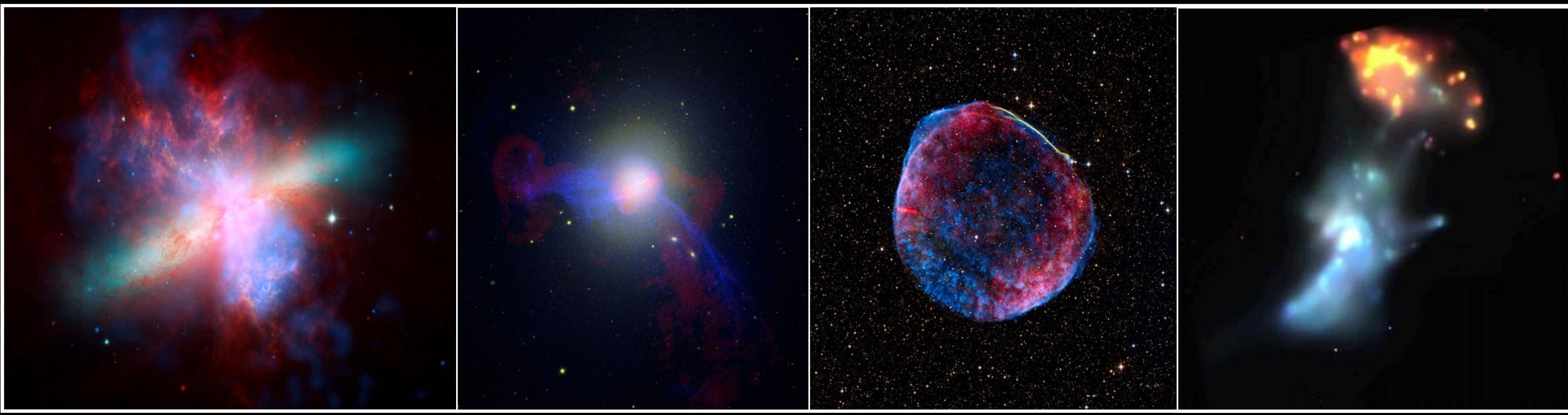

Opportunities for multi-TeV gamma-ray science

Jim Hinton ▪ University of Leicester

Detector Considerations

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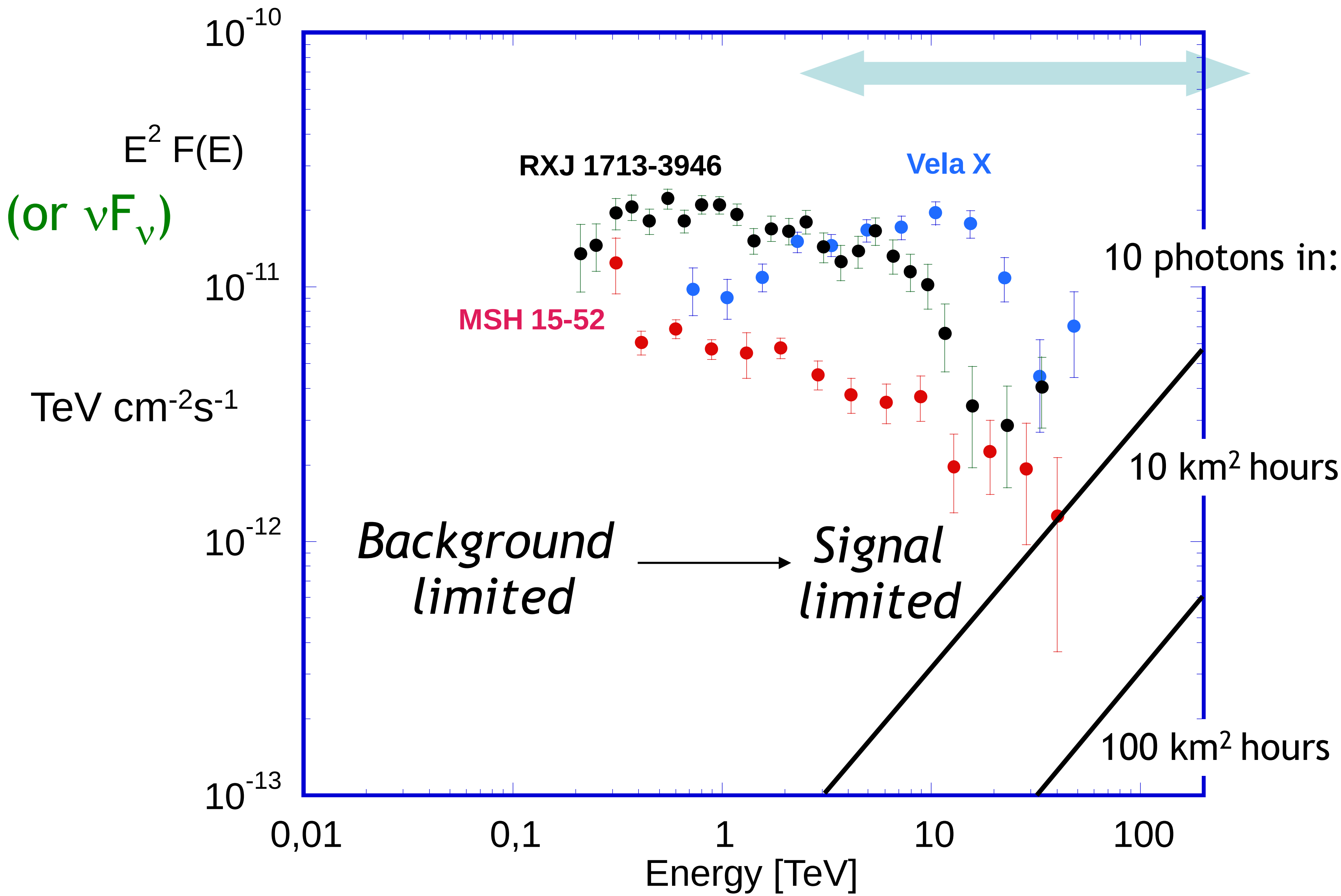
For a 3-300 TeV Imaging Atmospheric Cherenkov Telescope Array

- Collection area
  - Require several km^2 to reach 10^{-13} erg cm^{-2} s^{-1} @ 10 TeV
- Telescope size/separation
  - Separation >200m required for <100 telescopes
  - 100 pe images for 3 TeV shower @250m $\rightarrow$ 5m mirror
    - Relatively inexpensive (but camera cost dominates)
- Field of view
  - 250 m spacing implies typical offset of image from source of ~3° – need an 8° camera
- Angular resolution
  - 1’ @10 TeV - shower fluctuations ↓ with energy…

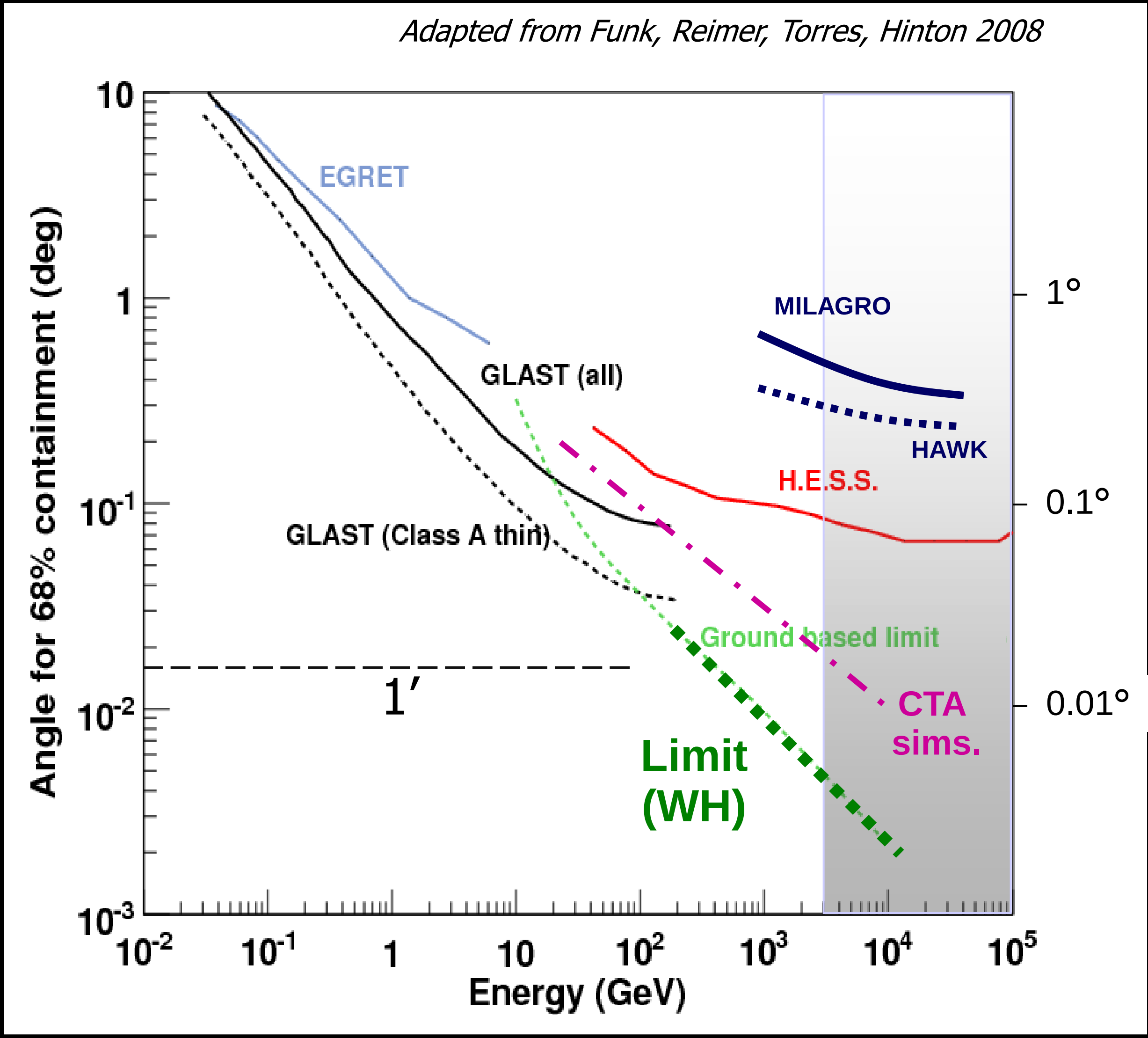
Adapted from
Werner Hofmann



Angular resolution

3-100 TeV

- <1 arcminute precision achievable **only** > TeV
- <1 arcminute achievable at 100 TeV with modest collection efficiency



Gamma-ray Emission

- Need >TeV parent particles
  - Decay of "exotic" particles
    - Neutralinos, topological defects, …
  - Accelerated
    - Protons and Nuclei
      - Dominant radiation via π_0 decay (PeV $\rightarrow$ 10-100 TeV)
    - Electrons
      - Dominant radiation is IC (at high energies) (bremsstrahlung dominates at 1 TeV only if n>200 cm^{-3})
    - Ratio?
      - $F(brems)/F(\pi_0) \sim 3\ (N_e/N_p)$ @ 1 TeV
- TeV Astronomy = High Energy Astrophysics + TeV-scale particle physics

