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Talk abstracts

Garima Singh - Optimizing coronagraphic observations at small inner working angle
The direct detection of young and warm extrasolar giant planets in the habitable zone of nearby cool stars is one of the major goals of current ground-based high-contrast imaging (HCI) instruments. The quest is to search for rocky exoplanets that holds the evidence for biosignatures. To characterize such exoplanets by spectroscopy of their atmospheres requires their direct imaging which is challenged by the ability to resolve planet signal above bright stellar background. Coronagraph suppresses the diffraction effects of the telescope by blocking the starlight but residual wavefront error scatters starlight over the science region of interest losing faint planet photons in stellar noise. Therefore, the optimized coronagraphic observation at small angle require focus on three major technical areas : 1) optimal and predictive control of the low- and high-order aberrations, 2) speckle suppression and its interaction with the wavefront control and 3) the real-time point spread function (PSF) calibration at the inner working angle (IWA) using the wavefront sensor telemetry. In this talk, I will first give an overview of the HCI techniques, the capabilities of the current ground-based direct imaging instruments and its significance. Then, I will introduce my PhD research, which focused on estimating the low-order wavefront aberrations at the IWA of a coronagraph and will present how my work has benefitted the HCI community. I will also provide a brief overview of one of my current projects : calibrating the coronagraphic PSF using the low- order wavefront sensor (LOWFS) telemetry to subtract the residuals left uncorrected by the LOWFS control loop at small IWA. As a closing remark, I will give a brief account of how these techniques can benefit the ELTs in the search of exoplanets at small angular separations.

Bachar Wehbe - Atmospheric Dispersion Measurements for Model Validation
Observations with ground based telescopes are affected by differential atmospheric dispersion, a consequence of the wavelength-dependent index of refraction of the atmosphere and the angle of observation. The design of Atmospheric Dispersion Correctors is based on dispersion models, although the requirements are set to the on-sky performance. With the arrival of large telescopes, and the need for high resolution spectrographs to reach an RV precision ~10 cm/s, stringent instrumental requirements are needed. As the models are not exact, there is always an imperfect compensation. Different models can give differences of a few tens of mas; this value is close to the requirement of current instruments. However, the accuracy of atmospheric dispersion models have never been evaluated with on-sky observations. We propose to directly measure this dispersion on sky, to both evaluate the accuracy of models and determine which one best reproduces the observations.

Cyprien Lanthermann - Characterization of a near infrared e-APD for interferometry at CHARA
Near Infrared interferometry has always been confronted to the sensitivity limit imposed by the noise floor of CMOS detector. That’s why the community shows a major interest in the new electron avalanche photodiode (e-APD) technology, with direct amplification of the signal in the pixel’s substrate. Nowadays, only a few e-APD are in routine operation, and the majority are used as sensing detectors (fringe-tracker, wavefront sensors) and not as primary science camera.

We present the characterization of the new science detectors of the MIRC-X instrument at the CHARA observatory. MIRC was upgraded in 2017 with the J- and H-band C-RED ONE camera from First Light Imaging. And we are currently testing a second camera to expand the wavelength coverage of the instrument to the K-band in 2018.

The first baffling and filtering configuration of the H-band camera suffered from significant background contamination. This background arises from an unexpected sensitivity at wavelengths longer than 3µm. This was dramatically improved with a second configuration. The background noise associated with our f/4 aperture at room temperature is lower than the readout noise for the typical integration time of 1-10ms. Consequently, the camera of MIRC is operated with a warm spectrograph with negligible loss in sensitivity.

We performed a full characterization of the intrinsic properties of the detector such as the system gain and the avalanche gain. This avalanche gain can reach a signal amplification of 300. We also measure the absolute effective sensitivity of the camera, including the quantum efficiency and the transmission of the filters and optics.

The classical mean-variance curves reveal an apparent sub-Poisson statistic of the noise at high gain. We conjecture that this could be the signature of a no (or partially) amplified flux, that increases with the avalanche gain. This signal highly contributes to the background but has a negligible effect on the noise. This brings a loss in dynamic at high avalanche gain, but not in sensitivity.

The camera electronic allows selecting the number of time we consecutively read a single pixel (before we read the next pixel) and the number of time we read the same line of pixels (before we read the next line). We explored various readout schemes in order to reach the lowest possible detector noise, while still achieving our goal of 1 to 10ms frame rate. With the improved baffling, the optimal readout scheme, and the use of the avalanche gain, we reach a total noise level about an order of magnitude better than the previous camera of the MIRC instrument. We discuss the improvement brought by this technology breakthrough with respect to the astrophysical performances of the instrument.

Steven Bos - Fully broadband vAPP coronagraphs enabling spectropolarimetric high contrast imaging

The direct imaging and characterization of Earth-like planets around nearby stars is one of the goals of modern astronomy. Detecting an Earth-like exoplanet demands a very challenging contrast of <1E-9 between the planet and host star, and its characterization requires information on both the polarization and spectrum of the light. Spectropolarimetry can reveal unique information on the atmosphere composition, cloud and surface structure and eventually biomarkers. Here I will present several techniques that naturally combine with the “vector Apodizing Phase Plate” (vAPP) coronagraph into one high contrast imaging instrument capable of delivering high contrast and spectropolarimetric information on the exoplanet. The vAPP coronagraph modifies the phase in the pupil plane such that it shapes the Point Spread Function (PSF) of the telescope into two PSFs with “dark holes” on opposite sides. A patterned half-wave liquid crystal layer will induce geometrical phase that is inherently achromatic. This enables imaging in broadband filters and thus the combination of coronagraphy with spectroscopy over large wavelength ranges. The geometrical phase induces the phase on the circular polarization states, which makes the combination of polarimetry with the vAPP coronagraph very natural. By adding quarter-wave plates, that convert circular polarization into linear polarization and visa-versa, the polarimetric vAPP system will operate on linear polarization. Quasi-static aberrations in the optics non-common to the science arm and main wavefront sensor arm degrade the raw contrast achieved by the coronagraph. We will utilise the diversity between the (at least) two PSFs created by the vAPP to measure these aberrations and correct them, this will allow the vAPP to achieve its designed contrast.

