Active Galactic Nuclei at (Very) High Energies

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TeV Blazar
T = theras = τερας = monster
(Homer's Iliad IV, 73)

Outline

- The Very High Energy γ-ray domain
- Modelling the multi-wavelength emission of high energy emitting AGNs: the VHE AGN tour
- Discovery of Seyfert 2 galaxies at high energies
- CTA, a future Cherenkov observatory

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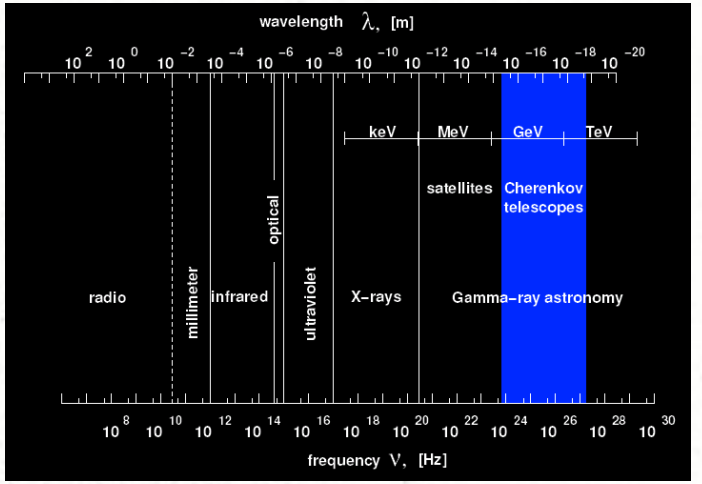
The Very High Energy domain

- VHE: E >100 GeV.
- Spaceborne instruments:
  "Low" and high energies
  (small effective area)
- Ground-based instruments
  (big effective area)
  → atmospheric Cherenkov technique.



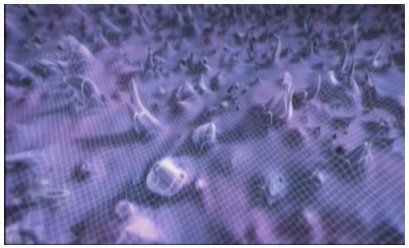
$$E_{\rm kin}^{\rm mosquito} \sim 10^{-8}\,{\rm J} \text{ with } m \sim 1{\rm mg},\ v \sim 20\ {\rm cm/s}$$

$$1\ {\rm TeV} \sim 10^{-7}\ {\rm J}$$

$$\Rightarrow h\nu_{\rm photon} \sim 10 E_{\rm kin}^{\rm mosquito}$$

The physics at VHE:
Among the key questions

- Non-thermal radiation → particle acceleration ?
- Origin of cosmic rays: supernova remnants ? Radio-galaxies ?
- Environment of supermassive black holes.
- Population studies (PWN, AGN).
- AGN: leptonic or hadronic emission ?
- Fundamental physics: dark matter, quantum gravity (structure of spacetime).



- Cosmology: The VHE/IR link: γ-ray horizon (EBL).

Imaging Atmospheric Cherenkov Telescopes

The current major IACTs to play with...

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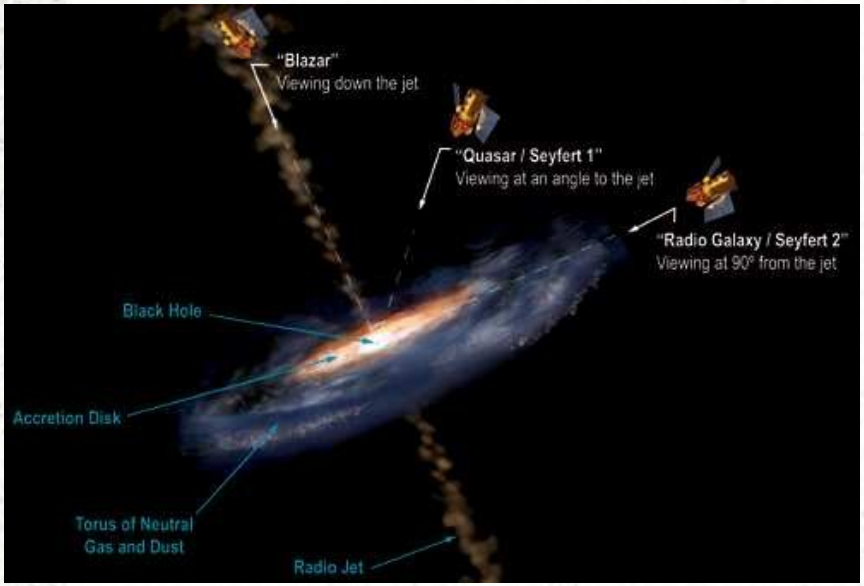
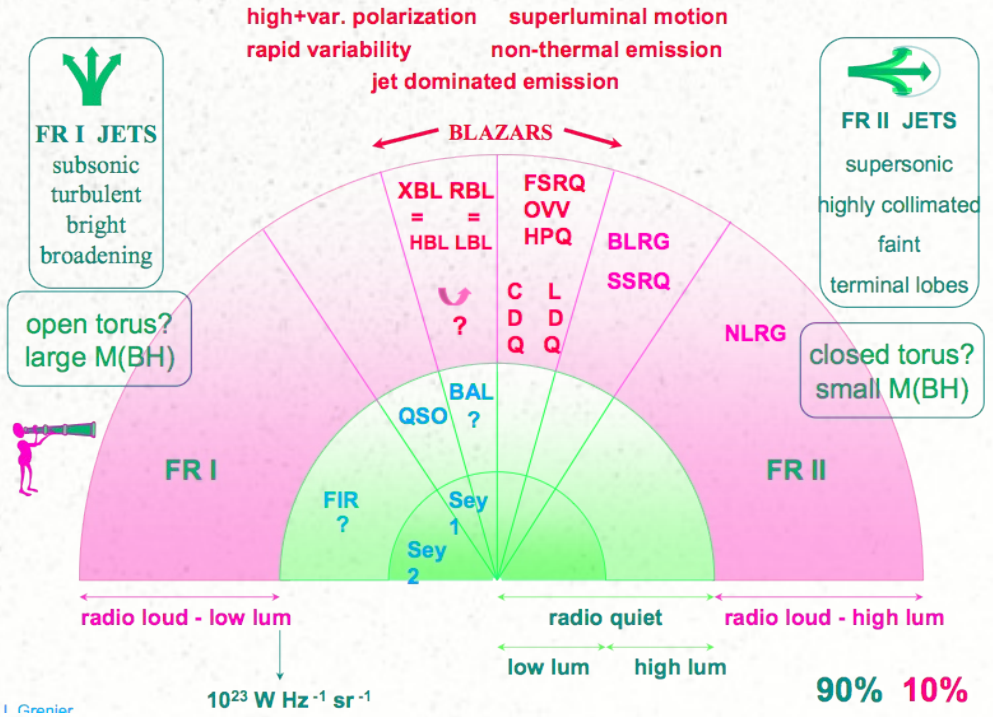
Active Galactic Nuclei (AGNs)

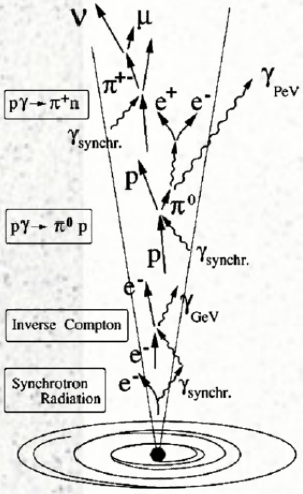


- AGN=10% of galaxies
- Unification paradigm:
  orientation angle ?
  accretion rate ?

