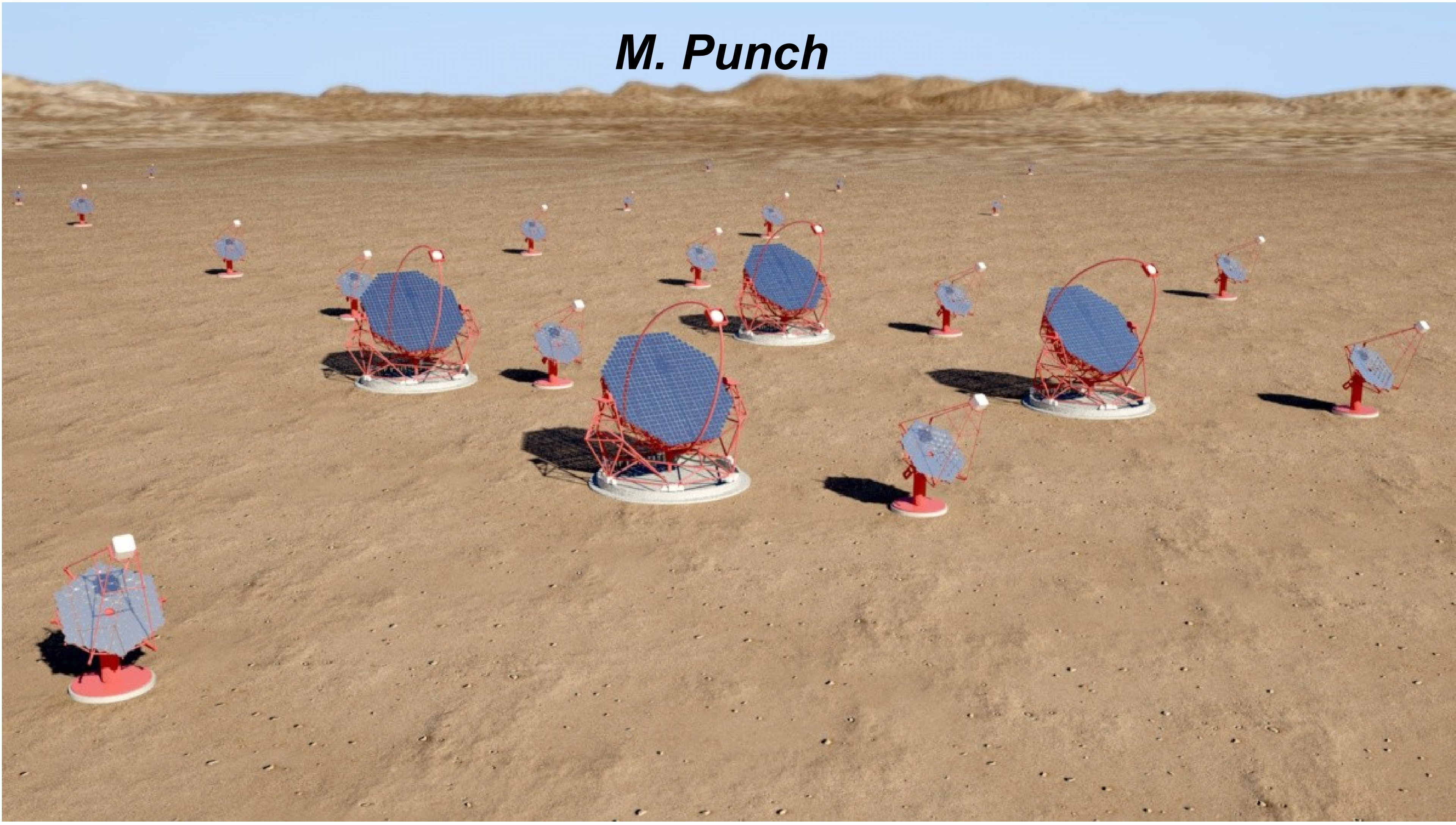
CTA - Cherenkov Telescope Array

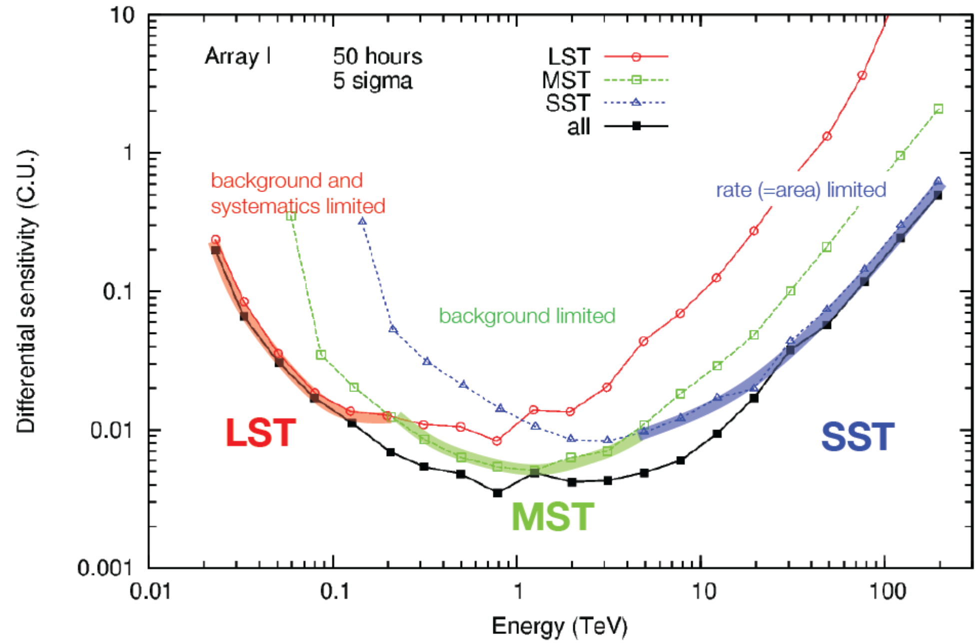
M. Punch

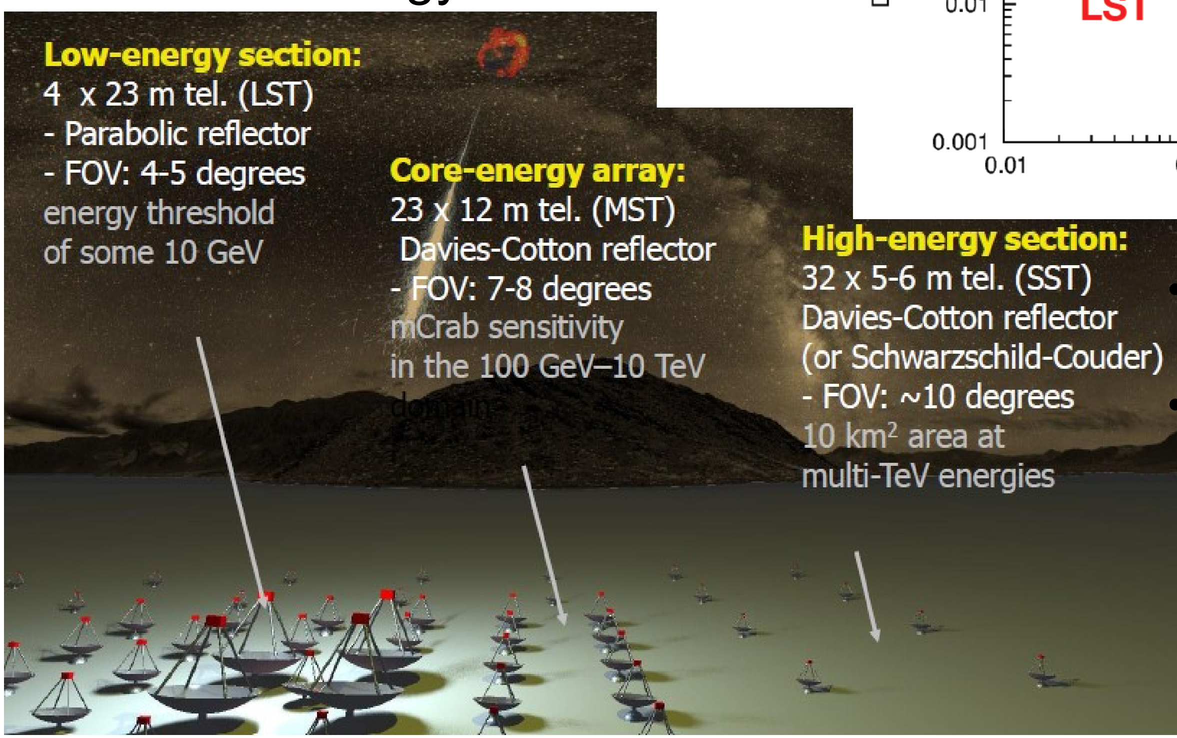


Brief Introduction to CTA.

CTA:

- x10 sensitivity
  of current instruments
- x10 energy range
- improved angular resolution
  and energy resolution



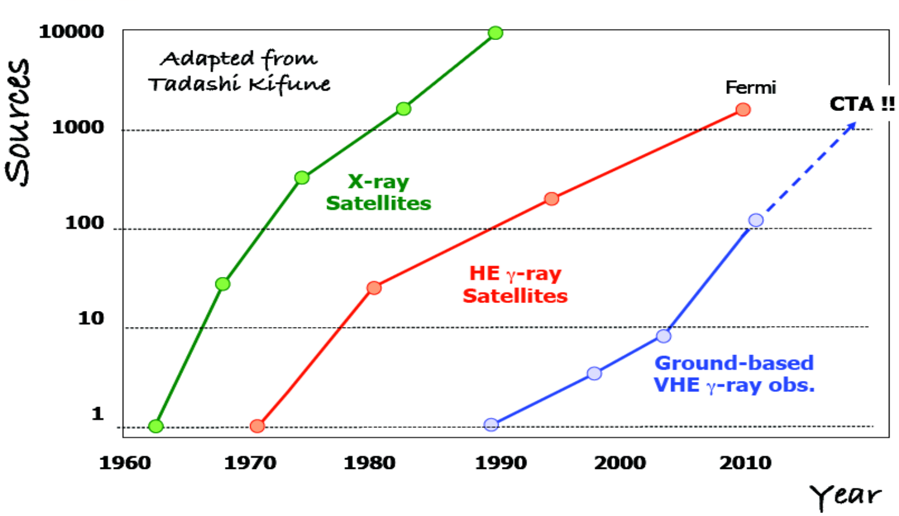


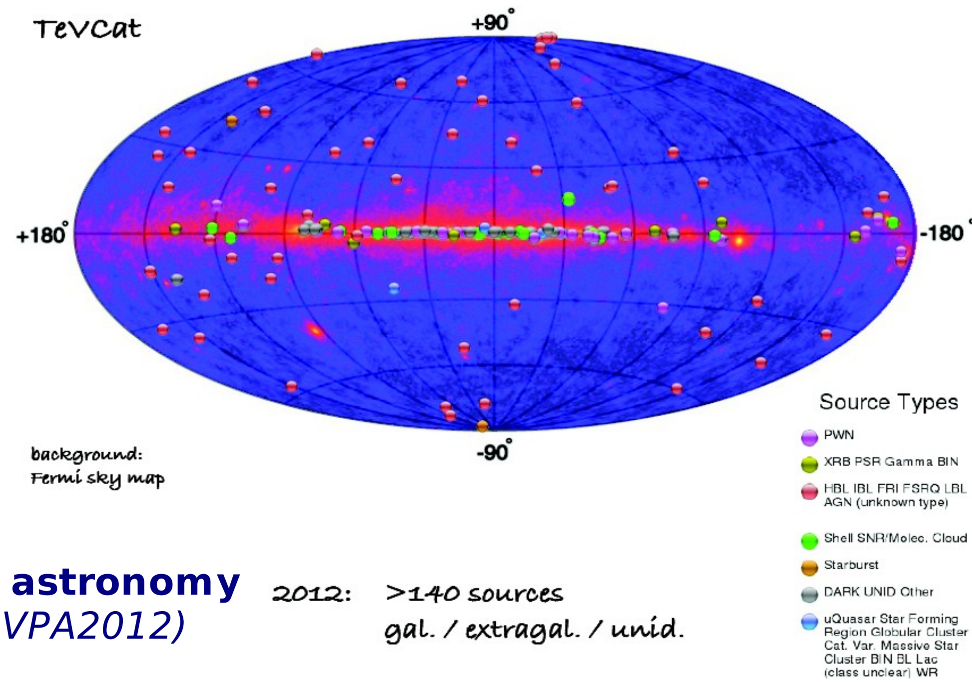
- 3 classes of telescope size
  → overlapping en. ranges
- North – South sites
  → all-sky coverage

