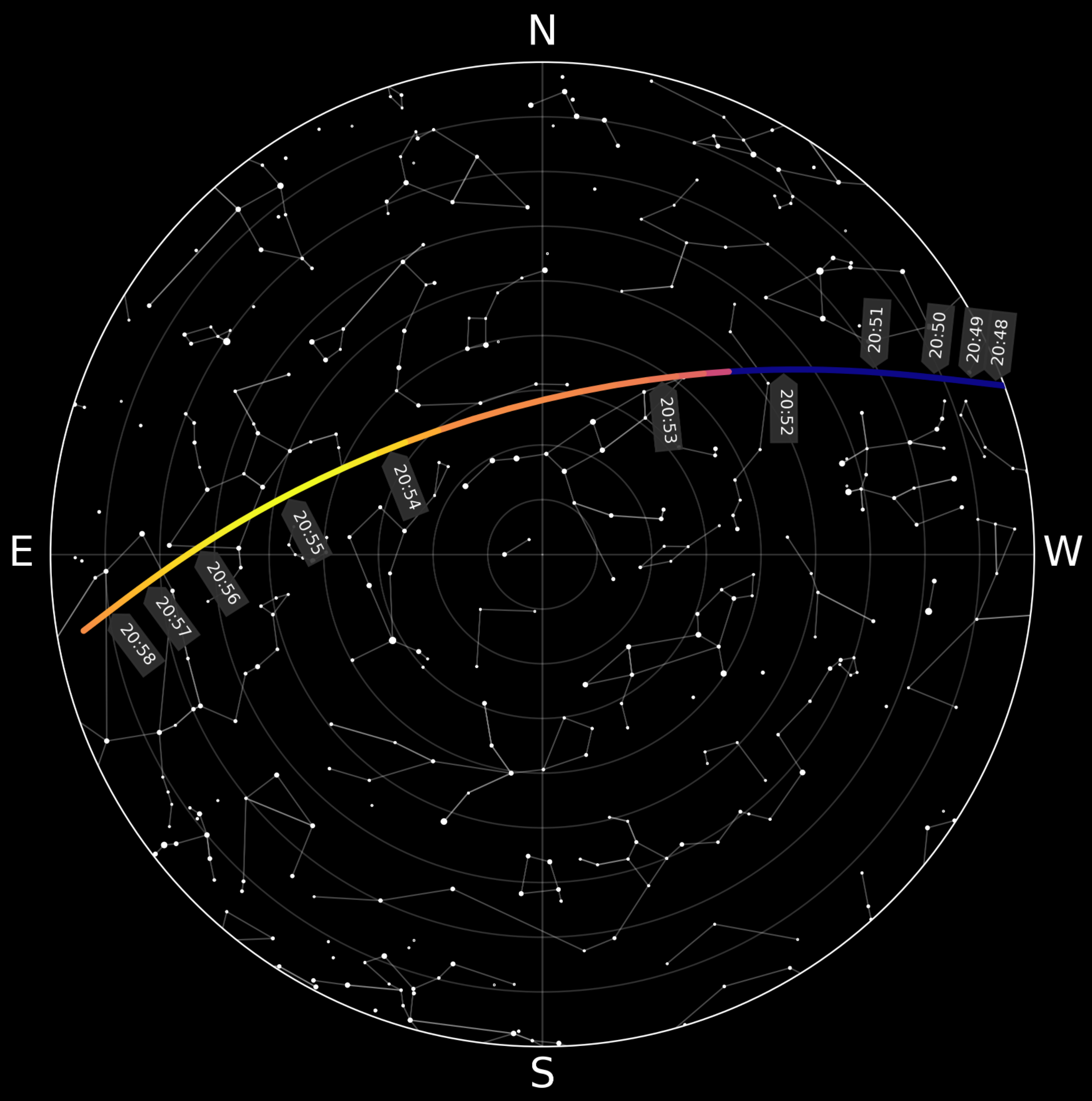
Satellite Optical Brightness



Forrest Fankhauser

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with thanks to co-authors

Tony Tyson and Jake Askari

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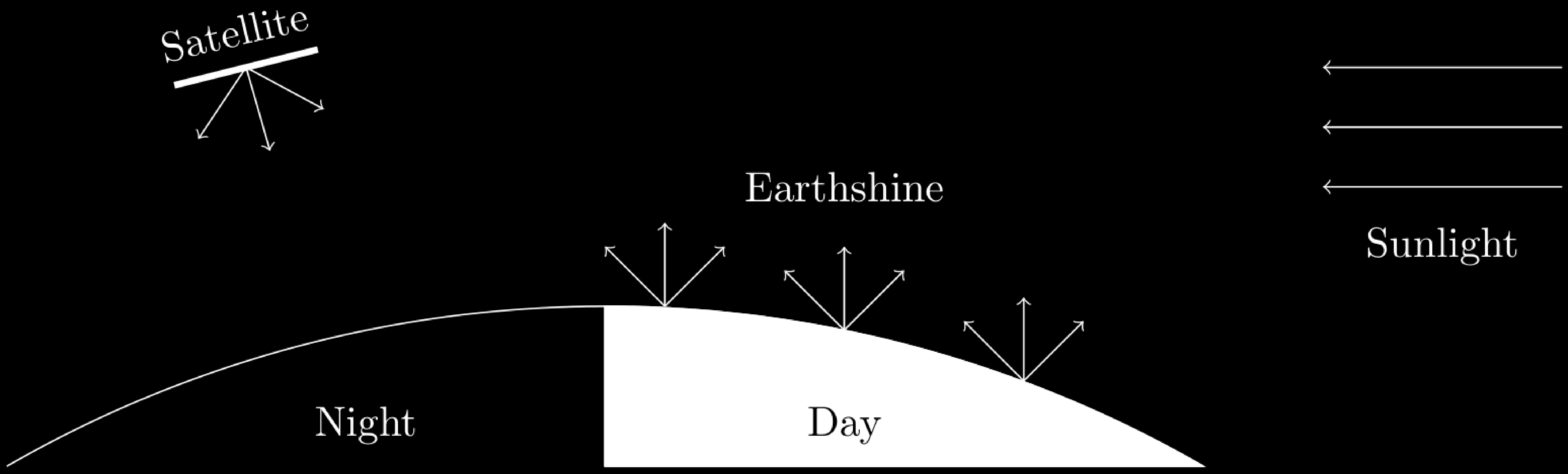
and support from

