The young massive stellar cluster Westerlund 1 in γ rays as seen with H.E.S.S.

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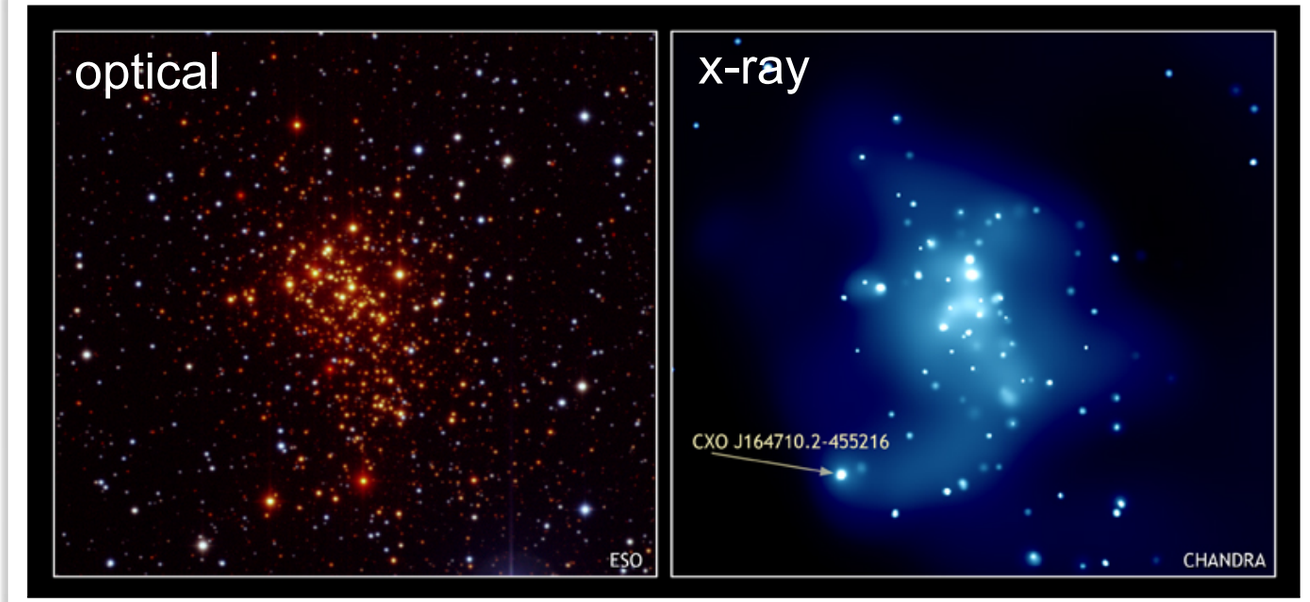
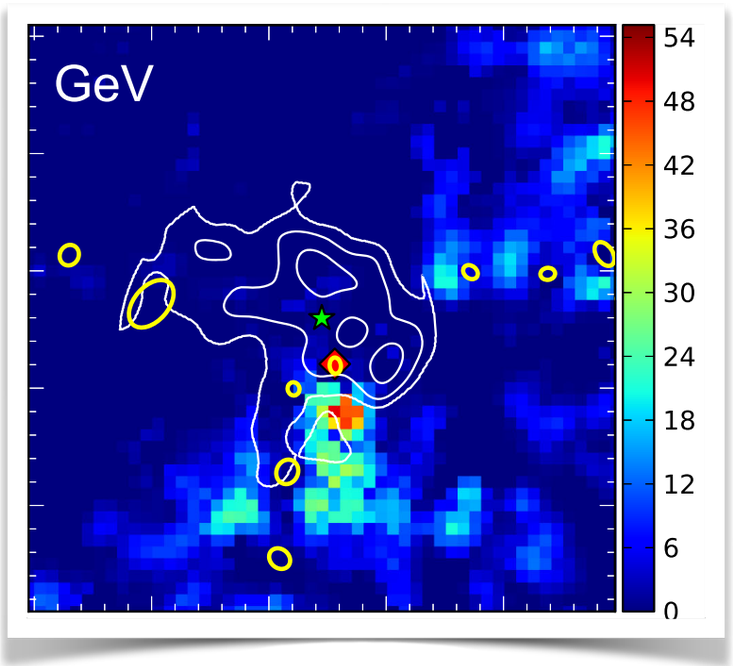
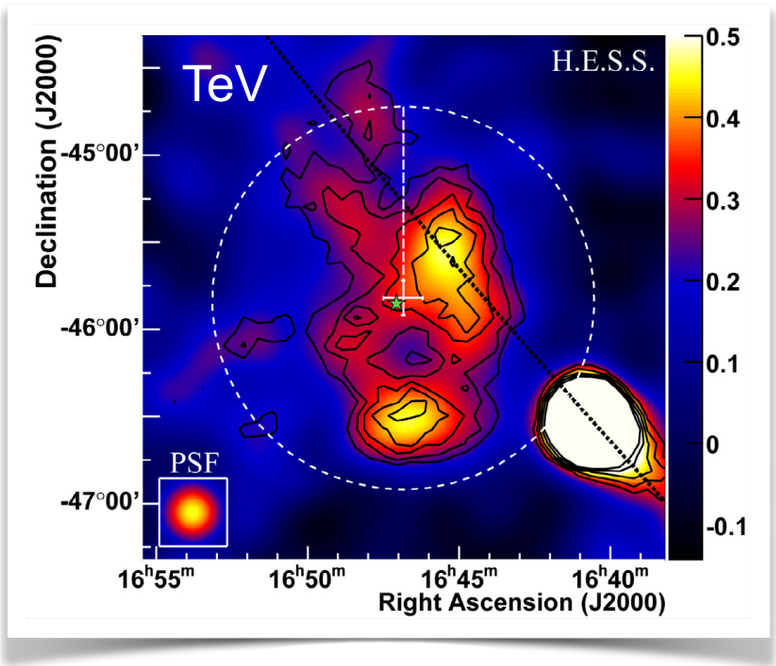
Westerlund 1

Credit: NASA/CXC/UCLA/M.Muno et al.



