Unveiling the Nature of Dark Matter and Dark Energy

Luca VISINELLI

Tsung-Dao Lee Institute and School of Physics & Astronomy, SJTU

luca.visinelli@sjtu.edu.cn

https://lucavisinelli.com

Short Bio:

- From Fall 2021: T. D. Lee Fellow, A&A Division
- 2020-Today: Fellini Fellow, Frascati National Laboratories
- 2019-20: GRAPPA Fellow, University of Amsterdam (with C. Weniger)
- 2016-19: Postdoc, Nordic Institute for Theoretical Physics (NORDITA), Stockholm (with K. Freese)
- 2013-15: Postdoc, Euro-Mediterranean Centre on Climate Changes (CMCC), Bologna (with S. Masina)
- Ph.D. 2011, The University of Utah (USA) (with P. Gondolo)

Research interests

I am a theoretical physicist working at the interface of particle physics, astrophysics, and cosmology.
My research directions explore the possibility that **new physics** exists beyond the Standard Model (SM) of particle physics, using data from astrophysics and cosmology.

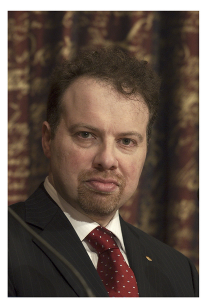
I want to answer the following questions:

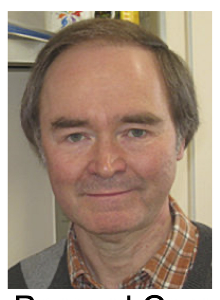
- What are the dark matter and the dark energy?
- What is the interplay between dark matter and black holes?
- Can we learn new physics using black hole imaging and spin?
- How did inflation proceed in the very early Universe?

Some high-profile collaborators


Katherine Freese
U Texas Austin & Stockholm U


Tsutomu Yanagida
TDLI & Tokyo U, IPMU


Adam Riess
Johns Hopkins U

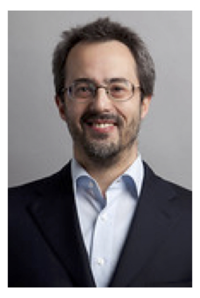

Bernard Carr
Queen Mary University of London


Anne-Christine Davis
Cambridge University


Frank Wilczek
MIT & TDLI & Stockholm & ASU


Ulf Danielsson
Uppsala U


Christoph Weniger
University of Amsterdam


Paolo Gondolo
Utah U

Publication summary

I have published 34 papers on astrophysics and cosmology.
7 (13) papers have more than 100 (50) citations
(Source: HEP-Inspire, July 2021).

	All	Since 2016
Citations	1950	1779
h-index	28	27
i10-index	36	36

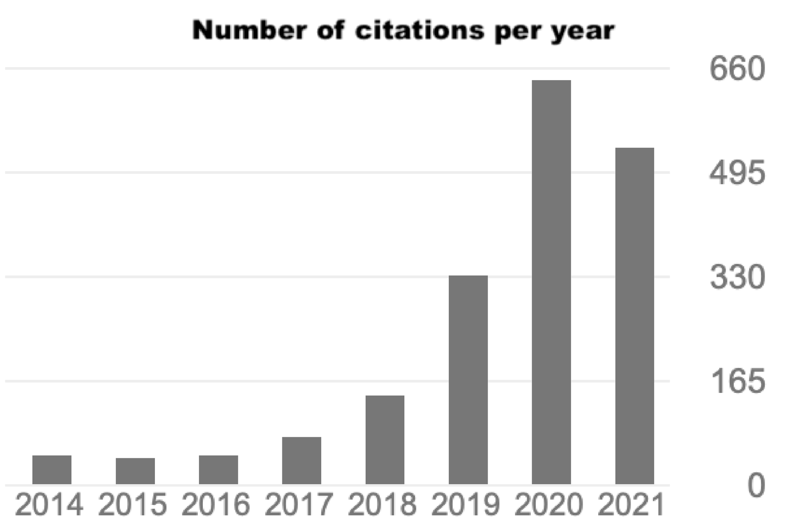


Figure 1: My citations are constantly growing every year.

