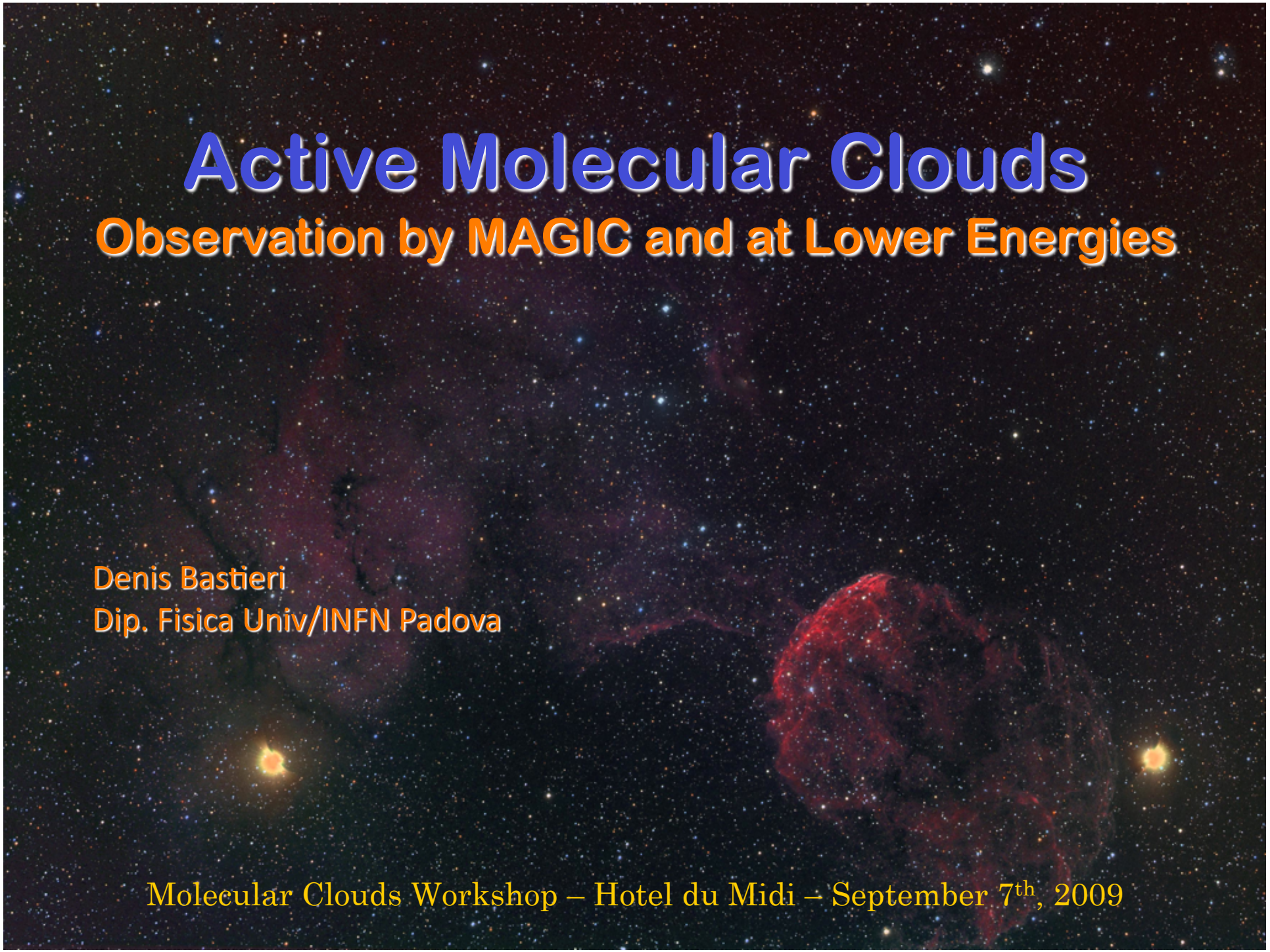


Active Molecular Clouds

Observation by MAGIC and at Lower Energies

Denis Bastieri
Dip. Fisica Univ/INFN Padova

Molecular Clouds Workshop – Hotel du Midi – September 7th, 2009

Active Molecular Clouds: An Overview

- Active Molecular Clouds:
  The case of the Jellyfish Nebula, IC 443
- From Radio to Gamma
- Modelling
- The MAGIC Telescope
- Gamma observations
- Conclusions

