Lithium, Beryllium, and Boron in RGB and AGB Stars

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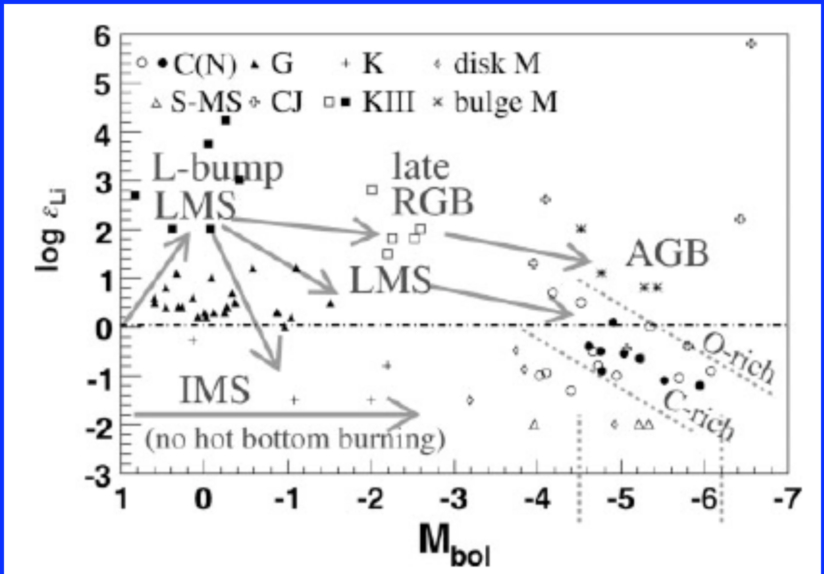
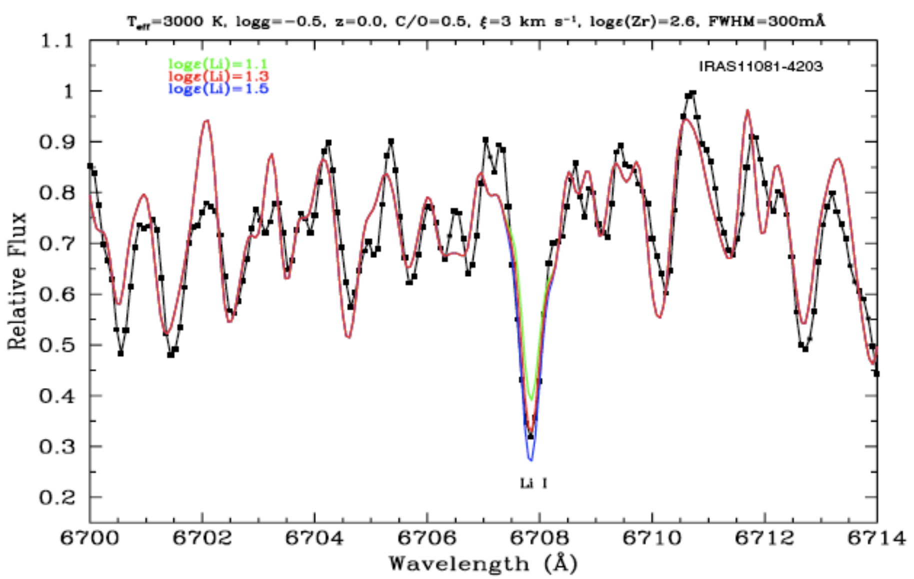
- Mixing along the RGB
- Lithium Production in AGB Stars
- The Mysterious Lithium-rich K-giants





Lithium Depletion, Mixing, and Stellar Evolution: Some History

- Bonsack (1959)

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- Wallerstein (1964)- "Capella F & G"

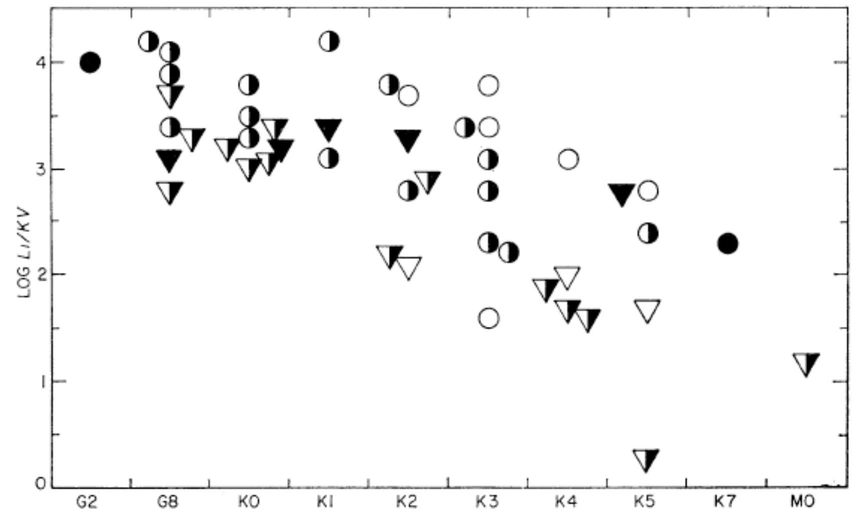


FIG. 5.—Abundance of lithium relative to vanadium, divided by constant K, correlated with spectral type. Circles are values from measured lines; triangles are upper limits. Open figures are stars of luminosity classes I*b* and II; filled figures are classes IV and V; and half-filled figures are intermediate luminosities.

- Iben (1965)

←

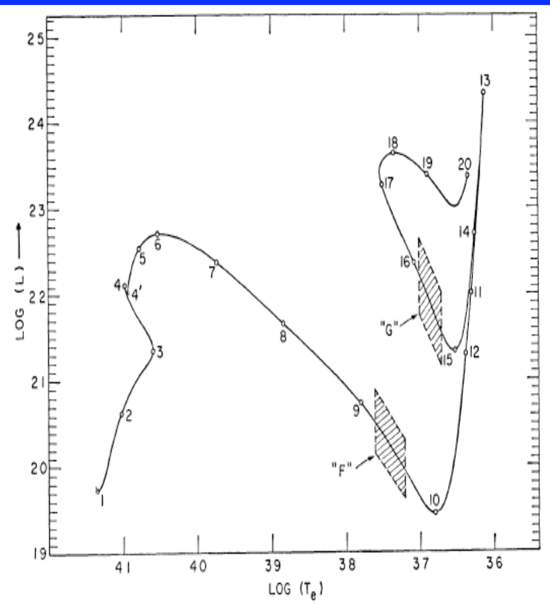


FIG. 1.—Path in the theoretical Hertzsprung-Russell diagram for a 3 $M_\odot$ population I star. Luminosity L is in units of 3.86×10^{33} erg/sec and surface temperature T_e is in units of °K.

