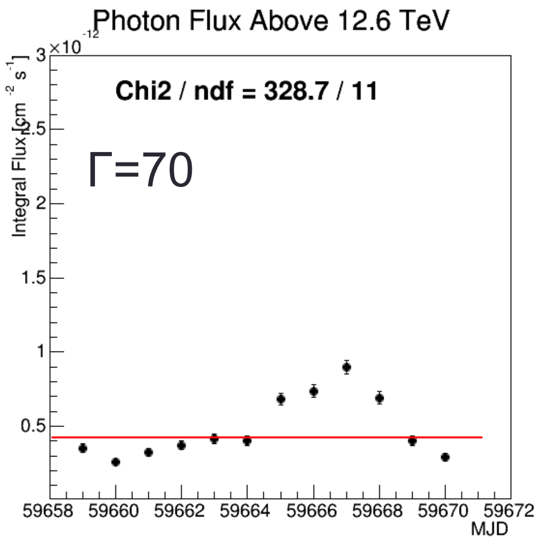
Flux Variation above 12.6 TeV

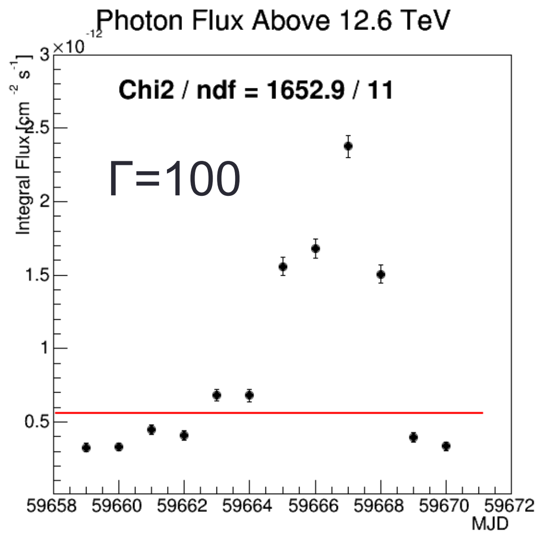






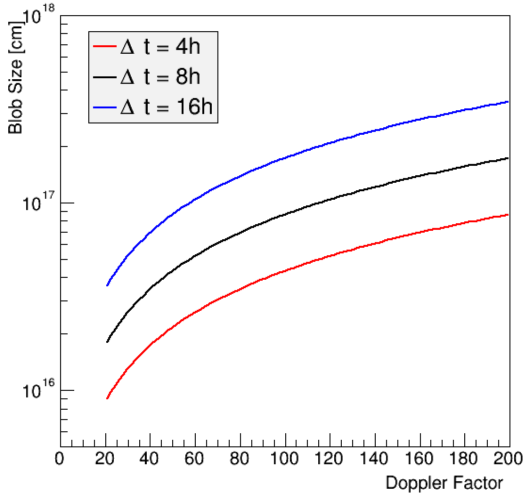




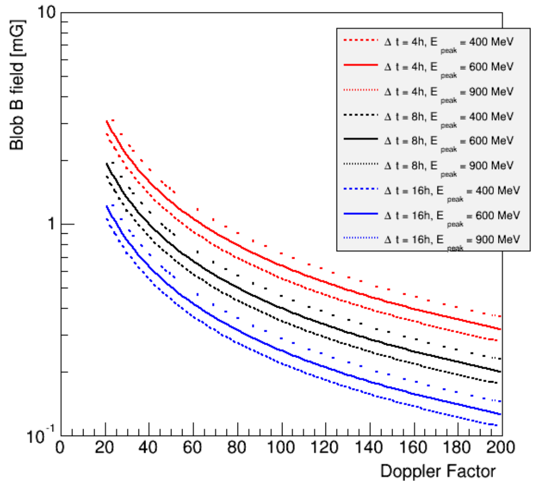


Determined Blob Parameters

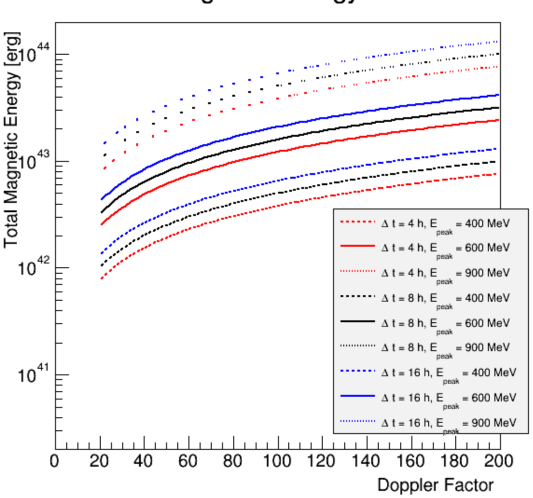
Blob Size



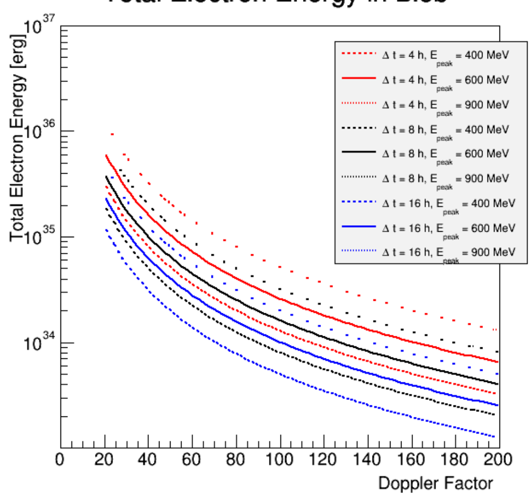
B field in Blob



Total Magnetic Energy in Blob



Total Electron Energy in Blob



Δt and E_{syn} are measured at GeV.
If Doppler Factor δ is determined by CTA observations, then following parameters of the blob could be known.

Blob Size: δcΔt

Magnetic filed strength:

$$B' = 2.2\,\mathrm{mG} \left(\frac{E_{\rm syn}}{10^2\,\mathrm{MeV}}\right)^{1/3} \left(\frac{\delta}{10}\right)^{-1} \left(\frac{\Delta t_{\rm obs}}{8\,\mathrm{h}}\right)^{-2/3}.$$

Total magnetic field energy:

$$U'_{\rm B} = \frac{B'^2}{8\pi} \times \frac{4}{3}\pi(\delta c \Delta t_{\rm obs})^3 = 4.8\times10^{41}\,\mathrm{erg} \times \left(\frac{E_{\rm syn}}{10^2\,\mathrm{MeV}}\right)^{2/3} \left(\frac{\delta}{10}\right) \left(\frac{\Delta t_{\rm obs}}{8\,\mathrm{h}}\right)^{5/3}.$$

Total electron energy

$$U'_{\rm e} = N'_{\rm e}(E'_{\rm max,e})E'_{\rm max,e} = 1.3\times10^{37}\,\mathrm{erg} \times \left(\frac{E_{\rm syn}}{10^2\,\mathrm{MeV}}\right)^{-7/6} \left(\frac{\delta}{10}\right)^{-2} \left(\frac{\Delta t_{\rm obs}}{8\,\mathrm{h}}\right).$$

Conclusion

- CTA is the next generation gamma-ray observatory.
  - 10 times better sensitivity above 20 GeV
  - Construction is going on.
  - Partial operation is expected in the up-coming years.
  - Observatory operations will start in year 2021
  - Full operations will start in year 2024

- CTA will be a powerful tool for understanding the Crab flares
  - Based on Moving blob model (Kohri et al., MNRAS 424, 2012), IC Compton component is expected at >10 TeV range.
  - If Doppler factor of the blob is >50, then CTA will clearly detect the modulation of flux above 10 TeV.
  - Then, several physics parameter of the blob could be determined, which should shed light on the mechanism of the Crab flare.