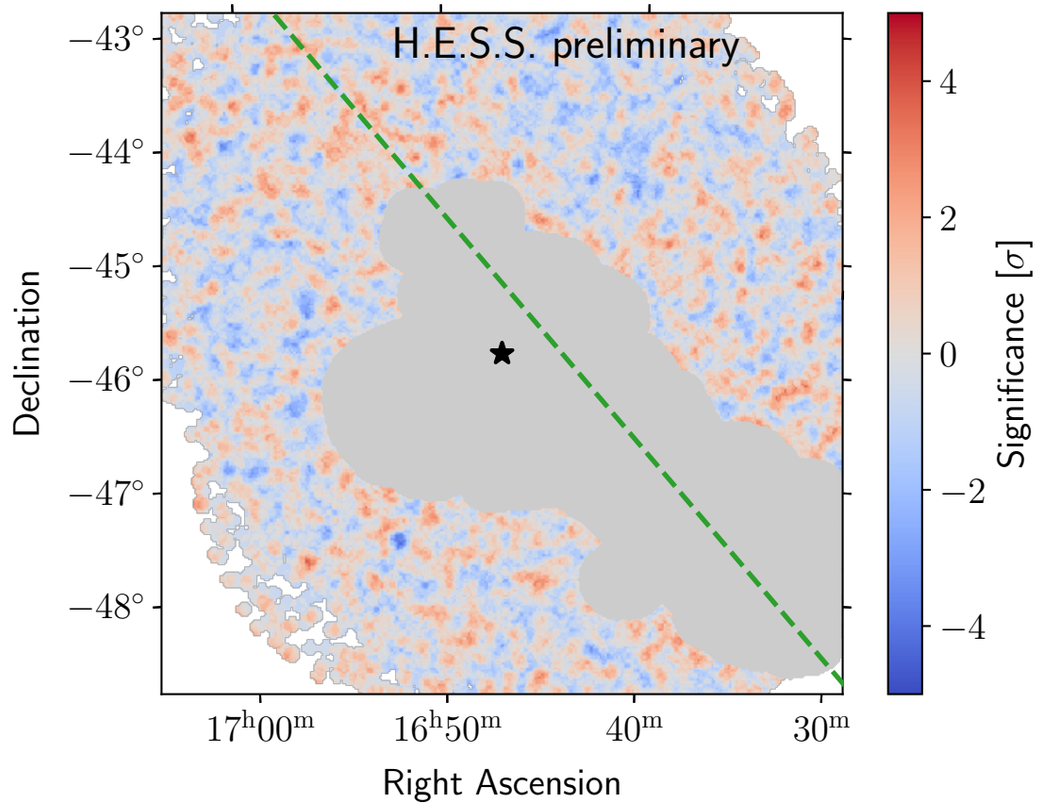
- Massive young stellar cluster
  - Age: $3.5 - 5\,\mathrm{Myr}$ [1]
  - Total mass: $\sim 10^5\,M_\odot$ [1]
  - Distance: $\sim 3.9\,\mathrm{kpc}$ [2]
  - (all uncertain / debated!)
- Harbours X-ray magnetar, but no other stellar remnants
- Diffuse GeV emission (*Fermi*-LAT) [3], largely extended TeV emission (H.E.S.S.) [4]
- Hypothesised as a PeVatron candidate [5]
- TeV γ-ray observations are key for confirming this!





