

# Boosted Dark Matter in IceCube and at the Galactic Center

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Based on work done in collaboration with

Jia Liu and Xiaoping Wang

arXiv:1503.02669

# Outline

1 IceCube and the high-energy Universe

2 Boosted dark matter

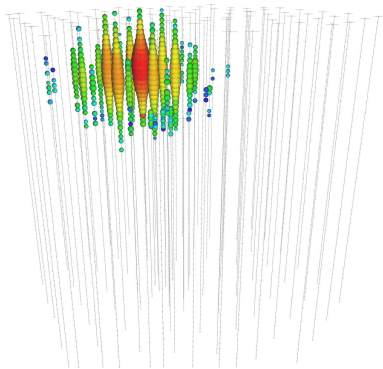
3 Constraints

4 Summary

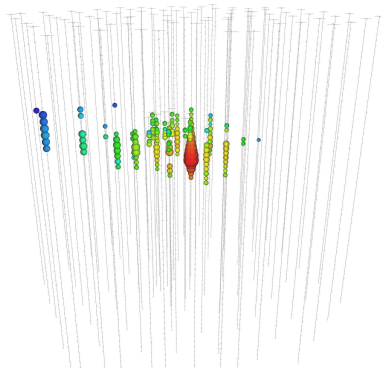


# IceCube and the high-energy Universe

# IceCube results

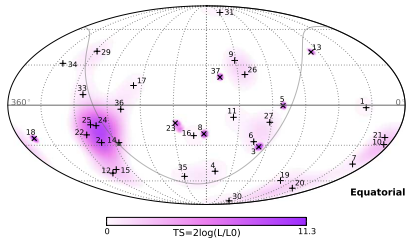
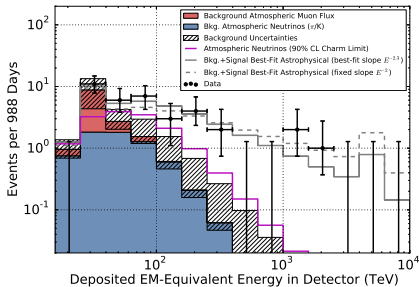


Shower event ( $\nu_e, \nu_\tau$ )



Track event (mostly  $\nu_\mu$ )

# IceCube results (2)



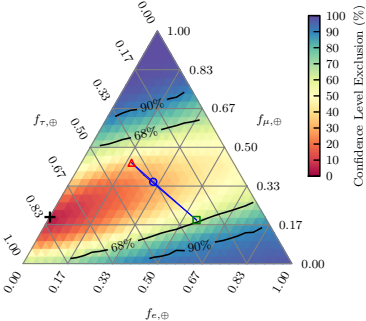
Significant excess of events  $\gtrsim 30$  TeV

Spatially uniform within uncertainties

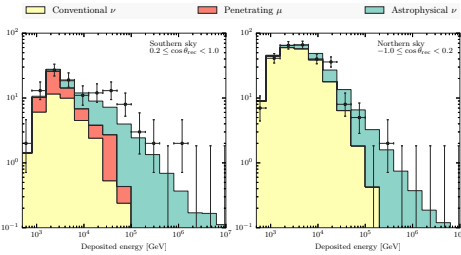
IceCube Collaboration, [arXiv:1405.5303](https://arxiv.org/abs/1405.5303)

Conventional interpretation:  
Astrophysical neutrinos from unknown sources.

# IceCube results (3)



Flavor ratios: more shower events  
(not significant yet)



Bump in the southern sky

IceCube Collaboration, [arXiv:1502.03376](https://arxiv.org/abs/1502.03376), [arXiv:1410.1749](https://arxiv.org/abs/1410.1749)

This talk:  
Alternative explanation in terms of  
boosted dark matter



Boosted dark matter



# Boosted dark matter Lagrangian

New particles:

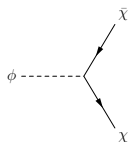
$\phi$  ... Main component of DM [ $\mathcal{O}(\text{PeV})$ ]

$\chi$  ... DM decay product [ $\mathcal{O}(10 \text{ GeV})$ ]

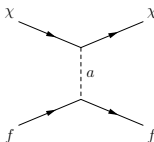
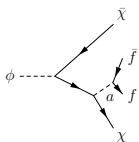
$a$  ... Pseudoscalar mediator [ $\mathcal{O}(10 \text{ GeV})$ ] of DM–SM interactions

$$\mathcal{L} \supset -y_{\phi\chi}\phi\bar{\chi}\chi + ig_{\chi}a\bar{\chi}\gamma^5\chi + i\sum_f g_{Y_f}\frac{\sqrt{2}m_f}{v}a\bar{f}\gamma^5f$$

