Optical Observations and the Cherenkov Telescope Array

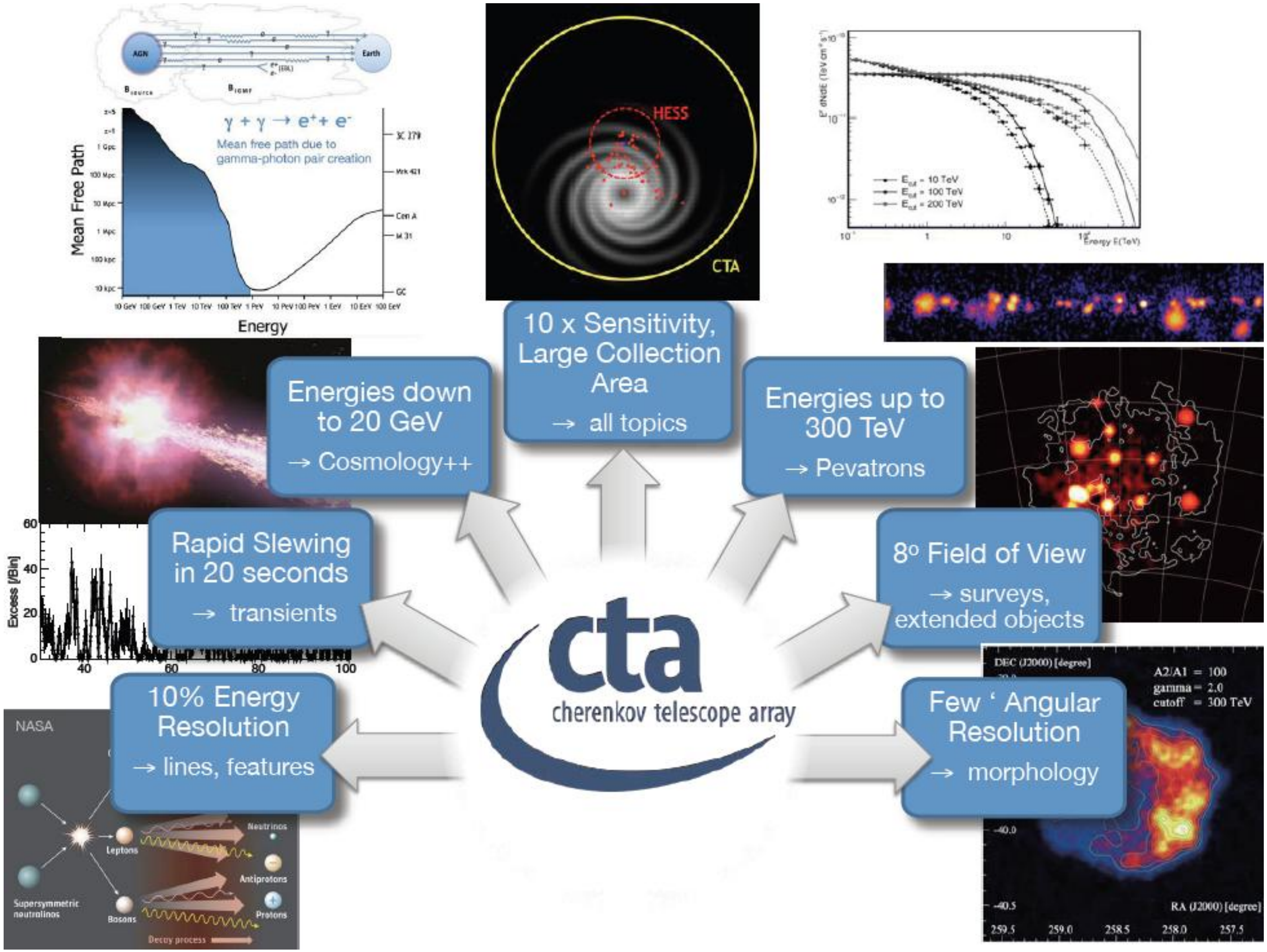
FILIPPO D'AMMANDO
(DIFA BOLOGNA and INAF-IRA BOLOGNA)

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

INAF Istituto di Radioastronomia

SEXTEN CENTER FOR ASTROPHYSICS

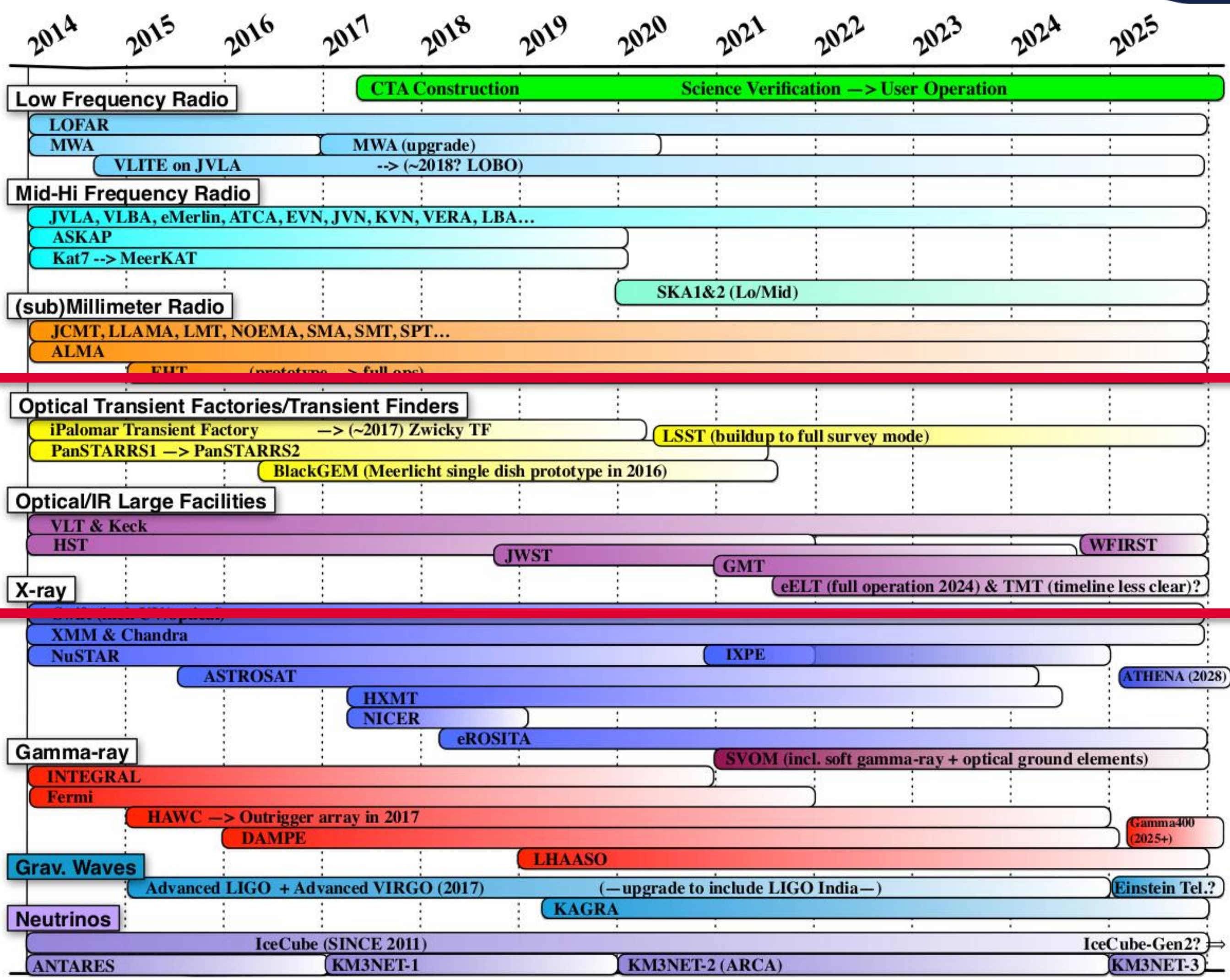
CTA Science


γ + γ → e⁺+ e⁻
Mean free path due to gamma-photon pair creation
Mean Free Path
Energy
HESS
CTA
10 x Sensitivity, Large Collection Area
→ all topics
Energies down to 20 GeV
→ Cosmology++
Energies up to 300 TeV
→ Pevatrons
Rapid Slewing in 20 seconds
→ transients
8º Field of View
→ surveys, extended objects
10% Energy Resolution
→ lines, features
Few ' Angular Resolution
→ morphology
cta
cherenkov telescope array
NASA
Supersymmetric neutralinos
Leptons
Bosons
Neutrinos
Antiprotons
Protons
Decay process
Excess [/Bin]
DEC (J2000) [degree]
RA (J2000) [degree]
A2/A1 = 100
gamma = 2.0
cutoff = 300 TeV

