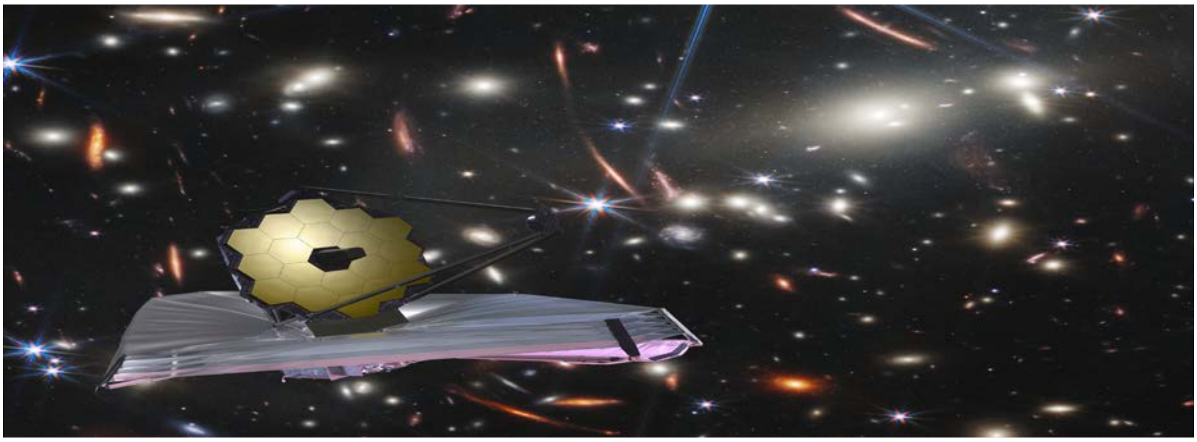


The Emergence of Galaxies and their Supermassive Black Holes as Seen by JWST in Concert with other Observatories

WE-Heraeus-Symposium
10 November 2022

Berlin Brandenburgische
Akademie der Wissenschaften (BBAW)
Berlin

WILHELM UND ELSE
HERAEUS-STIFTUNG

Aims and scope of the WE-Heraeus-Symposium:

The James Webb Space Telescope (JWST) with its 6.5m mirror will be the prime space-based observing platform for astronomers in the coming decades. After more than 25 years of preparation and construction, JWST was successfully launched on Christmas day 2021 and is approaching its full science operation capability. With the progress in commissioning, the focus is now shifting to the science exploitation of the unique capabilities of JWST. Studying the emergence of the galaxy population and its supermassive black holes from the "dark ages" to the present epoch is one of the main science cases for JWST. However, such studies can only unfold their full potential, if they are properly combined with other wavelength studies thus employing a whole array of leading facilities - in operation and under construction – ground based as well as space missions.

The symposium intends to take the start of the JWST science programme as an opportunity to have a holistic view on the field of galaxy evolution and some of its driving facilities presented by some of the leading researchers in the field. The focus is put on facilities in operation and under construction, but the symposium will also give a first look what is being anticipated for the next decade.

Scientific Organizers:

Prof. Dr. Matthias Steinmetz — Leibniz-Institut für Astrophysik Potsdam, Germany

Prof. Dr. Günther Hasinger — ESA, Madrid, Spain

Administrative Organization:

Wilhelm und Else Heraeus-Stiftung
Kurt-Blaum-Platz 1
63450 Hanau, Germany

info@we-heraeus-stiftung.de
www.we-heraeus-stiftung.de

08:00	*REGISTRATION / WELCOME COFFEE*	
09:00	Matthias Steinmetz	**Welcome and Introduction**
	Stefan Jorda	**Welcome Address**
	Chair: Joachim Wambsganß	
09:15	Jeyhan Kartaltepe	**What has JWST Taught us About Galaxy Structure in the Early Universe?**
09:45	Eva Schinnerer	**Uncovering Cloud and Star Formation in Nearby Galaxies with JWST**
10:15	Linda Tacconi	**A (Sub)mm View of Galaxy Formation and Evolution**
10:45	*COFFEE BREAK*	
	Chair: Cristina Chiappini	
11:15	Reinhard Genzel (online)	**The Formation and Early Evolution of Galaxies and their Central Black Holes**
11:45	Lutz Wisotzki	**Mapping the Gas around Galaxies with MUSE and HETDEX**
12:15	Debora Sijacki	**Unveiling the Emergence of First Galaxies and Supermassive Black Holes with Cosmological Simulations in the JWST Era**
12:45	*LUNCH BREAK*	
	Chair: Achim Stahl	
14:00	Melanie Habouzit	**Massive Black Holes across Cosmic Time: What Will We Learn from JWST and Other Next-Generation Facilities**
14:30	Alberto Sesana	**Gravitational Wave Astronomy – Studying Supermassive Black Holes with LISA**
15:00	Jason Rhodes	**Surveying the IR Cosmos with ESA's Euclid**
15:30	Phil Diamond	**The Impact of the Square Kilometre Array on the Study of the Emergence of Galaxies in our Universe**
16:00	*COFFEE BREAK*	

