Space weathering and the color-color diagram of Plutinos and Jupiter Trojans

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Relevant References:
.2015. Space weathering and the color-color diagram of Plutinos and Jupiter Trojans. *Icarus, 248, 1, 222-229.*
.2012. Space weathering and the color indexes of minor bodies in the outer Solar System. *Icarus, 221, 1, 12-19.*

Summary

- Introduction

  Nature/Nurture problem and what about Trojans and Plutinos

  – Color-Color diagrams

- Two processes in competition
  – resurfacing by collisions; timescales
  – surface weathering by ion bombardment; timescales

- Conclusions

NATURE vs. NURTURE

•surfaces of small bodies in the outer Solar System are rich in organic compounds (e.g. Barucci et al., 2008) –> can be responsible for red spectral slopes (colors) (Cruikshank et al., 1998; Doressoundiram et al., 2008)

Organics

- primary native component accreted during planetesimal formation
- dust deposition
- secondary component that is byproduct of ion and photon irradiation of simpler C-bearing volatile ices (Dalle Ore et al., 2011)

NURTURE

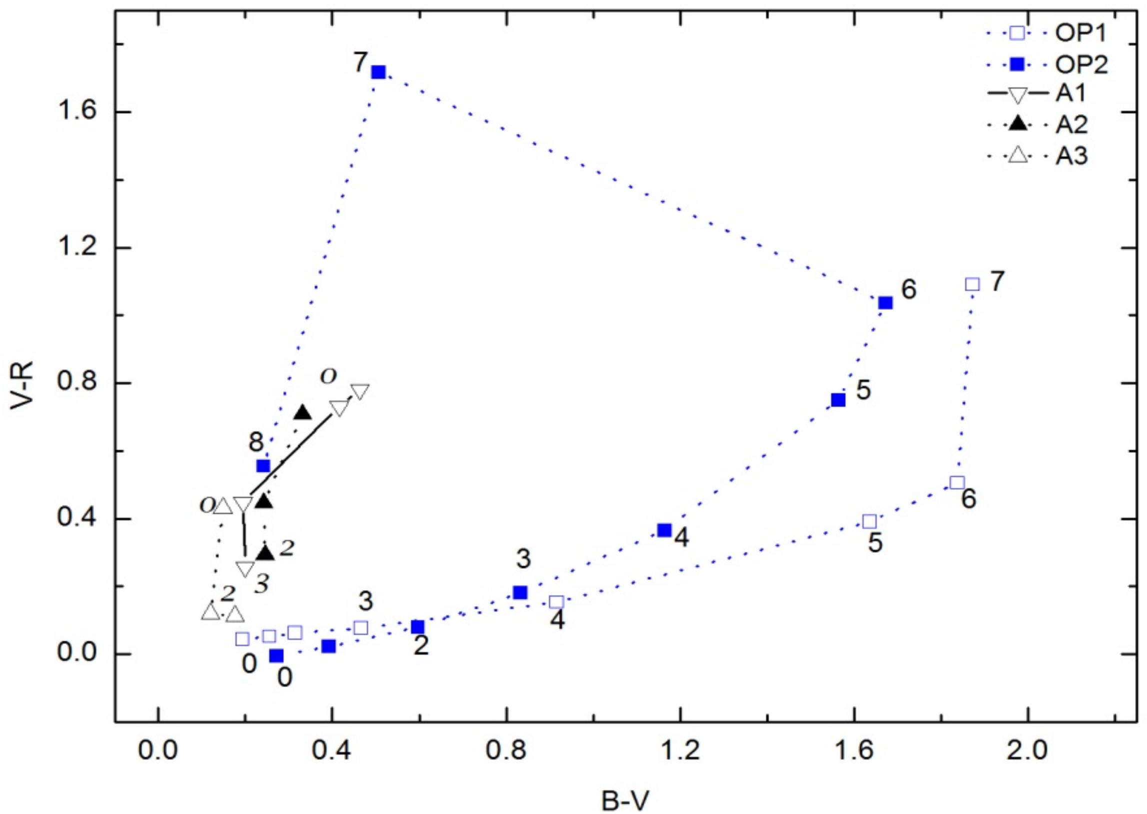
- space weathering (e.g. energetic ion bombardment) can produce red colored materials starting from spectrally flat ices
- resurfacing restores the original colors

→ spectral variety of those small bodies

NATURE

- different colors are due to the different primordial composition of different objects

