Junocam: the challenges of adding an imaging system to the Juno Mission. M. A. Caplinger[1], M. A. Ravine[1] and C. J. Hansen[2], [1]Malin Space Science Systems, 5880 Pacific Center Blvd, San Diego, CA, [2]Planetary Science Institute, Tucson, AZ.

Introduction: The Juno mission to Jupiter was initially proposed with a powerful suite of remote-sensing and other instruments but did not include visible imaging [1]. After the mission was selected for Phase A development, a visible camera, called Junocam, was added -- primarily for outreach purposes and funded from the mission's EPO budget. As such, the instrument's development was highly cost-constrained. To compound the difficulty, Juno is a spinning spacecraft and light levels are low at Jupiter, so imaging is limited to very short exposure times. The driving functional requirements were to image Jupiter's poles in color at low incidence angles and to survive at least eight orbits of the jovian radiation environment (roughly 400 Krads behind 100 mils of Al shielding at end of mission; about 20% of that through orbit 8) [2].

Development challenges and strategy: The desire for low cost motivated the use of an existing design to save development effort. The MARDI/MAHLI/Mastcam instruments designed for Mars Science Laboratory were chosen as the starting point (its fast readout made it less sensitive to transient radiation effects) [3], but the unique requirements of the Juno mission soon made it apparent that significant modifications would be needed. Additional shielding was the most obvious change, but the replacement of the design's less radiation-tolerant electronic parts was also critical. The MARDI Xilinx FPGA was replaced with a less-powerful but SEU-immune Actel FPGA, and the MARDI flash buffer was removed. This necessitated shifting the buffering and compression functions from the instrument to the spacecraft C&DH.

The optics were also redesigned, to use radiation-hard glasses and to add shielding for the optics itself and for the detector. Because of the low illumination at Jupiter and the 2 RPM spacecraft spin, Time-Delay Integration (TDI) had to be used to achieve acceptable SNR. TDI drove the optical design to be low-distortion, and the optics were made as fast as possible.

Adding to the challenge, an upscope to add 889 nm methane absorption-band imaging was accepted to enhance science return. The narrowness of the band and the optically-fast lens led to a wide range of focal plane incidence angle, making the interference filter design more difficult. The low near-IR QE of the MARDI-heritage sensor and the planet's very low albedo in methane absorption wavelengths led to the use of more lines of TDI (up to 64) and 2x2 summing to improve SNR. Even so, the science team accepted limited performance as preferable to not having methane imaging capability at all.

Requirements for robustness in the face of radiation-induced Internal Electrostatic Discharge (IESD) led to additional mass for shielding and analysis of harness effects.

Implementation: Junocam consists of two assemblies, the camera head (which does the imaging) and the digital electronics (which provides the interface with the spacecraft). An image of the Junocam fight hardware is shown in Figure 1. Additional functionality is provided in software that runs on the Juno spacecraft computer.

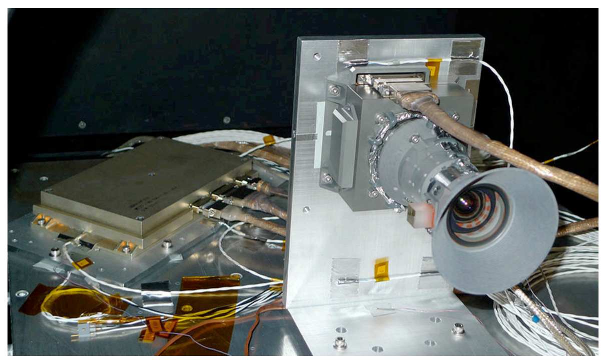

Figure 1. The Junocam flight hardware just prior to instrument thermal vacuum test (camera head, right, JDEA, left).

Camera head. The camera head uses a build-to-print MSL MARDI printed circuit board. The focal plane uses a monochrome rather than color CCD sensor with an integral pushframe color filter array bonded to it (using processes with MRO MARCI and LRO WAC heritage). Some parts were replaced with pin-compatible alternatives with better radiation resistance. The housing is 0.25-inch-thick titanium (versus the 0.1-inch-thick aluminum housing of MSL MARDI.) Inside the housing is a small "CCD vault" around the focal plane, made of copper-tungsten alloy with a mass of 0.5 kilograms. The lens design was required to provide more than one inch aluminum-equivalent shielding for both the lens housing and the optical path. This is shown in an exploded view in Figure 2. The camera head's FPGA logic was slightly modified to add TDI by adjustment of the CCD's normal interline transfer clocking pattern.

Digital Electronics. A new development for Juno, the Juno Digital Electronics Assembly (JDEA) is a derivative of the MSL DEA, with a rad-hard Actel

FPGA and a 128 MB DRAM buffer. Images are only buffered in the JDEA in raw form (more robust against single-event upsets), and only for as long as it takes to read them to the C&DH. Extensive use of inherited MRO CTX FPGA logic was made to reduce development cost.

