# Flavino dark matter in the $A_4$ flavor model

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**Symmetry and Effective Field Theory of Quantum**

**Matter@Niigata Univ.**

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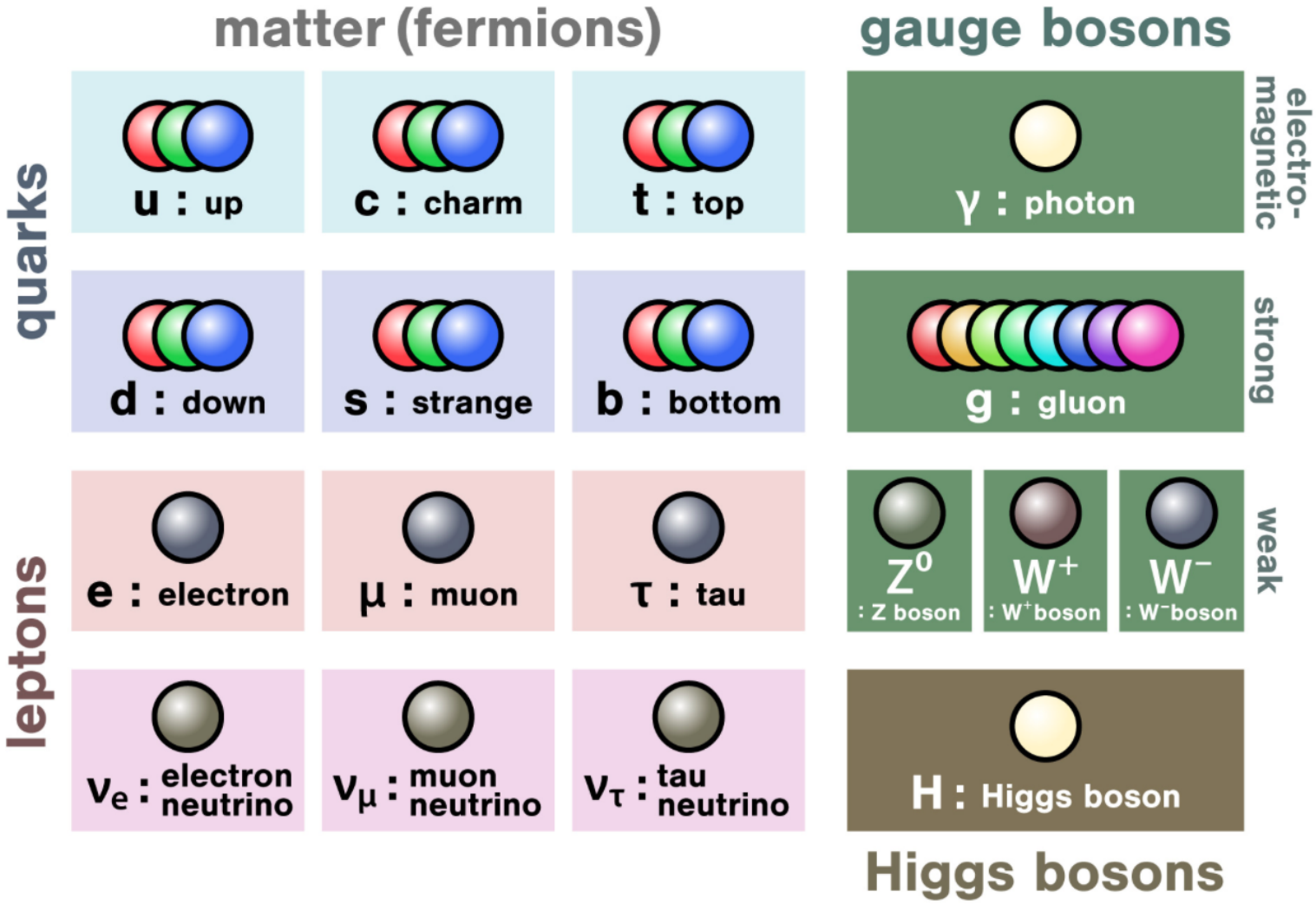
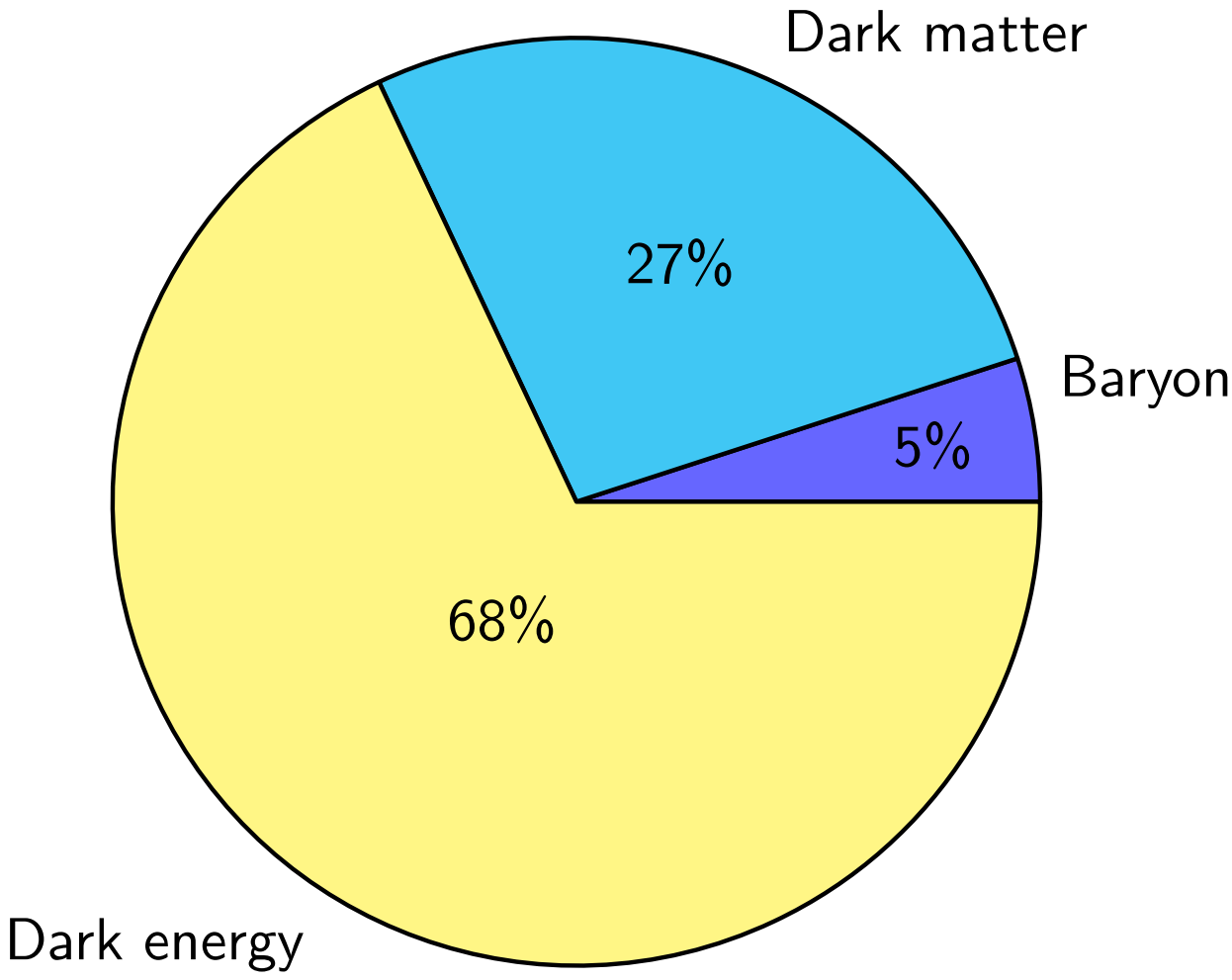
# Standard Model