Robert Harris - How can you supervise someone?
The student-supervisor relationship is probably the most important one during a PhD. Instead of a talk, I wish to discuss my feelings and experiences with this, taking feedback from the general audience. Things I will cover will include trying to work with different types of personalities and/or work ethics, different levels of ability and giving feedback.

Faustine Cantalloube - Dealing with non-common path aberrations for high-contrast imaging
One of the main limitation of high contrast imaging for exoplanets and disks is the presence of non-common path aberrations (NCPAs). Knowing the instrument and the observing conditions, we can potentially trace-back those NCPAs to get rid of them by post-processing or by sending the right command to the deformable mirror. In the context of multi-spectral images as provided by an integral field spectrograph, we can use the spectral diversity to estimate the NCPAs and recover the scientific information in the images. In this talk I will introduce the basics of the methods currently estimating the NCPAs and introduce the latest results obtained with the VLT/SPHERE instrument.

Philipp Maier - Stratospheric balloons as a platform for the next large far infrared observatory
Observations that require large physical instrument dimensions and/or a considerable amount of cryogens, as it is the case for high spatial resolution far infrared astronomy, currently still face technological limits for their execution from space. Due to these limits, the far infrared domain in particular is lacking behind other wavelength regimes in terms of angular resolution and available observational capabilities, especially after the retirement of the Herschel Space Observatory. Balloon-based platforms promise to complement the existing observational capabilities by offering means to deploy comparably large telescopes with comparably little effort, including other advantages such as the possibility to regularly refill cryogens and to change and/or update instruments. The planned European Stratospheric Balloon Observatory (ESBO), currently under preparation by a consortium of European research institutes and industry, aims at providing these additional large aperture far infrared capabilities, exceeding the spatial resolution of Herschel, in the long term. In particular, the plans focus on reusable platforms performing regular flights and an operations concept that provides researchers with proposal-based access to observations as also practiced on space-based observatories. It thereby aims at offering a complement to other airborne, ground-based, and space-based observatories in terms of access to wavelength regimes, spatial resolution capability, and photometric stability. In order to fully exploit the potential offered by regularly flying balloon platforms, ESBO foresees the option to exchange instruments and telescopes in between flights.

While the far infrared capabilities are a main long-term objective, ESBO will offer benefits in other wavelength regimes along the way. Within the recently launched ESBO Design Study (ESBO DS), financed within the European Union's Horizon 2020 Programme, a prototype platform carrying a 0.5 m aperture telescope for UV and visible light observations is being built and a platform concept for a next-generation far infrared telescope is being studied. A flight of the UV/visible prototype platform is currently foreseen for 2021. The talk will outline the scientific and technical motivation for a large aperture balloon-based far infrared observatory and the ESBO DS approach towards such an infrastructure. Secondly, I will present the technical motivation, science case, and instrumentation of the 0.5 m UV/visible platform.

Sebastiaan Haffert - On-sky results of the Leiden EXoplanet Instrument (LEXI)
The Leiden EXoplanet Instrument (LEXI) is a bench-mounted high-contrast spectrograph (HCS) and high- contrast imager(HCI). Both science instruments are mounted behind a common adaptive optics (AO) system. The AO can be controlled by several new wavefront sensors for which we will show the first on-sky results. There is a new pupil-plane wavefront sensors; the Generalized Optical Differentiation Wavefront sensor (g-ODWFS). LEXI can switch between two observing modes, the HCI mode or the HD-IFS mode. The spectrograph is very compact because it is fed by single-mode

fiber. The HD-IFS is an IFS that covers the spectral range of 600-800 nm with a constant spectral resolving power of 96000. The 2kx3k detector makes it possible to deliver diffraction limited spectra of up to 20 input fibers. The high-dispersion spectra of the HD-IFS allow for robust post-processing technique to remove residual stellar speckles and allows for direct characterization of the faint stellar environment. We will show the first successful on-sky results of the injection into a single-mode fiber with LEXI. In HCI mode an Apodizing Phase Plate (APP) is used to create a dark region around the star with an average design contrast of 1E-4. The APP is multiplexed with holographic modes to create the Coronagraphic Modal Wavefront sensor (cMWS) for non-common path error (NCPE) correction. The cMWS creates holographic copies in the focal plane that react linearly to aberrations. The holographic copies are measured simultaneously with the science target. There is no downtime for NCPE correction. We will show the first on-sky closed-loop correction of (NCPEs) with the cMWS.

Boris Safonov - Speckle polarimeter, an instrument for high angular resolution polarimetry
Speckle polarimeter (SPP) is a facility instrument of 2.5-m telescope of SAI MSU. By design it is a combination of two-beam polarimeter with rotating half-wave plate (HWP) and EMCCD-based speckle interferometer. The instrument operates in visible range: 0.5-1.1 microns. Simultaneous acquisition of orthogonally polarized radiation and fast modulation by rotating HWP allows to strongly suppress the effects of atmospheric turbulence and obtain a distribution of polarized flux at diffraction limited resolution (0.05 arcsec). As long as the method does not rely on coronagraphic mask the resolving of circumstellar environment as close as 0.05 arcsec to the star is possible. The SPP can be used either in Cassegrain or Nasmyth focus of 2.5-m telescope. For the latter case methods of compensation of instrumental polarization and polarization aberrations were developed. The instrument suits for study of bright and small dusty circumstellar environments of some young stellar objects, mira variables, semiregular variables etc. For V=7 objects SPP reaches contrast of 10^-3 for polarized flux at 0.15” from the central source. Using SPP we resolved the dusty disk wind of enigmatic YSO RW Aur A. Variable circumstellar nebulae were detected for V CVn on angular scales of 0.1-0.15”.

