UNIVERSITEIT GENT

Prof. Maarten Baes

Campus Sterre S9

Hidden in the shadows: Dark HI clouds

Project description

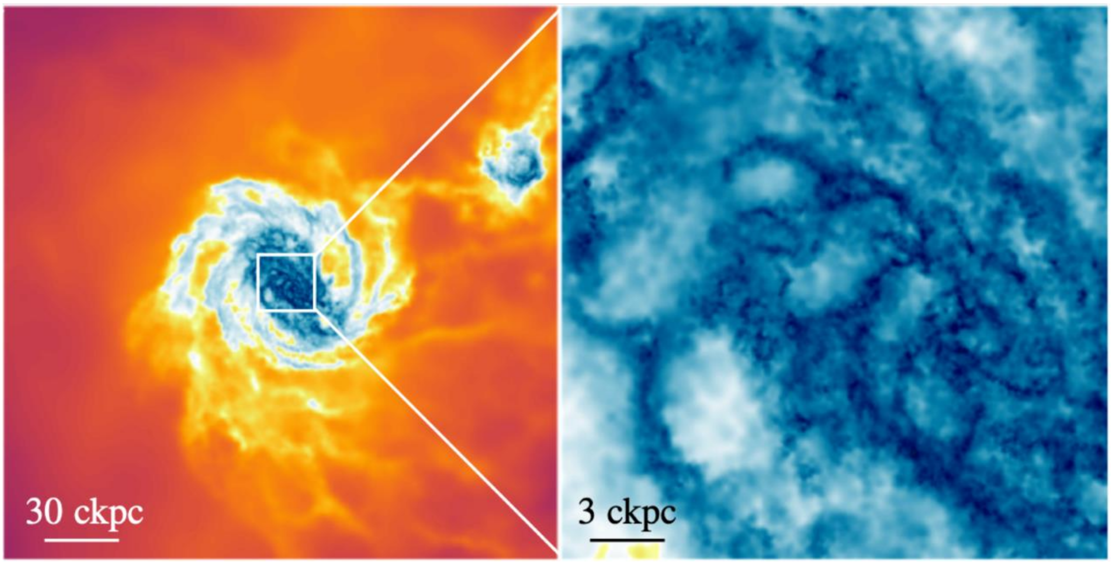
Atomic hydrogen (HI) is easily observed in nearby galaxies using the 21-cm line of HI. The 21-cm flux observed by radio telescopes is usually directly converted into a mass of HI within the observed galaxy. However, this comes with a crucial assumption: Each photon emitted by hydrogen atoms has to escape the galaxy without being absorbed by other hydrogen atoms ("optically thin assumption"). Since cold gas clouds in the interstellar medium can absorb 21-cm radiation, this is not necessarily true! Today it is still unknown how much HI is "hidden" in nearby galaxies. Simulations of galaxies can answer this outstanding question of hidden HI gas, but only if they are able to resolve the cold clouds in the interstellar medium. With the release of the FIREBOX simulation in 2022, such a study is now possible for the first time.

Goals of this thesis

The student will investigate the emission and absorption of 21-cm photons for a large (~1000 objects) sample of simulated galaxies from the FIREBOX simulation. To this end, synthetic 21-cm observations with the radiative transfer code SKIRT (developed by our research team) will be created and analyzed. The goal of this thesis is to assess how much HI is hidden in the interstellar medium, and if this hidden HI fraction depends on the properties of the host galaxy (e.g. stellar mass, inclination). These results will prove very useful for observational studies to accurately measure HI masses of nearby galaxies.

Supervision

Andrea Gebek and Maarten Baes



Reverberation Mapping Simulations of Active Galactic Nuclei

Project description

Active galactic nuclei (AGN) are the luminous central regions of galaxies, powered by the accretion of gas and dust onto a supermassive black hole. Currently, it is not possible to spatially resolve AGN in observations, due to their compactness and large distances. The most effective way to map out the AGN environment, is to use light echoes (or reverberations) produced by accretion disk emission that is reflected on the surrounding material. When the brightness of the accretion disk varies, the reflected emission component will vary in response. However, this response will be delayed with the light travel time towards the surrounding media, which could then be used to map out the geometry of the unresolved AGN environment. However, current state-of-the-art radiative transfer codes do not track light travel times, and therefore they cannot study this reverberation phenomenon.

Goals of this thesis

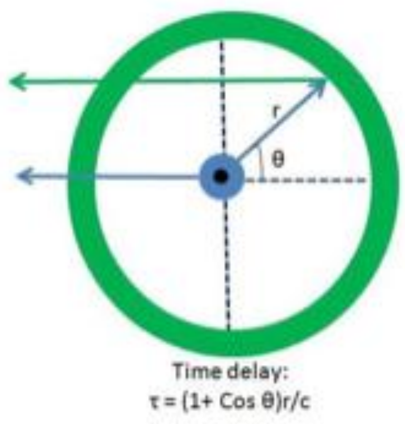
The goal of this thesis project is to study the reverberation mapping technique by performing radiative transfer simulations in simplified AGN geometries and analysing the resulting delay curves to infer physical information on the AGN environment. This is a computational project focussed on running Monte Carlo radiative transfer simulations, and interpretating large amounts of simulated time series. This project includes extending the Monte Carlo radiative transfer code SKIRT to record photon travel times during each simulation, as needed to produce delay time series.

Mobility

Possibility for a research stay at the Astronomical Observatory of Belgrade (Serbia)

Supervision

Bert Vander Meulen, Marko Stalevski, and Maarten Baes



Are Active Galactic Nuclei Obscured by their Host Galaxies in the X-ray band?

Project description

Active galactic nuclei (AGN) are the luminous central regions of galaxies, powered by the accretion of gas and dust onto a supermassive black hole. A promising way to study AGN is to look at their X-ray emission, which encodes information on the supermassive black hole and its circumnuclear environment. According to the AGN unification scheme, a toroidal structure of gas and dust exists in the equatorial plane, which obscures the X-ray emission depending on the viewing angle of the observer. However, gas and dust on galactic scales could have a similar effect on the AGN X-ray emission, although this host galaxy contribution has mostly been neglected in the literature. Properly accounting for this host galaxy obscuration could have quite some impact on the X-ray “torus” modelling field, and would set a baseline for observationally-driven obscuration population studies.

Goals of this thesis

The goal of this thesis project is to use the Monte Carlo radiative transfer code SKIRT to calculate the X-ray opacity for a set of TNG galaxies, as seen from the galaxy centre outwards. TNG is a suite of thousands of simulated galaxies, that can easily be imported and post-processed in SKIRT. This is a computational project focussed on post-processing simulated galaxies with SKIRT and analysing large amounts of simulated 2D opacity maps in Python. Finally, these finding will be interpreted in the light of the AGN unification scheme.

Mobility

Possibility for a research stay at the Astronomical Observatory of Belgrade (Serbia)

Supervision

Bert Vander Meulen, Andrea Gebek, Marko Stalevski, and Maarten Baes

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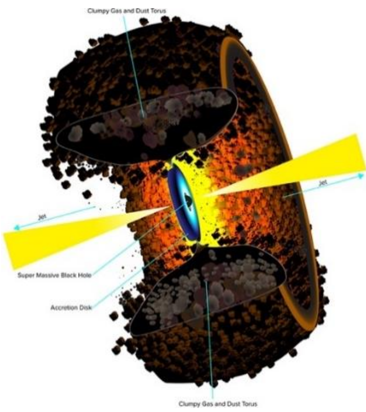


Predicting the Hard X-ray Spectra of Active Galactic Nuclei using Machine Learning on XRISM Data

Project description

Active galactic nuclei (AGN) are the luminous central regions of galaxies, powered by the accretion of gas and dust onto a supermassive black hole. A promising way to study the gas and dust surrounding AGN is to look at their X-ray emission, as the interactions between X-rays and the circumnuclear medium produce characteristic spectral features that contain information on this obscuring body of gas and dust, such as the Fe Ka line at 6.4 keV, and the Compton hump at 30 keV.

With a planned launch in 2023, the X-Ray Imaging and Spectroscopy Mission (XRISM) is destined to become the next major X-ray astronomy satellite. This JAXA mission will offer an unprecedented spectral resolution over the 0.4 to 12 keV soft X-ray range, which could revolutionize our understanding of AGN obscuration by gas and dust. However, the hard X-ray band will not be covered by XRISM, although this spectral range contains many interesting features (such as the Compton hump at 30 keV).