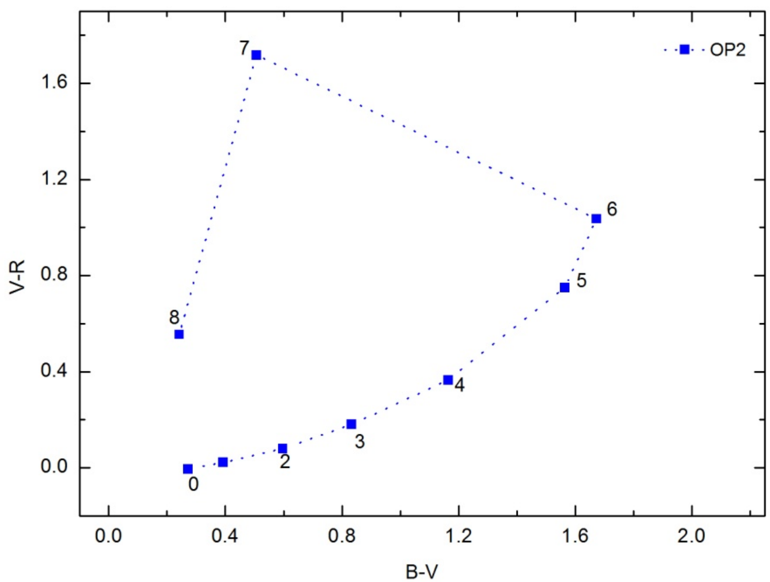
LABORATORY EXPERIMENTS AND COLOR MODIFICATION:



Color-color diagram for laboratory irradiated sample(s).(Kanuchova et al. 2012)

Our Template:

Polystyrene irradiated with different ion fluences
(Kanuchova et al., 2012)



No	F ions/cm^2	D eV/16u	solar wind timescales [yrs] at 5 AU	solar wind timescales [yrs] at 40 AU
1	6.3×10^{12}	1.2	7.5	4.5×10^{2}
2	1.9×10^{13}	3.7	2.2×10^{1}	1.4×10^{3}
3	3.8×10^{13}	7.4	4.3×10^{1}	2.7×10^{3}
4	7.5×10^{13}	14.7	8.5×10^{1}	5.4×10^{3}
5	1.5×10^{14}	29.4	1.8×10^{2}	1.1×10^{4}
6	2.3×10^{14}	45.1	2.8×10^{2}	1.8×10^{4}
7	6.0×10^{14}	117.6	6.8×10^{2}	4.3×10^{4}
8	4.3×10^{15}	842.5	5.0×10^{3}	3.2×10^{5}

Characteristics of the sample irradiated in laboratory and used in the model.
Columns report: step of irradiation (No), 400 keV Ar^{++} ion fluence, total energy dose, solar wind timescales at 5 AU and 40AU for 1keV protons in years .

MODEL WITH TWO SURFACE COMPONENTS :

1 Material characterized by a flat spectrum - i.e. having solar colors, these can be for instance pure methane (high albedo) or completely dehydrogenated carbons (albedo near to zero)

2 Materials whose colors have been affected by energetic processing (e.g. irradiated methane)

SPACE WEATHERING MODEL

- Based on laboratory experiments
- An appropriate combination of resurfacing by impacts or even sublimation and solar wind/cosmic ion bombardment weathering can reproduce the whole range of colors observed on the outer Solar System small bodies

TWO-COMPONENTS MODEL OF COLOR INDEX

Observed reflectance is a linear combination of:

•material with flat spectrum, different visual albedo
•material exposed to the cosmic radiation

•Resulting color index:

$$B{-}V = 2.5Log\frac{XRefl_V1 + YRefl_V2}{XRefl_B1 + YRefl_B2},$$

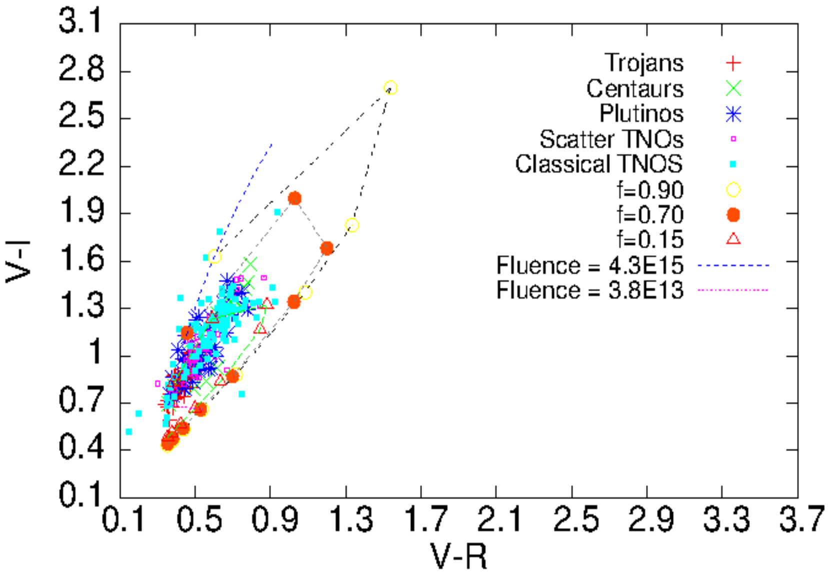
$$X + Y = 1$$

COLOR INDEX

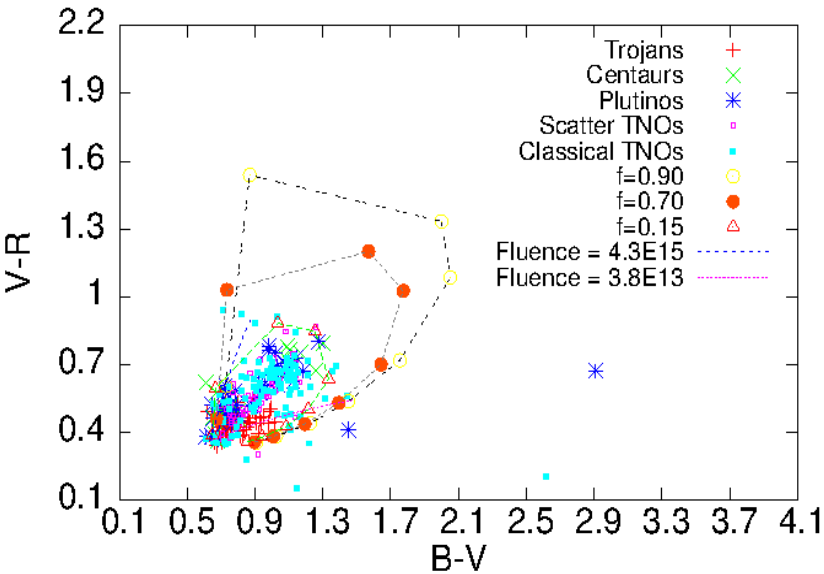
$$V - R = 2.5\log\frac{Refl_R}{Refl_V}$$

$Refl_x$ - diffused reflectance measured at selected wavelength

albedo 1: 4%



Trojans
Centaurs
Plutinos
Scatter TNOs
Classical TNOS
f=0.90
f=0.70
f=0.15
Fluence = 4.3E15
Fluence = 3.8E13
V-I
V-R
3.1
2.8
2.5
2.2
1.9
1.6
1.3
1
0.7
0.4
0.1
0.1 0.5 0.9 1.3 1.7 2.1 2.5 2.9 3.3 3.7



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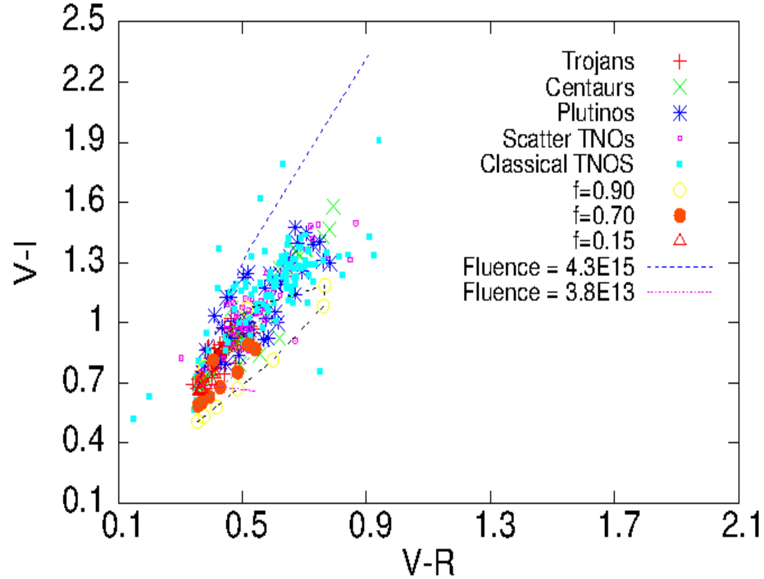
albedo 1: 100%



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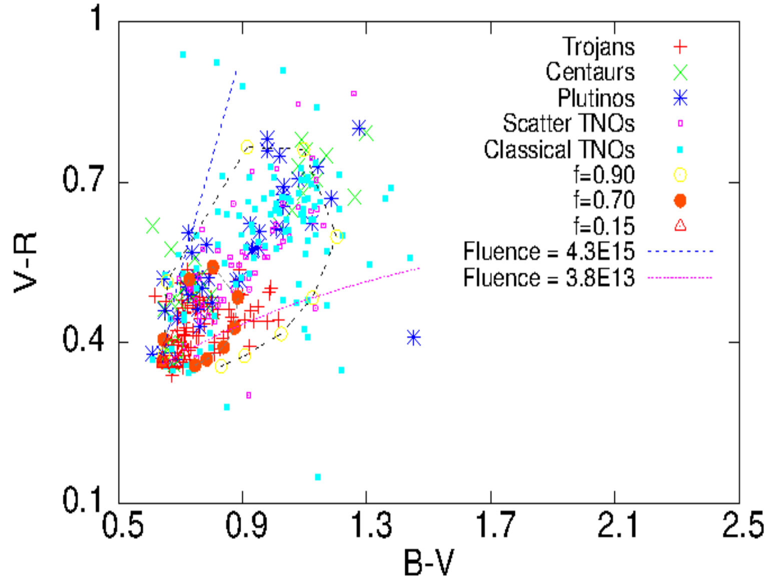