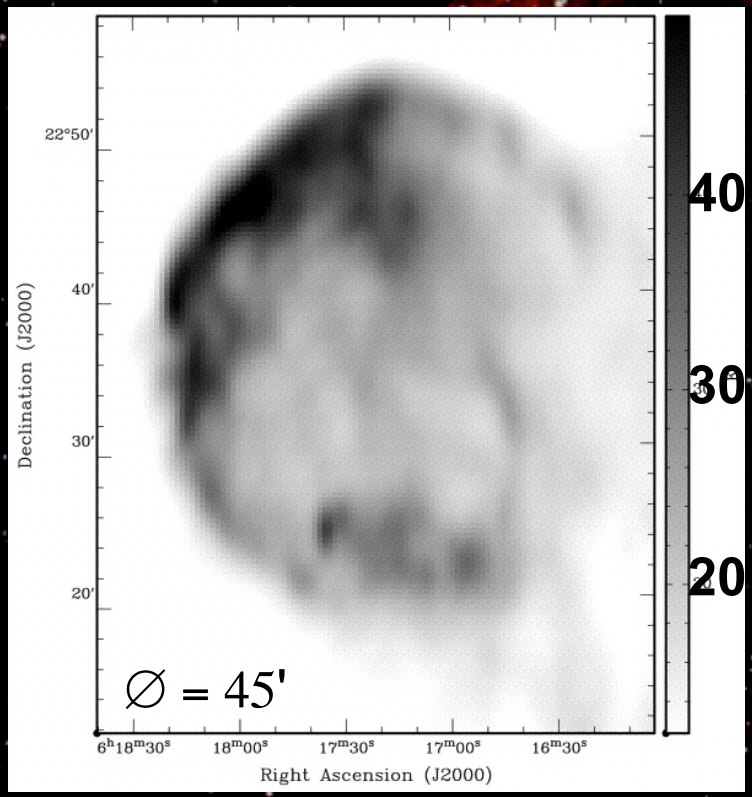
The Jellyfish Nebula: IC 443

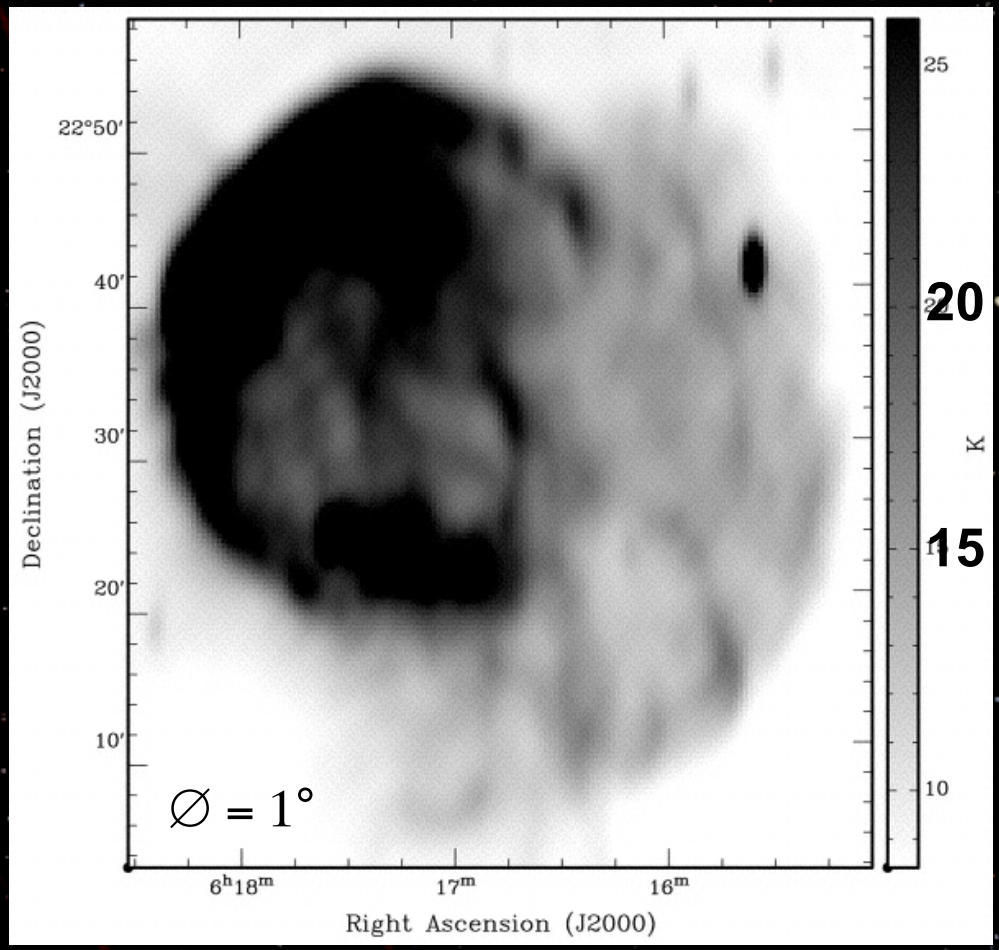
- SNR remnant
- Pulsar candidate: neutron star CXOU J061705.3+222127
- Distance: 1.5 kpc
- Diametre: 50'
- Close to η-Gem
- Age: 3÷30 ky
- G189.6+3.3 (100 ky) in the proximity

Hα 200 min, S II 100, Hα 200, O III 100
Credits: Jim Lafferty

IC 443: Radio observation @1420 MHz

Radio data from D.A. Lehay, AJ 127, 2277 (2004)

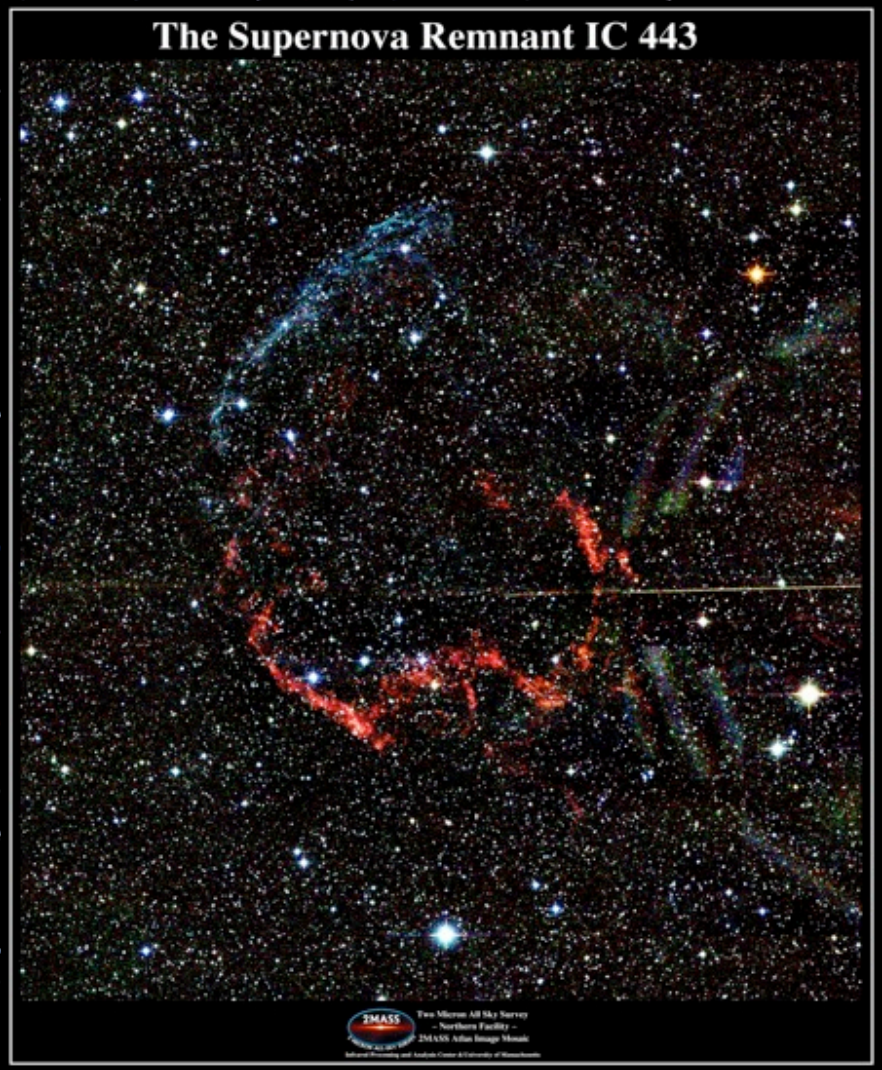




408 MHz data

45' ∅ ring: single structure

IC 443: 2MASS J, H and Ks Bands



Rho et al.
ApJ 547, 885 (2001)

