Future CTA constraints vs Colliders and Direct Detection

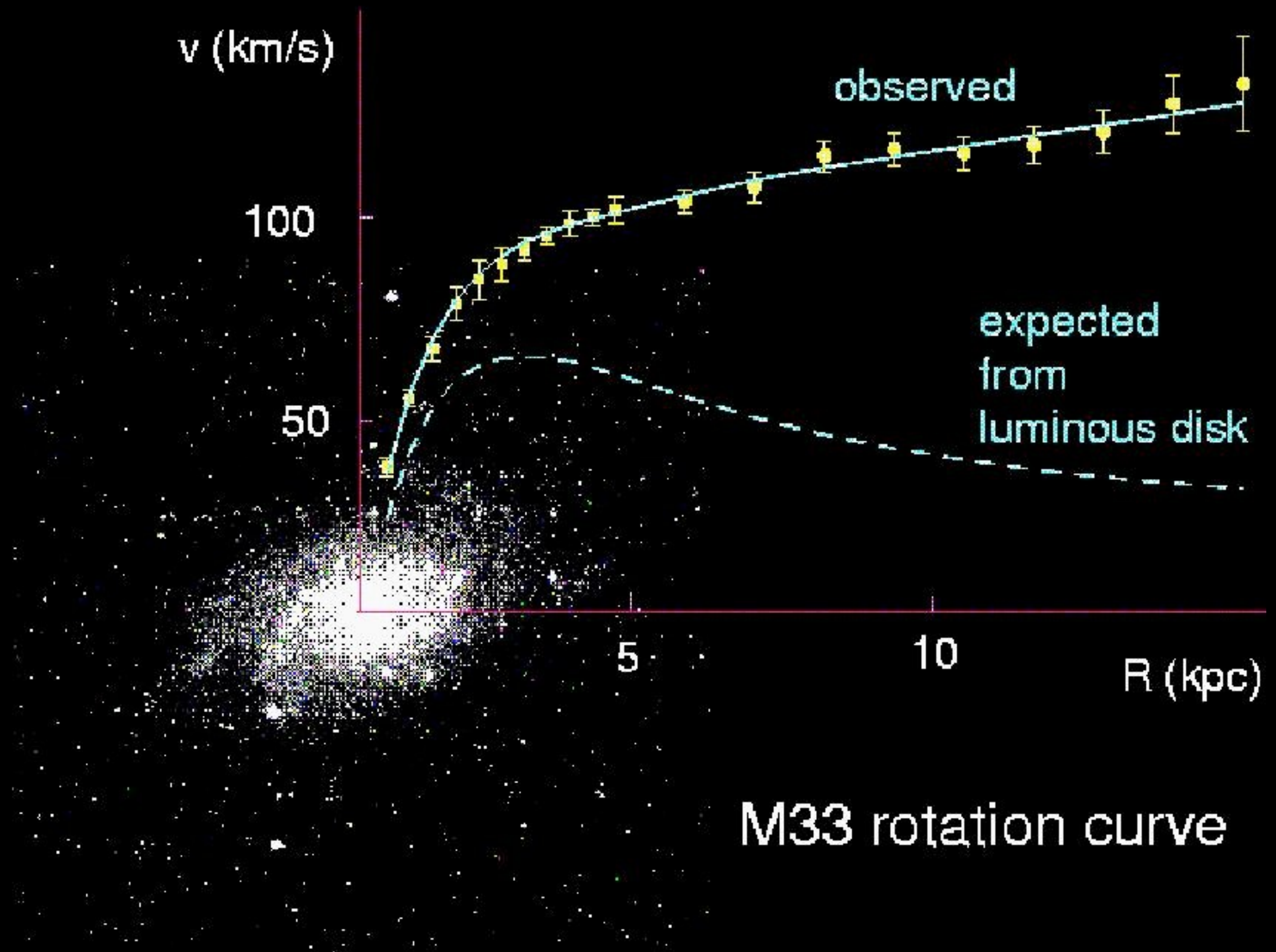
Thomas Jacques
with C. Balázs, J. Conrad, B. Farmer, T. Li, M. Meyer, F. S. Queiroz and M. A. Sánchez-Conde

