10 YEARS OF THE OSKAR KLEIN CENTRE

2008 - 2018

Oskar Klein centre

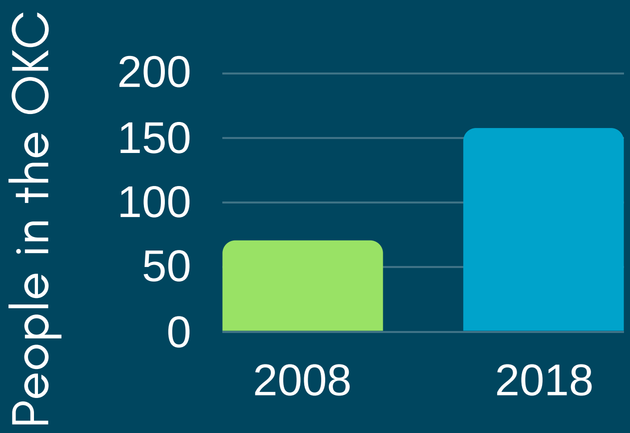
DIRECTOR'S FOREWORD

It is a great pleasure and privilege to introduce this celebration of the Oskar Klein Centre's first decade. The OKC began with an ambitious vision to forge new interdisciplinary connections in Stockholm, in order to answer some of the biggest questions in fundamental physics. In the subsequent decade, OKC members have been at the forefront in answering some of these questions and creating new paths to address new cosmic puzzles that have emerged since. The following pages celebrate OKC highlights from the past decade and some of the people behind them. I am excited about building on this strong foundation in the coming decade.

HIRANYA PEIRIS
Oskar Klein Centre Director

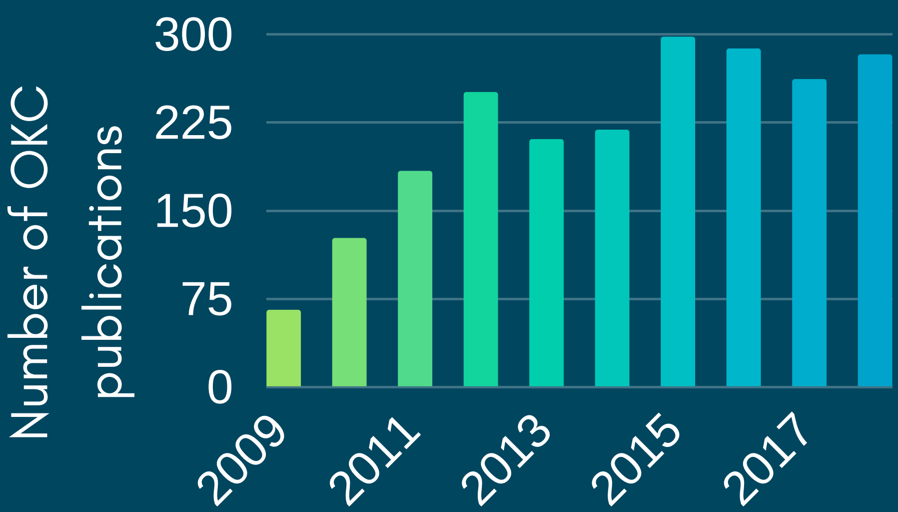
STATISTICS

2008-2018



OKC has the highest percentage of international publications of all the SU departments and collaborative centres.

(Analysis of International Research Collaborations at Stockholm University, 2018)



THE BEGINNING

The origins of the OKC can be traced back to the creation of what is now called the AlbaNova University Centre which was inaugurated in 2001. The unique environment for astronomy, particle, and astroparticle physics created at AlbaNova as the astronomy department moved in from its out-of-town location in Saltsjöbaden, and the physics departments of SU and KTH got a common location, was soon a melting pot for new collaborations. The first successful application, emphasizing the new opportunities at AlbaNova, was "The AlbaNova High Energy Astrophysics and Cosmology (HEAC) Centre". This was submitted in 2004 to the Swedish Research Council (VR) as a response to their call for "Contributions to strong research environments", and was granted 22 MSEK over 6 years, 2005-2011. Thus, the funding agency agreed with us about AlbaNova being a strong research environment in our field! HEAC was concentrating on financing PhD students and making a common PhD course curriculum for astronomers and physicists, and did not fund postdoctoral research. So in 2007, when VR announced a new scheme - the 10-year Linnaeus grants - we both enlarged the scope to include support for postdocs and an associate professor, and also included particle physics in the range of topics. The successful application was originally called "The Cosmoparticle Collaboration (CPC)".

