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JWST: Launch, Commissioning, and Cycle 1 Science

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JWST: Launch, Commissioning, and Cycle 1 Science

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Introduction

The James Webb Space Telescope (JWST) is expected to revolutionize our understanding of the near- to mid-infrared sky by enabling observations with an unprecedented combination of superb angular resolution and sensitivity. Since JWST is a general-purpose observatory, its scientific success is dependent on the broader scientific community to make new discoveries. The 2018 IAU General Assembly served as an important international platform and offered an ideal opportunity to inform the broader community about current JWST status, plans for commissioning and Cycle 1 science, and what to expect in the near-future for JWST. This was accomplished as part of a JWST focus meeting, held at the beginning of the General Assembly, August 20-22, 2018. During the first day of the meeting, we opened our session with a Key Note from Dr. Ewine van Dishoeck, the new IAU president, who provided a brief overview of the mission and the revolutionary science anticipated. This was then followed by members of the design team for the four JWST science instruments (MIRI, NIRCam, NIRSpec, and NIRISS) discussed the science potential of their instruments. Presentations set the context for the many technologies developed and challenges overcome along the way to a space telescope, alongside the anticipated science returns. The focus meeting also highlighted the science to be enabled by JWST early in its life cycle and touched on commissioning, Early Release Science (ERS), Guaranteed Time Observer (GTO), and General Observer (GO) programs slated for cycle 1. Over the second two days of the meeting, talks and discussion sessions centered around the broad science topics enabled by JWST, from our solar system to the edge of the universe. Speakers represented topics across the entire astronomical community, including: interstellar matter, the local universe, galaxies, cosmology, stars and stellar physics, planetary systems, and bioastronomy. Given the cross-disciplinary and international nature of JWST's mission, this focus meeting was the ideal opportunity to discuss the science that will be enabled with JWST in the near-term. In addition, the focus meeting welcomed officials from NASA and ESA to update delegates on the current status of JWST and what to expect before science operations commence in 2021. Meanwhile, poster presentations offered delegates an opportunity to explore certain science topics more in depth, learn about proposal tools, and to explore possible new observation techniques. Details, including presentation slides and posters can be found on the JWST Observers website: https://jwst.stsci.edu/news-events/events/events-area/stsci-events-listing-container/jwst-launch-commissioning-and-cycle-1-science?mwc=4

A taster of JWST science

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Abstract. JWST promises to examine every phase of cosmic history: from the epoch of re-ionization after the Big Bang to the formation of galaxies, stars and planets, the atmospheres of exoplanets and the evolution of our own solar system. Its leap in sensitivity, angular resolution and broad wavelength coverage from optical to mid-infrared compared with other missions will ensure major steps forward in many areas. At the GA, a brief 'taste' of JWST science has been presented, and synergies with other major facilities have been emphasized.

The four JWST instruments – NIRCam, NIRSpec, MIRI and FGS/NIRISS – cover the 0.6 – 28.8 μm range with imaging and spectroscopy up to R=3000 and with improved sensitivities up to two orders of magnitude. Examples of key science areas are:

• *High-redshift galaxies:* Because JWST sees much sharper and deeper it can identify better the youngest galaxies and star clusters. With many more filters, photometric redshifts are more reliable, and thus also the luminosity function at the faint end $z > 8$. Spectra provide key diagnostics of star formation rates, metallicity and hardness of the UV, as well as the photon escape fraction around the time of reionization.

• *Galaxy assembly:* The bulk of the stars in the Universe were formed at $1 < z < 6$. JWST can study the structure (e.g., gas accretion, mergers, disks) and physics of galaxies (e.g., ionization, outflows, AGN feedback) up to $z \approx 7$ with the same detail as is now done at $z \approx 2$. Spatially resolved stellar populations in nearby galaxies allow their star formation histories to be reconstructed ('archaeology'). JWST will be most powerful in the outskirts of galaxies (out to the Virgo cluster) whereas ELTs can sample the more crowded galaxy centers.

• *Galactic protostars and disks.* JWST can probe the physical processes by which stars and disks form and evolve through continuum imaging and spatially resolved infrared diagnostic lines that probe accretion, shocks, PDRs and high energy photons, e.g., H I recombination, atomic fine structure and H_2, OH and H_2O pure rotational lines, PAH features. Also, the onset of chemical complexity in ices that may become part of new solar systems can be observed in the 5–10 μm fingerprint region. In mature disks, JWST can probe the hot chemistry in the inner few au where terrestrial planets are forming.

• *Exoplanets.* JWST can perform deep searches for young planets in transitional and debris disks for which ALMA or scattered light images have suggested their presence. Direct imaging spectroscopy of mature exoplanets at large distances from their parent star will provide unprecedented information on their atmospheres. The broad wavelength coverage of JWST will allow much more accurate retrieval of atmospheric abundances (i.p., C/O) through transit spectroscopy. Earth-size ocean planets around M stars may be just reachable.

NIRCam: New Science Near and Far

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Abstract. The near-infrared camera, NIRCam, for JWST is a versatile instrument capable of obsevations ranging from direct imaging of exoplanets to searching for distant galaxies.

NIRCam provides two types of data for the JWST mission: it is the 0.6 to 5 um imager, and it is also the wavefront sensor used in maintaining the shape and phasing of the primary mirror. NIRCam is fully redundant with two benches mounted back-to-back, each with a full optical train. Either module can acquire the needed data for wavefront sensing with a substantial benefit to survey work as both modules can be run simulataneously which doubles the field of view to ~9.7 square arc min. The weak lenses used in wavefront sensing may also be useful for science imaging to spread starlight over a large number of pixels. Because NIRCam covers such a large wavelength range, each module is comprised of short and long wavelength arms with a dichroic beamsplitter dividing the light. The short wavelength arm covers 0.6 to 2.3μm and has a pixel scale of ~0.32 arc sec per pixel while the long wavelegnth arm covers 2.45 to 5μm with a pixel scale of ~0.64 arc sec per pixel. Both arms can be used at the same time to improve survey efficiency with two wavelengths observed at once. Each arm is equipped with filter and pupil wheels with a selection of broad (R~4), medium (R~10) and narrow (R~100) filters. The long wavelength arms also includes R~1500 grisms for slitless spectroscopy and transit observations. See Greene *et al.* (2017) for more details and Beichman *et al.* (2014) for transit use. Each module also includes a selection of coronagraphic masks and each arm includes Lyot stops for coronagraphy. Use of NIRCam's coronagraphs for direct imaging of planets is explored in Beichman *et al.* (2010). A prime program for the NIRCam instrument team will be carried out in collaboration with the NIRSpec instrument team to find and characterize the most distant galaxies. NIRCam will be used to observe ~46 square arc min to 1-σ =0.4 nJy at 2μm and ~190 square arc min to 1-σ =0.9 nJy at 2μm. These areas will be observed using seven wide filters covering 0.9 to 5μm. Photometric redshifts will be estimated from the NIRCam data, and then a selection of targets for detailed NIRSpec spectroscopy at both R~100 and R~1000 will be made. These observations should allow the collaboration to examine galaxy evolution through z~10 and beyond.
For more information about NIRCam, see http://ircamera.as.arizona.edu/nircam/ and https://jwst-docs.stsci.edu/display/JTI/NIRCam+Observing+Modes

The JWST near-infrared spectrograph NIRSpec

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Abstract. The near-infrared spectrograph NIRSpec is one of four instruments aboard the James Webb Space Telescope (JWST). NIRSpec is developed by ESA with AIRBUS Defence & Space as prime contractor. It offers seven dispersers covering the wavelength range from 0.6 to 5.3 micron with resolutions from R~100 to R~2700. Using an array of micro-shutters, NIRSpec will be capable of obtaining spectra for over 100 objects simultaneously. It also features an integral field unit with a 3 by 3 arcseconds field of view, and various slits for high contrast spectroscopy of individual objects and time series observations, including those of transiting exoplanets. We will provide an overview

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of the capabilities and performances of the three observing modes of NIRSpec, and how these are linked to the four main JWST scientific themes.

