Search for very-high-energy gamma ray and neutrino emission from microquasars with HESS and ANTARES/KM3NeT

Sébastien Le Stum

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What are microquasars?

- Binary systems with a compact object (Black Hole or Neutron Star)

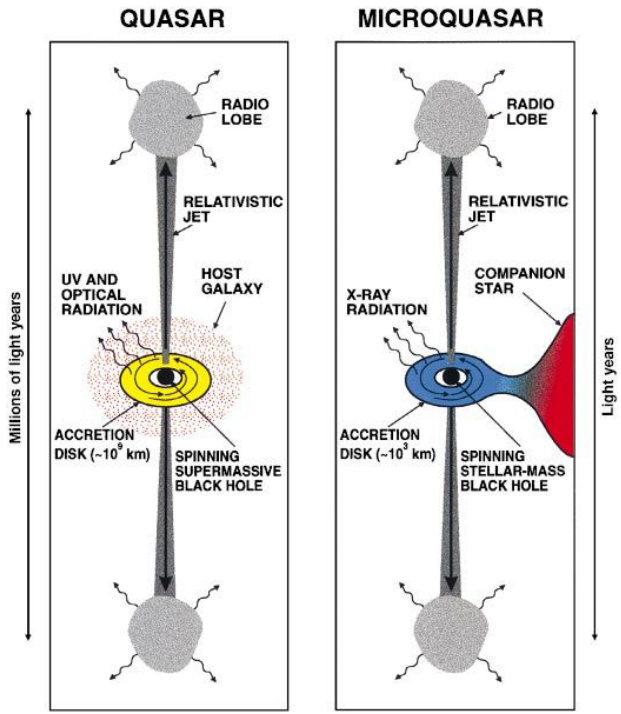
  and a companion star

- Matter transfer from the companion to the compact object

- Process of Accretion - Ejection:
  - Accretion through a **disk**
  - Ejection of matter through a **jet** (which can be relativistic)

- Emit mostly in X-Ray ⇒ XRB

- Transient with periods of **outburst**



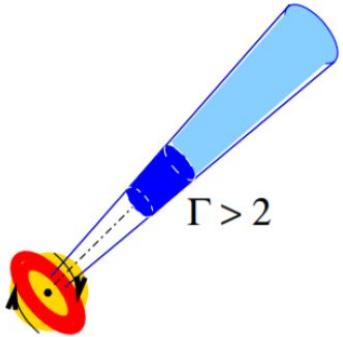
What are microquasars?

During an outburst, matter is ejected with relativistic bulk speed:

- ➔ Shocks are formed in the surrounding medium or previously expelled material (at lower speed)
- ➔ Possible particle acceleration to very high energy

Accelerated particles could produce

- (Very) High Energy Gamma
- Neutrinos (if the proton contribution dominates the electron one)



Leptonic process:

$$Inverse\,Compton:\ e^-_{accelerated} + \gamma_{LE} \rightarrow e^- + \gamma_{HE}$$

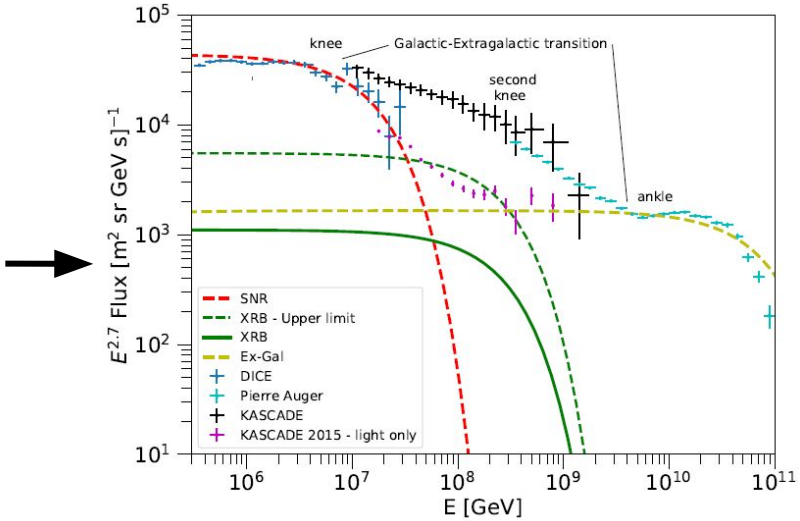
Hadronic process:

$$\left.\begin{array}{l} p_{accelerated} + p \longrightarrow X + \{\pi^0, \pi^-, \pi^+\} \\ p_{accelerated} + \gamma_{LE} \rightarrow \Delta^+ \rightarrow p\pi^0 \ or \ n\pi^+ \end{array}\right| \rightsquigarrow \gamma_{HE} \ or \ \nu$$

