# Fe II PROSPECTS IN SOLAR PHYSICS

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## 1. SOLAR PHYSICS OVERVIEW

Just like the other fields of astrophysics, solar physics changed with the advent of radio astronomy and space astronomy. The emphasis shifted from radiative transfer toward the nonthermal structures and phenomena exhibited by the solar atmosphere, most notably the flare and the magnetic structuring into photospheric tubes and coronal loops. Solar physics has become a field of MHD and plasma physics.

This is evident if you read the reviews collected in the NASA-CNRS volume "The Sun as a Star" (Jordan 1981; free copies are still available from S.D. Jordan, code 682, NASA-GSFC, Greenbelt MD 20771). That volume was intended to help re-establish the link between solar and stellar physics, traditionally strong in the era of radiative transfer research but weakened when the shift towards hydromagnetics made solar physics a somewhat isolated field. Now that the IUE and Einstein satellites have demonstrated that the other cool stars exhibit similar magnetic complexity, a new solar-stellar link called "magnetic activity" has formed, mainly populated by solar physicists turned stellar (e.g. A. Dupree, C. Jordan, J. Linsky, R. Noyes, R. Rosner and C. Zwaan with their coworkers).

(Another new solar-stellar link may be forged out of helioseismology. Its diagnostics of the solar interior are of obvious importance to the theory of stellar structure and stellar evolution. However, I wonder whether resolving the magnetic fine structure of the solar interior and generating the concomitant interpretative complexity may not temporarily result into similar isolation as studying the magnetic fine structure of the solar atmosphere did in the past).

There is a second space revolution coming up that follows naturally on the opening-up of the full electromagnetic spectrum: acquiring sufficient spatial resolution to study the processes that underlie the phenomena. This requires resolving the latter on the scale of the former, often about 0.1 arcsec in the photosphere (photon mean free path, pressure scale height). This revolution will undoubtedly come, the only question being when; by providing insights in dynamic, magnetic and plasma processes it will establish guidelines to

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the rest of astrophysics much as resolving the solar spectrum did for radiative transfer in the past. Fe II lines will play their role in this coming revolution. They are bound to be important diagnostics of the processes in the upper photosphere and lower chromosphere, which is precisely the layer where the magnetic field replaces the gas pressure as the chief structuring agent of the atmosphere.

The Sun does not stop at the angular scale of 0.1 arcsec in providing astrophysical enigma. The space age should mature enough that scales much smaller than 100 km become observable, through space interferometry, short-wavelength imaging and near-Sun observation. Far-future prospects have already been formulated ("Prospects for the $21^{st}$ Century", report of a National Solar Observatory Workshop, Jan. 1986).

## 2. SOLAR PHYSICS FACILITIES

The spatial-resolution revolution requires instrumentation that is now being realised, though much slower than anticipated. First and foremost, a large solar telescope must be put into orbit, able to resolve the photospheric flux tubes which constitute the basic ingredient of the activity phenomena. The decade-old Solar Optical Telescope project, originally planned for shuttle flights in the early eighties, was finally killed this spring just before the Challenger disaster. A scaled-down version called HRSO has taken its place, with its first flight planned for 1992. This is a facility as important for solar physics as Space Telescope will be for non-solar astrophysics.

In addition to a solar space telescope, there must be adequate ground-based instrumentation to pursue the new insights that space-resolved flux tubes, granules, sunspots etc. will generate. Ground-based observation can not compete with space observation in spatial resolution, but it provides the flexibility and the extended time coverage needed for evolutionary and follow-up studies.

The current situation is not good. The only facility where high spatial resolution is regularly obtained is the Sacramento Peak Observatory. Although an attempt to kill it last year was aborted, it appears now to be bled to death slowly. Taken together with the demise of solar physics at Mount Wilson and the scarcity of university programs in solar physics in the USA, this may imply jeopardizing the next generation of American solar physicists.

