Search for gamma-ray emission from the binary system HESS J0632+057

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on behalf of the Fermi-LAT collaboration

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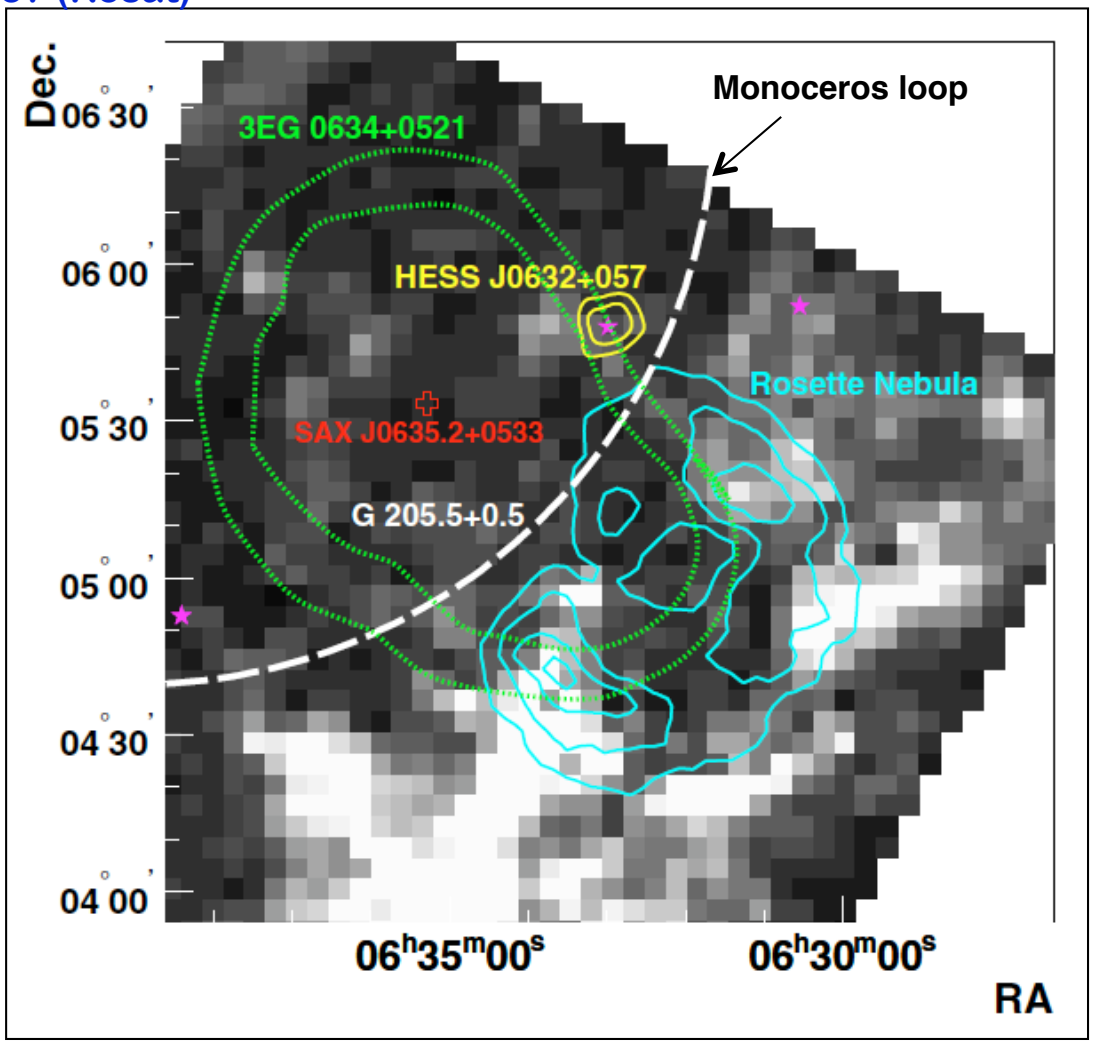
Discovery of HESS J0632+057

- The HESS Cherenkov Telescope's collaboration announced on 2007 the discovery of a new γ-ray source, located close to the rim of the Monoceros SNR
- HESS J0632+057 is point-like → HMXB candidate
- possibly associated with
  - the X-ray source 1RXS J063258.3+054857 (Rosat)
  - the GeV γ-ray source 3EGJ0634+0521
  - the Be-star MWC148



Velocity integrated ^{12}CO map (NANTEN Galactic Plane Survey)

-SAX J0635.2+0533: binary pulsar

-Monoceros SNR (Green catalog)

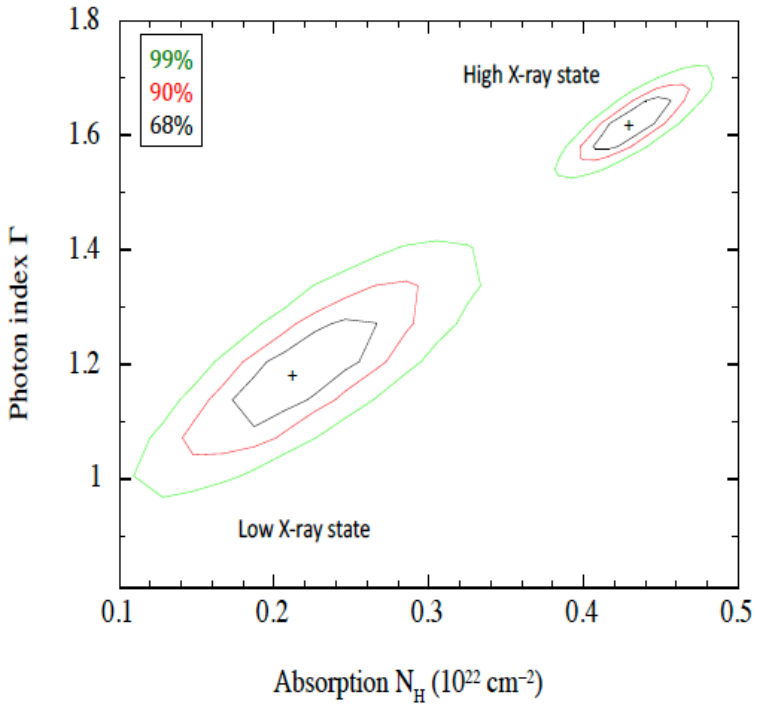
-Rosette Nebula (Radio)

