Estimating J-factors of dSphs for indirect dark matter detections

Shigeki Matsumoto (Kavli IPMU)

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[arXiv:1608.01749 (Mon. Not. Roy. Astron. Soc.)]
[arXiv:1706.xxxxx]

with IPMU members

(K. Ichikawa, M. N. Ishigaki, M. Ibe, H. Sugai and K. Hayashi)

The purpose of these studies is estimating the so-called J-factor(s), the astrophysical property of dSph(s), for the indirect TeV-scale WIMP detection utilizing γ-rays.

TeV scale WIMPs

The nature of WIMP is unknown!

→

Constraints:
Collider exp. (LHC)
Direct D. (LUX, …)

→

✓ $SU(2)_L$ (weak) charged WIMP
✓ Light WIMP (Light Mediator)
✓ Leptophilic WIMP, etc.

Among remaining possibilities of WIMP's property, we focus on weak-charged WIMPs (the WIMP close to a non-singlet $SU(2)_L$ eigenstate), for it is motivated well from the new physics viewpoint (e.g. Higgsino or Wino WIMP in MSSM).

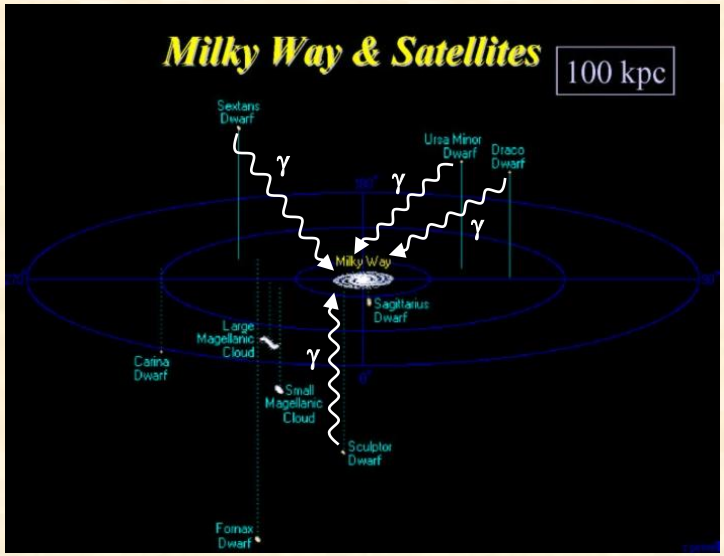
Generic property of such a fermionic WIMP (weak-charged one) is as follows:

1. Its mass is predicted from WIMP miracle mechanism to be around the TeV scale due to the weak interaction. It degenerates with its $SU(2)_L$ partner.
   → The WIMP is hard to be detected at collider experiments in near future.
2. The WIMP has a very suppressed WIMP-WIMP-Higgs coupling (and also a WIMP-WIMP-Z coupling), for it is close to a $SU(2)_L$ gauge eigenstate.
   → The WIMP is hard to be detected at direct detections in near future.
3. Annihilation between the WIMPs is boosted very much thanks to the so-called Sommerfeld enhancement effect. [J. Hisano, S. M., M. Nojiri, 2004]
   → The WIMP is efficiently detected at indirect detections in near future.

Indirect detection

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

- **We can expect enough strong signals, for dSphs are located very close to us and they are also known to be dark matter rich astrophysics objects.**
- **BGs against the signals are suppressed, for 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.

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

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

To detect or put a robust limit on the WIMP, 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-factors

Theory side

Collisionless Boltzmann eq.

⇓

Jean's equation derived.

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

↕

DM mass distribution [ρ(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 ρ(x) obtained. → J-factor is evaluated as the pdf of the analysis.

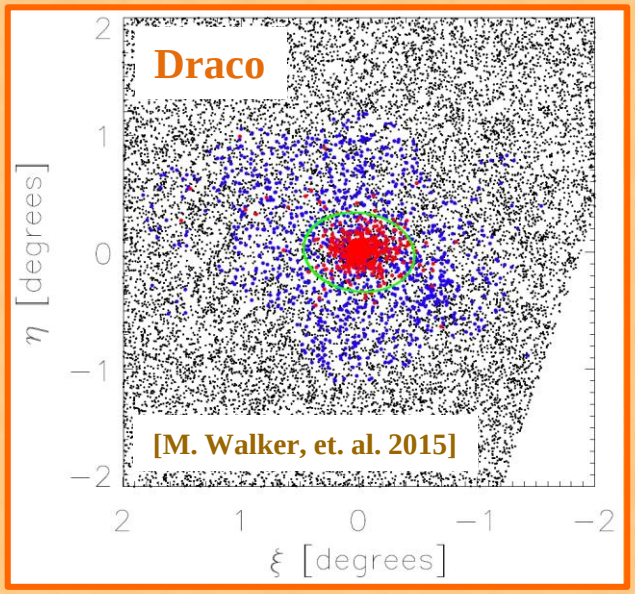
Current analysis does not include several systematic errors!!!

