Alpha Centauri at a Crossroads

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At the Dillon Dam Brewery

Liz and I were celebrating New Year's Eve up in the mountains, at the Dillon Dam Brewery, with our friend Sally. During the lull after the band's first set, Sally turned to me and asked, slyly, "So, Mr. Astronomer, what's up with the nearest star?" I hesitated, wary of an ASTRO-101 trick question from the mischievous Sally, an education specialist. Accordingly, I launched into a discussion of all the amazing new things we astronomers were learning about our Sun, especially why this cool star (if you consider 6000 Kelvin "cool") has a super-hot, million degree outer atmosphere, the corona. (Mention of the solar "coronal heating problem" caused Liz, of the biotech world, to glaze over a bit: she had heard all this before. To be sure, I often get the same response from colleagues on the "Dark Side," although to be fair, AGN also have hot coronae and their own coronal heating problem.) I continued with an impassioned description of all the good that the Sun does for our Earth, glossing over the bad stuff coming up in the far distant future (as the Sun inexorably brightens), except to mention the impact of solar "Space Weather" on our planet, reason enough to keep a watchful eye on our nearby star.

"Very cute, Tommy," Liz interrupted, "but you know Sally really was asking about the next nearest star." "Well, nice try," I thought. So, I shifted gears into a new mini-lecture about "Proxima b," an Earth-sized, probably rocky, planet in the Habitable Zone of Proxima Centauri, a diminutive red dwarf that still holds the title of the Sun's nearest stellar neighbor. But I didn't stop there. I went on to opine that Proxima was pretty wimpy, as stars go, but, remarkably, has a couple of bigger, more sunlike siblings close-by. Together, these three stars comprise the Alpha Centauri system.

The two larger stars, Alpha Cen A and B, are in a relatively tight 80-year orbit, about the size of the outer Solar System. Tiny C, not much bigger than Jupiter, revolves around the central pair at a great distance, a few hundred times that of Pluto from the Sun, taking perhaps half a million years to make a full circuit. C just happens to be on the sunward side of AB at the moment, temporarily claiming the honor "Proxima."

Alpha Cen A is an early-G-type dwarf, almost identical to our Sun, although slightly more massive, larger, and more luminous. Its companion, Alpha Cen B, is an early-K star, slightly less massive, smaller, and dimmer than the Sun. Stellar structure studies suggest that the system is metal-rich, about twice solar, with an age of perhaps 6 billion years, somewhat older than the Sun (Flannery & Ayres 1978; Eggenberger et al. 2004).

In fact, the nearby hierarchical triple contains examples of all the most common types of the Milky Way's cool stars: those that sustain outer convective envelopes. These "late-type" stars often are afflicted by surface magnetic "starspots" (whose intense fields suppress vertical kinetic transport of energy, leading to local darkening); the heart of stellar activity. This is what powers the Sun's Space Weather, mentioned earlier, with its numerous potentially bad consequences for our technological civilization (GPS and cell phones at risk, need I say more?).

Breakthrough Starshot: Voyage to Alpha Centauri

As I drifted into the discussion of magnetic activity, I sensed I was in danger of losing my—albeit small, though so far politely attentive—audience, so I decided to amp up the Alpha Centauri narrative. "Hey Sals," I asked, "have you heard about the crazy new project called Starshot, to send a swarm of nanobots to Alpha Centauri sometime this century?" Liz knew about this already, and rolled her eyes briefly. I went on to describe the out-of-the-box idea from the Breakthrough Initiatives Foundation to launch credit-card sized "starchips," carried by laser-propelled light sails, for a decades-long trip to nearby stars, ultimately to photograph, up close and personal, any habitable planets around them.

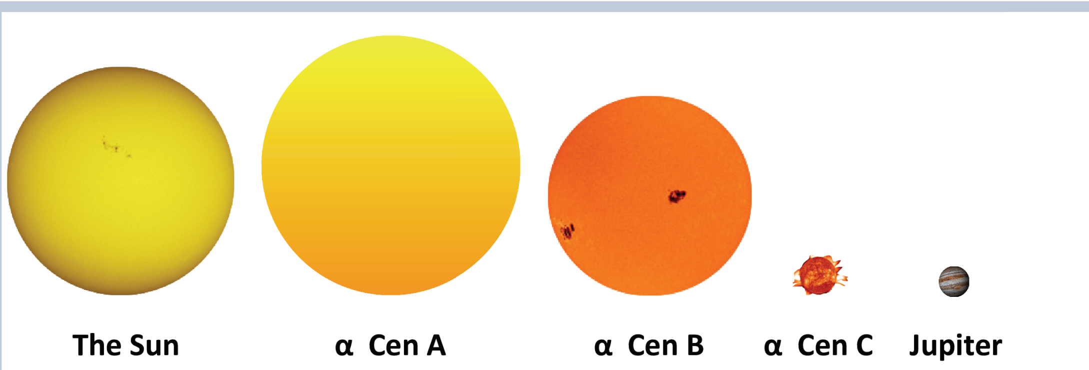
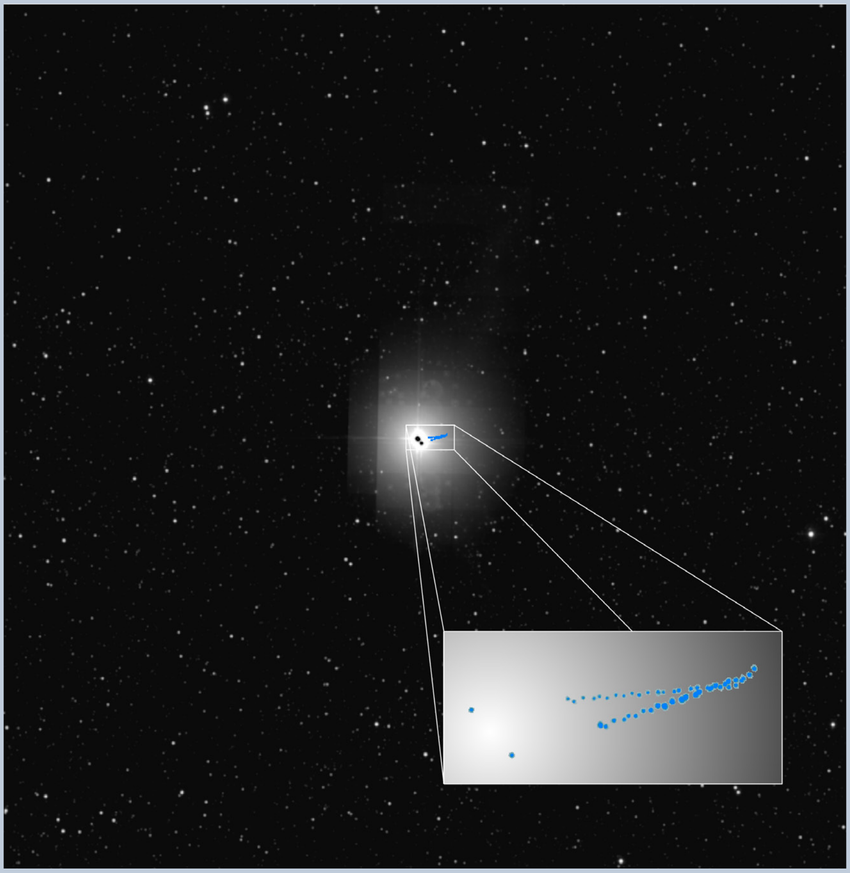