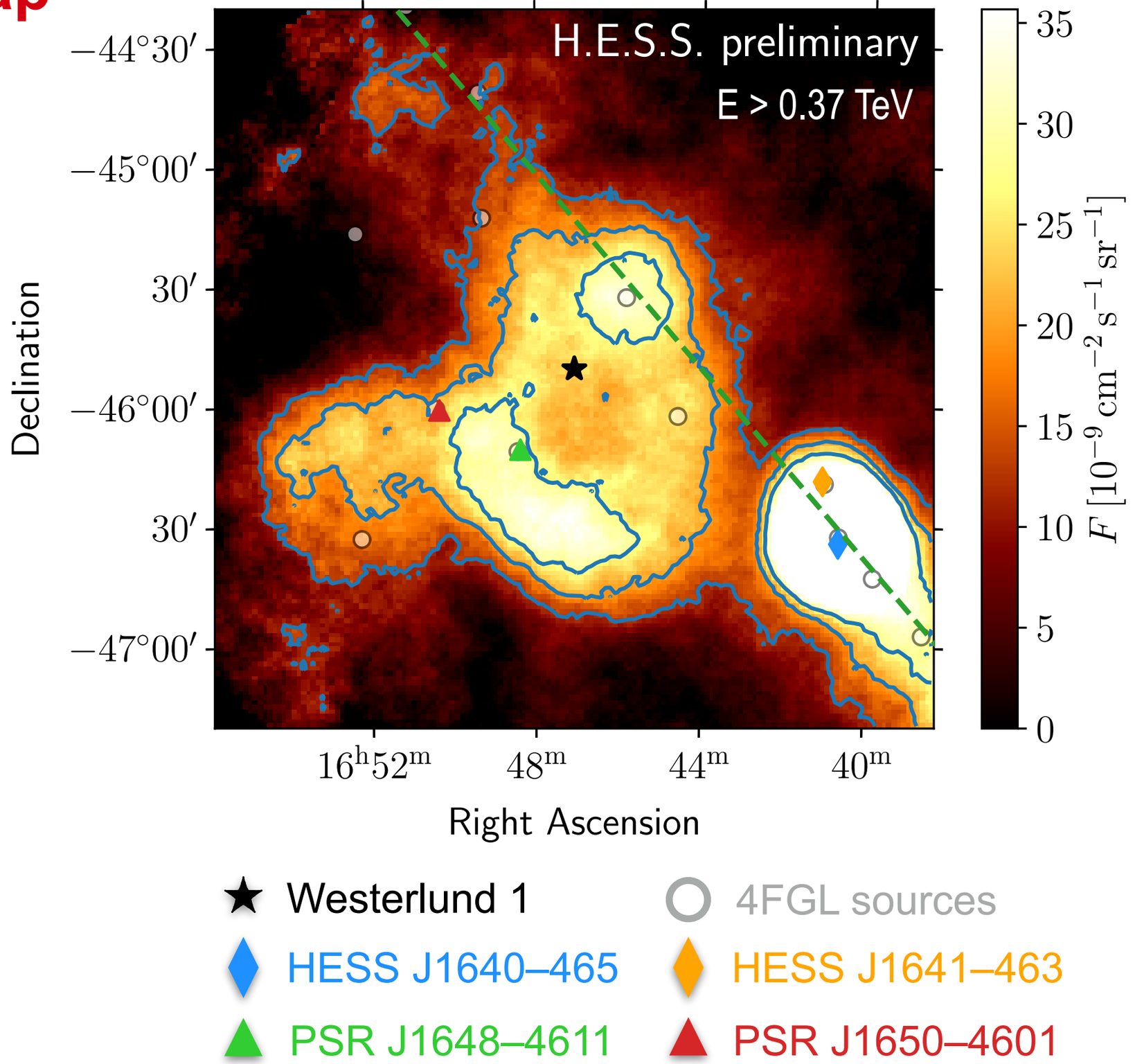
H.E.S.S. data set and analysis

- H.E.S.S. data set
  - 164 hours live time, taken 2004–2017
  - Small telescopes only
- Data analysis
  - Very large source extent & other nearby sources
    → background estimation from source-free regions not working well
  - Background model from archival observations [6]
  - Perform 3D likelihood analysis with Gammapy [7]
    (new method in IACT data analysis!)
- Background model adjustment
  - Adjust normalisation & spectral slope for each observation
  - Exclusion region from iterative procedure
  - Good agreement with data outside this region



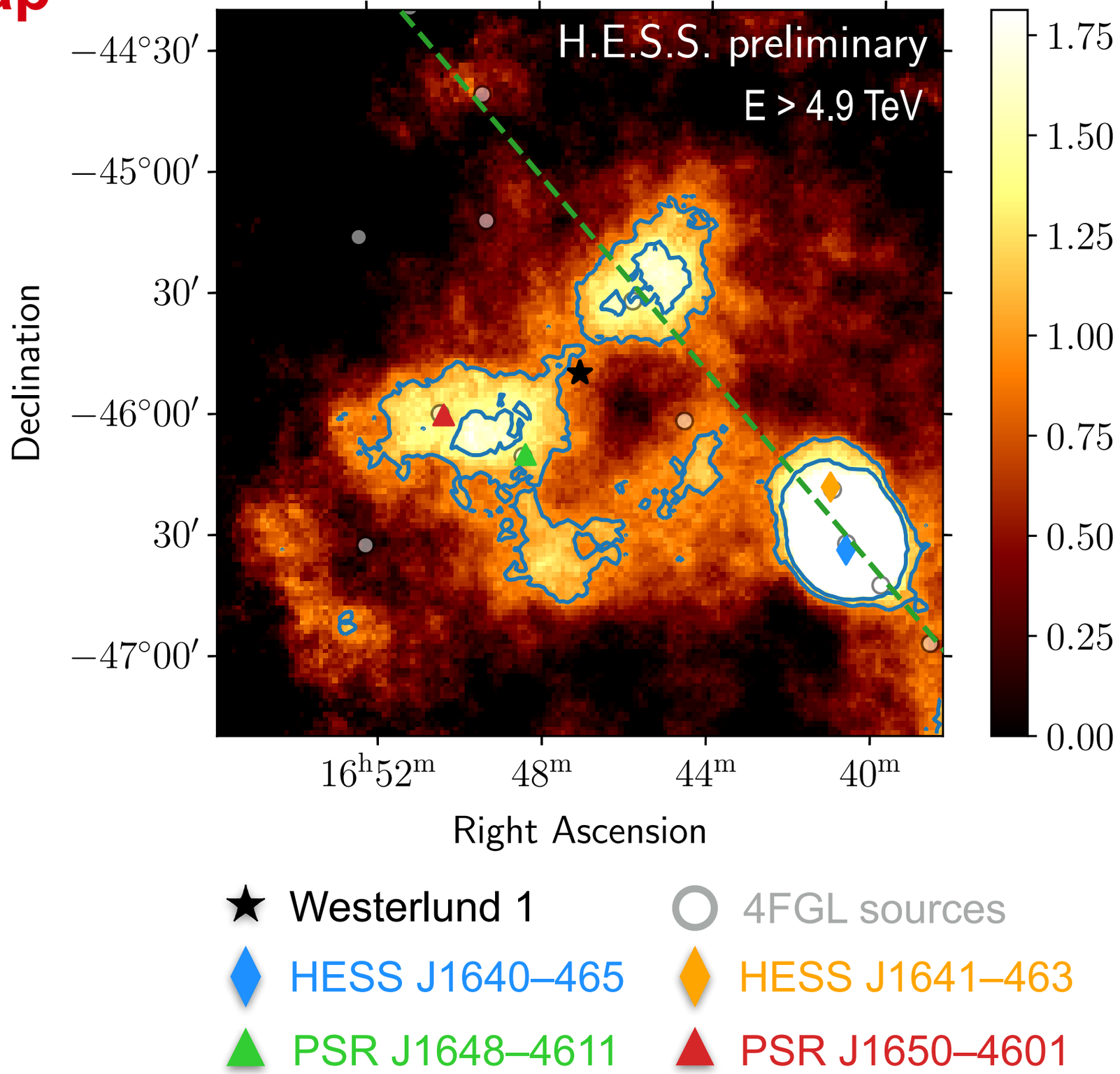
Results — Flux map

- Above 0.37 TeV
- Strong emission from nearby HESS sources
- Largely extended emission around Westerlund 1 (“HESS J1646–458”)
- Source morphology very complex
- Emission does *not* peak at stellar cluster position!