Lithium Depletion in Giants—First Ascent and Clump

- Brown et al. (1989): Lithium survey of 644 G-K giants.
- ~Disk Giants
- ~1% are "Li rich"
- Distribution of the rest suggest extra-mixing on the RGB

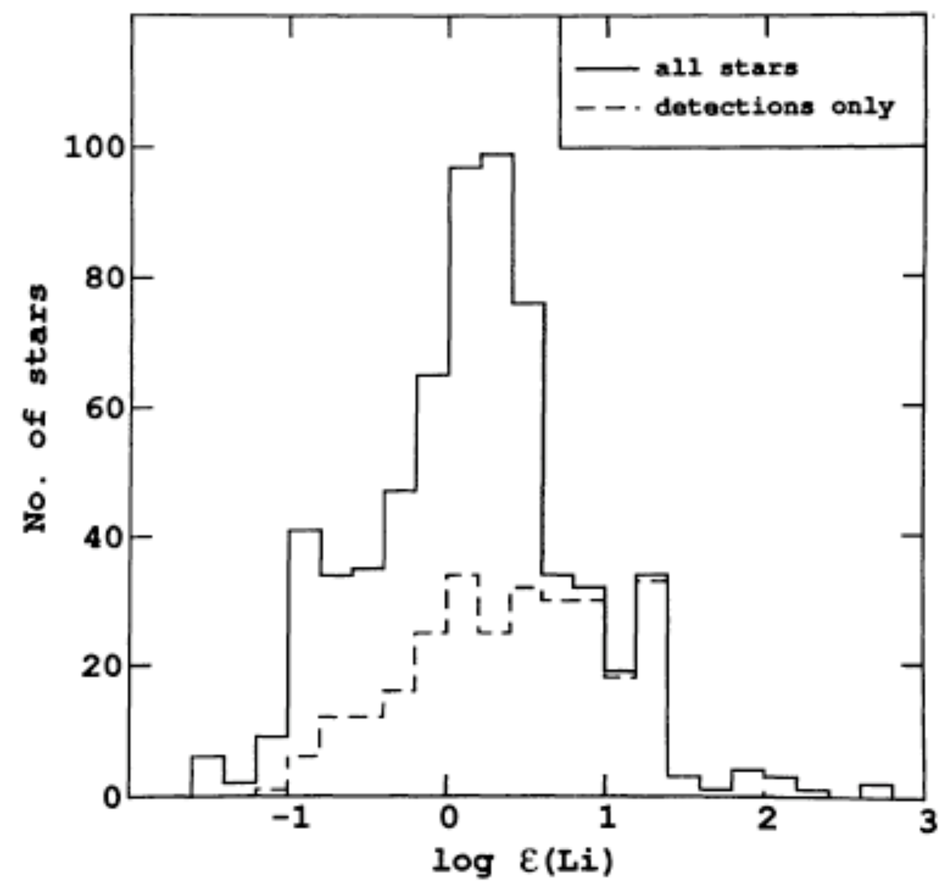
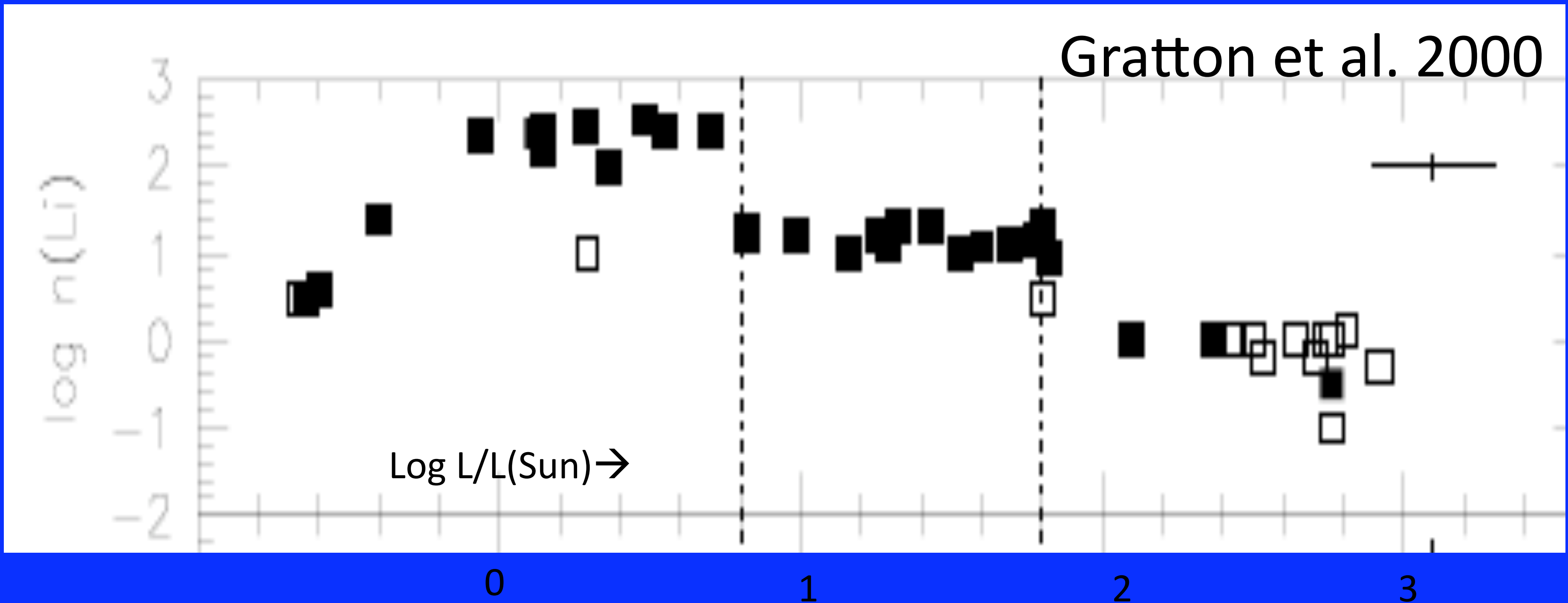


FIG. 13.—Histogram of Li abundances for the program stars. The bin size for the abundance groups is 0.2 dex. The nondetections dominate the statistics below log ε(Li) ≈ +0.5.