CTA Key Science Projects

1. Dark Matter Programme
2. Galactic Centre Survey
3. Galactic Plane Survey
4. Large Magellanic Cloud Survey
5. Extragalactic Survey
6. Transients
7. Cosmic-ray PeVatrons
8. Star-forming Systems
9. Active Galactic Nuclei
10. Cluster of Galaxies
11. Non-Gamma-ray Science

Synergies during CTA operation



CTA will have important synergies with many of the new generation of astronomical and astroparticles observatories

Multiwavelength needs of AGN KSP

- Long term monitoring program: well sampled, simultaneous light curves at different wavelengths (X-ray, optical, radio) are necessary to allow us to search for correlations and time-lags between different bands. ***Optical photometry and polarimetry from dedicated telescopes.***

- AGN flares: MWL coverage necessary, optical photometry and polarimetry from dedicated telescopes. ***Optical telescopes will provide source of alerts triggered by high flux states and changes in polarization.***

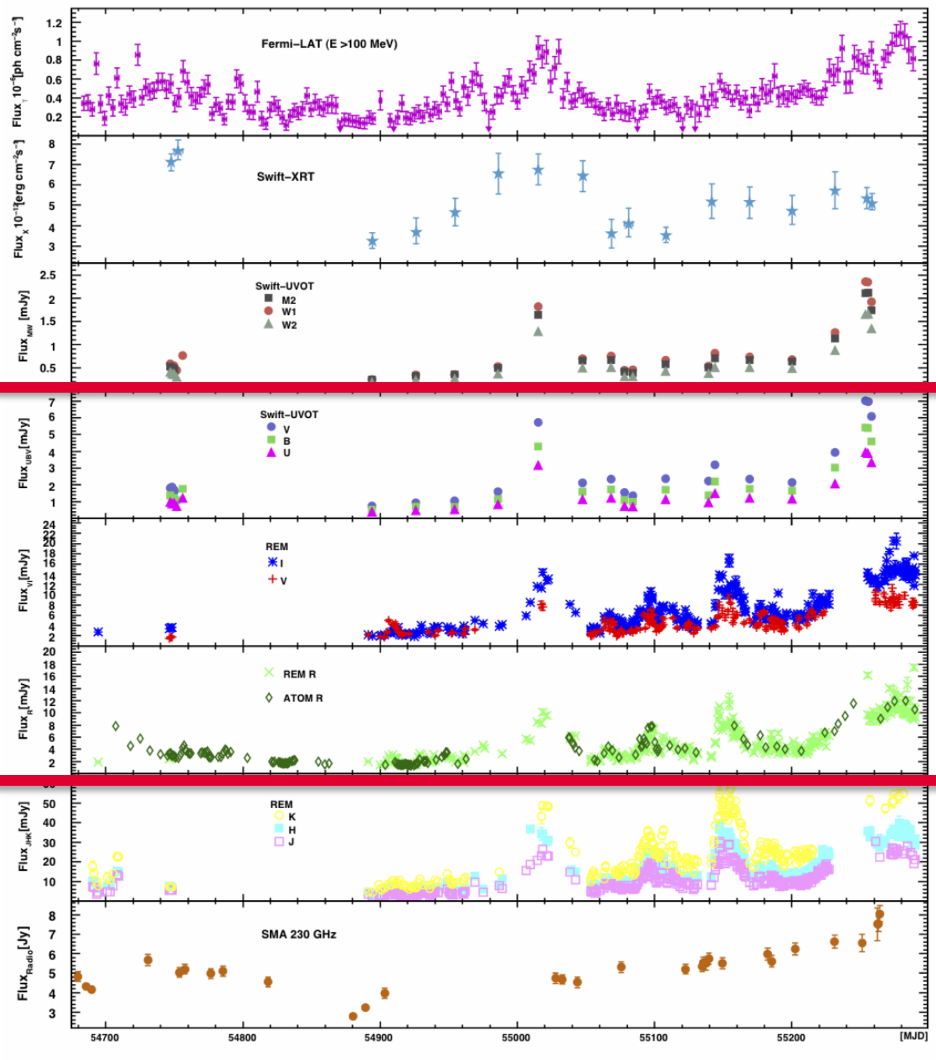
- High quality spectra: ***optical data will be very useful to compare the state of source vs. archival data.***

Optical monitoring of AGN

- MAGIC and HESS have dedicated optical support telescopes: **KVA** and **ATOM**
- Has been particularly useful for **blazar** observations
- Photometric long-term monitoring to study the long term behavior and to define the flaring activity states
- Before the *Fermi* era, the optical telescope was the main source of alerts for flaring AGN: e.g. with MAGIC > 50% of blazar discoveries result of optical trigger

