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X-ray observations of a PeVatron candidate HESS J1641−463

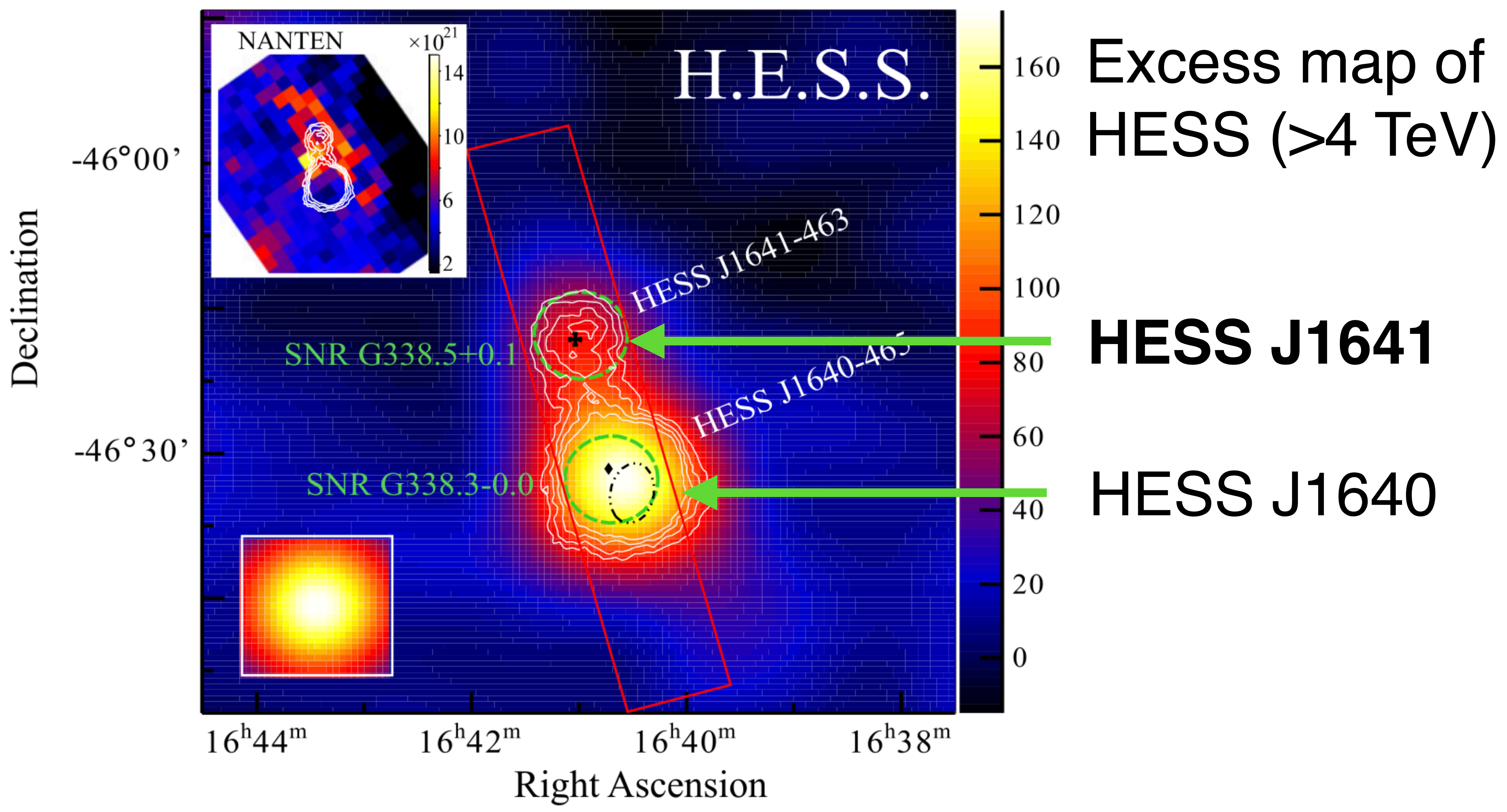
Naomi Tsuji (Kanagawa University)

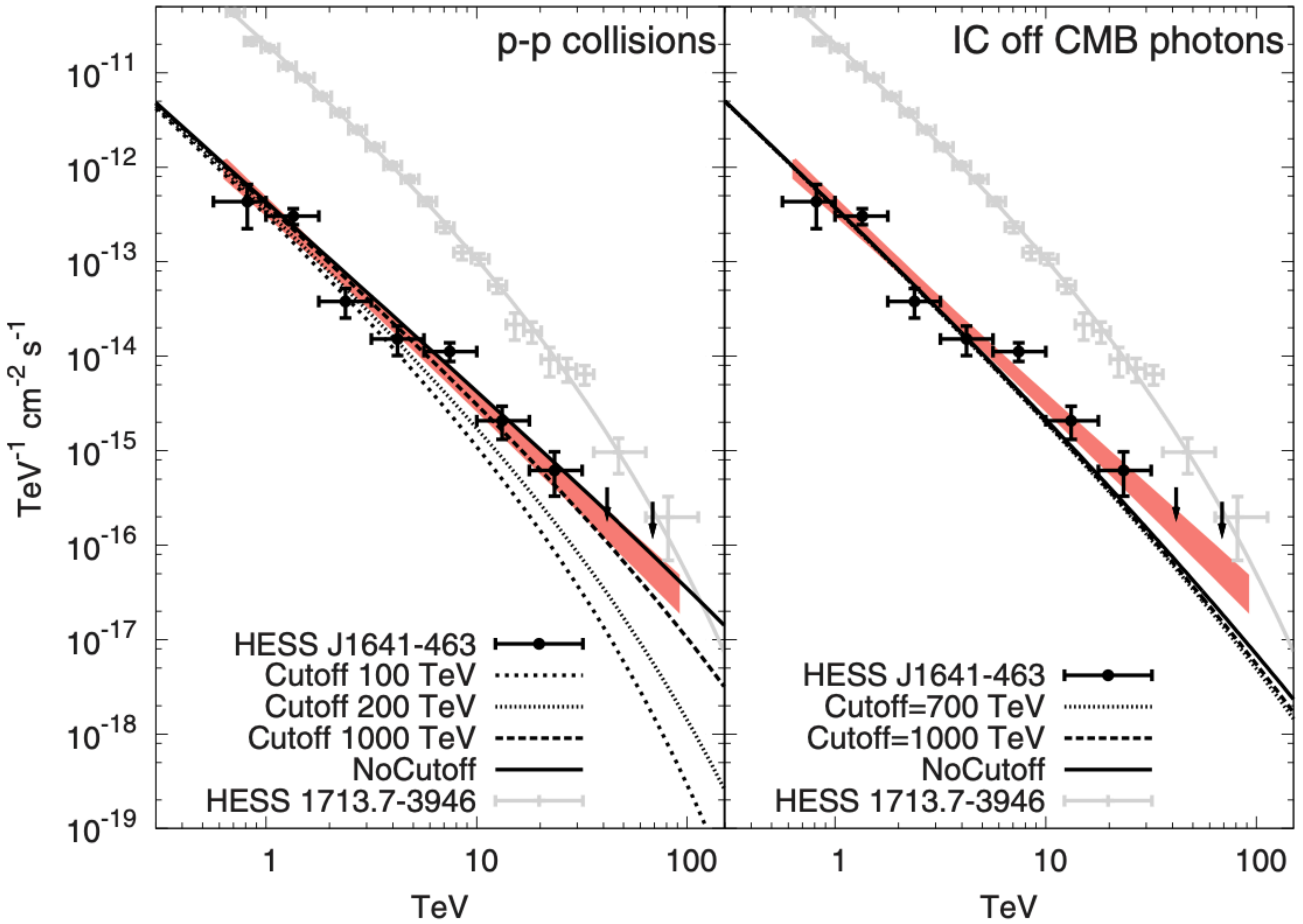
Takaaki Tanaka (Konan University), Samar Safi-Harb (Manitoba University), and Felix Aharonian (DIAS)

HESS J1641−463

HESS Collab. 2014

- Unidentified, extended TeV gamma-ray source on the Galactic plane (l, b) = (338.52°, 0.0906°)
- Hard TeV gamma-ray spectrum (Γ=2.07) → Ep,c > 100 TeV @99% C.L. → PeVatron candidate!
- Coincides with a radio SNR, G338.5+0.1
- X-ray domain has been unexplored





