11th Bcool meeting schedule
April 2024, ASTRON

Tuesday 9th

10:00 – 10:30	*Welcome coffee*
10:30 – 10:40	**Welcome – Rob**

I – Stellar winds and star-planet interactions (Chair: Rob Kavanagh)

10:40 – 11:00	**Catching the wisps: constraining mass-loss rates of cool stars at low frequencies** Sanne Bloot (ASTRON/Kapteyn Astronomical Institute, the Netherlands)
11:00 – 11:20	**Nonthermal motions and atmospheric heating in cool stars** Sudeshna Boro Saikia (University of Vienna, Austria)
11:20 – 11:40	**Habitability conditions and radio emission under calm space weather around Proxima b** Miguel Pérez-Torres (Instituto de Astrofísica de Andalucía, Spain)
11:40 – 12:00	**Searching for star-planet interactions: Insights into radio emitting M stars from NIR spectroscopic observations** Gudmundur Stefansson (University of Amsterdam, the Netherlands)
12:00 – 13:30	*Lunch*
13:30 – 13:50	**Atmospheric escape under sub-Alfvénic conditions** Aline Vidotto (Leiden Observatory, the Netherlands)
13:50 – 14:10	**Unveiling repeated and modulated star-planet Interaction signals in a benchmark Neptune-sized planet** Daniel Revilla Martínez de Albéniz (Instituto de Astrofísica de Andalucía, Spain)
14:10 – 14:40	**Session I discussion**

II – Stellar magnetism and activity (Chair: Ekaterina Ilin)

14:40 – 15:00	**Witnessing magnetic field cycles: long-term spectropolarimetric monitoring of BCool solar analogs** Stefano Bellotti (Leiden Observatory, the Netherlands)
15:00 – 15:30	*Coffee break*
15:30 – 15:50	**Spot transits in Kepler and TESS photometry of late main-sequence stars** Adras Haris (University of Helsinki, Finland)
15:50 – 16:10	**Investigating the variation of small-scale magnetic fields on stellar surfaces** Axel Hahlin (Uppsala University, Sweden)
18:00	*Early career researcher gathering at the Bospub*

Wednesday 10th

09:30 – 09:50	**On low-latitude emergence of starspots amid fast rotation** Emre Isik (Max Planck Institute for Solar System Research, Germany)
09:50 – 10:10	**Large-scale magnetic fields of cool binary stars: FK Aqr** Julien Morin (Universite de Montpellier, France)
10:10 – 10:30	**A visible and near-infrared spectropolarimetric monitoring instrument for the VLT?** Pascal Petit (Universite de Toulouse, France)
10:30 – 11:00	*Coffee break*
11:00 – 11:20	**A tentative study of the Rx vs Ro relationship using asteroseismically well-characterised stars** Camilla Pezzotti (University of Liège, Belgium)
11:20 – 11:40	**The magnetic and spin-down properties of slowly rotating M dwarfs** Victor See (ESA/ESTEC, the Netherlands)

11:40 – 12:10 **Session II discussion**

12:10 – 13:10 Lunch

13:10 – 14:10 Tour of the Dwingeloo radio telescope

III – Extreme energetic events (Chair: Sanne Bloot)

14:10 – 14:30 **A fully convective rapid rotator with a high latitude flare and a dim corona**
Ekaterina Ilin (ASTRON, the Netherlands)

14:30 – 14:50 **The effect of energetic particles on exoplanets orbiting low-mass stars**
Donna Rodgers-Lee (Dublin Institute for Advanced Studies, Ireland)

14:50 – 15:10 **Unraveling the mystery of coronal mass ejections in the intense magnetic environment of AB Doradus**
Dag Evensberget (Leiden Observatory, the Netherlands)

15:10 – 15:40 Coffee break

15:40 – 16:00 **Radio search for extrasolar coronal mass ejections**
David Konijn (ASTRON, the Netherlands)

16:00 – 16:20 **The influence of SEPs and cosmic rays on the early Earth atmosphere**
Shauna Rose Raeside (Dublin Institute for Advanced Studies, Ireland)

16:20 – 16:50 **Session III discussion**

18:00 Conference dinner at Hotel Wesseling

Thursday 11th

IV – Radiometric insights into (sub)-stellar systems (Chair: Harish Vedantham)

09:30 – 09:50 **Hide and seek: Using interferometry to hunt for hot Jupiters at decameter wavelengths**
Cristina-Maria Cordun (ASTRON, the Netherlands)

