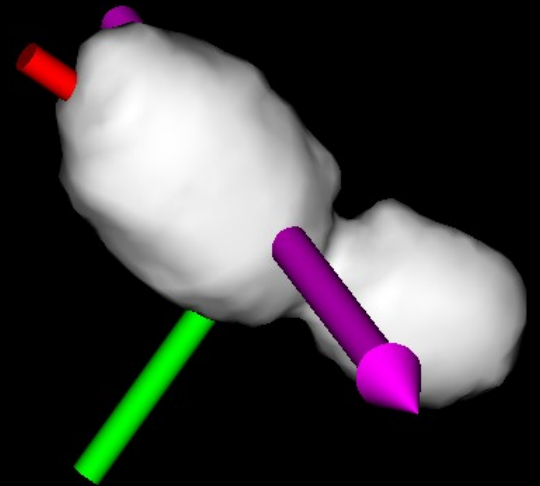
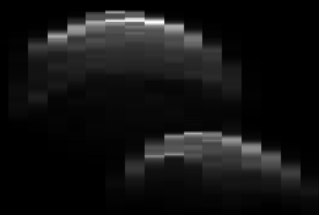
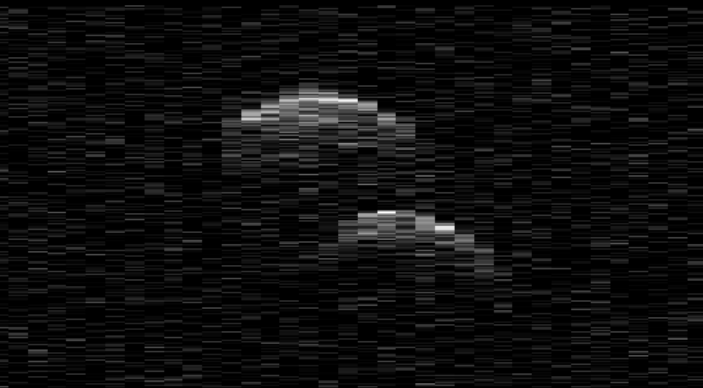
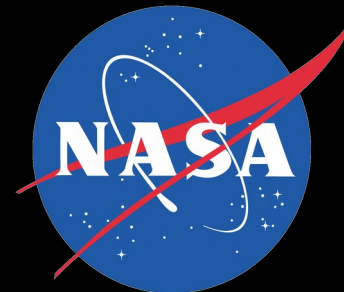


# Shape Modeling of Potentially Hazardous Asteroid (85989) 1999 JD6 from Radar and Lightcurve Data

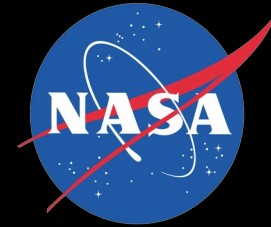
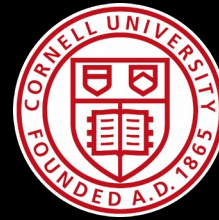


**Sean Marshall**

**And 25 others**



# JD6 Coauthors

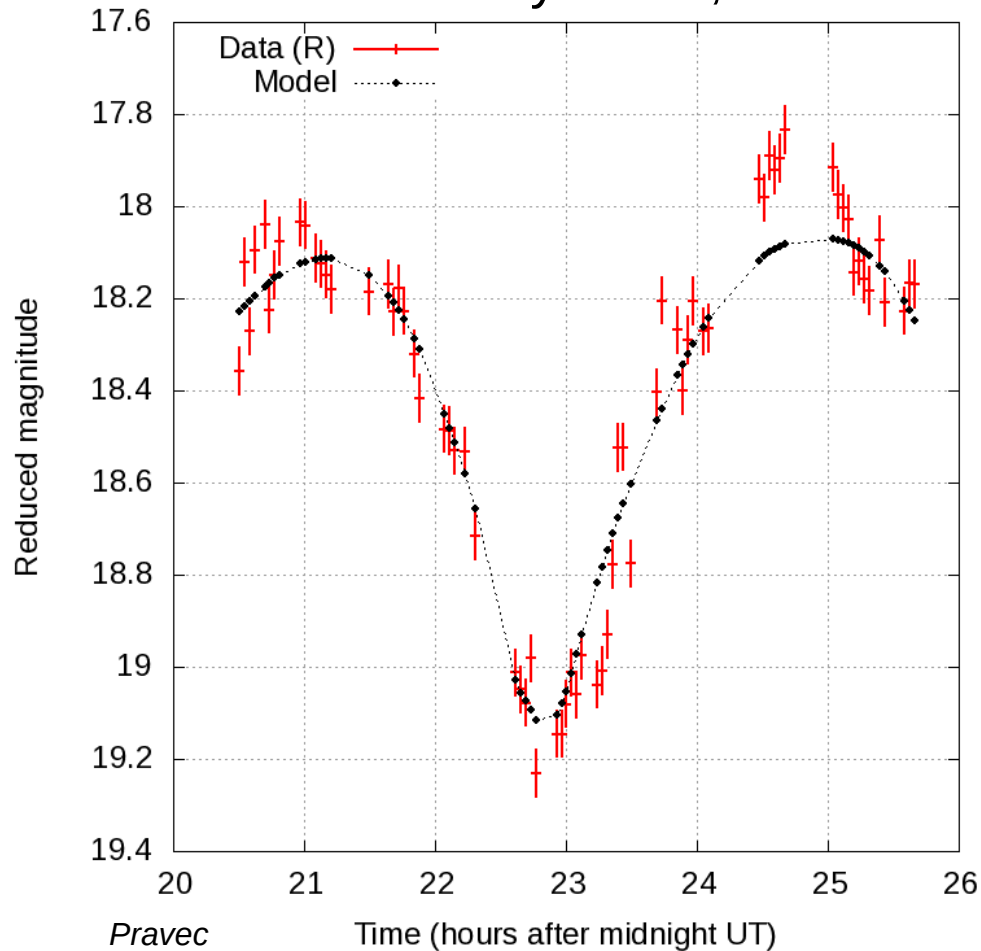


- Marina Brozović, Lance Benner, Shantanu Naidu, Jon Giorgini, Joseph Jao, Clement Lee, Michael Hicks (JPL)
- Donald Campbell (Cornell University)
- Christopher Magri (University of Maine at Farmington); Patrick Taylor, Linda Rodriguez-Ford (LPI); James Richardson (PSI); Ronald Vervack, Jr. (Johns Hopkins U. / APL); Yanga Fernandez (U. of Central Florida); Frank Ghigo, Adam Kobelski (Green Bank Obs.); Michael Busch (SETI Institute); Petr Pravec (Academy of Sciences of the Czech Republic); Benjamin Sharkey (U. of Minnesota); Ellen Howell, Michael Nolan, Jenna Crowell (U. of Arizona); Brandon Bozek (U. of Texas, Austin); Brice-Olivier Demory (U. of Bern & Geneva Obs.); Raoul Behrend (Geneva Obs.)

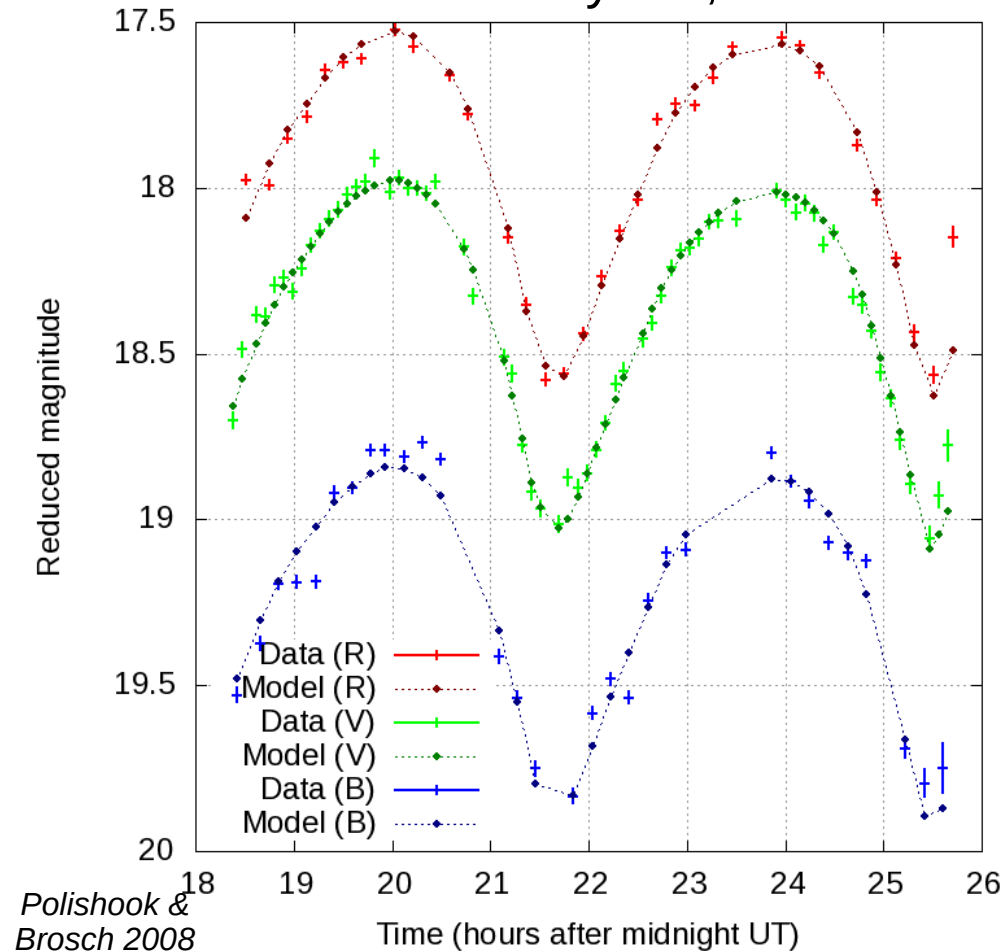
# 1999 JD6: Lightcurves

- Have lightcurves from six different years
- Rotation period  $\sim 7.66$  hours

