Computation Note: Estimate of the apparent brightness of the lunar surface north of Cabeus A1

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Abstract

In support of amateur imaging of the LCROSS impact ejecta plume on Oct. 9, 2009, a ROLO lunar image was examined to estimate the regional surface brightness in mpsas for the surface terrain near Cabeus A and the adjacent unnamed impact crater, Cabeus A1. An estimate of the apparent brightness of the region north of Cabeus A1, based on 12 pixels extracted from a a 512 x512 ROLO archive lunar image taken 2001-02-13 9:59UT from the ROLO facility near Flagstaff, Arizona when the Moon was at 68% illuminated fraction, is 1.07266×10^{-9} Watts m-2 arcsecs-2 μm-1 at 0.550μm. In terms of apparent brightness expressed as magnitudes per square arcsec (mpsas), the lunar surface north of Cabeus A1 at a 68% illuminated fraction has an mpsas of approximately 3.8 mpsas +- 8%, slightly brighter than the maximum 4.0 mpsas predicted apparent brightness of the LCROSS ejecta plume. The resolution of ROLO archive images did not permit evaluation of the apparent brightness of the shadowed portion of Cabeus, Cabeus A or Cabeus A1. Presumably, the plume will be brighter than the Earth-viewed shadowed portion of Cabeus A1, just as the surrounding 3.8 mpsas sunlit terrain is brighter than the shadowed portion of the crater.

September 28, 2009 Orig.

Source materials

In a prior note, an image processing protocol to extract camera values for a 4 x 3 pixel region-of-interest near Cabeus A from a 512 x512 ROLO archive lunar image taken 2001-02-13 UT09:59 from the ROLO facility near Flagstaff, Arizona is illustrated. The median radiance of the 12 pixel region-of-interest is reduced as 0.0456363 Watts m-2 sr-1 nm-1 at 550 nm with a standard deviation of 0.00189995 Watts m-2 sr-1 nm-1 (4.1 %) at 550 nm. The ROLO archive also reported that the pixel resolution of its images as 4.08250 arcsecs / pixel or an area of 16.6668 arcsecs^2 / pixel square.

On Sept. 11, 2009, LCROSS Team astrophysicist Dr. Diane Wooden informally released a chart describing the peak brightness ranges for the LCROSS impact plume at approximately 9×10^{-10} Watts m-2 arcsecs-2 μm-1. The chart was informally provided in response to inquiries for backmatter supporting the NASA LCROSS Team published description for use the amateur community that the plume would have an apparent brightness between 4.0 and 6.0 magnitudes per square arcsec (mpsas).

With respect to the maximum peak brightness of the LCROSS impact plume and the ejecta curtain chart, Dr. Wooden stated "I am posting 3 images and an ejecta flux prediction (W/(m^2 um arcsec^2)) versus Wavelength (um) for different values of the grain column density (1E7 m^-2 represents 4-20 sec; 2E5 m^-2 represents 30-90 sec). The brighter part of the ejecta plume reaches about 1.5 to 3 arc sec in height and spreads to 15"-30" wide in 120-240 sec." LCROSS [Amateur] Observation Group post 9-11-2009. The full dimensions (height and width) of the ejecta plume at its maximum brightness are not provided.

Conversion computation

1. Raw radiance value

0.0456363 Watts m-2 sr-1 nm-1 at 550 nm

2. sr / arcsecs^2

In[64]:=

N[steradiansperarcsecsq]

Out[64]= 2.35044×10^{-11}

3. 0.0456363 Watts m-2 sr-1 nm-1 × 2.35044×10^{-11} sr / arcsecs^2

0.0456363 × steradiansperarcsecsq

1.07266×10^{-12}

Watts m-2 arcsecs-2 nm-1 at 550 nm

4. Convert wavelength to microns for common units (× 1000 nm to micron (μm))

CabeusA1appbrightness := 0.0456363 × steradiansperarcsecsq × 1000

N[CabeusA1appbrightness]

1.07266×10^{-9}

Watts m-2 arcsecs-2 μm-1 at 0.550 μm

5. Algorithm to convert to magnitudes per square arcsec (mpsas)

$$\text{MPSASobj} = 2.5 \times \log10\left(\text{Bref} \,/\, \left(\text{Bobj} / \text{ObjectArea arcsec}^2\right)\right) + \text{Vref} \quad (1)$$

6. Zero point reference values for mpsas conversion

Cox (2000) and Bohlin and Gilliland (2007) provide the brightness and zero point reference values for the stellar magnitude system based on Vega:

In[53]:=

VegaVref := 0.0026

in magnitudes.

In[54]:=

VegaBref := 3.464×10^{-8}

in W m-2 micron-1 at 0.555 μm. This reference brightness approximates the ROLO image 550nm band. The 5nm wavelength difference is ignored for the purpose of this computation.

7. Mpsas conversion of the apparent surface brightness north of Cabeus A1

Applying Eq. 1, where the surface brightness unitized to 1 arcsec^2 for the region north of Cabeus A1 is already known -

LunarSurfacempsas := 2.5 × Log10[VegaBref / CabeusA1appbrightness] + VegaVref

N[LunarSurfacempsas]

3.77539

in units of mpsas.

