Turun yliopisto
University of Turku

FINCA
Finnish Centre for Astronomy with ESO

Finnish Centre for Astronomy with ESO

Annual Report

2016

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Cover illustration : The rotating sky above ESO's Very Large Telescope at Paranal. This long exposure shows the stars rotating around the southern (left) and northern (right) celestial poles, the celestial equator being in the middle of the photo — where the stars seem to move in a straight line. The motion of the VLT's enclosures are also visible.

Picture credit: ESO/Stéphane Guisard (www.eso.org/ sguisard)

FINNISH CENTRE FOR ASTRONOMY WITH ESO, ANNUAL REPORT 2016

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

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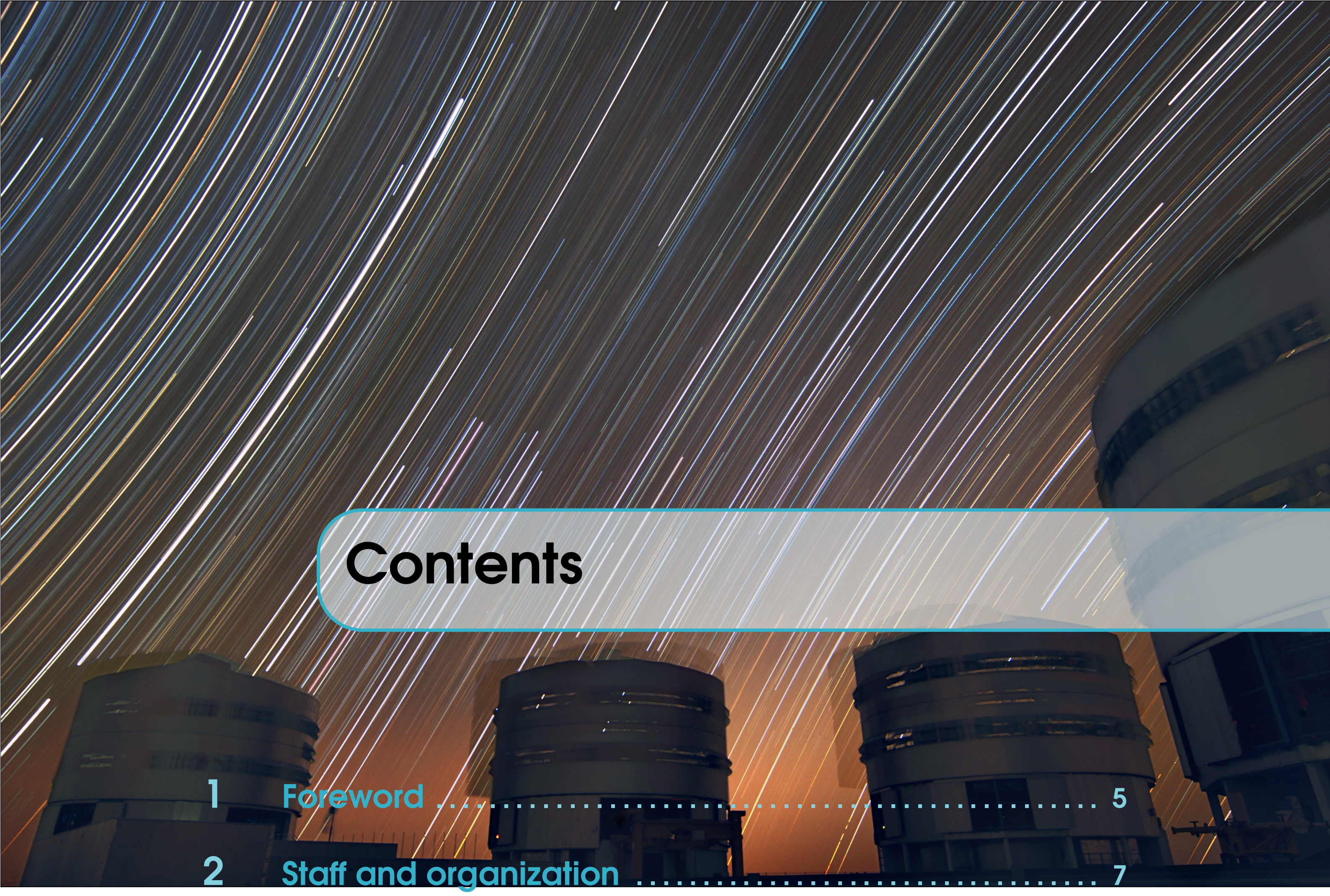
MAY 2017



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 15 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 2016 marked the 7th 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), 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 81 refereed scientific articles, and some of them are highlighted in this Report.

Our researcher training activities in 2016 focused on one hand in supervision of PhD and MSc students in the participating universities, and on the other hand in hands-on teaching of advanced observing, data reduction and analysis methods in observational astronomy as national collaboration. There were two such courses held in 2016, one of them the annual course on remote optical/infrared observing with the NOT, and the other one on using archival observational data from ESO.

The construction of the European Extremely Large Telescope (E-ELT), a 39 m diameter giant for infrared and optical astronomy, is well underway, with Phase 1 instruments being constructed, Phase 2 instruments being designed, and major contracts for the construction of the E-ELT being awarded. This keeps ESO on-track to remain in a world-leading position, when the E-ELT starts operations in 7-8 years time, bringing an enormous leap forward in sensitivity and resolution.

