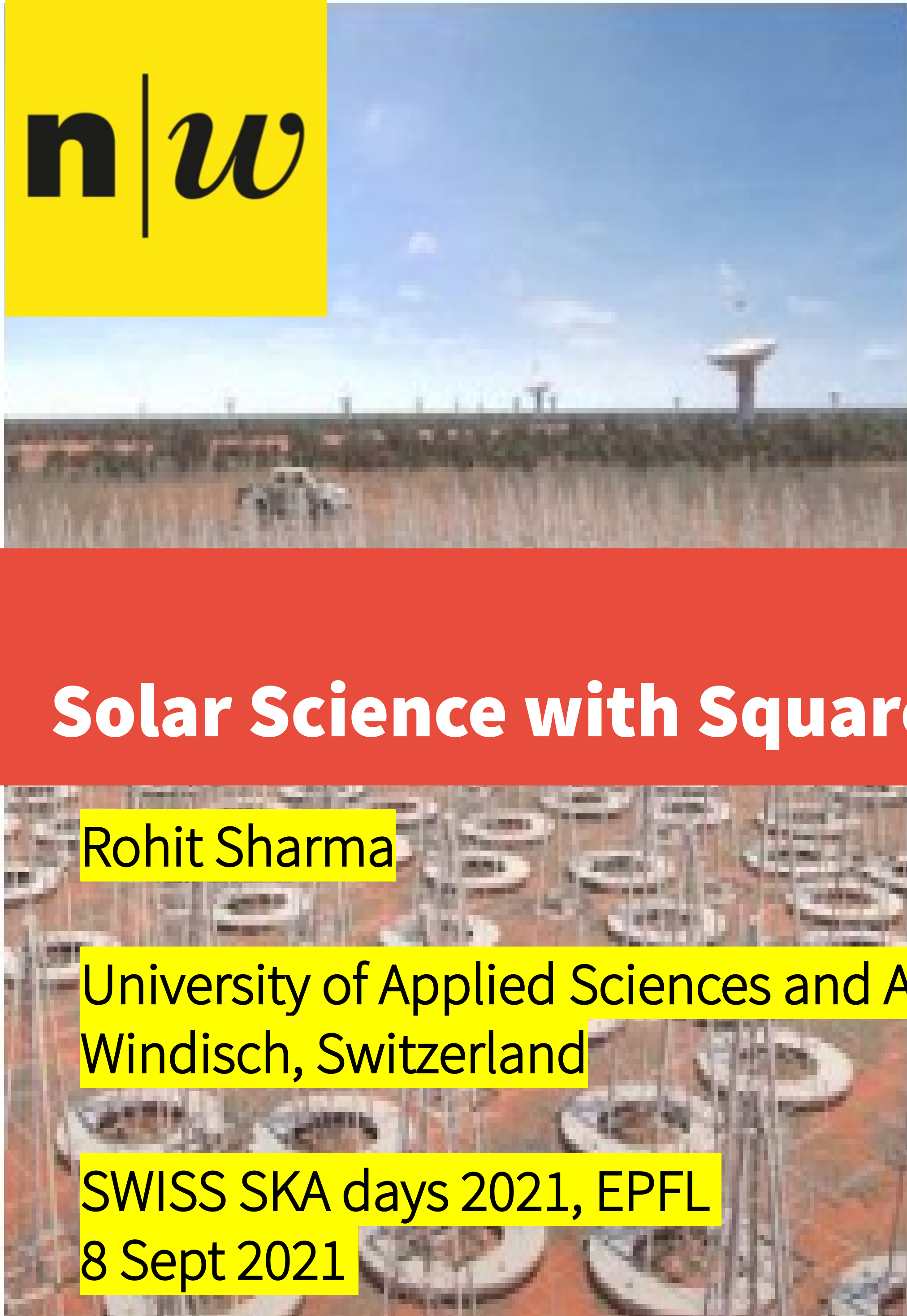


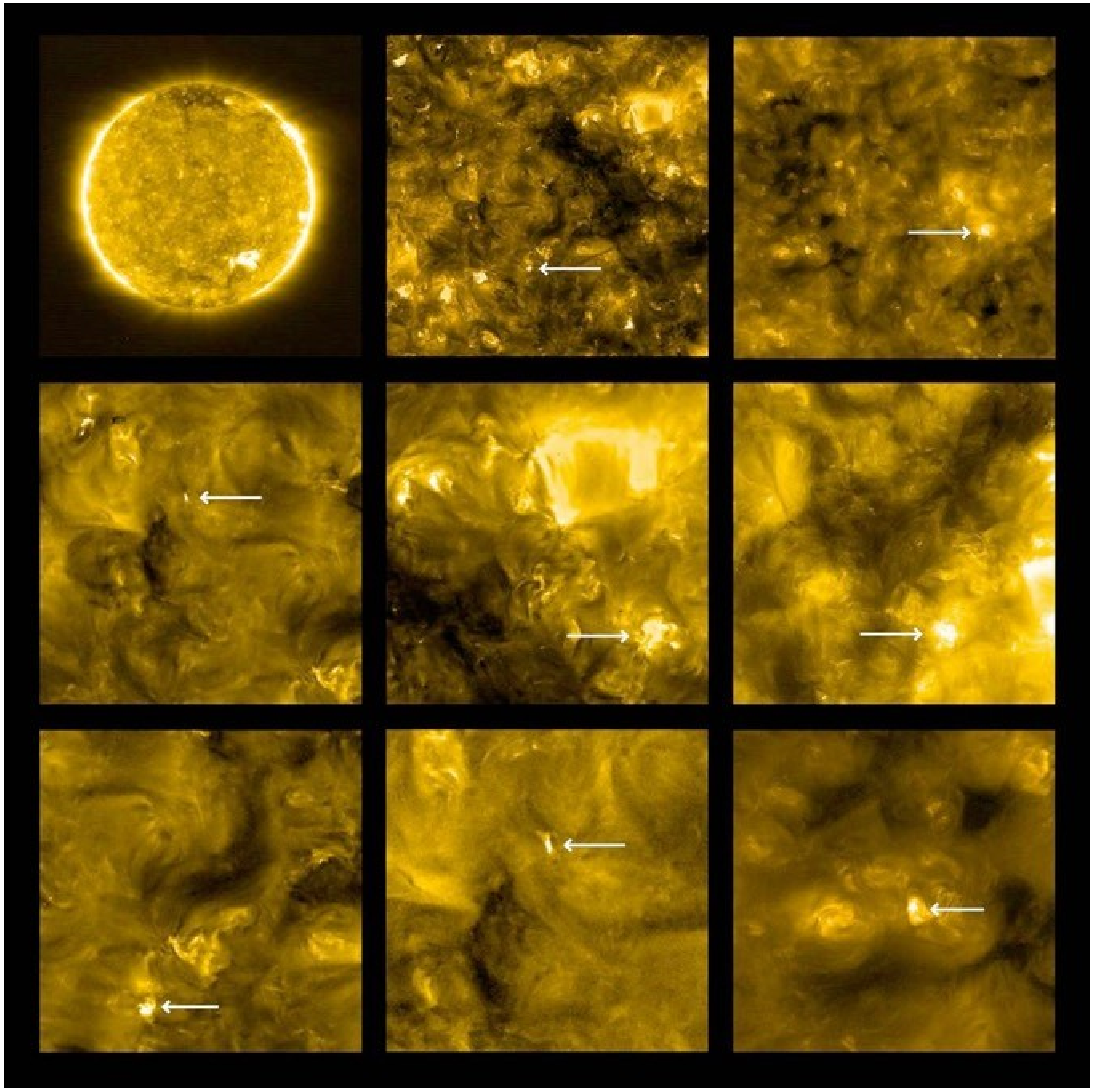
Solar Science with Square Kilometer Array (SKA)

Rohit Sharma

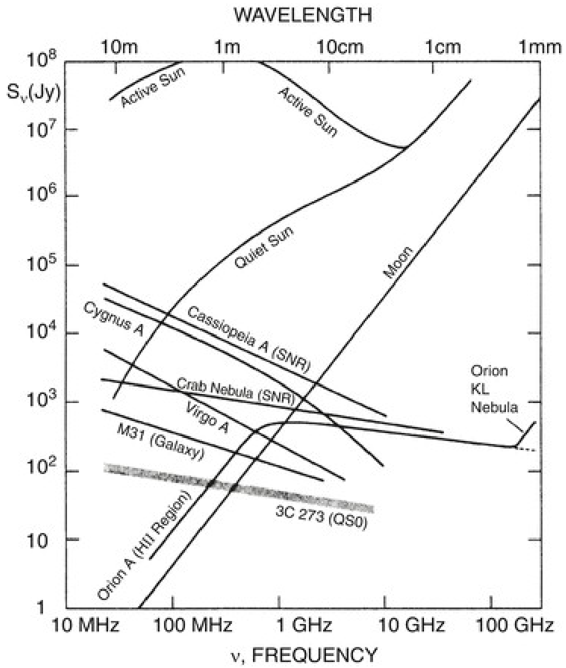
University of Applied Sciences and Arts Northwestern Switzerland,
Windisch, Switzerland

