
WLM, imaged by VLT

H.E.S.S. UNIVERSITÉ SAVOIE MONT BLANC LAPTh LAPP

DM searches towards
dwarf galaxies with H.E.S.S.

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Supervisors

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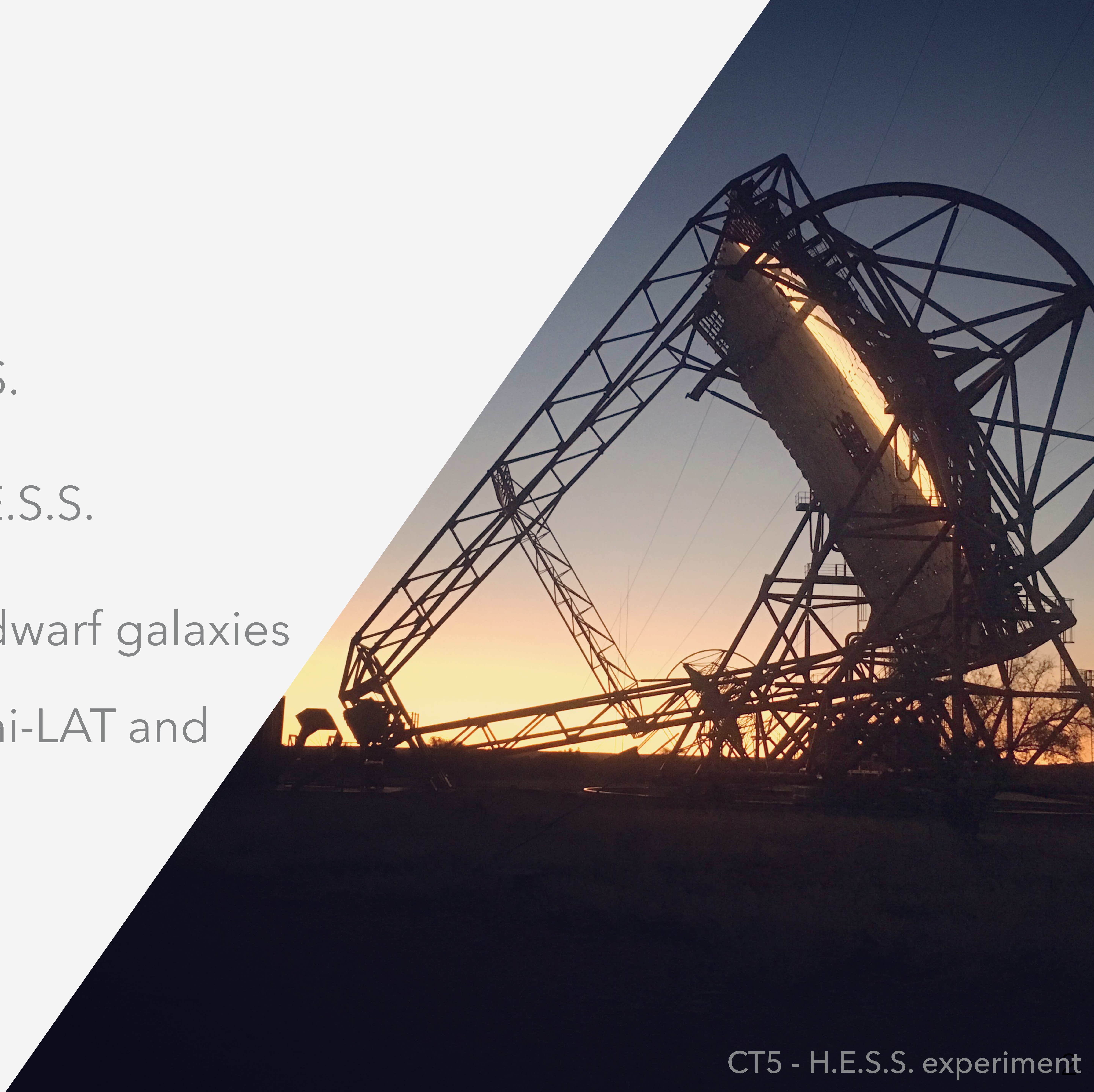
GAMMA-RAY MEETING - ANNECY - JULY 8TH, 2019