It was however, after the proposal was approved, soon given the name “The Oskar Klein Centre for Cosmoparticle physics” (OKC). This was done with approval from living relatives of the legendary theoretical physicist at Stockholm University, Oskar Klein. He is, of course, internationally famous for the Klein paradox, the Klein-Gordon equation, the Klein-Nishina formula and Kaluza-Klein theory, among other key discoveries and inventive ideas.

With the proposal for the OKC we tried to elucidate some of the main challenges in current astrophysics and particle physics: “What is dark matter? What is dark energy? How did structure form? What is the nature of the most energetic processes in the universe? How is the universe described by fundamental theory?” We tried to show that with our combined expertise, and, in particular, with new appointments at postdoctoral level, we could contribute significantly to the research surrounding these fundamental questions. We also funded the first years of one permanent position, for which Stephan Rosswog was selected after strong competition.

We prepared very carefully for the 2- and 6-year reviews, and in particular for the latter one we had rehearsals on how to present our case in the face-to-face meeting with the external evaluators. We cleared these obstacles successfully.

The hope for the OKC was to build one of the most significant European centres in our field, an aim that has been fulfilled. With the creation of the OKC, and e.g. our massive announcement in 2008 of ten postdoc positions, the word about the OKC spread very rapidly. Of course, thanks to developments in the last couple of years, the OKC environment has grown considerably, with several new people coming in. We were in total 70 people, including postdocs and PhD students, in the OKC environment when the grant started in 2008, and according to the latest count this has now grown to over 150.

The OKC was born in a positive spirit of collaboration and has remained so for 10 years now. The common activities, like the OKC Colloquia, the Working Group meetings, and the OKC days, have been essential for encouraging the “OKC spirit” – I hope these will survive for a long time to come.

Even though the original VR Linnaeus grant for OKC has now ended, I think the field is facing a great future – as is OKC!

LARS BERGSTRÖM

First Oskar Klein Centre Director

SCIENCE AT THE OKC

Tracing Diffuse Starlight in Galaxy Cluster Abell S1063
Photo credits: NASA, ESA, and M. Montes (University of New South Wales)

What is the structure and fate of our Universe? How do galaxies form and evolve?

A comprehensive picture of our Universe requires that it be examined and understood on both large and small scales. On large scales, OKC researchers who study the cosmic microwave background and the large-scale distribution of galaxies are working out the properties of the cosmological model. On small scales, OKC members investigate star formation in galaxies and the structure of the interstellar medium.

What is the nature of dark matter?

The presence of dark matter is inferred from its gravitational effects on, for example, the motions of stars inside galaxies and galaxies in clusters, and gravitational lensing. Members of the OKC seek to detect the particles that constitute dark matter, with a particular focus on Weakly Interacting Massive Particles (WIMPs) and axions or axion-like particles. OKC experimentalists work with both direct and indirect dark matter detection methods while OKC theorists are engaged in phenomenological interpretations of possible dark matter signals and theoretical predictions from models.

Involvement in dark matter direct detection experiments includes XENON and a nucleic acid detector. Indirect detection, looking for the annihilation or decay products of WIMPs, includes searches performed with gamma-ray observations by the FERMI-LAT satellite, the HESS Cherenkov telescope, and the neutrino telescope IceCube. Experimentalists working with ATLAS at the Large Hadron Collider are searching for evidence of dark matter produced in the detector and for other new particles and particle properties that are not predicted by the current Standard Model.

The XENON Experiment underground. Left, the water tank with a poster showing what is inside. Right, the three-story service building.

SCIENCE AT THE OKC

Understanding the behaviour and properties of supernovae, neutron stars, and black holes.

