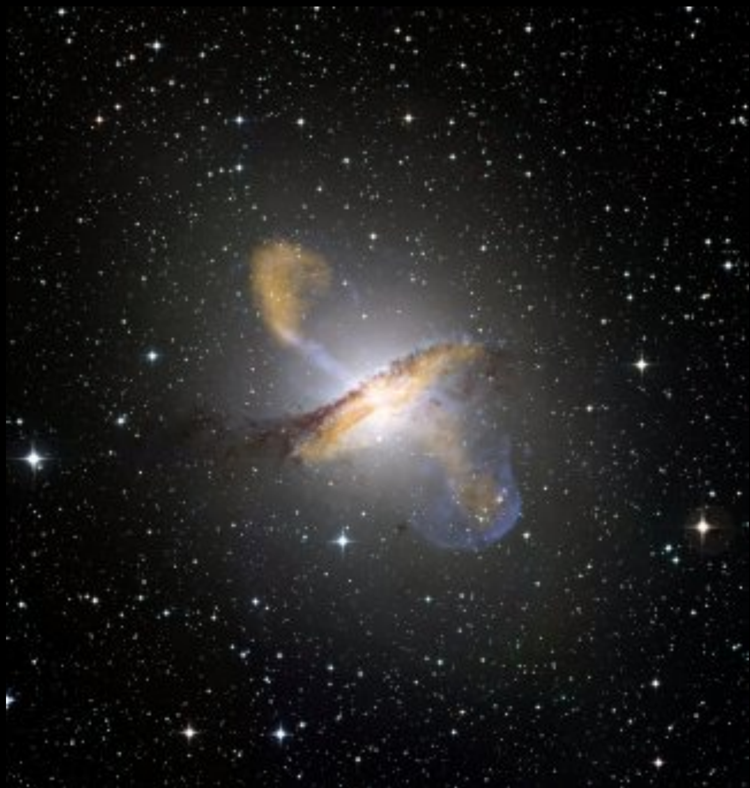
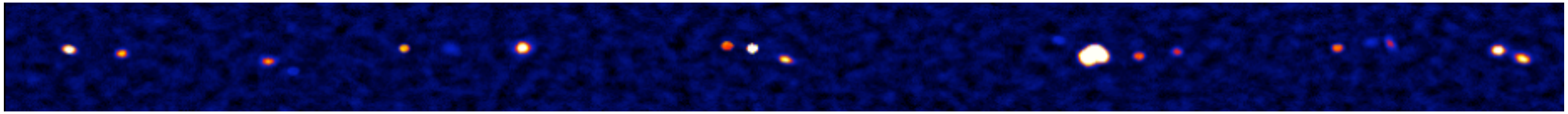
Synergies between IXO and CTA



Hélène Sol, for the CTA collaboration
CNRS and Paris Observatory

IXO Science Meeting, Paris, April 27-29th, 2010

Outline



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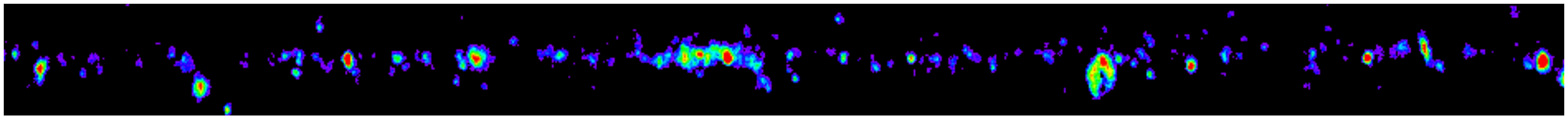
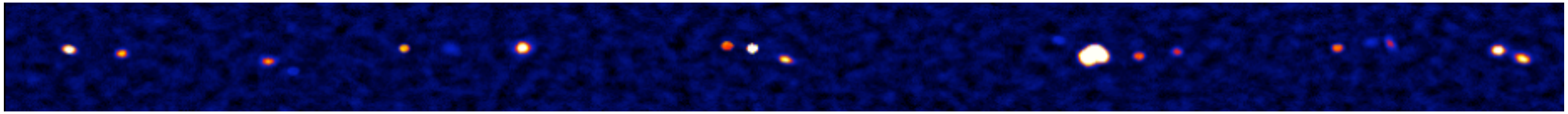


Outline



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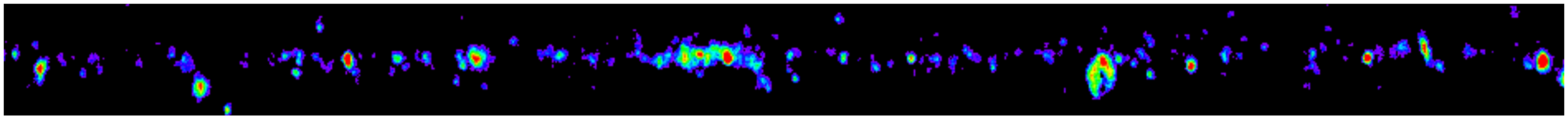
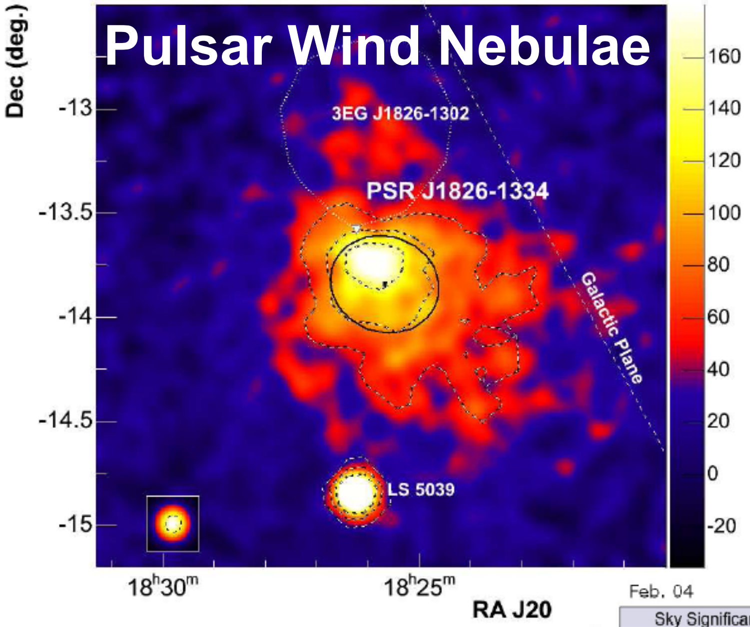
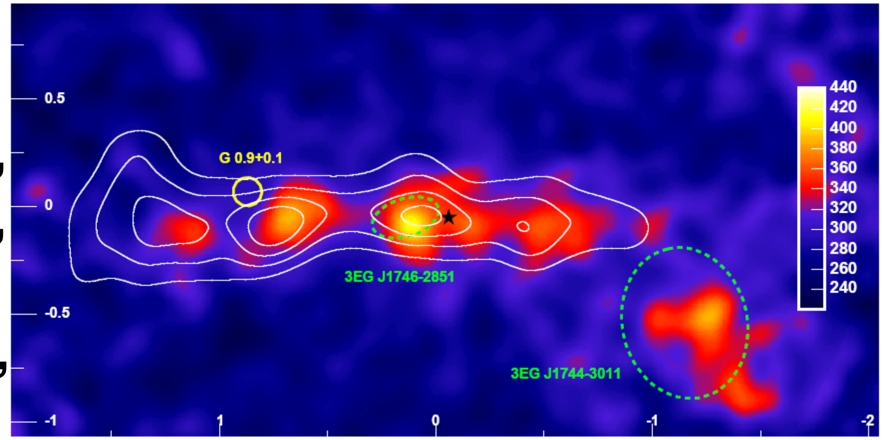


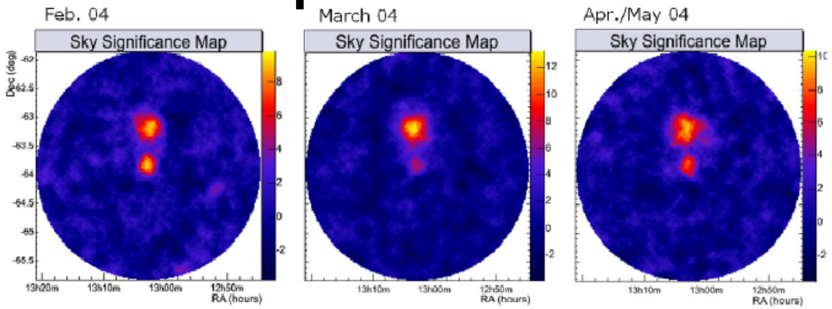
This decade :
start exploring the sky at VHE with Atmospheric Cherenkov Telescopes

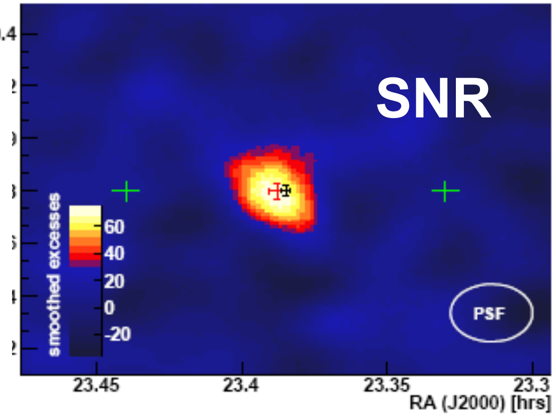


Diffuse emission, clouds, stellar clusters, G.C.

