# Using strong lensing and the Einstein radius to infer dark matter distribution in the scalar field dark matter model

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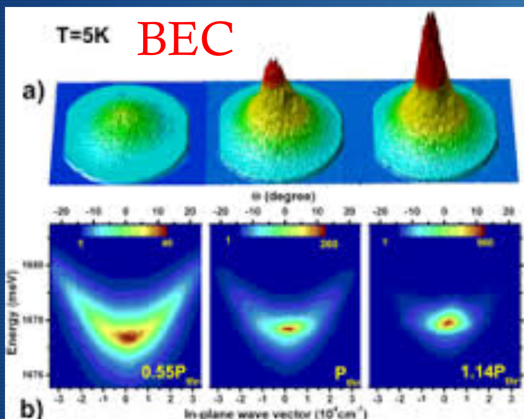
# Scalar Field Dark Matter (SFDM) (review Robles+2013)

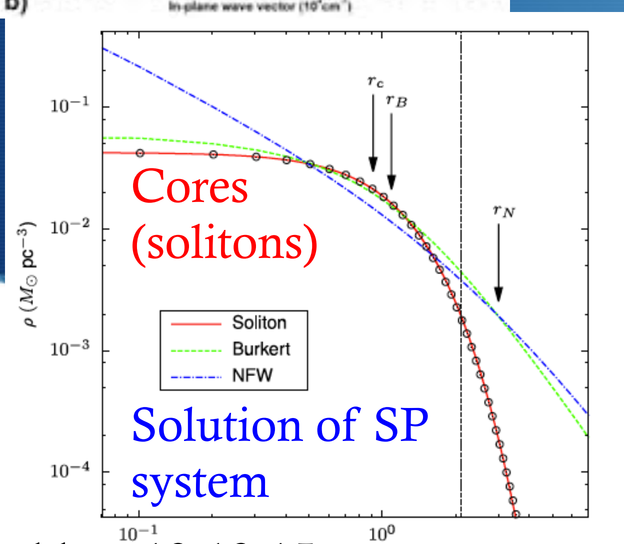
Basic Properties:

- DM is a spin-0 scalar field of $m_\psi <\sim 10^{-14} eV/c^2$
- Preferred mass by observations $m_\psi \sim 10^{-22} eV/c^2$ (Matos+01)
- High condensation temperature imply a cosmological BEC

