An interdisciplinary study between particle physics and astrophysics at Kavli IPMU

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[arXiv:1706.05481]

with IPMU members (S. Horigome, K. Ichikawa,
M. N. Ishigaki, M. Ibe, H. Sugai and K. Hayashi)

We introduce an interdisciplinary study between particle physics and astrophysics to detect $SU(2)_L$ weak-charged WIMP, one of unexplored candidates in WIMP paradigm!

Weak-charged WIMP

Various candidates in WIMP hypothesis → Serious test of WIMPs (LHC & direct detections) →

- ✓ $SU(2)_L$ (weak) charged WIMP
- ✓ Light WIMP w/ a mediator
- ✓ Leptophilic WIMP, etc.

Weak-charged WIMP is well-motivated from the viewpoint of particle physics!

- ✓ The WIMP is predicted by the split-type SUSY scenario based on the AMSB.
  (e.g. It is well studied in IPMU as Pure gravity mediation [Ibe, S.M., Yanagida, 2012])
- ✓ The WIMP is also favored in other new physics models. (e.g. MPP models, etc.)

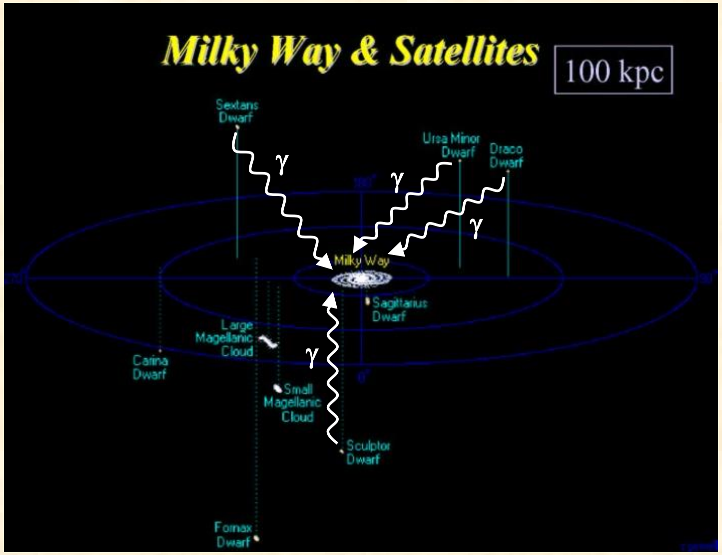
Generic property of a fermionic weak-charged WIMP

1. Its mass is about 1TeV and degenerates with its $SU(2)_L$ partners in mass.
   → The WIMP is hard to be detected at collider experiments in near future.
2. The WIMP scatters off a nucleon only radiatively (only via loop diagrams).
   → The WIMP is hard to be detected at direct detections in near future.
3. Annihilation is boosted by Sommerfeld effect. [J. Hisano, S. M., M. Nojiri, 2004]
   → The WIMP is effectively detected at indirect detections in near future.

Indirect detection

Among various indirect dark matter detections, observing gamma-ray from the WIMP annihilation in dSphs is the most robust and efficient detection:

- We can expect enough strong signal, for dSphs are located very close to us and they are also known to be dark matter rich astrophysics objects.
- BGs against the signal is suppressed, because there are few astrophysical activities in dSphs. Main BG is from cosmic-ray induced γs in our galaxy.



Gamma-ray flux formula from each dSph.

$$\Phi(E, \Delta\Omega) = \left[\frac{\langle \sigma v \rangle}{8\pi m_{DM}^2} \sum_f b_f \frac{dN_\gamma}{dE} \right] \times J_{\Delta\Omega}$$

$$J_{\Delta\Omega} = \int_{\Delta\Omega} \int_{\mathrm{l.o.s}} d\ell d\Omega \, \rho^2(\ell, \Omega)$$

To detect the signal or put a robust limit, it's mandatory to have the flux accurately!

