Issue No. 36 *July 2004*

DISTANT EKOs

The Kuiper Belt Electronic Newsletter

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CONTENTS

NEWS & ANNOUNCEMENTS

With the recent orbit insertion, Cassini now begins its tour of Saturn. On the way, it took some spectacular images of Phobe, which some argue has a Kuiper Belt connection:
`http://saturn.jpl.nasa.gov/news/press-releases-04/20040614-pr-a.cfm`
`http://www.nasa.gov/mission_pages/cassini/media/cassini-062304.html`

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In the May newsletter, I repeated the statement form a press release that 2003 VB12 (Sedna) may be the minor planet with the slowest known rotation period (possibly 20-50 days). It was subsequently brought to my attention that 288 Glauke may lay claim to that title with a period of about 50 days.

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There were 7 new TNO discoveries announced since the previous issue of *Distant EKOs*:

2004 HE64, 2004 DF77, 2004 DG77, 2004 EG96, 2004 EH96, 2004 EJ96, 2004 FU148

and no new Centaur/SDO discoveries.

Reclassified objects:

2003 GF55 (TNO $\rightarrow$ SDO)
2003 QE112 (SDO $\rightarrow$ TNO)
2003 QH91 (SDO $\rightarrow$ TNO)
2003 QY90 (SDO $\rightarrow$ TNO)

Re-identified objects:

2004 HE64 (= 2004 EJ96)

Current number of TNOs: 797 (and Pluto & Charon, and 12 other TNO binary companions)
Current number of Centaurs/SDOs: 147
Current number of Neptune Trojans: 1

Out of a total of 945 objects:

465 have measurements from only one opposition
352 of those have had no measurements for more than a year
196 of those have arcs shorter than 10 days

(for more details, see: `http://www.boulder.swri.edu/ekonews/objects/recov_stats.gif`)

PAPERS ACCEPTED TO JOURNALS

ESO Large Program on Physical Studies of Trans-Neptunian Objects and Centaurs: Final Results of the Visible Spectrophotometric Observations

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The Large Program on physical studies of TNOs and Centaurs, started at ESO Cerro Paranal on April 2001, has recently been concluded. This project was devoted to the investigation of the surface properties of these icy bodies through photometric and spectroscopic observations. In this paper we present the latest results on these pristine bodies obtained from the spectro photometric investigation in the visible range.

The newly obtained spectrophotometric data on 3 Centaurs and 5 TNOs, coming from 2 observing runs at the Very Large Telescope (VLT), show a large variety of spectral characteristics, comprising both gray and red objects in the two different populations. A very broad and weak absorption feature, centered around 7000 Å, has been revealed in the spectrum of the gray TNO 2003 AZ84. This absorption is very similar to a feature observed on low albedo main belt asteroids and attributed to the action of the aqueous alteration process on minerals. This process was previously also claimed as the most plausible explanation for some peculiar visible absorption bands observed on 2000 EB173 and 2000 GN171 in the framework of the Large Program (Lazzarin et al., 2003, de Bergh et al., 2004). This detection seems to reinforce the hypothesis that aqueous alteration might have taken place also at such large heliocentric distances.

We also report the results of a spectroscopic investigation performed outside the Large Program on the very interesting TNO 2000 GN171 during part of its rotational period. This object, previously observed twice in the framework of the Large Program, had shown during the early observations a very peculiar absorption band tentatively attributed to aqueous alteration processes. As this feature was not confirmed in a successive spectrum, we recently repeated the investigations of 2000 GN171, finding out that it has an heterogeneous composition.

Finally an analysis of the visible spectral slopes is reported for all the data coming from the Large Program and those available in literature.

Published in: Astronomy & Astrophysics, 421, 353 (2004 July)

