Lunar Occultations in the Far Infrared – A Niche for SOFIA?

Or Just a Crazy Idea?

Paul M. Harvey, UT Austin/U. Colorado

Outline

- Basics of lunar occultation technique and SOFIA
- Summary of the problems to be tackled
  - The lunar background and pointing
  - Number of likely events
  - Constraints on flight planning
- Summary of my Basic Science observing plan

Motivation I

- Far-IR angular resolution of even a 2.5-m telescope is very limited compared to neighboring wavelengths!
- When will the first far-ir interferometer fly?
- SOFIA is uniquely suited to observe lunar occultations – movability and insensitivity to high background!
- Technique used by optical and radio astronomers routinely prior to multi-aperture interferometry

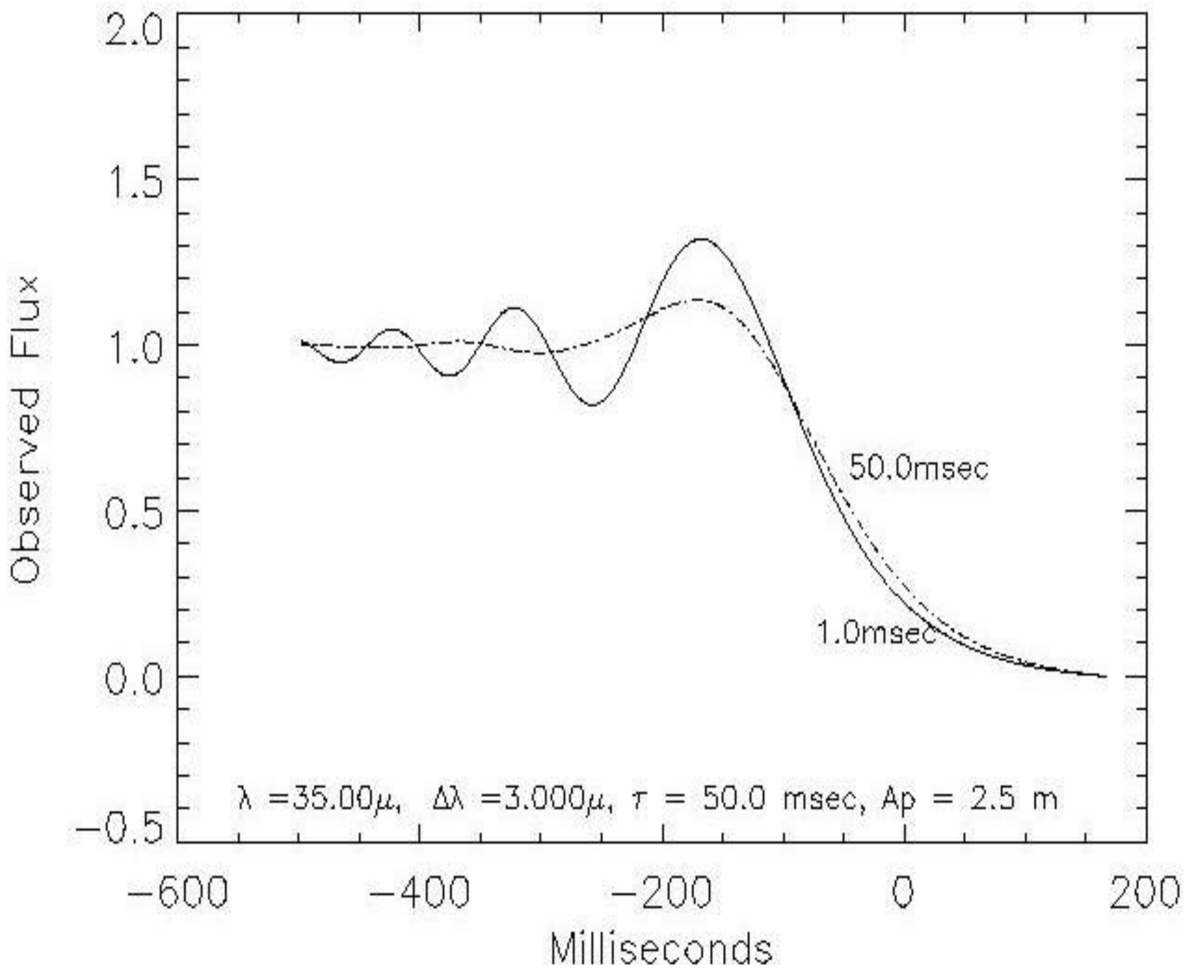
Motivation II

- Models for thermal emission are notoriously degenerate without angular size information, i.e. MANY different models can fit a particular spectral energy distribution, e.g. Vega debris disk
- Dust particle density, particle size, composition can all be derived much more confidently with angular size information, even just with limits

