



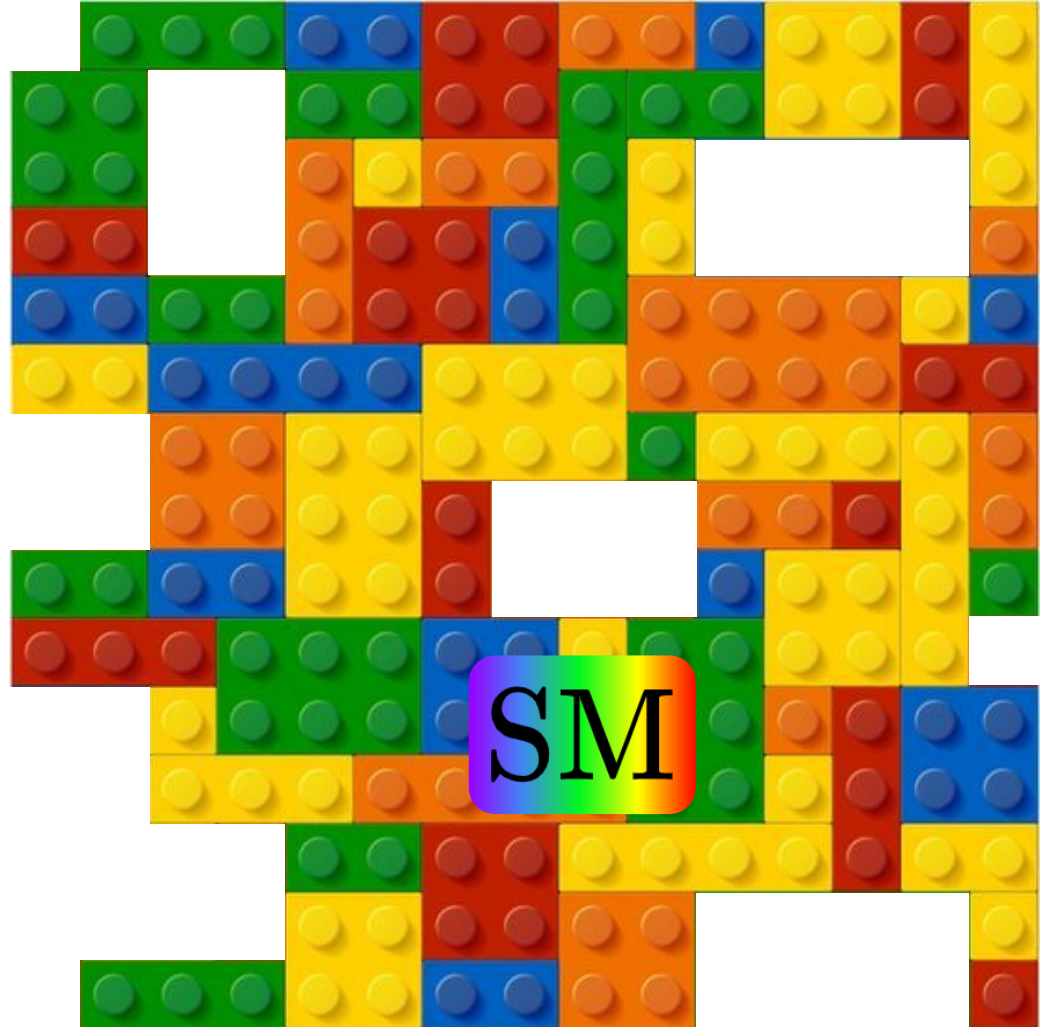
# Candidatos efectivos de Materia Oscura tipo escalar y fermion