arXiv:1706.01505

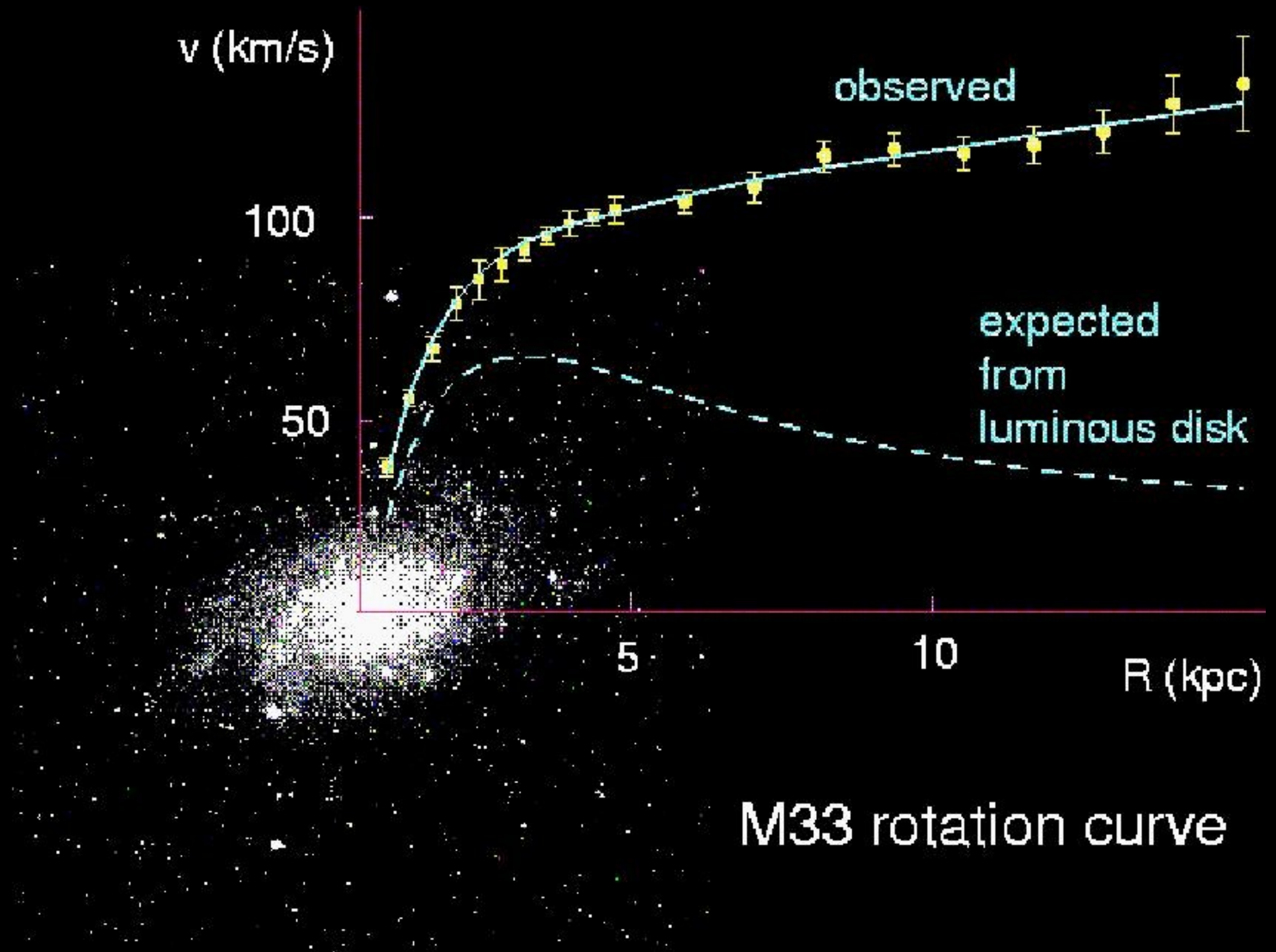
2017-09-25
ASTRO-TS, Trieste

Istituto Nazionale di Fisica Nucleare

ma per seguir virtute e canoscenza
SISSA



M33 rotation curve



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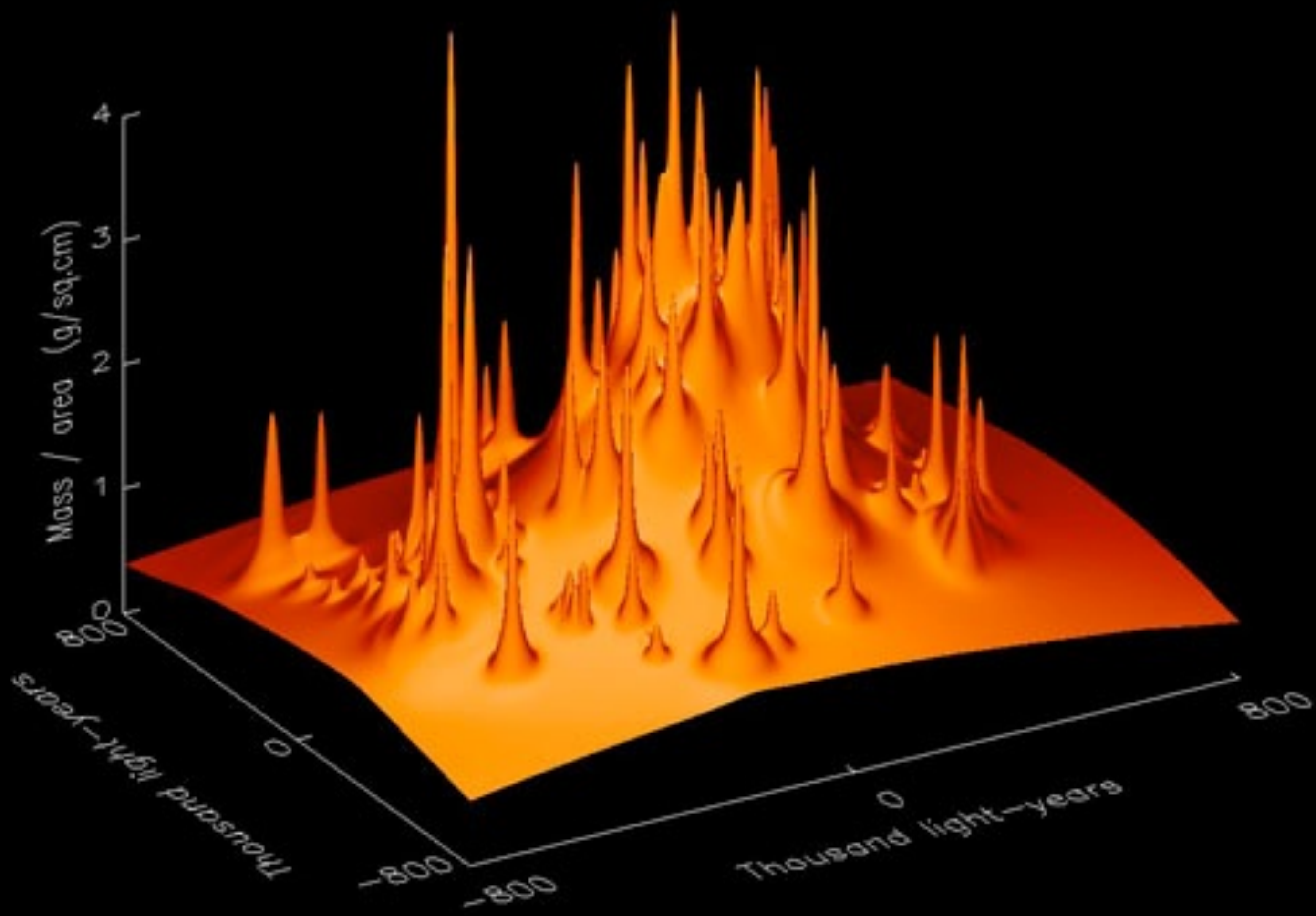
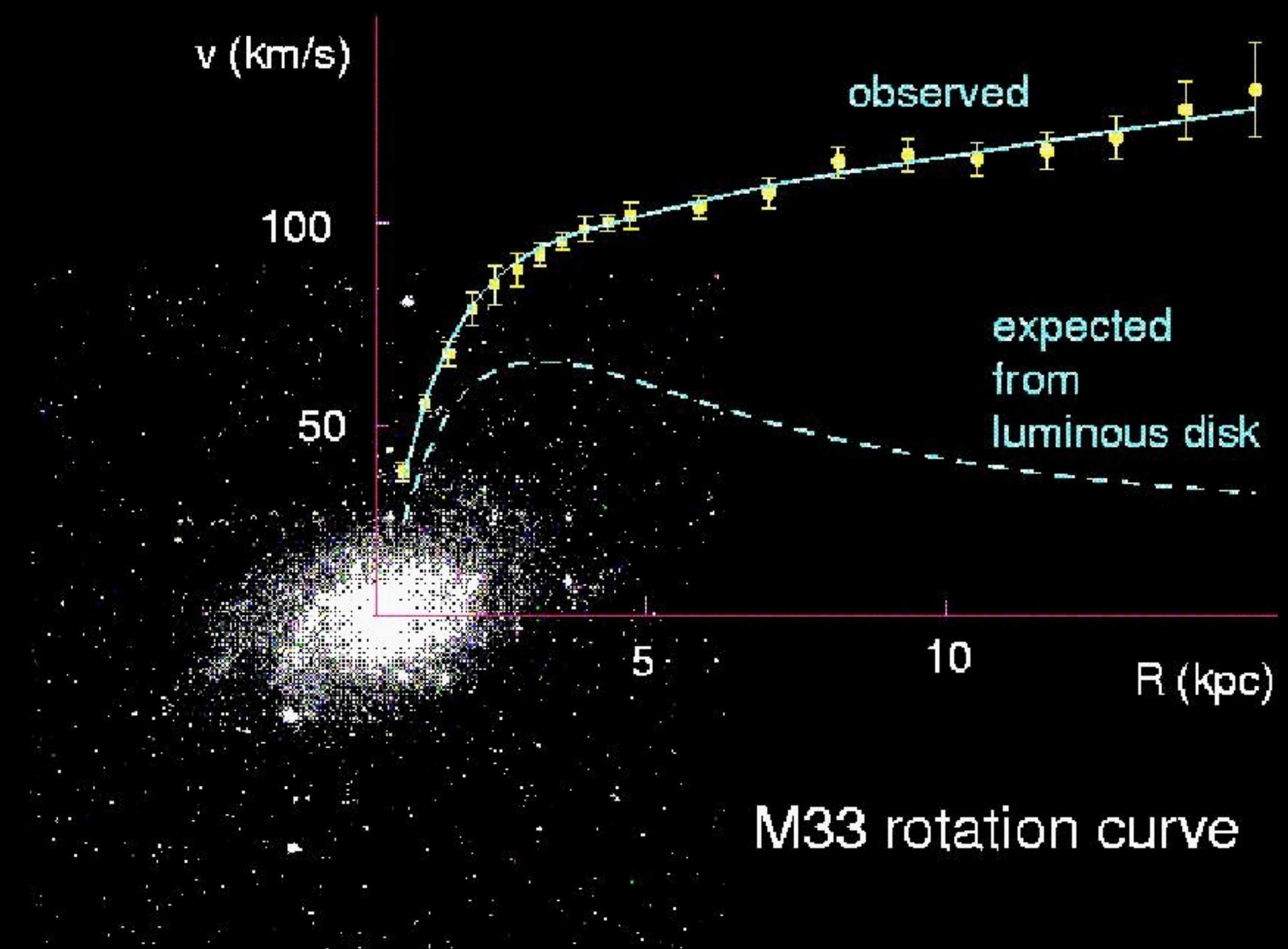
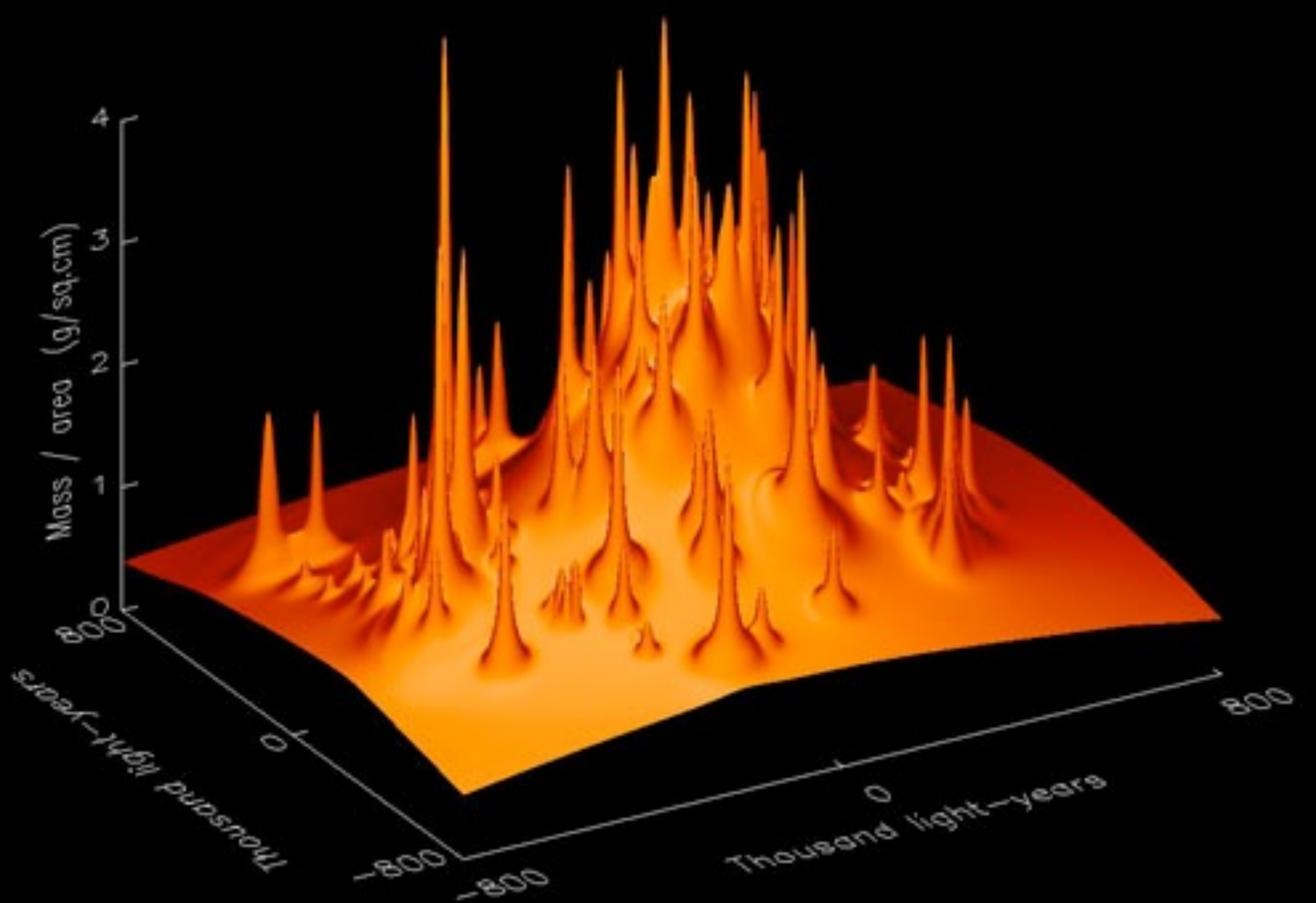
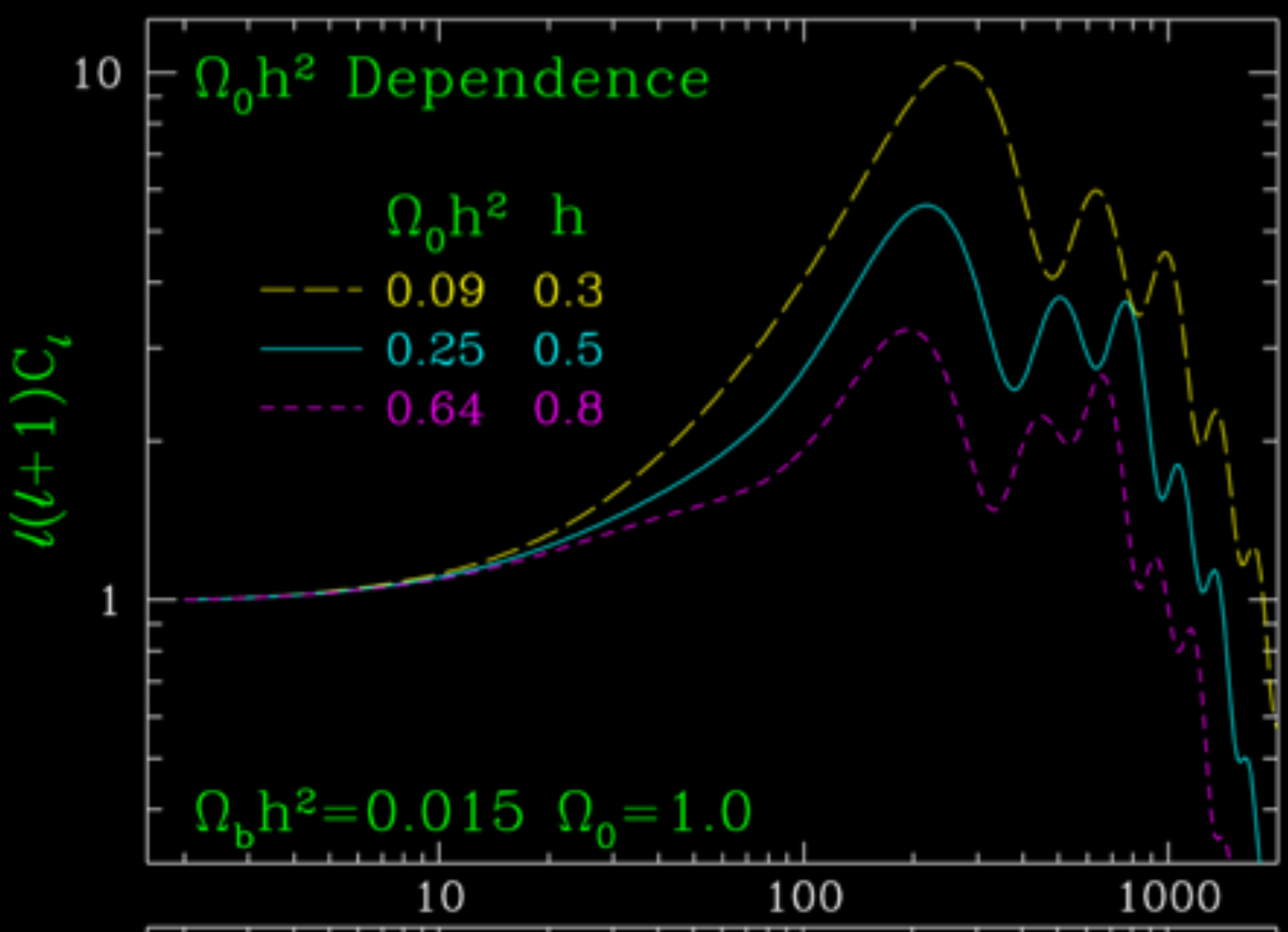
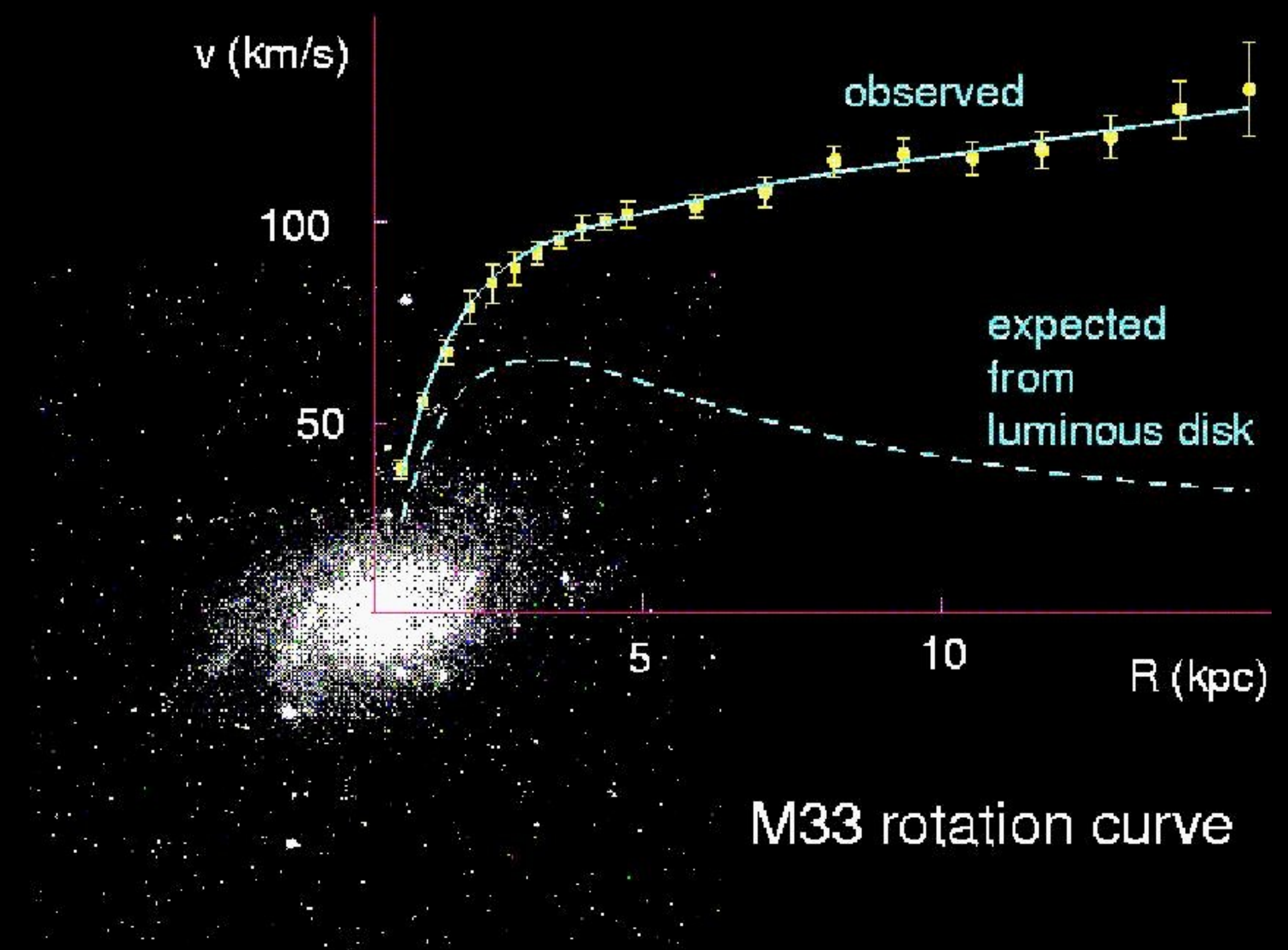



v (km/s)
observed
100
50
expected
from
luminous disk
5
10
R (kpc)
M33 rotation curve


Mass / area (g/sq.cm)
0
1
2
3
4
800
0
−800
Thousand light-years
−800
0
800
Thousand light-years