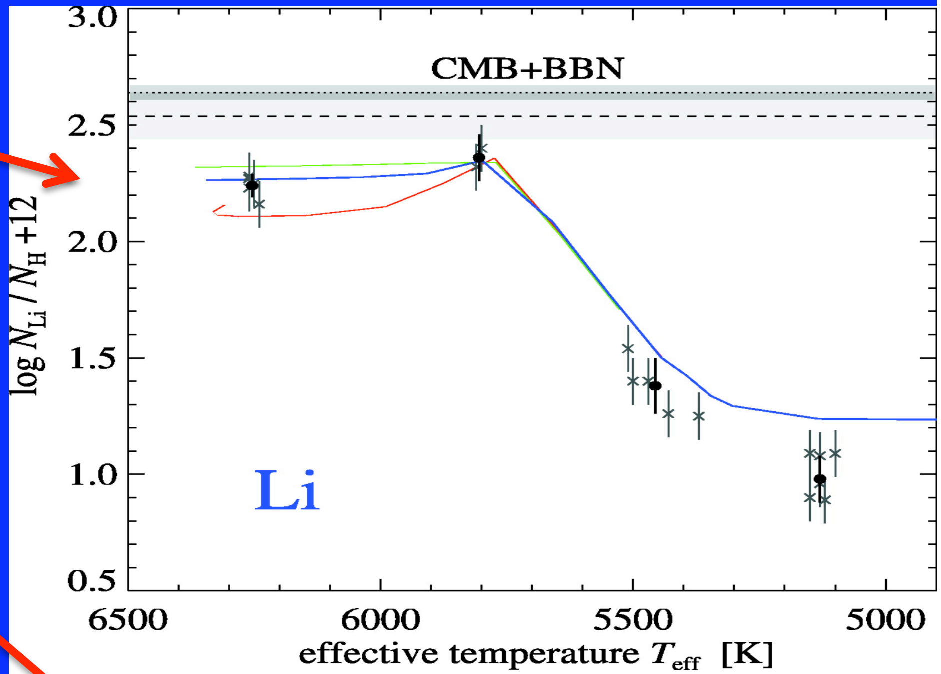
Lithium Depletion in Metal-Poor Field Red Giants

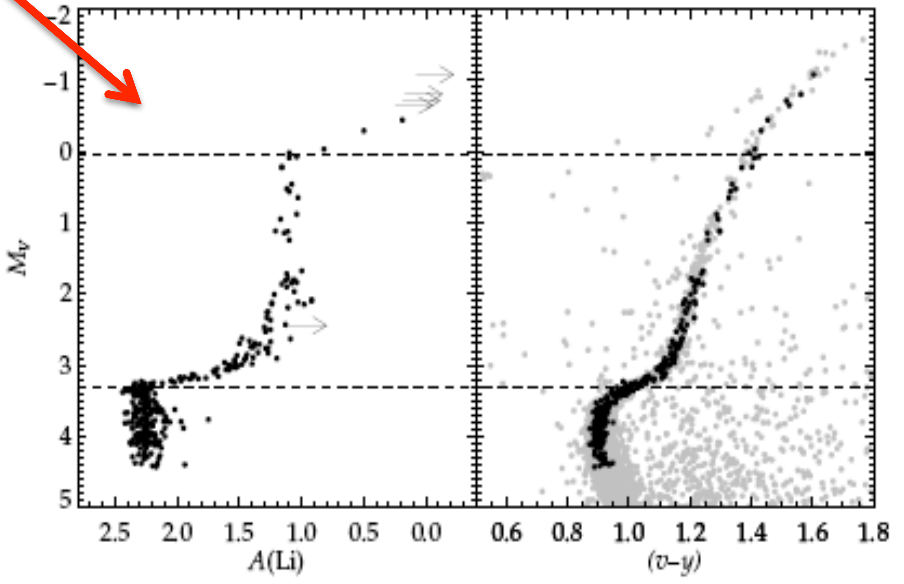


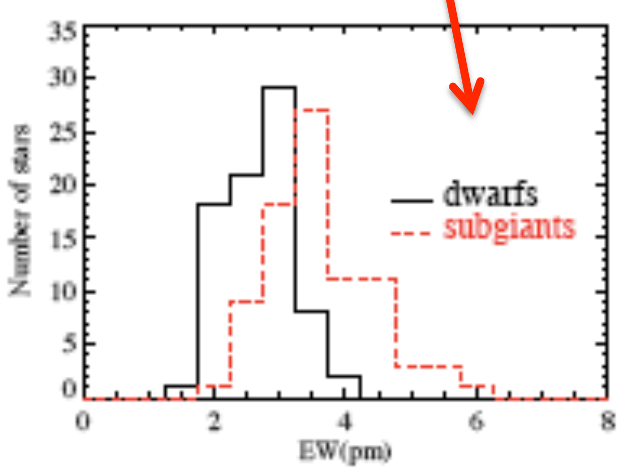
- [Fe/H]= -2 to -1.
- Mixing/dilution at RGB ~20x—agreement with models.
- Extra mixing near the location of the RGB Bump.

Lithium in NGC6397

- Korn et al. (2007) diffusion and mixing.
- Lind et al. (2009)
- Garcia Hernandez et al. (2009)