Results — Flux map

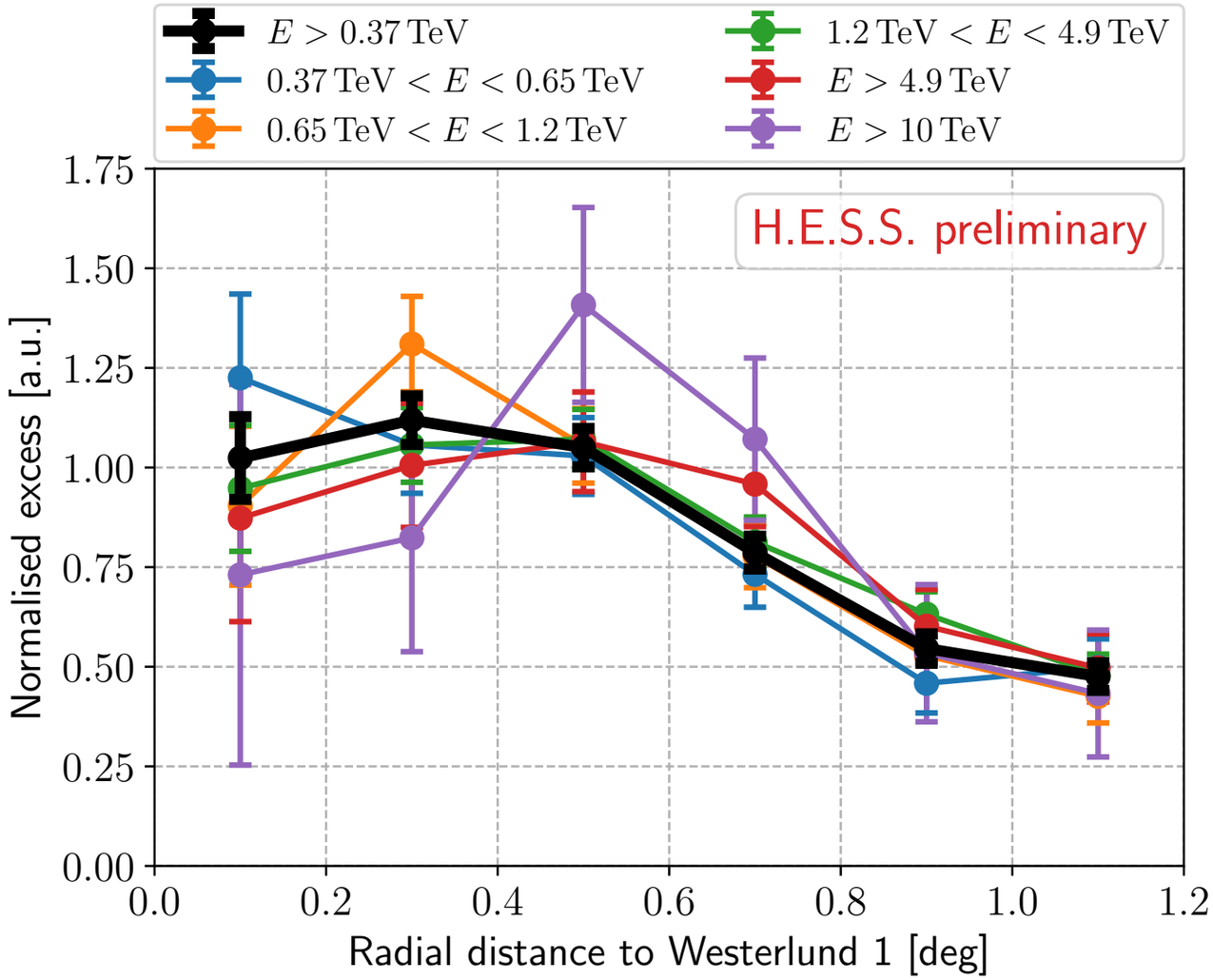
- Above 4.9 TeV
- Two bright “hot spots”, but also emission elsewhere
- One hot spot close to positions of two energetic pulsars



