

# **Chimera: A High Speed Three Color Photometer for Satellite Characterization**

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Avner, and Kris Rockowitz**


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# Outline

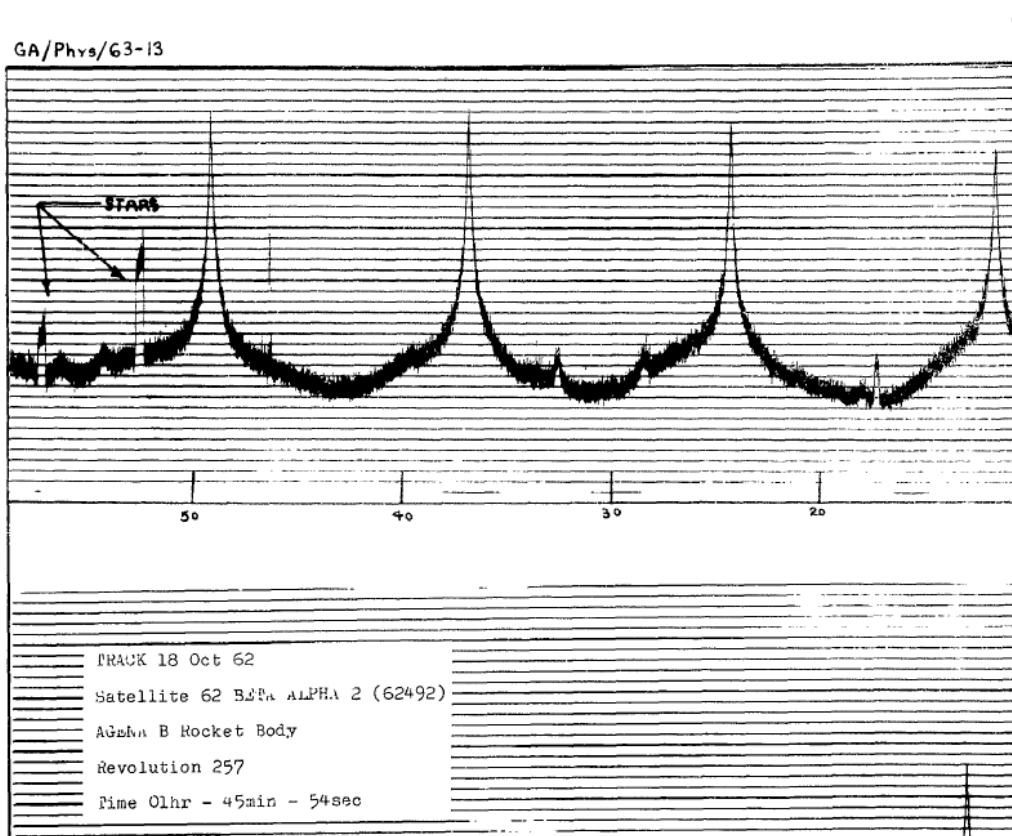
- 
- **Satellite Photometry**
  - **Approach and Technical Requirements**
  - **Chimera Photometer Overview**
  - **First Light and Science Data**
  - **Conclusion**



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# Satellite Photometry

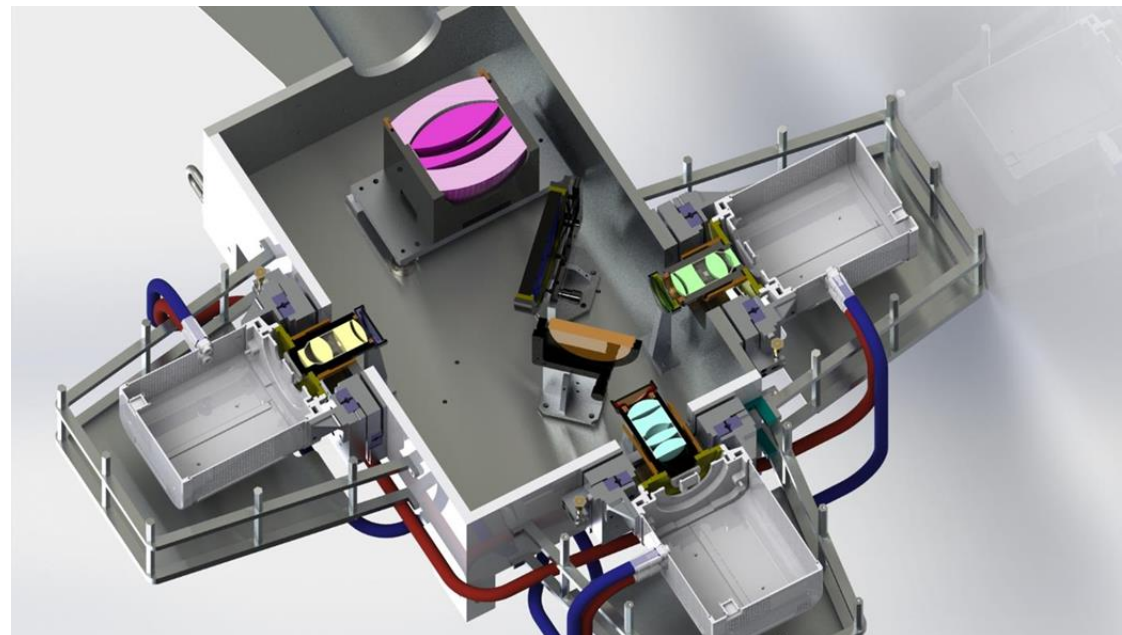


*Light curve of . From "Investigation of Photometric Data Received from an Artificial Earth Satellite, Eugene Vallerie II, USAF, September 1963.*

- Multi-color satellite photometry started shortly after satellites were launched
  - James Moore, US Naval Ordnance Test Station 1957
  - Vallerie, AFIT 1963
- Most US photometric exploitation has been light curve analysis of broadband signatures, and low-speed multi-color
- Replacement of old PMT photometers with CCDs reduced ability to collect high-speed photometry
- EM-CCDs change all that...