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 is in its Phase A study. 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 participating in a next generation instrument 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
Professor emeritus :	Mauri Valtonen
University Researchers :	Roberto De Propris Pasi Hakala Vitaly Neustroev (Oulu, from 16.5.2016) Kari Nilsson
Postdoctoral researchers	Ghassem Gozaliasl (Helsinki, from 1.12.2016) Karri Koljonen (Aalto, from 1.9.2016) Hanindyo Kuncarayakti (from 1.12.2016) Ronald Läsker Pasi Nurmi
PhD student	Vandad Fallah Ramazani (23.3.-22.4.2016 & 1.11-31.12.2016) Alejandro Olquin Iglesias (until 31.8.2016, from INAOE, Puebla, Mexico)

FINCA board

Member	Substitute member
vice-President Tuija Pulkkinen (Aalto)	doc. Merja Tornikoski (Aalto)
prof. Anne Lähteenmäki (Aalto) **co-chair**)	doc. Joni Tammi (Aalto)
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doc. Kari Nilsson (Turku; staff rep.)	doc. Roberto De Propris (Turku; staff rep.)

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Prof. Sofia Feltzing	University of Lund, Lund Observatory
Prof. Jens Hjorth	University of Copenhagen, Denmark
Prof. Rob Ivison	European Southern Observatory (ESO), Germany
Dr. Hans Kjeldsen	Aarhus University, Denmark
Prof. Reynier Peletier	University of Groningen, Netherlands

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. 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 2016, our research were reported in 81 refereed scientific articles, and some of them are highlighted below.

3.2 Research highlights

3.2.1 Galaxy evolution and cosmology

The host galaxies of active galactic nuclei with powerful relativistic jets

Alejandro Olguin-Iglesias (INAOE Puebla & FINCA), **Jari Kotilainen** (FINCA) and collaborators presented deep near-infrared (NIR) J- and H-band images of a sample of 19 intermediate-redshift ($0.3 < z < 1.0$) radio-loud active galactic nuclei (AGN) with powerful relativistic jets, previously classified as flat-spectrum radio quasars. They also compiled host galaxy and nuclear magnitudes for blazars from literature. The combined sample contains 100 radio-loud AGN with host galaxy detections and a broad range of radio luminosities, allowing to divide the sample into high-luminosity blazars (HLBs; 57%) and low-luminosity blazars (LLBs; 43%), to investigate the correlation between their central engine modes and the properties of their host galaxies. The radio-loud AGN with prominent relativistic jets are hosted by luminous and bulge dominated galaxies that follow the μe-Reff (Kormendy) relation for ellipticals and classical bulges. The two populations of blazars show different behaviours in the MK,nuclear -MK,bulge plane. While LLBs cover a narrow range of magnitudes, there is a statistically significant positive correlation observed for HLBs (**Fig. 3.1**). This correlation suggests a close coupling between the accretion mode of the central supermassive black hole and its host galaxy, which could be interpreted in terms of AGN feedback. These findings are consistent with semi-analytical models where low-luminosity AGN emit the bulk of their energy in the form of radio jets, producing a strong feedback mechanism, and

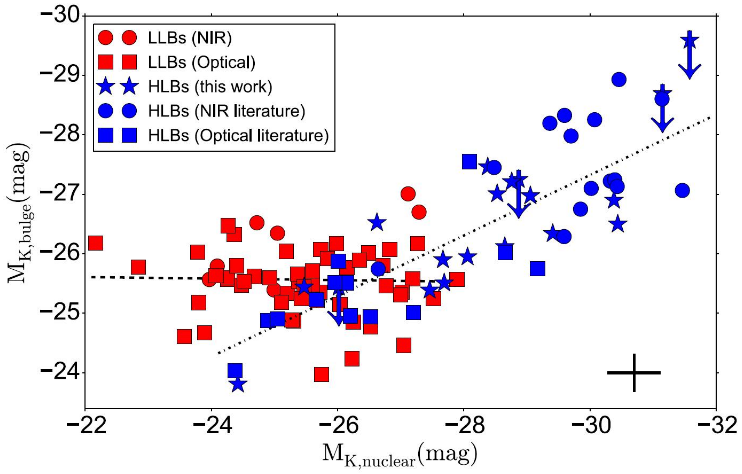

Figure 3.1: The nuclear K-band magnitude versus the bulge K-band magnitude. The best linear fits for LLBs and HLBs are shown as dashed and dotdashed lines, respectively. A statistically significant correlation is found for HLBs. Upper limits for unresolved galaxies are shown as down arrows. A typical error bar is shown in the lower right corner.

high-luminosity AGN are affected by galaxy mergers and interactions, which provide a common supply of cold gas to feed both nuclear activity and star formation episodes. The influence of the jet could induce an increment (or quenching) of star formation leading to an enhanced (or diminished) density of old stellar population contributing to a luminous (or faint) bulge. (Published in Olguin-Iglesias et al., 2016, MNRAS, 460, 3202)