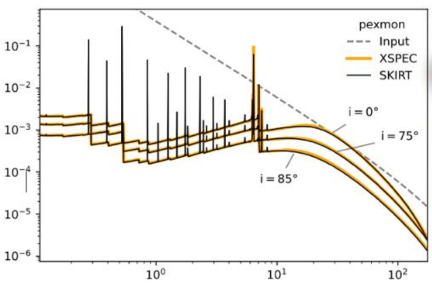
Recent developments in the field of machine learning offer a novel approach into extracting this missing information. Machine learning algorithms can be used to build models on existing data, which can then be applied to predict the missing hard X-ray part of the AGN spectrum, and extract the information contained within.

Goals of this thesis

The goal of this thesis project is to use simulated X-ray spectra (covering soft and hard X-rays) to train a machine learning algorithm, so it could predict hard X-ray spectral information from soft X-ray features that are visible in the XRISM band. This is a data science project focussed on preparing large sets of available X-ray spectra for further analysis, setting up a machine learning model (using a user-friendly Python framework), and interpreting the predicted results in the context of X-ray reprocessing in AGN circumnuclear media.

Supervision

Bert Vander Meulen, Inja Kovacic, and Maarten Baes

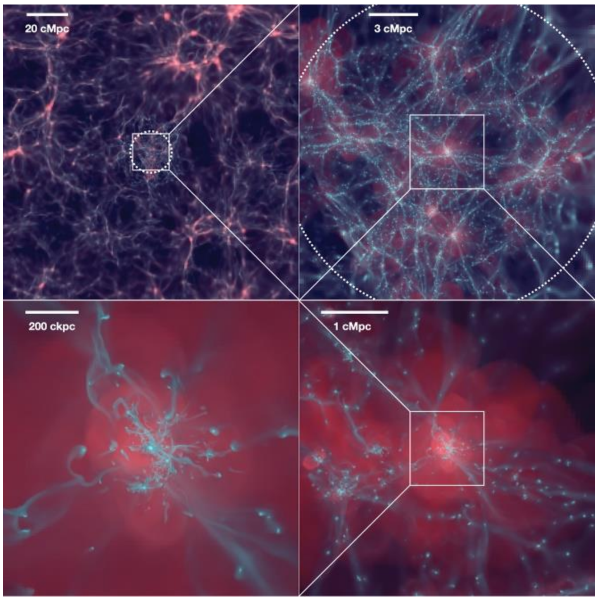


Multi-wavelength properties of galaxies in the NewHorizon cosmological simulation

Project description

Cosmological hydrodynamics simulations are an increasingly popular method to study galaxy formation and evolution. These simulations attempt to numerically emulate all the physical processes at play in the formation and evolution of galaxies, in a fully cosmological framework. The power and fidelity of cosmological hydrodynamics simulations has increased tremendously over the past few years. The NewHorizon simulation is a recent cosmological simulation can be considered as the current state of the art. With a resolution of up to 34 pc, it allows to capture the multi-phase nature of the interstellar medium of galaxies with some statistics. To test the simulation, it must be compared to actual multi-wavelength observations, which is not a trivial task.

Goals of this thesis



The SKIRT radiative transfer code developed by the UGent team has become a widely used tool to generate synthetic multi-wavelength observations for simulated galaxies. The goal of this thesis is to generate realistic synthetic multi-wavelength observations for NewHorizon galaxies using SKIRT and to compare them to actual observations. More specifically, the student will generate mock fluxes and images from UV to mm wavelengths, compute selected color-color relations and scaling relations for the simulated galaxies, and compare these to observed galaxies. These color-color and scaling relations are an important test for the validity and the limitations of the NewHorizon simulation.

Mobility

This project fits in a collaboration between UGent and Yonsei University (Seoul, South Korea). A research visit to South Korea is possible in the frame of this project.

Supervision

Maarten Baes and Sukyoung Yi

Radiative transfer on an unstructured tetrahedron grid

Project description

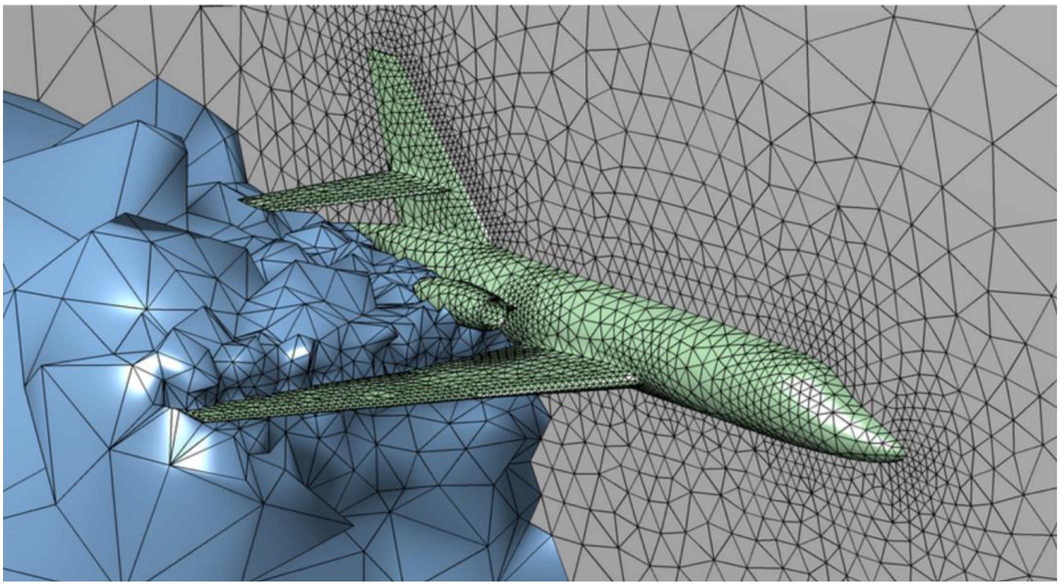
To model the interaction between radiation and matter astronomers mostly use Monte Carlo radiative transfer codes. These codes follow a gigantic number of photons individually through the system under study, which is subdivided into tiny cells. Usually, a regular or an octree grid is used, but in some cases unstructured grids are more appropriate.

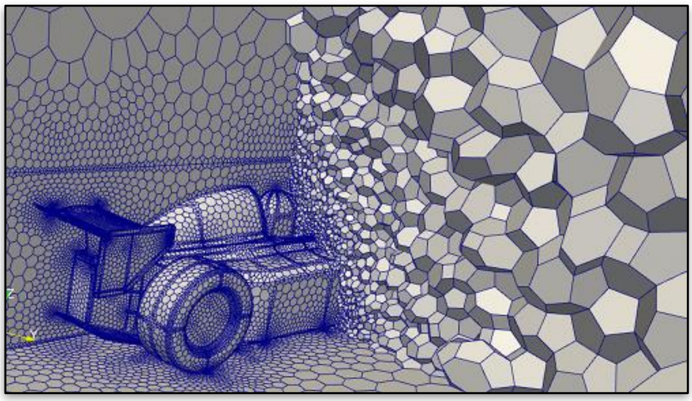
Goals of this thesis

The goal of this master thesis project is to investigate how photons can propagate efficiently through tetrahedron grids, that tis grids in which all individual cells are tetrahedra and explore the advantages and disadvantages of such grids for radiative transfer simulations.

Supervision

Maarten Baes





The first detection of cold gas flows in the early Universe

Project description

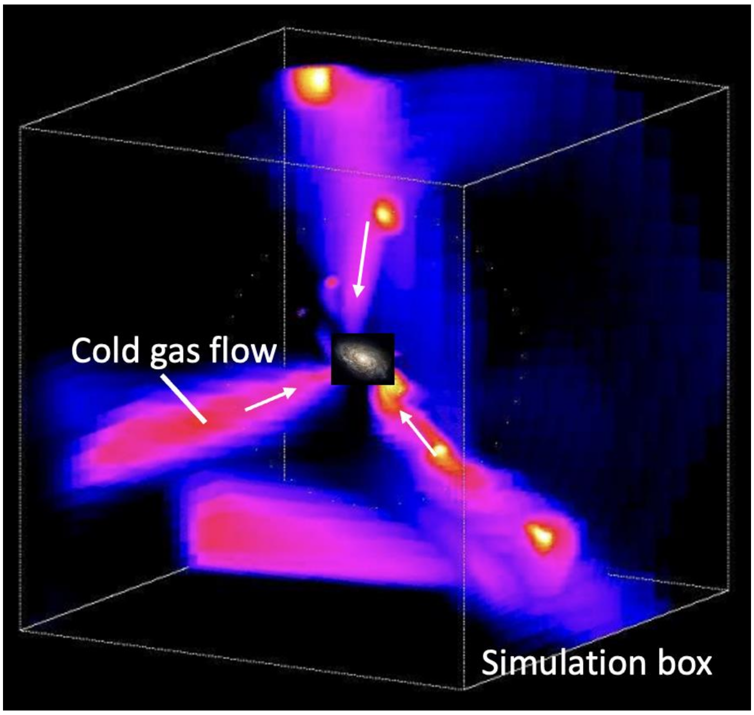
Understanding the evolution of galaxies through cosmic time is one of the most challenging topics in Astrophysics. How galaxies acquire cold gas to form stars in the early Universe is still debated, since accreted gas is heated when falling into the galaxy. Cosmological hydrodynamical simulations suggest that filaments of cold gas dragged by dark matter, "cold flows", can reach the interiors of galaxies and form stars. Since these cold flows hardly contain metals and molecules but consist of simple hydrogen and helium gas (which have no bright emission lines), it is extremely challenging to observe them. Until today, no cold flows have been detected observationally, hence it is still unknown whether such cold flows exist in the early Universe.

