Recent discoveries from TeV and X-ray non-thermal emission from SNRs

«From Neutrino to multimessenger astronomy»
Marseille

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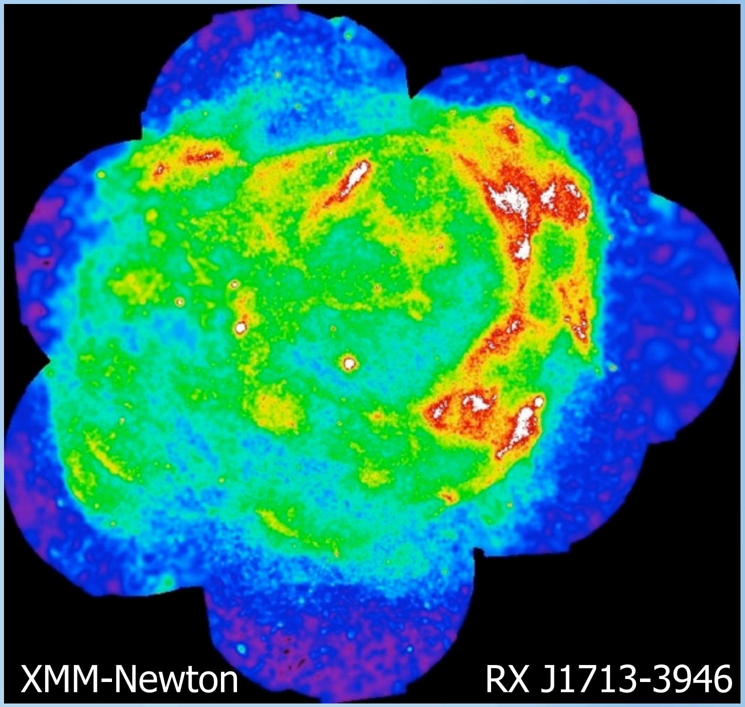
Outline

- Evidence of acceleration in SNRs using X-ray synchrotron
- Brief presentation of Cherenkov astronomy
- TeV emission from young shell SNRs
- The case of CasA and RX J1713-3946 : the GeV-TeV connection

