EXOPLANETARY SYSTEMS - NUAP Draft Report

Summary
This discussion document outlines the major scientific goals in Exoplanet research over the next 10 years. We highlight areas of excellence in the current UK programme and show how these map onto the scientific goals in the mid-to-longer term. We emphasize that in such a fast moving area a responsive mode for funding new initiatives is imperative.

Introduction
It is only 14 years since the first discovery of planet around a normal main sequence star. Since then the subject has undergone rapid development. The UK community was slow to engage with this new field, but initially through radial velocity surveys and dynamical simulations, and more recently through transit surveys and atmospheric modeling, has now developed world leading programmes.

In such a fast moving field, prediction is fraught with dangers. This fact was recognized in the 2007 STFC Exoplanet Strategy Panel Report (Chair M. McCaughran) which found that frequent examination of the program would be necessary to review and encourage new and innovative ideas. None-the-less, at times such as these, it is instructive to look at the goals of the research and examine where we are now, and look forward.

Note that the title of this report implies a more holistic approach then simply looking at the planets themselves. This is recognition that our understanding of planets is intimately related to that of the host stars. Consequently, we will also examine our understanding of the host stars, particularly in terms of their importance for exoplanet studies. Importantly, asteroseismology is the only way (apart from neutrinos) that we can probe the interiors of stars, hence is fundamental to our understanding of stellar evolution.

This report does not consider disk and planet formation or their earliest orbital evolution such as migration (areas of recognized UK excellence) - these are discussed in a complimentary report.

Goals of the Research

The immediate goal of exoplanet research is an understanding of the formation and evolution of exoplanetary systems, including full characterization of the host stars. This includes the search for biomarkers in the atmospheres of exoplanets. Ultimately, of course, the goal is to find and study Earth-like planets in the habitable zones of their stars – environments where life is possible. To reach our goals there are several milestones:

(a) The detection and confirmation of bright, habitable zone (HZ) transiting planets, including, in particular, terrestrial planets and Super-Earths. While difficult, the atmospheres of these planets could be studied via transmission spectroscopy.

(b) Obtaining the planet population statistics in order to provide a powerful test of models of planet formation and evolution, required to understand their origin in general, that of habitable planets more particularly, and that of planet Earth especially.

(c) Direct imaging of nearby, young and bright, and then old and faint giant exoplanets and their spectroscopic examination. Eventually, imaging and spectroscopy of terrestrial planets.

UK Areas of Excellence

The UK currently leads the world in a number of areas

1) Ground based transit surveys for large planets around bright stars. The WASP project is now the biggest provider of close in, giant planets. This will continue even in the era of CoRoT/Kepler as the SuperWASP host stars are significantly brighter and hence easier to follow up.

2) Molecular spectroscopy and planetary atmospheric models of gas giants and exo-earths at various stages with and without bio-signatures. Several UK groups are recognized as leading in this area (both observation and modeling).

3) CoRoT - both asteroseismology and planet detection aspects. This mission is the first significant attempt to detect transiting planets from space. In principle, while the telescope has a relatively small field of view, it has the potential to detect terrestrial planets with periods of several months. The CoRoT team recently announced the discovery of a $\sim 2R_{Earth}$ planet. While the UK is not leading this mission there are certain areas in which we can claim leadership such as asteroseismology and some aspects of the planet detection programme.

4) On UKIRT the near infrared WFCAM Transit Survey (WTS) is an ongoing UKIRT Campaign Survey awarded 200 nights of observations. WTS aims at detecting transiting planets around M dwarf stars at infrared wavelengths, and is probing new parameter space in terms of transiting planet size and host star temperature. WTS has attracted significant European interest and led to the EU Initial Training Network RoPACS (Rocky Planets Around Cool Stars), funded through the European Commission to search for and study cool star planetary systems and explore future space mission concepts to study exoplanets.

5) The AAO Planet search. This is one of the leading programmes for the radial velocity detection of exoplanets and has published objects with minimum masses as low as ~22M_{Earth}.

6) Ground based imaging of old planets around evolved stars. A high spatial resolution, proper motion survey of possible companions to a sample of nearby white dwarfs has been underway for several years. It has produced several candidates but is awaiting confirmatory, second-epoch observations.

7) In the microlensing area the UK is currently providing the lead technology to enable the detection of low mass planets (<1M_{Earth}) and to understand the statistics of the planet populations in the Galactic disk and bulge. This is achieved through the ARTEMiS (Automated Robotic Terrestrial Exoplanet Microlensing Search) software system. The only observational efforts currently realistically able to achieve these goals are those of the UK-led RoboNet-II, MiNDSTEp (some UK involvement), and MONET (German-led), together forming a world-spanning quasi-network, contending for the first detection of an Earth-mass planet.

Exoplanets and the search for life beyond the Earth remain one of the most exciting areas of public interest in astronomy. This is best demonstrated by the extensive coverage in BBC online news and the level of media interest in general (A. Heward & R. Massey, "Finding the Real Media Stars: Analysis of Media Coverage of the UK's National Astronomy Meeting", in "Communicating Astronomy to the Public", Issue 4, pp. 5-11, August 2008).

