The ionized-gas content of the edge-on spiral galaxy NGC 3501

Project description:

Context: The vertical structure of disk galaxies can be best studied when they are seen edge on. The edge-on spiral galaxy NGC 3501 is a young star-forming galaxy with apparently no complex (thin and thick-disk) structure (according to a previous morphological decomposition from Comerón et al. 2018). Using deep integral-field spectroscopy MUSE (`https://www.eso.org/sci/facilities/develop/instruments/muse.html`) data covering half of the galaxy with two pointings, we have mapped the stellar-population parameters (stellar age, metallicity and [Mg/Fe] abundance) and extracted the spatially resolved star-formation history. These results display important differences between different regions of the galaxy and suggest this young galaxy is forming an additional inner and thinner disk component (Sattler, Pinna et al., subm.). This project aims at adding another piece of the puzzle of the history of this galaxy, by extracting and analyzing spatially resolved properties of the ionized gas from our high-quality MUSE data.

Specific objectives and tasks: The proposed project is modular and the student can complete as many steps as the internship time and their previous knowledge allow them. The very first step would be to fit the emission lines in the spectra, to extract the spatial distribution of the ionized gas and its spatially resolved fluxes and kinematics. A second step would be to estimate the Balmer decrement (e.g., Groves et al. 2012) in order to map the intrinsic extinction of the galaxy caused by its dust. This will be necessary to correct the emission-line measurements. Then the student would produce a Baldwin, Phillips & Terlevich (BPT) diagram (Baldwin et al. 1981) to identify star-forming spaxels and map them. For those spaxels, the student will then compute and map the star formation rate (SFR) and gas-phase metallicity, and look at vertical and radial gradients. The student will qualitatively compare the stellar and gas components and look for correlations or anticorrelations of gas properties (velocity, velocity dispersion, SFR, metallicity) with the stellar properties in Sattler et al. (subm.). This will provide important insights on the past, present and future history of this intriguing spiral galaxy.

What the student will learn: The student will learn or expand their knowledge on how to handle integral-field spectroscopy data and extract ionized-gas properties from them. In particular, how to use emission-line fitting codes like GandALF (Sarzi et al. 2006). Then they will learn how to measure spatially resolved emission-line properties and interpret BPT diagrams, SFRs and gas metallicity. The interpretation and scientific discussion of the results will introduce them or expand their knowledge on the topic of galaxy evolution in general. The student will be invited to join our group meetings (in addition to all other MPIA activities), learn about different topics and techniques, and interact with all members of the group.

Desired skills:

Basic programming skills in Python will be necessary for this project. Although advanced programming skills are not necessary for this project, the more skilled the student is in Python, the faster the project will go and more steps will be performed by the student in a shorter time. Some experience in handling spectroscopic data or in galaxy evolution will help with the interpretation of the data and would be also positively valued (but it is not a requirement).

Example reading materials:

If the student is interested in knowing more, they can just use the references included in the text. Our first paper on this data will also appear soon on the ArXiv (Sattler, Pinna et al., subm.)

Formation of complex organic molecules via atom addition reactions

Project description:
Ice mantles on cosmic dust grains are the most important factories of interstellar complex organic molecules (COMs). So far, almost 300 molecules have been identified in the interstellar and circumstellar medium, and most of them are considered COMs. Although identified in the gas phase, many of them are formed in ice mantles on cosmic dust grains via solid state chemical reactions. In the Origins of Life Laboratory, we employ an ultra-high vacuum setup to simulate the chemistry on dust grains. Hydrogen or 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., Simons, M., Fedoseev, G., et al. 2022, AA, 659, A65. doi:10.1051/0004-6361/202142414
He, J., Toriello, F. E., Emtiaz, S. M., et al. 2021, ApJL, 915, L23. doi:10.3847/2041-8213/ac0a7c

Can stellar bars help the Milky Way ‘breathe’? - a quest with N-body simulations

Project description:

The ongoing Gaia mission (along with past Galactic surveys - SEGUE, RAVE, LAMOST) has revealed the presence of large-scale bulk vertical motions with stars on both sides of the Galactic mid-plane moving coherently towards or away from it - a trend which bears a close resemblance with the human respiratory mechanism. The existence of such non-zero bulk vertical motions in the Milky Way raises questions about the plausible driving mechanism(s), since, in an axisymmetric potential, the bulk vertical motions should be zero. Past theoretical efforts revealed that an $m = 2$ spiral density wave can drive such vertical breathing motion in Milky Way-like galaxies. While some recent studies have indicated an $m = 2$ stellar bar can also excite such breathing motions, however, a systematic study of bar-driven breathing motions is still largely missing. Within the framework of this project, we plan to carry out a careful, thorough investigation of characterising such bar-driven breathing motions by making use of a fiducial N-body model of a barred galaxy as well as using another high-resolution model which reproduced many observable properties of the Milky Way. The broad roadmap of this project is to quantify the properties of bar-driven breathing motion, how its strength and extent might have evolved with bar’s properties (e.g., strength, extent, pattern speed) and more importantly, implications of the findings on explaining the breathing motion observed in the Milky Way.

