Rosetta's view of an asteroid collision

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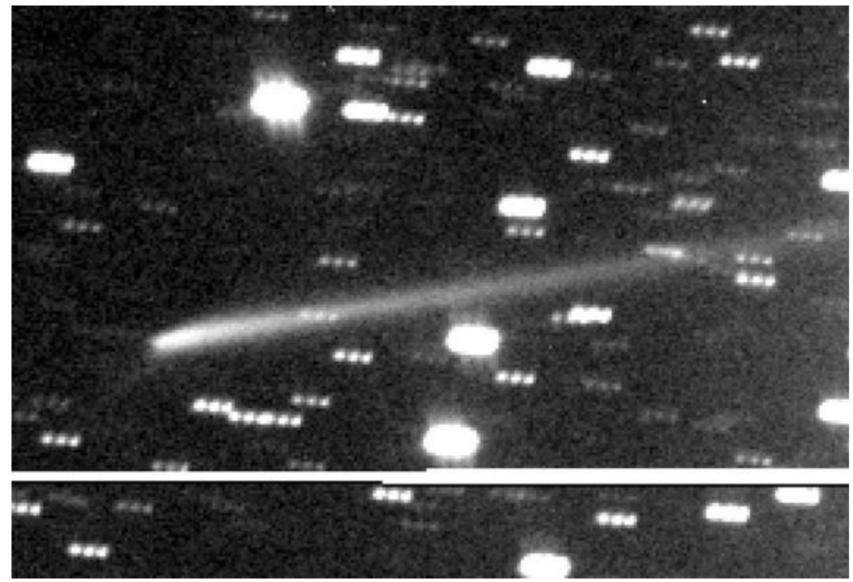
Comet P/2010 A2

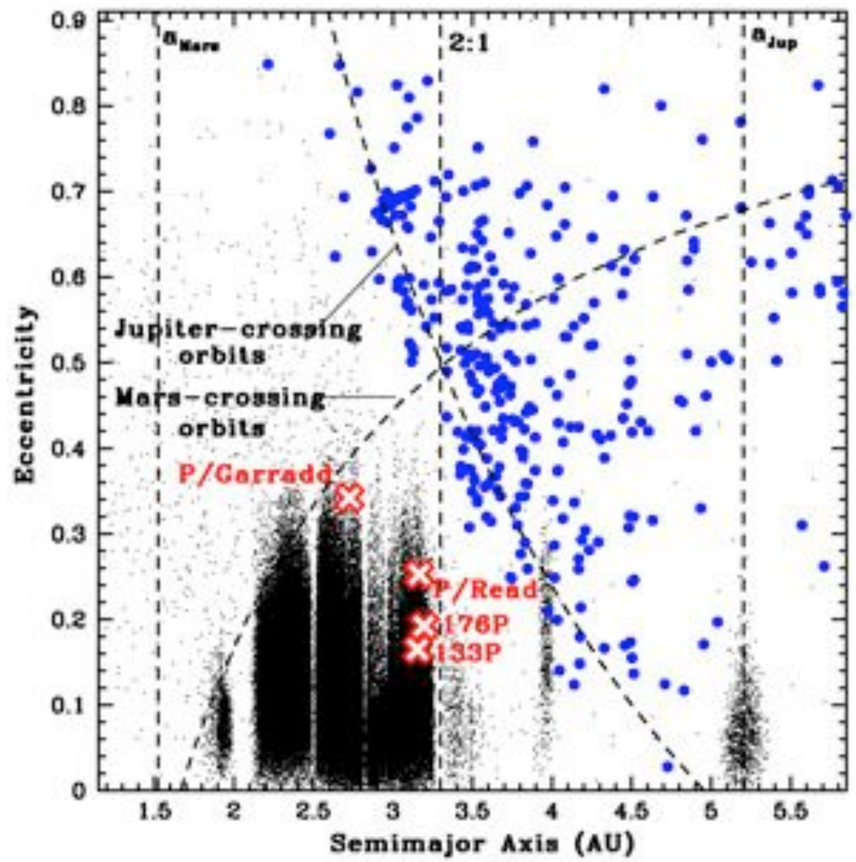
- Discovered on January 6th 2010 by LINEAR survey.
- Announced in IAUC 9105 on 7th January with a cometary designation due to the presence of a faint tail.
- Ground based follow up starts immediately, reveals “headless comet” with a tail but no coma.
- P/2010 A2 has an asteroid orbit in the inner main belt – a 5th MBC?



