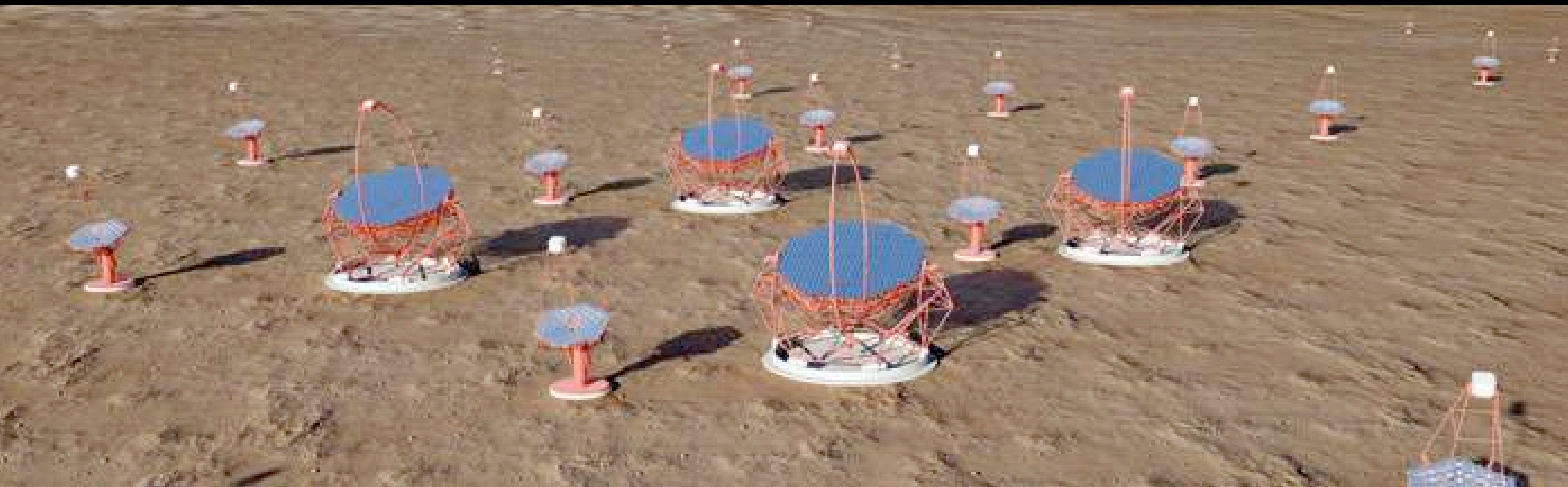
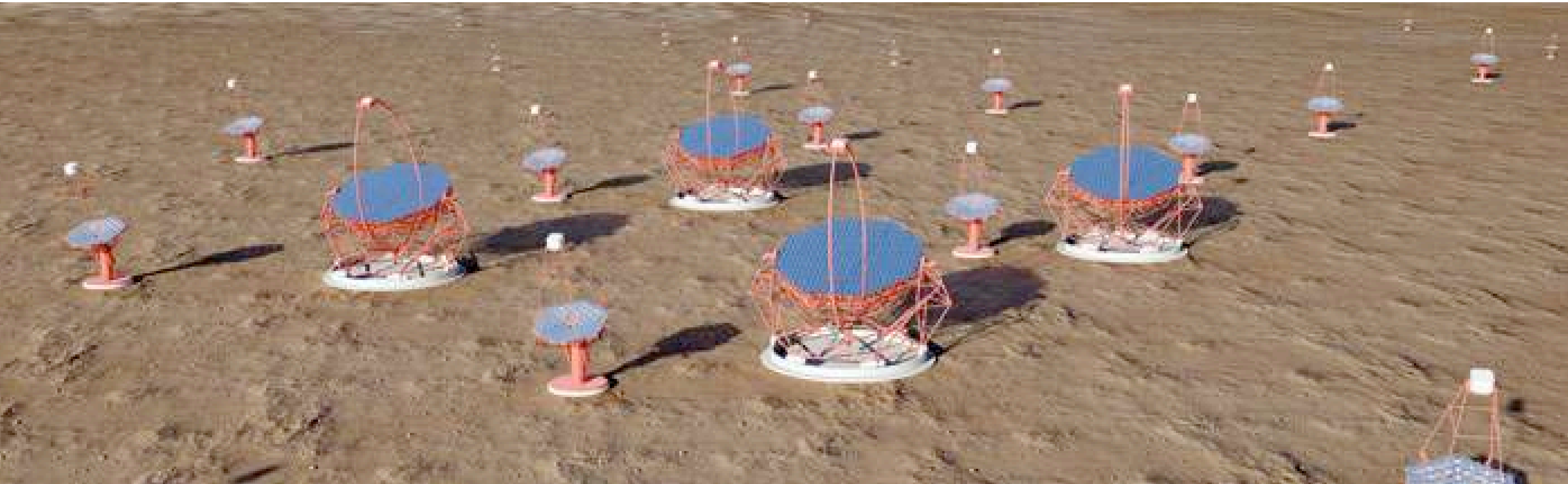
γ-ray signatures from UHECRs in blazars - what to expect from CTA

MACROS 2013 workshop

A. Zech, LUTH, Observatoire de Paris



What γ-rays have taught us about cosmic rays



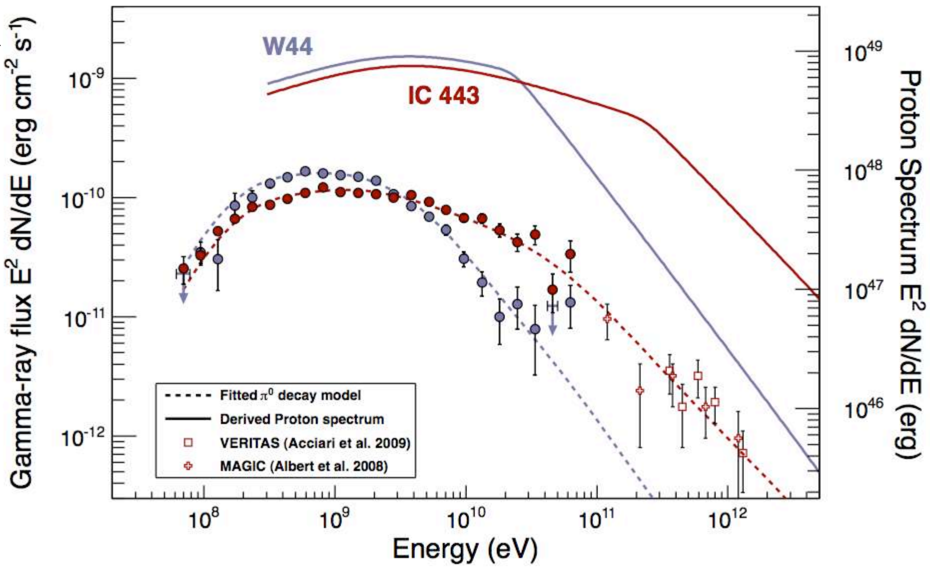
Galactic Cosmic Rays and Gamma Rays

γ-ray detections have led to crucial insight into galactic CR accelerators:

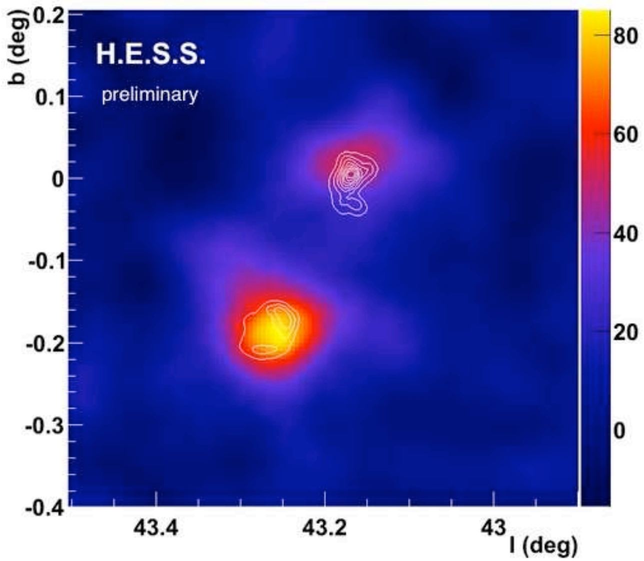
- shape of the GeV/TeV γ-ray spectra from SNR

  -> spectral modelling favours hadronic origin in certain cases (e.g. Tycho)

  -> Fermi results on IC443 and W44 *(Ackermann et al., Science 339 (2013) 807)* : detection of the pion-decay signature in the Fermi spectra.



- detection of TeV γ-rays from molecular clouds with H.E.S.S. (e.g. W49A&B)

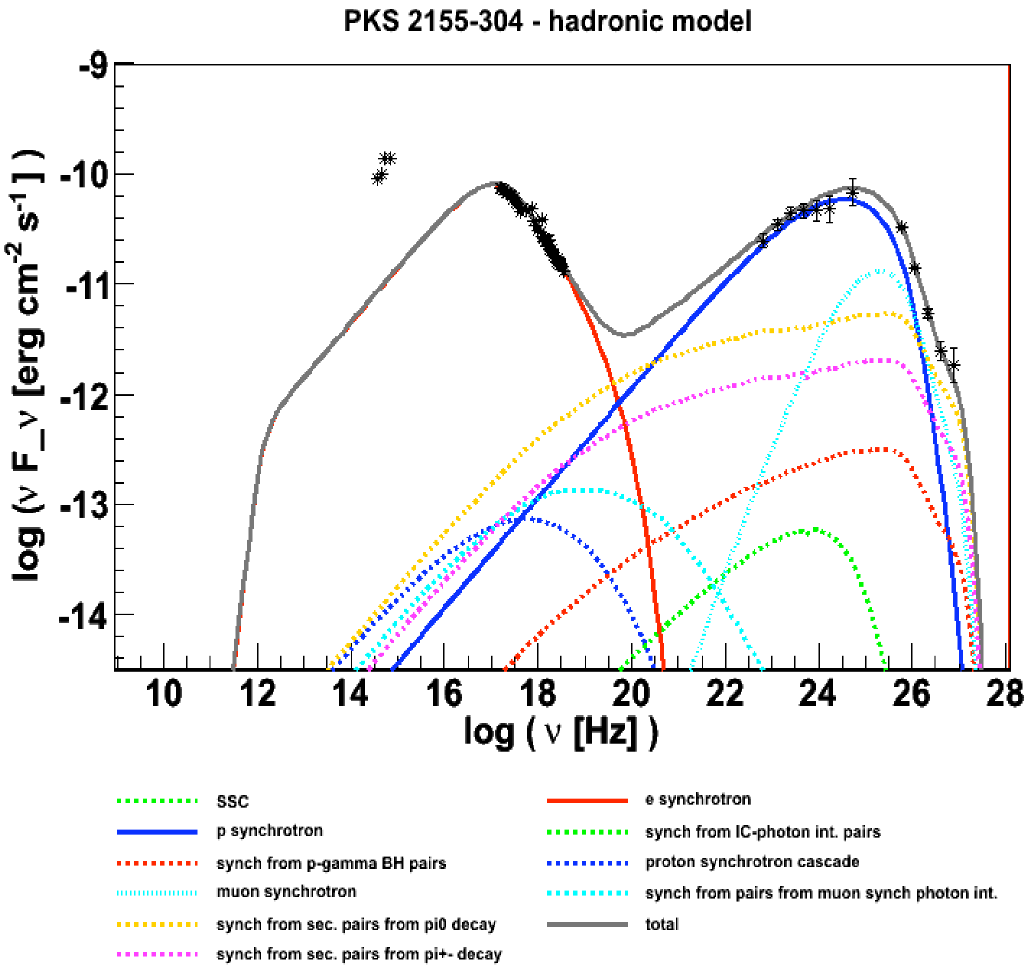


- detection of γ-rays from starburst galaxies (e.g. NGC253 & M82 seen in GeV+TeV)

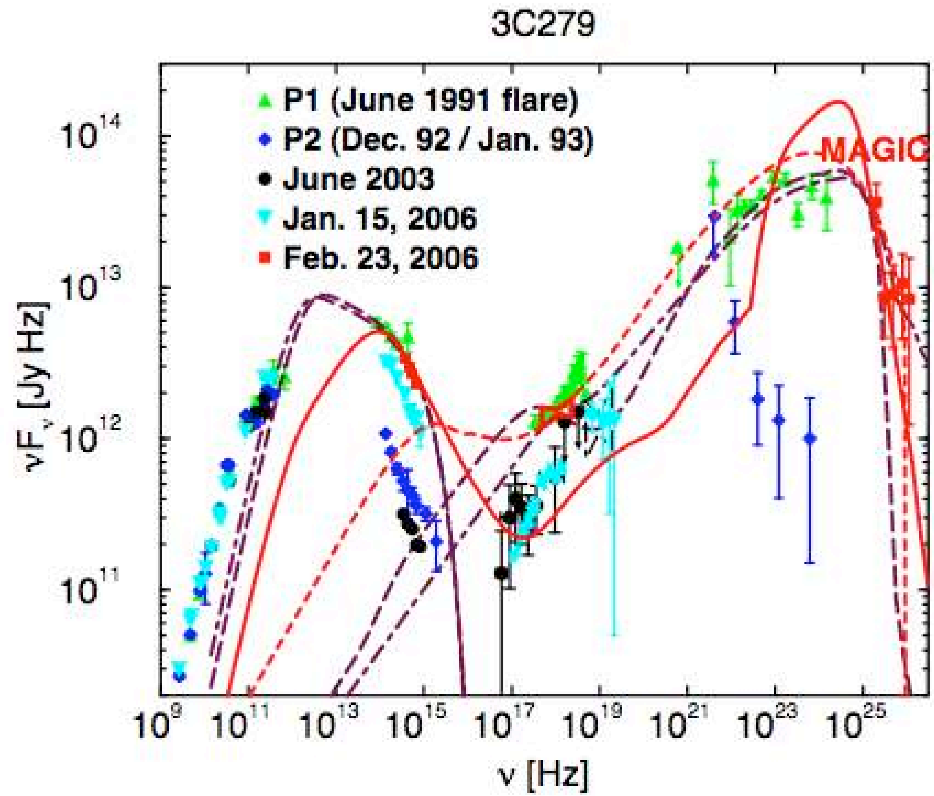
BUT: no answer yet whether SNRs are the main contributors to the galactic CR flux

UHECRs and Gamma Rays

Hadronic scenarios remain an option to explain γ-ray emission from AGN.



