Final Statement of the Workshop on Astrophysics: The James Webb Space Telescope

From first light to new world views

Summary

- The James Webb Space Telescope (JWST) is revolutionizing many areas in astronomy, from first galaxies to new worlds, thanks to exquisite images and rich spectra that are orders of magnitude more sensitive and sharper than those of previous facilities. The workshop covered exciting new science from the high-redshift universe, to the spectroscopy of exoplanet atmospheres, to the study of bodies in our own solar system.
- The success of JWST provides lessons in how any such large international interdisciplinary program can succeed. For society to build and take full advantage of a telescope like JWST, a key element is recognizing that in every stage progress is dependent on multidisciplinary teams. This requires a necessary humility among the members.
- The societal impact of this telescope includes important economic benefits such as technology spin-offs and the training of bright, highly skilled young people who can take this experience to other fields and endeavours. The success of JWST shows how large and seemingly intractable technical problems can be broken down and solved.
- To bring the universe as observed by JWST down to Earth requires a global effort, including true partnerships to promote the growth of astronomy with society and local institutions. This includes access to the data for scientists in the developing world. Among the partners in this dialogue, one should not neglect the potential role that local churches can play in both disseminating the science and putting it into a human context.

- An important recent challenge is the preservation of dark and quiet skies vital to the ground-based observations that complement JWST. Moreover, the sight of dark starry skies has been inspirational to humankind since prehistoric times, notably for Indigenous peoples. A spirit of cooperation may be more likely to succeed in mitigating the problem of light pollution than relying simply on confrontation, with the ultimate goal to turn best practices into a regulatory framework to be endorsed internationally and adopted by appropriate national agencies.
- One of the remarkable successes of JWST has been its ability to excite and inspire the imagination of the public. This is a testament of the excellent results of the observatory, but it also reflects years of careful study and work by the multidisciplinary team involved in creating the first color images and those who made themselves available to explain the science behind those beautiful images to the press and public.
- The astronomy represented by JWST provides an incentive to re-examine and re-appreciate our collective wisdom about the universe, from a dialogue with religion to a pondering of the possible existence of a multiverse. Staring into space with the huge communal eye of a telescope is a way of honoring the cosmos as a source of wonder and knowledge. In all of this, we encounter the other, the alien, not with fear but in an embrace, experiencing and responding to awe.

From first light to new world views

The James Webb Space Telescope (JWST) is revolutionizing many areas in astronomy, from the first galaxies to new worlds, thanks to its exquisite images and rich spectra that are orders of magnitude more sensitive and sharper than those of previous facilities. The workshop covered exciting new science from the high-redshift universe to planets in our own solar system.

Since its launch, JWST has produced outstanding data and one hopes it will continue to do so for many years – in fact, many more than we had originally anticipated. We note an important synergy of its work with that of other major facilities but also recognize that some of its instrumental capabilities are truly unique. There will not be another opportunity for more than 20 years or longer before a similar large facility will be in space.

At the same time, this workshop also has reflected on what this new knowledge means for science and society, deriving lessons learned from the JWST outreach and the public engagement program, which has reached billions of people around the world.

How JWST came to be

"*Science's task is a patient yet passionate search for the truth about the cosmos, nature, and the constituents of the human being*." (Pope Benedict XVI). The need for patience was certainly shown in the lengthy history that finally led to the launch of JWST. Likewise, the passion and the search for the truths it would reveal could be seen both in the commitment of the scientists and engineers toward this project, and the excitement elicited by its results.

JWST was thirty years in the making. Its original driver was to study the earliest galaxies (“first light”), but as it developed the discovery of exoplanets, i.e., planets around other stars than our Sun (“new worlds”), added to the impetus of its development. Advances in technology, such as the development of segmented large optics and new infrared arrays, were also crucial. But equally crucial was the ability to manage international teams with their mix of expertise to make this happen. Rather than being the vision of a single astronomer, JWST was the result of a large community where every person’s abilities became crucial, both in designing, building, testing and launching the telescope and its instruments, as well as ensuring that the mission actually did happen in spite of numerous technical, political, and budgetary challenges.

Exoplanets

Before JWST, our knowledge of exoplanets was, with only a small number of exceptions, limited to a two-dimensional survey of their sizes (or masses) and their distances from their central stars. However, JWST now provides a new dimension to our survey of these new worlds by providing exquisite tools for detecting and measuring the compositions of their atmospheres.