Goals of this thesis

The only way to observe cold flows is to detect 21-cm line emission from hydrogen atoms in the cold flows. Therefore, the goal of this thesis is to explore the possibility of the first detection of cold flows by a future large radio telescope, the Square Kilometre Array (SKA). To this end, the student investigates cold flows in a state-of-the-art cosmological simulation, TNG100, and analyzes the strength of the 21-cm emission signal from the cold flows. The main goal of this thesis is to assess the detectability of cold flows with the SKA telescope, for instance by determining the number of antennas and observation times required to detect cold flows.

Supervision

Kosei Matsumoto, Andrea Gebek, and Maarten Baes



The effect of local environment on dust temperature

Project description

Characterizing the properties of cosmic dust across different environments is essential in understanding the physics of the interstellar medium (ISM). Dust grains scatter and absorb roughly one third of the stellar radiation in galaxies. The absorbed energy is then redistributed as thermal emission in the mid- and far-infrared wavelength regimes. All these processes regulate the spectral energy distribution (SED) of galaxies. Consequently, it is important to track and quantify the interaction between the dust properties and the interstellar radiation field (ISRF) in various environments in the ISM.

Goals of this thesis

The student will compile spatially resolved, multi-wavelength synthetic images of simulated galaxies from cosmological hydrodynamics simulations. The synthetic images will be uniformly processed, analyzed, and compared with observations of nearby galaxies. The key quantities that affect the dust temperature will be derived from the dust emission SED, using state-of-the-art modelling tools (e.g. DustBFF, CIGALE). The goal of this project is to investigate the mechanisms that regulate the dust temperature and to verify the fidelity of the current cosmological hydrodynamics simulations.

Mobility

Possibility for a research stay at the Space Telescope Science Institute (STSci; Baltimore, USA).

Supervision

Angelos Nersesian, Jérémy Chastenet, and Maarten Baes

The Hunt for obscured AGNs

Project description

The typical spectral energy distribution (SED) of an active galactic nucleus (AGN) covers a broad wavelength range, from X-ray to infrared (IR), and is generated by different physical processes. Although X-ray surveys provide a reliable detection-method for obscured AGNs, many of the most highly obscured AGNs will be missed, restricting our census of the overall AGN population. Discovering those highly obscured AGNs is one of the hottest topics in astronomy. Multi-wavelength observations could allow the identification of X-ray undetected AGNs that produce luminous emission at other wavelengths (e.g., at IR, and optical), when the contaminating emission from the host galaxy is reliably accounted for using SED decomposition. Another promising method suggests that CO absorption lines in the near-IR may be indicative of obscured AGNs.

Goals of this thesis

The goal of this project is to model AGN SEDs from X-ray to IR simultaneously and self-consistently with CIGALE and decouple the AGN luminosity from the host galaxy in search of obscured AGNs. Depending on the progress of the project, another method can be considered by exploring the relationship between galaxies with CO absorption lines and obscured AGN for a statistically significant sample.

Supervision

Angelos Nersesian, Kosei Matsumoto, and Maarten Baes

Prof. Ilse De Looze

Campus Sterre S9

Coming out of darkness: recovering the stellar mass of high-redshift dusty sources

Project description

Infrared detections of dusty galaxies in the Early Universe have complemented our view of the optically detected galaxies at high-redshifts, and have demonstrated that the Early Universe hosts several extremely dusty galaxies without a counterpart in the rest-frame UV/optical wavelength range. This makes it very difficult to estimate the mass and ages of these galaxies, as the optically thick dust emission spectrum is insensitive to the spectrum of the local stellar population. Without properly being able to estimate the stellar mass and star formation activity in these dusty sources, our current view of galaxy build-up is biased.

Goals of this thesis

The student will run a set of physically-motivated radiative transfer models with the SKIRT radiation transfer code to correct the observed spectral energy distributions of high-redshift sources for dust extinction, and to recover the stellar masses and ages of these early Universe galaxies. Their optical thickness could hide massive stellar populations, potentially skewing the inferred distribution of galaxy's stellar masses by missing out on some of the most massive galaxies in the Early Universe. Several of these high-z galaxies will also be observed with the James Webb Space Telescope, enabling a direct comparison of the thesis' model results with observations.

Supervision

Ilse De Looze

Probing dust evolution in semi-analytical models of galaxy formation

Project description

The dust abundance in the interstellar medium plays a fundamental role in galactic physics, chemical evolution of matter and the absorption and re-emission of stellar light. Therefore, a complete diagnostic of dust physical characteristics and their relation to galaxy properties are essential.

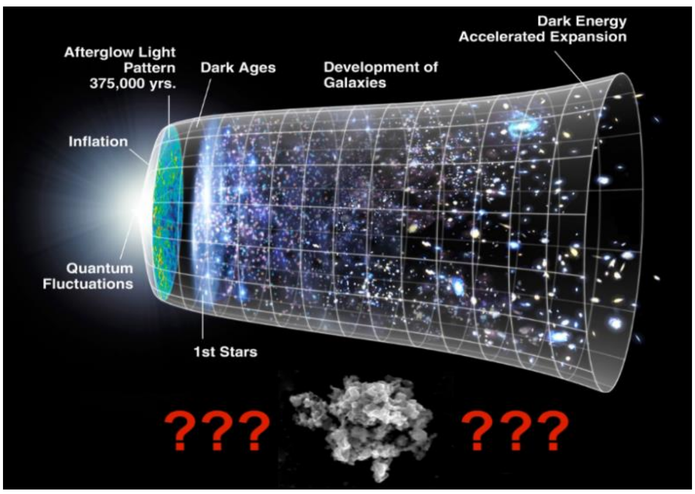
Thanks to the increasing number of observational probes out to very high-redshift, the last years have seen a surge in theoretical studies constraining the dust-abundance in galaxies. However, all these studies apply different baryonic physics prescriptions (e.g., formation of stars, accretion of gas onto galaxies, growth of black holes, stellar and AGN feedback) preventing a real comparison between different recipes to model dust evolution within galaxies.

Goal of this thesis

The goal of this project is to work in the framework of an individual, state-of-the-art, semi-analytical model of galaxy formation to test the impact of different prescriptions used to describe dust evolution (i.e. stardust production, dust growth in the dense interstellar medium, dust destruction by supernovae) from the high-redshift Universe up to present day. The results of the model will be compared with recent data from different observational programs (e.g., DustPedia, ALPINE, REBELS). It is worth mentioning that this will be the first time where a thorough comparison between different dust recipes available in the literature will be made in the framework of the same galaxy evolution model, highlighting their real effect on the dust evolution outcome.

Supervision

Marco Palla and Ilse De Looze



Chemical evolution of the Milky Way: The cosmic origin of phosphorus

Project description

In the last decade many different surveys and projects have been developed to study the formation and evolution of the Milky Way (MW), allowing us to build a very detailed chemical cartography of our Galaxy. At the same time, this mapping of chemical abundances has been fundamental to pin down the cosmic origin of most of the elements of the periodic table, thanks to the comparison with detailed models of galactic chemical evolution.

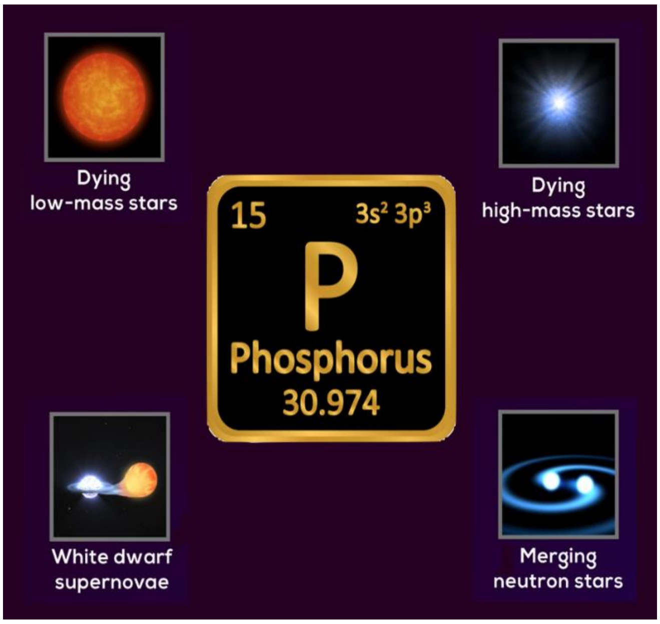
Despite being among the top 20 most abundant elements in the Universe, the understanding of the cosmic origin of phosphorus (P) remains extremely challenging. In fact, the lack of detectable optical transitions in stars have prevented large-scale survey studies to map phosphorus, at variance with most of the other chemical elements.