3 PROJECTS

I. Ultrafaint dwarf galaxies with H.E.S.S.

II. WLM irregular dwarf galaxy with H.E.S.S.

III. Combined analysis of the classical dwarf galaxies with H.E.S.S.S., MAGIC, VERITAS, Fermi-LAT and HAWC



CT5 - H.E.S.S. experiment

Goal

- Search for a DM signal in the HESS data towards dwarf galaxies
- Set some upper limits on <σv> if no signal is found for several annihilation channels

γ-ray flux

$$\Phi_\gamma(E_{\text{max}}, E_{\text{min}}) = \frac{1}{2}\frac{\langle \sigma v \rangle}{4\pi m_\chi^2} \cdot \int_{E_{\text{min}}}^{E_{\text{max}}} \int_0^\infty \sum_f B_f \frac{dN_\gamma^f}{dE_\gamma} A_{\text{eff}}(E_\gamma) R_{\text{corr}}(E_\gamma, E_\gamma^{'}) dE_\gamma dE_\gamma^{'} \cdot \mathcal{J}$$

Normalization Factor

Particle Physics Φ_{PP} Factor

Astrophysical J Factor

where

B_f = Branching ratio
dN/dE = differential spectrum
A_{eff} = Acceptance of H.E.S.S.
R_{corr} = Energy resolution

Different types of objects

Dwarf spheroidal galaxies (dSphs)

- No gas
- Non-rotating systems
- ~20kpc up to ~200kpc

Classicals

~150 - 2500 stellar tracers

Project III

Ultrafaints

- ~ A few dozen stellar tracers
- High uncertainties on their DM profile

Project I

Dwarf irregular galaxies (dIrrs)

- Star-forming region at their center
- Rotationally supported
- ~500kpc up to ~1Mpc
- Gas used a tracer
- Good constraints of their DM profile

Project II

Project I – Ultrafaint dwarf galaxies

Targets – Data taken in 2017 & 2018

- **Tucana II** - 16.4h
- **Tucana III** - 25.3h
- **Tucana IV** - 25.3h (in the field of view of Tucana III)
- **Reticulum II** - 18.2h
- **Grus II** - 19.2h

In collaboration with the CEA, Saclay

- **Main analysis** - Lucia Rinchiuso & Emmanuel Moulin
- **Cross check** - Vincent Poireau & Celine Armand