Figure 1: Rogues gallery: Sun, the Alpha Centauri stars, and Jupiter to scale.



Cover image: 2MASS near-IR field around Alpha Centauri A and B (center black dots) with superimposed montage of Chandra X-ray imaging (blue) of the pair over the past 15 years (see expanded view in inset image). Full map is about 0.5° on a side.

I explained that the nearest stars are in fact unimaginably far away. For example, our most advanced rocket-propelled spacecraft—New Horizons, which recently flew past Pluto—would need about a thousand centuries to reach Alpha Centauri, even at its record speed.

To break the "Tyranny of the Rocket Equation," Starshot envisions a one-way trip, traveling fast and light, relying on external propulsion. A giant Earth-based laser "beamer"—effectively a square-kilometer optical telescope—boosts the starchips to a stunning 20% of lightspeed. Even so, the journey to Alpha Centauri would take more than twenty years (with an another 4.3 years for any transmissions from the nanobots back to Earth).

The beamer blasts the photon-sails on their way, staged from a mother ship in high Earth orbit; but also receives, decades later, the faint laser downlinks from the starchips as they race through their brief, hours-long encounter with Alpha Cen. Because the journey has multiple hazards—mainly interstellar dust and gas along the way—you have to send many, perhaps thousands, of the nanobots to hope for a few to survive.

Alpha Cen is an obvious first target of Starshot, because second closest—"Barnard's Star," an unremarkable old red dwarf—is a couple of light years further on. Also, there are three possible hosts for habitable planets in the Alpha Cen system, and we already know there's at least one, Proxima b.

Wacky as it might seem, Starshot is the only way, with foreseeable technology, to explore the nearest stars. Thus, it's worth, well, a shot.

The Solar-Stellar Connection

Thankfully—for Liz and Sally—the band returned from its break, and the dancers re-took the floor, in anticipation of the New Year only an hour or so away. With my companions otherwise diverted, my thoughts wandered back to my first encounters with Alpha Centauri, culminating in my more recent high-energy adventures with *Chandra*.

I, and my colleagues, have long been interested in Alpha Cen AB because they are so similar to the Sun; perfect subjects for what we call the "Solar-Stellar Connection." We know a lot about the Sun for the simple reason that it is only light minutes away, whereas the nearest stars are several light years, or more. However, the Sun is just one example of a G-type star at a particular stage of evolution, formed with a specific set of initial chemical abundances, seed magnetic fields, rotation rate and other properties that might, or might not, be representative of G-type stars in general. It's like choosing a person from the crowd at the Dam Brewery, and examining her carefully to deduce what human beings are all about. Sure, you would learn a lot, but then again there would be a lot you would miss. It's the same idea with the Solar-Stellar Connection: build a basic framework anchored in the Sun, then extend outward through—necessarily more superficial—consideration of the more remote stars.

Back in the 1970's, when I was a grad student at Colorado, then postdoc at the Harvard-Smithsonian CfA, we were pretty much stuck analyzing optical activity indicators of the stars, like the faint "chromospheric" cores at the bottoms of the strong K and H resonance absorption lines of singly ionized calcium (at 3933 Å and 3968 Å). The more dependable X-rays (symptomatic of million-degree coronal gas) were mostly beyond reach. Aside from the Sun, only very intense emissions from compact binaries with neutron stars or black holes were known at the time.

The chromosphere, itself, is a temperature inversion layer in the solar atmosphere about 500 kilometers above the Sun's visible surface, something like the Earth's Thermosphere. In the 10,000 K chromosphere, the radiative equilibrium conditions of the cooler photosphere beneath give way to non-equilibrium kinematic and magnetic heating processes that ultimately power the enigmatic, much hotter, corona above. The amount of energy deposited in these layers is small, but the extremely low densities of the outermost regions throttle local cooling, forcing a thermal run-away, ultimately driving the temperatures up to a million degrees, or more. We also know from the Sun that the super-hot gas mostly is bottled up in fine-scale magnetic loops, although some fraction escapes entirely from the corona in the solar wind.

