Title and abstract

Solar variability after dark: evidence and some dead

> > ends from stars and planets

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> > By Wes Lockwood and a cast of scientific ancestors

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> > Detecting solar variability in the reflected light from

> > planets seemed like

> > a good idea in 1947 when Harry Wexler of the U. S.

> > Weather Bureau urged Lowell Observatory to give it a

> > try. Even though it didn't work, NOAA climatologist J.

> > Murray Mitchell, Jr. urged us in 1971 to sign up for

> another hitch. As the result of good luck and a

> > reluctance to quit, we ultimately detected sun-like

> > variations in solar type stars of all ages. In

> > combination with spectroscopic work at Mount Wilson

> > Observatory and Lowell

> > Observatory we were just beginning to think we

> > understood most of what was going on when the SORCE

> > satellite recently added another layer of complexity

> > to this enduring and fascinating problem. Along the way

> > we learned a few things about planetary atmospheres as

> > well. Some digging the Lowell archives

> > has revealed how climate science and federal funds kept

> > pushing us along for six decades.

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**Slides**

1. In this talk I hope to give you a quick 60 year tour of the search for solar variability using night-time observations. The idea is not a crazy as it seems. Postwar instrumentation developments provided a new tool – photoelectric astronomical photometry. This permitted quantitative measurements at a level of precision and sensitivity needed to study variations as small as those suspected of the Sun. Our story begins at Lowell Observatory,, moves west to the Mount Wilson Observatory, thence back to Lowell, and finally ends at a “telescope farm”: of automated telescopes in Southern Arizona, the Fairborn Observatory.

I will attempt to illustrate how an idea bounced back and forth, developed branches, flowered in some directions and withered in others. This is how science works and never mind the neat flowchart of the “scientific method” we all encountered in grade school. Reality of often much messier.

But first let me take a brief detour. You’ll see why in a moment.

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2. In the early 1890s a graduate of a small college in Connecticut took a job at the Harvard College Observatory. He soon attracted the attention of a wealthy Bostonian (**left photo)** with an itch to build a private observatory somewhere in Arizona Territory for his studies of the planet Mars. In a review of a biography of this young man, Jack Eddy gives a glimpse of his talent as a gifted writer. Eddy is of course the man in the lower left panel.

Eddy wrote:

***“What followed in six weeks of March and early April of 1894 was a comic opera of a one-man, whirlwind site-survey – made by rail and horse-drawn wagon with a small telescope and a large stack of Wes tern Union Telegraph blanks, the latter to keep his anxious employer advised, in real time, of nightly measures of the skies.”***

By 1894 the young man (**center photo)** had settled on Flagstaff, a railroad fuel and water stop on the Atchison, Topeka, and Santa Fe. It must have been the most superficial site survey in astronomical history. His employer was, of course, Percival Lowell, the founder and benefactor of Lowell Observatory.

The young man served his master faithfully for a decade, being in essence the site manager, especially during the 4 year period in which his employer languished in Boston, the victim of what was then called “nervous exhaustion.’ Eventually, however they had a falling out when the young man challenged his boss’s interpretation of certain barely visible (or perhaps imaginary) features on the disk of Mars.

He then relocated to Tucson Arizona Territory where he founded the Steward Observatory. But his real fame arose from a hobby – the study of the annual growth rings of trees, used to age-date archaeological sites in the southwest. Later he became enamored of the idea of a connection between the patterns in the tree rings and the solar activity, a claim subsequently firmly dismissed on the basis of statistical analysis.

At one point he was in contact with the British solar astronomer E. W. Maunder, whose studies of the solar cycle we will hear much about in this meeting. (**right photo).**

The next slide animation ages the young man by a half century or so. You may now recognize him as the famed founder of dendrochronology, A. E. Douglass, sometimes known as Tree Ring Douglass.

Why have I taken the first five minutes of my time in this digression?

First, to illustrate that Jack Eddy was not the first astronomy to develop a consuming interest in the solar cycle and its role (or not) in climate.

Second, to show by example that getting fired early in one’s career can sometimes lead to greater things. It certainly did for Jack eddy.

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. 3. The story, curiously, begins with a weatherman. Dr. Harry Wexler,(**left photo)**  chief of research at the U. S. Weather Bureau after the war, He was interested in seeing if cloud motions of the planets could teach us something about weather forecasting on Ear.th. Accordingly, in 1947, he approached the Lowell observatory with the offer of a contract to study planetary atmospheres, using as source material, the vast collection of planetary images collected over half a century at Lowell Observatory. The three elderly scientists then in charge of the observatory (all over 70) showed little interest in government money, but the
Sole Trustee Roger Lowell Putnam realized that the observatory’s survival depended upon in taking advantage of the grant and contract money that was beginning to flow from Washington in the postwar era.