Hugo Buddelmeijer - From KiDS to Euclid to MICADO
My career changed from ground-based optical (KiDS) into space-based infrared (Euclid) and will hopefully continue with ground-based infrared (MICADO). Should be easy, how different can these instruments be? Well, much more than I anticipated! Learn from my journey about the different challenges that these projects present.

Sreekanth Reddy V - Development and on-sky testing of tip-tilt adaptive optics system
A tip-tilt adaptive optics (AO) system is developed for 1.3 m telescope, Kavalur. It is mounted on the telescope for on-sky testing. The instrument is intended to improve the spatial resolution of the image. It is designed for visible band of the electromagnetic spectrum and has resolution of 0.08” with diffraction limited field of view (FOV) of 1.2’ . To evaluate the performance of the instrument, it is tested on pair of stars that are separated by few arcseconds (≈ 2”) to several arcseconds and of magnitude (mv) brighter than 6 in the visible band. The preliminary results have shown an ≈ 47% improvement in image resolution and slightly above 100% improvement in the peak intensity of the image over an integration time of 5 minutes. The instrument is tested for different correction loop frequencies over a field of view of ≈ 1.2” by observing a cluster of stars.

Huizhe Yang - PPPP on-sky experiment design
For the next generation of extremely large telescopes with the primary mirrors over 30m in diameter, focal anisoplanatism renders single laser guide star AO useless. The laser tomography AO (LTAO) technique demonstrates an effective approach to reduce focal anisoplanatism, although it requires

multiple LGSs & WFSs, and complex tomographic reconstruction. A novel LGS alternative configuration , termed Projected Pupil Plane Pattern (PPPP), associated with its corresponding wavefront sensing and reconstruction method has been demonstrated from Monte-Carlo simulation and a laboratory experiment. An on-sky experiment is now under design to verify this new technique, using a 1.8m telescope and 720W laser at 1064nm, including a site-related simulation and hardware design and a implementation of SH WFS as comparison.

Alvaro Menduina - Machine Learning techniques for the calibration of non-common path aberrations in spectrographs containing Image Slicers (ELT-HARMONI and ELT-PCS)
Direct imaging of exoplanets with coronagraphic and post-processing techniques requires suppressing stellar light down to contrast levels of around 10^-6 or 10^-8 at very small separations ranging from 30 to 100 milli-arcseconds. Under such demanding constraints, high contrast images suffer from residual speckles which look similar to exoplanet signals, thus greatly reducing detectability. These speckles originate from quasi-static optical aberrations due to surface roughness or alignment errors which remain undetected by adaptive optics systems in ground-based telescopes (non-common path aberrations, NCPA). Even small wavefront aberrations of around 50 nm RMS can impose severe limitations on the achievable contrast. Therefore, calibrating and correcting those aberrations is essential to enable direct imaging of faint companions.

In the context of the European Extremely Large Telescope (E-ELT) both HARMONI and ELT-PCS (Planetary Camera and Spectrograph) will provide AO-assisted integral field spectroscopy capabilities to detect and characterize exoplanets. Several calibration techniques for estimating NCPA are available, including kernel phase, phase diversity and differential optical transfer function (a method proposed for JWST), but some of these may not be well-suited for the particular design constraints of HARMONI or PCS. For instance, phase diversity requires defocusing the incoming light which can lead to light loss issues at the HARMONI image slicer unaccounted for in conventional phase diversity algorithms. In addition, an optimization problem must be solved every time a new calibration run is performed, reducing the available science time.

For this reason we have investigated the use of alternative techniques which do not suffer from those limitations. We have developed a novel method based on machine learning (in the form of neural networks) capable of estimating NCPA directly from images without the need for defocusing or optimization. The neural network is trained using thousands of simulated PSFs each associated with a random NCPA map, learning how to recognize typical NCPA patterns (in the form of Zernike polynomials) from the given images. Once trained, the neural network is tested on previously unseen images, for which it manages to recover the input NCPA accurately.

One of the main advantages of this new method is that once the neural network is trained, it can perform the calibration almost instantaneously without running any optimization. Moreover, as it relies only on unmodified images, it does not require defocusing the light or modifying the pupil as other techniques do, thus relaxing the hardware demands on the instrument. It only uses multi-wavelength PSFs readily available in the science data cube. This method, in combination with advanced post-processing techniques could provide unprecedented contrast levels for the exoplanet detection and characterization in the future ELT era.

Ryan Blackman - Novel Features of the Extreme Precision Spectrograph
The Extreme Precision Spectrograph (EXPRES) is a new exoplanet-hunting instrument recently commissioned at the 4.3 meter Discovery Channel Telescope, Lowell Observatory, USA. Designed to discover rocky exoplanets in the solar neighborhood, EXPRES is an environmentally stabilized, cross-dispersed echelle spectrograph operating at visible wavelengths with a resolving power reaching 150,000. A number of novel features make this a unique instrument, such as the use of a double scrambler/pupil slicer, chromatic exposure meter, and a tunable, LED-based, extended flat field light

source. Wavelength calibration is performed with a Menlo Systems laser frequency comb. The primary goal for EXPRES is to have the resolution and precision necessary to isolate and remove the effects of stellar activity from observed spectra, leaving behind the Doppler signatures of orbiting exoplanets. I will present an overview of the EXPRES hardware, and discuss ongoing work to verify the measurement precision of the instrument.

