The Visual Brightness of Starlink Satellites

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Dark & Quiet Skies for Science and Society II

2021 October 5

Visual Magnitude - A Metric for Science and Society

- **For Science**

  SatCon1 workshop report:

  Satellites fainter than V-band magnitude 7.0 can be removed from images

- **For Society**

  Visual limit is magnitude 6.0 under dark skies

- **SpaceX goal** "Making the satellites generally invisible to the naked eye within a week of launch"

Characterizing Magnitudes

- **Apparent magnitude**

  What you see by eye or record electronically

  Simple and directly applicable

  Magnitude at a standard distances

  Derived from apparent magnitudes

  550 km is the Starlink operational altitude

  1,000 km allows for comparisons

- **Magnitude as a function of illumination phase angle**
- **Starlink brightness function**

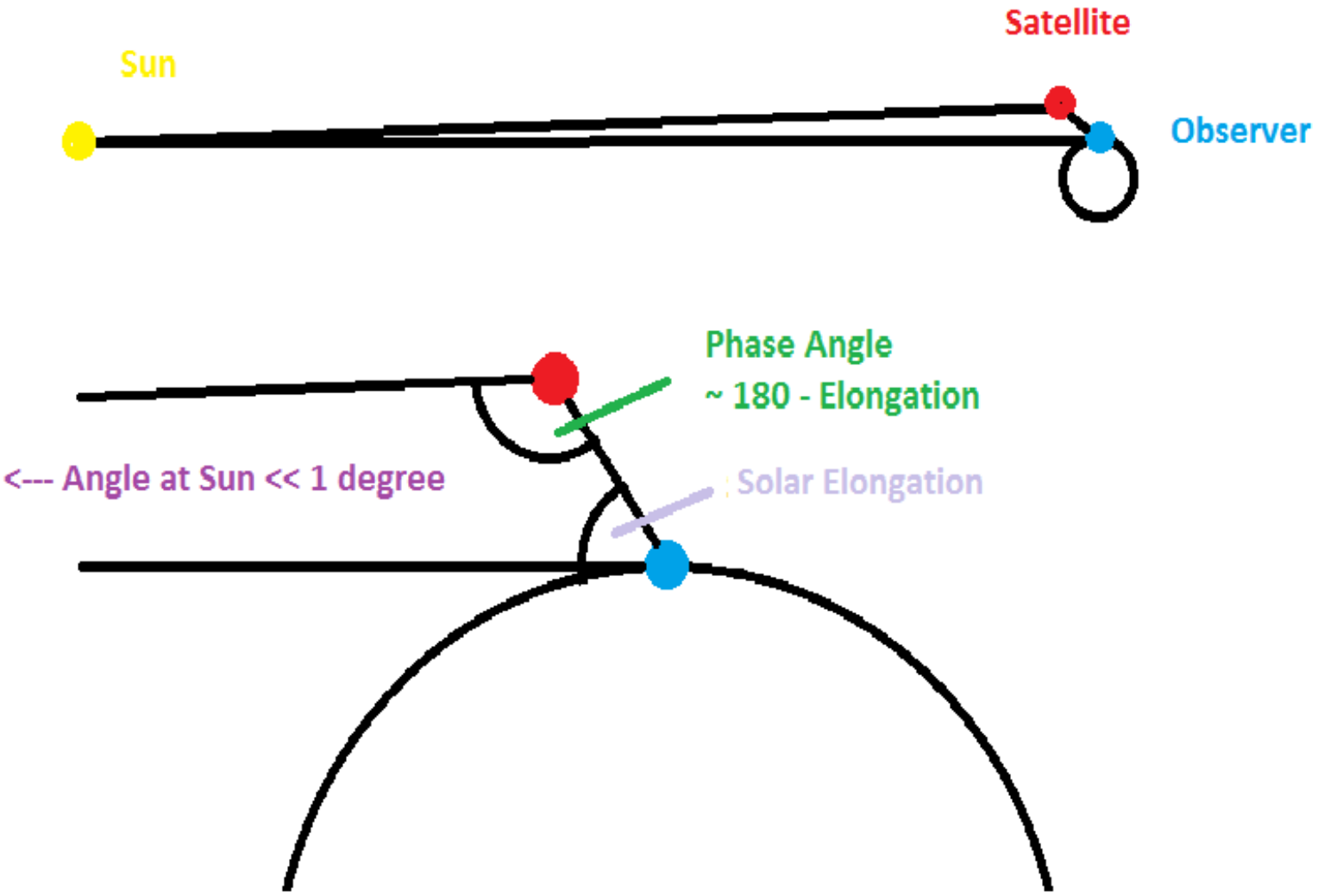
Visual Magnitudes at Standard Distances

Type	--- Mean --- 550 km	1,000	RMS	N	Ref.
VisorSat	5.92	7.22	0.85	430	a
Original	4.63	5.93	0.67	830	b