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

However, there are some intrinsic errors not improved:

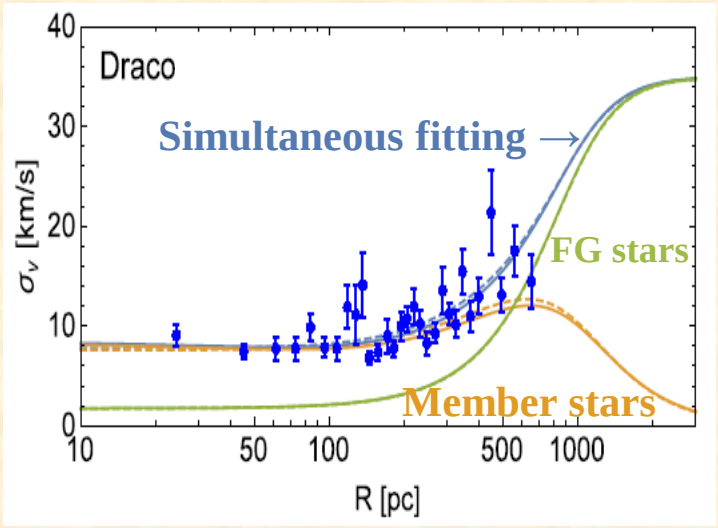
- ✔ The intrinsic error from the subtraction of foreground stars.
- ✔ The intrinsic error from the spherical assumption of dSphs.

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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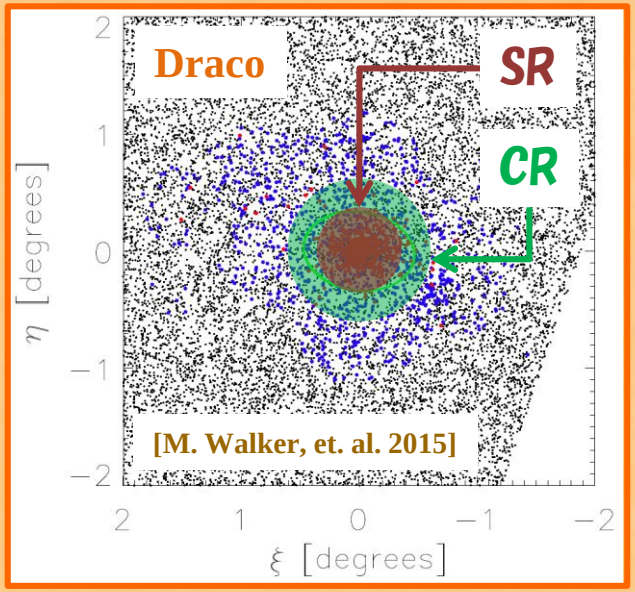

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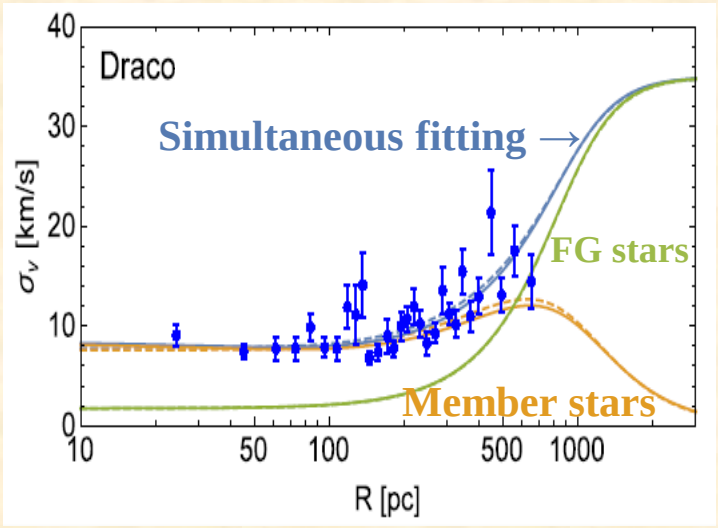

