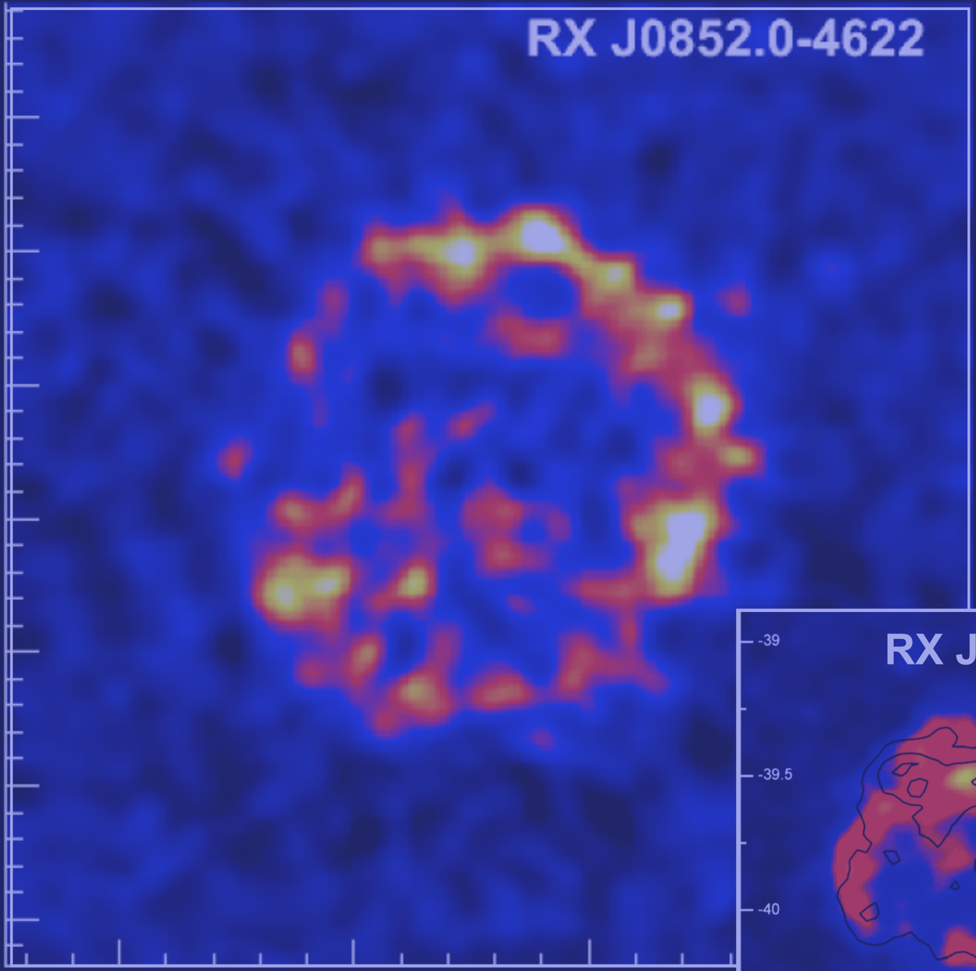
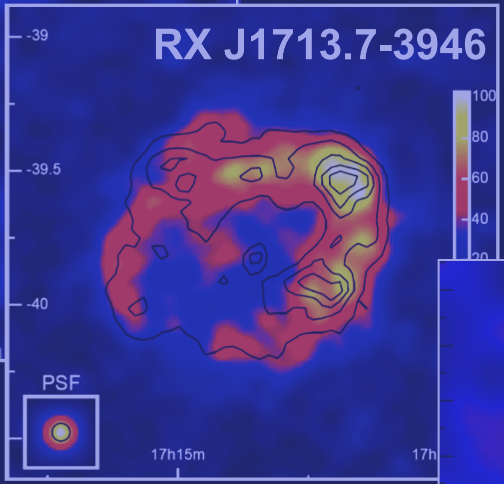
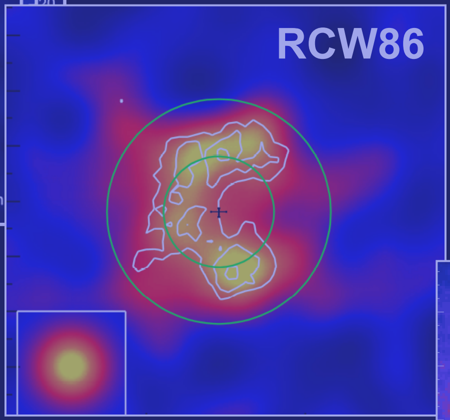
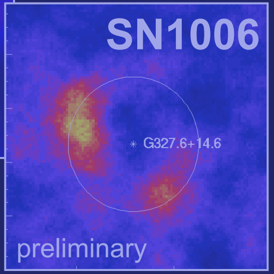
Observations of Shell-type Supernova Remnants in the VHE Band with H.E.S.S.





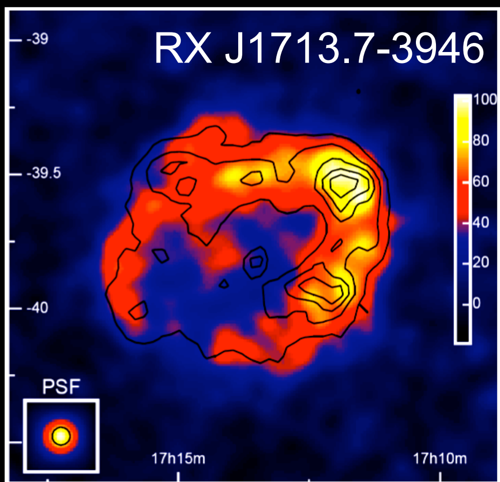


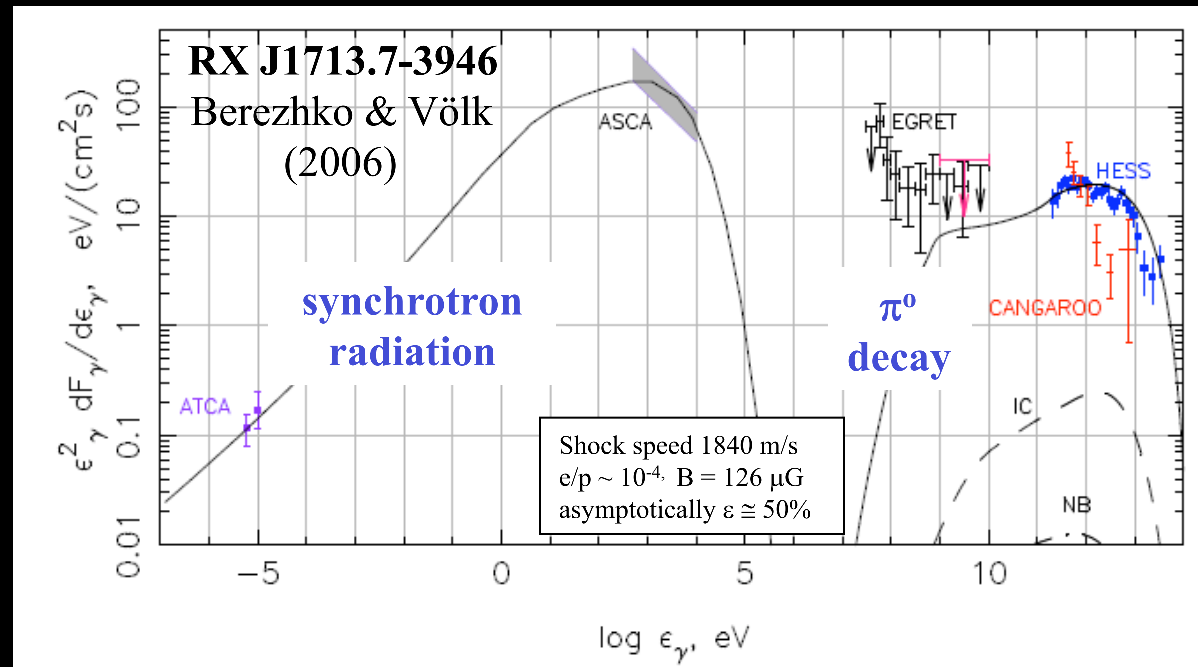


F. Acero, M. de Naurois,
D. Horns, D. Klochkov, Nu. Komin,
K. Kosack, M. Lemoine-Goumard,
M. Naumann-Godo, G. Pühlhofer,
for the H.E.S.S. collaboration