Key Science Goals for IN2P3

- Physics of G/galactic sources with CTA and the origin of Cosmic Rays
  - Acceleration in shocks and strong magnetic fields
  - Production of Hadronic & Leptonic Cosmic Rays
  - Production of UHECR (AGN BH/lobes, GRB, Pulsars)
- Dark Matter Searches (indirect detection)
  - Searches in Galactic Centre, Dwarf Galaxies, Clusters...
- Gamma-ray Sources as Probes of New Physics / the Universe
  - Extragalactic Background Light and 1st Stars and Galaxies
  - Intergalactic Magnetic Field
  - Search for Lorentz Invariance Violation / Axion-like particles
- AGN extragalactic Physics
  - Black Holes and their Environments
  - Exploring the Disk/Jet connection

Objects observed or targets for CTA





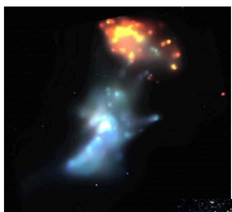
Notable publications in VHE Gamma-Ray astronomy
(selection of J.Knapp, TeVPA2012)

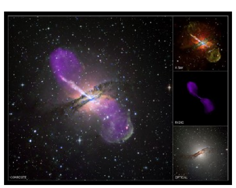
2012: >140 sources
gal. / extragal. / unid.

Supernova remnants: Nature 432 (2004) 75
Microquasars: Science 309 (2005) 746, Science 312 (2006) 1771
Pulsars: Science 322 (2008) 1221, Science 334 (2011) 69
Galactic Centre: Nature 439 (2006) 695
Galactic Survey: Science 307 (2005) 1839
Starbursts: Nature 462 (2009) 770, Science 326 (2009) 1080
Active Galactic Nuclei: Science 314 (2006) 1424, Science 325 (2009) 444
EBL: Nature 440 (2006) 1018, Science 320 (2008) 1752
Dark Matter: PRL 97 (2006) 221102, PRL 106 (2011) 161301
Lorentz Invariance: PRL 101 (2008) 170402
Cosmic Ray Electrons: PRL (2009)

Underlined → HESS contribution

Link between Physics Goals and Sources



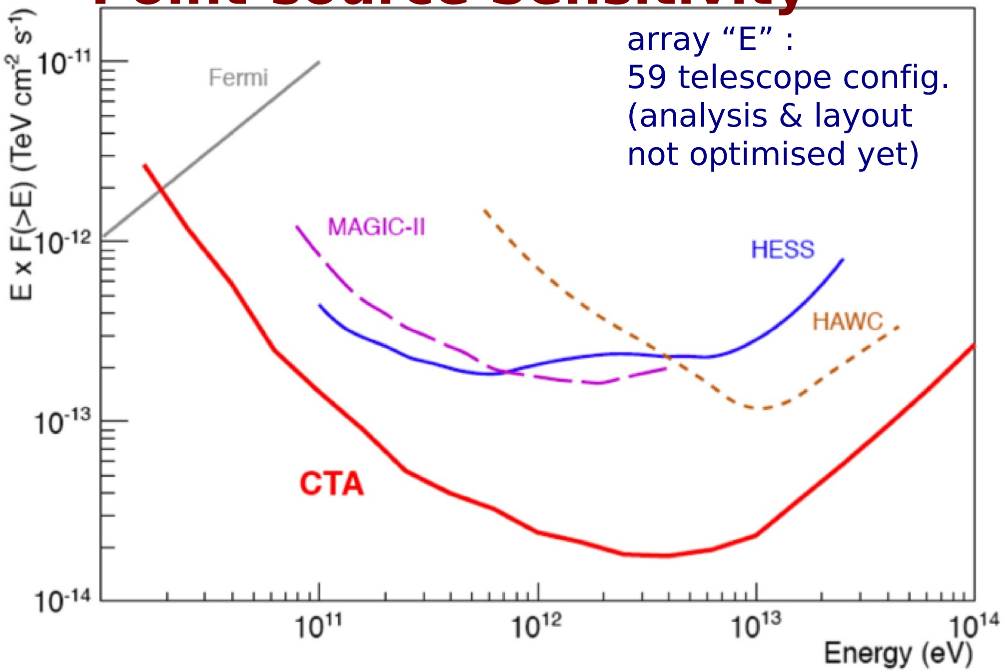


	RC prod.	RC prop.	BH nature & variety	DM dét. indirecte (annihilation)	Cosmo. & EBL Evol. 1ères étoiles & galaxies	IGMF et Formation de l'Univers	Structure de l'espace-temps et LIV
SNR - Restes de Supernova	✔	. . .		✘			
MC - Nuages Moléculaires		✔					
Pulsars	✔						✔ !
PWNe - Nébuleuses de Pulsar	✔			✘			
GC - Centre Galactique	✔	. . .	✔	✔ !			
Dwarf Gal. / Glob. Cl. - Gal. Naines / Amas Glob.				✔ !			
Galaxy Clusters - Amas de Galaxies	✔			✔ !			
Starburst galaxies - Gal. à flambée etoiles		✔					
GRB - Sursauts Gamma	✔						✔ !
AGN - Noyaux Actifs de Galaxie	✔		✔		✔ !	✔ !	✔ !
Mesure direct des RC chargées		✔					

CTA, the great leap forwards: characteristics

- **Enormous** improvement over current installations on all characteristics!

Point-source Sensitivity



Performance

Energy	Area	Ang. Res	En. Res	FoV
TeV	km^2	arc min	%	°
0.03	0.003	12	30	4-5
0.3	0.1	4	13	6-8
3	1.	2	8	7-9
30	3.	1.5	7	8-10

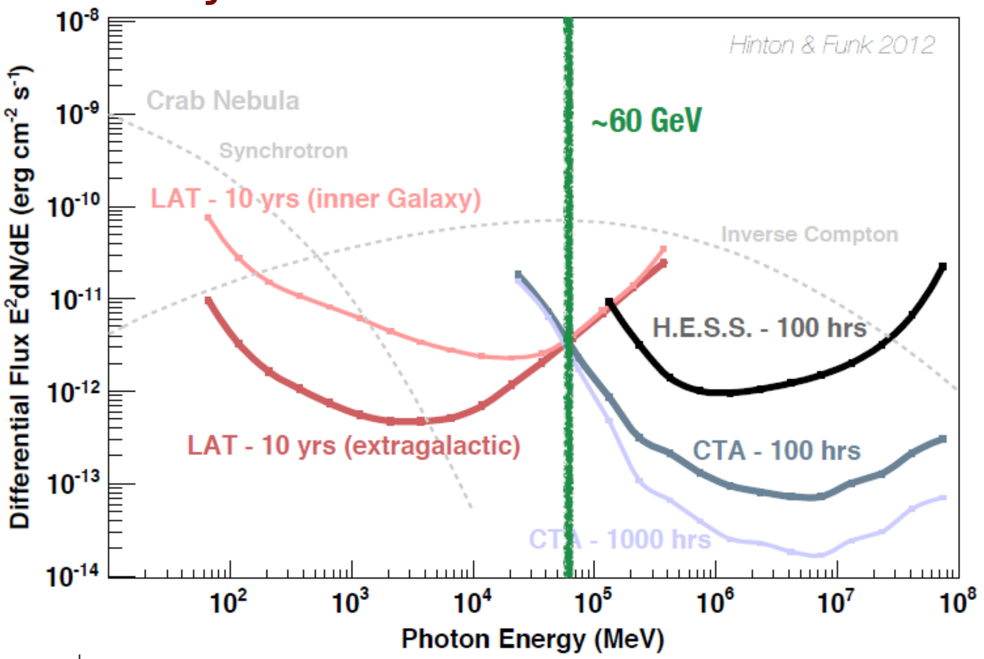
Improvement (relative to HESS) :

Diffuse continuum:	≈ x 5
Angular resolution for point sources:	≈ x 2
FoV for surveys:	≈ x 2
Energy resolution for lines:	≈ x 1.5
All-sky survey; point-like emission-line sources:	≈ x 30
Pointed observation of a 0.5°continuum source:	≈ x 5

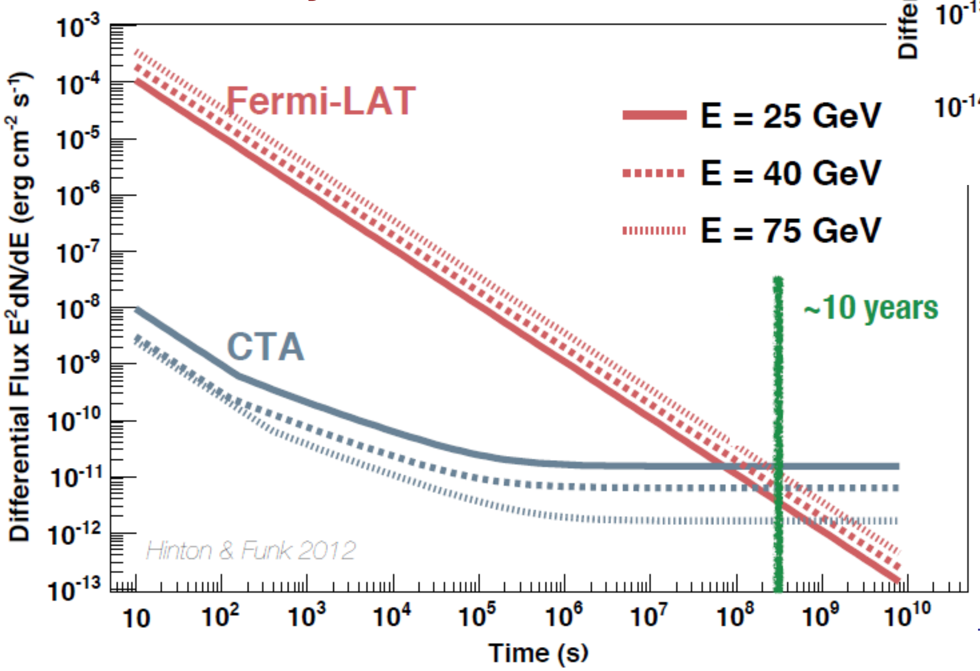
CTA, the great leap forwards: sensitivity

