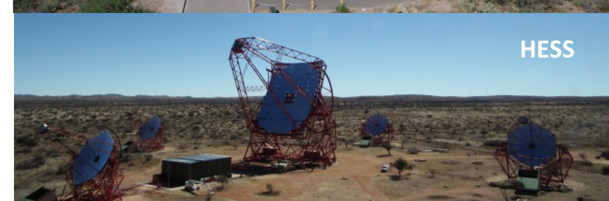




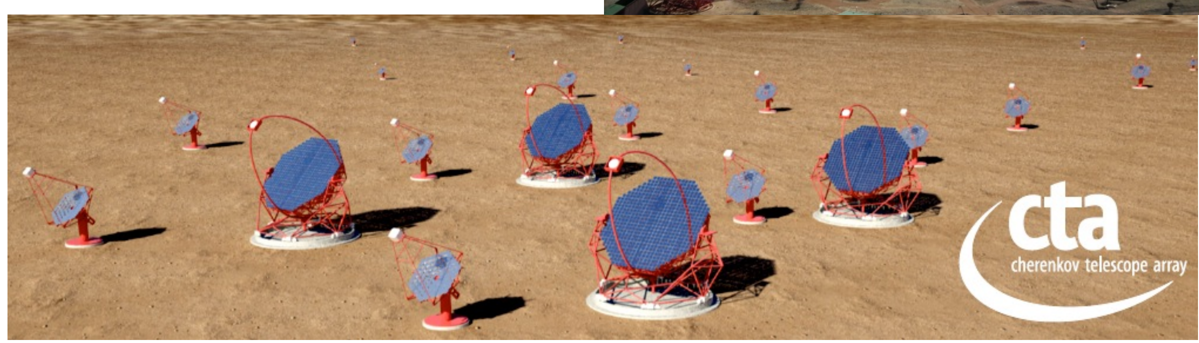




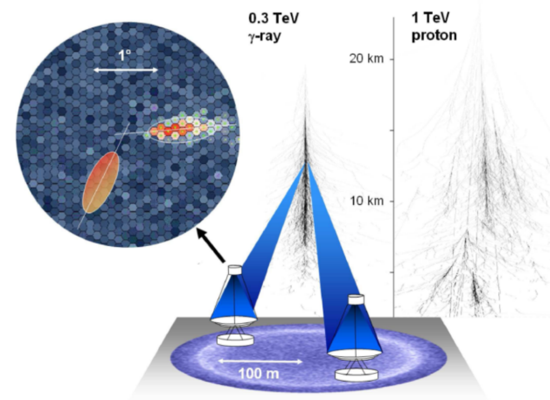

# Synergies Radio and High Energies

Helene Sol
LUTH, CNRS, Observatoire de Paris

SKA-LOFAR Radio Days
Paris, February 11-13, 2014



# Outline



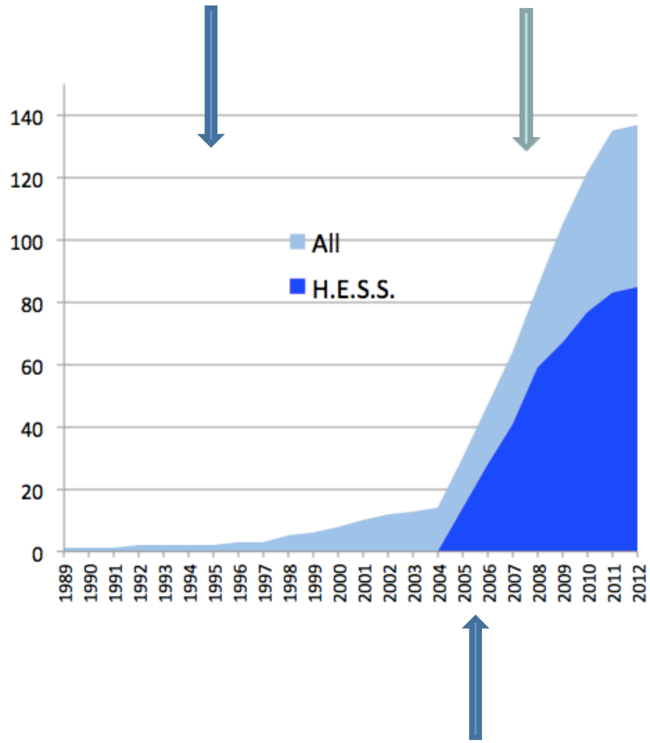

- The Very High Energy universe
- Non-thermal emission: the radio-gamma connection
  - Active Galactic Nuclei
  - SuperNova Remnants & Pulsar Wind Nebulae
  - Pulsars
- Perspectives at VHE with CTA

