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Summer 2022 Internship projects

Summer intern applicants should chose 3 projects from this list, which they are interested in. **Write a total of 1 page (!)**, why these 3 projects have caught your interest and why you are qualified to work on these projects. Each project has a different supervisor.

Understanding the formation and evolution of Milky Way and Andromeda-like galaxies with the TNG50 simulation

Project description:

In my team, over the past few years we have been focusing in extracting useful scientific results from the IllustrisTNG simulations: `https://www.tng-project.org/`, with a focus on the formation and evolution of galaxies in the cosmological context.

For a summer internship, I propose an analysis project based on the TNG50 cosmological simulation, which samples hundreds of massive galaxies (like our own Milky Way and above) while simultaneously resolving details of their internal structures.

Depending on the preference of the student, a summer project in my team could be related to ideas like the following, all focused on late-type galaxies similar to our Galaxy or Andromeda:

- What is the connection between stellar bars and“bars” in the gas phase?
- How do the physical and star-formation properties of the gas change within a galaxy body, i.e. across spiral arms, in the bar region or in the interarms?
- Are the physical and star-formation properties of the gas different between barred and non-barred galaxies?
- How do bars funnel gas towards the galaxy centres?
- Can we construct a machine-learning algorithm that replicates the visual inspection of galaxies for the identification of bars vs. Non-barred galaxies, e.g. with the Manga survey?
- How many disk stars MW/M31-like galaxies have been produced in-situ vs. Accreted from satellites and mergers?
- Etc.

See `https://www.tng-project.org/results/` for examples of scientific questions that can be addressed with our simulations.

Technically, the completion of the summer project would allow a student to become effective and efficient in coding e.g. in Python, also remotely at our supercomputers, to become familiar and proficient in analysing large and complex datasets, to learn how to make sense of the many physical phenomena that we think determine galaxy evolution, and to become familiar with the numerical and physics foundation of cosmological simulations for galaxy physics.

Desired skills:

Some knowledge in coding scripts e.g. with Python.
Some familiarity with working via Terminal.

Example reading materials

`https://ui.adsabs.harvard.edu/abs/2019MNRAS.490.3196P/abstract`
`https://www.tng-project.org`

Atomic oxygen involved chemical reactions in interstellar ices

Project description:
Oxygen is the third most abundant element in the universe, and the chemical reactions involving oxygen atoms are essential in the chemical evolution of interstellar clouds. Many of these reactions happen in the solid-state in the ice mantle covering cosmic dust grain surface, particularly those related to complex organic molecules. However, few laboratory studies on atomic oxygen involved solid-state reactions are available. In the Origins of Life Laboratory, we employ an ultra-high vacuum setup to simulate the chemistry on dust grains. Oxygen atoms are produced in an atomic source and sent to a cold surface together with another molecule, and the reaction products are analyzed by a mass spectrometer and an infrared spectrometer. This project would generate valuable data for the astrochemical modeling of interstellar clouds.
The student would learn various laboratory techniques including ultra-high vacuum generation, molecular beam, infrared spectroscopy, quadrupole mass spectrometry, and cryogenics. He/she would also learn the background knowledge related to solid-state astrochemistry, such as the basic physical and chemical processes that governs the formation of molecules in interstellar clouds. Computer skills he/she would acquire include data analysis and visualization using Python and controlling instruments using LabVIEW program.

Desired skills:
Python programming is desirable. Previous laboratory experience is desirable but not mandatory.

Example reading materials
He, J., Vidali, G., Lemaire, J.L. and Garrod, R.T., 2015. Formation of hydroxylamine on dust grains via ammonia oxidation. The Astrophysical Journal, 799(1), p.49.

Searching for High–redshift Quasars with Unsupervised Machine Learning

Project description:
Quasars at the highest redshifts (z>5) are unique objects to study the growth of supermassive black holes, their co-evolution with the first galaxies, the intergalactic and circumgalactic medium gas in the first billion years of the Universe. The majority of these objects were discovered in the last 5 years, and about ~ 400 are known today. However, recent works suggest that the traditional broad-band selection techniques might be biased towards certain types of quasars and might miss gravitationally–lensed systems. This project will explore the application of unsupervised machine learning techniques to find missing high-z quasars in existing ground- and space-based imaging surveys. The best candidate objects will be proposed for follow-up spectroscopy with the LBT or ESO telescopes.