Spacewatch 1.8m telescope, 8th January

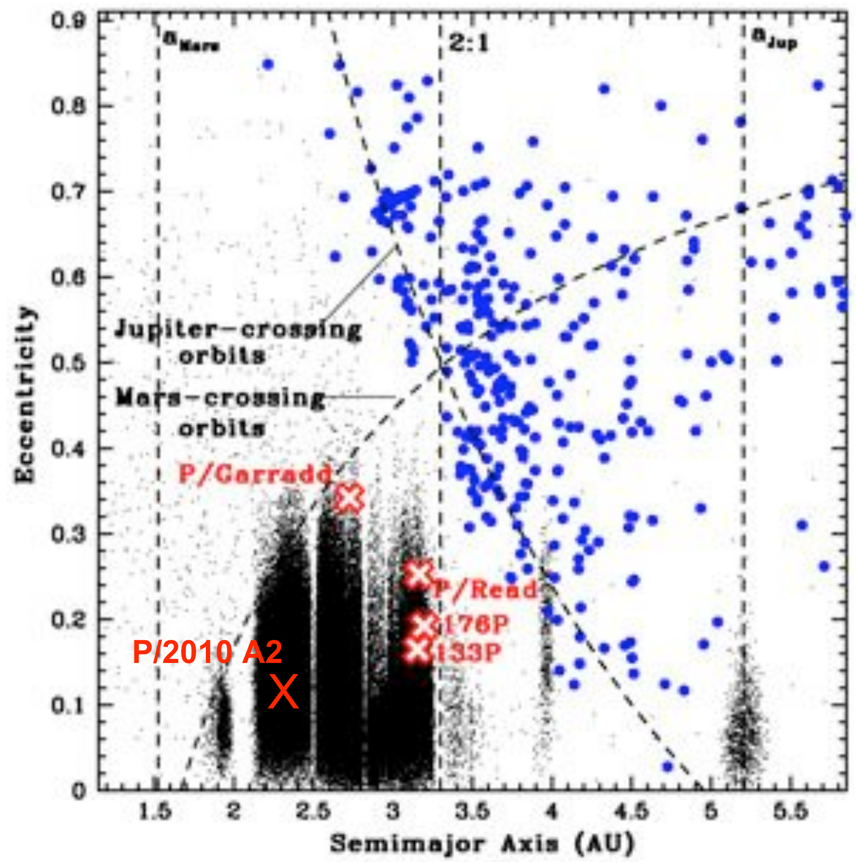
Main Belt Comet P/2010 A2

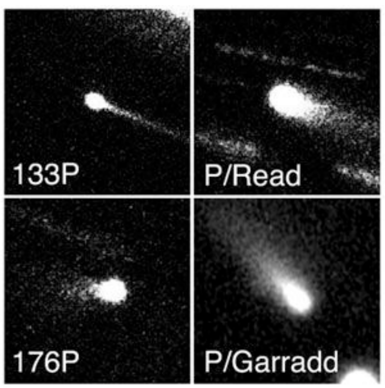
- The Main Belt Comets are a recently recognised population of comets that are native to the asteroid belt.
- They differ from other short period comets as their orbits are more circular and are decoupled from Jupiter.
- They orbit entirely within the main asteroid belt (hence the name).
- The 4 discovered before this year are all in the outer belt, where C-type asteroids are found.
- Two (maybe three) are associated with the Themis family – Themis has water ice on the surface.

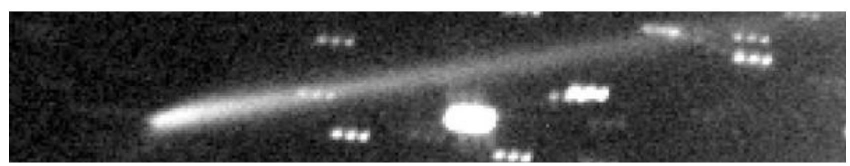


Main Belt Comet P/2010 A2

- P/2010 A2 is different.
- It orbits in the inner part of the main belt, where S-type asteroids are common.
- It is associated with the Flora family (S-types).
- There shouldn't be any ice here!
- Also, the headless comet appearance is unlike previous MBC detections.

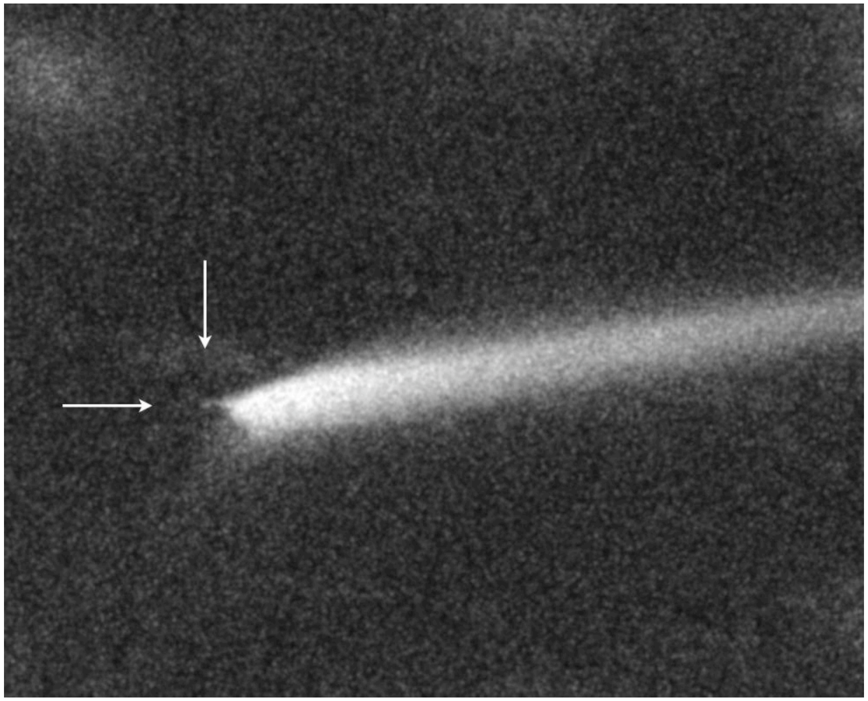






Main Belt Comet P/2010 A2 ?

- Within days of the discovery, various teams obtained follow up images with larger telescopes.
- Henry Hsieh and Olivier Hainaut were (by chance) at the 3.6m NTT at La Silla, observing for the ESO Large Programme on MBCs.
- Dave Jewitt and Jim Annis got observations with the WIYN 3.5m at Kitt Peak.
- Javier Licandro et al observed with the 2.5m NOT at La Palma.
- Detection of faint nucleus separated from tail, morphology is unlike anything seen in comets.



Jewitt & Licandro (independently) suggest an impact could be responsible, rather than out-gassing (IAUC 9109, 20th January).

Asteroid collision P/2010 A2 ?

- By the end of January follow up teams secured discretionary time on the largest telescopes.
  - Hsieh and Jewitt used Gemini & VLT (8m) for spectroscopy.
  - Licandro got images from GTC (10m).
  - Hainaut et al got images from Gemini.
  - Jewitt gets HST time.
- At this point the prevailing idea was that we have been lucky enough to see a recent impact.
- Dust trail was expected to evolve rapidly.
  - It didn’t.

