PLUTO: COLD AT THE SURFACE, HOT BELOW? D. Loane-Billings[1], M. Paquin[1], J. Di Sciullo[1], K. Immer[1], R.J. Soare[2], [1]SPACE, Dawson College, Montreal, Canada H3Z 1A4 (darcyloanebillings@dawsoncollege.qc.ca), [2]Dept. of Geography, Dawson College, Montreal, Canada H3Z 1A4.

Introduction: Due to their distality, little was known about Kuiper Belt objects (*KBOs*) prior to the fly-by of Pluto by the New Horizons spacecraft and its later encounter with Arrokoth. Kuiper Belt objects are simply any small bodies of rock, ice, comets or dwarf planets that reside in the Kuiper Belt (30-55 AU) **[1]**. Since Pluto's orbit is located inside the Kuiper Belt, it is identified as a *KBO* **[1]**. Speculative as it was, almost all of our foreknowledge about *KBOs* (composition, structure, etc.) was derived from comet-based observations, as most comets were/are assumed to have originated in the Kuiper Belt **[2]**. Typically, comets are small bodies possibly formed early in the history of the solar system and are made of different kinds of ices **[2-3]**. Overall, they are viewed as small objects with an average 10km diameter, not spherically shaped **[3]** and, when located far away from the Sun, are considered to be geologically inactive **[4]**. Because it is thought to be a *KBO*, and despite its relatively larger size and mass, Pluto was expected to show characteristics similar to these comets, i.e an ancient surface and very little internal differentiation and/or geological activity. Surprisingly, New Horizons showed that expansive surface regions were relatively youthful and uncratered, have possibly undergone glacial re-surfacing, and that cryovolcanism could be discharging material from a relatively warm lithosphere and core **[5-6] (Fig. 1)**. Here, we suggest that the most plausible explanations of why Pluto's internal surface is not cold to the core are not entirely satisfactory.

Dynamic Pluto: Vast plains of ice towering mountain ranges and geologically active terrains were imaged by the New Horizons spacecraft **[5-6] (Fig.1)**. Cryovolcanism, the process of volcanoes releasing large quantities of ice, water and other materials onto the surface **[7]**, was proposed to be the delivery mechanism for these surface features **[5]**. Pluto is also speculated to host a subsurface ocean **[8]**.

Dynamism explained or not?: For cryovolcanism on Pluto to be a viable explanation of its relatively youthful ice coverage and features, a relatively warm subsurface ocean needs to exist **[8]**. Generally speaking, it is thought that planetary, lunar and smaller bodies with solid surfaces and distal from exogenic sources of energy cool faster or slower proportional to their size and mass **[9]**. Against this backdrop, a relatively small body like Pluto that is 39 AUs from the sun ought to have become solidly frozen to the core long ago, however, as mentioned previously, some data from New Horizons suggests the contrary to be occurring on the dwarf planet.

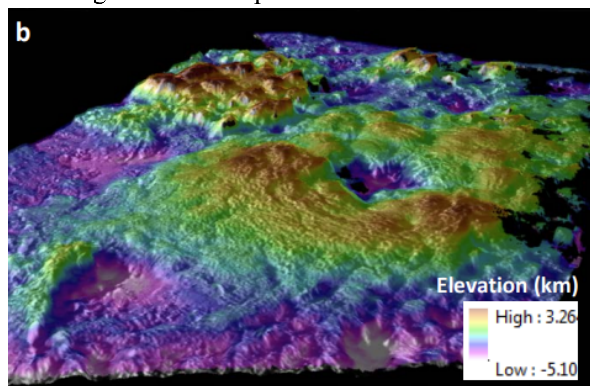

Fig.1: Wright Mons on Pluto. The mountain's flanks show evidence of a viscous flow through its numerous ridges, displaying an example of potential cryovolcanism on Pluto **[5]**.

Heat Sources?: Pluto is about 5.91 billion kilometers from the Sun **[10]** and its mean surface temperature is ~41° Kelvin **[11]**. Its thin atmosphere contains nitrogen, methane and carbon monoxide **[11-12]** and it contracts/expands marginally with accordance to Pluto's proximity to/distality from the Sun **[11]**.

A possible source of heating at the surface of Pluto and to depth is tidalism **(Fig. 2)**, i.e. the creation of heat inside a planetary body caused by the varying gravitational forces between two planetary bodies (moons and/or planets) **[13]**. Charon, Pluto's largest moon, and almost half its size, is in close proximity to the latter, i.e. 19,640 km from it **[14]**. Some recent work suggests that this distance is sufficiently small for tidalism to be deemed a possible catalyst of heat at the core of Pluto **[15] (Fig.2)**.