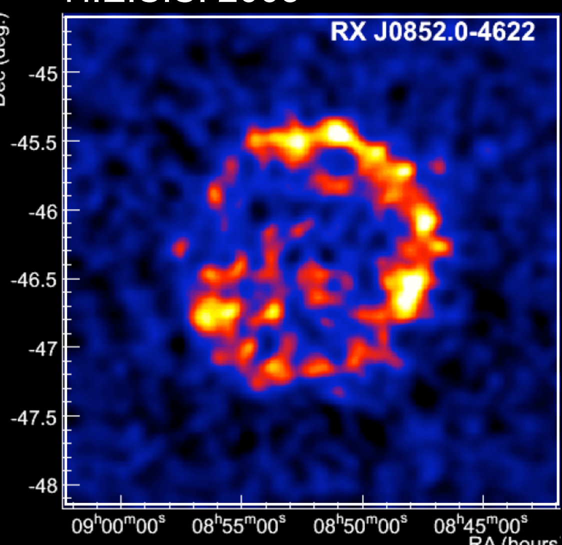
RX J1713.7-3946 + Vela Jr.

H.E.S.S. 2004





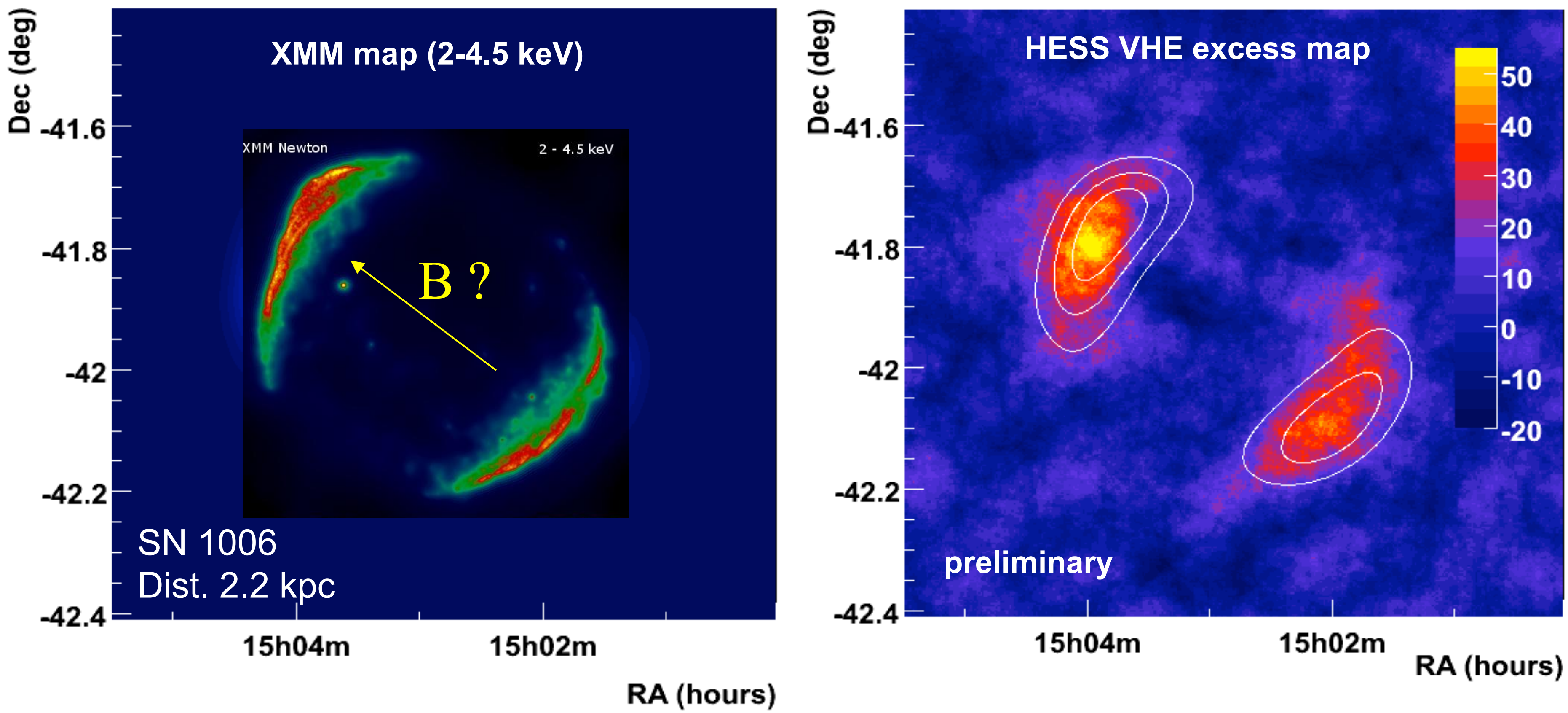
H.E.S.S. 2005



Probable scenario:

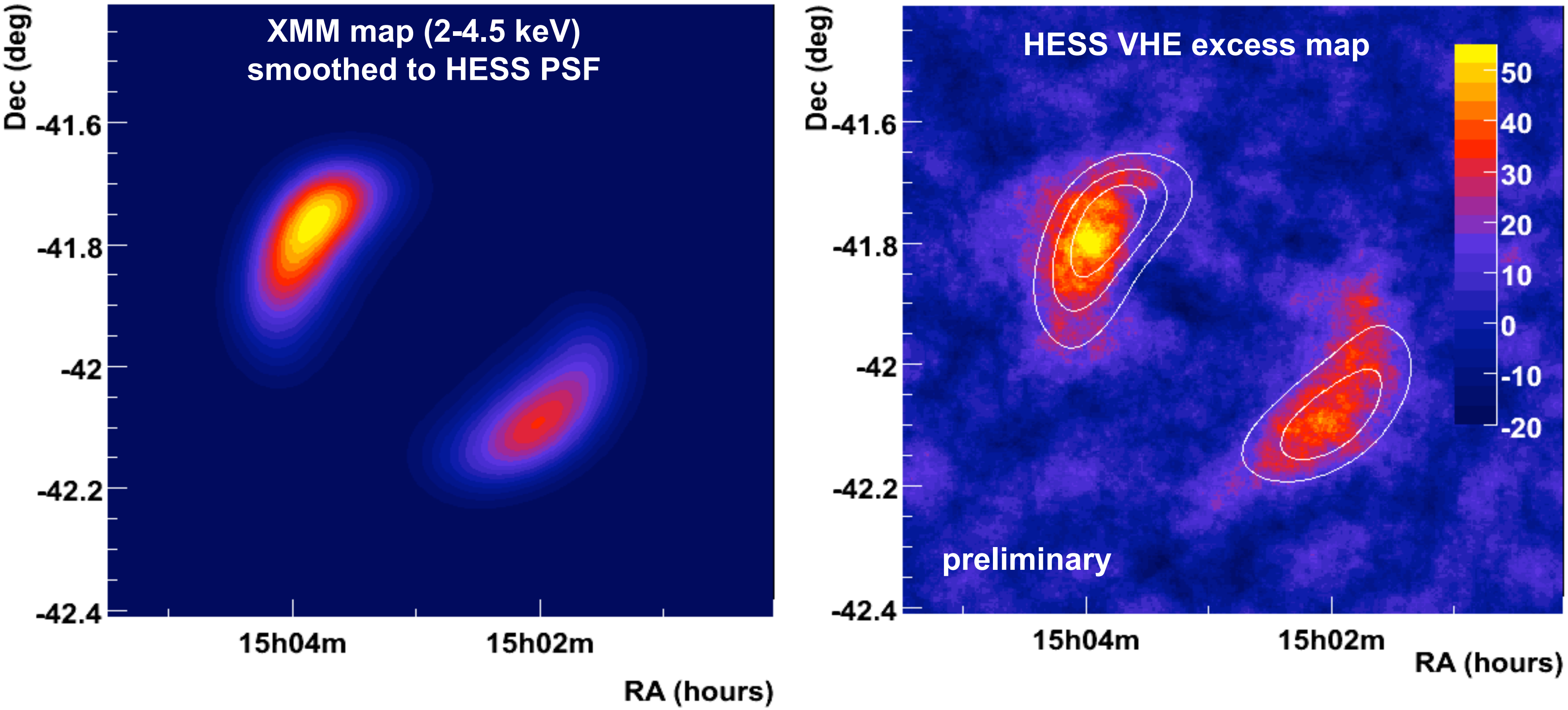
- Shock interacts with high density wind blown shell (probably inside molecular cloud)
- Dominant leptonic VHE gamma-ray emission scenario would require low B-field (magnetic field damping after shock to explain X-ray synchrotron morphology ?)
- Dominant hadronic VHE scenario fits nicely, but low level of thermal X-ray emission needs to be explained!

Latest addition to VHE shells: SN 1006



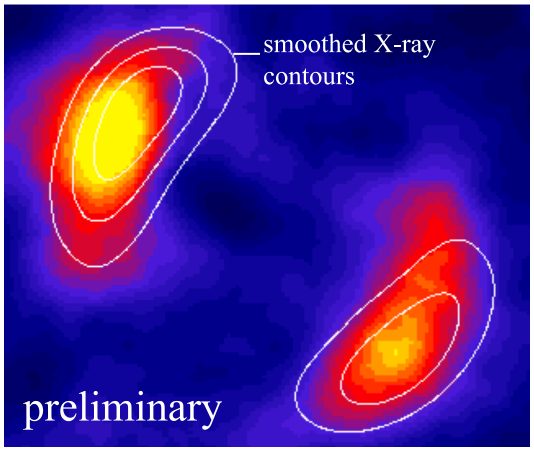
- Clear (bi)polar geometry in non-thermal X-rays
- Low density environment above Galactic plane, $N_H \sim 0.05\ cm^{-3}$
- TeV morphology compatible with polar geometry and thin rim

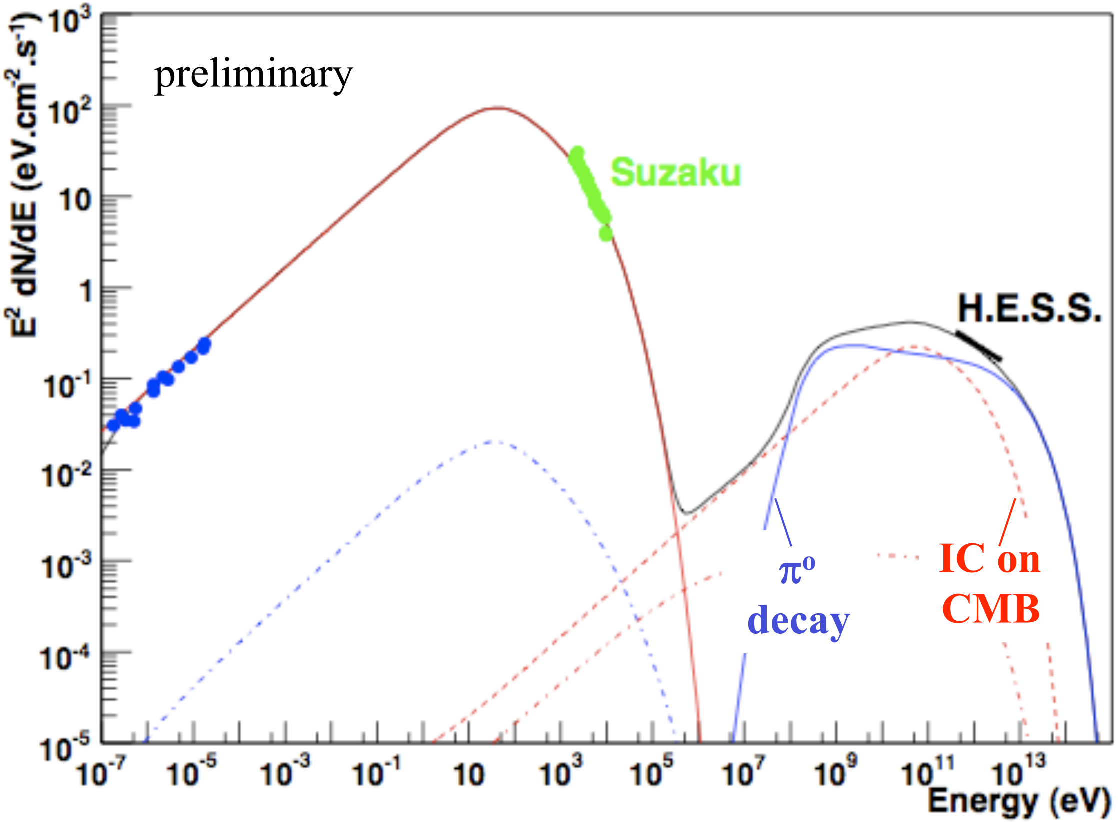
Latest addition to VHE shells: SN 1006



- Clear (bi)polar geometry in non-thermal X-rays
- Low density environment above Galactic plane, NH ~ 0.05 cm-3
- TeV morphology compatible with polar geometry and thin rim