Discovery of a pseudobulge galaxy launching powerful relativistic jets

Supermassive black holes launching plasma jets at close to the speed of light, producing gamma-rays, have ubiquitously been found to be hosted by massive elliptical galaxies. Since elliptical galaxies are generally believed to be built through galaxy mergers, active galactic nuclei (AGN) launching relativistic jets are associated with the latest stages of galaxy evolution. **Jari Kotilainen** (FINCA), **Alejandro Olguin-Iglesias** (INAOE Puebla & FINCA) and collaborators have used the NIR ISAAC camera on the VLT to image for the first time the host galaxy of PKS 2004-447, one of the six gamma-ray narrow-line Seyfert 1 (NLSy1) galaxies detected by the Fermi Gamma-ray Space Telescope, to characterise its structural galaxy components. The surface brightness distribution of host galaxy of PKS 2004-447 deviates significantly from a de Vaucouleurs profile, hence, does not share galaxy morphological features with the overall population of gamma-ray bright AGN (FSRQs, BLLacs and radio galaxies). Adding a disk component yields to better results. However, the presence of two aligned brightness enhancements in the residual images (**Fig. 3.2**) were further identified as the ansae or handles of a stellar bar. As a consequence, a bulge-disk-bar decomposition turned out to be the best representation of the host galaxy of PKS 2004-447. Since most of the observational properties of the best fitted bulge are consistent with those reported for pseudobulges, PKS 2004-447 arises as the first source where a fully developed relativistic jet, able to accelerate particles up to gamma-rays, could be launched from a pseudo bulge, i.e. a system where both the black hole and host galaxy have been actively growing via secular processes. This is evidence of an alternative black hole-galaxy co-

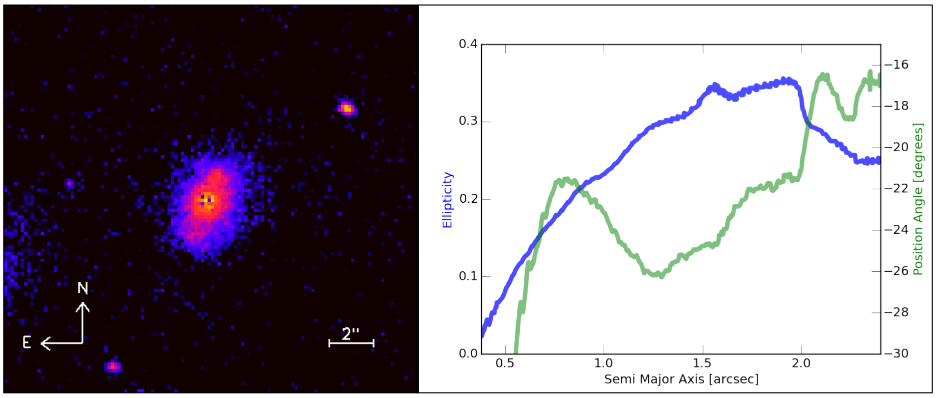

Figure 3.2: Left panel: Residual image obtained by subtracting the best nuclear and bulge components from the observed J-band images of PKS 2004-447. The central elongated structure is identified as a stellar bar. Right panel: Ellipticity and PA radial profiles. The ellipticity profile shows a sharp drop around 2 arcsec matching a change in PA. Moreover, the maximum value of ellipticity is larger than 0.25, fulfilling common criteria for stellar bars identification.

evolutionary path to develop powerful relativistic jets, which is not merger driven. (Published in Kotilainen et al. 2016, ApJ, 832, 157)

Structural parameters and colour gradients for cluster galaxies and the structure of the bulge of our Galaxy

Roberto De Propris and collaborators have continued our exploration of structural parameters and colour gradients for cluster galaxies using archival HST data. They concentrated on the CLASH sample, to explore how and when the presence of thin disks (observed in our $z > 1$ clusters) emerges. In **De Propris** et al. (2016) they showed that the morphological changes and quenching of disks must have taken place at $z \sim 1$ and is essentially complete by $z \sim 0.6$. They attributed this to the presence of two cluster populations: an old elliptical one which has been present since $z \sim 2.5$ and is unchanged, and a population of newly quenched thin disks that have been suppressed at $z \sim 1.5$ and are now evolving into S0 or disky ellipticals (see recent paper by Mitsuda et al. 2016).

They also continued their work on the structure of the bulge of our Galaxy. They are now concentrating on the older stellar component as probed by the RR Lyrae, which are also members of the bulge by virtue of their being accurate standard candles. The kinematic information suggests that there are multiple RR Lyrae populations in the bulge and that about 1% of the mass of the Galaxy may lie in a hot pressure supported bulge; this may be the remnant of the earliest phases of star formation in the Galaxy, but the data do not exclude the presence of an inner halo component (see Perez-Villegas et al. 2016). They obtained 6 nights of time on the AAT to continue this project.

Back-scattering of gravitational waves

In OJ287 a predicted optical outburst was observed in 2015 December (**Fig. 3.3**). It is the latest in a series of outbursts observed since year 1900. Their timing does not follow any periodicity or other obvious rule; thus their occurrence could not be correctly predicted until a theoretical framework emerged in 1996 (Lehto, Sundelius, Wahde and **Valtonen**). The model which gives the observed sequence of outbursts is a merging and precessing binary black hole system, with a spinning black hole primary. The outburst