Project I – Ultrafaint dwarf galaxies

Results

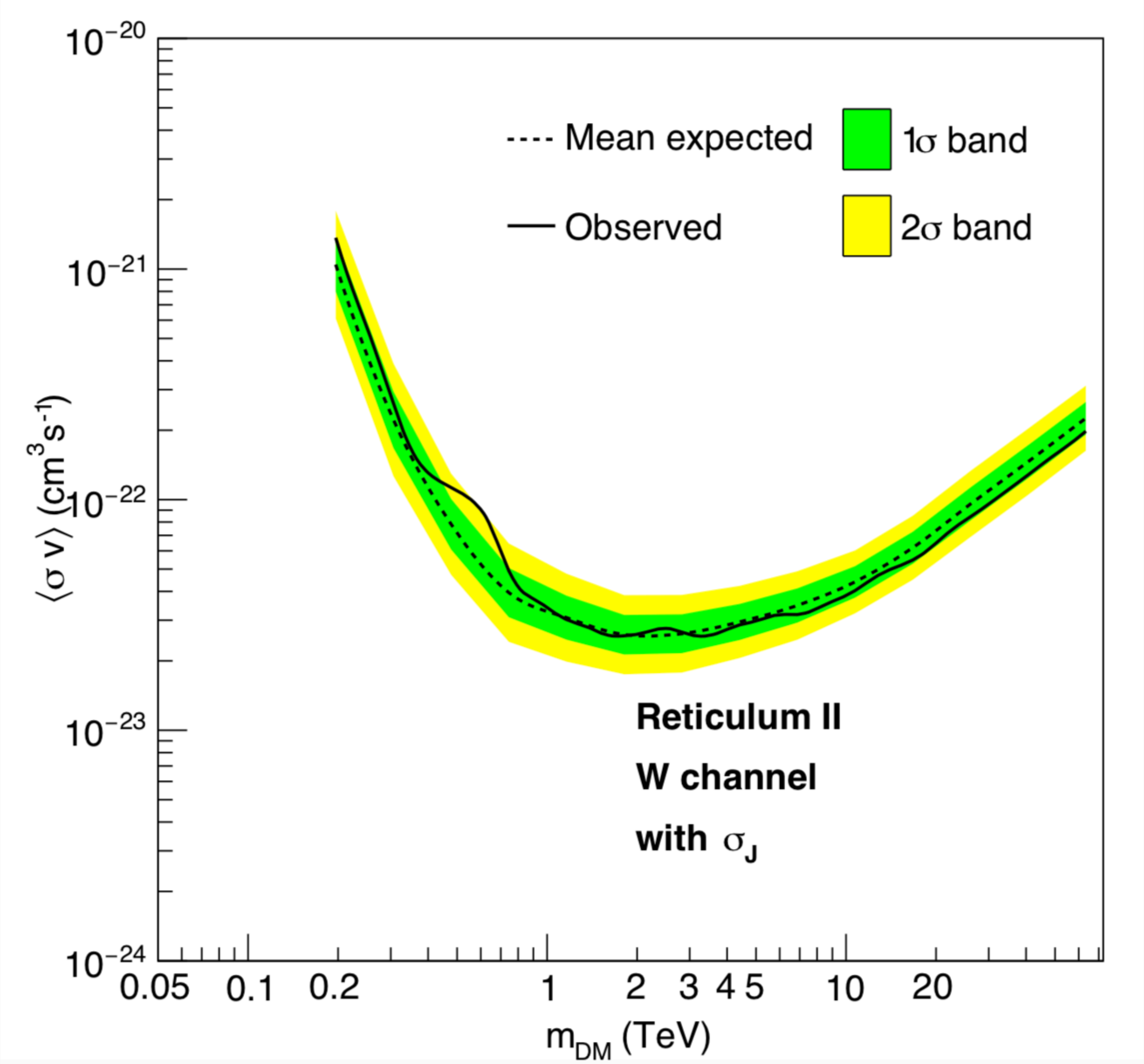
No significant excess

in the ROI of the ultrafaints

→

Upper limits at 95% C.L.

using a Loglikelihood Ratio test statistics



Example of Reticulum II

- **<σv> ~3e-22 cm3.s-1** at 1TeV
- WW channel + 7 others
- NFW profile
- J taken from G. Sameth+2015 (ref: 2015 ApJ 801 74)
- Uncertainties on J included

Project I – Ultrafaint dwarf galaxies

- H.E.S.S. internal review **done**
- **Talk** at the ICRC2019
- **Paper in circulation** within the collaboration before submission