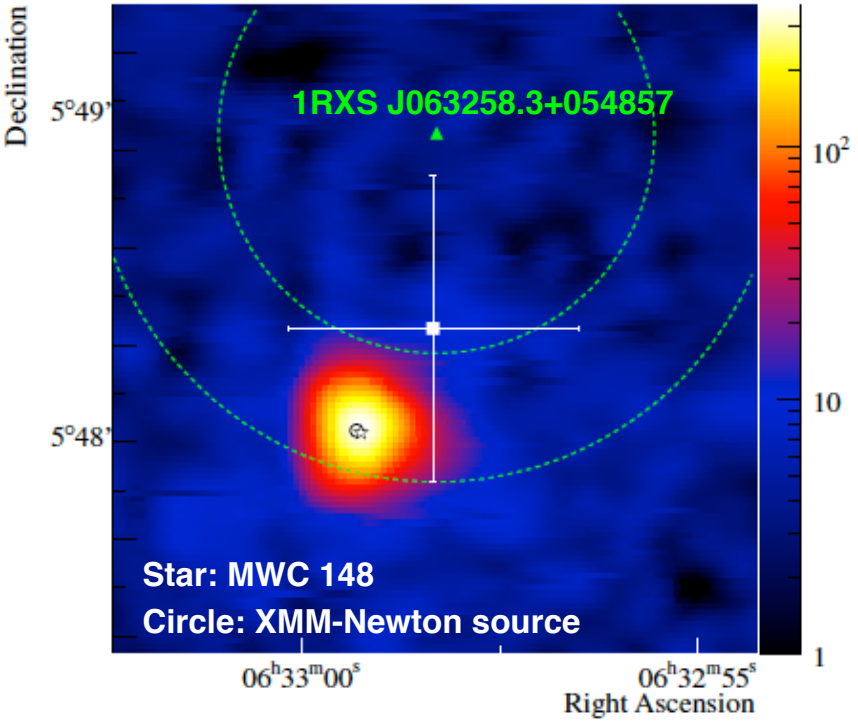
-3EG 0634+0521 (95%, 99% EGRET contours)

-Be stars (pink stars)

Follow-up by XMM-Newton, Swift, and Chandra

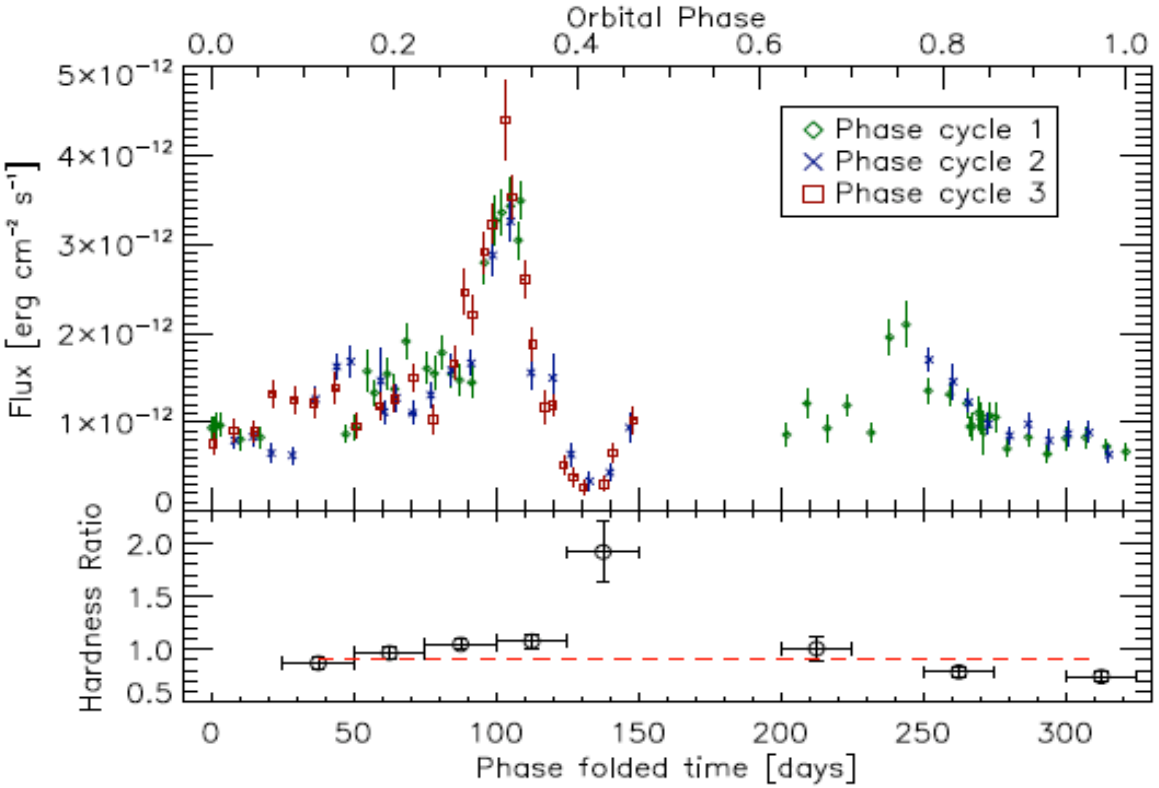
- XMM-Newton revealed an X-ray source coincident with the TeV emission and MWC 148
- Significant X-ray variability present on multiple time scales including days to months
- No detection of pulsations with Chandra data
- Spectral variability
  - Absorbed power-law
  - Variation in spectral index, and absorption (N_H)



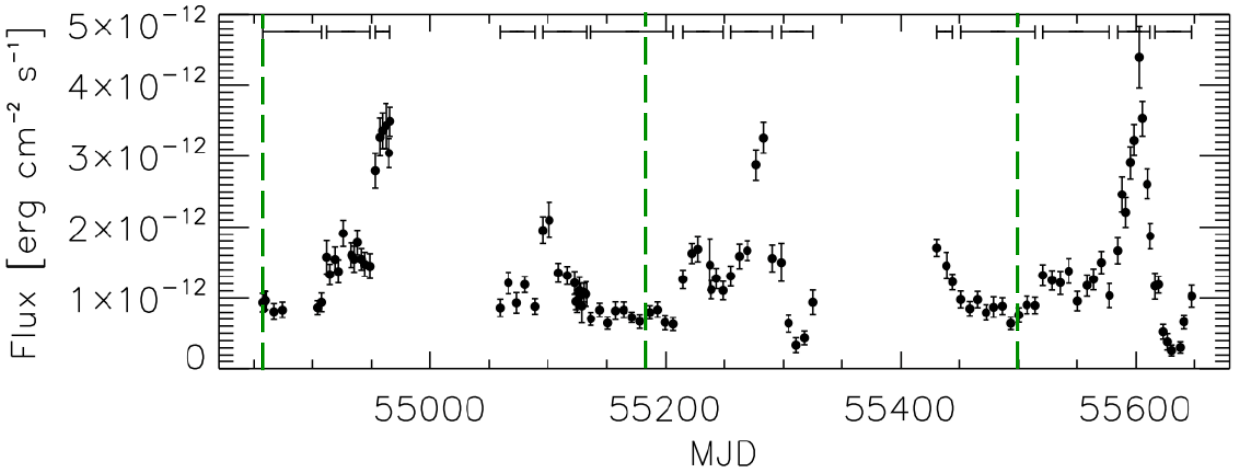


Hinton et al. 2009
Falcone et al. 2010
Rea & Torres 2011

X-ray period (Bongiorno et al. 2011)



