Turun yliopisto
University of Turku

FINCA
Finnish Centre for Astronomy with ESO

Finnish Centre for Astronomy with ESO

Annual Report

2015

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Cover illustration : The Sun bathes ESO's Very Large Telescope (VLT) in a warm, orange glow. Located at ESO's Paranal Observatory in northern Chile, the VLT is ESO's current flagship observational facility.

Picture credit: ESO/A. Ghizzi Panizza (www.albertoghizzipanizza.com)

FINNISH CENTRE FOR ASTRONOMY WITH ESO, ANNUAL REPORT 2015

EDITOR: PASI NURMI, FINCA, (PASNURMI@UTU.FI)

TYPESETTING WAS MADE USING LATEX, BASED ON THE TEMPLATE BY ANDREA HIDALGO: HTTPS://WWW.OVERLEAF.COM/ARTICLES/CLUSTERING-THE-INTERSTELLAR-MEDIUM/MTTHGYYFRDKN#.VPHOB8UFLHJ

APRIL 2016

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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 15 member states (Poland is the 15th, joined in July 2015), 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 2015 marked the 6th 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 magnetic activity, star formation and exoplanets 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), and the Nordic Optical Telescope (NOT) on La Palma, Spain, in the optical and near-infrared. Observational research is supplemented by modelling, simulations and theoretical work, that are essential in understanding the physics behind the observations. Our research were reported in 71 refereed scientific articles, and some of them are highlighted in this Report.

Our researcher training activities in 2015 focused on one hand in supervision of PhD and MSc students in the participating universities, and on the other hand in starting and developing hands-on teaching of advanced observing, data reduction and analysis methods in observational astronomy as national collaboration. There were two such courses held in 2015, one of them the annual course on remote optical/infrared observing with the NOT, and the other one a new North-European Radio Astronomy School.

These courses are described in this Report.

The construction of the European Extremely Large Telescope (E-ELT), a 39 m diameter giant for infrared and optical astronomy, is well underway, with agreements for all Phase 1 instruments signed, the access road and platform completed at Cerro Armazones, Chile, and the contract for the Dome and Main Structure awarded. This keeps ESO on-track to remain in a world-leading position, when the E-ELT starts operations in 6-8 years time. Now is a high time to start adjusting one's research goals for the enormous leap forward in sensitivity and resolution brought by the E-ELT!

FINCA continues in an active role to facilitate Finnish industry to participate as sub-contractors in building the E-ELT and its instrumentation. FINCA is participating on behalf of the Finnish community in one of the E-ELT instrument consortia, the MOSAIC (optical and near-infrared multi-object spectrograph), which has recently signed a Phase A study contract with ESO. Finland is one of Associated Partners in MOSAIC. FINCA is also participating in the NOT Transient Explorer (NTE), a new instrument for the NOT capable of simultaneous optical and near-infrared spectroscopy and imaging, with first light expected in 2018. As a followup to NTE participation, and to build a bridge toward involvement in ESO instrumentation, FINCA is also planning participation in one of the next generation instruments selected to the ESO 3.5-m New Technology Telescope (NTT), the Son Of X-Shooters (SOXS), a very similar instrument to the NTE.

Jari Kotilainen
FINCA Director

2. Staff and organization

FINCA staff (Turku, unless otherwise indicated)

Director :	Jari Kotilainen
1	
Professor emeritus :	Mauri Valtonen
University Researchers :	Roberto De Propris Pasi Hakala Heidi Korhonen Eija Laurikainen (Oulu) Seppo Mattila Kari Nilsson
Postdoctoral researchers	Sébastien Comerón (Oulu, until 31.7.2015) Ronald Läsker (since 5.10.2015) Andrew Mason (until 6.4.2015) Pasi Nurmi (since 1.8.2015)
PhD student	Alejandro Olguín Iglesias (since 31.7.2015, from INAOE Puebla, Mexico)

FINCA board

Member	Substitute member
vice-President Tuija Pulkkinen (Aalto)	prof. Anne Lähteenmäki (Aalto)
doc. Merja Tornikoski (Aalto; **co-chair**)	doc. Joni Tammi (Aalto)
prof. Hannu Koskinen (Helsinki)	prof. Karri Muinonen (Helsinki)
doc. Juhani Huovelin (Helsinki)	doc. Mika Juvela (Helsinki)
prof. Heikki Salo (Oulu)	prof. Ilya Usoskin (Oulu)
doc. Jurgen Schmidt (Oulu)	doc. Vitaly Neustroev (Oulu)
prof. Juri Poutanen (Turku)	doc. Aimo Sillanpää (Turku)
vice-rector Kalle-Antti Suominen (Turku; **chair**)	prof. Esko Valtaoja (Turku)
doc. Pasi Hakala (Turku; staff rep.)	doc. Seppo Mattila (Turku; staff rep.)

Scientific avdisory board

prof. Susanne Aalto (**chair**)	Chalmers University of Technology, Gothenburg, Sweden
Prof. Janet Drew	University of Hertfordshire, United Kingdom
Prof. Claes Fransson	Stockholm University, Sweden
Prof. Jens Hjorth	University of Copenhagen, Denmark
Dr. Hans Kjeldsen	Aarhus University, Denmark
Prof. Johan Knapen	Instituto de Astrofisica de Canarias, Spain
Dr. Bruno Leibundgut	European Southern Observatory, Germany

3. Research

3.1 Main research areas

The research at FINCA concentrates on observational astronomy carried out using radio to gamma-rays multi-wavelength data from large ground-based and space telescopes. The most commonly used methods are optical and infrared imaging, spectroscopy and polarimetry. 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 studies of the structure, kinematics and stellar population properties of nearby galaxies, to supernovae, their progenitor stars, and use as probes of their host galaxies, binary stars, stellar magnetic activity, interstellar medium, star formation and exoplanets in our own Galaxy. In 2015, our research were reported in 71 refereed scientific articles, and some of them are highlighted below.

3.2 Research highlights

3.2.1 Galaxy evolution and cosmology

Galactic archæology of the ESO 533-4 thick disc with VIMOS

The formation mechanisms of thick discs are under debate. Thick discs might have formed either at high redshift on a short timescale or might have been built slowly over the cosmic time. They may have an internal or an external origin. To solve the issue of the thick disc origin **Sébastien Comerón and collaborators** studied the kinematics and the stellar populations of the nearby edge-on galaxy ESO 533-4 (**Fig. 3.1**). Their work is the first Integral Field Unit (IFU) spectroscopy work with enough depth and quality to study the thick disc. This was done with VIMOS@VLT.

The IFU data were studied using the pPXF software. They extracted both the kinematics and the stellar populations of the thin and the thick discs.

They found that the thick disc of ESO 533-4 contains no counter-rotating material. This suggests an internal origin for the thick disc (as opposite to accreted in mergers, which would cause some amount of retrograde stars). The stellar population map indicates that the populations of the thin and the thick discs of ESO 533-4 are separated in the Age-log(Z/Z_{Sun}) plane. This implies that thin and thick discs are made of two

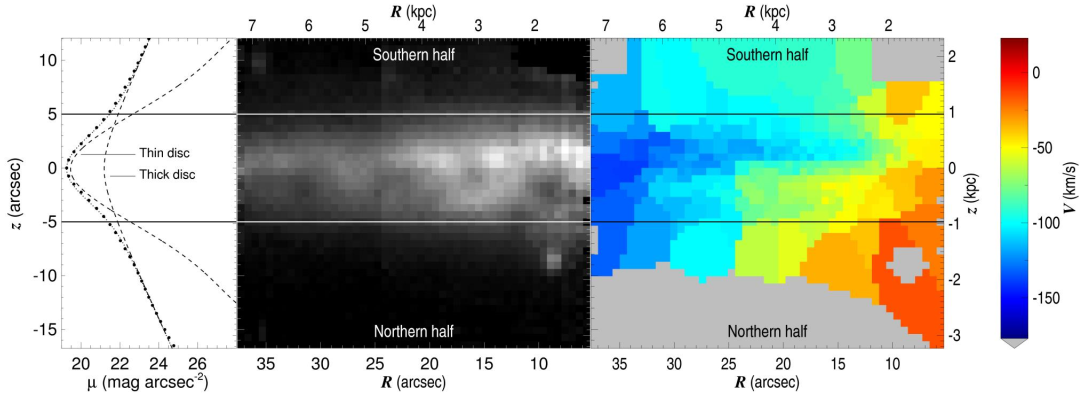

Figure 3.1: Left: Symmetrized 3.6μm luminosity profile and thin/thick disc decomposition of the $0.08r_{25} - 0.69r_{25}$ axial range of ESO 533-4. The horizontal lines indicate the height above which 90% of the light comes from the thick disc. Middle: image of the observed field. Right: velocity field of ESO 533-4. The horizontal axis indicates the axial distance to the galaxy centre and the vertical axis indicates the distance from the mid-plane.

