Observations of Asteroid 2003EH1; Possible Parent of the Quadrantid Meteoroid Stream

“ Is it still active ? ”

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Meteoroids 2016@ESTEC in Noordwijk, Netherlands

The near-Earth asteroid (196256) 2003 EH1

- Discovered on UT2003 Mar.6 by Lowell Observatory(Skiff 2003)

- The dynamical classification: Jupiter-Family Comet (JFC)

T_{J} = 2.06
a = 3.13 AU
e = 0.62
i = 70.8°
(q = 1.2 AU)

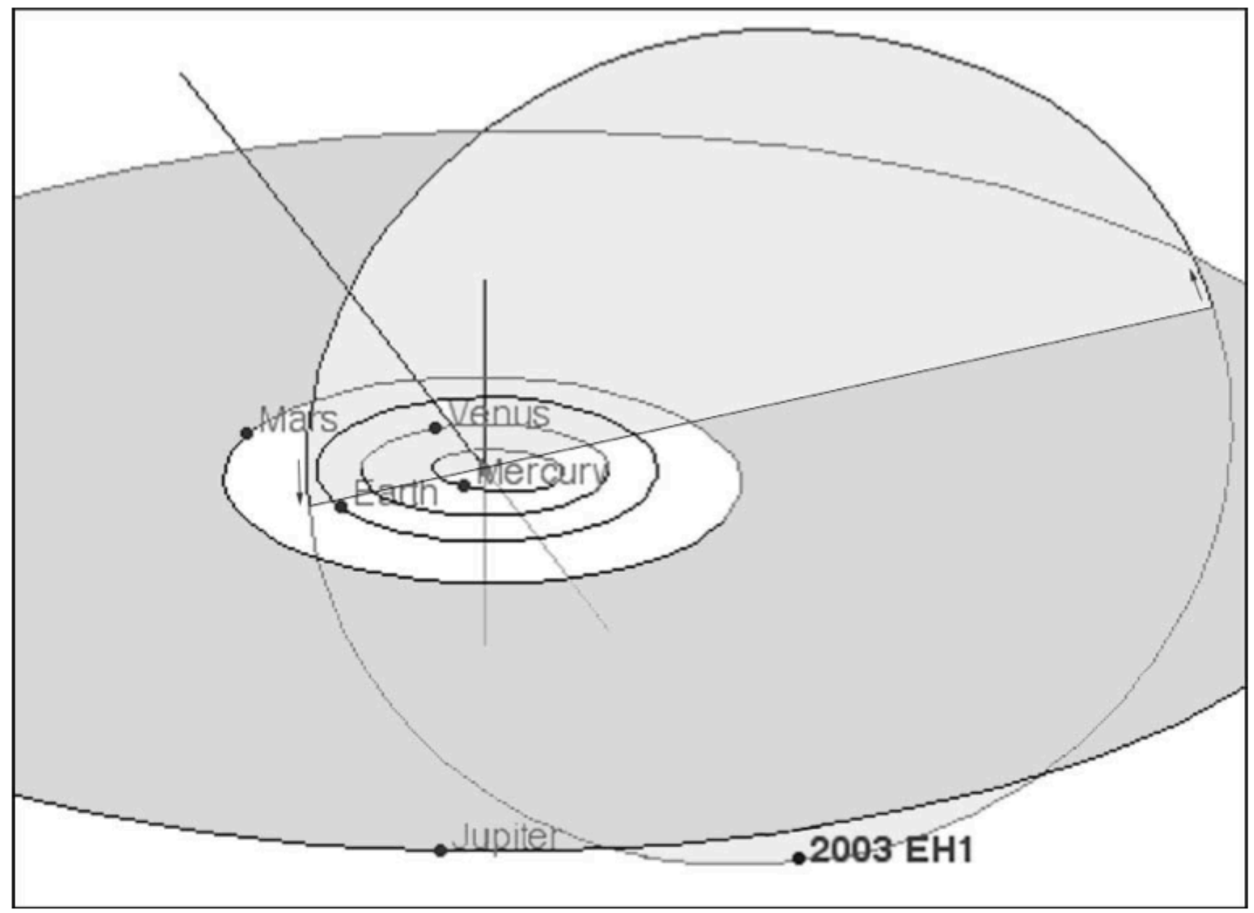


FIG. 1.—Orbit of 2003 EH$_1$ and position on 2004 January 4

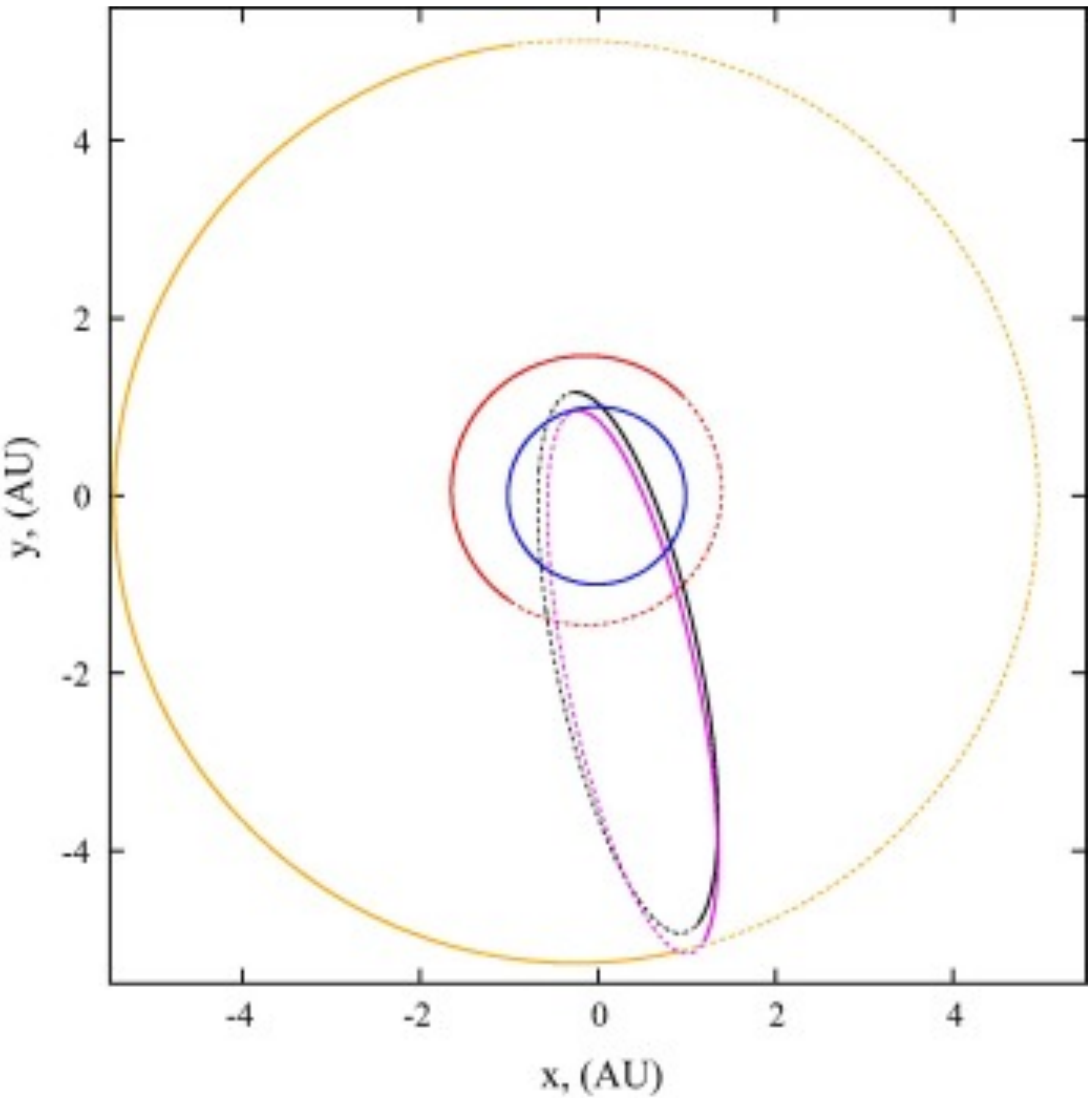
Jenniskens (2004)

