Mixed Wino-Axion DM in String Theory and the 130 GeV γ-line signal

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Based on:

1205.5789 (Acharya, Kane, P.K., Lu, Zheng)

1204.2795 (Acharya, Kane, P.K.)

Plan of the Talk

- Motivation
- DM Predictions from Theory
- The FERMI-LAT 130 GeV γ-line “Signal”.
- Interpretation within the Theoretical Framework.
- Correlated Falsifiable Predictions
- Conclusions.

When trying to connect String theory to the Real World, one is led to the following conundrum :

- String Theory seems to give rise to an enormous number of solutions which give rise to effectively 4D Universes.

- Widely criticized that "predictive power" of string theory has been lost.

Although situation challenging, not hopeless....

The Swampland &

The Landscape

Vafa -th/0509212
Ooguri, Vafa -th/0605264

Zoom in

If our Vacuum solution of String Theory, then ...

There exists a region in the landscape

- Gives rise to SM at low energies
- Consistent with all known experimental constraints

What typical features would one expect for Beyond-the-SM physics in this region?

– with mild theoretical prejudices

More concretely,

Study classes of solutions of compactified string/M-theories having the following properties:

1) Supergravity approx. valid, 2) Moduli are stabilized,

3) $M_{KK} \sim M_{GUT}$, 4) Spontaneous SUSY with ~ TeV scale $m_{3/2}$ & superpartners.

Such solutions have been constructed in various string/M theory corners.

Furthermore, many examples in literature with quasi-realistic matter and gauge spectra.

Also Yukawa couplings (including the CKM and PMNS matrices) nicely explained in various corners of string theory.

– many interesting talks at the conference. (assume that such constructions exist)

Here interested in trying to understand properties of BSM physics within this class

– focus on Dark Matter (rely on very simple and general arguments)

Generic Predictions for the above class of Vacua

(with some "mild" assumptions – see **Acharya, Kane, PK 1205.2795**)

Moduli Physics plays a crucial role !

B. Acharya's Talk
G. Kane's Talk

- Lightest Modulus mass ⟺ Gravitino mass ($m_{3/2}$)
- **Cosmological Moduli Problem :**

lower bound on lightest modulus mass ⟺ lower bound on $m_{3/2}$

– **Non-thermal Cosmological history before BBN.**

– Constrain scale of Squarks and Sleptons in the range 10-100 TeV .

Because m3/2 is the order parameter of SUSY breaking (when CC is tiny)

DM Predictions

Non-thermal Cosmology gives rise to qualitatively different predictions for DM than "standard" low-energy expectations

DM CANDIDATE - I

- **Axions (Closed String) – Imaginary part of Moduli**

Large number of Moduli ⇒ Axiverse (Acharya, Bobkov, PK 1004.5138; Arvanitaki et al 0905.4720; M. Goodsell's Talk)

Axion Stabilization ⇒ Masses vastly suppressed wrt $m_{3/2}$

One of them naturally solves Strong CP ---- B. Acharya's Talk

- **AXION DM abundance** = O(1) Ω_{WMAP}, even with $f_a \sim M_{GUT}$ with much less tuning

Moduli Decay ⇒ dilutes the axion abundance

WIMPs : DM Candidate II

- **WIMPs** → LSP provides WIMP DM candidate if R-parity conserved.

Traditional WIMP Miracle ⟺ **Non-thermal WIMP miracle**

$$n_\chi^{thermal} \sim \frac{H(T_F)}{\langle \sigma\, v \rangle_{\chi\chi}^{tot}}$$

Acharya, Kane, P.K., Watson 0908.2430

$$n_\chi \sim \frac{H(T_R)}{\langle \sigma\, v \rangle_{\chi\chi}^{tot}}$$

Decay of the Modulus itself generates DM abundance

$$n_\chi \sim n_\chi^{thermal} \frac{T_F}{T_R}$$

- **Favors larger cross-section relative to thermal case**

Natural candidate : **Wino-like LSP with a mass ~ EW scale and $M_{modulus}$ = 10-100 TeV gives roughly the correct abundance.**

In Vacua with gaugino masses suppressed relative to $m_{3/2}$

- **Top-Down :** 10-100 TeV Modulus mass & Wino LSP can be readily obtained within string/ M theory frameworks.

