



Geology & Planetary Mapping Winter School

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Planetary coordinate reference systems & mapping

Angelo Pio Rossi

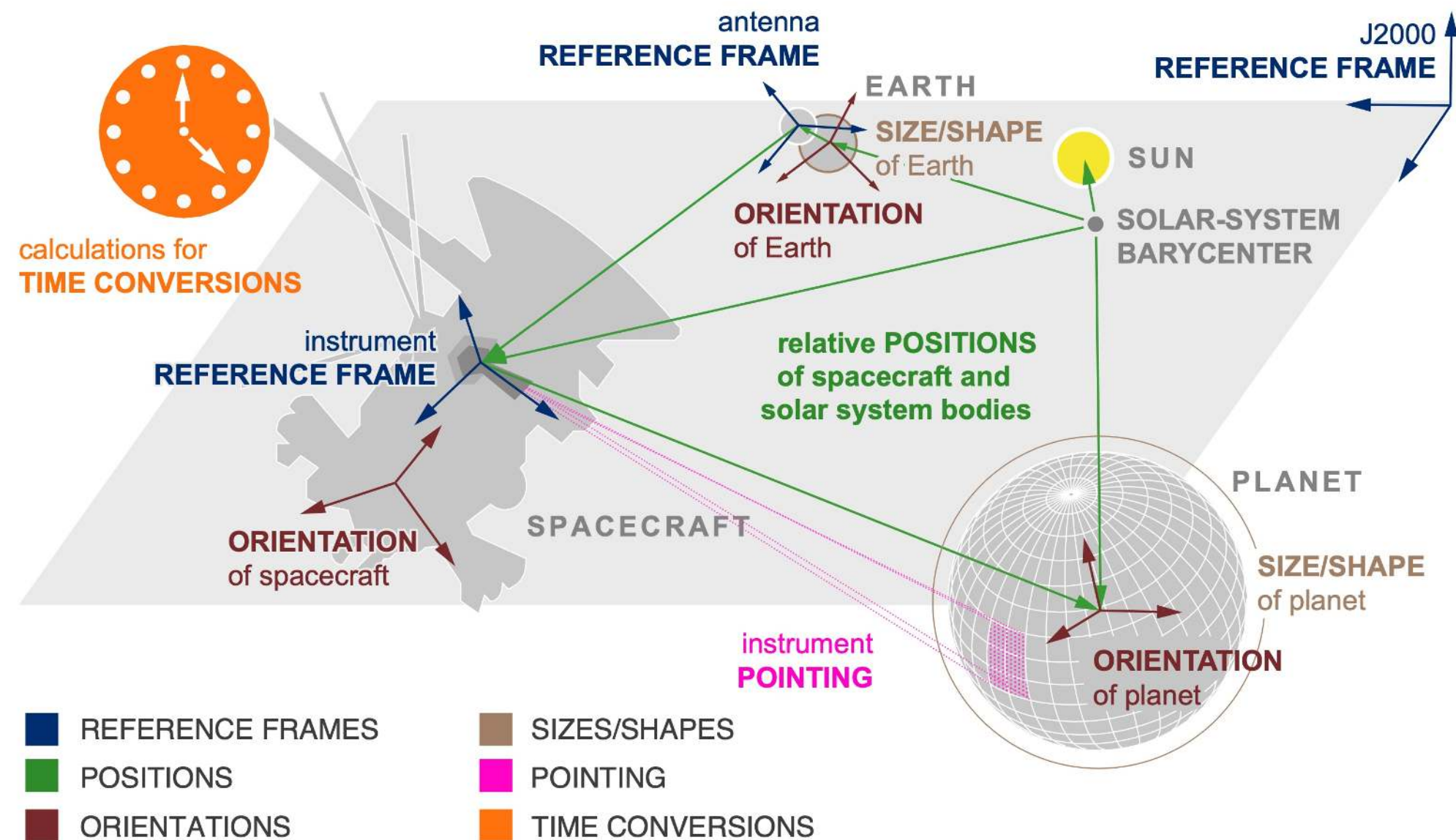
Constructor University - Bremen (Germany)



EU Horizon 2020 grant #871149

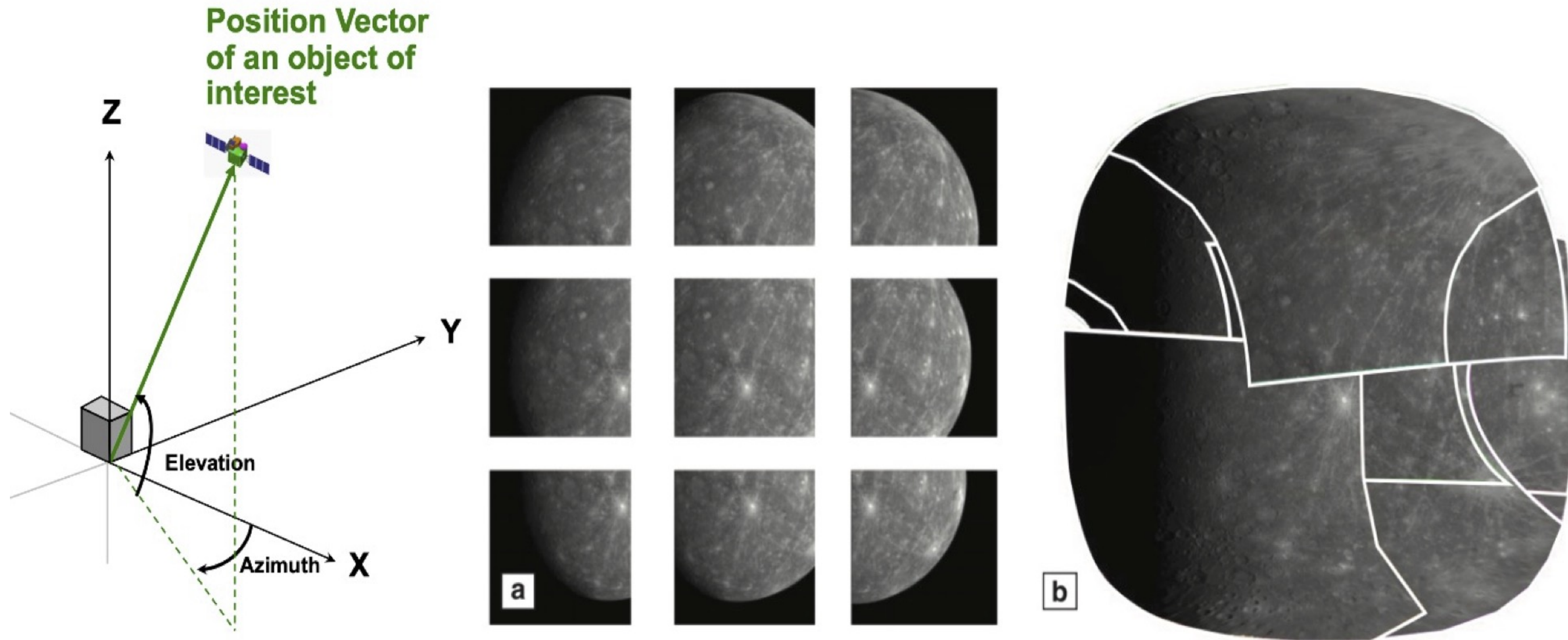
Background: [Collins et al. \(2013\)](#) / NASA / USGS

Reference frames



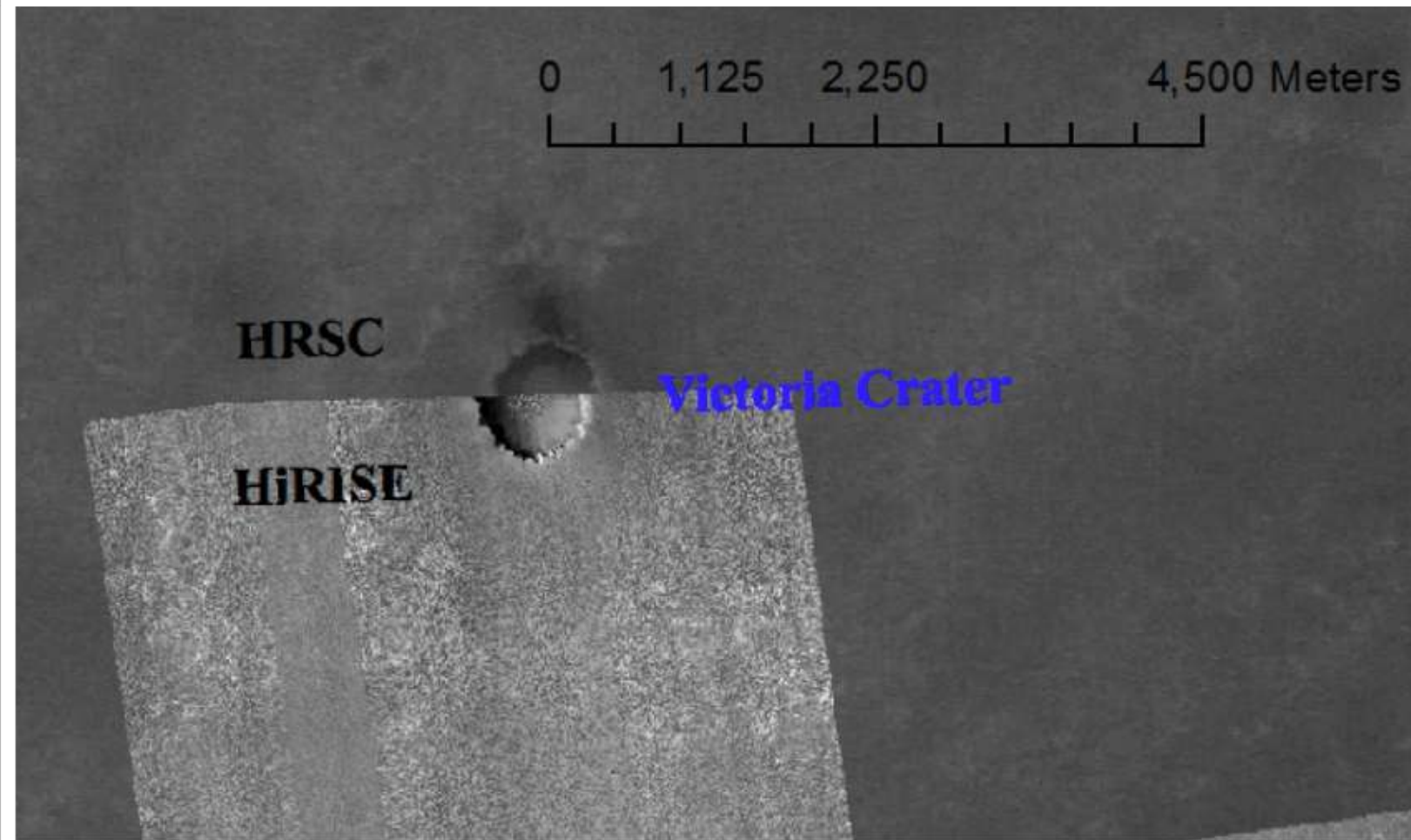
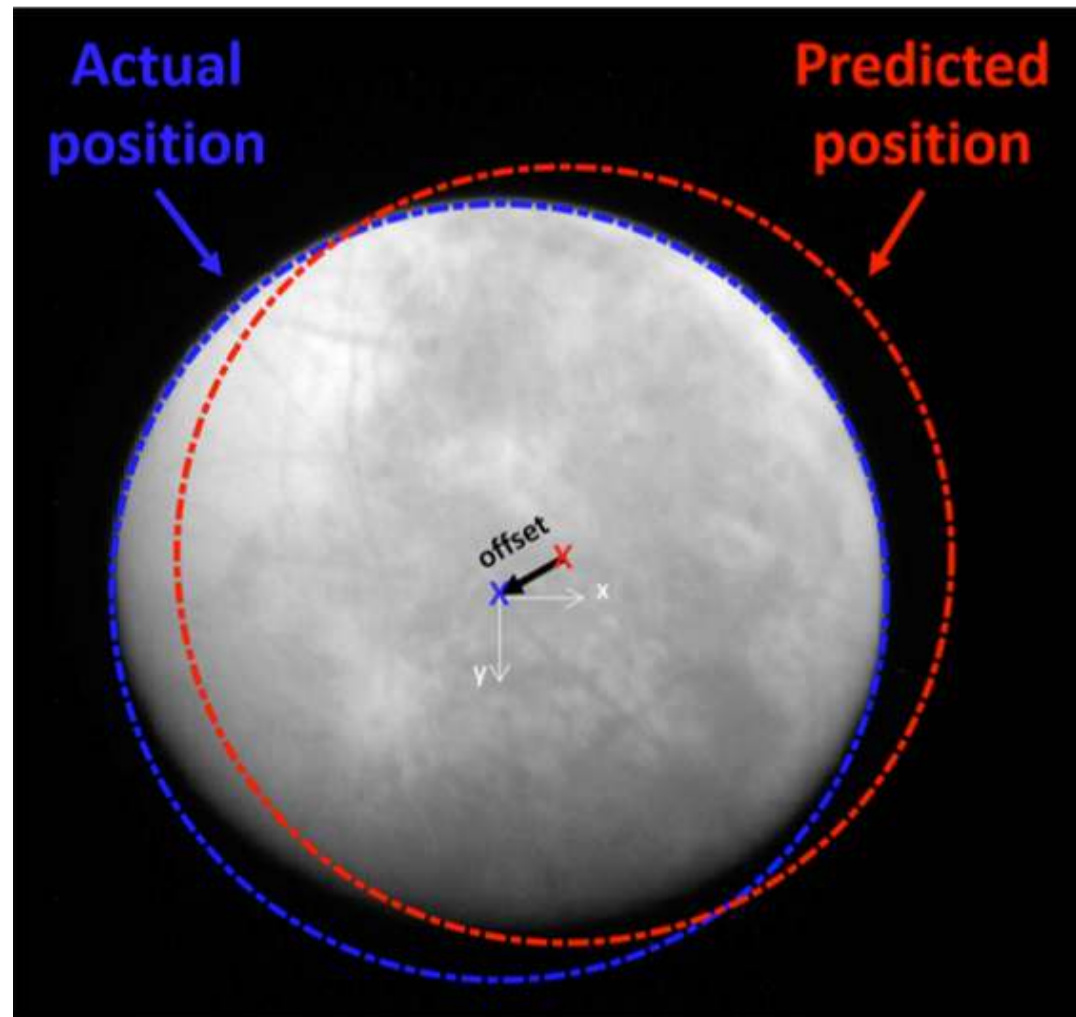
Source: [Hare et al. \(2018\)](#). See also [NASA/JPL/NAIF](#).

