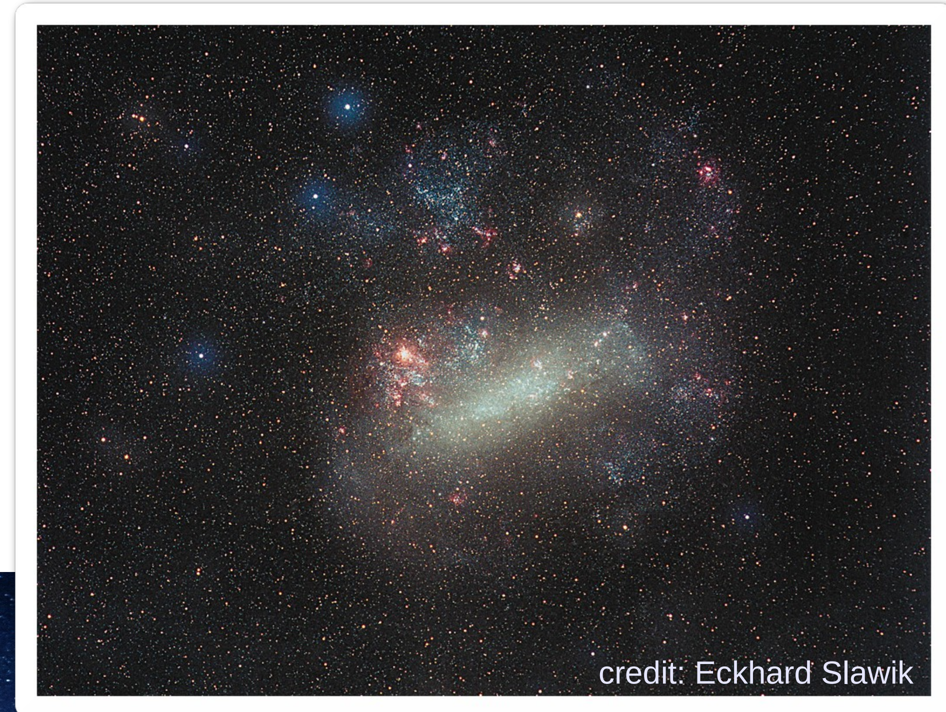
TeV Gamma-Ray Observations of the Large Magellanic Cloud

Dr Nukri Komin*
for the H.E.S.S. Collaboration

*School of Physics, Wits University, Johannesburg

What is the LMC?

- southern hemisphere
- a satellite galaxy of the Milky Way
- ~10° diameter (20x full moon)

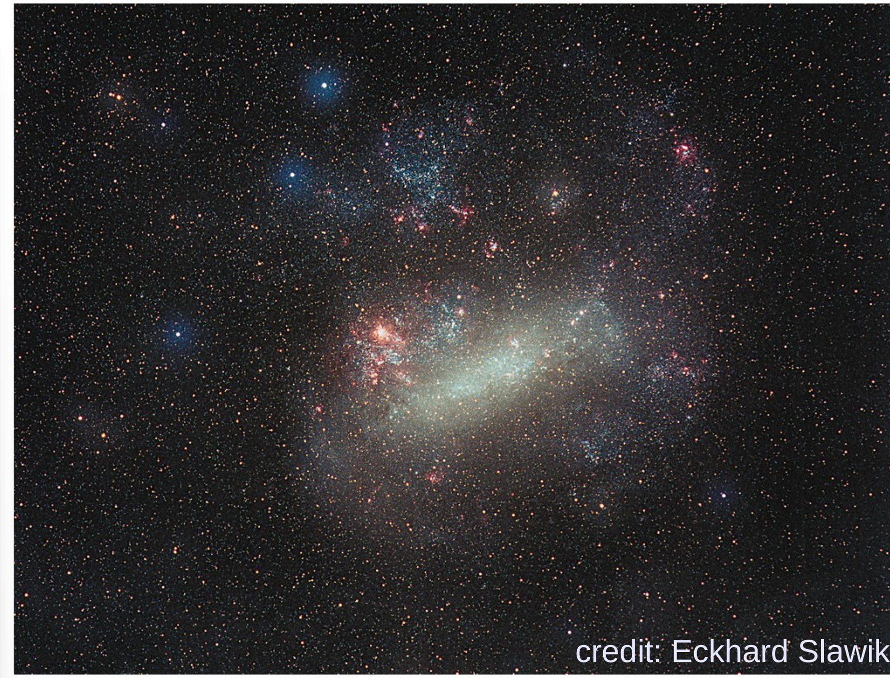


What is the LMC?

extension: 8 kpc
distance: 48 kpc [Macri *et al.* 2006]
(cf. Milky Way diameter 31...37 kpc)
inclination: 31° [Nikolaev *et al.* 2004]

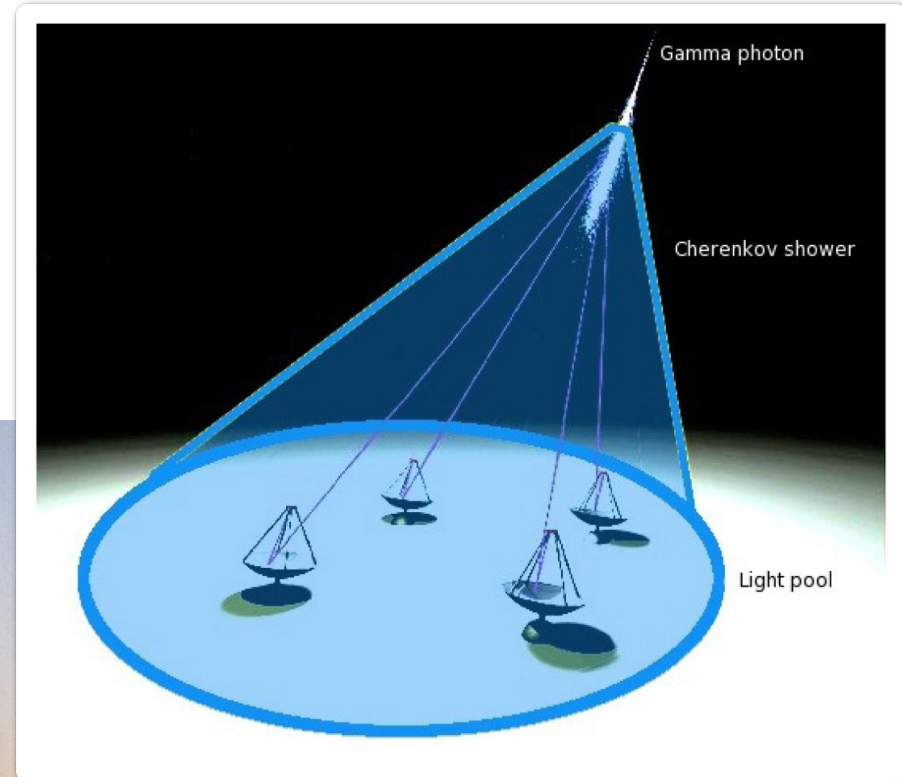
typical sources:

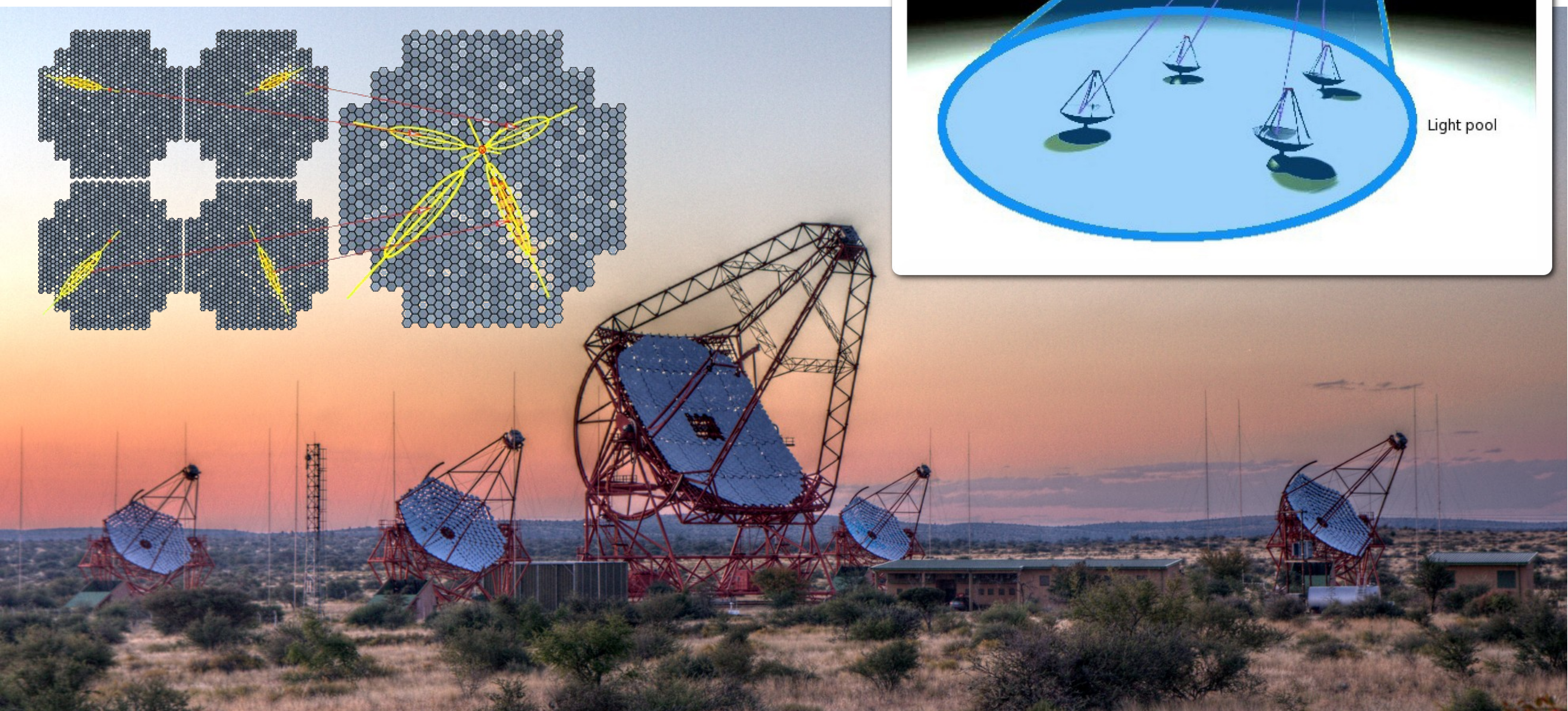
- pulsar wind nebulae
- supernova remnants
- star forming regions



What is H.E.S.S.?