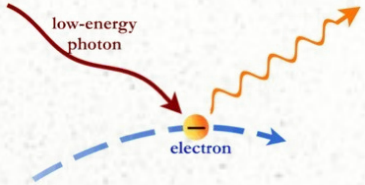


Modelling the multi-wavelength emission of VHE AGN

- Radiative processes:
  - **Leptonic**:



    - Synchrotron
    - Inverse Compton:
      - on the synchrotron radiation field: Synchrotron self-Compton (SSC)
      - on an external radiation field (CMB, starlight, accretion disk, BLR, ...) External inverse Compton (EIC)

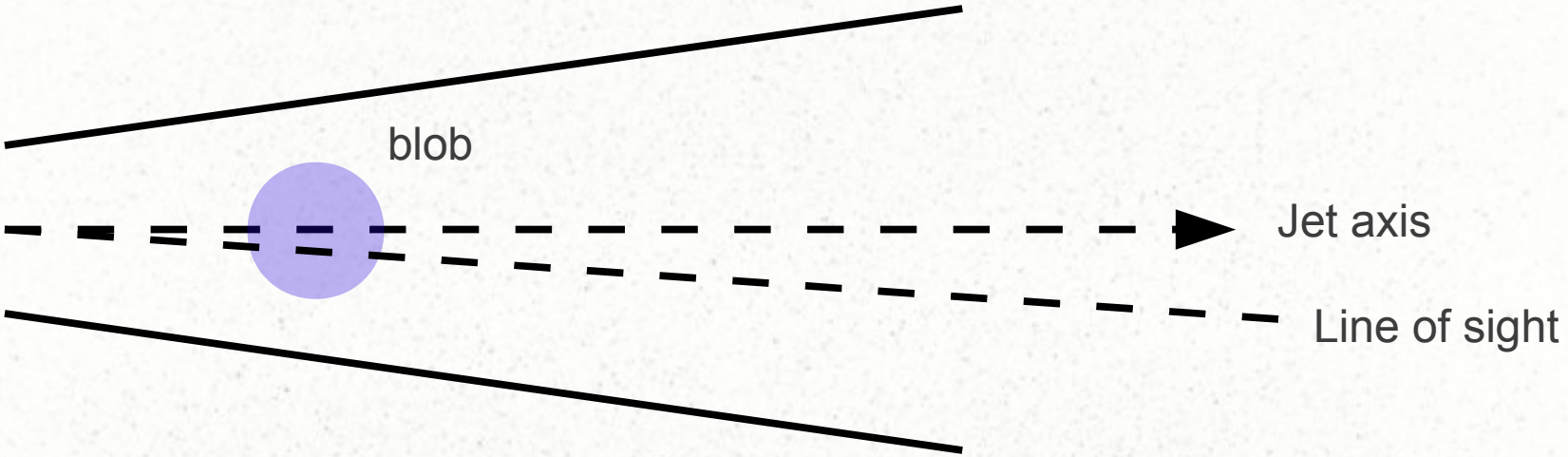


  - **Hadronic**:
    - *p*-γ
    - *p*-*p*
    - *p*-synchrotron

$$p + \gamma \rightarrow p + \pi^0$$
$$p + \gamma \rightarrow n + \pi^+$$
$$p + \gamma \rightarrow p + e^+ + e^-$$

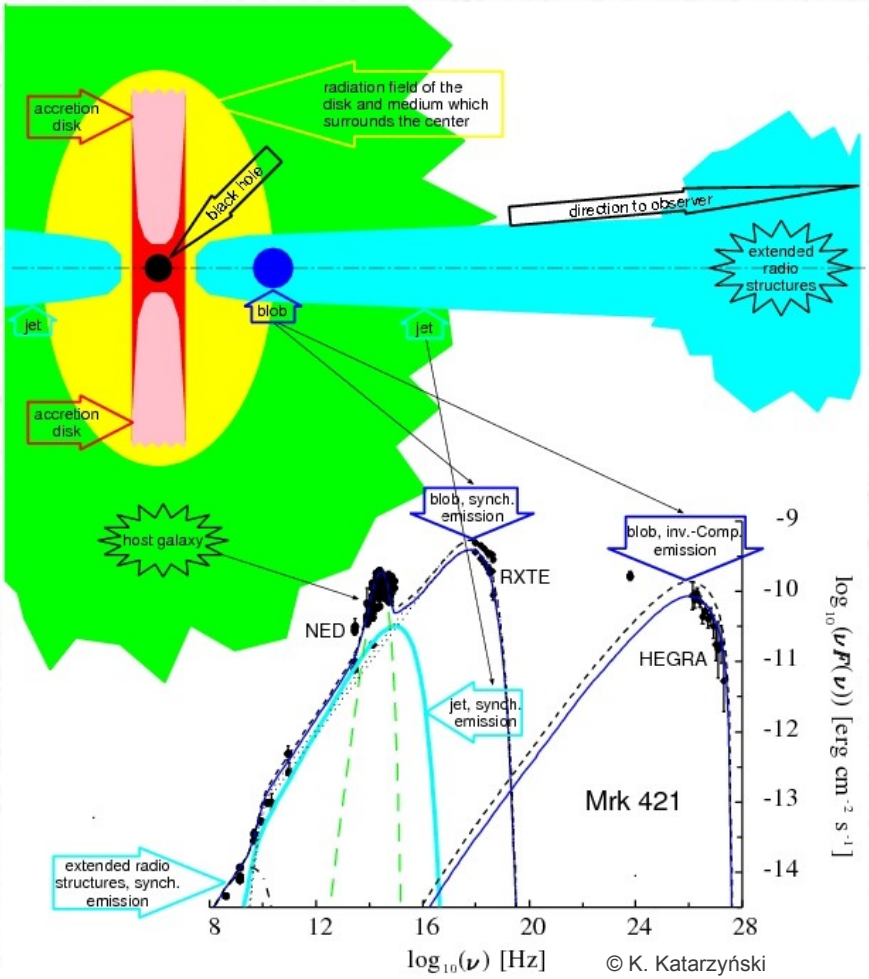
$$p + p \rightarrow p + p + a(\pi^+ + \pi^-) + b\pi^0$$
$$p + p \rightarrow p + n + \pi^+ + a(\pi^+ + \pi^-) + b\pi^0$$
$$p + p \rightarrow n + n + 2\pi^+ + a(\pi^+ + \pi^-) + b\pi^0$$

The model

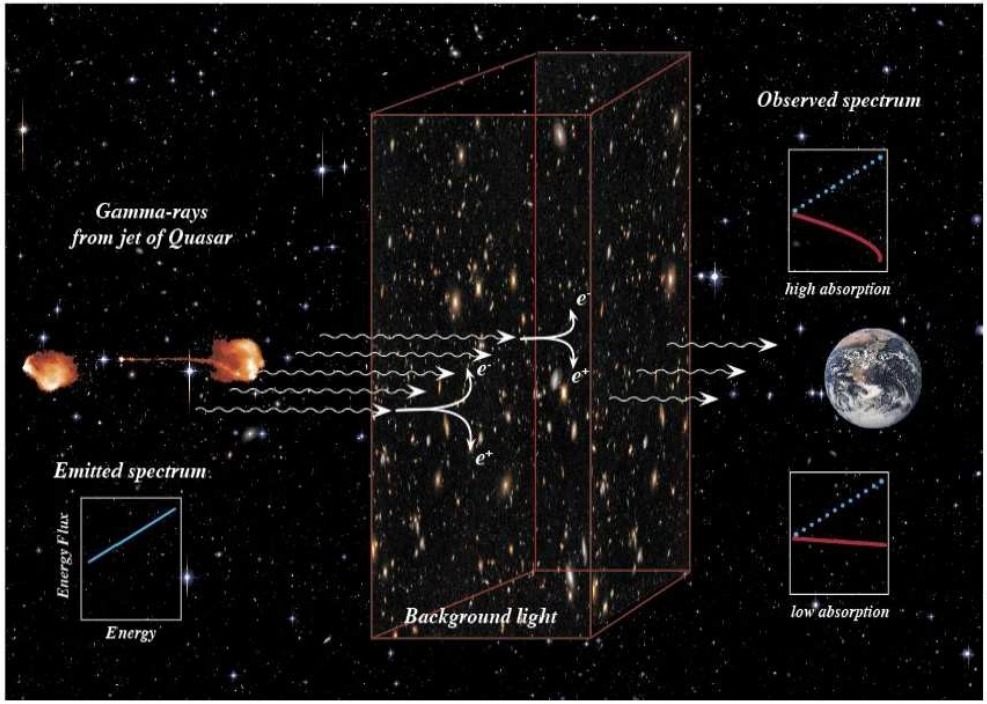


- Dense blob in jet filled up by tangled magnetic field
- Synchrotron of the blob → X-rays
- Inverse Compton scattering of this synchrotron field → γ-rays
- ↳ **Synchrotron self-Compton**

