Finnish Centre for Astronomy with ESO

Annual Report

2020

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FINNISH CENTRE FOR ASTRONOMY WITH ESO, ANNUAL REPORT 2020

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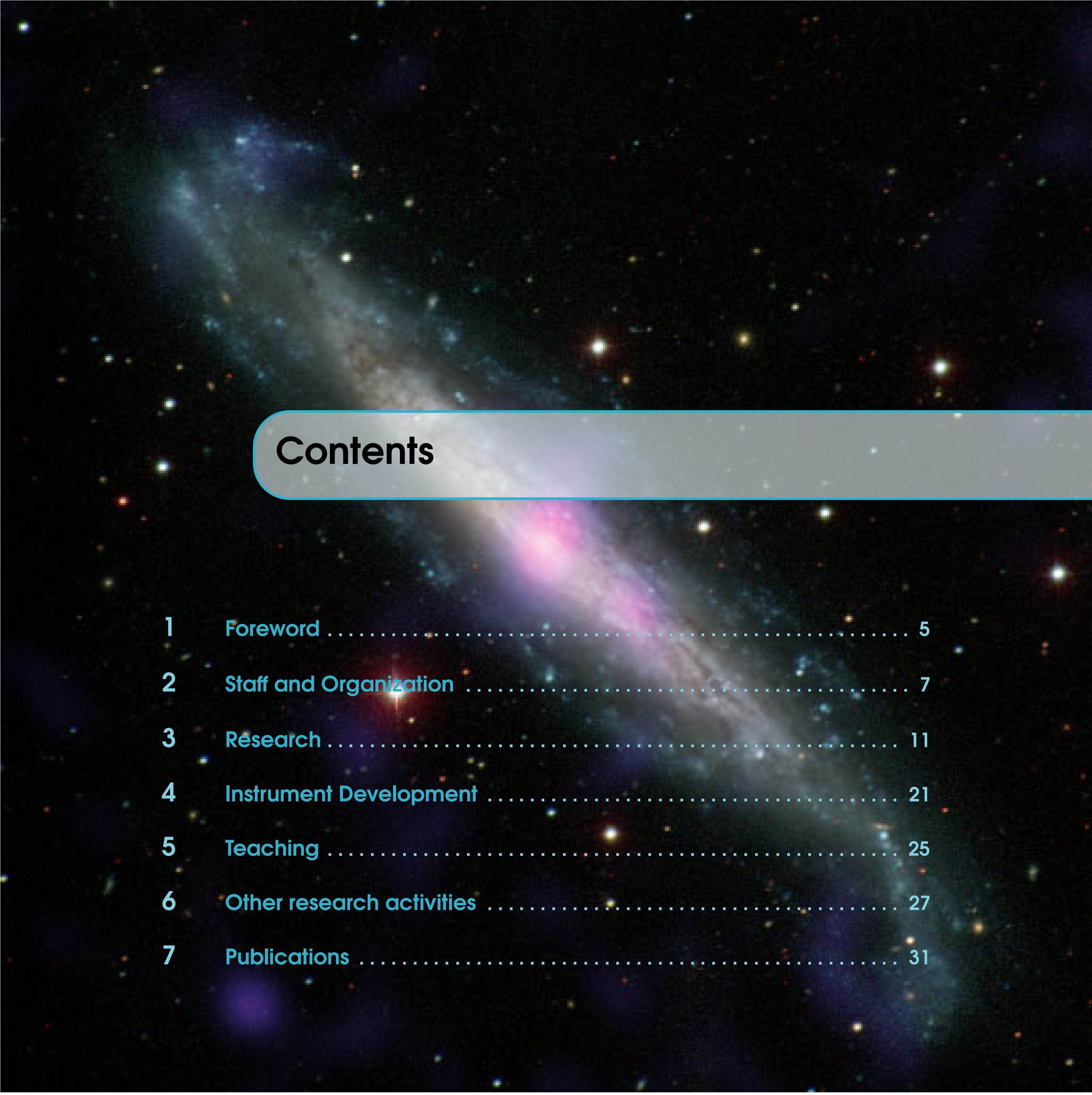
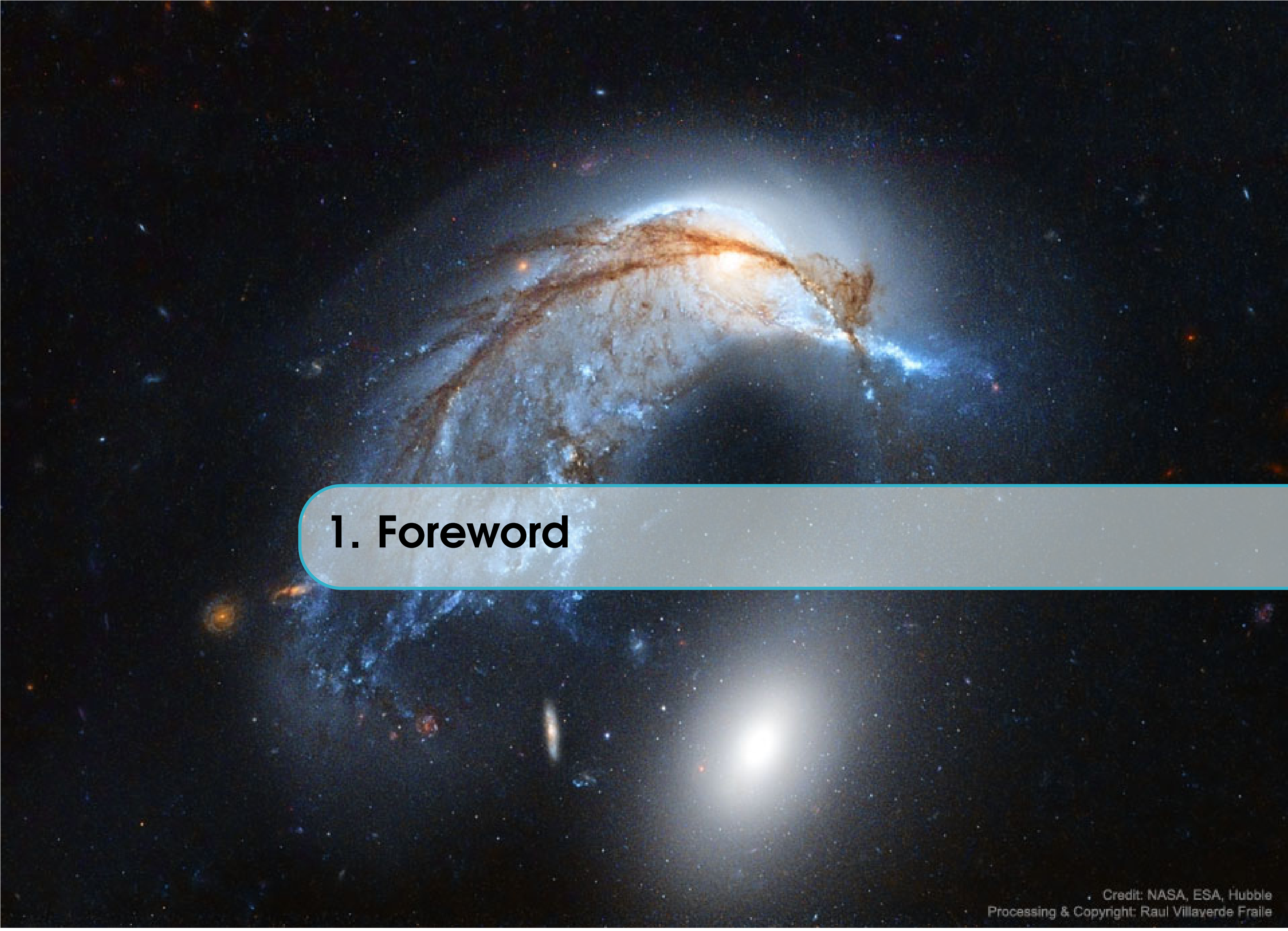
Cover: Milky Way above ALMA antennas (courtesy: ESO)



Contents



1. Foreword

Finland is a member of the European Southern Observatory (ESO) since 2004. ESO is a world leading astronomical research and technology organization, with 16 member states, headquarters in Garching, Germany, and three world-class observatories in Chile.

Finnish Centre for Astronomy with ESO (FINCA) is a national research institute for astronomical and astrophysical research in Finland. FINCA coordinates Finnish co-operation with ESO by networking into the ESO infrastructure and projects; practices and promotes high quality research in all fields of astronomy, and ESO-related technological development work; participates in researcher training in astronomy; and fosters and implements ESO-related co-operation of all the Finnish universities engaged in astronomical research. The ultimate goal of FINCA is to improve the scientific and industrial benefit of Finland's membership in ESO, and Finland's international competitiveness in astronomical research.

The year 2020 marked the 11th year of operation for FINCA, administratively a Special Unit of the University of Turku, and funded by the Ministry of Education and Culture, and by the participating universities (Aalto, Helsinki, Oulu and Turku). The highest decision-making body is the Board, chaired by Vice-Rector Kalle-Antti Suominen of the University of Turku, and comprising of two members from each participating university and one member from FINCA staff. The scientific activities of FINCA are overseen by an international Scientific Advisory Board (SAB), chaired by

Prof. Susanne Aalto (Chalmers University of Technology, Sweden),

The research at FINCA covers a large range in contemporary astronomy, from cosmology, active galaxies, and galaxy formation and evolution, through properties of nearby galaxies, to supernovae and their progenitor stars, stellar activity and star formation in our own Galaxy. In our research, we use radio to gamma-rays multi-wavelength observational data from large ground-based and space telescopes, especially from the four 8m ESO Very Large Telescopes (VLT), the Nordic Optical Telescope (NOT), and the Atacama Large (Sub)Millimeter Array (ALMA) in the optical, near-infrared and (sub)millimeter wavelengths. Observational research is supplemented by modelling, simulations and theoretical work, that are essential in understanding the physics behind the observations. Our research is characterized by strong collaboration both within FINCA, with astronomy departments in Finland and internationally.