Some Basic Principles

- $\lambda^{1/2}$ wavelength dependence because of Fresnel diffraction (infinite straightedge)
- Moon moves ~ 0.5 arcsec per second
  - Slower "off center" and slowed by SOFIA flight
- λ/D ~ 3" at 35μm, 10" at 100μm
- So can beat Airy diffraction with 1 sec time res
- Dark side of Moon ~ 90K (not dark in far-IR)

Theoretical Occultation Data



Fringes are blurred by: bandwidth, intg time, telescope aperture, source size

Multispectral Data in the Future?

No. 1, 2007 OBSERVATIONS OF LUNAR OCCULTATIONS. I. 545

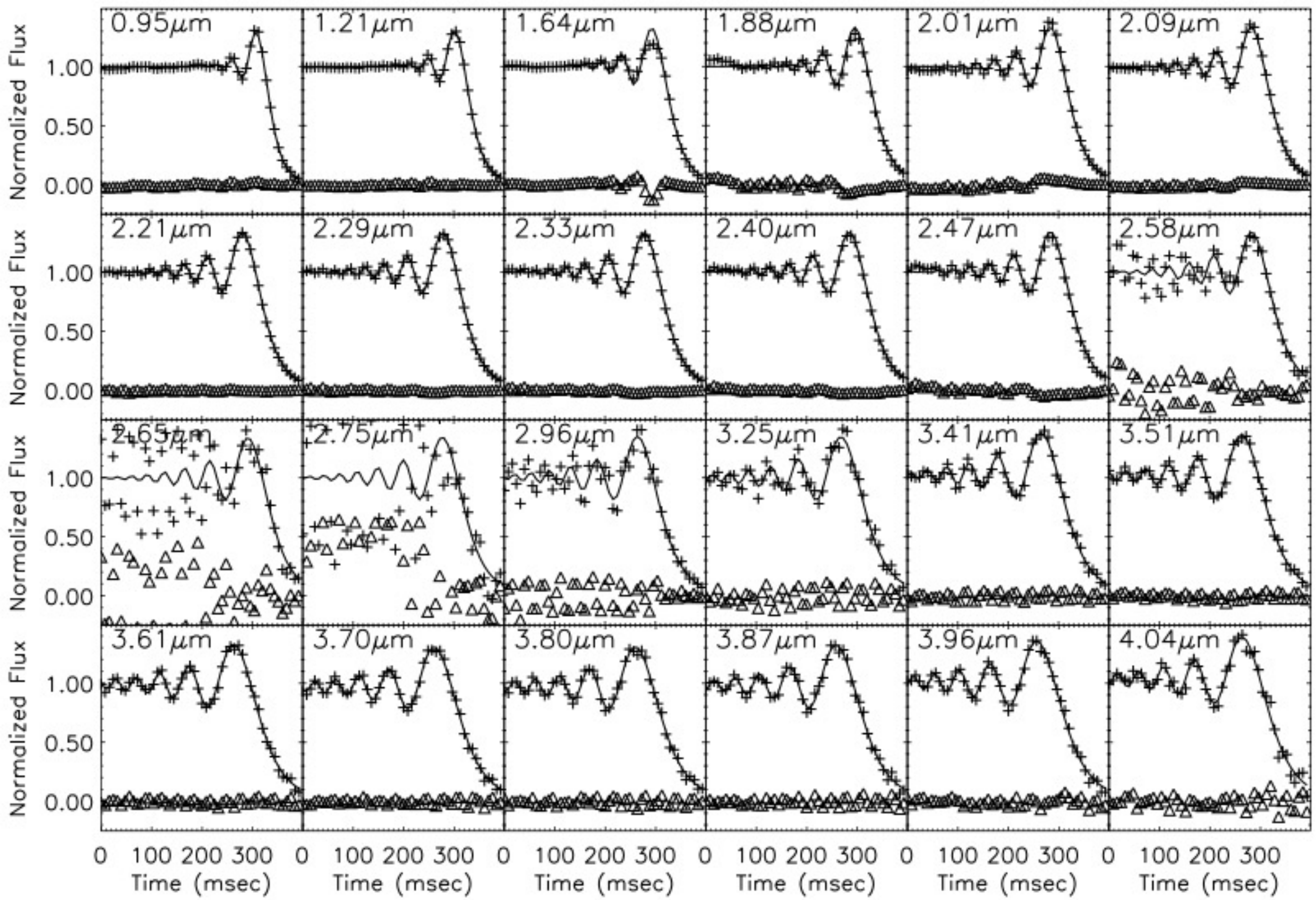


Fig. 1.