$\Omega_0 h^2$ Dependence
$\Omega_0 h^2$ h
0.09 0.3
0.25 0.5
0.64 0.8
$\Omega_b h^2 = 0.015$ $\Omega_0 = 1.0$
$l(l+1)C_l$
10
1
10
100
1000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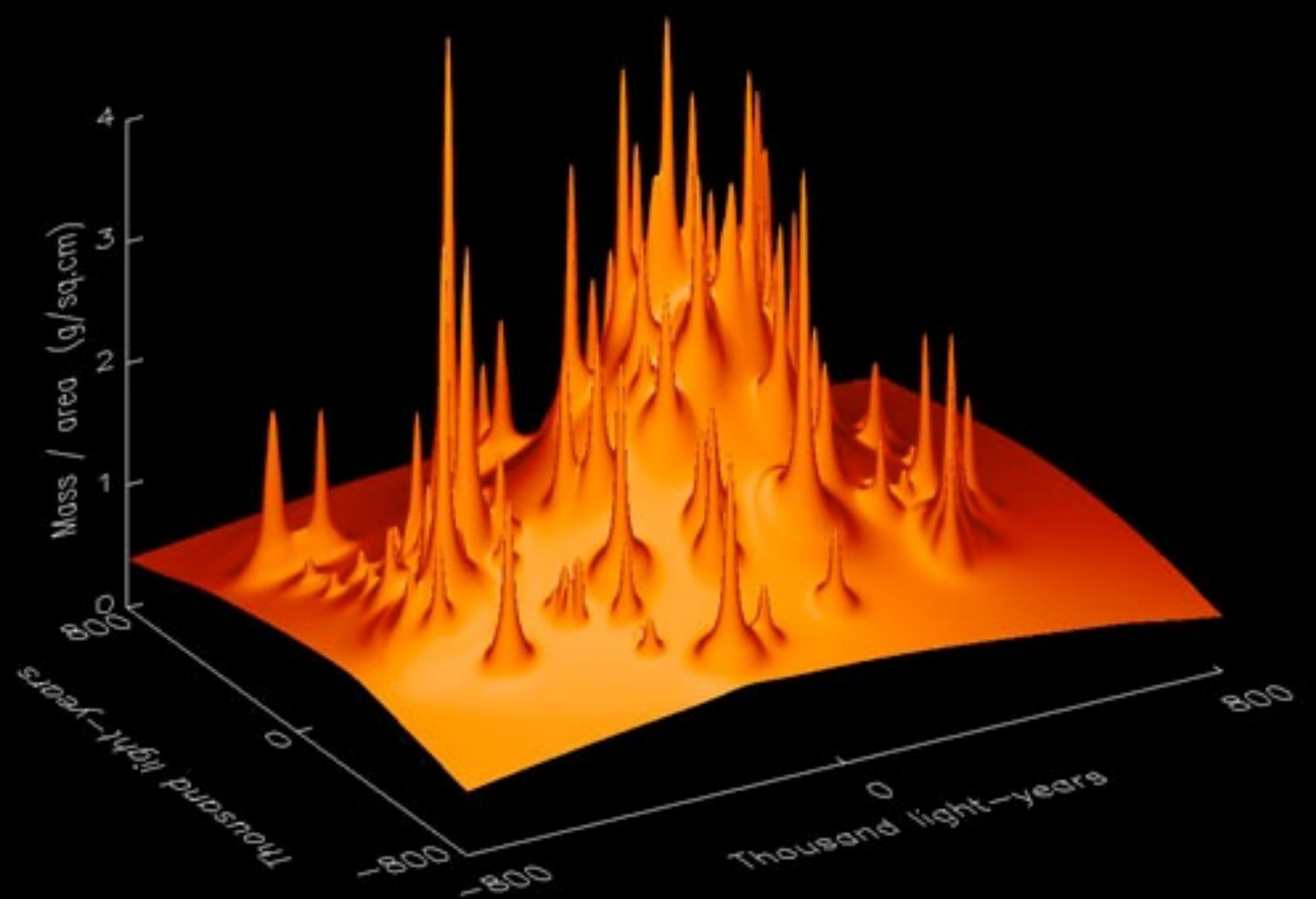
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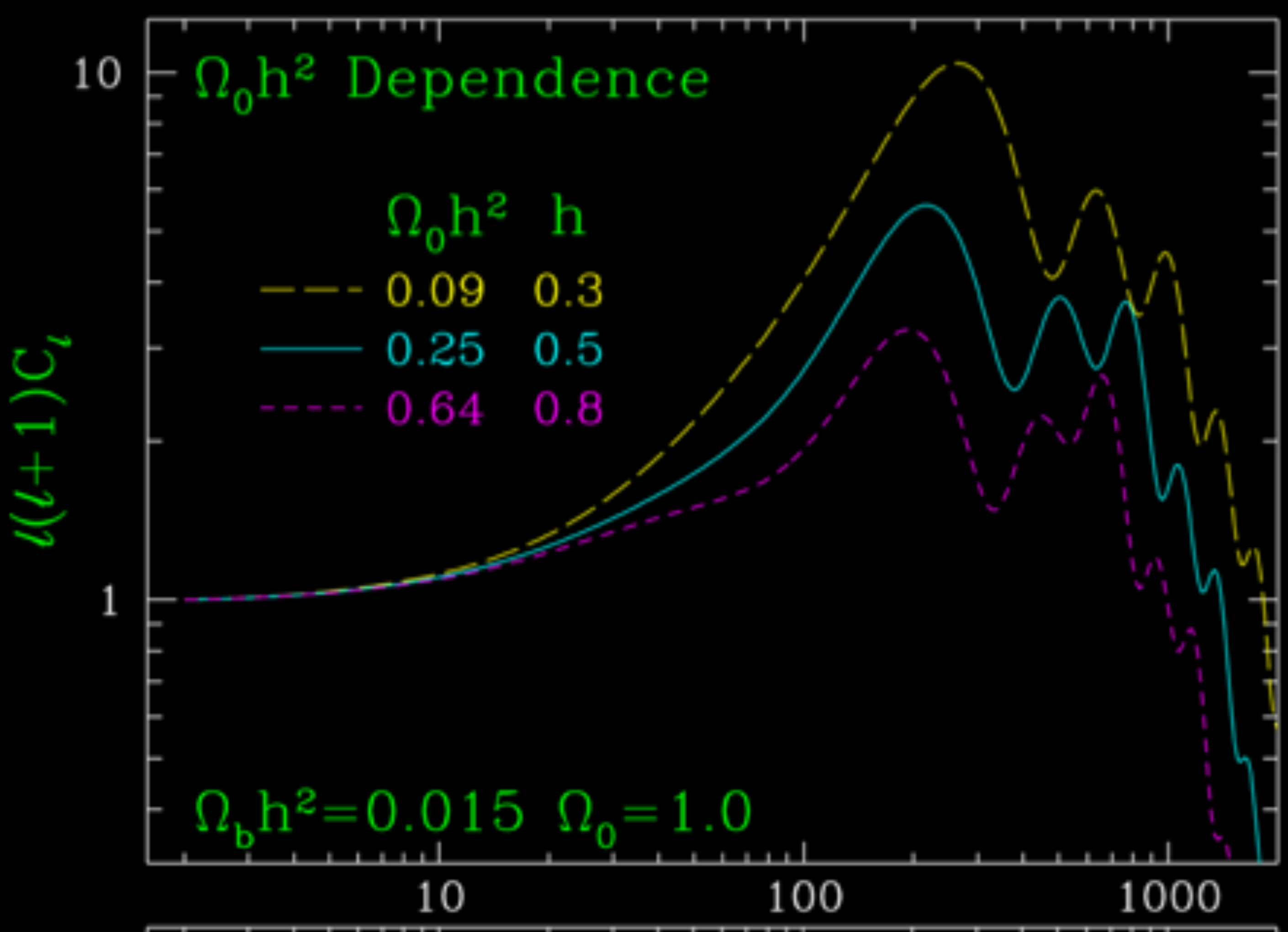
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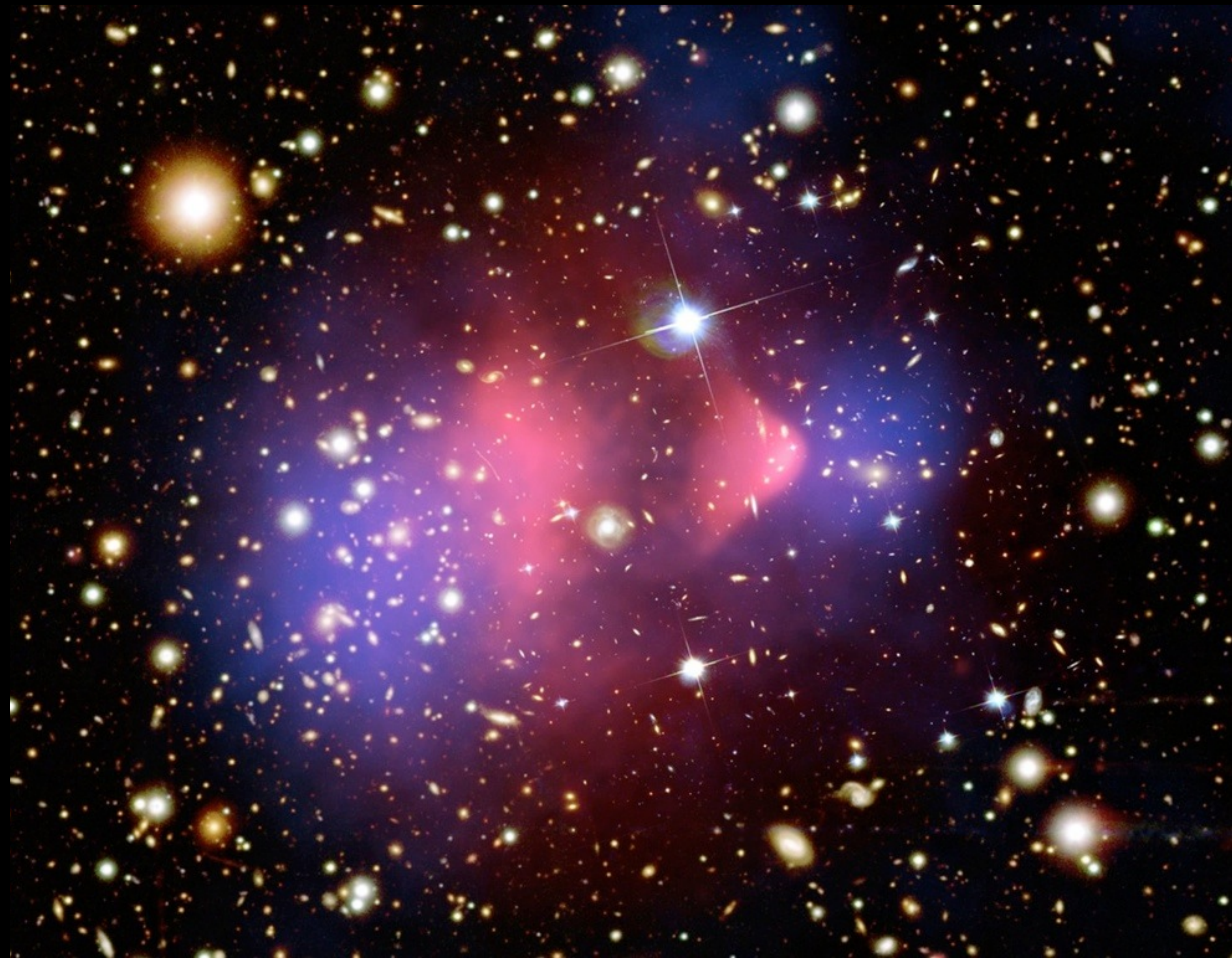
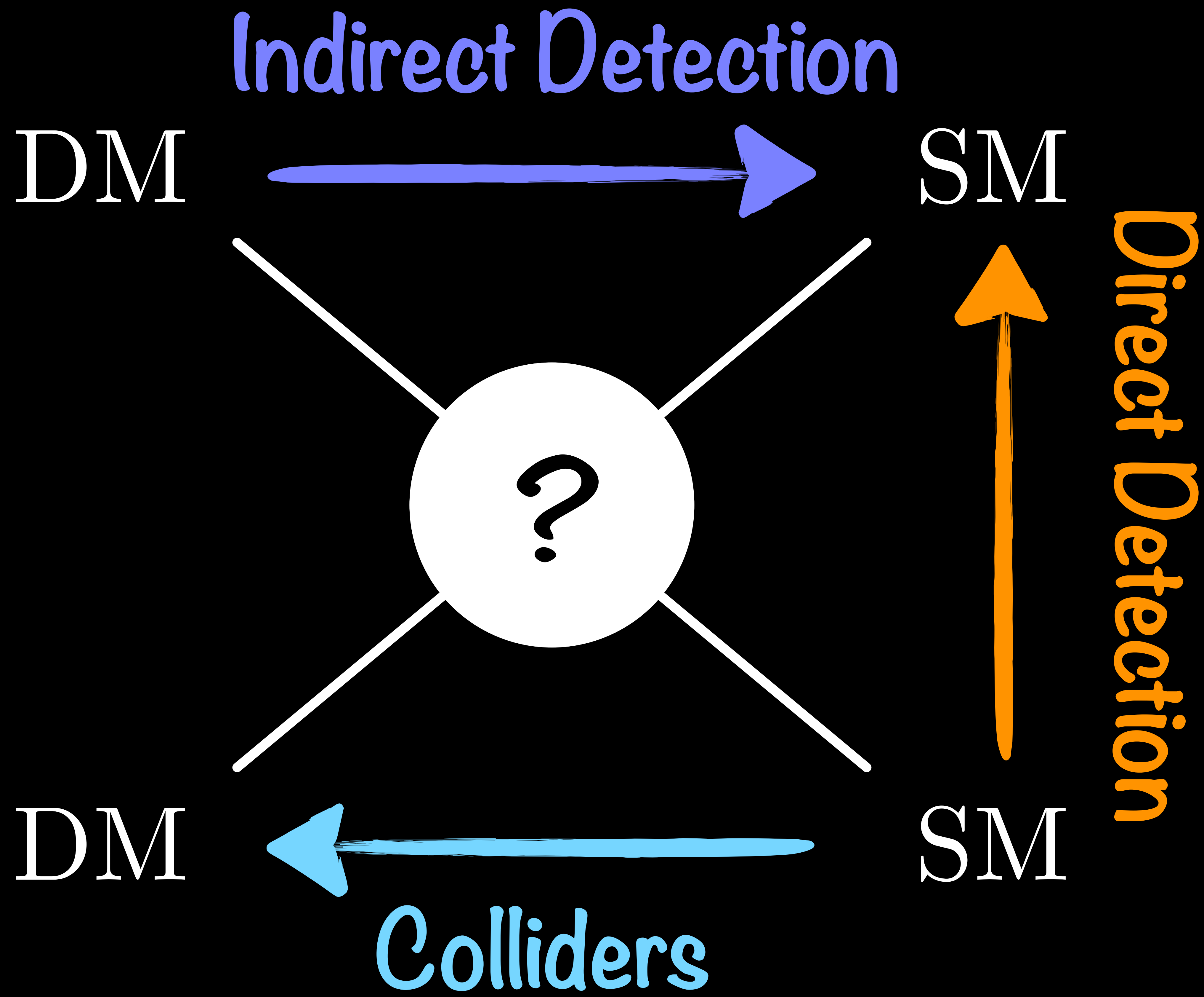
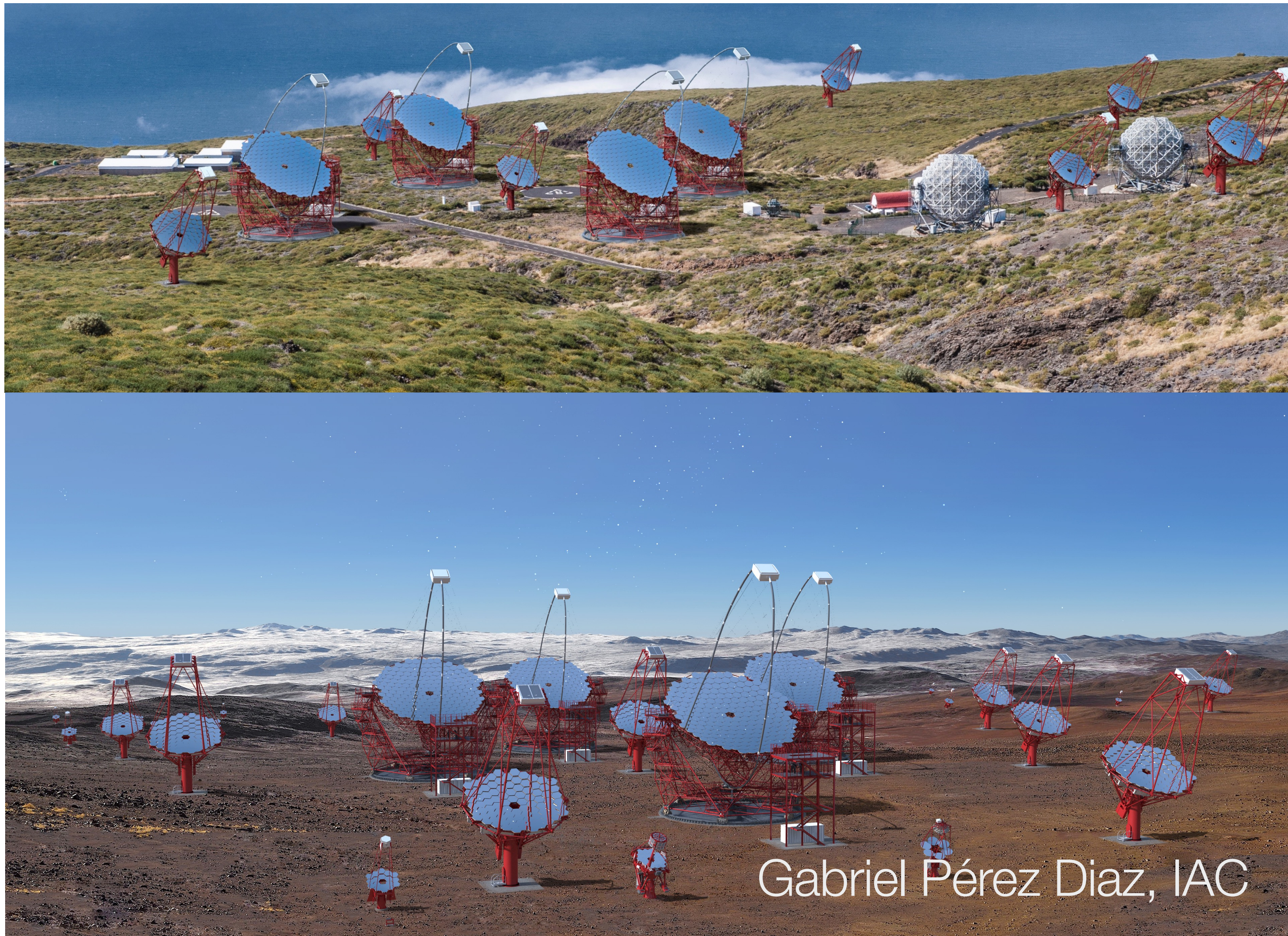