distinct populations. If the thick disc had a secular origin, we would observe a continuity in the Age-log(Z/Z_{Sun}) plane. Hence, we suggest that the thick disc of ESO 533-4 formed in a relatively short event at high redshift and that the thin disc has formed afterwards within it.

So far, the rotation curves of the thick discs of five massive galaxies is known (that includes the Milky Way and ESO 533-4). None of them has a significant fraction of counterrotating material in its thick disc. We thus suggest that the formation mechanism of ESO 533-4's thick disc is the standard one for massive disc galaxies. This indicates that probably the thick discs in massive galaxies were already in place at very early stages of the history of galaxies and that a thin disc has grown afterwards within them.

Analysis of high redshift clusters from HST archival data

In extragalactic astrophysics main result by **Roberto De Propris** and his co-workers has been the analysis of several high redshift clusters from HST archival data. We found that the luminosity function evolves passively and there is no evidence of a weakening of the red sequence out to z=1.25. We also found that high redshift cluster red sequence galaxies contain significant disk-like components and resemble local red spirals. The disks appear to have young ages and we detect significant age gradients that disappear at $z \sim 0.6$. A further paper (and others planned) is in preparation on this. In Galactic astronomy **Roberto De Propris** and collaborators have continued our work on the structure of the Galactic Bulge. We have identified a high speed RR Lyra star in our survey and there are indications that we have found the old bulge component at the 1% level.

Low-redshift quasars in the SDSS Stripe 82: Host galaxy colours and close environment

Jari Kotilainen and collaborators have continued studying quasars and inactive galaxies, closely matched in luminosity and redshift, based on a large and homogeneous data set of objects derived from the Sloan Digital Sky Survey (SDSS) Stripe 82 region, that

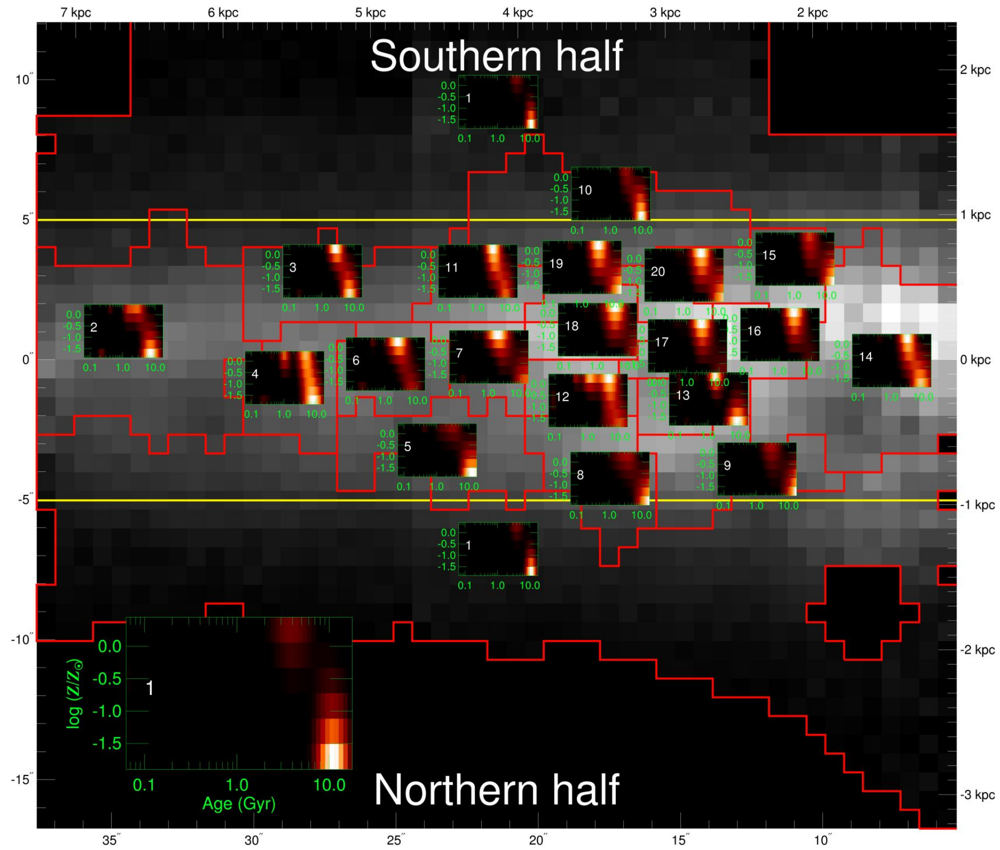

Figure 3.2: Stellar populations of ESO 533-4. The background image is the same as in the middle panel of the previous figure. The red lines indicate the spacial bins used for the analysis. The horizontal solid yellow lines indicate the height above which 90% of the light comes from the thick disc. On top of each bin there is a stellar population plot with the horizontal axis corresponding to the ages in Gyr and the vertical axis corresponding to the metallicities in $\log(Z/Z_{Sun})$. The two thick disc sections (uppermost and lowermost tiles) were actually treated as a single bin. The colours in the plots for each bin indicate the mass fraction of a given stellar population. The bottom left corner of the figure shows an enlarged version of one of the stellar population distributions to improve the readability of the axes.

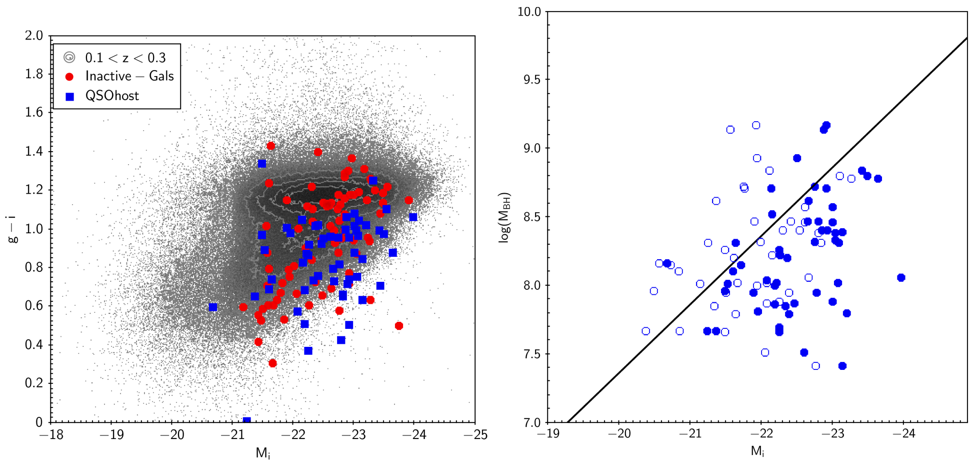

Figure 3.3: **Left**: Color-magnitude plot of the quasar hosts (blue squares) and inactive galaxies (red dots) superimposed to the distribution of all SDSS galaxies at 0.1<z<0.3 (small grey dots and contours). **Right**: The i-band absolute magnitude of the quasar host galaxies (filled blue circles) vs. their black hole mass (in solar masses). The reference (black) solid line is the local relation for inactive galaxies. Open circles refers to the bulge component only.

is up to 2 mag deeper than standard SDSS images. In Bettoni et al. (2015, MNRAS, 454, 4103) they investigated the ugriz color properties of the host galaxies and their close environment of 52 low redshift ($z < 0.3$) quasars. The quasar hosts were resolved in almost all objects in the g, r, i and z filters , and for about a half in the u-band. They find that:

(i) The overall mean colors of the quasar host galaxies are indistinguishable from those of inactive galaxies of similar luminosity and redshift. The most massive quasar hosts have slightly bluer colors and lower star formation rate, in the last 300 Myr, than the inactive galaxies. (**Fig. 3.3, left panel**)

(ii) About 60% of the quasars have companion galaxies at projected distance < 50 kpc. However, only $\sim$ 10% have confirmed companions at the same redshift as the quasar. Moreover, inactive galaxies of same luminosity/mass have similar fractions of companions.