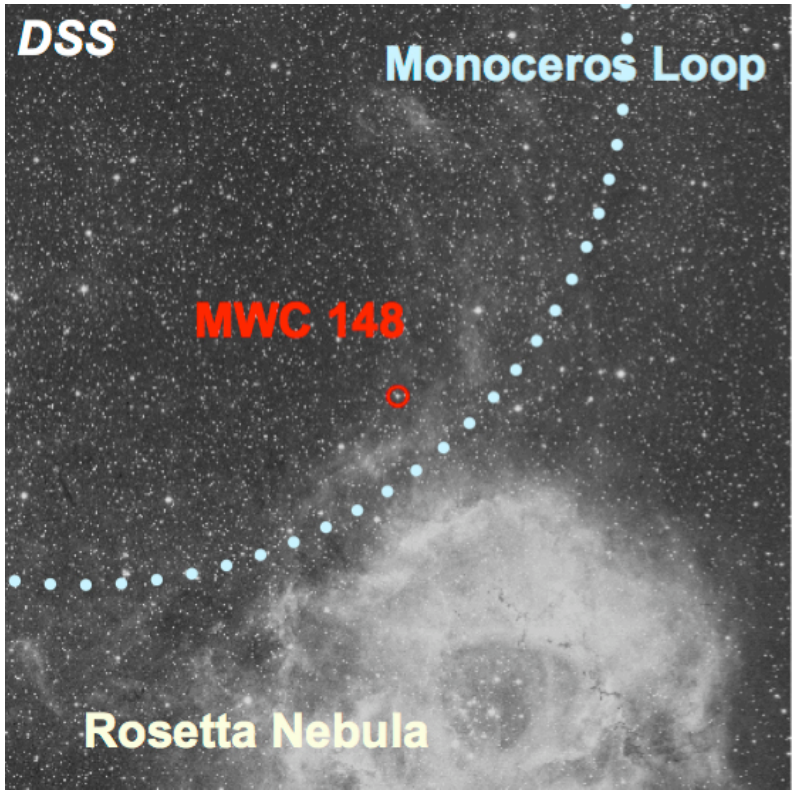
- Orbital period 321 ± 5 days
  - Swift/XRT observations since 2009 January to 2011 March
- High flux peak at phase 0.3, followed by a dip feature
- Moderate flux peak at phase 0.75
- The hardness reach a significant maximum when the light curve exhibits the dip feature

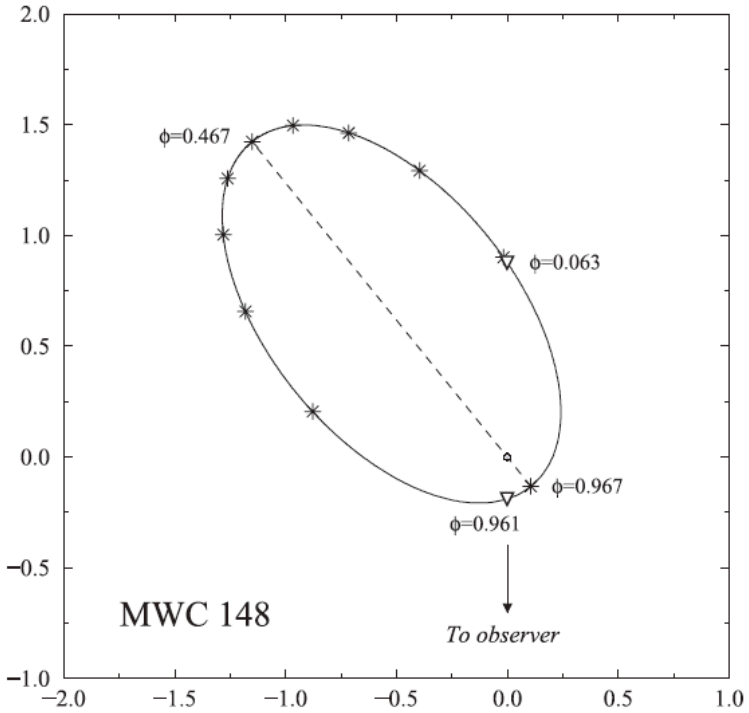


Optical counterpart MWC 148

- Be star
- Mass 13.2 – 19.0 $M_\odot$
- Distance 1.1 – 1.7 kpc
- Radius 6.0 – 9.6 $R_\odot$
- Stellar effective temperature 27500 – 30000 K