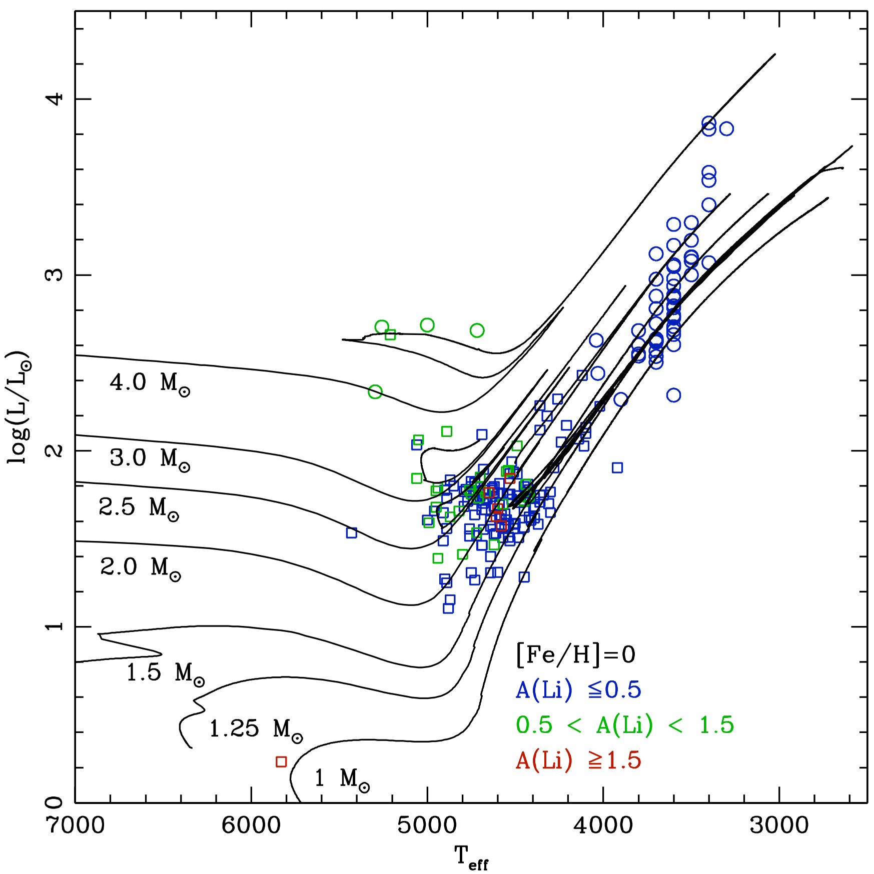


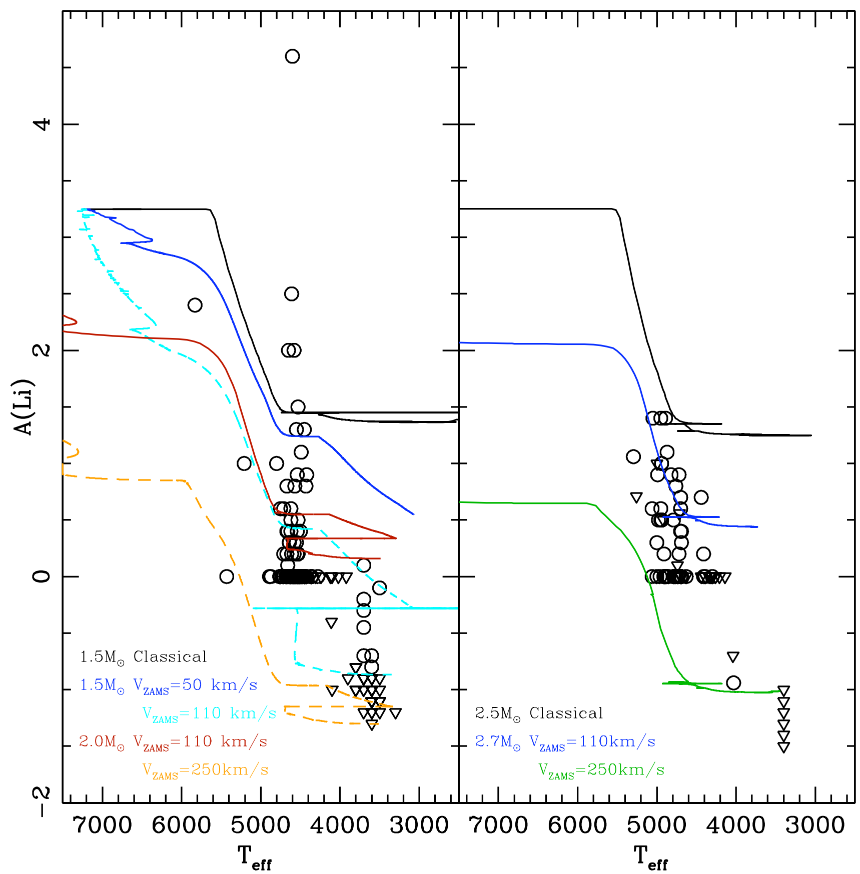




Lithium in Disk Red Giant Stars

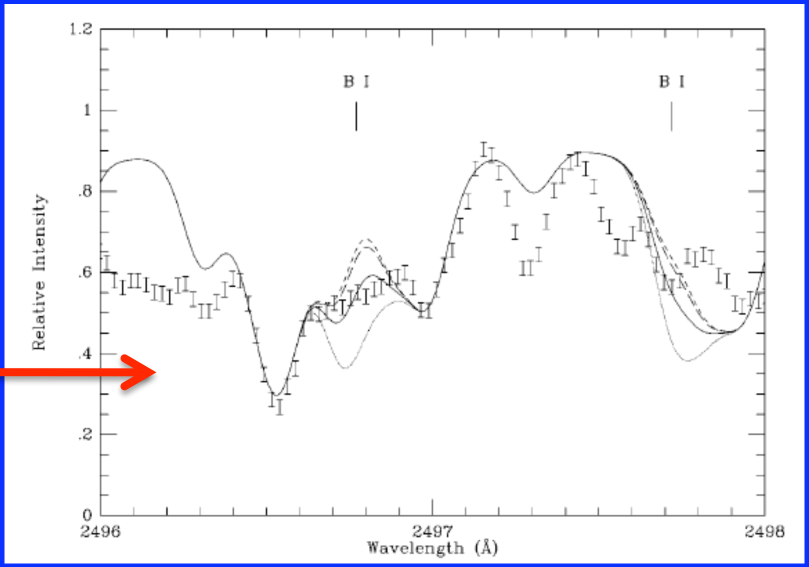
- Lagarde et al. (2009) – Poster.

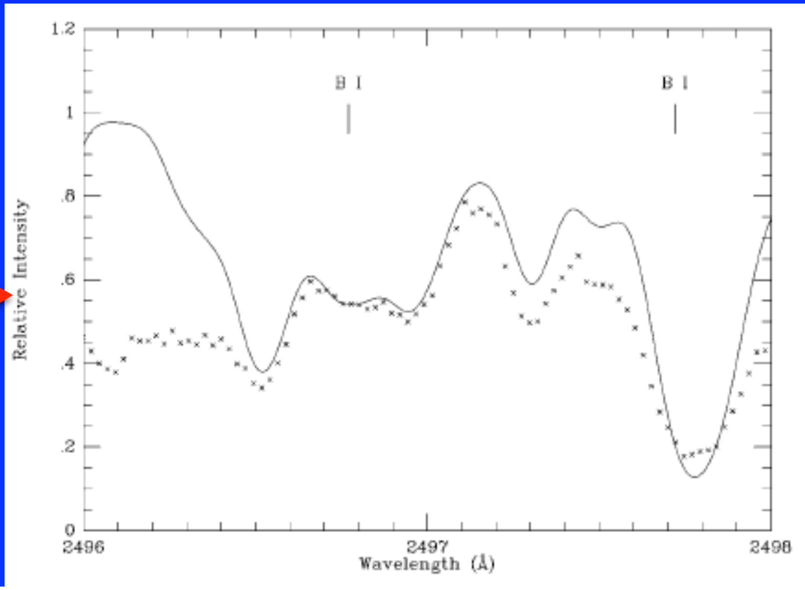




Boron Abundances and Mixing in Hyades Red Giants

- Duncan et al. (1998)—HST GHRS.
- Two Hyades giants + Beta Gem (K0).
- Depletion factor of ~10, in agreement with standard mixing.
- Hyades comparison F-dwarf.