JD6 on May 23-24, 1999



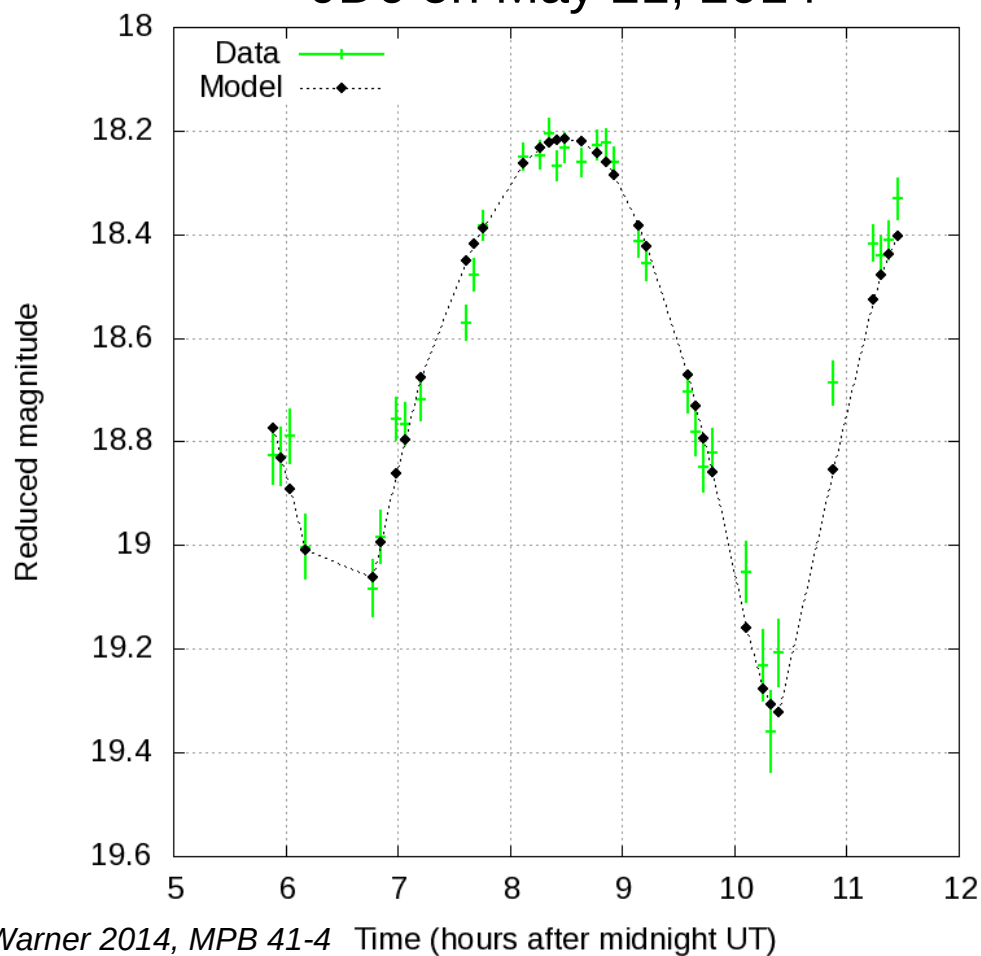
JD6 on July 8-9, 2005



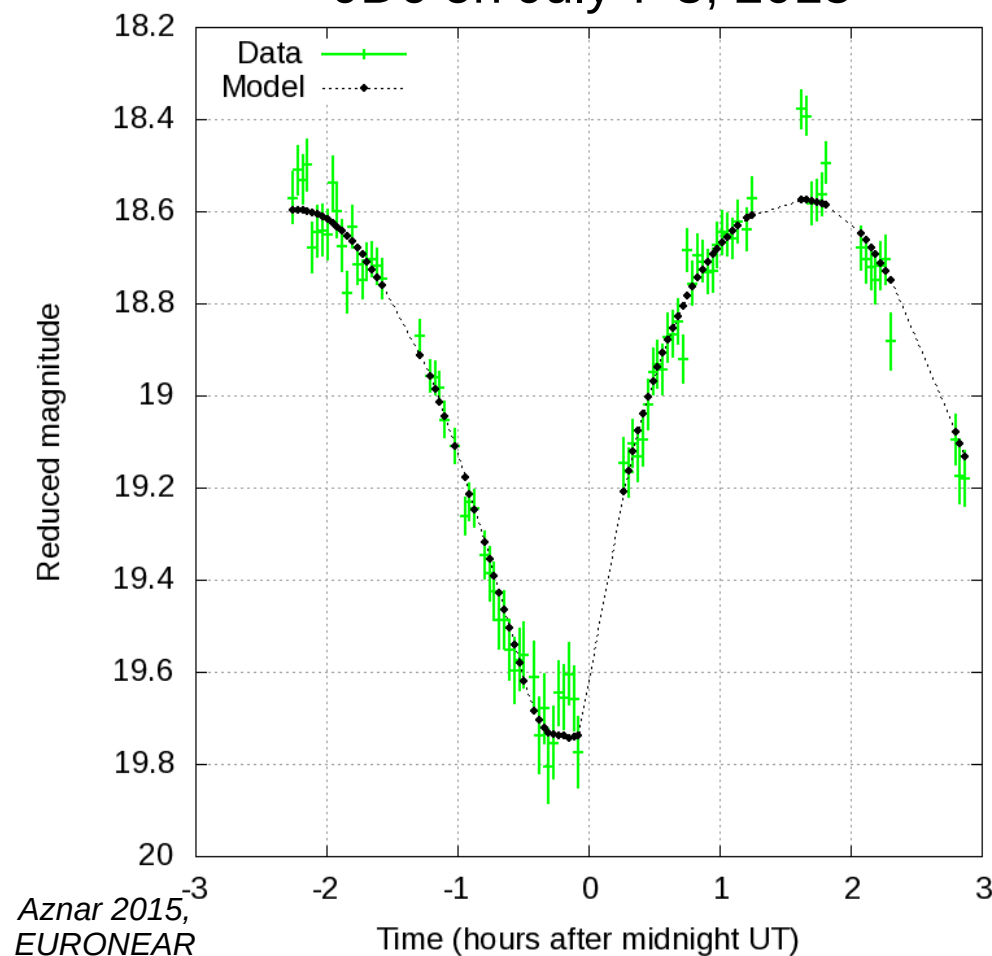
# 1999 JD6: Lightcurves

- Have lightcurves from six different years
- Rotation period  $\sim 7.66$  hours

JD6 on May 21, 2014



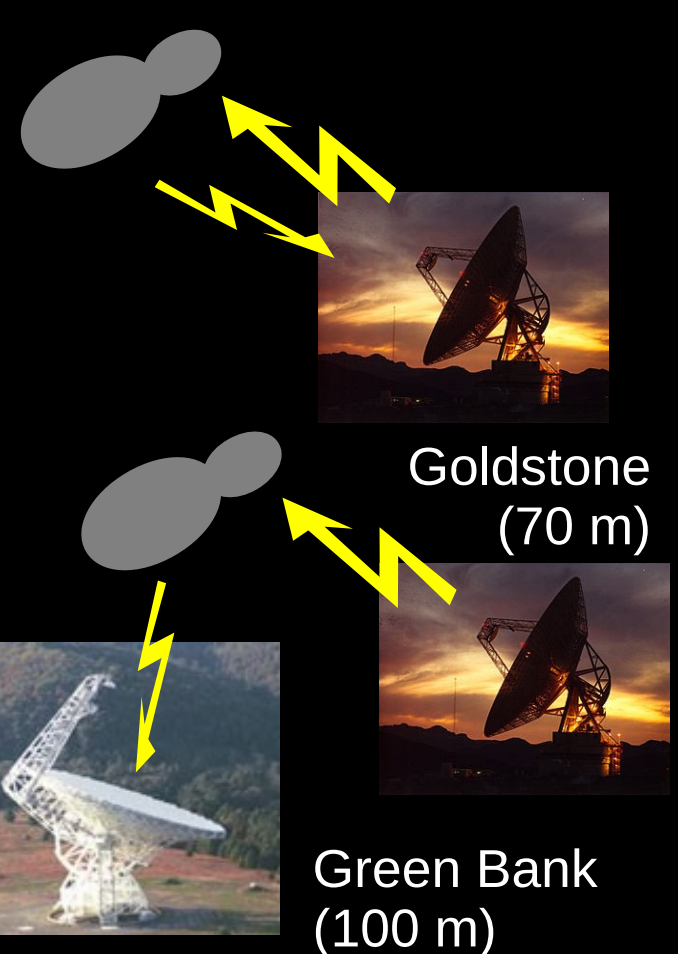
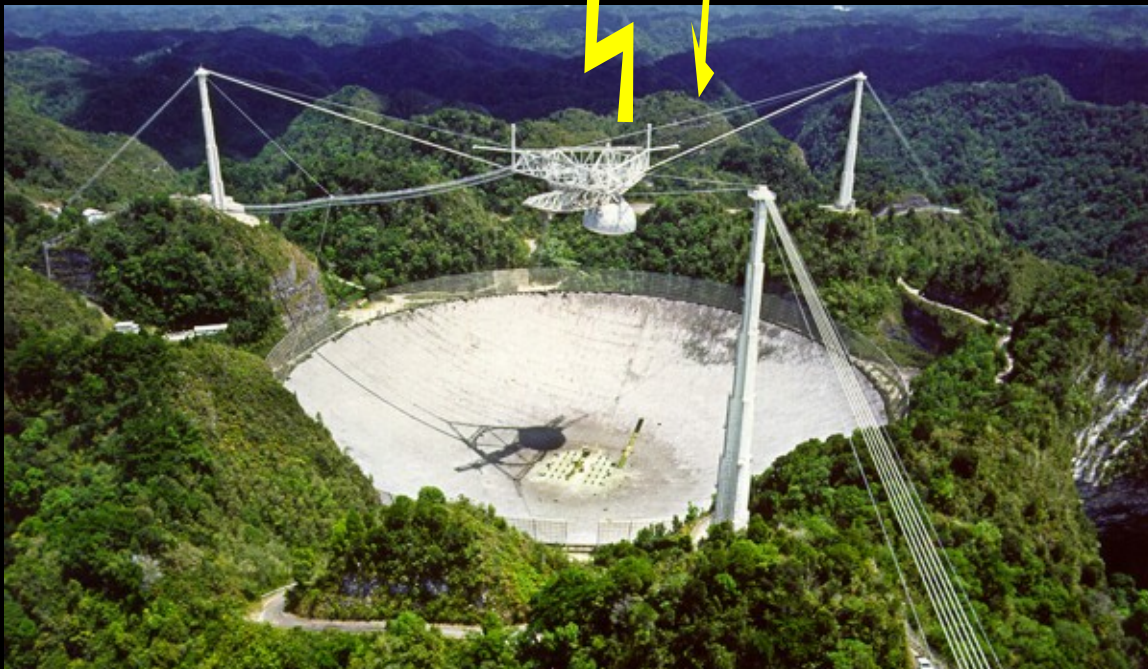
JD6 on July 7-8, 2015



