# Starbug – A Smart Focal Plane technology for ELT instruments

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**Abstract:** Starbug is a robotic positioning development concept for deploying many payloads, such as pickoff optics, optical fibres, integral field units, to micron level accuracy over a flat or curved focal surface. With a heritage of fibre positioners such as 2dF, OzPoz and FMOS-Echidna, this concept addresses some of the limitations of other positioning systems to provide a reliable, cost effective way of positioning multiple payloads in ambient or cryogenic environments. Starbug employs micro-robotic actuators that independently and simultaneously position multiple small payloads accurately across a field plate. In this paper we present the general Starbug concept and some selected results from the Starbug development program that so far has been primarily targeted at developing smart focal plane enabling technologies for ELTs.

**Keywords:** Smart Focal Plane Technology, Starbug, beam steering, robotic positioning, payloads, pickoffs.

## 1. INTRODUCTION

For many years the science drivers for large spectroscopic surveys have resulted in a large number of multi-object spectrographs in the visible region that have become workhorse instrumentation for 1 to 10m class telescopes, for example: SDSS (Sloan), 2dF (AAT), GMOS (Gemini), DEIMOS (Keck), VIMOS and FLAMES (VLT). With recent technological developments, large multi-object systems are being built for the infrared regime such as: IRIS2 (AAT), Flamingos-2 (Gemini), CIRPASS (Cambridge), FMOS and MOIRCS (Subaru), along with KMOS and MUSE (VLT). In order to limit infrared contamination from the thermal emission of the spectrograph components, all these spectrographs operate in cooled or cryogenic environments. This constraint introduces a number of technical challenges, many of which cannot be simply solved using conventional positioning technologies. In this paper we describe the Starbug concept[1] development for simultaneously deploying large numbers of arbitrary payloads over a focal surface with extremely high accuracy, potentially in a low temperature vacuum environment. The development is part of the Smart Focal Plane Technologies program (Cunningham et al., 2005), and uses the MOMSI instrument concept (Ramsey Howat et al., 2005) as a guide to the baseline requirements for such systems.

## 2. THE STARBUG HERITAGE

The Starbug concept, first described by McGrath and Moore (2004), builds on the heritage of fibre positioning systems such as 2dF (AAT), 6dF (UKST), the OzPoz positioner for the FLAMES system (VLT) and the near-completed FMOS-Echidna system for the Subaru telescope. The basic concept of providing mechanisms by which multiple payloads can be simultaneously placed in a telescope focal plane is clearly not new.

"Pick and place" systems such as 2dF (Lewis et al., 2005) address the positioning of up to 400 objects with a single robot positioning magnetic buttons (in this case carrying optical fibres) on a flat focal plate. Here, the configuration time is essentially proportional to the number of deployable payloads and could lead to unacceptable delays between observations. At the expense of mass and mechanical complexity, multiple exchangeable field plates allow preparation of one field while another is observing, to minimize or eliminate such "dead time". The planetary positioner (Ramsey Howat et al., 2005) proposed by the UKATC uses the same twin plate principle, but with curved focal surfaces in a similar fashion to OzPoz (Gillingham et al., 2003).

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The use of field plates is aimed at controlling flexure problems and reducing the large numbers of mechanisms required for "pickoff arm" designs such as those proposed for KMOS (Sharples et al., 2004). The FMOS-Echidna system (Gillingham et al., 2003), based on thin, fibre-carrying spines with specific patrol areas, was developed to address the packing density associated with systems at the fast prime focus of 8-10m and ELT class telescopes (~f/2). Each spine in the FMOS-Echidna system can be simultaneously and independently moved, effectively freeing its field configuration time from its former proportional dependence on the number of deployable payloads. Fast configuration times eliminate the large "dead times" between observations without the need for multiple field plates. This can have large space/mass savings, of particular value in typically space/mass limited cryogenic environment. Moving back to a single plate concept has the added bonus of halving the number of buttons/pucks over twin plate systems as only one field plate need to be populated with payloads, reducing mass, cost and complexity. The time taken to reconfigure a focal plane for a new field when employing simultaneous and independent movement should typically be absorbed in the time taken to slew to and acquire the next field. Furthermore, over wide fields, small adjustments can be made to spine positions in "real time" (micro-tracking) in order to compensate for atmospheric refraction effects that change the relative position of targets on the field plate during the course of an observation. To a limited extent, this effect may be accommodated in a suitably designed twin plate pick and place system. In this case it may be possible to anticipate when the target errors will reach unacceptable levels, and configure a "tweaked" field on the second plate with the positional adjustment included, then swapping field plates. This can have several adverse impacts, including the overhead of changing plates and re-acquiring the field on the plate, but more importantly in swapping plates the some optical path components change and this can lead systematic errors being introduced in the data.

