Planetary Systems Around Close Binary Stars: the Very Dusty, Sun-like, Spectroscopic Binary BD+20 307

B. Zuckerman (UCLA), A. Weinberger (Carnegie), F. Fekel, G. Henry & M. Williamson (Tenn. State Univ.), M. Muno (Lincoln Lab), C. Marois (HIA), C.Melis & E. Becklin (UCLA), I. Song (Univ. Georgia)

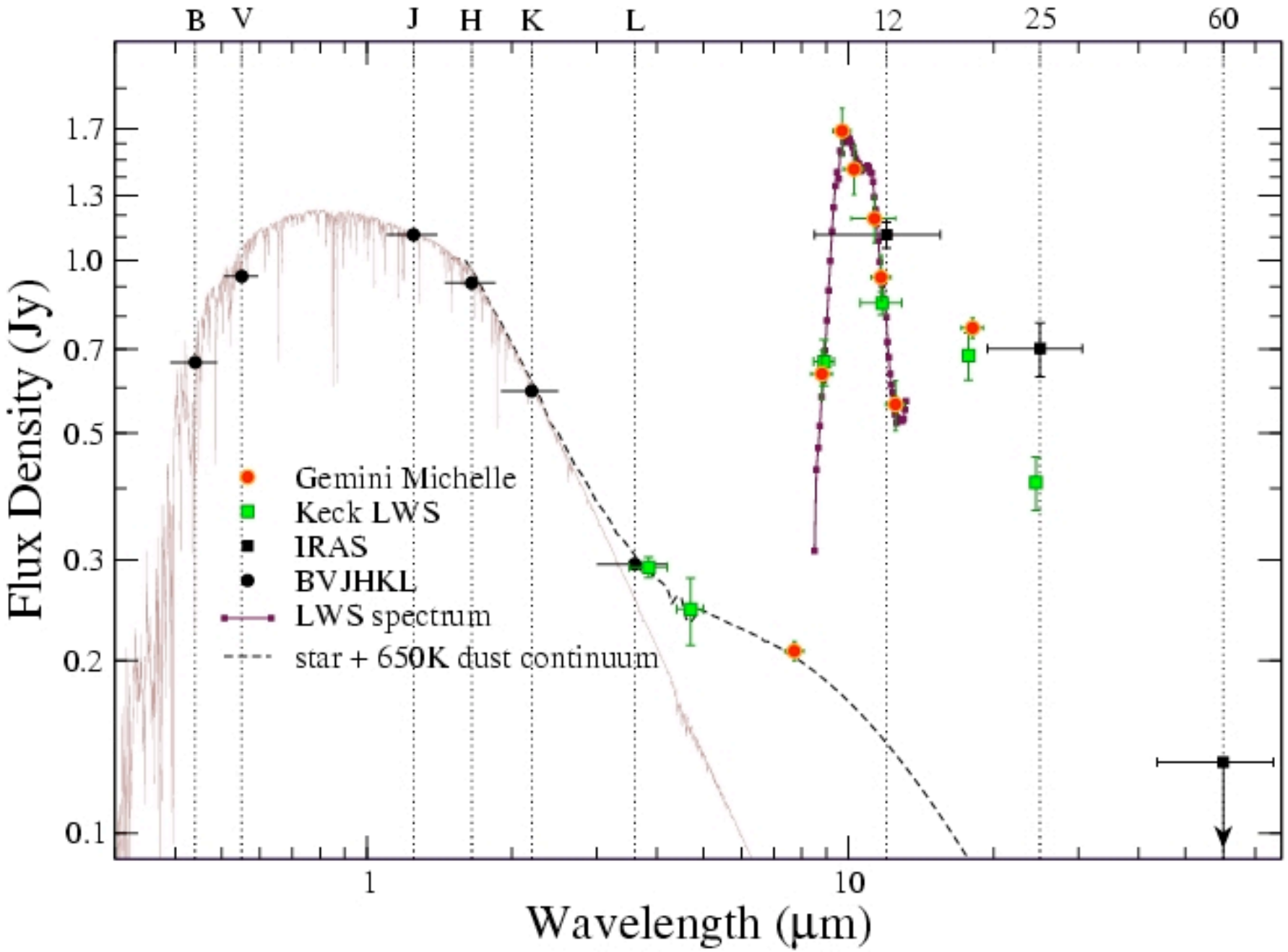
Kuiper Belt vs asteroid belt

The dust at almost all Vega-like stars is sufficiently cold to be orbiting with semi-major axes of 50 AU or more from the central star. Thus, the debris disks are almost always to be considered (young) analogs of the Sun's Kuiper Belt.