Pointing & imaging



Source: [Hare et al. \(2018\)](#), [NASA/JPL/NAIF](#).

Pointing & errors



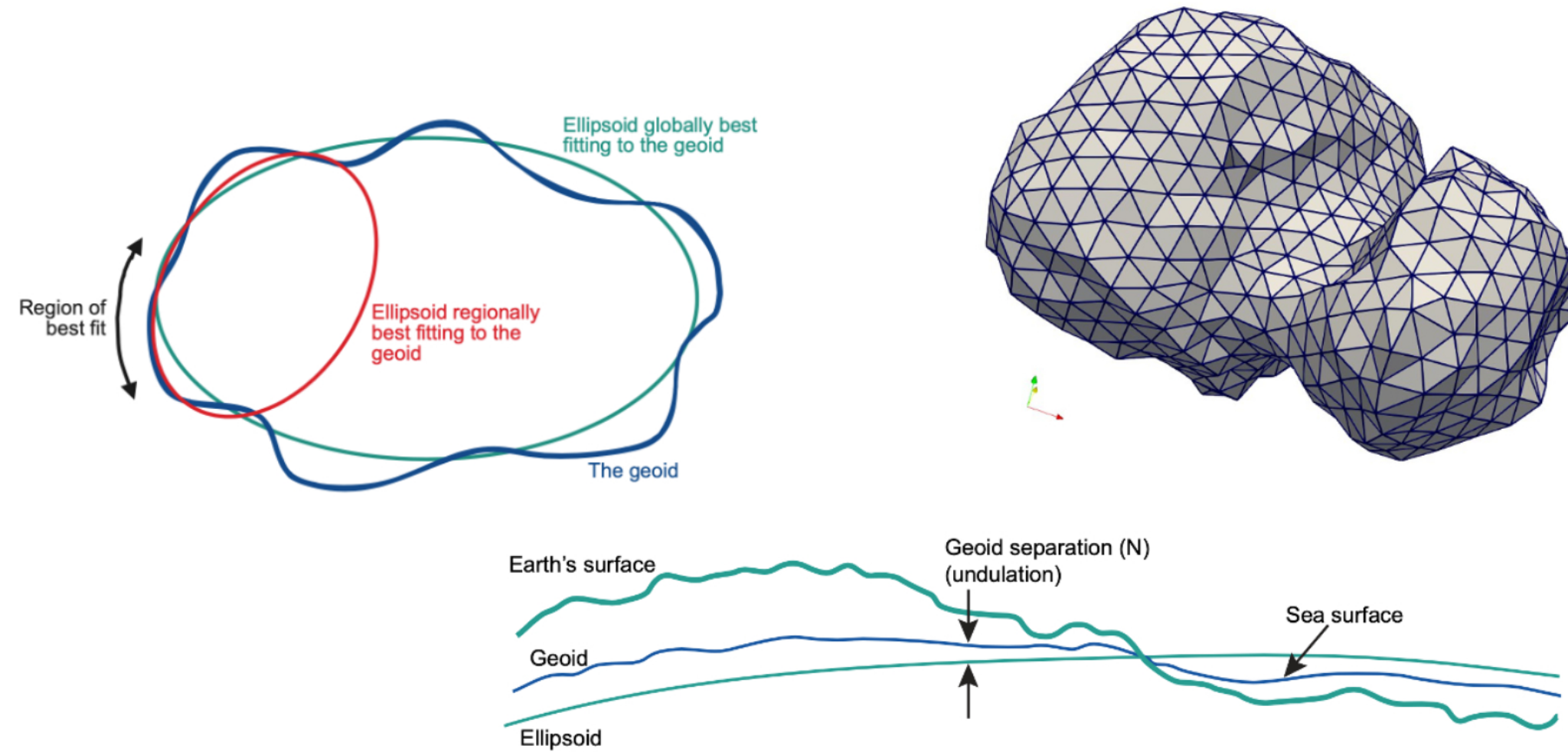
Source: Source: [Belgacem et al. \(2020\)](#); [Tao et al. \(2016\)](#).

Basic terminology

Many definitions, but to keep it short:

- **Map projection:** A model of the surface
- **CRS:** A model of the surface, and its reference body
- **GIS:** A computing / management/ visualisation / analysis system to deal with:
 - data with a CRS = (digital/ised) geospatial data

Reference surfaces

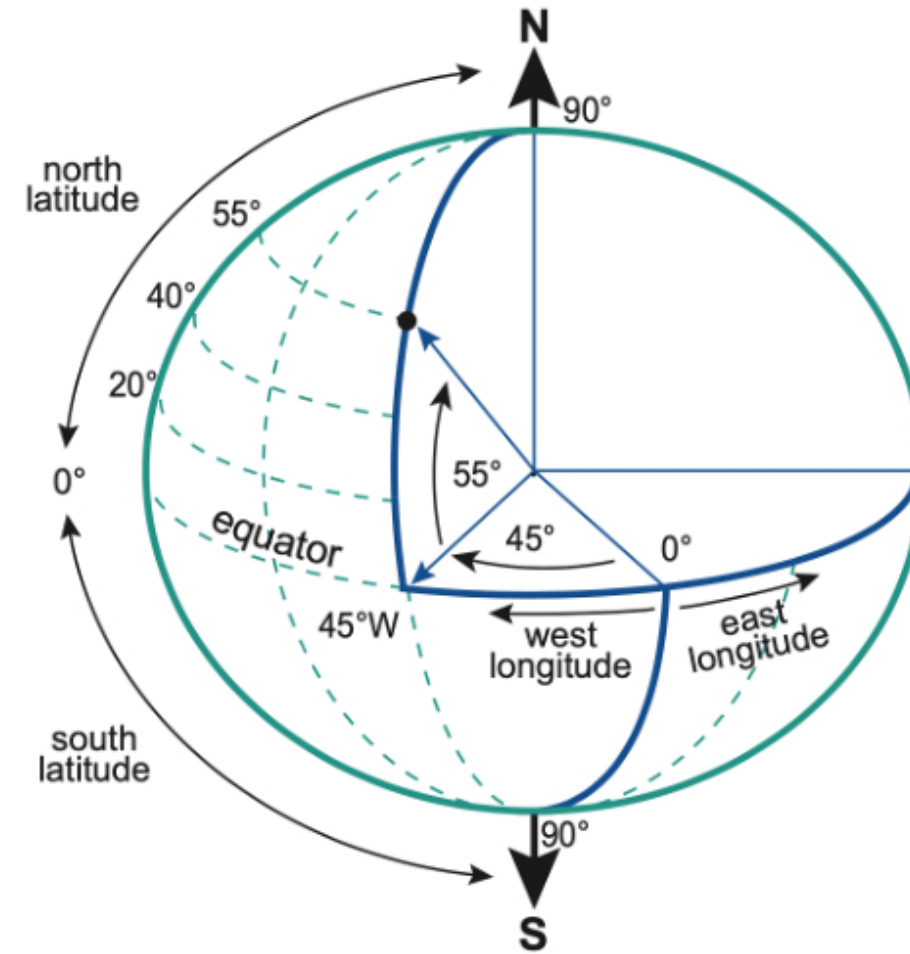
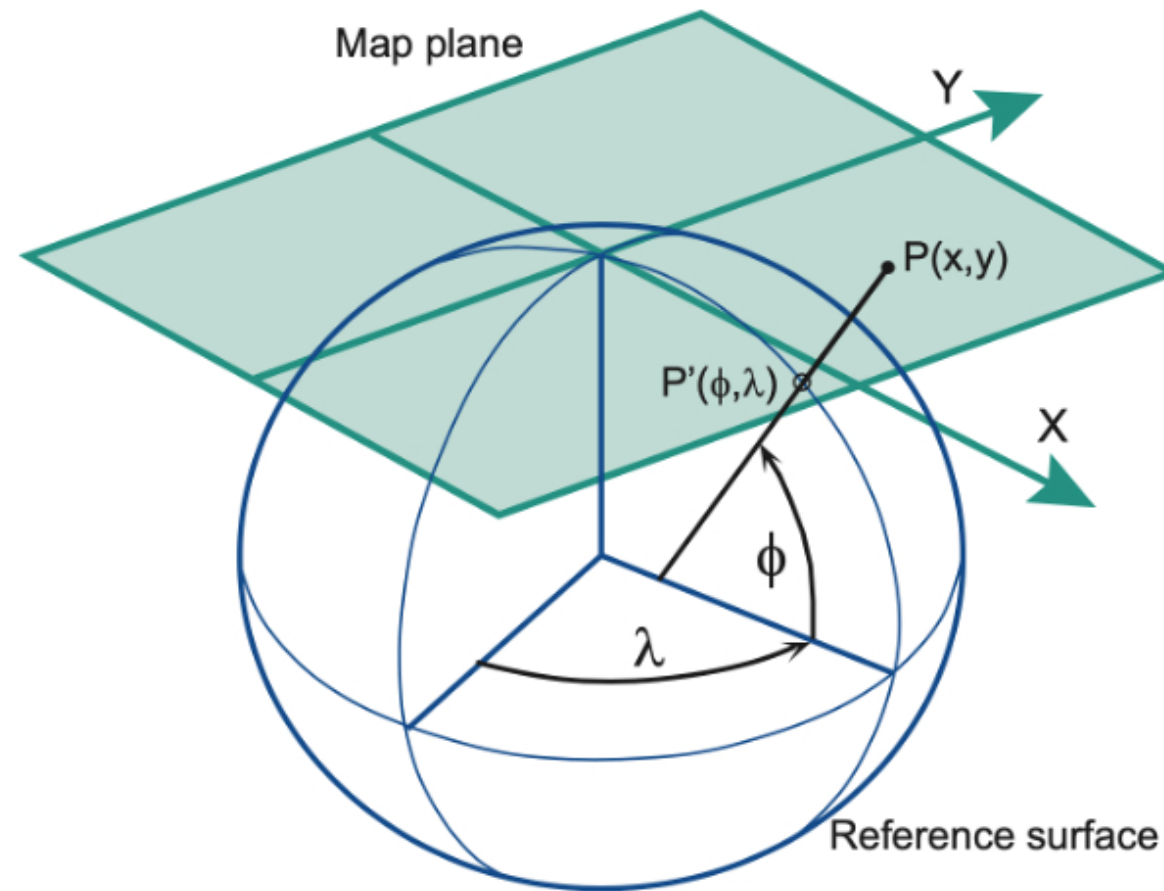


Source: [Knippers, \(2009\)](#), L. Penasa.