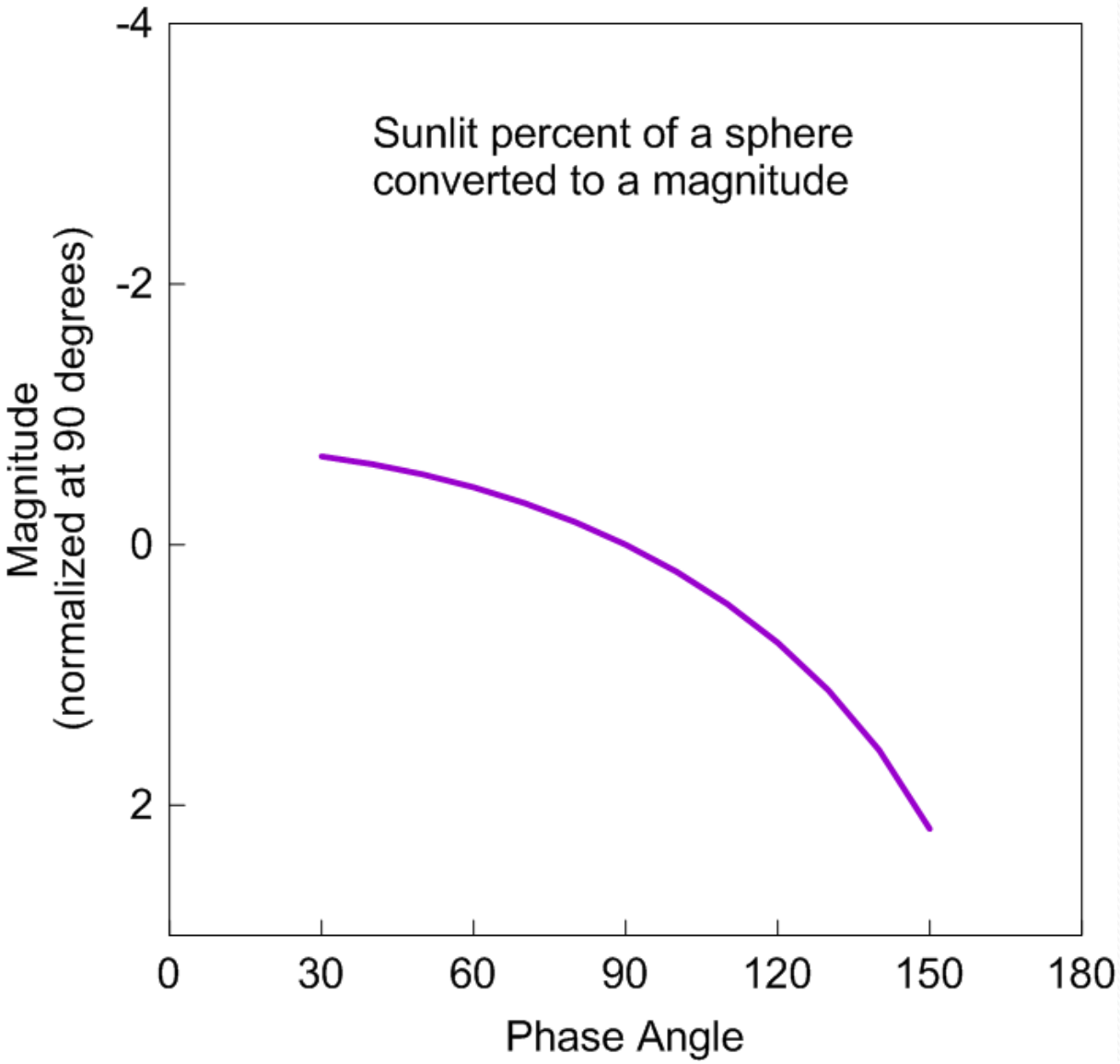
Difference = 1.29
VisorSat 31% as bright as Original