  Aragona et al. 2010



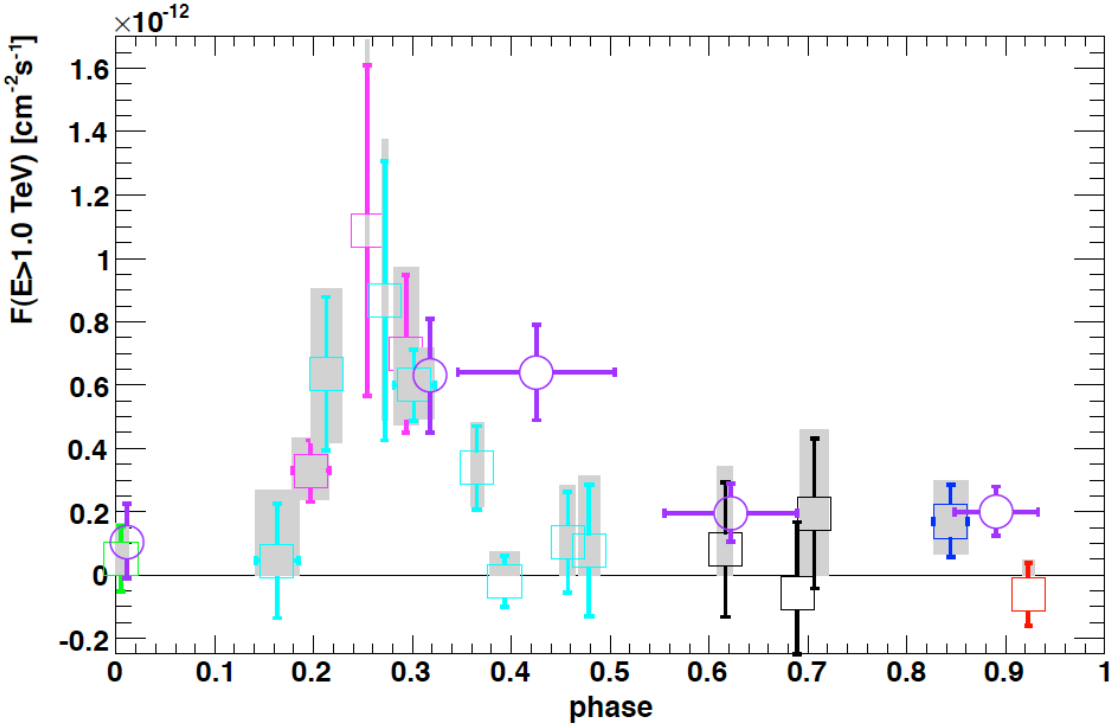


- Period 321 days
- Eccentricity 0.83 ± 0.08
- Longitude of the periastron 129°± 17°
- Projection of the semi-major axis 180 ± 60 lt-s

  Casares et al. 2011

Monitoring with Cherenkov telescopes

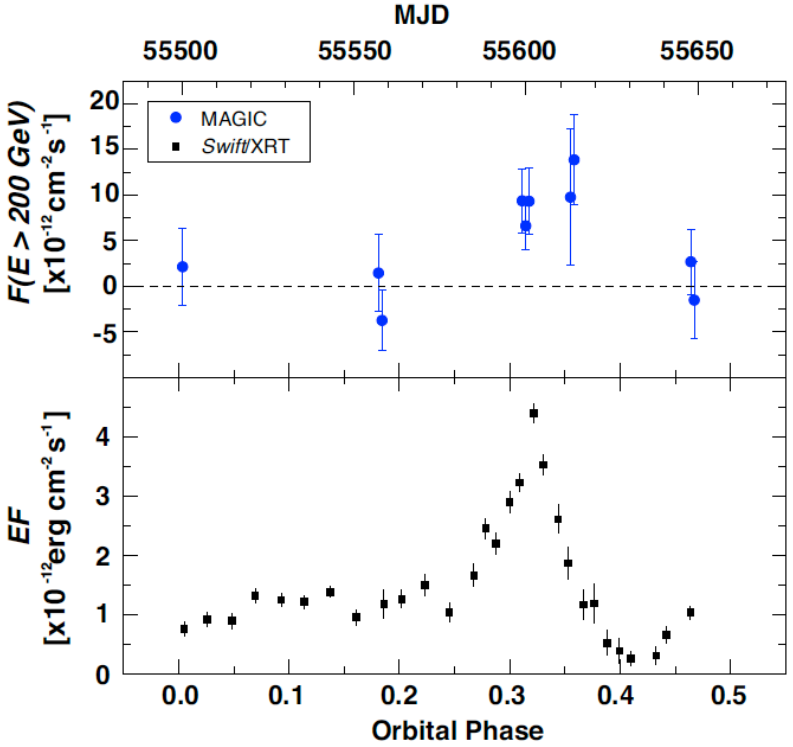
- **VERITAS monitoring: 2006-2009 → upper limits**
- **In 2010 - 2011: MAGIC & VERITAS detected the source simultaneously to the high X-ray peak**



