Evidence for CR escape: γ-Cygni the GeV to TeV Morphology with MAGIC and Fermi-LAT

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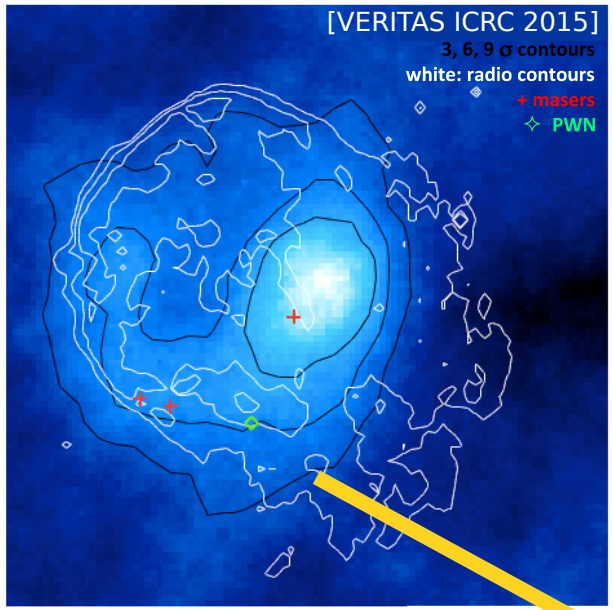
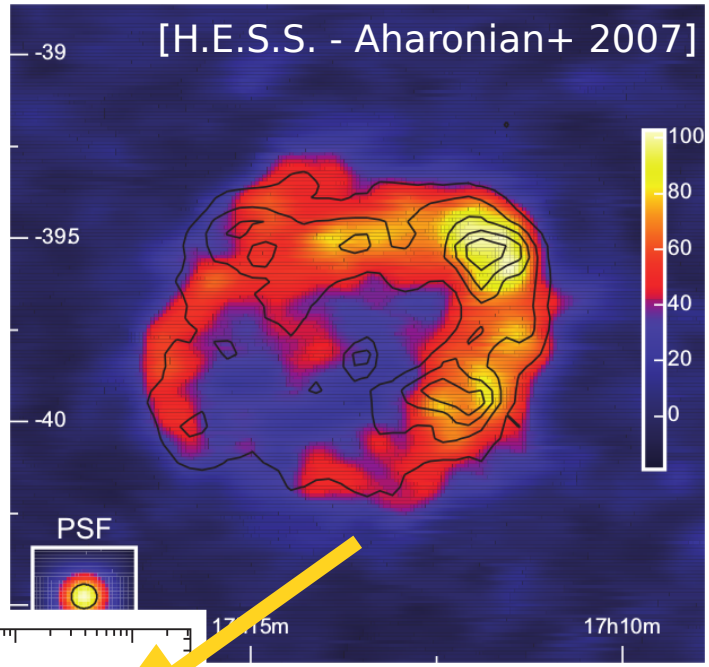
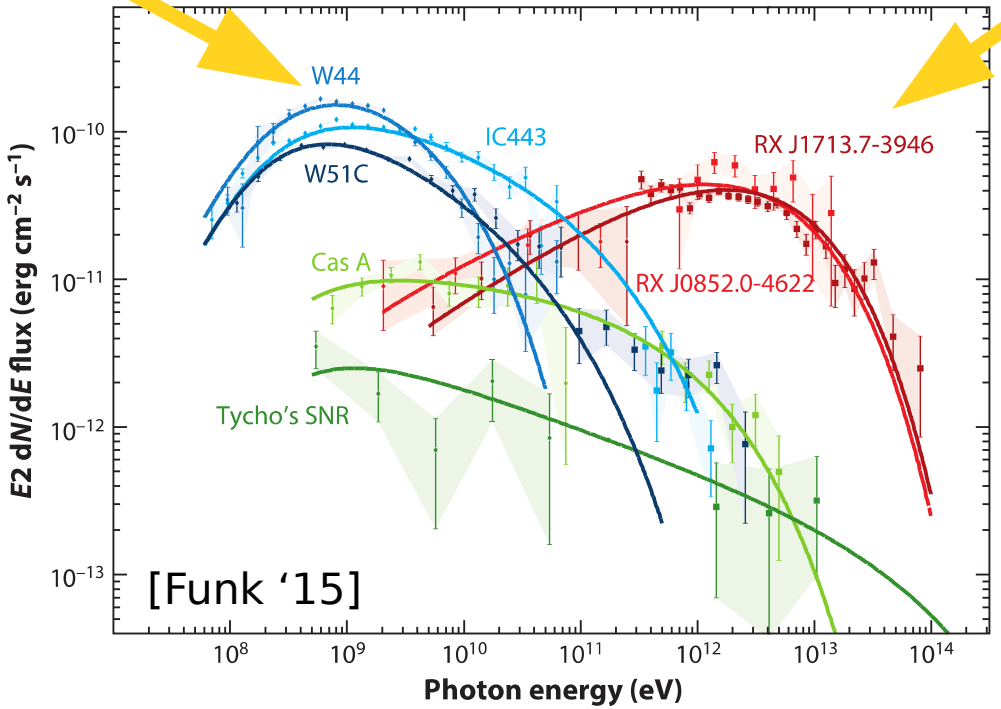
Gamma-ray supernova remnants



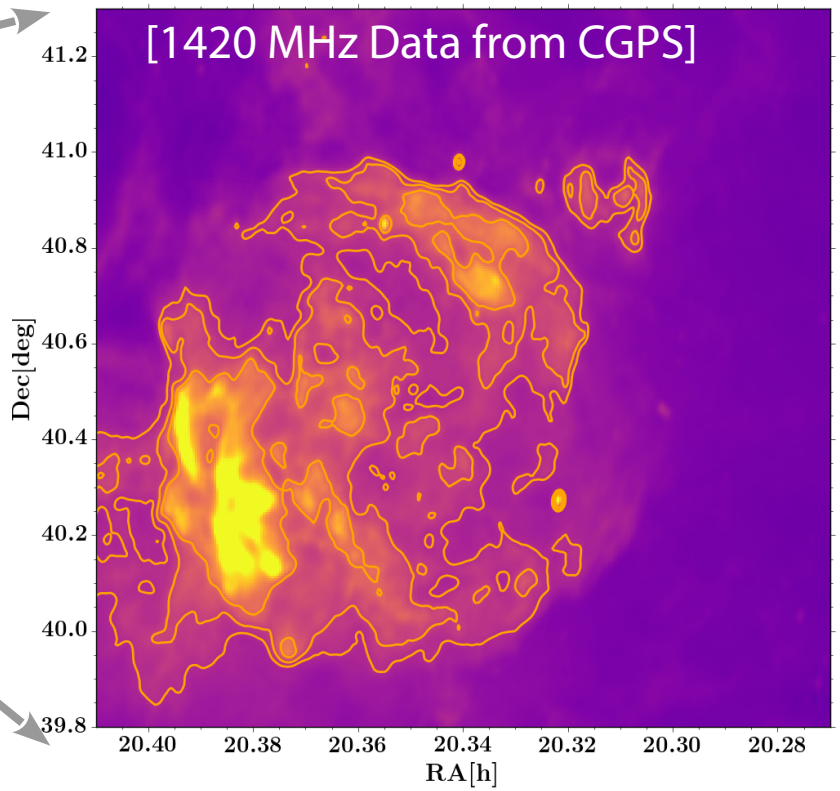


- π^0 Cutoff →Evidence for hadronic CRs
- Interaction region bright
- Matured SNRs (≈ 10^4 yrs)