Results — Radial excess profiles

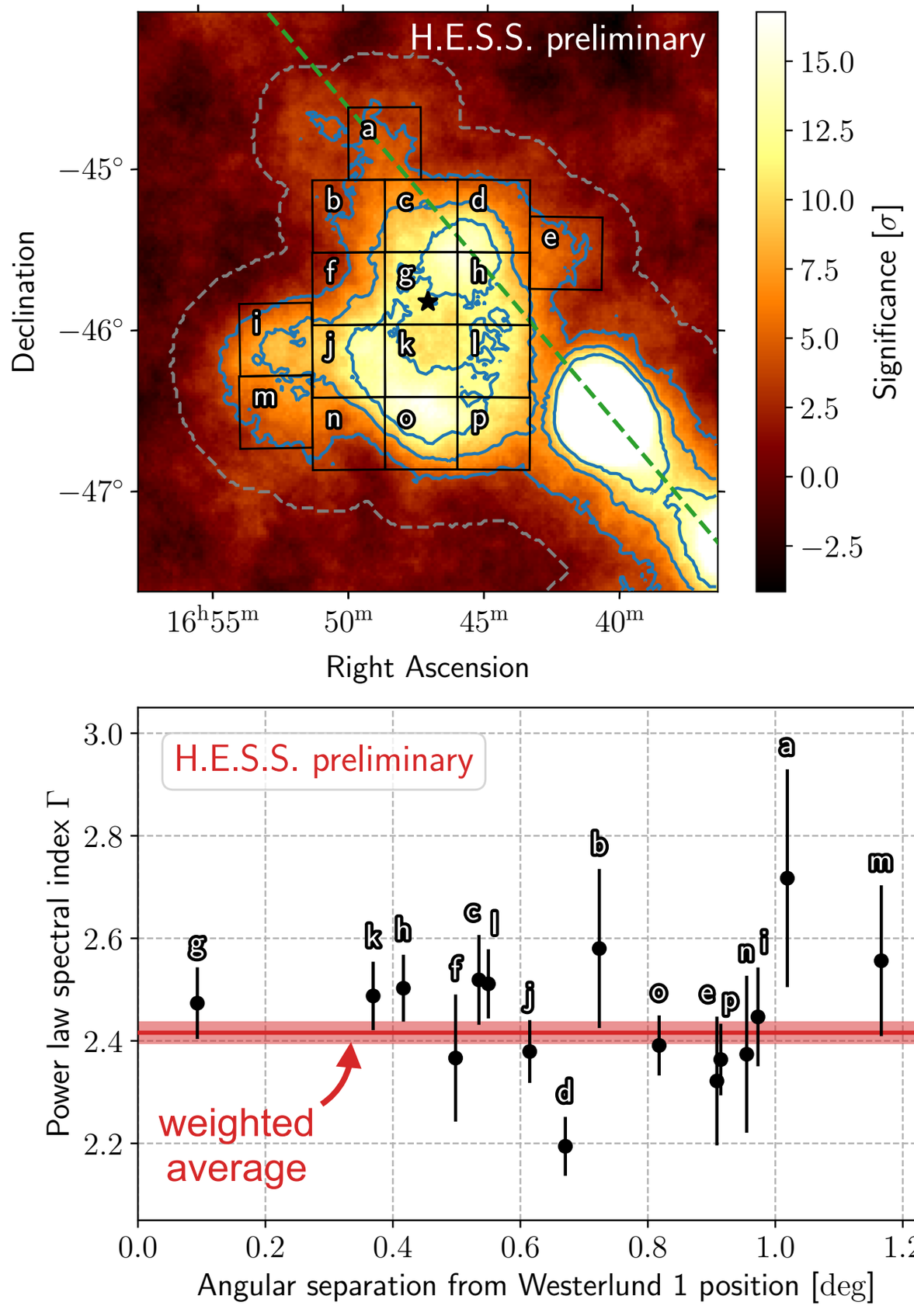
- Investigate source morphology as a function of energy
  → compute radial excess profile in energy bands
- Compare energy bands using χ^2-test
  → no indication for
  energy-dependent
  morphology!

Energy range [TeV]	Excess	χ^2 / N_{dof}
> 0.37	14 169	–
0.37 – 0.65	4852	5.43 / 6
0.65 – 1.2	3804	4.86 / 6
1.2 – 4.9	4448	4.30 / 6
> 4.9	1065	3.88 / 6
> 10	350	–



