Searching for TechnoSignatures in Astronomical Data

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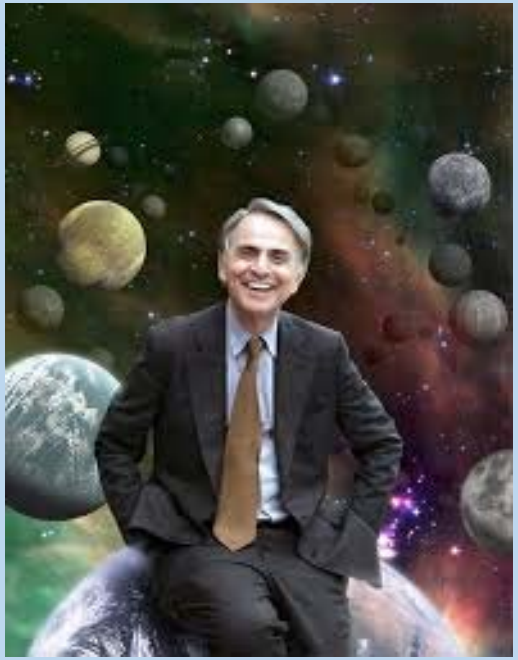
Sept 26, 2018

The Scientific Challenge of TechnoSignatures

David Hume (1748) “No testimony is sufficient to establish a miracle, unless the testimony be of such a kind, that its falsehood would be more miraculous than the fact which it endeavors to establish.”

Pierre Simon Laplace (1812): “The weight of evidence for an extra-ordinary claim must be proportioned to its strangeness.”



Carl Sagan: “Extraordinary claims require extraordinary evidence.”

Role of Astronomy and Astrophysics in the Search for TechnoSignatures

Astronomy

- Explore large areas of the sky, large volumes of space, and large numbers of objects "to **explore strange new worlds**, to seek out **new** life and **new** civilizations, to boldly go where no [astronomer] has gone before."
- Open new observational windows with orders of magnitude improvements in sensitivity and areal coverage
  - Electromagnetic (High Energy, UV-Optical, IR, radio)
  - Particles
  - Gravitational wave
- Open new instrumental capabilities:
  - Time domain (rapid cadence and long duration)
  - High precision photometry and spectroscopy
  - High precision astrometry
- Use data mining to identify anomalous objects

Astrophysics

- Use multi-wavelength pointed observations (spectroscopy!) to follow-up on anomalies (aka discoveries) to validate their reality and to understand their nature, number, and significance
- Use (astro-)physical theory to reveal the processes which might underlie the detailed properties of the object
- Use statistical properties of the sample and Occam's razor to assess the likelihood of various hypotheses as to nature of the phenomena

TechnoSignatures vs. Astrophysical Signatures

"Once is happenstance.

Twice is coincidence.

Three times is enemy action."

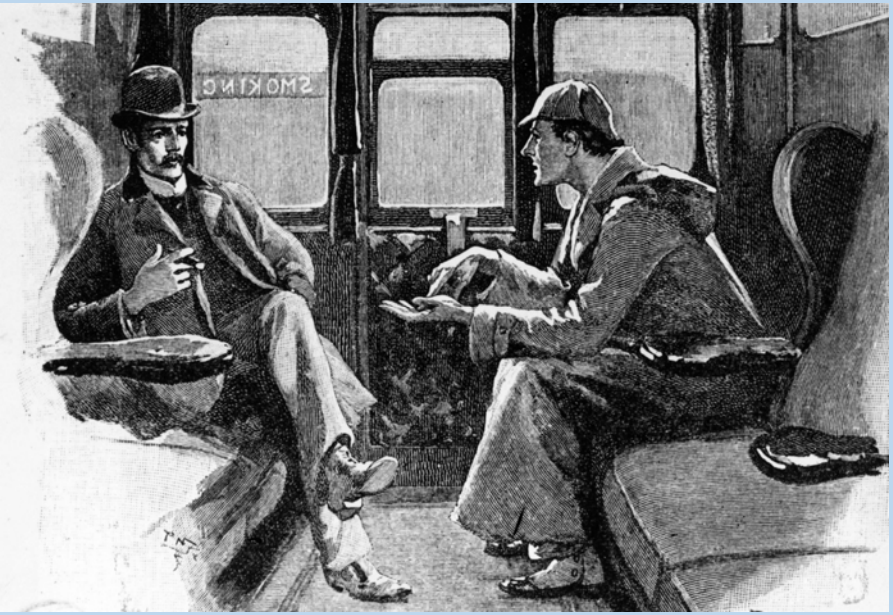
Ian Fleming (Goldfinger)

"Once is a possible TechnoSignature.

Twice is coincidence.

Three times is an astrophysical phenomenon."

Draw Your Conclusions: Astrophysics or TechnoSignature



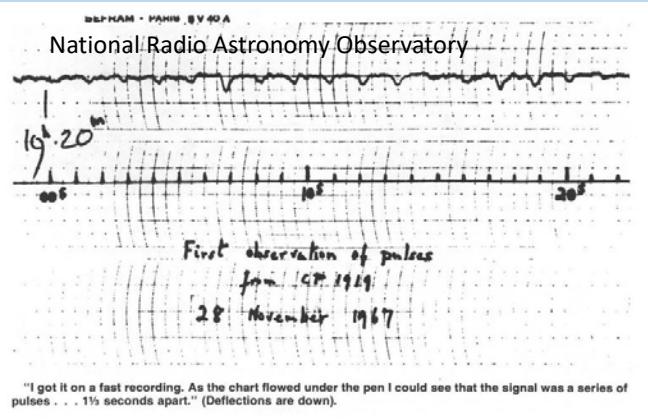
"Once you eliminate the impossible, whatever remains, no matter how improbable, must be the truth."