Within this project, the student will have the opportunity to gain first-hand experience in handling N-body simulation data and the associated post-processing techniques. In addition, there is an ample scope to gain theoretical knowledge about galactic dynamics, in particular, Milky Way’s dynamics and its connection with the ongoing Gaia mission.

Desired skills:

A good programming skill in Python is highly desirable. Additionally, a basic understanding of fluid dynamics and Classical Mechanics is preferred.

Example reading materials

A brief acquaintance with the following papers will be particularly beneficial for carrying out the project.

- Debattista, V. P., 2014, MNRAS Letters, Vol. 443, p. L1-L5
- Ghosh S. et al., 2022, MNRAS, Volume 511, Issue 1, pp.784-799
- Kumar A., Ghosh S. et al., MNRAS, 2022, Volume 516, Issue 1, pp.1114-1126

Improving the Orbits of Substellar Companions

Project description:

The goal of the project is to study the orbits of substellar companions (brown dwarfs and exoplanets) as well as stellar binaries on decades-long orbits. We will focus on systems with lots of data from multiple methods: radial velocities of the host star, astrometric information for the host star, and images of the companion that allow the relative positions to be derived. In general, for these systems there is lots of data - but the data covers only a limited portion of the orbit. For the project, we will pose two questions: (1) for a given system, which *new* data would be the most useful in improving our understanding of the orbits? Should we focus on collecting new radial velocities, new astrometry, or new images? (2) are there scenarios where the incomplete orbit introduces biases? Which *new* data would be the most useful in resolving those biases? There may also be the opportunity to work on brand new JWST data - the supervisor is leading an upcoming JWST project to image an exoplanet, for which orbit analysis will be an important part of understanding the system.

The student will learn about exoplanet orbits, and how these can be used to understand exoplanet populations. The student will learn to understand both radial velocity data and high-contrast imaging data in the context of exoplanets. The student will work with a pre-existing orbit fitting package and learn to work on collaborative code projects using tools such as github.

Desired skills:

Knowledge of python preferred (but not required).

Example reading materials

Rickman, Matthews et al. 2022: *Precise dynamical masses of new directly imaged companions from combining relative astrometry, radial velocities, and Hipparcos-Gaia eDR3 accelerations*
Available here: https://ui.adsabs.harvard.edu/abs/2022arXiv220912957R/abstract

Disky origins? Probing young Milky Ways with JWST

Project description:
Our understanding of the earliest phase in the formation of galaxies like our own Milky Way is still highly uncertain. What did these young galaxies look like? Did they form as disks from the start, or did the turbulent bulge emerge first? Since its launch, the James Webb Space Telescope (JWST) has already delivered a wealth of data with which we can finally begin to tackle these questions: these data resolve the stellar light from faint high-redshift galaxies that will have grown into Milky Way-like galaxies by the present day. This project will leverage high-resolution images from JWST to study low-mass galaxies at high redshifts. You will work on constructing models of the morphologies of these galaxies to quantify their shapes, sizes, and light profiles. Combined with measurements of other key properties, such as the colour and mass, this will provide crucial insight into the structural evolution of galaxies at early epochs.
In this project, the student will learn to analyse and interpret data from large surveys of high-redshift galaxies. This will entail working with catalogues, images, and relevant tools (e.g. topcat, pandas, astropy). The main component of the project will be to perform morphological fitting to imaging data, using readily available tools (e.g. galfit) that the student will have to learn to use and automate.

Desired skills:
Experience with python; some prior research experience and/or practical course work with a focus on data analysis.

Example reading materials

https://arxiv.org/abs/2210.01110

The Metallicity distribution of the Milky Way Nuclear Star Cluster

Project description:

In the center of the Milky Way there is a dense star cluster with a mass of $\sim 3 \cdot 10^7$ $M_\odot$, the so-called nuclear star cluster (NSC). The metallicity of about $\sim$1300 stars in the NSC was measured by fitting their spectra: Most stars have a higher metallicity than the sun, i.e., they have super-solar metallicities ([M/H]>0 dex), and about 15% of the stars have a lower metallicity than the sun, i.e., they have sub-solar metallicities ([M/H]$\sim$-1.5 to 0 dex). Interestingly, the sub-solar metallicity stars are not distributed uniformly in the NSC: In the North-Western region of the NSC, more than 20% of the stars have sub-solar metallicities, but only $\lesssim$10% of the stars in the South-Eastern region. In addition, sub-solar metallicity stars rotate faster compared to super-solar metallicity stars. These findings suggest that sub-solar metallicity stars originate from a merged star cluster or a dwarf galaxy. We obtained new spectra of almost 1000 stars, located in so far uncovered regions of the NSC, and we intend to investigate how far out the over-density of sub-solar metallicity stars extends in the NSC.