Acharya, Bobkov, Kane, PK, Shao 0801.0478

..continued

- We are thus led to two (non-negligible) sources of DM:

a) Wino-like WIMPs b) Axions

- Predicted in **Acharya, Bobkov, PK 1004.5138**

cations considered in [18]. For the M theory case with $H_I > M_{moduli}$ in particular, when combined with the results of [16], which show that, if stable, there is also a significant component of neutral Wino dark matter, we are led to predict two significant sources of dark matter.

and in the Broad Review

Acharya, Kane, PK 1204.2795

C. Summary

To summarize, the arguments in the previous sections imply the following generic prediction (with suppressed gaugino masses) for Dark Matter:

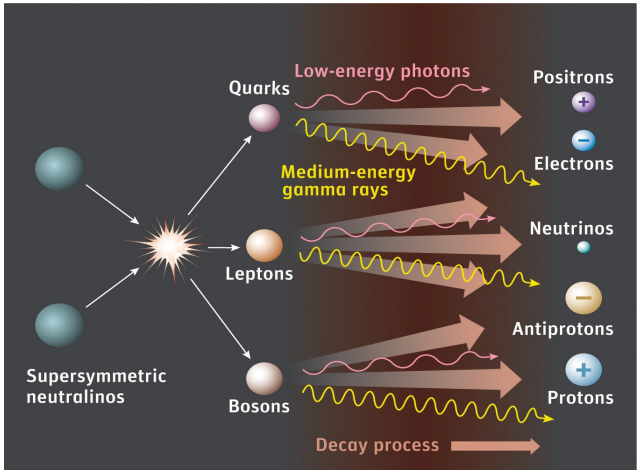
Both WIMPs and axions are predicted together to form the DM content of our universe, each of them generically having a non-negligible fraction. This is possible if the modulus decay constant f_X is around the string scale or GUT scale, hence smaller than the Planck scale by a few orders of magnitude. The precise fraction depends on the microscopic details of the compactification, and cannot be predicted with our current level of understanding. However, future experiments, especially for WIMPs, will be able to test this paradigm effectively and should either find firm evidence for it, or at least severely constrain it if not exclude it conclusively.

The FERMI 130 GeV γ-line "Signal"

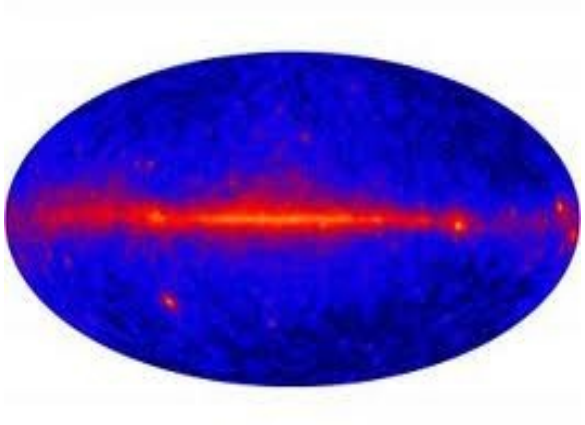
- Same day as the Review Paper **1204.2795,** another paper appeared on the arXiv:
  C. Weniger 1204.2797

A Tentative Gamma-Ray Line from Dark Matter Annihilation at the Fermi Large Area Telescope

DM annhilation from close to Galactic Centre



Look for monochromatic γ -rays in FERMI-LAT



"Indirect" Detection

Some Details

- Signal supposedly coming from a region ~ 4-5^0 around the Galactic Center (GC)
  - Line signal has no known astrophysical backgrounds ("smoking gun for DM"....)
- Confirmed by independent analysis by at least two more groups:
  - Tempel, Hektor, Raidal 1205.1045
  - Su, Finkbeiner 1206.1616 → Data-driven template analysis

    B. Allanach's Talk

  significance ~ 5 σ
- What about the official results from the FERMI-LAT collaboration?
  - No signal is claimed in their most recent paper 1205.2739 [LAT Collaboration]
  - But they exclude regions < 5^0 around the GC.

→ Two results consistent with each other

- Of course, updated Results from FERMI-LAT in the region < ~ 5^0 are eagerly awaited.