M. Cerruti, AZ, C. Boisson, S. Inoue, conf. proc. of Gamma 2012



M. Böttcher, A. Reimer, A.P. Marscher, ApJ 703 (2009) 1168

e.g. for a BL Lac

e.g. for an FSRQ

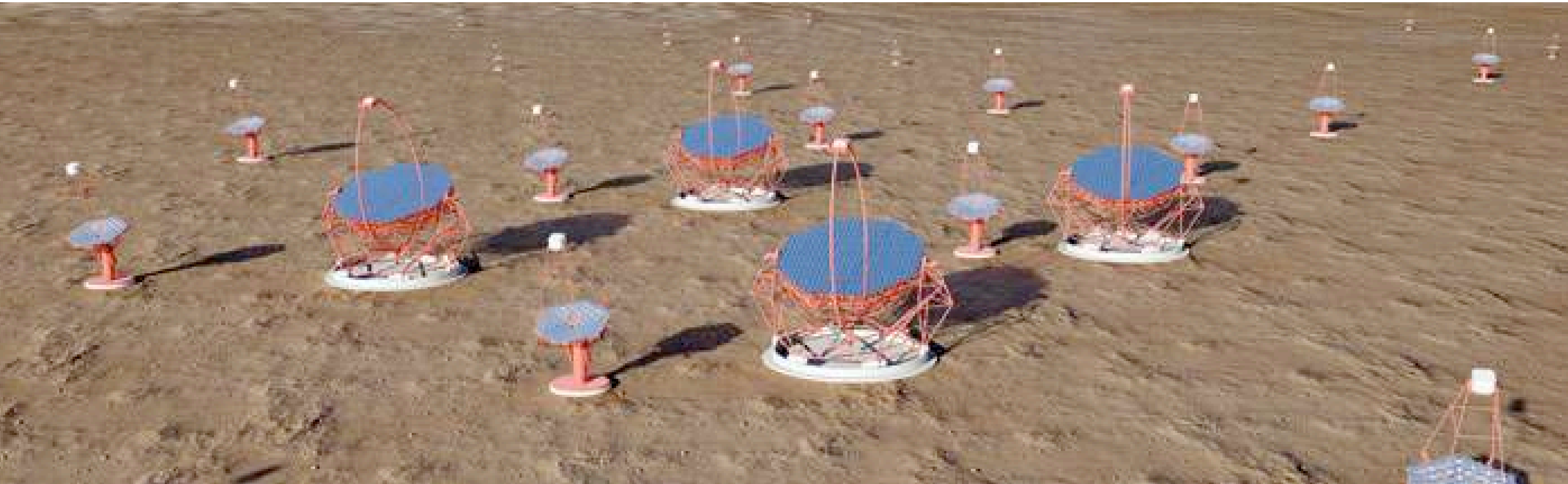
Potential AGN sources for UHECR acceleration

- **FR-II radio-galaxies / FSRQ**
  - powerful sources (accretion luminosity 10^{46} - 10^{47} erg/s)
  - sufficient power to accelerate protons to UHE
  - strong internal photon fields
    -> important contribution of photo-hadron interactions
  - but low space density of sources
- **FR-I radio-galaxies / BL Lacs**
  - about 3 orders of magnitude less powerful than FR-II / FSRQ
  - difficulty to accelerate protons to highest energies
  - low internal photon fields
    -> proton synchrotron emission supposed to dominate
- **low-luminosity AGN, dormant black holes**
  - particle acceleration in rotating BH magnetospheres
    (*Rieger & Aharonian '09, Neronov & Aharonian '07, Istomin & Sol '09,...*)
  - need very massive BH + weak radiation fields

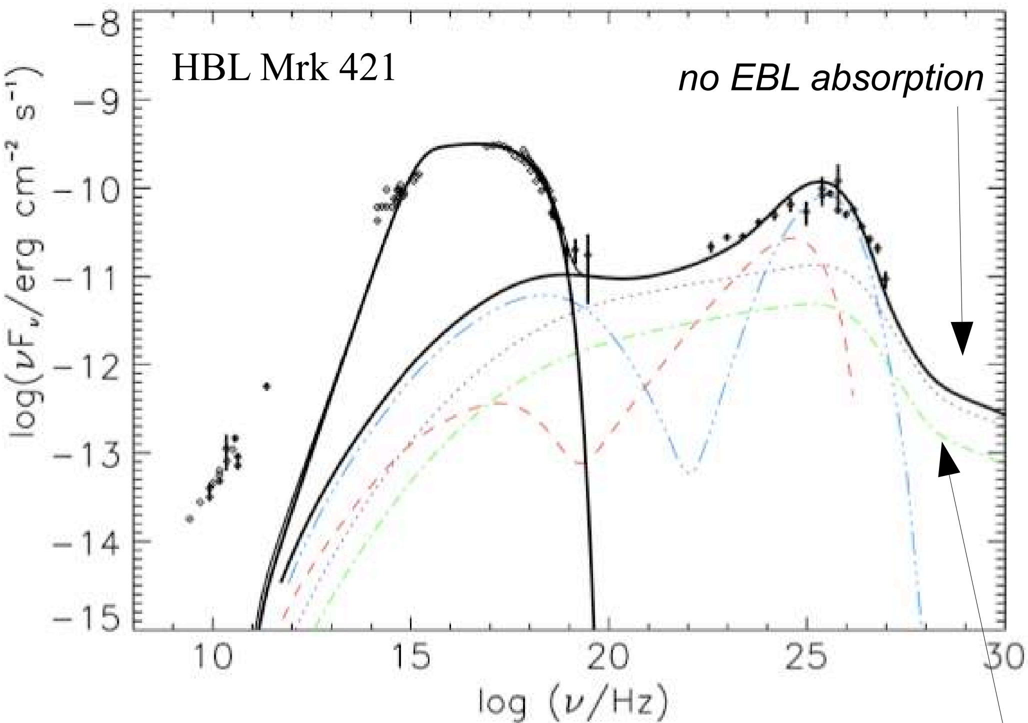
Common problem:

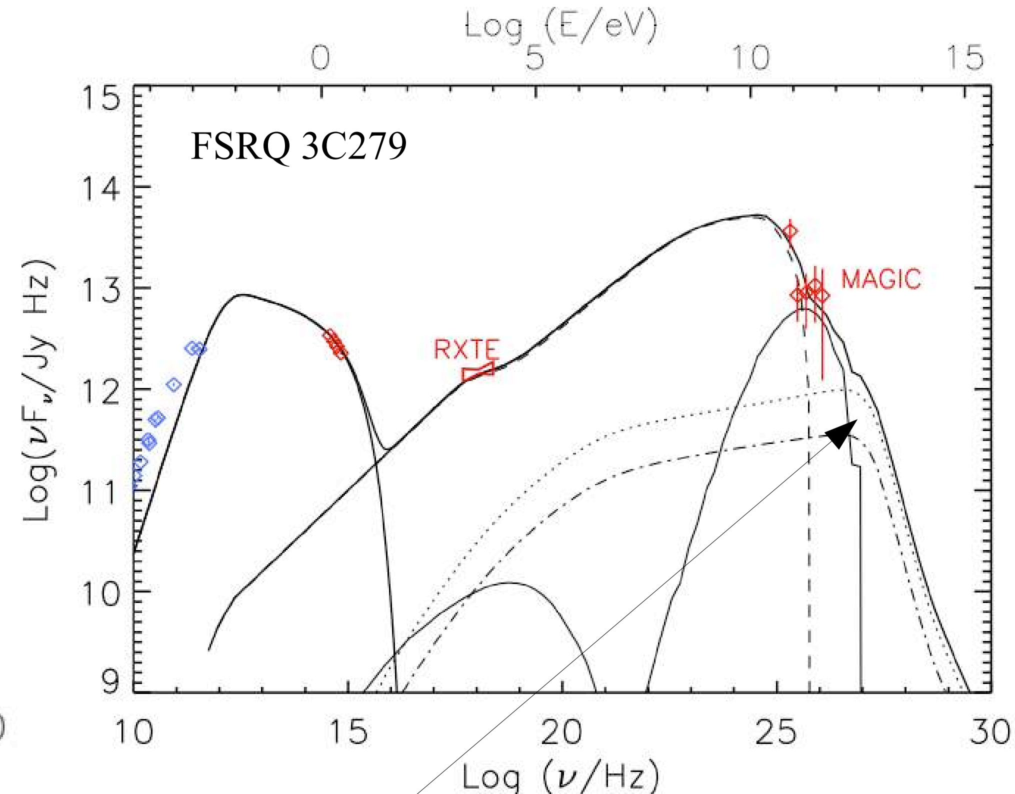
UHECR escape from acceleration & radiation region ! (neutrons ?)

Which γ-ray signatures to expect from UHECR emitting AGN ?



internal cascades





Abdo, A. A., Ackermann, M., Ajello, M., et al. 2011, ApJ 736, 131

Böttcher, Reimer, Marscher, AIP Conf.Proc.1085:427-430,2009

red: proton synchrotron + cascade
blue: muon synchrotron + cascade
violet: cascade from π0 photons
green: cascade from secondary e± coming from π±

spectral hardening in TeV range due to synchrotron-pair cascades triggered by photo-pion production from UHE protons

dashed: proton synch. + cascade
solid: muon synch. + cascade
dotted: π0 cascade
dot-dashed: π± cascade

here, muon synch. also adds to spectral hardening

external cascades...

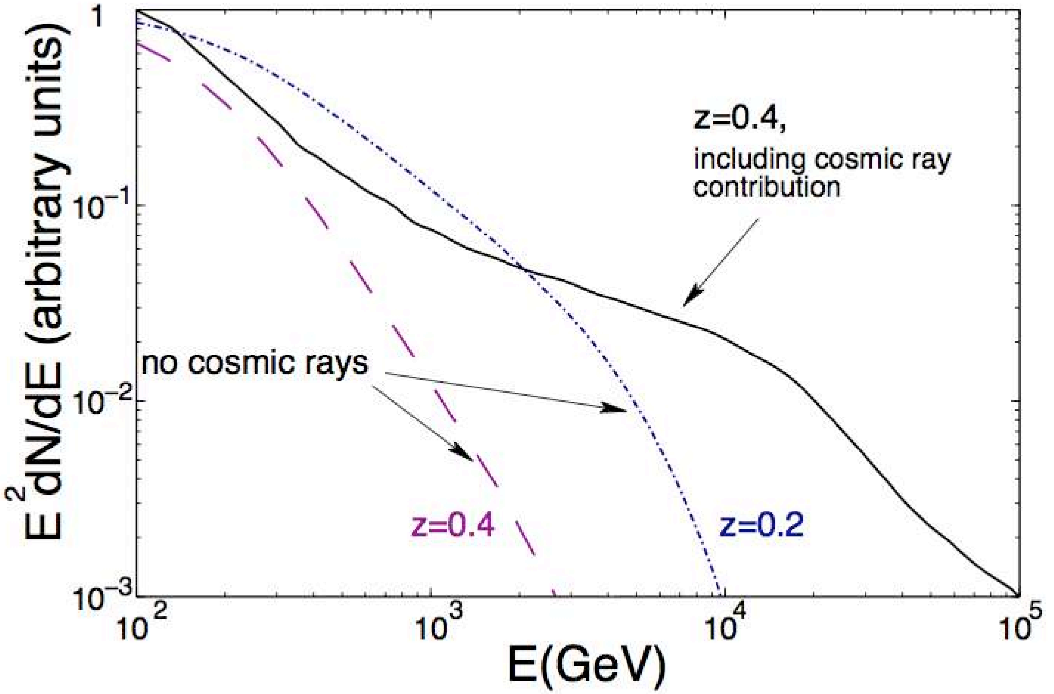
secondary gamma-ray emission may be produced **along the line of sight** due to:

- **VHE gamma-rays** (pair prod. with EBL + Compton upscattering of CMB)

- **UHE gamma-rays** (pair prod. with CMB + Compton upscattering of CMB) ->assumes relat. hadrons in source

- **UHE protons** (pair prod. & photo-meson prod. with CMB & EBL)

- **UHE nuclei** (pair prod. & photo-dissociation with CMB & EBL)



Prosekin, Essey, Kusenko, Aharonian ApJ 757 (2012) 183

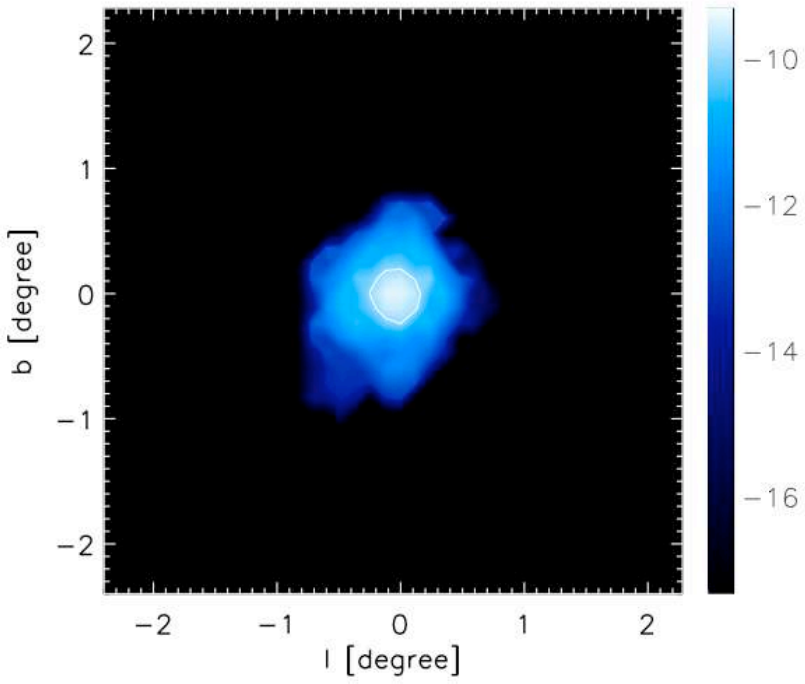
-> spectral hardening in the TeV range
-> distinct hadronic / leptonic signatures
-> cascades show no / only very slow variability

... and UHECR pair halos ?

Interactions of UHECR from AGN might also lead to synchrotron pair halos or extended Compton/pair cascades.

-> detectability only under ideal circumstances

-> need to distinguish UHECR pair halos from "ordinary" gamma-induced halos



Kotera, Allard, Lemoine, A&A 527 (2011) 54

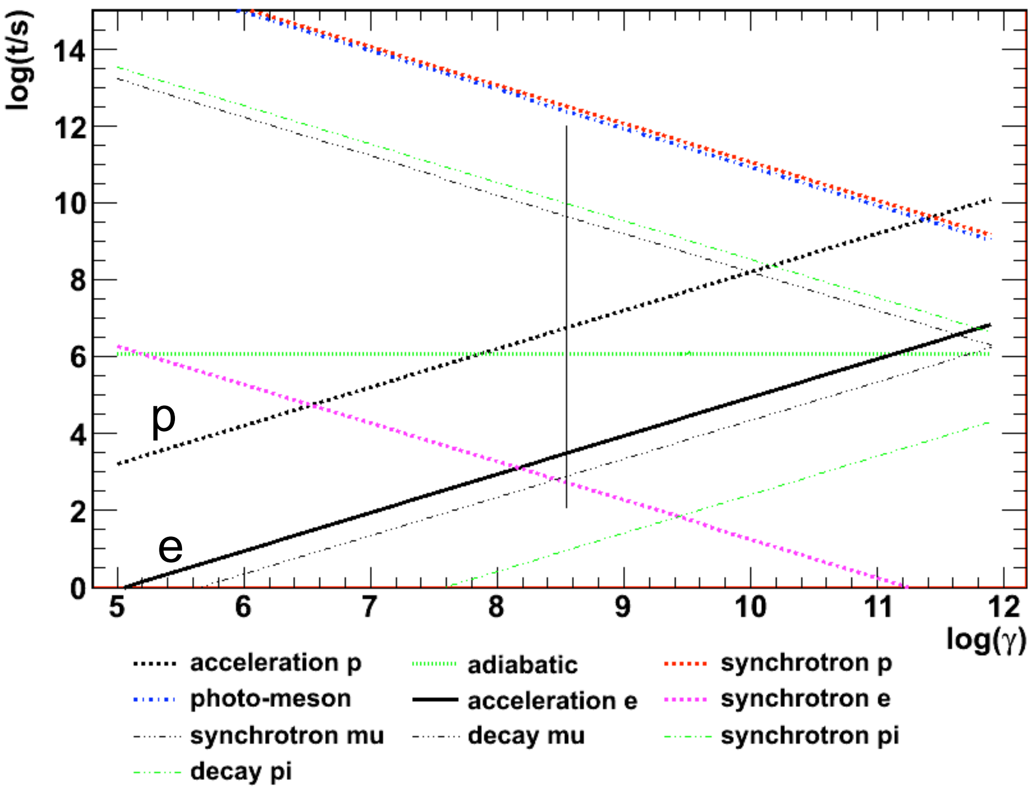
On external cascades and halos see also:
Murase, Dermier, Takamai, Migliori, ApJ 749, 63 (2012)
Prosekin, Kelner, Aharonian, A&A 536, A30 (2011)
W. Essey and A. Kusenko 2010, 2012
W. Essey, O. Kalashev, A. Kusenko, et al. 2010, 2011
W. Essey, S. Ando, A. Kusenko 2011
S. Razzaque, C. D. Dermer and J. D. Finke, 2012
Y.G. Zheng, T. Kang, 2013;
Armengaud et al. (2006);
Gabici & Aharonian (2005)

variability

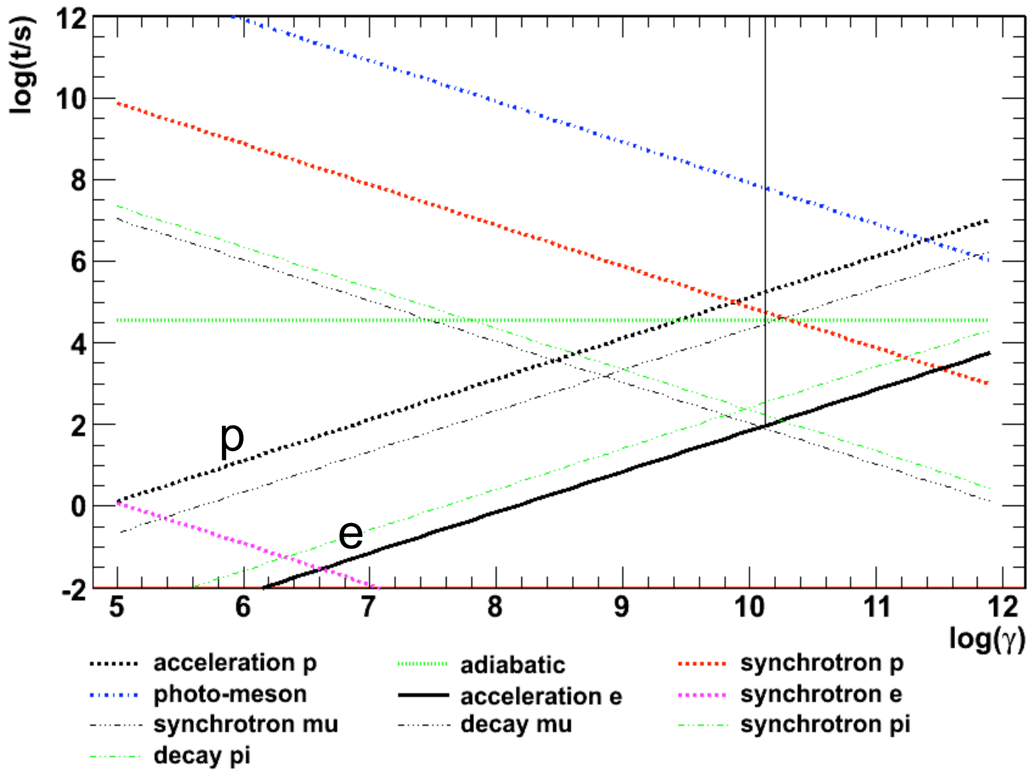
- variability time scale ~ **max($t_{cooling}$; $t_{acceleration}$; $t_{light\ crossing}$) / δ**

- rapid variability harder to explain for hadrons due to longer cooling- and acceleration times, but depends on source parameters

*ex.: time-scales for a specific SSC scenario (**B~0.1 G**)*



*ex.: time-scales for a specific hadronic scenario (**B=80G**)*

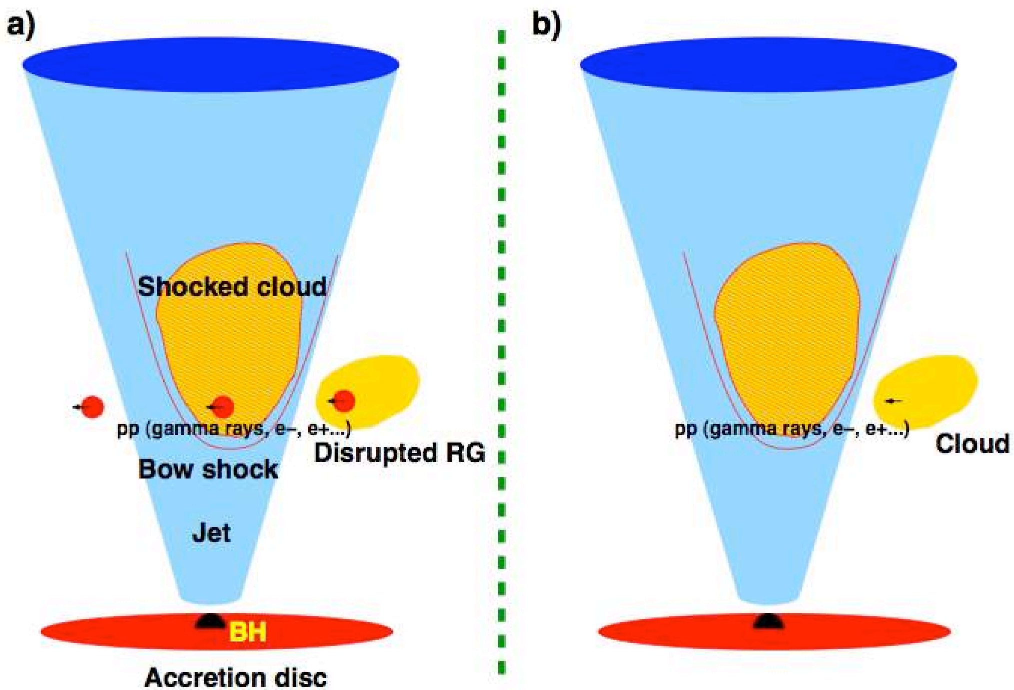


- rapid variability from geometric effects ?