# The emergence of the Very High Energy (VHE) gamma-ray astronomy

**Previous generation**: Whipple (US), Hegra (G, S, I), CAT/Celeste (F) …

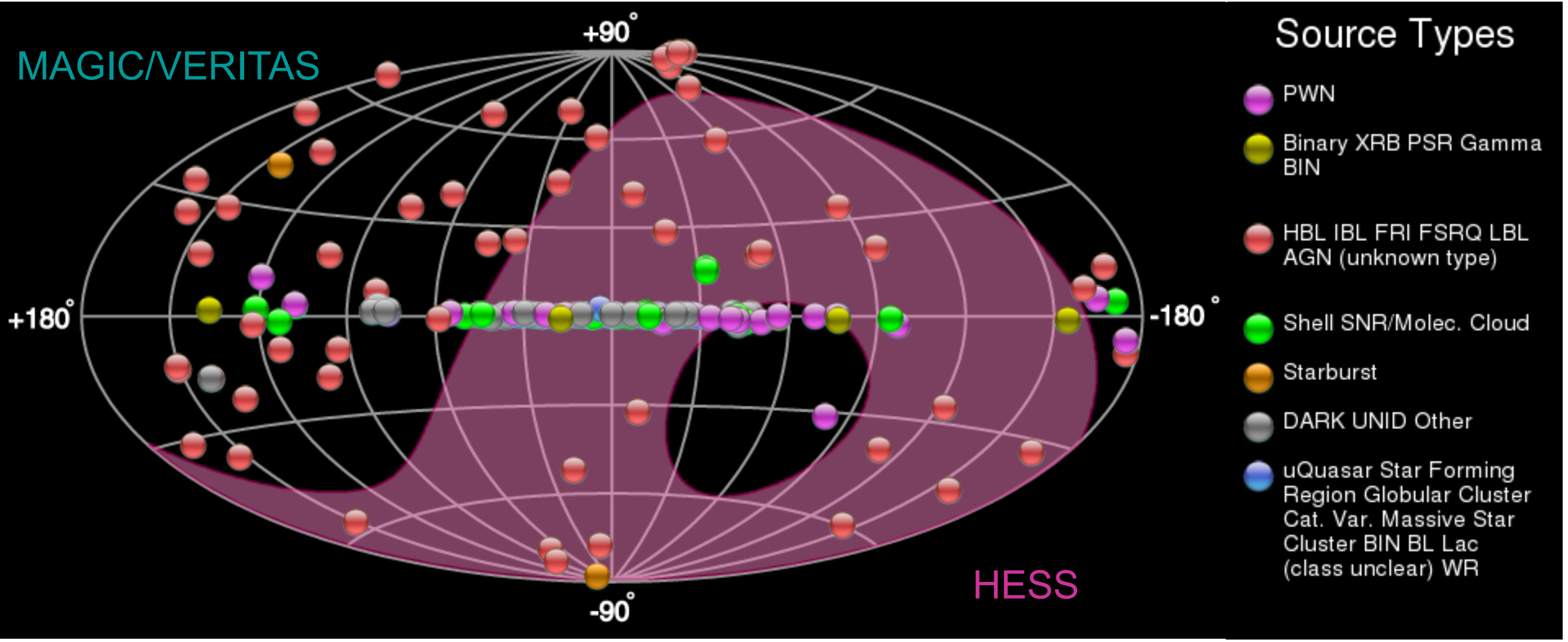
**Current generation**: HESS and HESS II, MAGIC, VERITAS, …

Number of confirmed VHE sources over years




Towards > 1000 VHE sources with CTA

**Next generation**: the global CTA project, from its very first mention in 2005




*147 VHE sources from TeVCat, on-line catalog*

Largest VHE samples to date: PWN & SNR, AGN, UnID sources
Also microquasars & binaries, pulsar, starbursts, clouds & star forming regions
Studying CR (cosmic rays), EBL (extragalactic background light) …
Current limits on Dark Matter, quantum nature of space-time, intergalactic magnetic field …

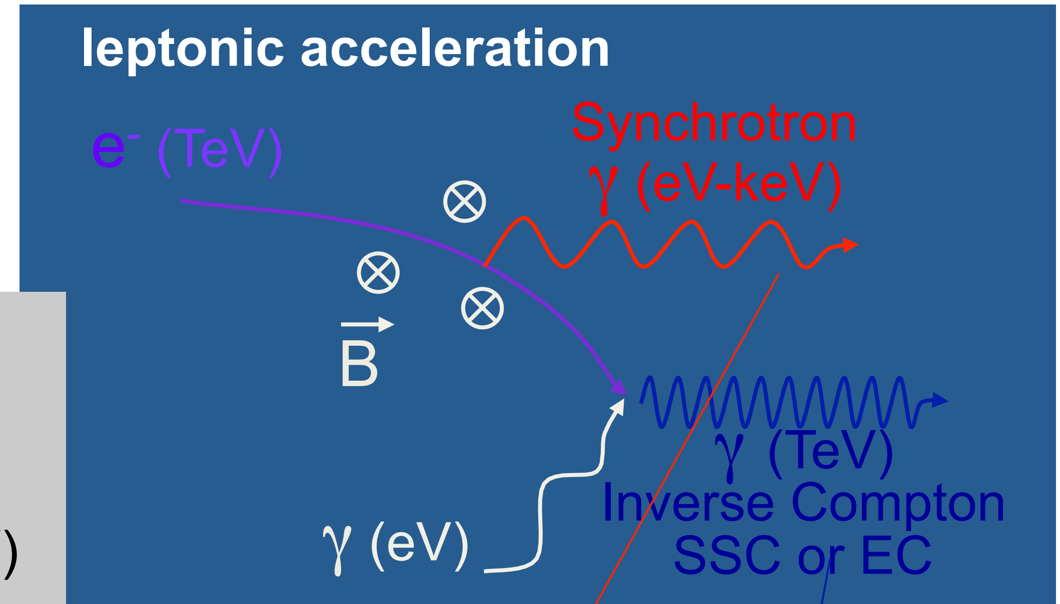
**Cosmic accelerators**:

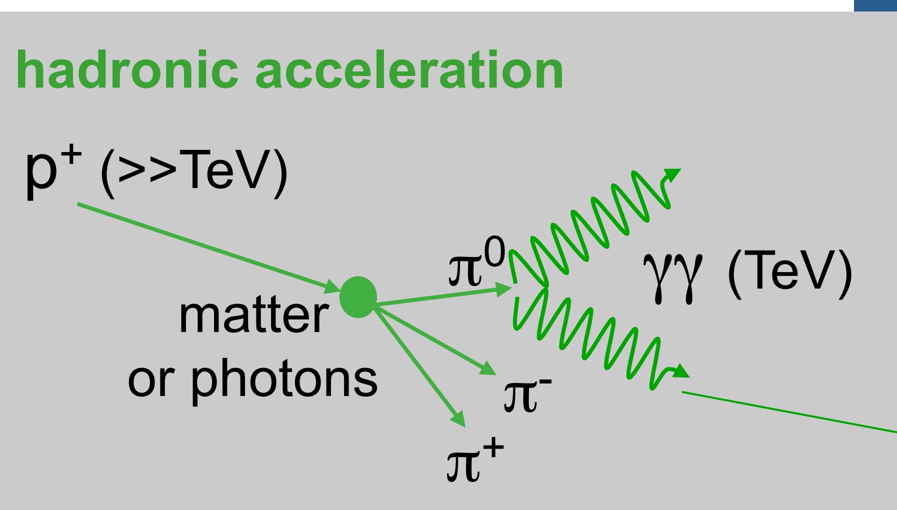
radiate by themselves *(active emittors as SNR, PWN, AGN, binaries, etc)*