Roadmap

We are fortunate that the UK has strength in some of the most important areas of current research (included here are ongoing projects with projected lifetimes extending beyond 3 yr from now):

Transits: The Roadmap to PLATO

Exploitation of CoRoT and Kepler. The UK has involvement in CoRoT planets and seismology. In the case of Kepler we have involvement through membership of the Kepler Asteroseismology Steering Committee and chairs of a number of subgroups.

Required resources: CoRoT/Kepler exploitation.

SuperWASP is the current UK led facility that has become the most successful transit detection system. Various improvements are being made to reduce systematic noise source and improve its photometric precision. We expect that the

SuperWASP facilities will become cheaper to run as the systems continue to be developed. Further photometric follow up is carried out via the Liverpool Telescope.

Required resources: operations and exploitation, access to the LT

As noted in the MacCaughran report, there is a need for a second generation optical/near IR wide-angle survey optimized for *bright* stars (IWAS). This would be capable of detecting ice giants or possibly Super-Earths with late type K/M dwarf hosts. The stars would be bright enough to enable followup observations with reasonable time allocations on 4m sized telescopes (radial velocity spectroscopy) and JWST (atmospheric characterization through transmission spectroscopy).

Required resources: construction (shared with Universities), operations and exploitation.

PLATO is an ESA Cosmic Vision candidate mission (launch 2017). Its objectives include the detection of Earth analogue systems around bright stars (unlike CoRoT and Kepler which have relatively small fields of view with few bright stars). PLATO will produce a database of well characterized exoplanetary system that will lead to a break through in our understanding of the evolution of exoplanetary systems. The UK is well positioned in this project with the PI of the Science Consortium and leadership of the focal plane detector arrays construction. The UK will be heavily involved in all aspects of the mission both at the science level and in the design and construction of the instrument itself (e.g. the current baseline design envisages 150 CCD detectors that will be supplied by e2V).

Required resources: mission and ground based preparation and exploitation.

Spectroscopy
The JWST/MIRI will lead to the possibility of obtaining transmission spectroscopy of Ice-giants and Super-Earths. This will lead to developments in atmospheric techniques. Candidates for these observations will come from NG-TS, SuperWASP, CoRoT, Kepler.

The concept of a high precision infrared radial velocity spectrometer has been vigorously supported by a variety of review processes as the most cost effective method to discover Earth-mass habitable zone exoplanets. The UKIRT Planet Finder (UPF) is a UK-led Project aiming to a precision radial velocity IR spectrograph at that facility.

The UPF will be vital in securing results from the WTS and while many of the IWAS targets will be bright enough for precision spectroscopy from HARPS-N at the WHT, but UPF will certainly be needed for the redder objects.

For PLATO, the candidates are sufficiently bright (generally brighter than SuperWASP candidates) that the reflex motion for an Earth analogue system could be confirmed with reasonable time allocations on the VLT and ELT. Asteroseismic analysis of the PLATO light curves themselves will give the masses and ages of the host stars with unprecedented accuracy.

Required resources: access to UKIRT, WHT, UPF construction/access, JWST, ESO, ELT, exploitation.

Transits: The WYFCAM and VISTA Transit Surveys

While the WTS is ongoing, new, more powerful surveys will become possible when VISTA becomes operational. In principle, this could be a rapid way to large numbers of rocky planets (around M dwarfs).

Required resources: access to UKIRT/VISTA, exploitation.

Direct Imaging

Imaging of exoplanets is notoriously difficult requiring high contrast and spatial resolution. Extreme adaptive optics and coronagraphic techniques are being developed. The UK has access, through guaranteed time, to both the Gemini Planet Imager and VLT/SPHERE instruments (both of which will also be common user facilities).

The UK has been slow to become involved in this technology. However, recently Oxford have made progress demonstrating good detection capability with a integral field unit based at the ESO AO-corrected SINFONI spectrograph on the VLT. In the short term it is possible to install a fast track coronagraph within this spectrograph for general usage. This group is also involved in the development of EPICS – the extreme AO imager for the ELT.

Direct imaging of young and warm exoplanets will also be possible at far IR/subMM wavelengths and maybe possible with ALMA.

In the longer term, imaging will best be served via an interferometric space mission such as Darwin. It is important to continue support for this technology.

Required resources: involvement in the ELT, ESO, exploitation, Darwin related technology.

Astrometry

With the launch of Gaia, astrometric techniques will become useful for planet detection. Indeed, this method compliments the radial velocity and transit surveys being best suited to longer period planets. The UK has gained considerable expertise in Gaia hardware and data reduction.

Required resources: exploitation of Gaia.

Microlensing
Our leading role in efficient fast-response microlensing follow-up to study planet populations would be further consolidated by the deployment of advanced 1m-class robotic telescopes through external sources (e.g. SUPA-II) and in cooperation with LCOGT and/or SONG, the latter not only being a network for exoplanet studies by means of microlensing and radial-velocity measurements, but also for asteroseismology. Together with detector developments, this will offer the opportunity to extend the sensitivity substantially below Earth mass.

Required resources: exploitation, collaboration (funding contribution) with LCO (and SONG?), SUPRA funding.

A Responsive Mode
The MacCaughran Report recognized that developments in the Exoplanet area were rapid and that it was important that ideas for development and exploitation had a rapid route through the system. The best example of this is the WASP project, which was originally funded as a small PPARC award in 2001. This has since attracted substantial university and private investment for the provision of hardware both at the observatories and in astronomical groups in the UK.