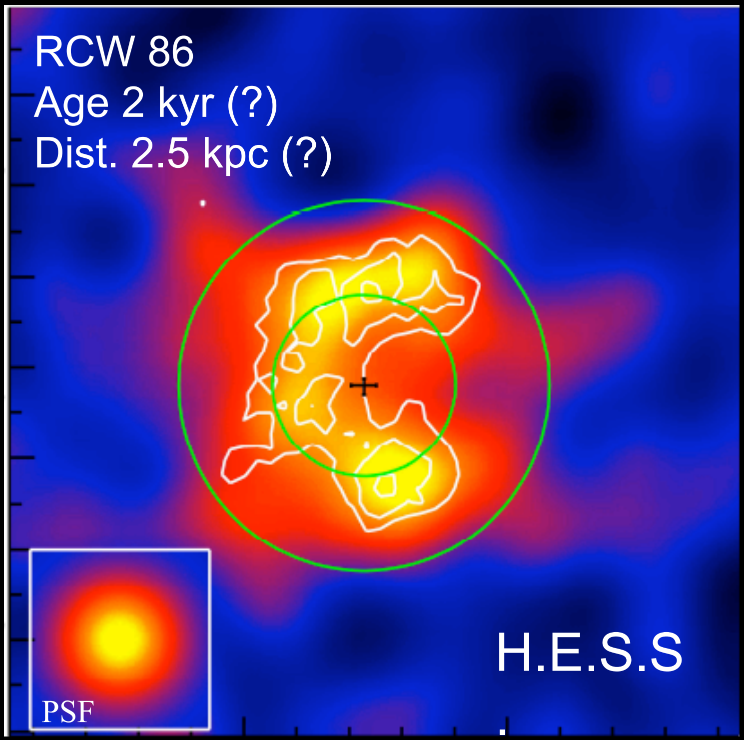
Latest addition to VHE shells: SN 1006

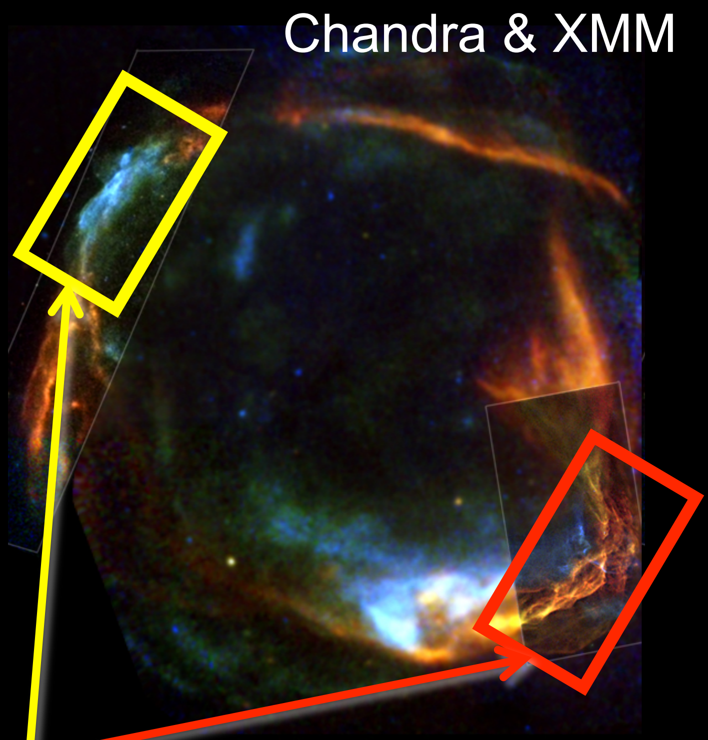




- Mixed model (superposition of leptonic and hadronic VHE emission) gives good description of data, reasonable $W_p \sim 12\%\ W_{SN}$
- Pure leptonic model may also work (reasonable B-field of 45μG)

RCW 86: Two worlds combined in one SNR?

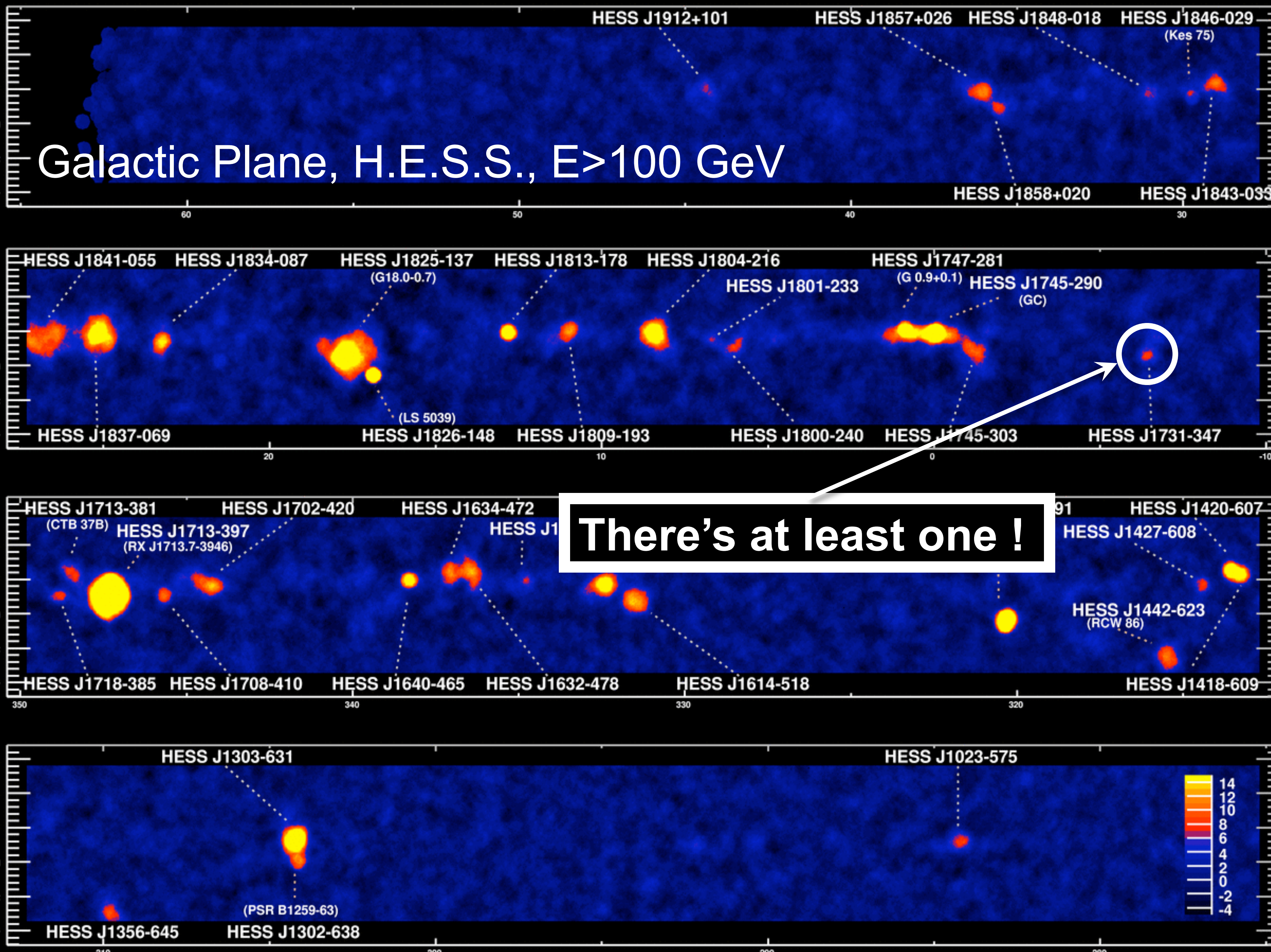




- SNR expands in wind-blown bubble (cf. RX J1713.7-3946 + Vela Jr.), but: distinct regions of **thermal (high ρ)** and **non-thermal (low ρ)** X-rays
- In **NE**, measured post-shock temperature (2.3±0.3 keV, from Hα line width) is much smaller than expected (40..70 keV, from shock velocity measured with Chandra) (Helder et al., Science 2009)
  ➔ >50% of energy in non-thermal component
  ➔ or in turn, efficient CR acceleration "cools" thermal X-ray temperature
- But: morphological comparisons not yet possible due to lack of VHE statistics

(More) puzzles:

- Can we detect also older („middle-aged“) shell-type VHE SNRs (i.e. where the VHE particles are still confined inside the SNR)?
  ➔ So far, all shell-type VHE SNRs are young (< few 1000 years).
  ➔ In middle-aged SNRs, p/e ratio could increase because of electron cooling (and also because of acceleration theory)
- Are there no more SNR shells in the Galactic plane amongst the many new VHE soures?