- Dormant or weakly active comet

(Koten et al. 2006; Babadzhanov et al. 2008; Borovička et al. 2010; Tancredi 2014)

q of 2003EH1 is Outside of the Earth Orbit

View from above the Ecliptic Plane



- Asteroid
  q = 1.2 AU
- Quadrantid Stream
  q = 0.98 AU
- Earth (the shower season)
  r = 0.98 ± 0.01 AU

Wiegert & Brown (2005), Abedin et al. (2015)

Sun-Approaching Dynamical State

by simulations ($< 10^4$ year backward)

The $a = 3.13$AU

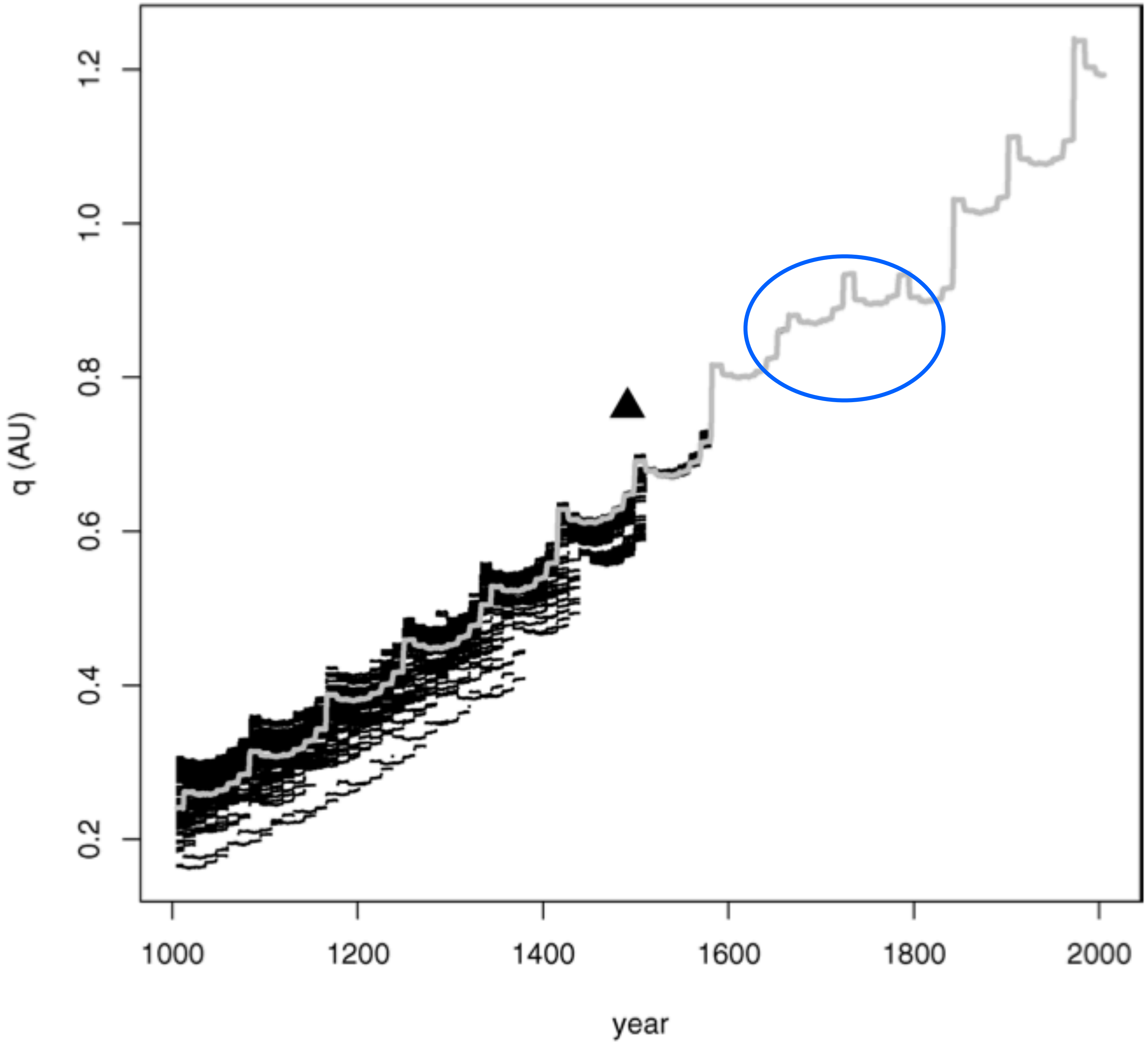
$\approx$ the 2:1 MMR with Jupiter at 3.27 AU

Strong Orbital Variations

Wiegert & Brown 2005; Neslušan et al. 2013a; Fernández et al. 2014

The q has increased

q = 0.2 AU (1000 years ago) → 1.2 AU (the present-day)