- High Energy Stereoscopic System
- 5 telescopes for observation of gamma-ray induced air showers in Cherenkov light





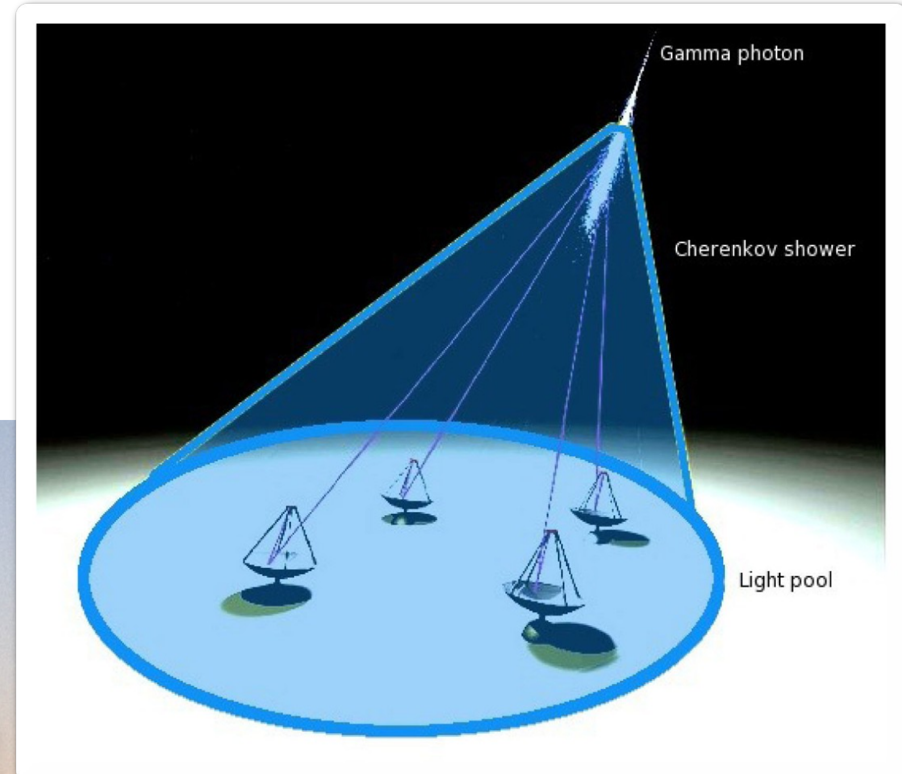
What is H.E.S.S.?

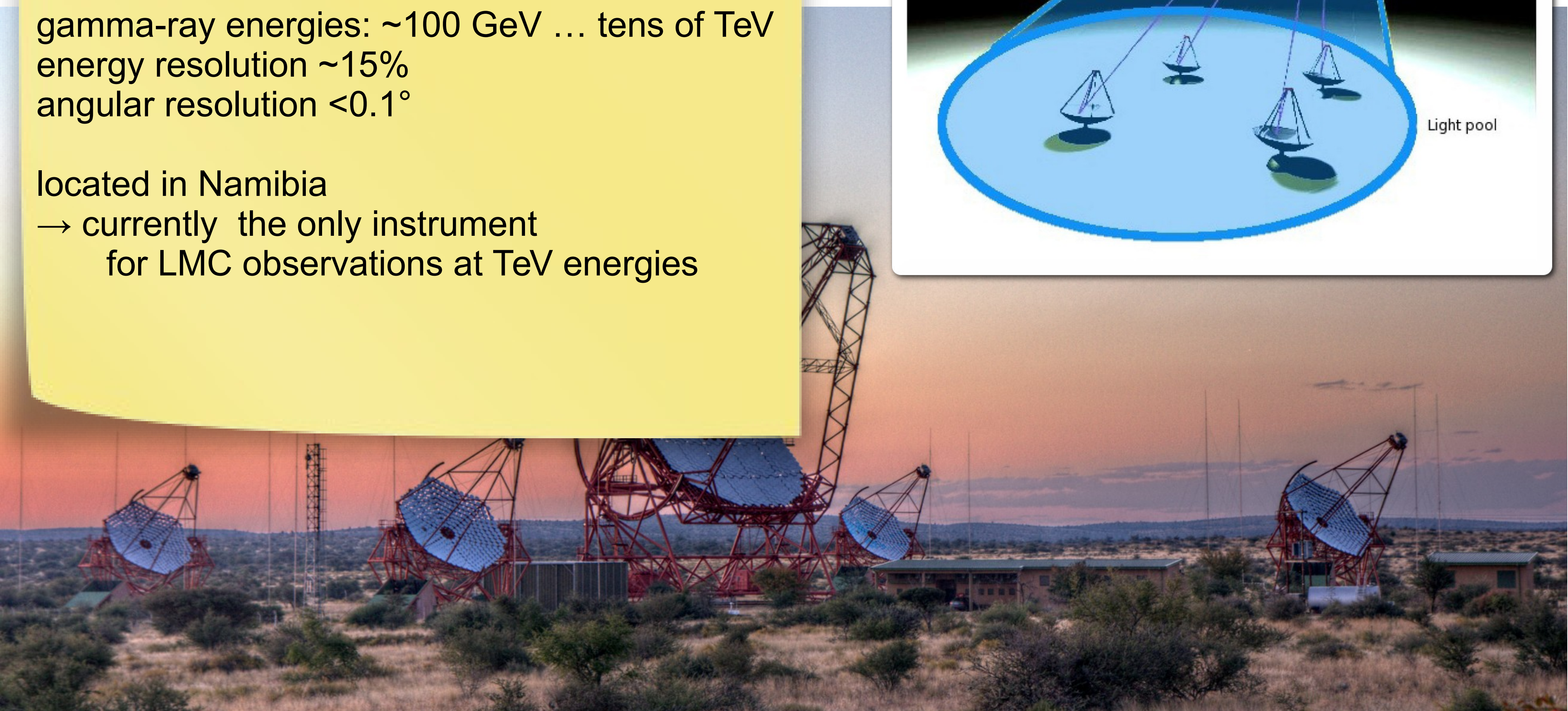
data presented here (up to 2009):

4 telescopes of 12m diameter
camera with 960 PMTs and 5° field of view

~50 000 m^2 effective area
gamma-ray energies: ~100 GeV … tens of TeV
energy resolution ~15%
angular resolution <0.1°

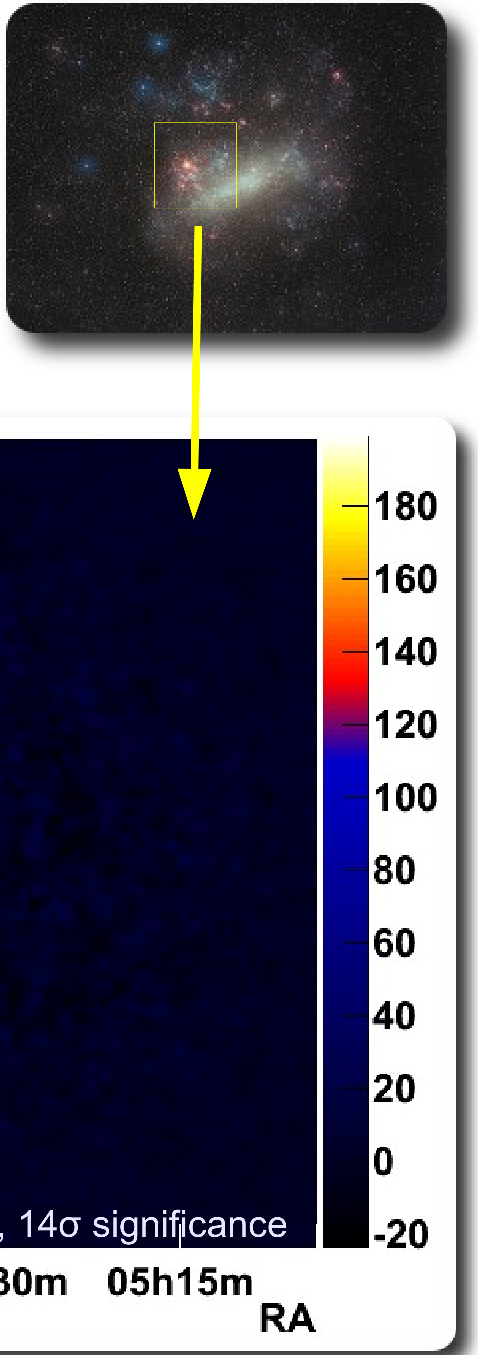
located in Namibia
→ currently the only instrument
for LMC observations at TeV energies





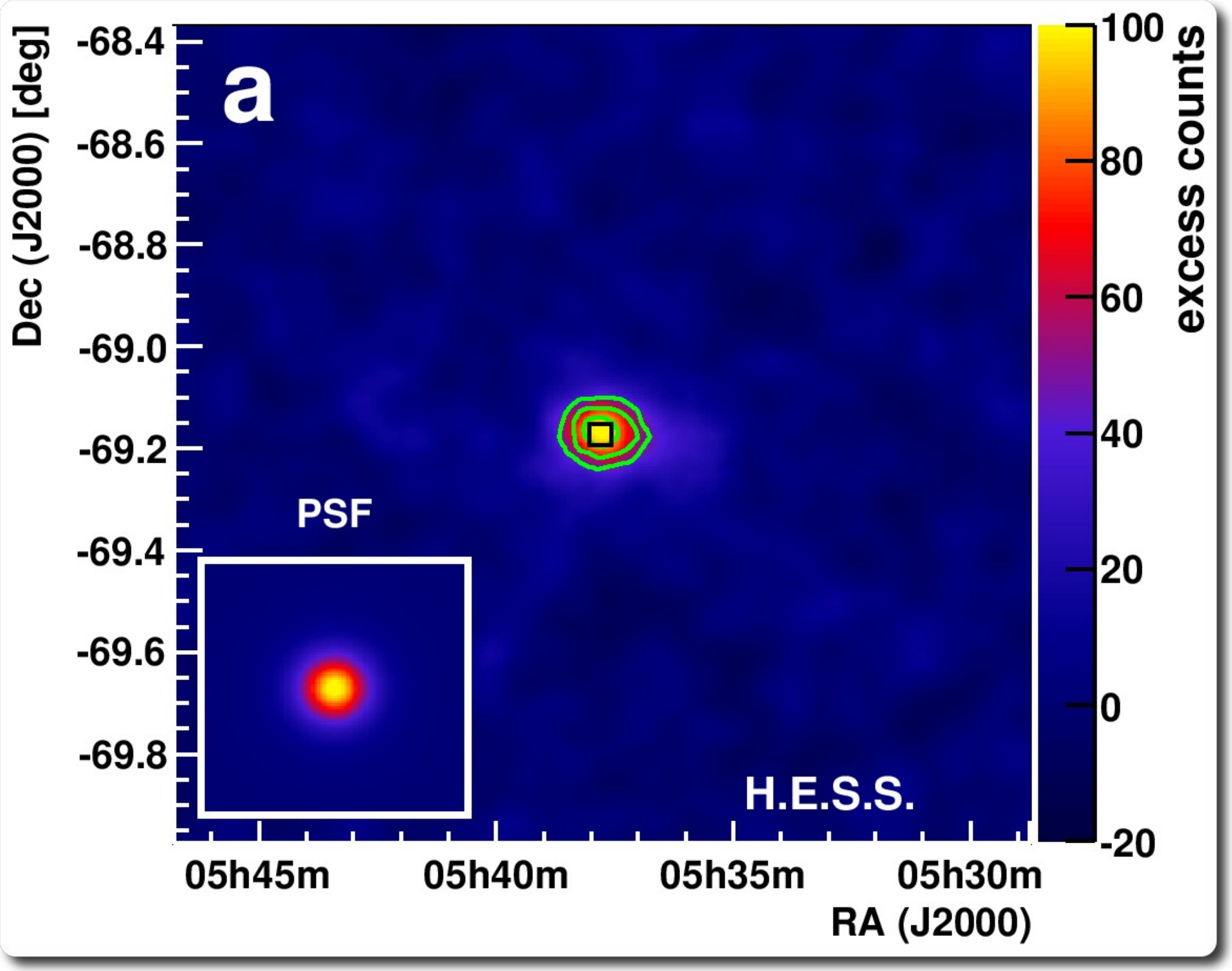
LMC in VHE Gamma Rays

- exposure 46h
- large zenith angles: ~47°
  → $E_{threshold}$ ~600 GeV
- spatial resolution ~0.06°
  (68% containment of PSF)
- significance from oversampling with radius 0.06°
  - adapted for search for point-like sources
- one TeV source exceeding 5σ