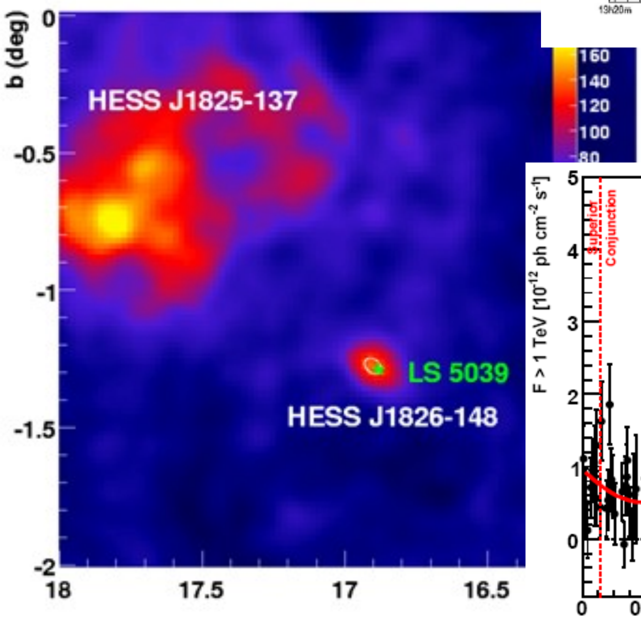


Sample of UnID sources

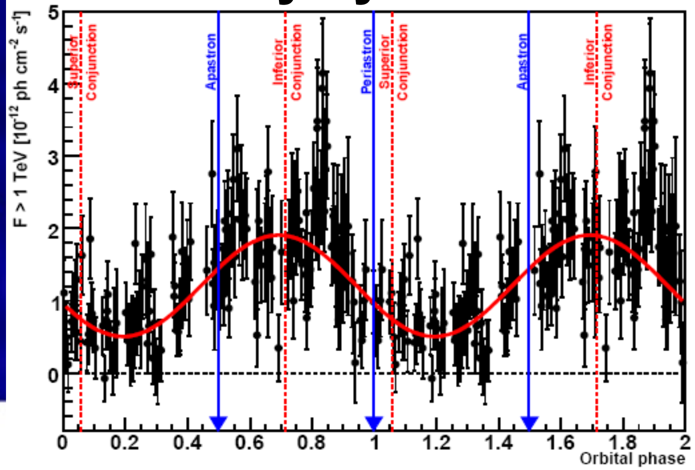


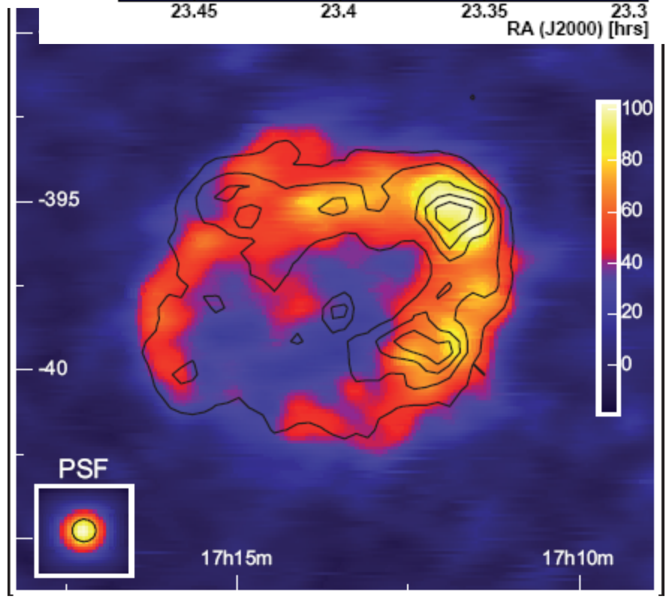


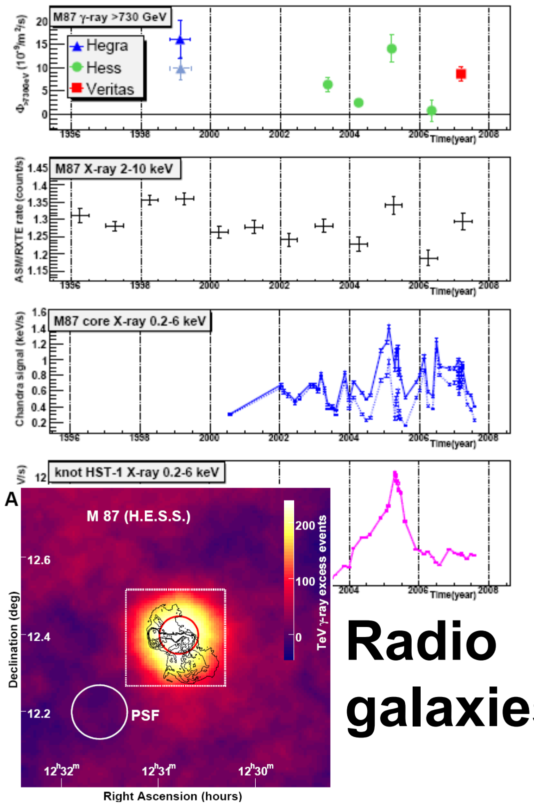
> 60 VHE galactic sources



Binary systems

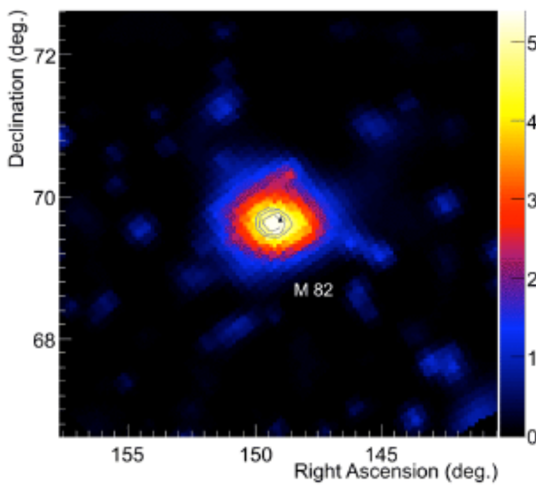




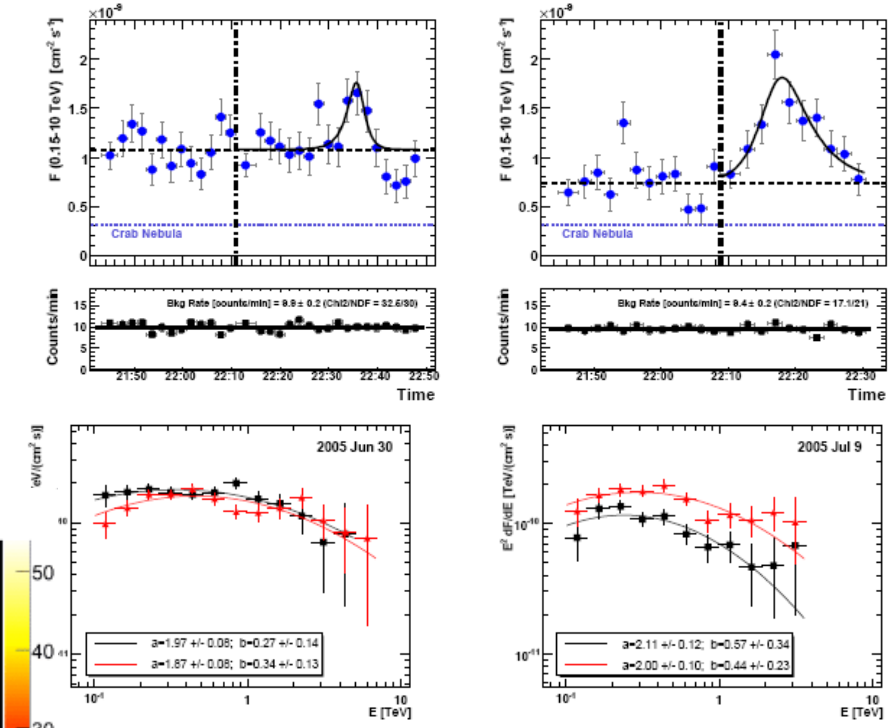


Radio galaxies

~ 30 VHE extragalactic sources

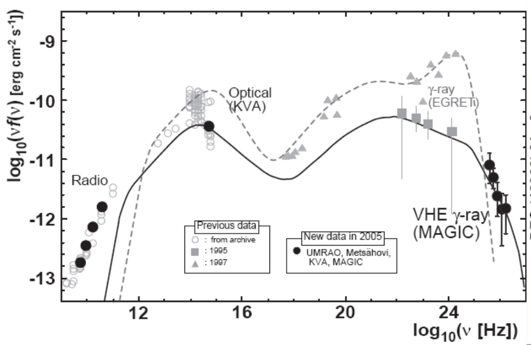


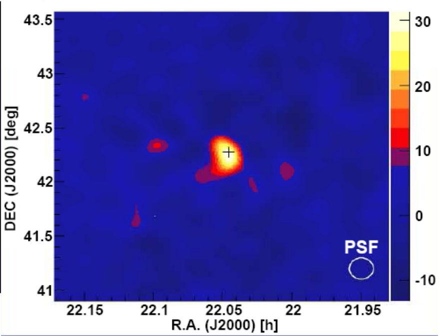
Starburst galaxies

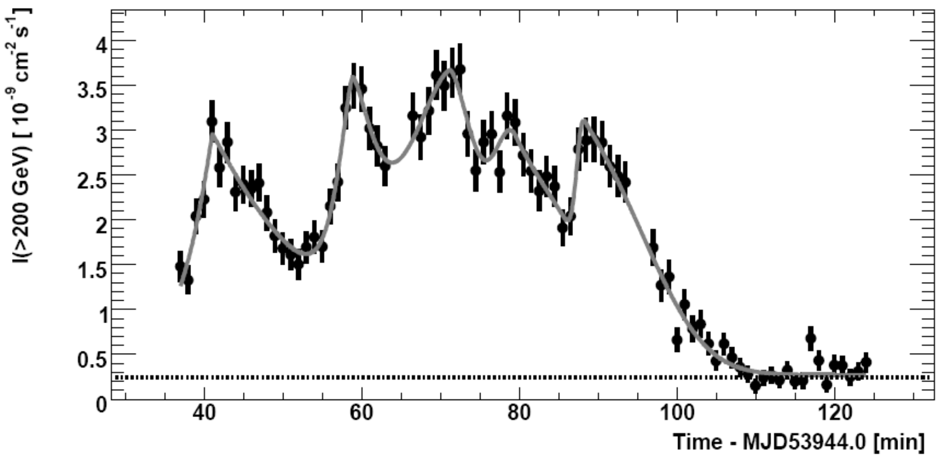


HBL Blazars

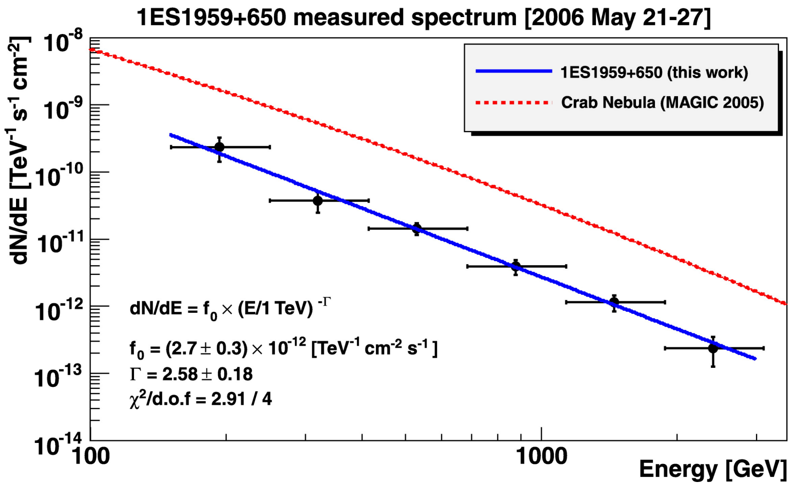
Other blazars (LBL, IBL, FSRQ)

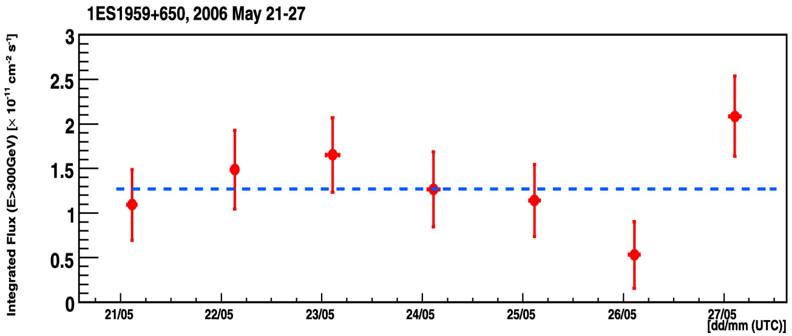


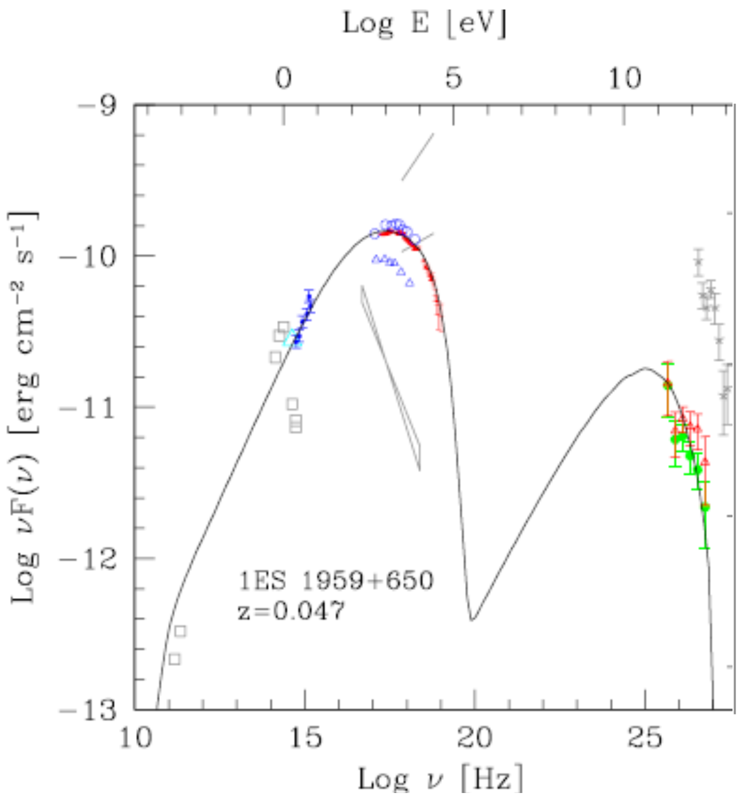




Typical example of VHE spectrum and SED

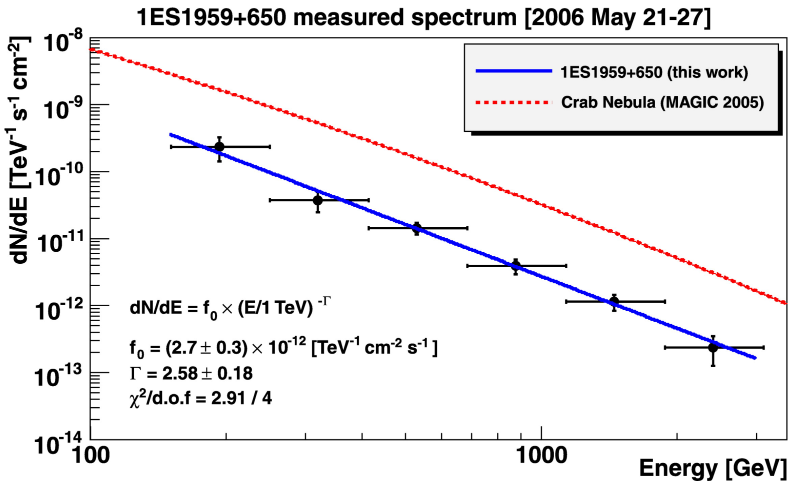


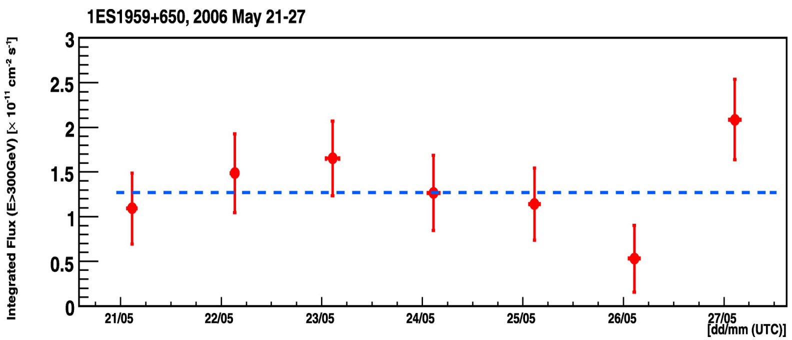


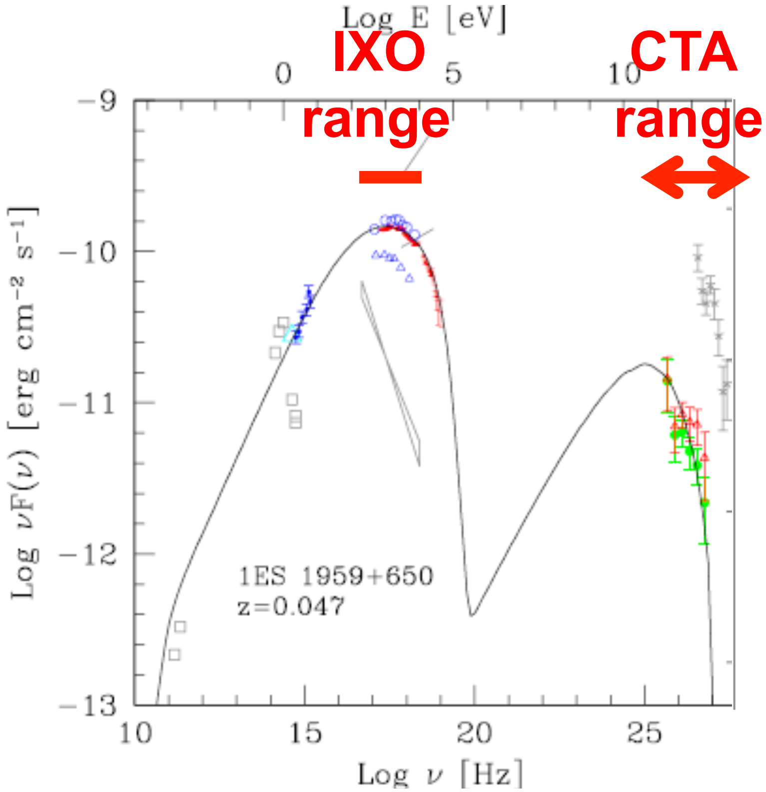


VHE power-law, two-peaked SED,
Variability (here AGN)