## 3. THE STARBUG CONCEPT

Starbug aims to provide a relative simple, cheap, scalable, reliable, and multiply redundant system for positioning of arbitrary payloads in both warm and cryogenic environments. It combines elements of Echidna-style positioners such as FMOS, and pick-and-place positioners such as OzPoz. Payloads are positioned on a curved (or flat) focal plate in the manner of OzPoz or the planetary positioner, but moved simultaneously and independently in the manner of Echidna spines. Two fundamentally different Starbug approaches are being investigated, the first with active bugs patrolling over a passive focal surface, and the second with passive bugs being positioned on and by an active surface.

### 3.1. Active Starbugs – Passive surface

The active Starbug concept is based on self propelled units that are able to move themselves to any point over a field plate and orientate themselves in rotation. For the MOMSI concept this requires that the deployable payloads be pointed at the relay optics (Figure 1) directing the target light from the focal plane into the integral field spectrographs. In one version of the optical pickoff designs currently considered for MOMSI, the payload consists of the lens and fold mirror as represented in Figure 2.

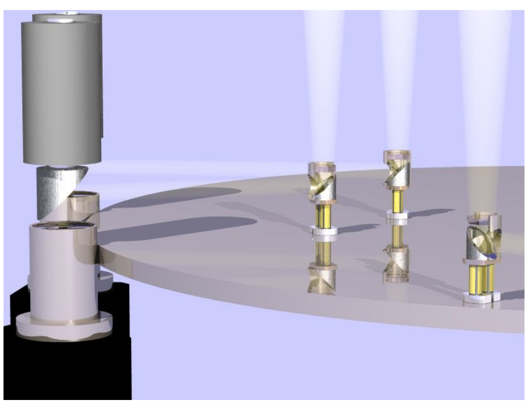

Figure 1: Representation of the basic Starbug concept for a focal plane pickoff system such as that required by MOMSI.

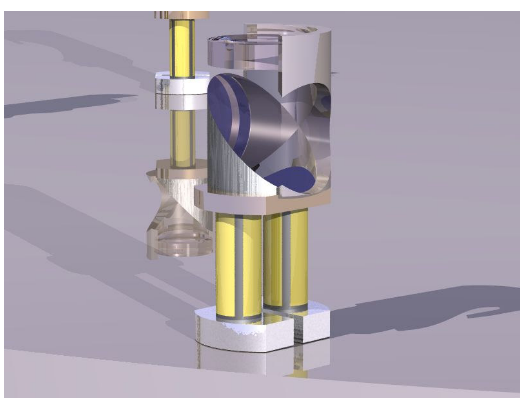

Figure 2: Representation of a Starbug unit carrying a mirror and lens combination payload. One of the pickoff concepts currently envisaged for MOMSI.

The AAO has prototyped and tested active Starbug units (bugs) based on a number of micro-robotic actuation principles building on experience, electronics and software developed for FMOS, these include: inchworms, inertial stick-slip and resonant inertial stick slip devices. Much, but not all, of the Starbug development has been targeted at providing deployable pickoff units suitable for the MOMSI concept. An example of one of the more successful prototype bugs is referred to as Res-J and is based on a quadrant tube piezo using resonant inertial stick-slip principles of operation. Res-J is shown under closed loop control in Figure 3. The crude dark disk with three white spots on top of the bug provides position and orientation feedback via the camera at the top of the picture. Res-J is shown in greater detail in Figure 4.

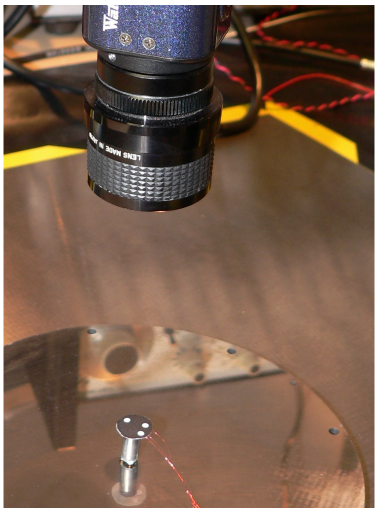

Figure 3: Res-J, a resonant inertial stick-slip Starbug in closed loop control experiment.

