Wino Dark Matter Revisited

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1. Why is the wino dark matter attractive?
2. Phenomenology of the wino dark matter
3. Summary & Discussions

Why is the wino DM attractive?

Wino DM = $SU(2)_L$-triplet Majorana fermion

DM properties

1. DM should be neutral.
2. DM should be stable.
3. DM int. should be weak.
4. DM should be cold.
5. $\Omega_{DM}h^2$ should be ~0.1.

⇒

Residual Z_2 symmetry of $U(1)_{B-L}$

Neutrino masses & mixings + BAU

↓

Three heavy R-handed neutrinos.

↓

Gauged $U(1)_{B-L}$ (∵ anomaly cancel)

⇓

Why $U(1)_{B-L}$ works?

- $U(1)_{B-L}$ can be spontaneously broken by a VEV having B−L charge 2.
- The SM involves only B−L odd fermions and B−L even (zero) bosons.

A New fermion (boson) with a even (odd) B−L charge becomes stable!
Particle (either fermion or boson) with a fractional B−L charge is OK.

↓

Wino DM is nothing but a fermion which is singlet under $U(1)_{B-L}$!

Wino DM is attractive from the viewpoint of DM stability!

Why is the wino DM attractive?

Wino DM = $SU(2)_L$-triplet Majorana fermion

Recent LHC results may indicate that BSM scale is much higher than 1TeV, and the Lagrangian below O(1)TeV is minimally given by SM + DM system.

⇒

SU(2) →	singlet	doublet	triplet
Scalar	①	③	⑤
Fermion	②	④	⑥

① is severely limited by direct detection experiments. (∵ $(\phi_{DM})^2\,|H|^2$)
② does not have any renormalizable interactions with SM particles.
③ must have a hypercharge to have a neutral component, resulting in a complex scalar DM and severely constrained by direct detections. (If we introduce higher dimensional operators to split the complex scalar into two real ones, the direct detection limit can be evaded.)
④ has the same situation as the case of ③.
⑤ can be a real scalar (representation), but severely constrained by direct detection experiments because of $(\phi_{DM})^2\,|H|^2$ type interaction.
⑥ can be a Majorana fermion. No worry about direct detection limits.

Wino DM is attractive from the viewpoint of minimality!

Why is the wino DM attractive?

Wino DM = $SU(2)_L$-triplet Majorana fermion

In the framework of the MSSM, the discovery of the ~126GeV higgs boson may indicate that the typical scale of sfermion masses is O(10-1000)TeV.

⇨

High-scale SUSY scenario

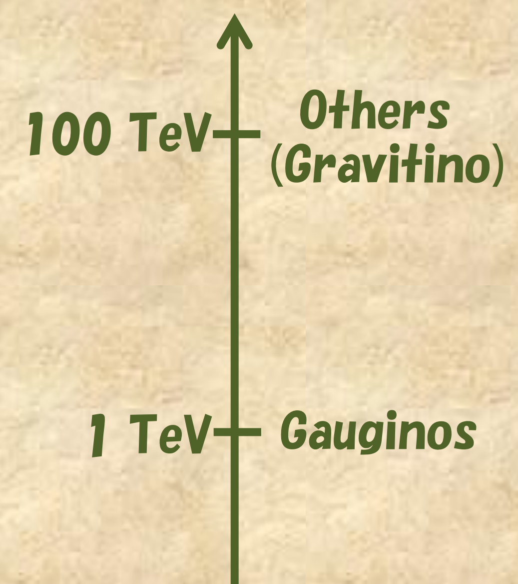
PGM [Ibe, Moroi, Yanagida, PLB644]

mSplit [A. Arvanitakia, et.al.,JHEP1302]

Spread [L. Hall, et.al., JHEP1031(2013)]

KLM [E. Dudas, et.al., EPJ C73 (2013)]

- Mediation of SUSY breaking can be very simple.
  [$m_0 \sim \mu \sim m_{3/2}$, while $m_{1/2} \sim m_{3/2}/(16\pi^2)$]
- SUSY CP/Flavor problems become very mild.
- Gravitino and Polonyi problems can be evaded.
  [Model can be consistent with Leptogenesis.]
- Gauge coupling unification becomes better.
- No SUSY signals expected at the current LHC.
- LSP is Wino because of the anomaly mediation.



