Five Tau Ceti Planets in the Signals, Two in the Habitable Zone

WES KELLY, TRITON SYSTEMS, LLC

This January the American Astronomical Society held its 221st meeting in Long Beach, CA. Comparable in size, attendance or disciplinary scope to the AIAA Aerospace Sciences conferences held during the same month elsewhere (Dallas/Ft. Worth), interests of the two communities intersect over satellite observatories launched into space requiring close coordination between engineers and astronomers. But what's more, increasing concern in the astronomical community with detection and characterization of "extrasolar" planets gives form, character and specific targets for high aerospace aspirations: travel to planets about other stars. At the least, findings of this nature point to spacecraft missions for direct imaging or atmospheric spectral analysis of extrasolar planets.

For anyone tracking the annual AAS winter meetings, it is clear that extrasolar planet sessions have increased remarkably over the last twenty years; from a few tentative papers to whole sessions (Table 1) on discoveries, detection techniques, assessment of atmospheres, size in comparison to solar system types ("Jupiters," "Neptunes," "Earths...") types of stellar primaries, formation process, habitability….(!) Planet confirmations approach 1000 and thousands of objects too small to be considered suns (e.g., brown dwarfs) add into a wider definition tally.

Which of the season's or the conference's reports or discoveries is most significant? We hesitate to say with so much to examine. Yet in prelude to the 2013 conference, the December 19th San Francisco Chronicle reported, "International astronomers, including a leading planet hunter at UC Santa Cruz, say they have detected five possible planets circling a distant star much like Earth's sun - and that one of those planets is apparently in the famed 'habitable zone' where water could exist on its surface. The

(Continued on page 20)

Above: Wes Kelly (at right) in an image from page 15 of the March and April 2012 issue of Horizons (page 15). At left is James C. McLane III. Image credit: Douglas Yazell.

Table 1. 221st American Astronomical Society Meeting Extrasolar Planet Sessions - January 2013

Session	Title
104	Circumstellar Disks I
109	Extrasolar Planet Detection from Spectroscopy and Micro-lensing
126	ExoPlanet Interiors and Atmospheres
135	Scientific Opportunities for the James Webb Telescope
144	Circumstellar Disks
149	Extrasolar Planets: Detection
158	Stars, Cool Dwarfs, Brown Dwarfs
205	Circumstellar Disks II
220	Circumstellar Disks III
224	Exoplanet Atmospheres
231	Planets and Planetary Systems Identified by Kepler
236	Newton Lacy Pierce Prize: Hot on the Trail of Warm Planets Orbiting Cool M Dwarfs
308	Planetary Systems Orbiting White Dwarfs
315	Transit Selection of Extra Solar Planets
324	Direct Detection of Exoplanets, Faint Companions and Protoplanetary Disks
333	Super Earths, M Dwarfs and Habitability
334	Survey and Catalogs of Extrasolar Planets
336	The Elemental Compositions of Extrasolar Planetesimals from Spectroscopy of Polluted White Dwarfs
343	Extra Solar Planet: Characterization, Theory and Detection
403	Dusty Debris in the Terrestrial Planet Zone II (?)
407	Kepler Exoplanets
424	Planetary Systems Orbiting White Dwarfs and Neutron Stars
435	Extrasolar Planets

Exoplanets

(Continued from page 19)

team led by Mikko Tuomi of the University of Hertfordshire used a new technique to find the planets around the star Tau Ceti using telescopes in Hawaii, Chile, and Australia. The planet that is in the habitable zone is only five times the mass of Earth, they calculate." Subsequent reports debate whether the discovery consists of one habitable planet or two.

Detection methods for these planets were distinct from the transit method employed by the Kepler observatory, true; but they are still based on Doppler radial velocity measurements, variations of absorption lines in the visual spectrum of the primary star, like the original 1990s planet discoveries by pioneers Mayor, Marcy and Butler. What is different now is that Bayesian statistical analyses are being used, combining spectrographic measurements from several observatories: at Hawaii, Chile and Australia. If you have seen the term "rolling average" in a stock performance report, then there's a big clue to what's new in extrasolar planet search software and technology.