The student will become familiar with the science topics associated with high-redshift quasars: early supermassive black hole growth, quasar properties, evolution and broad-band selection methods, and the epoch of reionisation. They will develop their coding skills and get experience applying unsupervised machine learning techniques (KNNs, SOMs, CNNs, AutoEncoders, Contrastive Learning, ...) to large datasets of astronomical images (DES, PanSTARRS, WISE, ...).

Desired skills:
Knowledge of Python (or C, C++, Java, etc..). Knowledge of machine learning desirable, but not necessary.

Example reading materials
On the only high-z lensed quasar: https://arxiv.org/abs/1810.11924
Reviews on associated science topics (really optional):
IGM, CGM, EoR: https://arxiv.org/abs/1510.03368
Early SMBHs growth: https://arxiv.org/abs/2110.10175

Adding thermo-chemistry to a protoplanetary disk model

Project description:
The goal of this project is to add heating and cooling processes to an existing protoplanetary disk chemical model, e.g. endo- and exothermic reactions. Such reactions are important for modelling chemistry in hot, low density regions such as those which will be observed by JWST. The student will add new reaction types to the current chemical reaction network and write new functions to calculate these reaction rates, using the existing functions as a template. The student will then run tests to insure the new thermal calculations converge to realistic values. Finally, time permitting, the student will use the updated model to predict chemical abundances in the planet-forming region of protoplanetary disks.
The student will learn about the physical and chemical structure of protoplanetary disks. They will also gain experience with programming in Fortran and using ordinary differential equation based chemical models.

Desired skills:
This project requires moderate programming experience. Knowledge of Fortran is useful but not requried.

Example reading materials
Du and Bergin 2014 (https://arxiv.org/pdf/1408.2026.pdf) describes the equations for chemical heating and cooling we will use as a template for this project.

Modeling the transit spectra of hazy exo-Neptunes

Project description:
Most of the transmission spectra of Neptune-sized exoplanets that have been observed to date are strongly shaped by aerosols, likely photochemically produced hazes. JWST will soon observe several of these planets with unprecedented resolution and wavelength coverage. Leading up to these observations, we are using 3D general circulation models (GCMs) to model the distribution of photochemical hazes in the atmospheres of the planned JWST targets. In the project, the student will create transit spectra from the 3D model output. These model transit spectra will help with the interpretation of the planned JWST observations.
The student will learn to use a tool designed to calculate transit spectra from the output of 3D atmospheric simulations of exoplanets and gain experience in coding in Python and applying Python-based tools. Further, the student will develop a better understanding of exoplanet transit spectroscopy, how to compare models to observations and how to interpret and present simulation data. Co-authorship of a publication is anticipated.

Desired skills:
basic programming skills required, knowledge of Python (including Numpy, SciPy and Matplotlib) highly desired

Example reading materials:

1. On 3D models of photochemical hazes:
   Steinrueck, M. E., Showman, A. P., Lavvas, P., Koskinen, T., Zhang, X., Tan, X. (2021): 3D Simulations of Photochemical Hazes in the Atmosphere of Hot Jupiter HD 189733b. Monthly Notices of the Royal Astronomical Society, 504, 2783–2799, doi:10.1093/mnras/stab1053. (Journal version | arXiv version)
2. On the observational motivation:
   Crossfield, I. J. M. and Kreidberg, L. (2017): Trends in Atmospheric Properties of Neptune-size Exoplanets. The Astronomical Journal, 154:261, doi:10.3847/1538–3881/aa9279. (Journal version | arXiv version)

Systematic search for positive age gradient in galaxies

Project description:
An interesting positive age gradient has been recently found in the outskirt of some nearby galaxies and also in our home galaxy, the Milky Way. The resolved and detailed observations of the Milky Way suggest that this positive age gradient is very likely due to radial migration of stars, an important secular process in galaxy evolution that is poorly constrained by observations, especially in external galaxies. The goal of this project is to improve our understanding of radial migration in external galaxies by searching for and studying the positive age gradient in some of these systems. Instead of looking at a few nearby cases in detail, we aim for a systematic search for this feature in the local Universe utilising to date the largest spatially resolved spectroscopic survey of galaxies with integral field unit (IFU) observations, MaNGA, which has completed observations this year and will publish the final data release to the public in December, 2021. We will build a large sample of galaxies with robust detection of positive age gradient in the outskirt and study the frequency of this feature in galaxies and its dependence on galaxy properties.
This internship program will help the student to get an idea of academic life and research in astronomy. Specifically from this project, the student will learn about the data product of IFU observations and stellar population synthesis, and how to work with large, high-dimensional data.