So, I, my thesis advisor Jeff Linsky, and collaborators Alec Rodgers and Bob Kurucz, dutifully modeled the faint optical Ca II chromospheric emission reversals of Alpha Cen AB; work we published in 1976. The stellar variants were very similar to their solar counterparts, indicating that the Alpha Cen twins shared the low-activity state of the Sun, in contrast to other examples of G dwarfs known at the time—mostly very young, fast rotators—that displayed intense Ca II emission cores.

Fortunately, a major transformation in the study of the Alpha Cen stars was about to happen: the dawn of the high-energy astronomy age.

Early High-Energy Exploration of Alpha Centauri

The late 1970's witnessed the birth of modern high-energy astrophysics. In quick succession there was the first High-Energy Astronomy Observatory (HEAO-I), launched August 1977, followed in November 1978 by HEAO-II (later named *Einstein*). Although the Alpha Cen stars are not particularly coronally active, they are so nearby that even this early wave of high-energy observatories was sensitive enough to capture them. In 1978, John Nugent and Gordon Garmire published the first X-ray detection of Alpha Cen AB by HEAO-I, albeit unresolved, at a combined coronal luminosity similar to the Sun at the peak of its 11-year sunspot cycle. Later that year, Leon Golub and colleagues described high-resolution imaging of Alpha Cen AB by the *Einstein* HRI, with the unexpected result that visually dimmer B was more than twice as bright in X-rays as companion A. (The general trend that cooler dwarfs tend to be more coronally active than their warmer cousins later was confirmed through broad stellar surveys by *Einstein* and subsequent X-ray observatories. Why this is the case still is hotly debated.)

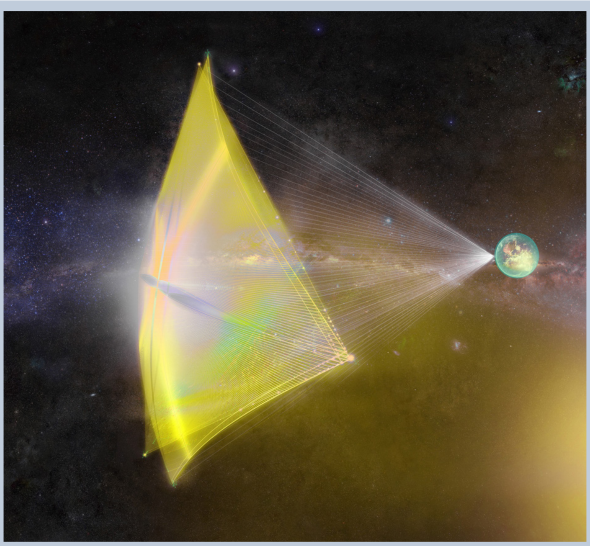


Figure 2: Starshot photon-sail far from Earth, still surfing on the concentrated laser beam from the ground-based phased optical array. Credit: Breakthrough Initiatives Foundation.

The next important advance was the Röntgensatellit (ROSAT), launched in June 1990. ROSAT not only performed an all-sky survey to put stellar coronae, among other high-energy phenomena, into perspective; but also was able to separate AB with its High-Resolution Imager (like that previously on *Einstein*), despite the shrinking Alpha Cen orbit at the time. ROSAT observed AB on a number of occasions, including two month-long campaigns in 1996 (reported by Juergen Schmitt and Carolin Liefke in a 2004 retrospective on the activity of solar neighborhood dwarfs). AB were found to display sunlike coronal variability during the two campaigns, and B was caught flaring a few times. During most of the ROSAT era, B was X-ray brighter than A, although in the final HRI observation in 1998, B had dropped down to A's level. This again reinforced the solar-like nature of the Alpha Cen dwarfs, and the fact that B is the more active of the pair (most of the time).

Contemporary High-Energy Views of Alpha Centauri

The new millennium brought a third generation of high-powered X-ray observatories. The two most significant for the Alpha Cen story were the Advanced X-ray Astrophysics Facility (AXAF, later christened *Chandra*), launched in July 1999, and the X-ray Multi-mirror Mission (re-named *XMM-Newton*) lofted in December of that year.

Alpha Cen was featured in early observations by *Chandra*. A Low-Energy Transmission Grating spectrum of AB was taken during the LETGS commissioning period in late-1999 (published by Ton Raassen and colleagues in 2003). The A and B spectral stripes were isolated spatially thanks to the 20" separation of the pair at the time, and the excellent 1" resolution of the HRC-S readout.

LETGS spectra carry many key tracers of coronal plasma conditions and composition, and can readily distinguish low- and high-activity objects. Ironically, the Alpha Cen X-ray spectra eclipsed anything then (or now) available for the Sun, in terms of broad wavelength coverage and energy resolution. In that epoch, AB were similar in X-ray luminosity; contrary to the *Einstein* observation twenty years earlier when B was brighter.

The "Darkening of the Solar Twin"

After the 1999 *Chandra* LETGS pointing, a several year X-ray hiatus ensued for Alpha Cen. Finally, in 2003, *XMM-Newton* picked up the slack with a long-term program instigated by Jan Robrade, Juergen Schmitt, and Fabio Favata. In 2005, they published a paper entitled, somewhat ominously, "The darkening of the solar twin." Jan and company described a remarkable—perhaps alarming—drop in the X-ray count rate of Alpha Cen A, something like a factor of 50 at the beginning of 2005. The decreasing separation of the AB orbit was beginning to infringe on the 10" resolution of the *XMM-Newton* cameras, but a signal from A should have been seen easily, and wasn't.