As Figure 1 shows, Tau Ceti is a defining member of the constellation Cetus the Whale visible in the northern hemisphere. If the constellation can be discerned by an observer, then this specific nearby star can be pointed to as well as a possible to planets similar to the earth, worthy of further study or exploration.

It is unavoidable to quote extensively from the report of Tuomi et al., posted on line at a Hertfordshire University site. To start, the authors provide the defining parameters for Tau Ceti (Table 2) on which their observations are based. And in conclusion they provide similar tables for five planets, the last two of which are of most immediate concern due to their similarity to earth in thermal surroundings, dimensions or mass (Table 3).

Beside parameters derived for the five possible planets, Table 3 with its "sigma" measures give us an indication of the radial velocity sensitivities of the three observatory instruments involved in the study: the HIRES, AAPS and HARPS spectrographs located respectively at three separate observatories, the Keck (Hawaii), the Anglo-Australian (Australia near Sydney) and the European (ESO) in Chile.

HIRES is a grating echelle spectrograph capable of operating between 0.3 and 1.0 microns (UV to IR) attached to the Keck Observatory on Mauna Kea on the island of Hawaii.

The AAPS is the Anglo-Australian Planetary Search program undertaken with the Australian Astronomical Observatory. The AAPS exploits the high stability of what was the University College of London

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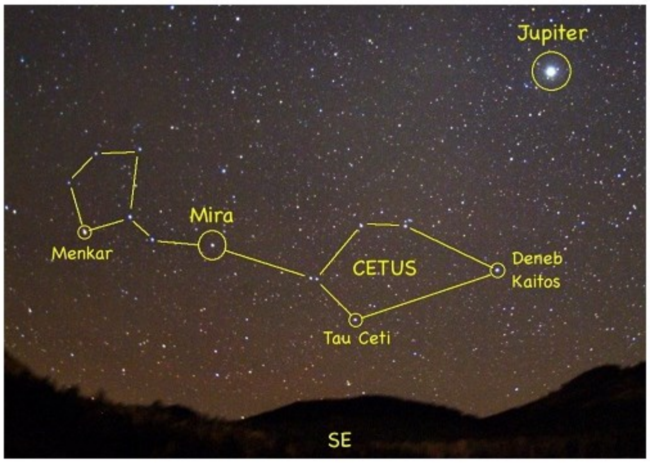

Image: Photograph of the constellation Cetus, with Tau Ceti identified. Credit: Westlake.

Figure 1. τ Ceti in the northern sky defining constellation.

Table 2. Estimated Stellar Properties of Tau Ceti or HD 10700.

Parameter	Units	Value	Notes
Spectral Type		G8.5 V	
log *R′*HK		-4.995	Magnitude
π	[milli-arcsecs]	273.96 ±0.17	Parsec measure
L_{star}	$[L_0]$	0.488 ±0.010	Luminosity
R_{star}	$[R_0]$	0.793 ±0.004	Stellar Radius
Mstar	$[M_0]$	0.783 ±0.012	Stellar Mass
T_{eff}	[° Kelvin]	5344 ±50	Effective Temperature
[Fe/H]	[vs. Solar]	-0.55 ±0.05	Metallicity
Age	[Giga-years]	5.8	
v sin i	$[kms^{-1}]$	0.90	Stellar Radial Velocity - Nominal
P_{rot}	[days]	34	Stellar Rotational Period

Table-3 System Summary – Nominal Orbital Solution of HD 10700 Radial Velocities

	Tau Ceti	b	c	d	e	f
Minimum Mass *	(Earths)	2.0	3.1	3.6	4.3	6.6
Semi-Major Axis	(AUs)	.105	.195	.374	.552	1.35
Period	(Days)	13.95	35.36	94.11	168.1	642
Eccentricity	-	0.16	0.03	0.08	0.05	0.03
ω	(radians)	1.5	3.0	4.0	5.5	3.9
t_0 **	(days)	4.17	20.62	2.31	37.42	168.49
M_0	(radians)	2.6	3.2	5.8	0.5	1.6
K	(m/sec)	0.64	0.75	0.59	0.58	0.58