Comet-like Asteroid P/2010 A2 • January 29, 2010

Hubble Space Telescope • WFC3/UVIS

NASA, ESA, and D. Jewitt (UCLA)

STScI-PRC10-07

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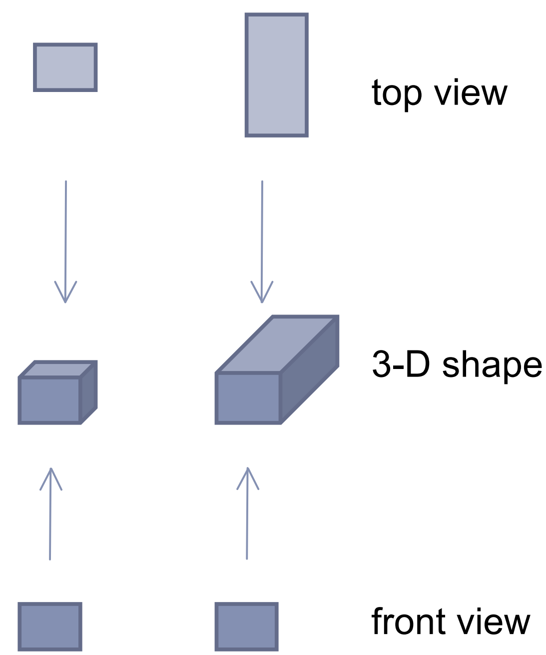
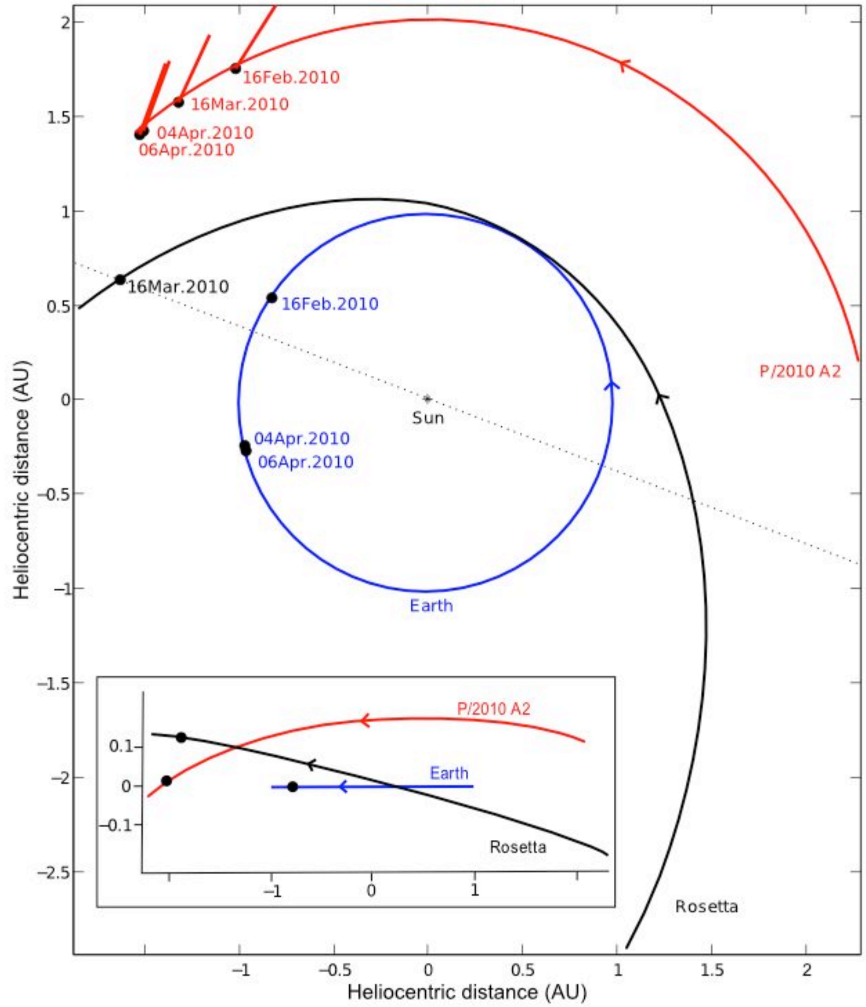
A 3-dimensional view.

- The problem with the understanding the true nature of the trail from these images is one of perspective.
- To understand the slowly evolving dust cloud, we realised that we needed to measure its true shape.
- To do this we needed a stereoscopic view.
- The orbital plane of P/2010 A2 is near to that of the Earth, which is why the view from Earth hardly changed over a period of months.
- So, we couldn’t get a significantly different view by waiting – we needed to look from far from the Earth.



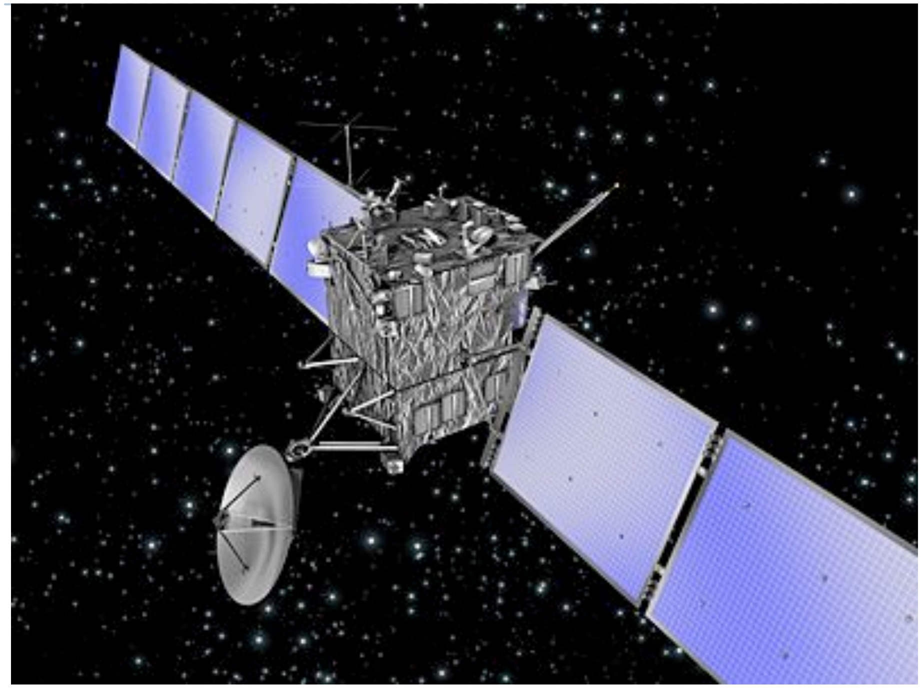
A camera in the asteroid belt

- At this time Rosetta was entering the asteroid belt for the Lutetia fly-by.
- Although we weren't lucky enough to be near to P/2010 A2, we were in the right general direction.
- The viewing geometry was significantly different from the Earth based one.
- The Rosetta orbit is inclined to P/2010 A2's orbital plane.
- By comparing with Earth based observations we could get a stereoscopic view.