X-ray observation of HESS J1641 region

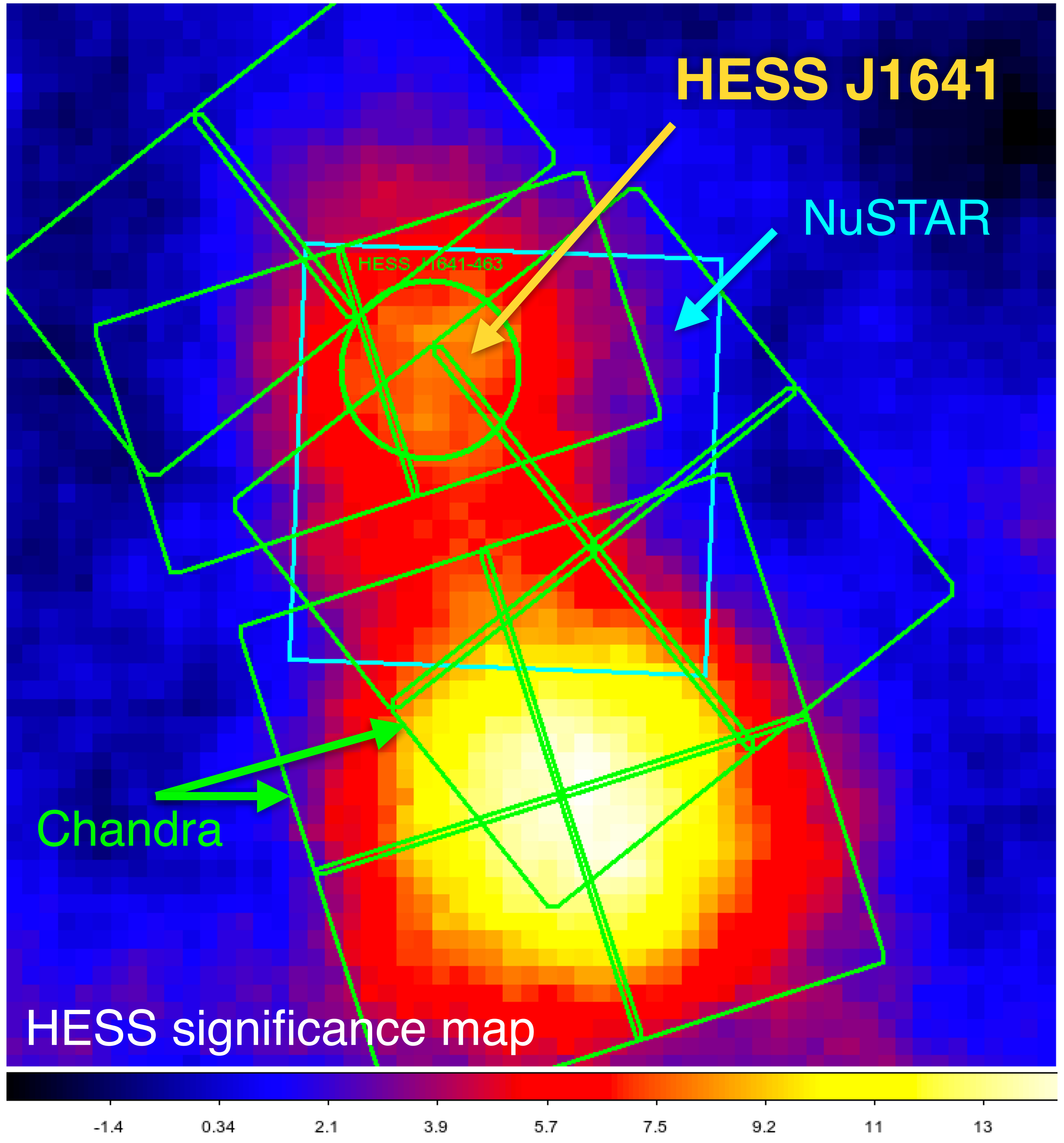
Data set

- No on-axis data in soft X-ray (Chandra and XMM)
- New hard X-ray data with NuSTAR

Satellite	Target name	Obs ID	Exposure (ks)	Date
Chandra	GLIMPSE 81	11008	39.6	2010-06-19
Chandra	Norma Region	12508	18.5	2011-06-06
NuSTAR	HESS J1641−463	40401004002	81.6	2018-10-11

↑

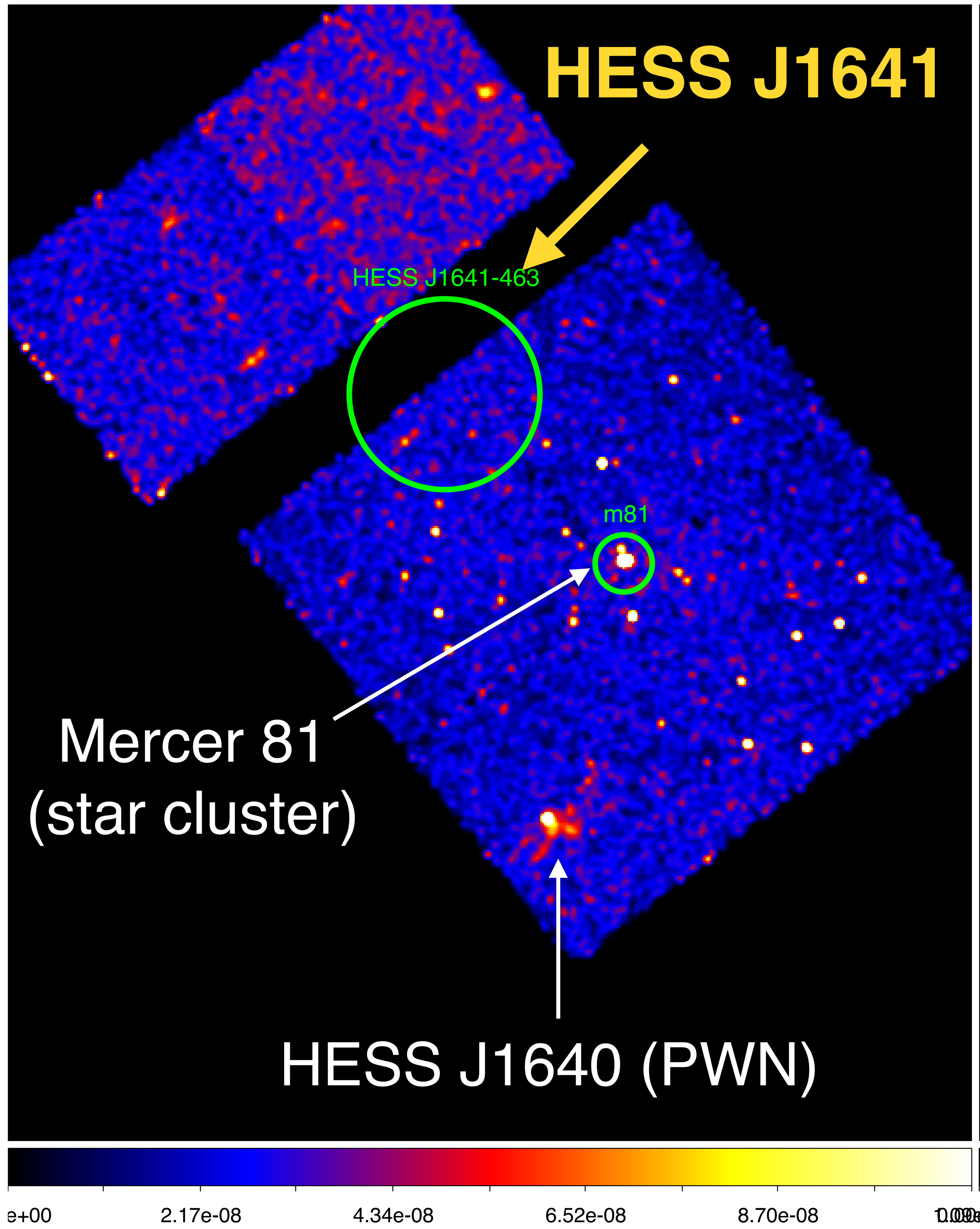
New (PI: Tanaka)



