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ULTRA-LIGHT ALP DARK MATTER

Axions & IAXO in Spain, October 27th, 2016

Outline of the talk

- PART I: Brief introduction to ultra-light ALP dark matter.

D.J.E. Marsh, Physics Reports, 643, 1-79 (2016)

- PART II: ULA dark matter and galactic offsets.

*A. Paredes and H. Michinel, Physics of the Dark Universe, **12**, 50 (2016)*

Part I:

Introduction to ultra-light ALP dark matter

What is ULA dark matter? (SFDM, ΨDM, FDM, BEC DM …)

- Part or all of dark matter consists of a (pseudo-) scalar particle with mass: $m_a \approx 10^{-22}\mathrm{eV}$
- (Non-relativistic) dark matter is governed by the wave equation:

$$\begin{aligned} i\hbar\partial_t\psi &= -\frac{\hbar^2}{2m_a}\nabla^2\psi + m_a\Phi\psi \\ \nabla^2\Phi &= 4\pi G\, m_a|\psi|^2 \end{aligned}$$

Notes:

- A local self-interaction term is sometimes added
- In comoving coordinates factors of *a* appear

Theoretical motivation

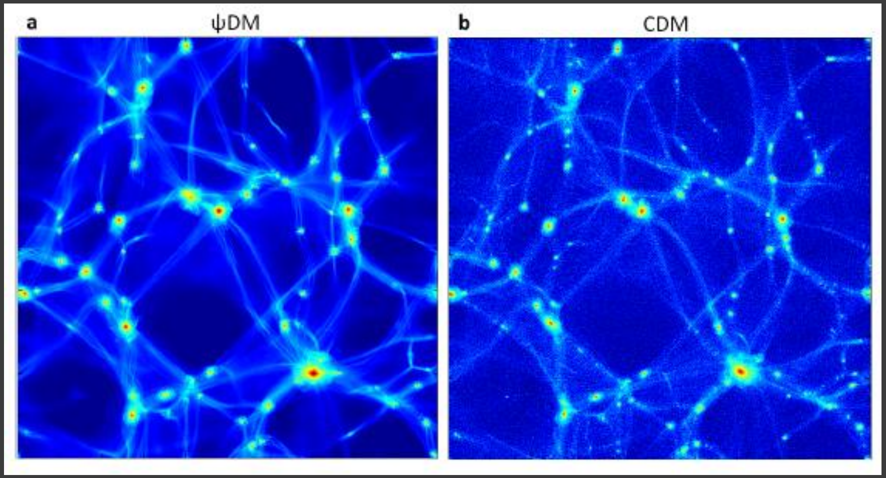
- Ultraviolet completions of the standard model naturally produce light (pseudo-) scalars.
- For instance, moduli from string theory compactifications.

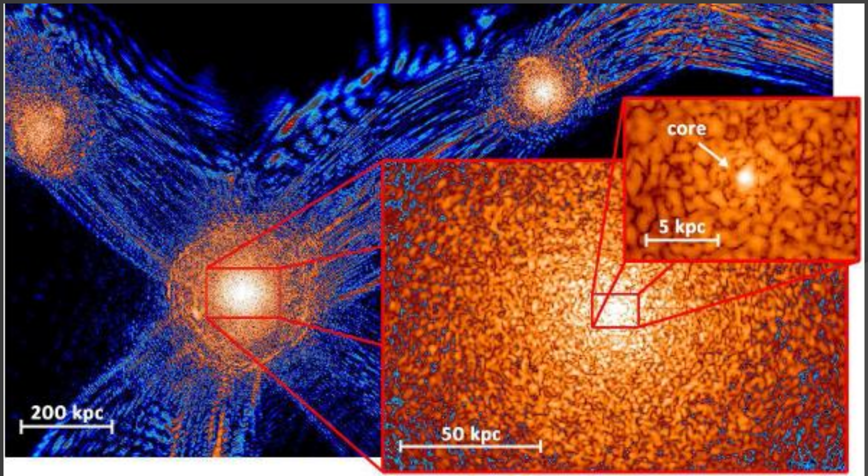
How to think about the ULA

- An ALP coming from a Peccei-Quinn mechanism with high symmetry breaking scale.
- The dark matter axions come from vacuum realignment

Observational motivation

- Solve the small-scale crises of ΛCDM: Missing satellite problem, cusp-core problem.
- Keep the large scale success of ΛCDM.
- It differs from ΛCDM below a length scale which depends on m_a.