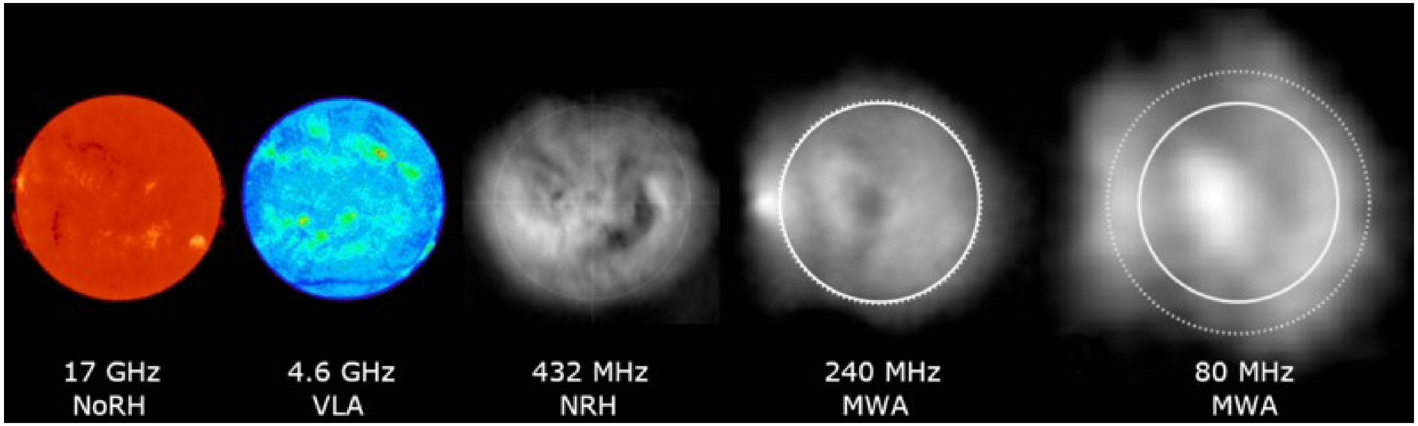
SWISS SKA days 2021, EPFL
8 Sept 2021

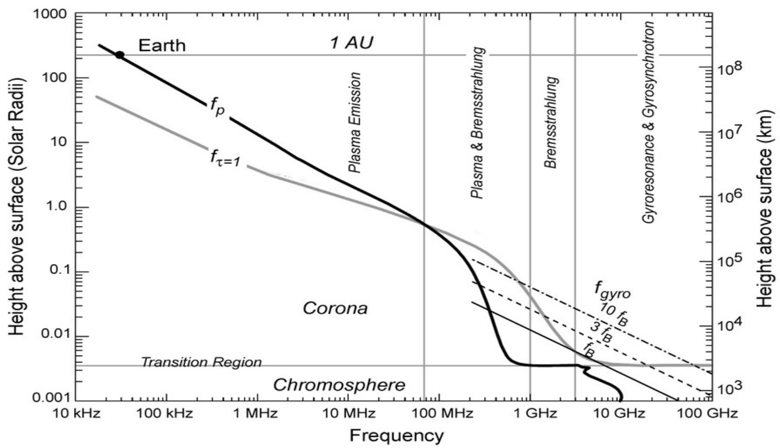
Dynamic ball of plasma

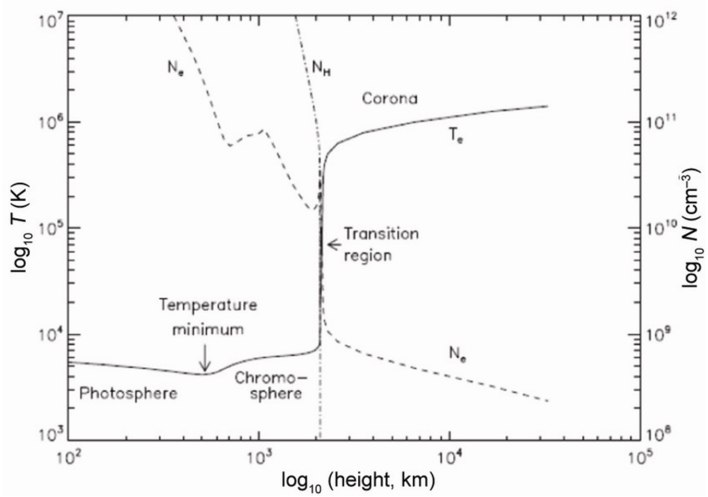


Diverse Scales of the Solar Plasma

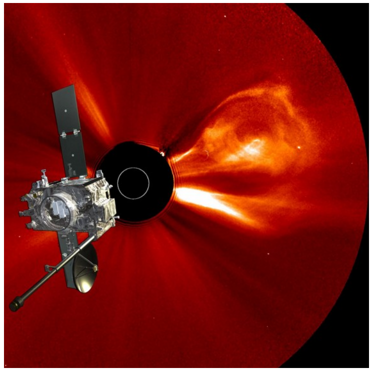








Current Best Radio Telescopes for Solar Observations

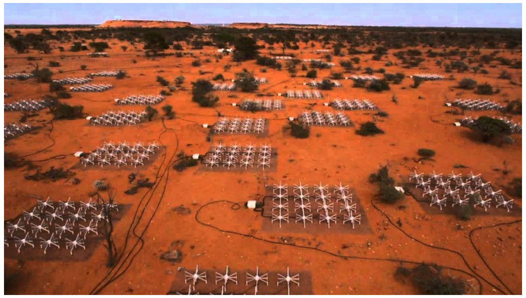


STEREO (Solar Terrestrial Relations Observatory)
10 kHz – 10 MHz

LOFAR
10–240 MHz

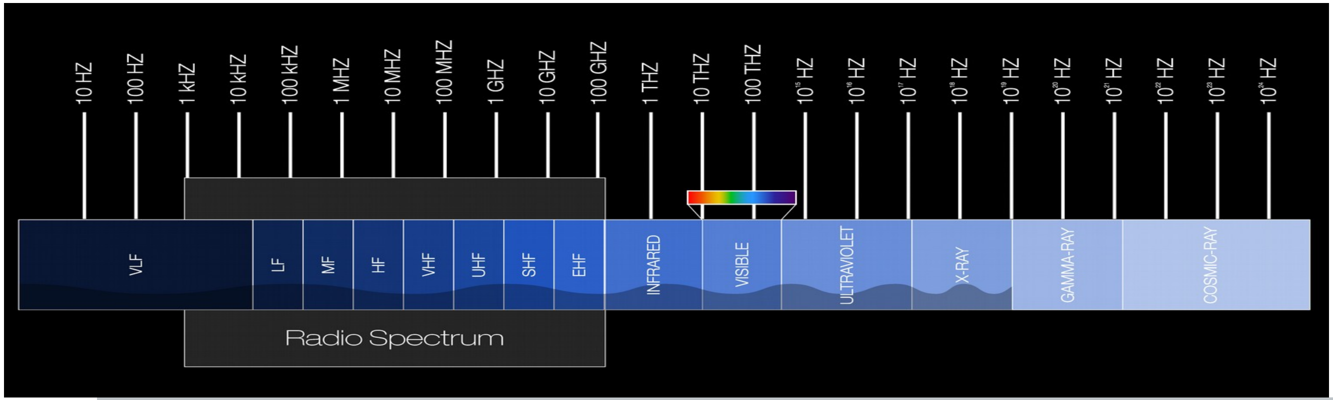
EOVSA (1-18 GHz)

Parker Solar Probe Radio Frequency Spectrometer (RFS)
10 kHz – 2 MHz



Murchison Widefield Array
80-300 MHz

VLA (1-50 GHz)



Improvements from Square Kilometer Array

Table 1: Instruments capable of performing solar radio spectroscopic imaging

Instrument	Frequency Range (GHz)	Spectral Resolution (MHz)	Time Resolution (msec)	Angular Resolution ($''$)	Solar dedicated
EOVSA	1-18	50	20	3-57	Yes
GMRT	0.15-1.50	0.05	100	2-20	No
LOFAR	0.03-0.24	0.1	10	60-540	No
LWA	0.02-0.08	0.008	1	2-8[a]	No
MUSER	0.4-15	25	25-200	1.3-50	Yes
NoRH	17, 34	1700	100	6-12	Yes
NRH	0.15-0.45	23-48	250	18-240	Yes
MWA	0.08-0.30	0.04	500	16-60	No
Siberian RH	4-8	10	560	15-30	Yes
VLA	1-50	1	100	1-35	No

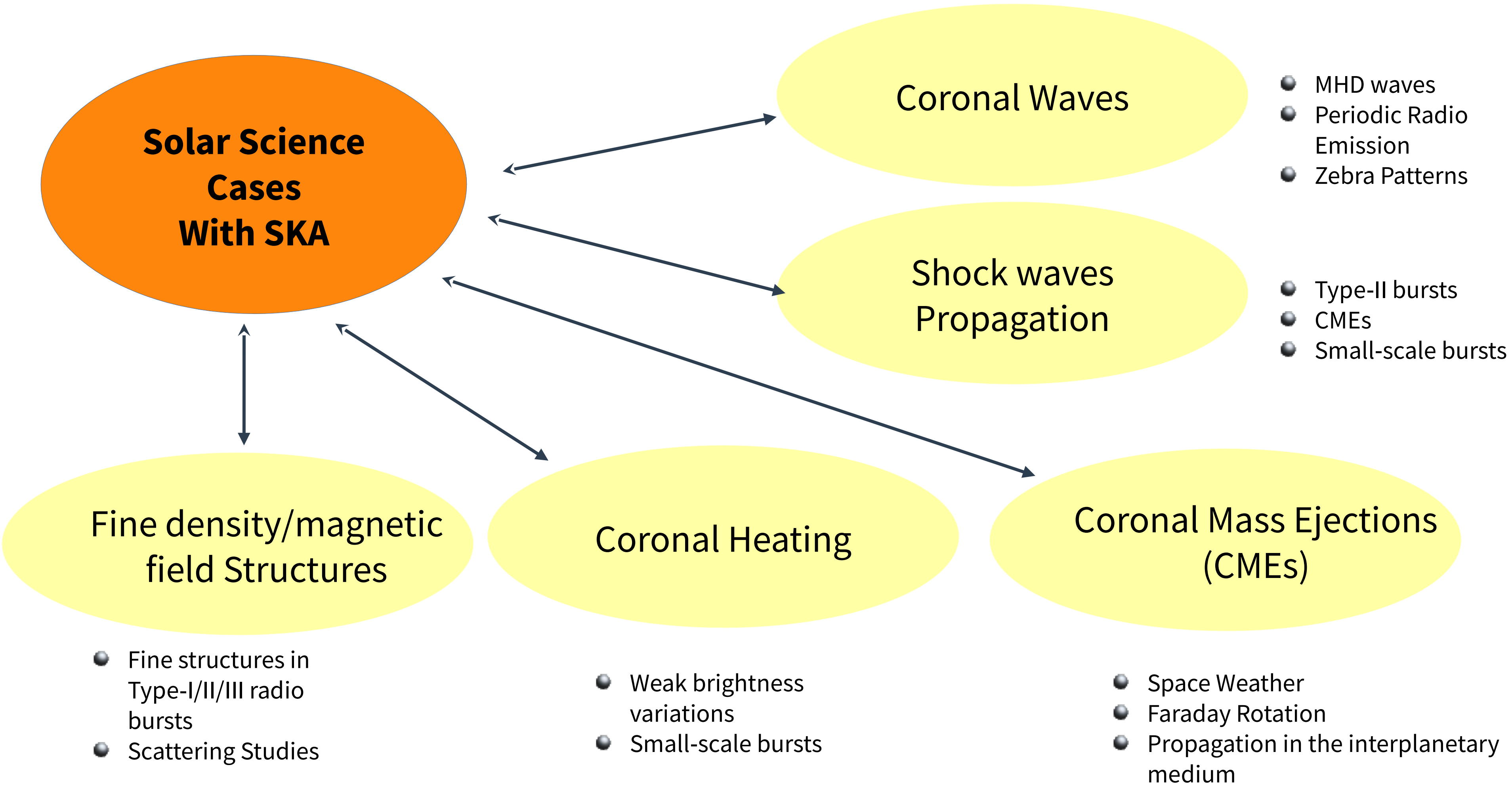
Table 2: Summary of SKA1 specifications

Parameter	SKA1-LOW value	SKA1-MID value
Frequency range (MHz)	50-350	350-15300
Angular resolution ($''$)	4-24	0.025-1
Time resolution (s)	0.001-9	0.001-9
Frequency resolution (kHz)	5	15-76
Field of view (deg^2)	2-39	$\leq$ 1.4
Largest angular structure ($'$)	60-500	15-80
Sensitivity ($\times 10^{-3}$ sfu)	0.46-4.00	0.16-0.90

