Solar Twins:
Are they the best candidates for finding Earth-like planets?

Chen Yuqin

Stellar Abundance and Galactic Evolution group,
National Astronomical Observatories,
Chinese Academy of Sciences,
Japan, 2009-10-09

The content of this talk

- What and why Solar Twins?
- Finding solar twins and the colors of the Sun
- Detect one new solar twin and its main characteristics
- Link solar twins with planet formation
- Summary

What are Solar Twins?

Definition: Cayrel de Strobel 1996

- Solar-type stars:late F to early K
- Solar analogs:only G0-G5 dwarfs
- Solar twins:stars almost identical to the Sun

Quantitative :Melendez et al. 2006,2007

- effective temperatures within 75 K of the Sun,
- logarithmic surface gravities within 0.10 dex
- iron abundances [Fe/H] within 0.07 dex

Why Solar Twins?

- The most important question for extrasolar terrestrial planet surveys is: which nearby stars should be searched for Earth-like planets? (Seager 2003).
- We are living proof that stars like our Sun can host habitable planets.
- Thus, stars identical to the Sun (solar twins) may be the best targets for future space missions that will probe Earth-like planets for signs of chemicals that are only produced when life is present.

Why Solar Twins?

- Determining the colors of the Sun
- used as the primary calibrator in stellar astrophysics (can be analyzed in a similar way as the objects of interest.)
- answering the long-standing question of the uniqueness of the Sun (e.g., Gustafsson 1998)

Solar Twins found in the literature

- Cayrel de Strobel (1996) :none is a “perfect good solar twin.”
- Porto de Mello & da Silva (1997) :18 Sco (HD146233) is “the closest ever solar twin.”
- Soubiran & Triaud (2004) :18 Sco is the top solar analog.
- King, Boesgaard & Schuler (2005): HD 143436 is a solar twin as good as 18 Sco.
- Recent works: HD98618,195034,HD101364

HD	
146233	
159222	(Soubiran 和Triaud 2004
129357	(King 等人2005)
138573	(King 等人2005)
142093	(King 等人2005)
143436	(King 等人2005)
98618	(Melendez 等人2006)
195034	(Takeda等人 2007)
101364	(Melendez 等人2007)
195934	(Takeda et al. 2007,2009)

Check on detected solar twins

New method for Teff
new Hipparcos parallax
(van Leeuwen 2007)

表 2.2 太阳孪生星候选体的基本参数

星名	有效温度 (K)	金属丰度 (dex)	绝对星等 (mag)	质量 ($M/M_{\odot}$)
HD98618	5690	0.05	4.65	0.95
HD 101364	5685	-0.04	4.59	0.95
HD 129357	5827	-0.02	4.49	1.00
HD 138573	5676	-0.03	4.79	0.95
HD 142093	5911	-0.15	4.83	1.00
HD 143436	5788	-0.04	5.01	1.00
HD 146233	5757	0.03	4.79	0.98
HD 159222	5765	0.05	4.65	0.97
HD 195034	5695	0.05	4.85	0.96