	Chair: Tanya Urrutia	
16:30	Lidia Tasca	**MOSAIC: The Multi-object Spectrograph for the ESO Extremely Large Telescope**
17:00	Roland Bacon	**WST - The Wide Field Spectroscopic Telescope**
17:30	Michael Kramer	**JWST in the German Astronomy Landscape**
18:00	Günther Hasinger	**Paving the Way to a New Center for Astrophysics in Lusatia (DZA)**
18:30	*RECEPTION*	
19:30	*END*	

WST - The Wide Field Spectroscopic Telescope

R. Bacon

[1] *CRAL, Lyon, France*

The WST project aim to study and built an innovative 10-m class wide-field spectroscopic survey telescope (WST) in the southern hemisphere with simultaneous operation of a large field-of-view (5 sq. degree) and high multiplex (20,000) multi-object spectrograph facility with both medium and high resolution modes (MOS), and a giant panoramic integral field spectrograph (IFS). The ambitious WST top-level requirements place it far ahead of existing and planned facilities. In just its first 5 years of operation, the MOS will target 250 million galaxies and 25 million stars at medium resolution + 2 million stars at high resolution, and 4 billion spectra with the IFS. WST will achieve transformative results in most areas of astrophysics. The project is supported by a large consortium of very experienced institutes plus ESO, representing 9 European countries and Australia.

The Impact of the Square Kilometre Array on the Study of the Emergence of Galaxies in our Universe

P. Diamond

[1] SKAO Observatory, Macclesfield, UK

The SKAO, like the JWST, will be one of the cornerstone astronomical facilities of the 21st Century. I will describe the scope, status and capabilities of the two SKAO telescopes, which are currently under construction. I will describe how they will impact on the study of the emergence of galaxies and their supermassive blackholes, which is one of the key areas of science to be tackled by users of the SKAO.

Prof. Reinhard Genzel
Direktor, MPI für extraterrestrische Physik, Gießenbachstraße 1, 85748 Garching
Professor of the Graduate School, Physics and Astronomy, University of California, Berkeley, USA

The formation and early evolution of galaxies and their central black holes

During the past two decades pan-chromatic observational studies from X-rays to radio wavelengths on the one hand, and ever more detailed numerical simulations on the other, have given us an increasingly detailed view of the evolution of galaxies in the past 12 Gyrs. We have learned that baryonic disks have grown from gas accreting along the cosmic web of dark matter filaments, formed stars mainly intrinsically, sometimes perturbed by minor and even major mergers, and ejected heavy-element enriched material back out of these star forming disks through supernovae and activity of accreting black holes. With the James Webb Telescope and the ground-based ELTs it will be possible to push these studies to still higher look-back times, when the first galaxies and black holes were formed. In this story, JWST likely will be the pathfinder, and the ELTs will be able to obtain spatially resolved information.

Massive Black Holes across Cosmic Time: What Will We Learn from JWST and Other Next-generation Facilities

M. Habouzit

[1]*Max Planck Institute for Astronomy, Heidelberg, Germany*

The population of massive black holes (BHs) is diverse and encompasses BHs hosted by dwarf to massive galaxies in the local Universe, active BHs through cosmic times, and extremely powerful quasars observed less than 700 Myr after the Big Bang. Constraining the origins of BHs and how they co-evolve with their host galaxies are currently among the most exciting and challenging aspects of galaxy formation.

In this talk, I will first review our current theoretical understanding of the BH population. Large-scale cosmological simulations have become, over the last decade, indispensable to face the challenge of understanding BH formation and growth and I will present what we have learned from them.

I will then describe the exciting discoveries that we expect in the near future from JWST and the other next-generation facilities that will revolutionize the field (e.g. LISA, Athena).