Typical example of
VHE spectrum and SED

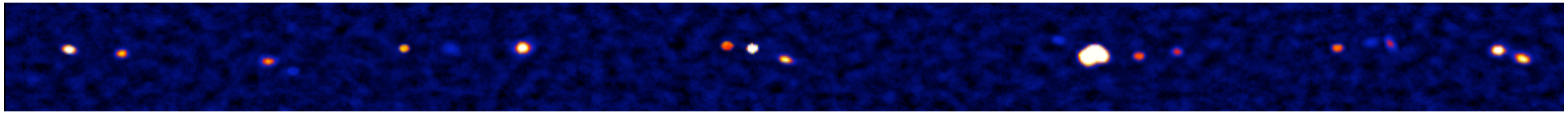






VHE power-law, two-peaked SED,
Variability (here AGN)

Outline



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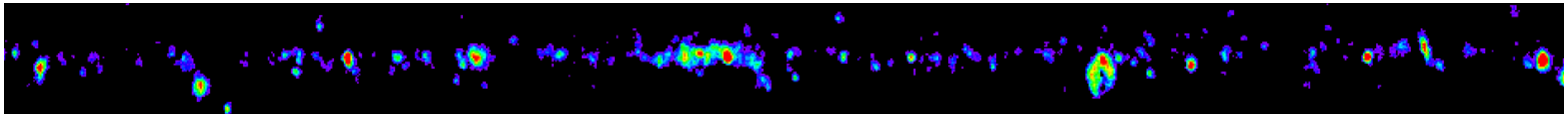
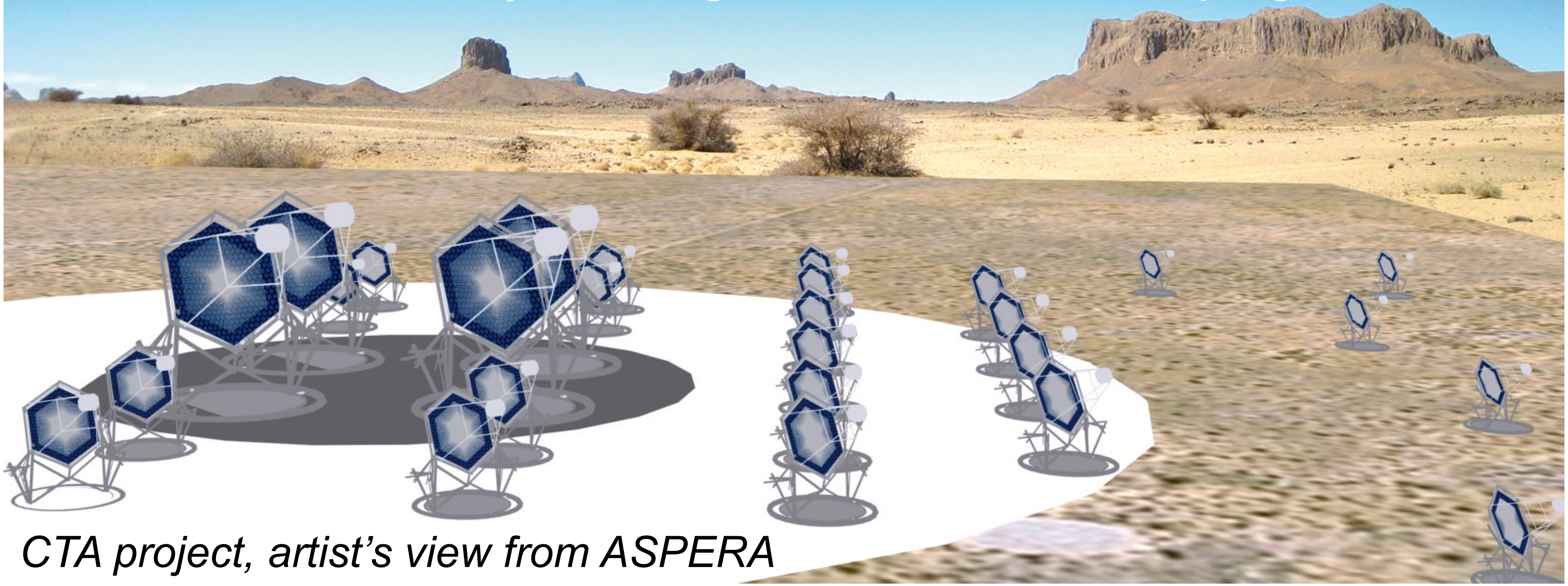


Performance goals for CTA

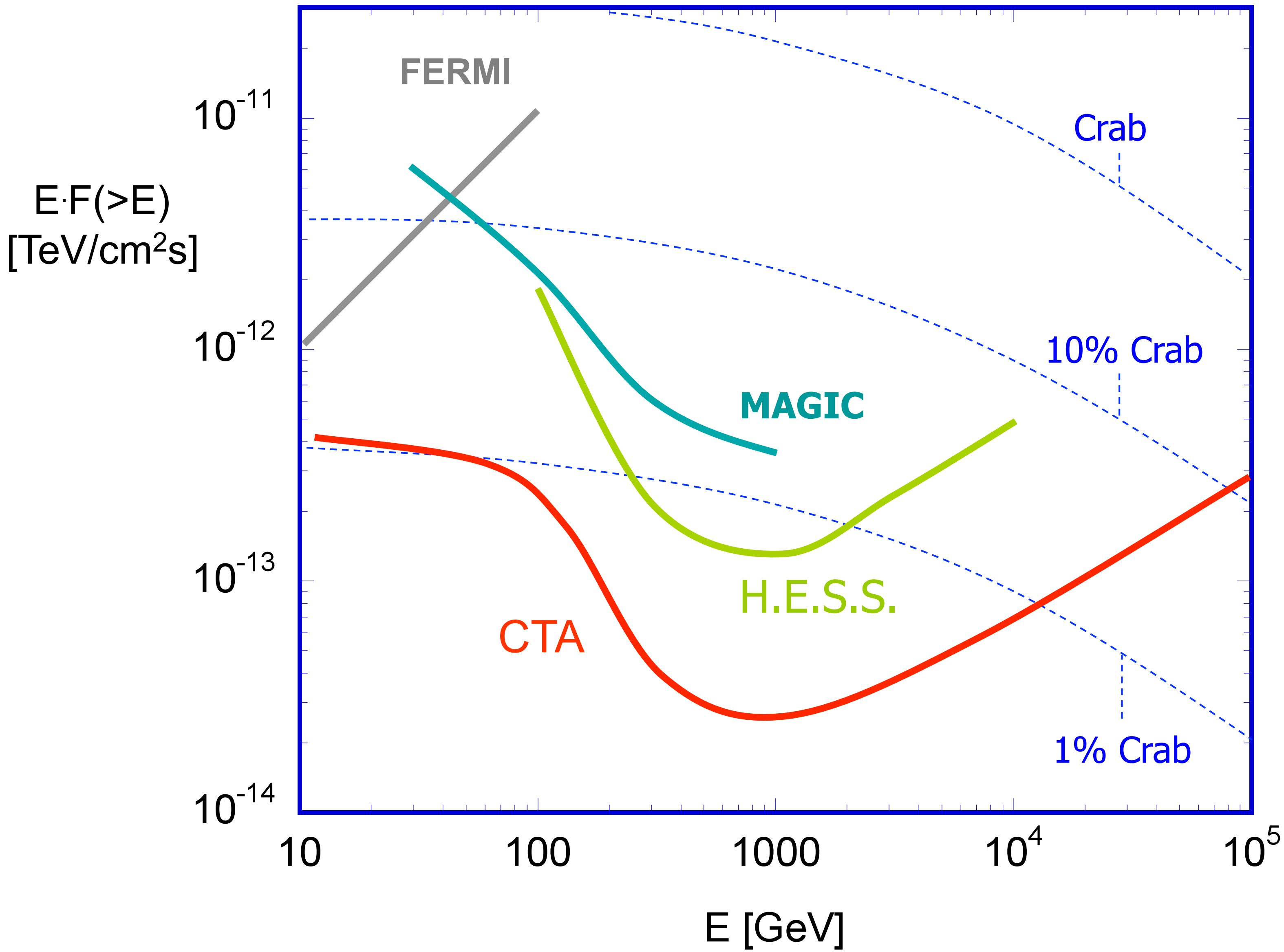
- Jump of factor 10 in sensitivity, down to **mCrab**
- Very large spectral coverage : **a few 10 GeV to above 100 TeV**
- Improved angular resolution down to **arc-minute range**
- Temporal resolution down to **sub-minute time scale**

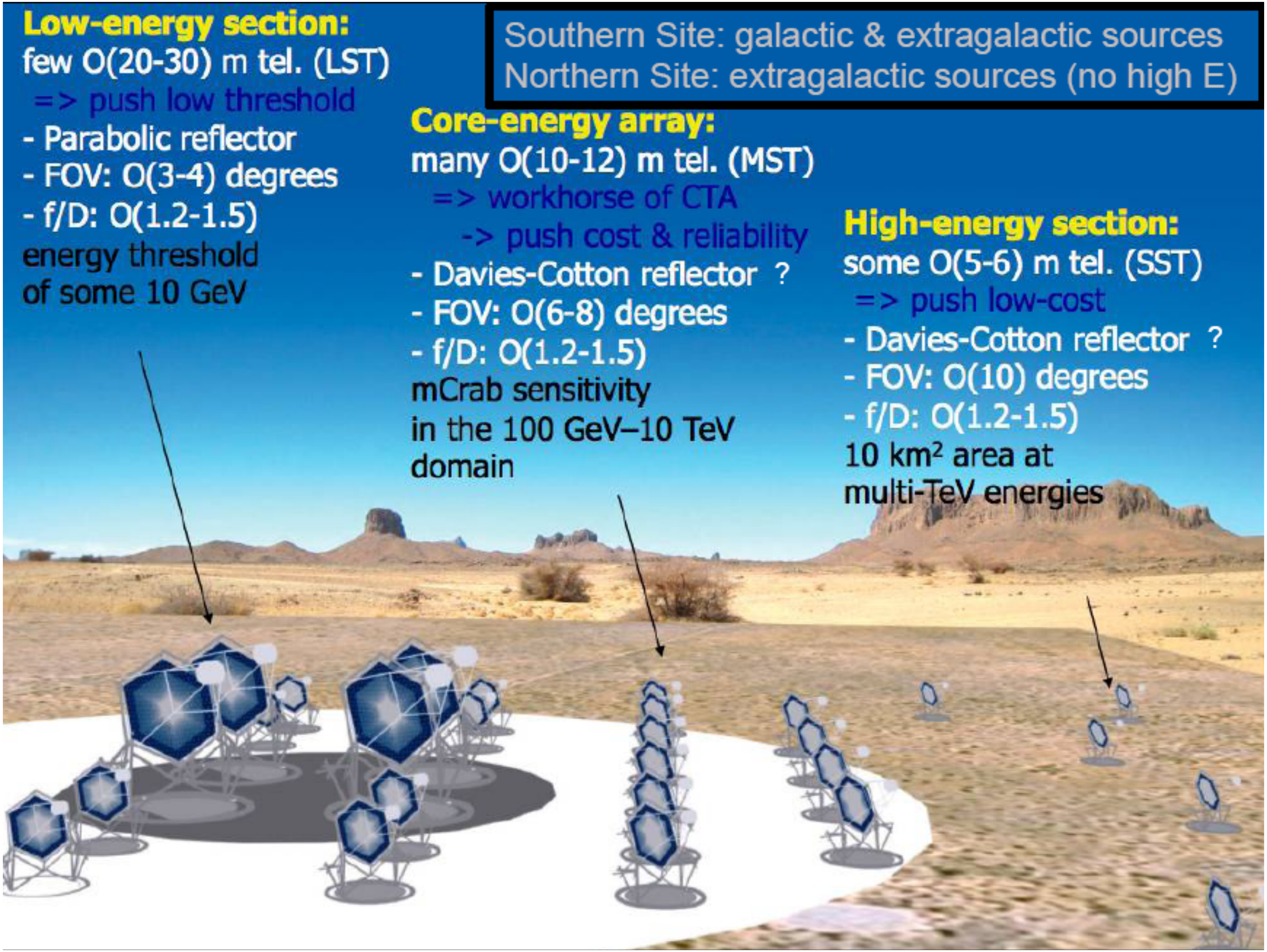
  → a VHE timing explorer
- **Flexibility** of operations : deep field, monitoring, survey, alarms, ToO, full sky coverage, multi-lambda campaigns.

