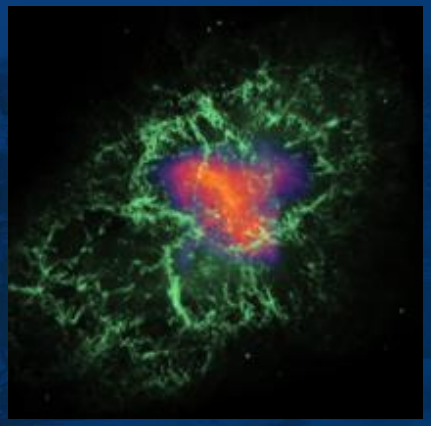
Fermi + HESS analysis on the Crab nebula



Tim Unbehaun – Synergies in Non-Thermal Astrophysics in Southern Africa
Erlangen, 30.07.2024

H.E.S.S.

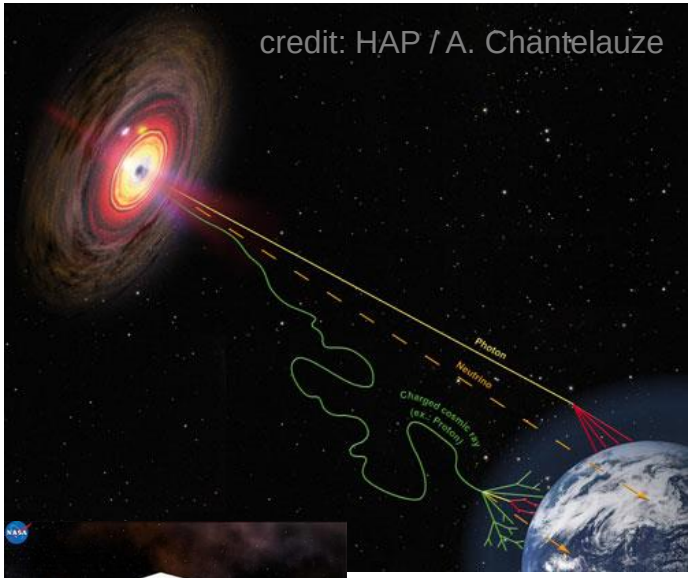
Fermi Gamma-ray Space Telescope

ECAP ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

FAU FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG

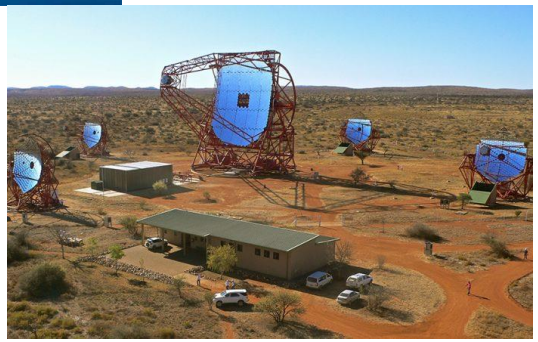
Motivation

- Crab nebula as bright, well studied gamma-ray source
- Test a joint-likelihood analysis where the data of the two instruments is combined at the event level
- Use Fermi-LAT + H.E.S.S. data to constrain the Inverse Compton spectrum and morphology of the nebula
- Combine with radio to x-ray data of the synchrotron regime
- Compare to the prediction of phenomenological Synchrotron-Self-Compton models
- Publication at https://arxiv.org/abs/2403.12608



Credit: NASA / Aurore Simonnet

Credit: HESS Collaboration



3D analyses with Gammapy

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- Binned likelihood analysis in 3D (2 spatial, 1 energy)
- Combination of different data sets at likelihood level
  → can fit same physical model to data from different instruments
- Requirement: instrument data (DL3) in common format
  → can also include i.e neutrino data,
  although package is designed for γ-ray data analysis

3D analyses with Gammapy

- **MapDataset** holds counts, IRFs (exposure, PSF, energy dispersion) background-model, source models
  - *Counts* cube with two spatial axes + one energy axis
  - *Npred* cube with model prediction (forward folded with IRFs)
- Likelihood fitting:
  - Poisson probability in pixel i to measure n counts given the model prediction $\nu(\xi)$ for parameters ξ

$$P\left(n_i \,\middle|\, \nu_i(\xi)\right) = \frac{\nu_i(\xi)^{n_i}}{n_i!} \times \exp(-\nu_i(\xi))$$