Transits have already been a powerful tool for discovering exoplanets, with the depth of the transit dip giving a measure of the planet’s size. Now with JWST, one can measure the depth of that dip as a function of infrared wavelength to much greater precision than previously possible. The absorption at a given wavelength by a constituent of the planet’s atmosphere produces a slightly larger dip at the absorbing wavelength, and thus a plot of transit depth versus wavelength becomes a transmission spectrum of the atmosphere. JWST can also observe infrared emission from some exoplanets by taking spectra just before and after the planet passes behind its host star. Meanwhile, more distant planets can be directly imaged by JWST, and their thermally emitted spectra measured.

Three major science questions being addressed by JWST are the composition of giant planet atmospheres compared to their parent star, providing clues on their formation; whether terrestrial planets around very low-mass stars have atmospheres at all; and the nature of sub-Neptune exoplanets.

With the discovery of atmospheres especially in temperate (potentially habitable) zone planets comes a renewed study of the possibility of life on these bodies. A particularly interesting subset of planets are the sub-Neptune and super-Earth planets with radii and masses a few times those of Earth. They have rocky cores but their atmospheres may consist of a mix of primary and secondary (outgassing) material. “Hycean” worlds, with hydrogen rich atmospheres and oceans, are just one fascinating example of the new chemical environments in which the study of life's origin can be explored.

Protoplanetary disks

The spatial resolution of JWST in the infrared, again coupled with other space and ground-based telescopes, now allows spatially-resolved observations of the environments of planet formation around the nearest young stars. Furthermore, the higher spectral resolution free of interference from the terrestrial atmosphere offered by JWST allows us to infer the composition of the material that makes planets.

With the ability to study hundreds to thousands of such disks, around stars of all masses, one can outline the many different factors that result in the observed variety of known exoplanet systems. These include stellar mass and composition, radiation environments, age, and random variations that may have profound effects on how a planetary system develops. Indeed, JWST has already found a large diversity in the composition of the inner regions of disks, from water-rich disks to water-poor but hydrocarbon-rich disks.

One can, and must, take account of the variation of composition, pressure, and temperature not only as a function of distance from the young star but also as a function of depth within the disk, from the disk surface to the midplane. Gaps in disks, dust traps where material can accumulate, and the migration of ices across the “snow line”, can now be directly observed, as well as the production of dust from the collisions of protoplanets in debris disks. Unlike the situation that held when the modeling of the solar nebula was first proposed, half a century ago, we now have a surfeit of data to model.

Life cycle of stars and the interstellar medium

Stars begin their lives in the tenuous clouds of gas and dust that are common throughout galaxies, and they return their material to interstellar space when they die. JWST probes all stages of this cycle out to large distances. The ability to study the formation of stars and stellar clusters in metal poor environments has implications not only for the nature of the stars and planets that might be found in earlier galaxies, but also the larger question of the evolution of galaxies in the earliest epochs of the universe.

The formation of young stars involves not only inflow of matter but outflows as well. Their supersonic jets light up at infrared wavelengths and produce beautiful images, showing what our Sun would have looked like when it was no more than a few ten thousands of years old and how it accreted most of its mass.

JWST, in conjunction with other observations, also allows us to identify and track the presence and roles of specific ingredients essential for life as we know it, such as water, various sulfur and nitrogen bearing species, ices, and complex carbon-bearing molecules produced in the earliest stages when the protostar is still deeply embedded in its natal cloud, or even before that cloud collapses to make a new star.

High redshift universe

First light is also earliest light. The results of discovering well-formed ("mature") and relatively metal rich galaxies with bright active galactic nuclei in the early universe, coupled with the confirmation of the dichotomy of the Hubble constant inferred from measurements of the Cosmic Microwave Background at the earliest times versus that directly measured (including by JWST) from galaxies at later cosmic epochs, highlights new challenges to the standard model of galaxy formation and cosmic expansion.

These new observations may suggest that important aspects in our understanding of the physics of the expansion of the universe and galaxy formation remain to be discovered and understood. Similarly, the high elemental abundances found in the early universe, if confirmed by future data, may challenge models for their formation and evolution.

Galaxy evolution

Galaxies are responsible for processing the baryons that make up the visible universe. JWST is opening an entirely new window on certain fundamental questions about galaxy evolution. How do galaxies get their shape and stellar mass? What drives galaxy evolution? What is the role of black holes? Why do galaxies stop forming stars? And how has this changed from "cosmic dawn", the first galaxies, to "cosmic noon", the peak of star formation?