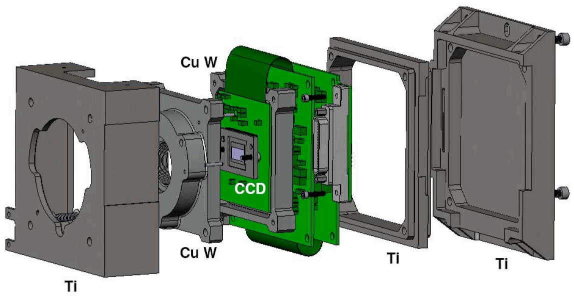

Figure 2. An exploded view of the Junocam camera head electronics, showing the detector sandwiched between two pieces of copper tungsten (Cu W) which form the "CCD vault."

Software. MSSS-supplied instrument software running in the spacecraft C&DH was used for command sequencing, buffering, and data processing and compression. This architecture was successfully used on the MS98, Odyssey, and MRO missions and most of the code was inherited. Image median filtering was added for Juno to reduce the effects of radiation transients.

Operations:

Cruise. To date Junocam has been operated in ten distinct sequences in cruise and has returned about 130 images. Activities include post-launch checkout (including far-departure imaging of Earth from a range of about 10 million kilometers), eight sequences of full-spin imaging of stars and searches for zodiacal light, and the Earth flyby sequence. The latter, in October 2013, returned fourteen images of Earth and Moon in both visible color and methane bands, saw the first operation of the instrument in a radiation environment as the spacecraft flew through the inner Van Allen belt, and allowed the validation of the pushframe image processing pipeline and data archiving software. Figure 3 shows a color-composite of the visible images.

At Jupiter. Juno's highly elliptical 11-day orbit concentrates most imaging opportunities in a three-hour period centered on perijove. Operations will always include inbound and outbound imaging of the polar regions to provide as close to global coverage as the orbit and terminator geometry will allow. Closer to perijove, Junocam may be used in both targeted and untargeted survey modes to look for features of interest. Targeting is an important outreach activity, as it requires the participation of ground-based amateurs to track cloud features and provides a motivation for the public to suggest image targets.

Farther from perijove, it may be feasible, depending on spacecraft geometry and downlink data rate, to obtain more global coverage at lower resolution. The possibilities of imaging during Juno's initial arrival at the planet and after orbit insertion, while not in the current mission baseline, are being discussed.

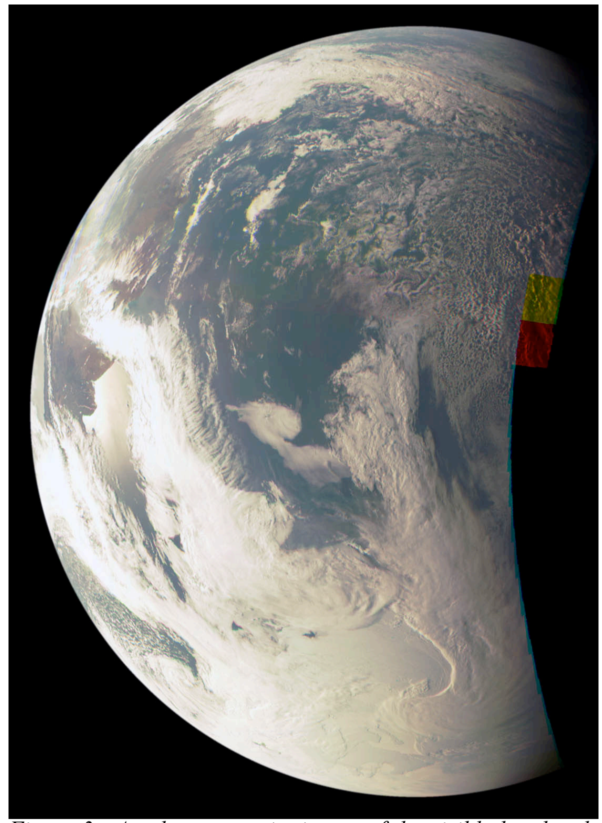

Figure 3. A color-composite image of the visible bands taken of Earth by Junocam near Juno's closest approach during Earth fly-by. Antarctica is at the bottom of the image, the eastern margin of South America is near the left limb.

References: [1] S. Bolton, et al. (2014) *Space Science Reviews,* in press. [2] C. J. Hansen, et al. (2014) *Space Science Reviews,* in press. [3] K. S. Edgett, et al. (2012) Curiosity's Mars Hand Lens Imager (MAHLI) Investigation, Space Science Reviews [pp.28-30]. doi:10.1007/s11214-012-9910-4.