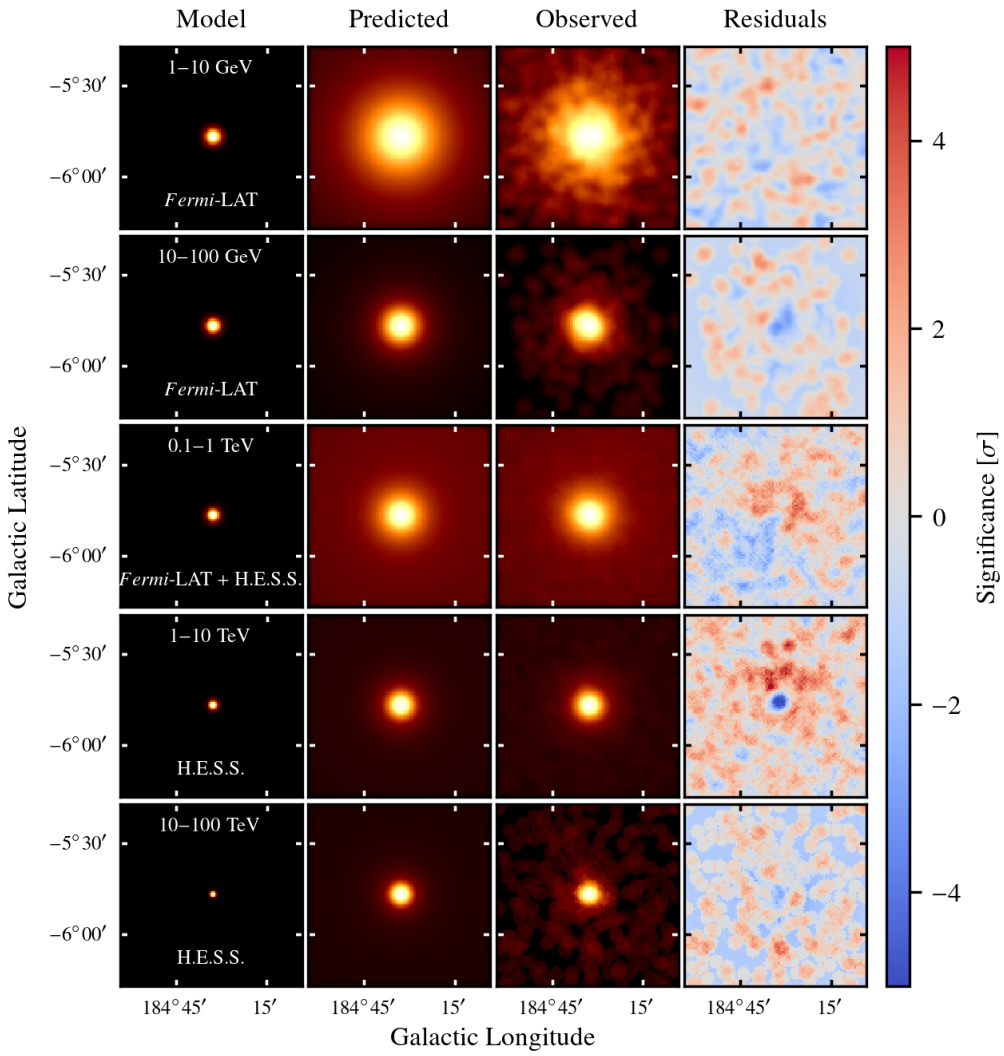
  - LogLikelihood:

$$-\ln \mathcal{L}(\xi) = -\sum_{i=1}^{N} \ln\left[\frac{\nu_i(\xi)^{n_i}}{n_i!} \times \exp(-\nu_i(\xi))\right]$$