# 1999 JD6: Radar Observations

- From Arecibo: 3 days in 2010, 6 days in 2015
- From Goldstone: 5 days (2 bistatic) in 2015

Arecibo (305 m)

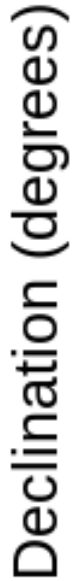


Goldstone  
(70 m)

Green Bank  
(100 m)



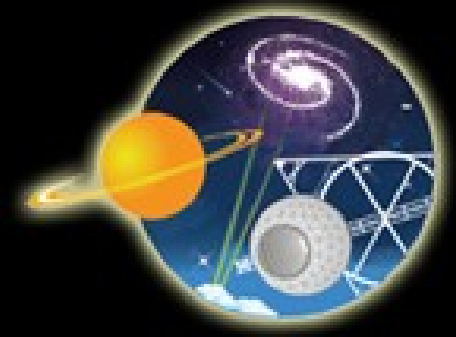
## Sky positions of 1999 JD6 during observations



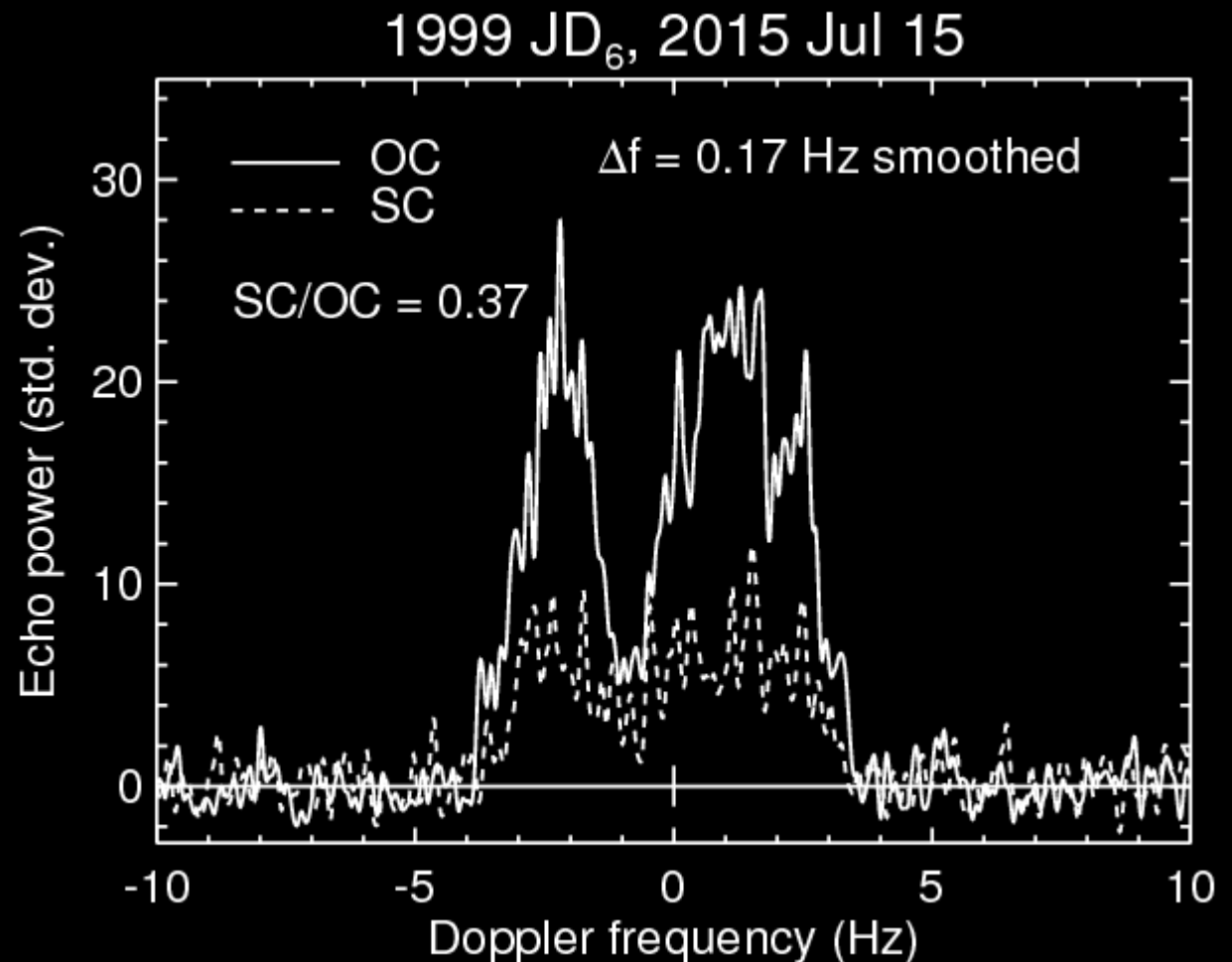
● Lightcurves ▲ Arecibo ▼ Goldstone



# JD6: Radar Observations

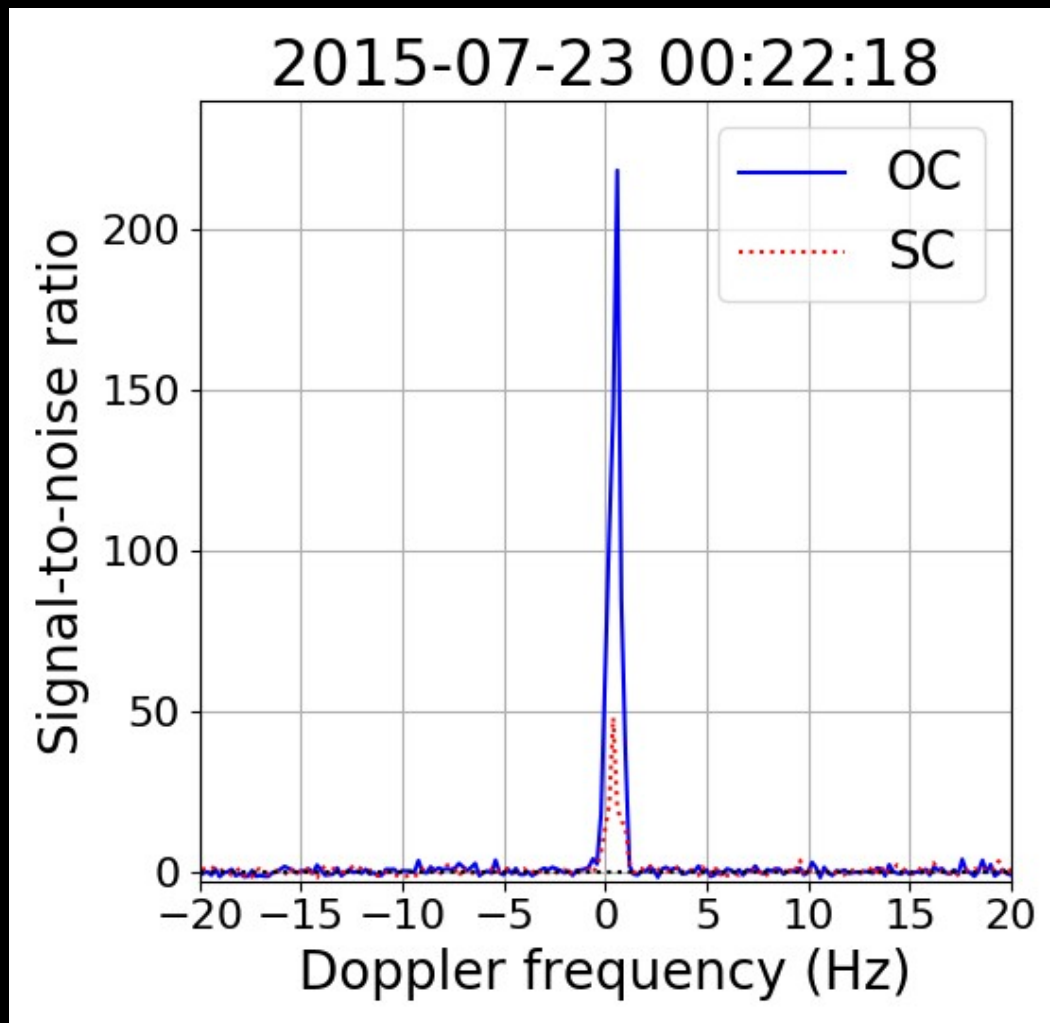


- From Arecibo (monostatic), July 15
  - Asteroid was 0.13 au away

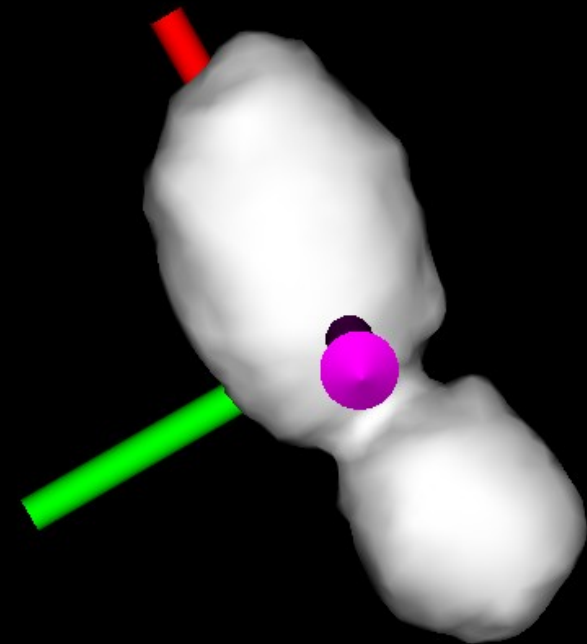


# 1999 JD6: Shape Modeling

- July 23, 2015 (DSS-14 monostatic): Very narrow bandwidth! Line of sight  $2^\circ$  from pole