Reference time(scale)

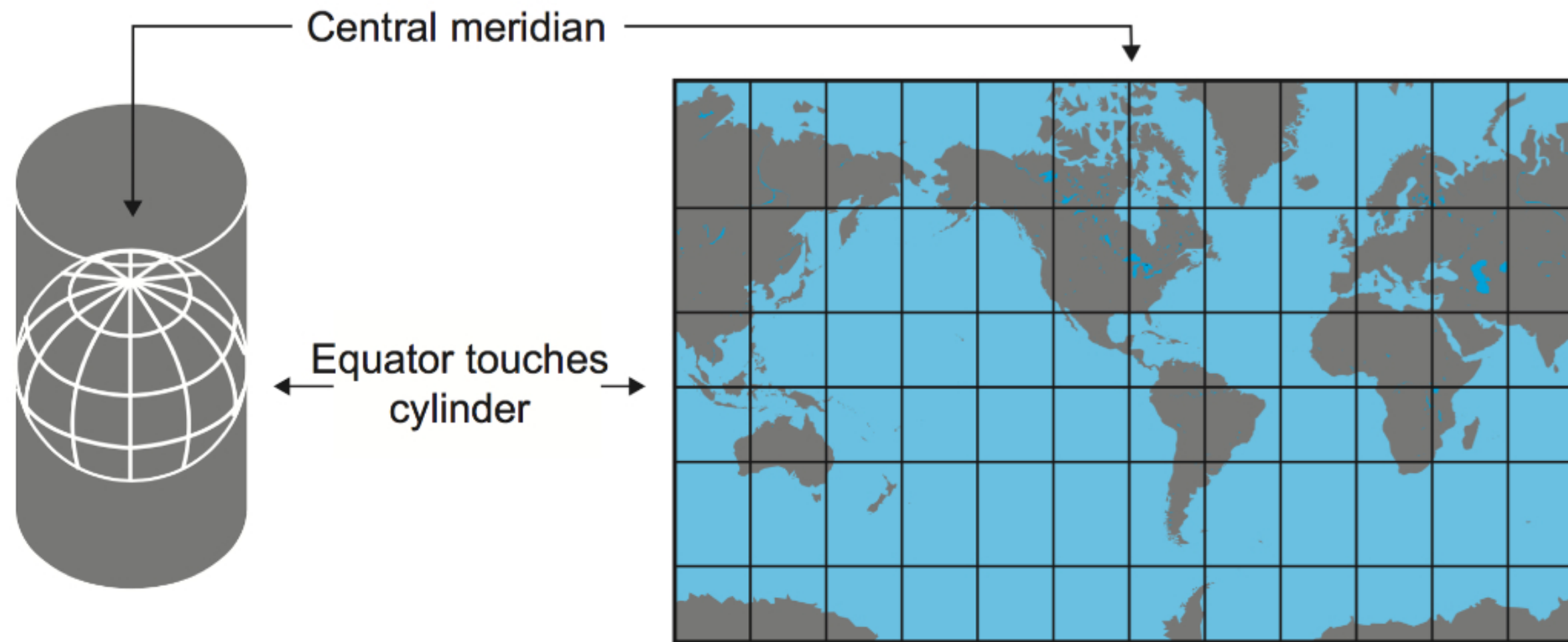
- Depending on the context/timescale, time might be negligible
- In reality, obviously it plays a (big) role
- Or not: e.g. Earth plates moving (little, \sim cm/y \sim dm/y)

Map projections



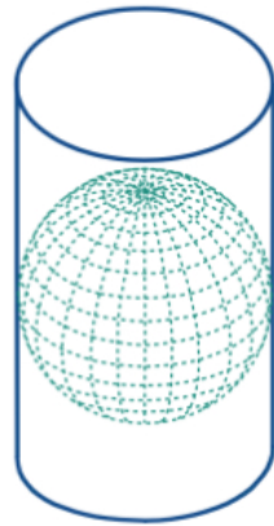
Source: [Knippers, \(2009\)](#).

Map projections

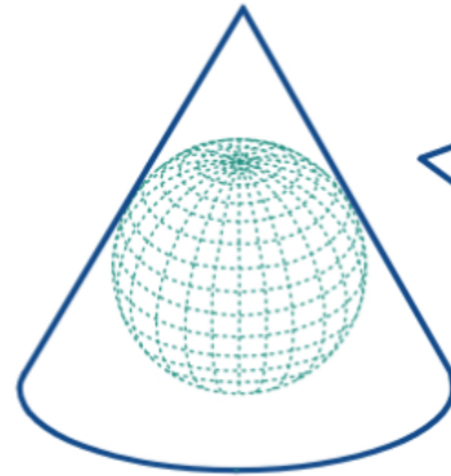


Source: [Hare et al. \(2018\)](#).

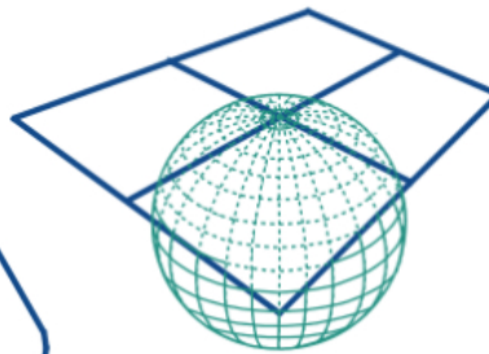
Map projection classes



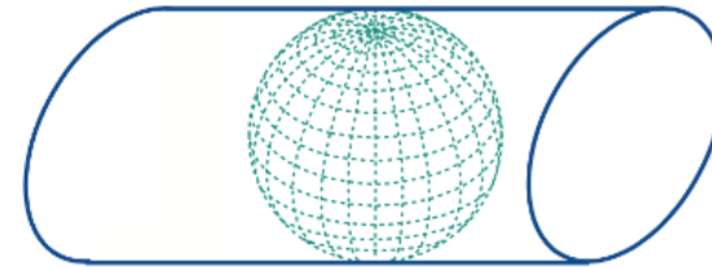
Cylindrical



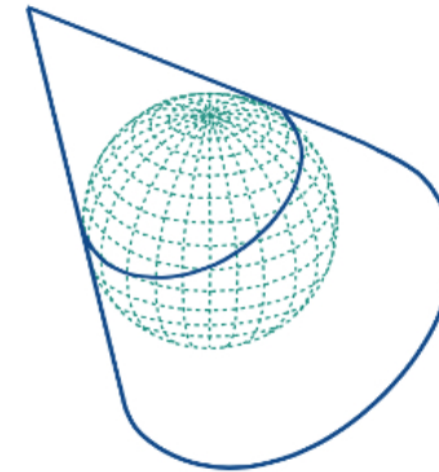
Conical



Azimuthal



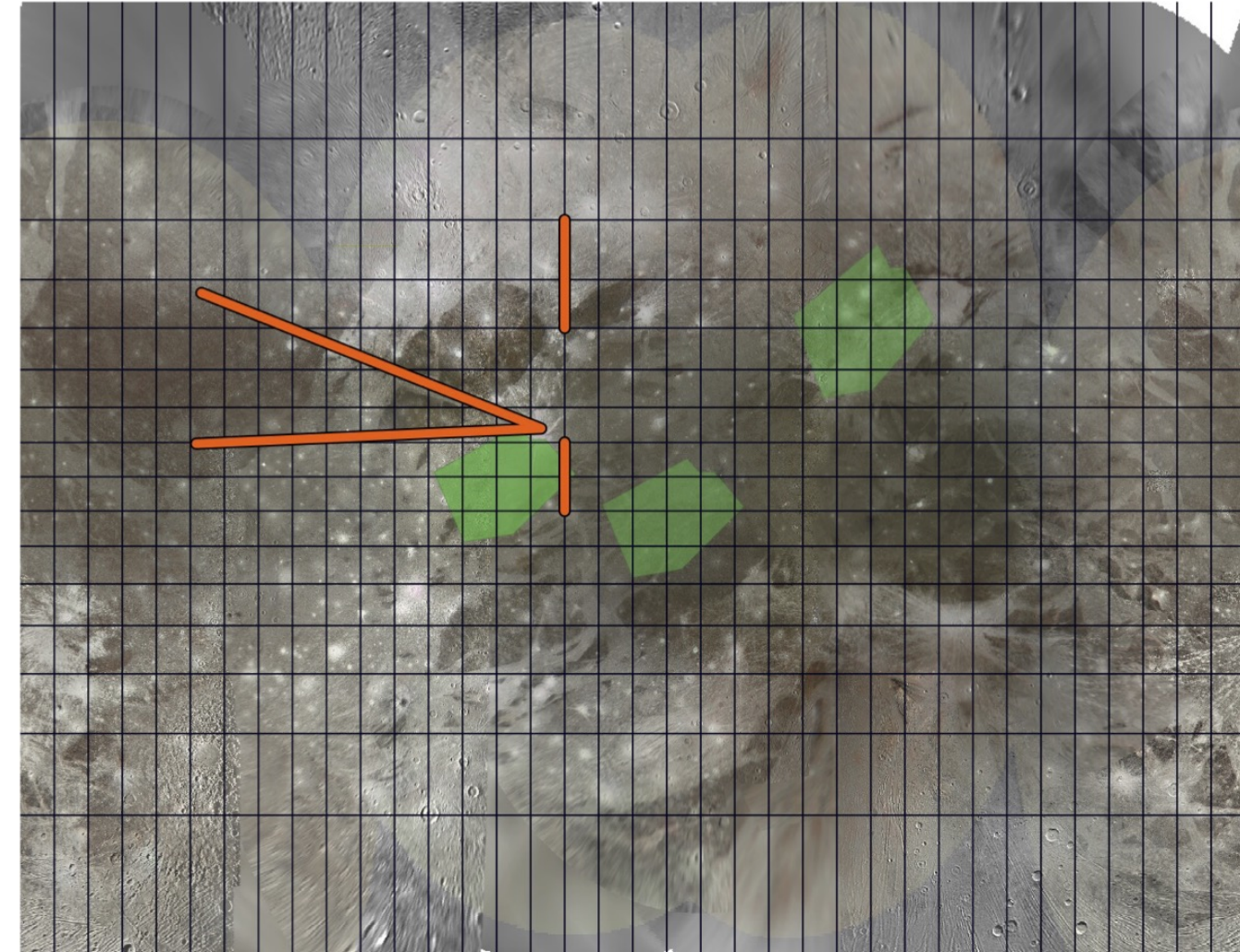
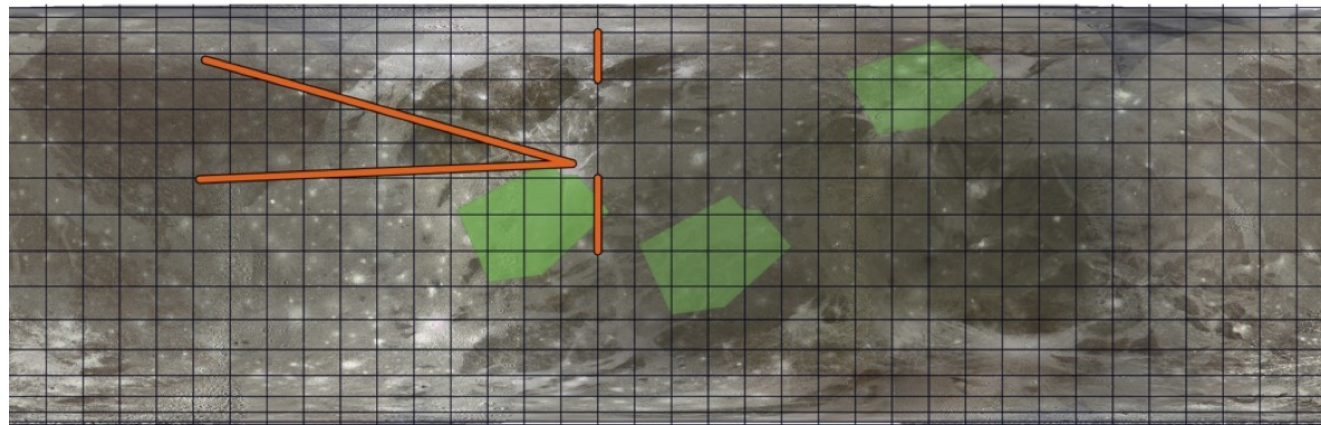
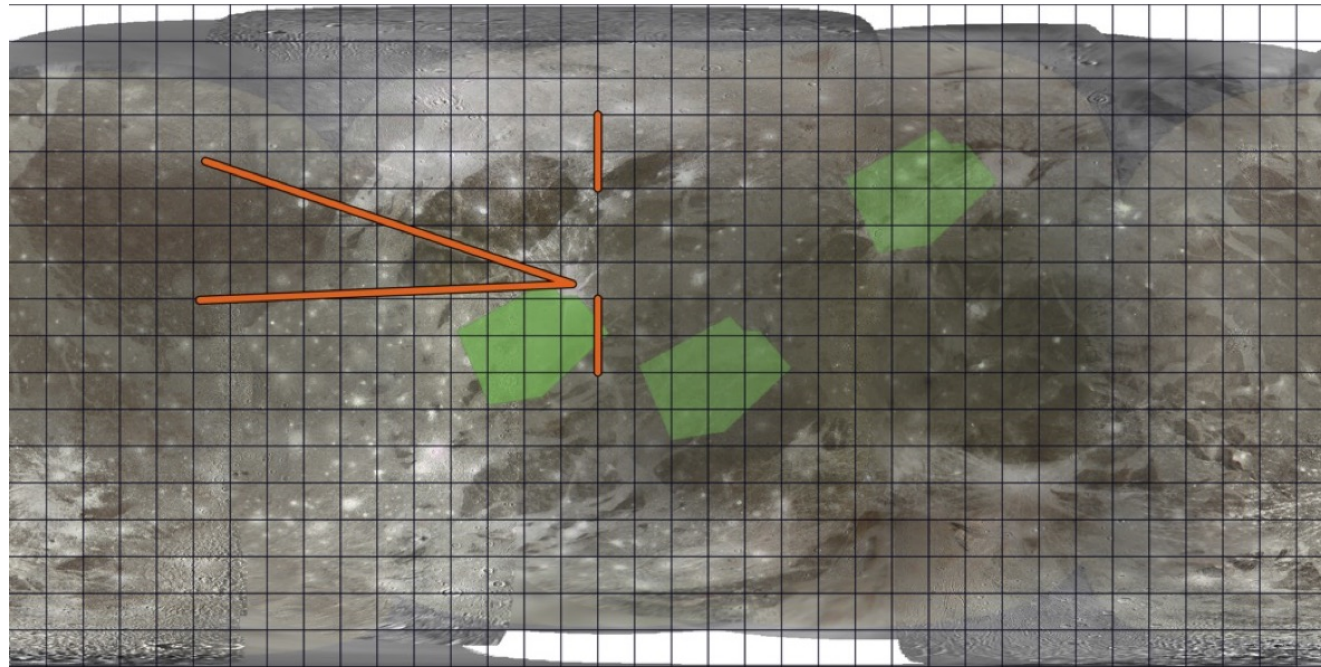
Transverse cylindrical