Goal of this thesis

The goal of this project is to work with state-of-the-art chemical evolution models extensively tested to reproduce the physical quantities observed in the MW disc and study the origin of this puzzling element. To this aim, different sets of stellar yield for different type of stars (AGB stars, core-collapse supernovae, Type Ia supernovae, novae) will be implemented in the models and results will be compared with the most recent abundances available in the literature (Maas et al. 2022).

Supervision

Marco Palla and Ilse De Looze



The star-formation history of low-Z dwarf galaxies using chemical evolution

Project description

The origin of heavy elements, such as carbon and oxygen, and dust grains is in stars through nuclear fusion with the amount depending on the type of stars formed and when these stars form. Currently, the most common method used to determine when the different types of stars are formed, also known as the star-formation history, is using spectral energy distribution (SED) fitting. SED fitting compares fluxes of galaxies in different bands to theoretical models of the emission. The fluxes are primarily being used to constrain the relative contribution of young stars, old stars, gas, and dust at different wavelengths. However, this methodology is insensitive to the evolution of the metallicity, i.e., the sum of elements heavier than helium produced by stars. A methodology using models that includes this evolution, called chemical evolution models, calculates the stellar lifetime and production of different elements in each formed star using the metallicity at defined points in time to determine when the stars will enrich the interstellar medium with fresh elements, but requires predetermined a star-formation history and gas inflow history.

Goal of this thesis

The goal of the project is to constrain the star-formation history of low-metallicity galaxies focused on the Large and Small Magellanic Clouds using a chemical evolution model. We will test common functional forms for the star-formation histories and compare the best fits with results from SED models or observational surveys such as SMASH either integrated or spatially resolved. The student needs to have an interest in the more mathematical side of galaxy evolution studies and creating scripts using Python to pilot the data reduction.

Supervision

Stefan van der Giessen, Marco Palla, and Ilse De Looze

Comparing photometric data from simulations with observations

Project description

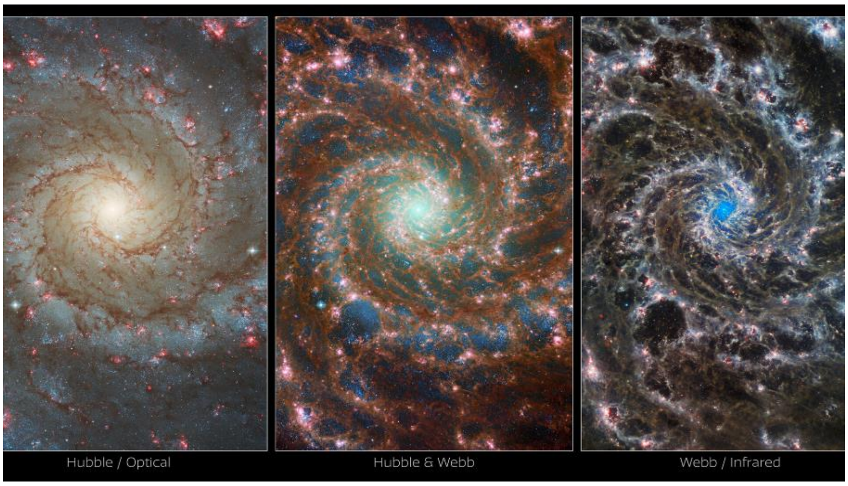
Constraining galaxy evolution is a difficult task since galaxies take 10 billion years to evolve, whereas the universe we can see is just a moment of evolution. Therefore, the only way to constrain galaxy evolution without requiring a large sample of observed galaxies at different redshifts, is to run computer calculations that model galaxy evolution and compare those results with observational data. Now, we are working on the calibration of galaxy simulations by aligning the physical properties with those from observed galaxies by creating spectral energy distributions, SEDs, for the simulations through SKIRT. SKIRT is a dust radiative transfer code that models the 3D distributions and interactions of stars and dust in galaxies by calculating the SED of a galaxy given the relative distribution of young stars, old stars, gas and dust, for a set of photometric filters used in telescopes.

Goal of this thesis

In this project, we calibrate our observational analysis by investigating the relation between emission and physical properties of a simulated Milky Way type galaxy. We will constrain stellar masses, dust masses, and star-formation rates of simulated galaxies using SKIRT processed images of the simulated galaxies and photometric relations and SED models from observational studies. The student will compare the newly derived properties with the original simulation and an observed local spiral galaxy to investigate whether we need to calibrate evolution parameters such as the star-formation rate or grain growth timescale. The student needs to have an interest in observational galaxy studies and creating scripts using Python to pilot the data analysis such as SED fitting.

Supervision

Stefan van der Giessen, Kosei Matsumoto, and Ilse De Looze



Mapping the tiniest dust grains at high-resolution in the Magellanic Clouds

Project description

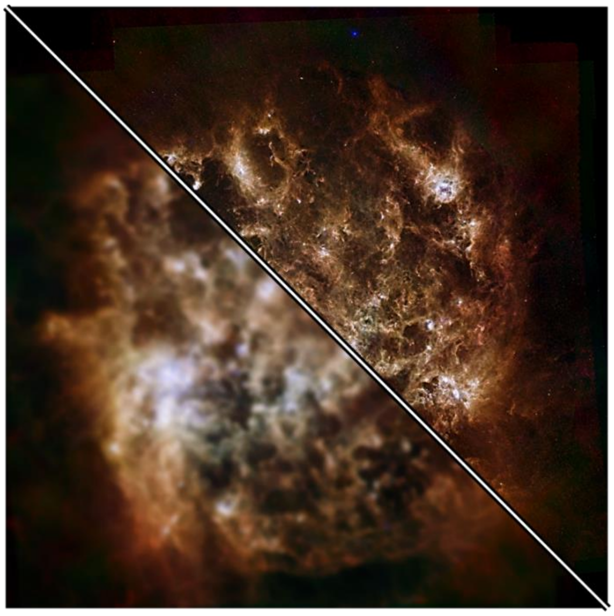
The quality of the images of cosmic objects is limited by the characteristics of the observing instruments. The Spitzer and Herschel missions observed our universe from space, in the infrared regime, allowing for an incredible amount of work to be done on external galaxies. The advent of the JWST brings new frontiers in imaging quality that challenge us to reconcile past and future work. In this specific case, our knowledge of interstellar dust, tiny grains of solid material floating within a galaxy between stars and mixed with gas, will tremendously leap forward when we manage to properly connect lower and high-resolution observations. In particular, we can now focus our effort on the smallest grain population: carbonaceous molecules that heavily affect the energy balance of gas and are linked to star formation itself. Despite their limited contribution to the mass of a galaxy, they are a key actor of their evolution.

Goal of this thesis

In this project, you will create the first ever high-resolution maps of the distribution of very small dust grains in our two closest neighbors: the Small and Large Magellanic Clouds. Your work will consist of using existing literature, both observational and theoretical, to artificially, but physically motivated, increase the mapping resolution of a key element in galaxy evolution. These new products will help the astronomy community to understand better dust evolution, and fully use the brand-new results in our hands.

Supervision

Jérémy Chastenet and Ilse De Looze



Investigating the systematic biases introduced in simple 0D dust models

Project description

Many properties of galaxies are obtained by comparing observational data and theoretical models. Specifically, astronomers often use the spectral energy distribution (SED) of galaxies in the infrared to infer the characteristics of small interstellar dust grains. Although this method has certainly proven its capabilities, the advent of more sensitive, higher-resolution data starts to unveil the limits of fitting dust emission with physical–but simple–dust models. By using the known truths of synthetic models, we can quantify these limits.

Goal of this thesis

This project is meant to quantify the systematic biases that are introduced in our understanding of interstellar dust by the simple use of a limited model. This necessary work will bring important nuance to existing and future works. You will be in charge of handling 3D radiative transfer synthetic cubes meant to reproduce the real 3D geometries of galaxies. After using the common fitting approach, you will be in a position to estimate how different results can be from the physical truth.

