# A 12U CubeSat (SUPERSHARP) for direct imaging of exoplanets

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## Project Outline

We propose to build and launch a low-cost 1.5m diffraction-limited space telescope to primarily directly image exoplanets. The mission will also support many other science programs across all of astronomy for the benefit of the UK astronomical community. The telescope will use the SUPERSHARP unfolding, self-aligning technology, which allows a primary mirror with a span of 1.5m to be folded into a 12U CubeSat launch format (12kg, 36cmx23cmx24cm). This gives a spatial resolution of 50mas at a wavelength of 300nm. The primary mirror is unfilled and segmented with a fill factor of ~25%. The telescope will capture images in the wavelength range 250-1000nm and will operate in a low earth orbit (~550km). It will have a coronagraph with a raw contrast of $1\times10^{-5}$ to $1\times10^{-6}$ and will detect exoplanets with a planet-star contrast $>1\times10^{-8}$ via precision subtraction techniques.

Currently, the SUPERSHARP concept (Segmented Unfolding Primary for Exoplanet Research via Spectroscopic High Angular Resolution Photography) is being developed in the lab using funds (~£200k) obtained through STFC and the UKSA. Once we have successfully demonstrated the concept in the lab, we plan to build and launch an in-orbit CubeSat technology demonstrator (either 3U or 6U) in the next 2-3 years. Funding for this (~£2M) could come from STFC but it could also come from sponsors who are primarily interested in Earth Observations (EO) for commercial reasons including UKSA, Innovate UK, and VC funding.

This science proposal will follow on from a successful in-orbit demonstration of the SUPERSHARP technology and so, once it gets to this stage, everything will be at TRL9 and it will have low technical risk. Essentially, our plan decouples the risky technology development program from the science program. The main science objective is to look at 20-50 nearby stars to directly image relatively bright (7-10 earth radii) exoplanets in orbits of 0.3 – 2.0 AU, via their **reflected light**. We will use RV data (amplitude >20m/s, biased to edge-on systems) and GAIA data (biased to face-on systems) to identify stars (M, K, G and F types) that have planets with contrasts in the range $1\times10^{-8}$ to $2\times10^{-7}$. This search will use ~2.5 of the 5 years of the mission lifetime. The data will help answer questions about planet occurrence rates, planetary system evolution and formation, planetary atmospheres and planetary interiors.

For the remaining time, the telescope will also be available to the whole UK community for general use and all data will be made available to the whole UK community.

## Science Case

Most of the >3000 exoplanets known have been indirectly detected (transits or RVs). Direct imaging, transit spectroscopy, and high spectral resolution observations detect photons from the planet itself, enabling direct measurement of atmospheric properties. Crucially, only direct imaging can characterise exoplanets at semi-major axes of 1-10 AU, similar to our own solar system. Ground based direct imaging efforts are limited by atmospheric turbulence and systematic errors -- the ~dozen directly imaged planets to date are all widely separated, young (<100 Myr), hot (~600-100 K) giant planets imaged via their thermal emission in the IR. Young stars are rare, limiting searches to more distant stars (and thus worse physical resolution). Older, cooler planets around nearby stars are too faint in the NIR and must be imaged via reflected light. This requires reaching planet-star contrasts of $>1\times10^{-8}$ and diffraction limited performance at 250nm - 600nm - possible only from space.

JWST will not have the time to study such a large sample and it does not have a coronagraph that operates in the visible part of the spectrum. WFIRST will launch after this project.

The mission proposed here will be a pathfinder for future, bigger missions including searching for bio-signatures (see arXiv:1801.06111). The SUPERSHARP concept is completely scalable.

In general, for all science areas, this will offer high precision photometry and high spatial resolution imaging (compared to ground based telescopes) including the wavelength range 250nm – 600nm, which may become completely inaccessible should HST stop working.

## Leadership and potential team members

In this document, Parry is the PI because he is the PI of the SUPERSHARP technology development program including the in-orbit technology demonstrator. The co-I's represent the UK's exoplanet direct-imaging community who are supportive of this proposal at this early stage. A broader team will be set up for the non-exoplanet science and to decide telescope time allocation.

## Societal and Economic Impact

The SUPERSHARP concept has tremendous commercial potential because of its applicability to EO. The PI aims to spin-out a company to sell SUPERSHARP telescope systems.

SUPERSHARP's unique selling point is that it provides 10× better resolution for a given launch cost. This has the potential to be a disruptive technology. The commercial products generated will be unfolding telescopes as both satellite sub-systems and complete satellites. We expect to be able to sell hundreds of units at price points ranging from hundreds of thousands to millions of pounds per unit and we estimate the Specific Addressable Market to be >£100 million.

The End users will be: 1) Large aerospace/EO companies such as Airbus (including SSTL) , Maxar (formerly MDA-DigitalGlobe), and Thales who sell imaging platforms at £1M to £100M per unit, and/or imagery via brokers such as Earth-I and LandInfo.com with archive/new tasking imagery selling from \$312.50/\$537.5 per 25km$^2$ unit. 2) EO small satellite start-ups that have received >\$150 million in venture capital such as Planet and Spire. 3) Large science projects such as the one described here. 4) Industrial partners working with us to develop custom platforms incorporating standard and larger scale SUPERSHARP technology on a consultancy basis.

An important capability development follows from the machine-learning and deep-learning techniques that will be applied to the large datasets that SUPERSHARP will produce.

We will actively seek opportunities to support technology transfer to business partners (including SMEs and enterprising students) and demonstrate the benefits of the project to policy makers in government and elsewhere. A small percentage of telescope time will be reserved for "student" projects to help train the next generation of astronomers. We also intend to make time available to the general public and media to support engagement activities for large groups and audiences.

## Scale of investment

This will be a small-scale (<£10M) project (compare for example with the "Skyhopper" 12U Australian CubeSat project – PI: Trente, Univ. Melbourne). Our ROM cost estimates are £2M for the in-orbit technology demonstrator and £7M for the 12U science mission.

These very low costs may seem too good to be true but they absolutely are not. They are a direct result of the "New Space Revolution" whereby the commercial sector has now become the dominant investor in what was, until 5 years ago, a field dominated by government agencies. Our costs are based on comparisons to other CubeSat missions and published prices for CubeSat components and launch services. There is now a tremendous opportunity to have high impact space-based science missions at much reduced costs compared to traditional NASA/ESA missions (see for example "On the verge of an astronomy CubeSat revolution" by Evgenya Shkolnik, Nature Astronomy, Vol 2, May 2018, 374–378). Currently, the UK is lagging behind and it is crucial that the UK does not miss out on this opportunity. The SUPERSHARP technology has the potential to make the UK a world-leader in this field. Also, with these low-costs it is possible to have several space telescopes serving different science areas and communities.