Shell SNRs in non thermal X-rays

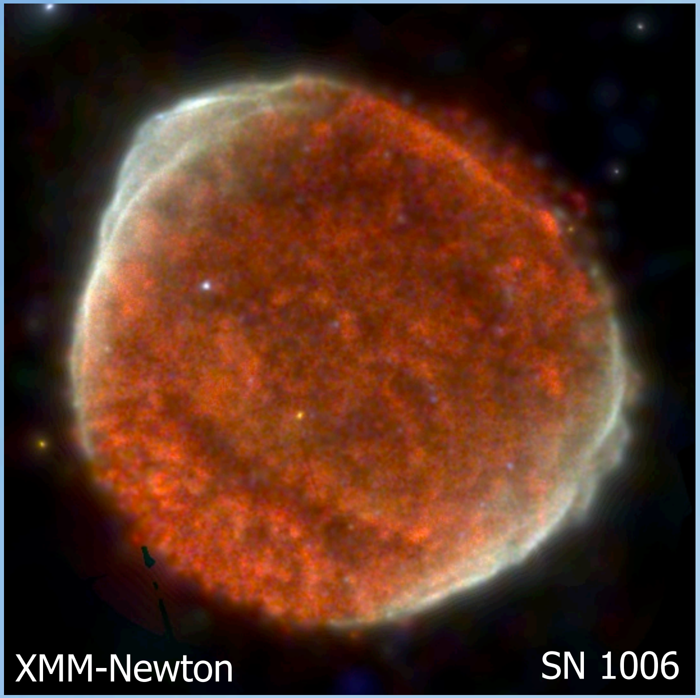
Non-thermal dominated

Vela Jr, RX J1713-3946

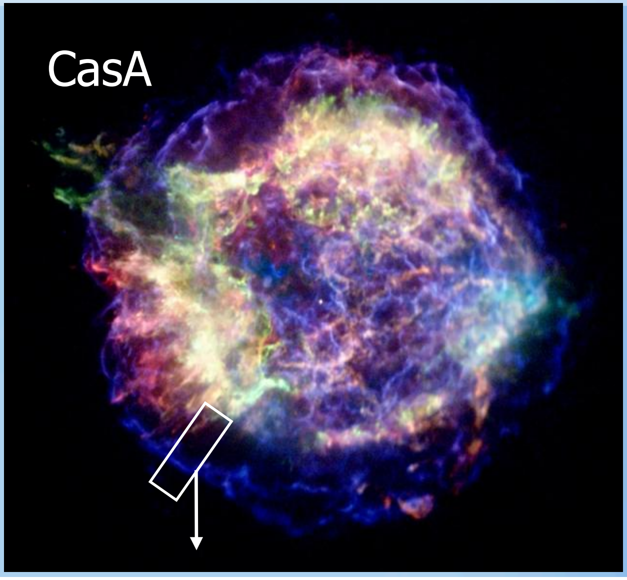


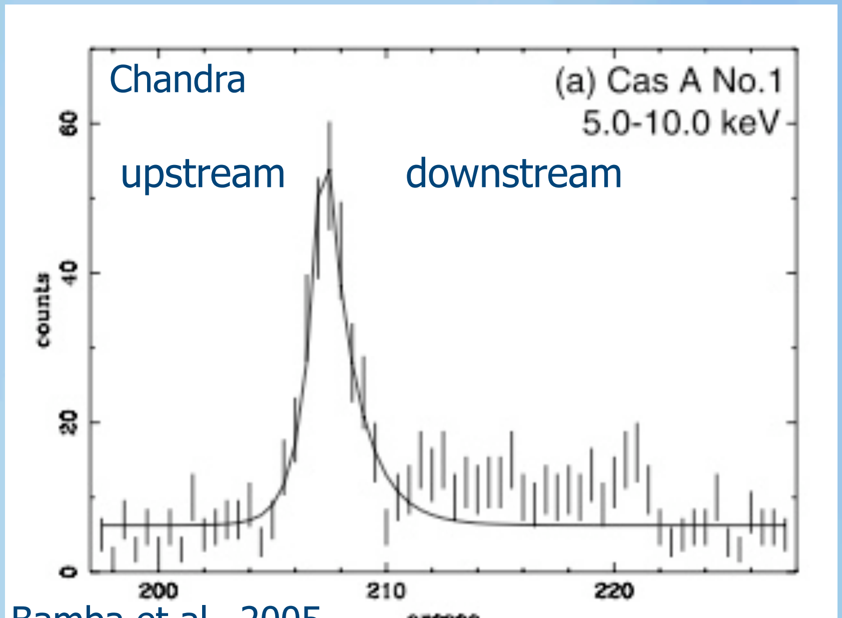
Thermal+Non-thermal

SN 1006, Tycho, Kepler, RCW 86, CasA, …



Highly amplified B





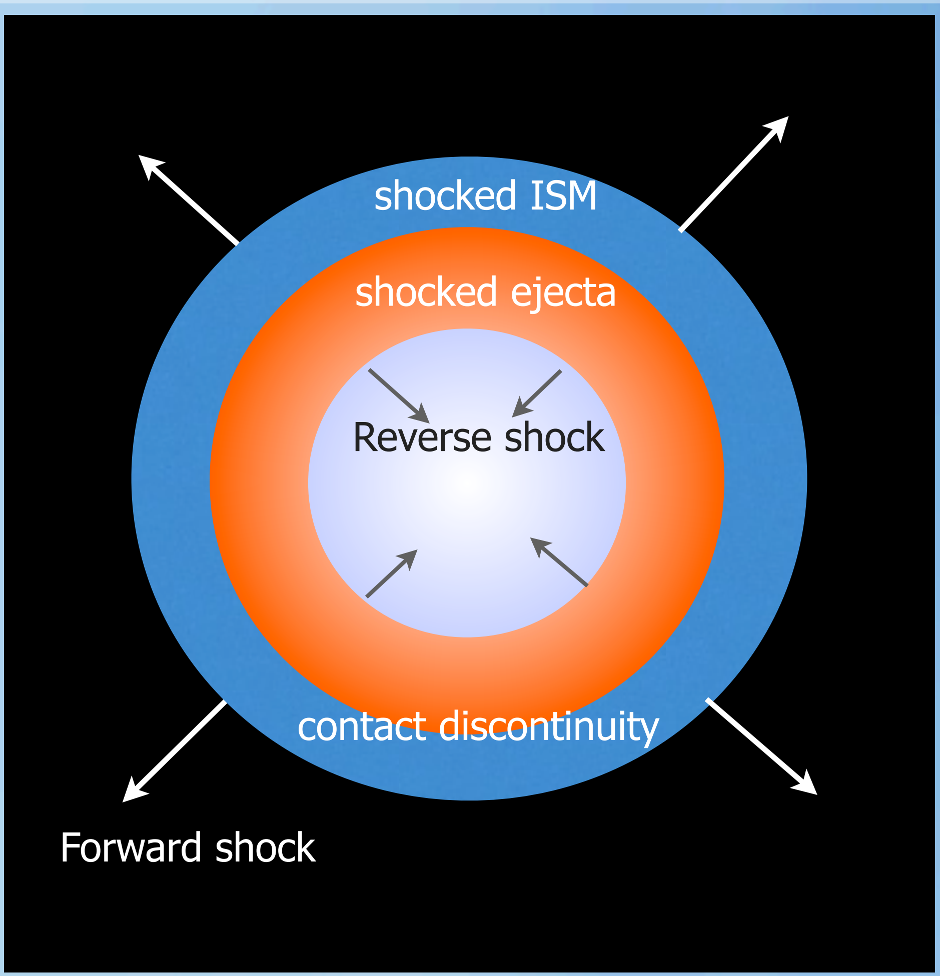
Bamba et al., 2005

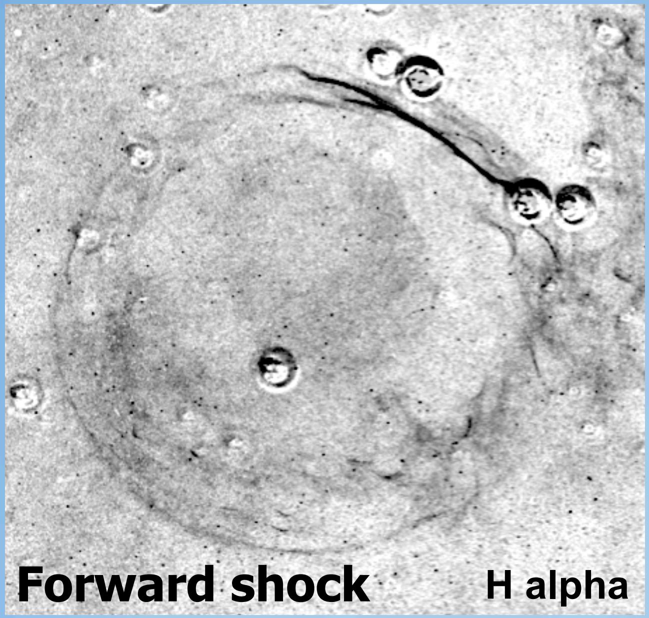
- X-ray emission confined in very thin filaments (arcsecs)
- Most likely due to synchrotron losses of high energy radiating electrons
- The derived magnetic field is highly amplified Vink & Laming, 2003, Berezhko & Voelk 2004, Parizot et al., 2006

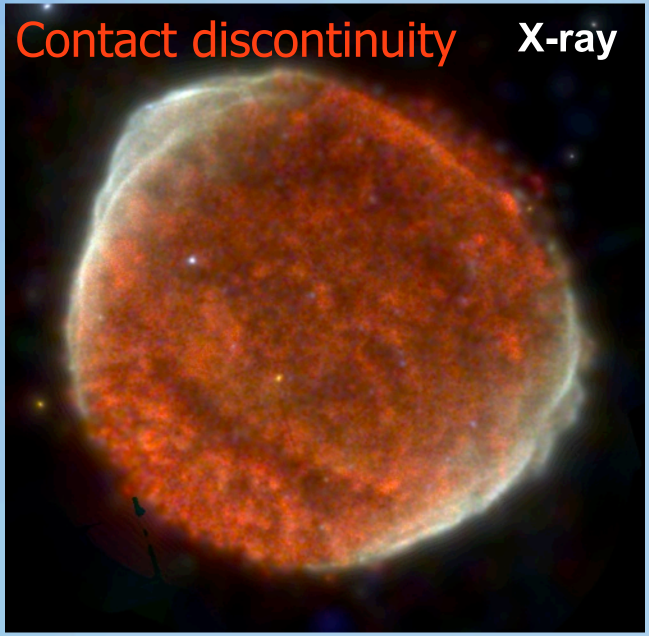
CasA -> B~500 μG (B_{ISM} ~ 5 μG)

- Could also be damping of B (Pohl et al., 2005)
  -> Not consistent with radio morphology in Tycho (Cassam-Chenaï et al., 2007)

SNR hydrodynamics



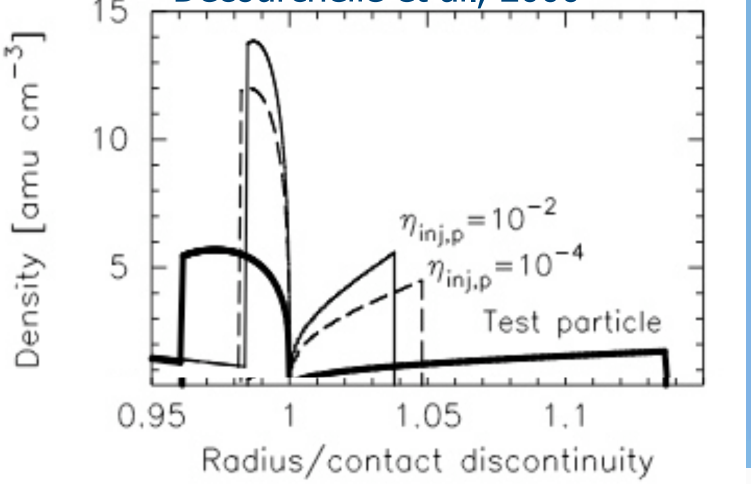


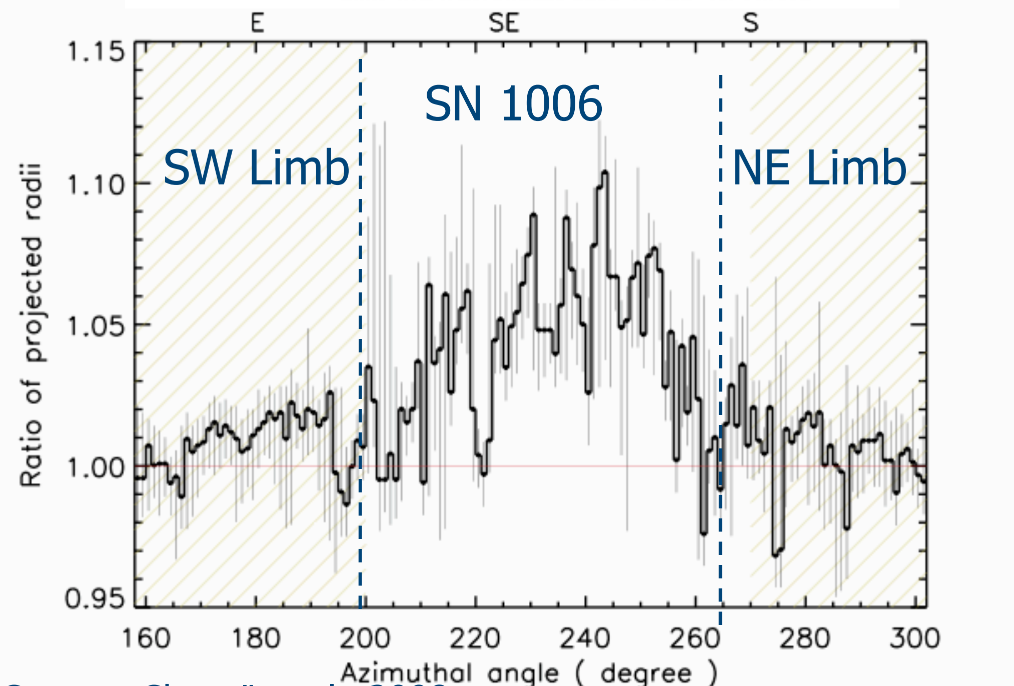


- Ratio of forward shock/contact discontinuity depends on the compressibility of the gas

