stars. On this aspect, more insights into the physical mechanisms can probably be expected when such attempts become more frequent. Although the workshop focused on solar-mass stars, many presentations also included related work on higher mass stars, such as the connection between solar-mass and high-mass young stars, or between AGB stars and supergiants.

All the talk and poster presentations, including the presentations of the interferometry primer, are available from the website of the workshop[1] in PDF format.

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Links

[1] http://www.eso.org/sci/meetings/stars2010

Report on the ESO/ESA Workshop

JWST and the ELTs: An Ideal Combination

held at ESO Garching, Germany, 13–16 April 2010

Markus Kissler-Patig[1]
Mark McCaughrean[2]

[1] ESO
[2] ESA

ESA and ESO jointly organised a workshop to explore the synergies between the JWST and ground-based, extremely large telescopes (ELTs). The main goal of the workshop was to bring the JWST and ELT (GMT, TMT, E-ELT) communities together, to identify the common science cases, and to outline instrumentation/upgrade priorities for the ELTs that would maximise the scientific return in key areas of scientific research requiring both facilities, namely: The End of the Dark Ages — First Light and Re-ionisation; The Assembly of Galaxies; The Birth of Stars and Protoplanetary Systems; and Planetary Systems and the Origins of Life. A lively meeting with intense discussions brought some interesting insights.

Motivated by the advance of the three international Extremely Large Telescope (ELT) projects: the Giant Magellan Telescope (GMT), the Thirty Meter Telescope (TMT) and the European Extremely Large Telescope (E-ELT), as well as by the rapid progress towards a launch in 2014 of the James Webb Space Telescope (JWST), the European Space Agency (ESA) and ESO decided to jointly organise a meeting in order to explore the synergies between these facilities.

Astronomers can look back on two very successful decades of science dominated by the interplay between the Hubble Space Telescope and the 8–10-metre-class ground-based telescopes. The lessons learned from this powerful combination are being taken into account by the new projects. Some similarities to the past exist: JWST will lead the ground-based ELT projects by a few years and it is a facility that has its strength in imaging and low-resolution spectroscopy combined with exquisite sensitivity. The ground-based ELTs will follow with a vastly superior photon-collecting power and a large and versatile number of scientific instruments. A few aspects will also differ. JWST will focus on longer wavelengths, with its main strength in the infrared and it will also have a limited lifetime of around 5+5 years, due to limited fuel. Also, the ELTs, assisted by adaptive optics, will provide a spatial resolution of almost an order of magnitude better than JWST. Thus, not only very high spectral, but also very high spatial, resolution might become the domain of the ground-based telescopes.

With this in mind, close to a hundred participants from Europe, North and South America as well as East Asia joined for the four day meeting held at ESO Headquarters in Garching, Germany. The sessions were not only of very high quality, thanks to very well prepared speakers, but were also very lively, with interesting and fruitful discussions. All talks can be found online on the web pages of the workshop[1].

An update on the status of the projects

The first afternoon was dedicated to an update of the various projects. Jonathan Gardner, deputy project scientist for JWST, reviewed the JWST capabilities and showed the impressive progress made in the last few years towards a launch in 2014. The large amount of flight hardware now assembled and being integrated and tested left the audience in no doubt that JWST is well on track (see Figure 1). Similarly, the four presentations on the the JWST instruments —NIRSpec, NIRCam, MIRI and TFI — demonstrated the advanced stage of the instruments. All the instrument demonstration models are either on their way to, or already at, the Goddard Space Flight Centre ready to be integrated into the Integrated Science Instrument Module flight structure. Besides being reminded of the capabilities of JWST and its exquisite sensitivity in the near- and mid-infrared, the audience got, if it was still needed, the wake-up call to start planning for JWST by the middle of the decade.

