



Observations of Starburst Galaxy: IC342

Tomoyuki Nagai (University of Utah)

Vladimir V. Vassiliev (UCLA)

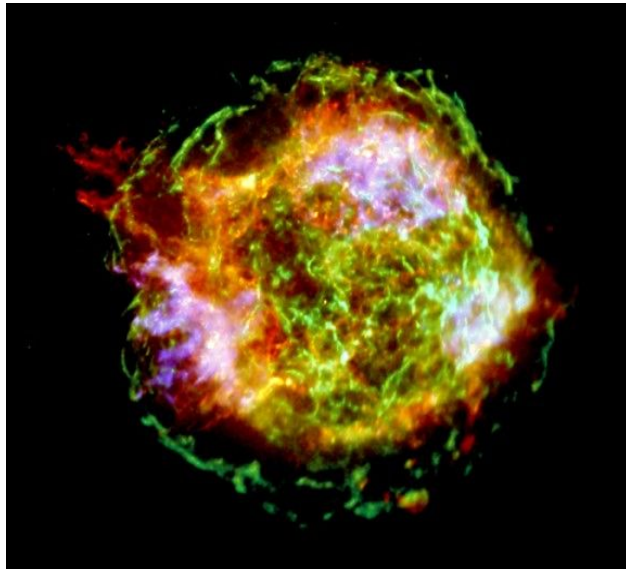
for the VERITAS collaboration

Content

- 1) Cosmic Rays, SNRs, and Starburst Galaxies;
What can we learn about them
by observing gamma-rays?**
- 2) Starburst Galaxy IC342 - Pros and cons**
- 3) Instrument for gamma-ray observations**
- 4) Data, Analysis, and Results**
- 5) What have we learned?**

Origin of high energy cosmic rays

Discovery of cosmic rays (CRs): 1912 by Hess



Cassiopea A - one of the youngest SN in Milky Way Galaxy

Image is courtesy of CHANDRA team

CR origin problem

Where are CRs accelerated?

What is the acceleration mechanism?

CRs with energy below $\sim 10^{15}$ TeV are **believed** to be produced at Supernova Remnants (SNR) by multiple shock waves via Fermi acceleration mechanism.

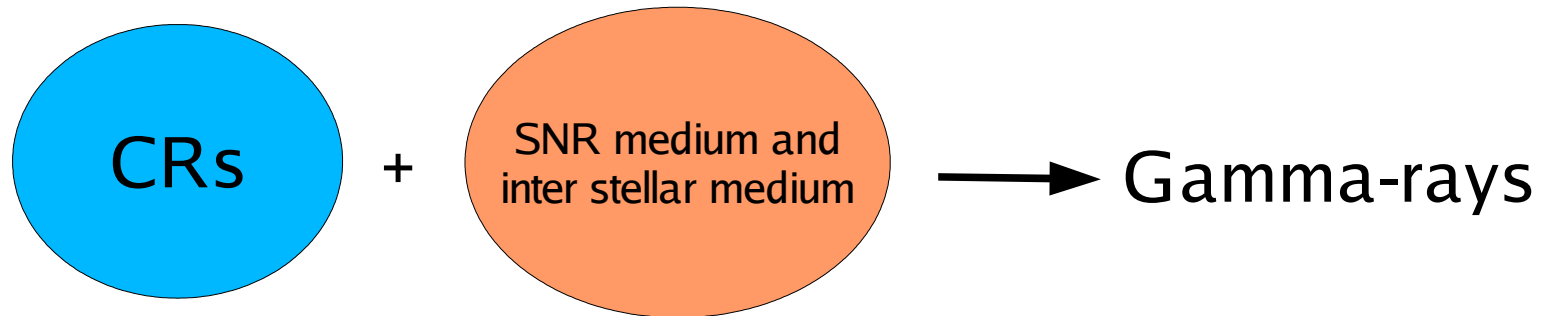
It has been more than half a century since SNR origin of CRs has been proposed and discussed.

Have we proved this hypothesis?

Gamma-rays as CR probe

Charged CRs, protons and electrons, are deflected by galactic magnetic field, just they can not be traced back to the acceleration site.

But,



Gamma-ray emission mechanisms:

- Inverse Compton scattering of thermal photons on relativistic CR electrons
- Secondary neutral pion decay in hadronic interactions
 $p + p \rightarrow \text{pion} \rightarrow \text{gamma-rays}$

Have we seen direct evidences from individual SNRs?