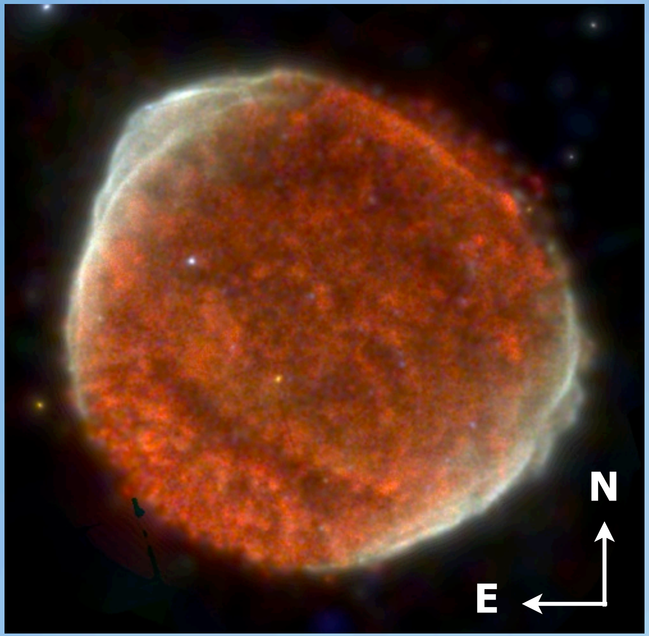
Back reaction of accelerated hadrons

Decourchelle et al., 2000





Cassam-Chenaï et al., 2008



- Efficient acceleration has modified the shock structure

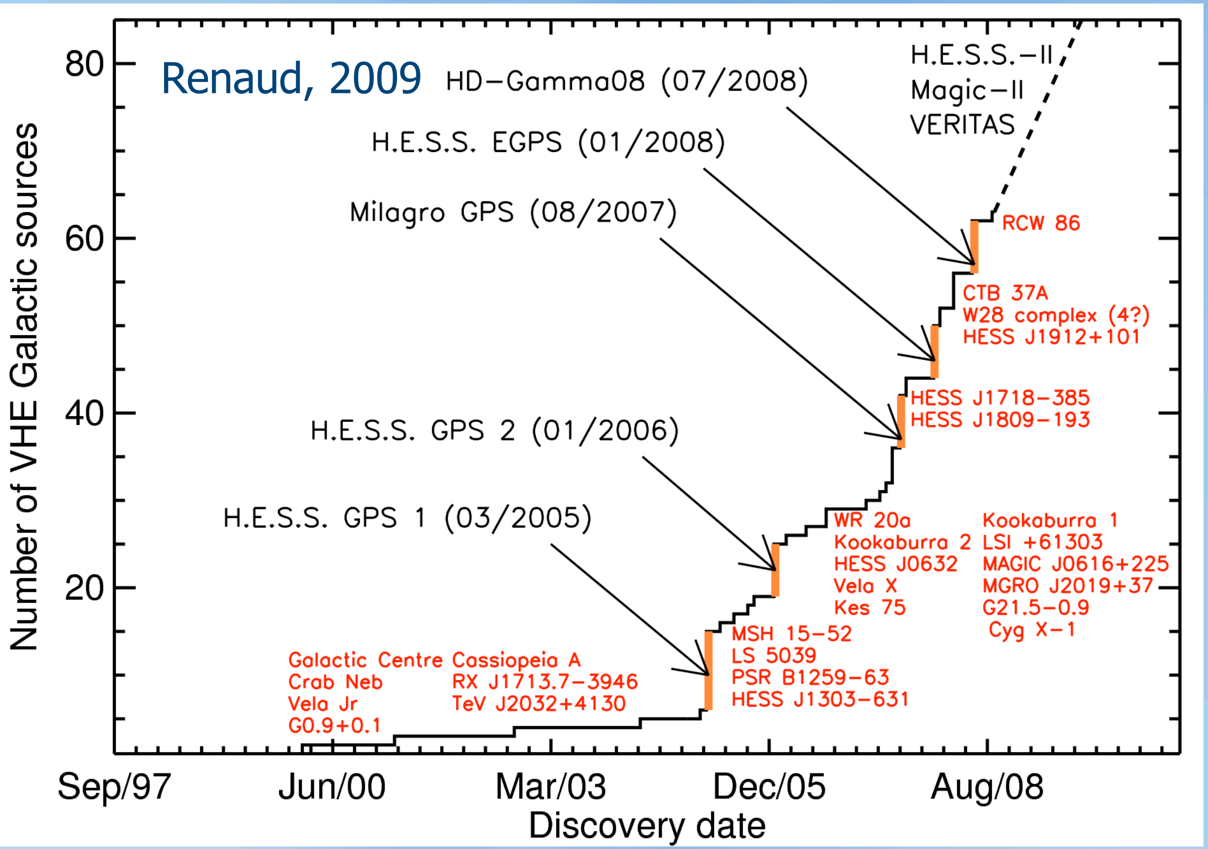
Indirect evidence of proton acceleration

Cherenkov astronomy

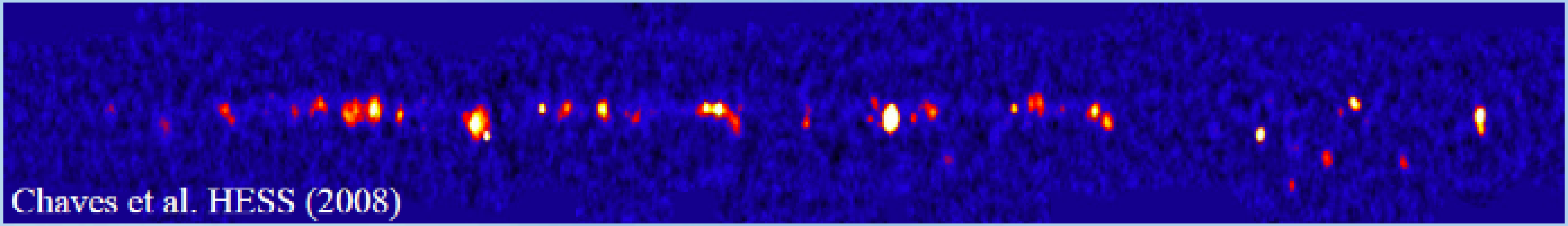
- At TeV energies satellite observations no longer possible
  collecting area and calorimeter depth

- Earth's atmosphere as part of the detector
  -> Imaging atmospheric Cherenkov telescopes (IACT)

Cherenkov astronomy



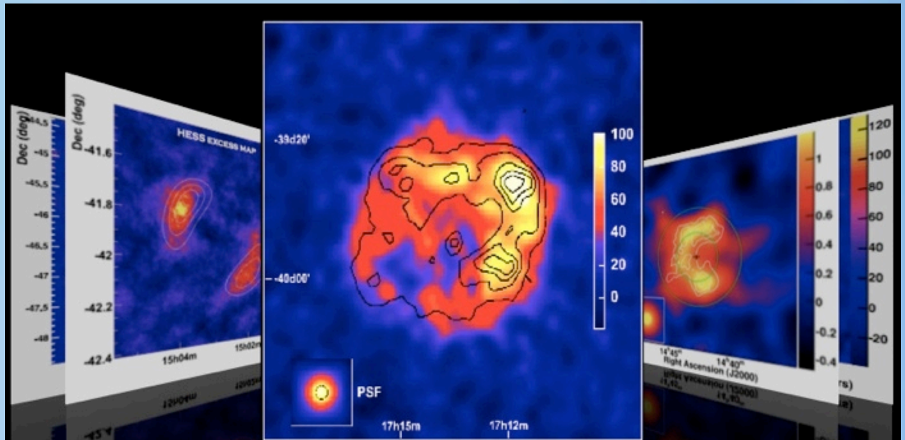
We have entered in the TeV astronomy era



TeV emitting SNRs

Shell-morphology

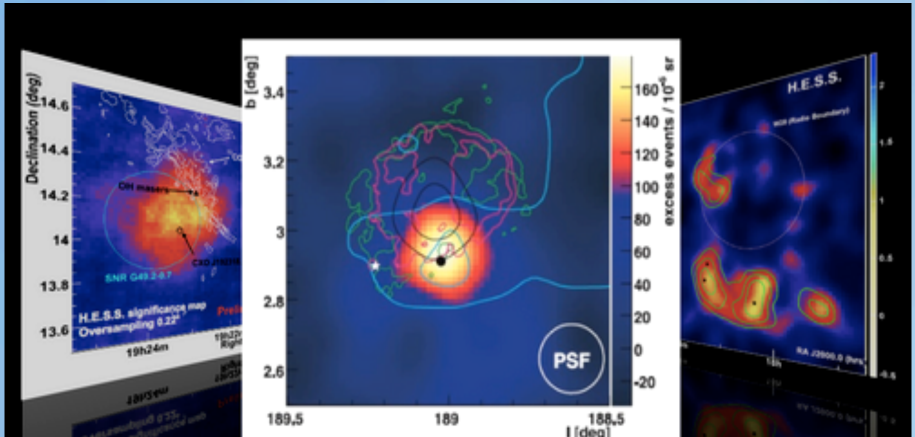
Vela Jr, RX J1713-3946,
RCW 86 (?), SN 1006


