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Living around Active Stars

Edited by

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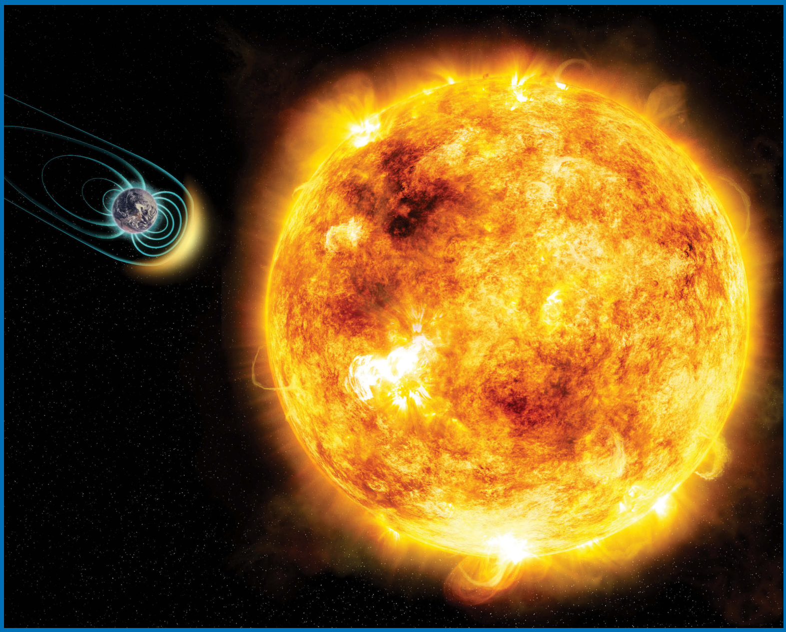

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COVER ILLUSTRATION:

In this artist's illustration, the young Sun-like star Kappa Ceti is blotched with large starspots, a sign of its high level of magnetic activity. New research shows that its stellar wind is 50 times stronger than our Sun's. As a result, any Earth-like planet would need a magnetic field in order to protect its atmosphere and be habitable. The physical sizes of the star and planet and distance between them are not to scale. Credit: M. Weiss/CfA

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LIVING AROUND ACTIVE STARS

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Preface: Living Around Active Stars

The variable activity of stars such as the Sun is mediated via stellar magnetic fields, radiative and energetic particle fluxes, stellar winds and magnetic storms. This activity influences planetary atmospheres, climate and habitability. Studies of this intimate relationship between the parent star, its astrosphere (i.e., the equivalent of the heliosphere) and the planets that it hosts have reached a certain level of maturity within our own Solar System – fuelled both by advances in theoretical modelling and a host of satellites that observe the Sun-Earth system. Based on this understanding the first attempts are being made to characterize the interactions between stars and planets and their coupled evolution, which have relevance for habitability and the search for habitable planets. In this scientific context, the International Astronomical Union Symposium 328 “Living around Active Stars” was organized in Maresias, Brazil from 17–21 October, 2016. The symposium brought together scientists from diverse, interdisciplinary scientific areas such as solar, stellar and planetary physics, atmospheric and climate physics and astrobiology to review the current state of our understanding of solar and stellar environments and its relevance for life and society.

The magnetic fields of stars originate deep in their interior via a magnetohydrodynamic dynamo mechanism that relies on interactions between plasma flows and magnetic fields. These fields manifest as star spots and small-scale magnetic features on the surface and are dispersed in the surrounding space through stellar winds. While some stars such as the Sun exhibit magnetic cycles, others display a diverse variety of activity output. Variation in this magnetic output contributes to radiative flux, particle flux and stellar wind modulation whose impacts are relevant throughout the astrosphere of the star. Energetic, transient events, e.g., flares and coronal mass ejections originate in magnetic structures in stellar atmospheres and generate extreme conditions that persist over several days in the stellar environment. Slower, long-term variation in the stellar radiative output forces planetary atmospheres and climate. Thus, planets and their parent star(s) share a physical bond across space and over a broad range of timescales that is not only important for forcing of planetary atmospheres but is also relevant for coupled star-planet evolution and habitability.

The advent of the space age and the consequent deployment of a host of satellites have led to the appreciation that there is a variable environment or weather in space. The ambient stellar wind forms the background environment. Although steady, the speed of the wind is coupled to the activity of the star and younger, more active stars are known to have stronger winds. It is also known that low-mass M-type dwarf stars have relatively stronger winds. These winds play an important role in atmospheric evaporation through sputtering processes, especially in the absence of a magnetosphere. Magnetic storms which carry significant amount of magnetized plasma perturb planetary magnetospheres and create ionospheric disturbances. Solar flares, which are accompanied by intense high energy radiation, impact the state of the Earth’s upper atmosphere. While causal connections between an event in the Sun and its heliospheric and planetary impact are being characterized and modelled routinely, to what extent significant, long-term perturbations of these nature impact the evolution of planetary atmospheres remains an open question.