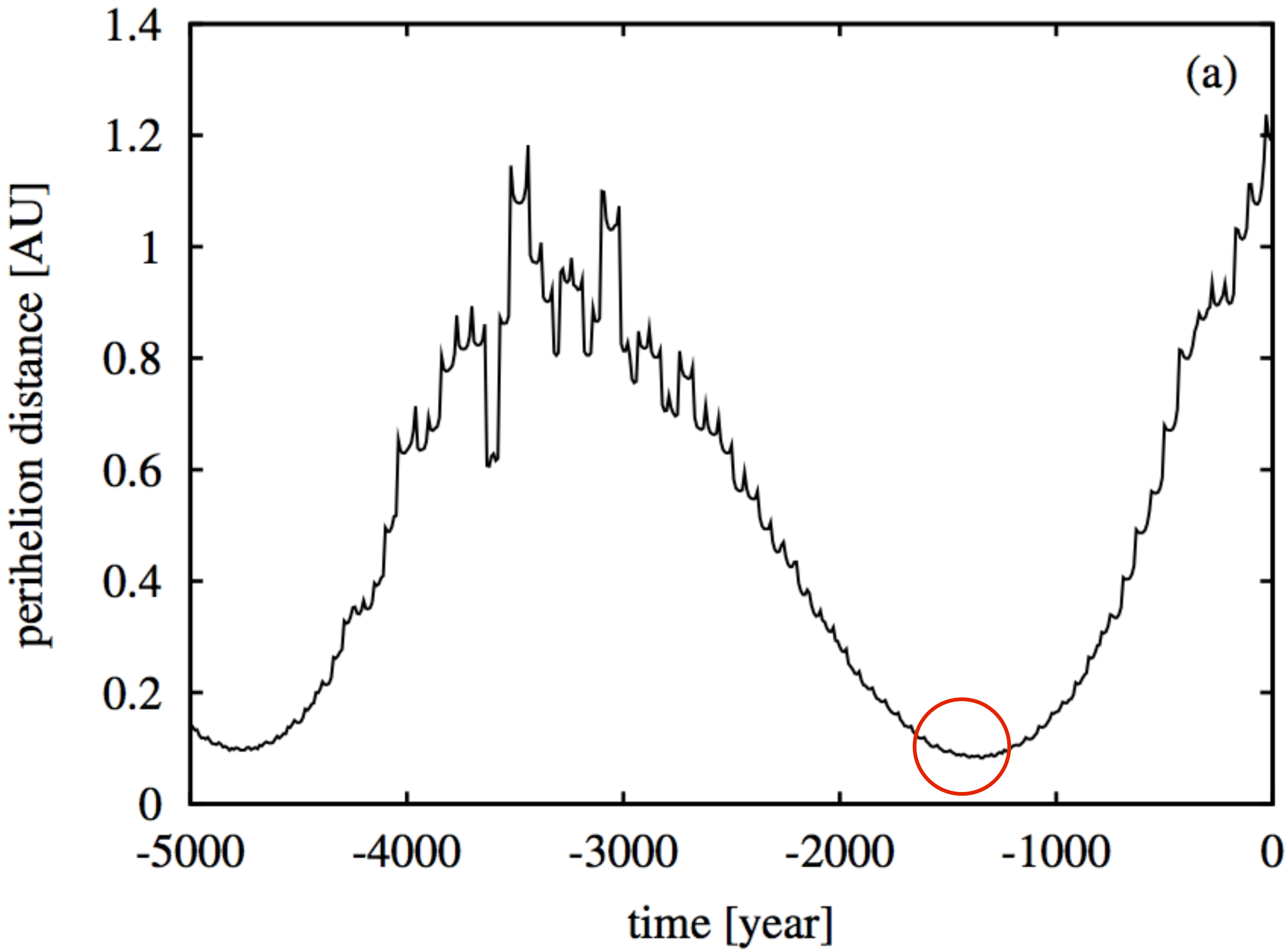
Meteoroids were released at q = 0.8–0.9AU in 1700–1800

(Young Stream: 200–300 years old)

Wiegert & Brown (2005); Abedin et al. (2015)

The minimum $q \approx 0.12$ AU

~1500 year ago



The surface layers should have been heated at the high temperatures (800 K < T < 1200 K)

Neslušan et al. (2013); Fernández et al. (2014)

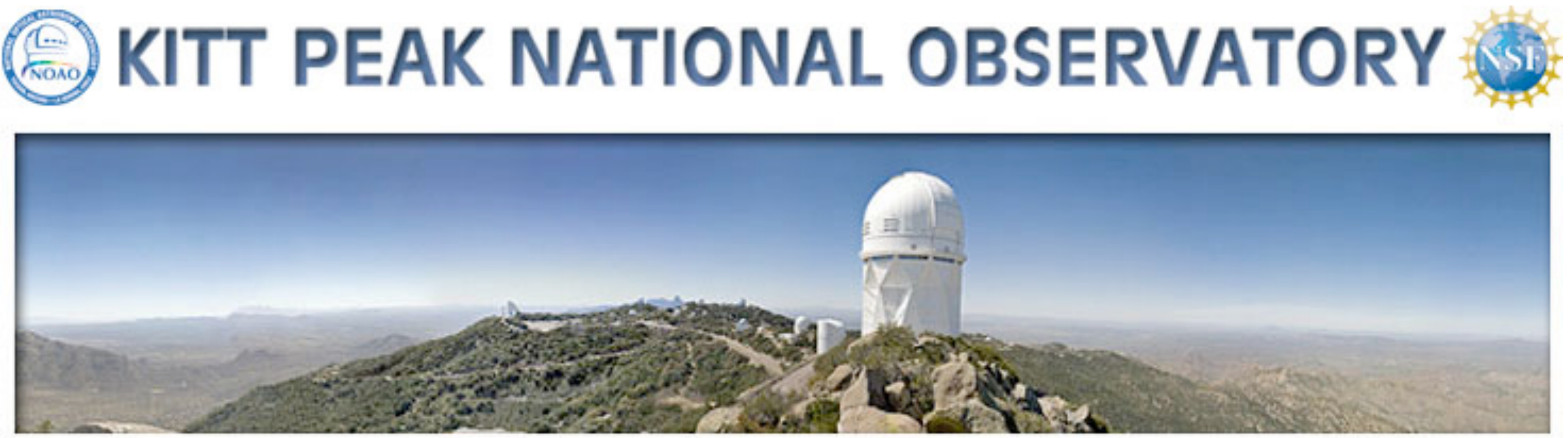
This Study

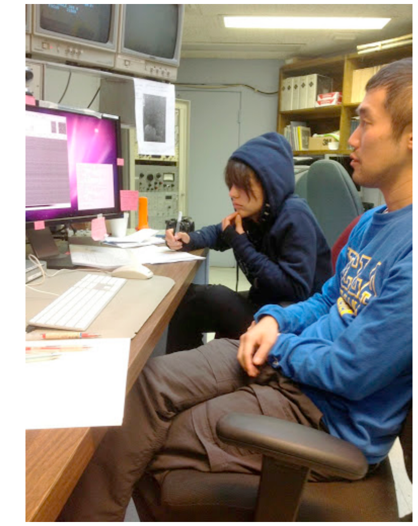
- The Young Quadrantid stream (200-300 years old)
  2003EH1 may still be active ?