# Simultaneous Three-Color Photometry

- Avoid the pitfalls of trying to do well calibrated absolute photometry under SSA's stressful operational conditions
  - Focus interpretation on color indices and short term temporal variations
  - Exploit specular flashes to isolate surfaces
  - Unambiguous color indices of short timescale signature features
- Leverage commercial EM-CCD technology
- Classic beam splitter optical design
- Emphasize near-IR to maximize utility for both satellite and near-Earth asteroid characterization
- Asteroid photometry, astro-seismology, rapidly variable objects



Band	EM-CCD	FOV (arcmin)	Full Frame (fps)			Photometric ROI 32x32 (fps)		
			1x1	2x2	4x4	1x1	2x2	4x4
Sloan z' > 820 nm	ProEM-HS 1024BX3 1024 × 1024 13 μm	9.7	25	48	89	481	675	847
Sloan r' 562-695 nm	ProEM-HS 512BX3 512 × 512 16 μm	6.0	61	120	228	711	1099	1506
						3470	5617	7490
Sloan i' 695-844 nm	ProEM-HS 512BX3 512 × 512 16 μm	6.0	61	120	228	711	1099	1506
						3470	5617	7490

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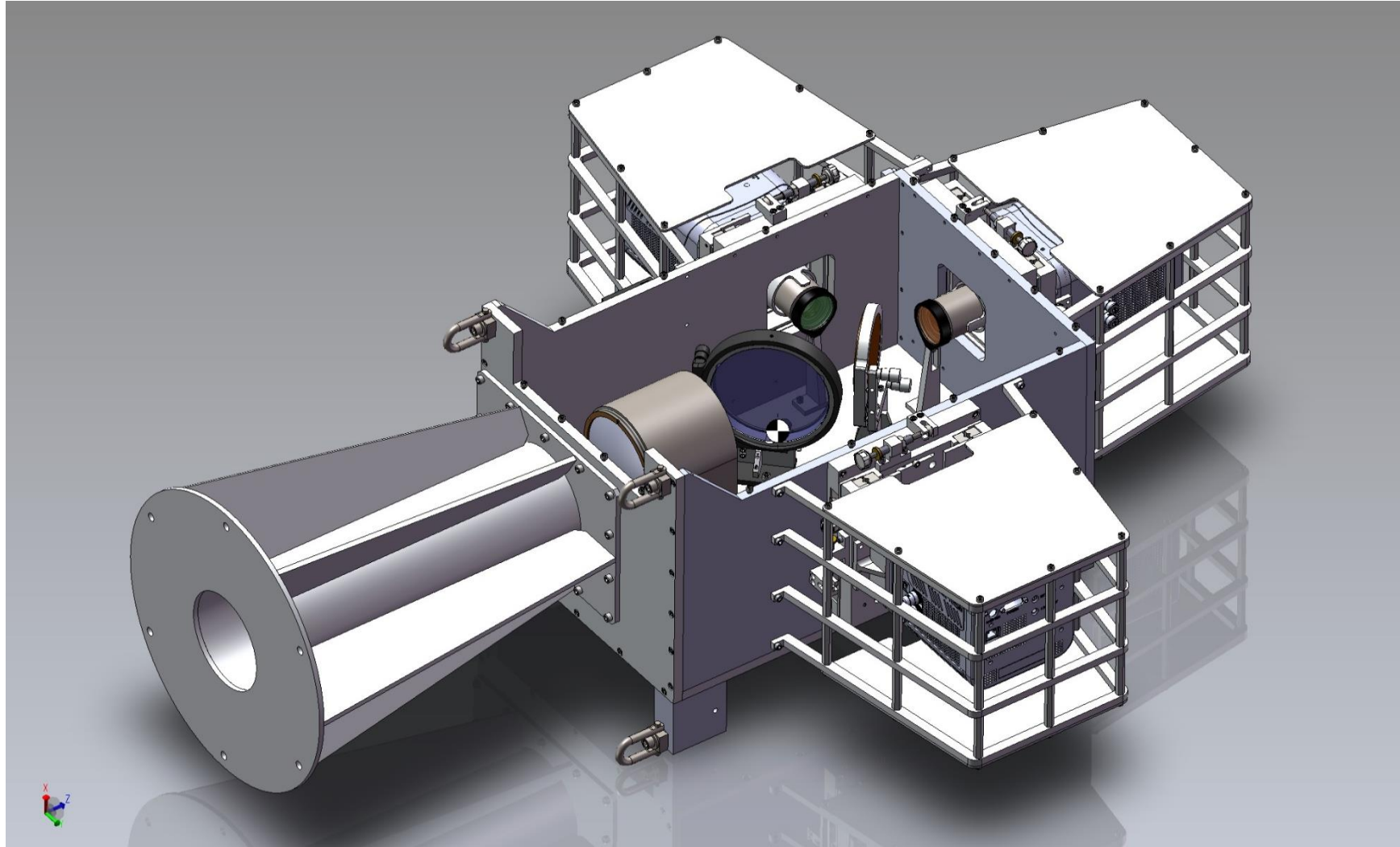


