Tahi: Dipole confinement of fusion-relevant plasmas

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In 1987, Akira Hasegawa proposed the levitated dipole configuration as a fusion reactor, inspired by magnetospheric plasma confinement [1]. Subsequent papers by Hasegawa, Mauel, and Chen further developed the physics basis for this approach [2, 3].

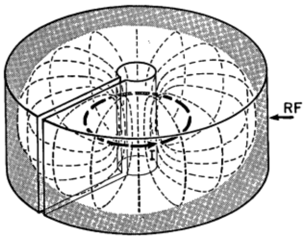

Figure 1: Reactor schematic from Hasegawa's seminal paper [1].

Edward Teller later advocated dipole fusion for interstellar propulsion [4]. The subsequent LDX and RT-1 experiments validated key principles: high beta operation and peaked density profiles driven by turbulence [5, 6, 7]. However, critical plasma physics questions remain: demonstrating high energy confinement, and both fast ion and fusion product retention. This demands high magnetic field strengths, requiring evolution from LTS (LDX) and 1G HTS (RT-1), through to 2G HTS. OpenStar is commissioning new levitated dipole devices leveraging advances in HTS magnet technologies. OpenStar's first experiment, "Junior", aims to replicate the results of LDX and RT-1 in a 5.2m vacuum chamber with a modest ECRF power <50kW. This experiment integrates novel HTS power supply technology onboard the dipole magnet, unlocking the pathway to fusion scale magnets.

Figure 2: OpenStar's "Junior".

Tahi, OpenStar's next machine, is designed to achieve dense, hot thermal ion populations: Peak ion temperatures $> 1\,\mathrm{keV}$ and peak electron densities $> 10^{20}\,\mathrm{m}^{-3}$. Planned for construction by 2027, Tahi offers significant upgrades to previous levitated dipole experiments in its heating systems, magnet performance, and plasma diagnostics, and will also demonstrate an innovative cryogenic technology addressing thermal management of the HTS magnet. Tahi's heating systems will include ECRH (klystrons, gyrotrons), neutral beam injection, and various ICRH scenarios. Tahi's diagnostic suite is designed to enable high-fidelity measurements of plasma parameters across multiple spatial and temporal scales, and will incorporate standard diagnostics such as core Thomson scattering, as well as many diagnostics for the first time in a levitated dipole experiment, such as neutron cameras/detectors and phase contrast imaging. The planned measurements will enable studies of plasma confinement and transport in parameter spaces previously unexplored in dipole configurations and enable experimental validation of theoretical models and scaling laws that predict levitated dipole performance, advancing understanding of the concept's potential for commercial fusion energy production. In doing so, OpenStar is the custodian of Akira Hasegawa's amazing idea, and it is a privilege to honor his legacy with such responsibility. He is an inspiration to the company and a personal inspiration to its staff.

References

[1] A. Hasegawa, "A Dipole Field Fusion Reactor," *Comments Plasma Phys. Control. Fusion*, vol. 11, no. 3, pp. 147–151, 1987.
[2] A. Hasegawa, L. Chen, and M. E. Mauel, "A D-^{3}He fusion reactor based on a dipole magnetic field," *Nucl. Fusion*, vol. 30, no. 11, pp. 2405–2413, Nov. 1990, doi: 10.1088/0029-5515/30/11/018.
[3] A. Hasegawa, L. Chen, M. E. Mauel, H. H. Warren, and S. Murakami, "A Description of a D-^{3}He Fusion Reactor Based on a Dipole Magnetic Field," *Fusion Technol.*, vol. 22, no. 1, pp. 27–34, Aug. 1992, doi: 10.13182/FST92-A30050.
[4] E. Teller, A. J. Glass, T. K. Fowler, A. Hasegawa, and J. F. Santarius, "Space Propulsion by Fusion in a Magnetic Dipole," *Fusion Technol.*, vol. 22, no. 1, pp. 82–97, Aug. 1992, doi: 10.13182/fst92-a30057.
[5] A. C. Boxer *et al.*, "Turbulent inward pinch of plasma confined by a levitated dipole magnet," *Nat. Phys.*, vol. 6, no. 3, pp. 207–212, Mar. 2010, doi: 10.1038/nphys1510.
[6] D. T. Garnier *et al.*, "Production and study of high-beta plasma confined by a superconducting dipole magnet," *Phys. Plasmas*, vol. 13, no. 5, p. 056111, May 2006, doi: 10.1063/1.2186616.
[7] H. Saitoh *et al.*, "High-beta plasma formation and observation of peaked density profile in RT-1," *Nucl. Fusion*, vol. 51, no. 6, p. 063034, May 2011, doi: 10.1088/0029-5515/51/6/063034.