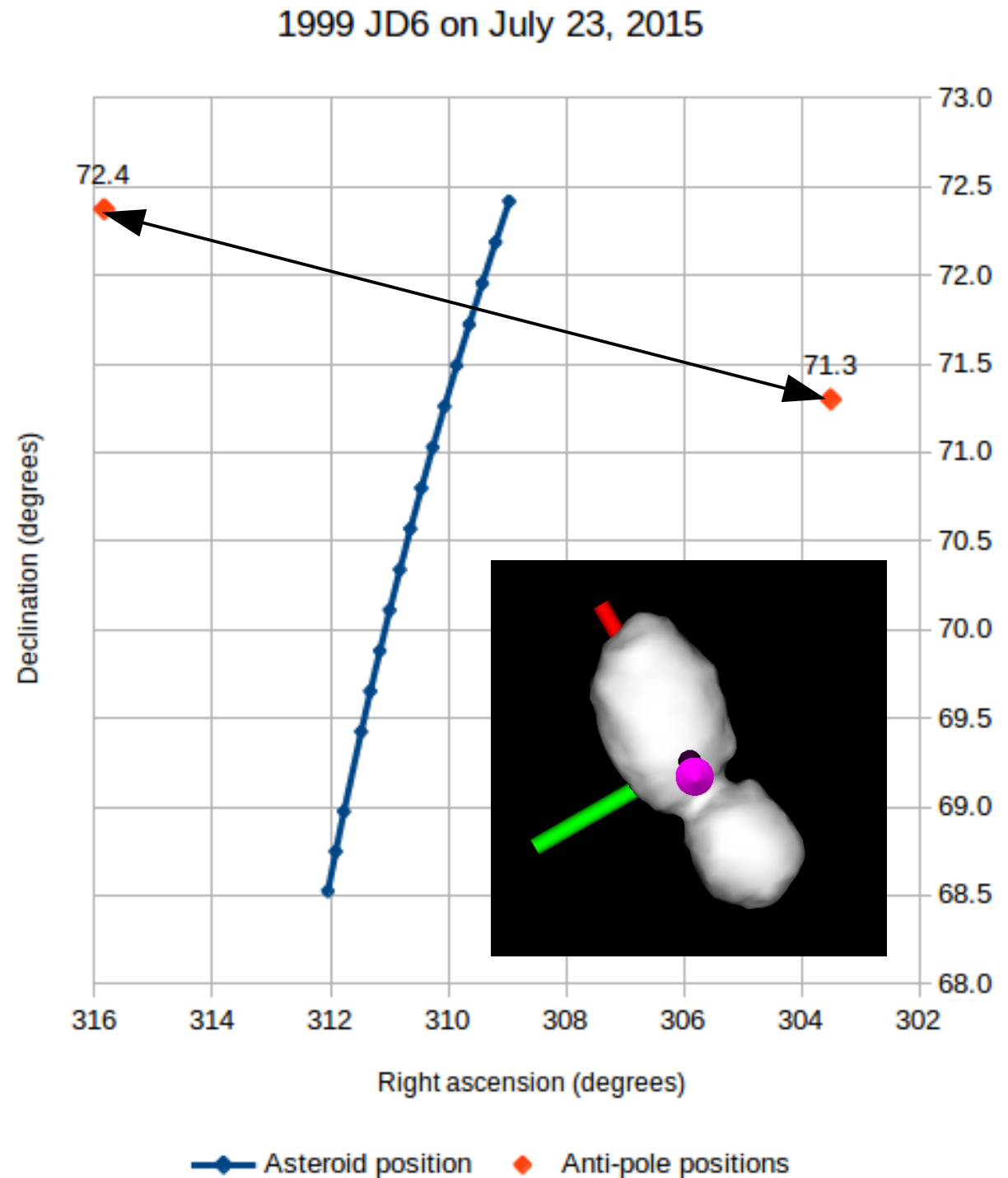


$$B = \frac{4 \pi D \cos \phi}{\lambda_0 P_{spin}}$$

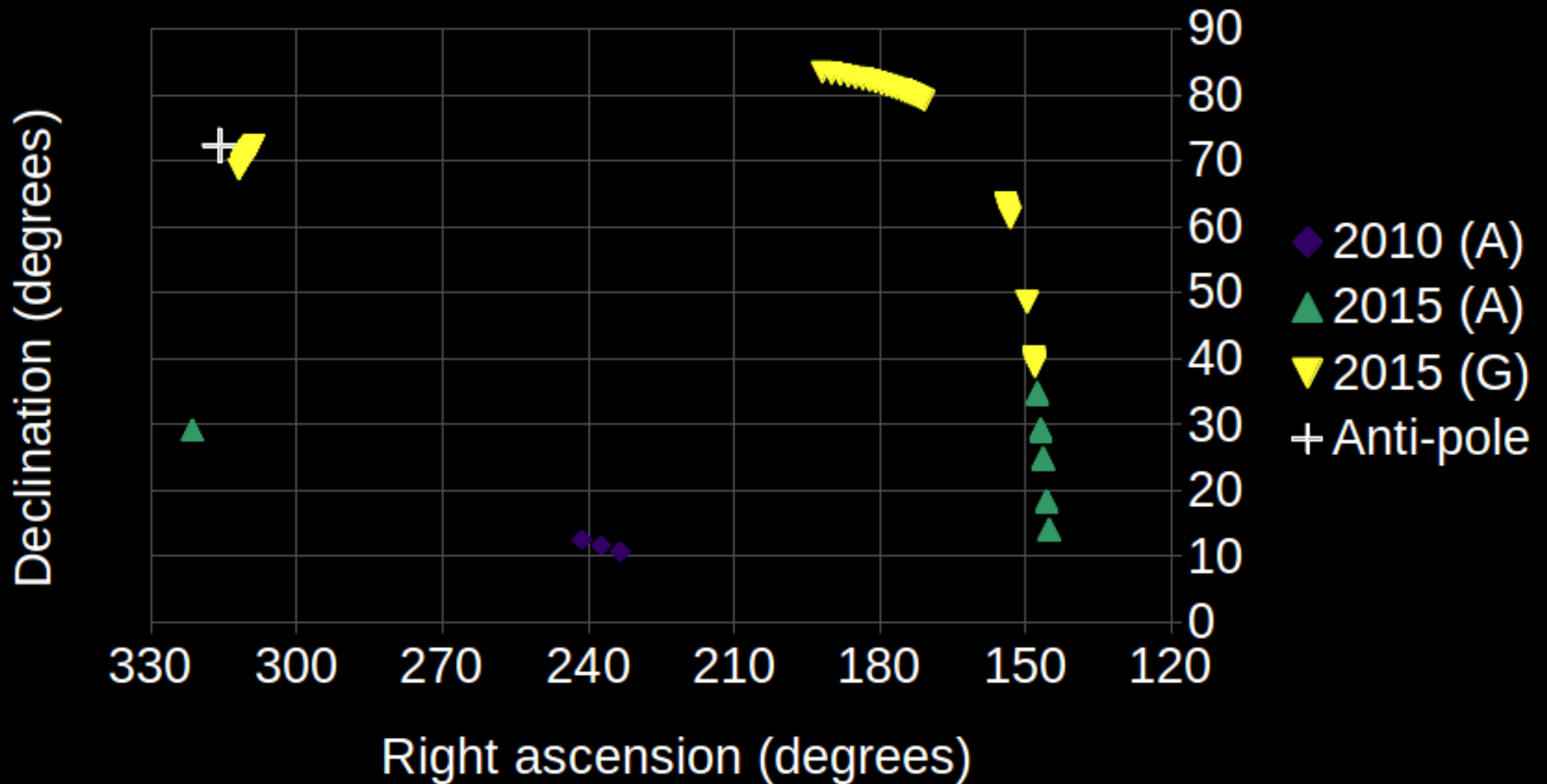




- July 23, 2015:  
Line of sight passed about  $2^\circ$  from the pole position
- The two marked positions are equal distances from the arc; only one of them matches the observed rotation phases



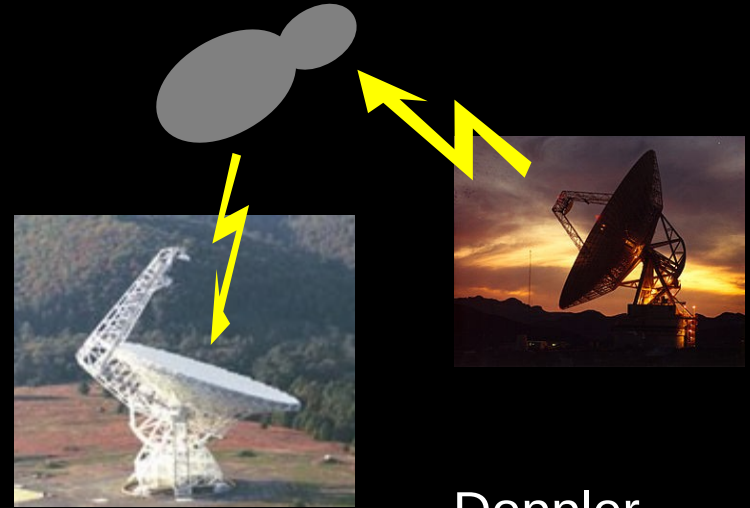
# Sky position of 1999 JD6 during radar observations



