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[111.10] The Lowell "Solar Variations" Telescope: 50 Years of Continuous Service to Planetary and Stellar Research

G. W. Lockwood (Lowell Observatory)

M. Jerzykiewicz (Astronomical Inst., Wroclaw Univ.)

Abstract

The return of Harold L. Johnson to Lowell Observatory in 1952 marked the beginning of a half-century of precise photoelectric photometry using a new 21-inch reflecting telescope that remains in service today. A 1953 newspaper headline proclaimed "Lowell's New Telescope to Train on Sun's Light," a somewhat misleading description that nevertheless captures the spirit of work carried out over the past half century. Johnson completed observations defining the *UBV* system and began regular measurements of Uranus and Neptune in a long-running effort to characterize solar variability by monitoring reflected planetary light. Although spacecraft measurements after 1980 show that the Sun's variation is less than 0.1% and thus undetectable from the ground, the "Solar Variability" theme motivated long-term studies of the variations of sunlike stars and solar system objects. Perhaps the telescope's most enduring contribution has been to supply data characterizing the sub-1% variability of sunlike stars and the power law relationship between photometric variability and mean chromospheric activity.

We illustrate the output of this highly productive facility with a sampling of results from the past half century, including 50-year lightcurves of Uranus and Neptune, a 29.5-year complete seasonal light-

curve of Titan, lightcurves of sunlike stars (now being extended into a third decade by automated telescopes at Fairborn Observatory), and shorter term projects on hot main sequence pulsators. It is unlikely that these projects would have been deemed feasible without guaranteed, uninterrupted, and convenient access to a dedicated telescope.

Work described here has been supported almost without interruption by the NSF Solar-Terrestrial program, NASA Planetary Astronomy, and the United States Air Force.

Lowell's 21-inch telescope in October 2005

Nighttime telescope photo credit: ©Will Viktora, October 2005

2005: The 21-inch telescope today (Why this poster?)

• This presentation is an acknowledgement of the pivotal role that Harold Johnson played in Lowell's entry into the era of photoelectric astronomy. After his arrival in 1952, Lowell built the 21-inch telescope for his work. Except for a new photometer (1971), four generations of computers for data recording (beginning in 1972) and another for position readout (1982), the telescope has hardly changed since 1953. Johnson left Lowell in 1959.

• Photoelectric photometry with small telescopes under an open sky has largely disappeared from today's astronomical scene. Today, the 21-inch is Lowell's only remaining manually slewed research telescope. After logging more than 2500 nights in the past 30 years, it still continues on a few dozen nights per year.

• The poster presents a few highlights of the past half-century.

• Sources: Lowell Observatory Archive for USAF contract reports, 1950-1966 and correspondence of Harold Johnson, Krzysztof Serkowski, Mikołaj Jerzykiewicz, Roger Lowell Putnam (Trustee), Gerald Kron, John S. Hall, J. Murray Mitchell, Jr.,V. M. Slipher

Some observers:

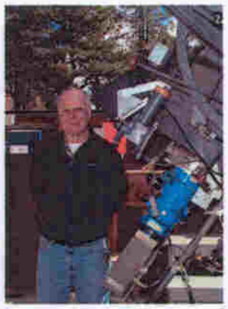
Harold Johnson 1950s

Krzysztof Serkowski 1976 at UA

Don Thompson ~1980

Brian Skiff 1996

Mike Jerzykiewicz 2003



Wes Lockwood 2003

1953: The "Solar Variations" project began

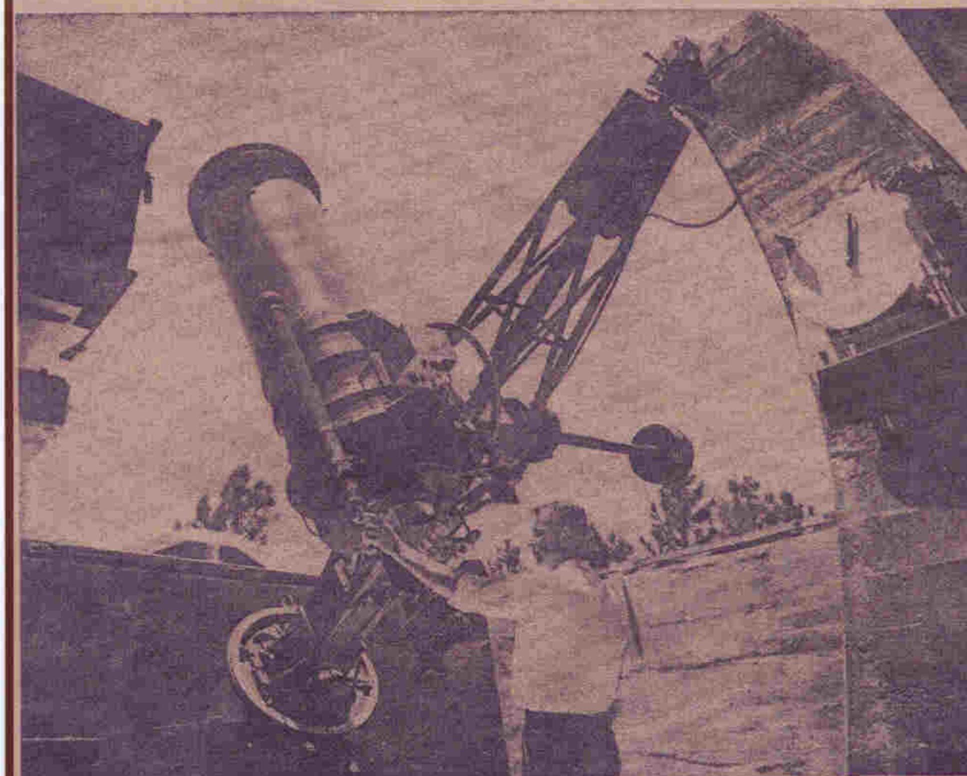
• In 1950, urged by the U.S. Weather Bureau, Lowell Observatory began a project to monitor the variability of sunlight reflected from Uranus and Neptune.

• H. L. Johnson put the program on a sound technical footing after the 21-inch telescope became operational in 1953.

• In 1966, when the project concluded, presumabely forever, no evidence of solar variability had been found, but an auxiliary program of measuring 16-sunlike stars, had shown that these stars, if they vary at all, do so at levels well below 1% over the 13-year period 1953–1966.

• NOAA climatologist J. Murray Mitchell, Jr., concerned in 1970 that no one was measuring the Sun, urged the Observatory to resume the "Solar Variations" project. And so, we did, beginning in 1971.

Lowell's New Telescope To Train On Sun's Light



Henry Giclas, Lowell Observatory astronomer, checks the newly-installed 21-inch telescope.

FLAGSTAFF

Lowell Observatory has a new project—one which may take many years to complete.

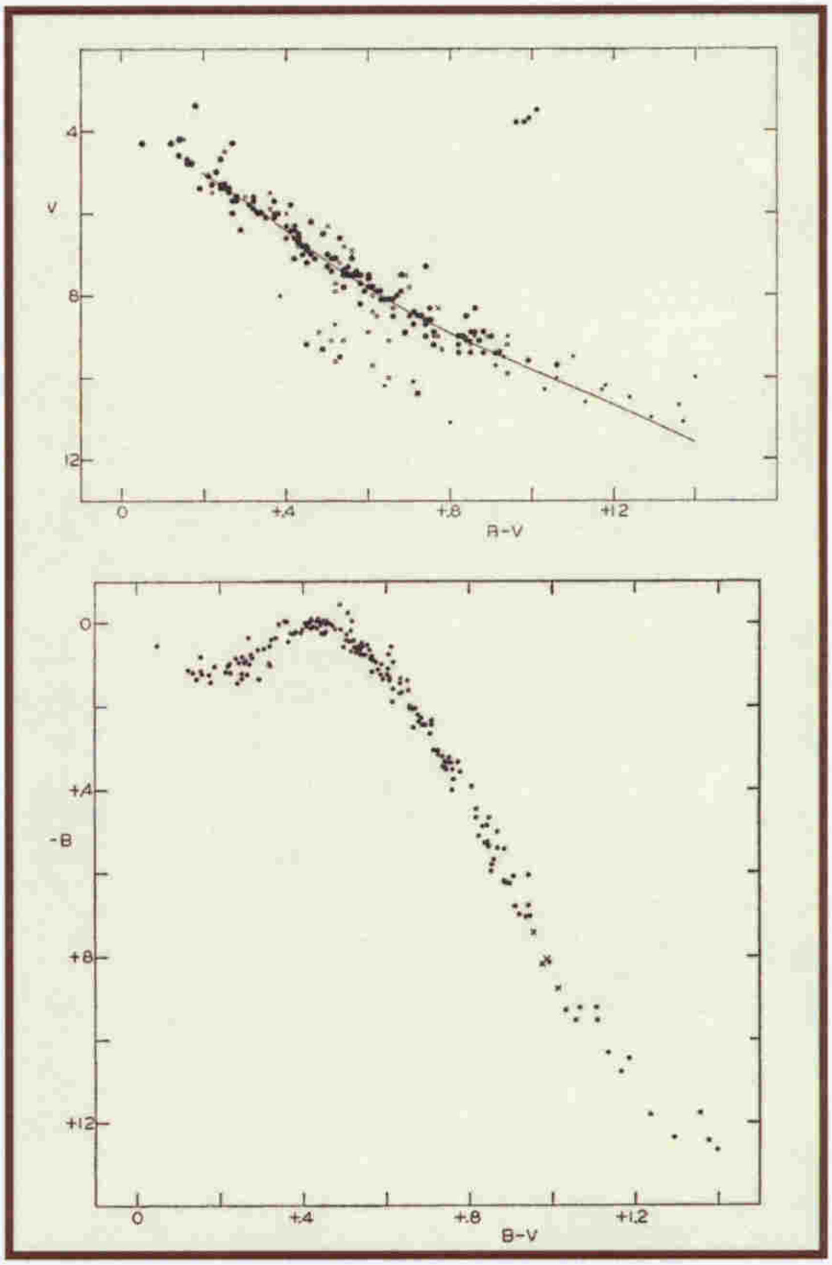
Through the medium of a new telescope, astronomers will attempt to find out why the Smithsonian Institution gets a variance of one-tenth of one per cent in its measurement of the sun's light from three different places throughout the world.