--- Sherlock Holmes

Radio Astronomers Discover LGM-1

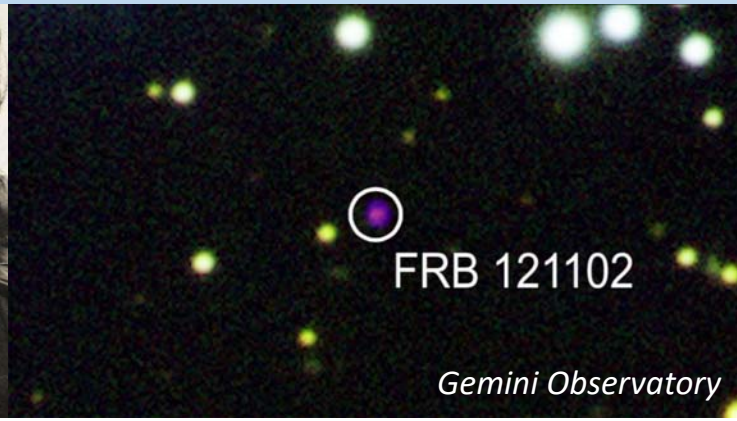
- First pulsar discovered by Jocelyn Bell and Tony Hewish (1967) was dubbed LGM-1 (Little Green Men)
- Then another pulsar was discovered and then another…
- A potential civilization became an astronomical phenomenon --- the neutron star remnant of a supernova explosion

- Fast Radio Bursts (FRBs) are a recent cosmic mystery. First discovered in 2007, they are bursts of radio waves lasting only a few milliseconds
- Nearly 40 FRBs are now known and one, FRB 121102 ,has now been associated with a distant galaxy (Chatterjee et al 2017). Neutron star orbiting a black hole or ???



"I got it on a fast recording. As the chart flowed under the pen I could see that the signal was a series of pulses . . . 1½ seconds apart." (Deflections are down).

Daily Herald Archive/SSPL/Getty Images



Gemini Observatory

The Gamma Ray Sky

- Vela satellites designed to search for nuclear tests (on Earth or behind Moon)
- In 1973 Klebesadel et al announced detection of 16 gamma-ray bursts observed by Vela satellites 1969-1972.
- Timing measurements ruled out solar or terrestrial origin, but otherwise unknown physical processes: stars, galaxies, black holes, or technosignature?

EXPRESS

Alien life BOMBSHELL: SETI institute makes MAJOR announcement

WWE news: Ronda Rousey sends message to Stephanie McMahon

Avengers Infinity War director finally reveals REAL REASON Bruce...

MERKEL CLINGS ON: Germany strikes deal with Greece to send back...

Cristiano Ronaldo: Juventus star reveals rea reason for leaving...

Gamma ray bursts are 'messages sent from ALIENS'

GAMMA ray bursts are actually alien signals sent out by extraterrestrials in an attempt to make contact with life elsewhere in the universe, a astronomer has sensationally claimed.

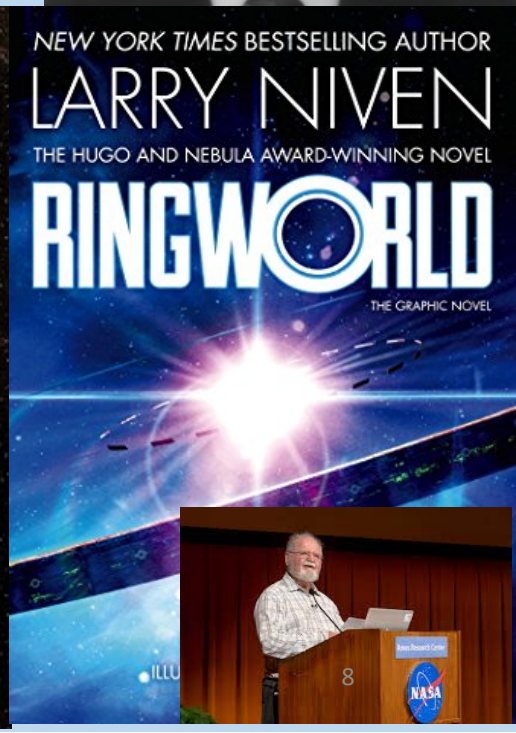
https://www.express.co.uk/news/science/905602/aliens-message-extraterrestrial-gamma-ray-bursts-GRB

Sixteen short bursts of photons in the energy range
1969 July and 1972 July using widely separated spacecr
0.1 s to ~30 s, and time-integrated flux densities from
cm^{-2} in the energy range given. Significant time structu
information eliminates the Earth and Sun as sources.

Astronomers Discover Kardashev Class II Civilizations?

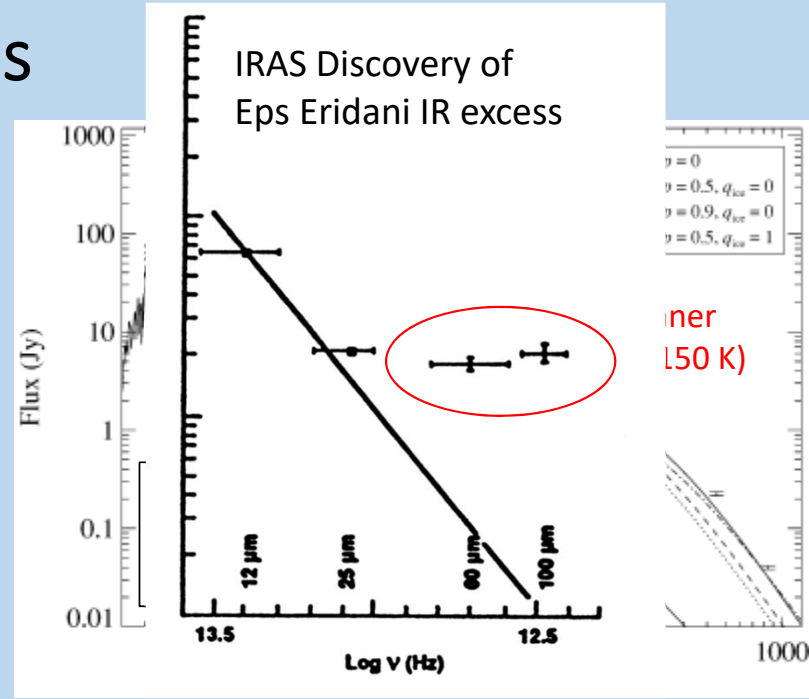
- Class II Civilizations capture the energy of its host star
- Dyson Sphere would capture star radiation with waste heat appearing in infrared
- Incomplete Dyson Spheres or Ring Worlds would capture a fraction of stellar luminosity yielding combination of stellar and IR excess emission

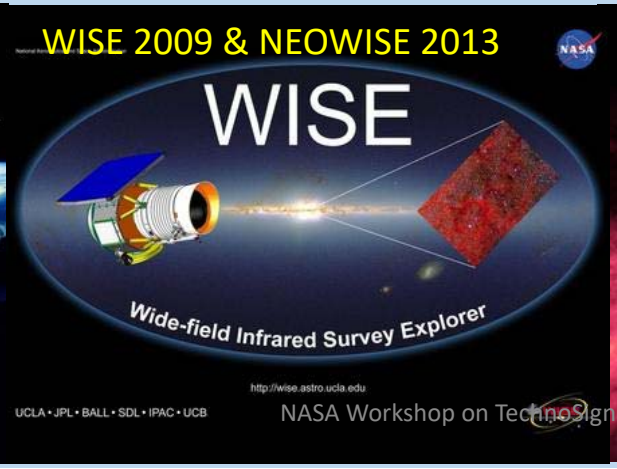
https://www.sciencenews.org/article/combat-expanding-universe-aliens-could-hoard-stars



