Radar observations of the lunar poles

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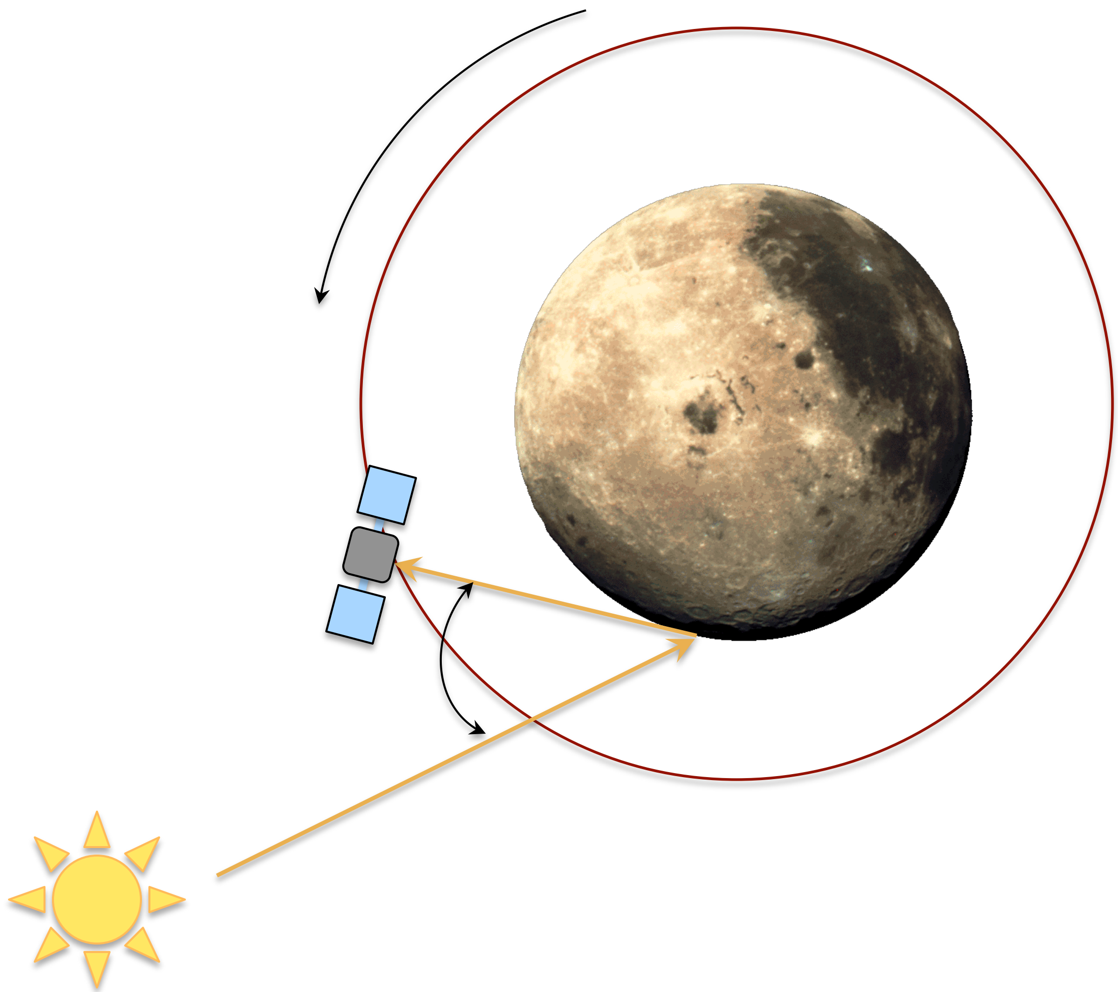
lunar volatiles

Regions of **permanent shadow** near the poles of the Moon are thought to contain **volatiles** such as water ice.

Radars are a good tool for detecting these volatiles for two main reasons:

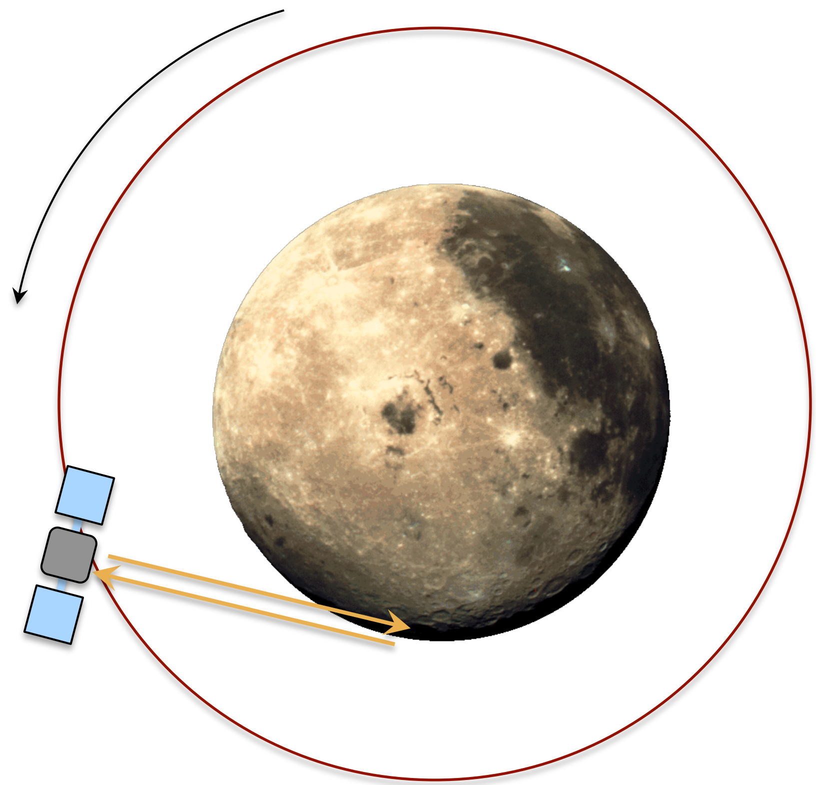
1. They are capable of ‘seeing in the dark’.
2. Ice has unique radar properties.

Most instruments rely on external sources of radiation (i.e. sunlight, starlight, cosmic rays, etc.) as their illumination source.



radar

Radars are **active instruments**, providing their own energy source. This allows the observer to 'see in the dark'.



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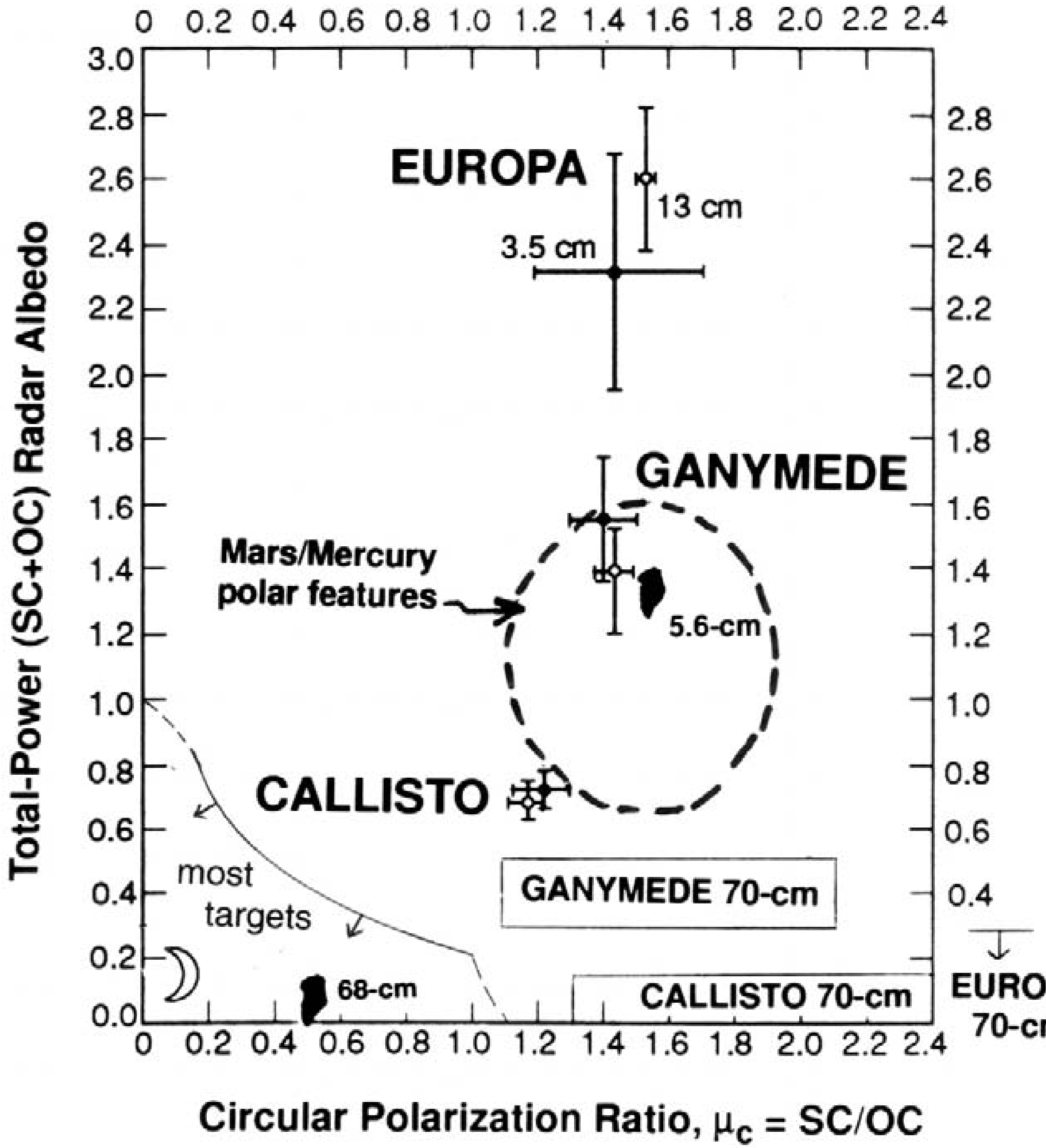
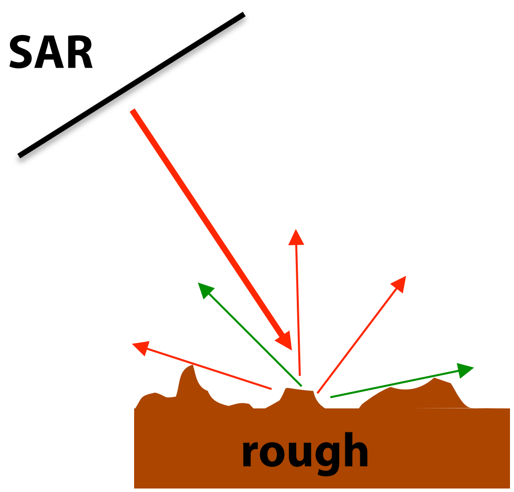
radar & ice



Ostro, 2006

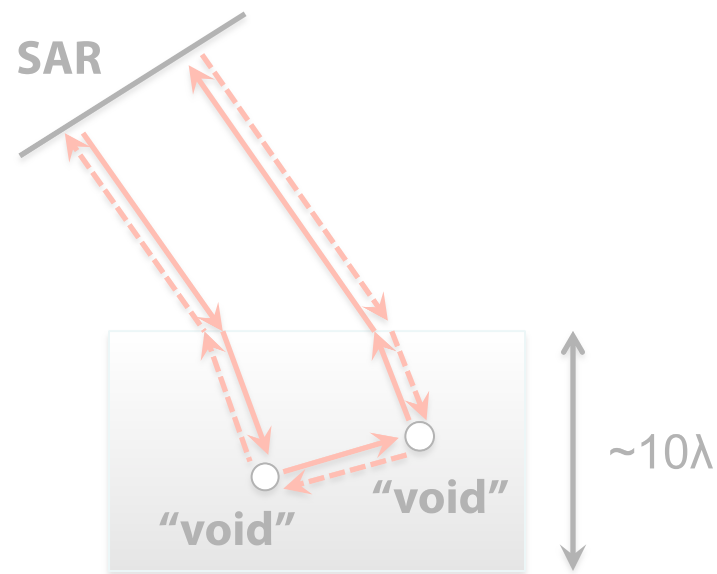
Ice has unique radar properties, with high values of the circular polarization ratio (**CPR = SC/OC**)

SC = radar with same polarization as transmitted beam
OC = radar with opposite polarization as transmitted beam



Multiple bounce backscattering on a rough surface randomizes polarization (OC ≅ SC)

MODERATE CPR (~0.5 - 1)



Forward scattering in ice preserves polarization (OC << SC)

HIGH CPR (> 1)