Modelling the multi-wavelength emission of VHE AGN

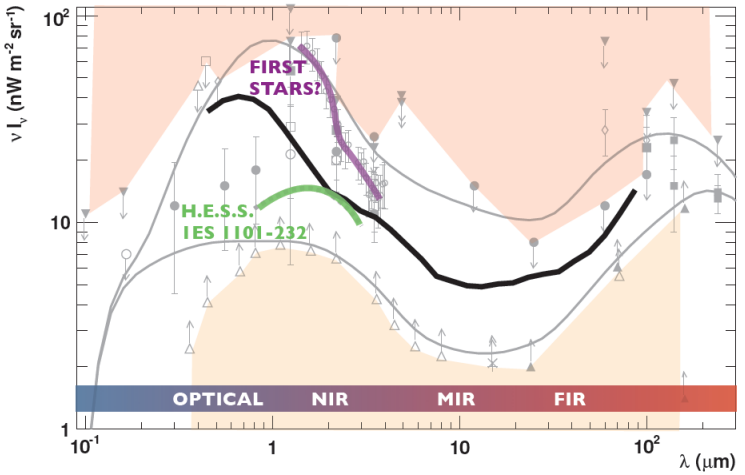


The VHE γ-ray horizon



Extragalactic Background Light (EBL): optical/infrared emission.

- Cosmology up to z~0.5
- Galaxy counts:
  lower limits on EBL.
- VHE observations:
  upper limits on EBL.

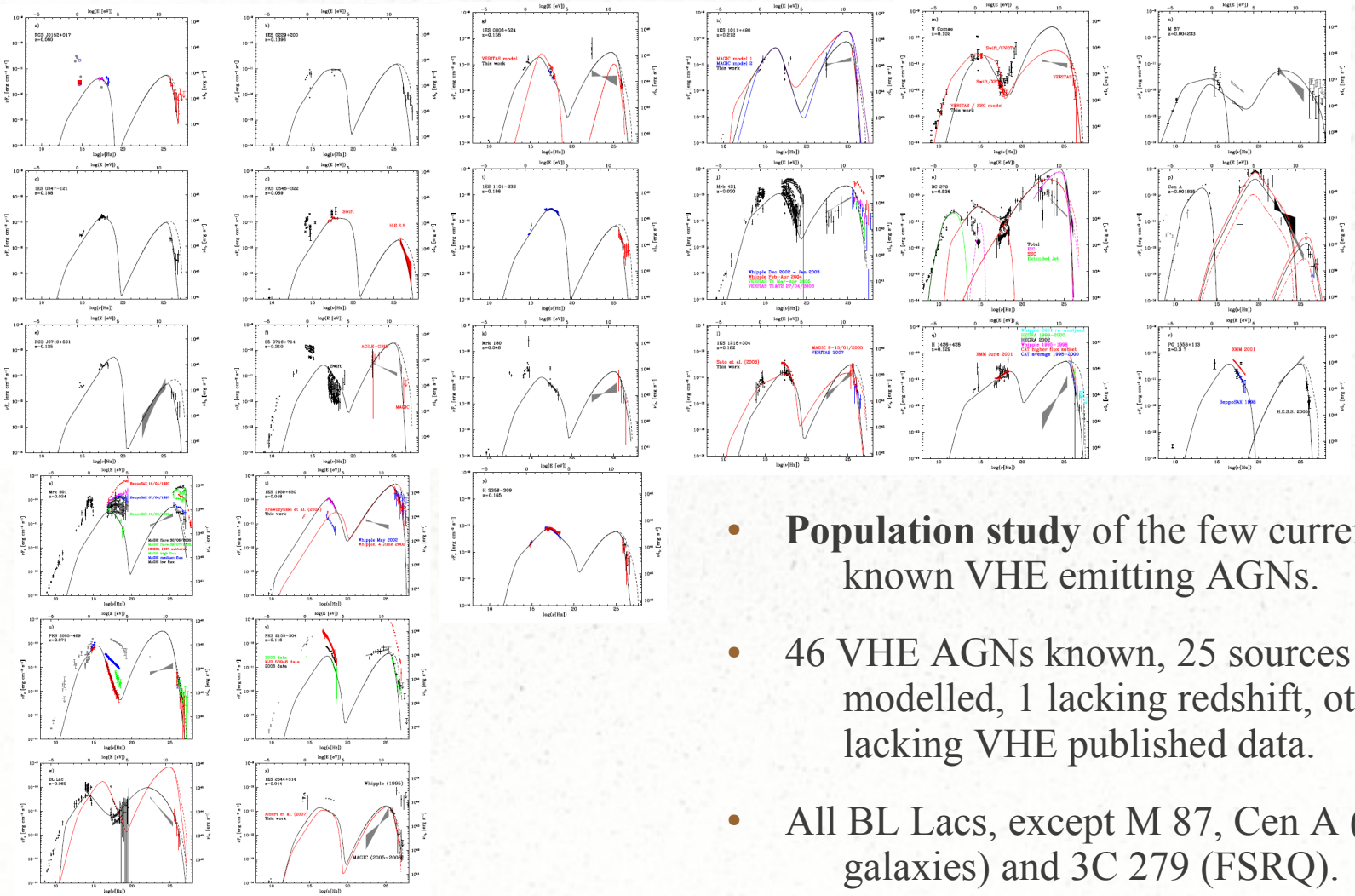


$$\gamma_{VHE} + \gamma_{EBL} \rightarrow e^+ + e^-$$

Emitted (intrinsic) spectrum should be well known.

A tour of VHE AGN

Collab. with M. Daniel, P. Chadwick, M. Ward (Durham),
C. Boisson, H. Sol (Paris)



- **Population study** of the few currently known VHE emitting AGNs.
- 46 VHE AGNs known, 25 sources modelled, 1 lacking redshift, others lacking VHE published data.
- All BL Lacs, except M 87, Cen A (radio galaxies) and 3C 279 (FSRQ).

VHE AGN tour: Correlation study

Strategy, assumptions & aims

- Reduce the number of free parameters: $\delta_b \sim 20$, $n_1 = 2.0$ (Fermi I acceleration process by strong shock), $B \sim 0.1$ G
- 24 VHE AGN modelled, including 3C 279, M 87 & Cen A
- Does an SSC modeling reproduce well the sample ?
- Correlations amongst derived parameters ?

Caveats

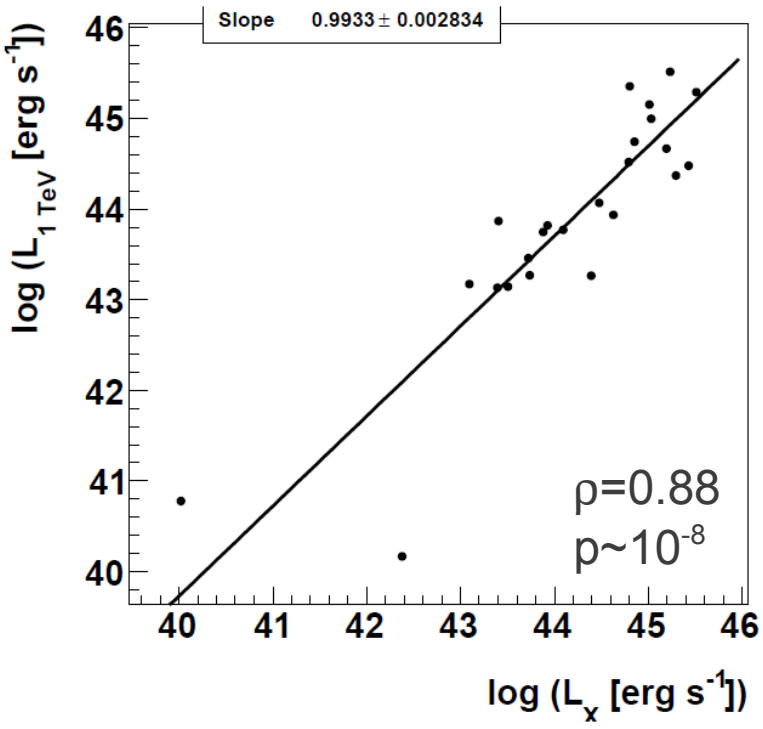
- Bias toward flaring states
- Bias toward HBL
- Small number of objects
- Model-dependent

VHE AGN tour: Correlation study

$$\log_{10}(L_{1\,\mathrm{TeV}}[\mathrm{erg\,s^{-1}}]) = (0.993 \pm 0.003)\,\log_{10}(L_{\mathrm{X}}[\mathrm{erg\,s^{-1}}])$$

→ Based on known F_X and z, we can estimate $F_{1\ \mathrm{TeV}}$.