RX J1713 -3946

Interacting with molecular clouds

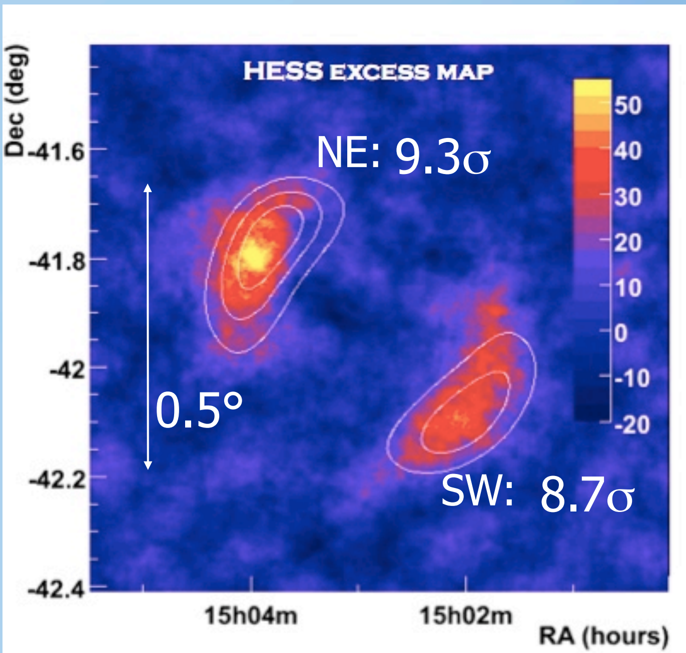
IC 443, W28, W51

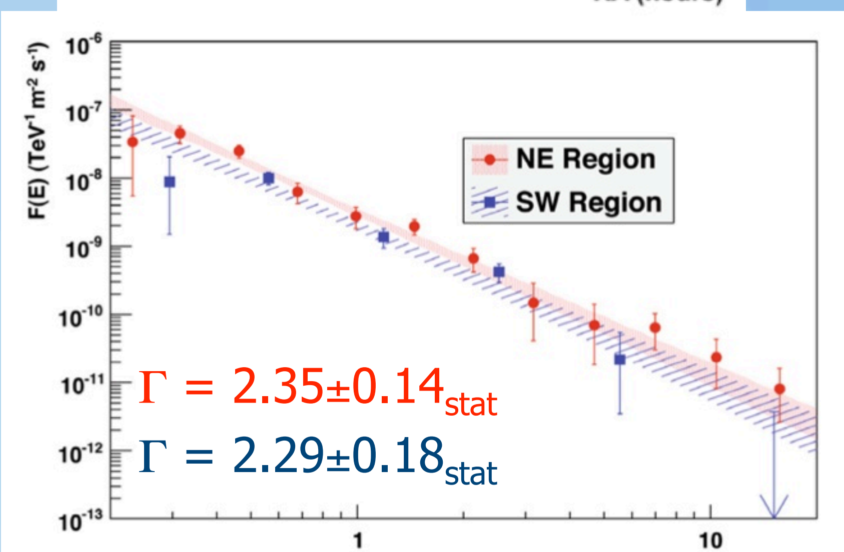
(See J. Mehault talk)


IC 443

- Possibility to directly investigate proton acceleration through hadronic process

SN 1006





HESS Collaboration, 2010

- 130h live time observation
  -> SN 1006 detected !
- Flux ~1% Crab
  -> one of the faintest VHE source detected
- Similar X-ray/γ-ray bi-polar morphology

Magnetic field

Filament:~70 μG

X/ γ:~30 μG

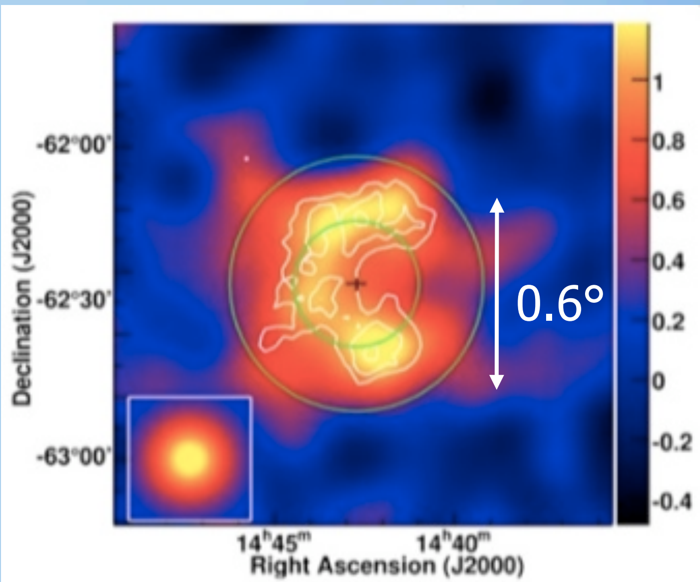
ID CARD

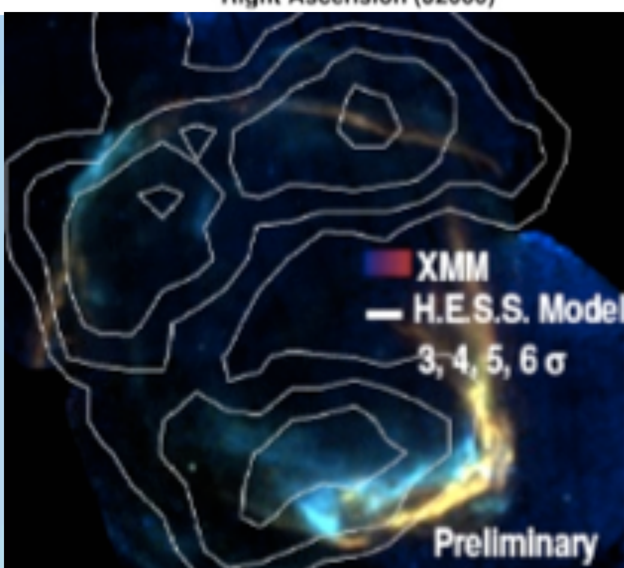
T = 1005 yrs

d = 2.2 kpc

RCW 86

Aharonian et al., 2009





Synchrotron
Thermal

- Indication of a shell morphology in gamma-rays (Not statistically significant)
- No strong enhancement in γ in the SW interaction region (dense material)
- $\Gamma = 2.54 \pm 0.12_{stat}$

Magnetic field

Filament: ~100 μG

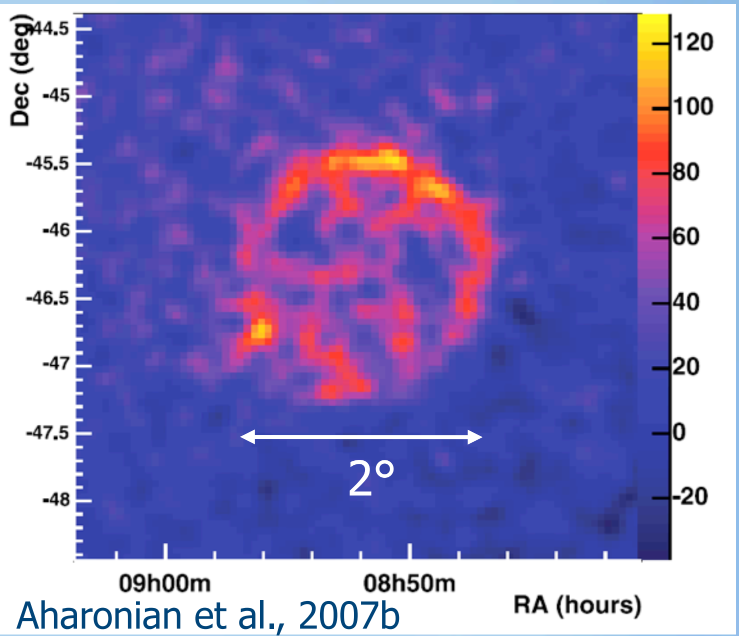
X/ γ: ~30 μG

ID CARD

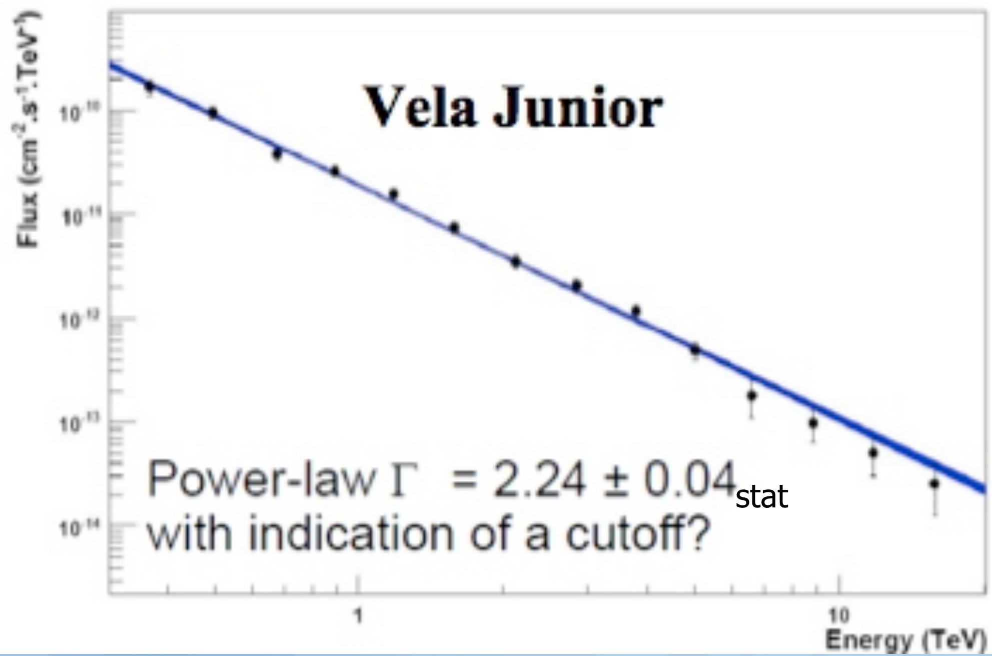
T = 1800 yrs

d ~ 2.5 kpc

Vela Jr



Aharonian et al., 2007b



- Largest SNR in TeV
- Thick shell in γ-rays : 18%*R_{SNR}
  Deprojected and deconvoluted from the PSF
- X-ray shell is only ~1%*R_{SNR}