See Anne's Talk

Gamma-ray Emission

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- Need >TeV parent particles
  - Decay of “exotic” particles
    - Neutralinos, topological defects, …
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    - Protons and Nuclei
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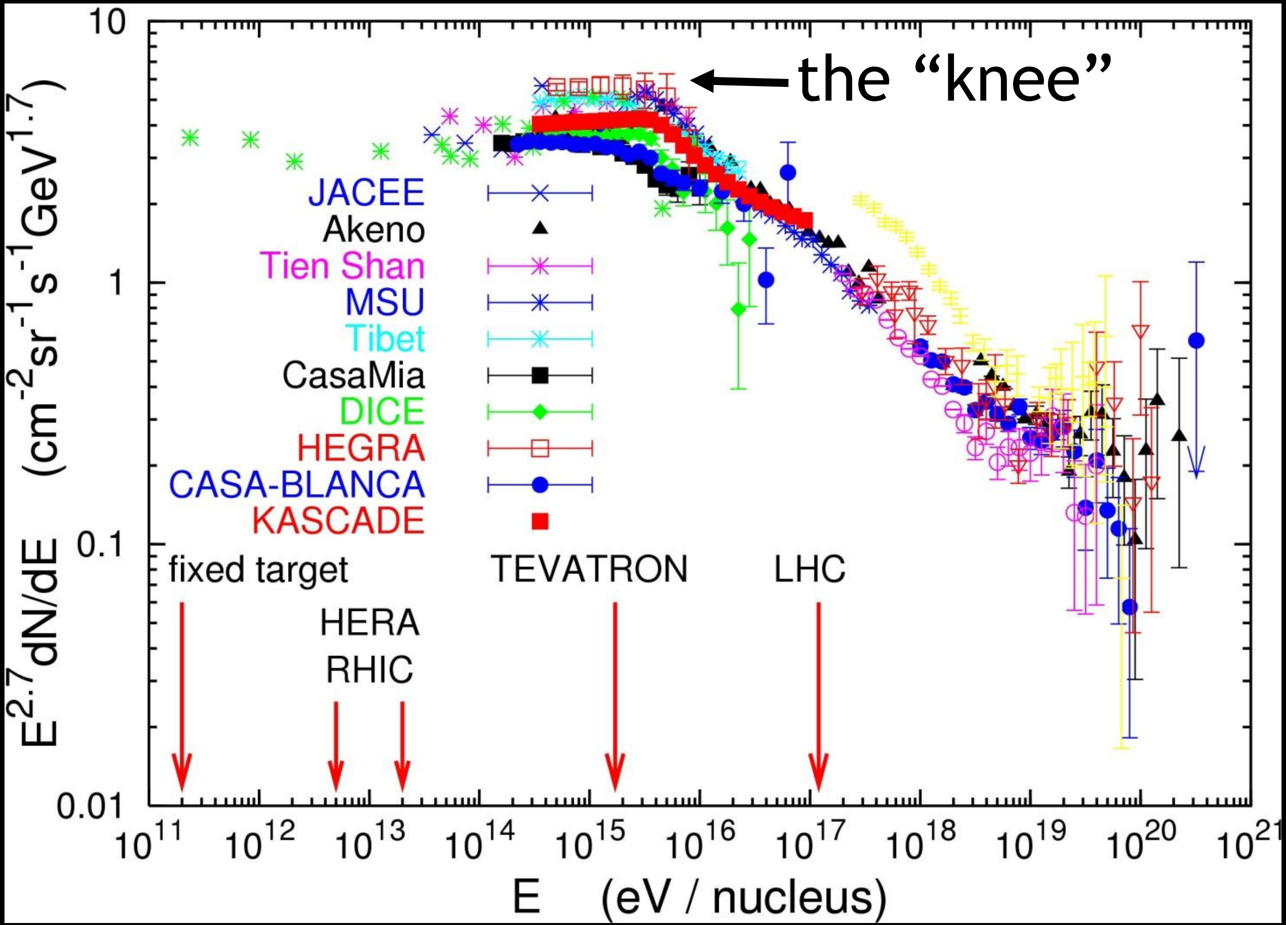
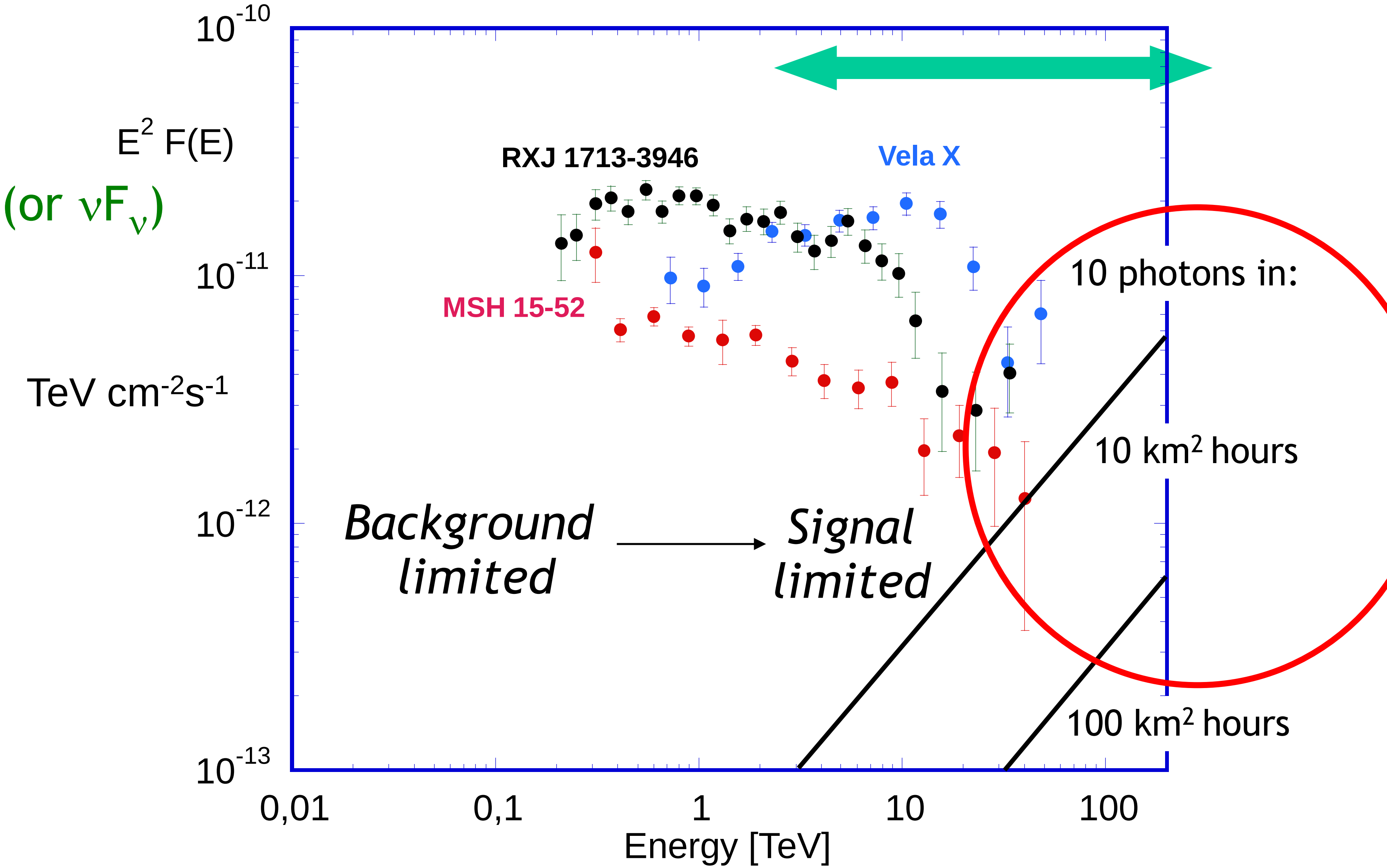
Galactic Pevatrons



- Locally measured cosmic ray spectrum
  - Extends smoothly to ~3 PeV (need 100 TeV photons)
  - Galactic origin at least this far

Adapted from
Werner Hofmann


10^{-10}
10^{-11}
10^{-12}
10^{-13}
E^2 F(E)
(or νF_ν)
TeV $cm^{-2}s^{-1}$
RXJ 1713-3946
Vela X
MSH 15-52
10 photons in:
10 km^2 hours
100 km^2 hours
Background limited
Signal limited
0,01
0,1
1
10
100
Energy [TeV]

X-ray Connection ?

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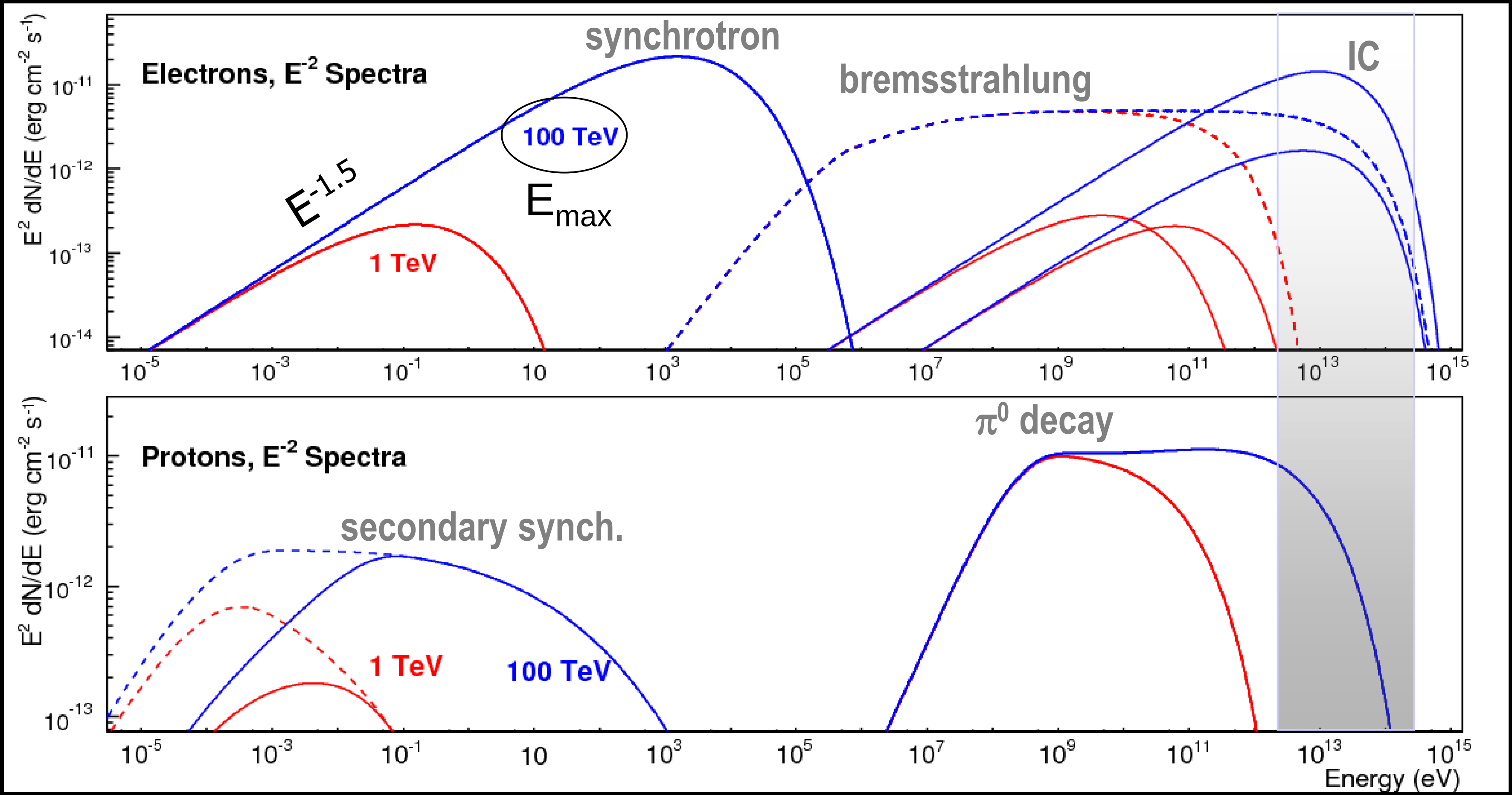
- IC & Synchrotron emission of VHE electrons
  - $E_{sync} \sim 2 (E_e/50\ TeV)^2 (B/10\ \mu G)$ keV
  - $E_{IC} \sim 20 (E_e/50\ TeV)^2$ (on CMBR) TeV
- For typical ISM B-fields: >10 TeV IC photons probe the same electron population as X-ray synchrotron emission
  - even with FIR target photons as then K-N effect
- Magnetic fields can then be inferred
  - *If* angular resolution of both measurements is sufficient