Instrument Sensitivities

$\sigma_{J,1}$	(HIRES)	(m/sec)	2.14
$\sigma_{J,2}$	(AAPS)	(m/sec)	2.13
$\sigma_{J,3}$	(HARPS)	(m/sec)	1.06

* **M_{PL} sin i (inclination to perpendicular to line of sight)**

** ω - argument of periastron, **t_0** - time of periastron, **M_0** - Mean Anomaly,

(Continued from page 20)

Echelle Spectrograph (UCLES) to obtain the few meter per second measurement precision in radial (line-of-sight) velocities of stars, i.e., the necessary minimum to detect the reflex stellar Doppler motion induced by the presence of a terrestrial mass planet.

The HARPS high accuracy radial velocity planet searcher is attached to the 3.6 meter European Space Observatory, located in the high deserts at La Silla, Chile. Since October of 2012, it has built to a capability of detecting a 0.96 meter second variation in visible spectral lines, perhaps currently the best such instrument on earth or in space.

Rolling Averages and Spectral Lines

As reported in an earlier Horizons, radial velocity measurement detection of planets is hindered by background noise from both instrumentation and stellar targets. Tuomi and the rest of the team, in targeting Tau Ceti were not so much intent on discovering planets as they were in isolating and modeling the jitter effects surrounding the planetary search process. Sifting through the three observatories cumulative measurements and comparing them, their statistical processing did much to clear away the noise. If polluting sonic frequencies can be erased by countering noise 180 degrees out of phase, then much the same can be done with light noise. In examining the sources of noise, it was necessary as well to adjust the filters with time for effects such as natural stellar overtones on other cycles. But when all of these measures were taken, the researchers were startled to find remaining Keplerian motions that had not been identified before.

Much of the argument in behalf of the detections is based on Bayesian statistics and “posterior distribution” parameters. As others have observed, some of these techniques have been used to significant effect by mathematicians and physicists working on Wall Street, the tools of the trade for “quants.” For a non-statistician, such as this reporter, “a priori” sounds more familiar than probability measures “posterior;” and the qualifier “Bayesian” often leaves one with dread. So, what can be said about this? Perhaps a simple situation comparison helps.

I have two coins with heads and tails, and then also I have two keys: one to an office building and then one to my office within. The keys are each difficult to distinguish from each other, especially in the dark. But the point is that likelihood of calling heads and tails with the two coins will have a different distribution than the likelihood of selecting the second key to the office door. This is because there are different underlying assumptions. Even if the wrong key is selected for the office building, the likelihood of selecting the right key for the second door is very high – unless one misplaces the keys all over again in the hallway dark.

Now what if the keys are not held in one’s right and left hand, eliminating uncertainty about which key was first used? And then what happens if the keys are dropped and the background light is adjusted down to a threshold where murk affects things much the same as full darkness? The certainty about

(Continued on page 22)

Exoplanets

(Continued from page 21)

which key is correct for the second lock is altered accordingly.