- Shell bright
- Leptonic / hadronic ?
- ≈ 1-5 10^3 yrs

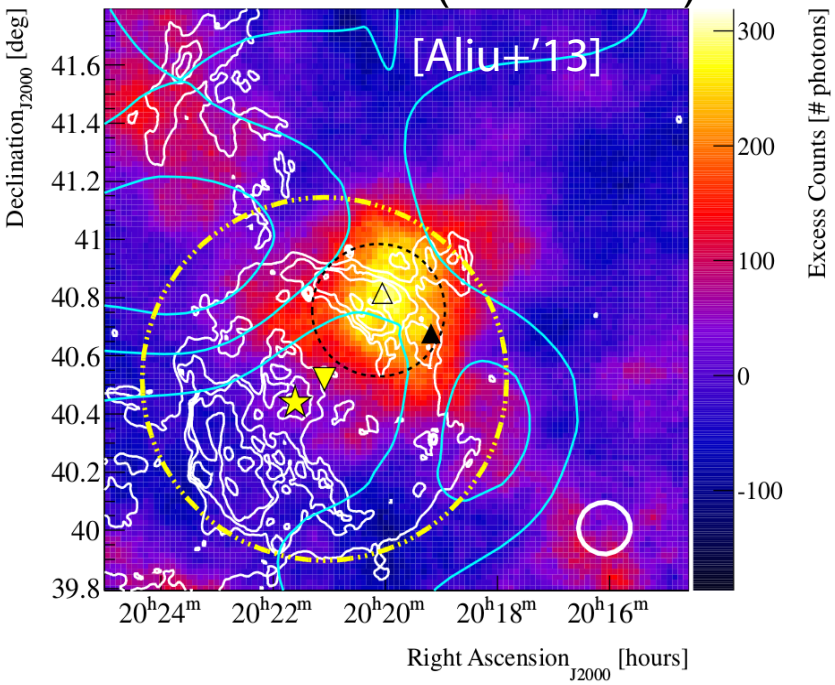
The γ-Cygni supernova remnant



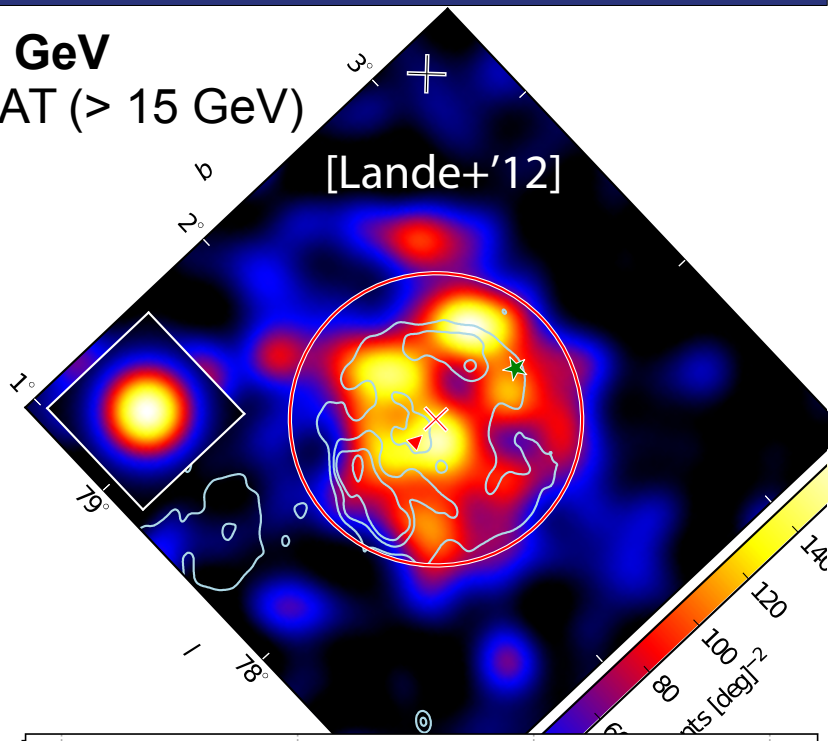
- Age: 5 – 10 kyr
- SNR clearly in Sedov phase:
  → reverse shock hit centre 1.5 kyr ago [Hui+'14]
- Remnant of a core-collapse SN
  (PSR at the centre)
- Distance: 1.5 – 2.6 kpc
- Extend: ≈0.56^{o} radius , (≈17 pc at 1.7 kpc)

γ-Cygni in γ-rays

TeV
VERITAS (> 320 GeV)



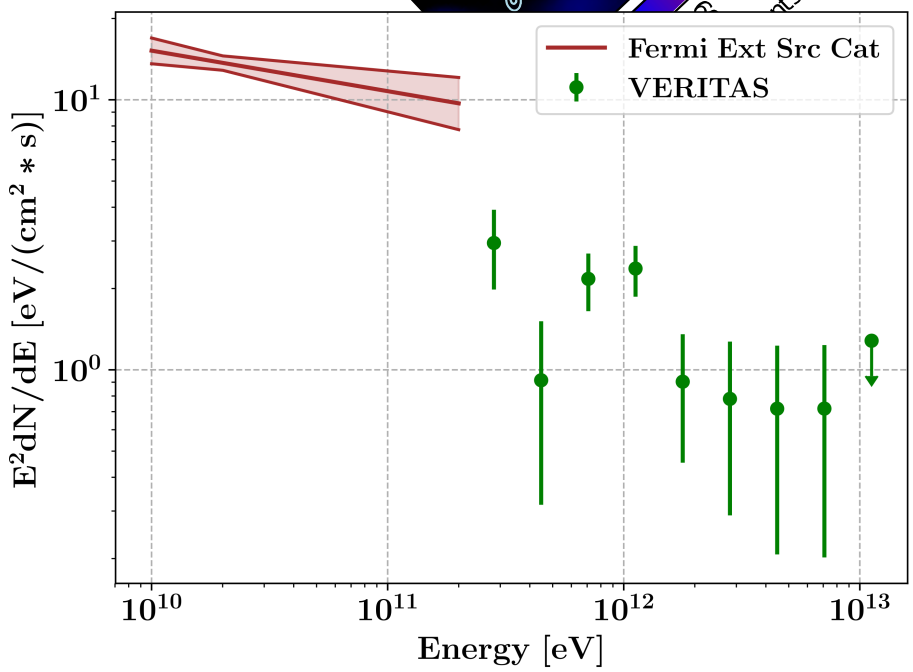
GeV
Fermi-LAT (> 15 GeV)