Gamma-ray observations of SNRs

Nearby SNRs have been surveyed.

Examples:

IC443, Tycho, gamma-Cygni, W44, W51 and W63 (Buckley et al. 1998)

→ No detection

RX J1713.7-3946 (Enomoto et al. 2002, HESS symposium 2004)

→ Detection - May be electrons?

Subject to intense debate

SN1006 there is state of the art theoretical model which predicts that we must see gamma-rays from protons

→ We don't - No detection (HESS symposium 2004)

We have no reliable evidence for high energy proton CR acceleration.

Is there any alternative way to test this hypothesis?

Starburst Galaxies: Testing lab for CR acceleration (cumulative effect)

Starburst Galaxies (SBGs):

High star formation rate

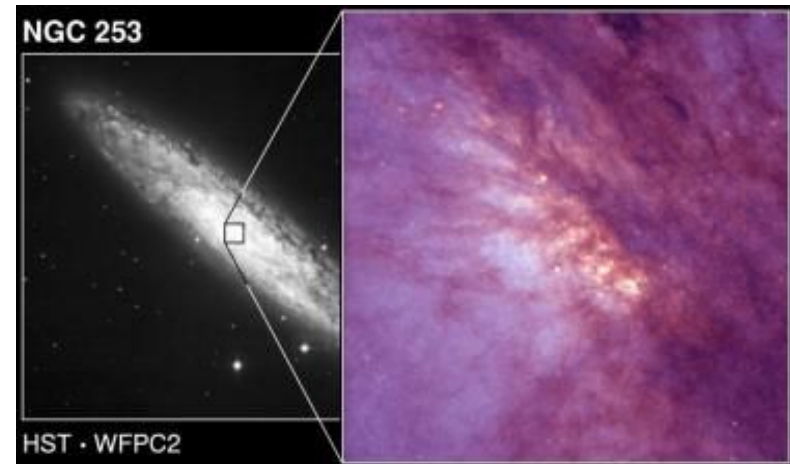
-high SN rate

Starburst region is often associated with dense gas clouds and strong magnetic field indicative of CR presence.

-More target protons

-confinement in the region

-enhancement of gamma-ray flux



NGC 253
(Hubble image)

CANGAROO group claimed detection from SBG, NGC253 (Itoh et al. 2002)
Not confirmed (HESS symposium 2004)

Limitting factors: distance



Galactic center (image by Southern Skies)



M82 (Whipple observatory)

Typical Parameter values:

	Milky Way	SBGs
Distance	~ Kpc	~ Mpc
Gas density	~1 H/cm ³	~10 ⁴ H/cm ³
Magnetic field	~3 μ G	~10 to 100 μ G
SFR	~3 M _{sun}	~10 to 100 M _{sun}

Very high gas density in SB region \longrightarrow interaction dominant
This factor can beat the distance.

Limiting factor: Phase of starburst evolution

Importance of the age of the SB region:

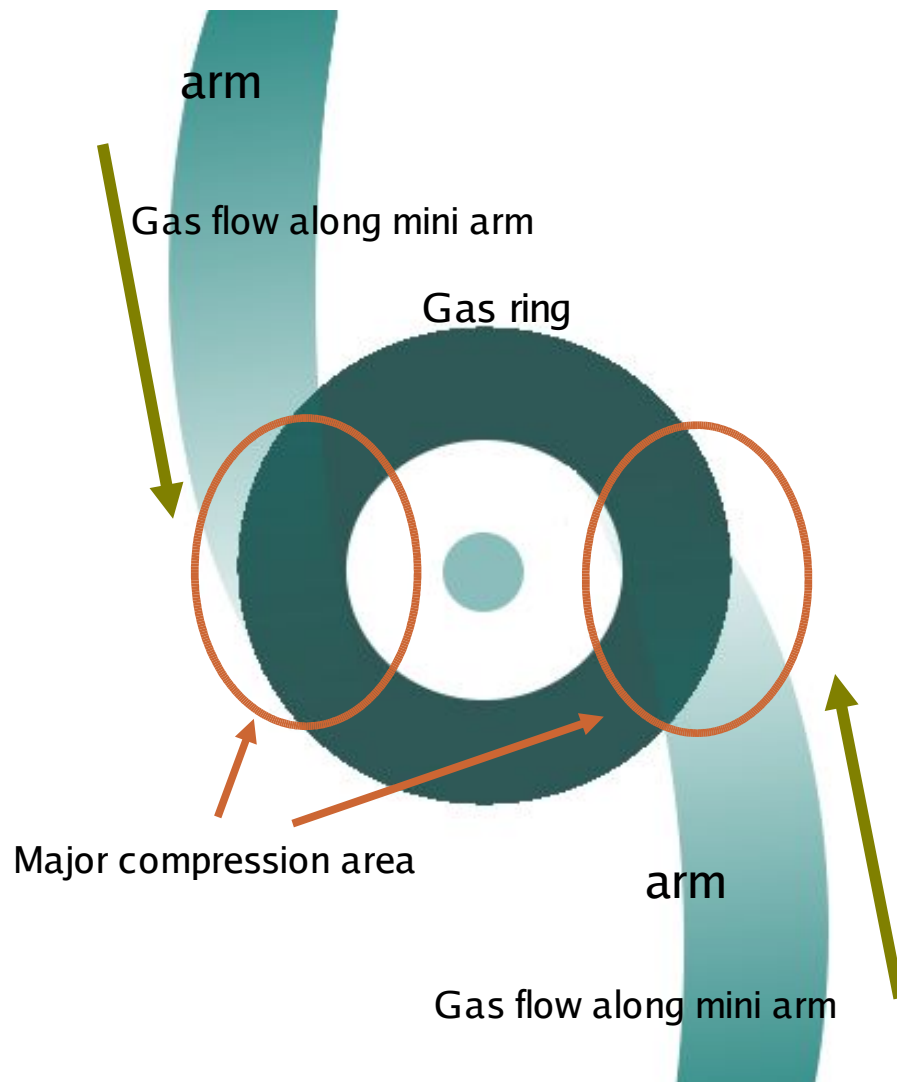
too young → not enough time for evolution of massive stars (O, B) to SN stage

too old → evacuation of gas from the SB region due to pressure from OB stars, and multiple SNe

Range of few millions of years to few tenth of million years

One can avoid this strict requirement if SF is ongoing process and gas supply is continuous.

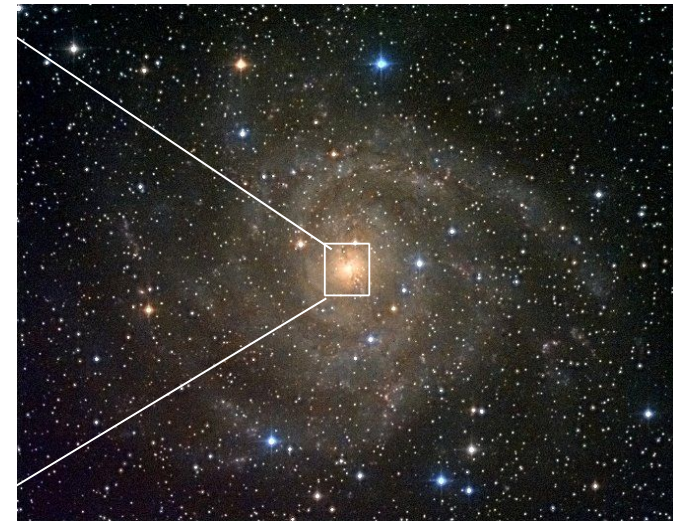
IC342



Central 15 arcsec of IC342

Starburst is ongoing mainly along the ring like nuclear gas region. Especially strong at the gas compression areas where gas flow along the arms meet the dense molecular ring, which means gas is continuously supplied.

This region coincides with one of the strong X-ray emission sites.



IC342 (courtesy of Chris Deforeit)

