Outline of Activities September 2019 onwards at Lund Observatory (LO)

Colin Carlile

There will be two main threads to my activities

1. Intensity Interferometry (II) Studies & Implementation

This work will be carried out in collaboration with Dainis Dravins.

I foresee completing my Masters thesis on II laboratory simulations in May 2019. This work has focussed on upgrading the experimental set-up at LO to a second-generation facility that more realistically simulates II on the ground. Our goal is to probe what technical challenges there would be in building a functional facility in the field and what scientific benefits would accrue. This work is by no means complete and will continue after my Masters study. There is now a need to try to understand as many aspects as possible – experimental and theoretical - to support the growing enthusiasm in realising an II capability on the ground where actual measurements of spatially resolved Main Sequence bright stars (rather than just their starlight) can eventually become routine. II represents a significant step-change in spatial resolution in the optical range.

The ultimate such observing platform would be CTA, the Cherenkov Telescope Array, which has been, up to now, dedicated to mapping Cherenkov light from gamma-ray interactions in the atmosphere. I have interacted with CTA management over the last two years with the goal of getting an II option accepted as a complementary science channel for CTA. Together with others in the II SWG (Science Working Group), these efforts have borne fruit. II represents a significant broadening of the scientific reach of CTA for a relatively modest investment and this has been recognised by the project leaders. This does however require political skills, which I believe my background allows me to bring to the initiative. This work is just beginning and resources need to be found through II SWG partners to fund this activity.

Sweden has, in the past, been a formal member country in CTA but this has now lapsed. It is time to reinvigorate Swedish interest at the VR level now that CTA is transitioning from a grass roots initiative to a professionally run observatory.

A stepping-stone to CTA and a small-scale proving ground of the technique and the science that will be generated exists in the shape of the four 12m diameter telescopes of the VERITAS array in Arizona. We are in close contact with the scientific team there and in Utah and this activity will be strengthened in coming years as we collaborate with measurements of appropriate targets and demonstrate the feasibility of the technique beyond the measurement of stellar radii.

II as an investigative tool was conceived and implemented for stellar studies more than 50 years ago by Hanbury Brown and Twiss. It challenged the conventional wisdom but was eventually accepted as being based on solid scientific foundations – the quantum correlation of photons. However, the method was sidelined soon afterwards by the advances in amplitude interferometry. In turn amplitude interferometry reached its own limits and the spotlight now turns to Intensity Interferometry in the pursuit of higher spatial resolution. Interestingly what became known as photon correlation spectroscopy (dynamic light scattering) in soft condensed matter or the HBT effect (Hanbury Brown and Twiss) in particle physics has been applied very successfully and widely in scientific fields other than astronomy. There is therefore great potential in making efforts to draw together the different practitioners of this effect to share methodology. Practically we have contact with a group at XFEL in Hamburg – the European X-ray Free Electron Laser facility who use the identical technique to us at LO in order to study the degree of coherence in a free electron laser. With MAX IV now considering the addition of an FEL to the synchrotron light source in Lund we can foresee beneficial mutual collaborations within LU also.

We are considering seeking funding for this activity, and political support, from the VR and an application will be made to the Royal Physiographic Society for travel funds. An international case is being considered for an application to the ERC.

2. Neutrino observations applied to astrophysics

I have been an active member for four years of an international collaboration led by Uppsala University (UU), where I am a Guest Professor. The goal is to study, design and eventually implement and operate a world-leading neutrino facility in Sweden by generating neutrinos at ESS and beaming them to Garpenberg, 540 km from Lund, where they would be detected in a megatonne Water Cherenkov detector. The scientific goal of the project is to accurately measure the degree of neutrino oscillations during their transit and thereby to shed light on parity violation in the lepton sector with the aim of understanding the matter-antimatter asymmetry in the Universe.

Although this is the principal goal of ESSnuSB, as the project is called, there is a broad, unexploited scientific potential to use the detector to study topics of astrophysical interest. This is facilitated by the fact that the ESS is a pulsed facility that generates beams of protons and neutrons for only 3 ms every 70 ms. The neutrino beam generated would also be pulsed, but in this case the pulse would be compressed to a width of only ~10 μs. The detector in Garpenberg will therefore be in standby mode for more than 99% of the time. Nevertheless neutrinos will continue to stream through the detector from a variety of natural sources and a significant number will be detected that have not been generated in Lund. These sources comprise terrestrial origins, solar origins, diffuse cosmic origins and supernovae. A wide range of scientific challenges can therefore be addressed. Many of these challenges sit on the boundary between particle physics and astrophysics and benefits would result if these two communities were encouraged to work together more closely. That is what I aim to do in order to broaden the scientific output of this large investment.

As an example, whilst the precise observation of the Cosmic Microwave Background (CMB) has led to insights into the condensation mechanisms that were occurring in the Universe ~380,000 years after the Big Bang, it is now, with such a large detector, becoming feasible to take the first steps in the study of the Cosmic Neutrino Background (CNB). These neutrinos are sometimes referred to as relic neutrinos since they are a witness to conditions only 1 second after the Big Bang. These neutrinos are very low energy and the cross-section for detection is therefore exceedingly low. Thus we are at the same point as when neutrinos themselves were experimentally discovered in 1956, having faced with what then was considered to be an impossible task. The PTOLEMY project, using tritium in graphene, represents a realistic path towards a first observation. Sitting side by side with the large water detector in Garpenberg such an instrument would concentrate the study of natural sources of neutrinos in Sweden. On a different tack, the stability or otherwise of the proton has consequences for a better understanding of the energetics of the early Universe. Even though the half-life of the proton must be greater than the age of the Universe there is a finite chance that proton decay could be observed in the detector at Garpenberg, given the large number of protons in the detection medium.

The study of these varied sources of neutrinos – terrestrial, solar, stellar and cosmic - is currently not considered as a prime activity within the ESSnuSB collaboration. I will continue to collaborate on ESSnuSB for CP (Charge-Parity) violation investigations but, as part of a future role at LO, I would be active in ensuring that the scientific uses of ESSnuSB for astrophysical interests are properly represented and assessed.

The ESSnuSB collaboration holds EU grants of ~3.5M€ in order to produce a Conceptual Design Report (CDR) by 2021. My appointment at UU is funded through these grants. However we are now looking to secure resources both to enable a fully detailed Technical Design Report (TDR) to be prepared as well as to study the scientific optimisation of the detector at Garpenberg, which is not yet financed. In these cases the funds that would fall to me could be administered by LO.

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24th November 2018