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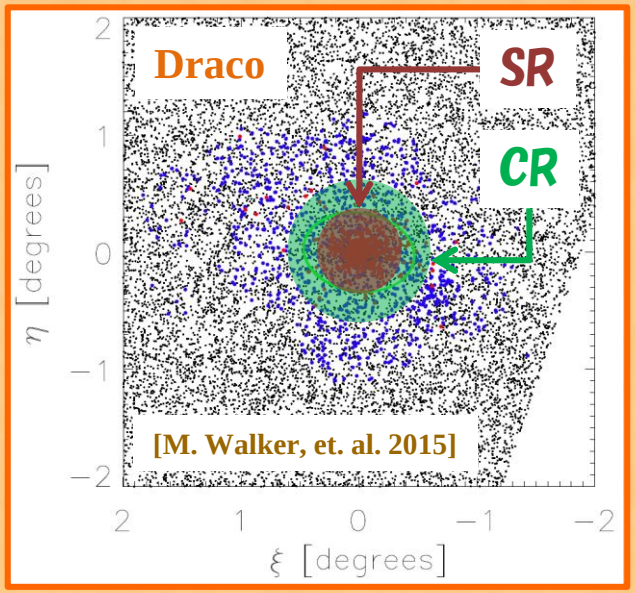

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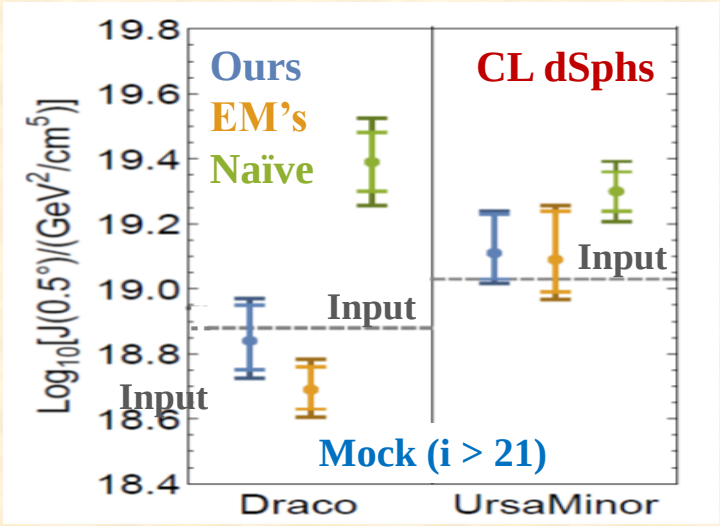
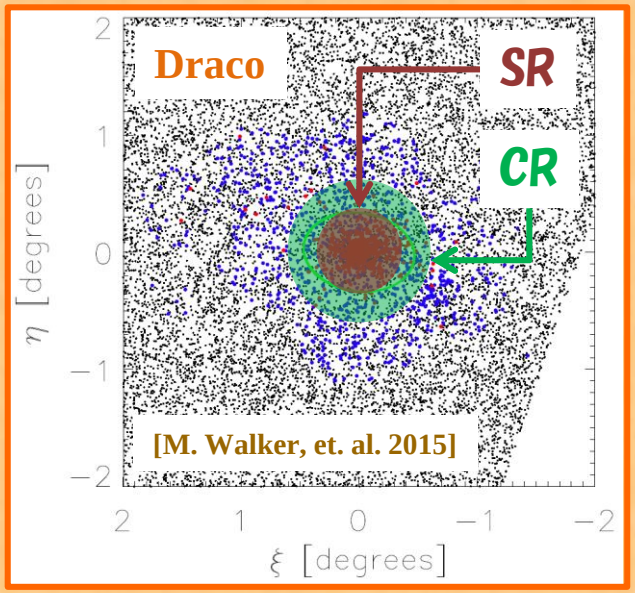


- ✓ The simultaneous fitting method works well for both the member and FG stars.
- ✓ The naive cut method always tends to overestimates J-factors of the dSphs.
- ✓ EM method avoids the overestimation, but some systematic errors remain.
- ✓ The simultaneous fitting method (ours) works well for both CL & UF dSphs.