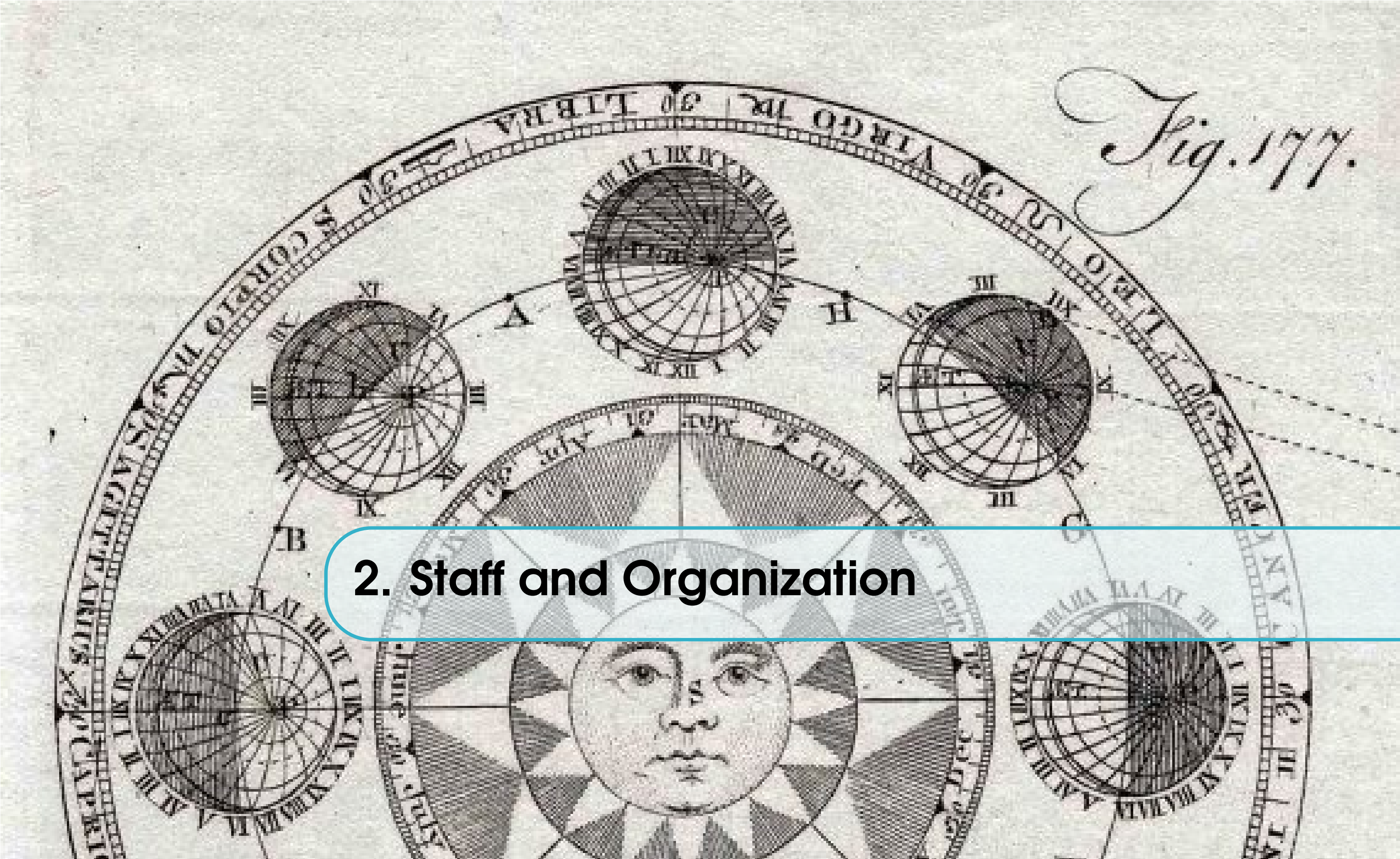
The corona situation affected our research activities. Starting from March 2020, international conferences were either canceled or moved on-line. Our successful visitor program, likewise, was discontinued. ESO and ALMA suspended their operations and are only recently opened up. Despite this, FINCA research was reported in 58 refereed scientific articles in 2020, and some of them are highlighted in this Report.

Our researcher training activities in 2020 focused on supervision of PhD and MSc students in the participating universities, whereas the hands-on teaching of advanced observing, data reduction and analysis methods in observational astronomy were affected by the corona situation. The annual course on remote optical/infrared observing with the NOT was not organized in 2020. On the other hand, it was possible to organize a practical course for Finnish high school students on remote observations with the NOT, led by Dr. Pasi Nurmi, the director of the Tuorla Science Center.

The construction of the ESO Extremely Large Telescope (ELT), a 39 m diameter giant for infrared and optical astronomy, is well underway, with Phase 1 instruments being constructed, Phase 2 instruments being in final design phase, all major contracts for the construction of the ELT been awarded, and construction started at Cerro Amazons. This keeps ESO on-track to remain in a world-leading position, when the ELT starts operations in 6 years time, bringing an enormous leap forward in sensitivity and resolution.

Our acquired external funding has increased significantly in recent years. Especially, the research infrastructure (FIRI) grant from the Academy of Finland has enabled our participation in ESO instrument projects, FINCA is participating on behalf of the Finnish community in the ELT first-light instrument consortium MICADO (near-infrared adaptive optics imager,), both by funding and by participating in the PSF reconstruction, in collaboration with the Department of Physics and Astronomy of the University of Turku, and the Lappeenranta University of Technology. This project is led by Academy Fellow Hanindyo Kuncarayakti (Dept. Physics and Astronomy, UTU). FINCA is also participating in a new instrument to the ESO 3.5-m New Technology Telescope (NTT), the Son Of X-Shooters (SOXS), with first light expected in 2021. Notably, the calibration unit of SOXS was built at the University of Turku, in collaboration with several local companies. FINCA is going to apply for more instrumentation funding from the Academy in the 2021 FIRI call to strengthen the position of the Finnish community toward the ELT era, including participation in another ELT instrument, MOSAIC (optical and near-infrared multi-object spectrograph).

Jari Kotilainen,
FINCA Director



2. Staff and Organization

FINCA staff (Turku, unless otherwise indicated)

Director :	Jari Kotilainen
Professor emeritus :	Mauri Valtonen
University Researchers :	Roberto De Propris Pasi Hakala Kari Nilsson
Academy Research Fellows	Talvikki Hovatta (Aalto/Turku) Elina Lindfors
Postdoctoral Researchers	Marco Berton (Aalto) Vandad Fallah Ramazani (1.4 to 31.12.2020) Esko Gardner (1.3 to 31.7.2020) Joachim Janz (Oulu) Claudia Gutierrez (from 1.10.2020) Karri Koljonen (Aalto) Yannis Liodakis (from 1.9.2020) Derek McKay (Aalto; from 1.9.2020) Suvendu Rakshit (until 30.11.2020) Clare Wethers Stephen Williams Laura Zschaechner (Helsinki, until 15.4.2020)

FINCA board

Members

Name	University
Anne Lähteenmäki	Aalto
Merja Tornikoski	Aalto
Jyrki Räisänen	Helsinki
Alexis Finoguenov	Helsinki
Juergen Schmidt	Oulu
Heikki Salo	Oulu
Kalle-Antti Suominen (Chair)	Turku
Seppo Mattila	Turku
Elina Lindfors (staff representative)	Turku

Deputy members

Name	University
Joni Tammi	Aalto
Tuomas Savolainen	Aalto
Karri Muinonen	Helsinki
Mika Juvela	Helsinki
Vitaly Neustroev	Oulu
Sebastien Comeron (until 15.10.2020)	Oulu
Aku Venhola (from 15.10.2020)	Oulu
Harry Lehto	Turku
Juri Poutanen	Turku
Roberto De Propris (staff representative)	Turku

3. Research

3.1 Main research areas

The research at FINCA concentrates on observational astronomy carried out using radio to γ-rays, multi-wavelength data from large ground-based and space telescopes. Especially, we make use of ESO's large ground-based facilities in the optical and infrared (the four 8m ESO Very Large Telescopes; VLT) and in (sub)millimetre (Atacama Large Millimeter Array; ALMA), together with the Nordic Optical Telescope (NOT) on La Palma, in the northern hemisphere. Our observational research is supplemented by modelling, computer simulations and theoretical work, that are essential in understanding the physics behind the observations. The present science topics at FINCA cover a large range in contemporary astronomy from observational cosmology, distant active galaxies, and galaxy formation and evolution, through properties of nearby galaxies, to supernovae and their progenitor stars, stellar activity and star formation in our own Galaxy. In 2020, our research were reported in 58 refereed scientific articles, and some of them are highlighted below.

3.2 Research Highlights

3.2.1 Cosmology and Extragalactic Astrophysics

Heavily Reddened Quasars in the Submillimetre

Current evolutionary models of massive galaxies predict the existence of a dust-obscured quasar phase following an active starburst, occurring as quasar-driven winds expel remnant dust and gas outwards from the central regions of the galaxy. This so-called blowout phase is not yet well understood, with multiple groups identifying several seemingly distinct dust-obscured quasar populations. Characterising obscured quasar hosts, the connection between their star formation, dust obscuration and quasar luminosity, remains critical in constraining models of quasar galaxy co-evolution. In particular, looking for evidence of recent starburst activity or over-dense environments associated with high rates of galaxy interactions is important in discerning whether heavily reddened quasars do indeed represent a phase in the lifetime of massive galaxies.

