The Saga of Procyon

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“Stars in Motion”

A Symposium in honor of

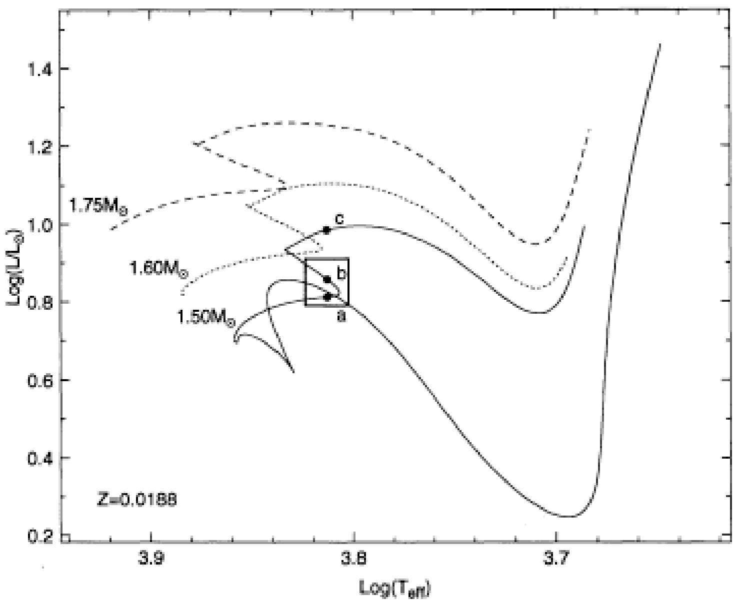
Bill van Altena

September 20-21 2008

Procyon

- Procyon, α Canis Minoris, is a binary system, long famous for its white dwarf secondary.
- This paper is about Procyon A, a bright F5 IV-V star.
- Procyon A has near solar metallicity.
- In 1951, K.A. Strand published a detailed study of the masses of Procyon A and B, yielding $M_A = 1.74M_\odot$ and $M_B = 0.63M_\odot$, respectively.
- But because of the large difference in brightness between components A & B, the orbit is difficult to measure with precision, resulting in a large uncertainty in the mass.

Evolutionary status of Procyon A



Guenther & Demarque 1993

- Convective core
- Very thin convective envelope
- Prime asteroseismic target, based on expectations from helioseismology
- See also Chaboyer et al. (1999), Straka et al. (2005)

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A REDETERMINATION OF THE MASS OF PROCYON

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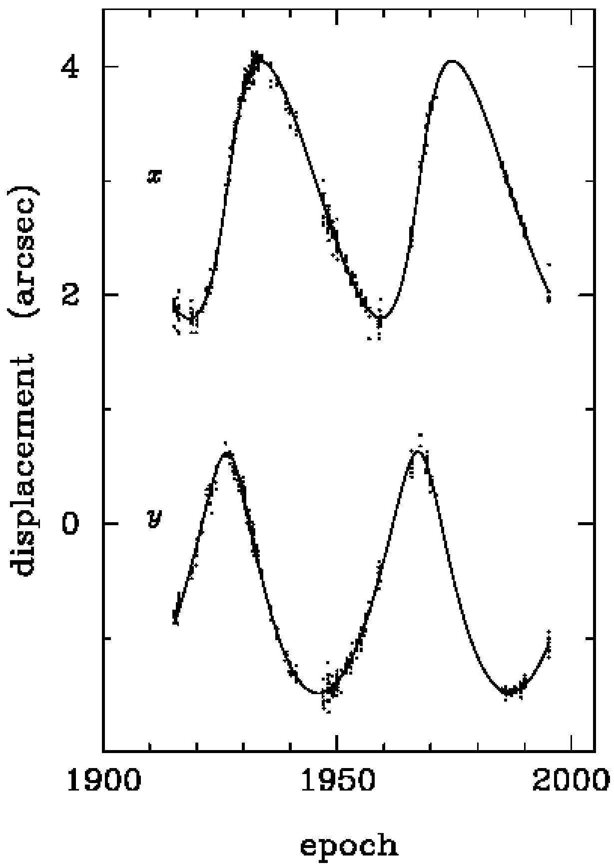
ABSTRACT

