TeV emission from the pulsar wind nebula Vela-X

prospects with the ASTRI mini-array proposed as a pathfinder for the Cherenkov Telescope Array

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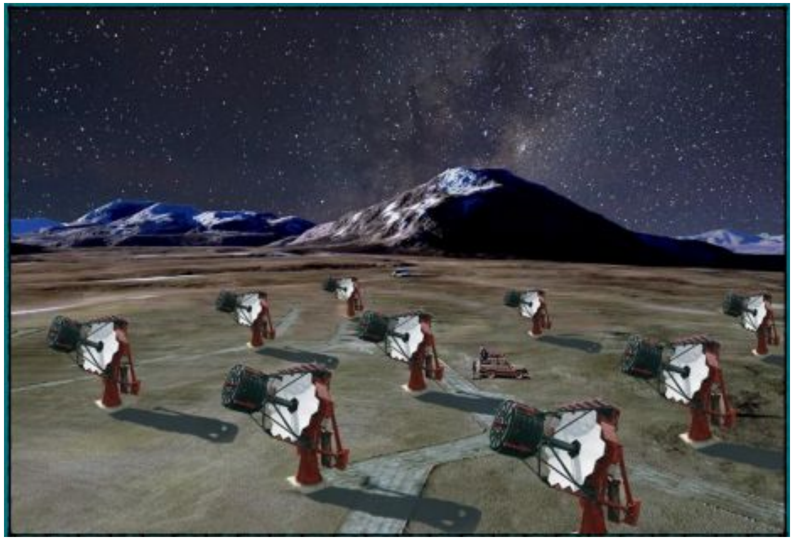
GCT
SCT
LST
SST-1M
MST
Telescope
Prototypes
ASTRI

The ASTRI-MA (Astrofisica con Specchi a Tecnologia Replicante Italiana- Mini Array)

- ASTRI-MA Proposed as a pathfinder for the CTA Observatory (South Site)
- It consists of an array of 9 SST of ASTRI telescopes
- 2-mirrors with ASTRI cameras (made of SiPM)
- Approved and funded by the 'Istituto Nazionale di Astrofisica' (INAF)
- An ASTRI prototype (ASTRI-Horn) has been installed on Mt. Etna (Sicily) in 2014
- **<u>Detection of the Crab pulsar in December 2018</u>** (Lombardi et al., A&A submitted).



ACDC project

- The ASTRI/CTA Data Challenge (ACDC) is an INAF project (PI. P. Caraveo) aimed at developing the Italian community of the TeV astronomy, developing know-how and experience for data-analysis in the light of the early science of the CTAO

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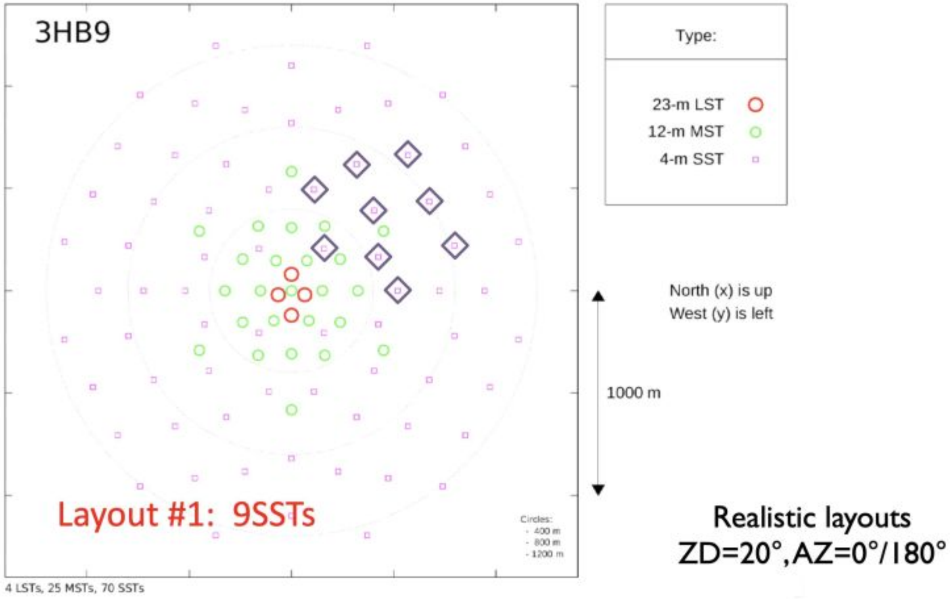
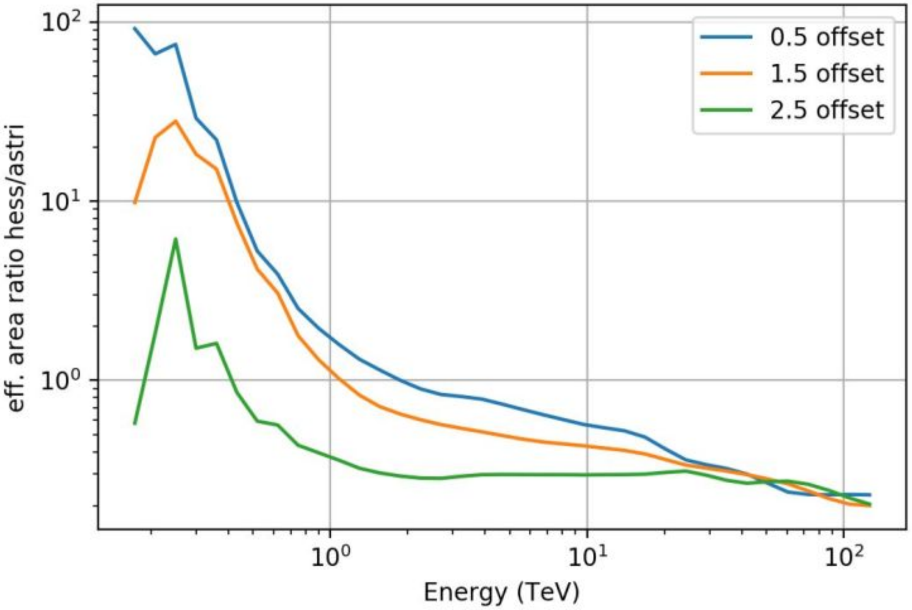
- End-to-end simulation of a realistic 3 years of observations of a sample of targets
- Specific Pointing plan
- Verify the possibility of an "early science" phase

