CONDENSE MATTER PROPULSION FOR MARS PROBES. G. A. Robertson, Marshall Space Flight Center, Huntsville, AL 35812, 256-544-7102; glen.a.robertson@nasa.gov

Challenge Area 3: Mars Surface System Capabilities. (Example 17) Advanced spacecraft subsystems that reduce cost and/or risk, reduce mass, or enable new and unique investigations. A new small energetic (high thrust and ISP) thrusters, which could enable new and unique investigations using small probe for both near Mars exploration and Mars descent is discussed.

Introduction: Propulsion methods cross the normal states of matter – solid, liquid, gas and plasma. However, there are other matter states *that have not been considered for propulsion*. One in particular is the low-temperature states – superfluids, Bose-Einstein & fermionic Condensates (BEC), Rydberg molecules and Quantum Hall states. Here a concept to excite a large Rydberg molecule (*i.e*., a highly condensed plasma) using a BEC of electrons under high voltage is discussed for use in a macron like thruster for Mars probes.

The condense matter thruster would produce a Rydberg molecule on the order of grams, where the Rydberg molecule is the projectile with exhaust velocities of 1 to 10 km/s. If achievable, the condense matter thruster could provide a new smaller propulsion system for rapid, efficient and affordable transportation to, from and around Mars and other space destinations not capable before using small probes.

Rydberg molecules: A Rydberg molecule is a cold condensed plasma system, usually composed of cold dirty plasma, dirty as it contains Rydberg atoms. Rydberg atoms, in contrast to atoms in their electronic ground states, possess extraordinary properties; possessing extremely long radiative lifetimes of the order of milliseconds. Rydberg atoms occur naturally in space from recombination.

When immersed into a condensate of ultracold (mK) ground state atoms, a conglomerate of Rydberg atoms become a complex many-body problem; forming a Rydberg molecule. Of interest here is that these dirty plasmas (Rydberg molecule) can, even at temperatures up to 100 K, retain their structure for milliseconds outside the confines of the electric and magnetic fields creating them. Whereby, they can be accelerated using typically plasma acceleratory methods; having a higher density, *i.e*., mass, provides for higher thrust levels for the same acceleration of plasma thrusters.

Macron propulsion: Effectively a condense matter thruster would be a hybrid between a *Pulsed Inductive Macron Propulsion* [1] and a *Magnetically Accelerated Plasmoid Thruster* (*MAP*) [2]. Macron propulsion systems electromagnetically accelerate gram-sized aluminum particles to achieve exit velocities between 5 and 10km/s with corresponding ISP between 500 and 1,000s and a thrust in the range of 10N with efficiencies upward to 90% [3].

Research supports the implementation of macron propulsion technology as a multi-purpose orbital maneuvering system but cautions the use of a macron propulsion system in a manner that could result in macrons (*i.e.*, aluminum particles) entering into stable orbital trajectories, where the ejection of the macrons poses a potential impact on the orbital debris environment.

Condensed Matter Thruster: In contrast, a Rydberg molecule being a dirty plasma will disperse into the vacuum of space, levitating the debris concern and opening macron propulsion for use across a wider spectrum.

In the nearer term, a condense matter thruster would be applicable to a wide variety of orbital maneuvering scenarios, relevant to contemporary and future space operations, *i.e*., Mars exploration. Specifically, replacing traditional propulsion methods (*i.e.* solid rocket motors), which are widely implemented. However on a larger scale, a condense matter thruster can be implemented as a primary in-space propulsion system for long term space explorations that *could* rival nuclear propulsion for interplanetary exploration with respect to its size and weight.

These factors then allow for the consideration of a condense matter thruster for rapid, efficient and affordable transportation to, from and around Mars and other space destinations not capable before using conventional lower thrust plasma thrusters.

Rydberg molecule Production: Rydberg atoms have not been produced in large quantities as the typical method of production uses lasers to cause droplets of cold gas to excite a few Rydberg atoms. And only Rydberg molecules composed of up to 91 Rydberg atoms have been produced [4]. However, in *Investigation of high voltage discharges in low pressure gases through large ceramic superconducting electrodes* [5], the author believes that a near 2 gram size of Rydberg helium molecule may have been produced. Although this was not a Rydberg molecule experiment, per say, one should not be surprised as you only need to search the term "Helium Rydberg States" to quickly find out that Helium Rydberg atoms are the atoms of choice for studying Rydberg states.