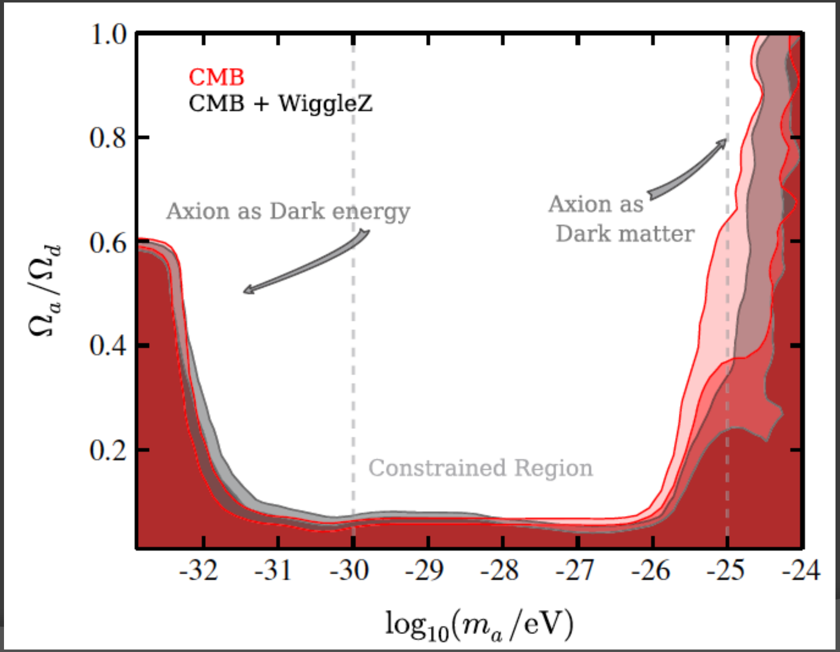




H.-Y. Schive, T. Chiueh, T. Broadhurst, Nature Physics, 10, 496 (2014)

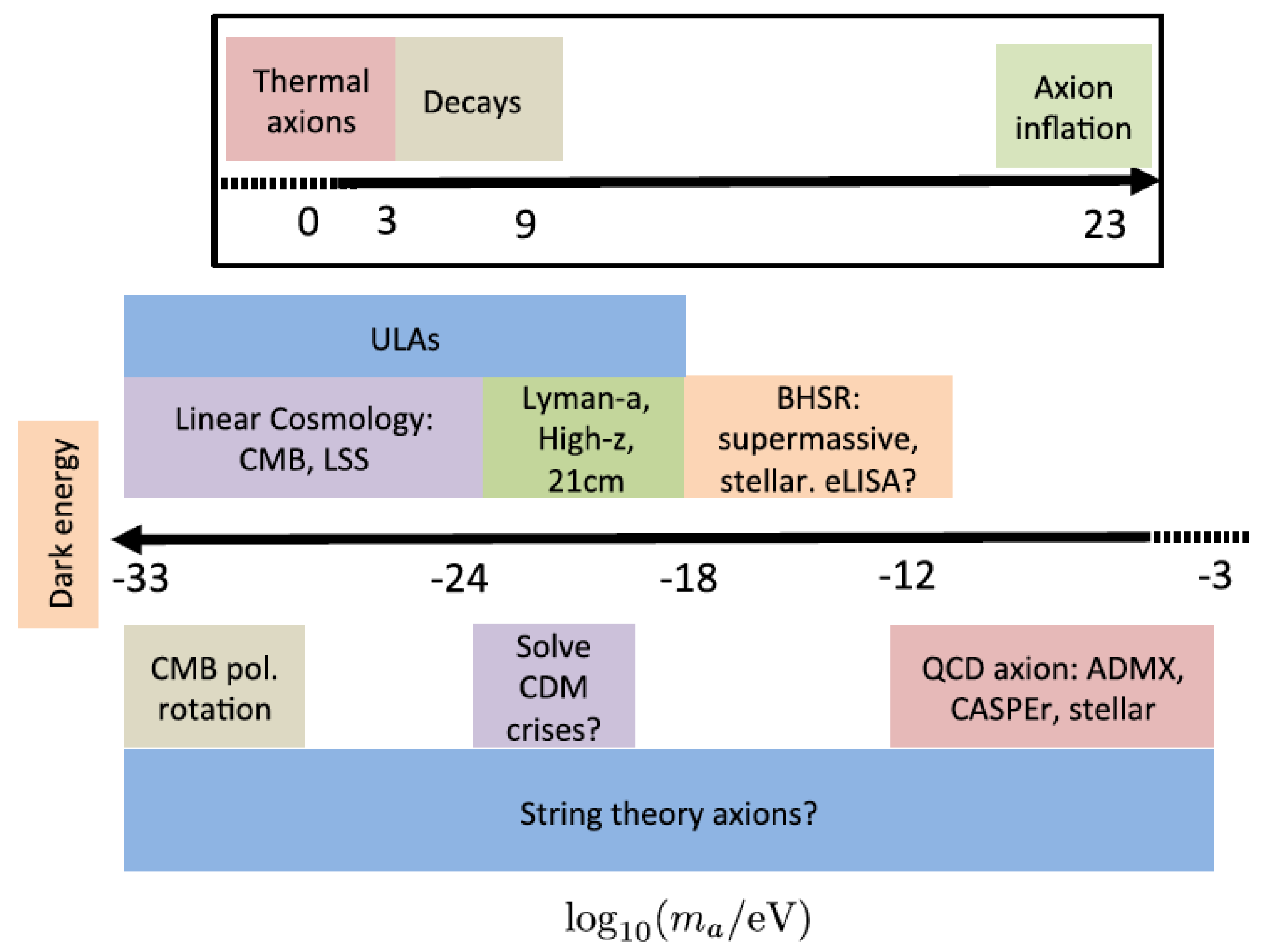
Constraints on the mass

- Consistency with CMB: $m_a > 10^{-24}$ eV
- Solve cusp-core problem: $m_a < 10^{-22}$ eV
- Consistent with structure formation at large *z* (Hubble ultra-deep field): $m_a > 10^{-22}$ eV



