THE SCIENTIFIC OBJECTIVES OF THE BEAGLE 2 STEREO CAMERA SYSTEM. A. D. Griffiths[1], A. J. Coates[1], J.-L. Josset[2], G. Paar[3], and M.R. Sims[4], [1]Mullard Space Science Laboratory, University College London, Holmbury House, Dorking, RH5 6NT, UK (adg@mssl.ucl.ac.uk), [2]SpaceX, Jaquet-Droz 1, Case postale, CH-2007 Neuchâtel, Switzerland, [3]Institute of Digital Image Processing, Joanneum Research, Wastiangasse 6A- 8010, Graz, Austria, [4]Department of Physics & Astronomy, University of Leicester, Leicester, LE1 7RH, UK.

Introduction: The Stereo Camera System (SCS) provides the primary imaging capability of the Beagle 2 lander[1]. Sensative to visible and near IR wavebands (440–1000 nm) it is composed of twin camera/filter wheel units. The 1024 by 1024 pixel frame transfer CCDs, wide-angle (48° field of view) stereo optics and a choice of 24 filters allow a wide range of scientific objectives to be addressed. The total system mass is 360 g, the required volume envelope is 747 cm^3 and the average power consumption is 1.8 W. A 10Mbit/s RS422 bus connects each camera to the lander common electronics.

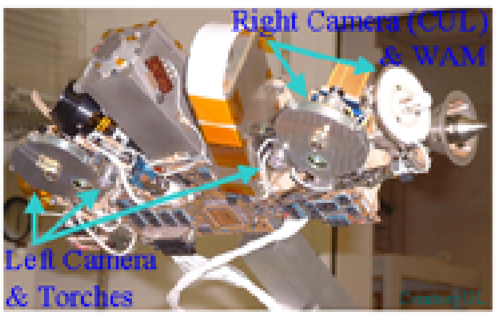

Figure 1: The location of the stereo cameras on the PAW.

Scientific Objectives: Stereo image pairs acquired shortly after landing will be combined to form a mosaic of the Beagle 2 robot arm (RA) workspace. The images will be processed to produce a Digital Elevation Model (DEM) of the rocks and soil present [2]. Due to the light time delay between Earth and Mars, an accurate DEM is vital to allow safe and accurate positioning of PAW instruments against scientifically interesting rock and soil surfaces.

The DEM will also be used to study the geomorphology and size distributions/area cover of small rocks and boulders.

The SCS design is similar in many respects to the Imager for Mars Pathfinder (IMP) [3], due to the strong synergy in observing at similar wavelengths at the two widely separated landing sites (Isidis Planitia and Ares Vallis respectively). With this in mind the following studies were chosen for the baseline SCS investigations:

- 360° (azimuth) panoramic colour imaging (at 440, 530 and 670 nm and with all twelve 'geology filters' later in the mission) to characterise the landing site. Stereo pairs at 670 nm will also be acquired.
- Multi-spectral imaging of rocks and soils to determine their mineralogy from reflectance curves. Images will be acquired in twelve 30-40 nm wide wave bands (table 2) selected to correspond with the IMP geology filters.
- Observations of the sun to measure the depth of the 935 nm water vapour absorption line relative to the nearby continuum. These measurements will complement similar global measurements made by the Mars Express Orbiter Instruments.
- Solar observations to determine the atmospheric optical density and aerosol properties.
- Astronomical observations of Phobos & Deimos to measure their spectral characteristics with the geology filters. Observations of Phobos against the background stars will allow the determination of the landing site location and the lander's orientation.
- Observations of lander surfaces, air bags and landing scuffmarks in soil to determine dust properties.
- Observations at night using the torch to determine the "true colour" of surface materials without the red light scattered from the daytime sky.
- Rock texture observations at 80 mm working distance using the close-up lens (CUL) providing 60 µm resolution intermediate between the 380 µm standard camera and 4 µm microscope resolution.

Read out noise	266 ± 116 electrons
Full well	788 ± 123 x10^3 electrons
Exposure time	1 to 65535 ms (in 1 ms steps)
Frame transfer	2 ms
Readout time	1132 ms
Spectral range	440–1000 nm
Gain	770 electrons/DN
A/D Conversion	10 bits/pixel
Number of Pixels	1024 x 1024 or 512 x 512
Pixel Size	14 µm x 14 µm

Table 1: CCD characteristics at –30 °C

Other possible observations include looking for transitory or seasonal changes (dune migration, surface frosts) at the landing site or in the sky above it (clouds, meteors and dust devils).

