A VERY SMALL LUNAR MAGNETIC ANOMALY: NEW HIGH RESOLUTION MAGNETIC FIELD MEASUREMENTS AND SPECRAL PROPERTIES

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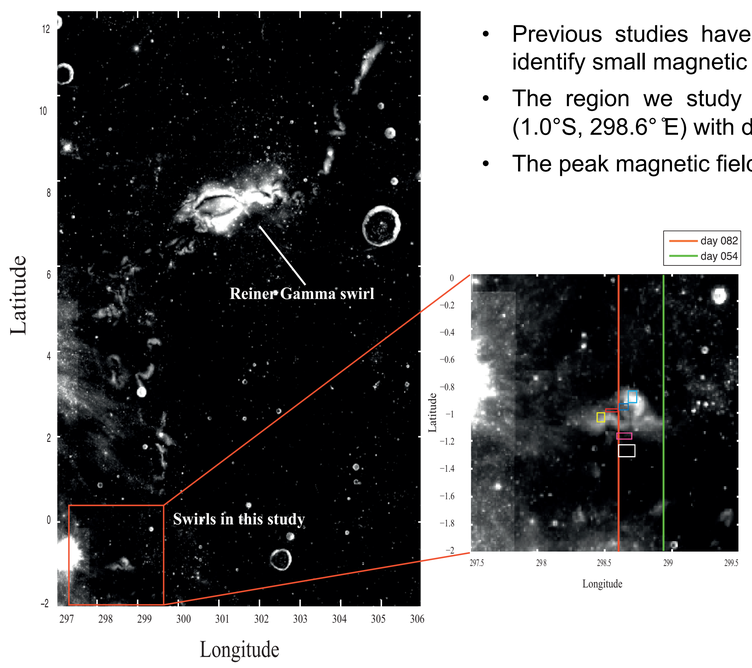
Introduction

When Lunar Prospector (LP) arrived at the Moon, it collected magnetic field measurements from January 8, 1998, to July 31, 1999. The original magnetic field data were collected at a 9 Hz sampling rate, but the published data were downsampled to 0.2 Hz to match the spin period of the spacecraft. The 0.2 Hz data are adequate for many purposes, including determining the global-scale magnetic properties of the Moon. They correspond to a surface spatial resolution of ~ 8 km when the spacecraft is at an altitude of tens of kilometers. However, when the spacecraft altitude approaches ~ 16 km, which is fairly common, a 0.2 Hz sampling rate approaches the Nyquist sampling rate, assuming that the field structure changes horizontally at the same rate as it changes with altitude. Thus magnetic anomalies are barely sampled at an adequate rate at this altitude. A higher resolution data set would provide greater resolving power for small magnetic anomalies. In this study, we examine how the high resolution magnetic field is associated with the albedo markings at this swirl-type anomaly. We will also attempt to use the magnetic field structure and albedo markings to infer the depth of magnetization, and ultimately the anomaly's formation mechanism.

Octopus anomaly



- Previous studies have not used 9 Hz Lunar Prospector data to identify small magnetic anomalies.
- The region we study here, called the "octopus", is centered at (1.0°S, 298.6° E) with dimensions of about 10 km x 20 km.
- The peak magnetic field is ~5 nT at 17.9 km altitude.

Figure 1. The Reiner gamma, one of the most famous magnetic anomalies and swirls, is located at the Southwest edge of Oceanus Procellarum. It is a distinct magnetic anomaly related with a high albedo optical feature. The octopus is located about 200 km to the south.