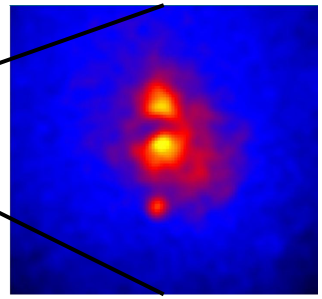
The ACDC project: expected performances ASTRI-MA

- IRF calculated partially from CTA Prod3b simulations and from the A-SciSoft software (Lombardi et al. 2016), with 9 SST in a realistic layout (Zenith angle: 20 deg)
- Energy range: 1-200 TeV
- Large FoV: ~10 deg2

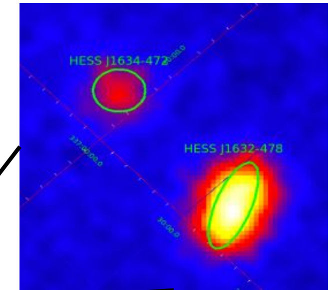




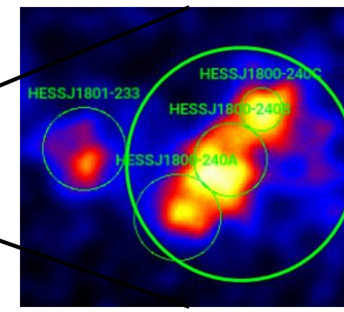
Selected targets



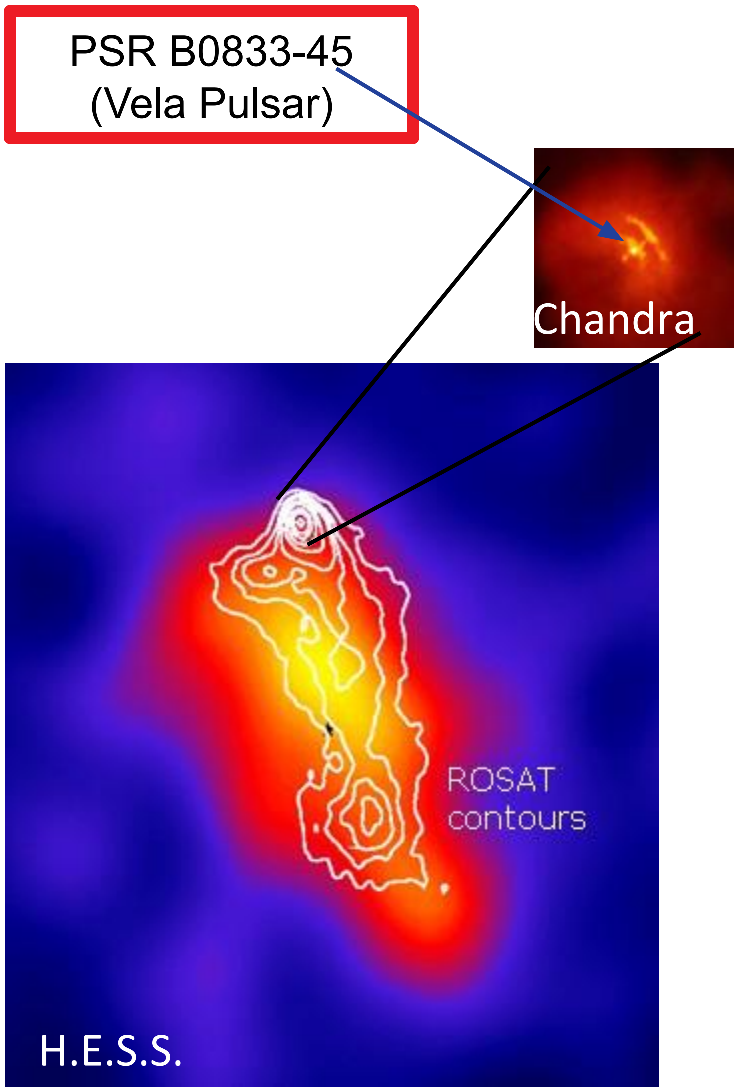
- LS 5039
- LMC P3
- Sculptor
- Reticulum II
- Tucana II
- HESS J1748-248
- HESS J1018-589
- HESS J1825-137
- HESS J1303-631
- Vela X



- HESS J1632-478 and HESS J1634-472
- HESS J1833-105
- SNR G0.9+0.1
- MSH 15-52
- NGC 1068
- W28
- Westerlund 2
- Crab
- PKS 2155-304