Simplest non-thermal SEDs

3-300 TeV



- dN/dE ~ E^{-2} primary particles, E_{max}=1/100 TeV

Simplest non-thermal SEDs

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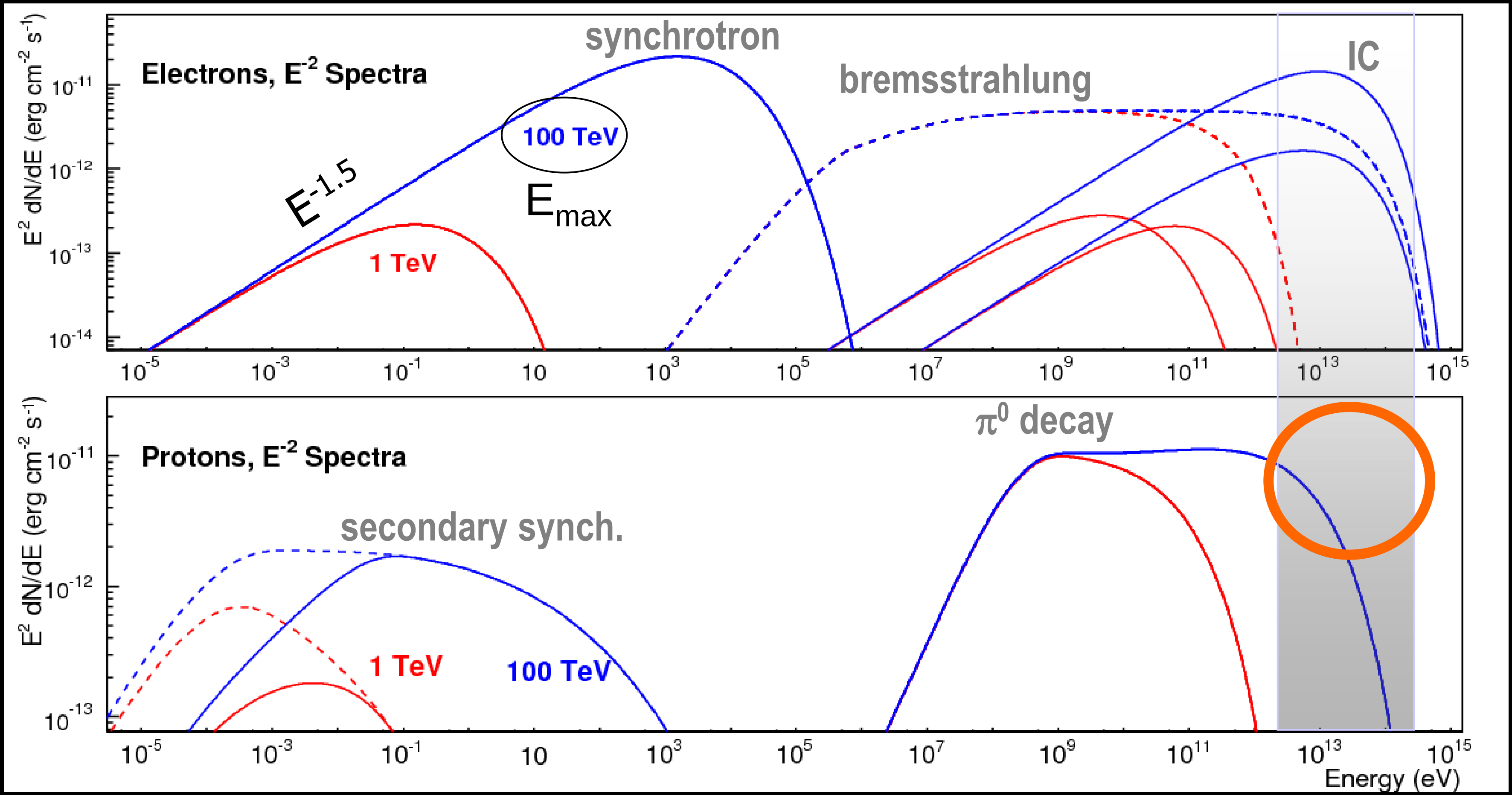
Proton acceleration beyond 100 TeV