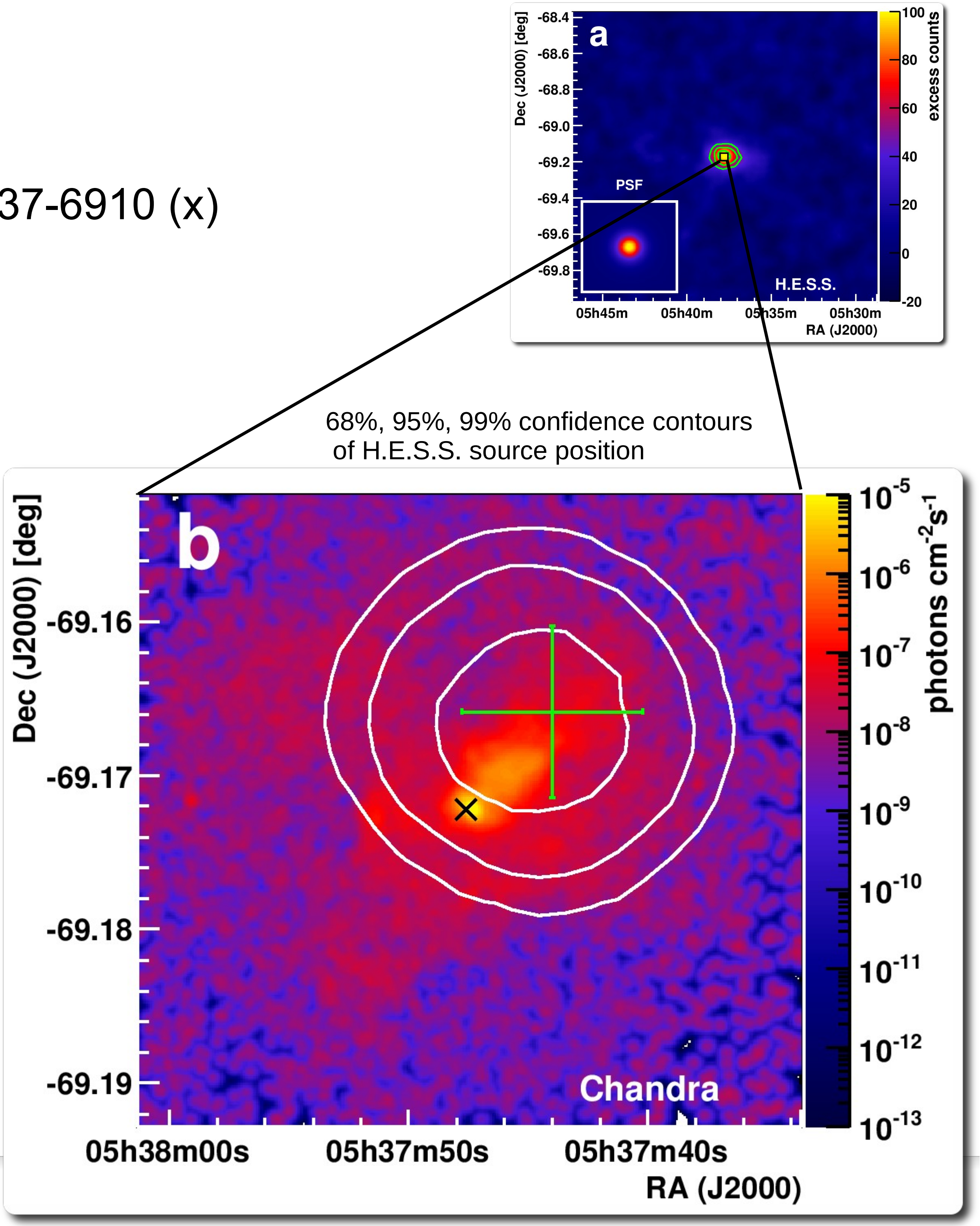
HESS J0537–691

- excess
  - 226 events
  - 14σ
- position
  - point-like source fit
  - RA $5^h 37^m 44^s$
  - Dec –69° 9' 57"
  - ± 11" (stat)
  - ± 20" (syst)



N157B

- position compatible with PSR J0537-6910 (x)
  - most energetic pulsar known
    - $\dot{E} = 4.9\ 10^{38}$ erg/s
  - spin-down age ~5000 years
  - bright PWN
  - displacement of TeV emission along tail is not significant!
- N157B supernova remnant
  - age ~5000 years
  - low-density environment

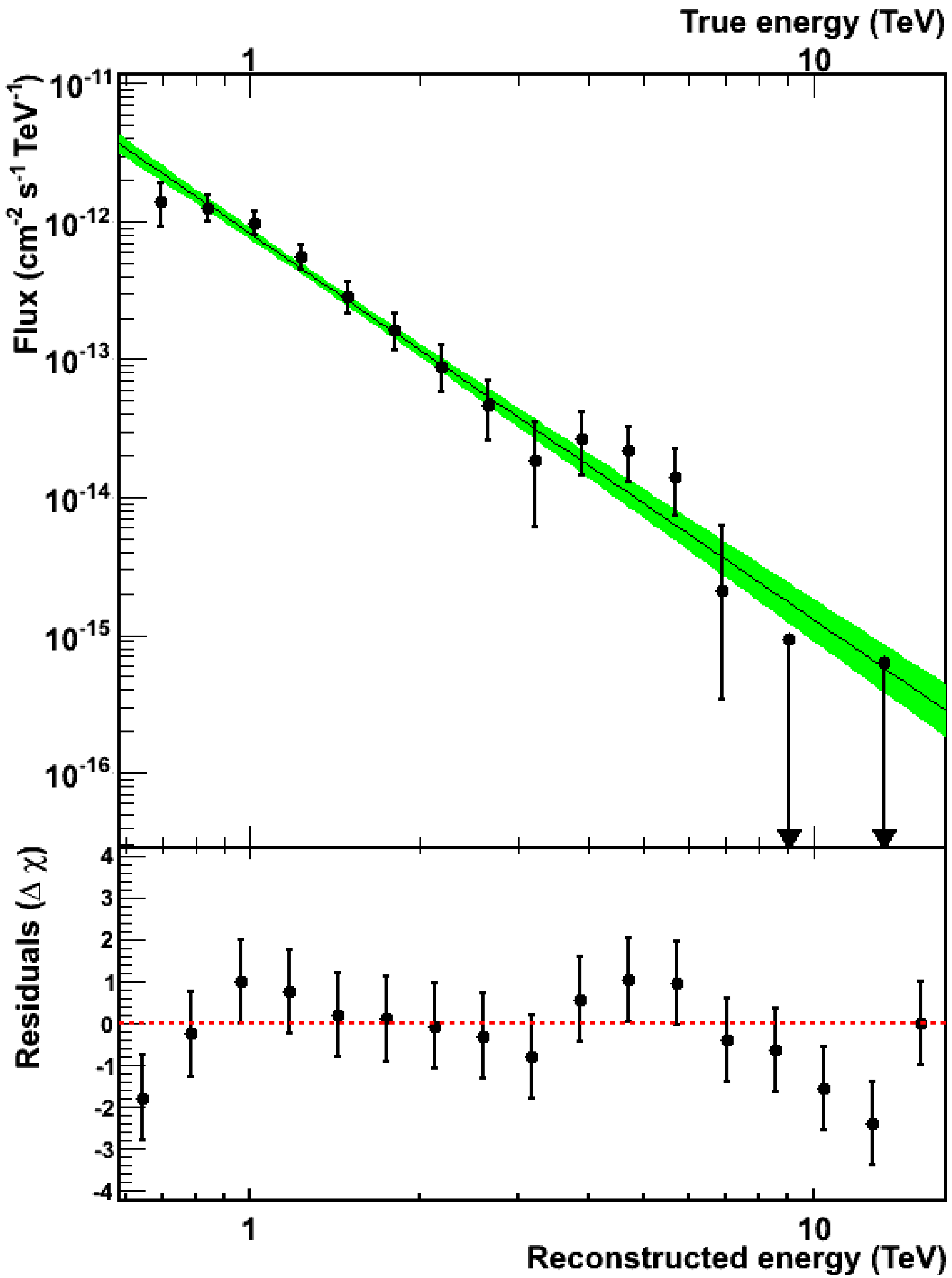


H.E.S.S.