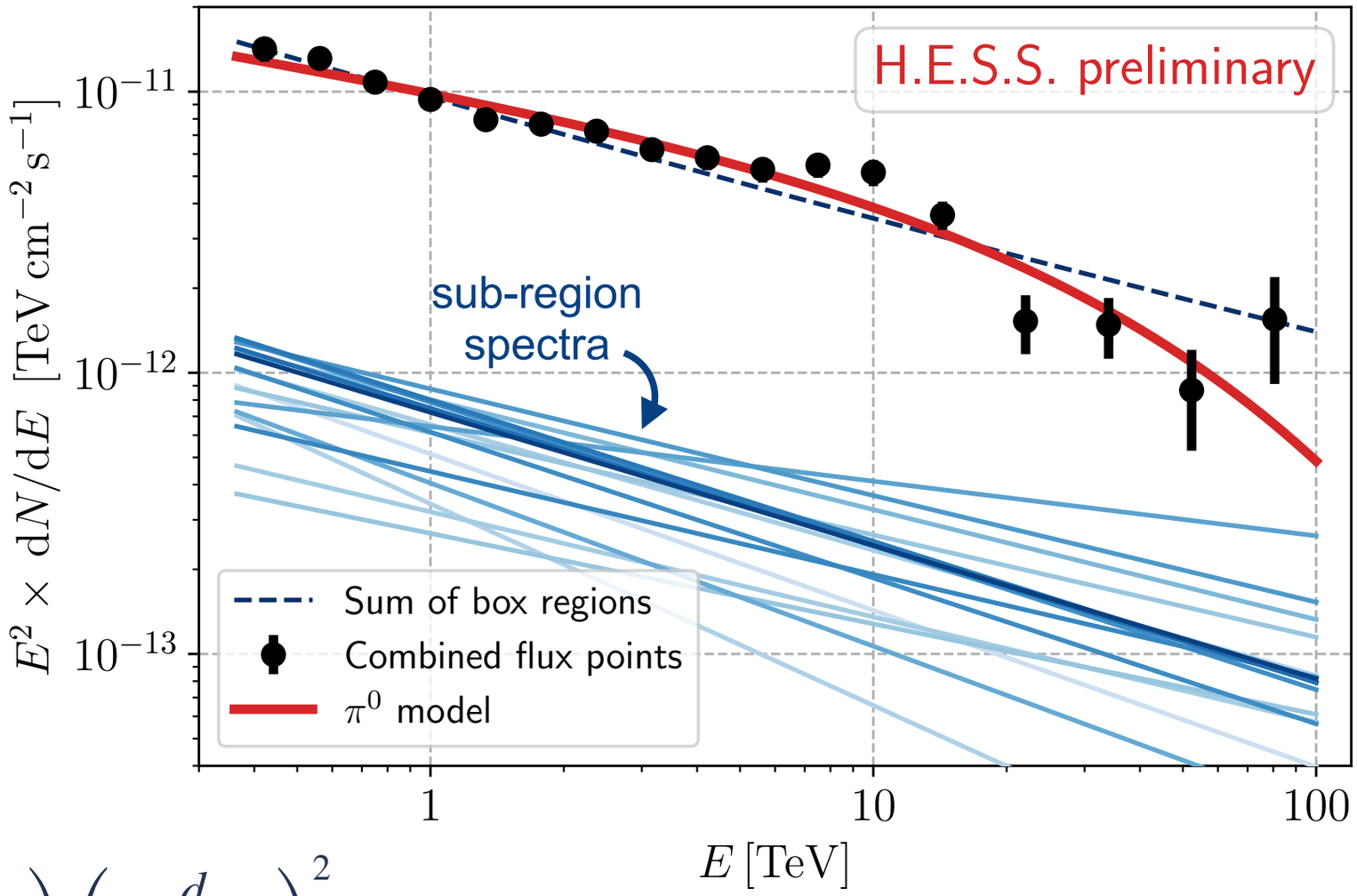
Results — Spectra in sub-regions

- Define 16 sub-regions that cover entire γ-ray emission
- Extract power-law spectrum for each region
- Fitted power-law slope shows no variation across source region
- Confirms non-observation of energy-dependent morphology



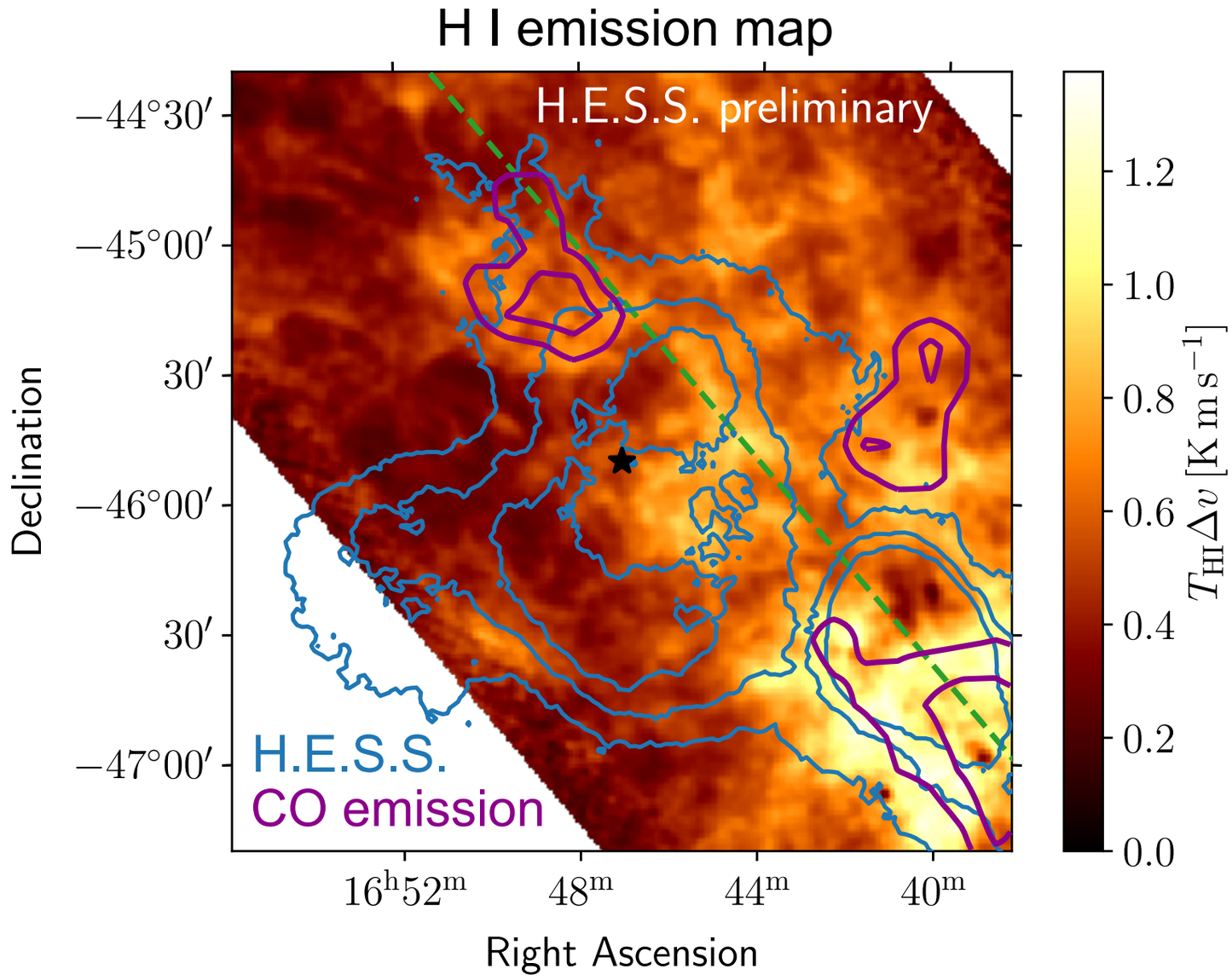
Results — Combined spectrum

- Sub-region spectra very similar → derive combined spectrum
- Sum up flux points of all sub-regions
- Spectrum extends to several tens of TeV
- Combined flux points not described well by power law
- Fit of primary proton spectrum (naima [8])
  - Proton spectrum cutoff at $\left(400^{+250}_{-130}\right)$ TeV
  - $W_{p,>1\,\mathrm{TeV}} \sim 5 \times 10^{49} \left(\frac{n}{10\,\mathrm{cm}^{-3}}\right) \left(\frac{d}{3.9\,\mathrm{kpc}}\right)^2 \mathrm{erg}$