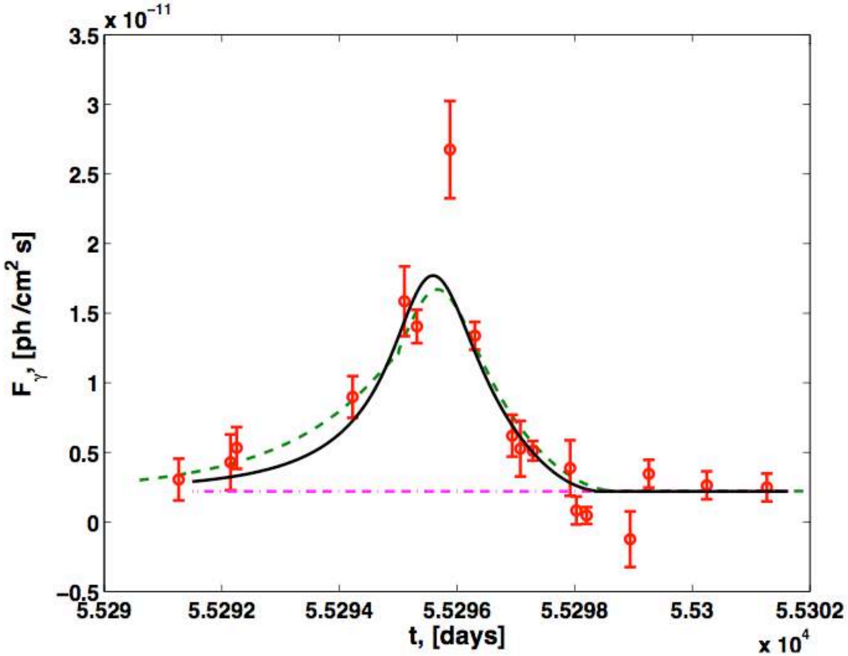
-> very rapid variability favors relativistic leptons, but cannot exclude the existence of relativistic hadrons in the source

very rapid variability

very rapid variability seems possible if relativistic hadrons in the jet interact with stellar envelopes (red giants) or gas clouds (BLR) via p-p, p-γ or p-synchrotron.
(*e.g. D.V. Khangulyan, M.V. Barkov, V. Bosch-Ramon, F.A. Aharonian, A.V. Dorodnitsyn, astro-ph/1305.5117*)



Bosch-Ramon, Perucho, Barkov, A&A (2012)

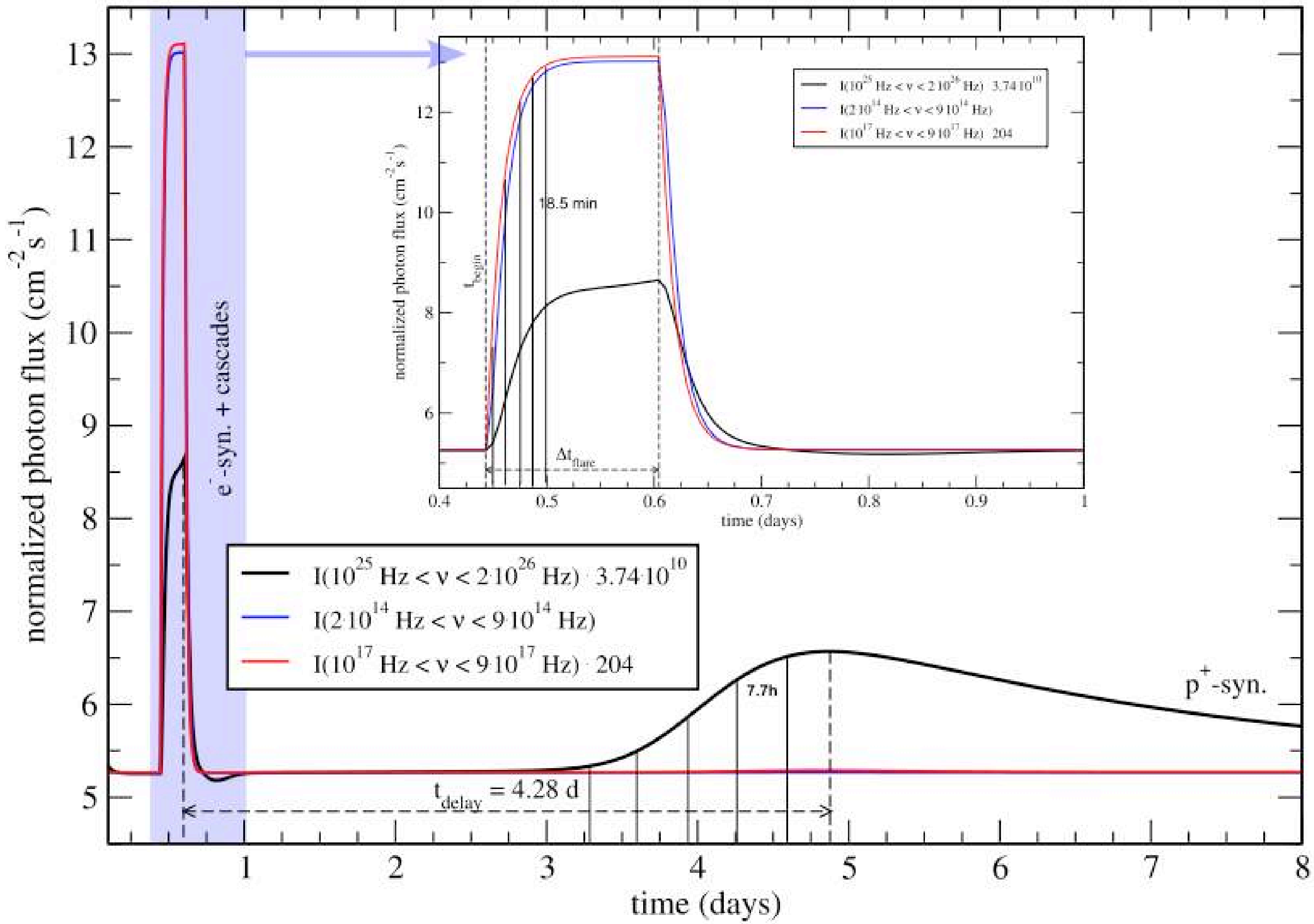


VHE flare of M87 in 2010,
Barkov, Bosch-Ramon, Aharonian, ApJ (2012)

A similar model might explain minute-scale variability of PKS2155-304 in 2006,
Barkov et al. (2011)

variability & orphan flares

Injection of more primary e^- and p^+ for $\Delta t \approx 4$ h.



Systematic Modeling of Active Galactic Nuclei   Matthias Weidinger, Rio de Janeiro 2013-07-08

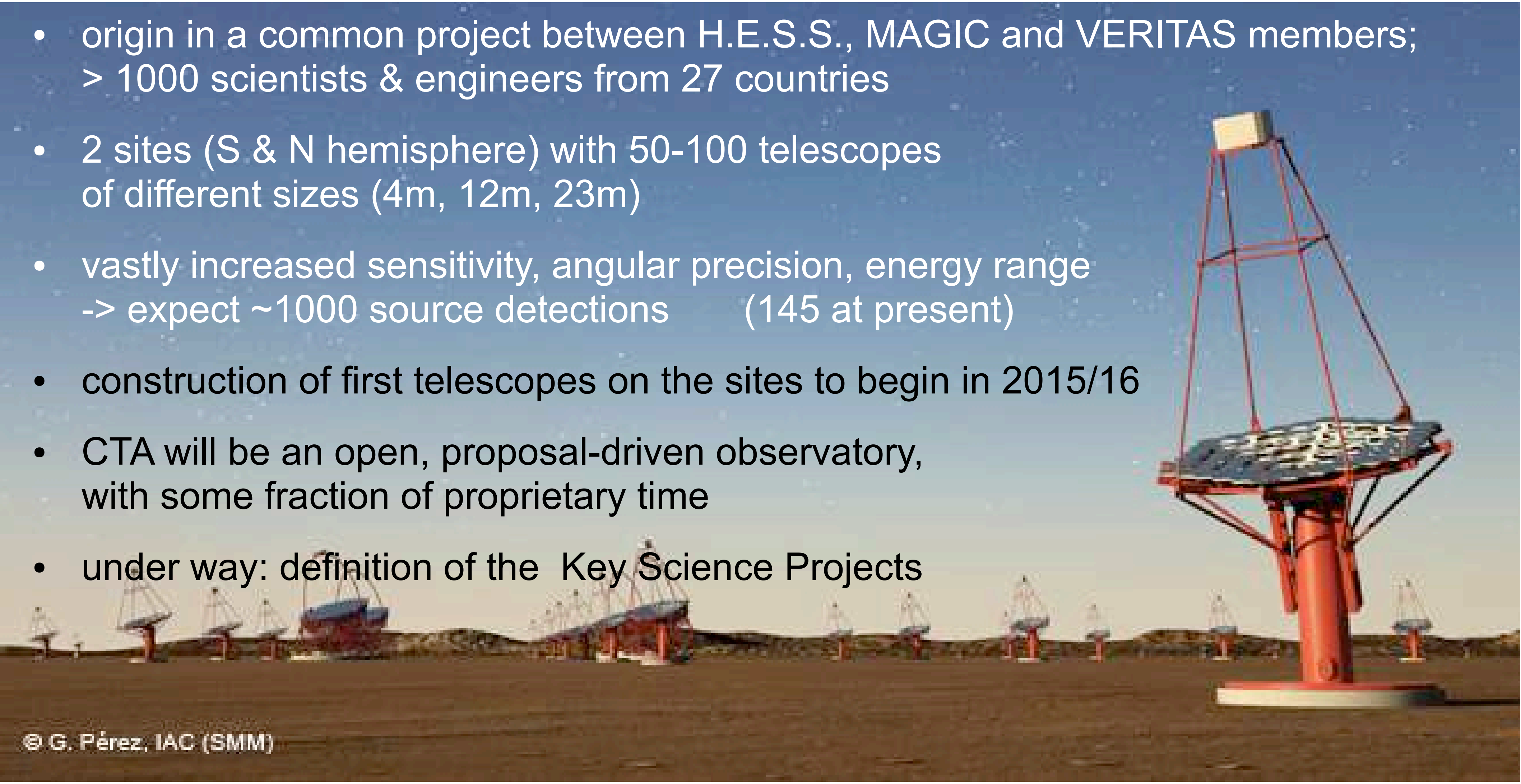
Characteristic signature for a simultaneous injection of p+ and e- in the acceleration zone:

time lag between the e-synch and p-synch peaks due to difference in acceleration time scales !

(*Weidinger et al., ICRC 2013*)

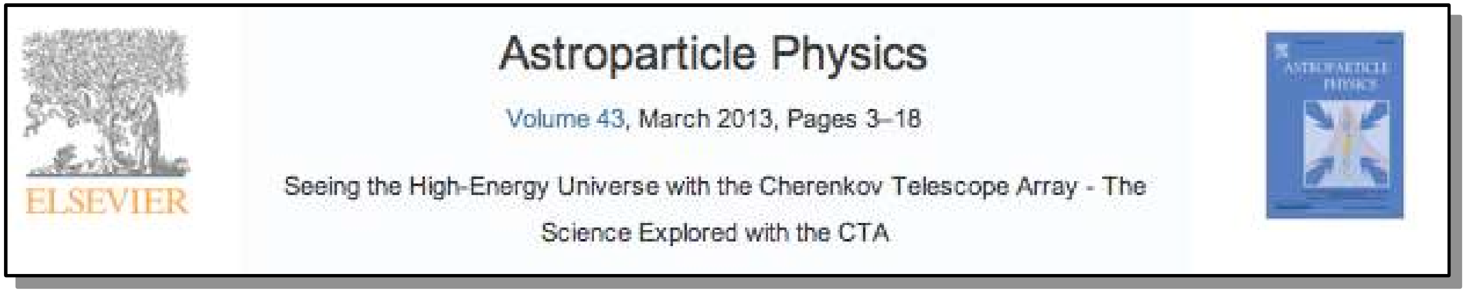
Introducing the Cherenkov Telescope Array

CTA: the first open VHE observatory



- origin in a common project between H.E.S.S., MAGIC and VERITAS members; > 1000 scientists & engineers from 27 countries
- 2 sites (S & N hemisphere) with 50-100 telescopes of different sizes (4m, 12m, 23m)
- vastly increased sensitivity, angular precision, energy range -> expect ~1000 source detections (145 at present)
- construction of first telescopes on the sites to begin in 2015/16
- CTA will be an open, proposal-driven observatory, with some fraction of proprietary time
- under way: definition of the Key Science Projects

Special Edition of Astropart. Phys. (24 papers) →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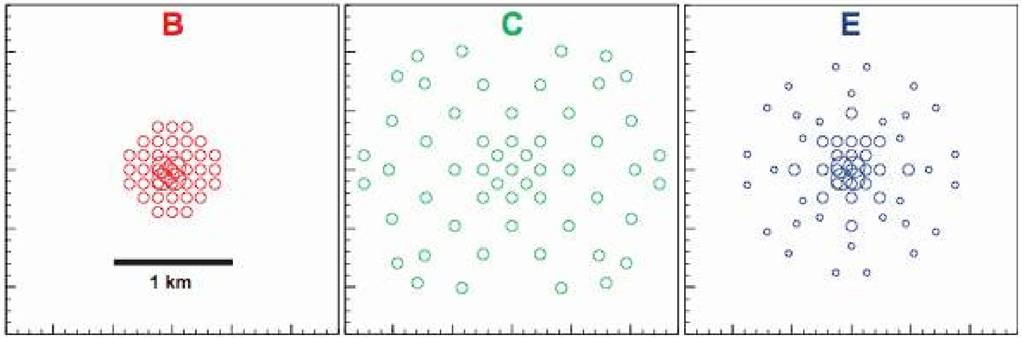
Astroparticle Physics