Searches for Dyson Spheres & Ring Worlds

- Constructing a Dyson Sphere or Ring World outside of the Habitable Zone would result in 200-400 K blackbody plus leakage of escaping stellar light
- This is the domain all sky IR surveys (1983 onward)
  - IRAS (12-100 μm: 245,889 sources)
  - WISE (3.4, 4.6, 12 and 22 μm: 747,634,026 sources and 42,759,337,365 individual measurements)
- Targeted surveys: and follow-up: Spitzer (5-160 μm), Herschel (55-670 μm), ALMA, SOFIA





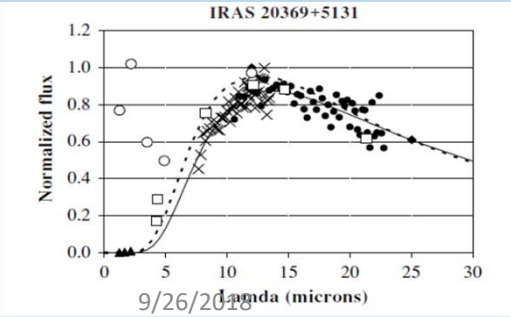
IRAS, Spitzer and WISE Identified Thousands of Potential Dyson Spheres and Ring Worlds

Dyson Sphere Candidates

- Large number of stars showing cold blackbody emission with little or no hot stellar emission
- Carrigan (2009) identified in IRAS/LRS spectra
- **Astrophysical explanations based on radio and other data→ mass-losing giant stars returning enriched material into ISM**

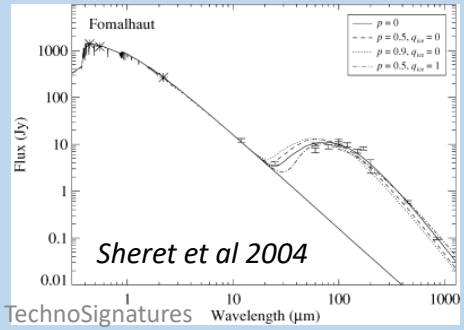
Ring World Candidates

- IRAS, WISE, Spitzer and direct imaging have revealed hundreds of "debris" disks orbiting nearby bright stars, often with rings/gaps associated planets (Meshkat et al 2019)
- **Astrophysical explanations invoke remnant dust in cold Kuiper Belts and warm asteroid belt analogs**

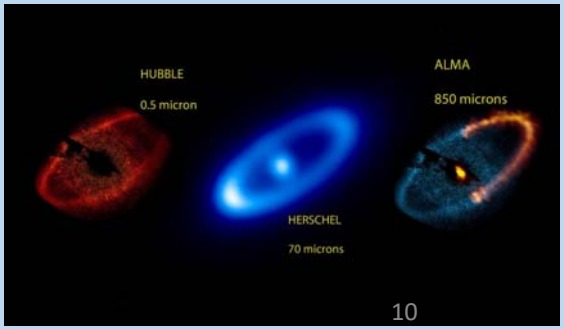


Carrigan ,ApJ,698, 2009

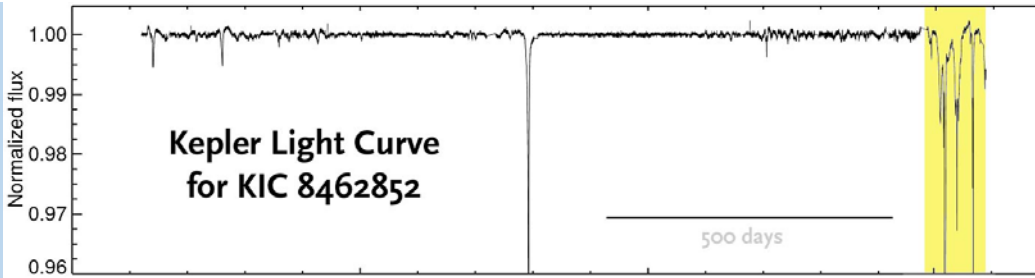
Selection	Sources
IRAS sample	245,889
Calgary LRS sample	11,224
FQUAL(12), FQUAL(25)>1	10,982
100 K ⩽ Temperature ⩽ 600 K	6521
Selecting C[a], F, H[b], P[b], U	2240
IDTYPE = 0, 2, 3, 4	1527
Possible sources by direct scan	295
-Line(166),classif(40),T(14),H(9),nonplnck(1)	65
Statistical uncertainty < 0.25	22
Somewhat interesting sources	16
Most interesting but with questions	3



Sheret et al 2004



Kepler's High Precision, Time Domain Astronomy



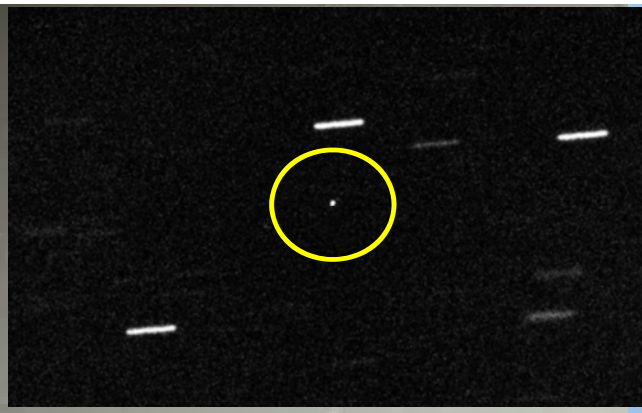
- Citizen scientists using Kepler found anomalous dimming pattern of Tabby's Star (20% in 5 years) and more over a decade from ground archives
- Numerous explanations included in-falling comets and *alien megastructures*
- Multicolor observations suggest orbiting clumps of small dust grains