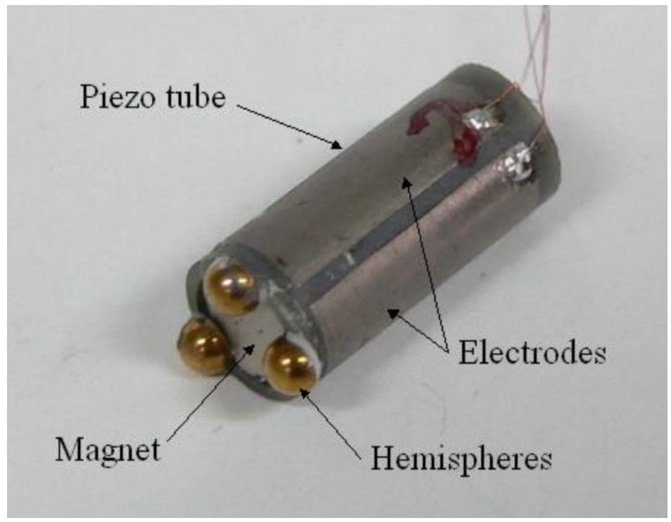


Figure 4: Res-J, a quadrant tube piezo inertial stick-slip Starbug

In the Figure 3 test arrangement, a computer controlled the motion of the bug with a position accuracy of less than 10µm, commensurate with the control and metrology system used for the tests. In open loop control Res-J has been demonstrated to achieve step sizes of less than 2µm, with other prototype bugs achieving step sizes of approximately 0.1µm. Testing under low temperature conditions showed a drop in speed of Res-J by a factor of about 4, whilst another resonant bug technology showed little change in performance upon cooling. Many of the Starbug prototypes were shown to operate at a variety of gravitational orientations, with Res-J operating on both horizontal and vertical surfaces with only a small variation in speed. Further development and testing of Res-J and the other promising active Starbugs is on going.

Table 1: Performance of Res-J prototype against target specification for the MOMSI deployable pickoff units

| Parameter | Target Specification | Achieved Performance |
|---|---|---|
| Size | Footprint <10mm diameter | 6mm diameter |
| Number of pickoff units | Minimum 100, Goal 1000 | 1 demonstrated, 100s in principle |
| Motion | X and Y | X and Y |
| Speed of Motion | >1mm/s | >5mm/s at ~20ºC,<br>>1mm/s at -100ºC |
| Minimum step size | <1µm | <2µm at ~20ºC |
| Minimum operational temperature | -100ºC | -100ºC |
| Gravitational orientation | Arbitrary | Horizontal and vertical surfaces |

The performance of the Res-J prototype is compared to the MOMSI deployable pickoff requirements benchmark in Table 1. It has been demonstrated to reach most of these, but further development and testing is required.

### 3.2. Passive Starbugs – active surface

The active field plate (active surface) Starbug approach can be demonstrated with the "Crowd Surfer" concept, shown in Figure 5 and Figure 6. In this particular case a flat field plate is made up of an array of actuators, each with magnetic contact at the top. The passive bugs are magnetically secured to the spherical tips of the actuators and are sized such that at least three contact points are under each, wherever they are on the surface. By "flexing" and "flicking" the actuators in an action similar to cilia (small whip like appendages of many living cells that are used to move fluid or to propel the cells along, with an oar-like motion), the bugs can be moved anywhere over the surface. Each actuator can be addressed and controlled individually, or in groups, enabling X, Y and rotational motion of every bug, individually or simultaneously.

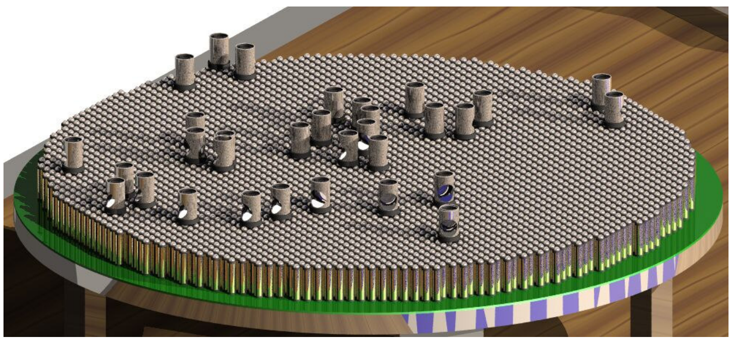

Figure 5: The Crowd Surfer concept: Passive bugs on an active field plate comprised a "field" of quadrant piezo tubes.