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JUPITER TROJANS and PLUTINOS

What do we observe
• red appearance

MBOSS - The minor bodies in the outer Solar System database **Hainaut and Delsanti, 2002**

•difference in the slope of two distributions

•The presence of complex organic material is believed to be the origin of the dark and red appearance

•Resonant populations (3:2 Neptune, 1:1 Jupiter)

•The surface properties of two groups will reflect the difference in heliocentric distance at which they are located

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Jupiter Trojans would be more altered than more distant Plutinos

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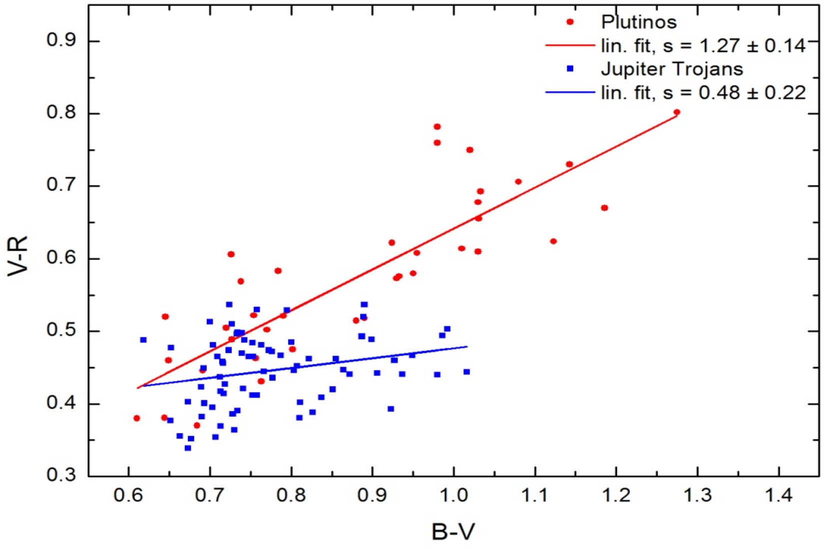

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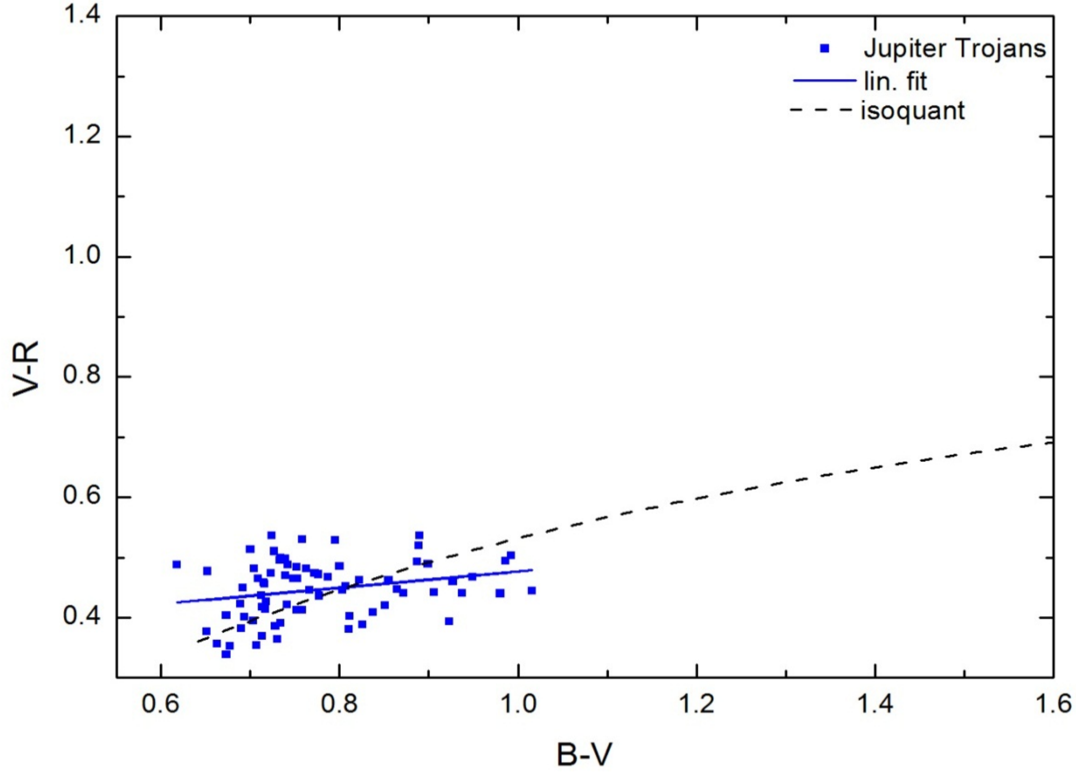
Isoquant

