Growing vortex crystals on giant planet poles

Supervision. Morgan E O'Neill (morgan.oneill@utoronto.ca)

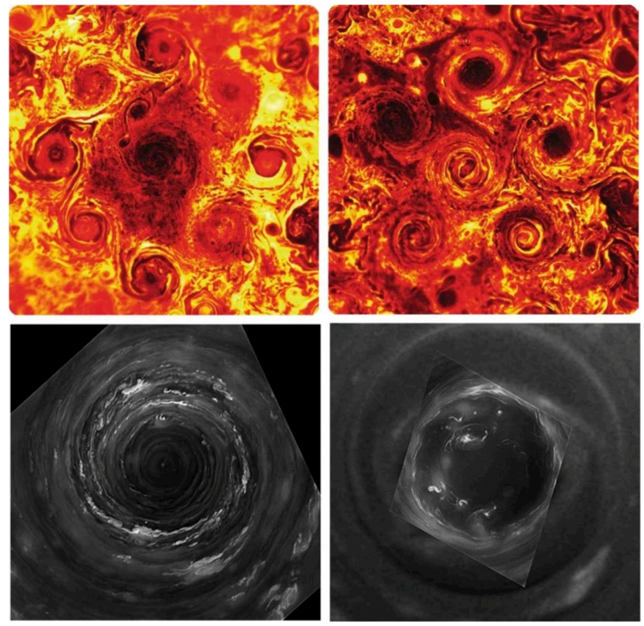

Figure 1, Sánchez-Lavega, Nature Physics, 2022, from NASA satellite imagery. Top row: Jupiter's poles (false color). Bottom row: Saturn's poles (black-and-white).

Project description: We have known about Earth-sized hurricane-like cloudy cyclones locked directly on each of Saturn's poles for the last two decades, thanks to the Cassini mission. NASA's Juno mission reached Jupiter in 2016 and entered a polar orbit, allowing us to see Jupiter's poles for the first time. Surprisingly, the Juno team found each pole to exhibit a packed polygonal structure of cyclonic vortices, rotating around a single central polar cyclone (Adriani et al. 2018). This phenomonen is reminiscent of 'vortex crystals' in 2D turbulence (e.g., Fine et al. 1995, Schecter et al. 1999).

Theoretical work has indicated that local, persistent moist convective activity in the polar regions can force an upscale cascade of energy capable of producing steady polar cyclones (O'Neill et al. 2015, 2016). This was recently observationally validated for Jupiter's poles (Siegelman et al. 2022a). Separate attempts at simulating polar vortices that do not merge, and instead co-rotate stably around the pole, have yielded exciting progress (Siegelman et al. 2022b). However, to date no simulation has been able to produce steady, packed polar vortices under forced-dissipative `convective' conditions.

The student will first convert a 2.5-layer forced dissipative shallow water model written in MATLAB to either python or Fortran. This model parameterizes moist convective forcing from below with mass sources and sinks between the layers. The student will then explore new forcings and parameters in a large, nondimensional phase space. This model has previously captured Saturn, Uranus and Neptune dynamics with some fidelity, but missed the uniquely steady packed-vortex structure seen on Jupiter, in part because of limited resolution and time integrations. We will work with colleagues to attempt to simulate Jupiter-like polar vortex crystals in a forced-dissipative framework.

Skills: The student should be comfortable with MATLAB and python, and ideally have some familiarity with Fortran and high-performance computing. The student should be comfortable with vector calculus and partial differential equations.

References:

Adriani, A. et al., Clusters of cyclones encircling Jupiter's poles. *Nature* **555**, 216–219 (2018).

Fine, K. S., A. C. Cass, W. G. Flynn, C. F. Driscoll (1995). Relaxation of 2D turbulence to vortex crystals. *Physical Review Letters* 75(18) 3277.

O'Neill, M. E, K. A. Emanuel, G. R. Flierl (2015). Polar vortex formation in giant-planet atmospheres due to moist convection. *Nature Geoscience* 8(7), 523-526.

O'Neill, M. E, K. A. Emanuel, G. R. Flierl (2016). Weak jets and strong cyclones: shallow-water modeling of giant planet polar caps. *Journal of the Atmospheric Sciences* 73(4), 1841-1855.

Schecter, D. A., D. H. E. Dubin, K. S. Fine, C. F. Driscoll (1999). Vortex crystals from 2D Euler flow: Experiment and simulation. *Physics of Fluids* 11, 905-914.

Siegelman, L., Klein, P., Ingersoll, A.P., Ewald, S.P., Young, W.R., Bracco, A., Adriani, A., Grassi, D., Plainaki, C., & Sindoni, G (2022a). Moist convection drives an upscale energy transfer at Jovian high latitudes. *Nature Physics* 18, 357-361.

Siegelman, L., W. Young, A. Ingersoll (2022b). Polar vortex crystals: emergence and structure. *Proceedings of the National Academy of Sciences* 119(17) e2120486119.