

4.1.2 Solar activity

4.1.2.1 Active regions

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Active regions (AR) in the upper layers of the solar atmosphere are related to and caused by the magnetic fields of sunspots and sunspot groups in the photosphere (cf., Sect. 4.1.2.3 “Sunspots”). The early work on ARs is compiled in [j, e, g]. ARs can now also be studied in sub-surface layers with time-distance helioseismology [06Kos]. They are characterized by strong magnetic fields with high temporal variability, and their magnetic field structure is reflected in the appearance of many loops in vacuum-ultraviolet (VUV) and X-ray images of the solar atmosphere [99Mal, 00Cha, 02War, 07Cir, 07Dos]; see also Fig. 2. The background corona significantly contributes to the AR emission [03DeZ]. It is thought to consist of unresolved loops [06Cir]. Often ARs are the sites of solar flares (cf. Sect. 4.1.2.7) and coronal mass ejections (see Sect. 4.1.2.5.3). The free magnetic energy available, e.g., for solar flares and coronal mass ejections, is an important parameter for ARs (cf., [07Reg]).

Studies in emission lines with values of the formation temperature between 200 000 K and 300 000 K showed frequent brightenings with durations of less than a minute in the brightest portions of ARs during the solar maximum [84Por]. A definition of the formation temperature is given in Fig. 1 together with an overview of the ionic fraction of iron ions (as emitters of prominent

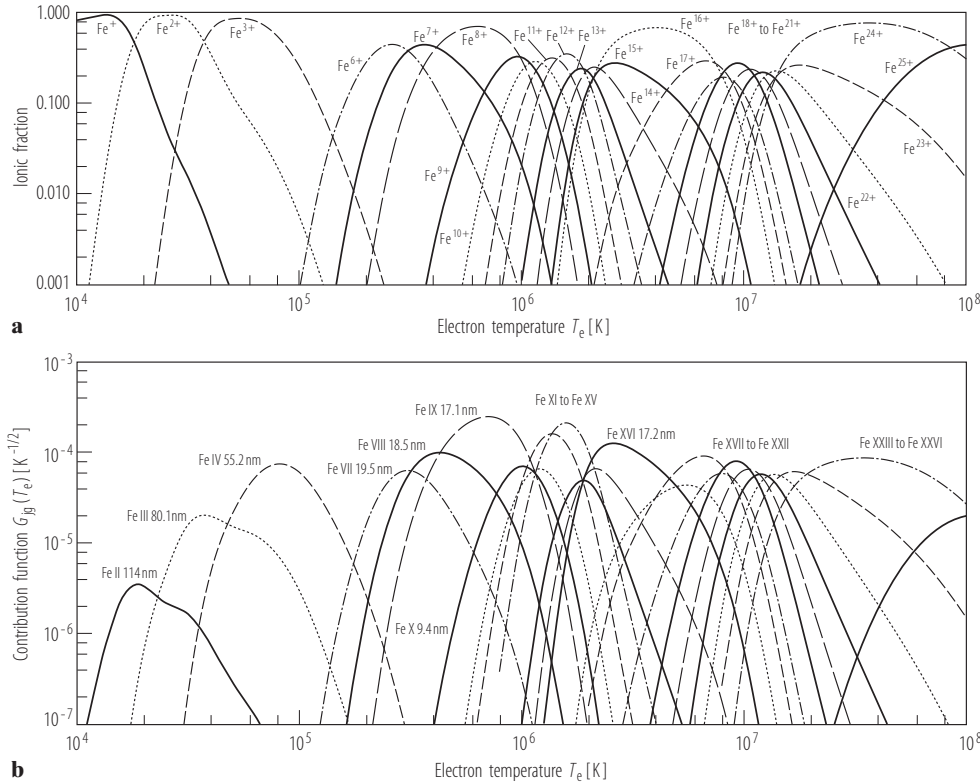


Fig. 1. (a) Ionic fractions of the iron ions Fe^+ to Fe^{25+} (after [i]) and (b) contribution functions of corresponding iron emission lines of the spectra Fe II to Fe XXVI. The curves are drawn in a style that cycles through a solid line to a long-dashed one with increasing charge numbers. The electron temperature at the maximum of a contribution function is defined as formation temperature of the spectral line in question.

high-temperature spectral lines in AR and flares, cf., [c]) and their corresponding contribution functions. Similar diagrams can be computed for other elements with data from [i]; cf., [h, 04Wil].