Paving the way to a new center for astrophysics in Lusatia (DZA)

G. Hasinger
ESA, European Space Astronomy Center, Villafranca de la Cañada, Spain

JWST deep observations of faint galaxies in the early Universe give a glimpse of the earliest star formation in the Universe. There is the exciting possibility that Dark Matter consists of primordial black holes. If this were true, star formation should have started substantially earlier than in the classical model, and JWST may well show the first circumstantial evidence for primordial black holes. The real proof, however, will require gravitational wave observatories of the next generation, in particular the Einstein Telescope (ET) and LISA. But also the Square Kilometer Array (SKA) will yield valuable constraints on the earliest str formation. Both radio astronomy with the SKA and gravitational wave observations with ET are the areas on which the new center for astrophysics in Lusatia (DZA) will concentrate first.

What has JWST Taught us About the Galaxy Structure in the Early Universe?

Dr. Jeyhan S. Kartaltepe

Rochester Institute of Technology, Rochester, NY, USA

The first images taken with the *James Webb Space Telescope* (JWST) are unveiling galaxies in the distant universe and enabling detailed studies of their properties. In this talk, I will present some of the first results on how our understanding of the growth of galaxy structure in the universe has changed based on these first images. We have conducted a comprehensive analysis of the evolution of the morphological and structural properties of a large sample of galaxies at z=3-9 using NIRCam images at 1-5 microns taken as part of the Cosmic Evolution Early Release Science (CEERS) Survey in June 2022. This sample consists of 850 galaxies at z>3 detected in both CANDELS Hubble WFC3 imaging as well as JWST CEERS NIRCam images to enable a comparison of HST and JWST morphologies. Our team conducted a set of visual classifications, with each galaxy in the sample classified by three different individuals. We also measured quantitative parametric and non-parametric morphologies using the publicly available codes Galfit, Galapagos-2/GalfitM, and statmorph across all seven NIRCam filters. Using these measurements, I will present the fraction of galaxies of each morphological types as a function of redshift, compare their morphologies to what we knew based on *Hubble* imaging, and discuss the implication of these results for galaxy evolution. I will also highlight what we expect to learn from future JWST observations in CEERS, COSMOS-Web, and other Cycle 1 surveys.

JWST in the German astronomy landscape

M. Kramer

Institute, Max-Planck Institut für Radioastronomie, Bonn, Germany

The JWST is one of the great new observatories that the global community will use in their exploration of the Universe and in its pursuit of answering some fundamental questions about our origin, that of the Universe and the fundamental laws that govern it. But these questions are so great that we do not expect that a single observatory on its own can answer them. The astronomical landscape considered is therefore even wider and richer, covering the whole electromagnetic spectrum and beyond, requiring a multitude of exciting instruments.

The German astronomical community reviews the outstanding big questions in regular intervals and summarises its findings and a pathway proposed to obtain the answers in the so-called “Denkschriften”. They play the role of a decal plan that is presented to the community, stakeholders, funding agencies and policy makers. Obviously, the JWST featured very heavily in the last “Denkschrift” which was published by the Council of German Observatories (“Rat Deutscher Sternwarten”, RDS) in 2017.

This talk will summarise the overall planning of German astronomy, its intended participation in international projects, as well as the challenges that the community is facing. Recently, the funding decision in favour of the “German Centre for Astrophysics” (Deutsches Zentrum für Astrophysik, DZA) addresses one of the structural challenges in German astronomy, as identified and discussed in the last “Denkschrift” and those before. The promises of the DZA and its role internationally will be discussed.

References

[1] Rat Deutscher Sternwarten, Denkschrift 2017, URL

Surveying the IR cosmos with ESA's Euclid

J. Rhodes[1]

[1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA

ESA's Euclid telescope, which will be ready for launch in 2023, is aimed at understanding the enigmatic dark matter and dark energy that constitute the bulk of the universe. Euclid's images and spectra will also offer a rich data set to attack the most pressing problems in astrophysics, ranging in scale from solar system objects, exoplanets, stellar populations, nearby galaxies, up to the large-scale structure of the universe. While JWST offers views of the infrared universe with unprecedented clarity and depth, it has, like Hubble before it, a limited field-of-view and thus looks at only small swaths of the sky. Euclid features a 1.2m mirror and two cameras, each with a half square degree field-of-view - one operating at visible wavelengths and one in the IR. These two cameras will allow Euclid to take photometric and spectroscopic observations over nearly the entire extragalactic sky over the course of its 6 year primary mission. Euclid's near diffraction-limited photometric observations and grism spectroscopy will usher in a Golden Age of optical and IR survey astronomy that will be augmented by the Rubin and Roman observatories later in the 2020s.