R. Hlozek, D. Grin, D.J.E. Marsh, P.G. Ferreira, Physical Review D 91, 103512 (2015)

In the ALP context



D.J.E. Marsh, Physics Reports, 643, 1-79 (2016)

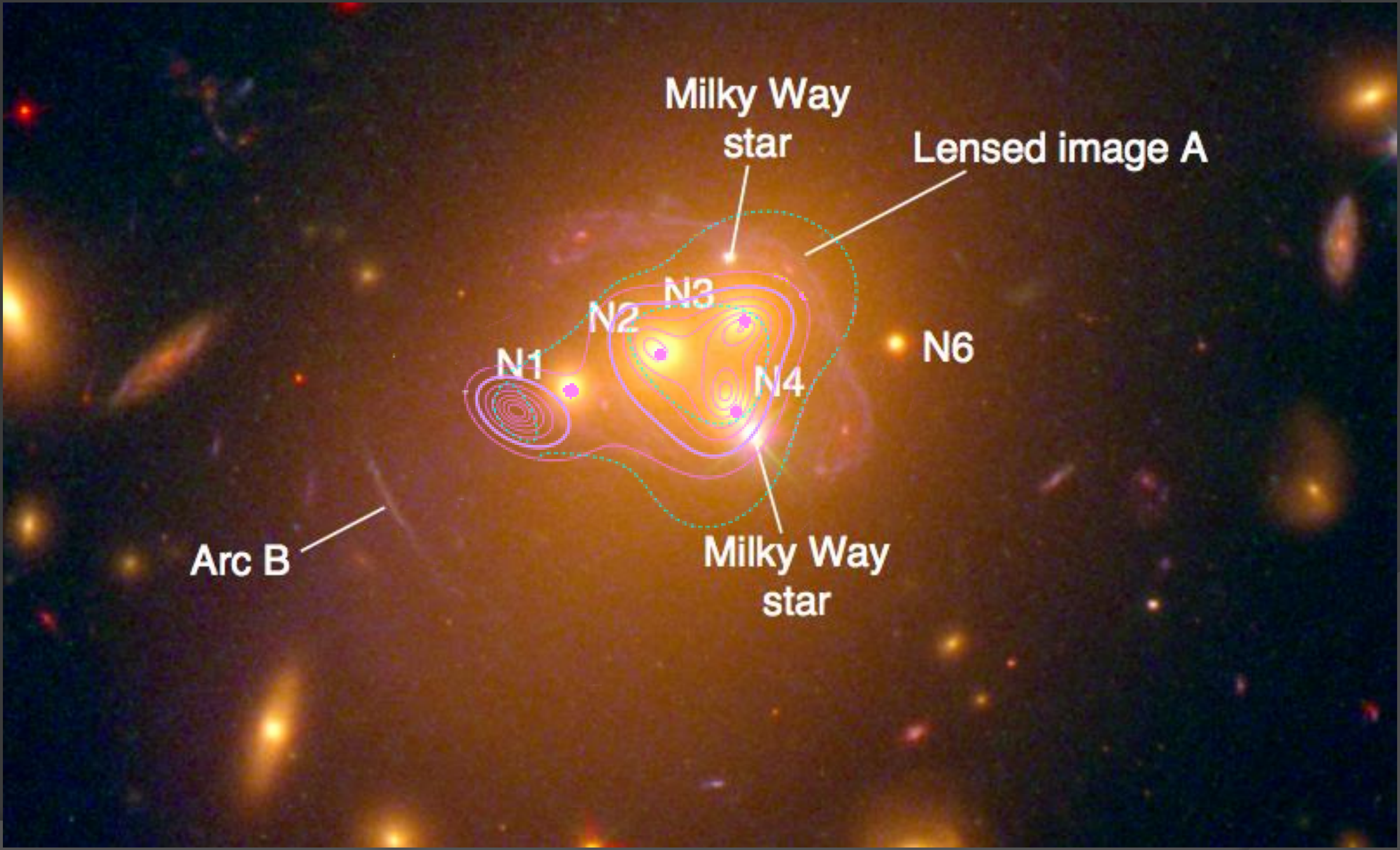
Part II:

ULA dark matter and galactic offsets.

