Probing proton acceleration in W51C with MAGIC

(An example how to use VHE-γ-Astronomy to detected Cosmic Ray sources)

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on behalf of

MAGIC
Major Atmospheric
Gamma Imaging
Cerenkov Telescopes

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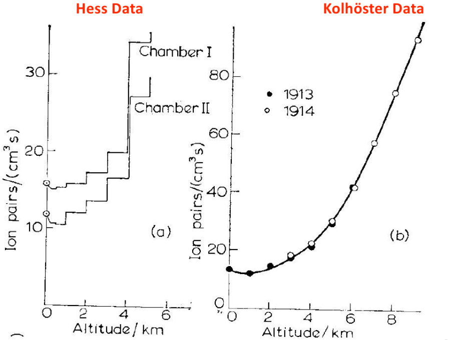
Outline

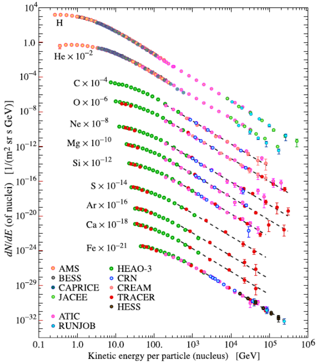
1. The big picture
   - Cosmic Rays
   - Supernova remnants
2. Very high energy γ-Astronomy
   - Imaging Air Cherenkov Technique
   - MAGIC
   - How to find a source
3. A prime candidate of a galactic Cosmic ray accelerator
   - W51

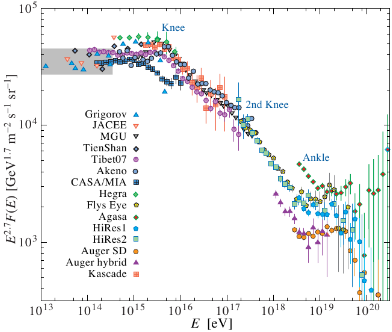
Cosmic Rays, historical measurements

Discovered by Victor Hess 1912



Cosmic Rays today





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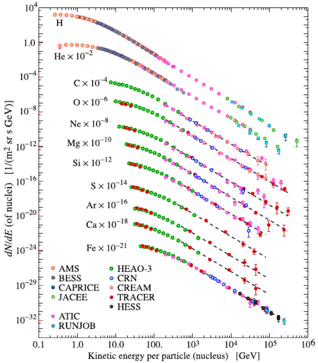
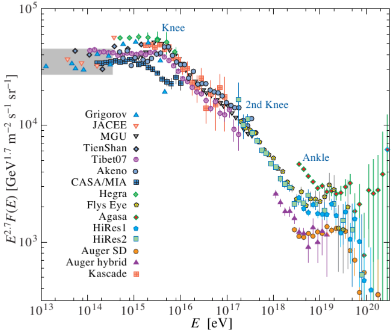
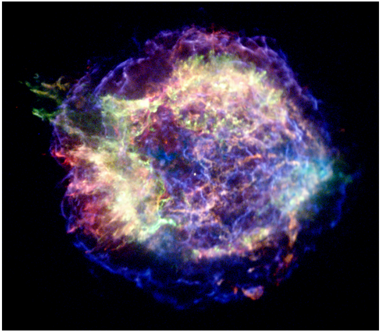


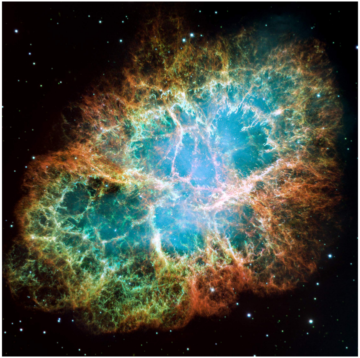


Requirements on galactic CR sources

- provide enough energy
- reproduce observed power-law spectrum
- accelerate CR up to the knee

Supernova remnants





Properties of SNR

- kinetic energy $\approx 10^{51}$ erg (5-20% needed for CR)
- diffusive shock acceleration $\rightarrow$ power-law spectrum
- self amplified magnetic fields $\rightarrow$ energies up to the knee

Current status of the origin of GCR

History

- Cosmic Rays detected: 1912 (Hess)
- Acceleration mechanism: 1946 (Fermi)
- SNR's claimed as sources of GCR: 1977-78
  (Axford, Krymskii, Blandford & Ostriker, Bell)

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Today

A lot of reasonable and clear hints from both theory and experiments

No proof!