To this end, **C. Wethers** and collaborators present new 850μm observations from the Submillimetre Common-User Bolometer Array 2 (SCUBA-2) for a sample of 19 heavily reddened Type-I quasars at redshifts $z \sim 2$ – a peak epoch in both black hole accretion and star formation. Three of the 19 quasars are detected at $> 3\sigma$ significance corresponding to an 850μm flux-limit of > 4.8 mJy. Assuming the 850μm flux is dominated by dust heating due to star formation, very high star formation rates (SFRs) of 2500-4500 $M_\odot$ yr^{-1} in the quasar host galaxies are inferred. Even when considering a potentially large contribution to the 850μm flux from dust heated by the quasar itself, significant SFRs of ~ 600 – $1500 M_\odot$ yr^{-1} are nevertheless inferred for two of the three detected quasars. Stacking the remaining 16 targets returns an average 3σ upper limit on the SFR of $< 880\ M_\odot$ yr^{-1}, meaning we cannot rule out high SFRs for even the undetected targets in our sample. While the number counts of sub-mm galaxies in the total survey area (134.3 arcmin^2) are consistent with predictions from blank-field surveys, higher spatial resolution and spectroscopic observations from the Atacama Large Millimetre Array (ALMA) confirm the presence of excess sub-mm sources physically associated with two of the quasars in our sample. Full results published as Wethers et al., 2020, MNRAS 492, 5280.

Testing the Evolutionary LoBAL Paradigm

Low-ionisation broad absorption line quasars (LoBALs) mark an important, yet poorly understood, population of dust obscured quasars showing direct evidence for energetic mass outflows. As such, they are valuable targets in directly studying not only the role of dust-obscured quasar phases in galaxy evolution, but also the effects of quasar feedback on the host galaxy. **C. Wethers, J. Kotilainen** and collaborators investigate IR star formation in a sample of 12 luminous ($L_{bol} > 10^{46}$ergs s^{-1}) LoBALs at $2.0 < z < 2.5$, which have been imaged as part of a targeted program with the Herschel Photodetector Array Camera and Spectrometer (PACS; 70 and 100μm) and Spectral and Photometric Imaging REceiver (SPIRE; 250, 350 and 500μm). Based on these IR observations, we derive prolific star formation rates (SFRs) ranging 740 – 2380 $M_\odot$ yr^{-1} for the detected targets, consistent with having undergone a recent starburst. Furthermore, the SFRs derived for our LoBAL sample appear enhanced compared to populations of both high-ionisation BALs (HiBALs) and non-BAL quasars, supporting an evolutionary paradigm in which LoBALs denote a short-lived phase in the lifetime of a galaxy. As part of this project, we were awarded 16.0 hours with NOTCam on the Nordic Optical Telescope (NOT) to obtain near infra-red (NIR) spectra for several of our LoBAL targets. We present new K-band NOTCam spectra for three of these targets, calculating their spectroscopic redshifts, black hole masses and bolometric luminosities, and increasing the total number of LoBAL targets in our sample with spectral information from five to eight. Full results published as Wethers et al., 2020, MNRAS 498, 1469.

Low-redshift quasars in the SDSS Stripe 82: Associated companion galaxies and signature of star formation

In Stone et al. (2021), **J.Kotilainen** (FINCA) and collaborators present optical spectroscopy of the close companions of 22 low-redshift ($z < 0.5$) quasars selected from a larger sample of quasars in the SDSS Stripe 82 region for which both the host galaxy and the large-scale environments have been investigated in their previous work. The new observations extend the number of quasars studied in a previous paper on close companion galaxies of 12 quasars. The analysis covers in total 34 quasars. They find that 15 quasars; $\sim 44\%$) have at least one associated galaxy. Many (12 galaxies; $\sim 67\%$) of the associated companions exhibit [O II] 3727 Å emission line as signature of recent star formation. The star formation rate (SFR) of these galaxies is modest (median SFR $\sim$ 4.3 Msun/yr). For eight quasars, they are also able to detect the starlight of the host galaxy from which three have a typical spectrum of a post-starburst galaxy. Both companion galaxies and quasar host galaxies show a trend where more massive galaxies and quasars have a higher SFR (Fig. 3.1). The results suggest that quasars do not have a strong influence on the star formation of their companion galaxies.

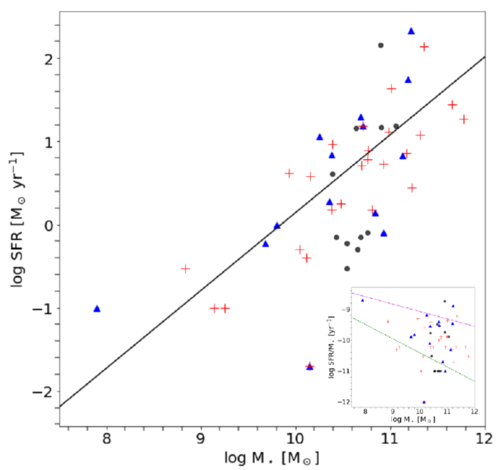


Figure 3.1: SFR versus galaxy mass for associated (blue triangles) and non-associated galaxies (red crosses), and for quasar host galaxies (black circles). For reference, the main sequence of star formation for the SDSS star- forming galaxies from Duarte Puertas et al. (2017). The inset shows the sSFR versus the stellar mass of the galaxies, overplotted with z0 (green dashed line) and z1 (magenta dash dot line) relations from Osborne et al. (2020). Figure adapted from Stone et al. (2021, MNRAS, 501, 419)

Discovery of the host galaxy of OJ 287

OJ 287 is an active galactic nucleus (AGN), which exhibits double-peaked flares at roughly 12-year intervals. There flares can be explained with a model where two supermassive black holes orbit each other with a 12-year period. Whenever the lighter black hole crosses the accretion disk of the heavier hole close to its perihelion, a fireball is created leading to the observed flares. This model can produce accurate predictions of the flares and gives a natural explanation why there are always two flares (two crossings near perihelion) and why the flares are not strictly regular (strong precession due to relativistic effects).

On on the key features of this model is the very high mass required for the heavier black hole, about 2×10^{10} solar masses. It has been found during the last decades that the mass of the central black hole correlates with the mass of the central black hole in such a way that heavier black holes reside in bigger galaxies. OJ 287 should thus be found in a very large and bright galaxy. Curiously, the galaxy has remained undetected, despite several attempts during the last two decades, three of which were made by K. Nilsson in 1996, 2003 and 2004. Detection of the host galaxy of AGN is not straightforward since the strong emission from the nucleus often outshines the galaxy by more than an order of magnitude.

The nuclear emission is highly variable, however, and at times can reach very low levels. The project coordinated by FINCA researches waited for such opportunistic moment and triggered observations at Gran Telescopio de Canarias. Augmented by earlier data obtained at Nordic Optical Telescope, the team (**K. Nilsson, J. Kotilainen & M. Valtonen**) was finally able to unambiguously detect the host galaxy of OJ 287. The galaxy turned out to be of average brightness for this type of AGN and about an order of magnitude "too faint" given the high mass implied by the binary model. However, OJ 287 is not the only such exception, as a handful of galaxies show a similar phenomenon of the central black hole being "too massive". In addition the galaxy may have been disturbed by a recent merger or a larger halo containing a significant portion of the mass may have been missed due to low surface brightness.

Spectra of distant supernovae

The light curves of Type Ia supernovae can be standardised to make them accurate distance indicators (Phillips 1993). This, combined with the very high luminosities (typically peaking at $M_B = -19.3$), means they can be used as cosmological probes. Observations of distant Type Ia supernovae led to the discovery that the expansion of the Universe is accelerating (Riess et al. 1998; Perlmutter et al. 1999). We published a paper on VLT spectra of the host galaxies of Type Ia supernovae at redshift > 1: Williams et al. (2020) “See Change: VLT spectroscopy of a sample of high-redshift Type Ia supernova host galaxies”, MNRAS, 495, 3859). This is part of the “See Change” project to observe Type Ia supernovae in galaxy clusters at redshift > 1, to use them in cosmology. See Change was based around a two-year Hubble Space Telescope programme of cadenced observations of 12 galaxy clusters in the redshift range z=1.1-1.8, which were used to discover the supernovae and measure their light curves. Due to their faintness, it was not feasible to spectroscopically confirm most of the discovered supernovae, so they had to be classified photometrically. As part of this project, the primary goals of the Williams et al. publication were: 1) to provide redshifts, which will be used in the cosmological analysis, but will also significantly improve the confidence in the photometric classification of the supernovae. 2) to derive parameters such as stellar mass for the host galaxies, which can be used to improve the standardisation of the supernova light curves. The primary aim of the whole project is to use these high-redshift supernovae to improve constraints on time-variable dark energy (Fig. 3.2).