MWL long-term monitoring of AGN

PKS 0537-441



γ rays

X-rays

UV

optical

optical

optical

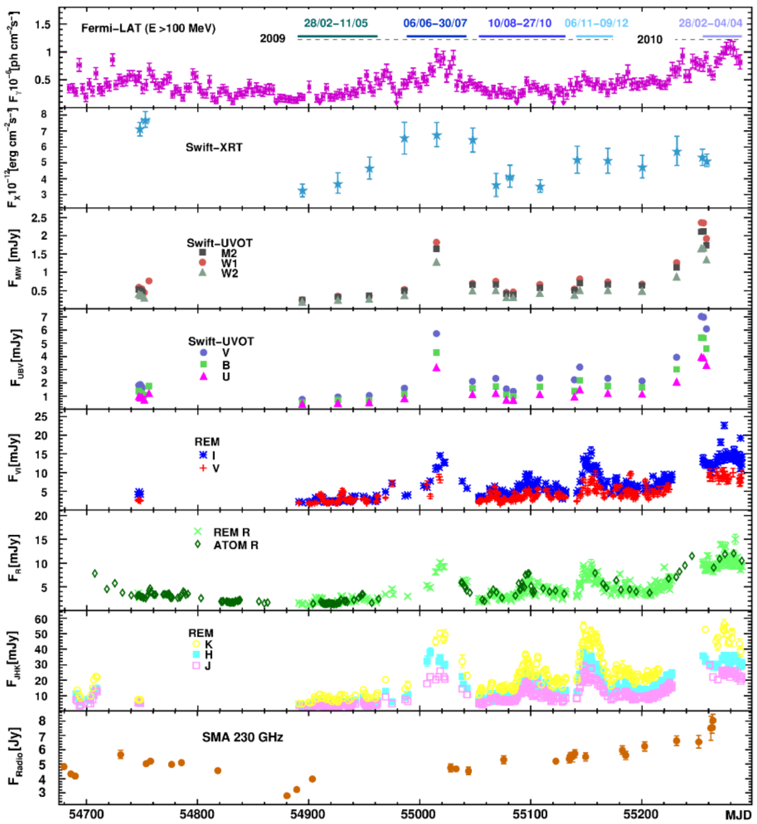
NIR

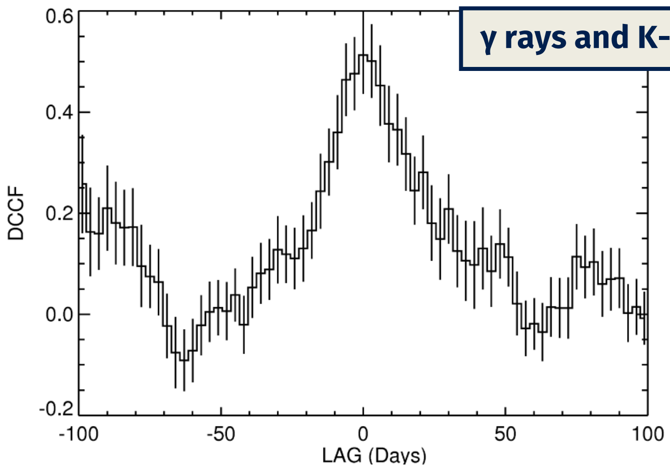
mm

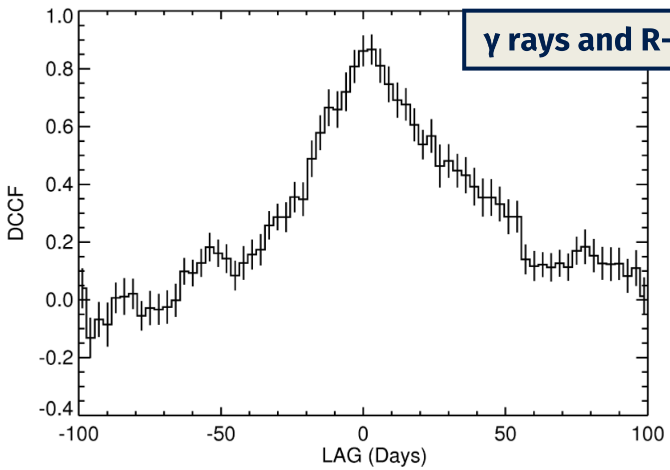
D'Ammando et al. 2013, MNRAS, 431, 2481

Cross-correlation analysis

PKS 0537-441

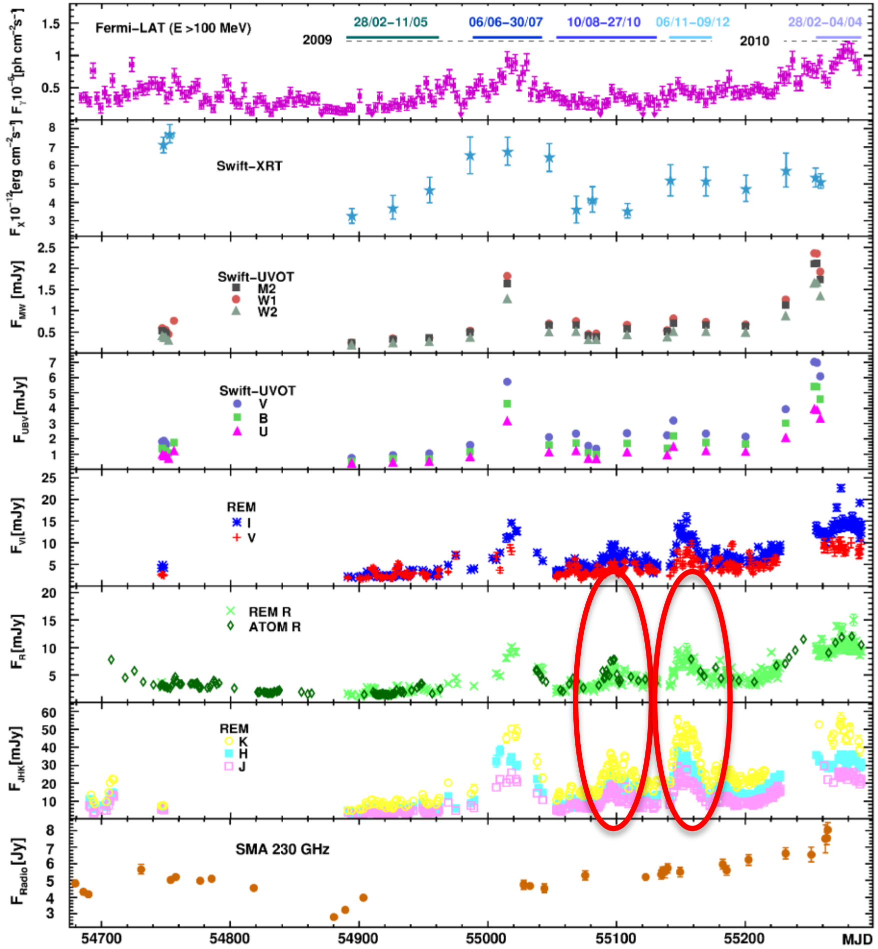






An overall correlation between the γ-ray band and both the R-band and K-band has been observed with no time lag. When inspecting the light curves on short time-scales some differences are evident.

Orphan flares in optical and NIR

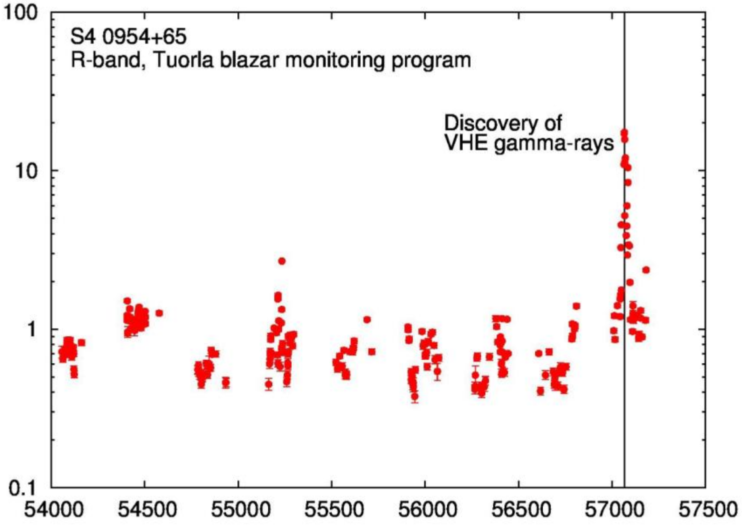


Flaring activity has been detected in near-infrared and optical bands **with no evident γ-ray counterparts** in 2009 September and November

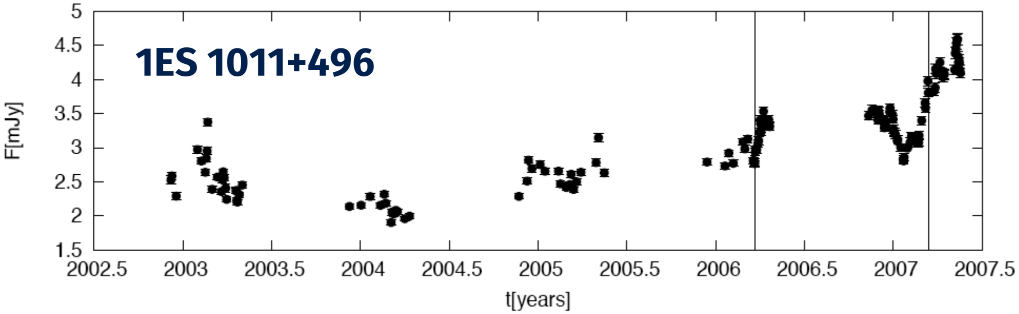
Optical monitoring for triggering

MAGIC has been triggered by optical observations since 2005

Many discoveries: Mrk 180, 1ES 1011+496, S5 0716+714, B3 2247+381, ON 325, H1722+119, 1ES 0806+524, S4 0954+65