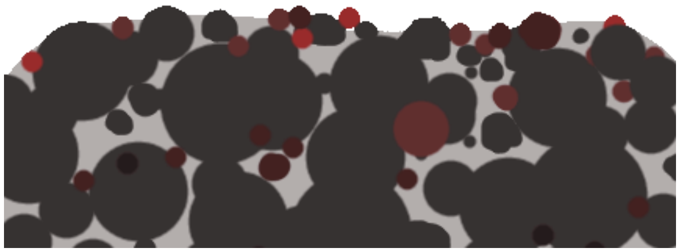
A theoretical trend of color distribution of objects differing in the amount of surface component 2 but weathered to the same level (the same amount of tiime exposure)

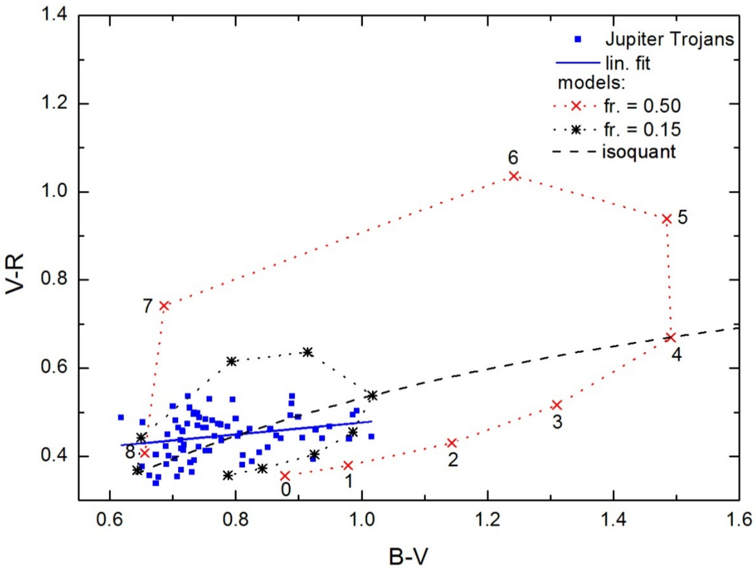
i.e. fixed reflectance of component 2 and changing X/Y ratio