- The Small *q* (≈ 0.12AU), 1500 yr ago
  Thermal Process ?

Physical Properties of 2003EH1
- Colors
- Limits on coma activity, size
- Mass loss rate
- Fractional active area on the object
- Rotational period
- Discussion
  The possible relation to the Quadrantid stream

Kasuga & Jewitt 2015





- UT 2013 August 8, 9, 12 and Oct.2

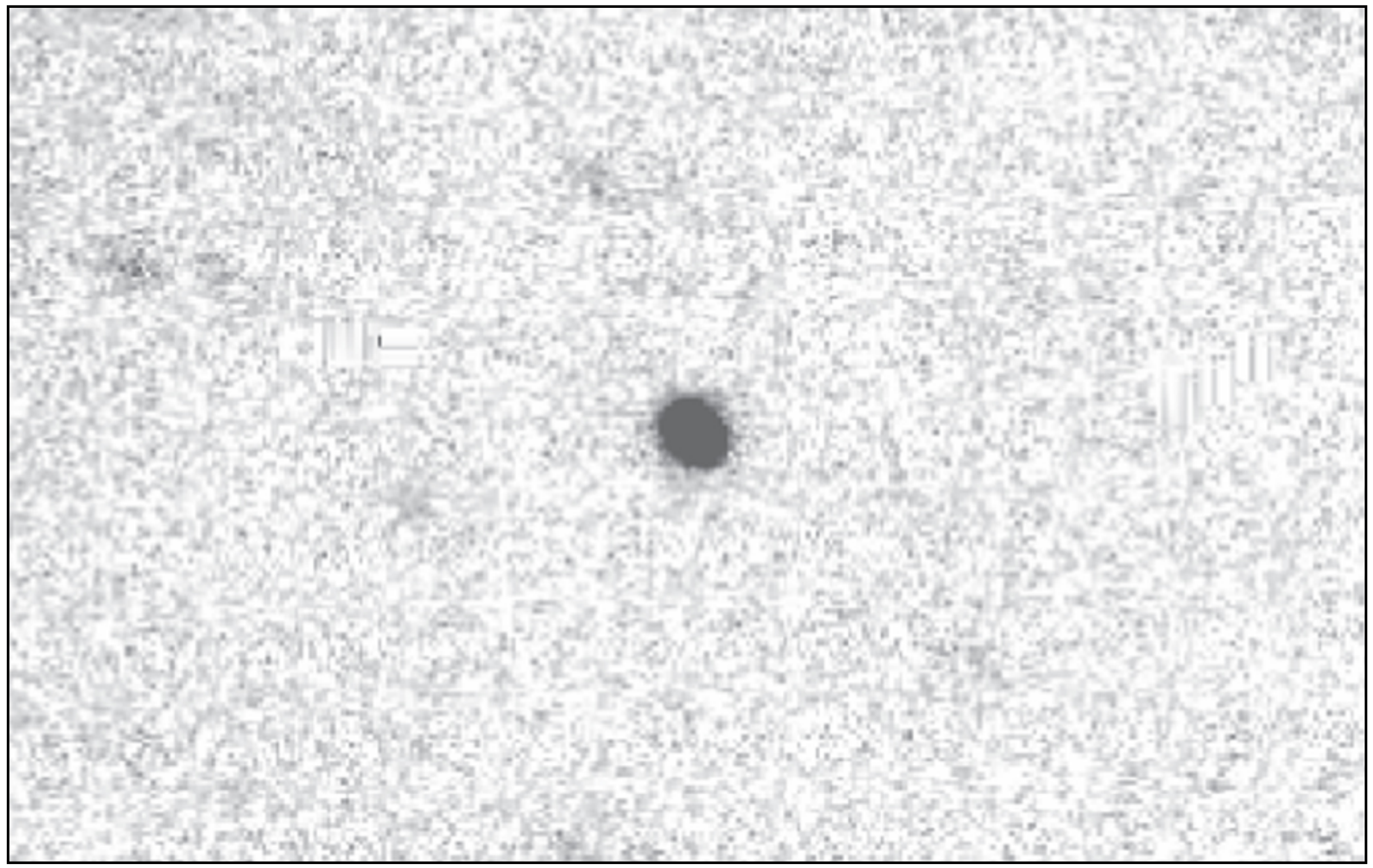
- Telescopes
  - Kitt Peak National Observatory 2.1m (Arizona)
  - Keck-I 10m (Mauna Kea, Hawai'i)