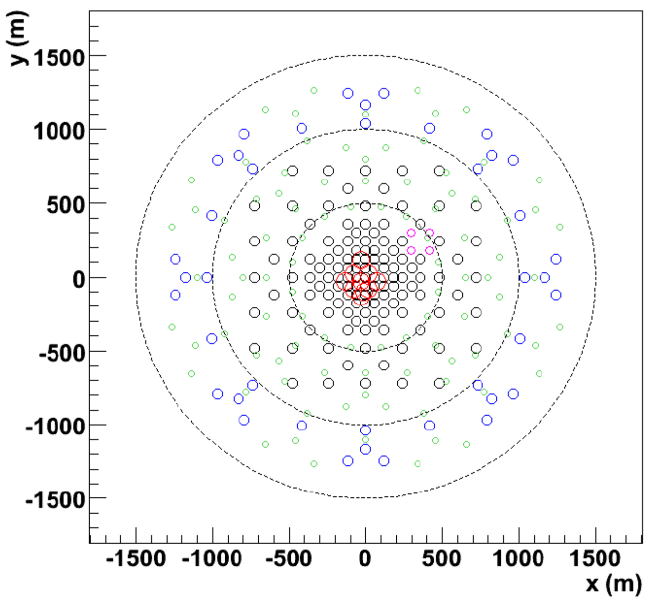


CTA project, artist's view from ASPERA

Goals for CTA sensitivity




Southern Site: galactic & extragalactic sources
Northern Site: extragalactic sources (no high E)
Low-energy section:
few O(20-30) m tel. (LST)
=> push low threshold
- Parabolic reflector
- FOV: O(3-4) degrees
- f/D: O(1.2-1.5)
energy threshold
of some 10 GeV
Core-energy array:
many O(10-12) m tel. (MST)
=> workhorse of CTA
-> push cost & reliability
- Davies-Cotton reflector ?
- FOV: O(6-8) degrees
- f/D: O(1.2-1.5)
mCrab sensitivity
in the 100 GeV–10 TeV
domain
High-energy section:
some O(5-6) m tel. (SST)
=> push low-cost
- Davies-Cotton reflector ?
- FOV: O(10) degrees
- f/D: O(1.2-1.5)
10 km² area at
multi-TeV energies

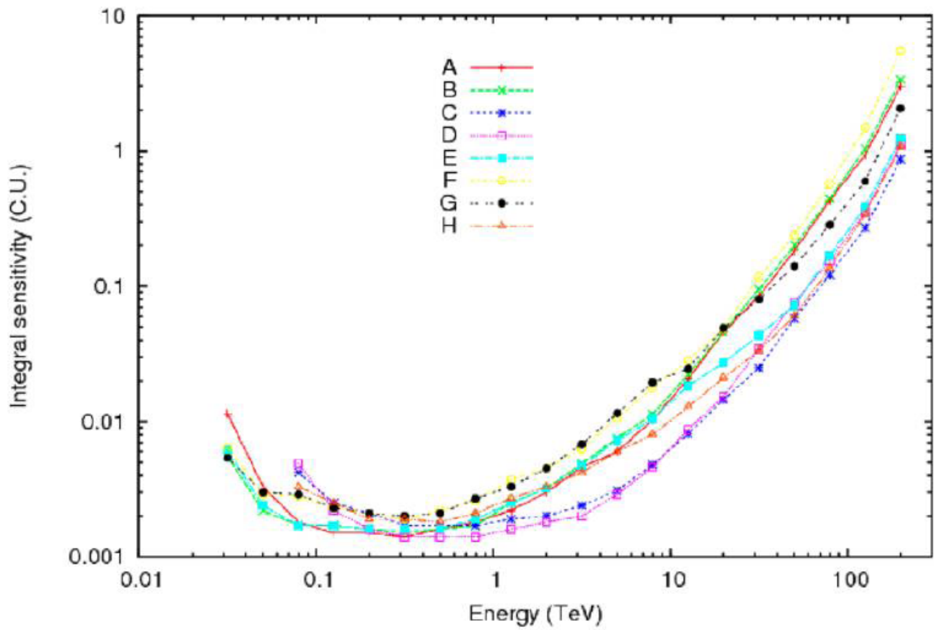


Complex optimization problem for the design studies : simulation of the sensitivity of various arrays

Large scale simulation of an hyper array with 275 telescopes of 5 different types.

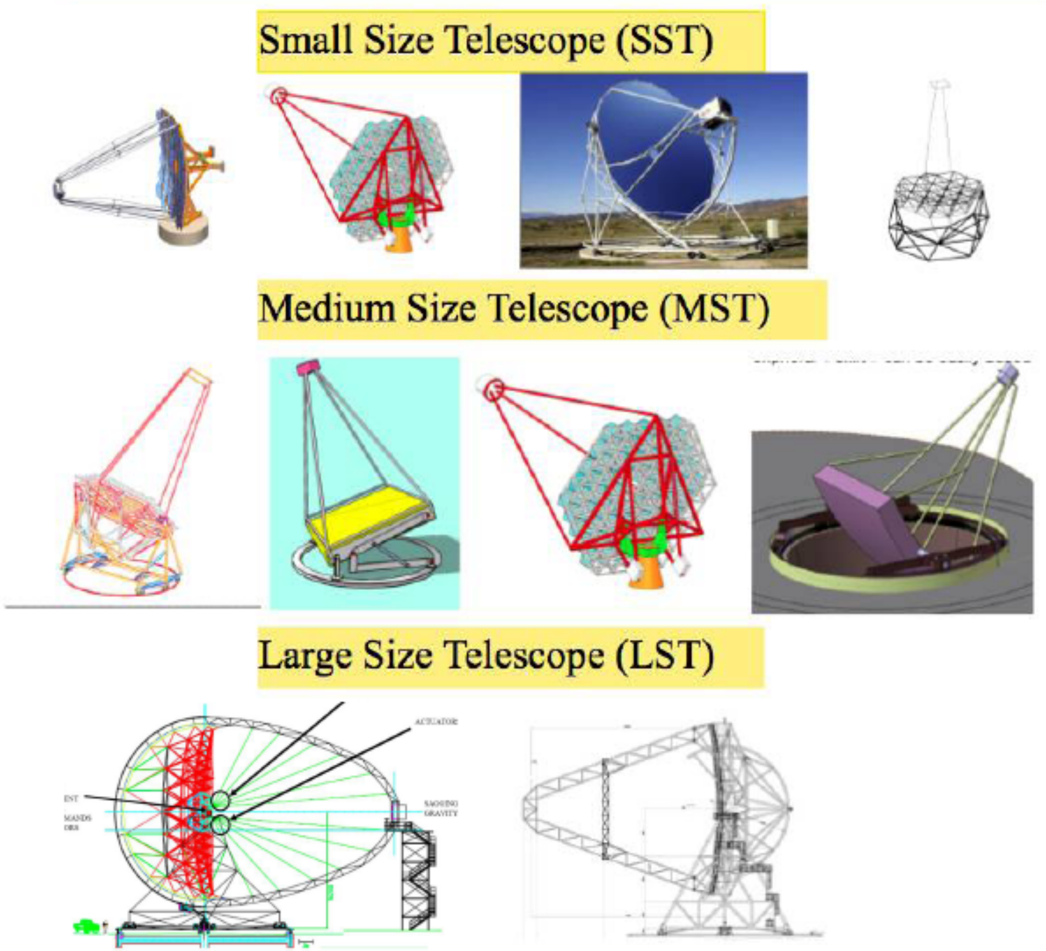
Performances of sub-arrays relatively to science goals

Preliminary – cuts not optimized !



Enabling Grids for E-sciencE

Several designs currently under study for telescopes and cameras …

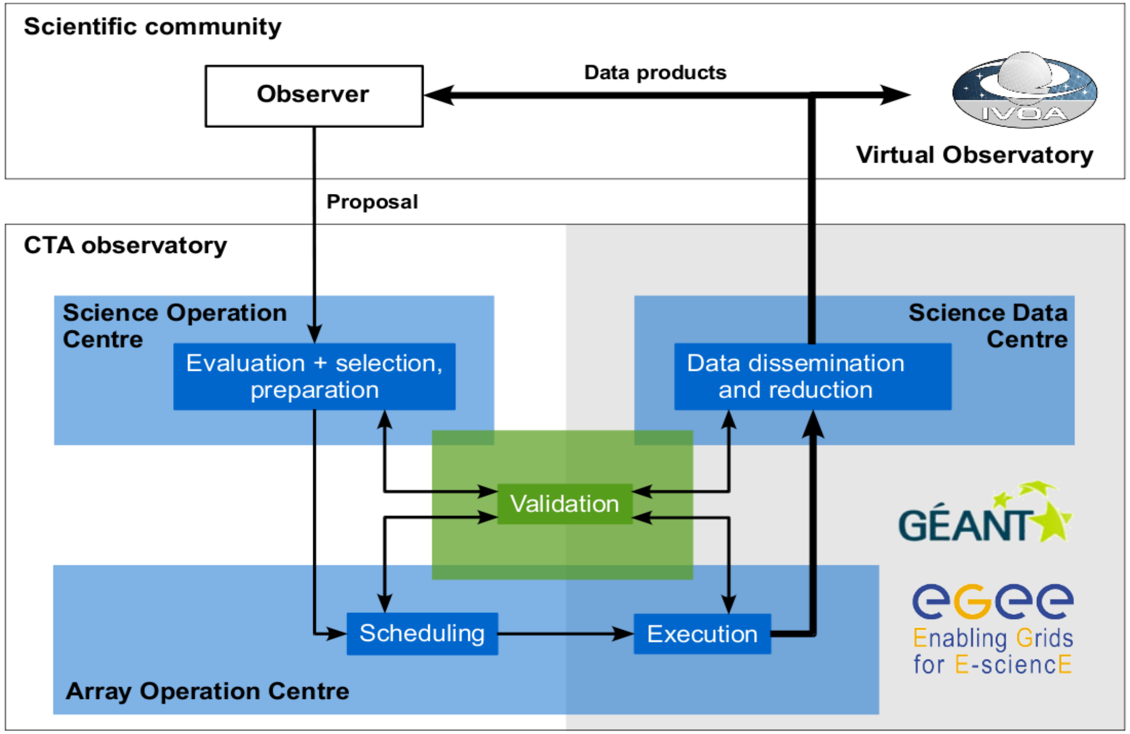


CTA : an open observatory with

- Science Operation Centre (organisation of observations)

- Array Operation Centre (on-site)

- Science Data Centre



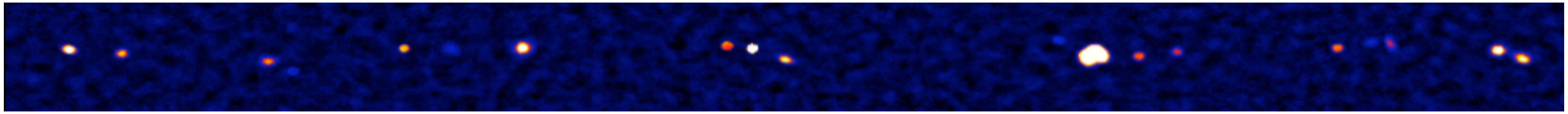
Total expected data volume from CTA: 1 to 3 PB per year

Time line of CTA

- Design Studies : up to 2010
  (soon a CDR)
- Preparatory Phase, prototype construction : 2010-2013
- Array construction : 2013-2018
- Partial operations : starting from 2014
- Fully operating : starting from 2018
- Lifetime ~30 years

Should have a rewarding overlap with IXO (launch : 2021) and other large astrophysical projects

Outline



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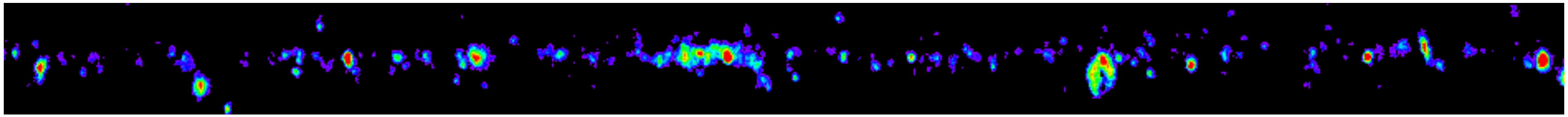
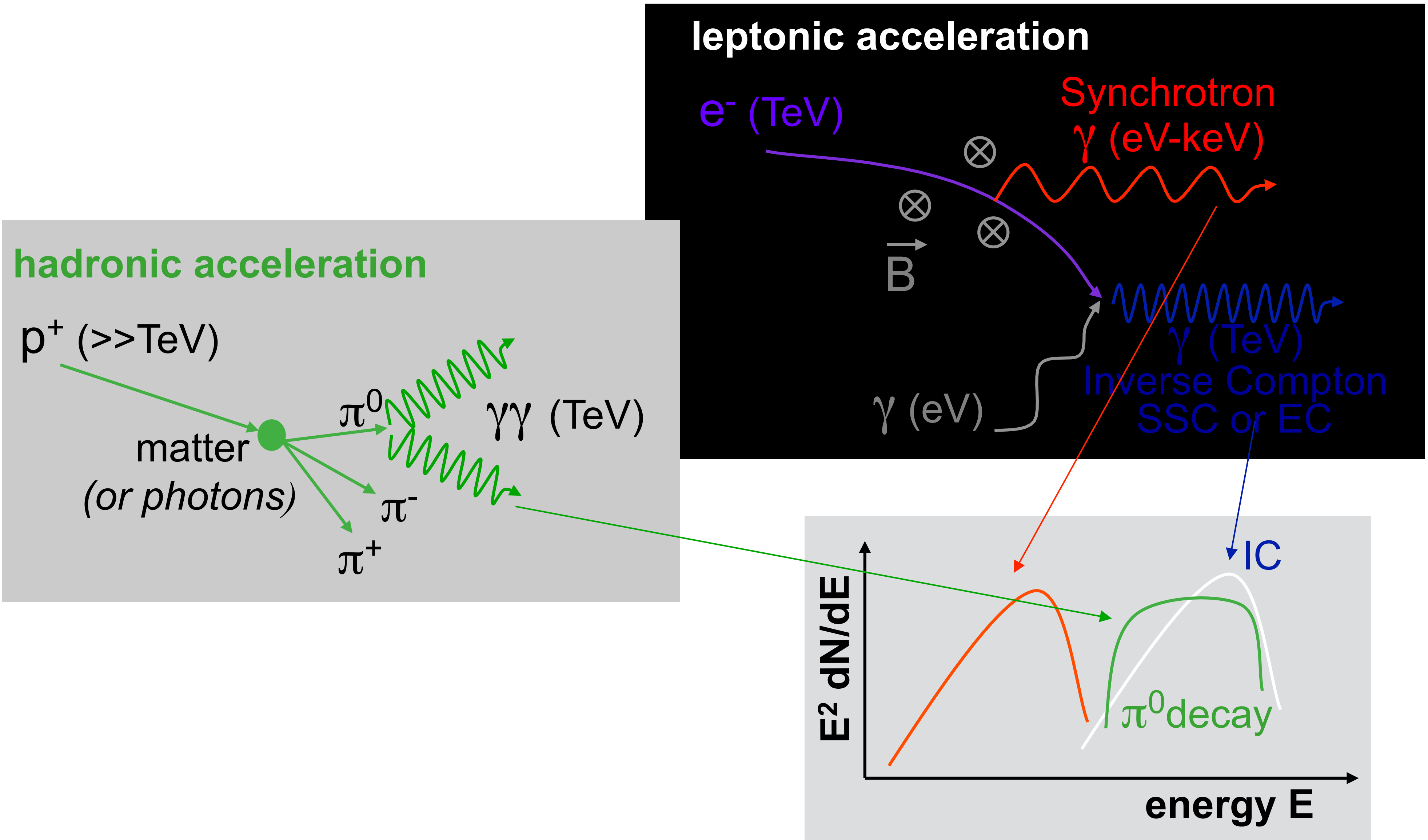