Indeed, the forefront in ground-based high-resolution solar physics seems to be shifting to Europe. The German solar physicists are installing a large observatory on Tenerife, including a major vacuum tower telescope (Schröter et al. 1985). The French are going to build a large polarization-free telescope at the same site (Mein and Rayrole 1985). The Swedes have just completed a simple but superb vacuum telescope on La Palma (Scharmer et al. 1985) which may prove to be the best on earth at the best location on earth for spatial resolution. The Swedes and the Norwegians are the driving force behind the LEST Foundation which aims to build a 2.40 m polarization-free vacuum telescope in the nineties (Stenflo 1985). The LEST Foundation is already the most international of the telescope-building consortia: current members are from Australia, China, Germany, Israel, Italy, Norway, Sweden, Switzerland and the USA. It has moved into its first phase of realization, with O. Engvold (Oslo) as project director.

## 3. FUTURE Fe II OBSERVATIONS

In conclusion I want to point out a promising specific type of Fe II observation from space, which is to study the behaviour of the Fe II lines near the solar limb. Although the solar limb spectrum observed during eclipse was the original motivation and testing ground for developing solar NLTE radiative transfer theory (Thomas and Athay 1961), the hazards and problems of eclipse spectrometry combined with its difficulty of interpretation have resulted in its decline when the outer solar atmosphere became observable from space, seen in projection against the solar disk at short wavelengths.

With the space revolution the limb becomes resolvable and highly interesting again. Optically thick observation inside the limb yields valuable diagnostics to radiative transfer because it shows lines still in photospheric conditions but raised to the height of formation where NLTE effects are dominant rather than second-order refinements. Examples are Canfield's (1969) classic analysis of rare earth limb emission lines, emission wings caused by coherency in resonance lines (Rutten and Milkey 1979; Rutten and Stencel 1980) and the large spatial intensity variation of Fe II lines seen near the limb (Canfield and Stencel 1976; Canfield et al. 1978; Rutten and Stencel 1980; Cram et al. 1980).

Above the limb, in optical thin conditions at least for the continuum, the solar spectrum at high spatial resolution is the ideal testing ground for checking NLTE mechanisms such as the pumping of Fe II by Ly-$\alpha$ (Johansson and Jordan 1984). The inhomogeneous nature of the chromosphere enriches this diagnostic by providing information with large variation in density and other state parameters, seen radially against the disk and laterally from the limb. This richness is evident in the literature on solar prominences, which seem to exist specifically to satisfy NLTE-PRD radiative transfer specialists.

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# PROSPECTIVES OF GROUND BASED OBSERVATIONS

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The study of FeII emission phenomena in quasars and other extragalactic objects will be revolutionized by the next generation of instruments being planned by ESO. In ten years it will be possible to obtain, for 16-mag objects and in a reasonable observing period, spectra with resolution exceeding $\lambda/\Delta\lambda = 5 \times 10^3$ with signal-to-noise ratios better than 30 throughout the optical/near infrared wavelength region. These spectra, when combined with UV spectra obtained with the Hubble Space Telescope (HST) will permit the detailed examination of FeII emission in the rest frame of selected extragalactic objects from below the Lyman limit to wavelengths longer than 1 μ-meter. It will then be possible to extend the techniques pioneered by H. Netzer and B. and D. Wills (Netzer and Wills, 1983; Wills, Netzer and Wills, 1985) to constrain the acceptable models of the $F_e^+$ region in quasars and active galaxies. The next generation spectra will have sufficient signal-to-noise ratios to identify and measure the strength of key multiplets, such as multiplets 191, 188 and 167 (Jordan, 1986; Wampler, 1985). It will be possible to measure the relative strengths of density dependent multiplets, such as the ratio of multiplet 36 to multiplet 42 (Wampler, 1985). And using deconvolution techniques one will be able to compare the FeII line profiles with those of the Balmer lines, MgII λ 2800 and CIV λ 1548. We will then be in a position to identify the excitation and ionization mechanisms of $F_e^+$, accurately determine the abundance of $F_e^+$ and study the possible evolution of this abundance with redshift.

Some of these next-generation instruments exist or are in construction. Oliva et al. (1986) have reported in this conference the first study of infrared forbidden FeII lines in supernovae remnants using the new ESO infrared spectrophotometer, IRSPEC. A description of the instrument is given in the June 1986 ESO Messenger (Moorwood et al., 1986). IRSPEC opens up the 1-3 μ meter band for spectrophotometric studies of the brighter quasars, nearby galaxies and galactic objects. Its resolution ($\lambda/\Delta\lambda \approx 2000$) is sufficient for isolating interesting features and resolving broad emission lines in active galaxies and quasars.

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