Supervision

Jérémy Chastenet, Angelos Nersesian, and Ilse De Looze

Irregularly shaped clumps in the supernova remnant Cas A

Project description

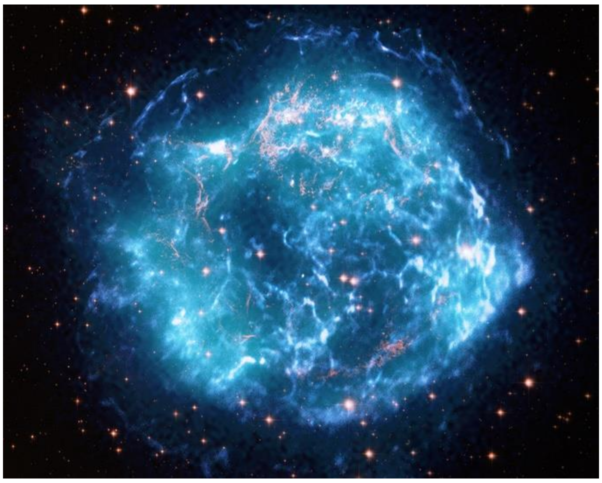
The remnants of supernova explosions offer ideal conditions for the formation of dust grains, and observations have proven the presence of dust material around a few tens of supernova remnants (SNRs). However, the SNRs are also pervaded by high-energetic shock waves that can destroy a significant amount of the freshly produced dust material. To estimate the net dust production per supernovae, it is important to gain the amount of surviving dust. Simulations of dust destruction in SNRs focus on the cloud-crushing scenario in which an overdense clump of gas and dust is impacted by a shock wave. The dust survival rate in this clump depends strongly on the surrounding gas conditions and on the properties of the clump. So far, models consider spherical, homogeneous clumps without any further structure. However, recent observations with the James Webb Space Telescope (JWST) have shown that clumps in the supernova remnant Cassiopeia A (Cas A) can have nearly arbitrary shapes - from complex filaments to elongated compact structures. It is expected that the clump structure can have a significant impact on the dust survival rate, though it is an open question to which amount.

Goal of this thesis

In this master thesis project, you will study the survival rate of dust in a SNR with irregularly shaped clumps. You will perform hydrodynamical simulations using the code AstroBEAR to simulate the shocked gas clumps at conditions comparable to Cassiopeia A. Using the post-processing code Paperboats, dust survival rates and dust maps will be calculated. The expected results will help to interpret observations of Cassiopeia A and the ongoing dust destruction in the remnant.

Supervision

Florian Kirchschlager, Nina Sartorio, and Ilse De Looze



The fast and furious – the disruption of high-speed rotating dust grains

Project description

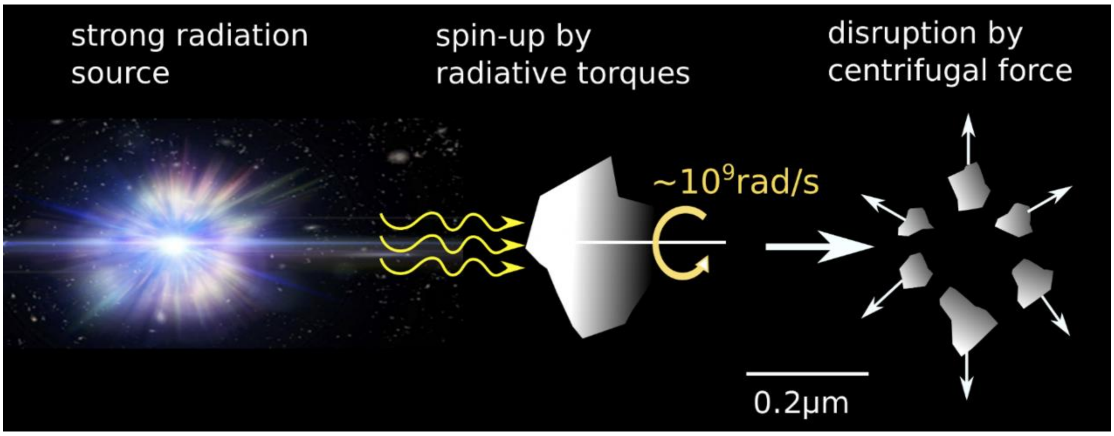
Dust grains in supernova remnants, but also in the interstellar medium, are exposed to harsh conditions. Shock waves travel through the medium, accelerate, compress and heat the gas to extreme temperatures, and destroy thus a significant amount of dust grains embedded in the gas. Recent dust destruction simulations include processes like thermal and nonthermal sputtering (gas-grain interactions) as well as fragmentation and vaporization (grain-grain interactions). However, these studies disregard the fact that dust grains can also be spun-up to suprathermal rotation by stochastic mechanical torques from gas-grain collisions or by anisotropic radiation. Such high-speed rotations can disrupt a small grain into small fragments because the induced centrifugal stress exceeds the maximum tensile strength of the grain.

Goal of this thesis

In this project, you will investigate the importance of rotational disruption of dust grains in supernova remnants and in the interstellar medium. You will study the various origins of this effect and analyze the rotational disruption of nanometre to (sub-)micrometer dust grains for specific environments. Using the code Paperboats, you will disentangle the interplay between sputtering, grain-grain collisions and rotational disruption. Removing the small dust grains, rotational disruption can directly decrease the dust survival probability in regions processed by shock waves. However, the decreased number of small grains also weakens the efficiency of grain-grain collisions, which increases the dust survival rate. It will be of great interest to see which of the competitive effects prevails.

Supervision

Florian Kirchschlager and Ilse De Looze



Analytical modeling of supernova reverse shocks

Project description

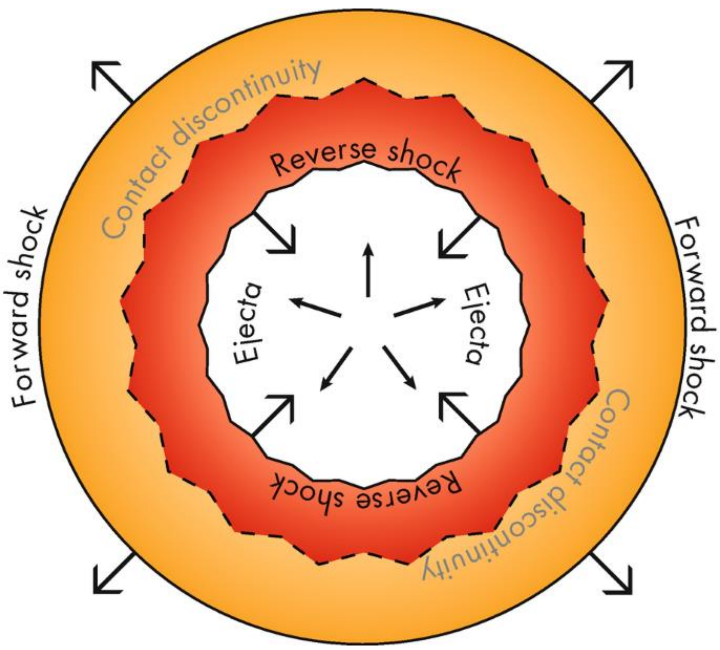
At the end of their life massive stars undergo a supernova explosion that enriches the surroundings with metals and is a prime location for the formation of interstellar dust. It is estimated that a single supernova can create something like a few hundreds of thousands of Earths worth of dust in just a couple of decades! The main question is what happens to this dust following its formation. A supernova explosion typically leads to the formation of two shocks: a forward shock, which expands in the interstellar medium (ISM) and a reverse shock, which moves into the ejecta. While the expansion of the forward shock is well understood the same can't be said about the reverse shock. Most hydrodynamical simulations today artificially introduce a shell with different conditions to both the ISM and the ejecta in order to force the production of a reverse shock and then adjust parameters to try and fit observations. This is an issue, not only because we would like to understand how the reverse shock forms, but also because this reverse shock is one of the main potential destroyers of newly formed dust.

Goal of this thesis

In this project you will take a closer look at the current implementation of reverse shock and its sensitivity to changes in parameters. Based on this investigation we will then explore developing a new improved prescription and run a few 2D hydrodynamical simulations to compare old and new models.