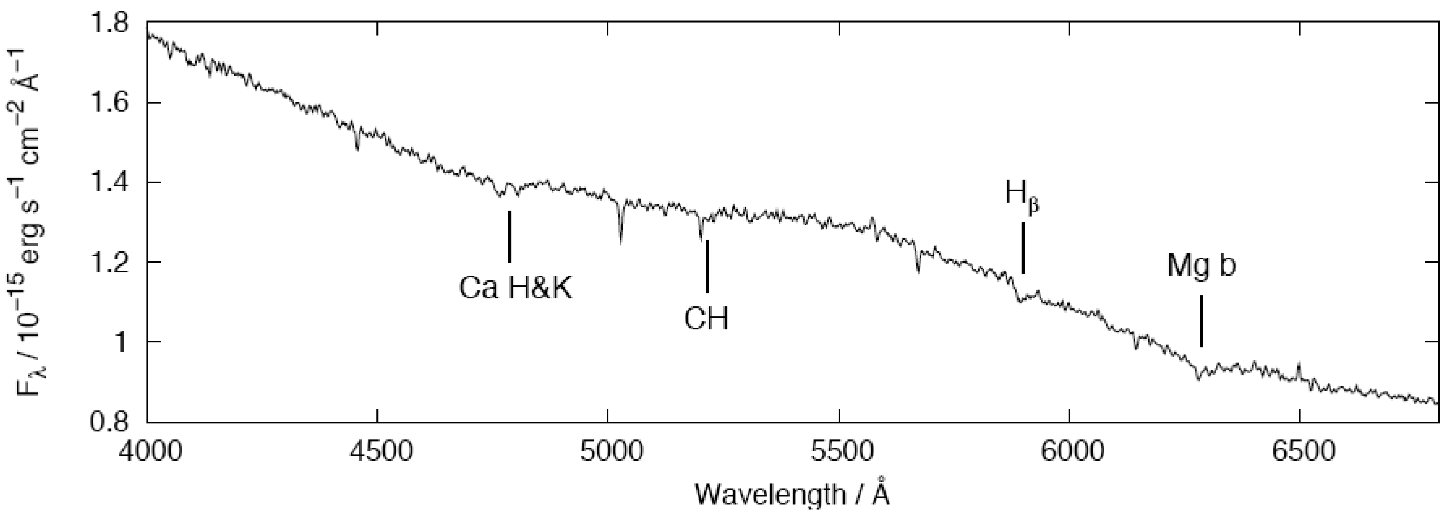
Trigger points



1ES 1011+496: optical spectrum

Redshift of z=0.200 was "guessed" for 1ES 1011+496 because of a possible association with Abell 950 (Wisniewski et al. 1986)

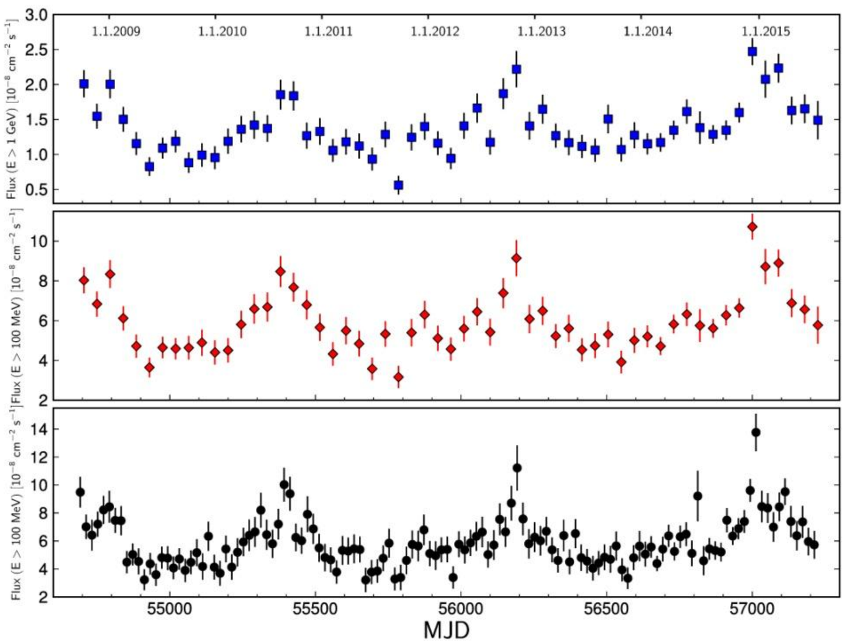
From the optical spectrum (E. Perlman), the MAGIC Collaboration determined the redshift to be **z = 0.212 ± 0.002**



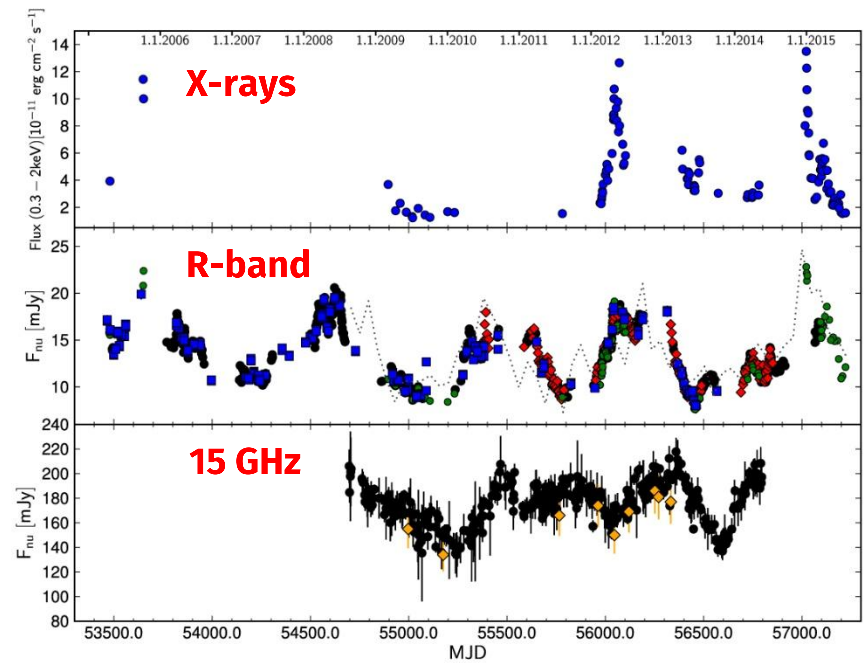
Albert et al. 2007, ApJ, 667, L21

Optical monitoring for AGN periodicity

PG 1553+113: Fermi-LAT quasi-periodicity

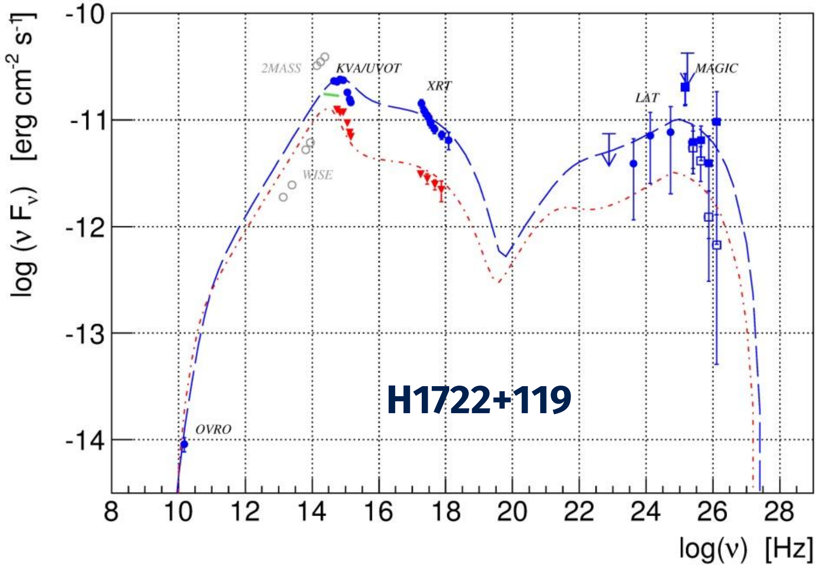


quasi-periodicity in other bands?