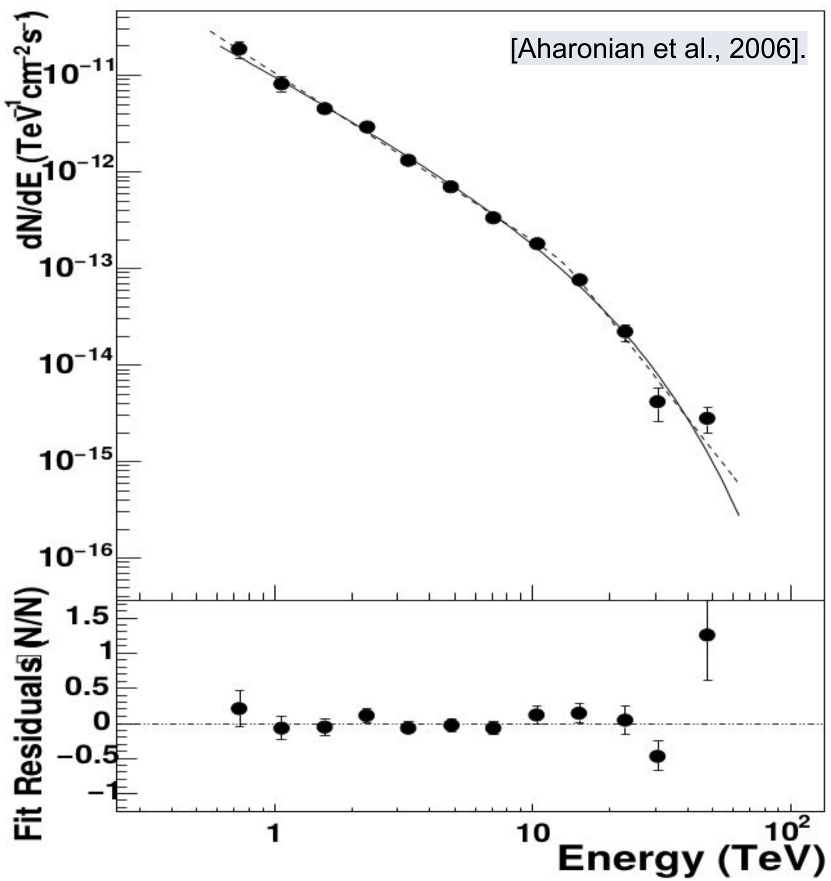


The Pulsar Wind Nebula Vela X



- Type: Pulsar Wind Nebula
- Age: 20 kyrs
- Distance: 290 parsec (Dodson et al., 2003)
- Extended Source observed by H.E.S.S. (<100 TeV)(Aharonian, F. et al. 2006)
- Located south of the pulsar
- Apparently the result of relic PWN being disturbed by asymmetric passage of the SNR reverse shock (e.g Blondin et al. 2001)

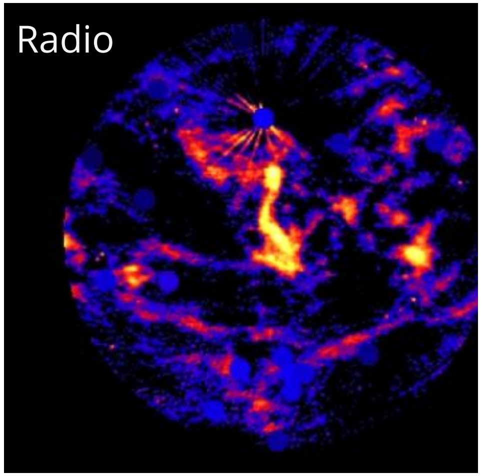
VHE emission from Vela X

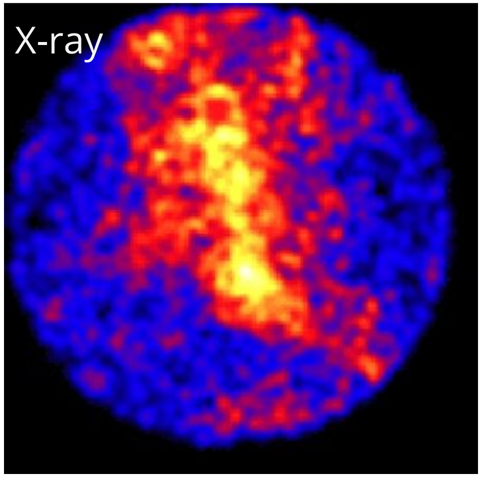


- Inverse-Compton up-scattering of ambient photons
- Spectra compatible with a exponentially cut-off power law
- Γ~1.32 flux ~95% crab unit
- Cut-off ~ 14TeV