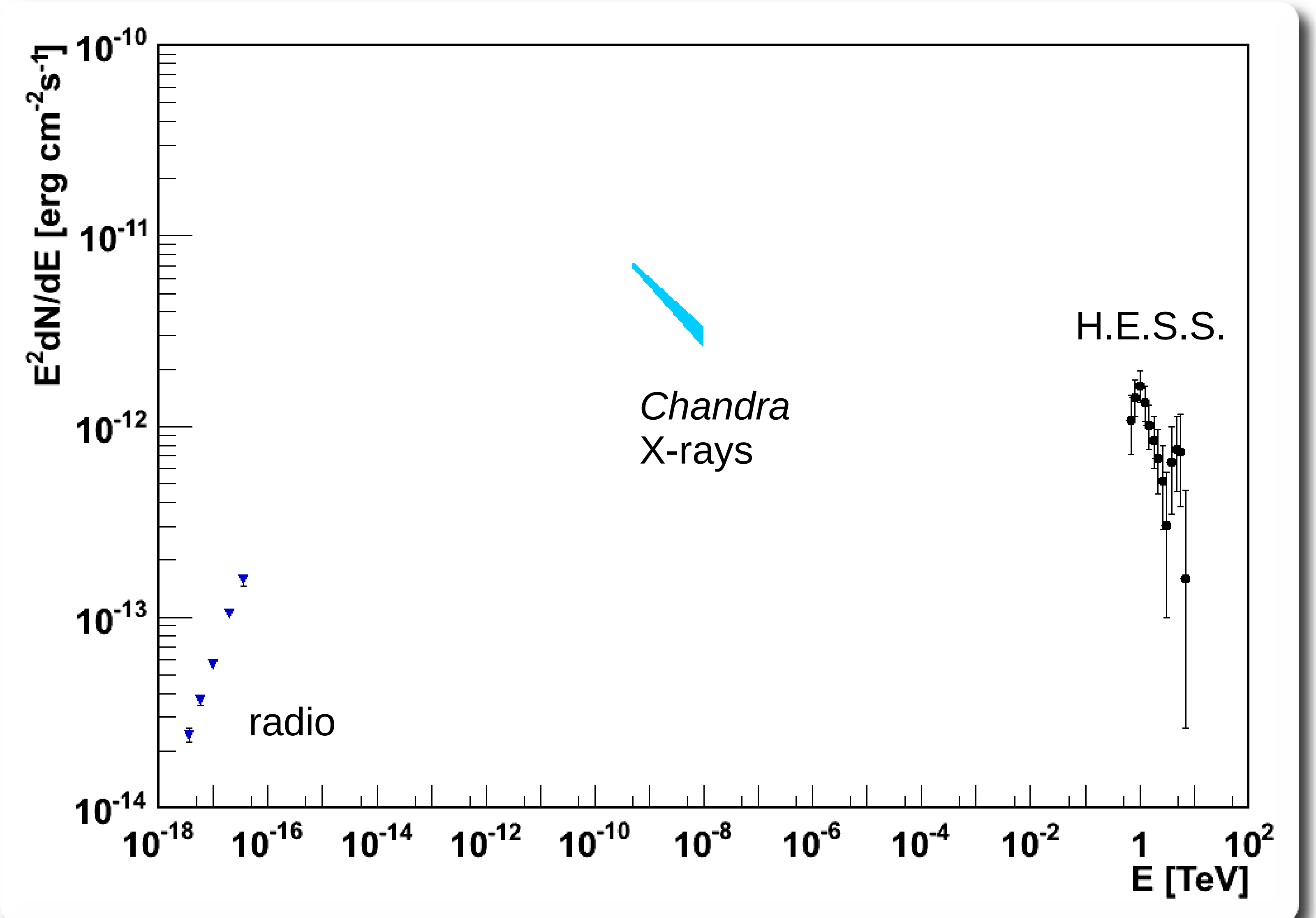
Energy Spectrum

- power law spectrum
  - Φ (1 TeV) = $(8.2 \pm 0.8_{stat} \pm 2.5_{sys})\ 10^{-13}\ cm^{-2}s^{-1}TeV^{-1}$
  - spectral index $2.8 \pm 0.2_{stat} \pm 0.3_{sys}$
- energy flux 1...10 TeV
  - $(1.4 \pm 0.1)\ 10^{-12}$ erg $cm^{-2}s^{-1}$
  - 2% Crab flux
- luminosity 1...10 TeV
  - $(3.9 \pm 0.3)\ 10^{35}\ d_{48kpc}$ erg s^{-1}
  - 0.08% $\dot{E}$

    → similar to Galactic PWNe
  - 100 times Crab luminosity
    → "Super-Crab"



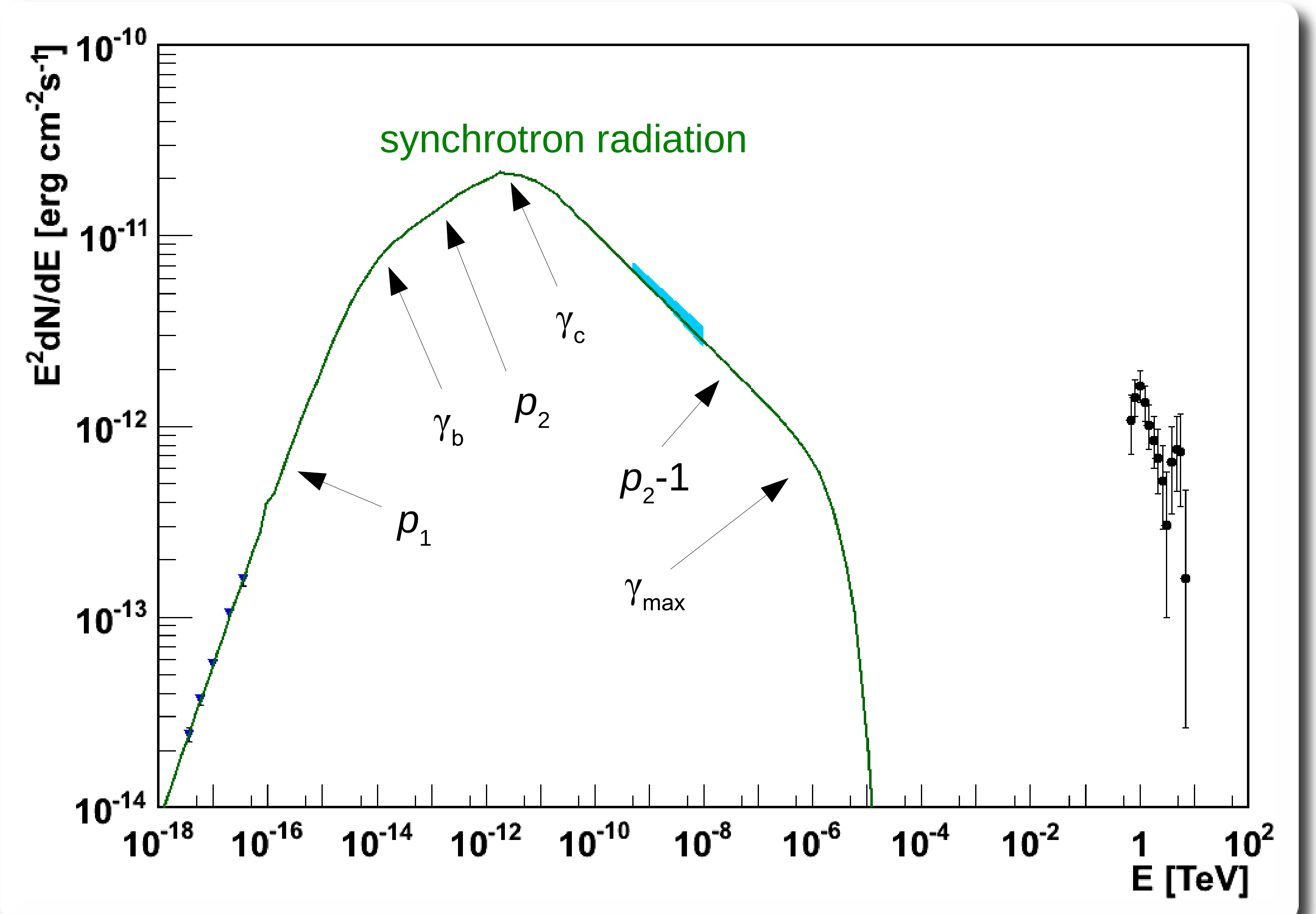
SED Modelling



SED Modelling

electron population:
[Venter & de Jager 2007]

$$Q(\gamma, t) = \begin{cases} Q_0(t)(\gamma/\gamma_b)^{-p_1} & \text{for } \gamma < \gamma_b , \\ Q_0(t)(\gamma/\gamma_b)^{-p_2} & \text{for } \gamma_b < \gamma < \gamma_{max} \end{cases}$$



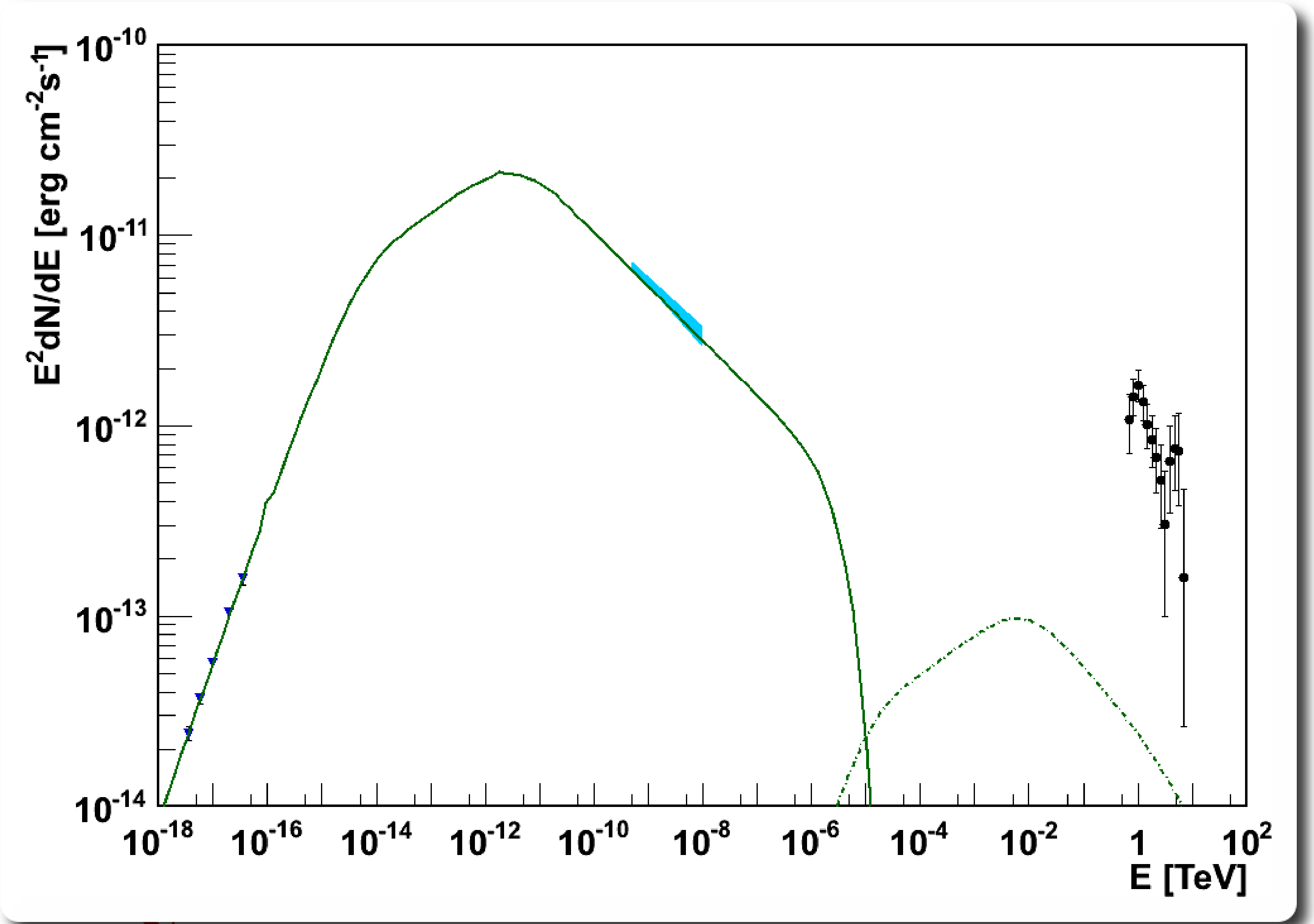
intrinsic break γ_b

max. energy
$\gamma_{max} = 10^{15}$eV

additional cooling break γ_c
where the remnant's age (5000 years) exceeds synchrotron cooling time