Wino DM is attractive from the viewpoint of the MSSM!

Phenomenology of the wino DM

Upper bound of m_{wino} from cosmology

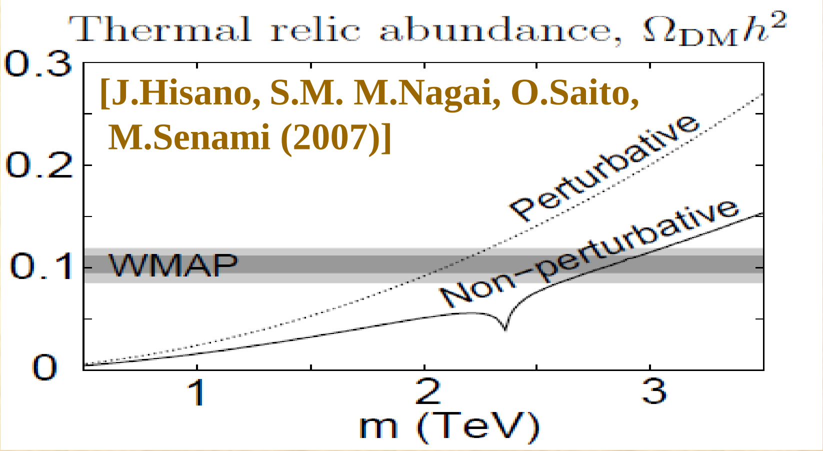
Two contributions to $\Omega_{DM}h^2$

1. Thermal contribution $\Omega_{TH}\, h^2$ →
2. Non-thermal contribution $\Omega_{NT}\, h^2$ (e.g., via gravitino decays, etc.)

[J.Feng, T.Moroi, L.Randall, M.Strassler, S.Su (1999)]

$(\Omega_{TH} + \Omega_{NT})\, h^2 = 0.11$

→ $m_{wino} < 2.8\,\mathrm{TeV}$



Lower bound of m_{wino} from LHC

Direct charged wino production

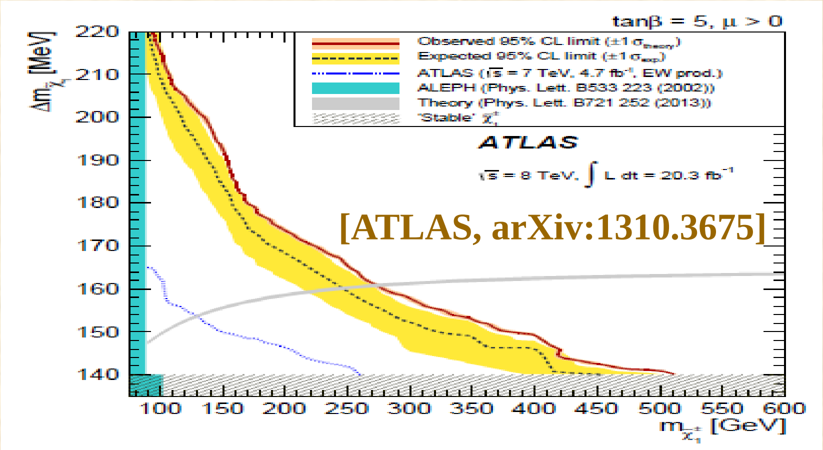
Signal: $pp \to$ jet $+ \chi^+ \chi^-$ (or $\chi^+ \chi^0$), followed by $\chi^\pm \to \chi^0 +$ soft $\pi^\pm$.