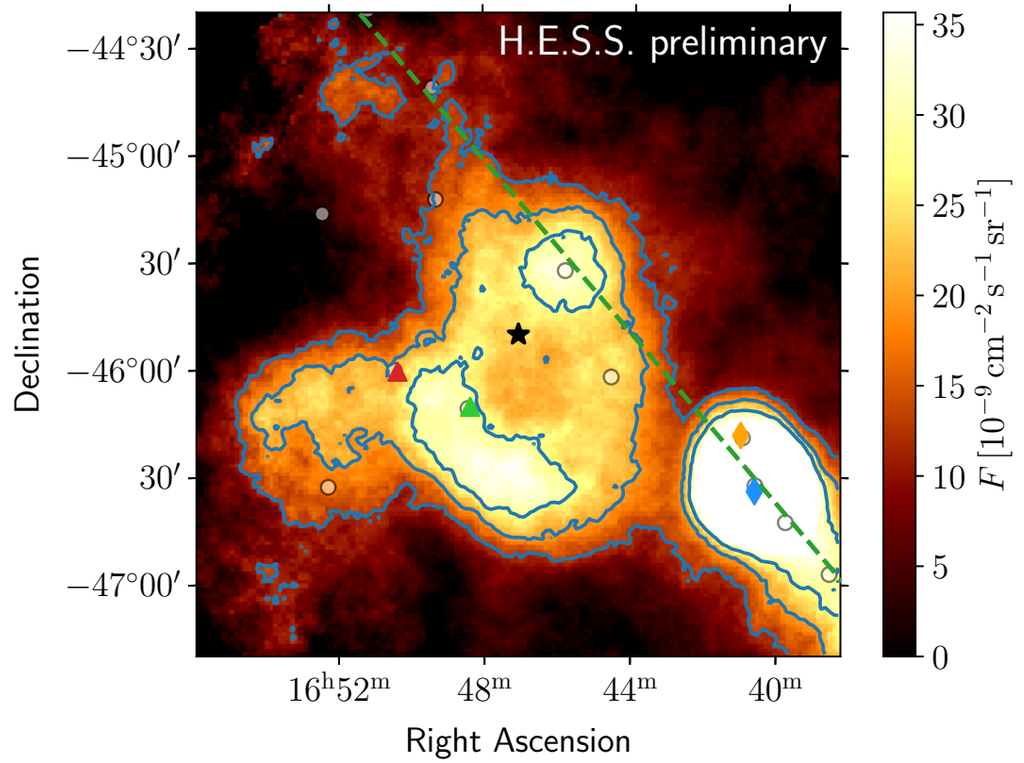
Results — Gas maps

- Hadronic scenario → requires existence of target material
- Infer presence of possible targets from radio observations
  - H I (SGPS survey [9]) → hydrogen gas
  - CO (Dame et al. survey [10]) → dense clouds of molecular hydrogen
  - Both integrated in velocity range (–60, –50) km/s (~3.9 kpc distance)
- Target material is present in general
- Correlation of γ-ray emission with dense clouds not striking

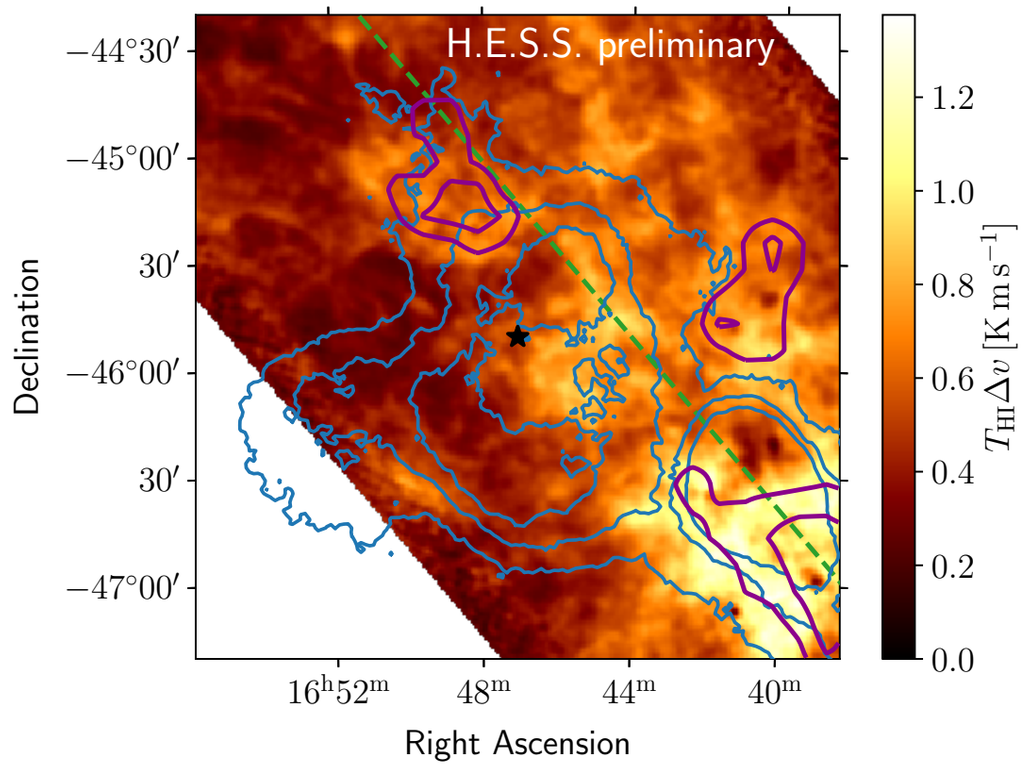


Discussion

- Leptonic scenario (IC)
  - Two high-$\dot{E}$ pulsars + magnetar in cluster could be high-energy electron sources
  - Complex structure of HESS J1646–458 & lack of energy-dependent morphology
    → leptonic origin of entire emission unlikely
  - Pulsars may contribute locally