Keywords. instrumentation: spectrographs

Overview of NIRSpec's capabilities

NIRSpec is a versatile near-IR spectrograph equipped with a micro-shutter array (MSA), an integral field unit for 3D spectroscopy, and five fixed slits for high-contrast spectroscopy, including a wider slit for bright object times series. It will be the first MOS in space, with a quarter of a million micro-shutters that can be individually addressed to be open or closed. Some aspects of planning NIRSpec/MOS observations are somewhat different than what is done on the ground. The MSA is fixed grid structure with several factors that impact the degree of multiplexing: it is a strong function of the density of targets in the input catalogue; in a typical use, the small shutters are combined to make up a *slitlet*, which together with the dithering strategy constrains the number of observable objects; not all shutters are viable (avoid spectral overlap, truncation, operability); constrains on centering are relevant for spectrophotometric accuracy but strongly impact multiplexing. Simulations show that with the current state of the MSA, for the densest target fields, one expects to observe in a single exposure about $\sim$200 targets for the PRISM (R$\sim$100) and $\sim$60 targets at R$\sim$1000. An important aspect to highlight is that NIRCam imaging and NIRSpec MOS follow-up observations will be allowed within the same observing cycle, resulting in a fast turn-around of scientific results. Another opportunity to maximize science return with JWST is the possibility to acquire NIRCam imaging in parallel to NIRSpec MOS observations. The impressive versatility of the NIRSpec instrument and its modes makes it a powerful and attractive instrument from the scientific point of view, but turns it into a challenge when it comes to calibration. Data from ground-test campaigns and simulations are being extensively used to develop and test the NIRSpec calibration concept, which will be verified and revisited once JWST is in orbit.

Science with NIRISS: The Near-Infrared Imager and Slitless Spectrograph

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Abstract. The NIRISS instrument on JWST provides four imaging and spectroscopic modes at wavelengths from 0.6 to 5 microns. These observing modes enable diverse science applications, from characterizing exoplanets that could host life to understanding the formation of galaxies prior to cosmic reionization.

The four observing modes of NIRISS are selected by choosing the relevant filters, dispersers or mask in the Filter Wheel and Pupil Wheel. The detector is a HAWAII-2RG HgCdTe device with 5.2μm cutoff, covering 2.2×2.2 arcmin^2 in full-frame.

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1. Wide-Field Slitless Spectroscopy (WFSS)

NIRISS contains two orthogonally-oriented, low-resolution ($R \approx 150$) grisms that disperse spectra of all the sources in the field across the detector. One of six band-limiting filters from 0.8 to 2.3μm is used to limit the spectra length, mitigating source overlap and reducing background. WFSS enables highly multiplexed spectroscopy with several thousand spectra per field in deep observations. Galaxy emission line maps can be generated to measure resolved metallicity and ionization of nebular gas, to investigate how gas cycles in and out of galaxies. Other WFSS applications include searches for blind emission line galaxies prior to cosmic reionization and cool substellar objects.

2. Single-Object Slitless Spectroscopy (SOSS)

The SOSS mode uses a cross-dispersing grism to provide a spectrum from 0.6 to 2.8μm at $R \approx 700$. The primary use case is time-series observations of bright, variable sources. By observing exoplanet host stars during transit, the planet atmospheric composition and physical properties can be measured. NIRISS SOSS covers transitions of important molecules such as water, carbon monoxide, hydrogen cyanide, methane, and ammonia.

3. Aperture Masking Interferometry (AMI)

The non-redundant mask in NIRISS enables high-contrast imaging at resolution $0.5\lambda/D$, the smallest inner working angle of any JWST imaging mode. This enables the detection of close-in planets and disks and high-resolution study of some extended objects such as galactic nuclei.

4. Imaging

The 12 filters in NIRISS can be used for imaging. Although NIRCam is the primary near-IR imager for JWST, NIRISS can be used in parallel with NIRCam for a 50% increase in imaging area. NIRISS imaging is also critical in WFSS operations to provide the source astrometry and wavelength solution, and to model spectral overlap.

More information on NIRISS and science applications at https://jwst-docs.stsci.edu.

Observing the evolving Interstellar Medium in galaxies with the James Webb Space Telescope

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Abstract. The James Webb Space Telescope (JWST) will excel at studying the Interstellar Medium (ISM) of galaxies at unprecedented levels of detail owing to its combination of sensitivity, the availability of integral field units, and high spectral resolution in the MIRI instrument. It is well-placed to enhance our understanding of the chemical and physical changes of the ISM in the context of galaxy evolution.

Keywords. infrared: galaxies, infrared: ISM, ISM: lines and bands, ISM: evolution, galaxies: ISM

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Previous space-based infrared observatories, like *ISO* and *Spitzer*, have revealed a plethora of spectroscopic features with diagnostic properties to observe the ISM. These features include amorphous and crystalline silicates; carbonaceous features such as polycyclic aromatic hydrocarbons (6.2, 7.7, 8.6, 11.3 and 12.7 μm) and fullerenes; various ices (methanol, CO, CO_2 and water ice); and molecular hydrogen (H_2).

The infrared molecular hydrogen lines provide a way to study the molecular content of low-metallicity galaxies, as in low-metallicity environments the CO dissociation occurs much further into the molecular clouds due to the low abundance of CO and the lower level of self-shielding. Using CO as a proxy for the molecular mass in low-metallicity galaxies overlooks the CO-dark gas, which may be a substantial fraction of the total molecular gas reservoir.

Another important diagnostic is provided by the Polycyclic Aromatic Hydrocarbons (PAHs), which show several resonances in the mid-infrared, due to specific bending and stretching modes in these molecules. For instance, the band ratio between the 11.3 and 12.7 μm features is a measure for the compactness of the PAHs, with less compact molecules presumed to be eroded by UV irradiation. The 11.3/7.7 μm versus 6.2/7.7 μm ratio provides a diagnostic that is sensitive to both grain size and ionization fraction at the same time. In spectral maps, changes in these band ratios reveal gradients in the conditions in the ISM.

Using mid-infrared spectroscopy it is also possible to determine the crystalline fraction of silicates. Crystalline silicates are only formed above $\sim$1000 K, while the silicates retain their lattice structure upon cooling. Amorphization occurs due to prolongued exposure to cosmic ray hits. Thus, the crystalline fraction reveals information about the formation history of silicates in stellar ejecta, and their residence time in the ISM. Crystalline silicates are absent in normal galaxies, but starburst galaxies show detectable amounts of crystallinity, and spectrally mapping such galaxies with MIRI may reveal hotspots in the star formation activity of these galaxies.

Galactic Nuclei Studies with JWST

Nora Luetzgendorf[1]

This presentation is made on behalf of the NIRspec/MIRI GTO team, and is based on the work done by a large number of people involved in the project.

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Abstract. The nuclei of galaxies and their immediate vicinity are unique laboratories for a number of complex physical processes. Observing a small number of selected nearby galactic nuclei with the IFUs of both NIRSpec and MIRI in the framework of the JWST GTO program will allow us to study them in unprecedented detail over the entire near- and mid-infrared spectral range ($0.7 - 28\mu$m). The unrivaled sensitivity and continuous wavelength coverage offered by the combination of JWST and NIRSpec/MIRI will provide access to a multitude of diagnostic spectral features, and mapping these over the central few hundred pc with the unique spatial resolution of JWST ($\sim$0.1, i.e. a few pc for nearby galaxies) will break new ground even for these relatively well-studied objects.

Keywords. galaxies: active, galaxies: nuclei, stars: kinematics

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Table 1. Overview of the target sample.

Name	**Distance**	**Comment**
Merkarian 231	175 kpc	nearest IR-bright quasar
Centaurus A	4 Mpc	closest radio galaxy
NGC 6240	97 Mpc	binary black hole
Arp 220	77 Mpc	closest ULIRG
Galactic Center	8 kpc	closest SMBH
NGC 4654	16 Mpc	double nuclear star cluster

Introduction

For the foreseeable future, JWST will be the most sensitive (and, in fact, only) facility to provide continuous spectra over the entire near- and mid-infrared spectral range ($0.7-28\mu$m). The NIRSpec and MIRI IFU data will provide 2-d maps for across this entire range with a resolution of $R \sim 2700-3000$, and thus will enable a full characterization the nuclear environment of the target galaxies on scales of a few pc.

The key objective of this joint GTO program between the NIRSpec and MIRI GTO teams is to obtain deep IFU data cubes of selected galaxy nuclei over the entire JWST wavelength range, and to employ the versatile tool kit of IR spectral diagnostics to better understand their physics. Because many of the diagnostic lines are rather faint, and ground-based IR instruments cannot reach the required S/N ratios due to the enormous thermal background from the Earth's atmosphere (or are absorbed by it), the use of JWST is mandatory for this purpose.