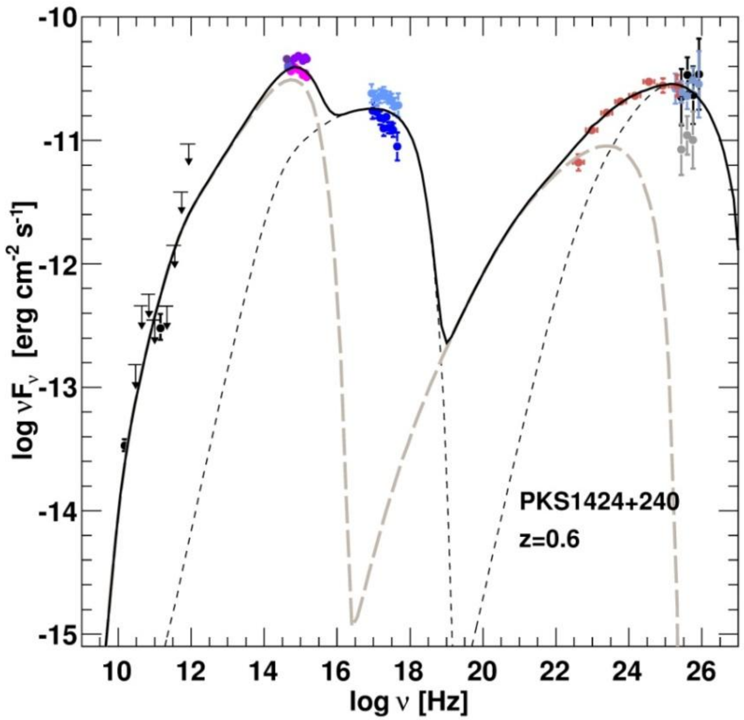


Ackermann et al. 2015, ApJ, 813, 41

Optical monitoring for physics interpretation



To constrain two-zone models

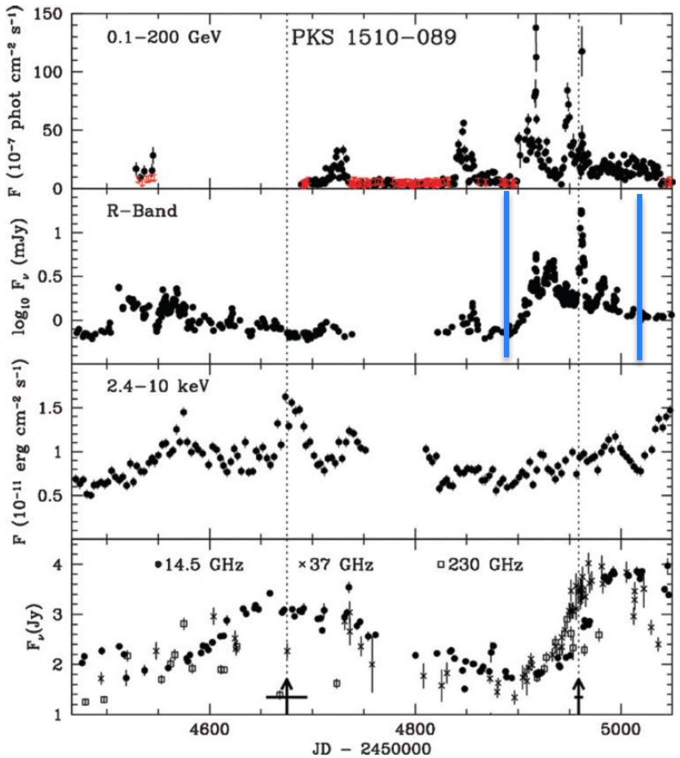


A helical jet model can explain the difference between the two states with a change of a few degrees in the jet orientation

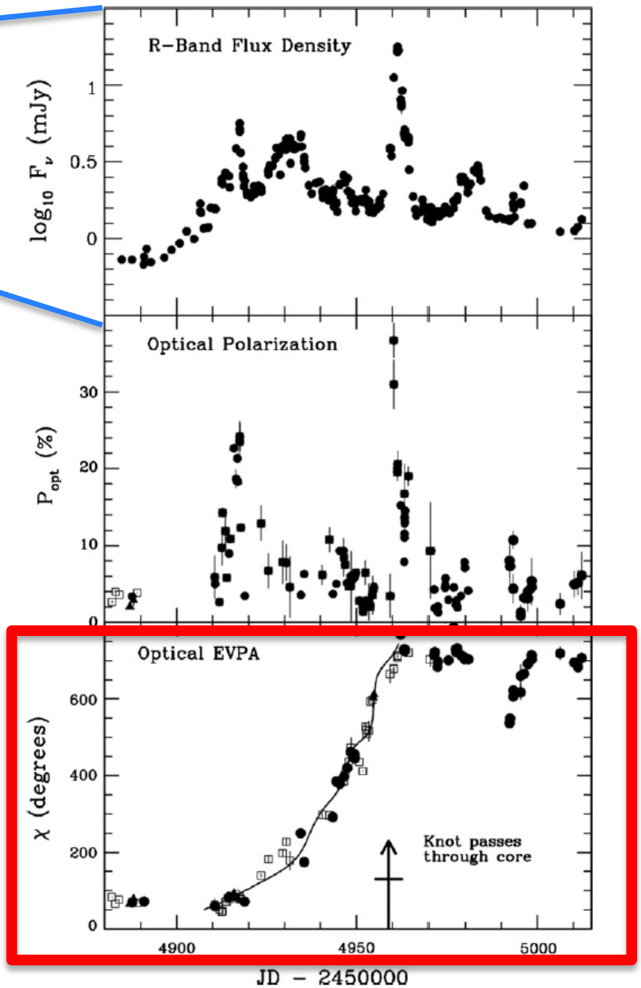
Ahnen et al. 2016, MNRAS, 459, 3271

Aleksic et al. 2014, A&A, 567, 135

Optical polarization signatures



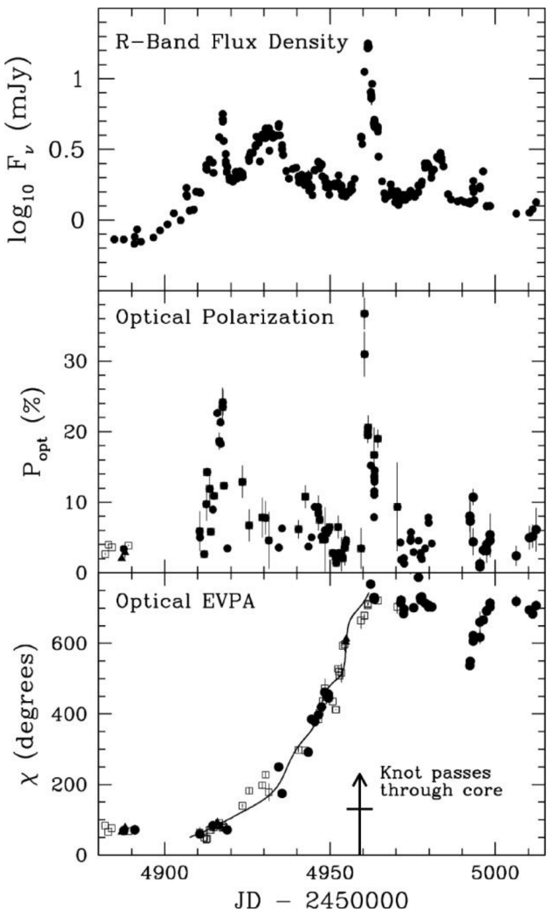
Marscher et al. 2010

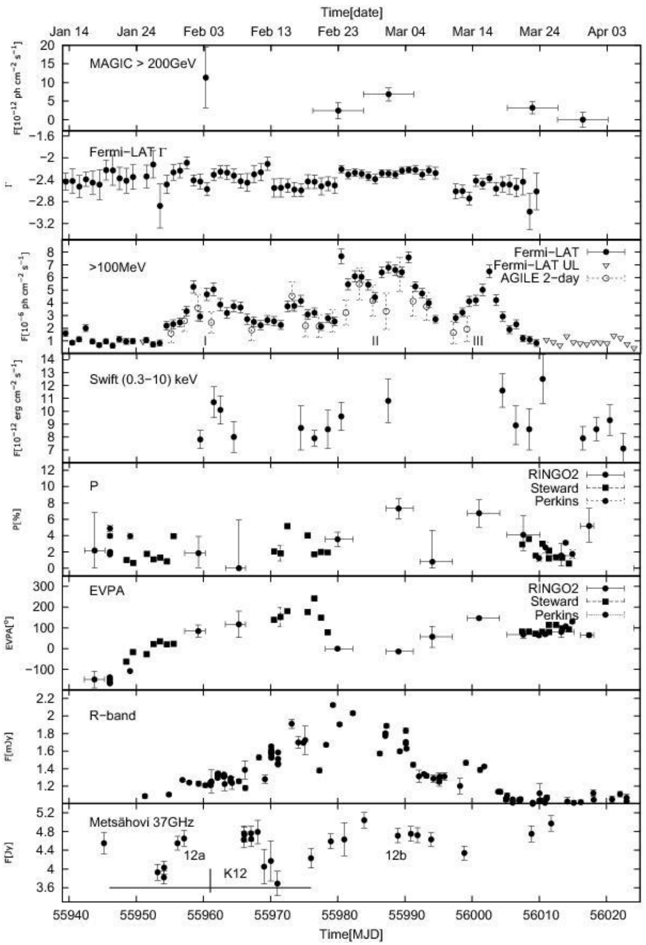


Polarization offers an ideal way of isolating the synchrotron/non-thermal component in case of mixed emission and of tracing the ordered magnetic field of the jet and can be modeified by shocks