Indirect Detection
DM
SM
Direct Detection
?
DM
SM
Colliders

Cherenkov Telescope Array

Thomas Jacques

- Planned imaging atmospheric cherenkov telescope array
- Will observe gamma-rays in energy range o(10 GeV) to ~300 TeV
- Order of magnitude more sensitive than existing observatories
- Two planned sites: Atacama desert & Canary Islands
- CTA Consortium includes 1,350 members from 210 institutes in 32 countries
- Not me! - Done in collaboration with CTA members, not an official CTA paper



Indirect Detection

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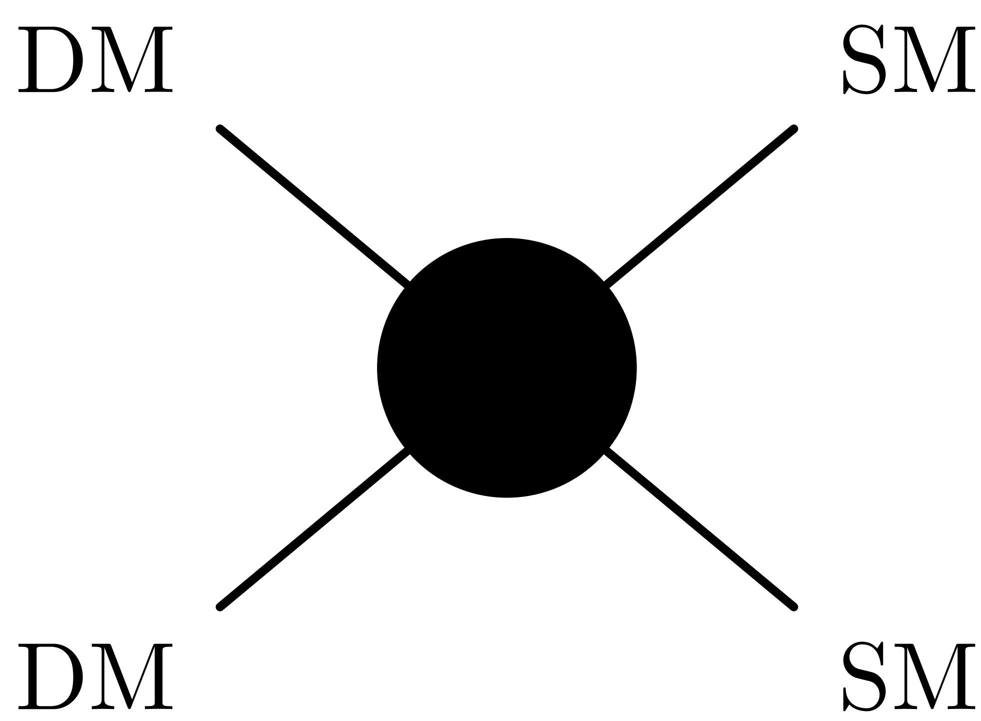
$$\frac{d\phi}{dE} = \frac{1}{8\pi}\frac{\langle\sigma v\rangle}{2m_\chi^2}\sum_f B_f \frac{dN_f}{dE} \int_{\Delta\Omega}\int_{\text{l.o.s.}} \rho_\chi^2(r)\, dl\, d\Omega$$



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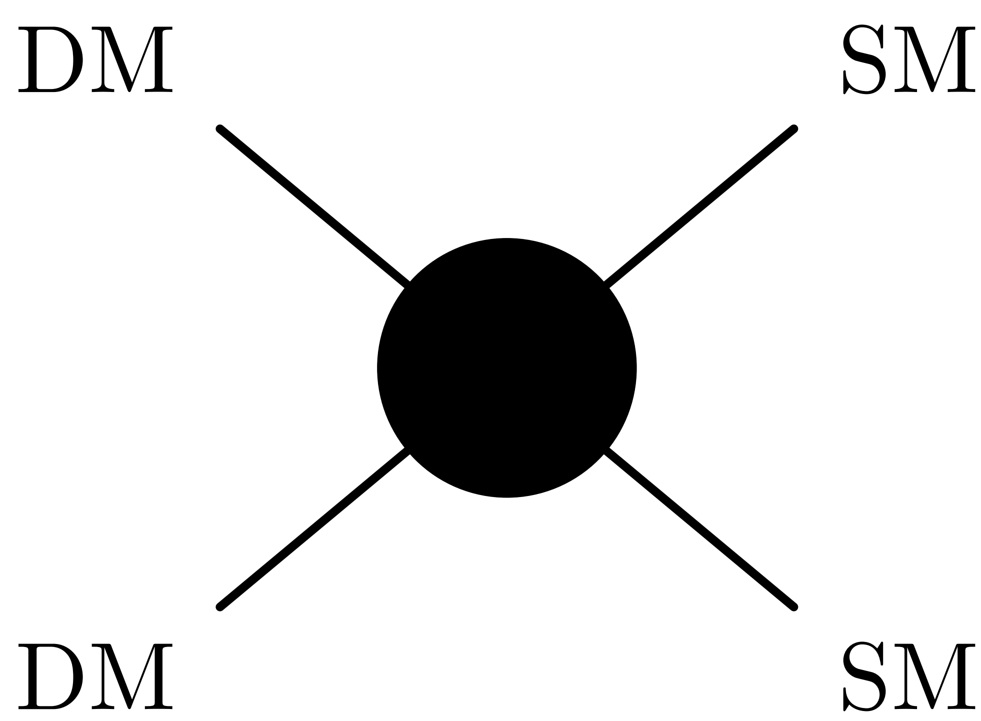

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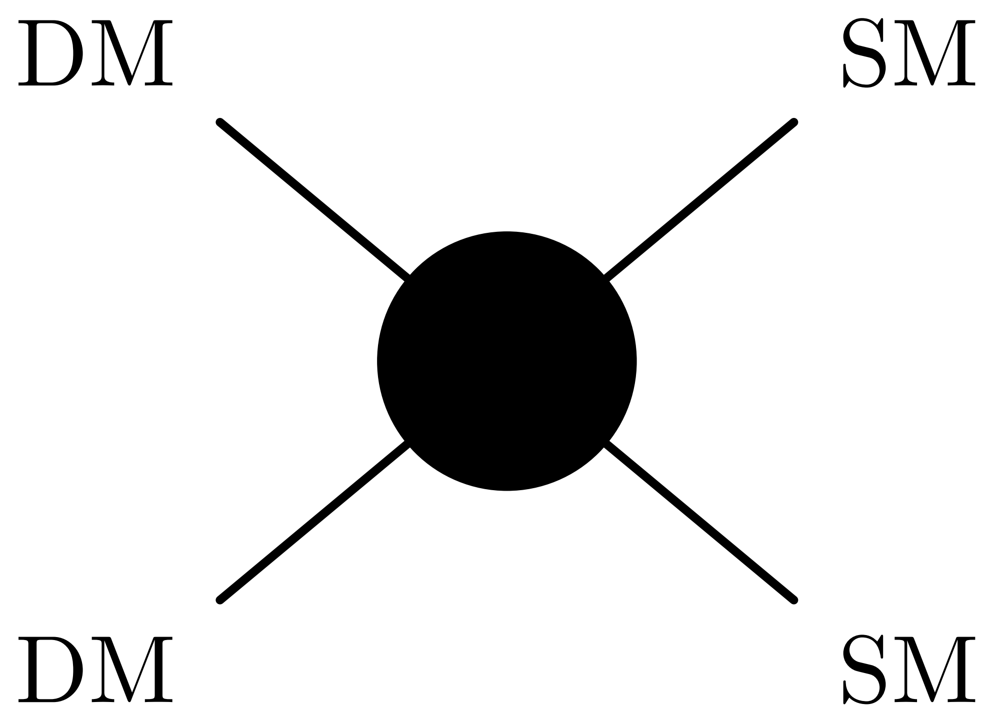

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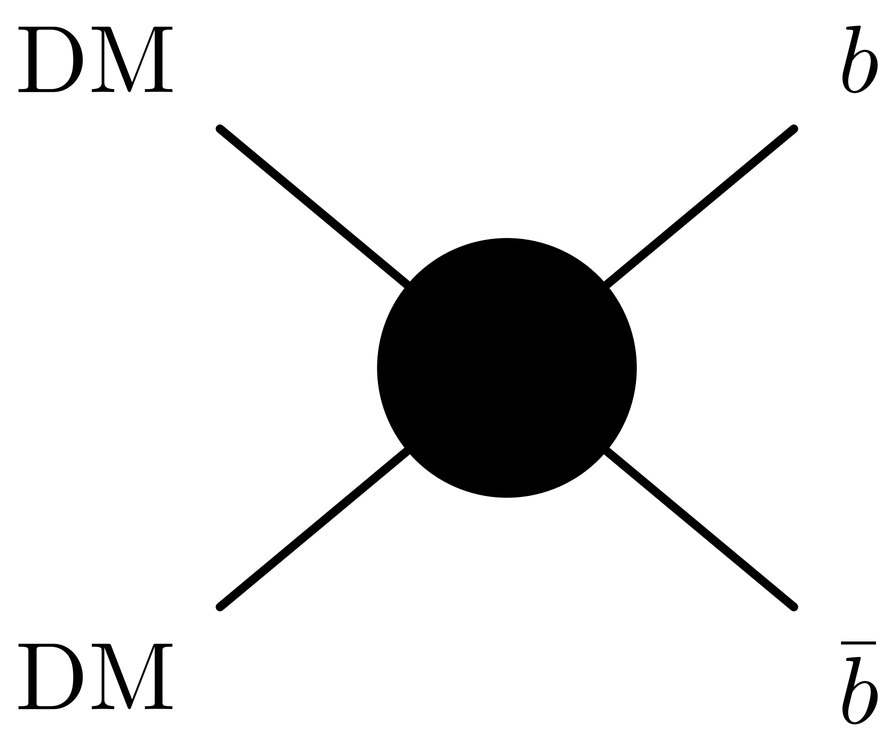

Indirect Detection

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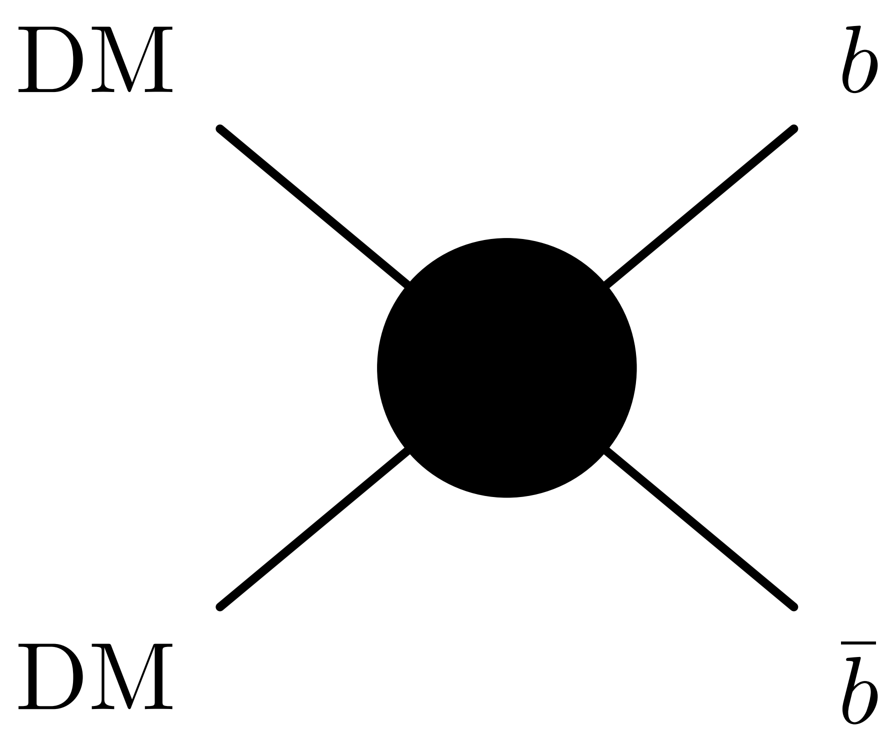

- Usually assume 100% branching to *b*-quarks

Indirect Detection

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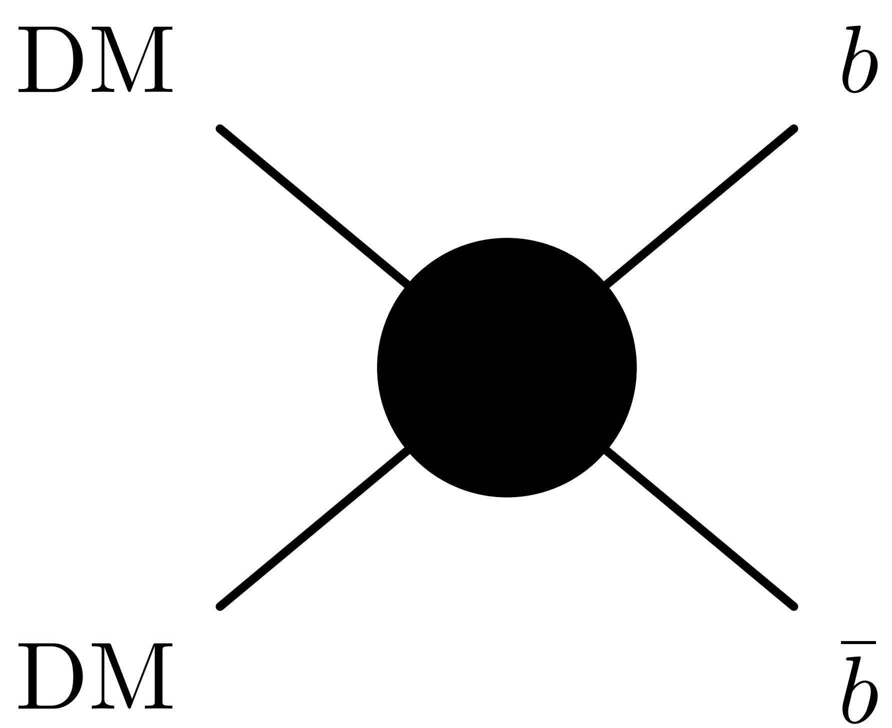

- Usually assume 100% branching to *b*-quarks

- Need an underlying model to get the branching ratios

Use Simplified Models and EFTs!