Required Cross-section & Implications

$$\frac{d\,\Phi_\gamma}{dE\,d\Omega}(\xi) = \frac{\langle \sigma\, v\rangle_{\chi\chi\to Z\gamma}}{8\pi\, m_\chi^2}\, 2\delta(E - E_\gamma) \int_{l.o.s.} ds\, \rho_\chi^2\,(r)$$

Particle Physics Factor

Astrophysics factor – depends on DM density profile (has uncertainties)

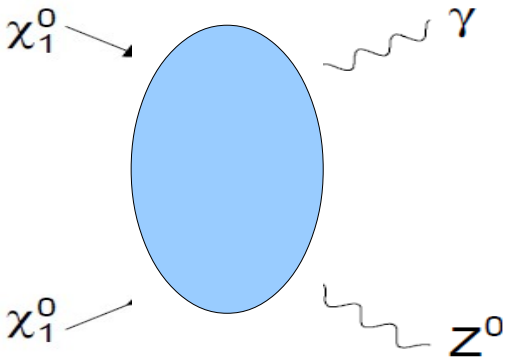
γ -line signal @ 130 GeV → determines the DM Mass, if Z γ : $m_\chi \approx 145$ GeV

$\langle \sigma v \rangle^{\rm reqd}_{\chi\chi\to Z\gamma} \approx 3.1 \times 10^{-27} {\rm cm}^3/{\rm s}$ – Einasto.

(Numbers change a bit for other profiles)

Crucial assumption – WIMPs form entire DM

Problematic for Simple SUSY Models & Thermal Cosmological History



One loop Suppressed !

$$\langle \sigma v\rangle_{\chi\chi\to\gamma\gamma} \lesssim \frac{1}{16\pi^2}\langle \sigma\, v^{therm}_{\chi\chi}\rangle \approx 1.9 \times 10^{-28}\,{\rm cm}^3/{\rm s},$$

since

$$\langle \sigma\, v^{therm}_{\chi\chi}\rangle \approx 3 \times 10^{-26}\,{\rm cm}^3/{\rm s}.$$

(ways out with elaborate model building...)

Interpreting the Signal within the Framework

- Generic predictions for DM : Both axions and WIMPs have non-negligible abundance within a non-thermal history

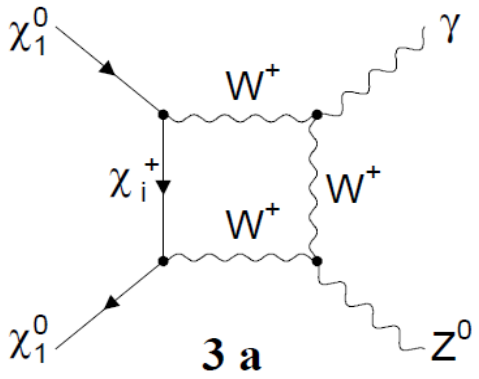
$$\Omega_\chi = \eta\,\Omega_{dm}; \quad J_\chi = \eta_{GC}^2\,J_{dm}, \qquad \text{where} \quad J_A \equiv \int_{l.o.s,\,\Delta\Omega} ds\,d\Omega\,\rho_A^2(r)$$

η= Global fraction of DM in WIMPs

η_{GC} = WIMP DM fraction along GC

$\eta \sim \eta_{GC}$ (upto astrophysical uncertainties)

- Since γ-line signal determines $m_\chi \approx 145$ GeV ,



$\langle\sigma v\rangle_{\chi\chi\to Z\,\gamma}$: completely fixed for Wino LSPs !

Winos have much larger cross-section (than "thermal")

So, loop suppressed process ⇒ roughly correct flux

$$\langle\sigma v\rangle_{\chi\chi\to Z\,\gamma} \approx 1.26\times10^{-26}\,\mathrm{cm}^3/\mathrm{s}$$

Also determines the LSP fraction of DM (from the Flux formula):

Roughly half of DM in the form of WIMPs (upto astrophysical uncertainties)

(& the remaining in axions)

$$\eta_{GC} \approx \sqrt{\frac{3.1\times10^{-27}}{1.26\times10^{-26}}} \approx 0.49^{+0.07}_{-0.08} \;-\text{Einasto}$$

- LSP fraction η ⟹ $\Omega_\chi h^2 \approx \frac{45}{2\pi\sqrt{10\, g_\star(T_R)}} \frac{m_\chi}{(\rho/s)_{crit}} \left(\frac{1}{m_{pl}\, T_R\, \langle \sigma\, v \rangle^{tot}_{\chi\chi}} \right)$ known

⟹ $T_R \approx 166\,\mathrm{MeV}$ with $g_\star(T_R) \approx 74$

$f_X \sim 2*10^{17}$ GeV ⟹ $m_{3/2} \sim 50$ TeV,

Modulus Decay Constant close to string scale gives m3/2 >~ 30 TeV.