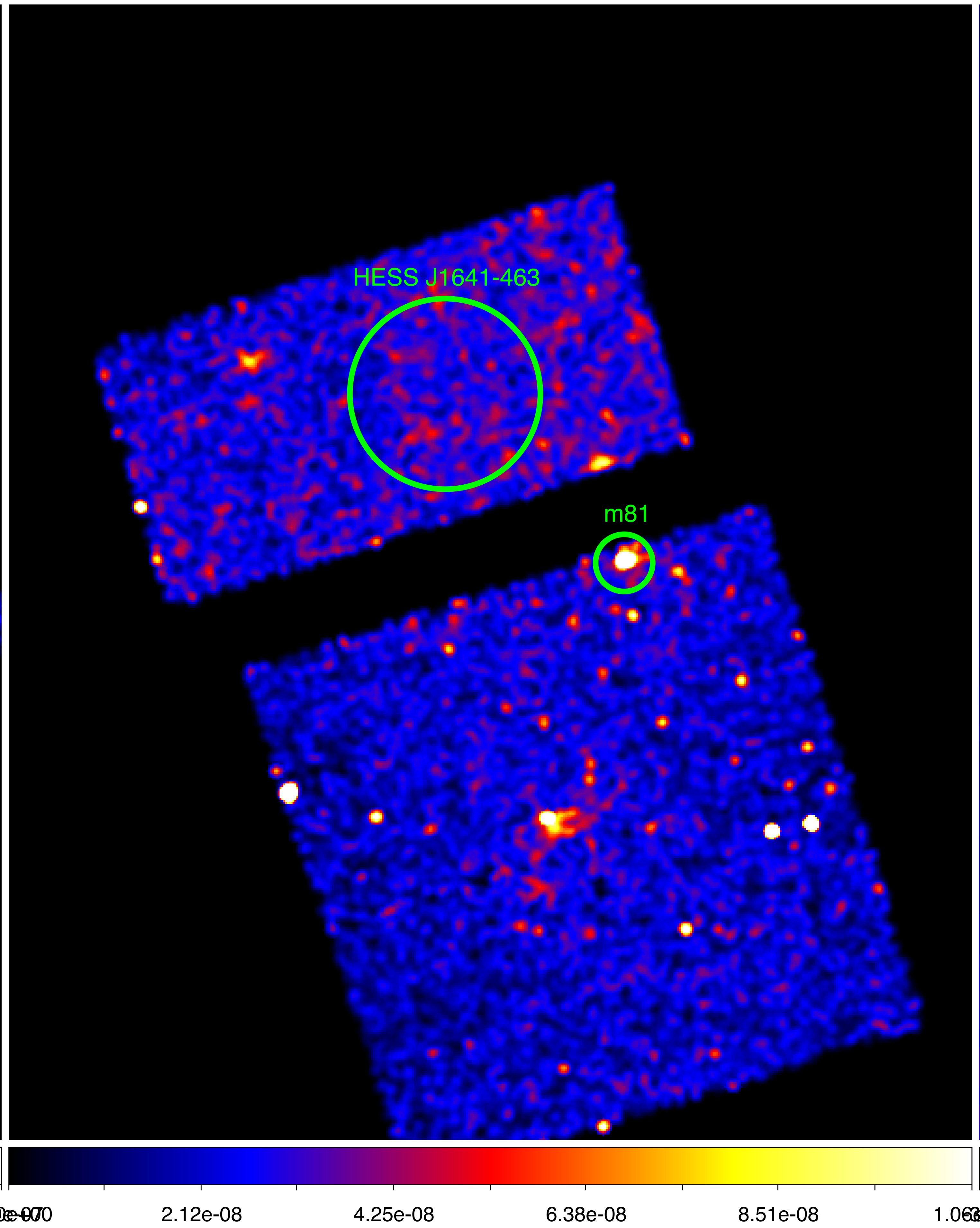
Chandra analysis

Flux image in 0.5-7 keV

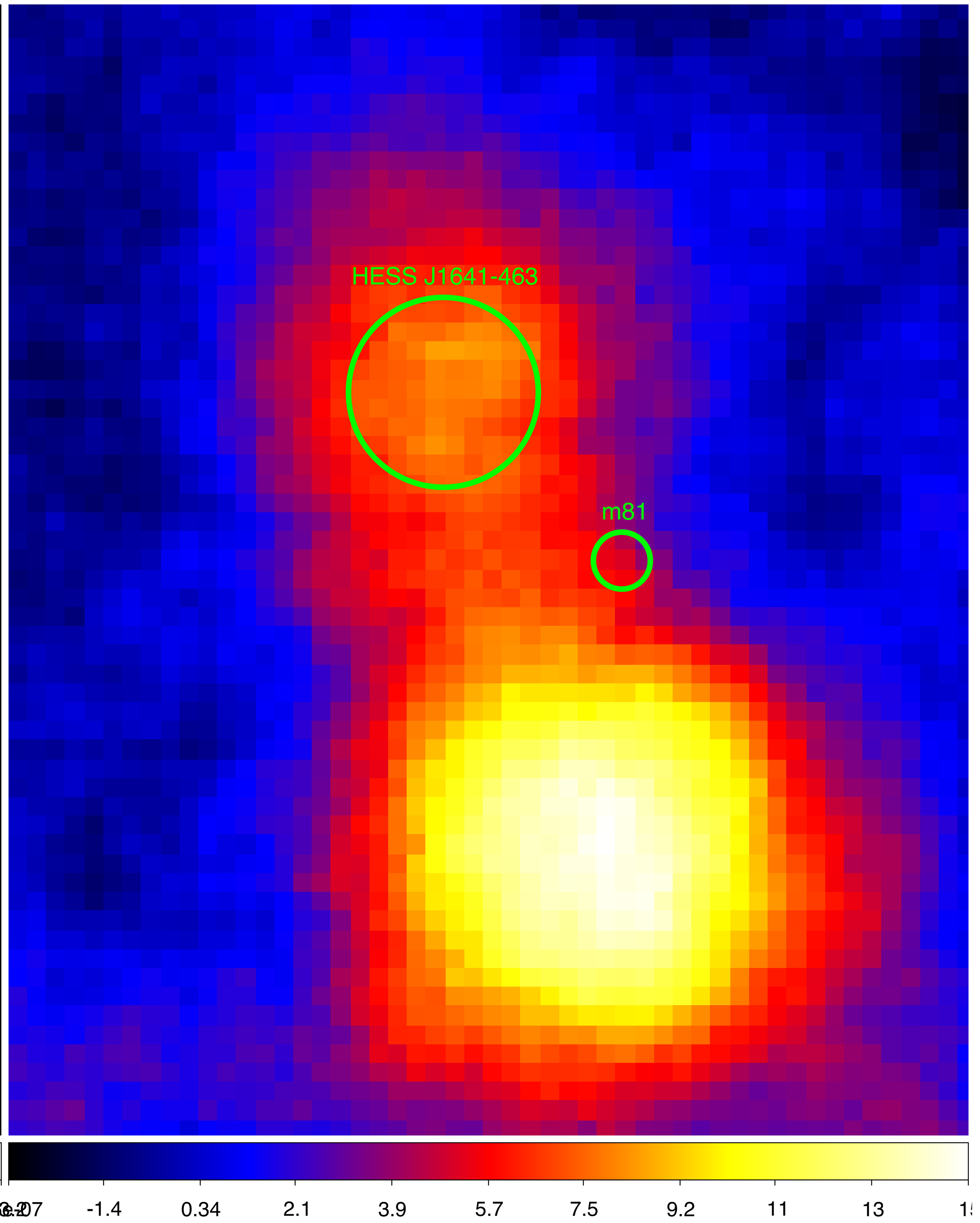
ObsID 11008 (39.6 ks)



ObsID 12508 (18.5 ks)



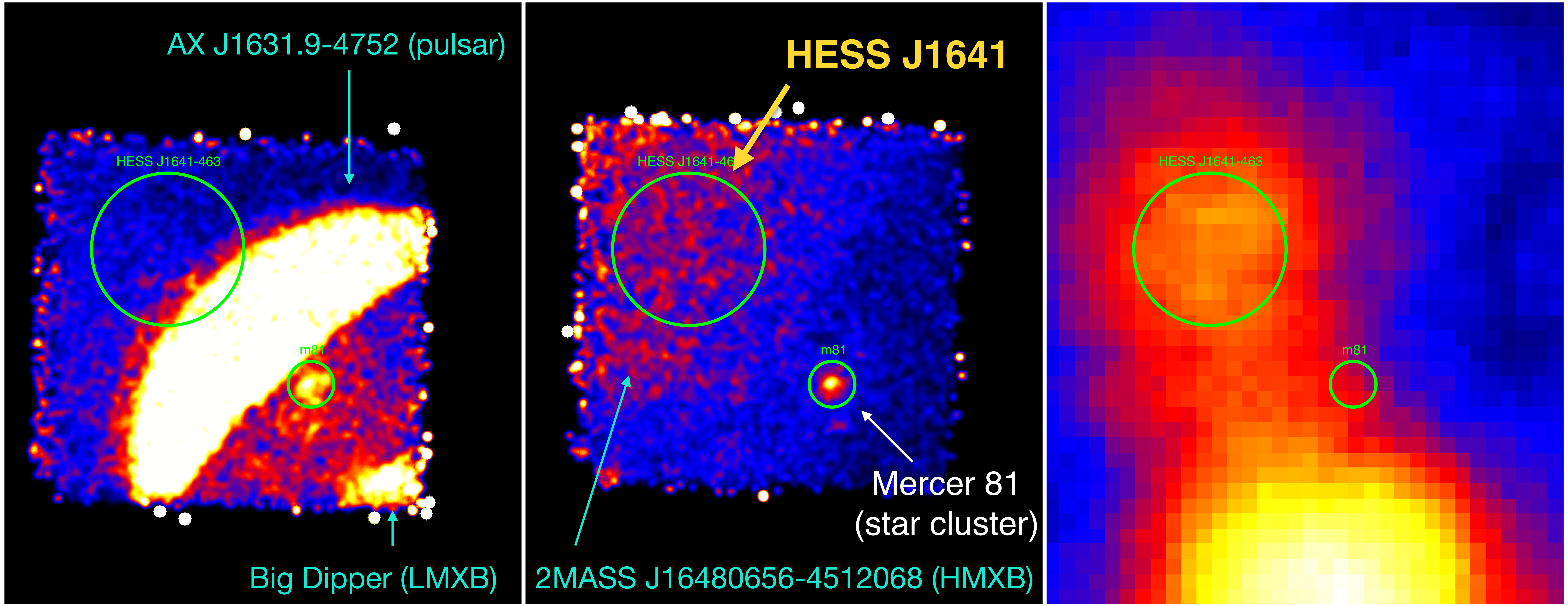
HESS significance map



NuSTAR analysis

Flux image in 3-20 keV & stray light

Left: FPMA
Middle: FPMB
Right: HESS



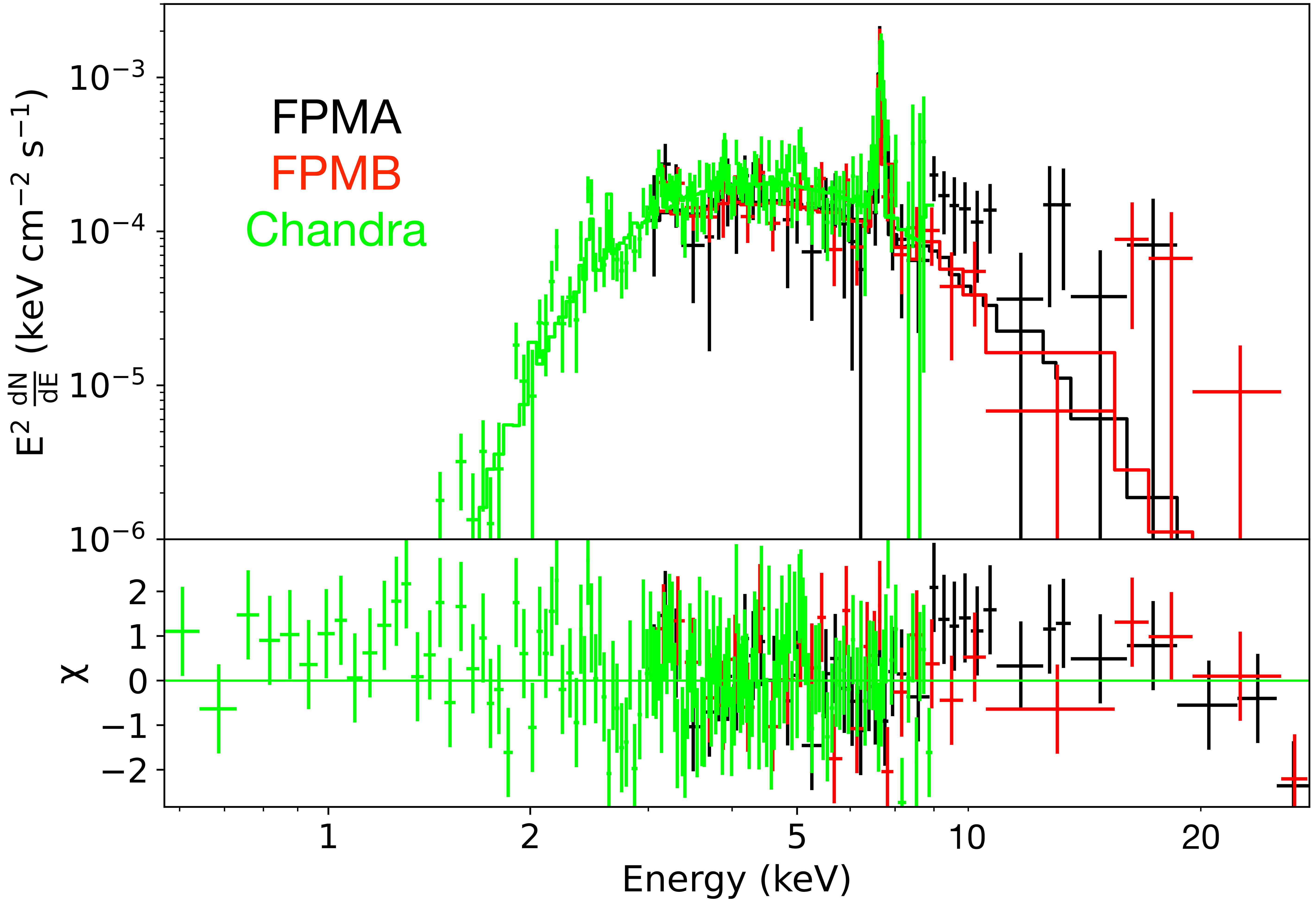
- We extract (annulus) background in the same FoV (local background)
- Exclude the stray-light contaminated region in FPMA and rescale the flux to the TeV gamma-ray extension (r=3 arcmin)