The parallax and astrometric orbit of Procyon have been redetermined from PDS measurements
ver 250 photographic plates spanning 83 years, with roughly 600 exposures used in the solution. Th
ta are combined with two modern measurements of the primary–white dwarf separation, one utiliz
ground-based coronagraph, the other, the Planetary Camera (PC) of the *Hubble Space Telesc*
ogether with the redetermined astrometric orbit and parallax, these yield new estimates of the co
onent masses. The derived masses are $1.497 \pm 0.037\ M_{\odot}$ for the primary and $0.602 \pm 0.015 M_{\odot}$ for
hite dwarf secondary. These mass values are heavily weighted by the PC separation measurem
hich, while being somewhat discordant with the ground-based measures, we argue is more precise
ore accurate and thus deserving of its greater weight. This stated, the long-standing discrepa
tween previous determinations of the observed mass of Procyon A ($1.75\ M_{\odot}$) and the value suppor
stellar evolution models ($1.50\ M_{\odot}$) appears to be reconciled.

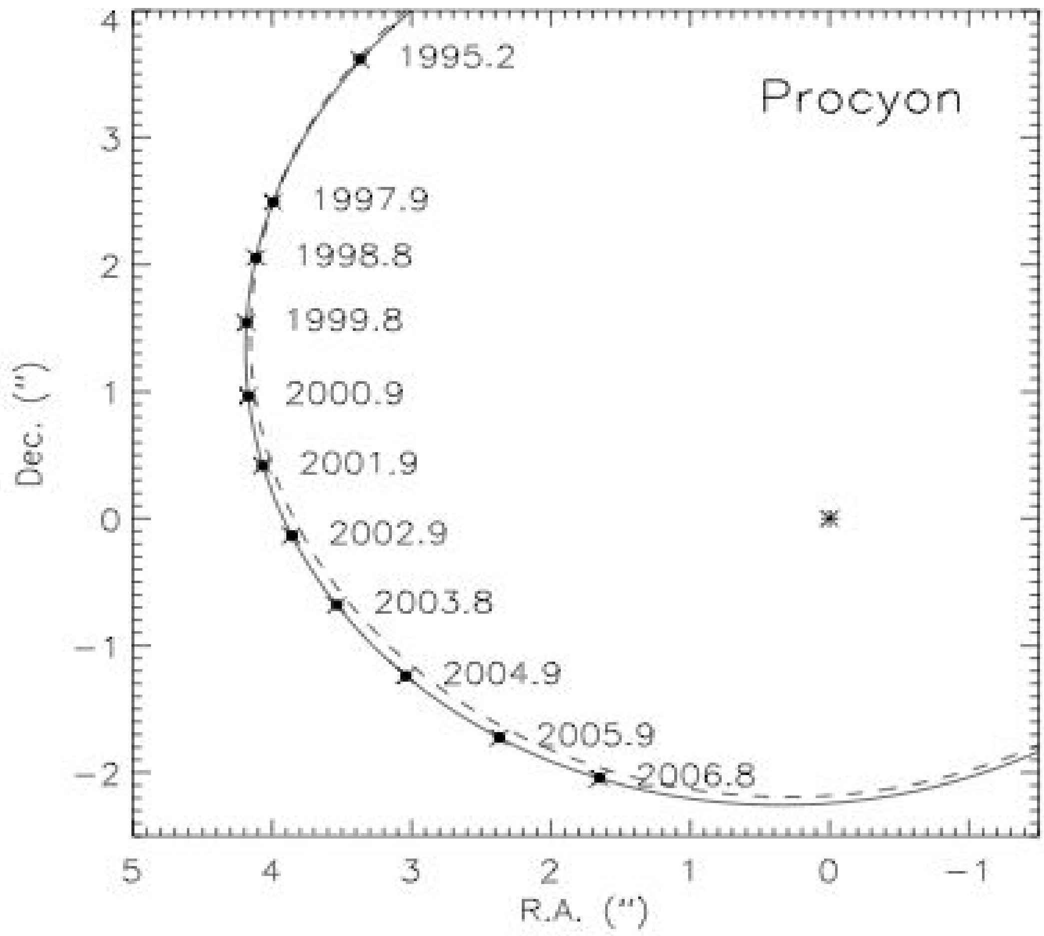
ey words: astrometry — stars: individual (Procyon)

Procyon orbit 2000



Using the Planetary Camera of the Hubble Space Telescope, Girard et al. (including W. van Altena) revised the mass of Procyon A to: $1.497 \pm 0.037 M_{♌}$

Latest Procyon Orbit



Ground-based seismic observations

- Radial velocity (Doppler) observations
- Martic et al. (2004)
- Eggenberger et al. (2007)
- Leccia et al. (2007)
- Agree reasonably well on large p-mode spacing, about 55 μHz, but observed individual frequencies vary from set to set … evidence for short mode lifetimes?