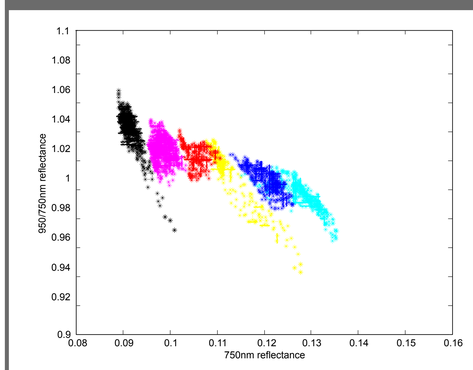
Magnetic field data and data processing

- We used LP three-axis magnetometer 9 Hz data of 23rd of February 1999 (day 054) and 23rd of March 1999 (day 082) to investigate the magnetic fields at the octopus.
- For subtraction of the background IMF(5 – 10 nT), we use a running average method that subtracts 5 or 10 minute mean fields from each data point. This data is compared with ACE satellite IMF data(Beak et al. 2017).

Spectral properties (OMAT)

- We use Clementine 750 nm and 950 nm reflectance data to investigate the spectral properties.

Spectral results



- Garrick-Bethell et al. (2011) and Hemingway et al. (2015) showed that swirls have characteristic spectral trends in the 750 and 950 nm spectral space.
- Here we find the same spectral trends at the octopus region: the brighter parts of the swirl show parallel spectral trends that are displaced to the right (Figure 2).
- Thus we conclude the octopus region is indeed a swirl.

Figure 2. Spectral trends at the octopus anomaly.

Magnetic field profiles

- Figure. 1 shows the two orbit tracks of day 054 & day 082.
- Figure. 3 shows the radial, east, north, and the total magnetic fields for each of the two days.
- These two orbits show repeated signals which indicate crustal magnetic field at the octopus. The peak total field at -1 ˚ latitude is the center of the octopus, based on the cleaner day 054 data.
- The repetition of the signal suggests that the field is the product of crustal magnetization and it is not a temporary IMF.
- These two orbits have 332 measurement points at approximately 18 km altitude and the two orbit passes are in a magnetically quiet time in the lunar wake.

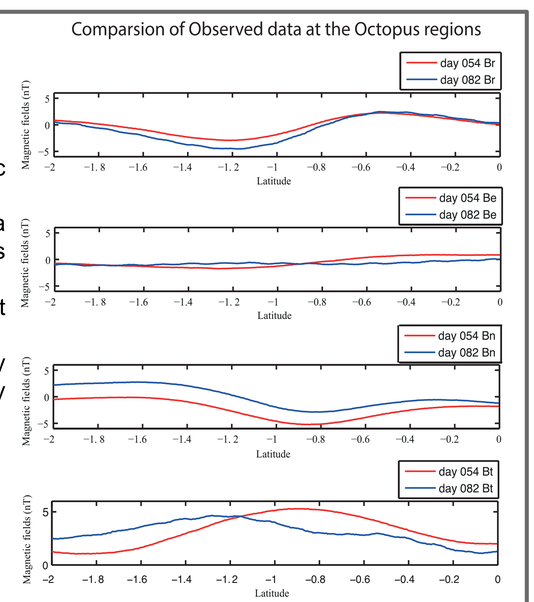


Figure 3. Lunar Prospector magnetometer measurements taken over the anomaly region, for the two best passes available. The measurements show clear repeatability.

Dipole source modeling

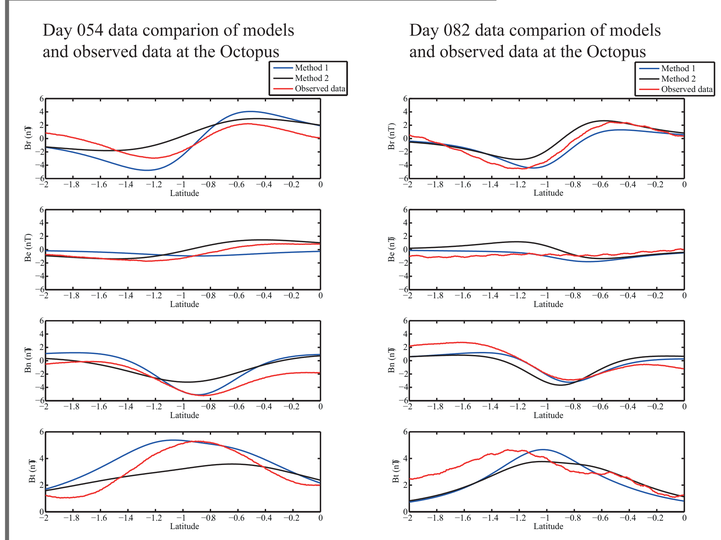
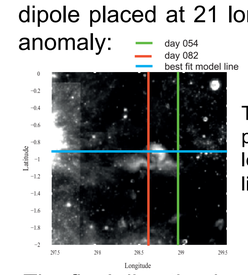


Figure 4. Comparison of single dipole modeling methods 1 & 2 and observed data at the octopus anomaly.