Ref a: Mallama, arXiv:2101.00374
Ref b: Mallama, arXiv:2006.08422

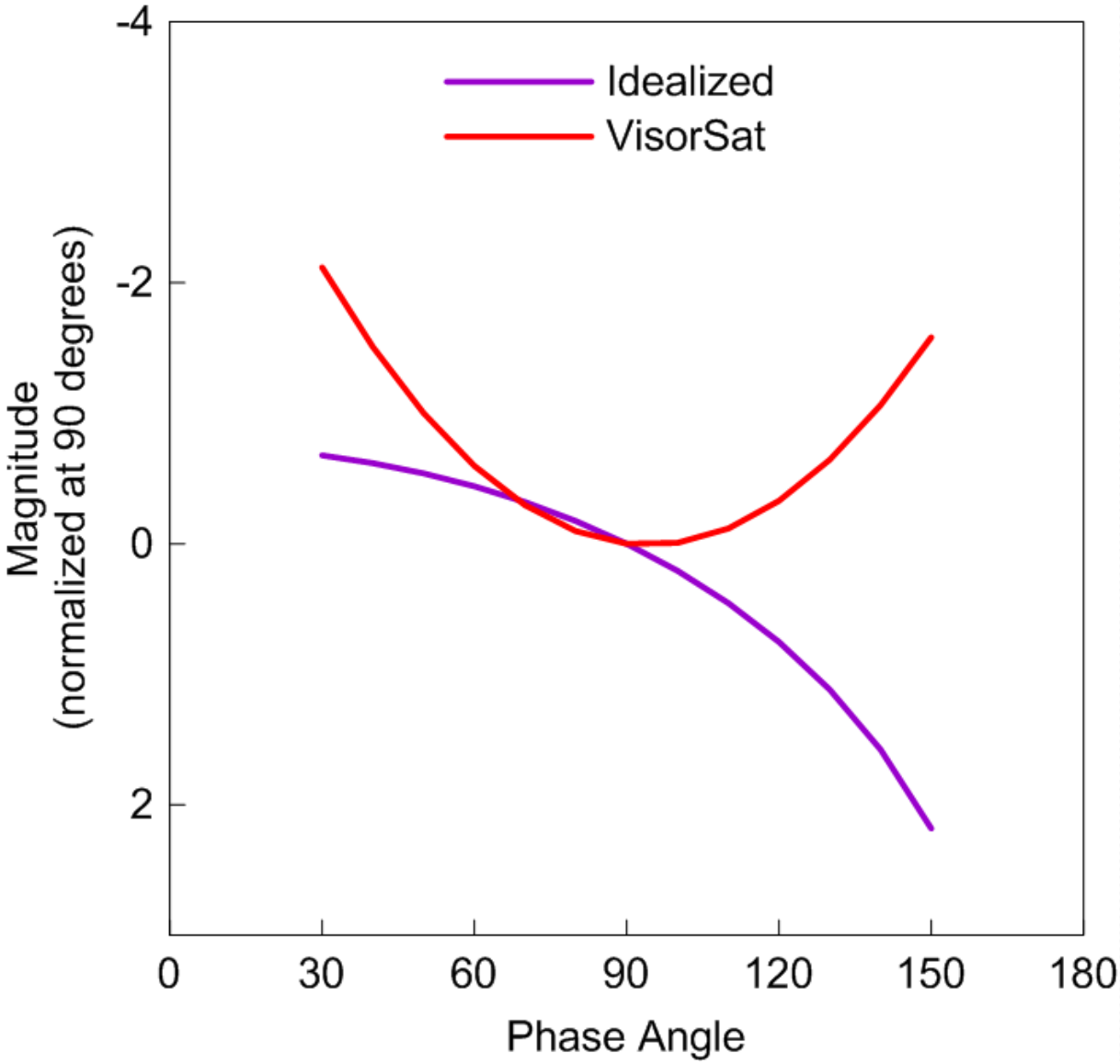
Phase Function Geometry



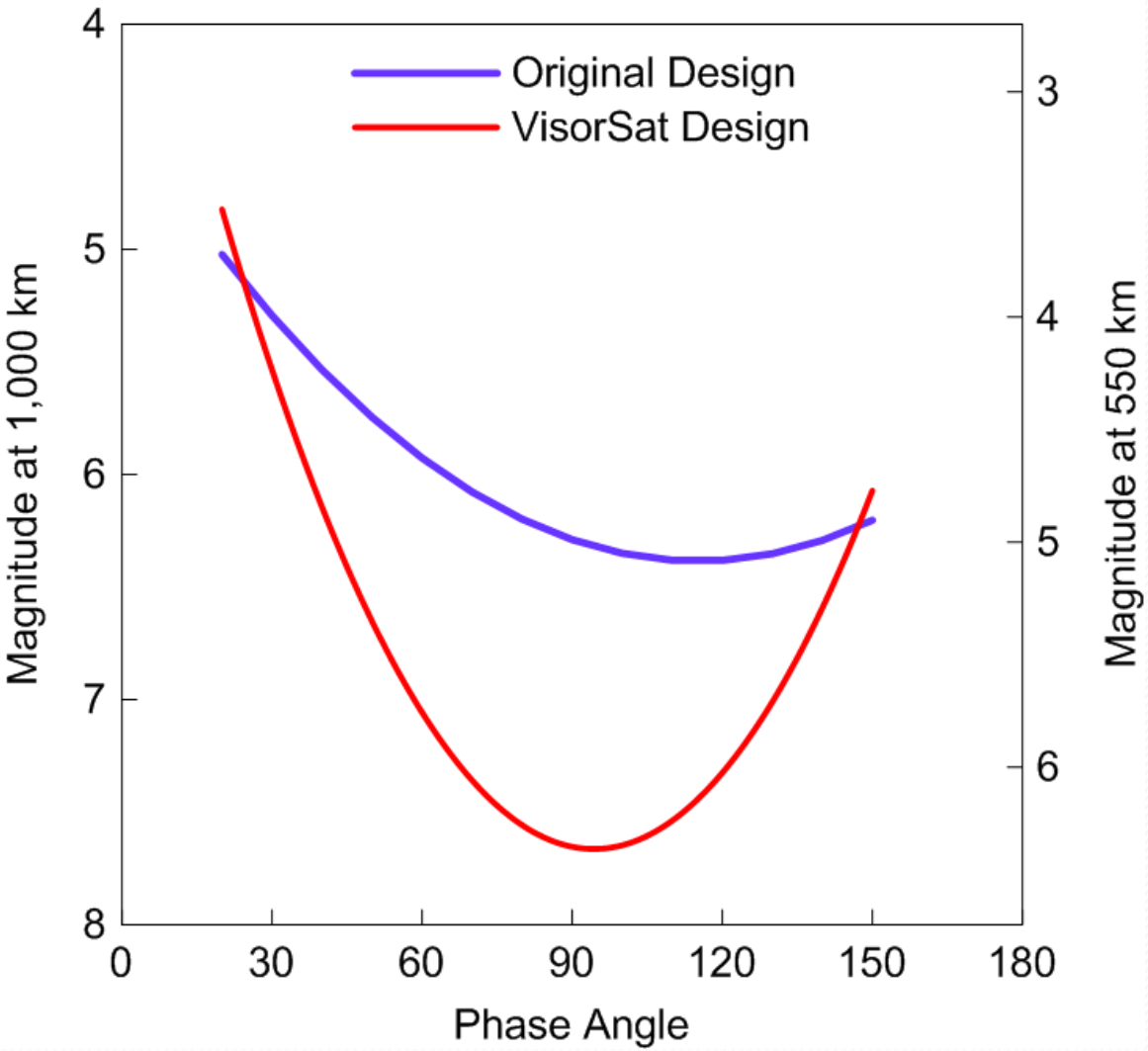
An Idealized Phase Function



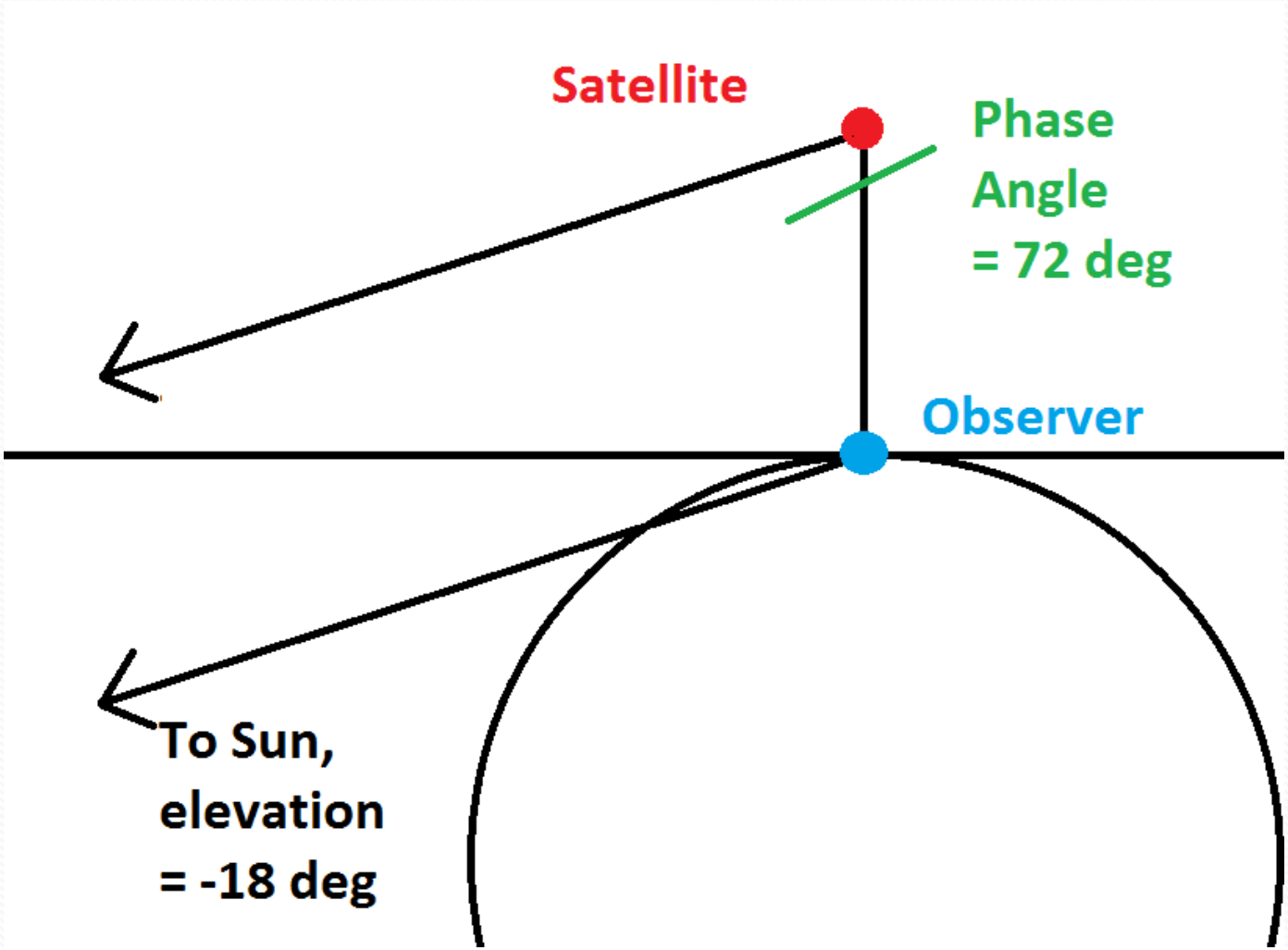