The "fainting" of Alpha Cen A, as the authors put it, was completely unprecedented for a sunlike star, as far as we understood at the time. Certainly, the Sun itself had not shown any such behavior during the modern era of high-energy monitoring. The solar soft X-ray flux does rise and fall with the 11-year sunspot cycle, but perhaps with only a factor of 6–10 spread, and Alpha Cen A already was in a relatively low coronal state at the first *XMM-Newton* pointing, prior to the dramatic fall.

There was, however, the outside chance that Alpha Cen A had entered an ultra-low X-ray state, possibly like the Sun's 17th Century "Maunder Minimum," a mostly sunspot-free period that lasted an astonishing seven decades. One line of thought held that this was a time of abnormally low magnetic flux production on a non-cycling Sun. Lacking sunspots, the corona itself might have disappeared, and the X-rays with it. Another school of thought viewed the Maunder episode as nothing more than a very extended normal minimum, and we know that the solar corona and its X-rays weaken, but do not disappear, in recent examples of such minima. However, given the lack of orbiting solar X-ray monitors during the 17th Century, there was no easy resolution to the debate. There also was a practical side to the matter: the Maunder Minimum coincided with the "Little Ice Age" in Northern Europe, and there were suspicions that solar activity, or lack thereof, might have been responsible in some way for that extreme climatic incident.

Prodded by the extraordinary coronal disappearance of Alpha Cen A, I appealed to the *Chandra* Director's Office (Harvey Tananbaum and Belinda Wilkes) for a small grant of discretionary time to verify the unexpected fading of the solar twin. I chose HRC-I for the experiment because it has a different design than the *XMM-Newton* EPIC cameras, and is much less susceptible to "red leak" from optically bright sources like AB than the CCD-based imagers (including *Chandra* ACIS).

The Director's Office graciously approved three short pointings at roughly six-month intervals. The first observation was carried out October 2005, about eight months after the *XMM-Newton* report of the fainting episode of Alpha Cen A, which had continued through a subsequent pointing in mid-2005. Perhaps a little surprisingly, the October *Chandra* HRC-I image now showed the A component clearly present.

To be sure, Alpha Cen A was in an X-ray low state in October 2005 compared to the LETGS image in late-1999, and the historical highs of the ROSAT era. However, we're only talking factors of 2 or 3, not 50. The subsequent two DDT pointings showed the same result: Alpha Cen A still was mired in an X-ray low state, but not much different from the Sun at sunspot minimum.

Meanwhile, Alpha Cen B was in a relative high state in the initial HRC-I observation of late-2005, well above the LETGS epoch, but similar to the ROSAT era. However, in the second and third HRC-I pointings, B had dropped back toward its historical (initial LETGS) lows.

Through subsequent Guest Observer programs, I and colleagues were able to continue the semi-annual X-ray monitoring of AB, right up to the present day. This remarkable history is summarized in the "streak image" of Figure 4, as well as in Figure 5, which collects together the ROSAT, *XMM-Newton*, and *Chandra* pointings on AB, from the mid-1990's to the present.

The shrinking AB orbit over the past two decades has been countered by improving resolution of the successive generations of high-energy observatories, although in recent years only *Chandra* has been able to cleanly separate the pair. Note the presence of A in the first *XMM-Newton* pointing (early-2003), but rapid fading subsequently. Yet, A was detected clearly in the initial HRC-I observation in late-2005, shortly after the "fainting" episode in *XMM-Newton*, extending to at least mid-year 2005.

So, how could we explain the disappearing act of Alpha Cen A in the *XMM-Newton* pointings 2004-2005? There were two possibilities. Either A had undergone a miraculous recovery from the fainting spell by the time of the HRC-I observation only a couple of months later. Or, there was some hidden issue causing a huge visibility difference between *XMM-Newton* and *Chandra* as far as the A source was concerned. When in doubt, a spectroscopist like myself knows exactly what to do: take a spectrum.

LETGS to the Rescue

We aficionados of spectroscopy always cast our proposals thusly: images are pretty, but spectra are the ultimate astrophysical "deciders." After all, the high-energy spectrum promises a trove of insights concerning the underlying object, or in this case its corona: plasma temperatures, densities, chemical composition, dynamics, and so forth. In reality, however, devious Nature often sees fit to make the true spectrum impossibly more complex to interpret than we would have dreamed possible. To my surprise,