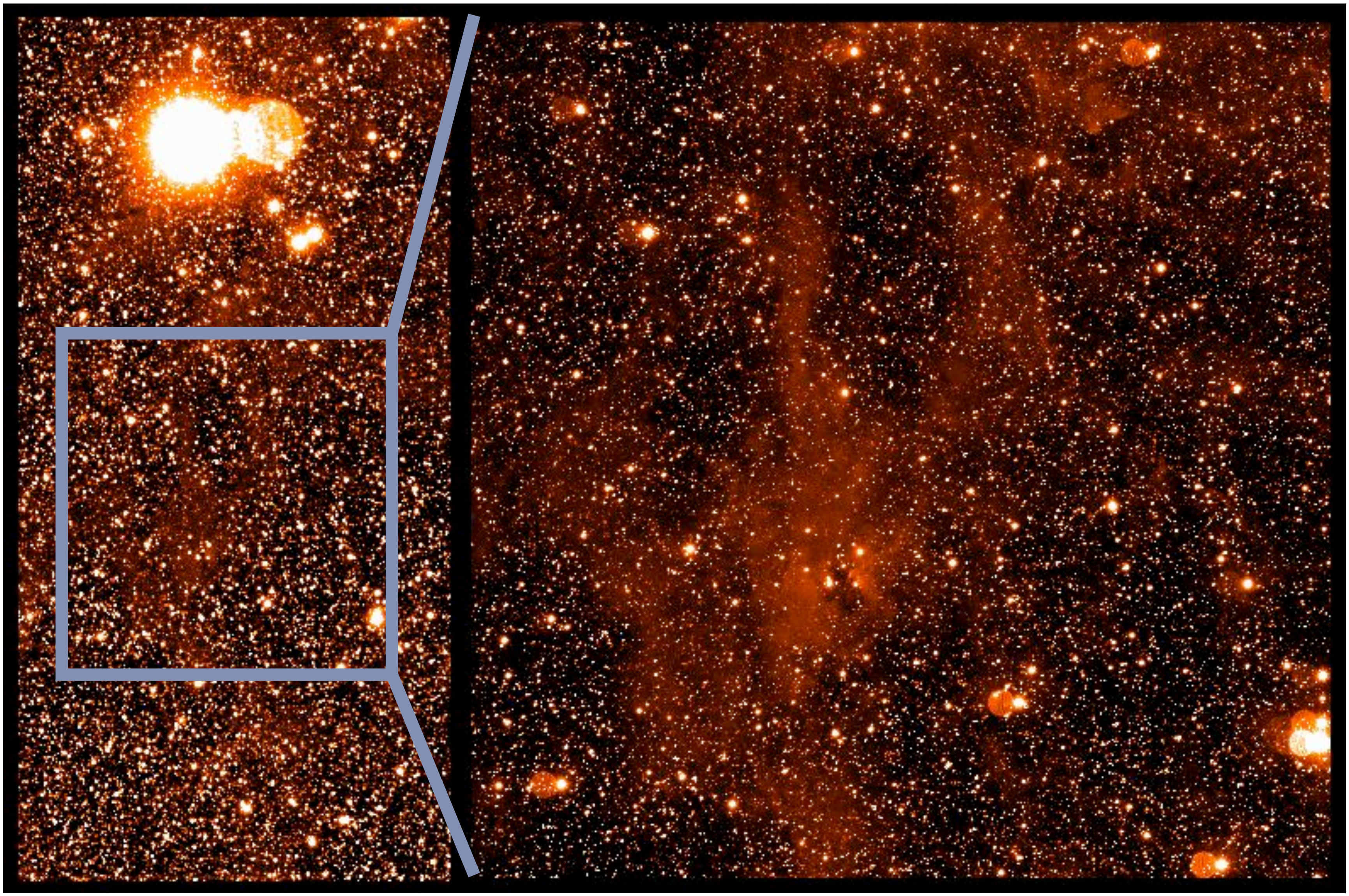


OSIRIS

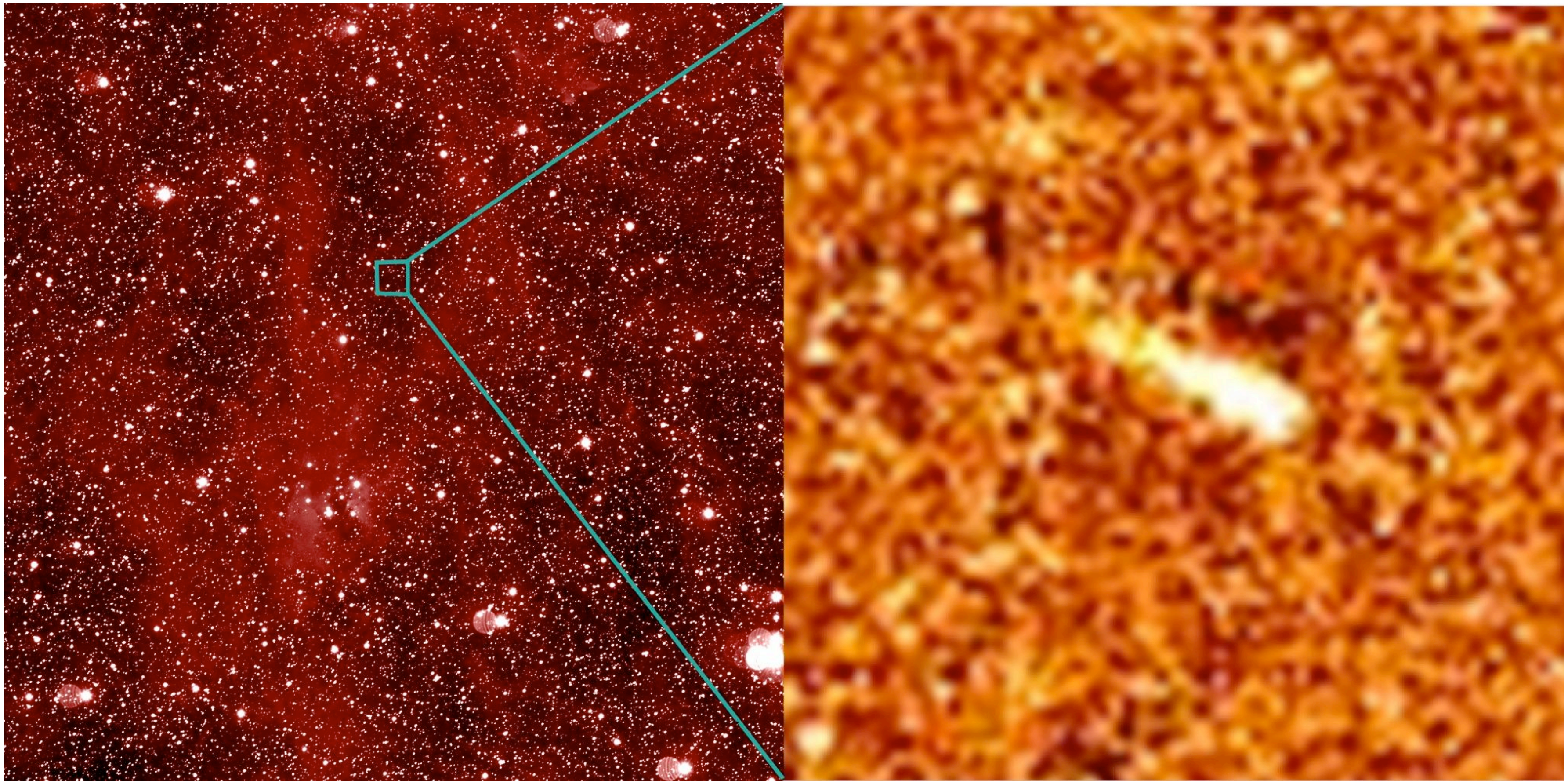
- The OSIRIS (Optical, Spectroscopic, and Infrared Remote Imaging System) cameras are the visible wavelength imagers on Rosetta.
- OSIRIS is made up of Narrow and Wide angle cameras (NAC & WAC).
- It is designed to return high resolution images of the comet and two asteroids that are Rosetta's targets, from close range.
- It is not designed to be used as a space telescope.