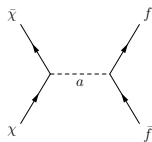
Phenomenology:



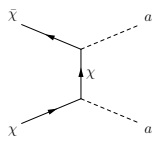
$\phi$  decay to **boosted**  $\chi$   
(possibly +  $a$  radiation)



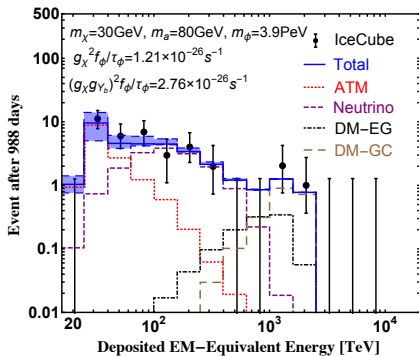
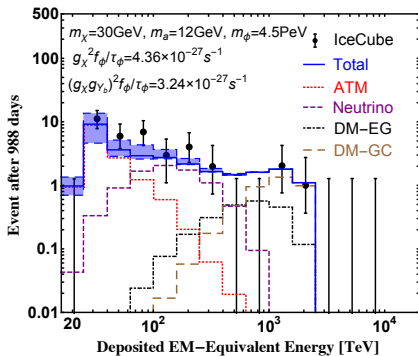
$\chi$  scattering



$\chi$  annihilation

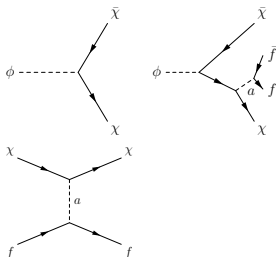


# IceCube signals

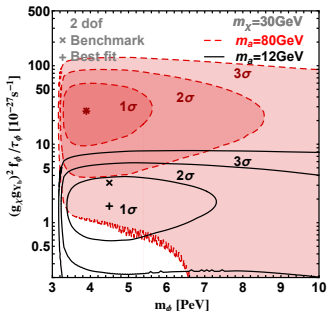
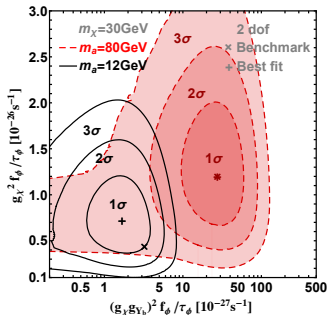
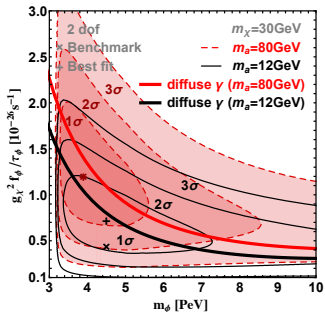


## Two signal components:

- ▶ **Scattering** of boosted  $\chi$ 
  - ★ Only shower-like events
- ▶ **Neutrinos** from decay of radiated  $a$ 
  - ★ SM-like flavor ratios
  - ★ Bumpy spectrum
- ▶ Small dip between the two components
- ▶ **Prediction:** Larger flux from South  
(where Galactic Center is located)



# IceCube fit



# Relic density

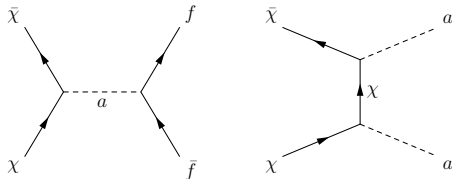
Several mechanisms to generate correct relic density for PeV-scale DM:

Harigaya Kawasaki Mukaida Yamada, [arXiv:1402.2846](https://arxiv.org/abs/1402.2846)

- Cascade decays of the inflaton
- Inelastic scattering of high- $E$  particles from inflaton decay on low- $T$  plasma.
- Thermal production and freeze-out during reheating, dilution as inflatons continue to decay after DM freeze-out.

What about the light DM species  $\chi$ ?

- Thermalization and freeze-out in the early Universe



- Abundance naturally **comparable** to abundance of heavy DM  $\phi$

# A Hooperon

Light DM particles  $\chi$  can annihilate in the galactice center.

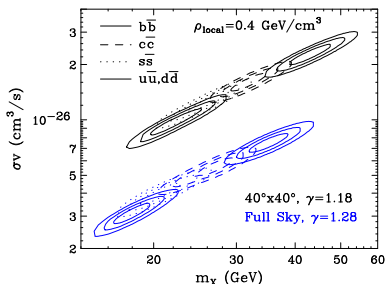
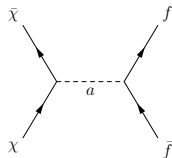
For  $m_\chi \sim 30$  GeV, and couplings

$$\mathcal{L} \supset i \sum_f g_{Y_f} \frac{\sqrt{2} m_f}{v} a \bar{f} \gamma^5 f$$

dominant annihilation mode is  $\bar{\chi}\chi \rightarrow b\bar{b}$ .