ARs are very dynamic in the transition region, but show less Doppler shifts, and thus bulk motions, at coronal temperature values [82Nic, 82Fel, 98Bry1, 99Kje, 00Spa, 00Bre, 02Fre]. Rotational motions around the loop axes were found with speeds up to 50 km s^{-1} . This motion may be related to twisted magnetic fields in ARs. A study of photospheric and coronal currents in ARs and the related field line twist has been conducted by [04Bur]. In a recent paper [05Lek], the authors argue that the twist available in ARs might be sufficient to trigger a kink instability.

Doppler shifts of lines emitted by highly-ionized iron from FeX to FeXVI indicate a dynamic and turbulent plasma in the AR core, but also suggest a net upflow of the hot material and a downflow of cooler material in the same region with relative speeds of about 15 km s^{-1} [99Bro]. Much higher LOS velocities of up to 60 km s^{-1} were observed in cool AR loops [97Bre]. Significant red shifts were found in steady loops [02Win]. Downflows of $\approx 10 \text{ km s}^{-1}$ to 30 km s^{-1} were observed for Ne^{7+} ions with a corrected Ne VIII rest wavelength of 77.0428 nm [99Dam, 99Pet]. Above an AR, the thermal velocity was found to be a linear function of the charge-to-mass ratio [05Wil].

A special form of extreme-ultraviolet (EUV) emission from the active transition region and low corona, the so-called “moss”, has been discovered by [00Srj, 99Beh]. A similar feature had earlier been identified in soft X-ray images [94Per]. The moss appears to be a mixture of dark absorbing material and hot coronal plasma at $\approx 1 \text{ MK}$ near the legs of even hotter coronal loops [00Mar]. An example of moss is shown in Fig. 2 together with AR loops.

The active transition region above sunspots is, in many cases, the site of sunspot plumes discussed in detail by [98Bry3, 98Mal]. It was found that the Doppler shift in these plumes indicate downward motions of the plasma. Above the umbral region of a sunspot, in general, however, outside of plumes, strong oscillations prevail in the line radiances and Doppler velocities of, for

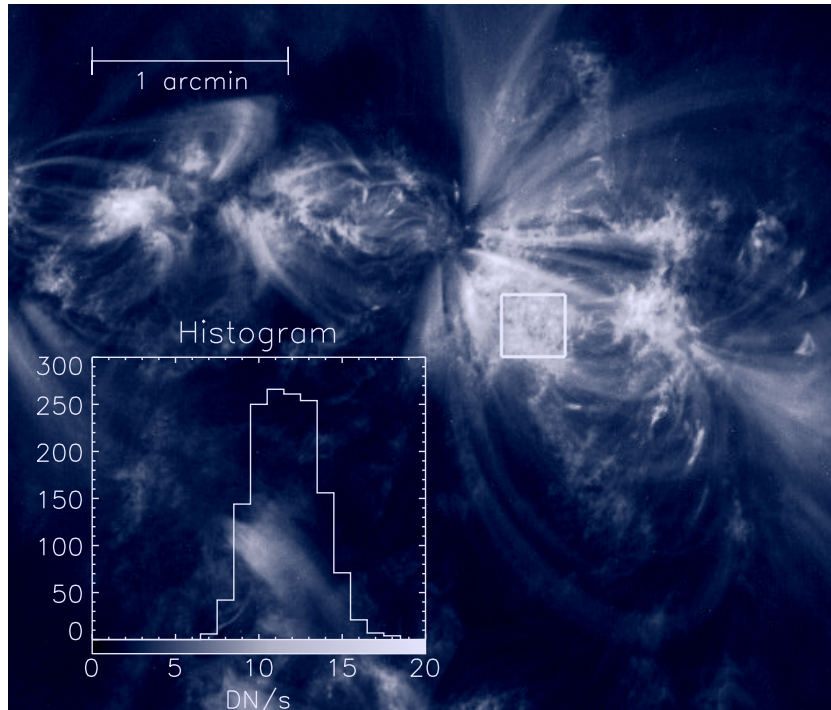


Fig. 2. (see color-picture part, page 615) Moss region observed in the 17.1 nm wavelength band on 6 June 1999. The square box with an angular size of $19'' \times 19''$ contains bright moss structures with a brightness distribution given in the histogram inset. AR loops can be seen in the neighbourhood (from [00Mar]).