Patrick Dorval - The HARPS3 Spectrograph and the Terra Hunting Experiment
The third version of the High Accuracy Radial velocity Planet Searcher (HARPS3) instrument is built for the Terra Hunting Experiment, a ten-year programme aimed at achieving 10 cm/sec radial velocity precision on nearby stars to search for Earth-like planets. HARPS3 will be commissioned on the to-be-roboticized 2.54-m Isaac Newton Telescope at La Palma in 2021. HARPS3 will include a novel dual-beam insertable polarimetric unit which allows for direct measurement of stellar activity signatures, which can be useful in correcting activity-induced radial velocity jitter in the search for Earth-like planets. In addition, to reach a radial velocity precision of 10 cm/sec on main sequence stars, methods must be developed to understand and reduce the stellar activity signatures, such as starspots, plages, oscillations, and more. This talk will discuss the HARPS3 instrument and its ten-year programme, and explore the difficulties in characterizing stellar activity signatures to reduce radial velocity jitter.

Henrique Lupinari - Testing G-CLEF Fiber Efficiency: the Impact of using Adaptive Optics
G-CLEF is a fiber fed spectrograph not designed to work as an Adaptive Optics (AO) instrument on GMT, however the insertion of an AO system could bring improvements to its measurements. The intention of this project is to perform laboratory experiments using optical bench setups simulating G-CLEF and GMT working with and without AO, mainly measuring the efficiency of the fiber, and compare them, studying how much the measurements would gain from an AO system. When the bench experiments are optimized, the project will follow to the next step which is making these same experiments but now on a more realistic environment, the Magellan Telescope.

Sarah Bougueroua - STUDIO: A first step towards a European Stratospheric Balloon Observatory
For most astronomical measurements, the atmosphere is an obstacle. Astronomical observations in the ultraviolet (UV) at wavelengths below ~320 nm are not possible from the ground because of atmospheric extinction by ozone. Early on, observers thus started to move their instrument as high above the perturbing atmospheric layers as possible. Spacecraft provide access to optimal observing conditions in this endeavour. However, they are not very accessible after launch and are comparably expensive. For some astronomical applications, though, particularly in the far infrared wavelength region and in some parts of the ultraviolet region, it is sufficient to take a smaller step up – into the stratosphere. At a height of 40 km, observations are feasible down to ~200 nm. Only in the range 240-260 nm, residual ozone reduces the transmission to ~20%. Therefore, a balloon-borne telescope enables UV observations that are usually only possible with space-based telescopes.

Within the ESBO DS (European Stratospheric Balloon Observatory – Design Study) project, financed within the European Union's H2020 programme, the Institute of Space Systems (IRS) is working to realise this step. In cooperation with five other European partners, the IRS works towards making the excellent observing conditions at an altitude of 30 to 40 km available to a broad scientific community. The explicit goal of the endeavour is to create a European research infrastructure featuring regular flights, exchangeable instruments, and open access to observation time. In practice, the work on the 3-year pilot project, which officially began on March 1st 2018, will focus on two immediate objectives:
1. On the development and construction of a prototype gondola and telescope, which shall perform technology tests as well as deliver first scientific results during its maiden flight with a newly developed UV-instrument and a visible light tracking camera.

2. On the development of a strategy for the long-term establishment and operation of the observatory – including the study of the technical feasibility of balloon flights with larger telescopes, particularly of the 5 m aperture class for far infrared observations.

The Stratospheric Ultraviolet Demonstrator of an Imaging Observatory (STUDIO) is the ESBO-DS prototype comprising a 50cm telescope aperture in a Cassegrain configuration. The telescope instruments platform (TIP) attached to the back of the optical tube assembly will house a beamsplitter, and two instruments;
1- A photon-counting microchannel plate (MCP) detector that shall perform observations in the UV band ~ 200-300 nm.
2- A visible light imaging instrument that will mainly serve as the tracking sensor in a closed-loop fine image stabilisation system, but that may also be used as an auxiliary science instrument.

Two science cases motivate the UV scientific part of STUDIO, namely a.) The search for variable hot compact stars, and b.) The detection of flares from cool dwarf stars.

Felix Bosco - SOWAT: Speckle Observations With Alleviated Turbulence
Adaptive optics (AO) systems and image reconstruction algorithms are indispensable tools when it comes to high-precision astrometry. In talk, I will present our work on the potential of combining both techniques, i.e. by applying image reconstruction on AO corrected short exposures. Therefore we simulated speckle clouds with and without AO corrections and created synthetic observations. We applied holographic image reconstruction to the obtained observations and found that (i) the residual wave fronts decorrelate slower and to a lower limit when AO systems are used, (ii) the same reference stars yield a better reconstruction, and (iii) using fainter reference stars we achieve a similar image quality. These results suggest that holographic imaging of speckle observations is feasible with longer integration times and fainter reference stars, obtaining diffraction-limited observations from basic ground-layer AO systems that are less restricted than complex AO systems.

David Doelman - High-contrast imaging using liquid-crystal technology
Observing extrasolar planets directly is very challenging; only a small fraction of the confirmed exoplanets have been directly imaged. Increasing this fraction not only requires bigger telescopes but also improving adaptive optics, coronagraphs and imaging systems. Liquid-crystal technology can be used to upgrade these three components of any high-contrast imaging system. The direct-write technology for liquid-crystal patterns allows for manufacturing of extreme geometric phase patterned optics that are inherently broadband. We present liquid-crystal vector-Apodizing Phase Plate (vAPP) coronagraph that can operate up to 100% bandwidth with contrasts <10^-5, installed on Subaru, WHT, LBT, Magellan and soon the VLT. We demonstrate operations of focal plane wavefront sensing combined with coronagraphy with the vAPP for the high-contrast imaging balloon system (HiCIBaS). We show the double-grating vector-vortex coronagraph operating from with a leakage below 0.1% from 1-2.5 micron. Other implementations of liquid-crystal technology include the vector-Zernike wavefront sensor for simultaneous phase and amplitude wavefront sensing and holographic aperture masking (HAM). Aperture masking using holography is enabled only by liquid-crystal technology and improves throughput, the number of measured closure phases and allows for large bandwidths (>30%).