ISOQUANT FOR TROJANS



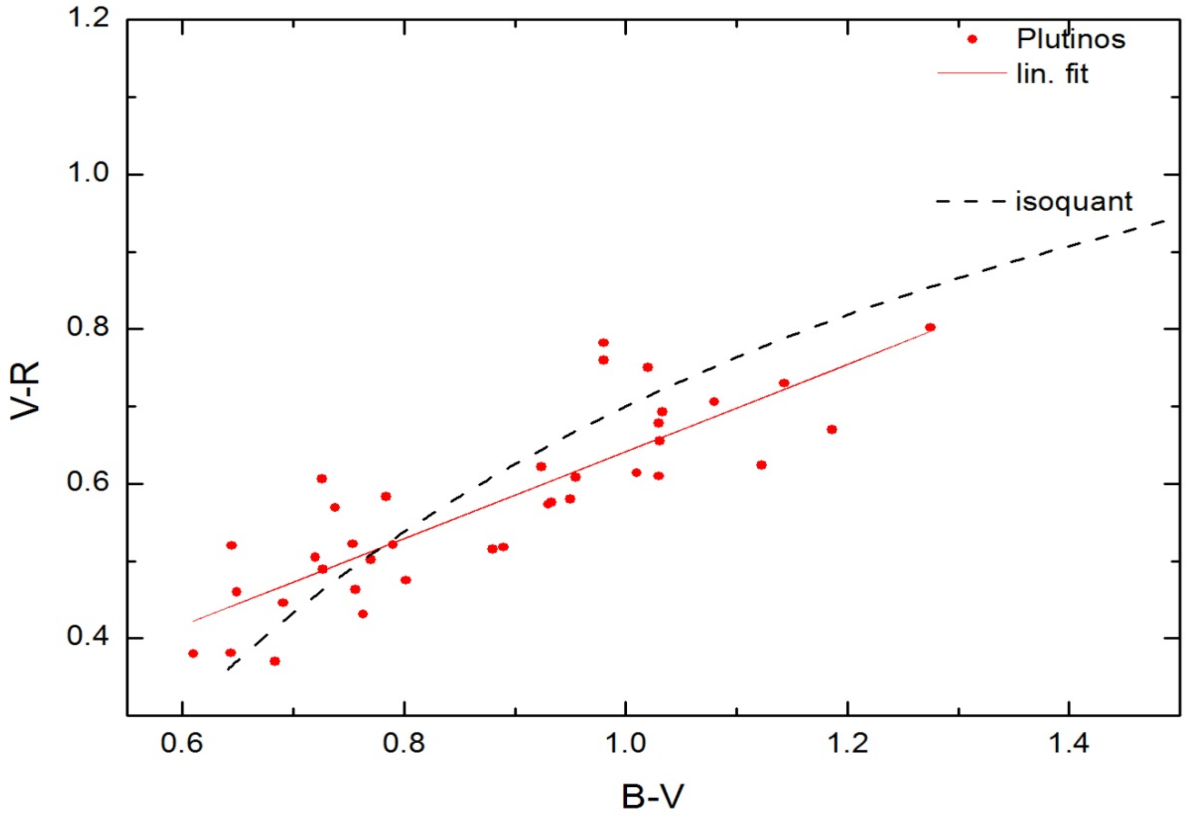
TROJANS



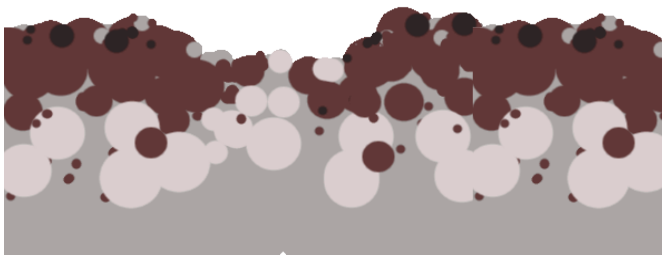


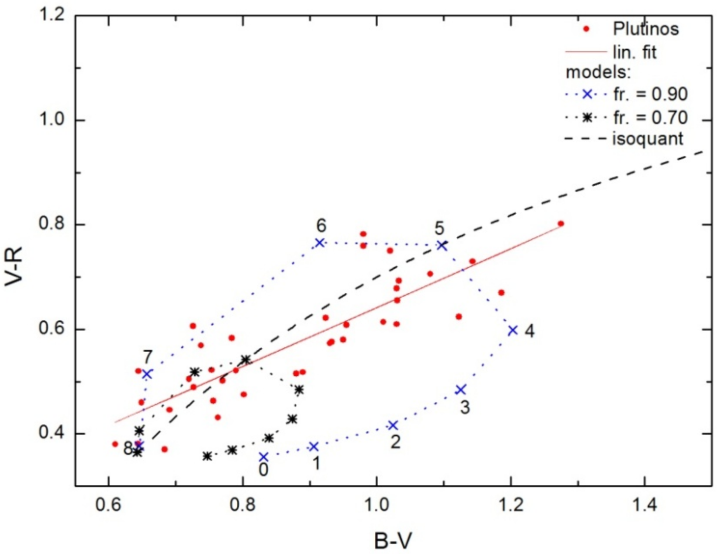
- "Mean (average) level of space weathering" of Trojans - around **10^2 yrs**
- colors of all Trojan asteroids can be covered using the model with a fraction of RED processed carbonaceuos matter smaller than **15%**, the rest is (already) **neutral and dark**
- Large background Trojans tend to be redder (Roig et al., 2008)
- Therefore faster re-juvenisation processes must expose red material to the surface

ISOQUANT FOR PLUTINOS



PLUTINOS





- “Mean (average) level of space weathering“ of Plutinos - around **10^4 yrs**
- For varying values of received dose, to contain all the objects within our model a large fraction of processed carbonaceous matter is needed - about **90%**

COLLISIONAL RESURFACING

τ collisional timescale – the time, in which the whole surface of a body is modified by collisions

$\dot{S}_a$ specific rate of collisional gardening

$\dot{S}$ -the rate of surface modifications

$$\tau = \frac{1}{\dot{S}_a}$$ (Gill-Hutton, 2002)

$$\dot{S}_a = \frac{\dot{S}}{4\pi R^2}$$

$$\dot{S} = \int_{a_{min}}^{a_{max}} \dot{N}(a)\ A_E(a)\ da$$

$$\dot{N}(a) = P_I\ (R+a)^2\ dN(a)$$

$$V_g = K_1\ \left(\frac{m}{\rho}\right)\left(\frac{a\ g(a)}{v^2}\right)^{\frac{-3\mu}{2+\mu}}$$

(Crater volume scaling from Holsapple 1993)

PARAMETERS USED IN THE τ ESTIMATION:

R - radius of target body

$\dot{N}(a)$ - number of collisions

dN(a) - derived from the power-law size distribution of Trojans (Jewitt et al., 2000) and Plutinos (Kenyon et al., 2008)

a - radius of an impactor : a_{min} 0.1m – 100m

a_{max} when TB is not disrupted, depends on ß

$A_E(a)$ - area covered by ejecta (paraboloid approximation)

P_I - intrinsic probability of collision: for Trojans $7x10^{18}$ $yr^{-1}km^{-2}$

for Plutinos $3.9x10^{-22}$ $yr^{-1}km^{-2}$

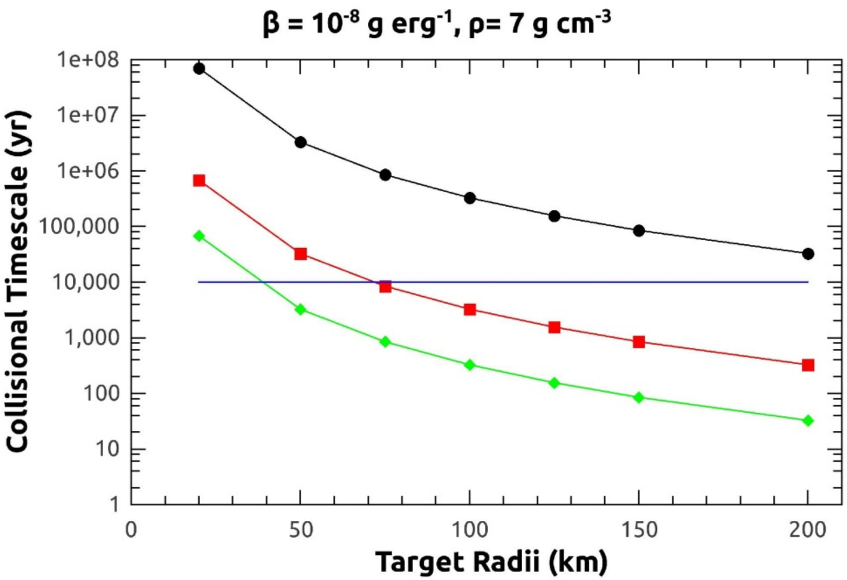
ρ - equal density of TB and IB: 1 g cm^{-3} ; to 7 g cm^{-3}

ß - crater excavation coefficient: 10^{-8} g erg^{-1} to $5x10^{-6}$ g erg^{-1}

v - impact relative velocity – proportional to the orbital velocity at heliocentric distance *r*