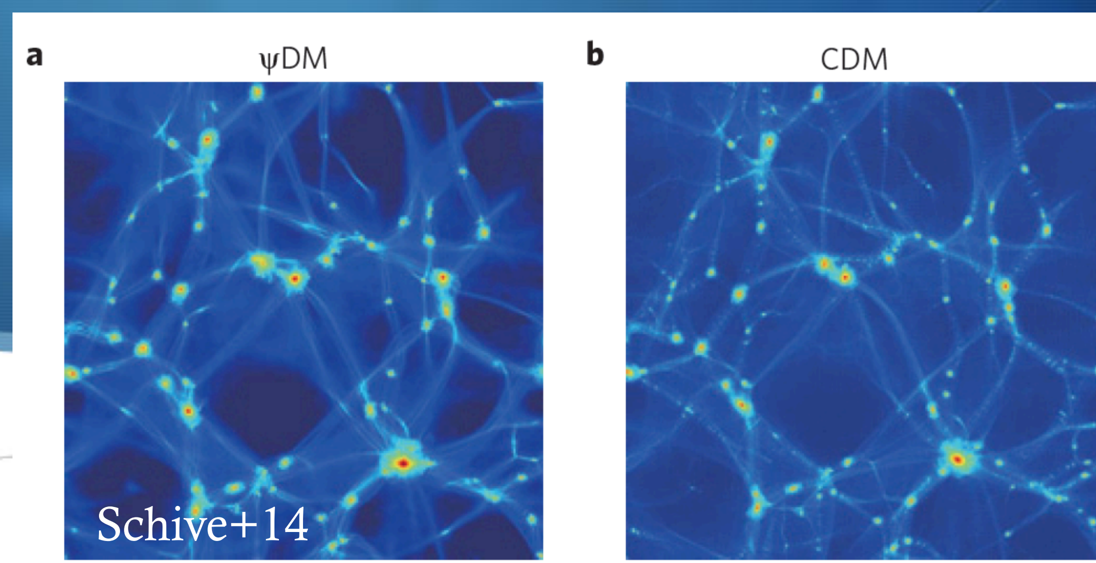
} DM candidate: PSYON



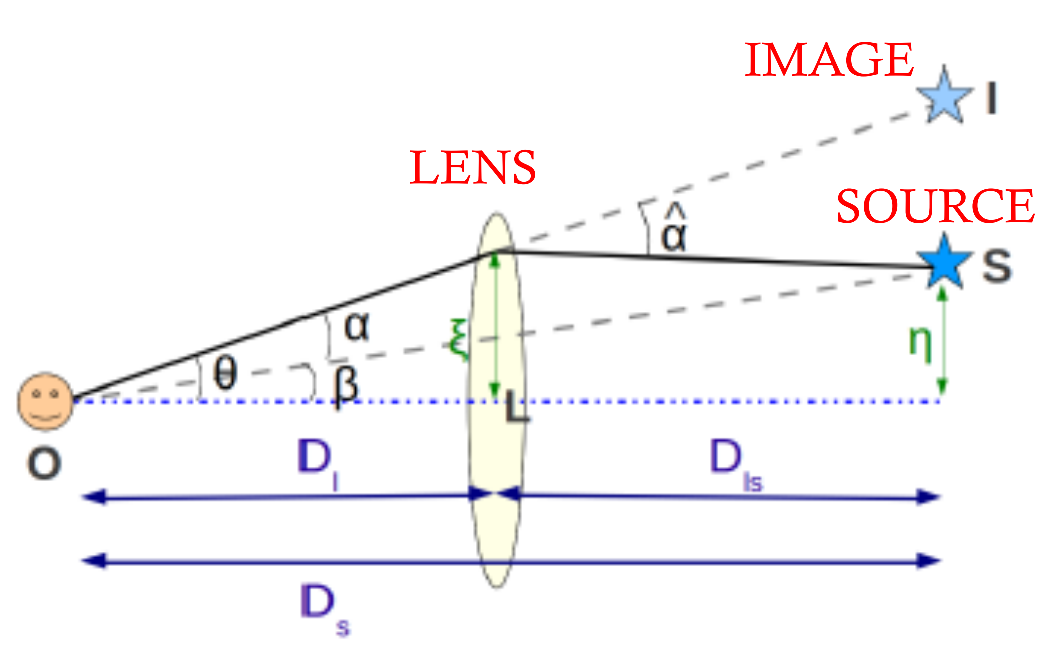

| Discrepancies | CDM | SFDM |
|---|---|---|
| Cusp-core issue | Require baryons | DM only |
| Satellite abundance | Many halos but no galaxies? | No low mass halos,no gal.! |
| Too big to fail | MW w disk + baryons | May not exist(?) |