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Tomorrow?!

A 100 years old question waits to be answered

I believe

From SNR's as CR sources to VHE-γ-rays

Search for CR sources

- Problem
  - CR's are charged
  - non homgeneous intestellar B-fields
  - isotropic distribution of CR's spectrum at Earth
- Solution
  - γ-rays
  - convert CR into γ's
  - γ's point back to interaction point

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Leptonic Channel

- Bremsstrahlung
  - matter
- Synchroton
  - magnetic fields
- Inverse Compton
  - photon fields

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Hadronic Channel

- π^0-decay
  - matter

Very high energy γ-Astronomy

- Young field of Astronomy
- Energy range GeV-TeV (wavlength $\leq 10^{-8} nm$)
- First source: Crab Nebula 1989 at the Whipple Observatory

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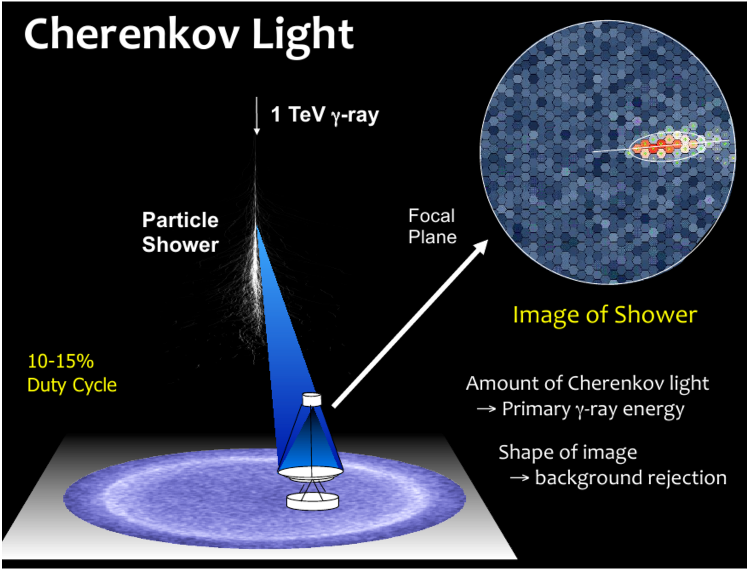
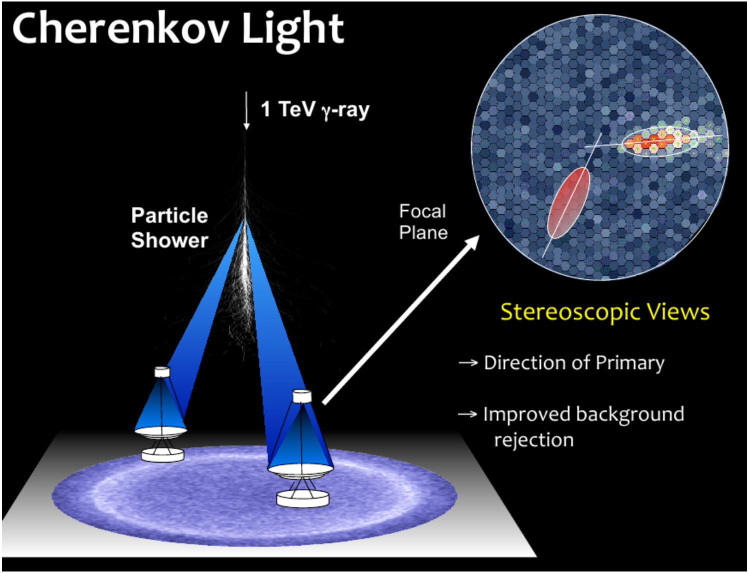
General comments

- No object in the universe is hot enough to radiate GeV photons
- Interaction of high energy particels needed
- Most *violent* objects are typical sources
  - Supernova remnants
  - Pulsars
  - Pulsar wind nebulae
  - Binaries with a compact object
  - Active galactic nuclei

Imaging Air Cherenkov Technique



Stereoscopie



The MAGIC Telescopes

Located on La Palma (Canaries)
Roque de los Muchachos
2200 meter a.s.l.