High voltage discharge experiment: It was reported that the high voltage discharge, ceramic superconducting electrode experiment [5] produced a flat coherent discharge of helium plasma. The discharge was emitted from an ~4" diameter Type II YBCO superconductor, kept at a temperature of ~40 K, which formed the cathode (emitter) in a high voltage vacuum discharge system. This flat glowing discharge separated from the superconductor emitter and moved to the target electrode (anode) with great speed. At a distance of 0.25 m, the time of the discharge as defined by a photo diode to be between 10^{-5} and 10^{-4} s (*i.e*., 25 km/s and 2.5 km/s).

The moving discharge became flat with the diameter corresponding to that of the superconductor emitter, which is a good indicator that atoms (*i.e*., helium gas) in the vacuum was polarized and attracted to the Type II superconductor; where possibly proximity effects caused the helium to condense at a higher temperature than normally needed to condense the helium gas.

Proximity Effects: Superconductor proximity effects are well known between superconductor and other materials – to include non-superconductive materials. For example when close enough, Josephson junctions can formed with electron pairing across the junction to include tunneling processes with electron tunneling times that can become arbitrarily large [*e.g*., 6]. Whereby excitation and neutralization of the electric field on the superconductor could produce an emission of BEC electrons, which could then force the production of Rydberg Helium atoms in the condensed Helium gas, forming a Rydberg molecule (more detail on the production of the Rydberg molecule will be presented in the paper).

Condense Matter Thruster: A Rydberg molecule has a relatively long life time compared to the acceleration times reported in the discharge experiment [5]. Therefore, it is feasible to assume that a condense matter thruster is achievable by simply using the technic reported, as it produced velocities in the range of current macron propulsion technology [3]. That is, electrically neutralizing and exhausting a 0.1 to 1 gram size Rydberg molecule from a probe would produce an impulse thrust on the order of macron propulsion, which is higher than conventional plasma thrusters, with an ISP in the range of conventional plasma thrusters.

Further acceleration of the Rydberg Helium molecule could be done using current macron propulsion technology [1-3], but it will increase the total propulsion system weight and complexity. However, doing so could improve both the ISP and thrust over current macron propulsion technology; extending its use for other in-space transportation applications.

Thruster: In general, a condense matter thruster would consist of a small high voltage (>500kV) electrical discharge chamber, contained in the appropriate housing for electrical and thermal shielding/containment, and a high voltage source. The chamber would contain a cathode composed of a Type II superconductor, say in tape form to reduce size, weight and cooling load, on one end and a ring anode with the inside of the ring open to space to allow the discharge (Rydberg molecule) to be expelled from the chamber.

High Voltage source: Due to the high voltage requirement to produce the Helium condensate from the gas in a vacuum, one may think that such a condense matter thruster would have to be very large. However, it is noted that stun gun technology has produced high voltage systems that you hold in your hand with voltages up to 5 MV [*e.g*. see 6]. Therefore, developing a small condense matter thruster is only a factor of experimental validation and engineering development.

TRL: The condense matter thruster is a TRL 1 - Basic principles observed and reported, technology. However, there are no major technology issues to overcome, beyond validation of the creation of the Rydberg molecule. *I.e*., the process of creating the Rydberg molecule entails using ~90% of the technology needed for a thruster demo. Plus the technology needed is simpler than needed for macron thrusters or conventional pulsed plasma thrusters.

This paper will bring it to TRL 2 - Technology concept and/or application formulated. Noting that component and/or breadboard validation in laboratory environment (TRL 4 to 5) could be easily accomplished in one year followed closely by a vacuum thruster test (*i.e*., TRL 6 System/subsystem model or prototype demonstration in a relevant environment - ground only). With proper funding, a three year program toward a flight test either on a satellite or the space station (*i.e*., mother ships) could bring the technology to TRL 8 - Actual system completed and "flight qualified" through test and demonstration (space). *I.e*., could be ready for Mars application in less than 10 years.

The proposed paper will discuss the condense matter thruster in more detail.

References:

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