Mauricio Flores Cabrales - Thermo-mechanical optimization of the metrology camera for the metrology and calibration system of MOONS
MOONS (Multi-Object Optical and Near-Infrared Spectrograph) will be the new fiber-fed multi-object spectrograph for the ESO VLT. MOONS will be capable to examine 1000 astronomical objects in one single exposure. To ensure the accurate positioning of the 1000 fibers over the focal plane, a metrology system has been designed to provide position measurements within ~15 microns. The metrology system is based on a circular array of 12 off-axis cameras located at the Rotating Front

End. Each fiber is mounted on little 2 DOF robots called Fiber Positioning Units, that uses an arm to hold the fiber and two metrology targets which are recognized by the metrology system. To achieve the accuracy required, the camera must be pre-heated controlling the internal pixel clock. The warm-up process causes thermal displacements of the detector and could generates air turbulence in the Focal Plane affecting the image quality and the measurement precision required for the correct operation of MOONS. Since the camera enclosure provided by the manufacturer proved not to fulfill the system requirement, we developed an in-house solution. This presentation shows the analysis and development of a new camera enclosure that allows the fast-thermal exchange between the detector and the environment and a mechanical mount based on auto-centering optomechanical mounts to compensate the thermal displacement of the detector. The results for the new design show a decrease in the temperature of the entire camera of 6.6 °C with respect to the off-the-shelf solution. It also ensures that the temperature at the front of the objective does not exceed more than 1 °C over the environmental temperature, which is required to avoid turbulences. The new mechanical mount proves a maximum displacement of the detector of about 0.08 pix which is 12 microns in the focal plane, meeting the requirement.

Maaike van Kooten - Your most important decision: which controller?
Performance of extremely large telescopes will be limited by the performance of their adaptive optics (AO) system. In order to obtain the performance needed to achieve our prescribed science goals, we need to implement smart controllers that allow us to overcome hard-ware constraints (e.g. time-lag). Many different control strategies have been presented in the past for different types of (AO) including LQG, and neural networks. I will give an overview of these different control schemes discussing the pros and cons. I will then talk about my own work on predictive control for high contrast imaging. Finally, I will discuss my efforts in improving disturbance modeling to better test the behaviour of these controllers before lab and eventual on-sky testing.

Alban Ceau - Statistics for full pupil interferometry
In astronomical imaging, binary sources with a high flux contrast between the primary and the secondary source, and a separation between the sources of the order of magnitude of the resolution of the telescope present a challenge: aberrations in the telescope smear the light of the primary source, masking the secondary in the image.

These kinds of problems are usually treated by the use of coronagraphs. These devices, even though they can provide extremely high contrasts, have trouble with the observation of objects very close to the primary source, and are very sensitive to any aberration.

This robustness problem can be mitigated using observables derived from closure phases, but applied to images acquired using full-pupil telescopes, in non chronographic mode. These observables, called Ker-phase are independent from small aberrations in the optical path.

I present the results of the deployment of these observables, coupled with a statistical framework that allows a control over the false positive rate for companion detection on realistically simulated JWST NIRISS images. I compare the capability of Ker-phases to the expected performances of other proposed observation modes and data reduction methods, such as PSF subtraction, and imaging using the embarked chronograph.

Felix Widmann - Polarization effects at GRAVITY and the VLTI
GRAVITY is a near-infrared interferometer, which coherently combines the four beams from the unit telescopes at the VLT. One of its main goals is to observe and better characterize the super massive black hole at the center of the Milky Way. GRAVITY is successfully observing since 2016 and has already led to several important scientific results. Nevertheless, we push further to continuously improve the instrument and get the most out of its capabilities.

One so far unexplored capability of GRAVITY is that one has the possibility to simultaneously observe different polarization states. However, to get the most out of this information we need to characterize all possible instrumentational effect on the polarization of the measured light. This includes a deep understanding of the beam combiner itself but also a characterization of the effects introduced by the VLTI facility in general, as birefringence can occur at different strength in the four arms of the interferometer.
My work aims to understand and characterize those different effects and see what needs to be improved to get the most out of the polarization measurements with GRAVITY. With this talk I will show the measurements on site which are necessary for the characterization of the effects, as well as the adaptations we have done so far and are planning in the near future, to fully use the polarization information we gain with GRAVITY.
The final goal of this work is to add the polarization measurement to the ongoing observation of the black hole and measure the polarization of the black hole in the quiet state as well as during the periodically occurring and heavily polarized flares. This would give us the possibility to further improve our knowledge of the origin of the flares as well as of the properties of the black hole in general.

Gilles Otten - HiRISE: Coupling SPHERE with CRIRES+ for high-contrast spectroscopy of directly imaged exoplanets
In this talk I will present our work at the Laboratoire d'Astrophysique de Marseille on coupling the direct imager SPHERE with the high resolution spectrograph CRIRES+ (HiRISE project, PI: Arthur Vigan).

Using its Adaptive Optics system and coronagraphs, SPHERE provides a high contrast close to the star, and although it is very well optimized for direct detection of exoplanets, it is less efficient for their characterization because it only provides low-resolution spectroscopy (R=50). With SPHERE it is possible to determine some of the fundamental parameters of the detected planets, such as their temperature, but the detailed composition of their atmosphere remains difficult to measure. To allow an accurate determination of their composition, an increase in spectral resolution of a factor 100 to 1000 is necessary.

CRIRES+ can provide a resolution of R=100,000 in YJHKM bands (overlapping with SPHERE's NIR branch in H and K band). As both instruments are sitting on the same VLT telescope (UT3), they can be coupled using a bundle of NIR fibers and a fiber injection and extraction unit, thereby combining their properties.

This combination therefore allows us to perform detailed atmospheric studies of known directly imaged exoplanets without the detrimental effect of starlight.

