UNIVERSITY OF MICHIGAN LSA ASTRONOMY

Astronomy Perspectives II- Measures and Testing Needs

Commercial Space and Astronomy Partnering in Best Practices and Guidelines for Brightness Mitigation

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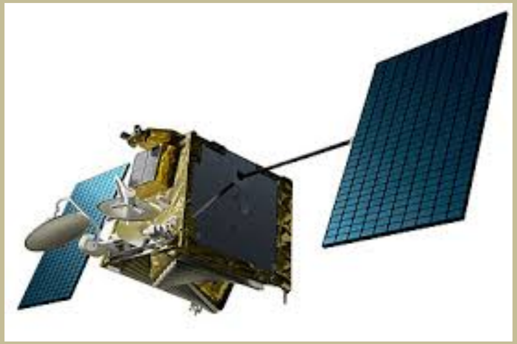
Brightness of satellites

Complicated problem!

Starlink

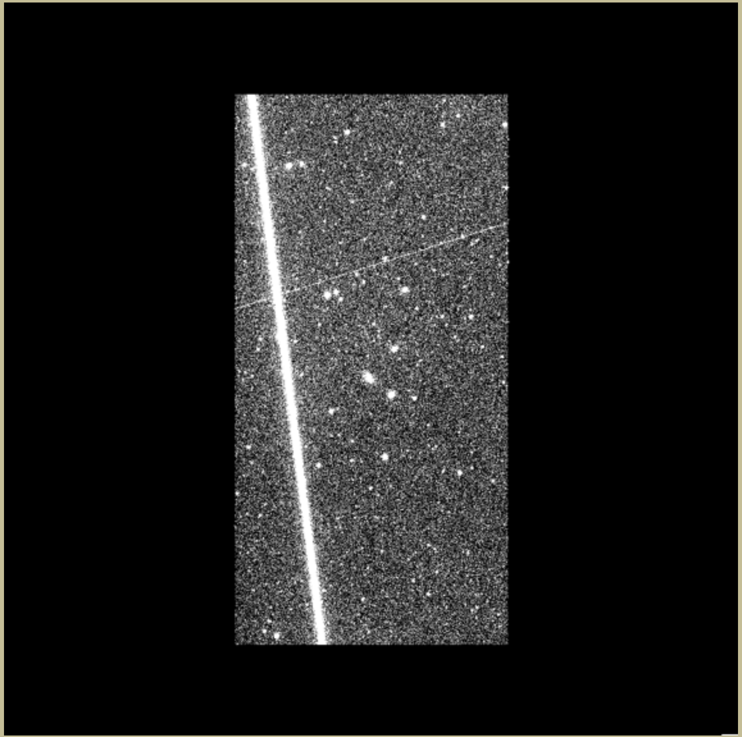
- Altitude (range).
- Attitude (orientation).
- Albedo.
- Size.
- Surface characteristics.
- Specular vs diffuse reflection.
- Self-shadowing.
- Solar phase angle.

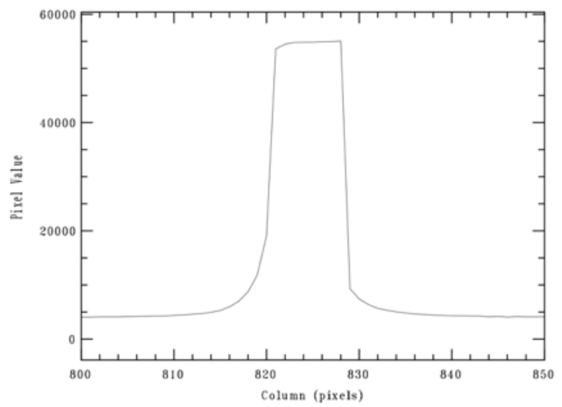


OneWeb

- Satellites are not Lambertian spheres! Do full BRDF analysis in design phase. Detailed modelling before launch.

