List of proposed PhD projects

PhD projects list for the call of November 15, 2011

Here follows a list of some representative PhD projects for applicants to the IMPRS for Astronomy and Astrophysics. In case of preference, please indicate the **Project Codes** in your application form. **It must be made clear that all these are only optional and indicative. It is highly recommended that you contact the scientific staff of the involved institutes for further suggestions, discussion and topics.**

The projects are organized in 6 groups each one of which corresponds to a scientific division of the participating institutes. Click the links below to jump to the corresponding group:

Note 1: At the end of each description there are links to link you back to the beginning of a group or the beginning of this document.

Note 2: A pdf version of the current file can be found at this link. Be aware however that it may be incomplete! The reference document must be the current html page.

Very Long Baseline Interferometry Group

Director: Prof. Dr. J. Anton Zensus

Group website

Code: **AZ01** From Black Holes to Jets: Active Galactic Nuclei

Very Long Baseline Interferometry in the radio regime (VLBI) provides highest resolution images of the central regions of Active Galactic Nuclei (AGN). In these inner parts of the most energetic objects of the Universe jets are created and collimated. The role of the accretion disk and the black hole in the launching of jets is still a matter of debate. Unification scenarios – relying on the same Jet/Accretion disk/Black Hole-system in all objects - explain different types of AGN as due to orientation effects. However, this cannot explain all observed jet-phenomena.

Project aims: The research for the PhD project concentrates on unusual phenomena in the jets of AGN in the vicinity of black holes. The current paradigm of "simple" outward motion is being questioned in a number of AGN. To investigate this unexpected behavior in more detail and to study the physical emission processes in jets in general and the connection between the central engine and jet launching, is the subject of this PhD project.

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Code: **AZ02** Supermassive Binary Black Holes & Merging Galaxies

The expected frequent mergers of galaxies over the course of their formation and cosmological evolution must lead to the formation of supermassive binary black holes. Black hole binary mergers could be responsible for many quasars. Detecting more such binary systems is therefore of great interest for key topics in astrophysics ranging from galaxy formation to activity in galaxies. A number of phenomena were attributed to the presence of binary systems, including X-shaped radio galaxies and double-double radio galaxies, precession of a jet emitted by one of the binary components, wiggling of a jet due to the orbital motion, periodic variations in the luminosity due to perturbation of an accretion disk around one of the holes, binary galaxies with radio-jet cores, and binary quasars, etc.

Project aims: The research planned for the PhD project focuses on the investigation of the connection between galaxy interactions and active galactic nuclei with particular emphasis on the proof of the existence and analysis of supermassive binary systems in the centers of AGN.

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Code: **AZ03** 1.3 mm Millimeter-VLBI Observations of AGN Jets

Active Galactic Nuclei (AGN) are amongst the most luminous objects in the Universe. Their enormous energy output (luminosity) is at present best explained via the assumption of matter accretion onto a central super-massive black hole and relativistic outflows. The SMBHs play an important role in the evolution of a galaxy over cosmic time. Many AGN show powerful radio jets, extending over up to millions of light years and often showing superluminal motion. The present PhD project addresses the question of how these radio jets are made, how they are launched from the BH, and how the acceleration up to highly relativistic velocities is done. Another aspect of this thesis is to study the cores of AGN at different cosmological distances and redshifts, to learn about the cosmological evolution of radio jet formation. Very Long Baseline Interferometry at short millimeter wavelengths (mm- VLBI) provides a unique tool to image the nuclear regions with extremely high angular resolutions of up to a few 10 micro-arcseconds (10E-10 degrees). These angular scales are un-reached by any other astronomical observing method and allow to make radio-images of spatial scales of only a few to a few 100 Schwarzschild radii around Black Holes. For nearby galaxies, like e.g. Virgo A (M87) or the Galactic Center (Sgr A*) mm-VLBI imaging offers a unique opportunity to directly image the regions around a Black Hole and to image its `Event Horizon'. For more distant Black Holes, multi-epoch observations reveal the kinematics of the moving inner jet, in a region where the jet is formed and collimated. Here it is possible to study the jet nozzle, which likely is to the Black Hole via rotating magnetic fields.

Project aims: We encourage young and qualified students to actively participate in this challenging field of BH research, trying to better understand the physical conditions in the centers of galaxies and near Black Holes. The successful applicant will participate in modern and state-of-the art observing methods, which push VLBI to new frontiers, using existing and upcoming new mm-telescopes. In particular the applicant can actively participate in all stages of experiment planning, observation and data reduction in a small group of young researchers and senior experts. Depending on personal interest and qualification, mm-VLBI offers room for differently qualified people, persons who are interested in hard and/or software development, in data reduction and/or in the application of existing astrophysical jet models to already existing data.

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Code: **AZ04** **High Angular Resolution Studies of Relativistic Outflows**

The origin of radio jets in AGN and the details of the jet launching, collimation and acceleration process is still enigmatic. A more detailed astro-physical understanding of the jet production will also lead to a better insight on the energy supply in Quasars and Radio-galaxies, which are the most powerful objects in the Universe. The study of different objects at different cosmological distances, will help to better understand their cosmological evolution.

Global VLBI at 7 millimeter (43 GHz) and 3 millimeter (86 GHz) wavelengths penetrates the opacity barrier in the centers of Active Galactic Nuclei (AGN), which blocks the direct view at the longer centimeter wavelengths (due to synchrotron self-absorption). With an angular resolution of up to 45 micro-arcseconds, global 3mm VLBI therefore allows to image the inner-most region in an AGN and the vicinity of their super-massive Black Holes in unsurpassed fine detail (e.g. the jet base in M87 with a resolution of 15 Schwarzschild radii).

The combination of the sensitive millimeter VLBI telescopes in Europe with the VLBA forms the so called Global Millimeter VLBI Array (GMVA, http://www.mpifr-bonn.mpg.de/div/vlbi/globalmm/). It is 3-4 times more sensitive than the VLBA alone and therefore is ideal for high dynamic range imaging of the sub-parsec scale regions in compact extragalactic radio sources. With the planned transition to larger observing bandwidth and the addition of more radio-telescopes in the future (e.g ALMA), the imaging capabilities of mm-VLBI will further grow.

In this PhD-project, the applicant is supposed to help to further develop the research which can be done with global mm-VLBI. This includes all steps from the planing of a VLBI experiment to the final imaging of mm-VLBI data and the scientific interpretation. The main focus of the research will be on the study of structure,
morphology and kinematics of the central regions in AGN and their emanating jets. Since polarimetric observations are now becoming feasible, research on the topology of the magnetic field at the jet base and near the Black Hole will reveal new insight to the physics near Black Holes, touching general relativity and magneto-hydrodynamics.

The combination of new and archival data from the GMVA and the VLBA, provides already a sufficient data base to ensure an immediate start of the PhD project. Depending on ability and interest, the focus of the PhD project can be matched to the technical aspects of mm-VLBI, the analysis software development/improvement, single/multiple object focused mm-VLBI imaging (any combination of this
is also possible).

