SNR and molecular cloud interactions: new HESS/*Fermi*-LAT results

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For *Fermi*-LAT and H.E.S.S. collaborations

LUPM - Montpellier

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CRISM – Montpellier

Contents

Molecular clouds as nurseries for massive stars

Eagle Nebula - Hubble space telescope

- Interstellar medium not homogeneous

- Temperature of cloud: 10 - 100 K
- Density inside cloud: 10^2 - 10^6 cm^{-3}
- Jean's Mass: $M_J \sim 10^5$ M$_\odot$
- Free fall time ($R \sim 10$ pc): $\tau \sim 10^6$ yrs

Molecular clouds as nurseries for massive stars

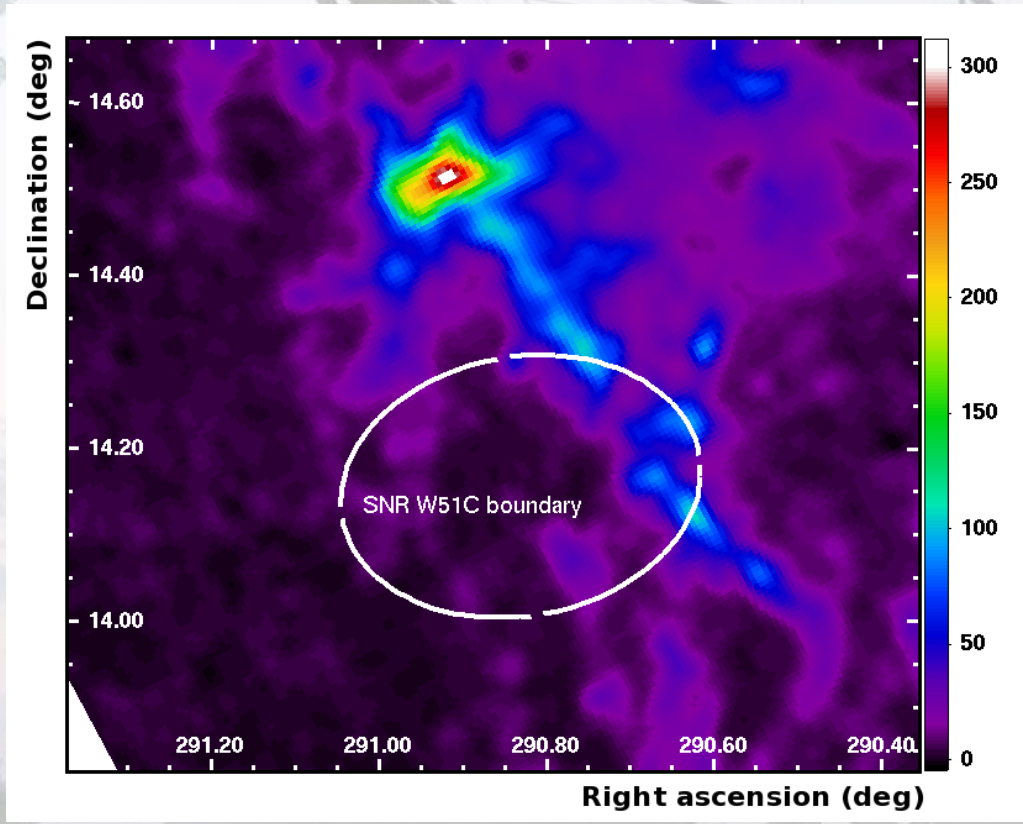
- Massive star born in OB star association
- They die in their progenitor cloud
- Size of supernova remnant (SNR):
  - $\sim$ 500 yrs $\rightarrow$ $\sim$ 5 pc (Tycho)
  - $\sim$ 20000 yrs $\rightarrow$ $\sim$ 30 pc (W44)
- If distance $\sim$ 5 kpc: SNR size is $\sim 0.07^\circ$ at $\sim$ 500 yrs

$\Rightarrow$ H.E.S.S. angular resolution: $PSF \leq 0.07^\circ$

- SNR MORPHOLOGY CAN BE PROBED IN DETAIL
- MWL CORRELATION STUDIES

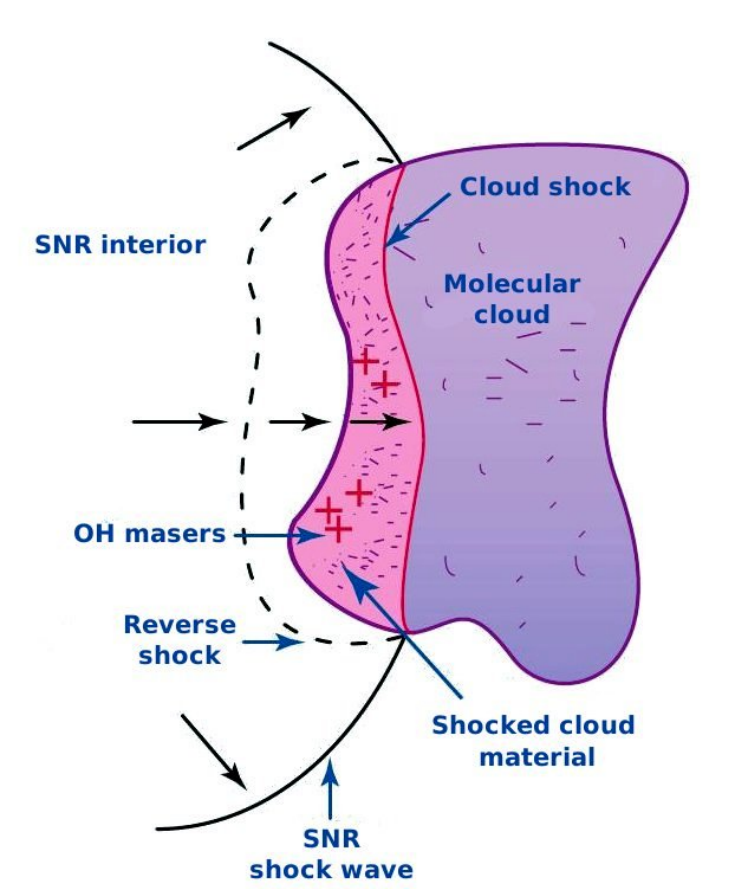
SNR shock waves efficient accelerators?