Interest to observe during outbursts ⇒ Multiwavelength and Multimessenger astronomy

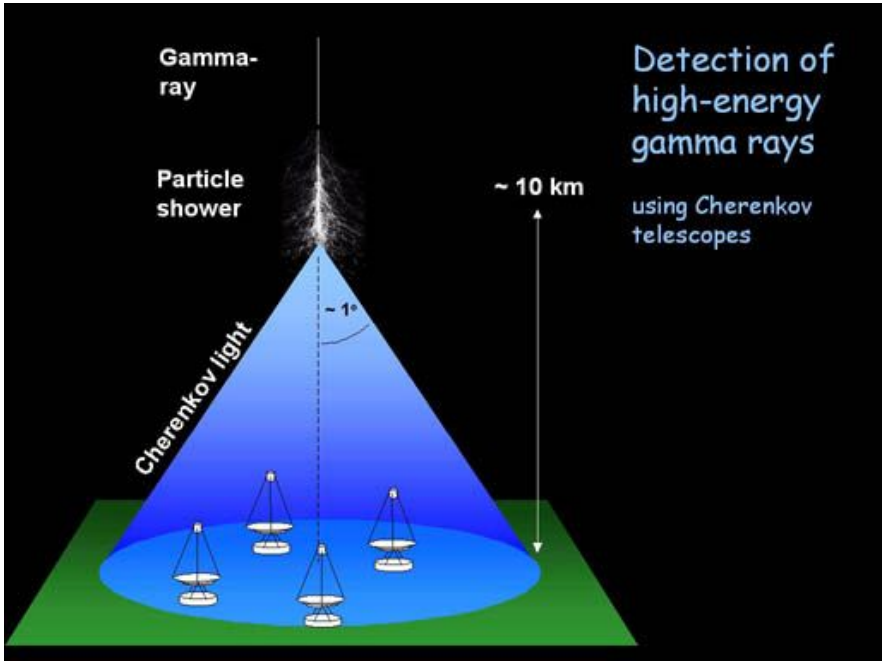
What can we learn?

- **Particle physics mechanism in jet** : Hadronic or leptonic
- **Mechanism of jet formation** : Jets powered by BH rotational energy are expected to contain electrons via pair production (Blandford & Znajek, 1977). A high leptonic fraction could indicate this mechanism.
- **Origin of intermediate energy cosmic rays** : If we have protons, we can explore the possibility of microquasars as candidates for origins of cosmic rays (Cooper et al,2020)
- **Location of particle acceleration** : As they are not absorbed, detecting neutrinos without gamma photons could indicate absorption. This would mean that particle acceleration is taking place in the inner parts of the system with higher density.