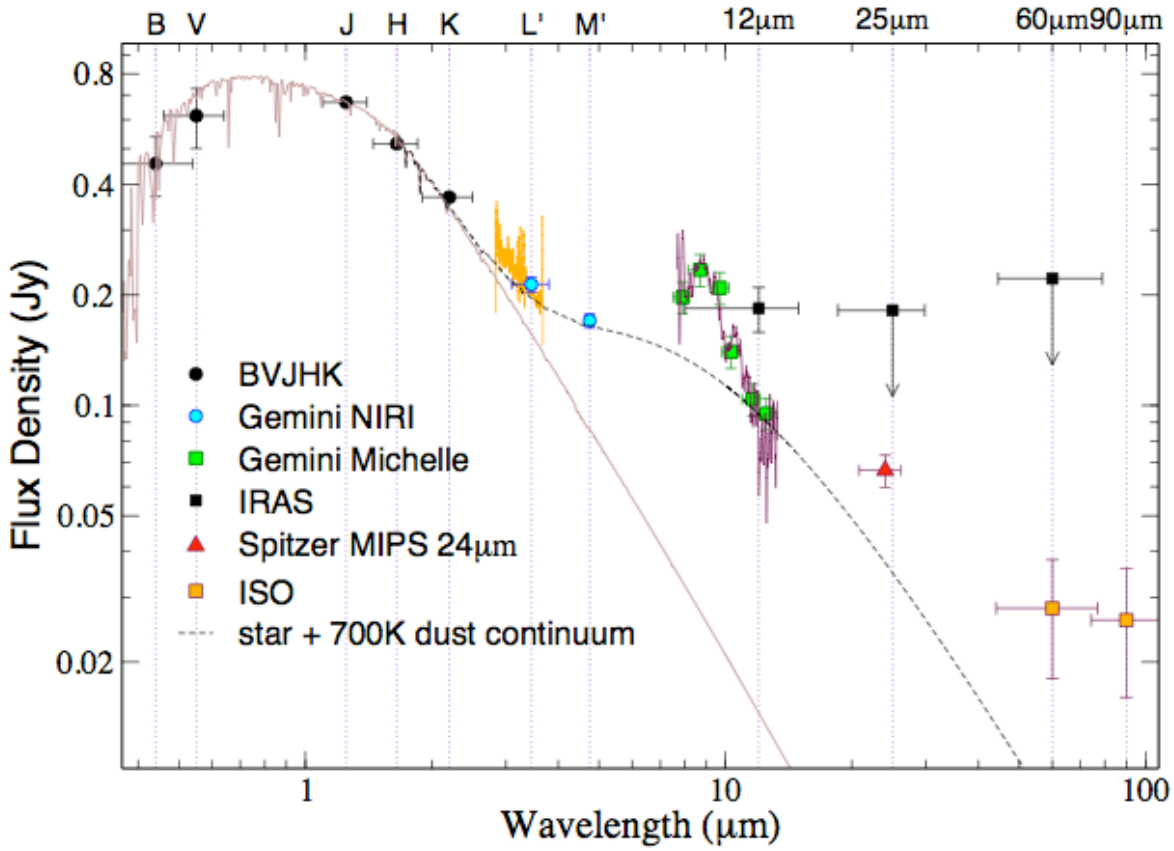
Paucity of warm dust is true even for stars with ages as young as tens of Myr. Thus, dust in the terrestrial region dissipates very quickly.

But consider two notable exceptions…


Two unusually dusty sun-like stars:
HD 23514: Pleiades member
BD+20 307: main sequence field star

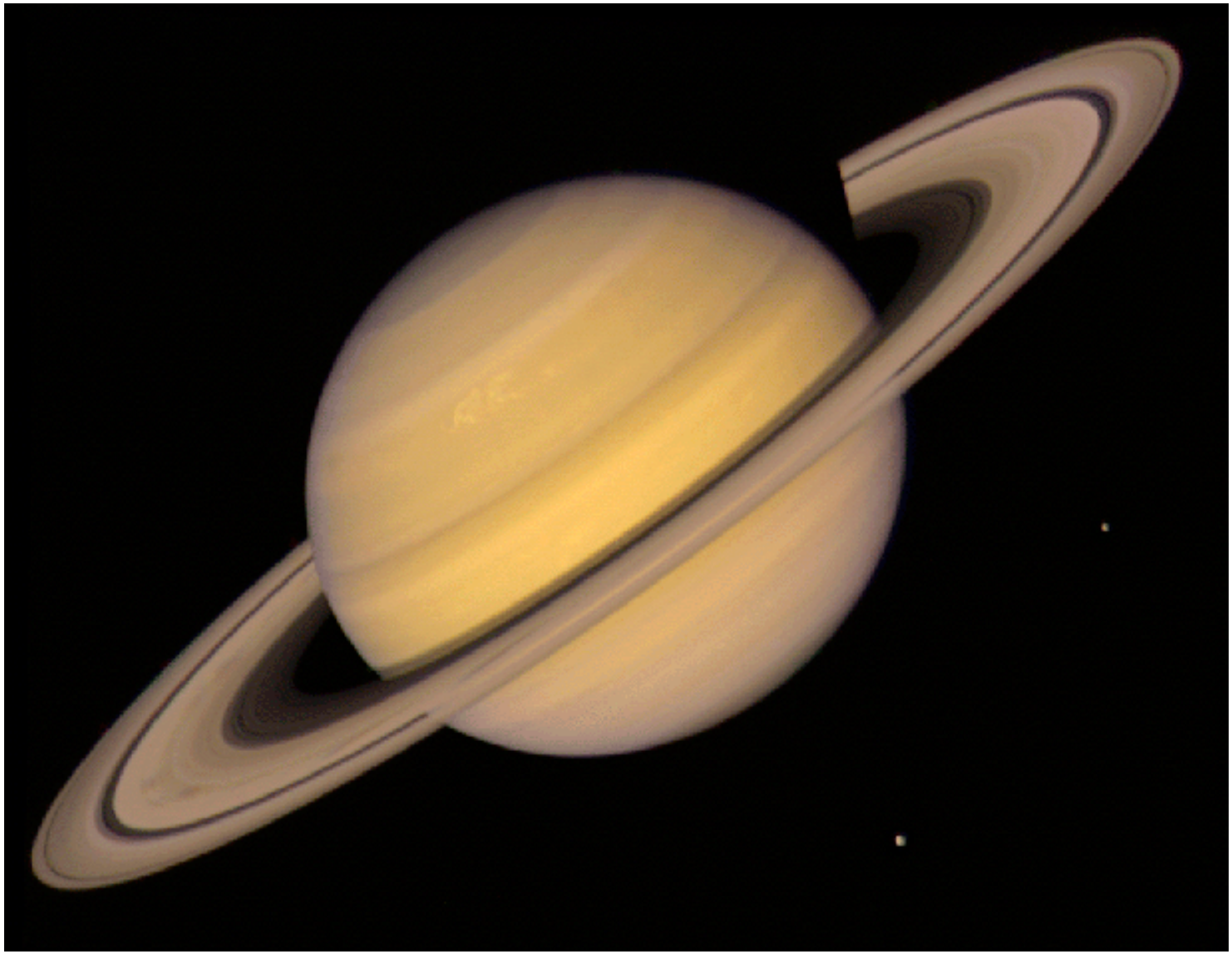

B
V
J
H
K
L
12
25
60
1.7
1.3
1.0
0.7
0.5
0.3
0.2
0.1
Flux Density (Jy)
1
10
Wavelength (μm)
Gemini Michelle
Keck LWS
IRAS
BVJHKL
LWS spectrum
star + 650K dust continuum