For preprints, contact `fornasier@pd.astro.it`

or on the web at

`http://www.edpsciences.org/articles/aa/abs/2004/25/aa0260-04/aa0260-04.html`

The Size Distribution of Trans-Neptunian Bodies

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We search 0.02 deg^2 of the invariable plane for trans-Neptunian objects (TNOs) 25 AU or more distant using the Advanced Camera for Surveys (ACS) aboard the Hubble Space Telescope. With 22 ksec per pointing, the search is $> 50\%$ complete for $m_{606\mathrm{W}} \leq 29.2$. Three new objects are discovered, the faintest with mean magnitude $m = 28.3$ (diameter ≈ 25 km), which is 3 mag fainter than any previously well-measured Solar System body. Each new discovery is verified with a followup 18 ksec observation with the ACS, and the detection efficiency is verified with implanted objects. The three detections are a factor ~ 25 fewer than would be expected under extrapolation of the power-law differential sky density for brighter objects, $\Sigma(m) \equiv dN/dmd\Omega \propto 10^{\alpha m}$, $\alpha \approx 0.63$. Analysis of the ACS data and recent TNO surveys from the literature reveals departures from this power law at both the bright and faint ends. Division of the TNO sample by distance and inclination into "classical Kuiper belt" (CKB) and "Excited" samples reveals that $\Sigma(m)$ differs for the two populations at 96% confidence, and both samples show departures from power-law behavior. A double power law $\Sigma(m)$ adequately fits all data. Implications of these departures include the following. (1) The total mass of the "classical" Kuiper belt is $\approx 0.010 M_\oplus$, only a few times Pluto's mass, and is predominately in the form of ~ 100 km bodies (barring a secondary peak in the mass distribution at < 10 km sizes). The mass of Excited objects is perhaps a few times larger. (2) The Excited class has a shallower bright-end magnitude (and presumably size) distribution; the largest objects, including Pluto, comprise tens of percent of the total mass whereas the largest CKBOs are only $\sim 2\%$ of its mass. (3) The derived size distributions predict that the largest Excited body should be roughly the mass of Pluto, and the largest CKB body should have $m_R \approx 20$—hence Pluto is feasibly considered to have originated from the same physical process as the Excited TNOs. (4) The observed deficit of small TNOs occurs in the size regime where present-day collisions are expected to be disruptive, suggesting extensive depletion by collisions. The Excited and CKB size distributions are qualitatively similar to some numerical models of growth and erosion, with both accretion and erosion appearing to have proceeded to more advanced stages in the Excited class than the CKB. (5) The lack of detections of distant TNOs implies that, if a mass of TNOs comparable to the CKB is present near the invariable plane beyond 50 AU, that distant population must be composed primarily of bodies smaller than ≈ 40 km. (6) There are too few small CKBOs for this population to be the reservoir of Jupiter-family comet precursors without a significant upturn in the population at diameters < 20 km. With optimistic model parameters and extrapolations, the Excited population could be the source reservoir. Implications of these discoveries for the formation and evolution of the outer Solar System are discussed.

To appear in: Astronomical Journal

Preprints on the web at `http://www.physics.upenn.edu/~garyb/PUBLICATIONS/`

The Size Distribution of Kuiper Belt Objects

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We describe analytical and numerical collisional evolution calculations for the size distribution of icy bodies in the Kuiper Belt. For a wide range of bulk properties, initial masses, and orbital parameters, our results yield power-law cumulative size distributions, $N_C \propto r^{-q}$, with $q_L \approx 3.5$ for large bodies with radii, $r \geq$ 10–100 km, and $q_s \approx 2.5$–3 for small bodies with radii, $r \leq 0.1$–1 km. The transition between the two power laws occurs at a break radius, $r_b \approx$ 1–30 km. The break radius is more sensitive to the initial mass in the Kuiper Belt and the amount of stirring by Neptune than the bulk properties of individual Kuiper Belt objects (KBOs). Comparisons with observations indicate that most models can explain the observed sky surface density $\sigma(m)$ of KBOs for red magnitudes $R \approx 22$–27. For $R \leq 22$ and $R \geq 28$, the model $\sigma(m)$ is sensitive to the amount of stirring by Neptune, suggesting that the size distribution of icy planets in the outer solar system provides independent constraints on the formation of Neptune.

To appear in: Astronomical Journal (2004 October)

Preprints available online at: `http://arxiv.org/abs/astro-ph/0406556`

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The Orbit, Mass, and Albedo of Transneptunian Binary (66652) 1999 RZ_{253}

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We have observed (66652) 1999 RZ_{253} with the Hubble Space Telescope at seven separate epochs and have fit an orbit to the observed relative positions of this binary. Two orbital solutions have been identified that differ primarily in the inclination of the orbit plane. The best fit corresponds to an orbital period, $P = 46.263 \pm {}^{0.006}_{0.074}$ days, semimajor axis $a = 4,660 \pm 170$ km and orbital eccentricity $e = 0.460 \pm 0.013$ corresponding to a system mass $m = 3.7 \pm 0.4 \times 10^{18}$ kg. For a density of $\rho = 1000$ kg m^{-3} the albedo at 477 nm is $p_{477} = 0.12 \pm 0.01$, significantly higher than has been commonly assumed for objects in the Kuiper Belt. Multicolor, multiepoch photometry shows this pair to have colors typical for the Kuiper belt with a spectral gradient of 0.35 per 100 nm in the range between 475 and 775 nm. Photometric variations at the four epochs we observed were as large as $12 \pm 3\%$ but the sampling is insufficient to confirm the existence of a lightcurve.