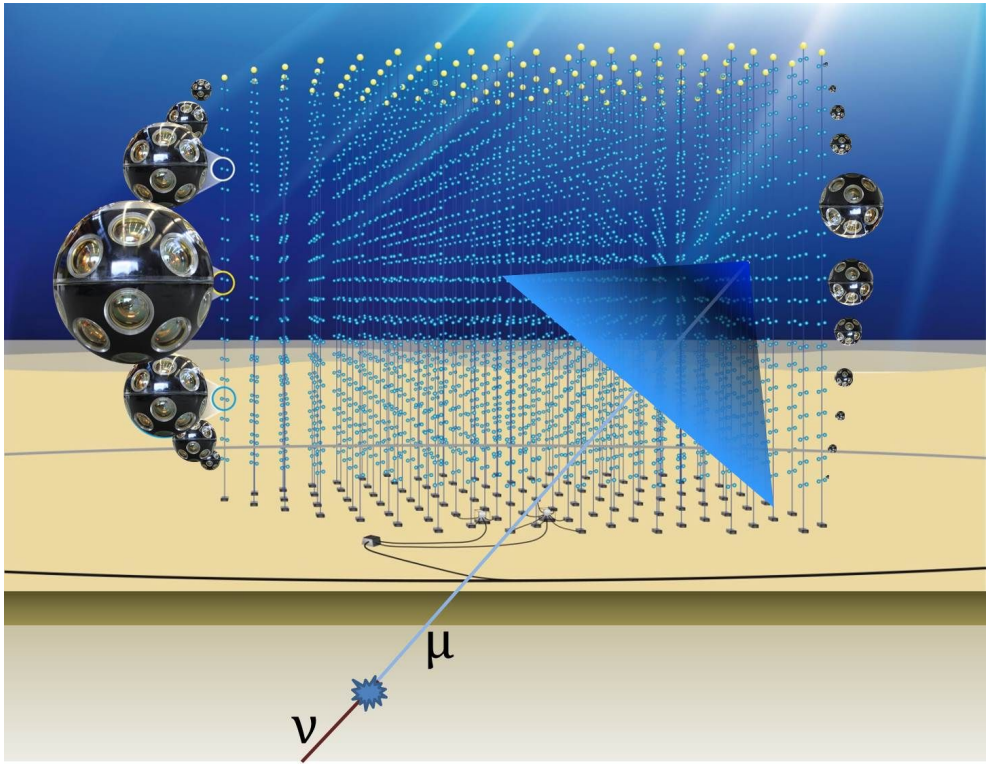
HESS Telescopes array

- High Energy Stereoscopic System
- Imaging Atmospheric Cherenkov Telescope array
- 4x12m + 1x28 m telescopes
- Very High energy gamma (~10s of GeV to ~10s of TeV)
- Inaugurated in 2004 in Namibia

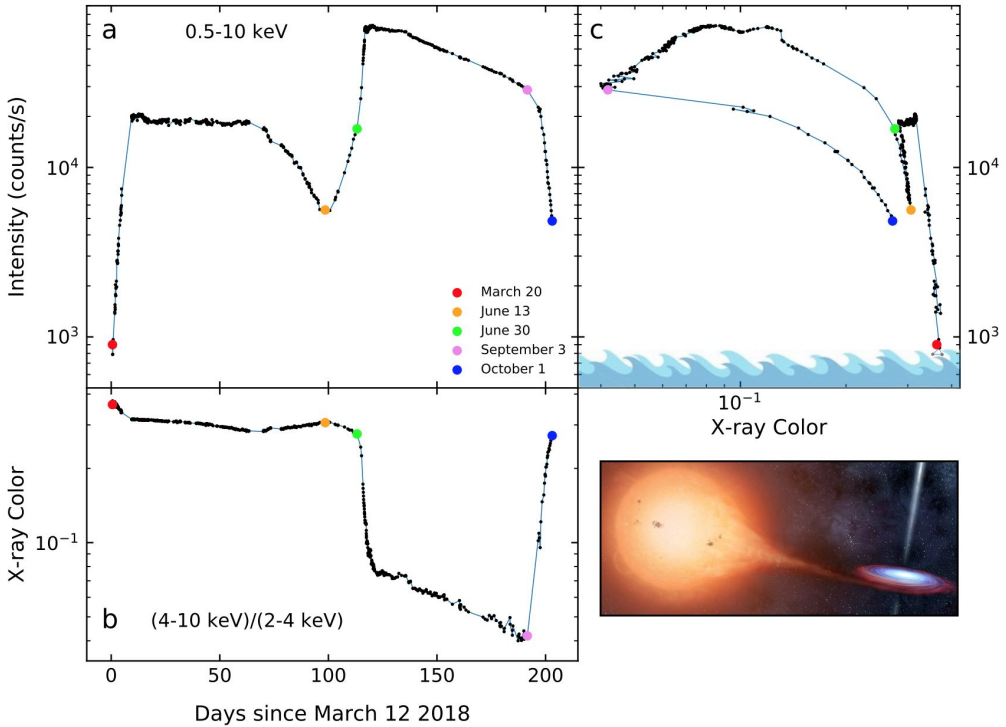


ANTARES and KM3NeT

- Neutrino telescopes
- ANTARES:
  - Operations from 2008 to 2022
- KM3NeT:
  - In construction
  - 2 sites
  - ORCA, near Toulon (Energy range: GeV to TeV)
  - ARCA, 100 km off-shore Portopalo di Capo Passero, Sicily (Energy range: TeV to PeV)