VERITAS (squares) and HESS (circle) folded light curve

VERITAS observations since 2006 to 2011

HESS observations in 2004 and 2010

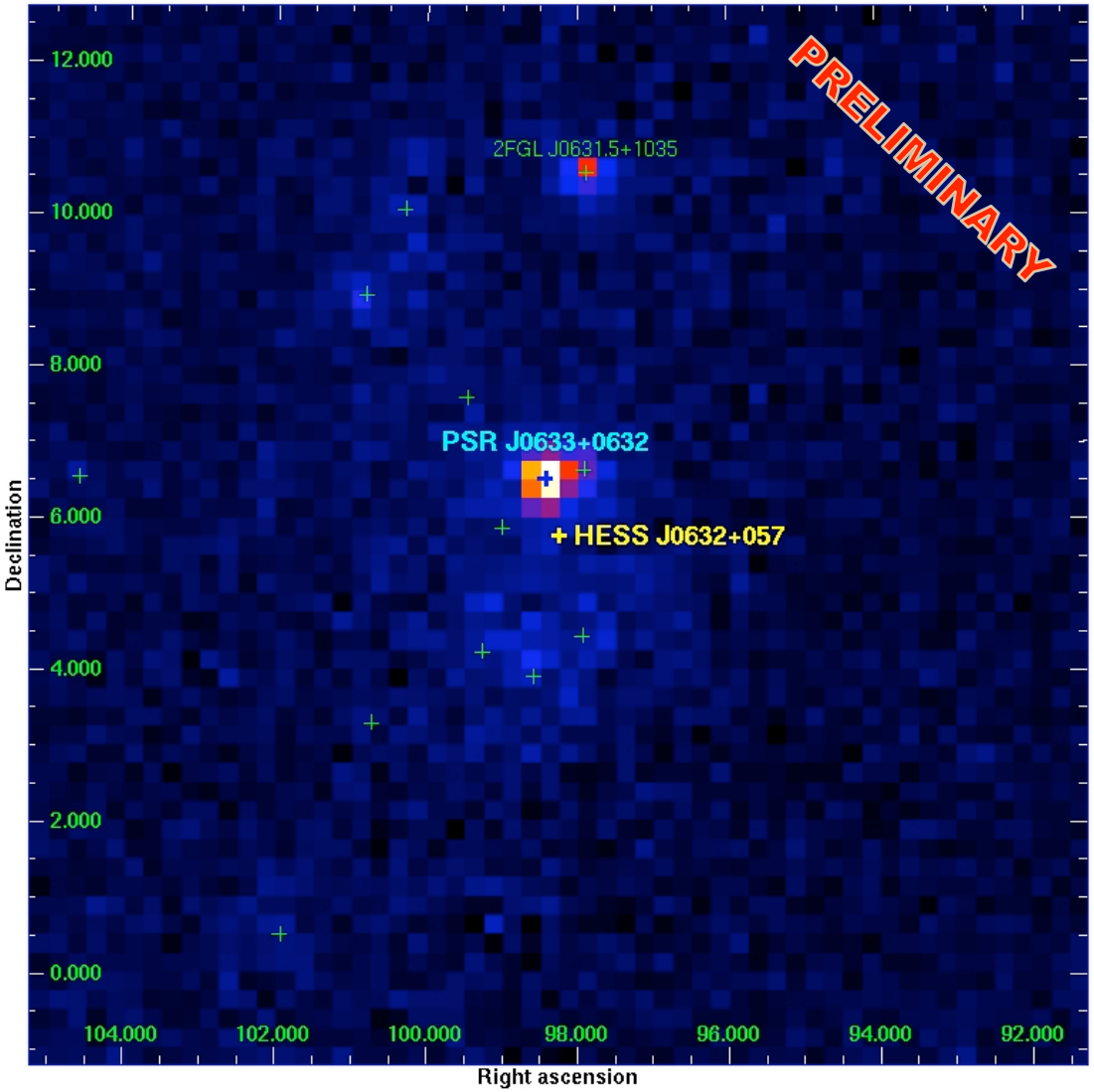


Top: MAGIC folded light curve of observations performed in 2010 – 2011.

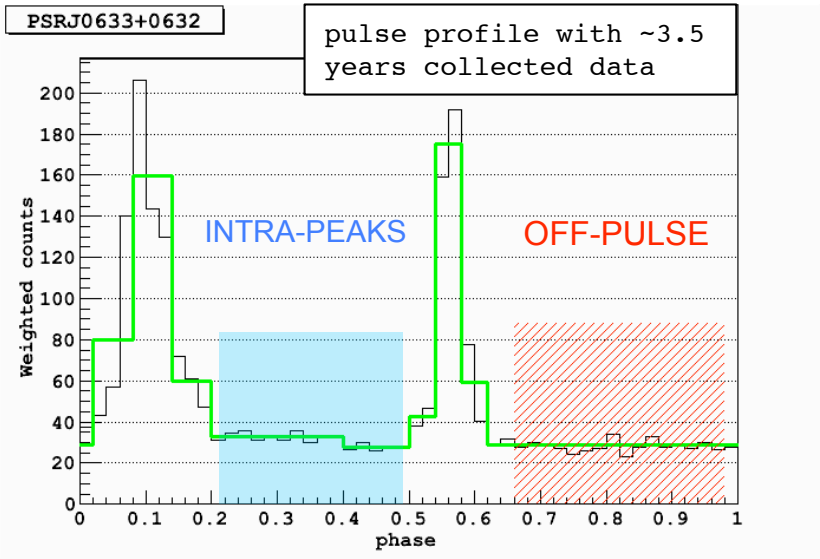
Bottom: Swift/XRT folded light curve

HESS J0632+057 observed by Fermi-LAT

FoV around HESS J0632



Diffuse subtracted count map for E>1GeV

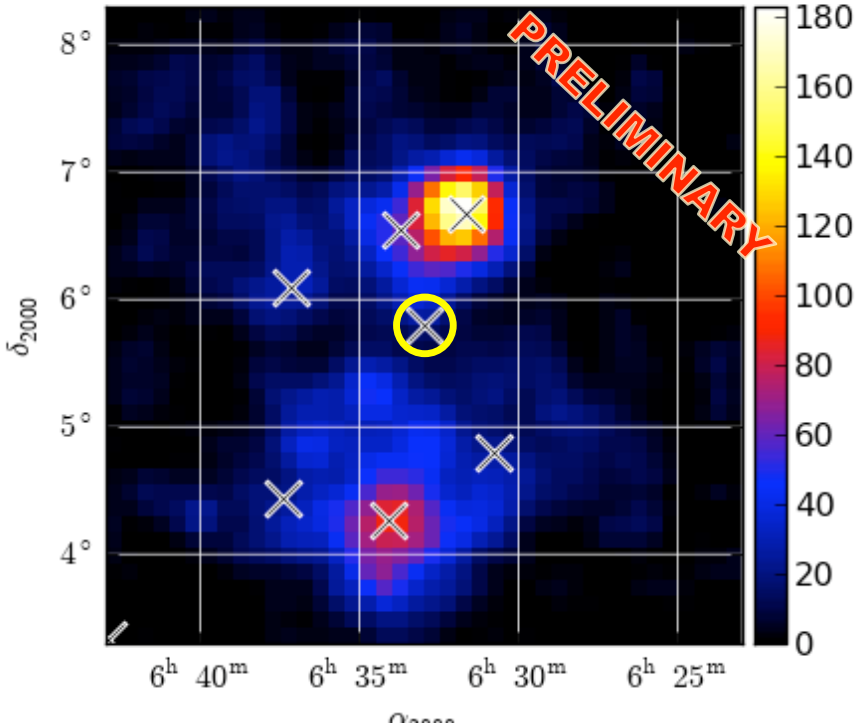


- The FoV around the position of HESS J0632+057 is dominated by the emission of the pulsar PSR J0633+0632 (F_{100}=8.4±1.4 × 10^{-8} ph cm^{-2} s^{-1})
- PSR J0633+0632 is a radio loud pulsar included in the first pulsar catalog of Fermi. It has a typical light curve composed by two narrow peaks separated by ~0.5 phase
- To avoid this strong emission, we looked in the OFF-PULSE defined using Bayesian block algorithm (green line), and in the INTRA-PEAK phases

The region out of the PSR peaks

- **Joining the OFF-Pulse + Intra peaks phases of PSR J0633+0632 the region around HESS J0632+057 appears like the TS maps plotted below**