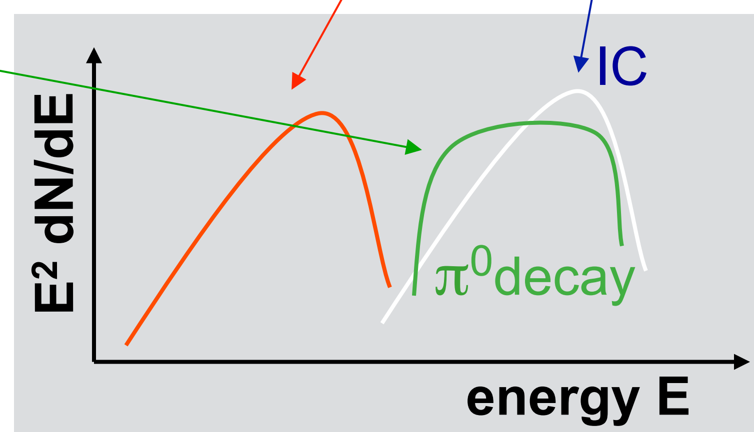
+ inject CR which propagate and interact with ambient gas *(passive emittors as clouds)*

# Radiation from VHE sources

Two main families of scenarios for the emission




VHE sources = often large band emittors

MWL data mandatory to constrain SED/lightcurves and models

Note the challenge of UnId HE/VHE sources!!

# VHE emission processes and MWL radiation

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

  $e + B \rightarrow e + B + \gamma$, in magnetic field B

  $e + \gamma_0 \rightarrow e + \gamma$, 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*

  Includes as well synchrotron radiation of VHE protons (+ possibly curvature).

→ **Such scenarios require efficient particle acceleration and radiation. From acceleration and radiative cooling, they all induce MWL non-thermal radiation down to radio.**

- Other possibility = top-down scenario, annihilation of Dark Matter particles : predictions of supersymmetric theories, Kaluza-Klein scenarios. No such detection yet. A great challenge for the future, which will require MWL data to be conclusive.

→ **Deep radio observations should constrain the picture and contribute to identify possible signatures of top-down scenarios**

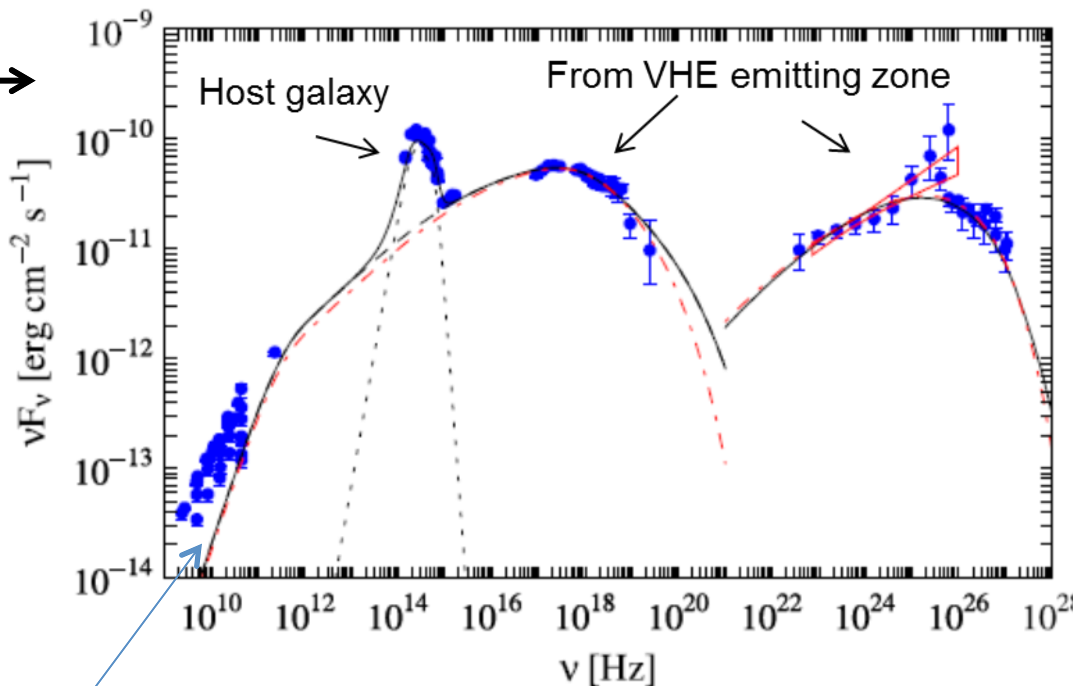
# A typical example of SED of a VHE source, with the two low and high energy bumps

Low activity state of the BL Lac Mrk 501 in 2009:
Standard one-zone SSC
+ host galaxy

VHE zone with
R ~ 1000 $R_G$ ~ 0.1 pc
~ a few VLBA core around 30 GHz
($R_G$ ~1.5 x $10^{14}$ cm)

VHE emission from base of relativistic jet dominated by particles.