09:50 – 10:10 **Cool stars go boom: Studying stellar activity across the M dwarf mass range using radio observations**
Puck Rooijakkers (Leiden Observatory, the Netherlands)

10:10 – 10:30 **Unravelling (sub)-stellar magnetospheres via radio observations**
Rob Kavanagh (ASTRON/University of Amsterdam, the Netherlands)

10:30 – 11:00 Coffee break

11:00 – 11:20 **Fine structures of radio bursts from flare star AD Leo with FAST observations**
Jiale Zhang (ASTRON, the Netherlands)

11:20 – 11:40 **Searching for magnetic star-planet interaction with radio in GJ 486**
Luis Peña-Moñino (Instituto de Astrofísica de Andalucía, Spain)

11:40 – 12:00 **Search for a spectral cut-off and periodic signal from a radio brown dwarf binary**
Timothy Wing Hei Yiu (ASTRON, the Netherlands)

12:00 – 13:30 Lunch

13:30 – 13:50 **Location and energy of the electrons producing the radio bursts from AD Leo observed by FAST**
Philippe Zarka (Observatoire de Paris, France)

13:50 – 14:10 **Searching for low-frequency emission from exoplanetary system HD 189733 with NenuFAR**
Xiang Zhang (LESIA, Observatorie de Paris, France)

14:10 – 14:30 **Session IV discussion & wrap-up**

I – Stellar winds and star-planet interactions

Catching the wisps: constraining mass-loss rates of cool stars at low frequencies

Sanne Bloot (ASTRON/Kapteyn Astronomical Institute, the Netherlands)

Stellar winds govern the lives of stellar systems, from dictating the evolution of the star itself to eroding the atmospheres of exoplanets. The impact of the wind on a stellar system is largely determined by the mass-loss rate – which is notoriously difficult to measure on dwarf stars since the wind is so tenuous. Currently, mass-loss rates of cool stars have to be modelled or inferred indirectly, for example from astrospheric Lyα absorption. In this talk, I will present a more direct method to constrain the mass-loss rate of a star using detections of low-frequency coherent radio emission, exploiting the lack of free-free absorption to place upper limits on the stellar mass-loss rate. We apply this method to M dwarfs detected with LOFAR at 120 MHz and find upper limits down to 4 times the solar mass-loss rate, independent of distance. While these limits are already competitive with other methods, we expect to reach upper limits of less than the solar mass-loss rate in the near future.

Nonthermal motions and atmospheric heating in cool stars

Sudeshna Boro Saikia (University of Vienna, Austria)

Nonthermal processes, e.g., Alfvén waves, magnetic reconnection, in the upper atmosphere of the Sun are the key drivers of coronal heating and solar wind acceleration. Optically thin emission lines in the far-ultraviolet show excess broadening due to these nonthermal processes, which can be used to constrain the magnetic energy that accelerate the solar wind. In this talk I will discuss how far-ultraviolet stellar spectra taken by the Hubble Space Telescope can be utilized to determine the nonthermal broadening in cool main-sequence stars. Thus providing a data-driven alternative way to constrain the magnetic energy in the wind simulations of cool stars belonging to a wide range of stellar properties.

Habitability conditions and radio emission under calm space weather around Proxima b

Miguel Pérez-Torres (Instituto de Astrofísica de Andalucía, Spain)

Proxima b, and its effect on the habitability of the planet and the radio emission arising from them, using the PLUTO 3D MHD code. We consider both sub- and super-Alfvénic regimes for Proxima b, as well as different values of the planetary magnetic field and of the inclination of the magnetic field with respect to the stellar wind.

We find that the magnetopause standoff distance of Proxima b is large enough for any planetary tilt, but the most extreme (close to 90 deg), to shield the surface from the cosmic radiation, for an Earth-like magnetic field and under calm space weather conditions.

We obtain the somewhat paradoxical result that the magnetopause standoff radius is, for the same values of the planetary tilt and planetary magnetic field, smaller in the sub- Alfvénic regime than in the super-Alfvénic one. We also find that the energy dissipation at the bow shock is essentially independent of the angle between the planet's magnetic dipole and the incident stellar wind flow.

