The connection between the radio and the very-high-energy sky.

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Laboratoire de l'Univers et de ses Théories

H.E.S.S.

cta cherenkov telescope array

Outline

Observing the sky in VHE γ-rays

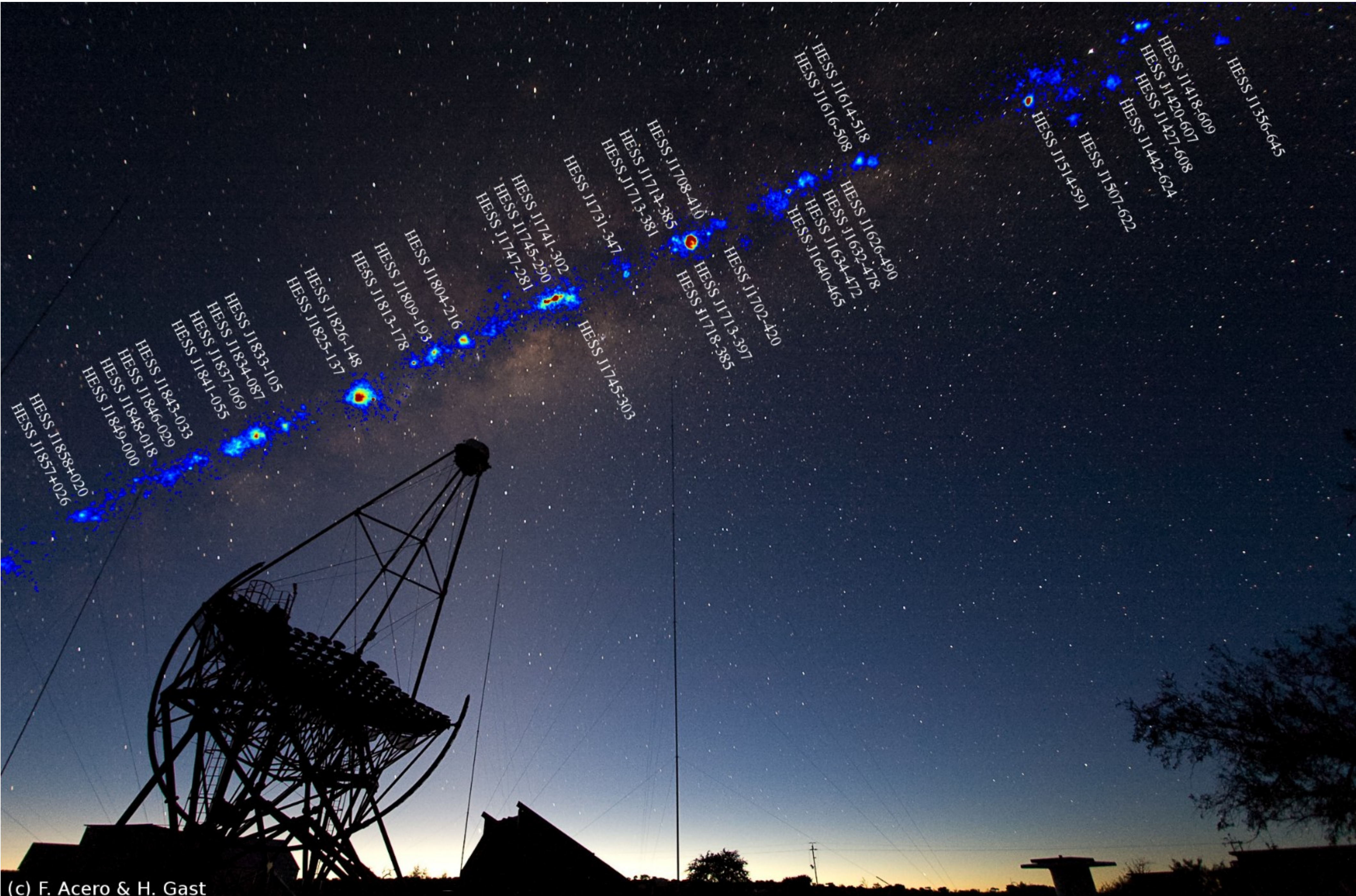
Links with radio observations :

-> e.g. radio galaxies & blazars

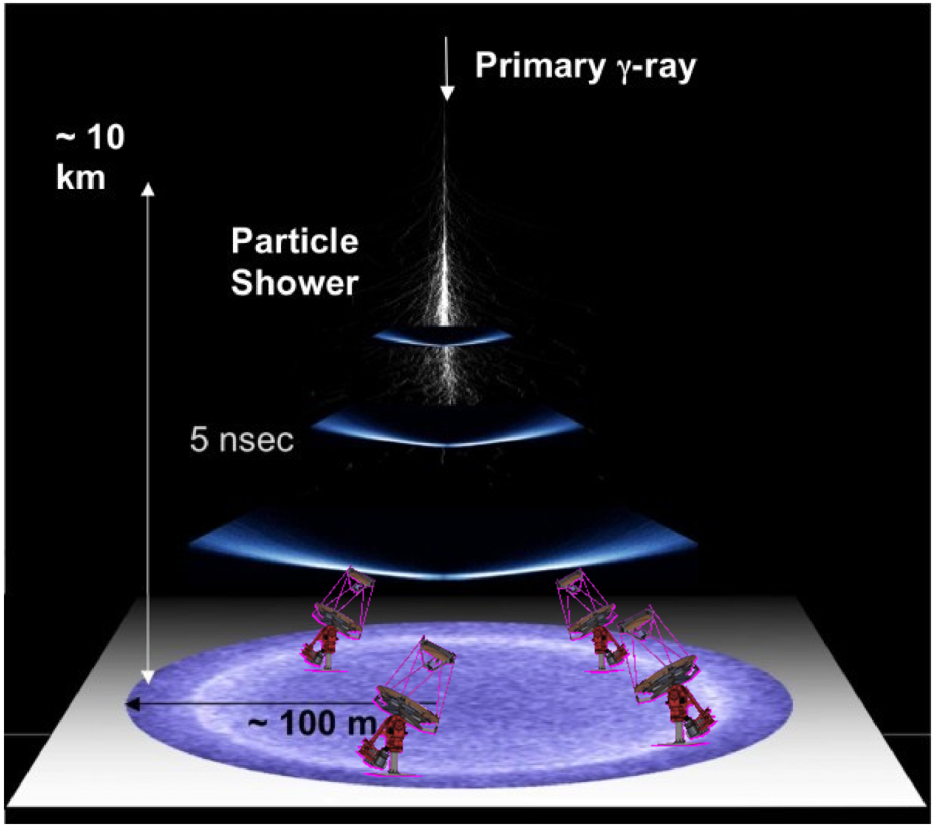
-> e.g. pulsars

Outlook : CTA Key Science Projects

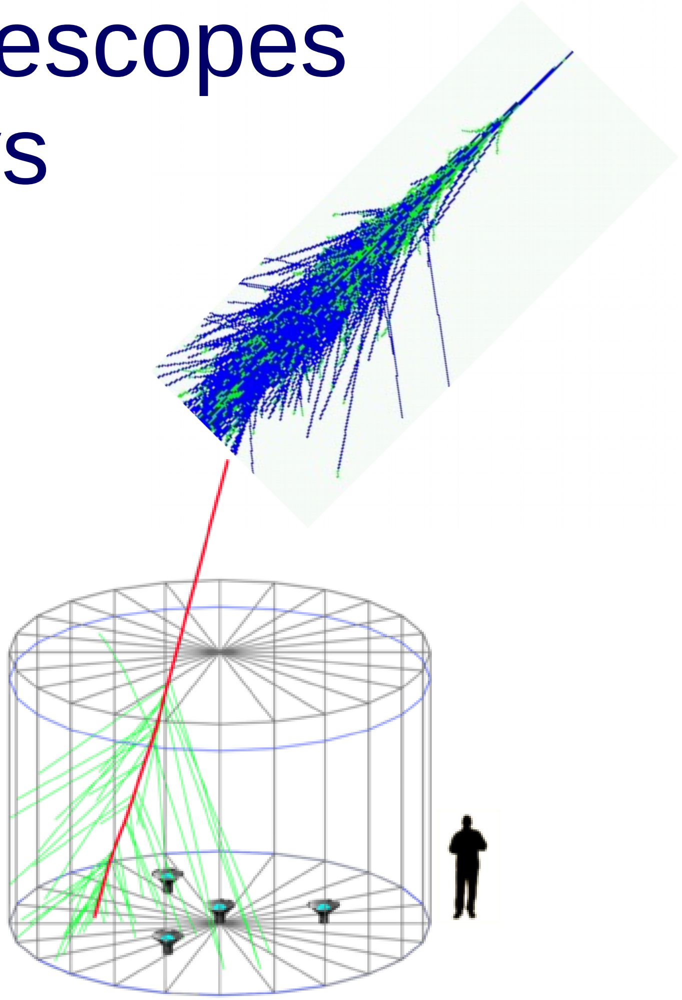
Observing the sky in VHE γ-rays



Imaging Air Cherenkov Telescopes & Air Shower Arrays



Cherenkov light from gamma-induced air shower (CTA Collaboration)



schema of a HAWC detector unit

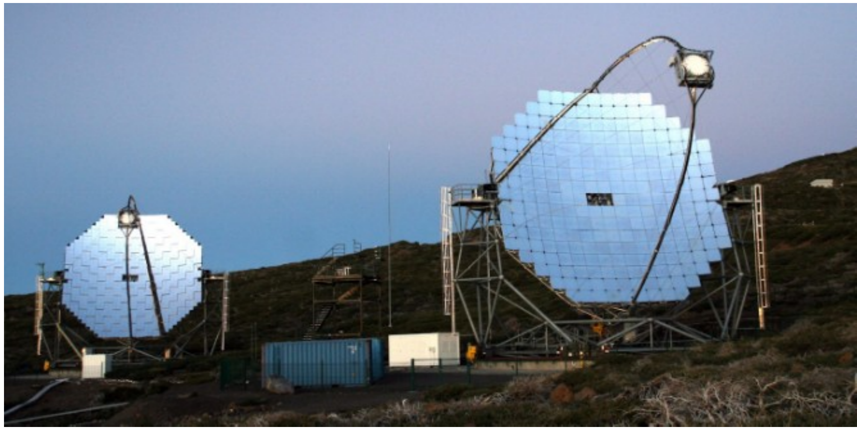
	IACT arrays	air shower arrays
duty cycle	~10-15 %	> 90 %
field of view	~ 5 deg x 5 deg	~ 2 sr
angular resolution	~0.06 deg (>10 TeV)	~ 0.1-0.2 deg (>10 TeV)
energy resolution	~ 20%	~ 50% (>10 TeV)
energy threshold	a few 10 GeV	a few 100 GeV

currently operational instruments

the largest IACT arrays :

H.E.S.S., MAGIC, VERITAS (run by international consortia)

- 2 to 5 telescopes of 12 to 28 m diameter
- design Davies-Cotton or parabolic; cameras equipped with PMTs
- wide field of view (3 - 5 deg); angular resolution several arc min.
- energy range of a few 10 GeV - a few 10 TeV



The MAGIC Array in La Palma.