Vera C. Rubin Observatory

National Science Foundation

A New Method for Satellite Brightness Calculation

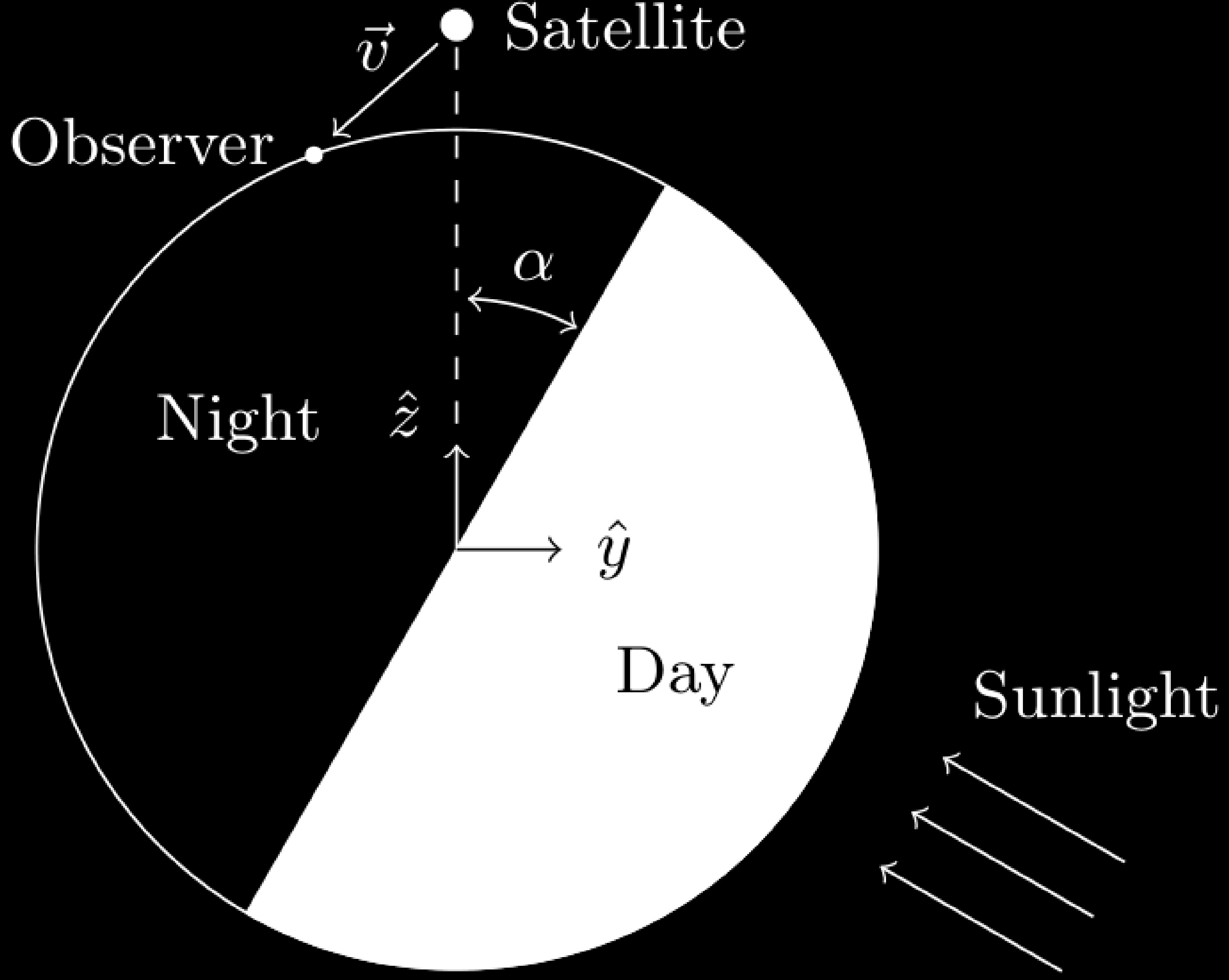
Brightness Mechanisms



Both sunlight and earthshine are scattered by the satellite onto the night side of Earth's surface

Satellite Centered Frame

- Reduces dependent variables
- Brightness distributions become functions only of satellite height and satellite angle past the terminator [α]
- Intuitive reference frame