Other observatories also are trying to solve the problem.

Lowell's recently-installed 21-inch reflector type telescope will measure heavenly bodies in the sky, in addition to its main duties. Optical parts for this telescope, the observatory's fourth, were manufactured by the Yirkes Observatory of Williams Bay, Wis. x x x

News article and photo: *Arizona Days and Ways*, 1953 (Lowell Observatory archives)

1955: Color-magnitude diagram for the Hyades



- Continuing work he had started at McDonald, Johnson obtained data for color magnitude diagrams and color-color diagrams for several nearby open clusters.
- In this paper he and Knuckles describe their work on the Hyades and Coma Berenices open clusters. The observations were made in the winter of 1954–1955.
- (*top*) Color-magnitude diagram for the Hyades. (*bottom*) Color-color diagram for the Hyades. The paper does not actually state what telescope was used (a common omission of the era) but a surviving 21-inch telescope logbook shows entries for this project.
- Richard Mitchell joined the Lowell staff in 1957 to work with Johnson, and cluster work continued apace (see references below).

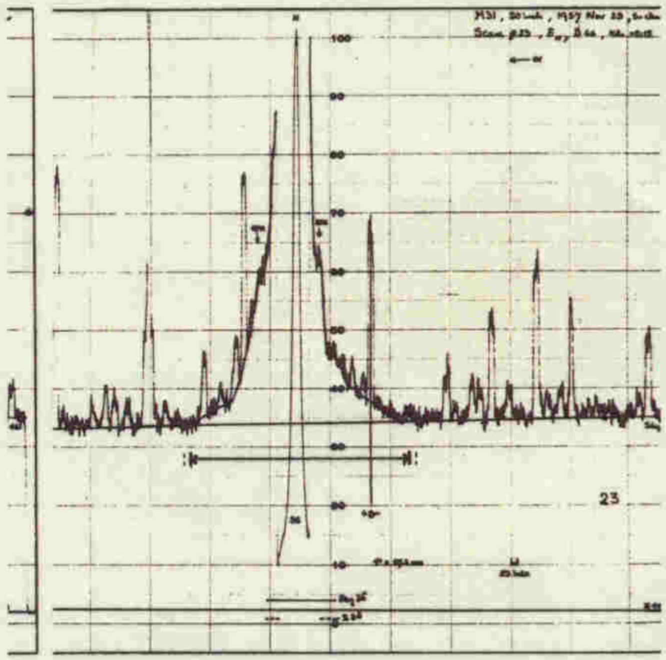
References:

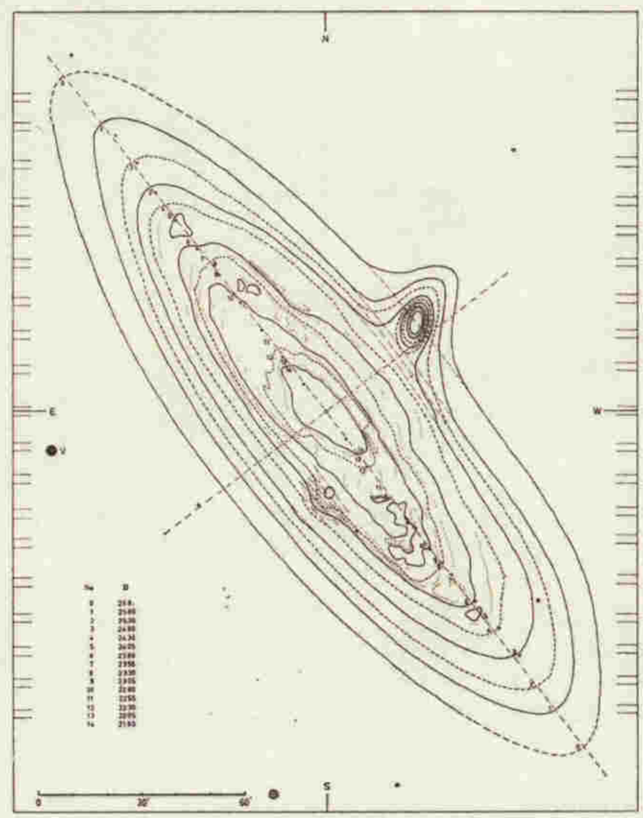
Johnson and Knuckles, 1955. *The Hyades and Coma Berenices star clusters*. ApJ, 122, 209

Mitchell and Johnson 1957.*The color-magnitude diagram of the Pleiades* ApJ, 123, 414

Johnson and Mitchell 1958. The color-magnitude diagram of the Pleiades cluster. II. ApJ, 128, 31

1958: Photometry of M31 in U, B, V





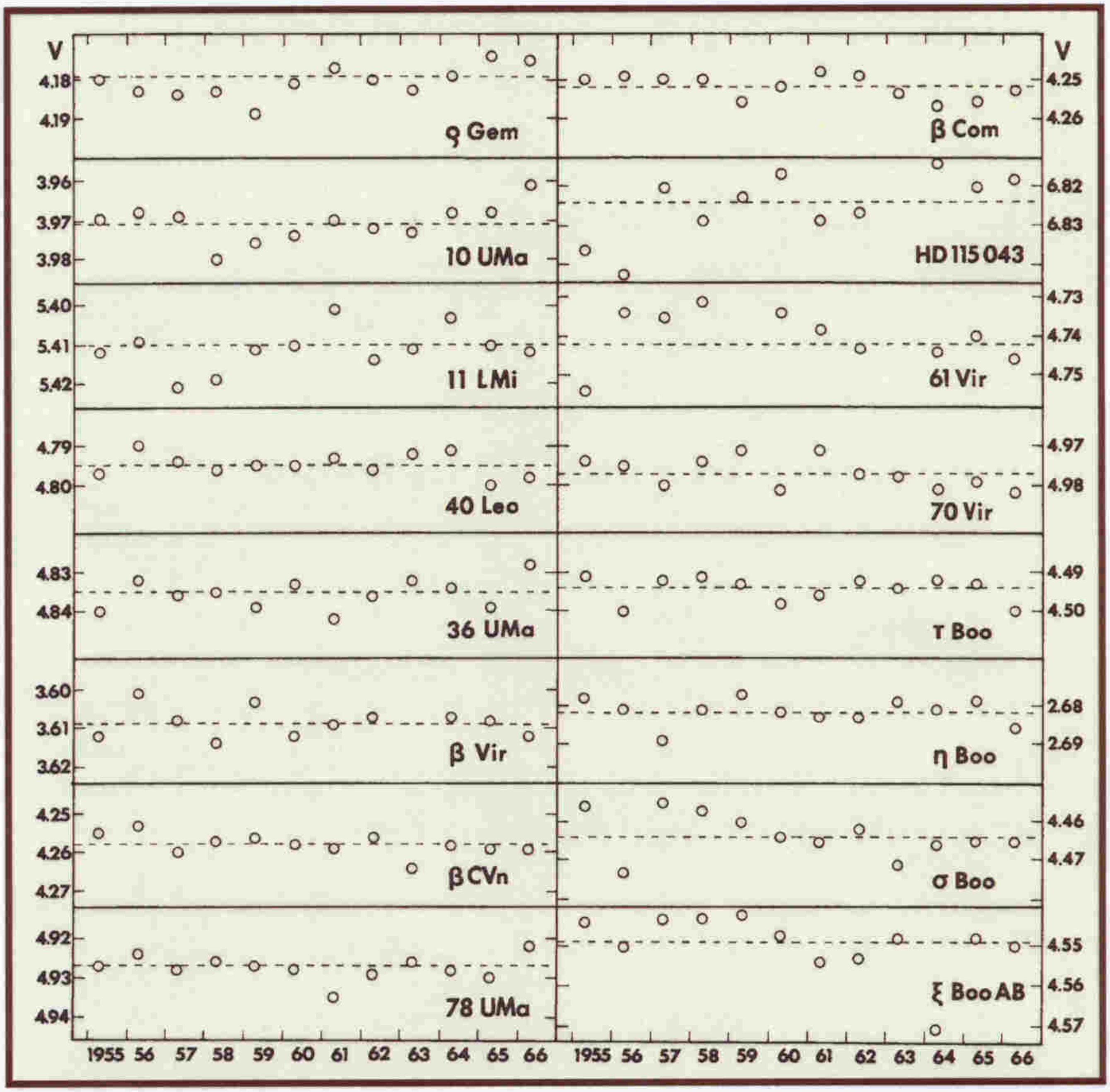
- Gerard de Vaucouleurs worked briefly at Lowell before moving to Harvard in 1958.
- While in Flagstaff, he used Johnson's photometer on the 21-inch in an almost unimaginably tedious project to derive isophotes of the Andromeda nebula (and later M33) by making drift scans at ~10' declination intervals.
- (*top*) A sample strip chart record showing a scan through the nucleus.
- *(bottomi)* Derived isophotes. Ticks show scan locations. The hatched circle at the bottom of the figure indicates the size of the circular aperture (138"). E-W scan registration involved scanning across field stars.
- This project is the most heavily cited work (259!) done at the 21-inch.