(iii) There is no significant correlation between the central black hole mass and the total luminosity of the quasar hosts (**Fig. 3.3, right panel**). This is contrary to previous claims that quasar hosts are found to be undermassive for a given black hole mass. Quasar hosts are more luminous than expected from the local black hole – galaxy relation, suggestive of a disc component that is not correlated with the black hole mass.

The comparison of color properties of the quasar host galaxies and their companion galaxies with those of inactive galaxies do not indicate any significant difference. This further supports a scenario where the activation of the quasar has negligible effects on the global structural and photometrical properties of the host galaxies. In particular the similarity of colors between active and inactive galaxies of similar mass indicate that also the stellar content of these galaxies is virtually unchanged by the presence of an active nucleus.

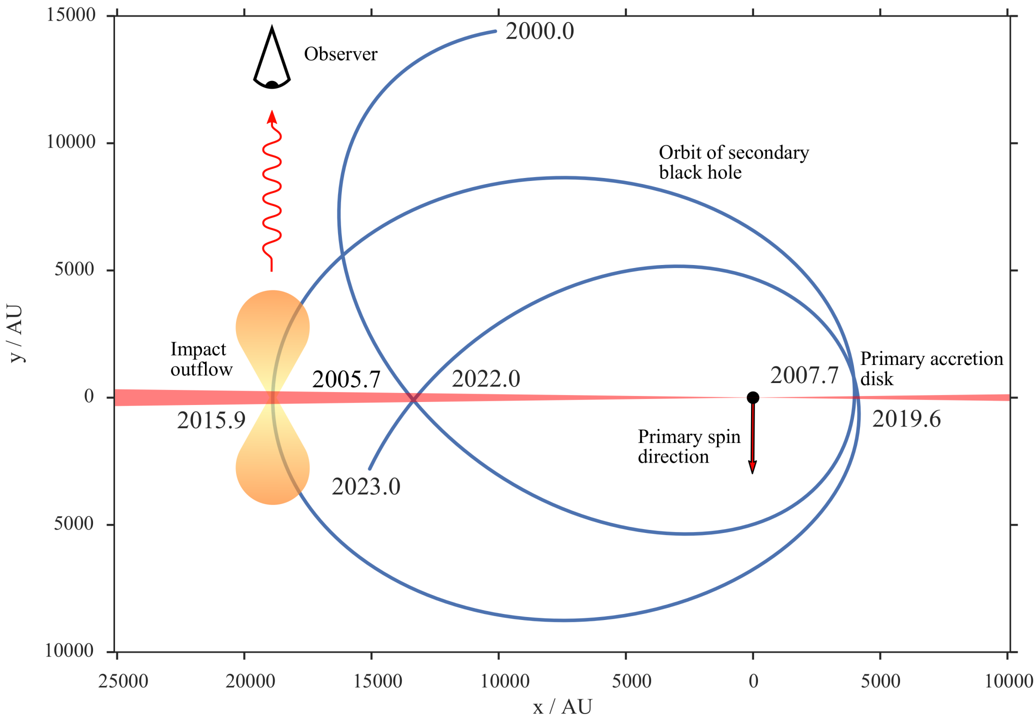

Figure 3.4: The orbit of the secondary black hole in OJ287 from year 2000 to 2023. The 2015 December thermal outburst comes from the disk crossing in 2013 while the nonthermal flux arises from a jet, parallel to the primary spin axis. The next two thermal outbursts are due in 2019 and 2022, following the crossing of the secondary black hole through the accretion disk.

Optical outburst in OJ287

Mauri Valtonen and **Kari Nilsson**, together with 90 astronomers from all around the world, have followed the predicted optical outburst in OJ287. It is a quasi-periodic quasar with roughly 12 year optical cycles. Its prominent outbursts are predictable in a binary black hole model (**Fig. 3.4**). The model predicted a major optical outburst in December 2015. They found that the outburst did occur within the expected time range, peaking on 2015 December 5 at magnitude 12.9 in the optical R-band, brightest it has been in over 30 yr. Based on Swift/XRT satellite measurements and optical polarization data, they find that it included a major thermal component. Its timing provides an accurate estimate for the spin of the primary black hole, $\chi = 0.315 \pm 0.025$. The outburst also confirmed the established general relativistic properties of the system such as the loss of orbital energy to gravitational radiation at the 2% accuracy level and it is consistent with the no-hair theorem of black holes within an accuracy of 30%. It opened up the possibility of testing the theorem with a 10% accuracy in 2019. The present outburst timing firmly confirms the correctness of the binary black hole central engine model for OJ287 within its specified parameter ranges, namely primary mass $(1.84 \pm 0.01) \times 10^{10}$ $M_\odot$, secondary mass $(1.4 \pm 0.1) \times 10^{8}$ $M_\odot$ and orbital eccentricity (as defined by using the apocentre/pericentre ratio) 0.700 ± 0.001.

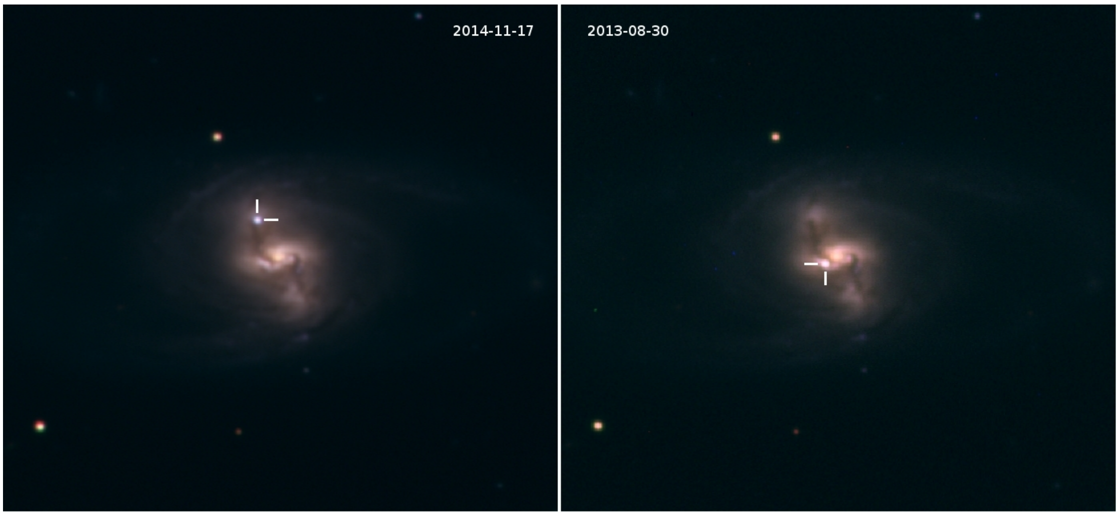

Figure 3.5: While monitoring Supernova 2013fc in the luminous infrared galaxy ESO 154-G010 with the ESO NTT as a part of the PESSTO survey, Tuomas Kangas a graduate student at the University of Turku serendipitiously discovered a new supernova (left) in the same host galaxy. Supernova 2013fc had exploded in this galaxy in the previous year (right).

