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

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LUPM - Montpellier

$4th - 6th\ April\ 2011$

From neutrino to multimessenger astronomy – Marseille

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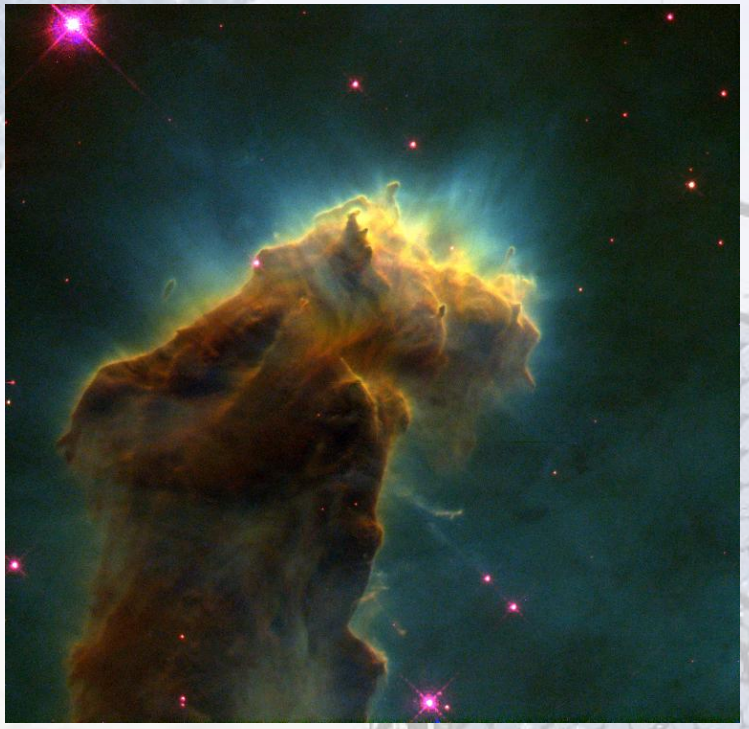
Molecular clouds as nurseries for massive stars



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

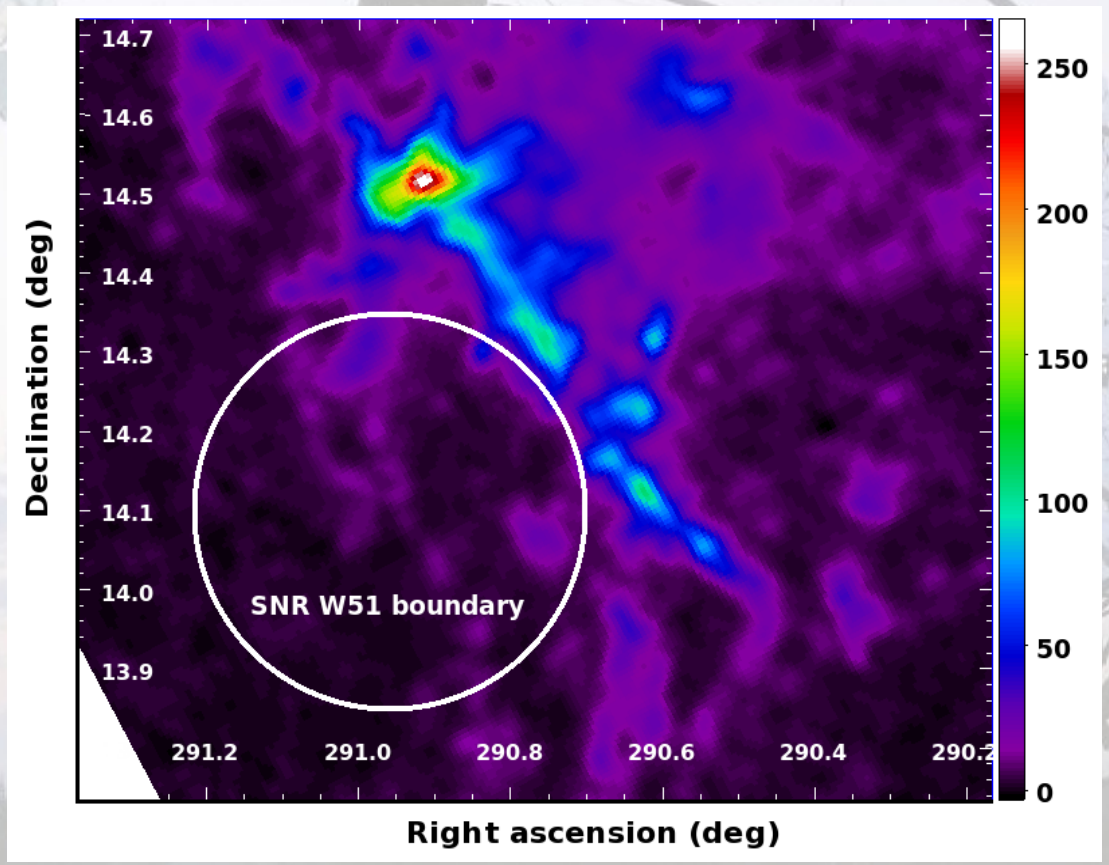
- Massive star born in OB star association
- They die in their progenitor cloud
- Size of supernova remnant (SNR):
  - 500 yrs $\rightarrow$ 5 pc
  - 1000 yrs $\rightarrow$ 10 pc
  - 20000 yrs $\rightarrow$ 30 pc
- If distance $\sim$ 5 kpc: SNR size is 0.06° at 500 yrs