- Filter ... BVR_cI_c

  2003EH1 ... $V \approx$ 21mag
  FWHM $\approx$ 0.”8 to 1.”5

https://www.noao.edu/kpno/

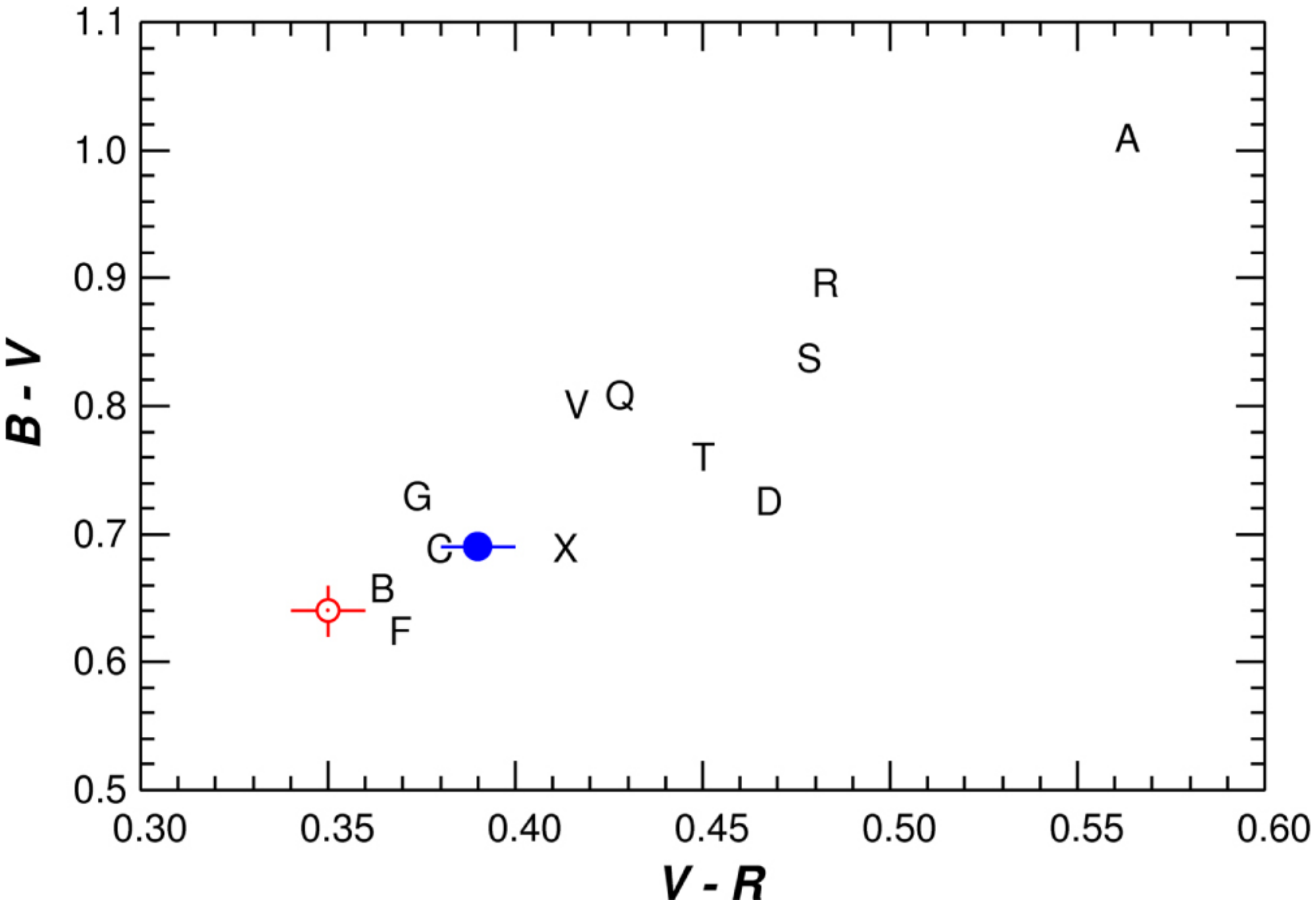
R_C-band image of 2003EH1 (at $r = 2.1$AU) taken by the Keck I on UT 2013 Oct. 2

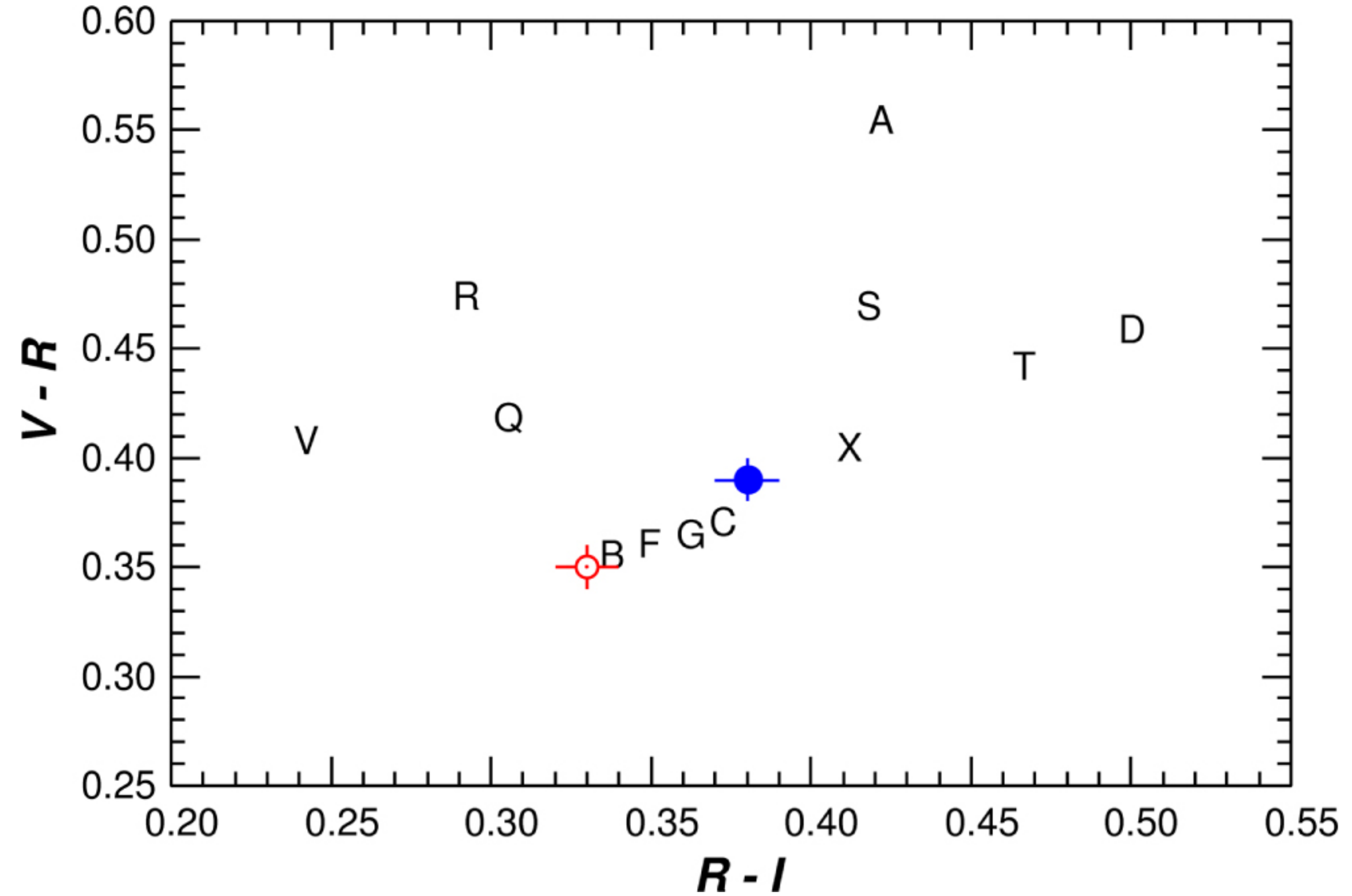


- FWHM ≈ 0."86
- Integration 360s
- 40'' × 25''