VisorSat Phase Function



VisorSat and Original Design Compared



Phase Angle 'Characteristic' Geometry (zenith at end of astronomical twilight)



Phase Angle Characteristic Magnitude

Phase angle 72 degrees

Type	Mag.
VisorSat	6.11
Original Design	4.81

Starlink Brightness Function

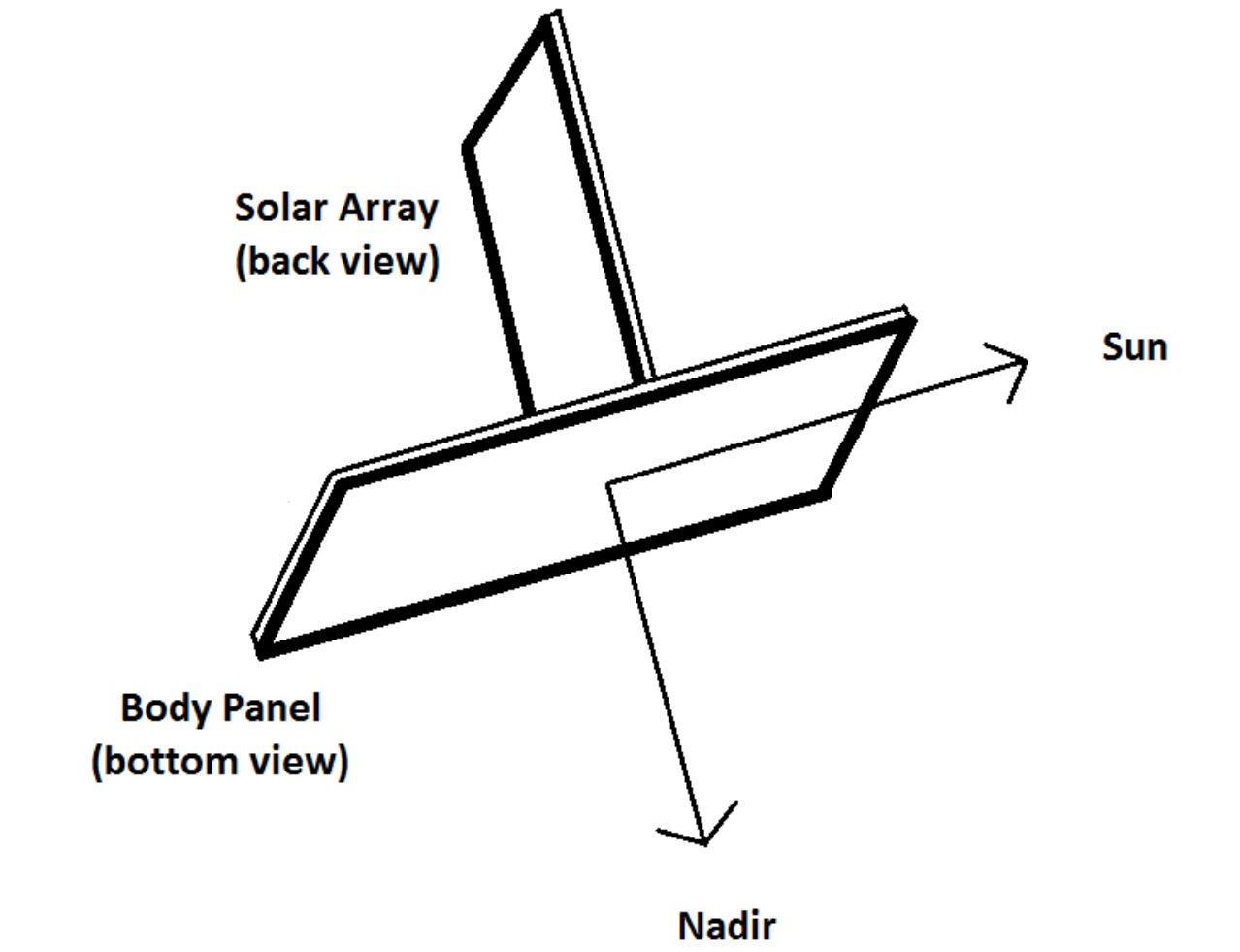
- Physically motivated by the shape of the satellite
- Defined in a satellite-centered coordinate system