3.2.2 Interstellar matter and Stellar astrophysics

Studies of supernovae at FINCA

The supernova researchers at FINCA continued actively participating in the Public ESO Spectroscopic Survey for Transient Objects (PESSTO) which is among the largest programmes running at the ESO telescopes and with the graduate students from the University of Turku working on datasets of interesting supernovae observed in PESSTO. University of Turku researchers were in charge together with the Institut d'Astrophysique de Paris of the November 2015 PESSTO observing run, with the graduate student Jussi Harmanen (Tuorla observatory) carrying out the observations with the ESO New Technology Telescope (NTT) and **Seppo Mattila** (FINCA) and the graduate student Tuomas Kangas (Tuorla observatory) processing the data. During the observing run multiple supernovae were monitored and 37 new transients were spectroscopically classified and reported in 8 Astronomer's Telegrams. During the November 2015 run the FINCA group also initiated and took charge of a follow-up campaign of a newly discovered type II supernova (**Fig. 3.5**).

Luminous and ultraluminous infrared galaxies (LIRGs and ULIRGs) dominate the star formation at redshifts between $\sim$1 and $\sim$2. Furthermore, due to their high star formation rates U/LIRGs can be expected to be the most prolific supernova factories in the Universe, however, the properties of this supernova population has remained poorly understood. Despite the high star-formation rates (and thus high expected core-collapse supernova rates) in these galaxies, only few supernovae have been discovered in them due to a high extinction in the dusty nuclear/circumnuclear regions where the strongest starformation takes place. Almost 90 per cent of the core-collapse supernovae have been missed in these regions by optical observations. However, a better understanding of the supernovae in LIRGs and ULIRGs is of great interest for measurements of the cosmic history of star formation, which is one of the most fundamental observables in astrophysical cosmology, indirectly from the observed supernova rates.

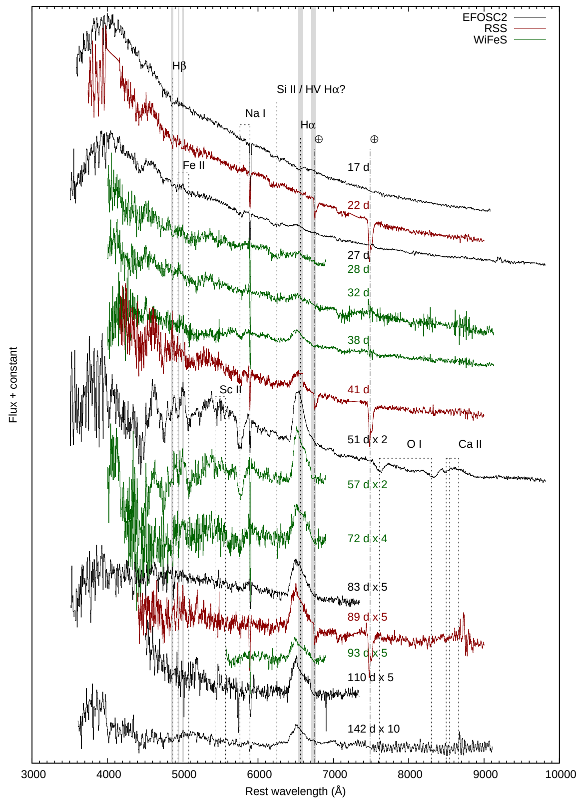

Figure 3.6: The optical spectral evolution sequence of SN 2013fc based on observations with the ESO NTT/EFOSC2 as a part of the PESSTO survey and with the SALT/RSS and ANU2.3m/WiFeS. The data from the follow-up campaign of SN 2013fc were published in Kangas et al. 2016, MNRAS, 456, 323 including the FINCA researchers Seppo Mattila and Jari Kotilainen.

In a recently published study the supernova researchers at FINCA presented photometric and spectroscopic observations of SN 2013fc (**Fig. 3.6**). The supernova was observed as part of the PESSTO using the ESO NTT, with the 10-meter Southern African Large Telescope (SALT) and with a number of smaller telescopes. SN 2013fc is an abnormally bright type II supernova that exploded in a circumnuclear star-forming ring (behind a high dust extinction) in the LIRG ESO 154-G010. Based on the photometry, a pseudo-bolometric light curve was constructed yielding a total radiated energy that is about 10 times higher than radiated by normal type II supernovae. The observed properties of the supernova indicate interaction between the ejecta and the circumstellar gas and a low Hydrogen envelope mass at the time of the explosion. It was thus suggested that SN 2013fc was consistent with a massive red supergiant (RSG) progenitor. Recent mass loss probably due to a strong RSG wind created the circumstellar medium illuminated through its interaction with the supernovae ejecta.

Stellar variability studies

The research of **Pasi Hakala** has, in addition to the ongoing analysis of XMM-Newton archival data and VLT-imagery of Ultraluminous X-ray sources, involved participation into analysis of NASA's Kepler/K2 mission data. The K2, which is a continuation of the very successful Kepler mission observing exoplanet transit and other variable objects, has provided unprecedented optical light curves of several variable sources. One of the recent highlights has been the three months long continuous K2 observations of the brightest persistent extrasolar X-ray source in the sky i.e. Sco X-1. This low mass X-ray binary, consisting of a neutron star and an evolved secondary star in a 18.9h orbit

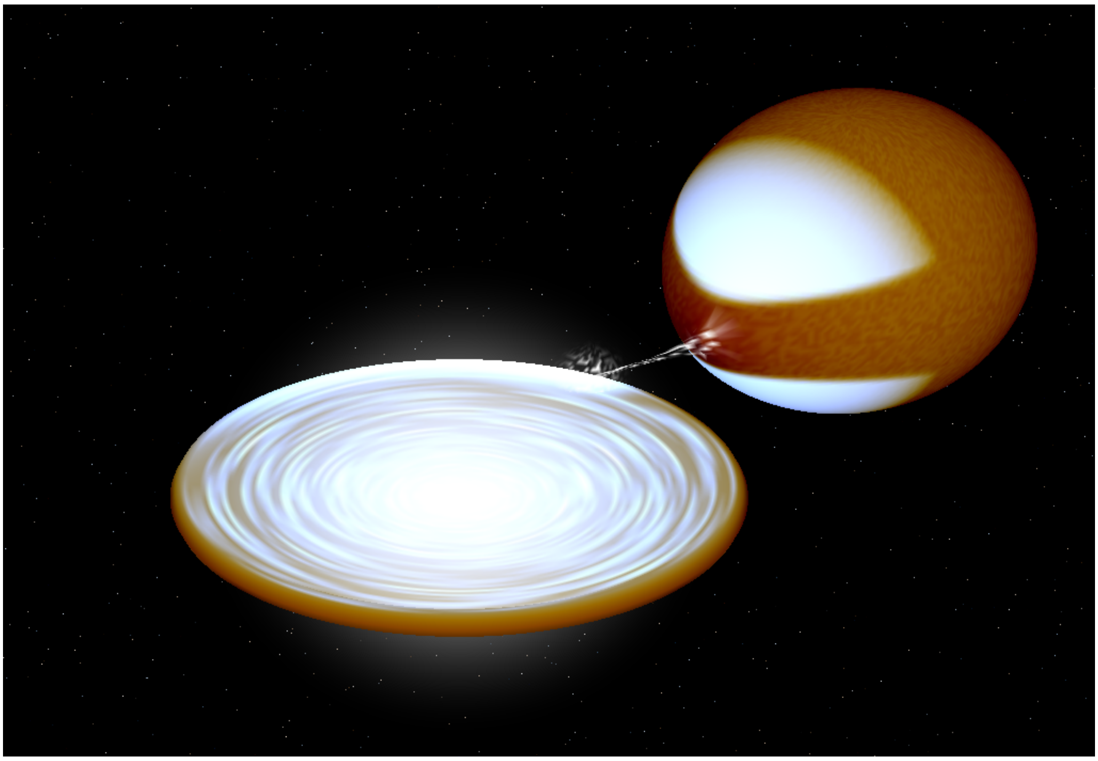

Figure 3.7: The model of the brightest persistent extrasolar X-ray source in the sky Sco X-1.