Galactic Plane, H.E.S.S., E>100 GeV
HESS J1912+101
HESS J1857+026
HESS J1848-018
HESS J1846-029
(Kes 75)
HESS J1858+020
HESS J1843-033
HESS J1841-055
HESS J1834-087
HESS J1825-137
(G18.0-0.7)
HESS J1813-178
HESS J1804-216
HESS J1801-233
HESS J1747-281
(G 0.9+0.1)
HESS J1745-290
(GC)
HESS J1837-069
(LS 5039)
HESS J1826-148
HESS J1809-193
HESS J1800-240
HESS J1745-303
HESS J1731-347
There's at least one !
HESS J1713-381
(CTB 37B)
HESS J1713-397
(RX J1713.7-3946)
HESS J1702-420
HESS J1634-472
HESS J1420-607
HESS J1427-608
HESS J1442-623
(RCW 86)
HESS J1718-385
HESS J1708-410
HESS J1640-465
HESS J1632-478
HESS J1614-518
HESS J1418-609
HESS J1303-631
HESS J1023-575
(PSR B1259-63)
HESS J1356-645
HESS J1302-638
14
12
10
8
6
4
2
0
-2
-4

HESS J1731-347: a source w/o identified counterpart

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HESS collaboration, A&A 2008:
~14 hours lifetime
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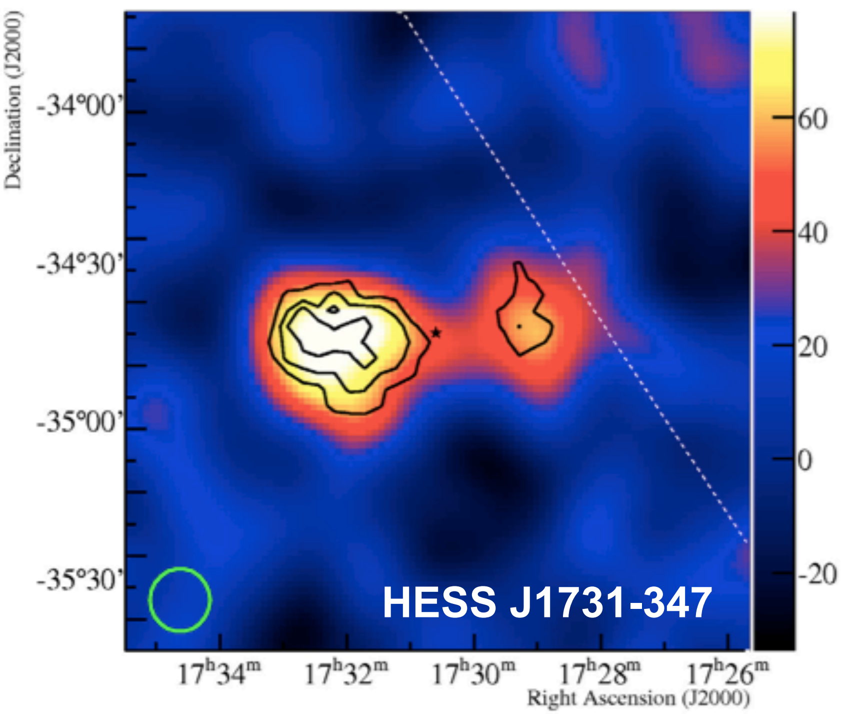
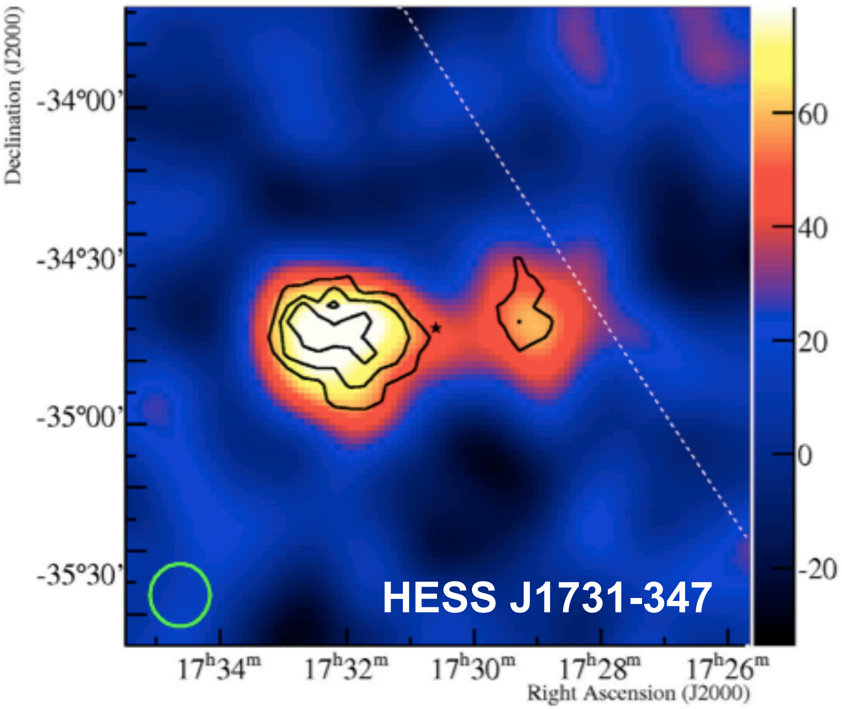


Color map: H.E.S.S. γ-ray excess
Contours: H.E.S.S. significance

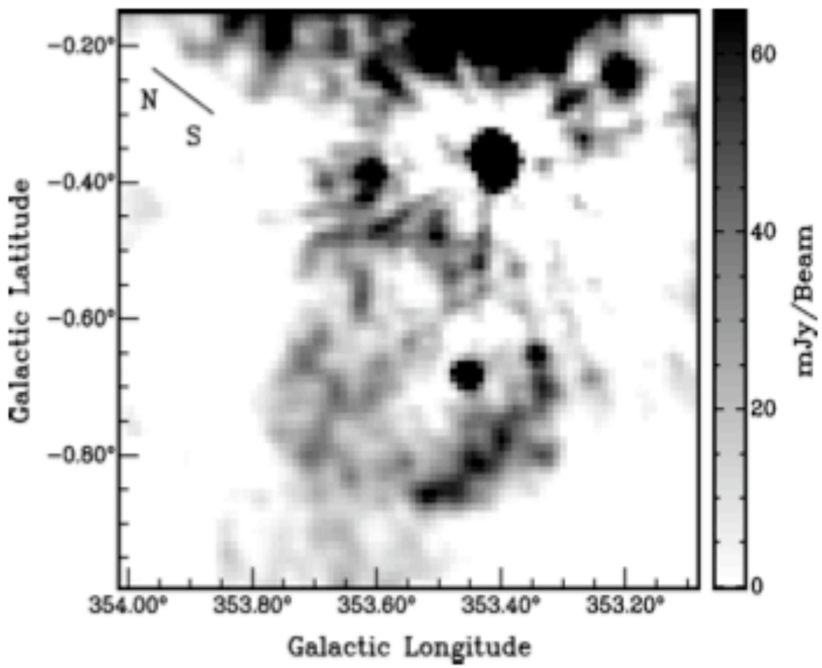
HESS J1731-347: a source with identified counterpart