We also find that the radio emission from the reconnection regions can be as high as 7E19 erg/s in the super-Alfvénic regime, and is on average almost an order of magnitude larger than the radio emission in the sub-Alfvénic cases. The energetic are enough to account for the observed radio emission from Proxima b, although this would require that this energy travelled back to the star. While this is not expected in the Alfvén wing model, where both the planet and the star are interconnected via magnetic loops, in the magnetic reconnection scenario we could expect that a fraction of electrons could travelled back to the star and eventually radiate at relatively high radio frequencies (~1.7 GHz) via the electron-cyclotron mechanism.

Searching for star-planet interactions: Insights into radio emitting M stars from NIR spectroscopic observations

Gudmundur Stefansson (University of Amsterdam, the Netherlands)

LOFAR has uncovered a curious population of nearby M stars that show evidence of polarized radio emission. Could the emission be compatible with star-planet magnetic interactions (SPI) due to close-in planets? We are carrying out a program—The Radio Exoplanet Survey (T-REX)—to use precision Radial Velocity (RV) observations to confirm / rule out the existence of planets in these systems that would be compatible with the SPI scenario. We will give an outline of the survey and discuss recent insights and results.

Atmospheric escape under sub-Alfvénic conditions

Aline Vidotto (Leiden Observatory, the Netherlands)

Atmospheric escape plays a key role in the evolution of exoplanets. In particular, close-in exoplanets, receiving a high flux of stellar high-energy photons, can show substantial escape through photoevaporation processes. As the atmosphere escapes, it interacts with the wind of the host star. This interaction changes the dynamics and geometry of escaping atmosphere, and therefore, alters the observable signatures of atmospheric escape. Another factor that can affect escape and its observational diagnostic is the presence of a planetary magnetic field. Through 3D radiative MHD modelling, I will show in this presentation how the planetary magnetic field changes the dynamics of escaping atmosphere, depending on whether the interaction with the stellar wind is super- or sub-Alfvenic, and how the observable signature of Ly-alpha spectroscopic transits is altered.

Unveiling repeated and modulated star-planet interaction signals in a benchmark Neptune-sized planet

Daniel Revilla Martínez de Albéniz (Instituto de Astrofísica de Andalucía, Spain)

Attributing a signal to Magnetic Star-Planet Interaction (SPI) is challenging because of its fluc- tuating and multifactorial nature. To date, no detection has been recurrently observed and thus confirmed. We have analyzed archival data and new spectroscopic observations in search of SPI signals in a benchmark star hosting a close-in Neptune-size planet. The data were gathered with multiple instruments spanning over several magnetic cycles of the star. Our analysis focuses on spectroscopic time series taken with HARPS and CARMENES of chromospheric activity indicators, in particular those using the Ca II H& K and the Ca II IRT lines. We identify temporal chromo- spheric enhancements in 2008 and again in 2016, at the same phase of the ~8-yr stellar magnetic cycle. This variability is modulated with the synodic frequency of the planet and tentatively ap- pears again in the observations being taken these days with CARMENES. This constitutes the first repeated (three occurrences) and potentially confirmed detection of SPI at a specific phase of the long-term magnetic cycle of the star.

Witnessing magnetic field cycles: long-term spectropolarimetric monitoring of BCool solar analogs

Stefano Bellotti (Leiden Observatory, the Netherlands)

The 22-yr-long solar magnetic cycle consists of two consecutive 11-yr sunspot cycles, and exhibits a polarity reversal at sunspot maximum. The large scale magnetic field is complex at cycle maximum, and assumes a more simple, dipolar geometry at minimum. Although solar dynamo theories have progressively become more sophisticated, the details as to how the dynamo operates and sustains magnetic fields are still subject of research. In this context, observing the magnetic field evolution of Sun-like stars advances our understanding on how key dynamo ingredients, like stellar mass and rotation, influence internal dynamo processes.

In this talk, I present the long-term spectropolarimetric monitoring of six Sun-like stars performed within the BCool programme. The masses of our stars are at most 6 percent larger than solar and the rotation periods span 3.5-21 d, so it is a practical sample to study magnetic evolution for Sun- like interiors and distinct activity levels. We applied Zeeman-Doppler imaging to map the large- scale stellar magnetic field from circular polarisation spectra collected with ESPaDOnS and Narval over 10-15 yr. We found that our solar analogs exhibit a dipolar field with clear polarity switches over 3-11 yr, while our fast-rotating stars have a complex, temporally stable field topology, with oscillations in field strength. These results emphasise the sensitivity of magnetic cycles to stellar fundamental parameters, specifically the stellar rotation period.