- p p $\rightarrow \pi^0$ X then $\pi^0 \rightarrow \gamma\gamma$
  - Illuminated clouds: CRs escaped from accelerator (see Stefano's talk)
  - Shocked cloud $\Rightarrow$ interaction SNR/MC (example of SNR/^{13}CO)

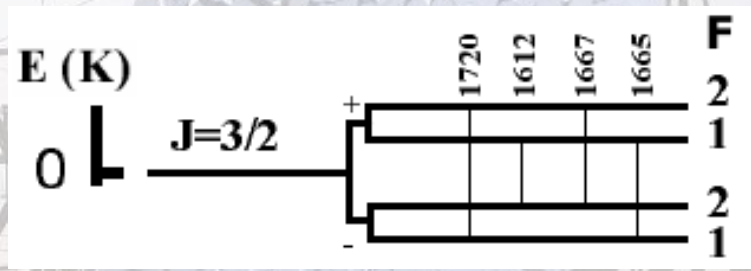


- Protons in cloud accelerated by shock wave (Fermi acceleration)
- Need a dense target to increase collision rate

SNR/MC Interaction - OH maser *(P. Lockett et al 1999)*

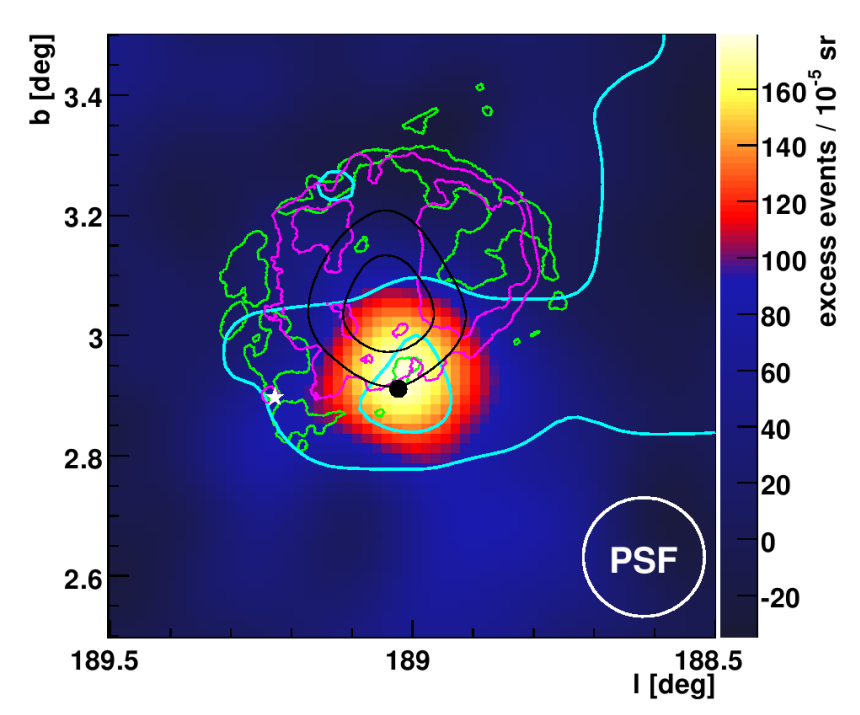


- see Dave's talk
- SNR near molecular cloud
- Shock wave $\Rightarrow$ pumping OH radical
- OH emission at 1720 MHz
- OH masers behind the shock