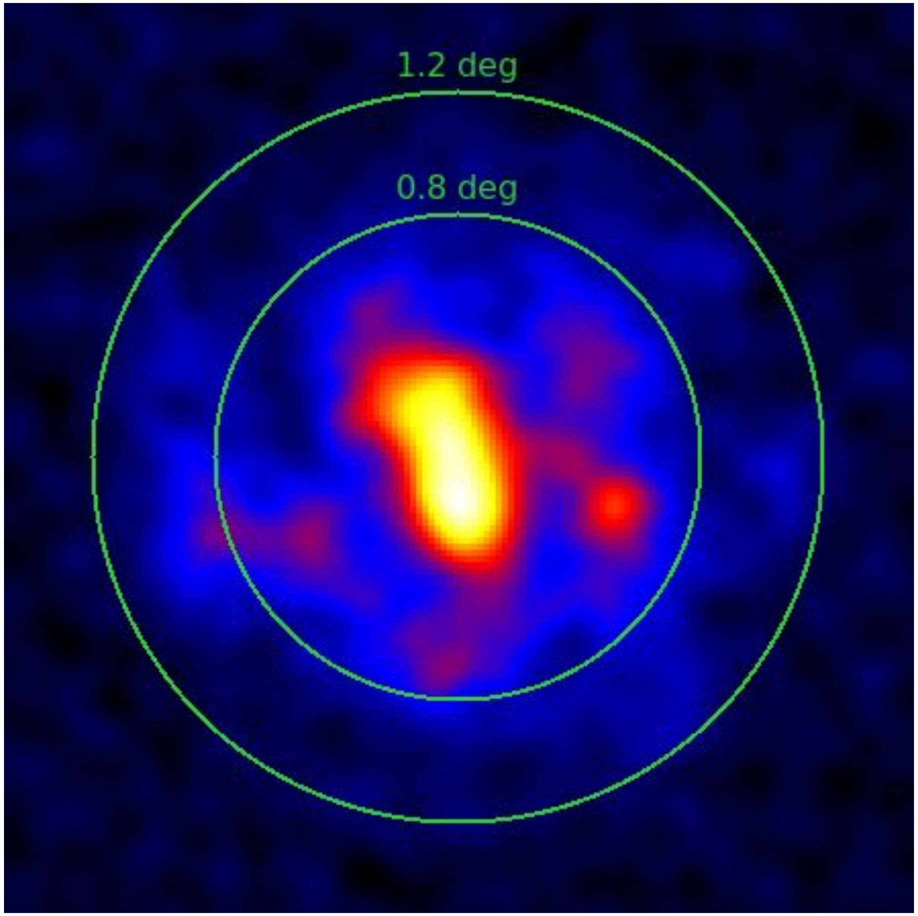
ASTRI-MA Vela X simulations

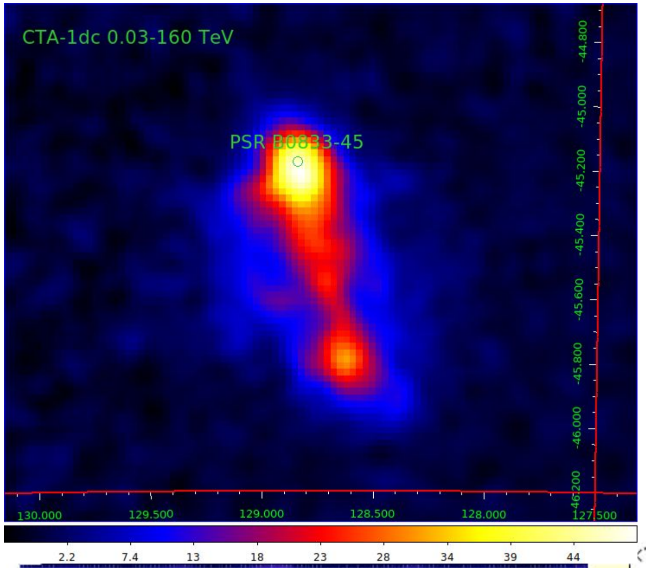
- A total of 300 observing runs were simulated of 20 min exposure each.
- We simulated a 100 hr observation with the ASTRI-MA assuming that the TeV morphology is the superposition of the radio (65% contribution) and X-ray (35% contribution) templates.
- We assumed a uniform exponentially cut-off power-law spectrum with Γ= -1.36 and E cut = 13.9 TeV for the inner region
- Sky model takes into account all sources and diffuse emission.
- Simulations obtained with CTOOLS 1.5.2

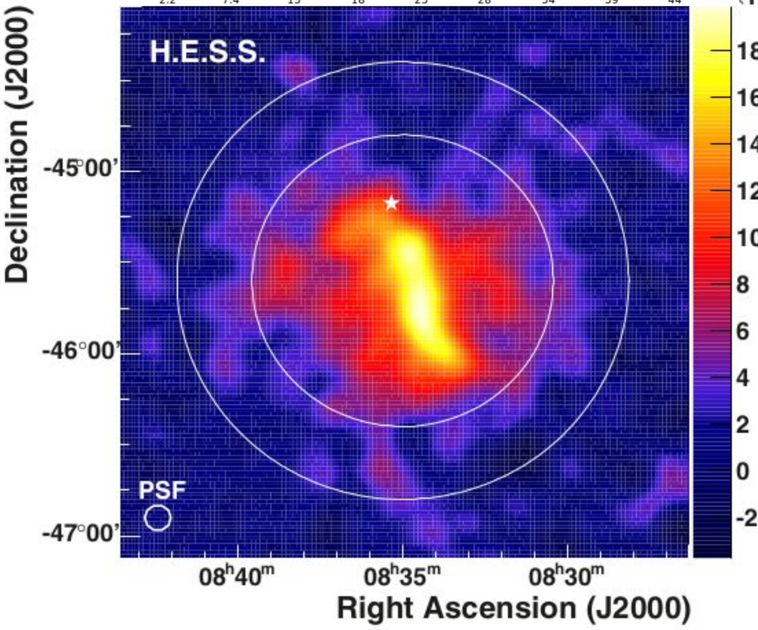




Imaging results: skymap with CTOOLS



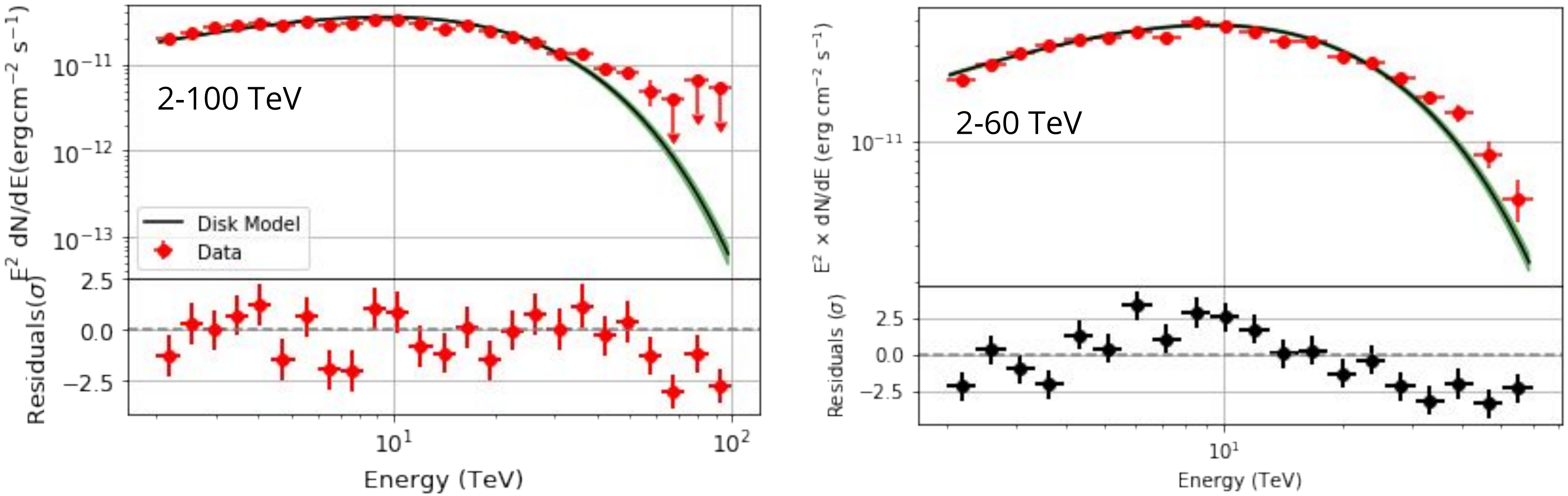




H.E.S.S. VHE γ-ray surface brightness of VelaX integrated between 0.75 TeV and 70 TeV. Image from [Abramowski et al., 2012]