Project II – WLM dwarf galaxy

Data taken in 2018

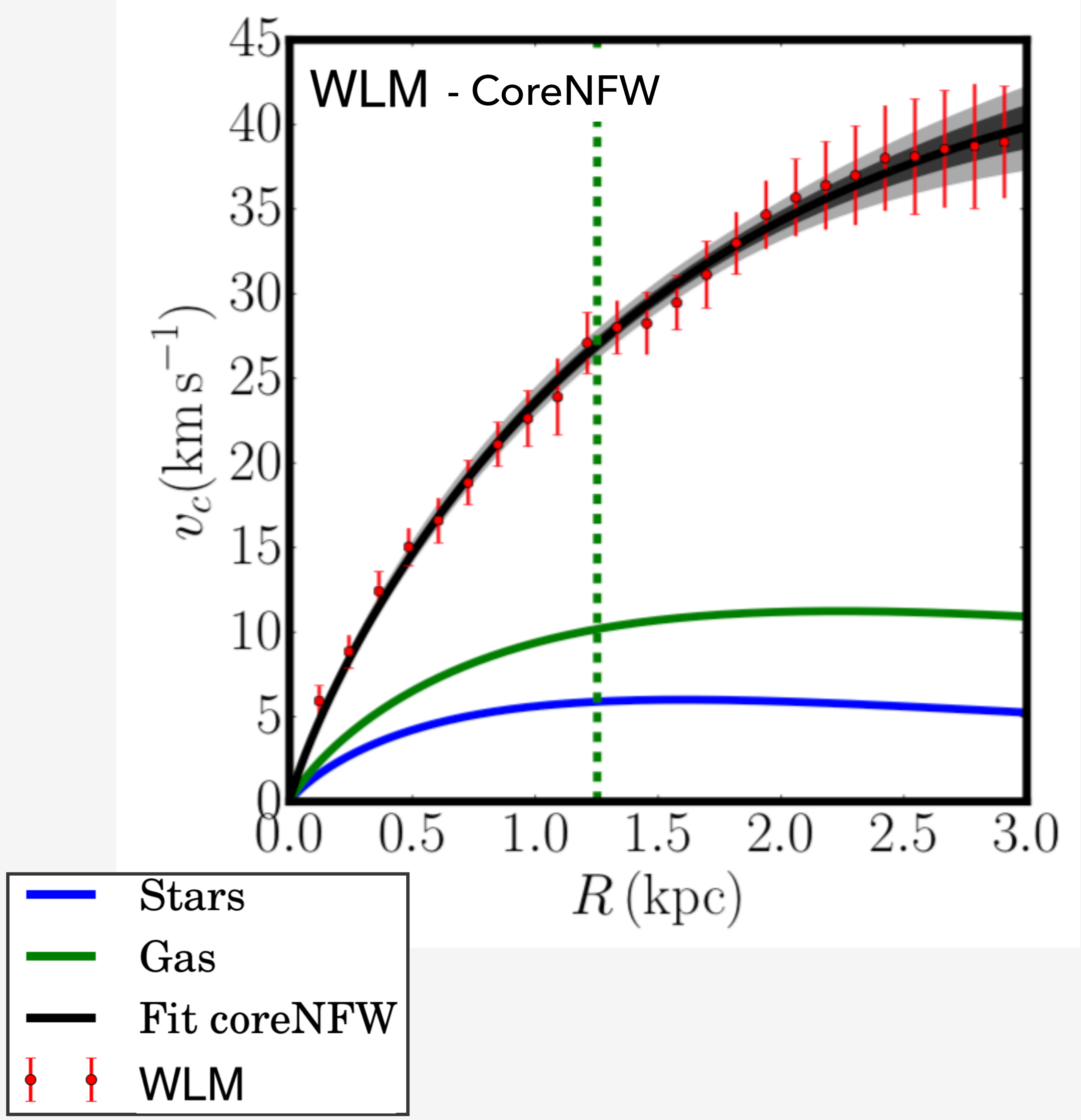
Wolf-Lundmark-Melotte (WLM) - 18.6h

A few properties

- Star-forming region
- Located at **~1Mpc** from the Milky Way
- **Excellent** HI data, photometry & stellar kinematics
- **Smooth** HI distribution
- **Smooth** rotation curve - Fitted by a **coreNFW** profile
- **1st dIrr** observed by H.E.S.S. and by an Imaging Atmospheric Cherenkov Telescope (IACT)

J. Read+2016

(ref: Mon. Not. Roy. Astron. Soc. 462, 3628 (2016))



In collaboration with the CEA, Saclay

- **Main analysis** - Vincent Poireau & Celine Armand
- **Cross check** - Lucia Rinchiuso & Emmanuel Moulin