(see **Fig 3.7** for artist's impression of the system), has surprised us by the wealth of optical variability at different time scales.

The system has two optical states i.e. high and low (in terms of optical brightness). The study, lead by Dr Hakala that also involved scientists from University of Southampton (UK), Armagh Observatory (UK) and NASA (USA), showed that the system changes in between the two states with a period of 4.8d and that the changes can occur rapidly (in less than 3h). The results imply that the accretion disc in the system is probably precessing with a 4.8d period, something that was not expected and which has implications on our understanding of accretion disc dynamics.

Imaging stellar surfaces

For a long time it was not possible to obtain direct, spatially resolved, images of the stellar surface, except in some very rare cases of near-by giant and supergiant stars. Doppler imaging is a method that can be used for detailed mapping of the stellar surface structures. High resolution, high signal-to-noise spectra at different rotational phases are used to measure the rotationally modulated distortions in the line-profiles. These distortions are produced by the inhomogeneous distribution of the observed characteristic, e.g., temperature. During the last ten years a breakthrough using long baseline infrared interferometers has occurred. These facilities now routinely produce images with milli-arcsecond angular resolution. Still, resolving features on stellar surfaces is very demanding.

Heidi Korhonen, together with her collaborators Rachael Roettenbacher and John Monnier from University of Michigan, has last few years been working on imaging

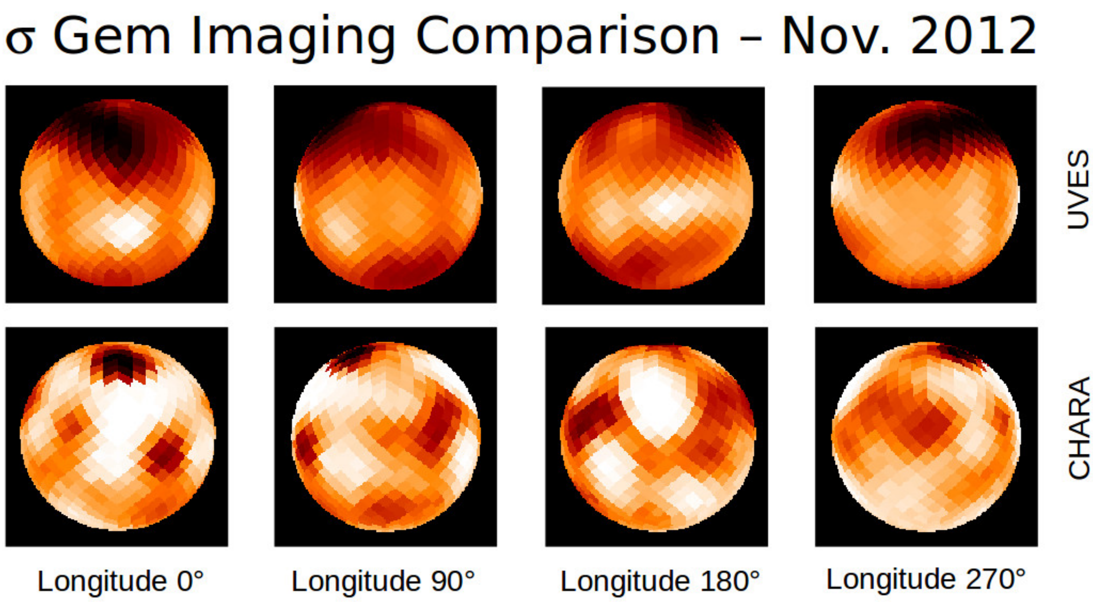

Figure 3.8: Image comparison between interferometric imaging from MIRC at CHARA and Doppler imaging using UVES data from VLT. The target is evolved K giant star sigma Geminorum. Stellar surface is shown from four different longitudes when the star rotates.

large sunspot-like temperature features on active stars with different techniques. In this project they combine fundamentally different methods for studying the stellar surface, and thus provide important new insights into the stellar surface features and underlying physical processes.

Due to the enhanced dynamo action in stars with thick, turbulent outer convection zones, rapidly rotating cool stars (both evolved and young) exhibit significantly stronger magnetic activity than is seen in the Sun. Doppler imaging has revealed that the spots on these stars are much larger and their lifetime can also be much longer than that of the sunspots. The latitudes at which starspots often occur are very different from those for the sunspots. In rapidly rotating late type stars the spots can appear at very high latitudes, which can be explained by the increase in the Coriolis force induced by the rapid rotation. Although, these calculations cannot explain the formation of the polar caps, i.e., spots that are located at the rotational poles of the star, except in very young stars. These polar spots are still often seen in the Doppler images of also older stars. In addition, polar caps can be produced as artefacts in the Doppler imaging process. Therefore their existence has been highly debated, especially in the early days of Doppler imaging.

The successful upgrade of the MIRC instrument at CHARA Array (Mt. Wilson, USA) from four telescopes to all the six telescopes available at the array made it possible to make high quality interferometric images of surfaces of active giant stars. The extensive CHARA campaigns led by Roettenbacher were combined with simultaneous Doppler imaging data obtained by Korhonen. The high-resolution data fro Doppler imaging comes from various different sources, among them the UVES spectrograph at ESO's Very Large Telescope. The first results from this project were recently accepted for publication in Nature. In this paper it is unambiguously shown that polar spots exist on an old, evolved star zeta Andromedae, putting stop to the discussion on the existence of polar spots. In addition to zeta Andromedae Roettenbacher, Monnier and Korhonen have also imaged other active stars. Here (**Fig. 3.8**) an example of K giant sigma Geminorum is shown.

4. Instrument development

The second national instrumentation meeting was held at Tuorla Observatory, University of Turku, on 6 November 2015, following the first such meeting in Helsinki in February 2014. The meeting reviewed and discussed the priorities of the community and the existing and potential Finnish involvement in current and future facilities for observational astronomy, both from the ground and space-based. The meeting was attended by 15 participants from all FINCA universities and the program with links to the presentations can be found at the meeting webpage[1].

In order to get involved in future larger ESO instrumentation projects and to engage collaboration with groups which have already first-hand experience in building instrumentation for ESO, FINCA has from the beginning been involved in the new instrument for the Nordic Optical Telescope, the NOT Transient Explorer (NTE), with first light expected in 2018. This instrument is being designed and built by a group at the Niels Bohr Institute, Univ. of Copenhagen. This group has previously been involved in designing and building the superb XShooter instrument for the ESO VLT. The NTE instrument (**Fig. 4.1**) utilizes novel design approaches which will make it and the NOT equal to none in the world of 2-4m class telescopes. It has two modes: medium resolution spectroscopy from UV to near-IR, and simultaneous imaging both in visible and near-infrared. FINCA is committed to working towards the realisation of this instrument that will keep the Nordic astrophysics in the forefront of research.

Participation in the NTE can also provide an important stepping stone for FINCA to become involved in instruments for the ESO telescopes. Together with Tuorla Observatory (Univ. Turku), FINCA is therefore planning participation in one of the next generation instruments selected to the ESO 3.5-m New Technology Telescope (NTT), the Son Of X-Shooters (SOXS), a very similar instrument to the NTE.

On a larger scale and longer timeframe, FINCA is participating, together with Univ. Helsinki and Univ. Oulu, in one of the E-ELT instrument consortia, the MOSAIC, which has recently signed a Phase A study contract with ESO. Finland is one of the Associated Partners in MOSAIC, and funding for Finnish participation is to be applied for in future Academy of Finland calls. MOSAIC, with first light expected in 2024, is going to be the work-horse among all the E-ELT instruments, having two main modes: multi-object spectroscopy, and integral field spectroscopy, both with full adaptive optics correction (**Fig. 4.2**). Recent press releases about MOSAIC can be found in the ESO announcement webpage[2] and University of Helsinki news webpage[3].