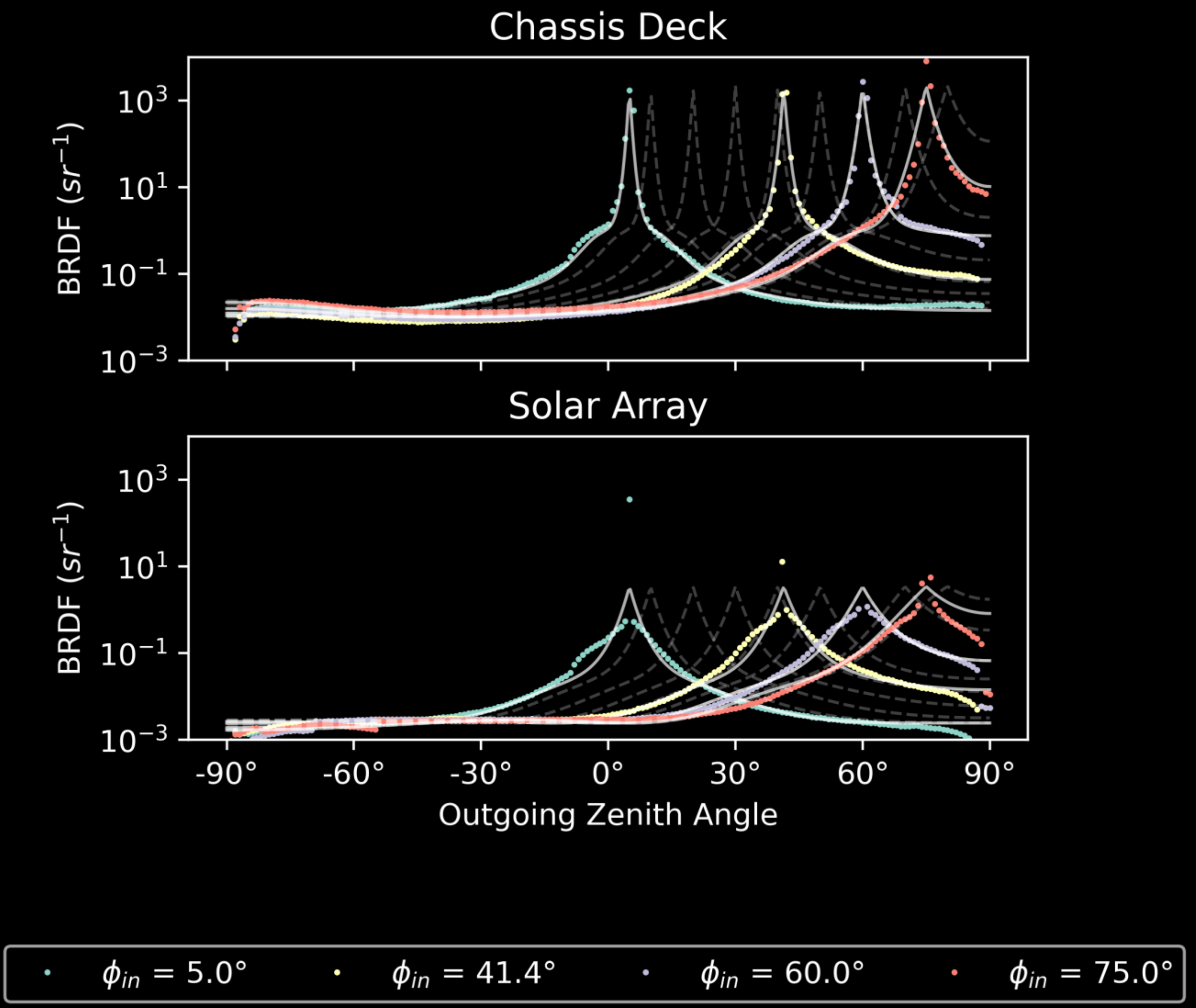


Bidirectional Reflectance Distribution Functions

- BRDF measures the scatter properties of a surface
  - Diffuse (paper)
  - Specular (mirror-like)

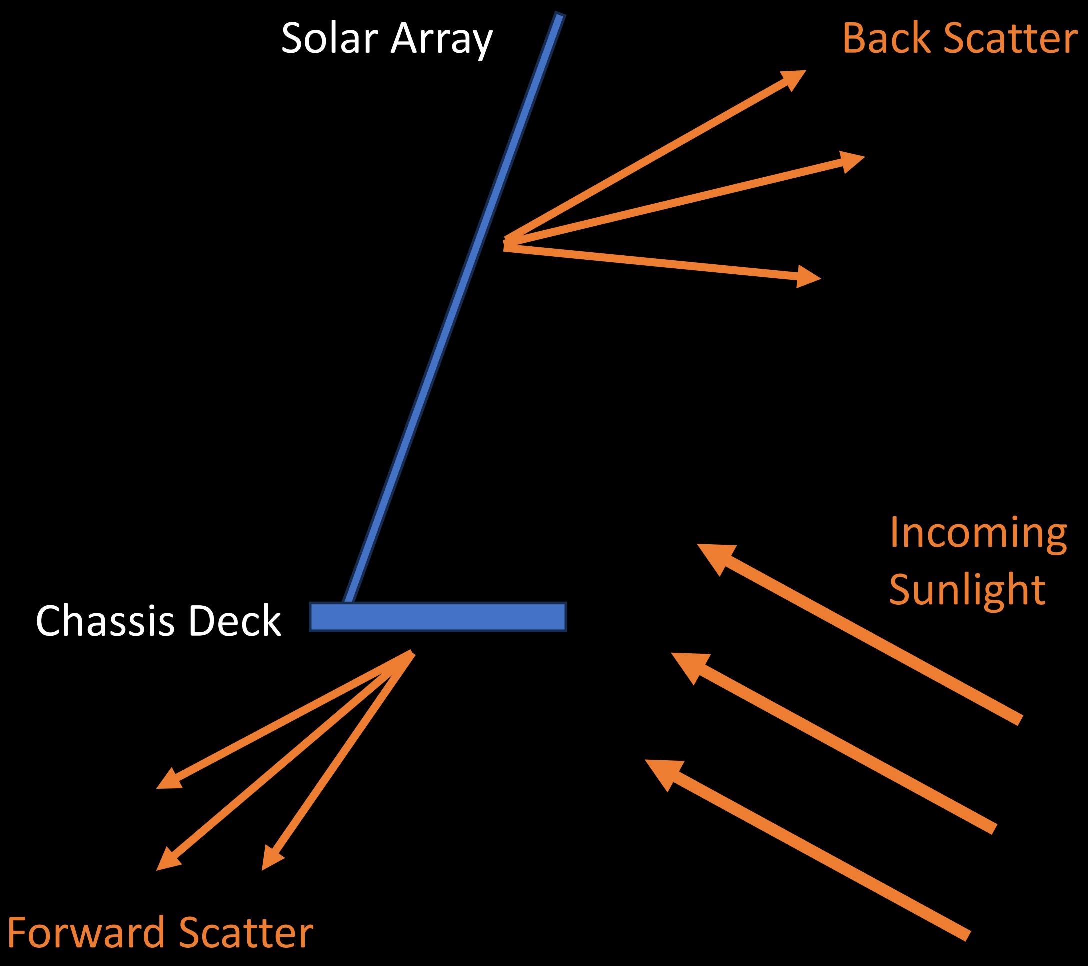
- Function of three vectors
  - Vector to light source
  - Vector to observer
  - Normal vector of surface