m - mass of an impactor

PLUTINOS



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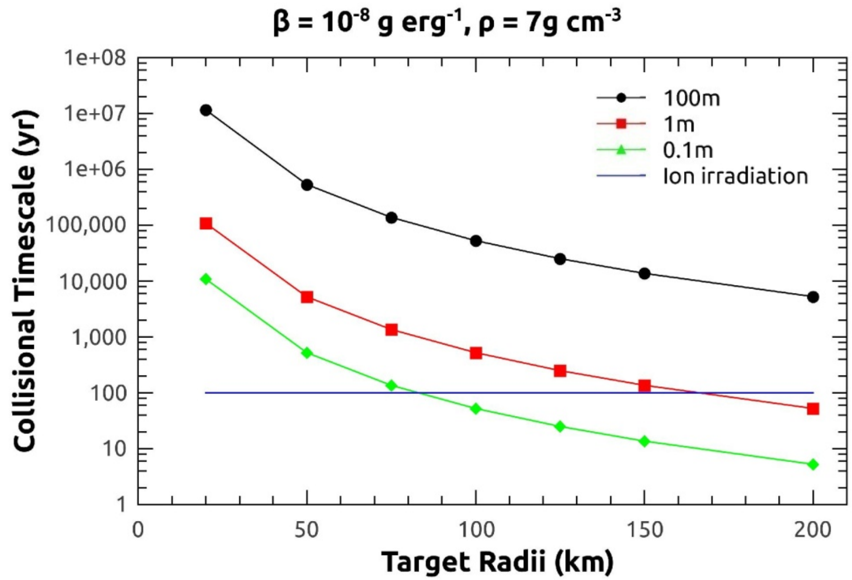
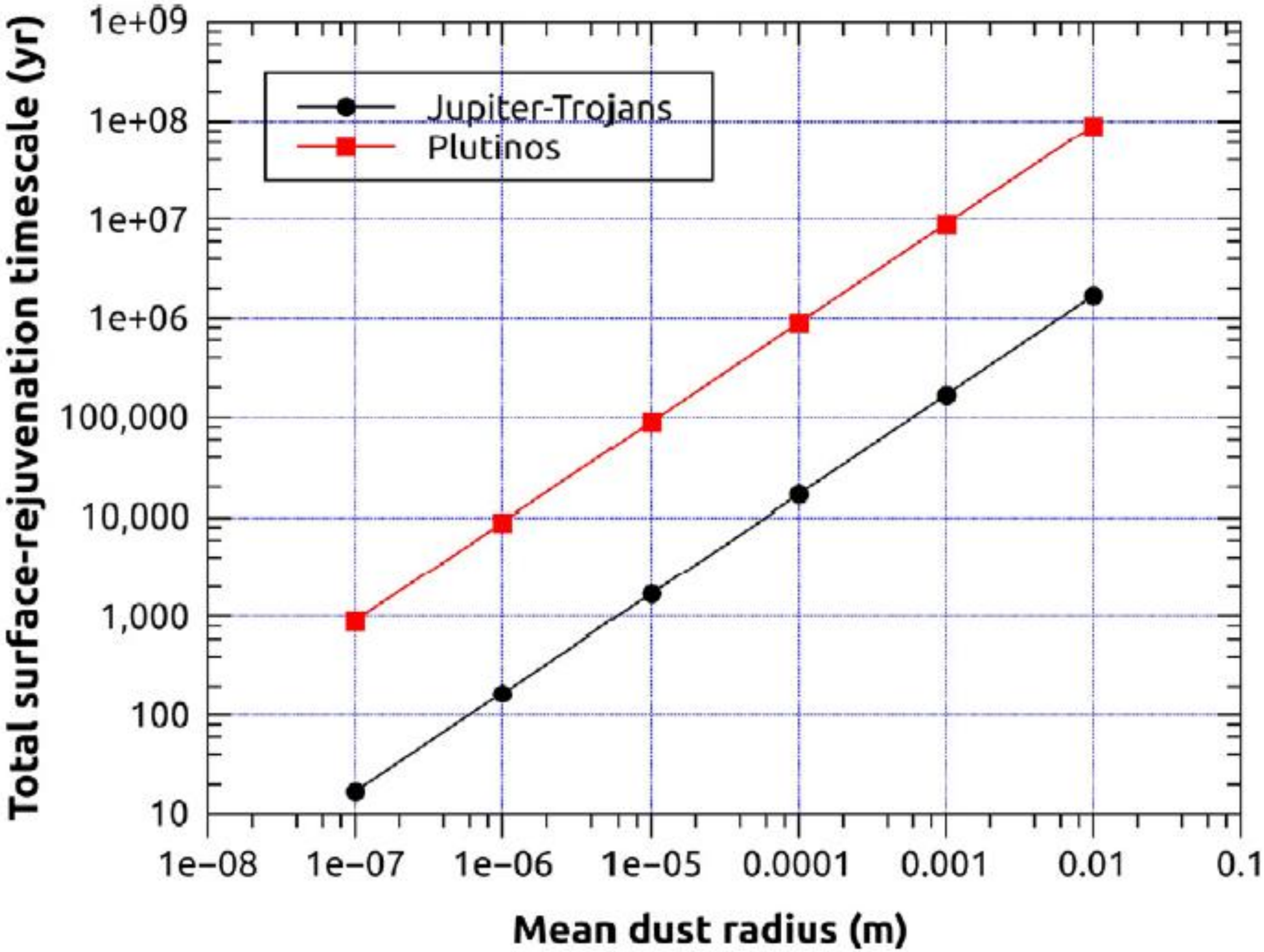


- our approximation does not take into account different crater morphologies (due to impact angle variations) → estimation is in order of magnitudes
- collisional timescale:
  - depends on the chosen size of the smallest impactors in the population
  - gets longer for smaller target bodies which may explain why large background Trojans tend to be redder (Roig et al., 2008), depending on the albedo of the smaller bodies.


Total surface-rejuvenation timescale (yr)
Mean dust radius (m)
Jupiter-Trojans
Plutinos
1e+09
1e+08
1e+07
1e+06
100,000
10,000
1,000
100
10
1e−08
1e−07
1e−06
1e−05
0.0001
0.001
0.01
0.1

CONCLUSIONS

- We have presented the curves in the color-color diagram (isoquants) describing the balance between space weathering and collisional resurfacing for two populations: Plutinos and Jupiter Trojans

- We have estimated the average time of the surface exposure of Trojans to be around 10^2 years, while the average exposure time of Plutinos is much higher: around 10^4 years

- Even though the Trojans are affected by higher ion flux than more distant Plutinos, thanks to the fast resurfacing processes the fresh material can be exposed to the ions for shorter time, explaining the difference in the correspondent isoquant and therefore the slope in the color-color diagram

- We believe that although our model well explains the observed color differences among the two populations, it still does not reject a contribution from initial composition or early processing of surface and sub-surface layers (by thermal or impact-induced alterations).

- Knowledge of albedo is of a key role.