Basic scenarios for SED modeling of VHE sources



A limited number of VHE γ-rays emission mechanisms

- Leptonic scenarios : synchrotron and Inverse-Compton (IC) radiation of relativistic electrons (positrons)

  $e + B \rightarrow e + B + \gamma$, in magnetic field B → **also X-rays**

  $e + \gamma_0 \rightarrow e + \gamma$, with $h\nu \sim \min[\gamma_e^2 h\nu_0, \gamma_e m_e c^2]$, IC on synchrotron emission (SSC) or on external photon field (EC)

- Hadronic scenarios : Interaction of energetic protons (CR) with local gas and radiation backgrounds

  $p + p \rightarrow N + N + n_1(\pi^+ + \pi^-) + n_2\,\pi^0$ (N = p or n)

  $p + \gamma \rightarrow p + \pi^0, n + \pi^+$, others (for $\gamma_p h\nu > m_\pi c^2$); or $p + e^+ + e^-$ (for $\gamma_p h\nu > 2m_e c^2$)

  Then decay **$\pi^0 \rightarrow 2\,\gamma$ produce VHE photons with $E_\gamma \sim E_\pi/2 \sim 10\%\ E_{p,i}$**

  + Decay pions → muons → *secondary e^- and neutrinos* → **also X-rays**

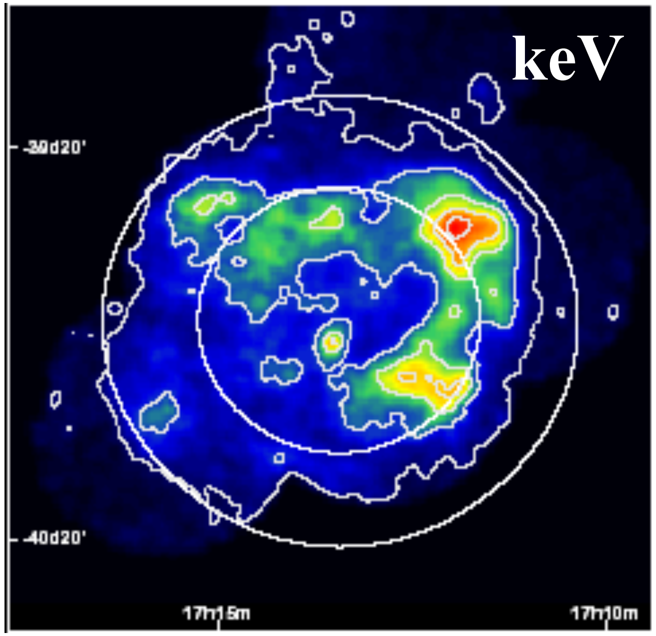
  Alternatives : curvature and synchrotron radiation of VHE protons.

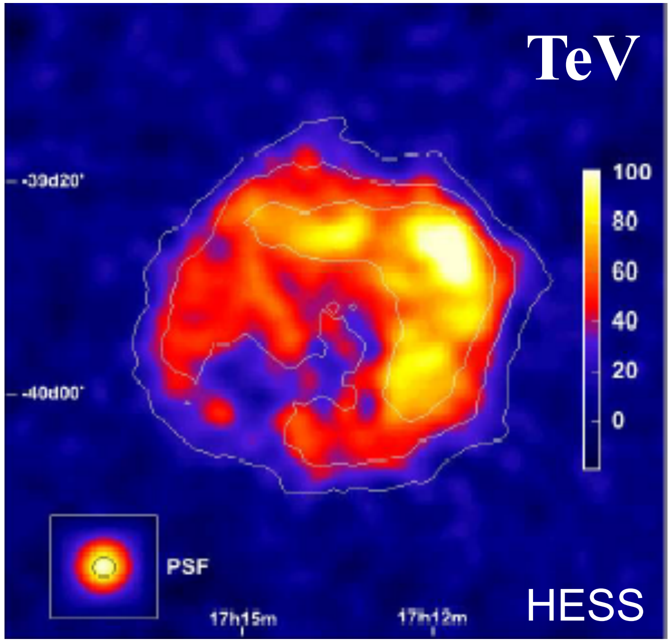
- *(Annihilation of Dark Matter particles : predictions of supersymmetric theories, Kaluza-Klein scenarios → open questions to explore. No detection yet. A great challenge, but not yet granted !)*

Probing « Particle acceleration »

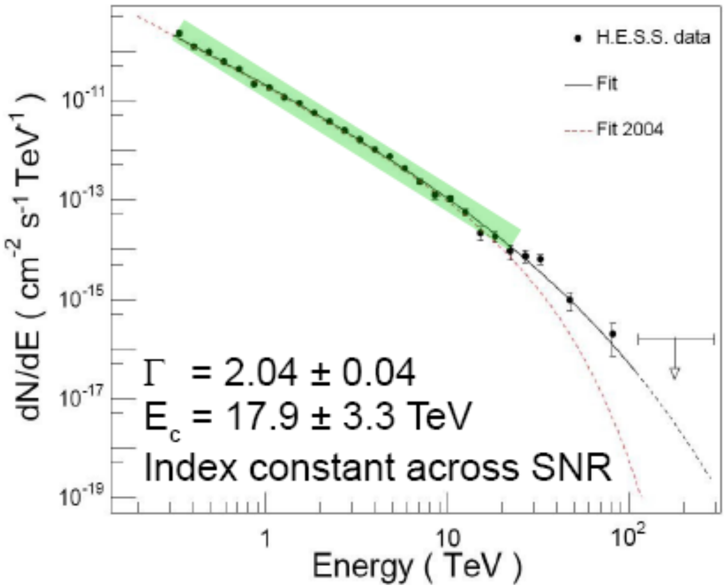
- VHE radiation reduces to one single need : having an efficient acceleration mechanism at work
- **Fermi acceleration : 1st and 2nd order processes in shocks and turbulence → widely invoked to explain VHE cosmic sources**
- Acceleration can be achieved in nonuniform velocity fields in low density plasmas, where hydrodynamic power is converted into that of HE particles (Energy density in HE particles grows until it affects the flow and the acceleration)
- Indeed, almost all VHE sources detected up to now have powerful outflows (or inflows). Except possibly passive sources (clouds).
- Alternatives : magnetic reconnection, direct electric forces, centrifugal force
- CTA studies of extreme cosmic accelerators → need multi-lambda approch of non-thermal universe

SuperNova Remnants RXJ1713.7-3946





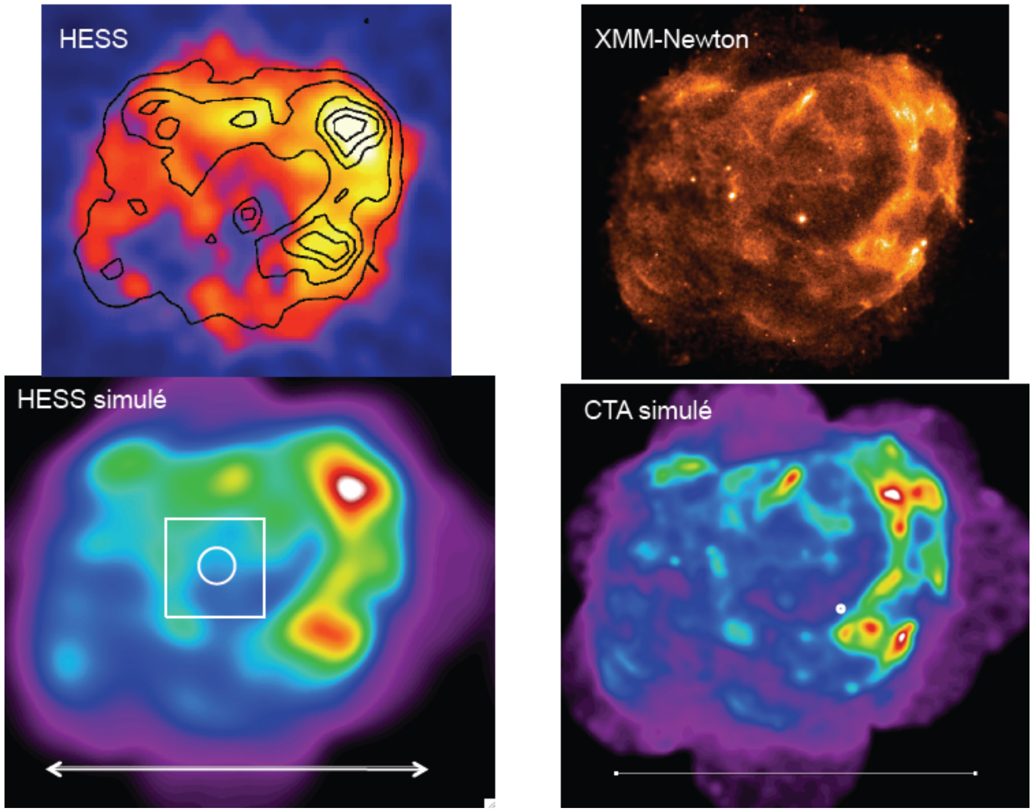
Shell-type SNR
D ~1.3 kpc
Complex V.H.E. morphology rather similar to X-ray map.



→ Presence of particles with E> 100 TeV inside the SNR(s). Origine of galactic C.R.

Origine of the VHE emission ?
Still an open question :
- Hadronic (amplified B, thinness of X-ray filaments)
- Leptonic (lack of thermal X-ray emission)

Constraining acceleration models in SNR
by HE and VHE spectro-imaging
Origine of cosmic rays : proton acceleration and maximal energy



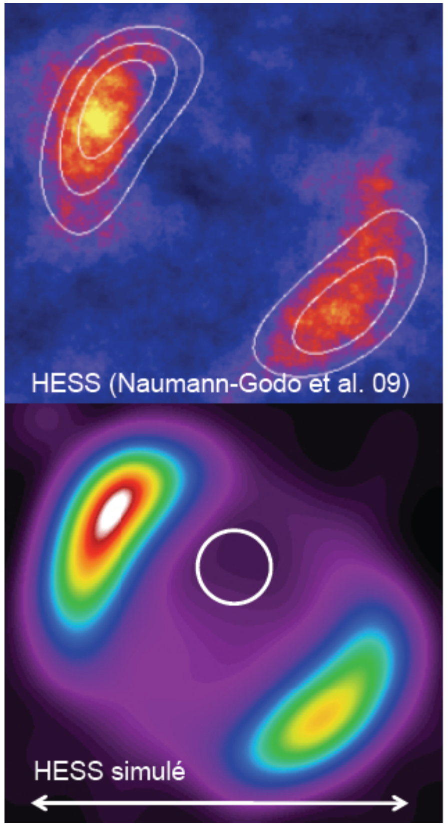
← HESS and CTA maps simulated from synchrotron emission observed by XMM

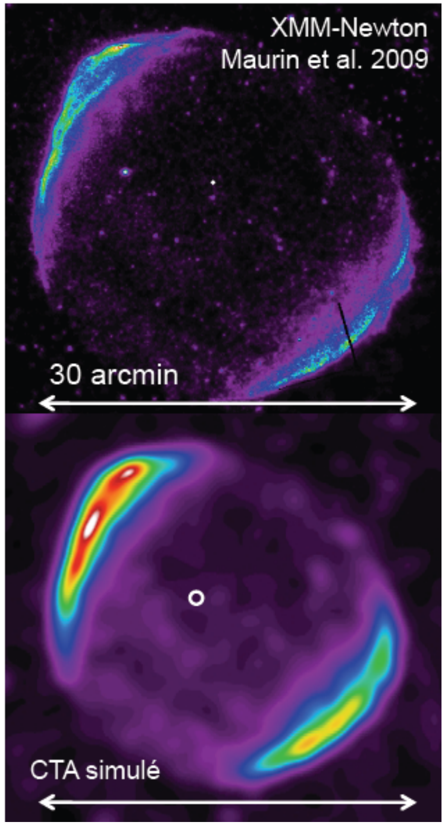
from F. Acero and A. Decourchelle

SN 1006 : located in a rather uniform MIS

Study the geometry of acceleration relatively to the orientation of the magnetic field