Magnetic field

Filament: 200 μG

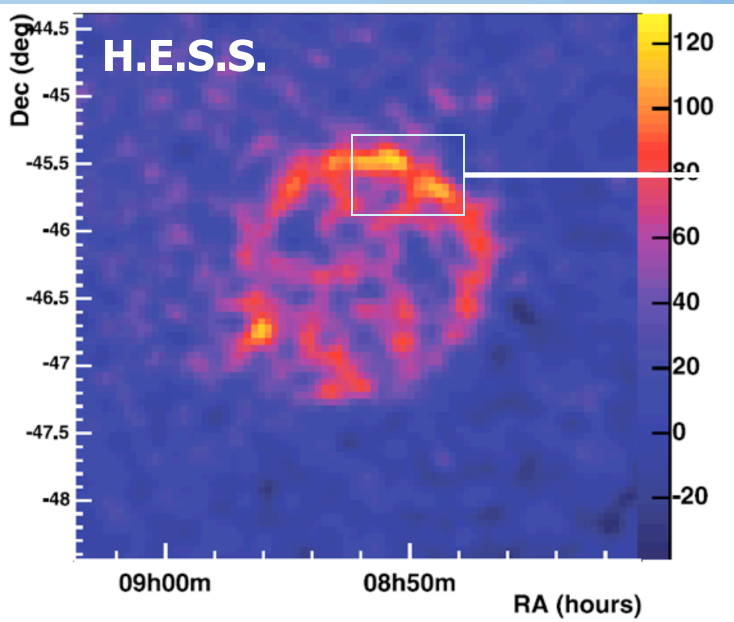
X/ γ:14 μG

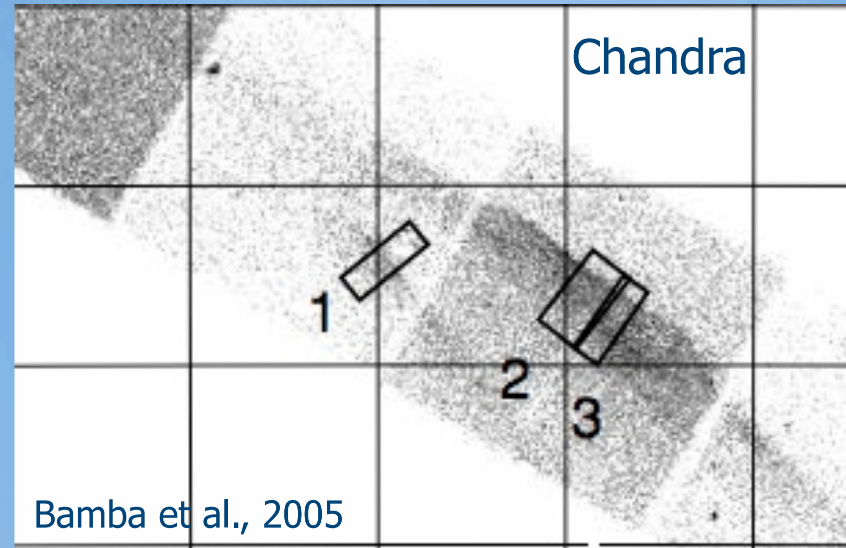
ID CARD

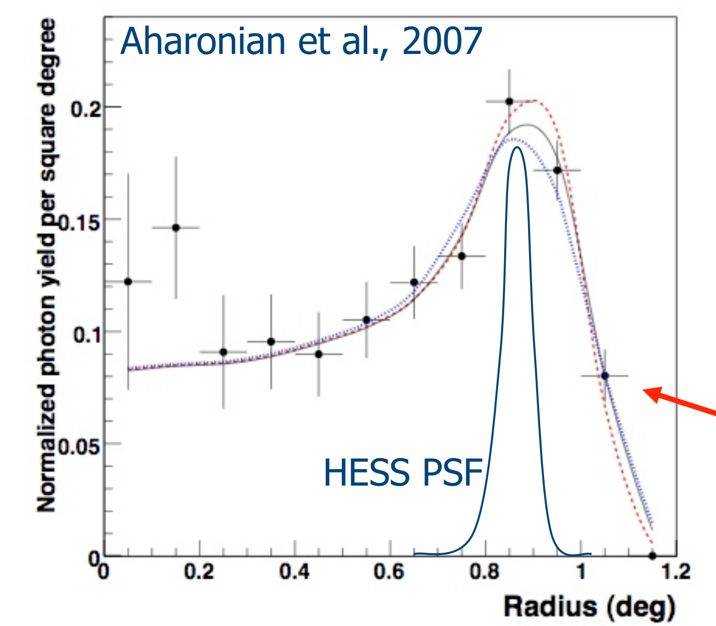
T ~ 4000 yrs

d ~ 800 pc

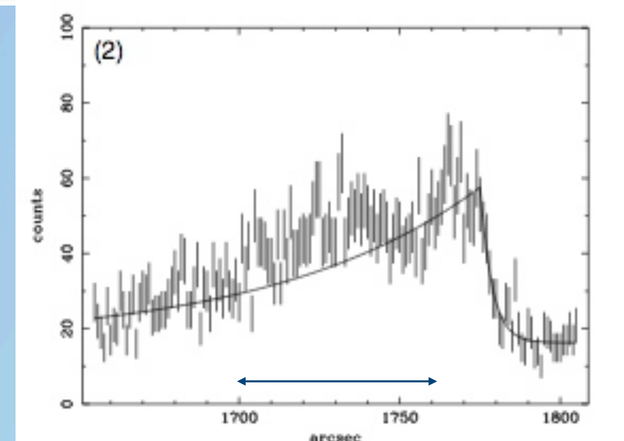
Gamma-ray spatially resolved shell







- X/gamma-ray emission do **NOT** stem from the same regions

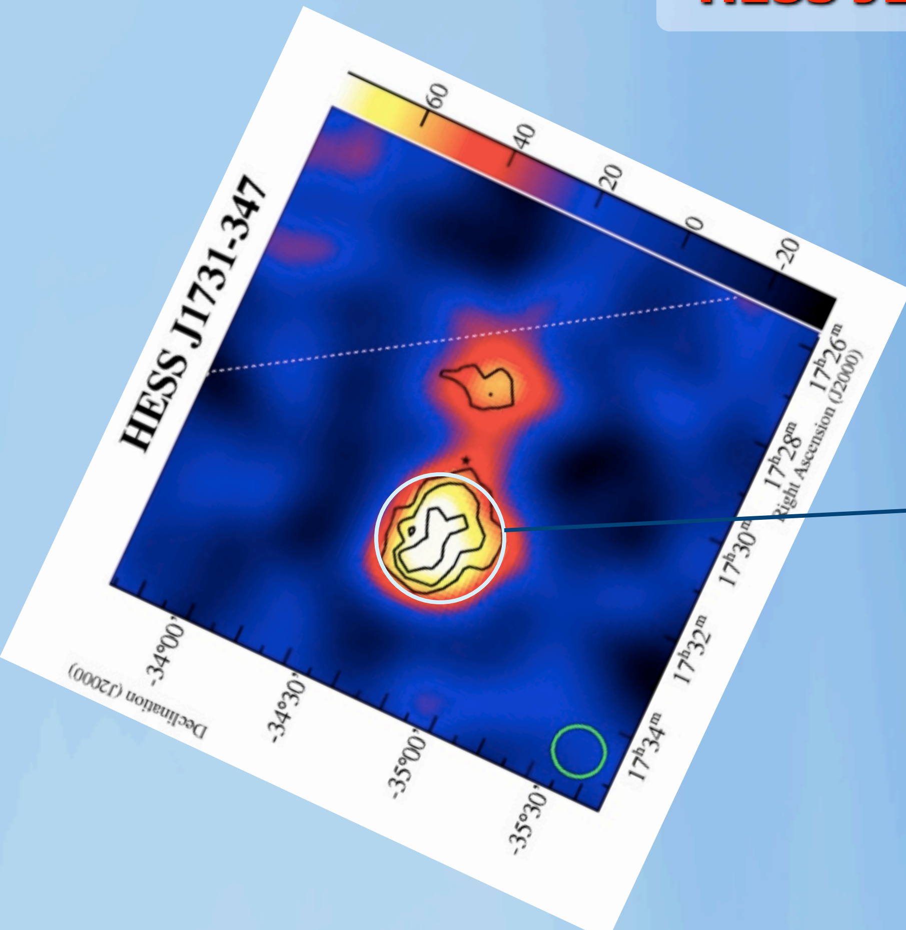


intrinsic thickness=0.18±0.03°

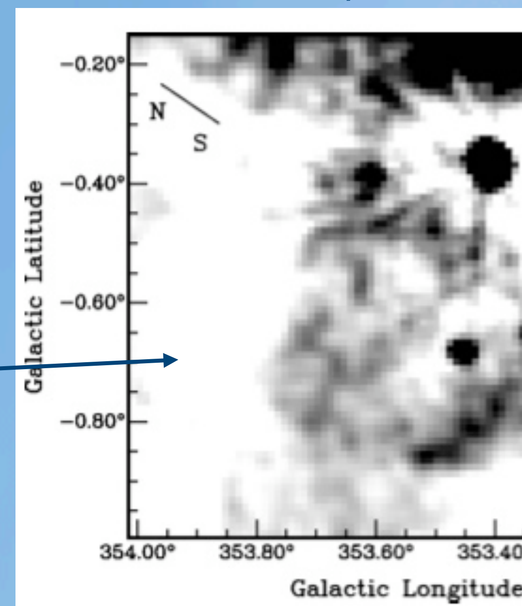
1 arcmin (0.016°)