The ELTs were presented in turn by Patrick McCarthy, who showed the advances of the GMT project, by David Crampton, who reviewed the progress of the TMT, and by Roberto Gilmozzi and Markus Kissler-Patig, who gave an update of the E-ELT programme. All three projects are in the process of transiting from their detailed design phase to the construction phase and aim at a first light before the end of the decade, about five years after the JWST launch. The suite of instruments investigated for these ground-based telescopes is impressive. A recurrent scheme is the support, with all possible flavours, of adaptive optics: at the diffraction limit, this capability will enable a spatial resolution between 3 and 10 milliarcseconds (depending on wavelength and telescope diameter), compared to > 60 milliarcseconds for JWST, even at its shortest wavelength.

The science sessions

The two following days were split into four topical sessions, following the main science areas of the JWST: The End of the Dark Ages — First Light and Reionisation; The Assembly of Galaxies; The Birth of Stars and Protoplanetary Systems; and Planetary Systems and the Origins of Life. Each session was introduced by a review before giving room to typically five to six more focused contributions.

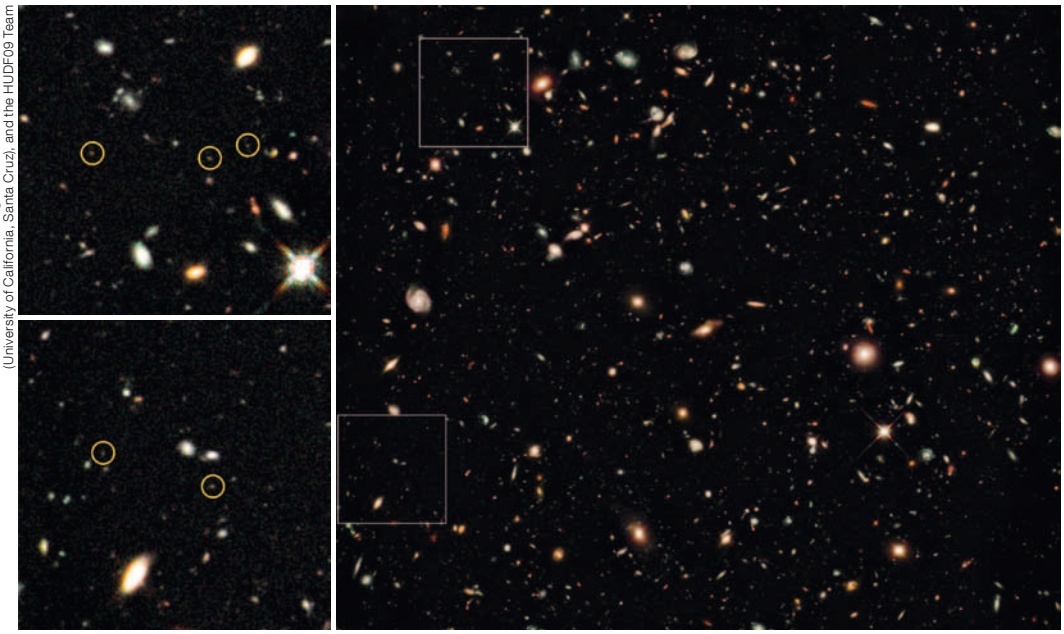
Credit: NASA/MSFC/Emmett Givens

Figure 1. Six of the 18 James Webb Space Telescope mirror segments being prepared to move into the X-ray and Cryogenic Facility, at NASA's Marshall Space Flight Center.

Avi Loeb opened the first session on First Light and Reionisation. He stressed that at high redshifts only a very small fraction of the galaxy mass had assembled and formed stars (i.e. looking at $z > 5$ is looking at < 10 % of today's stars), and that star formation mostly proceeded in very small (and thus faint) structures, beyond the reach of the current facilities. The subsequent talks confirmed this picture and emphasised how much progress had been made most recently in exploring the properties of galaxies at redshifts of six, seven and beyond (see Figure 2). For future progress, structures of angular sizes of 100 miliiarcseconds and below will have to be resolved at these high redshifts.