Table 1. Selection of spectral observations and emission line lists related to ARs.

Wavelength range, ^a λ [nm]	Spectral resolution, ^b $\Delta\lambda$ [pm]	Solar targets ^c	Reference
5.1 to 127	25	AR	[72Her]
6 to 38.5	4	AR	[72Beh]
8.4 to 121.6	40	disk (AR)	[59Vio]
9.1 to 44.7	11.5	AR	[00Bro1, 00Bro2]
13.9 to 79.4	100	AR	[70Fre]
17.1 to 33.5	5.5 (3)	AR; QS	[d]
17.1 to 44.8	< 8	AR	[94Tho]
28 to 137	180	AR, QS	[73Dup]
30.3 to 134.3	160	sunspot plume	[85Noy]
46.5 to 160.9	4.4 (2.2)	various	[f]
50 to 185	60	disk (AR)	[60Pur]
54.5 to 137.6	4.3 (2.2)	AR	[98Fel]
76.5 to 260	100	disk (AR)	[61Det]
119 to 173	1	AR; sunspot	[b]

^a In some cases, not the full range is covered. ^b Not all entries fully consistent (FWHM, resolution elements, etc.; second order in parentheses). ^c QS – Quiet Sun.

instance, the transition region line O V (62.9 nm) [99Bry1, 99Bry2, 03Bry, 04Bry1, 01Mal].

Many spectral studies were carried out in ARs. They significantly contributed to the identification of new VUV (and X-ray) spectra in the past as can be seen from Fig. 3. The first identification of an emission line is marked by circles in the upper right-hand side of the lower panel. See Table 1 for references related to AR spectra. The area of the circle is proportional to the elapsed time since the discovery (largest circles: 1953; smallest circles: 2000). The solar abundances are from [98Gre]; note, however, the newer abundance data by [07Gre]. Iso-electronic sequences follow dotted lines at an angle of 45°. Cr II and Co II lines have been identified at wavelengths greater than 200 nm [77Dos]. outside the VUV range. Some important X-ray spectra mainly relevant for flare plasmas (cf., Sect. 4.1.2.7) have been included for ions without lines in the VUV range [64Tou, 72Dos, 82Phi]. In the lower left-hand side are shown the temperature values of the maximum ionic fractions, T_{\max} , [a] as a function of the ionization charge states.

A detailed study of localized emission enhancements in AR was performed by [83Coo]. Systematic observations of ARs before and during the *SOHO*¹ and *TRACE*² era have been undertaken by sounding rocket payloads (e.g., the Solar EUV Rocket Telescope and Spectrograph – SERTS [94Tho, 98Dwi]) and *Yohkoh* [96Yos]. Plasma temperatures of 2 MK to 3 MK were obtained with a steep decrease of the emission measure above this range by [99Sme], and electron densities of $5 \times 10^9 \text{ cm}^{-3}$ have been deduced from Si IX emission-line ratios observed in the core of an AR [03Kee]. In Sect. 4.1.1.5.2, the non-thermal motions in the solar transition region have been introduced for quiet and active areas. The relationship between the radiance and width of the transition-region emission lines H I Ly β , O V (62.9 nm), O VI (103.2 nm), and the coronal line Ne VIII (77.0 nm) was studied with raster scans across ARs by [98Bry2]. The non-thermal velocities deduced from the line widths were $\approx 30 \text{ km s}^{-1}$ and increased with the formation temperature of the lines. Many line profiles have a complicated structure and indicate multiple flows in the field of view of one pixel [01Bry, 04Bry2]. Recent width measurements of the emission line Fe XII at 19.5 nm in ARs have been presented by [07Dos].