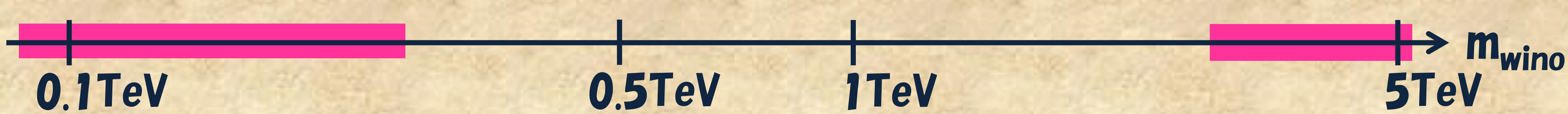
($c\tau$ of $\chi^\pm$ is about 7cm @ 2-loop)

[M. Ibe, S. M, R. Sato, PLB721 (2013)]

Mono jet + E_T + Disappearing Track

→ $m_{wino} > 270\,\mathrm{GeV}$ (500 GeV in future)





Phenomenology of the wino DM

~ Dark Matter detections to put robust limits ~

Detections	Method		Experiments	Comments
Direct			XENON100/LUX	$\sigma_{\chi N} \sim 1.5 \times 10^{-47}$ cm^2, so that it is difficult to detect it in near future.
Indirect CR			PAMELA/AMS-02	Propagation uncertainty is large.
Indirect ν			IceCube/DeepCore	Detection efficiency is small.
Indirect γ	dSph	line	Fermi-LAT/HESS	Signal flux is small to be detected.
		cont.		DM profile uncertainty is not large.
	CGR	line		Uncertainty of DM profile is large, but large DM density in this region.
		cont.		〃 + Difficulty of BG estimation.
	Clust.	line.		Signal flux is small to be detected.
		cont.		Good, but dSph observation is better.
	Diff.	line		Signal flux is small to be detected.
		cont.		Good, but dSph observation is better.

Indirect detection of the wino DM has an advantage, for its annihilation cross section is boosted by the Sommerfeld effect. [J. Hisano, S. M. M. Nojiri, PRL92 (2004)]

Phenomenology of the wino DM

Flux from galaxy satellites

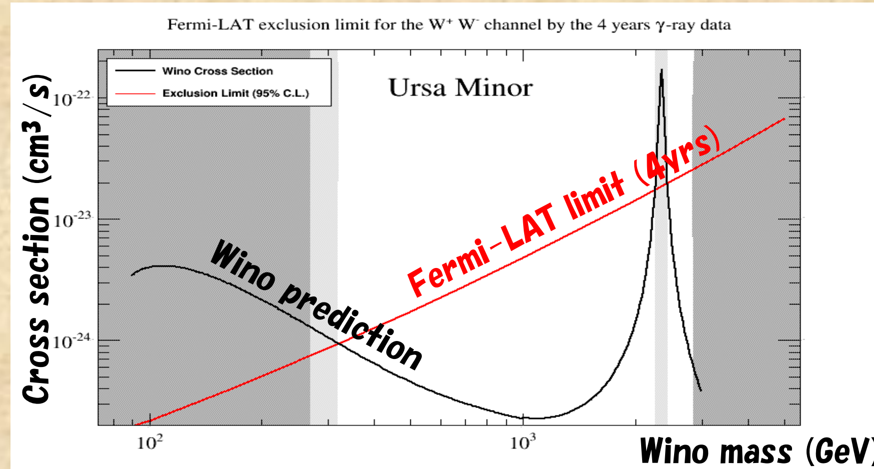
$$\frac{d\mathcal{F}}{dE} = \frac{\langle\sigma v\rangle}{8\pi m^2}\sum_f \mathrm{Br}(f)\frac{dN_f}{dE}\underbrace{\int_{\delta\Omega} d\Omega \int_{l.o.s.} dl\,\rho^2(\vec{r})}_{\text{J-factor!}}$$