In contrast to hundreds of stars, for which we have only a few years or decades of systematic observations, the Sun is the only star whose activity can be traced back for tens of thousands of years using diverse proxies (e.g., cosmogenic isotopes). This gives a unique opportunity to study solar activity on the time scale of thousands of the prominent

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cycle, thus providing clues to deciphering long-term solar variability and an assessment of extreme events. A hotly debated topic of current interest is the possibility of intense stellar super-flares and their impact on planets and life. How strong can stellar flares be in solar-like planet hosting stars, can observations of flares in other stars constrain the extremity of events in our solar system? Questions such as what role the presence of planetary magnetospheres play in moderating this interaction are just beginning to be asked.

The Sun's radiative output is the primary natural driver of planetary climates. Recently it is being appreciated that it may be more important to account for spectral irradiance variability and study the impact of UV radiation in climate dynamics (although the solar cycle variation of total solar irradiance is small, the variability in higher energy radiation is much stronger). The young Sun, and rapidly rotating stars would have had much higher levels of magnetic activity which would lead to stronger high energy radiative fluxes due to heating of stellar atmospheres. This leads one to conjecture on the role of changing solar radiative variability in shaping planetary climates and in governing the conditions in which life may have emerged.

Sun-like stars have a typical lifetime of 10 billion years in the main sequence stage. Stars are born as rapid rotators, plausibly with strong differential rotation and therefore stronger magnetic activity, extreme and frequent flares, stronger fluxes of high energy radiation and energetic particles. Thus, a young planet in a young stellar system would likely be subject to extreme conditions; conditions which would also influence habitability and the evolution of life. With age, and wind mediated loss of angular momentum, the young star would spin down gradually. The magnetic dynamo would become less efficient and so will stellar magnetic output reduce with time. Stellar models indicate the Sun was much fainter in total luminosity compared to the present. This leads to the faint young Sun paradox, which raises the enigmatic question, how life could have emerged in a planet that would, plausibly, have been frozen given the lower solar luminosity? What was the activity of the young Sun like, how did its activity evolve in time until the present, and how is it expected to evolve as the Sun ages? What can observations and modelling of other Sun-like stars tell us about long-term solar evolution? How does the habitable zone in an astrosphere evolve with an evolving parent star? These are open questions that have a direct bearing on the question of life around an active star.

Understanding the impact of an active star on its environment would help us not only to understand habitability but would also be useful in characterizing exoplanetary systems. A case in point is that planetary radio emission similar to that of Jupiter is expected from the interaction between stellar wind particles and exoplanetary magnetic fields. Searches are underway to detect such effects since they can characterise planetary magnetic fields thus setting constraints on exoplanetary dynamos and by extension the internal structure of planets. The detection of transit asymmetries – which are potentially linked to the interaction of the planet with its stellar environment – may also shed light on the loss of atmospheres and magnetic fields of exoplanets. Magnetic and tidal interactions between planets and host stars can also be explored through numerical modelling and observable signatures of anomalous stellar activity enhancement and spin-up that may show up in new observation campaigns.

Multiple current and planned future missions and instruments such as Kepler, COROT, LOFAR, JWST, CHEOPS, PLATO, SPIRou, HARPS, TESS, EXPRESSO (VLT) and HIRES (E-ELT) are seeking to characterize exoplanets and aid in the search for terrestrial planets orbiting within habitable zones. These instruments can also help us characterize the activity of host stars and their magnetism and through a synergy between observations and theoretical modelling, constrain their internal properties.

We are, therefore, standing at an epoch with the promise of unparalleled opportunities towards characterizing and understanding the environment and habitability around active stars. These considerations inspired this Symposium which was a functional outcome of the International Astronomical Union Working Group on "Impact of Magnetic Activity on Solar and Stellar Environments". The papers presented in this symposium and collated in this proceedings deals with many of these outstanding scientific questions – which are multi-disciplinary in character and immense in their scope.

On the one hand, this symposium sought to bridge the boundaries across these diverse disciplines which are each, independently important. On the other hand, the symposium sought to address those outstanding questions that can only be explored through an interdisciplinary approach that brings together diversity in expertise. We are hopeful that the deliberations in this symposium and the scientific papers in this proceedings will motivate coordinated research to explore the coupled evolution of star-planet systems and understand astrophysical conditions that have a direct bearing on living around active stars.

Dibyendu Nandy, Editor and SOC Chair
Adriana Valio, Co-Editor and LOC Chair
Pascal Petit, Co-Editor and SOC Co-Chair
Kolkata, India, 24 May 2017

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