$\Rightarrow$ HESS angular resolution: $> 0.06°$

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

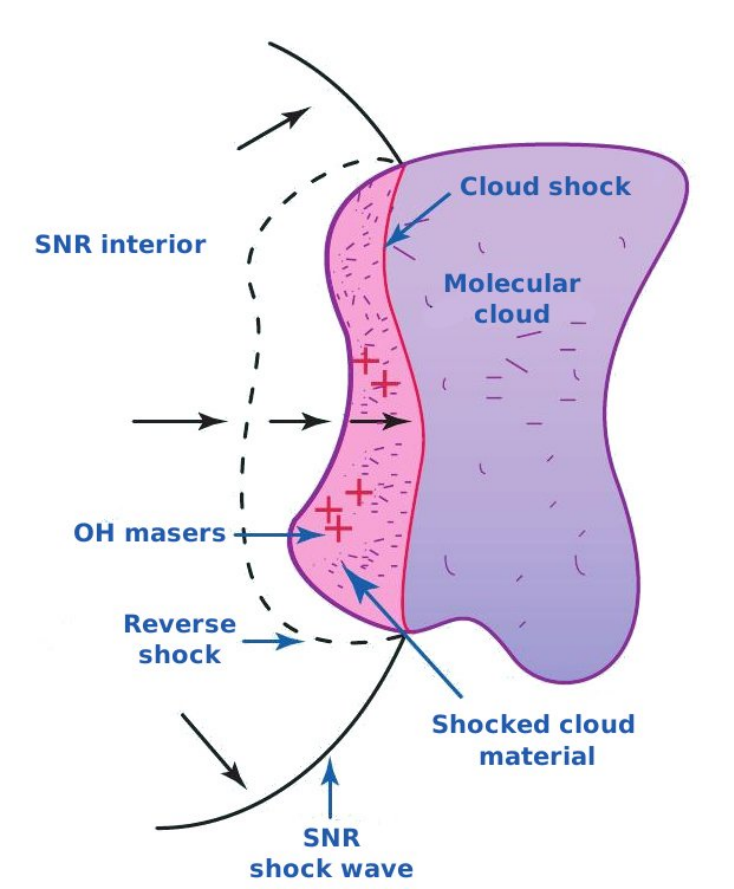
SNR shock waves efficient accelerators?

- 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)

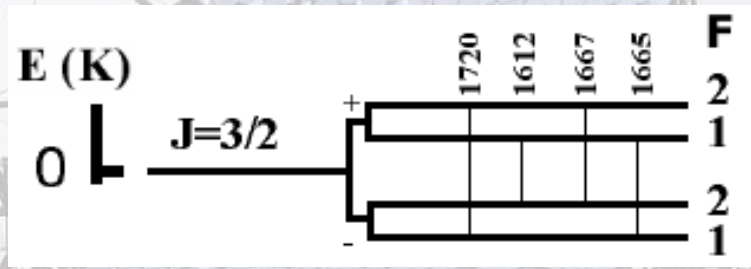


- Protons in cloud accelerated by shock wave (Fermi acceleration)
- Need a dense target to increase collision rate

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

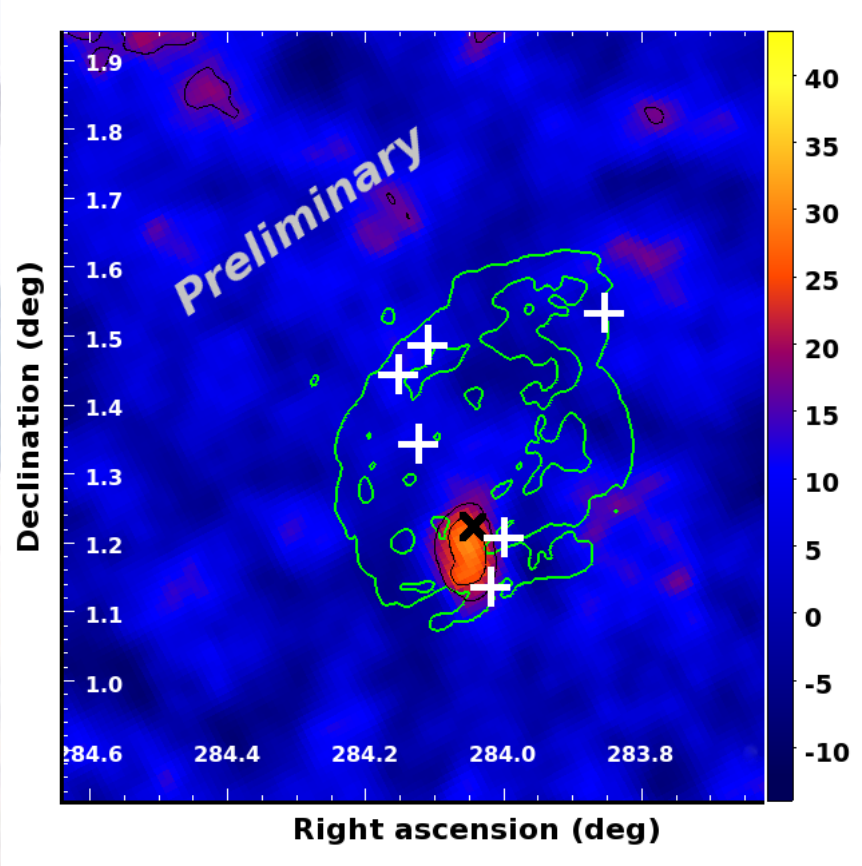


- SNR near molecular cloud
- Shock wave $\Rightarrow$ pumping OH radical
- OH emission at 1720 MHz
- OH masers behind the shock