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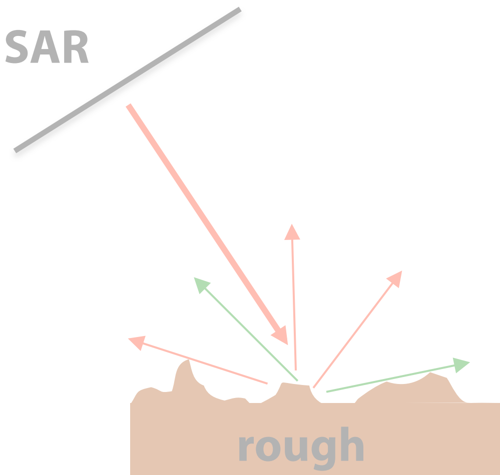

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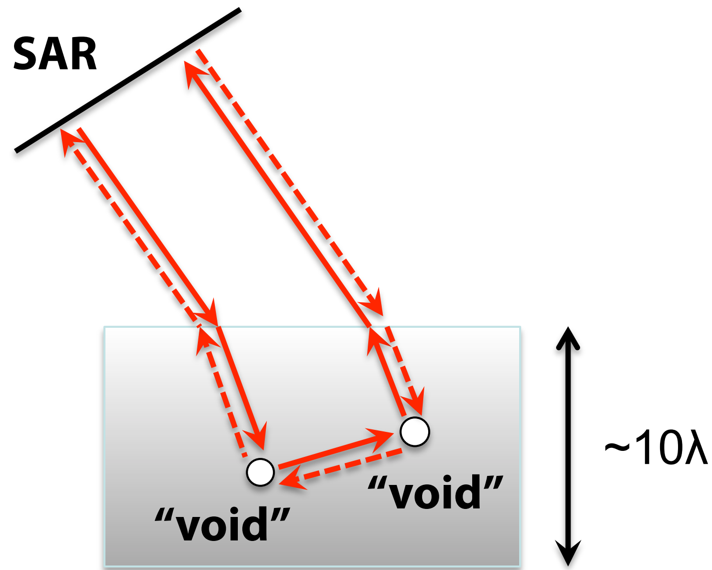
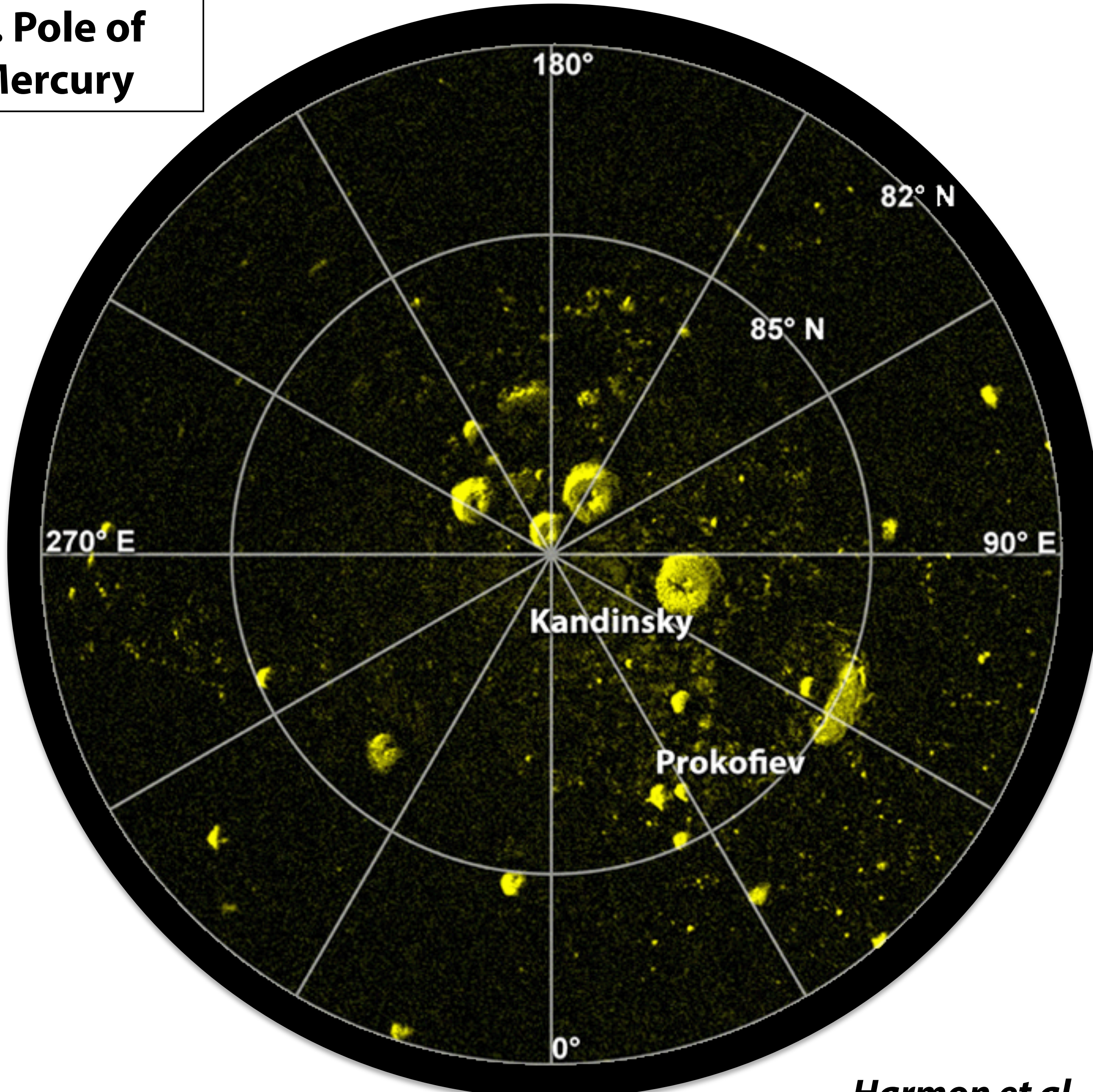


Forward scattering in ice preserves polarization (OC << SC)

HIGH CPR (> 1)

mercury

N. Pole of Mercury



Harmon et al., 2011

mercury

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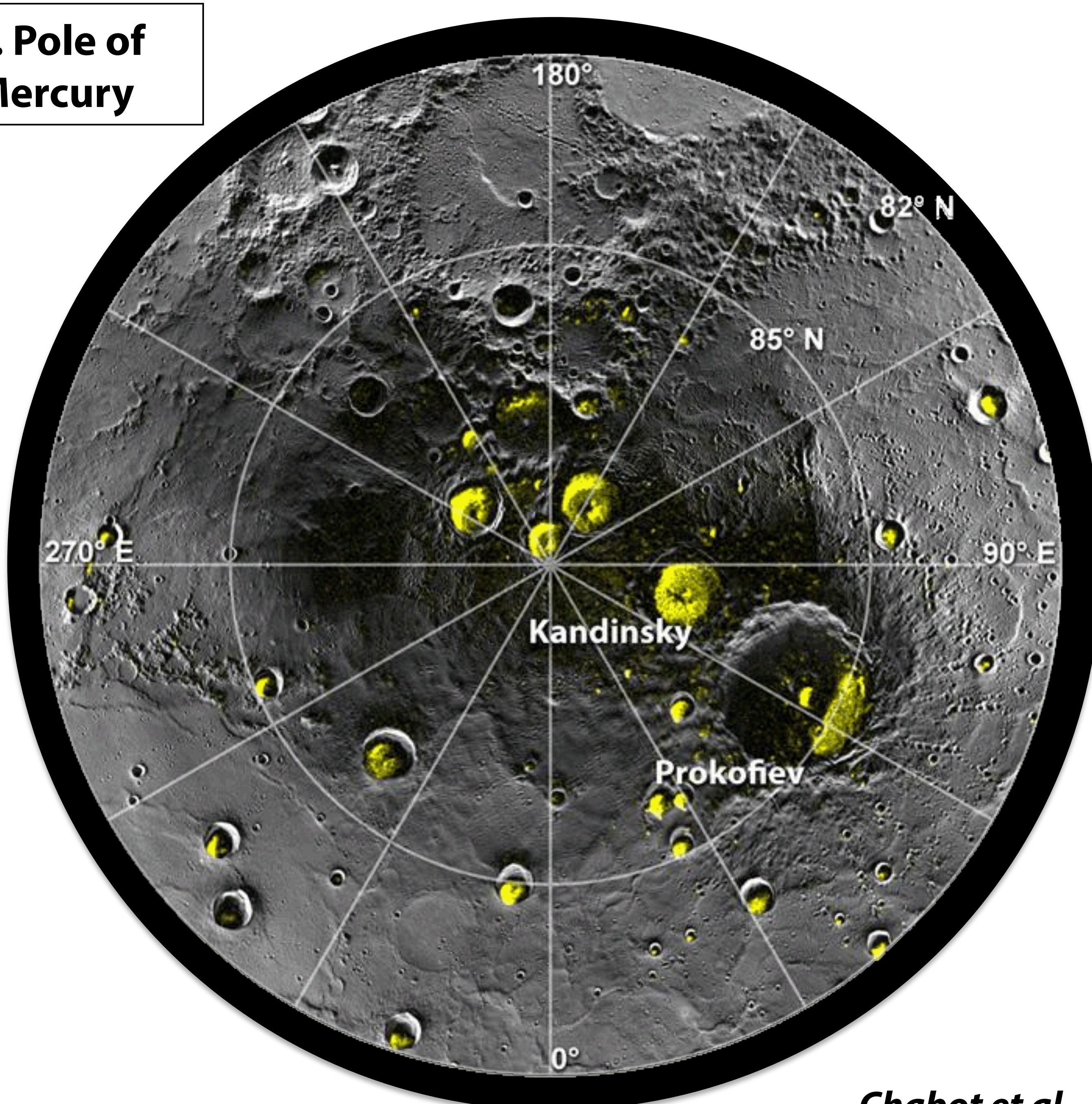
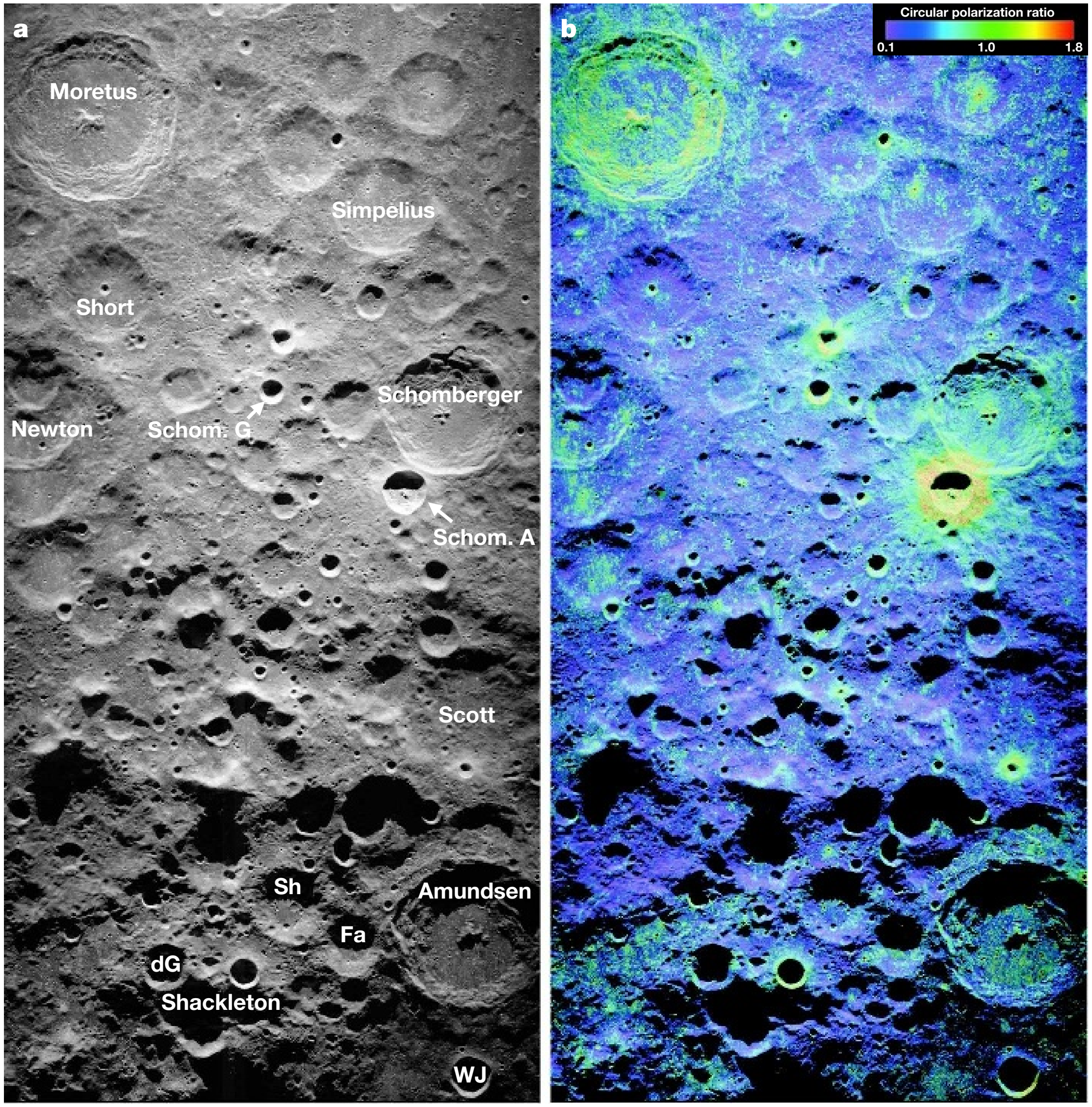