More efficient acceleration at « polar caps », when V_{shock} // B





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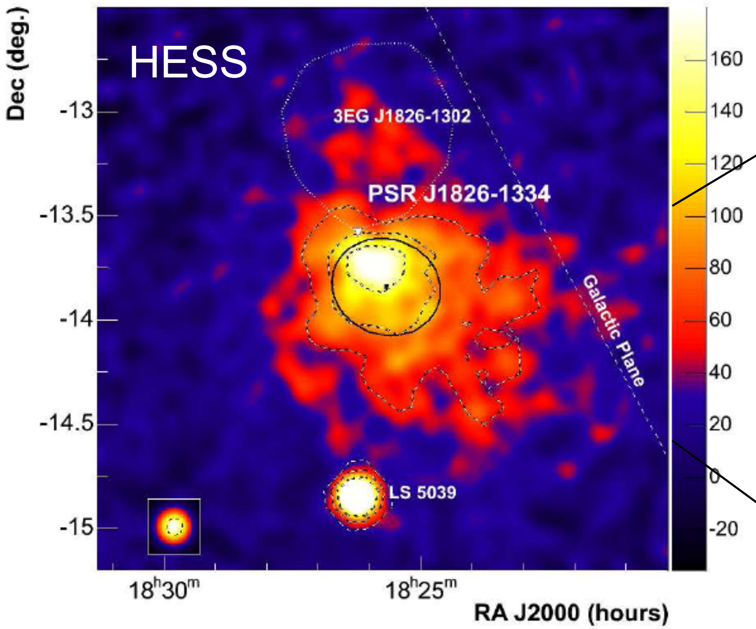
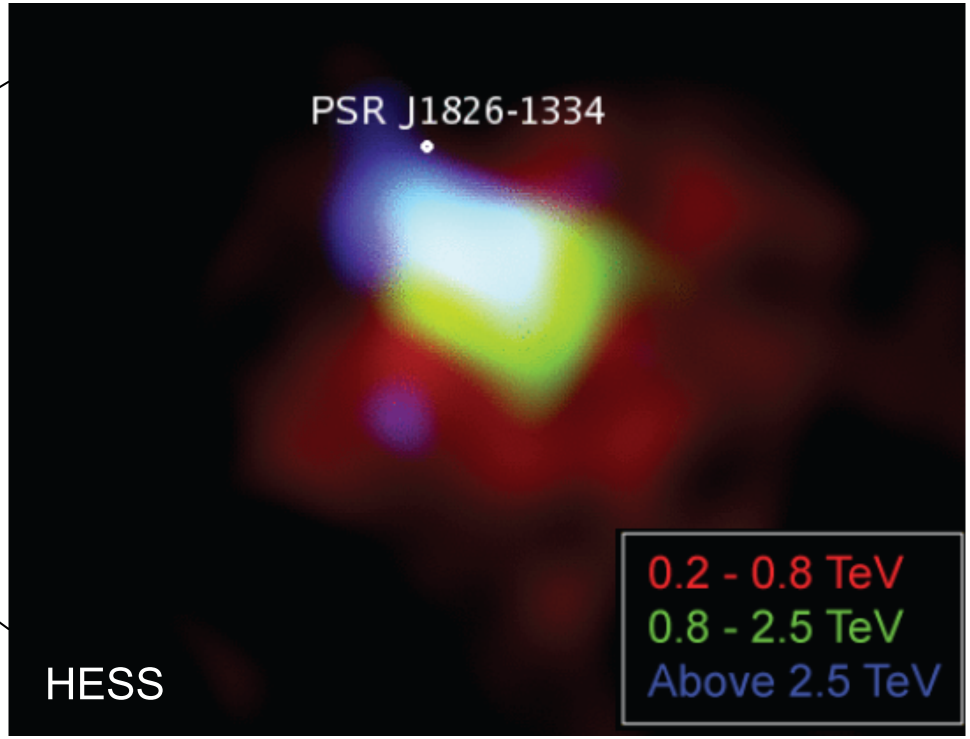
Pulsar wind nebulae

Ex 2 : HESS J1825-137
evolved (offset) PWN, t ~ 21.4 kyr

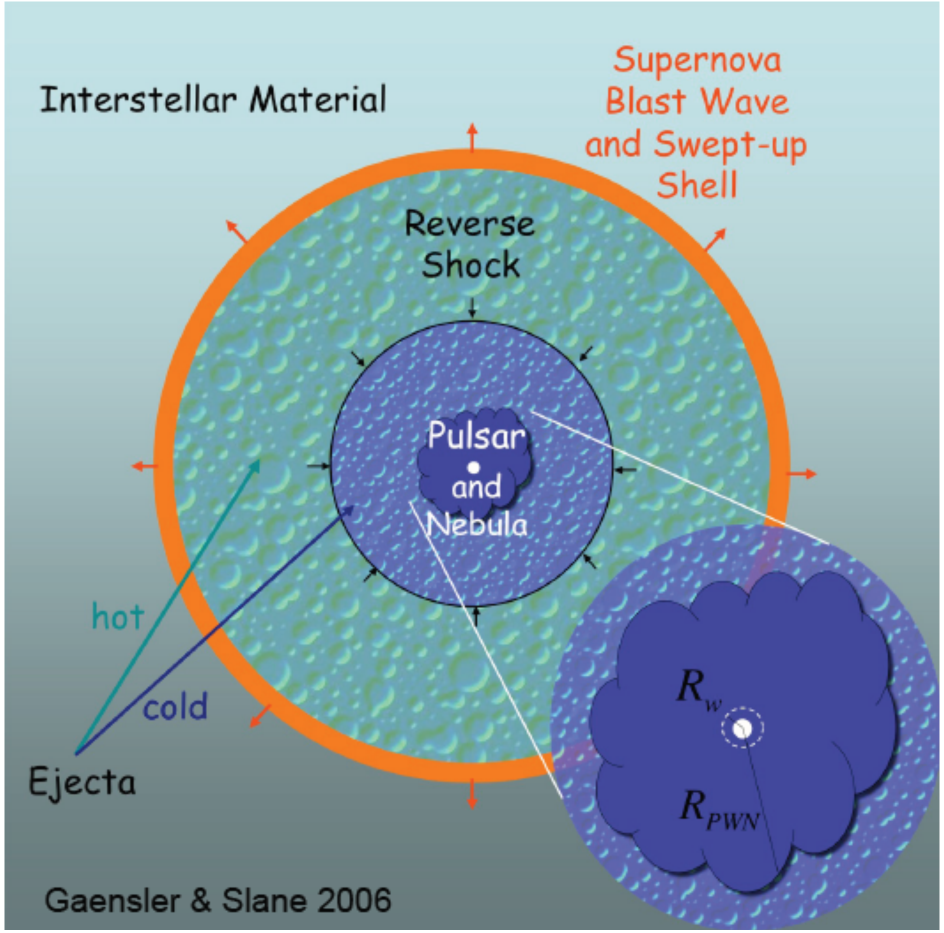




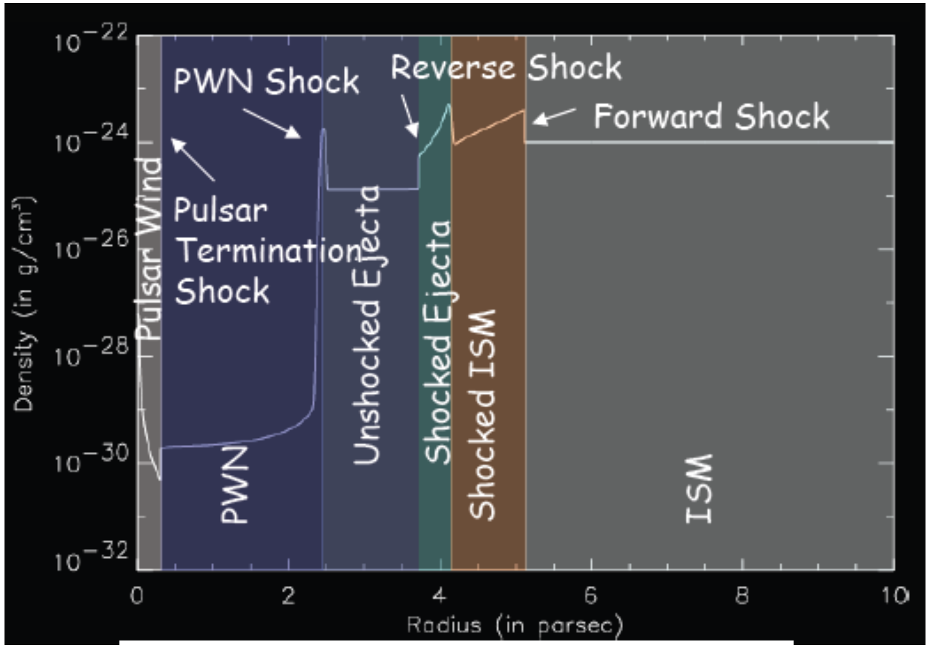
Observed spectral evolution with distance from pulsar → significant constraints. Favours leptonic scenario with radiative losses.

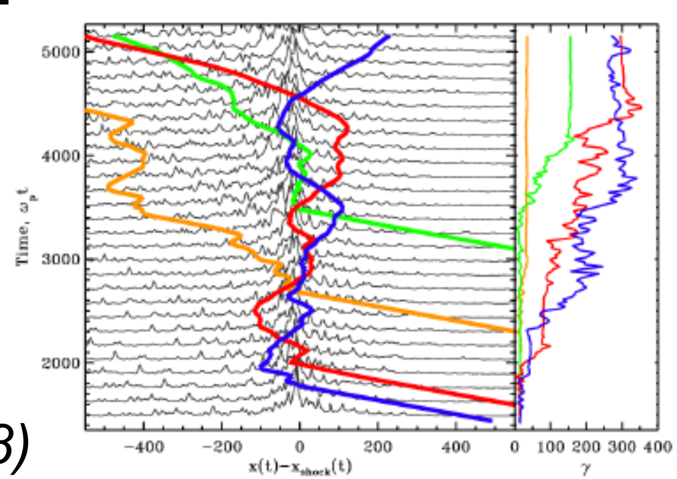
Detailed morphology → studies of particle transport, radiative losses …
Particle acceleration mechanisms
Fermi processes; contribution to CR?
Outer boundary conditions for physics of pulsar magnetospheres

PWN : laboratories to study particle acceleration in shocks and turbulence



A complex shock pattern, with constrained boundary conditions

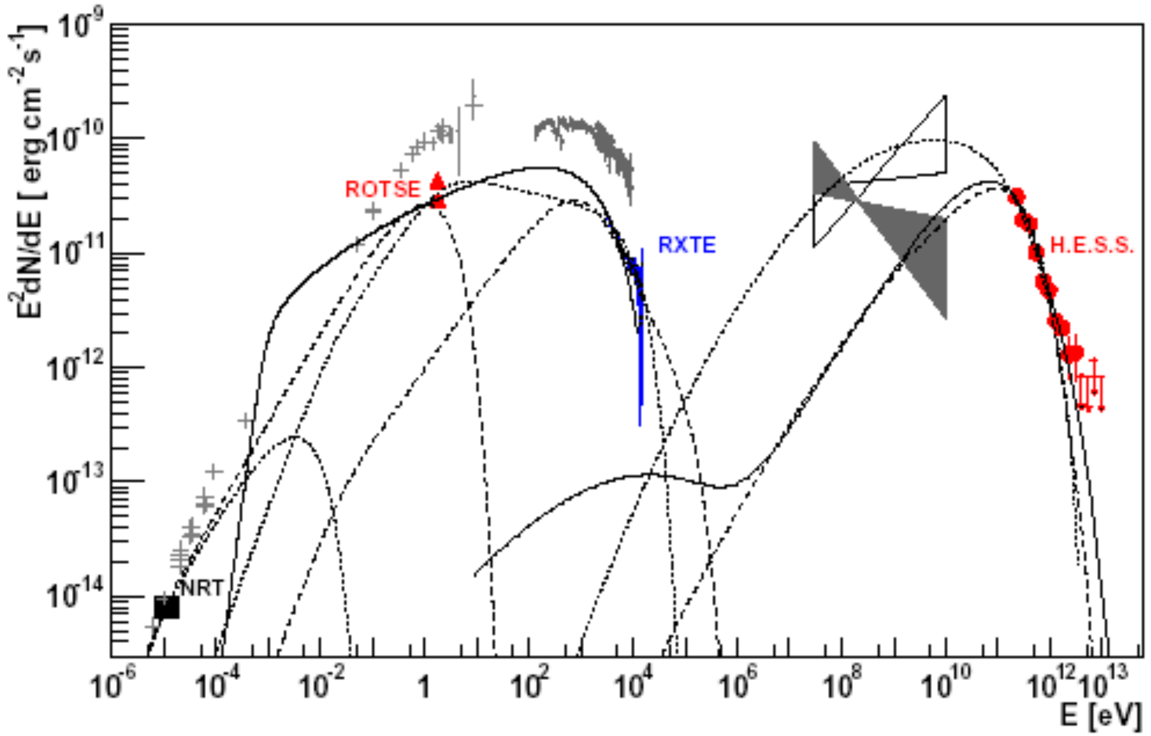




Acceleration at a relativistic shock : 1st observation of Fermi process in PIC simulations ? *(Spitkovsky, 2008)*