Distance: ~ 3.5 Mpc
Density: $\sim 10^5$ H/cm³
Age: < 10 Myrs

Gamma-ray flux estimates suggest we should detect emission from IC342

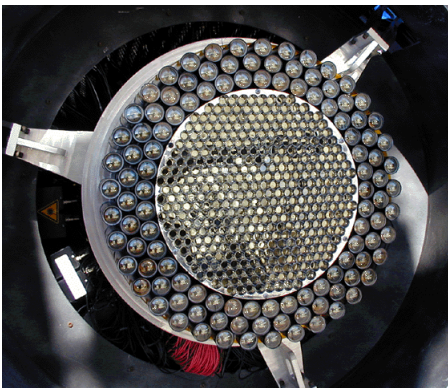
Instrument

Whipple 10m Gamma-ray Atmospheric Cherenkov Telescope

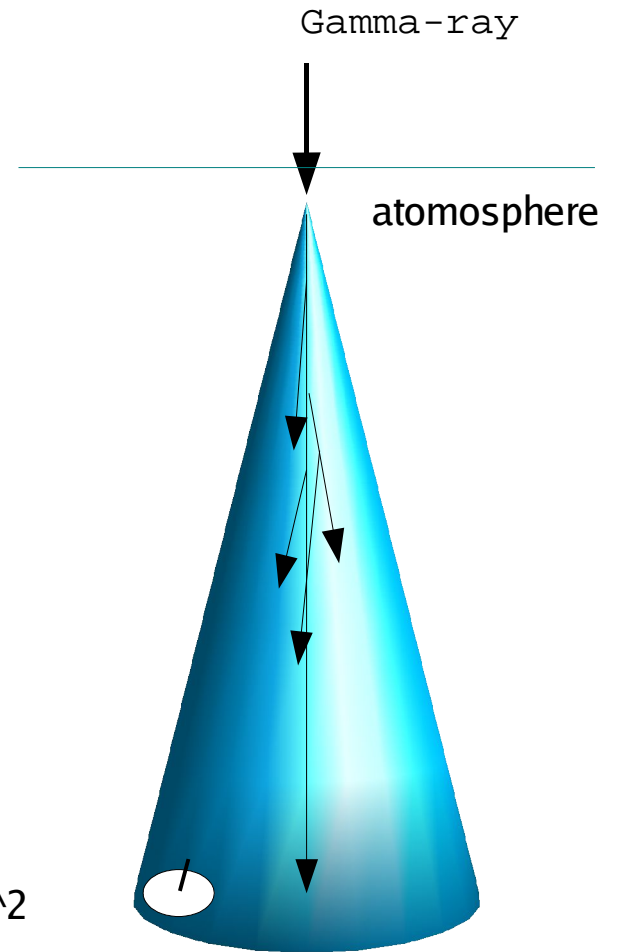


Telescope:
Aperture - 10m
Focal length - 7m

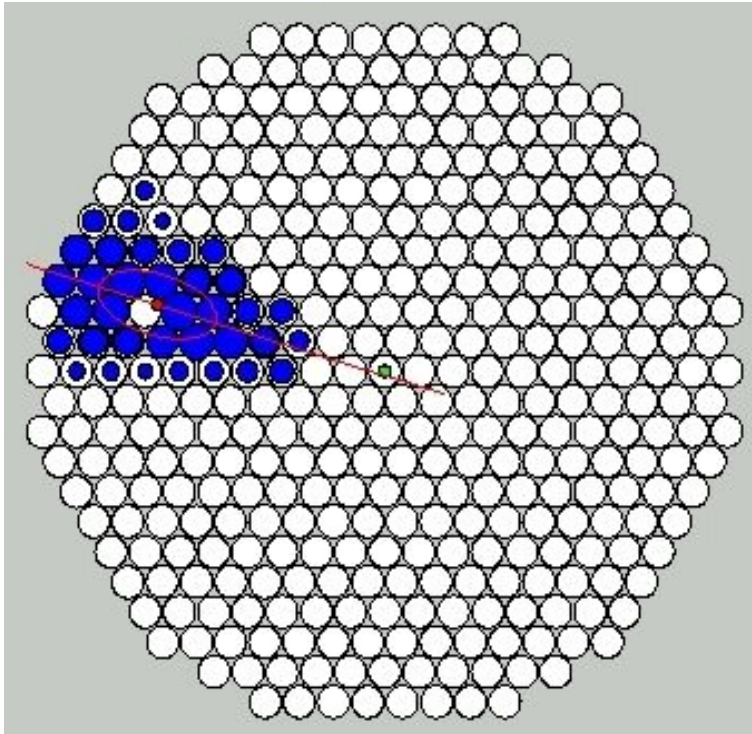
Focal plane:
Camera - 379 0.15
deg pixels
Field of view - 2.4°



Light collecting area of $\sim 10^5 \text{ m}^2$
is determined by the size of the
Cherenkov light pool, not by the aperture
of the gamma-ray telescope.



