Caractérisation de l'atmosphère d'exoplanètes avec le télescope Webb

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Résumé

Le James Webb Space Telescope (JWST) est en train de révolutionner notre connaissance des exoplanètes. Grâce à sa grande surface collectrice de lumière (25 m2) et à sa capacité d'observations spectroscopiques dans une grande gamme de longueurs d'onde (0.6 - 28 microns), le télescope permet de sonder l'atmosphère d'une large gamme d'exoplanètes, allant de Jupiters chauds à des planètes rocheuses tempérées. Grâce à notre forte implication dans le développement de l'instrument MIRI (Mid-InfraRed Instrument) du JWST, nous bénéficions de temps garanti d'observations et nous coordonnons le programme dédié à l'observation des exoplanètes. Les données fournies par le JWST sont d'une qualité remarquable.

Le travail de thèse consistera à réduire, analyser et interpréter les données fournies par le JWST pendant le cycle 1 et le cycle 2, à préparer des demandes de temps pour les cycles 3 et 4 à partir d'observations simulées. Le laboratoire est également très impliqué dans la mission Ariel. Un aspect de la thèse sera l'étude des synergies entre JWST et Ariel.

Summary

The James Webb Space Telescope (JWST) is revolutionizing our knowledge of exoplanets. Thanks to its large collecting area (25 m2) and its capacity for spectroscopic observations in a wide range of wavelengths (0.6 - 28 microns), the telescope can probe the atmosphere of a wide range of exoplanets, ranging from warm Jupiters to temperate rocky planets. Thanks to our strong involvement in the development of the JWST Mid-InfraRed Instrument (MIRI), we have guaranteed observing time and coordinate the programme dedicated to the observation of exoplanets. The data provided by the JWST are of remarkable quality.

The thesis work will consist of reducing, analyzing and interpreting the data provided by the JWST during cycle 1 and cycle 2, preparing time requests for cycles 3 and 4 from simulated observations. The laboratory is also very involved in the Ariel mission. One aspect of the thesis will be the study of synergies between JWST and Ariel.

Sujet détaillé

Extrasolar planet (or ‘exoplanet’) science is a fast-developing field. Twenty seven years after the discovery of the first extrasolar planet by M. Mayor and D. Queloz (1995), the tally of known exoplanets has reached more than 5000 (see for example: http://www.exoplanet.eu/catalog/). Classes of exoplanets with no equivalent in the Solar System have been discovered, such as hot Jupiters, inflated Jupiters, super-Earths or mini-Neptunes. The observed exoplanet population suggests that planetary systems are quite common, but that the architecture of the Solar system does not appear to be the “typical” architecture for planetary systems other than our own. Those findings have risen fundamental questions, such as: What is the origin of the observed exoplanet diversity? How and where did exoplanets form? What are they made of? Do they have an atmosphere? Are the atmospheric composition and temperature indicative of an environment which could host life? And ultimately: Are there any signatures of life in the exoplanet spectra?

The next step to get crucial information on exoplanets is to characterize their atmospheres using spectroscopic observations over a broad wavelength range in the visible and Infrared (IR). A wealth of atmospheric information can be extracted from spectroscopic observations of an exoplanet: the atomic and molecular composition, the presence of hazes and clouds, the vertical temperature-pressure profile, the presence of zonal circulation, just to name a few. Such information is needed to test and improve the chemistry and dynamics incorporated in the atmospheric models applied to objects which have no equivalent in the Solar System. Modelling such systems will enable us to explore the entire atmospheric parameter space and to study chemical processes and atmospheric dynamics very unlike those seen on Earth or in the Solar system.

Thanks to its large collecting area (25 square meters) and its large wavelength coverage (0.6 - 28 microns), the Webb telescope has started to revolutionize our knowledge of exoplanet atmospheres. Transits of exoplanets have been observed during the instruments commissioning (second trimester 2022). The stability of the telescope has been found to be exquisite (Rigby et al. 2022) and transit depths have been easily measured with a noise level in the 30 – 50 ppm range (1 sigma), very close to the photon noise. Science results have been obtained rapidly in the framework of the Early Release transiting exoplanet Program (Bean et al. 2018). The giant planet WASP 39 b has been observed with each of the three instruments observing in the 0.6 – 5 microns (NIRSPEC, NIRCAM and NIRISS); CO2 has been detected for the first time in the atmosphere of an exoplanet (Ahrer et al. 2022), in agreement with the predictions. Not anticipated has been the detection of S02; models taking into account photochemistry have been developed to explain the observations (Tsai et al. submitted). The JWST, thanks to the coronagraph mode of MIRI and NIRCam, can also study the emission of exoplanets detected by direct imaging. Here also the performances are at the best we could expect (Boccaletti et al. 2022) and an exoplanet has been for the first time detected in the mid IR : HIP65426 (Aarynn et al. 2022) in the framework of the ERS program to study exoplanet by direct imaging (Hinkley et al. 2022). These first results are excellent news for the program of exoplanet characterization we have developed in the framework of the Guaranteed Time Observations (GTO) we have got, following our contribution to the development of the MIRI instrument. We have 100 hours of observations (coordinator P.-O. Lagage). The first results also indicate that we can now propose ambitious programs for which we cumulate several transits or eclipses to get the needed signal over noise ratio. We have applied for such programs for cycle 2 observations (for example phase curve observation of Trappist1 b).

GTO observations are scheduled all along 2023 and we are the owner of the data during one year after the observations. The PhD student will have access to those data and the first part of this thesis will be devoted to analyze part of them (especially HAT-P12 b); he will have access to the TAUREX retrieval code, developed at UCL, to analyse the data and to the ATMO code developed by P. Tremblin at the ‘Maison de la simulation’. Another part of the thesis will be to upgrade the simulator we have developed and to make it even more realistic, especially in terms of systematics, by taking into account data from General Observing (GO) programs of cycle1, as they become public (especially the 40 hours observation of the phase curve of GJ1214) and in a second step the cycle 2 data from ambitious programs. Such a simulator is used to determine the degree of sophistication we need to develop the data reduction methods in order to remove the systematics. The student will also analyze analyze cycle2 data and prepare cycle3 data. Another part of the thesis will be the participation in the Ariel working group entitled ‘Synergies between JWST and Ariel’ and in the preparation of the Ariel dry run to be conducted in 2025. The PhD student will also be involve in the preparation of the observing Survey program of the Twinkle mission we are part of.