These events and objects are the end-result of the star formation process and are studied at the OKC both for their own sake and for their application to other outstanding problems in our Universe. For example, OKC researchers use Type Ia supernovae as standard candles with which to measure the expansion of the Universe. With gravitational wave observatories turning on, OKC scientists are working to predict and observe the electromagnetic signatures associated with the events which produce this type of radiation, including merging black holes and neutron stars. Theoretical work at the OKC underpins the extensive observational programmes to detect these sources and seeks to understand them in the context of different theories of gravity.

What is the correct theory of gravity?

Alternative theories of gravity are motivated by the desire to better describe the observationally-driven concepts of inflation, dark matter, and dark energy in our Universe. Theoretical researchers at the OKC are actively investigating and developing alternative gravity theories, including bimetric gravity and higher spin gravity.

Profiles : Josefin Larsson

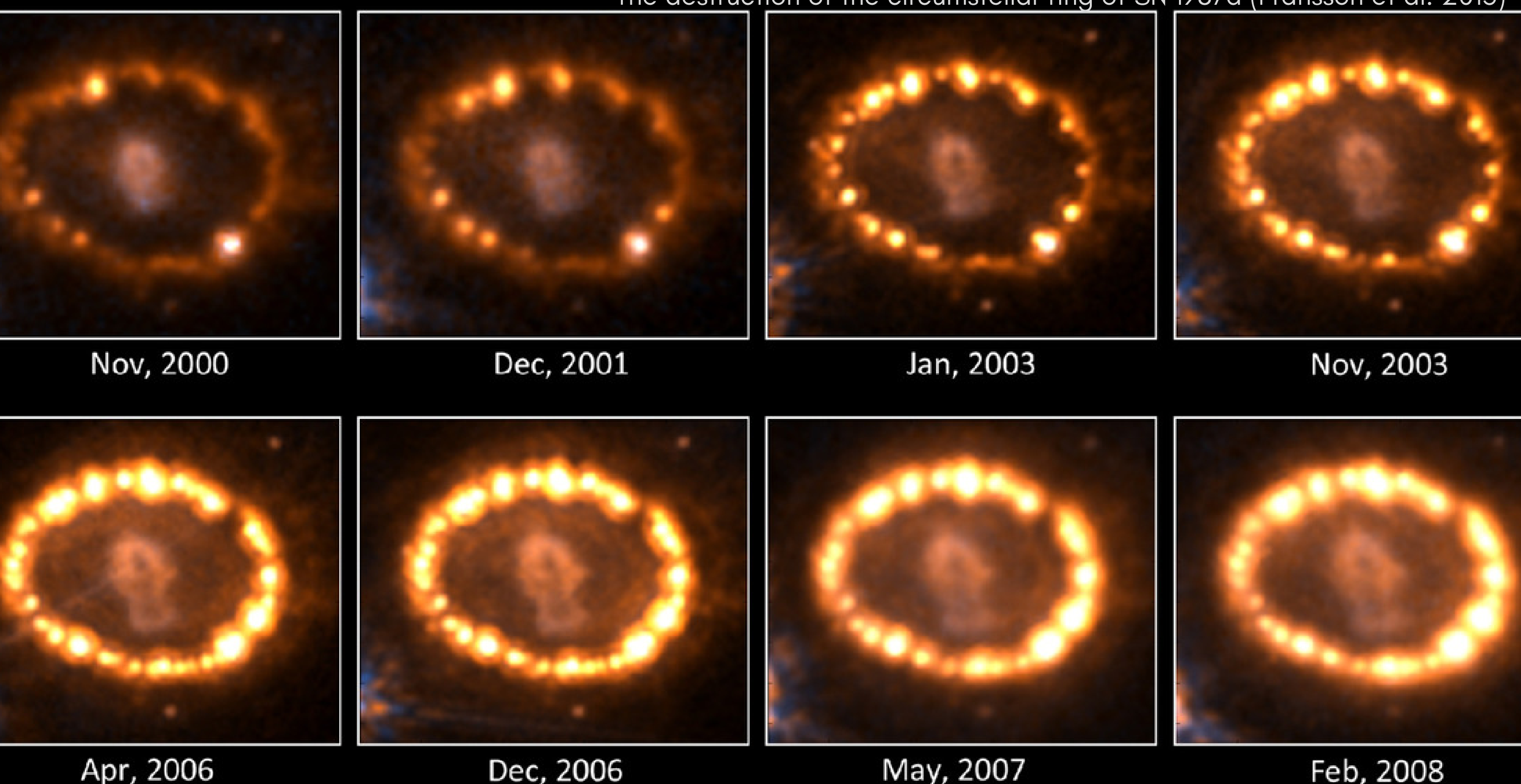
I think one of the unique things about the OKC has been the focus on funding postdoc positions. The postdocs have brought a lot of new expertise and energy to the research environment.