- Comparisons with FermiLAT,
- Overlapping energy range

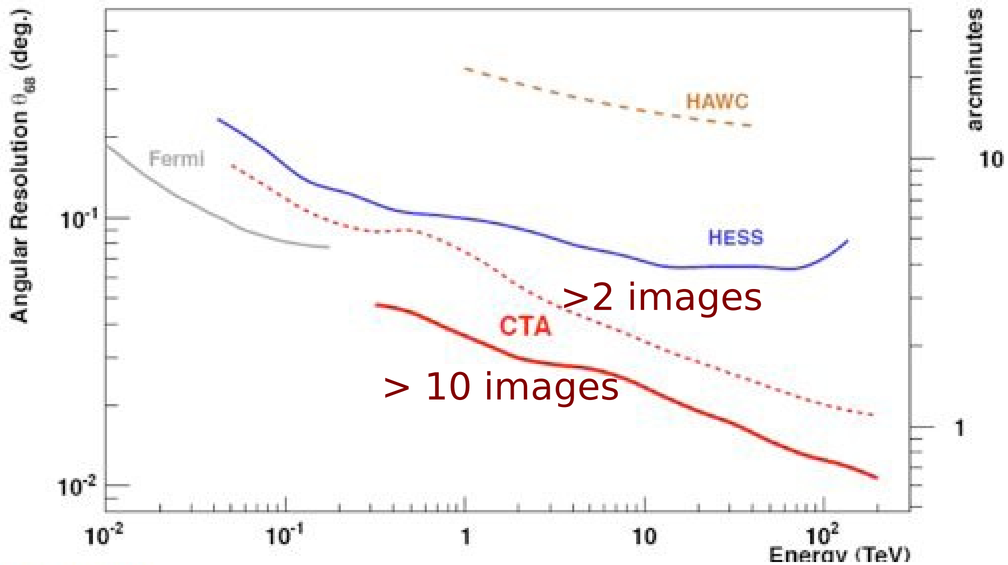
Steady sources



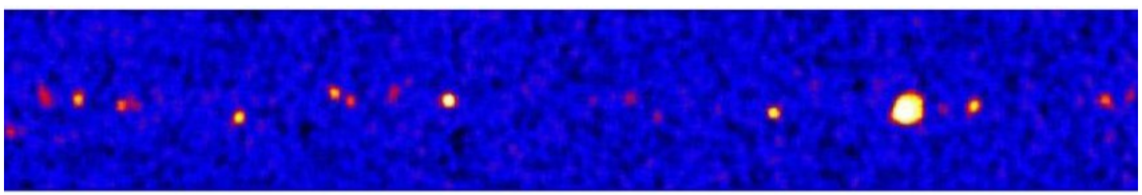
Variability & short timescales



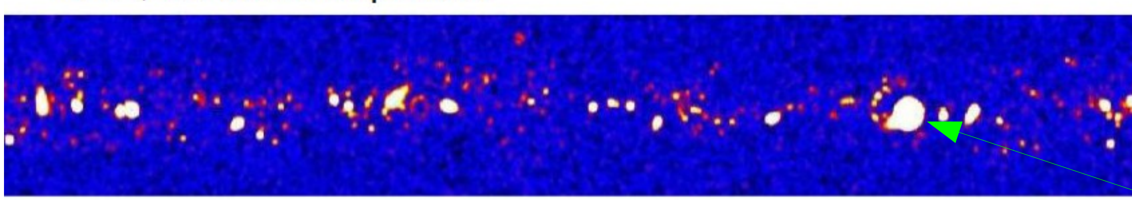
CTA, the great leap forwards: angular resol.



H.E.S.S.

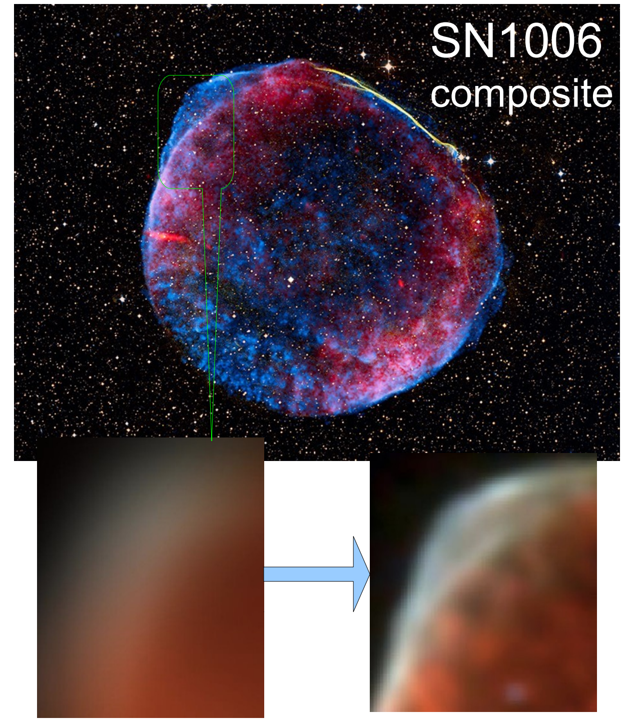


CTA, for same exposure



expect ~1000 detected sources

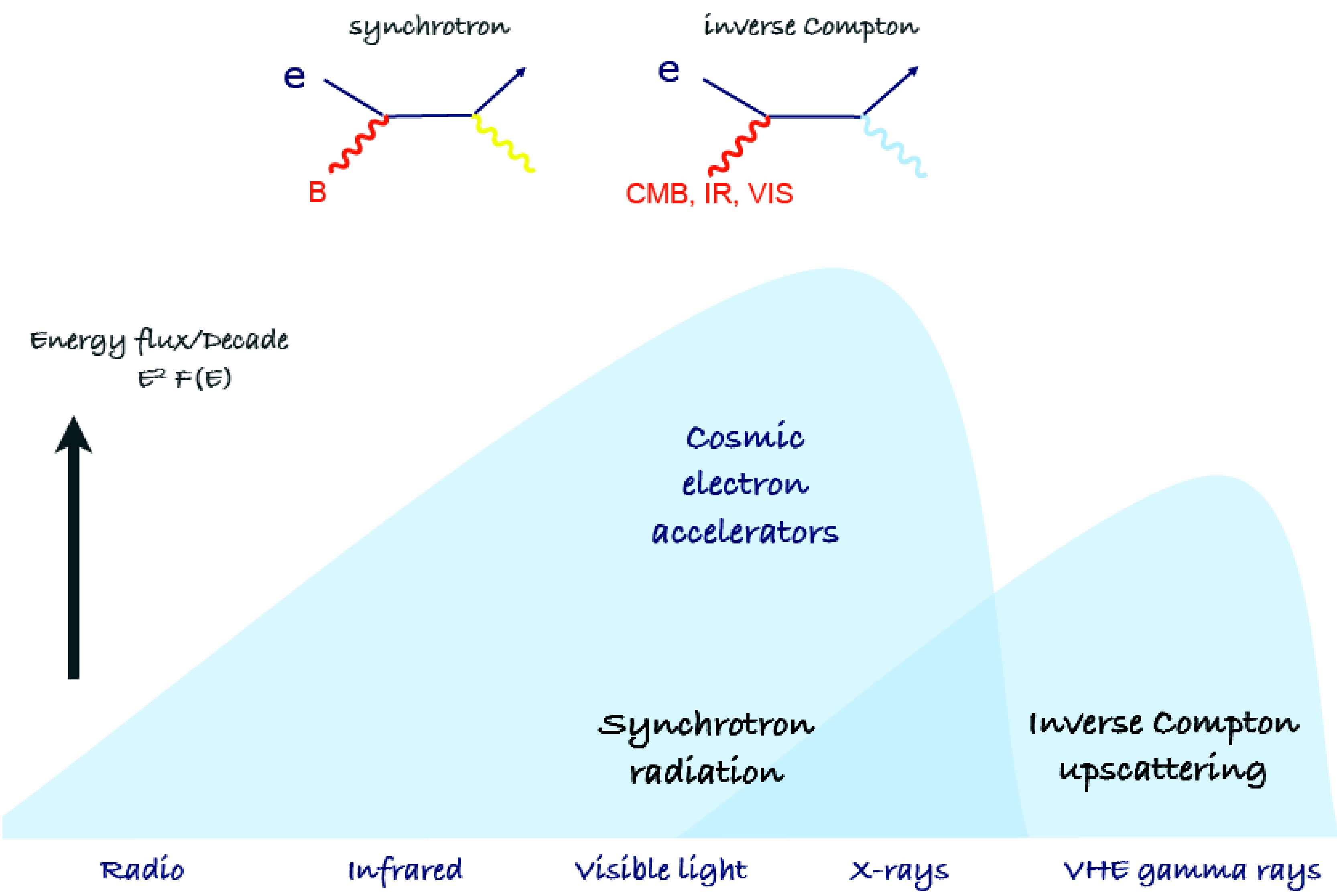
~1° circle
(RX J1713-3946)



@ HESS resolution

@ CTA resolution

Astrophysics Sources:
Gamma Ray production



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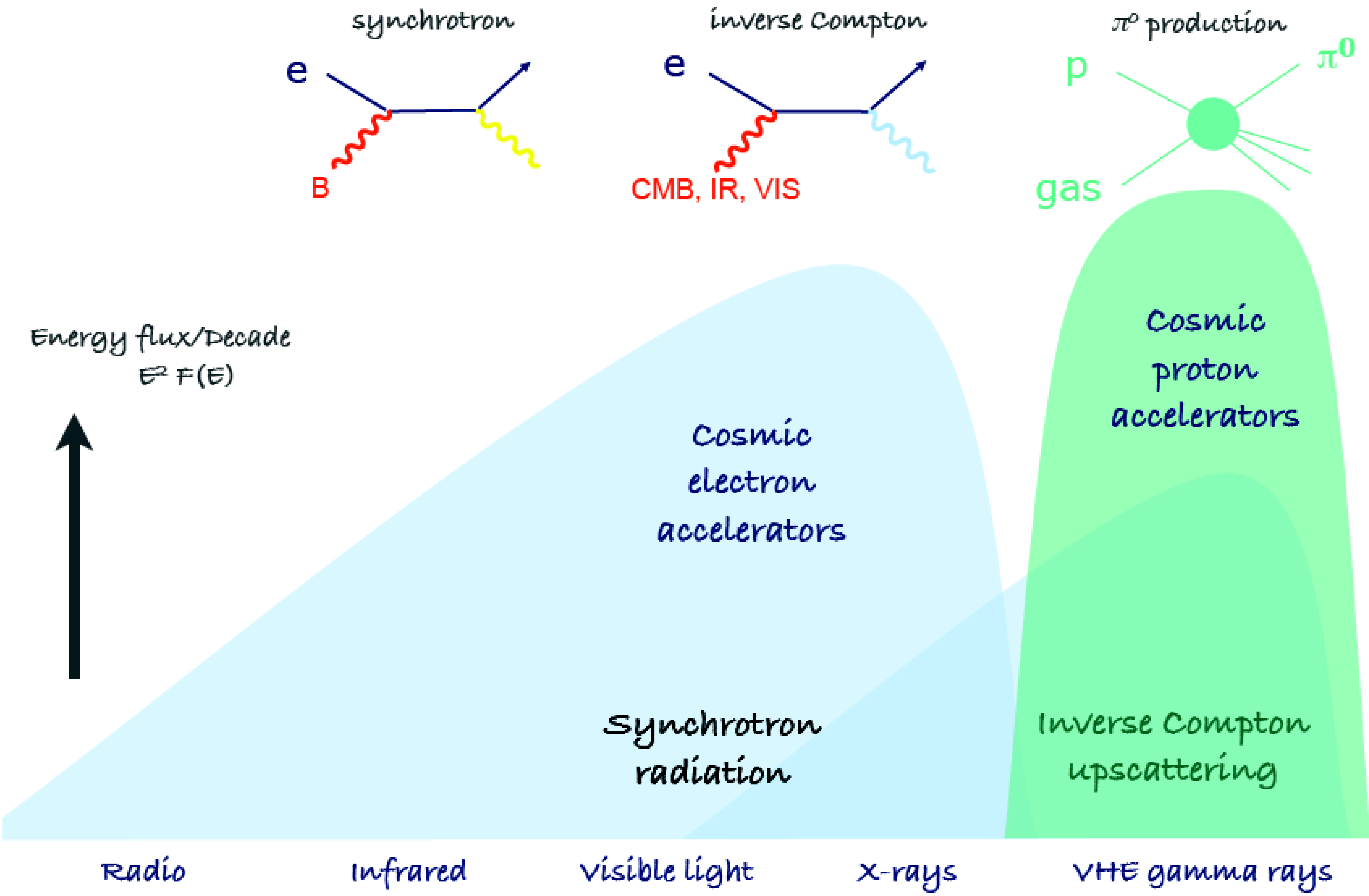
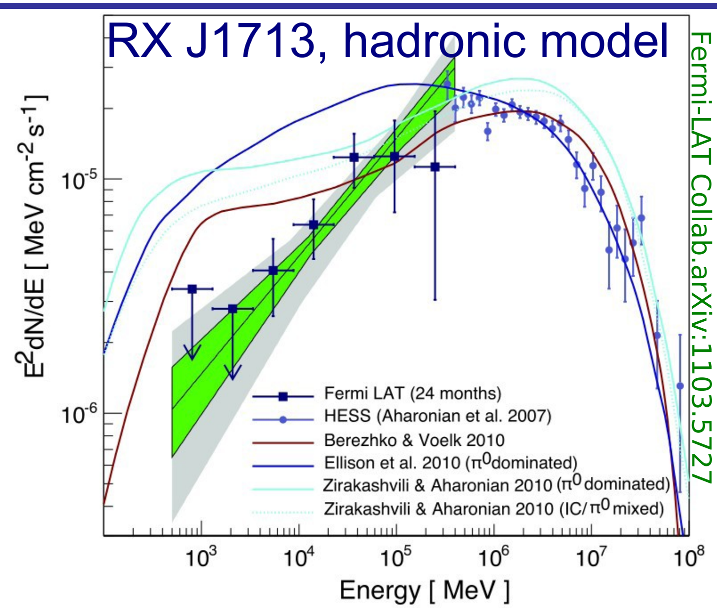
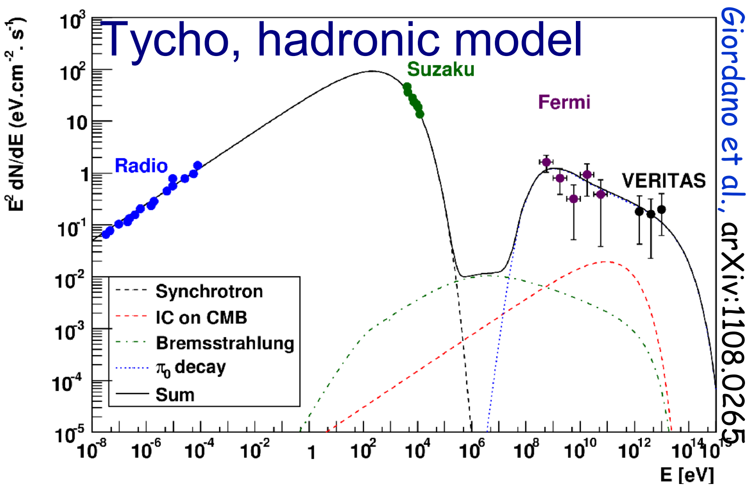
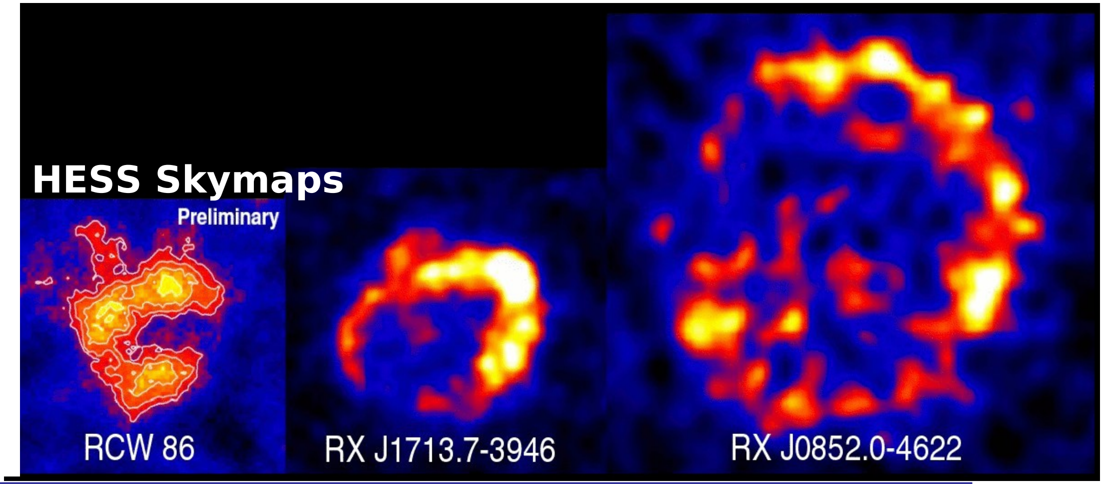