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# Chimera Opto-Mechanical Structure



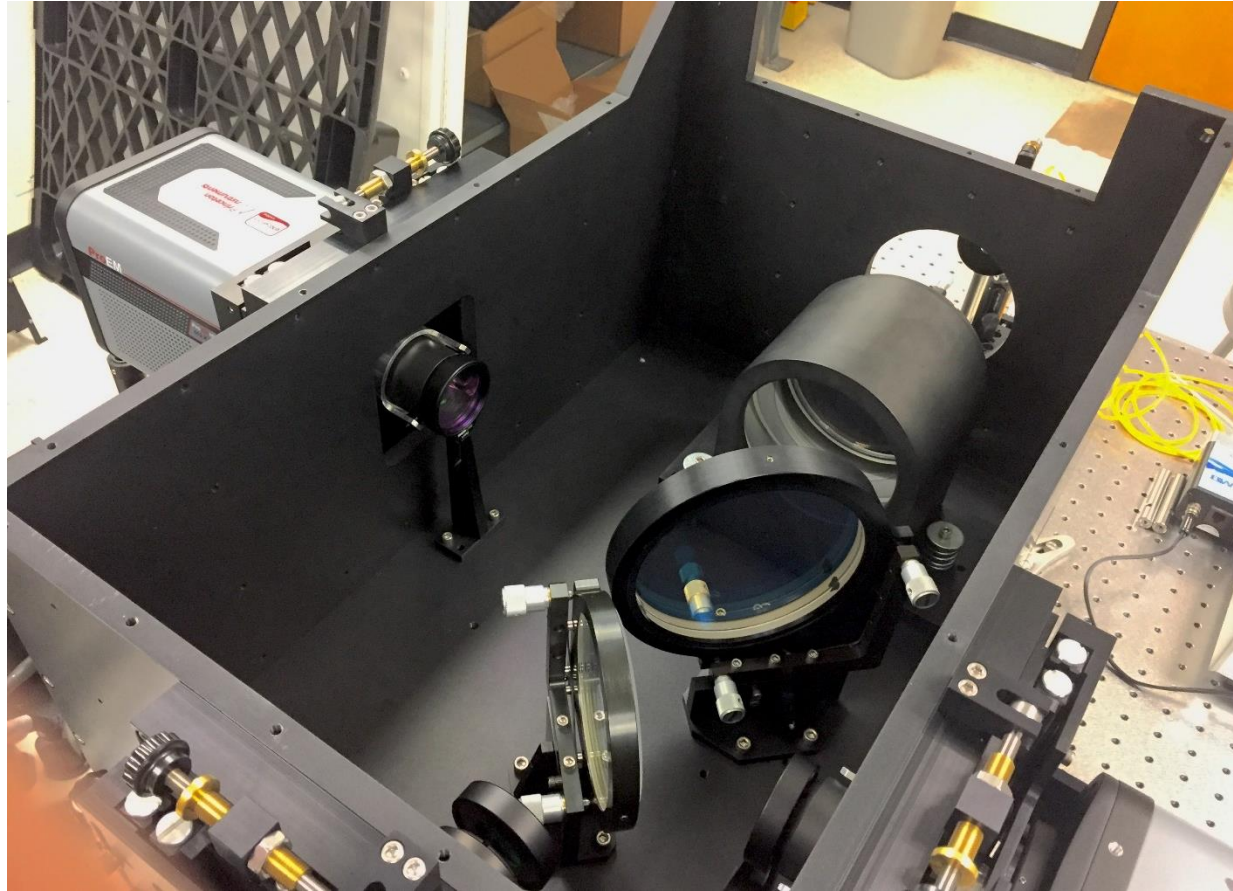
*Chimera's structure consists of a rectangular enclosure which houses the four optical assemblies. The three cameras mount to the sides of this enclosure. The round snout attaches to the backplate of the telescope*