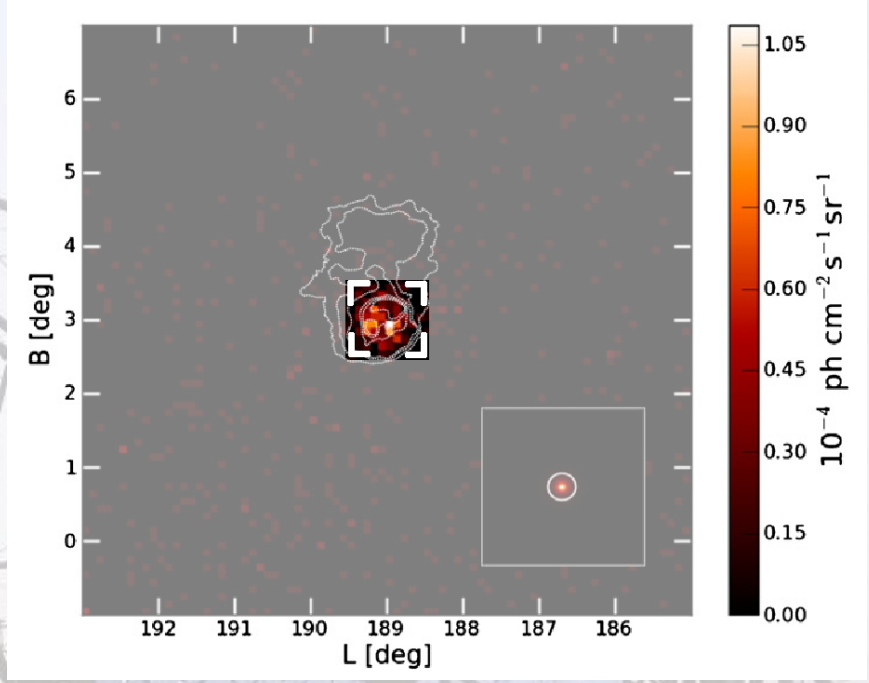
- Particular environment needed for stimulated emission:
  - Temperature: $T \in [50; 125]$ K
  - H_2 density of shocked material: $n_{H_2} \in [10^4; 5.10^5]$ cm^{-3}
  - Weakly ionised medium: $n/n_H < 10^{-4}$
  - OH column density: $n_{OH} \in [10^{16}; 10^{17}]$ cm^{-2}

IC443 as seen by MAGIC and *Fermi*-LAT



VHE γ-ray excess

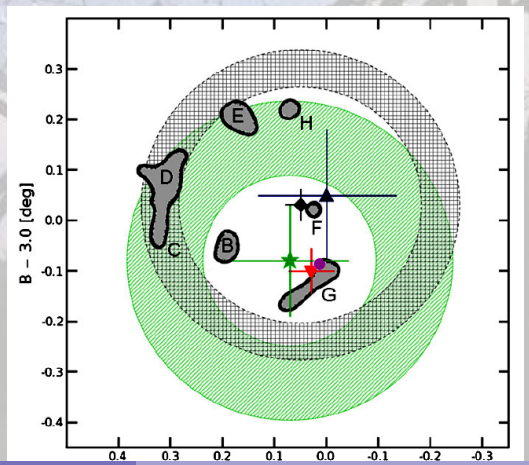
(J. Albert et al 2007)



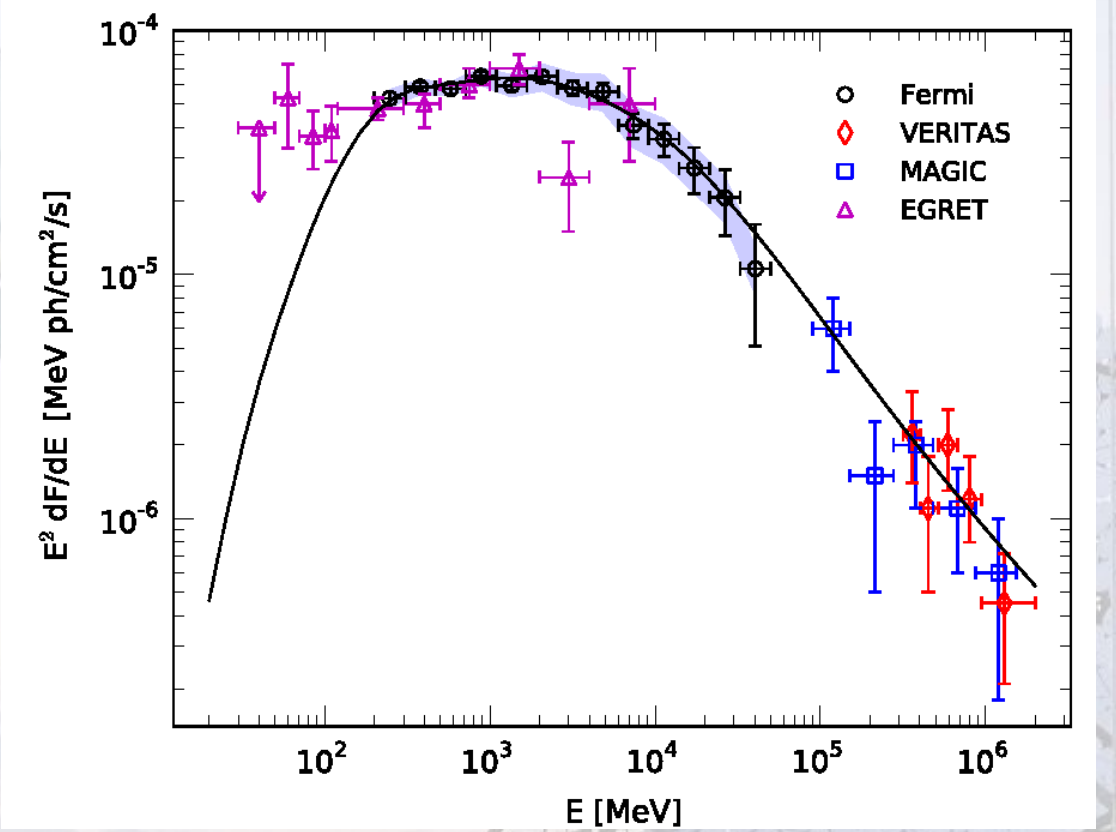
Intensity high energy (HE) γ-ray map

(A.A. Abdo et al 2010)