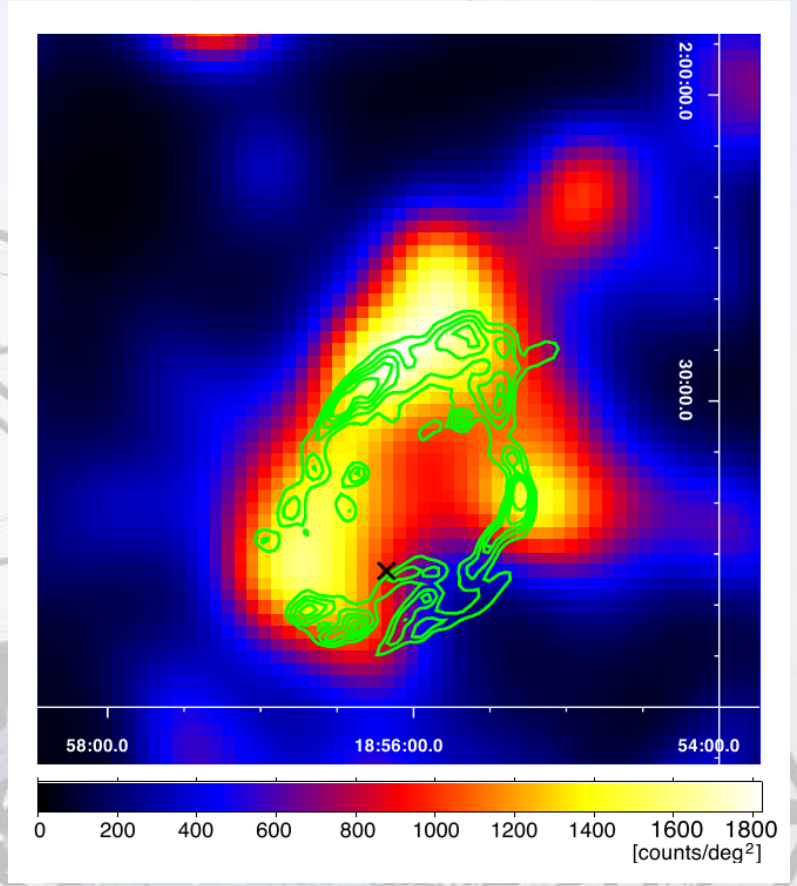


- Particular environment needed for stimulated emission:
  - Temperature: $T \in [50; 125]$ K
  - H_2 density of shocked material: $n_{H_2} \in [10^4; 5.10^5]$ cm^{-3}
  - Weakly ionised medium: $n/n_H < 10^{-4}$
  - OH column density: $n_{OH} \in [10^{16}; 10^{17}]$ cm^{-2}

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



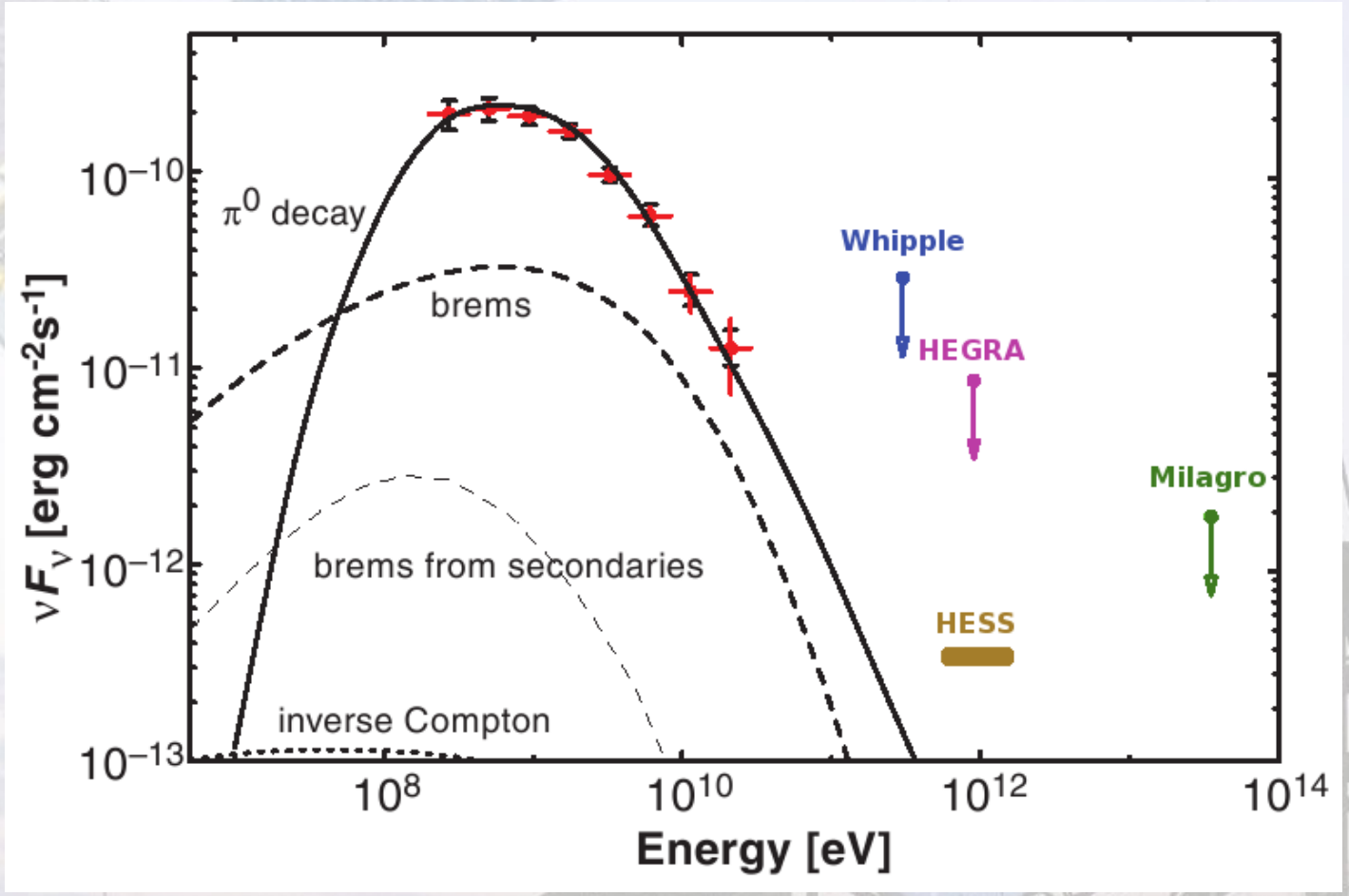
W44 as seen by HESS.