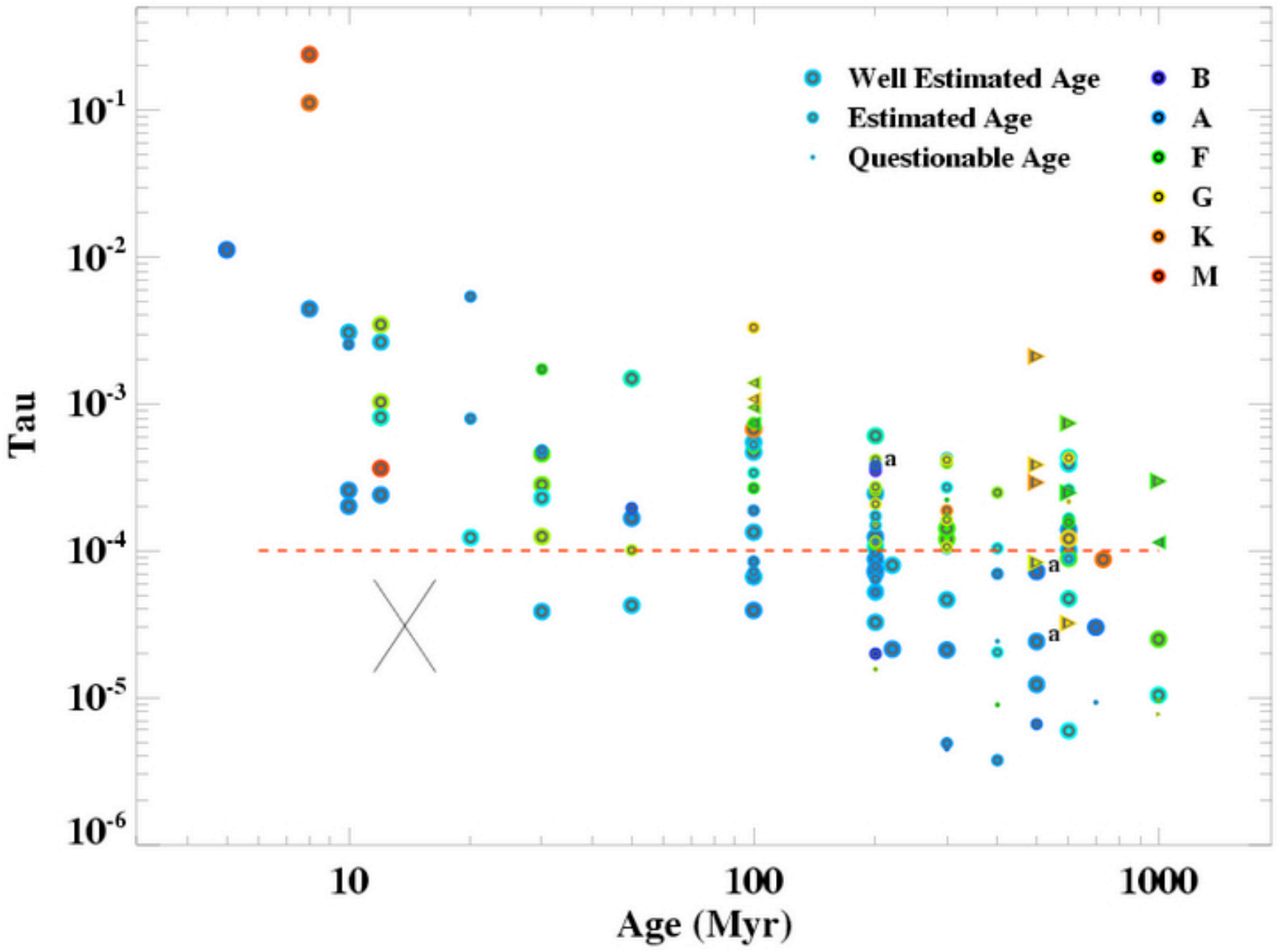
Pleiad HD 23514

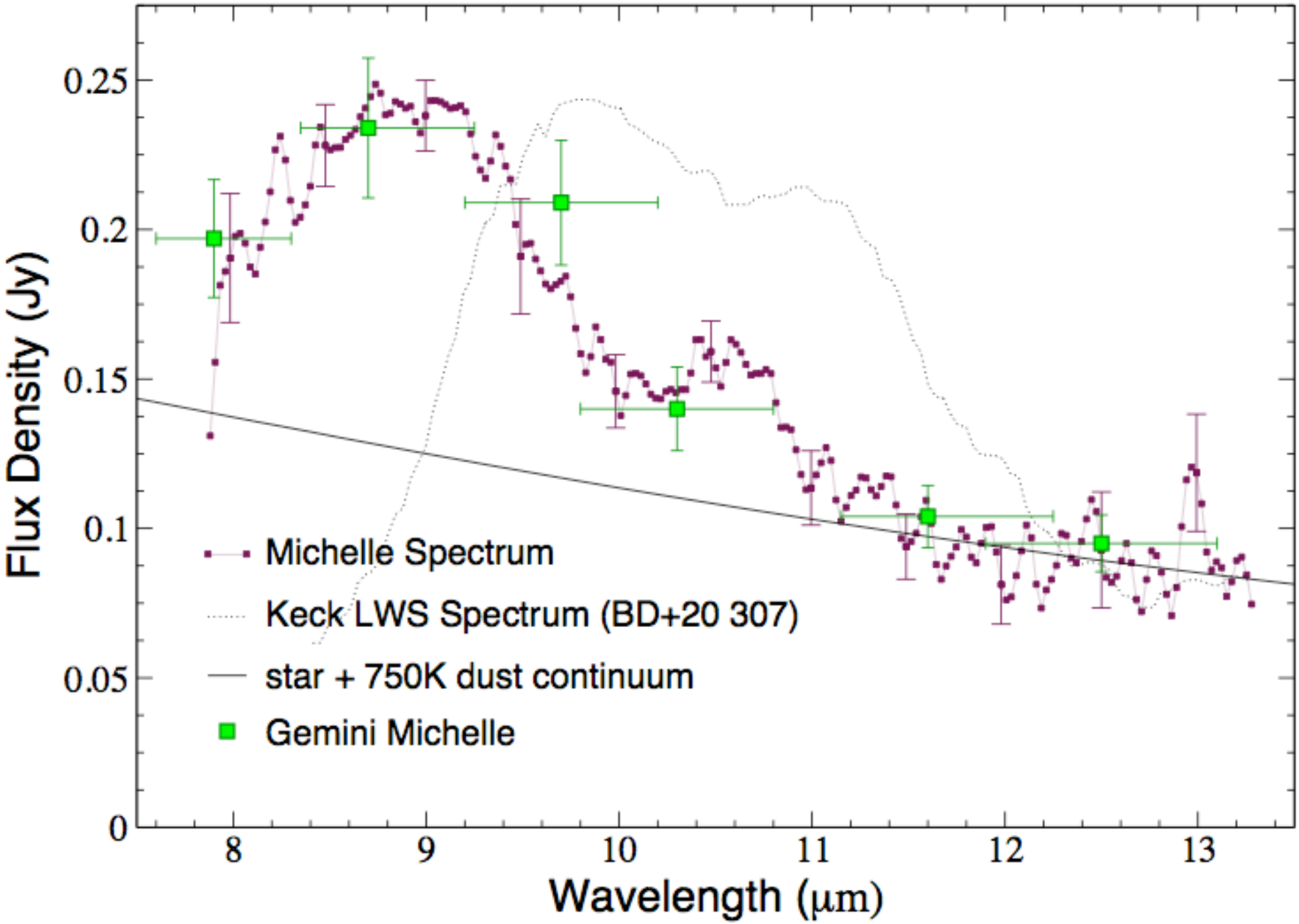


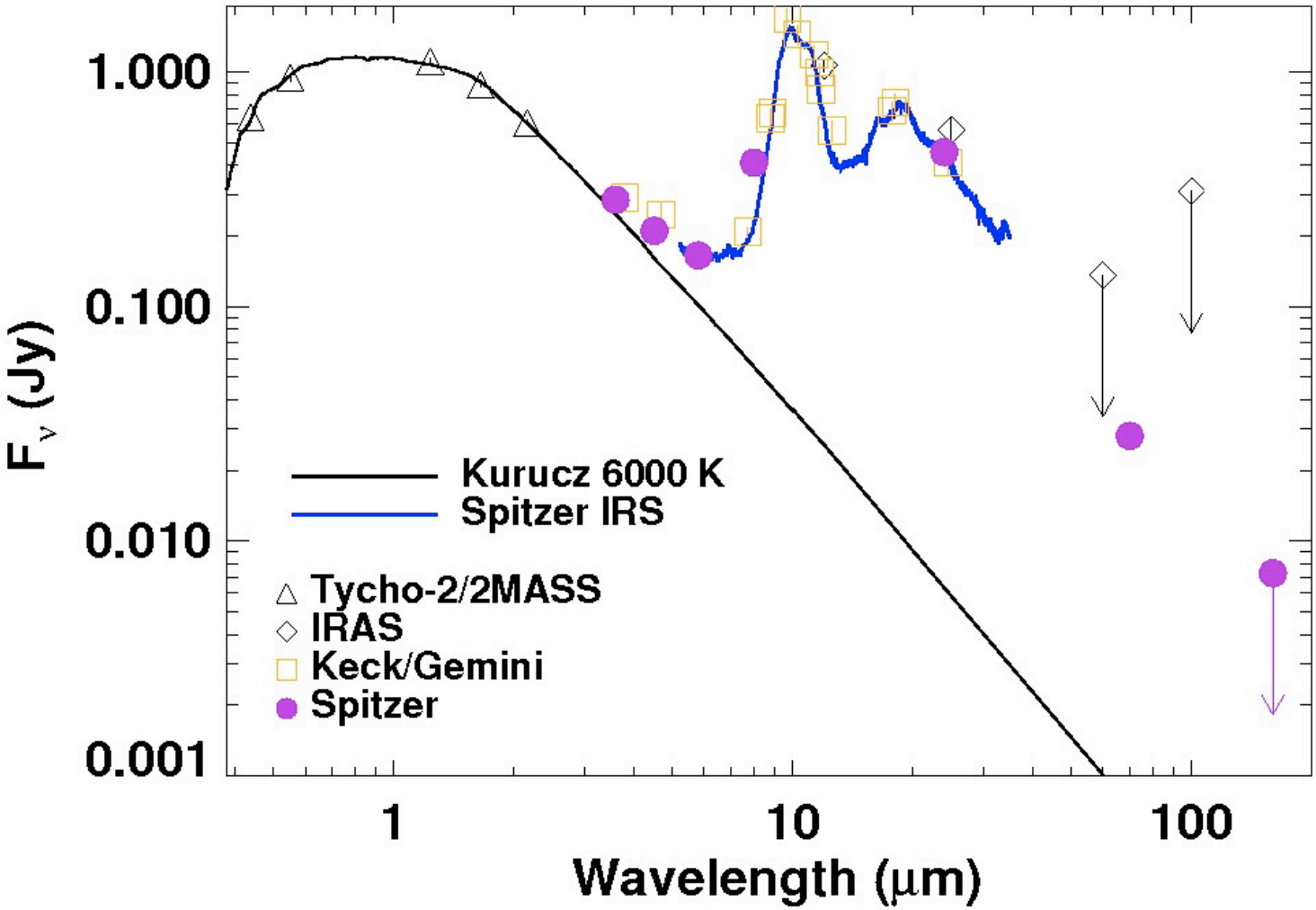
Comparison of L_{IR}/L_{Bol} in Sun's zodiacal cloud and in analogous regions at stars with warm dust