→ Establish list of new VHE source candidates from an X-ray sample.



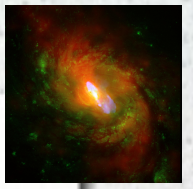
VHE AGN tour: New candidates at VHE

Prospects for future VHE AGN source candidates based on the BZCat catalogue.

Source denomination	z	F_X[a] (erg cm^{-2} s^{-1})	L_X (erg s^{-1})	$F_{1\,\mathrm{TeV}}$[b] (erg cm^{-2} s^{-1})	$L_{1\,\mathrm{TeV}}$[b] (erg s^{-1})
BZUJ0319+4130	0.018	2.0×10^{-10}	1.4×10^{44}	7.2×10^{-11}	7.0×10^{43}
BZQ J1229+0203	0.158	6.3×10^{-11}	3.7×10^{45}	1.5×10^{-12}	1.8×10^{45}
BZUJ2209−4710	0.006	3.5×10^{-11}	2.8×10^{42}	1.6×10^{-11}	1.4×10^{42}
BZB J1117+2014	0.139	3.4×10^{-11}	1.5×10^{45}	1.2×10^{-12}	7.3×10^{44}
BZB J1217+3007	0.130	2.5×10^{-11}	9.8×10^{44}	1.1×10^{-12}	4.8×10^{44}
BZUJ0433+0521	0.033	2.3×10^{-11}	5.5×10^{43}	6.4×10^{-12}	2.7×10^{43}
BZB J1728+5013	0.055	2.0×10^{-11}	1.4×10^{44}	3.9×10^{-12}	6.8×10^{43}
BZB J0930+4950	0.187	1.7×10^{-11}	1.4×10^{45}	2.3×10^{-13}	6.7×10^{44}
BZUJ1407−2701	0.022	1.5×10^{-11}	1.6×10^{43}	5.3×10^{-12}	8.2×10^{42}
BZB J1136+6737	0.136	1.5×10^{-11}	6.4×10^{44}	5.7×10^{-13}	3.1×10^{44}
BZB J0326+0225	0.147	1.2×10^{-11}	6.1×10^{44}	3.7×10^{-13}	3.0×10^{44}
BZUJ0425−0833	0.039	1.2×10^{-11}	4.1×10^{43}	3.1×10^{-12}	2.0×10^{43}
BZB J0643+4214	0.089	1.1×10^{-11}	1.9×10^{44}	1.1×10^{-12}	9.4×10^{43}
BZUJ0522−3627	0.055	1.0×10^{-11}	7.1×10^{43}	2.0×10^{-12}	3.5×10^{43}
BZB J0441+1504	0.109	1.0×10^{-11}	2.8×10^{44}	7.0×10^{-13}	1.4×10^{44}
BZB J1010−3119	0.143	1.0×10^{-11}	4.9×10^{44}	3.4×10^{-13}	2.4×10^{44}
BZB J1315−4236	0.105	8.8×10^{-12}	2.2×10^{44}	6.6×10^{-13}	1.1×10^{44}
BZB J1442+1200	0.163	7.8×10^{-12}	4.9×10^{44}	1.8×10^{-13}	2.4×10^{44}
BZB J1120+4212	0.124	7.8×10^{-12}	2.8×10^{44}	3.9×10^{-13}	1.4×10^{44}
BZUJ1715+5724	0.027	7.4×10^{-12}	1.2×10^{43}	2.3×10^{-12}	6.0×10^{42}
BZB J1257+2412	0.141	7.2×10^{-12}	3.4×10^{44}	2.5×10^{-13}	1.6×10^{44}

Using the BZCat X-ray catalogue of quasars and blazars + sensitivity limit of 10^{-13} cm^{-2} s^{-1} TeV^{-1} at 1 TeV (5σ in 50h for CTA):

- 71 source candidates.
- Conservative list: CTA will be sensitive down to ~30 GeV.



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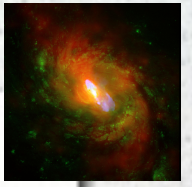
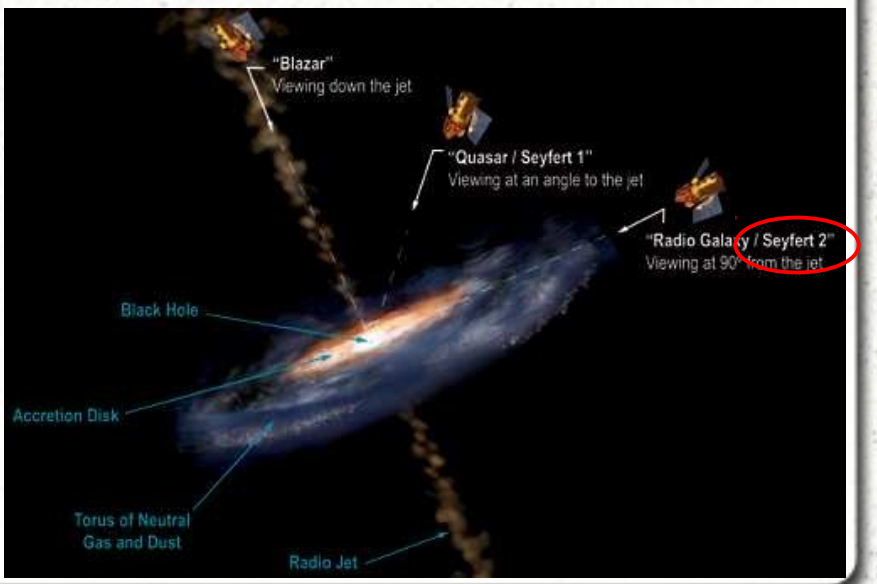