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

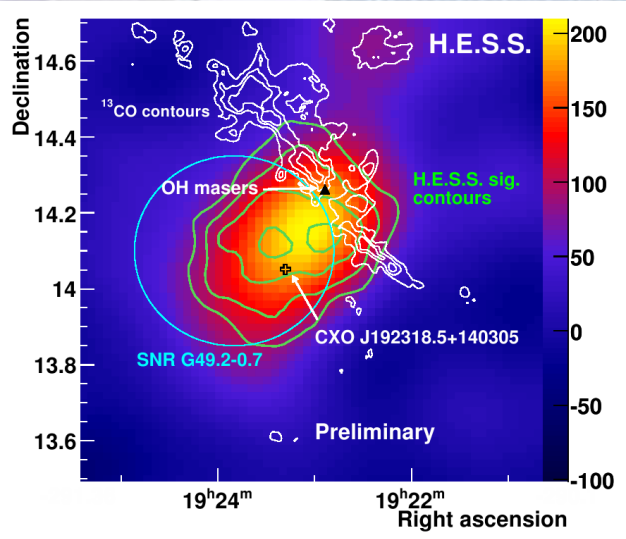
- Faint VHE γ-ray coincident with pulsar (black cross) $\Rightarrow$ need more data
- HE γ-ray coincident with shell and OH masers (white crosses)

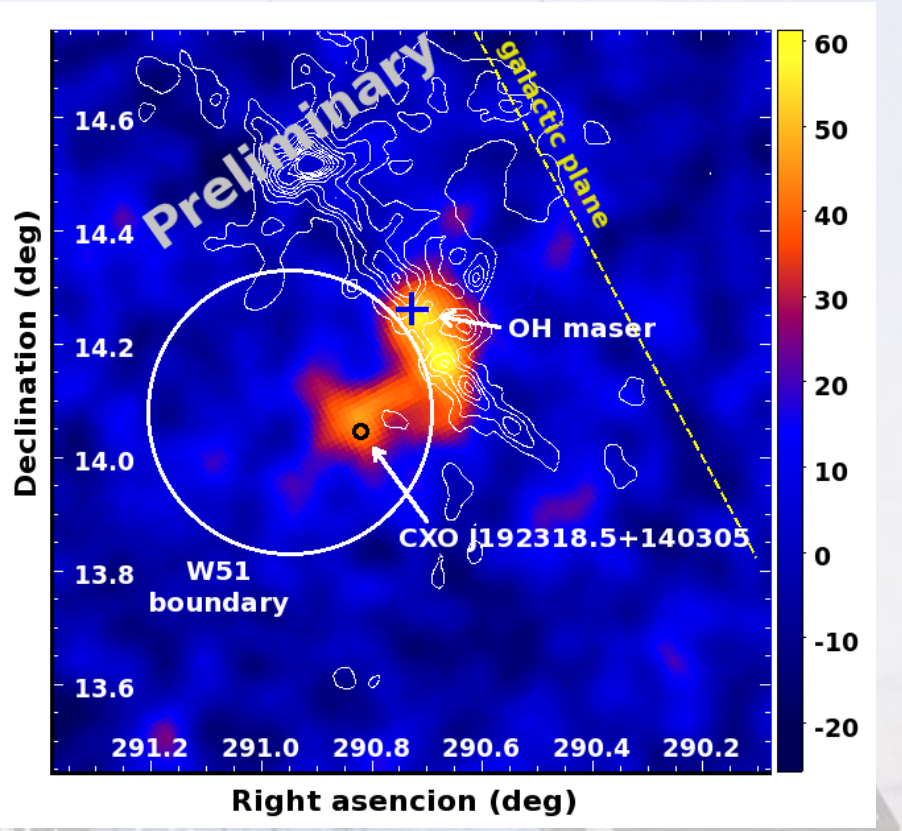
W44 Spectral Energy Distribution (A.A. Abdo et al 2010)



- 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 W51C - Detailed study at TeV energy