Chabot et al., 2012

ground-based radar

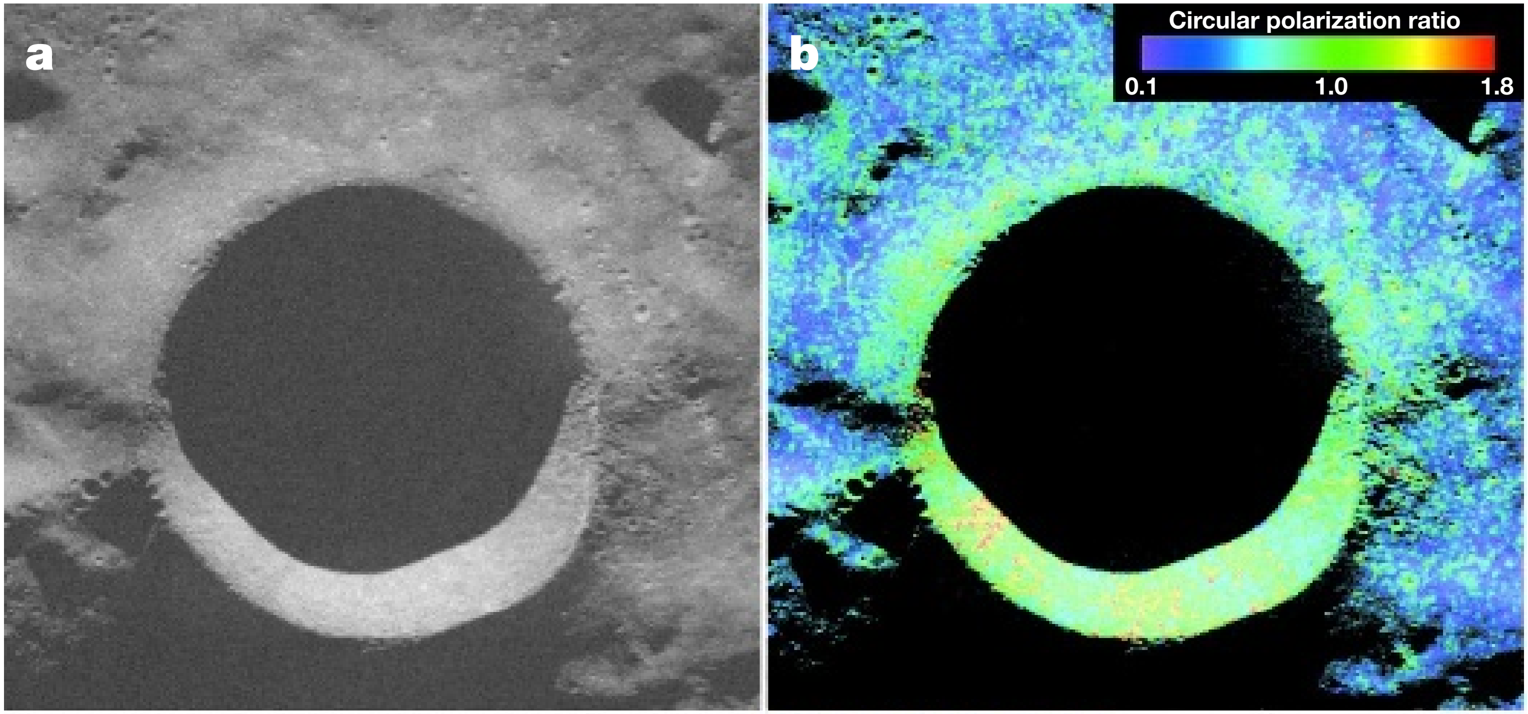
The first observations of the lunar poles in radar were taken by ground-based telescopes.



Campbell et al., 2006

ground-based radar

As you approach the poles, there are more and more radar shadowed regions. *An orbital radar is needed to probe many PSRs.*



Shackleton crater

Campbell et al., 2006

ground-based radar

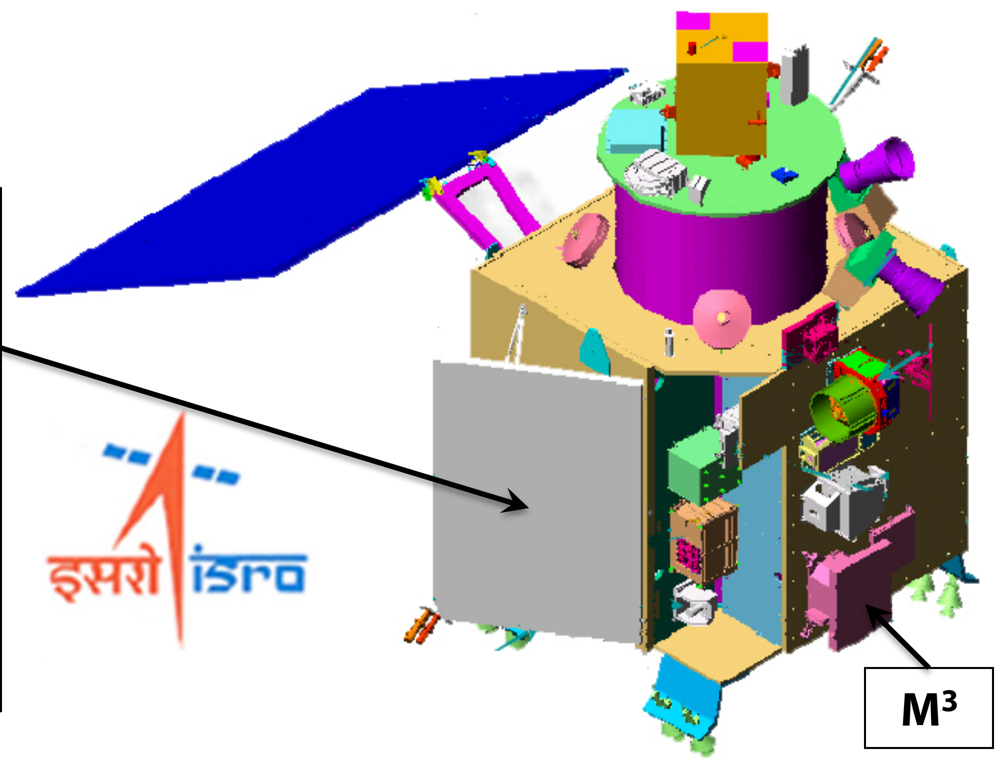
Arecibo visibility into PSRs on Nov. 9, 2013

Image courtesy of Andy McGovern

Forerunner

From November 2008 through August 2009, the Indian Space Research Organisation (ISRO) operated the **Chandrayaan-1** mission, carrying with it a miniature radar dubbed Mini-SAR or **Forerunner**.

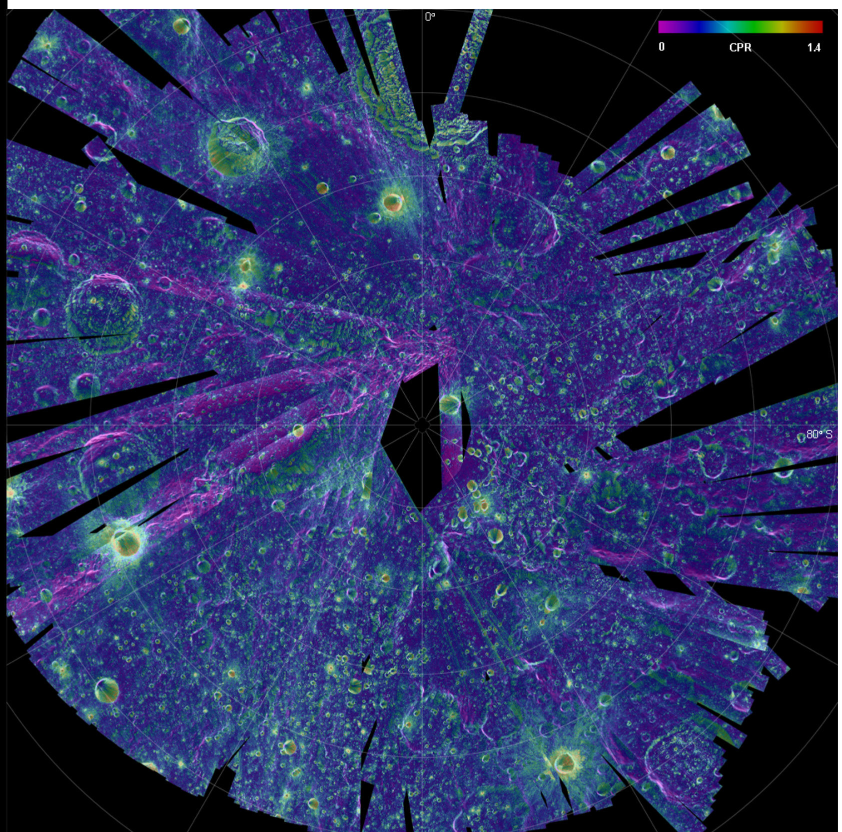
Forerunner operated at **S-Band (12.6 cm)** with a resolution of **150 m (baseline).**



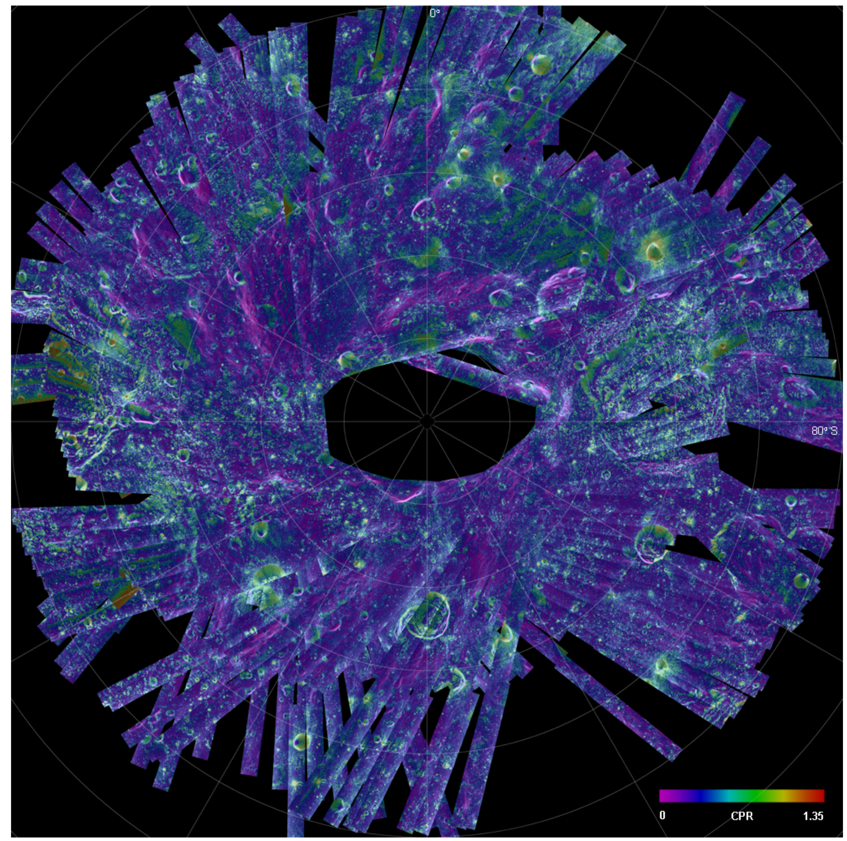
Chandrayaan-1

Forerunner

Forerunner acquired nearly complete (>90%) coverage of the lunar polar regions, and limited coverage of the equatorial regions (~ 20 strips)