Abani Shankar Nayak - Integrated Photonic Interferometry using Pupil Remapper and a novel-Beam Combiner at H-band
In recent past, the discovery of young stars, exoplanets, quasars, solar planets and black holes have boosted the astronomical community to find solutions to the unanswered questions that had once been remained puzzled. These were only possible due to trends in detection techniques, photonic technologies and telescopic instrumentation. High contrast imaging is achieved only with the direct detection techniques such as interferometry or cornography that directly studies the light and resolves the finer feature of any astronomical target, as opposed to indirect techniques such as transit or doppler. Interferometry has been evolving with the advent of photonic technologies with much greater accuracy and reduced footprint. In this talk, I will be talking about the performance metrics of a lab-on-chip interferometer using the technique of pupil remapping and a novel-beam combiner.

Aperture Masking is one of the powerful optical interferometry started in 1980s to get reliable complex images of astronomical source. In aperture masking, the primary pupil of a telescope is engineered in to several sub-apertures. Light from the sub-apertures are combined interferometrically in a non-redundant fashion. Pupil remapping is the same as that of aperture masking, but the light from the non-redundant apertures are reformatted/rerouted using Fibers or Waveguides (WGs).

After the non-redundant configuration from the input pupil is selected; these are reformatted using 3D WGs, maintaining same path length and injected into the 4 inputs of the novel-beam combiner. The beam combiner consists of an array of zig-zag 23 input Waveguides to have an optimum Signal-to-Noise Ratio (SNR) and is first calibrated to find out the Instrumental Transfer function or Visibility-2-Pixel Matrix (V2PM). After the calibration is done, the inverse of V2PM i.e. P2VM is computed and one can find out the simultaneous object visibilities and phases that are the key quantities used for the image reconstruction of any astronomical target.

I will use Corning Eagle glass substrate for manufacturing of these photonic components. The theoretical transmission for the 3D WGs is more than 80% at 1550 nm, considering bending and transition losses in to account. But, the complicacy due to fabrication will be addressed later. The average retrieved visibility is 1.0 per baseline and the retrieved phase is a linear ramp as expected for a point source. In this case, the monochromatic nature of laser used for the calibration is assumed to be a perfect point source. In presence of photon shot noise, the visibility SNR of the beam combiner shows a close resemblance with the ideal ABCD combiner used for the GRAVITY instrument in VLTI.

Momen Diab - Efficient Coupling of Starlight into Astrophotonic Instruments by Photonic Lanterns in presence of Partial AO correction
Photonic lanterns allow more efficient coupling of starlight into single-mode astrophotonic instruments when compared to direct coupling into single-mode fibers. While, in theory, most of the light collected by a terrestrial telescope can be coupled into the multimode end of the lantern provided that it has a large enough numerical aperture, the photonic lantern is only lossless if it has a number of single-mode ends at least matching the number of modes it supports at its multimode end. A 4-meter telescope under median seeing (Fried’s parameter r0 = 20 cm) would require about 400 modes supported by the lantern which means that a similar number of copies of the astrophotonic instrument need to be connected to the end of every single-mode fiber for all the collected flux to be utilized. A partial adaptive optics (AO) correction where the mean-square error of the received wavefront can be brought down to about 2 rad2 has the potential of reducing the necessary number of modes to the order of 10. We investigate numerically the modal throughput of photonic lanterns in presence of partial AO correction in order to find the optimal trade-off between the AO system complexity and the size of the lantern that provides an enhanced coupling compared to the single-mode fiber.

Saavidra Perera - P-REx: The Piston-Reconstruction Experiment
The sensitivity of infrared interferometers is affected by several noise sources such as, facility throughput, detector read-out noise and telescope vibrations. However, the fundamental limit is the atmospheric coherence time.

In interferometry the presence of the turbulent atmosphere induces fluctuations in the optical path difference between each telescope used (baseline). As a result, the observed fringes are unstable, randomly moving around the sidereal position. Therefore, control of the phase aberration caused by the atmosphere i.e. the piston stability, is necessary for interferometry.

Typically, this has been done by employing adaptive optics (AO) and fringe trackers to increase the sensitivity of interferometers. Here a new method, the Piston Reconstruction Experiment (P-REx), will be presented. P-REx requires only pseudo open loop AO data to reconstruct the temporal piston drift from the atmosphere. This has the advantage that the system can be easily implemented since all required hardware will already be available at the relevant interferometers.

The idea behind this method is that the piston drift is simply the product of the wind velocity (obtained by the spatio-temporal cross-correlation of the POL slopes) and the tip and tilt of the atmosphere.

P-REx has tested positively in simulation and on real on-sky LBTI data demonstrating the benefit of using this method as an auxiliary system to interferometers. The concept of P-REx, as well as a comparison between P-REx results and fringe tracking data will be discussed.

Angela Cortes - ERIS, how to improve performance of one instrument and re-design another
ERIS is one of the instruments that was developed to satisfy the needs that will be left uncovered after the obsolescence of two of the most important instruments currently in operation in Paranal, NACO and SINFONI. Integrating two instruments in one, and will be using the facility of the Adaptive Optics System installed in UT4 at Paranal, it will be a competitive instrument to JWST in several regimes. I will describe mostly the efforts to get the spectroscopy improved to the best that we can get up today and a small system overview of all the modules that composes the instrument, and the challenges that we are facing to bring the instrument on sky in 2020.

Ellen Schallig - Getting ready for metrology and calibration of the WEAVE fibre positioner
WEAVE is the new wide-field spectroscopy facility for the prime focus of the William Herschel Telescope on La Palma in the Canary Islands, Spain. It is a multi-object spectrograph with a 960 fibre multiplex behind a new dedicated 2-degree prime focus corrector. The spectrograph is made for the visible part of the spectrum, and is fed by optical fibres, which have to be positioned in the focal plane according to the targets' locations. A pick-and-place positioner positions these fibres.