The VERITAS Array in Arizona

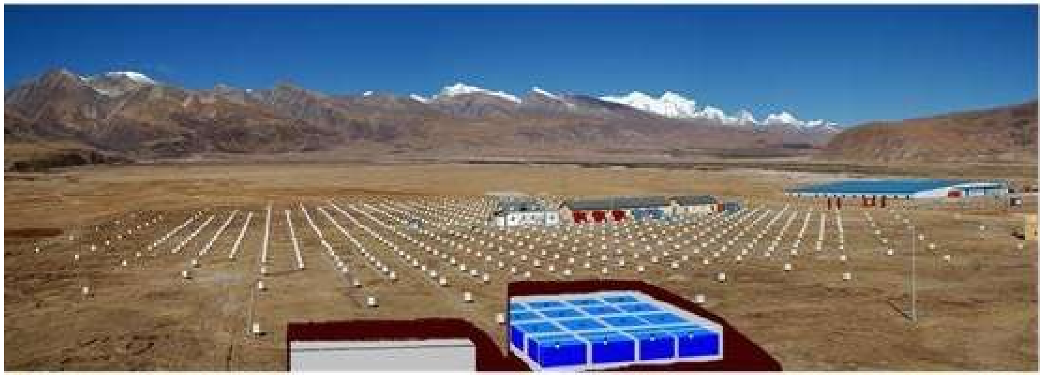
The H.E.S.S. Array in Namibia

currently operational instruments

the largest air shower arrays :

Tibet AS Gamma (China/Japan   1999)

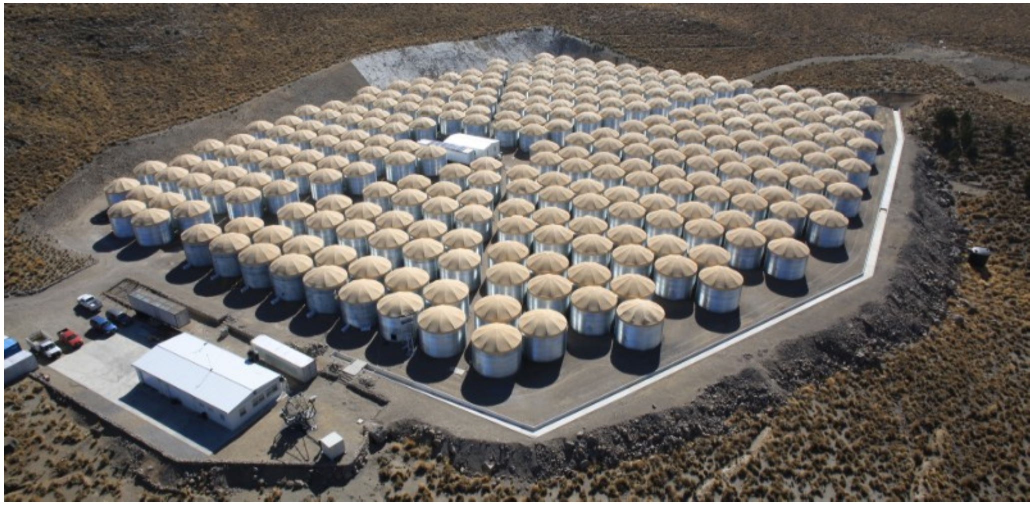
- array in Tibet consisting of ~600 scintillation detectors and underground muon detectors (water Cherenkov detectors)
- energy threshold of a few TeV



The Tibet AS Gamma experiment in Tibet.

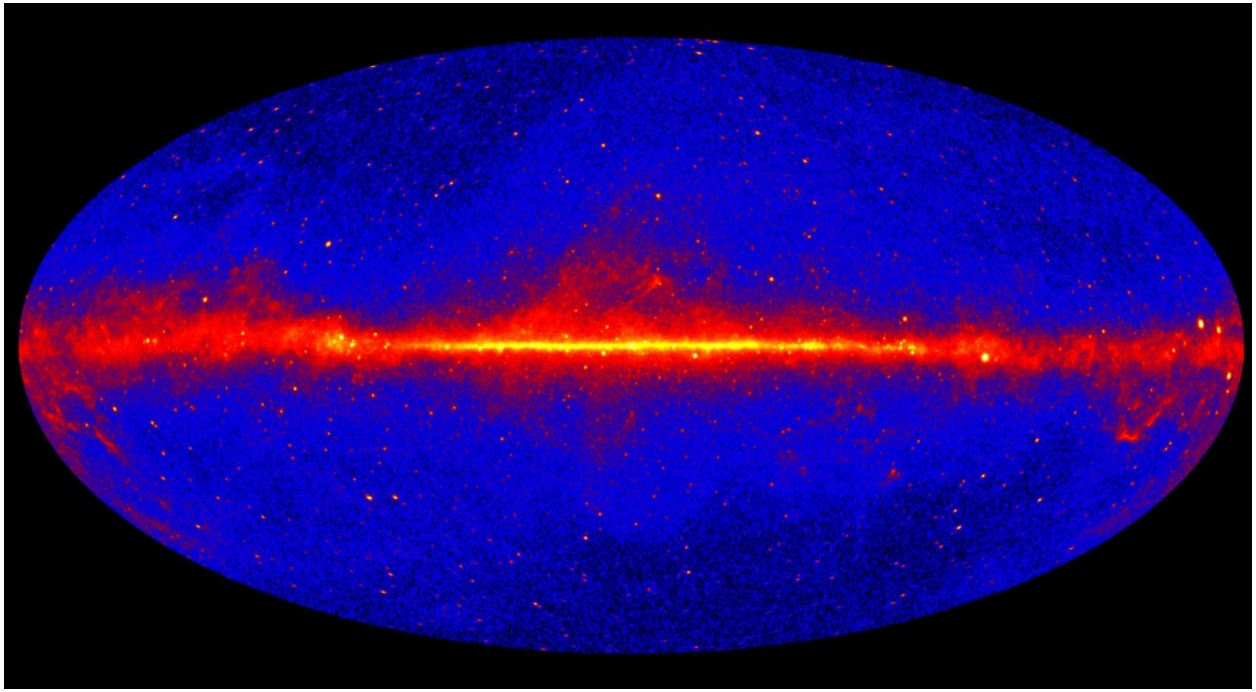
HAWC (US/Mexican collaboration 2015)

- array of 300 water Cherenkov tanks at high altitude
- instantaneous field of view covering 15% of the sky; 2/3 of the sky observed during each 24 h period
- energy threshold of a few 100 GeV, ~10 x more sensitive than Tibet array at a few TeV



The HAWC Observatory in Puebla, Mexico. Photo credit: INAOE

the high-energy sky (~GeV)



9 years of Fermi-LAT data > 1 GeV, Gal. Coord.

Fermi-LAT
11 years of operation:

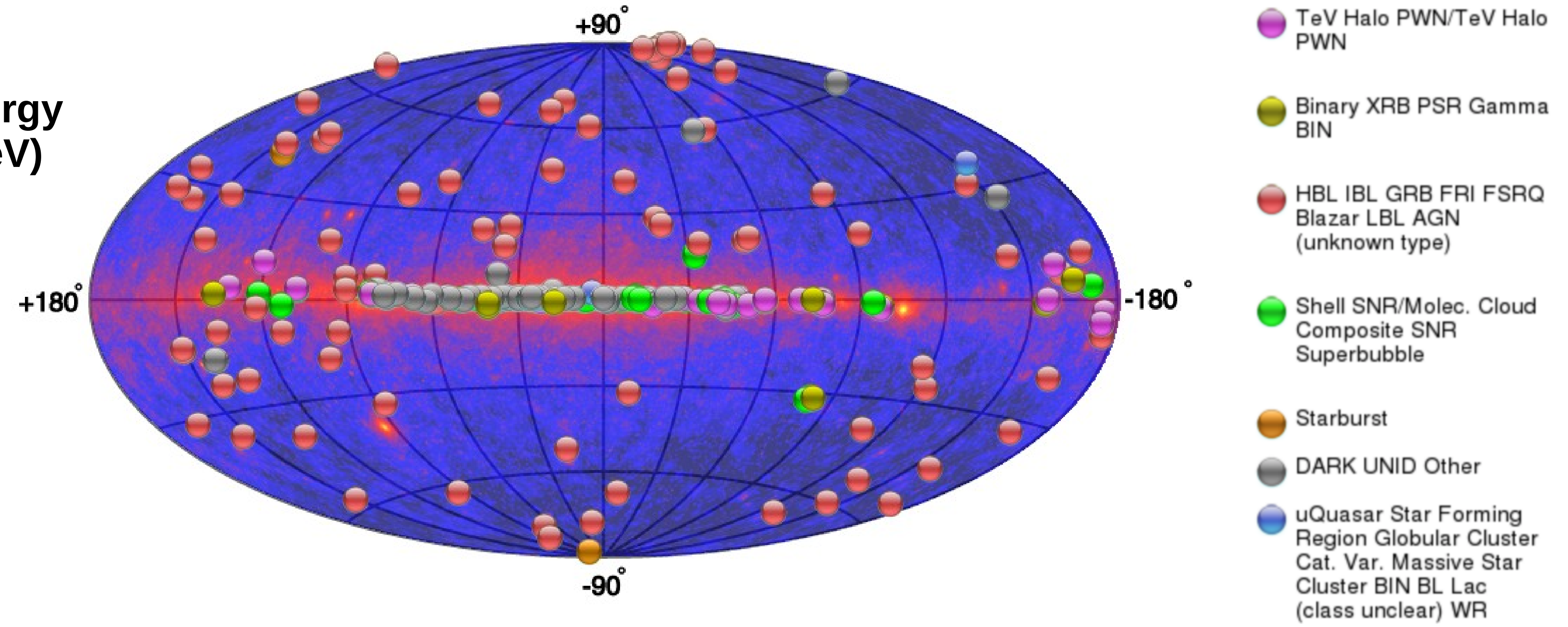
~3000 AGN

~200 GRBs

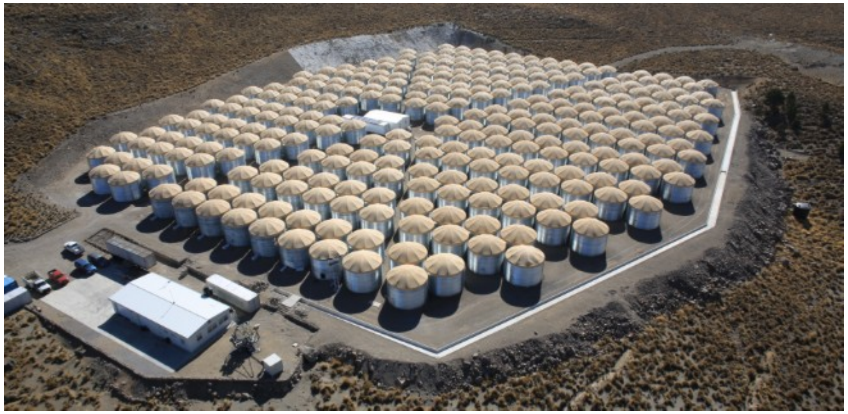
> 200 pulsars

several 10 PWN, SNR

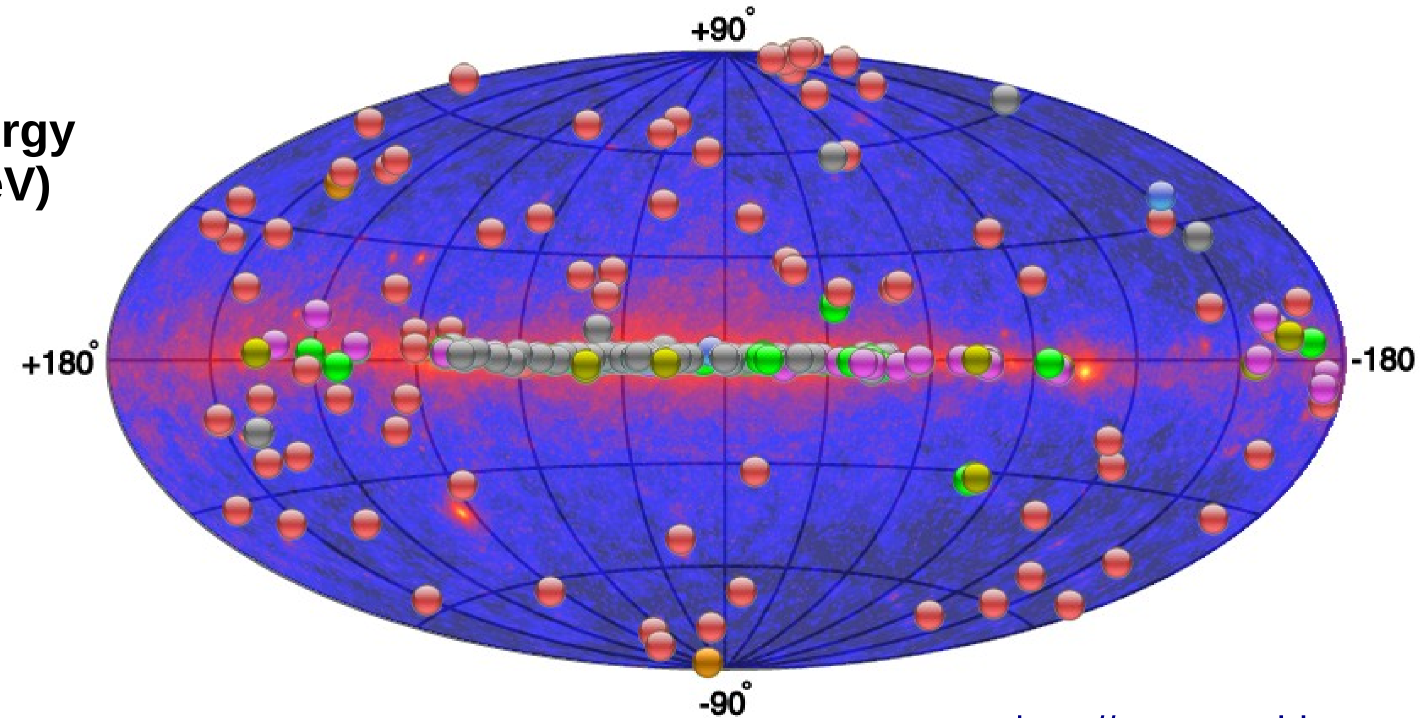
the very-high-energy sky (~TeV)



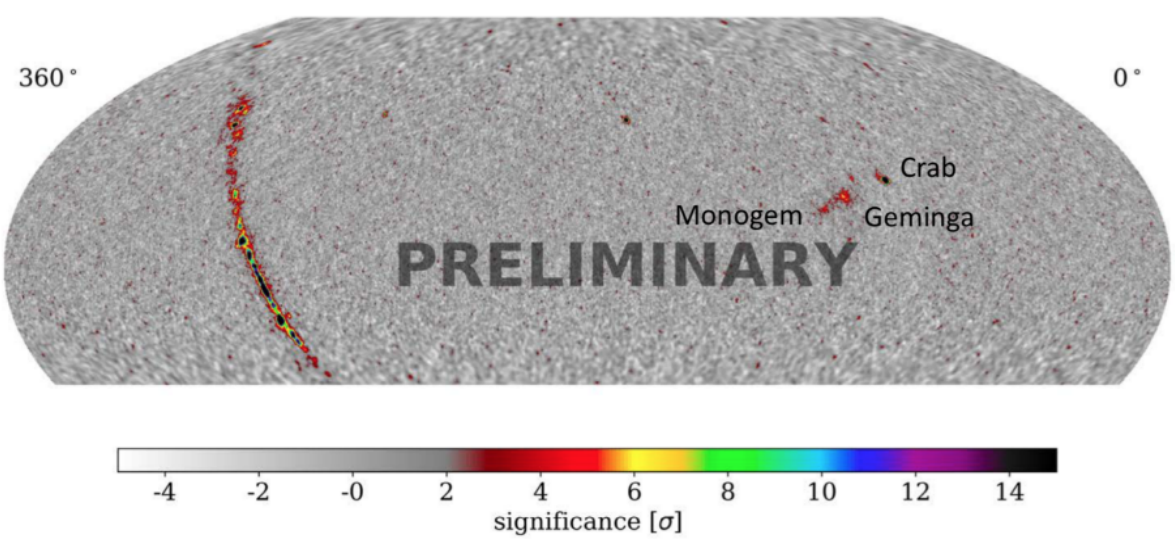
225 sources detected at VHE (75 AGN, 3 GRBs, 4 pulsars, 66 SNRs & PWNe, 11 binaries, 65 unidentified)
http://tevcat.uchicago.edu



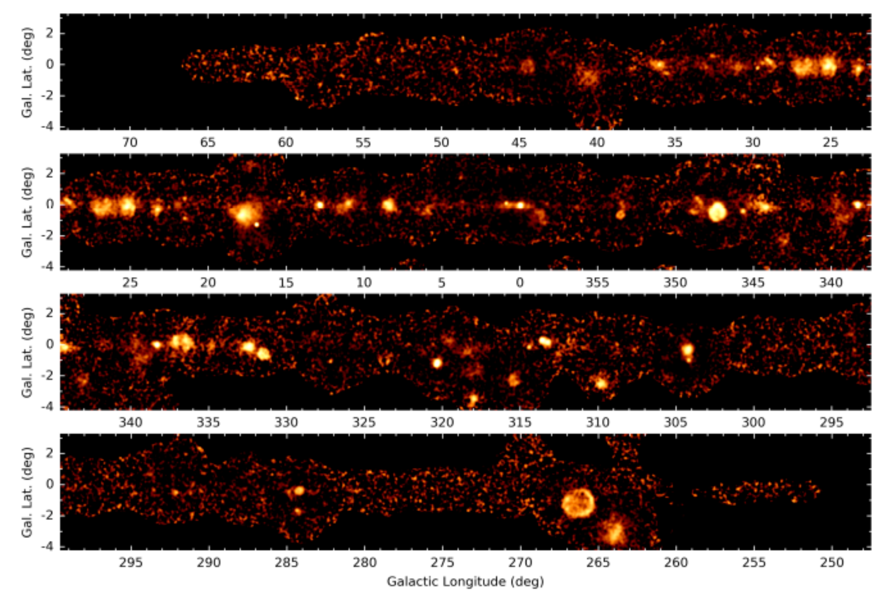
the very-high-energy sky (~TeV)



http://tevcat.uchicago.edu



HAWC sky map (1346 days), K. Tollefson, ICRC 2019, Equ. Coord.



HESS Galactic Plane Survey : 78 sources / 2700 hr

Cherenkov Telescope Array

(Int. Consortium of 1500 members from 31 countries , operations planned for ~2025)

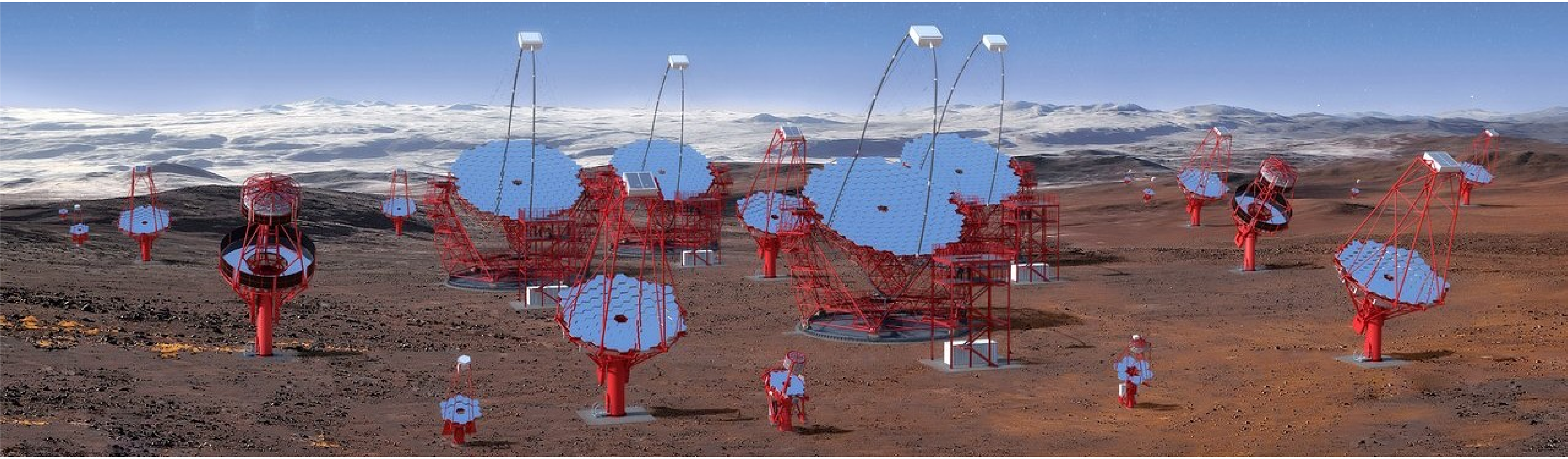
- Two arrays with four different types/sizes of telescopes: Canaries/La Palma (final layout 4 LSTs, 15 MSTs), Chile/Paranal (final layout 4 LSTs, 25 MSTs, 70 SSTs, several SCTs) for full-sky coverage

- Different telescope sizes permit coverage from a few 10 GeV to a few 100 TeV with high resolution (down to arc minute) and high sensitivity.

- **First open VHE observatory** : proposal driven observations, with a fraction of the observation time reserved for Key Science Projects by the Collaboration; data will be publicly released

- current status: tests with the first LST built in La Palma; infrastructure planning for Chile

https://www.youtube.com/watch?v=0QgnKA5AUDY



Cherenkov Telescope Array - prototypes

LST (23m) La Palma - Spain

MST (12m) Zeuthen - Germany

SCT (10m) Arizona - USA

ASTRI SST (4m) Etna - Italy

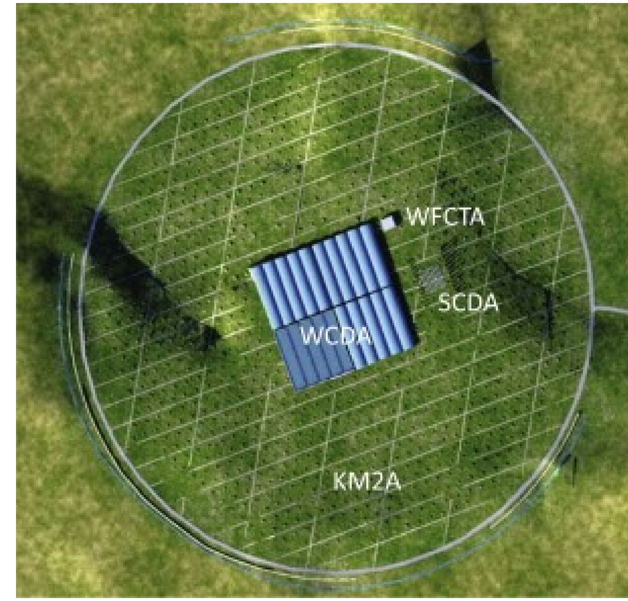
GCT SST (4m) Meudon - France

future air shower arrays

LHAASO (China , partial observations started in 2019)

- array at altitude for cosmic-ray and γ-ray physics
- γ-rays > 200 GeV to 1 PeV; sensitive mostly above a few TeV
- large array of scintillators and water Cherenkov tanks (KM2A); central large water Cherenkov detector (WCDA); 12 wide-field Cherenkov telescopes (WFCTA)
- survey of ~56% of the whole sky in a day

-> full operations by 2021

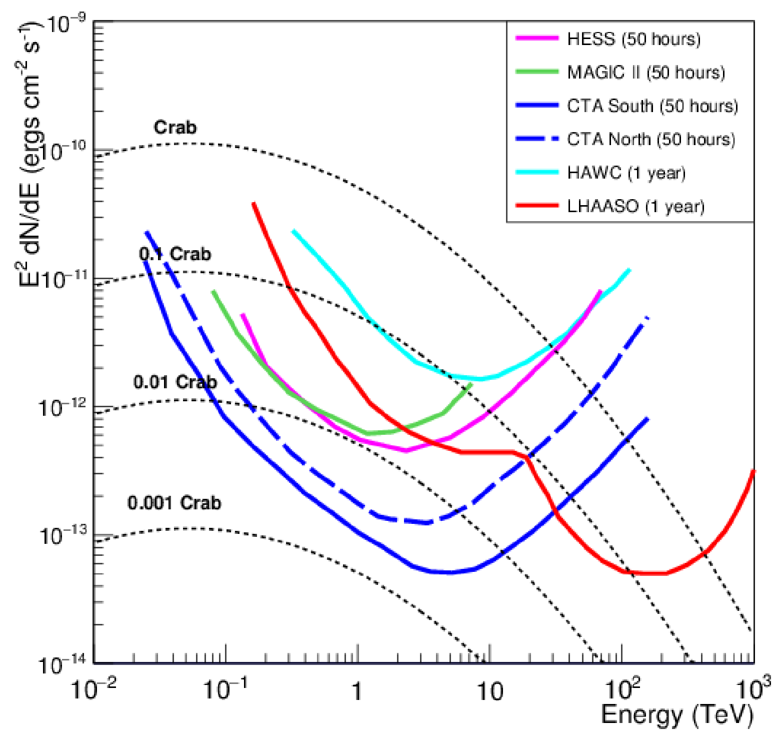


LHAASO array, ~1 km² surface.