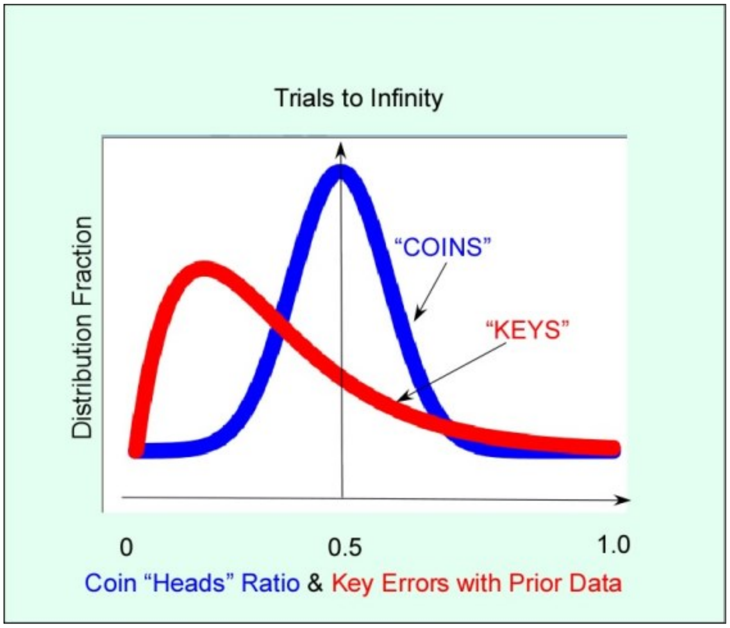

Figure 2. Altered distribution of results based on knowledge of keys vs. coins.

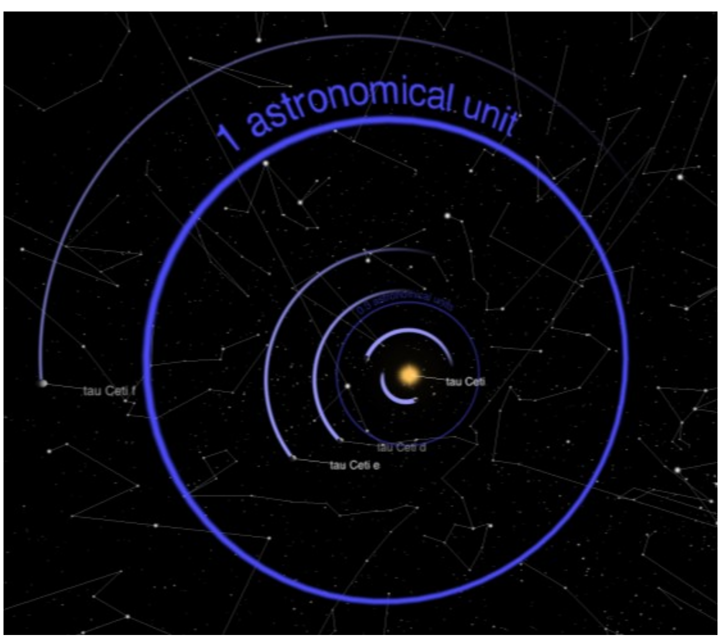

Figure 3. τ Ceti system of planets derived from radial velocity measurements showing that between planets "e" and "f" there exists a large gap.

And now suppose we have a hundred coins that we flip and a hundred embedded door and safe locks that generate heads or tails and yes or no decisions respectively. The statistics of the hundred coins with each successive trial will generate a distribution of results that will spread symmetrically about a 50-50 distribution of heads and tails. But the replay of the lock and key distribution will alter from these statistics as knowledge assumptions about the successive lock and key operations are changed, as Figure 2 suggests. Now suppose that beside a sequence of doors and safes to lock in dim light, one is also wearing night goggles sensitive to light within certain wavelengths and the system experiences jitter…

The point here is that knowledge about seemingly random processes surrounding stars and instrumentation is not entirely without clues to their nature – and that these processes can be modeled enough to clear away much fog.

Yet what is striking about the reported result is that if the values of K in Table 3 are considered as velocity magnitudes for the planet induced cyclic motions of Tau Ceti, all the values are well below the nominal sensitivities of the three instrument detection systems. Curious about Bayesian statistics and Markov chains now?

Planets as a Function of Inclination – And Then Density

Paradoxically, the best angle to get a reading on the orbital velocities of Saturn's rings is when they are hardly visible at all – when they are observed on edge. Then again, if the rings were observed from a surface normal, then no normal radial velocities could be obtained from their light. Yet although the Tau Ceti planets and their orbital plane might be invisible, the stellar spectral line shifts that they cause can be observed even if the line of sight to the star is parallel to the plane. In that case, with each orbit there would be two points at which non-radial velocities would be reduced to zero with each circular orbit. Using the convention of "inclination" adopted by astronomers for studying binary stars, zero inclination is observation of the system perpendicular to its plane. Hence, inclination of 90 degrees would be observation "edge on." If this can be demonstrated by transit events (such as observed with the Kepler observatory), then there is no uncertainty in mass due to inclination uncertainty and mass is well pinned down.