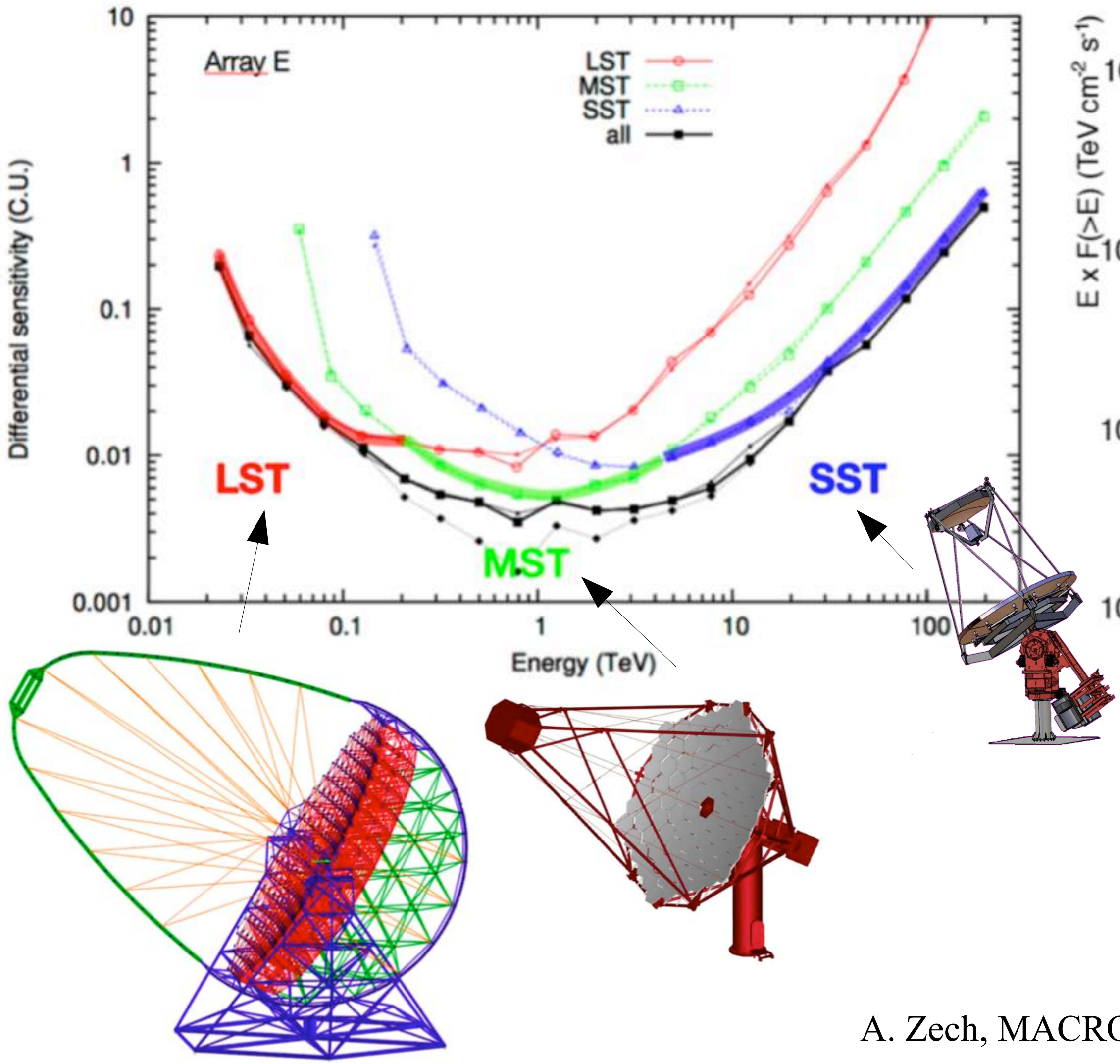
Volume 43, March 2013, Pages 3–18

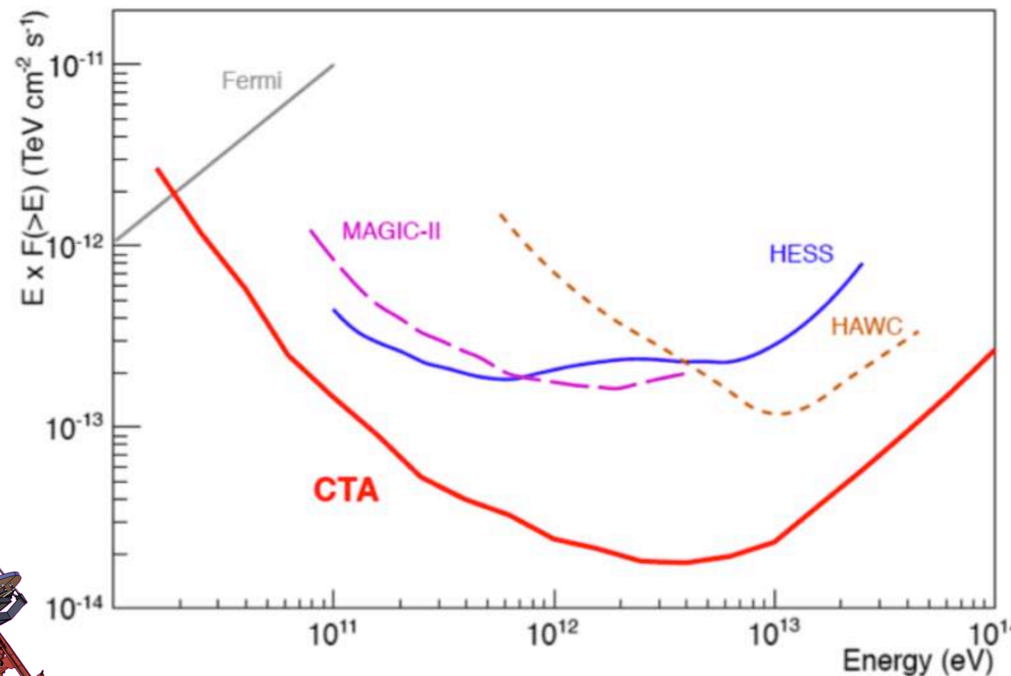
Seeing the High-Energy Universe with the Cherenkov Telescope Array - The Science Explored with the CTA

expected sensitivity



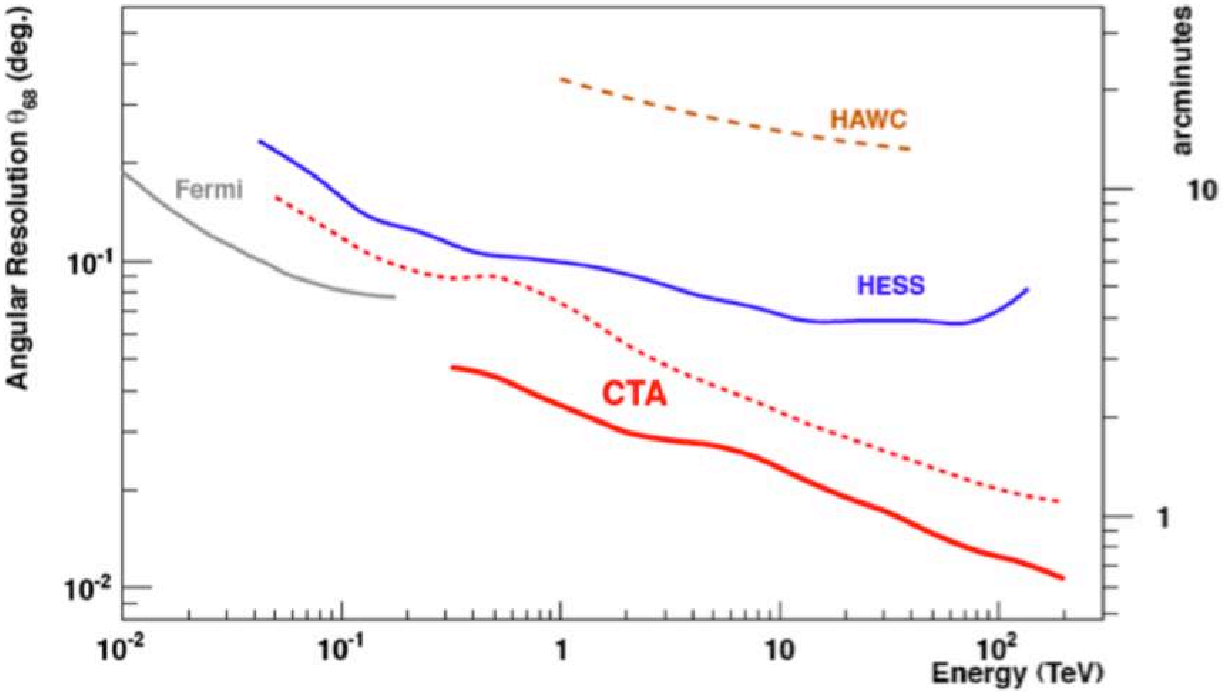
different array layouts under study; most likely candidate for the southern site is an array similar to "E" with more SSTs...



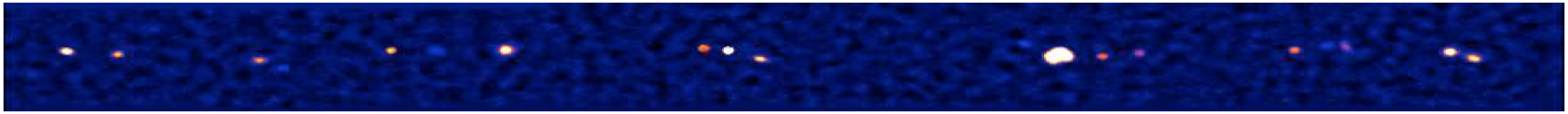


CTA will improve on current sensitivities by a factor ~10 and provide very rapid time resolution.

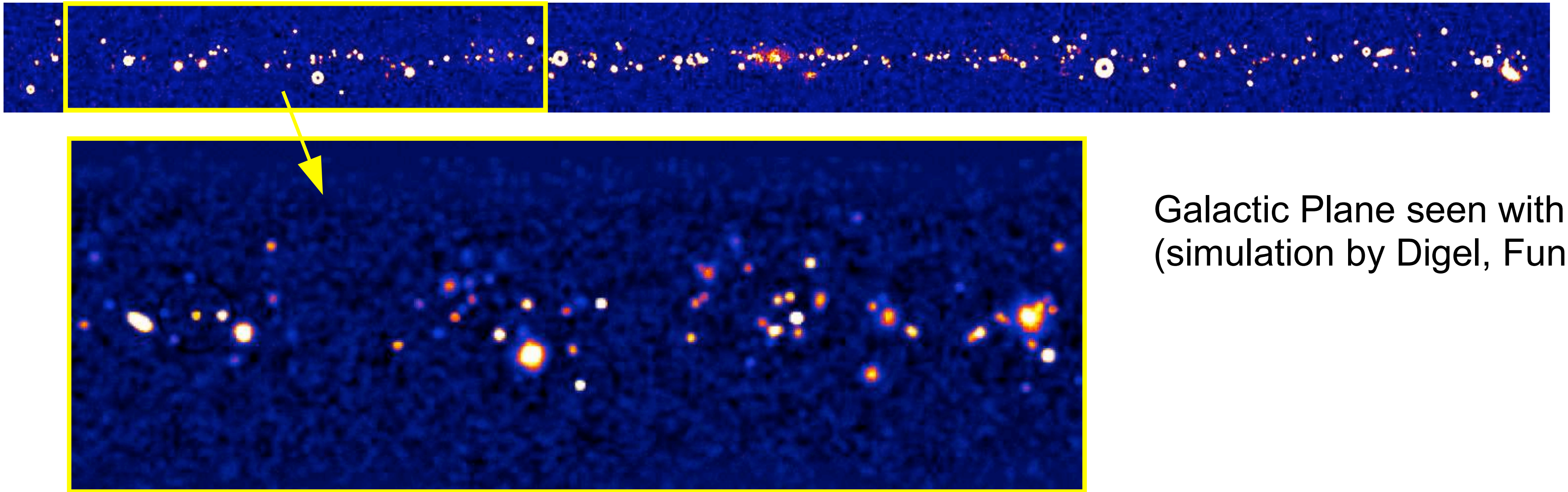
expected angular resolution



angular resolution down to the arc-minute and large field of view (4.5 - 10 deg)

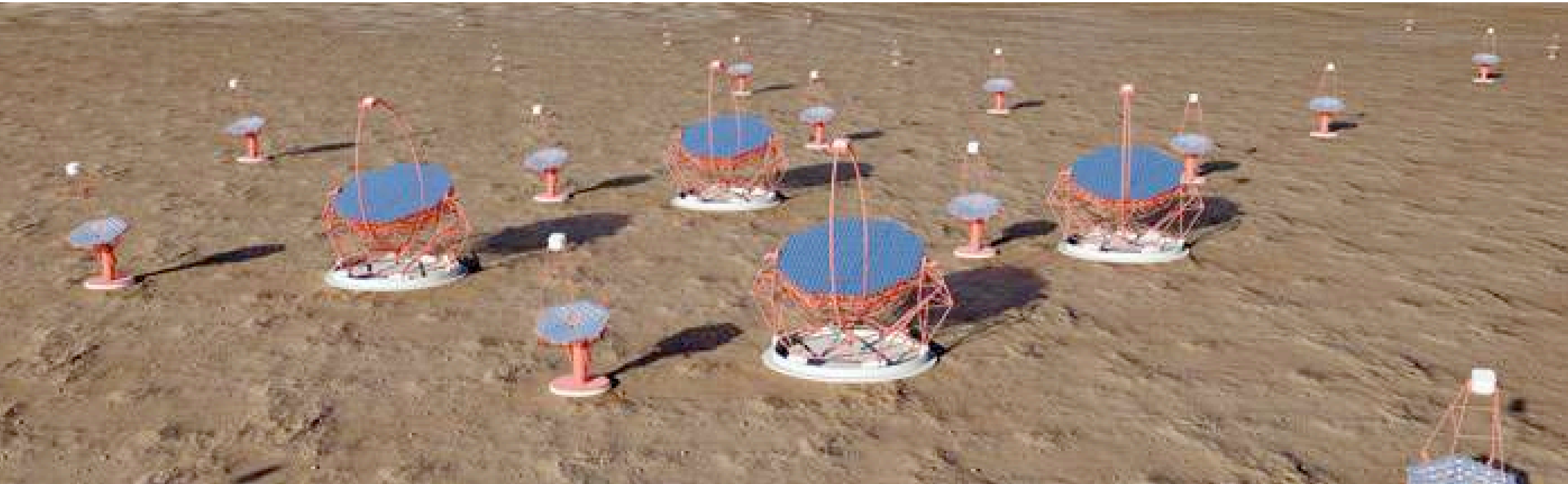


Galactic Plane H.E.S.S.



