esac trainees

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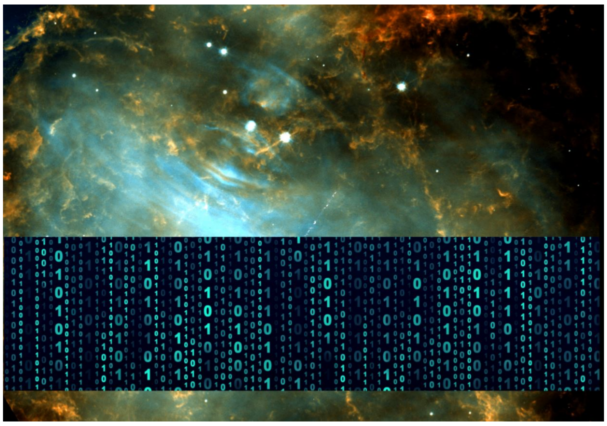
ASTRONOMY

1. AUTOMATIC IDENTIFICATION OF ASTRONOMICAL OBJECTS IN HST IMAGES WITH DEEP LEARNING

ESAC supervisor(s): Bruno Merín, Héctor Cánovas, Javier Durán, Sandor Kruk



The ESA data archive of the Hubble Space Telescope contains the full collection of over a million astronomical observations that have been produced over 29 years of observations, yielding more than 16,000 scientific publications and at least Nobel Prize.

So far, most of the searches through this and most other astronomical archives are based on metadata from the observations (date of observation, instrument, filter, proposer, target, etc), while there is an inmense amount of information content in the images that has not yet been fully exploited.

We propose to train a set of convolutional neural networks to perform automated classification of astronomical objects (e.g. stars, multiple stars, asteroids, nebulae, different types of galaxies, jets, etc) in images from the Hubble Space Telescope archive using our own astronomer expert assessments of pipeline products as training sets and then to apply it to create added-value metadata for complete mission datasets to enhance their scientific value. In the sort term, this classifier will be used to make optimal HiPS mosaics with the image collections (by identifying the most appropriate cut and stretch functions, possible astrometric offsets and the type of field, like extragalactic or galactic, for each image for example). In the long-term, it will provide the department with hands-on experience in these new IA technologies for their potential application in e.g. other scientific projects or future advanced exploitation services for our data archives.

Project duration: 6 months.

Desirable expertise or programming language:

- Computer Science background specialized in Machine Learning and Data Science,
- Programming experience (python preferably, but other languages would be possible),
- Some knowledge about physics and/or astronomy would be an asset.

2. DETECTING GALAXY CLUSTERS IN SIMULATION DATA IN PREPARATION FOR THE EUCLID MISSION

ESAC supervisor(s): Lyndsay Old, Bruno Altieri, Ivan Valtchanov, Nuria Alvarez

Galaxy clusters are the largest gravitationally bound objects in the Universe, and as such, they trace the extreme peaks in the matter density field of the early Universe. Measuring their number density and clustering as a function of mass and cosmic time can not only tell us about the structures themselves, but also the physical laws that govern our Universe on the smallest and largest scales. Powerful upcoming missions like Euclid, LSST, JWST offer outstanding potential for both galaxy cluster cosmology and galaxy evolution. With these wide-field surveys, we are moving into an era where samples of hundreds of thousands of galaxy clusters will be available out to high redshift (up to when the Universe was only 1/5th of it’s current age). To detect these galaxy clusters in future survey data, several ‘cluster-finding’ techniques have been developed in the Euclid Consortium, and tested extensively on Euclid mock data. The authors of this work identified two highly competitive algorithms, but also call for investigation into systematic effects including deducing which galaxies are gravitationally bound to galaxy clusters (‘cluster membership’) etc., and the need to independently test the Euclid-selected cluster finding algorithms on different datasets.

In this project, the trainee will apply galaxy cluster-finding codes to mock galaxy catalogues with the goal of testing how well these algorithms detect galaxy clusters in well-characterised and independent mock datasets. Time-permitting, the trainee will investigate how well these algorithms deduce which galaxies are gravitationally bound to galaxy clusters.

The trainee will gain experience of research in astrophysics, and astrophysical datasets and practical knowledge of programming and statistics.