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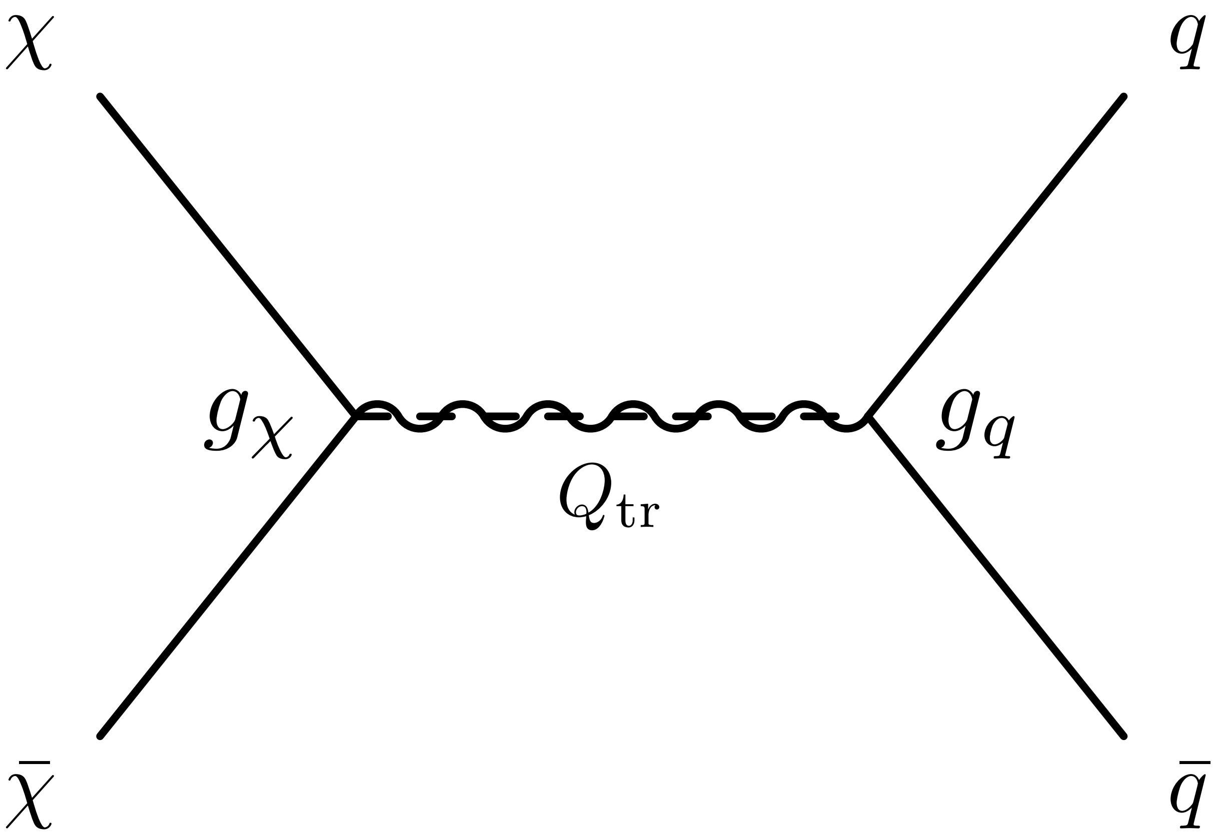

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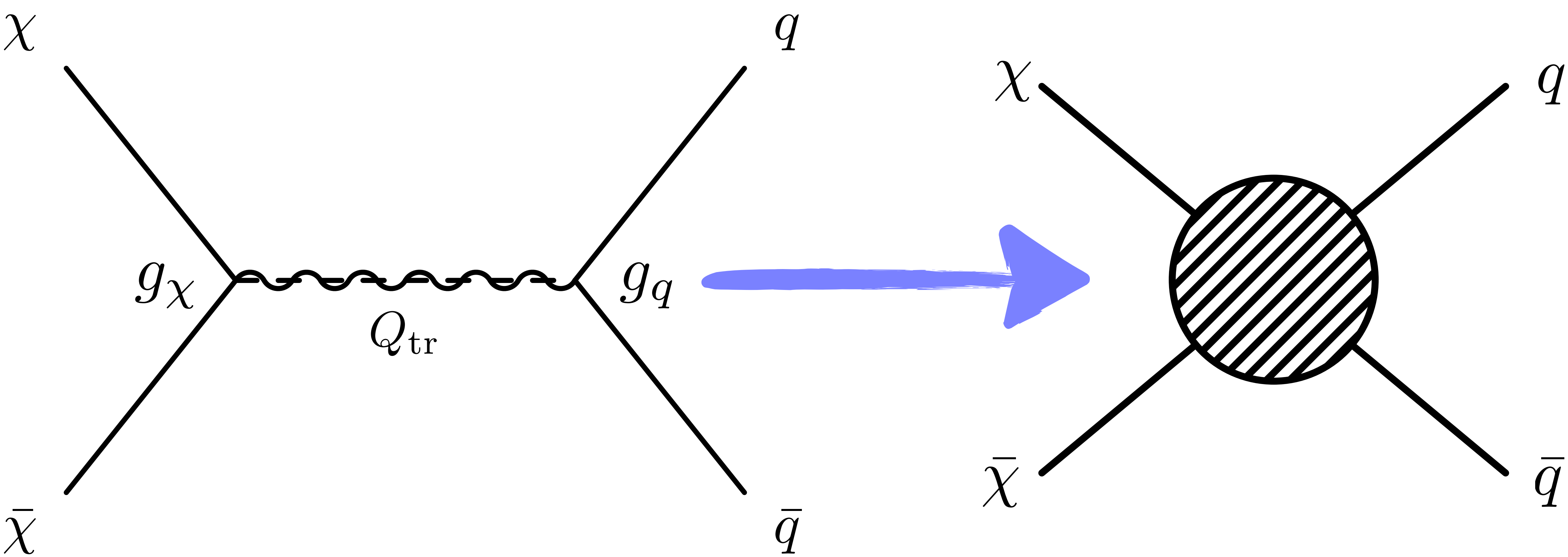

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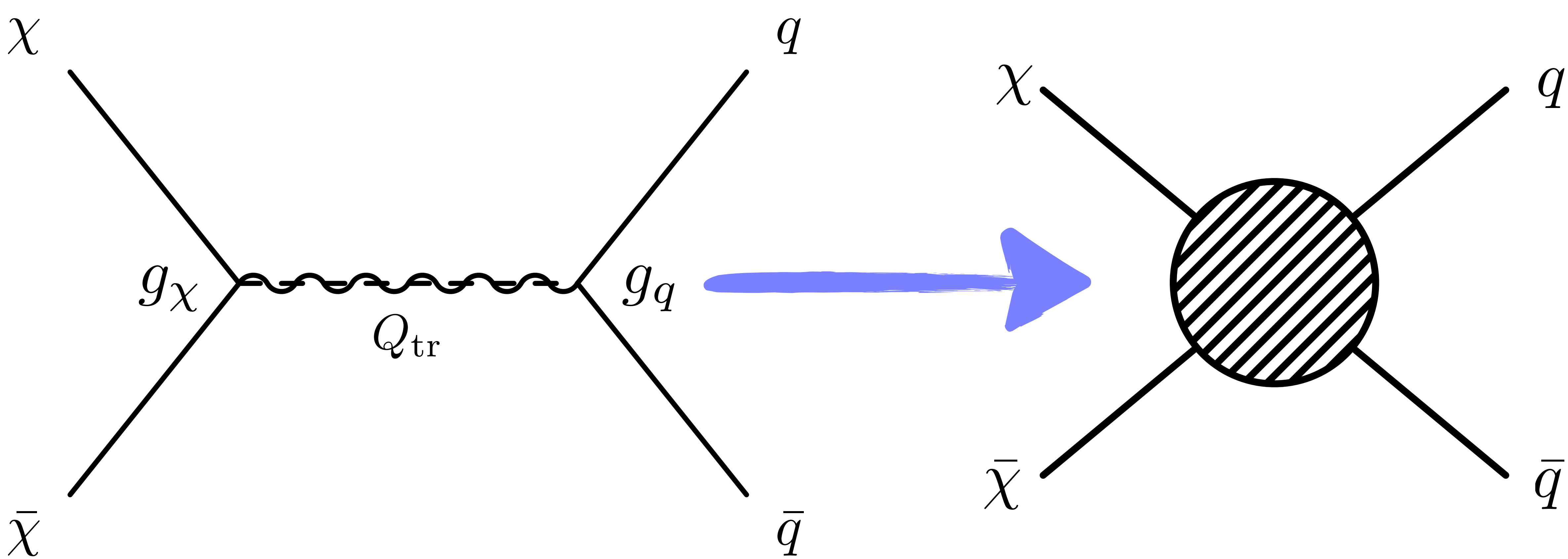

$$\frac{g_q g_\chi}{M^2 - Q_{\rm tr}^2} \simeq \frac{g_q g_\chi}{M^2} \equiv \frac{1}{{M_\star}^2}$$

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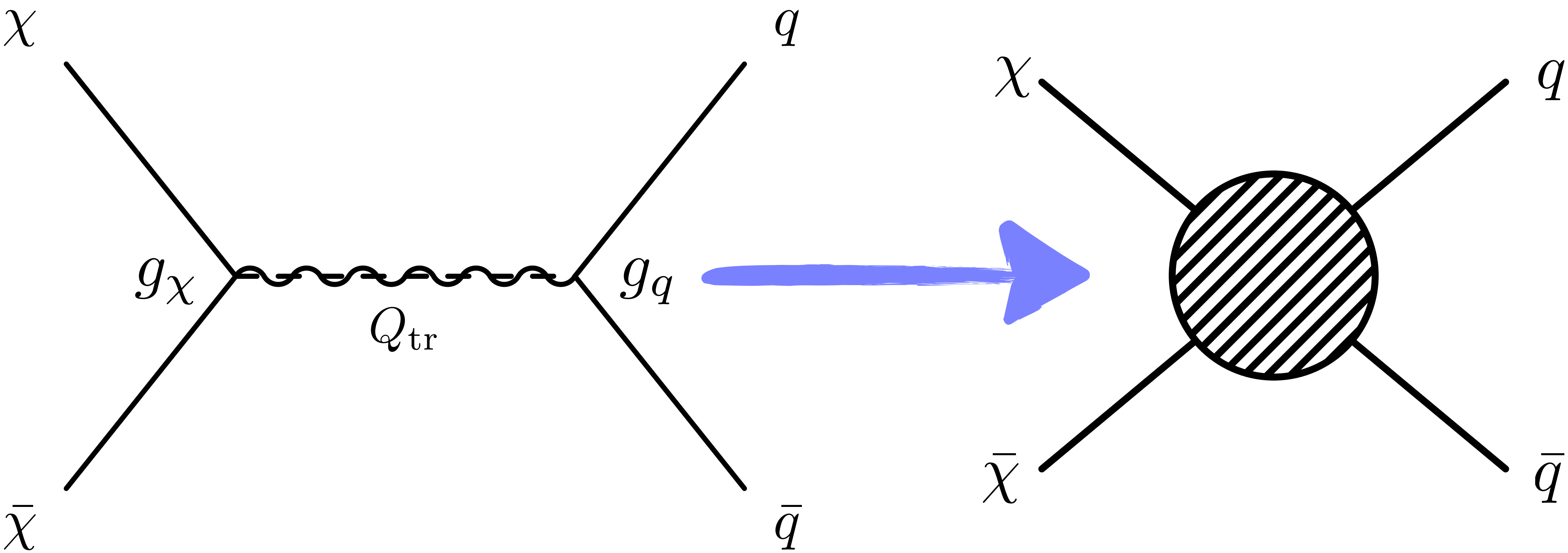

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- Effective Field Theories have fewer parameters, just m_{DM} and $M_\star$

Use Simplified Models and EFTs!

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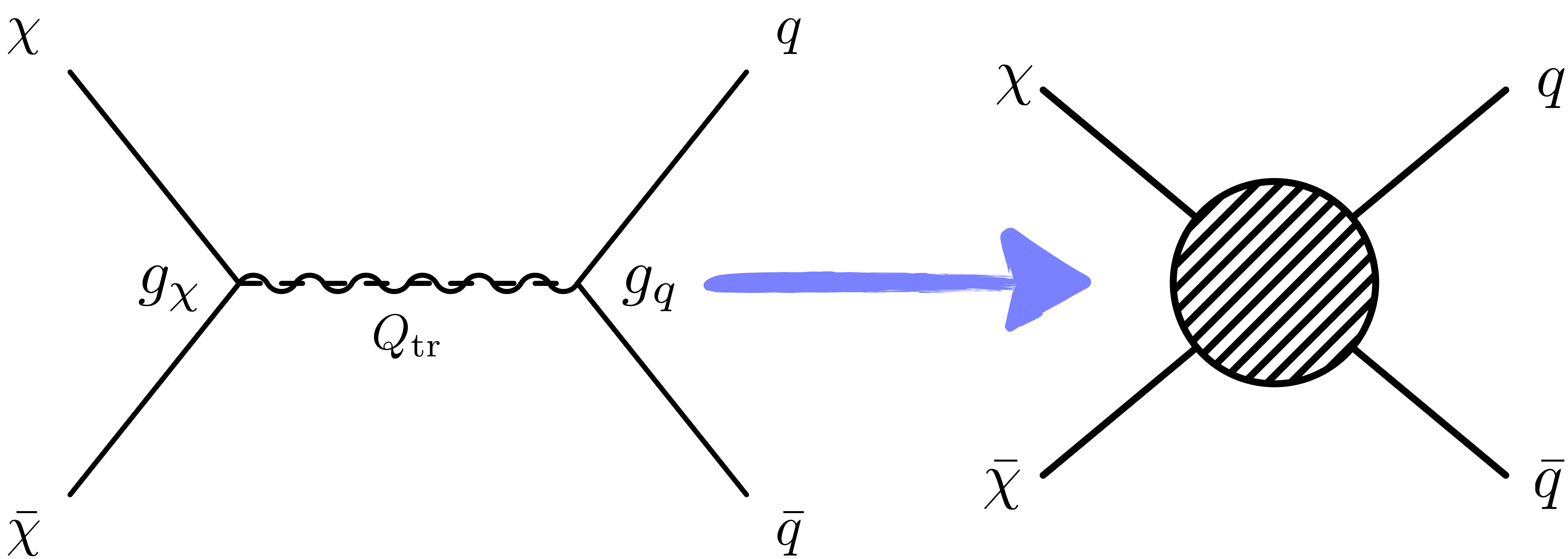

$$\frac{g_q g_\chi}{M^2 - Q_{\rm tr}^2} \simeq \frac{g_q g_\chi}{M^2} \equiv \frac{1}{{M_\star}^2}$$

- Effective Field Theories have fewer parameters, just $m_{\rm DM}$ and $M_\star$
- Simplified models have wider range of validity

Choice of Models

Thomas Jacques

Operator / Mediator	Operator	Annihilation Suppression	Scattering Suppression
Scalar	$\frac{m_q}{M_\star^3}(\bar{\chi}\chi)(\bar{q}q)$	v^2	1
Pseudo-scalar	$\frac{m_q}{M_\star^3}(\bar{\chi}\gamma^5\chi)(\bar{q}\gamma^5 q)$	1	$(\vec{s}_\chi \cdot \vec{q})(\vec{s}_N \cdot \vec{q})$
Vector	$\frac{1}{M_\star^2}(\bar{\chi}\gamma^\mu\chi)(\bar{q}\gamma_\mu q)$	1	1
Axial-Vector	$\frac{1}{M_\star^2}(\bar{\chi}\gamma^\mu\gamma^5\chi)(\bar{q}\gamma_\mu\gamma^5 q)$	$m_q^2,\ v^2$	$\vec{s}_\chi \cdot \vec{s}_N$