Connecting high-energy neutrinos with active galactic nuclei

Identifying the most likely sources for high-energy neutrino emission has been one of the main topics in high-energy astrophysics ever since the first observation of high-energy neutrinos by

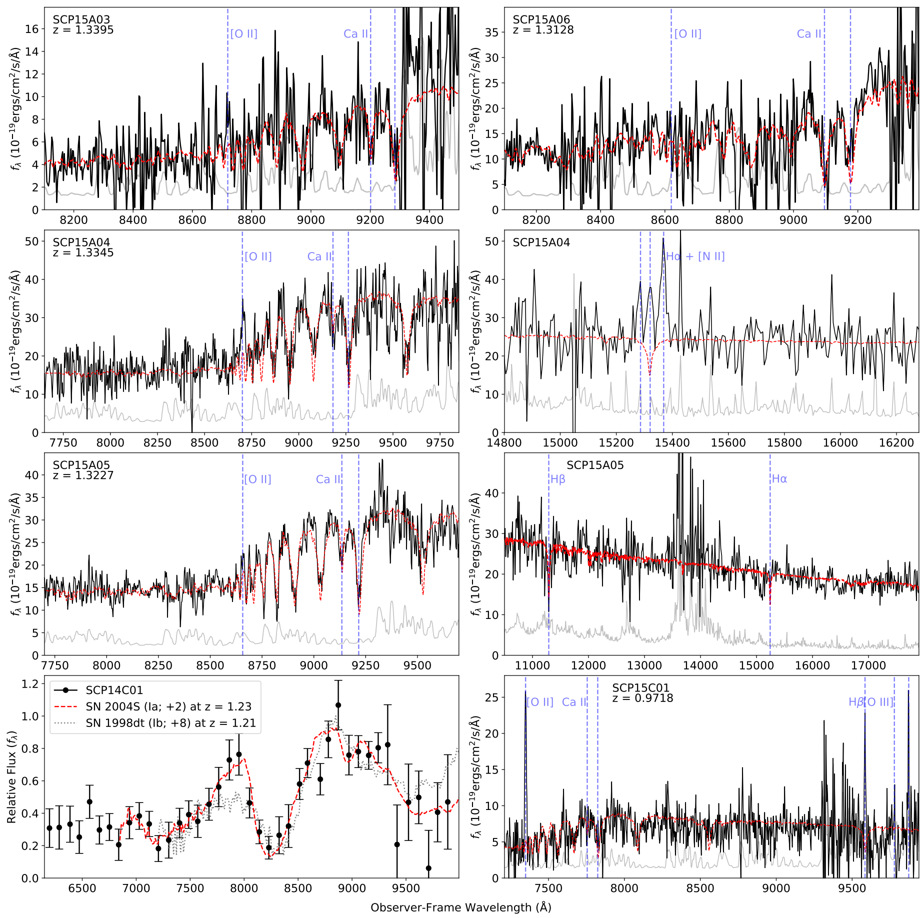


Figure 3.2: This figure shows some spectra from Williams et al. (2020). The spectra are in black, with best-fit SEDs in red (using FAST). Bottom left is a spectrum of an actual supernova from the survey (black), compared to a Type Ia and Ib supernova for comparison.

the IceCube Neutrino Observatory. Active galactic nuclei with relativistic jets, blazars, have been considered to be one of the main candidates due to their ability to accelerate particles to high energies. Previously, observational evidence has been found for one particular blazar, TXS0506+056, to be the origin of the astrophysical neutrino IC-170922A (IceCube Collaboration et al. 2018, with strong involvement from the MAGIC Collaboration (including FINCAns **Elina Lindfors, Kari Nilsson** and **Vandad Fallah Ramazani**). In 2020, **Talvikki Hovatta** and **Elina Lindfors** were leading a study (including also **Yannis Liodakis** from FINCA) on the connection between high-energy neutrinos and radio emission in a sample of blazars. Using radio light curves of blazars from Aalto University Metsähovi Radio Observatory and Caltech's Owens Valley Radio Observatory they found indications of a connection between large radio flares and high-energy neutrinos detected by the IceCube Neutrino Observatory. This has a major impact on the modeling of the emission of blazars, which would need to account for the existence of protons in the jets to be able to produce neutrinos. The work was submitted for publication in the end of 2020 and several follow-up studies have been initiated, including obtaining observing time with the XMM satellite (PI Y. Liodakis) to follow some candidate sources in X-ray energies.

Blazars as sources of very high energy gamma-ray emission.

Blazars are the most numerous sources in the extragalactic Very High Energy (VHE, $E > 100$ GeV) gamma-ray sky. FINCAns **Vandad Fallah Ramazani, Jenni Jormanainen, Elina Lindfors**, and **Kari Nilsson** together with **Talvikki Hovatta** (associated member of the MAGIC collaboration) continued to have an active role in the international MAGIC collaboration that operates the two Imaging Air Cherenkov Telescopes at La Palma, Canary Islands, Spain. In 2020 we also had a new associated member Yannis Liodakis joining the team.

In 2020 FINCAns were in a leading role in two very important papers by MAGIC Collaboration on blazars. The first one reported an observationally constrained two-component model for five different Very High Energy gamma-ray emitting blazars. There is growing observational evidence that there is more than one emission region in blazar jets that have a significant contribution to the multi-wavelength emission of blazars at any given time. However, doubling the number of parameters for the emission model is not desirable unless it is possible to significantly limit the values these parameters can take from the observations. In our paper, we derived observational constraints for model parameters from an extensive multi-wavelength dataset covering very long baseline interferometry, long-term radio and optical monitoring, and optical polarization monitoring data from Nordic Optical Telescope. The paper shows that spectral energy distributions of the five studied blazars are well described with a two-component model where the two emission regions are located far downstream in the jet and are embedded in each other.

In the second paper, **Vandad Fallah Ramazani** together with his collaborators in the University of Padova (Italy) studied the New Hard-TeV Extreme Blazars Detected with the MAGIC Telescopes. Extreme blazars (EHBLs) are BL Lac objects whose synchrotron emission peaks at exceptionally high energies (>1 keV). So far, only a handful of these objects has been detected at VHE gamma rays. Their GeV-TeV spectra are ideal probes to address the debates on the blazar sequence. Multi-wavelength observations of some of these blazars have provided evidence of a VHE gamma-ray emission extending to several TeV, which is difficult to explain naturally with standard, one-zone synchrotron self-Compton models for BL Lac objects. Ten EHBLs have been observed in different observing multi-wavelength campaigns between 2010 and 2017, aiming to increase the number of known EHBL TeV-emitters. Three new sources have been detected at TeV energies by the MAGIC telescopes. The extremeness of the sources was tested using the multi-year X-ray observation carried out by Swift-XRT telescope. It was clear that all but two sources have their synchrotron peak above 1 keV. Moreover, the broadband spectral energy distributions (SEDs) of all sources are built and modeled in the framework of a single-zone leptonic model. The SED of TeV-detected sources were also interpreted with a spine-layer model and a proton synchrotron model. The three models provide a good description of the SEDs. However, the resulting parameters differ substantially in the three scenarios. This paper presents the first mini-catalog of VHE gamma-ray observations of EHBLs.

Physical properties of narrow-line Seyfert 1 galaxies in the Southern hemisphere

Marco Berton and collaborators continued the characterization of a sample of southern active galactic nuclei (AGN) of the narrow-line Seyfert 1 (NLS1) class. The sample was selected by means of optical spectra from the Six Degree Field Galaxy Survey and published by Chen et al. (2018), and we obtained radio observations with the Karl G. Jansky Very Large Array (JVLA) at 5 GHz and an angular resolution of 3.5". The survey significantly increased the number of known radio-detected NLS1s in the Southern hemisphere, and confirmed that NLS1s do not typically show diffuse radio emission, suggesting that this class of objects may represent an early evolutionary stage of AGN life in which the diffuse radio emission has not yet formed (published as Chen et al. 2020, MNRAS, 498, 1278). Among these Southern objects we discovered a few sources with very interesting characteristics. In particular, we found a jetted NLS1 with an FRII-like morphology hosted by a spiral galaxy, whose jets are twice as large as the largest one measured to date ($\sim$200 kpc, see Fig. 3.3 and Vietri et al., in prep.). We also reclassified one of the sources in the sample using high-quality spectroscopic data, identifying the first non-local, interacting, late-type intermediate Seyfert galaxy with relativistic jet (published as Järvelä et al. 2020, A&A, 636, L12). Finally, we obtained new spectrophotometric data on the Southern sample with the ESO New Technology Telescope and the Nordic Optical Telescope. This unique survey will be the first study aimed at correlating the spectral properties of NLS1s with the physics of their host galaxy and with their radio properties, providing an unprecedented view on this peculiar class of AGN.

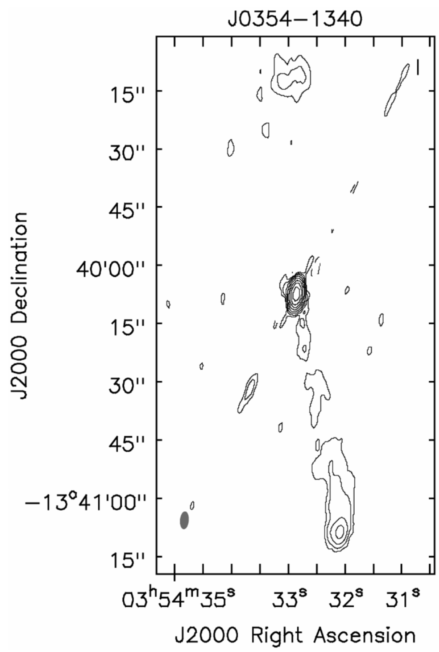


Figure 3.3: The NLS1 J0354-1340 with the JVLA observations, rms = 8 μJy beam^{-1}, contour levels at -3, 3×2^n, $n \in [0,7]$, beam size 7.38×3.47 kpc (Chen et al. 2020).

Signatures of quenching in dwarf galaxies in local galaxy clusters

Joachim Janz and collaborators followed up (arxiv:2101.10728) on correlations between surface brightness and colour found by Venhola et al. (2019) for Fornax galaxies binned by brightness or stellar mass. Venhola et al. interpreted the observed correlation of redder colour and fainter mean effective surface brightness for low-mass Fornax cluster galaxies as a result of a passive stellar evolution after the star formation was quenched by the cluster environment via ram pressure stripping. Janz and colleagues looked for similar correlations in the Virgo cluster and the results for both clusters are remarkably similar. Benefitting from the multi-band data from the Fornax Deep Survey and SDSS, the passive stellar evolution interpretation was scruitinised by comparing the correlations for multiple optical colours to stellar population models. While overall the colour-surface brightness correlations for low-mass galaxies can be explained, a more detailed look found that the characteristic correlations are found only for complete low-mass galaxies samples ignoring their morphological types and for late-type galaxy samples, but not for early-type dwarf galaxies. This is puzzling given the predominantly passive stellar populations of early-type dwarfs. Janz et al. conclude that this potential inconsistency can likely be reconciled with the passive evolution interpretation when the quenching happened a long time ago. In this case the passive evolution since the quenching by the cluster leaves a weaker imprint on the colour-surface brightness relations, which can more easiy be washed out by other processes that alter the stellar surface densities such as the gravitational harassment by close encounters and the cluster potential.