- VHE γ-ray excess coincident with:
  - HE γ-ray excess
  - OH maser (black point)
  - ^{12}CO maximum excess (cyan)



IC443 Spectral Energy Distribution (A.A. Abdo et al 2010)



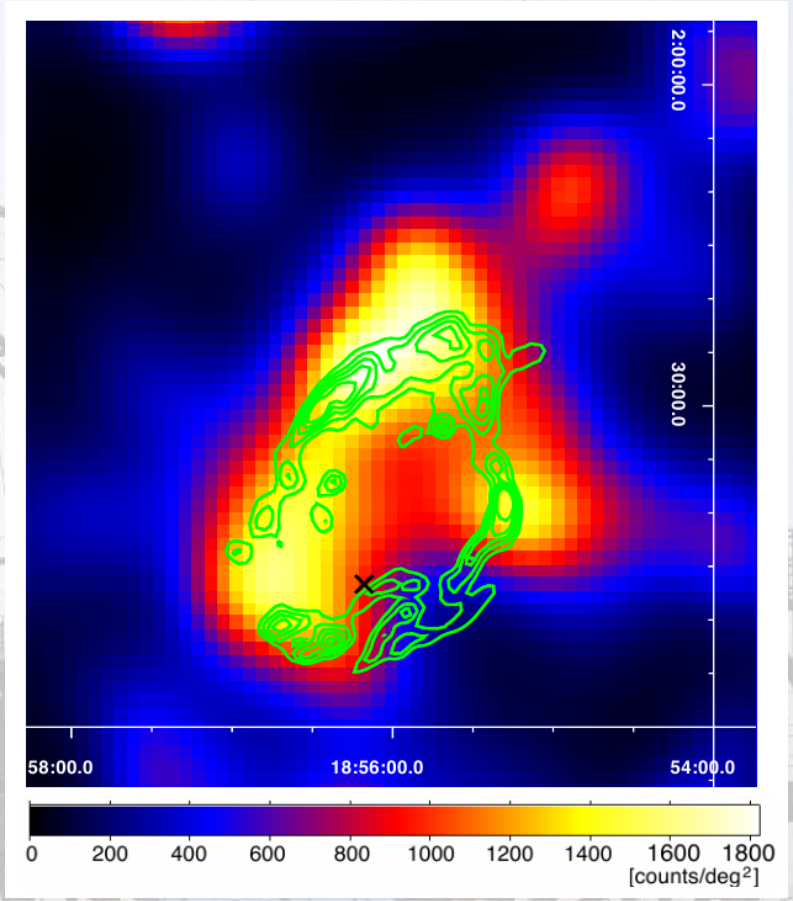
- Only hadronic scenario can explain it
- Density of ambiant medium $\gtrsim 10$ cm^{-3}
- Shocked cloud material $\sim 10^5$ cm^{-3}
- Cloud estimated mass: $\sim 10^4$ M$_\odot$

SNR W44 as seen by HESS and *Fermi*-LAT

?

Nothing published

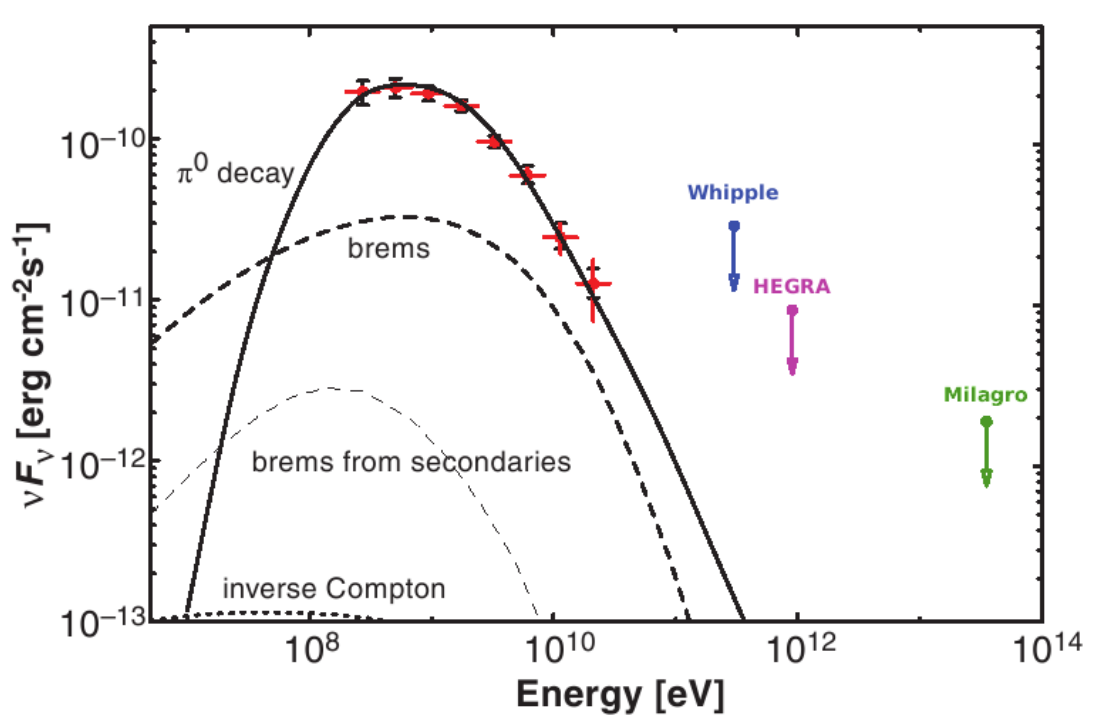
W44 as seen by H.E.S.S.