- We modeled the source magnetization as a single dipole, at 0.91° S, using two methods.
- Method 1 uses each individual observation in the orbit track to calculate the best-fitting dipole magnetization, in a least squares sense. From this suite of models, the lowest error observation is used as the final best-fitting model (Baek et al. 2017).
- Method 2 uses all available observations in the orbit track, and finds the best-fitting solution that matches them all simultaneously, in a least squares sense.
- In each method, the model field for the dipole source is calculated via:

$$B_{model}(r_i) = \left[\frac{\mu_0}{4\pi} M \cdot \nabla_s \frac{1}{r_i}\right] (i = 1 \cdots n)$$

- To estimate uncertainty in the source properties, we perform the modeling with a source dipole placed at 21 longitudes spanning the anomaly:



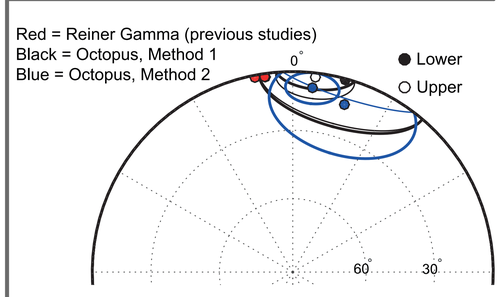
The source dipole was placed at 21 different locations along the blue line to estimate uncertainty.

Table 1. Summary of single-dipole modeling results at the octopus

Data	Altitude (km)	method	θ (deg)	Ø (deg)	Depth (km)	M (10^{11} Am^2)	I (deg)	D (deg)	Error (nT)
990223 day 054	17.9	1	0.91˚S	298.96	5	6.31	3.43	11.48	1.24
		2	0.91˚S	298.66	10	8.2	11.8	6.7	1.78
990323 day 082	17.4	1	0.91˚S	298.78	0	2.21	10.59	37.47	0.8
		2	0.91˚S	298.88	0	2.5	4.5	32.4	1.54

- The final direction is obtained from the mean of the best-fit models across the 21 different source locations above.
- The angular uncertainty is calculated from the Fisher precision parameter *k,* across the 21 source locations.
- Figure 5 compares the angular standard deviation and final, mean directions for the two methods.

Comparison with Reiner Gamma



- The magnetization direction at the octopus is very similar to that at Reiner Gamma, reported by previous studies (Figure 5).
- This implies that the two features may have formed at the same time, and via the same process.
- Wieczorek et al. (2012) suggested that some anomalies may have formed from iron rich ejecta from the South Pole-Aitken basin impactor. The relatively shallow formation depth of the octopus (Table 1), and the similar directions for it and Reiner Gamma, may support this hypothesis.

Figure 5. Similar magnetization directions at the octopus and Reiner Gamma (from [1], (Takahashi et al, 2014), and (Kurata et al. 2005)).

Conclusions

- The octopus is perhaps the smallest lunar magnetic anomaly observed from orbit, to date.
- The equivalent dipole burial depth is from 0 to 10 km; such a shallow depth might support the iron-rich ejecta hypothesis for the origin of some magnetic anomalies (Wieczorek et al. 2012).
- The inclination and declination of the source is similar to that of Reiner Gamma. Thus the formation mechanism and age of these two swirls may be similar.
- Future work will obtain better estimates of the source body characteristics of the 'Octopus' anomaly studied here, in particular, by regressing to data from both days 082 and 054 simultaneously.

References

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