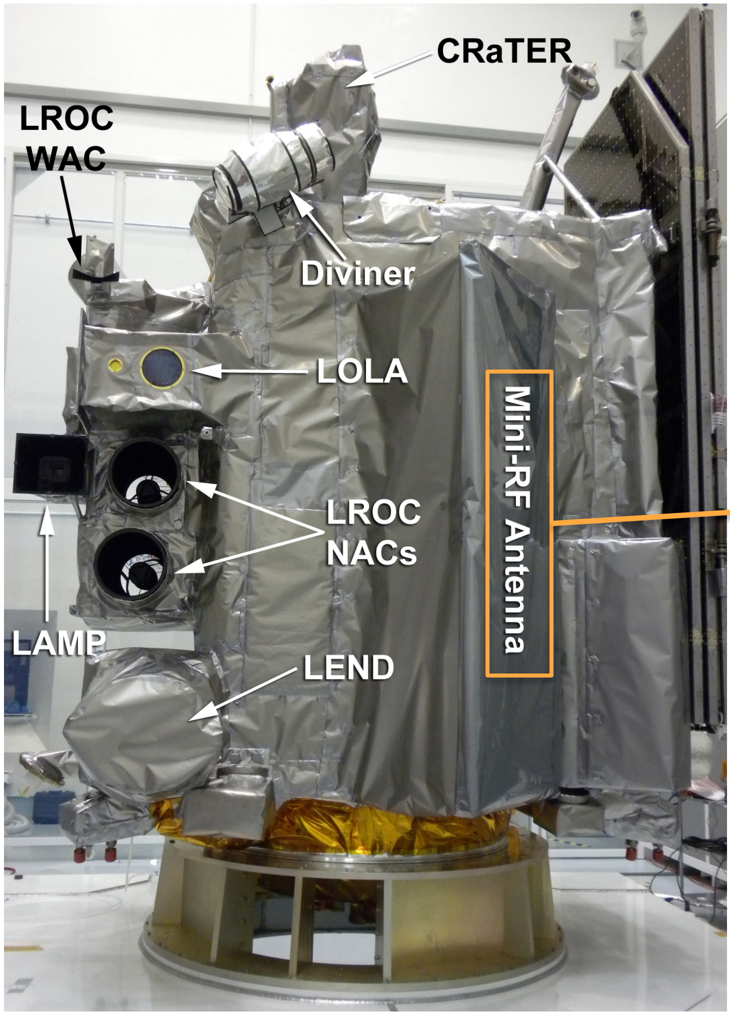


North Pole



South Pole

On June 18, 2009 the **Lunar Reconnaissance Orbiter** launched, carrying with it a radar dubbed **Mini-RF**



Mini-RF can operate at two wavelengths:

S-Band (12.6 cm)
X-Band (4.2 cm)

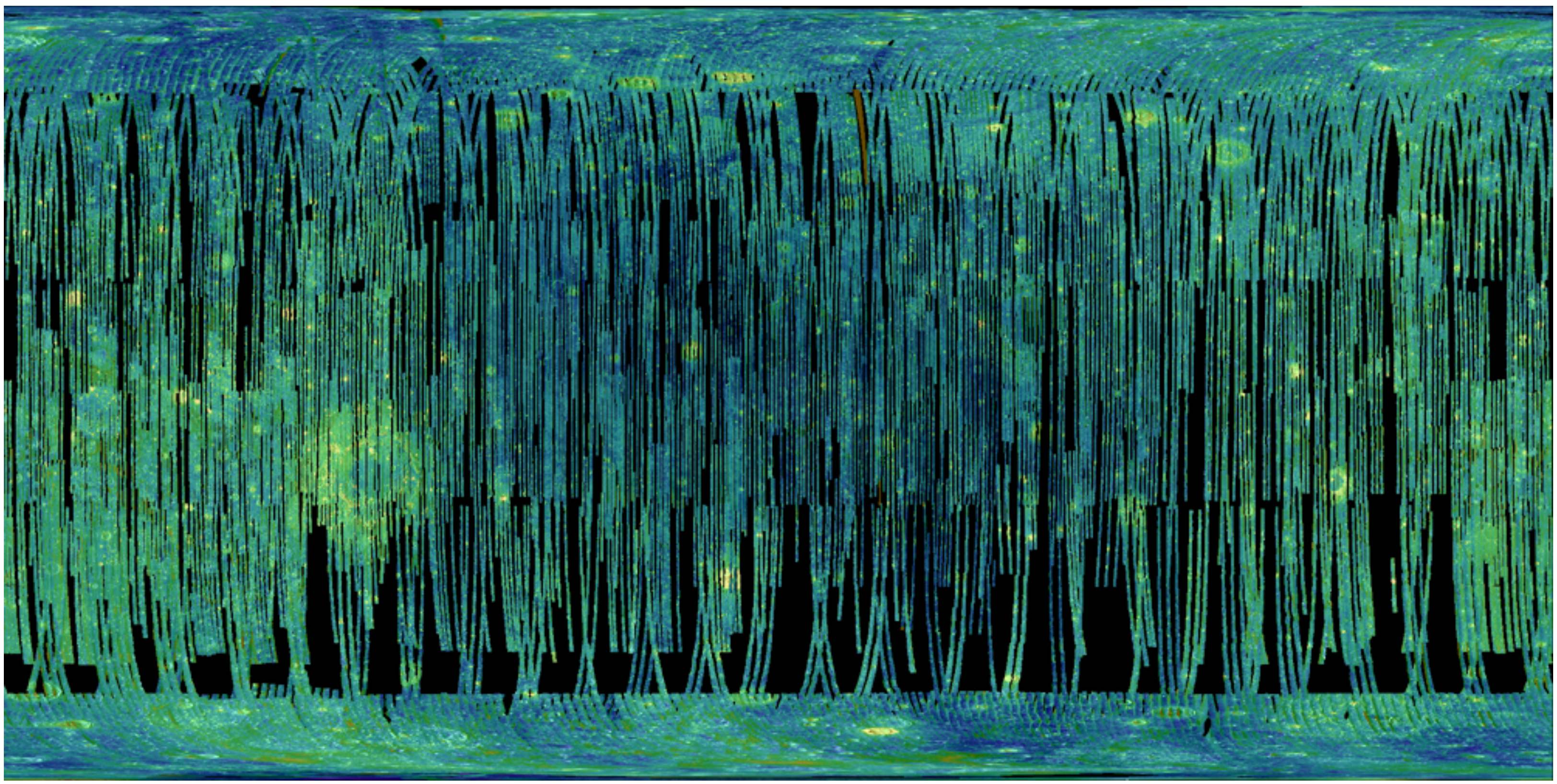
And two resolutions:

15 x 30 m (zoom)
150 m (baseline)

Mini-RF

Mini-RF acquired data over 66% of the non-polar regions of the Moon (< 70°), and nearly full coverage over the two poles at S-Band

First radar views of the **lunar far side!**



-180° 0° (near-side) 180°

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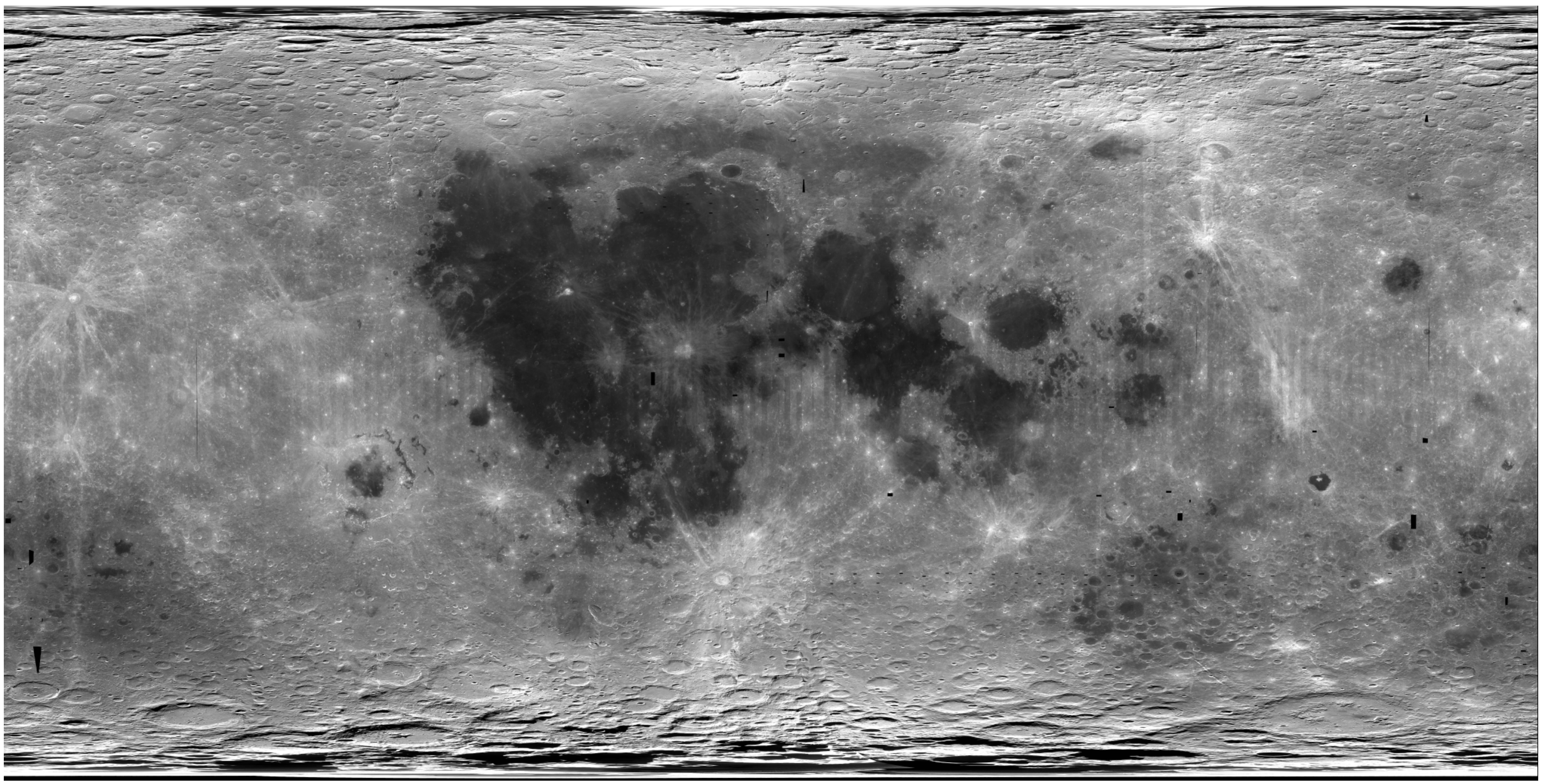
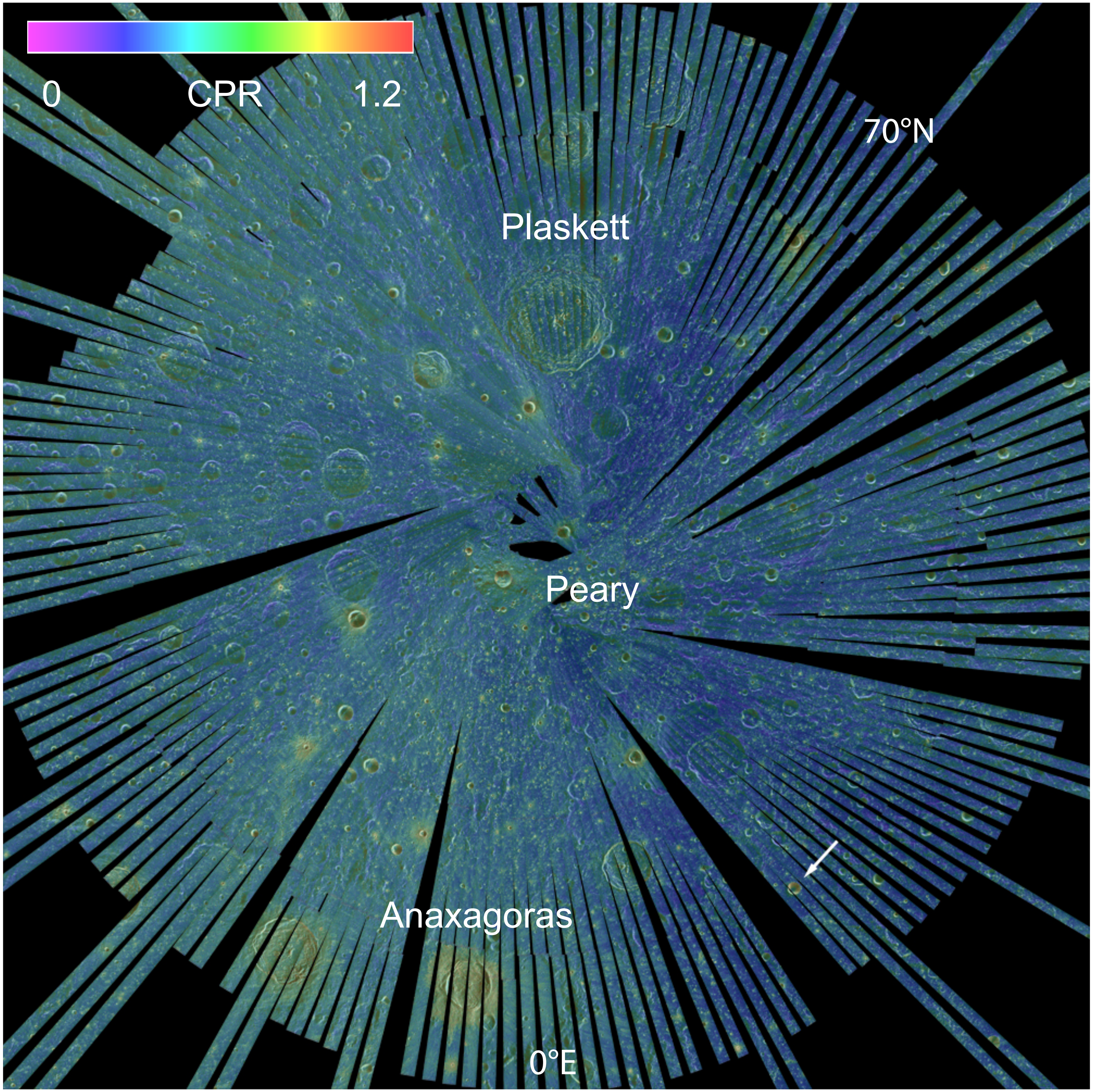
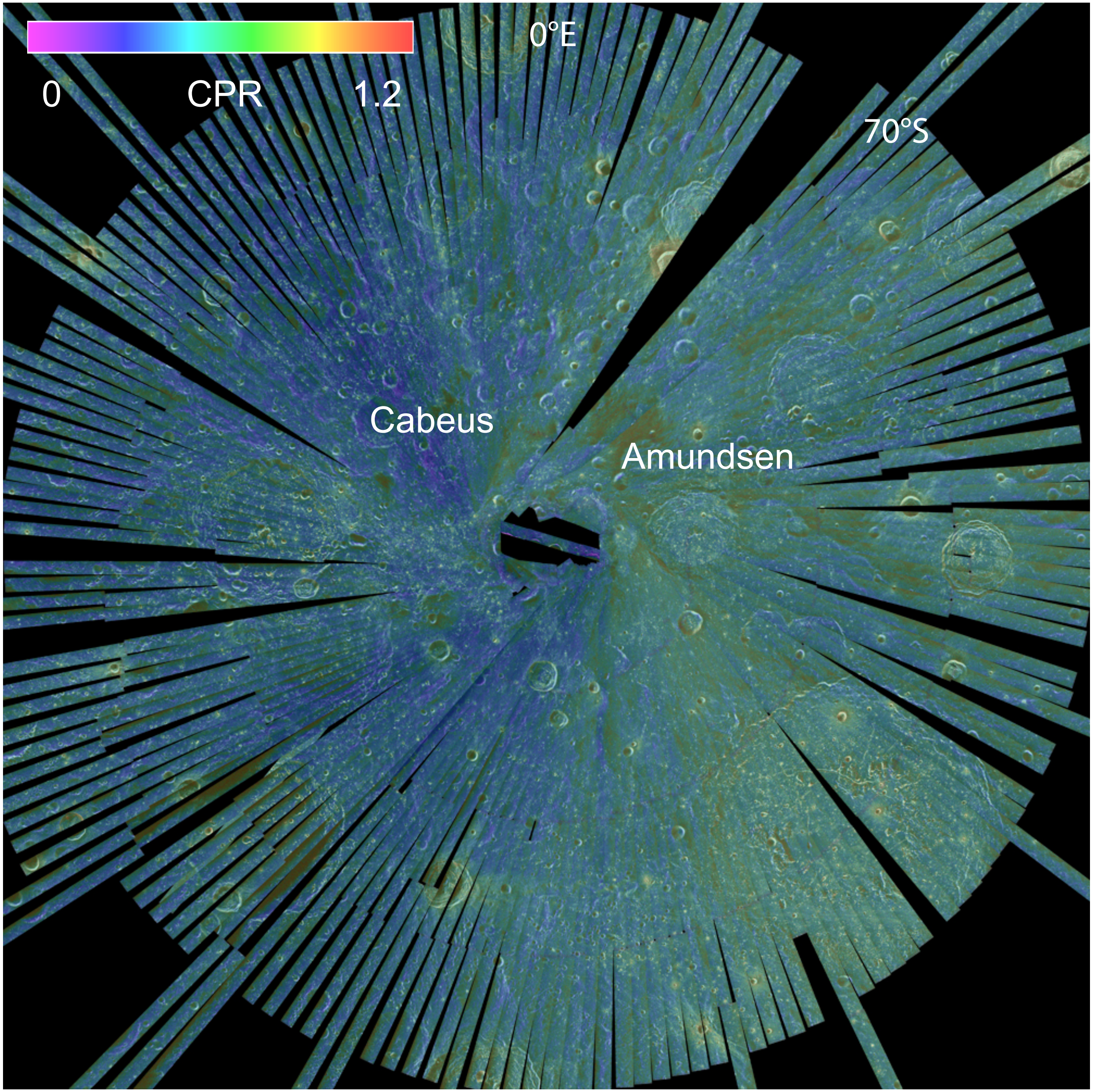