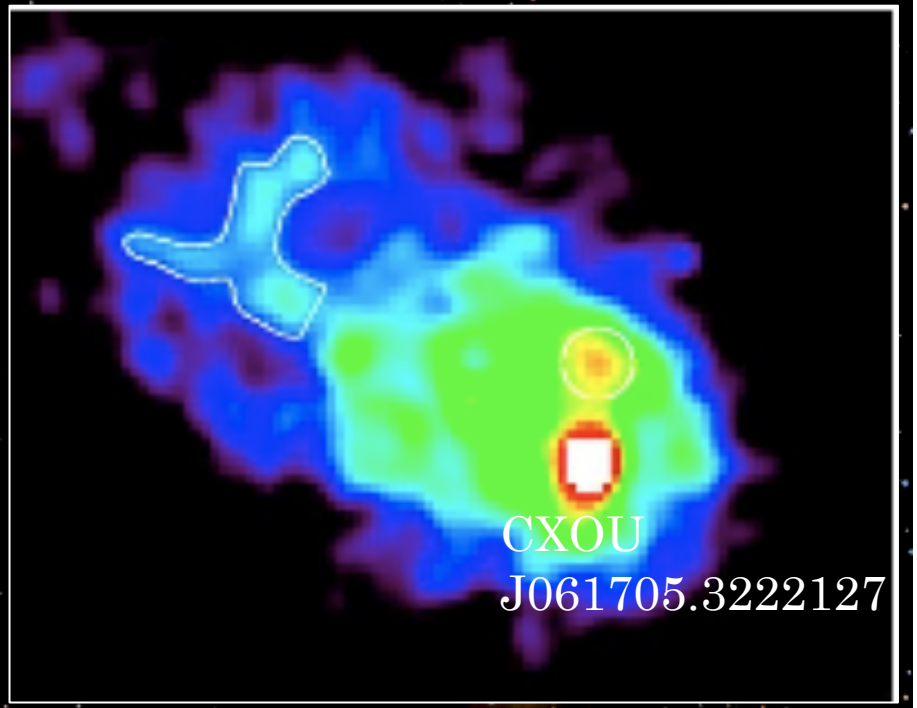
- Northeastern rim
  J+H bands
  ➔ [Fe II]

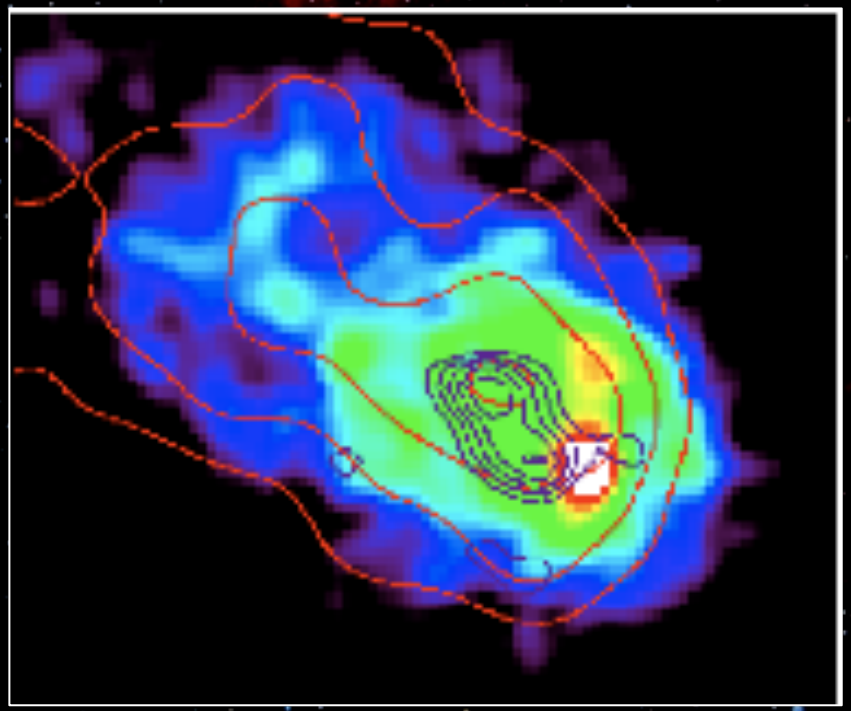
+ ISO: strong [O I]

- Southern sinuous ridge:
  K_s band
  ➔ Molecular Hydrogen (H_2)

IC443: Chandra

Chandra data and analysis
Olbert et al, ApJ 554, L205 (2001)
Gaensler et al, ApJ 648, 1037 (2006)
Weisskopf et al, Ap.Sp.Sci. 308, 151 (2007)

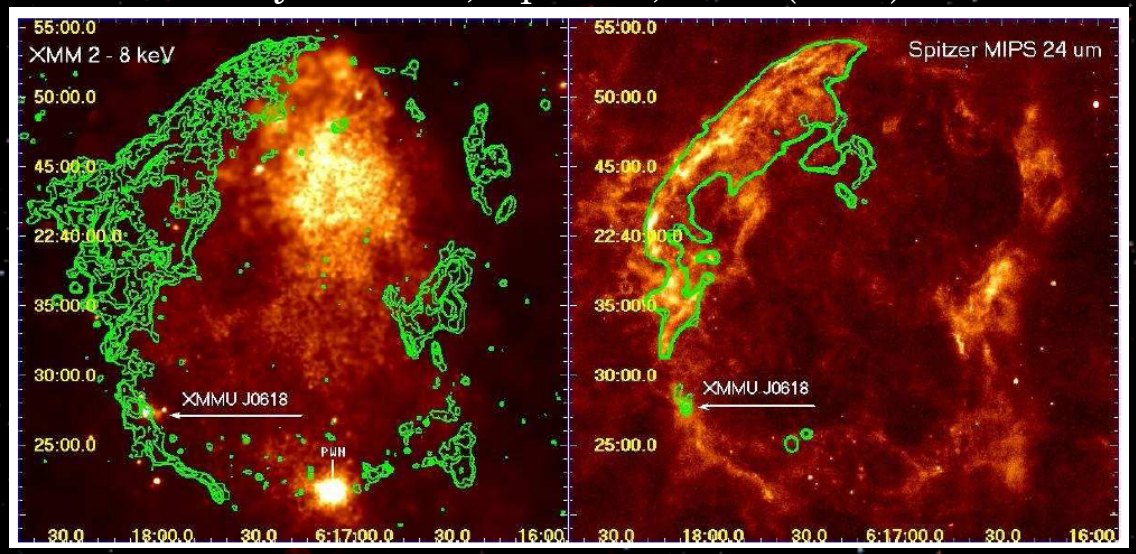




Superposition with VLA
Radio emission confined within the X-ray boundary
Classical PWNe radio-emission peaks on the outskirts