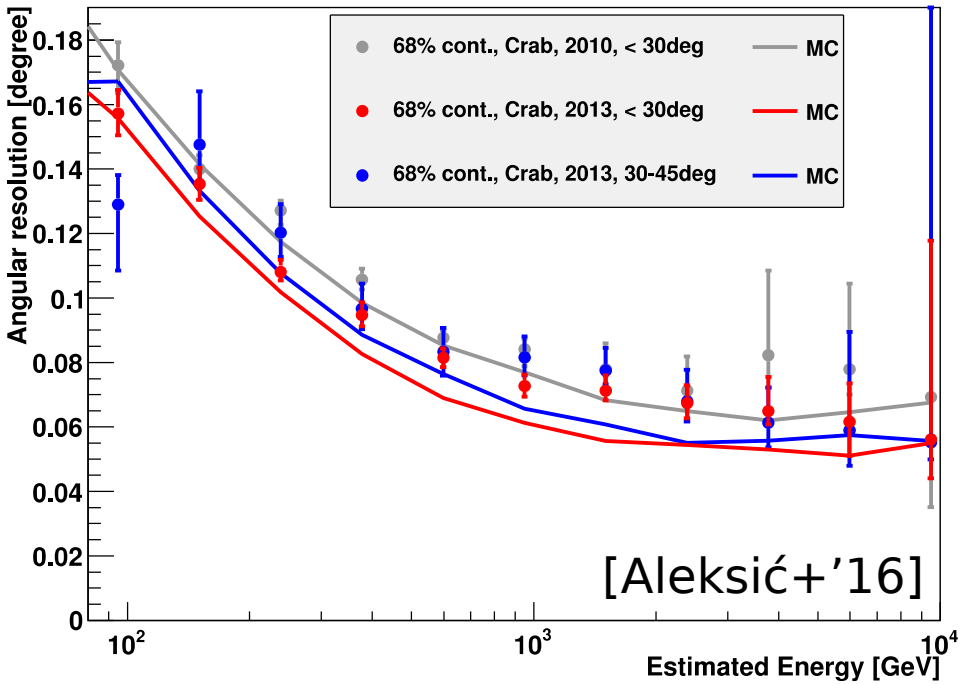
- Detected at TeV by VERITAS using 21 h obs. time
  → extended emission (σ=0.23°) towards north-west
  → power-law spectrum (Γ=2.37+/-0.14)
  → integral flux 3% Crab Units

- *Fermi*-LAT observes emission all over shell at GeV energies

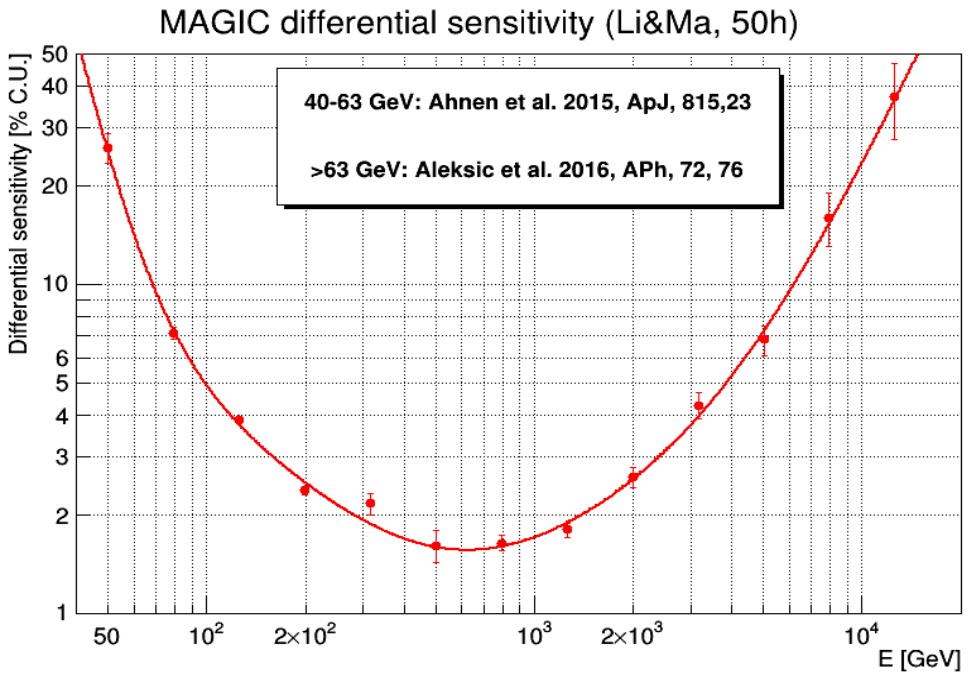
- < 10 GeV emission dominated by PSR J2021+4026
  → only known γ-ray variable PSR



MAGIC observations of γ-Cygni



- Situated at the Observatorio Roque de los Muchachos @ 2200 m a.s.l.
- Stereo system of 2 x 17m telescopes
- Energy range from 50 GeV – 50 TeV
- Obs. time 80 h
- Data selection: aerosol transmission (>80%) measured with LIDAR system