Lithium in AGB Stars: Stellar Nucleosynthesis

- McKellar (1940): Strong λ6707 Li I in the carbon star WZ Cas.

  ”One good comparison star examined was RS Cygni, type N0pe, in the spectrum of which the equivalent width of the sodium lines was measured 53 angstrom units. It thus appears that probably the reason for the occurrence of the λ6708 line in the spectrum of WZ Cassiopeiae is an unusually high abundance of lithium in this star.”

- Torres-Peimbert & Wallerstein (1966):

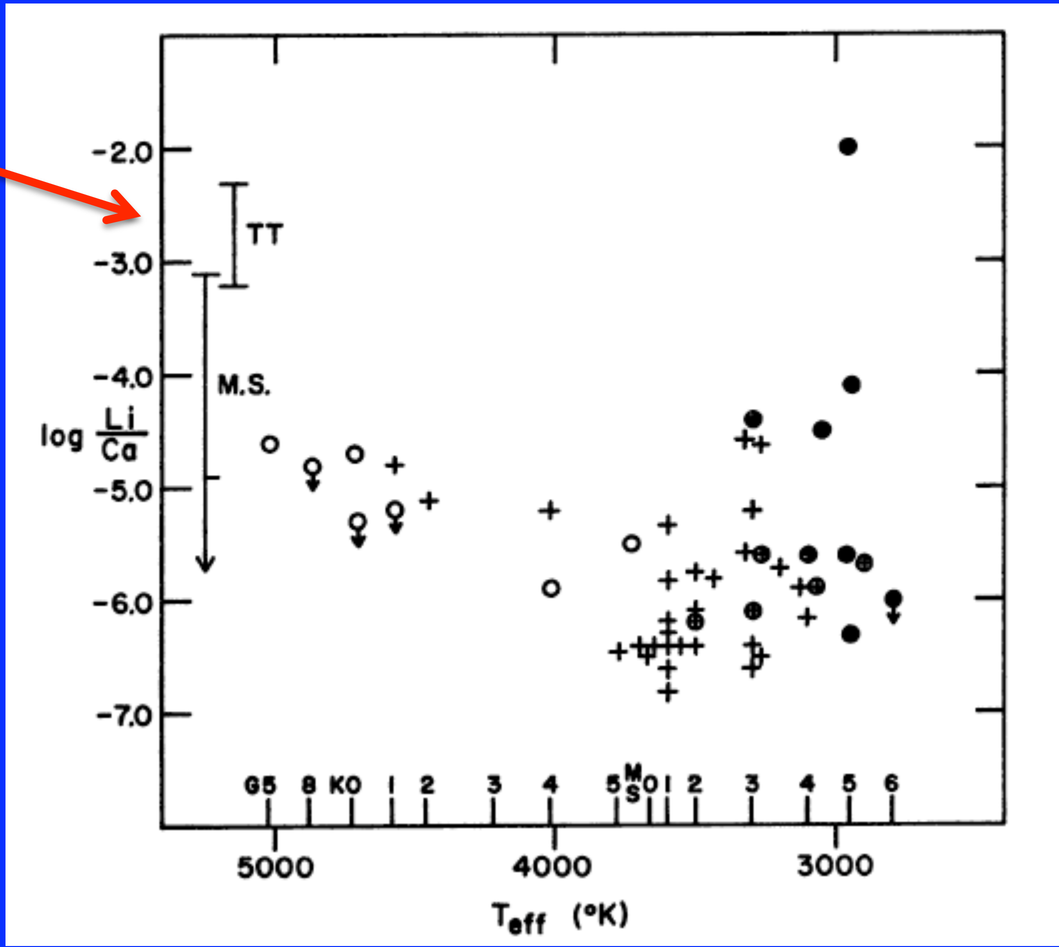
  C-star survey. 16 out of 30 disk C-stars have substantial lithium, 0 out of 5 high-velocity C-stars have detectable Li I—mass effect. Li/Ca abundance ratios vary of 6 orders-of-magnitude.

- Keenan (1967):

  S-star – T Sgr.

Placing Lithium Abundances in AGB Stars in a Stellar Evolutionary Context

- Boesgaard (1970)
  Quantitative Li/Ca in S stars.