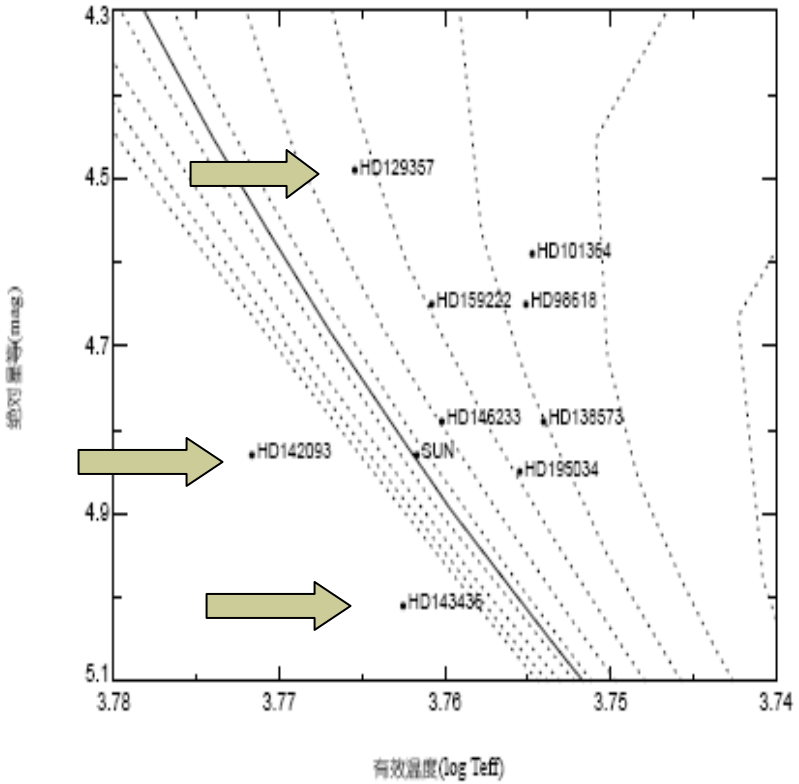


图 2.1 太阳孪生星候选体在赫罗图（Mv-log Teff）上的分布

The colors from six solar twins

表 2.3 六颗太阳孪生星候选体的测光数据

星等和色指数	HD98618	HD101364	HD138573	HD146233	HD159222	HD195034
V	7.658	8.673	7.232	5.503	6.528	7.090
(B-V)	0.640	0.647	0.656	0.652	0.639	0.642
(V-I)c	0.710	0.710	0.720	0.690	0.700	0.710
(B_T-V_T)	0.713	0.714	0.766	0.722	0.726	0.718
(J-H)	0.306	0.275	0.285	-	0.266	0.269
(H-K)	0.081	0.044	0.080	-	0.078	0.053
(v-y)	1.020	1.033	1.045	1.021	1.028	1.020
(v-b)	0.609	0.623	0.633	0.616	0.622	0.612
(u-v)	0.956	0.936	0.955	0.961	0.986	0.931
(b-y)	0.411	0.410	0.412	0.405	0.406	0.408

表 2.4 太阳颜色计算结果及比较

色指数	太阳[本研究结果]	太阳 Holmberg	|太阳[本研究]-太阳 Holmberg|
$(B-V)_\odot$	0.644±0.007	0.642±0.016	0.002
$(V-I_c)_\odot$	0.707±0.009	0.688±0.014	0.019
$(B_T-V_T)_\odot$	0.725±0.017	0.708±0.030	0.017
$(J-H)_\odot$	0.288±0.021	0.258±0.035	0.030
$(H-K)_\odot$	0.066±0.015	0.096±0.038	0.030
$(b-y)_\odot$	0.409±0.002	0.403±0.013	0.006
$(v-y)_\odot$	1.028±0.010	1.011±0.035	0.017
$(v-b)_\odot$	0.619±0.018	0.609±0.023	0.010
$(u-v)_\odot$	0.954±0.018	0.979±0.064	0.025

Zhao Z.S. et al. 2009, Science in China,G, 39,1161

The search for new solar twins

Selection criteria:
4.6< M v <5.0

0.62<(B-V)<0.67

0.40< (b-y)<0.42

V<8.5

表 3.1 11 颗极太阳星的大气参数

星名	Teff	Log g	[Fe/H]	ξt
15632	5824	4.58	0.08	1.29
19518	5739	4.27	-0.09	1.14
26736	5761	4.42	0.10	1.37
28068	5714	4.35	0.02	1.36
75767	5729	4.29	-0.10	1.20
146233	5760	4.47	0.09	1.12
158222	5781	4.40	0.04	1.37
[redacted]	5780	4.44	-0.02	1.22
168874	5847	4.48	0.04	1.39
187237	5786	4.43	0.03	1.22
195034	5705	4.38	-0.02	1.05