- No coma or tail is visible
- Radius $r_e = 2.0 \pm 0.2$ km
  (assuming an albedo $p_R = 0.04$)

Color Plots with Taxonomy

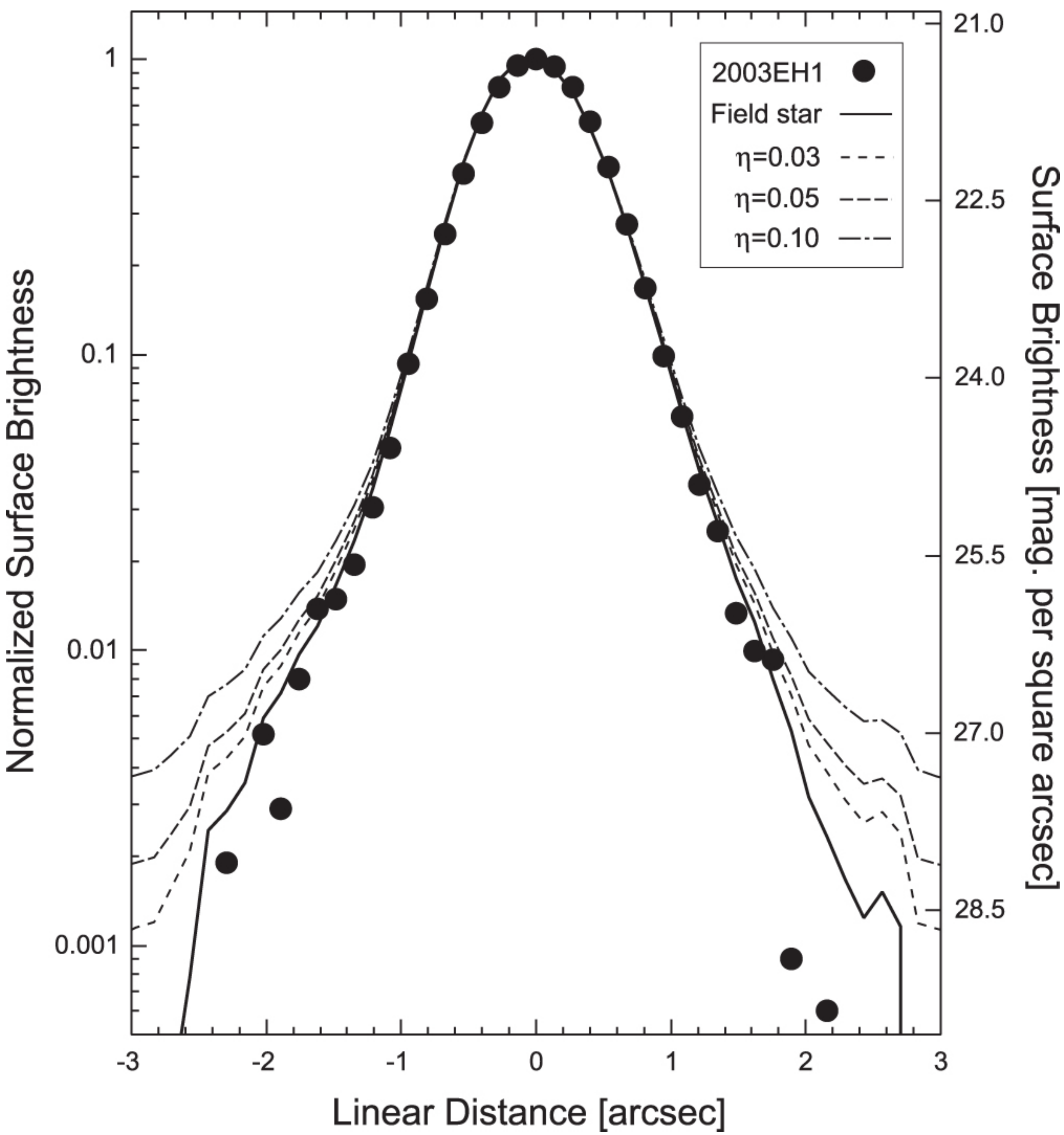




- 2003EH1 is C-type
- Remarkably less red than the cometary nuclei (D-types)
- Past thermal processing:
  ex. near-Sun asteroids ($q \leq 0.25$ AU, T $\geq$ 800 K)
  $$V - R = 0.36 \pm 0.01$$
- Dead comets, presumably result from mantling

(Jewitt 2002, 2013; Lamy et al. 2004)

