Cosmic ray ionization of Ice Giant atmospheres

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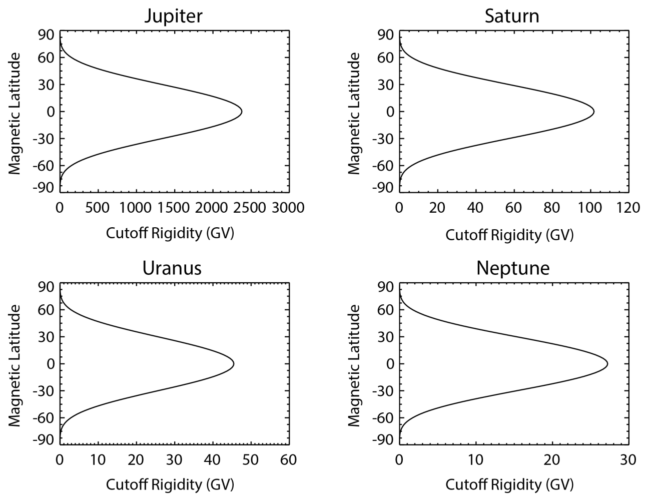
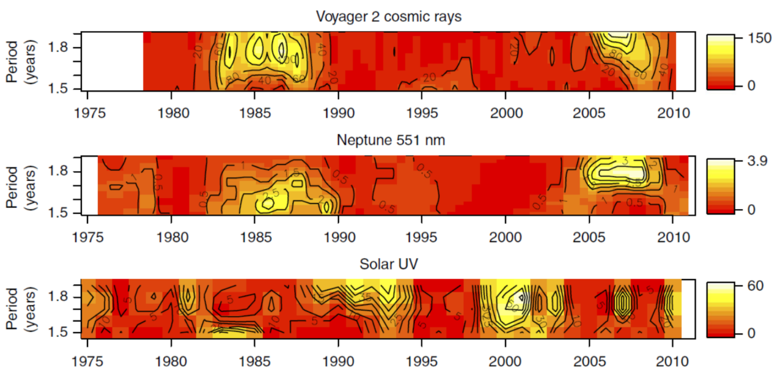
Galactic cosmic rays (GCRs) represent a major ionization source in planetary atmospheres. This is particularly true for deeper atmospheric layers that are largely unaffected by solar UV and charged particle precipitation. When GCR particles undergo inelastic collisions with atmospheric nuclei they create large numbers of secondary interactions, resulting in extensive nuclear and electromagnetic particle cascades with large horizontal and vertical extents.

In thick atmospheres, such as those of the giant planets, these cascades can develop much more extensively than what is the case on Mars and Earth. GCRs are also strongly modulated by the heliosphere, and therefore **GCR flux is significantly higher at the Ice Giants than in the inner Solar System while the solar UV flux is significantly lower**. In addition to this, the magnetic fields of Uranus and Neptune are significantly weaker than those of Jupiter and Saturn and therefore less capable of shielding out GCRs. The implication of this is that GCR effects may be relatively more important at the Ice Giants.



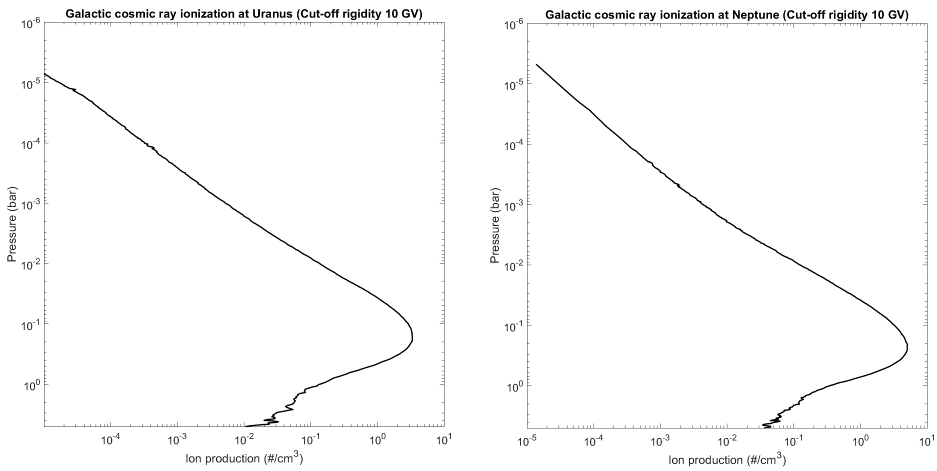
Calculated cosmic ray Störmer cut-off rigidities for the giant planets



Spectral power densities between 1.5 and 1.9 years. Top panel shows Voyager 2 LECP proton data, middle panel shows Neptune magnitude fluctuations at 551 nm, and the bottom panel shows solar UV radiation. From Aplin & Harrison (2017).

Observations of Uranus and Neptune show brightness variations that appear to be associated with GCR variability (Aplin & Harrison 2016;2017). A possible mechanism for this variation is GCR ion-induced nucleation of aerosols. On Neptune, the troposphere and stratosphere may be sufficiently supersaturated for ion-induced nucleation of, respectively, methane and diacetylene (Aplin & Harrison, 2016; Moses et al., 1992). No detailed studies have been carried out for Uranus, but the methane cloud layer on Uranus may also support ion-induced nucleation if suitably supersaturated. **The brightness observations indicate that GCRs may play an important role in the atmospheric chemistry, and possibly also climate, of Uranus and Neptune.** This is also highly relevant to Ice Giant type exoplanets that orbit far from their host star.

We have carried out the first ever detailed study of GCR interactions with Ice Giant atmospheres. This was done using a full 3D Monte Carlo particle physics code to model the interaction of GCRs and their secondary particles with atmospheric neutrals. This code takes into account discrete hadronic and electromagnetic interactions within the 'air shower' GCR particle cascade. **Our preliminary results indicate that GCRs can directly affect Ice Giant atmospheres to large depths (~100 bars or more).** We are currently pursuing additional modeling efforts to understand the GCR-induced effects on the atmospheric chemistry and climate of Ice Giants.



Computed GCR ionization rate profiles for Uranus and Neptune

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