3-300 TeV

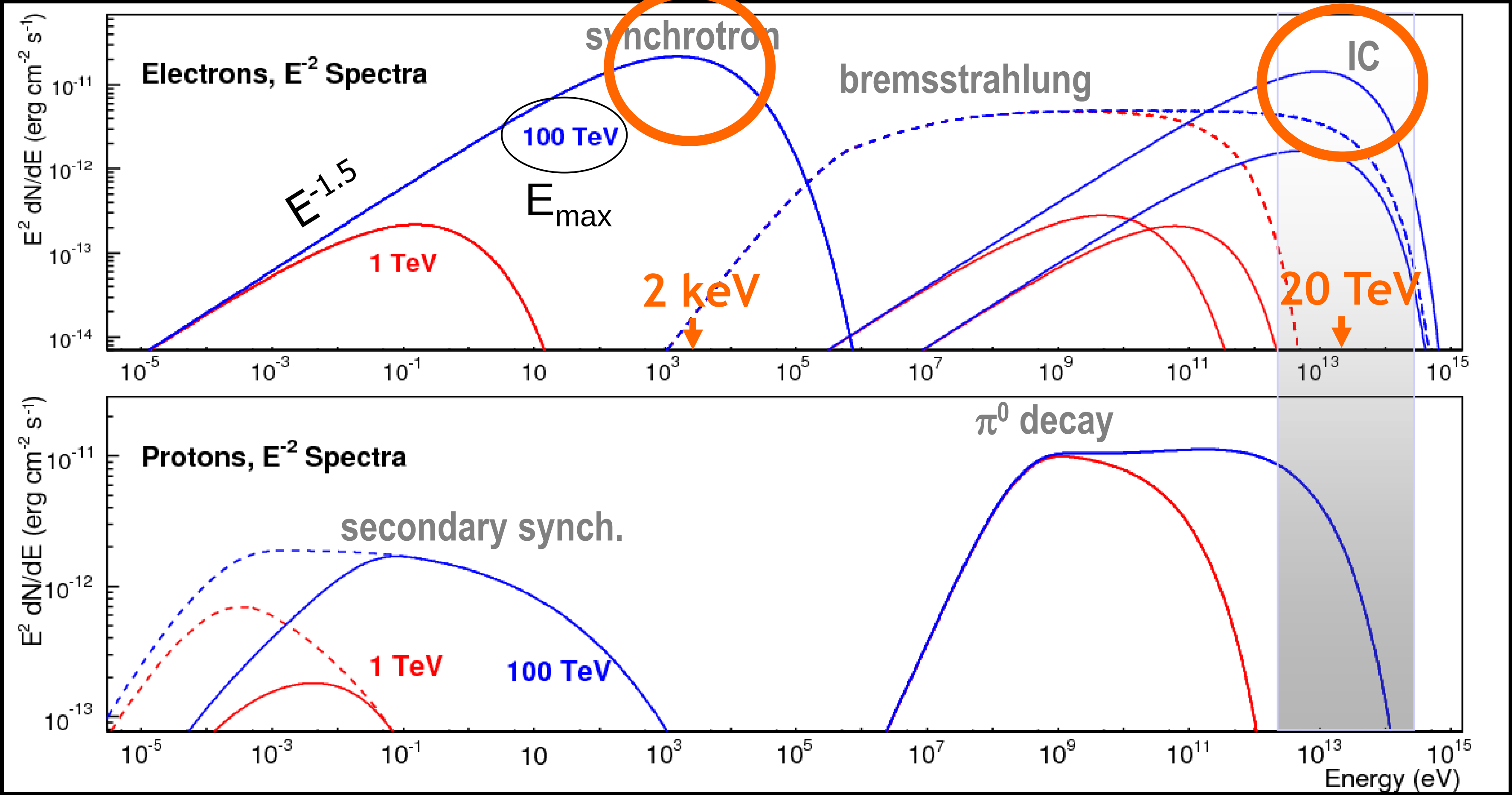


» $dN/dE \sim E^{-2}$ primary particles, E_{max}=1/100 TeV

Simplest non-thermal SEDs

ISM X-ray synchrotron emitting electrons

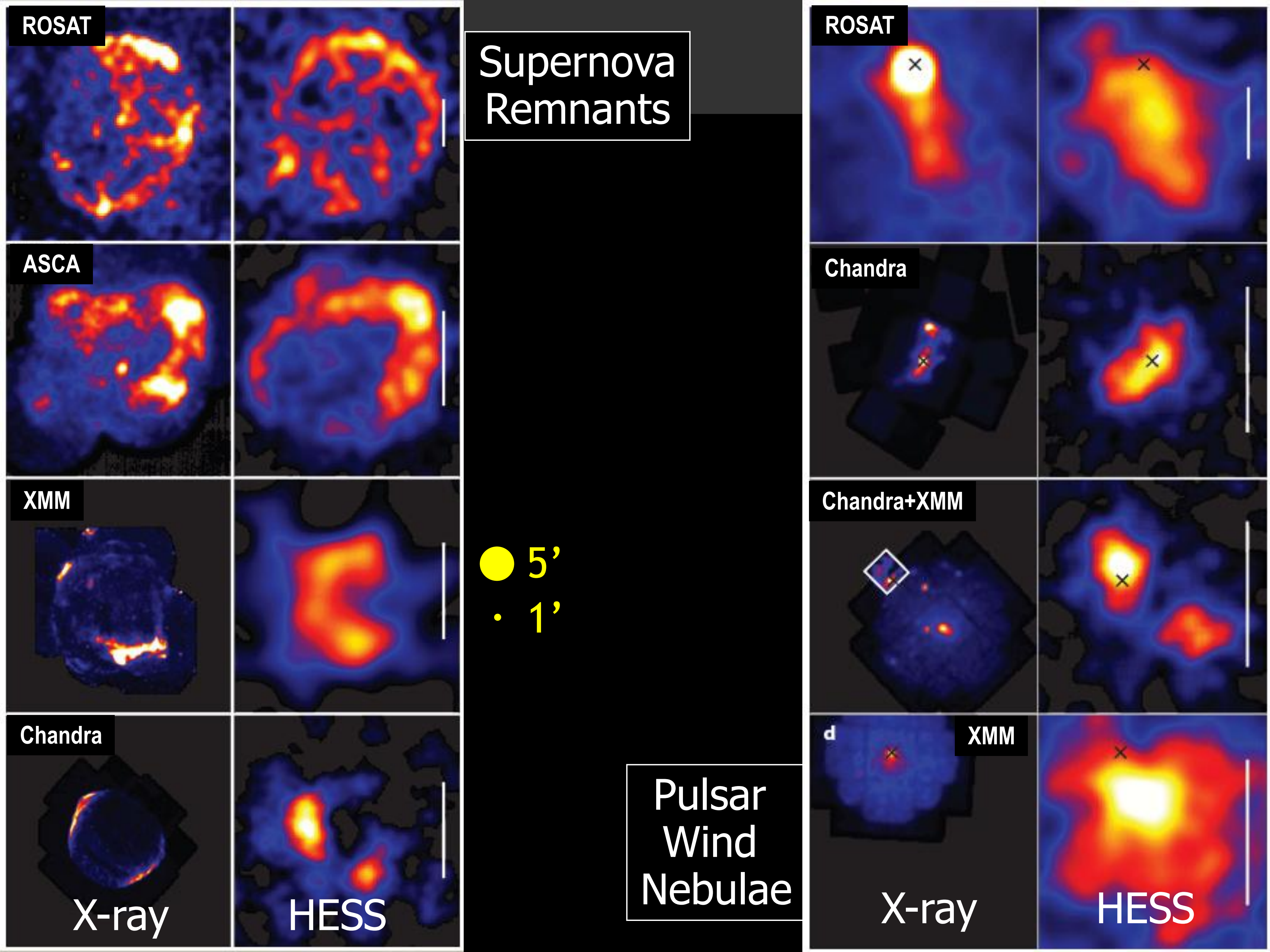
3-300 TeV



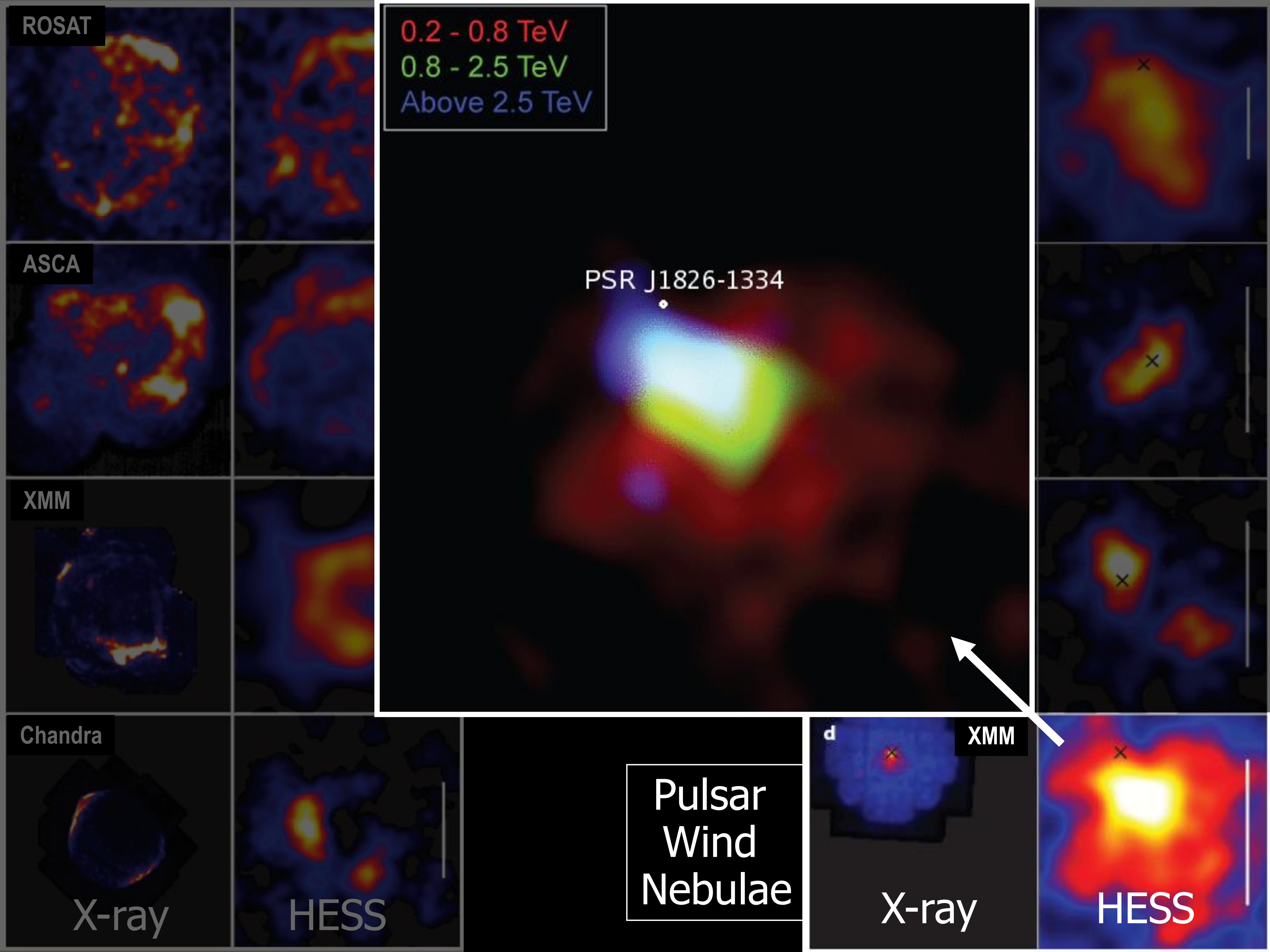
» dN/dE ~ E^{-2} primary particles, E_{max}=1/100 TeV

Source Morphology

- Emission region size
  - Protons and nuclei
    - likely *diffusion limited* – growing with energy
      $r \sim E^{\Delta/2}$, $\Delta = 0.3\text{-}1.0$
  - Electrons
    - likely *cooling limited* – shrinking with energy
      $t_{cool} \sim 1/E_e$, $r \sim t^a$
- Substructure
  - Electrons
    - Located very close to their acceleration sites at high E
  - Protons
    - Substructure from distribution of target material



Supernova Remnants
ROSAT
ASCA
XMM
Chandra
X-ray
HESS
5'
1'
ROSAT
Chandra
Chandra+XMM
d
XMM
X-ray
HESS
Pulsar Wind Nebulae


ROSAT
ASCA
XMM
Chandra
X-ray
HESS
0.2 - 0.8 TeV
0.8 - 2.5 TeV
Above 2.5 TeV
PSR J1826-1334
Pulsar Wind Nebulae
d
XMM
X-ray
HESS

With resolved E-dep. morphology

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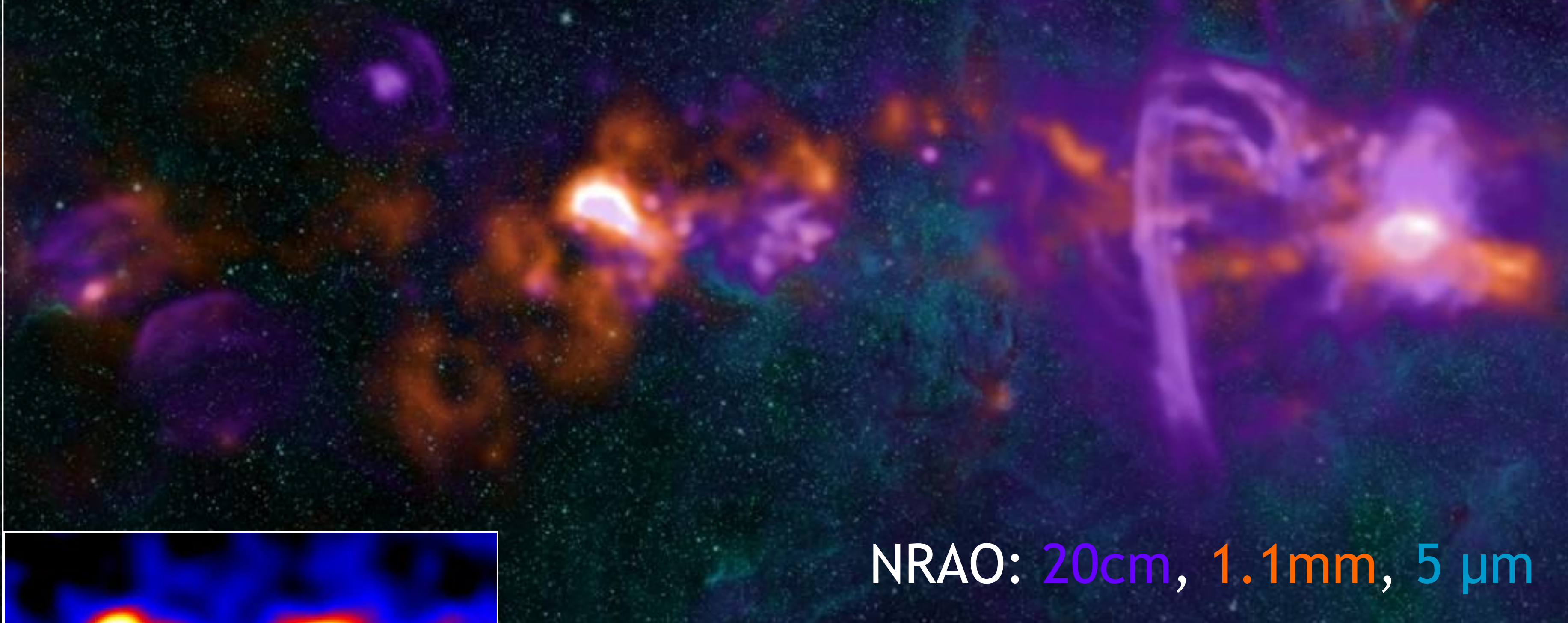
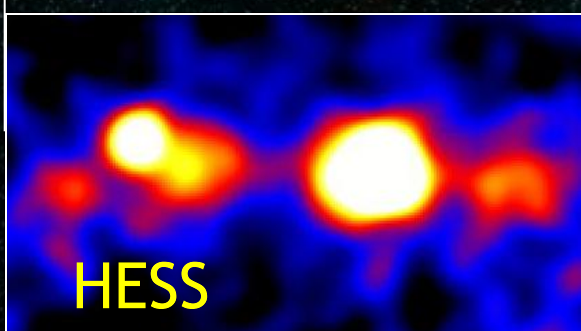
- Identification of the nature of the radiating particles (hadrons versus leptons)
  - Together with current and future X-ray and radio telescopes to probe synchrotron emission
- Understanding of the transport of ultra-relativistic particles
  - At the moment we know very little
- Understanding the magnetic field strength and structure in SNRs, PWN, …
- Identification of currently UnID sources
  - and better understanding of source evolution