Supervision

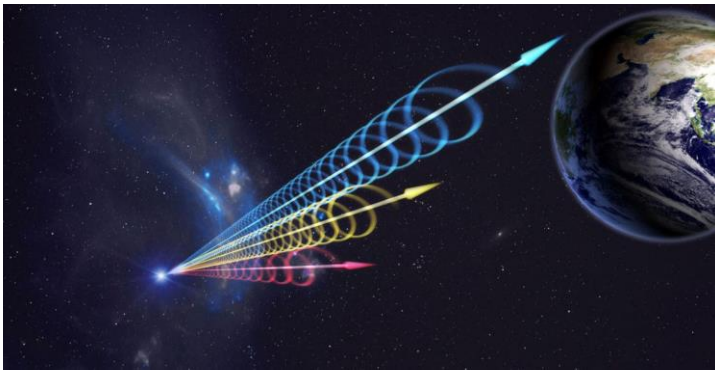
Nina Sartorio and Ilse De Looze



Tracing Fast Radio Bursts over cosmological time

Project description

Fast Radio Bursts (FRBs) are short (~ 1 ms long) bursts at radio wavelengths which originate from outside of our galaxy. FRBs are excellent cosmological probes as their signal gets dispersed by the free electrons lying between the source and the observer. Because the sources are extragalactic, the most significant contributor to this dispersion is the ionised gas in the intergalactic medium (IGM). The dispersion measure (DM) of the FRB signal allows us to probe the integrated electron column density and thus probe the ionisation state of the IGM. Thus, measurements of DMs from localised high redshift FRBs can help us constrain reionization of the intergalactic medium gas. Hundreds of FRBs have already been detected and although no FRBs have



been observed from the Epoch of Reionization, forecasts expect ~ 100 FRBs per day from $z > 6$ to be observed with SKA if the number of FRBs is expected to scale with the star formation rate. FRBs are a new source of cosmological information and can be used to constrain the baryon content of the Universe. If they are produced during the first billion years of cosmic history, FRBs could be used to probe the epoch of reionization. However, at the moment no FRBs beyond redshift $z = 3$ have been discovered, partially owing to observational limitations which will be relaxed in the future. In order to take full advantage of what hypothetical high-redshift FRBs could offer, we would need to detect a number of them at high redshifts. However, because their sources are still largely unconstrained the population of progenitors at high-z, and thus the expected number of FRBs, is unknown.

Goal of this thesis

In this project you will build a model to trace the magnetar population at high redshift in order to estimate the expected number of high-redshift FRBs. Recently a galactic magnetar SGR 1935+2154 has been detected to produce an FRB-like signal albeit a little less energetic. This is the first and only direct clue we have about FRB progenitors. While it is not certain that magnetars are the only astrophysical sources able to produce such signals, it is not unreasonable to assume that a proportion of them will lead to FRBs.

Supervision

Nina Sartorio and Ilse De Looze

UNIVERSITEIT GENT

Prof. Sven De Rijcke

Campus Sterre S9

De Metropolis radiative-transfermethode in deelnemende media

Probleemstelling

De Metropolis Light Transport (MLT) methode werd voor het eerst geïntroduceerd door Veach and Guibas (1997) in computer graphics. In plaats van de meer traditionele Monte-Carlo integratie, gebruikt de MLT techniek het Metropolis-Hastings algoritme om een reeks statistisch gecorreleerde lichtpaden te genereren. Eens een belangrijk lichtpad gevonden is, zal het algoritme zo op een natuurlijke manier de regio daarrond verkennen. Deze eigenschap maakt de MLT techniek zeer geschikt in situaties waar de bulk van de stralingsoverdracht gebeurt langs een klein deel van alle mogelijke lichtpaden.

In tegenstelling tot computer graphics, spelen in astrofysische stralingsoverdracht simulaties deelnemende media (verstrooiing, absorptie, emissie) bijna altijd een belangrijke rol. Dit maakt de originele formulering van het MLT algoritme onbruikbaar. Nieuwere methodes zoals Primary Sample Space MLT (PSSMLT, Kelemen et al., 2002) of Multiplexed MLT (MMLT, Hachisuka et al., 2014) zijn eenvoudiger uitbreidbaar naar settings met deelnemende media.

Doelstelling

Het doel van deze thesis is om de MLT techniek uit te breiden voor gebruik in simulaties met deelnemende media en na te gaan of deze methode een interessant alternatief kan zijn in situaties waar traditionele Monte-Carlo stralingsoverdrachtsmethodes ontoereikend zijn.

Promotoren

Sven De Rijcke and Yolan Uyttenhove

De programeertaal Rust in fysische simulaties: voordelen en uitdagingen

Probleemstelling

Simulaties spelen een cruciale rol in fysica en sterrenkunde aangezien onderzoekers zo complexe fenomenen kunnen bestuderen die niet zomaar experimenteel kunnen waargenomen worden. Door de resultaten van simulaties te vergelijken met observationele data kunnen onderzoekers ook de geldigheid van de gebruikte modellen testen om zo een dieper begrip te krijgen van de fysische processen die een rol spelen. Om zo groot of gedetailleerd mogelijke simulaties te kunnen doen, is efficiëntie uiterst belangrijk. Traditioneel wordt dan ook vaak gekozen voor systeemprogrameertalen zoals C, C++ of Fortran. Die zijn echter niet zonder problemen. C en C++ zijn gevoelig voor geheugen gerelateerde fouten zoals buffer overflows, dangling pointers, enz. die kunnen leiden tot crashes en verkeerde resultaten. C en Fortran missen moderne features en syntax van nieuwere programmeertalen, waardoor het moeilijker kan zijn om onderhoudbare en schaalbare code te schrijven. Rust is een relatief nieuwe systeemprogrammeertaal met moderne features zoals memory safety zonder garbage collection, zero-cost abstractions, type safety en een moderne syntax. Dit zou het eenvoudiger moeten maken om betrouwbare, schaalbare en onderhoudbare code te schrijven in Rust in vergelijking met C, C++ en Fortran en maakt Rust dus een interessante optie voor fysische en sterrenkundige simulaties. Programmeren in Rust is echter ook niet zonder uitdagingen (bv. geen shared mutable state).

Doelstelling

Het doel van deze thesis is om na te gaan wat de voor- en nadelen zijn van de programmeertaal Rust voor fysische en/of sterrenkundige simulaties. Hiervoor bestudeer je een bestaande simulatiecode, geschreven in C, C++ of Fortran en ga je ter vergelijking een subset van de functionaliteit van die code herimplementeren in Rust.

Promotoren

Sven De Rijcke and Yolan Uyttenhove

Hybride stralingsoverdracht op een grid

Probleemstelling

De Monte-Carlo methode voor stralingsoverdracht simuleert individuele fotonpakketten en hun interacties met een medium. In optisch dichte gebieden wordt de gemiddelde vrije padlengte van zo’n fotonpakket echter zeer klein. Dat wil zeggen dat fotonpakketten extreem veel interacties met het medium ondergaan voor ze uiteindelijk ontsnappen, wat de Monte-Carlo methode inefficiënt maakt. Efficiëntere, maar benaderende methodes bestaan, zoals de diffusiebenadering of moment-based radiative transfer. Het kan interessant zijn om een hybride aanpak te volgen, waarbij de volledige Monte-Carlo-integratie enkel in optisch dichte regio’s wordt vervangen door een efficiënte benadering zonder veel aan nauwkeurigheid in te boeten.

Doelstelling

Het doel van deze thesis is om methodes te onderzoeken om over te schakelen tussen de volledige Monte-Carlo integratie en een benaderende methode op de interfaces tussen optisch dunnere en optisch dichte regio’s. Concreet: wanneer het medium wordt gediscretiseerd op een grid, zal voor sommige cellen van het grid de stralingsoverdracht gesimuleerd worden met Monte-Carlo integratie en voor andere met een benaderende methode zoals de diffusie benadering of moment based RT. Het is dan cruciaal om op een accurate manier te kunnen schakelen tussen beide methodes op de faces tussen grid-cellen.

Promotoren

Sven De Rijcke and Yolan Uyttenhove

Natuurkunde met Physics-Informed Neural Networks (PINNs)

Probleemstelling

De laatste vijf jaar worden diepe neurale netwerken (NN) steeds vaker ingezet om fysisch relevante partiële differentiaalvergelijkingen (partial differential equations, of PDEs), zoals de hydrodynamicavergelijkingen, de Schrödingervergelijking en de Diracvergelijking, op te lossen. Preciezer gezegd: men traint een neuraal netwerk om aan een PDE of aan een set van PDEs te voldoen en tegelijk ook aan de opgelegde rand- of beginvoorwaarden te beantwoorden. De literatuur over dergelijke Physics-Informed Neural Networks (of PINNs) groeit momenteel exponentieel. PINNs slagen er in om de sterk niet-lineaire relatie tussen input en output in complexe fysische systemen accuraat weer te geven, ook als het probleem hoogdimensionaal is. Ze vergen geen complexe betegeling van tijd en ruimte (ze zijn 'mesh-free'), ze lijden minder onder de 'curse of dimensionality' (de complexiteit stijgt niet exponentieel met de dimensionaliteit van het probleem), en dankzij de 'automatic differentiation'-techniek (AD) kunnen partiële afgeleiden van de output naar de input accuraat en vlug berekend worden. Met andere woorden: PINNs lijken het gedroomde gereedschap voor elke tak van de natuurkunde waarin PDEs moeten opgelost worden (en in welke tak van de natuurkunde moet dat niet?). Ze kunnen ook gebruikt worden voor inverse problemen zoals het bepalen van de parameters in een PDE gegeven een set van experimentele meetwaarden.