However, the estimation of the J-factor, which is obtained by the WIMP mass distribution squared inside each dSph galaxy, has a large uncertainty!!!

Estimating the J-factor

Theory side

Collisionless Boltzmann eq.

⇓

Jean's equation derived.

Distribution of member stars [$f(x, v)$ of the member stars]

↕

DM mass distribution [$\rho(x)$]

Bayesian analysis ↔

Observation side

Astrophysical observations

Photometric data:
Locations of the member stars, etc. are obtained.

Spectroscopy data:
Velocity of the member stars, etc. are obtained.

DM profile $\rho(x)$ obtained. → J-factor is evaluated as the pdf of the analysis.

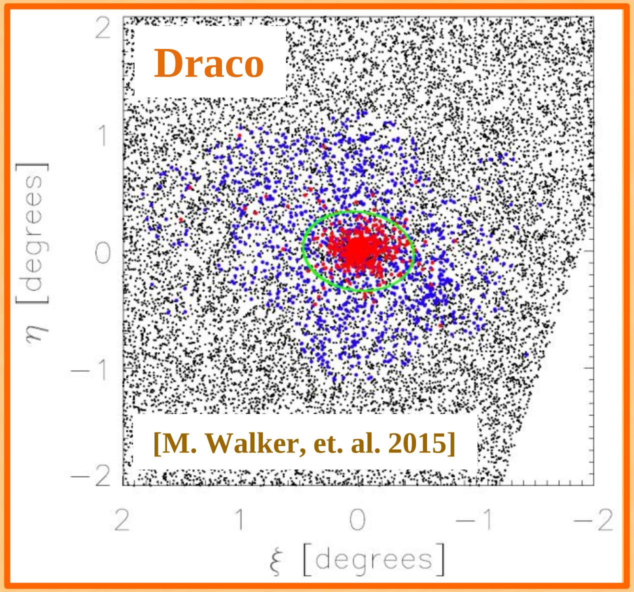
Current analysis does not include several systematic errors!!!

Most of the errors will be negligibly small when data is accumulated enough.

However, there are some intrinsic errors not improved:

- ✔ The intrinsic error from the spherical assumption of dSphs.
- ✔ The intrinsic error from the subtraction of foreground stars.

Non-sphericity of dSphs

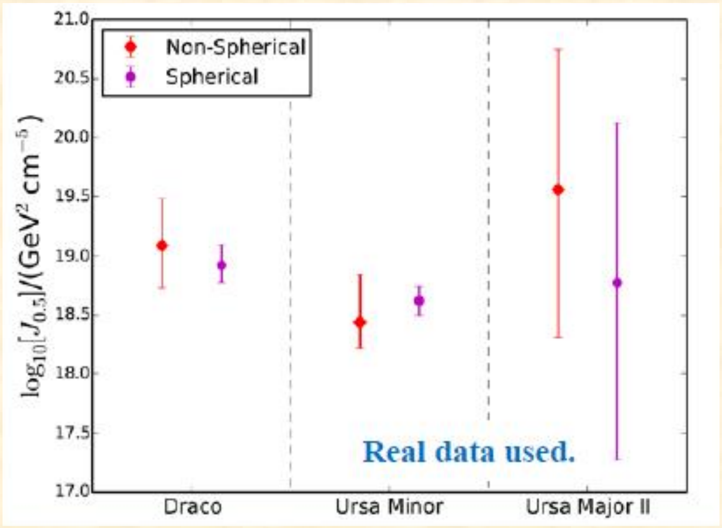


← The dSph doesn't look like completely spherical.

J-factor has been estimated so far assuming the spherical profile of dSph in all past works.