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FESC • UNAM

Taller “Más allá del Modelo Estándar y Astropartículas”  
IFUNAM

# El plan

- Evidencias de DM
- Detección indirecta
- Modelo Escalar
- Modelo Fermiónico

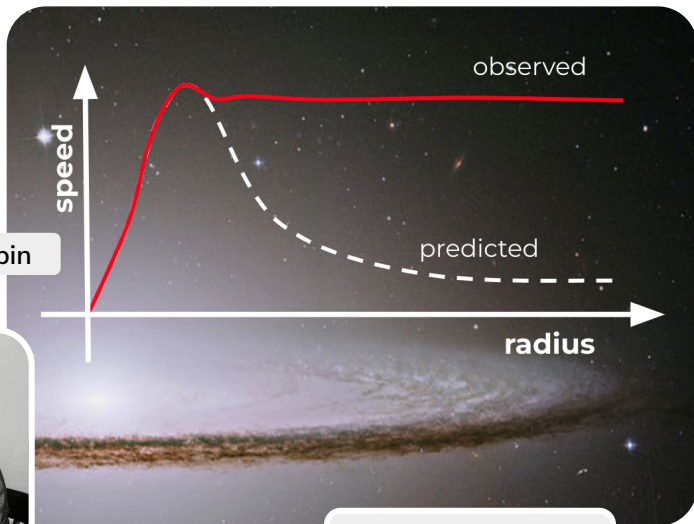




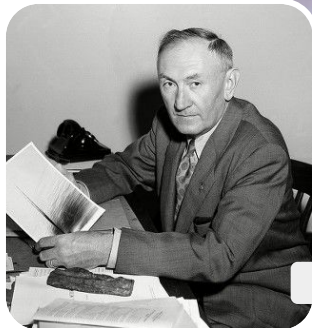
# Evidencias de Materia Oscura



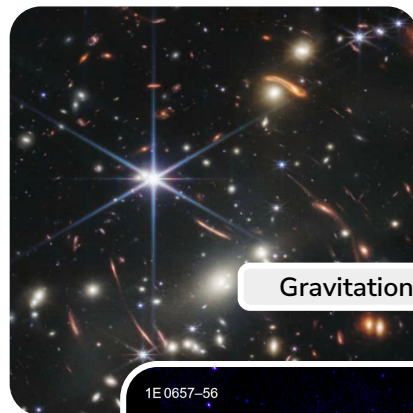
Vera Rubin



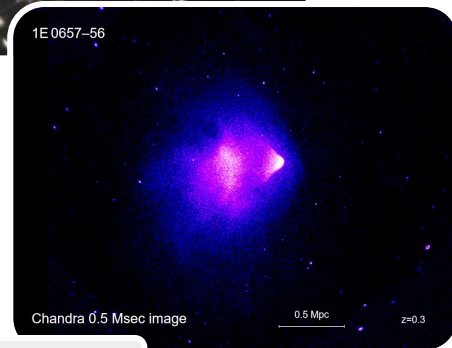
Radial velocity of galaxies



Fritz Zwicky

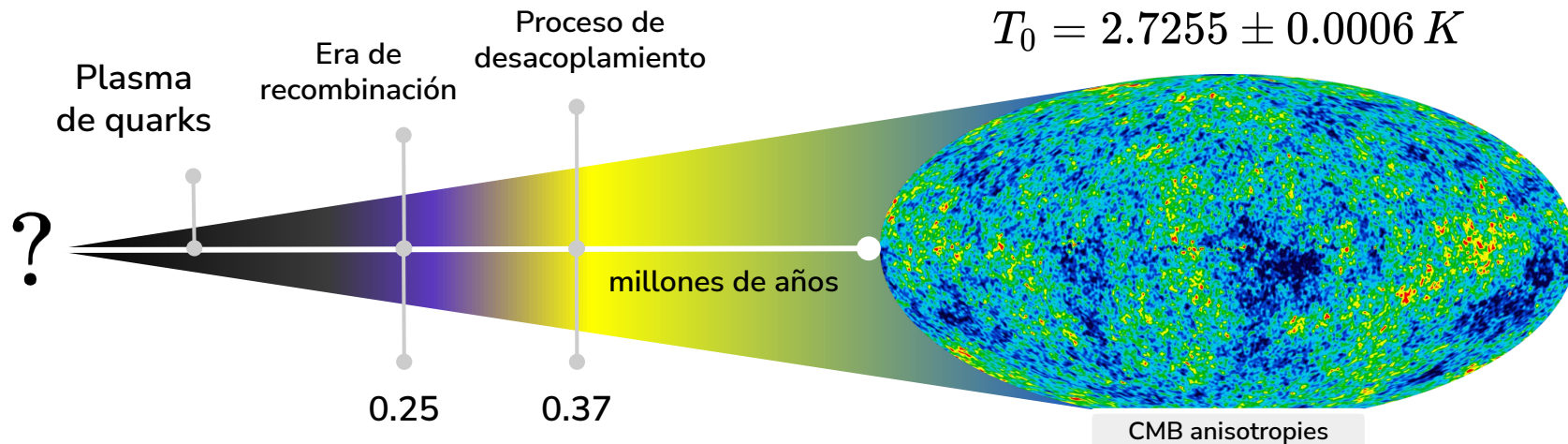


Gravitational lensing



X-ray halos

# Cosmología y altas energías

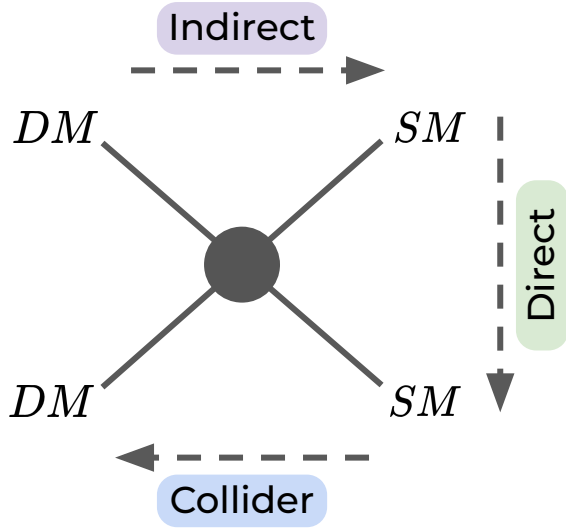


$$\Delta T \approx 10^{-5} T_0 < \Delta T_{\text{bm}} \approx 10^{-4} T_0$$

A. M. Green, Dark matter in astrophysics/cosmology (2021), [arxiv.org/abs/2109.05854](https://arxiv.org/abs/2109.05854).

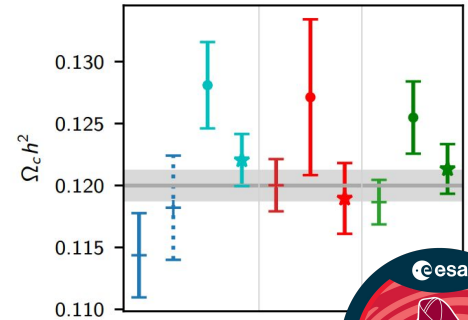
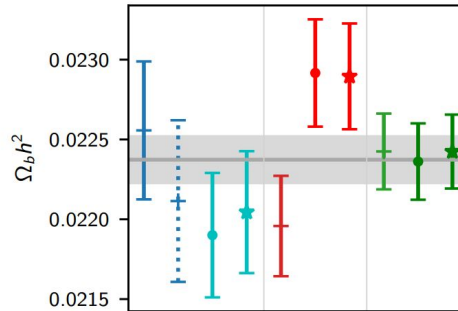