JWST has already highlighted that the earliest galaxies are small and actively doubling their number of stars every few tens of millions of years. Supermassive black holes may play an essential role in the early evolution of galaxies: they can stimulate vigorous early star formation but quench it at a later evolutionary stage. Spectroscopy is essential to reveal the kinematic and dynamical properties of young galaxies as they are being assembled.

JWST is significantly altering the way we think about galaxy shapes, though we still have a long way to go to make full use of its capabilities. Its spectroscopy can reveal the distribution of low ionization emission lines in central regions of a galaxy, to more centrally concentrated high ionization atomic lines that trace accretion disks around black holes, to aromatic hydrocarbon features in the rest-frame mid infrared that trace dust and its interaction with other components in the interstellar medium. We can now detect oxygen lines that are direct tracers of the amount of metals in a galaxy out to large redshifts.

By the peak of star formation, cosmic noon, JWST imaging can resolve the distribution of stars in very dusty galaxies. For the first time we are able to see structures like spiral bars in such regions and measure the bar fraction in early galaxies, which can allow us to quantify their role in funneling gas into the centers of galaxies.

Solar system

The solar system provides a wide suite of potential observation candidates, from trans-Neptunian objects (TNOs) to ice giants, dwarf planets to planetary satellites, gas giants and their rings to comets and asteroids. Even Mars has already been observed with JWST, likely the brightest object that the telescope will ever observe. In fact, one of the challenges of planetary observations is that the objects in question are much brighter than typical JWST targets, requiring a careful choice of filters and short exposure times. Another is the ability to track targets that move in the field of view, which required a special effort of software development early in the project.

Primary science results are based on fundamental spectroscopy of volatiles, tracing their distribution in the surfaces and atmospheres of active main belt asteroids and water-rich satellites. The available spectroscopic detail has even allowed the measurement of the isotopic composition of volatiles, for

example the deuterium and carbon-13 contents for the methane observed on the dwarf planet Eris. Among the achievements is the beginning of a spectral classification system for TNOs based on water and carbon dioxide spectral features. In many cases the data are outpacing what has been measured in the laboratory, sparking renewed efforts to identify organic compounds in JWST spectra.

Beyond the implications for the solar system, the study of the ancient composition of pristine bodies beyond the orbit of Mars provides the opportunity of comparative planetology with exoplanets and protoplanetary disks.

Outreach and public engagement

One of the remarkable successes of JWST has been its ability to excite and inspire the imagination of the public. This is a testament of the excellent results of the observatory, but it also reflects years of careful study and work by the multidisciplinary team involved in creating the first color images and those who made themselves available to explain the science behind those beautiful images to the press and public.

The importance of outreach ranges from the practical (letting the taxpayers see the result of their investment, and inspiring new generations of scientists) to the more profound understanding of why we (both society and ourselves) engage in the study of astronomy. Outreach should, by its nature, be maximally inclusive, and efforts have been undertaken to include underserved populations, such as ethnic minorities or the visually challenged.

Images have always had a remarkable power to change the way humanity sees itself and its place in the Universe. With this power comes a responsibility to understand what the public sees in the images, and how we can explain both the ways the images are made and the science behind the beauty. Outreach should emphasize not only that these images are beautiful, but that they are true.

Given that images from JWST are made electronically, matters of composition, resolution (number of pixels), dynamic range, and the removal of artefacts must be carefully attended to in order to produce an image that is impactful yet true. And given that the JWST images are made in infrared wavelengths, beyond the range accessible to the human eye, it is important to address the common question "Are the colors real?" and explain the mapping of the color palette from infrared to visible. Embracing the general public's curiosity triggered by the fascinating imagery can be beneficial to promote not only astrophysical knowledge but also key skills in modern society, such as data literacy and computational thinking.

In the face of ongoing concern of the proliferation of fake news and general mistrust of science and scientists by certain parts of society, one should engage the curiosity of the public with openness, not condescension. Questions and even skepticism from the public can be great ice breakers for a discussion. Trust comes from dialogue, two-way engagement with society, and it takes time, care, effort, and emotional energy to build that trust collectively.

Indeed, it is worth appreciating that science literacy and trust in science and scientists are increasing in many places. Furthermore, astronomers are well-liked and trusted by the general public (more so than many other kinds of scientists). We thus must see it as our responsibility, given this privileged platform, to have an open dialogue with the public about science and help promote their sense of awe, wonder, curiosity, and trust. A vivid example of such a dialogue was the public lecture held at Sapienza University of Rome as part of this workshop, attended by more than 200 students and members of the general public who were fully engaged with many questions about JWST and its science.