Spot transits in Kepler and TESS photometry of late main-sequence stars

Adras Haris (University of Helsinki, Finland)

Transit mapping is an effective method for detecting small starspots that may go unnoticed with other techniques used to study active stars' surfaces.

The Kepler and TESS space telescopes provide high-precision transit light curves for a large number of stars. The accuracy of these observations allows us to identify spot occultations that occur during planetary transits.

We conduct a systematic search for spot-transiting events using a Markov Chain Monte Carlo (MCMC) approach on all 60s and 120s cadence Kepler and TESS light curves of late-type stars with known transiting exoplanets. A more comprehensive occurrence statistics for small spots are presented for the Kepler and TESS sample. The geometric properties of the identified spots can be used to constrain the parameters of the stellar dynamo on these planet-hosting stars, which has implications for the atmospheric evolution and habitability of their planets.

Investigating the variation of small-scale magnetic fields on stellar surfaces

Axel Hahlin (Uppsala University, Sweden)

A common assumption when measuring the small-scale magnetic field stars is to use a time-averaged spectrum obtained from several observations. While there are obvious benefits with this approach, such as an improved S/N, there could be some potential pitfalls. One potential issue is that the small-scale field could change significantly during the observation sequence, meaning that valuable information would be lost by only analyzing the time-averaged spectrum.

We aim to investigate this possibility by studying any potential variation of the small-scale fields on stars. Our initial test case is the young star HIP 76768. This star has been previously investigated with

ZDI and therefore has a series of observations spanning a few rotational cycles that should be able to reveal any rotational modulation of the small-scale magnetic field.

Our early results indicate that there is a significant variation of the small-scale field that does follow the rotation of the star, which indicate that there is indeed valuable information that could be obtained by more closely monitoring the small-scale variations of stellar magnetic fields.

On low-latitude emergence of starspots amid fast rotation

Emre Isik (Max Planck Institute for Solar System Research, Germany)

Rapidly rotating solar-type stars are known to be dominated by high-latitude and polar spots. This is consistent with models of buoyantly emerging magnetic flux tubes through convection zones, undergoing strong poleward deflection by the Coriolis effect. However, many (Zeeman-)Doppler (ZD) images of fast rotators also show magnetic features near the equator, around one or more longitudes at the same time. Forward-modelled Doppler images of EK Dra indicated that they could be artefacts of opposite-hemisphere activity under specific conditions. However, low- latitude spots seem to be ubiquitous in independent (Z)D reconstructions of many fast rotators. Here, we propose a mechanism leading to exceptionally buoyant flux loops that end up at latitudes below ±10 degrees, for a solar-type convection zone with a surface rotation period of 3 days. In this scenario, flux tubes stem from a range of initial depths and field strengths below the base of the convection zone, where the deepest and strongest tubes starting near the equator obtain sufficient buoyancy, thereby emerging at low latitudes.

Large-scale magnetic fields of cool binary stars: FK Aqr

Julien Morin (Universite de Montpellier, France)

The aim of the BinaMIcS project is to understand the interaction between binarity and magnetism in close binary systems. Within our sample, the binary system FK Aqr is of particular interest since the two components have large convective envelopes with masses just above the fully convective limit, making the system an ideal target for studying effect of binarity on stellar dynamos.

Both components of FK Aqr feature a rather strong large-scale magnetic field (compared to single early M dwarfs with similar masses) with a mainly dipolar axisymmetric structure. This type of magnetic field is not typical for single early M dwarfs, and is rather reminiscent of fully convective dwarfs with later spectral types. The primary FK Aqr A is currently the most massive recognised main sequence M dwarf known to host this type of strong dipolar field.

A visible and near-infrared spectropolarimetric monitoring instrument for the VLT?

Pascal Petit (Universite de Toulouse, France)

We propose the development of a new VLT instrument designed for the monitoring of the dynamic atmospheres of exoplanets, subdwarfs, and stars. This facility comprises two high-resolution spectrographs, enabling simultaneous coverage of an extensive spectral domain spanning from the near UV to the thermal IR. Each spectrograph is coupled with a dedicated polarimeter optimized for its spectral range, adopting the VISION approach demonstrated at TBL and CFHT. We aim at a spectral resolution of 80,000 and a radial velocity precision of 1 m/s. Science drivers are vast and include: (a) probing weather patterns on giant exoplanets and subdwarfs, (b) conducting a search for Earth-mass exoplanets around active stars, leveraging the broad spectral coverage to effectively mitigate stellar activity noise, (c) unraveling the role of magnetic fields during the for- mation of stars and planets, (d) exploring stellar magnetism from nearby cool dwarfs to massive stars in the Magellanic clouds, and (e) providing essential ground-based follow-up observations for PLATO and ARIEL mission targets.