# Detección indirecta



- Xenon1T, Lux, CMS, ATLAS

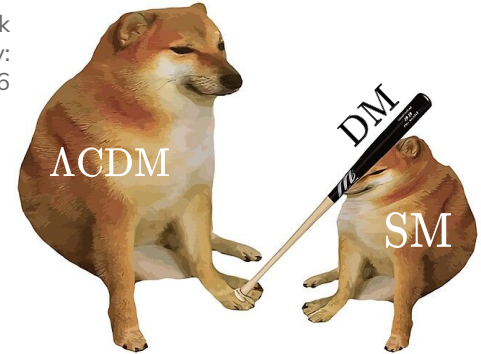
$$\Lambda\text{CDM} \left\{ \begin{array}{l} \Omega_c h^2 = 0.120 \pm 0.001 \\ \Omega_b h^2 = 0.0224 \pm 0.0001 \\ \Rightarrow \Omega_c h^2 \sim 5.3571 \Omega_b h^2 \end{array} \right.$$



Planck Collaboration, Aghanim, N. et al. (2018). Planck 2018 results. VI. Cosmological parameters. arXiv: 1807.06209

# La propuesta

Taoso, M., Bertone, G., & Masiero, A. (2007). Dark Matter candidates: A ten-point test. arXiv: 0711.4996



$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\bar{\psi}\gamma^\mu D_\mu\psi + h.c. + \bar{\psi}_i y_{ij}\psi_j\phi + h.c. + |D_\mu\phi|^2 - V(\phi)$$



DM

DM debe ser...

- no bariónica, débilmente interactuante, eléctricamente neutra.
- masiva, estable, no relativista,
- ~~se puede probar.~~

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{SM} + \mathcal{L}_{DM}$$



} LanHep → MicrOMEGAs

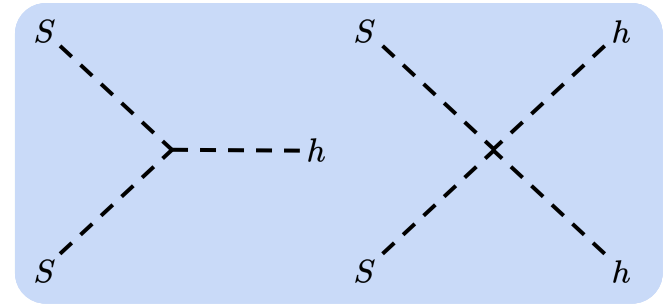


# Modelo escalar (Modelo de John McDonald)

$$\begin{aligned}
 H &= \begin{pmatrix} 0 \\ \frac{v+h}{\sqrt{2}} \end{pmatrix} \\
 S &= (s_1 + i s_2)
 \end{aligned}
 \left\{ \begin{aligned}
 \mathcal{L}_{S,H} &= \partial^\mu S^* \partial_\mu S - \mu^2 S^* S - \lambda_s S^* S H^\dagger H \\
 &= \partial^\mu S^* \partial_\mu S - \mu^2 S^* S - \lambda_s S^* S \left( \frac{h+v}{\sqrt{2}} \right)^2 \\
 &= \underbrace{\partial^\mu S^* \partial_\mu S - \mu^2 S^* S}_{\text{mass term}} - \lambda_s v S^* S h - \frac{1}{2} \lambda_s S^* S h^2
 \end{aligned} \right.$$

$$\begin{aligned}
 \mathcal{L}_{S,h} &= \partial^\mu S^* \partial_\mu S - m^2 S^* S - \lambda_s v S^* S h - \frac{1}{2} \lambda_s S^* S h^2 \\
 &SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1) \\
 \mathcal{L}_{eff} &= \mathcal{L}_{SM} + \mathcal{L}_S
 \end{aligned}$$

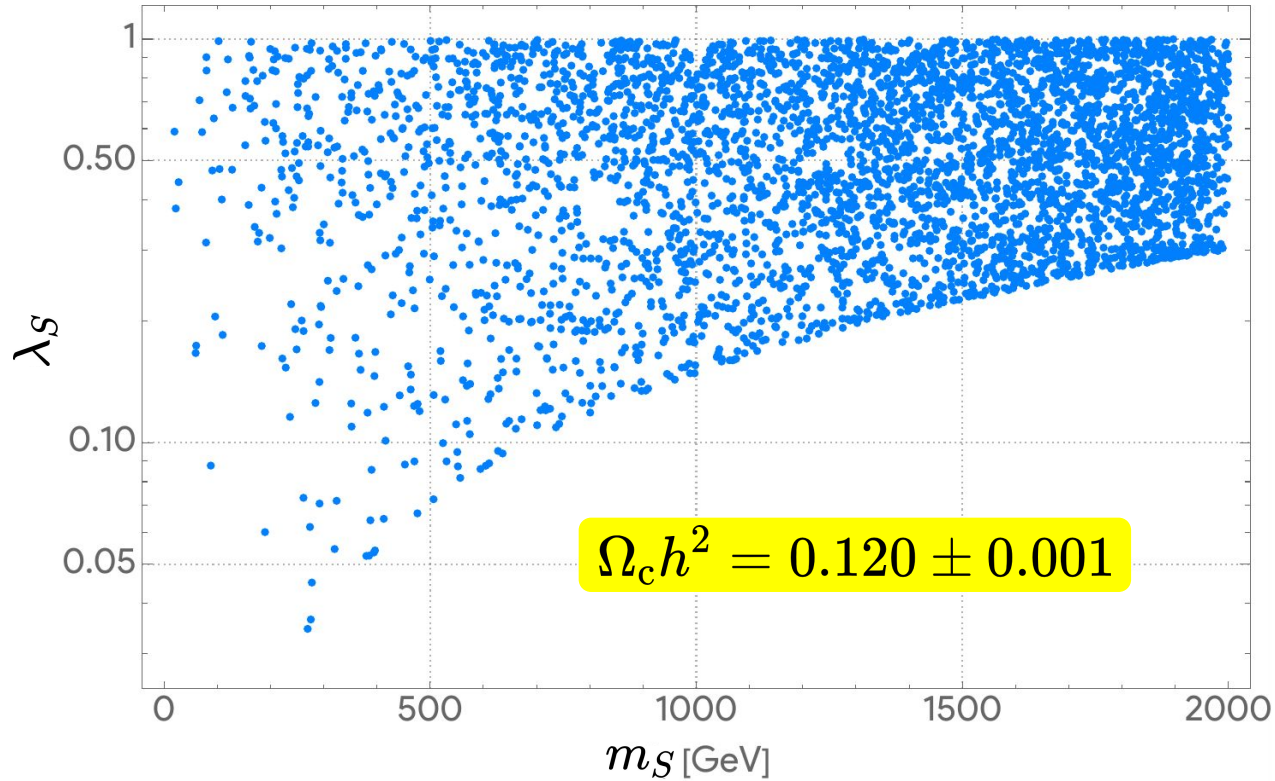
Espacio de parámetros:  $\{m_s, \lambda_s\} \rightarrow \Omega_c h^2$