Galactic Plane seen with CTA (simulation by Digel, Funk, Hinton)

What CTA will teach us about Cosmic Rays



Galactic Cosmic Rays with CTA

- probing cut-offs in SNRs to distinguish leptonic from hadronic acceleration

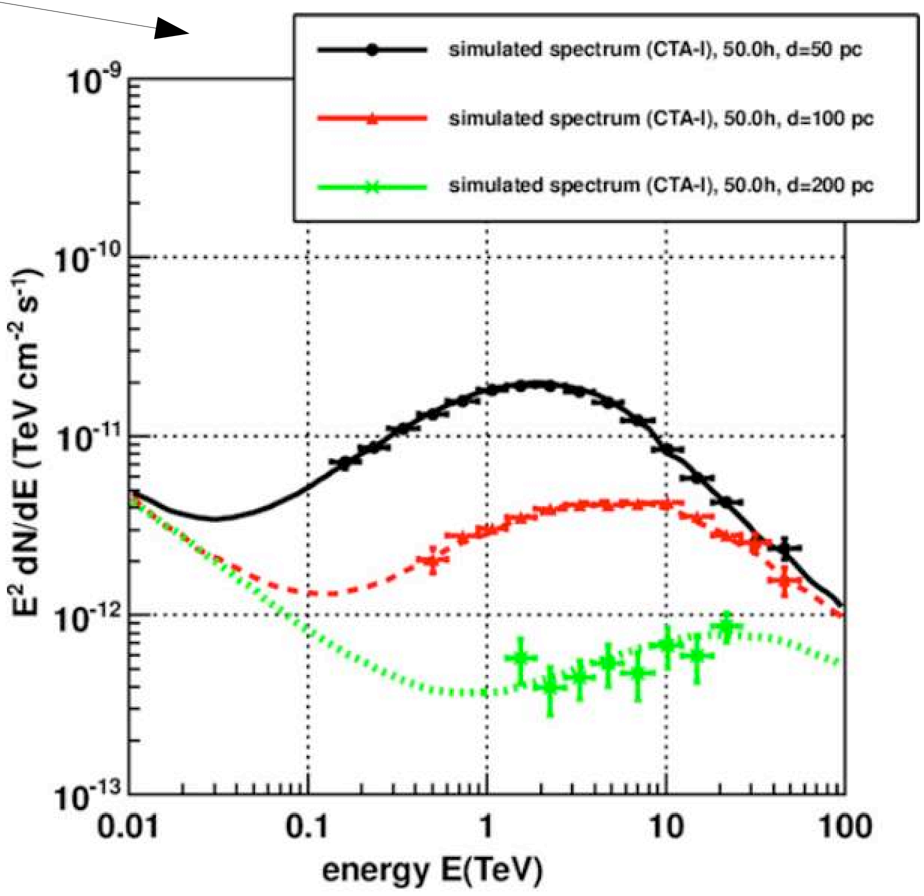
  -> largely increased number of SNR detections (~ 80 ? but not all resolvable!)

- search for gamma-ray bright Molecular Clouds to spot nearby CR accelerators

  -> Galactic Plane Scan with high sensitivity

- detection of gamma-ray binaries
  (~ an order of magnitude more sources ?)

- exploration of the spectral shape of starburst galaxies



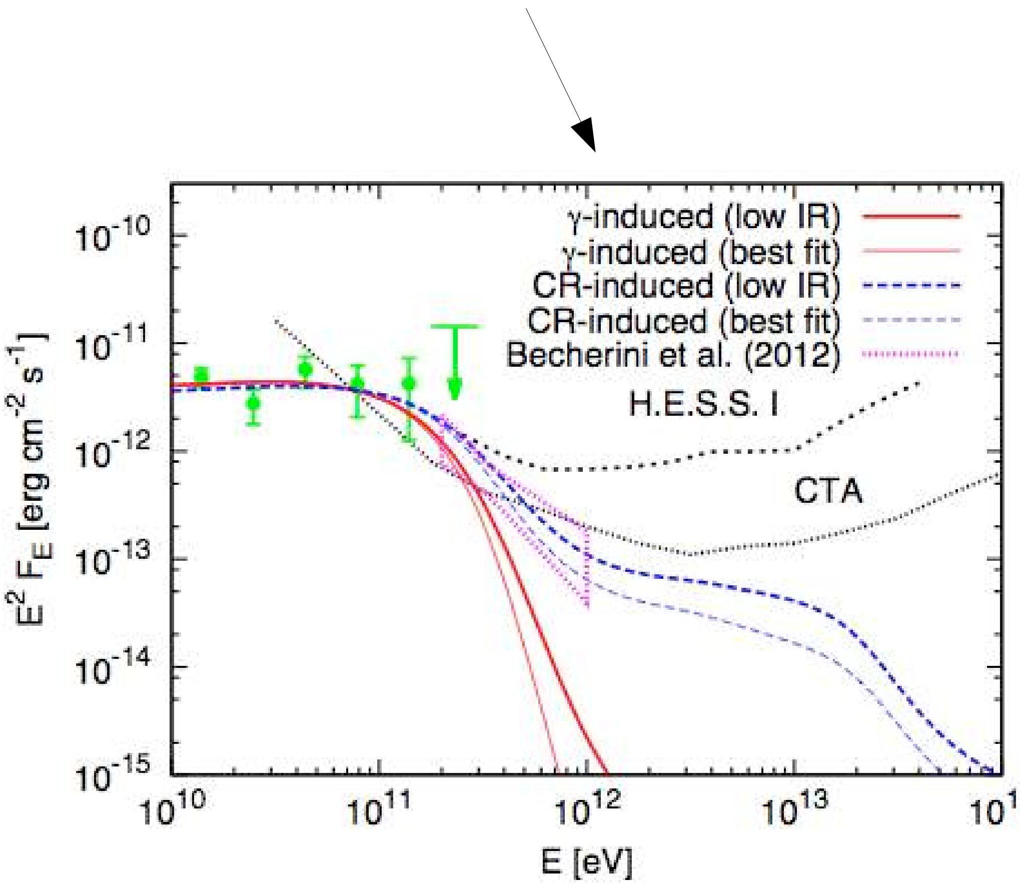
F.Acero et al., Ap. Phys. 43 (2013) 276

Extragalactic Cosmic Rays with CTA

- AGN: search for spectral features in different AGN classes
  - external UHECR induced cascades for high redshift blazars ?
  - variability studies
  - extended pair halos ?
  - low-luminosity AGN ?

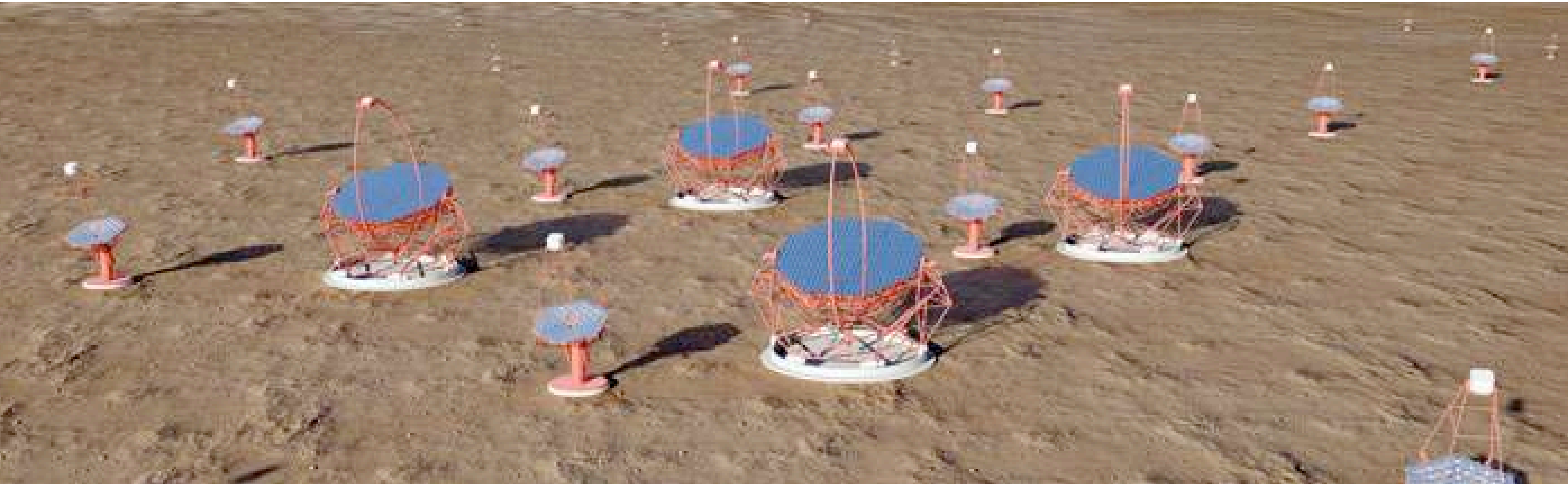
- search for galaxy cluster emission & starburst galaxies