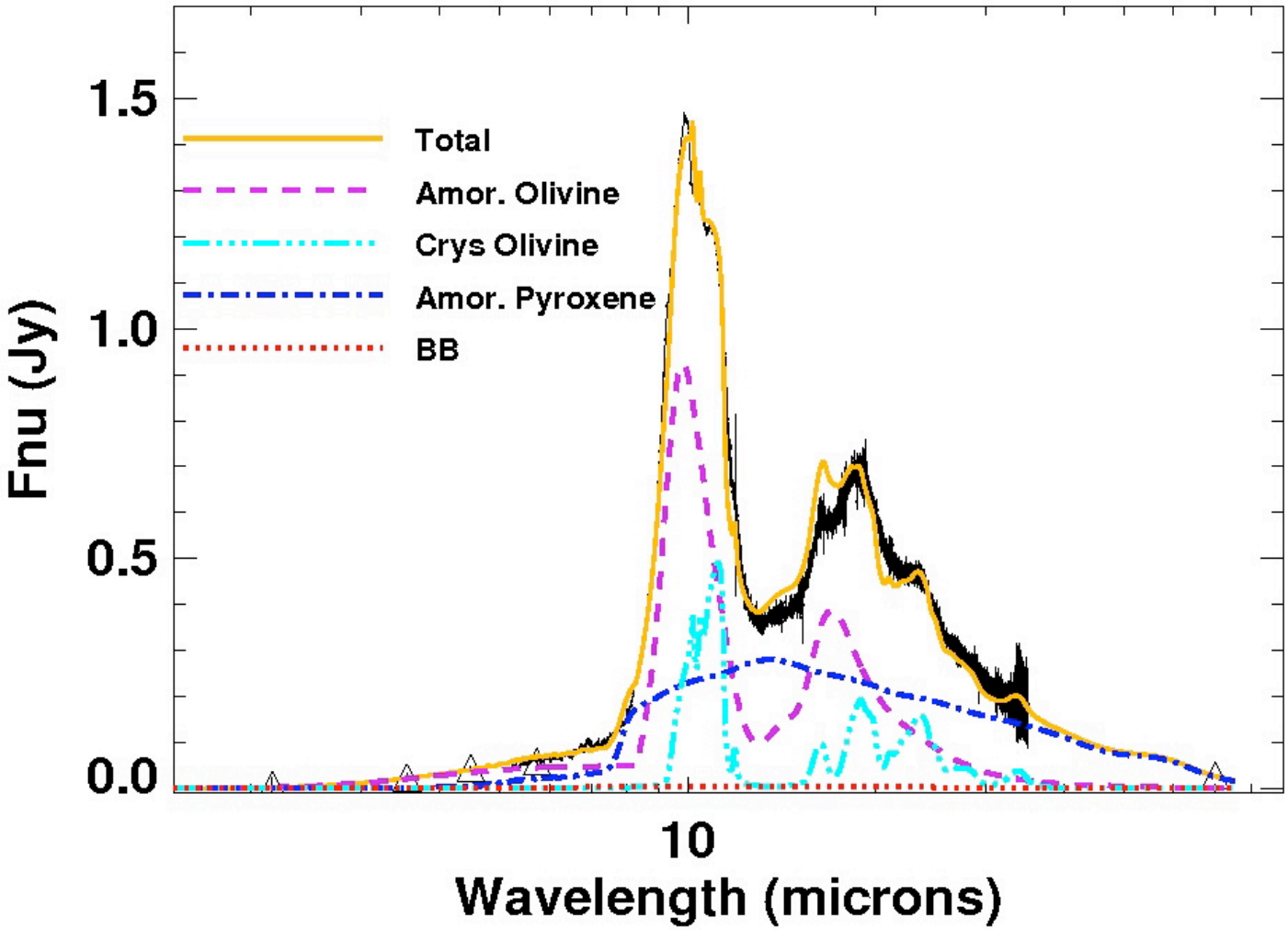
Name	Sp. Type	L_{IR}/L_{Bol}	Age (Myr)
ζ Lep	A3	0.65×10^{-4}	300
HD 23514	F6V	0.02	100
BD+20 307	G0V	0.04	???
η Crv	F2V	5×10^{-4}	600
HD 72905	G1.5	1×10^{-4}	400
HD 69830	K0V	2×10^{-4}	2,000
Zodiacal dust	G2V	10^{-7}	4,600




Well Estimated Age
Estimated Age
Questionable Age
B
A
F
G
K
M
Tau
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10
100
1000
Age (Myr)
a
a
a


Flux Density (Jy)
0.25
0.2
0.15
0.1
0.05
0
8
9
10
11
12
13
Wavelength (μm)
Michelle Spectrum
Keck LWS Spectrum (BD+20 307)
star + 750K dust continuum
Gemini Michelle


1.000
0.100
0.010
0.001
F$_\nu$ (Jy)
1
10
100
Wavelength (μm)
Kurucz 6000 K
Spitzer IRS
Tycho-2/2MASS
IRAS
Keck/Gemini
Spitzer


1.5
1.0
0.5
0.0
Fnu (Jy)
Total
Amor. Olivine
Crys Olivine
Amor. Pyroxene
BB
10
Wavelength (microns)

At HD 23514 and BD+20 307, the strong silicate emission features indicate the dust particles are of micron size (due to a collisional cascade?).

As a result, at these stars, PR lifetimes from <~1 AU, are very short. How can there be so much dust in such tight orbits around the two stars?