SM can not explain DM!!

# Dark matter



# Dark matter properties

- Neutral
- Gravitional interaction
- Long life time and stable
- Approximately 27% of the energy density of the universe
- $\Omega h^2 \simeq 0.12$
- Cold (non-relativestic) in structure formation

# Dark matter

DM candidates:

- WIMPs(Weakly interacting massive particles)
- Axion, Axion-like particle
- Primordial black hole
- Dark photon
- Right handed neutrino

e.t.c.

$\Downarrow$

New canditate is **Flavino**!!

# $A_4$ symmetry

In SM, there are three generations of fermions with the sama charge and different masses.

In SM,left handed leptons are SU(2) doublet.

$$\Downarrow$$

generation (flavor) symmetry

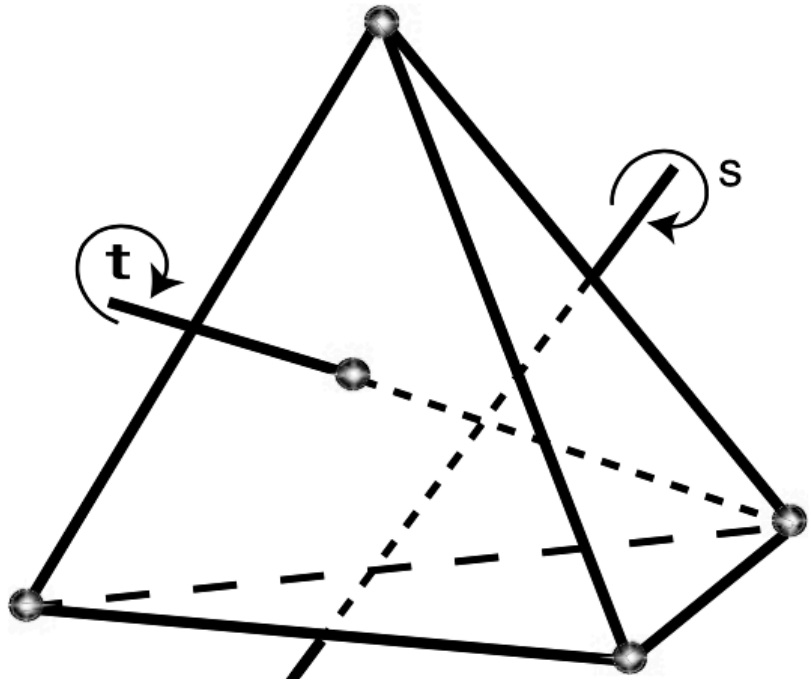
$\Rightarrow A_4$ symmetry

# $A_4$ symmetry

$A_4$ group is the symmetry group of a tetrahedron or the group of even permutation of four objects

Irreducible representation:1,1',1",3

The minimum group containing triplet without doublet.



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# Model

| | $\Phi_\ell = (\Phi_{\ell 1}, \Phi_{\ell 2}, \Phi_{\ell 3})$ | $\Phi_{e_R^c}$ | $\Phi_{\mu_R^c}$ | $\Phi_{\tau_R^c}$ | $\Phi_d$ | $\Phi_T$ | $\Phi_0^T$ |
|---|---|---|---|---|---|---|---|
| $SU(2)_L$ | $2$ | $1$ | $1$ | $1$ | $2$ | $1$ | $1$ |
| $A_4$ | $\mathbf{3}$ | $\mathbf{1}$ | $\mathbf{1''}$ | $\mathbf{1'}$ | $\mathbf{1}$ | $\mathbf{3}$ | $\mathbf{3}$ |
| $Z_3$ | $\omega$ | $\omega^2$ | $\omega^2$ | $\omega^2$ | $1$ | $1$ | $1$ |
| $U(1)_R$ | $1$ | $1$ | $1$ | $1$ | $0$ | $0$ | $2$ |

Table: The charge assignments of $SU(2)_L \times A_4 \times Z_3 \times U(1)_R$

Ref:T. Morozumi et al. Phys.C 42 (2018) no.2, 023102.

# Model

Flavon's vacuum expectaion value:

$$\langle \varphi_T \rangle = v_T(1,0,0), \qquad v_T = \frac{3M}{2g}, \qquad \langle \phi_0^T \rangle = (0,0,0)$$

Flavino:

$$X_R \equiv \tilde{\psi}^c_{\phi_{01}^T}, \qquad X_L \equiv \tilde{\psi}_{\varphi_{T1}}$$

Interaction term with Flavon:

$$\mathcal{L}_{\Phi_T} \supset \frac{M}{v_T}\left[2\varphi_{T1}\overline{X_R}X_L + \phi_{01}^T\overline{X_L^c}X_L + h.c.\right] + \frac{M^2}{v_T}\left[\varphi_{T1}\varphi_{T1}^*\varphi_{T1}^* + c.c.\right] - \frac{2M^2}{v_T}\left[\phi_{01}^T\phi_{01}^{T*}\varphi_{T1}^* + c.c.\right]$$

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# Dominant annihilation mode of Flavino

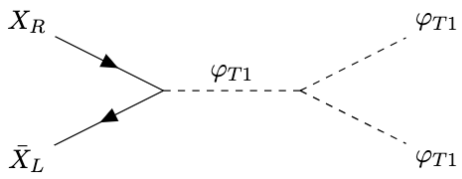
Main annihilation mode:

$$\overline{X}X \to \{\varphi_{T1}\varphi_{T1}, \overline{\varphi_{T1}}\ \overline{\varphi_{T1}}\}$$