# Goldstone to GBT

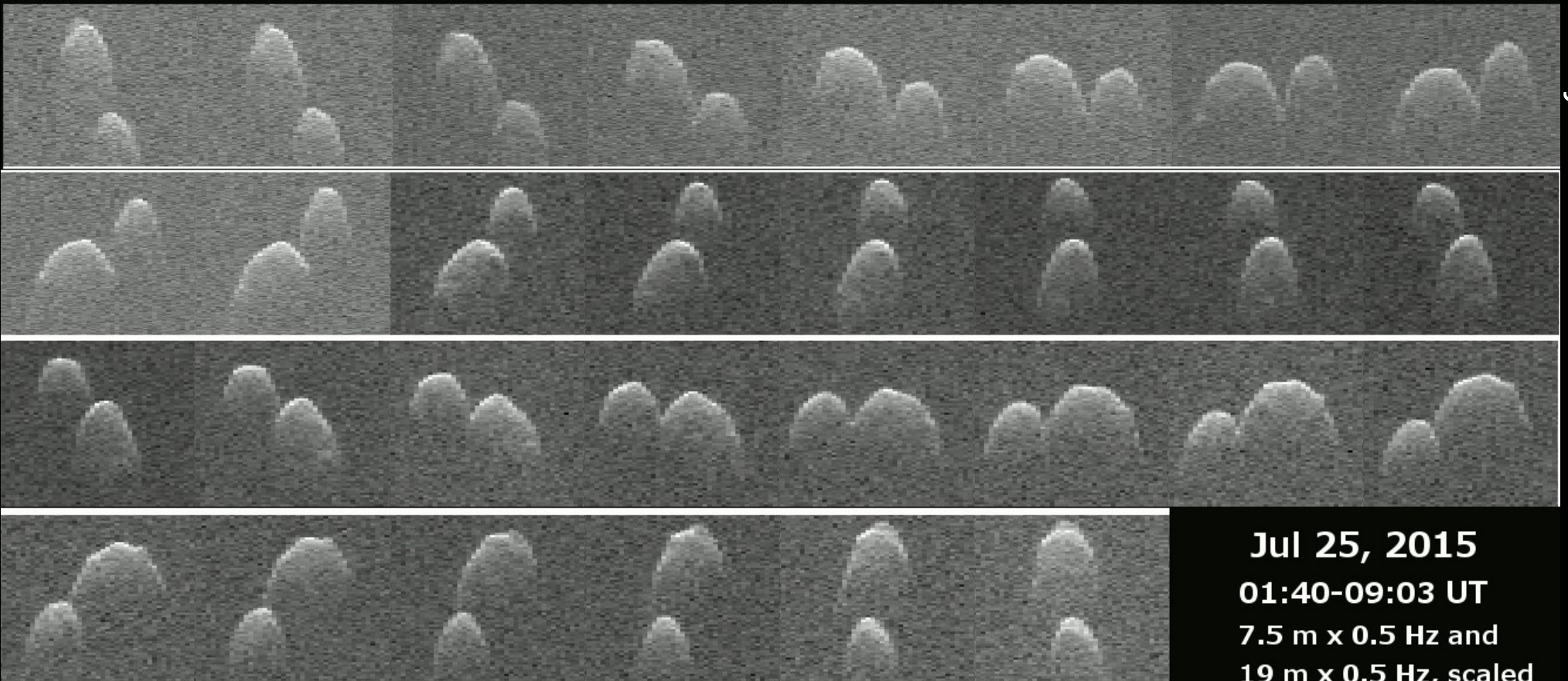
- Night of closest approach

0.048 au = 19 lunar distances



Doppler →

Delay →

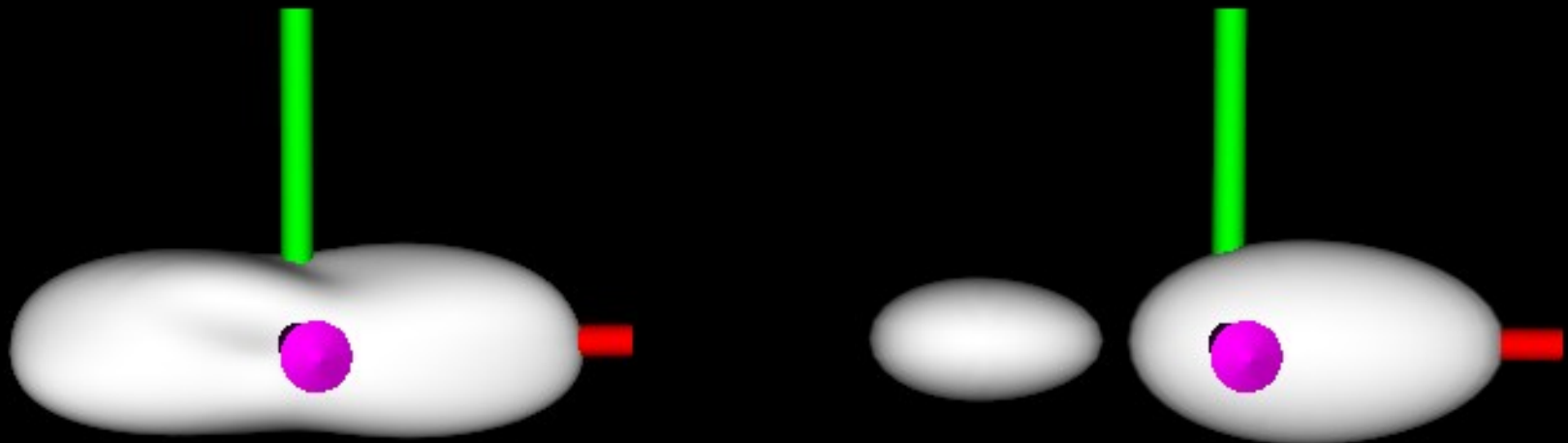


Jul 25, 2015  
01:40-09:03 UT  
7.5 m x 0.5 Hz and  
19 m x 0.5 Hz, scaled

**Goldstone-GBT bistatic radar images**

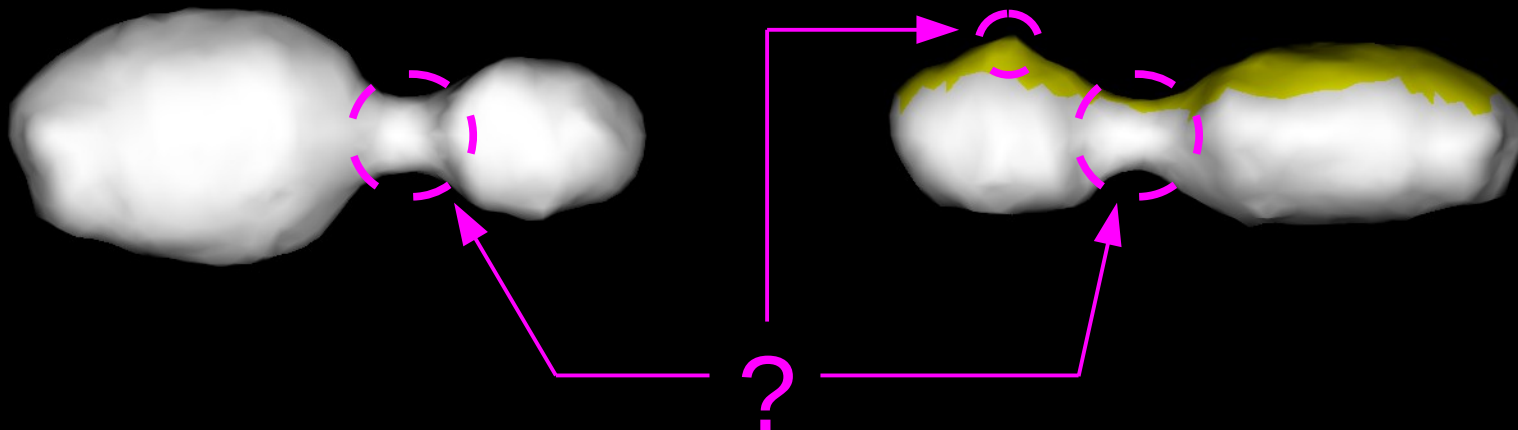
# 1999 JD6: First Shape Models

- Left: Spherical harmonic
- Right: Two ovoids (not overlapping)



# 1999 JD6: Early Shape Model

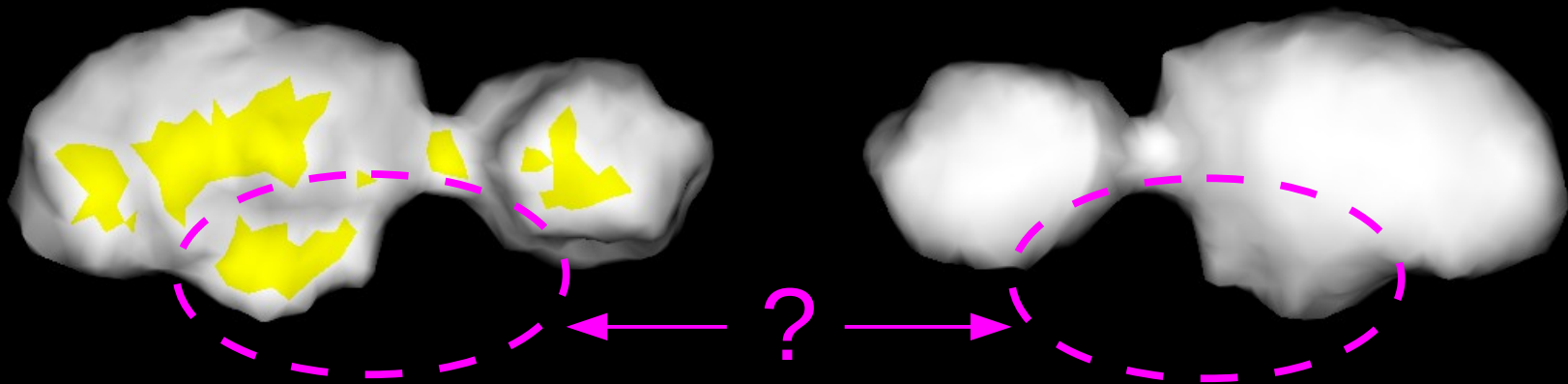
- Dimensions: 3.0 km  $\times$  1.2 km  $\times$  0.9 km
  - Volumetric mean diameter 1.4 km
- Sidereal rotation period  $\sim 7.66$  hours
  - Already known from lightcurves
- Pole position most likely  $(\lambda, \beta) \approx (36, +77)$ 
  - Or possibly  $(220, -73)$





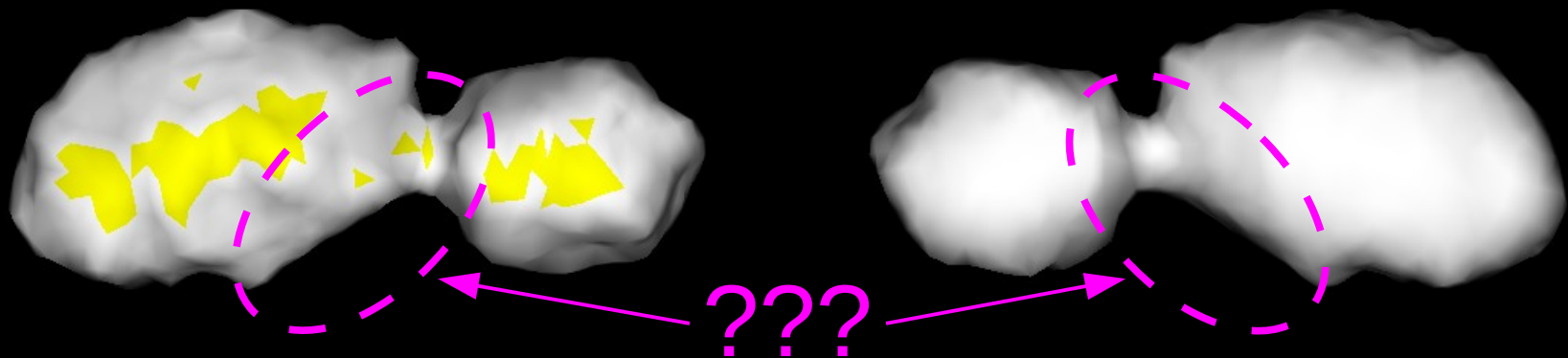
# 1999 JD6: Later Shape Model

- Dimensions: 2.75 km  $\times$  1.21 km  $\times$  0.98 km
  - Volumetric mean diameter: 1.33 km
- Sidereal rotation period: 7.6644 hours
  - Uncertainty: 0.0003 hours  $\approx$  1 second
- Pole position:  $(\lambda, \beta) = (220.5^\circ, -73.4^\circ) \pm 0.5^\circ$