The Galactic Centre

- Many targets
  - Angular resolution critical to disentangle them…





The Galactic Centre

- Many targets
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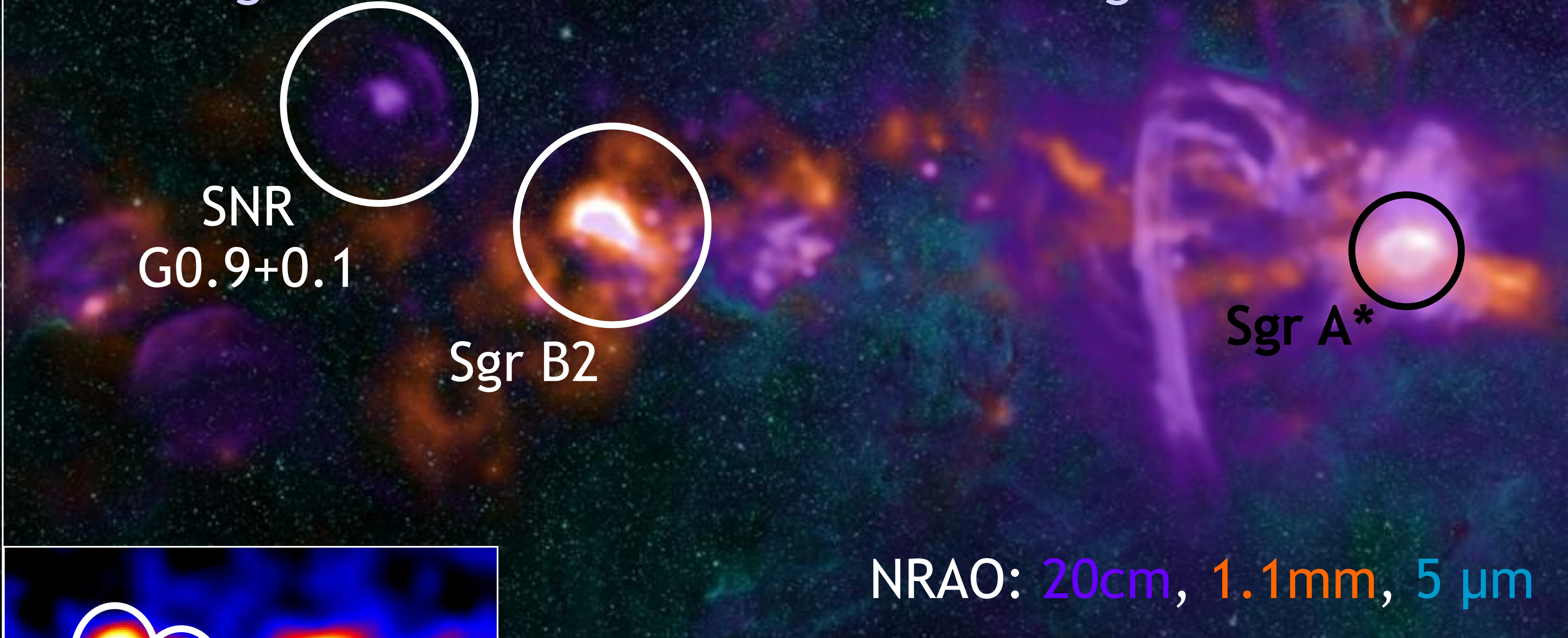

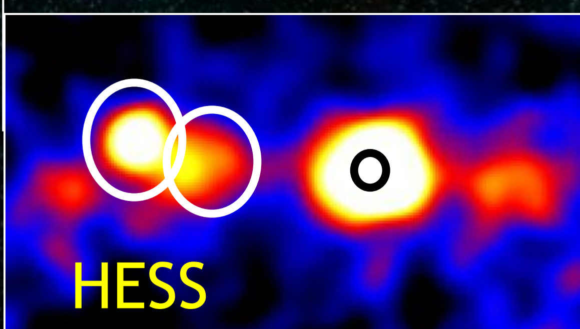

Cosmic Ray Diffusion

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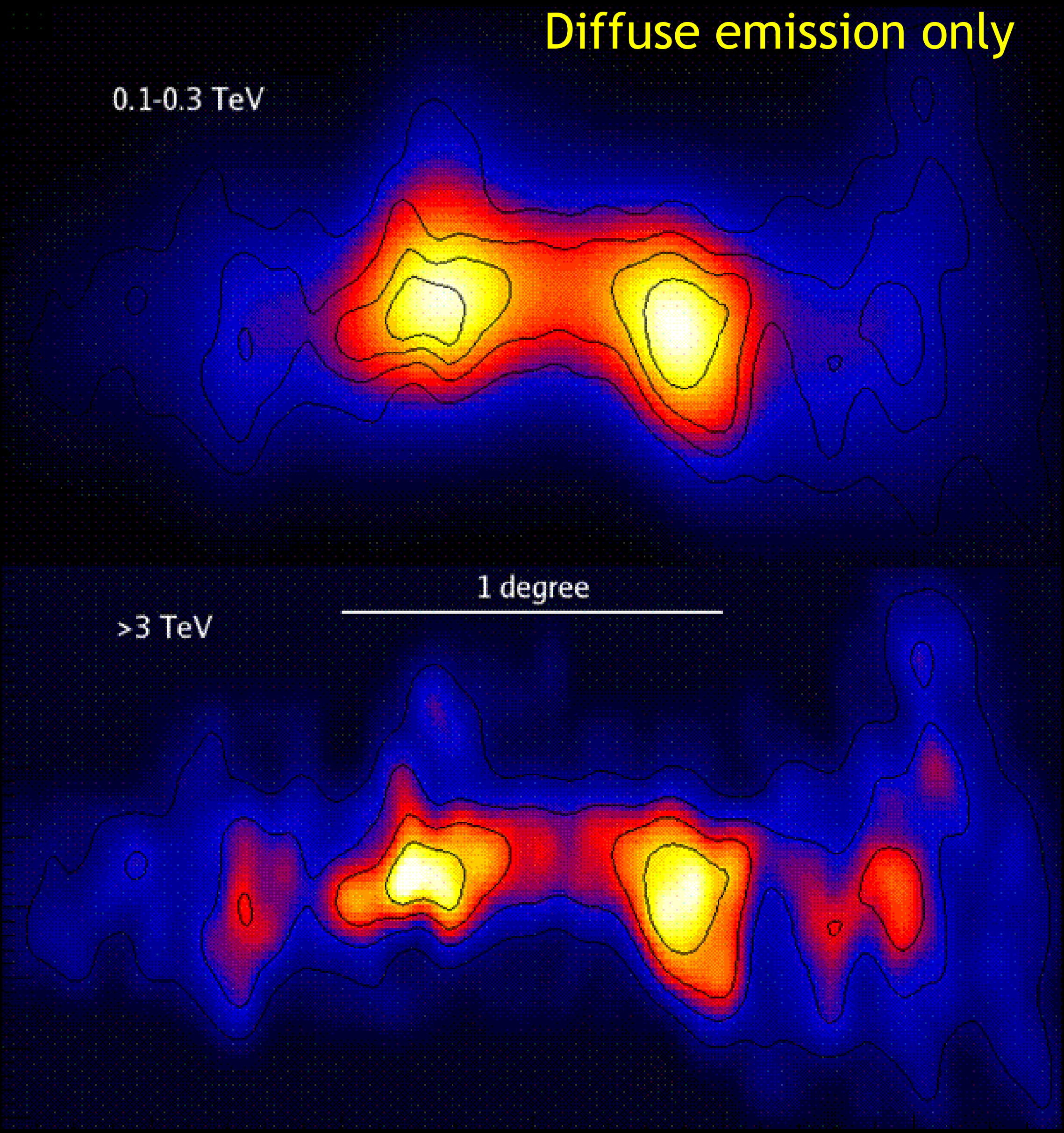
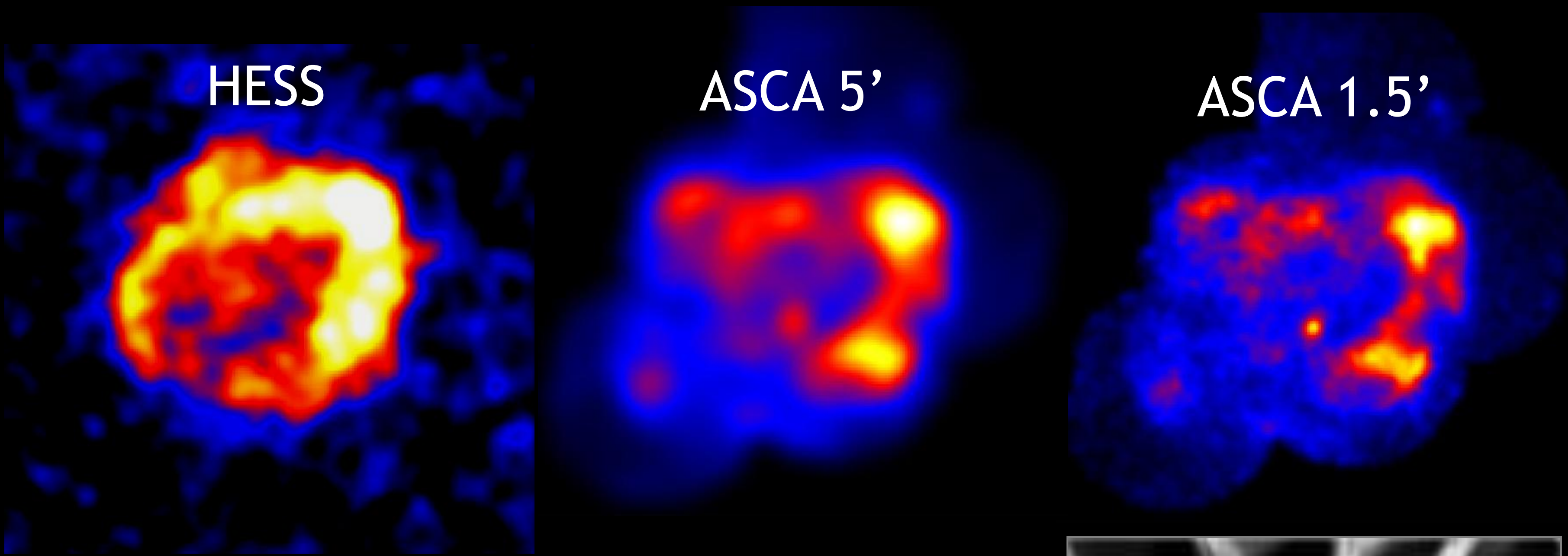
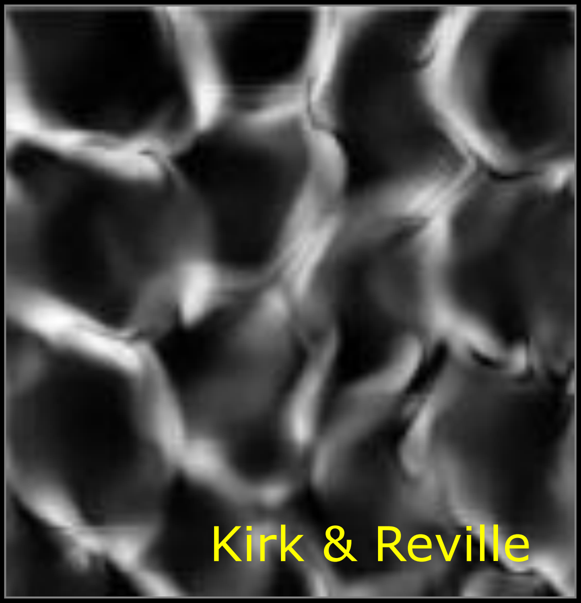
- Simulation of the GC region as seen by an instrument 10× more sensitive than HESS
  - p diffusion
  - p-p gammas
  - Instrument response
- Measure energy -dependence of Diffusion Coefficient



SNR RX J1713.7-3946



- Small-scale (<10% radius) structure of B-fields and CRs ?
- Test theory of magnetic field amplification in CR modified shocks



Unresolvable systems?