W44 as seen by Fermi-LAT. (A.A. Abdo et al 2010)

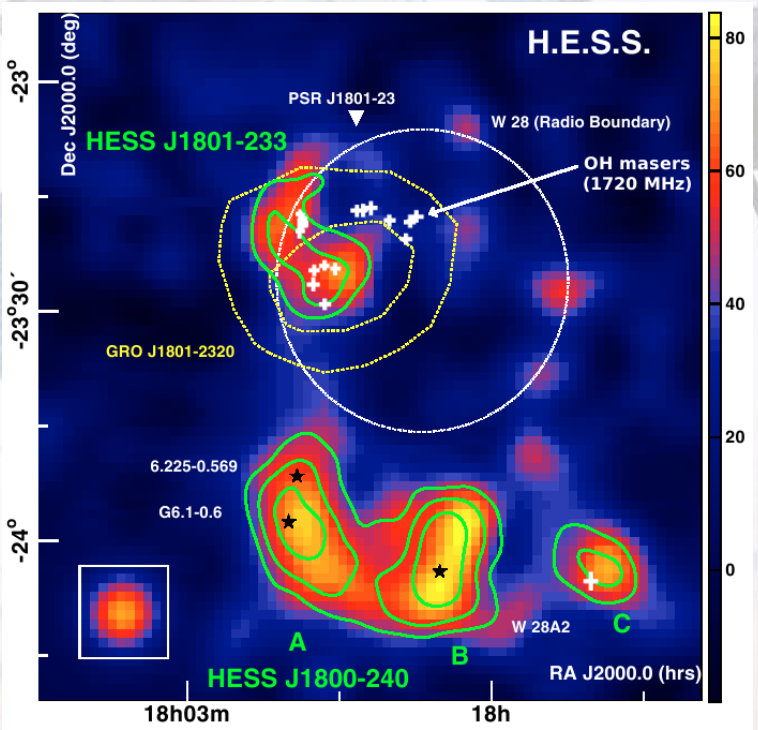
- HE γ-ray coincident with shell and OH masers (white crosses)
- VHE emission: $\Rightarrow$ *under investigations*

W44 Spectral Energy Distribution (A.A. Abdo et al 2010)