- We can fit empirical BRDFs to measured data
  - Laboratory measurements of material samples
  - Inferred from photometry of on-orbit satellites



Measured data and BRDF fits Starlink V1.5 Satellite surfaces

Starlink V1.5 Brightness Model



Primary Surfaces

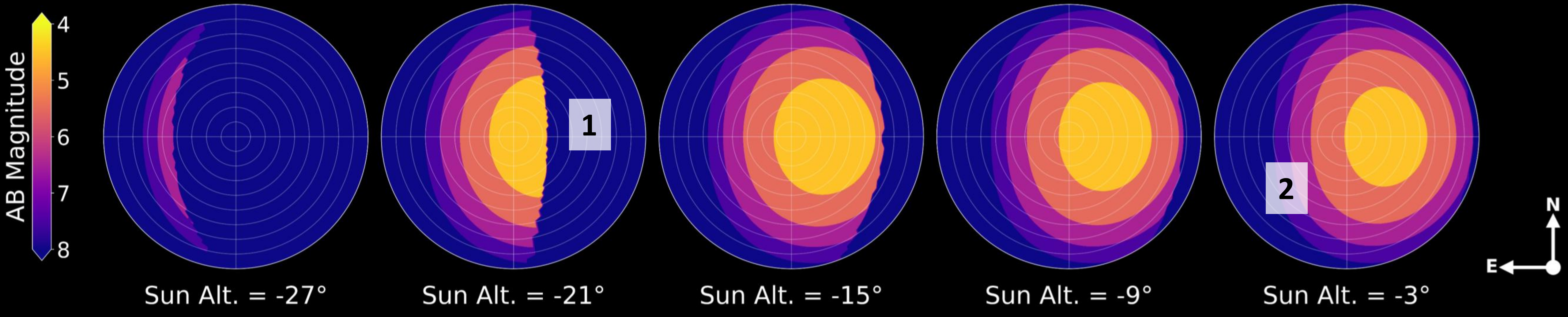
Solar Array

- Normal vector points towards sun
- Surface Area: 22.7 m^2

Chassis Deck

- Normal vector points to geodetic nadir
- Surface Area: 3.6 m^2

Starlink V1.5 Brightness on Night Sky
Diffuse Sphere Model



1 Satellites in the western sky pass into Earth's shadow

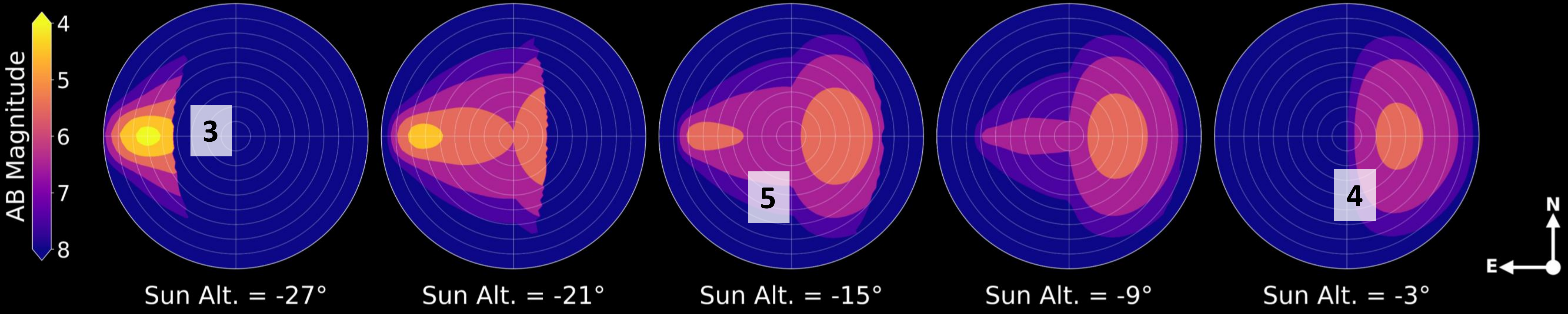
2 The diffuse sphere model is overly simplistic. Satellite brightness is a function of range and the illuminated fraction of the sphere.