north pole



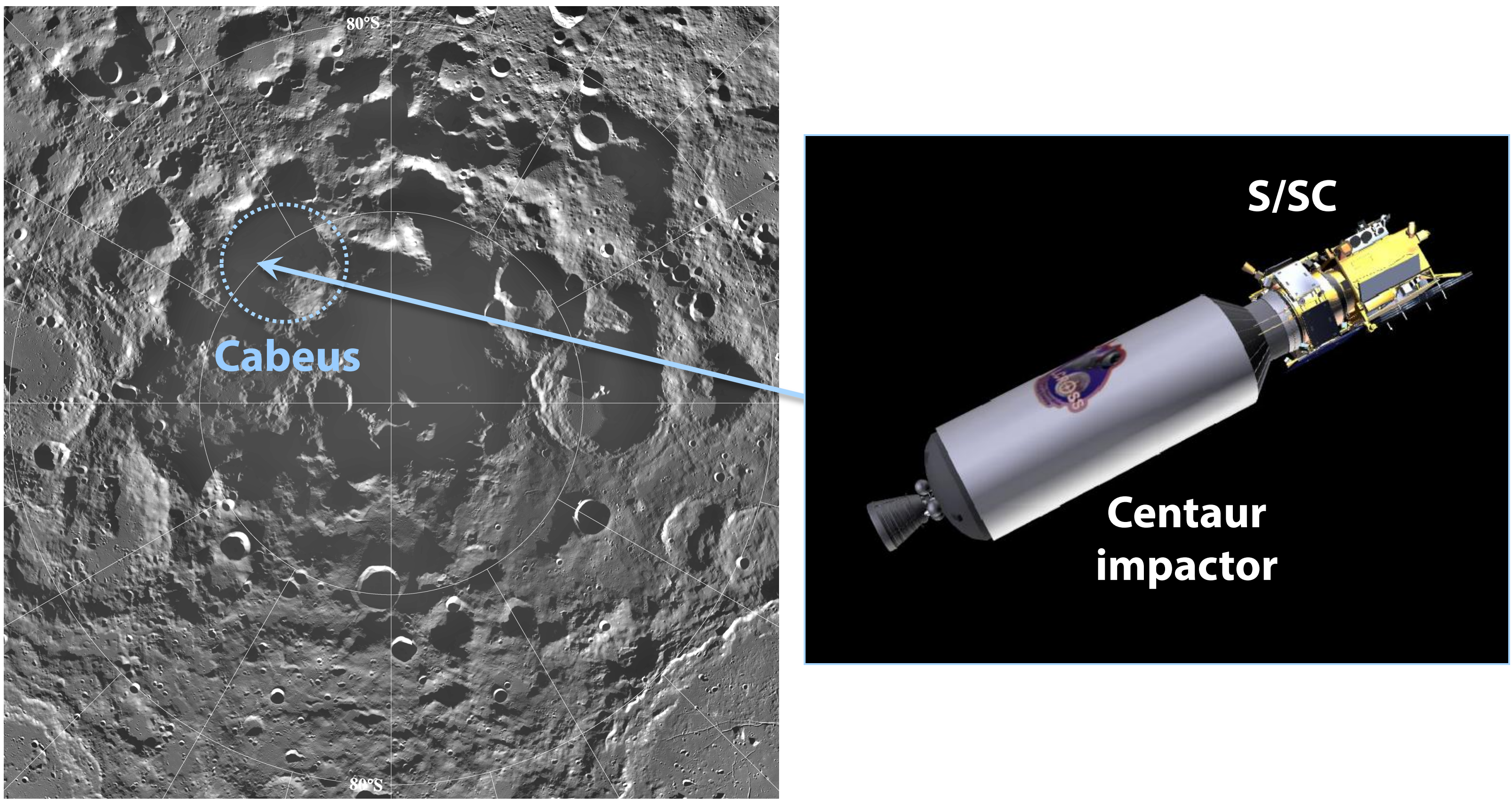
Slide 19

south pole



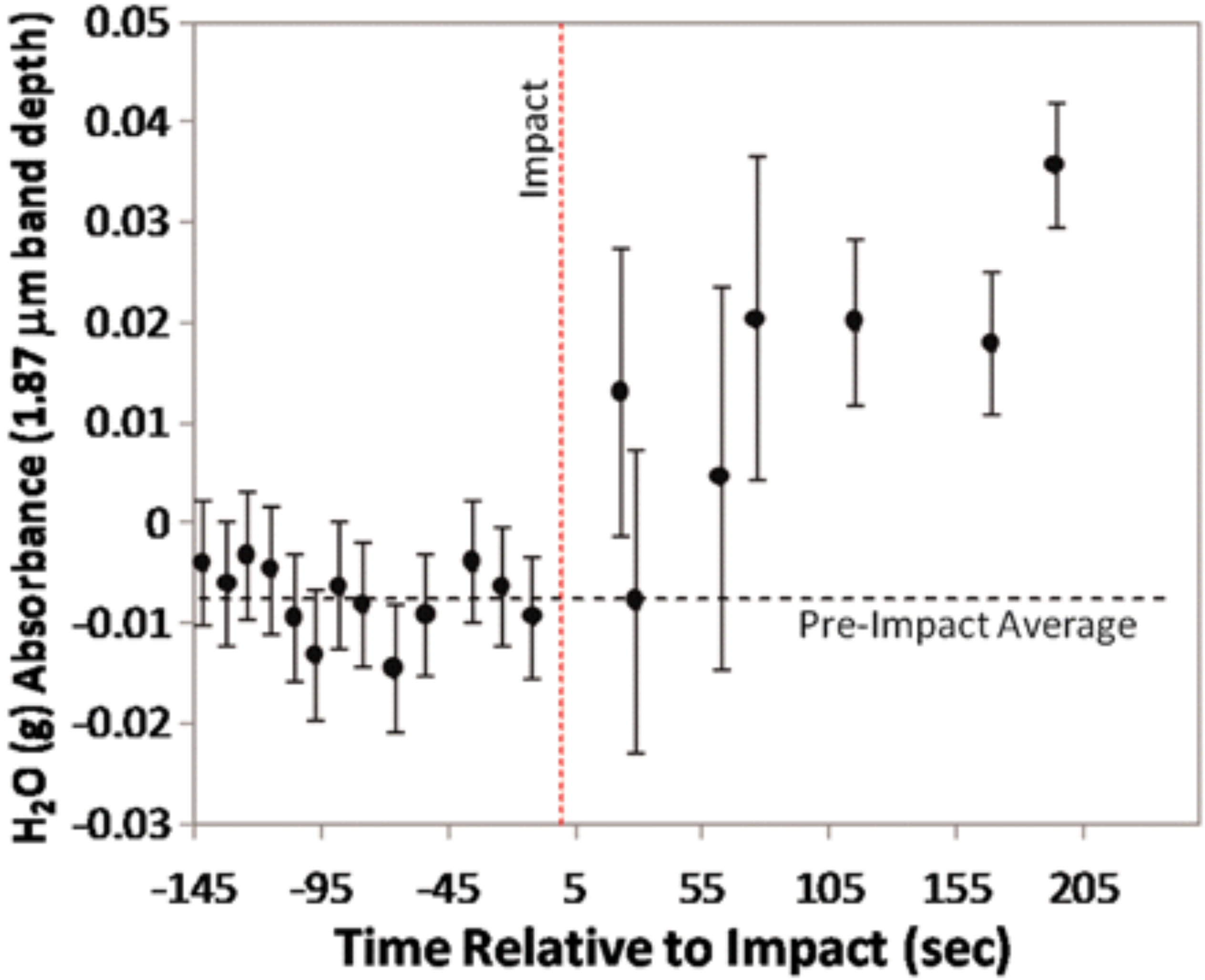
LCROSS

- **Observation**: The lunar poles do not look like the mercurian poles in radar
- **Question**: Is there radar evidence of lunar volatiles?
- **Test case**: LCROSS



LCROSS

- Reports from LCROSS indicate the **presence of water and water ice** in Cabeus crater (~5 wt. %)