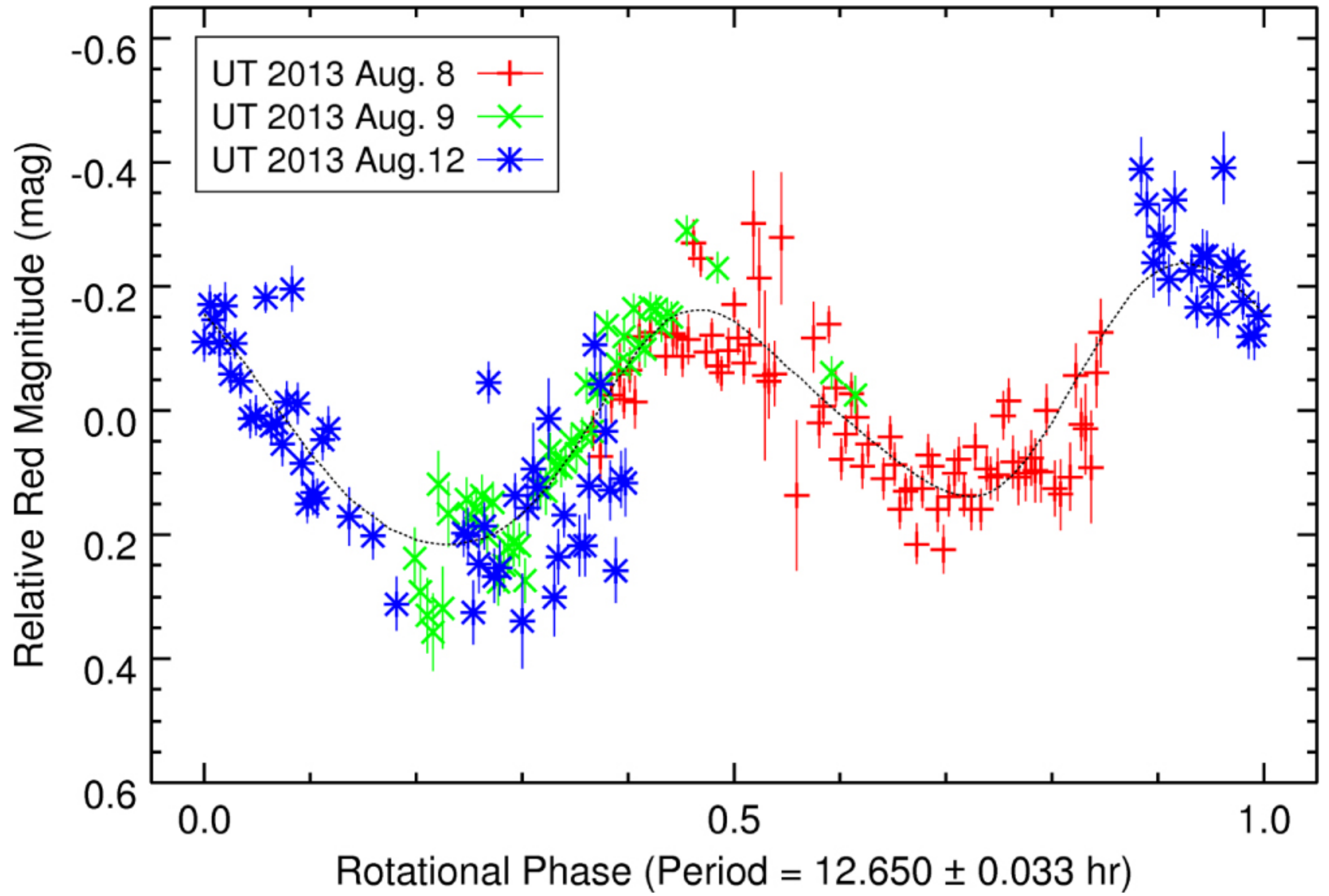
Surface Brightness



- Point-like Profile
- Activity level ≤ 2.5%
- Mass loss rate
  $\sim 2.5 \times 10^{-2}$ kg s^{-1}
- Fraction of active area
  (Water ice can occupy
  fraction of the surface)
  $f_A < 10^{-4}$

cf.
$f_A > 10^{-2}$: (active) comets
Tancredi et al. (2006)

Rotational Period: P_{rot} = 12.650 ± 0.033 hr

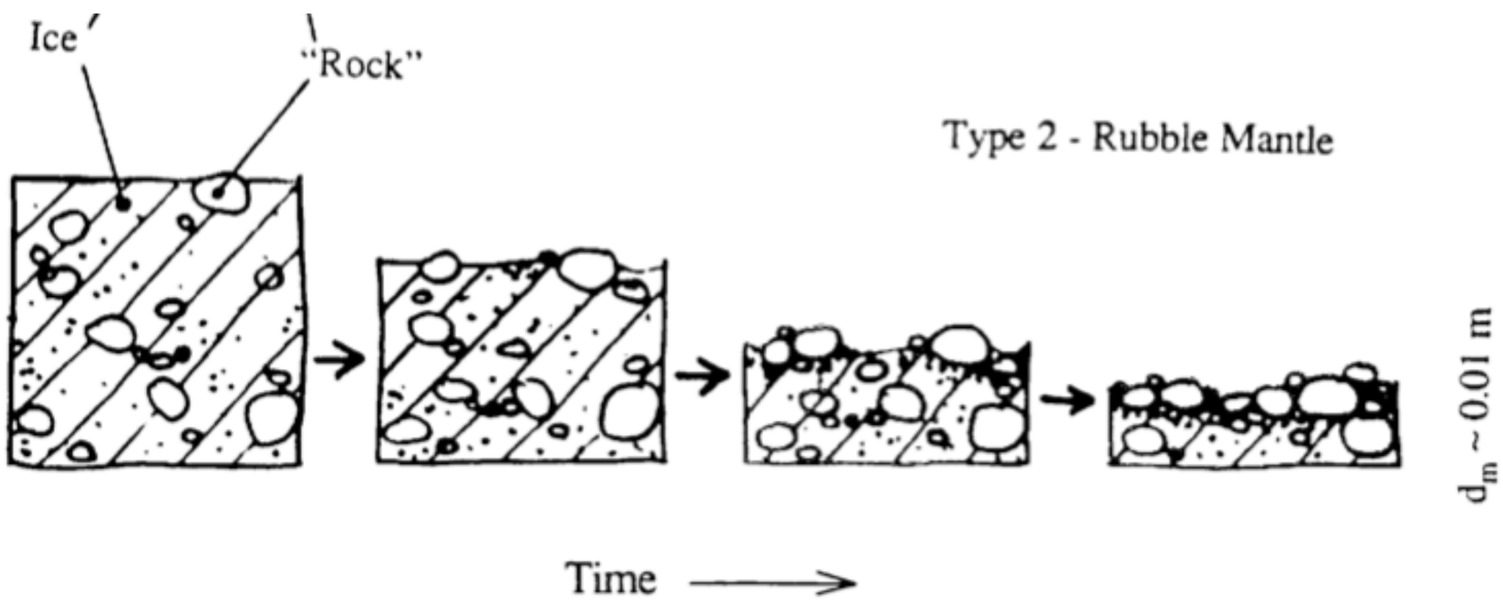


- Minimum axis ratio of 1.50 ± 0.01.
  ≈ typical cometary nuclei (tend to be elongated, a/b ≥ 1.5)

Jewitt (2004)

Surface & Interior

- Surface: Inert
  - → Choked by rubble mantle ($0.3 < \tau < 100$ yr)
    - → Very low (or absent) present-day mass loss



- Interior: Ice may survive
  - → Heat conduction: $\tau_h \sim 10^6$–10^7 yr $>$ $\tau_{JFC} \sim 10^5$ yr

(Levison & Duncan 1994)

2003EH1 looks dead, but may still alive

Discussion

How had the Quadrantid meteoroid streams been produced ?

open question

- The present-day activity (measured)

  too small → 10^8 kg << 10^{13} kg (stream mass)

  (Jenniskens 2006)

- The term suggested by simulations

  (at q = 0.8–0.9AU, 200–300yr ago)

  (Wiegert & Brown 2005; Abedin et al,2015)

  → takes 30 years

Mass supplied by volatile-driven process out of equilibrium ?
(e.g. cometary outbursts or break-ups)

Thermal processing

Low contents of Na (sodium) in Quadrantid meteors ?