Whipple Imaging concept



Simulated Gamma-ray Image

CR background rejection is based on
-image shape differences
-event arrival direction

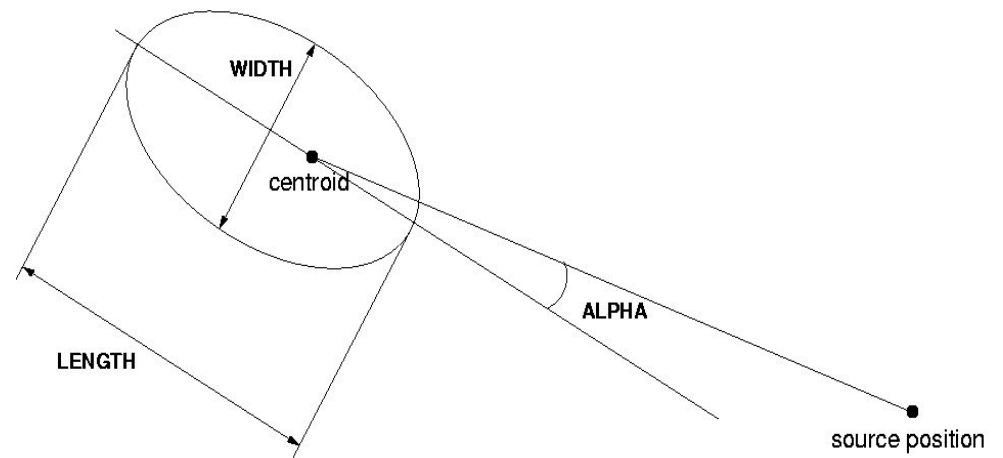


Image parametrization

IC342 Observation Summary

On source and background data was taken during last 2 Whipple observation seasons.

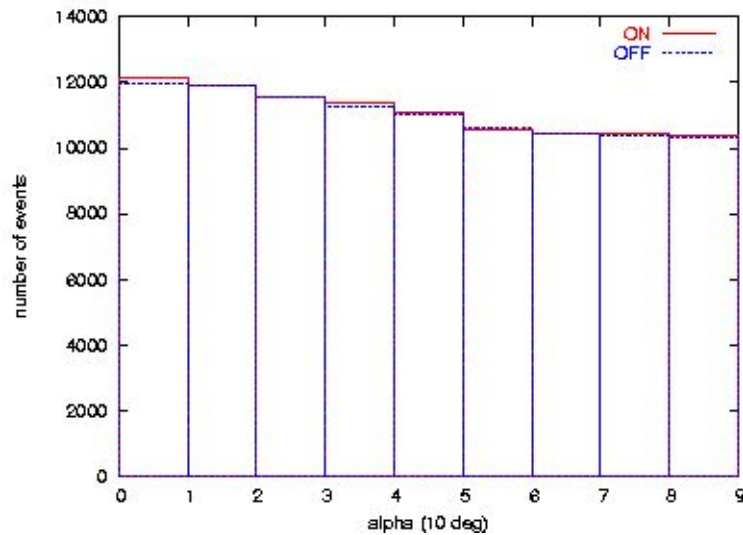


Season	Duration (k sec)	ON/OFF
2002-03	44.6	26.6/18
2003-04	175	90/85

Analysis and result

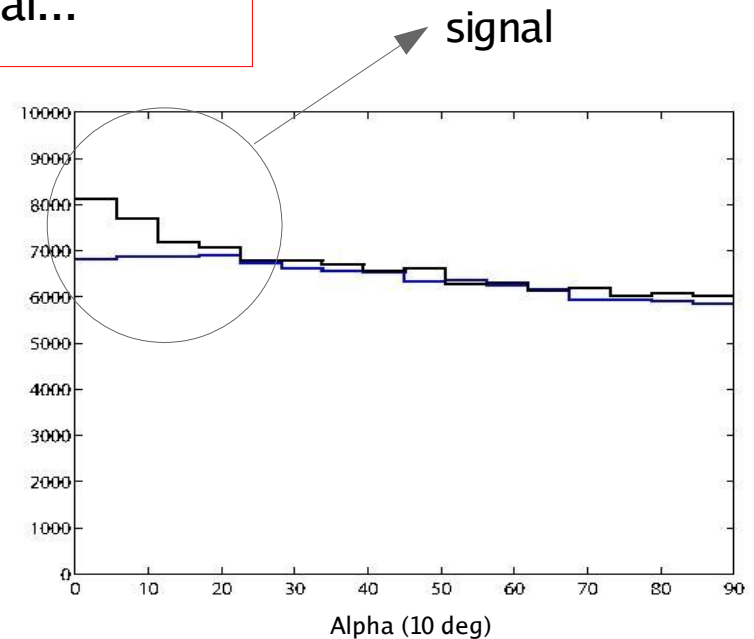
Standard and Multidimensional Maximal Likelihood spectrum dependent analysis are applied.