Microvariability & Oscillations of STars
Microvariabilité & Oscillations STellaires

- Aperture 15 cm.
- Ultra-high precision photometry 1ppm
- Limiting mag. 6
- Observing runs up to 2 months

Letters to Nature

Nature **430**, 51-53 (1 July 2004) | doi:10.1038/nature02671; Received 20 February 2004; Accepted 17 May 2004

There is a Brief Communications Arising (18 November 2004) associated with this document.

No stellar p-mode oscillations in space-based photometry of Procyon

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Pressure-driven (p-mode) oscillations at the surface of the Sun, resulting from sound waves travelling through the solar interior, are a powerful probe of solar structure, just as seismology can reveal details about the interior of the Earth. Astronomers have hoped to exploit p-mode asteroseismology[1] in Sun-like stars to test detailed models of stellar structure and evolution, but the observations are extremely difficult. The bright star Procyon has been considered one of the best candidates for asteroseismology, on the basis of models and previous reports[2,3,4,5,6,7,8] of p-modes detected in ground-based spectroscopy. Here we present a search for p-modes in 32 days of nearly continuous photometric satellite-based observations of Procyon. If there are p-modes in Procyon, they must have lifetimes

First MOST observations of Procyon A: null result

- 32 day run. If *p*-modes present, they must have

< 2-3 day lifetimes, or < 15 parts per million amplitudes.

- The MOST team plans further observations
- A puzzling result ! How does one reconcile the ground-based (Doppler) and space data (intensity)? In the Sun both agree; why not in Procyon?
- A very harsh response from some in the asteroseismology community …

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Astronomy & Astrophysics

The non-detection of oscillations in Procyon by *MOST*: Is it really a surprise?

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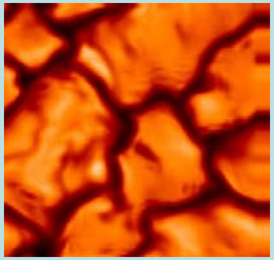
Theory enters the fray with a new tool: 3D RHD simulations&

- Procyon A convection zone very thin, with highly turbulent atmosphere
- Outer atmosphere dynamics modulated by granulation overshoot
- Large granules. Short *p*-mode lifetimes expected.

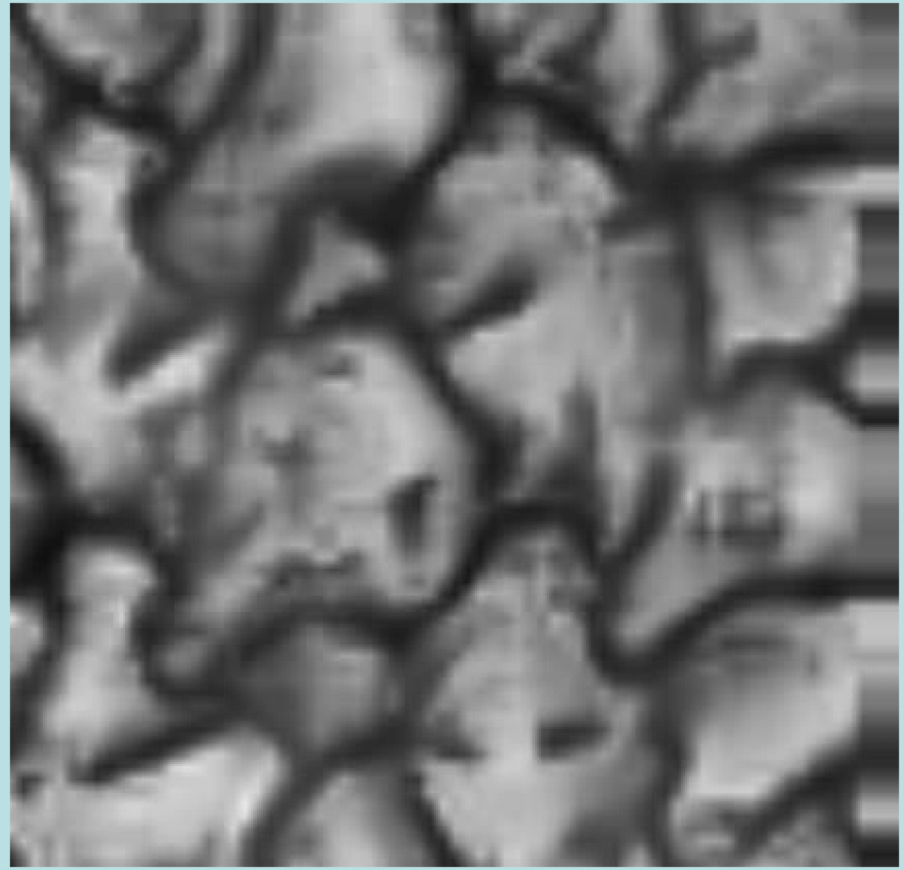
& See Robinson, Demarque, Guenther, Kim & Chan 2005 MNRAS, 2005, 362, 1031 and following papers