But if inclination is unknown and a mass is derived from the apparent Doppler shifts of the star due to radial velocity variations, actual planetary mass would vary as a function $M = M_0/\cos(i)$, where i is an inclination between 0 and 90^o. For "line of sight offsets" of 45 to 60^o, the mass increases by 40 and 100%, of course, as Figure 4 indicates. Consequently, if a nearly earth like planet has a density much like Earth's (~5 gm/cm3), then we could also derive changes in diameter with mass as well as differences in surface gravity. Venus, Earth and Mercury have similar densities; but yet the Moon and Mars have densities closer to 3/5 that of these terrestrial planets. Do we know whether these planets would have either density? No, not yet, but we can show

(Continued on page 23)

(Continued from page 22)

the effect of reduced density on radius and surface gravity (Figs. 5 and 6). Reasons for reduced density might include less iron relative to silicon – or more water condensation in formation. But depending on the surface albedo, greenhouse effects and location within the presumed habitable zone, low density could solve the high gravity problem in the event of human visitation, but there would remain an issue of whether the resulting planets would resemble Neptune or Venus more than the Earth with thick blankets of atmosphere merging into bottomless seas.

Habitability

Of course, we assume for starters that the Earth is inhabitable, but comparative interstellar planetology requires examining many stellar and planetary characteristics to mount a case for habitability elsewhere – and the data is not necessarily all there. To start with, thermal flux from Tau Ceti or another star must be calibrated with the sun before considering how that thermal flux is absorbed or reflected back into space by a planet we will eventually have to describe as well. Considering that total flux from a stellar spherical surface remains constant between its surface radius ($4 \pi R_{SURF}^2$) and the orbital radius of the planet, then we know that effective temperatures in space decrease with distance. That is, luminosity is constant.

$$L^* = \sigma 4 \pi R_{SURF}^2 T_{EFF}^4 = \sigma 4 \pi R_{PL}^2 T(R_{PL})^4$$

Allowing for some round-off or measurement uncertainties, and starting with the Earth-Sun relationship, the 700,000 km radius sun with a 5800° Kelvin surface temperature (T_{EFF}) would diffuse to a temperature of about 400 ° K at Earth's orbital radius of 1 AU (149.95 million km).

$$T(R_{PL}) = (R_{PL}/R_{SURF})^{0.5} T_{EFF} = 396.7^oK$$

Since Mars (R=1.52) and Venus (R=.67 AU) might provide rough bounds for habitability if their surface and atmospheric reflectances were tuned rather well to sustain near room temperature (300° K) conditions in the temperate zones, as with the Earth, then control volume temperatures at those regions would be rough bounds for the solar system's habitability belt. The cooler, smaller and therefore less luminous (0.488) Tau