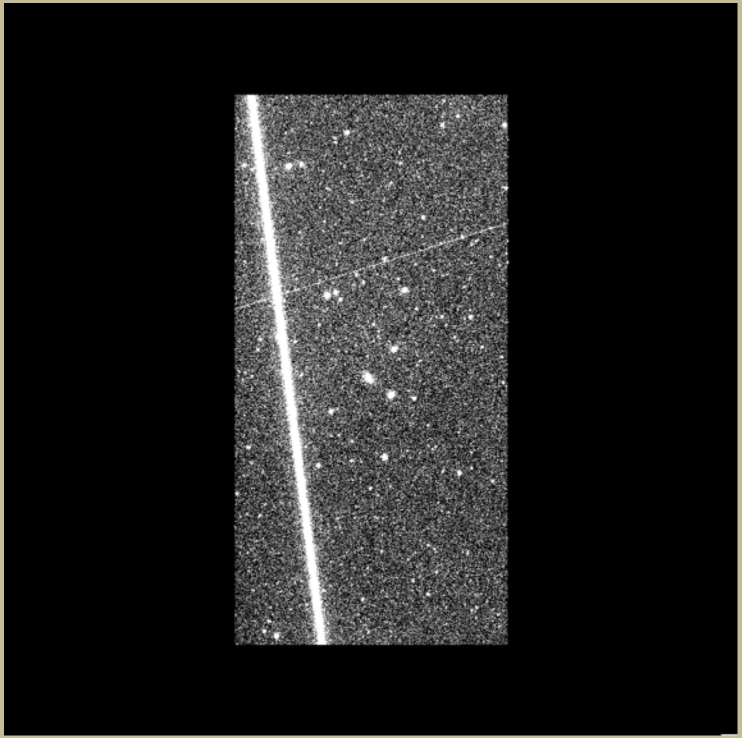
How do satellites affect observations on telescopes?
Bright satellite streak saturates detector!





- Loss of information in pixels.
- Cross-talk in electronics.
- Ghost images.
- Possible residual images.

How do satellites affect observations on telescopes? Bright satellite streak saturates detector!



For effect of satellite on image, two exposure times:

1. Image exposure time:
    1. Probability of satellite in image.
    2. Length of trail.

2. Brightness of satellite determined by how long satellite crosses a pixel or resolution element – milliseconds or less! Set by satellite orbit.

Recommendations for satellite operators from SatCon1 report

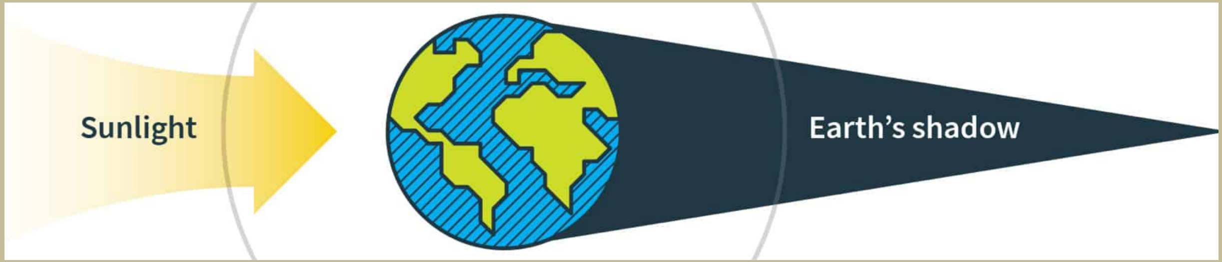
- Fainter than V ~ 7th magnitude.
  - Limit of gifted human eye in very dark site.
  - Avoids non-linear effects in Rubin Obs/LSST camera.

- Fly low – 600 km or less. Not a hard limit, but lower better for visibility and space safety.

- Provide very accurate and precise ephemerides to astronomers and the public. Where and when will a satellite appear? How fast will it be moving?

- Perform Bidirectional Reflection Distribution Function (BRDF) studies of spacecraft prior to launch – minimize brightness as design criteria!

When are satellites visible in optical?



Source: Viasat

- Observer in darkness:
  - Latitude.
  - Time of year.

- Satellite in sunlight or penumbra – not in the cone of Earth shadow:
  - Orbital inclination.
  - Altitude.
  - Time of year.

- Brightness of satellite:
  - Angle between Sun-satellite-observer.
  - Characteristics of satellite – attitude, specular or diffuse reflection, ……