3800km

3800km

The Sun



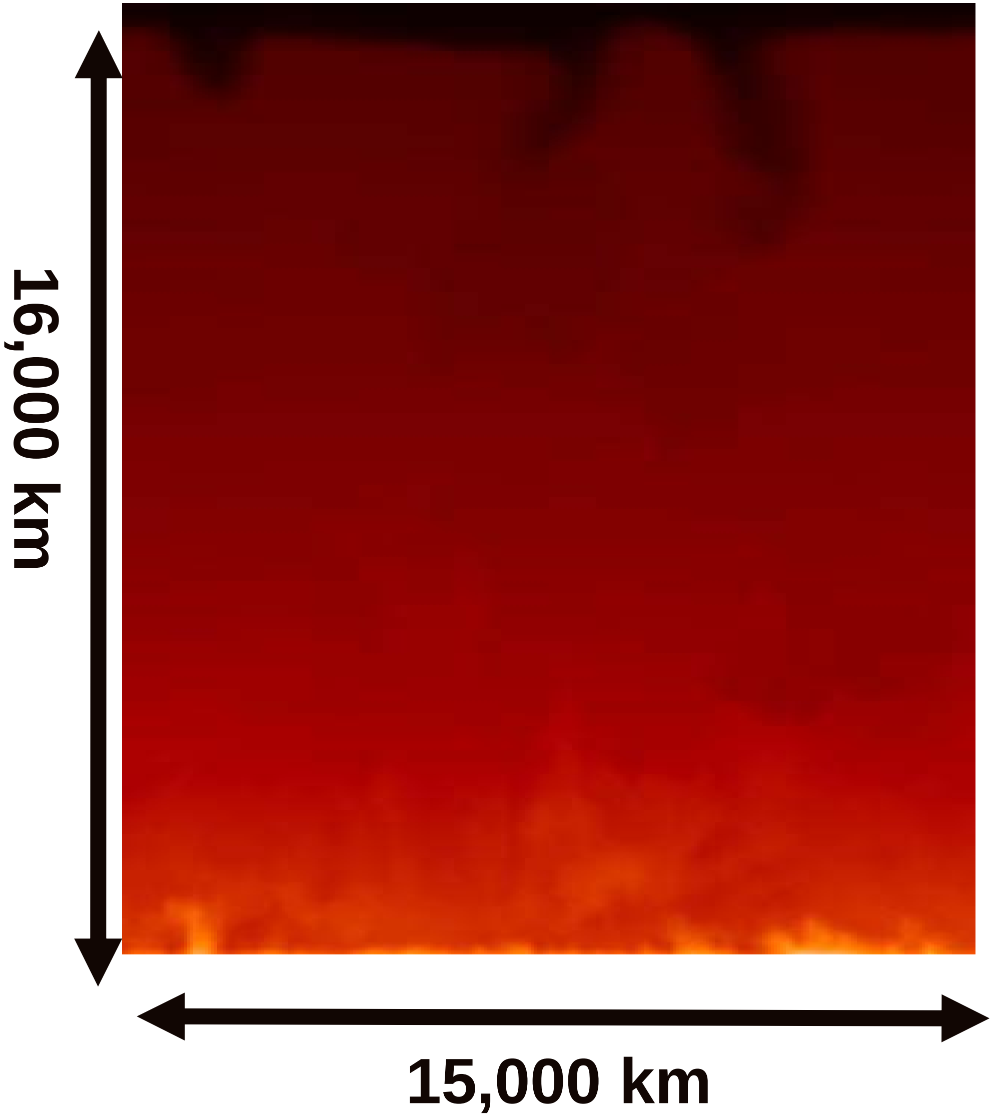
30,000 km

30,000 km

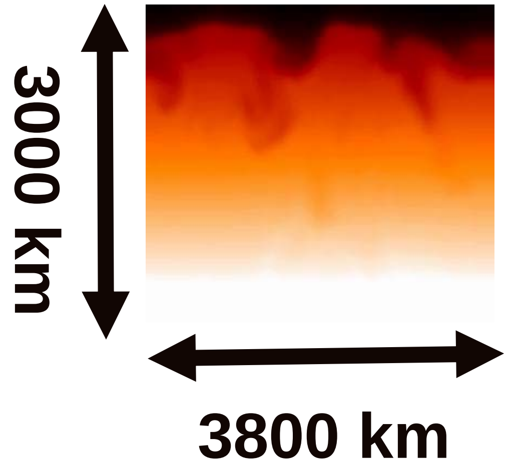
Procyon

Vertical Cross-sections

PROCYON



SUN