Astrophysics

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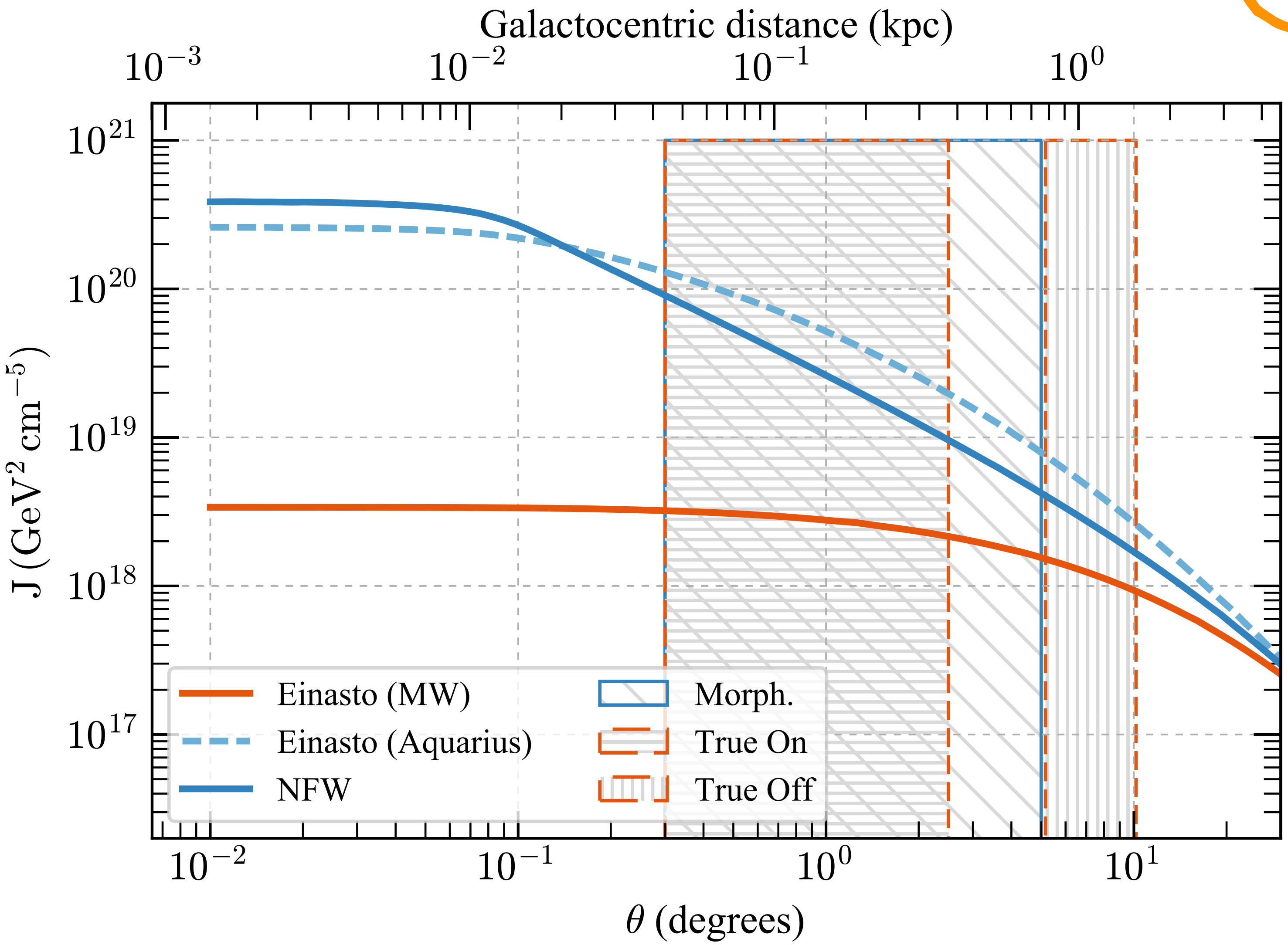
$$\frac{d\phi}{dE} = \frac{1}{8\pi}\frac{\langle\sigma v\rangle}{2m_\chi^2}\sum_f B_f \frac{dN_f}{dE} \int_{\Delta\Omega}\int_{\text{l.o.s.}} \rho_\chi^2(r)\, dl\, d\Omega$$



$$\rho_{\text{NFW}}(r) = \frac{\rho_0}{\frac{r}{r_s}\left[1+\frac{r}{r_s}\right]^2}$$

$$\rho_{\text{Ein}}(r) = \rho_0 \exp\left(-\frac{2}{\alpha}\left[\left(\frac{r}{r_s}\right)^\alpha - 1\right]\right)$$

$$\rho(r_{\text{sun}}) = 0.42\,\text{GeV}/\text{cm}^3$$

$$r_s = 20\,\text{kpc} \qquad \alpha = 0.36$$

- Cuspyness of inner core is uncertain:
  Use two density profiles, Einasto and NFW

- Large uncertainties in fit parameters, use recent best fit for MW

Analysis

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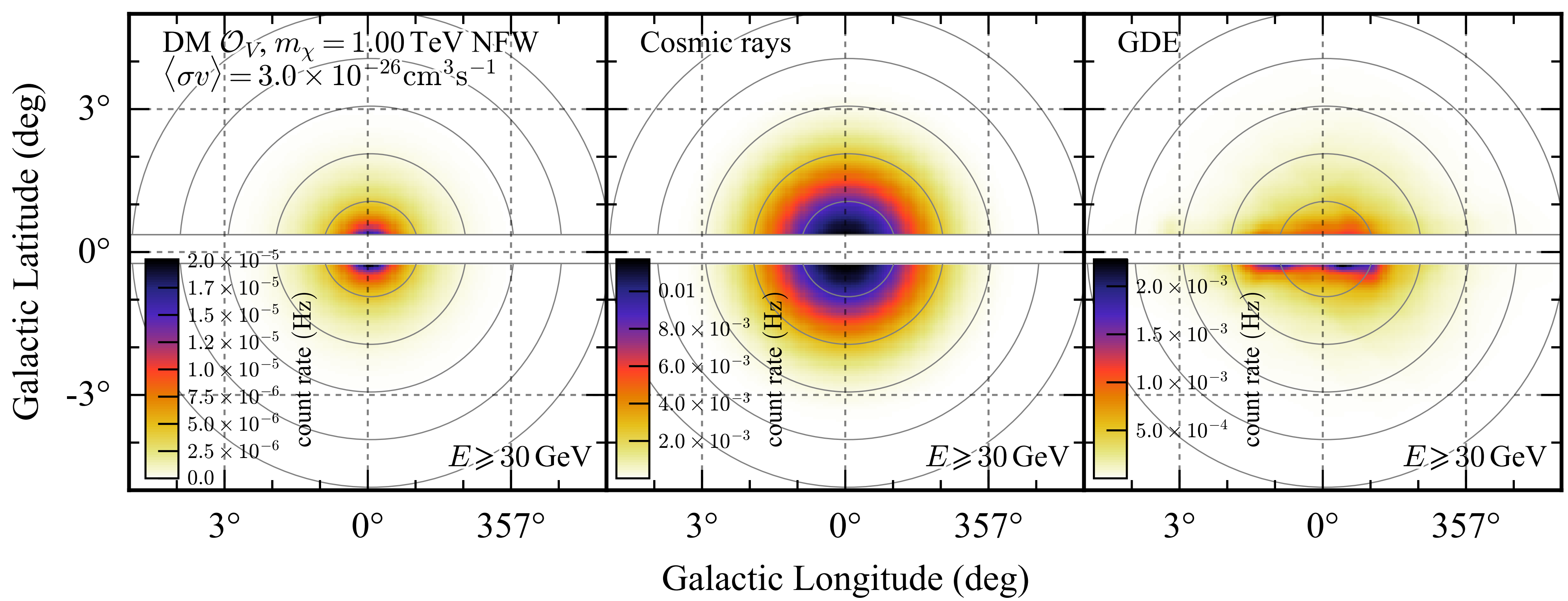
- Galactic Diffuse background taken from Fermi-LAT Template
- Cosmic Ray Background taken from CTA Monte-Carlo simulations



- Limit on ⟨σv⟩ converted to limit on model parameters (masses and couplings) using known analytic relationships

Limits

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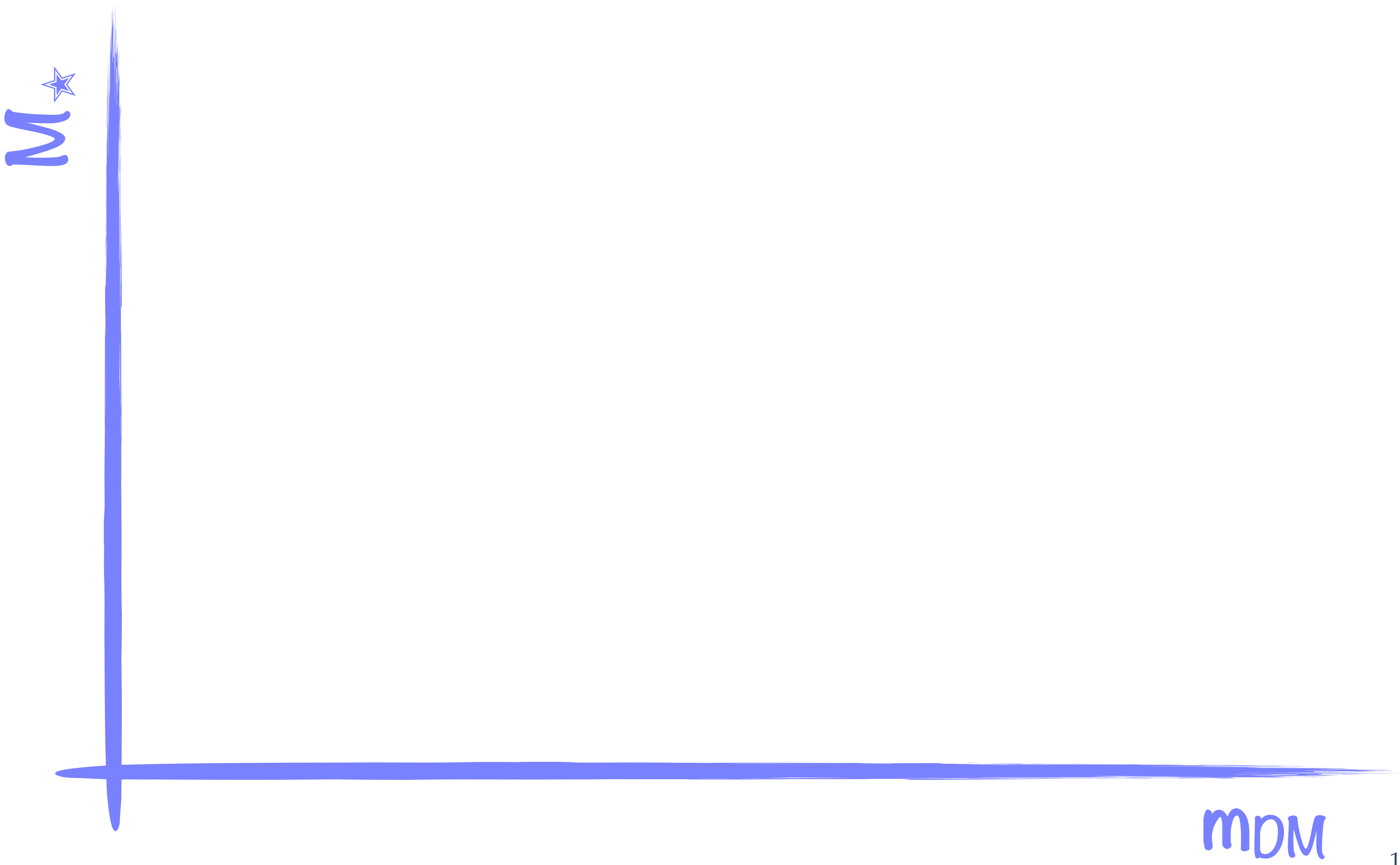

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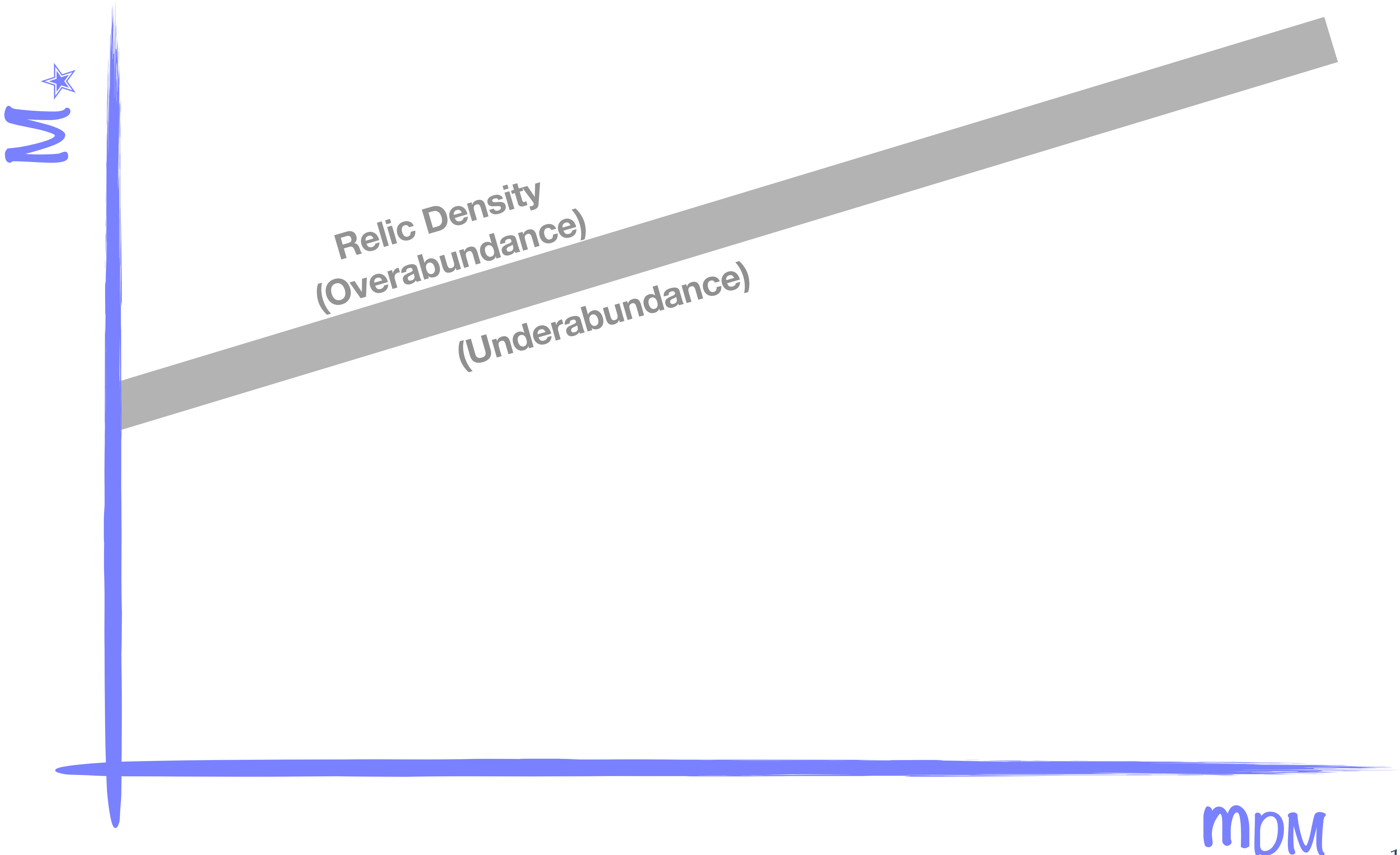