Spectrum (Chandra + NuSTAR)

Mercer 81

- Mercer 81
  - Star cluster candidate
  - Source: r=0.9 arcmin
  - Background: annulus around source

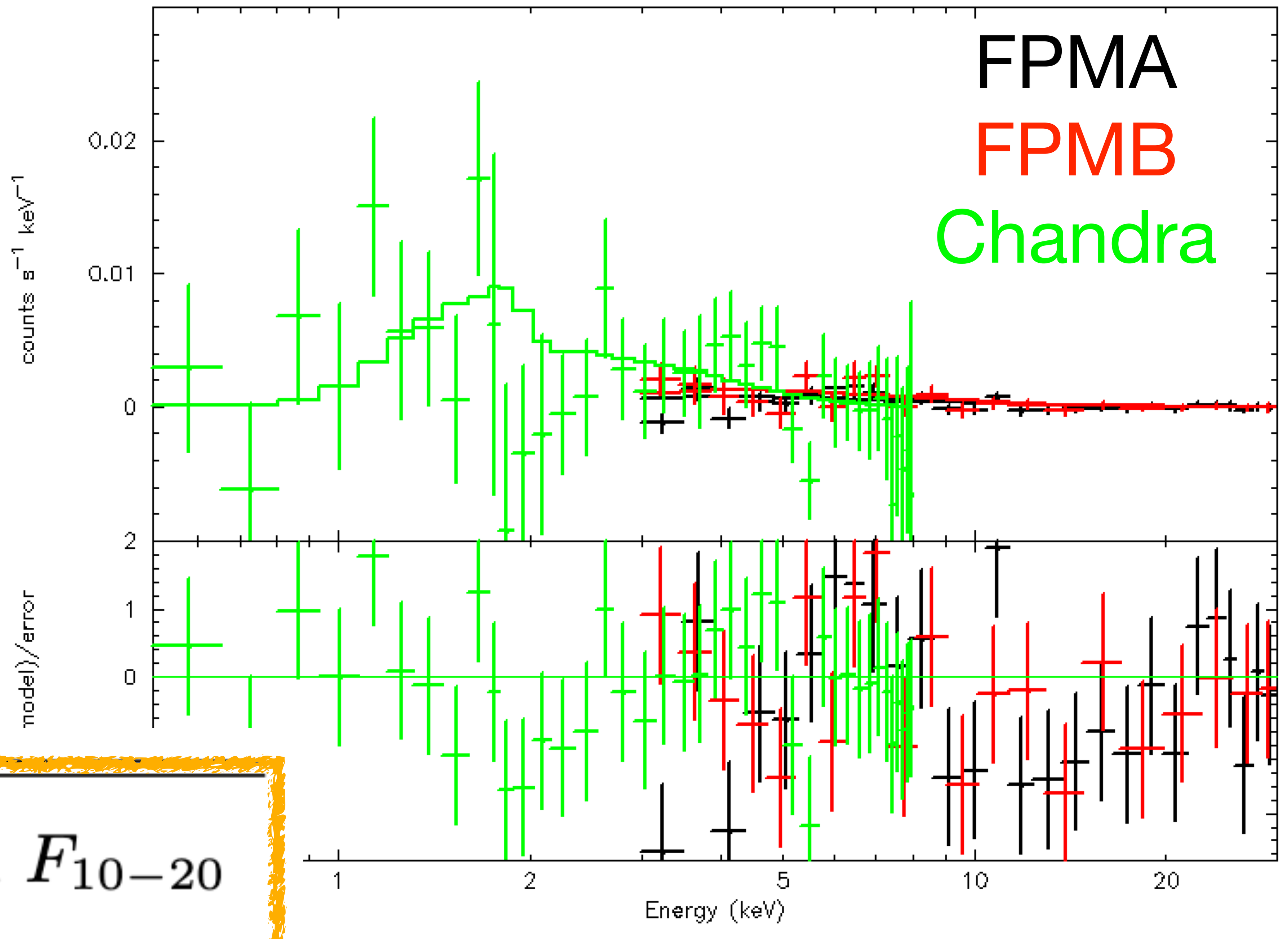
- Results
  - (1) absorbed (power law + Gaussian)
    - Photon index = 3.9 ± 0.4
    - Gaussian at 6.6–6.7 keV
  - (2) absorbed apec
    - kT = 2.1 ± 0.4 (for abund = 1)
  - **Normalization is in good agreement** between Chandra and NuSTAR.



Spectrum (Chandra + NuSTAR)

HESS J1641

- Fitting
  - Model: absorbed power law
  - $N_H = 2\times10^{22}$ cm^{-2} and $\Gamma = 2$ (fix)
  - Obtained 2-sigma flux upper limit
    - (6–7)x10^{-13} erg/cm^2/s in 2–10 keV
    - ~3 x10^{-13} erg/cm^2/s in 10–20 keV
    - Roughly consistent with Mares+ 2021

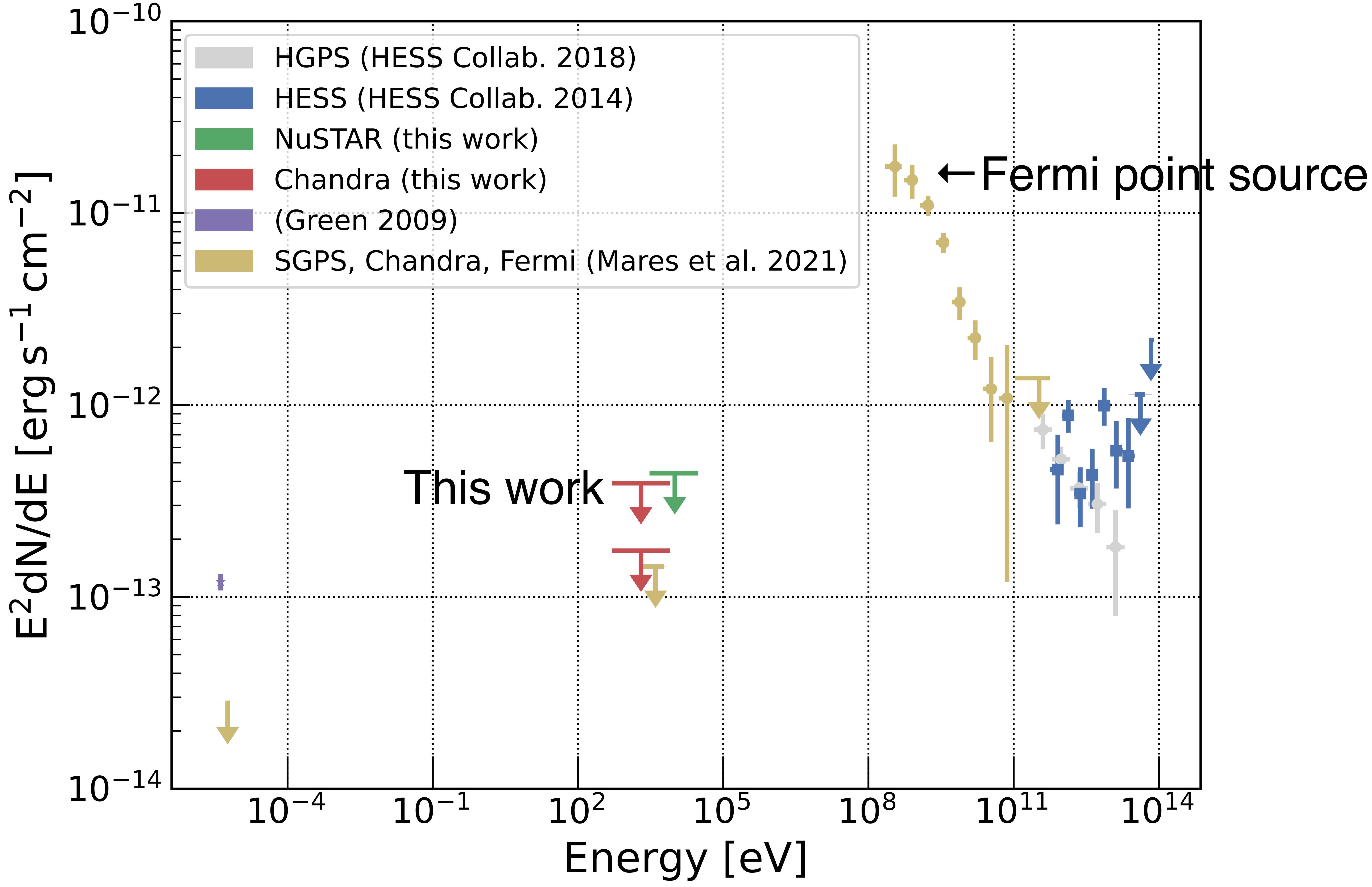


	Size (arcmin^2)	Detector	F_{2-10}	F_{10-20}	Scaled F_{2-10} (10^{-13} erg/cm2/s)	Scaled F_{10-20} (10^{-13} erg/cm2/s)
NuSTAR	18.1	FPMA	4.0	1.7	6.2	2.7
	28.3	FPMB	7.1	3.0	7.1	3.0
Chandra (12508)	22.8	ACIS-S (BI)	5.1	—	6.3	—
Chandra (11008)	15.35	ACIS-I	1.5	—	2.8	—

