

SOME DEVELOPMENTS IN OBSERVATIONAL AND THEORETICAL SOLAR ASTRONOMY SINCE 1970

Peter Foukal

*Heliophysics Inc., 192 Willow Road, Nahant,
MA 01908, USA.*

E-mail: pvfoukal@comcast.net

Abstract: Studies of the Sun are widely considered to provide the ‘Rosetta Stone’ for understanding the broader cosmos. Yet, the field has seldom been entirely appreciated within astronomy. This is surprising given its leadership in the organization of U.S. astronomy and in the development of new observational techniques. We explore some developments since the founding of the Solar Physics Division of the American Astronomical Society in 1970 as observational and theoretical techniques evolved, and note that the evolution towards ever ‘Bigger Science’ is unlikely to be sustainable. We suggest that future advances may need to rely more on thinking ‘outside the box’, and put forward some ideas that might prove fruitful in this respect.

1 A PICTURE IS WORTH MANY WORDS

Solar research has changed significantly in some respects since the founding of the Solar Physics Division (SPD) of the American Astronomical Society (AAS) in 1970, but very little in others. For example, in [Figure 1](#) we see from the picture of Hal Zirin’s Post-Doctoral Fellows at Caltech that the field was highly international

in 1972, as it is now. Jay Pasachoff was the only American of the six; the rest of us were Canadian, French, Indian, Japanese and Swedish. The absence of women in the photograph is not surprising. Even more than now, women were under-represented in the U.S. solar research community.



Figure 1: Harold Zirin’s Post-Doctoral Fellows at Caltech in 1972. Clockwise from upper left: Jay Pasachoff, the author, Dainis Dravins, Katsuo Tanaka, Arvind Bhatnagar, and Bernard Lazareff, plus Zirin at lower left; the occasion was a pool party at Hal and Mary Zirin’s house in Altadena (photograph: Peter Foukal).



Figure 2: The 30-cm Zeiss refractor at Anacapri with attendees of the 1971 meeting on prominences and the chromosphere. Those known to the author in the front row are Sara Smith (Martin) at lower left next to the organizer, K.O. Kiepenheuer. In the rear row Ed Frazier, Frank Orrall, Friedrich Meyer, Dave Rust. Middle row, Ulrich Anzer, Hermann Schmidt, Eberhardt Wiehr and Ejnar Tandberg-Hanssen (photograph: Peter Foukal).

2 THE STATUS OF SOLAR RESEARCH IN ASTRONOMY

Despite their great value as the ‘Rosetta Stone’ to the cosmos, solar studies have rarely been entirely embraced within astronomy. Thus, eight years after co-discovering helium, solar astronomer Sir Norman Lockyer (1836–1920; [Meadows, 1972](#)), founder of the journal *Nature*, declared that:

... spectroscopic examination of the Sun has been regarded by many professional astronomers and physicists ... as a matter of tenth-rate importance. ([Lockyer, 1874: xi](#)).

The relation improved somewhat when a solar astronomer, George Ellery Hale (1868–1938; [Wright, 1966; 1972](#)), was the first to move a major observatory from city to mountaintop (and co-founded the AAS and *Astrophysical Journal*) a century ago ([DeVorkin, 2001](#)). The Sun did provide a bright source required for the first steps into radio, UV, and X-ray astronomy from the 1930’s through 1950’s. Solar physicists also led astronomy into the eras of satellite-borne and astronaut-performed measurements through the Orbiting Solar Observatories (OSO) and Apollo Telescope Module (ATM) in the 1960s and 1970s. But these contributions did little to enhance the stature of the field. A continued feeling of under-appreciation of solar research underlay the formation of the SPD of the AAS in 1970.

3 EVOLUTION OF SOLAR RESEARCH OVER THE PAST CENTURY

There has always been interest in the Sun amongst stellar astronomers and physicists, and most of our understanding of its structure, composition, energy generation and dynamics has been contributed by major figures such as Stanley Eddington (1882–1944), Cecilia Payne (1900–1979), Hans Bethe (1906–2005), Hannes Alfvén (1908–1995), Horace Babcock (1912–2003) and Robert Leighton (1919–1997). However, none of these contributors was a ‘solar physicist’.