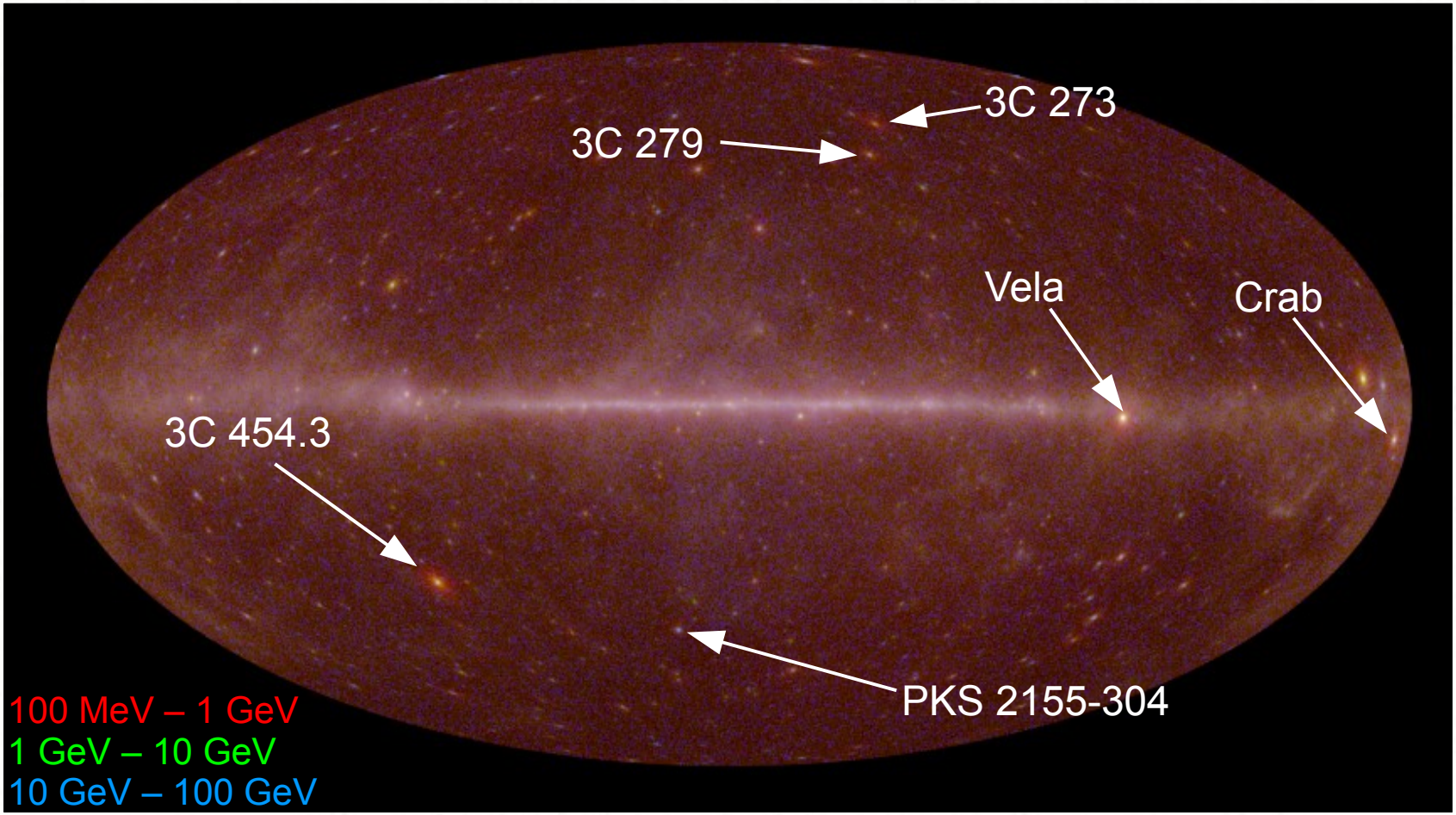
Non-blazar AGN @ high energies

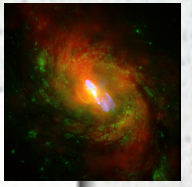
- The usual extragalactic suspects at HE/VHE: blazars, radio-loud objects.
- Starbursts galaxies discovered at the highest energies: M 82 (Fermi, VERITAS), NGC 253 (Fermi, H.E.S.S.).
- Radio-loud narrow-line Seyfert 1 with Fermi : PMN J0948+0022, PKS 1502+036, 1H 0323+342, PKS 2004−447.
- **⇒ can Seyfert 2 also be high-energy γ-ray emitters ?**
- In 1FGL catalogue: sources in the regions of **NGC 1068** and **NGC 4945**.



The Fermi/*LAT sky*

29 months data (2008-08-04 → 2011-01-01)

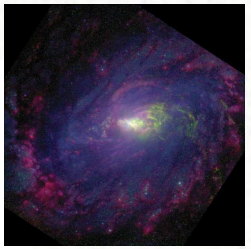


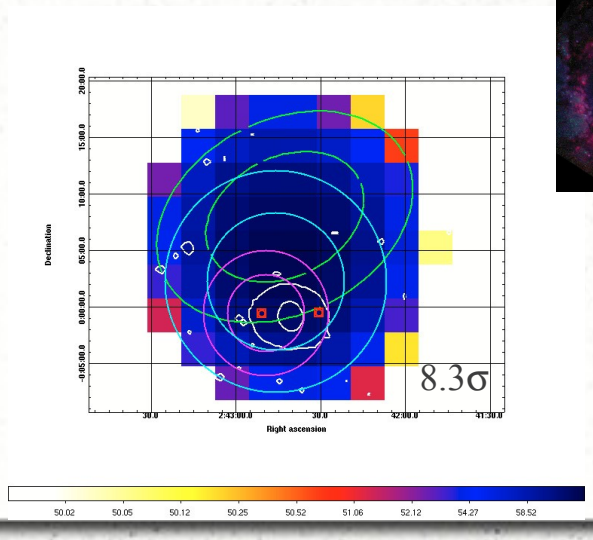


Seyfert 2 in the GeV range: jets and starburst

NGC 1068

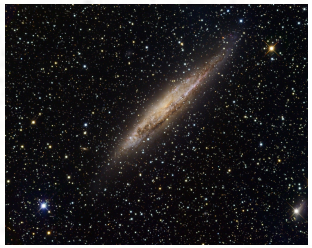
- Archetypal Seyfert 2 galaxy,
  Hidden Seyfert 1 core,
  AGN unification (Antonucci & Miller, 1985, *ApJ*)
- Very well-studied, nearby (14.4 Mpc), bright.
- Both starburst and AGN properties.
- Structured radio jet.

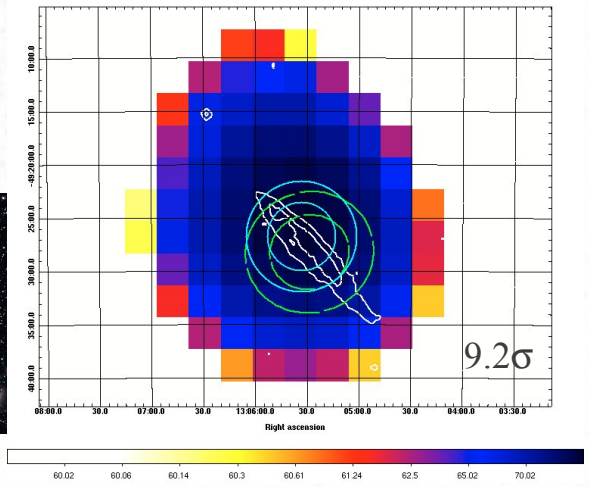


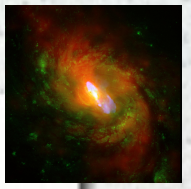


NGC 4945

- Edge-on spiral galaxy.
- Composite starburst/Seyfert 2 galaxy.
- *Fermi* source from 1FGL already associated with NGC 4945, although not clear whether HE emission from starburst or AGN activity.

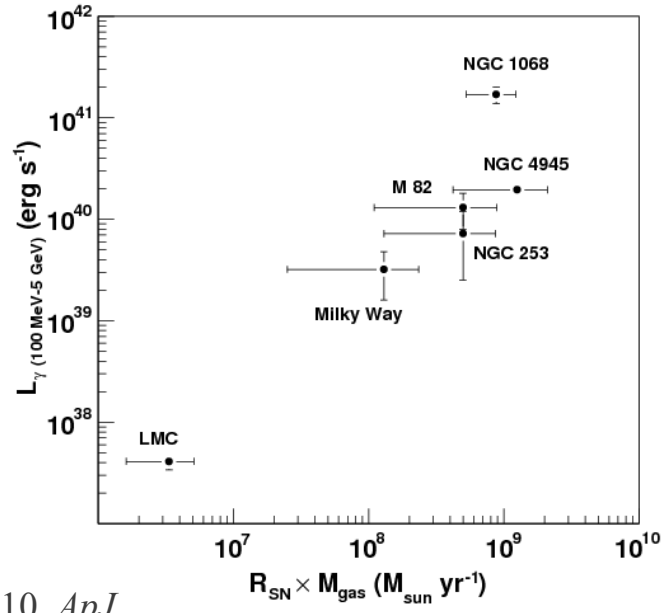




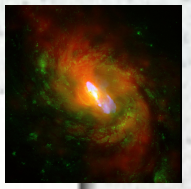


Starburst or AGN activity ?

- Variability ? Starburst activity is steady, variability would be due to AGN activity. Data statistically consistent with a constant.
- γ-rays from starburst: cosmic rays (ejected by supernovæ) interact with ambient interstellar medium: *p-p* interactions.
- → L_γ is believed to scale with:
  R_{SN} [CR] × M_{gas} [ISM]



cf. also Abdo et al. (*Fermi*/LAT collab.), 2010, *ApJ*



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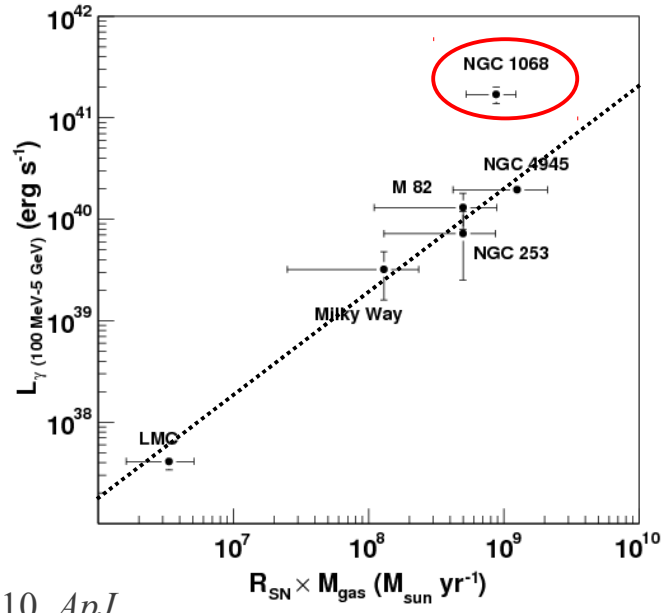
- → L_γ is believed to scale with:
  R_{SN} [CR] × M_{gas} [ISM]
- NGC 4945 is consistent with pure starburst activity.
- L_γ of NGC 1068 is higher than expectations from pure starburst.