- References

  Mallama, arXiv:2109.07345

  Cole, arXiv:2107.06026

SBF - Physical Motivation and Coordinate System



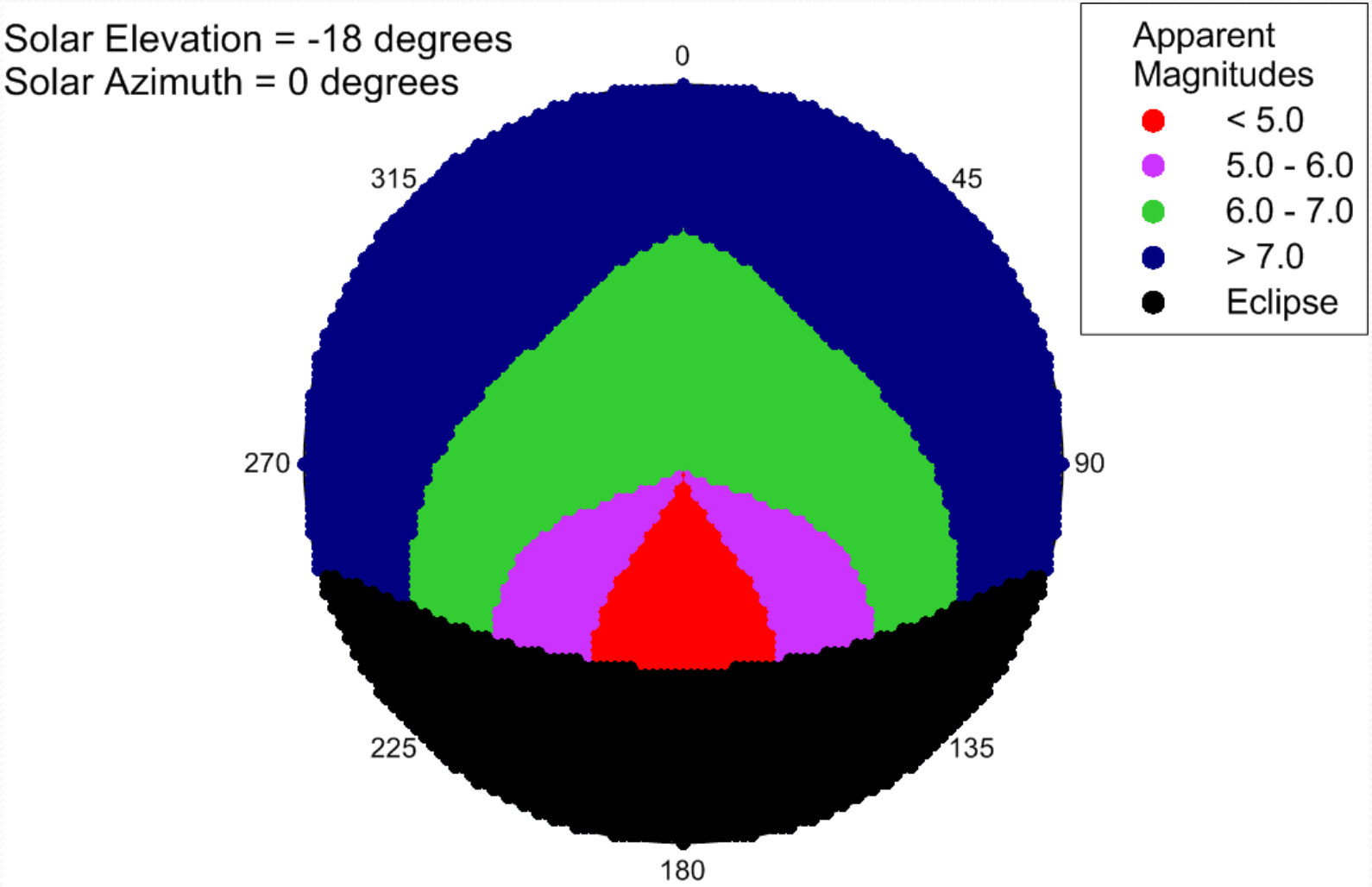
SBF Parameters

- Defined in the satellite-centered coordinate system:
- Elevation of the observer
- Elevation of the Sun