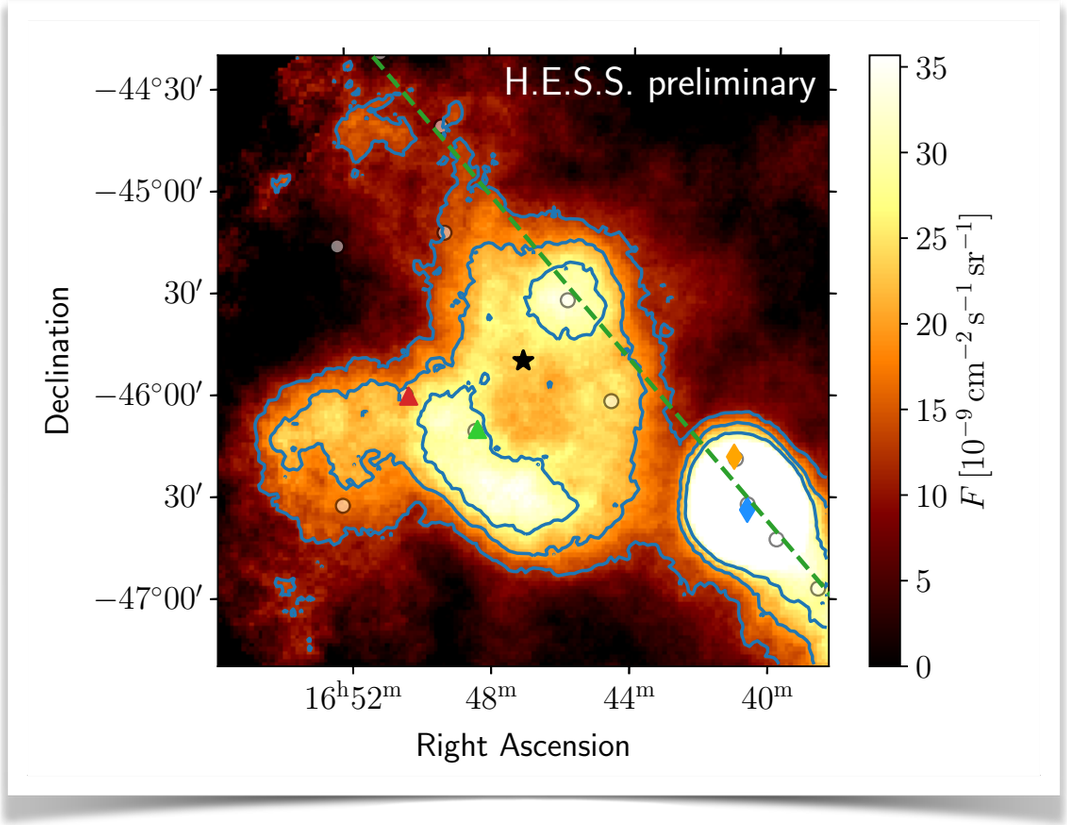


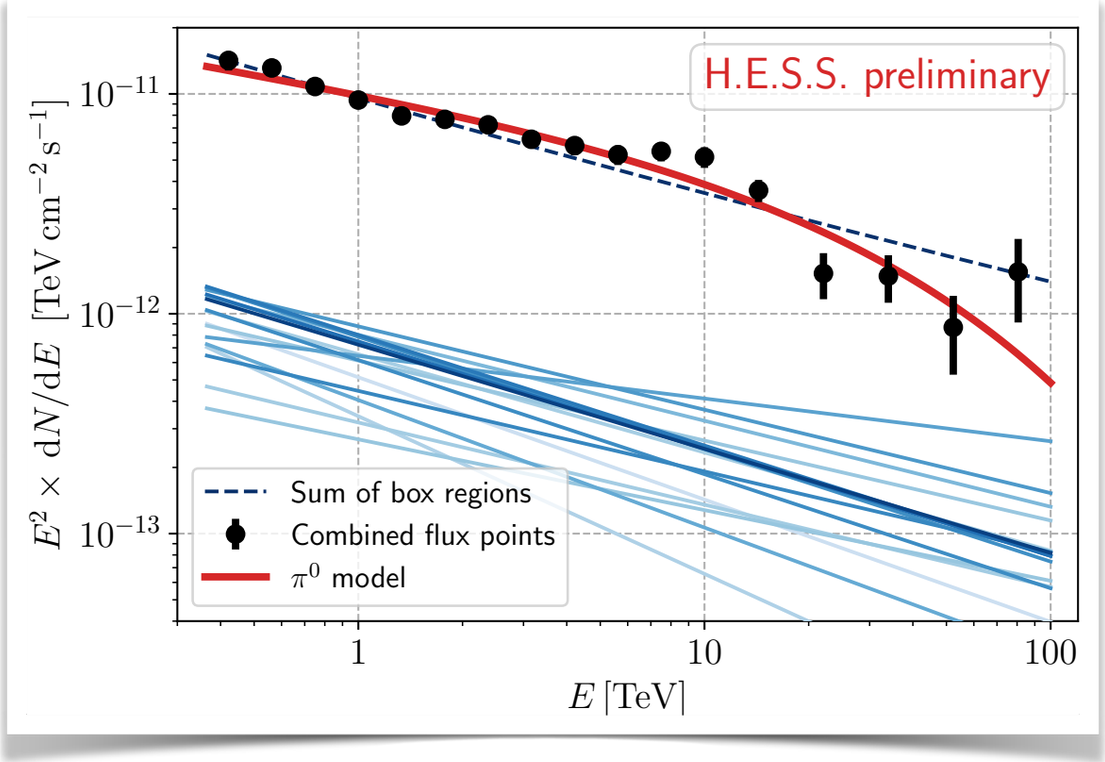
- Hadronic scenario (π^0 decay)
  - No known supernova remnant in / around Westerlund 1
  - Many supernovae in the past / interactions of winds of massive stars
    → stellar cluster plausible source of cosmic rays
  - Lack of correlation with dense gas clouds
    → wrong distance?
    → “CO-dark” gas?



Conclusion

- Presented an updated analysis of Westerlund 1 region with H.E.S.S.
- Successfully applied new analysis technique to H.E.S.S. data
- HESS J1646–458 is a γ-ray source with intriguing properties
  - Complex morphology, no variation with energy
  - Spectrum extending to several ten TeV
- Stellar cluster Westerlund 1…
  - …remains the most likely association
  - …is still a good PeVatron candidate
- Publication with more detailed interpretation forthcoming!





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