$\chi$  could thus explain the galactic center gamma ray excess.

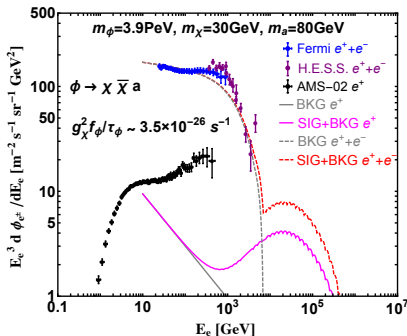
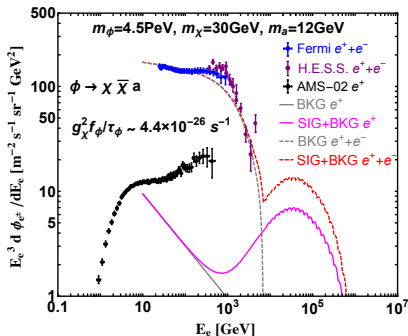
Goodenough Hooper [arXiv:0910.2998](https://arxiv.org/abs/0910.2998); Hooper Goodenough [arXiv:1010.2752](https://arxiv.org/abs/1010.2752)  
Daylan Finkbeiner Hooper Linden Portillo Rodd Slatyer [arXiv:1402.6703](https://arxiv.org/abs/1402.6703)



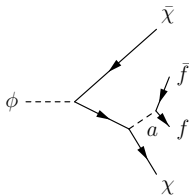


# Constraints

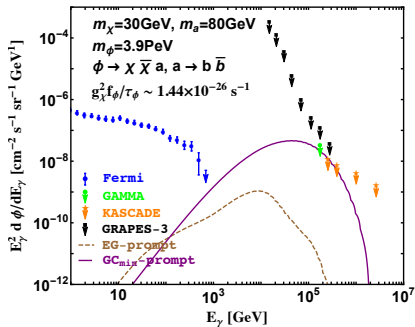
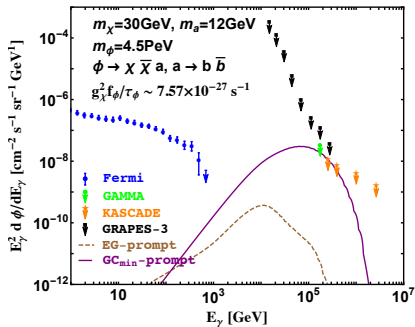
# Positron flux



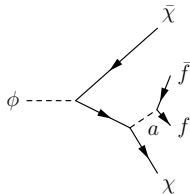
Positron flux from 3-body decays  $\phi \rightarrow \bar{\chi}\chi a \dots$  OK.



# Diffuse gamma ray flux



Diffuse  $\gamma$  ray flux from 3-body decays  $\phi \rightarrow \bar{\chi}\chi a \dots$  OK.





# Direct detection

Constraints **very weak** due to **pseudoscalar mediator  $a$**   
→ velocity-suppression

# Collider limits

## 3 UV completions of boosted DM model:

<i>MSSM-like</i>	<i>Flipped</i>	<i>Vector quark</i>
$a$ mixes with $A^0$ in type-II 2HDM	$a$ mixes with $A^0$ in flipped 2HDM	$a$ couples to new vector-like quarks, mixed with SM quarks

- $K$  and  $B$  meson decays to pseudoscalar  $a$ 
  - ▶ kinematically forbidden for  $m_a \gtrsim 10$  GeV
- $B_s \rightarrow \mu^+ \mu^-$ 
  - ▶ avoided for sufficiently heavy  $m_a$
  - ▶ Weakened in *Flipped* model
  - ▶ Absent in *Vector quark* model
- $h \rightarrow aa$ 
  - ▶ avoided for sufficiently heavy  $m_a$
  - ▶ Absent in *Vector quark* model



# Summary

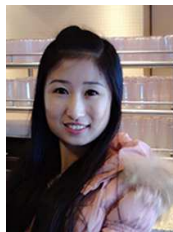
# Summary

Boosted DM can explain:

- Energy spectrum of IceCube events
  - ▶ Possible dip at several 100 GeV
- Morphology
  - ▶ Prediction: larger signal from the GC
- Flavor ratio
  - ▶ Prediction: only shower-like at PeV, SM-like at lower  $E$
- Galactic Center gamma ray excess



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Thank you!

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