One new solar twin

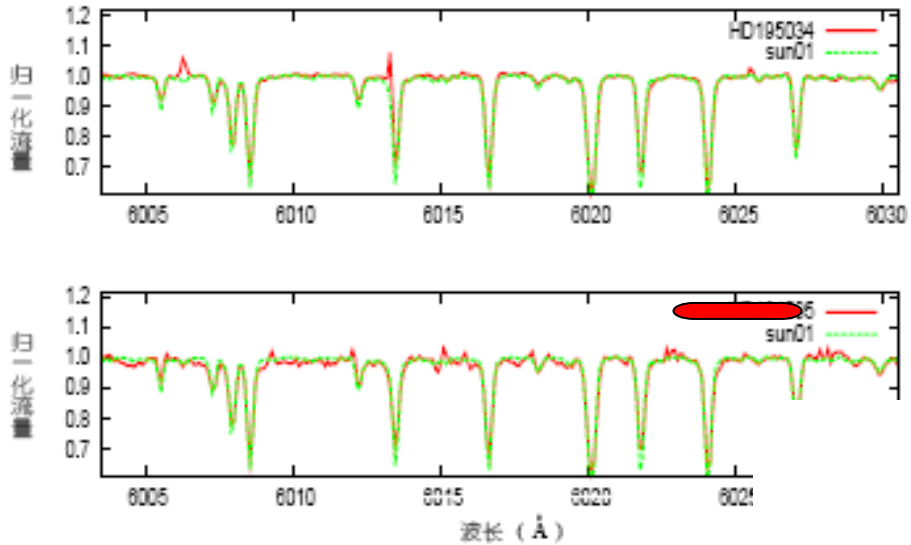


图 3.1 两颗太阳孪生星候选体(HD195034、HD16459

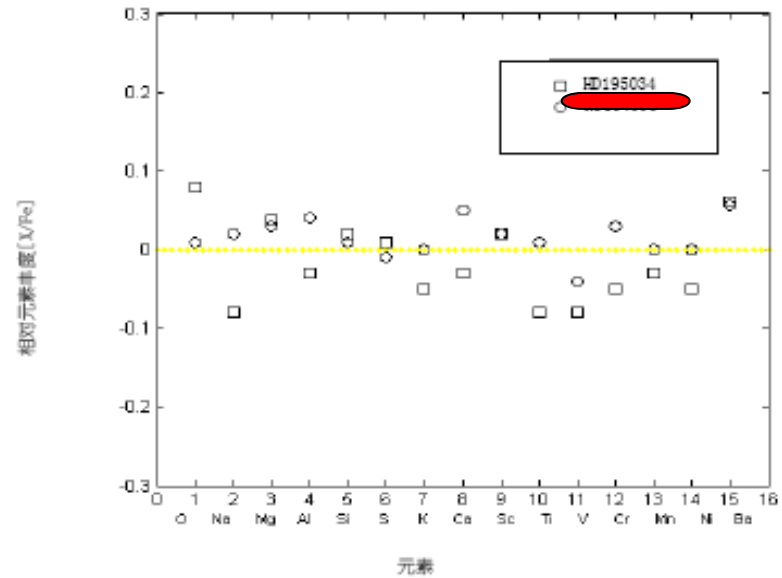


图 3.2 两颗太阳孪生星候选体(HD195034、)与太阳的化学组成比较

The characteristics of new solar twin

表 3.3 [redacted]、HD195034 的运动学参数比较

星名	U (km/s)	V (km/s)	W (km/s)	$Z_{最大值}$ kpc	$R_{平均}$ kpc	E
太阳	-10.0	5.2	7.2			
[redacted]	5.0	11.4	33.3	0.46	8.73	0.09
HD195034	-34.6	-9.8	-8.5	0.10	7.94	0.11

