Galaxia-Proxima

Atlas Galaxia Proxima: Star formation history of the local Milky Way using Gaia DR3 and machine learning

Programm / Ausschreibung	ASAP, ASAP, ASAP 18. Ausschreibung (2021)	**Status**	abgeschlossen
Projektstart	01.08.2022	**Projektende**	10.02.2025
Zeitraum	2022 - 2025	**Projektlaufzeit**	31 Monate
Keywords	machine learning, stellar clusters, star formation, solar neighborhood		

Projektbeschreibung

Die Entstehung von Sternen ist eines der wichtigsten offenen Themen der Astrophysik. Es ist inzwischen gut belegt, dass die meisten Sterne in dichten Molekülwolken in Gruppen von einigen Dutzend bis zu Tausenden von Sternen entstehen. Das Verstaendnis des Ursprungs und der Entwicklung dieser stellaren Strukturen beeinflusst auch Theories zur Entstehung und Entwicklung von Galaxien. Da sie aus demselben Gas und unter ähnlichen Bedingungen entstanden sind, bieten Sternhaufen - stellare Strukturen mit gleicher Geschwindigkeit - ein einzigartiges Labor zur Untersuchung der Entstehung und Entwicklung von Sternen und Planeten.

Die Entflechtung und Extraktion stellarer Populationen ist bekanntermaßen ein schwieriges Unterfangen. Nichtsdestotrotz haben Gaia-Daten die Suche und Charakterisierung von stellaren Strukturen dank der Abdeckung des gesamten Himmels und der unübertroffenen astrometrischen Qualität enorm beeinflusst. Die präzisen Messungen haben die Entdeckung neuer Arten von Sternstrukturen und die Überprüfung und Validierung von Modellen im 3D-Raum in einer nie zuvor möglich Art und Weise ermöglicht. Aufgrund des enomen Ausmaßes der Gaia-Datenbank sind heuristische maschinelle Lernverfahren bei der Analyse und Erkennung von Sternstrukturen unersetzlich geworden. Allerdings gehen diese Methoden oft mit einer Reihe von Annahmen einher, die nicht unbedingt auf die Charakterisierung und Identifizierung von Sternhaufen zutreffen.

Dieser Antrag sieht die Verwendung von SigMA und Uncover vor, zwei innovativen, von uns entwickelten "machine learning"-Anwendungen zur Identifizierung und Charakterisierung von Sternhaufen, um Altas Galaxia Proxima zu erstellen, einen hochpräzisen Hauptkatalog stellarer Strukturen im lokalen kpc. Wir haben die einzigartigen Fähigkeiten von Uncover erfolgreich an dem kürzlich entdeckten Meingast-1 stream demonstriert, bei dem wir die Anzahl der bekannten Quellen verzehnfacht haben. Wir haben die Leistungsfähigkeit von SigMA an der Scorpius-Centaurus-OB Assoziation demonstriert, der nächstgelegenen und am besten untersuchten OB-Assoziation, wo wir 48 stabile Untergruppen identifiziert haben, von denen viele zuvor unbekannt waren. Wir werden den Atlas-Galaxia-Proxima-Katalog verwenden, um die jüngste Sternentstehungsgeschichte der lokalen Milchstraße abzuleiten. Das Vermächtnis dieses Katalogs ist immens, da er als Grundlage für weitere Untersuchungen der grundlegenden Eigenschaften aller nahe gelegenen Sternpopulationen dienen wird und es Forschern in Österreich und darüber hinaus ermöglicht, Probleme wie die anfängliche Massenfunktion, die lokale Gassternentstehungsrate und die Zeitskalen für die Planetenbildung anzugehen.

Abstract

The formation of stars is one of the fundamental open topics in Astrophysics. It is now well established that most stars form in collapsing dense molecular clouds in groups of a few dozen up to thousands of stars. Understanding the origin and evolution of these stellar structures means understanding galaxy formation and evolution. Because they were born from the same gas under similar conditions, stellar structures, such as star clusters and associations, provide a unique laboratory for studying star and planet formation and evolution.

Disentangling and extracting stellar populations is notoriously difficult. Nevertheless, the advent of Gaia data has had a tremendous impact on the search and characterization of stellar structures, thanks to its all-sky coverage and unrivaled astrometric quality. Its accurate measurements have allowed the discovery of new types of stellar structures and the testing and validation of models in 3D space, in a way that was previously not possible. Due to the size of the Gaia data base, heuristic machine learning techniques have become irreplaceable in analyzing and detecting stellar structures. However, these methods often come with a set of assumptions that necessarily do not apply to the characterization and identification of co-moving groups.

This proposal plans to use SigMA and Uncover, two innovative stellar cluster identification and characterization machine learning tools developed by us, to construct Altas Galaxia Proxima, a high-accuracy master catalog of stellar structures in the local kpc. We have successfully shown the unique capabilities of Uncover on the recently discovered Meingast-1 stream, where we have increased the number of known sources tenfold. We demonstrated the power of SigMA on the Scorpius-Centaurus OB association, the closest and best-studied OB association, where we identified 48 stable subgroups, many of them previously unknown. We will use the Atlas Galaxia Proxima catalog to derive the recent star formation history of the Local Milky Way. The legacy of this catalog is immense as it will serve as a baseline for further investigations on the fundamental properties of all nearby stellar populations, allowing researchers inside Austria and beyond to tackle problems such as the initial mass function, local gas star formation rate, and timescales for planet formation.