SED Modelling

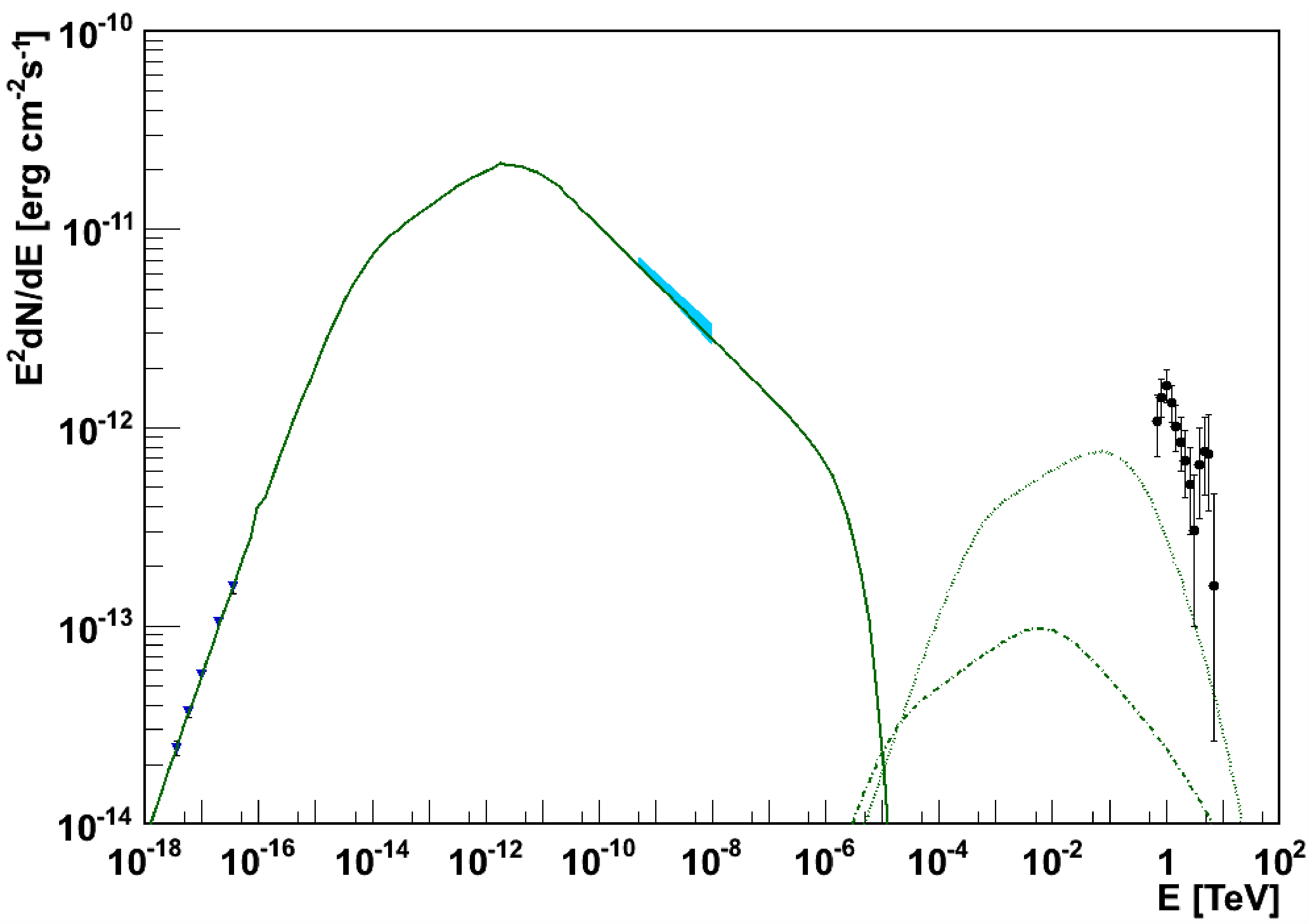
inverse Compton emission off:



- CMB

SED Modelling

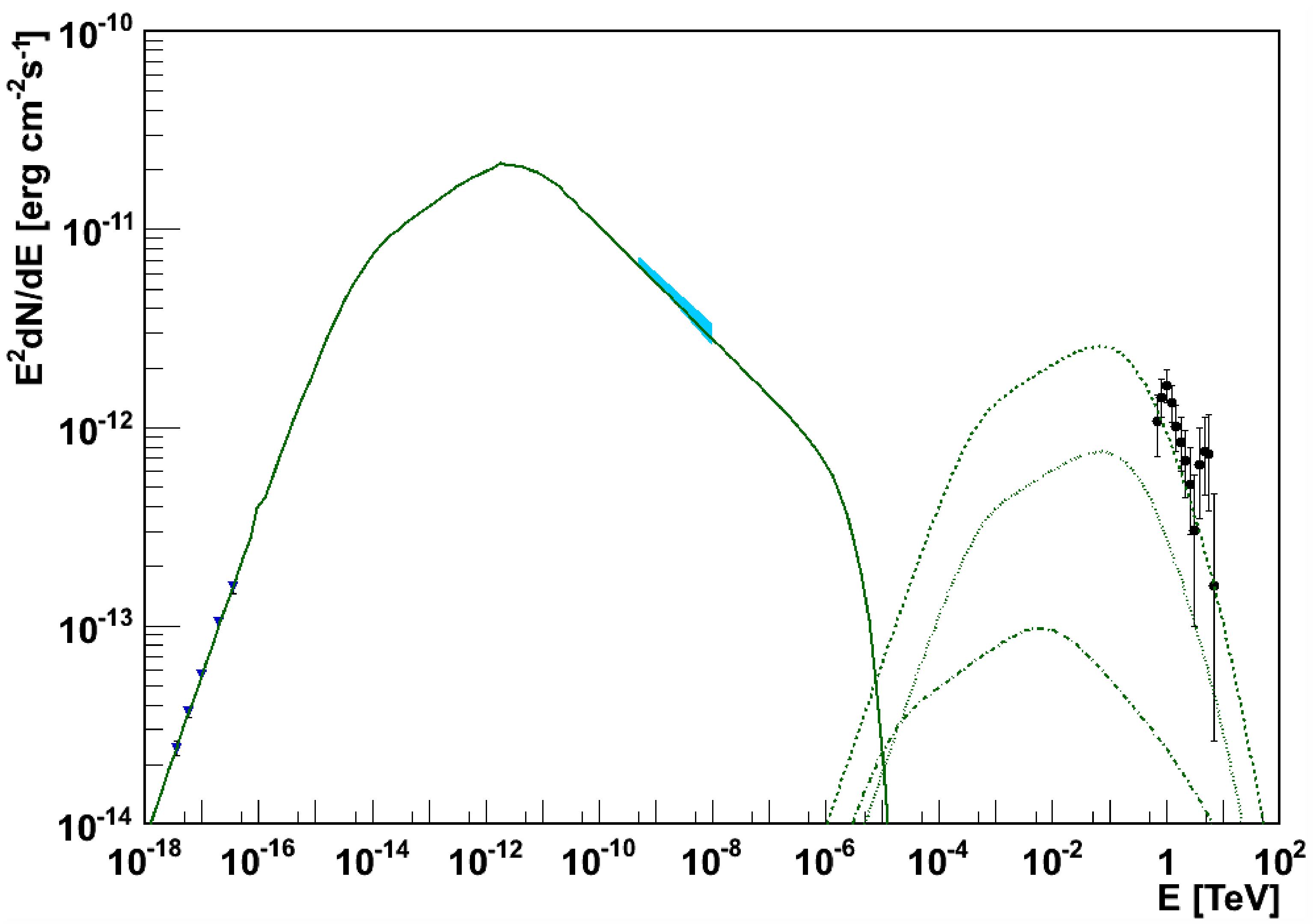
inverse Compton emission off:



- CMB
- infrared from 30 Doradus
  - 88K
  - 2.7 eV cm^{-3}

SED Modelling

inverse Compton emission off:



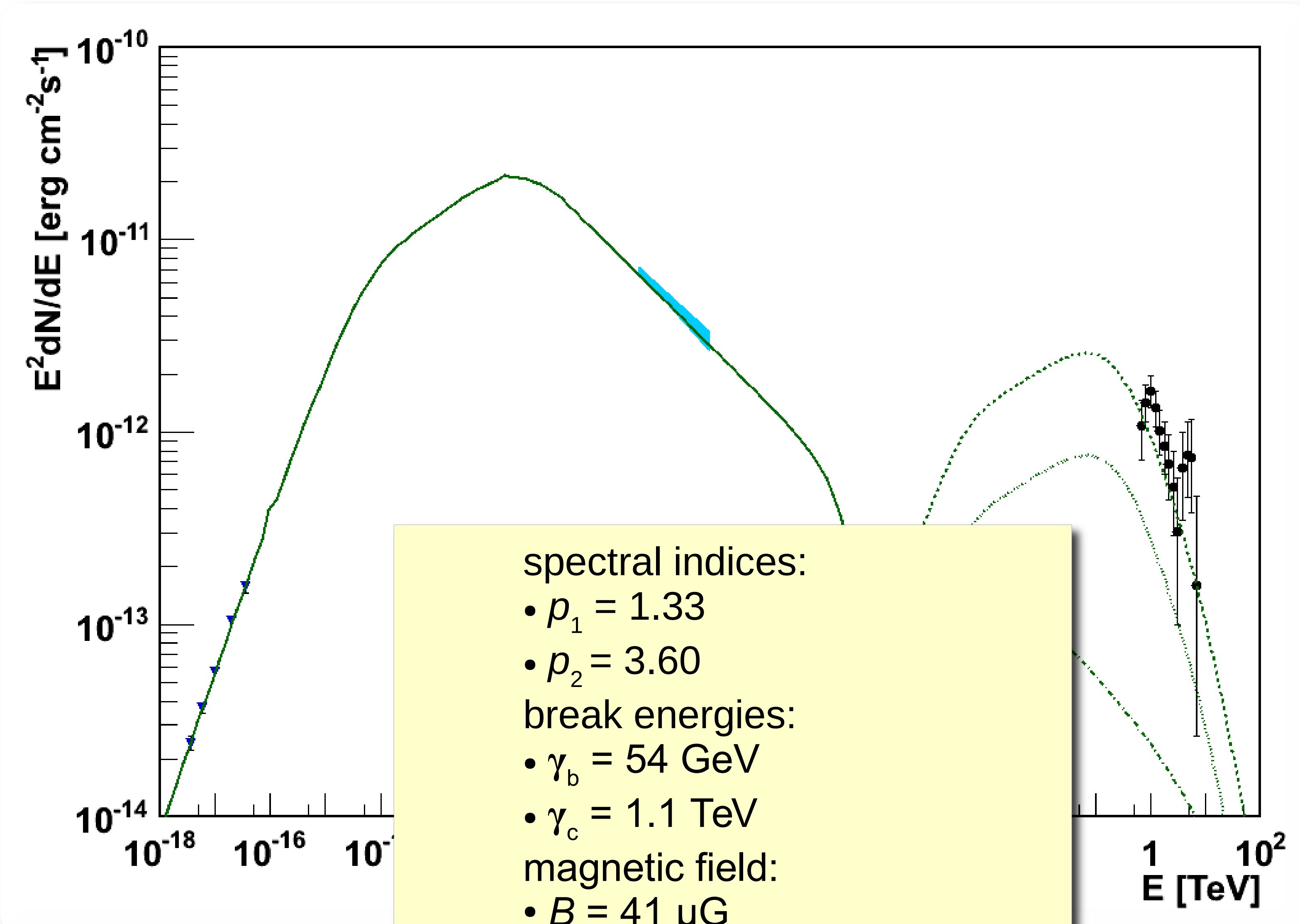
- CMB
- infrared from 30 Doradus
  - 88K
  - 2.7 eV cm^{-3}
- infrared from LH 99 (OB ass.)
  - 80 K
  - 8.9 eV cm^{-3}

strong IR fields dominate IC emission
→ reason for visibility at this distance

H.E.S.S.