Southern Wide-Field Gamma-ray Observatory
(Int. Collaboration , foreseen for 2026)

- similar technique as LHAASO and HAWC (water Cherenkov detectors), exact design to be decided
- close to 100% duty cycle and ~ sr field of view
- at altitude in South America
- a few 100 GeV to a few 100 TeV

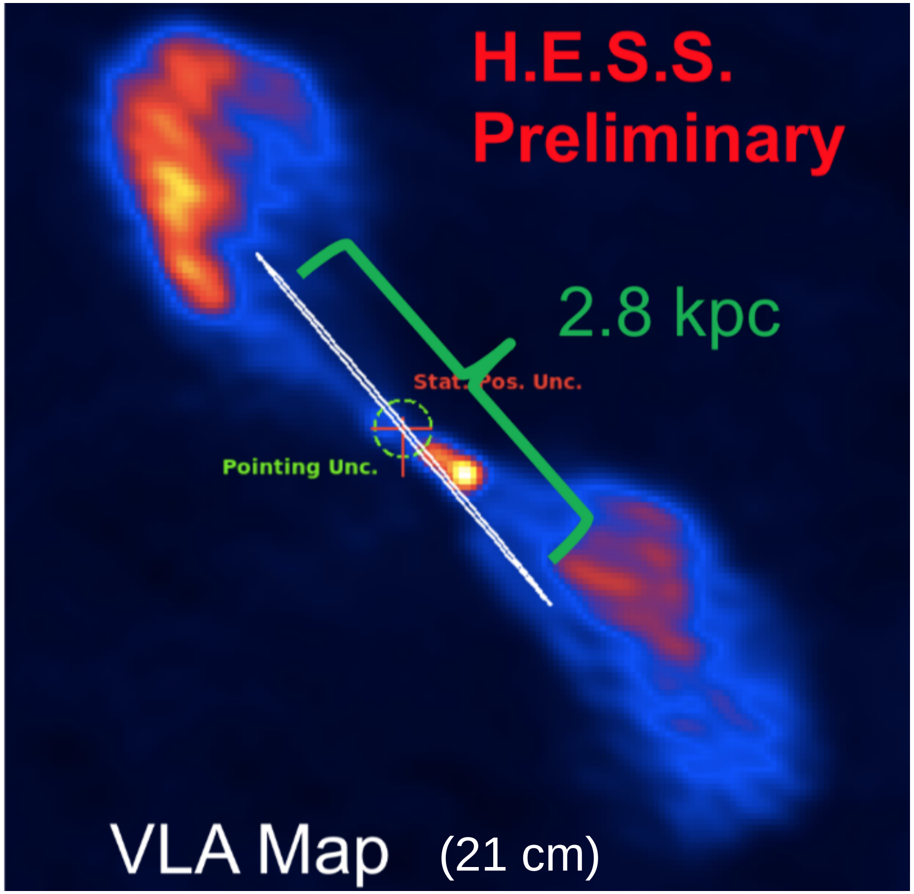
-> complementary to LHAASO and to the future CTA



Links with radio observations :

e.g. radio galaxies & blazars

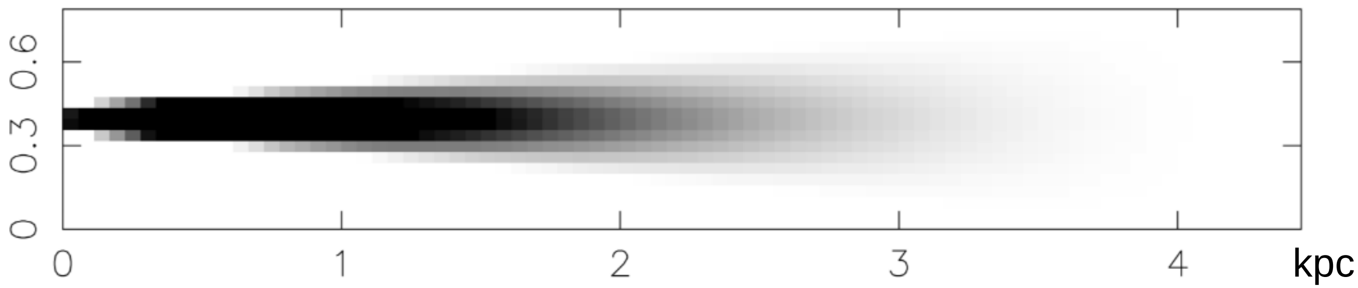
extended VHE emission from Centaurus A



- extended emission above 240 GeV : elliptical Gaussian preferred at TS = 19.4 over point source
- aligned with the kpc-scale jet
- extension of ~ 3 kpc

  -> highly energetic particles over large distances

  -> requires efficient re-acceleration mechanisms

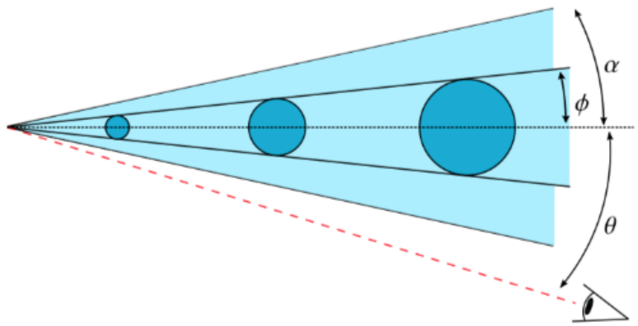


Upscattering of starlight along the kpc jet ?

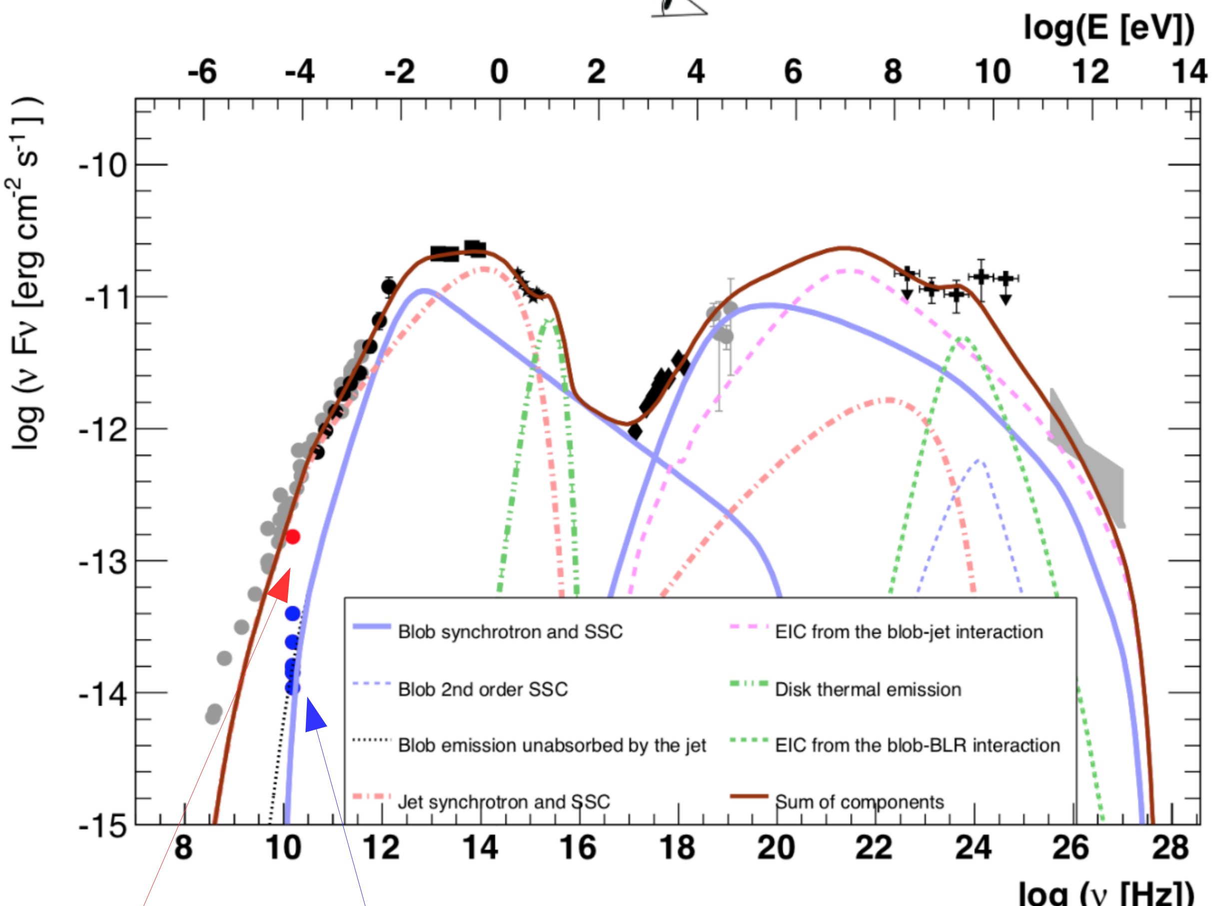
Figure 8. A map of 1-TeV IC emission from the jet of Cen A (assuming $\theta = 50^\circ$, $\beta = 0.51$, as described in the text). The image can be seen to be significantly brighter close to the active nucleus and the centre of the host galaxy (left-hand side) compared to the model synchrotron image of Fig. 1. Axis labels are in kpc.