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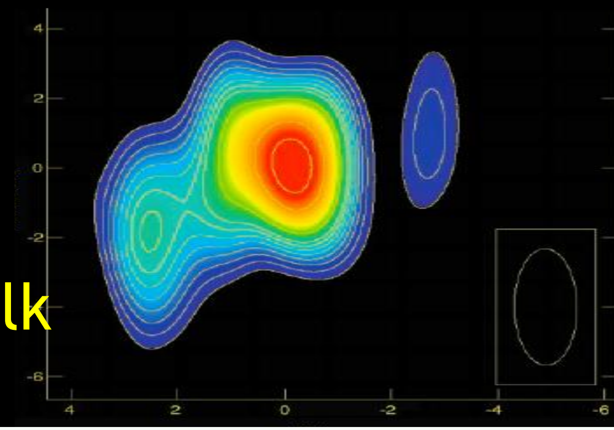
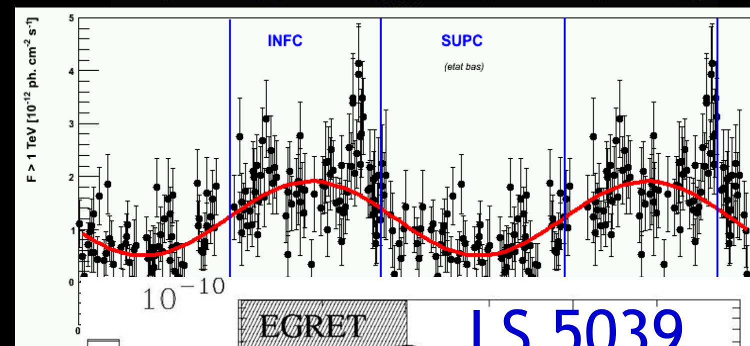
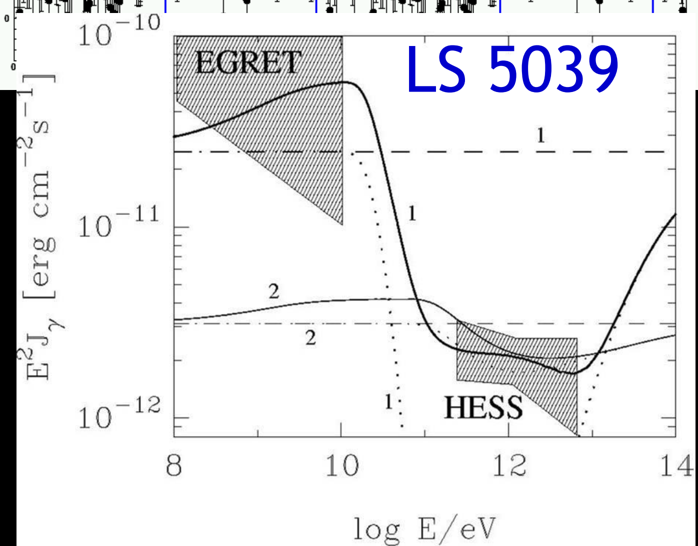
- Micro-quasars, binary PWN and colliding-wind binaries
  - Not resolvable, but…
- Orbital modulation

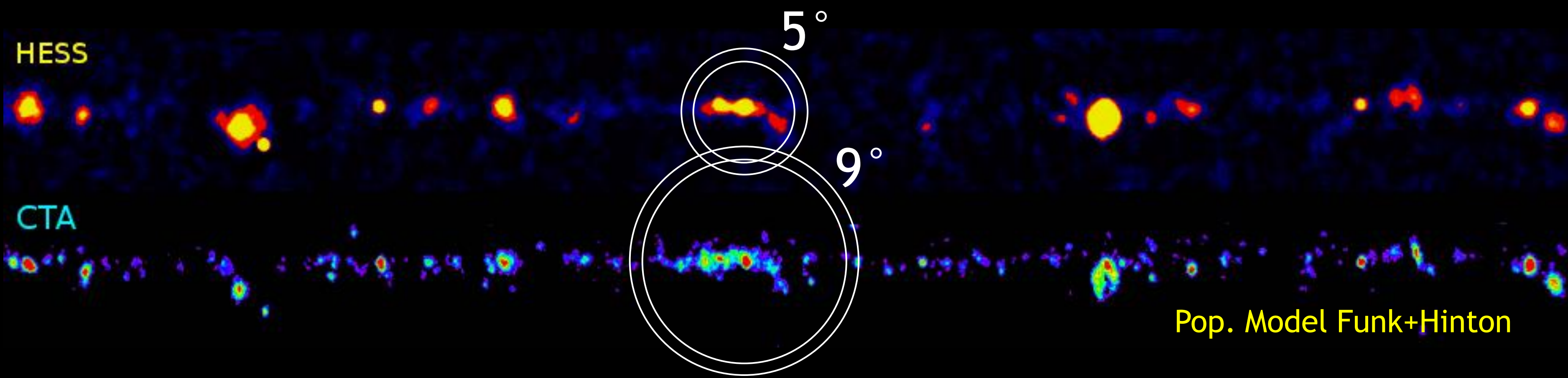
  See Julian's talk
  - Probe acceleration, transport etc under different conditions
  - Need better statistics / sensitivity to provide phase-resolved wide-band spectra
- Internal Cascading: $\gamma\gamma \rightarrow e^+e^-$
  - Cross section peaks at $(E_\gamma/\text{TeV}) \times (E_t/\text{eV}) \sim 0.9$
  - Recovery at higher energies
  - For $T \sim 10^4$ K, $E_t \sim 1$ eV
    - Back to intrinsic spectrum at 10 TeV





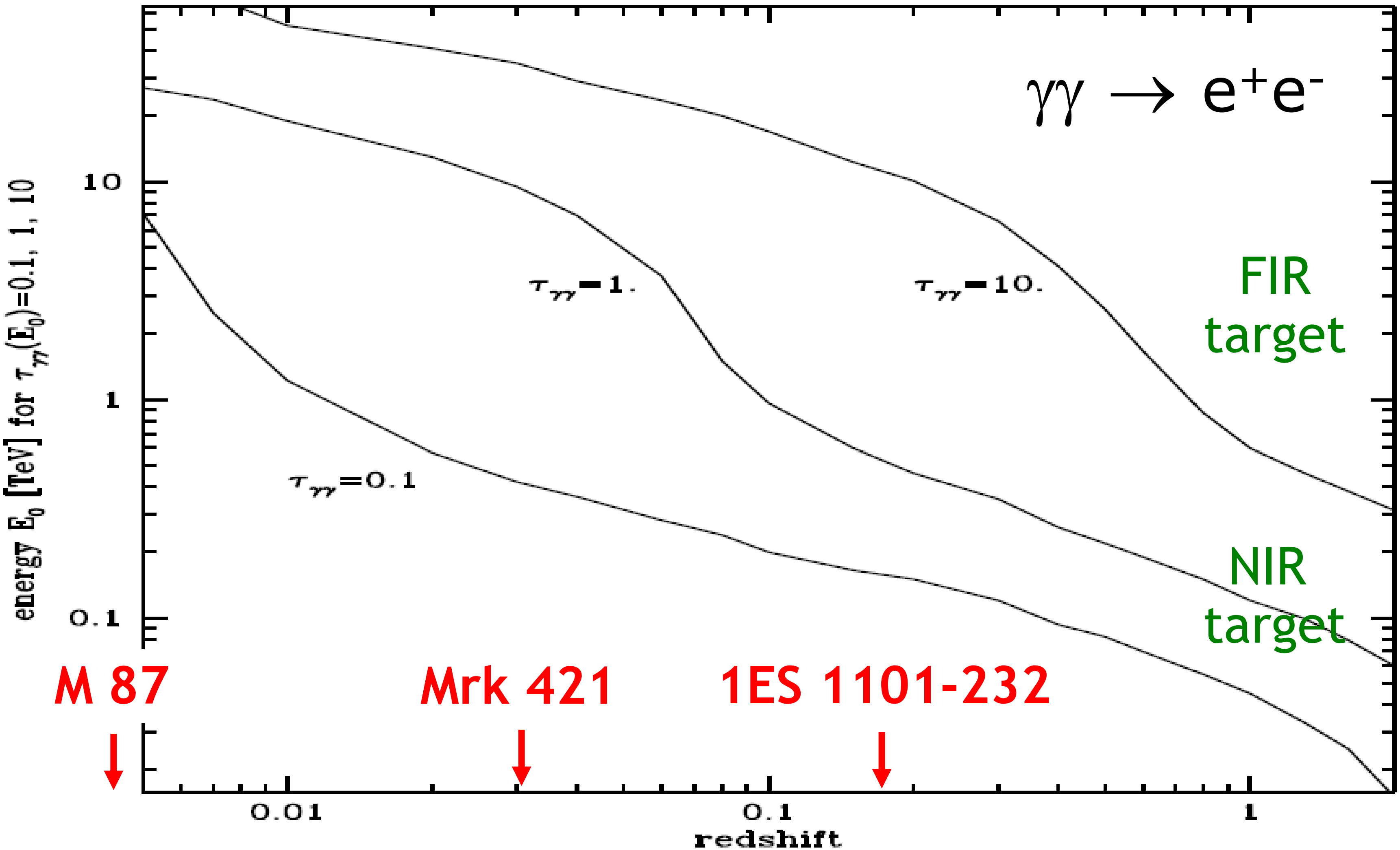


Galactic Source Populations



- Typical index 2.3 – no cut-offs below ~10 TeV
  - Many multi-TeV galactic sources
- Confusion limit reached for current angular resolution and a factor ~3 better sensitivity
  - A future TeV instrument must have better angular resolution
- Wide field of view
  - Improves survey sensitivity
  - Improves control of background (off-plane regions in FoV)