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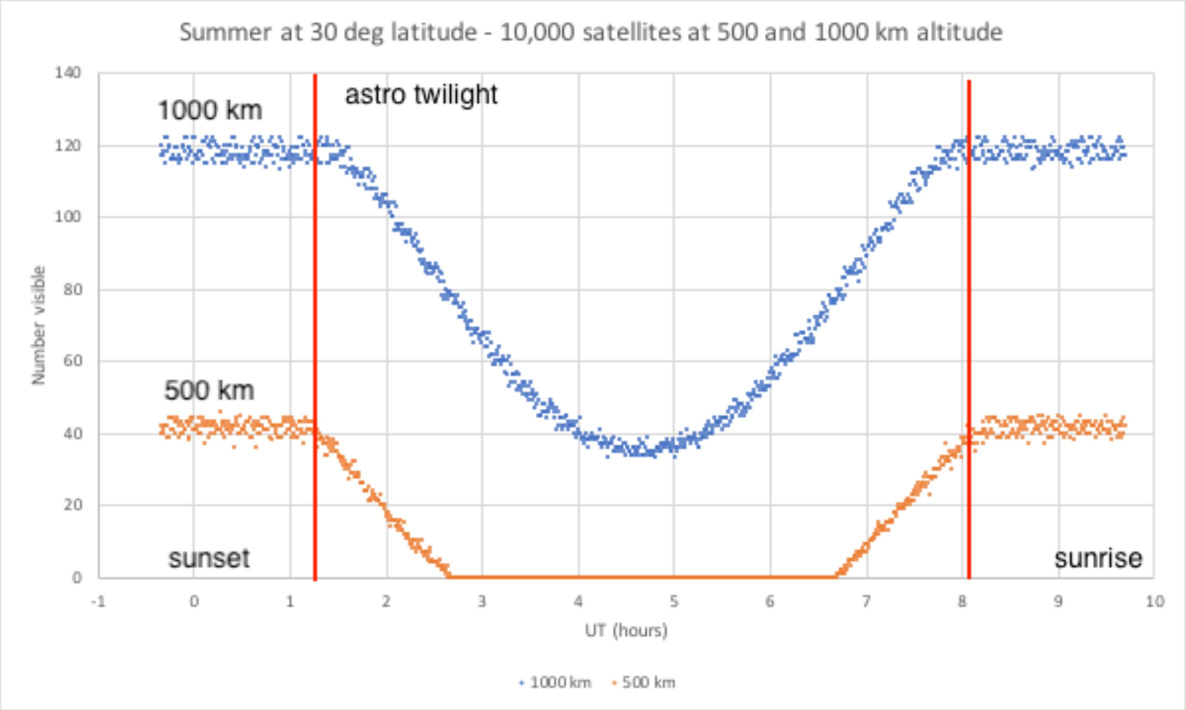
Sample constellations
10,000 satellites at 500 km and 10,000 at 1000 km

100 planes with 100 satellites per plane – inclination = 53 deg



Elevation > 30 deg

If 100 satellites in your constellation, then very few above 30 deg elevation.

3x that above horizon.

Higher altitude visible all night long in summer.

Depends on latitude, orbits, etc. Model effect!

Satellite trails in images obtained with space telescopes

- Yes – they do occur in Hubble Space Telescope (HST) images! Altitude = 569 km.

- “Approximately 2% of WFPC3 images have satellite trails in them. Constant percentage over many years”
  - Quoted figure of 8% refers to image stacks.
  - Very small field of view – 0.045 x 0.045 deg
  - Tom Brown, HST Mission head (private communication June 2022).

- For ground-based telescopes – two constraints for satellite to be visible:
  - Observatory in darkness, satellite in sunlight.

- For space-based telescopes – one constraint for satellite to be visible:
  - Only constraint is satellite in sunlight. Telescope can be in sunlight and still have dark sky.

Design and Operate to be Faint

- Design to be faint before launch. BRDF studies.

- Operate to be faint after launch.
  - Low **altitude** to maximize time in Earth shadow. (Tradeoff – brighter!)
  - Recommended less than 600 km (not a hard limit) – lower the better.

  - Control **attitude** of spacecraft to minimize reflected sunlight towards ground.

Did not consider problems with radio astronomy nor thermal Infrared (satellites glow in the dark at 10 micron wavelength).

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Directional Reflectance Spectroscopy of Spacecraft Materials

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Overview

Recommendation ***4*** *for LEOsat constellation operators from SatCon1 report* –
Lab bi-directional reflectance distribution function (BRDF) measurements as part of satellite design.

1. What is directional reflectance spectroscopy?

2. What is the BRDF and BRF?

3. How can we measure the BRDF/BRF?

4. Measurements of artificial spacecraft materials.

Presenter: Chris H. Lee (chl2019@rit.edu) *GRIT Lab PI:* Charles M. Bachmann, Ph.D (cmbpci@rit.edu)

Directional Reflectance Spectroscopy

Directional: Angular dependence of reflectance.