No signal...



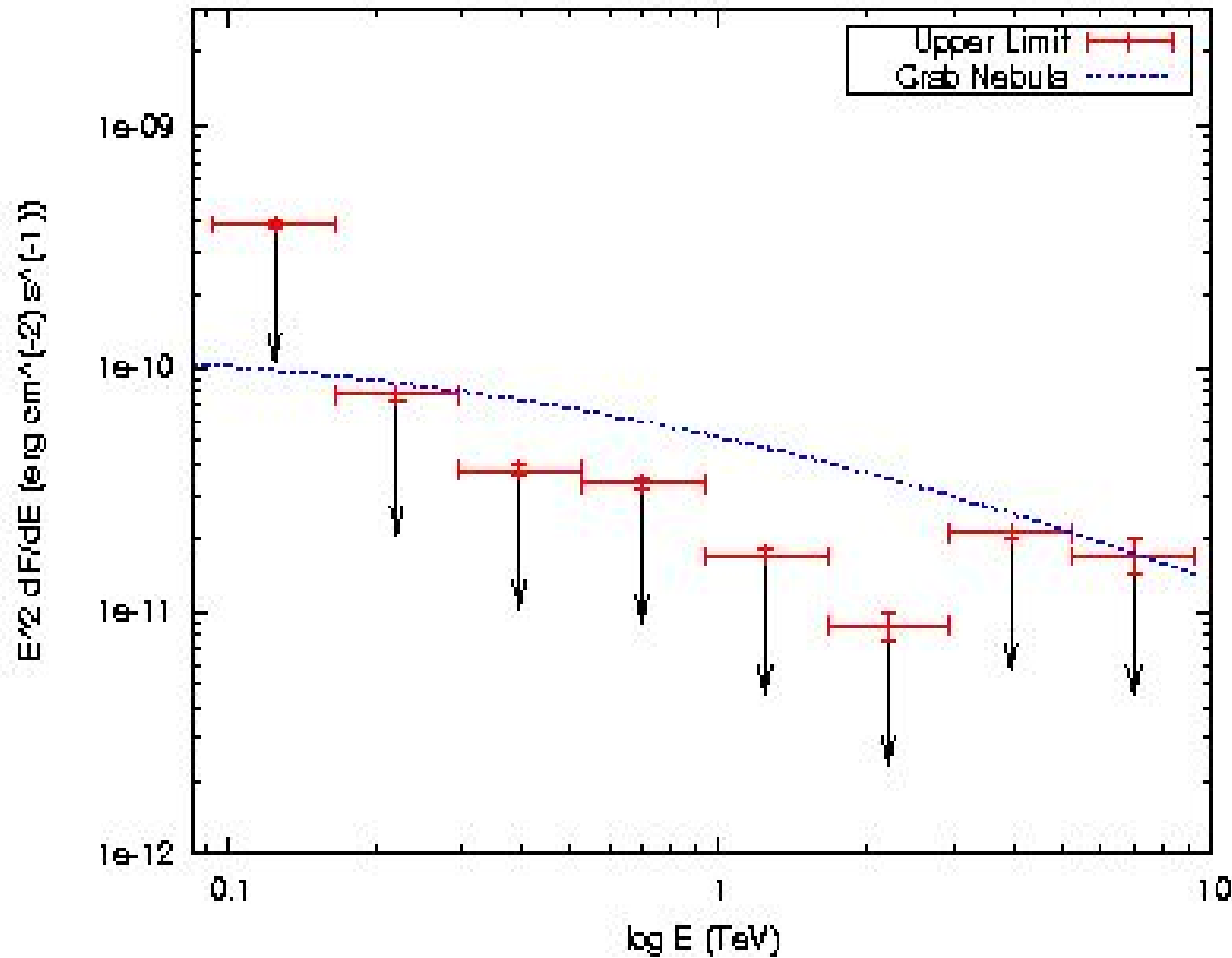
IC342 with filter "index 3.0"

Upper limits are derived for each spectral index from 2.0 to 3.5 with 0.5 increment.



Crab Nebula detection with the use of a filter optimized for a source with differential spectra index 3.0

IC342 Gamma-ray Flux Upper Limits



Binnig: equal energy bins in log space.
Bin width: $\log(E_{i+1}/E_{i-1})=0.187$.

Crab nebula flux curve shown in the plot is adapted from Hillas et al. 1998.

Conclusion

Where are the CR protons coming from?