MAGIC view on γ-Cygni

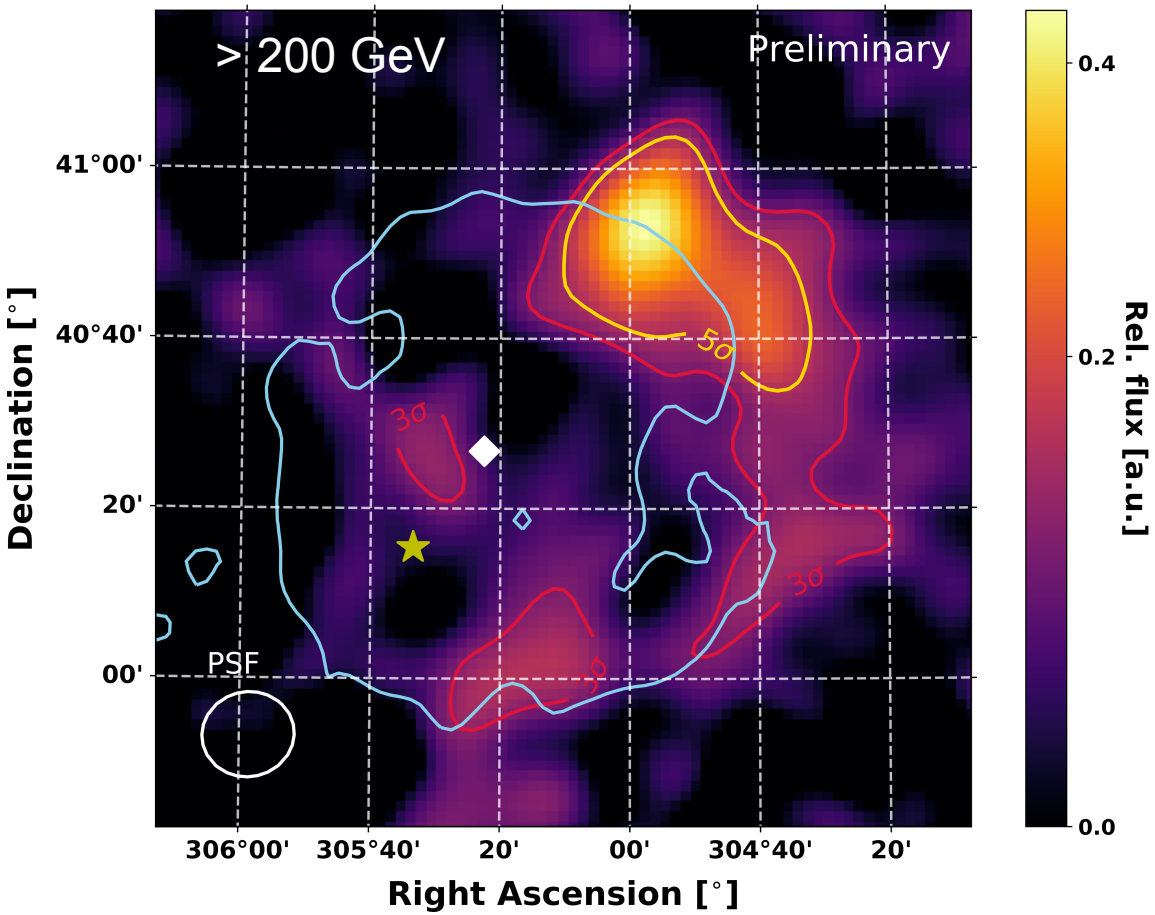
- Extended, multi-component source in the north-west of SNR

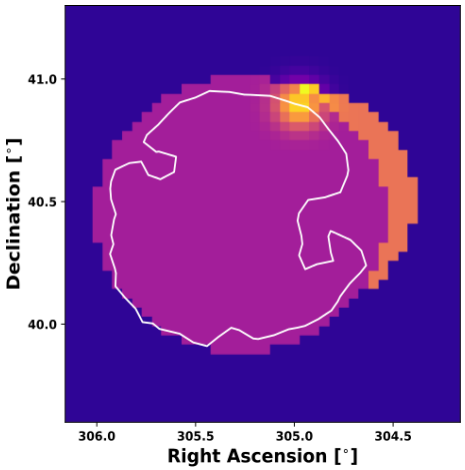
- Emission can be well described by multiple component model:

  → Disk matching radio shell
  → extended Gaussian source
  → Arc structure outside shell

- Simultaneous 2D-Likelihood fit with novel SkyPrism program (inspired by Fermi-tools)

  → 6.2 σ for **disk**
  → 13.7 σ for **Gaussian**
  → 7.4 σ for **arc**

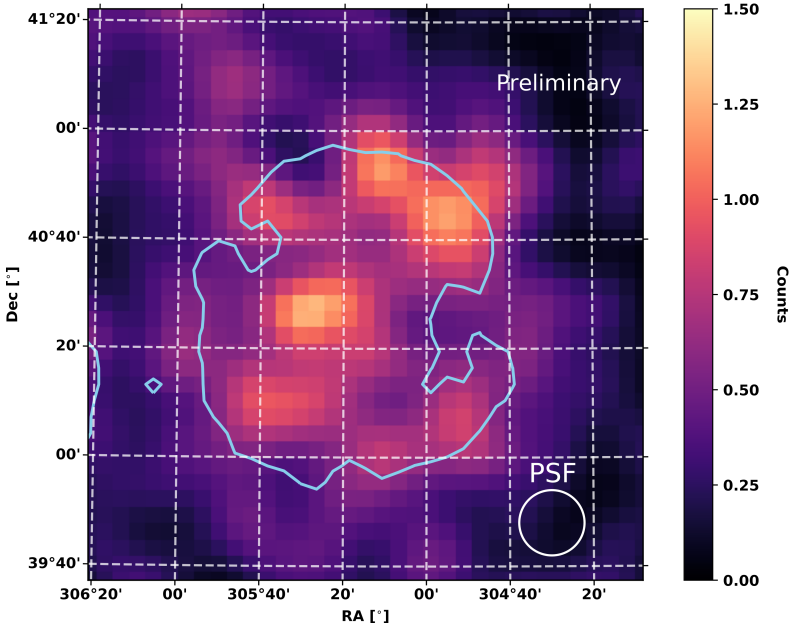




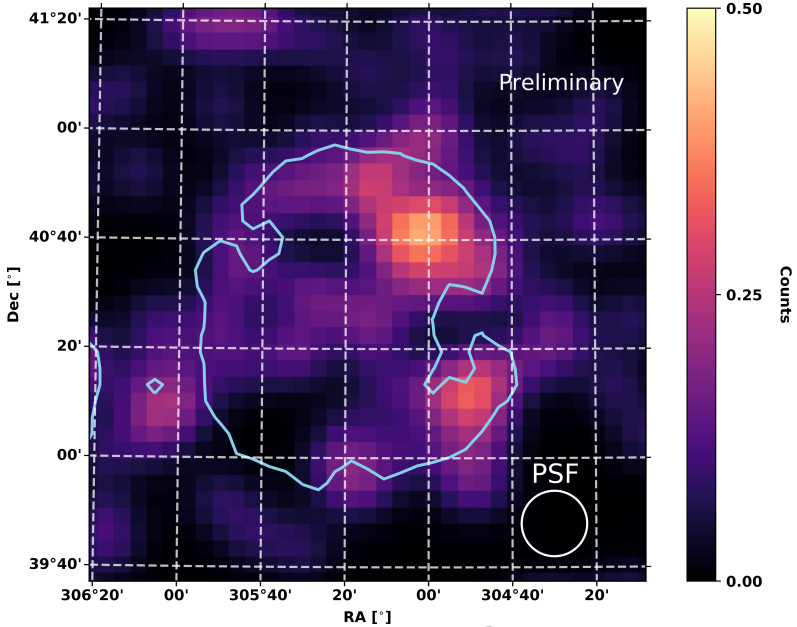
◆ : PSR 2021+4026
★ : Sadr (mag. 2.2)
– : 408 MHz Cont. (CGPS)