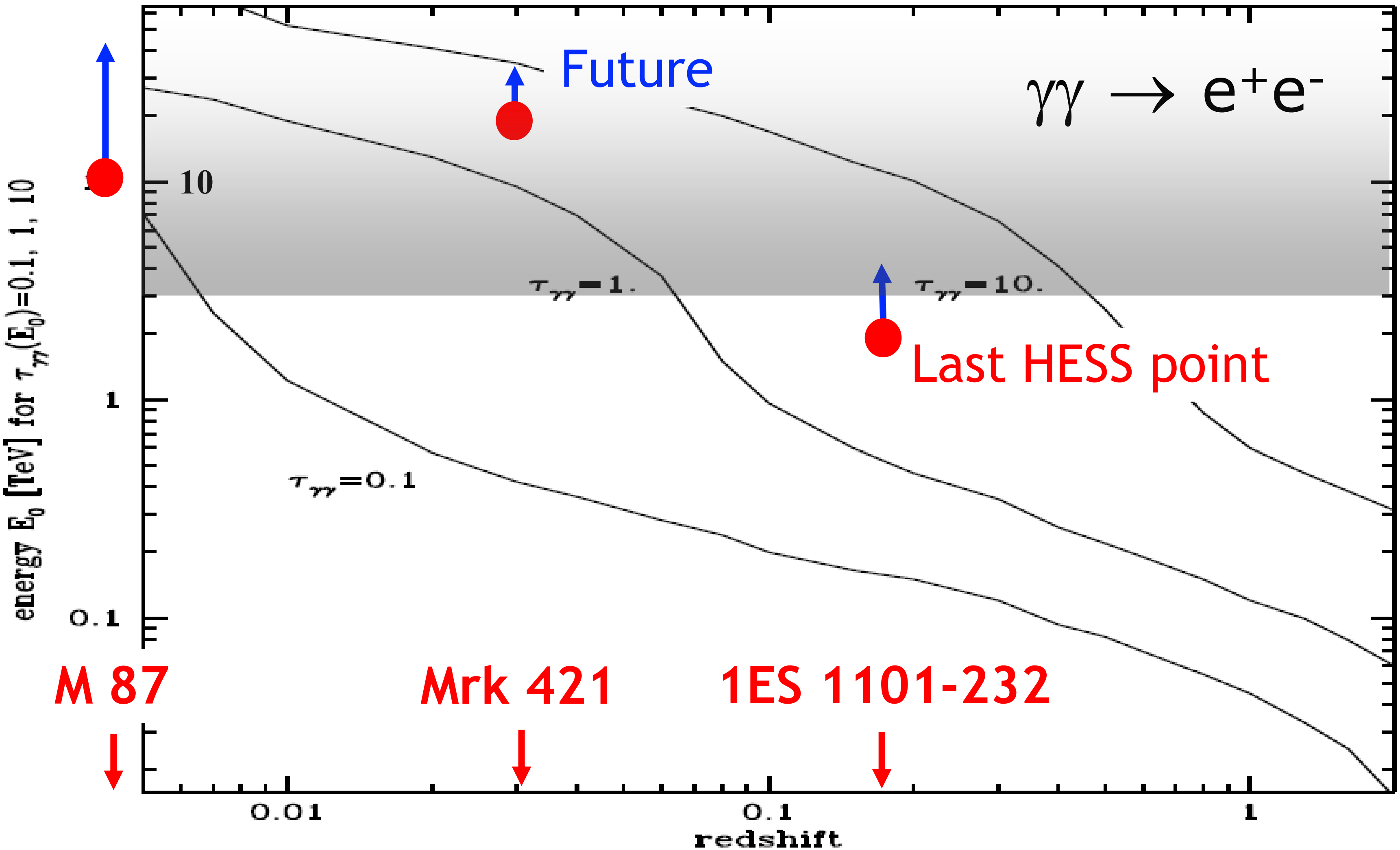
The gamma-ray horizon



From Franceschini et al 2009

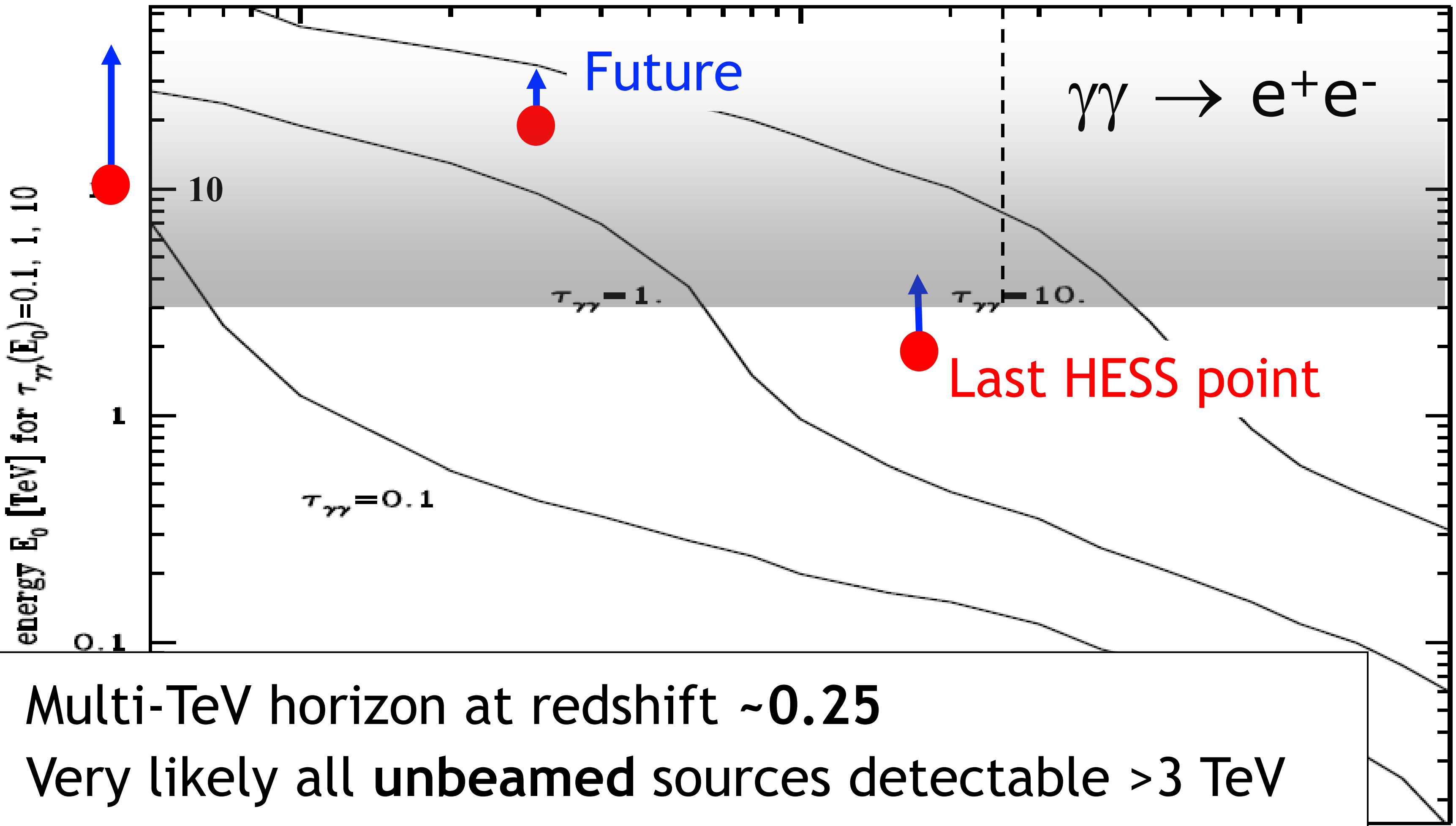
The gamma-ray horizon

University of Leicester



From Franceschini et al 2009

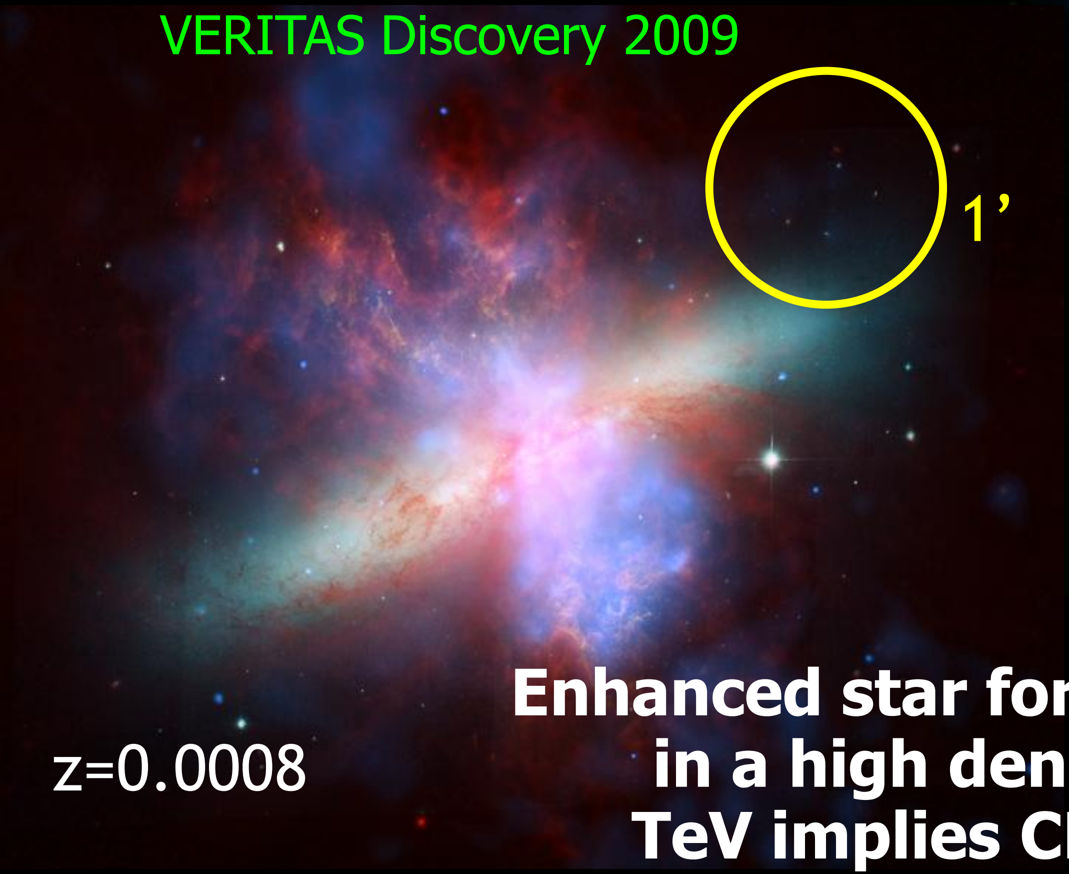
The gamma-ray horizon



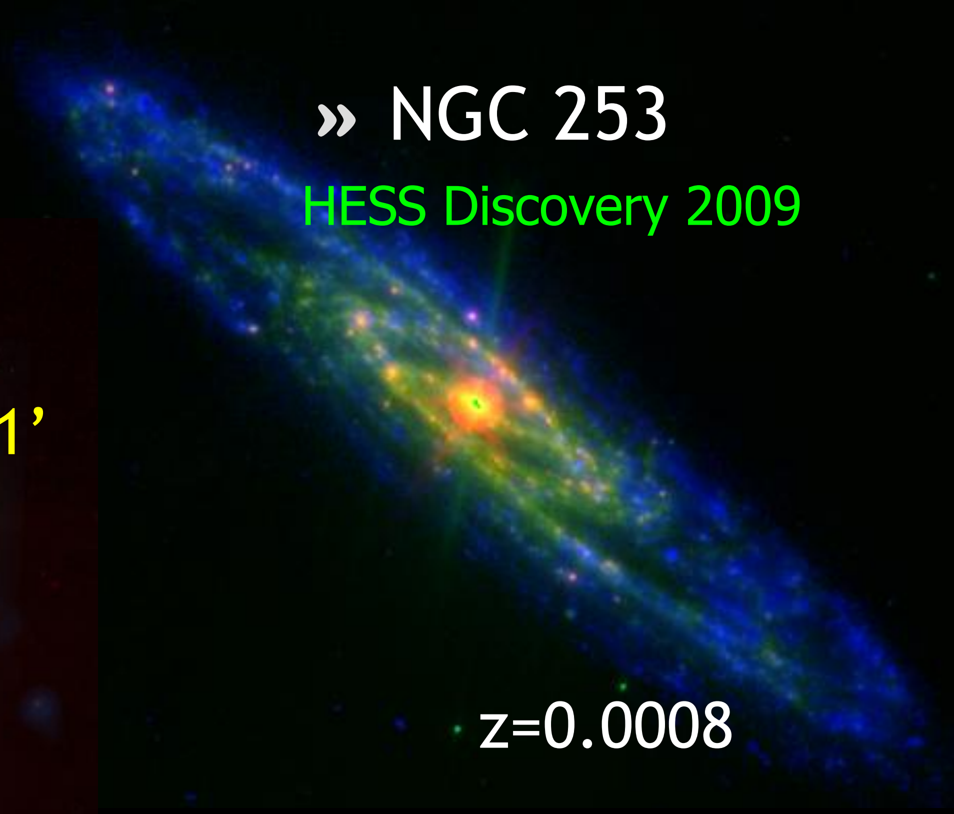
- » Multi-TeV horizon at redshift **~0.25**
- » Very likely all **unbeamed** sources detectable >3 TeV
- » Hard/strong sources detectable even with **τ=5**
- » Deeply absorbed TeV sources tightly constrain FIR EBL

