AEGIS INTELLIGENT TARGETING DEPLOYED FOR THE CURIOSITY ROVER'S CHEMCAM INSTRUMENT. R. Francis[1,2], T. Estlin[2], D. Gaines[2], G. Doran[2], O. Gasnault[3], S. Johnstone[4], S. Montaño[4], V. Mousset[5], V. Verma[2], B. Bornstein[2], M. Burl[2], S. Schaffer[2], R.C. Wiens[4], [1]Centre for Planetary Science and Exploration, University of Western Ontario, [2]Jet Propulsion Laboratory, California Institute of Technology, [3]Institut de Recherche en Astrophysique et Planétologie, [4]Los Alamos National Laboratory, [5]Centre National d'Études Spatiales. (raymond.francis@jpl.nasa.gov)

Introduction: The AEGIS (Automated Exploration for Gathering Increased Science) intelligent targeting system enables autonomous science-target selection and pointing refinement for Mars rover remote-sensing instruments. AEGIS was recently deployed on the Mars Science Laboratory (MSL) mission to perform target selection and pointing refinement for the ChemCam instrument. ChemCam uses a Laser Induced Breakdown Spectrometer (LIBS) to analyze the elemental composition of rocks and soil [1]. ChemCam's tightly-focused laser beam (350-550 μm) enables targeting of very fine-scale terrain features. AEGIS is being used with ChemCam in two ways. First, AEGIS is providing automated targeting of ChemCam during or after long drives by finding rock targets in Navigation Camera (NavCam) images. Second, AEGIS is enabling refined ChemCam pointing by detecting fine-scale targets, such as veins or concretions, in Remote Micro Imager (RMI) images.

Targeting features on Mars: ChemCam observations are very tightly-focused; the RMI has a field of view with 20 mrad diameter, and each LIBS measurement observes a very small 0.3-0.5 mm spot on the Martian surface. While wide-angle camera images can be captured without specific or precise pointing, these ChemCam observations are typically targeted at specific features. The usual process for ChemCam targeting has been to use stereo NavCam images returned from previous sols to identify and select targets, augmented when available by colour images from the MastCams. The images used for targeting must be acquired from the same rover position as the ChemCam observations being planned, precluding a drive between them. Data trasmission limits, and timing considerations, sometimes place significant constraints on the availability of post-drive targeting images. This can limit the view available to the instrument, or delay observations at a new locality and the subsequent option to drive again and continue to the next destination. Especially during mission phases when the delay in data delivery means that data is not delivered to Earth by the beginning of the next day's planning, waiting for targeting images (for ChemCam and other instruments) can slow mission progress

As an additional constraint, there are limits in the precision and accuracy of the stereo computation and localization of features, and in the pointing of the instrument. Intersting features, such as narrow veins in rocks, can be a challenge to precisely target from several metres away.

These constraints lead to challenges in ChemCam operations, and MSL planning generally. While the mission and instrument have been very productive, these constraints present a motivation to enable more science without the limits imposed by ground targeting.

Automated targeting technique: AEGIS, previously used to target the narrow-field PanCam on the Opportunity rover [2], uses computer vision techniques to identify meaningful rock targets in images. In particular, an algorithm called Rockster [3], which relies significantly on edge detection and regrouping of edge candidates to identify rock targets. Targets found, which consist of contiguous groups of pixels, are analyzed for properties such as size, shape, brightness, position. Targets can then be filtered and prioritized on any combination of these features. The combination of features required to retain a target through filtering, and to prioritize a target for selection, is called the 'target signature', and can be specified at each use by the science team when planning the activity. AEGIS guidance can be used for any type of ChemCam observation – LIBS, passive spectrometry, or RMI imaging.

Automated target-finding in NavCam: Delays can be avoided if ChemCam observations can be made without waiting for targeting images to be sent to Earth (and targeting commands sent back to Mars). A capability for 'blind targeting' has been used productively [4], but it does not allow any selection of target position or properties, measuring whatever lies at a fixed rover-relative position after a drive.

AEGIS can analyze NavCam stereo images after the drive completes, identify potential targets, filter them for instrument suitability and on other defined properties, then rank the targets. This process typically takes 4-8 minutes to run on MSL's RAD750 flight computer (including acquiring the NavCam image, all AEGIS processing, and the demanding stereo computation), and is immediately followed by ChemCam observations of the highest-ranked targets. These observations, if performed promptly after the drive, can be queued for delivery to Earth, often in time for the next planning cycle – when planning for targeted observations at the post-drive site would normally begin..

Importantly, AEGIS allows the science team to set the parameters for each run at sequencing time – on each use, AEGIS can be tuned to prioritize outcrop, or dark or light float rocks, or other target types. The system can also be adapted to new terrains as they are encountered. This allows the science team to specify the desired types of targets to suit science goals, such as measuring the variation in geochemical composition of the outcrop materials along a traverse.