Diffuse subtracted TS Map @ E>300MeV



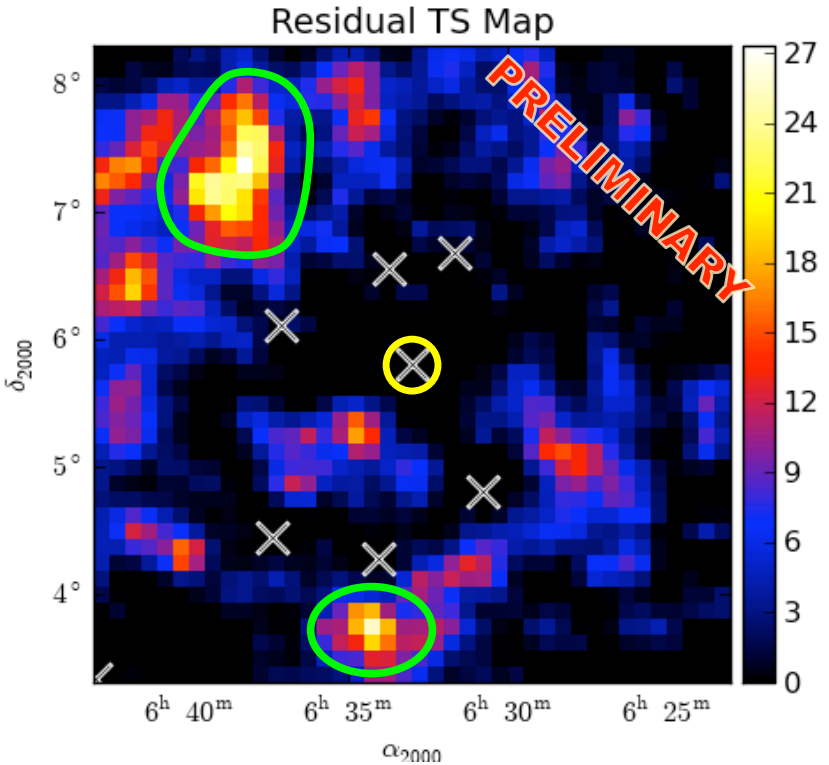
- The crosses correspond to 2FGL sources
- The yellow circle is HESS J0632+057
- There are several points with TS>40 that are not modeled by 2FGL sources

- **Likelihood ratio test**
  - **$TS = 2\ [\ \log(L_1) - \log(L_0)]$**
  - **L_0 = likelihood value from the fit of the model without the source (null hypothesis)**
  - **L_1 = likelihood value from the fit of the model with the source (test hypothesis)**
- **TS map**
  - **for each pixel of the map the TS is calculated assuming for the test hypothesis a point-like source at the center of the bin**

For the map showed in this slide the model for the null hypothesis includes only the diffuse Galactic and extragalactic emission.

In this way all the sources should be evident in the map

Modeling the region around HESS J0632+057



- In the residual TS map @ E>300MeV there are 2 excess with TS~25
  - We add two new sources on top of the excesses
  - The localization is refined with a dedicated procedure
  - Their spectrum is modeled with a likelihood fit

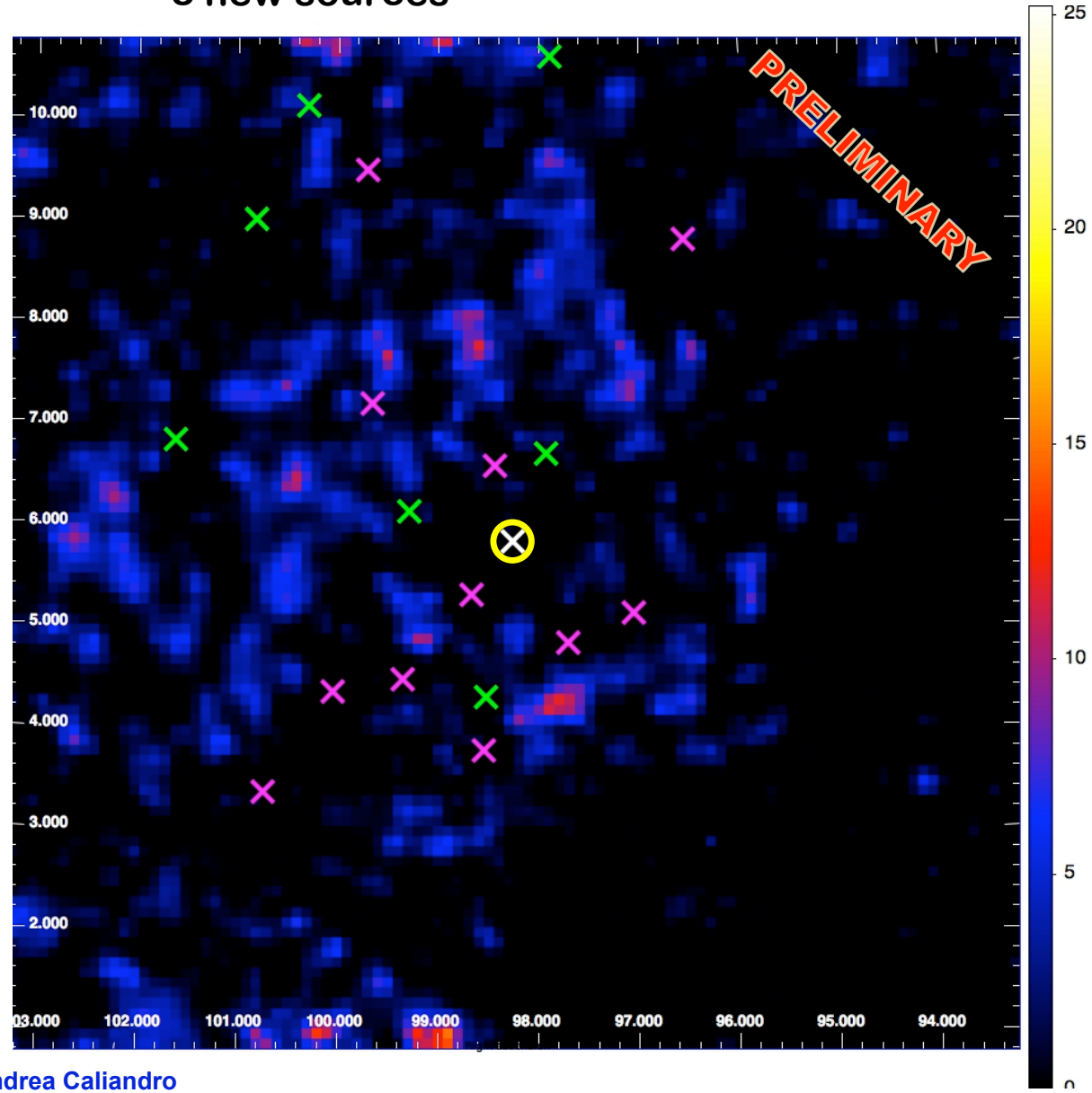
- We worked to model the region as well as possible
  - re-localization and modeling the 2FGL sources with TS<100
  - Iteratively adding new sources in coincidence of excesses in the residual TS maps
  - The iteration is stopped when there are not excesses with TS>15 in the residual TS map

The residual TS map is obtained including in the model of the null hypothesis all the sources already detected