Finally, FINCA is part of the Finnish consortium to participate in the Science

[1] http://www.utu.fi/en/units/finca/research/meetings/Pages/home.aspx
[2] http://www.eso.org/public/announcements/ann16017/
[3] http://www.helsinki.fi/facultyofscience/research/news/2016/mosaic.html

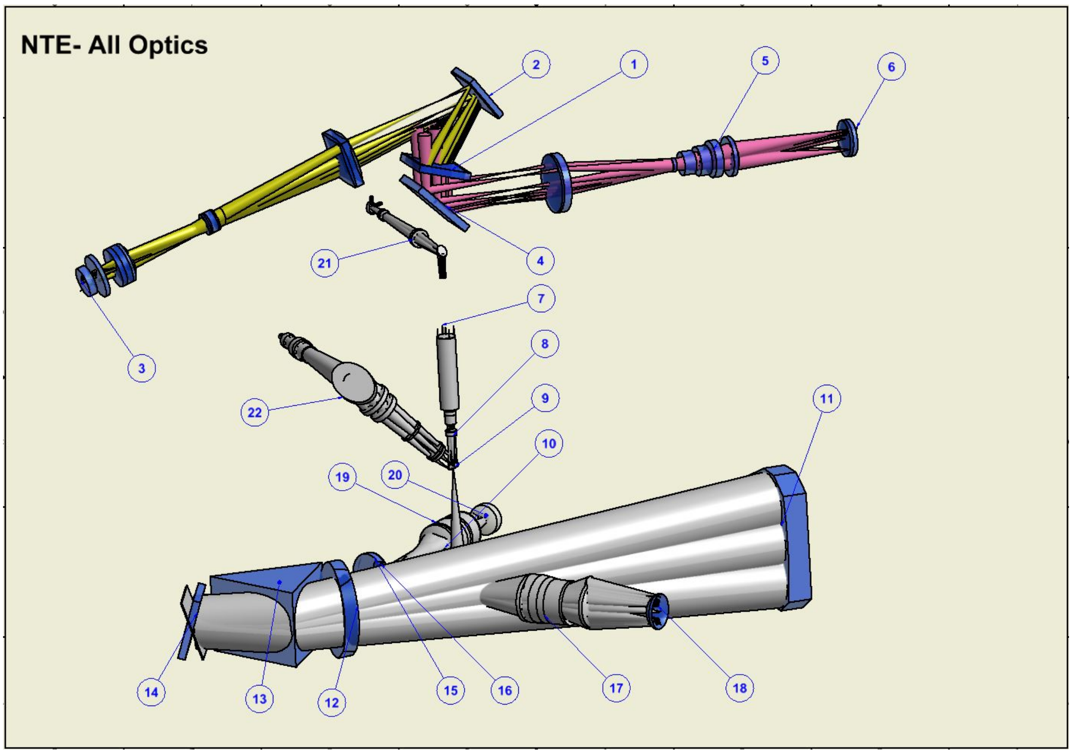

Figure 4.1: Schematic illustration of the NTE optics (M. Andersen, Niels Bohr Institute, Copenhagen).

Ground Segment activities of the Euclid mission of the European Space Agency (ESA). Euclid, with launch date expected late 2020, will survey the sky over 6 years, producing images of billions of galaxies and spectra of millions of galaxies. Its main goal is cosmology, especially the nature of dark energy and dark matter, but is has a strong legacy value for extragalactic astronomy. The consortium has already acquired funding from the Academy of Finland, with further applications pending.

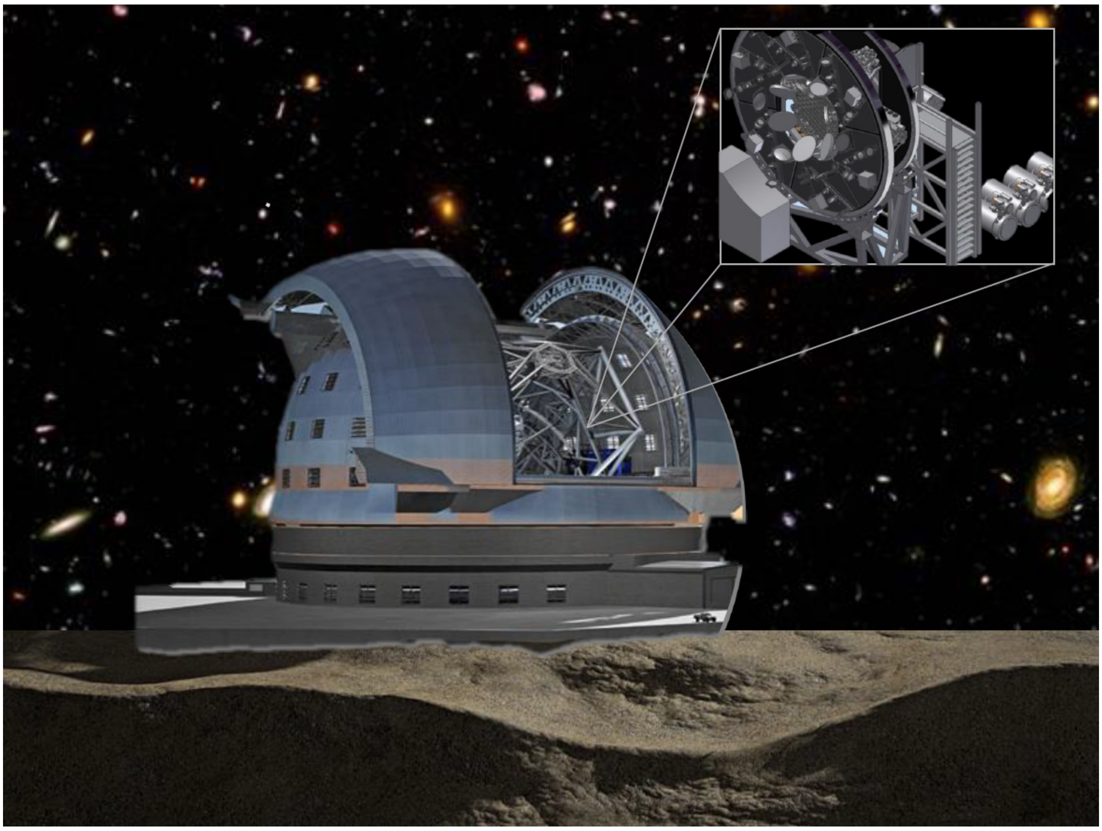

Figure 4.2: Image of the planned E-ELT. Upper right: vision of MOSAIC installed at one of the focal stations. (Credit: MOSAIC consortium)

5. Teaching

5.1 National and International Schools

In 2015 FINCA was the main organiser of one national and one international school.

In October FINCA (**Heidi Korhonen**) organised together with Tuorla Observatory (Silja Pohjolainen) and Aalto University (Anne Lähteenmäki and Merja Tornikoski) North-European Radio Astronomy School in Tuorla[1]. The aim of this school was to get Northern-European students acquainted with radio and sub-mm observations, and especially interferometric techniques. The course was mainly aimed at students and young postdocs who did not have much prior experience with radio/sub-mm observations. In total 20 students from Finland (8), Denmark (4), Sweden (3), Poland (2), Turkey (2), and Latvia (1) particpated in this school, which was funded by Radionet via an EU grant.

The school was structured to have lectures in the mornings and group exercises in the afternoons. The lectures were concentrating on radio and sub-mm astronomy techniques and interferometry. For the afternoons the students were divided into four groups working on one project throughout the school. The projects were lead by experienced astronomers and used archival data using APEX, ALMA, VLBI, and VLA. The tutors and lectures came from Tuorla Observatory, Univeristy of Helsinki, Metsähovi Radio Observatory and Onsala Space Observatory. The science topics covered star-formation, jets from Active Galactic Nuclei, and molecules in the distant universe. Results from the group work were presented during the last day of the school.