SED Modelling

inverse Compton emission off:



spectral indices:

- p_1 = 1.33
- p_2 = 3.60

break energies:

- γ_b = 54 GeV
- γ_c = 1.1 TeV

magnetic field:

- B = 41 μG

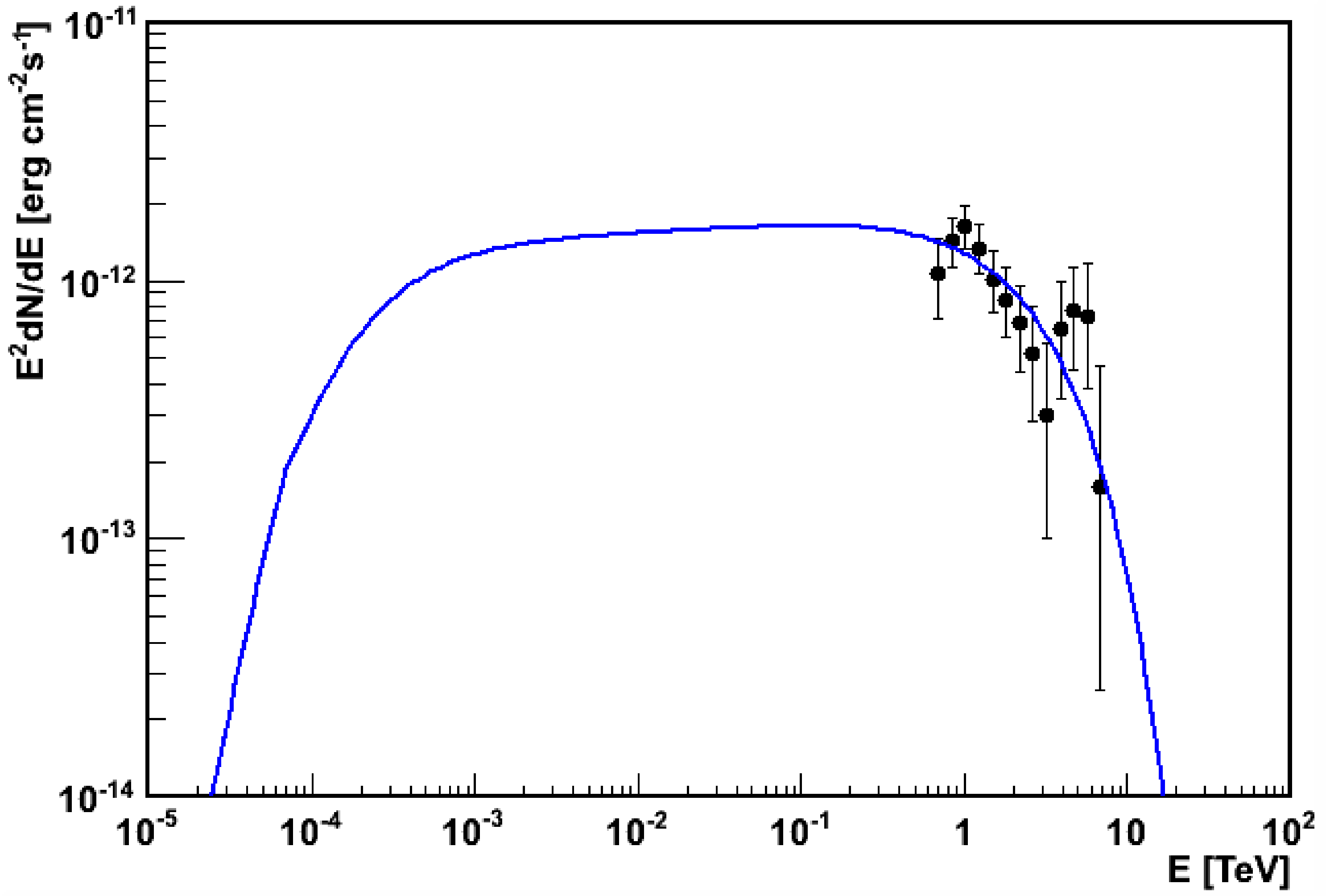
total energy in electrons:

- W_{tot} = 4 x 10^{49} erg

- CMB
- infrared from 30 Doradus
  - 88K
  - 2.7 eV cm^{-3}
- infrared from LH 99 (OB ass.)
  - 80 K
  - 8.9 eV cm^{-3}

strong IR fields dominate IC emission
→ reason for visibility at this distance

SED Modelling



hadronic model:
proton power-law index 2
exp. cut-off at 23 TeV
total energy in protons 1.8×10^{52} $(n/1cm^{-3})^{-1}$ erg

→ 100 cm^{-3} necessary for reasonable energy

SNR expands into low density medium
→ hadronic model excluded

Interpretation

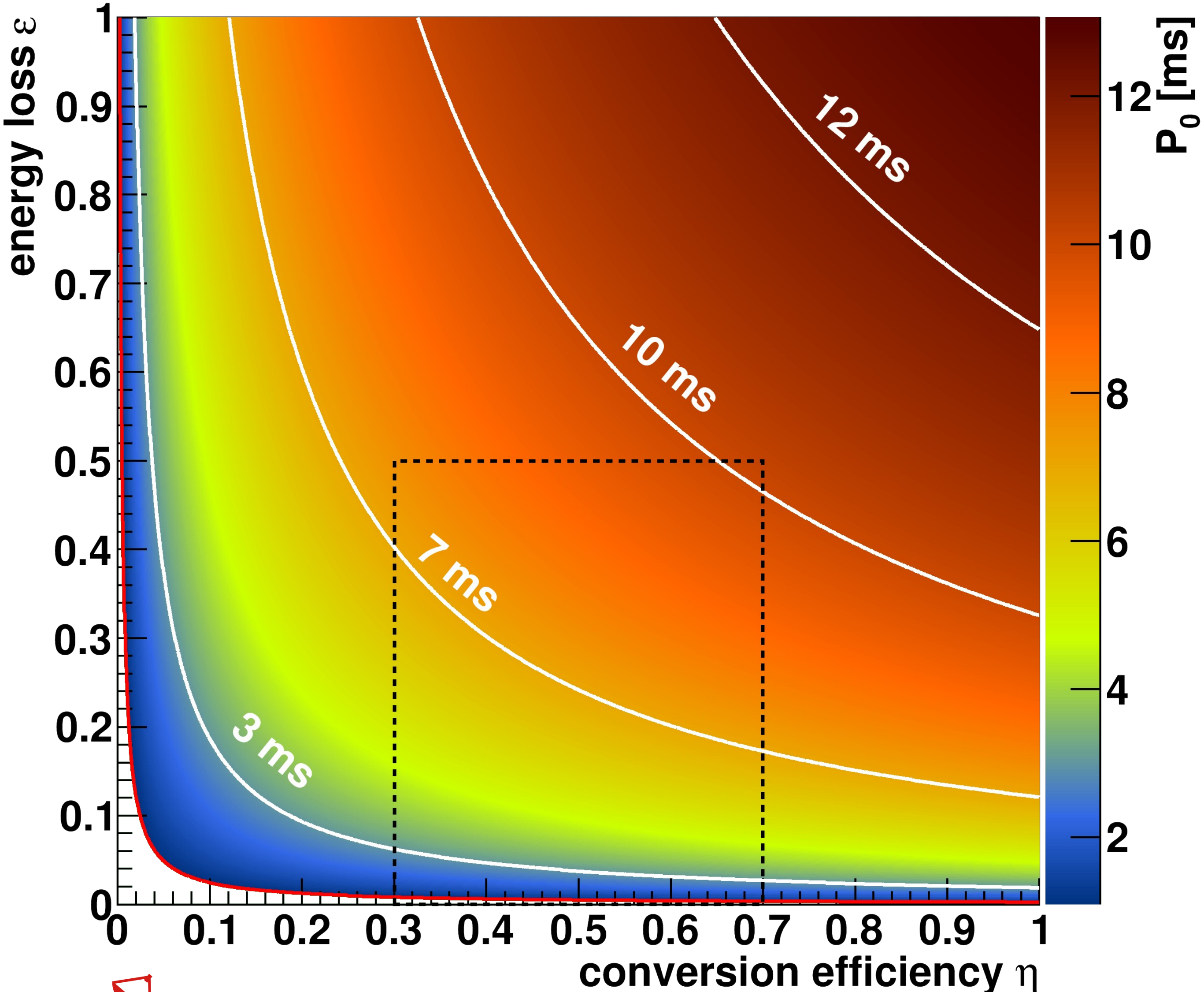
- W_{tot} = 4 x 10^{49} erg, estimate pulsar's birth period [de Jager, 2008]

$$
\begin{aligned}
W_{\rm tot} &= \epsilon\eta\left(E_{\rm rot,0} - E_{\rm rot}\right) \\
&= \epsilon\eta\frac{1}{2}I\left(\left(\frac{2\pi}{P_0}\right)^2 - \left(\frac{2\pi}{P}\right)^2\right) \\
&= 2\times10^{49}\epsilon\eta\frac{I}{10^{45}\,\mathrm{g\,cm^2}}\left(\left(\frac{10\,\mathrm{ms}}{P_0}\right)^2 - \left(\frac{10\,\mathrm{ms}}{P}\right)^2\right)\mathrm{erg}
\end{aligned}
$$

- P current period of 16.1ms [Marshall et al. 1998]
- η conversion efficiency of spin-down power into accelerated electrons
  - $\eta \gtrsim 0.3$, e.g. MSH 15-52 [Schöck et al. 2010]
  - $\eta \lesssim 0.7$, e.g. G21.5-0.9 [de Jager et al. 2008]
- $\varepsilon < 0.5$
  - $\varepsilon \approx 0.5$, from MHD simulations [de Jager et al. 2009]
  - further losses in earlier epochs makes it smaller

H.E.S.S.