IC443: XMM

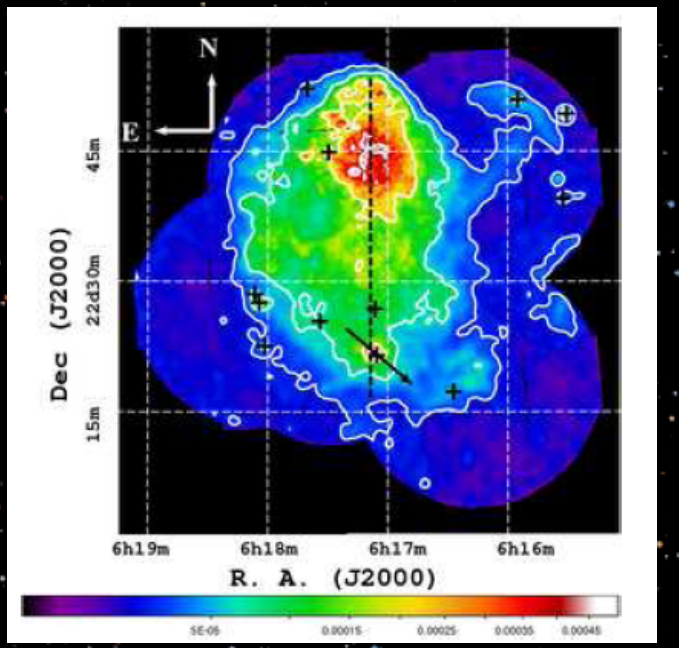
Bykov et al, ApJ 676, 1050 (2008)



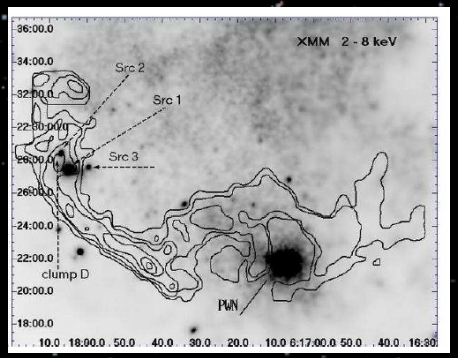
XMM 2–8 keV image
Spitzer MIPS 24 μm contours

Spitzer MIPS 24 μm image
VLA 1.4 GHz contours

Troja et al. A&A 485, 777 (2008)



1.4-5keV

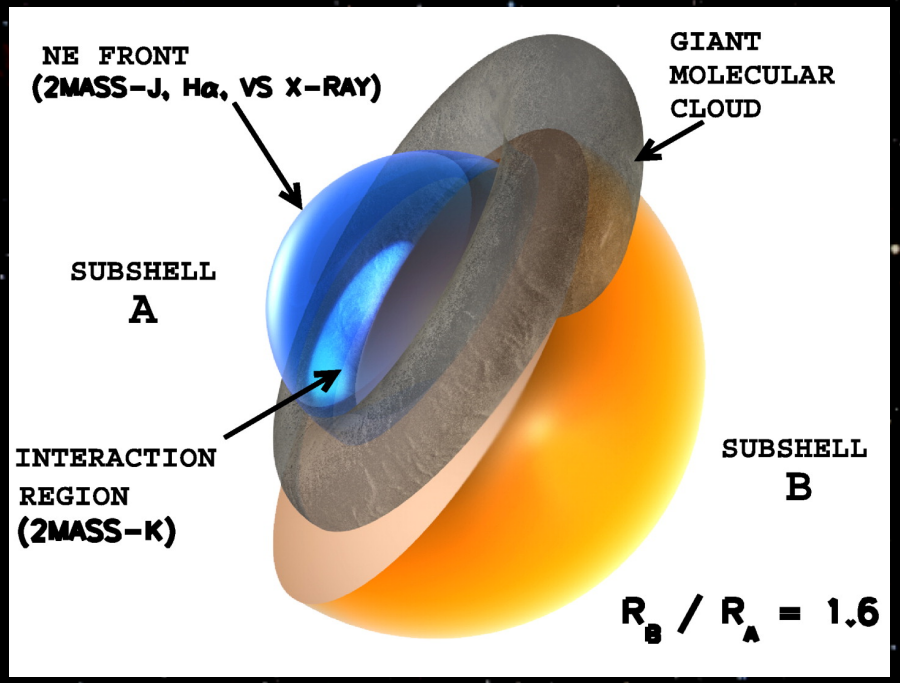


XMM-Newton (2–8 keV) image
2.122 μm H_2 emission contours
(Burton, QJRAS 28, 269, 1987):
Shocked molecular cloud!