Meanwhile, solar physics, which became a separate sub-discipline after the founding of the journal *Solar Physics* and of the SPD in the late 60’s, has focused mainly on solar activity, the outer atmosphere and wind. These topics have proven to be of more interest to interplanetary and magnetospheric researchers adhering to the American Geophysical Union, than to astronomers.

‘Solar-Stellar’ and ‘Sun-Climate’ connections based in large part on the pioneering work of Olin Wilson (1909–1994) and John Eddy

(1931–2009) respectively, provided a fruitful focus for solar physics in the 1970s and 1980s. But emphasis has shifted since the 1990s towards applications to ‘Space Weather’ prediction, in response largely to military and perceived commercial needs.

The founding of *Solar Physics* and of the SPD raised concerns that solar research might become isolated from astronomy and marginalized. The status of solar research at leading universities provides some insight into this issue.

Leading PhD-granting graduate schools with tenured faculty active in solar research in the 1970s included CalTech, Chicago, Columbia, Harvard, Stanford, and Yale in the USA, ETH (Zurich, Switzerland), and Cambridge and Oxford in England. Of those nine prominent universities, only Yale still retains a tenured solar faculty member. What happened? Certainly, other fine schools continue to offer doctorates in solar research,¹ but the loss of these outstanding universities from the list should give us cause to reflect.

4 HOW SOLAR RESEARCH WAS CARRIED OUT IN THE 1970’S AND NOW

Through the 1950s–1970s most important solar observational discoveries were still being made from the ground. For instance, the Sun’s five-minute acoustic oscillation was discovered by [Leighton et al. \(1962\)](#) with the 60-ft tower built in 1908 by Hale. That facility was also used by Leighton to discover the super-granulation. The ridge structure of the five-minute p-modes in the plane of spatial wavenumber versus temporal frequency was discovered by Franz Deubner using the 30-cm refractor installed by the German Freiburg Institute, located at Anacapri, Italy.

Computer-based data analysis and theoretical modeling were in their infancy.

Space-borne observations were beginning to produce important results in the 1970s and 1980s. Coronal transients (CME’s) were discovered with the coronagraph on the Skylab ATM and coronal holes were first studied with the X-ray telescopes on that mission. Modulation of the total solar irradiance by sunspots and faculae was discovered by Richard Willson with the ACRIM radiometer on the Solar Maximum Mission and by John Hickey with the ERB instrument on the Nimbus-6 satellite.

Advanced computer-based techniques enabled efficient analysis of the rising volume of data from imagers of increasing size and resolution. Fully non-linear computer simulations began to dominate theory in the 1990s.

Now, we have at our disposal six missions devoted to solar observations (Solar Orbiter, Solar Probe, Stereo, SOHO, Hinode and SDO). In addition, a host of interplanetary and magnetospheric missions are available to provide corollary data on solar behavior. We cannot complain!

But with the US national debt rising past \$25 trillion, it is doubtful whether the trend to ever 'More and Bigger' is sustainable. We will probably need to rely more on thinking 'out of the box'. I list below a few ideas based on my personal experience; others would undoubtedly have suggestions of their own.

5 SOME 'OUT OF THE BOX' IDEAS FOR THE FUTURE

- Understanding reconnection and particle acceleration requires measurement of *electric* (not only magnetic) fields using, e.g., Stark Effect (Foukal and Hinata, 1981).
- The dynamics of supergranulation remains unknown and *two-color imaging* to measure *radial gradients* of photospheric temperature (Foukal and Duvall, 1985), and also *bolometric imaging* (Foukal et al., 2004) offer promising new probes.