Interpretation



birth period is <13ms

birth period is likely <10ms

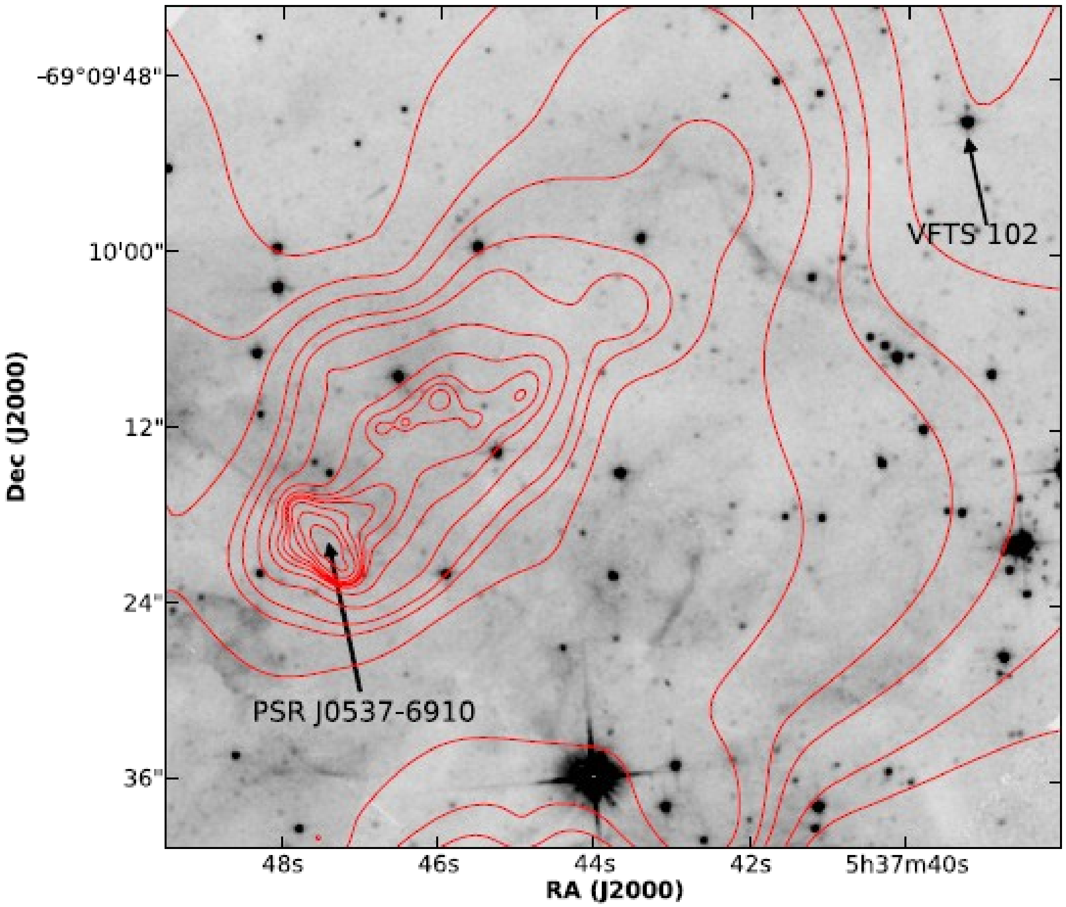
confirms earlier results:

- <10 ms
  - [Marshall et al 1998]
  - depend on age and braking index
- 11 ms
  - [Marshall et al. 2004]
  - from glitch extrapolation

Here: independent of age, braking index, glitch data

Spin-up in binary system?

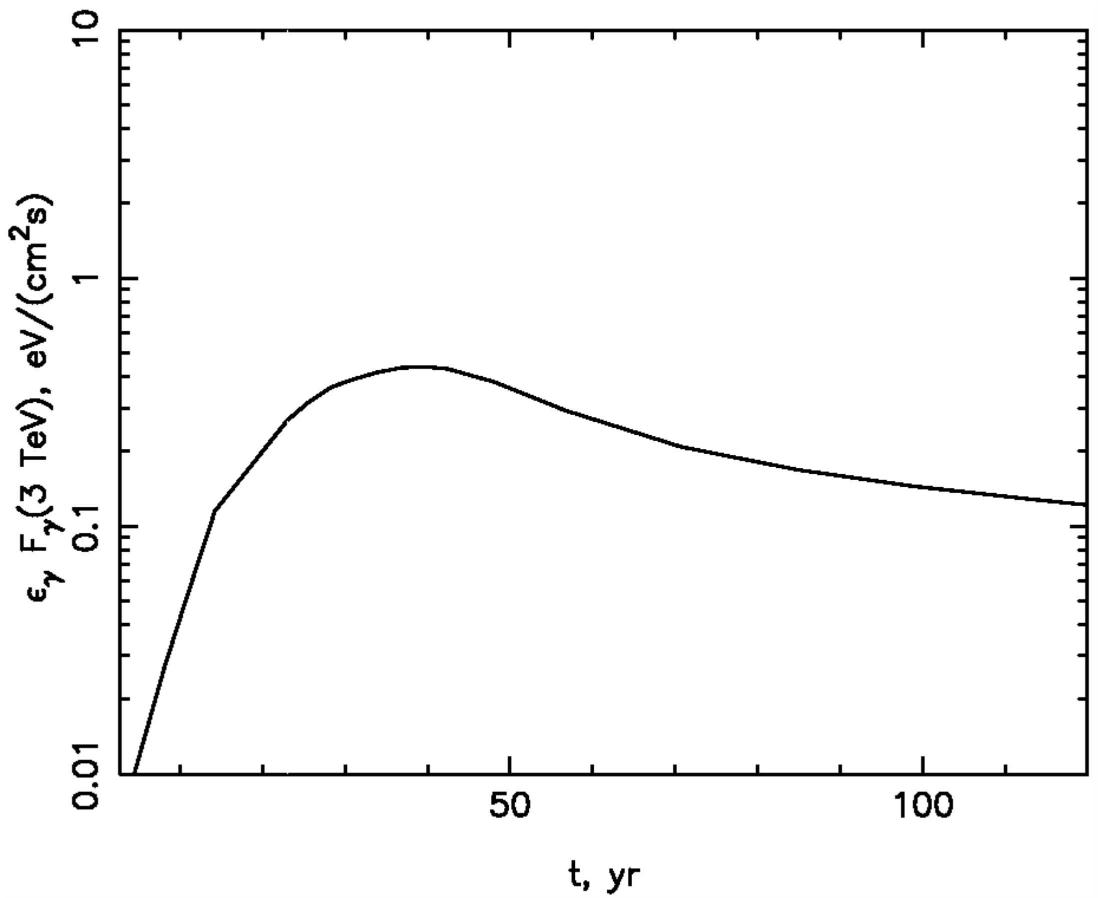
- [Dufton et al. 2011]
  - VFTS 102
    - proj. rotational velocity > 500 km/s
    - ~25 solar masses
    - along the major axis of PWN
  - suggest binary origin with velocity kicks to both objects in SN explosion
- possible, but
  - no proof that both are related
  - if so, they are long separated



H.E.S.S.

Supernova SN 1987A

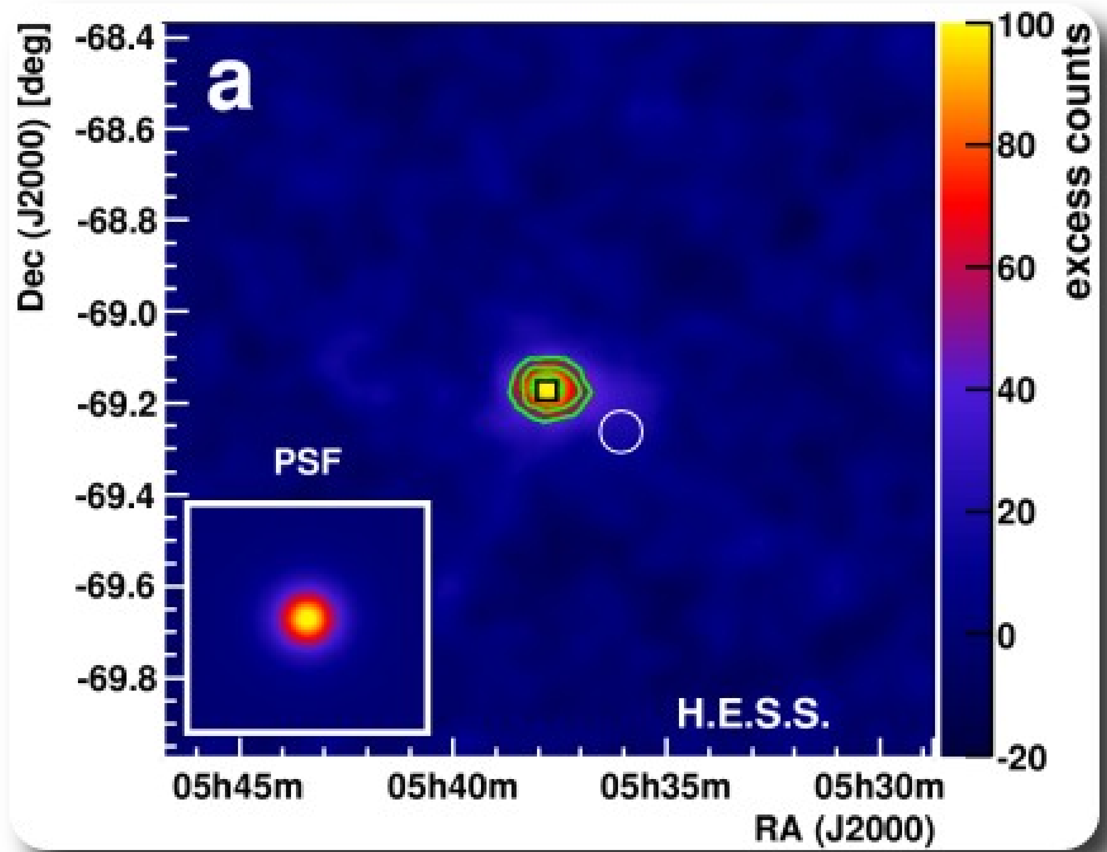
- supernova explosion in 1987
- detection of neutrinos
- known progenitor star
  - Sanduleak -69° 202
  - blue super-giant,
    with recent red super-giant phase
  - 20 solar masses
- predicted TeV gamma-ray emission from hadronic interactions
  - [Berezkho *et al.* 2010]
- initial target of H.E.S.S. observations



H.E.S.S.

SN 1987A

- nothing seen in sky map
- at test position:
  - 40 events
  - 3.8σ
  - spill-over from bright source
  - under investigation
- upper limit on the flux:
  - I (> 1TeV) < 1.1 10^{-13} $cm^{-2}s^{-1}$



SN 1987A

- upper limit consistent with predictions for 2010
- consistent with time line [HESS, ICRC 2011]
- flux will increase in next years
- → further observations with H.E.S.S. and CTA encouraged