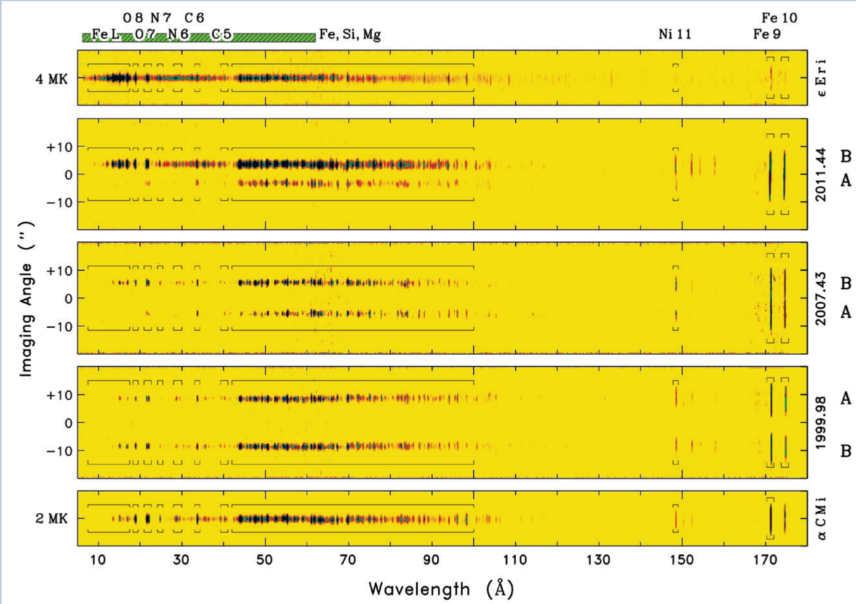


Figure 3: Chandra LETGS spectra of Alpha Cen AB in three epochs; flanked by two reference stars: low-activity mid-F subgiant Procyon (Alpha Canis Minoris) and higher activity early-K dwarf Epsilon Eridani. Chandra easily separates AB, even in 2011 when the orbit was closing rapidly. Also note that the AB positions are reversed in 2007 and 2011 compared with 1999, owing to opposite roll angles. Key spectral features are marked along the top of the panel. Green bar delimits the 0.2-2 keV soft X-ray passband commonly used in coronal comparisons. (Adapted from Ayres [2014].)

then, the second LETGS spectrum of Alpha Cen AB, taken in 2007, actually did completely solve the "case of the missing solar twin."

If you compare the AB traces in the 1999 panel of Figure 3, you will see that they have almost exactly the same appearance: strong Fe IX and Fe X emissions at 170 Å, a forest of Fe M-shell lines from 40–100 Å, sharp O VII and O VIII near 20 Å, and a few Fe L-shell lines below 20 Å. The Fe-L region is populated mainly when the coronal temperatures are a few million degrees, or hotter. If I had mislabeled the 1999 spectra, you would not have been able to tell the difference.

In the 2007 spectrum, the B tracing is almost identical to its counterpart seven years earlier. However, the A spectrum had changed dramatically. To be sure, the long-wavelength Fe IX and Fe X emissions still were prominent; and the intermediate Fe M-shell region still was a forest of barely resolved features. But, notably, the interval below 30 Å was nearly blank: O VII barely visible, O VIII missing, as were all the hotter features shortward in the Fe L-shell. The dimming of the spectrum below 30 Å is a signature of a strong "cooling" of the Alpha Cen A corona (to below a million degrees) in that epoch, and presumably also at the earlier times during the prominent *XMM-Newton* "fainting" episode.

I, and my colleagues Phil Judge, Steve Saar, and Juergen Schmitt, published the new Alpha Cen LETGS spectrum in 2008. Our conclusion was that A's corona had not disappeared after all, because there still was plenty of emission in the Fe M shell and at longer wavelengths; but simply was in a somewhat cooler state. Nevertheless, the effect on the spectrum below 30 Å was profound. If your X-ray detector had poor soft response, you might conclude that the source had disappeared.

In fact, the *XMM-Newton* EPIC cameras require a thick optical blocking filter for bright stars like AB, to avoid overloading the CCD-like sensors with visible photons. The presence of the filter undoubtedly degrades the soft response. Meanwhile, HRC-I can be run wide-open for AB, because its microchannel-plate design is immune to optical loading.

In fact, there is pretty good agreement between EPIC and HRC-I for the slightly more active B component over the epochs in common. It's well known that more active stars tend to have harder coronal energy distributions, and the same is true for a given star over its activity cycle: hotter at maximum, cooler at minimum. Very recently, Jan Robrade and Juergen Schmitt updated their ongoing *XMM-Newton* time series of Alpha Cen, announcing that the A component—which has been steadily increasing in X-ray luminosity in the *Chandra* pointings over recent years—finally had resurfaced in EPIC (although still partially blended with B owing to the coarser spatial resolution of *XMM-Newton*).

In short, how you view a stellar corona depends a lot on the energy response of your instrument, hard or soft. This is an important consideration if, for example, you want to know what the high-energy radiation environment is like, say, at the orbit of a planet in the Habitable Zone of a cool star. Significantly, for low-activity stars like the Sun and Alpha Cen AB, the bulk of the "coronal" luminosity is emitted at the longer wavelengths, beyond 30 Å, mostly outside the commonly used 0.2-2 keV (6-62 Å) reference band.

Thus, while emissions at the shorter wavelengths of, say Alpha Cen A, can vary enormously over the equivalent starspot cycle, the amount of energy involved is small and the "bolometric" X-ray modulation is dominated by the soft component, primarily at the longer wavelengths. At the same time, to be fair, the harder energy radiations might preferentially affect specific chemical pathways on the surface, or in the atmosphere, of an exoplanet, and in that case the cycle modulation could be enormous.