To appear in: Icarus

Preprint on the web at `http://xxx.lanl.gov/abs/astro-ph/0406588`

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Simultaneous Visible and Near-infrared Time-resolved Observations of the Outer Solar System Object (29981) 1999 TD_{10}

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The outer solar system object (29981) 1999 TD_{10} was observed simultaneously in the R, and J and H bands in September 2001, and in B, V, R, and I in October 2002. We derive $B-V = 0.80\pm0.05$ mag, $V-R = 0.48\pm0.05$ mag, $R-I = 0.44\pm0.05$ mag, $R-J = 1.24\pm0.05$ mag, and $J-H = 0.61\pm0.07$ mag. Combining our data with the data from Rousselot *et al.* (*Astron. Astrophys.* **407**, 1139, 2003) we derive a synodic period of 15.382 ± 0.001 hr in agreement with the period from Rousselot *et al.* Our observations at the same time, with better S/N and seeing, show no evidence of a coma, contrary to the claim by Choi *et al.* (*Icarus* **165**, 101, 2003).

To appear in: Icarus

Preprints on the web at `http://www.noao.edu/noao/library/preprints`

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Water Ice on the Surface of the Large TNO 2004 DW

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We have obtained visible and near infrared spectra of the Trans-Neptunian object 2004 DW, a few days after its discovery, at the Telescopio Nazionale Galileo (TNG). 2004 DW belongs to the plutino dynamical class and has an estimated diameter of about 1600 km, that makes it the largest known object, except Pluto, in the plutino and classical TNO populations. Our data clearly show the 1.5 and 2 μm bands associated to water ice, while the visible spectrum is nearly neutral and featureless. To interpret the available data we modelled the surface composition of 2004 DW with two different mixtures of organics (Titan tholin and kerogen), amorphous carbon and water ice.

To appear in: Astronomy and Astrophysics Letters

For preprints, contact `fornasier@pd.astro.it`

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Small Bodies and Dust in the Outer Solar System

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We present our current understandings of small bodies and dust grains located in the outer Solar System. Small icy bodies — Edgeworth-Kuiper Belt objects (EKBOs) and Oort Cloud objects — orbit the Sun at distances from Neptune's orbit outward to 10^4–10^5 AU. Both EKBOs and Oort Cloud objects are believed to be remnants of planetesimals formed in the proto-planetary disk. They provide

a possible source for icy bodies that enter the inner Solar System and are observed as comets. A possible scenario for the formation and dynamical evolution of icy objects under the influence of gas drag forces and gravitational scattering by proto-planets is briefly discussed.

The outer Solar System plays the role of a corridor for interstellar matter entering into the Solar System. Further dust grains existing beyond Neptune's orbit are produced as ejecta of icy dust particles from the EKBOs due to the impact of interstellar dust grains. Their expected amount and lifetimes are examined. Compared to the extension of the region of planetesimals around the Sun, the region of influence of the solar wind extends to relatively small distances of the order of several hundred AU. But both complexes are coupled through the presence of interstellar dust that depends on the extension and the physical parameters of the heliosphere. The existence of a stronger solar wind in the early stages of the Solar System indicates that the heliosphere in a distant past might have been 10-100 times larger than the current one which possibly influenced the evolution of the planetary system.

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For preprints, contact mukai@kobe-u.ac.jp
Web: http://adsabs.harvard.edu/cgi-bin/nph-bib_query?bibcode=2004AdSpR..34..172M

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Spitzer Observations of the Dust Coma and Nucleus of 29P/Schwassmann-Wachmann 1

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We obtained thermal images and spectra of comet and Centaur object 29P/Schwassmann-Wachmann 1 in late November, 2003. Images at 8, 24 and 70 μm reveal an extensive coma. At 24 μm the coma extends at least 8 arcmin from the nucleus, and exhibits a single jet. The dust production rate is estimated as < 50 kg/s. The 24 to 70 μm color temperature of the coma is 160 K. The debris trail is also detected at 24 μm, and has an optical depth $\sim 7 \pm 3 \times 10^{-9}$. Thermal models fitted to photometry at 8, 24 and 70 μm indicate a nuclear radius of 27 ± 5 km, larger than all previous size estimates, and a geometric albedo of 0.025 ± 0.01, lower than any other Centaur object, but consistent with other comets. Analysis of the jet morphology indicates a rotation period in excess of 60 days. The spectra reveal features at 11.3 and 34 μm which are tentatively identified as emission from olivine, including forsterite. This is the first identification of the minerology of the dust emitted by a Centaur object.