Stereo Camera Design: The SCS is part of the PAW, an integrated instrument package attached to the end of the RA. It consists of two identical (left and right) cameras attached at separate locations 208 mm apart (figure 1). The cameras are inclined towards each other so that their optical axes cross (i.e. 100% image overlap) at a distance of ~1.2 m from the PAW. The magnitude of this "toe-in" angle is 4.02° for each camera (measured from the normal to the PAW).

Each SCS camera consists of a micro-camera & optics (supplied by SpaceX), a filter wheel with 12 filters driven by stepper motor and gear wheel assembly and a housing with a wiper blade to remove dust from an optical window. An external AD590 sensor is used to monitor the temperature of each camera.

The filter wheel (FW) is mounted on a gear wheel with a 6:1 ratio to the pinion on the stepper motor shaft. The FW is limited to rotate a maximum of 330° (110 motor steps) in either direction by a simple end stop mechanism. Filters are selected by counting motor steps from the home position (position #12).

A stainless steel wiper blade is located between and above filters #1 & #2. Selecting filter position #1 causes the wiper to move across the window from one side to the other. Hence, the window is only wiped at the far extreme of FW motion. Development testing [4] showed the effectiveness the wiper in removing different dust size fractions and that over tens of wiping cycles the opportunity for hard dust particles to scratch the indium tin oxide conductive window surface coating is minimal.

The properties of the SpaceX CCD micro-camera are defined in table 1. The 48° field of view of the radiation hardened optics results in an angular scale of 0.75 mrad/pixel. The objective lens is optimised for viewing objects between 0.6 and 1.2 m. At greater distances 4 lenticular filters are used (i.e. ideal focus between 1.2 m and infinity).

The 24-filter set for the Beagle 2 stereo camera system is the result of a series of design trade-offs during the development period. The following sets of filters (table 2) were chosen to maximize the science return:

- 2 Stereo filters for DEM images (L7 & R7).
- 4 Lenticular filters for stereo and colour distance work (L8 & R8-10).
- 12 Geology Filters (L1-6 & R2-7) for mineralogical analysis. R7 is shared with the DEM filters and L2, L3 & R7 also give short range colour images.
- 1 CUL (R1 – equivalent to a geologist's hand lens) for rock texture studies.
- 6 Solar filters (L9-12 & R11-12) for atmospheric water vapour and aerosol studies.

Two components on the Beagle2 PAW enhance the effectiveness of the stereo cameras; these are the Wide Angle Mirror (WAM) and the torches.

Filter#	CW[a] (nm)	PB[b] (nm)	Type	Filter#	CW[a] (nm)	PB[b] (nm)	Type
L1	481	28	Geology	R1	720	560	CUL[c]
L2	439	22	Geology	R2	602	21	Geology
L3	532	32	Geology	R3	799	20	Geology
L4	750	18	Geology	R4	906	42	Geology
L5	857	34	Geology	R5	961	29	Geology
L6	930	32	Geology	R6	1003	28	Geology
L7	669	17	DEM	R7	668	17	DEM
L8	671	17	Far Stereo	R8	668	18	Far Stereo
L9	928	5.5	Water	R9	440	22	Far Colour
L10	936	5.6	Water	R10	532	32	Far Colour
L11	1000	6	Water/Dust	R11	449	4	Dust
L12	877	6	Water/Dust	R12	670	5.5	Dust

Table 2: Manufactured FM stereo camera system filter set.

[a]CW = centre wavelength; [b]PB = pass band; [c]close-up lens.

The purpose of the WAM is primarily to view the surface of Mars before the PAW is deployed from the lander and to act as a low mass alternative to the originally envisaged wide angle camera. It will also be used to observe mole deployment, retraction and surface operations. The WAM therefore swings up to a position 80 mm above the right hand camera once the lander lid has opened. At this range, the WAM must be imaged with the CUL to get a properly focused image. Once deployed the WAM fills a large portion of the field of view of the right hand stereo camera. The WAM is therefore attached to the microscope (which has 6mm travel for focussing) via a wire and spring, allowing it to be retracted out of the field of view of the camera for normal imaging.

The torches provide a known spectrum of light (from high efficiency white light LEDs) for the stereo cameras to enable a true colour image of the Martian surface to be created. The torches are attached to the structure of the PAW adjacent to each camera to ensure maximum light flux in the field of view of that camera.

References: [1] Sims, M.R., et al (1999) *Adv.Space Res*. 23 1925-1928. [2] Paar, G., Bauer, A. and Sidla, O. (1999). *SPIE Proceedings* 3827-22 Industrial Lasers and Inspection, Munich, June 14-17, 1999. [3] Smith, P.H. et al., (1997) *JGR* 102 (E2) 4003-4025. [4] Griffiths, A.D. et al, (2002) *LPSC XXXIII*, Abstract# 1012.

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