8. Mpsas conversion of the apparent surface brightness of the ejecta plume

A similar algorithm can be used to estimate the apparent brightness of the ejecta plume based on the LCROSS Team 9-11-2009 chart. An ejecta plume unitized apparent brightness taken-off the 9-11-2009 ejecta plume chart is approximately 9×10^{-10} Watts m-2 arcsecs-2 μm-1.

Applying Eq. 1, where the surface brightness unitized to 1 arcsec^2 for the ejecta curtain is already known -

Plumeappbrightness := 9×10^{-10}

Plumempsas := 2.5 × Log10[VegaBref / Plumeappbrightness] + VegaVref

N[Plumempsas]

```
3.96594
```

in units of mpsas.

9. Difference in apparent brightenss in mpsas between the lunar surface surrounding CabeusA1 and the maximum predicted LCROSS plume brightness

Plumempsas - LunarSurfacempsas

```
0.190544
```

in units of mpsas.

Discussion

Comparing the result of the foregoing reduction of apparent brightness from the ROLO archive 2001-02-13 9:59UT image data (1.07266×10^{-9} Watts m-2 arcsecs-2 μm-1) to a take-off from the LCROSS Team chart (9×10^{-10} Watts m-2 arcsecs-2 μm-1), the conclusion is that the ejecta plume, if it reaches its maximum predicted brightness will slighty fainter than the apparent brightness of the surrounding surface terrain.

ROLO images have a measurement precision of approximatley 4% (per the ROLO image library creator and archivist). The standard deviation of the extract pixel values from the 2001-02-13 ROLO image was about 4%.

Considering the uncertainty regarding both the prediction of the apparent brightness of the ejecta plume and the measurement of the surface brightness of the region north of Cabeus A1, an 0.2 magnitude difference in apparent brightness between the LCROSS ejecta plume and the surrounding lunar surface probably is not significant.

Conclusions

The lunar surface north of Cabeus A1 at a 68% illuminated fraction has an apparent brightness of approximately 1.07266×10^{-9} Watts m-2 arcsecs-2 μm-1 at 0.555 μm. In terms of apparent brightness expressed as mpsas, the lunar surface north of Cabeus A1 at a 68% illuminated fraction has an mpsas of approximately 3.8 mpsas +- 8%.

An underlying weakness of this reduced mpsas value is that the selected ROLO archive image was taken at a lunar libration in longitude of approximately 8 degrees, while the LCROSS impact lunar libration in longitude will be -2.5 degrees. A better match image has been requested from the ROLO image archive.

A recent LCROSS Team chart shows the predicted maximum apparent brightness of the ejecta plume at 9×10^{-10} Watts m-2 arcsecs-2 μm-1 at 0.55 μm or an apparent brightness of approximately 4.0 mpsas.

Comparing the result of the foregoing reduction of apparent brightness from the ROLO archive the chart takeoff regarding the brightenss of the ejecta plume, if the plume reaches its maximum predicted brightness will be of similar or slightly fainter apparent brightness to the surrounding surface terrain.

The resolution of ROLO archive images did not permit evaluation of the apparent brightness of the shadowed portion of Cabeus, Cabeus A or Cabeus A1. It is assumed that the shadowed areas visible from Earth are at least 1 mpsas darker than the surrounding surface terrain. Some contrast should be seen between the Earth-visible shadowed portion of Cabeus A1 and the LCROSS ejecta plume.

Disclaimer

This note is the work product of an amateur astronomer. This result should not be relied upon by either professionals or news reporters.

Acknowledgments

Thomas C. Stone of the U.S.G.S. ROLO Lunar Image Project (url: http://www.moon-cal.org/) provided the 550nm data slice from the ROLO image used here to estimate the surface brightness near Cabeus A1 and instructions for calibration of ROLO raw camera data into radiance.

References

Bohlin, R. C.; Gilliland, R. L. 2007. Hubble Space Telescope Absolute Spectrophotometry of Vega from the Far-Ultraviolet to the Infrared. AJ 127(6);3508-3515.
http://adsabs.harvard.edu/abs/2004AJ....127.3508B

Cox., A.N. 2000. Table 12. 7. In Allen's Astrophysical Quantities. Springer.

Wooden, D. NASA Ames (LCROSS Team). Sept. 11, 2009. Ejecta Flux Prediction (Chart). Posted to LCROSS [Amateur] Observation newsgroup. file: ejecta_flux_predict_09sep02.pdf
http://tinyurl.com/m6uqgj

Appendix A: Solid angle conversion coefficients

This initialization cell formatted group provides coefficients to convert solid angle measurements between steradians and square degrees, square arcmins and/or square arcsecs.

In[55]:=
```
degsperradian := 360 / (2 × π)
```

In[56]:=
```
arcminsperradian := (360 × 60) / (2 × π)
```

In[57]:=
```
arcsecperradian := (360 × 60 × 60) / (2 × π)
```

In[58]:=
```
degssqpersteradian := (degsperradian)^2
```

In[59]:=
```
arcminssqpersteradian := (arcminsperradian)^2
```

In[60]:=
```
arcsecsqpersteradian := (arcsecperradian)^2
```

In[61]:=
```
steradiansperdegssq := 1 / degssqpersteradian
```

In[62]:=
```
steradiansperarcminsq := 1 / arcminssqpersteradian
```

In[63]:=
```
steradiansperarcsecsq := 1 / arcsecsqpersteradian
```