Flux scaled to HESS's extension

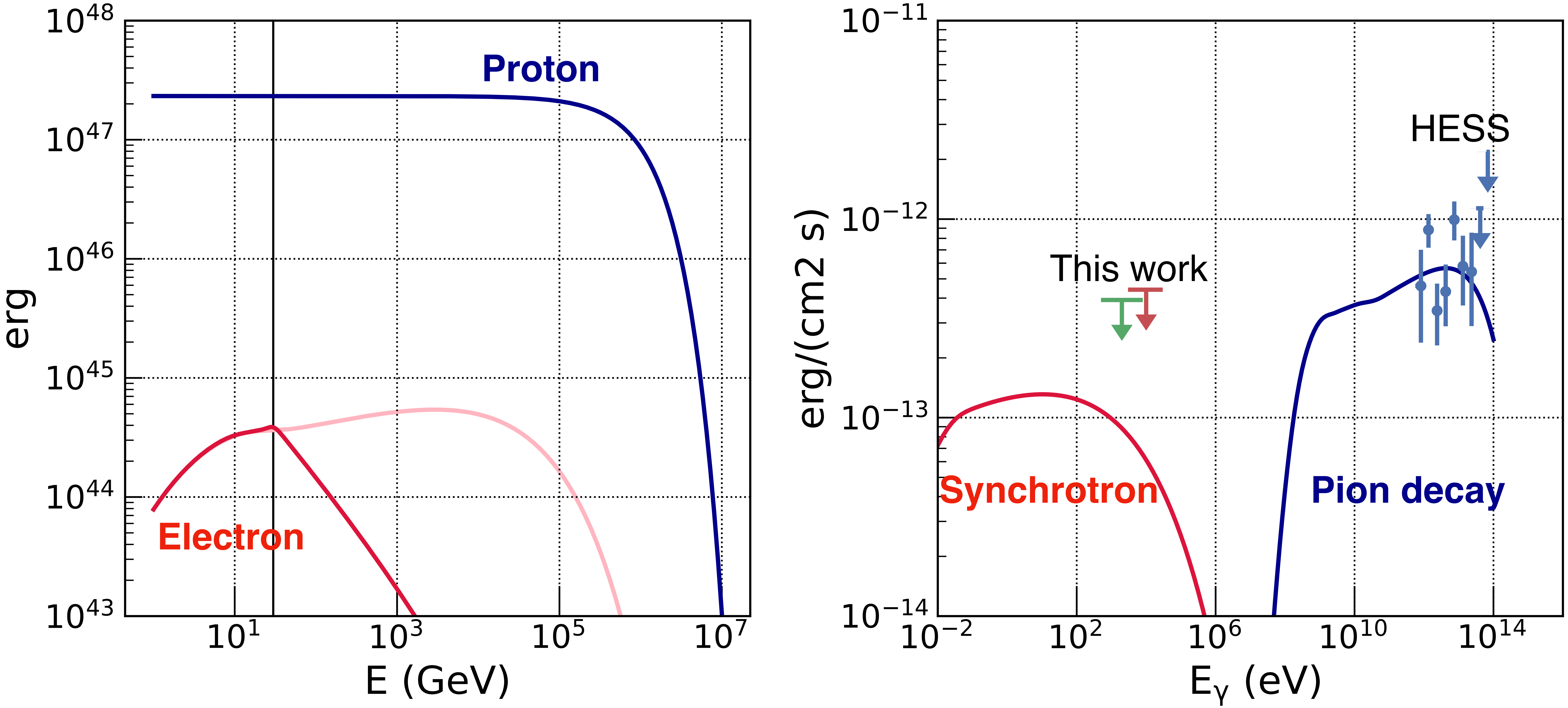
Broadband SED

Radio, X-ray, and gamma-ray



Modeling

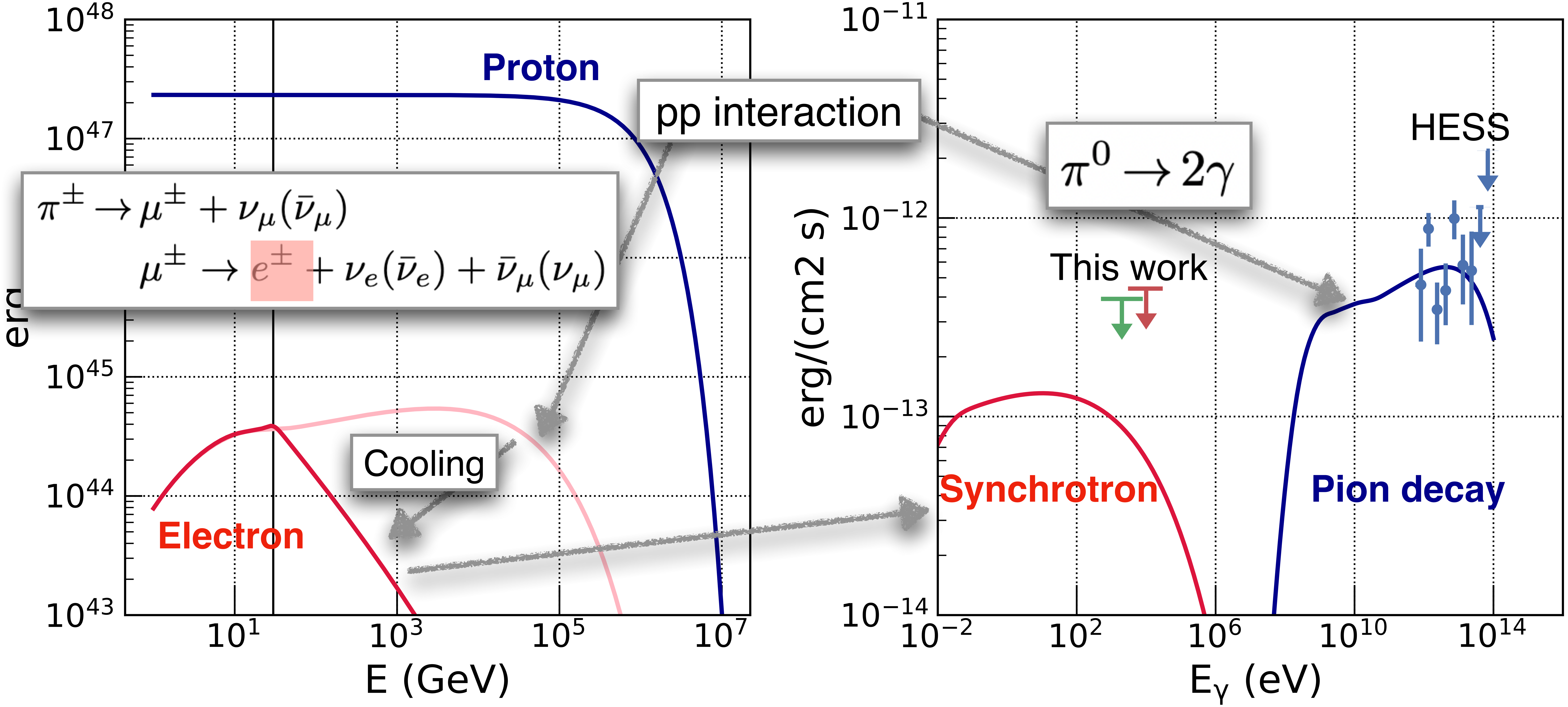
Synchrotron X-ray from secondary e± in pp interaction



n (cm^{-3})	100
B (μG)	300
Age (kyr)	5
d (kpc)	11
Proton	
index	2
Ec (TeV)	1000
Wp (erg)	1.5×10^{48}