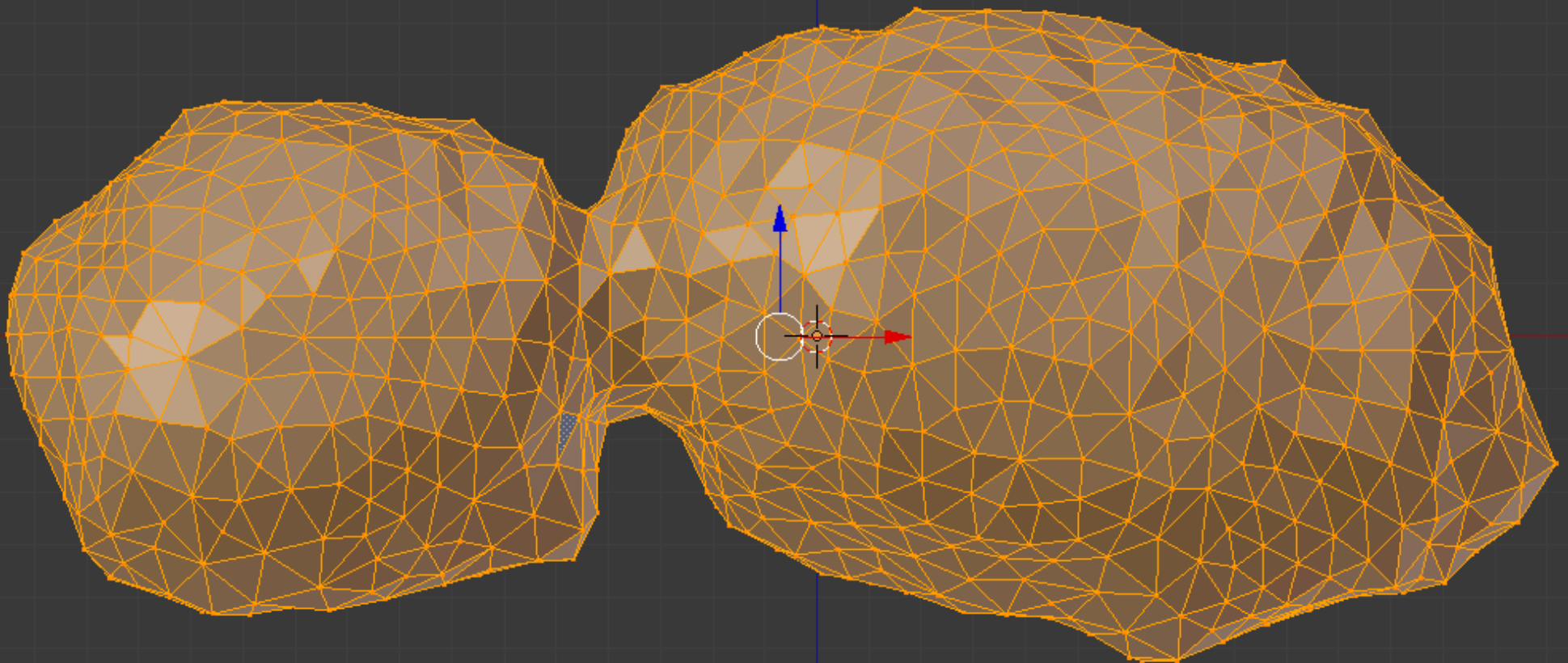
# 1999 JD6: Later Shape Model

- Dimensions:  $2.74 \text{ km} \times 1.11 \text{ km} \times 0.99 \text{ km}$ 
  - Volumetric mean diameter:  $1.34 \text{ km}$
- Sidereal rotation period:  $7.6644 \text{ hours}$ 
  - Uncertainty:  $0.0003 \text{ hours} \approx 1 \text{ second}$
- Pole position:  $(\lambda, \beta) = (220.5^\circ, -73.4^\circ) \pm 0.5^\circ$



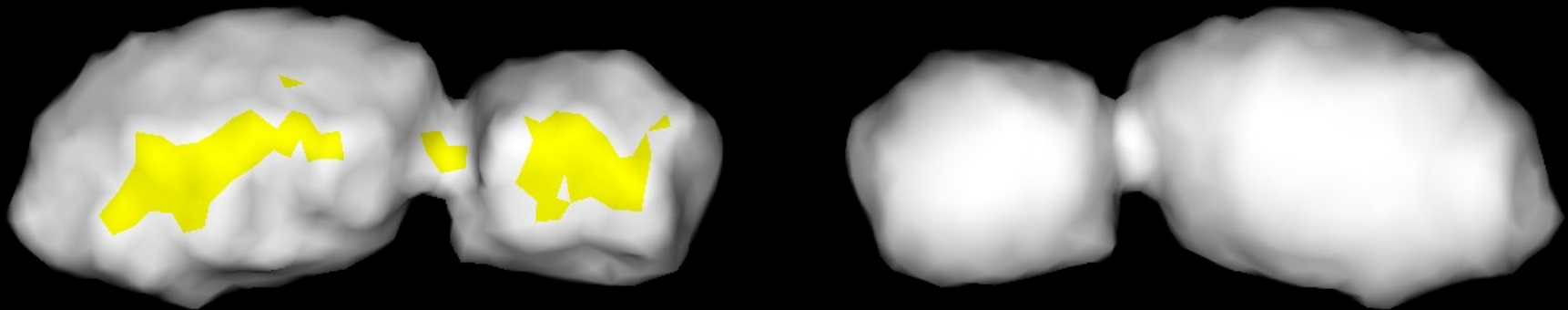
# 1999 JD6: Penultimate Shape Model

- Individual triangular facets, as seen with Blender
  - <https://www.blender.org/>



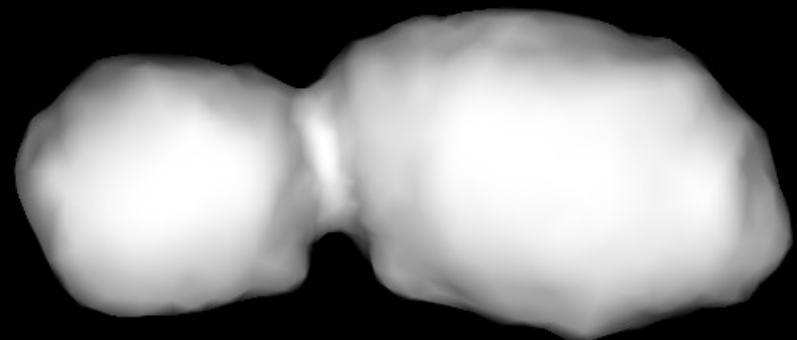
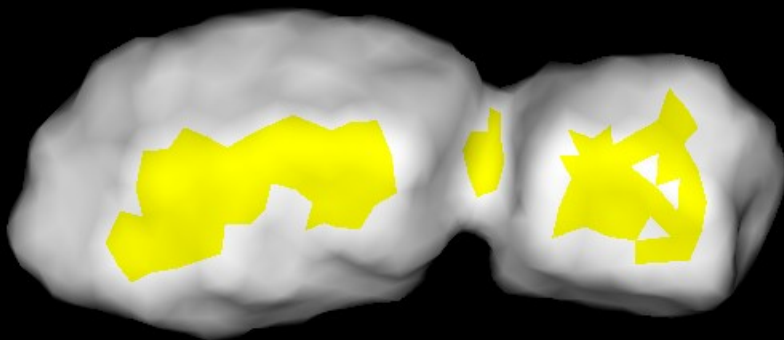
# 1999 JD6: Penultimate Shape Model

- Dimensions: 2.97 km  $\times$  1.25 km  $\times$  1.03 km
  - Volumetric mean diameter: 1.45 km
- Sidereal rotation period: 7.6643464 hours
  - Uncertainty: 0.0000056 hours  $\approx$  20 milliseconds
- Pole position:  $(\lambda, \beta) = (220.3^\circ, -73.43^\circ) \pm 0.2^\circ$



# 1999 JD6: Final Shape Model

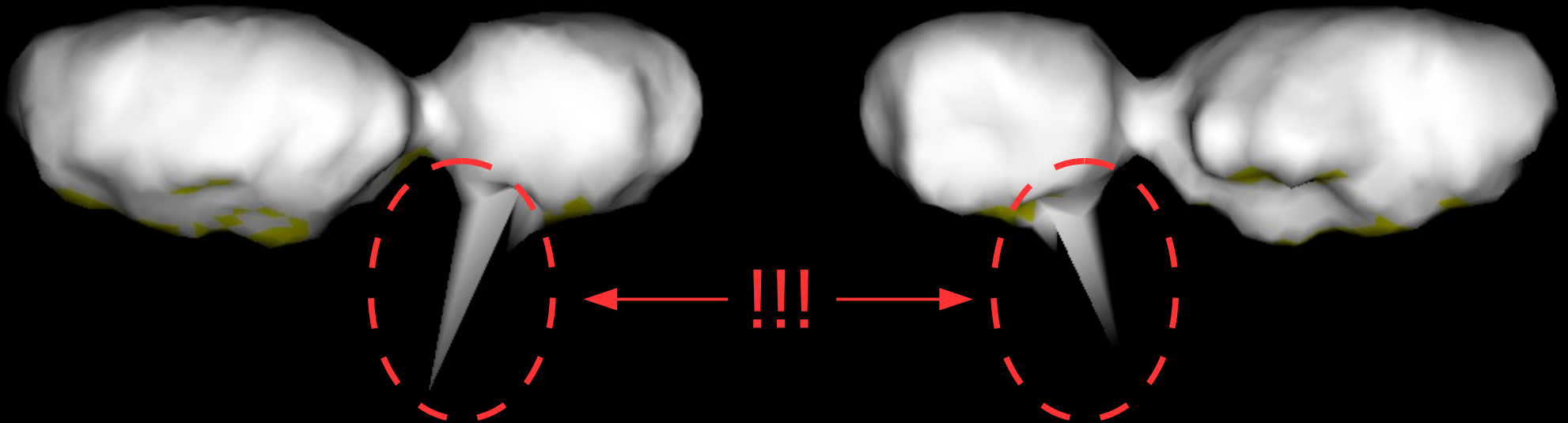
- Dimensions: 2.93 km  $\times$  1.26 km  $\times$  1.05 km
  - Volumetric mean diameter: 1.48 km
- Sidereal rotation period: 7.6643463 hours
  - Uncertainty: 0.0000056 hours  $\approx$  20 milliseconds
- Pole position:  $(\lambda, \beta) = (220.4^\circ, -73.41^\circ) \pm 0.2^\circ$