3.2.2 Stellar Astrophysics

Cataclysmic Variables

During 2020, **Pasi Hakala** has been involved in launching several new NOT observing programmes. These include spectropolarimetry of faint, wind accreting magnetic cataclysmic variables, measuring spin periods of white dwarfs in cataclysmic variables and studying the fast rotating active M dwarfs spectroscopically. He has also been active in opening up new research collaboration with University of Athens observatory to study the shortest period contact binary systems (Gazeas et al. 2021). In addition he has been working on developing new data analysis techniques for binary star research.

The fate of the outburst of microquasar GRS 1915+105.

Karri Koljonen and **Talvikki Hovatta** observed the enigmatic microquasar GRS 1915+105 with Atacama Large Millimeter Array (ALMA) during an anomalous, low-luminosity state never seen before during its outburst (Koljonen & Hovatta 2021). GRS 1915+105 started its outburst in 1992 and has consistently emitted 10-100% of the Eddington luminosity in the X-ray band over the last three decades. However, in mid-2018, GRS 1915+105 entered a seemingly new accretion state presenting unprecedentedly low fluxes throughout its spectral energy distribution.

Together with ALMA and almost daily X-ray monitoring observations with Neutron Star Interior Composition Explorer, we showed that the X-ray and millimeter spectral, timing, and polarization properties are consistent with those of a typical decaying X-ray binary outburst indicating that the outburst might be switching off. Specifically, we measured a linear polarization in a millimeter band for the first time for an X-ray binary. The jet emission in the millimeter wavelengths is consistent with a compact, steady jet with approximately 1% linear polarization and the magnetic field likely aligned with the jet position angle. Relating the millimeter emission to the X-ray emission reveals that the source presents a millimeter/X-ray correlation index of 0.6 (Fig. 3.4). Similar tight relation is seen in many X-ray binaries and active galactic nuclei and is one of the most important pieces of observational evidence in connecting the mass accretion rate onto the compact object during an outburst event to the mass-loading of the jet.

Later observations of GRS 1915+150 have shown even more diminished X-ray emission interspersed with strong and sporadic flares pointing towards a heavily obscured but possibly a bright accretion state (Koljonen & Tomsick 2020). Therefore, it is not altogether clear what is the fate of the outburst enhancing the importance of future studies on this source. Nevertheless, the peculiarities of GRS 1915+105 likely arising from the large disk size and our near-edge-on viewing angle to the disk allows us to study the geometrical effects of the accretion flow in great detail with changing mass accretion rates. This might give us important information also on the structure of disks in obscured active galactic nuclei that might share a similar inclination and accretion phase.

As part of hardware development, **Derek McKay** is working on the prototyping and evaluation of components that will contribute to a new fully-digital, high bandwidth backend for the Metsähovi Radio Telescope. The new system will record and correlate signals from two linear polarisations, which is imperative for advancing studies of large-scale magnetic field structure and engery dissipation in blazar jets. To supplement this work has also commenced on characterising the effect the Metsähovi radome has on the polarisation observations.

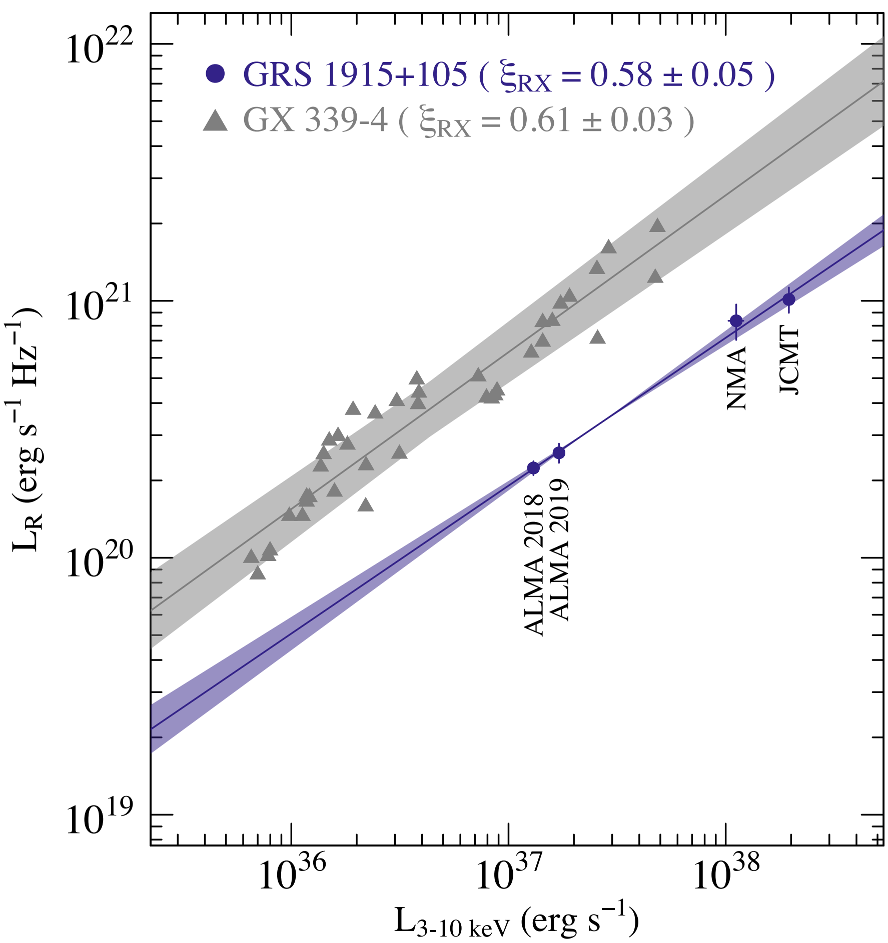


Figure 3.4: GRS 1915+105 mm/X-ray correlation (blue points). The high-luminosity data are from James Clerk Maxwell Telescope (Ogley et al. 2000) and Nobeyama Millimeter Array (Ueda et al. 2002) together with quasi-simultaneous Rossi X-ray Timing Explorer observations. In comparison, the X-ray binary GX 339-4 hard-state radio/X-ray correlation is shown (gray triangles; same X-ray band, but radio luminosity is from 8.4 GHz; from Koljonen & Russell 2019). Both have similar correlation slopes (assuming flat spectrum), indicating a change in the evolution of the outburst to a low-luminosity hard state typically seen in the rising and decaying parts of an X-ray binary outburst.

4. Instrument Development

Son of X-Shooter (SOXS) calibration unit construction started and the Finnish node consolidation

The SOXS instrument has entered the construction phase. The calibration unit (CU) of SOXS, Finland's contribution through FINCA, is being constructed in the SOXS lab at Quantum building, University of Turku.The work is led by Academy Fellow Hanindyo Kuncarayakti (Department of Physics and Astronomy, Univ. Turku). SOXS CU incorporates commercially available parts and custom-made components, some are manufactured by University of Turku's Protopaja workshop. At the end of the year, the CU is fully constructed with the upper part lightbox houses the lamps and the lower part houses the relay optics and pinhole/illumination selector motor. The CU is controlled by an electronics subrack that houses the power supply units of the CU calibration lamps and the control electronics. The control system uses Beckhoff programmable logic controller modules, and features sensors and an interlock system that cuts off electricity when the CU case is opened. This is meant to prevent accidental UV lamp exposure to a service personnel. The construction of the subrack is done in parallel with the CU. After the construction phase, SOXS CU will undergo tests and final verification before being shipped to the SOXS consortium headquarter in Italy.

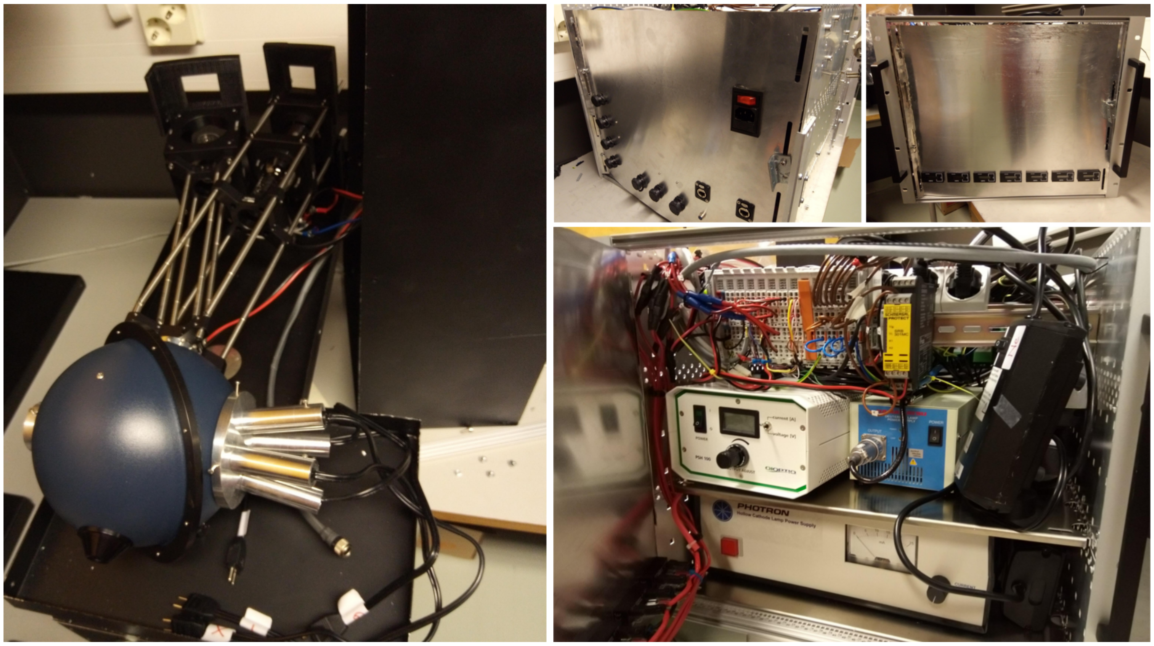


Figure 4.1: (Left) The Calibration Box with top cover removed, showing the integrating sphere and lamps. (Right) The CBX electronics subrack, outside view (top 2 panels), and inside view (bottom panel), showing the lamp power supplies and Beckhoff modules..