Previously unidentified sources

HESS J1731-347



Radio, ATCA telescope



Tian et al., 2008

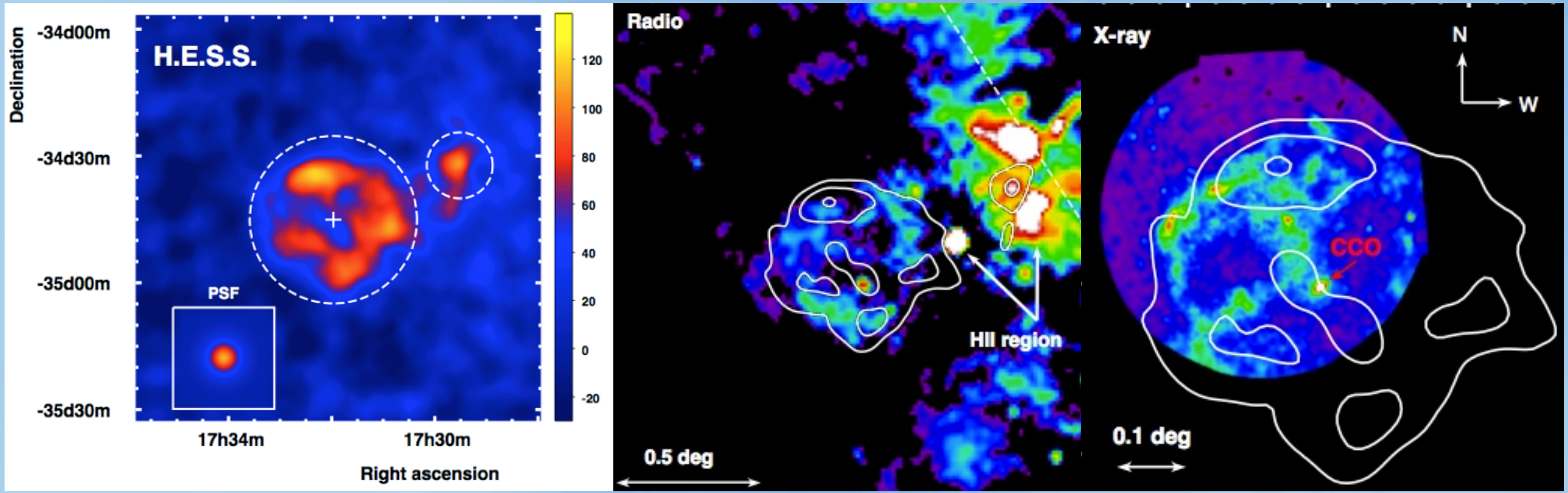
Unidentified HESS source
Aharonian et al., 2008

→

Shell of SNR in spatial coincidence

HESS J1731-347

A new SNR



F. Acero for the HESS collaboration, 2011

- The 4th SNR with TeV shell type morphology
- Most luminous shell type TeV SNR (> RX J1713)
- $\Gamma = 2.32 \pm 0.06_{stat}$

Magnetic field

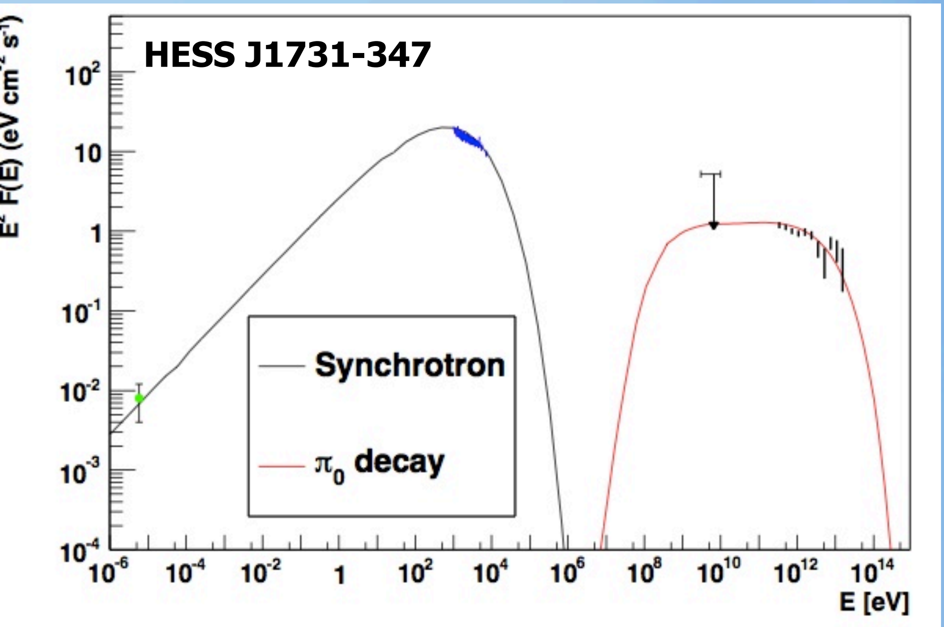
X/ γ:~25 μG

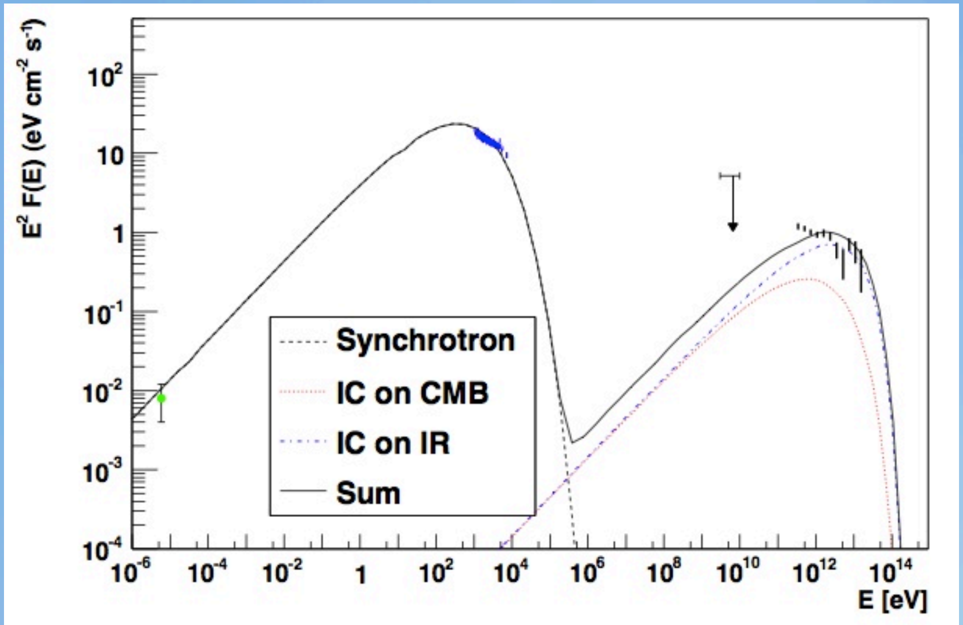
ID CARD

T = ? yrs

d > 3.2 kpc

Nature of the γ emission : hadronic vs leptonic





F. Acero for the HESS collaboration, 2011

- High density required : $n \sim 1\ cm^{-3}$
-> Not in agreement with lack of thermal X-ray emission