Project II - WLM dwarf galaxy

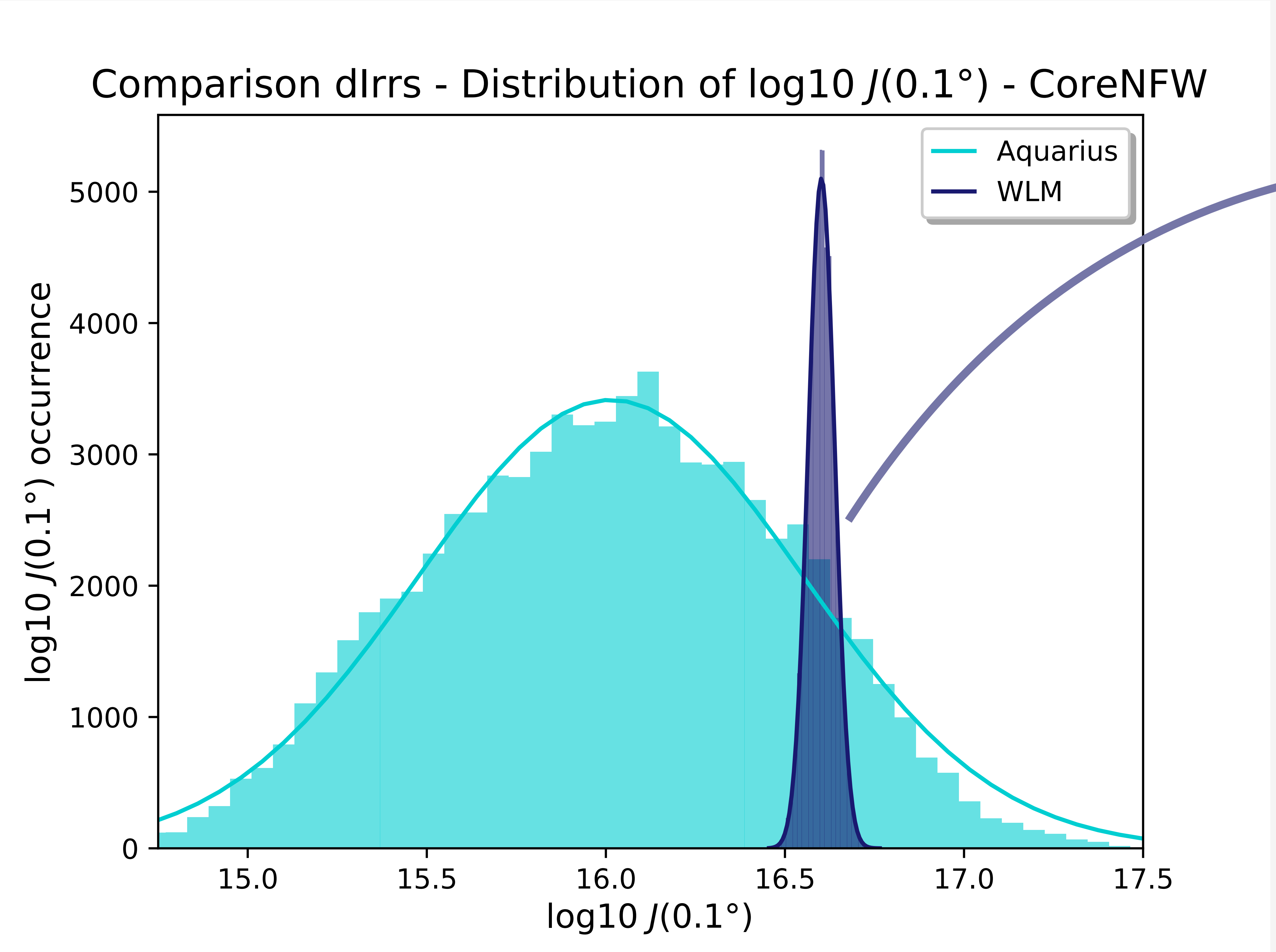
New DM profile - coreNFW