CL. dSphs: Ursa Minor, Draco, …
(DM profile is well estimated.)

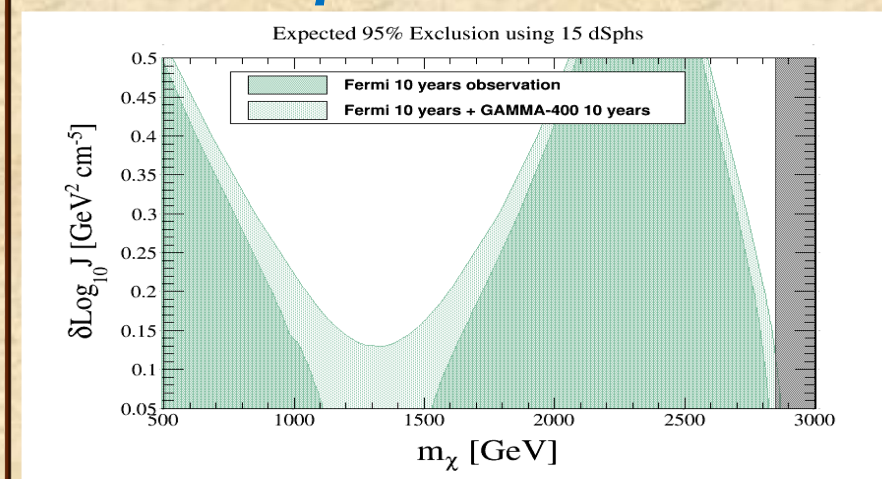
UF. dSphs: Ursa MajorII, Seque1, …
(Kinematical data is still poor.)

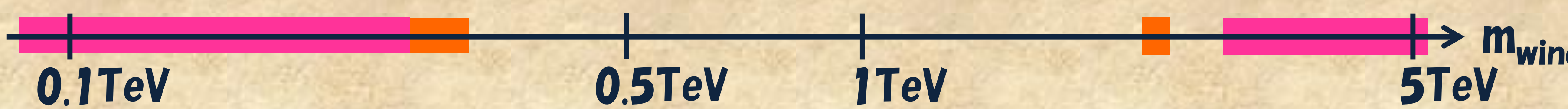
- Robust limit (Right-upper fig.)
  → $0.32\text{TeV} < m_{wino} < 2.25\text{TeV}$
  $2.44\text{TeV} < m_{wino}$
- Future limit (Right-lower fig.)
  It depends how small the error of J factor can be in each dSph.
  If $\Delta(\log_{10}J) = 0.1$, all region covered.

- Current limit



- Future expected limit





Phenomenology of the wino DM

Flux from Central Galactic Region

$$\mathcal{F} = \frac{\langle \sigma v \rangle_{\rm line}}{8\pi m^2} \underbrace{\int_{\delta\Omega} d\Omega \int_{l.o.s.} dl\, \rho^2(\vec{r})}_{\text{J-factor!}}$$

○ Estimation of the J-factor

$\boxed{\text{DM profile + Disc + Bulge}}$

↕ comparison

$\boxed{\text{Data of circular velocities}}$

○ Generalized NFW ($x = r/\alpha_R$)

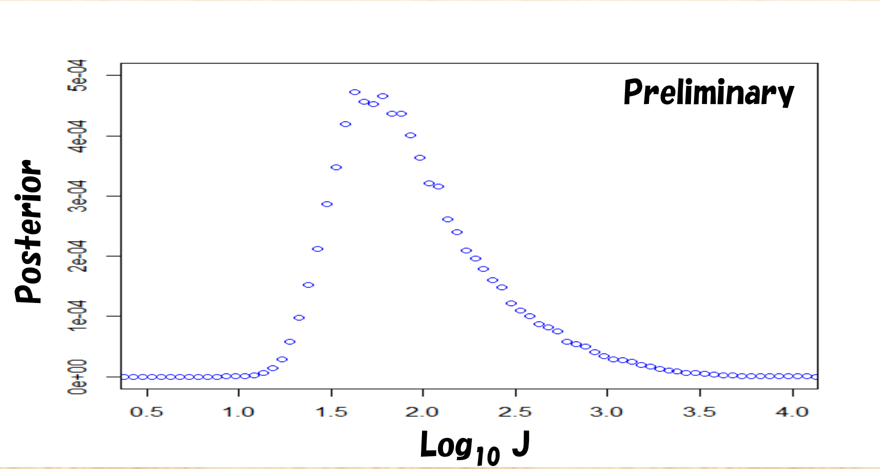
$$\rho(x) = \rho_R/[x^\gamma (1 + x^\alpha)^{(\beta-\gamma)/\alpha}]$$