Multi-Wavelength behaviour of microquasars

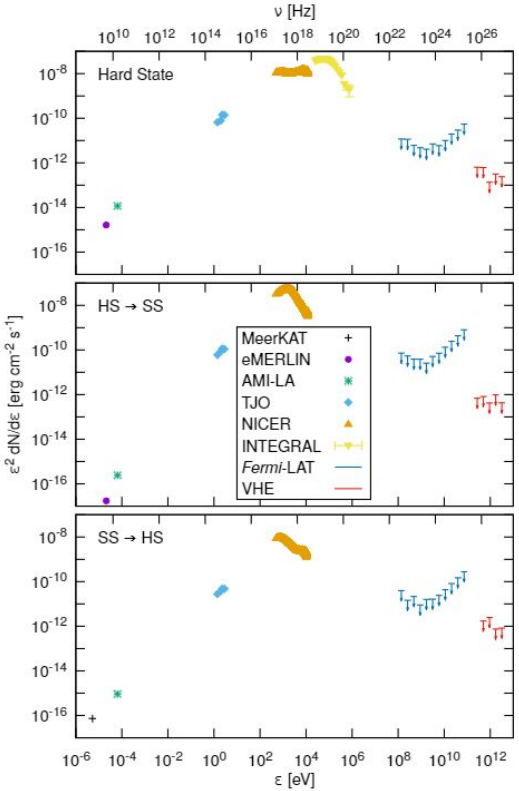


- Outbursts exhibit different phases in X-ray and radio
- These phases translate to different phenomenologies in the system
- **Phase transitions** are especially interesting for high energy emissions

⇒ Need to perform a multi-wavelength analysis

MAXIJ1820+070 From NICER (X-rays)

Search for VHE in a microquasar outburst



- MAXIJ1820+070 during 2018 outburst
- Joint observations with HESS/MAGIC/VERITAS
- No significant signal was detected, but limits on the emission location were drawn
- Common paper accepted in MNRAS (arXiv:2209.09785)

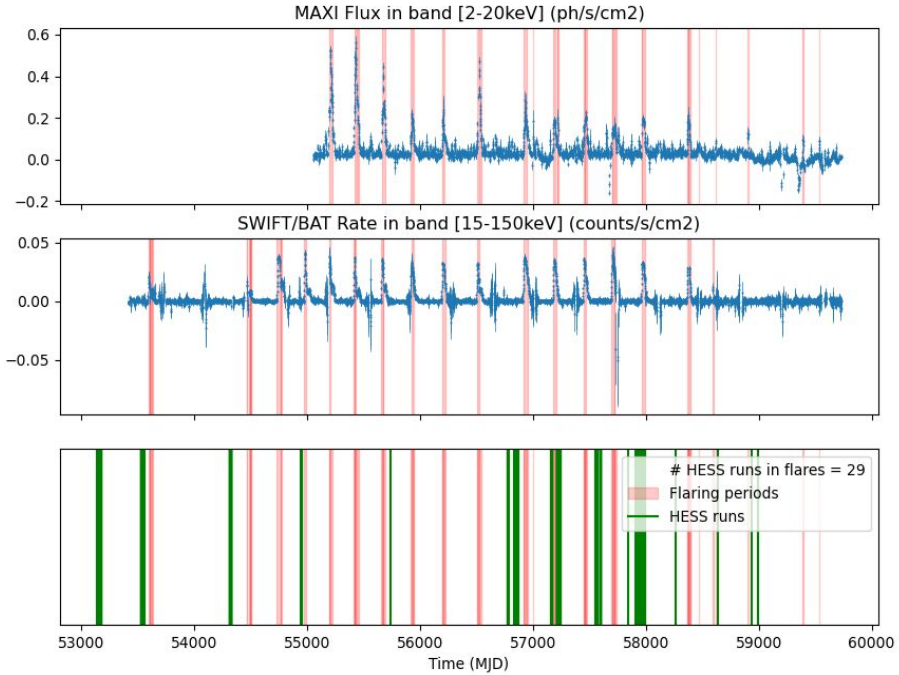
Flaring periods determination

- Using **Swift/BAT** and **MAXI** publicly available data
- Method:
  - Sliding window
  - Baseline cleaning by ignoring every point outside 3 std dev in the window
  - Data point considered in flaring state when:

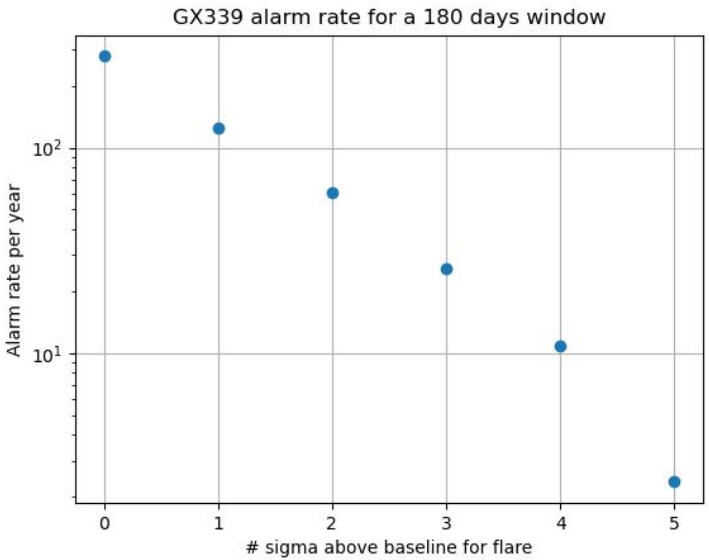
$$F - \delta F > \mu_{BL} + N\sigma_{BL}$$

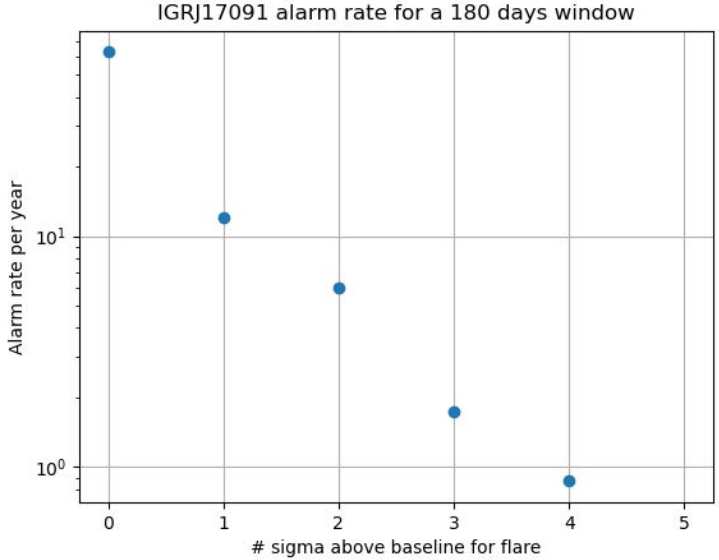
Flux, error	Baseline mean	Baseline Std. Dev

- Parameters:
  - Window size
  - Window slide step
  - Number of baseline Std.Dev, N sigma for defining a flare



Alarm Rates





- Compute the number of alarms that would have been sent
- Use it to compute alarm rate for each sources

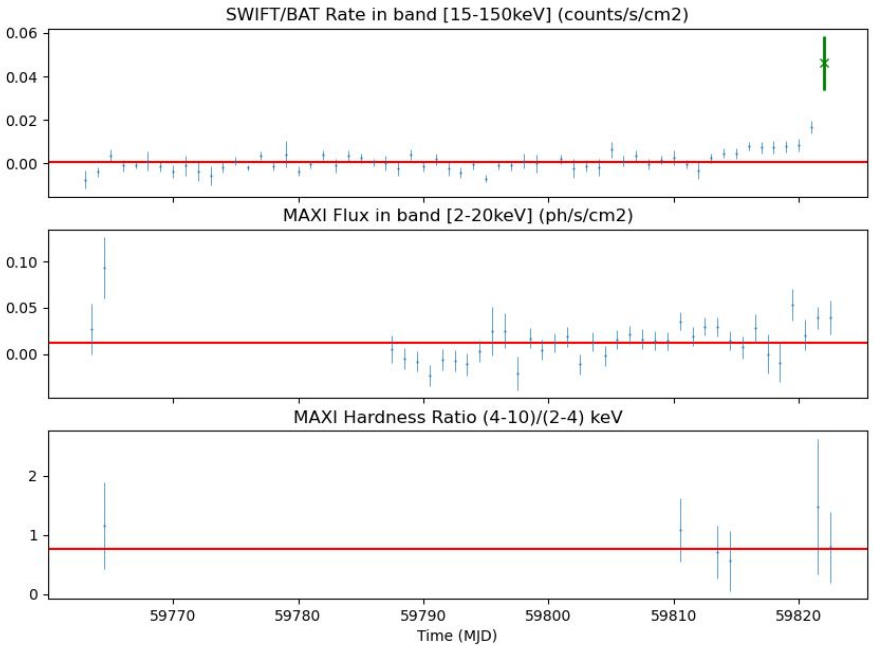
Multi-messenger search during flaring periods

