Internship in ESA's Advanced Concepts Team
On
Dark Matter Density Inversion using AI Techniques

European Space Research and Technology Centre
ESA ESTEC

Candidates interested are encouraged to visit the ESA website:
www.esa.int/gsp/ACT/

Topic description

Dark matter may account for approximately 85% of the matter in the universe. Its presence is implied by diverse observed phenomena that cannot be explained using well accepted physical models except if some additional 'unseen' mass distribution is assumed.

A recent trend in the use of Deep Neural Networks [1-4] to gain insight on the dark matter distribution has shown how artificial intelligence methods can be of use to invert observations into plausible dark matter densities. Inverting complex physical observations to some underlying density is also the subject of a promising works [5-6] concerned with image reconstruction and gravity inversion. These methods have not been used yet by astronomers in relation with dark matter densities, a direction for further studies of certain interest.

The purpose of this internship is to assess a number of ideas that leverage Neural Radiance fields (NERF) and Neural Density Fields (geodesyNETs) type of artificial neural network trainings as to produce constraints on dark matter density distributions. Lensing effects as well as star accelerations and velocities will be looked at as observables to be inverted into the dark matter densities.
According to the details of a few proposed and most promising directions, a simulated universe will be used to produce synthetic data as well as real observations from the latest astronomical campaigns.

Candidate's tasks

- Review all indirect dark matter observations.
- Propose a number of inversion schemes based on modern AI techniques.
- Perform, either on simulation or from real data, a preliminary assessment of the capabilities of the most promising a technique.

The ideal candidate

- Knowledge on classical gravity.
- Knowledge on dark matter astronomy.
- Passion for Physics and Astronomy.
- Knowledge on Deep Learning.

References

[1] Rivero AD, Dvorkin C. Direct detection of dark matter substructure in strong lens images with convolutional neural networks. Physical Review D. 2020 Jan 21;101(2):023515.
[2] Ramanah DK, Charnock T, Lavaux G. Painting halos from cosmic density fields of dark matter with physically motivated neural networks. Physical Review D. 2019 Aug 9;100(4):043515.
[3] Alexander S, Gleyzer S, McDonough E, Toomey MW, Usai E. Deep Learning the Morphology of Dark Matter Substructure. The Astrophysical Journal. 2020 Apr 8;893(1):15.
[4] Jeffrey N, Lanusse F, Lahav O, Starck JL. Deep learning dark matter map reconstructions from DES SV weak lensing data. Monthly Notices of the Royal Astronomical Society. 2020 Mar;492(4):5023-9.
[5] Mildenhall B, Srinivasan PP, Tancik M, Barron JT, Ramamoorthi R, Ng R. Nerf: Representing scenes as neural radiance fields for view synthesis. InEuropean conference on computer vision 2020 Aug 23 (pp. 405-421). Springer, Cham.
[6] Izzo D, Gómez P. Geodesy of irregular small bodies via neural density fields: geodesyNets. arXiv preprint arXiv:2105.13031. 2021 May 27.