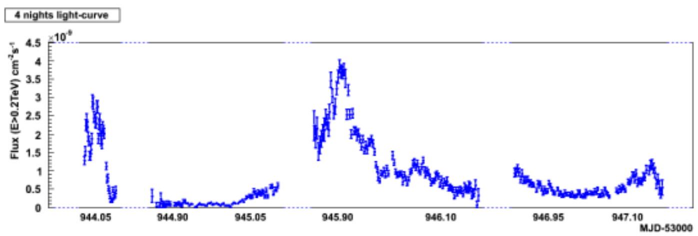
→



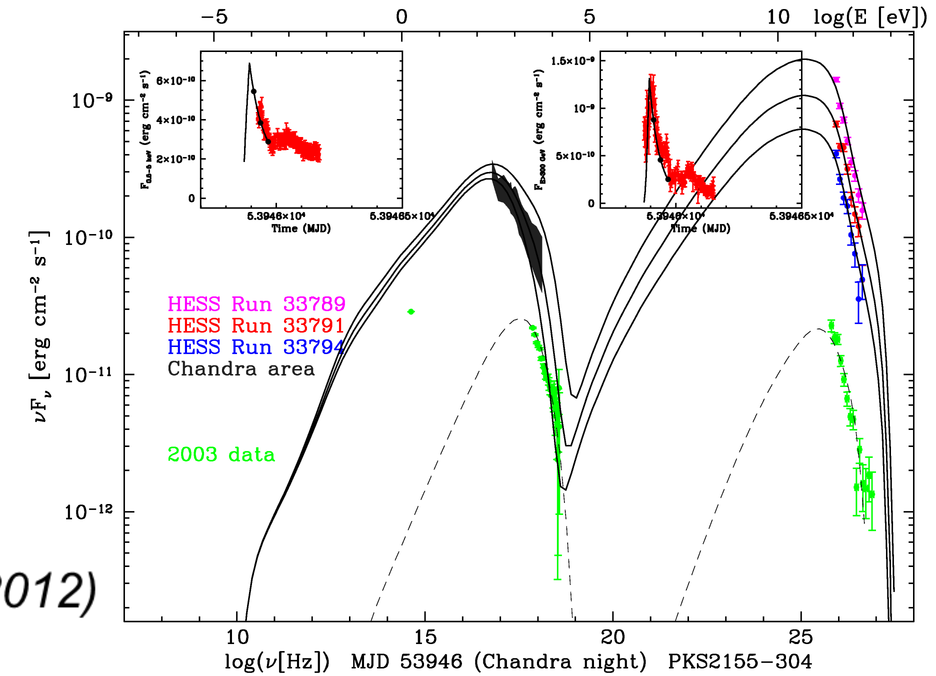

*(Abdo et al, 2011)*

Note: HE and VHE modelling often fit the compact radio component of blazars, but there are usually additional (extended?) radio contributions

# Active Galactic Nuclei: examples of the « elusive » radio-gamma connection




VHE light curve with two extremely big flares in 2006




*(Abramowski et al, 2012)*

Fits of the big flares of PKS2155

by SSC time-dependent modeling (blob + more extended zone):

Reproduce light curves and spectra of flares in X and gamma rays

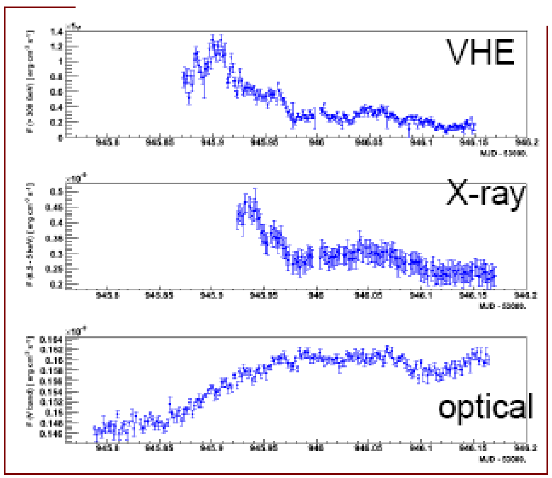
→ X-rays and VHE highly correlated during flares

*(Quiescent state : well reproduced by SSC. Hadronic scenarios can also work.)*

# PKS 2155-304 (*very active state):*

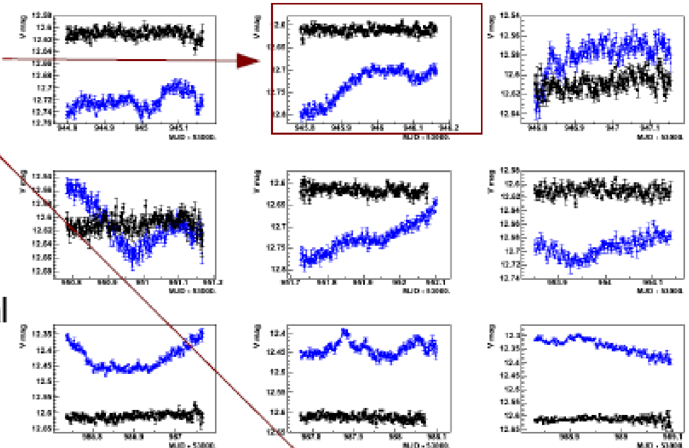
## SSC well reproduce X-VHE flares, but do not explain the MWL behavior in optical and radio ranges

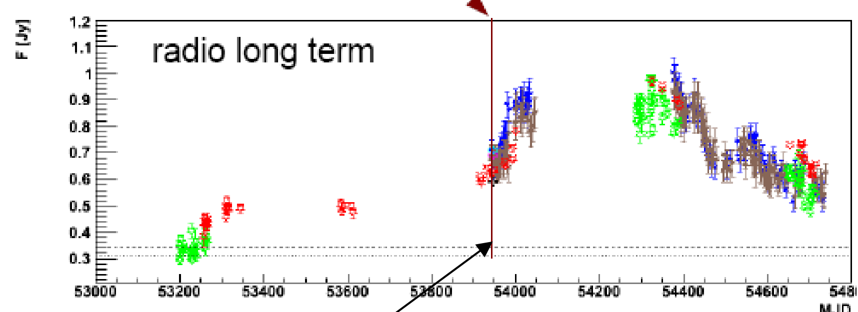
2006 high state




"2nd flare"

optical for several nights






- correlation VHE - X
- overall increase in the optical
- long term increase in radio

[radio data from Nançay, HartRAO, and ATCA]