Past students

- Nicklas Ramberg (Master student, Uppsala U) now Ph.D. student at Mainz U
- Co-supervised:Sunny Vagnozzi (Ph.D. student, Stockholm U)
- Co-supervised: Janina Renk (Ph.D. student, Stockholm U)

One dark matter candidate: the axion

Background and my past work

The QCD axion is a hypothetical extremely light particle that addresses internal problems in QCD.
The axion behaves as dark matter once coherent oscillations of its field start:

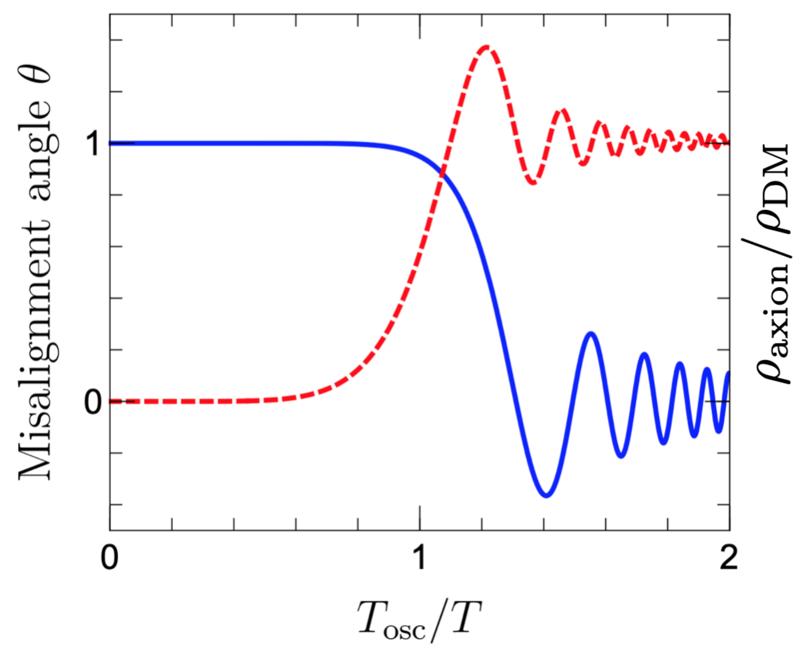


Figure 2: The axion angle θ (blue solid line) and the energy density of axions in units of the present DM energy density (red dashed line), as a function of the inverse plasma temperature in units of $T_{\rm osc}$.

I have worked extensively on axion DM, with some of my most important achievements summarized as follows:

OPEN QUESTIONS	MY ACHIEVEMENTS	IMPACT
Do axions exist? Are they a sizeable part of the dark matter in the Universe? How can we test this?	I proposed various techniques for testing the existence of axions in cosmology, astrophysics, and in the laboratory.	**Recognized leading expert:** di Luzio, Giannotti, Nardi, Visinelli, Phys. Rept. **870**, 1-117 (2020) 100+ citations
On which conditions do axions make up the dark matter in the Universe?	I have computed for the first time the abundance of axion dark matter in models beyond ΛCDM. I have refined the computations in the standard scenario.	**Some highly cited papers:** Visinelli&Gondolo, PRD **80** 035024 (2009), 176 citations Gondolo&Visinelli, PRL **113** 011802 (2014), 113 citations Visinelli&Vagnozzi, PRD **99** 063517 (2019), 54 citations
Do axions form bound self-gravitating structures? What is the role of self-interaction? What is the inner distribution of these objects?	Assessed the configuration, the size and the mass of substructures (axion miniclusters and axion stars) in the Galaxy	**Some highly cited papers:** Visinelli+ PLB **777**, 64 (2018) 103 citations

Figure 3: Open questions on axions and the impact of my solutions.