HESS collaboration, A&A 2008:
~14 hours lifetime



Color map: H.E.S.S. γ-ray excess
Contours: H.E.S.S. significance

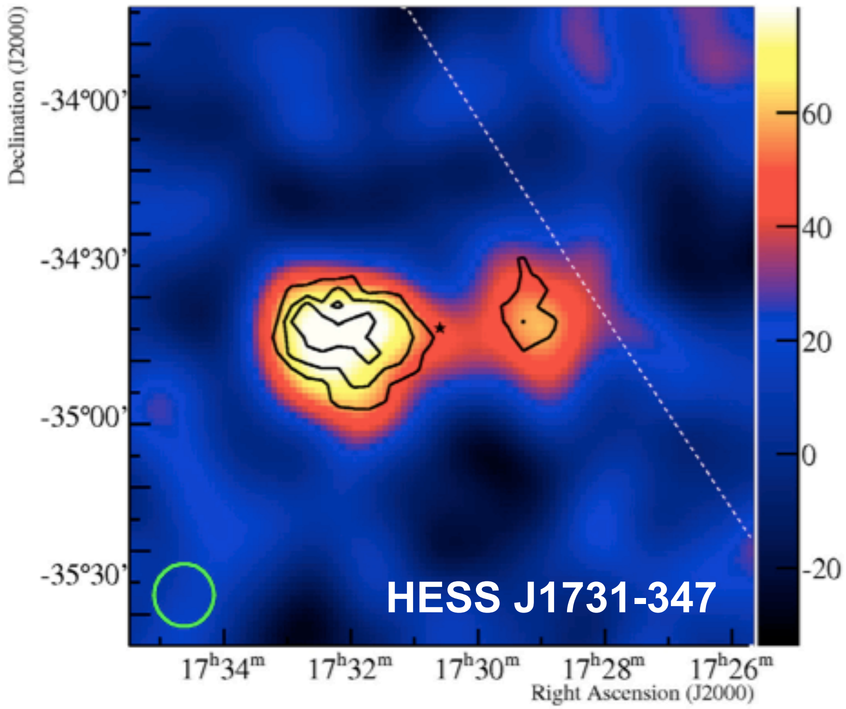
Tian et al., ApJ 2008



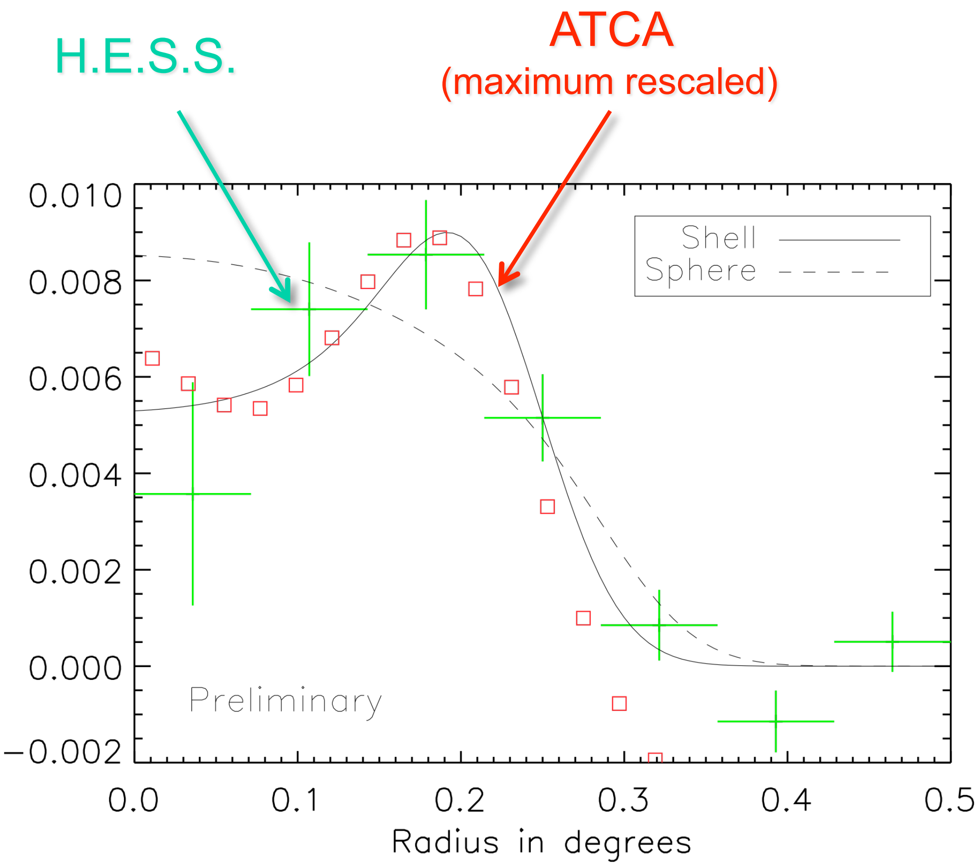
B&W map: ATCA 1.4 GHz

HESS J1731-347: radial profiles

HESS collaboration, A&A 2008:
~14 hours lifetime



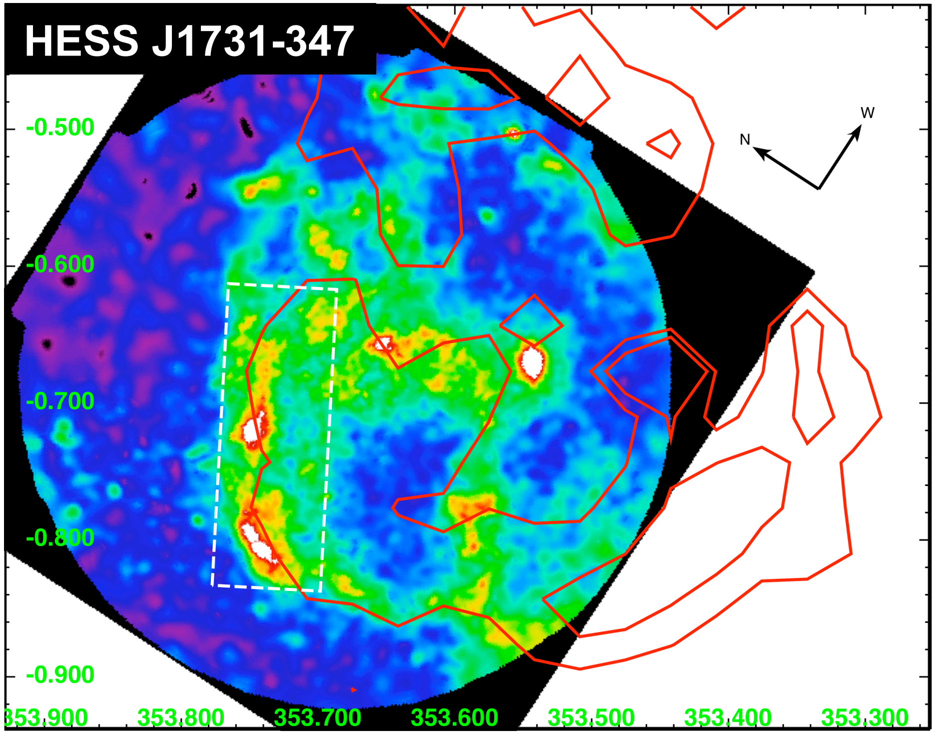
HESS collaboration:
~30 hours lifetime



Color map: H.E.S.S. γ-ray excess
Contours: H.E.S.S. significance

Shell model preferred at the 2.1σ level
→ more H.E.S.S. data under way

High sensitivity X-ray follow-up observations