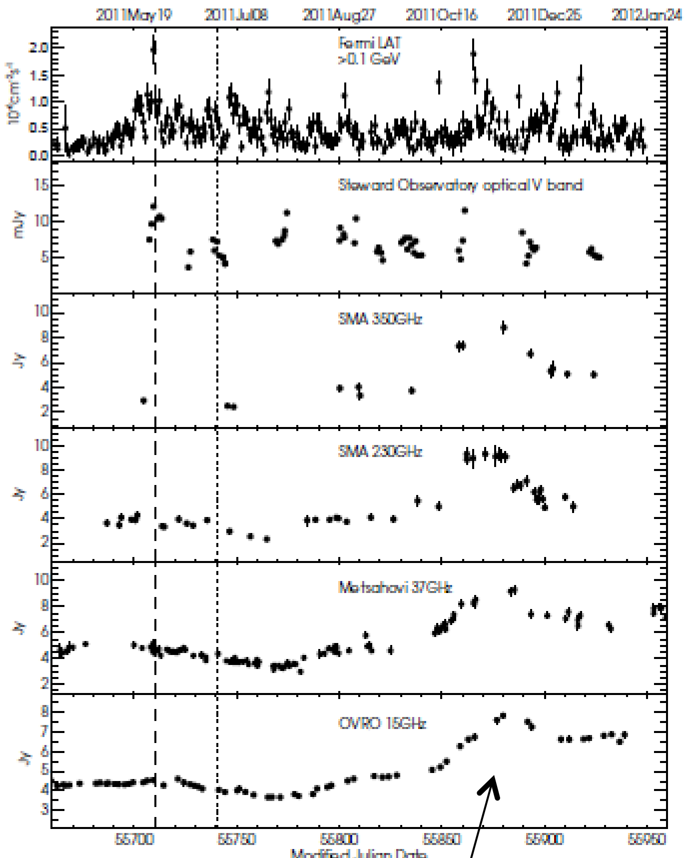
High VHE flares at the beginning of long term increase of radio flux

*(Abramowski et al, 2012)*

# Emergence of new VLBI superluminal components from the core, at the time of TeV flares
# Example observed in BL Lac:

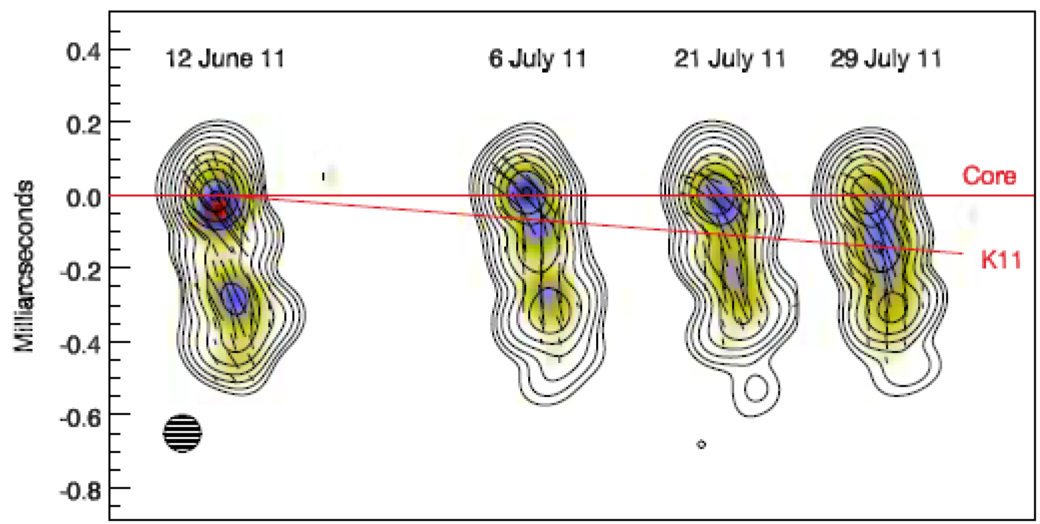
VHE flaring activity on June 28, 2011
*from Arlen et al, 2013*