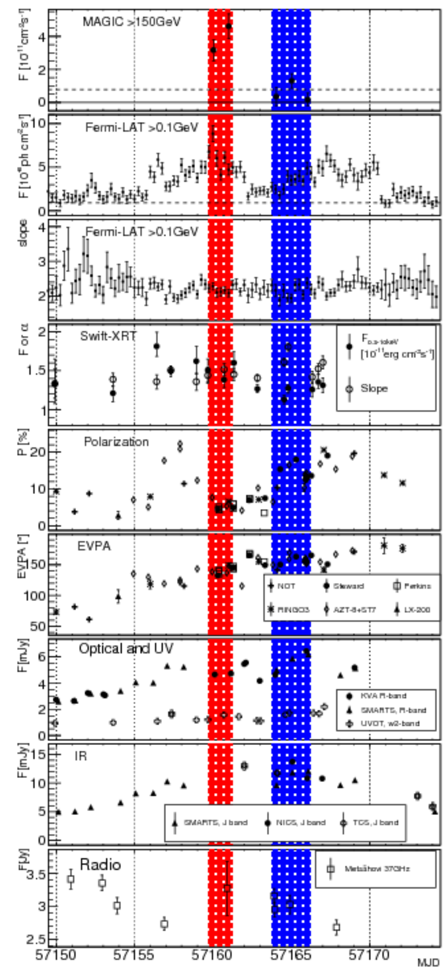
Optical polarization monitoring: single source

PKS 1510-089: repeating optical polarization swings during VHE detections (2009, 2012, 2015)



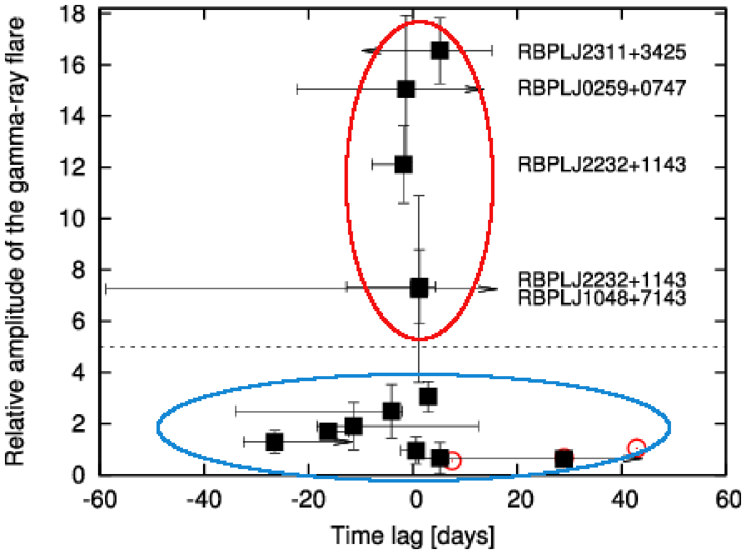


Aleksic et al. 2014, A&A, 569, A46



Ahnen et al. 2017, A&A, 603, A29

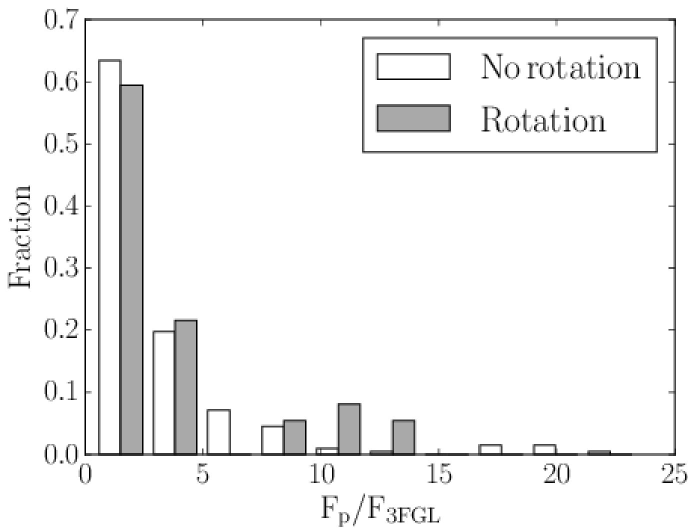
Optical polarization monitoring: sample of sources (Robopol)



16 rotations in 14 blazars

- Time lags are too small to be random
- Possible sign of two types of rotations

Blinov et al. 2015



The rotation of polarization angle cannot be explained either by a difference in the relativistic boosting or by selection effects caused by a difference in the average fractional polarization

Blinov et al. 2016

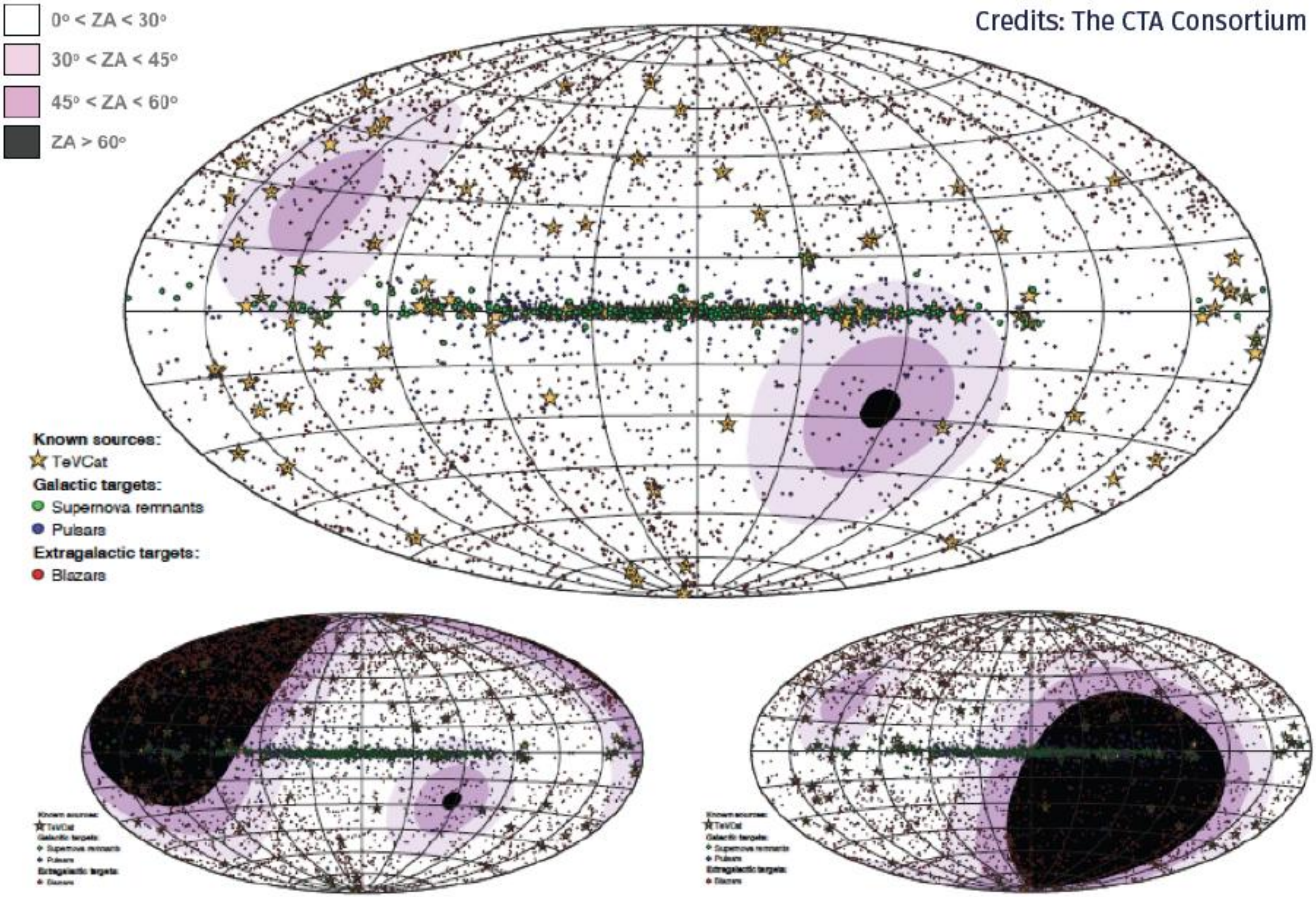
Existing facilities at La Palma and Chile with polarimetric capability