Galactic Sources: SNRs

- SNRs as sources of Galactic CR?
  - Now, have 6-7 SNR sample
  - Open questions on diffusive shock acceleration
- CR spectrum universality?
- Inconclusive/Current status
  - e.g. Tycho, dominant hadronic
  - e.g. RX J1713, dominant leptonic contribution
- Simulations of SNR population
  - If all shine ~3000 yr at VHE → ~60 VHE shells in Galaxy!
- **CTA**
  - 20-55 detectable, with 7-12 resolvable (config-I)
  - 2x improvement in resolution → 2x resolvable SNRs
- **CTA will increase sample, zoom-in on shocks, allow to estimate SNR contribution to G-CR**







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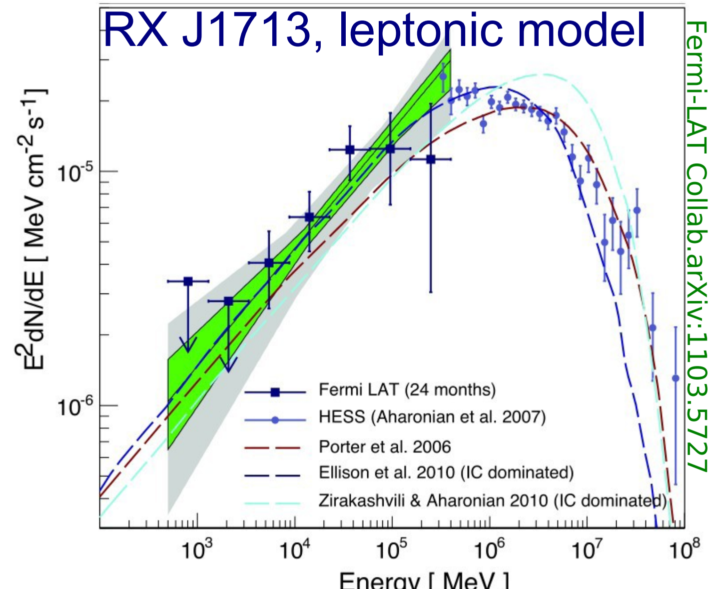
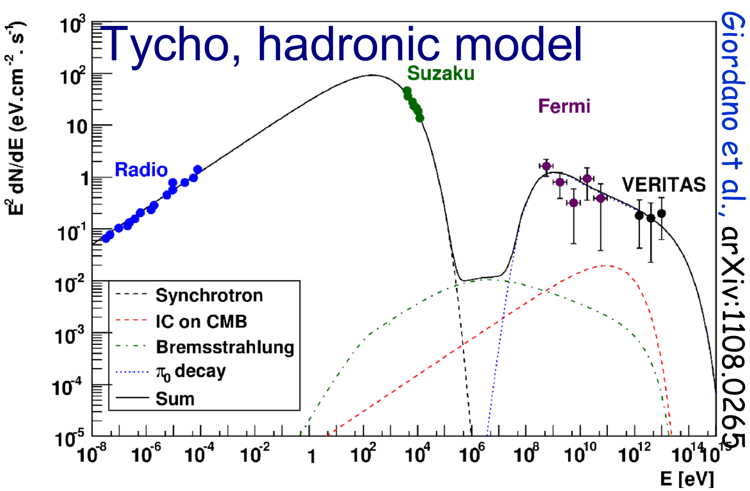
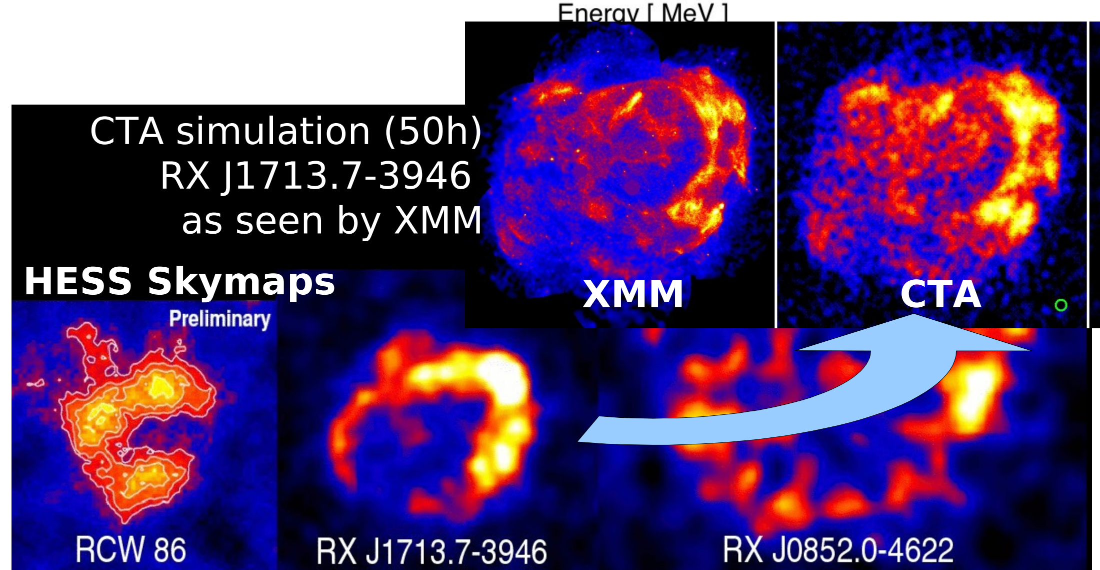
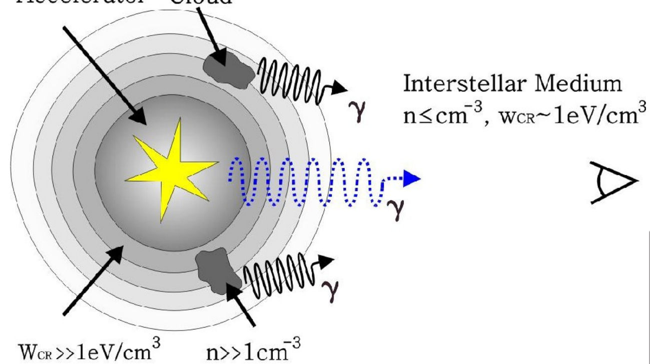


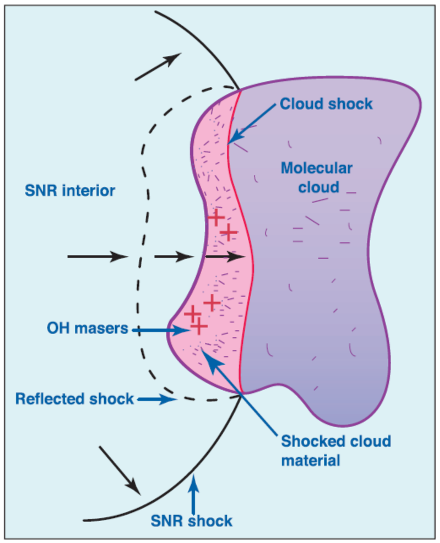




“Galactic” Sources: SNRs+MCs, Pevatrons, Starbursts

- SNR - MC associations:
  Correlation with molecular material (and atomic gas) hints at hadronic emission (W28, W51C, IC 443, W44), see also Galactic Centre ridge
- With CTA sensitivity, may be able to detect passive clouds (only lit by CR from local “sea”)
  → **CTA can probe the Galactic distribution of CR**

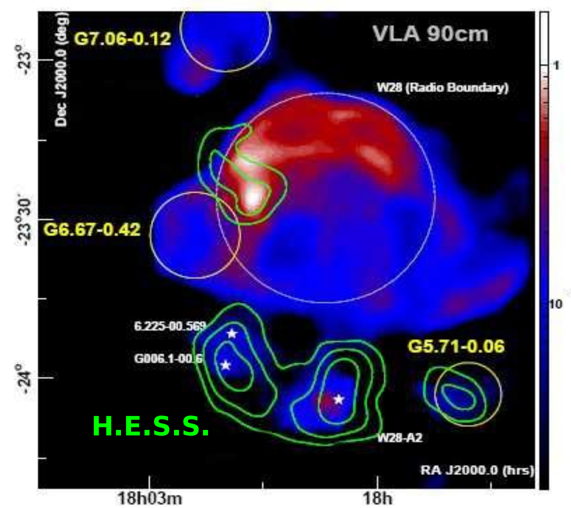




Wardle et al. 2002

- Starburst galaxies:
  CTA can probe production / diffusion of CR in nearby Starbursts (e.g. NGC 253, M 82)