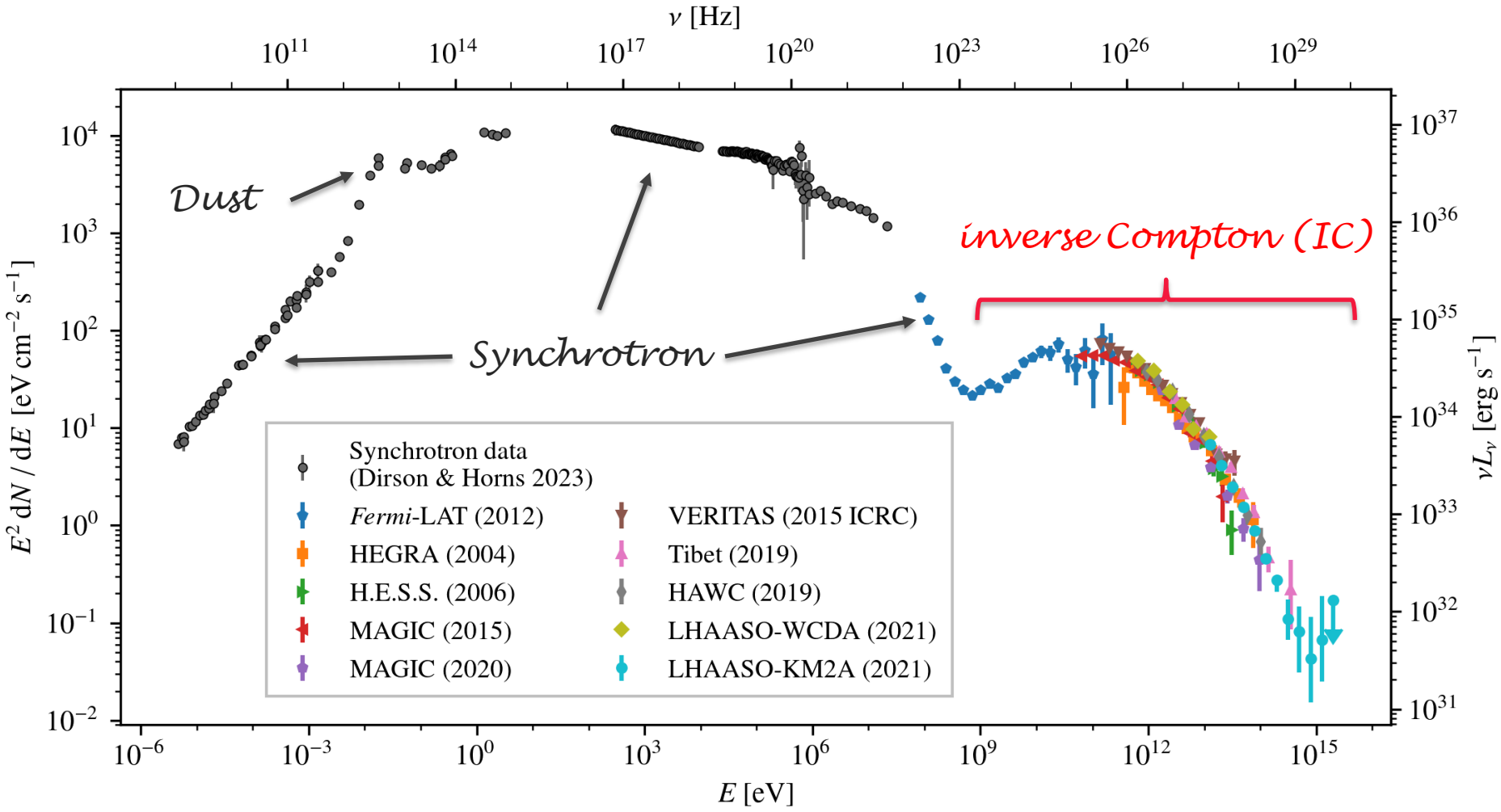
  - Minimizing $\mathrm{TS} \equiv -2 \ln \mathcal{L}$ maximizes the Likelihood

Fermi + HESS on the Crab

- Models predict flux as function of spatial and energy coordinates
- Forward folding of the model prediction using the respective IRFs of each instrument
- Minimizing the combined likelihood with respect to the binned counts