Oblique conical

Source: [Knippers, \(2009\)](#).

Map projection properties




















Source: NASA/USGS.

Map projection properties

- Area → Equal Area
- Distance → Equidistant
- Angles/Shape → Conformal

Map projection properties

Type of map projection	Cylinders				Cones				Pseudo-Cylinders		Miscellaneous	
	Mercator	Oblique Mercator	Transverse Mercator	Modified Transverse Mercator	Equidistant Conic (or Simple Conic)	Lambert Conformal Conic	Albers Conic Equal-Area	American Polyconic	Elliptic Oblique Conic Conformal	Sinusoidal	Eckert No. 6	Van Der Grinten
Line of tangency (straightness)	Meridians are straight and parallel	Meridians are straight lines converging to a point	Meridians are straight lines converging to a point	Meridians are straight lines converging to a point	Meridians are straight lines converging to a point	Meridians are straight lines converging to a point	Meridians are straight lines converging to a point	Meridians are straight lines converging to a point	Meridians are straight lines converging to a point	Meridians are straight lines converging to a point	Meridians are straight lines converging to a point	Meridians are straight lines converging to a point
Line of latitude (straightness)	Parallels are straight and parallel	Parallels are straight lines converging to a point	Parallels are straight lines converging to a point	Parallels are straight lines converging to a point	Parallels are straight lines converging to a point	Parallels are straight lines converging to a point	Parallels are straight lines converging to a point	Parallels are straight lines converging to a point	Parallels are straight lines converging to a point	Parallels are straight lines converging to a point	Parallels are straight lines converging to a point	Parallels are straight lines converging to a point
Gridline spacing	Meridians are straight and parallel	Meridians are straight lines converging to a point	Meridians are straight lines converging to a point	Meridians are straight lines converging to a point	Meridians are straight lines converging to a point	Meridians are straight lines converging to a point	Meridians are straight lines converging to a point	Meridians are straight lines converging to a point	Meridians are straight lines converging to a point	Meridians are straight lines converging to a point	Meridians are straight lines converging to a point	Meridians are straight lines converging to a point
Linear scale	Linear scale is true along the equator	Linear scale is true along the line of tangency	Linear scale is true along the line of tangency	Linear scale is true along the line of tangency	Linear scale is true along the line of tangency	Linear scale is true along the line of tangency	Linear scale is true along the line of tangency	Linear scale is true along the line of tangency	Linear scale is true along the line of tangency	Linear scale is true along the line of tangency	Linear scale is true along the line of tangency	Linear scale is true along the line of tangency
Notes	Projection is conformal	Projection is conformal	Projection is conformal	Projection is conformal	Projection is conformal	Projection is conformal	Projection is conformal	Projection is conformal	Projection is conformal	Projection is conformal	Projection is conformal	Projection is conformal
Uses	Navigation, nautical charts	Navigation, nautical charts	Navigation, nautical charts	Navigation, nautical charts	Navigation, nautical charts	Navigation, nautical charts	Navigation, nautical charts	Navigation, nautical charts	Navigation, nautical charts	Navigation, nautical charts	Navigation, nautical charts	Navigation, nautical charts
Examples												

Type of map projection	Planes (Azimuthal)				
	Azimuthal Equidistant	Lambert Azimuthal Equal-Area	Orthographic	Stereographic	Gnomonic
Line of tangency (straightness)	Meridians are straight lines radiating from the point of tangency	Meridians are straight lines radiating from the point of tangency	Meridians are straight lines radiating from the point of tangency	Meridians are straight lines radiating from the point of tangency	Meridians are straight lines radiating from the point of tangency
Line of latitude (straightness)	Parallels are straight lines perpendicular to the line of tangency	Parallels are straight lines perpendicular to the line of tangency	Parallels are straight lines perpendicular to the line of tangency	Parallels are straight lines perpendicular to the line of tangency	Parallels are straight lines perpendicular to the line of tangency
Gridline spacing	Meridians are straight lines radiating from the point of tangency	Meridians are straight lines radiating from the point of tangency	Meridians are straight lines radiating from the point of tangency	Meridians are straight lines radiating from the point of tangency	Meridians are straight lines radiating from the point of tangency
Linear scale	Linear scale is true along the line of tangency	Linear scale is true along the line of tangency	Linear scale is true along the line of tangency	Linear scale is true along the line of tangency	Linear scale is true along the line of tangency
Notes and uses	Projection is conformal	Projection is equal-area	Projection is conformal	Projection is conformal	Projection is conformal
Examples					

REFERENCES

1. Snyder, J.P. (1982). *Map Projections: A Practical Guide*. US Geological Survey Bulletin 1532. Washington, DC: US Government Printing Office.

2. Snyder, J.P. (1987). *Map Projections: A Practical Guide*. US Geological Survey Bulletin 1532. Washington, DC: US Government Printing Office.

3. Snyder, J.P. (1994). *Map Projections: A Practical Guide*. US Geological Survey Bulletin 1532. Washington, DC: US Government Printing Office.

4. Snyder, J.P. (2000). *Map Projections: A Practical Guide*. US Geological Survey Bulletin 1532. Washington, DC: US Government Printing Office.

5. Snyder, J.P. (2004). *Map Projections: A Practical Guide*. US Geological Survey Bulletin 1532. Washington, DC: US Government Printing Office.

6. Snyder, J.P. (2008). *Map Projections: A Practical Guide*. US Geological Survey Bulletin 1532. Washington, DC: US Government Printing Office.

7. Snyder, J.P. (2012). *Map Projections: A Practical Guide*. US Geological Survey Bulletin 1532. Washington, DC: US Government Printing Office.

8. Snyder, J.P. (2016). *Map Projections: A Practical Guide*. US Geological Survey Bulletin 1532. Washington, DC: US Government Printing Office.

9. Snyder, J.P. (2020). *Map Projections: A Practical Guide*. US Geological Survey Bulletin 1532. Washington, DC: US Government Printing Office.

10. Snyder, J.P. (2024). *Map Projections: A Practical Guide*. US Geological Survey Bulletin 1532. Washington, DC: US Government Printing Office.

See also: [Snyder \(1982\)](#).

Earth globe



E.g. Vesta

$a = 572.6 \text{ km}$

$b = 557.2 \text{ km}$

$c = 446.4 \text{ km}$

Source: [Threjs](#), based on [original](#) at [JAXA/Japan Planetarium Association](#).
Shape model from [NASA PDS SBN](#).

E.g. Vesta

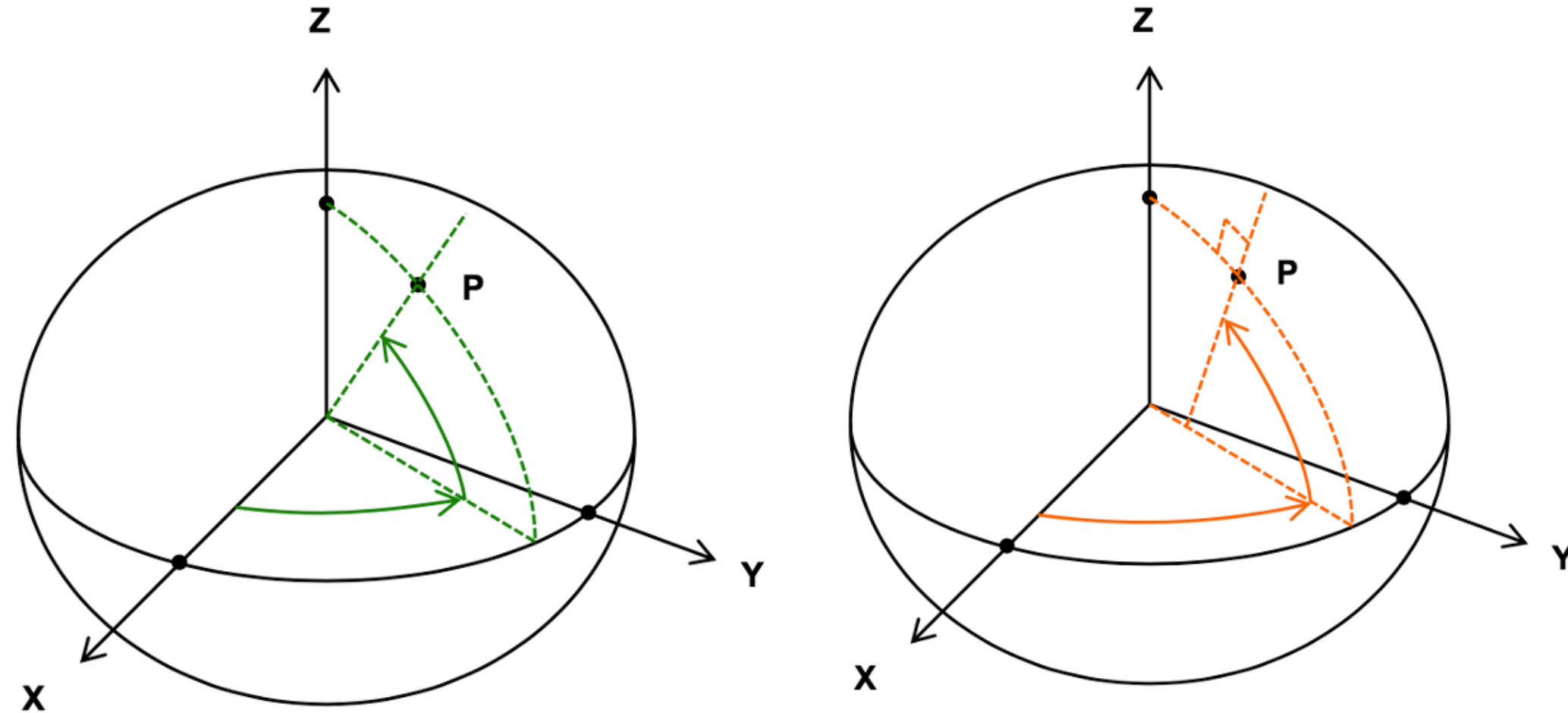
$a = 572.6 \text{ km}$

$b = 557.2 \text{ km}$

$c = 446.4 \text{ km}$

Source: [Threjs](#), based on [original](#) at [JAXA/Japan Planetarium Association](#).
Shape model from [NASA PDS SBN](#).