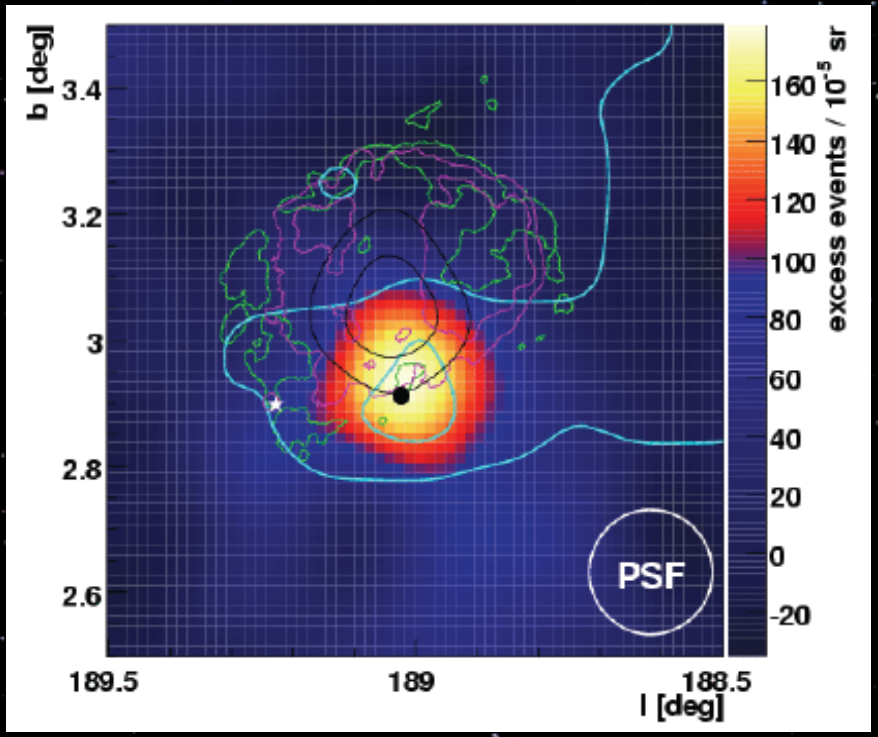
IC 443: modelling its morphology

- Variety of interactions
- Interaction of SNR shocks with mol. & atomic clouds (two subshells)
- Small scale structure:
  - Interaction with G189-6+3.3
  - Shock front + dense mol clouds: mol. line emission
  - Interaction between PWN and environment

Troja et al. ApJ 649, 258 (2006)



MAGIC J0616+225: Albert, ApJ 664, L87 (2007)

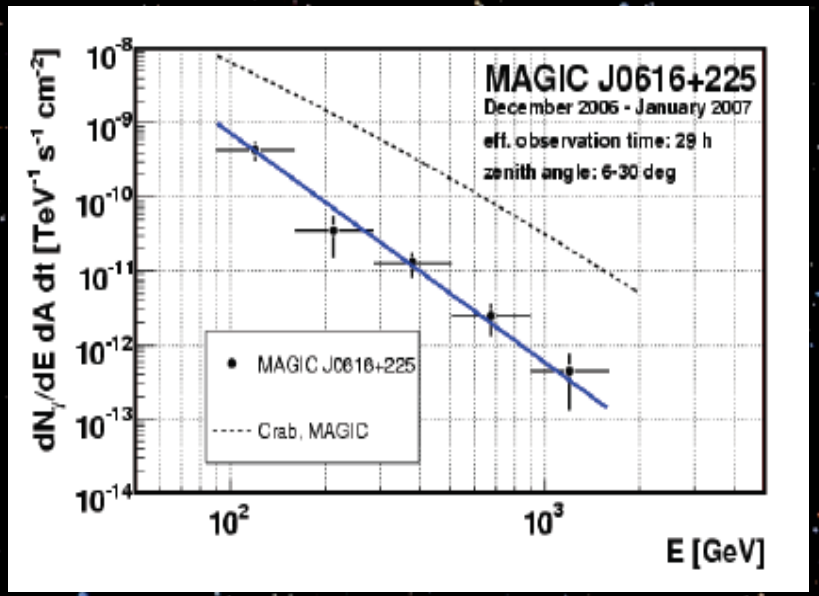


DISCOVERY!

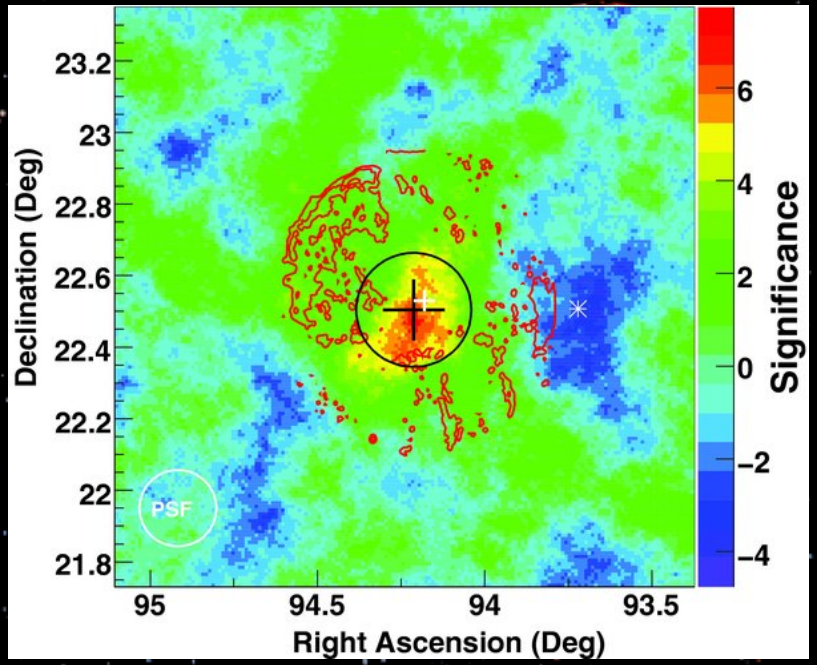
IC443 is also a VHE emitter!

- 6.5% CU @100GeV, 3% CU @300GeV
- spct. idx 3.1 ± 0.3
- no flux variations
- pointlike emission
- correlated w/ mol. clouds (10^4 $M_\odot$)
- well corr. w/1720 MHz maser (shock?)