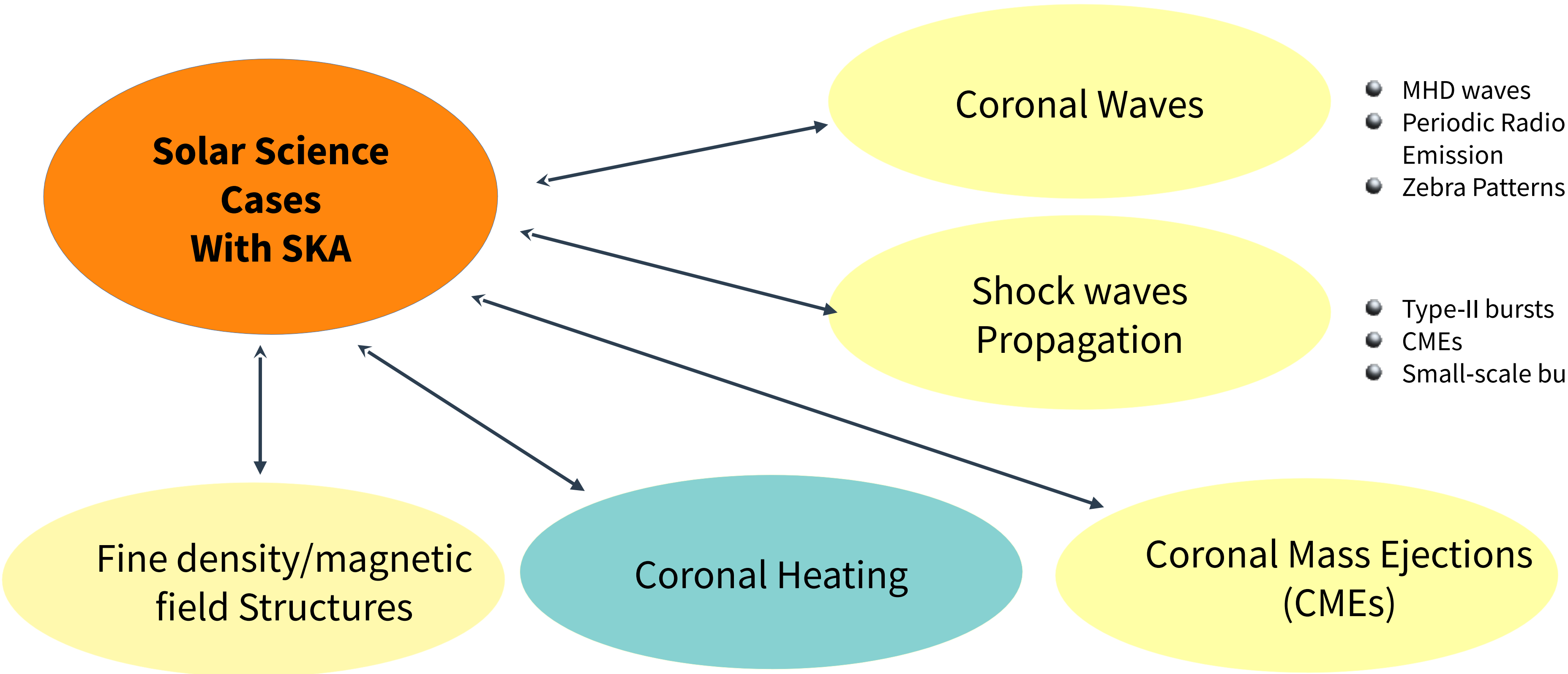
- Improvement of spatial resolution upto 10 times
- Time resolution improvement upto 5 times
- Sensitivities / Fidelity improvements by 10 times at low frequencies

Nindos A., Kontar E. P., Oberoi D., 2019, Advances in Space Research, 63, 1404

Science Cases



Science Cases



Coronal Waves
- MHD waves
- Periodic Radio Emission
- Zebra Patterns

Shock waves Propagation
- Type-II bursts
- CMEs
- Small-scale bursts

Fine density/magnetic field Structures
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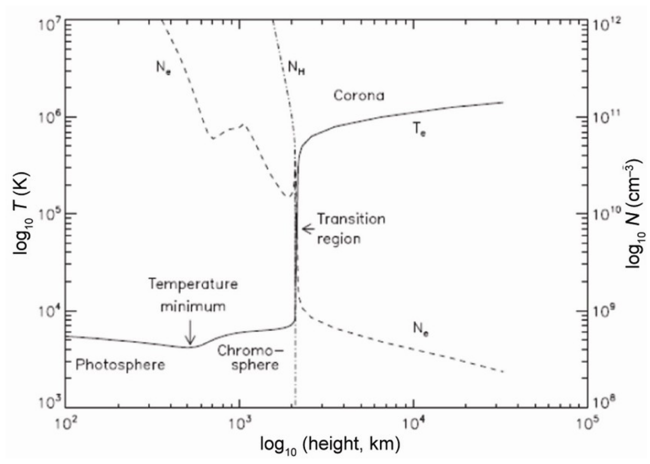
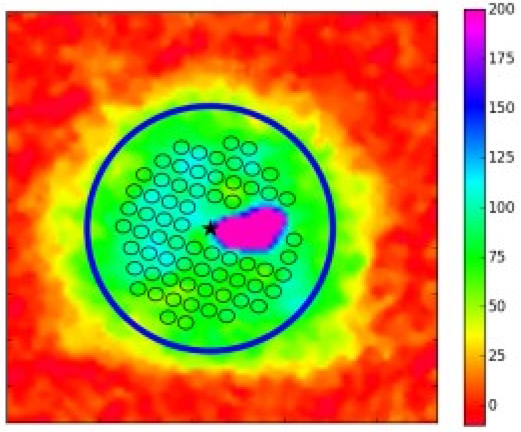
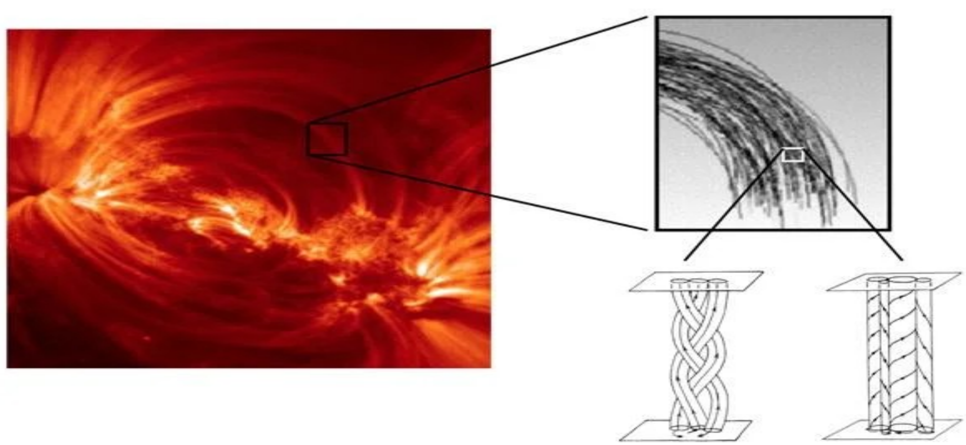
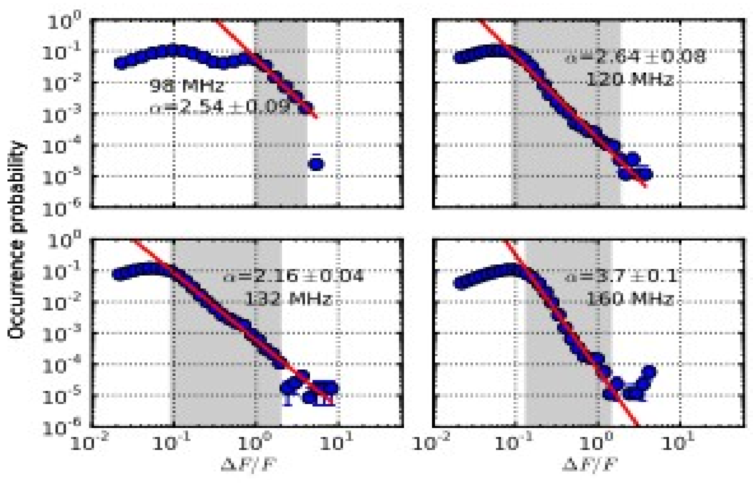
Quiet Sun Studies

- Significant prevalence and strength of the weak impulsive nonthermal emission (Sharma & Oberoi 2018).
- Recent MWA (Mondal et al 2020) observations reported the detection of what are now known as Weak Impulsive Narrowband Quiet Sun Emissions (WINQSEs).
- The mSFU level emissions are the weakest nonthermal solar bursts detected yet.