- Plots show how bright a satellite would appear at a given point in the sky

- Sun azimuth = 90° (East)
- This corresponds to sunrise for an observer at the Equator

Starlink V1.5 Brightness on Night Sky

Our Model: Lab Measured BRDFs



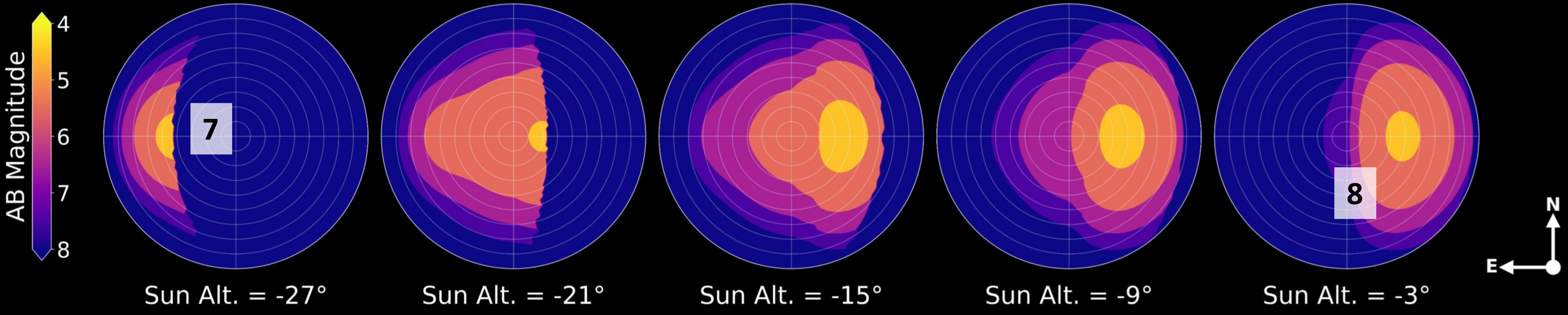
3 Brightness in the eastern sky is driven by forward scatter from the chassis nadir

4 Brightness in the western sky is driven by backscatter from the solar array

5 Both forward scatter from the chassis and back scatter from the solar array are visible

Starlink V1.5 Brightness on Night Sky

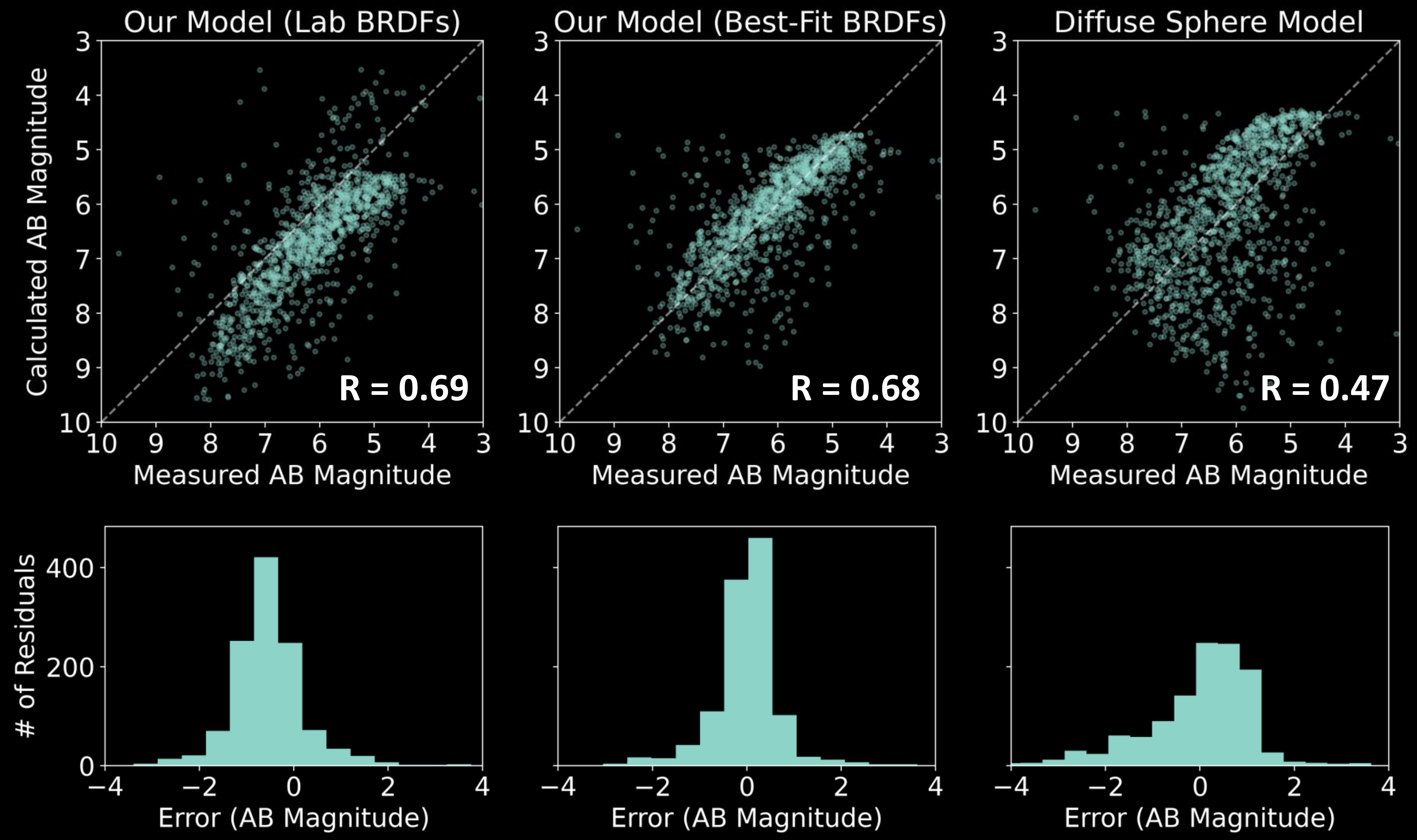
Our Model: BRDFs fit to satellite observations