Project duration: 4-6 months

Desirable expertise or programming language:

- Programming experience (python is preferable, but other languages would be possible),
- Background or interest in extragalactic astronomy or cosmology,
- High level of proactivity.

3. ASTROMETRIC RESIDUALS ANALYSIS

ESAC supervisor(s): Jose Hernandez, Alex Bombrun

ESAC is responsible for the computation of the astrometric solution based on the Gaia observations using AGIS software. The astrometric solution is one component of a bigger optimisation problem that includes also millions of calibration parameters. The calibration models are defined and tuned by multiple analyses of the residuals. A typical example is the filtering of the bad data intervals. This process is currently done manually by some visual inspection of the data. In this project we propose to apply and develop machine learning algorithms to the automatisation of this task.

Project duration: 6 months

Desirable expertise or programming language:

- a bachelor degree in physics, mathematics, computer science or engineering,
- programming experience with Python.

4. CUBESAT: ATTITUDE DETERMINATION AND CONTROL SYSTEM

ESAC supervisor(s): Xavier Dupac, Julio Gallegos, Fernando Martín-Porqueras, Marcos López-Caniego

A CubeSat is a nano-satellite originally developed at Stanford and CalPoly (San Luis Obispo) Universities and was proposed as a project to support hands-on university-level space education and opportunities for low-cost space access
The prime objective of this project is to complement the attitude determination and control system based on reaction wheels with magneto-torquers; this will imply the construction of a Helmholtz cage for testing and working with the air-bearing demonstrator. The two sensor and actuator sets (gyro+RW and MS+MT) will work together to demonstrate the cubesat ADCS can achieve high accuracy in determining and controlling the attitude of the spacecraft for astronomical applications.
A ground station (GS) for cubesats (UHF/VHF/S-band) is operational since mid-2017 at ESAC. The cubesat communication system, including S-band for telemetry will be ready by early 2020 and you will work on testing the link between the ground station and the cubesat. You will be involved in other subsystems (power, on-board computer, etc.) and other activities of the group (microwave calibrators, patch-antenna development, etc.) according to your interest.

The main objectives are:

- Build the ADCS based on magneto-sensors and magneto-torquers
- Build a Helmholtz-cage to test the full ADCS system
- Test the link between GS and cubesat demonstrator.
- Command the cubesat attitude from the GS

Additionally, you will have the opportunity to design outreach activities for young students related to your work on the cubesat. You will have a great time learning and working on all aspects of the project.

Project duration: 6 months

Desirable expertise or programming language:

- C/Matlab/Simulink,
- use of microprocessors (ARM),
- control theory,
- knowledge of spacecraft systems engineering,
- basic knowledge of CMB experiments.

5. SUPER-RESOLUTION AND DE-NOISING OF XMM-NEWTON IMAGES USING MACHINE LEARNING TECHNIQUES

ESAC supervisor(s): Eva Verdugo, Ivan Valtchanov, Pedro Rodriguez, Maggie Lieu, Antonia Vojtekova

Nowadays significant advances in image restoration and de-noising are possible with machine learning (ML) techniques. There are methods based on convolutional neural networks (CNNs) with significant success at de-noising photographs obtained at non-optimal conditions (low light, short exposure time): the Learn to See in the Dark project. Successful application of ML methods achieved an increase of the resolution of digitally zoomed photographs: Zoom to Learn, Learn to Zoom project. During the ESAC traineeship in 2019, the "Learn to See in the Dark" approach was successfully implemented for astronomical images from the Hubble Space Telescope, achieving a factor of 1.3-1.5 in terms of signal-to-noise ratio for CNN produced denoised images (Vojteková et al, in preparation).
The goal of this project will be to use these ideas and to try and develop ML-based methods for super-resolution and denoising but on X-ray images from ESA's XMM-Newton space telescope. The X-ray images are in Poisson noise regime and have different properties in comparison with the images from optical telescopes, like the Hubble Space Telescope. The X-ray photons are recorded with their arrival time, position on the detector and their energy, so light-curves (i.e. the number of photons per time interval during the observation) and images in different spectral bands can be constructed. Incorporating these characteristics as inputs to the network and then deciding on the best network architecture will be challenging. The trained network could be used to improve the quality of the XMM-Newton images, both in terms of noise properties and higher spatial resolution for features in extended sources. As the XMM-Newton Science Archive contains observations spanning about 20 years, the amount of data is a goldmine for such projects. At the end of the day, improving the quality of the already available data is also of a great interest for the astronomical community and for the lasting legacy of the XMM-Newton.