Era of heavy bombardment in early solar system

- Until ~600 Myr following the formation of the Sun, the bombardment rate in the early solar system was sporadically heavier than at present by factors up to 1000.
- At BD+20 307, which is ~1,000,000 times dustier than the present solar system, the current bombardment rate might be incredibly large!

Very recent collision of two planet-mass objects??

- To account for the estimated dust mass at BD+20 307, one must pulverize a 300 km diameter object (e.g., Davida, the 5th largest asteroid) into micron-size particles.
- Perhaps something analogous to the collision postulated to explain Earth's moon has occurred recently within a planetary system at BD+20 307.

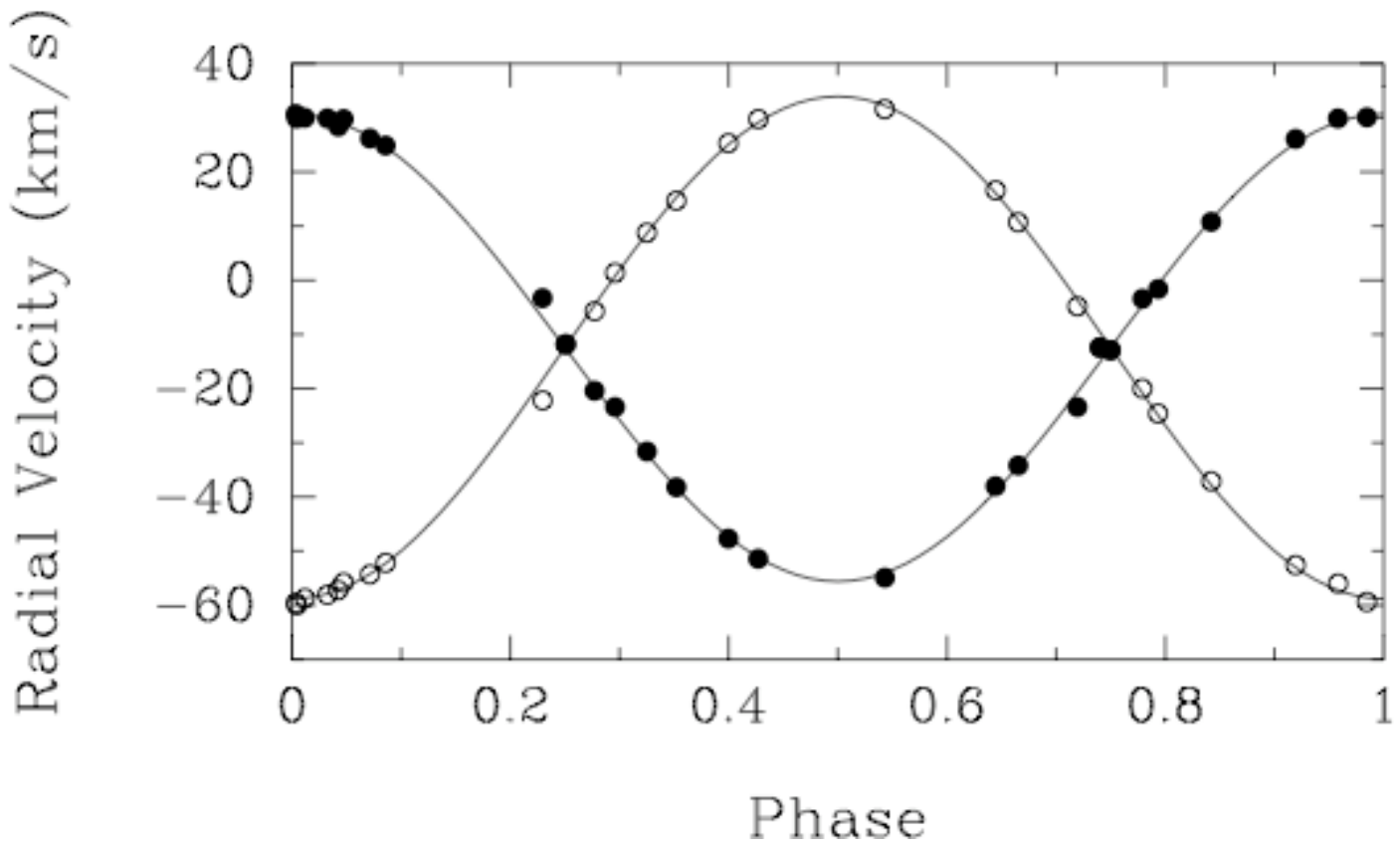
How old is BD+20 307?

~300 Myr (Song et al 2005)

Based on lithium content, Galactic space motion (UVW), and upper limit to ROSAT X-ray flux

In late October 2007, Alycia Weinberger made the surprising discovery, from observations on 3 successive days, that BD+20 307 is ~3.5 day period double-line spectroscopic binary!

This was surprising because the 2004 epoch, Song et al echelle spectrum showed no suggestion of binarity