References:

de Vaucouleurs 1958. *Photoelectric photometry of the Andromeda nebula in the U, B, V system.* ApJ, 128, 465

de Vaucouleurs 1959. *Photoelectric photometry of Messier 33 in the U, B, V system.* ApJ, 130, 728

1966: Variability of Sunlike stars



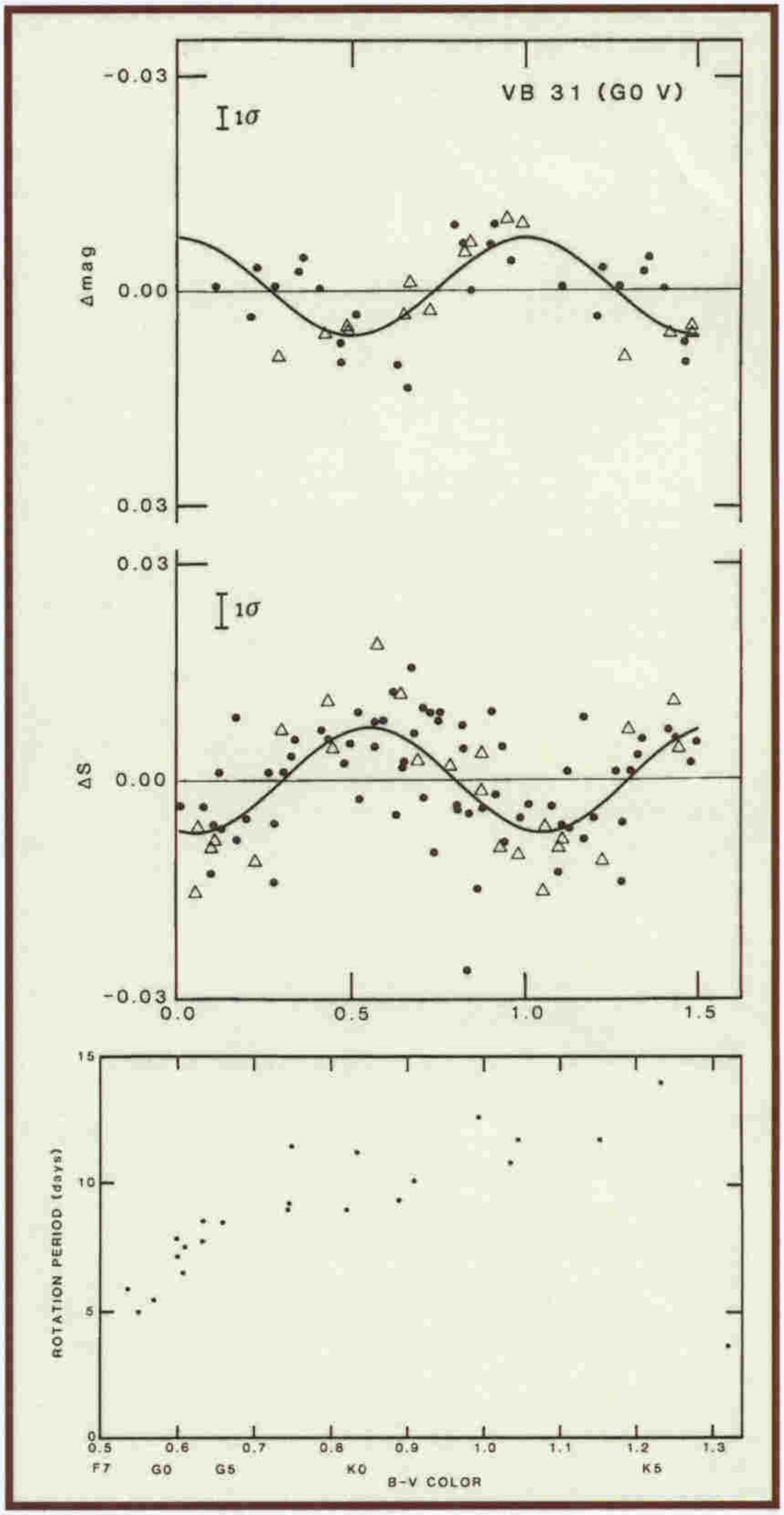
- These *V* observations of Johnson's "10-year standards" were made from 1953 to 1966 in conjunction with the observations of Uranus and Neptune.
- The authors conclude: "***In our opinion, this long sequence of photoelectric observations has taught us more about the variability of solar-type stars than about the sun itself***."

Reference:

Jerzykiewicz & Serkowski 1966. *The Sun as a variable star. III. Photometry of Uranus, Neptune, and F and G type stars*. Lowell Obs. Bull., 6, 295 (no. 137)

1987: Rotation periods for Hyades dwarfs

- From light curves like these (*center*) obtained at the 21-inch and parallel HK data from Baliunas at Mt. Wilson (*top*), 1982–1984, we learned that brightness variations are anti-correlated with chromospheric emission.
- We obtained photometric rotation periods for 23 stars from F8 V to K8 V (*bottoml*).
- Observations continued until 1992, but apart from some relations between color and brightness variability, we found no discernible long term patterns of variability