- **La Palma**:
  - Liverpool (Robotic)
  - NOT (with ALFOSC)
  - TNG
  - WHT

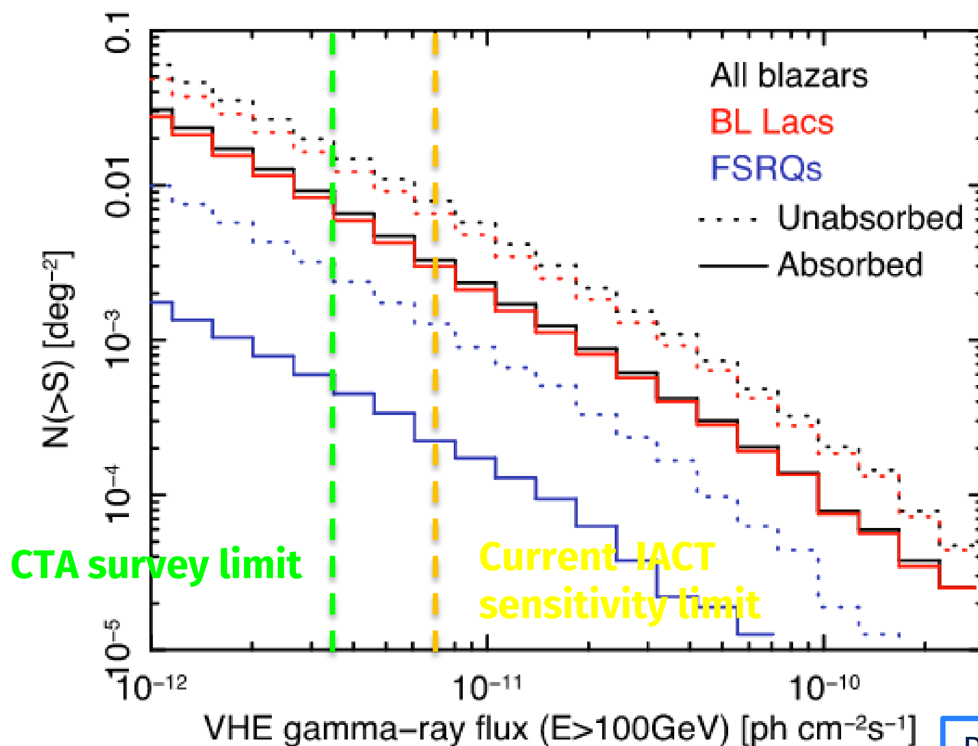
- **ESO sites**:
  - NTT EFOSC
  - VLT FORS2

CTA as an *all-sky Observatory*

Credits: The CTA Consortium



Extragalactic Survey

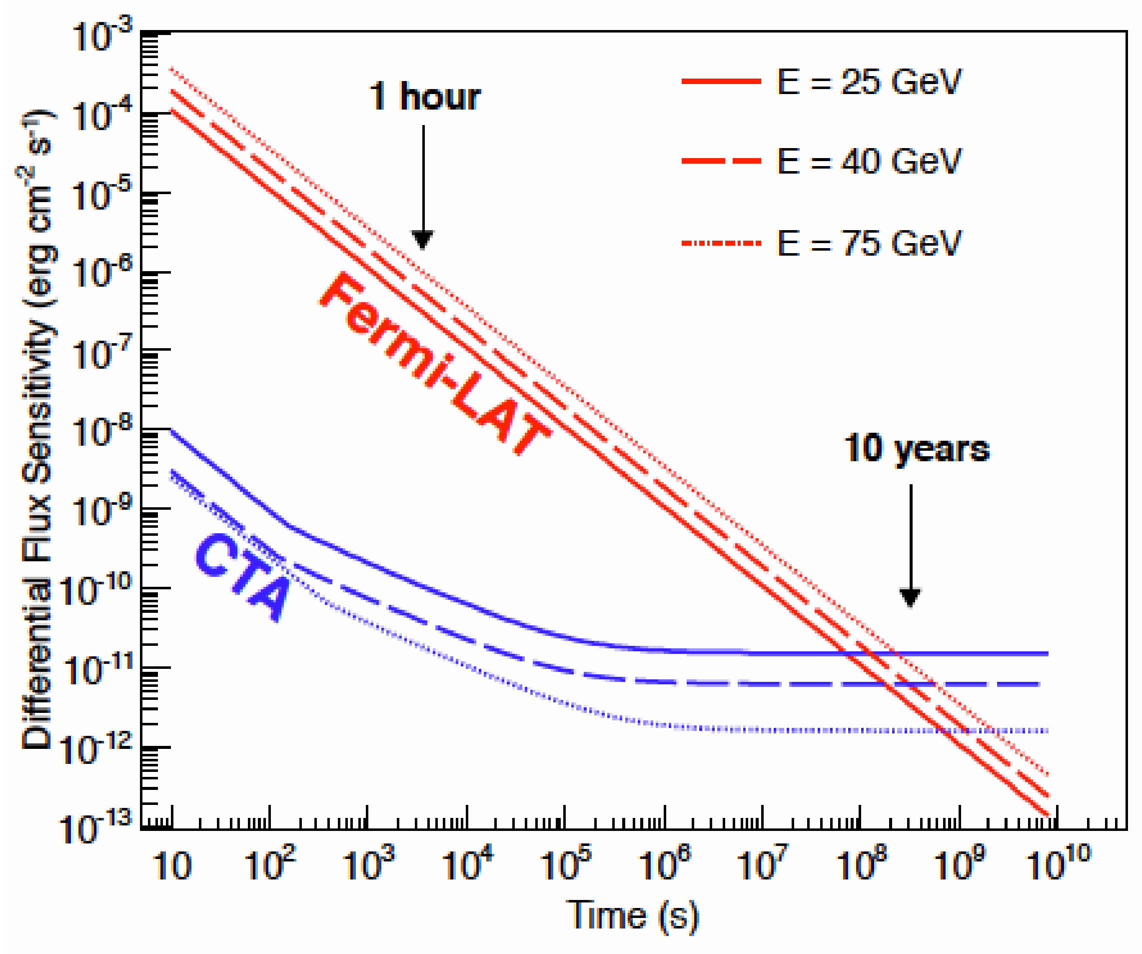


Padovani and Giommi 2015

Padovani & Giommi (2015) derived the expected number of blazars on the sky in the GeV–TeV domain. With the 5 mCrab sensitivity during the proposed survey, **CTA should detect around 100 sources in 10,000 deg².**