Figure 4.2: The logos of the participating institutes of the MICADO consortium

MICADO: a first-light ELT instrument

Participation in the much larger scale ELT instrument projects is necessary for the Finnish community to strengthen its position in front-line astronomical research. These instruments are going to be built by international consortia between institutes in ESO member states. It is paramount to get involved in a first-light ELT instrument, as it represents a unique opportunity for the Finnish community to get access to ELT data from the start. For this purpose, we are full members in and have used the FIRI2016 funding to start participating in the MICADO consortium, including in-kind contribution led by UTU (chiefly, Academy Fellow Hanindyo Kuncarayakti). MICADO will be one of the first-light ELT instruments, the adaptive optics (AO) -assisted diffraction-limited near-infrared imager and long-slit spectrograph, which will start operations in 2026. MICADO has much better sensitivity and spatial resolution than any current facility, and addresses key science topics, such as the dynamics of dense stellar systems, black holes in galaxies, the star formation history of galaxies through resolved stellar populations, the formation and evolution of galaxies in the early universe, planets and planet formation, and the solar system. The primary science cases for MICADO are an excellent match with science interests in all FINCA universities. MICADO's Final Design Review (FDR) will be in 2021, followed by the construction phase.

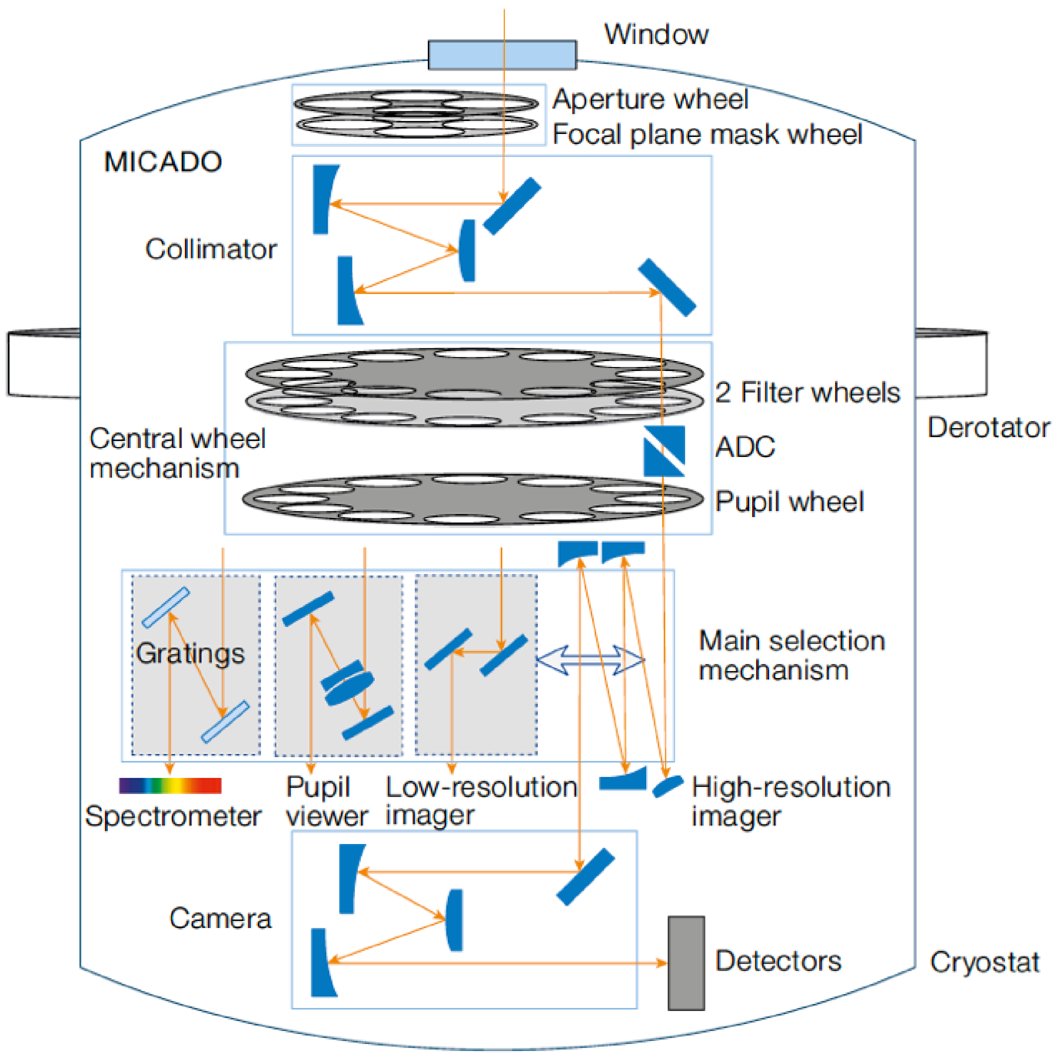
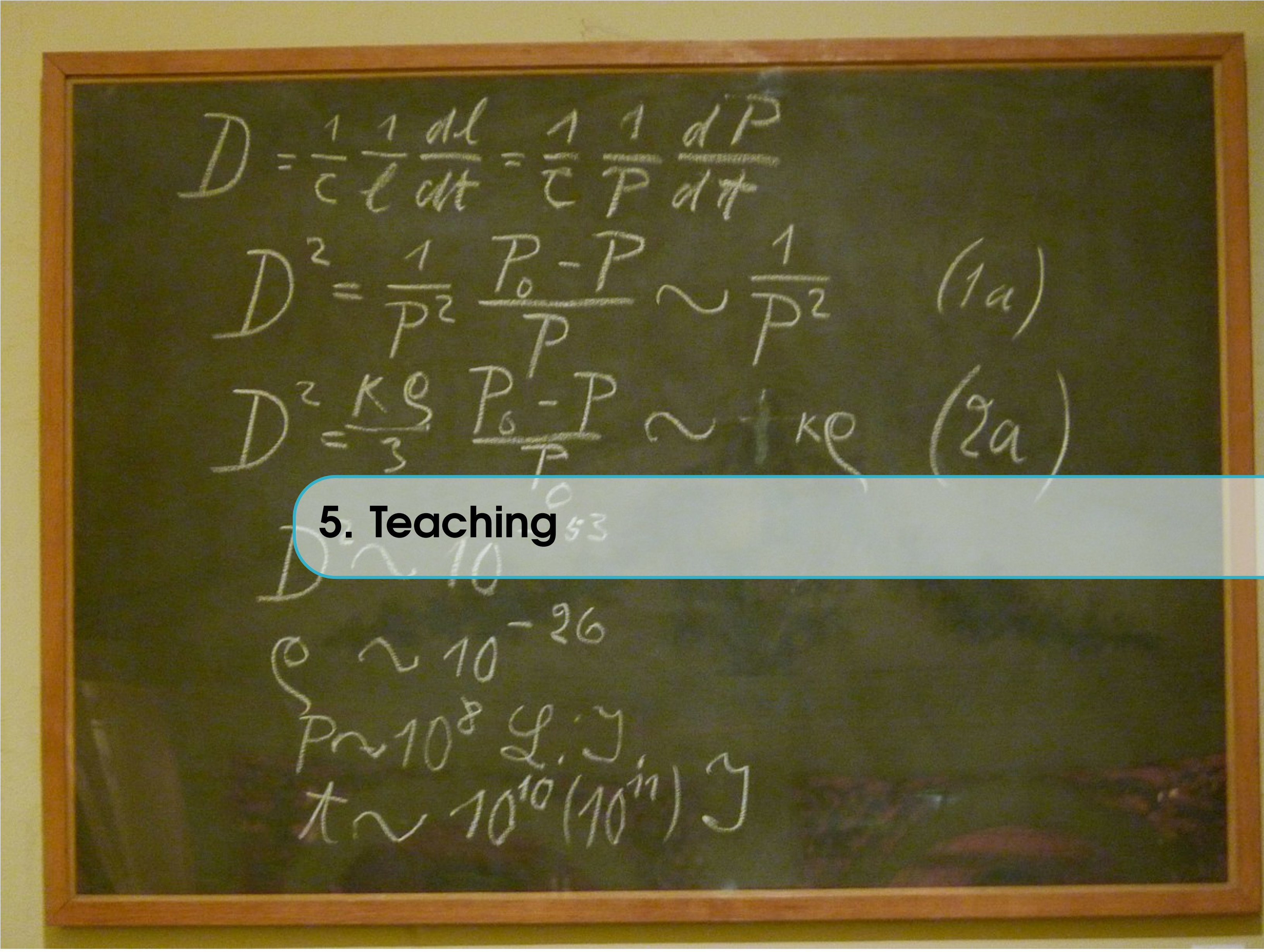


Figure 4.3: Schematic view of the MICADO design concept, illustrating how the cold optics and mechanisms are assigned to separate modules that can be tested separately and then integrated together in the cryostat.