Radial Velocity (km/s)
40
20
0
−20
−40
−60
0
0.2
0.4
0.6
0.8
1
Phase

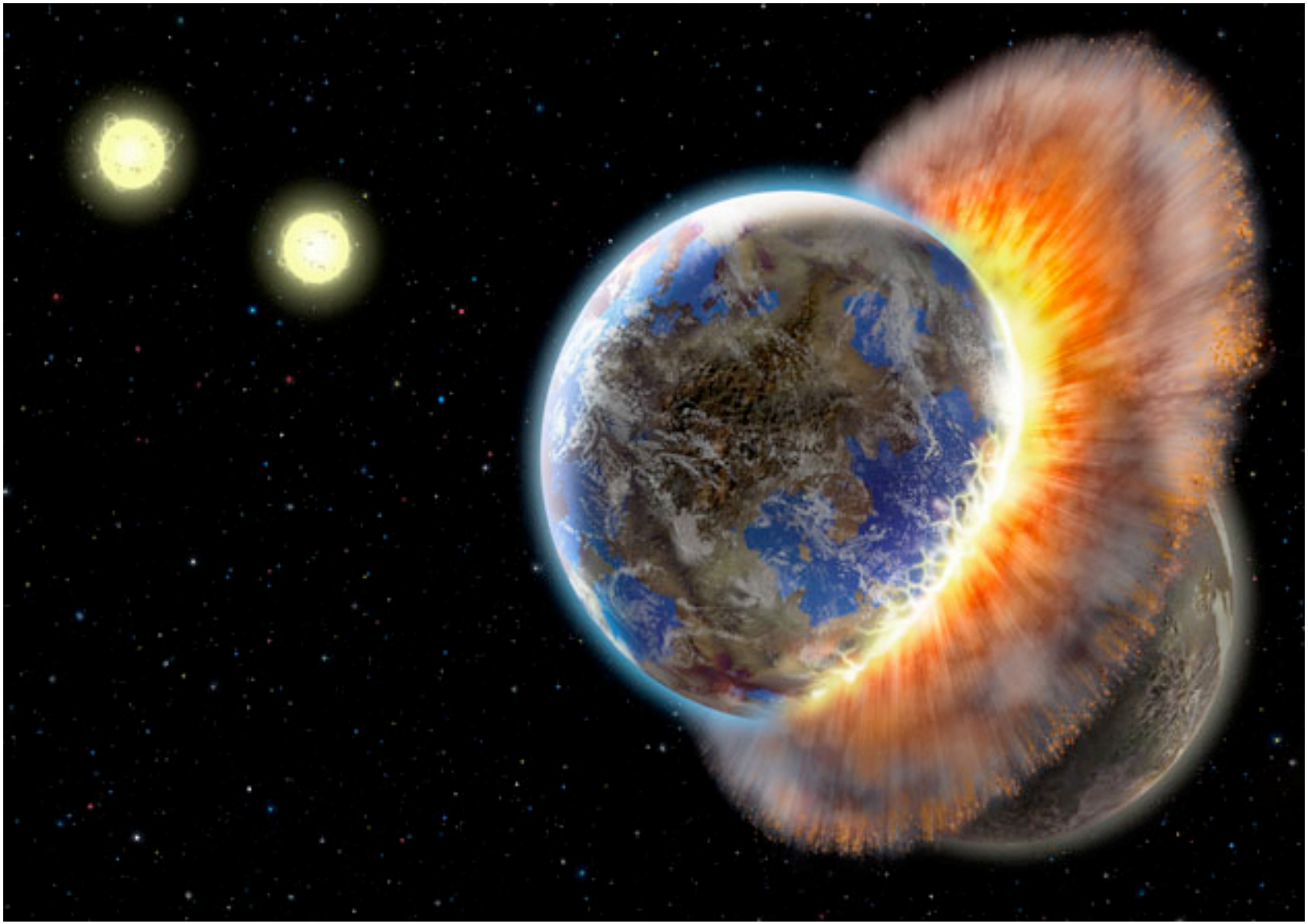
Where do things stand now?

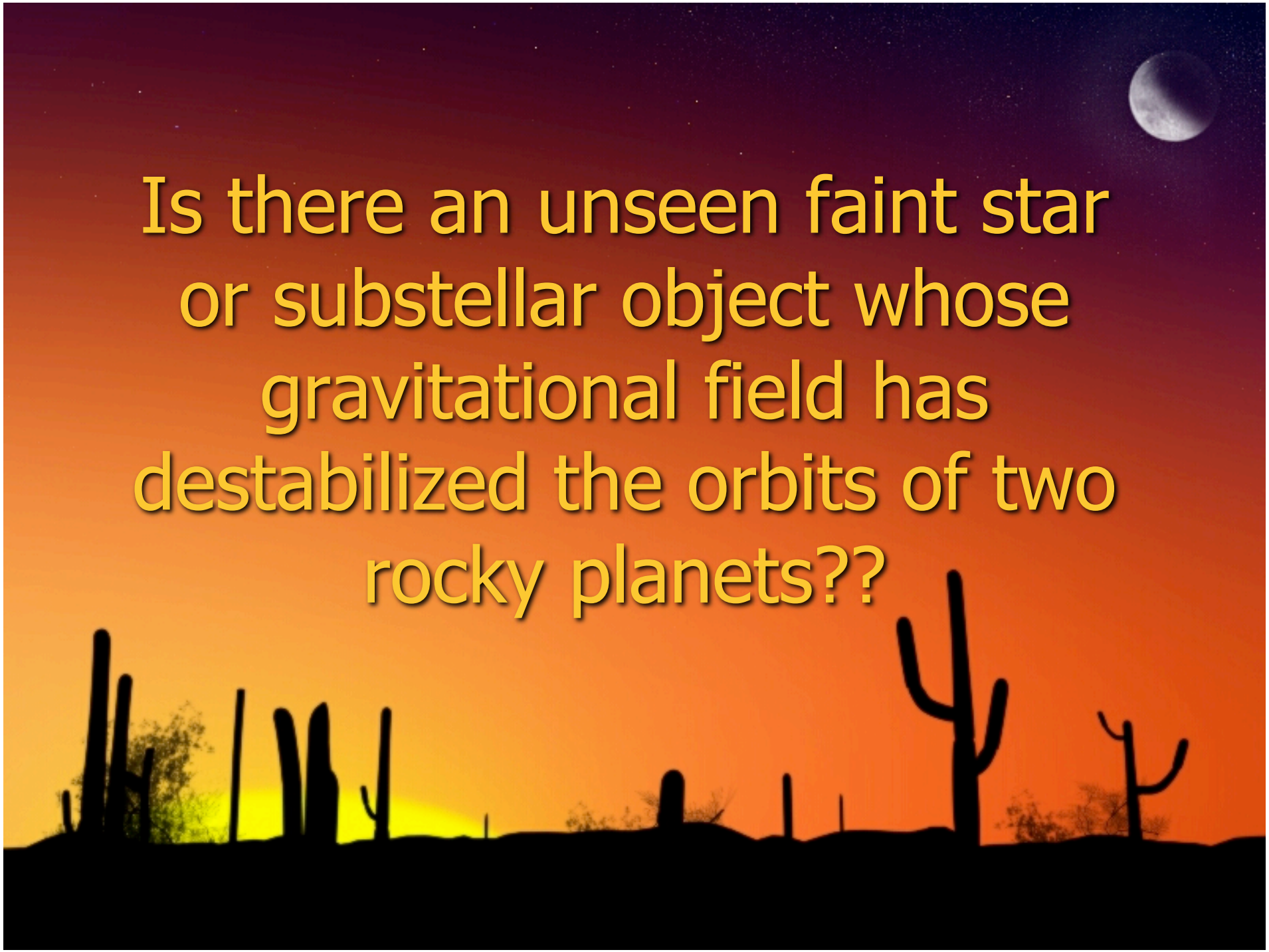
Because of the short orbital period (in conjunction with the [weak] 6708 A lithium absorption line strength), we can be confident that the orbital and rotation periods are synchronized and that neither the rotation period, nor any activity indicators that depend on it, (e.g. X-ray flux), tell us anything about the age of BD+20 307