Tabetha Boyajian

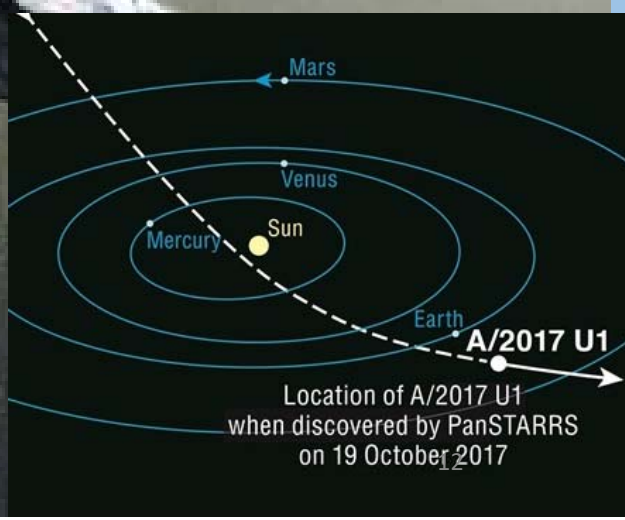
NASA

Marc Ward/Stocktrek Images/Getty Images

Physical Artifacts from Technological Civilizations

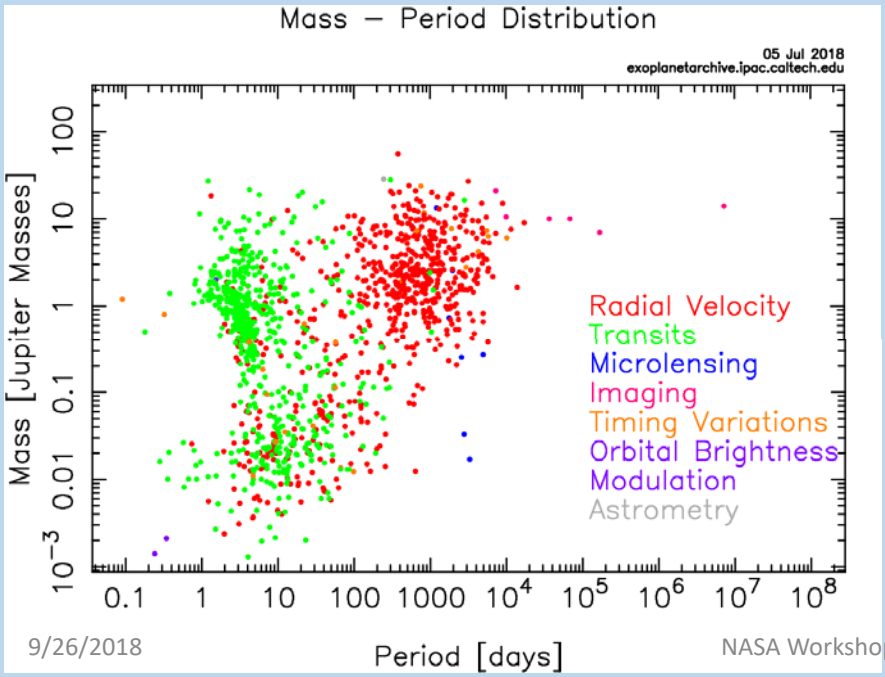


- In October 2017 PanSTARRS identified ‘Oumuamua (1I/2017 U1) as an interstellar comet, 230x35 m in size.
- Not associated with any nearby star or planetary system (Mamajek 2017)
- Radio telescope limits to transmitted power (Enriquez et al 2018)
- Deep, intensive optical and IR sky surveys (LSST, ZTF, PanSTARRS, NEOCAM) might find a few objects like this per year, but proving a technological origin will be challenging



Astronomy's Most Obvious Role: Where to look for TechnoSignatures

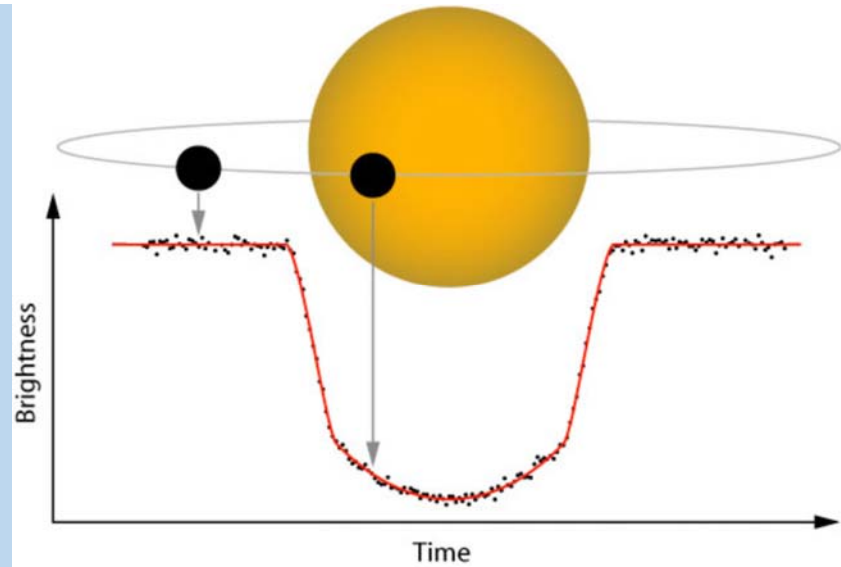
- About 30% of FGK stars have 1 or more Kepler-like planets (R>1 $R_{\oplus}$, P<400 d; Zhu et al 2018). Multiple systems are common
- M stars have ≥1 planet with 25% being Habitable Zone Rocky planets (Dressing and Charbonneau 2015)