Subtracting FG stars



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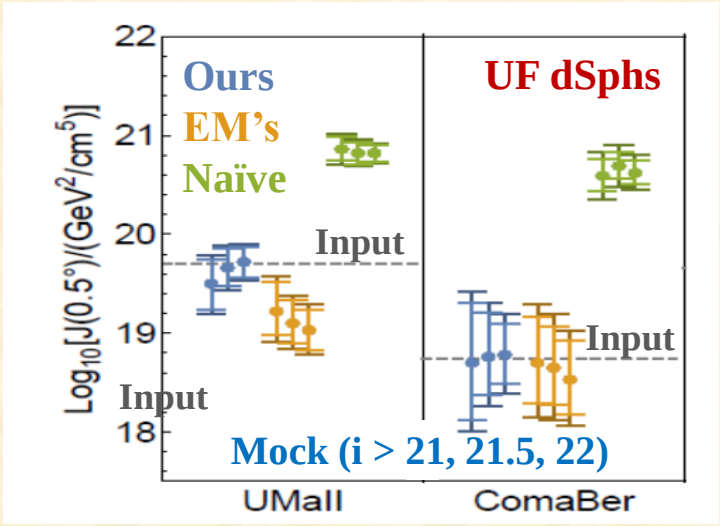

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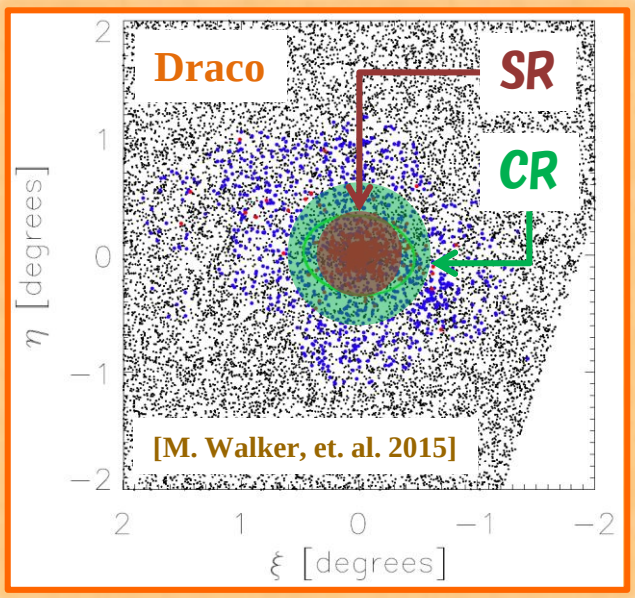
Non-sphericity of dSphs



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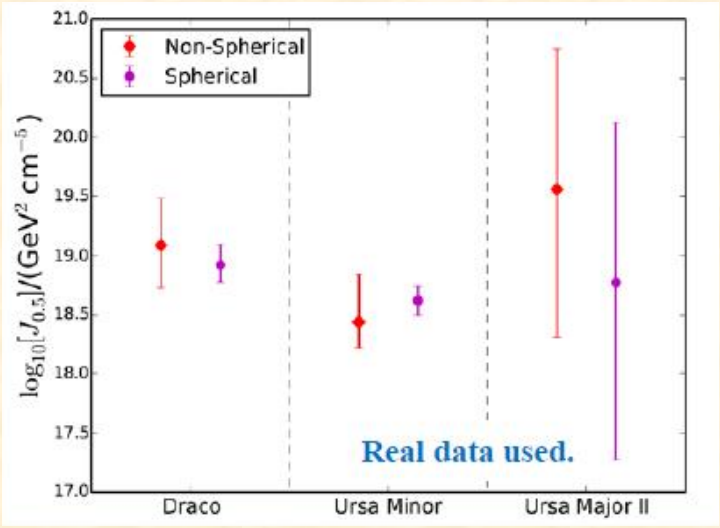

- ✓ The axisymmetric model always gives better fitting than the symmetric one.
- ✓ Central values of the J-factors does not seem to be altered significantly.
- ✓ Errors of the J-factors are increased for the CL dSphs (2-3 times larger).
- ✓ Errors of J-factors for the UF dSphs seems to be governed by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

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, observation of gamma-rays from dSphs are the most robust one to detect 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 important role!