SIMULATION, Hardcastle & Croston, 2011

Linking VLBI and VHE in Ap Librae



"blob-in-jet" model



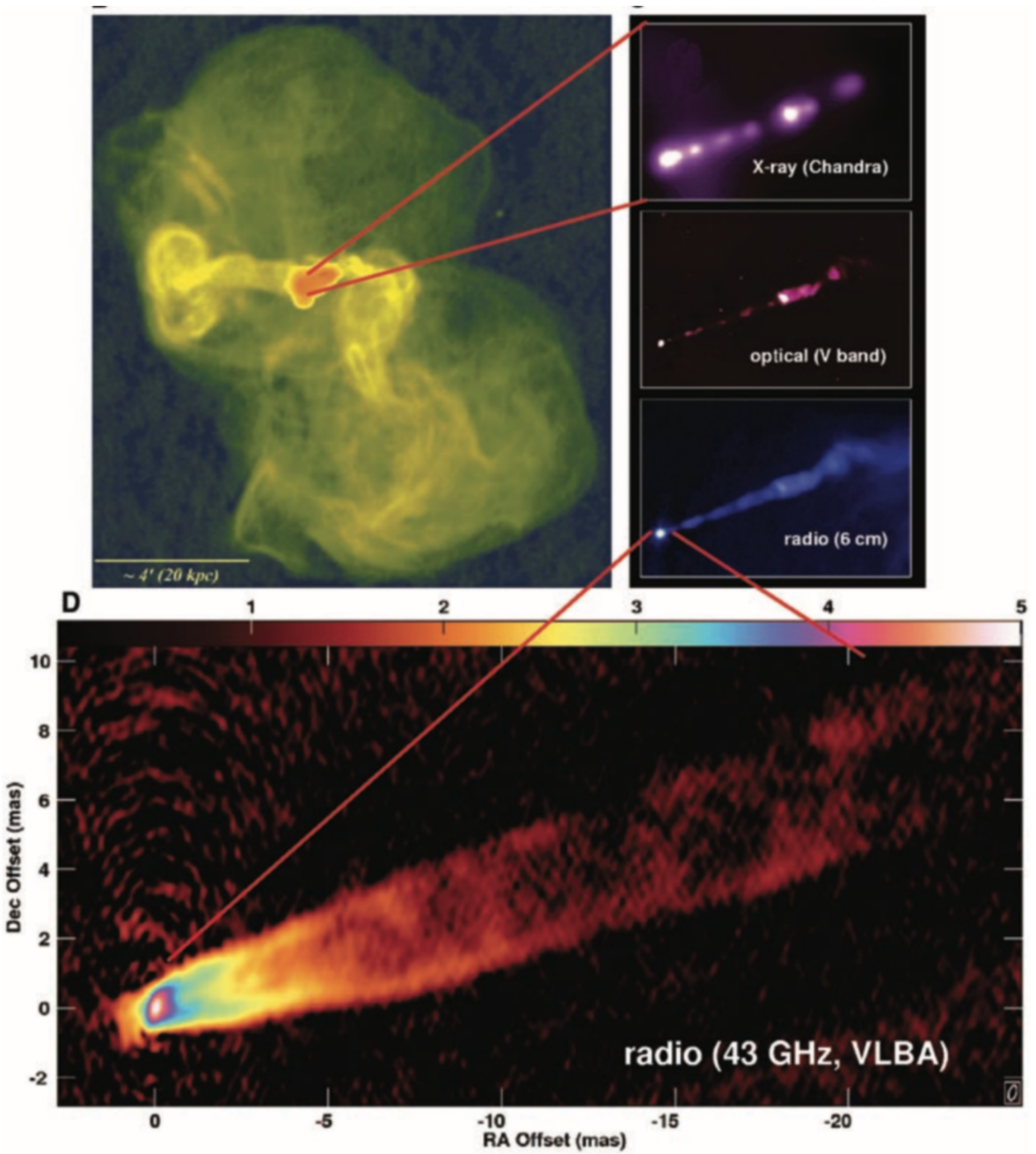
- Ap Librae is one of the few "low-frequency peaked" BL Lac type blazars detected at VHE.
- Combining information from VLBI features (MOJAVE) and high-energy emission (HESS)
- high-energy emission mostly due to "blob" electrons up-scattering "jet" photons.

VLBI radio core ("jet")

VLBI radio knots ("blob")

O. Hervet et al. 2018

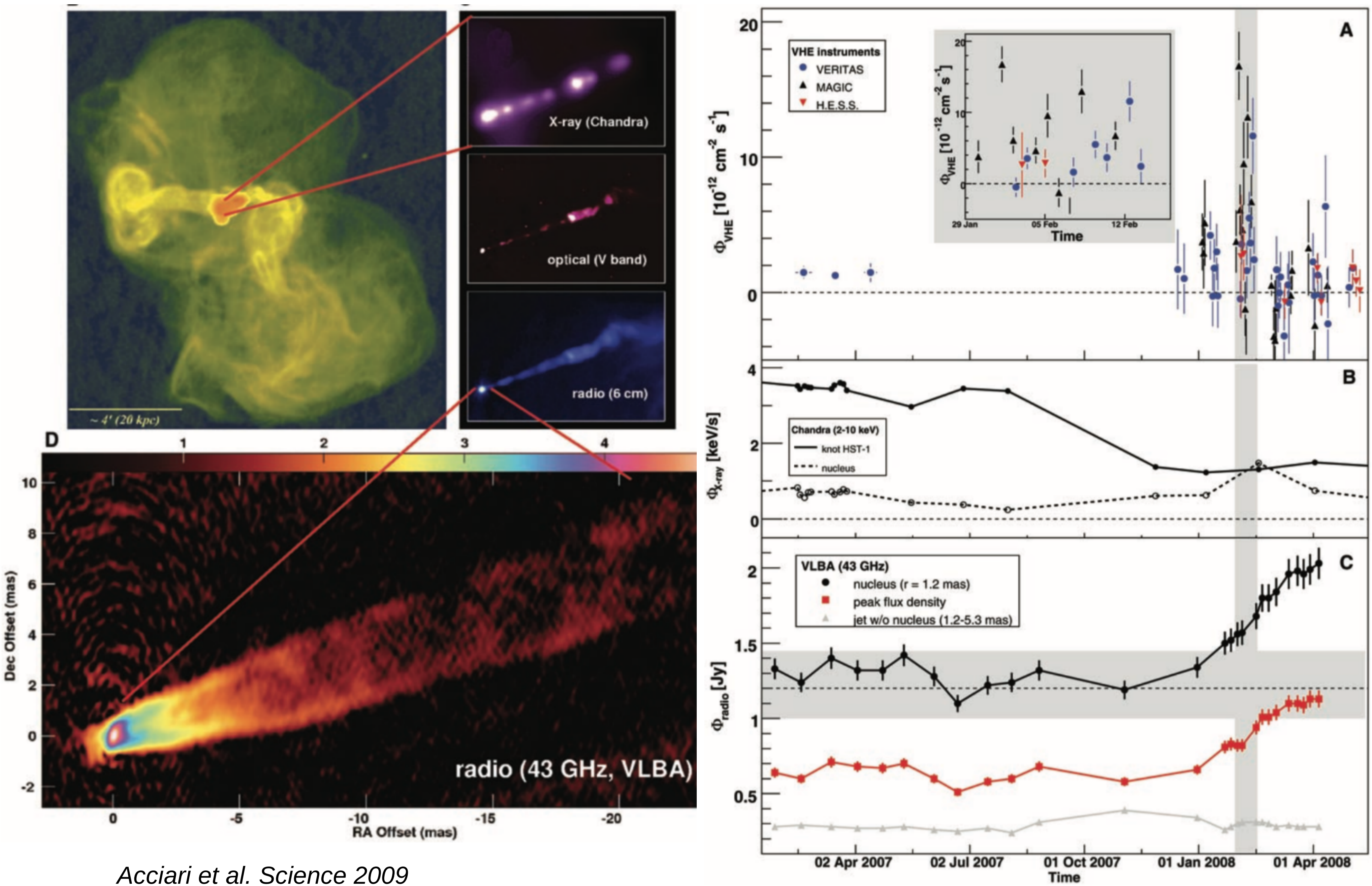
MWL flares from M 87



Acciari et al. Science 2009

Correlated variability during flares allows to match low- and high-energy components.

MWL flares from M 87



Acciari et al. Science 2009

MWL flares from M 87

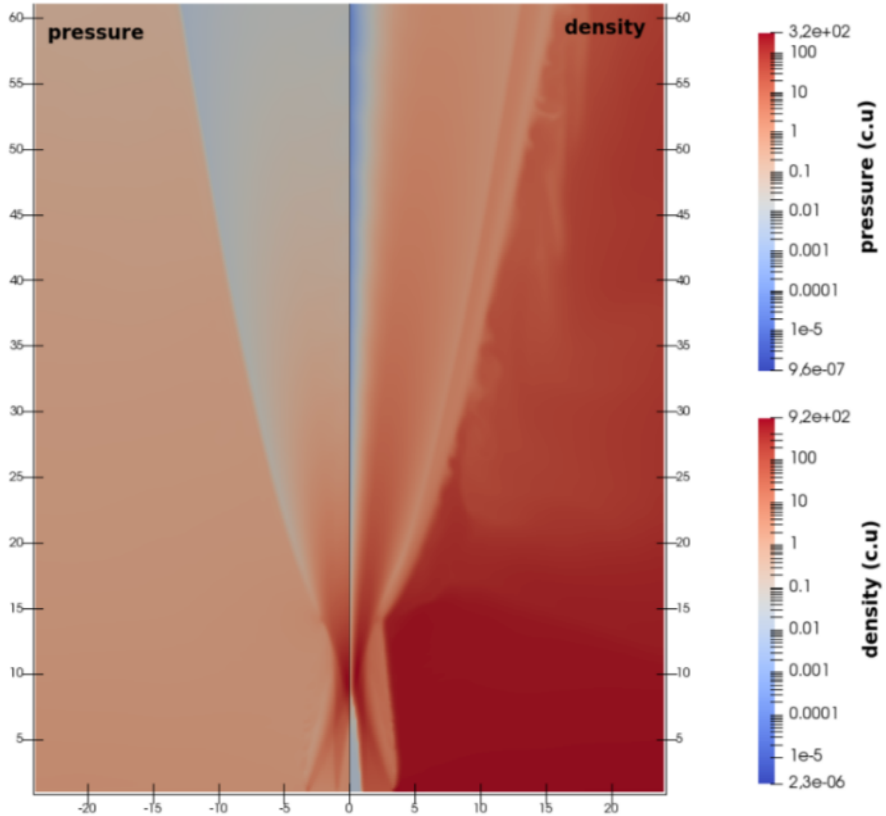


Figure 14: An open structured toroidal jet to simulate M 87.