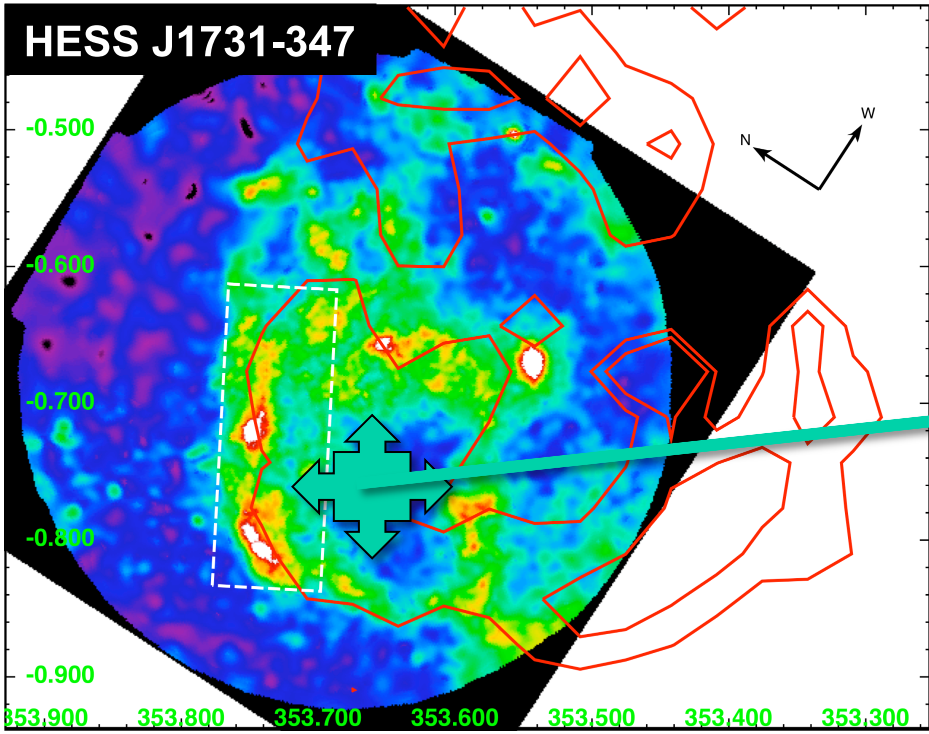
Color map: XMM-Newton

Technical details: MOS1+MOS2, 0.5-4.5 keV, 23 ksec

Red contours: ATCA 1.4 GHz

All X-ray observations (Suzaku, XMM-Newton, Chandra) focused so far on the (X-ray-) bright Eastern part of the source

High sensitivity X-ray follow-up observations



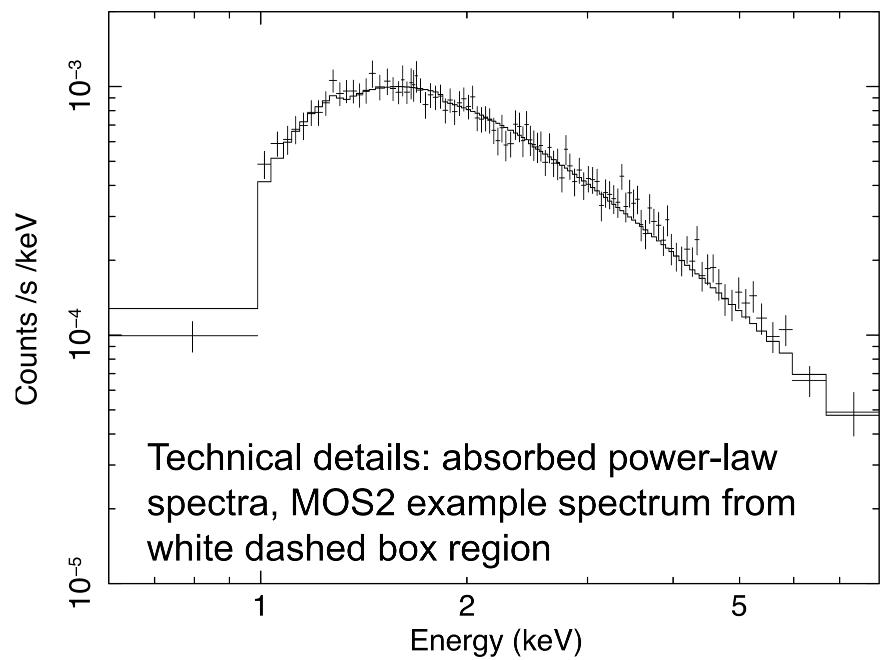
Color map: XMM-Newton

Technical details: MOS1+MOS2, 0.5-4.5 keV, 23 ksec

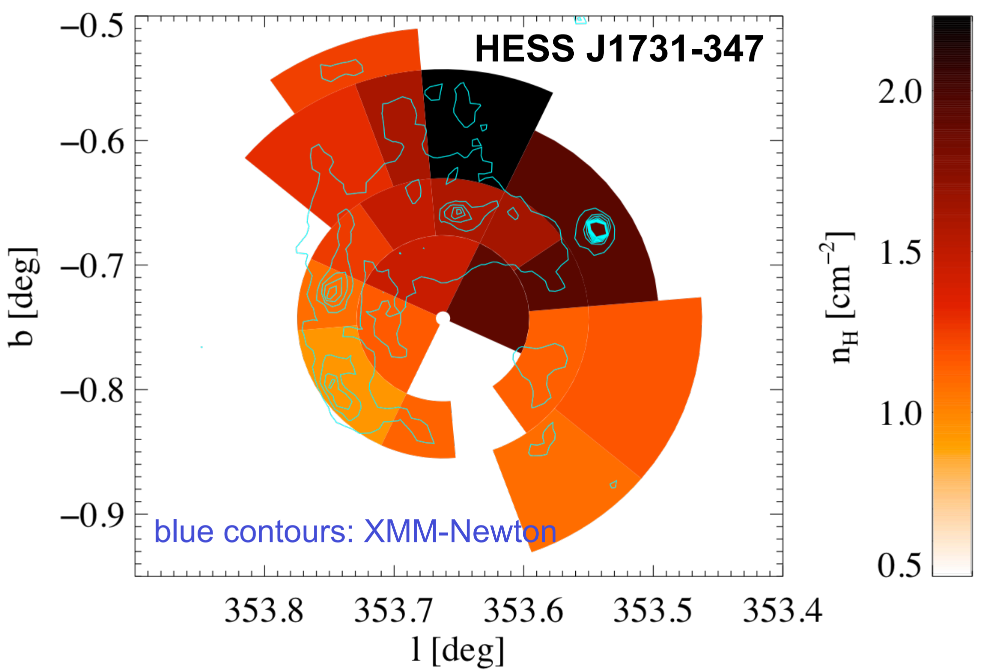
Red contours: ATCA 1.4 GHz

Diffuse, pure non-thermal X-ray emission

(with somewhat not yet clear morphology, to be resolved with further observations)