Associated (falsifiable) WIMP Predictions

If "signal" real, and if our interpretation correct, then in the near future:

- **Should observe γ-ray lines (with smaller strength than the Z γ line) from the GC at E ~ 145 GeV from the γγ process.**
- **Should observe diffuse γ-rays from dwarf galaxies.**

Falsifiable LHC predictions

- Until now, results quite general and hold for a very large class of Vacua

  (with the general properties stated earlier)

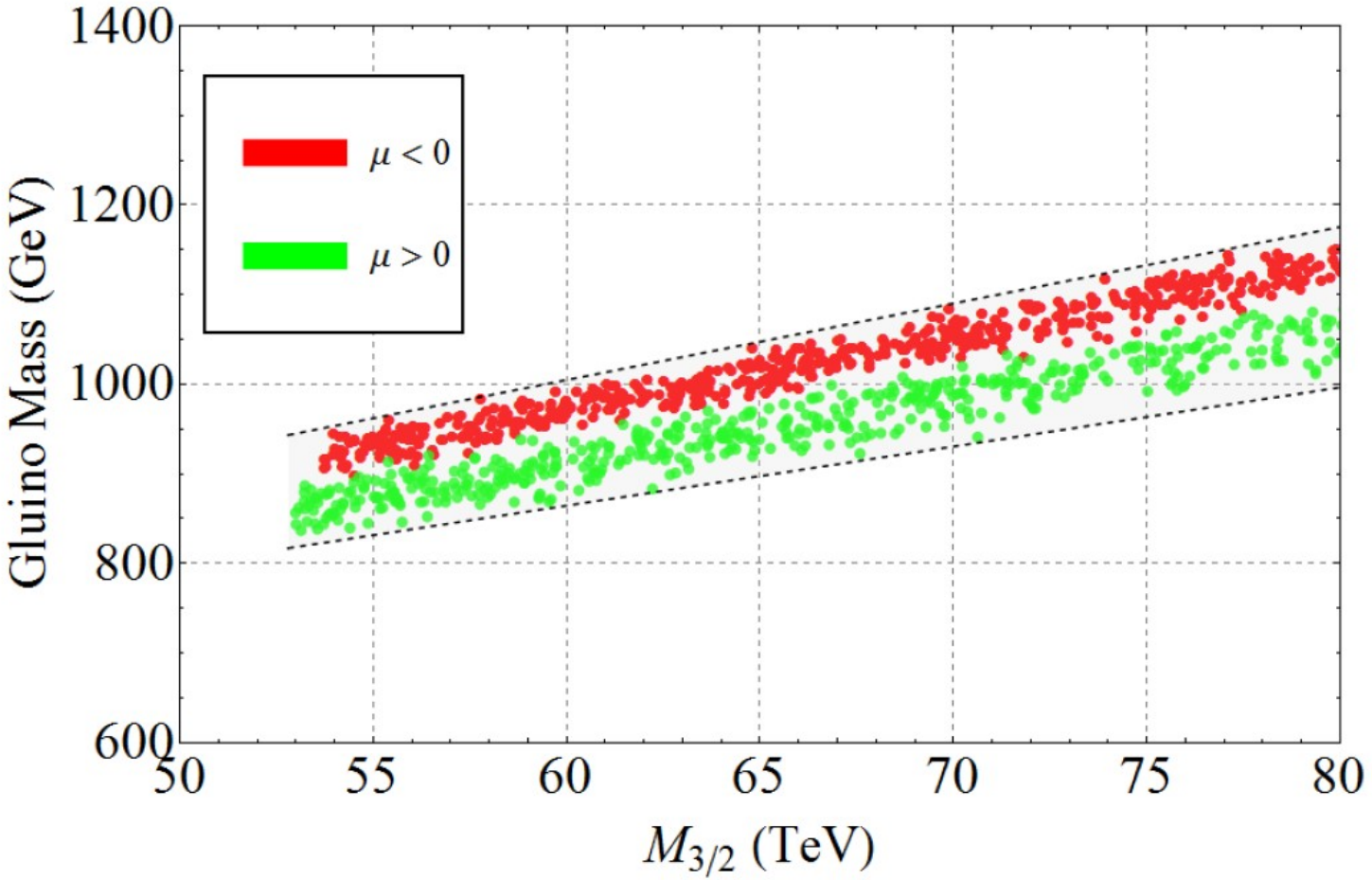
- A Wino LSP with mass $m_{\chi} \approx 145$ GeV strongly constrains other superpartner masses