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# Optical Assemblies



*Interior view of the optical assemblies and dichroic beam splitters.*



*Chimera Instrument loaded on the transportation cart.*



# Chimera Among Peers

<b>ULTRACAM 2002</b> V.S. Dhillon University of Sheffield	<b>HiPERCAM Expected 2017</b> V.S. Dhillon European Research Council Advanced Grant	<b>Xinglong 2013</b> Yong-Na Mao National Astronomical Observatories Chinese Academy of Sciences	<b>GROND 2007</b> Jochen Greiner Max Planck Institute for Extraterrestrial Physics	<b>CalTech CHIMERA 2014</b> L.K. Harding CalTech	<b>TOφCAM 2008</b> Blackrock Castle Observatory Science Foundation Ireland	<b>UA-Chimera 2018</b> E.C. Pearce University of Arizona
<b>William Herschel Telescope (WHT) 4.2 m La Palma</b>		<b>NAOC 1 m</b>	<b>MPG/ESO 2.2 m La Silla, Chile</b>	<b>Hale 200"</b>		<b>Kuiper 61" Mt. Lemmon</b>
<b>E2V 47-20 CCDs Frame transfer Back illuminated</b>	<b>Custom E2V 4-channel frame transfer imagers</b>	<b>Andor iKon-L (g') Princeton NTE (r') Andor iXon-888 (i')</b>	<b>EV2 BI CCDs (vis) Rockwell HAWAII-1 (NIR)</b>	<b>Andor iXon-888</b>	<b>Andor iXon+ DU88</b>	<b>Princeton Pro-EM HS 1024BX3 (z') 512BX3 (i' and r')</b>
<b>2-dichroic beam splitters</b>	<b>4-dichroic beam splitters</b>	<b>Phillips Prism</b>	<b>Folded multiple dichroic beam splitters</b>	<b>Single dichroic beam splitter</b>	<b>Dichroic beam splitter</b>	<b>2-dichroic beam splitters</b>
<b>5.1 arcmin</b>	<b>10.2 arcmin</b>	<b>18.8 arcmin</b>	<b>5.4 arcmin (vis) 10 arcmin (NIR)</b>	<b>5 arcmin</b>		<b>9.70 arcmin (z') 5.97 arcmin (r', i')</b>
<b>3 channel u', g' + (r', i', or z')</b>	<b>5 channel u', g', r', i', z'</b>	<b>3 channel g', r', i'</b>	<b>7 channel g', r', i', z', J, H, K</b>	<b>2 channel (u' or g'), (r', i', z')</b>	<b>2 channel</b>	<b>3 channel r', i', z'</b>
<b>400 Hz</b>	<b>1600 Hz</b>	<b>7.4 Hz (r') 11.8 Hz (g') 47 Hz (i')</b>	<b>&lt; 1 Hz</b>	<b>26-1000 Hz</b>	<b>26-1000 Hz</b>	<b>120-1500 Hz</b>



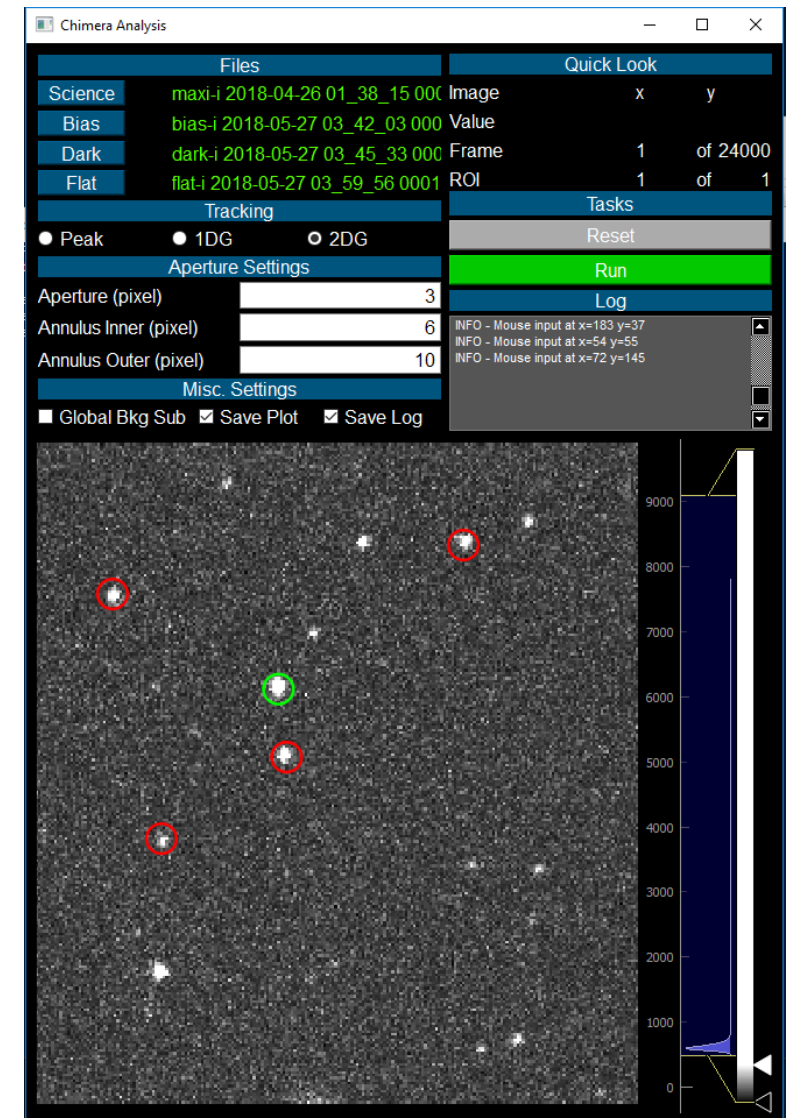
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# Control and Data Processing

- **Software challenges**
  - High parallel data rates
  - Integrating of Princeton Lightfield software with photometric processing pipeline
  - Efficient and optimal configuration of three cameras
- **Characterization of the performance of readout and amplification modes underway**
  - Princeton Lightfield automatically optimizes camera readout for ROI selections, but ROIs near the serial registers will result in higher data rates
- **Real time analysis**
  - Integrated GUI under development to simplify camera configuration
  - Real time data visualization and period determination