- Pevatrons: very young SNRs
  (at the beginning of the Sedov phase),
  strongly favoured for PeV particle acceleration.
- Acting as Pevatrons for a short time
  → expect few objects in the galaxy
- **CTA can search for these sources of CR at the “knee”**



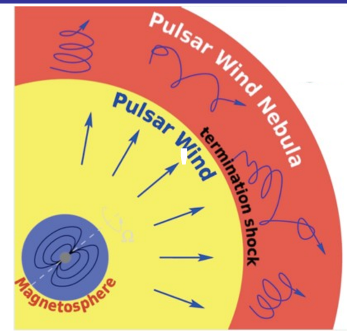
Galactic Sources: PWNe, Pulsars, & Gamma-Binaries

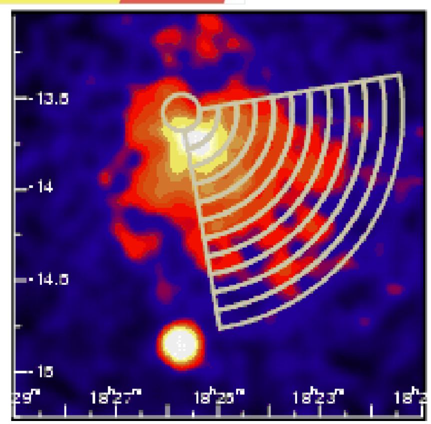
- PWNe most numerous category (~30)
- Young (<10kyr),
  large spin-down power, relativistic winds
- Energy dependent morphology,
  larger in VHE than in X-rays,
  VHE spectral softening with distance
  → history of electron cooling

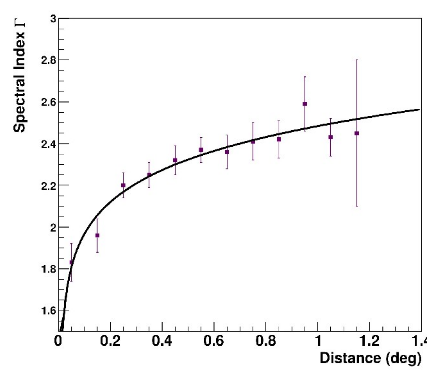
- CTA can reproduces these results
  in 5h (vs. 50h), & to larger extension
  → probe max. size, understand dark srcs
- **CTA sensitivity**
  → if PWNe shine for 10,000 years,
  ~ 200 will be detected in the Galaxy

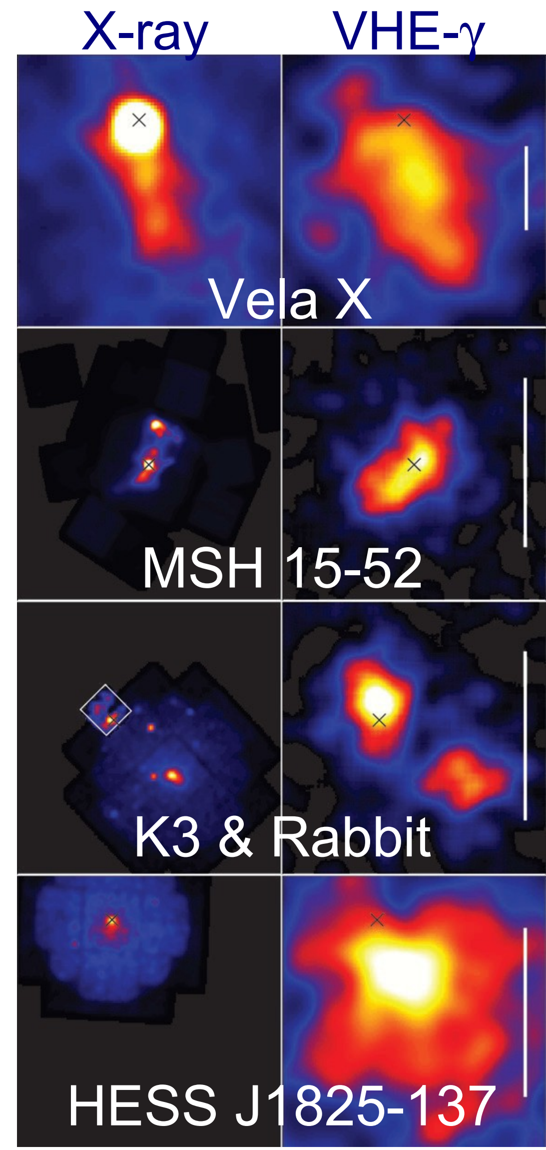
- Production of positrons
  → **foreground for DM** from nearby PWNe

- Current Gamma-binaries
  best explained as "periodic PWNe"
  → good laboratory for examining behaviour









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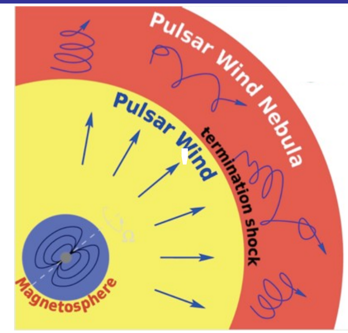

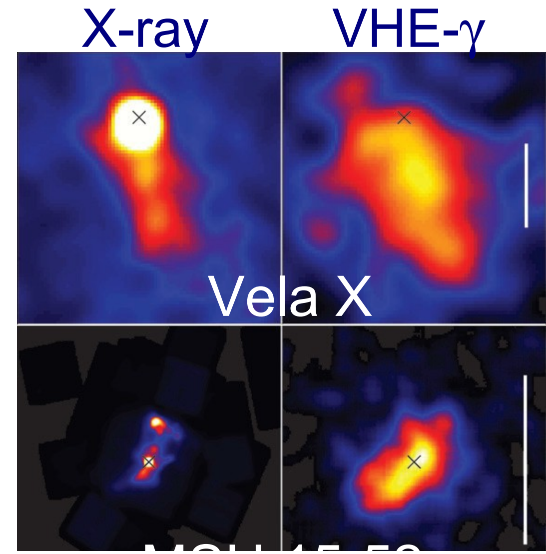

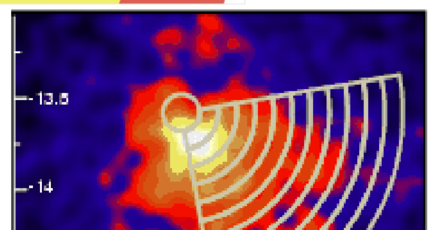

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  in 5h (vs. 50h), & to larger extension
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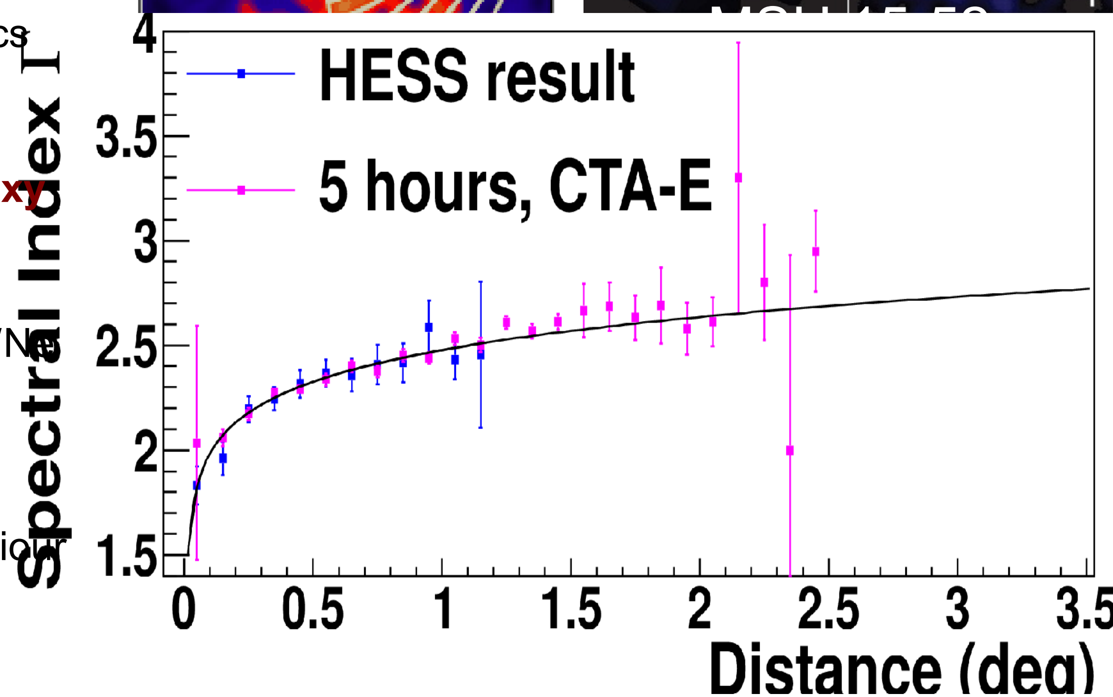
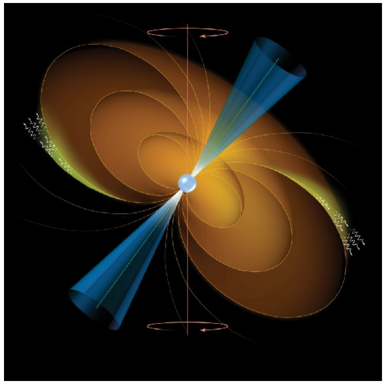
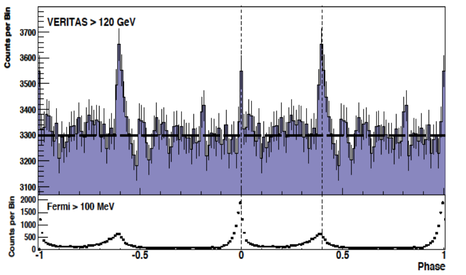
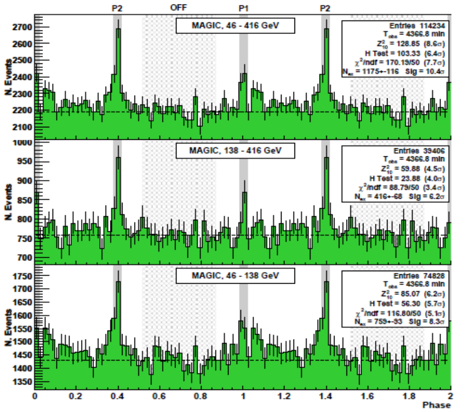


Galactic Sources: PWNe, Pulsars, & Gamma-Binaries

- Pulsars, large population (117) found by Fermi
- Surprising VHE emission discovered from Crab Pulsar by VERITAS, MAGIC implying Power-law spectrum (no exp. cut-off)
  - Pulsar magnetosphere at r>10 stellar radii (preferred outer gap models)
  - Cold ultra-relativistic wind at r>20 r_{Lc}
- CTA can reproduce these results in 1h, and detect the spectrum up to 1 TeV
- CTA can also study the recently-discovered Crab Flares