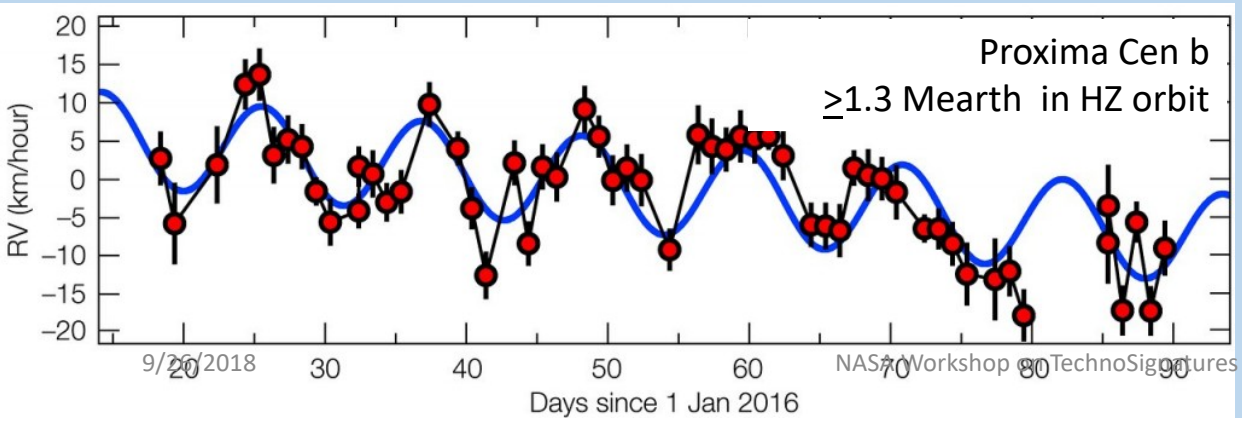


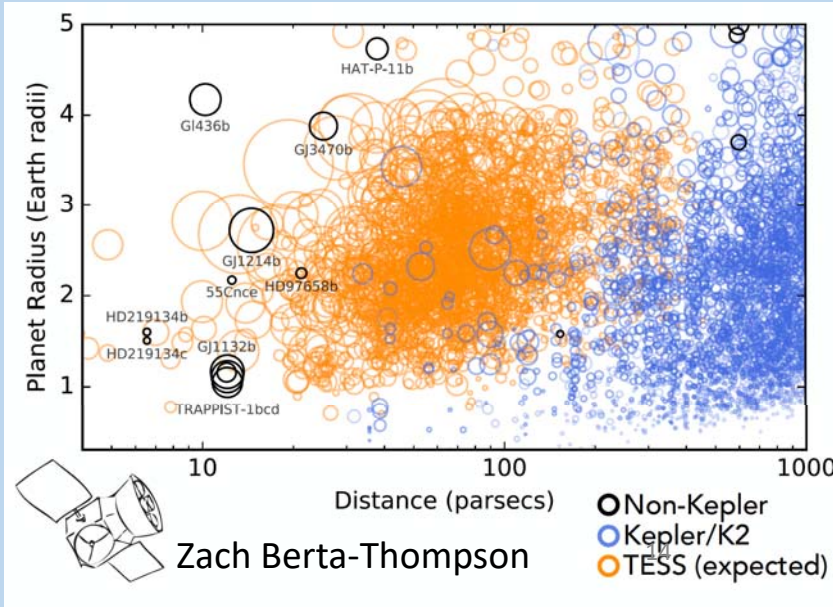
All Exoplanets	**3748**
Radial Velocity	674
Imaging	44
Transiting *	2927
Kepler Confirmed	2344
Habitable Zone (HZ)	
(180 K < Teq < 310 K)	290
HZ & R ≤ 1.25 R_{Earth}	22
Kepler Candidates	4496
Transit Timing	15
Microlensing	64
Astrometry**	1

Finding the Closest Habitable Planets

- TESS will find thousands of **transiting** planets orbiting **nearby** (few 10s of parsec) stars, including a few Earth-sized planets orbiting in the habitable zones of their host stars. These will be targets for JWST spectroscopy and searches for TechnoSignatures
- But only 1-10% of HZ planets are aligned well enough to transit their host star. The remainder must be identified by other means --- **precision radial velocity** (PRV)







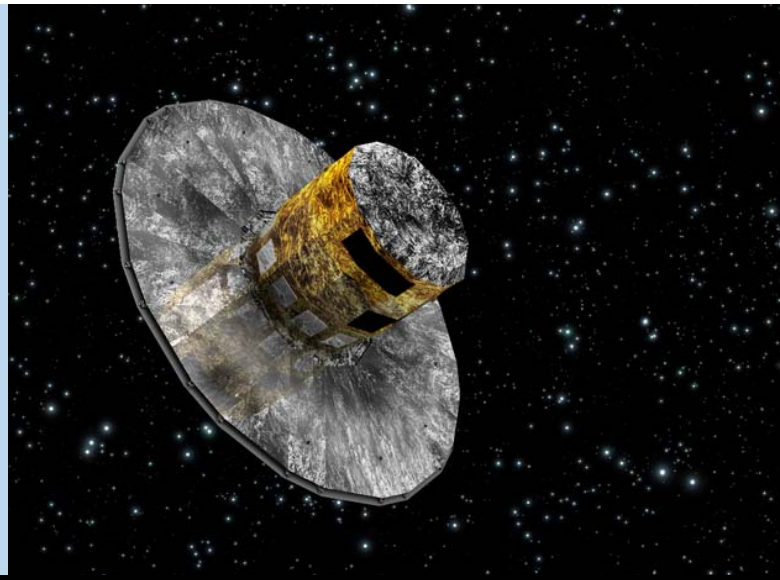
Zach Berta-Thompson

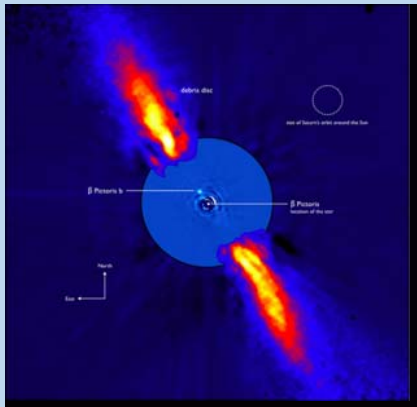
Trappist-1: Nearby System of Earth-like planets

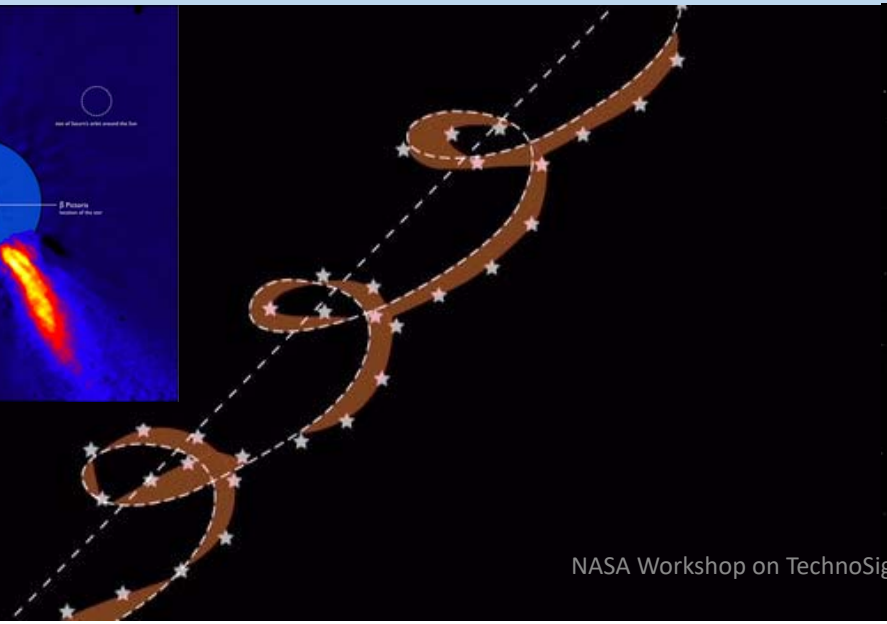
- A ground-based transit survey and the Spitzer Space Telescope found 7 planets orbiting a nearby M star only 13 pc away
- All are rocky worlds roughly the size and mass of Earth with ~3 in the habitable zone
- Trappist-1 targeted for SETI searches