From a list of 12 microquasars:

- ~ 50 hours of HESS observations in the Field of View of other targets
    - Analysis done (results not public yet!)
- ANTARES analysis ongoing for a search on the flaring periods

Real-time monitoring

- Goal: trigger gamma and neutrinos searches as fast as possible in the event of a new flare
- Same principle as the archival analysis
- List of sources monitored continuously as the data is updated



GX339-4 recent flare (reported in ATel#15578)
Baseline is shown in red, alert sent from green data point

Real-time Microquasar flares detection

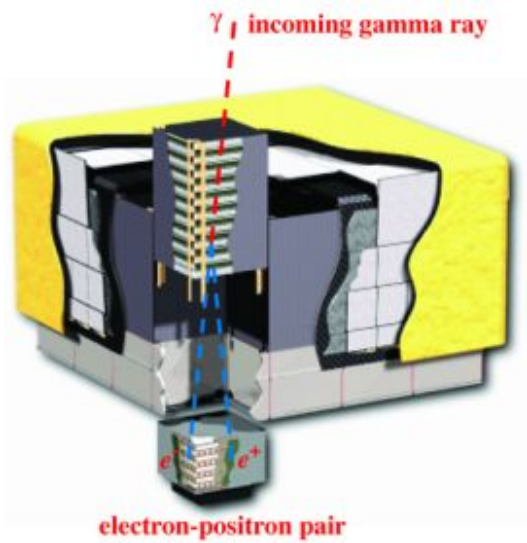
If an flare is detected, send alert as a VOEvent through a COMET server

⇒ Follow-up with FERMI/LAT Analysis (HE gamma)

- Binned Likelihood Analysis
- Search for new, uncatalogued, source at the alert position
- Time window: 24h before alert time up to last available data

Alert levels:

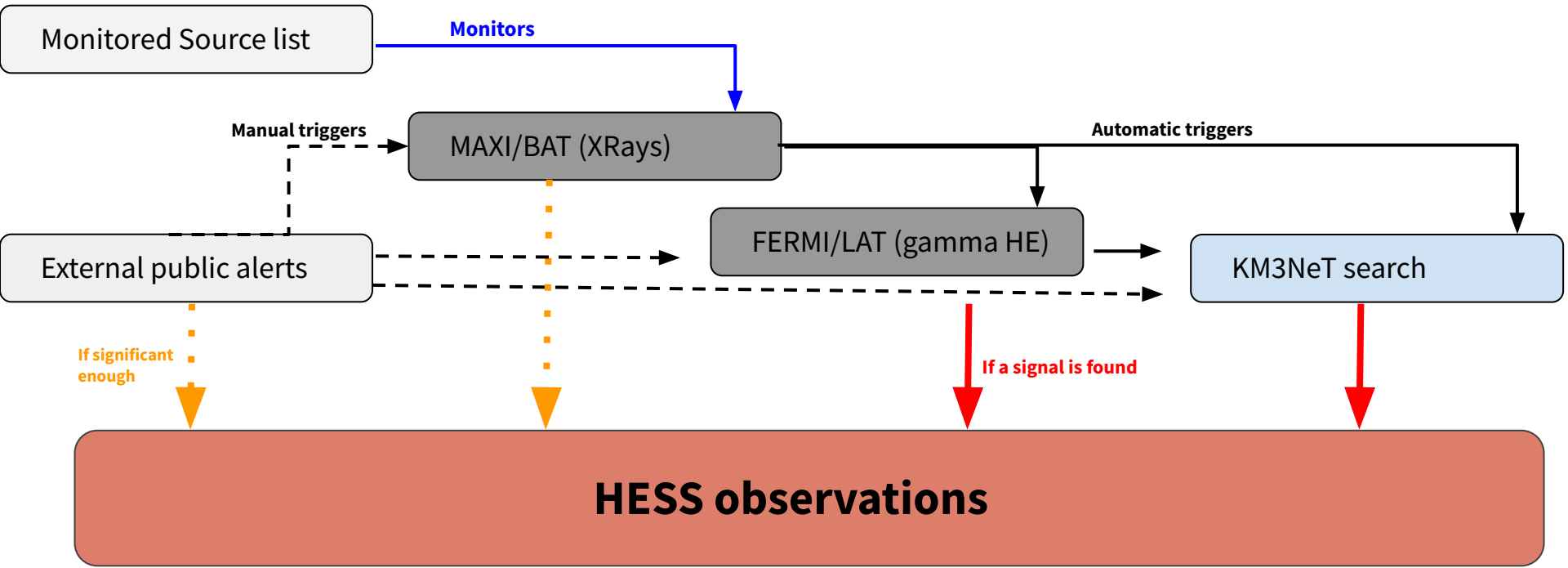
- Level 1: X-Ray flux increase OR hardness ratio transition
- Level 2: X-Ray flux increase AND hardness ratio transition
- Level 3: FERMI HE gamma signal