A tentative study of the Rx vs Ro relationship using asteroseismically well-characterised stars

Camilla Pezzotti (University of Liège, Belgium)

The Rx (Lx/LBol) vs Ro (Prot/tconv) relationship for low-mass stars has been intensively studied in the past years, given its relevance in the attempt to understand the interconnection among stellar activity - rotational evolution- magnetic braking - stellar age, which are believed to operate in a feedback loop through the action of a dynamo operating in the convective interiors.
Understanding the Rx vs Ro relationship is of great relevance also in star-planet interaction studies, considering the key role of X-rays in heating the upper atmospheric layers, and inducing strong mass loss.

Previous studies on the Rx vs Ro relationship determined the existence of two regimes of emission, the so-called saturated and unsaturated regimes, described by a broken power-law with a knee at approximately Ro ~ 0.15. Nevertheless the stellar parameters used in these studies (Age, Mass, Radius, Radius at the base of the convective zone, …), suffered from the uncertainties deriving from the use of classic methods for the determination of the stellar properties (isochrones fitting, evolutionary tracks fitting, …), with a consequent non-negligible impact on the study of the Rx vs Ro relationship.

Thanks to the advent of space-based photometry missions, such as CoRoT, Kepler and TESS, and the future launch of PLATO, asteroseismology has established itself as a powerful tool for the derivation of fundamental stellar properties, providing a level of accuracy that couldn't otherwise be reached by using standard classical methods. In particular, the Kepler mission provided unprecedented high-quality data for two samples of stars analysed by Silva Aguirre et al. (2017) (Kepler LEGACY), and Davies et al. (2016) (planetary hosts). These stars will probably represent the best-characterised sample of objects from now to the launch of PLATO.

The goal of this tentative study is to use these Kepler best-characterised stars to re-analyse the Rx vs Ro relationship, with a particular look at the determination of the slope in the unsaturated regime of emission. Given the average age of the Kepler stars considered here, we expect most of these objects to end up in this regime of emission. Once a new recalibration of the Rx-Ro relationship is derived, its impact on the evaporation of planetary atmospheres will be studied (e.g. Kepler-444) and compared with the results obtained from previous calibrations.

The magnetic and spin-down properties of slowly rotating M dwarfs

Victor See (ESA/ESTEC, the Netherlands)

Over the past two decades, Zeeman-Doppler imaging (ZDI) has been used to study the magnetic field strengths and topologies of low-mass stars over a wide range of spectral types and rotation rates. A notable absence from these studies was slowly rotating mid/late M dwarfs. However, this has been rectified by a recent ZDI study of six slowly rotating M dwarfs. This study showed that these stars appear to have stronger magnetic fields than one might expect based on their position in the activity-rotation relation. In this talk, I will look at the magnetic properties of these new stars in more detail and compare them to the magnetic properties of other stars across the HR diagram that have been mapped with ZDI. I will also use the ZDI maps of these slowly rotating M dwarfs, in conjunction with braking laws, to estimate their angular momentum loss rate. Finally, I will discuss how these results fit in with the puzzling rotation evolution of M dwarfs.

III – Extreme energetic events

A fully convective rapid rotator with a high latitude flare and a dim corona

Ekaterina Ilin (ASTRON, the Netherlands)

In 2020, the Transiting Exoplanet Survey Satellite (TESS) observed a rapidly rotating M7 dwarf, TIC 277539431, produce a flare at 81 deg latitude, the highest latitude flare located to date. This is in stark contrast to solar flares that occur much closer to the equator, typically below 30 deg. The mechanisms that allow flares at high latitudes to occur are poorly understood. We studied five Sectors of TESS monitoring, and obtained 36 ks of XMM-Newton observations, to find that TIC 277539431's corona does not differ significantly from other low mass stars on the canoni- cal saturated activity branch with respect to coronal temperatures and flaring activity, but shows lower luminosity in soft X-ray emission by about an order of magnitude, consistent with other late, rapidly rotating M dwarfs. The lack of X-ray flux, the high latitude flare, the star's viewing geome- try, and the otherwise typical stellar corona taken together could be explained by the migration of flux emergence to the poles in rapid rotators with reduced X-ray flux, such as TIC 277539431, that drain the star's equatorial regions of magnetic flux, but preserve its ability to produce powerful flares.