My work has been on this positioner. In the past years we have done two test builds of the positioner, and we will start the final build in September. The main parts of the positioner are its two fibre positioner robots, a focal plane imager robot, two fieldplates and a tumbler that tumbles the field plates in and out of the focal plane, and some 350 retractors that house the movable lengths of the MOS and mIFU fibres. When building the positioner, the metrology of these parts is vital for the positioner's positioning precision.

After the positioner is fully rebuilt, we will have to calibrate all the different coordinate systems in the positioner. We do this by measuring a grid that is machined into the fieldplate with cameras that are part of either robot system. We can then also use these measurements to calibrate out rotation, shear, and offsets between the robot axes, which stay the same between measurements. The cameras themselves have to be calibrated as well, and we have to find the rotation centre for each robot.

In this talk I will present methodologies I have developed to tackle the above challenges. Depending on the exact timings in the rebuild process, I may be able to present some final results for the positioner as well.

Daniele Vassallo - A virtual coronagraphic test bench for SHARK-NIR, the second-generation high contrast imager for the Large Binocular Telescope
In this talk, I will present a simulator conceived for the conceptual study of an AO-fed high-contrast coronagraphic imager. The simulator implements physical optics: a complex disturbance (the electric field) is Fresnel-propagated through any user-defined optical train, in an end-to-end fashion. The effect of atmospheric residual aberrations and their evolution with time can be reproduced by introducing in input a temporal sequence of phase screens: synthetic images are then generated by co-adding instantaneous PSFs. This allows studying with high accuracy the impact of AO correction on image quality for different integration times and observing conditions. In addition, by conveniently detailing the optical model, the user can easily implement any coronagraphic set-up and introduce optical aberrations at any position. Furthermore, generating multiple images can allow exploring

detection limits after a differential post-processing algorithm is applied (e.g. Angular Differential Imaging). The simulator has been developed in the framework of the design of SHARK-NIR, the second-generation high contrast imager selected for the Large Binocular Telescope.

Davide Greggio - Ingot wave-front sensor: a pupil plane wfs for laser guide stars
Laser Guide Stars, due to their finite distance from the telescope and their spatial extension, present some peculiarities with respect to natural guide stars. In particular, their image is not formed in a 2D focal plane, but extends in a 3D region which depends on the height and thickness of the sodium layer and the position of the laser projector with respect to the telescope entrance pupil. Such characteristics generate some disturbances on commonly used wavefront sensors like spot elongation in a SH WFS or loss of sensitivity in a pyramid WFS. The ingot wavefront sensor is a novel kind of pupil plane wavefront sensor which is specifically designed to deal with extended and elongated sources. The working principle is the same one of the pyramid wavefront sensor, where light from the reference star is split at the level of the focal plane to produce multiple images of the telescope pupil which are then used to retrieve the first derivative of the wavefront. The splitting can be easily achieved by means of a reflective roof-prism working at grazing incidence and producing three images of the pupil.
I will present the on-going work for the design, numerical simulation and lab test of an ingot wavefront sensor in the framework of MAORY, the E-ELT first-light MCAO module.

Andrea Alejandra Hidalgo Valadez - Cryogenic camera lens mounts for HARMONI, the first light spectrograph of the Extremely Large Telescope
The University of Oxford is leading the HARMONI project, an integral field spectrograph for the Extremely Large Telescope (ELT), which is currently in construction at Cerro Armazones in Chile. HARMONI employs Integral Field Spectroscopy (IFS) to acquire spatial and spectral information of a target in a single observation. Spatially and spectrally resolved observations produce detailed data for scientific exploitation of extended objects, such as planets, galaxies, and clusters. HARMONI will observe in the visible and near-infrared (NIR) wavelength ranges, and be assisted by advanced 'adaptive optics' to provide highest resolution integral field spectroscopy ever achieved. The instrumentation part of my doctorate project will be the development of procedures and to test technology to build the HARMONI instrument in compliance with the scientific requirements. The first task is the development of the cryogenic camera lens mounts. The lenses inside the barrels of the infrared and visible cameras contain six types of optical glasses each with its own thermal and mechanical properties. A lens mount close to invariant to thermal and mechanical stress fitted for every lens is currently under test. The lens mount design is based on KMOS and FMOS designs heritage. Nonetheless, further development is required to validate the expected alignment accuracy. The aim of this task is to develop a mounting procedure and alignment, test the performance of the KMOS lens mount in terms of alignment accuracy (axial and radial), survivability to mechanical stress (transport, earthquake), and survivability to cold down cycles. This project will be accompanied by a scientific project which will be the study of the surface chemistry of the Galilean satellites through IFS observations with existing instruments. Observations of Io and Ganymede will be acquired on August from the MUSE Narrow Field Mode Science Verification as part of this project.

Nicolas Dubost - Lab demonstration and future upgrades for CAWS, a pupil-modulated point-diffraction interferometer

In high-contrast adaptive optics (AO) systems, non-common path aberrations (NCPAs) between the wavefront sensing and the science paths need to be highly corrected. To perform an improved calibration, we have developed the Calibration and Alignment Wavefront Sensor (CAWS), a pupil-modulated point-diffraction interferometer (m-PDI). The instrument can measure the amplitude and the phase of the electric field at a pupil without explicit reconstruction. Part 1 reports the results of the integration of CAWS into CHOUGH, the Durham high-order adaptive optics system. Closed-loop experiments with static aberrations are both performed with monochromatic and polychromatic light. With monochromatic light, the residual error RMS is brought down to 55 nm across the entire pupil and 12 nm within a smaller area around the centre. Independently, PSF measurements show Strehl ratio increases from 0.20 to 0.66. Part 2 presents a discussion on potential upgrades. Simulations using reflective gratings or patterned liquid crystals as small-angle beam-splitters, show throughput improvements of approximately a factor of 2 over Ronchi rulings. This improvement is without much detriment to chromatic bandwidth, which leads to an overall gain in the amount of light going into the sensor.