5. Teaching

5.1 Lectured courses (in whole or in part)

Basic level - in Finnish

Teacher	Course	Credits	Location
Talvikki Hovatta (co-lecturer)	Introductory Astronomy (Radio)	5	Turku

Intermediate level - in Finnish or English

Joachim Janz	Astronomy Research Project I	5	Oulu

Advanced level - in English

Roberto De Propris (co-lecturer)	Galaxies and Cosmology	6	Turku
Talvikki Hovatta (co-lecturer)	Radio Astronomy and Interferometry	5	Turku
K. Koljonen	Space Instrumentation	5	Aalto
Elina Lindfors (co-lecturer)	TÄHT7032 Active Galactic Nuclei	6	Turku
Jari Kotilainen (co-lecturer)	TÄHT7032 Active Galactic Nuclei	6	Turku

5.2 Completed theses

MSc theses

Nischal Acharya , *The environment of nearby quasars in the GAMA survey*, University of Turku, co-supervisors: Jari Kotilainen and Roberto De Propris

Alexandros Binios, *Multiwavelength spectral analysis of accretion disk and astrophysical jet connection in low-mass X-ray binaries*, Aalto University, co-supervisor: Karri Koljonen

Giorgia Peluso, *Long-term variability of the gamma-ray emitting NLSy1 PKS2004-447*, University of Padova, supervisor: Marco Berton

PhD theses

Vandad Fallah Ramazani, University of Turku, *BL Lac Objects - View from the Highest Energies*, co-supervisors: Elina Lindfors and Kari Nilsson

6. Other research activities

Memberships in conference SOC/LOC and other committees

T. Hovatta	Finland's representative in the ESO Scientific Technical Committee
	Member of the European Science Advisory Committee (ESO/ALMA)
	Member of the European VLBI Network Programme Committee
	Member of the CTA Consortium
	Member of the SOC of EAS2020- SS6: Multiwavelength polarization of blazar jets (European Astronomical Society virtual meeting 2020)
E. Lindfors	Deputy Physics coordinator of the CTA Consortium
	Member of the Time Allocation Committee of the MAGIC Collaboration
	Member of the Collaboration Board of the MAGIC Collaboration
	Opticon and Radionet Package on "Optical and IR schools" member of the board
K. Nilsson	OPTICON Trans national Access Time Allocation Committee
R. De Propris	HST Time Allocation Committee member (Large Scale Structure panel)
Vandad Fallah Ramazani	Member of the Executive Board of the MAGIC Collaboration
J. Janz	Astronomers Days LOC

Conference presentations

E. Lindfors	European Astronomical Society meeting- June 2020, virtual- "Connection between rotation of optical polarization angle and emission of VHE gamma-rays in blazar jets?" (invited talk)
M. Berton	EAS 2020, June 28 - July 2, Virtual meeting
C. Wethers	IAU Symposium 359: Galaxy Evolution and Feedback Across Different Environments (GALFEED), March 2nd – 6th, Bento Goncalves, Brazil (Oral presentation: “No Evidence for Quenching in Quasars”)

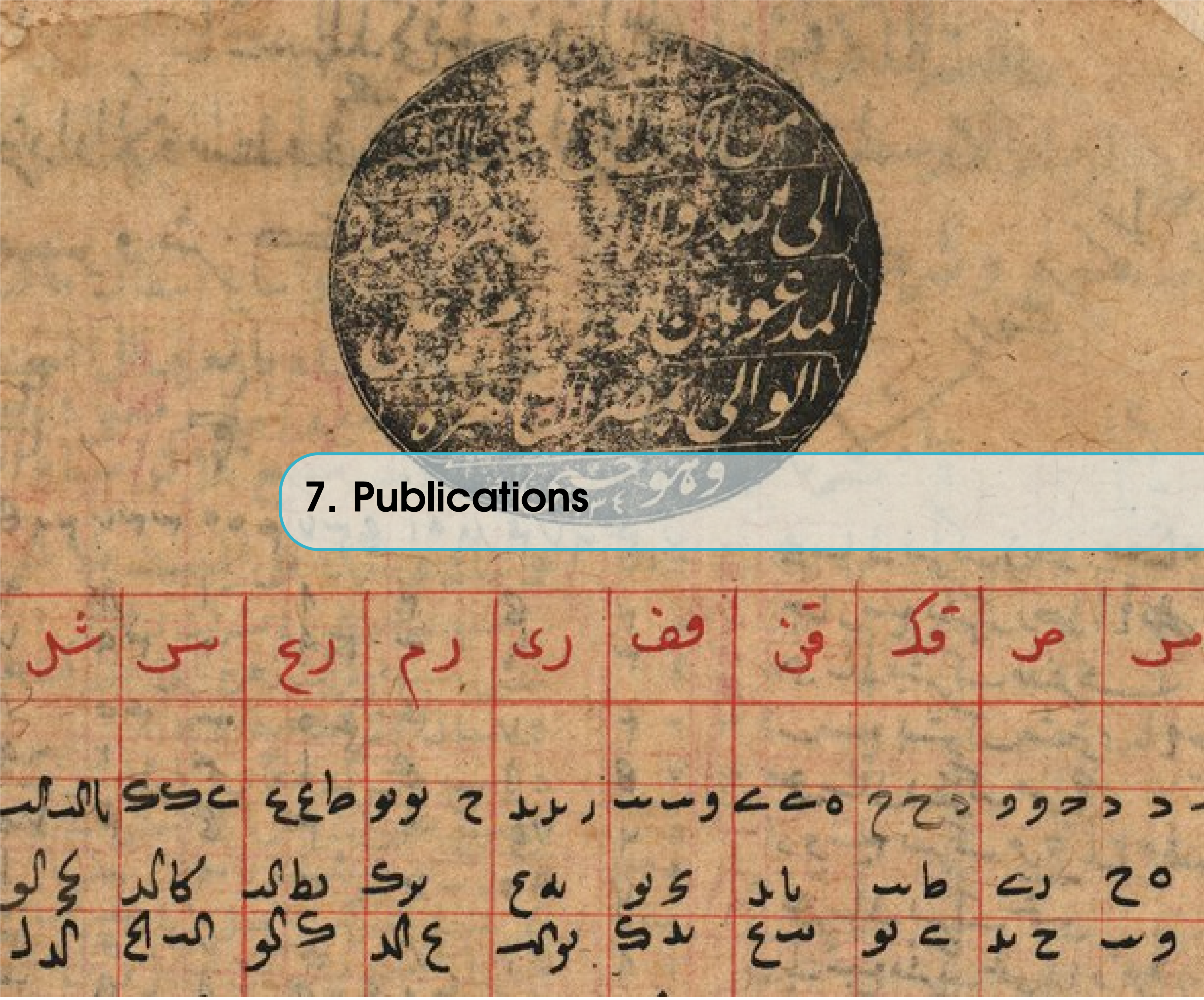
Other talks

E. Lindfors	"Locating blazar zone?" University of Iceland, seminar, February 2020
K. Koljonen	”The end of the outburst of GRS 1915+105”, Metsähovi Radio Observatory, Finland, 20 October 2020
	“The outburst of GRS 1915+105 in 15 minutes”, FINCA, Finland, 2 November 2020
M. Berton	“Rogue NLS1: an AGN story”, ESO Vitacura, 9 July 2020 (virtual)
D. McKay	"The day our Galaxy disappeared – extreme disturbances in ionospheric radio-propagation" FINCA Seminar, 5 October 2020
	"The End of Civilisation – On the looming environmental catastrophe of space debris", Metsähovi Science Seminar, 3 November 2020

Research Visits

Hosted visitors

Stefano Ciroi, University of Padova, Italy – Host: M. Berton
Serena Loporchio, INFN Bari, Italy – Host: E. Lindfors



7. Publications

Refereed publications by FINCA staff 2020:

1. Aalto, S. et al. (including **Kotilainen**) *ALMA resolves the remarkable molecular jet and rotating wind in the extremely radio-quiet galaxy NGC 1377*, 2020, A&A, 640, A104

2. Abeysekara, A. U. et al. (including **Fallah Ramazani, Hovatta, Lindfors, Nilsson**) *The Great Markarian 421 Flare of 2010 February: Multiwavelength Variability and Correlation Studies*, 2020, ApJ, 890, A97

3. Acciari, V. A. et al. (including **Fallah Ramazani, Lindfors, Nilsson**) *MAGIC very large zenith angle observations of the Crab Nebula up to 100 TeV*, 2020, A&A, 635 A158

4. Acciari, V. A. et al. (including **Fallah Ramazani, Lindfors, Nilsson**) *New Hard-TeV Extreme Blazars Detected with the MAGIC Telescopes*, 2020, ApJS, 247, A16

5. Acciari, V. A. et al. (including **Fallah Ramazani, Lindfors, Nilsson**) *Monitoring of the radio galaxy M 87 during a low-emission state from 2012 to 2015 with MAGIC*, 2020, MNRAS, 492, 5354

6. Acciari, V. A. et al. (including **Fallah Ramazani, Lindfors, Nilsson**) *Study of the variable broadband emission of Markarian 501 during the most extreme Swift X-ray activity*, 2020, A&A, 637, A86

7. Acciari, V. A. et al. (including **Fallah Ramazani, Lindfors, Nilsson**) *A search for dark matter in Triangulum II with the MAGIC telescopes*, 2020, Physics of the Dark Universe, 28, 100529

8. Acciari, V. A. et al. (including **Fallah Ramazani, Lindfors, Nilsson**) *Broadband characterisation of the very intense TeV flares of the blazar 1ES 1959+650 in 2016*, 2020, A&A, 638, A14

9. Acciari, V A. et al. (including **Fallah Ramazani, Hovatta, Lindfors, Nilsson**) *Unraveling the Complex Behavior of Mrk 421 with Simultaneous X-Ray and VHE Observations during an Extreme Flaring Activity in 2013 April*, 2020, ApJS, 248, A29

10. Acciari, V. A. et al. (including **Fallah Ramazani, Lindfors, Nilsson**) *Bounds on Lorentz Invariance Violation from MAGIC Observation of GRB 190114C*, 2020, PRL, 125, 2, 1301

11. Acciari, V. A. et al. (including **Fallah Ramazani, Lindfors, Nilsson**) *Testing two-component models on very high-energy gamma-ray-emitting BL Lac objects*, 2020, A&A, 640, A132