# 1999 JD6: Bad Shape Model

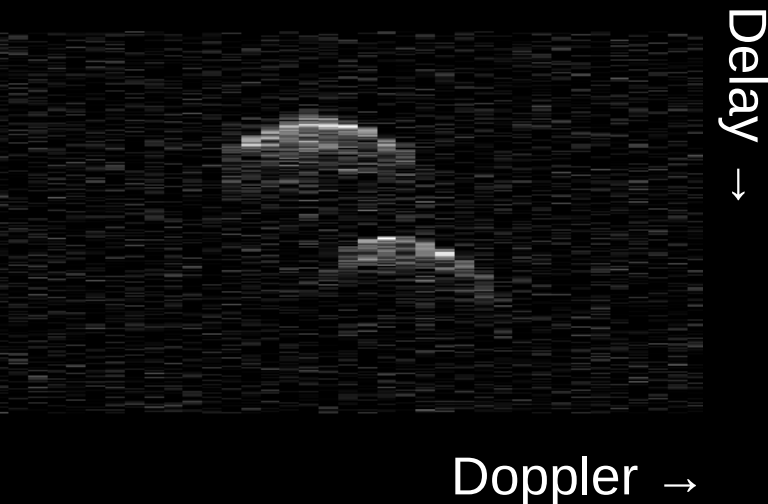
- That spike probably isn't real...



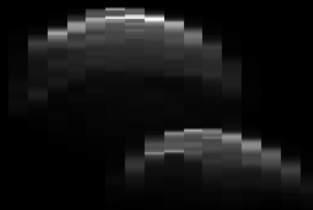
# 1999 JD6: Shape Modeling

- July 25, 2015: Goldstone DSS-14 bistatic to Green Bank Telescope
  - $0.050 \mu\text{s} \times 0.50 \text{ Hz}$
  - Radar image shows two lobes, but not the “neck”

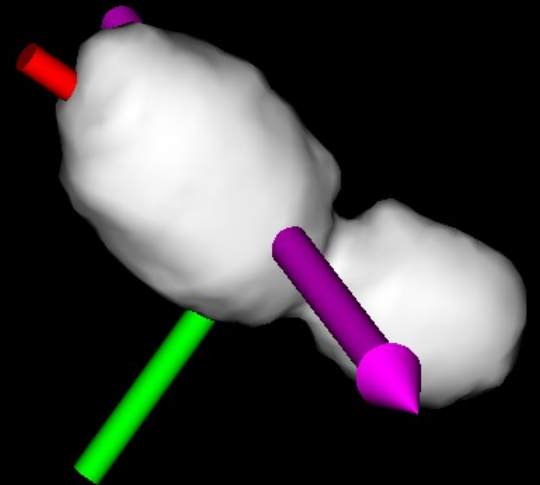
Data



Model



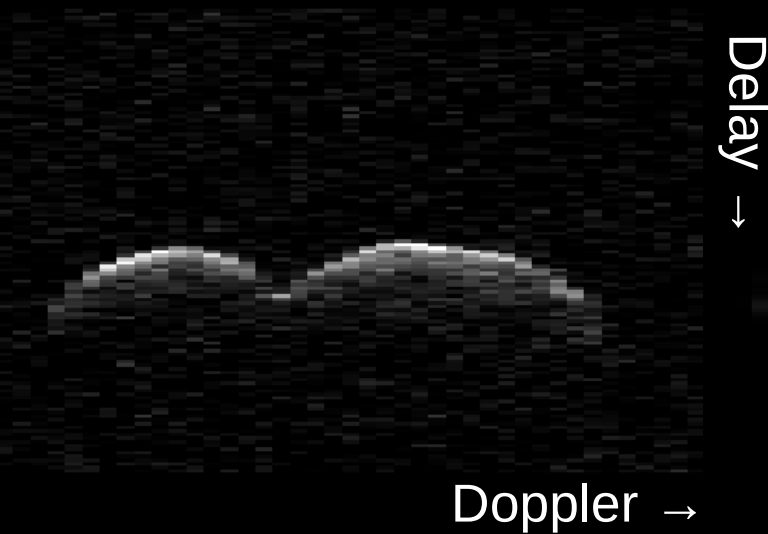
Plane-of-sky



# 1999 JD6: Shape Modeling

- July 25, 2015: DSS-14 bistatic to GBT
  - $0.125 \mu\text{s} \times 0.50 \text{ Hz}$
  - Is there really a “neck”? Or should the lobes overlap?

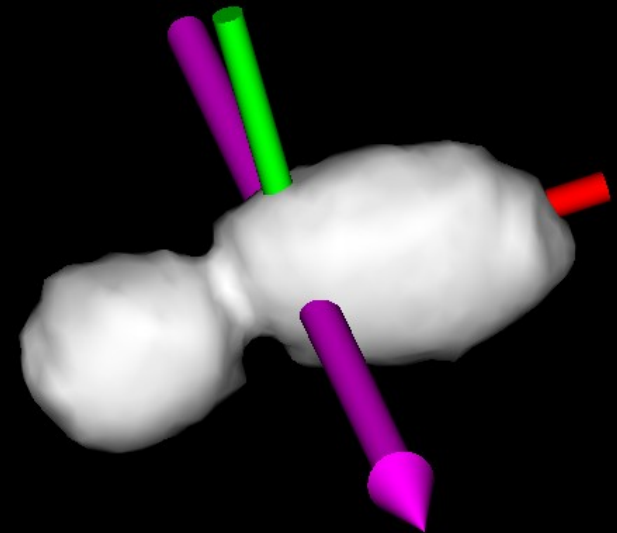
Data



Model



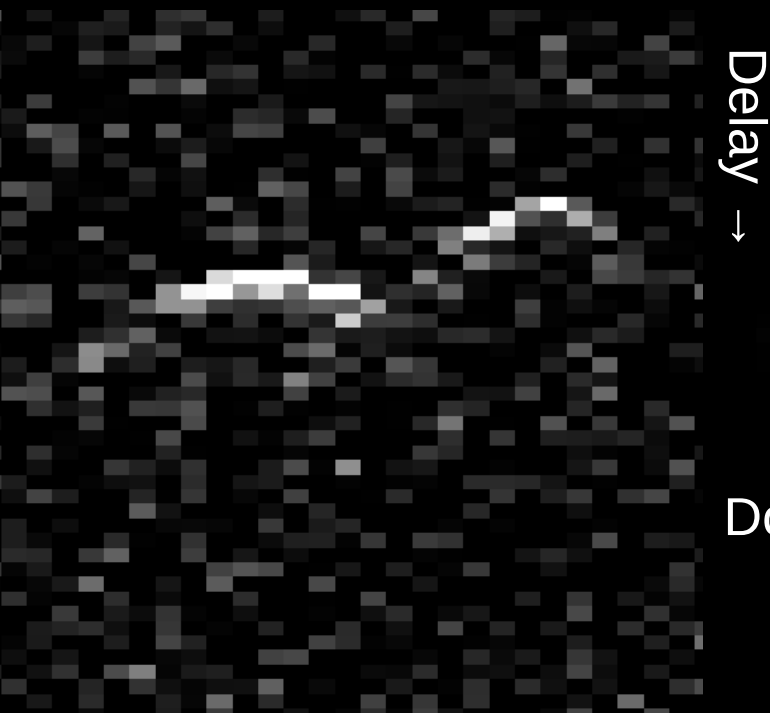
Plane-of-sky



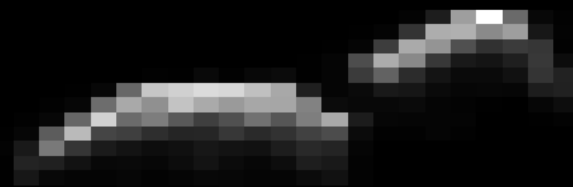
# 1999 JD6: Shape Modeling

- August 2, 2015: Arecibo monostatic
  - $0.500 \mu\text{s} \times 0.48 \text{ Hz}$
  - Best views of this side were when JD6 was farther away (could only get images from Arecibo)