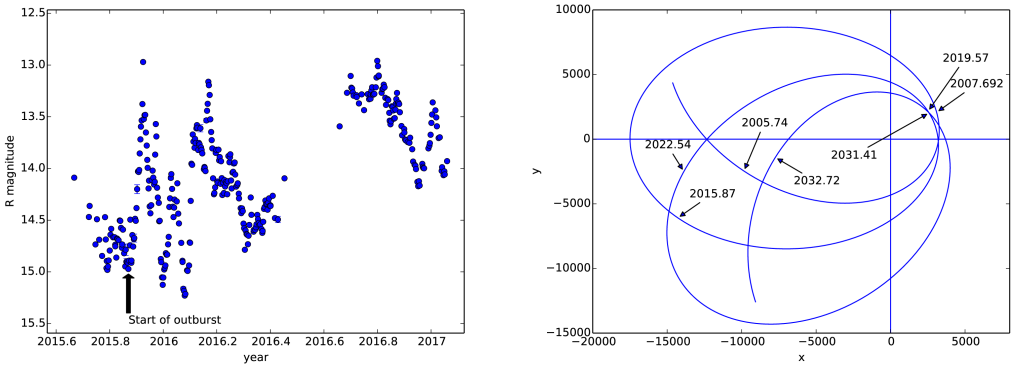

Figure 3.3: Left: A large international campaign was formed to monitor the expected optical outburst in OJ287 in December 2015, and the follow-on secondary outbursts. Figure shows the R-magnitude light curve from this campaign in daily averages. The arrow points to the beginning of the big flare, called General Relativity Centenary Flare for the coincidence in timing with the completion of General Relativity by Einstein exactly 100 years earlier. The beginning of the flare is used in the construction of the exact binary orbit. The campaign was highlighted e.g. by AAS Nova (*http://aasnova.org/2016/03/23/dance-of-two-monster-black-holes/*). Among the 90+ participants in the campaign were M.Valtonen, K.Nilsson and V.Piirola from FINCA and A.Bergyugin, V. Fallah Ramazani, E. Lindfors, L.Takalo and J. Harmanen from Dept. of Physics in University of Turku. Right: The orbit of the secondary black hole around the primary (at coordinate center 0,0, coordinates in units of AU). The positions of the secondary are marked for the beginning of the outbursts; they occur somehat after crossing the plane of the accretion disk (x-axis). This section of the orbit from 2004 to 2036 includes times for three recent outbursts (2005, 2007 and 2015) and four future outbursts. The times are labeled by years and their fractions, and are accurate to the last decimal point given.

signals arise from the impact of the secondary on the accretion disk of the primary, with a delay due to optical transparency effects. The OJ287 binary system is now one of the best laboratories for testing (**Fig. 3.4**) the radiation reaction of gravitational waves. The waves are not directly measurable under current technology, but their influence on the orbit is clearly seen. The 2015 outburst added another fixed point to the orbit solution, and it became possible to determine the wave emission from the OJ287 system exactly. It turns out that integrated over the orbit the emission is only 96% of the 'standard', so called Newtonian value. That is, the gravitational wave formula used by practically everybody in the field is in error by 4%. Together with A. Gopakumar and L. Dey from Mumbai, India, **Mauri Valtonen** has studied the reason for this discrepancy. A higher order (first Post-Newtonian term, of 1 PN) radiation reaction term was added in the equations of motion. However, the 1 PN correction is too large (10%), even though in the right direction. No orbit solutions for OJ287 are possible if only this term, and nothing else, is added. The next higher order (1.5 PN) term comes from back-scattering of the waves from earlier emitted waves. Its calculation is not trivial, as it depends on the history of the system, not only on its current state. This avenue looks promising, and in fact it looks like we have detected the back-scattering of gravitational waves for the first time. This finding will be confirmed in future OJ287 outbursts that occur in 2019, 2022, 2031, 2032, and later.

Formation and evolution of galaxies in massive haloes

Ghassem Gozaliasl studies the formation and evolution of galaxies in massive haloes and identification of high-z X-ray galaxy groups and clusters. He is collaborating with the Euclid Finnish team in designing and developing the Euclid Data Quality Common Tools with the Euclid Finnish team.

Massive halos are important from the galaxy evolution point of view – we know galaxy populations in clusters and groups are different from field galaxies at $z \leq 1$. This segregation is likely due to interactions with galaxies and also with intracluster gas in dense environment. However, whether such environmental effects persist at high redshifts or not, remains unclear because of the lack of the sufficient number of spectroscopically confirmed high redshift groups and clusters to date. Spatially extended X-ray emission is a ubiquitous feature of massive halos and it is an ideal tracer of massive groups and clusters in the Universe across all the redshifts. We have searched for high redshift groups of galaxies using the latest X-ray data of Chandra and XMM-Newton observatories and multi-wavelength optical-IR data in some astronomical galaxy fields such as UDS and COSMOS and identified a number of groups at z>2.

Galaxy and galaxy group properties in the large-scale structure

Galaxies and their dark matter halos have grown hierarchically, forming larger systems, such as groups, clusters, filaments, and superclusters of galaxies, separated by enormous voids. In observations, this large-scale distribution of dark and baryonic matter manifests itself as a complex web of galaxies. This cosmic web includes a wide range of scales from the mega-parsec (Mpc) galaxy group scale to several tens to hundreds of Mpc in superclusters. As a result, galaxies are located in a variety of small and large-scale environments during their evolution. There is now a common consensus from theory and observations that the halo environment, where galaxies are initially formed, plays the dominant role in shaping the properties of galaxies. However, correlations between galaxy and group properties and environments have been found to exist also on scales much larger than halos and there is no clear understanding on how the environment at cosmological scales affects galaxy and group evolution.

This problem was studied in the (Poudel et al. 2016, including **Pasi Nurmi**) and we found that the low mass end slope of the stellar mass function of satellite galaxies is steeper in high-density environments compared to low-density environments (**Fig. 3.5**) We also found that groups with similar masses are richer in high-density environments compared to lowdensity environments, irrespective of the galaxy morphologies. These results contradict with several other studies which indicate that the halo occupation distribution at fixed halo mass is statistically independent of the large-scale environment. In simulations, the cut of mass at the massive end of the dark matter halo mass functions is the highest in clusters and gradually decreases toward filaments, sheets, and voids. Thus, any correlation between surrounding large-scale structure and internal galaxy properties may simply be due to the differences in halo masses in different cosmic web environments.