J. McDonald, Gauge singlet scalars as cold dark matter,  
 Physical review D: Particles and fields 50 (1994)  
 36373649, 10.1103/physrevd.50.3637

Candidates constrain to  $\Omega_c h^2$

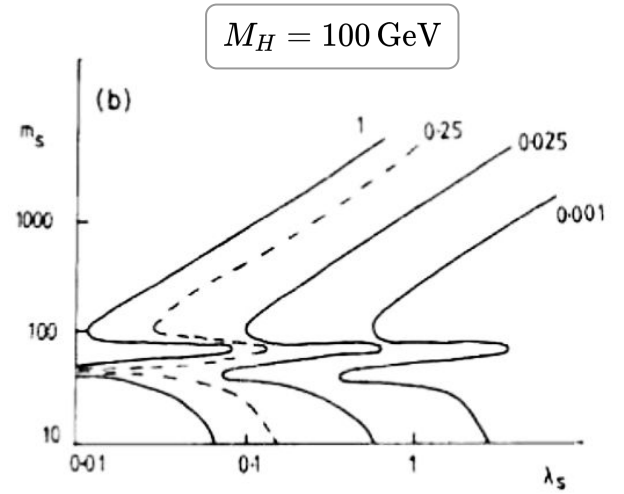
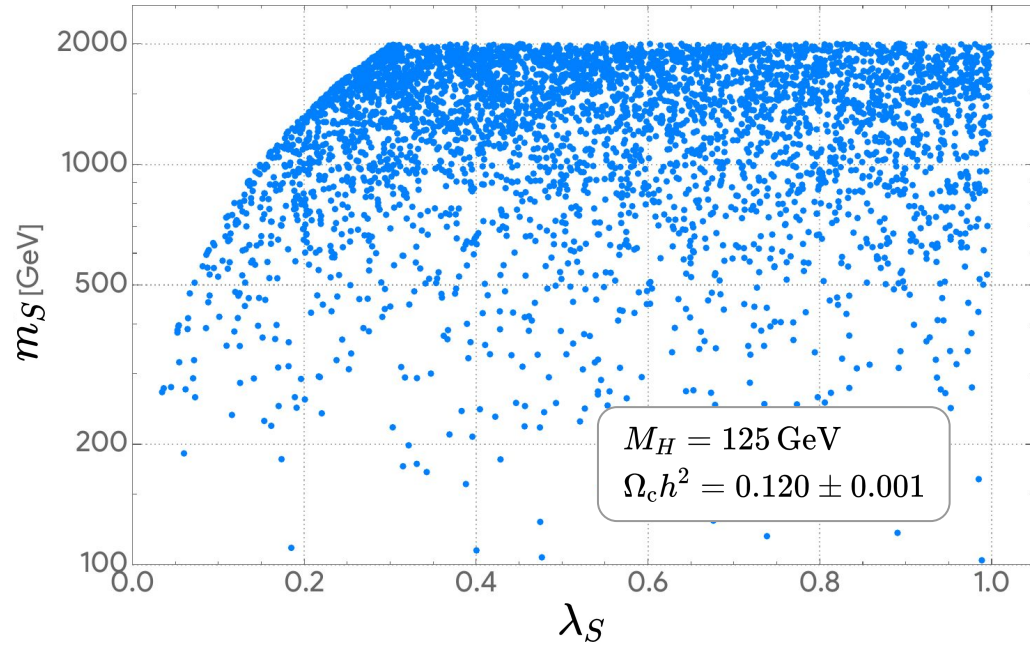
(Higgs coupling)



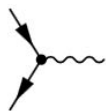


# Compare with McDonald results

(Higgs coupling)

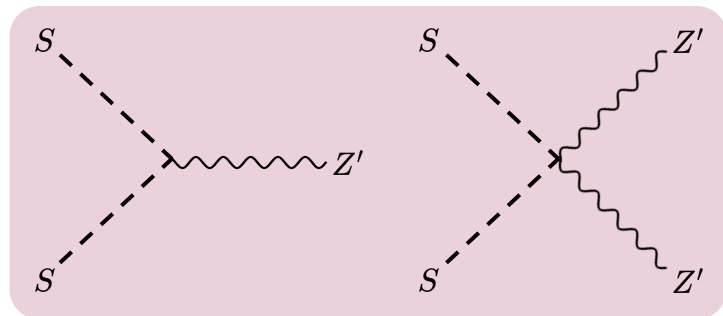
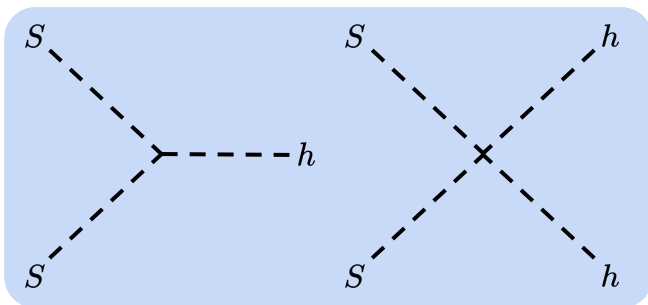


arXiv: 0702143



# Modelo escalar (Acoplamiento con $H$ y $Z'$ )

$$\mathcal{L}_{S,h,Z'} = \mathcal{L}_{S,h} + \frac{1}{2} m_z^2 Z'_\mu Z'^\mu - \lambda_v \partial_\mu S^* S Z'^\mu - \lambda_v S^* S Z'_\mu Z'^\mu + \bar{F}_i \gamma^\mu (c_{vi} + c_{vi} \gamma^5) F_i Z'_\mu$$