Using MCMC method, its error is estimated (Right-upper fig.).

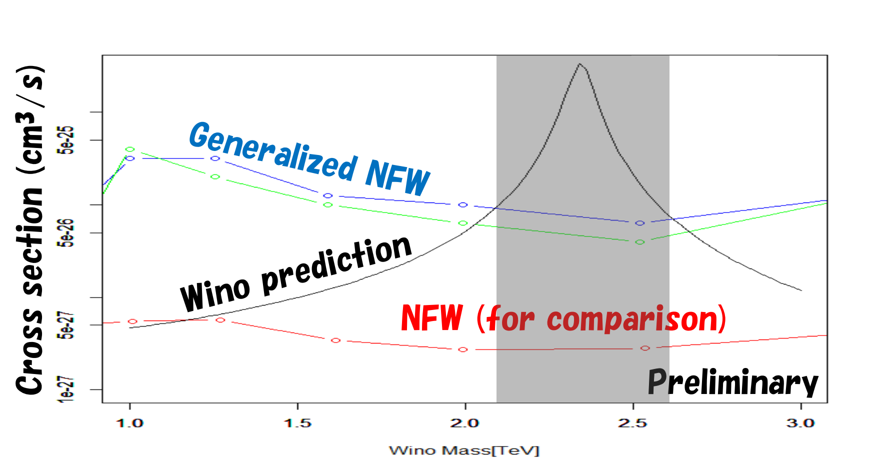
○ Robust limit (Right-lower fig.)

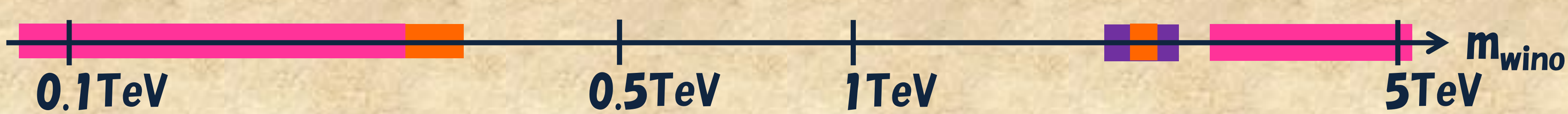
2.1TeV < m_{wino} < 2.6TeV excluded.

• Error on J-factor estimation



• Current limit





Summary & Discussions

- According to current results at LHC on the higgs discovery and new physics searches, the neutral wino seems to be attractive! The wino dark matter is indeed favored from viewpoints of its stability, minimality, and MSSM (in the high-scale SUSY scenario).
- Robust upper and lower limits on the wino mass are obtained by cosmology and LHC, 0.27TeV $< m_{wino} <$ 2.8TeV. DM signals at the direct detection experiments are very weak, while DM signals at indirect detection experiments are good. From continuum γ-ray observations from dSphs and line γ-ray from CGS put limits as 0.32TeV $< m_{wino} <$ 2.1TeV & 2.6TeV $< m_{wino} <$ 2.8TeV.
- In near future, γ-ray observations still play important roles to test the wino dark matter, because its systematic error can be well controlled. Continuum γ-ray from dSphs can be completely test the dark matter if errors on J-factor are reduced. About line γ-ray from CGR, observing γ-ray from regions around the exact center will be also important for cored DM profiles.