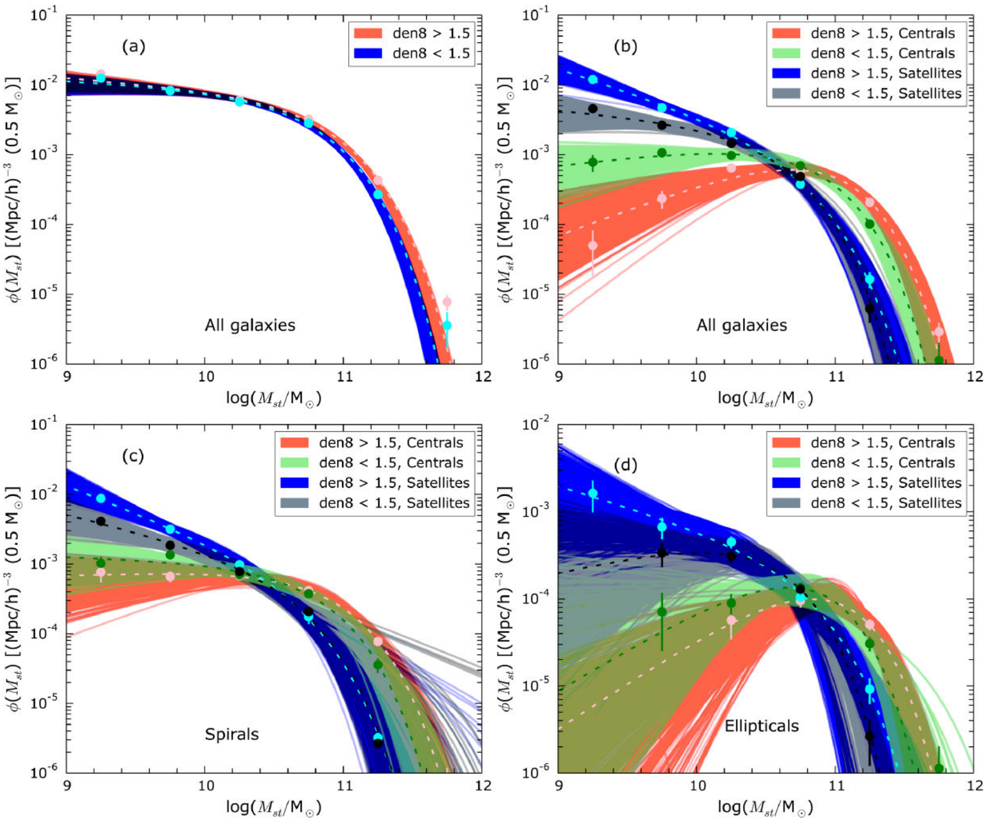

Figure 3.4: a) Stellar mass function of galaxies in high- (light red points) and low- (sky blue points) density large scale environments. The light red and sky blue dashed lines represent the best single Schechter function fits of galaxies in high- and low-density environments, respectively. The red and blue solid lines, which form red and blue shaded regions, show individual single Schechter function fits to the galaxy stellar mass functions obtained from all bootstrap samples of galaxies in high- and low-density environments, respectively. b) Stellar mass function of central and satellite galaxies in high- and low-density, large-scale environments. The light red (sky blue) and dark green (black) dashed lines represent the best single Schechter function fits of central (satellite) galaxies in high- and low-density environments, respectively. The red (blue) and light green (gray) solid lines which form red (blue) and light green (gray) shaded regions show individual single Schechter function fits to the central (satellite) galaxy stellar mass functions obtained from all bootstrap samples in high- and low-density, large-scale environments, respectively. c) Same as b) but for galaxies with spiral morphologies. d) Same as b) but for galaxies with elliptical morphologies. In all of the plots, the points and error bars represent the mean densities and error in densities calculated using the bootstrap resampling technique.

3.2.2 Stellar astrophysics

Close interacting binary stars

An important reason to investigate close interacting binaries is that they provide an unparalleled way to study two fundamental astrophysical processes: binary star evolution and nearly all aspects of the accretion of gas onto compact objects. Our general understanding of binaries with compact components and theoretical progress is often driven by new observational discoveries. In order to enhance our theoretical understanding of accretion and binary evolution, the researchers at FINCA have observed the principal objects whose behaviour is a real challenge to existing theories.

Cataclysmic variables are binary systems consisting of a white dwarf as primary and a low-mass main-sequence star or a brown dwarf as secondary component. According to standard evolutionary theory, cataclysmic variables evolve from longer to shorter orbital periods until a minimum period is reached ($\sim$80 min) when the donor star becomes of a substellar mass and partially degenerate, resulting in a kind of a brown-dwarf-like object. The star is driven out from the thermal equilibrium and at some point its radius stops contracting in response to mass loss and even grows. As a result, the binary begins to evolve towards longer orbital periods. The 'period bouncers' are such cataclysmic variables that have passed beyond P_{min} and are evolving back towards longer periods, with the donor star now extremely dim. This has long been predicted to be the 'graveyard' and current state of 70 per cent of all cataclysmic variables, however only about a dozen of more or less robust candidates for such period bouncer systems have been identified until now, out of a thousand of known cataclysmic variables. **Vitaly Neustroev** has been working to improve this situation shedding light into the late evolution stages of cataclysmic variables through the observation of interesting short-period binaries (Kato et al. 2016; Namekata et al. 2017). In particular, **Vitaly Neustroev** has recently initiated a new project to systematically search for period-bounce candidates by means of time-resolved photometric and spectroscopic observations over a wide range of wavelengths. Leading a large collaboration of scientists from around the world, **Vitaly Neustroev** reported extensive 3-yr multiwavelength observations of the WZ Sge-type dwarf nova SSS $J122221.7-311525$ during its unusual double superoutburst, the following decline and in quiescence. The data used were obtained with the ESO/VLT (UT1 and UT3) and the 6.5 meter Magellan Telescopes, and many other smaller telescopes. The spectroscopic and photometric data revealed a very low mass ratio of the system, $q<0.045$. With such a small mass ratio even if the white dwarf was close to the Chandrasekhar limit the donor mass must be below the hydrogen-burning minimum mass limit. The observed IR flux in quiescence is indeed much lower than is expected from a cataclysmic variable with a near-main-sequence donor star. This strongly suggests a brown-dwarf-like nature for the donor and that SSS $J122221.7-311525$ has already evolved away from the period minimum towards longer periods, with the donor now extremely dim. The relatively long orbital period of SSS $J122221.7-311525$ (109.8 min) suggests that it is by far the most evolved post-period minimum cataclysmic variable known to date.