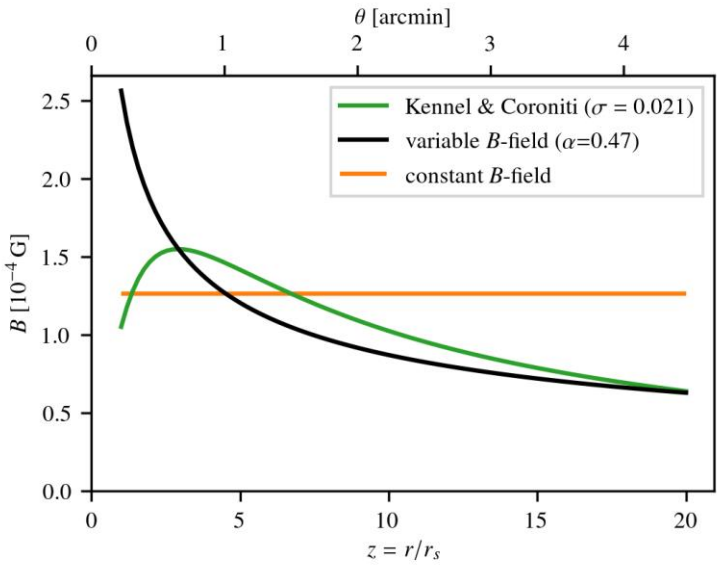


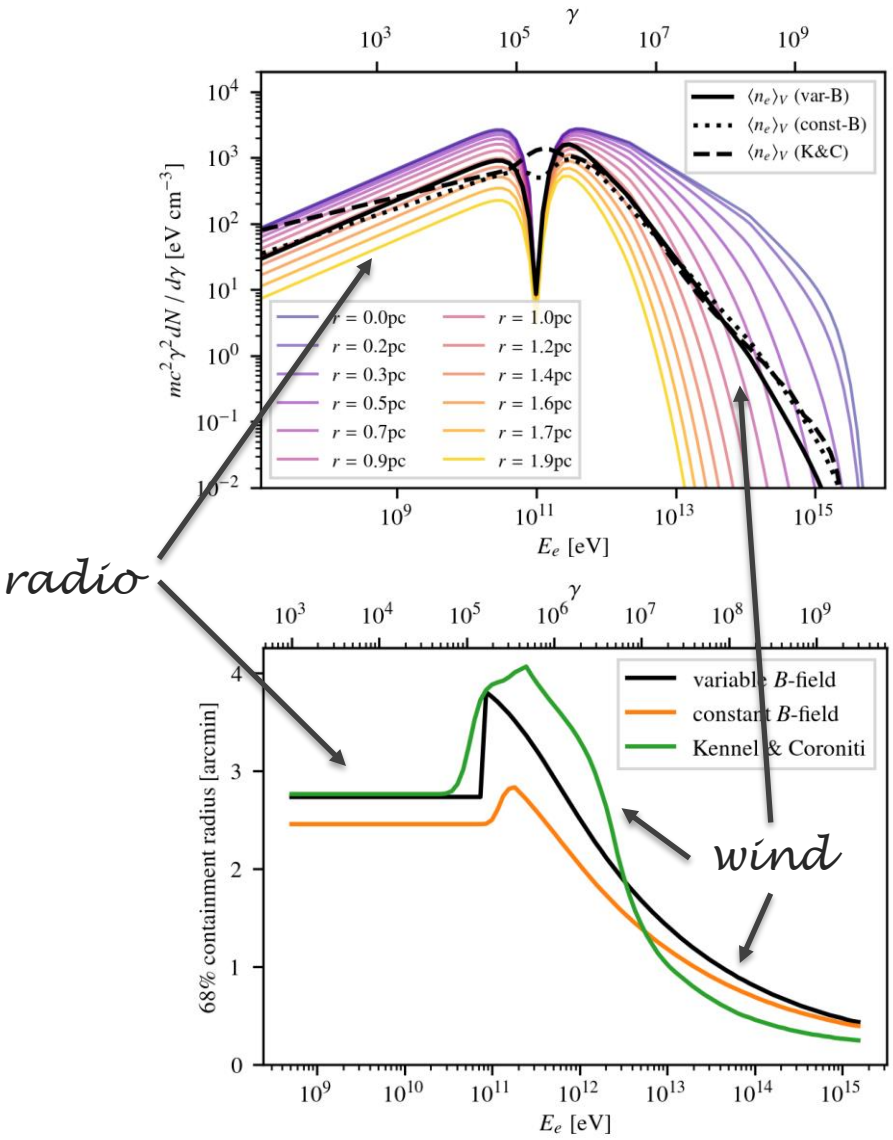
The spectrum



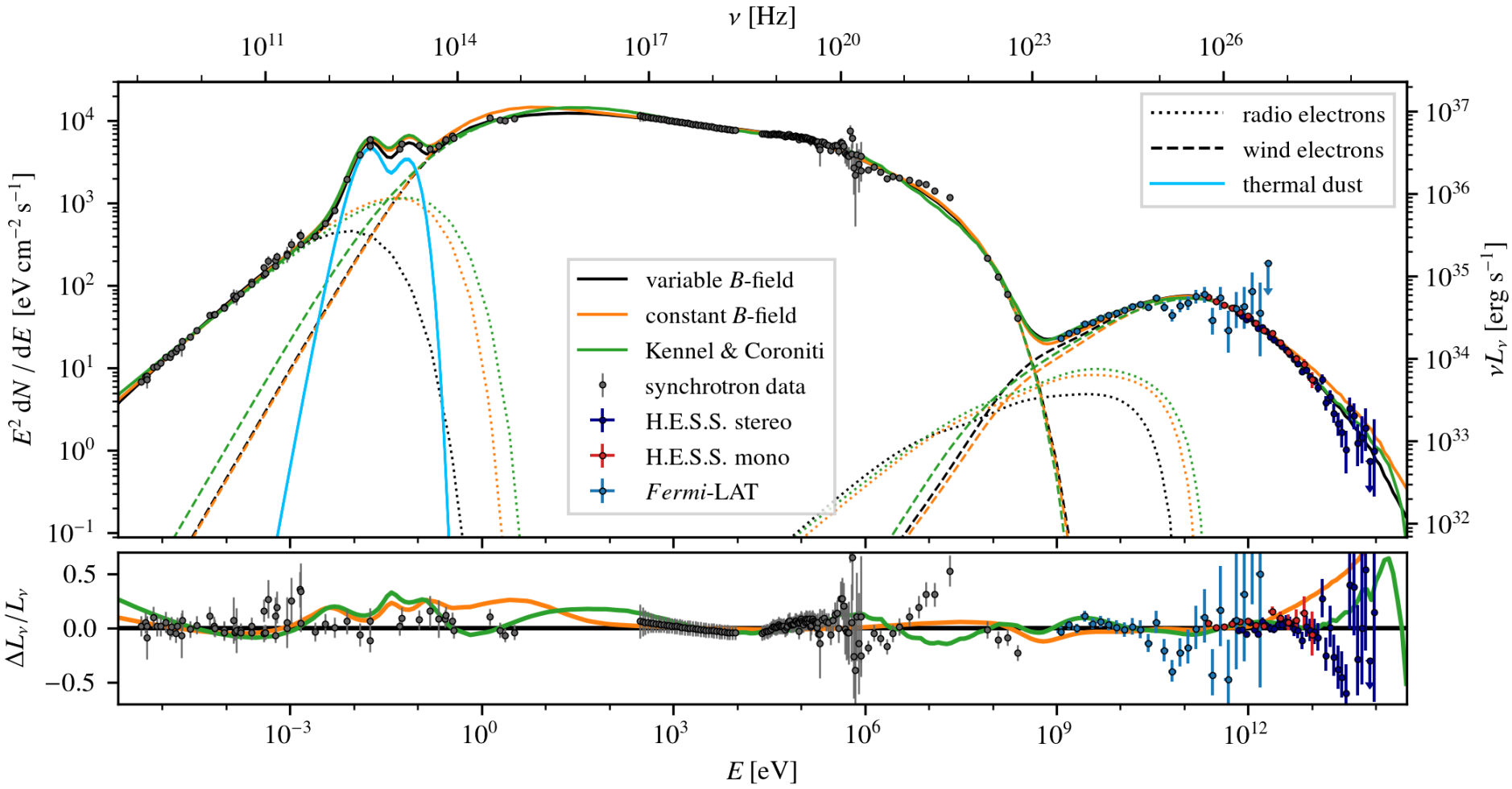
The models

- Parametrized distribution of relic ‘radio’ electrons (low energy, constant extension) and injected ‘wind’ electrons (high energy, decreasing extension)
- The models mostly differ by the assumed B-field profile