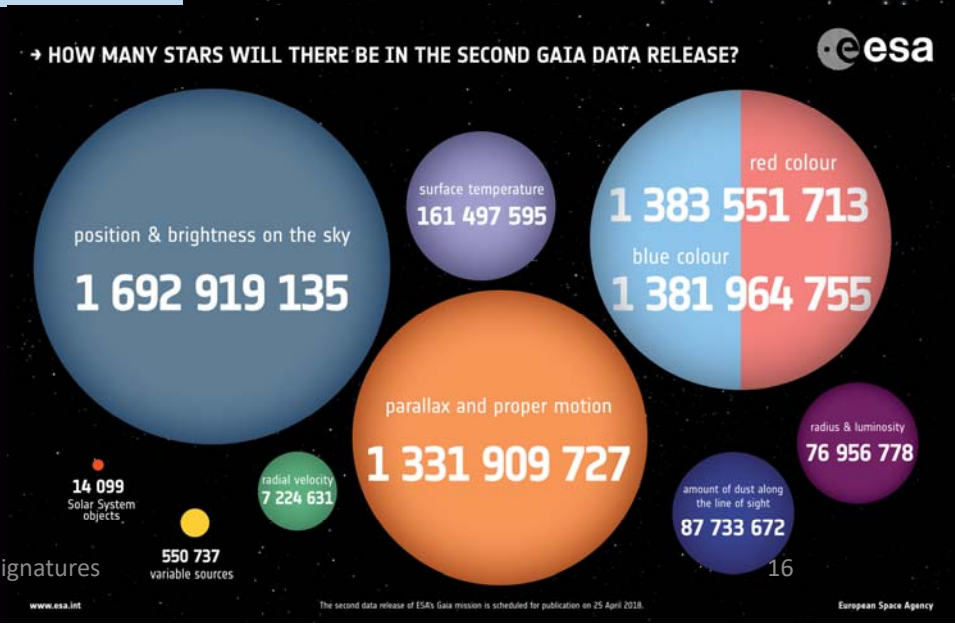
Distances, Time Series Photometry and Stellar Properties

- ESA's Gaia spacecraft measuring the properties of over 1 billion stars with 50-100 measurements of each star
- Astrometry to identify 10,000 new exoplanetary systems
- Already detected astrometric signature of beta Pic's planet (11±2 M_{jup})







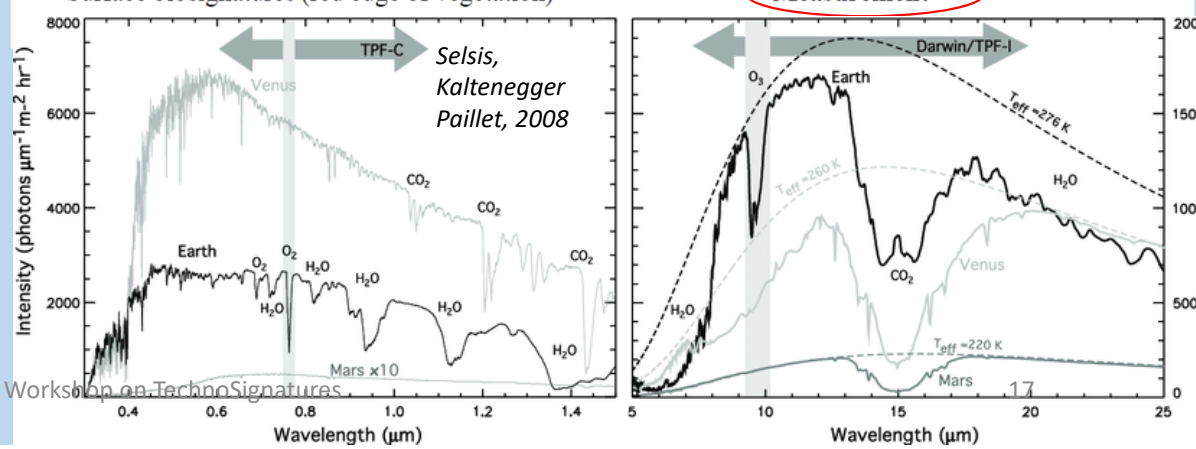


Searching for Habitability and Signs of Life

- Total planetary context defines a habitable environment: mass, radius, density, orbit stability, equilibrium temperature, solid surface, plate tectonics
  - Imaging and spectroscopy from UV to mid-IR for atmospheric properties
  - Dynamical measurements critical
- No single atmospheric signature defines the presence of primitive life --- numerous false positives and false negatives

Beichman, Fridlund, Traub, Stapelfeldt, Quirrenbach, Seager 2006

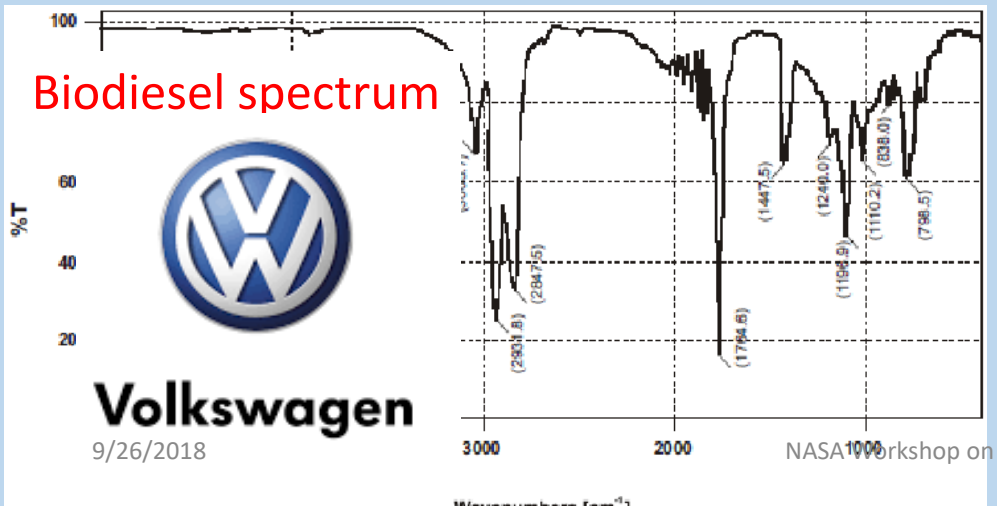
	PRV or Astrometry	HabEx or LUVOIR	TPF-I Darwin
Orbital Parameters			
Stable orbit in habitable zone	**Measurement**	**Measurement**	**Measurement**
Characteristics for Habitability			
Planet temperature	Estimate	Estimate	**Measurement**
Temperature variability due to eccentricity	**Measurement**	**Measurement**	**Measurement**
Planet radius	*Cooperative*	*Cooperative*	**Measurement**
Planet albedo	*Cooperative*	*Cooperative*	*Cooperative*
Planet mass	**Measurement**	Estimate	Estimate
Surface gravity	*Cooperative*	*Cooperative*	*Cooperative*
Atmospheric and surface composition	*Cooperative*	**Measurement**	**Measurement**
Time-variability of composition		**Measurement**	**Measurement**
Presence of water		**Measurement**	**Measurement**
Solar System Characteristics			
Influence of other planets, orbit coplanarity	**Measurement**	Estimate	Estimate
Comets, asteroids, and zodiacal dust		**Measurement**	**Measurement**
Indicators of Life			
Atmospheric biomarkers		**Measurement**	**Measurement**
Surface biosignatures (red edge of vegetation)		**Measurement**	