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Code: **AZ05** **Rapid Variability of Compact Radio Sources**

At radio-wavelengths, the nuclei of Galaxies, Quasars and BL Lacertae objects are known to vary in flux density and polarization on time scales of hours to years. While the variations on the longer week-to-year time scales are thought to be source intrinsic and related to the broad-band activity of the "central engine" (e.g. the black hole), the physical interpretation of the very rapid inter- to intra-day variability, is subject of controversial scientific discussion. For these sources, causality and the light travel time argument limits the size of the variable emission regions to less than a few light-hours, causing extremely high photon energies and brightness temperatures. Distant objects of such high compactness, however, are smaller than the scattering size, which is set by the ionized interstellar medium in our Galaxy. Similarly to the twinkle of star light in the atmosphere, ultra-compact radio sources therefore also scintillate. The physical properties of the interstellar medium determine the variability characteristics of ultra-compact radio sources, which in turn can also be used to set constraints on the interstellar medium itself.
The main aim of this research project is to study the most rapidly variable radio sources. The observations are done at all accessible bands of the electromagnetic spectrum (from radio to gamma- rays). A wavelength range, which in the past was not yet well covered is the mm-band at frequencies at and above 30 GHz. One major aim of this PhD project is to search for radio sources, which show prominent variability at mm-wavelength (30-300 GHz), in a regime where interstellar scattering vanishes. In studying the frequency dependence of the rapid variability it will be possible to disentangle between source intrinsic variability and propagation induced variability. Part of the project is the planning and performance of multi-frequency observing campaigns, including the observation of polarization at radio, mm- and optical bands.
The successful applicant is expected to actively participate in all stages of experimental planning, setup, observation and data analysis. Depending on his/her personal preferences and aptitudes, various options for his/her contribution exist, ranging from observational to more theoretical work, and from the development of better data analysis methods (time series) to the various aspects related to intrinsic AGN/jet variability and the interstellar medium.

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Code: **AZ06** **Polarimetric Study of the Black Hole in the Galactic Center with mm-/submm-VLBI**

In the next years, the so called Event Horizon Telescope (EHT) will be build up. This new VLBI array will consist of 5-8 sub-mm telescopes in Europe, the USA and South America, which operate at 1.3mm wavelength and shorter. The main aim of sub-millimeter VLBI observations is to image the 'Event Horizon' of the Black Hole in the Center of our Galaxy and study its time evolving structure. Einstein's General Relativity predicts a curved space-time metric, which observationally leads to relativistically distorted images, which are affected by gravitational light bending and framedragging. From the detailed shape of the anticipated VLBI radio images, it is possible to deduce the Black Hole mass, the Black Hole spin and some properties of the accretion disk, which rotates around the BH. Observations in polarized light will also help to clarify to which extend magnetic fields play a role near BHs and if they are a necessary ingredient for jet formation in Quasars (GR-Dynamo).

Project aims: The main aim of this PhD project is to develop the methods for future polarimetric VLBI imaging of BH candidates at short millimeter and sub-millimeter wavelengths. In a first step, the applicant will actively participate in planned polarization sensitive VLBI pilot studies at 1.3mm, using the two IRAM telescopes (Pico Veleta, Plateau de Bure interferometer), the newly equipped APEX telescope in Chile and other available telescopes. The project has a technical part, which deals with the correction and removal of the instrumental polarization from the data, and a scientific part, which aims at the detailed micro-arcsecond scale study of the (time-variable) structure of the 4 Million Solar- mass BH in the Galactic Center.

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Code: **AZ07** **86 GHz VLBI Survey of Ultracompact Radio Emission in Active Galactic Nuclei**

Very Long Baseline Interferometry (VLBI) Observations at a frequency of 86 GHz (wavelength of 3 mm) reach a resolution of about 50 microarcseconds and enable detailed studies of ultracompact radio emission in active galactic nuclei. Coming from innermost regions of radio jets, this emission reflects processes governing acceleration and collimation of relativistic flows and probes physical conditions in the immediate vicinity of central supermassive black holes on scales down to a few tens of gravitational radii. Systematic studies of radio sources on such scales offer the best opportunity to understand generic properties of relativistic flows and address intricate evolution of individual objects. Founded upon the success of several earlier millimeter VLBI surveys (cf., Lobanov et al. 2001, Lee et al. 2008), this project will benefit from recent improvements in sensitivity and calibration accuracy of the Global Millimeter VLBI Array network. The target sample consists of more than 400 objects, signifying roughly a four time increase in the total number of objects imaged with VLBI at 86 GHz. Combined with data from existing large VLBI surveys at lower frequencies (VLBA, MOJAVE, VCS, and USNO surveys), this project will provide an excellent opportunity to study intricate processes in the vicinity of supermassive black holes, at the earliest stages of formation and evolution of extragalactic relativistic outflows.

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Code: **AZ08** **Multi-band study of structural and emission evolution of the quasar 3C273**

The first quasar discovered, 3C273 remains an archetype object for studies of relativistic flows and physical processes in the vicinity of supermassive black holes in active galaxies (cf., Courvoisier 1998). Since 1970-s, 3C273 has been monitored almost uninterruptedly in all bands, most notably at high- energies with space observatories INTEGRAL and FERMI and at a milliarcsecond resolution in the radio regime with very long baseline interferometry (VLBI). Combining various extended monitoring programs offers undoubtedly the best opportunity to understand the physics of formation and evolution of relativistic flows, and this approach has been applied to observations of 3C273 covering the period through 2000 (Türler et al. 2000). We would like to extend this program to include the latest high-energy and optical observations of 3C273 and combine them with the vast observational database of VLBI observations of the radio emission in this object. This would enable studies of internal structure (cf., Lobanov & Zensus 2001) and spectral evolution (cf., Lobanov & Zensus 1999, Türler et al. 2000) of the flow, and provide the best physical framework for understanding the physical mechanism and location of the production of high-energy emission in AGN.

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Code: **AZ09** **Localization of non-thermal continuum production in AGN**

Localizing the sites where non-thermal continuum is produced in AGN is pivotal for understanding their physics. Presently, this localization is largely based on information obtained from observations of the SED and correlated variability of the broad-band continuum emission in AGN. High-resolution radio observations made with Very Long Baseline Interferometry (VLBI) enable in some cases direct spatial localization of the optical, X-ray and Gamma-ray flares in AGN. Correlations observed between parsec-scale radio emission and optical and gamma-ray continuum indicate that a significant fraction of non-thermal continuum may be produced in extended regions of relativistic jet, thus requiring serious rethinking of existing models for the high-energy emission production. The project will be a continuation of our recent efforts in this field (see references). The work will be focussed on further exploration and better understanding of radio-gamma and radio-TeV relations in powerful AGN, using Fermi/LAT and HESS/MAGIC data in combination with extensive VLBI monitoring data from the MOJAVE survey, geodetic VLBI data and new VLBI observations.