Planetocentric v.s -graphic / -detic



Source: [NAIF/JPL](#).



Planetographic vs. centric

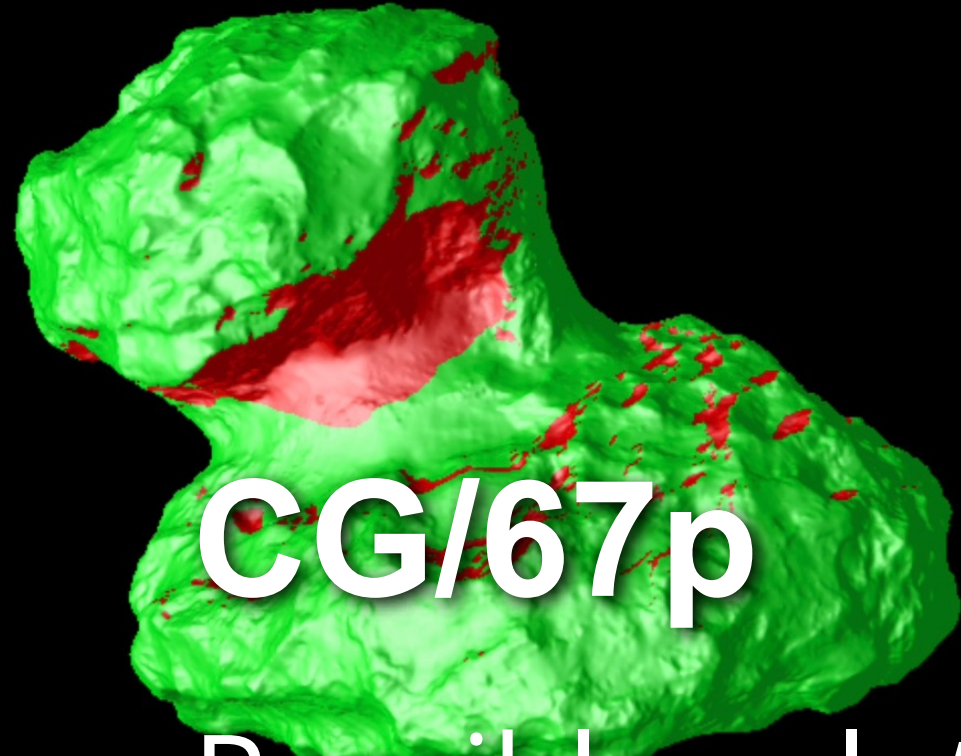


Planetographic vs. centric

CG/67p

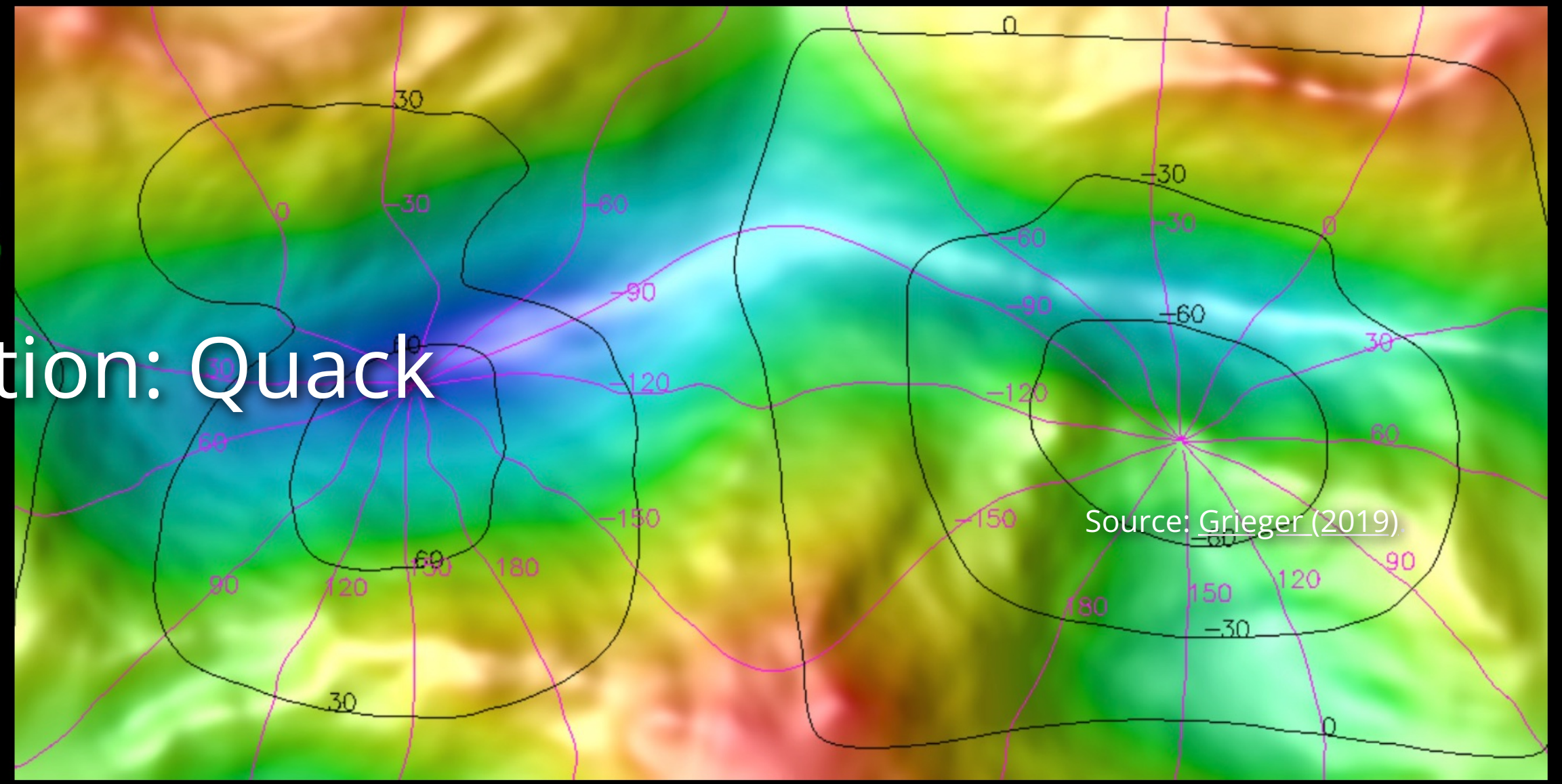
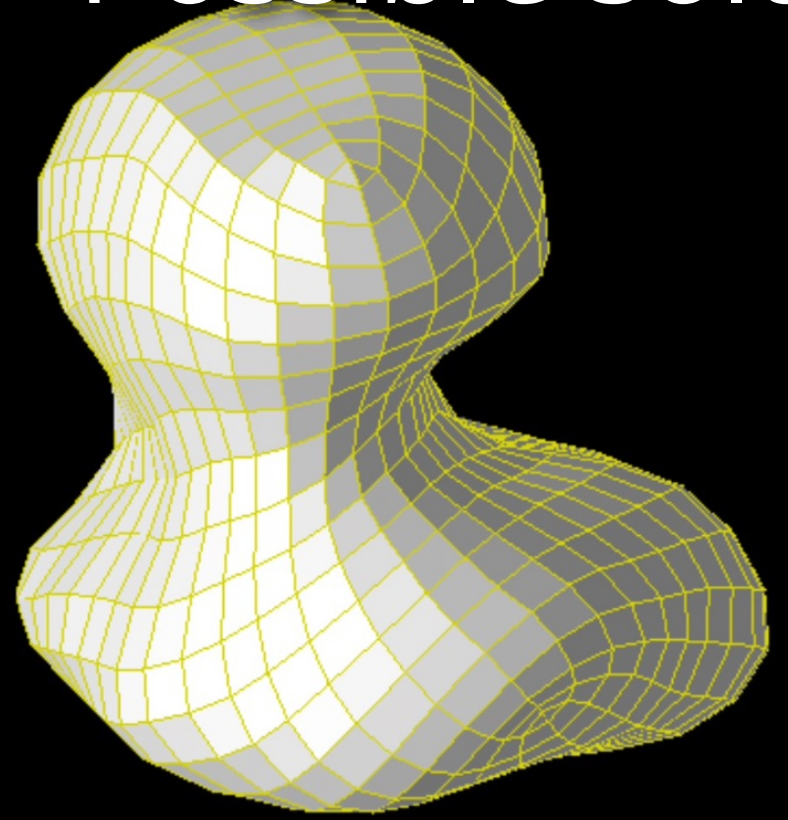
Non-uniqueness of latitude, longitude

Source: [Threjs](#), based on [original](#) at [JAXA/Japan Planetarium Association](#).
Shape model from [ESA/ROSETTA/OSIRIS](#), [Preusker et al. \(2017\)](#), L. Penasa.