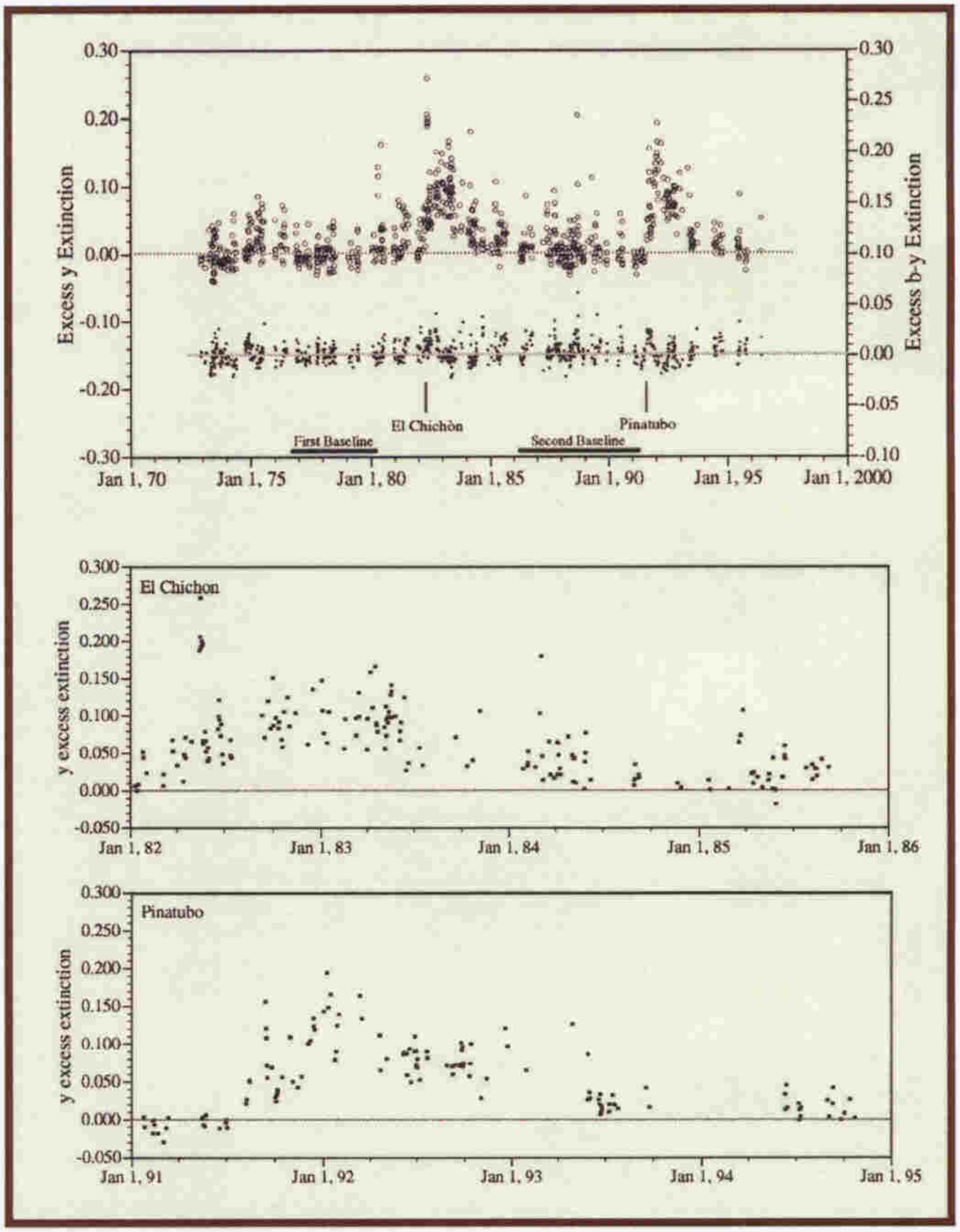
References:

Lockwood, Thompson, Radick, Osborn, Baggett, Duncan, and Hartmann 1984. *The photometric variability of solar-type stars. IV. Detection of rotational modulation among Hyades stars*. PASP, 96, 714

Radick, Thompson, Lockwood, Duncan, & Baggett 1987. *The activity, variability, and rotation of lower main-sequence Hyades stars*. ApJ, 321, 459

Radick, Lockwood, Skiff, & Thompson, 1995. *A twelve-year photometric study of lower main-sequence Hyades stars*. ApJ, 452, 332

1996: Atmospheric extinction



- Atmospheric extinction measurements are a routine byproduct of photometry.
- With some observations somewhat disrupted by volcanic debris after eruption events in 1982 and 1994, we advertised our measurements of extinction instead.
- In this display we have subtracted the seasonally-varying mean extinction to show the effects of the El Chichón and Pinatubo volcanic eruptions. There are 797 observations on the upper graph.

References:

Lockwood, White, Thompson, & Tüg 1984. *Spectrally resolved measurements of the El Chichón cloud, May 1982–August 1983*. Geof Int, 23–3, 351

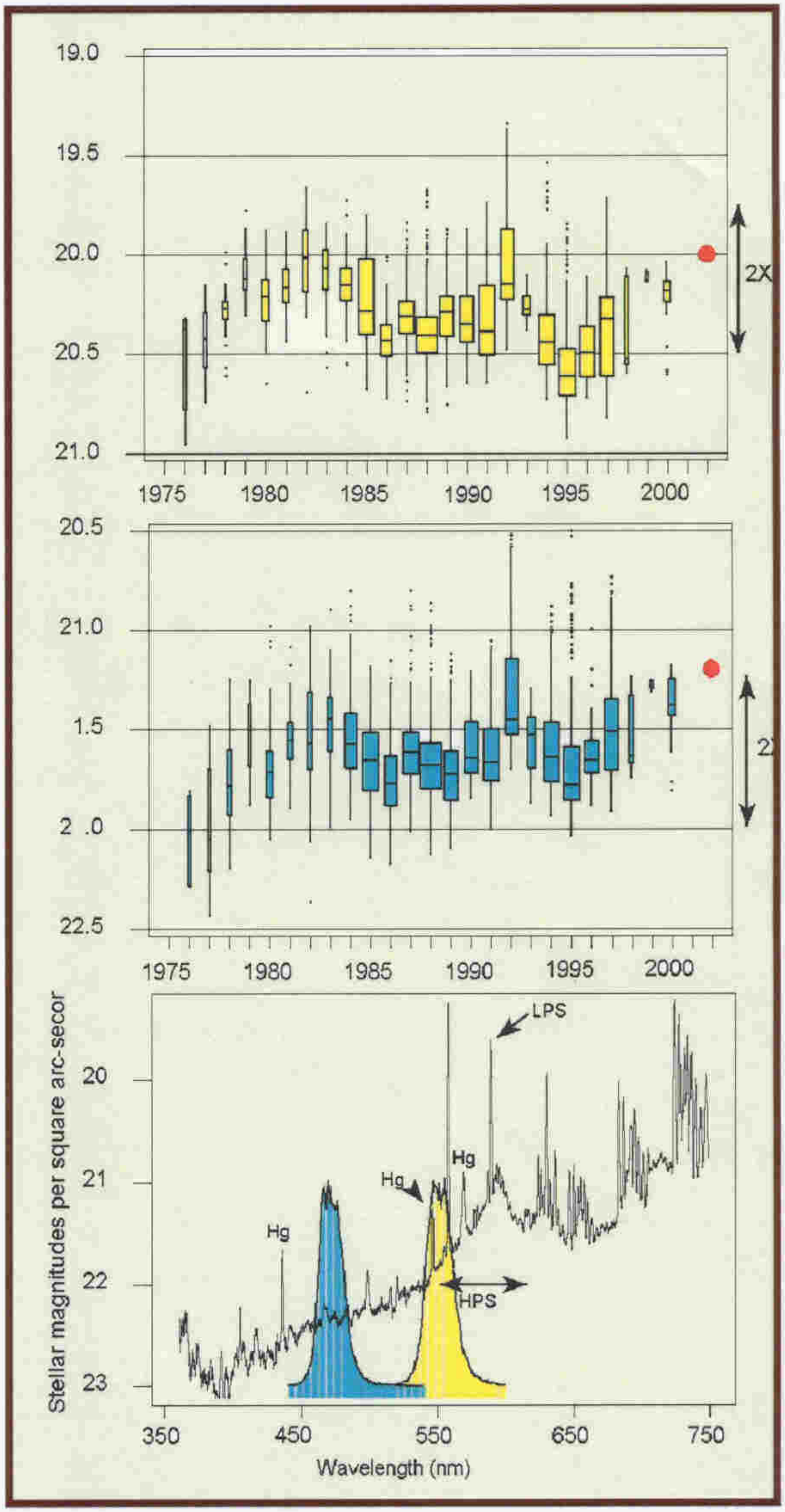
Lockwood & Thompson 1986. *Atmospheric extinction: The ordinary and volcanically induced variations, 1972–1985*. AJ, 92, 976

Thompson & Lockwood 1996. *Atmospheric transparency at Flagstaff, Arizona, 1972–1996: Baseline and volcanic episodes compared* GRL, 23, 3349

2003: Sky brightness above Mars Hill

- A by-product from 21-inch telescope is this series of sky brightness data in Strömgren *b* (*center*) and *y* (*top*).The data mainly reflect a transition from mercury vapor illumination in the 1970s to a mixture of high- and low-pressure sodium today. City zoning required LPS for new parking lots and most roadways after 1989.

- To the eye, the sky has brightened over the past 30 years. However, the *b, y* filters (*bottom*) are blind to the sodium line at 589 nm.