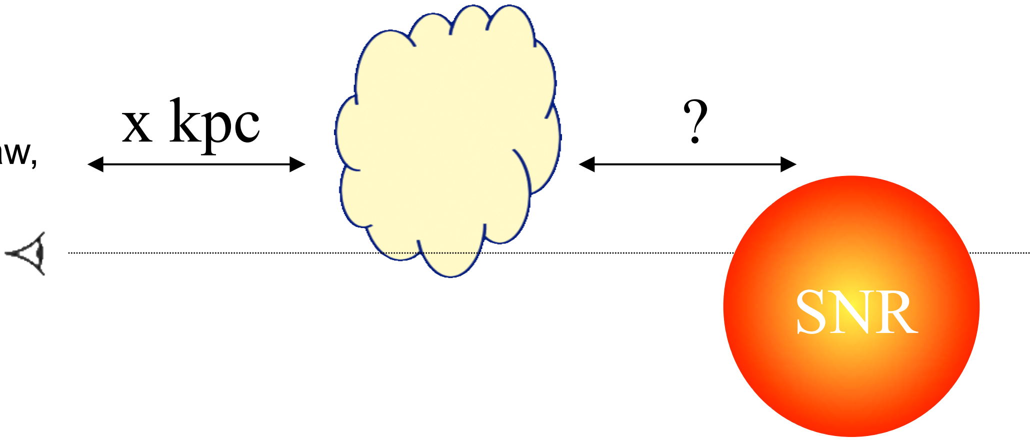
Variable absorption across the source



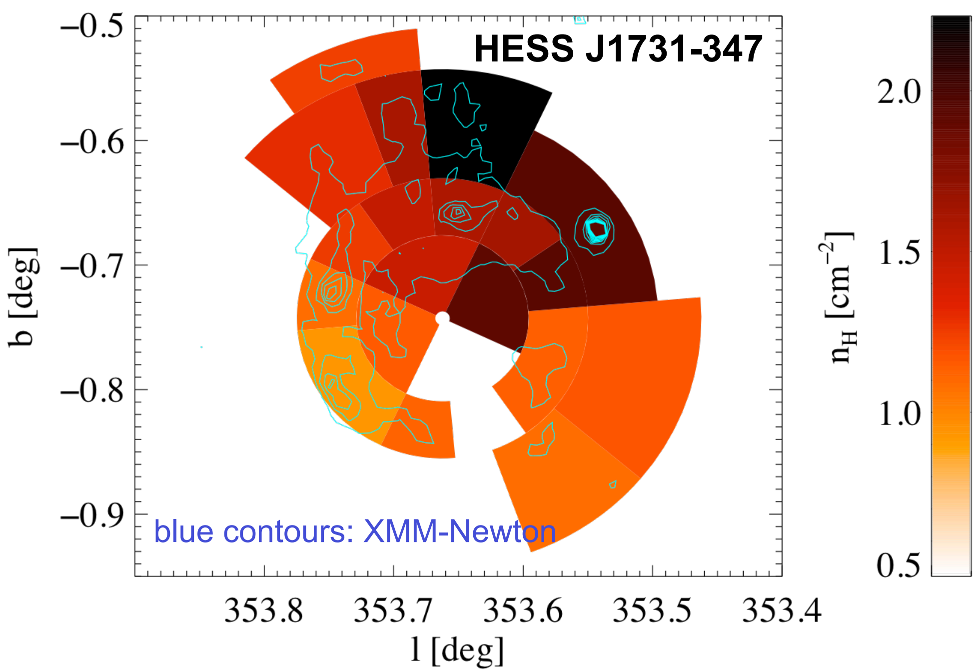
Significant gradient of absorption column $N_H = 1.0 .. 1.7 \times 10^{22} cm^{-2}$

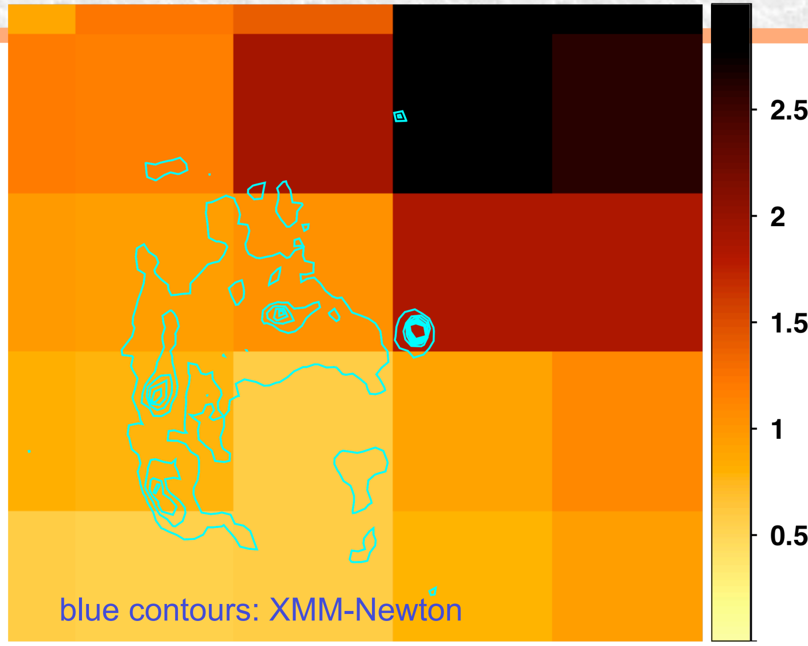
Technical details: assumption of a pure power law, „wabs“ absorption model

→ opens up possibility for a distance estimate!



A minimum distance to the SNR





$[N_H] = 10^{22} cm^{-2}$

Significant gradient of absorption column $N_H = 1.0 .. 1.7 \times 10^{22} cm^{-2}$

Technical details: assumption of a pure power law, „wabs“ absorption model

Matching increase in absorption derived from ^{12}CO observations

Technical details: CfA CO survey data; map integrated from LSR velocities between 0 and -17 kms^{-1}, where first peak towards the SNR appears; CO-to-H_2 mass conversion factor $2.5 \times 10^{20} cm^{-2} K^{-1} km^{-1} s$

→ Object is at least 3.5 kpc away!

Technical details: Galactic rotation model from Fich et al. 1989

Conclusions

- The class of VHE-emitting SNR shells is slowly growing; latest addition is SN 1006
- Hadronic vs. leptonic VHE emission scenarios (so far) usually employ spectral and morphological comparisons to X-ray emission
- HESS J1731-347: If association of VHE emission with the SNR (radio) shell will be confirmed, then HESS J1731-347 is the most distant spatially resolved VHE SNR shell detected so far
- With the same caveat, HESS J1731-347 could be the oldest yet identified shell-type VHE SNR; from a simple Sedov solution:

$$t_{SNR} \approx 4800 \left(\frac{n_0}{0.1\ \mathrm{cm}^{-3}} \right)^{\frac{1}{2}} \text{years (if } E \approx 10^{51}\,\text{erg)}$$