In this way only un-modeled excesses appear in the map

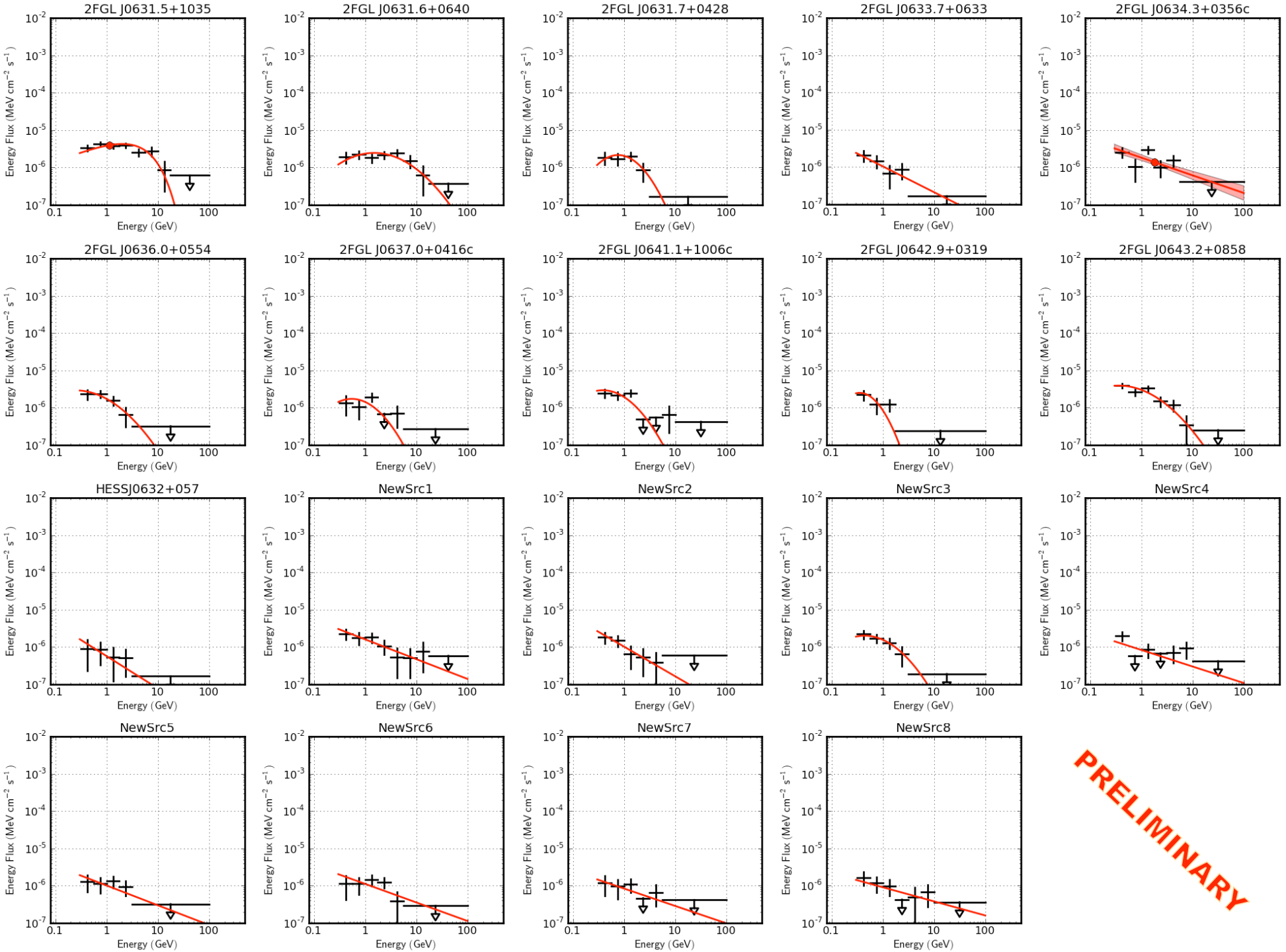
Final residual TSmap 10ºx10º

- No excesses with TS>15
- 8 new sources



Source name	TS
2FGL J0631.5+1035	350
2FGL J0631.6+0640	140
2FGL J0631.7+0428	45
2FGL J0633.7+0633	37
2FGL J0634.30356c	64
2FGL J0636.0+0554	54
2FGL J0637.0+0416c	27
2FGL J0641.1+1006c	71
2FGL J0642.9+0319	30
2FGL J0643.2+0858	170
HESS J0632+057	4.7
New1	36
New2	34
New3	53
New4	22
New5	24
New6	28
New7	23
New8	25

In magenta sources with TS<50


2FGL J0631.5+1035
2FGL J0631.6+0640
2FGL J0631.7+0428
2FGL J0633.7+0633
2FGL J0634.3+0356c
2FGL J0636.0+0554
2FGL J0637.0+0416c
2FGL J0641.1+1006c
2FGL J0642.9+0319
2FGL J0643.2+0858
HESSJ0632+057
NewSrc1
NewSrc2
NewSrc3
NewSrc4
NewSrc5
NewSrc6
NewSrc7
NewSrc8
Energy Flux (MeV cm^{-2} s^{-1})
Energy (GeV)
PRELIMINARY

Likelihood analysis of HESS J0632, and UL

- The GeV emission of HESS J0632+057 is still under the sensitivity of Fermi-LAT
- We infer upper limits in different energy ranges

E range	TS	95% UL flux
0.1 - 1 GeV	6.6	2.0 E-8 ph/cm^{2}s
1 - 10 GeV	3.3	1.3 E-9 ph/cm^{2}s
10 - 100 GeV	0.1	0.8 E-10 ph/cm^{2}s