Josefin joined the OKC in 2009 as an OKC Fellow after finishing her PhD at the University of Cambridge. Her PhD research focused on X-ray observations of accreting black holes in the centers of galaxies. After joining the OKC her research interests broadened and she now works on gamma-ray bursts and supernovae (SN 1987a, in particular) using data from across the electromagnetic spectrum.

Her research attempts to understand explosions and jets in dying stars. Jets, narrow streams of plasma traveling at close to the speed of light, are seen from accreting black hole systems and in dying stars. They are thought to be at the heart of the mysterious gamma-ray bursts. Josefin wants to connect models of jets to physical properties of sources, including the speed of plasma in the jet.

Josefin is now an Associate Professor at the KTH Royal Institute of Technology. She is also a Wallenberg Academy Fellow.

The destruction of the circumstellar ring of SN 1987a (Fransson et al. 2015)



Profiles : Chad Finley

Chad Finley's research is in astroparticle physics, primarily focused on neutrino astronomy. He has been a member of the IceCube Neutrino Telescope project since 2006. He joined the OKC in 2009 as an OKC Fellow, where he continued as point-source analysis coordinator for IceCube.

High-energy neutrinos can be used to understand extreme environments in the universe, mysterious places where particles can be accelerated to ultrahigh energies, such as the regions near black holes. Neutrinos travel unabsorbed by matter and undeflected by magnetic fields, providing a unique view of the heavens that is complementary to what is seen with light. Chad uses neutrinos to try to identify the astronomical sources where cosmic rays are born and understand the physical processes that create them.

Chad is now Associate Professor in the Physics Department at Stockholm University and Deputy Director of the OKC.

At the OKC one is continually exposed to new ideas as they emerge in neighbouring fields, creating a superb environment for cross-disciplinary research.

OKC Science Highlight : High Energy Neutrinos

Situated at the South Pole the IceCube Neutrino Observatory looks for Cherenkov light that is produced when subatomic particles zip through the clear ice. The direction and energy of the particle can be recovered. OKC researchers have been involved in the IceCube Collaboration since its beginning. In 2013 the collaboration reported an analysis of their data that presented 28 events. The two highest energy events are about 1 PeV each, the highest energy neutrinos ever observed. These neutrinos were seen from many different directions in the sky. Later an even more energetic neutrino was discovered from an active black hole in a distant galaxy.

The IceCube Lab at the South Pole with aurora
Credit: Icecube/NSF

In this artistic rendering, based on a real image of the IceCube Lab at the South Pole, a distant source emits neutrinos that are detected below the ice by IceCube sensors, called digital optical modules.

Profiles : Stephan Rosswog

I love the enormous concentration of expertise at the OKC and its vibrant interdisciplinary atmosphere.

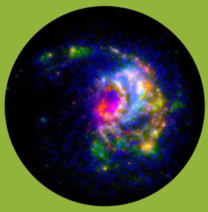
Stephan Rosswog earned his PhD in theoretical physics with Friedrich-Karl Thielemann at the University of Basel. After postdoctoral positions in Cologne (Germany) and Leicester (UK), he took up a faculty position in Bremen, Germany in 2003. In 2012 he joined the Oskar Klein Centre at Stockholm University as a professor in the Astronomy Department.