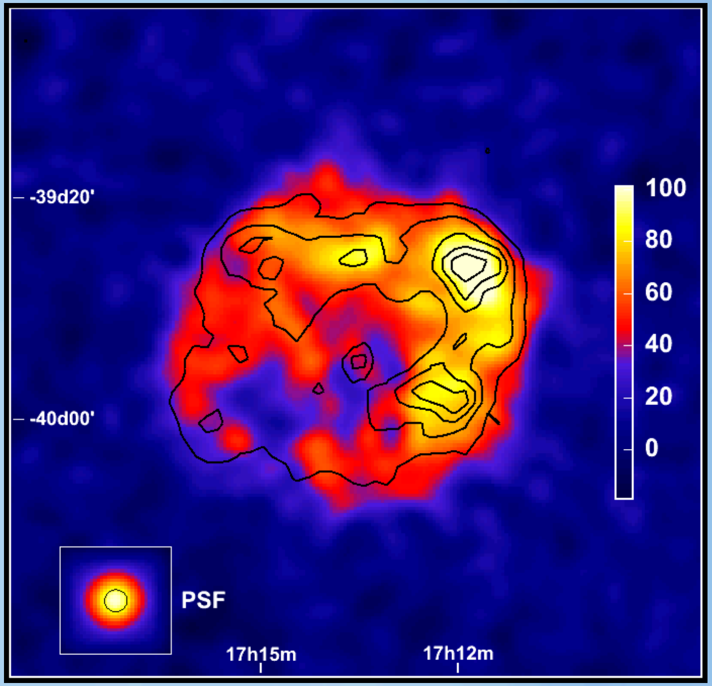
- Loophole : efficient acceleration can decrease thermal emission behind the shock (Drury et al., 2009, Helder et al., 2009)

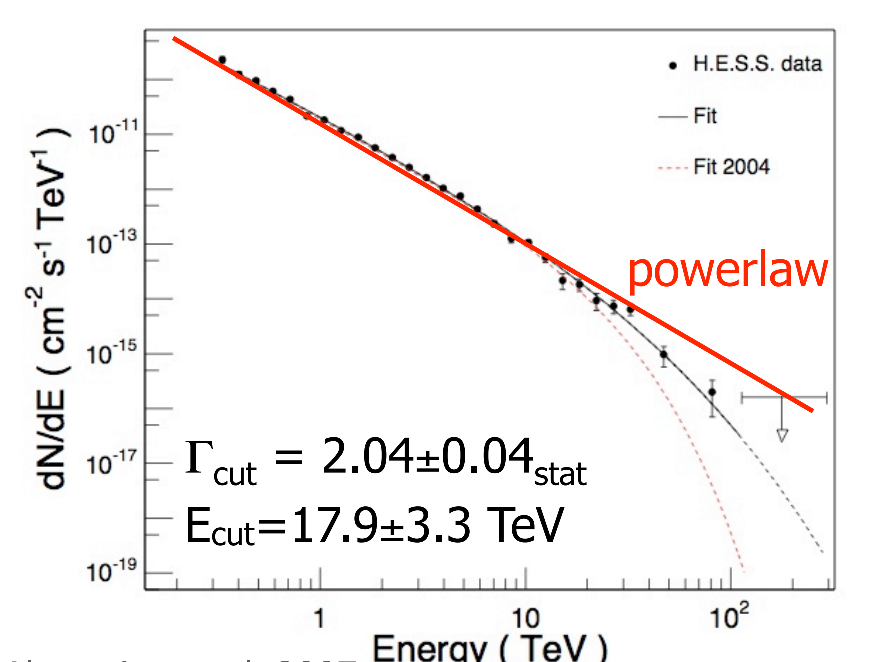
- Difficulties to reproduce the TeV slope

- Lower magnetic fields than derived from X-ray filaments

- Loophole : multi-zone models

RXJ 1713-3946





Aharonian et al, 2007a

- Unique example of cutoff in SNR
  -> Maximum energy if protons
  γ : 18 TeV -> p : ~200 TeV

- Thick shell in γ-ray : 48%*R_{SNR}
  Deprojected and deconvoluted from the PSF

Magnetic field

Filament:~70 μG

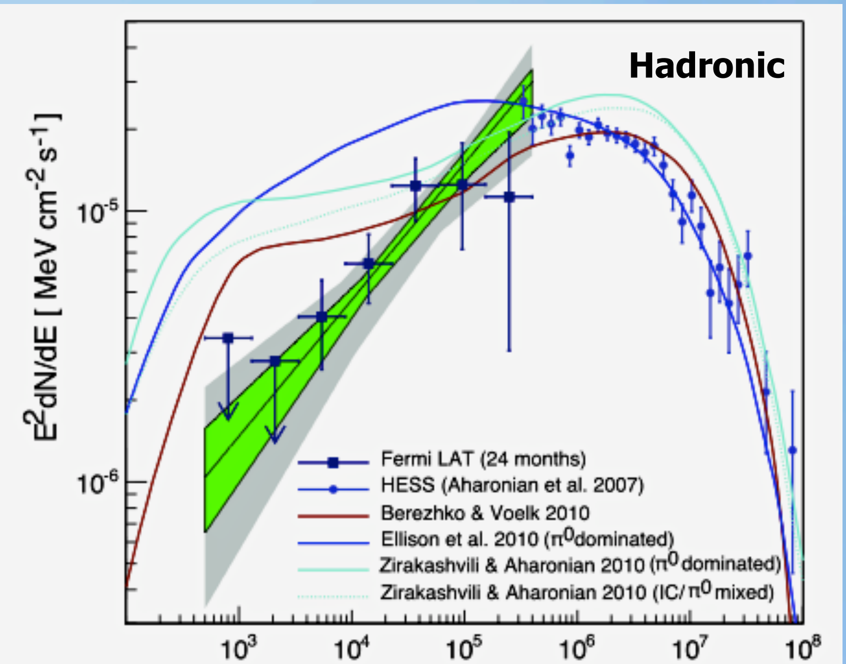
X/ γ ~10 μG

ID CARD

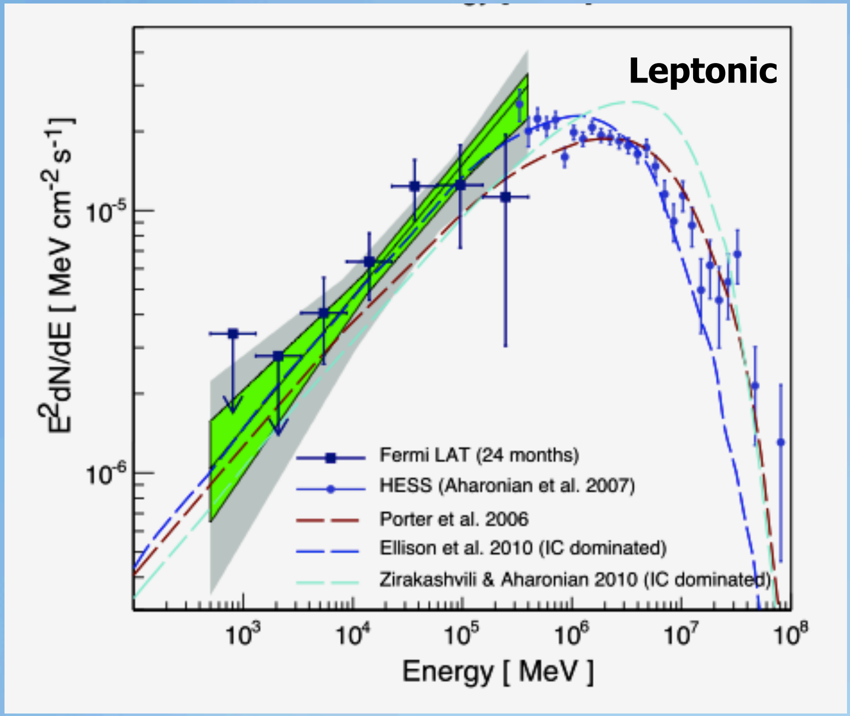
T = 1600 yrs

d ~ 1 kpc

RX J1713-3946 : hadronic or leptonic ?



Abdo et al., 2011

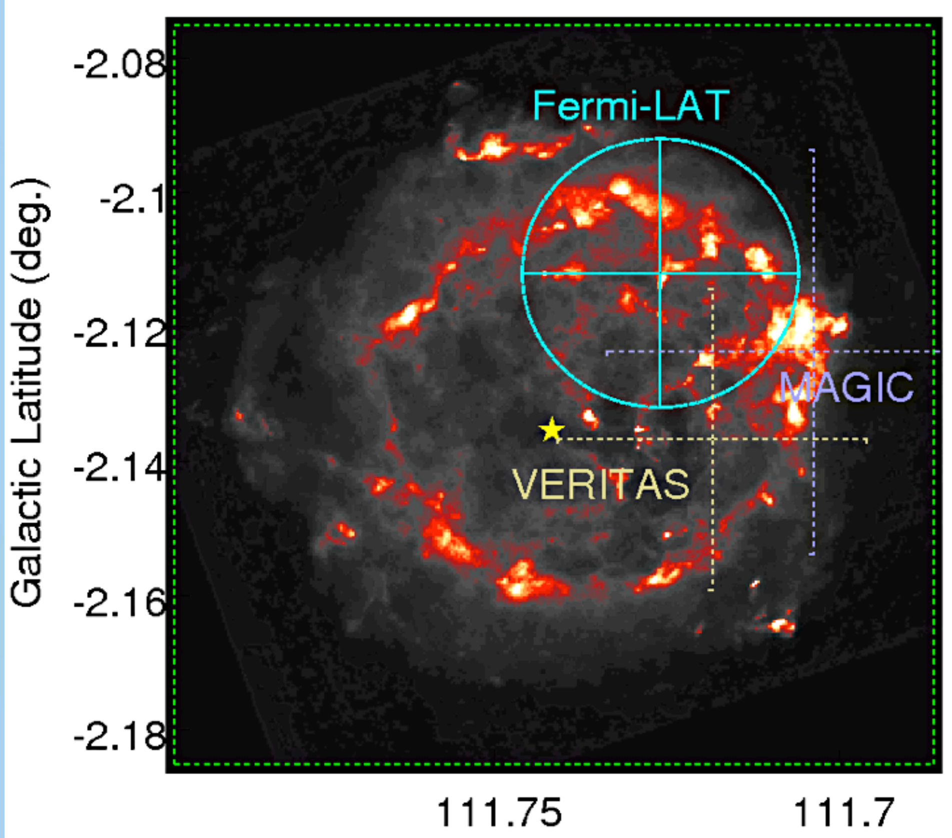


Red --- (Berezhko 2010) :
B=142 μG
n_H=0.25 cm^{-3} (bubble cavity)
W_p=0.45 x 10^{50} ergs