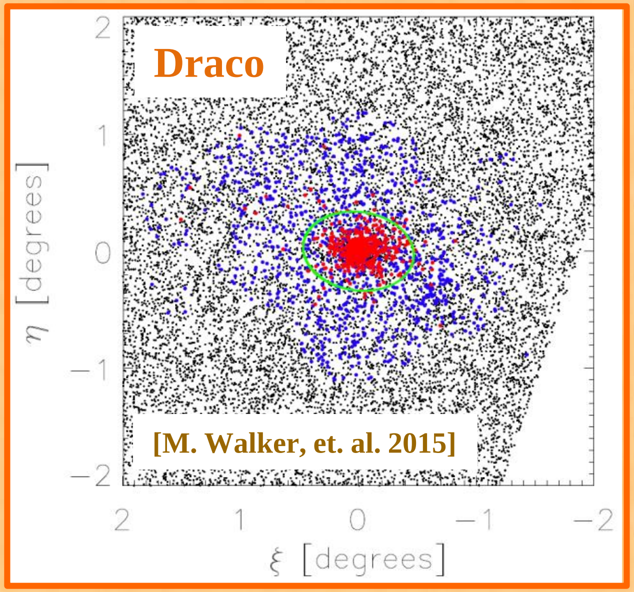
We have estimated the J-factors of (almost) all dSphs which are related to indirect dark matter detections assuming the profile of the dSphs to be non-spherical, to be precise, axisymmetric.

Our result is frequently referred at many talks and papers by theorists and experimentalists.



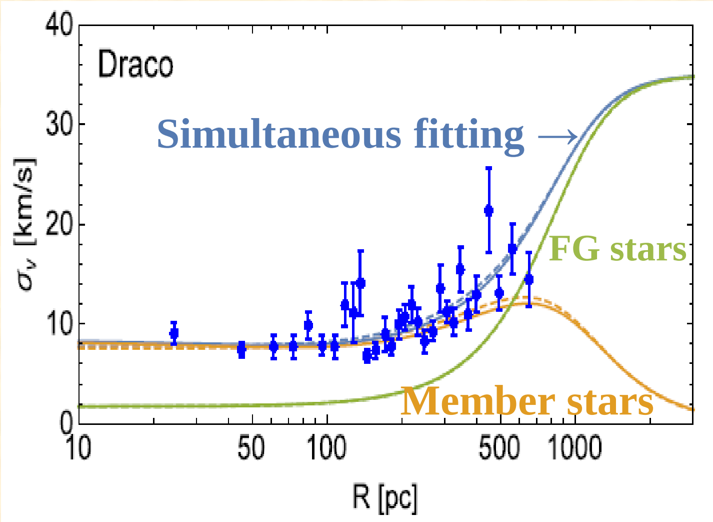
- ✓ The axisymmetric model always gives better fitting than the symmetric one.
- ✓ Central values of the J-factors does not seem to be altered significantly.
- ✓ Errors of the J-factors are increased for the CL dSphs (2−3 times larger).
- ✓ Errors of J-factors for the UF dSphs seems to be governed by statistics.

Subtracting FG stars



← Stars by photometric color-magnitude criteria.
Member stars selected by a naive selection cut.
Member stars selected by the conventional way.

1. Foreground star contamination increases at outer region, making J-factor overestimated.
2. EM method (conventional analysis) avoids the problem, but is difficult to treat sys errors.
3. We have developed a method to solve it based on simultaneous fitting of member & FG stars.



✓ The simultaneous fitting method works well for both the member and FG stars.