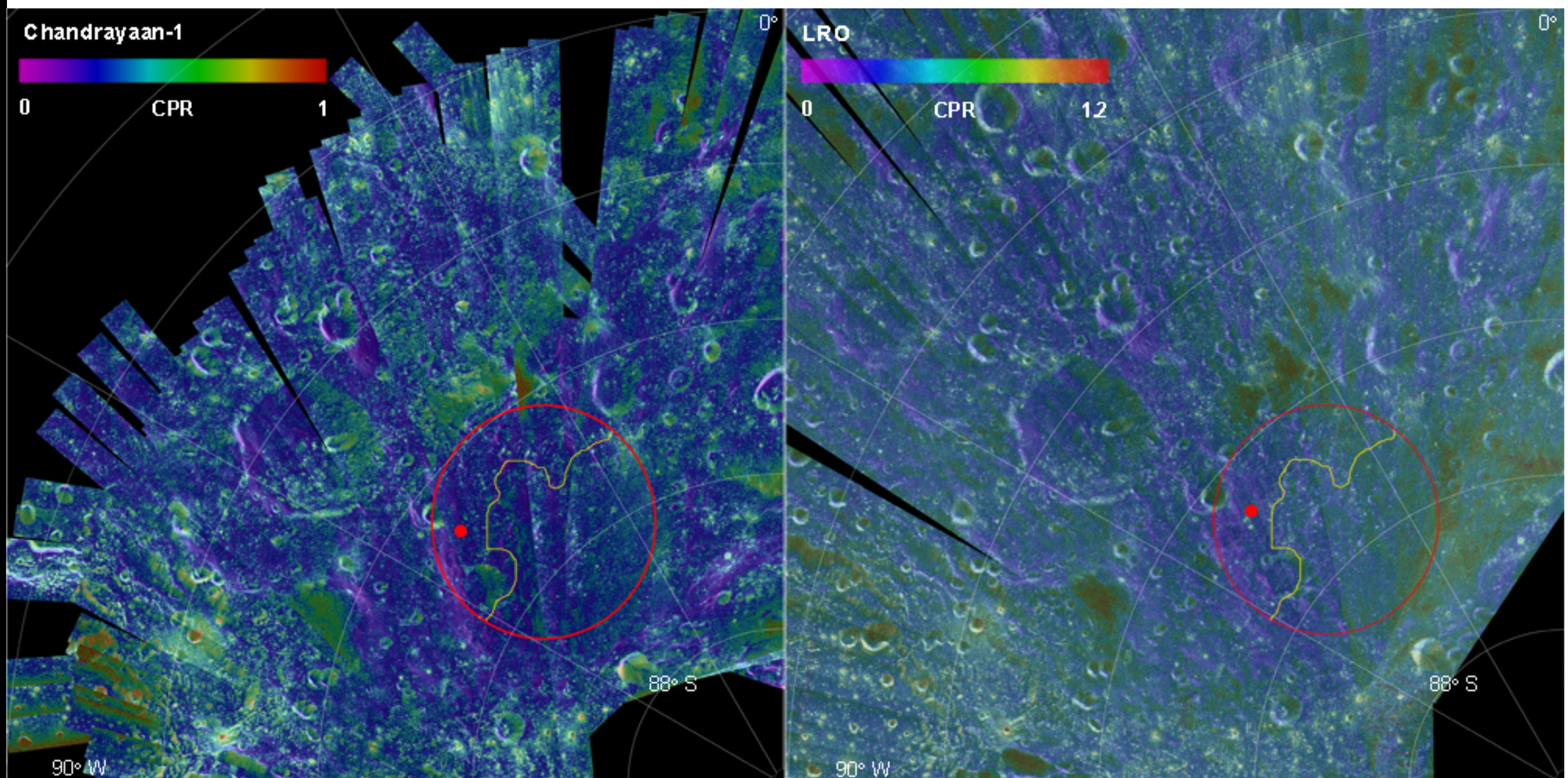


Colaprete et al. 2010

Low radar return indicates that there is no near-surface, thick deposits of ice in Cabeus crater

- This water must therefore be interspersed in the regolith as small grains less than ~10 cm in size

Chandrayaan-1 **LRO**

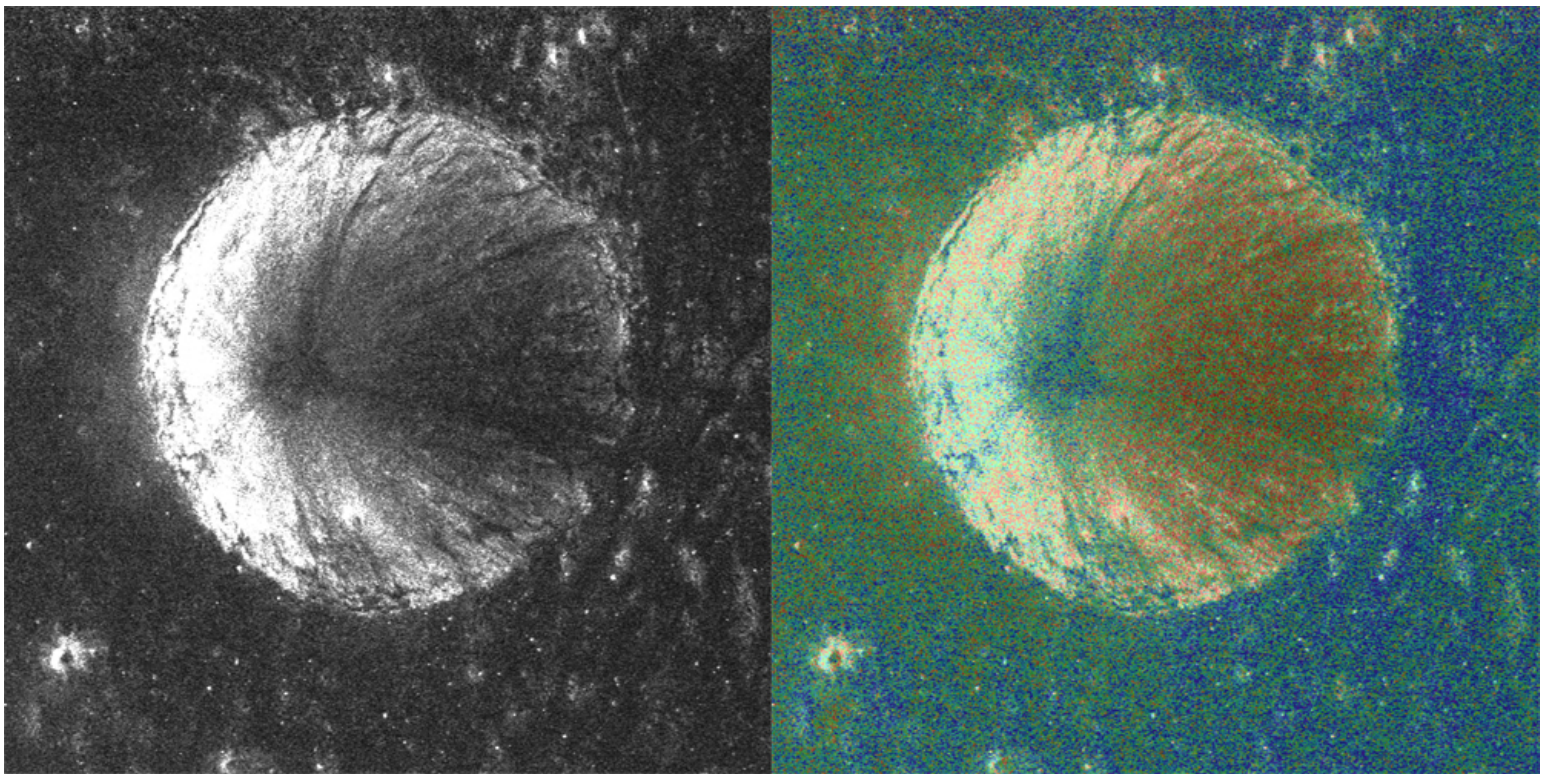


● = approximate location of LCROSS impactor

Neish et al., 2011

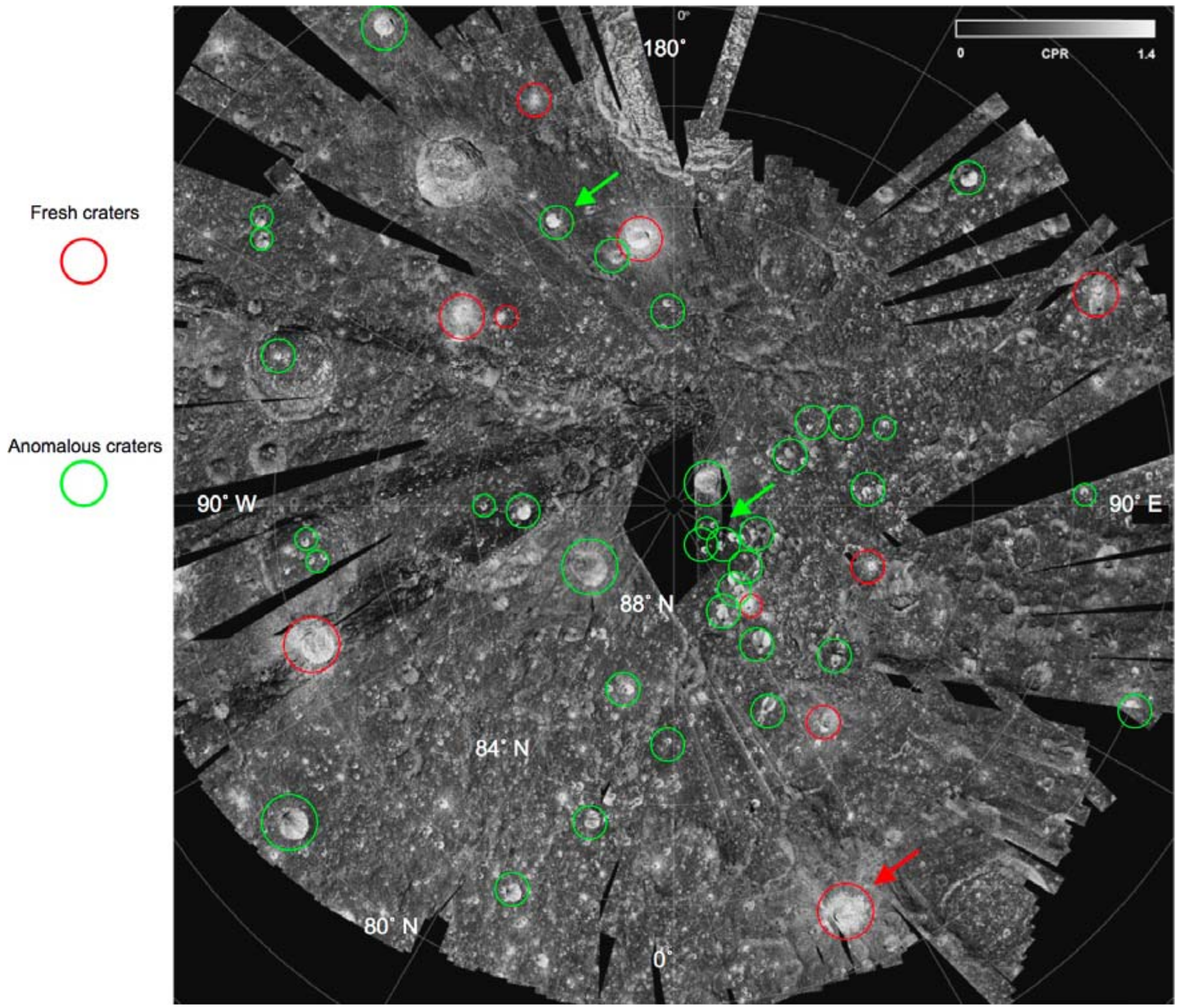
BUT there are many "anomalous" craters near the north pole which are good candidates for ice

ex. "Anomalous" craters like this one in Rozhdestvensky have high CPR (>1) inside the crater, and low CPR outside the crater



ice in north pole?