  (Gluino mass for e.g.) within a theoretical framework for supersymmetry breaking.

These predictions depend on more details of the Framework :

- Studied the M-theory framework with MSSM below the compactification scale
  - found ranges for the Bino and Gluino Mass.
  - results valid for the same framework which gives Higgs mass in the range 122-129 GeV

    – G Kane's Talk
- Different theoretical framework – such as in Type IIB, Heterotic, etc.
  - Will make different predictions for gauginos in general → so can distinguish among them.



Gluino Pole Mass as a function of $m_{3/2}$ with Wino LSP in the range 140-150 GeV

Should be observed by the LHC in the near Future!

R. Lu's Talk

CONCLUSIONS

In this data-rich era, ultimate scientific metric for the viability of any theory

How does it compare with Data?

(because Physics is ultimately an Experimental Science)

- **Pragmatic Approach –** Allows us to make many predictions which can be confronted with real data.

  (with some assumptions of course)

Approach very useful in both events

- **Agree with Data:**
  - Great !
  - Justify the Philosophy & Assumptions
  - insights about other fundamental questions.

- **Do NOT agree with Data:**
  - Depending on the nature of data, could tell us which assumption(s) need to be relaxed?
  - Still provide a lot of useful insight about nature of microscopic theory.

Extra Slides

$$\alpha_h^{-1} = \frac{1}{2\pi}\frac{PQ}{Q-P}\log\left(\frac{A_1 Q}{A_2 P}\right);$$

$$\alpha_{vis}^{-1} = \sum_i N_i^{vis}\, s_i;\ s_i \sim \frac{1}{N_i}\frac{1}{\alpha_h};\ i = 1,..,N;$$

$$\frac{m_{3/2}}{m_{pl}} = e^{K/2}\frac{W}{m_{pl}^3} = A_2\frac{|Q-P|}{Q}\alpha_h^{7/2} e^{-\frac{2\pi}{Q\alpha_h}}$$

$$M_{1/2}^{tree}(M_{GUT}) = \sum_{i=1}^{N}\frac{F^i\,\partial_i f_{vis}}{2\,i\,\mathrm{Im}(f_{vis})} \simeq -\frac{\alpha_h\, Q}{6\,\pi}\, m_{3/2}\,(1+...)$$

$$\simeq -\frac{1.9\, m_{3/2}}{P_{eff}}\,(1+\epsilon) \qquad (15)$$

Vanishing C.C → Peff ~ 61.6

Gaugino masses at GUT scale only depend on {m3/2, ε}

30 < m3/2 < 80 TeV; -0.6 < ε < 0.2

$30\,\mathrm{TeV} \le m_{3/2} \le 80\,\mathrm{TeV}$	$0.05\, m_{3/2} \le \lvert\mu\rvert \le 0.15\, m_{3/2}$
$-0.6 \le \epsilon \le 0.2$	$1.0\, m_{3/2} \le A_t \le 1.5\, m_{3/2}$

An Example

If squarks/sleptons observed at the LHC:

– contradiction with some of the basic assumptions/results of the framework.

- Imply one of the following possibilities:

  a) Moduli Super- and Kahler- Potential non-generic (very special).

  b) $H_{inflation} <\sim m_{3/2}$.

  c) Late period of Thermal Inflation.

  d) Some form of sequestering is realized.

None of these possibilities seem to be realized within String constructions yet

Provide very useful insight about Theory !

- Would be a challenge to realize any one of the above within a string theory framework, consistent with experimental constraints.