Modeling

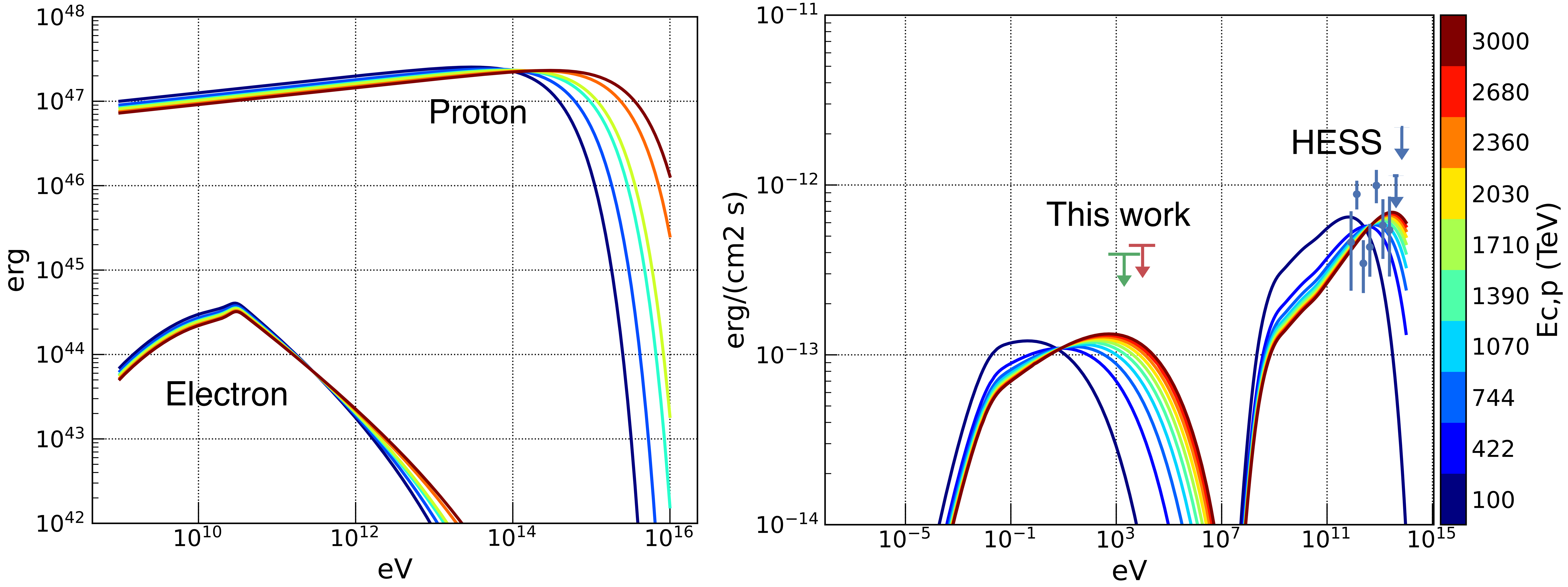
Synchrotron X-ray from secondary e± in pp interaction



n (cm^{-3})	100
B (μG)	300
Age (kyr)	5
d (kpc)	11
Proton	
index	2
Ec (TeV)	1000
Wp (erg)	1.5×10^{48}

Modeling

Synchrotron X-ray from secondary e± in pp interaction

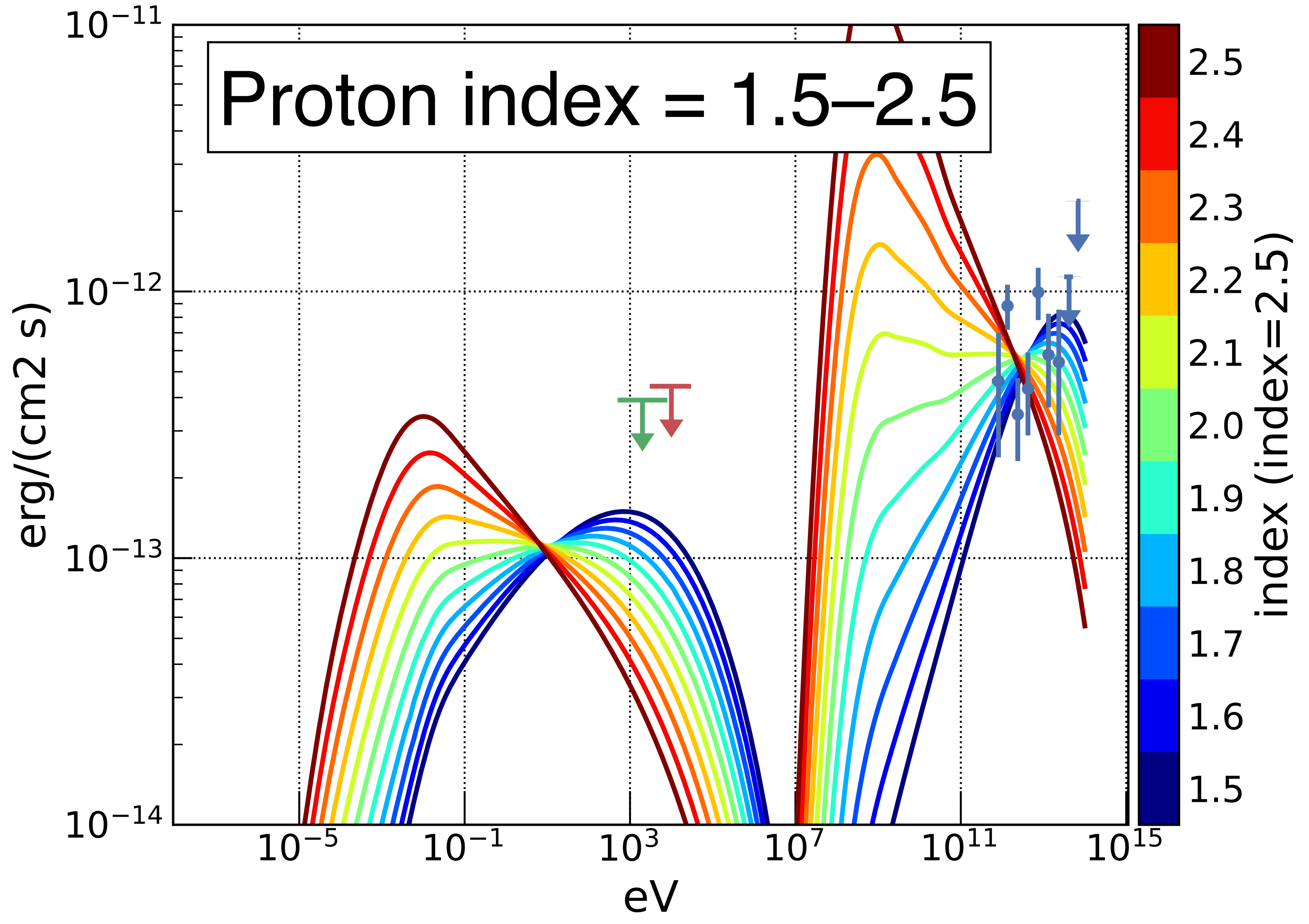


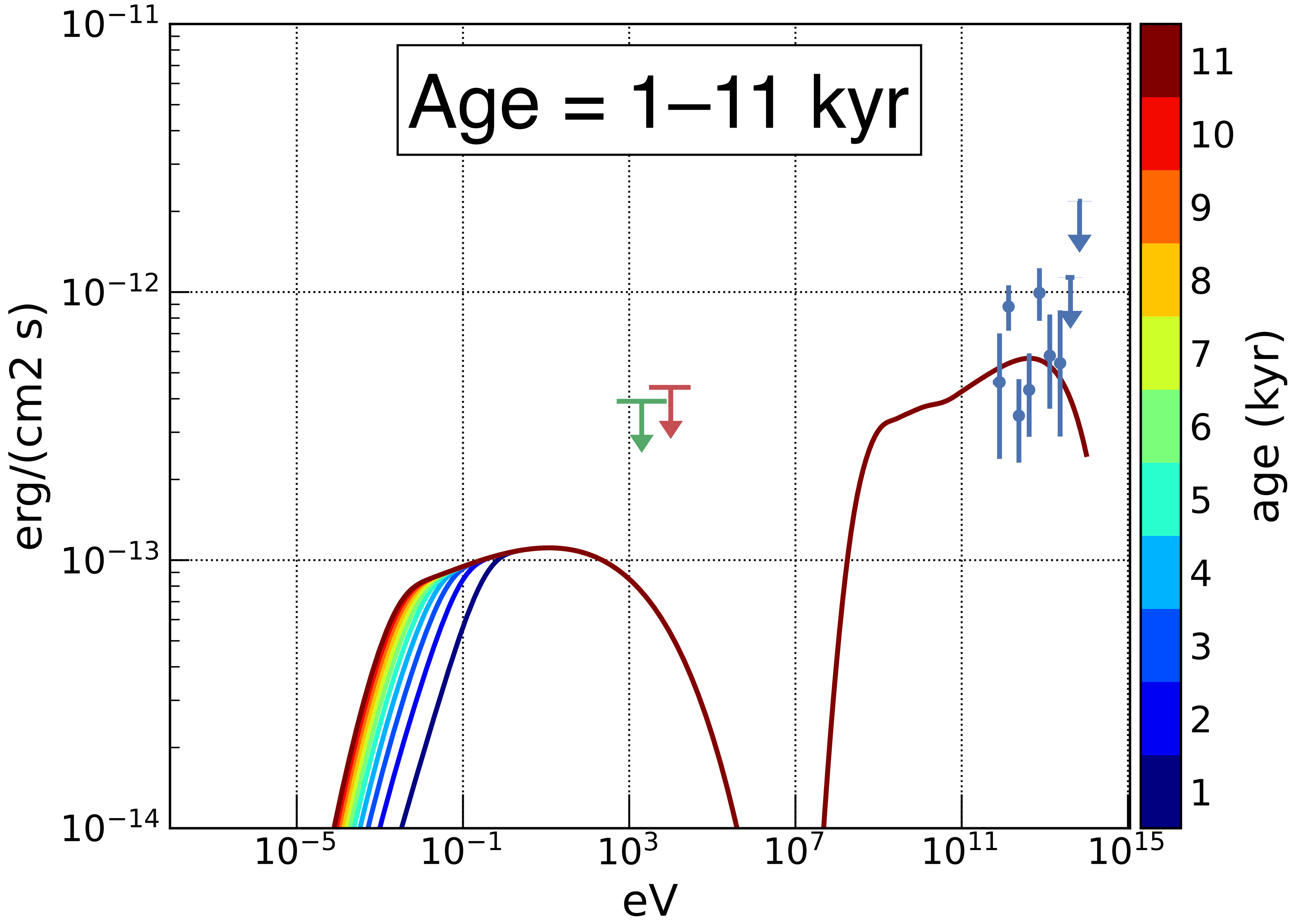
n (cm^{-3})	100
B (μG)	300
Age (kyr)	5
d (kpc)	11
Proton	
index	1.9
Ec (TeV)	**100–3000**
Wp (erg)	1.5×10^{48}