^{12}CO emission (cyan), 20 cm VLA (green)
ROSAT (purple), EGRET (black),
CXOU J061705.5+222127 (white star),
1720 MHz OH maser (black dot)



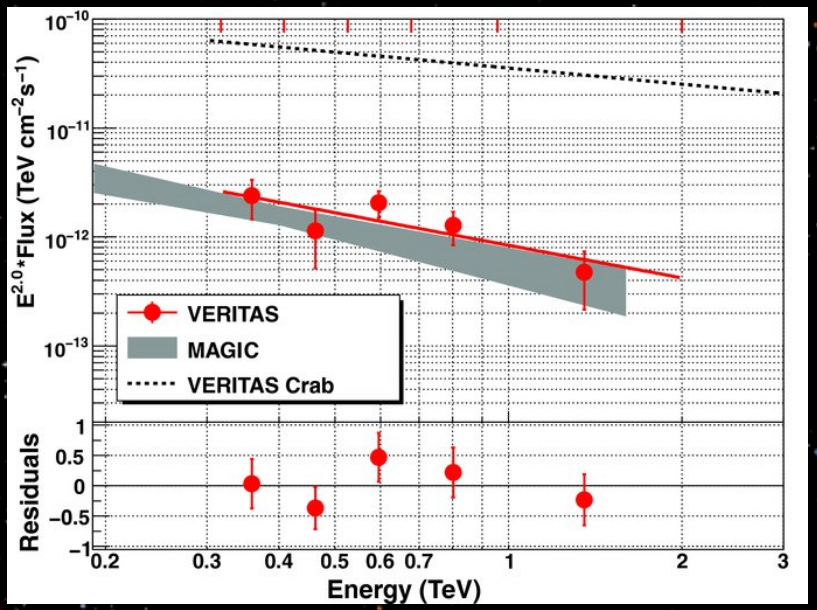
IC 443: VERITAS confirmation



Acciari, ApJ, 698, L133 (2009)

Black circle: Veritas extension
Black cross: Veritas 1σ (stat $\oplus$ sist)
White cross: MAGIC 1σ (stat $\oplus$ sist)
Red contours: optical (McLean et al. 2000)
White star: η Gem

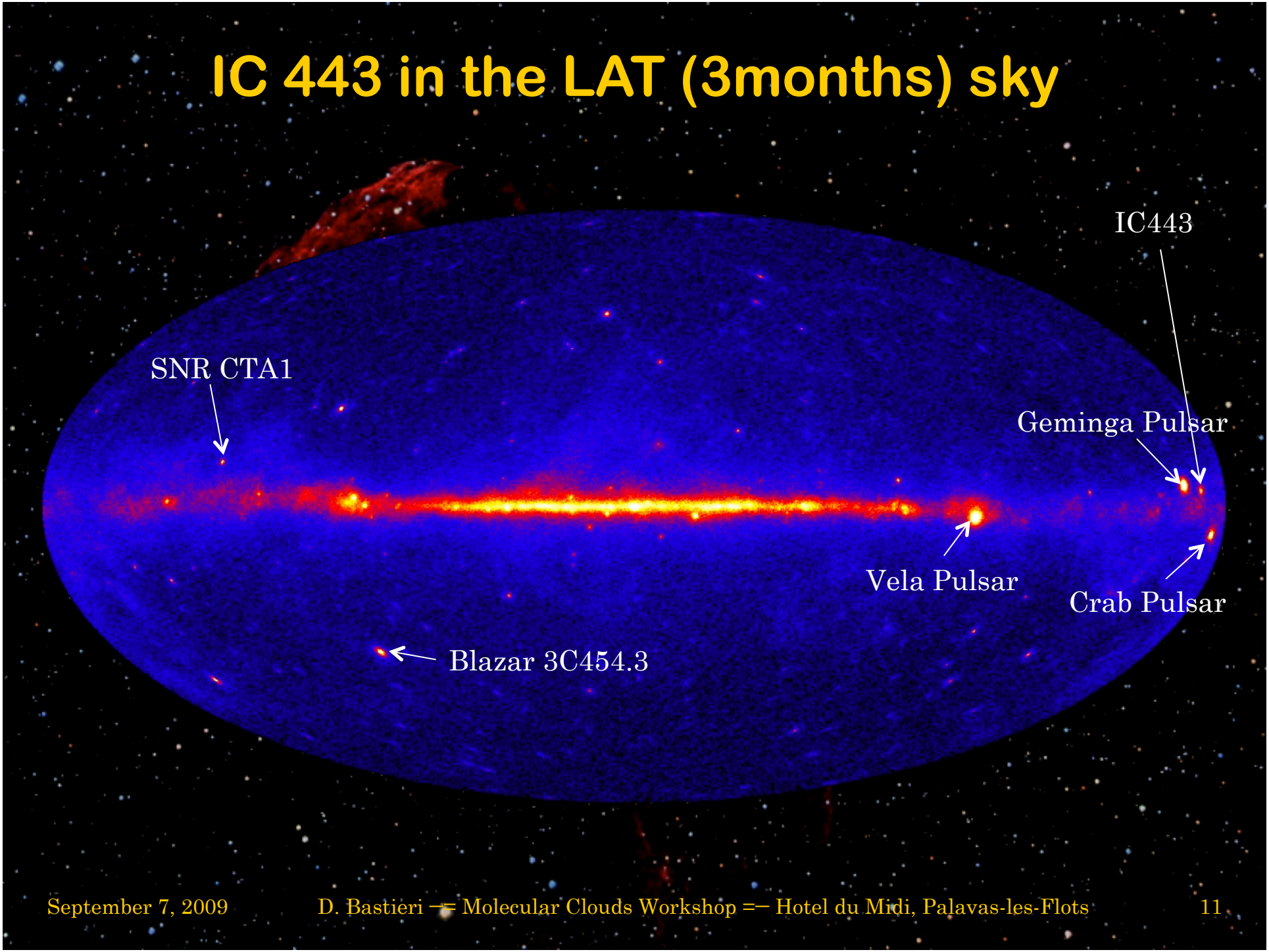
IC443 is an extended source!