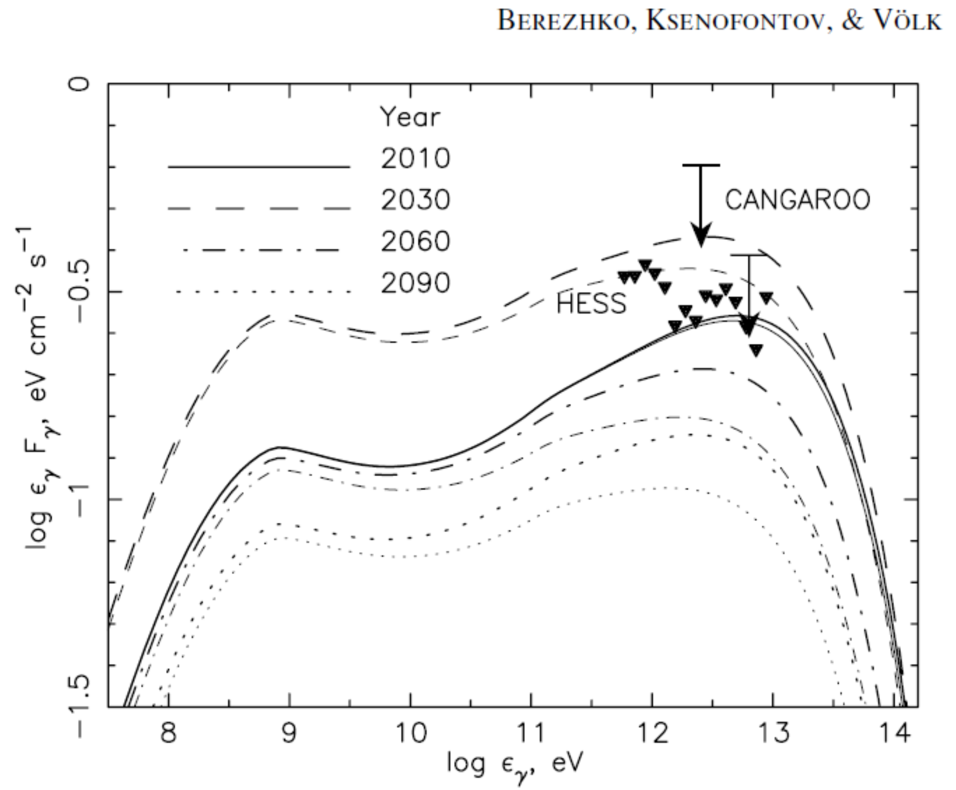
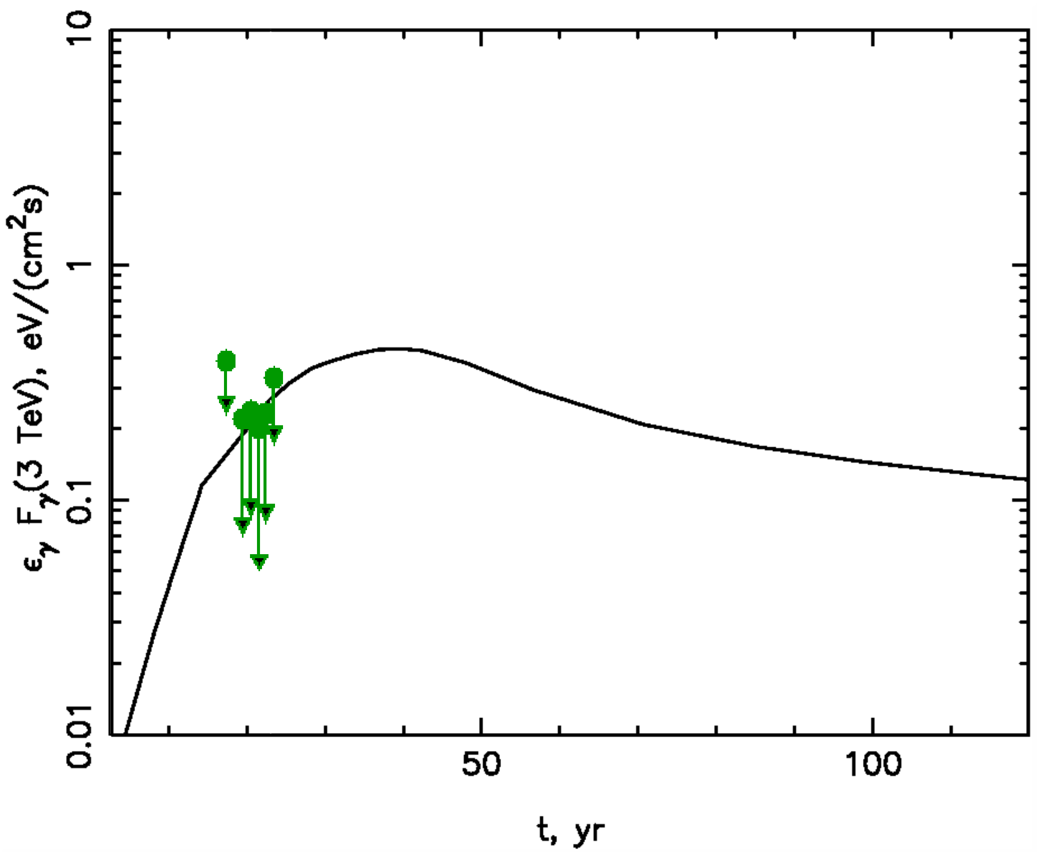


Figure 5. Integral γ-ray energy flux from SN 1987A, calculated for four epochs. The CANGAROO (arrows; Enomoto et al. 2007) and the latest H.E.S.S. (triangles; Komin et al. 2010) upper limits are shown as well.



H.E.S.S.

Summary

- medium deep exposure with H.E.S.S. on the LMC
- detection of N 157B
  - Crab-like pulsar wind nebula
  - very luminous in TeV
  - MWL modelling → very short birth period
  - [H.E.S.S. Collaboration, *A&A* **545**, L2]
- non-detection of SN 1987A
  - upper limit on TeV emission consistent with predictions
  - TeV emission will increase in the next years → remains interesting target
- full data set of about 200h
  - publication in preparation

Backup Slides

Progenitor Star

- it's mass
  - [Heger et al. 2005]

TABLE 4

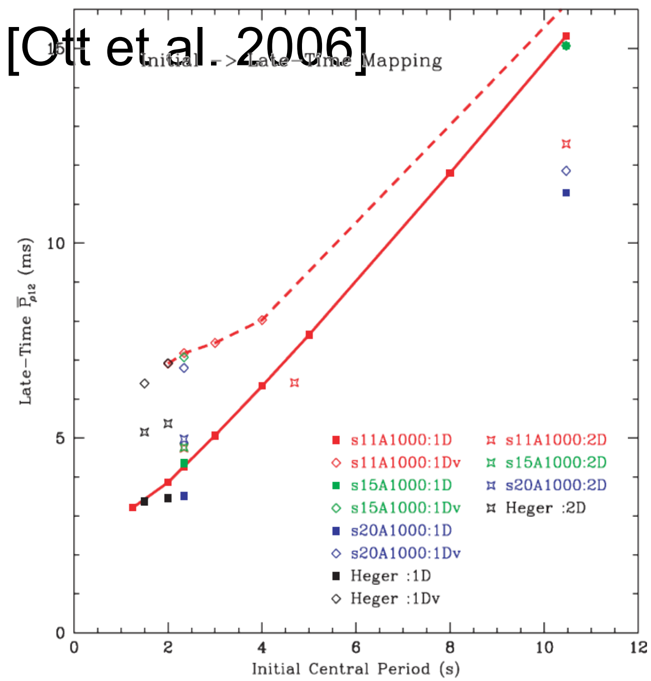
PULSAR ROTATION RATE WITH VARIABLE REMNANT MASS[a]

Mass ($M_\odot$)	Baryon[b] ($M_\odot$)	Gravitational[c] ($M_\odot$)	$J(M_{bary})$ (10^{47} ergs s)	BE (10^{53} ergs)	Period[d] (ms)
12...........	1.38	1.26	5.2	2.3	15
15...........	1.47	1.33	7.5	2.5	11
20...........	1.71	1.52	14	3.4	7.0
25...........	1.88	1.66	17	4.1	6.3
35...........	2.30	1.97	41	6.0	3.0

  >15 solar masses

  - [Chen et al. 2006]
    20 – 35 solar masses
  - close to black hole formation
    ~25 solar masses [Fryer 1999]

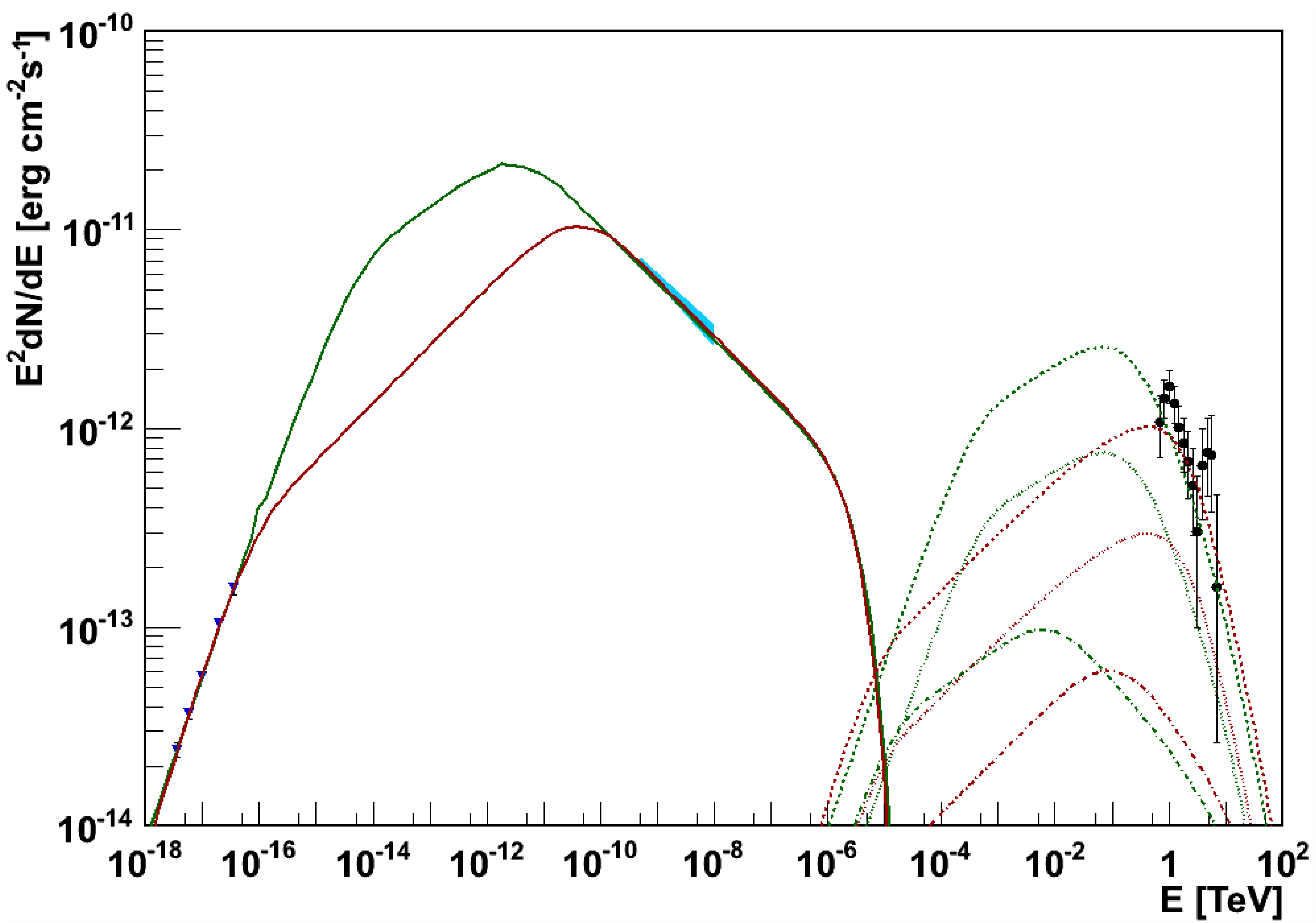
- it's iron-core spin period
  - [Ott et al. 2006]



  - < 8s

→ **progenitor was very massive and/or rapidly spinning**

SED Modelling



conservative model:

- independent of age
- minimal intrinsic break
- maximal cooling break
- minimises total energy
- γ_b = 7 GeV
- γ_c = 4.22 TeV
- B = 47 μG
- W_{tot} = 2 x 10^{49} erg

H.E.S.S.