Robles+12,13,15



# Strong lensing(SL): Lens equation

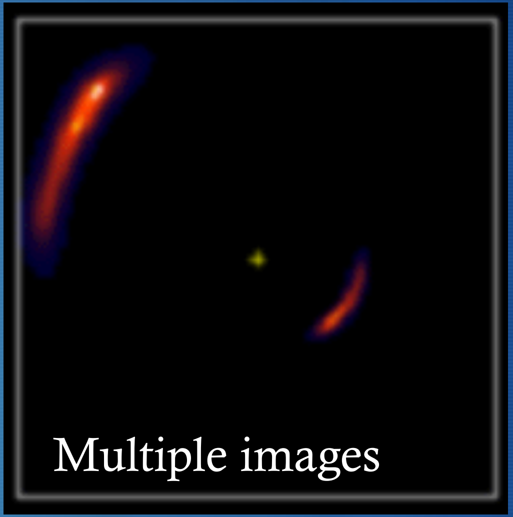


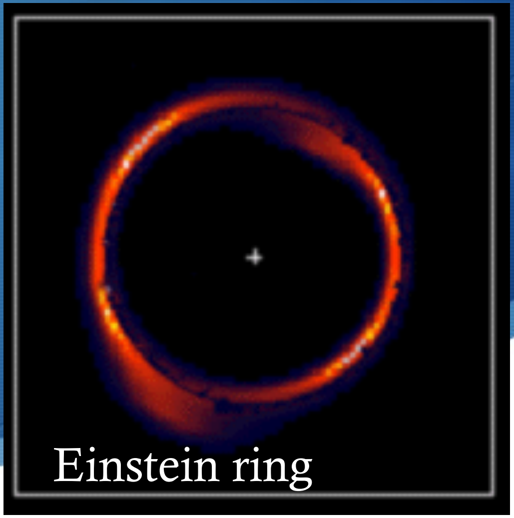

$$\beta = \theta - \frac{M_p(\theta)}{\pi D_{OL}^2 \theta \Sigma_{crit}}$$

Lens equation

$$\Sigma_{crit} \equiv c^2 D_{OS} / 4\pi G D_{OL} D_{LS}$$

$$f_{dist} \equiv d_{OS}/d_{OL}d_{LS}$$



# SFDM: Mass of the lens (Robles &Matos 2013,2015)

$$M_p(\xi) = 2\pi \int_0^{\xi} x\, dx \int_{-\infty}^{\infty} dz\, \rho(\sqrt{x^2 + z^2})$$

The projected mass enclosed within a projected radius $\xi$

$$m(\xi_*) \equiv M_p(\xi_*)/\rho_0 R^3$$

R=outermost radius of integration~halo size

$$\theta_* \equiv \theta D_{OL}/R$$

$$\beta_* \equiv D_{OL}\beta/R$$

$$\beta_*(\theta_*) = \theta_* - \lambda_T \frac{m(\theta_*)}{\theta_*}$$

The parameter $\lambda_T$ determines the properties of the SFDM profile lens.

Substituting our analytical mass profile we obtain:

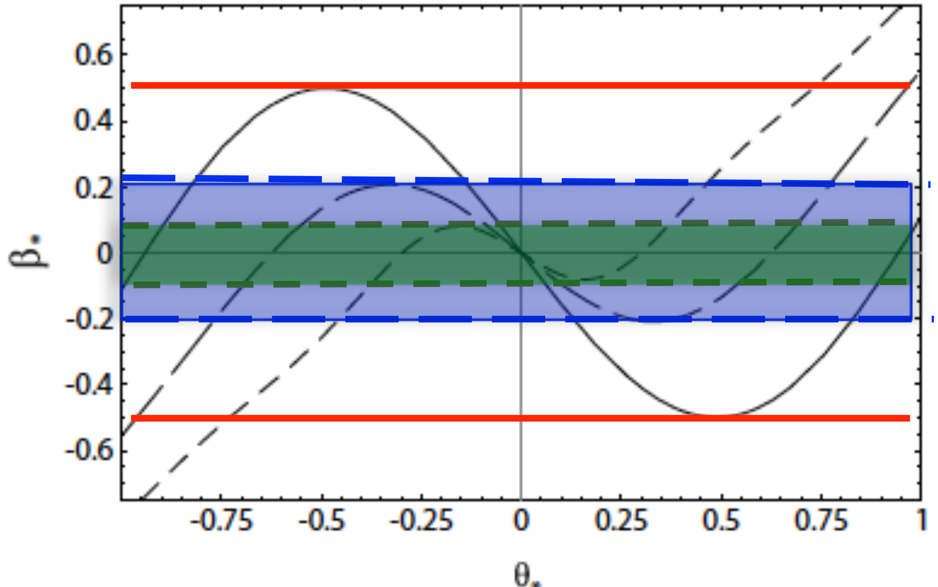
$$\lambda_T = \frac{\rho_0 R}{\pi \Sigma_{crit}} = 0.57h^{-1} \frac{\rho_0}{M_\odot\ pc^{-3}} \frac{R}{kpc} \frac{1}{f_{dist}}$$

Halo parameters $\rho_0$ and R can be constrained by imposing strong lensing condition(multiple images)

TABLE I. Minimum values of $\lambda_T$ to produce strong lensing for $j$=1,2,3,4,5. $j$=0 corresponds to a zero temperature halo.

| j | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| $\lambda_{T,min}$ | 0.27 | 0.35 | 0.66 | 0.98 | 1.32 | 1.63 |

Line style — — — – –




# RESULTS

There is strong lensing(SL) (multiple images) if:

$$|\beta_*| \leq max[\beta_*(\theta_*)]$$

-For excited states, SFDM halos can be larger or have higher inner densities the the ground state.