References

[1] Laureijs, et al., arXiv:1110.3193, (2011)

Uncovering cloud and star formation in nearby galaxies with JWST

E. Schinnerer[1], A.K. Leroy[2], J.C. Lee[3], K. Sandstrom[4], E. Rosolowsky[5]
and PHANGS collaboration
[1]Max Planck Institute for Astronomy, Königstuhl 17, 69117 Heidelberg, Germany
[2]Ohio State University, Department of Astronomy, 140 West 18th Ave, Columbus, OH 43210, U.S.A.
[3]NOIRLab, 950 N Cherry Ave, Tucson, AZ 85719, U.S.A.
[4]University of California San Diego, CASS, 9500 Gilman Drive, La Jolla CA 92093-0424, U.S.A.
[5]University of Alberta, 4-183 CCIS, Edmonton, Alberta, Canada

Where do stars form and how is their formation regulated across galactic disks are two critical questions for our understanding of the star formation process. High angular observations of nearby galaxies allow us to sample the star formation process across entire galactic disks reaching now regularly the scales of the star-forming units, namely Giant Molecular Clouds (GMCs) and HII regions. Such data provide new insights on the cold gas reservoir and its role in the star formation process as well as information on the importance of galactic components such as bulges, stellar bars, spiral arms and active galactic nuclei (AGN) in the conversion of that gas into stars. The PHANGS (Physics at High Angular resolution in Nearby GalaxieS) survey combines cloud-scale observations of all relevant constituents in this process. JWST observations are the latest addition to this multi-wavelength dataset and provide a sharp new unobstructed view on the gas, dust, and stellar cluster. I will present highlight from the ongoing research of the collaboration exploring the spectacular JWST data.

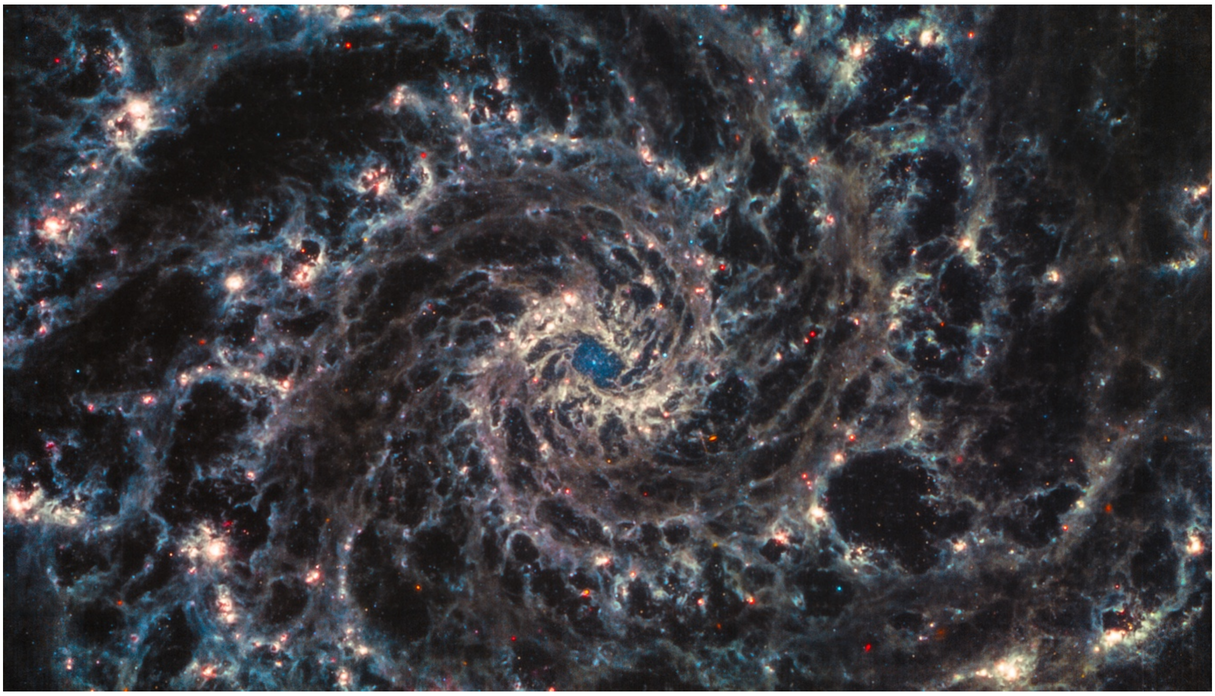


Figure shows the distribution of dust in the Phantom galaxy (NGC628 or Messier 74) as seen via JWST MIRI camera combining information from three filters.