12. Acciari, V A. et al. (including **Fallah Ramazani, Hovatta, Lindfors, Nilsson**) *An intermittent extreme BL Lac: MWL study of 1ES 2344+514 in an enhanced state*, 2020, MNRAS, 496, 3912

13. Acciari, V. A. et al. (including **Fallah Ramazani, Lindfors, Nilsson**) *Studying the nature of the unidentified gamma-ray source HESS J1841-055 with the MAGIC telescopes*, 2020, MNRAS, 497, 3734

14. Acciari, V. A. et al. (including **Fallah Ramazani, Lindfors, Nilsson**) *MAGIC observations of the diffuse γ-ray emission in the vicinity of the Galactic center*, 2020, ApJ, 642, A190

15. Acciari, V. A. et al. (including **Fallah Ramazani, Lindfors, Nilsson**) *Detection of the Geminga pulsar with MAGIC hints at a power-law tail emission beyond 15 GeV*, 2020, A&A, 643, L14

16. Ahnen, M. L. et al. (including **Fallah Ramazani, Lindfors, Nilsson**) *Statistics of VHE γ-rays in temporal association with radio giant pulses from the Crab pulsar*, 2020, A&A, 634, A25

17. Aller, M., Hughes, P., Aller, H., **Hovatta, T.** *Diagnosing Magnetic Field Geometry in Blazar Jets Using Multi-Frequency, Centimeter-Band Polarimetry and Radiative Transfer Modeling*, 2020, Galaxies, 8, 22

18. Anjun, A., Stalin, C. S., **Rakshit, S.**, Gudennavar, S. B., Durgapal, A. *Mid-infrared variability of γ-ray emitting blazars* , 2020, MNRAS, 494, 764

19. Balmaverde, B. et al. (including **Berton, M.**) *Te-REX: a sample of extragalactic TeV-emitting candidates*, 2020, MNRAS, 492, 3728

20. Bidahar, B. et al. (including **Janz, J.**) *On the accretion of a new group of galaxies on to Virgo: I. Internal kinematics of nine in-falling dEs* , 2020, MNRAS, 497, 1904

21. **Berton, M.** et al. *Absorbed relativistic jets in radio-quiet narrow-line Seyfert 1 galaxies*, 2020, A&A, 636, A64

22. Boekholt, T. C. N., Portegies Zwart, S. F., **Valtonen, M.** *Gargantuan chaotic gravitational three-body systems and their irreversibility to the Planck length*, 2020, MNRAS, 493, 3932

23. Chamani, W., **Koljonen, K.**, Savolainen, T. *Joint XMM-Newton and NuSTAR observations of the reflection spectrum of III Zw 2* , 2020, A&A, 635, A172

24. Chen, S. et al. (including **Berton, M.**) *Radio morphology of southern narrow-line Seyfert 1 galaxies with Very Large Array observations* , 2020, MNRAS, 498, 1278

25. Cho, H. et al. (including **Rakshit, S.**) *Variability and the Size-Luminosity Relation of the Intermediate-mass AGN in NGC 4395* , 2020, ApJ, 892, A93

26. Congiu, S. et al. (including **Berton, M.**) *The radio structure of the narrow-line Seyfert 1 Mrk 783 with VLBA and e-MERLIN* , 2020, MNRAS, 499, 3149

27. Darnley, M. J., et al. (including **Williams, S.** *AT 2016dah and AT 2017fyp: the first classical novae discovered within a tidal stream*, 2020, MNRAS, 495, 1073

28. Gonzalez, A. G. et al. (including **Berton, M.**) *Characterizing continuum variability in the radio-loud narrow-line Seyfert 1 galaxy IRAS 17020+4544*, 2020, MNRAS, 496, 3708

29. Harvey, E. J., et al. (including **Williams, S.** *Two new nova shells associated with V4362 Sagittarii and DO Aquilae*, 2020, MNRAS, 499, 2959

30. Järvelä, E. et al. (including **Berton, M.**) *SDSS J211852.96-073227.5: The first non-local, interacting, late-type intermediate Seyfert galaxy with relativistic jets*, 2020, A&A, 636, L12

31. Kipper, R., Benito, M., Tenjes, P., Tempel, E., **De Propris, R.** *Tidal forces from the wake of dynamical friction: warps, lopsidedness, and kinematic misalignment*, 2020, MNRAS, 498, 1080

32. **Koljonen, K.** & Tomsick, J. A. *The obscured X-ray binaries V404 Cyg, Cyg X-3, V4641 Sgr, and GRS 1915+105*, 2020, A&A, 639, A13

33. Komossa, S. et al. (including **Valtonen, M.**) *The 2020 April-June super-outburst of OJ 287 and its long-term multiwavelength light curve with Swift: binary supermassive black hole and jet activity* , 2020, MNRAS, 498, L35

34. Kool, E. C. et al. (including **Berton, M.**) *AT 2017gbl: a dust obscured TDE candidate in a luminous infrared galaxy*, 2020, MNRAS, 498, 2167

35. Kunder, A. et al. (including **De Propris, R.**) *The Bulge Radial Velocity Assay for RR Lyrae Stars (BRAVA-RR) DR2: A Bimodal Bulge?*, 2020, AJ, 159, A270

36. Kvammen A., Wickstrøm, K., McKay, D., Partamies, N. *Auroral Image Classification With Deep Neural Networks*, 2020, Journal of Geophysical Research: Space Physics, 125, Issue 10, article id. e27808

37. Larionov, V. M. et al. (including **Hovatta, T.**) *Multiwavelength behaviour of the blazar 3C 279: decade-long study from γ-ray to radio* , MNRAS, 482, 3829

38. Laine, S. et al. (including **Valtonen, M.**) *Spitzer Observations of the Predicted Eddington Flare from Blazar OJ 287*, 2020, ApJ, 894, L1

39. **Nilsson, K., Kotilainen, J., Valtonen, M.** et al. *The Host Galaxy of OJ 287 Revealed by Optical and Near-infrared Imaging*, 2020, ApJ, 904, A102

40. Ohja, V., Chand, H., Dewangan, G. C., **Rakshit, S.** *A Comparison of X-Ray Photon Indices among the Narrow- and Broad-line Seyfert 1 Galaxies*, 2020, ApJ, 895, AA95

41. Olguín-Iglesias, A., **Kotilainen, J.**, Chavushyan, V. *The disc-like host galaxies of radio-loud narrow-line Seyfert 1s*, 2020, MNRAS, 492, 1450

42. Phiillips, S. et al. (including **De Propris, R.**) *Galaxy And Mass Assembly (GAMA): Defining passive galaxy samples and searching for the UV upturn*, 2020, MNRAS, 492, 2128

44. Punsly, B. et al. (including **Berton, M.**) *The Energetics of Launching the Most Powerful Jets in Quasars: A Study of 3C 82*, 2020, ApJ, 898, A169

44, Punsly, B ., Marziani, P., **Berton, M.**, Kharb, P. *The Extreme Red Excess in Blazar Ultraviolet Broad Emission Lines*, 2020, ApJ, 903, A44

45. Ragone-Figueroa, C. et al. (including **De Propris. R.**, *Evolution and role of mergers in the BCG-cluster alignment. A view from cosmological hydrosimulations*, 2020, MNRAS, 435, 2436

46. Rajput, B., Stalin, C. S., **Rakshit, S.** *Long term γ-ray variability of blazars*, 2020, A&A, 634, A80

47. Rich, R. M. et al. (including **De Propris, R.**) *The Blanco DECam bulge survey. I. The survey description and early results*, 2020, MNRAS, 499, 340

48. **Rakshit, S.** *Broad line region and black hole mass of PKS 1510-089 from spectroscopic reverberation mapping* , 2020, A&A, 642, A59

49. **Rakshit, S., Kotilainen, J.**, Stalin, C. S. *Spectral Properties of Quasars from Sloan Digital Sky Survey Data Release 14: The Catalog*, 2020, ApJS, 249, A17

50. Russell, T. D.. et al. (including **Koljonen, K.**) *Rapid compact jet quenching in the Galactic black hole candidate X-ray binary MAXI J1535-571*, 2020, MNRAS, 498, 5772

51. Safna, P. S., Stalin, C. S., **Rakshit, S.**, Blesson, M. *Long-term optical and infrared variability characteristics of Fermi blazars*, 2020, MNRAS, 498, 3578

52. Tripathi, S. et al. (including **Berton, M.**) *Tracking the year-to-year variation in the spectral energy distribution of the narrow-line Seyfert 1 galaxy Mrk 335*, 2020, MNRAS, 499, 1266

53. Valverde, J. et al. (including **Fallah Ramazani, Hovatta, Lindfors, Nilsson**) *A Decade of Multiwavelength Observations of the TeV Blazar 1ES 1215+303: Extreme Shift of the Synchrotron Peak Frequency and Long-term Optical-Gamma-Ray Flux Increase*, 2020, ApJ, 891, A170

54. **Wethers, C., Kotilainen, J.**, Schramm, M., Schulze, A. *Star formation in luminous LoBAL quasars at* $2.0 < z < 2.5$, 2019, MNRAS, 498, 1469

55. **Wethers, C.**, Banerij, M., Hewett, P. C., Jones, G. C. *A SCUBA-2 850 μm survey of heavily reddened quasars at* $z \sim 2$, 2020, MNRAS, 492, 5280

56. **Williams, S. C.**, et al. *AT 2019abn: multi-wavelength observations over the first 200 days*, 2020, A&A, 637, A20

57. **Williams, S. C.**, et al. *See Change: VLT spectroscopy of a sample of high-redshift Type Ia supernova host galaxies*, 2020, MNRAS, 495, 3859

58. Woo, J.-H., Son, D., **Rakshit, S.** *The Correlation of Outflow Kinematics with Star Formation Rate. VI. Gas Outflows in AGNs*, 2020, ApJ, 901, A66