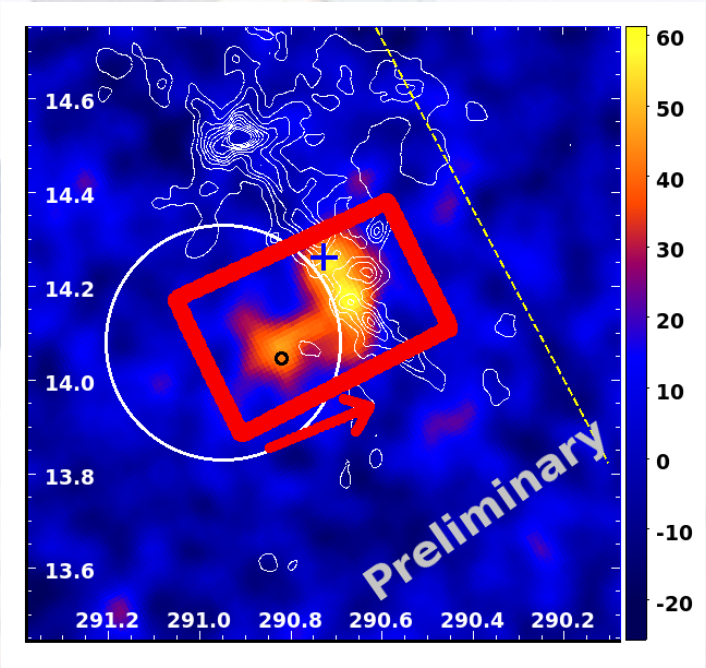


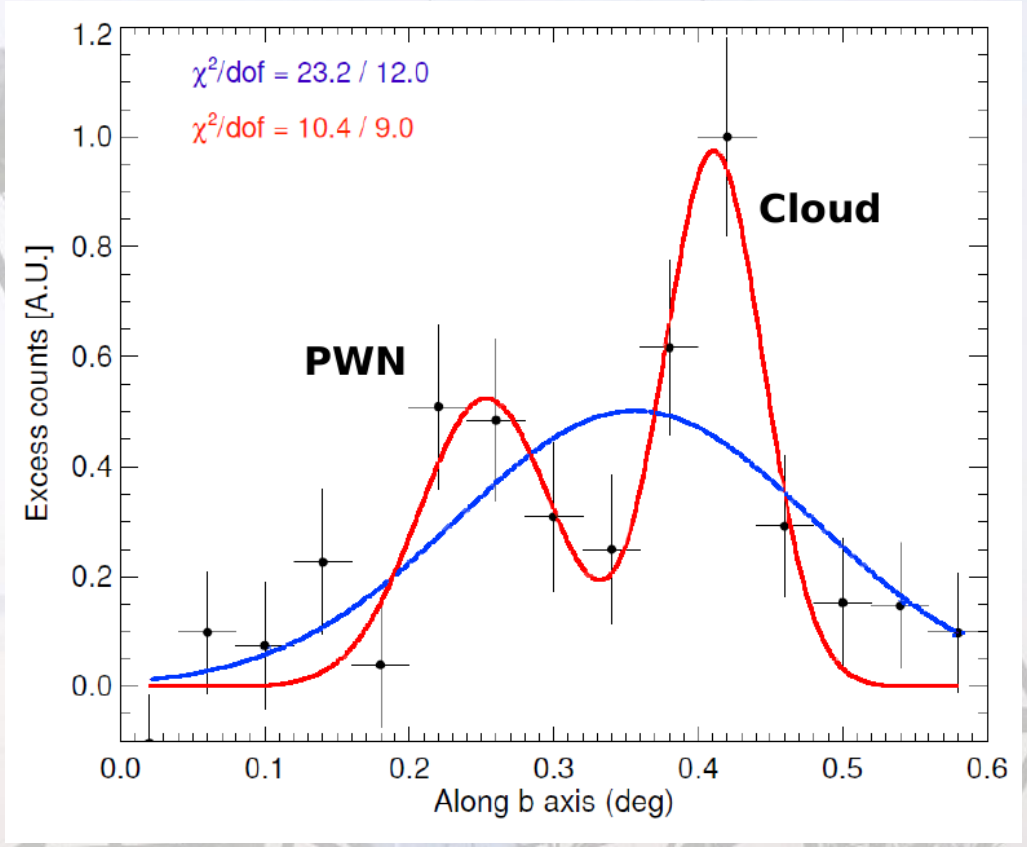


- 2 counterparts:
  - pulsar wind nebula (open cross)
  - shocked molecular cloud (white contours) $\longrightarrow$ OH maser (triangle)
- 43 hours cumulated – smoothed with gaussian ($\sigma = 0.06°$)
- Very efficient analysis method:
  - hard photons selection
  - better angular resolution
- Maximum excess compatible with cloud and OH maser

SNR W51C - Detailed study at TeV energy

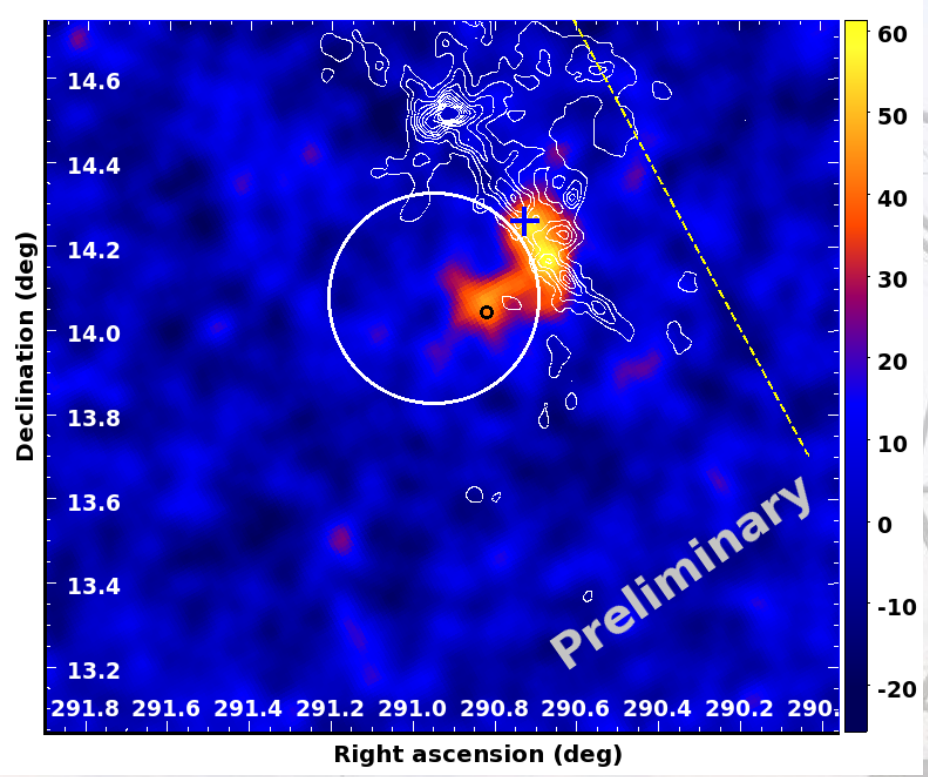
▷ How many excesses?

