

“THE FOREST AND THE TREES” – SUMMARY OF AN ATACAMA WORKSHOP

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This intriguing title was chosen not by me, but by the Chairman of the Scientific Organizing Committee with reference to Fred Whipple’s talk at the Heidelberg Conference on Halley in 1989. It may seem a bit strange in the middle of the dry Atacama region, but if we would have had a conference about small objects in the outer solar system at that time, 14 years ago, there would have been about as much to talk about as there are trees beyond the mountains surrounding the city of Antofagasta.

However, this is certainly no longer the case and the present conference is a clear demonstration that we now know many orders of magnitude more about this subject. We owe this progress to a comparative small number of inspired and hard-working individuals, some of whom are here today. They have persistently pushed outward the borders of knowledge in the solar system, gradually opening a whole new world to us.

The fact that some of the early, major advances took place in Uruguay and Hawaii may have been one of the reasons for choosing a geographically intermediate site for this meeting! Another, perhaps more obvious one is the recent advent of extremely powerful astronomical telescopes, several of which are located in this beautiful country. We are certainly grateful to our Chilean hosts for the excellent arrangements made and also to those Chilean and international institutes that have contributed to the eminent success of this gathering.

A Modern Tale of a Far-way Kingdom

Complex issues are sometimes easier to comprehend when you change the communication carriers. So let me introduce you to the concept of a modern fairy tale, in the expectation that the use of allegories will make you see the subject in a somewhat different light... But please remember to take some of this with a grain of salt!

It was many and many a year ago, in a Kingdom by the sea... Oh sorry, that may be fine for where we are now, but it does not work so well for today’s topic! Let us try again...

Once upon a time, there was a Kingdom far, far away

- At the edge of the known territories, beyond *Ultima Thule*
- Rumours had that it was a *peaceful region*, very *sparsely populated*
- It was a land of eternal winter, a *cold and dark abyss* whose icy inhabitants – whoever they were – were moving sedately about their individual



trajectories, rarely having the opportunity to greet each other during close encounters

- They guarded a *great secret* out there. It was known simply as the “*recipe*” and it was the *complex formula of primordial stuff* of which we (and some of our dreams) are made

How we wanted to get hold of that formula! But as in all real fairy tales, this was not easy – there were many obstacles to be overcome and trials to be passed, demanding no small measure of ingenuity and stubborn will of the daring explorers.

To begin with we knew very little about this Kingdom:

- We first saw the Overlord in 1846. We called him *Neptune* and he was a majestic sight indeed. We later found out he is accompanied with several servants, the largest of which we gave the name *Triton*
- We had glimpses now and then of Messengers from that distant realm, passing rapidly through our sunny territory, suffering from the heat and sweating profusely, some of them barely surviving the passage, others disintegrating completely at the roadside. We refer to most of them as *long-period comets*, but that term really says more about the short span of our own lives than about those ephemeral objects

But then, we gradually developed better technology enabling us to peer more clearly into those distant regions and finally also to identify and learn more about the nature of the inhabitants, their social behaviour, their travel habits and the general demography of that Kingdom. The progress was slow, but steady:

- *Pluto*, the Overlord’s largest Vassal. He later turned out to have a close and faithful companion, *Charon*, not unlike himself, but of somewhat less stature,
- The *Oort Cloud*, the domain of the outermost Border Posts, sometimes reverberating from intruders from beyond the frontier
- The nature of the *long-period comets* in terms of the icy nucleus model
- *Chiron and other Centaurs*, those innermost Border Posts, venturing nearer to the central regions while suffering periodical hiccups
- Model-charting the *topography of the territory* and the first migration theories
- 1992 *QB₁*, the first common Citizen to be sighted, followed by 769 *others* until March 3, 2003 – these including
- *Varuna, Ixion* and other big (and heavy?) Citizens
- Several *binary objects*, i.e. *couples are common*, also there
- Moreover, relatively large amounts of *dust* (“smog”)

All profitable undertakings, especially those which promise great returns attract a lot of clever people of many different trades. With the prospect of

discovering that secret formula, the study of this Kingdom has been no exception – here is a simple classification of them, by trade:

- The “*Observers*” or, should we say, the “*Watchers*”, who may be divided into
 - *Surveyors*, who spend much of their time at their telescopes and jump of joy when they see small moving blobs that might occasionally be real
 - *Discoverers*, who can prove by clever statistics why their initial hopes to find dozens/hundreds of new objects were anyhow unfounded
 - *Photometrists*, who can also make nice pictures in different colours of background nebulae and galaxies when they have enough exposures
 - *Spectrophotometrists*, who are the really tough ones who want to know it all and who are particularly fond of slight depressions
- The “*Modelers*”
 - *Orbiters*, who pick up the data and can produce 1 million orbits in 10 s from a 3-h arc
 - *Dynamicists*, who use ever bigger and faster computers to put some order – but more often chaos – into the whole thing
 - *Alchemists (modern-age)*, who transform sticky substances into unmentionable ones – changing them from dark to light and from red to gray and back, while trying to figure out what the surfaces are made of
 - *Astro-internists*, who watch for signs of rotational (dis)equilibrium and also make models of varying size, age, composition, stratigraphy, porosity, etc. hoping to learn what is going on inside

So what do we call this new scientific field? It seems that a name has not yet been chosen – otherwise the title of this Workshop would have been much shorter.