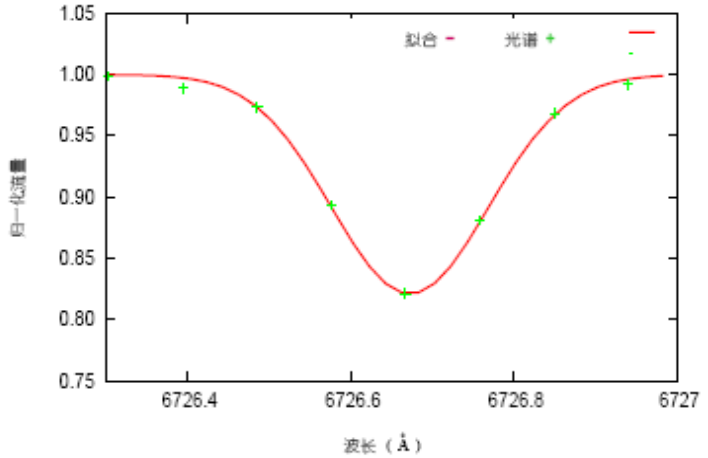


图 3.4 光谱综合技术确[redacted]在 FeI 6726 谱线处的高斯卷积速度

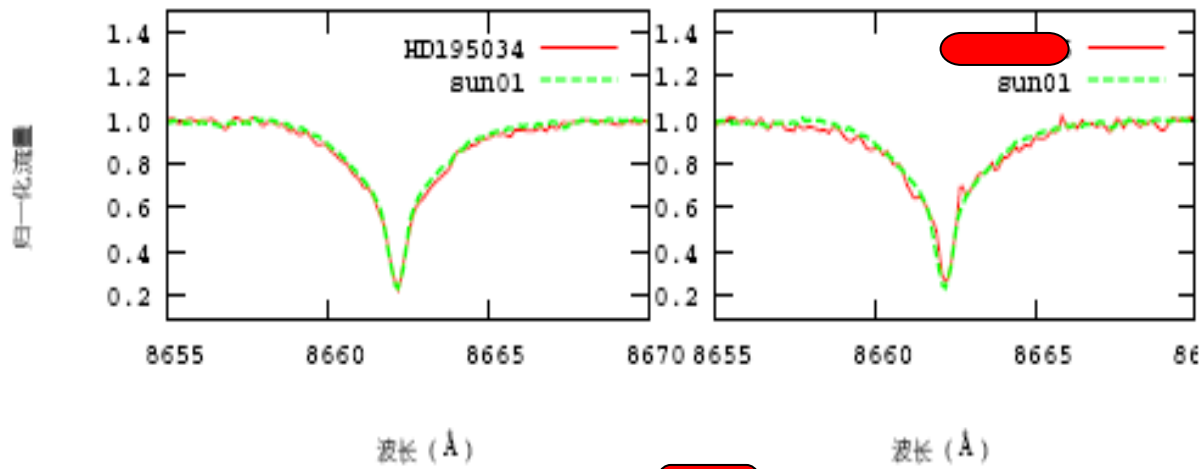


图 3.5 太阳孪生星候选体（HD195034、H[redacted]）和太阳的 CaII 8662 线比较

Age and Li abudances

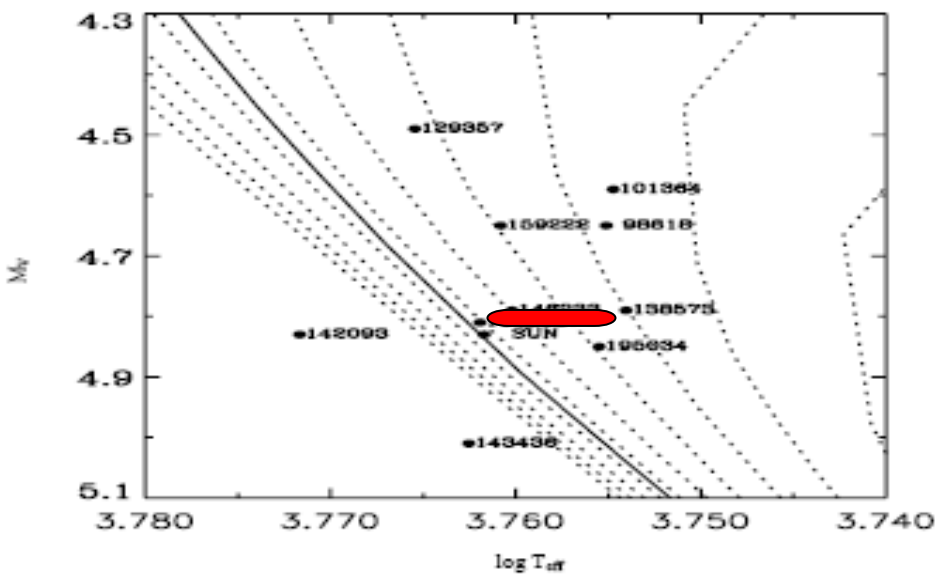
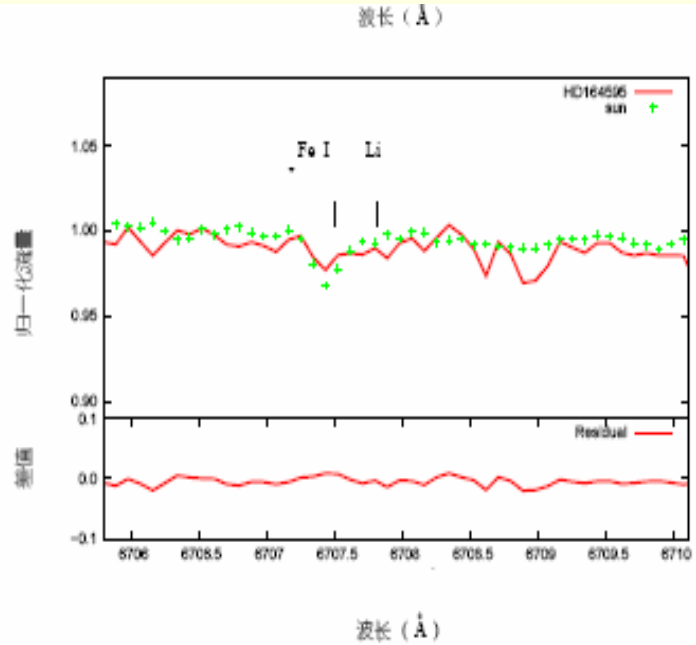