—Plots of observed light curves (*plus signs*) vs. computed model light curves for the 4.5 mas uniform disk model of IRC +00233 at a sampling of the range of wavelengths observed between 1 and 4 μm. In each panel the lower curve of triangles shows the difference of observed minus model.

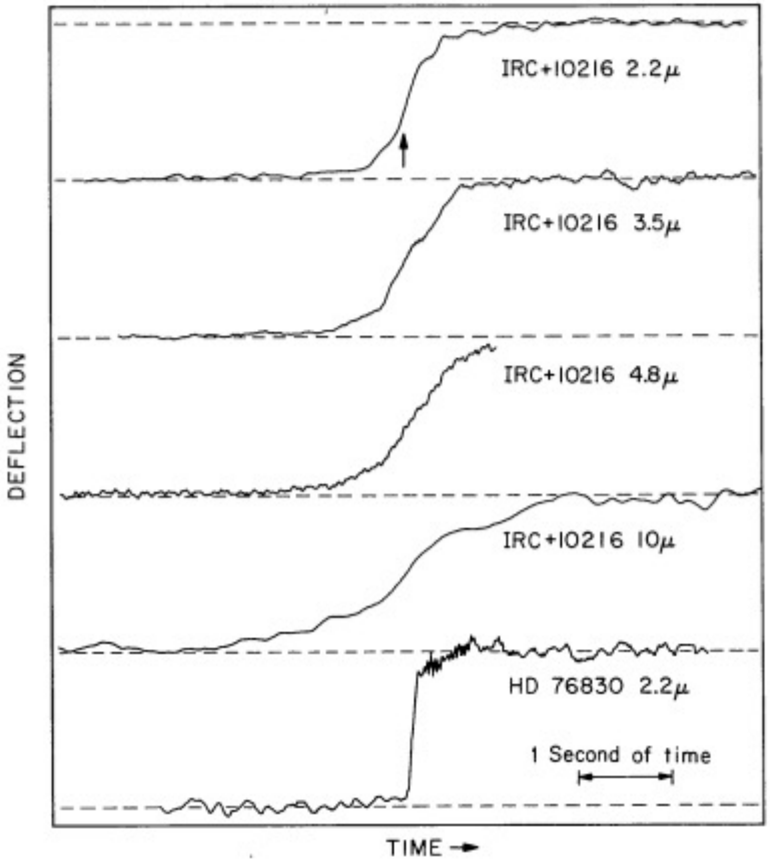
1972ApJ.

TABLE 1

Object	Date (UT)	Telescope (inches)	λ_{eff} (μ)	Magnitude*
IRC+10216..........	1971 Jan 14	60 Mount Hopkins	2.2	0.1
IRC+10216..........	1970 Nov 20	24 Mount Wilson	3.5	−2.6
IRC+10216..........	1970 Nov 20	60 Mount Wilson	4.8	−4.4
IRC+10216..........	1970 Nov 20	200 Palomar	10.2	−7.2
HD 76830............	1970 Nov 19	24 Mount Wilson	2.2	1.2

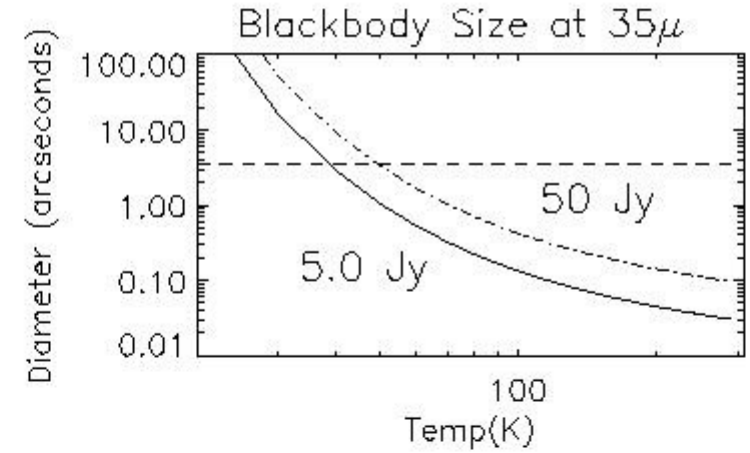
* On 1970 November 20 the 2.2-μ magnitude of IRC+10216 was +1.0.