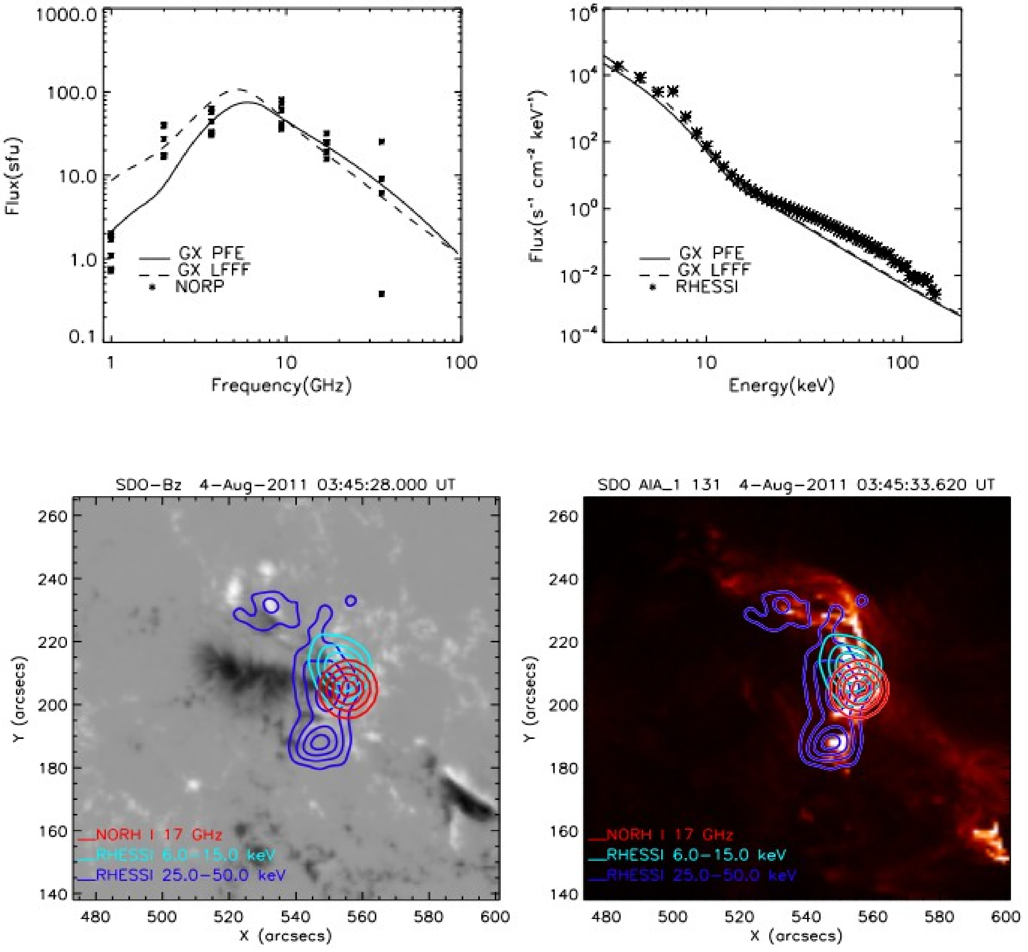






Observations of flaring loops in the solar corona with SKA1-MID

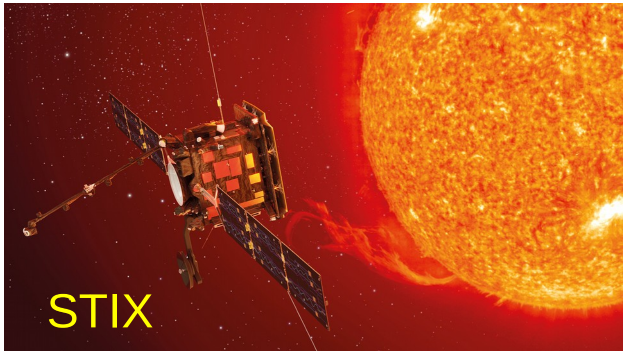
- Radio emission of the flares is an important diagnostic tool, because it is highly sensitive to the parameters of plasma, magnetic field and energetic particles. In particular, the emission in the microwave range (~5 GHz and above) is produced mainly due to the incoherent gyrosynchrotron mechanism, which is relatively simple and well-studied at the micro-level. Inferring the emission
- Observations with high angular resolution and (ii) simultaneous imaging observations at many frequencies. The SKA1-MID Band 5 (4.6-13.8 GHz, with planned extension up to 24 GHz in SKA2)observations are perfectly suited for the flare diagnostics.

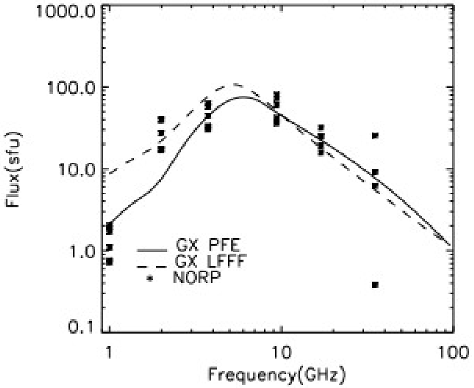


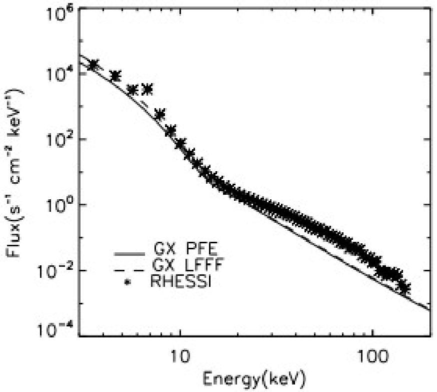
Nita, G. ApJ, 799:236 (15pp), 2015

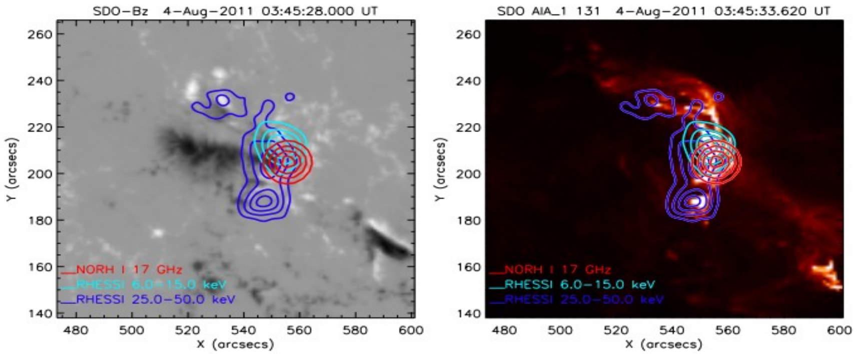
X-ray (STIX) and SKA-mid

- The Spectrometer Telescope for Imaging X-rays (STIX) on Solar Orbiter is a hard X-ray imaging spectrometer covering the energy range from 4 to 150 keV
- Developed by i4Ds, FHNW, Brugg, Switzerland









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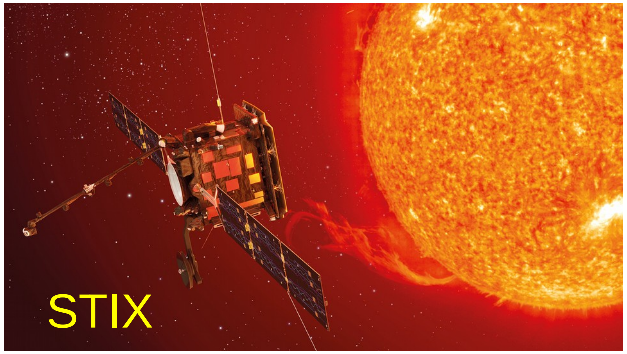
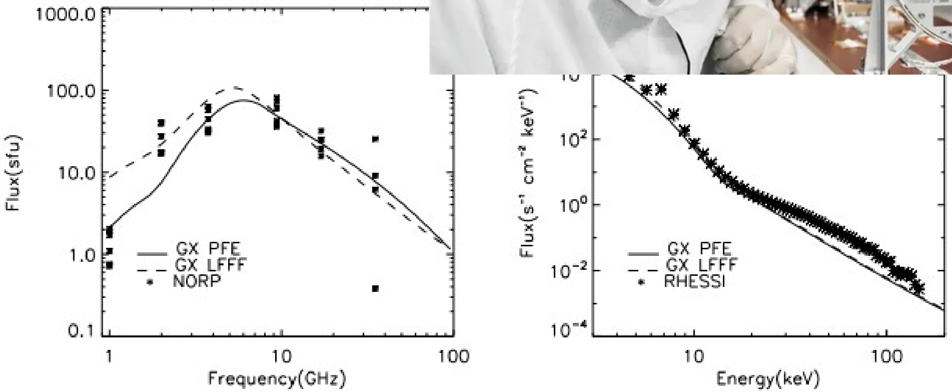
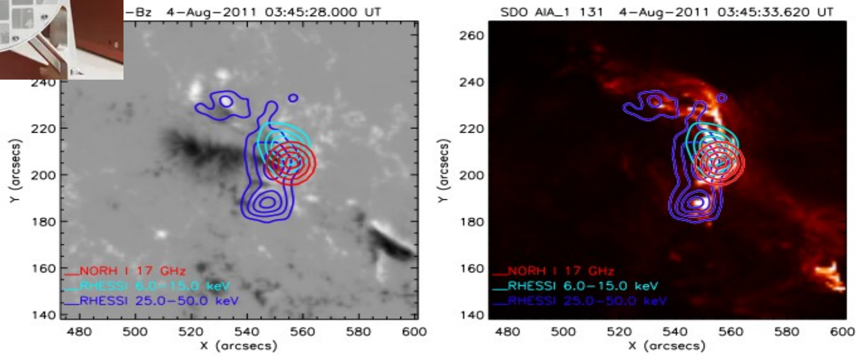
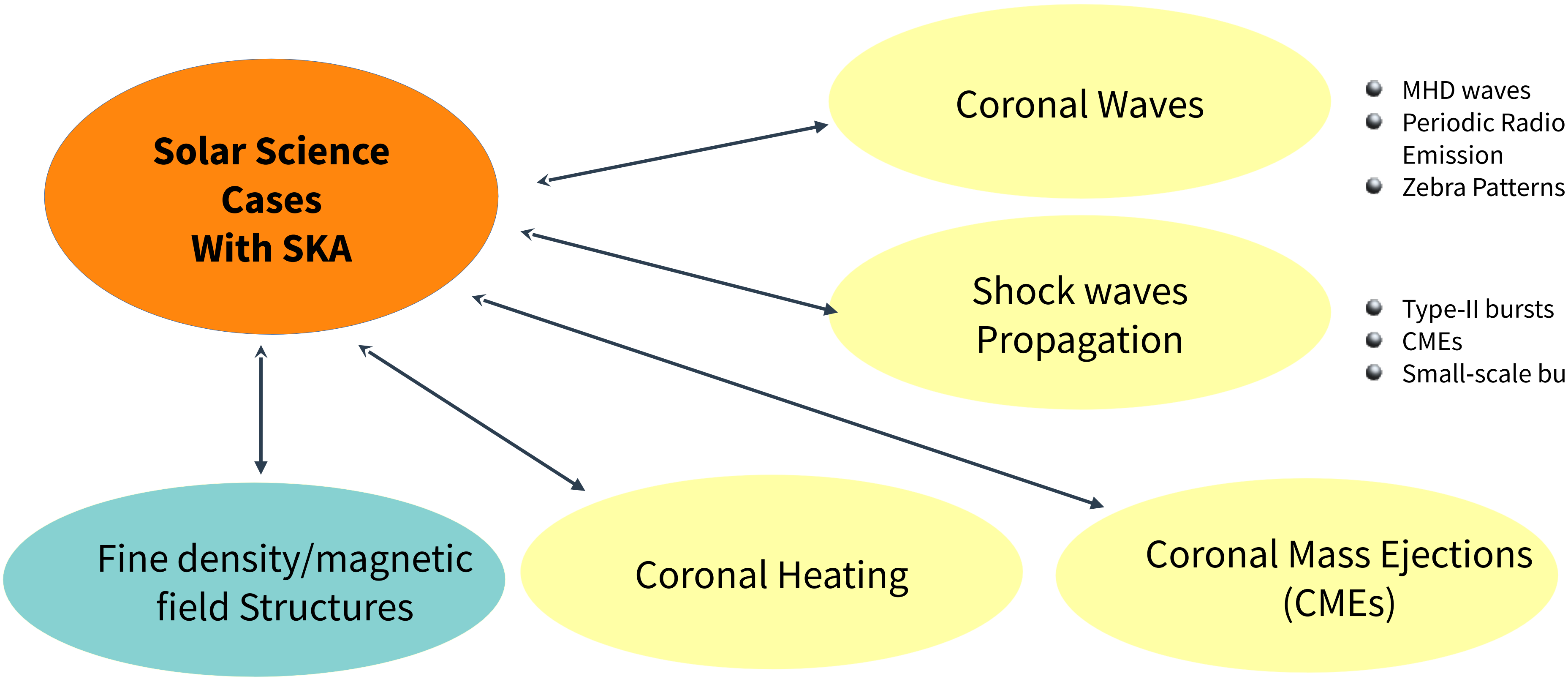