Gravitational Wave Astronomy – Studying supermassive black holes with LISA

A. Sesana[1]

[1]Dipartimento di Fisica "G. Occhialini ", Universita` di Milano-Bicocca, Piazza della Scienza 3, 20100, Milano

Supermassive black holes are observed in the center of virtually all massive galaxies and are thought to play a pivotal role galaxy evolution. In the frame of the hierarchical clustering scenario of galaxy evolution, they are thought to grow starting from a population of black hole seeds at high redshift via a sequence of gas accretion episodes and mergers with other black holes. The details of the physical processes driving their emergence and early growth is still a matter of debate, and although JWST will provide new insights on the early growth of these objects, an unprecedented wealth of information will come from the planned Laser Interferometer Space Antenna (LISA). Scheduled fol launch in 2035, LISA will observe the gravitational waves emitted from merging massive black hole binaries anywhere in the Universe up to the epoch of the assembly of the first protogalaxies following the dark ages. In this talk I will describe the main features of the LISA mission and how its observations will contribute to unveil the cosmic history of massive black hole binaries.

Unveiling the emergence of first galaxies and supermassive black holes with cosmological simulations in the JWST era

D. Sijacki[1]

[1]*Kavli Institute for Cosmology, Cambridge and Institute of Astronomy, University of Cambridge, UK*

The James Webb Space Telescope (JWST) is a stunning technological achievement. It is the largest and most powerful space telescope ever built and has sensitivity up to three orders of magnitude higher in parts of the infrared than its predecessors. JWST promises to be a formidable cosmic `time machine' allowing us to peer back in time to only a few hundred million years after the Big Bang, when the very first stars, galaxies and supermassive black holes emerged from the `Dark Ages'. The first results have already stirred the observational and theoretical communities, with spectacular discoveries bound to come in the next few years.

In this talk I will review the state-of-the-art in our theoretical efforts to understand the physics governing the evolution of the very first cosmic structures from the time of the `Dark Ages'. I will discuss the complex interplay of galaxies and supermassive black holes in the early Universe, from the formation of dwarf galaxies hosting perhaps the elusive intermediate mass black holes, to the most massive proto-clusters harbouring 'gargantuan' black holes. I will emphasize what we can learn from the latest cosmological simulations of these objects in conjunction with the incoming JWST data. Finally, I will also discuss synergies of JWST with other upcoming space missions, such as Athena and LISA, which will fully unlock the multi-messenger view of our Universe.

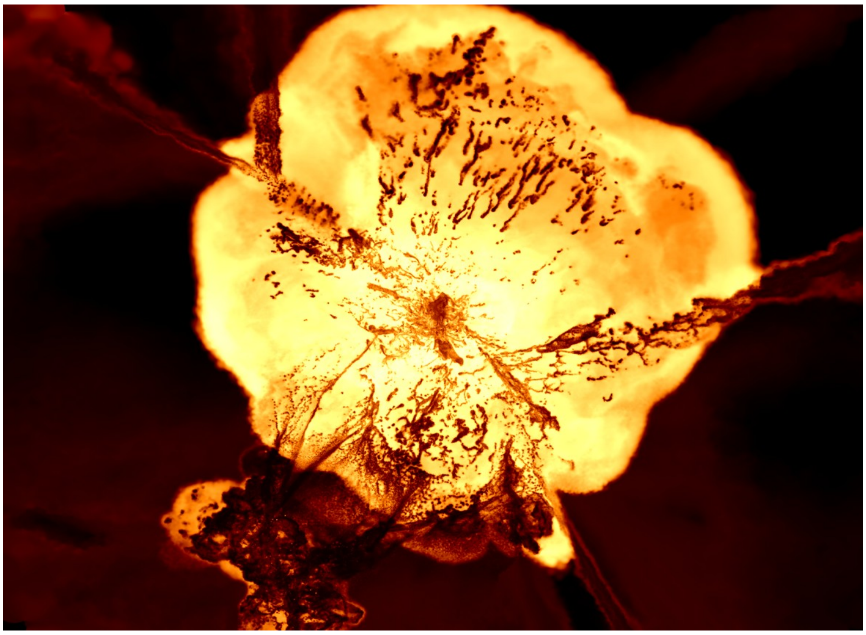


Fig. 1: Large scale view of a 'super-refined' proto-cluster simulation at z = 6 (Bennett & Sijacki, 2020). The colour encodes gas temperature, with yellow-white showing hot gas heated by the central supermassive black hole and dark-red showing cosmic filaments and thermal `precipitation' in the CGM.