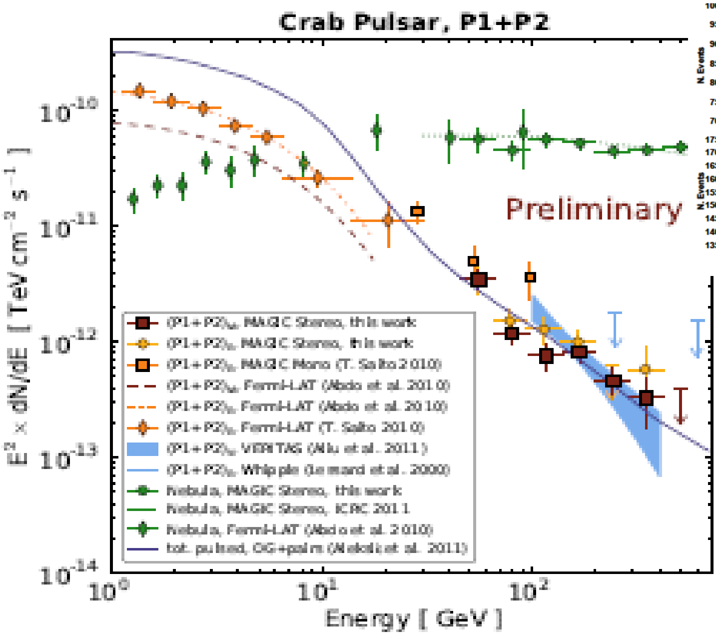


- **CTA could detect all Fermi pulsars,** if similar spectral behaviour as Crab,

or

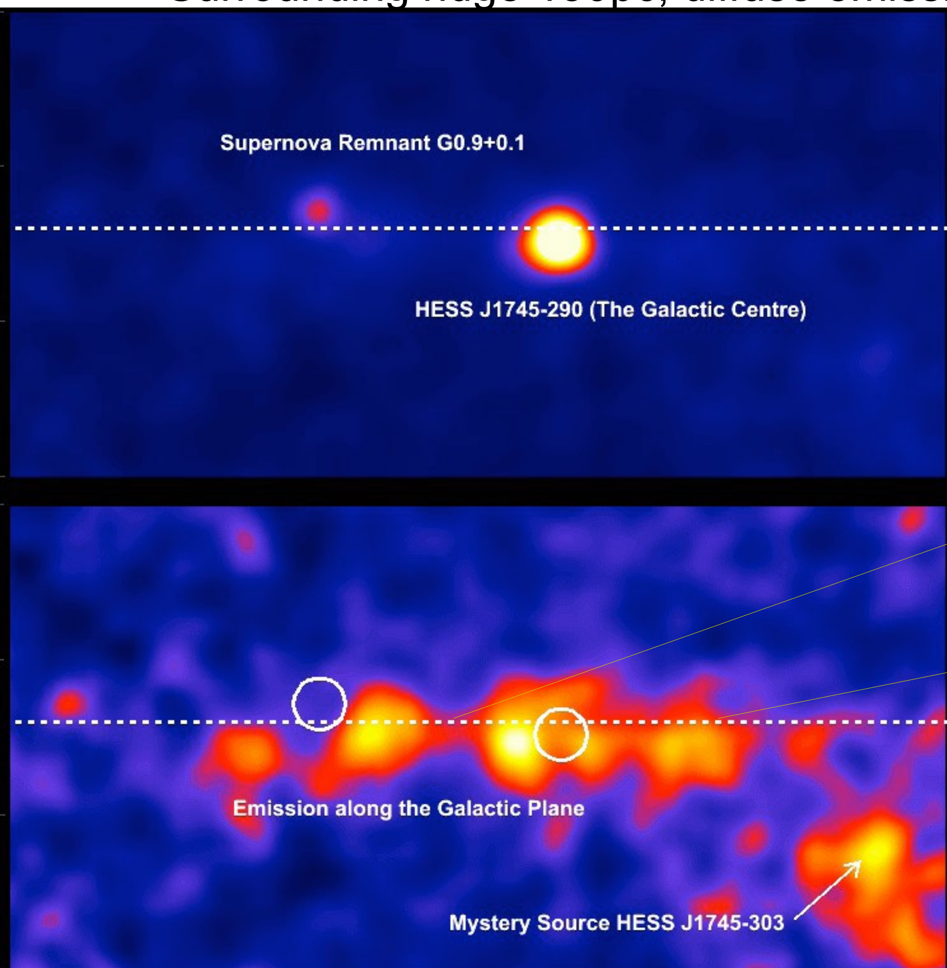
46-66% of Fermi pulsars, if they follow a Broken Power Law

- **CTA results will boost our understanding of particle acceleration in Pulsars**



Galactic Sources: The Galactic Centre

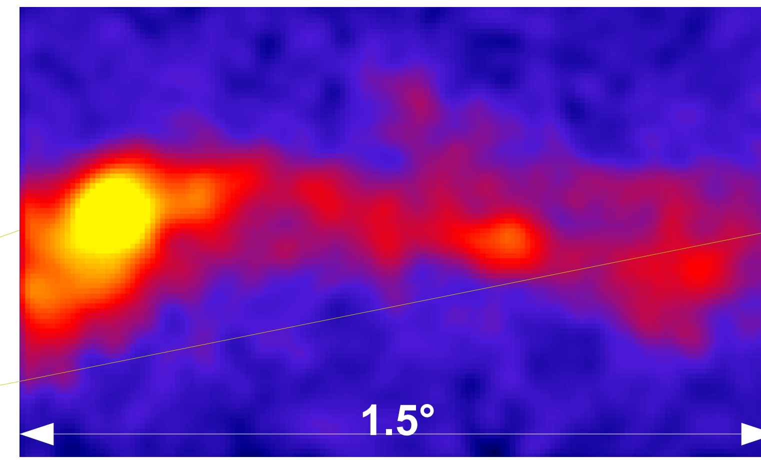
- GC, complex region
  - Central source (SBMB?)
  - Surrounding ridge 150pc, diffuse emission tracing matter



HESS: arxiv:0603021

CTA skymap simulation for GC region:

If CRs distributed uniformly in central 200 pc, (matter distribution from Herschel, Molinari et al 2011), after subtraction of central source.



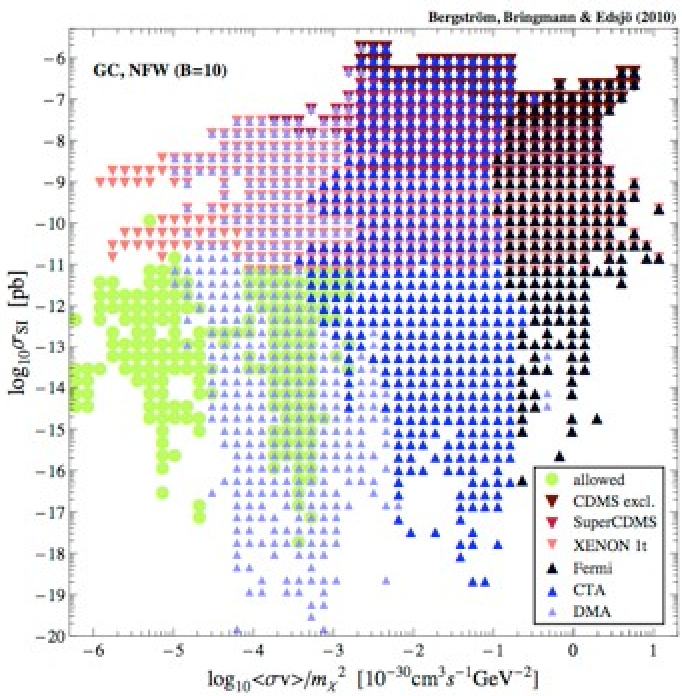
M. Renaud, LUPM

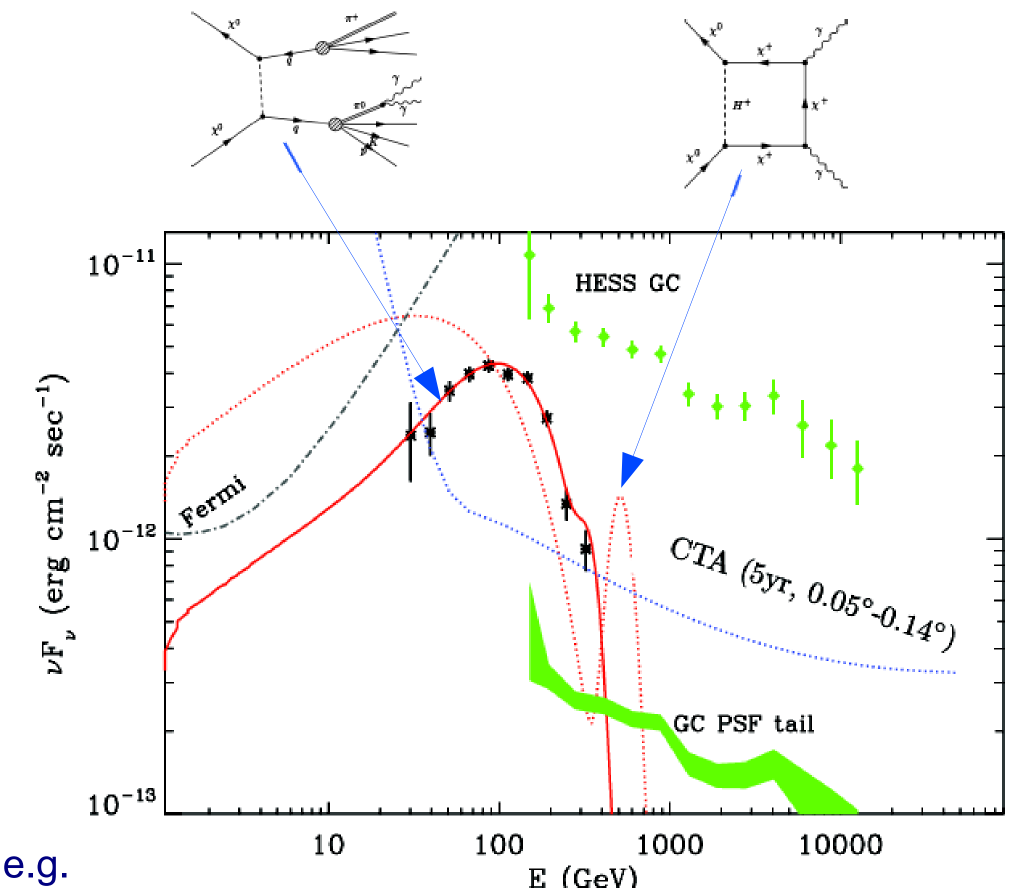
CTA could distinguish between Molecular Clouds “lit-up” by a source of RCs (exploding 10kyr previously), and electon acceleration by PWNe hidden in clouds

DM searches:
in Galactic Centre or with Galactic halo

- DM annihilation
  produces also gamma-rays
- Can search for signature,
  over a range of mass, x-section
- Note, need to understand GC astrophysics v. well,
  CTA angular resolution essential for possibility to detect GC DM

$$\frac{d\Phi(\Delta\Omega, E_\gamma)}{dE_\gamma} = B_F \cdot \underbrace{\frac{1}{4\pi}\,\frac{\langle\sigma_{\rm ann} v\rangle}{2\,m_\chi^2}\sum_i BR_i \frac{dN_\gamma^i}{dE_\gamma}}_{Particle\ Physics} \cdot \underbrace{\widetilde{J}(\Delta\Omega)}_{Astrophysics}$$





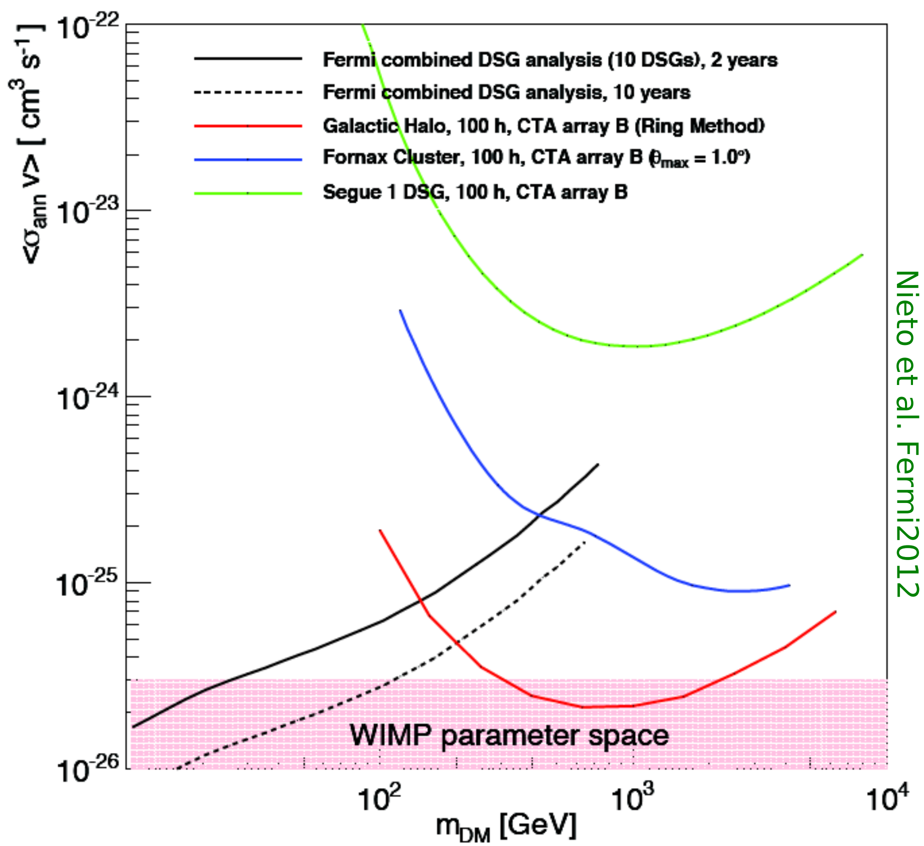
e.g.
CTA can detect >100-200 GeV neutralinos in 5yr/500hr
… less time needed if Sommerfeld or Astrophys. boost