A. Paredes and H. Michinel, Physics of the Dark Universe, ***12****, 50 (2016)*

The Abell 3827 cluster

R. Massey et al., Mon. Not. R. Astron. Soc., 449, 3393 (2015)



The Abell 3827 cluster

- Fortunate circumstances make this cluster very special
- Dark matter clump displaced from its stars
- First evidence of the interaction of dark matter with itself?

The offset

- The galaxy N.1 is shifted by 1.6kpc from the center of its dark matter halo.

How can it be explained?

- Inconsistent with collisionless dark matter!! (Schaller et al. (2015))
- But self-interacting dark matter is in tension with the absence of offsets in the Bullet cluster. (Kahlhoefer et al (2015)).
- A new small-scale crisis?

Can ULA DM help?

Galactic dark matter in the ULA model

- There is a coherent core (soliton) surrounded by an incoherent halo.

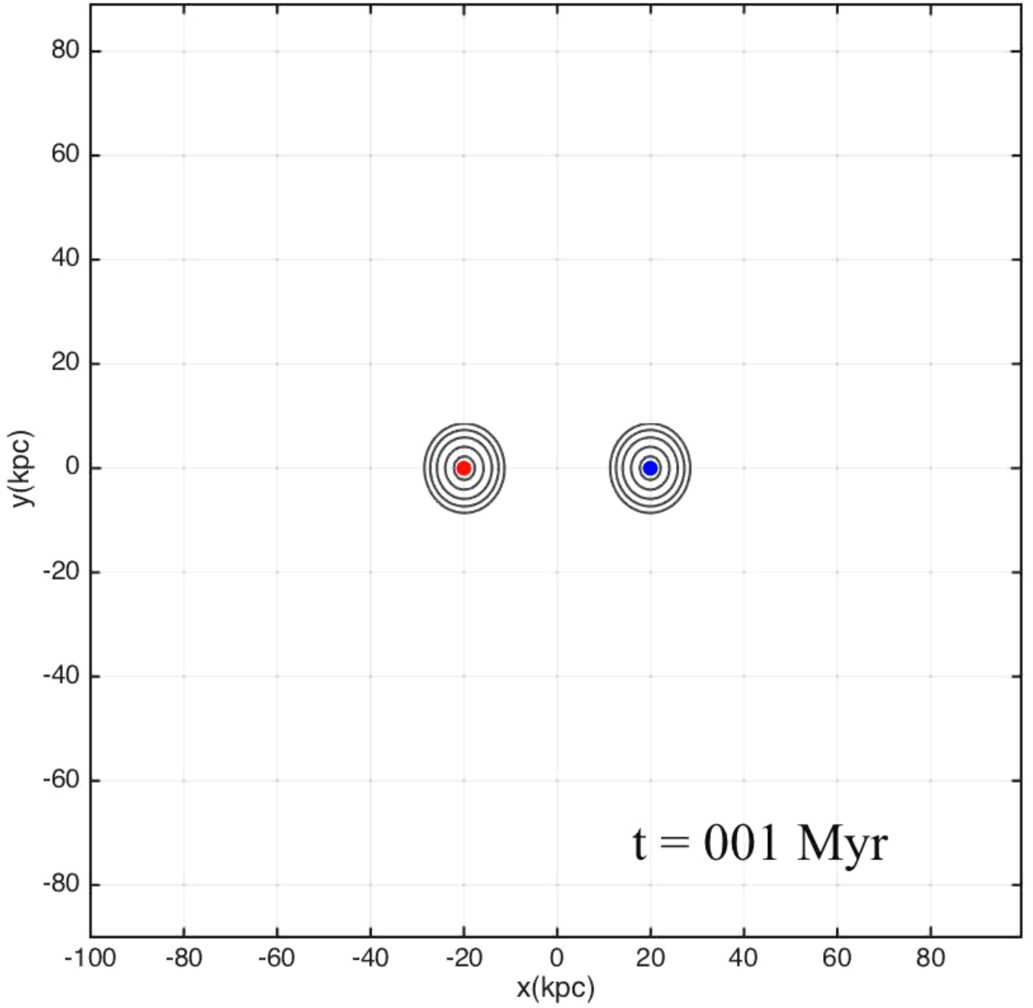
Our proposal

- Interference can induce large effective forces on dark matter.
- It affects cores (it does not affect halos or baryonic matter).