The national remote observing school using the Nordic Optical Telescope, was organised in early November[2]. **Heidi Korhonen** from FINCA (together with **Seppo Mattila** and **Kari Nilsson**) was the main organiser of this school, which collected 18 students from all the universities in Finland that have astronomy teaching (Aalto, Helsinki, Oulu and Turku). The students were organised in small groups, in which they planned, obtained, reduced and analysed data with an experienced tutor. The tutors and lectures came from FINCA, and Helsinki, Oulu and Turku University. The group projects covered many different astronomical topics from Solar System objects to galaxy clusters, and from cataclysmic variable stars to blazers and star-formation in quasars. The final results from the group projects were presented at the Physics Department of the Helsinki University in December 2015.

[1] *http://www.utu.fi/en/units/finca/research/Tuorla2015/Pages/home.aspx*

[2] *http://tube.utu.fi/courses/doku.php?id=not_2015:program*

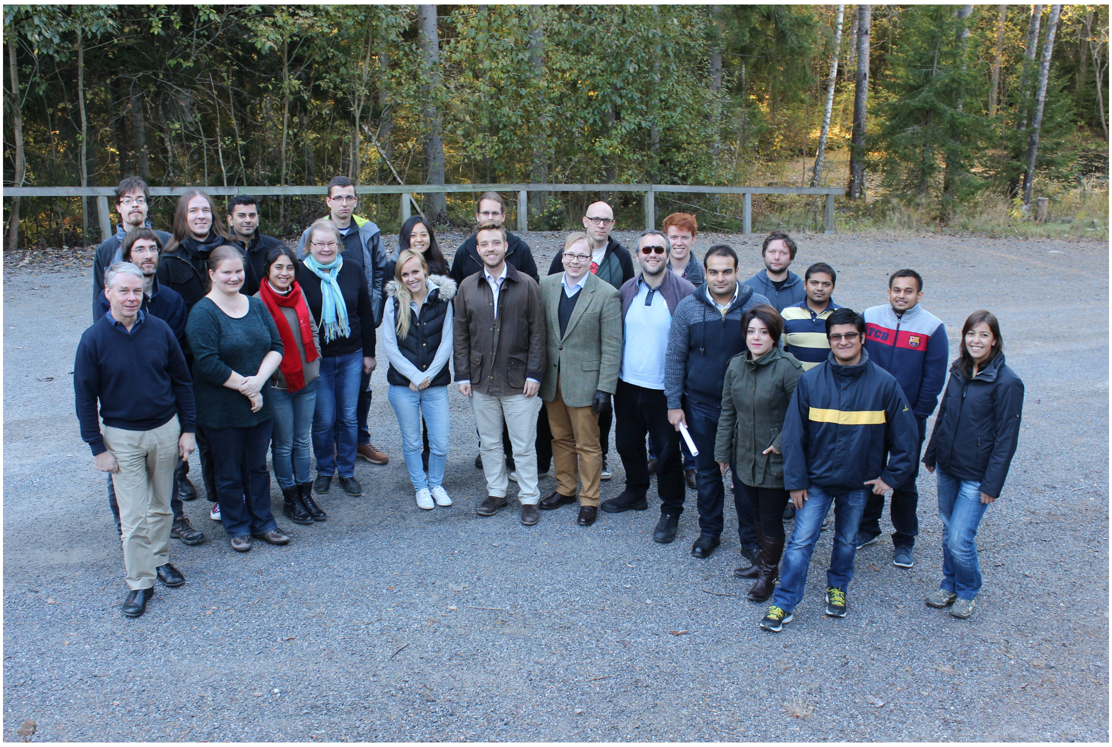

Figure 5.1: The group picture from the North-European Radio Astronomy School with all of the students and several of the teachers/tutors.

5.2 Lectured courses

Basic level - in Finnish

K. Nilsson	Optics (Optiikka)	4	Turku

Intermediate level - in Finnish or English

S. Comerón	Introduction to Cosmology	5	Oulu
K. Nilsson	Laboratory works I (Tähtitieteen Harjoitustyöt I)	4	Turku, co-instructor

Advanced level - in English

S. Comerón	Stellar Structure and Evolution	7	Oulu
H. Korhonen	Methods of observational astrophysics I	6	Turku, coordinator
	Radio Astronomy and Interferometry	8	Turku, co-lecturer
	The Tenth NEON Observing School (winter school)	-	Asiago Observatory, co-lecturer
	North-European Radio Astronomy School (summer school)	-	Turku, coordinator
J. Kotilainen	Quasar Research	6	Turku
	Observational astronomy I	5	Turku, co-lecturer
	NOT-school		Turku, co-lecturer
S. Mattila	Astrophysical spectroscopy and interstellar medium	6	Turku
K. Nilsson	Methods of observational astrophysics I	6	Turku+Helsinki, tel. operator
	Methods of observational astrophysics II	5	Turku+Helsinki, co-lecturer

5.3 Completed theses

MSc theses

Nick Henden, "*Bright blue galaxies in clusters”*, University of Bristol, Roberto De Propris.

6. Other research activities

Memberships in conference SOC/LOC and other committees

S. Comerón	Secretary of the Finnish Astronomical Society
J. Kotilainen	Finnish delegate in ESO Council
	Finnish National Committee of IAU, member
	Finnish National Committee of COSPAR, member
H. Korhonen	Chairman of the Optical Infrared Co-ordination Network (OPTICON) Common telescope Time Allocation Committee (cTAC)
	Board member of the OPTICON working group 13, 'Enhancing Community Skills - Integrating communities'
	Member of the IAU working group 'Impact of Magnetic Activity on Solar and Stellar Environments'
	Science Team member of the new instrument for the Nordic Optical Telescope, NTE
	Consortium member of the new instrument being negotiated for NTT, SOXS
S. Mattila	Member of the Nordic Optical Telescope (NOT) OPC
	Member of the board of the Doctoral Programme in Physical and Chemical Sciences of the Univ. of Turku graduate school (UTUGS)
	Science Team and board member, NOT Transient Explorer (NTE)
	Substitute member of FINCA
	Co-organiser of the Sharp Eyes on European Skies workshop, 23-25 Sept. 2015, Univ. of Cambridge, UK

Conference presentations

R. De Propris	"Morphological Evolution of Red Sequence Cluster Galaxies: The Past 9 Gyr" (oral) in *In the footsteps of galaxies*, Soverato, CZ, Italy, September 2015
H. Korhonen	"Superflares and Activity of the Sun in the Cycle Formation Epoch" (invited) in *Magnetic activity of young stars*, Katsrin/Tel Aviv, Israel, 28.4-1.5.2015
	"Properties of stellar activity cycles" (invited) in *IAU General Assembly Focus Meeting 13: Brightness variations of the Sun and Sun-like stars*, Honolulu, USA, 5.-6.8.2015
	"Imaging Spotted Stars with Simultaneous Interferometry, Spectroscopy, and Photometry" (poster) in *IAU General Assembly Focus Meeting 13: Brightness variations of the Sun and Sun-like stars*, Honolulu, USA, 5.-6.8.2015
	"Activity induced detection limits for Earth-sized planets from radial velocity studies" (poster) in *IAU General Assembly Focus Meeting 8: Statistics and Exoplanets*, Honolulu, USA, 3.-5.8.2015
	"Correlating chromospheric and photospheric activity of FK Com" (poster) in *IAU General Assembly Division G meeting*, Honolulu, USA, 7.-10.8.2015
J. Kotilainen	"Galaxies of Many Colours: Star formation across cosmic time" (oral) in *Dissecting the Bird: a spectacular off-nuclear LIRG starburst with gas outflows*, Sweden, Marstrand, 1.-5. June 2015
S. Mattila	"Nuclear SNe with Gaia" (oral) in *PESSTO Meeting VIII*, 2-4 Feb. 2015, Univ. of Cambridge, UK
	"Observations of supernovae" (invited talk) in *Workshop on Relativistic Astrophysics*, 17-21 Aug. 2015, Piikkiö, Finland
	"Supernovae as tracers of cosmic star formation" (oral) in *Sharp Eyes on European Skies workshop*, 23-25 Sept. 2015, Univ. of Cambridge, UK
	"Nuclear supernovae with Gaia" (oral) in *The sixth Gaia Science Alerts workshop*, 10-13 Nov. 2015, Liverpool John Moores University, UK