¹Solar and Heliospheric Observatory

²Transition Region and Coronal Explorer

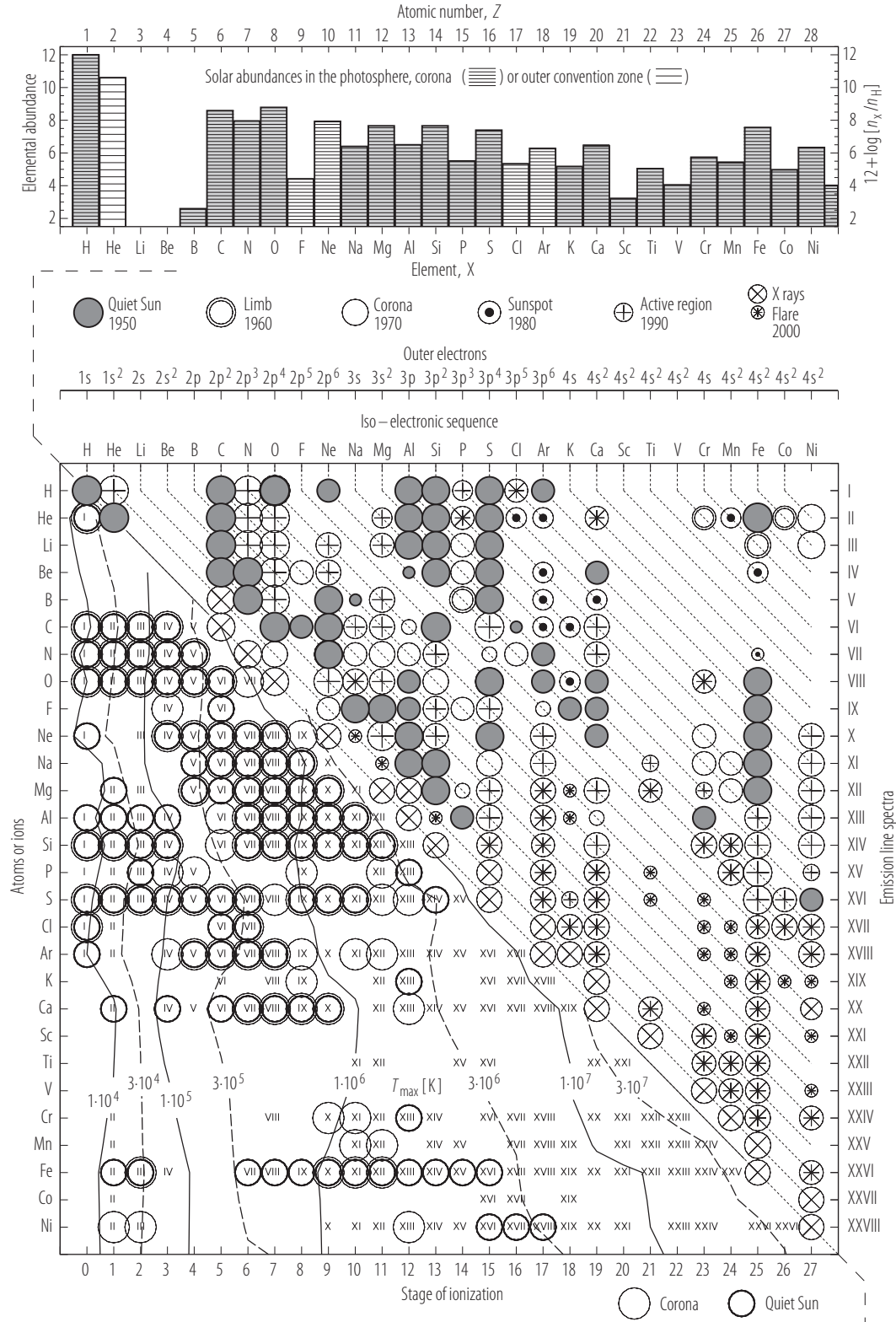


Fig. 3. Summary of observed solar VUV and some X-ray emission lines, and the history of their identification from [03Wil]. See text for more explanations. The solar elemental abundance data in the top diagram are taken from [98Gre].

The disturbance caused by an AR in the solar interior can be detected on the other side of the Sun by helioseismology. It is thus possible to monitor the development of ARs on the far side with the help of solar oscillation observations (cf., e.g., [07Zha]).

4.1.2.1.1 References for 4.1.2.1

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