CG/67p

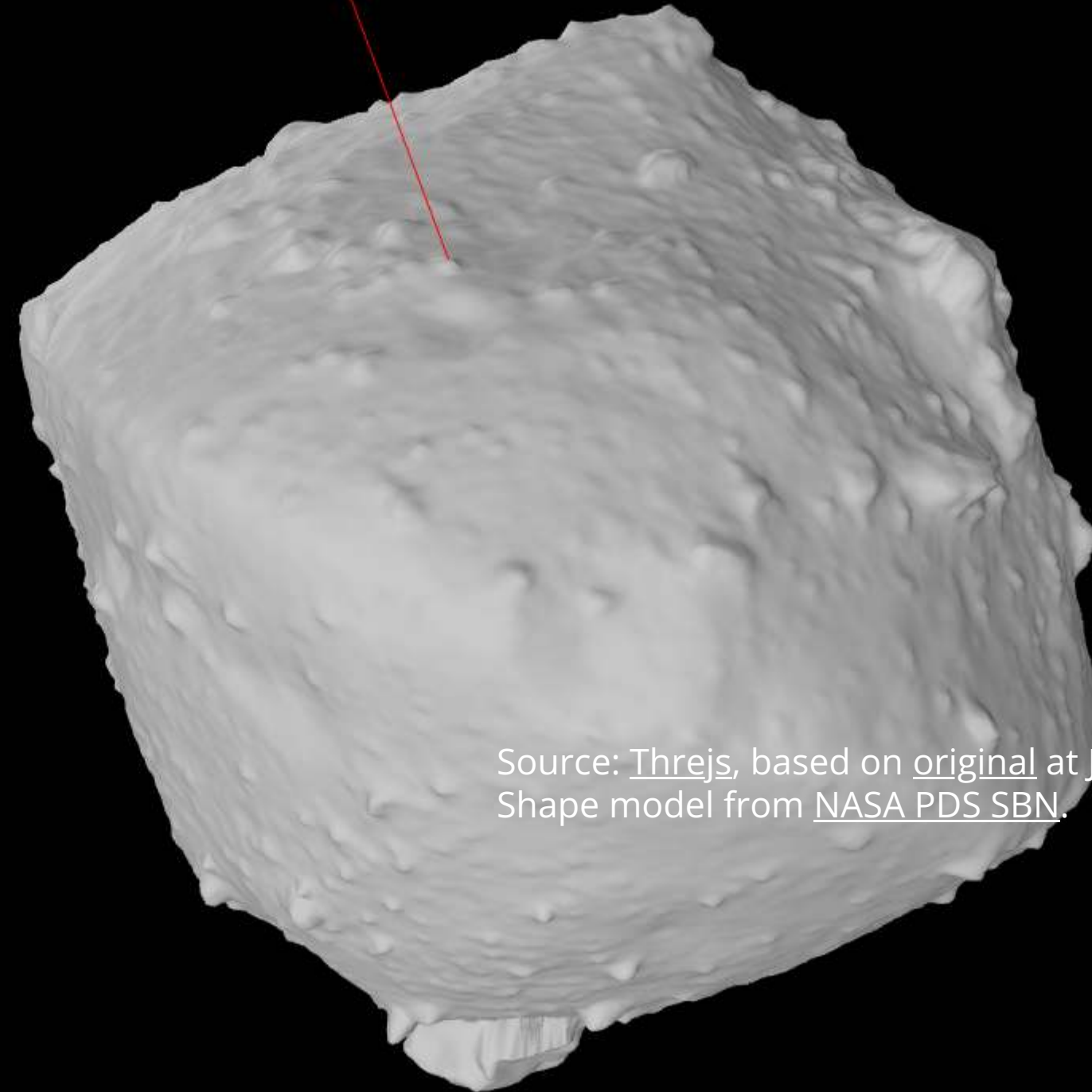
Possible solution: Quack



Ryugu

$a = 1004 \text{ m}$

$b = 876 \text{ m}$



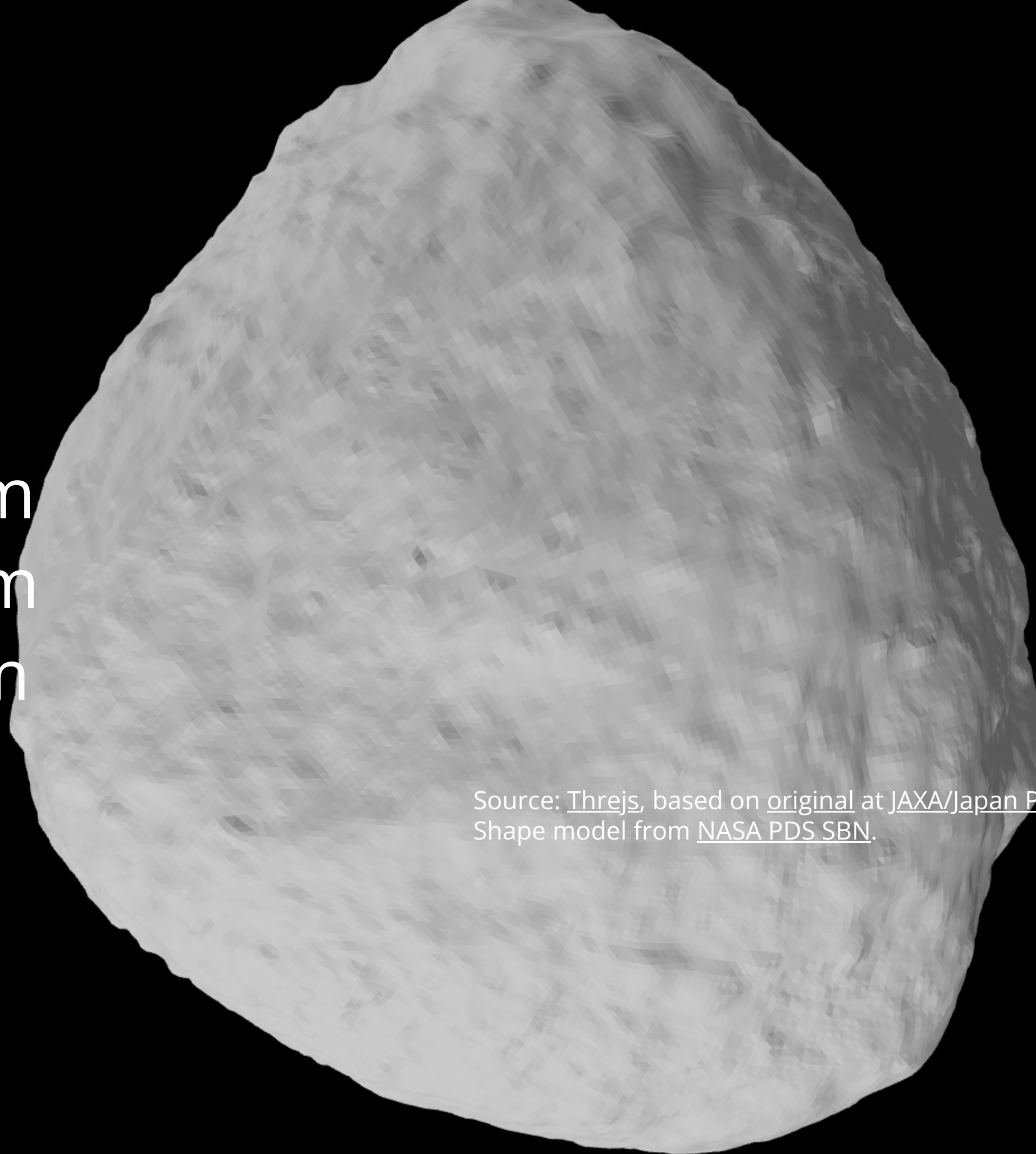
Source: [Threjs](#), based on [original](#) at [JAXA/Japan Planetarium Association](#).
Shape model from [NASA PDS SBN](#).

Bennu

$a = 565 \text{ m}$

$b = 535 \text{ m}$

$c = 508 \text{ m}$



Source: [Threjs](#), based on [original](#) at [JAXA/Japan Planetarium Association](#).
Shape model from [NASA PDS SBN](#).

Eros

$a = 33 \text{ km}$

$b = 13 \text{ km}$



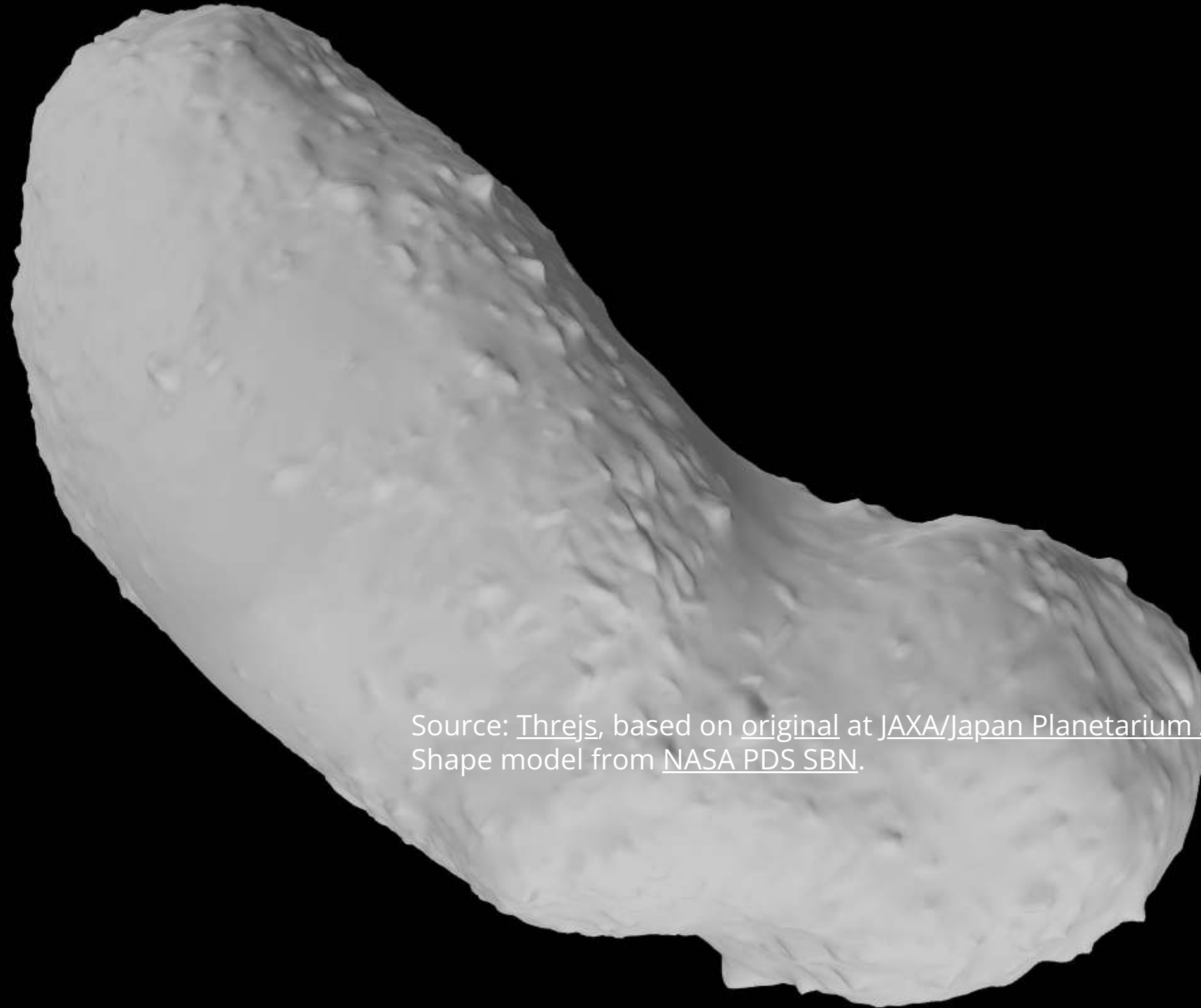
Source: [Threjs](#), based on [original](#) at [JAXA/Japan Planetarium Association](#).
Shape model from [NASA PDS SBN](#).

Itokawa

a= 540m

b= 270m

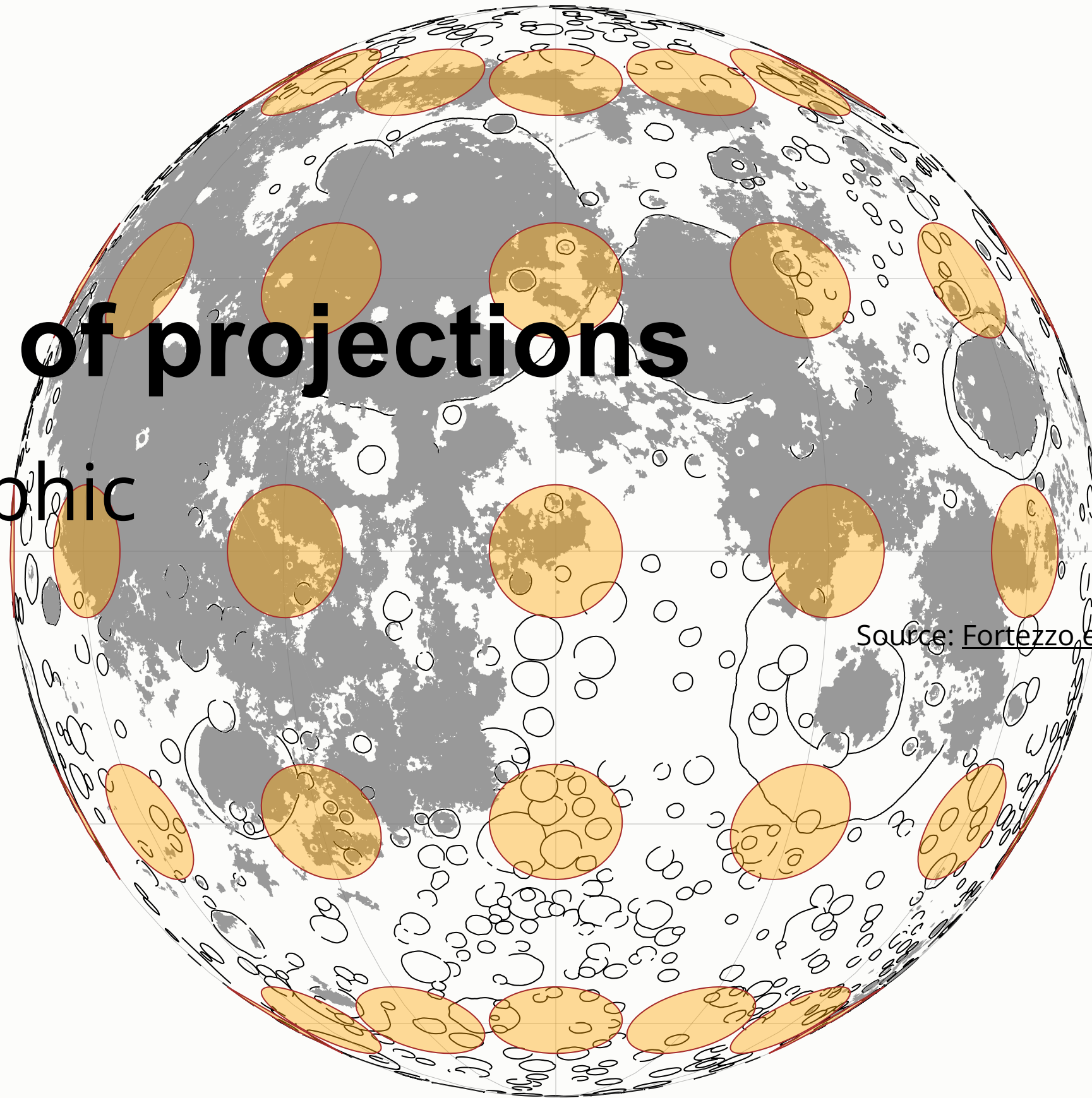
c= 210m



Source: [Threjs](#), based on [original](#) at [JAXA/Japan Planetarium Association](#).
Shape model from [NASA PDS SBN](#).