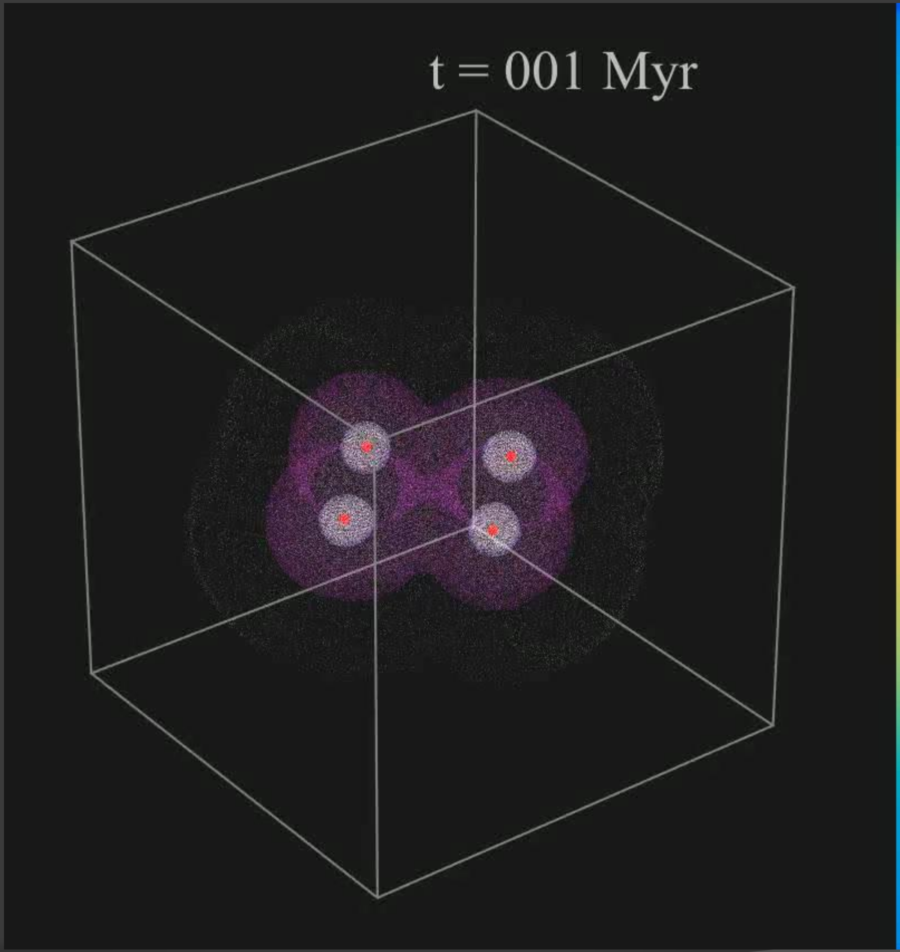
Some simulations

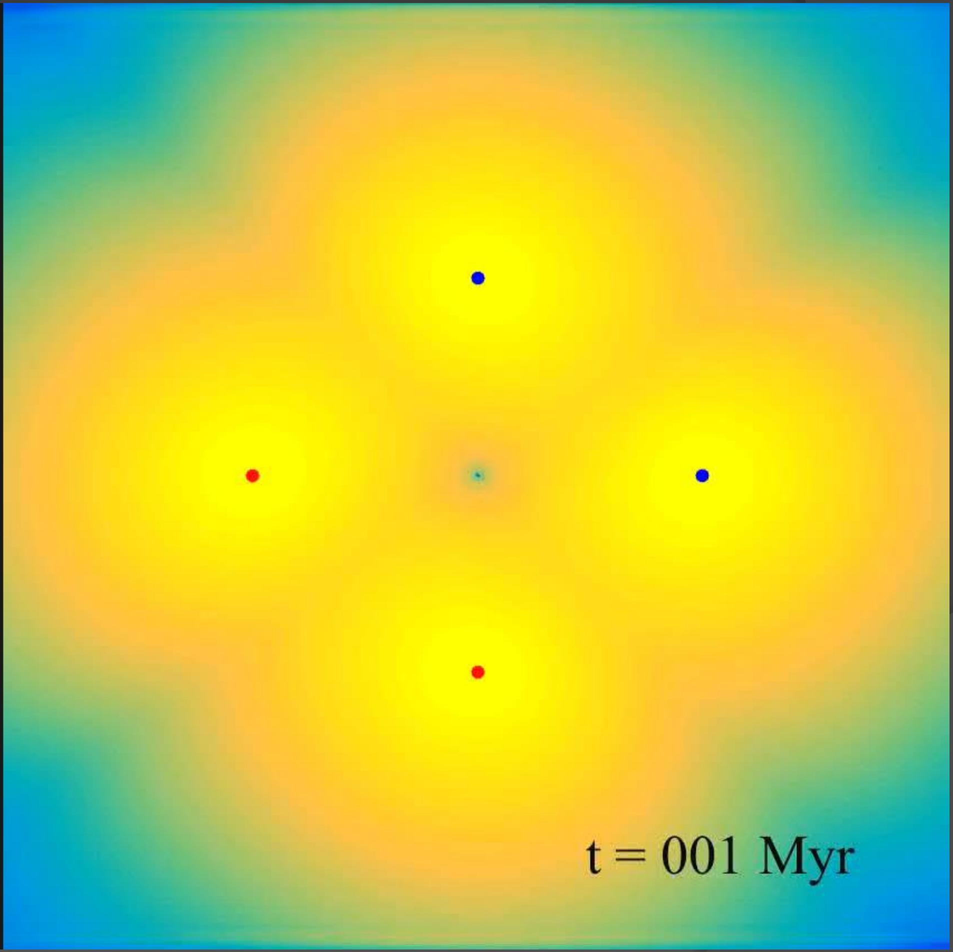
- Numerical integration of Schrodinger-Poisson equation.
- Stars as test particles