The effect of energetic particles on exoplanets orbiting low-mass stars

Donna Rodgers-Lee (Dublin Institute for Advanced Studies, Ireland)

The energy stored in the magnetic fields of stars relates to coronal mass ejections, flares and the stellar winds that they drive. Alongside these processes, energetic particles are accelerated. Stellar energetic particles and Galactic cosmic rays interact with magnetised stellar winds before impact- ing exoplanet atmospheres. Energetic particles should lead to chemical effects in warm gas giant atmospheres that can be observed with JWST. This in turn would help us understand the magnetic environment of exoplanets and their host stars.

I will present our results that modelled the number of energetic particles reaching the mini-Neptune, GJ436 b. I will show how the energetic particles then lose their energy as they travel through the exoplanet atmosphere. I will discuss how, in the region of the atmosphere likely probed by JWST, stellar energetic particles dominate over Galactic cosmic rays. However, I will also show that at larger orbital distances and/or deeper in the atmospheres Galactic cosmic rays can dominate. Our energetic particle fluxes can be used to model the chemical effect of energetic particles in exoplanet atmospheres.

Unraveling the mystery of coronal mass ejections in the intense magnetic environment of AB Doradus

Dag Evensberget (Leiden Observatory, the Netherlands)

AB Doradus, a young solar-type star, has a magnetic field strength that surpasses the Sun's by a factor of 100 to 1000. Such intense magnetic fields are traditionally thought to inhibit the oc- currence of stellar coronal mass ejections (CMEs). This belief is challenged by the observation of coronal dimming on AB Doradus, a phenomenon usually linked to CMEs. Our investigation ad- dresses this contradiction by suggesting that CMEs on AB Doradus might originate from regions at high latitudes where the magnetic field configuration is predominantly open. This theory is sup- ported by evidence of active regions near the star's poles and the extended duration of observed dimming events, which imply that these areas are subject to continuous observation. To explore this concept further, we performed a detailed study using global coronal magnetohydrodynamics simulations for twenty-one different CME scenarios. These simulations were based on a surface magnetic map of AB Doradus, created through Zeeman-Doppler imaging, into which CMEs were introduced at various high-latitude locations with open and closed magnetic configurations. Our results show that CMEs can escape through areas with open magnetic fields, indicating that the constraining effect of magnetic fields on CMEs might be less pervasive in young stars like AB Doradus than previously thought.

Radio search for extrasolar coronal mass ejections

David Konijn (ASTRON, the Netherlands)

Coronal mass ejections (CMEs) are a dominant contributor to space weather in the Solar System, with the potential to erode planetary atmospheres. Traditional stellar activity probes, such as flares, cannot indicate if a CME is present. Based on solar studies, we know that a characteristic radio burst (called Type II burst) is an unambiguous CME signature. However, there has not been an unequivocal detection of an extrasolar Type II burst. In this talk, I will present a progress report of our project to search the entire Low-Frequency Array Two Metre Sky Survey - 12 petabytes of data - to identify extrasolar CMEs. In particular, I will present the first extrasolar analogue of a solar type-II burst that signals the presence of a CME. I will detail how such a detection fits within the Solar paradigm and its implications for how common such events are on stars other than our Sun. At the end, I will outline a search for extrasolar (so-called) type-III bursts that trace energetic particle events.

The Influence of SEPs and Cosmic Rays on the Early Earth Atmosphere

Shauna Rose (Dublin Institute for Advanced Studies, Ireland)

Solar energetic particles and cosmic rays are high energy particles that impact Earth's atmosphere. One key way that these particles interact with the material in the atmosphere is by ionising atoms and molecules, resulting in changes in the atmosphere's chemistry. They may even have contributed to the formation of prebiotic molecules, the "building blocks" for life, on Earth's surface at the time when life is thought to have begun on Earth. Therefore, understanding the number of high-energy particles reaching the Earth's surface at this time is of key importance.

I consider the number of cosmic rays and SEPs at the top of Earth's atmosphere 4.4 billion years ago after a moon-sized impact produced a transient hydrogen-dominated atmosphere.
The intensity and energy of the energetic particles reaching the top of Earth's atmosphere in this post-impact scenario depend heavily on the young Sun's magnetic field strength and solar wind velocity.