BUT there are many “anomalous” craters near the north pole which are good candidates for ice



Spudis et al., 2010

HOWEVER, high CPR can also be explained by extremely blocky surfaces (**CPR = SC/OC**)

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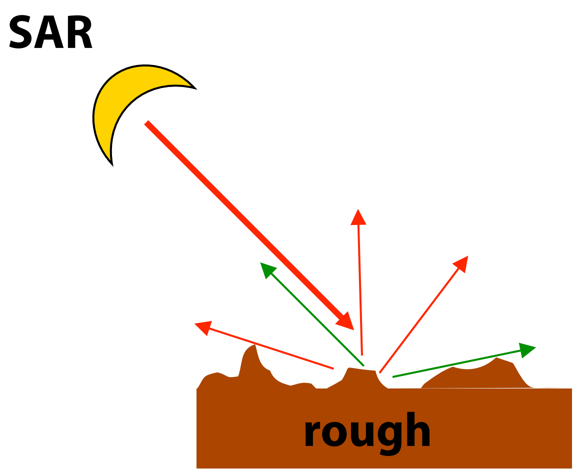

Multiple bounce backscattering on a rough surface randomizes polarization (OC ≅ SC)

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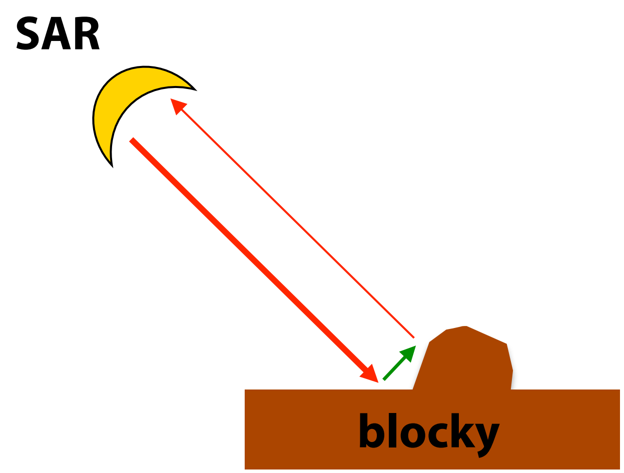
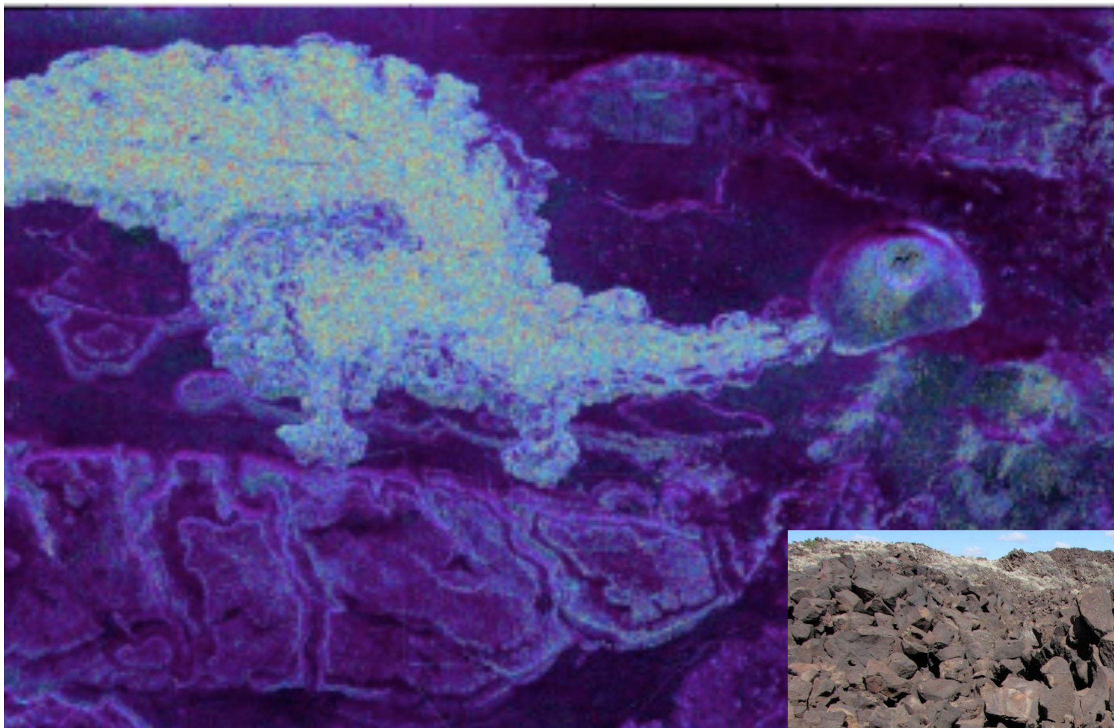


Blocky surfaces may act as corner reflectors, causing double bounce backscatter (OC << SC)

HIGH CPR (> 1)

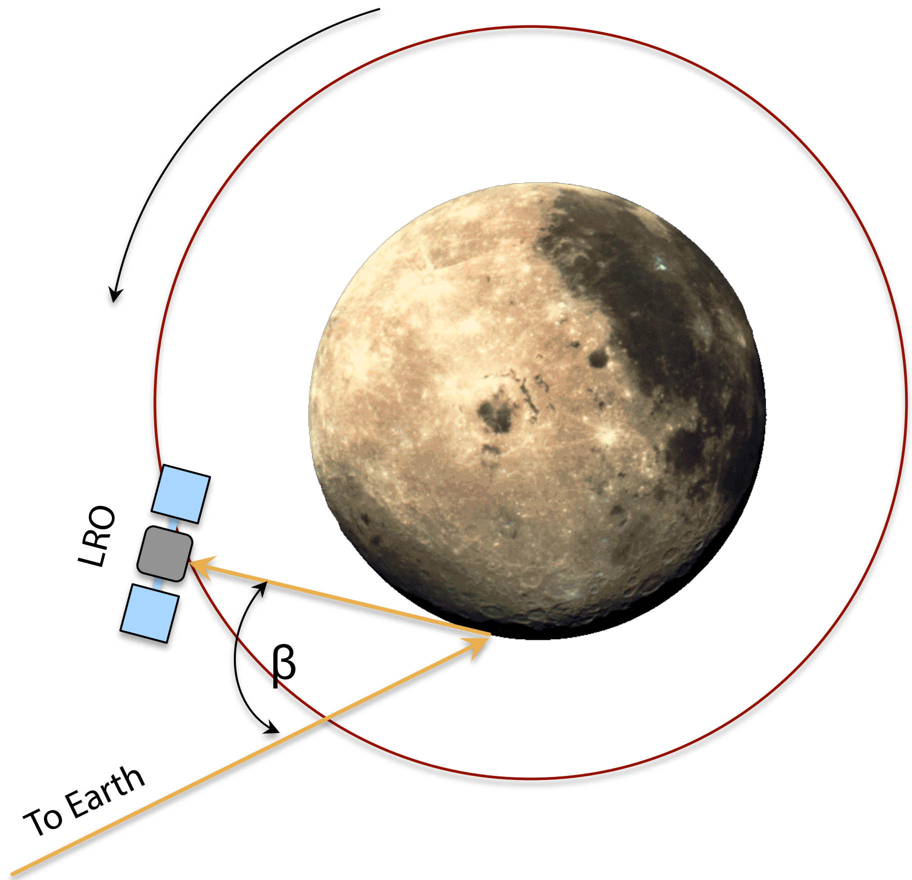
HOWEVER, high CPR can also be explained by an extremely blocky surface (**CPR = SC/OC**)

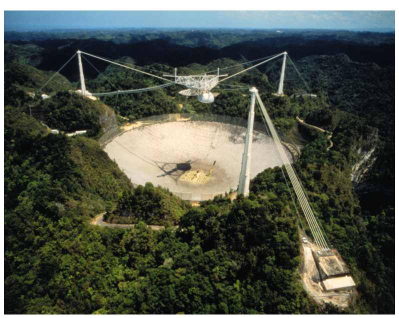


SP Flow in northern Arizona, as observed by AIRSAR

bistatic

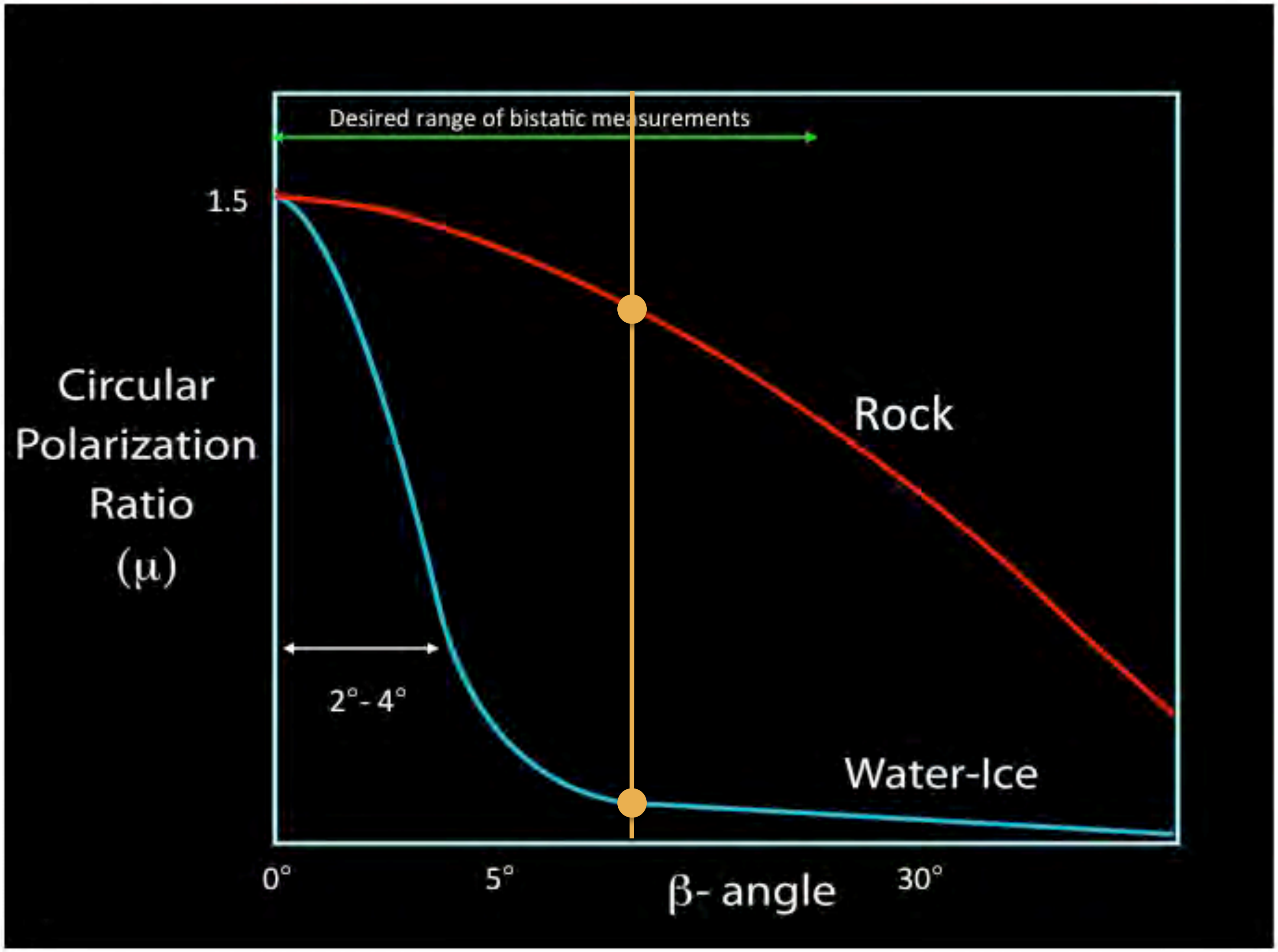
At a beta angle of zero, high CPR is not a unique indicator of water ice. Rough, blocky surfaces can also produce CPR > 1. Need a **bistatic measurement** to distinguish between the two possibilities.





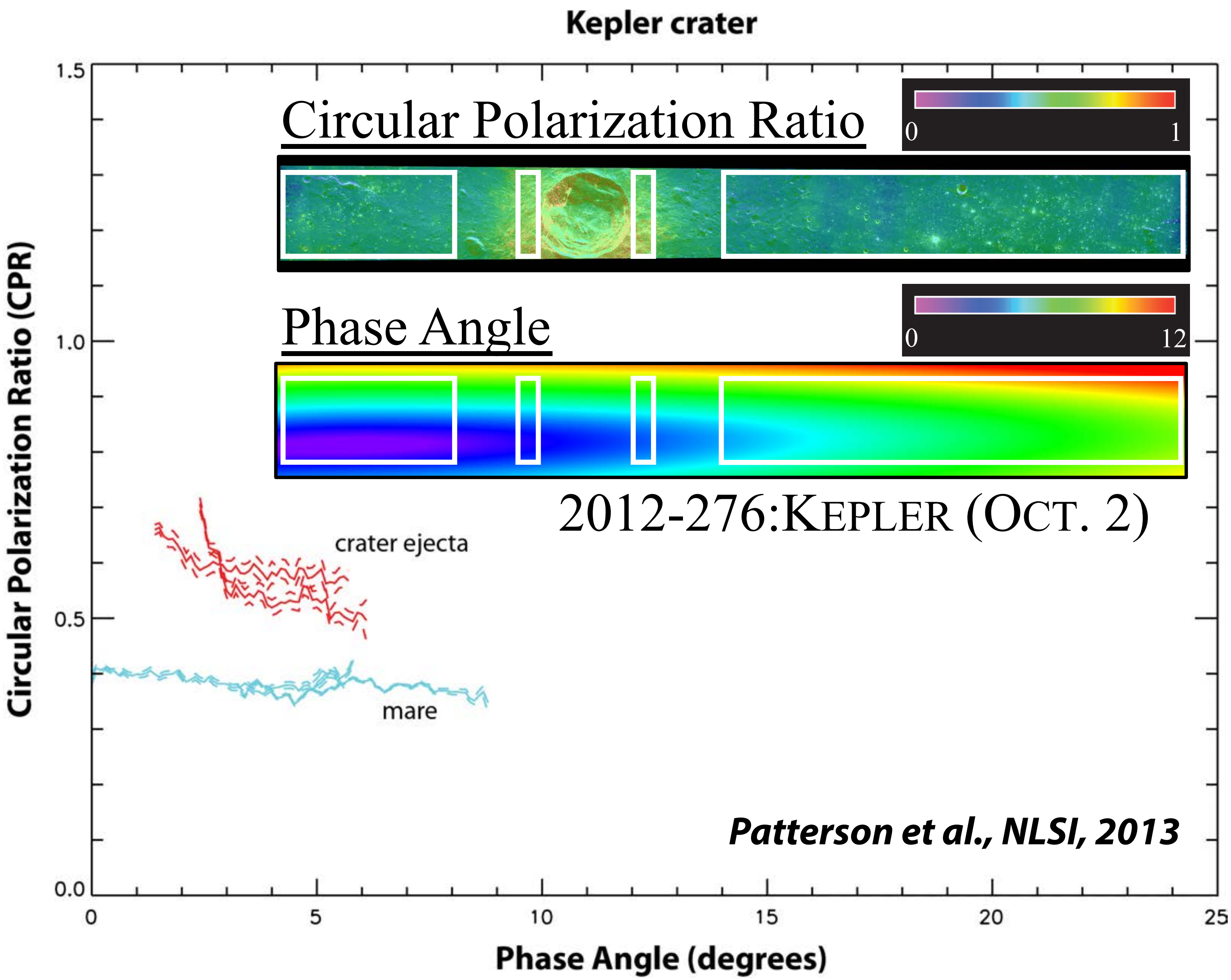
bistatic

At a beta angle of ~10°, we can distinguish rocky surfaces from buried ice.