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Code: **AZ10** **Fermi-GST Multi-frequency Monitoring Alliance (F-GAMMA): AGN astrophysics in the Fermi-GST era**

Unlike the normal galaxies where the observed radiation is simply the sum of mostly the light produced by their stellar population, Active Galactic Nuclei appear to radiate inconceivable amounts of energy from a very small - compact - nuclear region. These extraordinary systems are believed to be powered by a Super Massive black hole (~106 Msun) hosted by their galactic center. Matter is accreted through a candescent accretion disk surrounding the black hole and then it is shotted ionized into relativistic plasma jets perpendicularly to that disk. The plasma jets emit primarily via synchrotron mechanism which is consequently involved in several secondary process such as Inverse Compton scattering.

This simple, at first glance, configuration is creating an enormous variety of phenomenologies blended in a whole “zoo” with families, classes and sub-classes. The plasma jets can reach distances of kpc to Mpc while the involved relativistic velocities induce effects unseen in other systems. The enormous magnitude and complexity of these systems and the plurality of their constituents not only intrigues our need to understand the complicated emission processes but also gives AGNs the first role in the cosmic scene. Their jets for instance is believed the regulate the activity in members of clusters of galaxies while the claimed relation between the AGN activity as a stage in the interaction of galaxies allows the study of extreme gravitational fields.

Despite the decades of research the exact processes at play are intensely debated. What mechanisms produce the jets, how are the particles accelerated, what is the role of the magnetic fields, how exactly is the radiation produced and what is the location of the high energy emission, how is the jet activity influencing the environment, are only some indicative questions to be addressed among a series of astrophysical problems to be attacked. Among all the classes of AGNs, “blazars” are characterized by very small viewing angles to the jet axis. This implies extreme characteristics, such as: extremely broad-band emission, intense variability, large degree of polarization and intense polarization variability, highly superluminal speeds and many more. Consequently they are unique probes of the AGN physics. simultaneous multi-frequency studies of blazars hold a great potential in AGN research. The gamma- ray satellite Fermi-GST launched in summer 2008 has revolutionized this field by providing several daily scans of the entire gamma-ray sky allowing for the first time ever really simultaneous studies.

In January 2007 the VLBI group of the MPIfR formed a scientific alliance between several state-of-the- art facilities (F-GAMMA program) in order to conduct coordinated multi-frequency studies of selected blazars in collaboration with the Fermi-GST satellite. The main facilities are: the 100-m telescope in Germany, the 30-m IRAM telescope in Spain and the APEX telescope in Chile. Additionally, we have developed an extended network of collaborators such as the 40-m OVRO telescope in California, the 1,2 m optical telescope in Crete, the MOJAVE VLBA survey team, the AGN group of the university of Perugia and others. Currently, the F-GAMMA team consists of four scientists and 2 students and it is ever growing.

After 4.5 years of the program there is an immense volume of high quality data ready to be analyzed. The team has a broadest approach to blazar physics and is involved in all possible directions such as, emission mechanisms, population studies, spectral energy distribution studies, variability studies, VLBI blazar studies, cross-band polarization studies, gamma-ray and radio correlations etc. Potential students will have the opportunity to choose from a variety of topics. They will be encouraged and guided to write proposals for and travel to observing facilities in the world, to travel to schools and conferences and to gain broad experience in observing techniques.

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Code: **AZ11** **TANAMI (Tracking Active Galactic Nuclei with Austral Milliarcsecond Interferometry)**

TANAMI is an international project done in collaboration with the Universities of Würzburg and Valencia and NASA's Goddard Space Flight Center to monitor the parsec-scale structures of relativistic jets in active galactic nuclei in the Southern Hemisphere. The jets south of -30 deg declination are being monitored at 1.3 cm and 3.6 cm radio wavelengths by means of very-long-baseline interferometry. TANAMI uses the Australian Long Baseline Array complemented with additional stations extended towards South Africa, the Antarctica and Chile. Observations started in 2007, prior to the launch of the gamma-ray Fermi satellite, which is also probing those sources in the other extreme of the spectrum, with the aim of relating the emission in the radio and at high energies. Correlated multiwavelength observations are being done with modern X-ray telescopes (XMM-Newton, Swift, INTEGRAL) as well as in the NIR/optical regime. The PhD project will investigate the nature of active galactic nuclei, their supermassive black holes and relativistic jets, making use of unprecedented data across the whole electromagnetic spectrum.

Project Aims:
The most powerful extragalactic jets of the Southern Hemisphere are being probed by Fermi in the gamma-ray regime, and by single-dish and interferometric TANAMI observations in the radio band. The imaging and further analysis of individual sources and of the complete data set is planned in this PhD project: data debugging, image analysis, spectral studies of the jets, correlation study of the morphological and brightness variation in the context of a multi-band approach are the main goals of the project. The data being collected are unique, for its quality and for coming from the relatively unexplored Southern skies. The project guarantees integration in the NASA Fermi/LAT collaboration, high-impact publications and a long time baseline for collaboration, since Fermi/LAT will operate for the next 5-10 years, and TANAMI is expected to keep collecting data during this time.

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See full publication list at http://pulsar.sternwarte.uni-erlangen.de/tanami/pubs/

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Code: **AZ12** **Monitoring of Jets in Active Galactic Nuclei with VLBA Experiments**

About ten percent of the active galactic nuclei (AGN) eject jets of plasma at relativistic speeds from their central regions. The rapidly variable non-thermal emission and apparent superluminal motions in the jets imply that they contain highly energetic plasma moving nearly directly at us at speeds approaching that of light. Understanding the acceleration, collimation, and stability properties of these flows is one of the central topics in the modern relativistic astrophysics. The recent advances in the numerical simulations of highly relativistic magnetized plasma in strong gravitational fields are suggesting that fast, stable outflows can be generated by accreting, rotating billion-solar-mass black holes and their magnetized accretion disks. High-dynamic-range, high-resolution radio imaging of (sub-)parsec-scale structures in the jets is essential to derive observational constraints for the physical conditions in the jets close their launching site.

Very long baseline interferometry (VLBI) imaging with its unsurpassed angular resolution allows direct studies of the innermost parsecs of the jets. Within a collaboration between European and American scientists, we run one of the largest VLBI survey programs ever carried out. The MOJAVE program monitors structural changes in the parsec-scale jets of 300 AGN by taking sequences of milliarcsecond-resolution radio images with the Very Long Baseline Array. Particular strengths of the program include high dynamic range of the images, frequent time-sampling, and statistical completeness of the sample. Some of the monitored sources have over 15 years of well-sampled observations providing an unprecedented data set for studying the evolving jet structures.