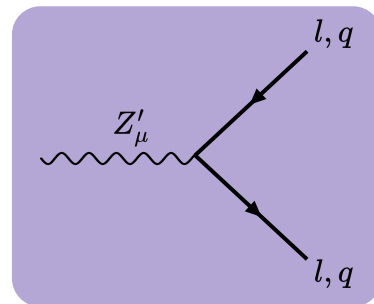


97% :  $SS \rightarrow Z' Z'$

2% :  $SS \rightarrow tt$

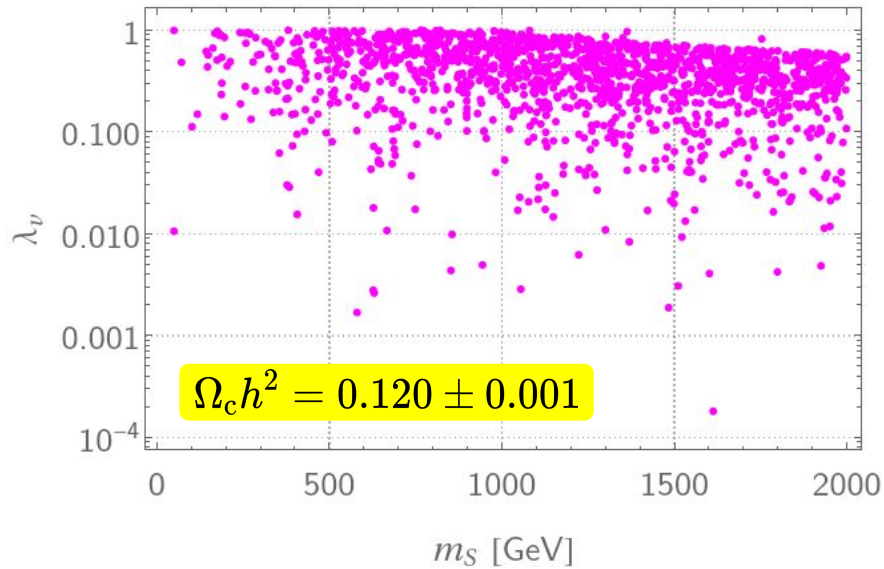
1% :  $SS \rightarrow hh$

$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \mathcal{L}_{S,h,Z'}$$

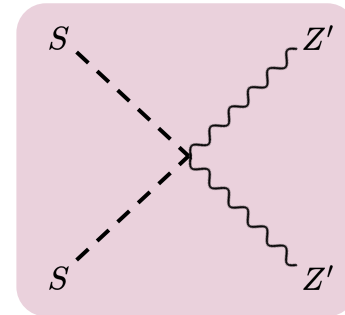


Espacio de parámetros:  $\{m_s, \lambda_s, \lambda_v, c_{vt}, c_{at}\} \rightarrow \Omega_c h^2$

Candidates constrain to  $\Omega_c h^2$

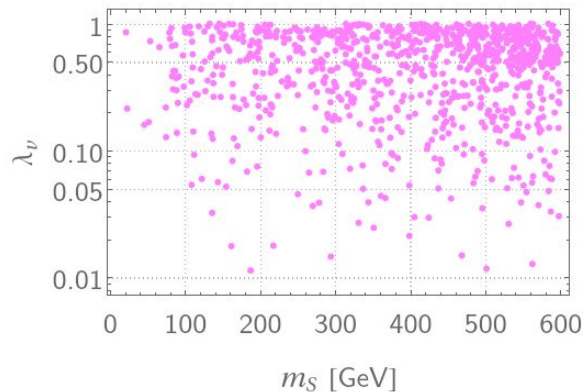
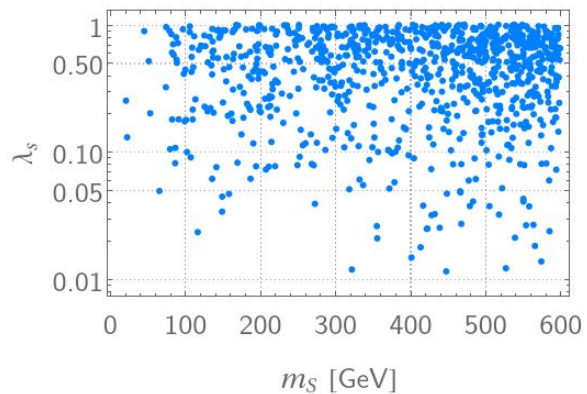


(Z' coupling)