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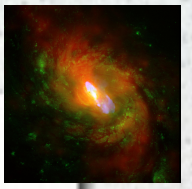
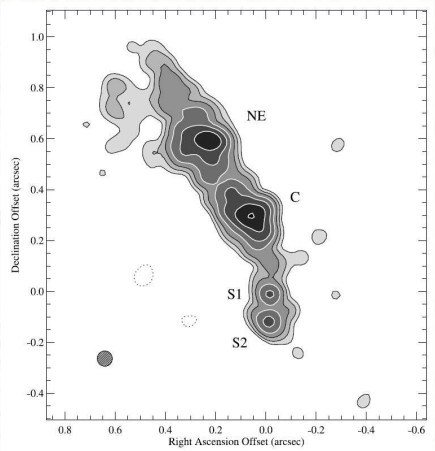
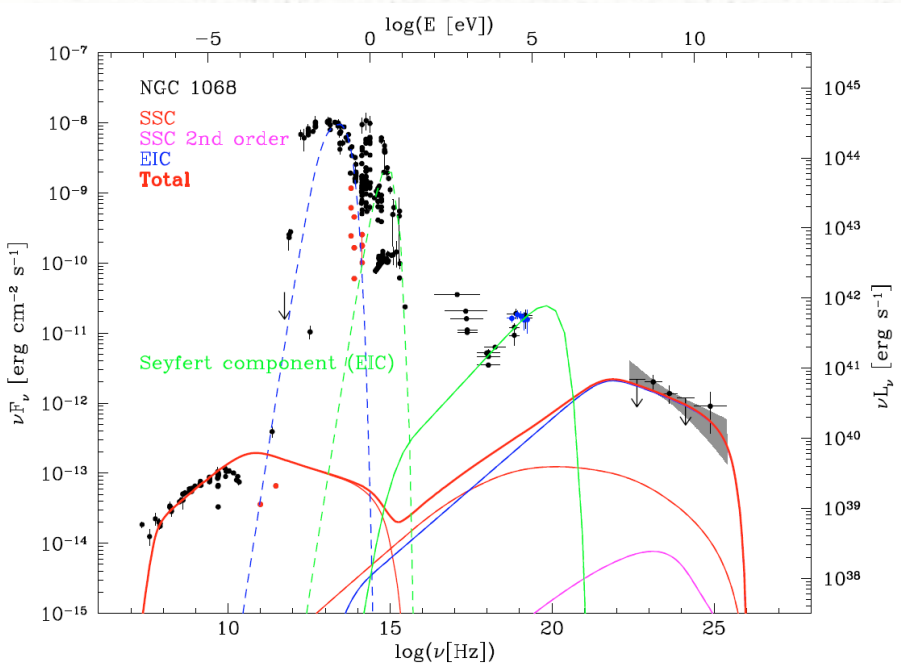


Seyfert 2 in the GeV range: NGC 1068: modelling the beast !

- NGC 1068 has a structured jet.
- Let's assume the HE γ-rays originates from the relativistic outflow @ ~350 pc from the core (radio component "A", Pedlar et al., 1983, *MNRAS*).



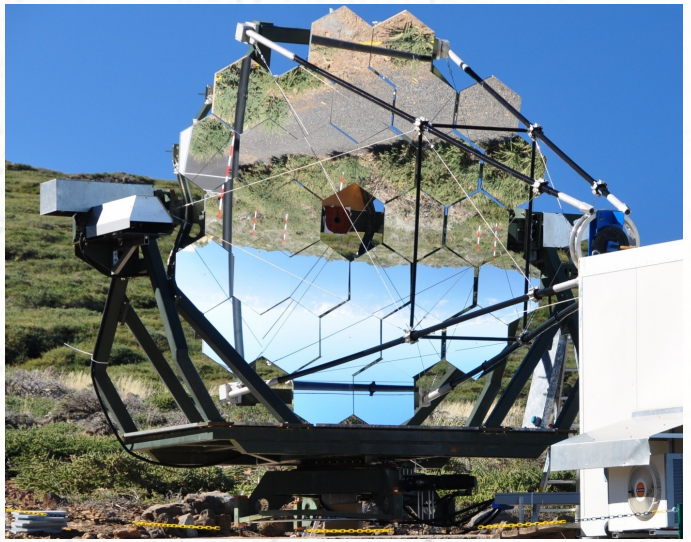
NGC 1068: MERLIN 5 GHz image (Gallimore et al., 2004, ApJ)



- If confirmed in other Seyfert 2 galaxies, new class of sources.
- Much more numerous than blazars → expect a lot of discoveries ?

FACT: First G-APD Cherenkov Telescope

- Affordable monitoring VHE telescope.
- Observe few bright AGNs.
- Old CT3 from HEGRA refurbished (∅~3m).



- Proof of concept: replace PMT by Si-based photosensors.
  (G-APD=Geiger mode Avalanche PhotoDiode)
- Data will be public !
- Part of the DWARF network: Dedicated Worldwide AGN Research Facility.

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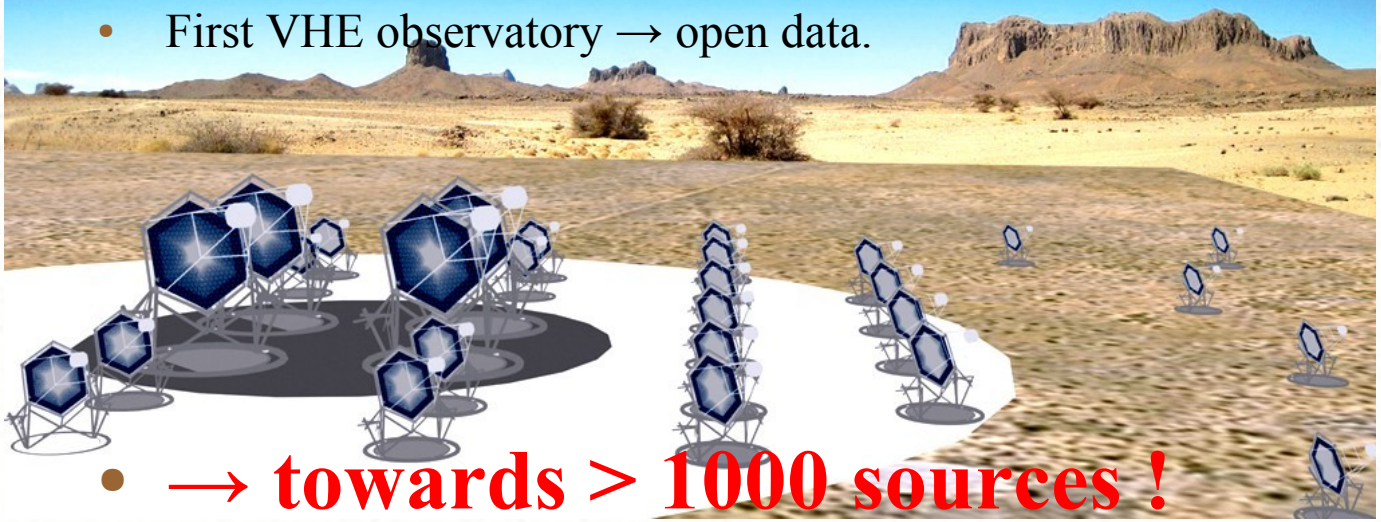
CTA: Cherenkov Telescope Array