Blue --- (Ellison, 2010) :
B=10 μG
n_H=0.25 cm^{-3} (uniform ISM)

γ-ray emission is dominated by leptonic processes

Cassiopeia A



Abdo et al., 2010

- First SNR discovered in TeV
  by HEGRA : 5 σ in 232 hrs (!!)

  Aharonian et al., 2001

- Assuming all TeV emission is leptonic :
  X/γ flux ratio -> B~100 μG

- Very thin X-ray filament -> B~500 μG

- MAGIC :TeV spectral index Γ = $2.3 \pm 0.2_{stat}$

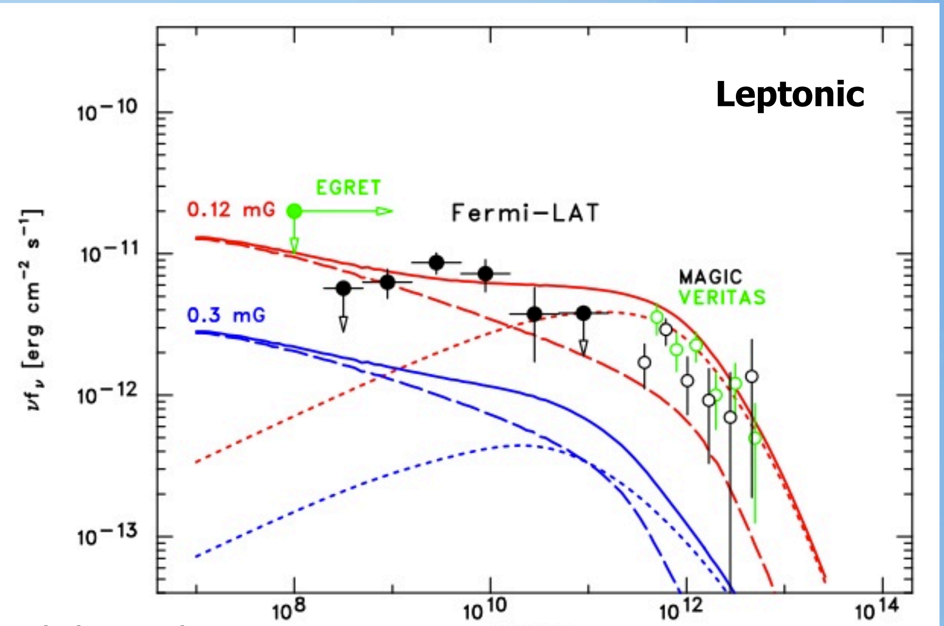
  Albert et al., 2007

ID CARD

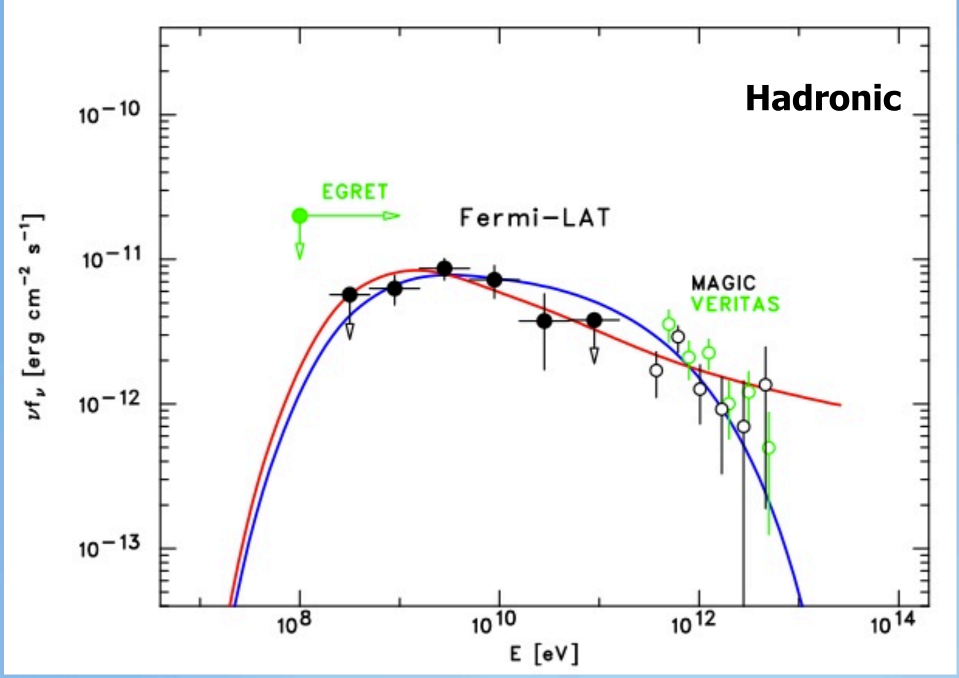
T = 330 yrs

d = 3.4 kpc

Cassiopeia A : hadronic or leptonic ?



Abdo et al., 2010



Red : bremsstrahlung + IC
B=120 μG

Blue : B=300 μG

Red : Γ=2.3 and no Ecut

Blue : Γ=2.1 and Ecut=10 TeV
W_p=3.2 x 10^{49} ergs for n_H=10 cm^{-3}

Conclusion

- Indirect evidence of accelerated hadrons (high B, modified hydrodynamics)

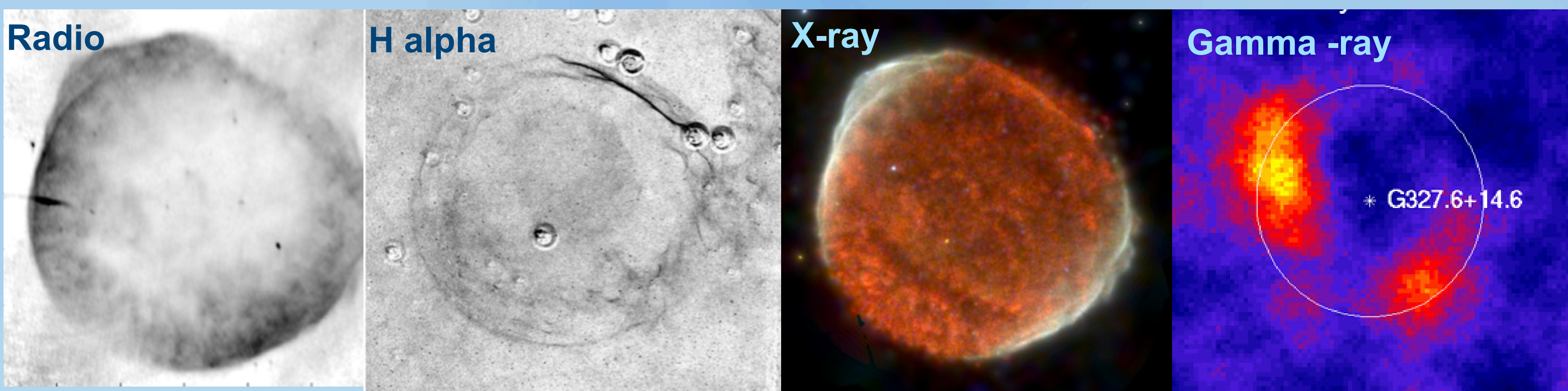
- All TeV SNRs have $\Gamma>2$; Are we in the cutoff of those SNRs
  - -> Difficulties to reach the knee (3000 TeV) in SNRs
  - -> Cutoff seen in RX J1713-3946 at 200 TeV

- The γ-ray emission seems dominated by the leptonic scenario (RX J1713).
  n_{target} is too weak around SNRs for a significant hadronic scenario

- For significant neutrino flux, high n_{target} around SNRs is required :

  Targets of interest : CasA SNR, interacting SNRs (e.g. IC 443)

Thank you !



SN 1006