Reflectance: Material reflectance, or albedo, intrinsic material property.

Spectroscopy: Measurement of light as function of wavelength.

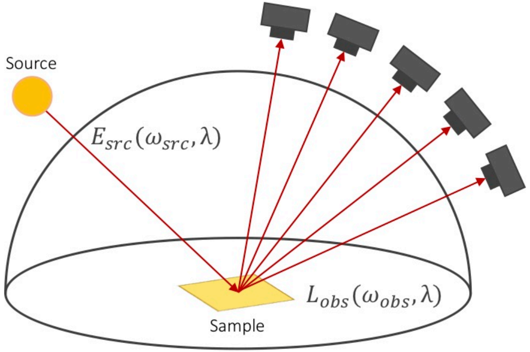
- Ways to characterize material reflectance?
  - **B**i-directional **R**eflectance **D**istribution **F**unction **(BRDF)**.

$$\rho_{\boldsymbol{BRDF}}(\omega_{src}, \omega_{obs}, \lambda) = \frac{L_{obs}(\omega_{obs}, \lambda)}{E_{src}(\omega_{src}, \lambda)} \quad [1/sr]$$

  - **B**i-directional **R**eflectance **F**actor **(BRF)**.

$$\rho_{\boldsymbol{BRF}}(\omega_{src}; \omega_{obs}, \lambda) = \frac{L_{obs}(\omega_{obs}, \lambda)}{L_{diff}(\omega_{obs}, \lambda)}$$

Normalized w.r.t Lambertian panel



Depiction of a BRDF measurement. *Credit: Self.*

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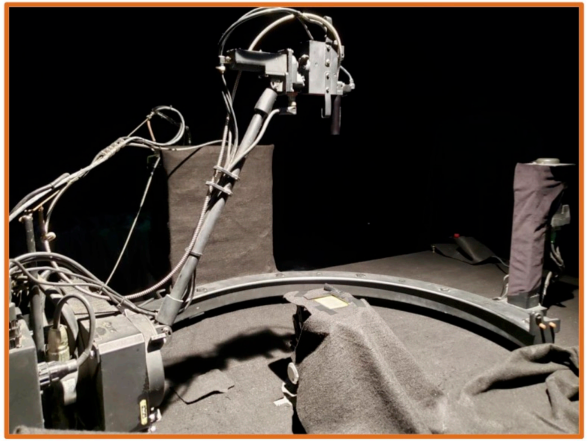
Measuring the BRF

- **GRIT-T:** Goniometer of the Rochester Institute of Technology-Two.
  - 350 nm – 2500 nm @ 1 nm.
  - External adjustable light source for any illumination angle.
- Simplified process:
  1. Set source illumination angle.
  2. Measure Lambertian reference panel.
  3. Scan sample hemisphere.
  4. Convert DNs to Radiances to BRFs.



Goniometer of the Rochester Institute of Technology-Two **(GRIT-T)**. *Image Credit: Self.*

J. Harms, C. Bachmann, B. L. Ambeau, J. Faulring, A. Ruiz Torres, G. Badura, E. Myers, 2017. "A fully-automated laboratory and field-portable goniometer used for performing accurate and precise multi-angular reflectance measurements," Journal of Applied Remote Sensing, 11(4): 046014-1-046014-15, https://dx.doi.org/10.1117/1.JRS.11.046014.

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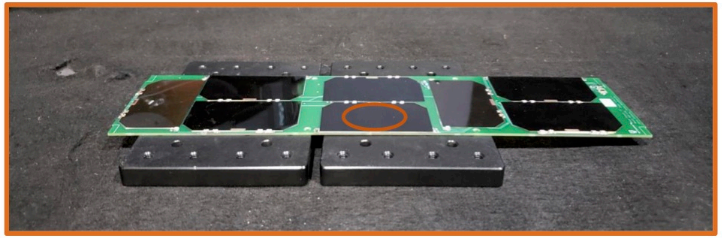
BRF Measurement Samples

- CubeSat solar panel board.
  - Shared by University of Michigan Aerospace Engineering Department.
- Sample of satellite multilayer insulation (MLI).
  - Shared by NASA JSC Orbital Debris Program Office.