Constraint on SFDM halo density and radius to produce SL :

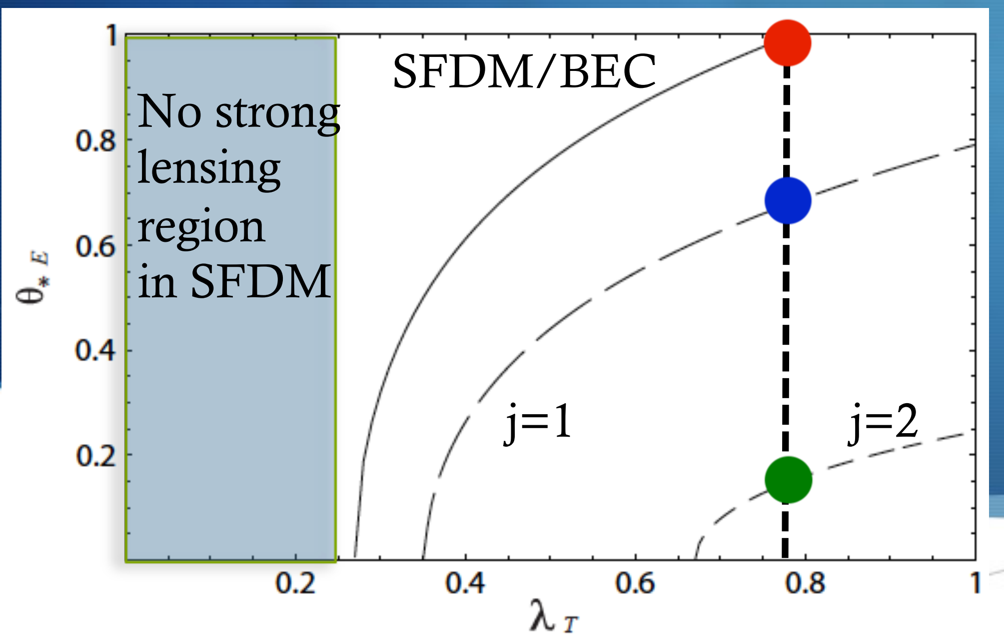
$$\rho_0 R(M_\odot pc^{-2}) \geq 1245.60 \lambda_{T,min} f_{dis}$$

Robles &Matos 2013

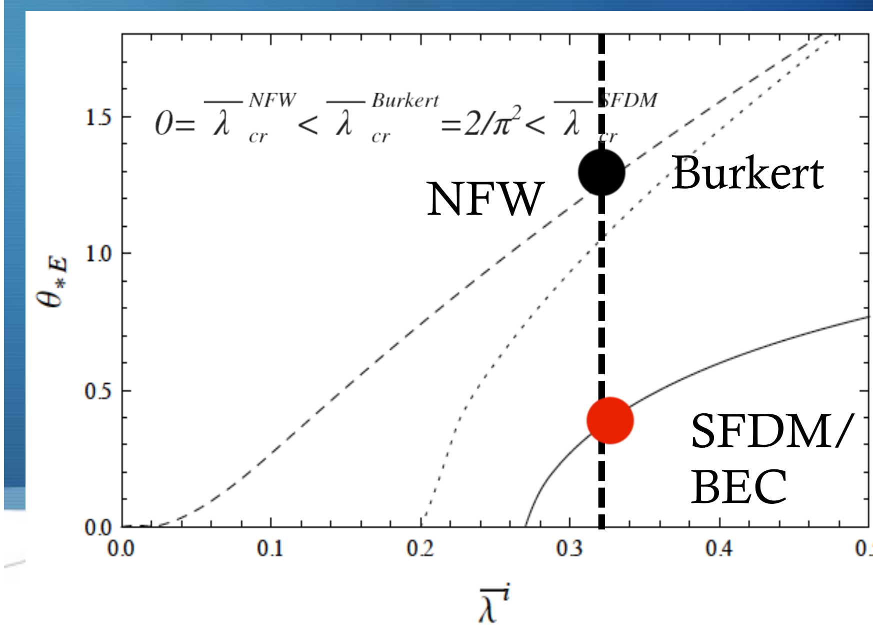
CONCLUSIONS

- Higher excited states imply smaller Einstein radius than CDM
- Modeling large sample of DM halos ( $\rho$ ,R)+ Einstein Radii data would allow to determine the halo excited state and test DM models.

- If DM is indeed a psyon, galaxy formation will be different from CDM(work in progress)




Robles &Matos 2013




Gonzalez-Morales+13