Scientific goals

The galaxies to be observed are summarized in Table 1. In what follows, we describe some of the specific questions that will be addressed by this program.

Highly Obscured Nuclei All nuclei in our sample exhibit strong dust extinction, especially the Galactic Center and Cen A. At optical wavelengths, it is therefore difficult to derive the true emission line fluxes and - especially - ratios. In the NIR/MIR regime, in contrast, these problems are much more manageable because the extinction is drastically reduced, and can be more easily quantified. The hydrogen recombination line ratios in the NIRSpec spectral range, in particular, will provide maps of the patchy obscuration towards the ionized gas on scales of a few pc.

Kinematics of Gas and Stars The combined integral-field spectra from NIRSpec and MIRI provide a unique data set to investigate the kinematics of stars as well as of the different phases of the ISM, from warm molecular gas to hot coronal gas. For the stars, the strong CO absorption bands at 2.4m will provide the stellar velocity field on the finest spatial scales, and thus establish accurate measurements of the enclosed dynamical mass. A similar analysis can be done for the various gas phases, and comparison of gaseous and stellar rotation curves yields additional insight into the energetics in the various nuclei.

Quantitative comparison between AGN and star formation One of the outputs of the proposed IFU spectra will be a quantitative estimate of the fraction of the bolometric luminosity attributed to the AGN on the one hand, and the star formation activity on the other. Infrared spectra obtained with the sensitivity and spatial resolution of JWST will allow us to measure the relative strength of various emission lines (many of them too weak to be detected from the ground) that trace either type of activity. In order to further characterize the AGN in our sample, we will employ state-of-the-art photoionisation models in order to infer the continuum shape of the (hidden) ionizing SED, and hence derive the Eddington ratios.

Icy Dust in Molecular Cores: A JWST/NIRCam GTO Project

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Abstract. This GTO project will study the spatial distribution of continuum extinction and ice absorption features in three nearby molecular cores using JWST/NIRCam slitless spectroscopy.

Keywords. space vehicles: instruments, (ISM:) dust, extinction, infrared: ISM

Our project aims at studying the early phases of ice mantle deposition on grains in molecular clouds. The onset of ice formation is observationally identified by the strong H_2O and CO_2 features that indicate the adsorption and subsequent processing of H, O and CO. At higher densities, molecular cloud CO is adsorbed so rapidly as to overwhelm the surface chemical reactions, so that a CO ice feature becomes observable, followed by the reaction product CH_3OH, the first step in reaction chains leading to more complex organic molecules, as recently reviewed by Boogert *et al.* (2015).

We will study the ice features in absorption against background stars, which, after spectral classification, serve as a known illumination source. Our target objects are nearby, isolated small molecular clouds (globules): B68, a quiescent core, L694-2, a collapsing core, and B335, a star-forming core. They are all situated in front of a dense field of background stars so that numerous lines of sight are available for absorption spectroscopy.

JWST offers two instruments capable of multi-object medium resolution spectroscopy over the wavelength range of 2.5 - 5 μm for our studies: MSA spectroscopy with NIRSpec and slitless spectroscopy with NIRCam (Greene *et al.* 2017). Despite its lower sensitivity due to higher sky backgrounds, we decided to use the slitless grism spectroscopy capabilities of NIRCam since this method does not require prior precise knowledge of the star positions. We will obtain slitless spectra of all stars in the field in the six wide and medium bandwidth NIRCam filters over the wavelength range from 2.5 - 5.0 μm. Our observing program uses multiple dither pointings to completely cover the dense cores of the globules. For each of our three objects, we expect about 100 usable background star spectra. These will give maps of the continuum and ice feature absorption depth with unprecedented spatial resolution and will allow us to study the formation and early chemical processing of ice mantles in detail.

Lensing-corrected 1.1mm number counts in the ALMA Frontier Fields Survey: A science case for JWST

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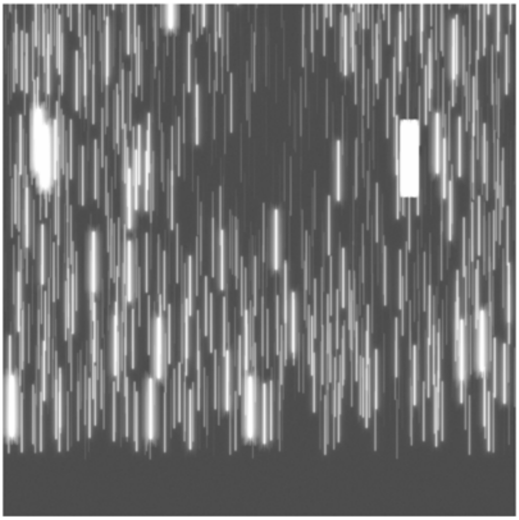

Figure 1. AXESIM simulation of NIRCam slitless spectroscopy in the F430M filter of B335 using UKIRT K-band data for the bright stars and a model of the faint star population based on the TRILEGAL galaxy model. It shows that the problem of spectrum overlap is quite manageable, and that at least 50% of all spectra can be extracted in a straightforward way.

Abstract. We present galaxy number counts around five strong-lensing galaxy clusters as part of the ALMA Frontier Fields Survey. This aims to characterize the population of faint, dusty star-forming galaxies at high redshift, benefiting from the magnification power of the clusters. Our study combines the analysis of deep (rms ∼55-71 μJy/beam) ALMA 1.1 mm continuum data over ∼23 square arcmin (lens plane) from this survey, with gravitational lensing models produced by different groups. Our estimates for the lensing-corrected number counts consider source detections down to S/N=4.5. Most of these detections lack spectroscopic redshifts, and from those having NIR counterparts, the majority are quite red. Moreover, some detections lack counterparts at other wavelengths, despite the extremely deep Hubble and Spitzer data available for the Frontier Fields clusters. Our ALMA detections thus comprise an interesting population for follow-up observations with JWST, as a robust determination of the missing spectroscopic redshifts will provide better constraints on the source properties, as well as more accurate estimates for the derived number counts.

Keywords. gravitational lensing, galaxies: high-redshift, submillimeter

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Characterizing the sub-mm number counts of faint dusty star-forming galaxies (especially at sub-100 μJy; Casey *et al.* 2014) is currently a major challenge even for deep, high-resolution, observations with recent sensitive interferometers. These sources are predicted to account for approximately half of the total extragalactic background light at those sub-mm wavelengths. We exploit ALMA's unique capabilities to search for sources behind five well-studied galaxy clusters, which are part of the Hubble Frontier Fields survey (Lotz *et al.* 2017). In González-López *et al.* (2017) we present the ALMA observations for three of these galaxy clusters: Abell 2744, MACSJ0416.1-2403 and MACSJ1149.5+2223. Using these data, in combination with recent publicly available lensing models, we derive the faint end of the 1.1 mm number counts in these fields (Muñoz Arancibia *et al.* 2018). Our counts are consistent with previous estimates from

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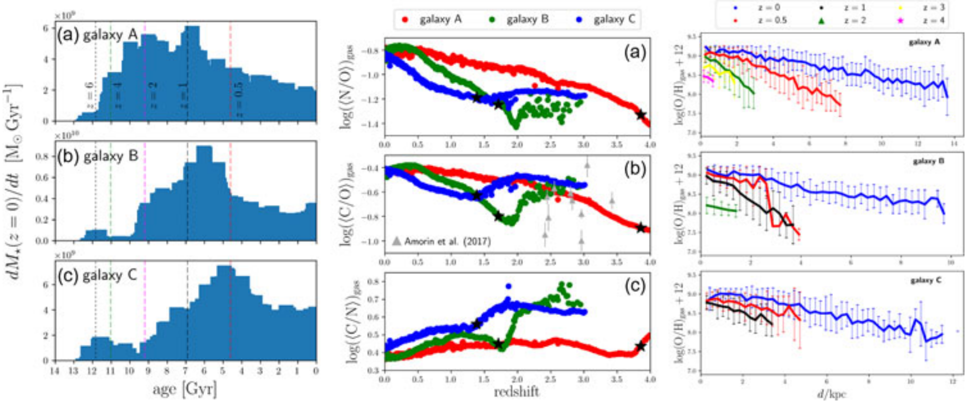

Figure 2. *Left*: Distribution of the present-day total stellar mass as a function of the star particle age. *Middle*: Average SFR-weighted gas-phase log (N/O), log (C/O) and log (C/N) as functions of redshift. We only show the predictions of our simulation for the redshifts when the galaxy stellar mass $M_* \geq 10^8 M_\odot$. The black star symbol on each track marks the redshift when $M_* \simeq 10^9 M_\odot$. See VK18a for the observational data source (grey triangles with the error bars). *Right*: Redshift evolution of radial gradients of elemental abundance ratios at $z = 0$ (blue), 0.5 (red), 1 (black), 2 (green), 3 (yellow), and 4 (magenta lines).

deep ALMA observations (e.g. Fujimoto *et al.* 2016, Aravena *et al.* 2016) at a 3σ level, nevertheless, below ≈ 0.1 mJy, our cumulative counts are lower by ≈ 1 dex, suggesting a flattening in counts at faint fluxes. These results are supported by a preliminary analysis of the remaining two galaxy clusters in our survey (Abell 370 and Abell S1063).