The goals of this project are to 1) measure the metallicities and line-of-sight velocities of almost 1000 stars in the NSC on new K-band spectra, 2) compare the metallicity and velocity distribution in different regions of the NSC, and 3) compare the stellar kinematics of sub- and super-solar metallicity stars.
The student will learn to analyze spectroscopic data using the full-spectral fitting code STARKIT (written in PYTHON), and to visualize the data by creating maps and histograms of various measurements (e.g. metallicity).

Desired skills:
Some knowledge of a programming language would be desirable. Existing code is written in PYTHON and IDL.

Example reading materials

Feldmeier-Krause, A., et al. (2020) "Asymmetric spatial distribution of subsolar metallicity stars in the Milky Way nuclear star cluster", MNRAS, 494, 396
Feldmeier-Krause, A., et al. (2017) "KMOS view of the Galactic Centre - II. Metallicity distribution of late-type stars", MNRAS, 464, 194

Searching for Complex Molecules in a Protoplanetary Disk

Project description:

Complex organic molecules (COMs), those with six or more atoms, are observed throughout the ISM, in starless cores, and in comets. A subclass of COMs called prebiotic molecules are thought to be involved in the processes leading to the origins of life. To date, very few COMs have been observed in protoplanetary disks, the sites of planet formation. In this project the student will hunt for COMs in the protoplanetary disk around the hot, rapidly accreting star V883 Ori using ALMA observations. The student will learn how to image spectroscopic ALMA data using in CASA. They will learn how to assign spectra to a given molecule. Finally, they will analyze weak spectral line emission in Python, using techniques such as Keplerian masking, spectral stacking, and matched filtering.

Desired skills:

Knowledge of Python is useful but not required for this project. Prior knowledge of spectroscopy and radio astronomy is also helpful.

Example reading materials

For an example of COMs previously detected in the V883 Ori disk see the paper by Jeong-Eun Lee et al. 2019 in Nature Astronomy.

Developing a tool for orbital characterization of exoplanets

Project description:
The detection and characterization of multi-planetary systems using high-precision transit and Radial Velocity (RVs) data is exciting research field. The discovery of new systems requires estimating the planetary orbital parameters more precisely by stability constraints and understanding the extrasolar planet formation, dynamics, and orbital evolution. However, analyzing high-precision Doppler/transit data consistent with multiple planet systems is often very challenging. It requires an understanding of many observational and astrophysical phenomena and also knowledge of statistics and coding.

Exo-Striker analyzes exoplanet orbitals, performs N-body simulations, and models the RV stellar reflex motion caused by dynamically interacting planets in multi-planetary systems. It is is a multi-functional fitting tool available to the astronomy community used with a user-friendly GUI, command line, or with jupyter/ipython, or as a stand-alone python lib. The Exo-Striker is currently in an advanced stage of development, but many parts of the code would benefit from more testing and debugging. The prospective student would incorporate new algorithms and ensure the code is well-documented and structured professionally.

More importantly, the student would also have the opportunity to do science while working on Exo-Striker! I have a large archival and propitiatory RV data taken with HARPS, FEROS, and CARMENES (open time), which surveys for multiple-planet systems. The student will be motivated to use the available RV data and those from TESS while testing Exo-Striker. Thus, during the summer internship at the MPIA the student is expected to gain strong knowledge in the exoplanet field.

Desired skills:
Candidates with good knowledge of Python, Fortran or C/C++ is strongly encouraged to apply.

Example reading materials
Exo-Striker exoplanet toolbox documentation Exo-Striker

Searching H-α and [OIII] emitters using JWST

Project description:
The evolution of the cosmic star formation rate density (SFRD) is one of the key elements to describe the history of the Universe. SFRD is well constrained at low redshift with a number of different tracers. However, at high redshifts ($z > 6$), most measurements are based only on the rest-frame UV luminosities. JWST will make it possible to use star formation rate (SFR) tracers previously not accessible to observations. Using NIRCam on board JWST, it is possible to identify Hα and [OIII] emitters through the excess flux in the narrow band. Both emission lines can be used as SFR tracers. In June, 2023, the JWST-legacy narrow-band survey of H-α and [OIII] emitters in the epoch of reionization will be completed (GO program 2234). The survey covers the same area as the Cosmic Evolution Early Release Science survey (CEERS). The student will use publicly available CEERS data to learn to measure photometric redshifts and galaxy properties using spectral energy distribution fitting. The student will have an opportunity to work with the narrow band data after the survey is completed.

Desired skills:
Knowledge of python, matplotlib or another plotting tool.

Example reading materials
Finkelstein, S. L., Bagley, M. B., Ferguson, H. C., et al. 2022, arXiv:2211.05792