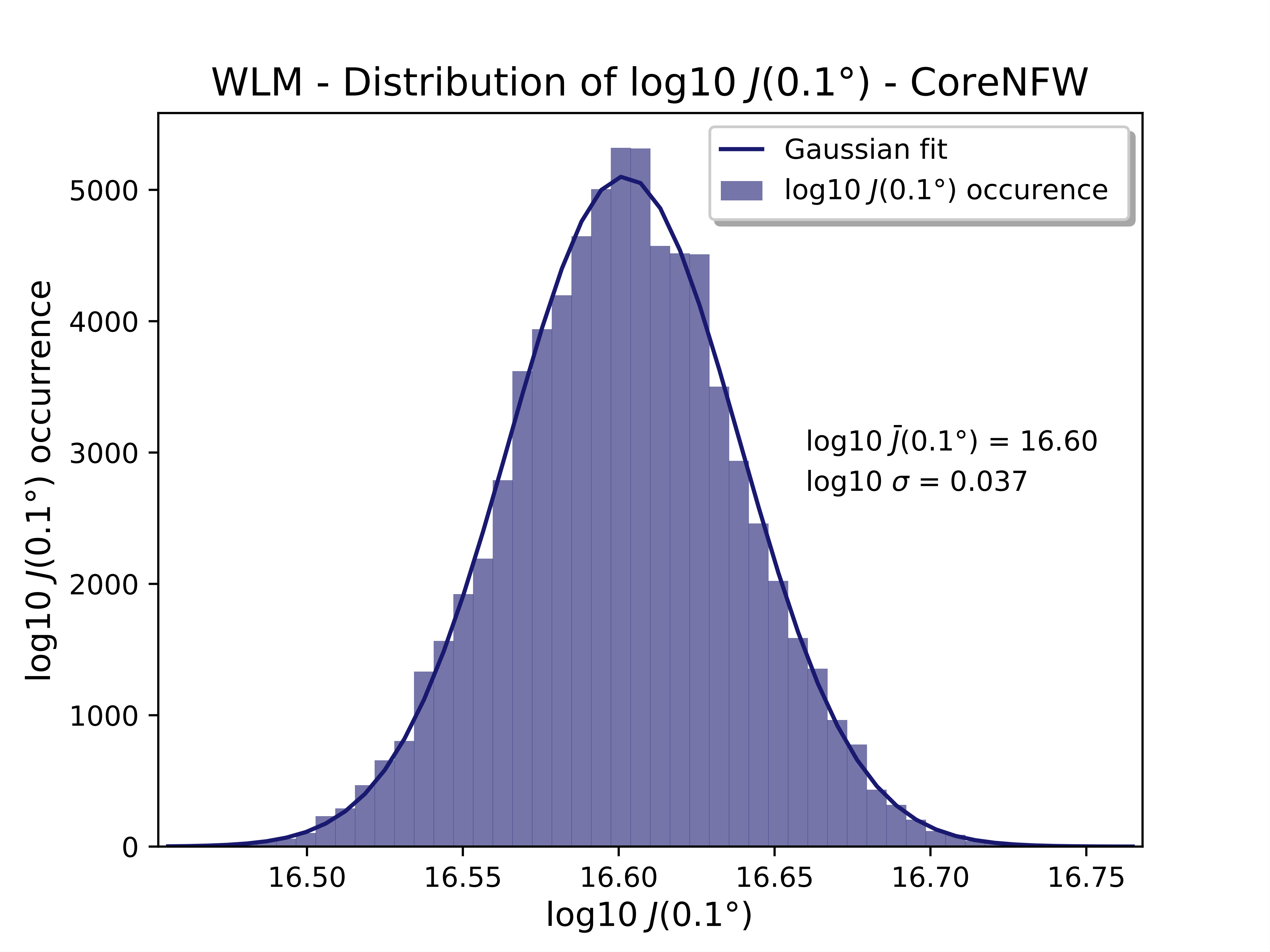
J. Read+2016 (ref: Mon. Not. Roy. Astron. Soc. 462, 3628 (2016))