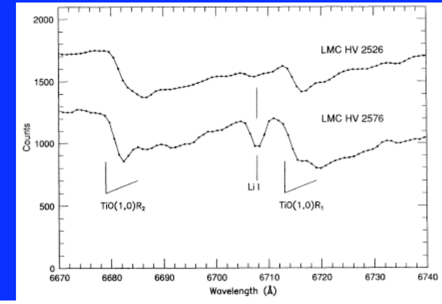


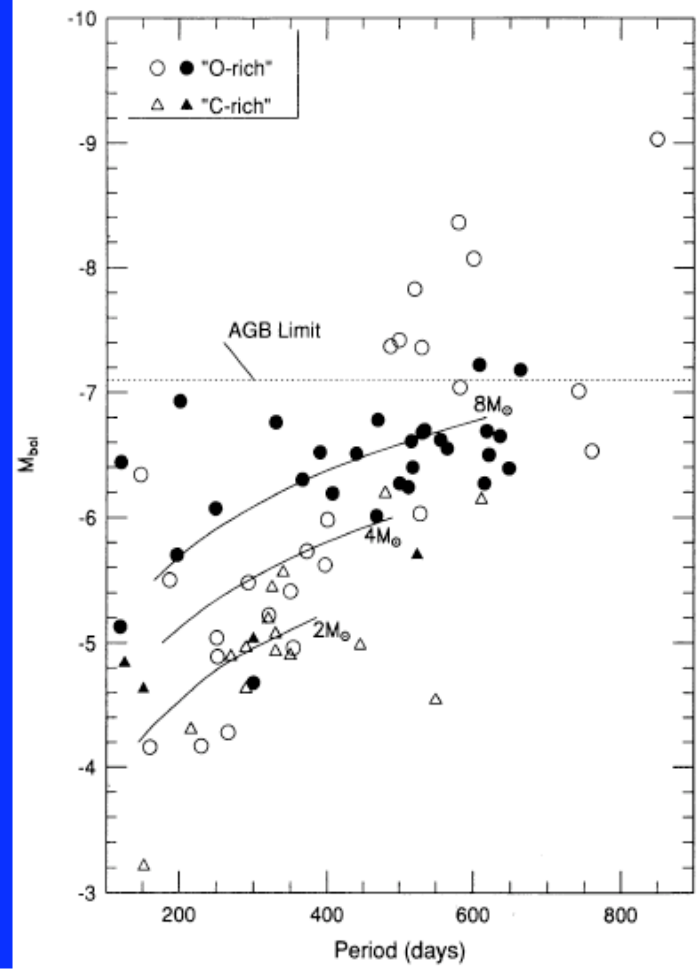
Interpretation

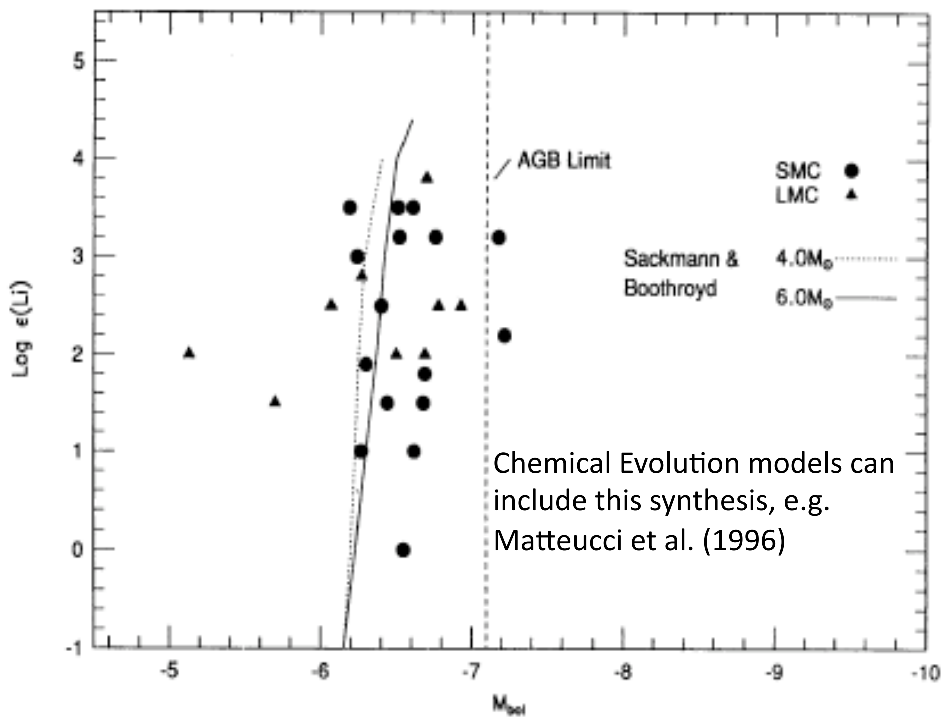
- Cameron (1955)
  $^{3}He(\alpha,\gamma)^{7}Be$
  $^{7}Be(e^{-},\nu)^{7}Li$
- Cameron & Fowler (1971)
  Association with AGB thermal pulses (TP-AGB).
- Scalo, Despain, Ulrich (1975)
  Hot Bottom Envelopes.

Lithium and AGB Hot-Bottom Burning in the Magellanic Clouds

- Smith & Lambert (1989;1990)
- Plez, Smith, & Lambert (1993)
- Smith et al. (1995)