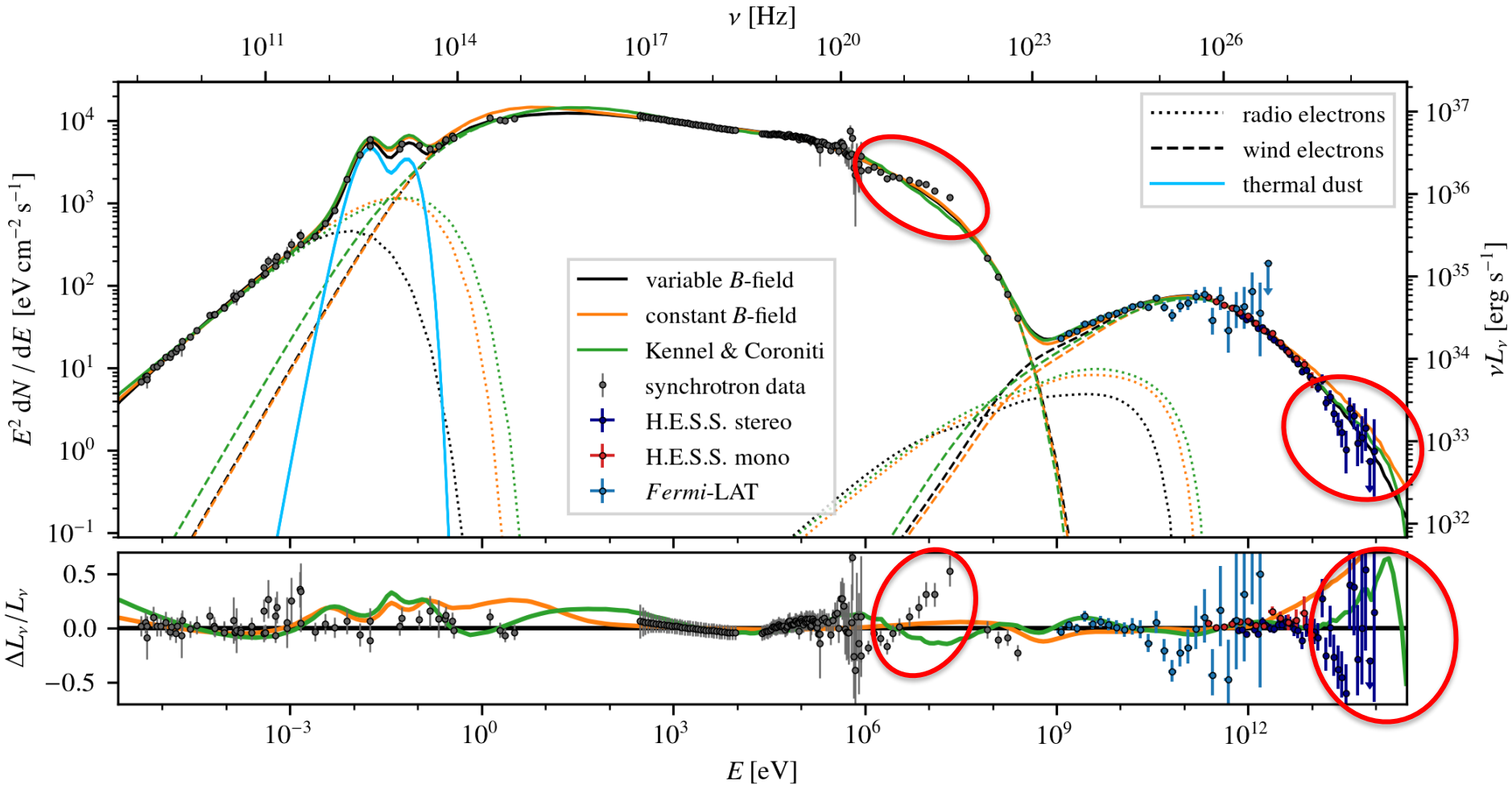




The spectrum

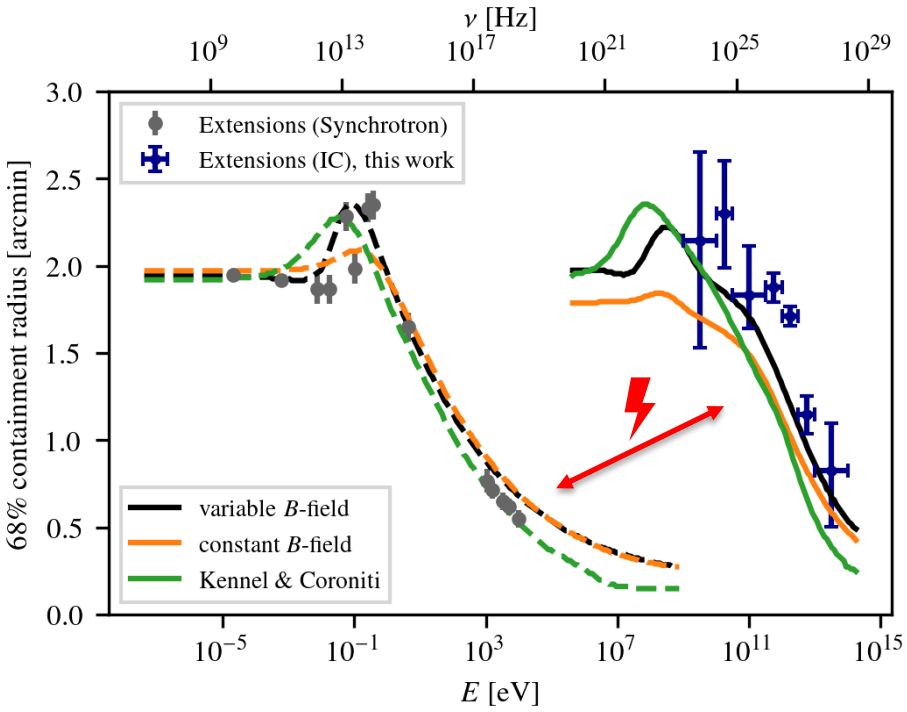


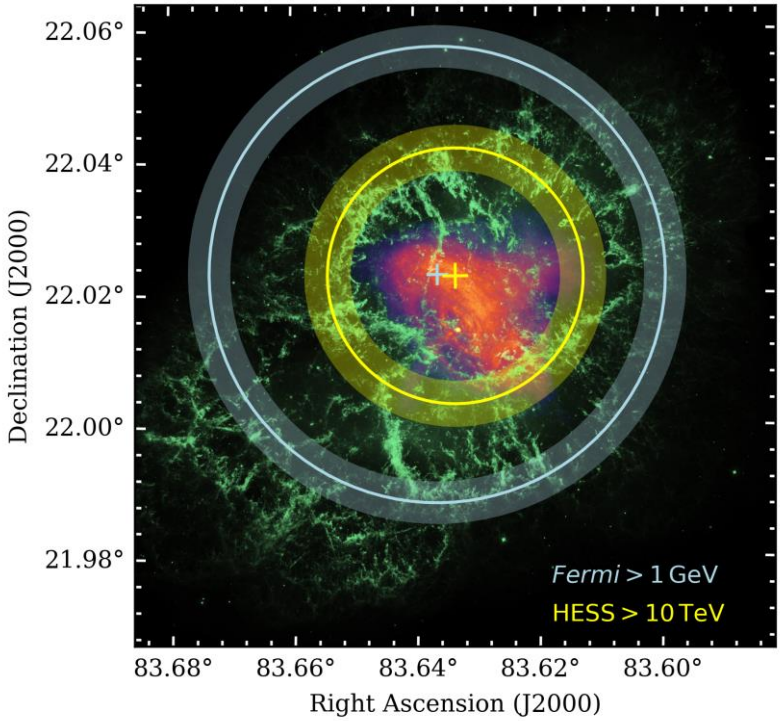
The spectrum



The extension

- The models underpredict the hard x-ray flux while overpredicting the highest energy gamma-ray flux (same electrons responsible for both)
- The small x-ray extension seems to be in conflict with the larger IC extension of the nebula if both are indeed produced by the same electrons





Thanks for your attention!

Bundesministerium
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