J. Read+2019 (ref: Mon. Not. Roy. Astron. Soc.484, 1401 (2019))

Markov Chain results provided by Justin **Read**

Computation of **75000** J factors





WLM - Extremely small uncertainties on J

log10 J(0.1°) = 16.6 ± 0.037

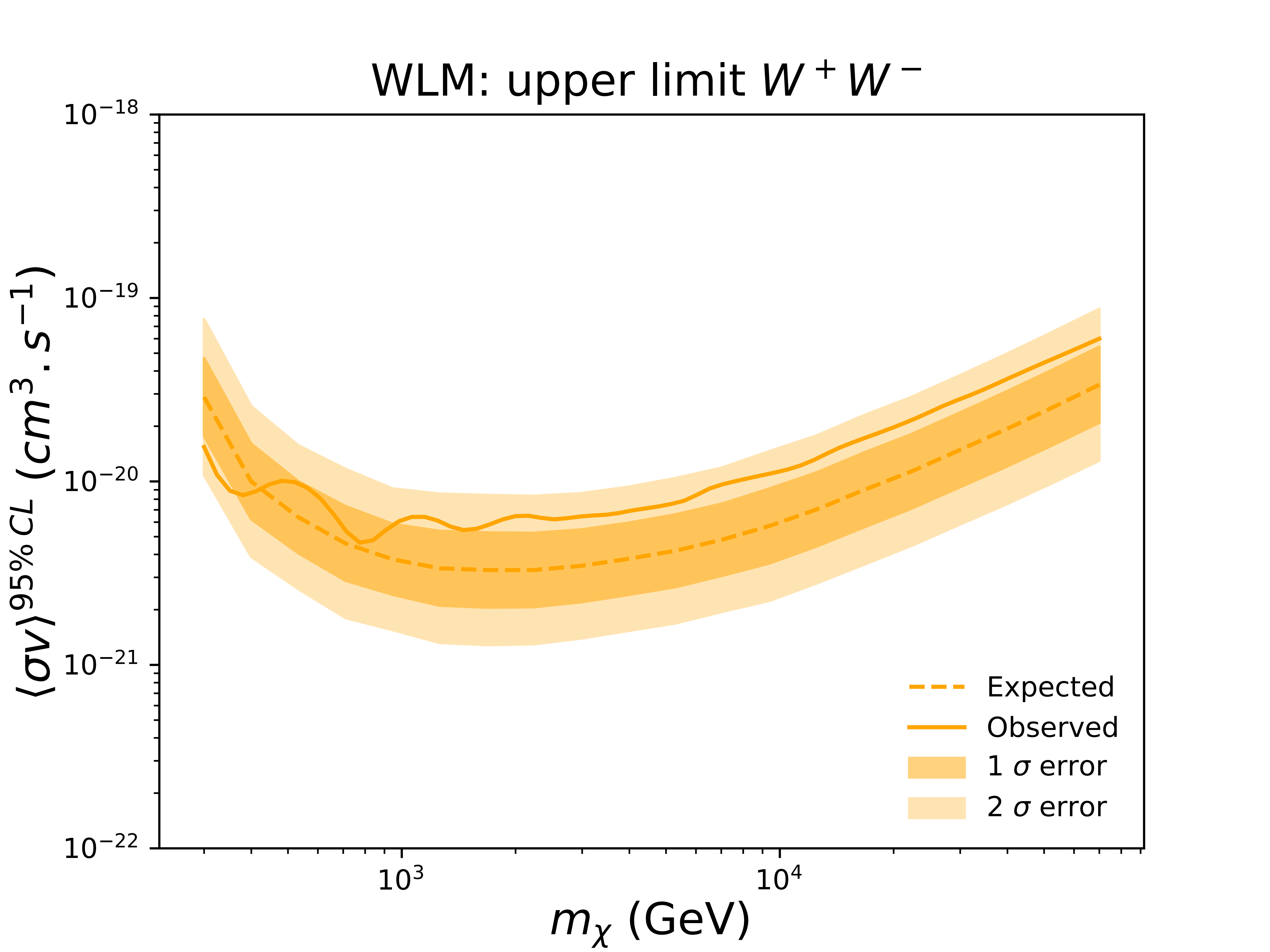
Project II – WLM dwarf galaxy

Results

No significant excess
towards WLM

→

Upper limits at 95% C.L.
using a Loglikelihood Ratio test statistics



- **<σv> ~5e-21 cm3.s-1** at 1TeV
- WW channel + 7 others
- coreNFW profile
- Uncertainties on J included