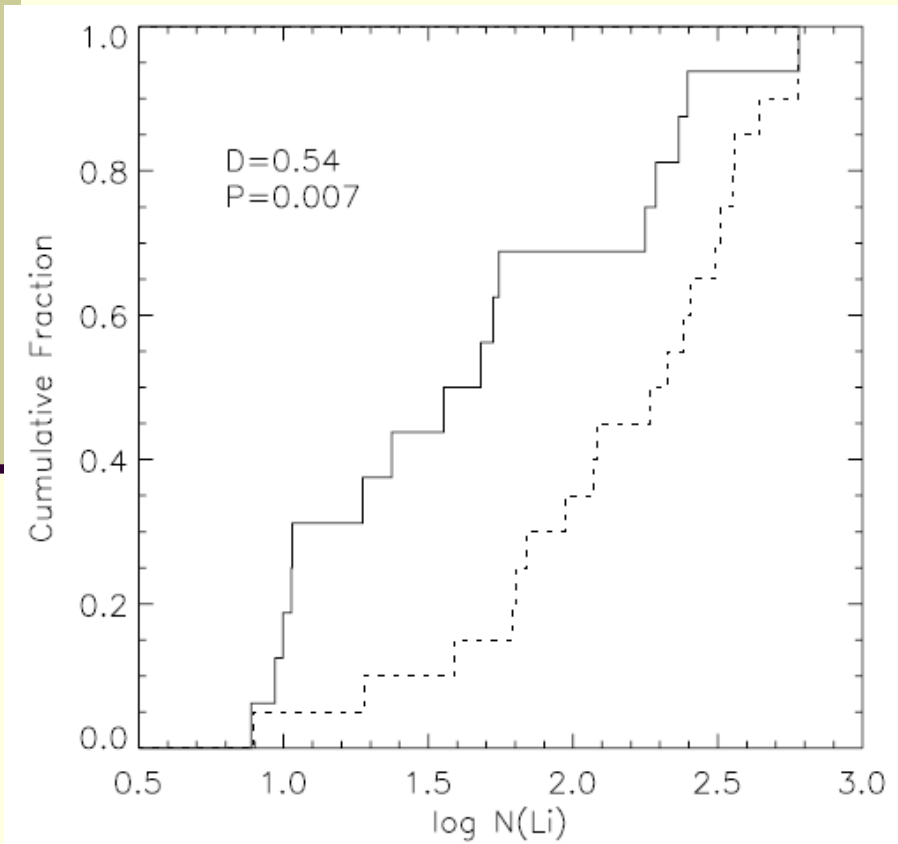
图 3.6 太阳孪生星候选体在赫罗图（Mv-log Teff）上的分布



- Low Li aundance for SWPs: Israelian et al. 2004; Takeda&Kwanomoto 2005; Chen&Zhao 2006)
- Low Li solar twins: HD101364、HD138573,HD[redacted]