The team of young meteorologists assembled for this study was later to become distinguished in their field. They included Edward Lorenz, the father of chaos theory, Ralph Shapiro, Franklin Gifford, Yale Mintz, Alfred Blackadar, Wow!

Out of this study came the idea of attempting to verify or better measure solar variability by monitoring the sunlight reflected from the two outer planets Uranus and Neptune. The technique would utilize the then new field of astronomical photoelectric photometry, then in its infancy. We w ill later discover why this approach was doomed to failure, but at the time, and for decades thereafter it offered promise.

The task of initiating this program fell to young Henry Giclas, then about age 40. Henry is shown on the **second photo**.

The work went badly at first, and in fact was an heroic and futile struggle with instrumentation and electronics, aggravated by Flagstaff’s notoriously bad electric supply in which the voltage could vary bo 30 volts and the frequency was similarly unpredictable. Finally, Lowell hired a true genius of astronomical instrumentation and photometric technique, the pioneer Harold Johnson (**third photo).** Astronomers inthis crowd will remember that Johnson was the father of t he so-called UBV system of stellar photometry, still in use today.

By the time Johnson departed in 1959, the program was running well, and was conducted for the next 7 years by a young Polish astronomer, K. Serkowski,**(fourth photo)** then replaced by M. Jerzykiewicz. That’s a recent pho to of Mike on the right

 The first statement of intent, written by Giclas, in a report to the sponsoring agency, the u. S. Air Force, is in the panel below. He mentions the need to compare results with the Smithsonian program, i.e. Charles Abbot’s program of direct solar radiometry. .

Thus “solar variations” entered into the suite of studies to be conducted at Lowell Observatory over many decades to come.

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**4.**This slide shows at **upper left** the most commonly used photomultiplier tube of that era. It’s the RCA model 1P21. It’s task is to turn starlight into a faint but measureable stream of electrons that can be accumulated in a capacitor and later measured, or pulsed that can be counted with an electronic counter.

**At lower left** is the humble structure with a roll-off roof that houses the 21-inch telescope used since 1953 exclusively for the study of brightness variations of stars and planets. I still use it today.

Finally**, on the right** is a1953 press release describing this 21-inch t telescope as an instrument to be trained on sun’s light. That’s Henry Giclas shown in the photo. Except for the addition of computers the telescope looks much the same today as it did in 1953,

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5. Well, what did they learn?

I’ll get to the planets (and hence the Sun in a minute). Let’s first examine what was an almost accidental byproduct of Johnson’s initial design for this program. Thinking that a string of solar color stars in the sky along with Uranus and Neptune would provide a nice comparison for the planetary photometry he selected a set of a dozen or so so-called 10-year standards. It was the collected measurements of this small group of stars, patiently measured night after night for years that first gave quantitative estimates of how much the Sun (by analogy) might vary.

Each point on each chart represents the mean of many observations collected in a single observing season. The scale of each chart is the same, about 1% per division on the y axis. You see that hardly any star deviated by a percent from the mean.

Jerzykiewicz and Serkowski, in the final Air Force report in 1966 described the essence of this finding in fir first paragraph. I quote:

***In the authors opinion, this long sequence of photoelectric observation has taught us more about the variations of solar type stars than about the sun itself. The observations of 15 stars of spectral types F and G in the years 1955-1966 indicate that for none of these stars does the standard deviation of the yearly mean magnitude exceed 0.008 [that’s less than1 %]***

***No evidence in the stars which are similar to the sun has been detected in this program. If we assume the sun acts in similar fashion to each of these stars, its variability over a 15-year period probably does not exceed one half of one percent.***

‘What about Uranus and Neptune? The magnitudes or these planets over the same interval revealed no clear pattern. . Is there evidence of solar variability? J and S wisely declined to comment. Their work was done, and frankly, they didn’t have a dog in this fight. S went on to a distinguished career at Mt. Stromlo and the U of Arizona. J was and remains a foremost authority on pulsating variable stars. He is retired and still lives in Poland. .

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6. As is typical of Lowell Observatory in that era, it was left to an outsider to resurrect the 1966 report and try to interpret the planetary variations. The first record I found was by D. Labs, a German physicist, TSI pundit, and calibrator of total solar irradiance. Labs overplotted the observed variability of Uranus and Neptune with the sunspot number. The vertical scale divisions are 1 percent. Here, the x’s and o’s are the magnitudes of Uranus and Neptune each year and the small dots are the sunspot number. I added the connecting red line (**next animation step, same slide)** so you can see better how the sun’s activity varied during the period of planetary measurement. Conclusion: no correlation whatsoever!

7. Now the story moves to the famous Mount Wilson Observatory in California where the eminent stellar spectroscopic Olin C. Wilson was working. Also taking advantage of postwar photomultipliers and electronics, they had build a scanning spectrometer attached to the 100-inch reflector

Wilson had the idea that emission in the cores of two lines of ionized Calcium might reveal the signature of stellar activity, the analog of sunspots. He selected a set of 81 roughly sun like stars and set to work. His experimental design and rationale was described in a lovely paper, well written, clear, and succinct. Read it as literature.