OSIRIS view

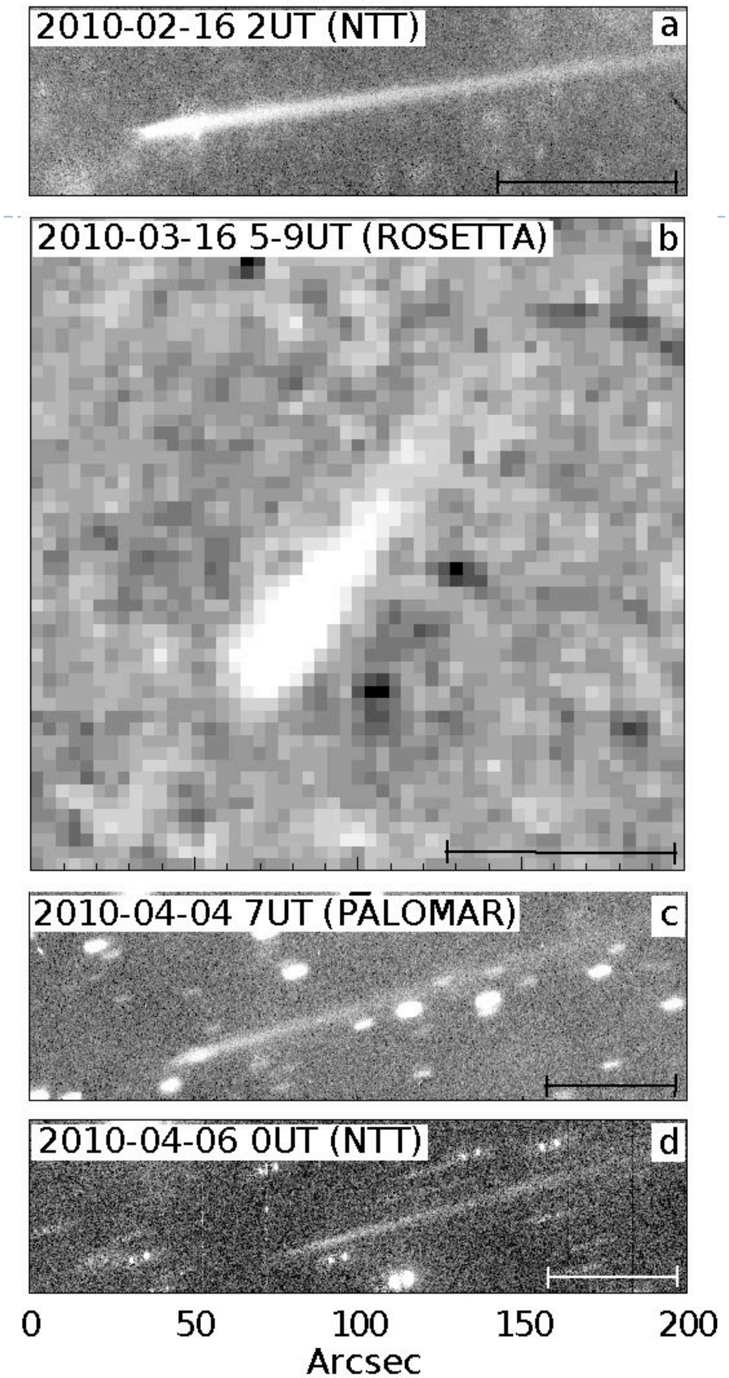


OSIRIS view



3-D view

- Comparing the view from OSIRIS with that from Earth, we see that the geometry is quite different.
- We have therefore achieved our goal of obtaining a stereoscopic view – combination of the two views strongly constrain the true shape and orientation of the trail in space.
- The Earth based observations used here were obtained at the NTT and at the Hale 200” at Palomar.