Energy dependent morphology

15 - 50 GeV - *Fermi*-LAT



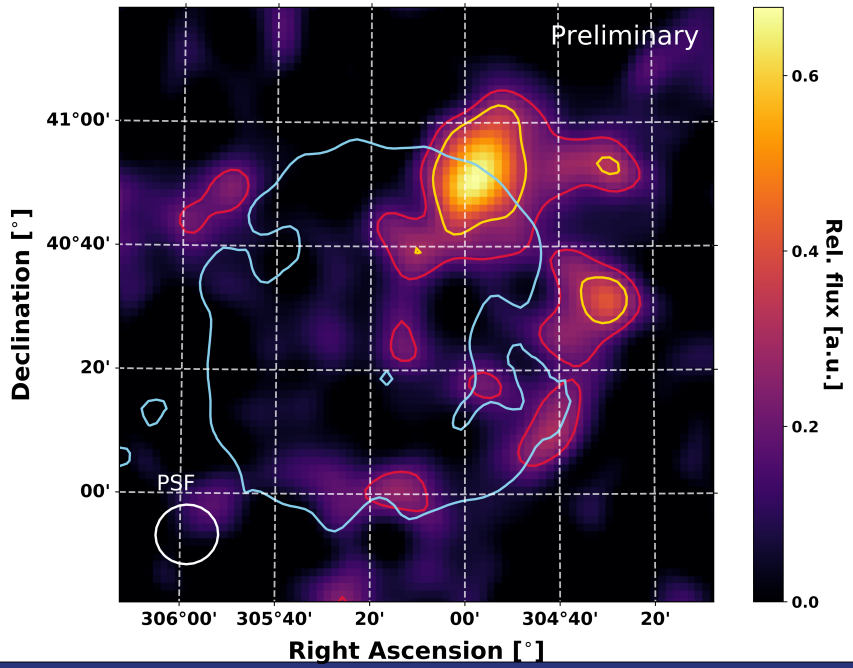
50 - 200 GeV - *Fermi*-LAT



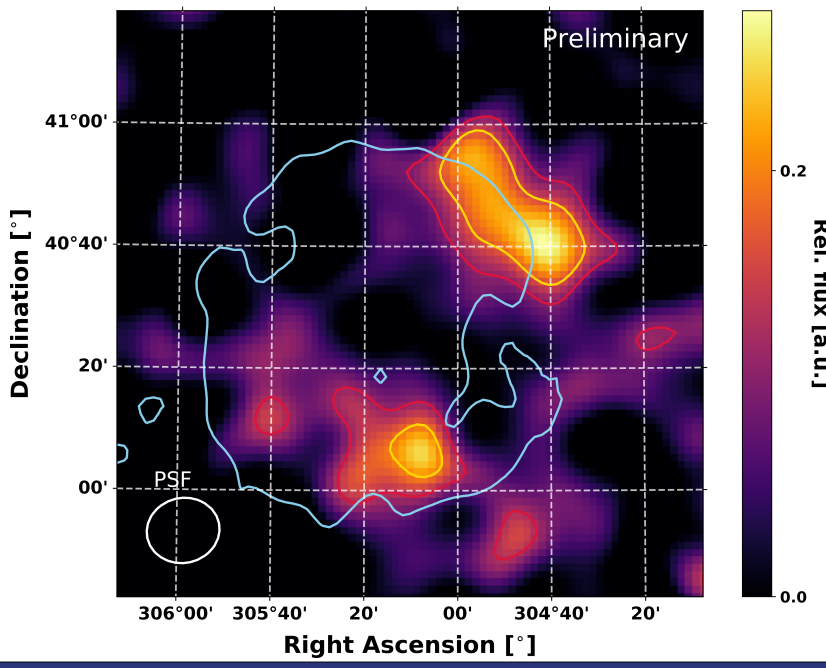
***Fermi*-LAT**

Energy

> 450 GeV



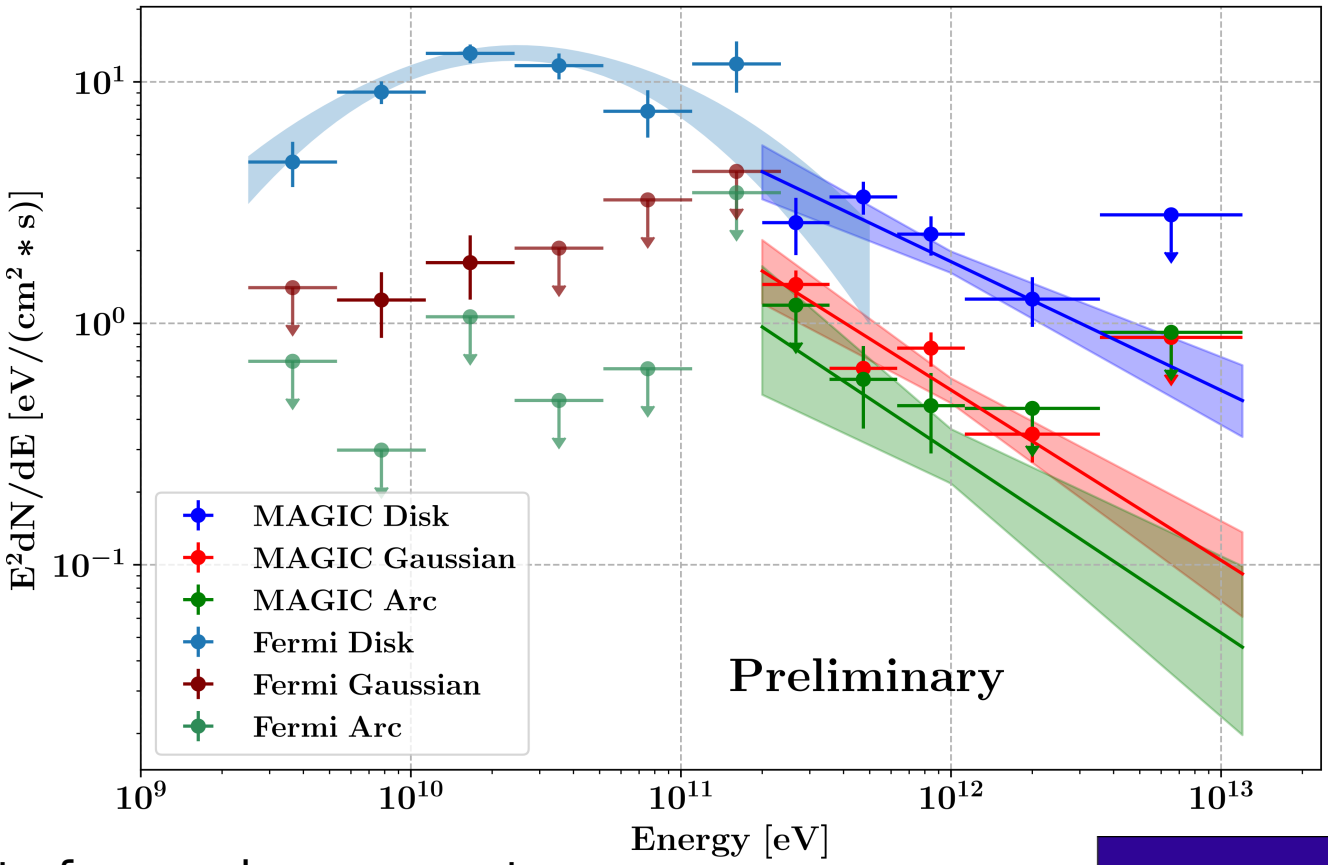
200 - 450 GeV



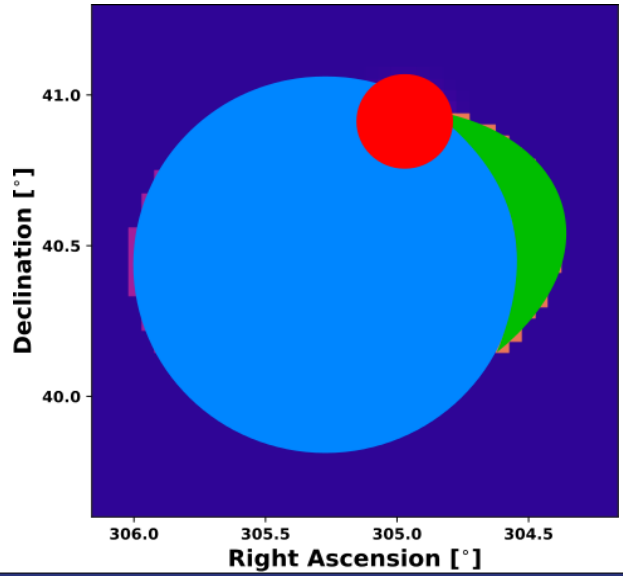
MAGIC

- > 50 GeV emission concentrated towards north-west, compare [Fraija+'16]