Pick your choice:

TNOlogy, KBOlogy, or EKOlogy?

SOME RECENT ACHIEVEMENTS

Now, that was a circuitous introduction, a presentation of the participants on both sides. But what have we learned in the past 10 years? Of course, we only knew Pluto and Chiron and a few Centaurs at that time, so almost everything presented at this conference is new. Here are some of those developments that have impressed me particularly. I will mention them in a slightly different order than they were brought forward here. I also do not mention any names to be sure to avoid any individual omissions.

General

- 770 TNOs known, but nearly 50% with single opposition orbit (many lost)
- presently, *no very obvious correlation between orbital and physical parameters* (except that low-inclination low-eccentricity classical KBOs are dark and red; possibly with collision probability index)
- *The meaning of surface material colour changes has become very unclear* – impacts uncovering “fresh material” vs. cosmic and solar irradiation
- *Determination of masses* possible via lightcurves and binary orbits
- *Primordial matter* (if any) only in the smaller ($R < 75$ km?) objects

On surveys

- *Large efforts* continue in different parameter spaces
- Less deep, but *large sky area* (Caltech, Lowell, Mt. Stromlo)
- *Extremely deep pencil-beam* (e.g., Subaru, VLT, HST/ACT)
- Effective methodology for “*automatic*” *object recognition*
- Final, *visual verification* mostly still needed (an interesting fact!)
- *Cumulative luminosity diagram* to 28 mag (soon deeper), with break at ~ 24 mag(?)
- Critical *follow-up bottleneck* – many new objects are lost

On the physical properties

- *Visual bands (BVRI; > 100 objects) + N-IR bands (JHK; > 20)*
- Almost *complete overlap of different orbital classes* in two-colour diagrams
- About 20 *visual spectra* – all very flat – two possible detections of water-ice
- About one dozen *NIR spectra* – few features seen
- First *polarimetric* measurement (Ixion)
- Modeling with laboratory spectra *not constrained* by available observations
- *Low densities* apparent, wherever deduced (except Pluto)
- *Changes in Pluto’s atmosphere* from well-observed occultations

On the dynamics

- *Two dynamical groups* clearly present (classical KBO, SDO)
- Additional *subgroups* (Centaur, ESD)
- *Webservice for orbit calculations* with extensive error analysis (Lowell/Helsinki)
- *Orbital migration and capture* into resonances quite well understood
- *Edge at ~ 50 AU* almost certainly real
- Despite valiant efforts, *only weak evidence for correlation between orbital and photometric properties*
- *Missing-mass problem* far from solution

On the future:

- The Credo: *“More observations!”*, *“More models!”*, *More laboratory work!”*
- Unlimited number of themes for PhD theses
- Very powerful facilities coming: More AO systems, Interferometers, SIRTf, ALMA, Pan-Starrs, JWST, “OWL”, Pluto-KBO-Express
- Every reason to start planning for a full-week next Decadal Review

And finally – how it was said!

Science is not just hard work – it is also exciting and fun. It is great to discover new objects and processes and to understand better what is going on in nature. It is also wonderful to get together and exchange news, to have the opportunity to see and sense the emerging “great” picture of the current research in this particular field. And it is always enjoyable to listen to what is said how during a conference. The following is a small selection of interesting and revealing statements culled by this author during the past 3 days:

On the subject of this conference

- *...well, it does subtend a small angle seen from out there...* (remark by a courageous extragalactic astronomer who went into the lion’s den)
- *Anything that is annoying to cosmologists should have intrinsic value...* (remark by brave participant from the other camp)

On Neptune

- *Neptune never saw the missing mass in the Kuiper belt* (no help there!)
- *In fact, I could start Neptune much closer to the Sun*
- *It migrated into a sea of hot particles* (if not Neptune, who then?)

On nomenclature challenges

- *The two flavours of KBOs*
- *Notice those yellow 5-to-2 guys*
- *The Cubewanos... I mean the classical ones*
- *We call them Twotinos*
- *Here come the hot evaders*
- *I don’t like the word Plutinos*

On models

- *I usually do not understand half of what you say...* (modeler about observers)
- *This is our present knowledge about orbits that are compatible with observations*
- *If you don’t have many constraints, you can model anything* (oh, those observers...!)
- *We are missing the noise in the migration*

- *...putting in a migration rate that does not depend on where it comes from...*
- *This could be a potential smoking gun for migration!*
- *A family is the result of a collision*
- *Even if you have no excitation yourself, you may get hit by another guy*
- *These large objects are dynamically high*
- *Some TNOs fit our laboratory data*

On very fresh data

- *I received the data just one week ago*
- *In fact, the data were reduced in the airplane coming down here*
- *That diagram I did at 4 o'clock this morning*
- *I spent the night re-arranging things*
- *He is observing at this moment, so we don't have the data yet*

On (attempts to) hiding evidence

- *Unfortunately, the website is written in Japanese...*
- *There must be water ice there, but we don't know how they hide it from us*
- *It is hard to see, but maybe that is good, because I have a mistake down here*

About fate

- *We need more bright KBOs*
- *Entrada no detectada (the beamer)*
- *Of course it is exaggerated a little bit since it comes from the Press Office!*

And, in a tragic class of its own:

- *There are many ways to end a survey*

About statistics

- *The chi-square has not changed much, but it looks better*
- *There are single power laws and there are broken power laws*
- *There may possibly be a slight correlation here... (long pause) ...perhaps*