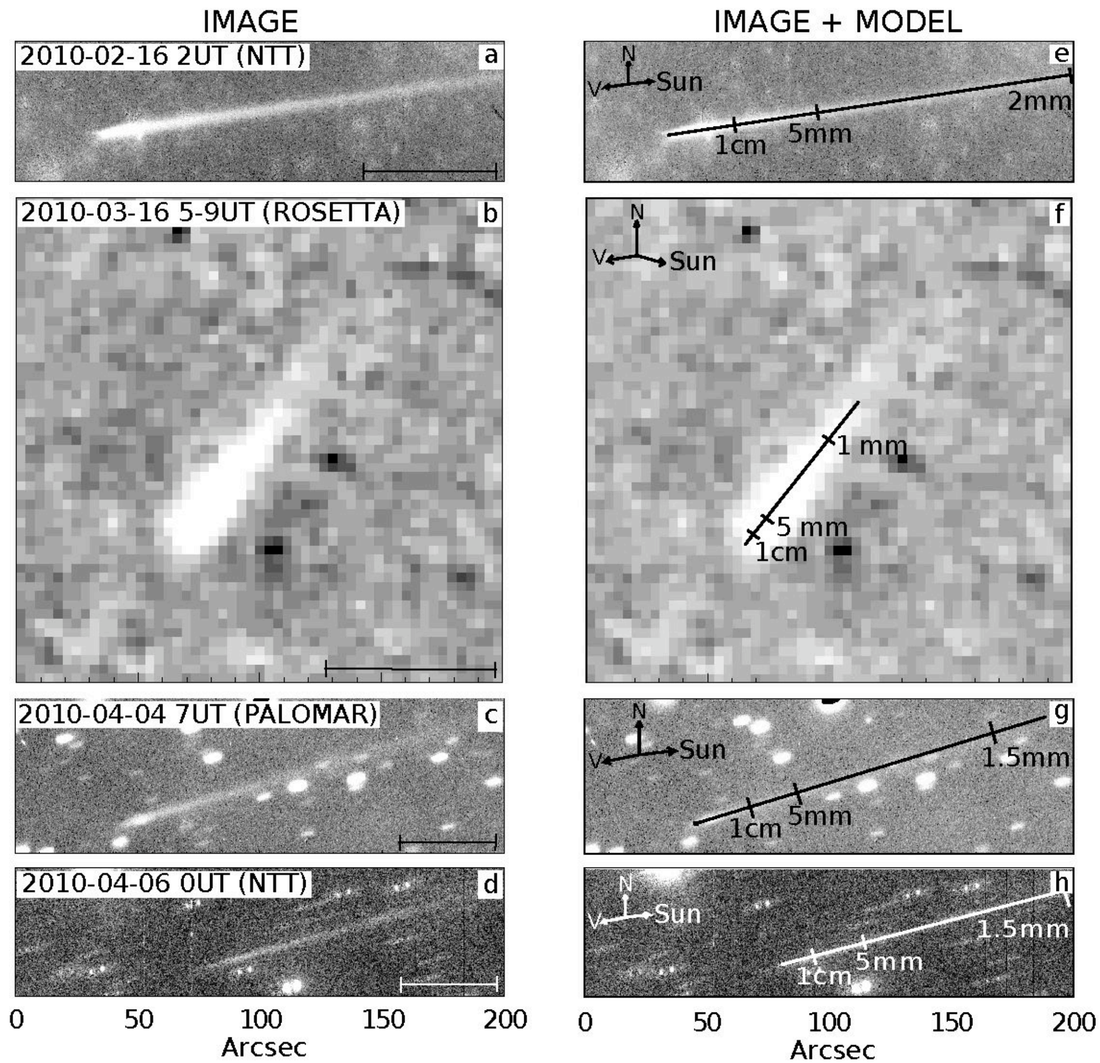


Trail models

- To understand the true 3-D shape of the trail and what this meant for the dust creation process, we had to build a model of the trail to match with the observations.
- We used the technique of Finson-Probstein modelling that has long been applied to comet tails.
- This technique models the motion of dust grains under the influence of the two forces that act on them, gravity and solar radiation pressure.
- Once a dust grain has left a comet (or asteroid) its motion is controlled by these forces – the gas from a comet gives the dust its initial acceleration off of the surface, but gas and dust in cometary comae are decoupled within a few radii of the comet.
- The gravitational influence of the comet or asteroid can also be ignored as these bodies are so small.
- Each particle is on its own orbit around the Sun, closely linked to the parent body's orbit.