Societal impact of JWST and astronomy

The widespread interest in JWST reflects the advantage that astronomy has in providing the public with a better understanding of how science itself works – both of its promise and its limitations. One is much more likely to engage a stranger by saying "I am an astronomer" than by saying "I am a physicist"!

One of the lessons that the JWST experience can teach society at large is the importance of teamwork over a "superstar" model of approaching large problems. The ability of teams of scientists and engineers to work together, across international borders and oceans, to solve seemingly intractable problems has a special resonance in the less developed world, such as much of Africa, where the distance between rich and poor in society can seem especially daunting.

But the success of JWST itself provides lessons in how science in general, and indeed any such large international interdisciplinary program, can be achieved. What kind of society is needed to build and take full advantage of a telescope like JWST? A key element is the necessity of humility among the members; in every stage, progress is dependent on multidisciplinary teams.

For example, by making proposals for JWST time “dual-anonymous”, where the reviewers do not know the identity of the proposers, and making all data publicly available after at most one year, a large number of younger and otherwise underrepresented communities have been able to be part of the scientific process. In the longer run, the JWST community will need to consider the balance between various observing programs (and types of programs) to ensure that major science questions are addressed, that the archive is homogeneously populated, and that JWST’s unique capabilities are optimally used.

The societal impact of this telescope includes important economic benefits. These include, but go beyond, technology spin-offs. Particularly important is the training of bright, highly skilled young people who can experience how large and seemingly intractable technical problems can be broken down and solved.

This finally leads to the broader question of how to bring the universe, as observed by JWST, down to Earth. This requires a global effort, including true partnerships to promote the growth of astronomy *with* society and local institutions, including access to the data for scientists in the developing world. Among the partners in this dialogue, one should not neglect the potential role that local churches can play in both disseminating the science and putting it into a human context.

Preservation of dark and quiet skies

A seemingly daunting but important recent challenge is the preservation of dark and quiet skies which are important to obtain high quality ground-based observations that complement JWST. While providing important benefits for society, satellite constellations in Low Earth Orbit reflect sunlight to create streaks that degrade optical/infrared images; and they emit radio transmissions against which the highly sensitive systems at radio observatories can be unprotected.

Moreover, a dark and starry night sky is not only essential to advancing our understanding of the universe, but the sight of dark starry skies has been inspirational to humankind since prehistoric times. This holds most notably for Indigenous Peoples, for whom viewing the unpolluted night sky is an integral part of their cultures.

A spirit of cooperation and teamwork is more likely to succeed in mitigating the problem than relying simply on confrontation or attempting restrictive legislation. The International Astronomical Union’s Centre for the Protection of the Dark & Quiet Sky against Satellite Constellation Interference (IAU CPS) and its partners are taking multiple approaches to mitigate negative impacts.

CPS-affiliated policy and space law experts have developed and are refining recommendations for ultimately turning best practices into a regulatory framework to be endorsed internationally and adopted by national agencies in licensing and oversight. Because of the IAU raising awareness, the UN Committee on the Peaceful Uses of Outer Space (COPUOS) is now adopting a five-year agenda item to consider the effects of satellite constellations on astronomy.

Philosophical perspectives, new world views

A telescope is often presented as something apolitical, a thing of objective science and facts. But it can be much more than that. In these times, searching for the furthest horizons is possibly an act of resistance to a society suspicious of the "other"; searching for life in alien form is a way of staying open for the otherness that some would try to make us fear.

The astronomy represented by JWST provides an incentive to re-examine and re-appreciate our collective wisdom about the universe and its very nature. This can range from a dialogue among those with deep religious convictions, to a pondering of the possible existence of a multiverse. In all of this, we encounter the other, the alien, not with fear but in an embrace, experiencing and responding to awe.

The James Webb Space Telescope can help remind us of the intrinsic value of the universe we inhabit, beyond a commodity from which private companies can profit. Staring into space with the huge communal eye of a telescope is a way of honoring the non-commercial values of the universe, honoring the cosmos as a source of wonder and knowledge. The search for habitable planets and possible alien presence makes us understand the stars as a force of life, as something to relate to. It is an antidote, aliens against alienation.

In one of her poems the Canadian astronomer Rebecca Elson formulated something called a *responsibility to awe*. In that phrase, she expresses the insight that we have a duty to honour the poetry of astronomy. Gathering data through a telescope is not about finding facts. It is about starting a conversation that keeps us connected with the universe we inhabit.