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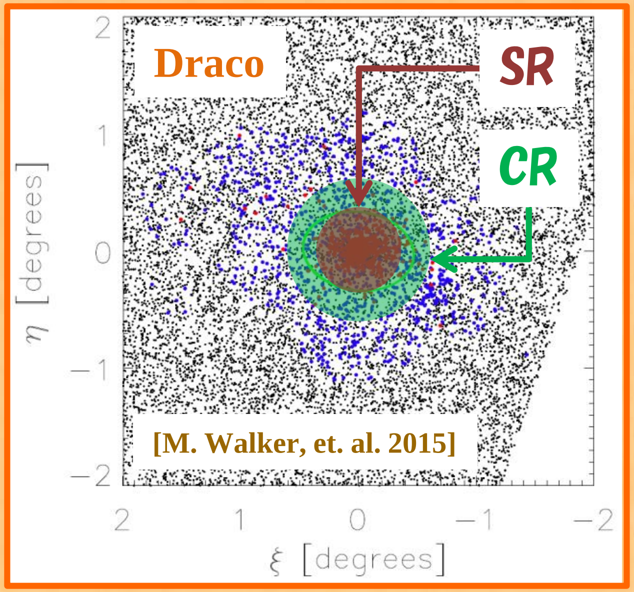

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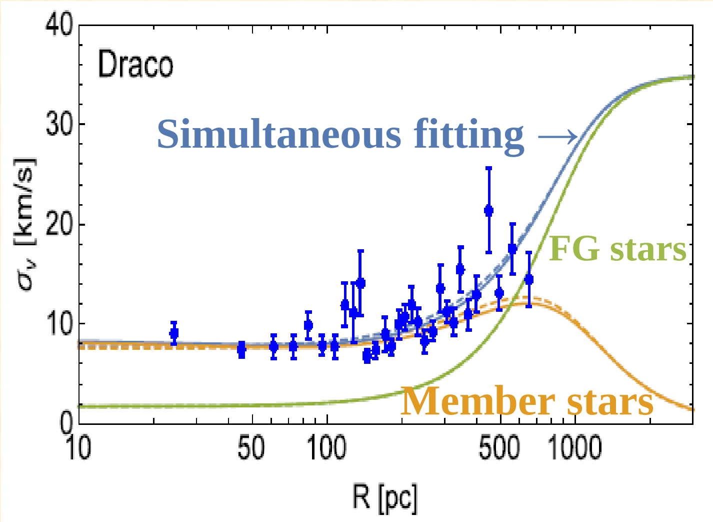

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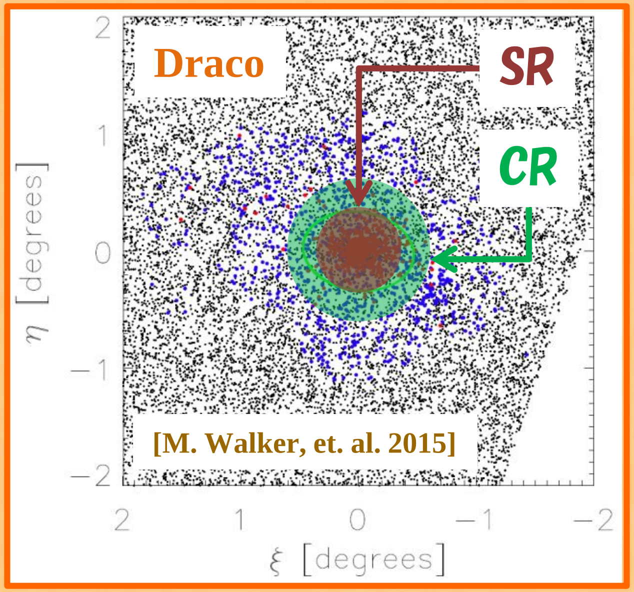

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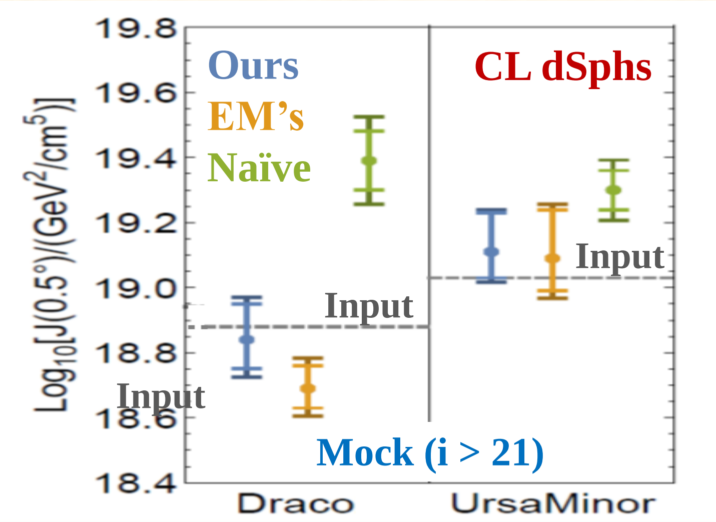