Choice of projections

Orthographic



Source: [Fortezzo et al. \(2020\)](#), ASU/LROC, D3

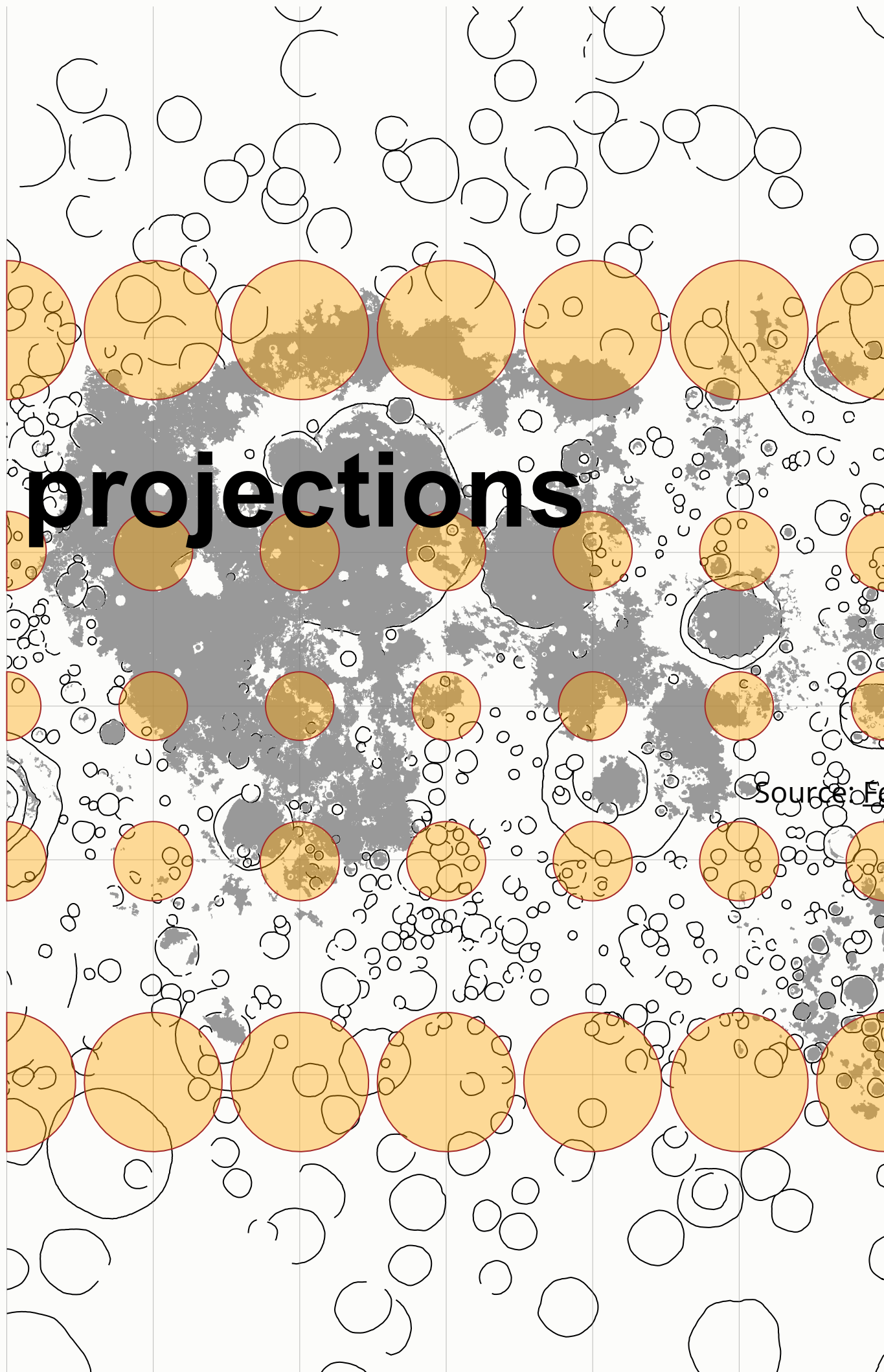
Choice of projections

Equidistant Cylindrical

Source: [Fortezzo et al. \(2020\)](#), ASU/LROC, D3

Choice of projections

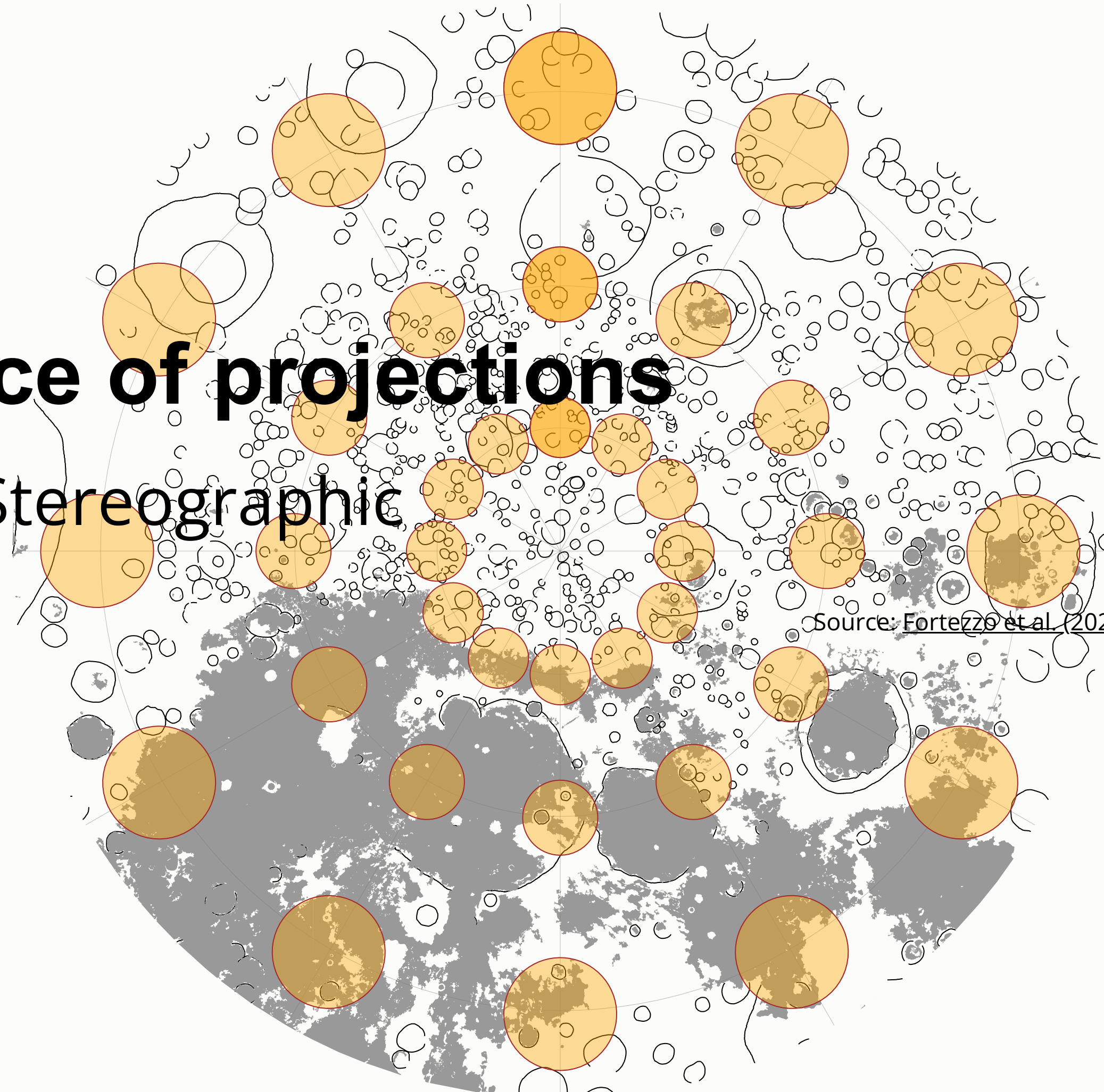
Mercator



Source: Fortezzo et al. (2020), ASU/LROC, D3

Choice of projections

Polar Stereographic



Source: [Fortezzo et al. \(2020\)](#), ASU/LROC, D3

Deformation & extent

Equidistant Cylindrical

Source: [NASA/LRO/LOLA/ASU/USGS](#).

Deformation & extent vs. Orthographic

Source: [NASA/LRO/LOLA/ASU/USGS](#).

Deformation & extent vs. Orthographic

Source: [NASA/LRO/LOLA/ASU/USGS](#).

Deformation & extent

Orthographic extent projected

Source: [NASA/LRO/LOLA/ASU/USGS](#).

Deformation & extent (the other hemisphere)

Source: [NASA/LRO/LOLA/ASU/USGS](#).



E.g. Ganymede



- Ganymede
- Named craters
- Unit contacts

E.g. Ganymede



Equidistant Cylindrical - Clon 180



Equidistant Cylindrical - Clon 0



Cylindrical Equal Area - Clon 0



Orthographic - Clon 0





Orthographic - Clon 180





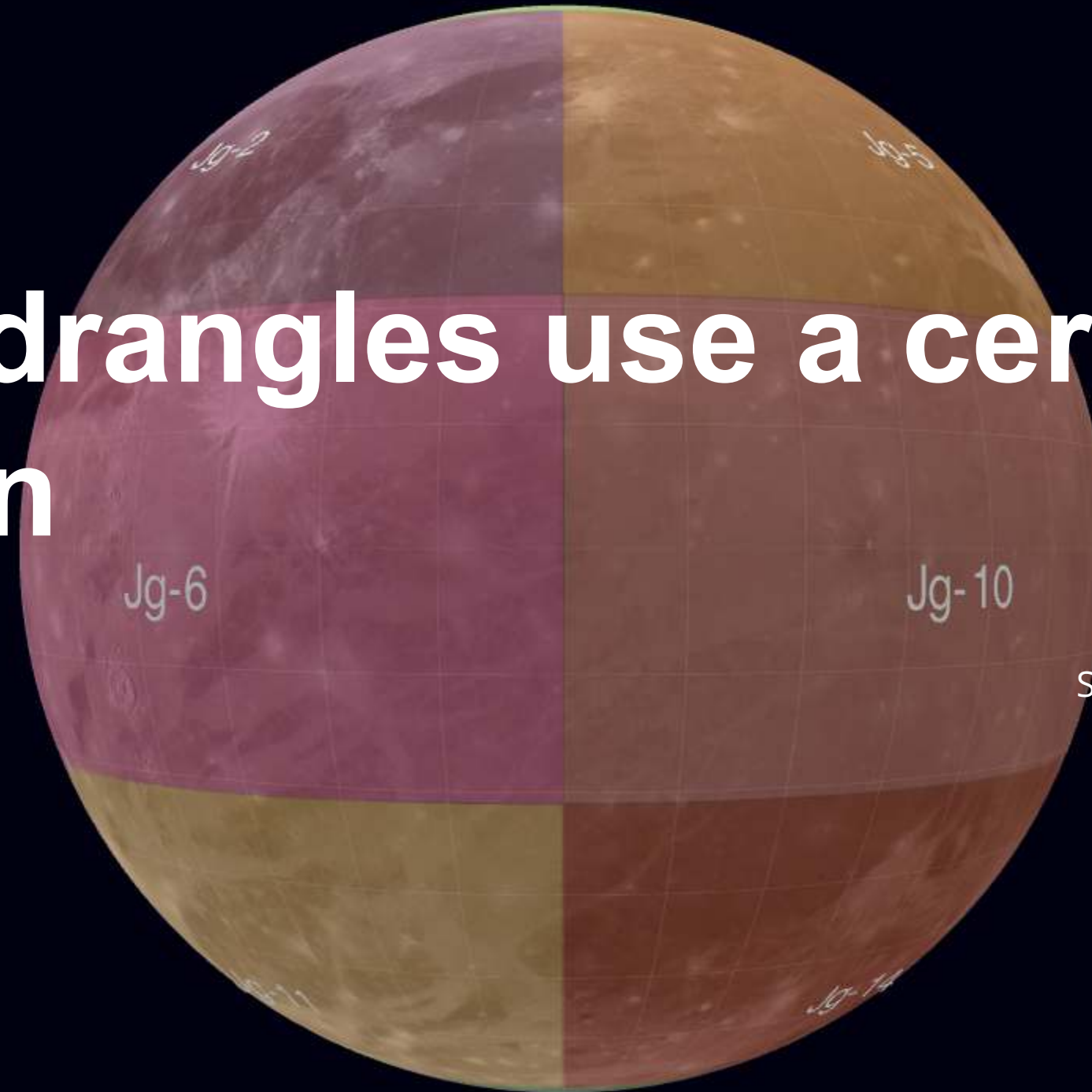
Robinson - Clon 0

Choosing projections



Source: NASA/Voyager/Galileo/USGS.