Li abundances in SWPs and non-SWPs

- Chen & Zhao 2006



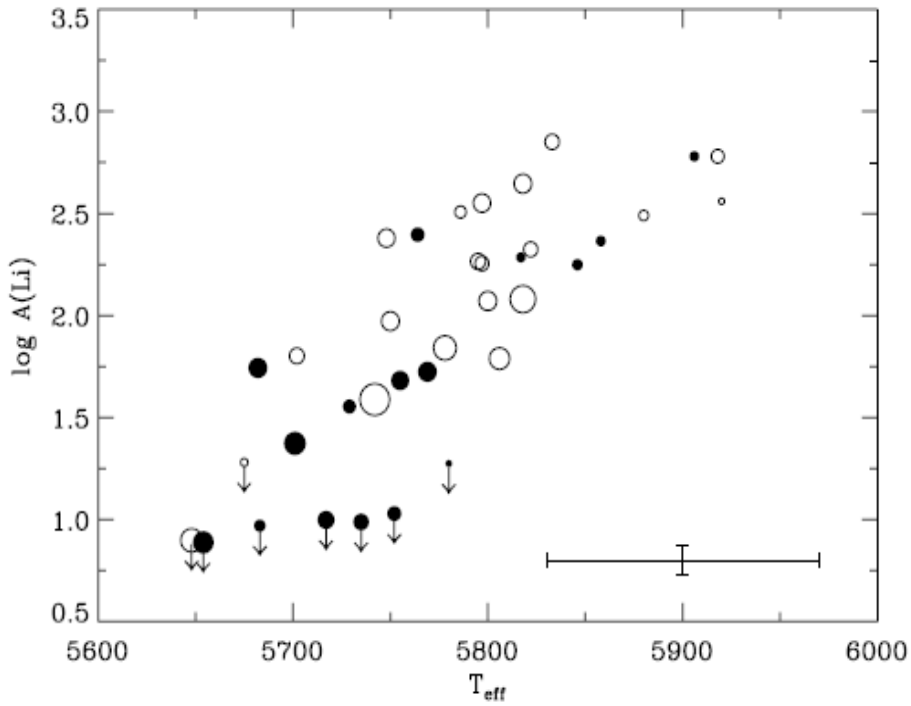