Project II – WLM dwarf galaxy

- H.E.S.S. internal review **in progress**
- **Poster** at the ICRC2019
- **Proceeding in circulation** within the collaboration before submission
- **Paper** in preparation

Project III – Combined analysis

Goal

Combine published results on the dwarf galaxies observed by H.E.S.S., VERITAS, MAGIC, FERMI-LAT, HAWC

Targets

- **20 dSphs** observed by one or more instruments
- All **previously published** by individual collaboration
- **No significant excess** in the data
- Combinaison of the UL for the **first time**

Source name	Experiments
Boötes I	HAWC, VERITAS, Fermi
Canes Venatici I	HAWC, Fermi
Canes Venatici II	Fermi
Carina	HESS, Fermi
Coma Berenices	HAWC, HESS, Fermi
Draco	VERITAS, HAWC, Fermi
Fornax	H.E.S.S., Fermi
Hercules	HAWC, Fermi
Leo I	HAWC, Fermi
Leo II	HAWC, Fermi
Leo IV	Fermi
Leo T	Fermi
Leo V	Fermi
Sculptor	H.E.S.S., Fermi
Segue I	MAGIC, VERITAS, HAWC, Fermi
Segue II	Fermi
Sextans	HAWC, Fermi
Ursa Major I	HAWC, Fermi
Ursa Major II	MAGIC, Fermi
Ursa Minor	VERITAS, Fermi

Project III - Combined analysis

Combinaison

- **Upper limits at 95% C.L.** using a Loglikelihood Ratio test statistics
- Each experiment provides a **table of Likelihood vs. <σv>**
- For **each DM mass** and **8 annihilation channels**
- Combinaison from the **product of the likelihood**

From the H.E.S.S. side

H.E.S.S. Collaboration
(ref: Phys.Rev. D90 (2014) 112012)

- Publication of 2014 - **No Likelihood table was saved** at that time
- Needs to **redo the analysis** on Sculptor, Fornax, Carina, Coma Berenices

In collaboration with the CEA, Saclay and Humboldt University Berlin

- **Main analysis** - Vincent Poireau & Celine Armand
- **Cross check** - Louise Oakes

Project III – Combined analysis

- H.E.S.S. internal review **done**
- **Highlight talk** at the ICRC2019
- **Proceeding in circulation** within the collaboration before submission

Conclusion

Conclusion

- **No excess** has been observed in the data
- Set **upper limits** for 8 annihilation channels

Project I - Ultrafaints

- **Paper** in circulation in the collaboration
- **Talk** at the ICRC

Project II - WLM

- **Proceeding** in circulation in the collaboration
- **Poster** at the ICRC
- **Paper** in preparation

Project III - Combined analysis

- **Proceeding** in circulation in the collaboration
- **Highlight talk** at the ICRC

Backup

Likelihood

Poisson likelihood

$$\mathcal{L}(N_{ON}, N_{OFF}, \alpha | N_S, N_B) = \frac{(N_S + N_B)^{N_{ON}}}{N_{ON}!} e^{-(N_S+N_B)} \frac{(\alpha N_B)^{N_{OFF}}}{N_{OFF}!} e^{-\alpha N_B}$$

Loglikelihood Ratio Test (LLR)

Ref: Cowan et al, 2010

$$\text{LLR} = \begin{cases} -2\ln \frac{L(\mu, \hat{\hat{\boldsymbol{\theta}}}(\mu))}{L(0, \hat{\hat{\theta}}(0))} & \hat{\mu} < 0 \,, \\ -2\ln \frac{L(\mu, \hat{\hat{\boldsymbol{\theta}}}(\mu))}{L(\hat{\mu}, \hat{\boldsymbol{\theta}})} & 0 \leq \hat{\mu} \leq \mu \,, \\ 0 & \hat{\mu} > \mu \,. \end{cases}$$

$N_S \leftrightarrow \mu$

$N_{\mathrm{ON}} - N_{\mathrm{OFF}}/\beta \leftrightarrow \hat{\mu}$

$N_{\mathrm{OFF}}/\beta \leftrightarrow \hat{\boldsymbol{\theta}}$