Elemental Abundances across Cosmic Time

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Stars in a galaxy are fossils that retain the information on star formation and chemical enrichment histories in the galaxy. This approach is called the galactic archaeology, and can be applied not only to our Milky Way Galaxy but also to other galaxies (e.g., Kobayashi 2016). Thanks to the collaboration between nuclear physics and astrophysics, we now have good understanding of the origin of elements in the Universe. The observed trends and scatters of elemental abundances from O to Zn in the solar neighborhood can be well reproduced with a chemodynamical simulation of a Milky Way-type galaxy (Kobayashi & Nakasato 2011). We show with our cosmological simulations that elemental abundances can provide strong constraints on the formation and evolutionary histories of galaxies, which can be studied with the James Webb Space Telescope.

Our simulation code is based on Gadget-3 and includes all relevant baryon physics such as UV background radiation, radiative cooling, star formation, supernova feedback, and chemical enrichment from asymptotic giant branch (AGB) stars, core-collapse supernovae (SNe II and hypernovae), and Type Ia supernovae (Kobayashi *et al.* 2007). Taylor & Kobayashi (2014) introduced a new model of AGN feedback in the code, where seed blackholes (BHs) originate from the formation of the first stars, which is different from

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the 'standard' model by other simulation groups such as EAGLE and Illustris. The modelling of the growth of BHs and feedback is the same as in other simulations. Our model parameters are determined in order to match the observational constraints, i.e., cosmic star formation rates, size-mas relation of galaxies, and $M_{\rm BH}$–σ relation.

On a cosmological scale, chemical enrichment takes place even more dramatically (see a movie by Philip Taylor, https://www.youtube.com/watch?v=jk5bLrVI8Tw). There is gas accretion along the cosmological filaments, where star formation and chemical enrichment are already occurring. This results in strong supernova-driven winds because of the shallow potential in the filaments. As the central galaxy grows through the accretion, a super-massive BH also grows (following the $M_{\rm BH}$–σ relation), which eventually causes even stronger winds driven by the active galactic nuclei. Metallicity is very spatially inhomogeneous; the center of massive galaxies can reach super-solar metallicity at high redshifts, while the accreted component has only one-hundredth of solar metallicity as it is mainly fed from the intergalactic medium. The wind component has about one-tenth of solar metallicity as it is a mixture of the inflow gas and supernova ejecta.

As a result, we obtain good agreement with the observed stellar mass function and mass–metallicity relations (MZRs) of galaxies for both gas-phase and stellar populations (Taylor & Kobayashi 2015). These relations evolve as a function of time; the stellar MZR does not change its shape, but the metallicity significantly increases from $z \sim 2$ to ~ 1, while the gas-phase MZR does change its shape, having a steeper slope at higher redshifts ($z \lesssim 3$, Taylor & Kobayashi 2016). Within galaxies, metallicity radial gradients are produced. We find a weak correlation between the gradients and galaxy mass, which is consistent with available observations (Taylor & Kobayashi 2017).

In Vincenzo & Kobayashi (2018a, hereafter VK18a), from another cosmological simulation (with side 10 h^{-1} Mpc) we create a catalogue of 33 stellar systems at redshift $z = 0$, all embedded within dark matter (DM) halos with virial masses in the range $10^{11} \leq M_{\rm DM} \leq 10^{13}\, M_\odot$. The mass and spacial resolutions of gas are $6.09 \times 10^6\, h^{-1} M_\odot$ and $0.84\, h^{-1}$ kpc, respectively. We first focus on three disc galaxies (Galaxy A, B, and C) with different star formation histories (SFHs, left panels of Fig. 2). We then predict how the C, N, and O abundances within the interstellar medium (ISM) of galaxies evolve as functions of the galaxy SFH. At the beginning of galaxy formation, CNO are produced by core-collapse supernovae, N is enhanced by intermediate-mass AGB stars ($\gtrsim 4 M_\odot$), then C is enhanced by low-mass AGB stars ($\lesssim 4 M_\odot$). Therefore, we predict that the average N/O and C/O steadily increase as functions of time, while the average C/N decreases, due to the mass and metallicity dependence of the yields of AGB stars; such variations are more marked during more intense star formation episodes.

Within a galaxy, the distributions of elements are not uniform either, and the central parts of the galaxies are more metal-rich than the outskirts of the galaxies. This radial gradient of elemental abundances also evolves as a function of time, which are shown in the right panels of Figure 2. In disk galaxies, the metallicity gradients become steeper at higher redshifts because of inside-out formation of discs. In Vincenzo & Kobayashi (2018), using all disk galaxy sample in the catalog, we succeed in reproducing the observed N/O–O/H relations, both for individual ISM abundances within single spatially-resolved galaxies and for average abundances in the whole ISM of many unresolved galaxies.

AGN demography with *JWST*

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[3] *CAST stands for Chasing dusty-AGN up to redShift Two and is a team comprised by ∼40 members who contributed to the current status of the project.*

Abstract. With a 5 to 10 year life-span and being a 6 m-class telescope in space, the *James Webb Space Telescope* (*JWST*) will be a highly competitive relatively short-lived tool toward knowledge revolution, with considerable operation overheads. As a result, it is both of interest to the community and facility to conduct observations as efficiently as possible. This brief manuscript highlights a colour criterion to select active galactic nuclei (AGN) from the local Universe as far back as the end of the epoch of reionization ($0 < z \lesssim 6$). Depending on the targetted Universe cosmic time, one is able to conduct a demographic study of dusty AGN with only up to four broad-band filters required (F200W, F440W, F770W, F1800W), three of which can be observed at the same time. Such observations will also allow for the community to assess stellar assembly in galaxies or to identify very high-redshift sources.

Keywords. galaxies: active, galaxies: photometry, galaxies: structure, infrared: galaxies

Infrared broad-band selection of AGN

When dust in the vicinity of AGN is heated by the radiation emanating from the accretion disc, it will radiate in the near- to mid-IR (∼2–60 μm) as a continuum continuously rising with wavelength. This appears distinct from a host-like spectral energy distribution (SED) characterised by a stellar continuum decaying long-wards from the 1.6 μm-bump together with Polycyclic Aromatic Hydrocarbon (PAH) emission-band features (mostly dominant at $\gtrsim 6\,\mu$m) and a colder dust continuum (dominating at $> 10\,\mu$m). This yields the $1 - 7\,\mu$m rest-frame spectral range as the one to pinpoint dusty AGN.

Ideally, one would use spectroscopy to assess this spectral range, but it is time consuming and likely limited to one galaxy at a time with the MIRI IFU. The alternative is to do a contiguous multi-band imaging survey, providing a very low spectral-resolution IFU. However, the time to achieve such survey is also time consuming and eventually difficult to schedule. This will be attempted by the JADES GTO and the CEERS ERS teams, which combined will only provide 40 arcmin^2 worth of multi-band MIRI imaging. For the community at large wishing to target different fields and larger ones, especially important for the $z < 2$ cosmic epoch, a less telescope-time consuming approach is needed.