Starburst Galaxies

» M 82



» NGC 253



Enhanced star formation / supernova rate in a high density starburst region
TeV implies CR density ~ SFR , but
TeV emission from π_0 inside starburst or IC in superwind, or …

Active Galactic Nuclei

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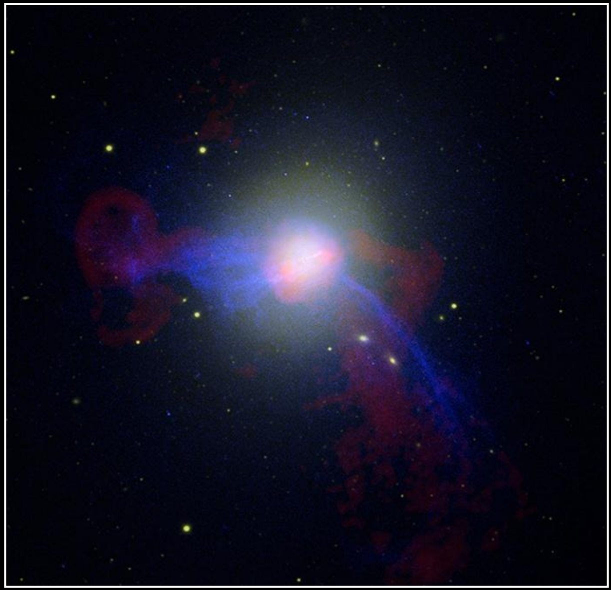
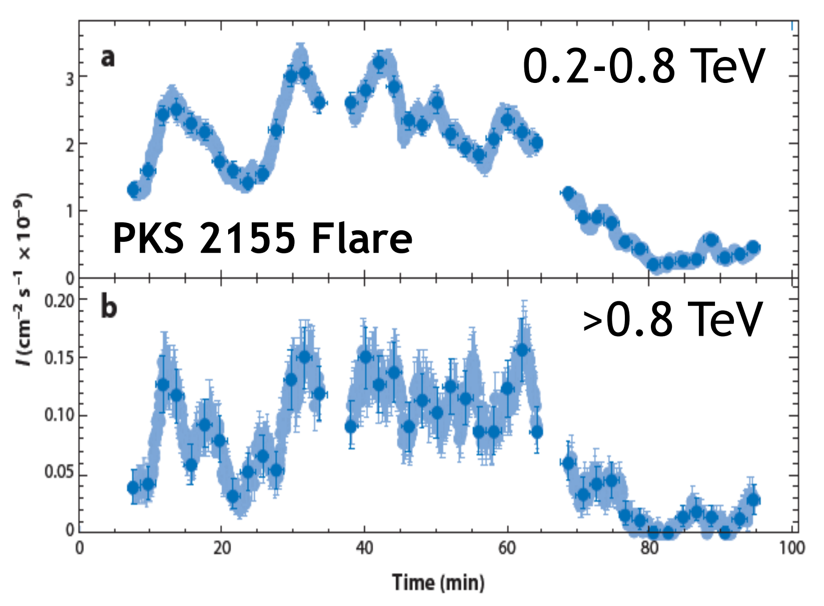
- Nearby Radio Galaxies
  - See Martin's talk
  - M 87
    - Probe fast variability close to SMBH
  - Cen A
    - Separating lobes from nucleus



- Blazars
  - Several are close enough for detailed studies @ ~3 TeV
    - Acceleration, cooling lags [factor ~50 more statistics]
  - LIV constraints - see Ulisses' talk



Cluster-scale AGN outbursts

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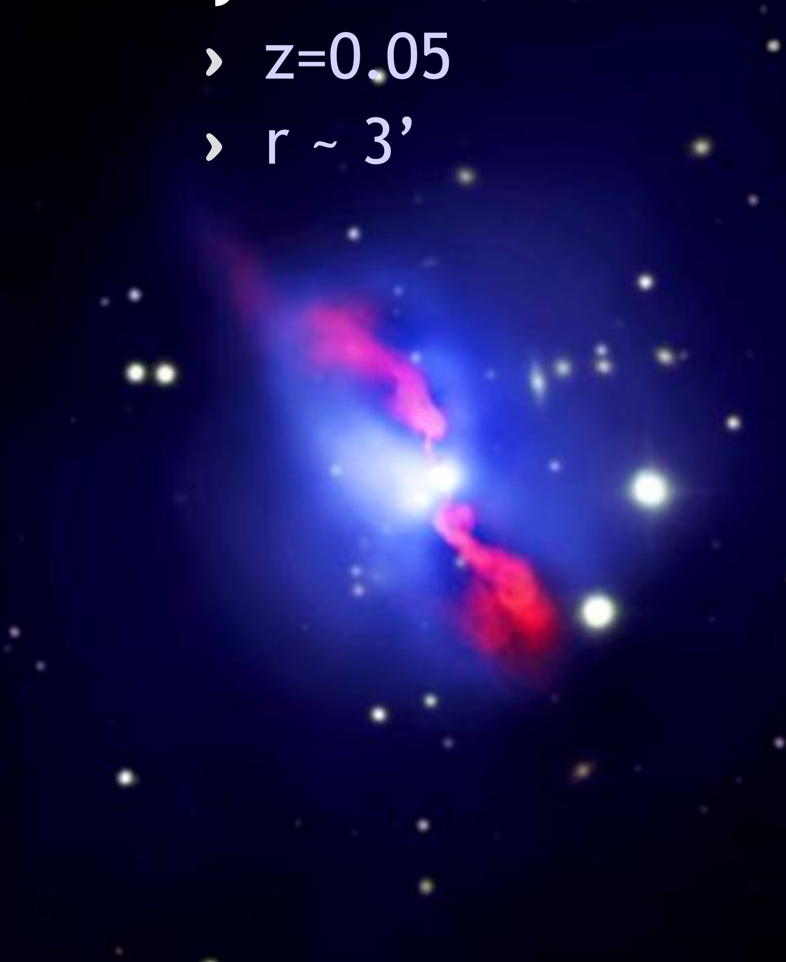
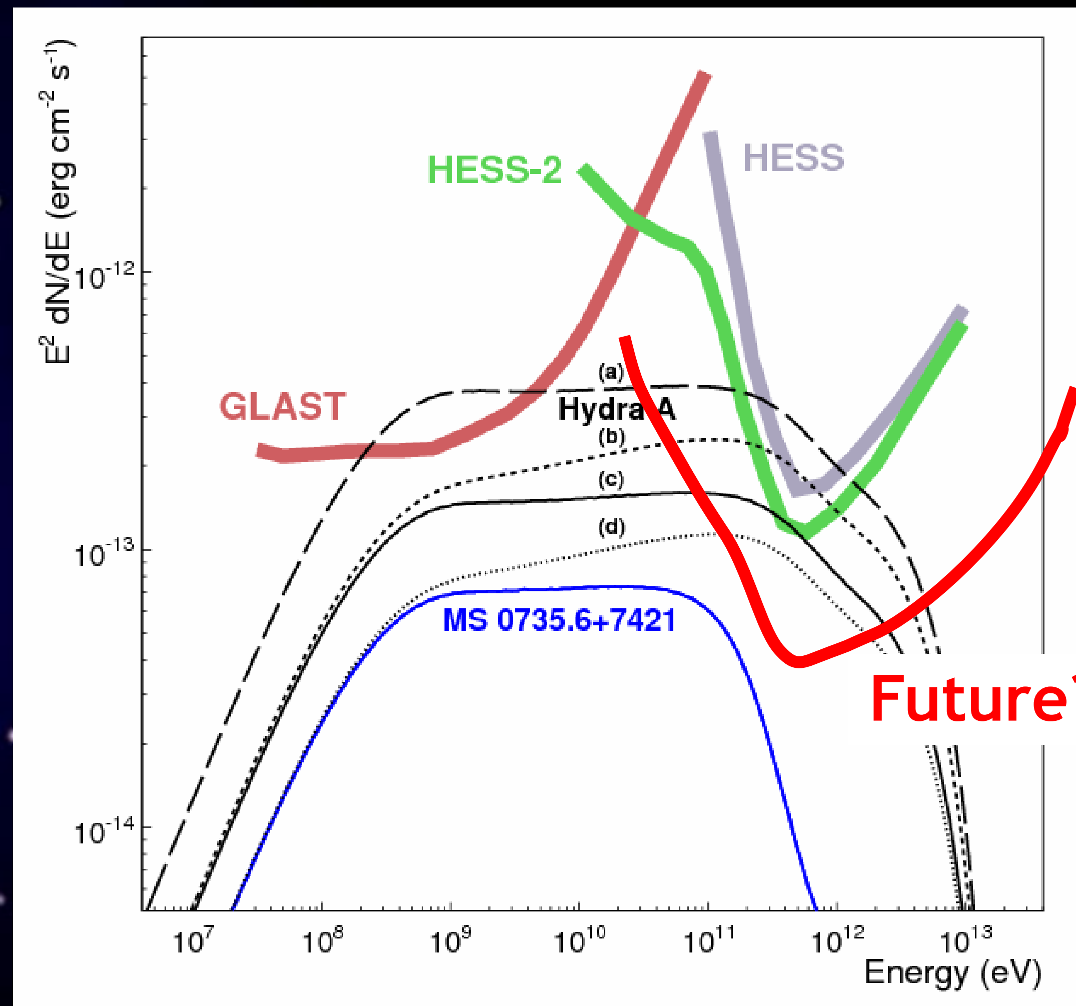
Hinton, Domainko & Pope 2007

- Hydra A cavity system
  - z=0.05
  - r ~ 3'





Conclusions

- 3-300 TeV sensitivity is critical to address the major questions in high energy astrophysics / particle astrophysics
- Excellent angular resolution (the best possible anywhere above ~100 keV) is both possible and **required**