He is interested in the multi-messenger astrophysics of compact objects, in particular their fluid dynamics, gravitational waves, nucleosynthesis and electromagnetic emission. To that end, he performs computer simulations of the involved physical processes. He is studying events such as tidal disruptions of stars by black holes, collisions between white dwarfs, and compact binary mergers involving neutron stars.

He has co-authored the widely used textbook "Introduction to High-Energy Astrophysics" (Rosswog and Brüggen, Cambridge University Press, 2007).

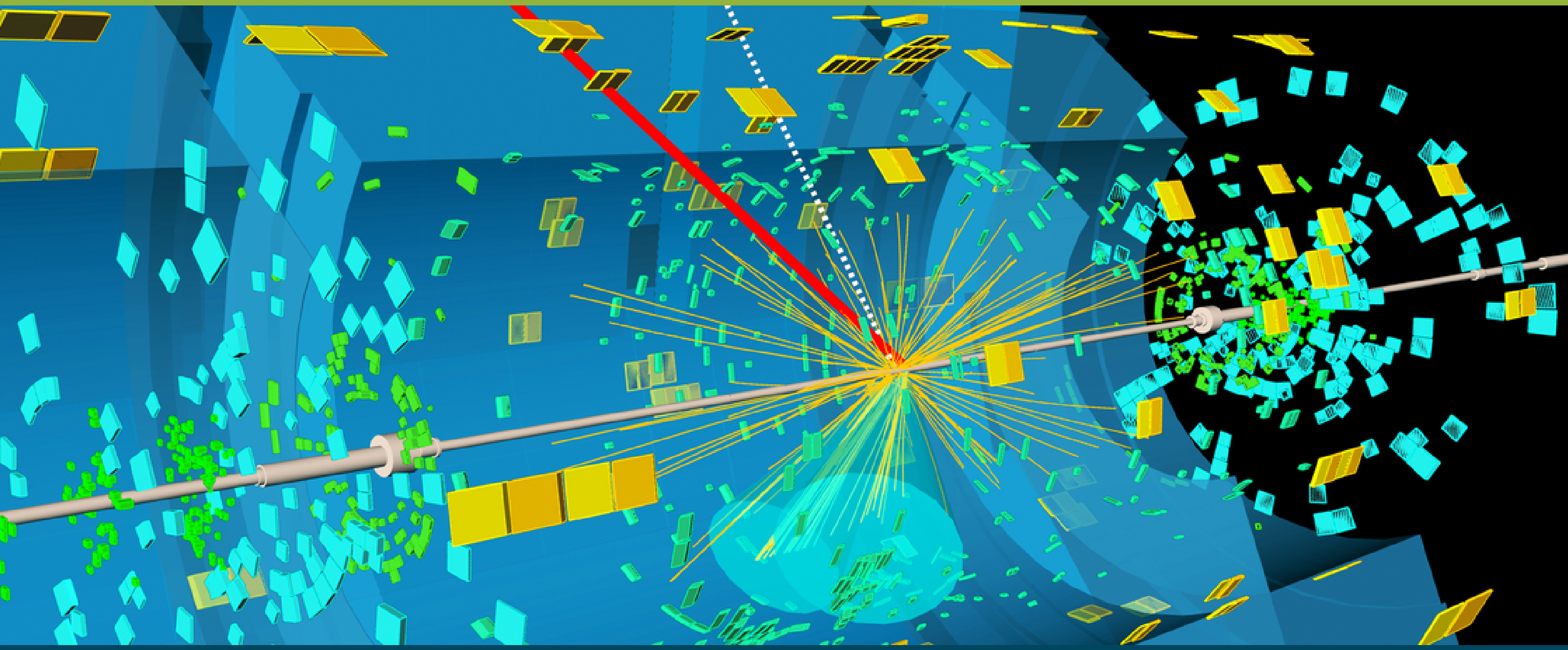
OKC Science Highlight :
Gravitational Waves from Merging Neutron Stars

On August 17, 2017 gravitational waves from the merger of two neutron stars were detected for the first time. Within a few hours, scientists around the world had pinpointed the source to a galaxy 130 million light years away. This is the first time scientists have observed any astrophysical phenomenon in both gravitational waves and electromagnetic radiation. OKC researchers participated in the study of the electromagnetic counterpart, the search for neutrinos from the event, and a modelling study of the production of heavy elements from these mergers.