In this scenario the number of cosmic rays at the top of Earth's atmosphere is lower than the present day as the faster solar wind and stronger solar magnetic field suppress the cosmic rays moving into and through the solar system. SEP numbers at the top of Earth's atmosphere are increased in this scenario due to the higher activity expected from the younger Sun.

I will discuss how I simulate the transport of both SEPs and cosmic rays through this post-impact early Earth atmosphere and calculate the ionisation rate as a function of height due to these energetic particles. I will discuss how these ionisation rates can be used in chemical models to calculate the abundances of prebiotic molecules in a hydrogen-dominated atmosphere. Understanding how life emerged on Earth will improve our understanding of the likelihood of life beginning on exoplanets.

IV – Radiometric insights into (sub)-stellar systems

Hide and seek: Using interferometry to hunt for hot Jupiters at decameter wavelengths

Cristina-Maria Cordun (ASTRON, the Netherlands)

Gaseous exoplanets generate low-frequency radio emission (<40 MHz), which is associated with aurorae via circularly polarized cyclotron maser mechanism and is directly related to the surround- ing space weather. To obtain a detailed analysis of this mechanism, one must measure the stellar wind's electron density and the planet's magnetic field, which is only possible with observations at radio frequencies. Besides many efforts, direct imaging of radio exoplanets has not been success- ful until today, with only a handful of tentative detections. The Low-Frequency Array (LOFAR) is ideally suited for this task because it can observe at frequencies below 40 MHz and has high sensi- tivity. However, imaging at such low frequencies is challenging due to high interference levels and rapidly varying ionospheric conditions. To overcome the technical challenges of imaging below 40 MHz, I will present a new pipeline that corrects for all the known instrumental and ionospheric effects. Then, I will show the deepest images down to 15 MHz of a radio exoplanet candidate and use them to constrain the scaling laws that predict the exoplanet's radio luminosity. A clear de- tection of Tau Bootes b would be the first in the field of radio exoplanets and a step forward for imaging at low frequencies. I will end with a brief overview of the learned lessons and introduce an ongoing major LOFAR upgrade that will facilitate deeper imaging down to 15 MHz.

Cool stars go boom: Studying stellar activity across the M dwarf mass range using radio observations

Puck Rooijakkers (Leiden Observatory, the Netherlands)

Stellar radio astronomy can provide many insights into magnetic fields and stellar plasma, giving us a tool to directly probe the space weather of far-away planetary systems. Although the Sun has been extensively studied in radio, few long (>~100 h) monitoring campaigns using radio telescopes have been completed on other types of stars. Over the last few months, we have used the Australia Telescope Compact Array (ATCA) to study four stars covering the M dwarf mass range to study their emission, which can provide a direct measurement of the plasma density and magnetic field strength at the location where the emission is produced. In particular, we search for periodicity in the radio emission coming from these stars and whether it is related to their rotation. Such a detection unambiguously determines the mechanism generating the emission. In this talk, I will present examples of coherent and incoherent emission from AD Leonis, EQ Pegasi A and B and V374 Peg, and discuss the possible mechanisms which have created the radio flares we observe.

Unravelling (sub)-stellar magnetospheres via radio observations

Rob Kavanagh (ASTRON/University of Amsterdam, the Netherlands)

Knowing if an exoplanet is magnetised or not is a key ingredient for assessing exoplanet habitability. Magnetic fields can protect the planet from incident energetic particles, and also prevent (or facilitate) the stripping of the planet's atmosphere due to the wind and coronal mass ejections from the host star. Magnetic fields can be directly measured by observing either the Zeeman effect or cyclotron emission. However, the Zeeman effect is beyond the detection capabilities of current instrumentation in the sub-stellar regime. On the other hand, bright radio emission suggestive of cyclotron emission associated with aurorae has been detected from brown dwarfs for over two decades. Interestingly, some M dwarfs have begun to show similar behaviour from long-term radio monitoring. Being beamed in nature, cyclotron emission can provide valuable information to infer the underlying magnetic field geometry. For exoplanets particularly, knowing the geometry of their magnetic fields allows us to determine how they are shielded from incoming plasma from their host stars. In this talk, I will discuss our recent efforts to infer the magnetic geometry of stars and brown dwarfs from radio observations. This methodology will have fantastic applications for exoplanets with the advent of sensitive ultra-low frequency radio observations, which will allow us to directly probe exoplanetary magnetospheres for the first time.