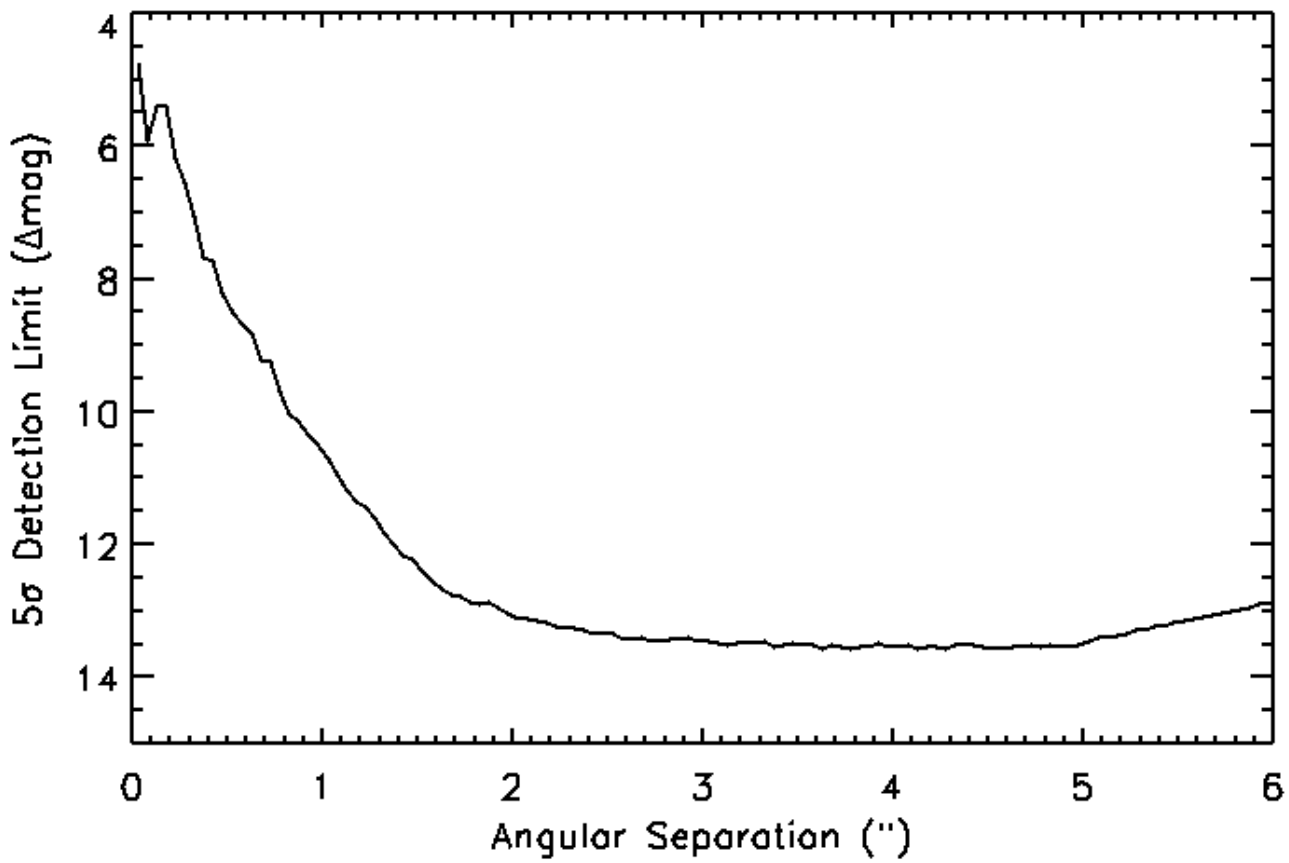
Instead, for an age estimate, we must use other indicators, such as lithium line strength, Galactic space motion (UVW), metallicity, and placement on the HR diagram

In summary, BD+20 307 is probably a few Gyr old, and possibly considerably older.

Can we be witnessing the aftermath of a collision of two terrestrial planets orbiting such an old star!?




Is there an unseen faint star or substellar object whose gravitational field has destabilized the orbits of two rocky planets??


4
6
8
10
12
14
5σ Detection Limit (Δmag)
0
1
2
3
4
5
6
Angular Separation (")

Suppose a tertiary star is a mid-M dwarf [0.3 M(sun)]

a (AU)	Period (yrs)	Semiamp K (e=0) km/s	K (e=0.5) km/s
10	21	1.8	2.1
5	7	2.6	3.0
2	1.8	4.1	4.8

These velocity amplitudes for the center of mass of the binary pair can be compared with its measured change over a period of order 1/2 year:

With one caveat, the systemic velocity is constant to within the measurement uncertainties of a few tenths of a km/s

Whatever its age, if the massive amounts of dust do point toward the presence of terrestrial planets, then BD+20 307 is the first known example of planets of any mass in orbit around a close binary star.