# Outline

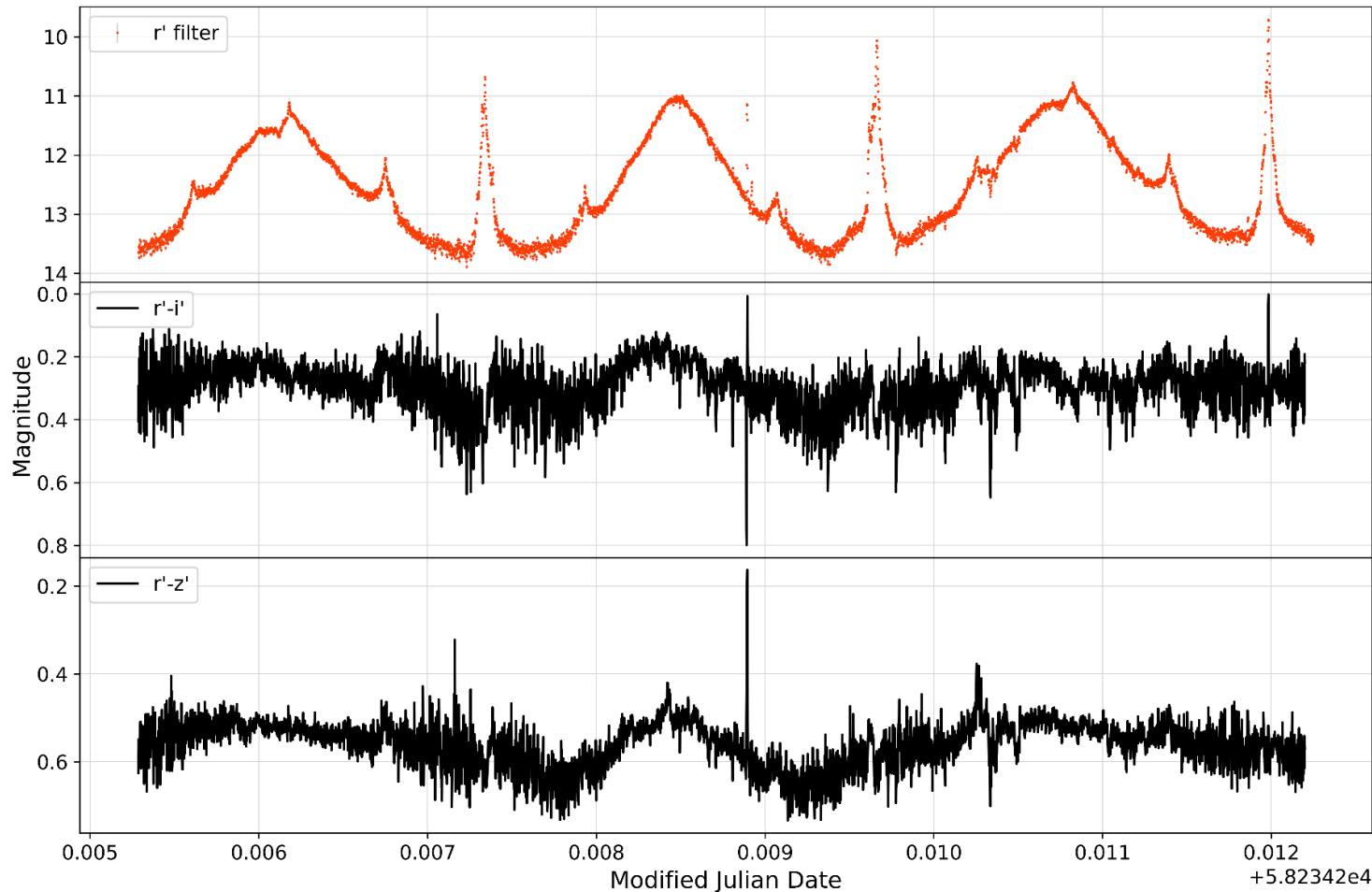
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# Multi-Color Light Curve of Echostar 2