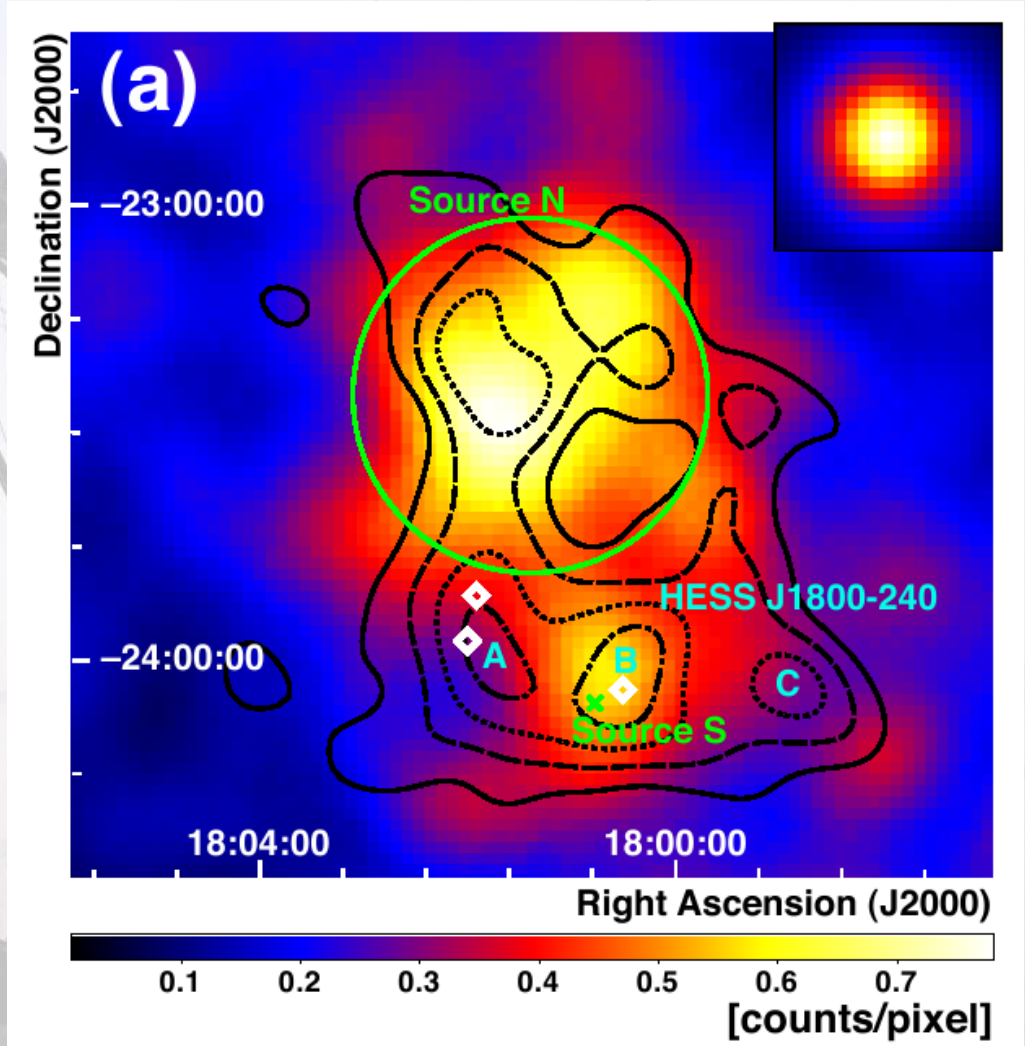


- Only hadronic scenario can explain it
- Density of ambiant medium $\gtrsim 5$ cm^{-3}
- Shocked material density $\in [10^3; 10^5]$ cm^{-3}
- Cloud estimated mass: $\sim 10^6$ M$_\odot$

SNR W28 as seen by HESS and *Fermi*-LAT



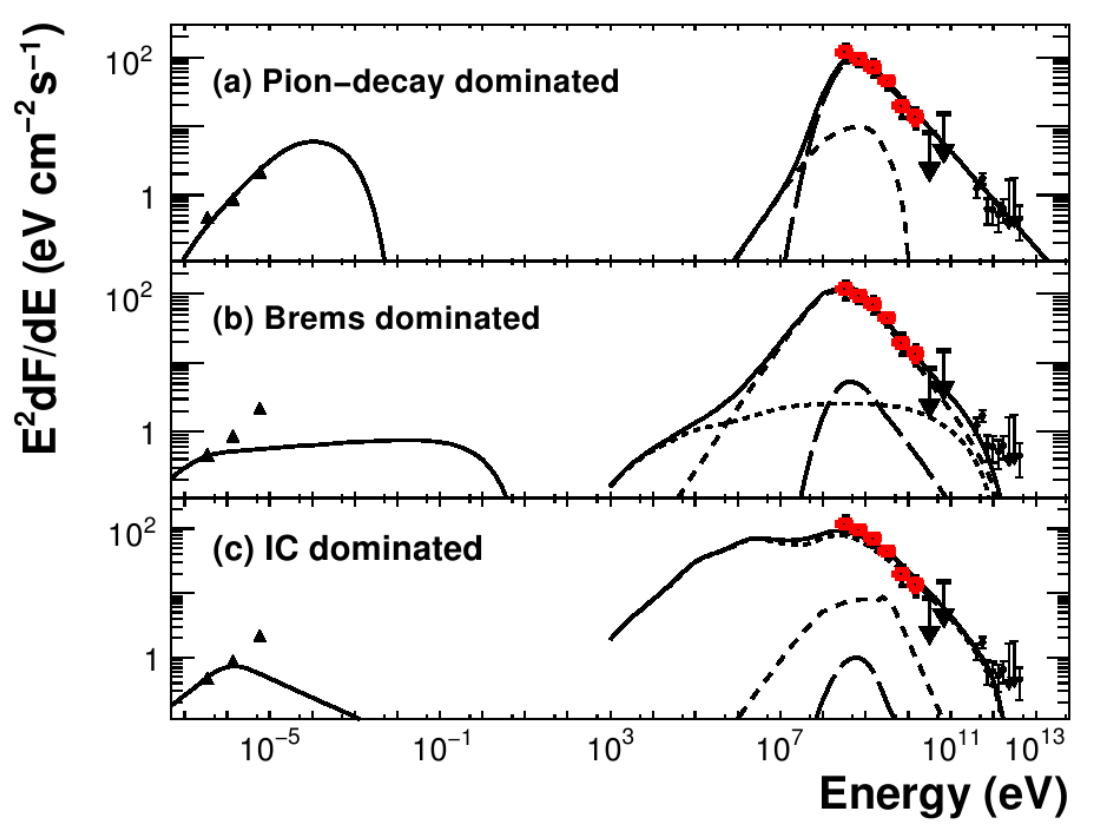
W28 as seen by H.E.S.S.
(F. Aharonian et al. 2008)



W28 seen by Fermi-LAT (A.A. Abdo et al. 2010)