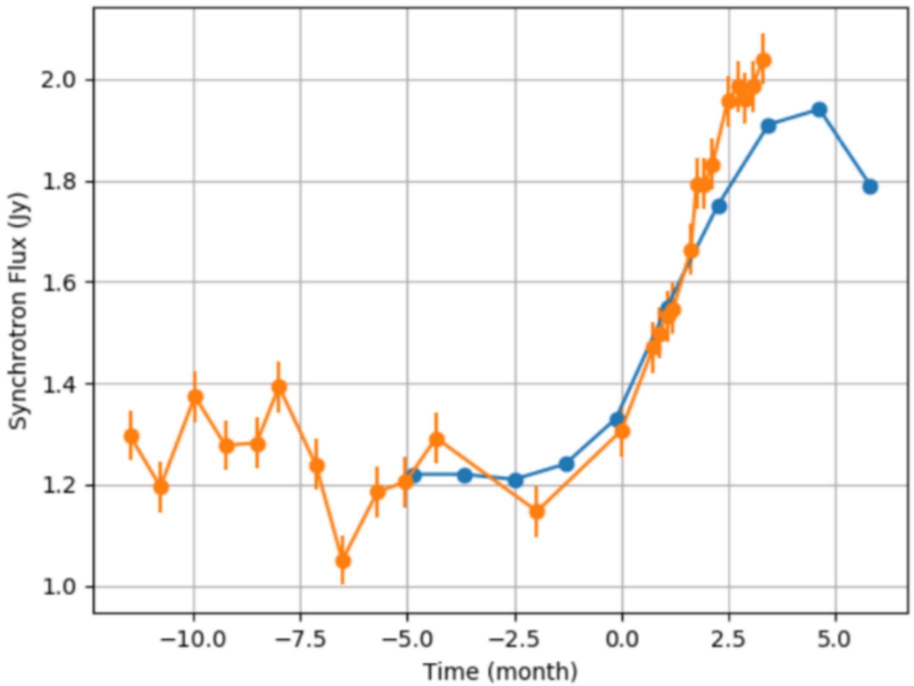


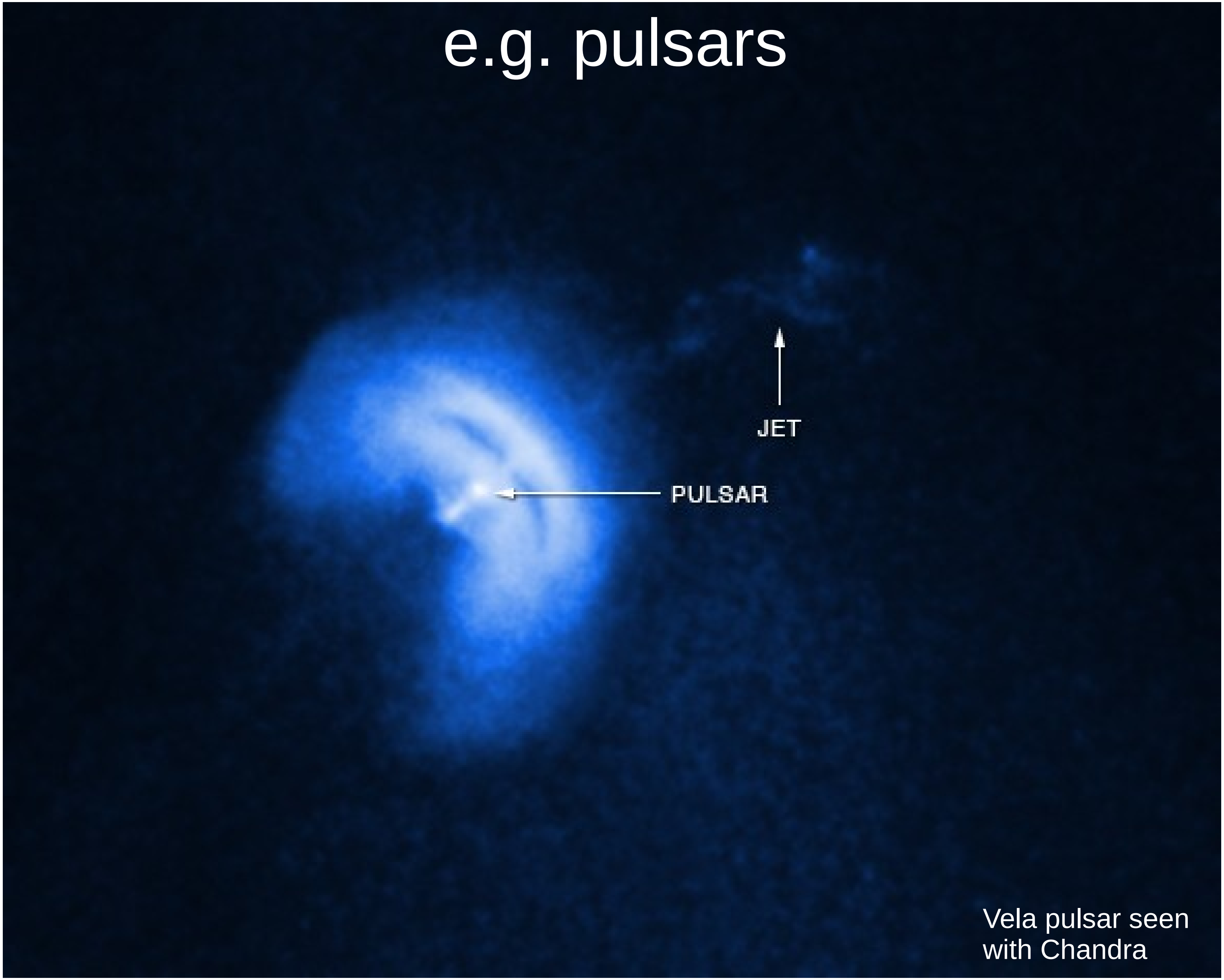
Figure 15: Observed radio light curve for M 87 with one ejecta in the observer frame. (orange: data from VLBA at 43 GHz; blue: our simulation)

- hybrid SRMHD & radiative modelling of MWL emission from relativistic jets in γ-loud AGN

- flares arise when ejecta of dense plasma interact with standing (recollimation) shocks in the jet

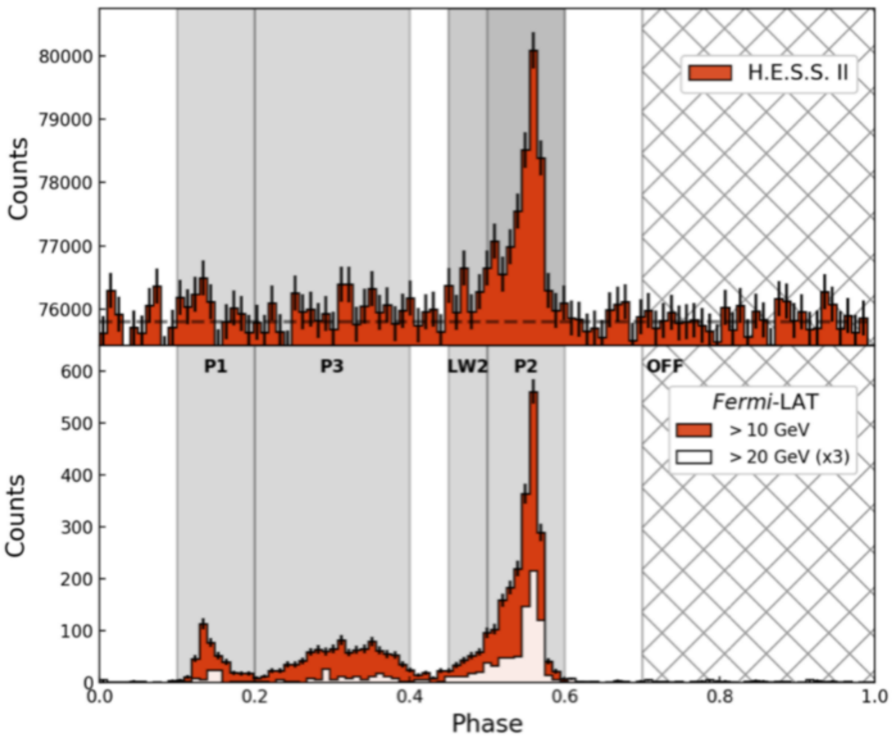
G. Fichet de Clairfontaine, Z. Meliani, AZ, HEPRO 2019 proceedings (PoS)

Links with radio observations :
e.g. pulsars

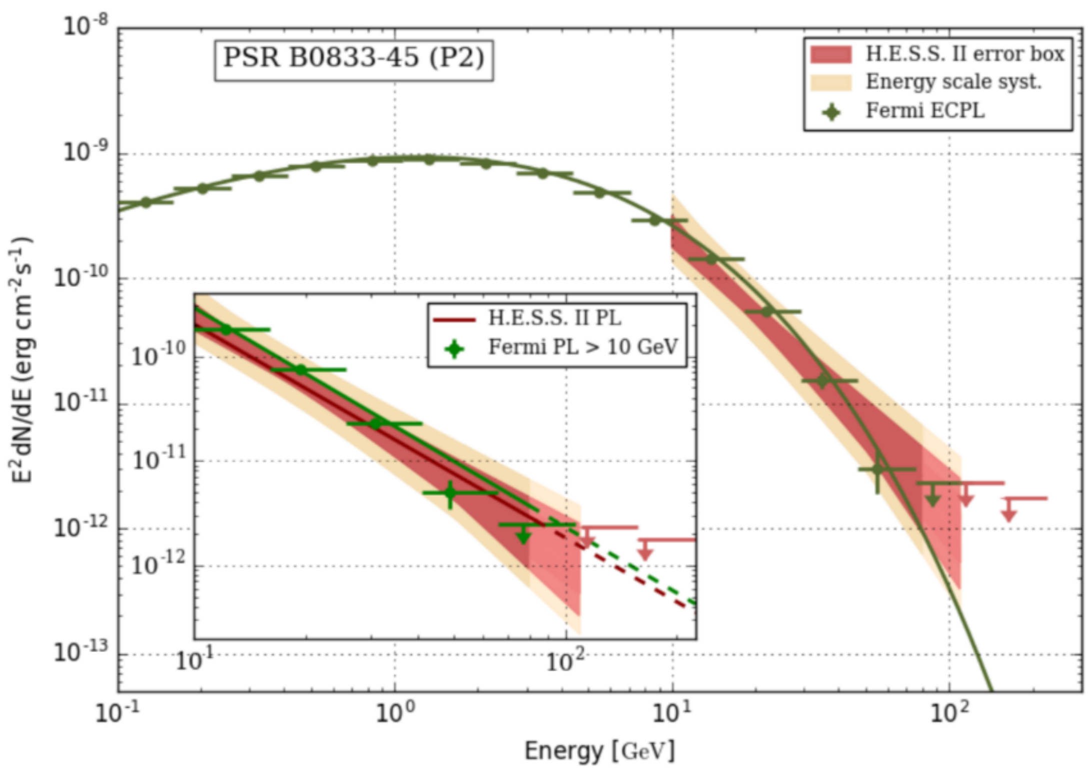


Vela pulsar seen with Chandra

e.g. the Vela pulsar at VHE



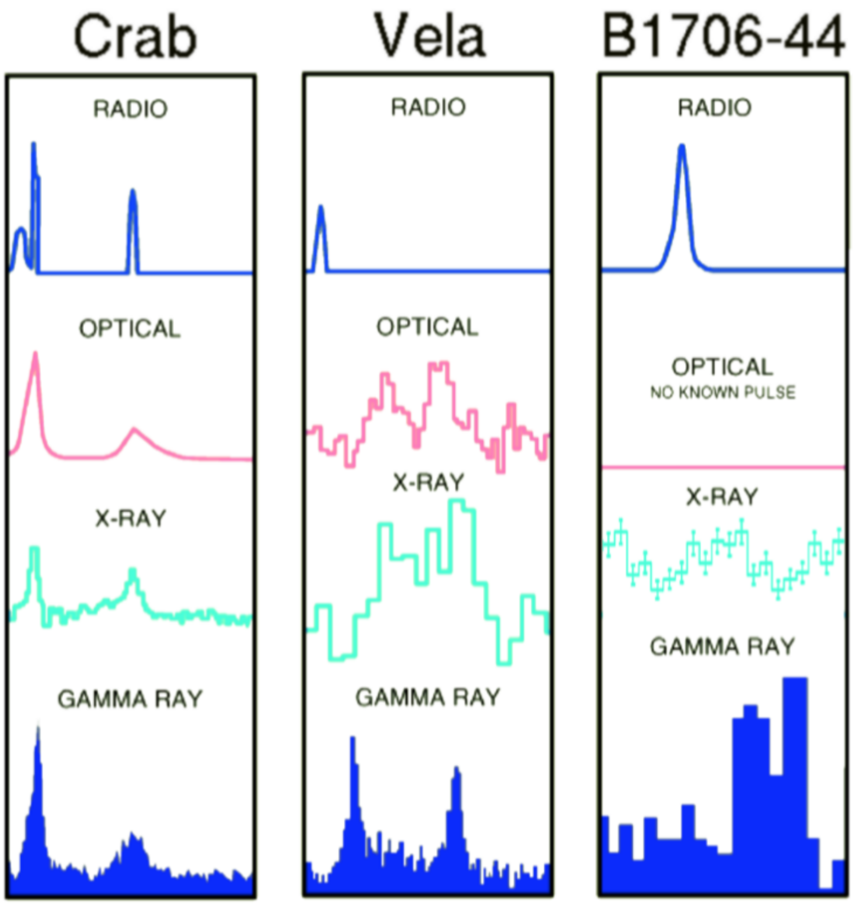
- 40 hr of observations with HESS II
  CT5 mono analysis from ~10 GeV to 100 GeV
  + 8 yr of Fermi-LAT data



- peak spectrum curved in 10 - 100 GeV range, with sub-exponential cutoff

- evidence for a hard spectral component beyond 100 GeV before the peak !

pulses in MWL



- so far only four detections of pulsed emission with Cherenkov telescopes (Crab, Vela, Geminga, B1706-44)
- great variety of pulse profiles at different energies
- in general, VHE emission only possible at a sufficient distance from the pulsar surface to avoid γ-γ absorption.