Toch is niet alles rozengeur en maneschijn. De wiskunde achter PINNs staat nog in haar kinderschoenen en veel zaken moeten nog theoretisch worden uitgeklaard. Het is bvb. nog onduidelijk hoeveel lagen of hoeveel neuronen per laag het NN achter een PINN moet hebben voor een optimaal resultaat. Hoe hangen het trainingsproces en het uiteindelijke resultaat af van de activeringsfunctie of de gebruikte optimizer? Dat wordt momenteel met 'trial and error' uitgeprobeerd. Wel wordt uit de boomende literatuur duidelijk dat PINNs een beloftevolle alternatieve oplossingsmethode bieden voor veel problemen in de numerieke natuur- en sterrenkunde.

Doelstelling

Doel van deze thesis is een aantal gepubliceerde en nieuwe numerieke problemen in de natuur- en sterrenkunde aan te pakken met behulp van PINNs (hydrodynamicavergelijkingen, Schrödingervergelijking, ...). Je implementeert een PDE of een systeem van PDEs in c++ en je traint een PINN om deze op te lossen. Je maakt hierbij gebruik van de reeds in de literatuur verschenen 'best practices'. Je moet natuurlijk niet van nul beginnen: zo is er bvb. libTorch, een C++-pakket waarmee je neurale netwerken kan creëren en trainen. Je experimenteert met de eigenschappen van de PINN (aantal neuronlagen, aantal neuronen per laag, activatiefuncties, optimizer, ...) in functie van de complexiteit en dimensionaliteit van het probleem en je probeert op basis hiervan vuistregels en 'best practices' af te leiden. Sommige belangrijke vergelijkingen in de natuurkunde (zoals de Boltzmannvergelijking) zijn integrodifferentiaalvergelijkingen (integro-differential equations, of IDEs). Je onderzoekt hoe goed PINNs het doen bij het oplossen van IDEs.

Deze thesis levert verschillende types resultaten:

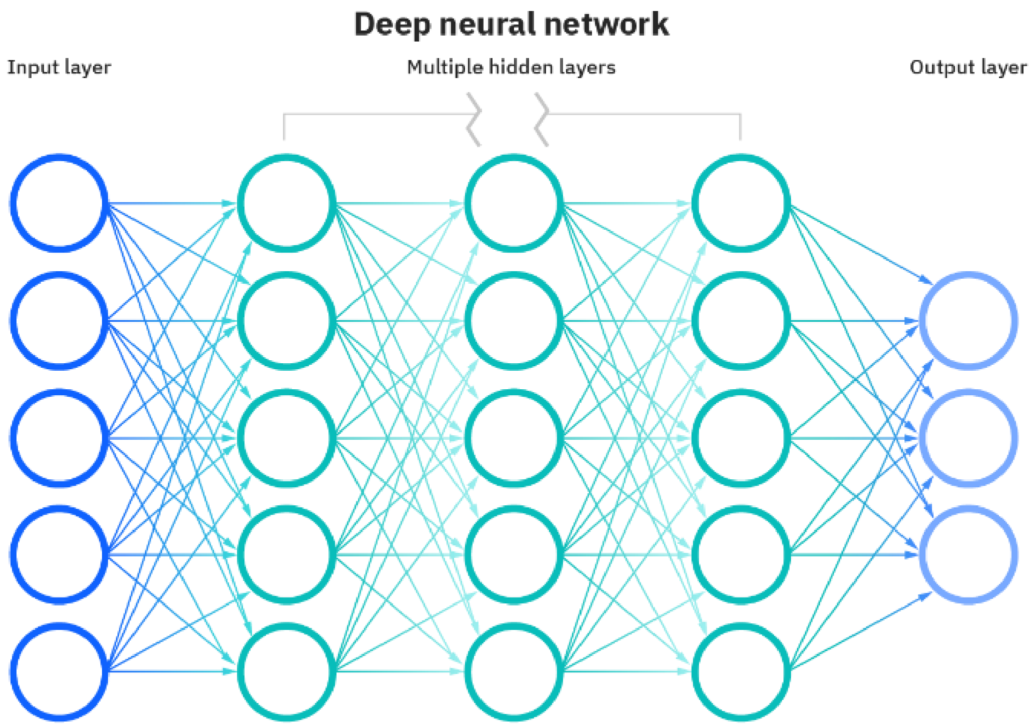
- eerst en vooral los je de PDEs op van enkele bekende fysische problemen, wat je natuurkundige inzichten oplevert,

- bij ontstentenis van een rigoureuze theoretische onderbouw zijn heuristisch afgeleide 'best practices' broodnodig,

- het trainingsproces en het finale PINN-model van een fysisch systeem kunnen aantrekkelijk gevisualiseerd worden om zowel de fysica als de basisprincipes van neurale netwerken aan een niet-expertenpubliek uit te leggen (wat interessant kan zijn voor de educatieve master).

Promotoren

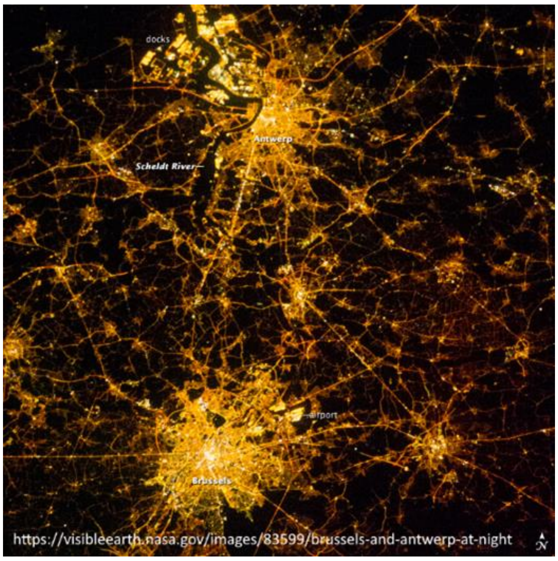
Sven De Rijcke



Quantifying light pollution in the wider Ghent area

Probleemstelling

Light pollution is a consequence of illuminating buildings and roads during the night. Poorly adjusted lighting, or the inevitable reflection of (street) light into the sky, means that nights are no longer dark. Light pollution is also increasing recently, with, moreover, a greater contribution at shorter wavelengths (in blue), including through the use of certain LED lights. Although satellite images are available with the upwardly directed light, this does not necessarily describe the complex optical situation experienced on the ground. Moreover, the current satellites used for this purpose are quite insensitive to blue light. You can also see this in the satellite image to the right. With this project, we want to quantify light pollution in Ghent. Not only by looking at the total intensity, but also by analysing the spectral distribution of light pollution. Since each type of lamp has its own optical fingerprint, the spectrum thus also reveals the source of light pollution.



Doelstelling

In this project, you will build a measurement setup based on an available high-sensitivity spectrometer to scan the sky, with a given angular resolution. A previous undergraduate project already provided prototypes and useful insights, so this setup can be realised in a relatively short time frame. You then provide automated processing of the many measured spectra into a sky map. By analysing the spectra, and using reference spectra of types of lamps (LED lamps, sodium lamps, mercury lamps...), you determine the different contributions, as quantitatively as possible. The time evolution during the night can also be determined, depending on wheather conditions and light pollution reduction measures (i.e. architectural lighting being switched off at a certain moment). Then you make the link with local sources of light pollution (e.g. Ghelamco Arena, greenhouses VIB, monumental lighting and lighting plan of the city of Ghent, motorway lighting...) and with satellite images. This can be achieved by measuring in different places in and around Ghent, in order to triangulate specific sources. The goal is to go as quantitatively as possible, in order to reach guidelines relevant to policy makers.