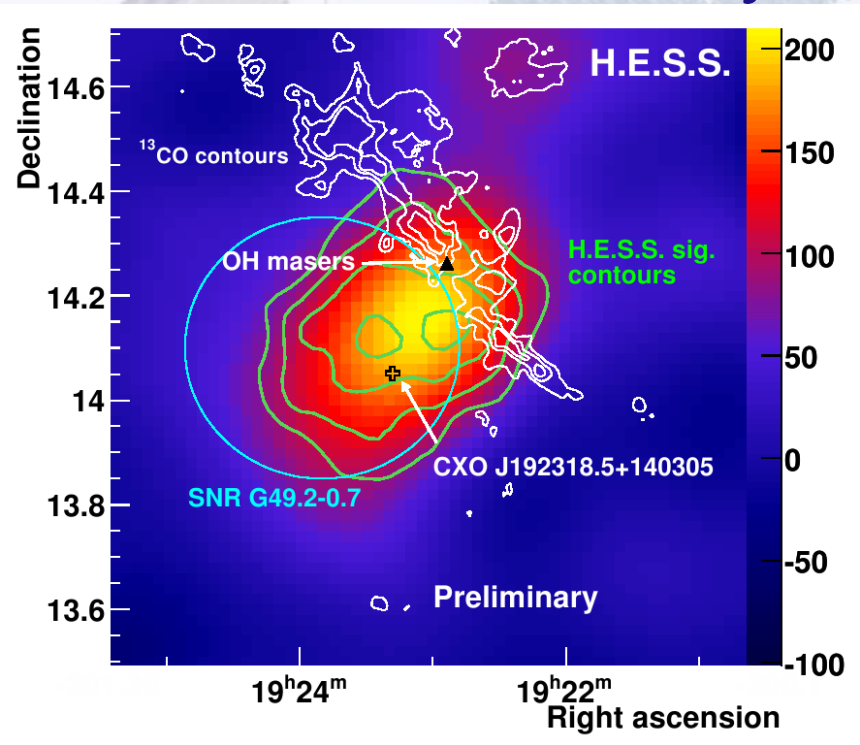
- W28 associated with shocked MC in north (OH masers)
- VHE and HE γ-ray emission (north) coincident with OH masers

W28 (north) Spectral Energy Distribution (A.A. Abdo et al 2010)



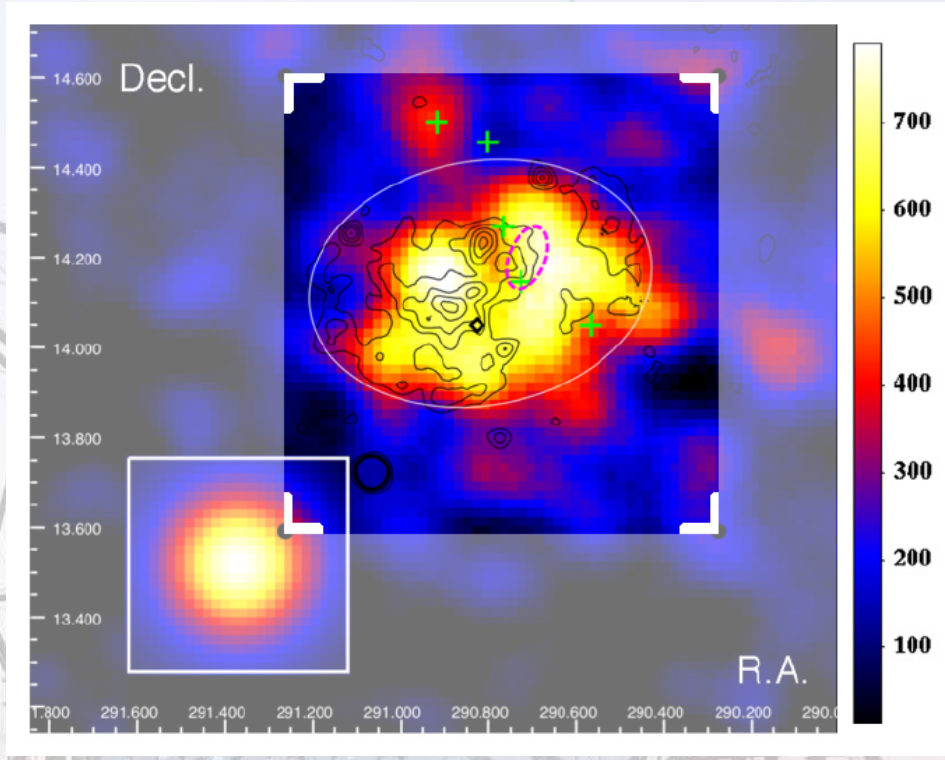
- Any scenarios can explain γ-ray emission
- But only hadronic using radio data
- Shocked gas density $\sim 10^4$ cm^{-3}
- Cloud estimated mass: $\sim 5.10^5$ M$_\odot$

SNR W51C as seen by HESS and *Fermi*-LAT



W51 as seen by H.E.S.S.

(A. Fiasson et al. 2009)