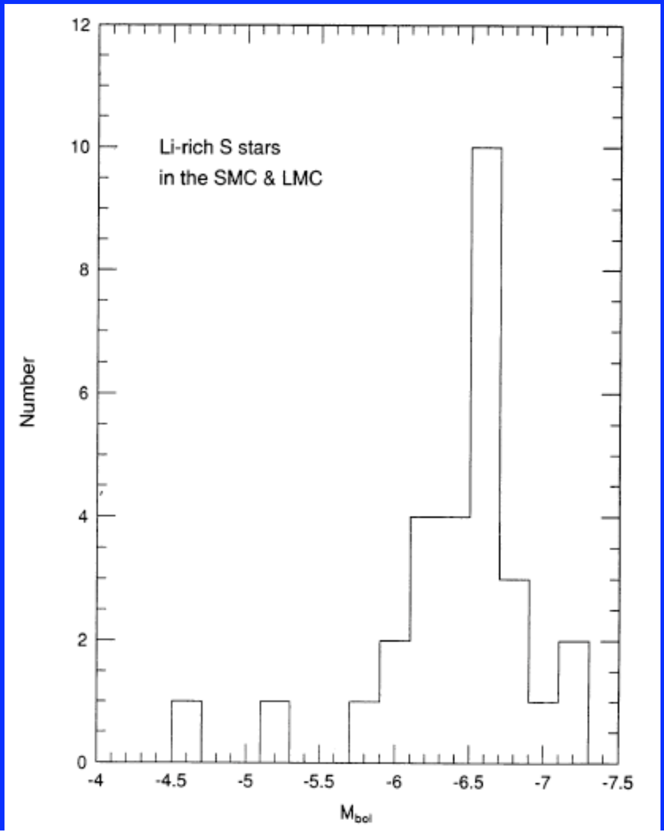


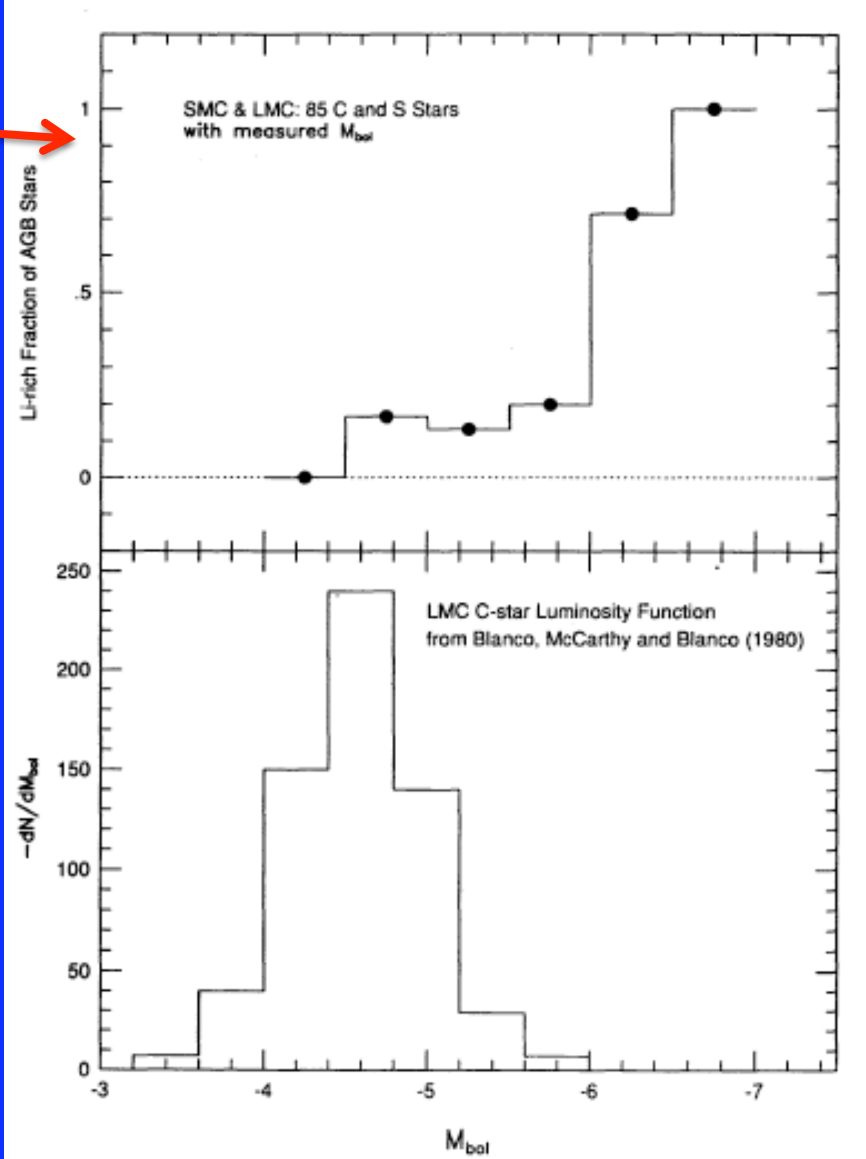


Chemical Evolution models can include this synthesis, e.g. Matteucci et al. (1996)

Hot-Bottom Burning as a Link between Carbon Stars and the Luminous S-stars

- Smith et al. (1995)
- Driven by the suggestion in Wood, Bessell, & Fox (1983)

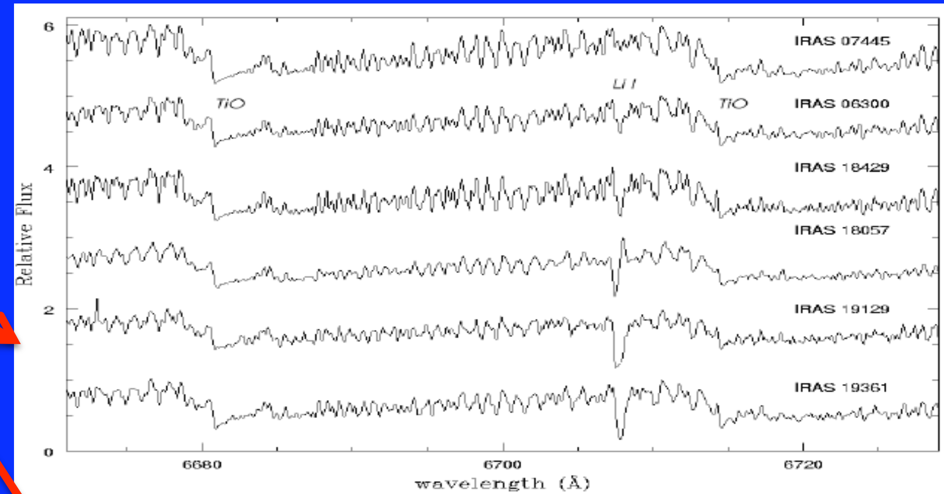


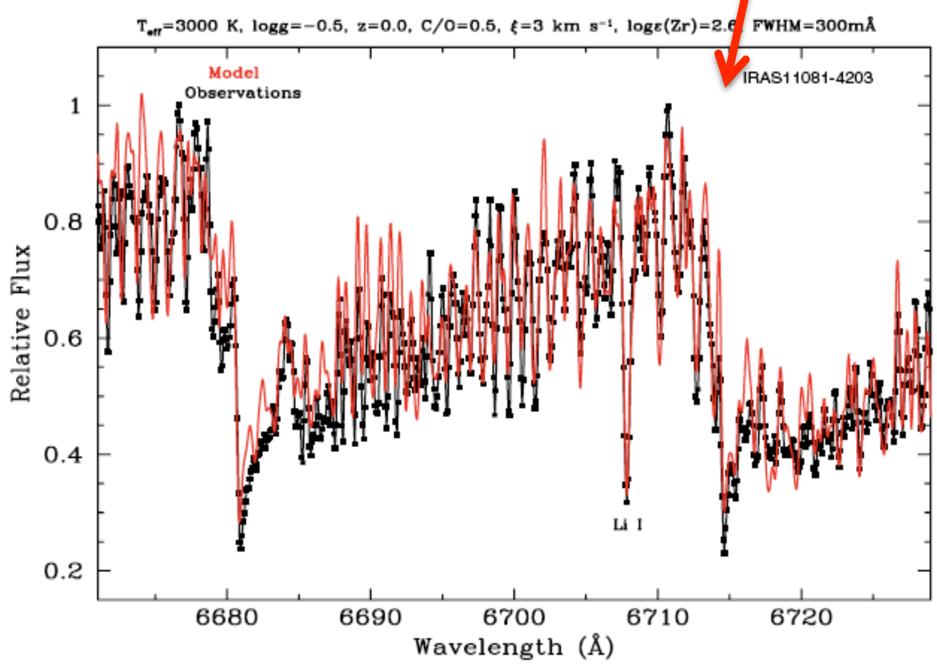


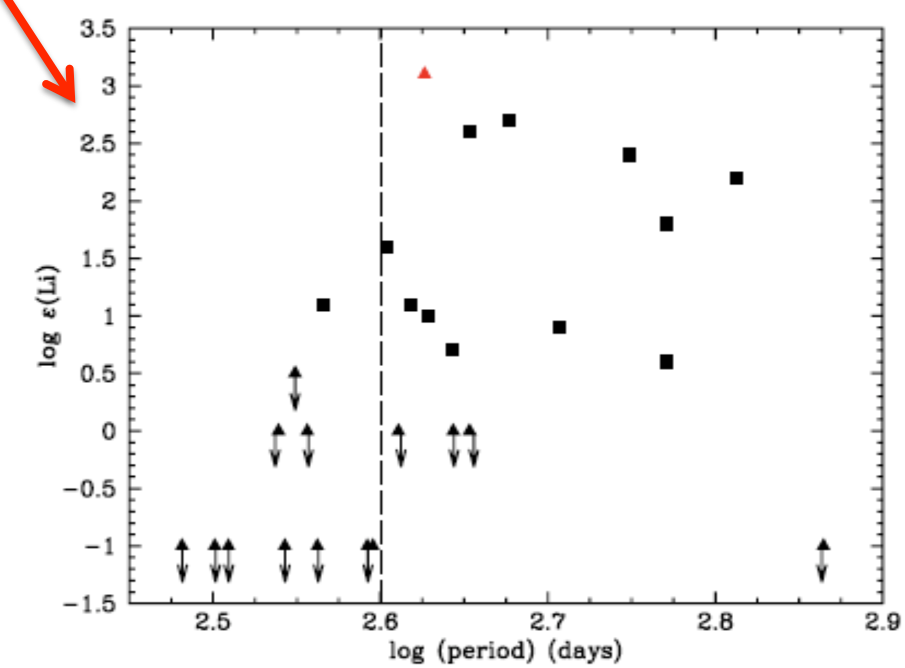
Back to the Milky Way with AGB Hot-Bottom Burning