Endberichtkurzfassung

The project Atlas Galaxia Proxima , funded under the ASAP 18 initiative, set out to investigate recent star formation in the solar neighborhood of the Milky Way. By combining highly precise astrometric data from the European Space Agency’s Gaia mission with custom-designed machine learning algorithms, the project has delivered transformative insights into how stars and stellar groups form, evolve, and disperse in the Galactic disk.

At the core of the investigation lies the concept of stellar structure , which refers to how stars are spatially and kinematically organized into groups, clusters, and streams. These structures reflect the formation conditions of stars and their subsequent evolution within the dynamic environment of the Milky Way. Understanding the structure of nearby stellar populations provides critical constraints on the timescales and physical mechanisms that shape the birth and development of stars and planetary systems.

A Detailed Reconstruction of the Scorpius–Centaurus Region

One of the main goals of the Atlas Galaxia Proxima project was to investigate the Scorpius–Centaurus (Sco-Cen) region, the nearest large star-forming complex to the Sun. This region, located a few hundred light-years away, has long been thought to consist of just three major parts. However, using advanced machine learning methods and precise data from the Gaia space telescope, the project revealed a much more detailed picture: Sco-Cen is not a collection of three simple groups, but rather a complex network of dozens of smaller, distinct stellar clusters.

These stellar clusters are groups of stars that formed together and share similar properties, such as a common age and motion through space. By determining the ages and positions of each of these clusters with high accuracy, the team was able to reconstruct how star formation unfolded in this region over the past 20 million years. What emerged was a clear sequence of four major star-forming events, each occurring roughly 5 million years apart. This regular timing supports the idea of stellar feedback, a process where powerful radiation from massive stars in the form of supernovae and stellar winds compress nearby gas, setting off new waves of star formation. Analyzing the motions of these clusters within Sco-Cen we found that they are being driven apart at unusually high velocities, faster than can be explained by natural gravitational processes alone. This suggests that energy from previous generations of massive stars has acted as a powerful force, accelerating younger clusters outward like ripples expanding from a stone dropped in water. This force, we hypothesise, has created the long, characteristic cluster chains we identify in Sco-Cen which are made up of individual star clusters that formed in sequence.

The detailed age map of Sco-Cen also provided a valuable opportunity to study the early stages of planetary system development. Around young stars, disks of gas and dust often form which are the birthplaces of planets. By comparing the ages of many clusters, the project was able to estimate how long such disks typically persist. The results suggest that they remain intact for about 6 million years on average, longer than previously believed. This finding has important implications for understanding how and when planets form around new stars.

During our detailed analysis of the Sco-Cen region, we recovered not only the individual subpopulations of this nearby star foming complex but our analysis also revealed a striking discovery: a long, thin stream of stars passing through Sco-Cen, unrelated to the region’s own star formation history. This stellar stream appears to be disrupted by and pulled apart by the strong gravitational forces of the massive gas clouds from which the Sco-Cen complex has been formed. The stars in the stream are being stretched and scattered, a dynamic event that, for the first time, provides a direct view of such a disruption happening in real time within our galactic neighborhood.

A New Census of Disk Streams

The discovery of a disrupted stream within Scorpius–Centaurus was not an isolated finding. Our team identified in total twelve highly elongated, narrow “rivers of stars”, known as disk streams, within our local region of the Milky Way. These stellar streams are made up of stars that were born together and continue to move through space in the same direction, like threads in a cosmic fabric.

Unlike dense star clusters, these streams are diffuse, with their stars stretching over many light-years. Because they are faint and loosely connected, they have long escaped detection. However, using advanced algorithms and the precise measurements provided by Gaia, the project team was able to uncover them all within the vicinity of Sco-Cen.

Out of the twelve streams identified, eleven could be linked to previously known star clusters where in most cases only a fraction of their members inside a small core region was known. One stream, however, appears to be entirely new. What makes this discovery especially remarkable is the sheer number and subtlety of these structures. Some contain as few as one star per 5,000 cubic light-years, a density so low that they were once thought to be undetectable. Yet our findings show that these streams are far more common than previously expected, suggesting that the Milky Way’s disk could contain several thousands of such features.

These streams are thought to be the fading remains of former star clusters. Over time, gravitational forces from the galaxy slowly pull star clusters apart, stretching them into thin, elongated trails. In this way, disk streams offer a unique glimpse into the later stages of how star clusters evolve and dissolve. They allow astronomers to trace the life cycle of stars long after their birth, providing valuable clues about the forces that shape the Milky Way on both small and large scales.

Significance and Outlook

The discoveries made in Atlas Galaxia Proxima represent a major advancement in the understanding of recent star formation and stellar dynamics within the solar neighborhood. By delivering the most detailed mapping of nearby stellar structures to date, the project has redefined existing paradigms about how stars form, evolve, and dissolve into the field population of the Milky Way.

The identification of fine-grained cluster substructure in Sco-Cen, the reconstruction of sequential star formation episodes, the quantification of disk lifetimes, and the large-scale census of disk streams collectively provide new benchmarks for the astrophysical community. These results will inform future models of galactic structure, stellar feedback, and planet formation.

Looking ahead, upcoming data releases from the Gaia mission will further enhance the resolution and reach of these analyses. The methodology and findings of Atlas Galaxia Proxima lay the foundation for future research across a wide range of star-forming regions in the Milky Way and beyond.

Projektpartner

- Universität Wien - Research Network Data Science