Probing the birth environments of supernovae

At the end of their lives, massive stars explode as supernovae. These explosions come in different flavours, showing wide diversity in the spectra that reflects the different characteristics of the supernova progenitor stars. Finding out which type of massive star gives rise to which type of supernova is one of the most important tasks in the field of supernova astrophysics.

Hanindyo Kuncarayakti and collaborators has been collecting a large dataset of the explosion sites of nearby supernovae, obtained using integral field spectroscopy (IFS). The work was done using multiple instruments, including VIMOS, SINFONI, and MUSE at the VLT. The use of IFS enables the acquisition of both spatial and spectral information of the explosion site, at the same time. This allows the identification and subsequent analysis of the parent stellar population of the supernova progenitor star. As the progenitor star was born from this stellar population, its characterisation can provide clues on the star's physical parameters such as initial mass and metallicity. These two fundamental parameters are traditionally considered as the main drivers of stellar evolution. Preliminary results show overlaps in progenitor mass and metallicity between supernovae of different types, which means that these two parameters are possibly not the only contributing factors in determining the supernova type. It has been long proposed that other factors such as binary interactions and mass loss may also play a vital role in the evolution of the progenitor. The results of the current study are in accord with this view, and further stress the importance of the other mechanisms affecting stellar evolution.

Stability of Triple Stars

Together with S. Mikkola, A. Mylläri and A. Pasechnik, **Valtonen** has developed a formula for determining the stability of three-star configurations which arise during numerical N-body simulations of star cluster evolution. The question of how to treat such systems without actually using time for their orbital integration during N-body process, has been an outstanding problem for many decades. The reliability of such a formula is a key to many problems in stellar evolution, e.g. in estimating how frequently merging black hole binaries arise in the universe. This is one of the primary questions in gravitational wave research. The new formula was developed combining analytical theory in stellar dynamics with a large number of numerical orbit calculations. Typically a hierarchical triple system was followed up to 10 000 revolutions of the outer orbit, unless the hierarchy was broken before. Some millions of orbits were calculated, and the results were condensed in a single formula which contains all relevant orbital elements of the inner and the outer orbit. Somewhat related to this was writing a popular account of the three-body problem entitled 'The Three-Body Problem from Pythagoras to Hawking' which covers the whole history of the problem from predicting solar eclipses to today's testing of General Relativity in systems like OJ287. The authors of this book, published by Springer in 2016, are **Mauri Valtonen**, J. Anosova, K. Kholshevnikov, A. Mylläri, V. Orlov and K. Tanikawa.

4. Instrument development

4.1 Euclid Cosmology Mission - probing dark energy

Euclid is the next cosmology mission of ESA after Planck, complementing Planck ideally in improving our understanding of the universe. The principal objective of the Euclid mission is to solve the central problem in modern cosmology, the mystery of dark energy, the cause of the accelerated expansion of the universe. Euclid will also map the distribution of dark matter in the universe, based on its gravitational lensing effect on the light from galaxies, and help to solve the questions of the nature of dark matter and the origin of structure in the universe. The mission will also produce immense amount of legacy data to study cosmology related questions like evolution of the black holes and host galaxies of active galactic nuclei and evolution of the cosmic star formation rate.

Euclid will be launched in 2020 and will take data for at least six years. Euclid will produce a very large amount of observational data that will be complicated to analyse. The main effort before the launch will be the development of the methods, software, and infrastructure that will be able to perform this analysis. Finnish researchers have also the obligations to operate SDC-FI, one of the 9 Euclid Science Data Centers, where the data will be analyzed. The team will develop data quality common tools, a task in the Euclid System Team for which the team members have the main responsibility and participate in the development of methods to produce simulated Euclid data.

To ensure the participation of Finnish cosmologists and astronomers in the most important observational cosmology project of the next decade, a research team consisting of physicists and astronomers from the Univeristy of Helsinki, University of Turku and University of Jyväskylä was set up. The team members have key responsibilities in Euclid data analysis and is ideally positioned to reap a rich scientific benefit from the data. The team includes the people who carried the main Finnish responsibilities in Planck data analysis This consortium received funding from the Academy of Finland for 2016-2020 in 2016 with FINCA receiving 314 910 eur (FINCA PI **Kari Nilsson**).