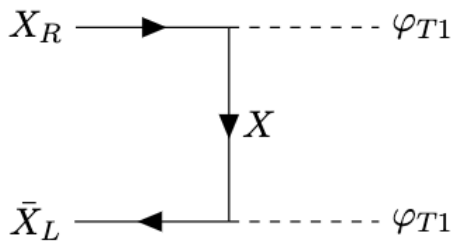
$$XX \to \overline{\phi_{01}^{T}}\ \overline{\varphi_{T1}}, \quad \overline{X}\ \overline{X} \to \phi_{01}^{T}\varphi_{T1}.$$

# DM annihilation cross section

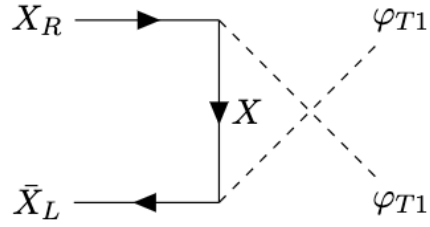
(i) $X\bar{X} \longrightarrow \varphi_{T1}\varphi_{T1}$, $X\bar{X} \longrightarrow \overline{\varphi_{T1}}\,\overline{\varphi_{T1}}$




(a) s-channel




(b) t-channel




(c) u-channel

Diagrams for the process $\bar{X}X \to \varphi_{T1}\varphi_{T1}$.

# DM annihilation cross section

Matrix elements:

$$\mathcal{M}_s = -\left(\frac{2M}{v_T}\right)\left(\frac{2M^2}{v_T}\right)\frac{1}{s-M^2}\bar{v}_{(p_2)}P_R u_{(p_1)}$$

$$\mathcal{M}_t \sim \mathcal{M}_u \sim \left(\frac{2M}{v_T}\right)^2 \frac{1}{M}\bar{v}_{(p_2)}P_R u_{(p_1)}$$

(assumption:$t, u \ll M^2$)

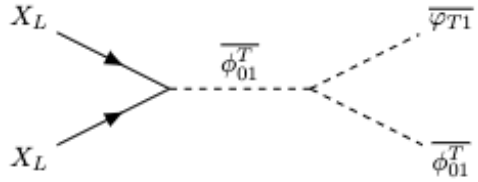
$$\mathcal{M} \sim \frac{20M}{3{v_T}^2}\bar{v}_{(p_2)}P_R u_{(p_1)}, (s \sim 4M^2)$$

Cross sections:

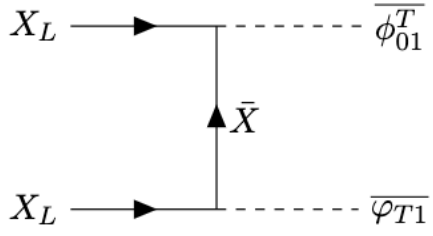
$$\sigma_{X\bar{X}\to\overline{\varphi_{T1}}\,\overline{\varphi_{T1}}} = \sigma_{X\bar{X}\to\varphi_{T1}\varphi_{T1}} \sim \frac{25}{144\pi}\frac{M^2}{{v_T}^4}$$

# DM annihilation cross section

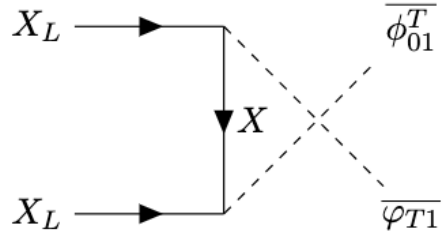
(ii)$XX \longrightarrow \overline{\phi_{01}^T}\,\overline{\varphi_{T1}},\ \bar{X}\bar{X} \longrightarrow \phi_{01}^T\varphi_{T1}$




(a) s-channel




(b) t-channel




(c) u-channel

Diagrams for the process $XX \to \overline{\varphi_{T1}}\overline{\phi_{01}^T}$

# DM annihilation cross section

Matrix elements:

$$\mathcal{M}_s = \left(\frac{M}{v_T}\right)\left(\frac{2M^2}{v_T}\right)\frac{1}{s-M^2}\bar{v}_{(p_2)}P_L u_{(p_1)}$$

$$\mathcal{M}_t \sim \mathcal{M}_u \sim \left(\frac{2M}{{v_T}^2}\right)\bar{v}_{(p_2)}P_L u_{(p_1)}$$

$$\mathcal{M} \sim \left(\frac{14M}{3{v_T}^2}\right)\bar{v}_{(p_2)}P_L u_{(p_1)}$$

Cross sections:

$$\sigma_{\bar{X}\bar{X}\to\phi_{01}^T\varphi_{T1}} = \sigma_{XX\to\overline{\phi_{01}^T}\,\overline{\varphi_{T1}}} \sim \frac{49}{288\pi}\frac{M^2}{{v_T}^4}$$