bistatic

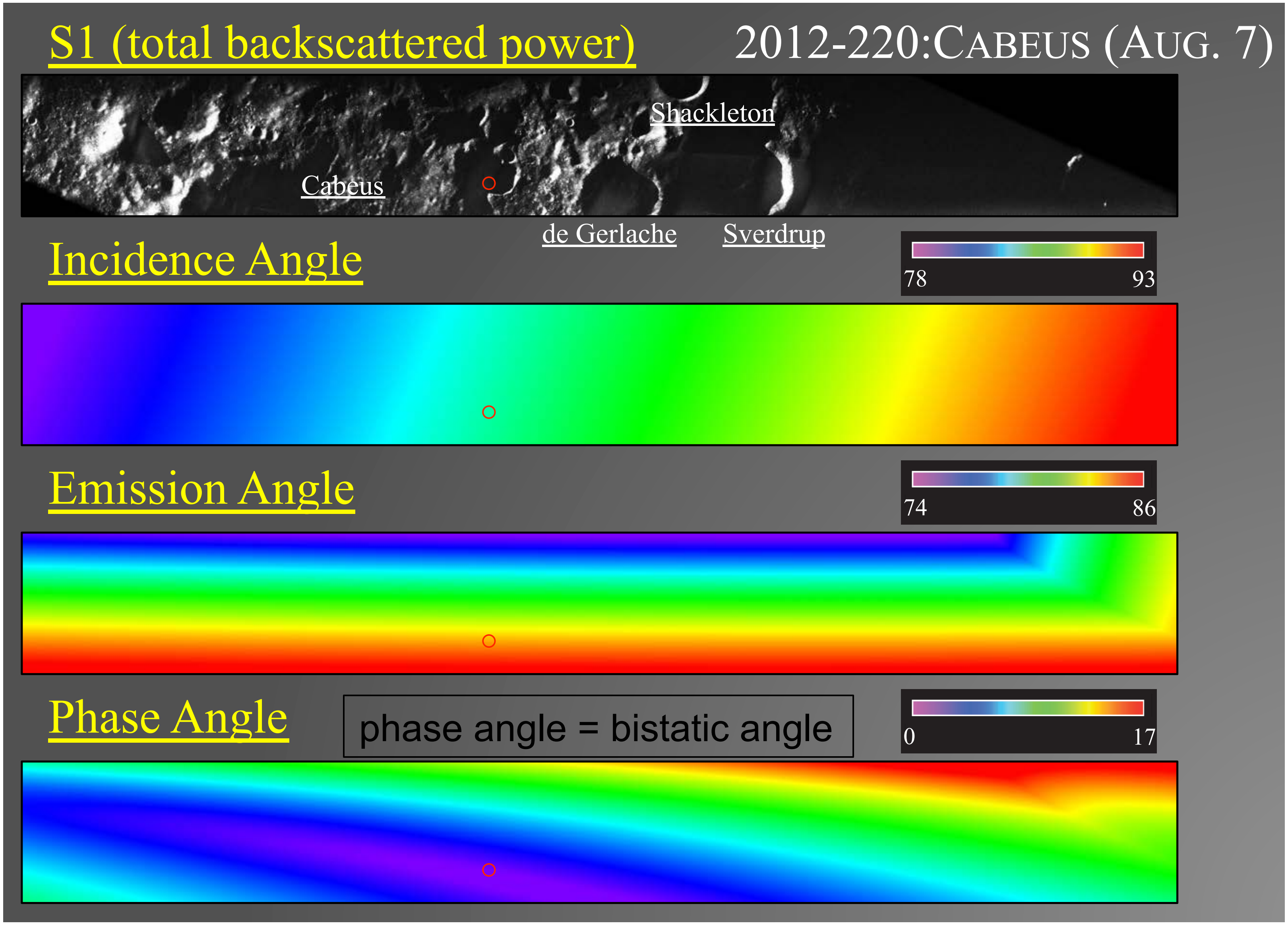
Step 1: Characterize the CPR curve for rocks.



Note: phase angle = bistatic angle

bistatic

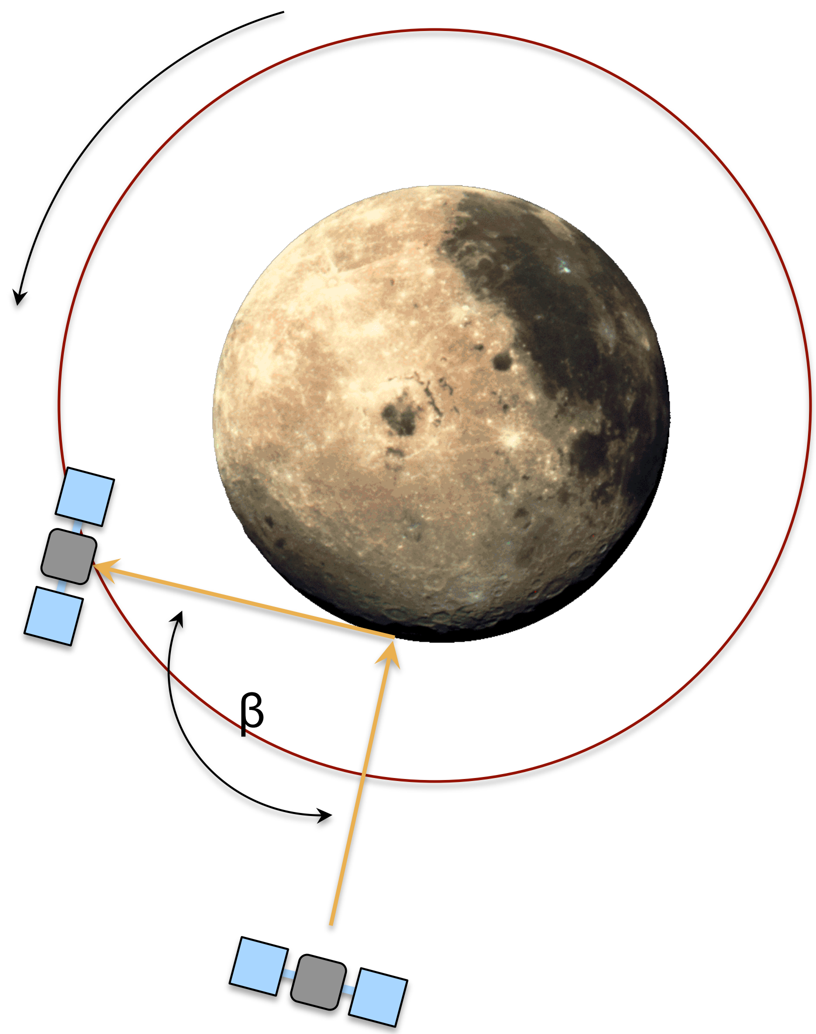
Step 2: Determine CPR curve for PSRs.



Patterson et al., NLSI, 2013

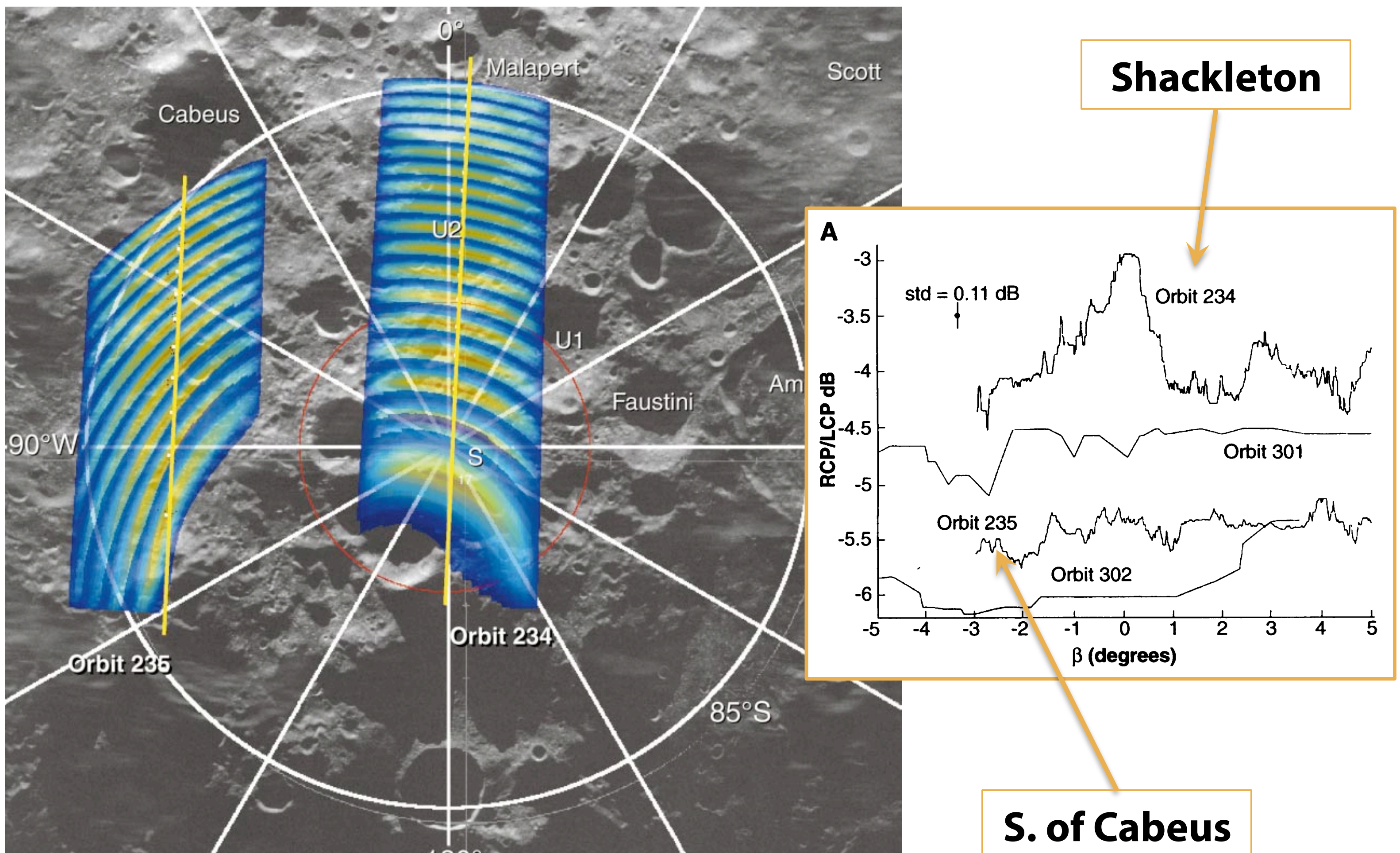
bistatic

A two spacecraft radar mission would allow us to more effectively probe the permanently shadowed regions.



Previous bistatic attempts:

1. *April 1994: Clementine (controversial results)*
2. *August 2009: C1/LRO (failed)*



Nozette et al. 1996, 2001

summary

There is evidence for **ice in permanently shadowed regions** near the poles of the Moon.

In some craters, such as Cabeus, the ice appears to be **present as small grains** (< 10 cm) mixed into the regolith.

Bistatic radar observations can be used to distinguish radar returns caused by thick deposits of ice and those caused by rocky surfaces.