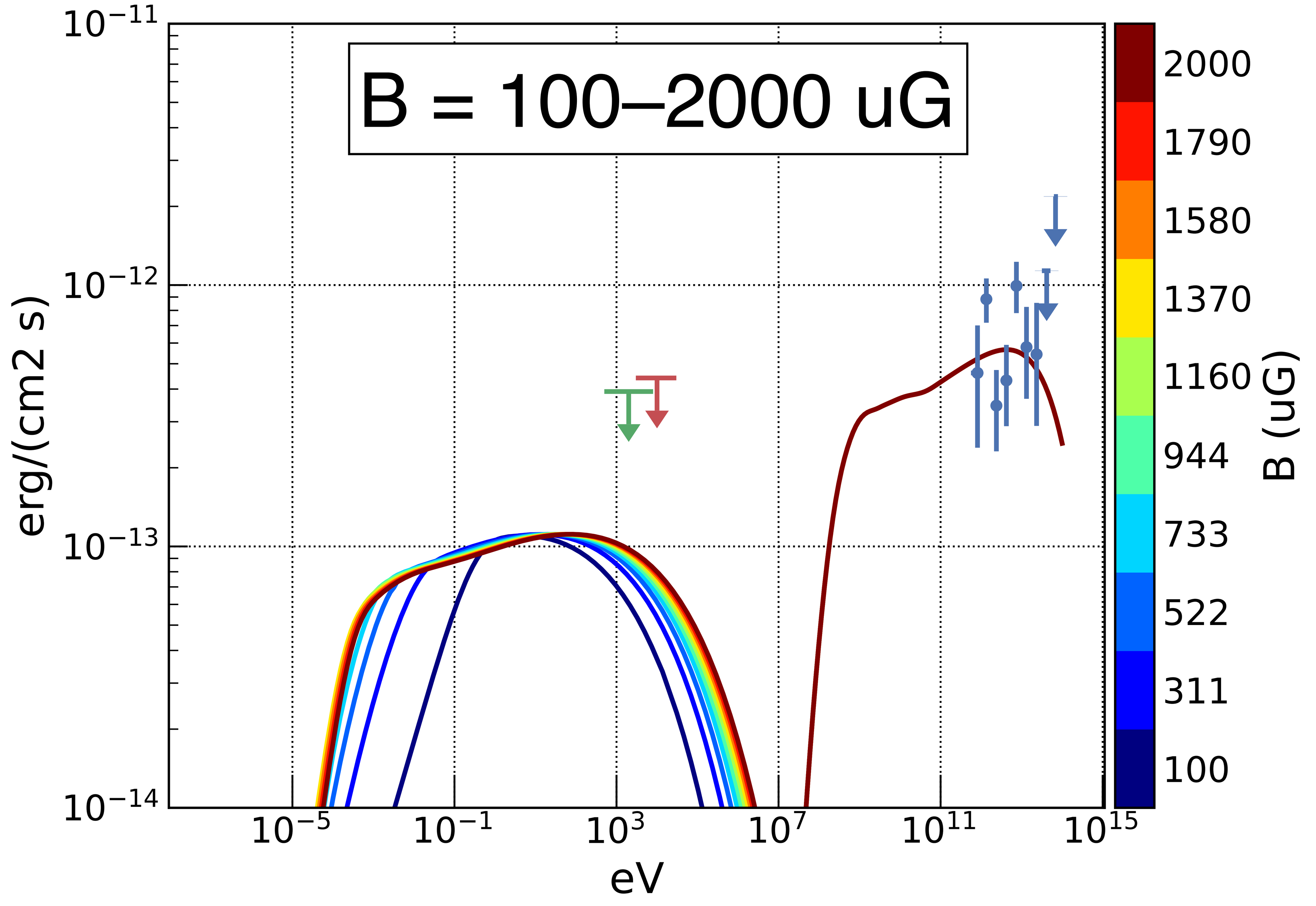
- X-ray upper limits (this work) cannot place tight constraint, but PeVatron scenario is not excluded

Modeling

Synchrotron X-ray from secondary e± in pp interaction







n (cm^{-3})	100	Proton	
B (μG)	300	index	2.0
Age (kyr)	5	Ec (TeV)	100
d (kpc)	11	Wp (erg)	1.5×10^{48}

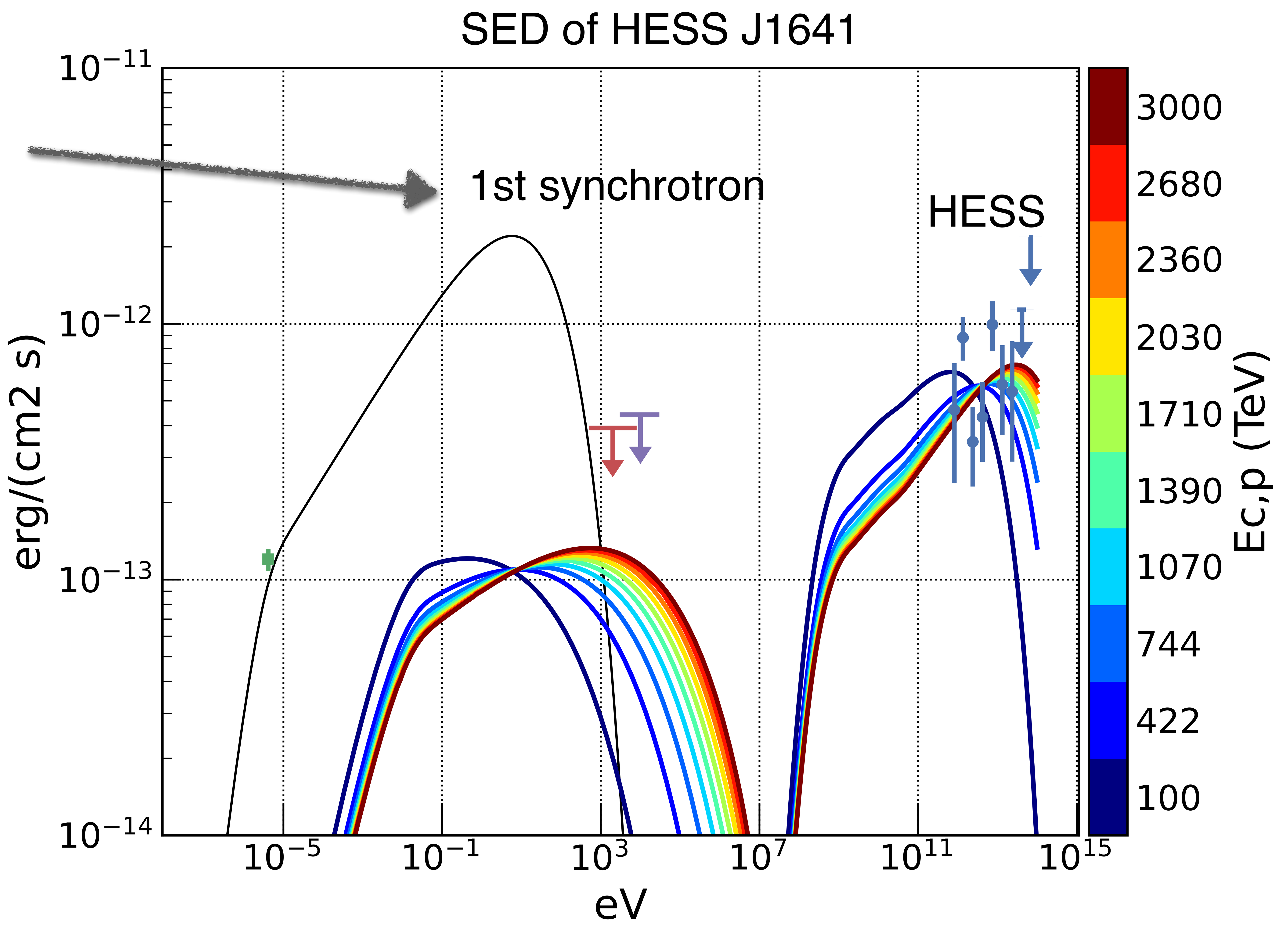
Future prospect

Detectability of 2nd electrons

- Needs hard X-ray observation (w/ better angular resolution) to distinguish from primary electrons

- Future hard X-ray mission
  - HEX-P (NASA), FORCE→JEDI (JAXA)