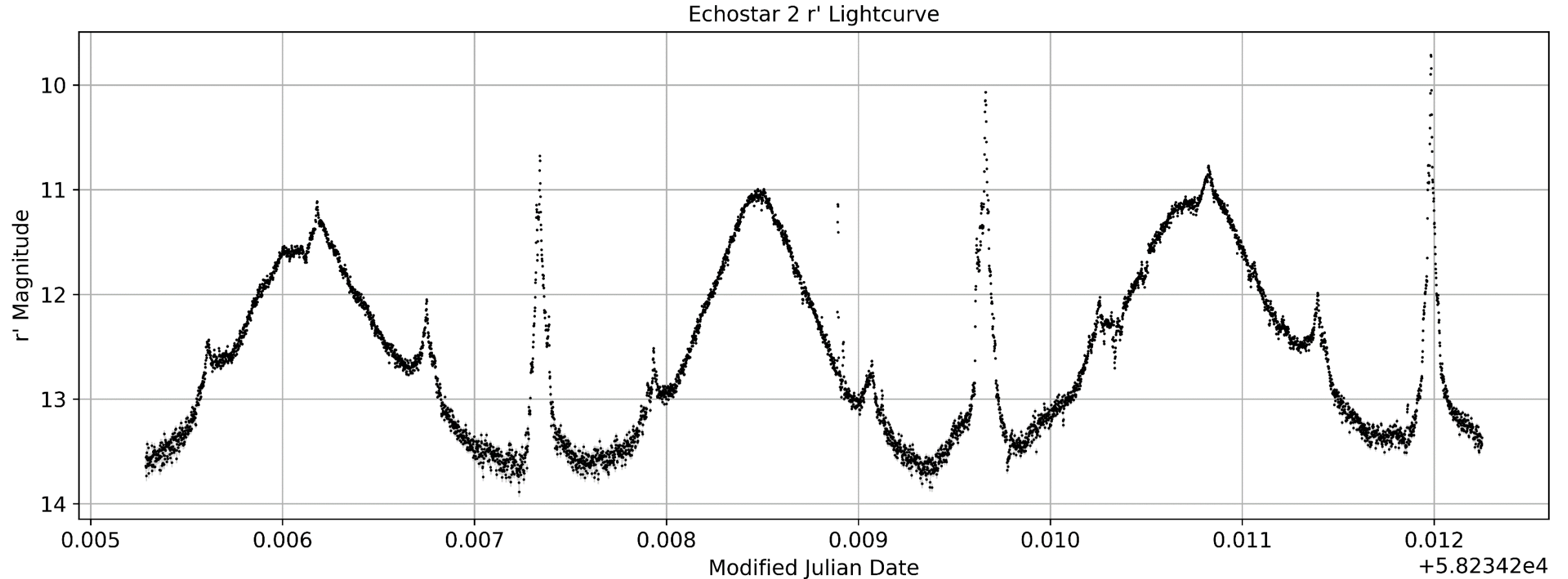


- Echostar 2 Sloan  $r'$  and  $(r'-i')$  and  $(r'-z')$  color curves
- 406 s rotational period and asymmetry of the two sides apparent
- Color variation between the two sides



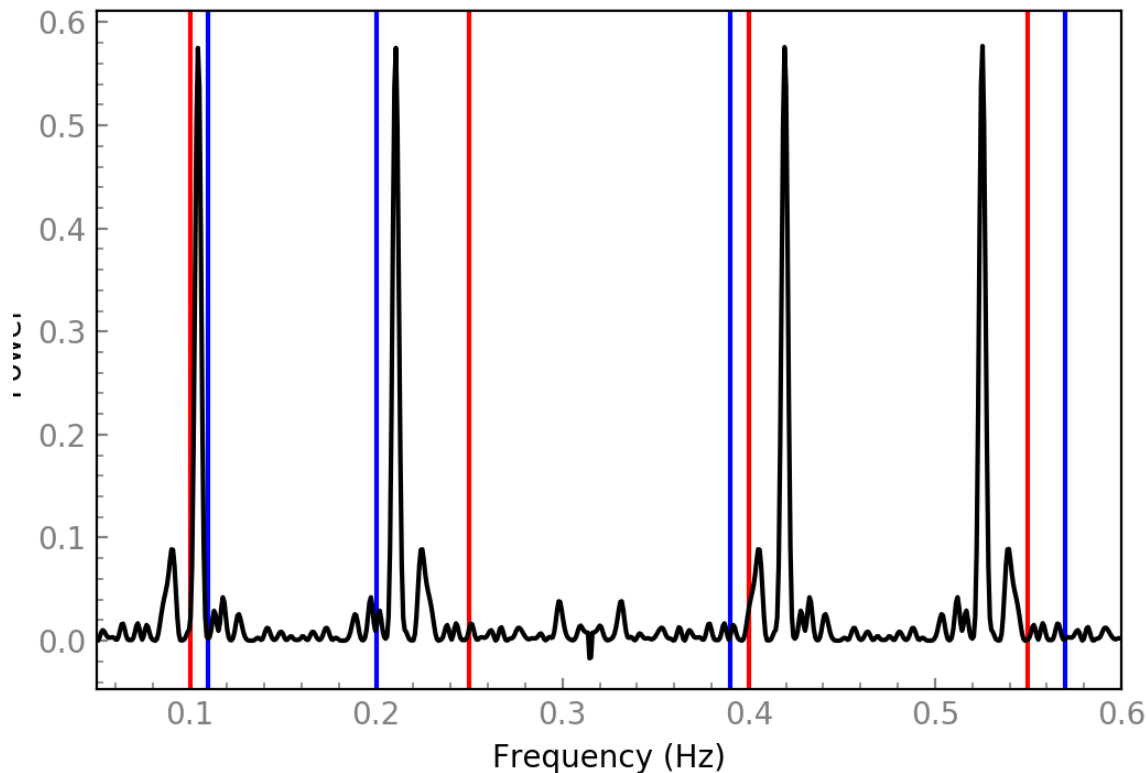


# Echostar 2



*Echostar 2 signature showing the exquisite detail available with high speed photometry with a larger telescope. Note the different shape of the two maxima, and the detail in the secondary specular features.*