Emiel Por

In the last few decades, the use of coronagraphy has become a necessary ingredient for any high-contrast imaging system. The field of stellar coronagraphy has been prolific, providing an abundance of different optical implementations of a coronagraph. Many of these coronagraphs have designable parts, such as the shape of the Lyot stop, or the pattern of the pre-apodizer or the focal-plane mask. The reason for these added masks vary wildly, from decreasing the inherent chromaticity of the coronagraph to making the coronagraph work at all for complex telescope apertures. Typically, designs are made using analytical descriptions or fairly-simple optimization strategies that yield suboptimal but usually adequate solutions. These optimization methods provide no guarantee of global optimality, or even an estimate of the upper-bound on the planet throughput. That is, we don't know how close to the globally-optimal solution we are, and perceived physical limitations of the coronagraph may actually be due to flaws in the optimization procedure.

In this talk, I will present the basis of globally-optimal coronagraph design, and its applications to the apodizing phase plate coronagraph, the apodized Lyot coronagraph and the vortex coronagraph.

Micha Heilman - Developing Low-Cost Integral Adaptive Optics Telescopes for Long-Baseline Optical Interferometry

The Earth's atmosphere above Anderson Mesa near Flagstaff, AZ is effectively a phase screen which, when considered as part of a telescope's optical system, is inflicting wavefront errors on the order of ~1μm over ~10cm scales on one's aperture. Our research examines the use of adaptive optics (AO) in tandem with low-quality optics – optics which produce wavefront error similar to the atmosphere's – to determine if diffraction limited results can be achieved using active corrective optics. The 1μm scale of wavefront corrections provided by AO systems are substantially greater than the ~50nm construction specifications of typical telescopes. Thus, this pairing of optics and software could increase image quality while decreasing cost by significantly (~20×) relaxing mechanical requirements.

As a baseline, we measured a 6-in λ /20 (Peak to Valley of 32μm) lab reference flat with a Zygo phase-shifting interferometer, an instrument built for surface inspection of diffraction-limited high-quality optics, and obtained excellent agreement.

To contrast this result, we similarly inspected a low-quality (household bathroom) mirror measuring 12-in x 12-in. For this 'optic', we found roughly 2 full waves – about $1\mu m$ – of smoothly varying static wavefront distortion across the ~5-in Zygo inspection aperture. This very closely matches the dynamic wavefront distortion caused by observations through the Earth's atmosphere.

To test active correction of such glass, our lab setup consisted of a Thorlabs AO Kit, model 7, with light source, Thorlabs deformable mirror (DM), and Shack-Hartmann wavefront sensor (WFS). The system was set up to reflect a 2.5cm beam expanded from a 0.34 mW laser diode to the low-quality mirror, which was then retro-reflected into the AO system and re-collimated to 5mm to match the sensor diameter of the WFS. Fifteen data sets were collected to find the Peak-to-Valley (PV) and root-mean-square (rms) of the wavefront measured from the low- quality mirror. Another fifteen sets were collected to measure the PV and rms of the reconstructed wavefront corrected by the DM. This second data set was used to calculate the difference between the measured and reconstructed wavefronts. The process was repeated by replacing the low-quality mirror with a 5cm lab-quality mirror rated to $\lambda/20$.

The PV measurement for the low-quality mirror was 55μm with a rms of 12.7μm, compared to the lab-quality mirror whose PV was 53μm with a rms of 10.8μm. The difference between the household-quality mirror's wavefront and the DM reconstructed wavefront was a PV of 0.21μm with a rms of 0.04μm. The resultant wavefront corrected 80% past it's predicted outcome of 1μm.
The combination of AO software and low-quality mirrors results in adequate wavefront corrections, compensating for 80% of atmospheric disturbances. Our results indicate it would be advantageous to use a telescope design that assumes integral AO from the outset; further benefits come from tailoring the telescopes to the narrow set of specifications that emphasize use in a narrow-angle long-baseline optical interferometry system.

Nick Cvetojevic - Photonic beam-combination with phase control for high-contrast imaging and next-generation interferometry
FIRST (Fibered Imager foR a Single Telescope) is a post-extreme AO instrument module undergoing commissioning at the Subaru Telescope that enables high-contrast imaging at sub-diffraction limit spatial scales. With the aim of increasing the instrument's stability, sensitivity, and dynamic range, a major upgrade of FIRST's interferometric components to a new series of photonic on-chip beam combiners is under way. These next-generation beam combiners contain electro-optic components that enable the precise and high-speed control of phase in each baseline. The development of this technology has benefits for many other astronomical applications where phase-control in an important factor.

Chris de Jonge - High-Contrast Imaging Balloon System, an experiment to direct-image exoplanets from the stratosphere
Acquiring spectra, orbits, mass and other characteristics of Earth-like exoplanets will become possible by means of direct imaging. To achieve the high contrast ratio at small angular separation required to direct image these Earth-like planets in the visible/near-infrared wavelength region, the bright glare of the nearby star has to be suppressed and the optical wavefront has to be extremely stable. In preparation for a large future space mission, HiCIBaS (*High Contrast Imaging Balloon System)* is a demonstration of the fundamental technologies required to do high-contrast imaging and wavefront correction using adaptive optics from near-space. HiCIBaS was launched on August 25, 2018 from Timmins, Canada, using a stratospheric balloon provided by CNES (French Space Agency) to an altitude of 38km.

HiCIBaS features adaptive optics using a deformable mirror for wavefront control and a novel vAPP coronagraph with modal wavefront sensor developed by the Universiteit Leiden. In this presentation, the results of the HiCIBaS mission will be presented, including an overview of the instrument, the control algorithms for the wavefront correction, camera readout, instrument flight software and communication to the ground during the mission.