- > 450 GeV emission outside shell

Energy spectrum of γ-Cygni



- Likelihood fit of several components (Disk + Gaussian + Arc)
- Fermi and MAGIC results of the disk match
- Gaussian source needs to have flatter spectrum if MAGIC and Fermi see same source [Fraija+16]
- Arc seen by MAGIC only → more peaked spectrum than the other components

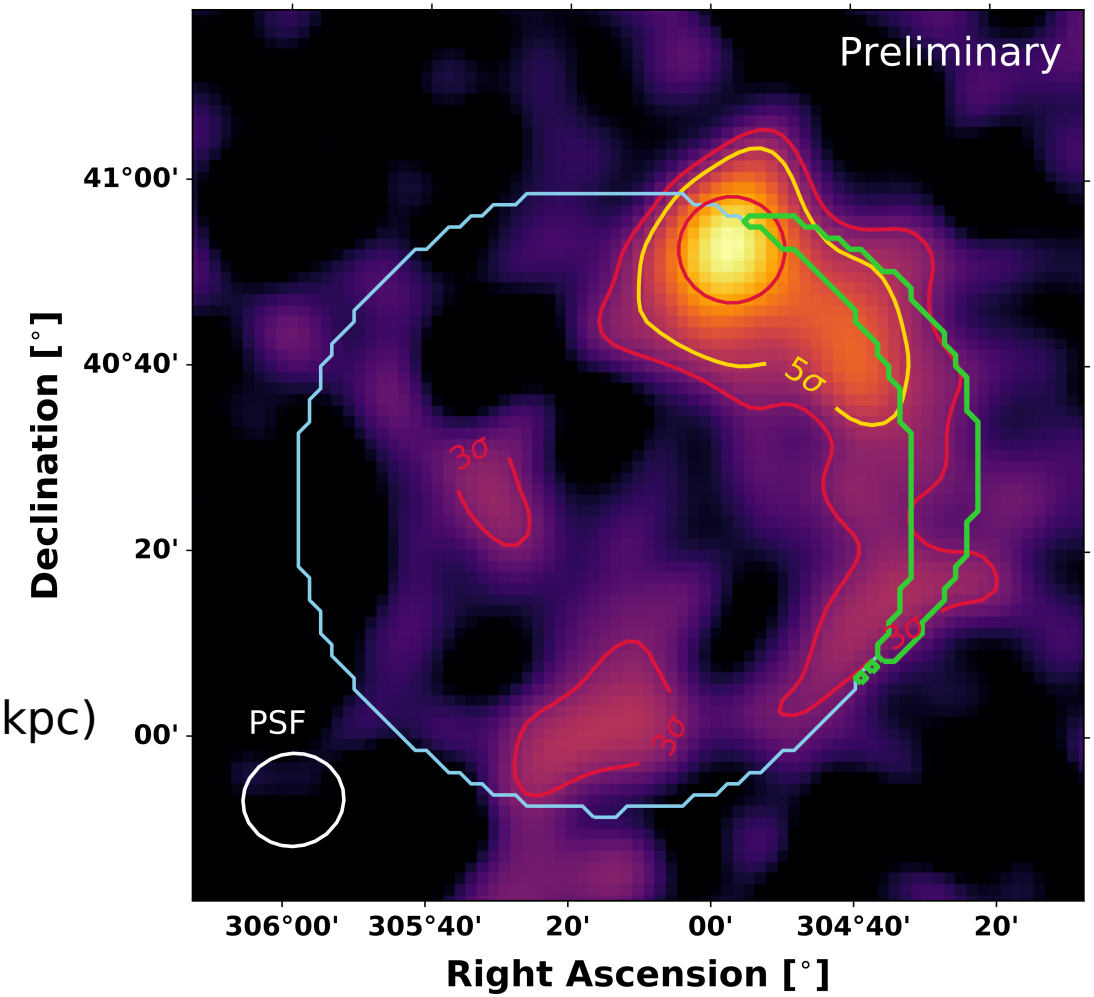


Shock precursor or CR escape?