To appear in: Astrophysical Journal Supplement, Spitzer Special Issue
For preprints, contact stansber@as.arizona.edu
or on the web at http://ssc.spitzer.caltech.edu/pubs/journal2004.html

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PAPERS RECENTLY SUBMITTED TO JOURNALS

The Orbit and Albedo of Transneptunian Binary (58534) 1997 CQ_{29}

Keith S. Noll[1], Denise C. Stephens[1], Will M. Grundy[2], David J. Osip[3], and Ian Griffin[4]

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Submitted to: The Astronomical Journal

For preprints, contact noll@stsci.edu

OTHER PAPERS OF INTEREST

The Debris Disc Around τ Ceti: A Massive Analogue to the Kuiper Belt

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An excess of far-infrared emission is seen towards the nearby G8V star τ Ceti, and this has been attributed to orbiting dust particles generated in planetesimal collisions. A new 850 μm image shows that there is indeed such a debris disc, extending out to $\sim$55 AU (15 arcsec) radius. This is the first disc around a Sun-like star of late main-sequence age to be confirmed by imaging. The dust mass is at least an order of magnitude greater than in the Kuiper Belt, although the dimensions of the systems are very similar and the age of τ Ceti exceeds that of the Sun. Modelling shows that the mass in colliding bodies up to 10 km in size is around 1.2 Earth masses, compared with 0.1 $M_\oplus$ in the Kuiper Belt, and hence the evolution around the two stars has been different. One possibility is that τ Ceti has lost fewer comets from the outskirts of the system, compared with the Sun. Alternatively, a greater number of comets could have been forced out by a migrating planet, compared with the case of Neptune in the Solar system. Notably, the disc of τ Ceti fits the expected decline with time compared to that of the younger nearby star ϵ Eridani. Among these three stars, the Sun would then be the case with the least dust and a 'minimal Kuiper Belt' — a situation which may be beneficial in terms of less bombardment and better stability for life.

Published in: Monthly Notices of the Royal Astronomical Society, 351, L54

For preprints, contact jsg5@st-andrews.ac.uk

or on the web at

http://adsabs.harvard.edu/cgi-bin/nph-bib_query?bibcode=2004MNRAS.351L..54G

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The Formation and Evolution of Planetary Systems: First Results from a Spitzer Legacy Science Program

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We present 3–160 μm photometry obtained with the IRAC and MIPS instruments for the first five targets from the Spitzer Legacy Science Program "Formation and Evolution of Planetary Systems" and 4–35 μm spectro-photometry obtained with the IRS for two sources. We discuss in detail our observations of the debris disks surrounding HD 105 (G0V, 30 $\pm$10 Myr) and HD 150706 (G3V, $\sim$700 $\pm$300 Myr). For HD 105, possible interpretations include large bodies clearing the dust inside of 45 AU or a reservoir of gas capable of sculpting the dust distribution. The disk surrounding HD 150706 also exhibits evidence of a large inner hole in its dust distribution. Of the four survey targets without previously detected IR excess, spanning ages 30 Myr to 3 Gyr, the new detection of excess in just one system of intermediate age suggests a variety of initial conditions or divergent evolutionary paths for debris disk systems orbiting solar-type stars.

To appear in: Astrophysical Journal Supplement Series (2004 September)
For preprints, contact mmeyer@as.arizona.edu
or on the web at http://xxx.lanl.gov/abs/astro-ph/0406301

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A Computational Procedure to Detect a New Type of High-dimensional Chaotic Saddle and its Application to the 3D Hill's Problem

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A computational procedure that allows the detection of a new type of high-dimensional chaotic saddle in Hamiltonian systems with three degrees of freedom is presented. The chaotic saddle is associated with a so-called normally hyperbolic invariant manifold (NHIM). The procedure allows us

to compute appropriate homoclinic orbits to the NHIM from which we can infer the existence of a chaotic saddle. It also allows us to detect heteroclinic connections between different NHIMs. NHIMs control the phase space transport across an equilibrium point of saddle-centre-sdotsdot sdot -centre stability type, which is a fundamental mechanism for chemical reactions, capture and escape, scattering, and, more generally, 'transformation' in many different areas of physics. Consequently, the presented methods and results are of broad interest. The procedure is illustrated for the spatial Hill's problem which is a well-known model in celestial mechanics and which gained much interest, e.g. in the study of the formation of binaries in the Kuiper belt.