Why quadrangles use a certain projection



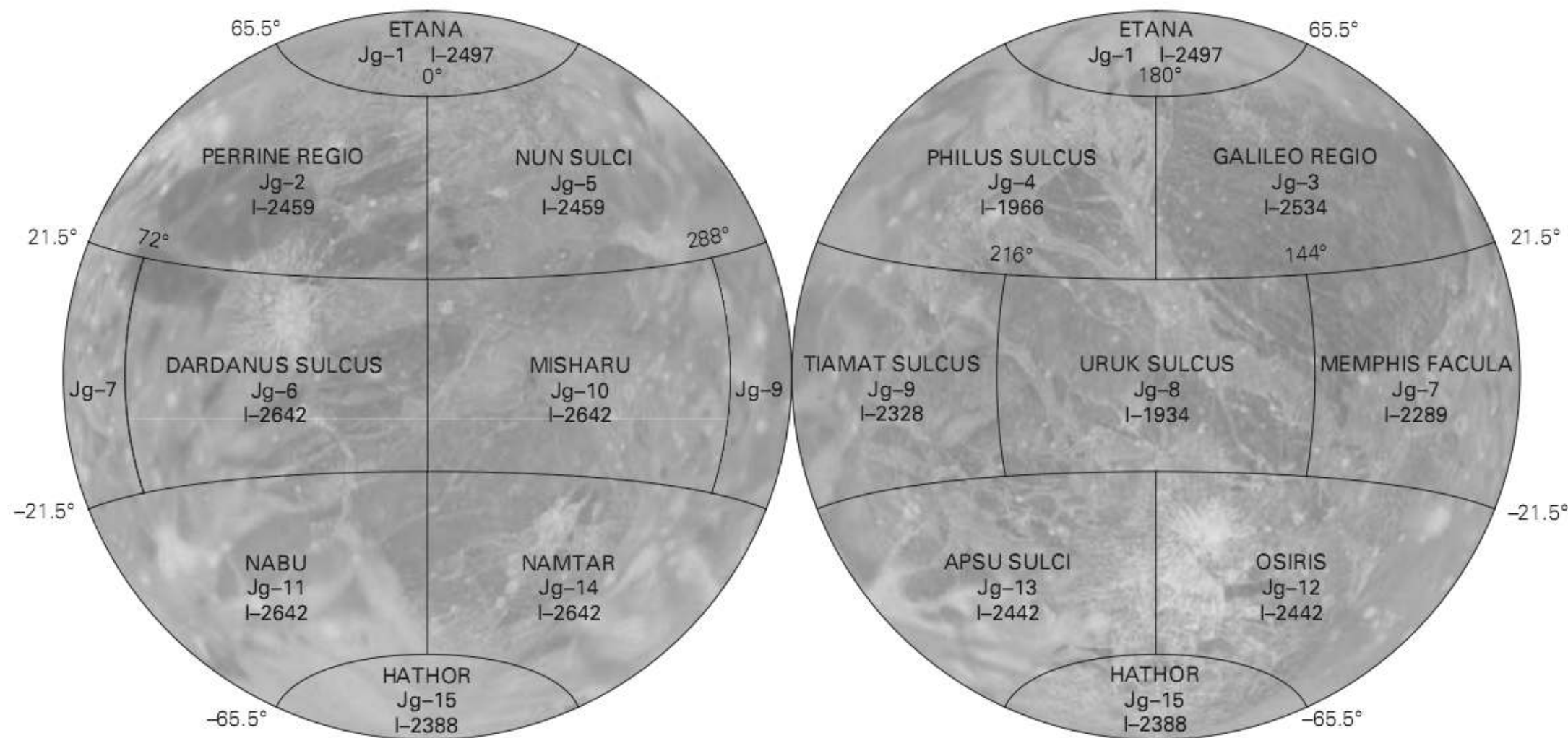
Source: NASA/Voyager/Galileo/USGS.

Could it have been like this?
Possibly...



Source: [Three-geojson](#), [h3](#)

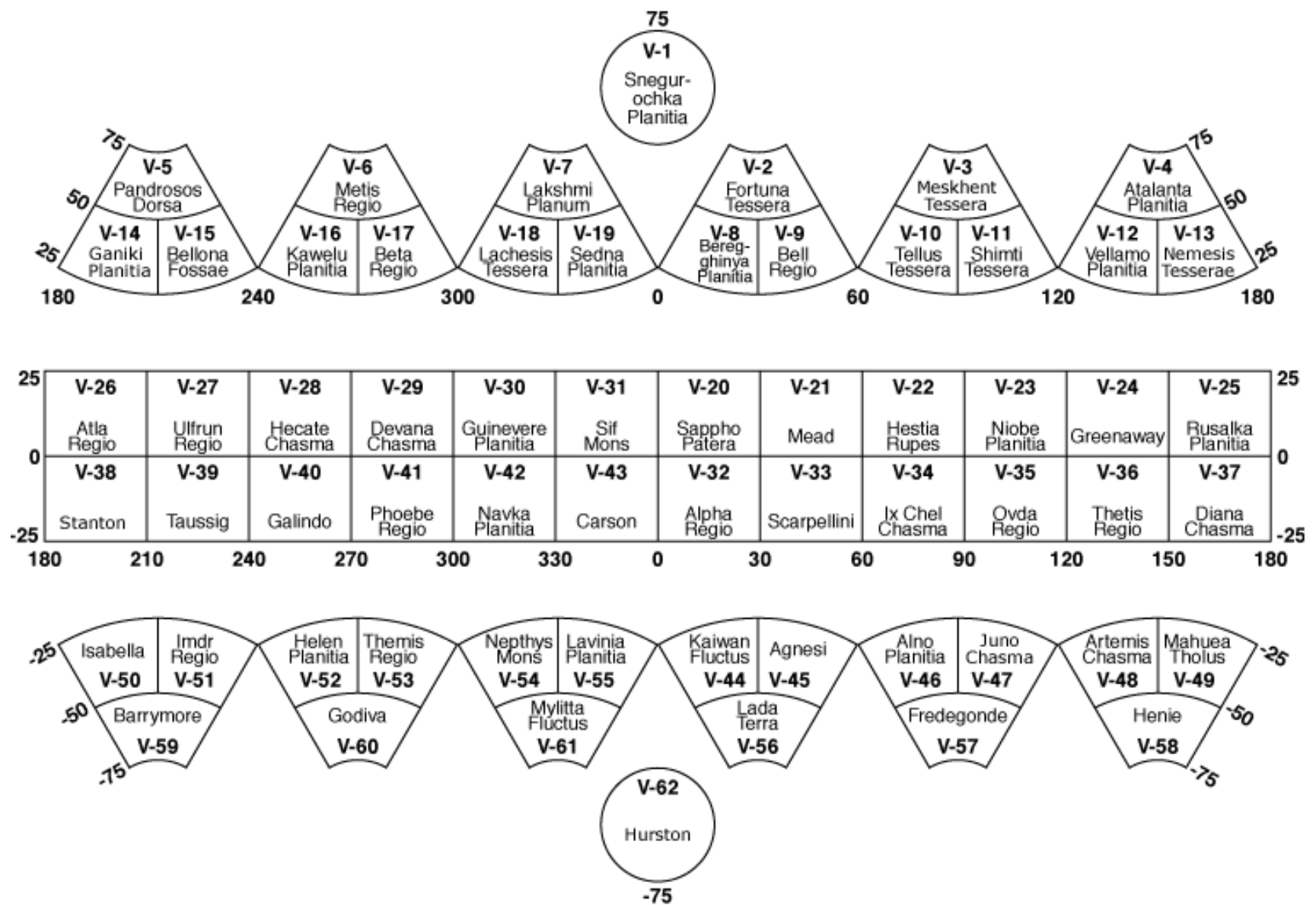
Ganymede: Quadrangles



QUADRANGLE LOCATION
Number preceded by I refers to published geologic map

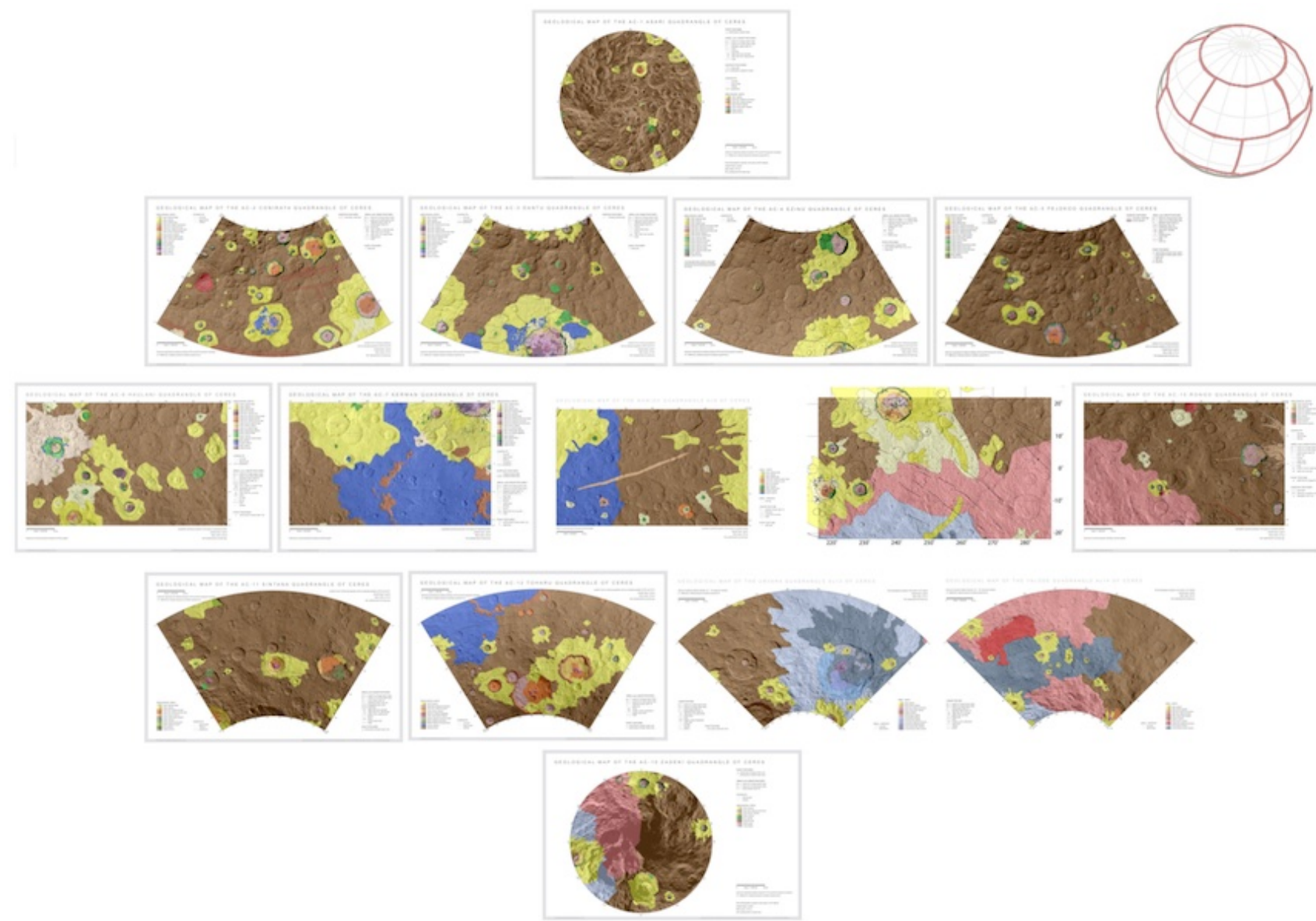
Source: [USGS/wikipedia](https://www.usgs.gov/).

Venus: Quadrangles



Source: USGS.

Vesta: Quadrangles



Source: [Naß and van Gasselt, \(2023\)](#).

Venus: specific aspects

- IAU reference body
- East-positive longitude (0-360), planetocentric latitude
- In most GIS applications: de facto standard Est+, planetocentric & sphere
- See also e.g. [IAU OGC registry](#).

Jupyter and Saturn system satellites: specific aspects

- IAU reference body
- West-positive longitude (0-360), planetographic latitude
- In most GIS applications: de facto standard Est+, planetocentric & sphere
- See also e.g. [IAU OGC registry](#), [IAU/USGS Gazetteer](#)

Small bodies: specific aspects

- IAU reference body / shape models
- Variable complexity
- In most GIS applications for e.g. Ceres, Vesta, planetocentric & sphere
- See also PDS SBN CRS

Relevant references

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