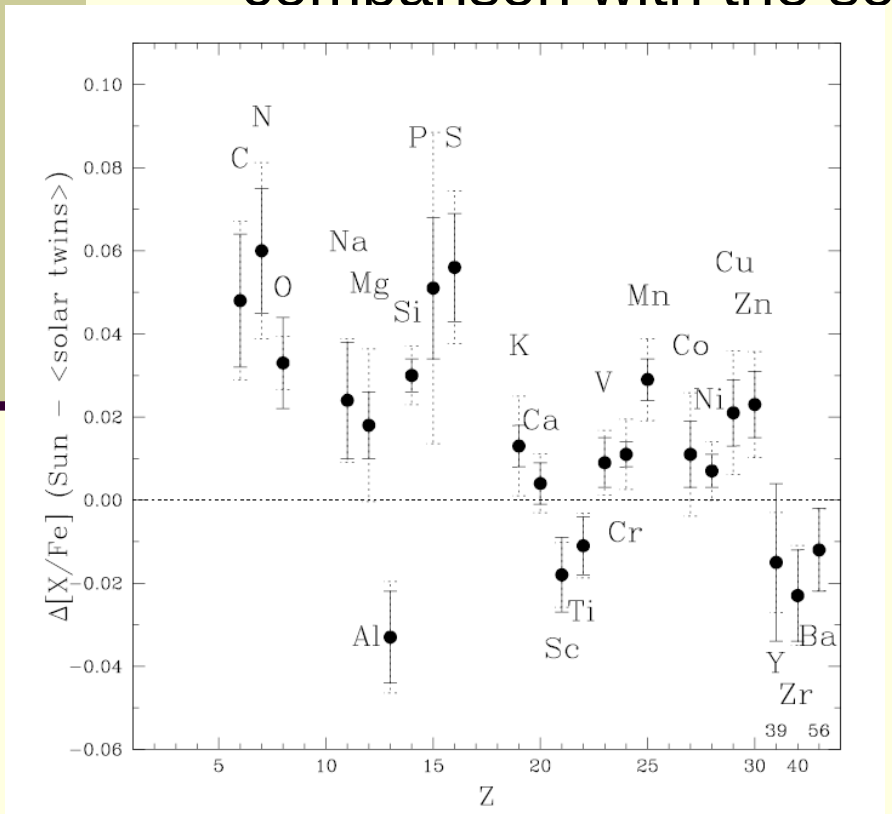
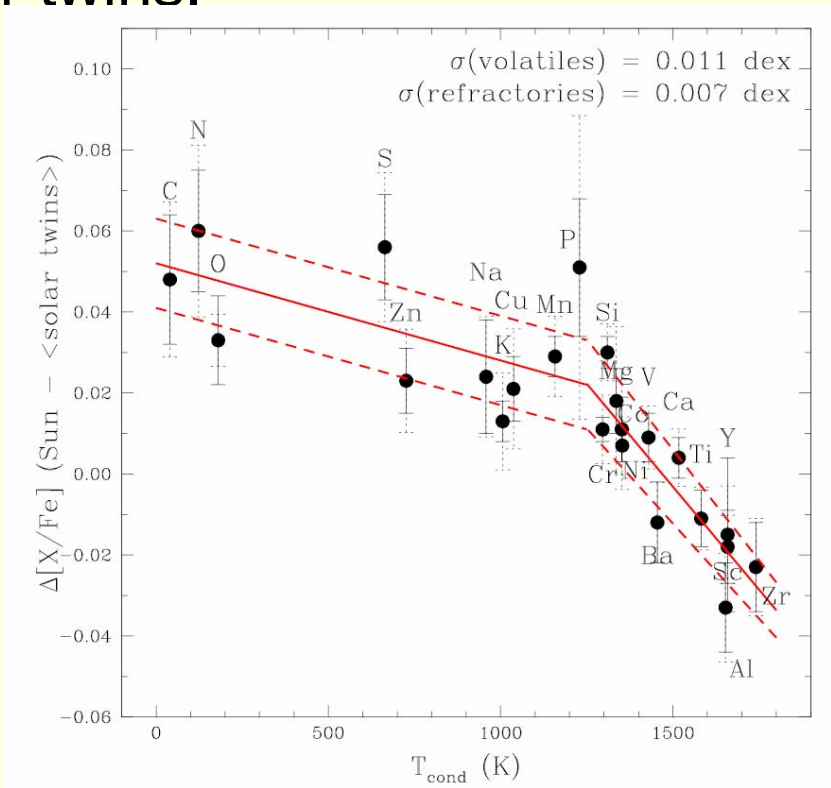