Nita, G. ApJ, 799:236 (15pp), 2015

Science Cases



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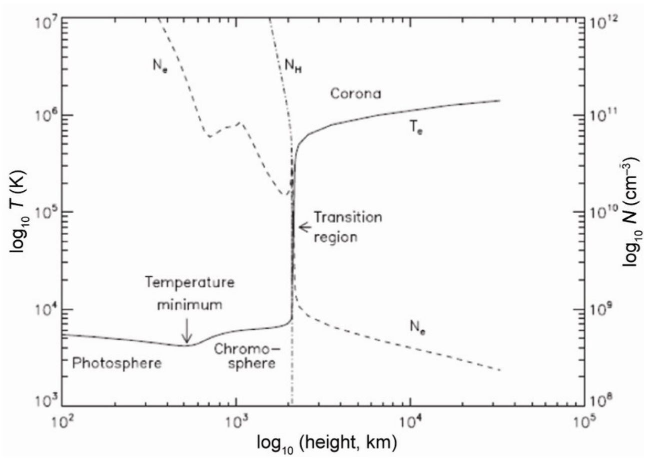
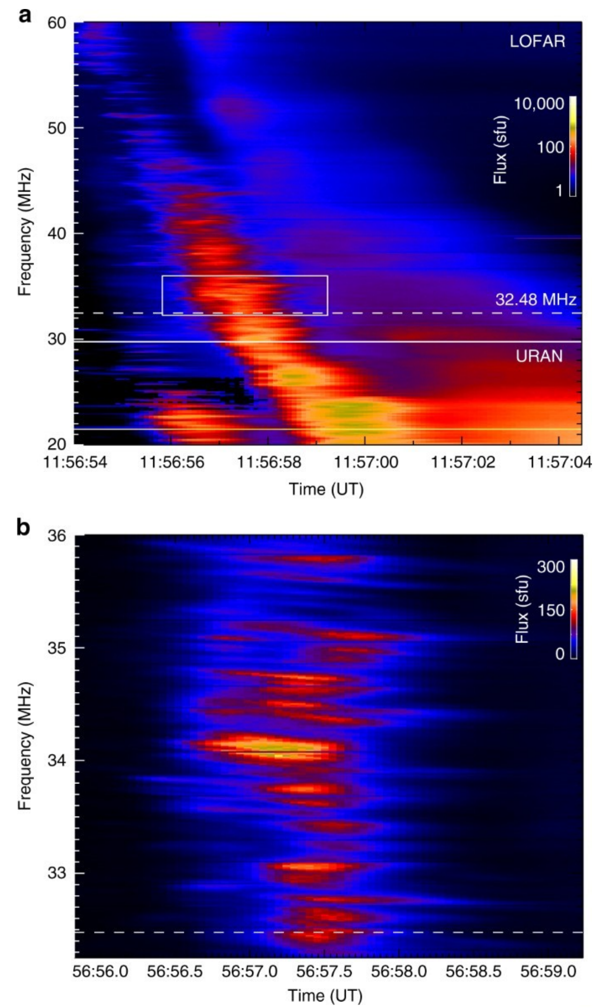
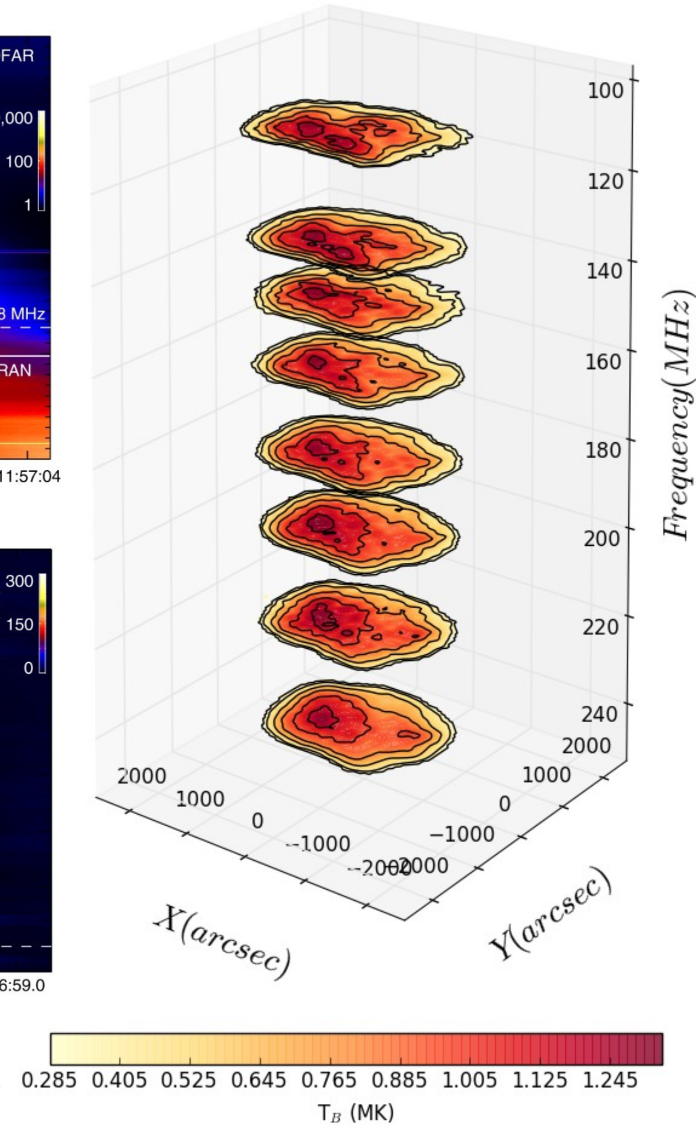
Coronal Turbulence



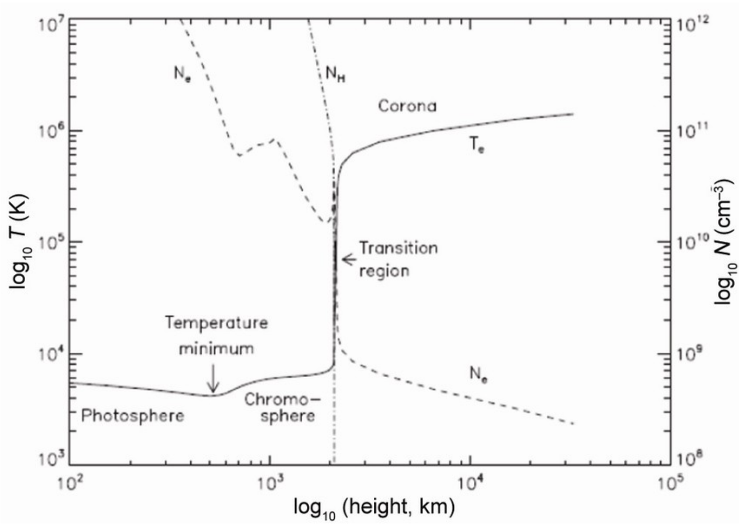




- Radio wave propagation effects, and not the properties of the intrinsic emission source, dominate the observed spatial characteristics of radio burst images.
- Quiet sun observations can be used to address a variety of science objectives, e.g. investigations of coronal inhomogeneities and turbulence via studies of propagation effects (Sharma and Oberoi, 2020).

Kontar, E.P., Yu, S., Kuznetsov, A.A. et al. Imaging spectroscopy of solar radio burst fine structures. Nat Commun 8, 1515 (2017).