Current research: axions and neutron stars

- Axions couple to photons, giving rise to new electromagnetic phenomena.
- Axions might convert into a radio signal inside the magnetic field of a neutron star.
- Is it possible to pick up this unique signature?
- I am exploring this possibility both from theory and from collaborating with an international effort to collect radio data.
- At TDLI, I also plan to search for this unique signature using facilities located in China.

Figure 4: A representation of a neutron star.

Axions and dark energy

- We have observed the accelerated expansion of the Universe since 1998, thanks to the measurements of receding supernovae. We believe this is the action of dark energy.
- We do not know much about the nature of dark energy. Is it a cosmological constant, a quintessence field, a modification of gravity, a phantom field, or what else?
- An extremely light boson of mass of the order of the Hubble constant $m \sim H_0$ would behave as a dark energy component.
- Light bosons can manifest from an underlying theory of quantum gravity and could be used as a probe [1].
- Axions as dark energy predict unique features that will soon be within reach of tests [2].

Dark energy phenomenology

Can **dark energy** be detected in the laboratory?
I have explored the possibility that quanta of a chameleon-like field can be produced in the Sun, propagating towards Earth and interacting with an experimental apparatus like XENON1T [3].

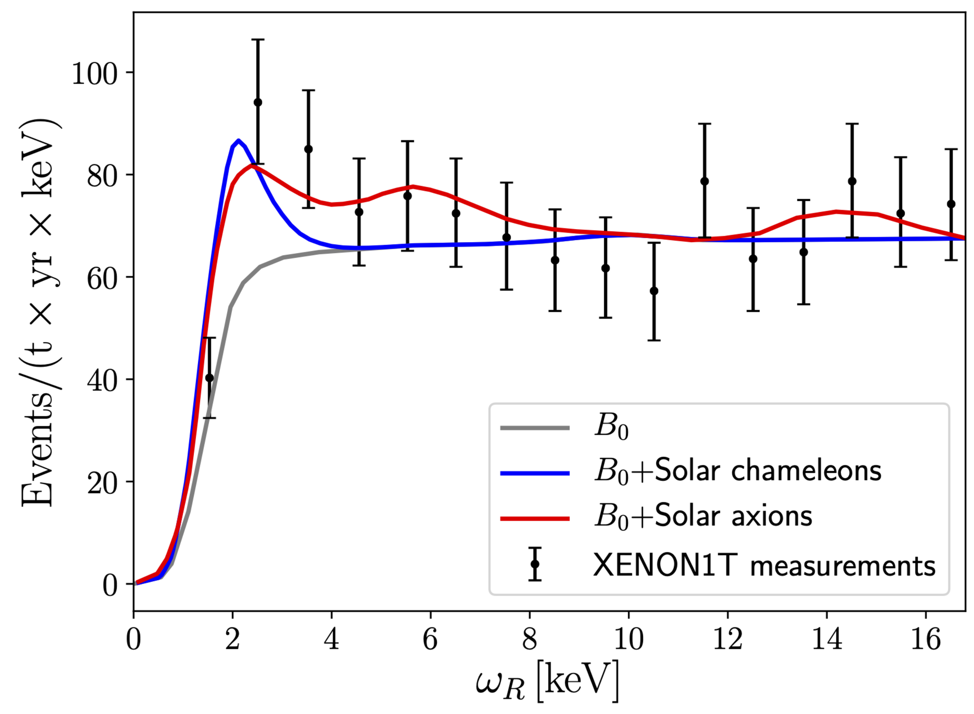


Figure 5: Expected rate of detection for solar chameleons (blue) and solar axions (red) in the XENON1T apparatus.

Dark matter and black hole physics

We expect dark matter to aggregate around **black holes** (BHs) formed in the early Universe.
In this scenario, we can look for the γ-ray annihilation of DM around these dense structures [4, 5].