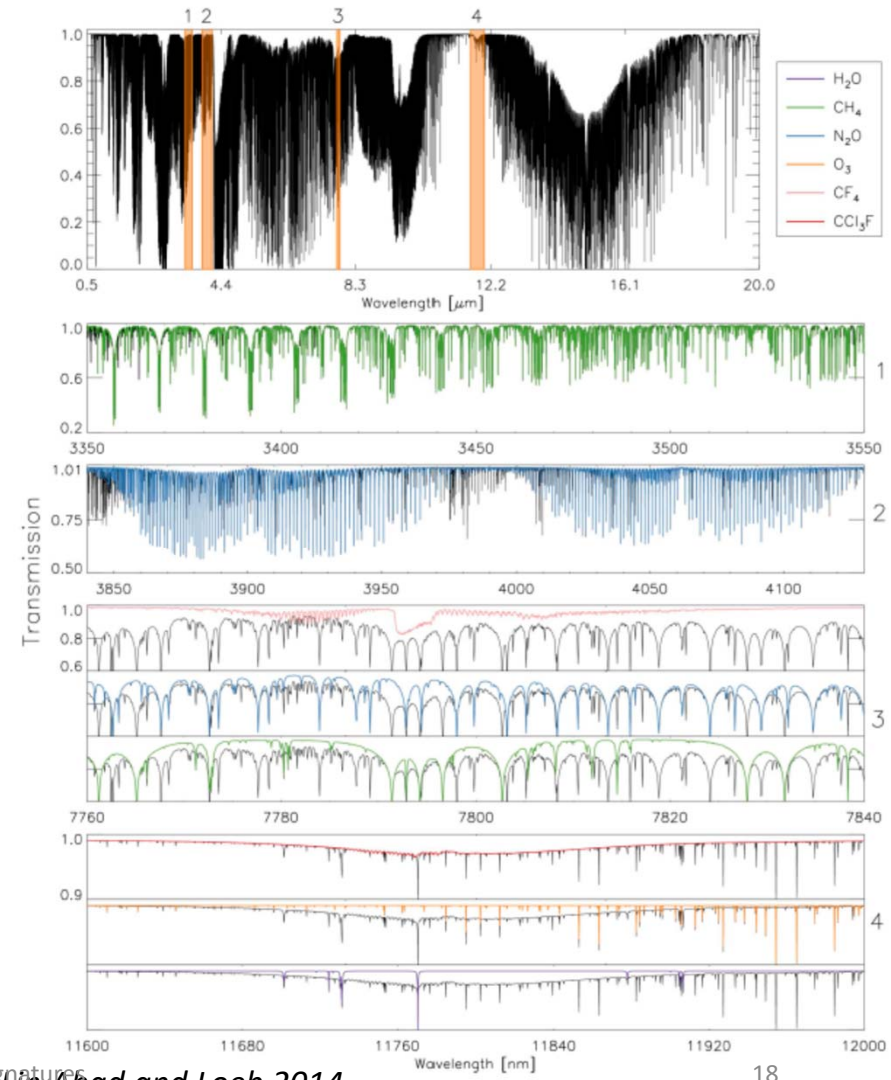


Selsis, Kaltenegger Paillet, 2008

Signs of Advanced Life

- Atmospheric signatures such as CFCs and NOx may be detectable (Lin et al 2014)
  - By JWST in an Earth transiting a white dwarf at 10x present level or by future direct imaging
- Significant challenge to achieve adequate spectral resolution (R~3000) and SNR to disentangle from other features





Lin,Abad and Loeb 2014

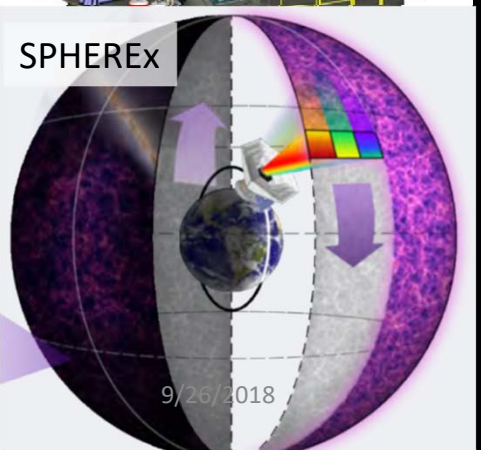
Critical Facilities for Discovery and Follow-up

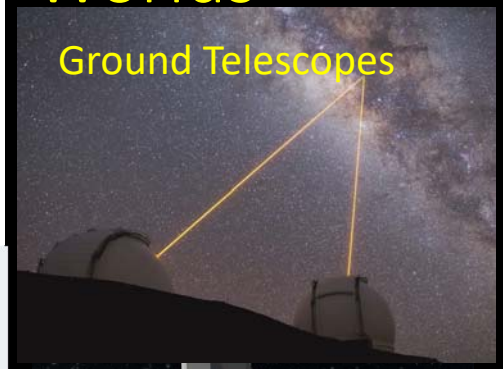
Facility	Wavelength	Domain
Various	Radio	Fast Radio Burst Surveys
IRAS	Mid-farIR	All-sky photometry
WISE/NEOWISE*	Mid-IR	All-sky photometry
NEOCAM*	Mid-IR	All-sky (±45° ecliptic)
SPHERE-X*	Near-IR	All sky IR spectroscopy
Gaia*	Visible	All sky photometry, spectra, astrometry
Pan-STARRS, ZTF, LSST*	Visible	High Cadence, 3~4π sky
TESS, PLATO	Visible	Transit Surveys
SWIFT, FERMI, eROSITA	High Energy	All Sky GRB coverage
EELT, GMST, TMT,	Visible, NIR	Survey M stars for habitable planets
WFIRST/CGI, HabEX, LUVOIR	Visible	Survey 10s to 100s of stars for (habitable) planets