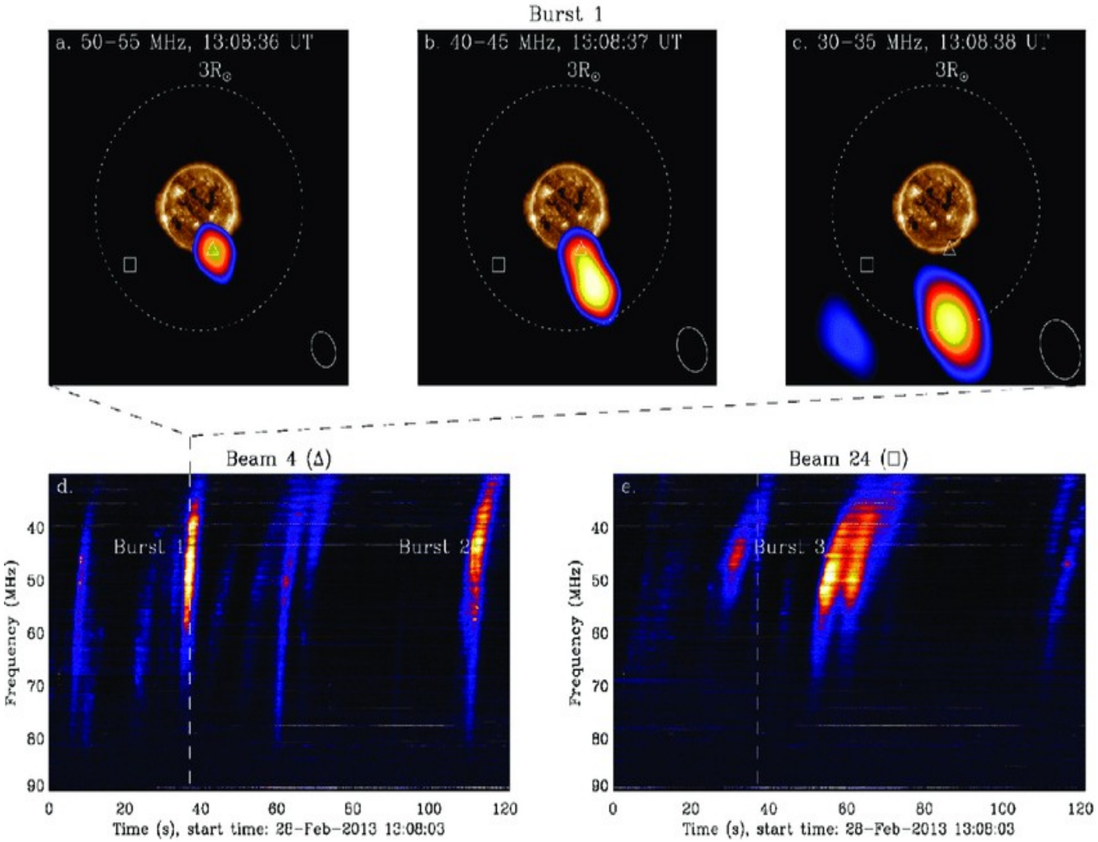
Transport of escaping solar electrons -- Solar type III radio burst observations with SKA1 Low



- The radio band of 50-350 MHz provides very useful diagnostic tool of plasma processes in the Solar corona. Energetic electrons that are produced during solar flares give rise to detectable radio signatures via coherent plasma emission.

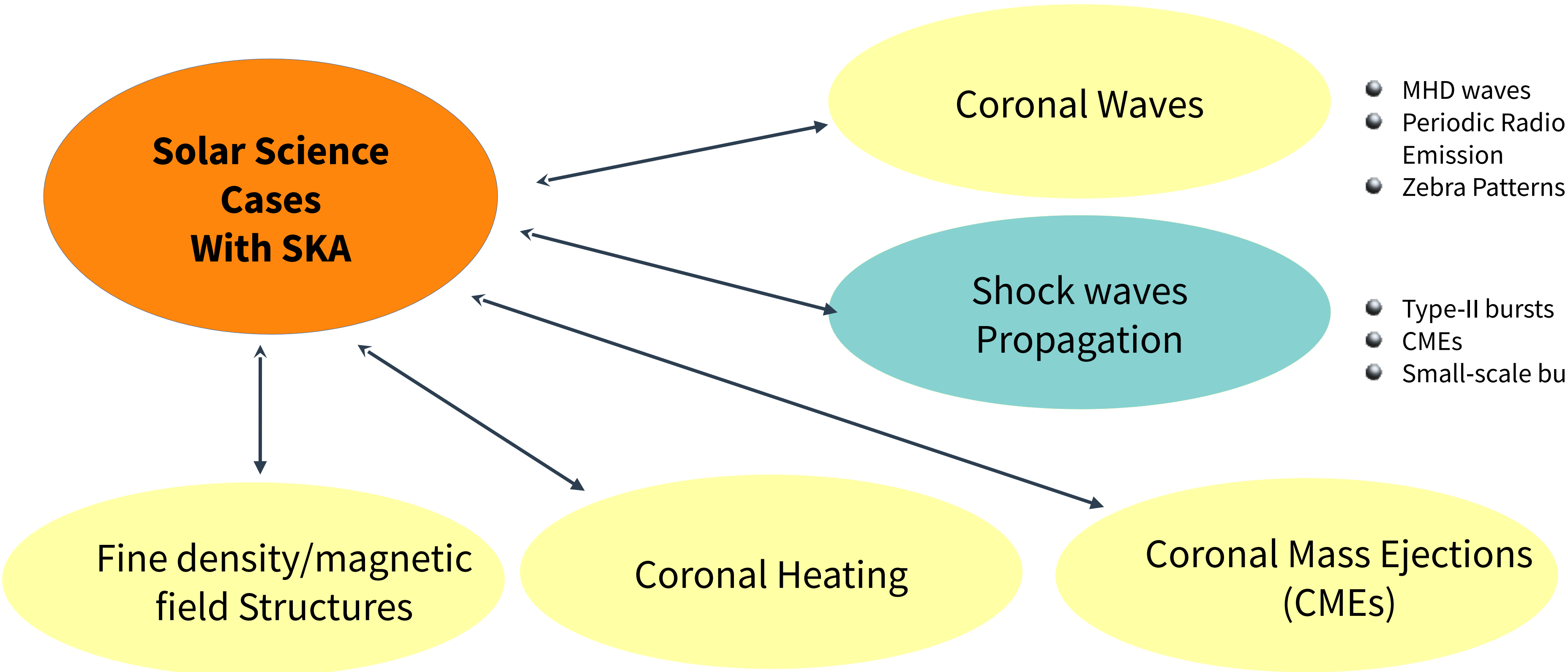
- With spatial and spectral observations of the bursts, this project will address:

• What is the starting location (i.e. acceleration site) and propagation path of Type III bursts?
• How do the burst spectra change as a function of time and position?
• What physical processes govern the transport of energetic electrons from the Sun to the Earth?
• How is the strong coherent radio emission produced in different solar bursts?



Morosan, D. A&A 568, A67 (2014)

Science Cases



Coronal Waves:

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Shock waves Propagation:

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Fine density/magnetic field Structures:

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Coronal Heating:

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- Small-scale bursts

Coronal Mass Ejections (CMEs):

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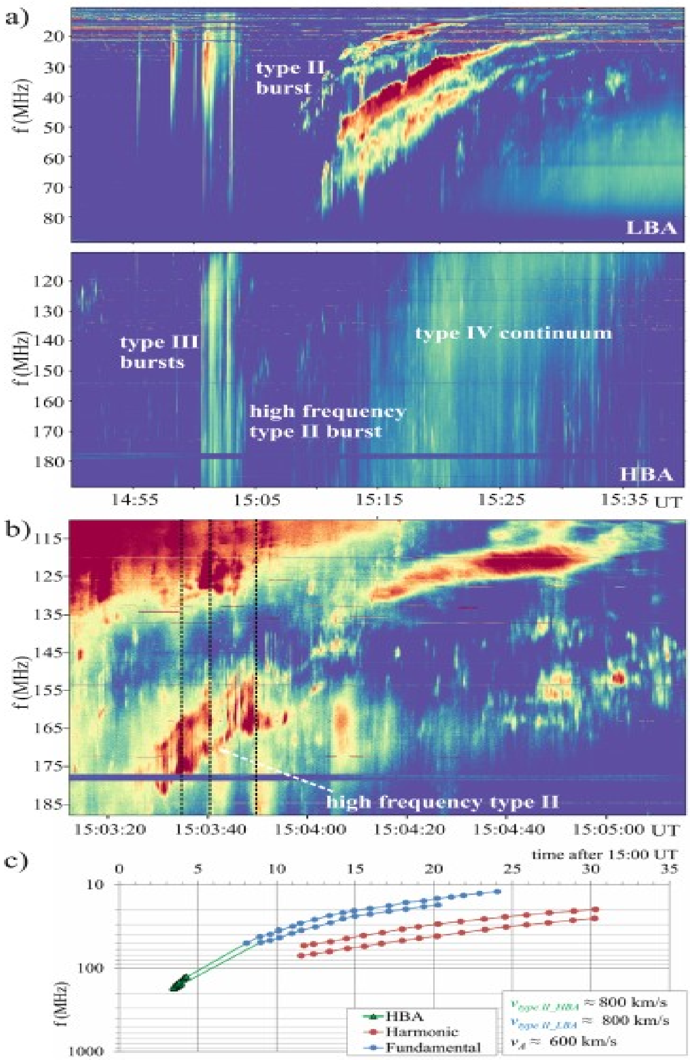
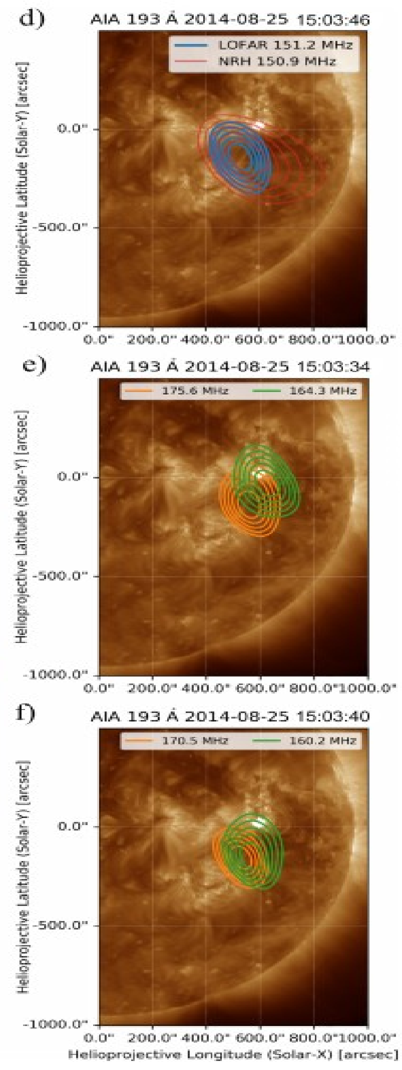
Shocks waves, CMEs, Type II bursts