- GRBs: MWL studies of spectral evolution

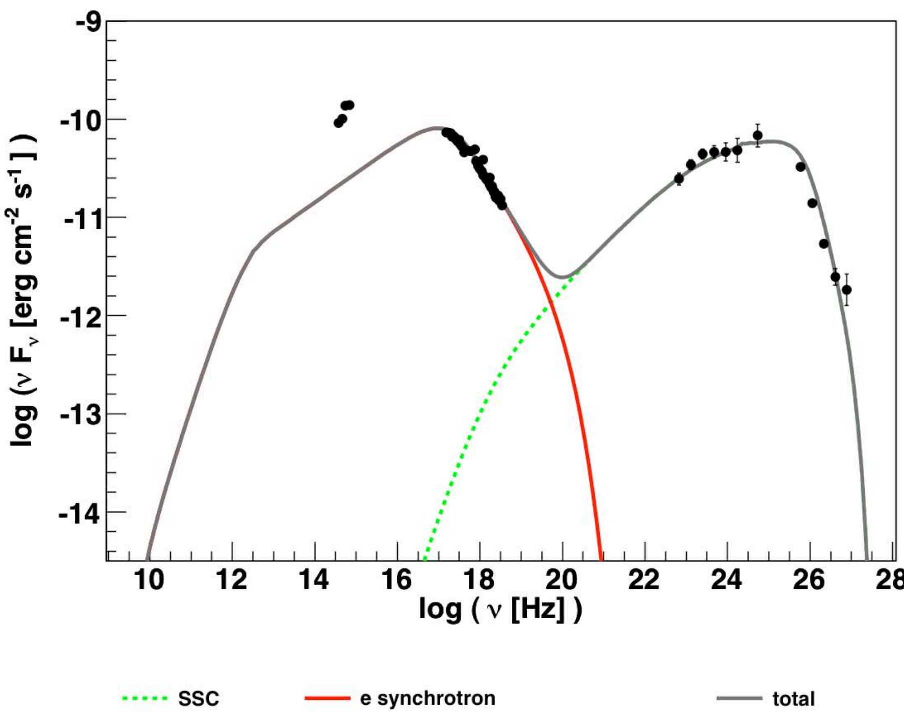


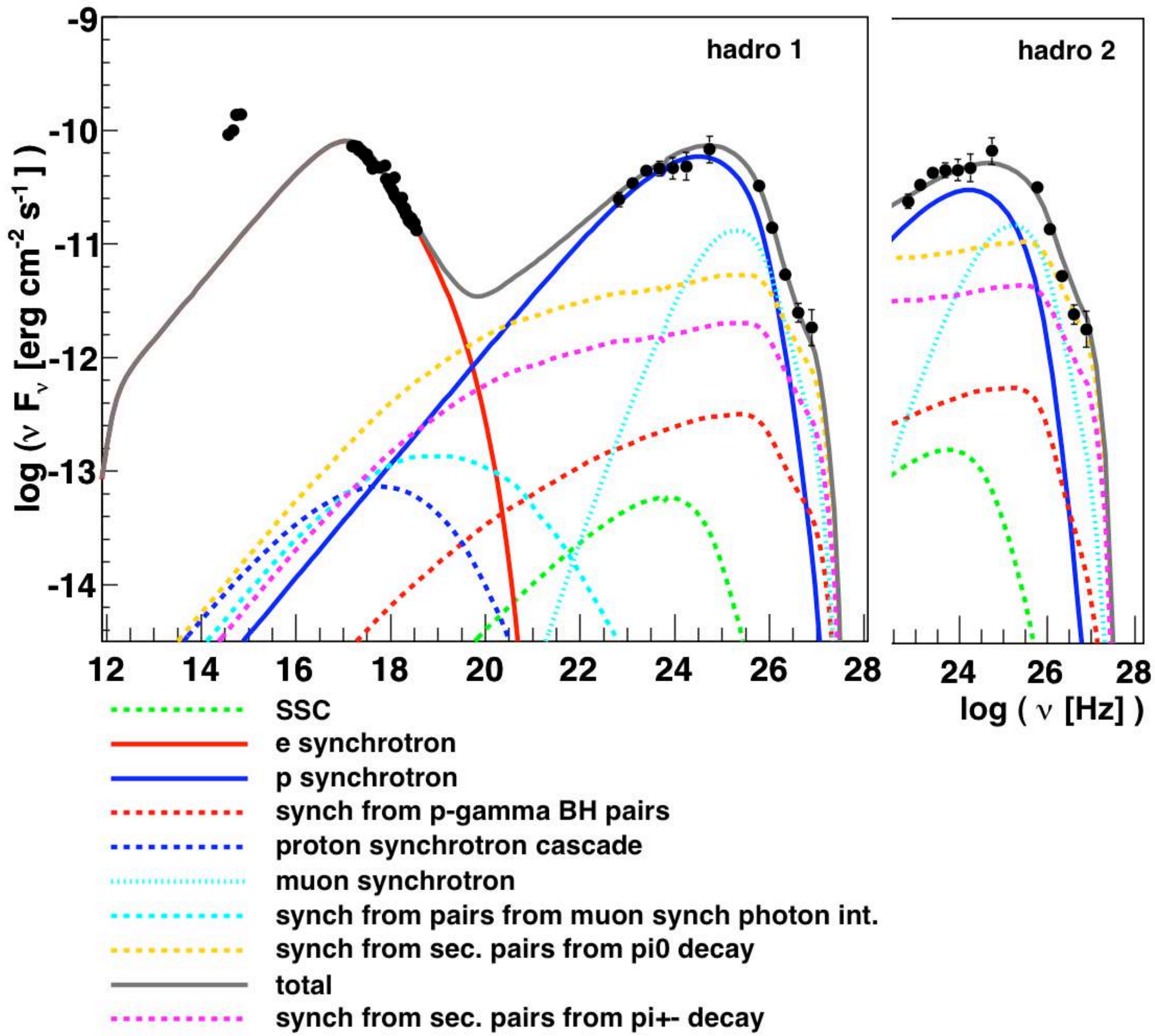
Takami, Murase, Dermer, ApJL 771 (2013) 32

Focus on intrinsic UHECR signatures in blazar spectra



PKS 2155-304 - a case study





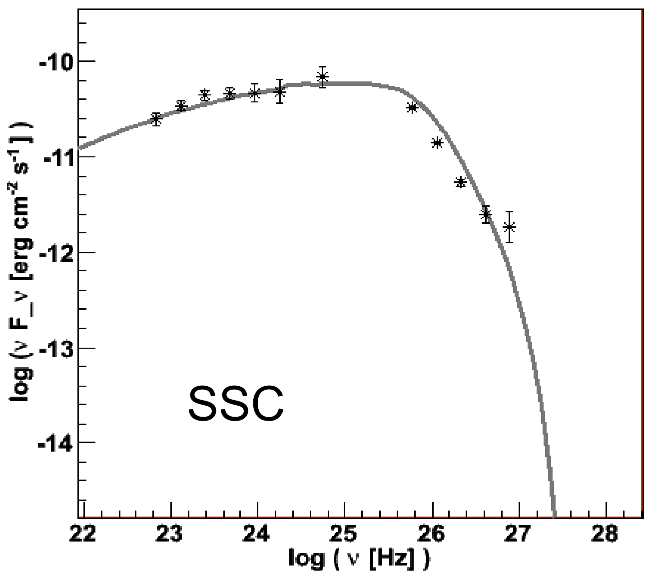
SSC:
δ=30
B = 0,07 G
R = 2e16 cm
L=4e43 erg/s

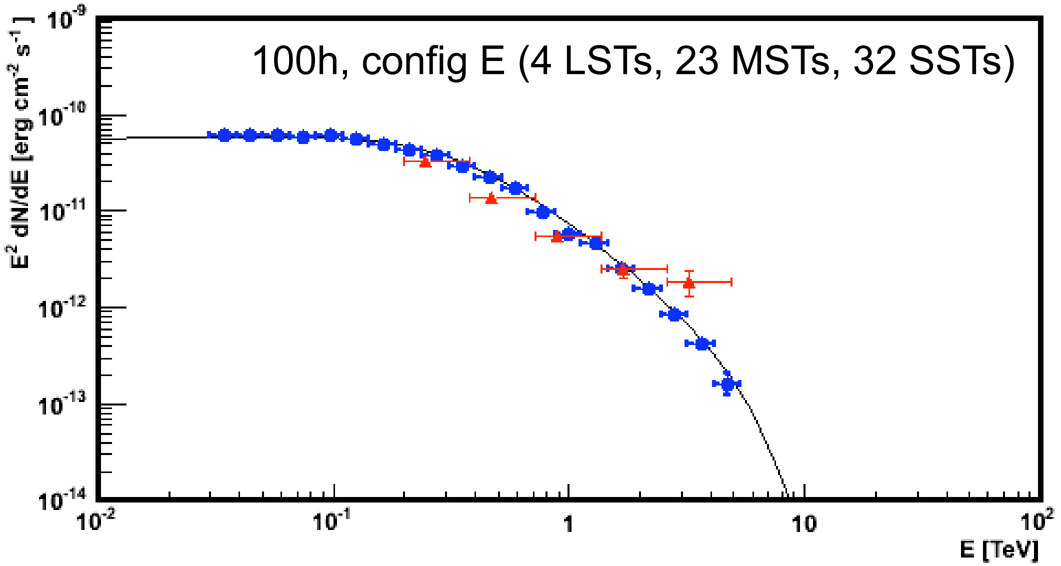
hadro 1:
δ=30
B = 80 G
R = 5e14 cm
γ_p,max = 1e9
density_p = 1e4 @ γ=1
L=4e45 erg/s

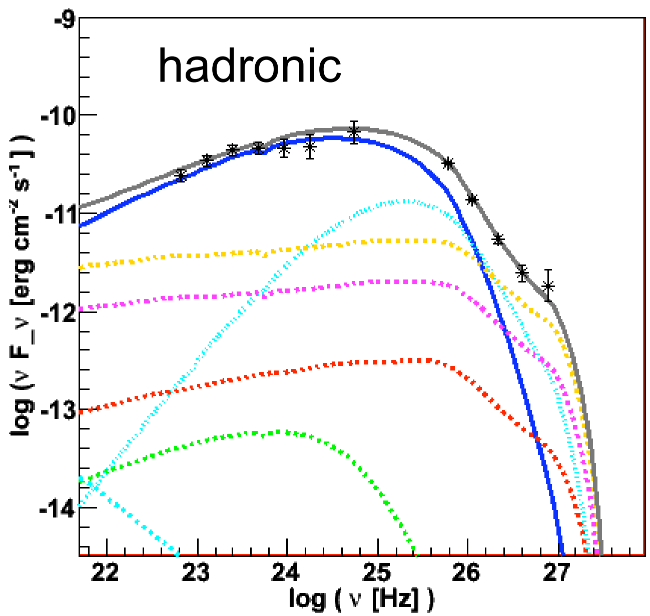
hadro 2:
δ=30
B = 50 G
R = 3e14 cm
γ_p,max = 1e9
density_p = 6e4 @ γ=1
L=2e45 erg/s

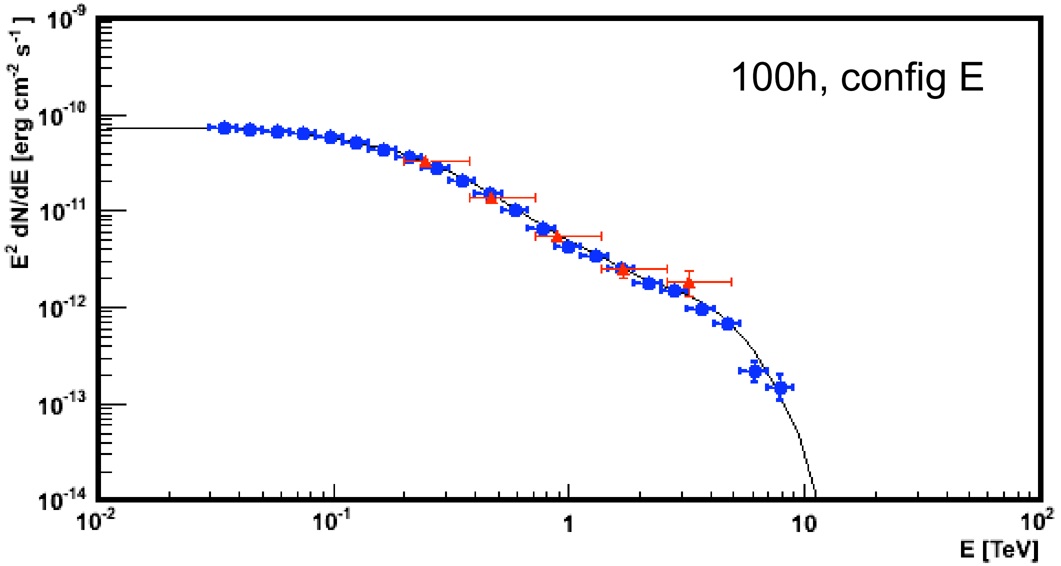
-> level of cascade contribution depends on the ratio of B-field to proton & photon density.