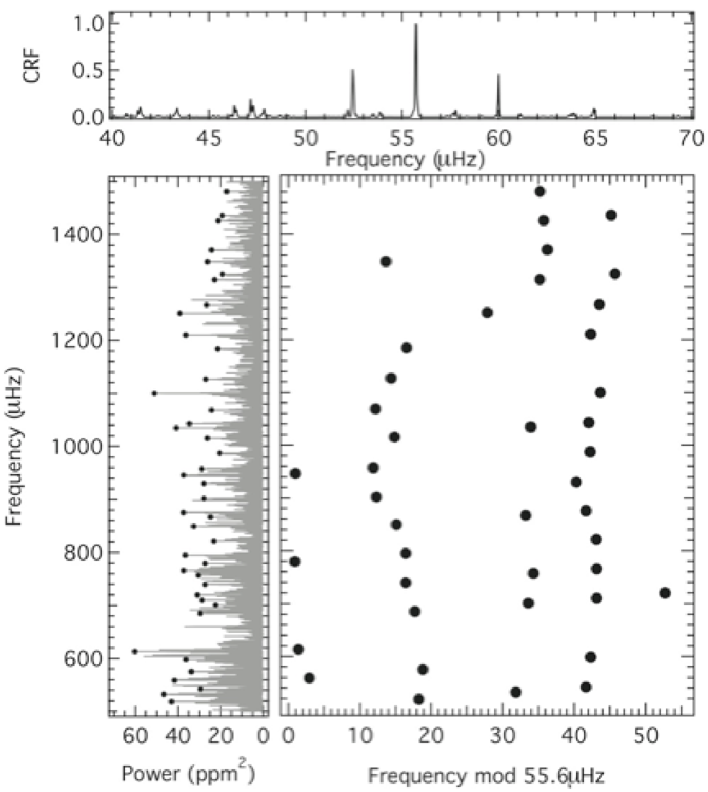
Coherent structures: granules, plumes

Analysis of ground based data + 2nd and 3rd MOST runs

- Consistency only in large separations
- 55.6 µHz
- Likely explanation:

oscillation modes have short lifetimes

Broad implications for future asteroseismic observations

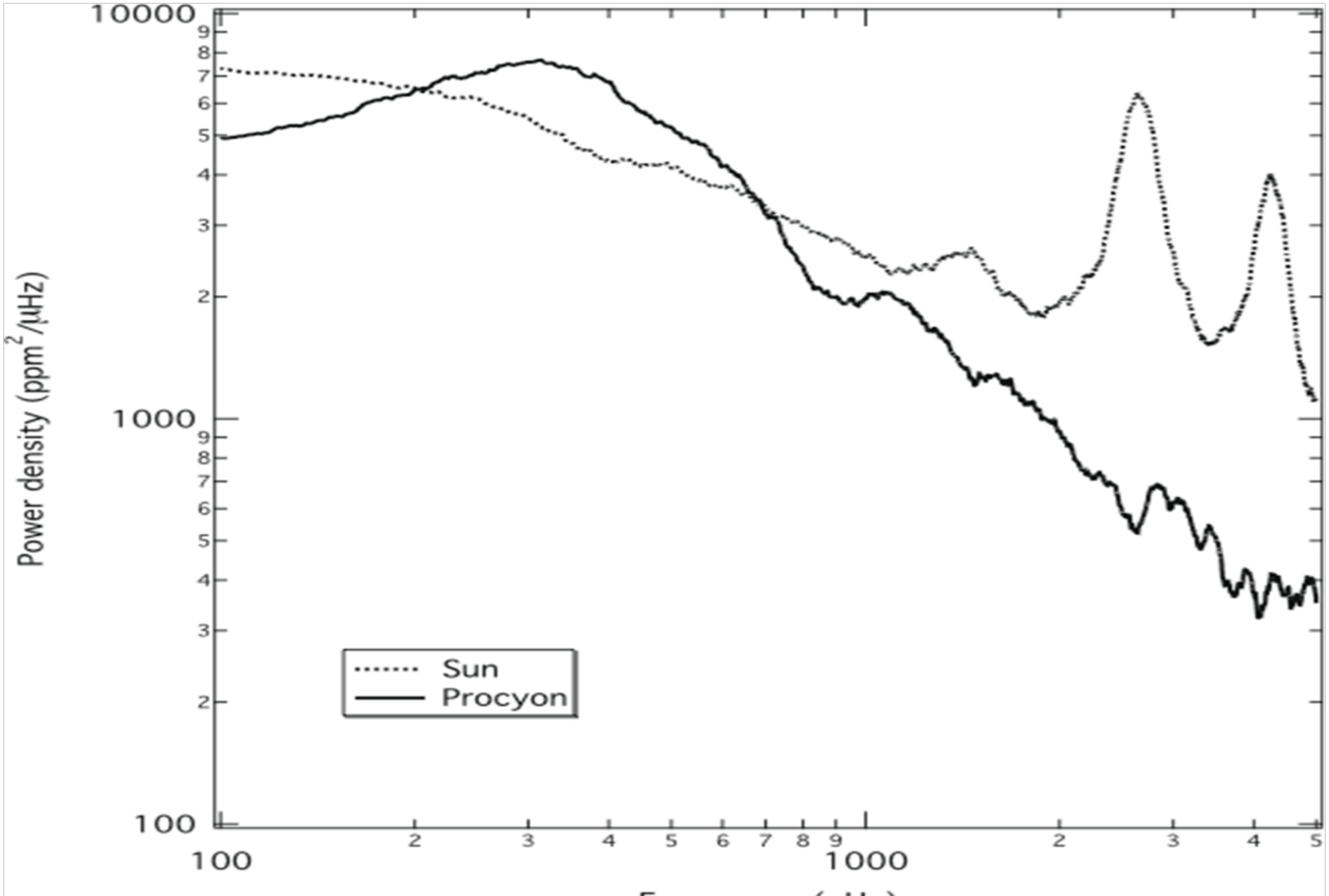


Guenther et al. ApJ in press 2008

A mystery resolved

- Why, unlike the Sun, are the p-modes more easily observed in Doppler measurements than in intensity measurements in Procyon A?
- The 3D simulation provides the answer: the difference in granulation power

Power density vs. frequency



to appear in ApJ
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A MULTI-SITE CAMPAIGN TO MEASURE SOLAR-LIKE OSCILLATIONS IN PROCYON. I. OBSERVATIONS, DATA REDUCTION AND SLOW VARIATIONS

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to appear in ApJ

Multi-site campaign (2008): harmony + a new result

- High precision velocity measurements with eleven telescopes
- Broad plateau of excess power centered at 0.9 mHz (compare to 3D simulations)
- Mean amplitude of radial modes is 38.1 ± 1.3 cm s^{-1} (2.0 solar), consistent with all previous ground based and space observations
- Mode lifetime is $1.5_{-0.8}^{+1.9}$ day
- Discovery of slow variation in radial velocity interpreted as rotational modulation of active regions (similar to Sun). Amount of power indicates that the fractional area of Procyon A covered by active regions is slightly higher than in the Sun
- A new challenge for MOST; observations are underway

Happy Retirement, Bill !

Credit: Jerome Demarque