- 2003EH1 at $q = 0.12$AU (1500 years ago)

  800 K < T < 1200K

Example;

- Phaethon at $q = 0.14$AU

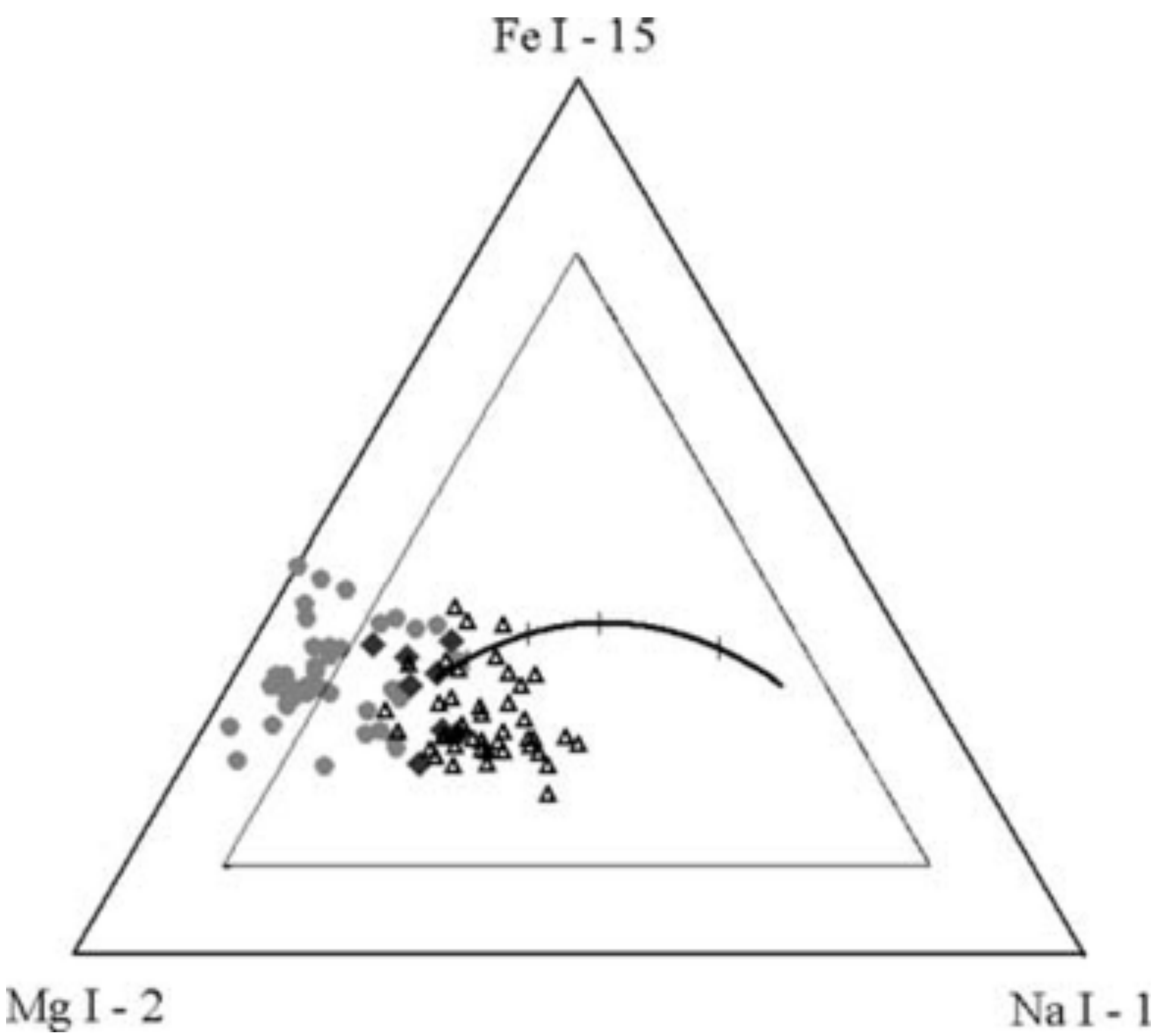
  750 K < T < 1100K

Ohtsuka et al.(2009)

Na depletion in Geminid meteors

e.g. Kasuga et al.(2005); Borovicka et al.(2005)

Na is less depleted than in the majority of Geminid meteors



♦ ... Quadrantids

◯ ... Geminids

Less thermal process on 2003EH1 than on Phaethon

Dynamical lifetime (at small *q*)

- 2003EH1 ... 10^5 yr

(≈ a few 100yr in the last 5000yr)

Neslušan et al. (2013)

- Phaethon ... $10^{6\text{-}7}$ yr

Koten et al.(2006); Borovička et al. (2010)

Summary

1. The absolute red magnitude, $m_R(1, 1, 0) = 15.82 \pm 0.17$ mag, corresponds to an effective radius $r_e = 2.0 \pm 0.2$ km assuming a red geometric albedo $p_R = 0.04$. The ratio of the nucleus mass to the Quadrantid stream mass is ~3–6, although uncertainty remains because both masses are approximate.

2. The surface brightness profile is point-like, limiting the fractional light scattered by steady-state, near-nucleus coma to $\leq 2.5\%$. The maximum mass loss rate deduced from a model fitted to the profile is $\sim 2.5 \times 10^{-2}$ kg s^{-1}. Water ice can occupy a fraction of the surface no larger than $f_A < 10^{-4}$.

3. The two-peaked rotational light curve has a period $P_{rot} = 12.650 \pm 0.033$ hr. The photometric range, $\Delta m_R = 0.44 \pm 0.01$, indicates a minimum axis ratio of 1.50 ± 0.01.

4. The optical colors ($B - V = 0.69 \pm 0.01$, $V - R = 0.39 \pm 0.01$, and $R - I = 0.38 \pm 0.01$) are slightly redder than the Sun and consistent with the mean colors of dead or dormant cometary nuclei.

5. Current dust production from 2003 EH1 is orders of magnitude too small to supply the mass of the Quadrantid core meteoroid stream in the 200–500 year dynamical lifetime. If 2003 EH1 is the source of the Quadrantids, we infer that mass must be delivered episodically, not in steady-state.

Kasuga & Jewitt (2015), *AJ*, Vol.150, 152(10pp)