Radiogenic heating, based on the energy generated by the radioactive decay of "hot" materials at Pluto's core, is another possible source of long-term heating. The half lives of these long-lived radioisotopes, such as Uranium 238 and Thorium 232, can last for billions of years and, if the core presence of them is massive enough, could moderate lithospheric and surface temperatures through much of Pluto's early life. Uranium 238's half life is four and a half billion years **[16]** while Thorium 232's half life is longer than the age of the universe, i.e. 13.9 billion years **[17]**. This allows these isotopes to heat the dwarf planet from its creation, four and a half billion years ago through to the present day.

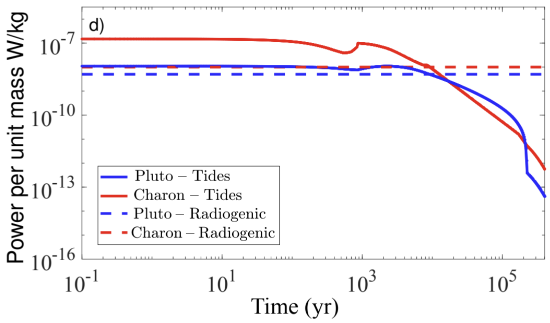

Fig. 2. Possible heat resulting from tidalism of the Pluto-Charon system and radiogenic isotopes as a function of time **[15]**.

Limitations to the Proposed Hypotheses: The eccentricity of the body's orbit is key to understanding its potential account of tidal heating. For example, Charon has an orbital eccentricity of 0.0022 **[18]**, and Io's is 0.0041 **[18]**. Although their respective eccentricities are comparable, the differential tidal forces on these bodies may reflect the situation better. Accounting for these orbital eccentricities, as well as their diameters, mass, and radius of the bodies, the calculations render very distinct values ($1.23x10^{-2}$ N/kg differential force per unit mass for Io and $6.64x10^{-5}$ N/kg for Pluto) **[18]**. The strength of the tidal forces that Jupiter exerts on Io are 185 times greater than those exerted by Charon on Pluto. This result is based on calculations involving the distances, masses and diameters of Io and Pluto **[18]**. Despite there being many instances of tidal heating on Io **[19]**, it is possible that Charon' tidal influence on Pluto is too weak to properly warm up its interior.

Despite the fact that radiogenic heating presents a possible source of heat for Pluto, the probability of finding heavy elements, like uranium and thorium, so far out in the solar system, and in significant abundance to heat up sections of these bodies remains to be discussed. As was observed in the Orgueil Meteor's CI chondrite composition (0.00810 ppm uranium and 0.0300 ppm thorium) **[20]** it suggests there is a low abundance of uranium and thorium on the surface of KBOs. This possibly suggests a lack of these elements beneath the surface of Pluto as well, preventing such radiogenic heating from having a significant impact on the overall heating of the surface. Additionally, the mass percentage of metallic cores in the terrestrial planets of the solar system and their heliocentric distances appear to be inversely proportional to each other **[21]**, further highlighting the low probability of finding significant deposits of these heavy elements on Pluto to sustain it thermally.

Conclusion: Despite its remote distance from the Sun, the unexpected geological activity observed on Pluto points to the possible presence of a warm, possibly hot core. The proposed hypotheses of tidal heating and radiogenic heating present possible heat sources. Although, due to their limitations and unlikelihood of providing Pluto with sufficient heating to describe the dynamism observed, no sufficiently plausible explanation of Pluto's heating has been proffered so far. More research related to these sources of heating and the nature of *KBOs* is needed to strengthen these hypotheses.

References: **[1]** NASA. (2021) solarsystem. nasa.gov/solar-system. **[2]** McKinnon *et al.* (2008) Lunar and Planetary Institute. **[3]** Comets. vanderbilt.edu. **[4]** Sunshine *et al.* (2016) JGR Planets. **[5]** Singer *et al.* (2018) Cryovolcanism in the Solar System Workshop. **[6]** Martin and Binzel. (2021) Icarus 356, 113763. **[7]** Thornton. (2022) National Geographic Society. **[8]** Robuchon and Nimmo. (2011) Icarus 216, 426-439. **[9]** Seligman. (2012) cseligman.com. **[10]** Cool Cosmos, IPAC, coolcosmos.ipac.caltech.edu. **[11]** NASA. (2021) solarsystem.nasa.gov/planets/dwarf-planets. **[12]** Jovanovic et al. (2019) Pluto System After New Horizons, LPI Contrib. No. 2133. **[13]** Lunine (1997) *Encyclopedia of Planetary Sciences*, 828. **[14]** NASA. solarsystem.nasa.gov/moons/pluto-moons. **[15]** Bagheri *et al.* (2022) 53rd Lunar and Planetary Science Conference **[16]** Depleted UF6, web.evs.anl.gov/ uranium/faq. **[17]** Rubesin.(2012) Case 308, Thorium 232. **[18]** NASA. solarsystem.nasa.gov/moons/pluto-moons/charon/by-the-numbers. **[19]** Moore. (2003) Journal of Geophysical Research: Planets. **[20]** Palme *el al.* (2014) par.nsf.gov. **[21]** McDonough and Yoshizaki. (2021) *Prog Earth Planet Sci* 8, 39.

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