Active Galactic Nuclei :

About 30 AGN now detected at VHE

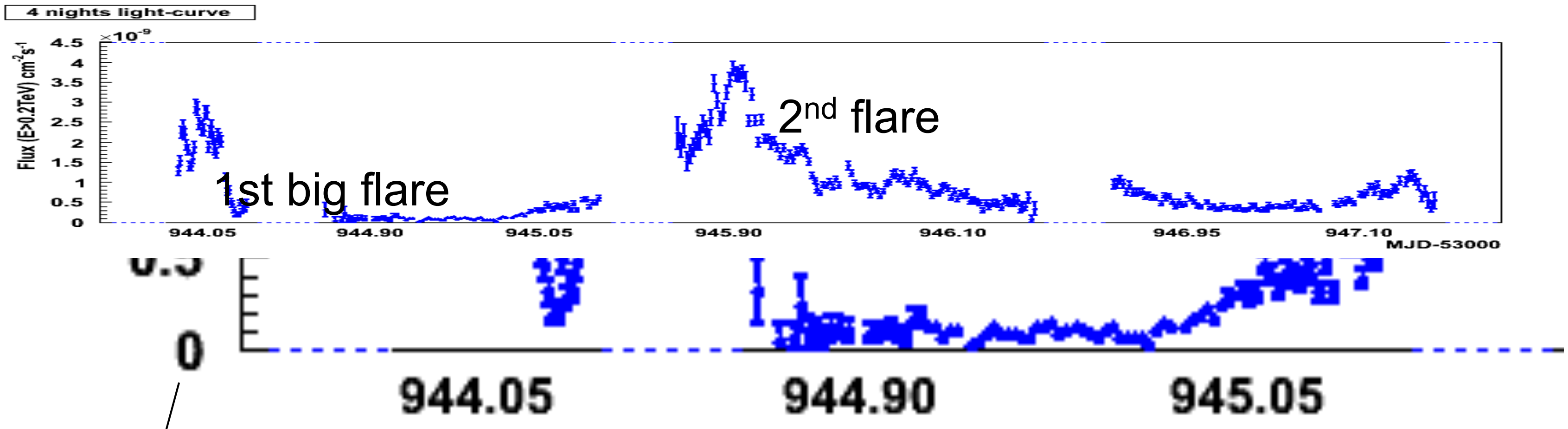


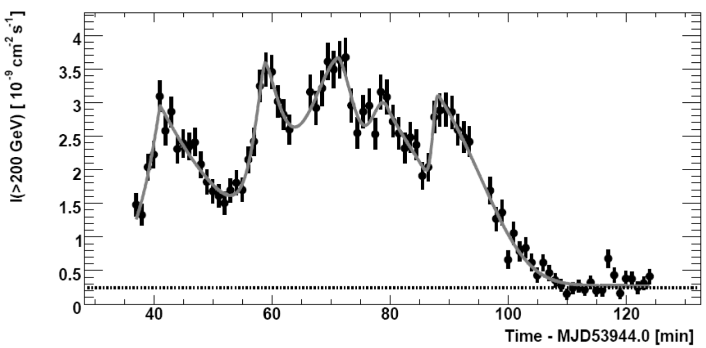
Various hadronic and leptonic models can often fit present available spectra of blazars

ex : SED of PKS2155-304 in quiescent state

→ Need better spectral (multi-lambda) coverage and variability studies to constrain scenarios

Probing highly variable events in TeV blazars

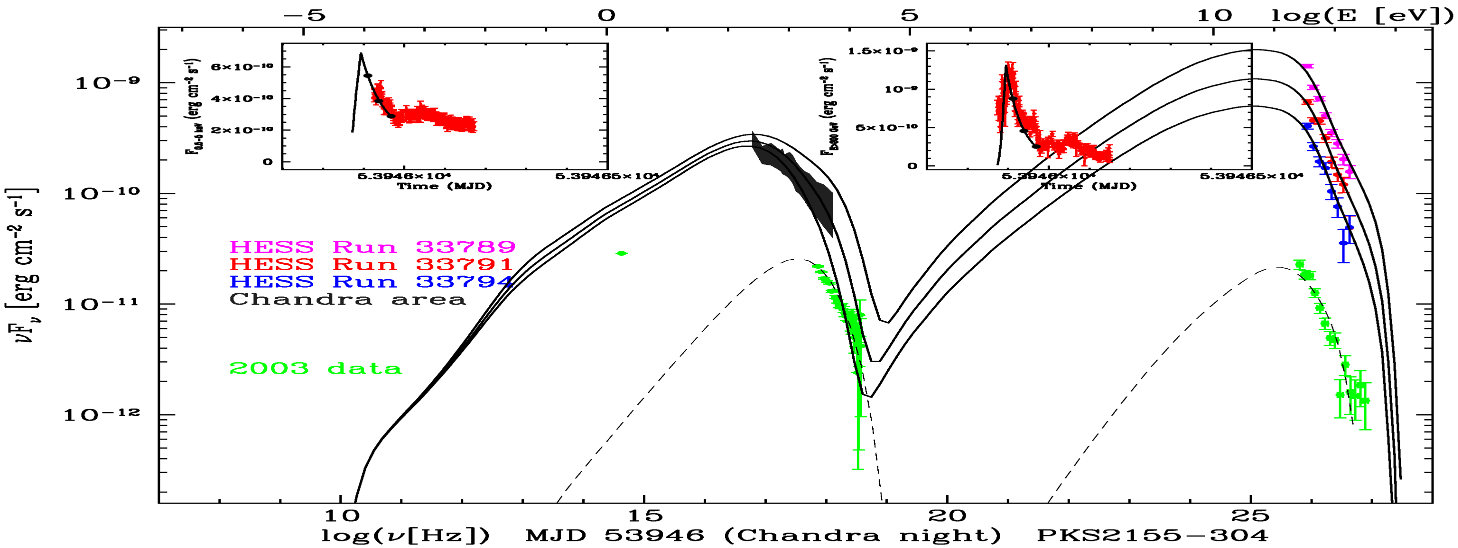


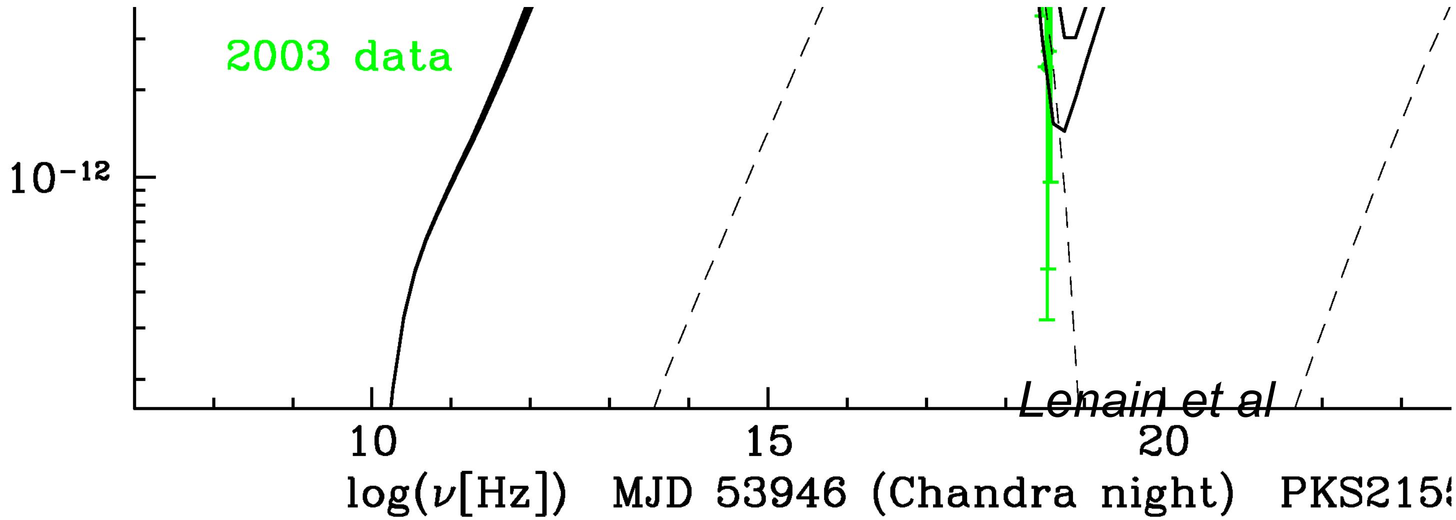


Monitoring an extraordinary active state of PKS 2155-304 in 2006, detected by HESS + multi-lambda campaign.

Down to minute time scale !
→ Emitting zone smaller than R_g or very high bulk Lorentz factor

→ **Probe the close BH environment**

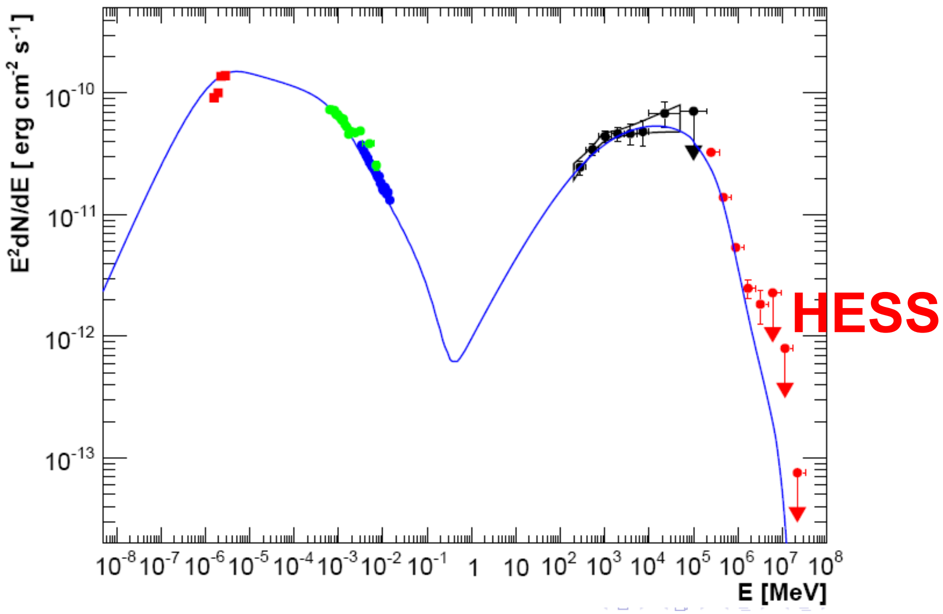




Fit of the 2nd flare of PKS2155 by SSC time-dependent modeling :
Reproduce light curves and spectra of flare in X and gamma rays

→ X-rays and VHE highly correlated in flare

However, PKS 2155 in 2008 (lower state):



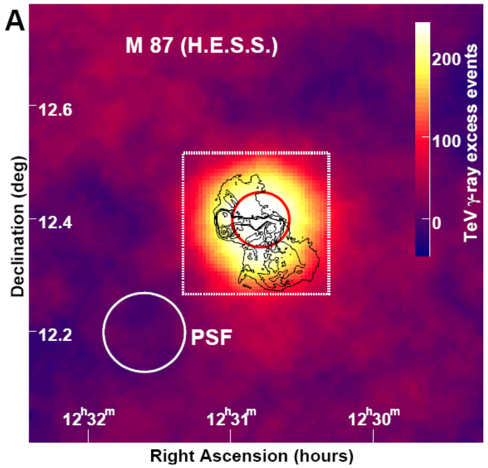
New multi-lambda campaign in 2008, including HESS, Fermi, RXTE, SWIFT, ATOM

Find complexity of correlation between various lambda :
Simple SSC model can not explain all correlation properties.
Correlations appear different between active and low states.