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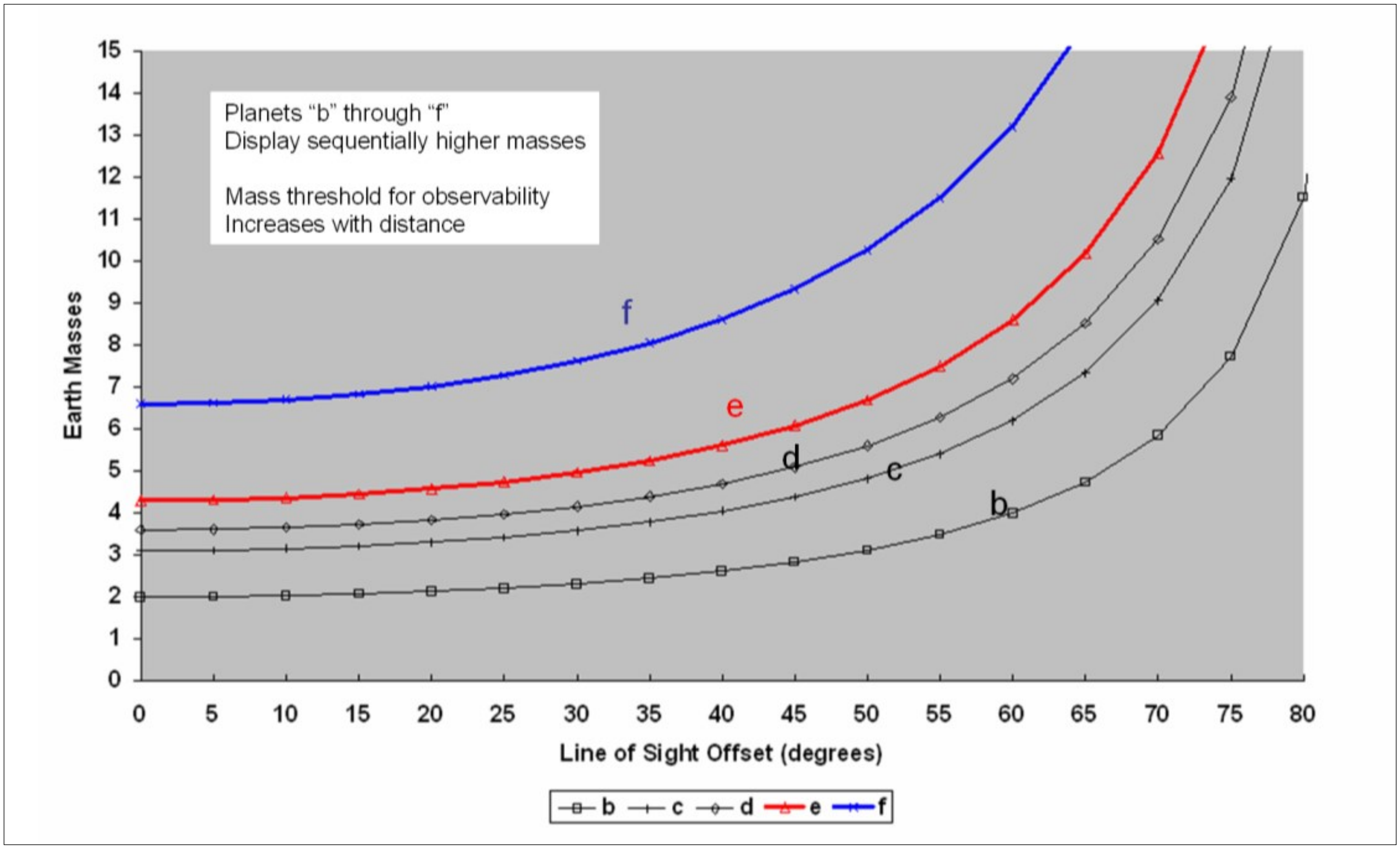

Figure 4. Tau Ceti planets b through f – mass as a function of inclination from line of sight.

Exoplanets

(Continued from page 23)

Ceti produces the same temperature at a radius of about 0.698 AU. The "Venus-Mars" bounds can be redrawn for Tau Ceti accordingly as 0.48 and 1.06 AU the limits of habitability.

So, do we have any possibility of winners? The planets "e" and "f" are located at orbital distances (semimajor axes) of 0.552 and 1.35 respectively (illustrated in Fig. 3). By the rules described so far, "e" would qualify as a habitable planet and "f" at first glance would be considered more hostile than Mars. And yet the prospects in our own solar system for present day "habitability" for Mars are far greater than that of Venus, though perhaps billions of years back, water and earth-like temperatures or atmospheric pressures might once have prevailed on both.

Ignoring the layered equilibrium temperatures of a thick cloud cover or other elaborate heat transport mechanisms, the planetary surface reflectance (inverse: albedo) would give us an estimate of how much of that stellar flux is radiated back into space. Greenhouse effects near the outer limit would be more supportive for the case of habitability there.