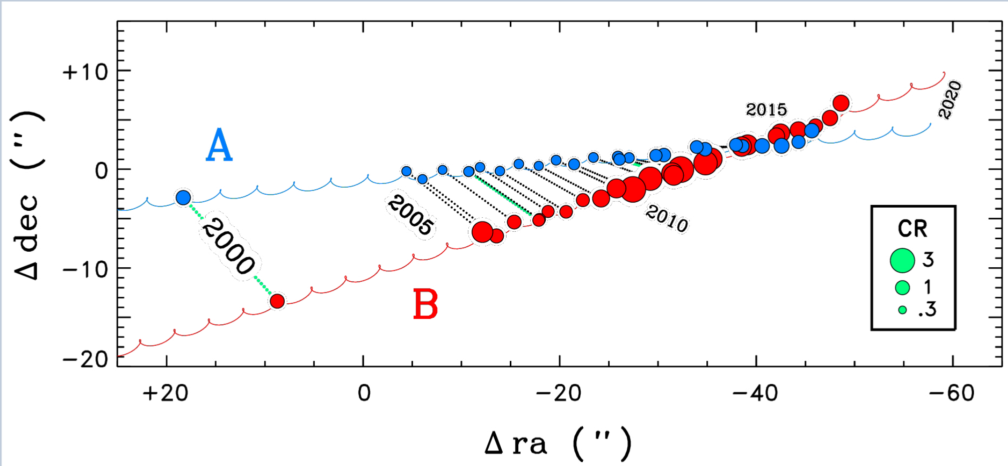


Figure 4: Cartoon version of the Chandra streak image on the front cover. North is up; East to left. Blue dots represent Alpha Cen A, red for B. Squiggly curves are predicted paths on the sky of A and B, including proper motion, orbit, and parallax. Where possible, AB points in the same epoch are connected; green highlights LETGS observations. Sizes of dots represent average count rates according to the legend at lower right.

In the final analysis, then, it is important to characterize stellar X-ray cycles at a range of energies, to fully trace the potential influences on orbiting planets, not to mention ferreting out the astrophysical origins of the underlying magnetic oscillation in the first place (Gene Parker's [1970] "Dynamo"). In this sense both *XMM-Newton* and *Chandra* have been acting synergistically in the specific case of Alpha Cen A, which is at the extreme soft end of normal stellar coronal sources.

The Ups and Downs of Alpha Centauri

Although the original purpose of the Director's Discretionary time program was to explore the puzzling disappearance of Alpha Cen A in X-rays, the subsequent GO efforts shifted focus to the activity cycles of AB. After all, at the time we knew almost nothing about stellar high-energy cycles, because only a handful of late-type stars had been subjected to any kind of long-term X-ray scrutiny. Alpha Cen was far and away the best example, with spatially resolved detections of AB dating back to *Einstein*.

When crafting a long-term X-ray program like that for AB, one has to confront a few practical issues. One of the most important is temporal sampling. The more recent *Chandra* (and *XMM-Newton*) efforts have adopted a semi-annual cadence; much shorter than a solar-like cycle (about a decade), but much longer than typical rotational timescales (about a month for the Sun and AB). Can such "snapshot" measurements provide an unbiased view of the coronal evolution?

Fortunately, we have the two periods of intensive, almost daily, monitoring of AB by ROSAT HRI back in 1996; as well as the long-term daily records of the Sun's soft X-ray flux (e.g., from the LISIRD database at CU's Laboratory for Atmospheric and Space Physics). Both examples suggest that X-ray modulations on rotational timescales generally are modest compared with the overall cycle amplitude, so are merely an annoyance.

Transient flares, however, are a bigger worry. A large outburst could temporarily outshine the X-ray star, and skew the semi-annual record. The way around this is to make sure that each high-energy observation is long enough that any transient X-ray enhancements can be recognized above a "quiescent" level. Thankfully, most stellar flares rarely last more than an hour, so a few-hour pointing is sufficient.

Figure 6 illustrates the totality of the time-resolved HRC-I observations of AB. Note the impulsive flare in ObsID 8906 for B, and the decays in both ObsIDs 10980 and 14234, also for B. There are no conspicuous events for A. Also note the "crossing" of the AB count rates toward the end of the sequence, as A is rising to a local maximum, while B is sinking toward a minimum. Coincidentally, this occurred at the same time as the trajectories of the two stars on the sky were intersecting (Figure 4), a double "crossroads" if you will. (Perhaps a triple considering the new attention lavished on Alpha Cen by Starshot, a clear turning point in the study of the system.)

Figure 7 illustrates the X-ray cycles of the Alpha Cen stars in the modern era. The "X-ray Index" is the stellar X-ray luminosity L_X (0.2-2 keV) divided by the bolometric (total) luminosity of the star (L_{bol}), in units of 10^{-7}. The normalization allows a fairer comparison of activity levels. The points to the left (pre-2000) are from ROSAT HRI, while those at 2000 and later are from *Chandra* HRC-I/S (solid circles) and *XMM-Newton* EPIC (asterisks: B only; A would be off-scale on the low side). Blue points are for A; red for B. Small gray dots in the solar time series (middle) are daily values; larger, darker symbols represent 81-day averages (three rotations).

Dot-dashed curves for A (blue) and B (red) are an attempt to match the time series with a log-sinusoidal model. If one accepts these fits at face value, the period for B is about 8.4 years, and for A nearly 20 years; both bracketing the Sun's 11 year average (although the span between the Sun's apparent Cycle 23 MAX, circa 2002, and that of current Cycle 24 in 2015, is on the long side at 13 years).