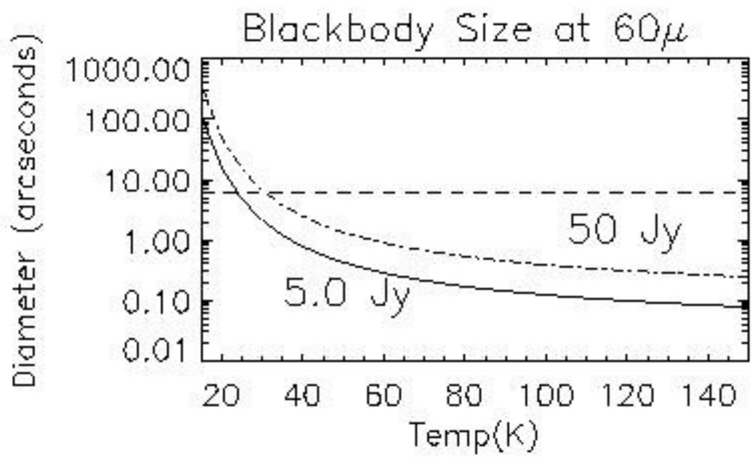
Occultations in the Geometric Limit Can Still Be Quite Important

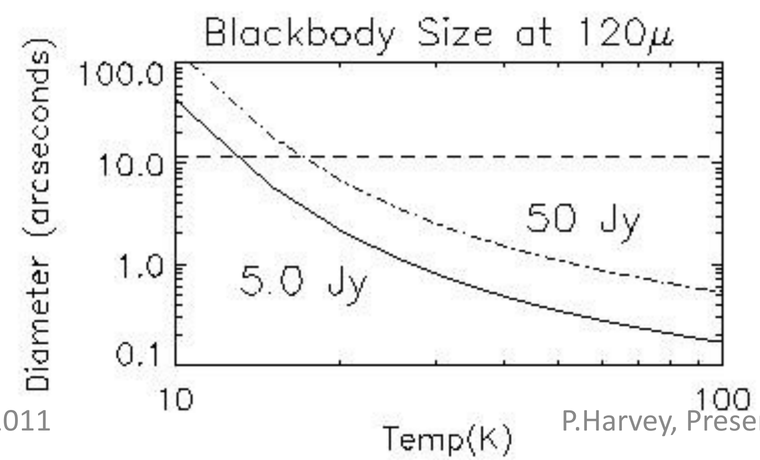


Some Relevant Considerations

- Start with 35μm observations with FORCAST
  - Better ratio of Moon to typical source flux than longer λ
  - Large format 2-D array helps
- 6 arcsec "pixel" captures most of flux with some leeway for pointing issues
- Sky flux is ~ 20,000 Jy into 6" pixel
  - Background statistical noise in 100 msec ~ 2 Jy
- Moon flux is ~ 6000 Jy into 6" pixel