The topic of the Assembly of Galaxies was reviewed by Guinevere Kauffmann. A key message was the current discrepancy between some observational facts (e.g., the integrated star formation rate exceeds the stellar mass formed?!) and the associated problems of the theoreticians to connect models with data. Despite tremendous progress, our picture is still very incomplete and unsatisfactory. Subsequent talks explored how JWST and ELTs could help resolve these problems by investigating the properties of low- to intermediate-redshift galaxies. Detailed studies of nearby ($z \sim 0$) galaxies could compete in the future with high-redshift ones when it comes to understanding the evolution of galaxies across time.

The second day started with a review by Michael Meyer on The Birth of Stars and Protoplanetary Systems. He emphasised that JWST would dominate in sensitivity and field of view, while the domain of the ELTs would be high spectral and spatial resolution. The combination of sensitivity of JWST in the infrared and the high spatial resolution of the ELTs promises fantastic progress in the study of star formation and protoplanetary discs. This theme was picked up by the other speakers of the session who expanded on the advance that would become possible in the study of star formation throughout the Local Group. It was also stressed that ALMA will of course strongly complement the JWST and ELTs. Yet, the audience was reminded that both JWST and the ELTs will all play a transformational role on their own.



Credit: NASA, ESA, G. Illingworth and R. Bouwens (University of California, Santa Cruz), and the HUDF09 Team

Figure 2. Early HST WFC3 near-infrared imaging observations have revealed $z > 7$ galaxies from photometric redshifts in the Chandra Deep Field South.

The fourth session on Planetary Systems and the Origins of Life was introduced by Drake Deming. The prediction is that the race for characterising the atmosphere of a super-Earth in a habitable zone will be won by transiting planets, observed with JWST (c.f. Figure 3). Subsequently, more systematic atmospheric studies of exoplanets will probably await the planet imagers on ELTs. The advantage of JWST will be its high stability, required for precision differential work on exoplanets, while the ELTs will be able to exploit their high resolving power. The speakers agreed that the trend goes in the direction of searching for exoplanets around low-mass stars, for which planets in the habitable zone are easier to detect. Thérèse Encrenaz took the audience closer to home and provided an overview of the impressive Solar System science that the combination of JWST and ELTs would enable.

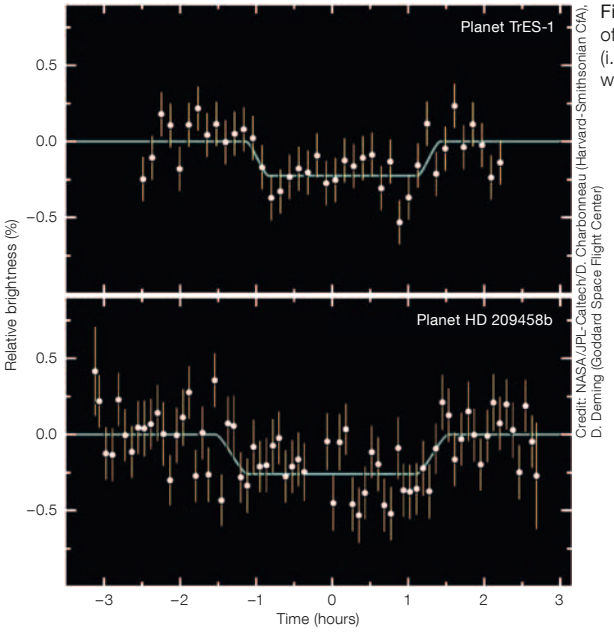


Figure 3. Two examples of light curves of exoplanet secondary eclipses (i.e. planet behind the star) observed with the Spitzer Space Telescope.

A final session on the last day peeked into a few more topics such as high time resolution and the complementarity with the Gaia mission, before moving into a long and lively general discussion.

Discussion

The general discussion centred on a collection of questions that had been raised during the previous days. The questions are reproduced below, followed, for some, by the strongly abridged (and subjective, for which the authors of this report apologise) answers. Rather than final answers, this should be seen a list of questions to think about further.

Session 1

Should JWST and/or the ELTs aim at very deep surveys to see the first galaxies?