Soliton collision in phase opposition generating an offset

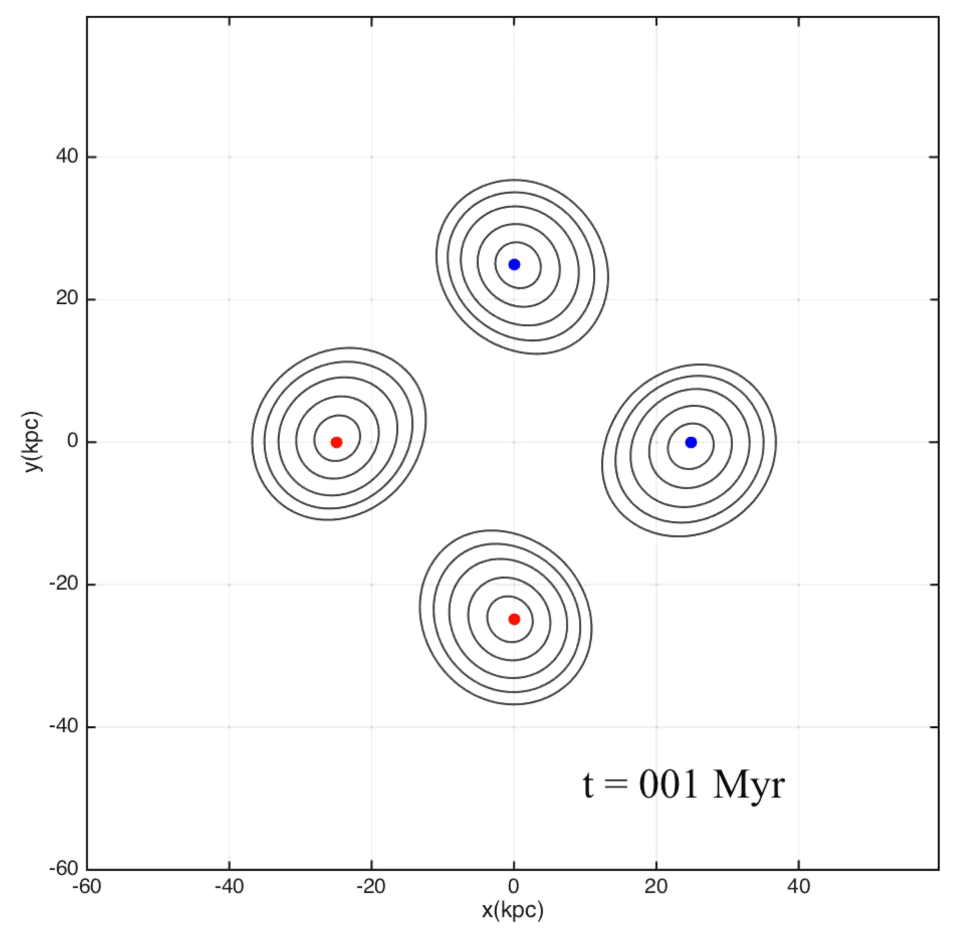


Offsets in a vortex-like configuration