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- ✓ The naive cut method always tends to overestimates J-factors of the dSphs.
- ✓ EM method avoids the overestimation, but some systematic errors remain.
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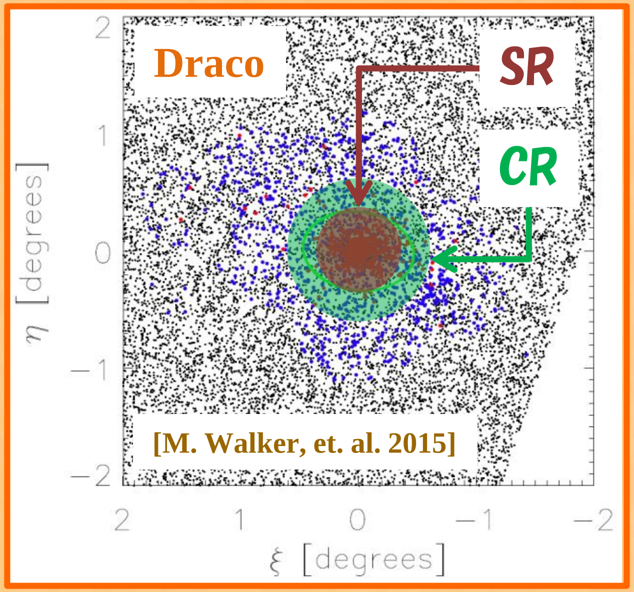

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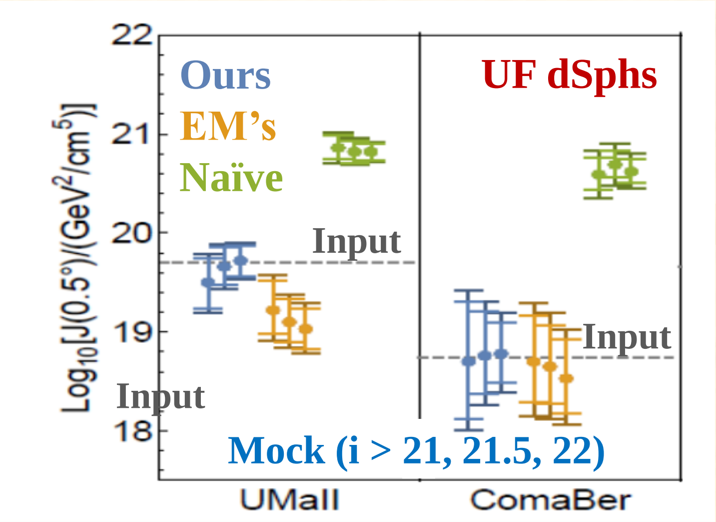

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Summary

- WIMP which has a weak charge attracts many attentions after the Higgs discovery. Only indirect dark matter detections allow us to detect the WIMP in near future, for it has O(1)TeV mass.
- Among various indirect dark matter detections, the observation of gamma-rays from dSphs are the most robust one to detect the signal of, or to put a constraint on the TeV scale WIMP.
- It is important to predict the signal flux for this purpose, and it requires the careful estimation of J-factors involving the treatment of FG star contamination and the DM & stellar non-sphericity. Future spectroscopic measurements such as PFS in SuMIRe project will play an very important role!