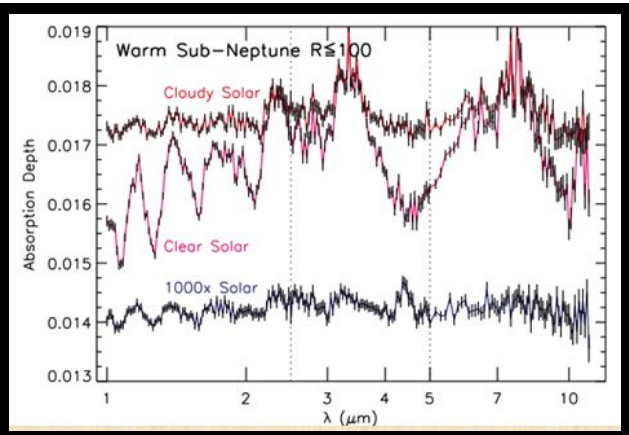
Facility	Wavelength	Domain
VLA, eVLA, ALMA,SKA	Radio, millimeter	Spectroscopy, imaging
IRAS, Spitzer, Herschel, SOFIA	Mid-far IR	Spectroscopy, imaging
JWST, ARIEL	Near-, mid-IR	Spectroscopy, imaging
NEID, other PRV	Visible, NIR	Transit follow-up, nearest RV planets
Keck, VLT, Gemini,	Visible, NIR	Follow-up imaging and spectroscopy
EELT, GMST, TMT,	Visible, NIR	Follow-up imaging and spectroscopy
Chandra/XMM Lynx/Athena	Xray	Spectroscopy, imaging

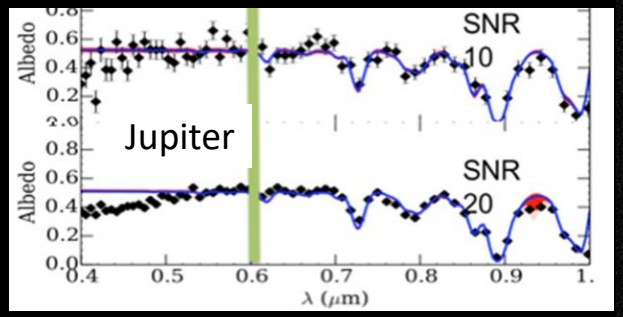
* Over 1 billion objects in survey

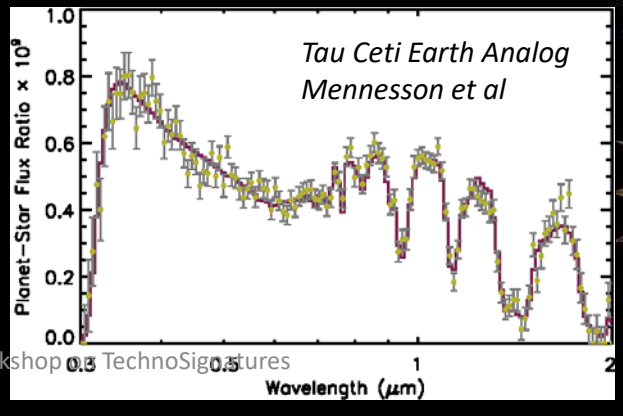
Astronomical Searches for Techno-Signatures and Habitable Worlds



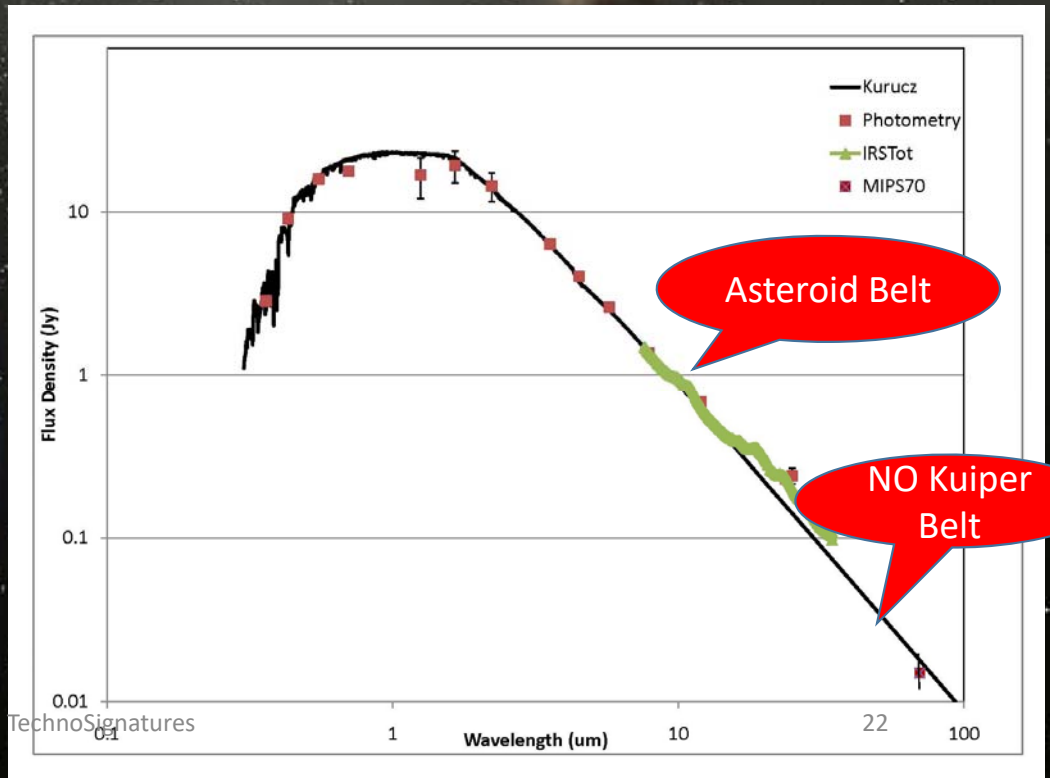








Finding Habitable Worlds

HD 69830: RingWorld Construction Site or A Period of Late Heavy Bombardment?

Nearby (12 pc), mature (2-5 Gyr) bright K0 hosts a massive asteroid belt (1000x our Zodiacal Cloud) and 3 Neptune-sized planets in 0.08, 0.16, 0.63 AU (near Habitable Zone)