Stereoscopic system of two IACT's

Reflector diameter 17 m

- Energy treshold 50 GeV
- Performance > 300 GeV:
  - sensitivity $\sim 0.8\%$ Crab $[50\,\text{h}]$
  - angular resolution ~ 0.07 deg
  - energy resolution $\sim 17\%$

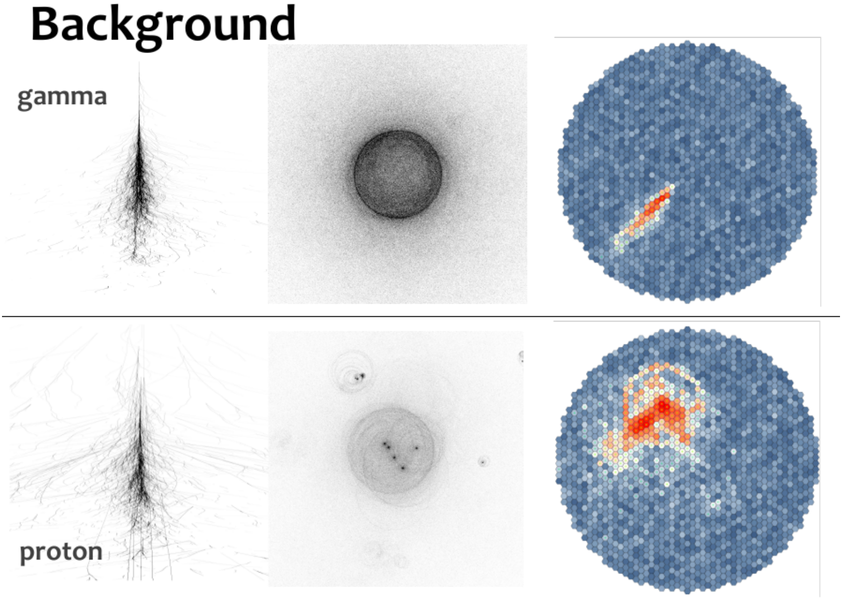
Detecting a signal

- DAQ-rate $\approx$ 200 Hz
- Gamma-like events rate ($>$130 GeV) $\approx$ 1.3 Hz
- γ-rate (crab$>$130 GeV) $\approx$ 0.13 Hz
- background-rate ($>$130 GeV) $\approx$ 0.02 Hz
- 1% crab source signal/background ratio $\approx$ 0.065

How to find a source?!

- Separate signal from background
  - Gamma-Hadron separation (like an overall filter)
  - Arrival direction (Excess = Difference between ON-source and OFF-source)

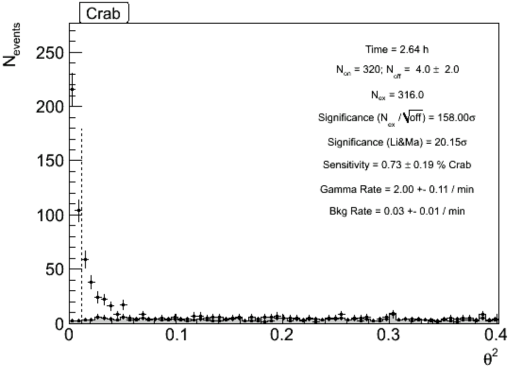
Event discrimination



Detection plot, so called θ^2-plot

θ^2 = (source position minus reconstructed arrival direction$)^2$

grey histogramm = OFF source
black points = ON source



- strong source (crab)
- medium energies ($\sim$300 GeV)

  $\Rightarrow$ easy detecion
  clear signal

Usually more difficult

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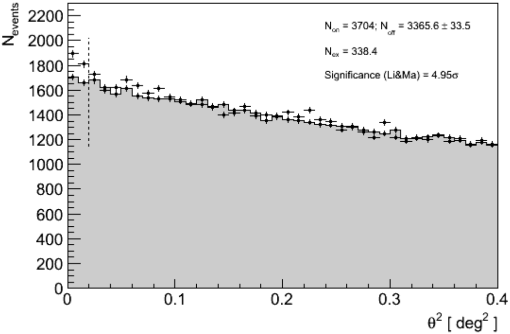
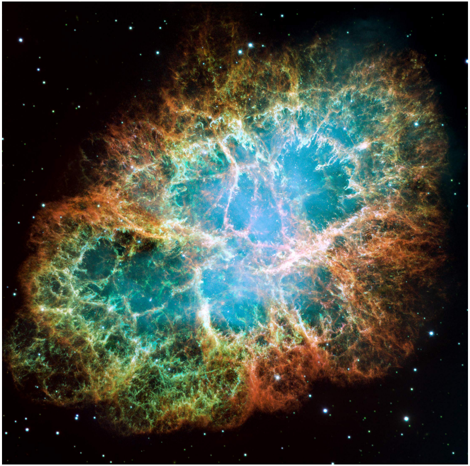