Then there might still be an as yet undetected planet between "e" and "f" with a mass more near that of Earth's. Our calculations of spheres of influence with increase of planetary mass do not rule this out. Examining spacing (.105, .195, .374, .552, 1.35 AUs), mass (2.6, 3.0, 5.8, 4.3, 6.6) and period (13.95, 35.36, 94.11, 168.12, 642 days), there is no obvious reason there should not be a planet or two between detected "e" and "f." And habitable or not, observing the other planets from that point in the mid habitable zone would be spectacular in comparison to events in our system's ecliptic plane.

Wrap Up

Just last August this writer had the occasion to see the Discovery Channel video Alien Planet which described a visit to a nearby extrasolar planet by a future robotic spacecraft. Many of the features of the story seemed to suggest they were describing Tau Ceti, or a similar nearby star.

I believe the destination star was fictional. But had the writers and contributing scientists known!

References and Figure 6

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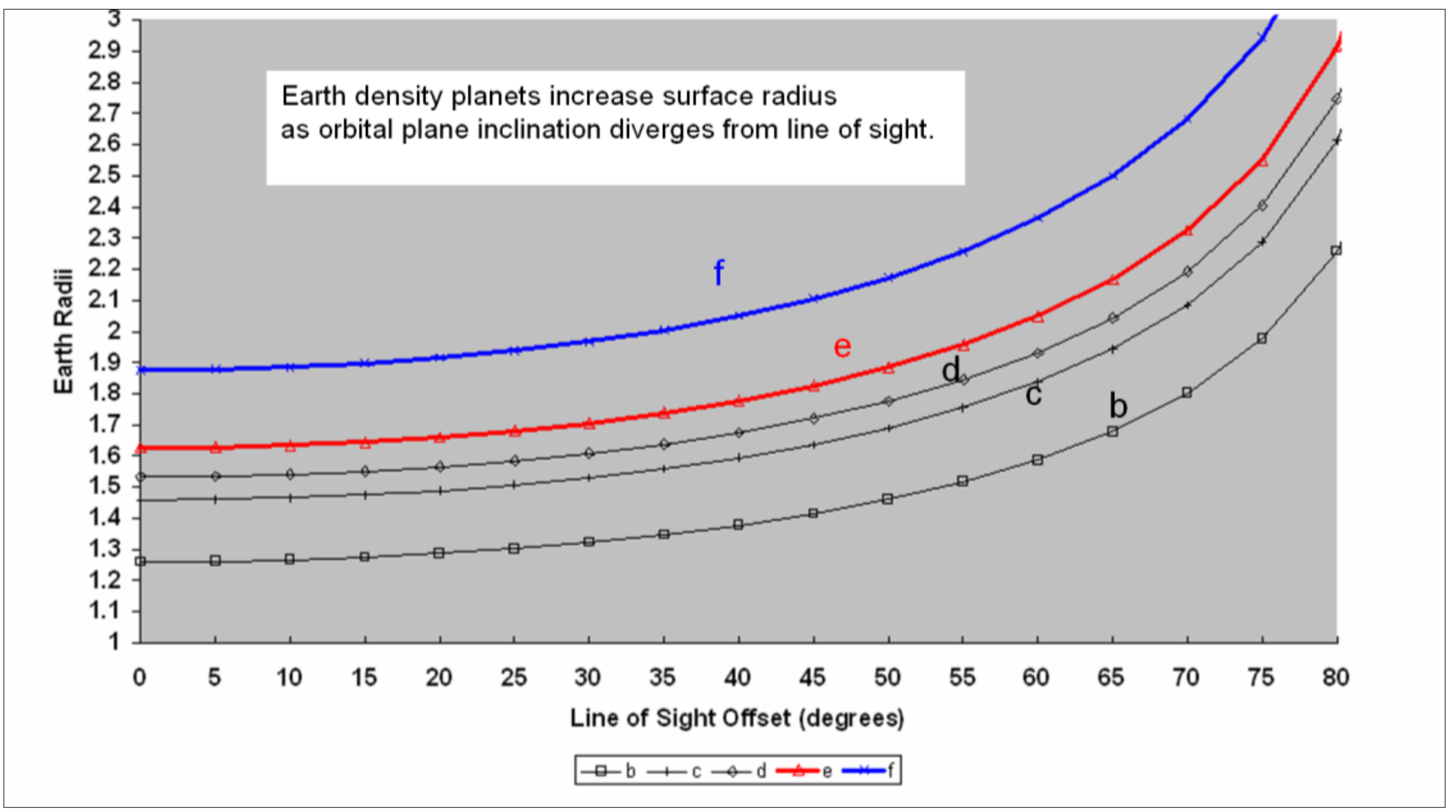