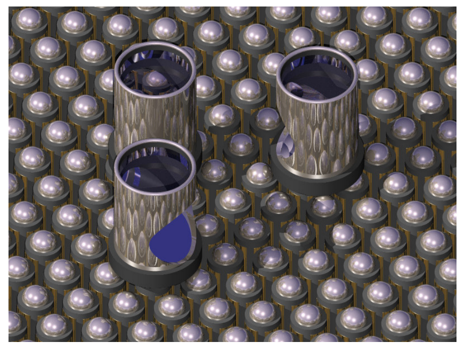

Figure 6: Passive bugs/pucks of the Crowd Surfer concept with their fold mirror payloads.

At the time of writing the prototype of the Crowd Surfer concept had only undergone a very limited development test program, but the basic principle has been demonstrated, showing controlled movement of bugs ranging in mass from 1 to 100g on a horizontal active surface. This work also validated performance models of the concept.

Significant further development and testing is required to clearly demonstrate the full viability of this system for astronomical instrumentation. However, one clear advantage of the active surface technologies is the system provides a natural solution to managing the provision of power and control signals for the actuators. Unlike active bugs, these services can be applied at the back of the active surface and well clear of the focal plane. This is likely to be an advantage for applications such as MOMSI, where no fibres or other physical connections are required by the instrument concept. Concepts and schemes for managing the power and control wires of active bugs are being developed, including wireless bugs that can receive power via the field plate, however, the active surface concept neatly sidesteps the whole issue.

### 3.3. Future development plans

The development program has shown the basic viability of a number of approaches to the Starbug concept, and though considerable further work is required to demonstrate we have an "instrument ready" system, Res-J prototype bug has already achieving some of the key target specifications for the MOMSI concept for OWL.

The next phase of the Opticon funded Starbug development will target metrology/control system(s) providing position feedback for closed-loop system, including micro-tracking and control of multiple bugs simultaneously. The AAO also plans to proceed with detailed testing, characterization and assessment of the most promising technologies, such as stick-slip actuators and the Crowd Surfer concept with an aim to mature the technology to such a level that they may be considered low enough risk for inclusion in the next generation warm and cryogenic instrument systems. Development will initially include service feed management schemes for power and control, and later the development of wireless active bugs for applications with crowded fields where many hundreds of miniature robots roam over the field plate.

Wireless technologies are rapidly developing and are available in small packages on scales that should be appropriate for even the smaller scale Starbug applications such as MOMSI.

## 4. CONCLUSIONS

The Starbug development continues to be part of Smart Focal Plane Technologies, part-funded by the European Union Framework 6 program, and aimed at enabling the maximum usage of limited focal plane resources in astronomical instruments, providing optimal matching of the instrument design to scientific goals. Starbug is clearly targeted at maximizing multiplex advantages, providing a potentially huge multi-object capability over small and large fields in both warm and cryogenic environments. Addressing some of the weaknesses of current positioning systems and providing a reliable, cost effective way of positioning multiple payloads, the Starbug concept employs micro-robotic actuators (either using active bugs or an active field plate) that can independently and simultaneously position multiple small payloads accurately across arbitrarily sized and/or curved surfaces. One significant advantage over most conventional pick and place schemes is the ability to make small positional adjustments in “real time” during an observation correcting for residual atmospheric refractive effects and instrument flexure.

At the time of writing, the Starbug development has already achieved significant successes, demonstrating minimum actuator step size at the sub-micron level, operation under closed loop control and at temperatures down to -100ºC, using a variety of low cost technologies and approaches. However, significant further development is required before these technologies can be regarded as sufficiently mature, and able to provide a low risk, reliable, cost effective, highly flexible focal plane positioning for applications in mainstream astronomical instrumentation.

## REFERENCES


1. S. Ramsey Howat, et al. *these proceedings.*
2. C. Cuuningham, et al. *these proceedings.*
3. A. McGrath and A. M. Moore. *Proc of the SPIE,* Vol. 5495, pp. 600-610, 2004.
4. I. J. Lewis, K. Glazebrook, K. Taylor. *Proc. Fiber Optics in Astronomy III. ASP Conference Series,* Vol. 152, pp. 152-171, 1998.
5. P. R. Gillingham, D. Popovic, et al. *Proc. of the SPIE,* Vol. 4841, pp. 1170-1179, 2003.
6. P. R. Gillingham, A. M. Moore, et al. *Proc. of the SPIE*, Vol. 4841, pp. 985-996, 2003.
7. R. M. Sharples, R. Bender, et al. *Proc. of the SPIE*, Vol. 5492, pp. 1179-1186, 2004.