Perseus in Sicily: from black hole to cluster outskirts

# Perseus – a Huge reservoir of dark matter investigated with MAGIC

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Noto, Mav

#### It all started with cluster

Fritz Zwicky (1898, 1974)



Astronomers are spherical bastards. No matter how you look at them they are just bastards.

— 7ritz Zwicky –

F. Zwicky, while examining the Coma galaxy cluster in 1933, was the first to use the **virial theorem** to infer the existence of unseen matter, which he referred to as **dunkle Materie 'dark matter'**.

$$2 E_K = -U \quad \Rightarrow \quad v(r) = \sqrt{\frac{GM($$

 He calculated the gravitational mass of the galaxies within the cluster and obtained a value at least 400 times greater than expected from their luminosity



The technique was refined by Vera Cooper (Rubin) for galaxies in the '60s

#### **Dark Matter Evidence at all scales**



#### A lot of DM



#### Our heads in a dark cloud



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## 1/ Dark Matter mass (cutoff position) & Dark matter branching ratios (spectral shape)



#### 2/ Universality of Dark Matter Spectra



#### What influences the flux on Earth



- Hunting the highest Jfactor
- Left with huge uncertainties in the particle physics



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#### If you need to point, where to point?



#### **MAGIC Facts**

- Started as a single telescope in 2004
- Operating in **stereo-mode** since 2009
- Designed optimized for: low-energy, fast repositioning
- Collaboration of ~160 scientists from Armenia, Brasil, Germany, Spain, Italy, Switzerland, Finland, Croatia, Bulgaria, Poland, India and Japan
- 17m diameter dish
- Energy range: 70 GeV-30 TeV (with standard trigger) and down to 30 GeV (with sumtrigger)
- ✤ Angular resolution: <0.08°; Energy resolution: ~15-25%</p>
- Pointed mode observations (Field of View: ~3.5°)

Astronomic Observatory of Roque de Los Muchachos (~2200 m a.s.l.), La Palma (Spain)

#### A continuous effort



https://magic.mpp.mpg.de/uploads/pics/Magic\_performance\_integral\_sensitivity\_history.gif

- Mono:
  - Light Gray circles: first installation (2005)
  - Dark gray: different readout system (2008)
- Stereo-phase:
  - Black triangles: stereo phase 1 (2010)
  - Squares: stereo after camera upgrade:
    - zenith angle below 30° (red, filled),
    - 30 45° (blue, empty)
- Sum-trigger allowed <50 GeV</li>

← 16 times less needed observation time!



#### The MAGIC "catalogues"



#### From TeVCat 2.0 http://tevcat2.uchicago.edu/



- MAGIC is in the N-hemisphere: optimized for extra-gal. physics
- MAGIC hunts the farthest objects due to lowest energy. threshold

**Dark Catalogue** (many sources pointed and not detected)



#### A long campaign

A long campaign						Prelimin		
							- Inna	
		Telescope Pointing						
			A			$\mathcal{B}$		
Period	Dates	All data [h]	Data Selection			Data Selection		
			quality [h]	quality +	All data [h]	quality [h]	quality +	
				specific [h]			specific [h]	
$\mathcal{P}1$	2009.11.01-2011.06.01	94.7	56.4	45.4	-	-	-	
P2	2012.09.01-2013.01.17	9.2	9.1	9.1	59.4	40.2	36.8	
P3	2013.07.27-2014.08.05	17.5	16.7	14.8	55	30.2	28.9	
<i>P</i> 4	2014.08.31-2014.11.22	16.6	10.4	10.1	21.7	21.7	7.5	
P5	2014.11.24-2016.04.28	6.8	3.9	3.9	29.3	22.32	21.9	
<i>P</i> 6	2016.04.29- <mark>2017.08.</mark> 02	44.1	41.9	12.2	20.5	16.02	11.1	
TOTAL		185.9	138.4	106.1	188.9	119.2	96.2	

Global sample selected

202.2 h

• Consider duty cycle is roughly 1000h/year

#### A very fruitful campaign



J. Aleksić et al. *Astrophys. J.*, 710:634–647, 2010a.
J. Aleksić et al. *Astrophys. J.*, 723:L207, 2010b
J. Aleksić et al. *Astron. Astrophys.*, 541:A99, 2012c.
J. Aleksić et al. *Astron. Astrophys.*, 539:L2, 2012d.
J. Aleksić et al. *Astron. Astrophys.*, 563: A91, 2014a.
J. Aleksić et al. *Astron. Astrophys.*, 564:A5, 2014b.
J. Aleksić et al. *Science*, 346:1080–1084, 2014d

- MAGIC campaign on Perseus CG proved to be very fruitful:
  - the strongest limits on Cosmic Ray (CR) acceleration in the core of the cluster and on the CR to thermal pressure (Aleksić et al., 2010a, 2012c);
  - the radio-galaxy NGC 1275, at the center of the cluster, was clearly detected and modelled (Aleksić et al., 2012d, 2014b); and
  - the peculiar radio-galaxy IC 310, located at 0.6 deg from the Perseus CG center, was detected and provided important evidences related to the acceleration of CRs close to black holes (Aleksić et al., 2010b, 2014a,d).

See backup slides

### PERSEUS CLUSTER DARK MATTER HALO

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#### Sky scan strategy



- Consider gamma-ray excess are seen over the CR background
- Complex observing region





- We follow the prescription in **Sanchez-Conde et a**l. (2011)
- We use **30% systematics on mass estimation** for Perseus CG (Reiprich and Boehringer, 2000; Chen et al., 2007)







#### **MAGIC** results put into context

#### **Summary and conclusions**

- Clusters of galaxies are optimal targets for decaying DM searches, given their huge expected DM content.
- The MAGIC telescopes observed the Perseus CG for about 400 h during several years.
- MAGIC reached limits of the order of  $2 \times 10^{26-27}$  s for TeV DM particles
- These are the most constraining limits on the decay lifetime of DM particles in the TeV energy range produced by ground-based gamma-ray instruments.
- Unlikely that a dwarf satellite galaxies provide stronger constraints