The student will be involved in the MOJAVE program and analyse the survey data. Depending on student's interests, the project can concentrate e.g., on studying the collimation and growth of instabilities in the jets, or studying shocked regions of the flows that are likely responsible for spectacular broad-band flux variations typical for these sources. A joint project with the F-GAMMA program, which carries out an extensive radio-to-mm-waveband spectral evolution monitoring of blazars, is also possible. There the student would study how the type of the spectral evolution during the flares depends on the observed outflow characteristics.

The project would be conducted within the VLBI group of the MPIfR led by Prof. Dr. Anton Zensus. The group's research is mainly focused on understanding the physics of relativistic outflows in AGN and on advancing the high angular resolution techniques of radio astronomy.

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Code: **AZ13** **Origin of the gamma-ray emission from AGN jets**

One major open question regarding relativistic jets in AGN is related to their energy dissipation and origin of the different, highly variable components of their spectral energy distribution (SED). The SED of a jet-dominated AGN (blazar) has two broad components: one peaking between far-IR and X-ray wavelengths and the other peaking at gamma-ray energies. While it is well-established that the low-energy emission peak is due to synchrotron radiation of highly relativistic electrons in the jet, the origin of the high-energy component of the SED is more open. It may be due to inverse Compton scattering of low-energy photons by the same relativistic electrons that are responsible for the synchrotron emission, but there is currently a substantial controversy about the origin of the seed photon field and the site of the gamma-ray emission and the main energy dissipation region of blazar jets. The seed photons may come from the broad line region, accretion disk, dust torus or from synchrotron radiation of the jet itself, and the Compton scattering may take place for example near the base of the jet or in a recollimation shock parsecs downstream.

In order to tackle the questions about the location of the gamma-ray emission site and the emission mechanism as well as dissipation of the bulk flow energy we are obtaining very frequently sampled images of the jets of two archetypical quasars, 3C273 and 3C279, with sub-parsec linear resolution. At the same time we are monitoring their whole SEDs. The quasars are being observed for one year with the following instruments: Very Long Baseline Array will take polarimetric radio images of the innermost portion of the jets once every 20 days at 15, 24, 43, and 86 GHz. This data will be used to produce "movies" of the structural, spectral and polarization changes in the jets. Fermi Gamma-Ray Space Telescope, Swift X-ray satellite, and several ground-based optical, near-IR, mm and radio telescopes monitor the SEDs from radio to GeV gamma-rays with a matching time sampling. This multi-frequency data set will allow a detailed cross-analysis between the "jet movie" and the SED variability in order to test the proposed blazar models and to constrain several physical properties of the jets.

The student involved in this project would reduce data from the several participating telescopes (especially from the VLBA), perform correlation analysis of the multi-waveband data, and carry out astrophysical interpretation of them. The project gives a good chance to learn state-of-the-art observational techniques at several wavelength regimes.

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Millimeter and Sub-millimeter Group
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Group website

Code: **KM01** **The evolution of the radio supernova SN 2008iz**

Radio supernovae are rare events. So far only about two dozen have been detected and most of them were quite distant and rather weak. This makes it difficult to study them in great detail. We have discovered a new radio supernova (SN 2008iz) in the nearby starburst galaxy M82. It is the nearest and brightest radio supernova for 15 years. The evolution of this supernova will be followed in the radio over the next few years. High resolution VLBI observations will evolution of this supernova will be followed in the radio over the next few years. High resolution VLBI observations will directly measure the expansion of the ejecta from the supernova explosion. Very Large Array observations will measure the radio lightcurve at different frequencies. So far, the evidence indicates that either the explosion or the surrounding medium were highly asymmetric. Following the expansion of the ring will allow studies of many different phenomena, e.g. measure the expansion speed more reliably (currently it is based on two epochs), pinpoint the date of explosion, detect deceleration of the shock front, estimate the mass loss rate of the progenitor star, the magnetic field in the radiating region, or measure/limit the proper motion of the supernova shell relative to M81.

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Code: **KM02** **The Megamaser Cosmology Project**

Dark Energy (DE) accounts for 73% of the energy density of the universe, dominates its present expansion, and determines its ultimate fate. Understanding DE may be the most important problem in fundamental physics today. The Cosmic Microwave Background (CMB) on its own cannot provide a high precision estimate on DE's equation of state. To constrain the nature of DE, the best complement to CMB data is a measurement of the Hubble constant (Ho) to better than 3%.

A particularly promising path to measure Ho to such high precision involves direct geometric distance determinations of circumnuclear water masers in galaxies in the Hubble flow, at distances of 50-200 Mpc. The Megamaser Cosmology Project (MCP) is an ambitious project to achieve this goal. Luminous water vapor masers, as they move on Keplerian orbits around supermassive black holes, are observed at high spatial resolution, using the tools of Very Long Baseline Interferometry (VLBI). Aside of distances, the measurements also allow for accurate mass determinations of the central engines and provide first maps of the shape and morphology of the circumnuclear disks of active galaxies.

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Code: **KM03** **The role of jets and outflows in massive star formation**

Because high-mass stars dominate the energy input and chemical enrichment of galaxies, it is especially important to understand their formation. However, although the formation of low-mass stars is well-understood, the story for high-mass stars is far less clear and the exact mechanism by which high-mass stars acquire their mass is still controversial. Detailed studies of outflows and jets from massive young stellar objects (YSOs) are needed to determine their properties and compare them with those of outflows from low mass objects.

This project is dedicated to the analysis of jets and outflows from massive YSOs to elucidate their nature, and how these compare with their low-mass counterparts. This will be reached through high angular resolution observations of several sources at mm and submm wavelengths in transitions of the SiO molecule. By mapping jets and outflows, the driving sources will be identified, their multiplicity constrained, and important inferences will be made concerning the orientation of the discs that feed the outflows and how constant this orientation is. Previous work using 12CO and 13CO lines has suffered from confusion, because these molecules also trace swept-up material (as distinct from the jet proper) and the material of the ambient envelope. This problem will be avoided by using SiO lines; SiO is generated by sputtering of grains, and is therefore an unambiguous tracer of the shocks at the working surfaces of jets.

The idea behind the project is to perform a SiO multi-line analysis to estimate the physical conditions (temperature and density) of the gas along outflows driven by high-mass YSOs based on observations with interferometers (VLA, SMA, PdBI, ALMA) and single dish telescopes (e.g., APEX) of higher energy lines.

During the three years of the PhD, the student will be trained in observing and data reduction techniques, and apply them to single-dish APEX and IRAM observations of SiO emission from jets in high-mass star formation regions. Sources suitable for follow-up observation with the PdB, SMA nd VLA interferometers will be identified and observing proposals submitted accordingly. The call for early science of the ALMA interferometer will also happen during the time scale of this project. The student will benefit of strong interaction not only with the group of Prof. Menten working in the field of massive star formation, but also with a strong collaboration with Dr. Claudio Codella in Arcetry, Florence, who actively works on jets from low- and high-mass YSOs.