Outlook : CTA KSPs

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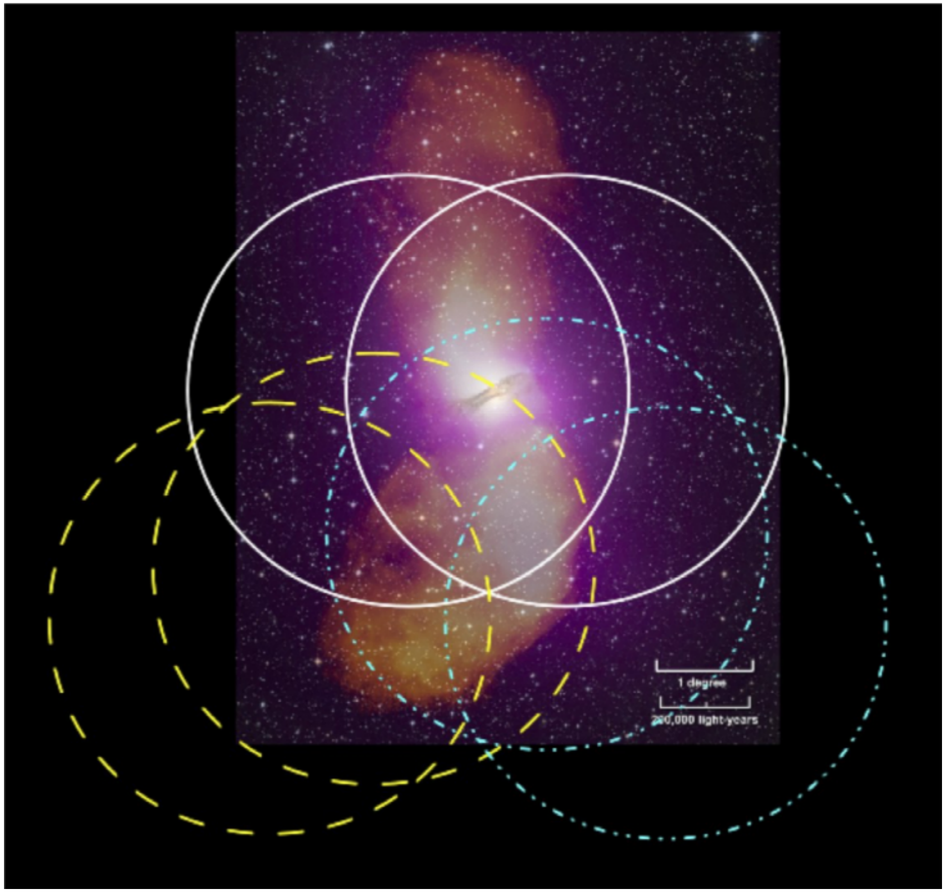


Several deep exposures of Centaurus A to confirm / search for extended emission (kpc jet, radio lobes)

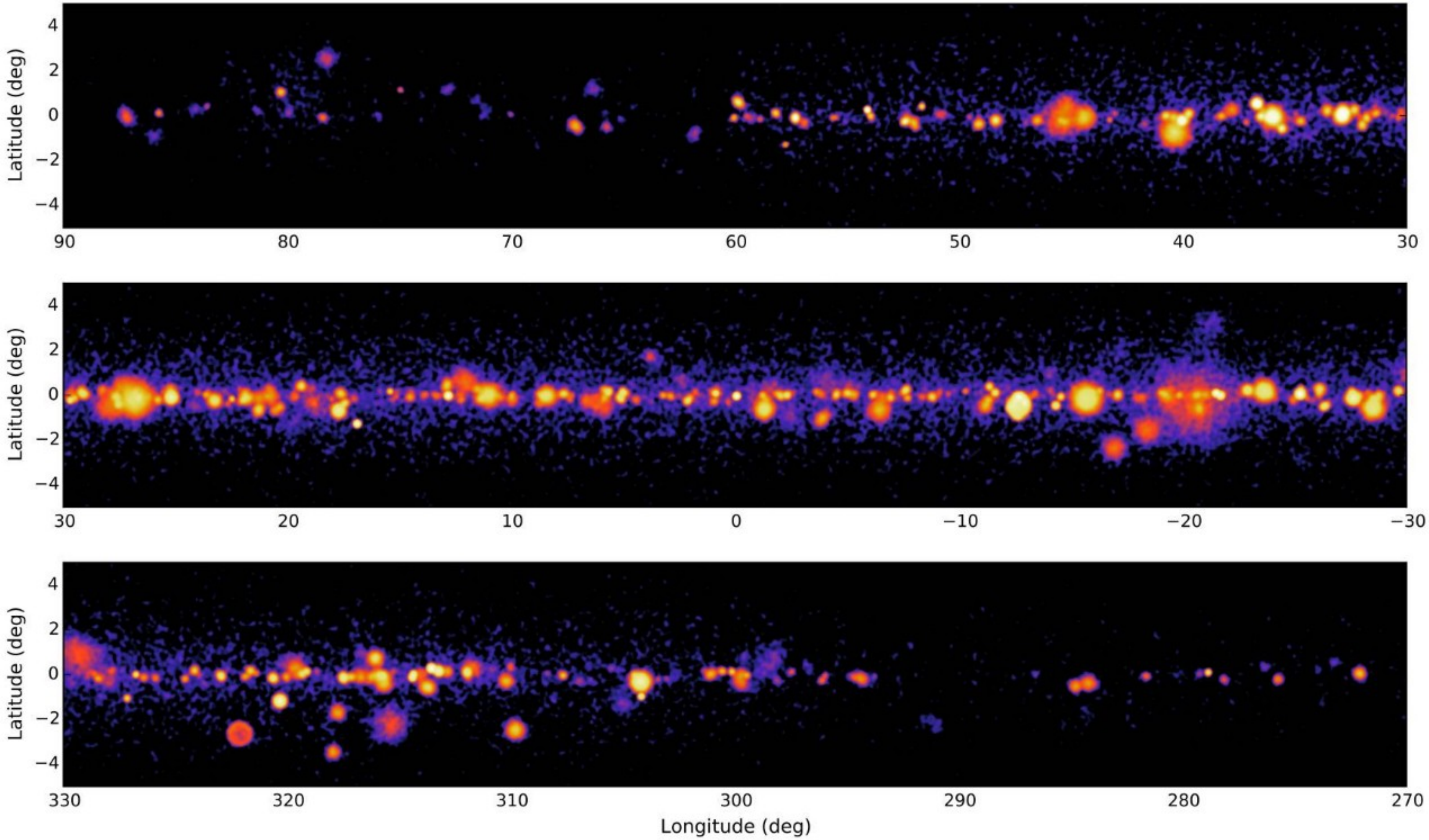
The **AGN KSP :**

- pointed observations of a selection of AGN

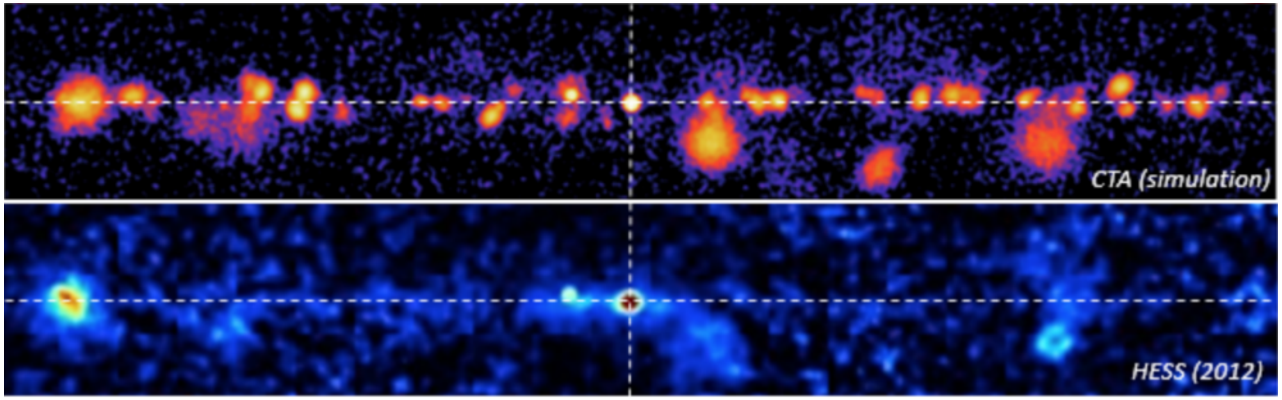
- follow-up of AGN flare alerts

- long-term monitoring of light curves, together with MWL coverage, for ~10 sources.

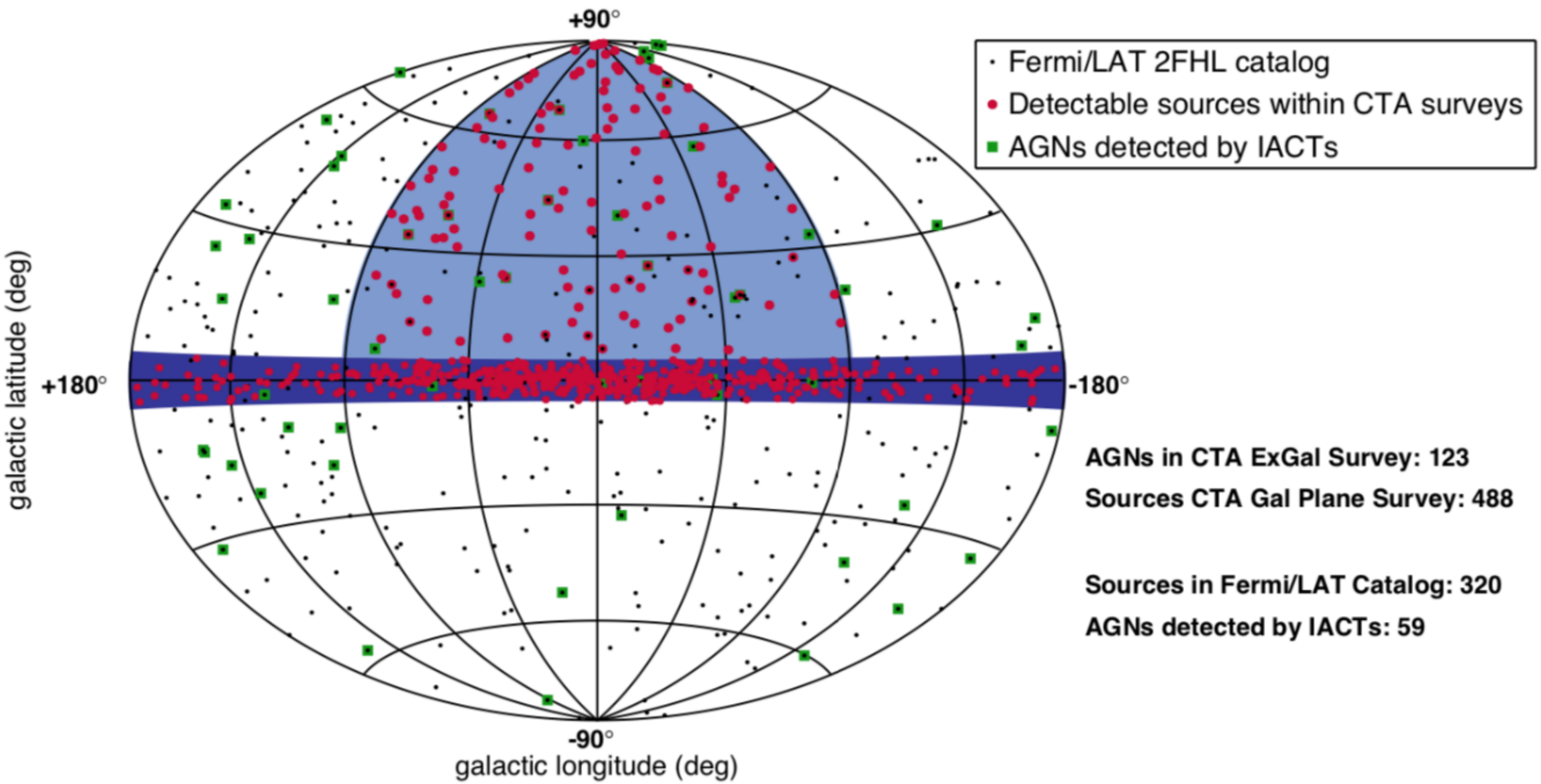
Outlook : CTA KSPs



Galactic Plane Survey KSP :
full GP coverage at the level of
a few mCrab



Outlook : CTA KSPs



AGNs in CTA ExGal Survey: 123

Sources CTA Gal Plane Survey: 488

Sources in Fermi/LAT Catalog: 320

AGNs detected by IACTs: 59

An **extragalactic survey** is foreseen to cover
1/4 of the sky at about 6 mCrab for AGN population
studies.