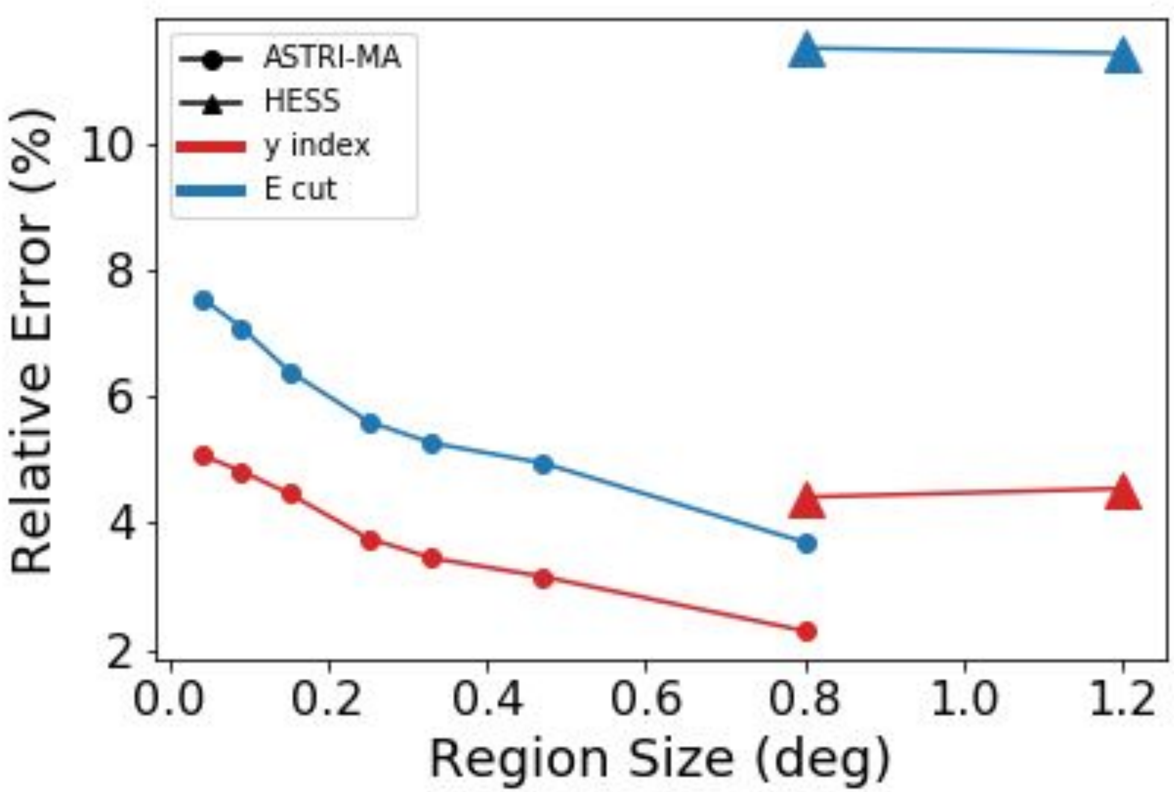
Binned spectral analysis

100 hrs. in 20 energy channels



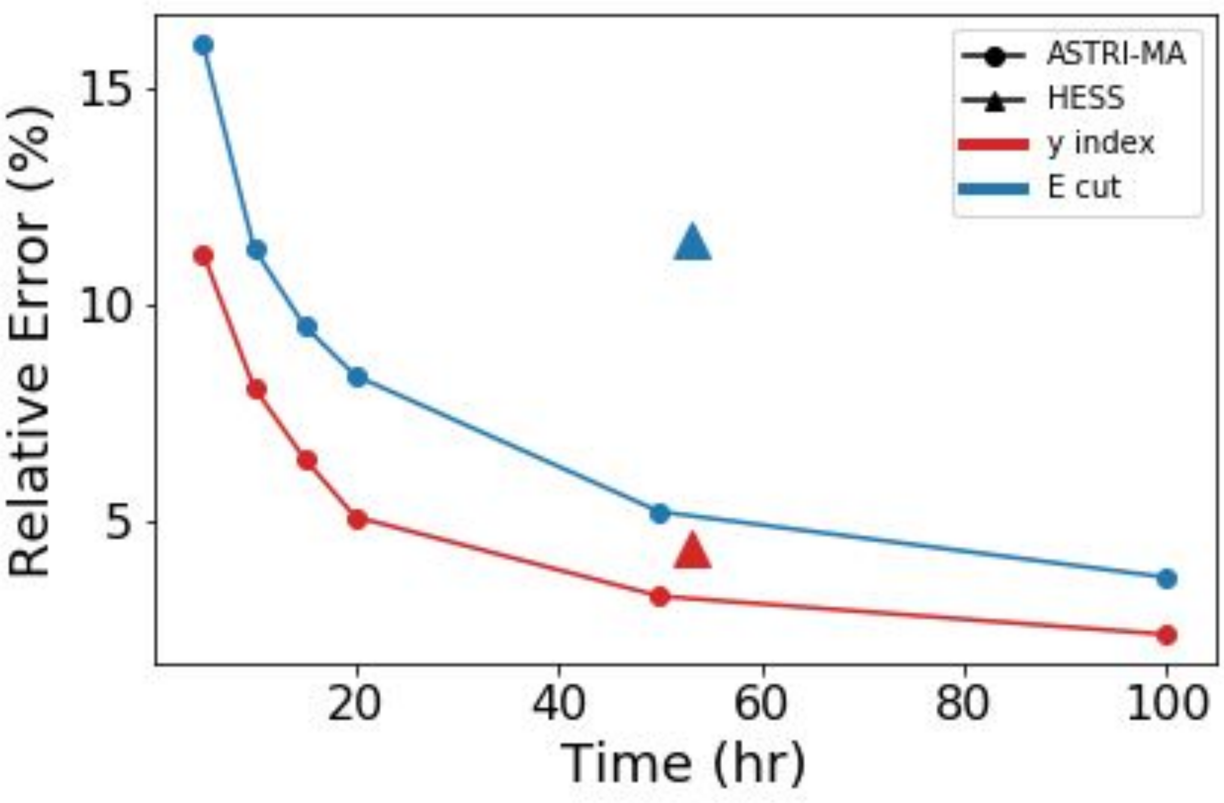
Relative Error VS Region Size

We compute the relative error of the spectral index (y index, in red) and of the Energy Cutoff (E cut, in blue) as a function of the size of the region extraction.



Relative Error VS Time

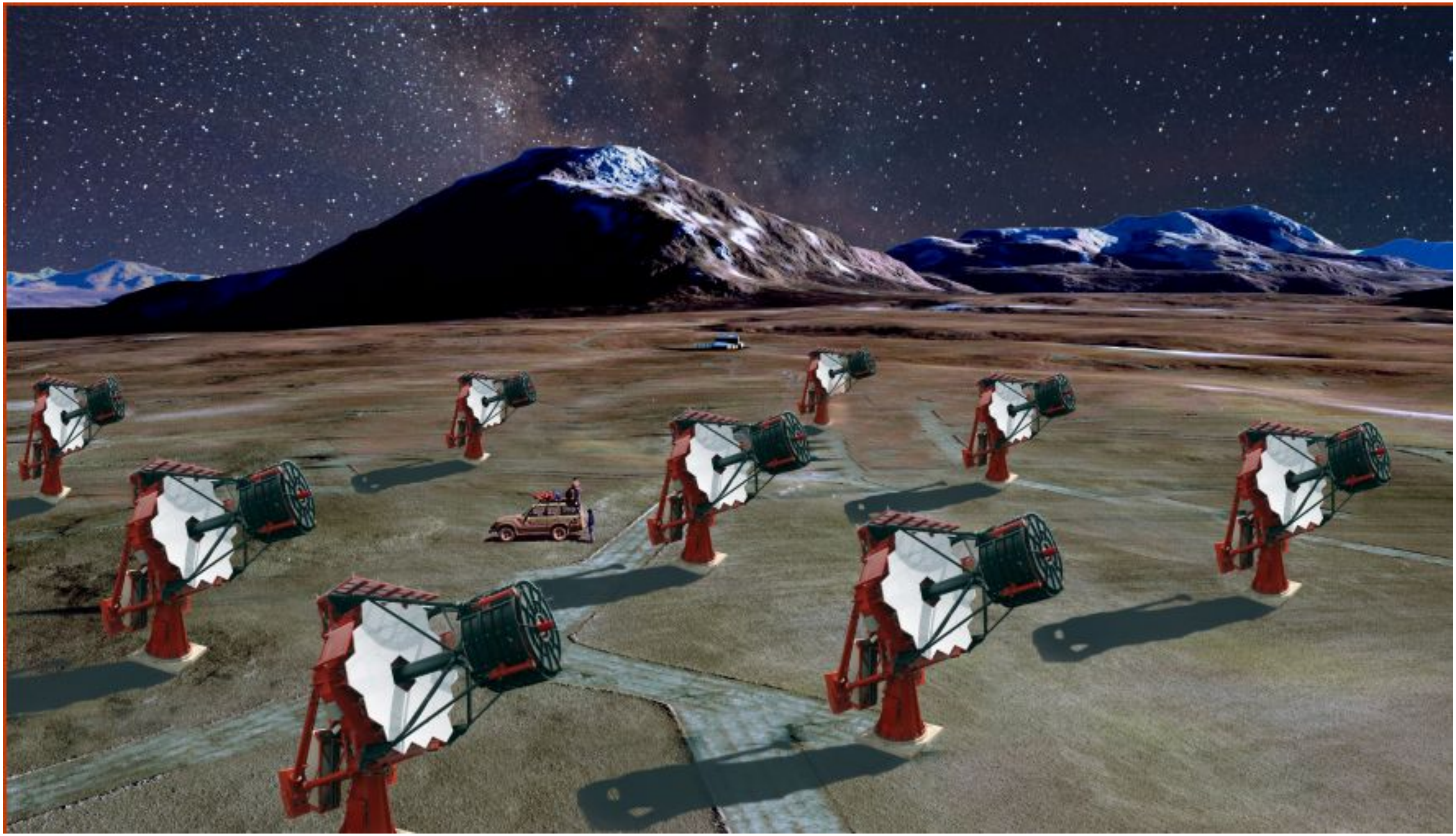
Same as before but for the observation time.