List of Participants

1. **Prof. Dr. Joachim von Braun,** President, The Pontifical Academy of Sciences
2. **Cardinal Peter K.A. Turkson,** Chancellor, The Pontifical Academy of Sciences
3. **Msgr. Dario E. Viganò,** Vice Chancellor, The Pontifical Academy of Sciences
4. **Prof. Ewine van Dishoeck,** PAS Academician, Leiden University
5. **Rev. Brother Guy Consolmagno SJ**, PAS Academician, Director Specola Vaticana
6. **Dr. Stacey Alberts,** Research Professor University of Arizona

7. **Prof. Andrea Banzatti,** Assistant Professor Texas State University
8. **Prof. Piero Benvenuti,** Interim General Secretary International Astronomical Union
9. **Dr. Olivier Berné,** CNRS research scientist in astrophysics, Institut de Recherche en Astrophysique et Planétologie
10. **Prof. Karina Caputi,** Professor, Kapteyn Astronomical Institute, Groningen
11. **Dr. Anna de Graaff,** Max Planck Institute for Astronomy Heidelberg
12. **Prof. Rene Doyon,** Professor & Director Universite de Montreal – iREx
13. **Dr. Adriano Fontana,** INAF
14. **Prof. Jonathan Fortney,** University of California, Santa Cruz
15. **Dr. Steven Gillman,** DAWN - DTU Space
16. **Mr. Kevin Govender,** Director, IAU Office of Astronomy for Development
17. **Ms. Marjolijn van Heemstra,** Space Poetry
18. **Prof. Sasha Hinkley,** Associate Professor, University of Exeter
19. **Prof. Thomas Hertog,** KU Leuven
20. **Prof. Dr. Inga Kamp,** Kapteyn Astronomical Institute, University of Groningen
21. **Dr. Jeyhan Kartaltepe,** Rochester Institute of Technology
22. **Dr. Janice C. Lee,** Project Scientist for Strategic Initiatives, Space Telescope Science Institute
23. **Dr. Nikole Lewis,** Associate Professor, Cornell University
24. **Mr. Lars Lindberg Christensen,** Director of Communication, NSF's NOIRLab/IAU
25. **Prof. Jonathan Lunine,** Professor and Department Chair, Cornell University
26. **Dr. Melissa McClure,** Leiden University
27. **Prof. Nikku Madhusudhan,** Professor, University of Cambridge
28. **Prof. Roberto Maiolino,** Professor, University of Cambridge
29. **Dr. Margaret Meixner,** Astrophysics and Space Sciences Section Manager Jet Propulsion Lab/California Institute of Technology
30. **Dr. Henrik Melin,** STFC James Webb Fellow University of Leicester
31. **Dr. Stefanie Milam,** JWST Deputy Project Scientist for Planetary Science NASA Goddard Space Flight Center
32. **Dr. Claudia Mignone,** Public outreach specialist - INAF
33. **Dr. Michiel Min,** SRON
34. **Dr. Matt Mountain,** President, AURA
35. **Dr. Takahiro Morishita,** Caltech/IPAC
36. **Dr. Nathalie Nguyen-Quoc Ouellette,** JWST Outreach Scientist Université de Montréal
37. **Dr. Antonella Nota,** Executive Director ISSI
38. **Prof. Karin Öberg,** Harvard University
39. **Ms. Teresa Paneque-Carreño,** Leiden Observatory
40. **Dr. Klaus Pontoppidan,** Jet Propulsion Laboratory
41. **Prof. George H. Rieke,** Regents' Professor of Astronomy and Planetary Sciences Steward Observatory; & Professor, Lunar and Planetary Lab University of Arizona
42. **Prof. Marcia Rieke,** Principal Investigator for The Near-Infrared Camera (NIRCam).

Professor of Astronomy, University of Arizona

43. **Dr. Pedro Russo,** Leiden University, the Netherlands
44. **Dr. Colette Salyk,** Associate Professor of Astronomy on the Maria Mitchell Chair Vassar College
45. **Dr. Massimo Stiavelli,** Astronomer and Head, JWST Mission Office, Space Telescope Science Institute
46. **Dr. Sandro Tacchella,** Assistant Professor, University of Cambridge
47. **Dr. Łukasz Tychoniec,** Postdoctoral Researcher Leiden Observatory
48. **Prof. Gillian Wright,** Director, UK Astronomy Technology Centre
49. **Dr. Yao-Lun Yang,** Research Scientist RIKEN