In Messias *et al.* (2014) we proposed two colour criteria using respectively the F200W, F440W, and F770W filters for the $0 < z < 2.5$ range, adding F1800W for higher-redshifts. The fine spatial resolution enabled by JWST will allow one to deblend host and AGN light, hence selecting less-luminous AGN, a phase where AGN pass most of their life-cycle.

Finding Embedded AGN with MIRI

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Abstract. The many photometric bands available in the JWST instruments allow construction of multi-color diagrams that are much more diagnostic than similar diagrams constructed from *Spitzer* or *WISE* data. This capability is illustrated with an example that successfully separates galaxies with subtle indications of embedded AGN from purely star forming galaxies.

Keywords. galaxies: active, quasars: general

Infrared photometric surveys are a powerful means to identify Active Galactic Nuclei (AGN), and can complement other approaches to discover forms of AGN that are not apparent by other selection methods (e.g., Donley *et al.* (2005), Del Moro *et al.* (2016)). A number of powerful methods for finding AGN have been developed using color-color diagrams of *Spitzer* IRAC and *WISE* photometry (e.g., Lacy *et al.* (2004), Stern *et al.* (2005), Donley *et al.* (2012), Stern *et al.* (2012)). Nonetheless, these methods are primarily useful for AGN with power law infrared spectra, e.g., type-1 objects of large enough luminosity to dominate the stellar output (Donley *et al.* (2012)); in addition, star forming galaxies invade the AGN identification criteria at redshifts above ~ 1.5 (Donley *et al.* (2008)).

Color-color diagrams and related methods complement more sophisticated modeling because they can be less affected by initial assumptions; model fitting is efficient at finding objects that resemble the input models but may miss ones that do not. Fortunately, the many bands available with the Mid-Infrared Instrument (MIRI) on JWST allow, particularly in combination with the NIRCam bands, construction of more complex and more diagnostic diagrams. An example is shown in Figure 1, which combines 11 different photometric bands. This diagram is tuned to differentiate objects where the SED minimum near 4.5 μm in a stellar photospheric dominated SED is filled in by the emission of an AGN. The diagram has been tested using approximately 300 galaxies with high-quality *Spitzer* IRS spectra (not just with templates). As shown in the figure, it is effective in isolating spectra where this filling in is very subtle. The success of this diagram should encourage development of other similar approaches using alternative combinations of the multiple photometric bands provided by the JWST instruments.

AGB Stellar Populations in Resolved Galaxies with JWST

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Abstract. Thanks to its spatial resolution and infrared filters, JWST is expected to greatly expand the volume accessible for studies of resolved AGB star populations, hence potentially impacting the calibration of theoretical models for this critical evolutionary phase. In this talk, I will present the predicted appearance of evolved stars in nearby galaxies using the JWST NIRCam and MIRI filters, investigating, in particular, which filter combinations allow for a better separation of the different types (M and C) of AGB stars, and their expected numbers in SMC-like galaxies located at 4 Mpc. Finally, I will discuss the expectations from The Resolved Stellar Populations Early Release Science Program (ID 1334, PI Dan Weisz), which includes the nearby star-forming dwarf WLM.

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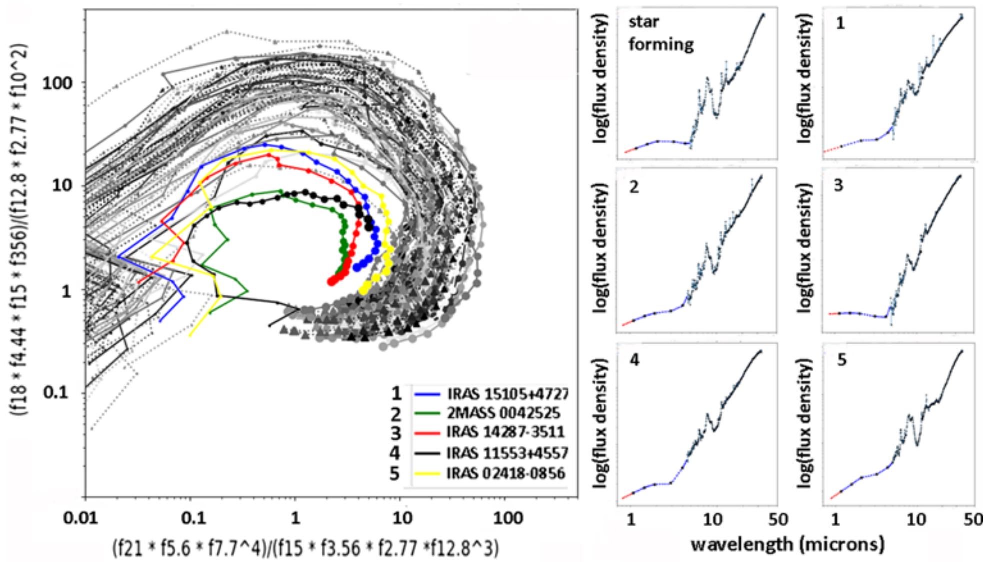

Figure 3. Performance of a MIRI/NIRCam multi-color diagram in identifying embedded AGN. The left panel shows the tracks for star forming galaxies (gray-scale) running from z = 0.5 to z = 2.4 with symbols growing in size with increasing z. It superimposes similar tracks for five galaxies selected for very subtle AGN characteristics in the 4 to 6 μm range. The panels to the right show a typical star forming galaxy SED and the SEDs of the five galaxies with embedded AGN. The SEDs for both parts of the figure combine spectra from *Spitzer* IRS with a fit to JHK, W1, and W2 photometry to represent the stellar continua. The individual SEDs show how the characteristic SED peak from stars in the $1.5 - 3$ μm range is subtly modified by the emission of an embedded AGN, which also dilutes the aromatic features at 6 - 8 and 11 μm. The multi-color diagram successfully identifies these differences independent of redshift.

Keywords. stars: AGB and post-AGB, evolution, mass loss, galaxies: stellar content, infrared: stars

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Overview

The Thermally Pulsing Asymptotic Giant Branch (TP-AGB) phase, experienced by low- and intermediate-mass stars at the end of their lives, plays a critical role across astrophysics, affecting the interpretation of astronomical data from various sources, e.g. from the chemical composition of presolar meteoric grains to the integrated light of distant galaxies. Despite its relevance, the modelling of the TP-AGB phase suffers from severe uncertainties due to the complexity of the physics involved. It follows that a proper calibration of the uncertain parameters, mainly related to the efficiencies of mass loss and convective mixing (the third dredge-up), needs to be carried out with the help of high-quality observations of resolved stellar populations. JWST will provide and excellent tool to investigate AGB stars. The use of suitable combinations of NIRCam and MIRI filters will allow to classify resolved AGB stars (M or C types; see e.g. Boyer *et al.* 2013). Moreover, with JWST we will greatly expand the statistics of AGB stars up to large distances, enabling a detailed analysis of AGB stellar populations in resolved galaxies up to few Mpc far from us. In this contribution I show a few examples of colour-colour diagrams where the evolutionary tracks of O-rich (with surface C/O<1) and C-rich (with surface C/O>1) stars form separate sequences, and

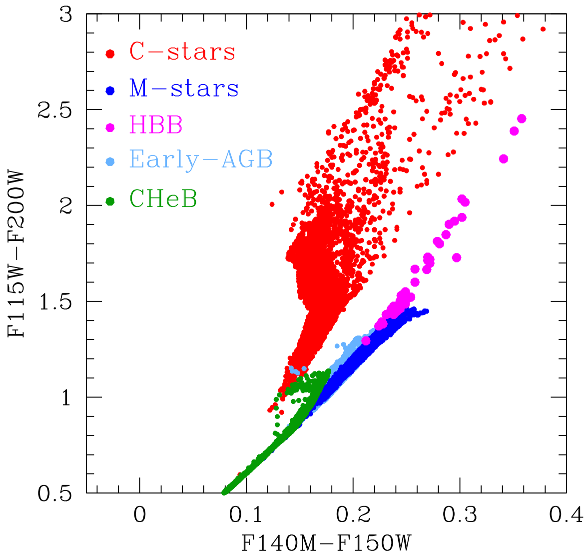

Figure 4. Synthetic stellar populations for an SMC-like galaxy as predicted in a JWST colour-colour diagram. Stars in various post-main sequence evolutionary stages are marked in colour. Note the clear separation of the C-star sequence (red) from the other stars (blue: M-type TP-AGB stars, light blue: Early AGB stars; green: Core-helium burning stars), and the location of AGB stars with hot-bottom burning (magenta). The effect of circumstellar dust forming in the winds of AGB stars is included.

others in which the location of AGB stars that undergo hot-bottom burning (with initial masses $> 3 - 4\,M_{\odot}$) stands out clearly (see Fig. 4). I discuss the main expected properties of resolved stellar populations in typical galaxies (irregulars, spirals, and ellipitcals) as seen in appropriate JWST infrared colour-magnitude diagrams, taking into account the effect of circumstellar dust from mass-losing AGB stars. The STARKEY team (ERC project, PI Marigo) is ready to provide the community with all theoretical tools (tracks, isochrones, spectra, bolometric corrections; Marigo *et al.* 2017) necessary for analysing the data of resolved AGB stars that JWST will release in the future.