- weak source (few % crab)
- low energies
  ($\sim$ 80 GeV)

  $\Rightarrow$ strong background,
  very difficult

Classical astronomy vs. VHE-γ-astronomy



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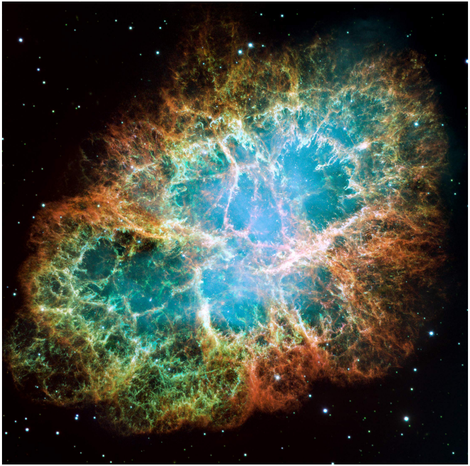
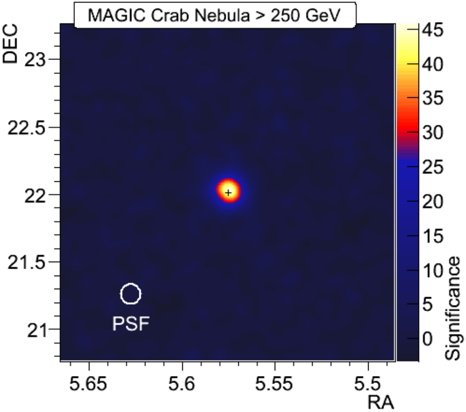
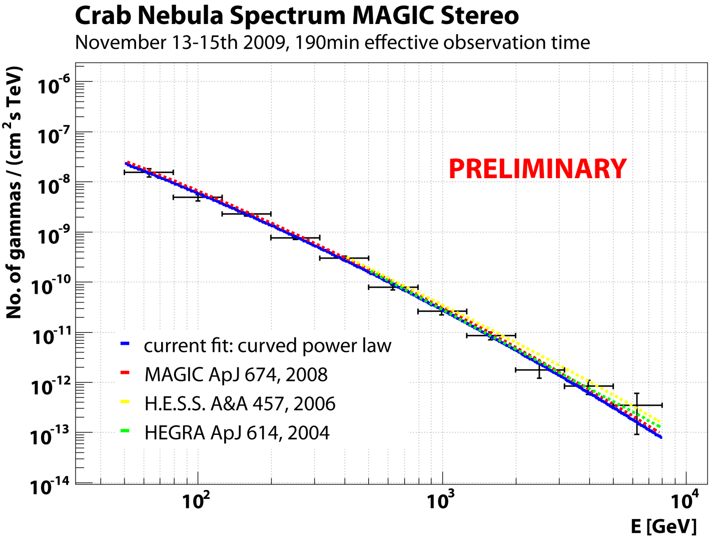
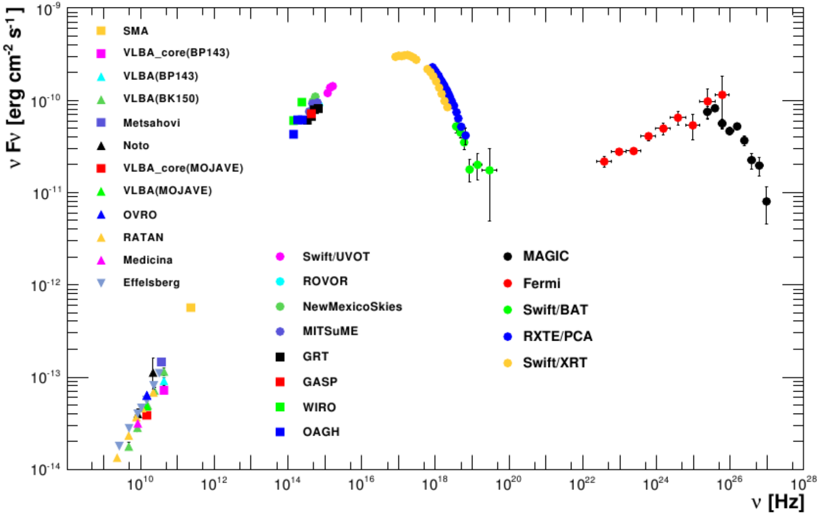