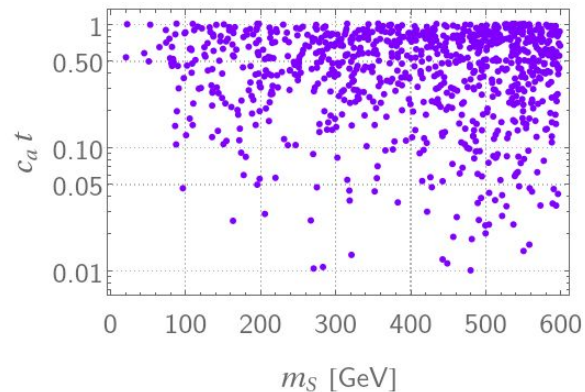
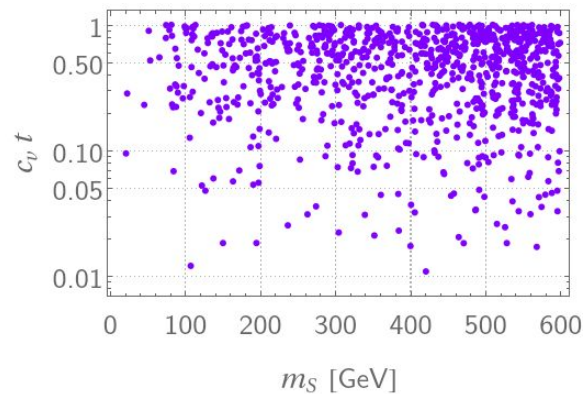


$$\mathcal{L}_{S,Z'} = \partial_\mu S^* \partial^\mu S + m_s^2 S^* S - \lambda_\nu S^* S Z'_\mu Z'^\mu$$

...contribuyen con la masa de  $S$



...No contribuyen con la masa de  $S$





# Modelo fermiónico

$$\begin{aligned}
 \mathcal{L}_{f,h,Z'} &= \bar{f} (i\gamma^\mu P_R \partial_\mu - m_f) f + \bar{f} (c_{sc} + c_{ps} \gamma^5) f H \\
 &+ \frac{1}{2} m_{Z'}^2 Z'_\mu Z'^\mu + \bar{f} P_R \gamma^\mu (c_{ve} + c_{ax} \gamma^5) P_L f Z'_\mu \\
 &+ \bar{F}_i \gamma^\mu (c_{vi} + c_{ai} \gamma^5) F_i Z' + h.c.
 \end{aligned}$$

$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \mathcal{L}_{f,h,Z'}$$

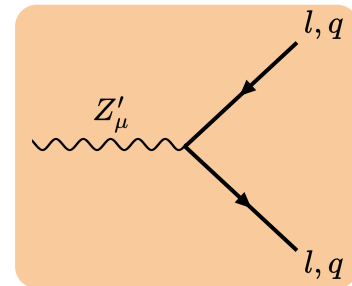
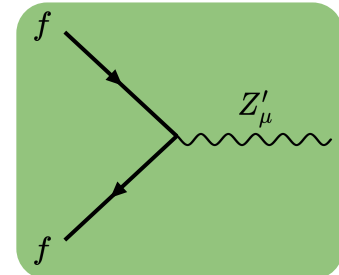
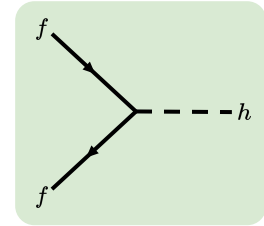
76% :  $f f \rightarrow t t$

10% :  $f f \rightarrow W^+ W^-$

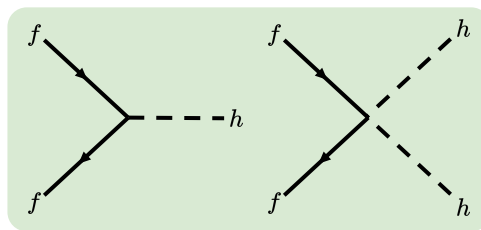
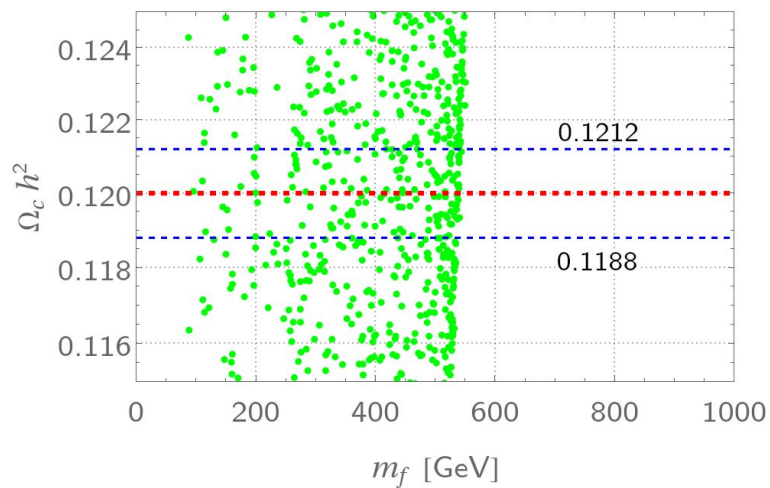
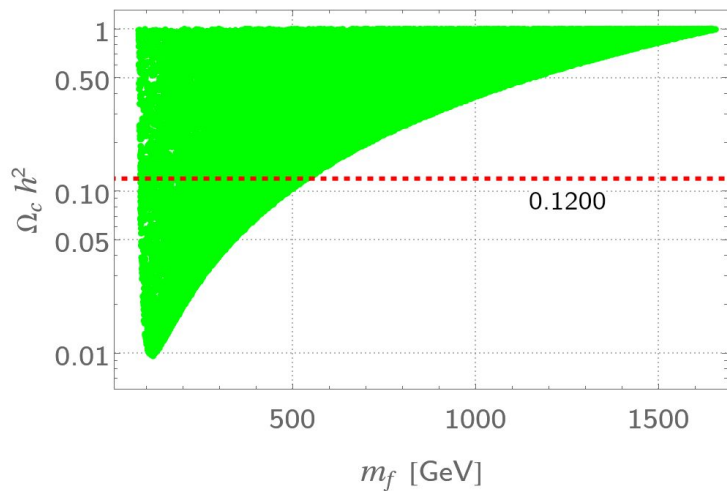
8% :  $f f \rightarrow Z' Z'$