Promotoren

Philippe Smet (WE04) and Sven De Rijcke

UNIVERSITEIT GENT

Prof. Arjen van der Wel

Campus Sterre S9

A Unique Graviational Lens at High Redshift

Project description

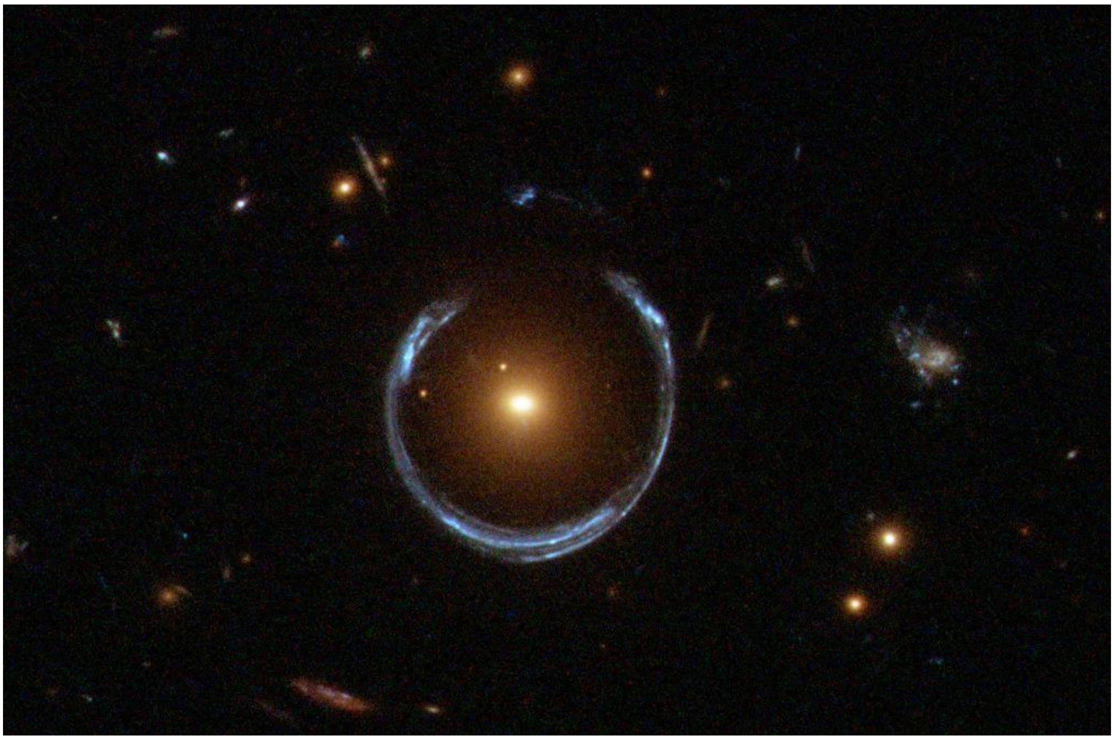
A unique galaxy at redshift z=0.7 can test our understanding of the composition and fundamental properties of galaxies. This particular galaxy is aligned along our line of sight with a much for distant galaxy, gravitationally lensing this more distant galaxy, producing a so-called Einstein ring. The diameter of the Einstein ring tells us, without systematic uncertainties, the enclosed mass of the galaxy. Together the estimates of the total mass from kinematic measurements and the stellar mass, the gravitational lens sets an absolute mass scale and directly constrains the presence of dark matter.

Goals of this thesis

The student will perform various mass estimates (from gravitational lensing, kinematic measurements and photometry) and compare them in order to disentangle the various mass components (stars and dark matter). The analysis tools exist, and the challenge lies therein to gain sufficient understanding from a broad range of astronomy topics in order to come to a coherent narrative and conclusion.

Supervision

Arjen van der Wel



The ISM of Early-Type Galaxies at Redshift z ~ 1

Project description

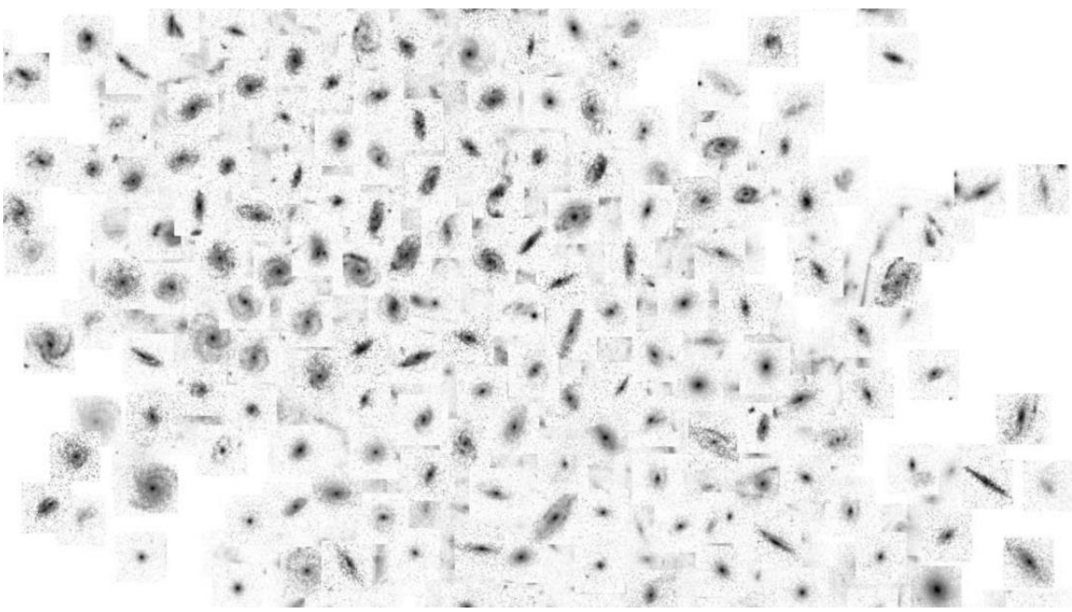
Cosmic dust is an important component of the interstellar medium (ISM) of galaxies. Dust grains absorb and scatter UV-to-optical light, causing the reddening of the observed flux densities at those wavelengths. The absorbed energy is then re-radiated in the mid-infrared (MIR), far-infrared (FIR), and submillimeter (submm) wavelengths. Most high-redshift studies on dust properties have been limited to star-forming galaxies, since quiescent galaxies tend to be faint at FIR and submm wavelengths. Therefore, galaxy population studies are often limited to stacking analyses. However, stacked samples can suffer from contamination by dusty star-forming galaxies, either due to misclassification or from neighboring galaxies via source blending in the lower spatial resolution FIR data. To mitigate these risks, a better approach is to study the dust emission of individual galaxies, leveraging on *Herschel* and ALMA imaging data.

Goals of this thesis

The student will compile multi-wavelength observational data (photometric and spectroscopic) for a sample of individual quiescent galaxies at redshift~1, from the LEGA-C catalog. One can infer the dust properties (e.g. dust temperature and dust mass) by fitting the spectral energy distribution (SED) of galaxies, using state-of-the-art SED modelling tools (e.g. Prospector, CIGALE). The goal of this project is to measure the dust temperatures (T_d) of individual high-redshift galaxies that are characterized by low star formation and investigate the evolution of T_d with redshift.

Supervision

Angelos Nersesian and Arjen van der Wel



The Point Spread Function of the James Webb Space Telescope Near-Infrared Camera

Project description

JWST/NIRcam is the most sensitive, highest-resolution camera ever built, and its performance exceeds expectations. The true point-spread function (PSF) is smaller than the current models and not yet known with sufficient precision to accurately determine the internal structure of distant galaxies. This Master thesis research project aims at constructing accurate PSF models for the various new JWST datasets.

Goals of this thesis

Stars provide, by definition, an empirical model for the PSF of any astronomical camera, and therefore stars that happen to lie within the deep JWST/NIRCam images used to search for and study distant galaxies in the early Universe can be used for that purpose. But because of the sensitivity and high spatial resolution of NIRCam the brighter stars are saturated and the fainter stars too noisy to serve as PSF models. Available theoretical PSF models are only approximately realistic. The student's task is to create a hybrid theoretical-empirical PSF model.

Supervision

Arjen van der Wel and Marco Martorano

What is Wrong with the Spectral Energy Distributions of Distant Galaxies?

Project description

Older near-IR photometric measurements of distant, high-redshift (z~1) galaxies suggest that their stellar populations are not well understood… or that the data suffer from unknown systematic uncertainties. JWST/NIRCam provides highly accurate flux density measurements of large samples of galaxies. These new data will rule out or confirm that the discrepancies between data and models are physical in nature.

Goals of this thesis

The newly available photometry from JWST/NIRCam makes it possible to obtain, for the first time, highly accurate and precise measurements of the near-infrared colors of galaxies. The test is simple: do those colors agree with pre-existing data of inferior quality, or do they disagree with the model predictions for stellar spectral energy distributions? If the former, the thesis will focus on errors in the pre-existing data implying flawed analysis in hundreds of published articles. If the latter, the thesis will focus on exploring possible avenues to address the tension between models and data.

Supervision

Arjen van der Wel and Marco Martorano