References:

Lockwood, Floyd, & Thompson 1990. *Sky glow and outdoor lighting trends since 1976 at the Lowell Observatory.* PASP, 102, 481

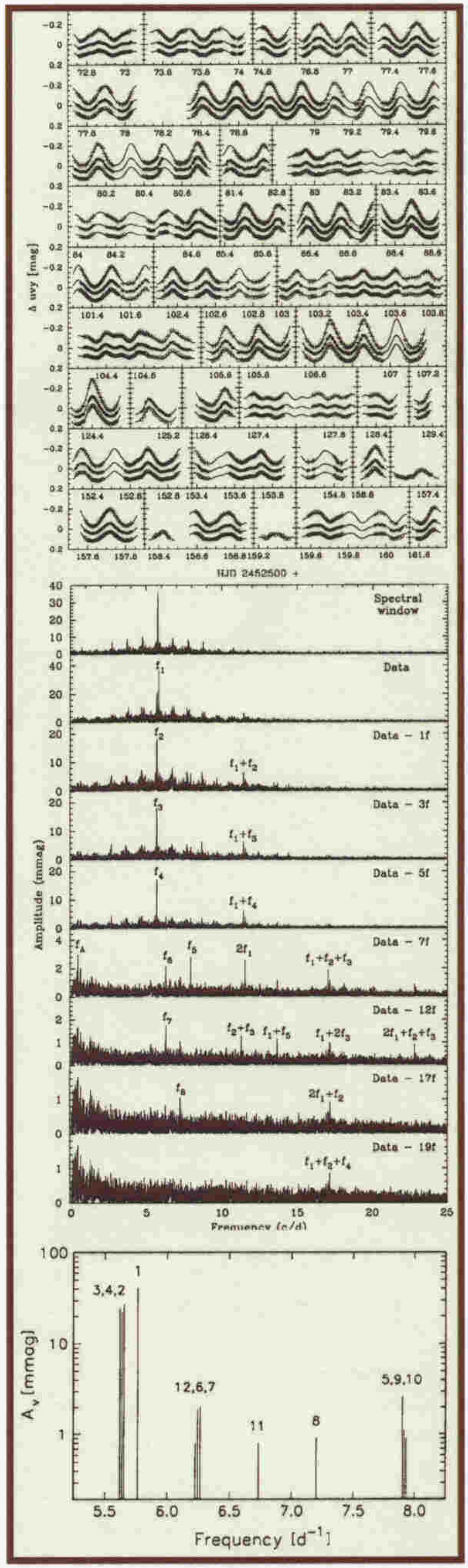
Mount Hopkins sky spectrum superposed on the filter transmission curves, bottom panel, from Phil Massey

2005: Asteroseismology

• Two ambitious multisite campaigns to observe the β Cep star ν Eri in 2002–2003 (11 telescopes, 605 hrs.) and 2003–2004 (5 telescopes, 529 hrs.) result in the light curve segments, power spectrum display with successive frequencies removed, and the frequency map shown here.

• At Lowell, Jerzykiewicz used the 21-inch telescope for 46 hours on 10 nights in 2002 and 87 hours on 25 nights in 2003.

• The oscillation spectrum includes 12 high frequencies and two low ones.

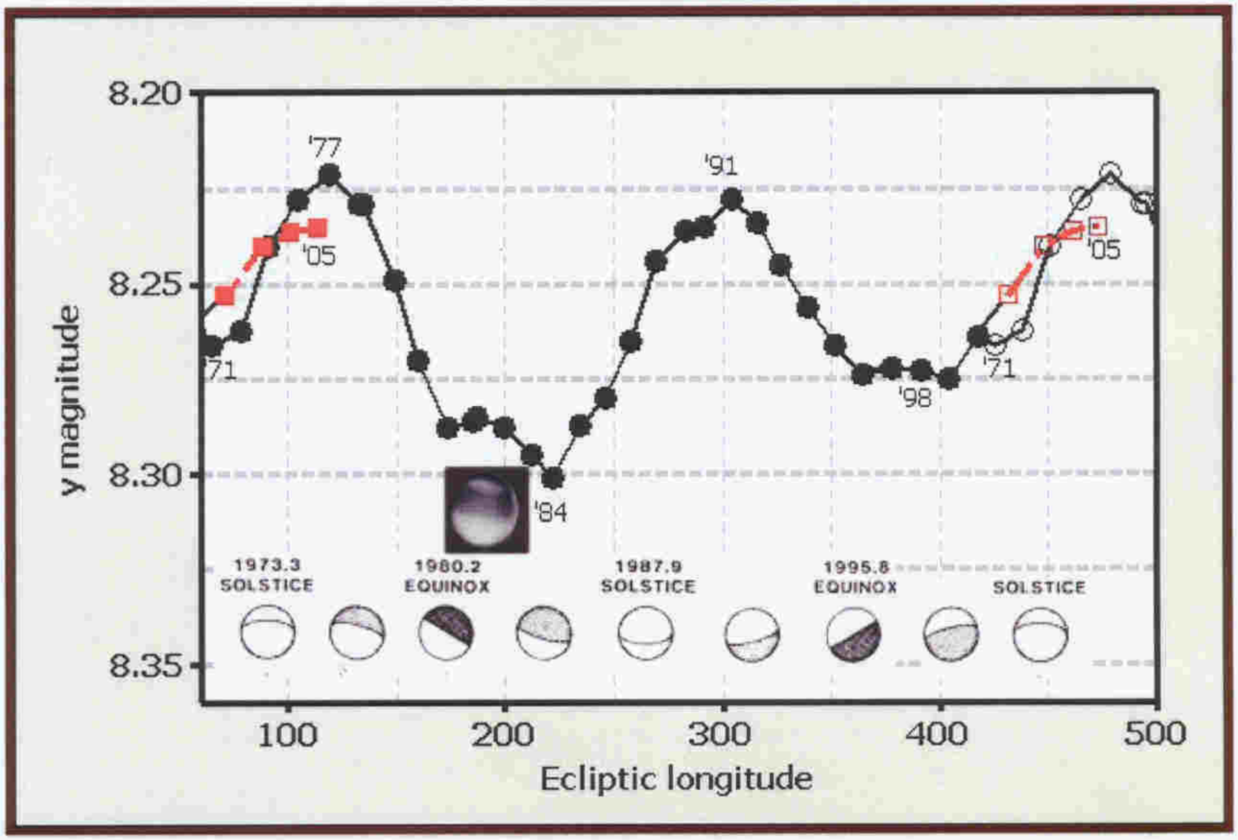


The composite illustration was adapted from :

Handler, Shobbrock, Jerzykiewicz, et al. 2005. *Asterseismology of the β Cephei star ν Eridani – I. Photometric observations and pulsational frequency analysis*. MNRAS, 347, 454

Jerzykiewicz, Handler, et al. 2005. *Asteroseismology of the β Cephei star ν Eridani. IV. The 2003–2004 multisite photometric campaign and the combined 2002–2004 data.* MNRAS, 360, 619

2005: Titan's lightcurve over a Saturn year



- In 1971, we added Titan as a new solar variations target to the new *b, y* program along with Uranus and Neptune. By 1975, it was obvious that Titan was varying, either seasonally or in some manner to be determined. The light curve shows Titan's variation in *y; b* is similar.

- The N-S contrast boundary shown at Voyager encounter in 1980 plus the photometric record led Sromovsky et al. to predict the sequence of contrast changes in the cartoon strip in this figure. Subsequent photometric observations plus HST images in the 1990s showed that this model was basically correct.