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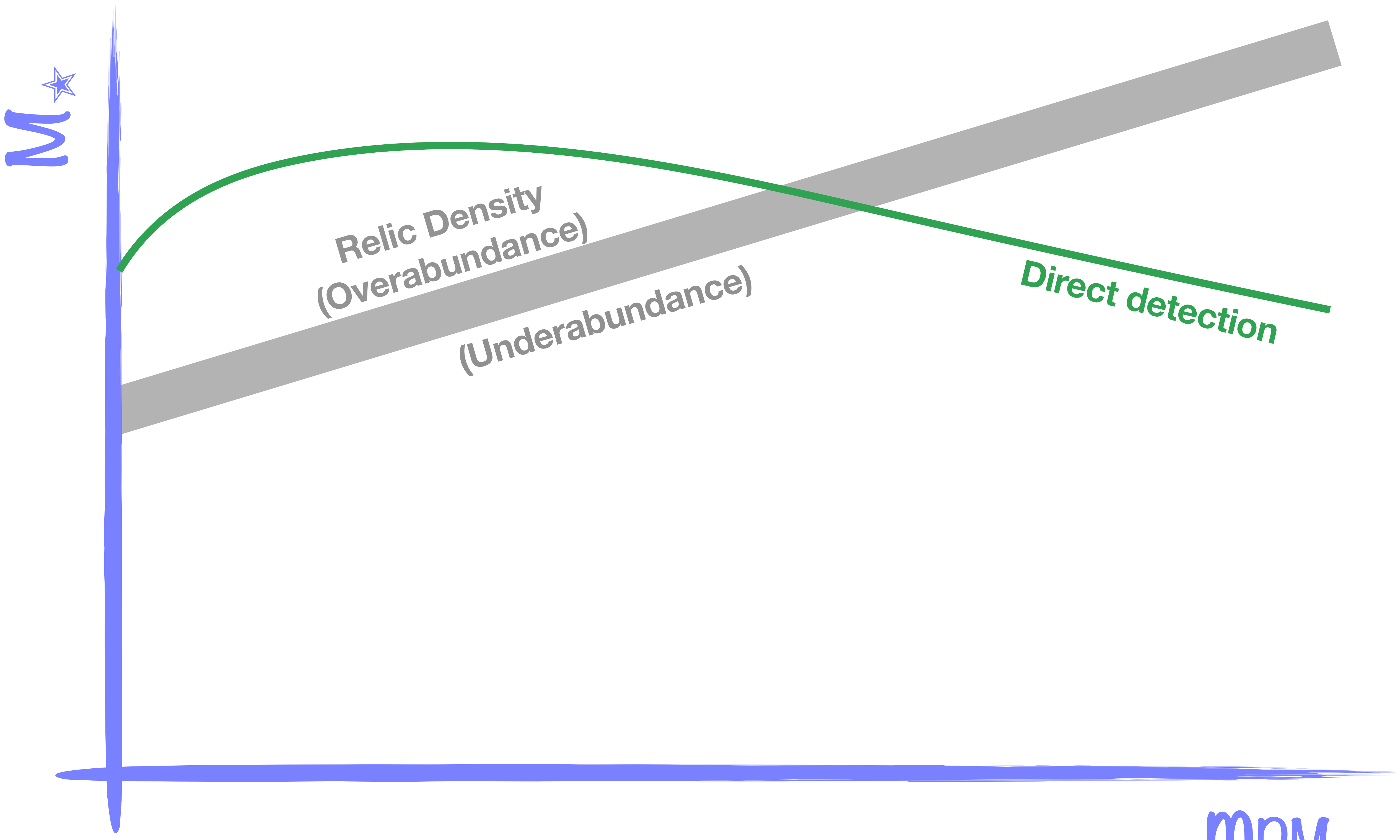

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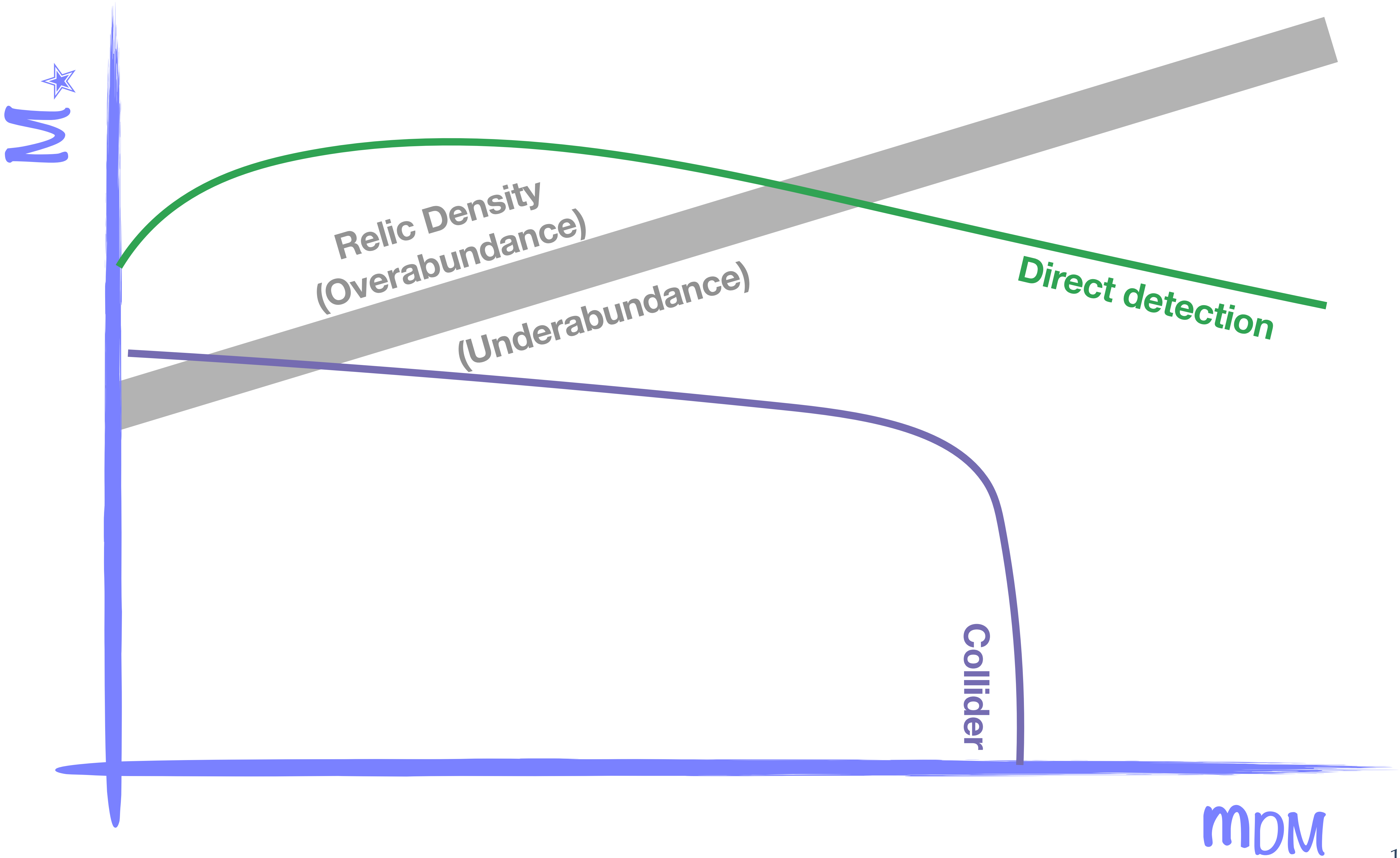

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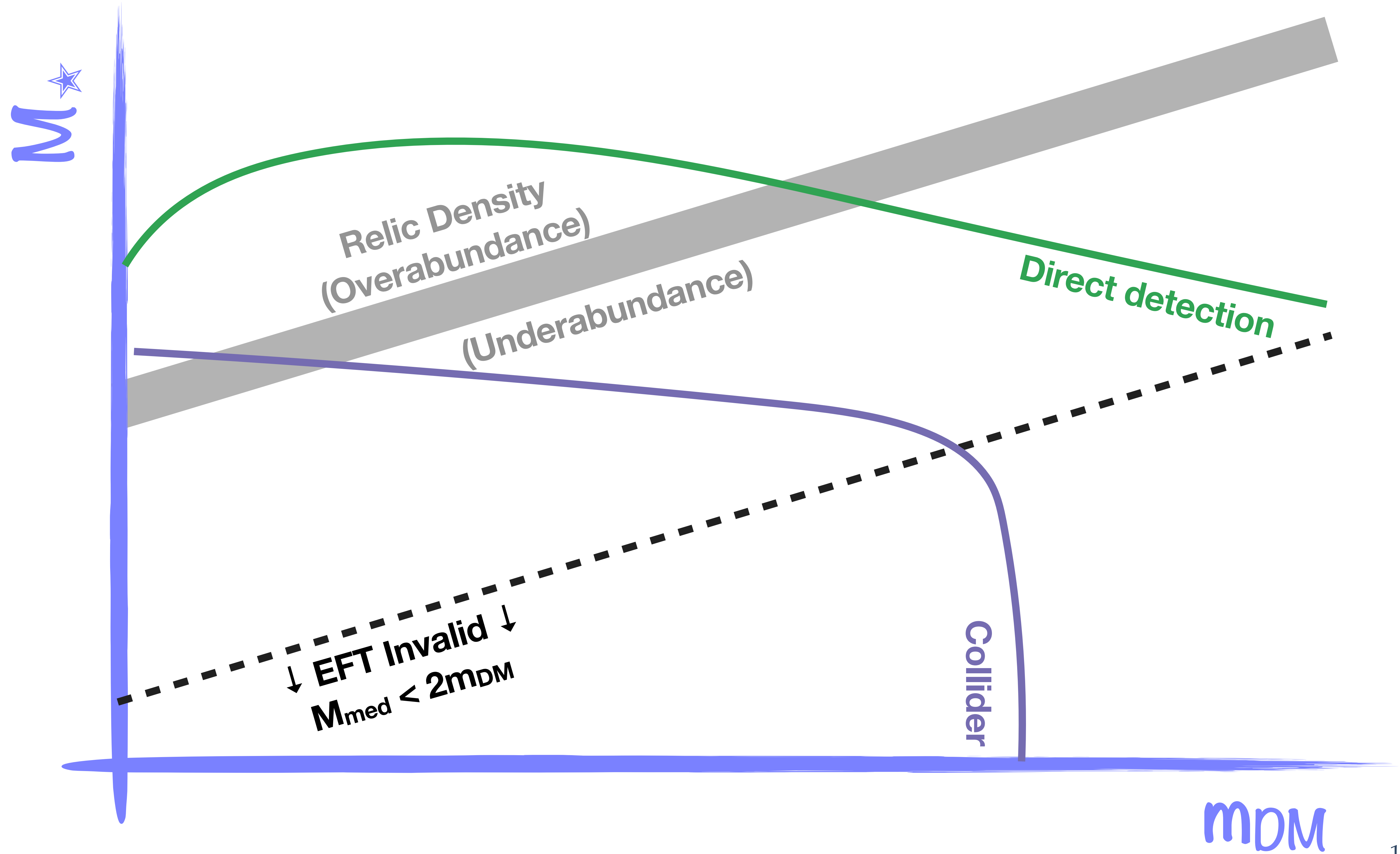

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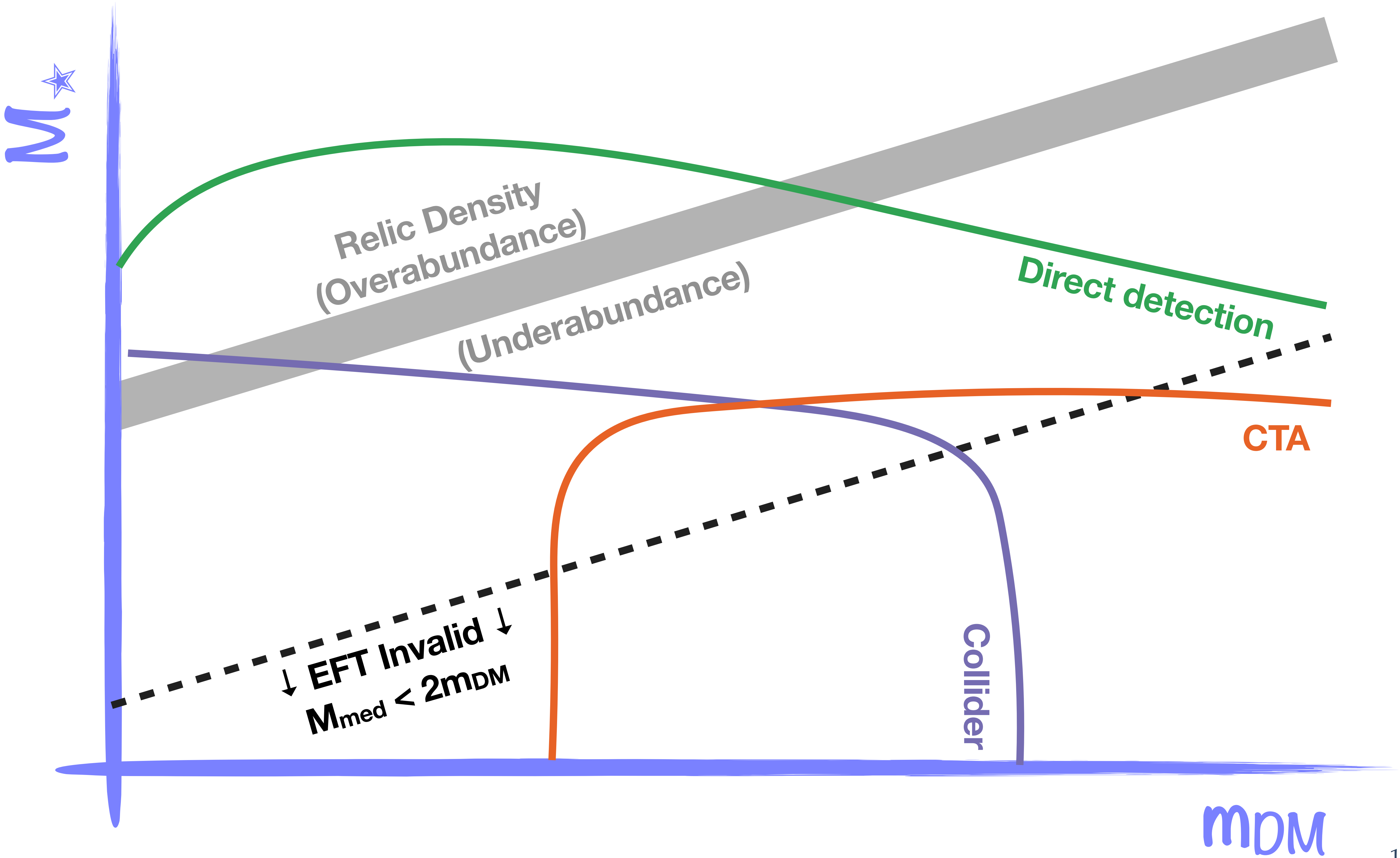