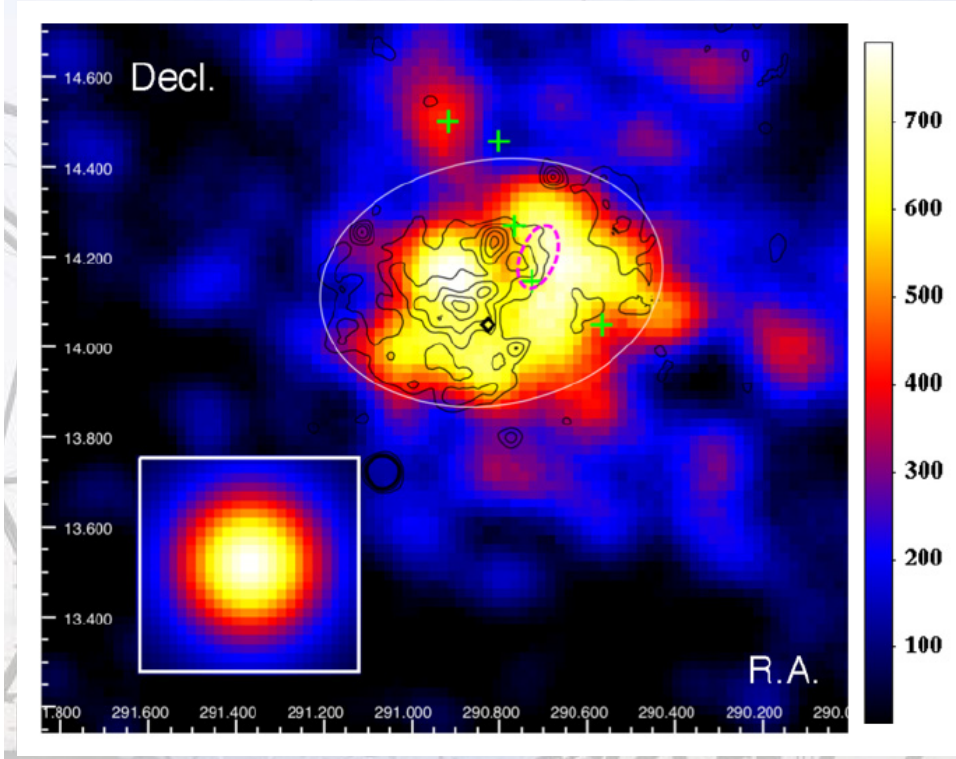




- Profile perpendicular to the cloud ⇒ 2 emitters!
- Each excess coincident with a counterpart