Other talks

R. De Propris	“Morphological Evolution of Red Sequence Cluster Galaxies: The Past 9 Gyr”, Tartu Observatory, 19 May 2015
	“Lecture on Galaxies”, Maria Mitchell Institute, 17 July 2015
	“Morphological Evolution of Red Sequence Cluster Galaxies: The Past 9 Gyr”, Osservatorio Astronomico di Brera, Milano, 11 Sep. 2015
H. Korhonen	”In search of small exoplanets”, Tuorla Observatory, 5 March 2015
S. Mattila	“Core-collapse supernovae as tracers of cosmic star formation”, 14th Oct. 2015, University of Sheffield

Research Visits

R. De Propris	Maria Mitchell Observatory, July 2015
H. Korhonen	Leibniz-Institute for Astrophysics Potsdam, 27.-28.10.2015, collaborators Prof. Klaus Strassmeier and Dr. Silva Järvinen
J. Kotilainen	ESO, Chile, 5.-12.10.2015 Council vist and research visit to ESO Chile and PUC Santiago
S. Mattila	Institute of Astronomy, University of Cambridge, 2-5.2.2015, collaborators H. Campbell, M. Fraser, S. Hodgkin and N. Blagorodnova
	Institute of Astronomy, University of Cambridge, 29.6.-3.7.2015, collaborators H. Campbell, M. Fraser, S. Hodgkin, and N. Blagorodnova
	Institute of Astronomy, University of Cambridge, 1.9.-17.12.2015, collaborators G. Gilmore, H. Campbell, M. Fraser, S. Hodgkin

Hosted visitors

All visitors in the Tuorla observatory/FINCA seminar programme, 2015 – Host: R. De Propris

Nadia Blagorodnova, Institute of Astronomy, University of Cambridge, 8-23.1.2015 – Host: S. Mattila

Nadia Blagorodnova, Institute of Astronomy, University of Cambridge, 8-12.6.2015 – Host: S. Mattila

Kalliopi Dasyra, Univ.Athens, Greece, 8.-22.5.2015 – Host: J. Kotilainen

Morgan Fraser, Institute of Astronomy, University of Cambridge, 19-23.1.2015 – Host: S. Mattila

Prof. Johan Fynbo, DARK, University of Copenhagen, 18.-20.3.2015 – Host: H.Korhonen

Prof. Peter Lundqvist, Department of Astronomy, Stockholm University, 6-10.7.2015 – Host: S. Mattila

Rachael Roettenbacher, University of Michigan, 8.-13.2.2015 – Host: H.Korhonen

Petri Väisänen, SAAO, South Africa, 13.7.-3.8.2015 – Host: J. Kotilainen

Awards and recognitions

H. Korhonen	Opponent of the Licentiate seminar of Naum Rusomarov, 'Magnetic fields of Ap stars from four Stokes parameter observations', March 2015, University of Uppsala
	National representative of Finland during the first week of IAU General Assembly XXIX, Honolulu, USA

7. Publications

Refereed publications by FINCA staff 2015:

[1] Ackermann, M., Ajello, M., Albert, A., Atwood, W. B., Baldini, L., Ballet, J., Barbiellini, G., Bastieri, D., Gonzalez, J. B., and et al., (including **Nilsson**, K. and **Valtonen**, M. J.), *Multiwavelength evidence for quasi-periodic modulation in the gamma-ray*, 2015, ApJ, 813:L41.

[2] Aleksic, J., Ansoldi, S., Antonelli, L. A., Antoranz, P., Babic, A., Bangale, P., Barres de Almeida, U., Barrio, J. A., Becerra Gonzalez, J., Bednarek, W., and et al., (including **Nilsson**, K. and **Valtonen**, M. J.), *Multiwavelength observations of Mrk 501 in 2008*, 2015, A&A, 573:A50.

[3] Amanullah, R., Johansson, J., Goobar, A., Ferretti, R., Papadogiannakis, S., Petrushevska, T., Brown, P. J., Cao, Y., Contreras, C., Dahle, H., and et al., (including **Mattila**, S.), *Diversity in extinction laws of Type Ia supernovae measured between 0.2 and 2 μm.*, 2015, MNRAS, 453:3300-3328.

[4] Andersen, J. M., **Korhonen, H.**, *Stellar activity as noise in exoplanet detection - II. Application to M dwarfs.*, 2015, MNRAS, 448:3053-3069.

[5] Bachelet, E., Bramich, D. M., Han, C., Greenhill, J., Street, R. A., Gould, A.,D'Ago, G., AlSubai, K., Dominik, M., Figuera Jaimes, R., and et al., (including **Korhonen**, H.), *Red Noise Versus Planetary Interpretations in the Microlensing Event Ogle-2013-BLG-446.*, 2015, ApJ, 812:136.

[6] Bettoni, D., Falomo, R., **Kotilainen**, J. K., Karhunen, K., Uslenghi, M., *Low-redshift quasars in the SDSS Stripe 82. Host galaxy colours and close environment.*, 2015, MNRAS, 454:4103-4113.

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[10] Calchi Novati, S., Gould, A., Udalski, A., Menzies, J. W., Bond, I. A., Shvartzvald, Y., Street, R. A., Hundertmark, M., Beichman, C. A., Yee, J. C., and et al., (including **Korhonen**, H.), *Pathway to the Galactic Distribution of Planets: Combined Spitzer and Ground-Based Microlens Parallax Measurements of 21 Single-Lens Events*, 2015, ApJ, 804:20.

[11] Chen, T.-W., Smartt, S. J., Jerkstrand, A., Nicholl, M., Bresolin, F., Kotak, R., Polshaw, J., Rest, A., Kudritzki, R., Zheng, Z., and et al., (including **Kankare**, E.), *The host galaxy and late-time evolution of the superluminous supernova PTF12dam*, 2015, MNRAS, 452:1567-1586.

[12] Cole, E. M., **Hackman**, T., Käpylä, M. J., Ilyin, I., Kochukhov, O., Piskunov, N., *Doppler imaging of LQ Hydrae for 1998-2002.*, 2015, A&A, 581:A69.

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[20] Fraser, M., Kotak, R., Pastorello, A., Jerkstrand, A., Smartt, S. J., Chen, T.-W., Childress, M., Gilmore, G., Inserra, C., Kankare, E., and et al., (including **Mattila**, S.), *SN 2009ip at late times - an interacting transient at+2 years*, 2015, MNRAS, 453:3886-3905.

[21] Frisch, P. C., Andersson, B.-G., Berdyugin, A., **Piirola**, V., Funsten, H. O., Magalhaes, A. M., Seriacopi, D. B., McComas, D. J., Schwadron, N. A., Slavin, J. D., and Wiktorowicz, S. J. and et al., *Evidence for an Interstellar Dust Filament in the Outer Heliosheath*, 2015a, ApJ, 805:60.

[22] Frisch, P. C., Berdyugin, A., **Piirola**, V., Magalhaes, A. M., Seriacopi, D. B., Wiktorowicz, S. J., Andersson, B.-G., Funsten, H. O., McComas, D. J., Schwadron, N. A., and et al., *Charting the Interstellar Magnetic Field causing the Interstellar Boundary Explorer (IBEX) Ribbon of Energetic Neutral Atoms*, 2015b, ApJ, 814:112.

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[35] **Korhonen**, H., Andersen, J. M., Piskunov, N., **Hackman**, T., Juncher, D., Jarvinen, S. P., Jorgensen, U. G.,*Stellar activity as noise in exoplanet detection - I. Methods and application to solar-like stars and activity cycles*, 2015, MNRAS, 448:3038-3052.

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