7 Forward scatter from the chassis is captured in this model

8 Back scatter from the solar array is also captured quite well

Model Validation & Comparison



- **Our Model (Lab BRDFs)**
  - Systematically underpredicts brightness since not all components are modeled
  - Good correlation
  - Doesn't require any on-orbit data
- **Our Model (Best-Fit BRDFs)**
  - Good correlation and low bias
- **Diffuse Sphere Model**
  - Bad correlation
  - Not physically based

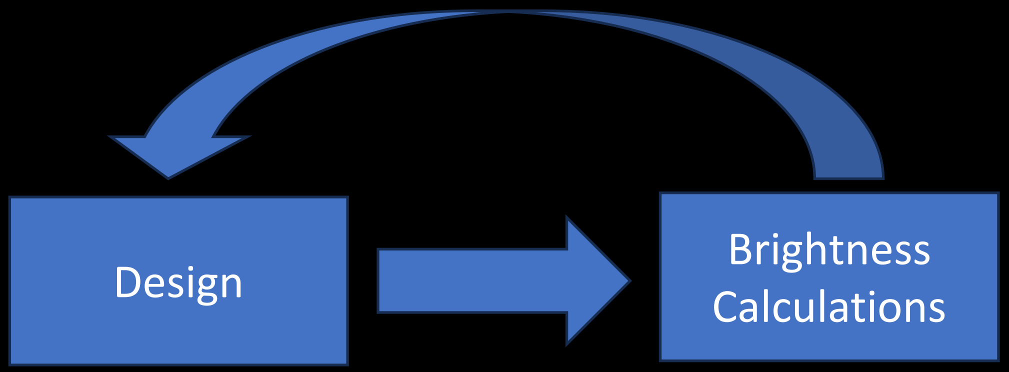
Applications

Satellite Design Trades

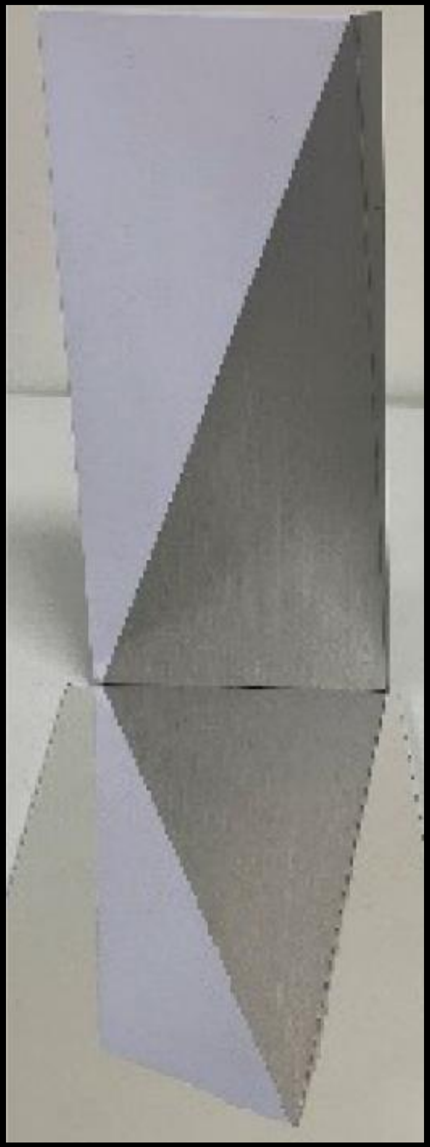
Used by SpaceX to inform brightness mitigation for V2 & V2 Mini Satellites

Doesn’t require on-orbit observations!

- Specular materials on chassis nadir
- Development of dark paints
- Off-pointing of solar arrays



Gen 1 Chassis Sticker*



Gen 2 Chassis Sticker*
Less diffuse scatter!

*api.starlink.com/public-files/BrightnessMitigationBestPracticesSatelliteOperators.pdf