MLI closeup with measurement area approximately circled. *Credit: Self.*



CubeSat solar panel closeup with measurement area approximately circled. *Credit: Self.*

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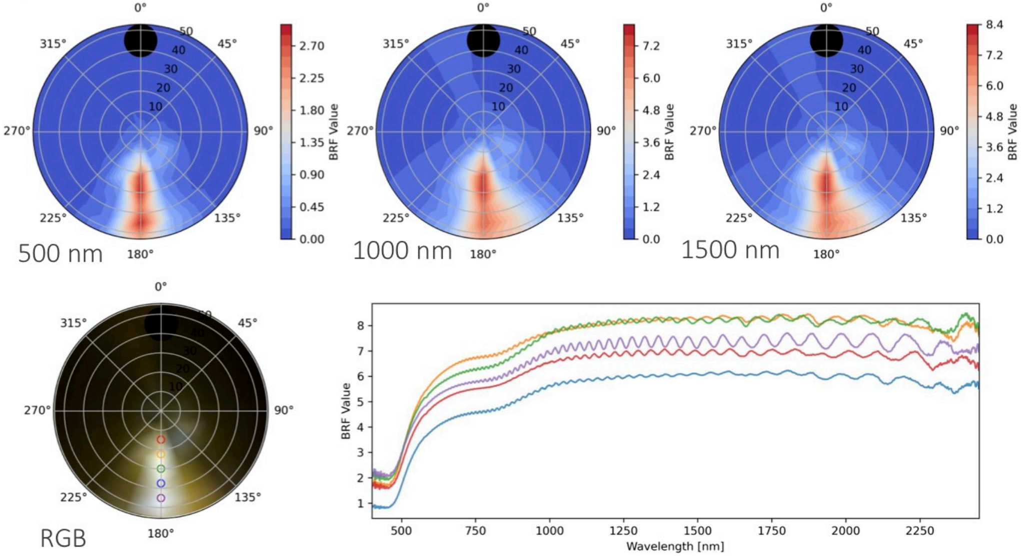
BRF Measurements and Select Peaks of **MLI**



- **45 degrees** light illumination zenith angle.
- BRFs at four wavelengths.
- RGB-constructed BRF colormap.
- Select individual spectra from wide peak show interference effects throughout the near-IR.

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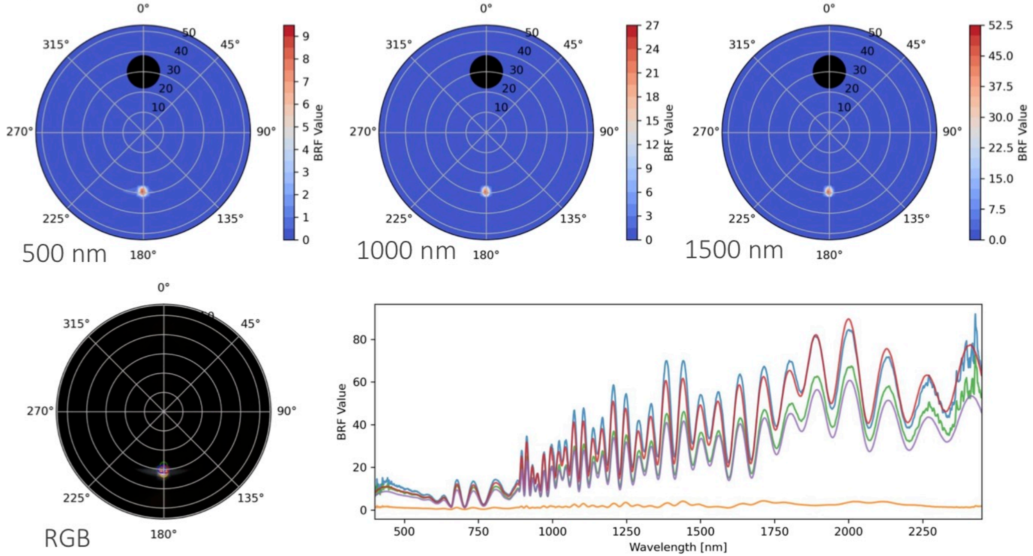
BRF Measurements and Select Peaks of **Solar Panel**



- **30 degrees** light illumination zenith angle.
- BRFs at four wavelengths.
- RGB-constructed BRF colormap.
- Select individual spectra from narrow peak show wildly varying interference effects through the spectrum.