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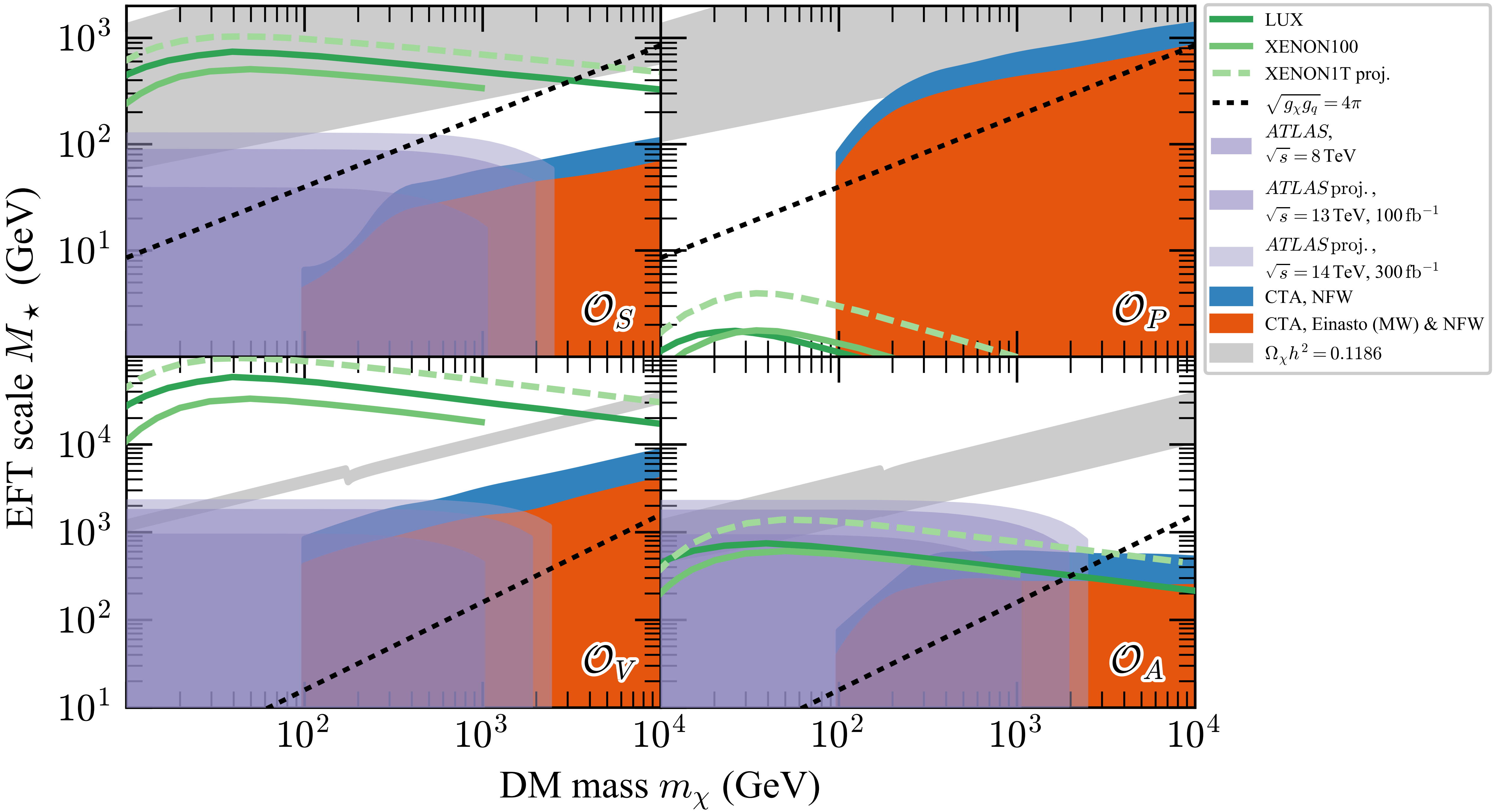

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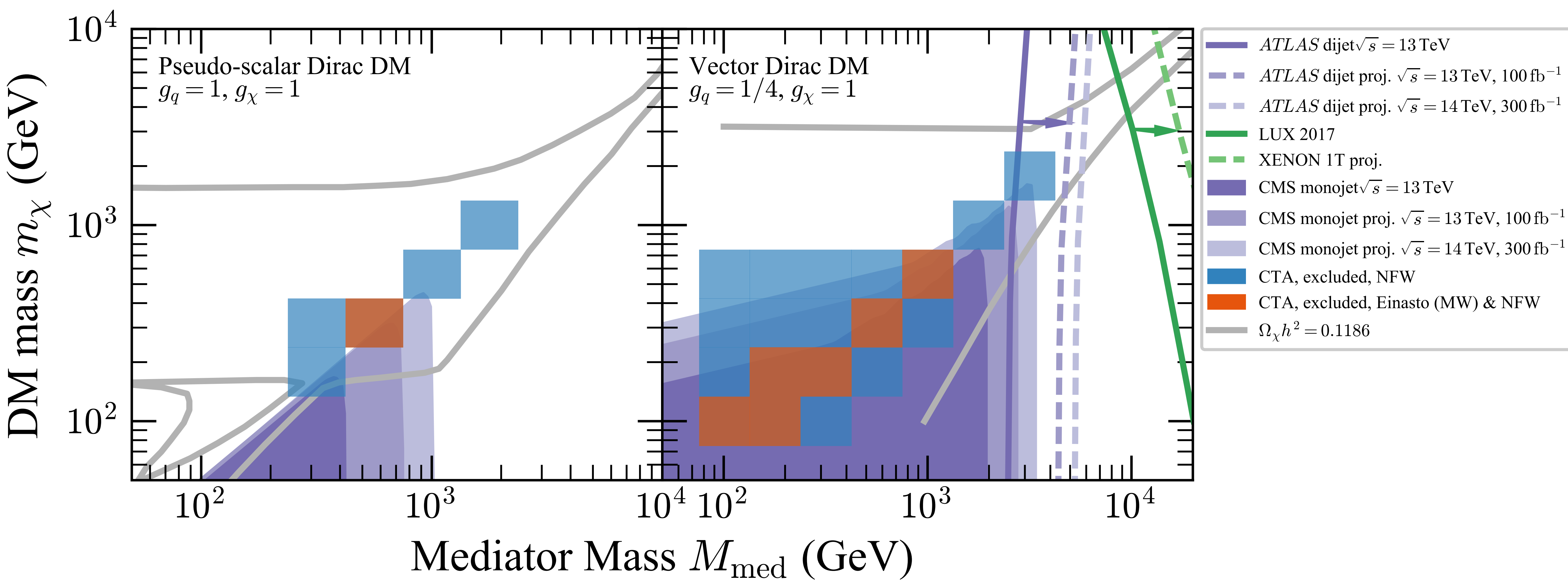
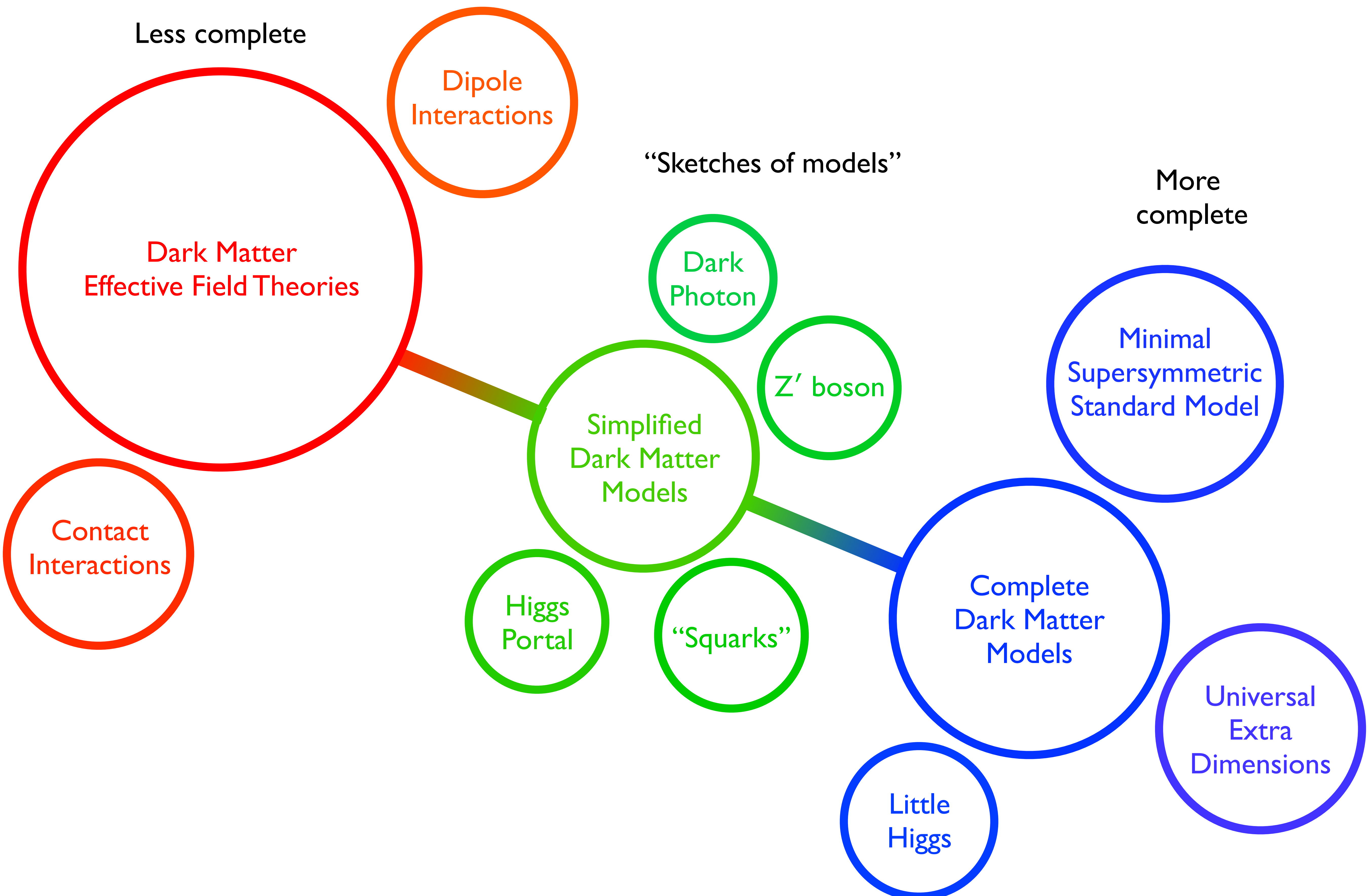


Conclusion

Thomas Jacques

- Though we have strong evidence for the existence of dark matter, its particle nature remains unknown
- A wide array of complementary experimental efforts are underway to probe the nature of dark matter
- Effective Field Theories and simplified models allow for an elegant comparison of constraints from a wide range of experiments
- CTA will place strong constraints on dark matter
- In particular, CTA will provides strong constraints on Vector mediated dark matter, and will lead the field in constraints on Pseudoscalar models

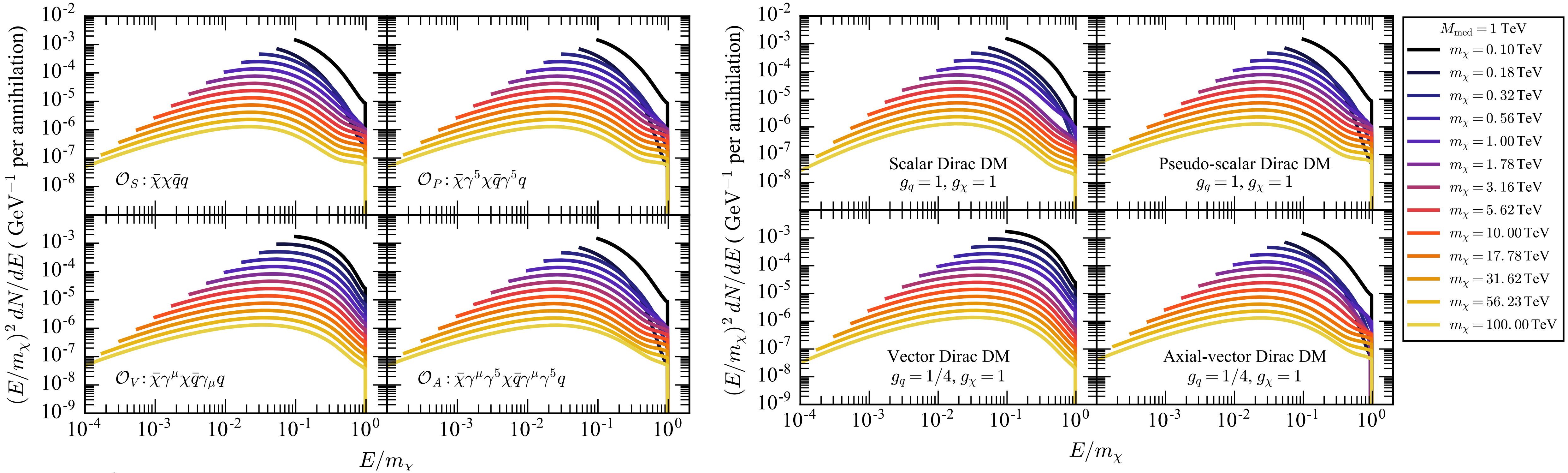
Backup

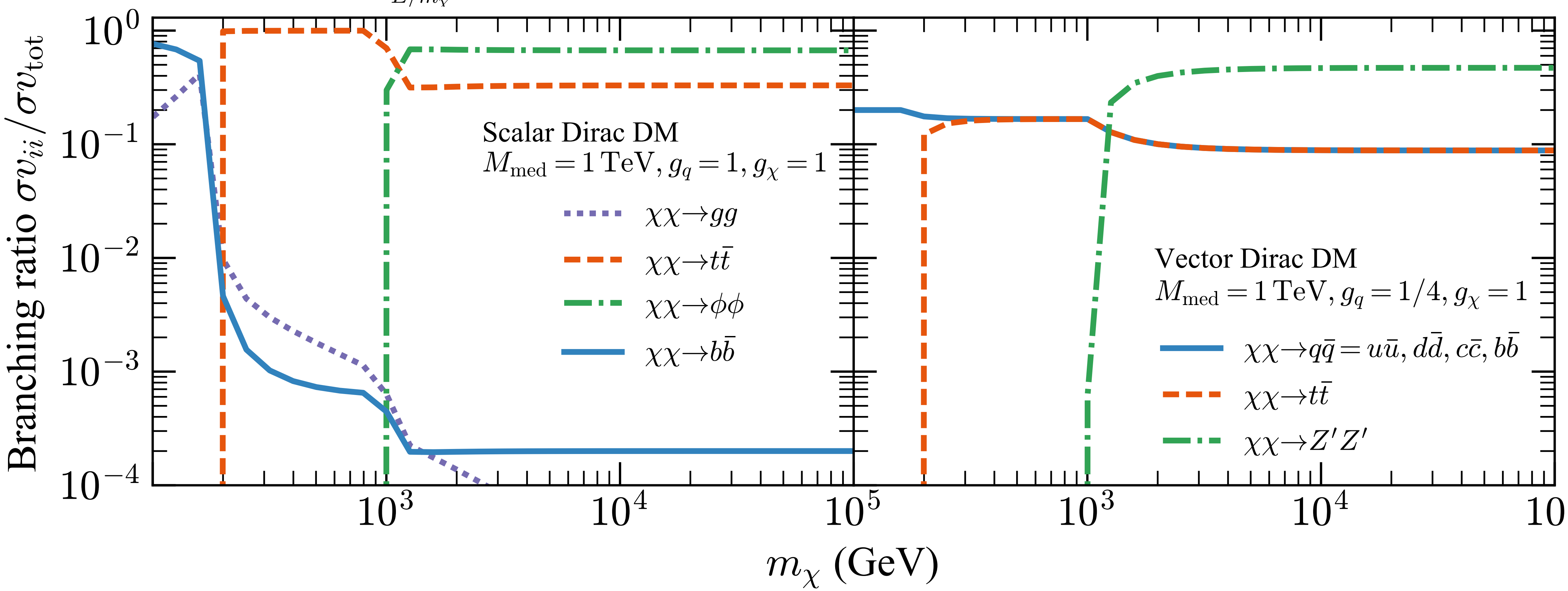


Tim Tait, via Worm et al arXiv:1506.03116

Spectra and branching ratios

Thomas Jacques





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