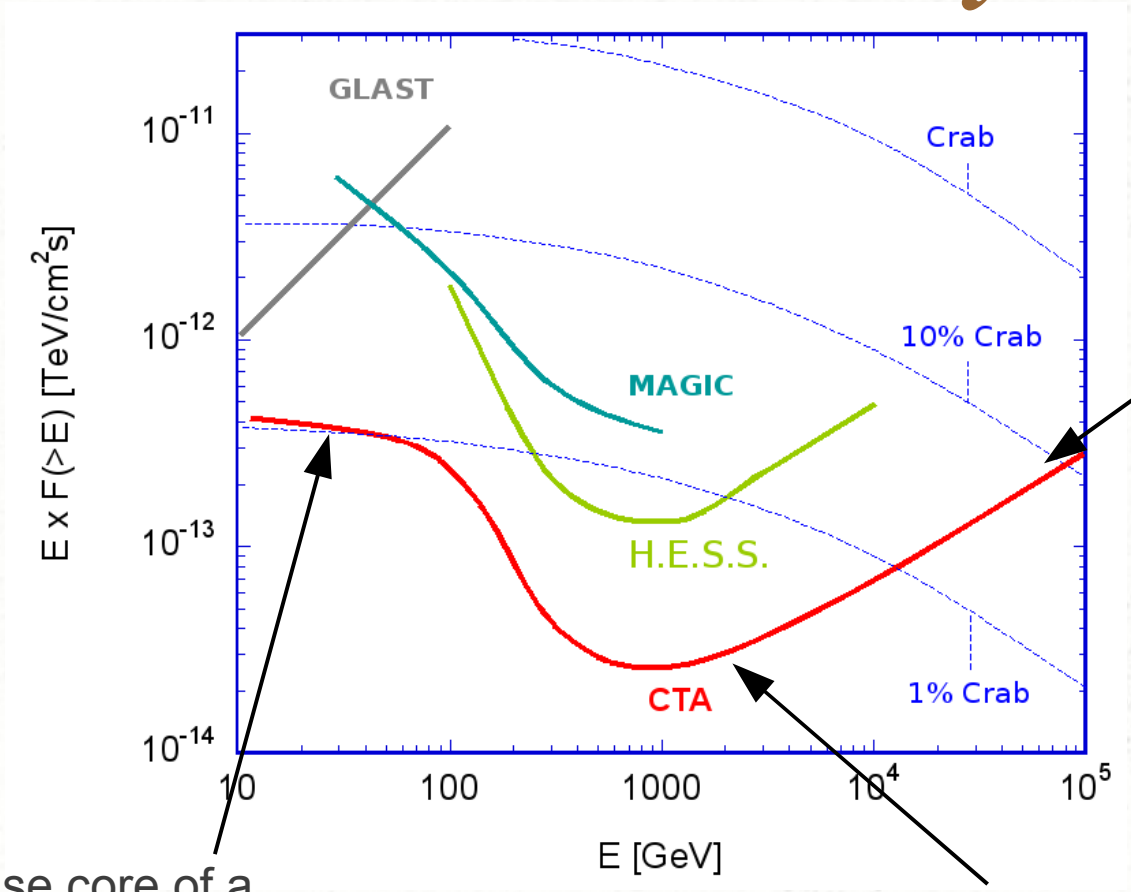
- 10 × better sensitivity than current IACTs.
- Larger energy coverage, better angular and energy resolutions.
- 2 arrays of ~100 telescopes each (North & South).
- 2 or 3 types of telescopes.
- ~700 scientists in 24 countries.
- First VHE observatory → open data.



- **→ towards > 1000 sources !**

Not to scale !

CTA: Cherenkov Telescope Array Sensitivity



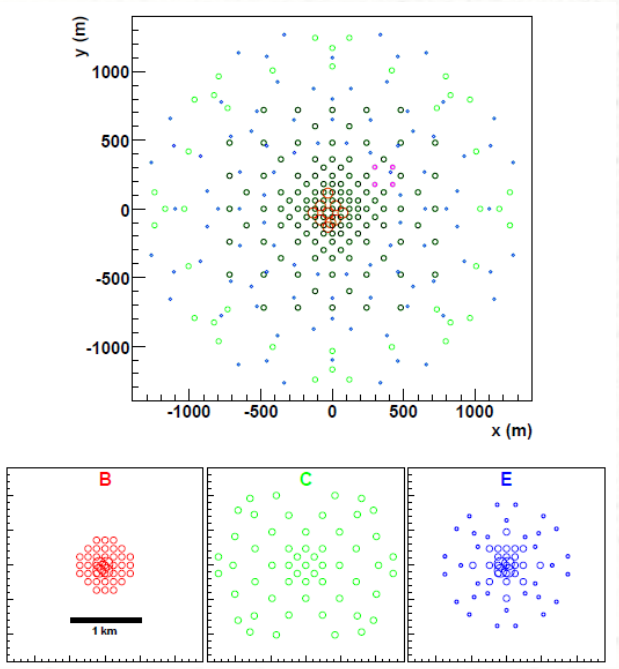
• Sparse array of small-sized tel.
• Probing the highest energies in Galactic sources.

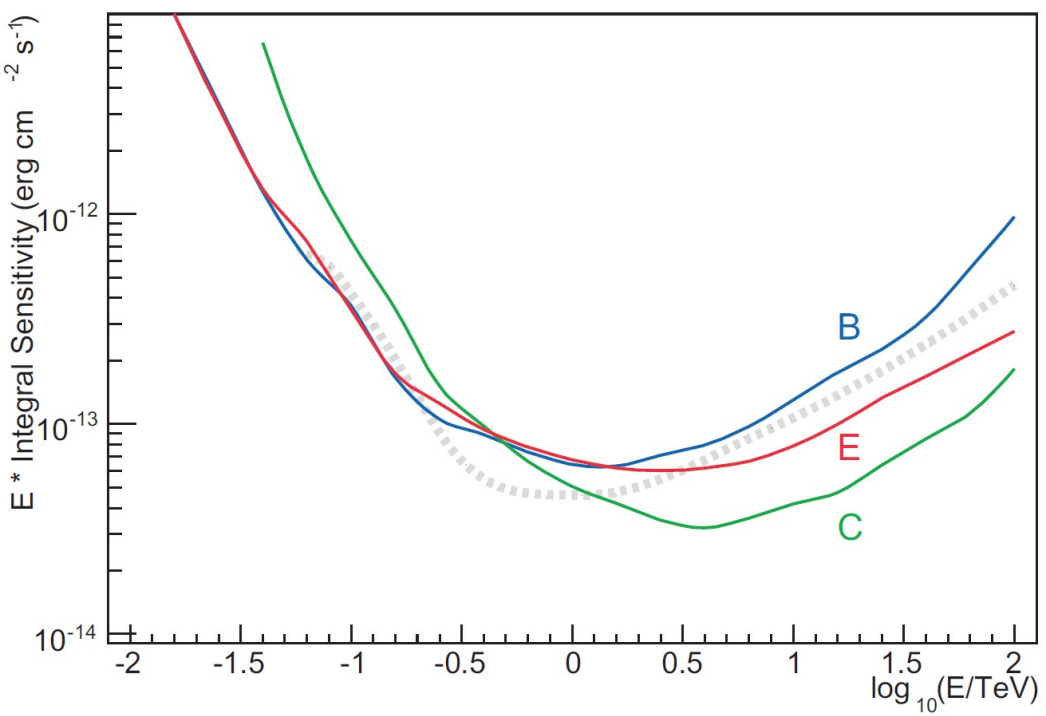
• Dense core of a few big telescopes.
• AGN and pulsars.

• Heart of CTA, mid-sized telescopes.
• Deep TeV sky observations.