FIG. 4.—Li abundance vs. T_{eff}. The symbols are the same as in Fig. 1.

Solar twins and the Sun: Other abundance ratios

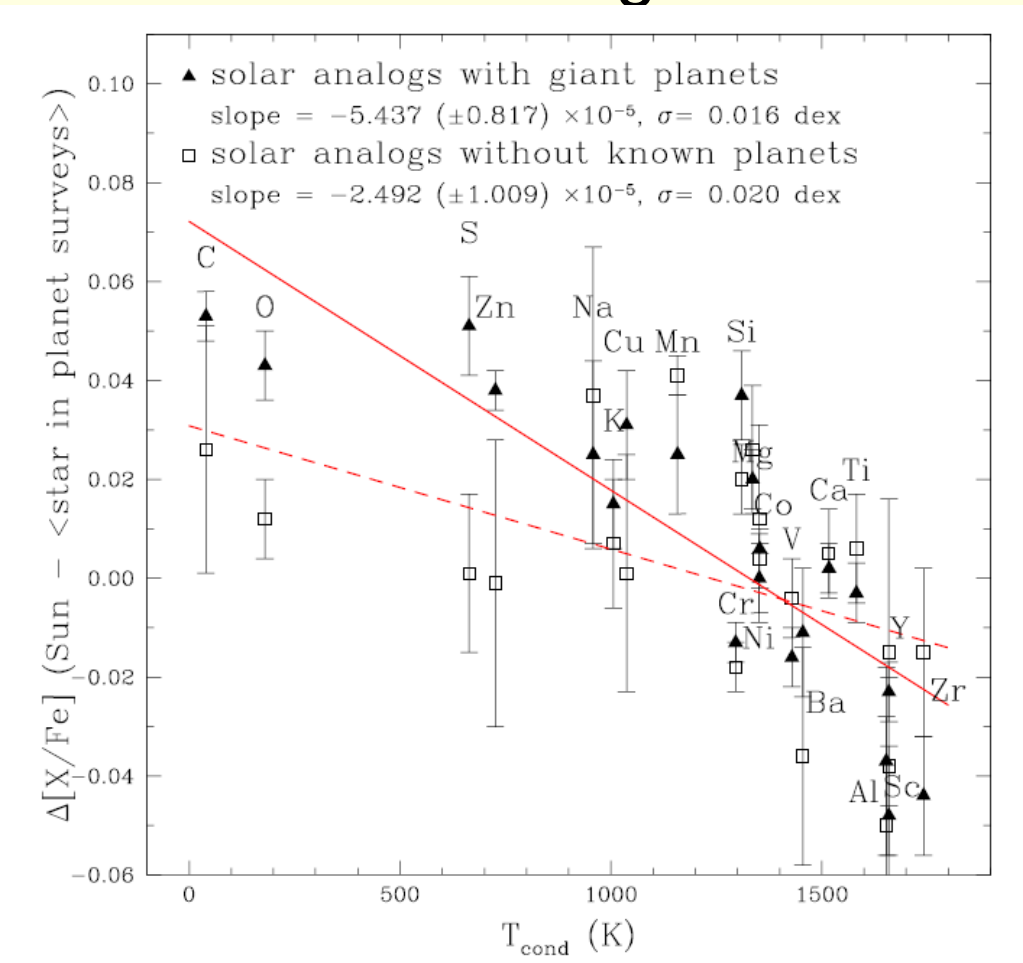
- Melendez et al. 2009, astro-ph/0909.2299:
- the Sun shows a 20% depletion of refractory elements relative to the volatile elements in comparison with the solar twins.





Solar twins and the Sun: Other abundance ratios

- results for solar analogues



Solar twins and the Sun: different stories

- Sun is unusual in its abundance pattern.
- This may be circumstantial: first have been cleansed from dust by radiation from hot luminous stars
- The accretion onto the Sun of the proto-planetary solar nebula, chemically affected by dust condensation and planet formation
- The early Sun was never fully convective,make it easier to imprint a dust-cleansed abundance signature (Nordlund 2009). supported by the dynamical star-formation calculations.

Solar twins: **Are they best candidates for searching Earth-like planets?**

- No giant planets are known around solar twins because most of them have not been searched for planets.
- California and Carnegie Planet Search Project (see, e.g., Marcy et al.2005):not any hot Jupiters around HD146233 or HD 98618.
- Marcy et al. (2005): undetected Jupiter-mass planets orbiting nearby FGK stars (<30 pc) may reside in orbits beyond 3 AU or have masses less than MJup;the habitable zones of 18 Sco and HD 98618 should be very close to 1 AU.
- If further radial velocity observations show that the inner region around 18 Sco and HD 98618 is free of giant planets, then these stars have the potential to host terrestrial planets around their habitable zones.
- We need long-term radial velocity monitoring of these stars

Solar twins: **Are they best candidates for searching Earth-like planets?**

- Solar analogues with known close giant planets do not show the solar pattern: their gas disks were accreted earlier;the planetary signatures were erased.
- Solar-like stars with planetary systems similar to our own are a relatively rare occurrence.

What about solar twins with low Li abundance?

Summary and outlook

- Solar twins are not popular in the solar neighborhood. New search is needed.
- Solar Li abundance is unique among solar twins. Finding more low-Li solar twins.
- The abundance-condensation temperature correlation is unexplained.
- Potential link to planet formation, but need observational evidence: abundance difference between low-Li and normal-Li solar twins.

The End!

Thanks!