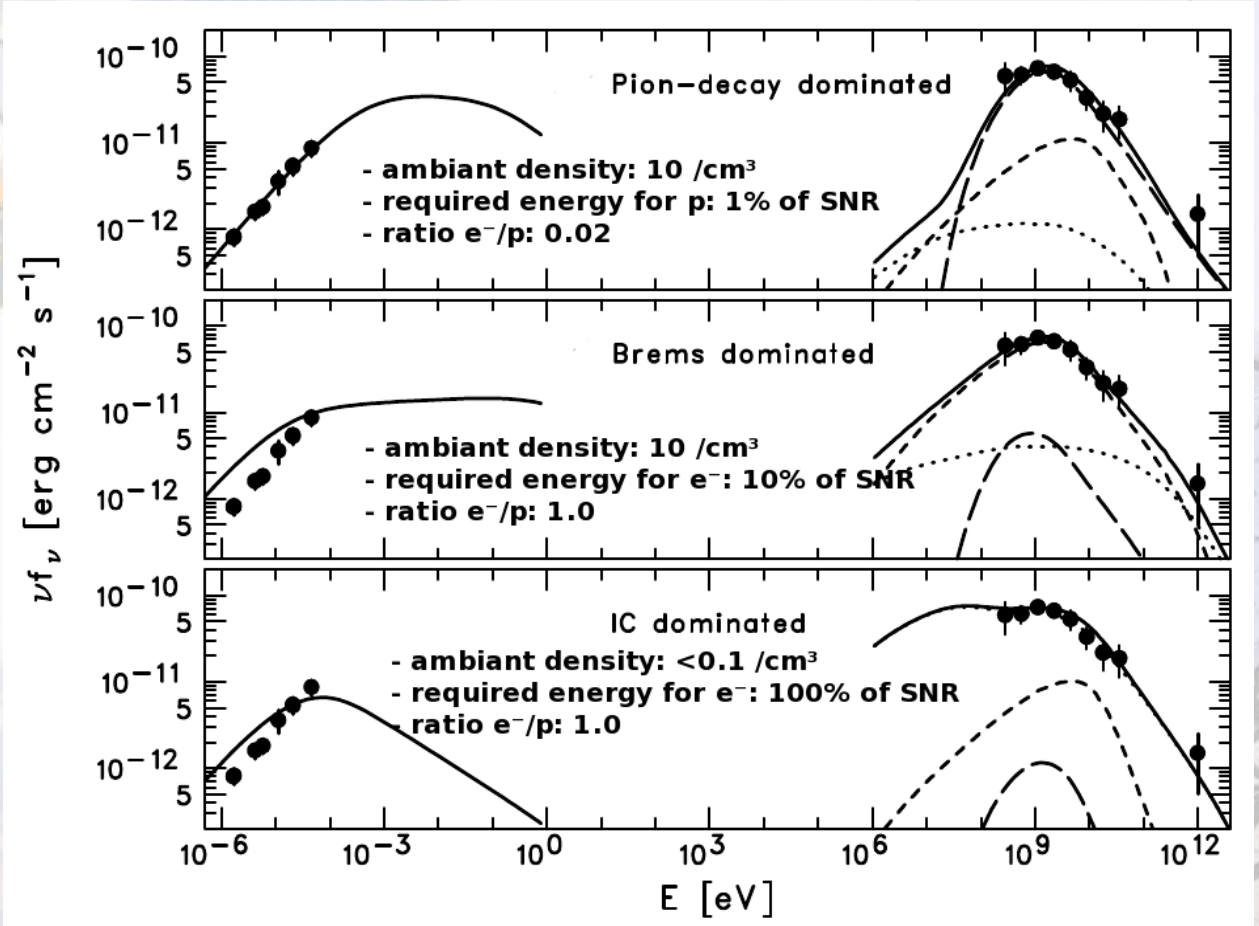


W51 as seen by Fermi-LAT

(A.A. Abdo et al 2010)

- 2 possible counterparts:
  - pulsar wind nebula (open cross)
  - shocked molecular cloud (white contours) $\rightarrow$ OH maser (triangle)
- Can morphology help discriminate? $\Rightarrow$ ***under investigations***

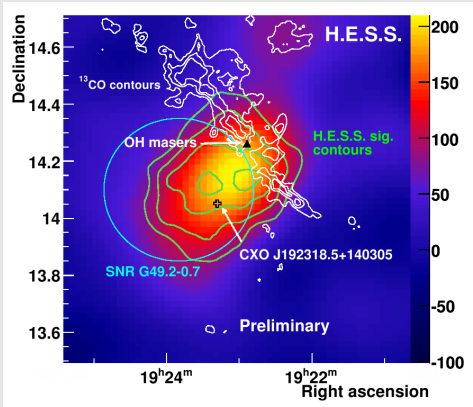
W51C Spectral Energy Distribution (A.A. Abdo et al. 2010)

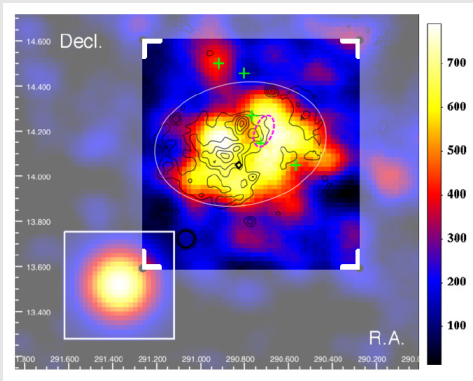


- Hadron-dominated scenario explain γ-ray and radio emissions
- Density of ambiant medium needed: $\sim 10\ \mathrm{cm}^{-3}$
- Cloud estimated mass: $10^4\ \mathrm{M}_\odot$

Conclusion

- Massive stars born in molecular cloud
  - ▷ SNR in dense interstellar medium
  - ▷ Proton acceleration $\Rightarrow$ Proton-Proton collision
- γ-ray produced by π^0 decay
- OH maser as tracer of shock material
- Most significant case of interaction SNR/MC
  - IC443, W44, W28, W51C
- Others SNRs candidates (see Ryan's talk)
- W51C:
  - Spectra strongly suggest hadronic
  - ***Morphological analysis in progress***
- **Multi-wavelength needed to constrain scenarios**





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