Spectrum of a source



Example for a multi-wavelength study



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To detect the hadronic channel look for *purely* hadronic sources

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high magnetic fields

hadronic CR amplify B-fields
leptonic synchroton losses $\rightarrow$
high energy γ's hadronic

- SNR requierements
  - very young ($\approx$ 1kyr)
- disadvantages
  - very few objects ($\approx$15-50)
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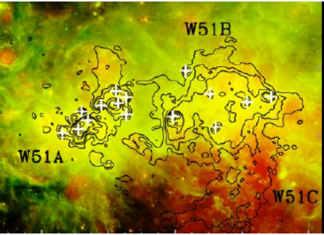
dense targets

molecular clouds
leptons $\rightarrow$ Bremsstrahlung
hadrons π^0-decay

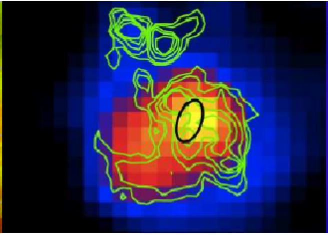
- SNR requierements
  - very close cloud $\approx$ pc
- disadvantages
  - few objects ($\approx$ 200)
  - leptonic γ's

The W51 complex

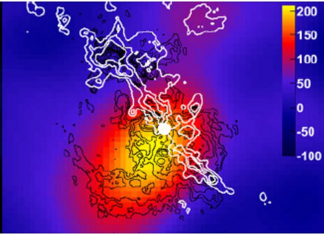
MIPS & IRAC
24 (red) & 8.0 (green) μm
Miju Kang et al. 2009 ApJ 706 83



Fermi / LAT
2-10 GeV
arXiv:1104.1197v1



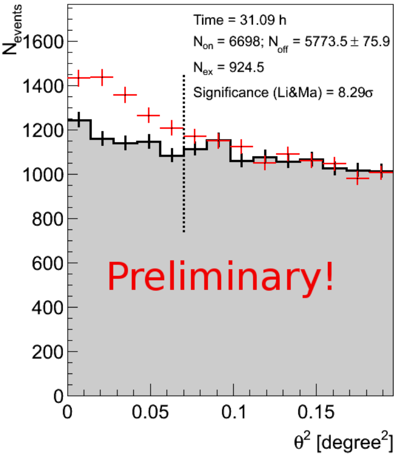
H.E.S.S.
$>$1 TeV
ICRC 2009



- One of the most luminous star forming regions (distance $\sim$ 6kpc)
- W51C is a medium age ($\sim$ 30kyr) supernova remnant [SNR]
- The shell of the remnant interacts with the surrounding molecular clouds
- Discovered by *Fermi* / LAT ($\sim$ GeV) and H.E.S.S. (4.4σ, flux > 1 TeV)

Promising candiate to test and study cosmic ray acceleration in SNR's

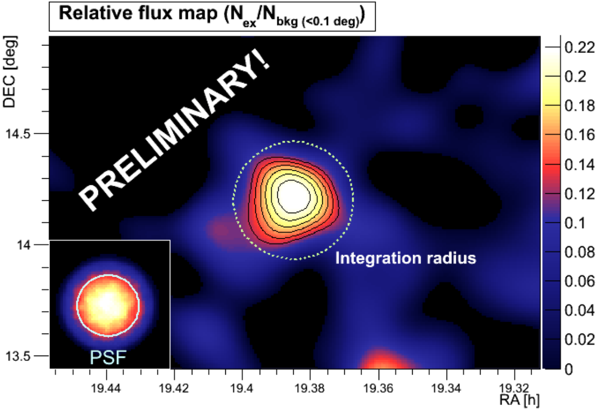
Observations of W51C with MAGIC



- center of observations:
  Ra $= 19.385\,[\mathrm{h}]$
  Dec $= 14.19\,[\mathrm{deg}]$
- stereoscopic wobble data
- data from May to August 2010
- zenith angle 14-35 degree
- total of 31.09 h effective time