K11 = new VLBI component

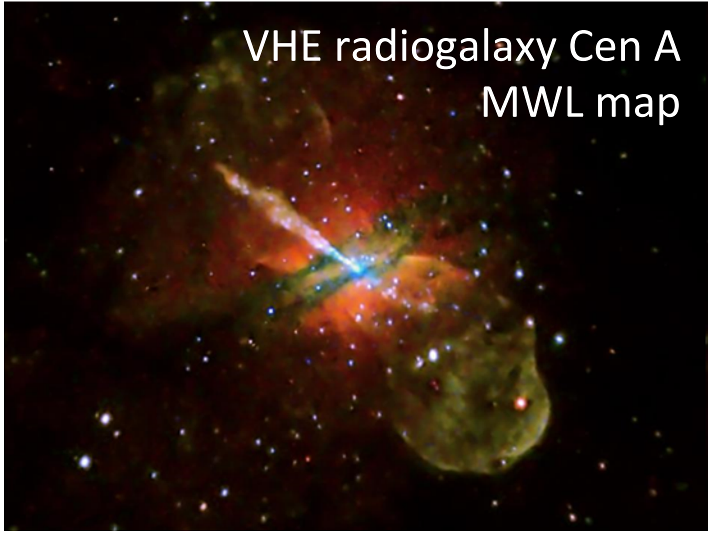



TeV and MWL flare

Radio flare ~ 4 months later



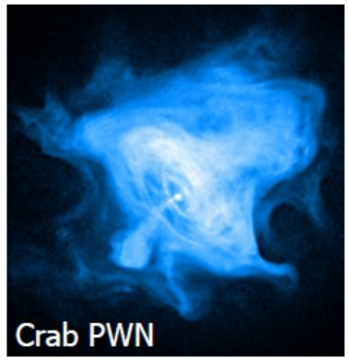
# Radio-gamma synergy for AGN

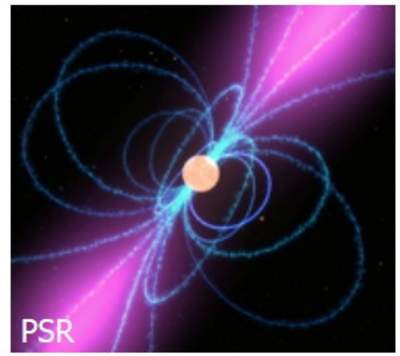


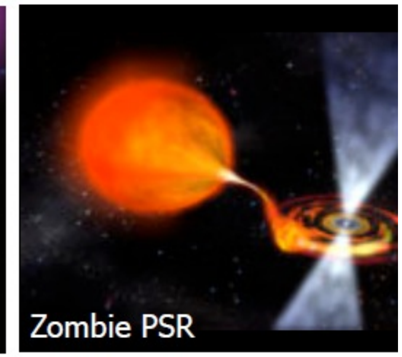

- Elementary bricks for VHE emission: OK
- Still to be reached: a **comprehensive global picture of the VHE zone** (location, dynamics, properties, links to other AGN components
- Understanding the link between HE/VHE and radio properties seems mandatory for that
- Radiogalaxies detected at VHE have very different properties in radio (M87, Cen A, NGC 1275 …): requires further studies
- Are radio and HE/VHE emitting particles: produced by the same large-band accelerator? produced by different (although correlated) accelerators? Deduced one from the other (radio = time evolution of gamma)?
- Coordinated monitoring to find the causality effects → **revisited global view of AGN**, **new light on AGN unification schemes**

# SNR, PWN and pulsars

**SNR, PWN, Pulsar, Recycled Pulsar**


| | | | |
|---|---|---|---|
| **Acceleration at:** | | | |
| Front shock | Relativistic shock | Polar cap, slot gap ? | Polar cap, slot gap ? |
| **Powered by:** | | | |
| Explosion Energy | PSR rotation | Electric field generated by PSR rotation | Momentum transfer (accretion) |
| **Acceleration lasts[1]:** | | | |
| few kyrs | few 10 kyrs | few 100 kyrs | ~ Myrs |

→ After Death Timescale

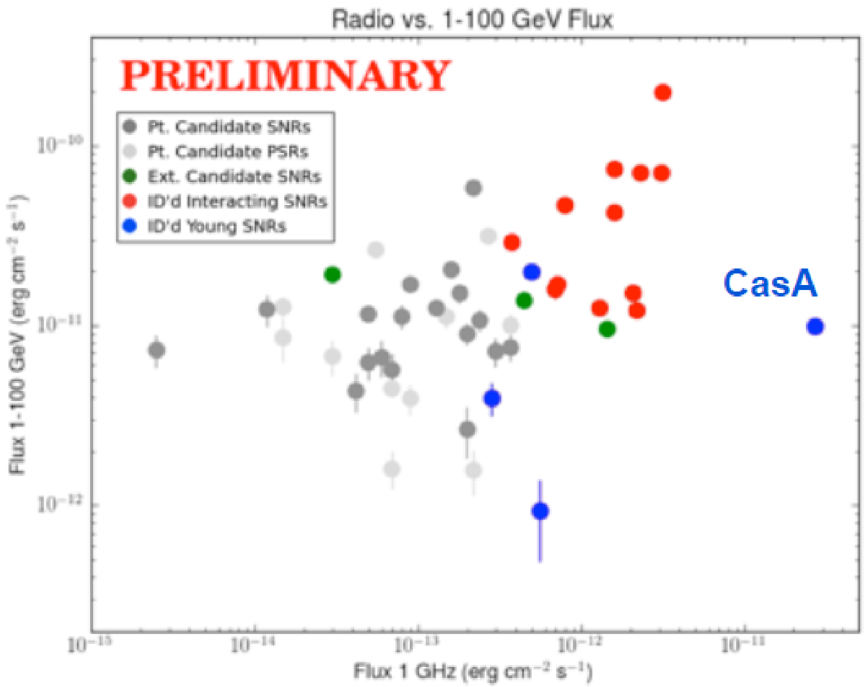
(1): Acceleration of high energy particles (~GeV-TeV)

*Slide from F. Acero, 2014*

# Radio-gamma connection


Interaction between PWN & SNR
Can constrain parameters (B, …)
(Acero+12)