- Azimuth of the observer (relative to the Sun)

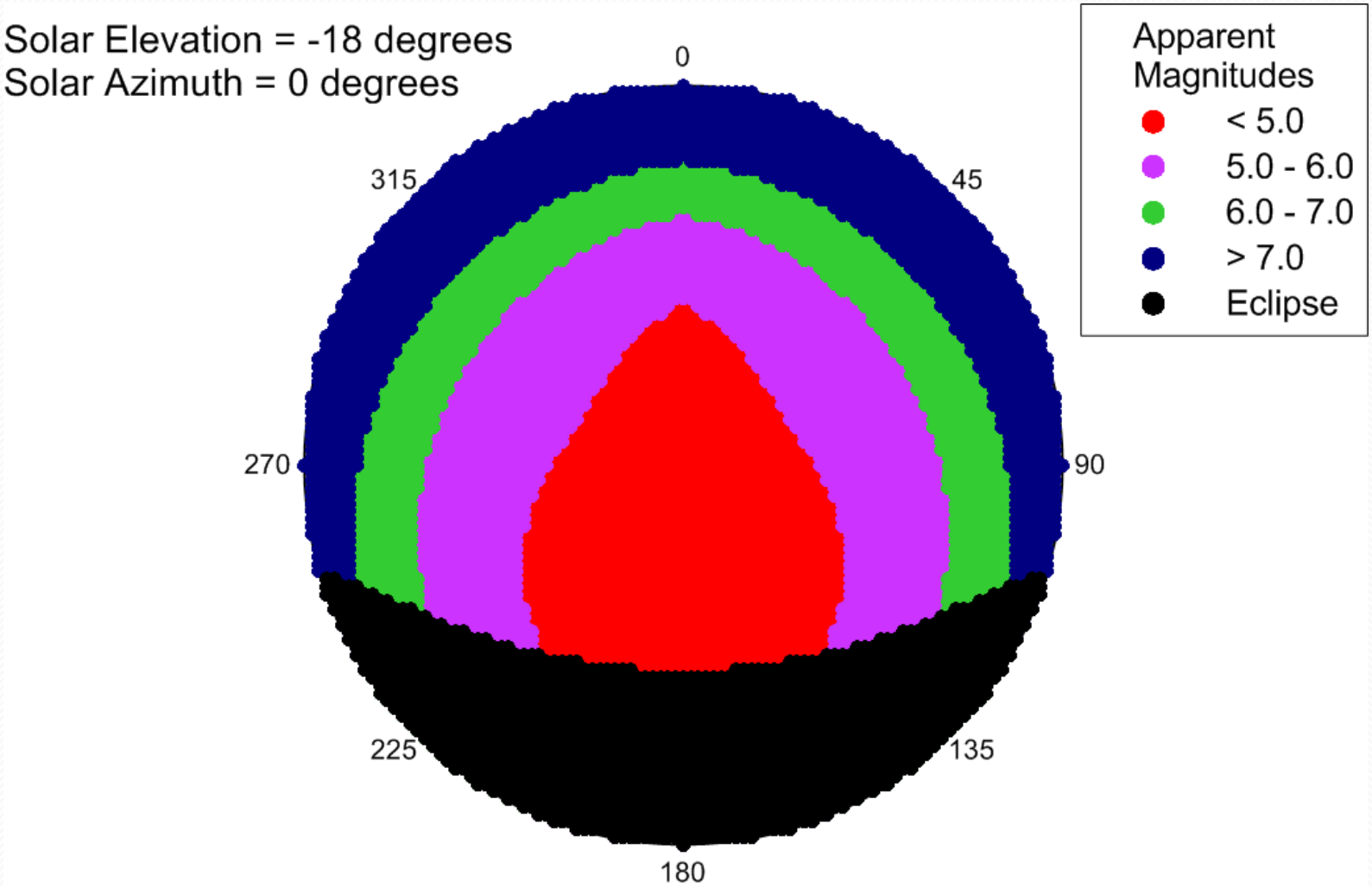
SBF Observational Data

- MMT9 robotic observatory
- Located with the Russian 6 meter telescope
- Matches V-band to about 0.1 magnitude
- 20,000 observations used in this solution
- (This processed data is available upon request)