- 8 σ detection $>$ 150 GeV
- Extended emission region

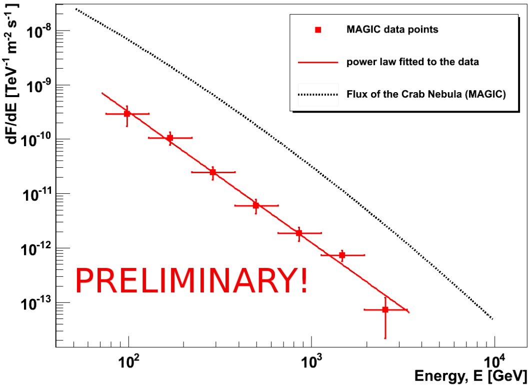
Source position and extension > 150 GeV



- angular resolution 0.085 deg
- smearing kernel 0.1 deg
- contour levels from test statistics
  Starting at 3.5 ($\approx 3.5\,\sigma$)
  in steps of 0.5

- Source position:
  Ra: $19.387 \pm 0.002\,\mathrm{h}$
  Dec: $14.18 \pm 0.02\,\mathrm{deg}$
- Extension
  0.16 ± 0.02 degree

MAGIC high energy γ-ray spectrum of W51C



- integration radius 0.26 deg
- from 75 up to 3300 GeV
- well fitted by power law $\chi^2/\text{d.o.f.} = 4.51/5$
- flux $\sim 3.8\%$ crab

hard index suggests only small propagation effects $\rightarrow$ CR source spectrum

PRELIMINARY spectral energy distribution:

$$\frac{\mathrm{dF}}{\mathrm{dE}} = (1.25 \pm 0.18_{\mathrm{stat}}) \times 10^{-12} \left(\frac{\mathrm{E}}{\mathrm{TeV}}\right)^{(-2.40 \pm 0.12_{\mathrm{stat}})} [\mathrm{TeV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$$

Revisiting models based on *Fermi* / LAT and radio

Astrophys.J.706:L1-L6,2009

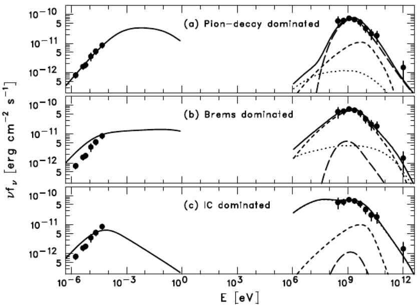


Fig. 4.— Three different scenarios for the multiwavelength modeling (see Table 1). The radio emission (from Moon & Koo 1994) is explained by synchrotron radiation, while the gamma-ray emission is modeled by different combinations of π^0-decay (long-dashed curve), bremsstrahlung (dashed curve), and IC scattering (dotted curve). The sum of the three component is shown as a solid curve.

Pion decay dominated

- known cloud interaction
- agrees with radio

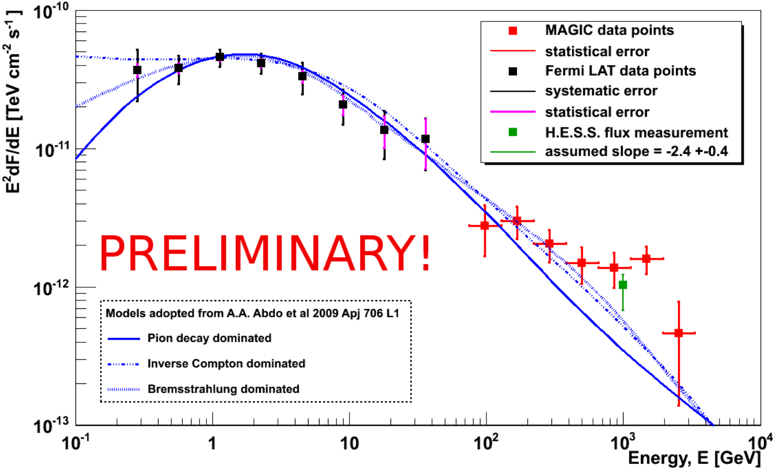
Bremsstrahlung dominated

- needs e/p ~ 1
- disagrees with radio

Inverse Compton dominated

- needs e/p ~ 1
- needs $\mathrm{n_H} < 0.1\mathrm{cm}^{-3}$
- needs $\mathrm{W_e} \sim 10^{51}\mathrm{erg}$
- disagrees with radio