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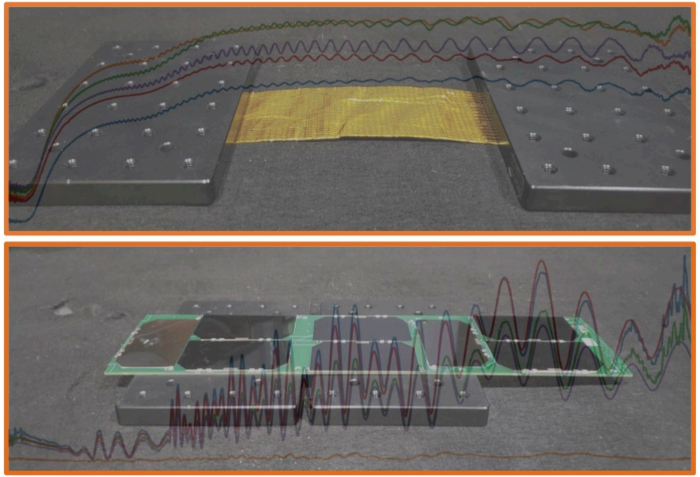
Comments on Measurements

- Directional spectral reflectance of (artificial) space materials is complex.
- MLI is highly IR reflective.
- Strong interference effects from solar cell.
- BRDF/BRF is one (important) way of many to spectrally characterize material reflectance spectra.



Images of samples overlaid with their spectral reflectance peaks. *Credit: Self.*

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Did not consider problems with radio astronomy nor thermal Infrared (satellites glow in the dark at 10 micron wavelength).

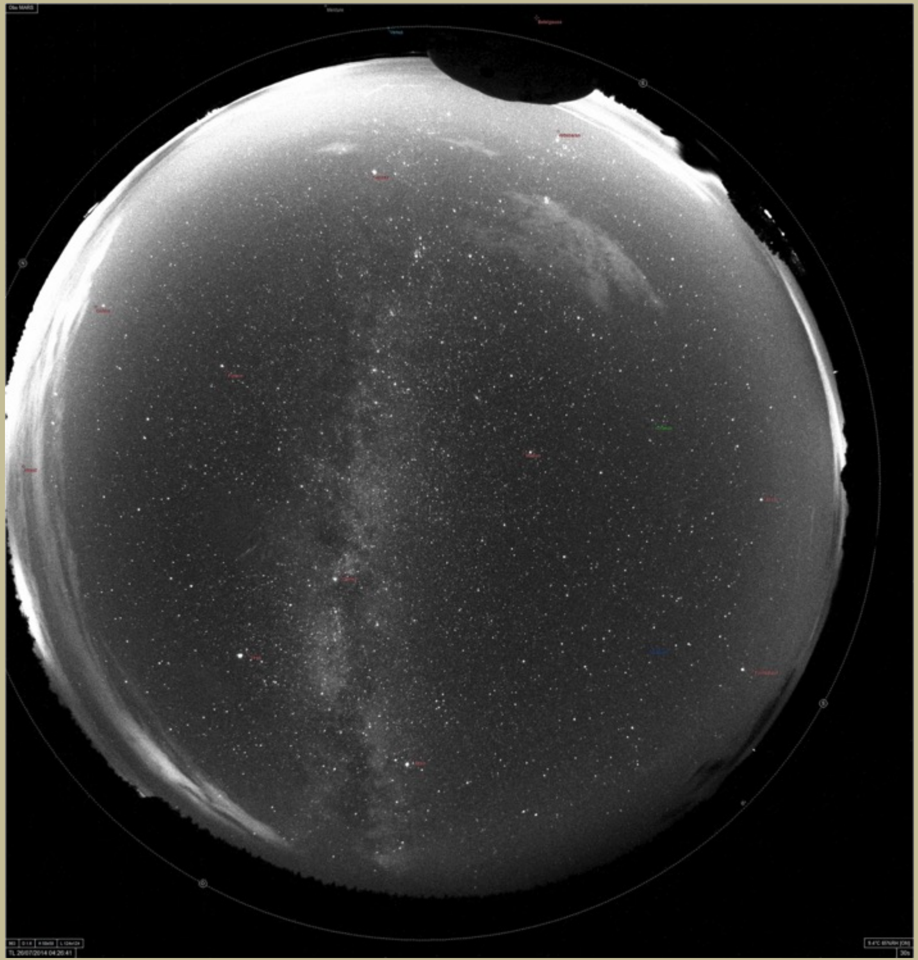
The night sky is changing!

Go see the dark night sky.

New moon.

Very dark site – darksky.org.

Now!



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