# Data Analysis

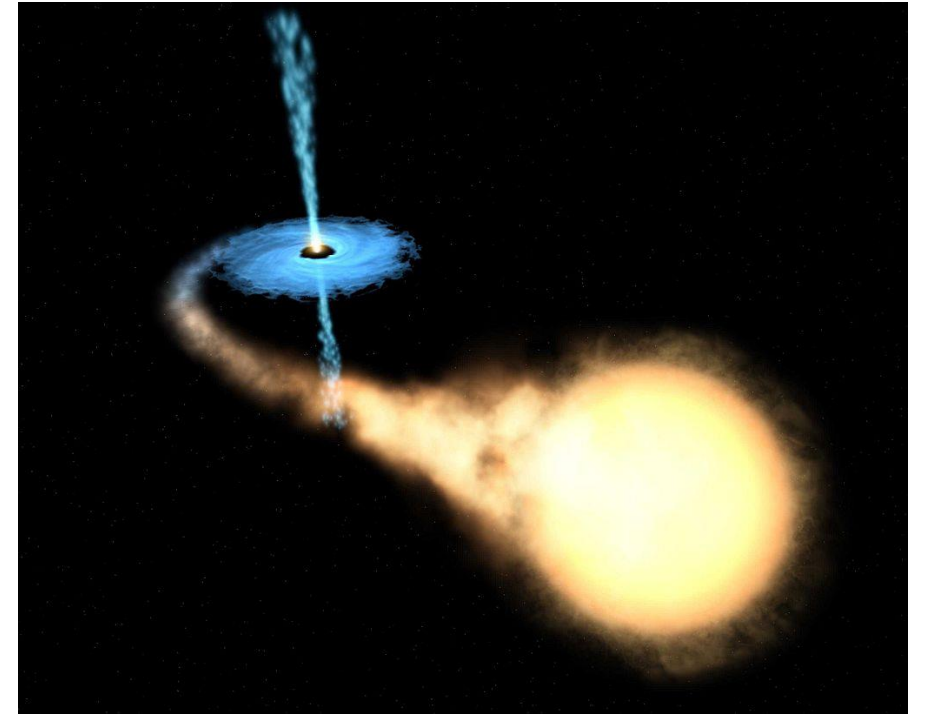
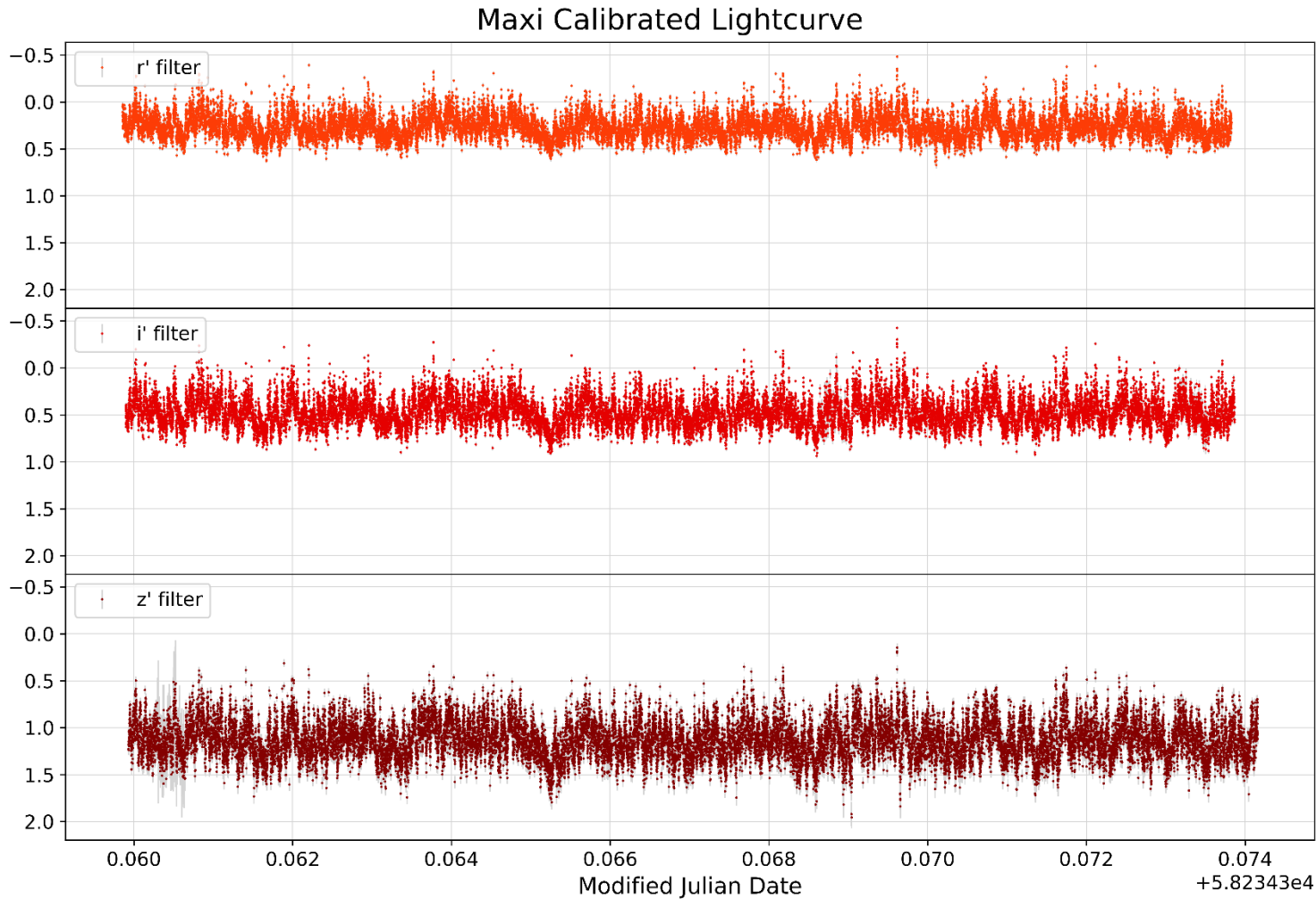


*The period analysis within the Chimera Analysis software plotted with published frequency measurements for SL-12 38104. The red and blue vertical lines represent the published observations taken May 2013 and December 2013 respectively*