Radiative Feedback from Massive Stars

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Abstract. Massive stars disrupt their natal molecular cloud material by dissociating molecules, ionizing atoms and molecules, and heating the gas and dust. These processes drive the evolution of interstellar matter in our Galaxy and throughout the Universe from the era of vigorous star formation at redshifts of 1-3, to the present day. Much of this interaction occurs in Photo-Dissociation Regions (PDRs, Fig.5) where far-ultraviolet photons of these stars create a largely neutral, but warm region of gas and dust. PDR emission dominates the IR spectra of star-forming galaxies and also provides a unique tool to study in detail the physical and chemical processes that are relevant for inter- and circumstellar media including diffuse clouds, molecular cloud and protoplanetary disk surfaces, globules, planetary nebulae, and starburst galaxies.

We will provide template datasets designed to identify key PDR characteristics in the full 1-28 μm JWST spectra in order to guide the preparation of Cycle 2 proposals on star-forming regions in our Galaxy and beyond. We plan to obtain the first spatially resolved, high spectral resolution IR observations of a PDR using NIRCam, NIRSpec and MIRI. We will observe a nearby PDR with well-defined UV illumination in a typical massive star-forming region. JWST observations will, for the first time, spatially resolve and perform a tomography of the PDR, revealing the individual IR spectral signatures from the key zones and sub-regions within the ionized gas, the PDR and the molecular cloud (Fig. 1). These data will test widely used theoretical models and extend them into the JWST era. We will assist the community interested in JWST observations of PDRs through several science-enabling products (maps of spectral features, template spectra, calibration of narrow/broad band filters in gas lines and PAH bands, data-interpretation tools e.g. to infer gas physical conditions or PAH and dust characteristics). This project is supported by a large international team of 140 scientists.

Keywords. (ISM:) HII regions, ISM: lines and bands, ISM: atoms, ISM: molecules, (ISM:) dust, extinction, ISM: globules, infrared: ISM

Establishing Extreme Dynamic Range with JWST: Decoding Smoke Signals in the Glare of a Wolf-Rayet Binary

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Abstract. Dust is a key ingredient in the formation of stars and planets. However, the dominant channels of dust production throughout cosmic time are still unclear. With its unprecedented sensitivity and spatial resolution in the mid-IR, the James Webb Space Telescope (JWST) is the ideal platform to address this issue by investigating the dust abundance, composition, and production rates of various dusty sources. In particular, colliding-wind Wolf-Rayet (WR) binaries are efficient dust producers in the local Universe, and likely existed in the earliest galaxies. Our planned JWST observations of the archetypal colliding-wind binary WR 140 will study the dust composition, abundance, and formation mechanisms. We will utilize two key JWST observing modes with the medium-resolution spectrometer (MRS) on the Mid-Infrared Instrument (MIRI), and the Aperture Masking Interferometry (AMI) mode with the Near Infrared Imager and Slitless Spectrograph (NIRISS). Our observations will investigate the dust forming properties of WR binaries and establish a benchmark for key observing modes for imaging bright sources with faint extended emission. This will be valuable in various

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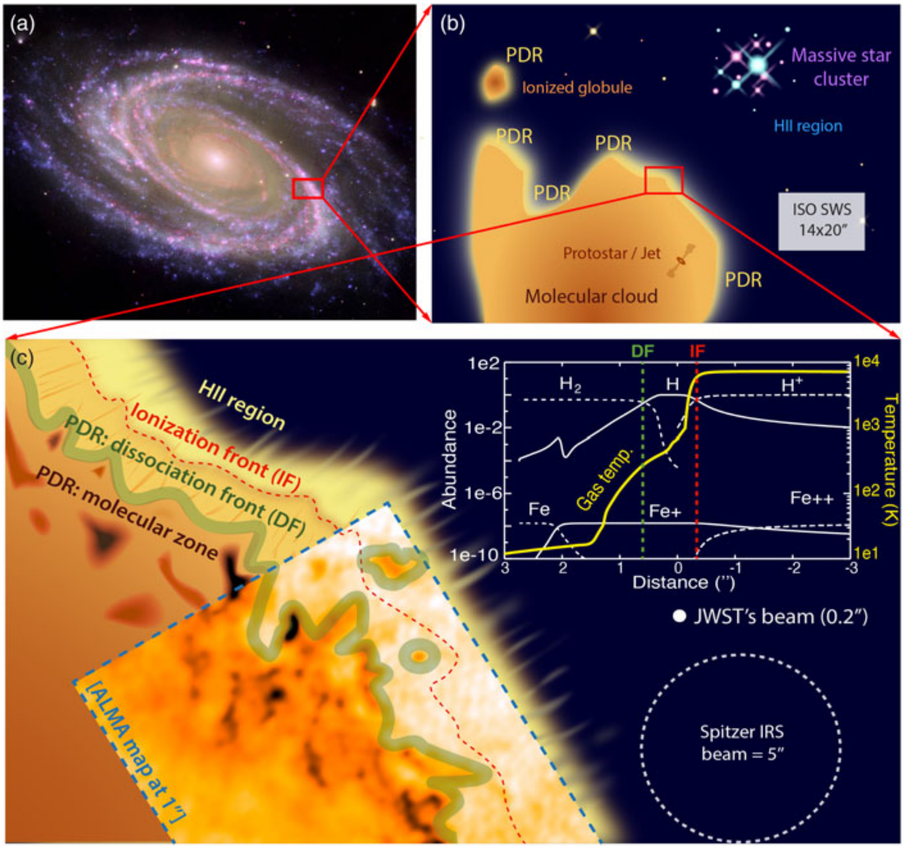

Figure 5. Zooming into a PDR. **a)** Multi-wavelength view of a Galaxy (M81): UV tracing massive stars (blue), optical light tracing HII regions (green), and PAH emission tracing PDRs (red). **b)** Sketch of a typical massive star-forming region (at a distance of 2 kpc). **c)** Zoom in on one of the numerous PDRs, showing the complex transition from the molecular cloud to the PDR dissociation front, the ionization front and the gas flow into the ionized region. Inserted is the ALMA molecular gas data of the Orion Bar, at a resolution of 1" (dashed lines; Goicoechea et al. 2016). The inset shows a model of the structure of the PDR. The scale length for FUV photon penetration corresponds to a few arcsec. The beam sizes of ISO-SWS, Spitzer-IRS and JWST-MIRI are indicated. JWST will resolve the 4 key regions.

astrophysical contexts, including mass-loss from evolved stars, dusty tori around active galactic nuclei, and protoplanetary disks. We are committed to designing and delivering science-enabling products for the JWST community that address technical issues such as bright source artifacts in addition to testing optimal image reconstruction algorithms for observing extended structures with NIRISS/AMI.

Keywords. infrared:stars, stars: Wolf-Rayet, stars: individual: WR 140, stars: winds, outflows

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The goals of this JWST Early Release Science (ERS) program are to investigate how dust forms and evolves around massive stars, and to provide community resources and tools regarding key modes of JWST to observe faint IR emission near bright central sources with high spatial resolution and imaging contrast. We plan to use the MIRI MRS and NIRISS/AMI to perform high-resolution mid-IR imaging and spectroscopy of a prototypical dusty WR binary system, WR 140, which produces shells of dust every eight years due to colliding-wind interactions near periastron passage. MIRI MRS and NIRISS/AMI observations will probe the detailed dust morphology and measure the abundance, energetics, and mass of dust surrounding the bright, central heating source. We will provide the JWST community with science-enabling products including higher level data reduction software for addressing the bright source artifacts for the MIRI MRS, documentation describing bright source artifacts in MIRI MRS and NIRISS/AMI data, and observing strategies to mitigate these effects. Our data products will help to calibrate the achievable image contrast for bright source imaging with MIRI MRS and NIRISS/AMI. Deriving the maximum achievable image contrasts from real data is important to help the JWST community assess the viability of potential observing programs to measure faint emission from structures such as protoplanetary disks, dust shells, and accretion disks around bright sources.