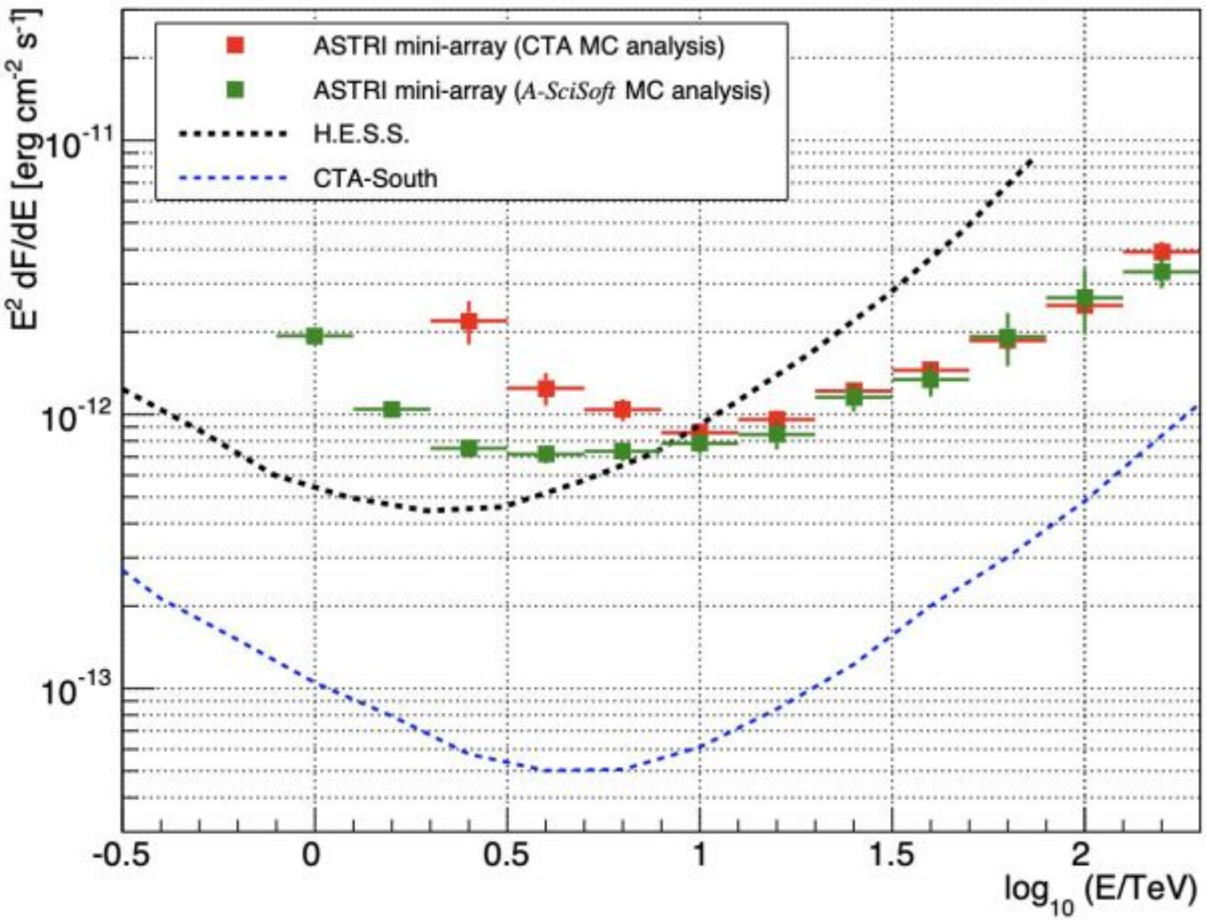
Conclusions

- We simulated an end-to-end DC for the ASTRI-MA, using the most updated IRF and configuration, and developing sky modelization of science case and a realistic pointing plan.
- We obtained good imaging results with respect to H.E.S.S. and we expect ASTRI-MA to stand out in the spectral analysis above few TeV.
- Results comparable or even better than HESS with similar exposures.
- A complete analysis is still on-going, stay tuned!

Thank you for the attention

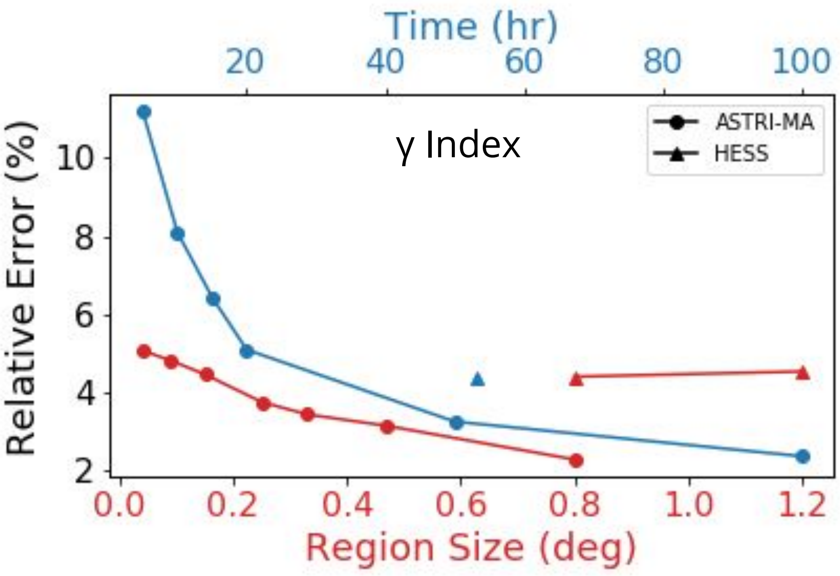


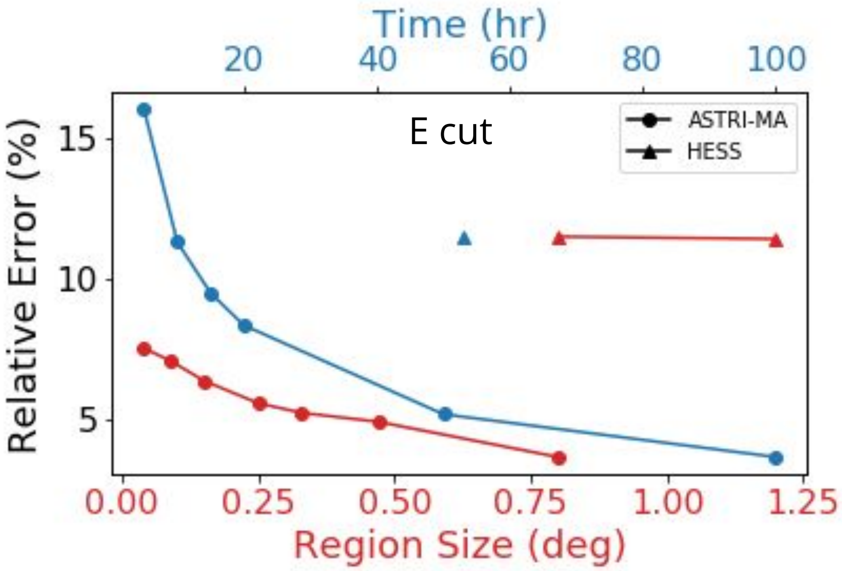
Array (9 SSTs) differential sensitivity (5σ,50h)



Relative Error VS Time(Region Size)

We compute the relative error of the spectral index (y index, on the left) and of the Energy Cutoff (E cut, on the right) as a function of the observation time (blue) and of the size of the region extraction.