DM searches:
Dwarf Spheroidal Galaxies, Clusters

- About 23 D-Sph.G:
  - DM dominated, mass-light ratios > 100
  - “classical”, 100-1000 stars,
    DM profiles (well) determined
    (stellar velocity dispersion measurements)
  - ultra-faint, 10s stars,
    nature under debate
- Advantages
  - nearby < 100 kpc → strong signal
  - clean of background, limited uncertainties

- Currently, 1—2 orders of magnitude
  out of reach of Fermi, VERITAS, HESS …

- **→ CTA sensitivity essential for possibility of detection of DM in D-Sph.**



Fermi dwarf spheroidal and CTA Galactic centre searches are complementary

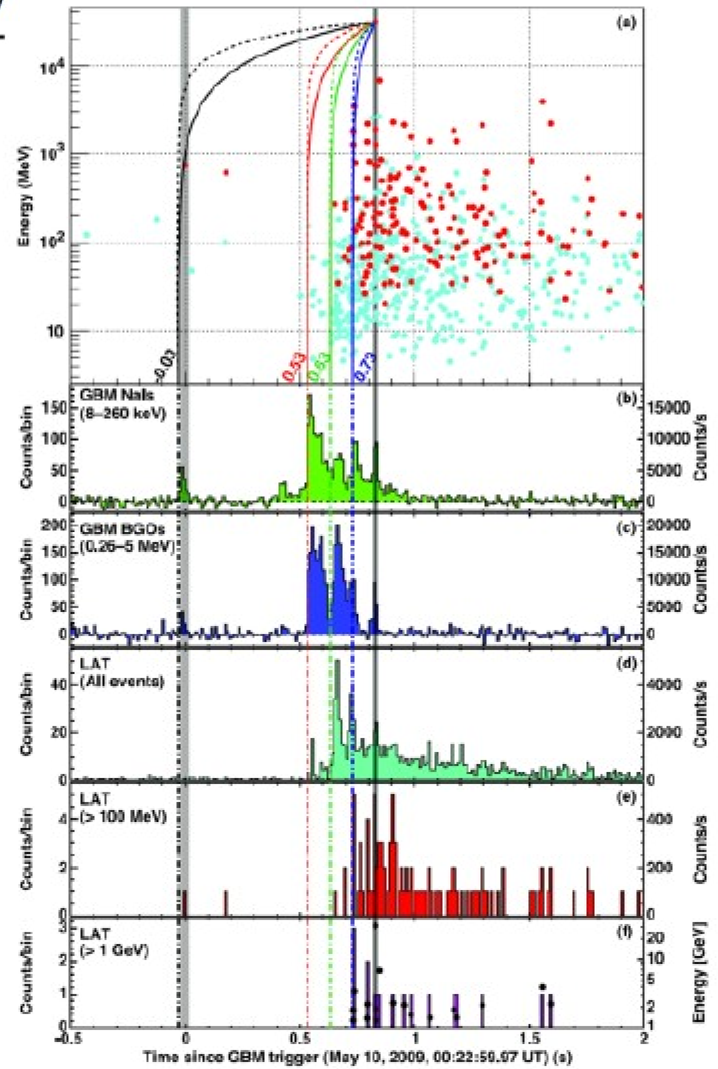
Fundamental Physics:
Search for Lorentz Invariance Violation

- Distant AGNs or GRBs as probes, search for timing effects vs. energy
- Need large samples
  to understand / disentangle effects from astrophysics
- Also, search possible with Pulsars
  (closer but faster)
- **CTA timing resolution / sensitivity essential to test quadratic or higher-order dependencies**

$$\Delta t \simeq \left(\frac{\Delta E}{\xi_\alpha E_{\mathrm{Pl}}}\right)^\alpha \frac{L}{c}$$

with α=1 or 2

Fermi-LAT & GBM, GRB090510



Strong limit on linear term from Fermi (LAT+GBM)

$E_{QG,1} = \xi_1 E_{Planck}$

$\xi_1 > 1.2$

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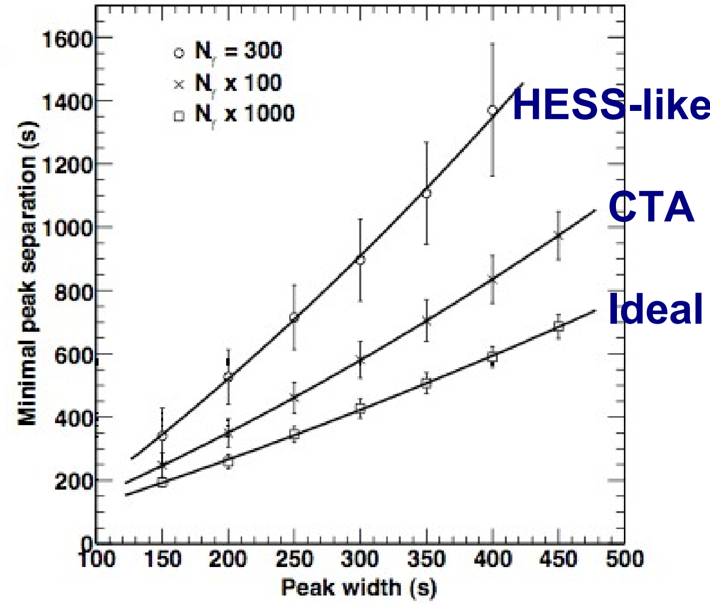
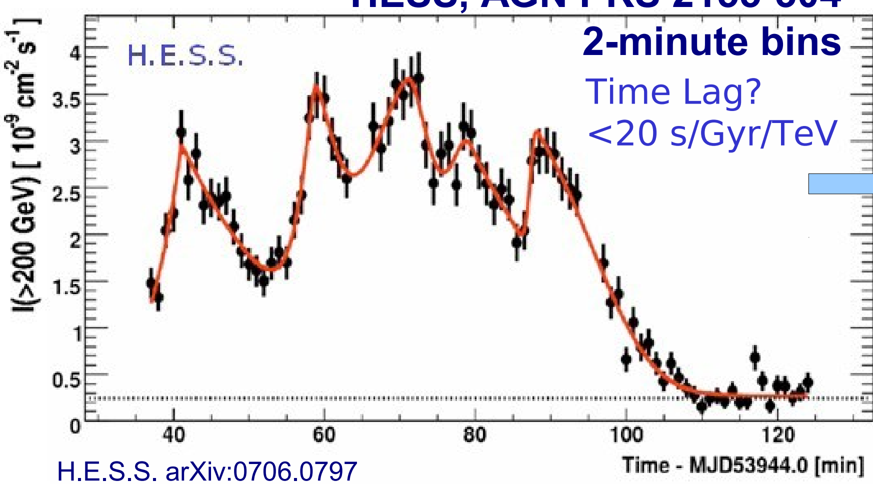
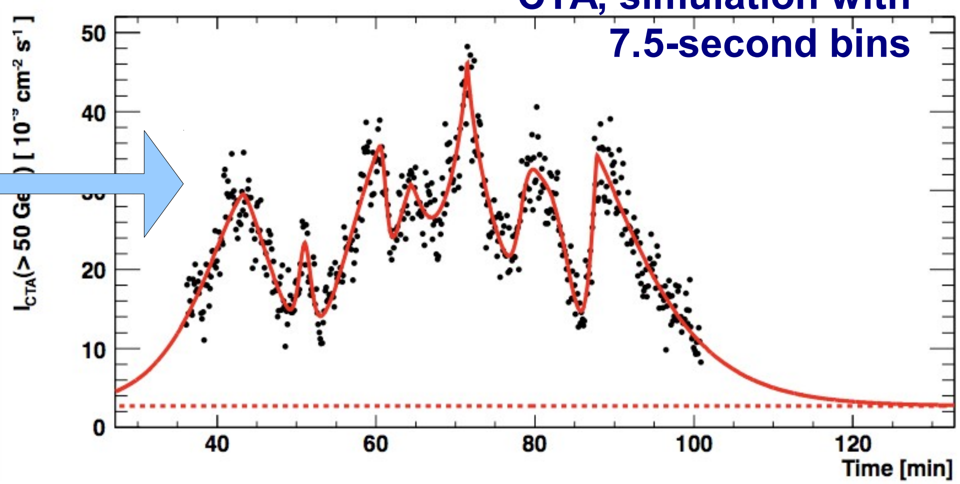


HESS, AGN PKS 2155-304



H.E.S.S. arXiv:0706.0797

CTA, simulation with 7.5-second bins

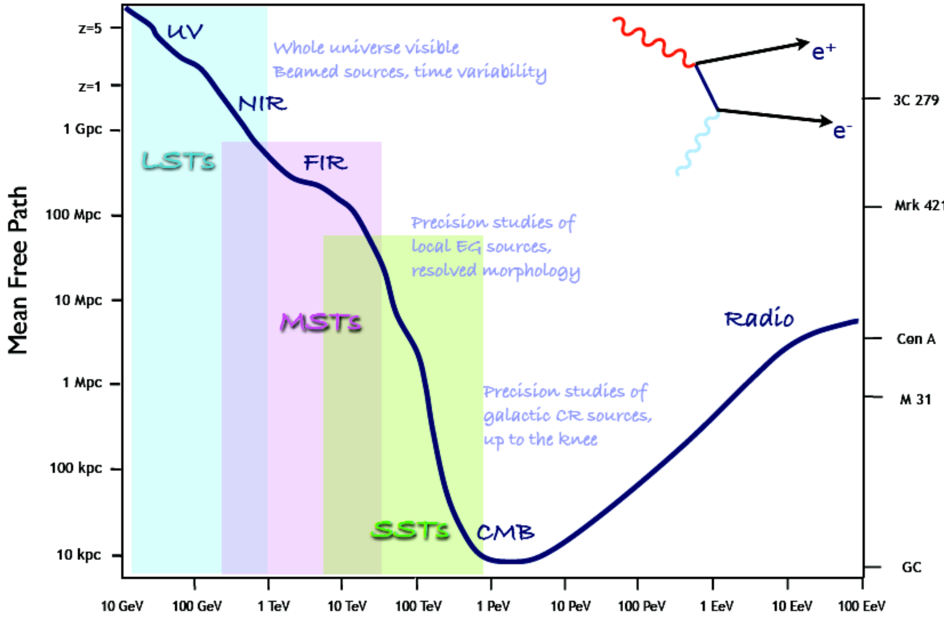


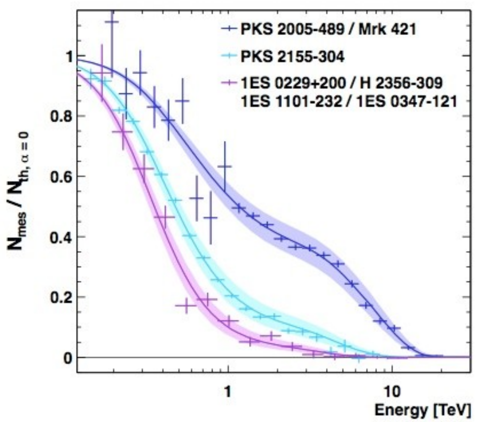
Fundamental Physics: Measurements of EBL, light from 1st Stars & Galaxies