OKC Science Highlight :
The Lyman Alpha Reference Sample

Bright star-forming galaxies contain large amounts of neutral hydrogen gas. This gas makes up the majority of the fuel that becomes molecular gas and can be used by the galaxy to form stars. Astronomers at the OKC use the Hubble Space Telescope to image the Lyman Alpha emission from this gas in nearby galaxies. This helps them to better understand the same type of light from galaxies in the early universe. OKC researchers also study clusters of newly formed stars in these nearby galaxies and compare them to stars forming in isolation. These observations are used to estimate how long star clusters live before breaking up and dissolving into the galaxy.



Higgs boson decaying to two b-quarks. ATLAS Collaboration

OKC Science Highlight :
Discovery of the Higgs Boson

On the 4th of July, 2012 the discovery of a new particle was announced. The ATLAS and CMS experiments at the Large Hadron Collider reported the observation of a strong excess of proton-proton collision events compatible with the Higgs boson with a mass of 125 GeV. Detection of the Higgs verifies the Standard Model which explains the properties and forces between particles in our Universe. The Nobel prize in 2013 went to Francois Englert and Peter Higgs for predicting the existence of this particle 50 years ago. OKC members are involved in many different aspects of the ATLAS experiment.

OKC Science Highlight : Bimetric Gravity

Elementary particles and the fields that mediate interactions between them are classified based on their "spin". Interactions of fields with spin 0, 1/2 and 1 are well understood. These, when arranged in appropriate multiplets, form the building blocks of the Standard Model of particle physics (SM). The existence of field multiplets and their mixings are crucial for the viability of the theory. In contrast to the intricate structure of the SM, General Relativity (GR) which is the currently accepted theory of gravity, is the simplest possible theory of a single spin-2 field, the so called "metric" field.

By now there are many theoretical and experimental indications that new physics, beyond what the SM and GR can describe, exists. Since many of these are associated with gravitational phenomena, it is natural to consider extending General Relativity in analogy with the Standard Model. However, until a few years ago, attempts to write a theory of two or more interacting spin-2 fields generally resulted in inconsistencies, leading to a belief that such theories may not exist. This is no longer the case. The "bimetric" theory, constructed in 2011 by OKC researcher Fawad Hassan and OKC Fellow Rachel Rosen and later worked on by many other OKC researchers, is a theory of two interacting spin 2 fields which does not suffer from the earlier inconsistencies. Physically, it describes a theory of gravity in the presence of an extra species of massive spin 2 particles with negligible interactions with Standard Model fields. The new massive particle could serve as a dark matter candidate. Another interesting feature of the theory are contributions to dark energy even in the absence of a cosmological constant. Examples of theories of multiple spin 2 fields, with more than two fields interacting at a vertex, were constructed in 2018. The hope is that these constructions will lead to an understanding of spin 2 theories on par with the lower spin theories and allow us to construct extensions of GR and SM that can adequately address the problems of new physics.

OKC:ers Working Outside Academia

Postdoctoral researchers and graduate students from the OKC are using their skills to solve new and exciting problems in many different roles for industry, governmental agencies, and other organizations. These include data science, particle and photon therapies for medical treatments, environmental policy, carbon footprint estimation, renewable energy, communication and marketing, entrepreneurship, analytical consultancies, project management, and software development, among others.

A New Eye on the Changing Heavens

The Large Synoptic Survey Telescope (LSST) is one of the largest astronomy projects of the next decade. It aims to survey 10 billion galaxies out to a redshift of four including the ability to detect objects 100 times fainter than those seen with current large surveys. LSST will take pictures of the entire southern sky every few days for a decade, creating a motion picture of the heavens. Comparing these images will allow OKC scientists to discover and study transient phenomena -- when objects change in brightness or explode. Also, researchers will learn about dark matter by mapping its distribution and evolution and studying low surface brightness galaxies which are currently not explained in cold dark matter galaxy formation scenarios.


LSST Facility construction. Photo credit M. Park/Inigo Films/LSST/AURA/NSF

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