Jasmina Magdalenic et al 2020 ApJL 897 L15

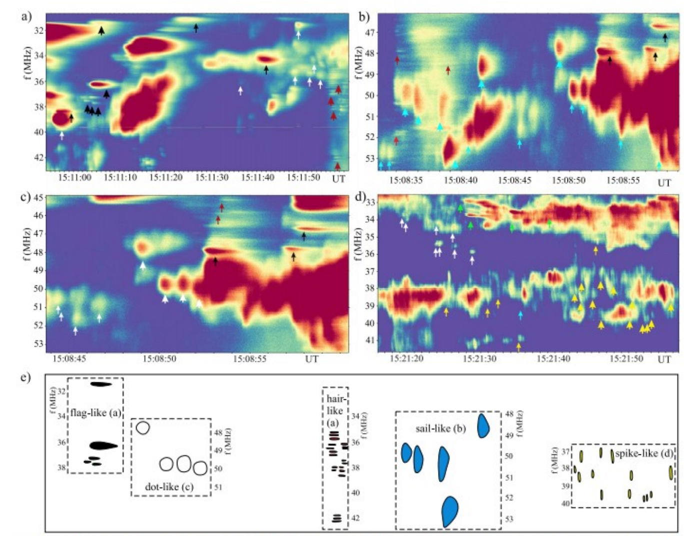
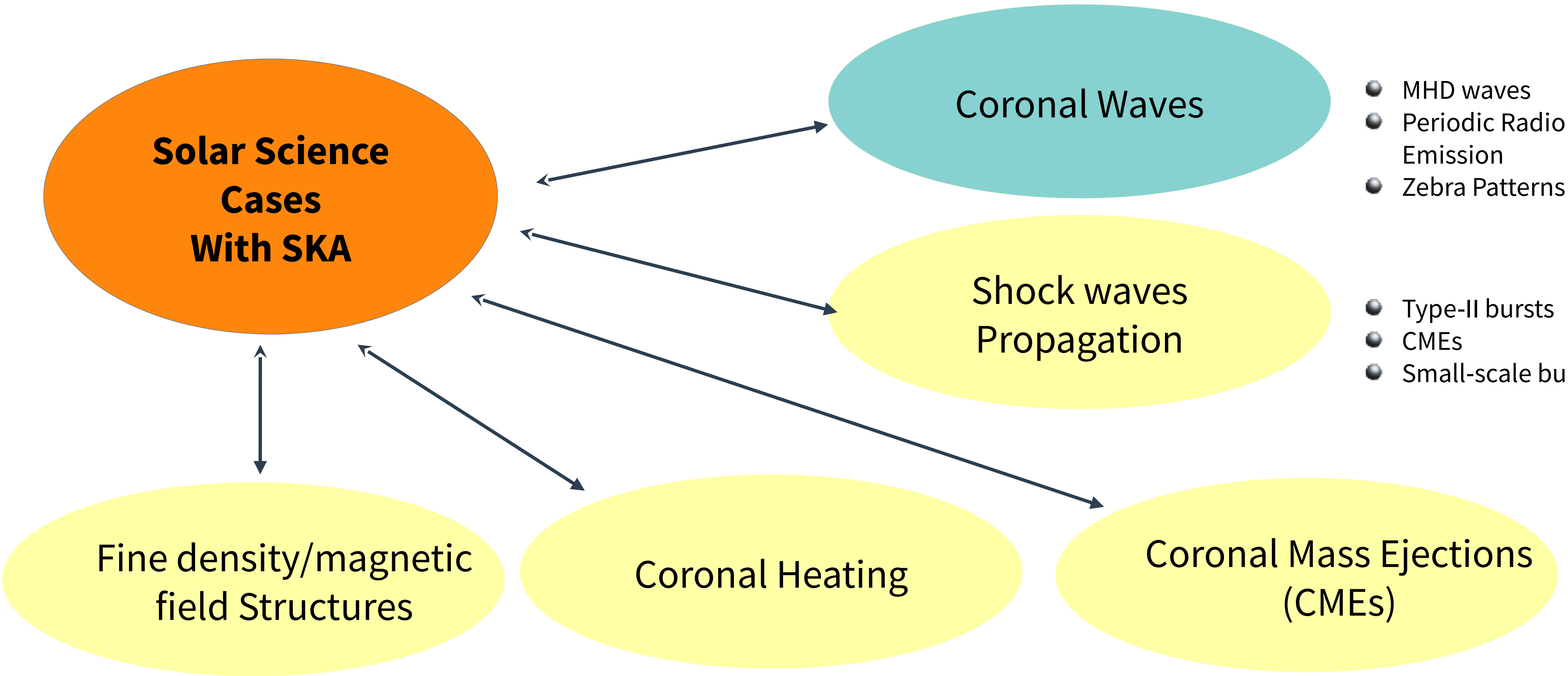


Figure 3. Panels (a)–(d) show LOFAR dynamic spectra of different narrowband FSs in the type II burst. In all dynamic spectra flag-like bursts are denoted with thick black arrows, dot-like with white, sail-like with blue, hair-like with red, and spike-like with yellow arrows. (e) One-to-one schematic presentation of selected groups of FSs presented in panels (a)–(d).

LOFAR results

- Fundamental and Harmonic bands
- Multiple Spilt-bands
- Narrowbands, broadbands and complex fine structures
- Hair-like fine structures
- FSs are generated when the shock wave propagates in a strongly inhomogeneous and turbulent plasma, with various structures of density and magnetic field

Science Cases



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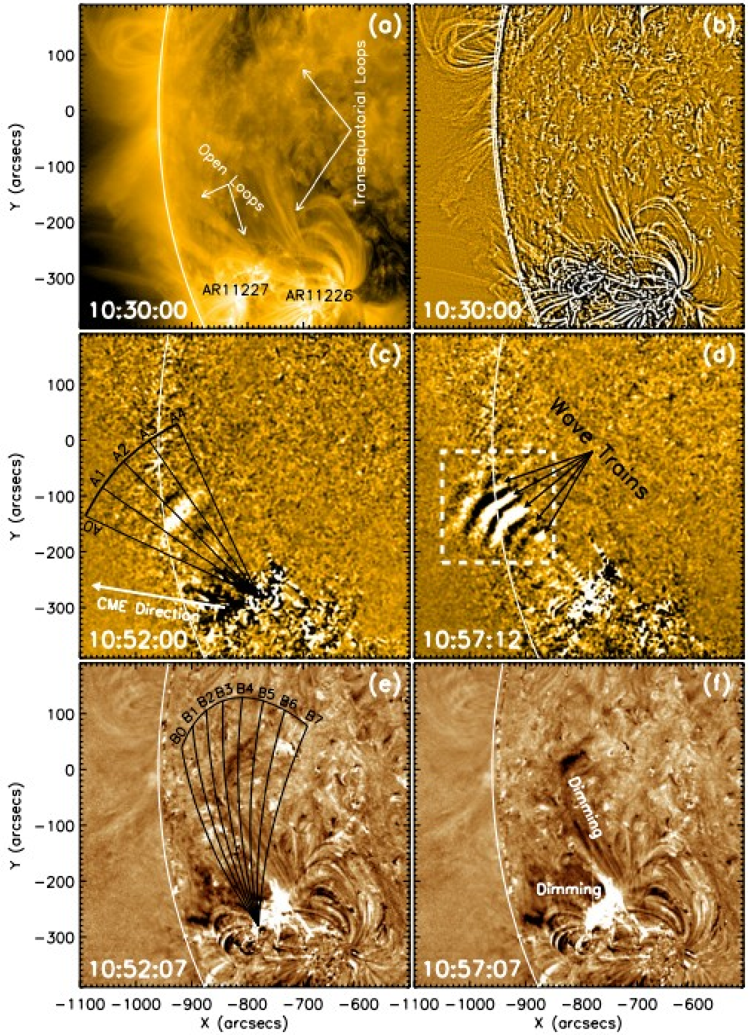
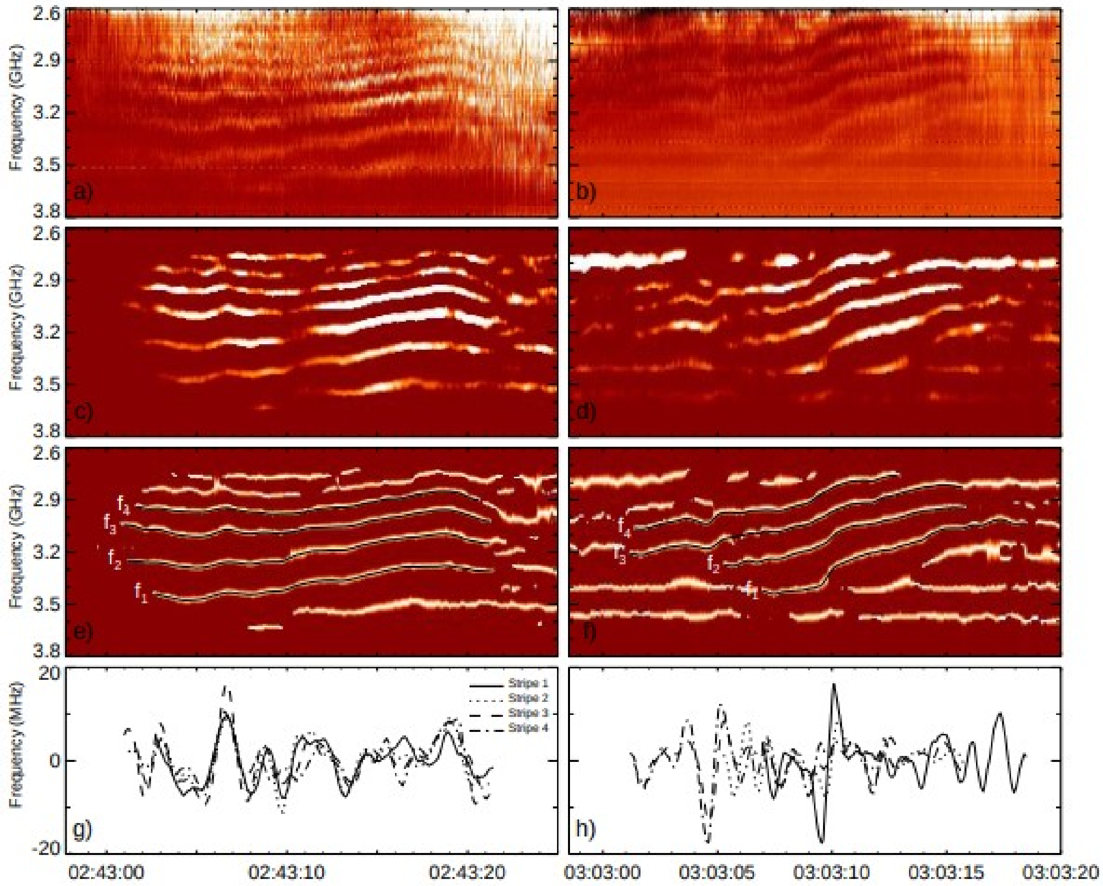
Study of spatially and spectrally resolved MHD waves with solar radio bursts