- **Capability to process light curves for period determination with Lomb-Scargle**
- **Used with both UKIRT WFCAM and Chimera photometry**
  - Robust to a wide range of data frequency and sampling
- **Ultimate goal is to integrate this into real-time graphical user interface**
  - Real-time data quality assessment
  - Immediate determination of activity of transient astronomical targets

# Astronomical Collections

## Binary Black Hole Candidate MAXI J1820+070



*Left: High speed three-color light curve of Binary Black Hole MAXI J1820+070.*

*Right: Artist rendition of a accreting black hole binary system. From NASA.*



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# Conclusion

- **Exploitation of satellite photometry has been six decades in the making**
- **US techniques have focused on absolute photometry, light curves, and phase angle variations**
- **Simultaneous high-speed multi-color photometry**
  - Reduces ambiguity
  - Gives insight into specific surfaces of satellites
  - Robust to poor observing conditions
- **The Chimera Photometer designed specifically for satellite characterization**
  - Data rates up to and greater than 1000 Hz
  - Three simultaneous bands (Sloan  $r'$ ,  $i'$ , and  $z'$ )
- **Chimera is peer to best high-speed multi-color photometers in the astronomical community**

"The suggestion that this study be undertaken was made by Mr. Kenneth Kissell of the General Physics Research Laboratory, Aerospace Research Laboratories... A long time satellite observer, he suggested that there are many unanswered questions about the variations in the reflected light intensity from satellites."

"It is definitely recommended that the compiling of a catalogue of the optical characteristics of various satellites be started."

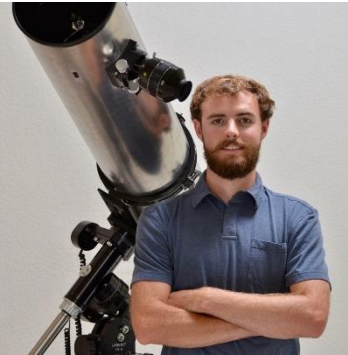
*From introduction remarks and concluding recommendations in "Investigation of Photometric Data Received from an Artificial Earth Satellite, Eugene Vallerie II, USAF, September 1963, AF Institute of Technology Masters Thesis*



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# Contact Information



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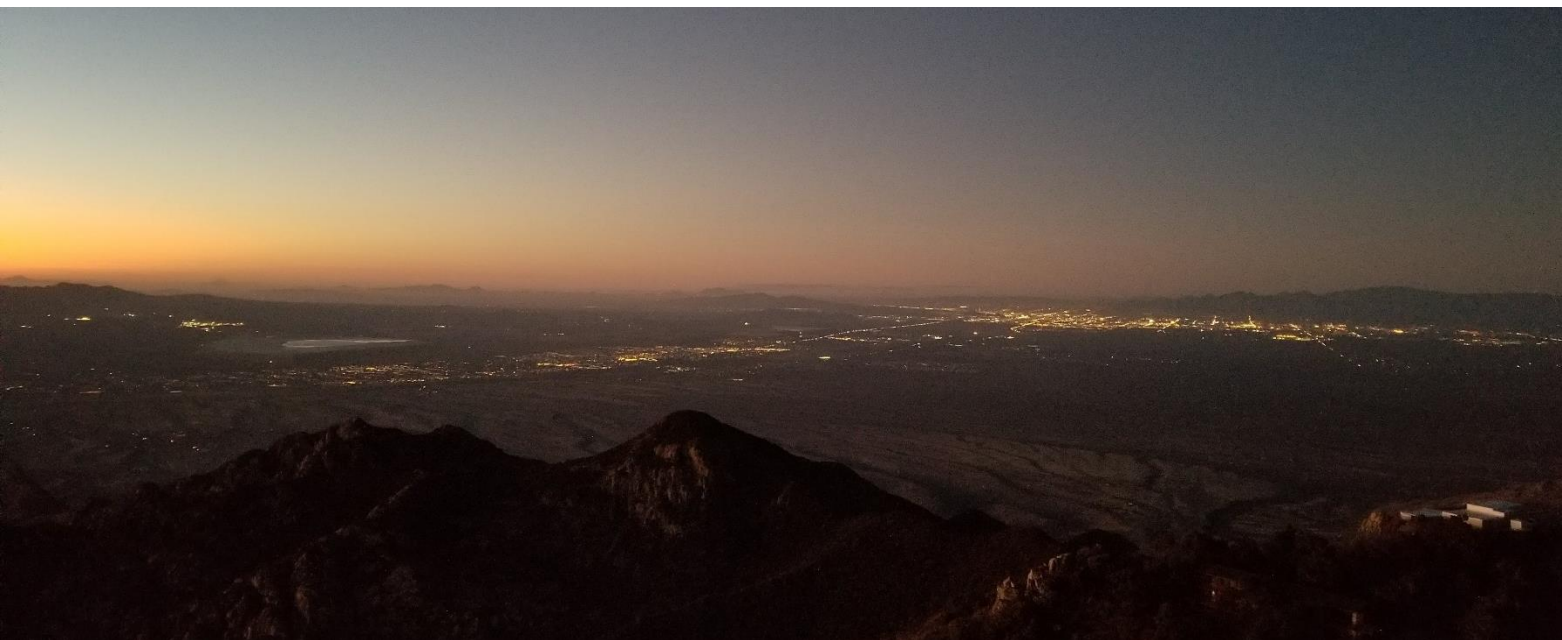
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