Desired skills:

Some basic knowledge of python will be ideal, but not required, to work on this project.

Example reading materials

For a better understanding of this project before start, it would be helpful to read this paper, Ruiz-Lara et al. 2017[1], which studied the signature of radial migration, including positive age gradient, in a sample of ∼200 galaxies in CALIFA IFU survey.

[1]https://www.aanda.org/articles/aa/pdf/2017/08/aa30705-17.pdf

3D evolution of the molecular clouds in the Milky Way

Project description:

For centuries, molecular clouds have been studied in the solar neighbourhood; yet most of our understanding is limited to the projected two-dimensional view. Recent Gaia space mission provides us with a unique opportunity to add new dimensions to our analysis. It delivers astrometric information with unprecedented accuracy that allows detailed studies of the local molecular clouds in the Milky Way. In this project, we will explore the 3D structure of some of the nearby, star-forming regions. We will use state-of-the-art 3D dust maps to determine different components of the clouds along the line of sight. We will then use the Gaia data to get the 3D positions of different stellar populations and combine that with the clouds' components in order to understand star formation scenarios for nearby clouds.

The student will have the chance to work with the latest release of the Gaia data and gets familiar with challenges related to dealing with a large dataset of such. They will also gain an understanding of the physical processes involved in the lively field of star formation.

Desired skills:

Some coding skills and basic knowledge in Astronomy are desirable. In addition, some familiarity with stellar evolution and/or star formation would be helpful but is not required.

Example reading materials

The following paper can provide more details about the project:
Rezaei Kh. et al. 2020: https://arxiv.org/pdf/2007.01331.pdf

The Structure of the Milky Way behind the Galactic bar

Project description:

The characterisation of the structure of the Milky Way disc behind the Galactic bar is hampered by the extreme interstellar extinction that limits its analysis to the infrared regime. In this way, red clump stars are easily detectable in the near infrared and serve as distance estimators. Recent work by Gonzalez et al. (2018) used de-reddened VVV data to build a K_s luminosity function around the red clump feature in the Galactic plane. They detected the presence of a faint red clump peak that they interpret as a spiral arm beyond the Galactic bar ($\sim 12 - 13\,\text{kpc}$ from the Sun). In this project, we aim to explore alternative scenarios to explain the secondary red clump peak, such as the existence of stellar populations with different ages and/or metallicities, and the presence of red giant branch stars.

The student will learn how to: 1) Work with near infrared photometry. 2) Correct for extinction creating extinction maps. 3) Create de-reddened luminosity functions and fit them with models. 4) Estimate the extinction towards different stellar populations.

Desired skills:

A good knowledge of some programming language (e.g. python, IDL) as well as some basic astronomical concepts would be desirable.

Example reading materials

Gonzalez, O. A., Minniti, D., Valenti, E., et al. 2018, MNRAS, 481, L130

Nogueras-Lara, F., Schoedel, R., Dong, H., et al. 2018b, A&A, 620, A83

Nogueras-Lara, F., Schoedel, R., Gallego-Calvente, A. T., et al. 2020a, Nature Astronomy, 4, 377

Data reduction and imaging of H I data

Project description:
Molecular clouds (MCs) in the vicinity of the sun are ideal laboratories to study the process of star formation and the cycle of matter in the interstellar medium (ISM). Utilizing an interferometer at cm wavelength, the Very Large Array (VLA), we have conducted a survey of H I, OH, radio recombination lines, and radio continuum observations within the scope of the Orion and nearby clouds Dynamics of Ionized and Neutral gas program (ODIN).
In order to interpret the data in an astronomical and physical sense, we need to calibrate, reduce, and image the raw data. We are therefore looking for a student who would like to gain first experience and/or deepen their skills in the data reduction process of interferometric H I observations. Furthermore, the student will be involved in the interpretation of the results. This is an exciting project diving into the understanding of interferometry as well as the physics of the interstellar medium.
The student will gain hands-on experience in working with observational data. The python-based CASA package will be used to conduct the data reduction of H I observations obtained with the VLA.

Desired skills:
basic knowledge of python; some experience with the Common Astronomy Software Applications (CASA) would be preferable (but is not a must!)

Example reading materials
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