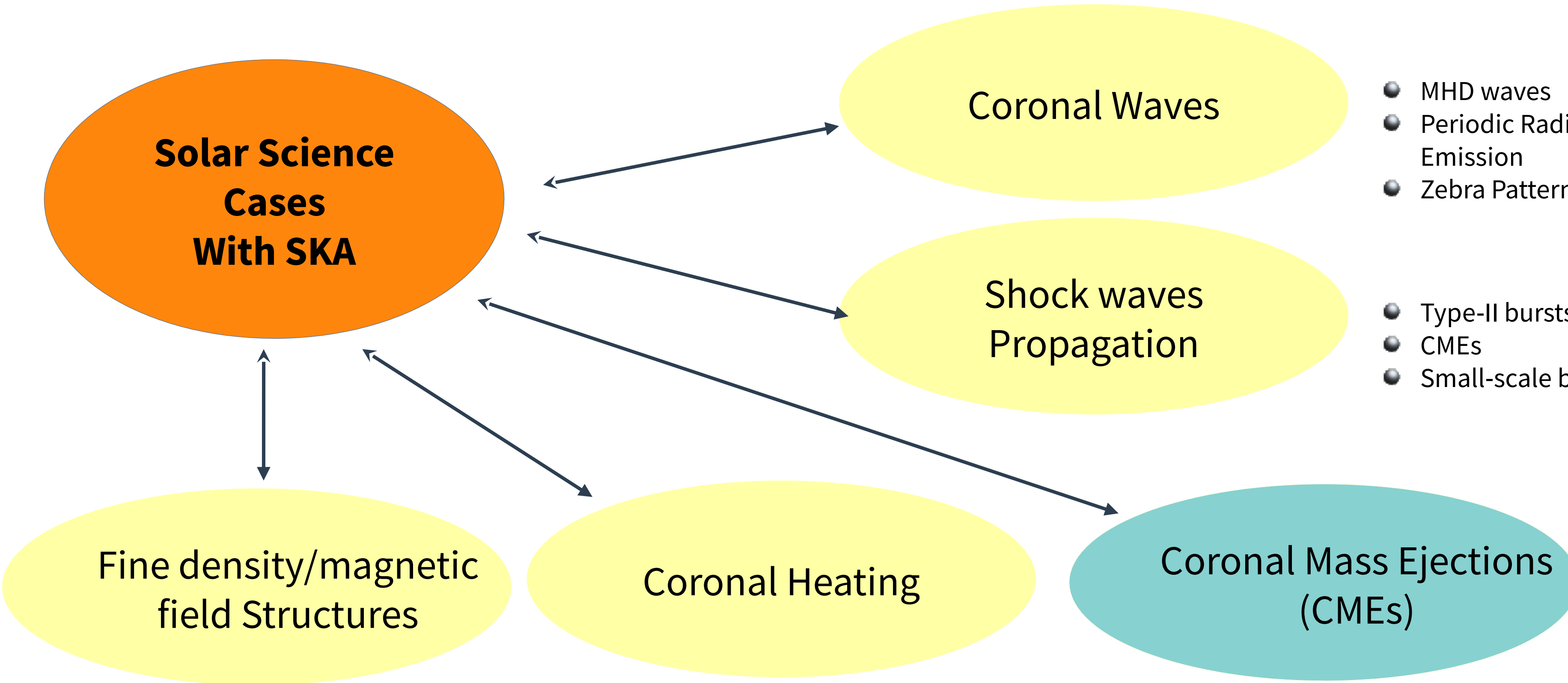


Shen et al. 753:53 (12pp), 2012



Yu,S. et al ApJ, 777:159 (7pp), 2013

Science Cases



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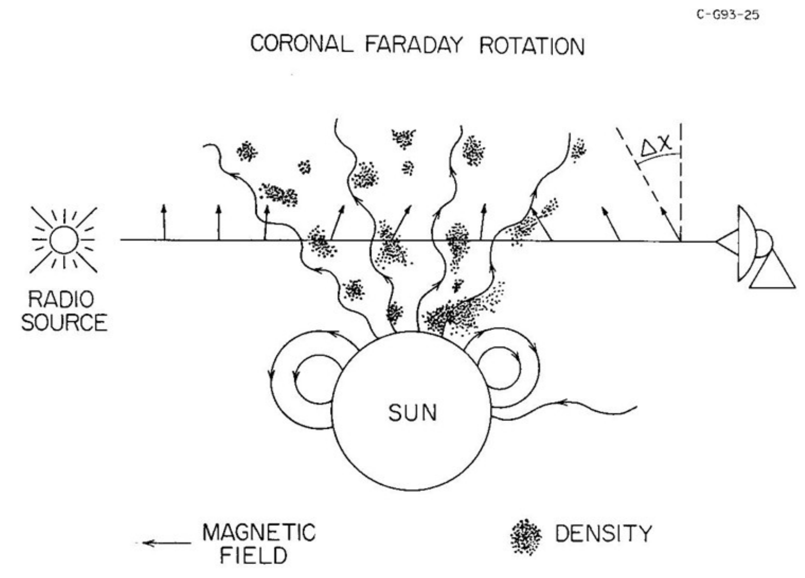
Predicting Space Weather using Coronal Mass Ejection studies

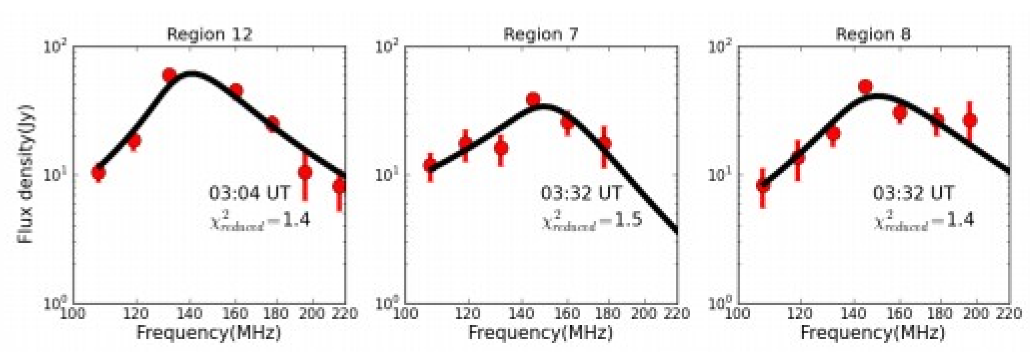
There are two aspects to this work:

(1) Characterising the magnetic fields and other physical properties of CMEs by measuring and modeling the thermal and nonthermal (gyrosynchrotron; GS) emission while they are close to the Sun, and

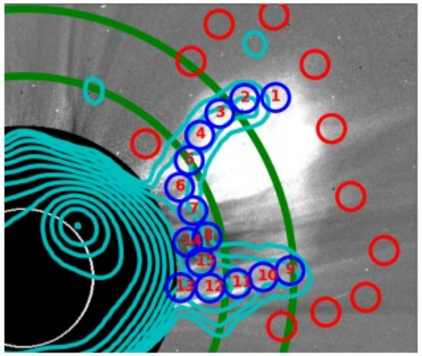
(2) Measuring and modelling the Faraday rotation (FR) of linearly polarised emission from astronomical sources through the CME plasma as it moves away from the Sun, to build a 3D model for the CME magnetic field and eventually enable space weather prediction.

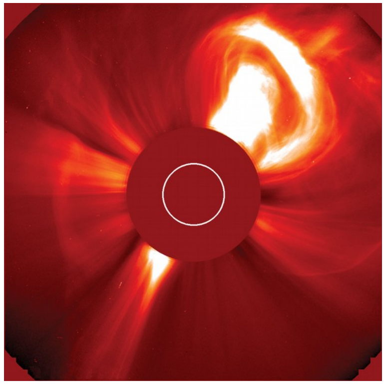


$$\Delta X = \frac{e^3}{2\pi m_e^2 c^2 f^2} \int n_e \vec{B} \cdot \vec{ds}$$



Mondal, S. et al 2020 ApJ, 893, 28





Summary

- SKA will vastly enhance capabilities for doing solar physics
- Detailed observations has potential to discover fine structures
- Tests for various dynamic plasma phenomenon
- Improvements in the Space Weather Prediction models

Imaging the inner heliosphere and Space Weather

- The direction of the interplanetary magnetic field is an essential parameter in the prediction of space weather impact on the environment around Earth, but observation before spacecraft measurements at the L1 point have proved challenging.
- A technique to accomplish such observation is the use of Faraday Rotation. Observations using pulsars in close proximity to the Sun have been taken with LOFAR for this purpose. A more interesting line of research is to use a Galactic polarised background to "image" the Faraday Rotation across a wide field of view.