The JWST ERS Program for the Direct Imaging of Extrasolar Planetary Systems

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Abstract. We describe our accepted JWST Early Release Science program, which will perform: a) NIRCAM & MIRI coronagraphy of a newly discovered exoplanet and a well-studied circumstellar debris disk; b) NIRSPEC & MIRI spectroscopy of a wide separation planetary mass companion; and c) deep NIRISS aperture masking interferometry. These observations have been tailored to generate representative datasets in common modes and deliver science enabling products to empower a broad user base to develop successful future investigations. Along with the approved GTO programs, these will be among the first observations to characterize exoplanets for the first time over their full spectral range from 2-28 μm, and debris disk out to 15 μm. We present a summary of these observations and our planned science enabling products in order to inform the community ahead of the launch of JWST.

Keywords. instrumentation: high angular resolution, techniques: high angular resolution, telescopes, techniques: image processing

Science Background & Rationale for an ERS Program

Exoplanet Direct Imaging (Bowler *et al.* 2016) remains an extraordinarily powerful technique to constrain the overall frequencies of extrasolar planets at very wide separations (∼10-1000 AU), and to obtain *direct* spectroscopy of these objects. Indeed,

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aside from some Spitzer/AKARI observations free-floating brown dwarfs (Cushing *et al.* 2006), observations of exoplanets redward of $\sim 5\,\mu$m remain completely out of reach. Thus JWST is expected to be transformative for understanding many of the physical characteristics of exoplanets (e.g. mass, gravity, and atmospheric composition), and allow us to measure the abundances of dominant molecules in the atmosphere (e.g. CH_4, CO, CO_2, H2O, NH_3). At the same time, JWST should have the sensitivity to discover completely new classes of directly imaged planets: Saturn analogues in many cases, and down to Neptune mass planets in the most favorable cases. However, JWST can only achieve these tasks if the user base can rapidly develop a deep understanding of the optimal strategies for observations, calibrations and data post-processing. Specifically, the community dedicated to exoplanet imaging will need an exquisite understanding of the instrument response, PSF stability, and the most effective strategies for PSF subtraction. Indeed, the performance of HST required several cycles to fully understand, and the techniques are still being perfected nearly 25 years later (e.g. Schneider *et al.* 2016). Disseminating an understanding of the performance of JWST to the community as rapidly as possible after launch will be essential for preparing for Cycle 2 and beyond.

Program Description & Expected Science Enabling Products

Our 52-hour program can be divided into three categories which we describe in more detail below: Exoplanet and debris disk coronagraphy (39 hours); Spectroscopy of planetary mass companions (6 hours); and Aperture Masking Interferometry (7 hours).

1) Coronagraphy of Exoplanets & Debris Disks: We will perform coronagraphy of the directly imaged exoplanet HIP6526b (Chauvin *et al.* 2017) using NIRCAM from 2-5 μm and MIRI at 11 and 15 μm. We will also observe the HR 4796 debris disk at 3.0 and 3.6 μm using NIRCAM, and at 15 μm with MIRI. We will rapidly disseminate information about the performance of JWST in these bands (e.g. contrast curves), identify the optimal PSF subtraction techniques, and release a Python-based high-contrast imaging pipeline based on the existing pyKLIP package.

2) Spectroscopy of Planetary Mass Companions: Using the NIRSpec IFU from 1.7-5.3 μm and the MIRI Medium Resolution Spectrograph from 5-28 μm, we will gather spectroscopy of VHS 1256b (Gauza *et al.* 2016), a substellar companion with an angular separation of $\sim 8''$, which greatly reduces any contaminating host starlight.

3) Aperture Masking Interferometry (AMI): We will use NIRISS operating in the AMI mode on the HIP65426 system to characterize the residual phase errors that set the overall contrast floor. We will test the expected sensitivity of 8-9 magnitudes at $\sim \lambda/D$ angular separations, providing sensitivity to young planets at orbital separations of $\sim$15 AU. We will make public a Python-based pipeline for processing AMI data enabling rapid sensitivity estimates for Cycle 2 proposers, and fast analysis of Cycle 2 data.

The Transiting Exoplanet Community Early Release Science Program with *JWST*

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Abstract. The *James Webb Space Telescope (JWST)* presents the opportunity to transform our understanding of planets and the origins of life by revealing the atmospheric compositions, structures, and dynamics of transiting exoplanets in unprecedented detail. However, the high-precision, time-series observations required for such investigations have unique technical challenges, and prior experience with *Hubble*, *Spitzer*, and other facilities indicates that there will be a steep learning curve when *JWST* becomes operational. Here, we briefly describe the science objectives, observations, and community engagement plans of the recently-approved Transiting Exoplanet Community Early Release Science (ERS) Program. Bean *et al.* (2018) provide a more detailed description, including scientific and technical motivations, for this program.
Keywords. planets and satellites: general

Science Objectives

The goal of this project is to accelerate the acquisition and diffusion of technical expertise for transiting exoplanet observations with *JWST*, while also providing a compelling set of representative datasets that will enable immediate scientific breakthroughs. To reach this overarching goal, we have three strategic objectives: (1) determine the spectrophotometric time-series performance of the key instrument modes on timescales relevant to transits for a representative range of target star brightnesses, (2) jump-start the process of developing remediation strategies for instrument-specific systematic noise, and (3) provide the community with a comprehensive suite of transiting exoplanet data to fully demonstrate *JWST*'s scientific capabilities in this area.

Observations

The Transiting Exoplanet Community ERS Program will exercise the time-series modes of all four *JWST* instruments that have been identified as the consensus highest priorities, observe the full suite of transiting exoplanet characterization geometries (transits, eclipses, and phase curves), and target planets with host stars that span an illustrative range of brightnesses (see Figure 6).

The Panchromatic Transmission Program will obtain a near-infrared (NIR, 0.6 – 5.2 m) transmission spectrum of a single planet to demonstrate *JWST*'s ability to obtain precise atmospheric composition measurements and to exercise the instrument modes that will likely be the workhorses for observations of planets ranging from hot giants to temperate terrestrials. The program has been designed to include the necessary wavelength coverage to cross-compare and validate the three NIR instruments, and thus establish the best strategy for obtaining transit spectroscopy measurements in future cycles.

The MIRI Phase Curve Program will test the hour-to-hour stability of *JWST* and MIRI/LRS. Phase-curve observations pose unique challenges that will not be tested with shorter transit- or eclipse-only observations (e.g., high-gain-antenna moves occur every 10,000 s and may disrupt the pointing). We will evaluate potential instrumental noise sources, including long-term flux variations caused by the thermal background and/or the detectors themselves using the science light curves, as prior experience with *Hubble* and *Spitzer* has shown that standard spacecraft calibration data do not characterize such effects at the required precision. We will also investigate other potential sources of

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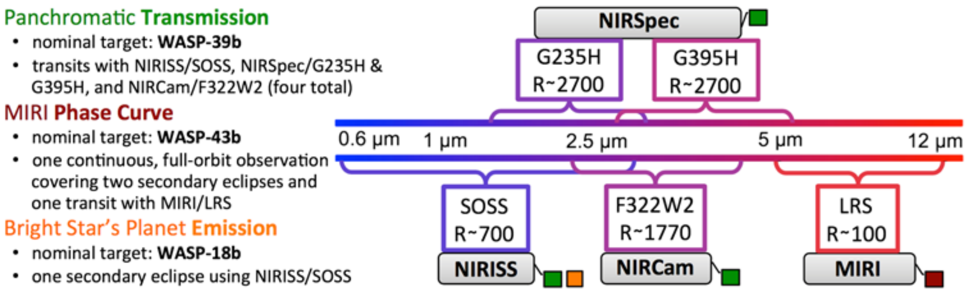

Figure 6. Summary of the three *JWST* observing programs that comprise the Transiting Exoplanet Community ERS program. The schematic on the right indicates the wavelength coverage of the instrument modes that will be utilized. Note that the color coding on the text to the left corresponds to the instrument mode labels on the right. Figure from Bean *et al.* (2018).

systematics including persistence, pointing drifts combined with intra-pixel sensitivity variations, flat-field errors, cosmic ray latency, and jitter.