Figure 1 shows an example of ChemCam targets selected by AEGIS in a NavCam image.

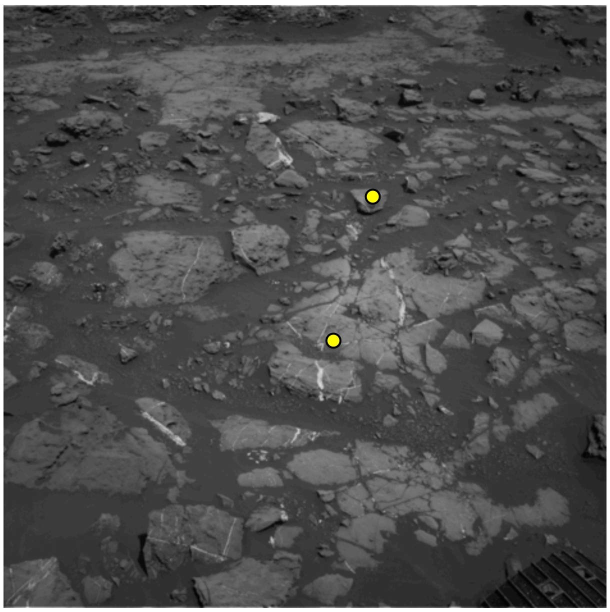

Fig 1: NavCam image acquired for AEGIS targeting on MSL sol 1187. The top two targets are marked; follow-up ChemCam data on these targets was acquired by AEGIS without ground in the loop.

Pointing refinement in RMI: AEGIS can also be used to analyse RMI images. This application is typically used to refine the pointing of ground-targeted observations at small-scale features. Small features, such as the veins shown in Figure 2, are often of interest to the science team. But their thin shape can make them difficult to see and localize accurately from several metres away in the NavCam images used for targeting, and it is possible to miss the veins on the first try – a loss of valuable observation time.

AEGIS allows real-time pointing refinement for such observations. The science team selects an area for targeting, and commands a ChemCam observation of it as usual, preceded by AEGIS analysis. AEGIS acquires an RMI image with the commanded pointing, analyzes it for the target type specified by the science team (often bright veins), and chooses a revised ChemCam pointing that will centre a LIBS raster on the top-ranked feature. This AEGIS work typically adds 90-100 seconds to the beginning of a ChemCam observation.

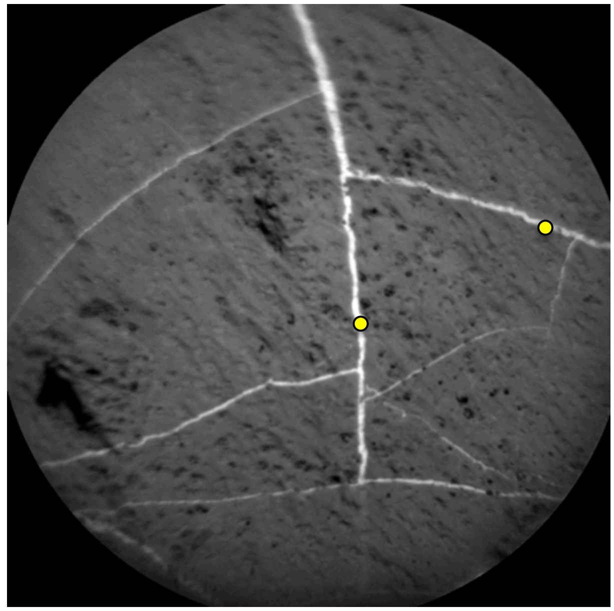

Fig 2: ChemCam RMI image acquired for AEGIS targeting on MSL sol 1184. The top two targets are marked; follow-up ChemCam data on these targets was acquired by AEGIS without ground in the loop.

Dual-camera mode: The two types of AEGIS analysis can be combined – a NavCam stereo frame can be acquired and analyzed, the top target selected, an RMI image taken of that target, and the pointing-refinement process applied to that RMI to guide follow-up LIBS or other activities.

Current status: The AEGIS software, adapted for MSL and ChemCam, was integrated into the Curiosity rover's flight software in October 2015. As of this writing, the planned software checkout series has been successfully completed to allow intelligent targeting in either NavCam or RMI. Use on each camera has given very positive performance results, and the system is expected to be in regular use by the MSL science team in the near future.

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References: [1] Wiens R. C. et al. (2012) Space Sci Rev 170:167-227, [2] Estlin T. A. et al (2012) 11th i-SAIRAS, [3]Burl M. et al. (2015) JAIS *in print.* [4] Cousin A. et al (2014) LPSC XXXXV, abstract #1278