Figure 7 emphasizes how solar-like AB are in their overall X-ray levels. At the same time, the cycle periods are more

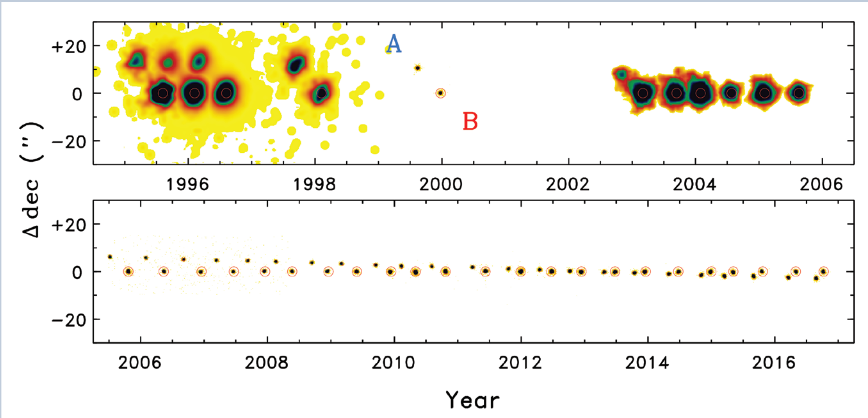


Figure 5: Two decades of soft X-ray imaging of Alpha Cen AB: ROSAT, upper left (including co-added images from two month-long campaigns in 1996); XMM-Newton, upper right (pre-2006, only); initial Chandra LETGS, upper middle; and Chandra HRC-I, lower panel. Images are aligned to predicted location (red circles) of (generally brighter) Alpha Cen B in each epoch, but the AB orientation is preserved.

disparate: shorter for B, longer for A. This behavior must be an important clue to the operation of the cycling Dynamo; especially for more evolved A, which might be on the verge of developing a convective core (Bazot et al. 2016).

Chandra Astrometry and the Orbit of Alpha Centauri

There is a final aspect of the *Chandra* Alpha Cen time series worth mentioning. Figure 8 depicts the orbit of less-massive B around heavier A (usual binary star convention). Orange points mark HRC-I positions, while the lone green dot is from Hipparcos, circa 1991; together covering a fair fraction of the orbital arc. For *Chandra*, the photon-noise error on a single measurement of the AB relative position is only about 20 milliarcseconds.

Small crosses in Figure 8 represent predictions from the recent Pourbaix & Boffin (2016) ephemeris for AB, derived mainly from high-precision radial velocities collected by the HARPS spectrograph at the VLT in Chile. The agreement is pretty good, but there are discrepancies (e.g., the Hipparcos point). The average vector deviation in RA and DEC was 60 mas: small to be sure, but highly significant with respect to the two dozen measurements. The ability to recognize such small systematic effects is testament to the excellent aspect reconstruction of *Chandra*. This might be of some interest to the Starshot folks, because you'd like to know exactly where A and B will be some decades from now, to properly aim the swarm of nanobots.

Back to the Dam Brewery

My reminiscing was interrupted when I realized the music had stopped, and the people around me were counting down to midnight. I toasted Liz and Sally, and wondered what the New Year might bring. I hoped, of course, for peace and goodwill to all the World's people. But, somewhat selfishly, I thought it would be awesome to not only continue tracking the Alpha Cen stars in their decadal coronal dance, but also enroll other subjects in what you might call the "Dynamo Clinical Trial:" checking the magnetic heartbeats of cool stars. Close visual binaries are a good choice, because you get two stars for the price of one pointing; and semi-annual sampling is not too onerous on the *Chandra* schedulers. HRC-I also is just what the doctor ordered for the coronal soft states of optically bright sunlike stars.

The champagne finally was beginning to do its job, and I had a sudden flashback to my first evening in Rio de Janeiro,

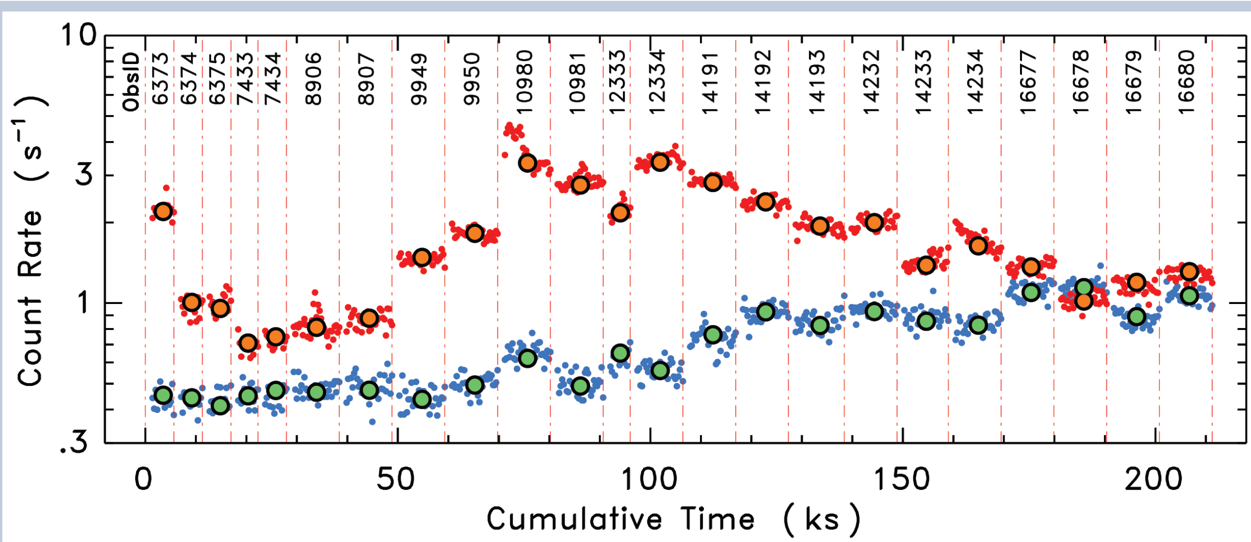


Figure 6: HRC-I time series for Alpha Cen A (blue/green) and B (red/orange). Smaller dots represent count rates binned over 300 second intervals; larger circles are "flare-free" mean values. Vertical dot-dashed lines separate the semi-annual "ObsID" pointings (Adapted from Ayres [2014].)