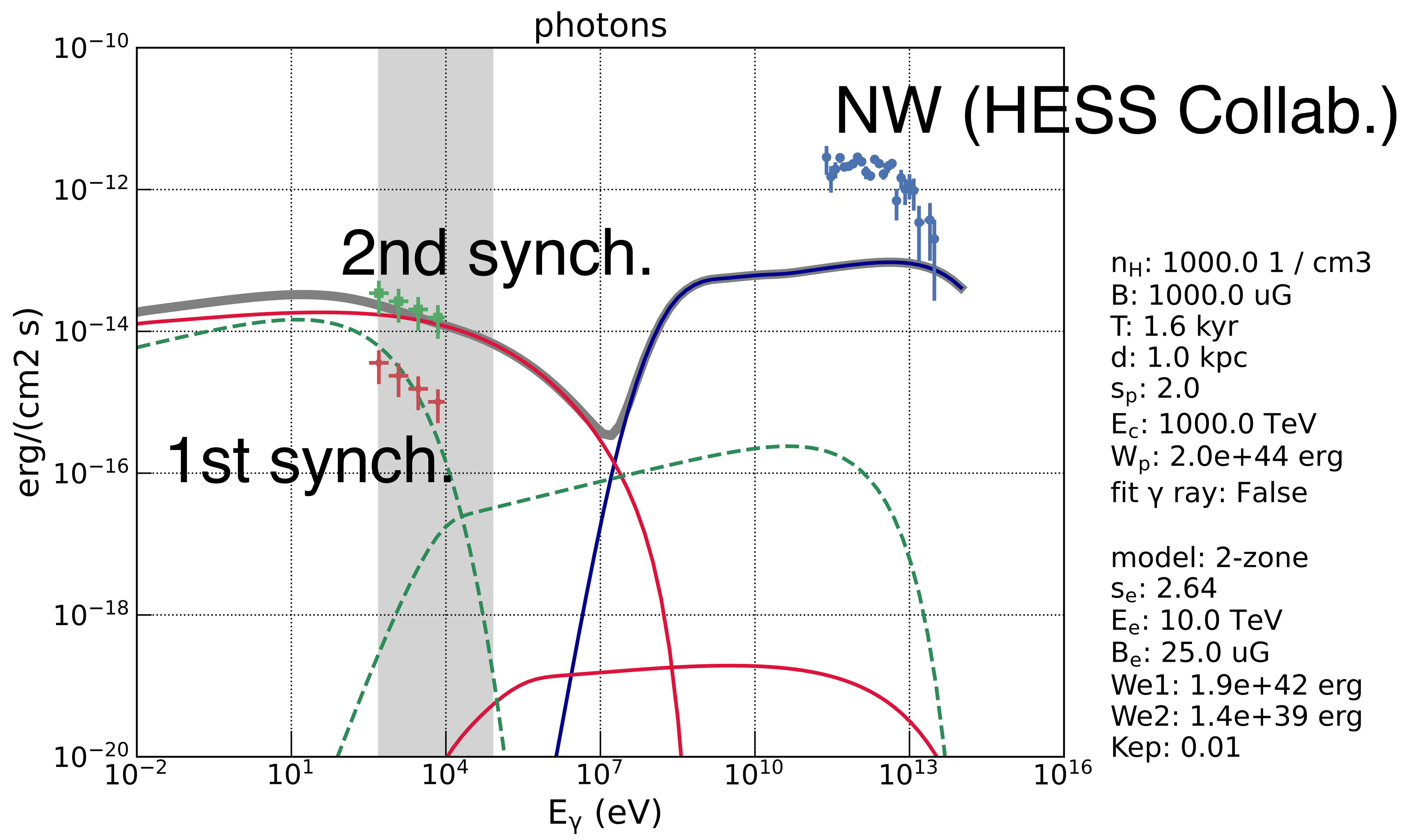
- Requirement (the case of HESS J1641)
  - Flux >1.8×10^{-14} erg/cm^2/s in 2-10 keV
  - Flux >4.9×10^{-15} erg/cm^2/s in 10-50 keV (Ec>100 TeV)



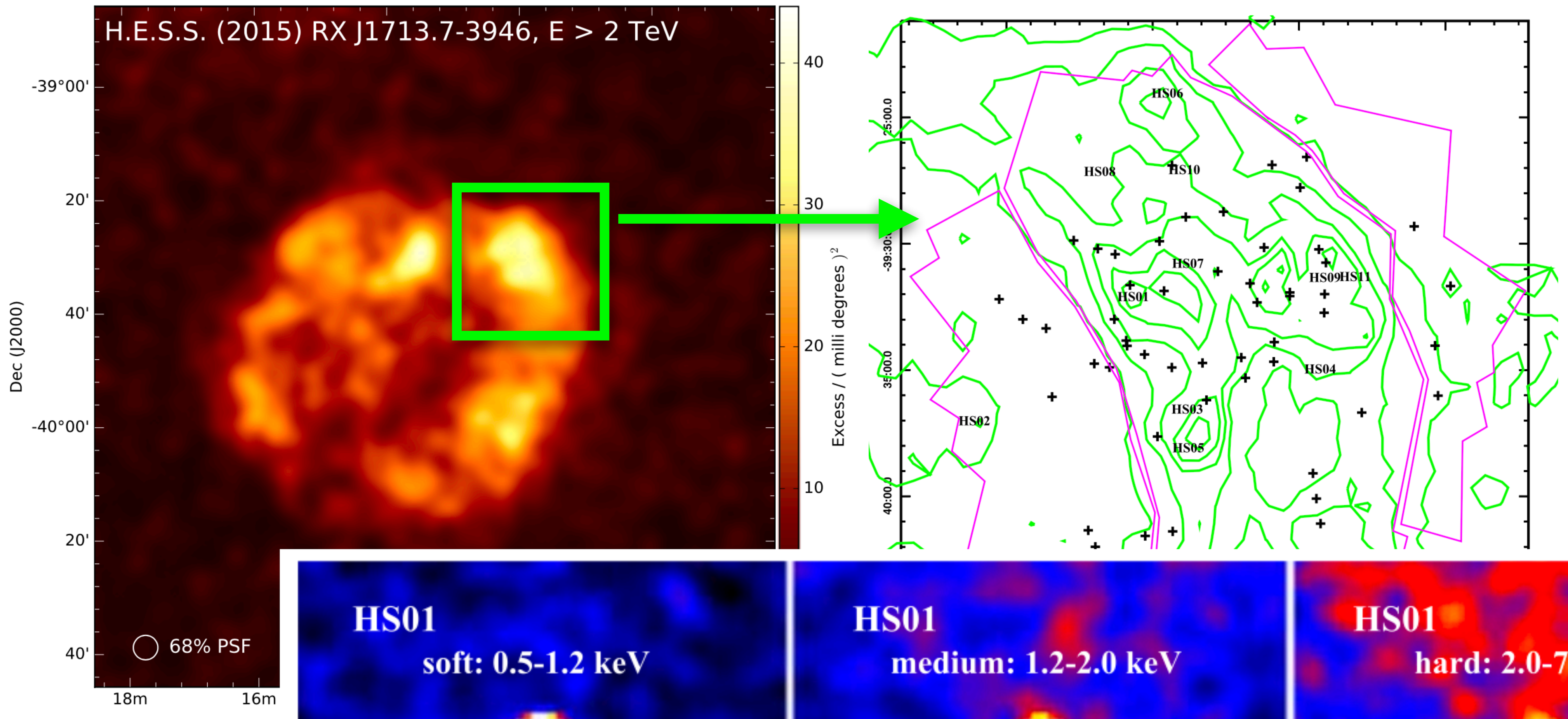
Future prospect

Detectability of 2nd electrons

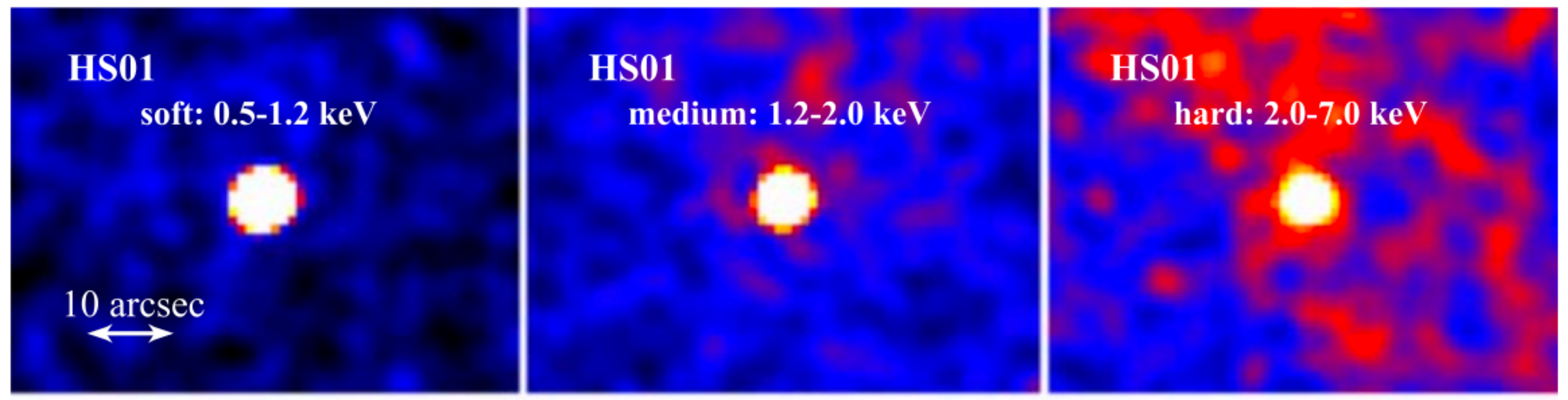
- Best target?
  - Hard TeV gamma-ray spectrum
    - 2nd synchrotron flux <10% of π^0 γ-ray
  - High density
  - Low flux of soft X-rays (thermal and 1st synchrotron)
  - ↓
  - Stellar cluster, TeV unidentified sources, …



- Hotspots in SNR RX J1713
  - Some might be cores of molecular clouds
  - Requirement
    - 2-10 keV Flux (2nd syn.) $= 2.0\times10^{-14}$ cgs
    - 10-50 keV Flux (2nd syn.) $= 1.5\times10^{-14}$ cgs
    - Angular resolution <15 arcsec
      - Otherwise, 1st synchrotron dominates



Many X-ray hotspots in NW shell (Higurashi, NT, Uchiyama, 2020)



Summary

- HESS J1641–463 is an unidentified, extended TeV gamma-ray source

- X-ray (Chandra and newly taken NuSTAR) data analyses
  - No apparent counterpart
  - Obtained flux upper limit
    - $(6–7)\times10^{-13}$ erg/cm^2/s in 2–10 keV
    - $\sim3\times10^{-13}$ erg/cm^2/s in 10–20 keV

- Modeling
  - Calculated synchrotron emission from secondary electrons in pp interaction
    - All models are below the observed X-ray flux
    - Will be tested by future (hard) X-ray missions