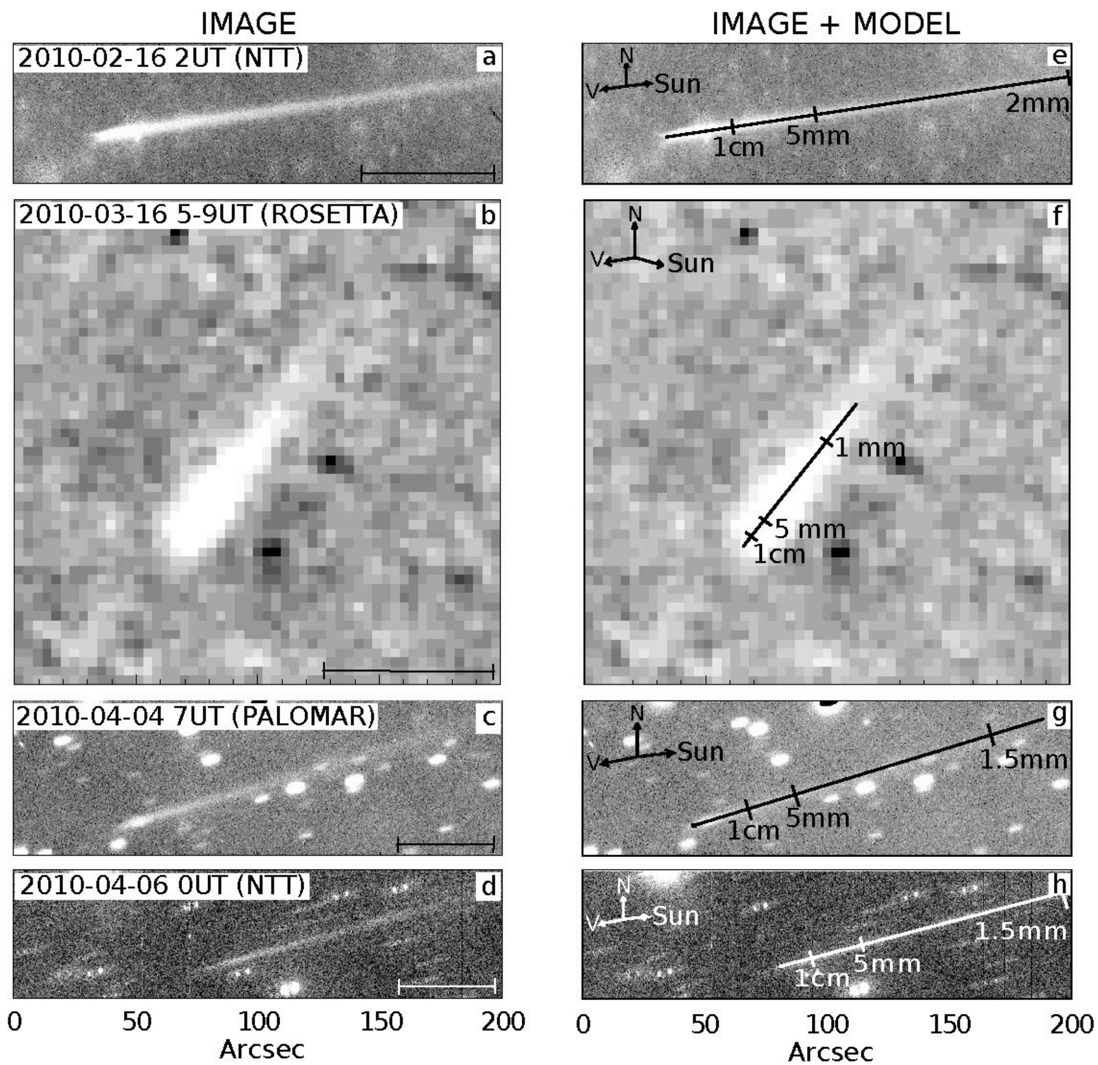
Finson-Probstein models of P/2010 A2

- To get a fit to all images it was necessary to use a model with dust ejection over a very narrow window – essentially all the dust must have been released at the same time.
- As we change the date of this dust creation the angle of the trail in from the Rosetta view point changes quickly.
- Therefore we could constrain the date of the creation of the trail with high accuracy.
- We find a date of February 10th, 2009, ± 5 days.



Finson-Probstein models of P/2010 A2

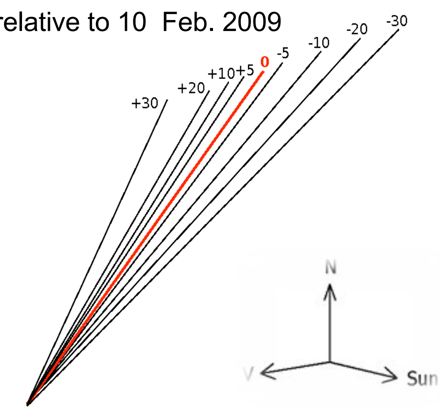
- The assumed beta parameter changes the curvature of the observed trail.
- To get the straight trails observed from both viewpoints requires beta of ~10^{-4} – 10^{-5}.
- This corresponds to particle sizes of mm to cm size for a k appropriate for rock dust.
- Smaller particles have probably already been dispersed below our detection limits.



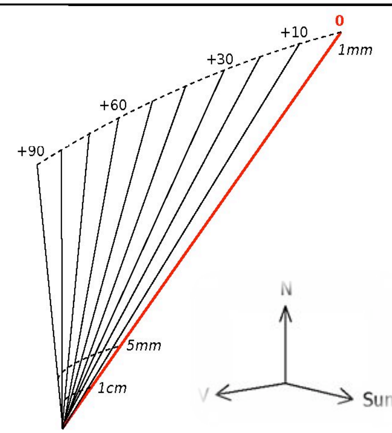
Alternative models?

- Alternative models (comet like activity over a period of time, or smaller particles) produce very different geometries in the Rosetta view.
- However, all of these models fit the Earth images.

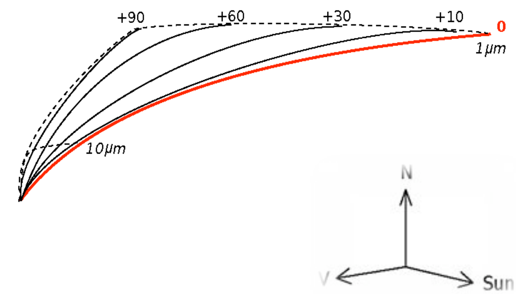
Days relative to 10 Feb. 2009



large particles (mm – cm) and a burst of activity on a single day



large particles (mm-cm) and ongoing activity over an extended period



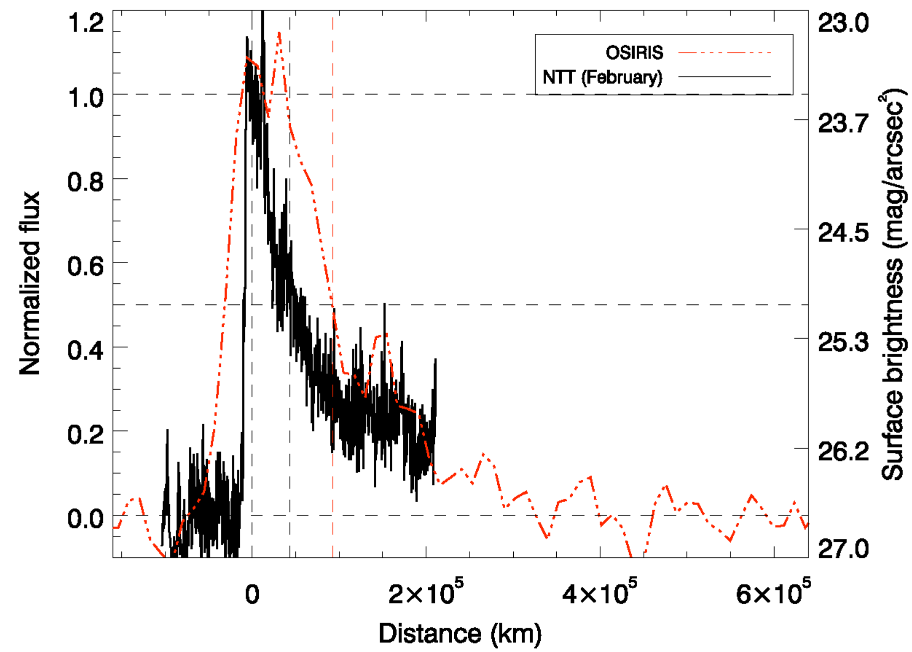
small particles (μm-size) and ongoing activity over an extended period