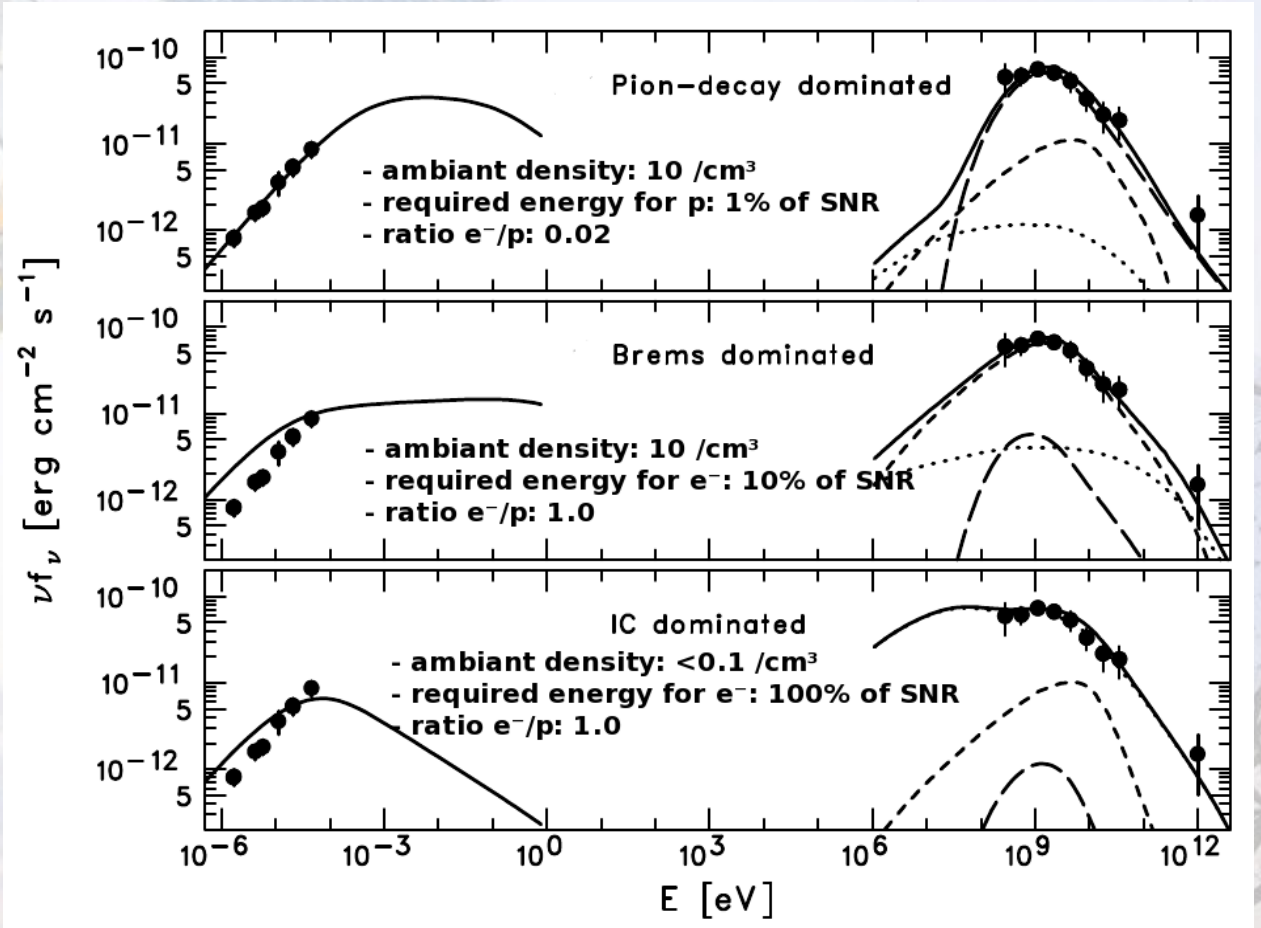
SNR W51C





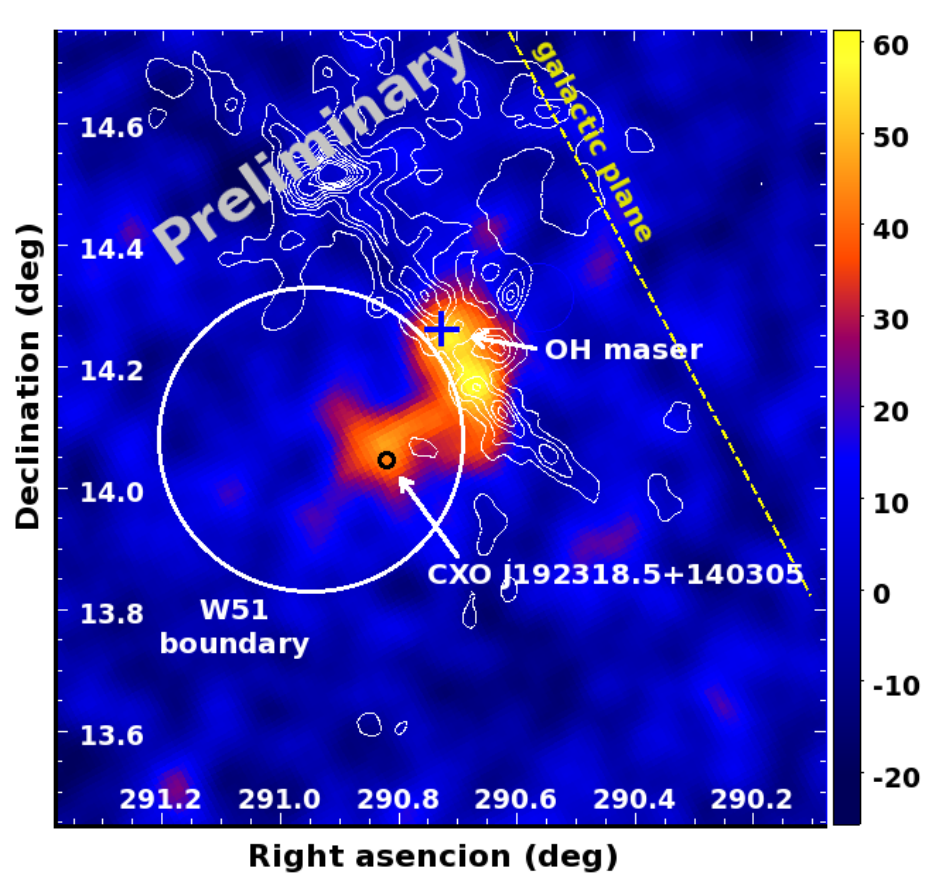
- 13 months *Fermi*-LAT data
- HE γ-ray count map for $E_\gamma \in [2; 10]$ GeV
- Extended emission centered on W51C