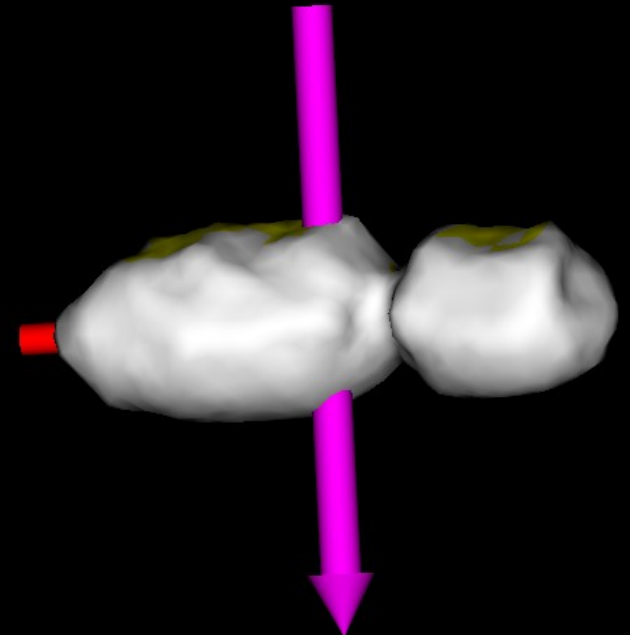
Data



Model

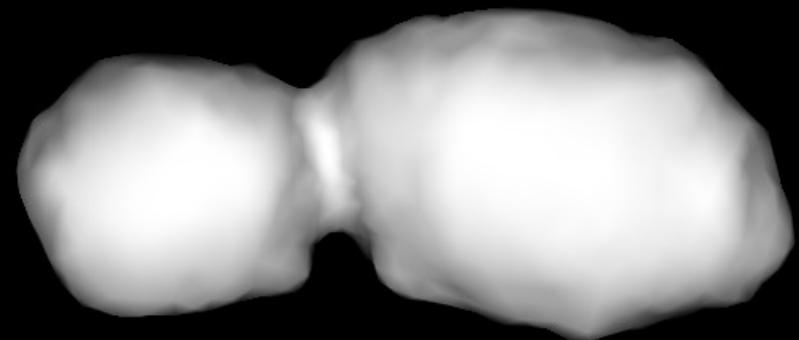
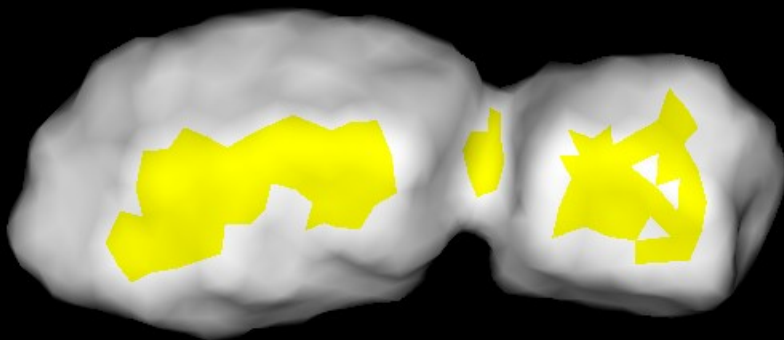


Plane-of-sky



# 1999 JD6: Final Shape Model

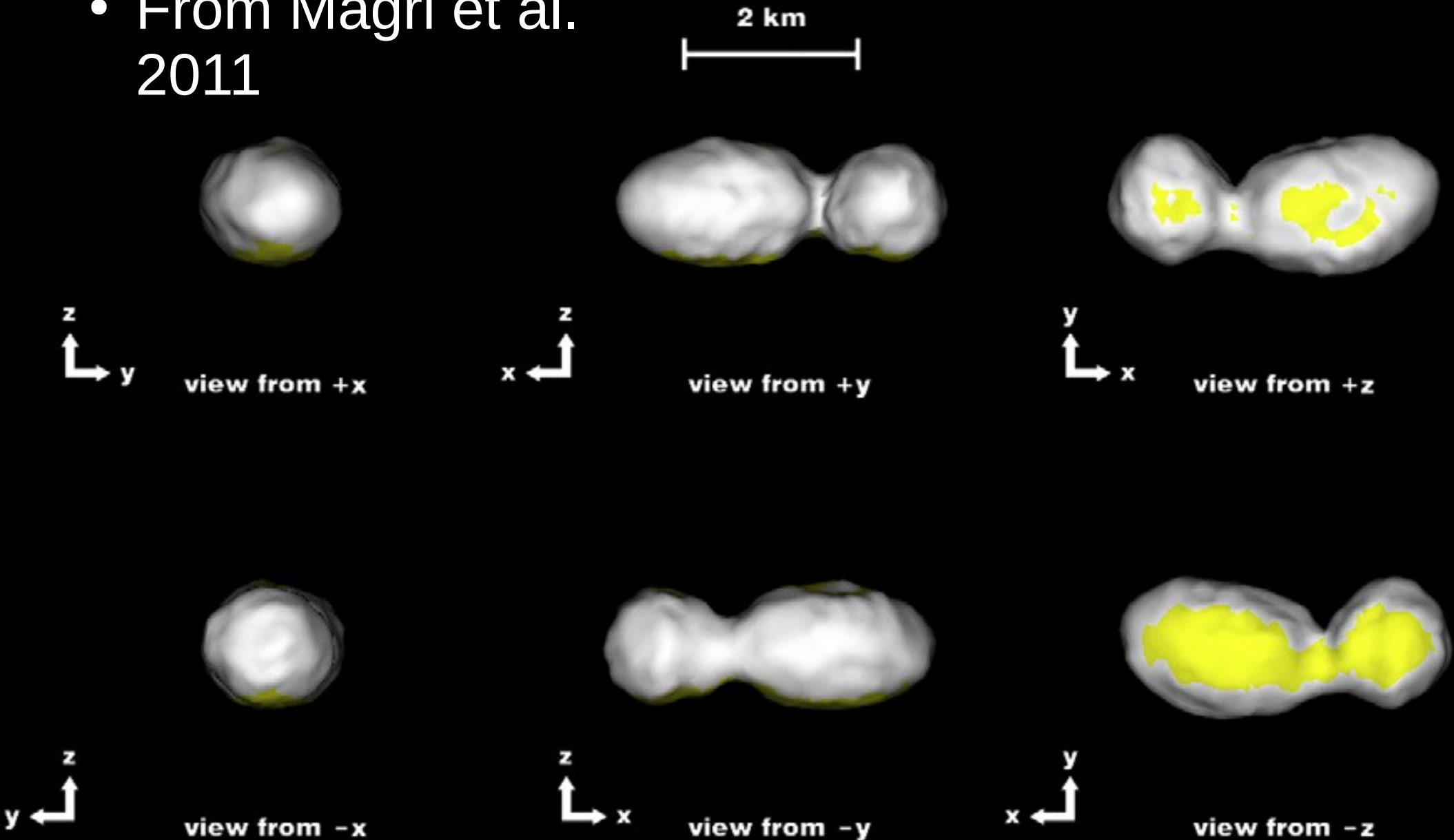
- Dimensions: 2.93 km  $\times$  1.26 km  $\times$  1.05 km
  - Volumetric mean diameter: 1.48 km
- Sidereal rotation period: 7.6643463 hours
  - Uncertainty: 0.0000056 hours  $\approx$  20 milliseconds
- Pole position:  $(\lambda, \beta) = (220.4^\circ, -73.41^\circ) \pm 0.2^\circ$



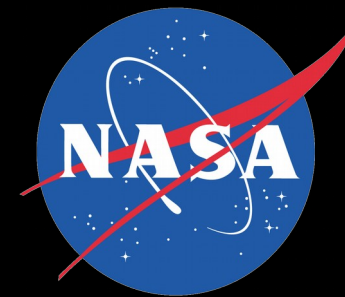


# Shape Model for (8567) 1996 HW1

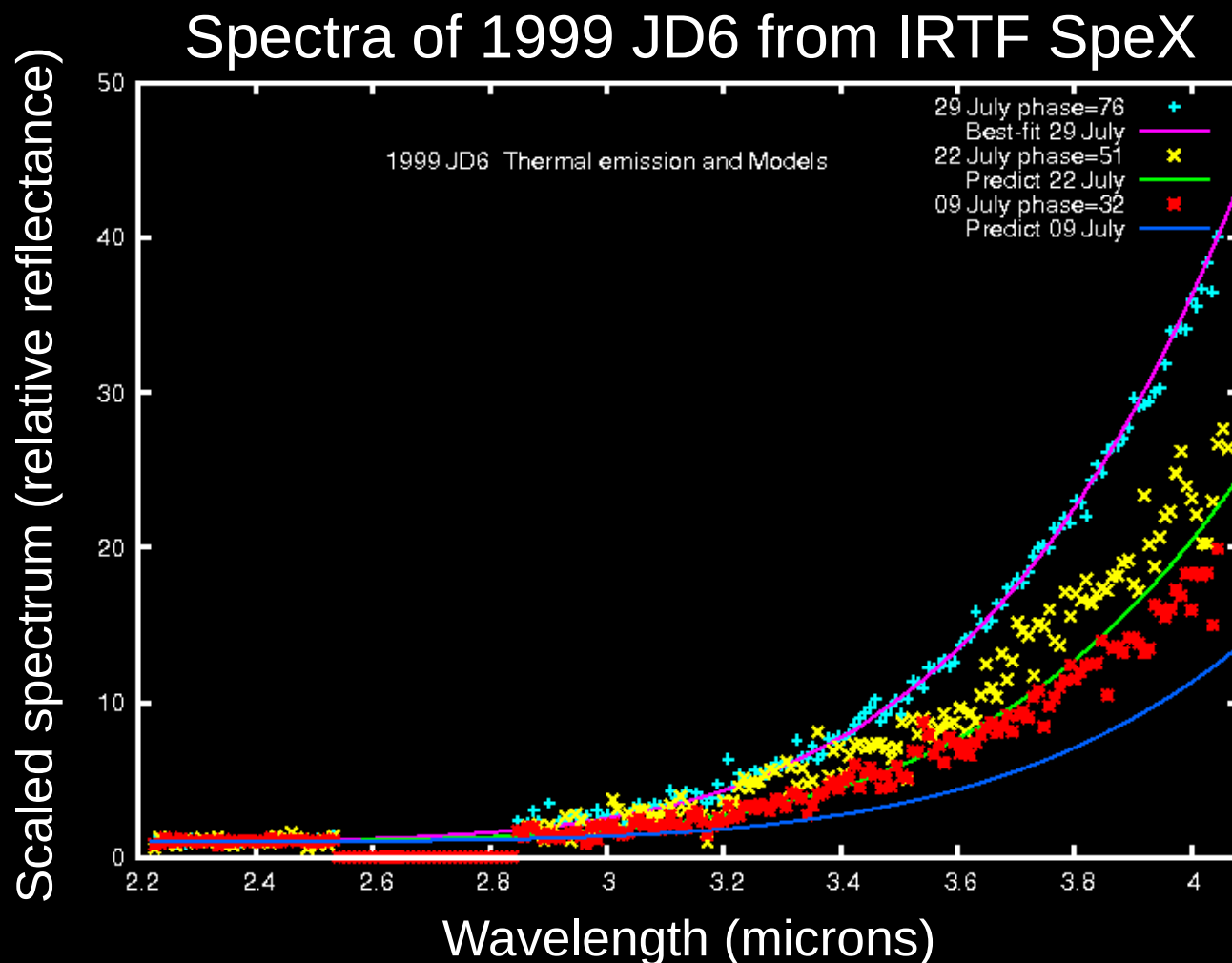
- From Magri et al. 2011



# Infrared Observations



- Using the NASA InfraRed Telescope Facility (IRTF)
- SpeX
  - Full range 0.8 to 5.0  $\mu\text{m}$



(switch to third file)