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Code: **KM04** **Square degree mapping of giant star forming complexes at 350 micron**

The APEX Telescope Large Area Survey of the Galaxy (ATLASGAL), which has just been completed, reveals for the first time the structure of the cold interstellar medium over several 100 sq. deg. The survey was conducted with LABOCA at the APEX telescope; This instrument allows, both, to resolve sources of 0.1 pc size within 1 kpc, and to map the dust component in the interstellar medium on large scales little explored so far. The main goals are to reveal objects related with high mass star formation in various evolutionary stages, to study their timescales and distribution.

Targeted follow-up observations were performed with SABOCA at 350 micron. The spatial resolution of SABOCA corresponds to 0.1 pc at 3 kpc. However, the LABOCA data reveal giant star forming complexes on the degree scale. Little is known about the properties of the cold interstellar medium on such large scales, such as dust emissivity and temperatures. More follow-ups are planned to map several square degrees of the inner Galactic plane with SABOCA. When combining the LABOCA and SABOCA data with the ongoing Hi-GAL survey at 60 to 600 micron, it will be possible to:

• derive evolutionary stages for a representative sample of star forming clumps
• compute dust emissivity and temperature over a large star forming complex
• analyze how the physical conditions vary within one giant complex
• study the fragmentation of clumps into cores that can give birth to individual stars

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Code: **KM05** **Molecular excitation and abundances through the evolution of massive star forming regions**

The just finished ATLASGAL project conducted an unbiased survey of the inner Galactic disk using the APEX telescope. One of the major goals is to reveal objects associated with massive star formation at various stages, to study their timescales and their distribution in the inner Galaxy. With a large field of view of 11 arcmin, and a resolution of 18" at 870 micron, the MPIfR-built bolometer array LABOCA is the perfect tool to conduct such a large scale survey in a limited amount of time. This instrument allows, both, to resolve sources of 0.1 pc size within 1 kpc, and to map the dust component in the interstellar medium on large scales little explored so far.

Spectral line follow-ups of newly identified massive star forming clumps have been started in the 4th quadrant of the Galaxy and will now be continued with the powerful new EMIR receivers at the 30m. The prime goals are:

• virial masses of the clumps will be derived from line width measurements
• the kinematical signatures of outflows and infall will be studied
• density and temperatures will be measured with various molecules and detailed excitation modeling
• the chemical evolution will be studied by measuring molecular abundances and comparing them with chemical models

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Code: **KM06** **Probing the inner workings of massive star forming regions**

The just finished ATLASGAL project conducted an unbiased survey of the inner Galactic disk using the APEX telescope. One of the major goals is to reveal objects associated with massive star formation at various stages, to study their timescales and their distribution in the inner Galaxy. With a large field of view of 11 arcmin, and a resolution of 18" at 870 micron, the MPIfR-built bolometer array LABOCA is the perfect tool to conduct such a large scale survey in a limited amount of time. This instrument allows, both, to resolve sources of 0.1 pc size within 1 kpc, and to map the dust component in the interstellar medium on large scales little explored so far.

The logical next step in the analysis of the newly found massive star forming regions is to conduct high angular resolution interferometer follow ups of a representative and well-chosen subsample to investigate the evolutionary sequence and inner workings of massive star forming regions. With ALMA early science just around the corner, the soon most powerful mm/submm interferometer, ALMA, will be used for these follow ups. The prime goals are:

• to investigate the details of the fragmentation process.
• to study outflows in massive star forming regions.
• to search for disks around massive (proto) stars
• to study the physical and chemical conditions close to the forming stars.

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Code: **KM07** **Airborne observations of OH in star forming regions**

OH, the hydroxyl radical, is one of the key oxygen bearing species in the interstellar medium. Being the first molecule detected at radio wavelengths, it has been widely studied in molecular clouds by observations of its centimeter lambda doubling transitions but its interpretation is complicated by excitation effects within the hyperfine levels. A more direct probe of OH is possible via its rotational lines in the far-infrared. Several of these lines will be soon observable with the GREAT instrument onboard of SOFIA, the Stratospheric Observatory for Infrared Astronomy.

In this project a comprehensive study of OH in star forming regions will be conducted to investigate the role of OH in interstellar chemistry and in the cooling of star forming regions. In addition, absorption lines from the OH ground state line can be used to study the kinematics of the star forming regions on the line of sight.

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Code: **KM08** **A comprehensive Galactic plane radio wavelength star formation survey**

Understanding the circumstances of massive star formation is one of the great challenges of modern astronomy. In the last years, our view of massive star forming regions has dramatically been changed by Galactic plane surveys covering centimeter to infrared wavelengths. These surveys enable us for the first time to study ALL evolutionary stages of massive star formation in an unbiased way. With the exciting results of the new submm/FIR surveys from the ground (ATLASGAL) and space (Hi-GAL) the massive and cold dust clumps from which massive cluster form are now detected in an unbiased way. Complementary, the EVLA will allow incredibly powerful and comprehensive radio- wavelength surveys of, both, the ionized and the molecular tracers of star formation in the Galactic plane.

In this project, the extremely wideband (4â8 GHz) new C-band receivers of the EVLA will be used for an unbiased survey to find and characterize star-forming regions in the Galaxy. This survey of the Galactic plane will detect tell-tale tracers of star formation: compact, ultra-, and hyper-compact Hii regions and molecular masers which trace different stages of early stellar evolution and will pinpoint the very centers of the early phase of star-forming activity. Combined with the submm/infrared surveys it will offer a nearly complete census of the number, luminosities and masses of massive star forming clusters in a large range of evolutionary stages and provide a unique dataset with true legacy value for a global perspective on star formation in our Galaxy.

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Fundamental Physics in Radio Astronomy Group
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Group website

Code: **MK01** **Monitoring the Interstellar Weather with Pulsars**

Our Galaxy is a dynamical and constantly evolving system. The interstellar medium (ISM) appears constant at large scales (~kpc) but is turbulent at small scales (~pc). These changes impact on many of the observed properties of astronomical objects but rarely does one have the opportunity to monitor those changes as accurately as with pulsars. The amount of pulse dispersion by the ISM across our observing band is given by the Dispersion Measure (DM), which is equal to the integrated amount of interstellar matter between the pulsar and the observer. The wide observing bands of modern instruments and the low observing frequencies attainable with telescopes like LOFAR conspire towards very accurately measured dispersion delays and, hence, DMs. Also, the pulsed emission from pulsars is highly polarized and the magnetic field of the ISM causes the plane of polarization to rotate as those pulses travel through the Galaxy. The integrated amount of this rotation is expressed with the Rotation Measure (RM) and, again, can be measured with great accuracy across wide frequency bands. Both DM and RM should remain constant with time in a static system but are constantly changing in the dynamical Milky Way. Using a high number of bright, polarized pulsars we can closely track those changes and interpret them as changes of the matter distribution in the Galaxy and changes in the Galactic Magnetic field.