6% :  $f f \rightarrow Z Z$

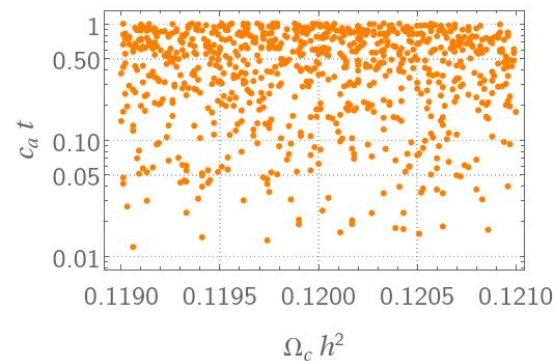
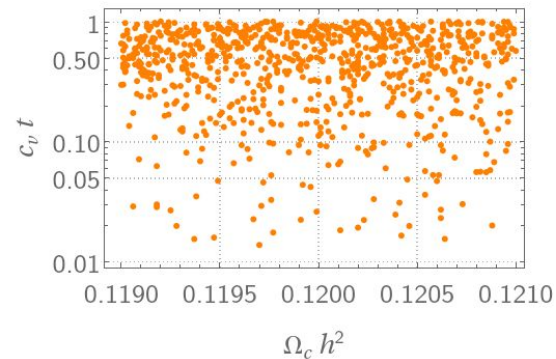
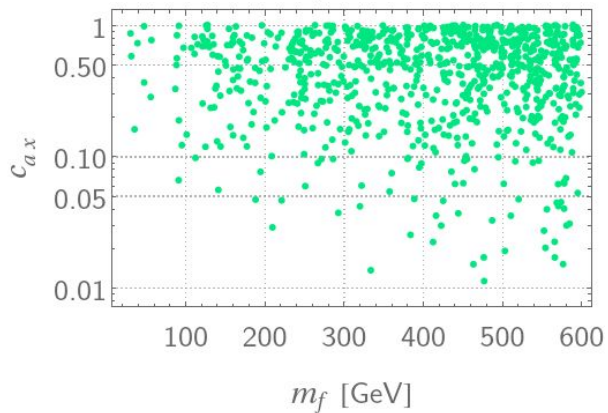
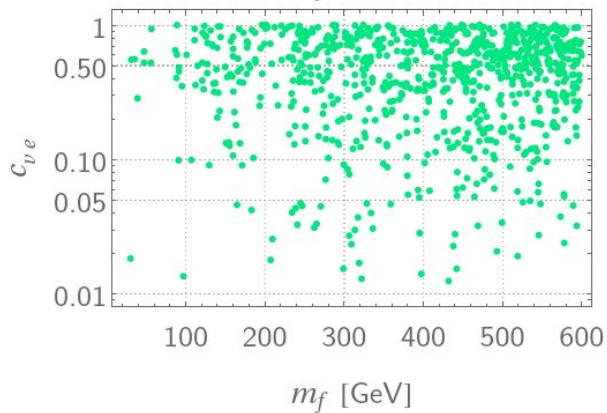
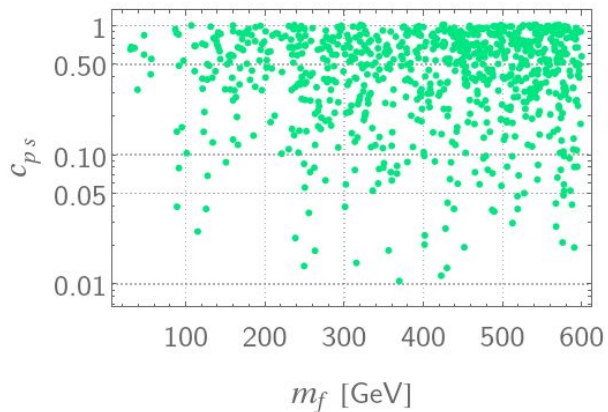
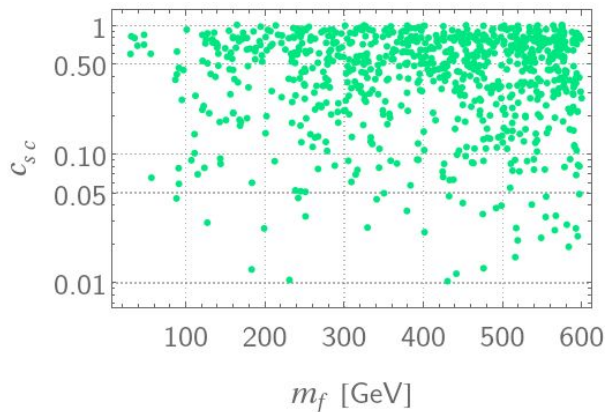
Espacio de parámetros:  $\{m_f, c_{sc}, c_{ps}, c_{ve}, c_{ax}, c_{vt}, c_{at}\} \rightarrow \Omega_c h^2$