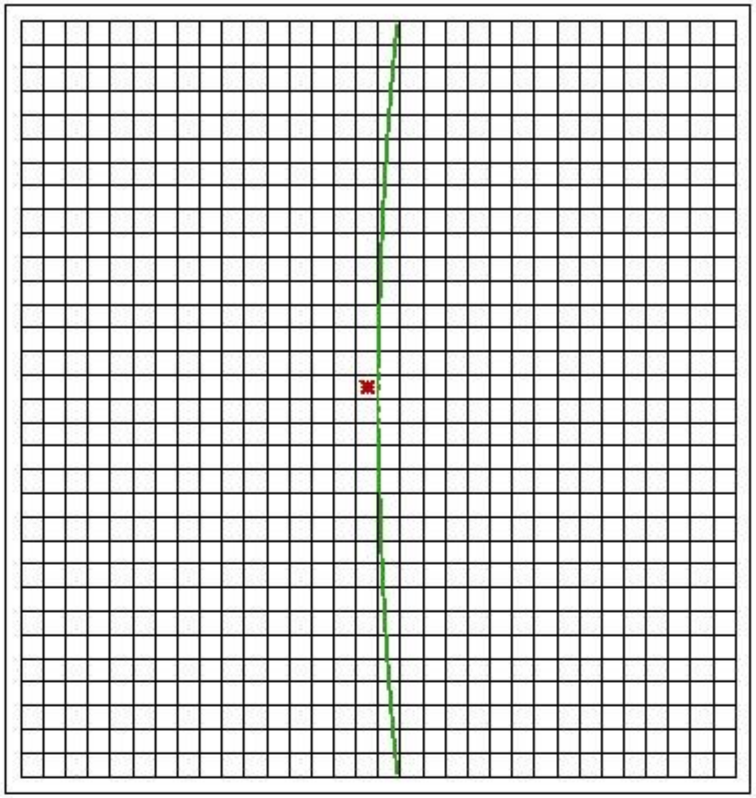


What Brightness Sources Might One Consider?

How Many Opportunities?

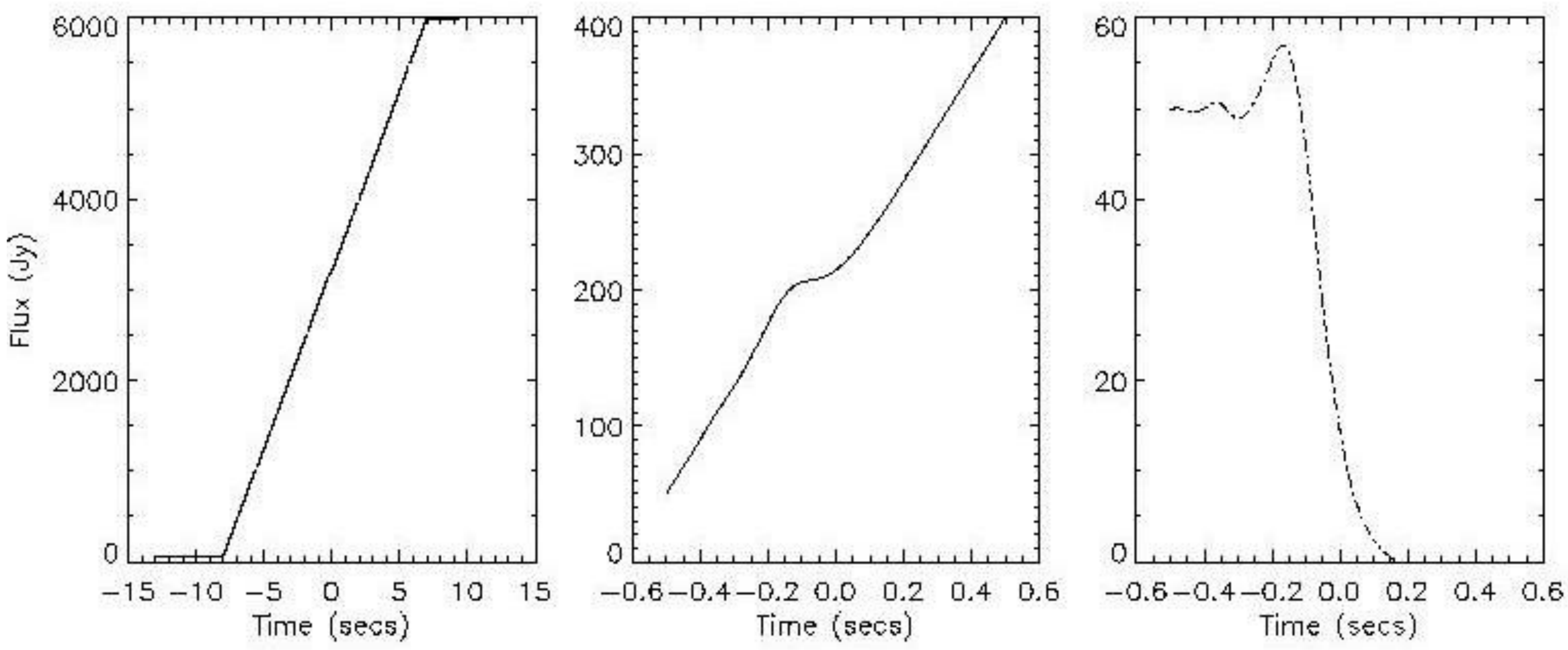
- Over the 18 yr occultation cycle
  - 190 objects > 50 Jy @ 25μm
  - 450 objects > 20 Jy
  - 920 objects > 10 Jy
- Some familiar names
  - IRC +10011 (CIT 3), U Ori, VX Sgr
  - IRC +10216
  - L1551 IRS5

How To Observe?