The Bright Star Program will observe a single secondary eclipse of a hot Jupiter orbiting a bright host star using NIRISS/SOSS. This observation will not only demonstrate the utility of *JWST* data for revealing the atmospheric thermal structures and energy budgets of transiting exoplanets, it will also enable us to determine how precisely *JWST*'s instruments can measure transit spectra in the limit of low photon noise (i.e., a high number of recorded photoelectrons). By pushing the expected noise to very low levels, we will test *JWST*'s behavior at the limit of its achievable precision, in preparation for the compelling transiting exoplanets that TESS will find around bright stars. The performance of *JWST* in this regard is unknown, as there are no design requirements, yet it is a key metric that will ultimately determine if terrestrial exoplanet atmospheres are accessible.

The observations in this program were defined through an inclusive and transparent process that had participation from *JWST* instrument experts and international leaders in transiting exoplanet studies. The targets have been vetted with previous measurements, will be observable early in the mission, and have exceptional scientific merit.

Community Engagement

A core goal of this ERS program is to catalyze broad engagement in *JWST* and to train a community of capable *JWST* exoplanet observers. To address this goal, we will host a multi-phase Data Challenge to spark world-wide collaboration and focus the exoplanet community's creativity on analyzing *JWST* data. This Challenge will comprise online interaction and two face-to-face meetings, bringing together instrument/telescope specialists, observers, and theorists. It will facilitate the speedy validation of our scientific results and construction of our science-enabling products. These activities are not limited to those scientists who were on the original ERS proposal; they are open to the entire community.

Exoplanet Atmosphere Characterization in the framework of the MIRI European Consortium Guaranteed Time Observations

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Abstract. In this paper, we shortly present the program of characterization of exoplanet atmospheres to be conducted in the framework of Guaranteed Time Observations of the MIRI European Consortium.
Keywords. infrared: general, (stars:) planetary systems

Introduction

The consortia who have built an instrument for the JWST benefit from Guaranteed Time Observations (GTO). The MIRI instrument has been built in collaboration between US and Europe (Rieke *et al.* 2015, Wright *et al.* 2015) and the European Consortium has got half of the GTO that an instrument consortium can get. About 25% of that time (110 hours) is used to study exoplanets.

Sources to be observed and challenges to be faced

Out of the 110 hours of GTO, 60 hours are devoted to observe 3 transiting exoplanets (HAT-P-12 b, WASP-107 b and TRAPPIST-1 b), 40 hours to observe 10 exoplanets detected by direct imaging and 10 hours to observe 7 brown dwarfs. The program has been elaborated in coordination/collaboration with the other GTO holders. Details on the program are available at: jwst-docs.stsci.edu/. Coronagraphic observations are discussed in Danielski *et al.* (2018). Given the JWST launch delay, the list may be revised.

Given the large wavelength coverage and the large sensitivity provided by the JWST, uncertainties in the atmospheric models can become a limiting factor (for example Baudino *et al.* 2017), model simplification usually made in retrieval technics can no longer be valid (for example Rocchetto *et al.* 2016), and novel data reduction techniques have to be developed and tested on simulated data. Since January 2018, such activities are developed in the framework of the ExoplANETS-A project (http://exoplanet-atmosphere.eu), partially funded by the European Commission Grant N° 776403.

JWST Commissioning from Launch to Science Observations

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Overview

The *James Webb Space Telescope* (JWST) has an extensive ground test campaign to confirm workmanship and verify Observatory performance prior to launch (e.g., McElwain *et al.* 2018, Kimble *et al.* 2018). JWST commissioning will be used to activate, checkout, and make initial calibrations for the Observatory, which is estimated to take roughly 6 months. Commissioning will conclude when the Observatory is ready to begin the Cycle 1 science program. Following commissioning, each observing Cycle will have dedicated calibration time to build a full suite of calibration data and characterize the technical nuances of the Observatory.

These commissioning activities are separated into three major phases: 1) orbital insertion, spacecraft, and deployments, 2) the telescope, and 3) the science instruments. The commissioning timeline provides a baseline sequence of activities that will be carried out to enable Cycle 1 science observations, depicted with annotations of major events/milestones in Figure 7. In practice, some activities can be moved within the timeline and we anticipate certain scenarios encountered will require contingency activities.

The timeline begins with launch aboard the Ariane 5 rocket. Shortly thereafter, JWST separates from the launch vehicle (LV) and the solar array is deployed to be power

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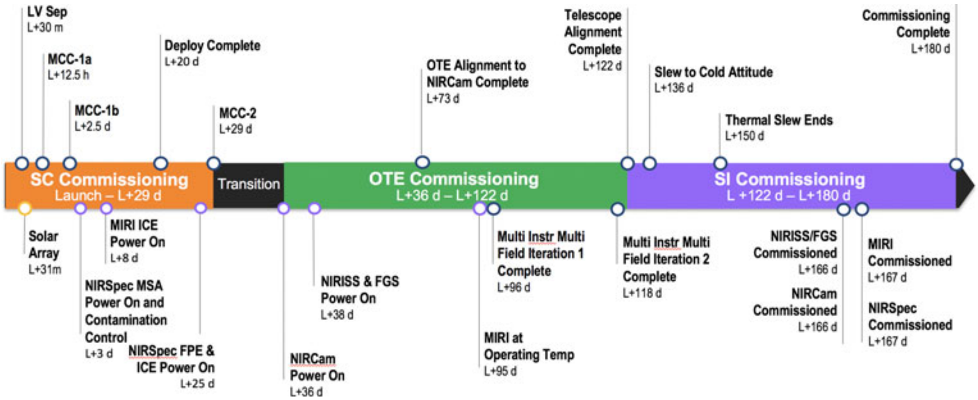

Figure 7. The JWST commissioning timeline consists of the baseline activities and sequence needed to enable Cycle 1 science. The major phases are designated by spacecraft (SC), optical telescope element (OTE), and science instrument (SI), with key events/milestones annotated. During the transition period following the deployments, the telescope and science instruments are passively cooled to their operational temperatures. Additional cooling of the Mid-Infrared Instrument (MIRI) is provided by an active cryocooler.

positive. The next critical activity is a trajectory correction burn, called a mid-course correction (MCC), to add energy required to reach L2. A second trajectory correction burn will be made after ~2.5 days, which is followed by numerous deployments that need to take place to transform from the stowed to operational Observatory. The most complex deployment is the sunshield, which enables passive cooling of the telescope and science instruments.

When cold, the segmented telescope will be aligned by identifying segments, providing wavefront control at the segment-level, co-phasing segments, and correcting the image quality over the large focal plane feeding the science instruments. It will initially be aligned and phased in the NIRCam field of view, followed by the full multi-instrument alignment. The wavefront error will be monitored every 2 days through the remainder of commissioning and throughout the life of the mission. Wavefront corrections are expected to be made approximately every 2 weeks to keep the error within specifications. Telescope commissioning is the longest duration activity in the plan, expected to take approximately 80 days.

As soon as the telescope commissioning is complete, about 4 months after launch, the science instrument commissioning activities associated with observing astronomical sources will commence. These include photometric, astrometric, flatfield, and dark current characterizations; PSF characterizations in the imagers, spectrographs, and coronagraphs; and scattered light measurements. Operational functionality will also be demonstrated including target acquisition and moving target performance, as well as the capabilities of the Operations Script Subsystem (OSS) to execute the observations specified by observers using the Astronomers Proposal Tool (APT). Some observing modes of each instrument will be commissioned and enabled for science before other, more complicated modes. We anticipate starting science observations with each mode as it is enabled in order to begin the science return of this successor to the *Hubble Space Telescope*.

With the exception of the launch segment, all of these activities will be carried out at the Science & Mission Operations Center, located at the Space Telescope Science Institute (STScI). Commissioning will be completed by the JWST mission operations team (MOT), which is comprised of the international partners from NASA, ESA, and CSA, as well as aerospace industry partners such as Observatory contractor Northrop Grumman Aerospace Systems, and STScI.

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