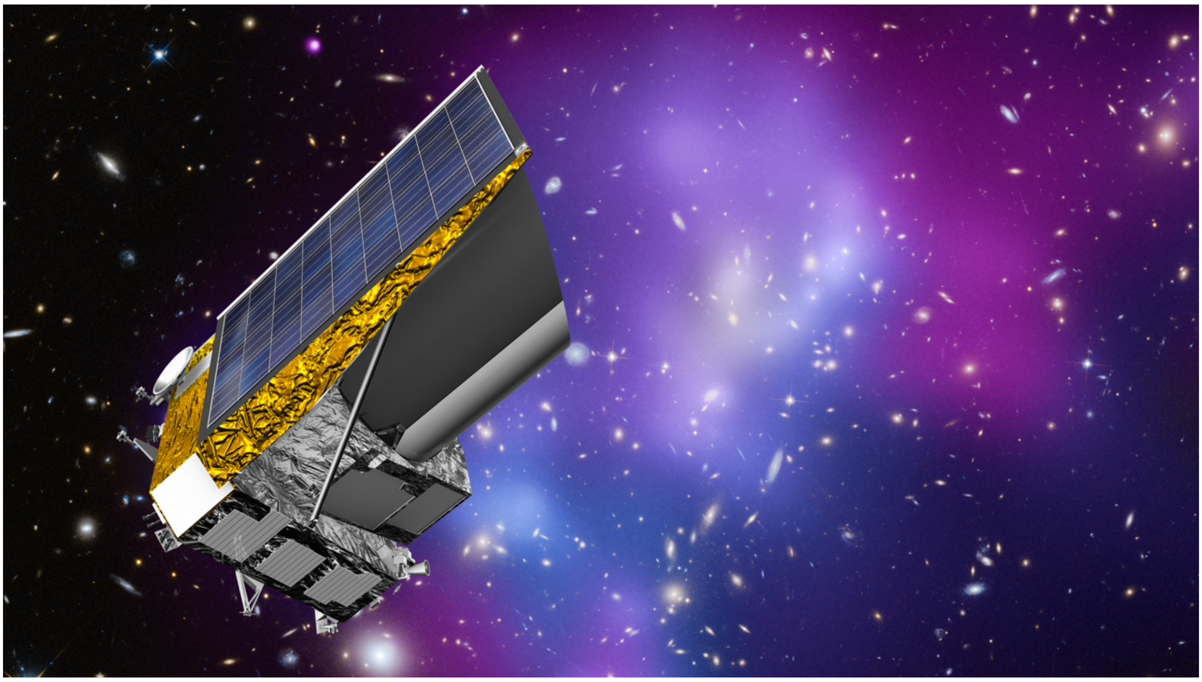

Figure 4.1: Artist's impression of Euclid, Copyright: ESA/C. Carreau

5. Teaching

5.1 National and International Schools

The national remote observing school using the Nordic Optical Telescope, was organised in early November. Seppo Mattila was the main organiser of this school and from FINCA **Jari Kotilainen**, **Kari Nilsson**, **Vitaly Neustroev** and **Pasi Nurmi** participated to organising the school. The course collected 18 students from all the universities in Finland that have astronomy teaching (Aalto, Helsinki, Oulu and Turku). This year also students from Tartu Observatory, Estonia were participating the course. 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 2016.

5.2 Lectured courses

Basic level - in Finnish

J. Kotilainen	Observational Astronomy I (Havaitseva tähtitiede 1)	5	Turku, co-lecturer
K. Nilsson	Optics (Optiikka)	4	Turku
P. Nurmi	Project in Physics (Projektityö)	3	Turku

Intermediate level - in Finnish or English

V. Neustroev	Observational Astrophysics and Data Analysis (Tähtitieteen peruskurssin harjoitustyöt)	6	Oulu
K. Nilsson	Laboratory works (Tähtitieteen peruskurssin harjoitustyöt)	4	Turku, co-instructor

Advanced level - in English

R. De Propris	Galaxies and Cosmology	8	Turku, co-lecturer
J. Kotilainen	Methods of observational astrophysics II		Turku+Helsinki, co-lecturer
	NOT-school		Turku, supervision of a student group
V. Neustroev	Methods of observational astrophysics I	6	Turku+Helsinki, co-lecturer
K. Nilsson	Methods of observational astrophysics I	6	Turku+Helsinki, tel. operator
	Methods of observational astrophysics II	5	Turku+Helsinki, co-lecturer
P. Nurmi	Methods of observational astrophysics I	6	Turku+Helsinki, tel. operator

5.3 Completed theses

MSc theses

Juan Pablo Cordero, “*The Dry Merger rate in the Coma Cluster*”, Universidad de Chile, Roberto De Propris

6. Other research activities

Memberships in conference SOC/LOC and other committees

J. Kotilainen	Finnish delegate in ESO Council
	Astronomy Days, Tampere, 23.-25.5.2016, SOC member
	pre-examiner, PhD thesis of Jarkko Laine, *Univ. Oulu Spring 2016
V. Neustroev	ESO OPC (Observing Programmes Committee): Periods 97-98
P. Nurmi	Tuorla-Tartu annual meeting 2016: Building blocks of the Universe, 28-30.9.2016, SOC and LOC member

Conference presentations

J. Kotilainen	“Recent star formation and nuclear activity in low redshift quasars” (oral) in *Physics Days*, Finland, Oulu, 29.-31. March 2016
	"The host galaxies of active galactic nuclei with powerful relativistic jets” (oral) in *AD2016*, Finland, Tampere, 23.-25. May 2016
	”The host galaxies of active galactic nuclei with powerful relativistic jets” (oral) in *EWASS2016*, Athens, Greece, 4.-8. July 2016
	”The host galaxies of gamma-ray loud Narrow Line Seyfert 1 galaxies” (oral) in *EWASS2016*, Athens, Greece, 4.-8. July 2016
V. Neustroev	“Correlated X-ray and optical variability in intermediate polars during their outbursts” (oral) in *20th European Workshop on White Dwarfs*, UK, University of Warwick, 25.-29. July 2016