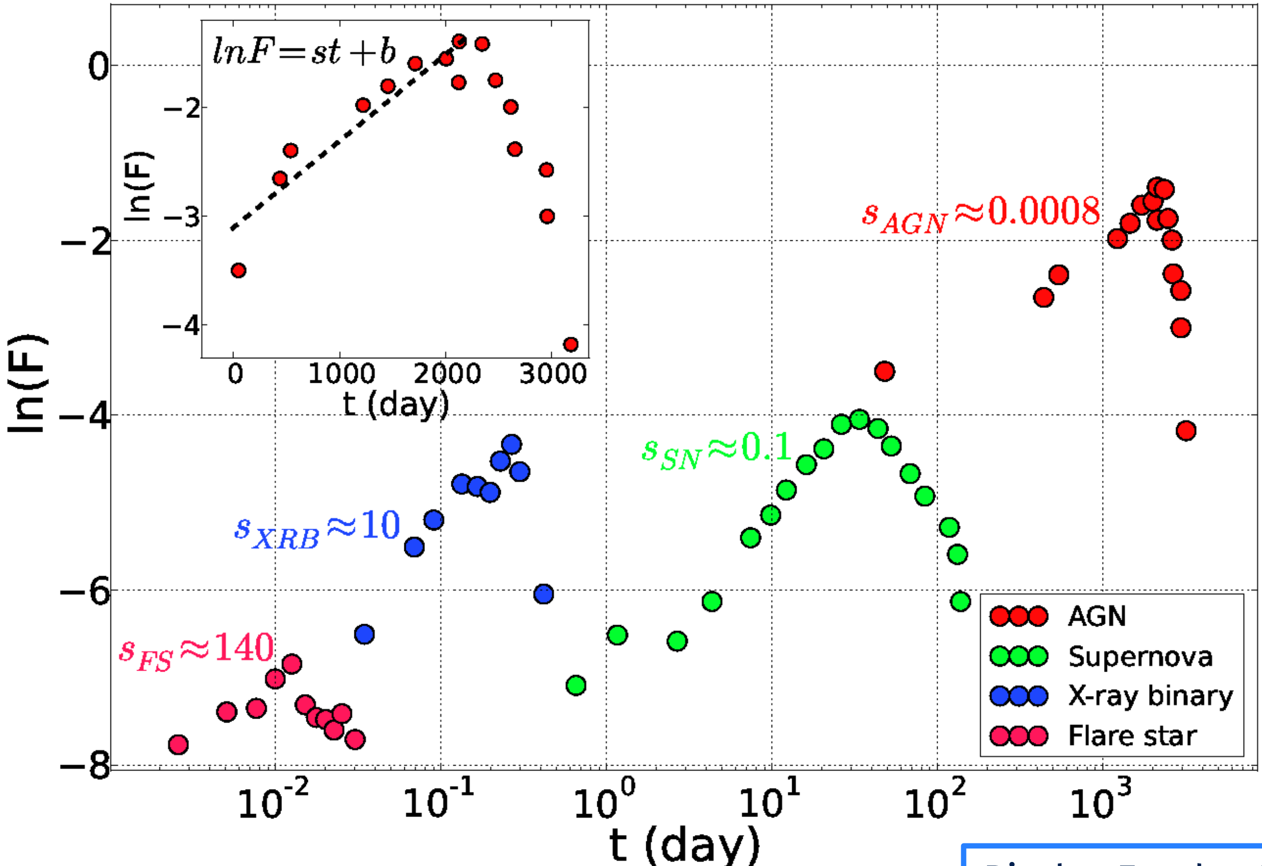
Ideally, we would like to observe the same field simultaneously in the optical to identify the new TeV sources.

CTA as a *transient factory*



Funk and Hinton 2013

Synchrotron transients zoo



Pietka, Fender & Keane 2015

Many high-energy sources emit detectable levels of synchrotron emission in optical with very fast variability, making the optical part of the spectrum important for MWL exploration, and especially for producing transient alerts

Transient discovery and follow-up

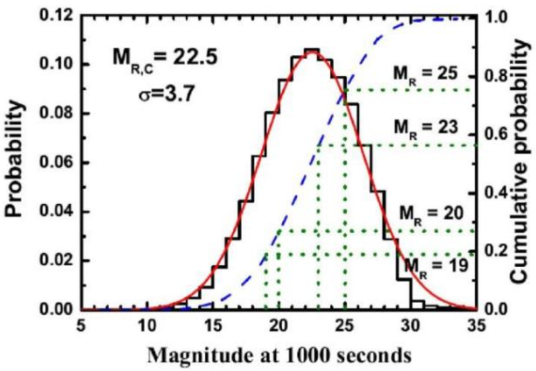


Fig. 8.— The observer-frame probability distributions of the apparent R band magnitude at $t = 10^3$ seconds (histogram) along with the Gaussian fit (smooth curve). The cumulative probability distribution is also shown with a dashed line. The peak of the probability distribution is $M_{R,c} = 22.5$ mag. The dotted lines mark the probabilities of the optical afterglow detection at the instrument thresholds $M_R = 19$ and $M_R = 23$, which correspond to small robotic telescopes and the VT onboard the future mission SVOM.

If such unprecedented events are found, immediate follow up will be needed in other bands, particularly optical for **better localisation** and **source characterisation**.

simultaneous optical and γ-ray observations are of great importance to understand the origin and the physical emitting mechanisms of GRB, Neutrino, GW

- ToO optical observations triggered by CTA detections will not make it possible
- ToO optical observations on external facilities triggered every time we start observing with CTA is also not optimal: extremely time consuming

Transient discovery and follow-up

- GRB optical emission can be faint: GRB science case prefers high sensitivity telescopes and high sensitivity polarimetry

- Neutrino and GW science case would benifit of an optical telescope with a large field of view (few degrees), also true for Fermi GBM GRB

- Telescope characteristics:
  - rapid pointing
  - > 1 m (> 2m for polarimetry)
  - always pointing at CTA pointing
  - > 1 filter
  - small FoV: good for sensitivity and polairmetry
  - large FoV: good for localization of multi-messenger counterparts

Transient factories

- **Panoramic Survey Telescope and Rapid Response System (Pan-STARRS)** -> PanSTARRS 2
  - 1.8 m telescope(s) to image the sky in 5 filters
  - the first telescope is located in Hawaii
  - 3 degrees FoV
  - 6000 square degrees of sky image every night

- **Intermediate Palomar Transient Factory (iPTF) -> ZTF**
  - fully automated wide-field survey in R-band (and g-band)
  - 1.2 meter telescope
  - limiting magnitude of 21 in R-band
  - 7.8 square-degrees FoV

- **BlackGem**
  - for identification counterparts of GW
  - it will be operational by September 2018
  - 3 telescopes of 65 cm diameter, the first station will be located at La Silla

Existing / future optical wide-field surveys

- **Zwicky Transient Facility (ZTF) (Palomar, California)**

– 47 square-degree FoV
– Scans 3750 square degrees in an hour to limiting magnitude of 20.5-21
– In the survey mode, images the entire Northern sky every 3 days
– Starts operations in 2017, science goals / strategy in 2020 unknown

- **Large Synoptic Survey Telescope (LSST) (Chile)**

– 9.6 square-degree FoV
– Observes the Southern sky
– In full operation by 2023
– Details of the cadence / observing strategy not yet available

- **Catalina Real-Time Transient Survey (CRTS)**

– 3 telescopes with FoV from 1.2 to 8.1 square degrees
– Limiting V-band magnitude of 19-21.5
– Both hemispheres, cadence unknown
– Unknown if will operate in CTA era

Summary

- An efficient MWL coverage is essential for almost all the possible CTA targets.

- Optical telescopes support needed to maximize the science and to optimize the CTA observational strategies

- Optical coverage of AGN is crucial for follow-up observations of the most prominent flares, for variability studies and dynamical spectral modelling of low and high activity states

- Optical telescopes will provide for AGN a source of alerts triggered by high flux states and changes in polarization

- Another aspect of complementary optical observations concerns the early organization of redshift campaigns for blazars (especially for BL Lac)

- Follow-up of properly selected alerts from optical (and radio, IR, X-rays) transient factories with CTA will pave a new and unexplored path to study the universe at VHE