Asteroid Collision P/2010 A2

- We therefore conclude that P/2010 A2 is the trail of material from an asteroid collision that occurred on Feb 10th 2009.
- This result was independently verified by Jewitt et al using HST.
- Jewitt also suggests the possibility of rotational break up of an asteroid, rather than a collision.
- This possibility isn't ruled out – technically we demonstrate that the dust all came from a single event rather than a period of activity, which doesn't necessarily mean collision.
- We say collision as this is most likely (as far as we know).
- YORP spin up can make asteroids disrupt, but a small body such as the P/2010 A2 parent can spin very fast.

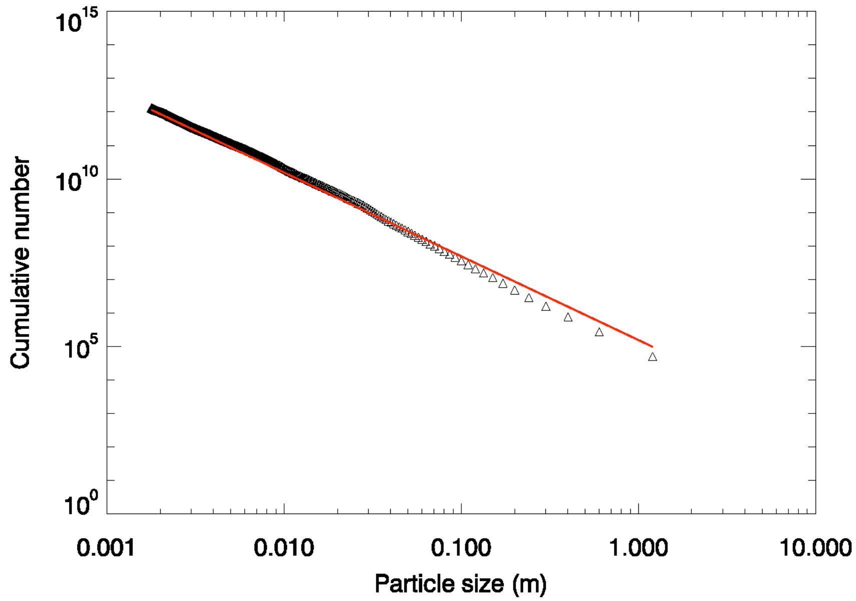
The collision

- We constrain some properties of the collision based on the observed trail.
- From the Finson-Probstein models we have a measurement of the size of particles with distance along the trail.
- From the NTT observations we have accurate photometry of the trail.
- We convert the measured brightness to a total reflecting area (as a function of distance along the trail), assuming an S-type asteroid like albedo (15%).
- We then use the particle size at each distance to get a total number of particles as a function of their size (size distribution).



The collision

- From the size distribution we get the total volume of particles ejected, by summing over all particles.
- The largest particles dominate, so any smaller dust which is no longer seen in the trail does not significantly affect the total volume estimate.
- The total volume is 2.8 x 10^5 m^3, or 16% of the total volume of a 120m diameter parent body.
- Assuming that this volume all comes from a hemispherical crater, the crater must have a diameter of 80m.
- Assuming a density for the material of 2.5 g/cc gives a total mass of the dust of 3.7 x 10^8 kg.



The collision

- The very low speed of the ejecta (< 0.2 m/s) initially seems to be at odds with a high velocity collision.
- Typical collision speeds between asteroids in the main belt are around 5 km/s.
- While a lower velocity collision could be possible between members of the Flora family (on similar orbits) it is still highly improbable that the collision speed was very low.
- A potential explanation that would put some constraints on the parent body is that high speed collision experiments with porous targets produce low velocity ejecta.
- However, recent hydrocode numerical simulations show that the majority of the ejecta from an asteroid collision has a maximum velocity near to the escape velocity of the asteroid, independent of the material properties.
- Therefore such a small parent body will always produce low velocity ejecta, whether it is a rubble pile or a monolith with strength.

The collision

- We place some constraints on the size of the 2^{nd} body using the crater size, using crater scaling laws (Holsapple & Housen 2007).
- These give an impactor size in the range 6-9m for a low strength, porous S-type asteroid.
- We then consider the impact rate, based on the probability of a collision between asteroids of these sizes.
- Using the model of collision rates based on the main belt population from Bottke et al (2005), we find that a parent body with the orbit of P/2010 A2 is hit by 6-9m impactors once every 1.1 Gyr.
- As there are thought to be around 9×10^7 objects of around 120m diameter then on average such collisions occur once every 12 years.
- Combined with the calculated mass ejected, this lets us constrain the average contribution to the zodiacal dust cloud from collisions of this size.
- We find this rate to be 3×10^7 kg/yr, which is 3 or 4 magnitudes less than the total rate of dust production by comets.

Conclusions

- P/2010 A2 is not a comet.
- The dust trail was produced in a single event on February 10th, 2009.
- This was most likely a collision.
- The view point from Rosetta, far from Earth, was critical in reaching this conclusion.
- This is the first collision between asteroids that has been directly observed.
- We find that the impactor was a few m in diameter and produced a large crater on the parent body.
- The total dust mass produced by such collisions is much smaller than that from comets.