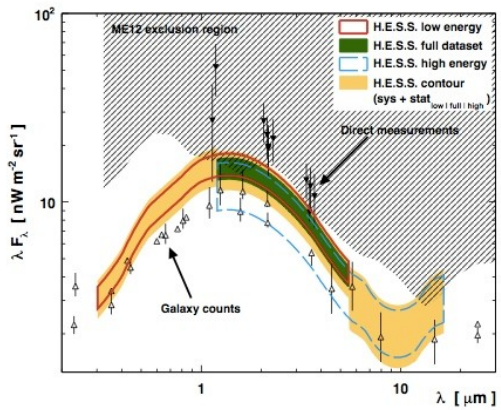
- EBL, redshifted light from
  1st stars & galaxies (esp. Pop. III stars)
- Direct measurement difficult due to foregrounds
  (Zodiacal light, instrument heat ...)
- Measurement possible with
  large sample of AGNs
  using spectral modification of ensemble
- Need to understand overall
  astrophysical spectra of the sources

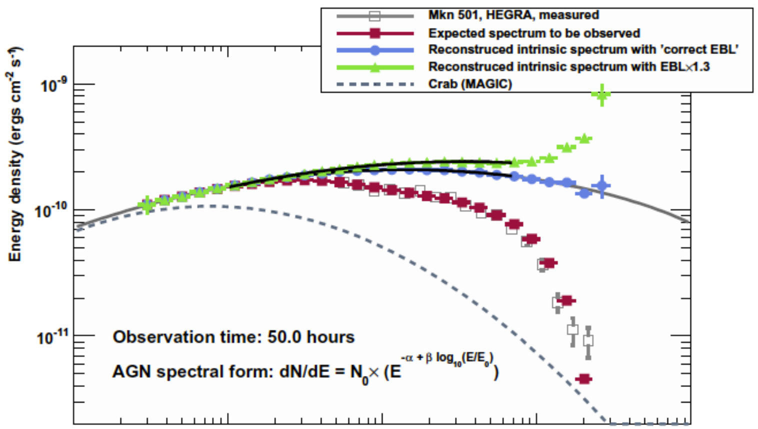
- **CTA energy resolution (spectra) and sensitivity (for large sample) essential**
- **CTA could provide**
  measurement of evolution of EBL over time, so measure evolution of early Universe

The Gamma-Ray Horizon $\gamma_{VHE} + \gamma_{..} \rightarrow e^+e^-$



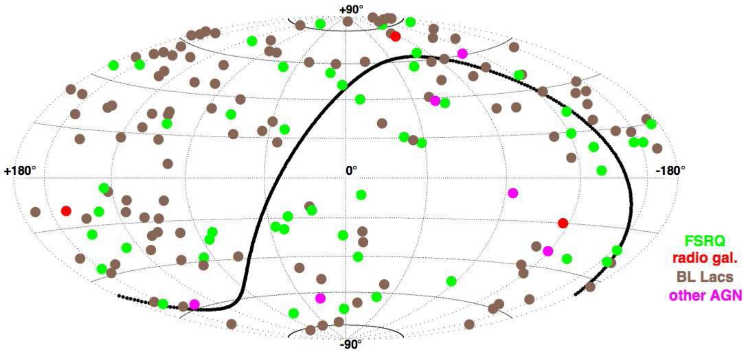


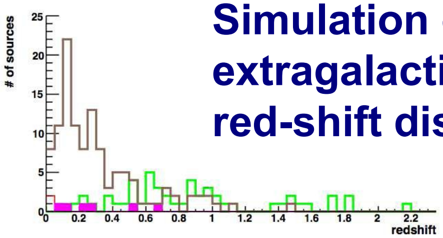




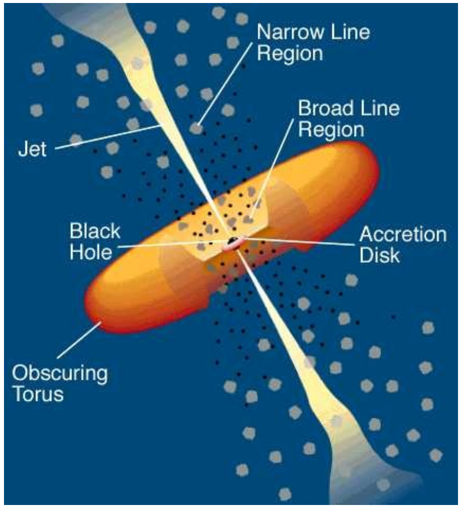
Astrophysics of AGNs

- AGNs: disk/torus, jet, particle acceleration & gamma-ray production
- Possible location for UHECR production (radio lobes, BH itself)
- Currently ~ 40 AGNs, redshift z<~0.6
- **CTA will expand to ~170 AGNs,** also increasing the low-sample AGN classes (FQRQ,radio galaxies), and **increase the distance range to z~2** !
- Population studies will increase understanding of the production processes for VHE particles

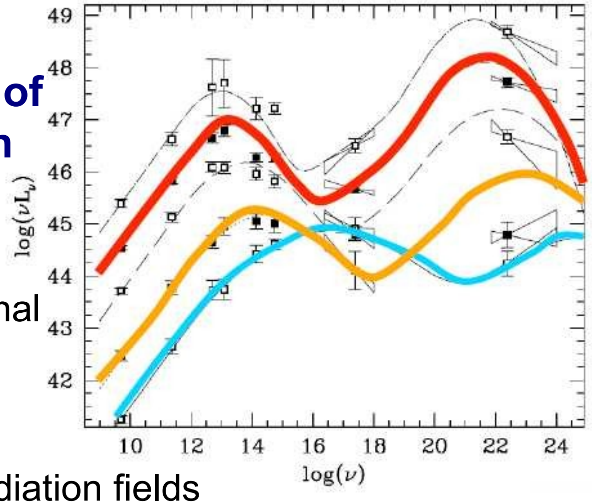




Simulation of the CTA extragalactic sky & red-shift distribution



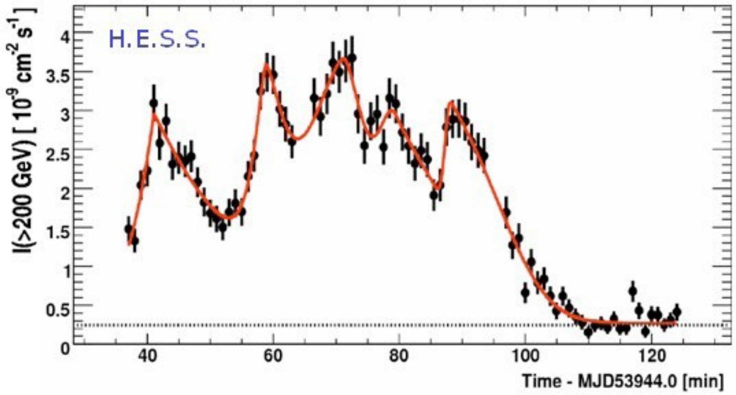
CTA can test "unified scheme" of AGN classification



LBL:powerful, substantial external radiation fields
IBL: in between
HBL:low power, weak external radiation fields

Astrophysics of AGNs

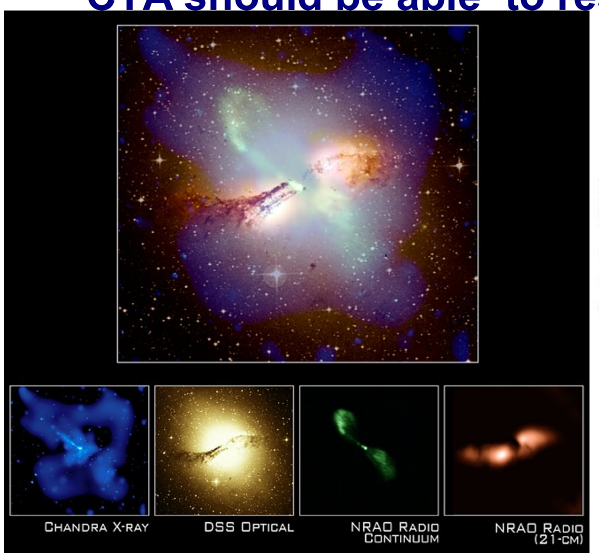
- Timing and spectral properties,
  especially multiwavelength (MWL) observations
  → clues on production processes
  aceleration & cooling times,
  time evolution of shocks & turbulence
- CTA has much finer timing resolution than currently
- Correlations with X-rays, radio ?
  “Orphan flares” ?
  → information on the nature
  of the production
- CTA angular resolution, for nearby radiogalaxies

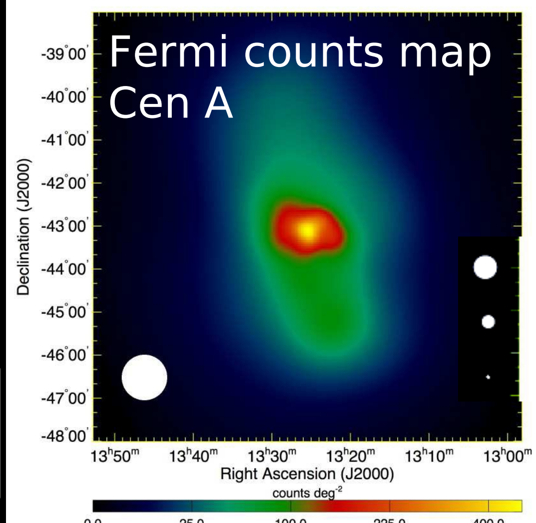


Variability timescale, ~200s,... ~1% R_S c

Causality → $R < c t_{var} d$,
→ emission region very small, &
bulk motion with $\Gamma > 50$

CTA should be able to resolve Cen A



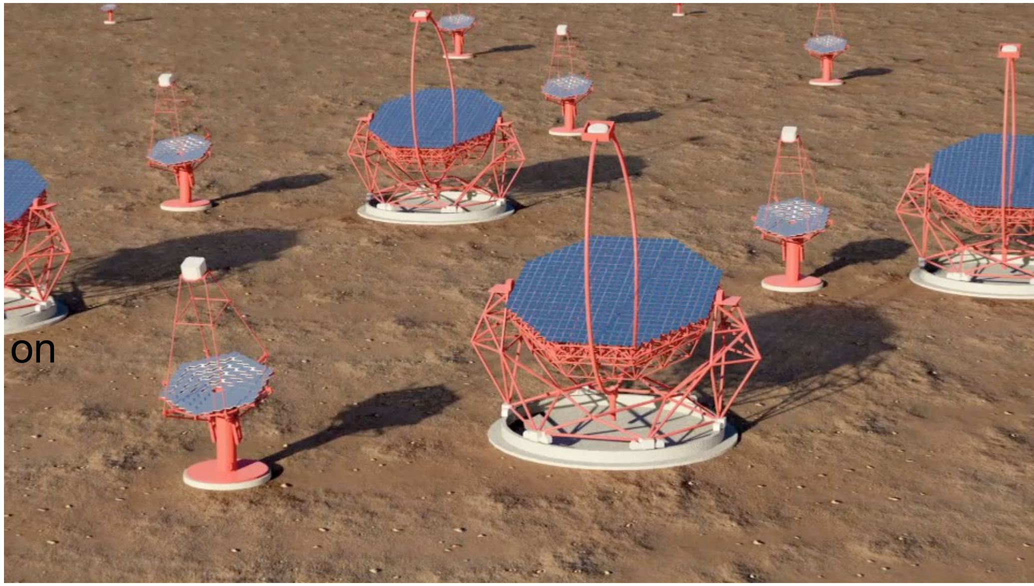


Fermi PSF at 10 GeV
CTA PSF at 100 GeV (≥2 images)
CTA PSF at 300 GeV (≥10 images)

Conclusions

CTA:

- **Huge science potential** (for a moderate price)
- Offers an attractive mix of **discovery potential** &
  a wealth of **"guaranteed" good physics**
  - **Astrophysics** of several categories of sources needed **to understand evolution of our Galaxy & Universe**
  - **Fundamental physics discovery potential** (Dark Matter, LIV, ALPs, EBL, IGMF, Cosmology …), strongly intertwined with Astrophysics
- CTA is almost production ready,
  no major technical problems
- Strong **international support**
  (scientists & funding agencies)



... a new project in Astroparticle Physics

- CTA will considerably advance knowledge on
  - **cosmic accelerators**
  - **high-energy astrophysics**
  - **fundamental physics**