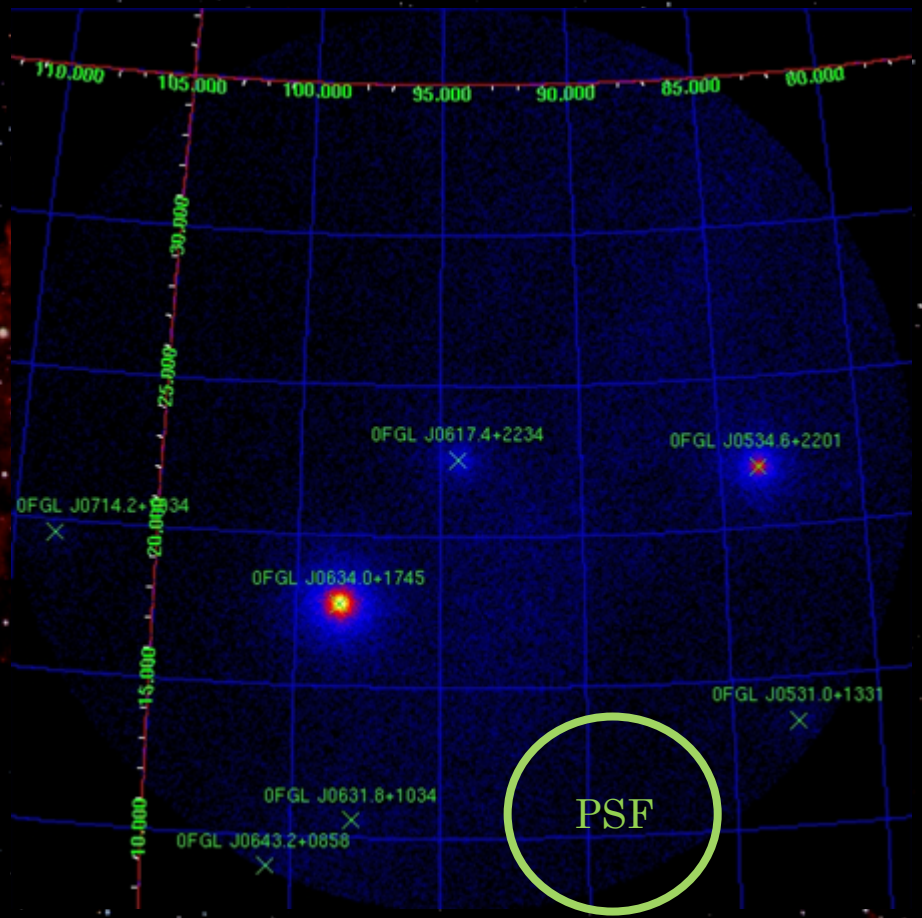
Good agreement also for the flux.

Gray band: MAGIC spectrum (1σ stat) extending down to 90 GeV.
Red points: Veritas spectrum (1σ stat)
Red line: power-law fit
Dotted line: Veritas spectrum of the Crab

IC 443 in the LAT (3months) sky



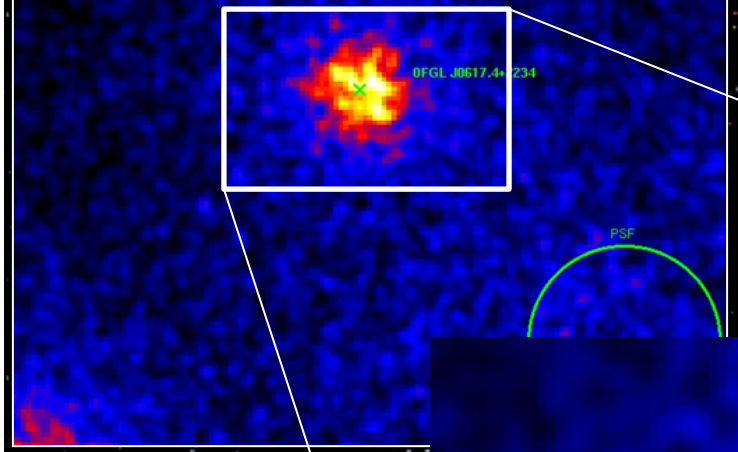
IC 443: LAT observation E > 100 MeV



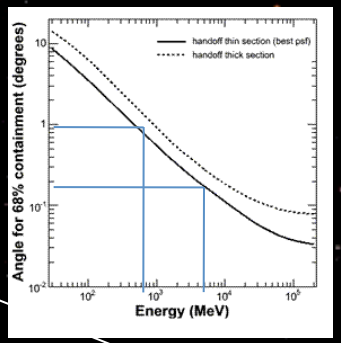
LAT Count map
Courtesy of
Francesco Giordano
(RICAP 2009)