Conclusions

- VLBI information of major interest for our interpretation of γ-loud AGN.

- Low-frequency radio emission from AGN important for a complete picture of jet launching and energetics

- γ-ray and VHE detections of pulsars find new spectral components that challenge current models.

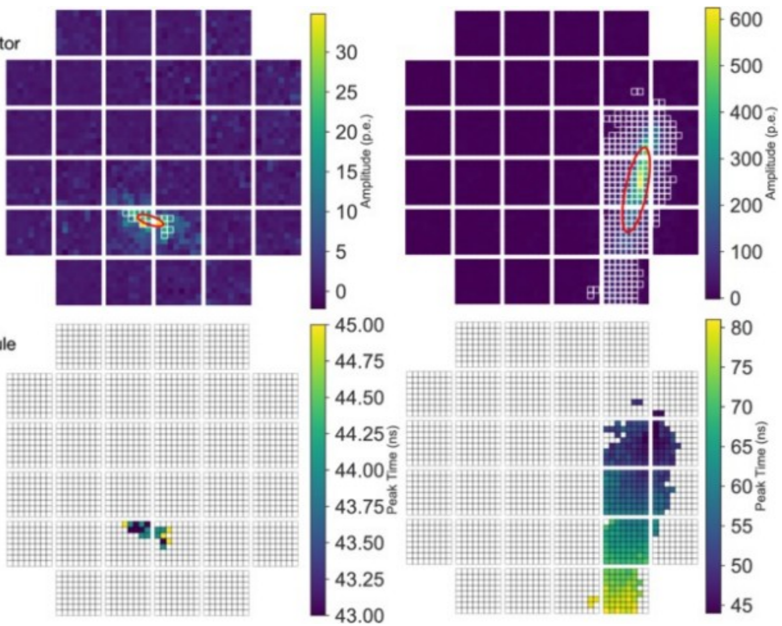
- There will certainly be many more common science topics between the future radio and VHE instruments ! (Contacts between CTA and SKA have been established.)

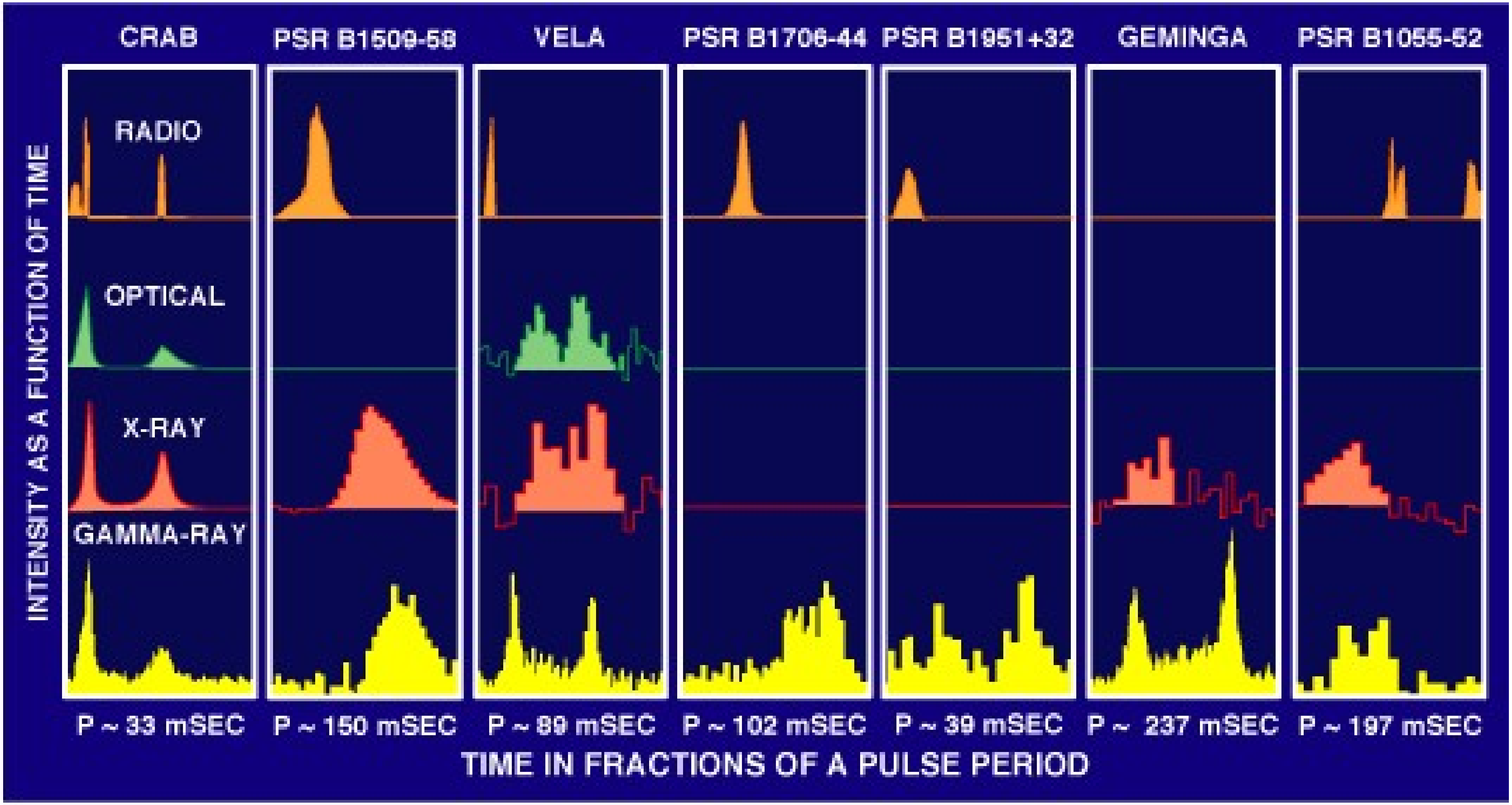
future instruments

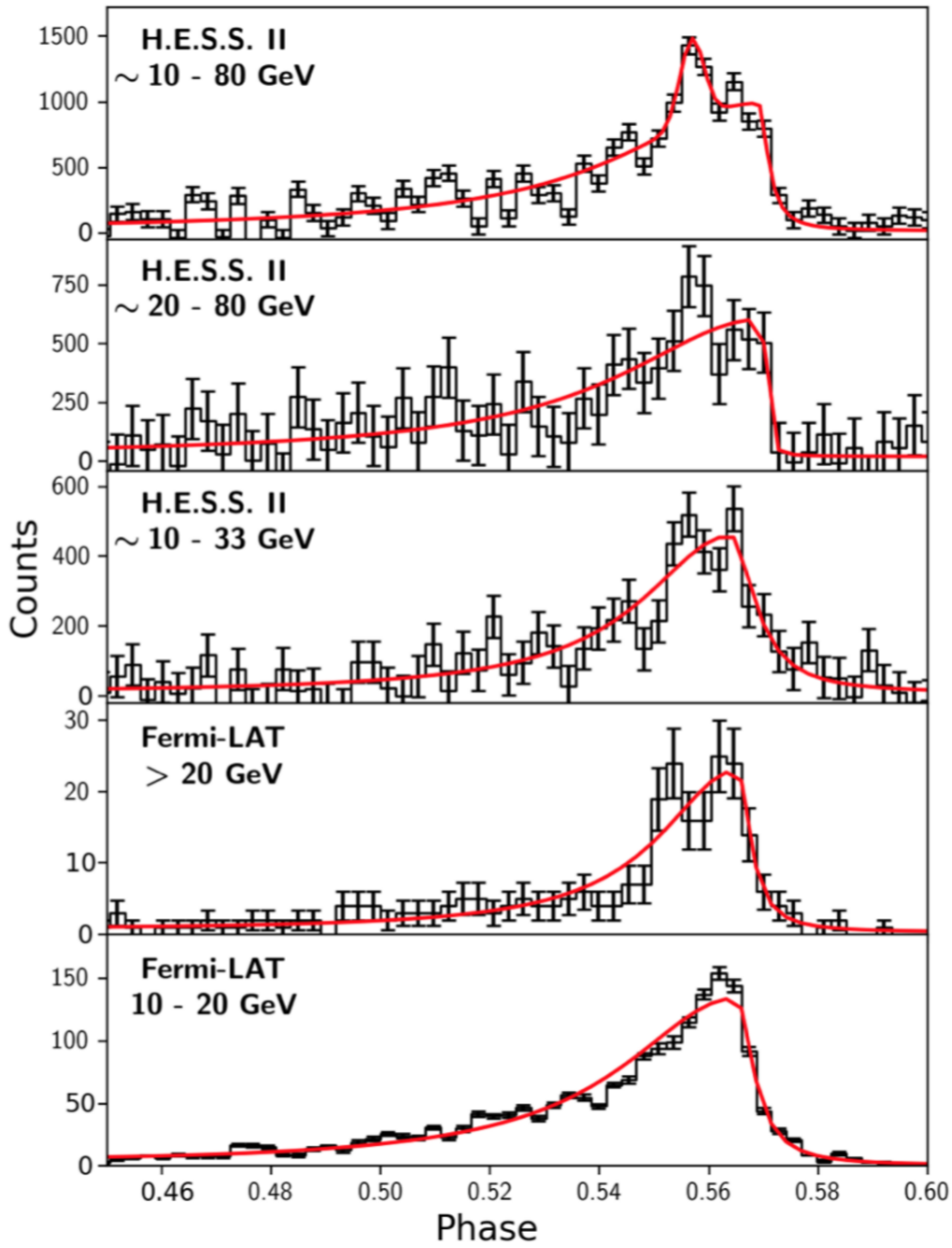
Gamma-Cherenkov Telescope (GCT) - a prototype for CTA in Meudon

- first operational Schwarzschild-Couder telescope
- first observation of cosmic-ray air showers in Meudon in December 2015
- telescope developed at the OP (LUTH, GEPI), camera developed by UK/Japan/Germany
- first camera design was using MaPMTs, updated design using SiPMs

-> The final design for the small-size telescopes (SSTs) of CTA
will be a similar Schwarzschild-Couder telescope.




CRAB
PSR B1509-58
VELA
PSR B1706-44
PSR B1951+32
GEMINGA
PSR B1055-52
RADIO
OPTICAL
X-RAY
GAMMA-RAY
INTENSITY AS A FUNCTION OF TIME
P ~ 33 mSEC
P ~ 150 mSEC
P ~ 89 mSEC
P ~ 102 mSEC
P ~ 39 mSEC
P ~ 237 mSEC
P ~ 197 mSEC
TIME IN FRACTIONS OF A PULSE PERIOD


H.E.S.S. II
~ 10 - 80 GeV
H.E.S.S. II
~ 20 - 80 GeV
H.E.S.S. II
~ 10 - 33 GeV
Fermi-LAT
> 20 GeV
Fermi-LAT
10 - 20 GeV
Counts
Phase
1500
1000
500
0
750
500
250
0
600
400
200
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30
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150
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