The illustration below, produced by my colleague Jeff Hall, shows t he spectral feat ures to be measured in 4 passbands., one each to the red and t he blue of the Ca II lines to serve as a refer ence, and two narrower bandpasses that isolate the Ca Ii emission. The likes have the historic designation from the nineteenth century of H and K, and so this became the “Mount Wilson HK program.” Its fame endures.

The ratio of the summed line strengths H and K relative t o the continuum regions V and R defines the so-call HK index, commonly designated as S.

In 1978 Wilson published his monumental final catalog of HK time series for 91 stars. It’s a classic.

Almost as a throwaway line in the introduction he estimated that in his opinion, and citing the stellar work by Jerzykiewicz and Serkowski, he estimated that solar variability, if over observed, would likely not exceed 0.1 percent. How right he was!

8. Wilson’s work was deemed to essential that after he retired, the observatory kept it going for more than twenty years more, first by Arthur Vaughan, who ported it to the 60-0inch telescope nearby with a new spectrophotometer. Later, Sallie Baliunas moved it back to the 100 inch after Mount Wilson was tuned over to a private non-profit detached from the Carnegie Institution, it’s original owners. Baliunas kept it going until 2000 oo so when it finally expired due to the dead weight of labor and money required.

 The illustration below shows examples of three types of stellar activity variability observed among the 91 s tars. Each point is a night’s work and each clump of points is a year’s work.

**On the left** a cycling star with a period near 10 years. Thus is born the idea of a cycling solar analog star.

Many s tars don’t vary at all. Some were utilized as standards,(**center)** an essential component of any long term observing program.

Finally, some vary with no discernible pattern. (**right)**

One might think that after three decades there would be little else to learn.. Wrong.

Later when Lowell began observing sun like stars for sun like levels of variability we would select many from Wilson’s sample and thereby have the advantage of simultaneous photometry and spectroscopy.

This was to occupy **Richard Radick** and me for about 25 year.

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9. Meanwhile, in earth orbit, a satellite called Solar Maximum Mission was about to bust the whole game wide open. **Richard Willson**, shown here, built an instrument to measure total solar irradiance. It wasn’t the first but it was a notable advance on earlier devices.

A classic rep[ort in Science shows an early result. The upper set of slices shows the passage of a sunspot group across the face of the sun on successive days.

The lower graph shows the output of the radiometer. The sun’s total output dipped by about a quarter percent due t o the cooler sunspots blocking radiation in the earthward direction. .

This is an AHA moment: sunspots caus the sum t o dim. Was there a measurable stellar analog to this observation? This is about the time that Radick and I began working together, using the Lowell 21-inch telescope, just as Jand S ha done, to measure stellar variability. Would we find anything.

Our first joint project involved the young but sunlike stars in the Hyades open cluster. Fortunately we also had access to Mt. Wilson S data for the same stars,

We found a rotational variation of about 2% in stellar brightness that we attributed to starspots. The S index varied in the reverse sense: as S increase (starspots present) the s tar dimmed. Bingo.

In retrospect, this was like shooting fish in a barrel. Ultimately we derived rotation periods for a dozen s tars in the Hyades open cluster, all arising from the passage of invisible but certain-to-be-real starspots. There can be no other sensible explanation.

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10.. Could we detect variations in s tars similar to the Sun? This was a daunting prospect because by then we knew that the Sun only varied by about 0.1 percent over the par t of the cycle observed up to 1984 or so.

With a jumpstart of some Air Force contract funds, we began, again turning to the venerable 21-inch telescope. We hired an observer, Brian Skiff, who proved an ideal match, observing on1200 nights over 15 years. Our technique w as differ ent from that of the earlier study at Lowell and we had better equipment, and we imagined that me might better their precision. Indeed we did. In our first season, we found a varying field star hat gave us courage to continue.

We use a technique called differential photometry in which one star is alternated with another in rapid succession t o cancel out fluctuations of atmospheric transparency. It’s a standard trick of precision photometry. Our improvement on this was to adopt quartets of stars observed in succession thereby giving 6 pair wise comparisons. Correlations of the stacked time series shows which stars vary and which do not.

Illustration on the right is a sample from one quartet group, individual nights from 11 seasons shown on the left and the annual means on the right. The variable star is shown up in panels 1, 4, and 5 while the two stars in the 3rd and 6th panels are commendably flat.

This is an ideal situation. Often a comparison star goes bad and we have to start over. Sometime, no pair of comparison stars is reliable. As time goes by, tension mounts. But in a statistical sense our large program is a huge success.