The recently commissioned LOFAR station at Effelsberg as well as the 100m Effelsberg single-dish radio telescope will provide excellent frequency coverage from several GHz to tens of MHz, thus providing the means to monitor pulsar DMs and RMs with unprecedented accuracy. Both instruments incorporate very large bandwidths, with LOFAR having 48 MHz at 150 MHz (high band) and Effelsberg reaching up to 1 GHz of bandwidth with the newly installed Digital Filterbank. The telescopes will be easily accessible from MPIfR and are expected to generate a large amount of total-flux and polarization data from regularly monitored pulsars, which will be analyzed by the project's investigators.

The project will be conducted within the Fundamental Physics in Radio Astronomy group of the MPIfR lead by Prof. Michael Kramer. His team's research concentrates on various aspects of fundamental physics, namely the Galactic population of neutron stars, their use for precision tests of general relativity and alternative theories of gravity, the detection of low-frequency gravitational waves and the structure and properties of super-dense matter".

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Code: **MK02** **Searching the Galaxy for pulsars**

The largest telescopes in the world are currently undertaking surveys to search for pulsars. The group in Bonn is a part of surveys using the 305-m Arecibo telescope in Puerto Rico, the 64-m Parkes telescope in Australia and, of course, our 100-m Effelsberg telescope near Bonn. Their locations allow these telescopes cover the whole sky. Although nearly 2000 pulsars have been discovered to date it is the most unusual pulsars that can really push forward research areas such as,for example general relativity, pulsar evolution and emission mechanisms. In addition to using large telescopes these new surveys use cutting edge hardware. New receivers and a new generation of data recording 'backends' have increased the sensitivity of these surveys dramatically over previous efforts, allowing us to search deep into the Galaxy for the periodic pulsar signals.

The successful applicant would be take part in the observations and data taking. They would be involved in the processing using powerful computer clusters (in Bonn and at partner institutions) and work on the development of the processing pipeline. Finally they would be expected to lead the follow up any interesting discoveries.

The project will be conducted within the Fundamental Physics in Radio Astronomy group of the MPIfR lead by Prof. Michael Kramer. His team's research concentrates on various aspects of fundamental physics, namely the Galactic population of neutron stars, their use for precision tests of general relativity and alternative theories of gravity, the detection of low-frequency gravitational waves and the structure and properties of super-dense matter.

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Code: **MK03** **Einstein goes Digital: Developing new state-of-the-art digital equipment to test general relativity**

One of the main research area of the Fundamental Physics in Radio Astronomy group is the direct detection of the cosmic gravitational wave background by accurate timing of radio pulsars and tests of various theories of gravity. For this purpose and various other scientific projects, the Effelsberg 100-m radio telescope will be equipped with a 0.5 - 3.0

GHz ultra broad band (UBB) receiver in the near future. The advent of high speed ADCs and FPGAs has opened up the possibility of direct RF sampling the broad band signal from this receiver. Accurate timing of pulsars is greatly aided by coherent dedispersion of the signal, which is a computationally intensive operation. Therefore wide bandwidths are processed as smaller, non-overlapping subbands. The subbands are produced by an efficient implemention of a digital filterbank using polyphase decomposition technique. The subbands are then processed by a compute cluster based on GPUs or multicore-CPUs. This method of distributed signal processing also needs the subbands to be packed as UDP datagrams which can then be easily demultiplexed by Layer-3 switches to the compute units.

The candidate is expected to work on the polyphase implementation of a 128- or 256-channel digital filterbank that maps on a FPGA capable of 1.5 GHz fabric clock. A technical risk could the logic available on the FPGA for the large filter bank. In this case, a coarser filterbank (~8 to 16 channels) can be implemented on the high-speed FPGA, followed by a second stage filterbank based on a slower FPGA. Second aspect of the project is to quantify and correct the distortion introduced by the polyphase filterbanks in the folded pulse
profiles. The candidate is also expected to take part in commissioning the instrument at the radio telescope.

We seek a PhD candidate with an expertise in VHDL/Matlab Simulink environment and programming knoweldge in C, Python. Affinity to astronomical signal processing is a plus. For the interested candidate, the project also offers the possibility of combining pulsar emission mechanism studies, or pulsar timing.

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Code: **MK04** **Continuum Halos of Nearby Galaxies – an EVLA Survey (CHANG – ES) and its Faraday tomography**

As part of an international consortium a survey of about 40 nearby spiral galaxies seen edge-on is going to be observed with the **E**xpanded **V**ery **L**arge **A**rray (**EVLA**) in Socorro, New Mexico, in different configurations in the L-band (about 1.5 GHz) and C-Band (about 6 GHz).
While full operation of the EVLA will begin in 2013, this project runs as an RSRP program in order to offer early access in the growing capabilities of the EVLA. The increased sensitivity of the **E**xpanded VLA (by about a factor of 10 compared to that of the VLA) allows to trace the halo emission to larger distances from the galactic midplane with higher resolution, the increased band widths offer a much more detailed spectral index analysis. Both will open a new era of understanding the origin and physical conditions in galactic halos including cosmic ray transport and galactic winds.

The new spectral capability of the EVLA offers the chance to receive full polarization information in a huge number of frequency channels and over a variety of spatial scales which allow to apply the novel method of ‘RM Synthesis’ technique (spectro-polarimetry). This transforms the data into a cube with Faraday depth as the third coordinate. Emitting and Faraday rotating sources along the line of sight can be separated, and the magnetic field structure in the galaxies can be investigated in 3D.

Single-dish measurements as obtained with the 100-m Effelsberg telescope will also be used in order to fill in the missing large-scale structures of the interferometer.

The PhD candidate is expected to take fully part on the data reduction and assist with the commissioning of the EVLA, including a period of residence in Socorro, New Mexico. The candidate may also be involved into further improvements with help of wavelet functions into the RM Synthesis technique.

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Code: **MK05** **Low-frequency radio polarimetry of spiral galaxies**

Radio continuum observations of galaxies at 350 MHz are currently being carried out with the Westerbork Synthesis Radio Telescope in the Netherlands. The main aims are twofold. First, the extent of the relativistic plasma (high-energy particles and magnetic fields) is to be determined. These will be complemented by future observations at still lower frequencies using the Low Frequency Array (LOFAR). Since these observations incorporate all Stokes parameters, they also allow to apply "RM Synthesis", a novel powerful tool to study the magneto-ionic properties of the interstellar and intergalactic media. Applied to data at low radio frequencies, this technique allows to disclose small rotation measures and thus probe the magnetised plasma at the lowest densities.

The PhD project will first comprise the data reduction, with emphasis on the careful calibration of linear polarisation. Removing man-made signals (RFI) and calibrating the data stream from the multi-channel backend are a challenge. Comparison of the resulting total-intensity images with data at other (lower and higher) frequencies allows to study the distribution and variation of the spectral index of the synchrotron radiation in the target galaxies. Applying RM Synthesis to the polarisation data cubes results in
a thorough "tomographic" investigation of these galaxies.