Fine structures of eadio bursts from flare Star AD Leo with FAST observations

Jiale Zhang (ASTRON, the Netherlands)

Aurora-like radio emission has been detected from many nearby M-dwarfs. It is presently unclear if the acceleration mechanism powering the emission is coronal (i.e. Sun-like) or magnetospheric (i.e. Jupiter-like). Millisecond-timescale structures in the radio emission hold clues to identifying the emission mechanism, but they have been rarely detected. In this talk, I will report the high time-resolution observations of a flare star AD Leo with the Five-hundred-meter Aperture Spherical radio Telescope. The data, taken over a 2-day campaign, shows numerous millisecond timescale structures (sub-bursts). Sub-bursts on the first day display stripe-like shapes with nearly uniform frequency drift rates, which are possibly stellar analogs to Jovian S-bursts. Sub-bursts on the second day, however, reveal a different blob-like shape with random occurrence patterns and are akin to solar radio spikes.

Our observations show that radio emission from AD Leo is driven by electron cyclotron maser instability, which may be powered by interactions with a close-in exoplanet or a persistent pool of trapped high energy charges produced by numerous ongoing stellar flares.

Searching for magnetic star-planet interaction with radio in GJ 486

Luis Peña-Moñino (Instituto de Astrofísica de Andalucía, Spain)

We observed GJ 486 with the Giant Metrewave Radio Telescope (GMRT) in the frequency range from 550 to 750 MHz in nine different epochs, between October 2021 and February 2022, covering almost the entire orbital phase of GJ 486b.

Our aim is to detect radio emission arising from star-planet interaction in the M-dwarf system GJ 486, which hosts a rocky, Earth-like planet. The confirmation of such a signal would validate radio observations as an independent way to detect exoworlds.

We obtained radio images and dynamic spectra of the total and circularly polarized intensity for each individual epoch.

The results set some potential constraints on some physical properties of both the star and the planet, as well as the geometry of the system.

Search for a spectral cut-off and periodic signal from a radio brown dwarf binary

Timothy Wing Hei Yiu (ASTRON, the Netherlands)

Brown dwarfs display Jovian auroral phenomena such as coherent radio emission, which is a probe of magnetospheric acceleration mechanisms and allows us to directly measure the emitter's magnetic field strength. Radio observations of the coldest brown dwarf are particularly interest- ing since their magnetospheric phenomena may be very similar to those in gas-giant exoplanets. Here, we present the radio data of J1019, a brown dwarf binary, from 3 different telescopes. From these observations, we shall show that J1019 exhibits pulsed coherent emission that repeats on hour-timescale and present our latest efforts to find a cut-off in J1019's radio spectrum to directly measure its B-field strength. Additionally, the fact that J1019 is in a binary implies that we can constraint its mass, which allows us to (a) test dynamo scaling theories which predict the B-field strength of brown dwarfs/gas-giant exoplanet, and (b) study magnetospheric interactions which may be powering J1019's radio emission.

Location and energy of the electrons producing the radio bursts from AD Leo observed by FAST

Philippe Zarka (Observatoire de Paris, France)

In a recent paper, we presented circularly polarized radio bursts detected by the radiotelescope FAST from the flare star AD Leo, that were attributed to the electron cyclotron maser instability. In that context we use here two independent and complementary approaches to constrain the source location (magnetic shell, height) and the energy of the emitting electrons. These two approaches consist in (i) modelling the overall occurrence of the emission with the ExPRES code, and (ii) fitting the drift-rate of the fine structures observed by FAST. We obtain consistent results pointing at 15-20 keV electrons on magnetic shells with apex at 2-5 stellar radii. Constraints on the plasma frequency is related to the emission mode detected by FAST. We provide elements of comparison with solar system radio bursts (Jovian and Solar) and discuss the perspectives of future observations at very low frequencies (<100 MHz).

Searching for low-frequency emission from exoplanetary system HD 189733 with NenuFAR

Xiang Zhang (LESIA, Observatorie de Paris, France)

Radio emissions from exoplanets can either originate from their magnetospheres or result from interactions with their host stars. In the case of emissions stemming from magnetospheres, analogies with Jupiter suggest that we should expect only low-frequency emissions ($\leq$100 MHz). NenuFAR, a French ground-based radio array operating in the range of 10-85 MHz, is specifically engineered to investigate such phenomena. In this presentation, we will introduce the NenuFAR observing campaign of an exoplanetary system, HD 189733, describing the methodologies employed and pre- liminary results. We will also discuss a few bursts detected in another direction within the same field.