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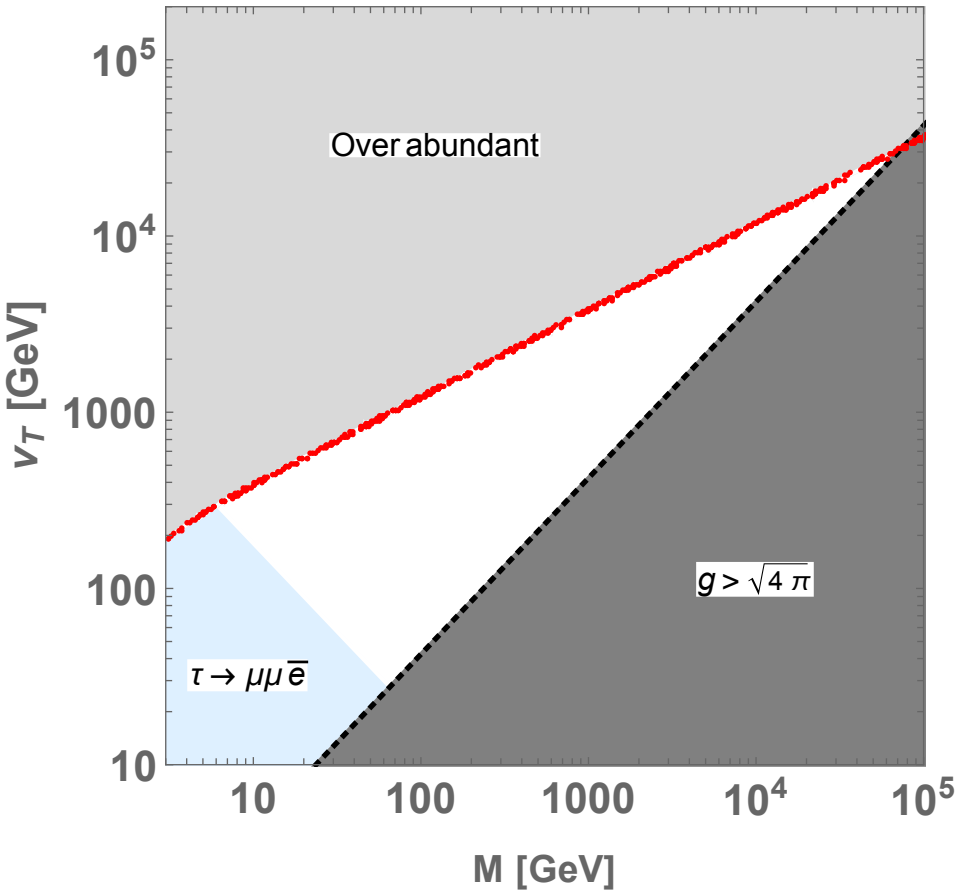
# Calculation result

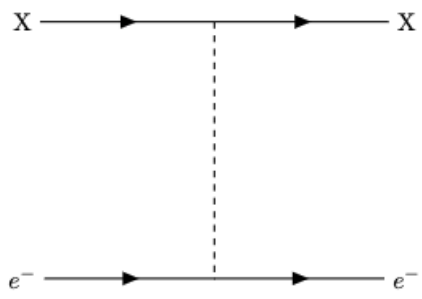



Horizontal axis:The lightest flavon's mass

Vertical axis:Flavon's vacuum expectaion value

# Detection

- **Direct detection**

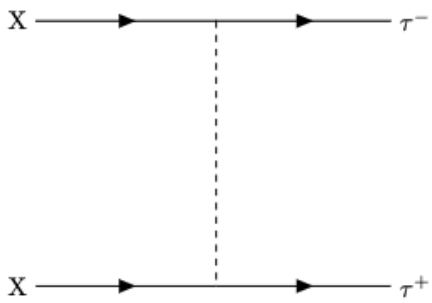



There is no flavino-flavino-Higgs interaction.

Flavino can interact with electron via flavon $\varphi_{T1}$ exchange but cross section is tiny since flavon-electron coupling is proportional to electron mass.

# Detection

- **Indirect detection**




The coupling $m_\ell/v_T$ is small, so the cross-sectional area is about $\sim 10^{-26}\text{cm}^3/\text{s}$. Thus the model is safe from indirect detection constraints.

# Summary

Assume Flavino in $A_4$ flavor model as DM.

The lightest Flavino's mass is 6[GeV] $\sim 6 \times 10^4$[GeV].

Flavon's vacuum expectaion value is 30[GeV] $\sim 2 \times 10^4$[GeV].