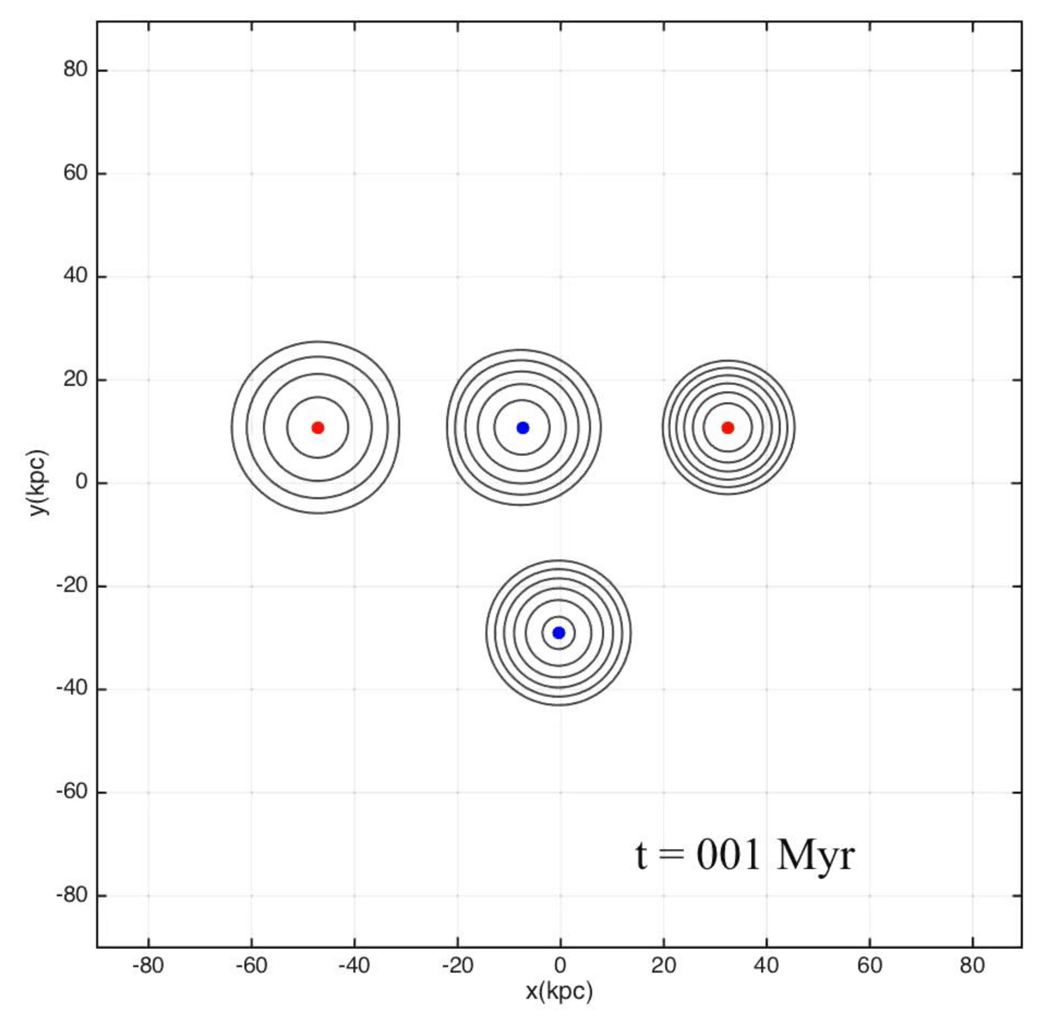




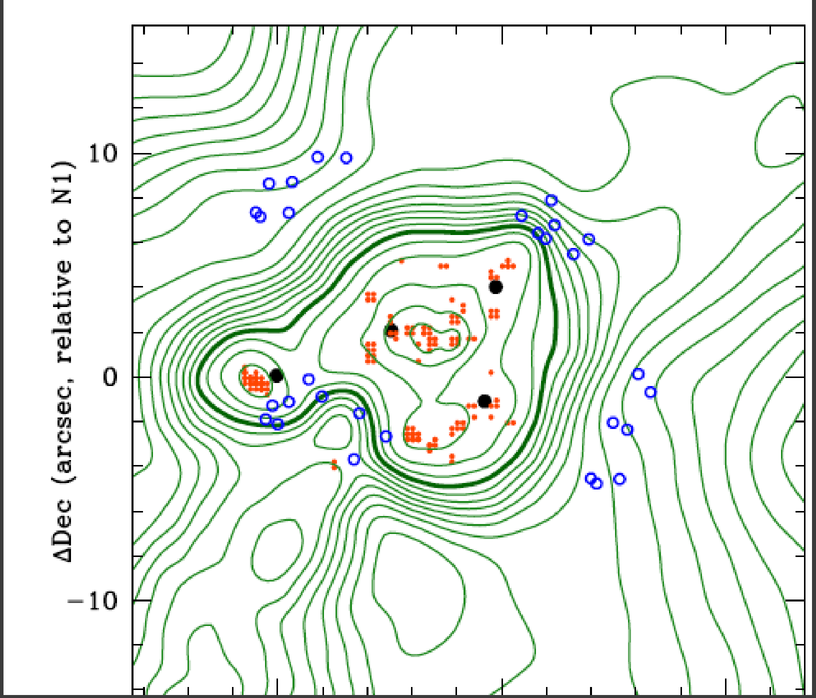
Offsets in a vortex-like configuration (again)