Other talks

R. De Propris	“The Morphological evolution of cluster galaxies”, Trieste Observatory
	“The New Bulge”, Milan Observatory, Italy
	“The New Bulge”, Tartu Observatory, Estonia
V. Fallah Ramazani	"1ES 2037+521: Extreme BL Lac in VHE γ-ray band", Dortmund, Germany, 21 November 2016
H. Kuncarayakti	“IFU study of supernova environments and progenitors”, Piikkiö, Tuorla Observatory, 8 December 2016
V. Neustroev	“A systematic search for highly-evolved post period-minimum cataclysmic variables”, Piikkiö, Tuorla Observatory, 2 November 2016
	“A systematic search for highly-evolved post-period-minimum cataclysmic variables. The case of SSS J122221.7-311525 - the most-evolved CV known to date”, Piikkiö, Tuorla Observatory, 15 December 2016
P. Nurmi	"Galaxies and galaxy groups in LSE", Tuorla Observatory, 30 September

Research Visits

V. Fallah Ramazani	MAGIC Telescopes, Centro de Astrofisica de La Palma, 22.3.-22.4 and 14.12-31.12, collaborators MAGIC team
J. Kotilainen	ESO Chile (Council meeting) + research visit to ESO Chile and PUC Santiago, 5.-12.10
V. Neustroev	University of Copenhagen, Dark Cosmology Centre, 31.7-7.8, collaborators Lise Christensen and Heidi Korhonen

Hosted visitors

All visitors in the Tuorla observatory/FINCA seminar programme, 2016 – Host: R. De Propris

Susanne Aalto, Chalmers, 18.-19.1 – Host: J. Kotilainen

Petri Väisänen, SAAO, South Africa, 11.7.-2.8 – Host: J. Kotilainen

Michael West, Lowell Observatory, 24.9-22.10 – Host: R. De Propris

7. Publications

Refereed publications by FINCA staff 2016:

[1] Aalto, S., Costagliola, F., Muller, S., Sakamoto, K., Gallagher, J. S., Dasyra, K., Wada, K., Combes, F., García-Burillo, S., Kristensen, L. E., Martín, S., van der Werf, P., Evans, A. S. and **Kotilainen**, J., *A precessing molecular jet signaling an obscured, growing supermassive black hole in NGC 1377?* , 2016, A&A, 590A:73A.

[2] Aartsen M. G, Abraham K., Ackermann M., Adams J., Aguilar J. A., Ahlers M., Ahrens M., Altmann D., Andeen K., Anderson T., and et al., (including **Neustroev, V. and Nilsson K.**, *Very high-energy gamma-ray follow-up program using neutrino triggers from IceCube* , 2016, Journal of Instrumentation, 11:11.

[3] Ahnen, M.L., Ansoldi, S., Antonelli, L.A., Antoranz, P., Arcaro, C., Babic, A., Banerjee, B., Bangale, P., Barres de Almeida, U., Barrio, J.A., and et al., (including **Nilsson**, K.), *Detection of very high energy gamma-ray emission from the gravitationally lensed blazar QSO B0218+357 with the MAGIC telescopes* , 2016, A&A, 595A:98A.

[4] Ahnen, M.L., Ansoldi, S., Antonelli, L.A., Antoranz, P., Arcaro, C., Babic, A., Banerjee, B., Bangale, P., Barres de Almeida, U., Barrio, J.A., and et al., (including **Nilsson**, K.), *Search for VHE gamma-ray emission from Geminga pulsar and nebula with the MAGIC telescopes* , 2016, A&A, 591A:138A.

[5] Ahnen, M.L., Ansoldi, S., Antonelli, L.A., Antoranz, P., Arcaro, C., Babic, A., Banerjee, B., Bangale, P., Barres de Almeida, U., Barrio, J.A., and et al., (including **Nilsson**, K.), *Super-orbital variability of LS I +61*deg*303 at TeV energies* , 2016, A&A, 591A:76A.

[6] Ahnen, M.L., Ansoldi, S., Antonelli, L.A., Antoranz, P., Arcaro, C., Babic, A., Banerjee, B., Bangale, P., Barres de Almeida, U., Barrio, J.A., and et al., (including **Nilsson**, K.), *Investigating the peculiar emission from the new VHE gamma-ray source H1722+119* , 2016, MNRAS, 459:3271A.

[7] Ahnen, M.L., Ansoldi, S., Antonelli, L.A., Antoranz, P., Arcaro, C., Babic, A., Banerjee, B., Bangale, P., Barres de Almeida, U., Barrio, J.A., and et al., (including **Nilsson**, K.), *Long-term multi-wavelength variability and correlation study of Markarian 421 from 2007 to 2009* , 2016, A&A, 593A:91A.

[8] Ahnen, M.L., Ansoldi, S., Antonelli, L.A., Antoranz, P., Arcaro, C., Babic, A., Banerjee, B., Bangale, P., Barres de Almeida, U., Barrio, J.A., and et al., (including **Nilsson**, K.), *MAGIC observations of the February 2014 flare of 1ES 1011+496 and ensuing constraint of the EBL density* , 2016, A&A, 590A:24A.

[9] Ahnen, M.L., Ansoldi, S., Antonelli, L.A., Antoranz, P., Arcaro, C., Babic, A., Banerjee, B., Bangale, P., Barres de Almeida, U., Barrio, J.A., and et al., (including **Nilsson**, K.), *Multiwavelength observations of the blazar 1ES 1011+496 in Spring 2008* , 2016, MNRAS, 459:3.

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