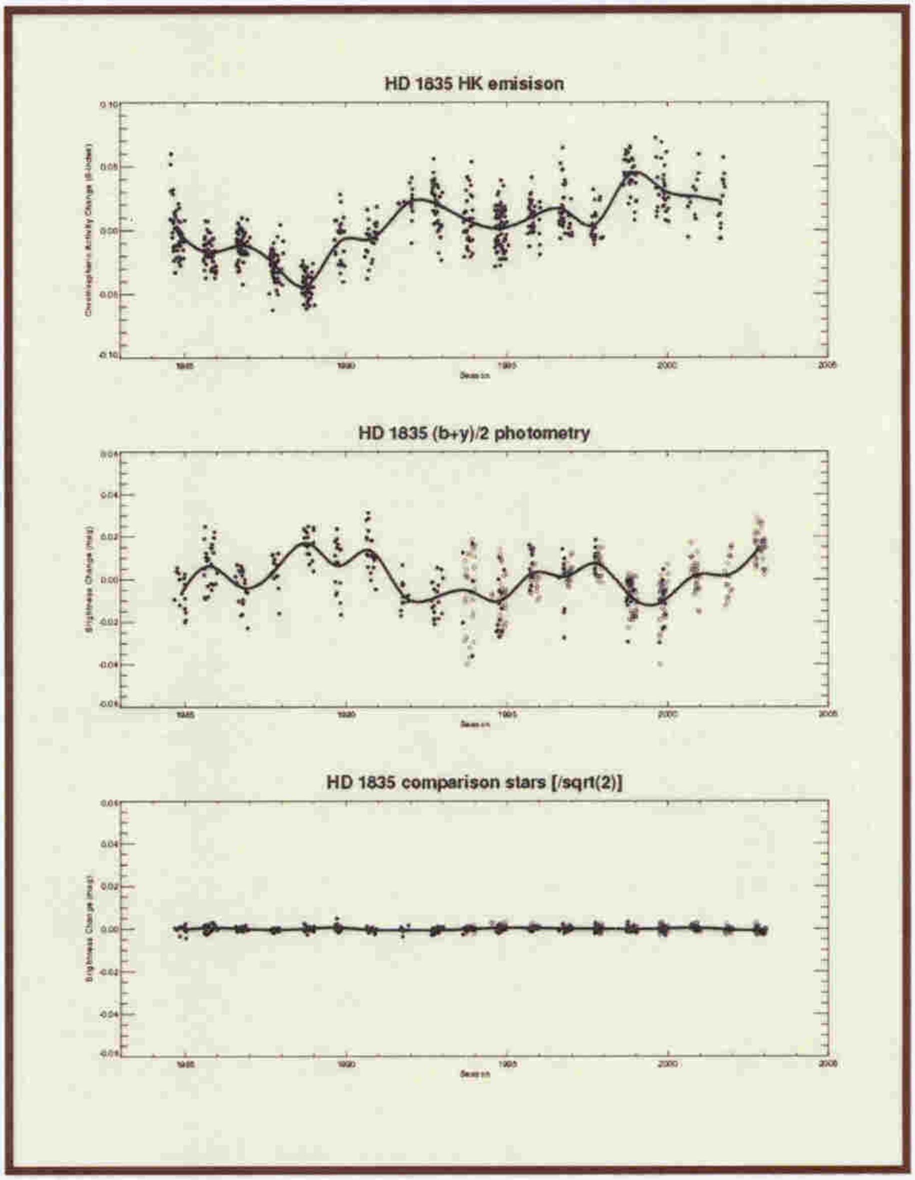
- The segment in red shows the beginning of a 2nd Titan year.

References:

Sromovsky et al. 1981. *Implications of Titan's north-south brightness asymmetry*. Nature, 282, 698.

Lorenz, R. D., Lemmon, Smith, Karkoschka, Lockwood, and Caldwell 1997. *Titan's north-south asymmetry from HST and Voyager imaging: Comparison with groundbased photometry and models*. Icarus, 127, 173

2006: Microvariability of Sunlike stars…



- With Air Force and NSF funding, we began measuring Sunlike stars in earnest in 1984. Skiff logged more than 1200 nights before the program ended in 2000.
- Observations continue using robotic telescopes at Fairborn Observatory.
- (*top*) Variability in the Mount Wilson "S-index" of chromospheric activity measured in the H&K lines of Ca II of the young star HD 1835.
- (*center)* The light curve of HD 1835. Open circles after 1994 are parallel observations from a robotic telescope at Fairborn Observatory.
- (*bottom)* Light curve of one comparison star minus the other.

References:

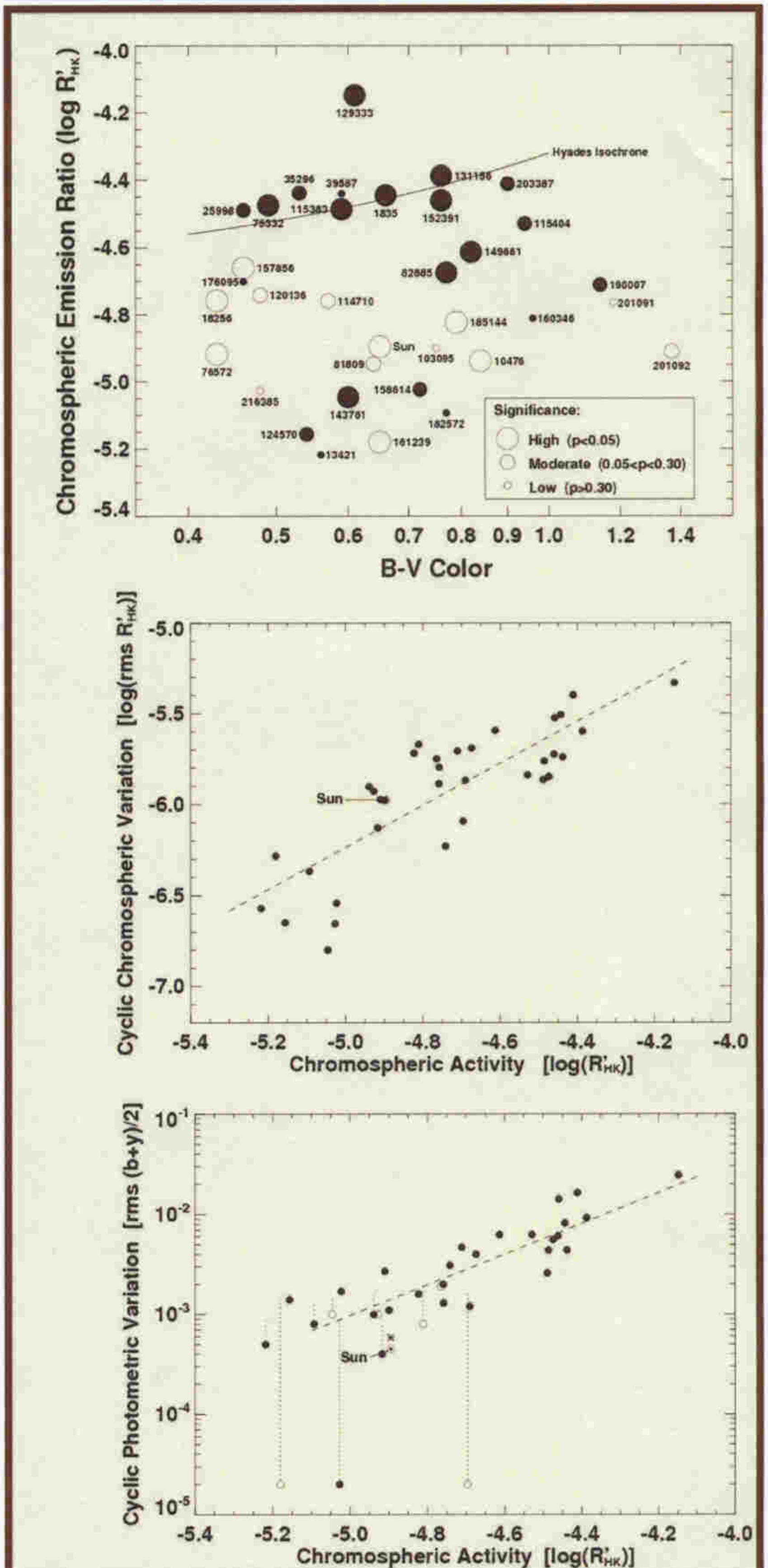
Lockwood, Skiff, & Radick 1997. *The photometric variation of sunlike stars: Observations and results, 1984–1995*. ApJ, 485, 789

Radick, Lockwood, Skiff, & Baliunas1998. *Patterns of variation among sunlike stars*. ApJS, 118, 239–258