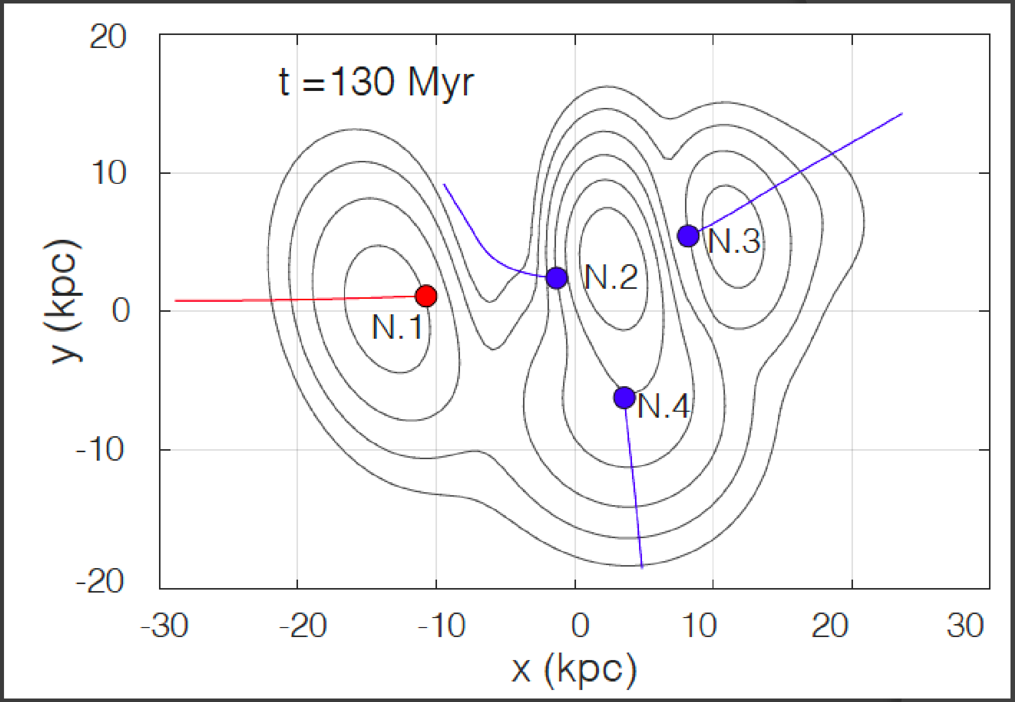
Dynamical generation of an offset similar to Abell 3827



Observations (potentially) explained



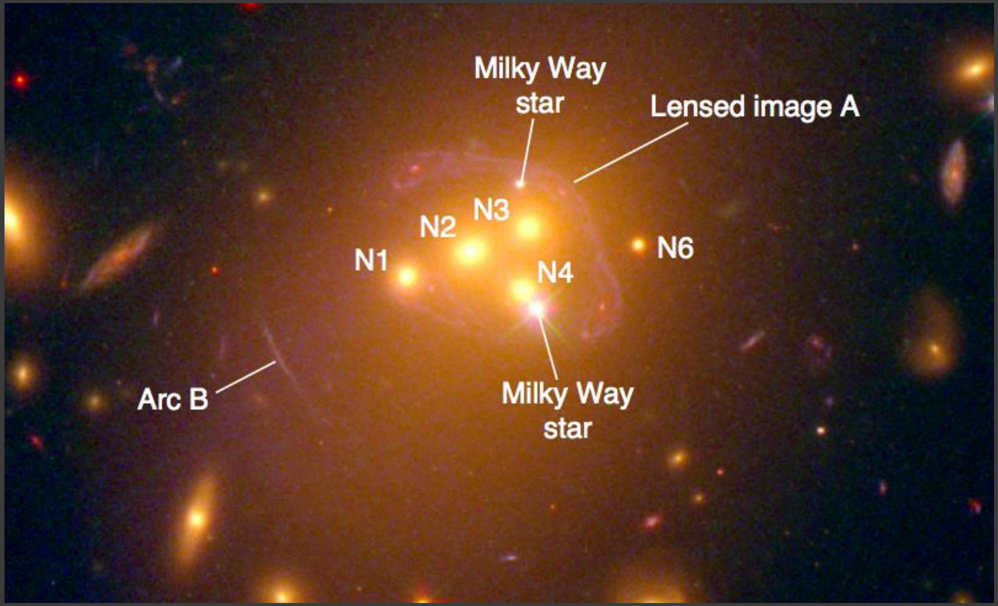
R. Massey et al., Mon. Not. R. Astron. Soc. 449, 3393 (2015)



Our model
(no fine tuning required)

What mass do we need for that?

$$M_{sol}d_{sol} \approx \frac{5.36\hbar^2}{m_a^2 G} \approx 4.6 \times 10^{10} \left(\frac{m_a c^2}{10^{-23}\mathrm{eV}}\right)^{-2} \mathrm{kpc}M_\odot,$$



Masses of around 10^{11} solar masses separated by 10 kpc

$$m_a c^2 \approx 2 \times 10^{-24}\mathrm{eV}$$

Conclusions

- Ultralight axions are plausible candidates for dark matter. They behave as a nonlinear wave.
- For $m_a \approx 10^{-22}$ eV, they modify ΛCDM at the galactic scale.
- Collisional dynamics of galaxies is affected by the wave-like behaviour: possible role for galactic offsets.

Notes

- QCD axions and other ALPS might satisfy the same (or very similar) wave equation !! Does that have any implication?

A.H. Guth, M.P. Hertzberg, C. Prescod-Weinstein, Physical Review D, 92, 103513 (2015)

- Interesting scenario for laboratory analogues of cosmic phenomena.

A. Navarrete, A. Paredes, J.R. Salgueiro, H. Michinel, "Spatial solitons in thermo-optical media from the nonlinear Schrodinger-Poisson equation and dark matter analogues"

- Thanks for your attention !
- Questions/comments?
- Lunch time!