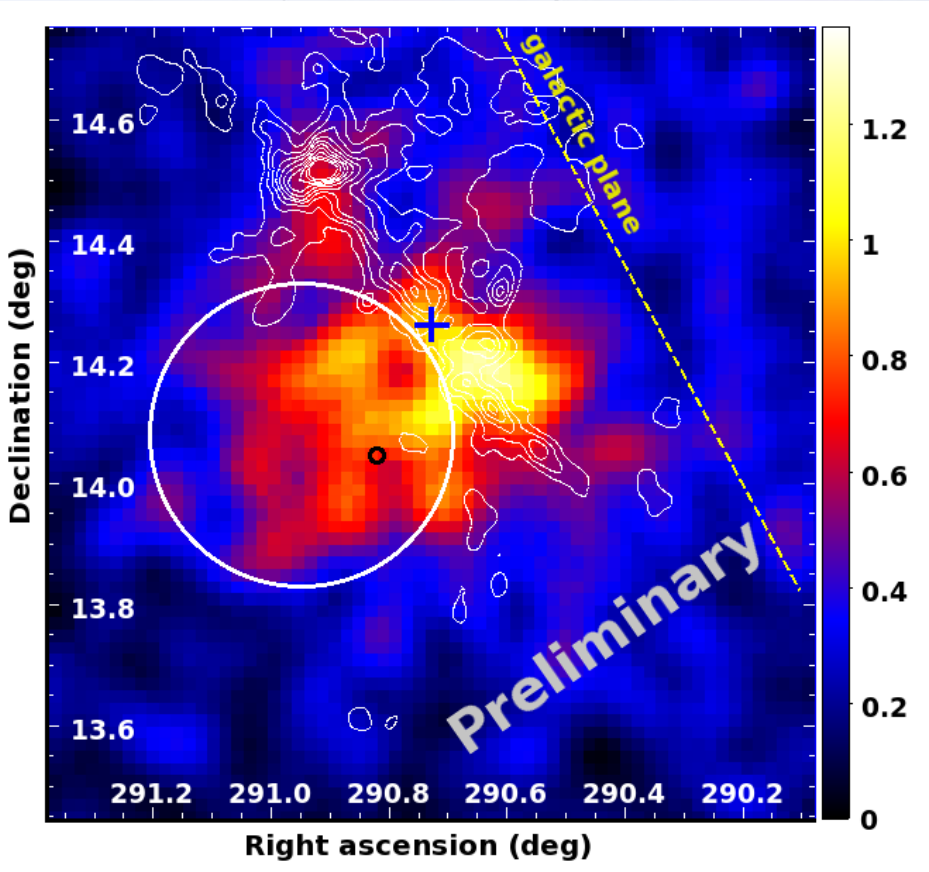
W51C Spectral Energy Distribution (A.A. Abdo et al 2010)



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

SNR W51C Fermi update





- 24 months *Fermi*-LAT data
- HE γ-ray count map for $E_\gamma \in [2; 10]$ GeV
- Maximum GeV excess centered on cloud

Can we detect more examples? (J.W. Hewitt et al 2009)

▷ OH maser and/or γ-ray emission for $\sim$ 10% of SNR

l	b	SNR	Diameter (′)	Distance (kpc)
{SNR + OH maser} + gamma-ray emission associated				
6.4	−0.1	W28	42	2.0
34.7	−0.4	W44	30	2.5
49.2	−0.7	W51 C	30	6
189.1	+3.0	IC 443	50	1.5
{SNR + OH maser} + gamma-ray emission not associated				
0.0	+0.0	SgrA East	2.5	8.5
5.7	−0.0		9	3.2
8.7	−0.1	W30	45	3.9
337.8	−0.1	Kes 41	5	12.3
348.5	+0.1	CTB 37A	10	11.3
359.1	−0.5		10	5.0
{SNR + OH maser} without gamma-ray emission				
1.0	−0.1	Sgr D SNR	8	8.5
1.4	−0.1		10	8.5
5.4	−1.2	Duck	35	5.2
9.7	−0.0		11	4.7
16.7	+0.1		4	2/14
21.8	−0.6	Kes 69	20	5.2
31.9	−0.0	3C 391	8	9
32.8	−0.1	Kes 78	20	5.5/8.5
337.0	−0.1	CTB 33	3	11
346.6	−0.2		8	11
348.5	−0.0		10	13.7
349.7	+0.2		2	>11
357.7	+0.3	Square	24	6.4
357.7	−0.1	Tornado	5	>6

- 4 interacting SNRs known
- Not clear for 6 SNRs
- 14 SNRs without γ-ray emission

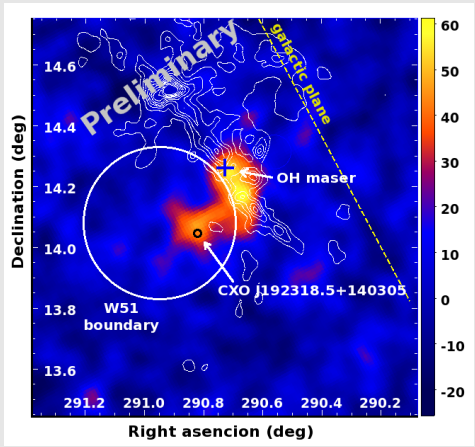
$\Rightarrow$ Many other γ-ray excesses coincident with {SNR + OH maser} possible

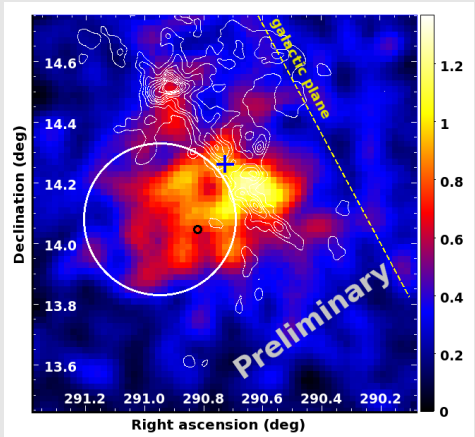
$\Rightarrow$ γ-rays detectors with better sensitivity

- Needed to find the cosmic rays origin

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 shocked material
- Most significant cases of interaction SNR/MC with γ-ray emission detected
  - IC443, W44 - W51C
  - Not shown here: W28 and G359.1-0.5
- W51C:
  - Now possible to separate TeV emitter!
  - GeV emission coincident with TeV and maser
- MWL very important to constrain scenario
- 10% of SNR with OH maser: other discoveries !





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