- Emission outside shell suggests CR escape or precursor scenario

Precursor scenario

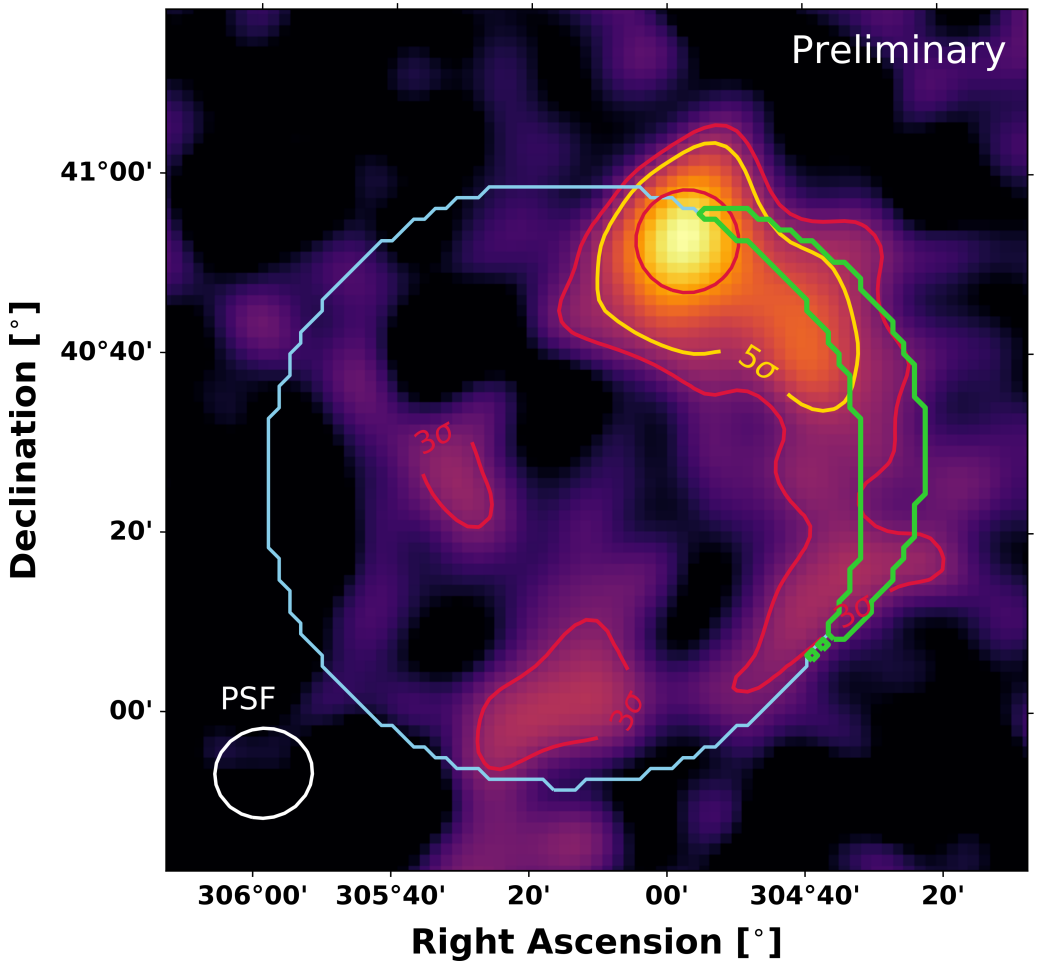
- Spectrum at the arc should be harder than the one of the disk
- Diffusion coefficient based on size of the Arc (~ $0.15^{o} \triangleq 30\%\ R_{SNR}$, 5pc at 1.7kpc) $\lambda_p = D/u_{sh}$ leads to acceleration time of ~4×10^4 yrs ($5 \times t_{SNR}$)
- Unlikely that we see the shock precursor



Escape scenarios of γ-Cygni

Damping of magn. waves (due to e.g. ion-neutral friction)

- Also low energy CR should escape
- Disagrees with Fermi observations



Diffusive escape:

$$l_{diff} = \sqrt{4\,D\,t}$$

$$\Leftrightarrow \quad D = \frac{l_{diff}^2}{4t} \simeq \frac{\left(R_{SNR} + \Delta_{arch} - R_{ST}\right)^2}{4\left(t_{SNR} - t_{ST}\right)}$$

$$= 2.8 \times 10^{26}\ cm^2\,s^{-1}$$

($n_0 = 0.3$ cm^3, $T_{SNR} = 8$ kyr, $E_{SN} = 10^{51}$ ergs, $M_{ej} = 10\ M_\odot$)

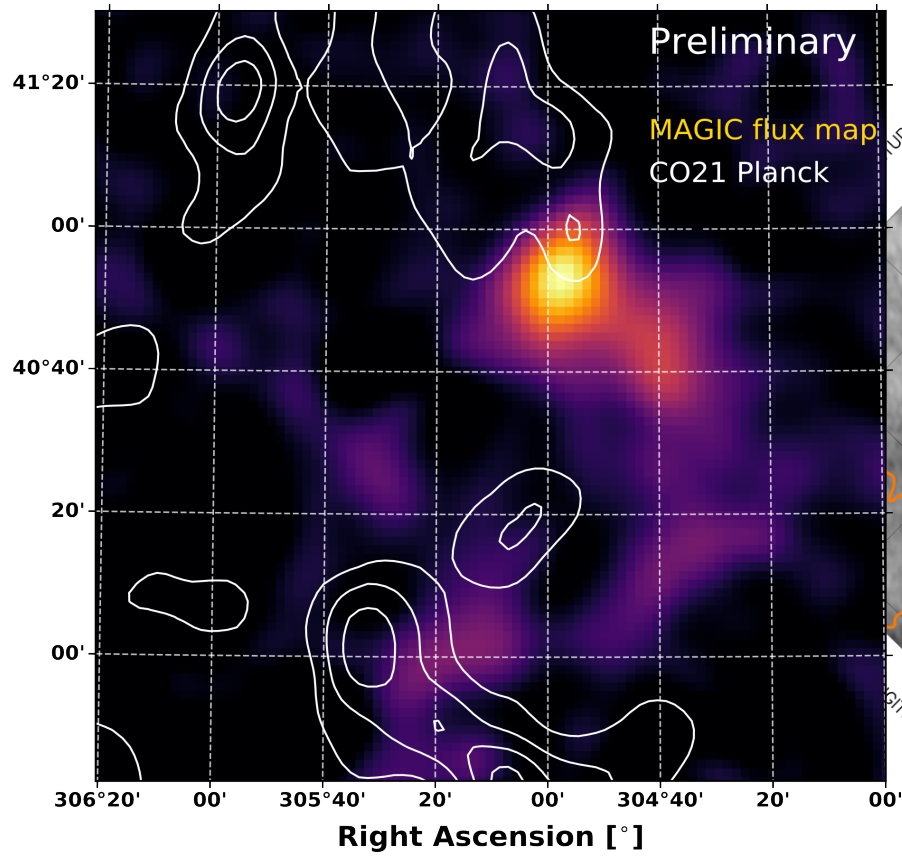
- 280 times lower than average D_{gal} (20 TeV)

$$D_{gal} = 3 \times 10^{28} \left(\frac{E}{GeV}\right)^{\frac{1}{3}} cm^2\,s^{-1} = 8 \times 10^{29} \left(\frac{E}{20\ TeV}\right)^{\frac{1}{3}} cm^2\,s^{-1}$$