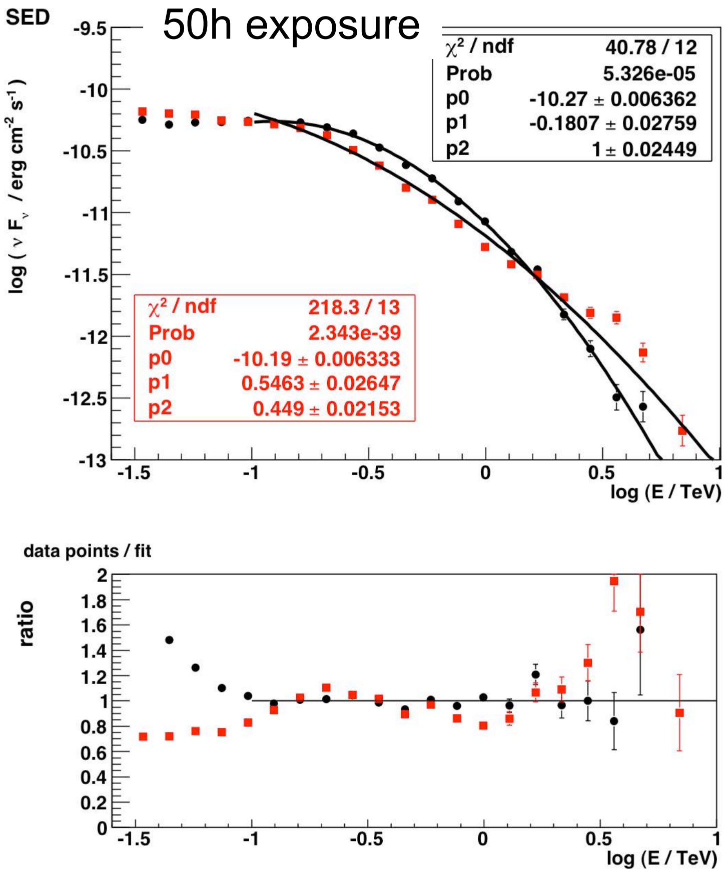
Simulating CTA spectra





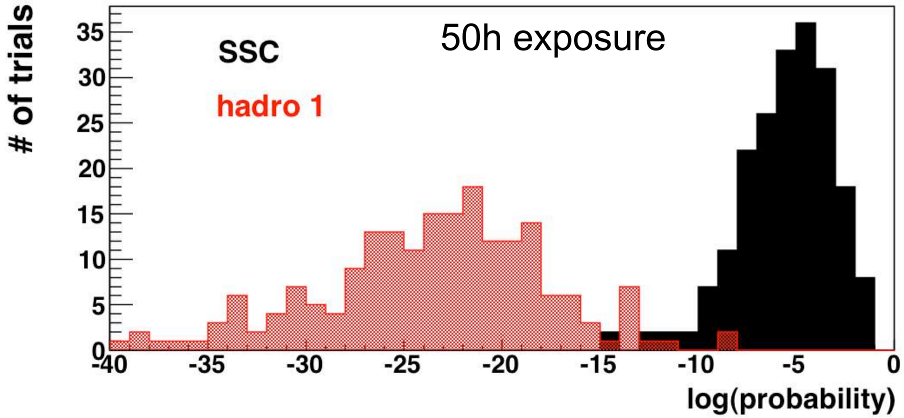


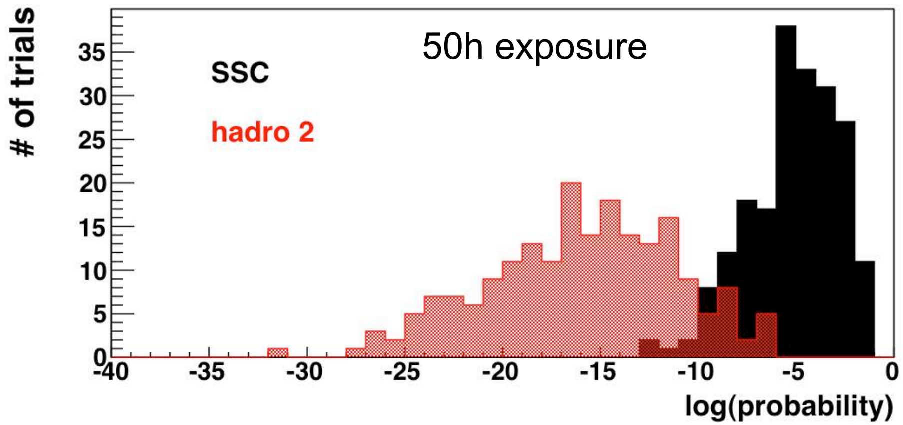




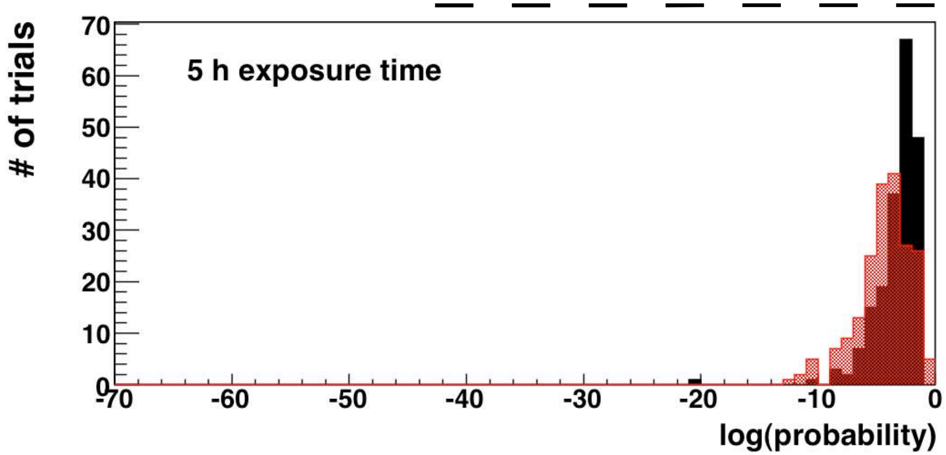
a simple logparabolic fit arrives at a discrimination of SSC and hadronic spectra

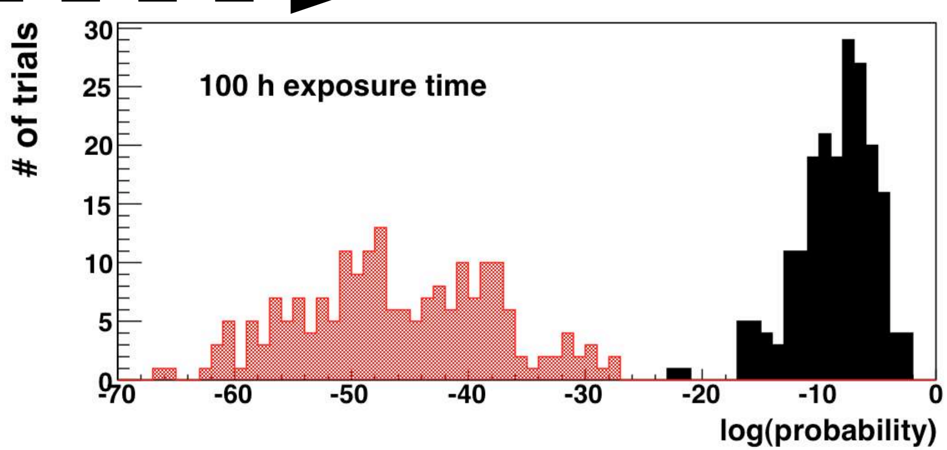
(200 simulated spectra with statistical fluctuations)



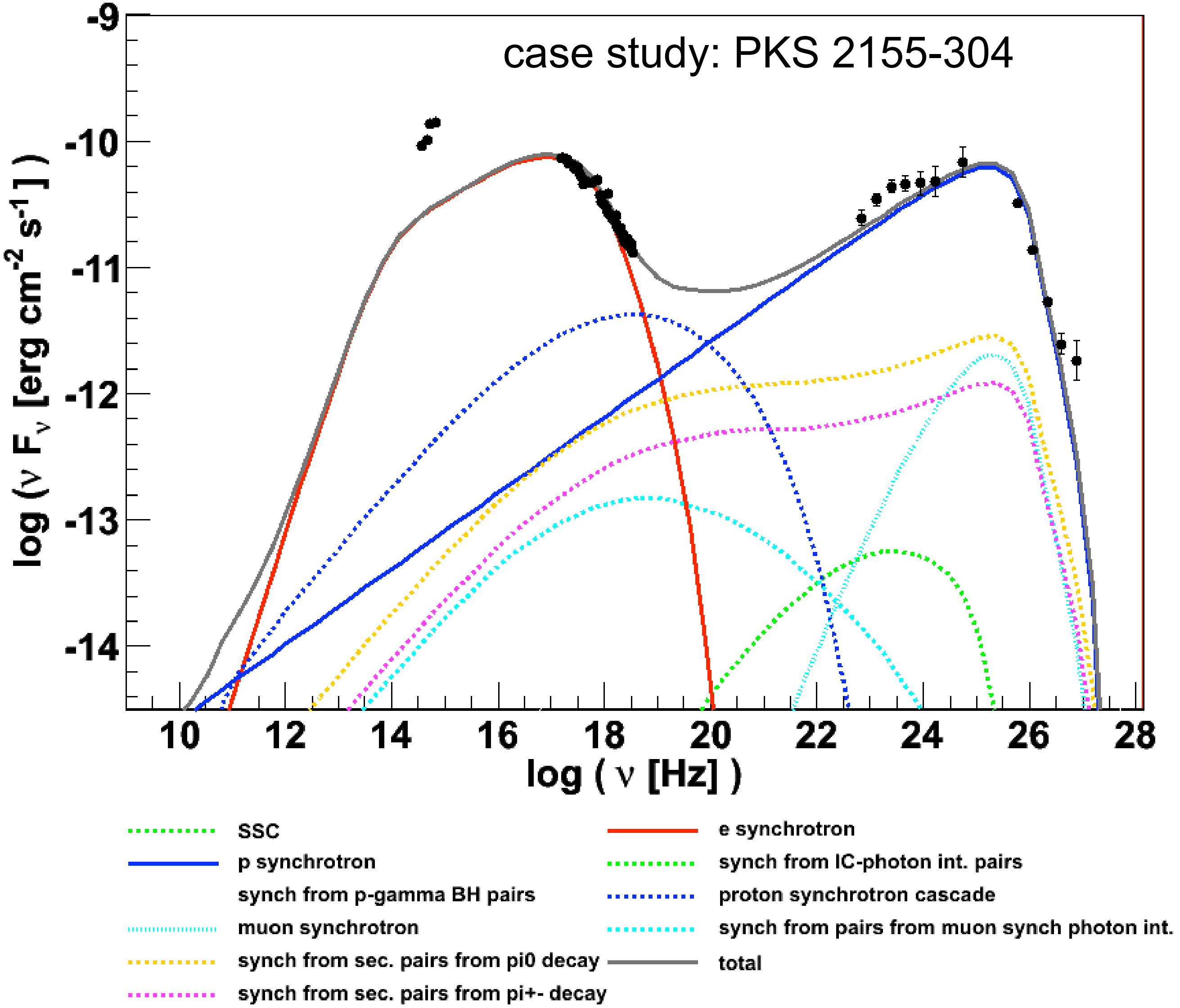


The discriminative power increases with exposure time.





Try higher proton energies...



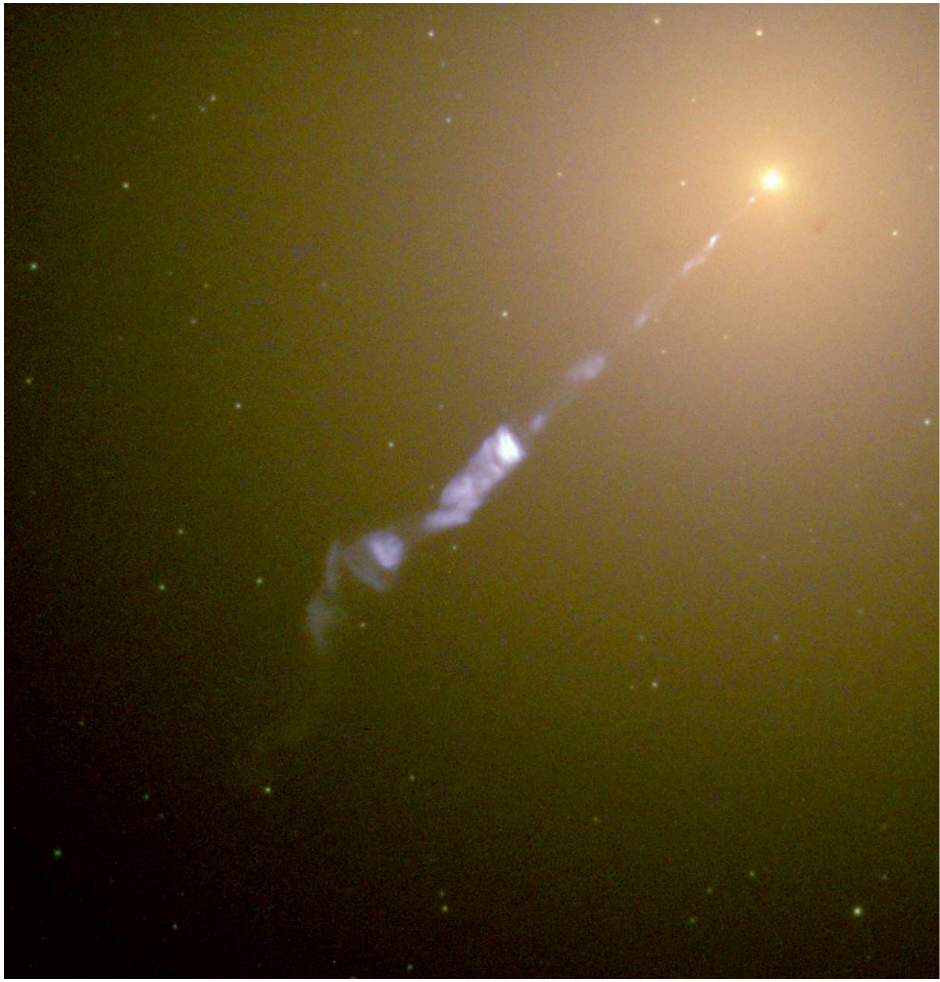
δ=10
B = 20 G
R = 2e16 cm
γ_p,max = 3e10
density_p = 2e5 @ γ=1
L=6e47 erg/s

- very high jet luminosity
- had to use relatively dense EBL (Kneiske et al. 2004) to describe the steep HESS spectrum
- low Doppler factor , large source size , relatively small B => slow variability
- **HE/VHE component largely dominated by proton-synchrotron => no "cascade bump"**

Which sources to target ?

AGN targets for intrinsic cascade signatures:

- low redshift -> strong EBL absorption can "wash out" intrinsic features
- bright sources with hard spectra -> for good spectral resolution



AGN targets for other UHECR signatures:

external cascades: bright, high redshift sources

UHECR pair halos: bright, nearby sources ?

To probe acceleration in the magnetosphere:

- LLAGN with very high black-hole mass
- weak radiation field
- nearby sources

Conclusions

- Cosmic-ray physics figures prominently in the CTA science case, but we have to reinforce the case for UHECRs.
- Need to study more systematically the expected hadronic signatures from AGN and link them to expected (escaping!) UHECRs.
- Several ways to improve current hadronic emission models
  - time-dependent models (problem: inclusion of muon-synchrotron)
  - include nuclei
  - combine intrinsic emission and external cascades