Predicting Satellite Passes

Pass of Starlink-3831

Location: *Tucson, AZ, USA*

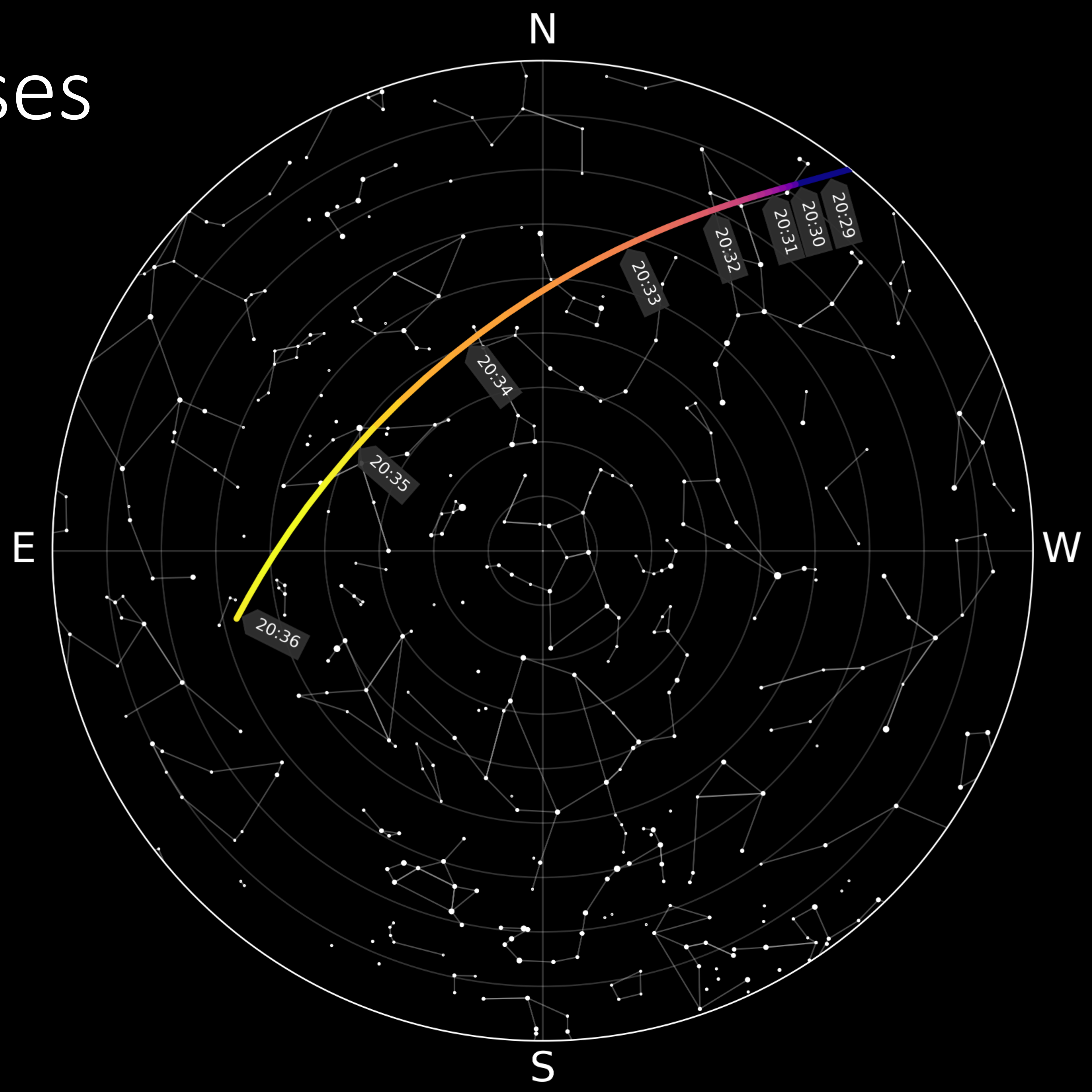
Time: *10:34 PM on August 10, 2023*

Peak Brightness:

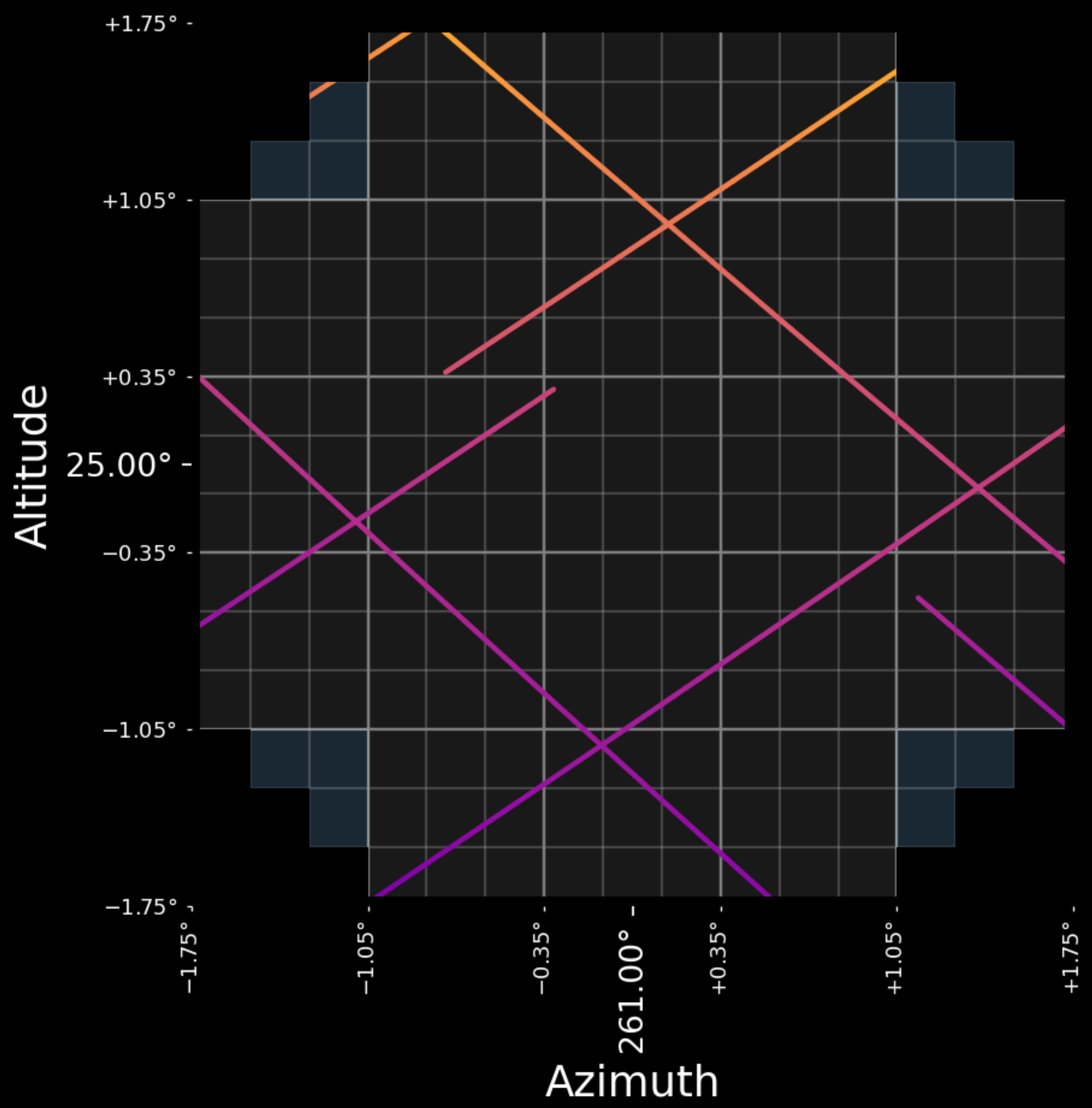
Magnitude: *5.3*

Altitude: *43°*

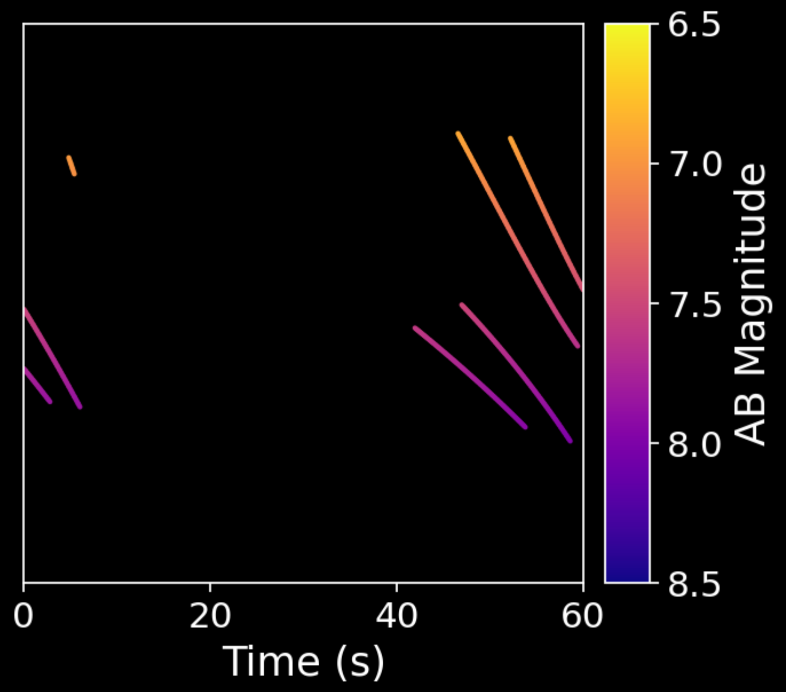
Azimuth: *86 ° (East)*



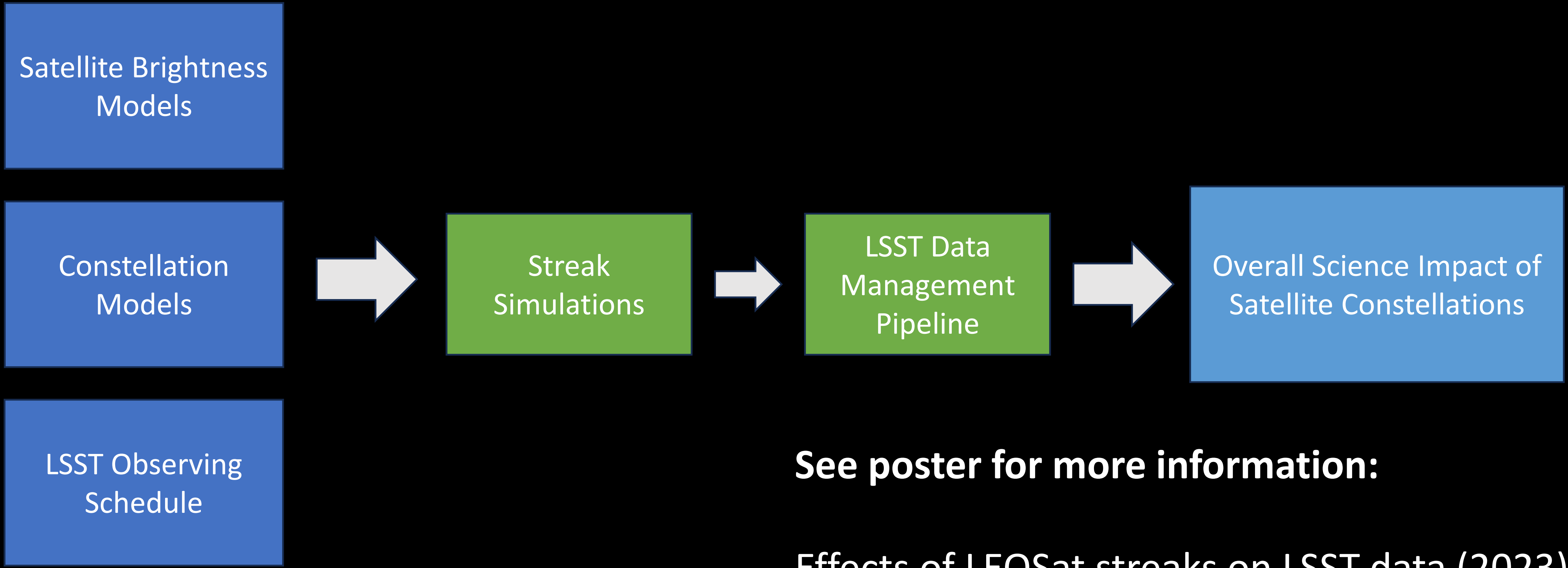
Simulating Streaks on the LSST Detector



- *Toy* constellation model of 30,000 satellites
- *Toy* brightness model meant to represent Starlink V2 (full size)
- 7 streaks visible over a period of 60 seconds
- Brightness of streak can vary by 2x across an image



LSST Lifetime Simulations



See poster for more information:

Effects of LEOSat streaks on LSST data (2023)
by Phan Kandula, Forrest Fankhauser, J. Anthony Tyson

For more information, please see:

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