The trainee will follow the ideas in "Learn to See in the Dark" and in "Zoom to Learn, Learn to Zoom" and implement, train, test and validate a neural network with suitable architecture to allow for inputs based on the characteristics of the XMM-Newton images.
The trainee will gain experience of research in astrophysics, use of science archives X-ray observations and data products, will learn or improve their knowledge and practical skills on using different machine learning frameworks.

Project duration: 6 months

Desirable expertise or programming language:

- Python, Tensorflow or other framework (desirable)
- Background or interest in astronomy and astronomical observations.

6. UNDERSTANDING THE X-RAY VARIABILITY OF BLACK HOLES

ESAC supervisor(s): Michael Parker, Gabriele Matzeu, Nuria Alvarez, Felix Fuerst, Andrew Lobban, Willam Alston

The supermassive black holes in the centers of galaxies feed on the surrounding gas and dust, radiating huge quantities of energy in all wavelengths, particularly in the UV and X-ray bands. Because the accreting material around the black hole gets hotter further in, the corresponding emission shifts to higher energies, so using X-ray telescopes allows us to study extreme physics close to the black hole.

Because this emission region is very compact, it can vary on short timescales. This variability gives us an alternative method for understanding the behaviour of astrophysical black holes. One of the most commonly used tools for this is the RMS or excess variance spectrum, a measure of the variability of a black hole as a function of X-ray photon energy. These spectra are easy to calculate, but hard to model: the standard spectral models normally fit to X-ray data are simply not appropriate for variability spectra.

The aim of this project is to develop tools and models corresponding to different physical processes, which can then be used to fit the RMS spectra of variable accreting black holes. The successful applicant will gain experience of research in astrophysics and practical knowledge of programming and software. If the project is successful, we anticipate publishing the results in the astrophysics literature, and if time permits the student will take a leading role in this.

Project duration: 3-6 months

Desirable expertise or programming language :

- Astronomy or physics background,
- familiarity with python.

7. THE HISTORIC X-RAY LIGHT CURVE OF THE BLAZARS MRK421 AND PKS2155-304 ON THE 20TH ANNIVERSARY OF XMM-NEWTON.

ESAC supervisor(s): Nuria Álvarez Crespo, Ignacio de La Calle

Active Galactic Nuclei (AGN) are active Supermassive Black Holes at the center of some galaxies. Their observed properties vary depending on their orientation toward our line of sight according to the Unification Model. A small fraction of AGNs show jets, a collimated flow of particles accelerated to velocities close to the speed of light. Blazars are AGNS in which the relativistic jet points towards our line of sight, so properties such variability and luminosity are relativistically boosted, making them the most energetic objects in the Universe. The X-ray observatory XMM-Newton uses the blazars Mrk 421 and PKS 2155-304 as calibration sources. The X-ray brightness of these blazars and their regular monitoring makes them ideal for the extraction of information at both long and short timescales.

The goal of this project is to contribute to the extraction of the historic light curves over 20 years of XMM-Newton data for both sources. Once this curve is extracted, it is possible to analyse variability and spectral properties in different states. Additionally, these sources have been monitored in the gamma-rays and their flaring states are well determined. Exploring potential correlation between the light curves of the X-ray and the higher energies could help us understand if both come from similar regions in the jet and hence if the physical processes responsible for both emissions are related. A comparison of the behavior of both sources is necessary to discern whether the conclusions are similar for both objects therefore extrapolable to more blazars or on the other hand there are peculiarities intrinsic to any of those sources.

The trainee will gain experience of research in astrophysics and X-ray analysis. After the completion of this project the student should be able to analyse and interpret X-ray data from XMM-Newton. Depending of the results, the outcome is potential to be published as a refereed paper.

Project duration: 4-6 months

Desirable expertise or programming language:

- Basic Astrophysics background
- Linux at user level
- Good level of English, spoken and written, is required
- Perl, Python and XSPEC will be used to simplify tasks and produce the desired output, so familiarity with any of these tools is desirable