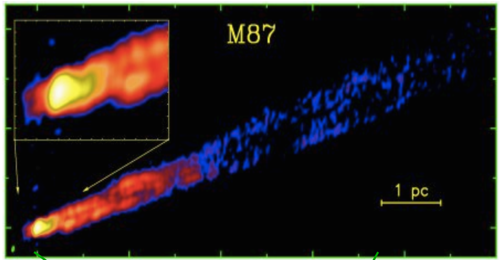
→ **need detailed X- γ monitoring for complete scenario**

Active Galactic Nuclei :

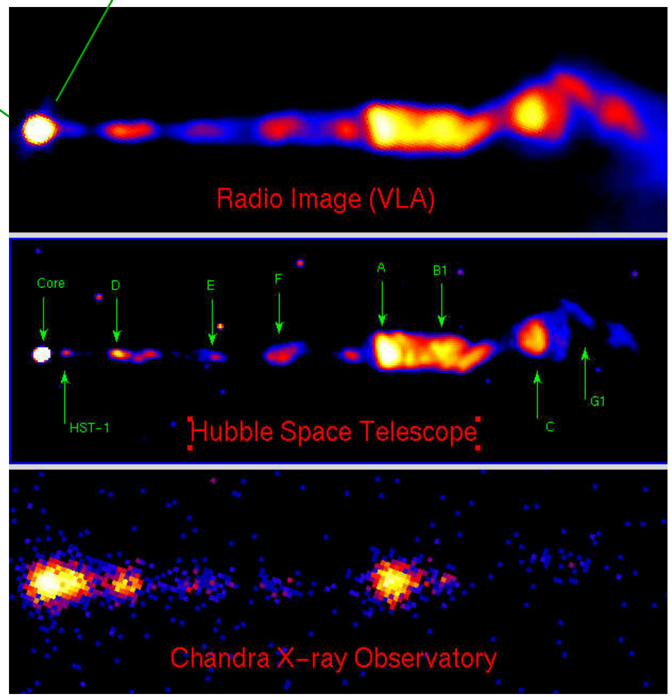
...two **radiogalaxies** now detected at TeV energies, M87 and Cen A



TeV



radio

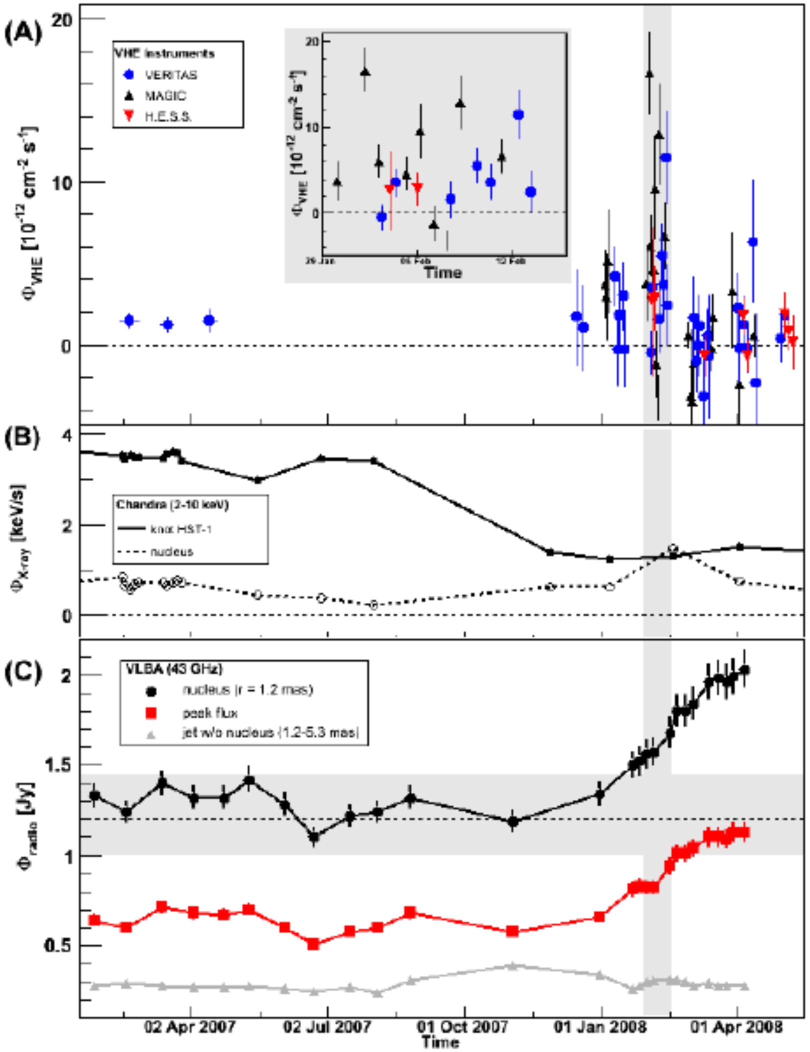


HST

X

M87 : 3 possible TeV emitting zones

- The peculiar knot HST-1 at ~ 65 pc from the nucleus
- The inner VLBI jet
- The central core and the black hole environment



X-ray light curve of HST-1 obtained by Chandra in 2008 does not follow the TeV one

Correlated core emission (radio, X and VHE) → seems to favour scenarios with TeV emission from inner jet or central core.

Inner jet :

Spine-layer SSC+EC scenario

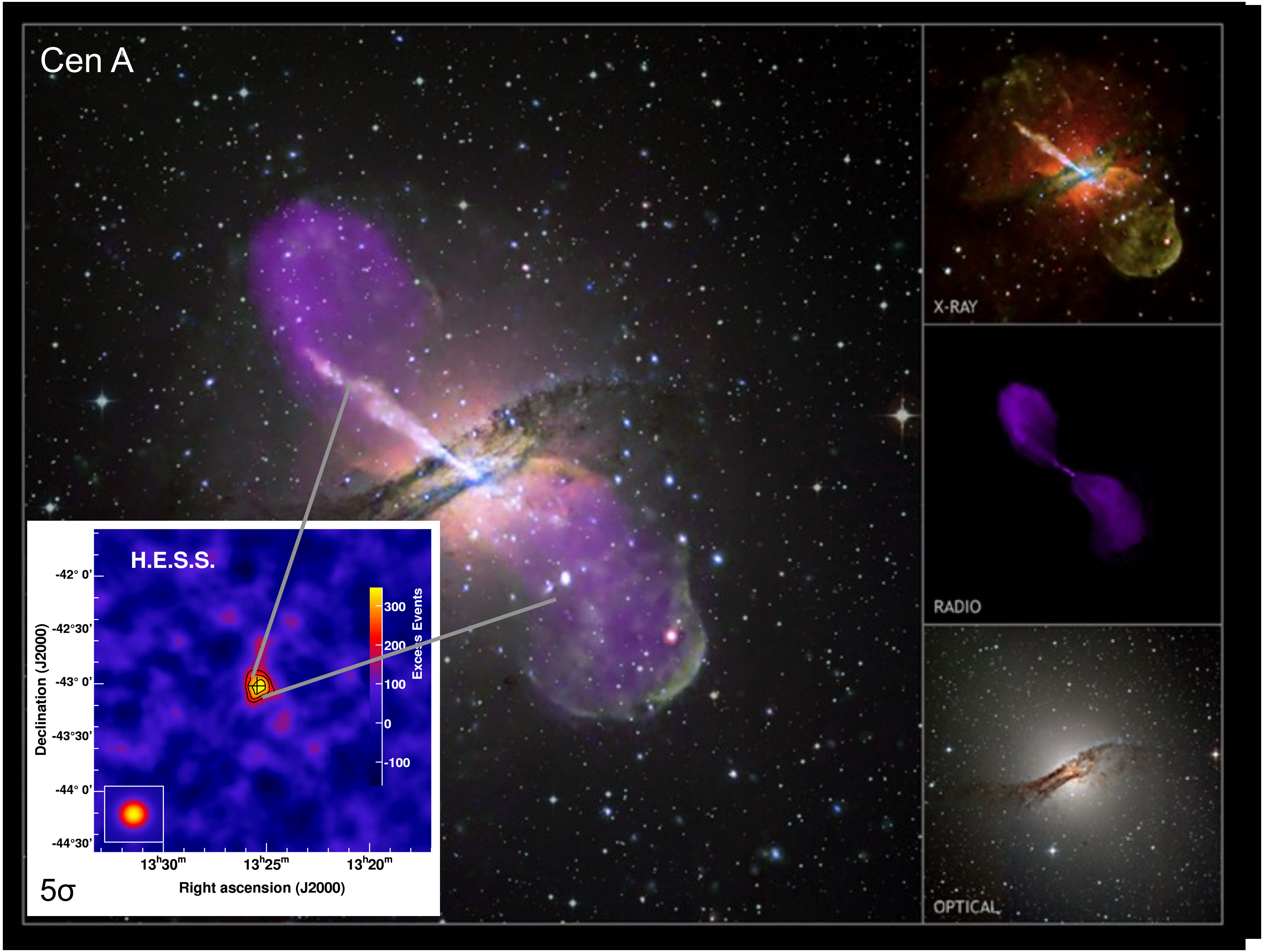
(Tavecchio, Ghisellini, 2008)

Multi-blob SSC scenario at $100R_s$

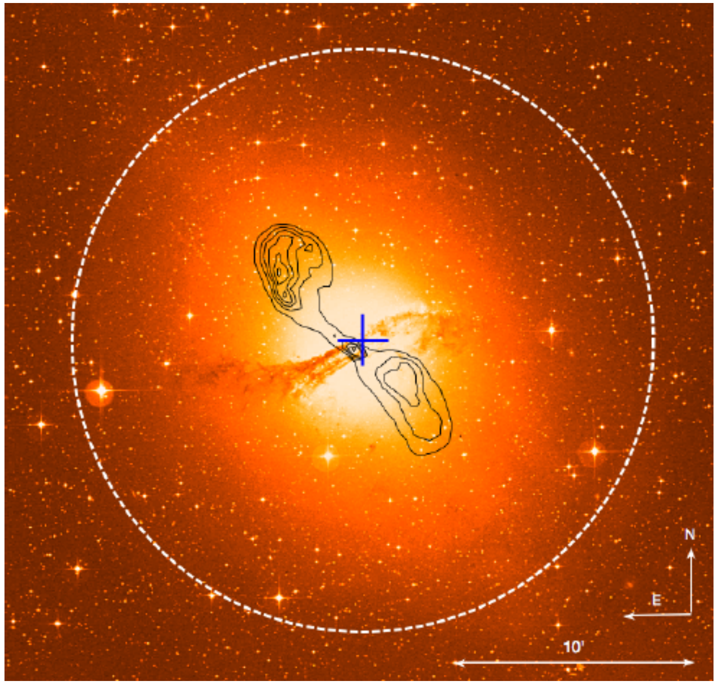
(Lenain et al, 2008)

Core : Acceleration in Black Hole magnetosphere

(Neronov, Aharonian, 2007; Rieger, Aharonian, 2008; Istomin, Sol, 2009)



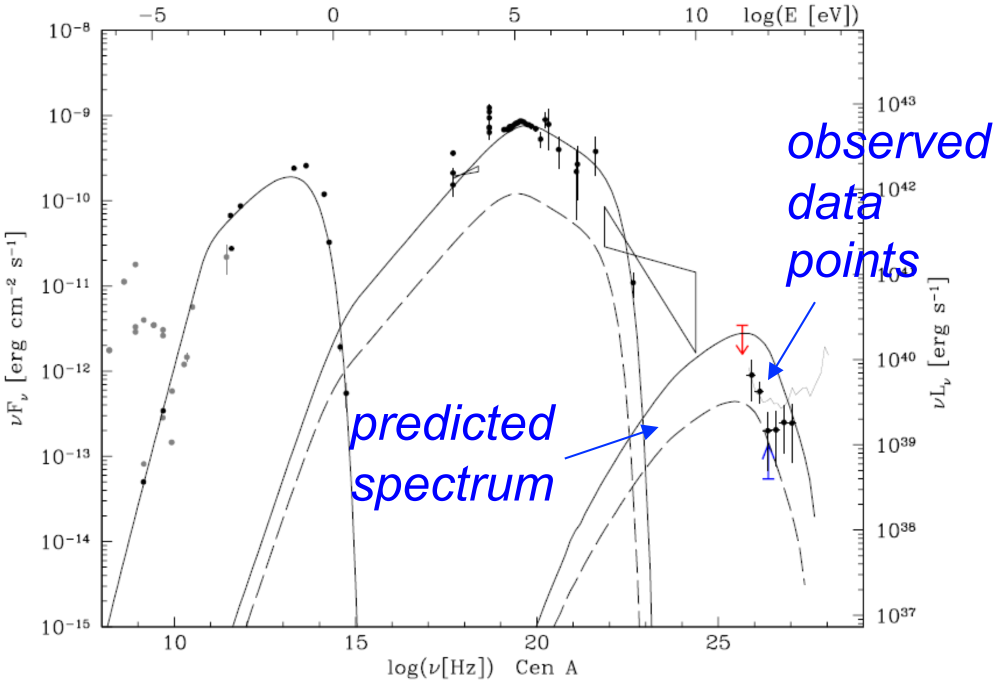
Cen A
H.E.S.S.
-42° 0'
-42°30'
-43° 0'
-43°30'
-44° 0'
-44°30'
Declination (J2000)
13h30m
13h25m
13h20m
Right ascension (J2000)
300
200
100
0
-100
Excess Events
5σ
X-RAY
RADIO
OPTICAL



Origin of the VHE emission ?
Compatible with radio core and inner kpc jets of Cen A

Possible VHE zones ?
- BH magnetosphere
- base of jets
- jets and inner lobes
- pair halo in host galaxy

Link to UHECR ?



SSC emission from jet formation zone

Synergies IXO-CTA on AGN

- Explore *variability at the shortest time scales*
  → identify the VHE emitting zones
  → jet physics, particle acceleration and radiation processes; search for VHE emission from large scale radio jets and hot spots, related to X-rays
  → physics of supermassive Black Hole environnement; constraints on accretion physics; BH spin effect on jet and VHE emission ?
  → explore in depth the accretion-ejection cycle if « appropriate » sources can be found (with accretion events and accreted hot spots seen with IXO and ejection events seen with CTA)

- Gather samples of different VHE AGN types to allow *statistical studies* for classification, unification schemes, AGN evolution. Check the 'blazar sequence', probe the quiescent states … Look for HE or VHE emission from « dormant » BH or « dead » quasars (could provide evidences for missing SMBH) → Census of AGN. Studies of *AGN and SMBH evolution*, AGN feedback and co-evolution with host-galaxies.

Perspectives

- CTA : foresee significant return on plasma physics and acceleration processes, outflows and winds, Black Hole physics, AGN and SMBH, non-thermal emission from cosmic sources.

- Important to plan an X-ray Observatory as IXO during the lifetime of CTA.

  - Coordinated monitoring : multiply the scientific return on HE and VHE sources, often variables.

  - Two spectral ranges X and VHE : provide two different views of the same population of particles (leptonic scenarios with synchrotron X-rays and IC gamma-rays), or on two related populations (hadronic scenarios with secondary electrons)
    → significantly constrain scenarios.

  - VHE data avoid confusion with thermal radiation; X-rays ones bring angular resolution for imaging, and allow identifying yet non-identified VHE sources.

Key science for IXO

- Matter under extreme conditions
- SMBH growth
- Matter orbiting BH
- Neutron star equation of state

- Formation of structure
- Nature of DM and DE
- Cosmic feedback
- Missing baryons

- Life cycle of matter and energy
- Origin and dispersion of elements
- Particle acceleration
- Planet formation
- Stellar magnetic fields

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