“Deep field” observations are conceivable, however time on these facilities will be too precious for classical surveys, which are better conducted with specialised facilities.

What is the best strategy with JWST and ELTs to find Population III stars?
Unclear. Serendipitous observations might be the key and slitless spectroscopy is the promising new kid on the block.

In order to study the highest-z galaxies: should we split the task into imaging with the JWST and spatially resolved spectroscopy with the ELTs?
While the strength of each facility is recognised, enforcing a splitting does not make sense — scientists and TACs are trusted to ensure the best use of the facilities.

Should ELTs aim at resolving z > 6 objects if these are << 0.1 arcseconds in size? If so, what is the best strategy?
A realistic goal seems to be to resolve larger structures into 0.1-arcsecond components, but resolving the latter appears challenging even for ELTs.

Session 2

In order to study the "causality" in the process of galaxy formation and evolution, both gas and stars need to be understood: how can JWST and ELTs synergise?
The "answer" was given in several talks.

What are the physical parameters of z ~ 2–3 galaxies that should be studied?
"The usual suspects" and these will require spatially resolved spectroscopy.

Which redshift is most interesting to look at: z ~ 2, the peak of the star formation rate, or z ~ 6–10 the epoch of reionisation?
Both are equally important and JWST+ELTs will provide us with the opportunity to study *z* ~ 2–3 galaxies in unprecedented detail, as well as for *z* ~ 6–10 galaxies at the same level of detail as *z* ~ 2–3 galaxies today.

Session 3

Should ELTs work at low spatial/spectral resolution, despite excelling at high resolution?
Definitely. ELTs will complement JWST at short wavelengths and by having some particular modes (integral field spectroscopy, high time resolution, polarimetry).

After five years of JWST operations (and nearly ten years of ALMA operations), what will be the most pressing questions to address with the ELTs?
Many convincing answers were given, followed by the convincing argument that all predictions will turn out to be wrong.

How important is the synchronicity of JWST and the ELTs?
While iterating/bouncing between facilities (as today between HST and the 8–10-metre-class telescopes) is an advantage, no strong science case seems to call for it.

Is the new "blue wavelength range" the near-infrared?
It was felt that with the blue cut-off of JWST, with the push towards redder wavelengths due to adaptive optics for the ELTs, and with the strong science cases at high redshift and in star-forming regions, the science might indeed experience a push towards the red/infrared.

Given the strong case for mid-IR instruments on ELTs — if one could put two mid-IR instruments on an ELT, which would they be? How important is low spectral resolution work from the ground given the JWST superiority?
The mid-infrared wavelength range was indeed prominently advocated in Sessions 3 and 4 — advantages of distributing resources over the ELTs are seen and will be explored.

Session 4

Should the ELTs (and JWST) do any exoplanet detection work, or should they focus on their characterisation?
Detection of many hundreds of exoplanets will have happened by the time the ELTs come online. Characterisation might then draw more attention. As stated above: long survey/detection campaigns will probably be too time-consuming to be conducted on the ELTs.

Solar System work: do the JWST and the ELTs envisage tracking at non-sidereal rates (and at which)?
Yes, both JWST as well as all the ELTs plan to track at non-sidereal rates, typically at rates such as to follow objects beyond the orbit of Mars.

Biomarkers: they are challenging — should we nevertheless aim at looking for them? If so, what is the best strategy?
Drake Deming had the final word on this question and proposed the "Zen approach": search for life beyond the Solar System by not looking for it. In other words: life might appear in forms that our imagination is unable to grasp yet, thus a detailed study of exoplanet atmospheres and the possible detection of anomalies might be the best approach to search for biomarkers.

In Isaac Asimov's words: "The most exciting phrase to hear in science, the one that heralds new discoveries, is not 'Eureka!' (I found it!) but 'That's funny ...'". This workshop told us that the decade ahead of us, with the advent of the JWST and three ELTs, might become a really funny one.

Acknowledgements

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Links

[1] http://www.eso.org/sci/meetings/jwstelt2010/program.html