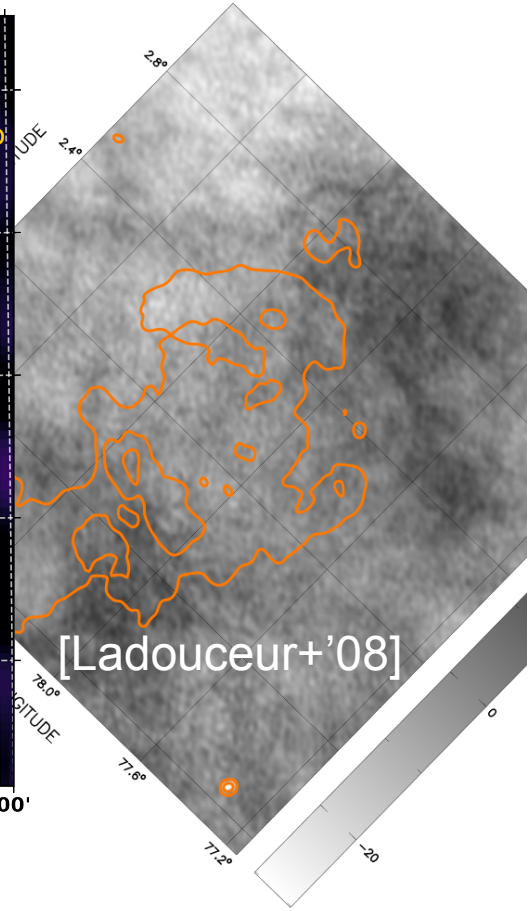
- Compatible with CR amplifying local turbulences e.g. [Malkov+13] [Nava+16]
- Turbulences locally enhanced by other mechanisms (Cygnus Cocoon)
- Projection effects may effect size of the arc (factor 2x → D increases by ~1.7)

ISM around the SNR

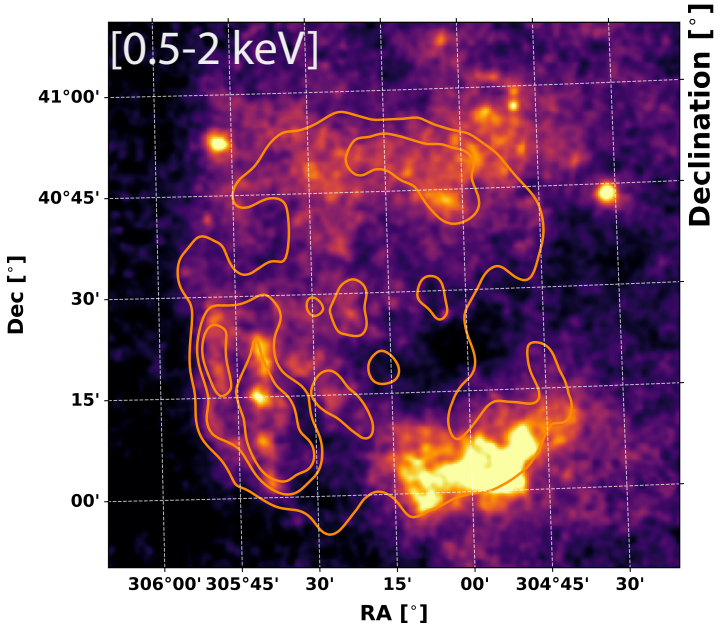
CO 2->1 contours + MAGIC flux map (Planck)



HI [-11 to -19 km/s]



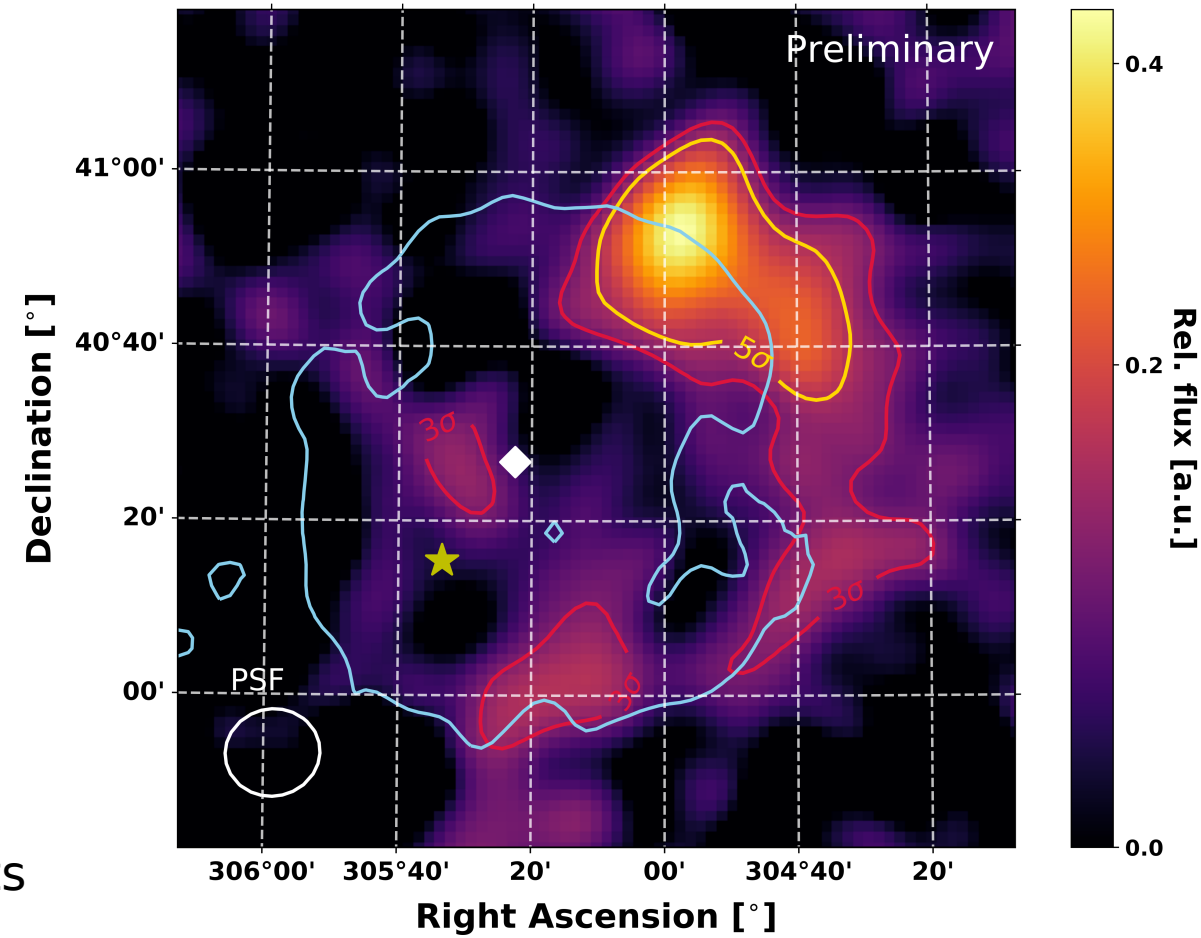
ROSAT PSPC



- Soft X-rays show shock heated gas in north → denser medium, but no Maser found
- AGN close to SNR, but no counterpart where TeV emission is found
- CO emission next to MAGIC emission region
- Hint for a HI shell surrounding the SNR, cavity wall created by progenitor [Ladouceur+'08]

Summary

- MAGIC observations revealed multi-component morphology
- Energy dependent morphology:
  → LE confined in shell
  → HE extending beyond
- Evidence for CR escape
  → diffusive escape
  → diff. coefficient lower than D_{gal}
- Synergy between IACT and Fermi
  → identification of src. components
  → triggered development of new analysis tools



Thank you for your attention and interest!