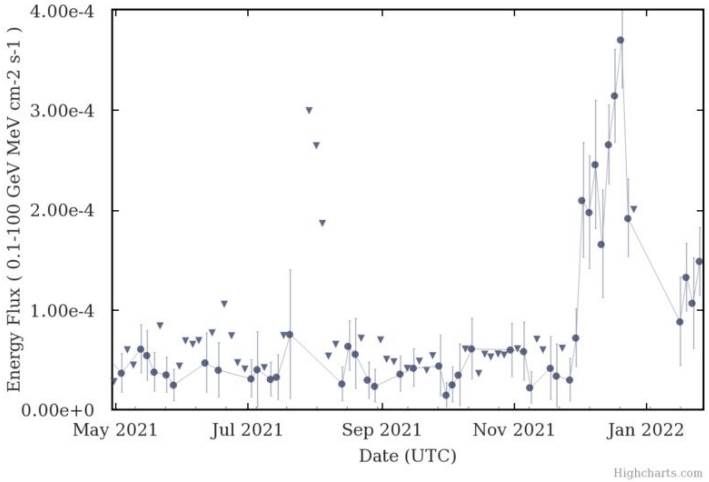
FERMI/LAT Telescope

⇒ KM3NeT follow-up analysis
⇒ HESS observations to be triggered if a signal is found

Real-Time monitoring summary



Astronomy with KM3NeT : follow ups on IceCube alert associated with blazars

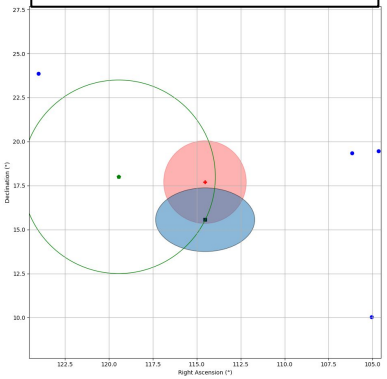


PKS0735 FERMI lightcurve

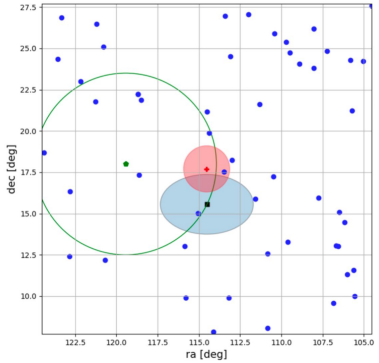
Results:

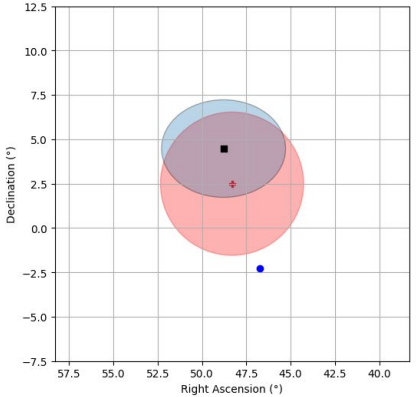
- 1 associated neutrino candidate with PKS0735 in the 1 month time window, p-value = 0.14
- No association for the other blazars
- Reported in [ATel#15290]

ORCA PKS0735 1 month skymap



ARCA PKS0735 1 month skymap





ORCA TXS0310 2 day skymap

Conclusion

- Multi-wavelength and multi-messenger picture of microquasars
- Flaring periods identified
- 2 main goals:
  - Data analysis from archives in HESS and ANTARES
  - Preparation for new observations in HESS and KM3NeT during future outbursts
- Next steps:
  - Compare results to modelling
  - Complete automation of KM3NeT data analysis in case of incoming alerts

Thank you for you attention!