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For preprints, contact H.Waalkens@bris.ac.uk
or on the web at http://arxiv.org/abs/nlin.CD/0403059

THESES

Signatures of Planets in Circumstellar Debris Disks

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Main sequence stars are commonly surrounded by debris disks, composed of cold dust continuously replenished by a reservoir of undetected dust-producing planetesimals. In the outer Solar System, Kuiper Belt (KB) objects produce dust by mutual or interstellar grain collisions.

The orbital evolution of KB dust has been numerically modeled. Its equilibrium radial density distribution can be accurately estimated even though there are inherent uncertainties in the prediction of structure, owing to the chaotic dynamics of dust orbital evolution imposed by resonant gravitational perturbations of the planets. The particle size distribution of dust is greatly changed from the distribution at production, as a result of radiation forces and the perturbations of the planets. The contribution of KB dust to the population of interplanetary dust particles collected at Earth may be as low as a few percent.

Gravitational scattering by giant planets creates an outflow of large grains. We quantify the characteristics of this large-particle outflow in different planetary architectures, discuss its implications for exo-planetary debris disks, and for the interpretation of in-situ dust detection experiments in space probes traveling in the outer Solar System. These outflows may contribute to the clearing of circumstellar debris in planetary systems, affecting the particle size distribution of their local ISM.

In anticipation of future observations of unresolved debris disks with *Spitzer*, we are interested in studying how the structure carved by planets affects the shape of the disk's spectral energy distribution (SED), and consequently if the SED can be used to infer the presence of planets. We numerically calculate the equilibrium spatial density distributions and SEDs of dust disks originated by an outer belt of planetesimals (35–50 AU) in the presence of different planetary configurations, and for a representative sample of chemical compositions. The dynamical models are needed to estimate the enhancement of particles near the mean motion resonances with the planets, and to determine how many particles drift inside the planet's orbit. Based on the SEDs and predicted *Spitzer* colors we discuss what types of planetary systems can be distinguishable from one another.

Dissertation directed by Renu Malhotra.
Ph.D. awarded in June, 2004 from the University of Arizona.
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The Behaviour of Small Bodies in the Outer Solar System

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A study is made of the dynamical behaviour of Centaur objects over time. In order to properly analyse the results of the study, a new classification scheme is developed which allows Centaurs with different orbital characteristics to be easily differentiated. The scheme also standardises the classification of cometary bodies in general, from the Edgeworth-Kuiper belt and other Trans-Neptunian objects, to the short-period comets. A variety of results are obtained for the Centaurs studied, including halflives and transfer probabilities.

A mathematical model to describe the changing populations of Centaurs is presented, and interesting possible behaviours displayed by individual Centaurs are highlighted by the study of ten individual cases.

Also, an in-depth study of the biases which affect observations of comets is undertaken, and the results used to re-examine work on the possible existence of a tenth planet within the solar system.

D.Phil. Thesis under the supervision of N. W. Evans.
Thesis accepted April 2004, Department of Theoretical Physics, Oxford University.
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The 7:4 Mean Motion Resonance and Dynamical Structures in the Transneptunian Belt

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The transneptunian belt is believed to be composed of the remnants of planetesimal accretion in the outer solar system. Far to be in cold dynamical conditions, in the classical region it is observed an unexpected orbital excitation, dynamically distinct populations and the presence of chaotic regions. The latter is usually associated with mean motion resonances with Neptune. For instance, the 7:4 mean motion resonance appears to have been causing unique dynamical excitation according to observational evidences. In order to explore this resonance dynamics and to better comprehend those characteristics pointed above, I present extensive computer simulation results using thousands of test particles and a chaotic diffusion numerical experiment to follow paths in phase space over 4–5 Gyr. The 7:4 mean motion resonance is weakly chaotic causing irregular eccentricity and inclination evolution for billion of years. Particles in stable resonance locking are rare and there is escape in 10^8–10^9 yr time scales. A few percent of the resonant escapees survived in the scattered region with direct influence of other neptunian mean motion resonances, showing that resonance sticking is an extremely common phenomenon. In the same region, the so called extended scattered objects are able to form via very long resonance trapping under certain conditions. Inclination dependence and resonance dynamics demonstrate that the classical and scattered regions have been evolving continuously until present.

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BOOKS

The First Decadal Review of the Edgeworth-Kuiper Belt

Davies and Barrera, Eds.

Earth, Moon, and Planets, volume 92
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