CTA: Cherenkov Telescope Array

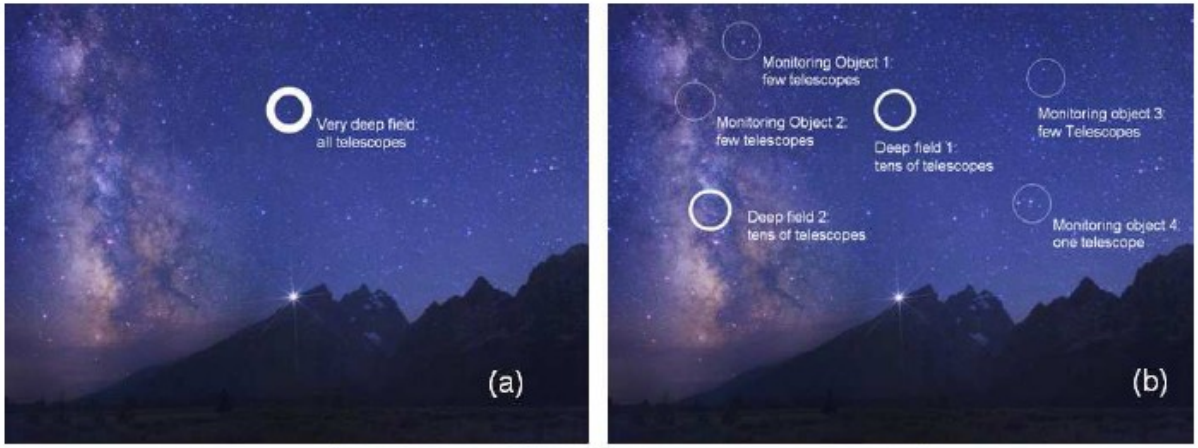
Performances studies for the best layout/site



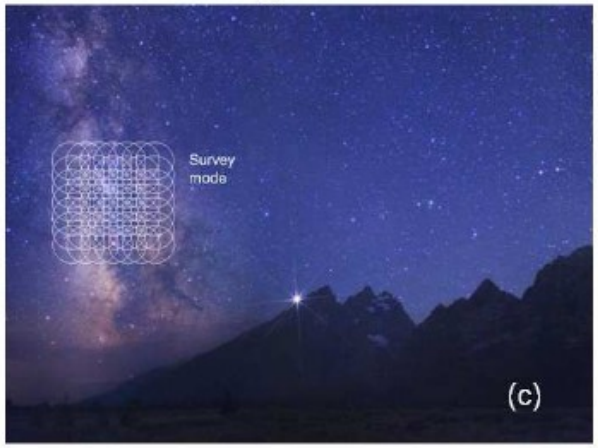


Ongoing studies (ISDC, OBSPM):
- High altitude (3700 m) ?
- Observations with moon light ?

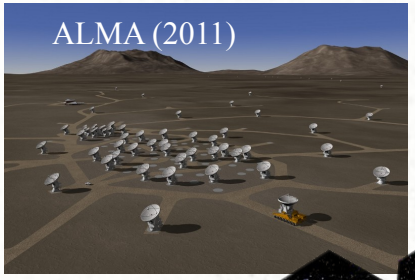
CTA: Operation modes

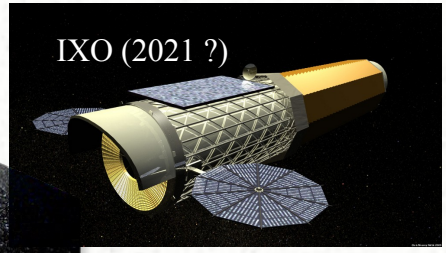


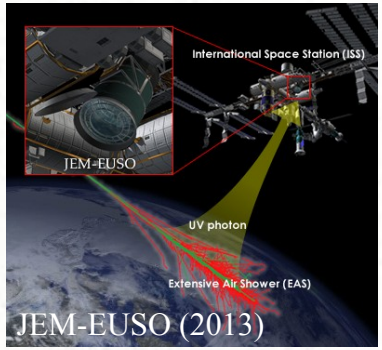
- (a) Deep field.
- (b) Multiple operation modes simultaneously.
- (c) Survey mode.

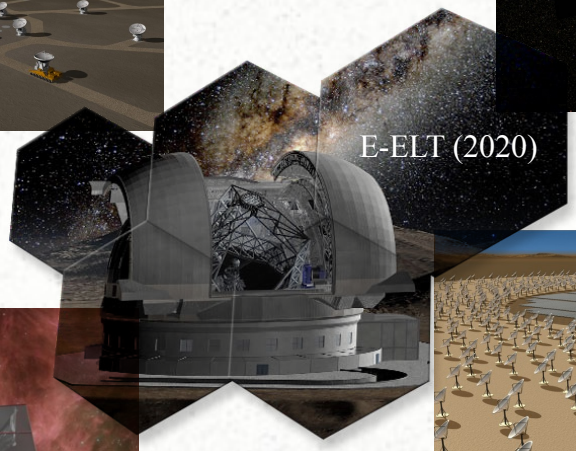


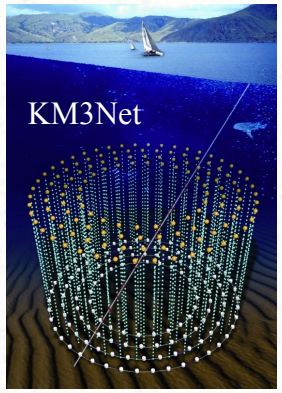
Multi-wavelength/messenger aspects

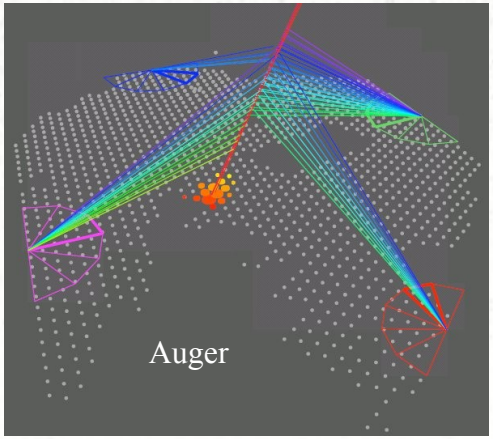




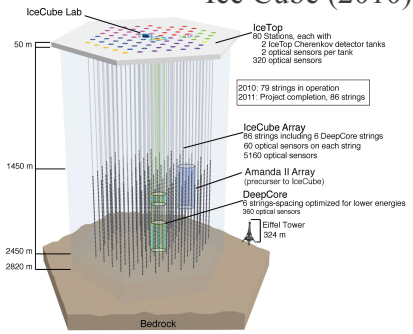




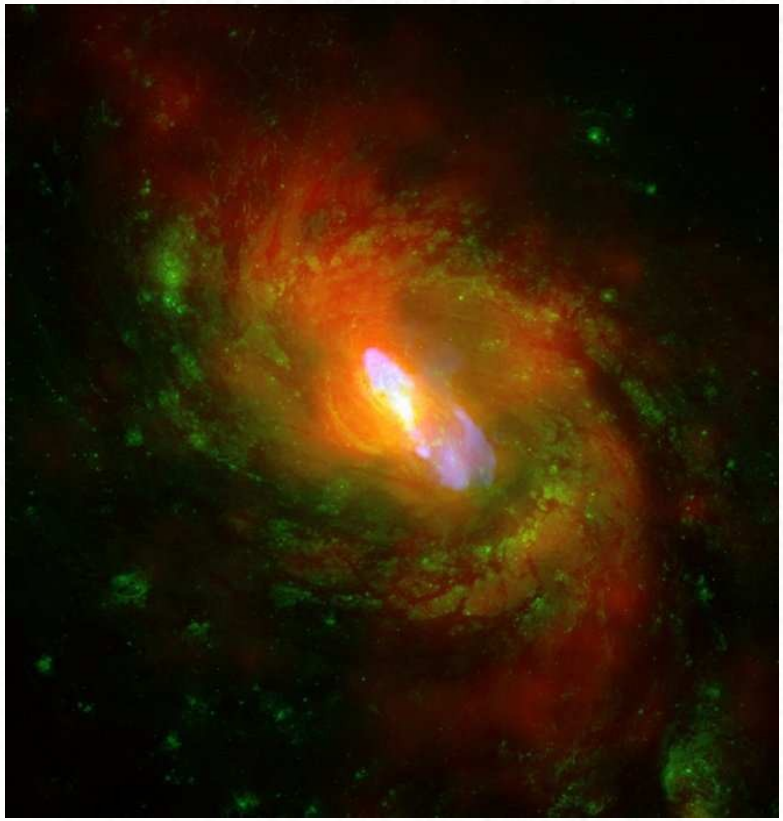




Ice Cube (2010)



Thanks !



NGC 1068: *Chandra*, *HST*, VLA

Cen A: La Silla, ATCA, *Fermi*