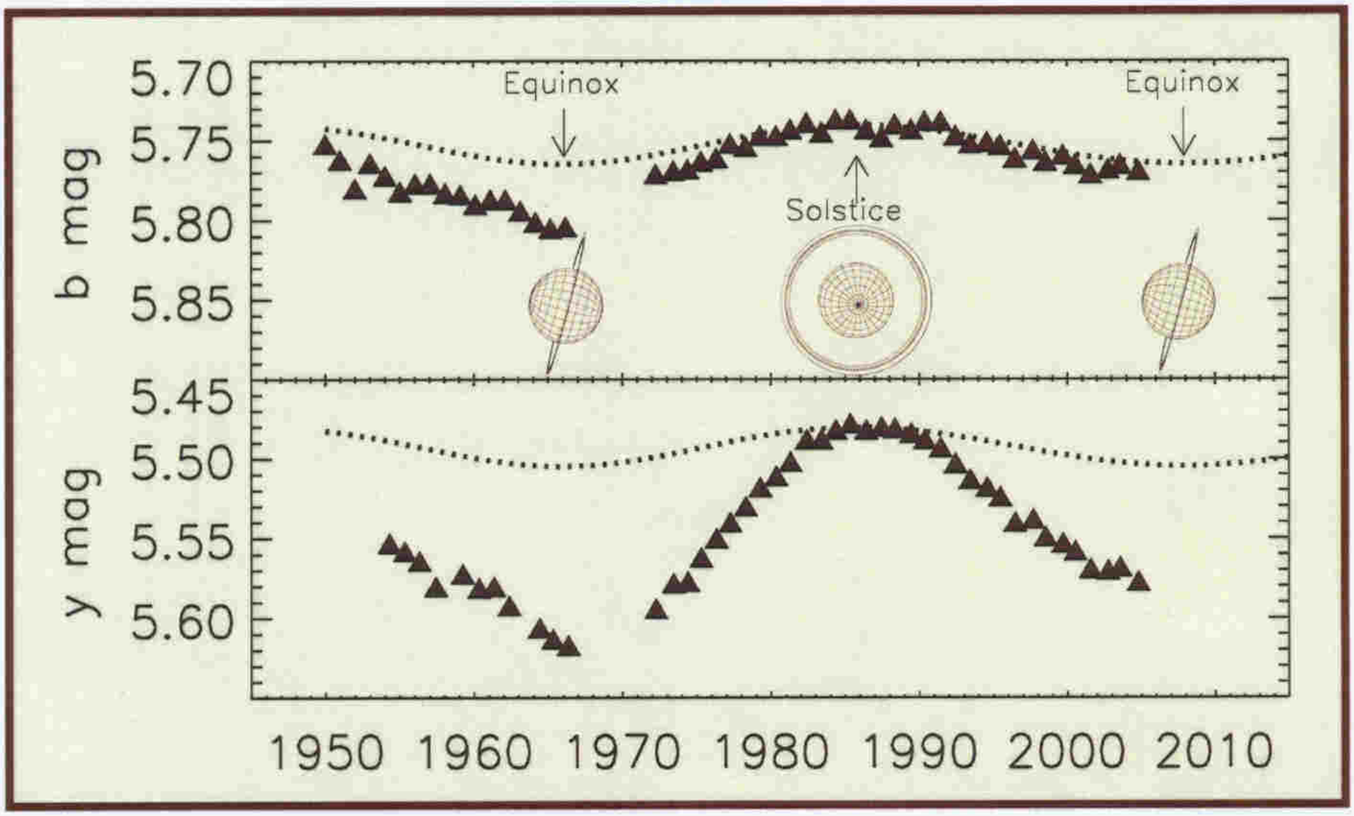
Lockwood *et al.* 2006. *Patterns of photometric and chromospheric variation among Sunlike stars: A 20-year perspective.* ApJ in prep.

…and their patterns of variability

- These panels update our 1998 "Patterns" paper with additional data from Lowell and Fairborn, extending the time series to 20 years (Lockwood *et al*. 2006 in prep.)
- (*top*) Filled circles are young, active stars whose chromospheric and photometric variation is anti-correlated. Open circles denote older, less active stars that behave as the Sun does.
- (*center*) A power law relationship for chromospheric activity on cycle timescales (based on Mt. Wilson HK data).
- (*bottom*) a power law relationship for photometric variability on cycle timescales. The Sun is a bit low compared with the stellar cohort, perhaps an artifact of our sample.



2006: Variability of Uranus 1950-2005



- Giclas and Hardie obtained the first *B* photometry of Uranus in 1950. In 1954, regular measurements began at the 21-inch under Johnson's supervision. The *B, V* series ended in 1966 with a total of 554 nightly measurements, shown as annual means on the chart above after adjustment to the *b, y* scale. The new *b, y* series began in 1972, for a total of 291 measurements.

- The dotted line indicates the variation expected for a uniform disk, 0.02 oblateness. The annual mean magnitudes, adjusted for changing heliocentric distance, deviate from this ideal curve because of an equator-to-pole albedo gradient plus temporal variability.

- Observations continue on ~8–10 nights each year but may end when funding runs out in 2007.

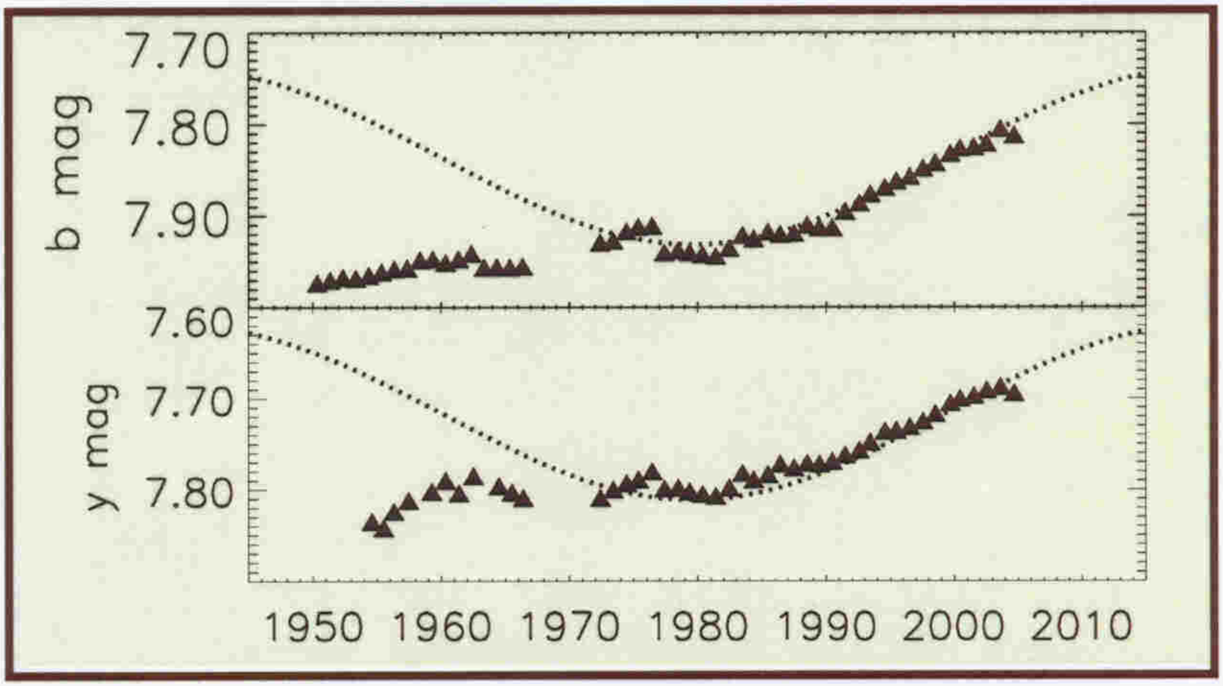
References:

Jerzykiewicz and Serkowski 1966. *The Sun as a variable star. III. Photometry of Uranus, Neptune, and F and G type stars*. Lowell Obs. Bull., 6, 295 (no. 137)

Lockwood and Thompson 1999. *Photometric variability of Uranus, 1972–1996*. Icarus, 137, 2

Lockwood and Jerzykiewicz 2006. *Photometric variability of Uranus and Neptune, 1950-2004*. Icarus, 180, 442

2006: Variability of Neptune 1950–2005



- Neptune, often observed on the same nights as Uranus, shows a generally increasing smooth brightness increase over half a century.
- Neptune reached southern summer solstice in 2005, but the brightening trend shows no sign of ending.
- A lagged sinusoidal model proposed by Sromovsky et al. (2003) shown above as a dotted line fits part of the data but fails to account for the observations from 1953 to 1966. A more comprehensive model is needed.
- The ready availability of a dedicated photometric telescope has made this time series possible. Nightly observations, which are continuing, require only about one hour at the telescope.