After 15 years we published our final paper, and in this one we hand off the project to the automated telescopes of the Fairborn Observatory in southern Arizona.

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11. With the Mount Wilson HK program expected t o end, scientists at the HAO, led by Dimitri Mihalas sensed an urgent need for something like the HK program to continue elsewhere e., But where? JHAO had no stellar telescopes. The instrument ultimately devised was a dual solar and stellar spectrograph thus enabling comparative studies of solar and stellar activity **with the same instrument.** it’s actually two spectrographs in one, one for HK and the other for the visual – red spectral regions where other interesting spectral lines reside.

**Upper left** shows the 1.1-m telescope to which the fiber fed spectrograph is connected. **Lower left** shows the solar feed, a naked fiber attached to the building exterior. It’s arguably the world’s smallest solar telescope **Upper right** shows the innards of this beautiful instrument.

\Our current program includes 3x weekly measurements of sunlight and monthly stellar runs on about 100 sun like program s tars.

Do we find cycles? Of course we do, that‘s not new information. We concentrate now on stars that might be in grand minima, such as the sun in the Maunder Minimum, stars that might be changing from cycling to non-cycling state, and stars whose correlations with brightness variation might change over time. It’s all a tough question and we have no glib set of neat results. Stay tuned.

12.H re is the Fairborn observatory telescope farm where the photometry continues. The resident genius, **Lou Boyd**, is shown **upper left.** Data toes via modem or interned to **Greg Henry** at Tennessee State University in Nashville. Greg has the duty of standing at the end of the firehose.

The robotic telescopes are only marginally more precise than the manual observations obtained at Lowell by Skiff. But the sheer weight of numbers reduces the uncertainty of annual mean magnitudes substantially, and progress is therefore being made as we work together, Fairborn for photometry and Lowell for spectra.

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13.This chart shows the behavior of our entire sample wit h filled symbols indicating stars in which activity and brightness vary inversely (ie. Spots make the stars dimmer on long term)

Open symbols are stars like the sun.

Aces are activing (upward) and temperature (increasing to the lerft)

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14. Finally a chart that requires some explanation. Non astronomers might wato take a coffee break. I apologize for the complexity, but it’s time to show you that we are actually getting somewhere.

Both charts show observed stellar activity year to year (**vertical scale**) as a function of a measure of their mean activity level. This also is conveniently an estimator of age, so I’ve simply labeled the axes ;’AGE”

Look first at **the left hand** chart. This is a measure of chromospheric HK activity. And the sun is near center on the chart near the regression. Actually t he Sun is a bit more active than its age cohort, but not by much. (Recall that the Sun has been quite active in the last few cycles --we can imagine that in future in might drop down a bit on this chart.

So far, so good. Now the **right hand** chart. In which the brightness variability of our sample of s tars in plotted, more variation in the upward direction. The drop lines indicate uncertainty due to noise in the observations and t he symbols represent an estimate of upper limit variability. Aha, you might observ, the sun is an outlier, lying below the regression line for our sample Does this mean that the Sun is more quiescent than average/? Well maybe, but let’s not jump to conclusion. After all, our sample is biased by the stars that we see vary and many stars are below our limit of detection. It’s a fact of life, this is the best we can do and it’s not good enough to detect variation of stars as quiet as the Sun.

The animation shows some improvement.

15. What’s next?

Lowell and Fairborn will soldier on with an increasingly tight sample of the best solar analogs looking for transitions from cycling to non cycling, grand minima, and changes from direct to indirect vari tion

Kepler might produce surprises

Finally, the Uranus and Neptune program continues with NASA support and the interest of planetary sciences.

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16. Did the story end there? Well no. it’s now 1970 and we still have no idea whether the Sun varies significantly or not. Another weather and climate scientist enters the fray. This time it’s NOAA climatologist J. Murray Mitchell, Jr. who is fretting over delays in the first satellite intended to measure solar irradiance. In frustration he appeals to Lowell observatory to resume planetary measurements with the hope that improvements in instrumentation since the 195d and 1960sd would permit detection of what has thus far eluded all who tried.

In a letter to Lowell Director John Hall, Mitchell wrote:

***I am distressed that we are already into the year 1970, four years after the Lowell program was discontinued, and not only do we not yet have the satellite measurements in question but the latest NASA schedules do not show them beginning until at least 1972 and probably 1972 or 1973”***

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17. What about the planetary photometry? Almost as soon as re resumed measurement of Uranus and Neptune (and Saturn’s moon Titan) in 1971 we realized we were seeing variations way too big to be solar variations. We fell into some dead end interpretations that later proved wrong, but the result was a nice set of curves of the seasonal variations of each object. Here I show Uranus, a thing of beauty, but of no further relevance to this talk or the study of solar variability, Nonetheless NASA remains interested and is willing to pay for it and so we continue to observe these objects with the same 210nch telescope where the work began 60 years ago. .