Experience with handling continuum data obtained with radio interferometers would be a helpful prerequisite for the successful applicant, but is not a must.

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Code: **UB01** **Studying the nature of dark energy with X-ray galaxy clusters**

In the last years, observations have shown that the expansion of the Universe is accelerating, despite all the massive galaxies in it attracting each other gravitationally. The reason for this acceleration is unknown; it may be related to a missing link in fundamental physics (the ``problem'' of Einstein's cosmological constant). Currently, the best way to study the nature of this ``dark energy'' component is through astronomical observations. Large efforts are being undertaken presently across many countries for this study. One method uses the evolution with time of the most massive clearly defined structures in the Universe: galaxy clusters.
With the ultimate goal of helping constrain this evolution as well as the physics of galaxy clusters, the thesis work would concentrate on reduction, analysis, and interpretation of X-ray, optical, or radio data of X-ray galaxy groups and clusters. Data available to the research group include XMM-Newton, Chandra, Suzaku, and (in the future) eROSITA X-ray satellite observations, weak lensing observations taken with various ground-based optical telescopes, as well as radio observations. Travel to the USA or Chile may also be required for obtaining additional ground-based observations.

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Code: **UB02** **The Stellar Initial Mass Function**

Investigate (theoretically) how unresolved multiple stellar systems affect an observed mass or luminosity function of stars, and extract the true underlying mass distribution. The full-scale modelling of Galactic-field populations requires treatment of ages, stellar evolution, metallicity distributions and multiplicity of stars as well as Galactic structure. The shape of the IMF below the hydrogen burning mass limit remains uncertain with the possibility of a discontinuity near the stellar/sub-stellar transition region. This is to be studied theoretically using available observational data.

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Code: **UB03** **The dynamical evolution of young and old star clusters**

Star clusters are known to be the fundamental building blocks of galaxies as most stars form in clusters. The physical processes driving early cluster evolution are to be studied with the aim of increasing our understanding of the formation and survival of clusters and the impact on the morphology of entire galaxies of these processes. Theoretical and computational methods will be used to investigate the physics of internal cluster evolution as a result of binary-star activity, stellar evolution and gas expulsion. External influences resulting from time-varying tidal fields of various strengths are to be studied with the aim of better understanding the observed cluster radius-age data including the outer reaches of the Milky Way and in extragalactic systems.

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Code: **UB04** **The mass function of star clusters**

The physical processes leading to early and old cluster evolution influence the observable mass distribution of star clusters. This is to be studied using semi-analytical and numerical methods in order to map-out the dependency of the cluster mass function on the host environment.

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Code: **UB05** **Dwarf galaxies and dark matter**

Fundamental physical principles (energy and angular-momentum conservation) imply that during early cosmological times when gas-rich pre-galactic rotationally supported structures merged to form the present-day galaxies, tidal tails were expelled and locally fragmented to form tidal-dwarf galaxies (TDGs). Cosmological arguments suggest this population of non-traditional dwarfs to be possibly very significant and that it may dominate the low-luminosity end of the galaxy luminosity function. These TDGs would not contain dark matter and may thus pose a major "contaminant" of the classical or cosmological galaxy population. The dynamical evolution of TDGs in host potentials is to be studied numerically and semi-analytically with the special attention on the Milky-Way satellite population to see if any of the satellites may be ancient TDGs.

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Code: **UB06** **The dynamical evolution of the brown-dwarf population in star forming regions**

Recent work suggests that brown dwarfs form together with stars but that they follow a different mass distribution which is disjoint from the stellar initial mass function. The fraction of binary systems among brown dwarfs (15 per cent) is also much lower than for stars (50 per cent or more), and their binding energy distributions are very different such that the brown dwarf binaries have an energy truncation at a higher level than stars. This project aims to bring this evidence together to investigate various formation mechanisms of brown dwarfs, and to study theoretically how they disperse throughout their birth cluster comparing their binary, spatial and kinematical properties with those of stars. The work will be performed with the GPU-based supercomputing platforms stationed at the Argelander-Institut and with dedicated codes.

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Code: **UB07** **The star-formation rates of dwarf galaxies and the origin of matter**

Recent work in Bonn has been showing that dwarf galaxies appear to have the same short (3 Gyr) gas- consumption timescales as major galaxies. The aim of this project is to extend this finding to spectro- photometric modeling of dwarf galaxies and to study the possible origin of the matter that must be replenishing the star-forming material.

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Code: **UB08** **Development and testing of a new cosmological model**

Assuming energy conservation to be valid on a cosmological scale, a new cosmological model can be derived which leads to good agreement with the SNIa data and other recent observational findings such as the star formation behaviour of galaxies of different mass. In this project, the student will work on the growth of structure in this new cosmology and further tests of it.

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Code: **UB09** **Measuring the thermodynamic state of intra-cluster plasma**

Understanding the distribution and thermodynamic properties of the hot, ionized intra-cluster medium, which fills the space between the galaxies in galaxy clusters and contains most of its baryonic mass, is a major topic of research in galaxy cluster cosmology today. Through better understanding of this intra-cluster medium (ICM) we aim to provide precision mass scaling relations for cosmological studies, as well as understand the ICM's effect on the evolution of the galaxy population. In addition to the X-ray observations, study of the Sunyaev-Zel'dovich (SZ) effect is a prime tool to detect and model this intra-cluster gas. The APEX-SZ team at the University of Bonn is actively involved in this field of research, and the prospective student is expected to join this effort by taking part in observation and analysis of the data from the APEX-SZ experiment. The main goal is to develop and test a parameter-free modeling method to describe the observations. Data from several other SZ as well as X-ray and optical experiments shall also be analysed in the framework of this project.

Bibliography:
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Code: **UB10** **Pair-instability supernovae in the local universe**

The most massive stars, assuming mass loss is not too strong, are thought not to form iron cores, but rather to become unstable due to electron-positron-pair formation before central oxygen burning. The collapsing oxygen-rich core will then ignite oxygen explosively, which may lead to pair-instability supernovae, leaving no compact remnant. While such explosions have been predicted since 50 years ago, they were often assumed to only occur in the early universe. However, very recently, pair- instability supernovae have been found observationally in the local universe. This PhD project aims at constructing the first progenitor and explosion models for local, i.e., finite metallicity pair-instability supernovae, using our most modern hydrodynamic stellar evolution code. The idea is to characterize the observable properties of the progenitor and of the supernovae, and to make predictions for the nucleosynthesis yields of pair-instability, which could well dominate the metal production in their host galaxies.