A (Sub)mm View of Galaxy Formation and Evolution

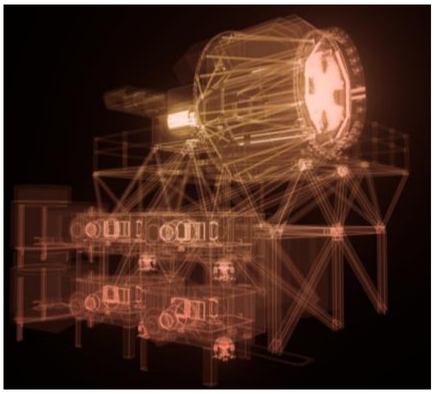
L. Tacconi

[1] *Max Planck Institute for Extraterrestrial Physics, Garching, Germany*

Over the past decade comprehensive and systematic studies of star formation and the gas contents of galaxies during the epochs that are associated with the peak ($z \sim 1$-3), and subsequent winding down ($z<1$) of star formation have enabled us to illustrate the important role that cold gas plays in the assembly of galaxies across cosmic time. These studies show that star forming galaxies contained significantly more molecular gas at earlier cosmic epochs than at the present time. Global rates of galaxy gas accretion, which vary with cosmological expansion, primarily drive this increase in cold gas and star formation rates in the dominant main sequence galaxy population. Studies also show that the molecular gas depletion time depends mainly on redshift or Hubble time, and at a given z, on the vertical location of a galaxy relative to the “star formation main sequence”. In this talk, I will present various strategies and methods used to determine the evolution of cold gas contents, and discuss some of the most promising areas for future work, especially in light of likely new insights from JWST.

MOSAIC: the multi-object spectrograph for the ESO Extremely Large Telescope

Lidia Tasca[1], on behalf of the MOSAIC Consortium
[1]Laboratoire d'Astrophysique de Marseille, France



MOSAIC is the multi-object spectrograph (MOS) of the ESO Extremely Large Telescope (ELT). It will take advantage of the full resolution of a 39m telescope combined to a GLAO adaptive optic correction. It will use the widest possible field of view provided by the ELT and will have three operating modes that cover observations in visible and infrared light for more than one hundred sources simultaneously. At the horizon 2030, MOSAIC will be the first MOS on an ELT allowing to tackle a large variety of scientific cases going from the study of resolved stellar populations beyond the Local Group to the study of galaxies at the reionisation epoch going through the galaxy mass assembly.

I will review the status of the project.

Mapping the gas around galaxies with MUSE and HETDEX

L. Wisotzki

Leibniz-Institut für Astrophysik Potsdam (AIP), Germany

Galaxies build up gradually through the accretion of gas from the intergalactic medium (IGM). They also lose mass, driven out by galactic winds or by external effects such as tidal forces or ram pressure stripping. Understanding these processes and their interplay is key to understanding galaxy evolution. The principal battleground between inflows, outflows, and gas recycling is located far outside of the main stellar body of a galaxy, but gravitationally still bound to its potential – now generally denoted as the 'circumgalactic medium' (CGM). The low densities in the CGM, and even more so in the IGM, imply that detecting this gas directly in emission has been largely impossible until recently. Most of our knowledge of IGM and CGM stems from absorption lines in the spectra of bright but rare background sources.

Recent developments in wide-field imaging spectroscopy have now opened a new and powerful probe of the circumgalactic and possibly even the intergalactic medium. Of particular relevance here are two major new astronomical facilities, MUSE on the ESO Very Large Telescope in Chile, and VIRUS/HETDEX on the Hobby-Eberly Telescope in Texas. Both instruments combine – in very complementary ways – the spectro-mapping capabilities of an Integral Field Unit (IFU) with substantial areal coverage. Here I present an overview of some of the main achievements with MUSE as well as first results from HETDEX.

MUSE in particular has provided us with unprecedented access to the low surface brightness emission of cool-warm gas around galaxies, detectable at high redshifts ($z \gtrsim 3$) in the Lyman-α line of hydrogen and more recently also through metal line emission of intermediate redshifts ($z \lesssim 1$) systems. The interpretation of these observations is theoretically challenging, but making excellent progress. Further insights in particular on the statistical aspects and the large-scale distribution of CGM and IGM emission can be obtained from the HETDEX survey. Here the scientific exploitation has only just started, but already showing great potential.