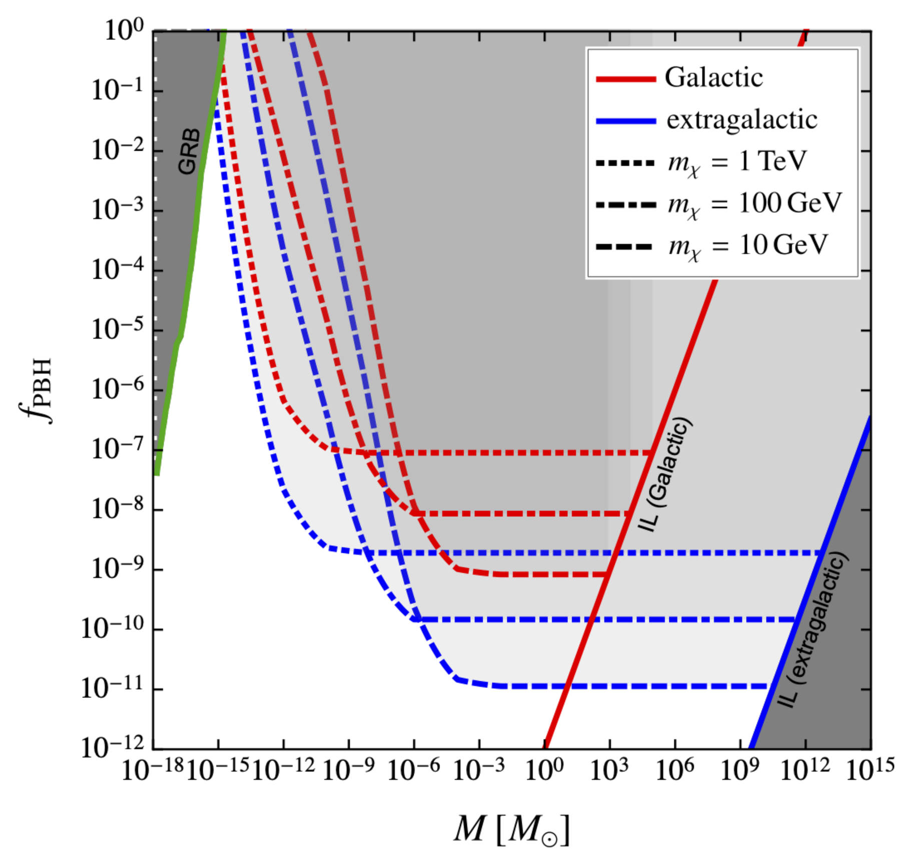


Figure 6: Constraints on the fraction of BHs $f_{\rm PBH}$ as a function of their mass from Galactic (red) or extragalactic (blue) γ-ray background and DM mass.

Conclusions

The future is exciting: more methods to probe the dark sectors are being developed. I plan to be protagonist on this search, training students in the process.
The potential rewards of my research are:

1. If a new light boson is discovered, its key features would shed light on the details of the new physics
2. A cosmic background of light bosons could be part of the dark sectors observed (dark matter and dark energy)
3. If the QCD axion is discovered, it would solve a major problem in fundamental physics

References

[1] **L. Visinelli**, S. Vagnozzi, *Cosmological window onto the string axiverse and the supersymmetry breaking scale*, Phys. Rev. D **99** 6, 063517 (2019).

[2] G. Choi, W. Lin, **L. Visinelli**, T. T. Yanagida, *Cosmic Birefringence and Electroweak Axion Dark Energy*, submitted to Phys. Rev. Lett. (2021).

[3] S. Vagnozzi, **L. Visinelli**, P. Brax, A.-C. Davis, J. Sakstein, *Direct detection of dark energy: the XENON1T excess and future prospects*, submitted to Phys. Rev. D (2021).

[4] B. Carr, F. Kühnel, **L. Visinelli**, *Black Holes and WIMPs: All or Nothing or Something Else*, to appear on Mon. Not. Roy. Astron. Soc. (2021).

[5] B. Carr, F. Kühnel, **L. Visinelli**, *Constraints on Stupendously Large Black Holes*, Mon. Not. Roy. Astron. Soc. **501**, 2029 (2021).