Bibliography:
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Code: **UB11** **Structural analyses of the gas distribution of high-velocity clouds, based on the Effelsberg-Bonn HI Survey (EBHIS)**

tba

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Code: **UB12** **The HI structure of nearby galaxies as explored by the Effelsberg-Bonn HI Survey (EBHIS)**

tba

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Code: **UB13** **The Rotation Rates of Stars**

Many massive stars spin very quickly, nearly at their break up velocity, while others spin slowly or not at all. The cause of their spin, or lack of it, is not known. State-of-the-art stellar evolution models suggest that the rapidly rotating stars should have peculiar surface chemical abundances, e.g. enhanced nitrogen, but this is also not always seen. Nobody knows why.

The VLT-FLAMES Tarantula survey of about 1000 stars in the Large Magellanic Cloud is in the process of improving our observational database of surface abundances and rotational velocities of massive O and B type stars, many of which are binary systems. This project is part of the effort to understand these already puzzling observations. It will involve developing quantitative algorithms for a new stellar population model which combines nucleosynthesis and mixing, circumstellar discs, magnetic fields and, most crucially, binary stars.

Bibliography:
Evans et al. (2011) A&A 530, 108.

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Code: **UB14** **The Origin of Carbon-rich Stars in the Galactic Halo**

The Galactic halo contains many carbon-rich stars, according to some surveys up to 20% of halo red giants are carbon rich. These stars defy an explanation in standard stellar evolution theory because carbon is made during helium-burning while these stars are still hydrogen-burning. One solution is that they accrete material from a binary companion which is now a white dwarf, but models predict about 2% should be carbon rich.

The most recent observations suggest there may in fact be two populations in the halo with different carbon-rich stellar fractions. The aim of this project is to understand the origin of this difference and, in turn, identify why there are so many carbon-rich stars in the Galactic halo. Is the binary model applicable for most of them? Is another source of carbon required? Is star formation different in the halo? This will lead to an understanding of the oldest stars in our Galaxy and hence shed light on the origin of the Milky Way itself.

Bibliography:
Izzard et al. (2009) A&A 508, 1359
Carollo et al. (2011) arXiv 1103.3067.

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University of Cologne
1st Physikalisches Institut

Group website

Code: **UK01** **Physics of Low-Luminosity Radio Nuclei**

tba

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Code: **UK02** **NIR Studies of the Black Hole at the Center of our Galaxy**

The compact source Sgr A* that can be associated with the massive black hole at the center of the Milky Way shown a strong variability from the radio to the X-ray wavelength domain. The most recent results from a near-infrared observations revealed polarized NIR flare emission of Sgr A*. This can be interpreted as emission from spots which are on relativistic orbits around Sgr A*. Emission from a possible jet or outflow from such a disk can also contribute. We also find that the variable NIR emission of Sgr A* is highly polarized and consists of a contribution of a non- or weakly polarized main flare with highly polarized sub-flares. The flare activity shows a possible quasi-periodicity of 20±3 min consistent with previous observations. The highly variable and polarized emission supports that the NIR emission is non-thermal and is consistent with emission from a jet or temporary disk. Alternative explanations for the high central mass concentration involving boson or fermion balls are increasingly unlikely. Observations with the VLT, VLTI and in future with the LBT will allow us to better discriminate Sgr A* from the surrounding stars, to register the light curves with a higher signal to noise, and to further develop the theoretical models.

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Code: **UK03** **VLBI Studies of the Black Hole in the Center of our Galaxy**

The compact radio source in the center of our Galaxy, Sagittarius A* (Sgr A*), is probably the best candidate of a super-massive black hole (with approx. 3.5 - 4 million solar masses). At centimeter wavelengths, the radio image of Sgr A* is scatter broadened, not allowing a direct view into the nucleus. At short millimeter-wavelengths, however, the scatter broadening vanishes and the underlying source begins to shine through. With Very Long Baseline Interferometry (VLBI) at 3 mm wavelengths and below, it is therefore possible to study the immediate environment of a super-massive black hole. With a spatial resolution of a few ten Schwarzschild radii, one is not too far from the scale, where general relativistic effects should become visible. Direct signatures of the metric near the black hole, e.g. a shadow (with possible distortion, depending on whether the black hole is rotating or not), are expected to become observable. A first VLBI observation at 1 mm already indicated a size of < 20 Schwarzschild radii. Clearly more data are needed to confirm and improve this first estimate. The new project focuses on more extensive mm-VLBI monitoring of Sgr A* in order to search for possible signatures of the black hole and for variations in its source structure, the latter likely being related to the observed quasi-periodic brightness variations in the infrared bands. In addition to the 3mm-VLBI monitoring of Sgr A*, it is further planned to perform new VLBI experiments at shorter wavelengths (2mm, 1mm), adding new mm-telescopes, as they now become available for VLBI.

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Code: **UK04** **Near-Infrared Instrumentation for Large Interferometric Observatories**

The 1st Physics Institute of the University of Cologne is participating in two international collaborations to develop near-infrared detector systems for leading interferometric telescopes. For the Very Large Telescope Interferometer in Chile the institute is contributing two spectrometers to the GRAVITY project, a six-baseline interferometric camera for the K band. For the Large Binocular Telescope in Arizona the institute is developing the fringe and flexure tracking unit for the LINC-NIRVANA project, a direct imaging interferometric camera for JHK bands. Both local project teams consist of senior scientists, post docs, PhD students and technicians. The student can get involved in either of the the two projects by designing and testing of actual hardware components in the laboratories of the institute, by writing of control software, or by building and operating accompanying laboratory experiments which demonstrate crucial sub-functions of the final instrument. The student will actively take part and experience the work of a distributed multi-national consortium of scientists, engineers, and technicians. Complementary to the instrumentation work and in collaboration with the MPIfR (Prof. Anton Zensus), the student will participate in the observational astronomy projects of the workgroup of Prof. Andreas Eckart covering sources that are active from the radio to the infrared wavelength domain.

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Code: **UK05** **Physical and chemical structure of high-mass star forming regions**

The study of high-mass star formation is a very active field of astrophysics, and has seen a lot of progress in the last years. This trend is going to continue, since new and exciting data have or will soon be available, mainly through the data from the Herschel Satellite (already in orbit), the SOFIA airplane observatory and the ALMA interferometer commencing operation end of 2011, but also through other instruments like the Submillimeter Array (SMA) in Hawaii, and both data analysis and physical and chemical models of high-mass star formation are also advancing at a rapid pace.
The main open questions concern the initialization of the star formation, the process of fragmentation in clusters, and the termination through onset of feedback, such as outflows and ultraviolet radiation. In the framework of the Cologne/Bonn SFB956 "Conditions and Impact of Star Formation", which is a collaboration between the Universities of Cologne and Bonn and the MPIfR, a very detailed characterization of the physical and chemical structure of high-mass star forming regions by means of detailed radiative transfer methods and chemical modeling will be carried out to help answering these questions. This will build upon line survey results from the Guaranteed Time Key Projects from the Herschel/HIFI instrument and interferometric data from SMA and eventually ALMA.

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