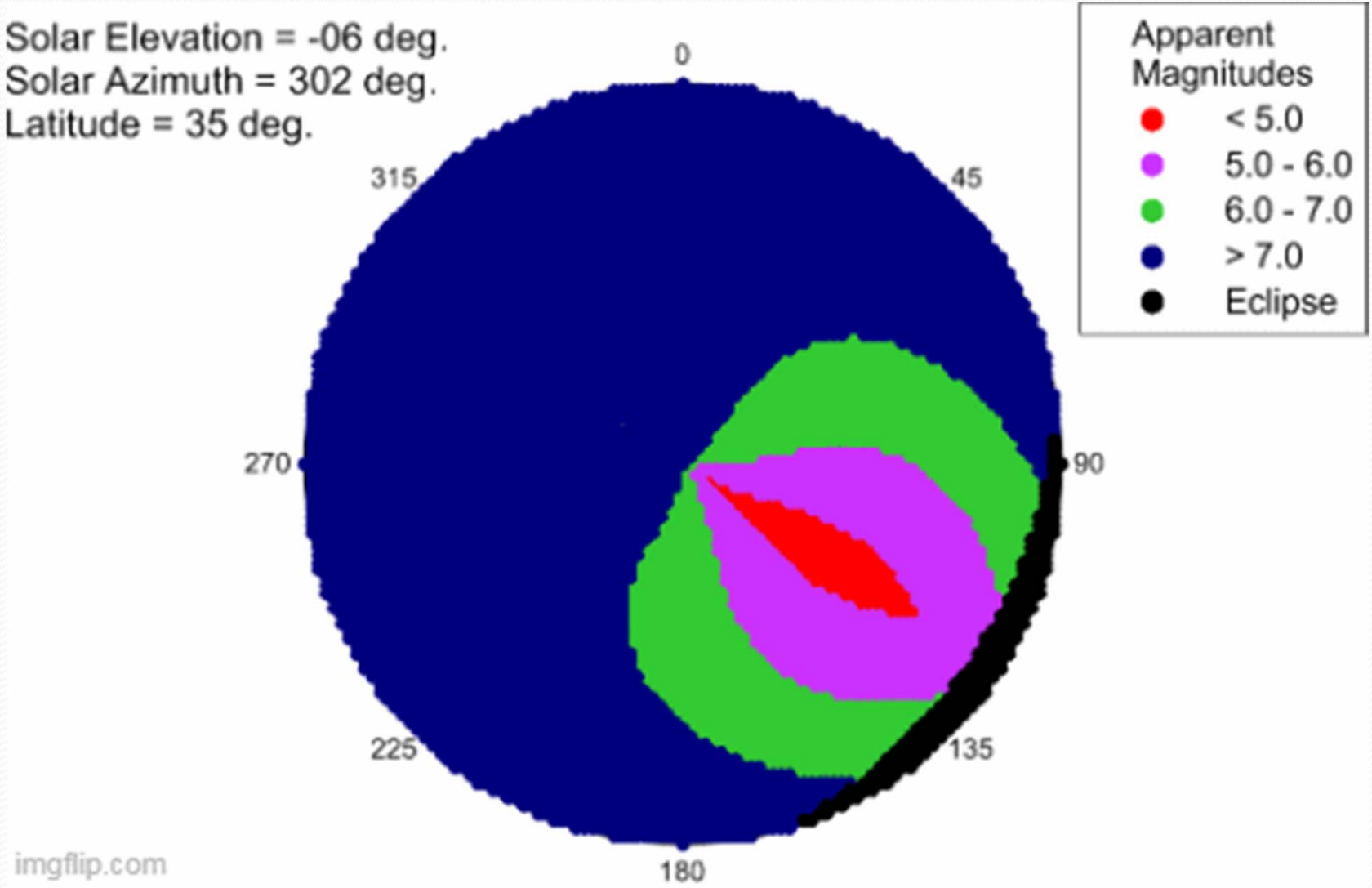
SBF – VisorSat Apparent Magnitude
Sky Map When Astronomical Twilight Ends



SBF – Original Design Apparent Magnitude Sky Map When Astronomical Twilight Ends



Animation of VisorSat Sky Maps



Future Work

- Process and analyze 100,000 MMT9 observations
- Study changes of brightness from 2019 through 2021
- Analyze the brightness of polar orbiting Starlinks

Acknowledgments

- Richard Cole and Jeremy Tregloan-Reed for discussions and ideas
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