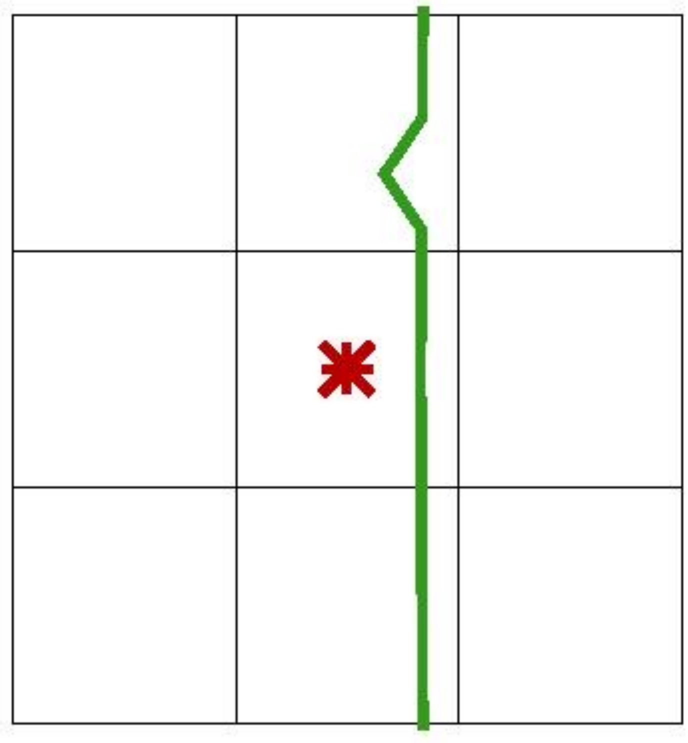


- 1x1 6” pixel for object
- 1 x 32 6” pixels to measure lunar flux
- 16x32 6” pixels to measure sky flux
- Chopping?
- Chop parallel to limb?
- Tracking? Lunar or sidereal?

Getting Rid of Backgrounds



The Real Problem?



Irregularities on lunar limb + SOFIA pointing?

Typical lunar mountain ~ 1” =>
150 Jy

What will be the pointing jitter at the relevant frequencies (1-20 Hz)
for occultation observations?

Flight Planning Issues

- Ground-based experience and software shows time accuracy of prediction to be a few secs
- Calibration requirements probably just include observing one point-like source once per instrument configuration at most
- Total time req’d per event ~ 30 min
- There will always be a tradeoff between science case and distance from base

Basic Science Observing Plan

- Use FORCAST in “flow mode”, readout rate set for max S/N (~ 150 Hz), 256 x 256 full frames for 10 sec
- Use 31.5μm filter with no dichroic for max S/N
- Some unchopped, some chop parallel to lunar limb
- Some tracking on Moon, some sidereal

“AORs” Submitted

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I. Observing Plan

Setup tracking on Moon with dark limb centered in array
Setup chopping parallel to Moon's limb with throw of ~ 90"
Move completely off Moon, ~ 10 arcminutes

Take 10-sec data stream on blank sky with no chopping
Move back onto Moon's dark limb
Take 10-sec data stream tracking on Moon
Turn on chopping parallel to limb
Take 10-sec data stream with chopping and tracking on Moon

Setup tracking at sidereal rate (on nearby star?)
Move completely off Moon, ~ 10 arcmin
Take 10-sec data stream with chopping
Move back onto Moon's dark limb, but position telescope 10" east of centered on limb
Take 10-sec data stream with chopping while Moon drifts across array
Turn chopping off
Reposition telescope 10" east of centered on limb
Take 10-sec data stream with no chopping
Move completely off Moon, ~ 10 arcmin
Take 10-sec data stream with no chopping
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Summary

- The observations will be difficult!
- Creative observing techniques may help
- Minimizing pointing jitter @ 0.2-20 Hz is good!
- The payoff is large
  - Hundreds of sources
  - Angular size measurements nearly always are crucial for narrowing the range of emission models relevant to a thermal source
- There is ***no competition***