for the IAU a few years back. I was on the rooftop of my hotel at a bar overlooking Copacabana beach. I saw then, for the first time, my old friend Alpha Centauri shining brightly above me, together with its neighbor Beta Cen pointing to the iconic Southern Cross. Under that celestial spell, I contemplated the ups and downs and several crossroads of my run-ins with the Alpha Cen system over now four decades. At that moment, I was tempted to shout out loud to the sky, "Twinkle, twinkle little (double) star…" But, thankfully, I ignored the temptation and took a sip of my Caipirinha instead. ▪

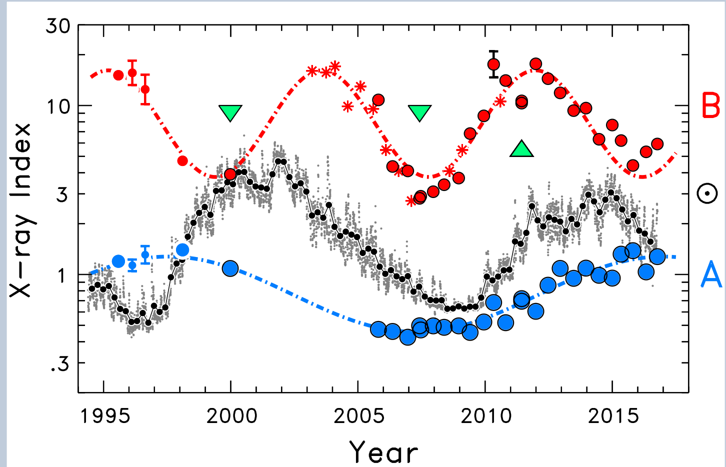


Figure 7. The X-ray ups and downs of Alpha Cen AB, and the Sun, over the past two decades. Green triangles mark times when LETGS spectra were taken. Fortuitously, the LETGS epochs cover nearly the full range of activity states of the two stars. (Adapted from Ayres [2015].)

References

For an overview, I recommend Martin Beech's 2012 article, "A journey through time and space: Alpha Centauri." (Astron & Geophys, 53, 6.10)

For a recent summary of the Breakthrough Starshot project, see "Near-Light-Speed Mission to Alpha Centauri," by Ann Finkbeiner, in Scientific American, 316, 30. (March 2017)

Ayres, T. R. 2014, AJ, 147, 59

Ayres, T. R. 2015, AJ, 149, 58

Ayres, T. R., Judge, P. G., Saar, S. H., & Schmitt, J. H. M. M. 2008, ApJ, 678, L121

Ayres, T. R., Linsky, J. L., Rodgers, A. W., & Kurucz, R. L. 1976, ApJ, 210, 199

Bazot, M., Christensen-Dalsgaard, J., Gizon, L., & Benomar, O. 2016, MNRAS, 460, 1254

Eggenberger, P., Charbonnel, C., Talon, S., et al. 2004, A&A, 417, 235

Flannery, B. P., & Ayres, T. R. 1978, ApJ, 221, 175

Golub, L., Harnden, F. R., Jr., Pallavicini, R., Rosner, R., & Vaiana, G. S. 1982, ApJ, 253, 242

Nugent, J., & Garmire, G. 1978, ApJ, 226, L83

Parker, E. N. 1970, ARA&A, 8, 1

Pourbaix, D., & Boffin, H. M. J. 2016, A&A, 586, 90

Raassen, A. J. J., Ness, J.-U., Mewe, R., et al. 2003, A&A, 400, 671

Robrade, J., & Schmitt, J. H. M. M 2016, arXiv:1612.06570

Robrade, J., Schmitt, J. H. M. M., & Favata, F. 2005, A&A, 442, 315

Schmitt, J.H.M.M.,& Liefke, C. 2004, A&A, 417, 651

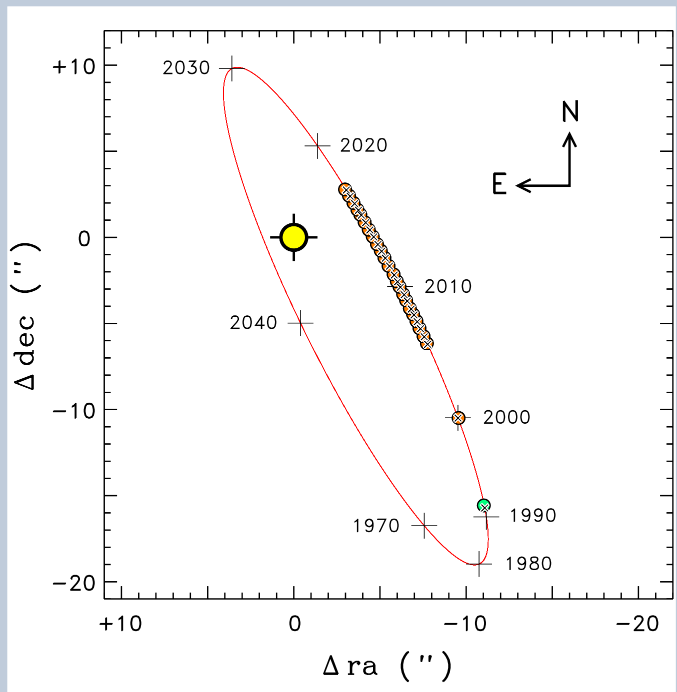


Figure 8. Alpha Cen AB relative orbit as recorded by Chandra (orange dots) and Hipparcos (green dot), compared with predictions (small x's). Decade timestamps (large pluses) are marked around the circumference of the orbit (period is almost exactly 80 years).