**Young SNR**: have shell-morphology
**Older ones**: interact with molecular clouds




**Trend:**
**LAT-detected SNRs are also radio bright**

**Interacting SNRs show a general correlation, suggesting a physical link**

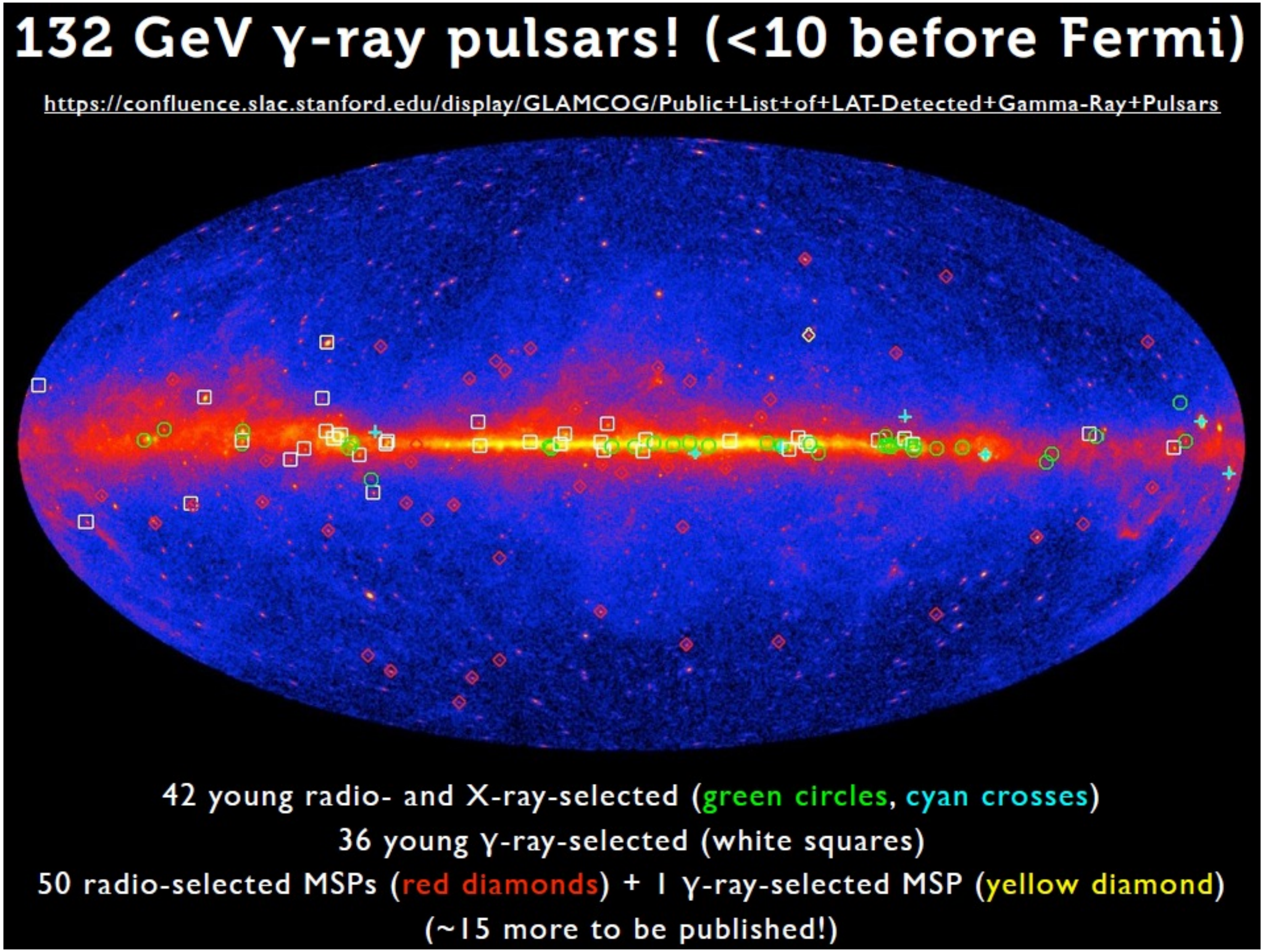
**Young SNRs show more scatter**

**Some new candidates fall along this potential correlation**

*from F. Acero, 2014*

# Pulsars

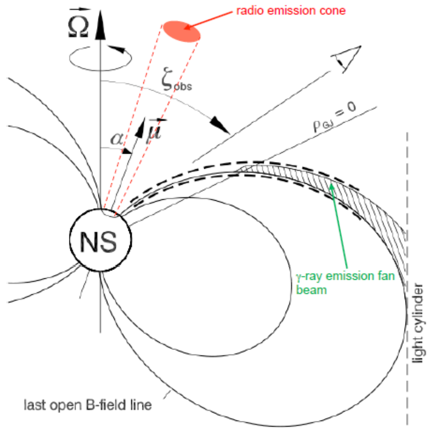
At HE:




At VHE: only one seen so far, the Crab pulsar

*(from L. Guillemot & I. Cognard, 2014)*

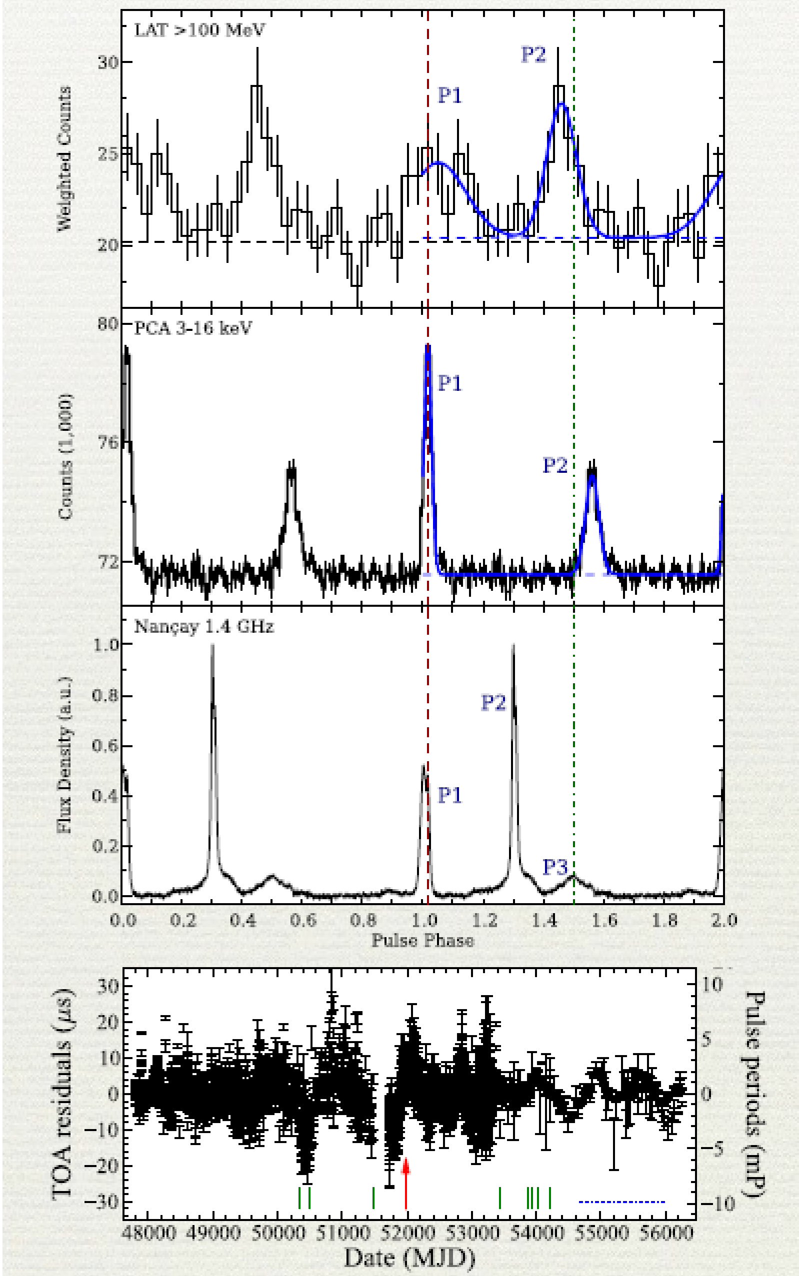
# Radio-gamma connection




Blind **search** of HE/VHE pulsars : difficult as long as the rotation period is not known
Radio data provide decisive information for the **timing models** to be applied (rotational frequency and time derivatives, plus orbital parameters for binary pulsars)

Towards a **global comprehensive view of pulsar magnetospheres, their geometry and evolution.**

*(from L. Guillemot & I. Cognard, 2014)*

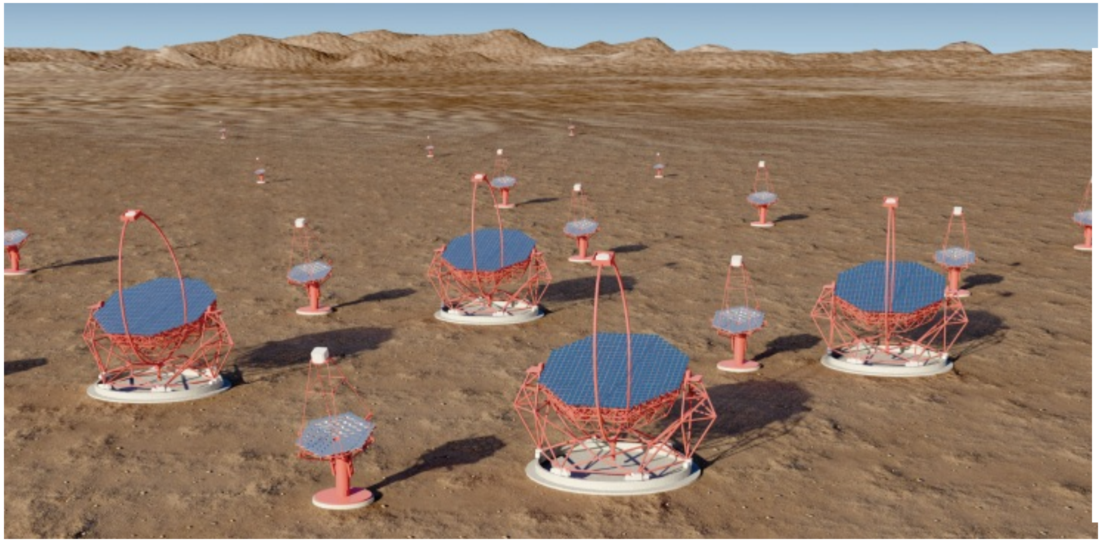


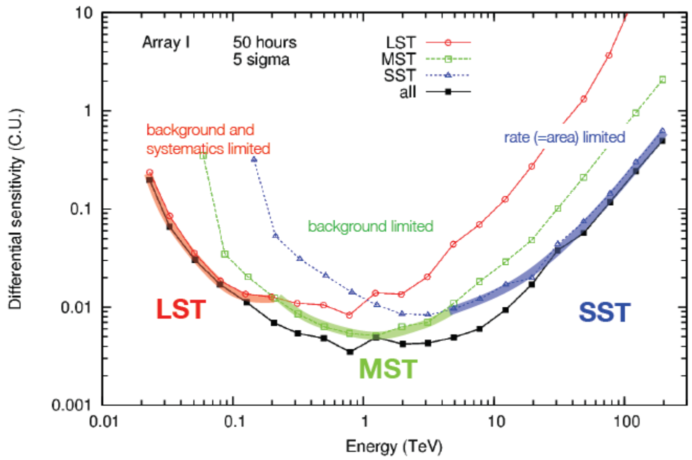

Radio, X-ray, and gamma-ray observations of B1821-24A (Johnson et al. ApJ 778, 106, 2013)

# Next generation of VHE astronomy with CTA, Cherenkov Telescope Array

- 10-fold increased sensitivity at TeV energies (mCrab)
- 10-fold increased effective energy coverage
- Larger field of view (5° to 10°)
- Improved angular resolution
- Full sky coverage (North and South)

→ Should reach more than 1000 sources, hundreds of AGN of various types, better maps of galactic sources …






One possible configuration for the future southern array:
- Low-energy section with 4x 23 m parabolic tel (LST) at > some 10 GeV
- Core-energy array with 23 x 12 m DC tel (MST) in the range 100 GeV-10 TeV
- High-energy section with 32 x 5-6 m DC or SC tel (SST) at multi TeV energies.

# Perspectives with CTA

- Site development & first telescopes: in 2015/2016
- First sciences: from 2016/2017
- Full array: horizon 2020
- A user facility, proposal-driven observatory
- **Agenda** in agreement with LOFAR and SKA. X and gamma satellites?

- Will deepen or open **new fields** at VHE, with **interesting radio-gamma synergies**, among them:

  - clusters of galaxies,
  - starbursts galaxies,
  - EBL and IGMF,
  - GRB and Gravitational Wave events,
  - ISM, shocks, and Cosmic Rays acceleration, propagation, and impact
  - star forming regions
  - dark matter search
  - population of non-identified HE and VHE sources

Large infrastructures as SKA, LOFAR, CTA and space missions in X and HE offer by themselves garanteed scientific return in several astrophysical and cosmological fields + high discovery potential in fundamental physics.

Synergies in basically all fields.

Global network to manage coordinated programmes and alerts could help to optimize the general scientific return.

*(or bilateral MoU?)*