Spectral energy distribution in the γ-ray regime

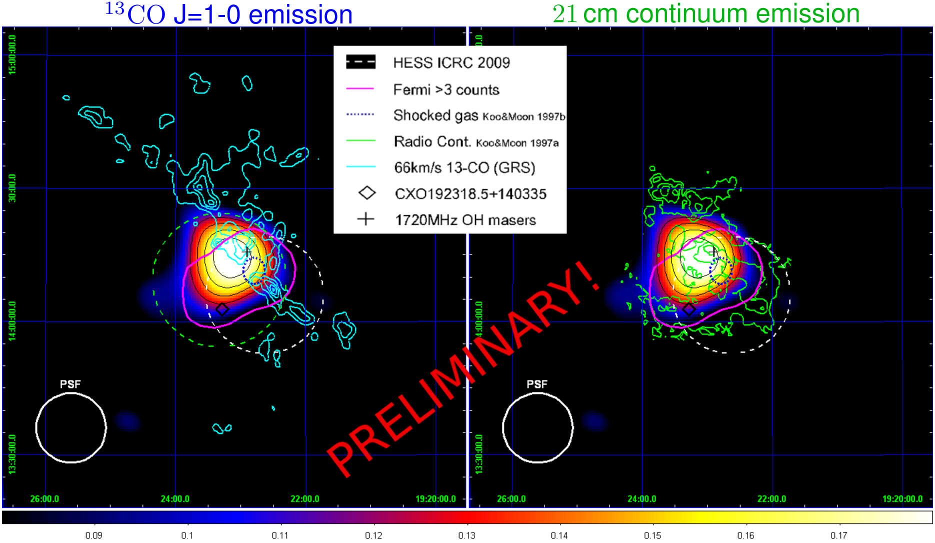


VHE-γ-ray flux (> 800 GeV) harder than the model predictions

Possible explanations:

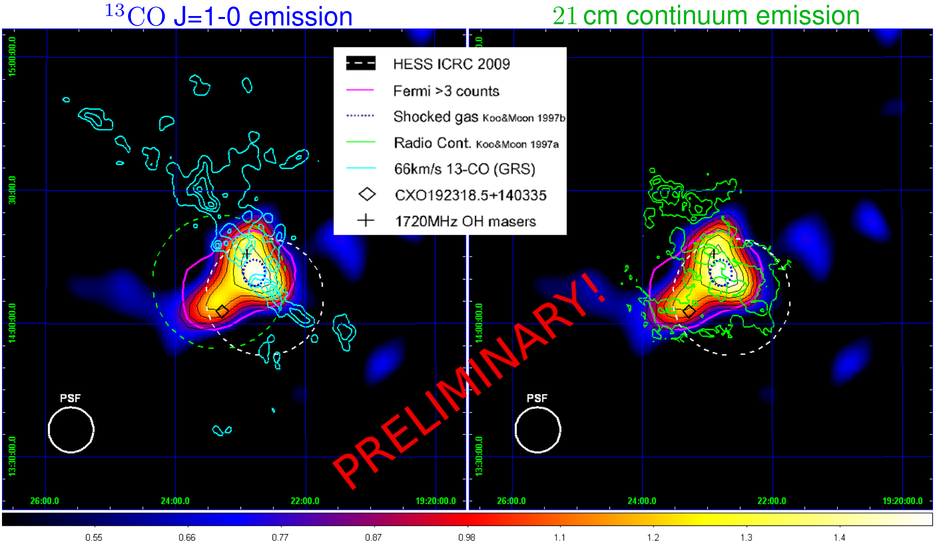
- particle spectrum hardens at high energies
- possible contribution from other sources at high energies

Relative flux map from 150 to 700 GeV



- angular resolution ~ 0.085 deg
- smearing kernel $= 0.1$ deg

Relative flux map > 700 GeV



- angular resolution ~ 0.054 deg
- smearing kernel $= 0.065$ deg

Now... ?!

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Summary

- CR origin is still an open issue
- VHE-γ-astronomy
  - new window
  - acceses highest energy particles
  - reached high sensitivity
  - $\sim$ 100 sources known
- *perfect* sources to study GCR
  - knwon state/enviroment
  - multiwavelength approach
- W51
  - very likely hadronic
  - need detailed modeling
  - determine E^p_{max}
  - ...