## Explore the mass parameter around $\Omega_c h^2 = 0.120 \pm 0.001$



...contribuyen con la masa de  $f$



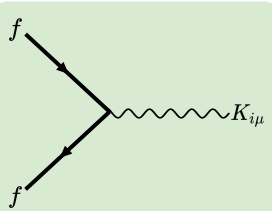
# Simetría $SU(2)$

$$\chi = \begin{pmatrix} F_L \\ F_R \end{pmatrix} = F_R + F_L ; F_L = \begin{pmatrix} \beta_L \\ f_L \end{pmatrix}, F_R = f_R ; \mathcal{L} = i\bar{\chi}\gamma^\mu D_\mu\chi - m\bar{\chi}\chi$$

$$D_\mu = \partial_\mu + i\eta T_i K_{i\mu}, K_{i\mu} \rightarrow K_{i\mu} - \partial_\mu\alpha_i - \eta\epsilon_{ijk}\alpha_j K_{k\mu}$$

$$m\bar{\chi}\chi = m(\bar{f}_R F_L + \bar{F}_L f_R)$$

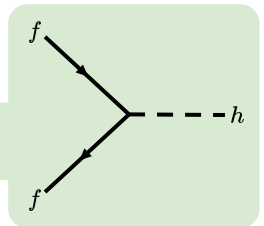
$$\mathcal{L}_{Yf} = y_f(\bar{f}_R\phi^\dagger f_L + \bar{f}_L\phi f_R) = y_f\frac{v+h}{\sqrt{2}}(\bar{f}_R f_L + \bar{f}_L f_R) + h.c., \quad m_f = y_f\frac{v}{\sqrt{2}},$$



$$y_f\bar{f}fh = \bar{f}(c_s + c_p\gamma^5)fh, \quad y_f = (c_s + c_p\gamma^5)$$

$$\mathcal{L} \rightarrow i\eta T_i \bar{f} f K_{i\mu} \sim i\eta \bar{f} \gamma^\mu (c_v + c_a \gamma^5) f K_{i\mu}$$

$$\{y_f\}, \{c_s, c_p\} \rightarrow \Omega_c h^2$$



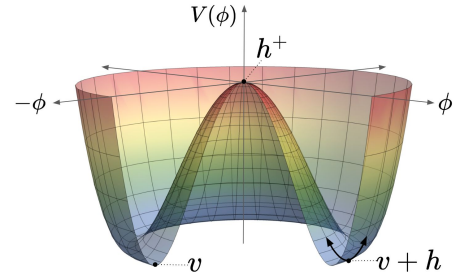


$$T_i K_{i\mu} = \begin{pmatrix} K'_\mu & K_a - iK_b \\ K_a + iK_b & -K'_\mu \end{pmatrix} = \begin{pmatrix} K'_\mu & 0 \\ 0 & -K'_\mu \end{pmatrix}, \quad \begin{pmatrix} W_{3\mu} \\ B_\mu \\ K'_\mu \end{pmatrix} = \begin{pmatrix} c\theta_w & s\theta_w & 0 \\ -s\theta_w & c\theta_w & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} Z_\mu \\ A_\mu \\ Z'_\mu \end{pmatrix}$$

$$(D_\mu \phi)^\dagger (D^\mu \phi) = \frac{1}{2} (\partial_\mu h)^2 + \frac{(v+h)^2}{8} \left[ g^2 W_\mu^\pm W^{\pm\mu} + (gW_{3\mu} - g'B_\mu - \eta K'_\mu)^2 \right]$$

$$(gW_{3\mu} - g'B_\mu - \eta K'_\mu)^2 = (W_{3\mu} \ B_\mu \ K'_\mu) U^\dagger \begin{pmatrix} g^2 & -g g' & -g\eta \\ -g g' & g'^2 & -g'\eta \\ -g\eta & -g'\eta & \eta^2 \end{pmatrix} U \begin{pmatrix} W_{3\mu} \\ B_\mu \\ K'_\mu \end{pmatrix}$$

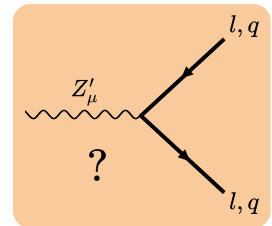
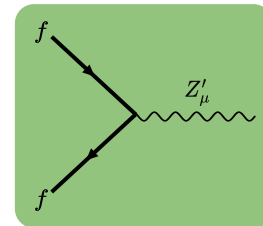
$$= (Z_\mu \ A_\mu \ Z'_\mu) \begin{pmatrix} g^2 + g'^2 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & \eta^2 \end{pmatrix} \begin{pmatrix} Z_\mu \\ A_\mu \\ Z'_\mu \end{pmatrix} = Z_\mu Z^\mu (g^2 + g'^2) + Z'_\mu Z'^\mu \eta, \quad m_{Z'} = \frac{v\eta}{2}$$



$\eta < g \rightarrow DM$

$\{y_f\}, \{c_s, c_p, \eta\} \rightarrow \Omega_c h^2$

$\mathcal{L} \rightarrow$

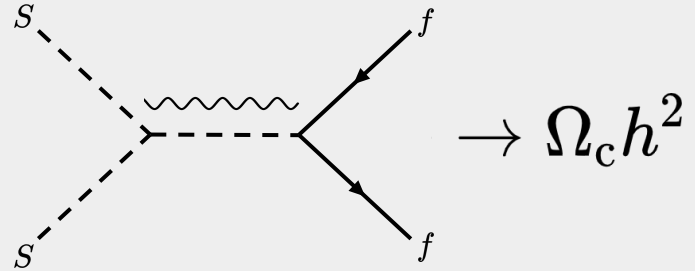


# En conclusión...



Valores bajos  $\rightarrow$  Menos candidatos

- URGEN correcciones efectivas de los modelos o búsqueda de **nuevas simetrías**.
- Búsqueda de fenomenología que permita constreñir el espacio de parámetros y los candidatos en los modelos.
- Detección directa...



	$u$	$c$	$t$	$g$	$\underbrace{\begin{matrix} H \\ S \end{matrix}}_{\text{spin}-0}$
	$d$	$s$	$b$	$\gamma$	
	$e$	$\mu$	$\tau$	$Z$	
$f$	$\nu_e$	$\nu_\mu$	$\nu_\tau$	$\pm W$	
	spin-1/2			spin-1	



¡ Gracias por su atención !



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[josehalim@gmail.com](mailto:josehalim@gmail.com)