References:

Jerzykiewicz and Serkowski 1966. *The Sun as a variable star. III. Photometry of Uranus, Neptune, and F and G type stars*. Lowell Obs. Bull., 6, 295 (no. 137)

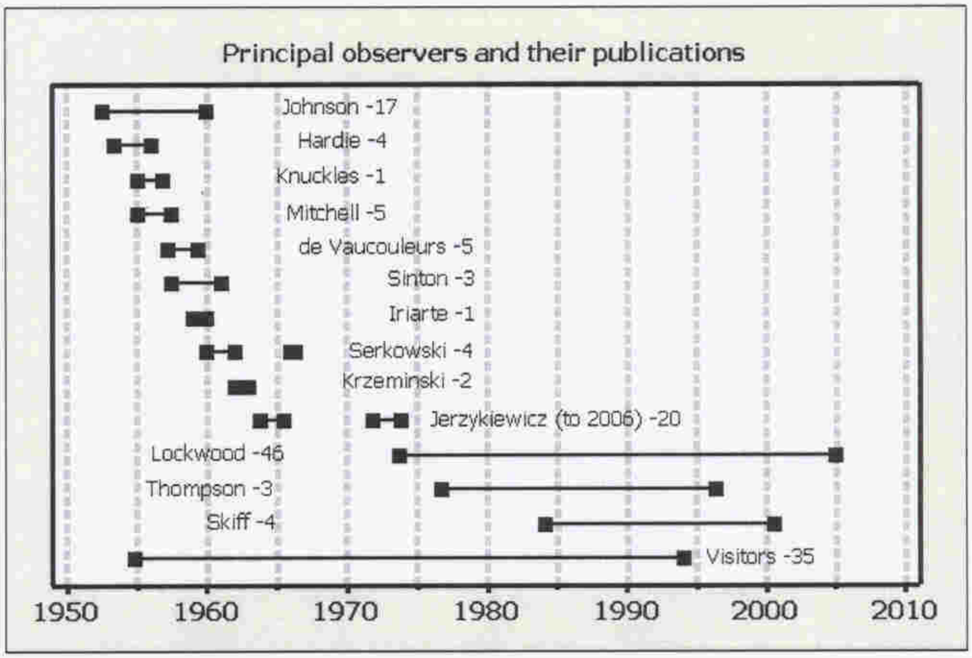
Lockwood and Thompson 1999. *Photometric variability of Neptune. Photometric variability of Neptune 1972–2000*. Icarus, 156

Sromovsky et al. Fry 2003. *The nature of Neptune's increasing brightness: Evidence for a seasonal response.* Icarus, 163, 256

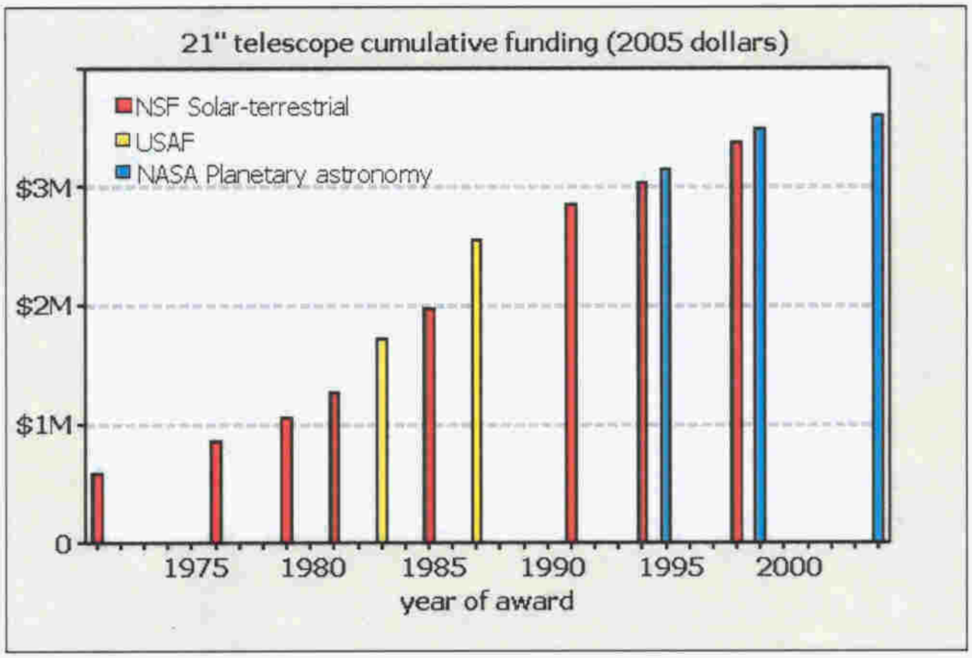
Lockwood and Jerzykiewicz 2006. *Photometric variability of Uranus and Neptune, 1950-2004*. Icarus, 180,442

Staffing and grant funding

• Timelines on this chart show the principal observers since 1953 and the number of publications resulting from their work.



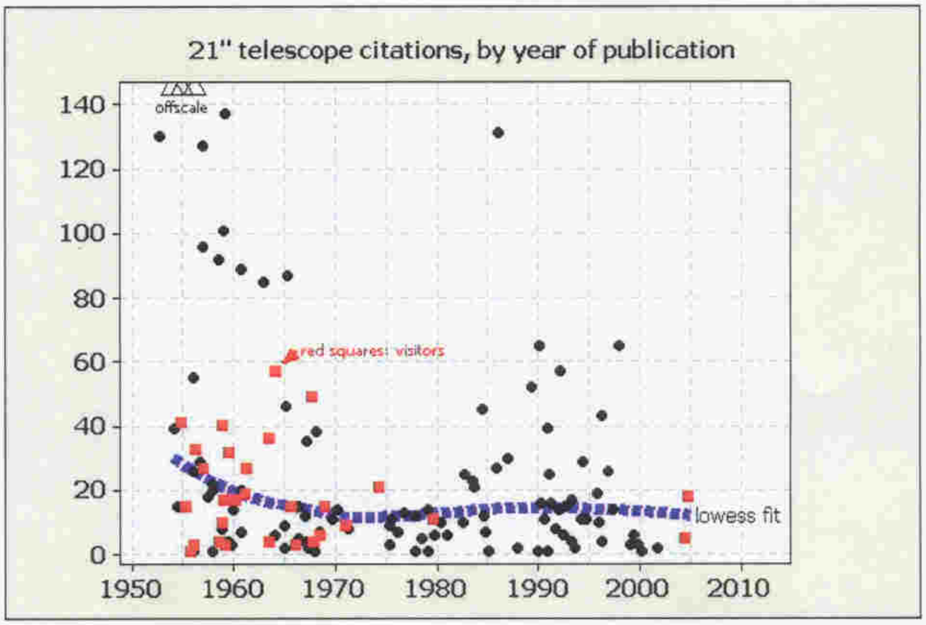
• The Office of Naval Research funded much of Johnson's work in the 1950s. The Air Force Cambridge Research Laboratory funded the Solar Variations project until 1966.



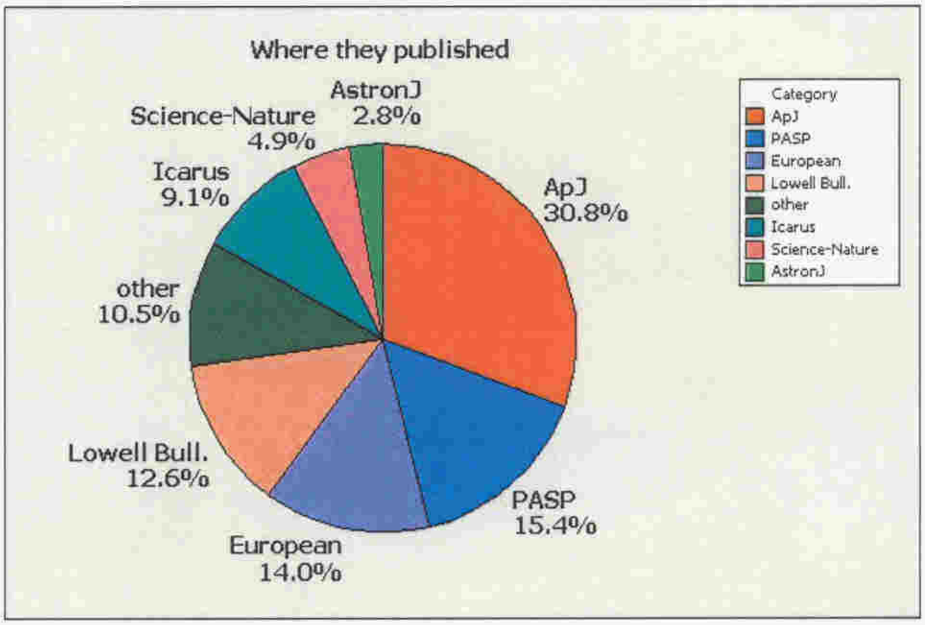
• After 1971, almost all the observations of Titan, Uranus, Neptune, the Galilean satellites, and the long-term studies of the variability of sunlike stars were covered by a series of 3-year grants totaling $3,500,000 (2005 dollars). Further planetary work is funded through 2007.

Publications and citations

• Citation statistics from ADS for 150+ journal articles from the 21-inch. (Abstracts are omitted from this tally.) There was a lull in the 1970s as three Lowell telescopes on Anderson Mesa became available.



• The publication pace picked up again after we moved two funded long-term projects back to the 21-inch on Mars Hill. For these intensive projects, easy 100% access (and no nightly commute) insured regular usage, 2500 nights between 1973 and 2005.



• A *Lowess* fit (*blue dotted line*) shows that the citation rate has held remarkably steady for 40 years.

• Most of the early work appeared in *ApJ* or *Lowell Bulletins*. Since 1973, the planetary work has gone mainly to *Icarus*.