- Focus more on observations that *don't* fit models: e.g. if magnetic fields heat coronae, why are sunspot coronae so cool (Foukal et al., 1974)?
- A simple explanation of the *sub-photospheric shear layer* was published in 1975 (Foukal and Jokipii, 1975); what can we learn from it about the rotation of deeper layers?
- The mechanism of TSI modulation by spots and faculae has been understood since 1982 (Foukal et al., 1983; Spruit, 1982). The search for additional, secular TSI variation might be optimized using *cryogenically characterized* (Foukal et al., 1990; Kopp et al., 2007) pyrheliometer measurements focused on activity minima.

6 NOTES

1. Jay Pasachoff (pers. comm., 2021) pointed out that a list of current (2020) graduate programs in solar physics appeared in *Solar News* for September 2020 (<https://solarnews.nso.edu/list-of-graduate-programs-in-solar-physics-available-on-spd-website/>).

6 REFERENCES

- DeVorkin, D., 2001. *The American Astronomical Society's First Century*. Washington (DC), American Astronomical Society.
- Foukal, P., Huber, M., Noyes, R., Reeves, E., Schmah, E., Timothy, J., Vernazza, J., and Withbroe, G., 1974. Extreme-ultraviolet observations of sunspots with the Harvard spectrometer on the Apollo Telescope Mount. *Astrophysical Journal*, 193, L143–L145.
- Foukal, P., and Jokipii, R., 1975. On the rotation of gas and magnetic fields at the solar photosphere. *Astrophysical Journal*, 199, L71–L73.
- Foukal, P., Fowler, L.A., and Livshits, M., 1983. A thermal model of sunspot influence on solar luminosity. *Astrophysical Journal*, 267, 863–871.
- Foukal, P., and Duvall, T., 1985. Differential photometry of magnetic faculae. *Astrophysical Journal*, 296, 739–745.
- Foukal, P., Hoyt, C., Kochling, H., and Miller, P., 1990. Cryogenic absolute radiometers as laboratory irradiance standards, remote sensing detectors, and pyroheliometers. *Applied Optics*, 29, 988–993.
- Foukal, P., and Hinata, S., 1991. Electric fields in the solar atmosphere: a review. *Solar Physics*, 132, 307–334.
- Foukal, P., Bernasconi, P., Eaton, H., and Rust, D., 2004. Broadband measurements of facular photometric contrast using the solar bolometric imager. *Astrophysical Journal*, 611, L57–L60.
- Kopp, G., Heuerman, K., Harber, D., and Drake, G., 2007. The TSI Radiometer Facility – absolute calibrations for total solar irradiance instruments. In Butler, J.J., and Xiong, J. (eds.), *Earth Observing Systems XII*. Proceedings of SPIE, Volume 6677. Pp. 667709-1–667709-12.
- Leighton, R.B., Noyes, R.W., and Simon, G.W., 1962. Velocity fields in the solar atmosphere. I. Preliminary report. 135, 474–499.
- Lockyer, J.N., 1874. *Contributions to Solar Physics*. London, MacMillan.
- Meadows, A.J., 1972. *Science and Controversy: A Biography of Sir Norman Lockyer*. Cambridge (Mass.), MIT Press.
- Spruit, H., 1982. Effects of spots on a star's radius and luminosity. *Astronomy & Astrophysics*, 108, 348–355.
- Wright, H., 1966. *Explorer of the Universe: A Biography of George Ellery Hale*. New York, Dutton & Co.
- Wright, H., 1972. *The Legacy of George Ellery Hale*. Cambridge (Mass.), MIT Press.



Dr Peter Foukal was born in Prague (Czechoslovakia) in 1945, but grew up in Montreal (Canada). He graduated in physics from McGill University in 1966 and received a PhD in astronomy from the University of Manchester (UK) in 1969.

Peter has over 50 years of experience in research and teaching at CalTech and Harvard, and was the founding CEO of the high-tech firm Cambridge Research and Instrumentation, Inc. He has published more than 120 refereed research papers, including cover articles in *Nature*, *Science* and *Scientific American*, and the textbook *Solar Astrophysics* (Wiley-VCH, 3rd Edition, 2013).