IC 443: LAT obs. at higher energies

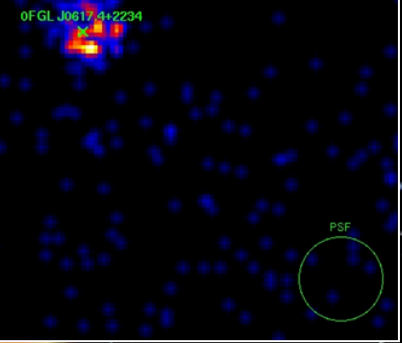
E > 500 MeV

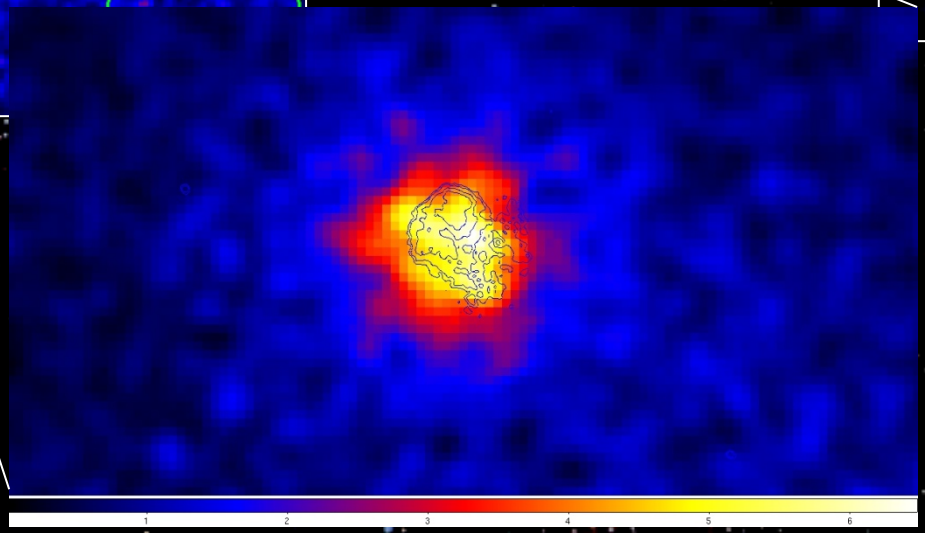


LAT PSF



E > 5 GeV





Contours by ROSAT

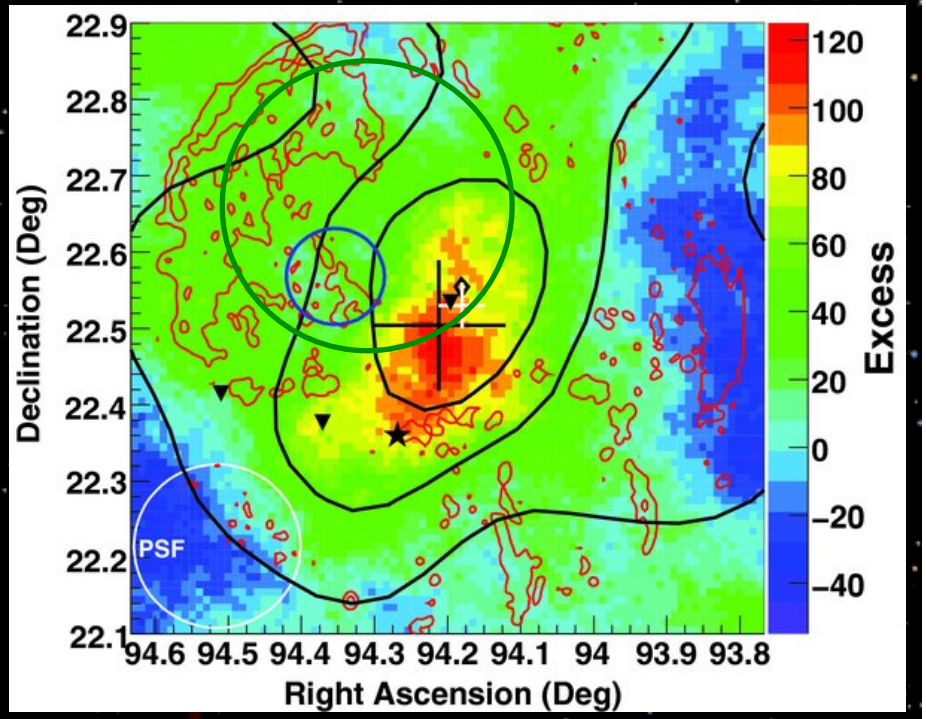
LAT Count maps Courtesy of Francesco Giordano (RICAP 2009)

IC 443: GeV - TeV connection

Acciari, ApJ, 698, L133 (2009)

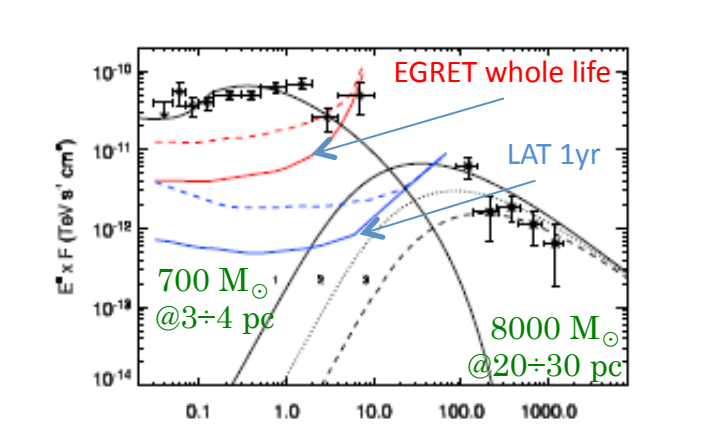
Black cross: Veritas 1 σ (stat $\oplus$ sist)
White cross: MAGIC 1 σ (stat $\oplus$ sist)
Red contours:
optical (McLean et al. 2000)
Black contours: CO survey
(Huang & Thaddeus 1986)
Black star: CXOU J061705.3+222127
Green circle:
95% cl radius for EGRET
Blue circle:
95% cl radius for LAT
Black triangles:
OH masers (Claussen et al. 1997)

Acceptance-corrected excess map



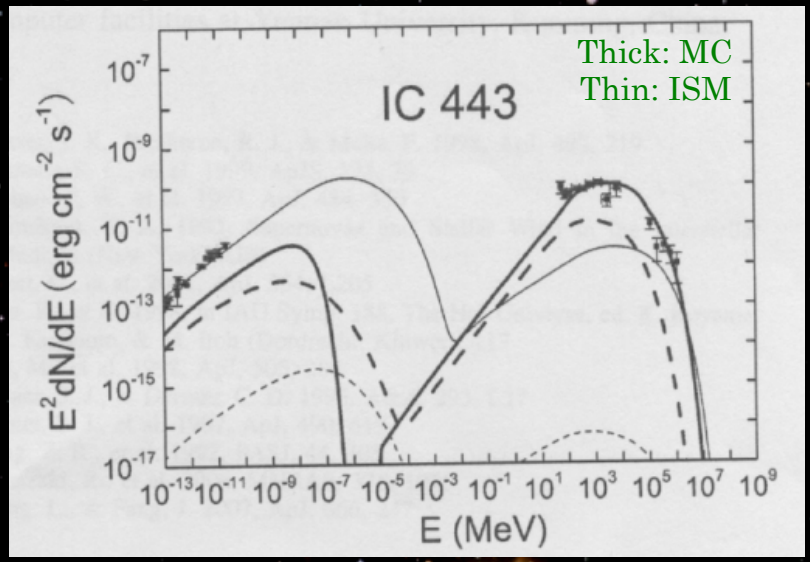
HE/VHE Model Comparison

Torres et al. MNRAS 387, L59 (2008)



Delayed TeV emission from CR interacting with a 8 kM$_\odot$ cloud located 20, 25, 30 pc away in the SNR foreground

Zhang & Fang, ApJ 675, L21 (2008)



Preliminary LAT spectrum analysis

- Flux $E > 200$ MeV
  $\sim 2 \times 10^{-7}$ γ × cm^{-2} sec^{-2} MeV^{-1}
- BPL (~1.9 to ≥ 2.5) E_{break}: few GeV

Comparison

Zhang & Fang
EGRET and TeV sources should be co-spatial.

Torres et al.
Shifting of the source position is smooth and function of the energy

Bykov et al ,ApJ 676, 1050 (2008)
HE/VHE due to collision of SN ejecta with molecular clouds

Conclusions

- Active MC are intriguing sources:
  - Very complex environment
  - Many emission mechanisms involved
- IC443 a paradigm of the class: need MW!

  High energy behaviour:
  - No strong position constraint yet
  - HE and VHE centroids displaced
  - VHE related to cloud G
- Prescriptions for CTA
  1. Increase angular resolution
  2. Low Energy threshold
  3. Increase flux sensitivity
  4. Help from space?

     GRIPS @MeV!

G. Kanbach @SciNeGHE08