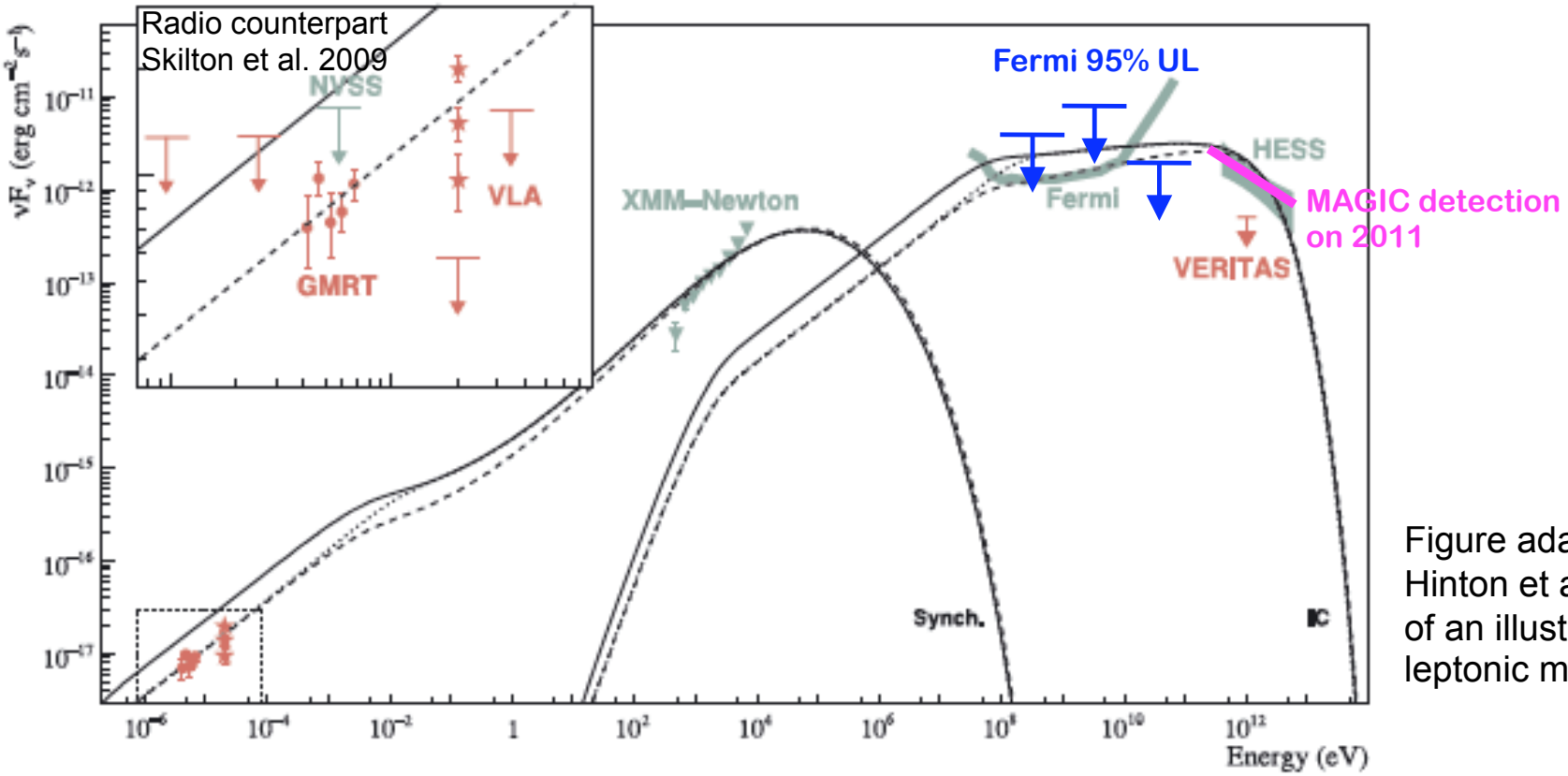
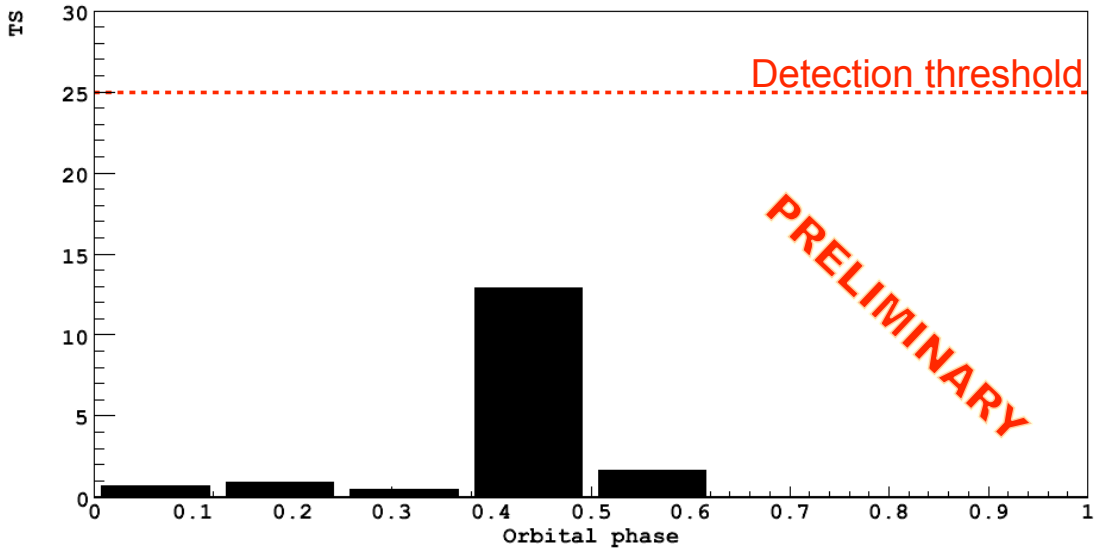


Figure adapted from Hinton et al. 2009 of an illustrative leptonic model

Folded analysis

- The source is analyzed folding the photons with the orbital period of the system (321 days), and dividing the orbit in 8 bins.
- For each bin a likelihood ratio test is performed



- All the bins are below the detection threshold (TS=25 → 4.6 σ)
- The highest bin has a TS value that depending on the setting of the parameters of the nearby sources varies as TS = 8 - 16

Summary

- We are searching for evidence of GeV emission from HESS J0632 using 3.5 years of LAT-data
- We modeled the region around HESS J0632+057 as well as possible, working in the Off-pulse + Intra-peaks of PSR J0633+0632
- HESS J0632+057 remains undetected in GeV energy range
  - We inferred 95% upper limits in different energy ranges
- We analyzed HESS J0632+057 folding the photons with its orbital period
  - All the bins are below the detection threshold (TS=25)
  - Even the highest bin has a TS value that corresponds to less than 3 sigma

Comparison with other gamma-ray HMXB systems

- Gamma-ray HMXB systems are those systems whose emission is dominant in GeV - TeV energy range

Name	γ-ray activity	Star type	Orbital period [days]	Eccentr.	Distance [kpc]	γ-ray flux (>100MeV) [E-8 ph/cm^{2}s]
HEES J0632+057	VHE	Be	321	0.83	1.5	<2.0
LS I +61 303	HE, VHE	Be	26.50	0.54	1.9	95
PSR B1259-63	HE, VHE	Be	1236.79	0.87	2.3	~150 peak after the periastron passage
LS 5039	HE, VHE	O	3.91	0.35	2.5	61
1FGL J1810.6-5856	HE, VHE?	O	16.58	--	5.4	2.9