	ASTRI MA						HESS
Time(hr)	5	10	15	20	50	100	
TS	721	1407	2134	2900	7321	14786	
	Spectral Model						
N_0 ($\frac{ph}{cm^2 \cdot s^1 \cdot MeV^1}$)	8.3 ± 1.2	7.7 ± 0.9	8.2 ± 0.7	8.8 ± 0.6	9.0 ± 0.4	9.0 ± 0.3	11.6 ± 0.6
γ	1.2 ± 0.1	1.15 ± 0.09	1.18 ± 0.08	1.23 ± 0.06	1.22 ± 0.04	1.22 ± 0.03	1.36 ± 0.06
E_{cut} (TeV)	11.5 ± 1.8	11.9 ± 1.3	11.9 ± 1.1	12.7 ± 1.1	12.1 ± 0.6	12.0 ± 0.4	13.9 ± 1.6
	Spatial Model						
R.A. (°)	128.75						
D.E.C. (°)	-45.6						
Radius (°)	0.8						
	Background Model						
N_0	0.95 ± 0.03	1.00 ± 0.02	0.99 ± 0.02	0.98 ± 0.02	0.98 ± 0.01	0.986 ± 0.007	
γ	0.07 ± 0.02	0.05 ± 0.01	0.05 ± 0.01	0.01 ± 0.01	0.056 ± 0.006	0.056 ± 0.004	

	ASTRI MA					
Model	Reg 1	Reg 2	Reg 3	Reg 4	Reg 5	Reg 6
TS	5533	6111	7263	9401	10631	11638
	Spectral Model					
N_0 ($\frac{ph}{cm^2 \cdot s^1 \cdot MeV^1}$)	1.6 ± 0.1	1.7 ± 0.1	1.9 ± 0.1	2.6 ± 0.1	3.0 ± 0.1	3.8 ± 0.2
γ	1.20 ± 0.06	1.18 ± 0.06	1.16 ± 0.05	1.17 ± 0.04	1.19 ± 0.04	1.20 ± 0.04
E_{cut} (TeV)	10.5 ± 0.8	10.6 ± 0.8	10.8 ± 0.7	11.3 ± 0.6	11.7 ± 0.6	11.8 ± 0.6
	Spatial Model					
R.A. (°)	128.79					
D.E.C. (°)	-45.49					
Pa (°)	23.6					
R_{min} (°)	0.03	0.05	0.09	0.15	0.18	0.21
R_{max} (°)	0.04	0.09	0.15	0.25	0.33	0.47
	Background Model					
N_0	0.994 ± 0.006	0.995 ± 0.006	0.995 ± 0.006	0.955 ± 0.006	0.994 ± 0.006	0.992 ± 0.006
γ	0.157 ± 0.003	0.155 ± 0.004	0.150 ± 0.004	0.142 ± 0.004	0.136 ± 0.004	0.128 ± 0.004

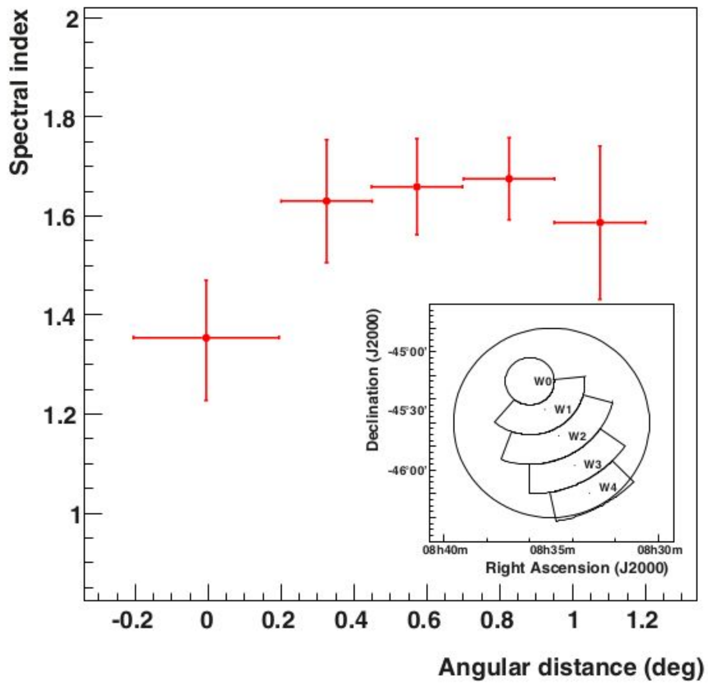
Next Step: spectral softening?

Abramowski+2012 searched for the spectral variation in the cocoon as a function of the distance from pulsar.

They obtain compatible spectral indixes with error-bars pretty high, and they did not detect any cut-off above 10 TeV because of the limited statistics.

We will simulate the same 5 regions of the cocoon with different spectral indexes (within the HESS error-bars), and inserting some cut-off above 10 TeV.

This will allow us to check if ASTRI can detect spectral and/or cut-off variation along the cocoon.



Spectral indices as a function of radial distance to the pulsar position along the major axis of Vela X. The insert shows a graphic of the five sectors on the sky-map (with radial distances of 0° (W0), 0.325° (W1), 0.575° (W2), 0.825° (W3) and 1.075° (W4), respectively) from which the differential energy spectra were extracted. Image from [Abramowski et al., 2012].