Figure 5. Tau Ceti planets surface radii assuming Earth density & inclination effect.

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References and Links

http://www.centauri-dreams.org/?p=25935#comments

Signals embedded in the radial velocity noise

Periodic variations in the τ Ceti velocities

http://star-www.herts.ac.uk/~hraj/tauceti/paper.pdf

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http://aas.org
Abstracts for the 221st meeting are no longer available on line, but this sight provides information about coming astronomical conferences and astronomical news.

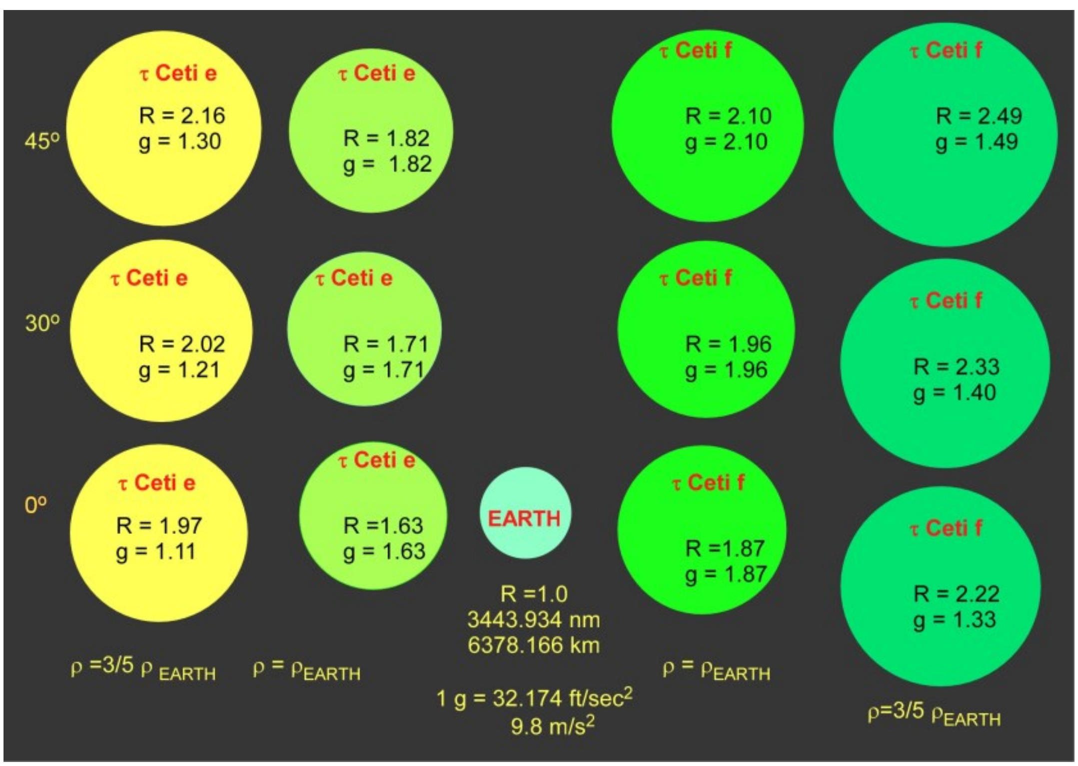

Figure 6. τ Ceti planets "e" and "f": surface radii & gravity for nominal & "3/5" densities mass calculations for 0°, 30° and 45° inclinations of orbital plane to line of sight.