- Garcia-Hernandez et al. (2007): Massive O-rich AGB stars.
- Vanture et al. (2008):

  Tc, Li, galactic lat.







K-Giants with Enhanced Lithium Abundances

- Evolutionary status?
- Where does the Li come from?

More history
May 1980

A K GIANT WITH AN UNUSUALLY HIGH ABUNDANCE OF LITHIUM: HD 112127

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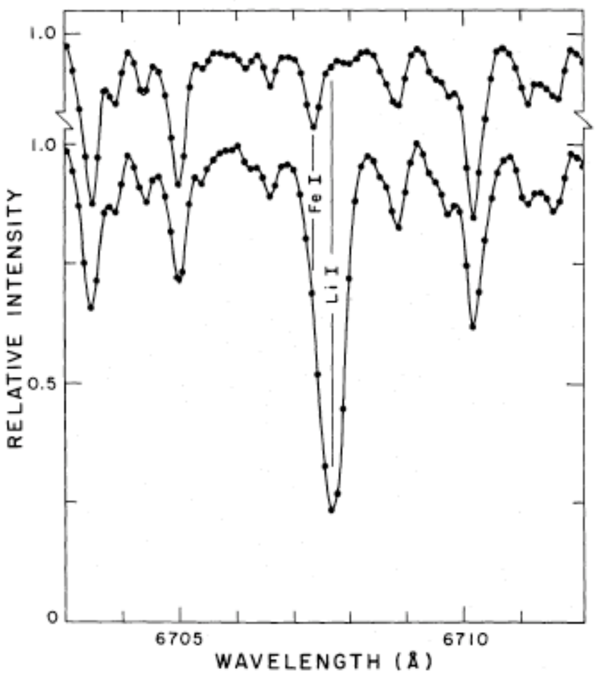
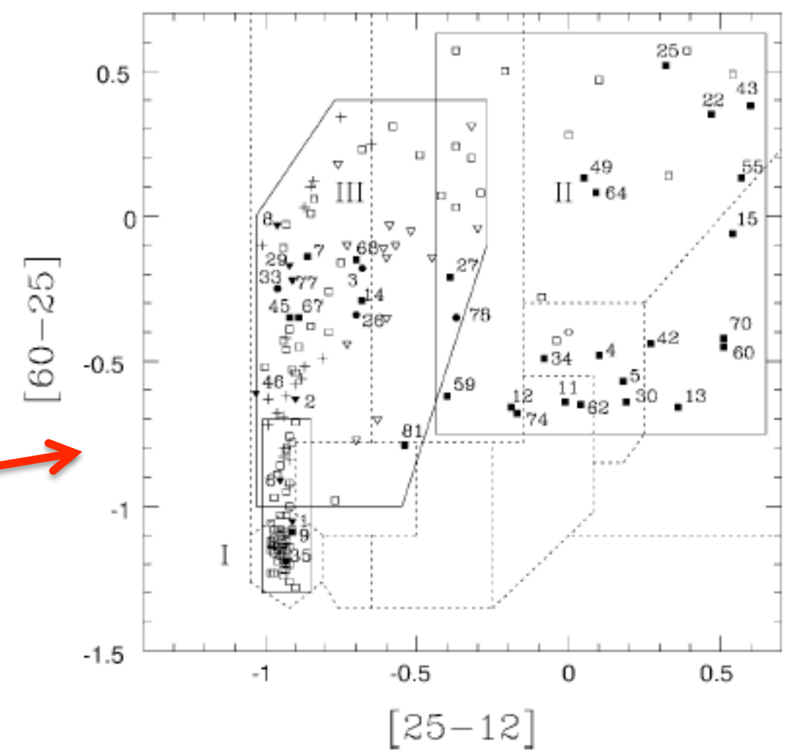
Received 1981 August 11; accepted 1981 October 28

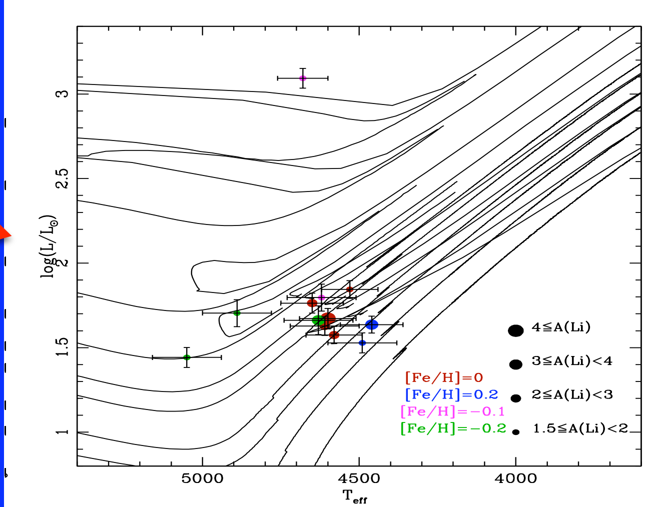


There remains one hypothesis for the origin of lithium in a few red giants that should be mentioned, no matter how unlikely it appears to be. Alexander (1967) suggested that the abundance of lithium in a red-giant atmosphere could be enhanced when a lithium-rich planet is consumed by an evolving star. Alexander's hypothesis suffers from gross uncertainties in the mass, composition, and orbit of such a planet but could also be related to the enhancement of the metals in the atmosphere of a red giant. Unfortunately, we see no way that ^{13}C could be enhanced when a red giant consumes its nearby planet(s). Such putative planetary systems, however, might be good candidates for the search for extraterrestrial intelligence because the inhabitants of their outer planets might be screaming for help as they watch their inner planets disappear into their central star.

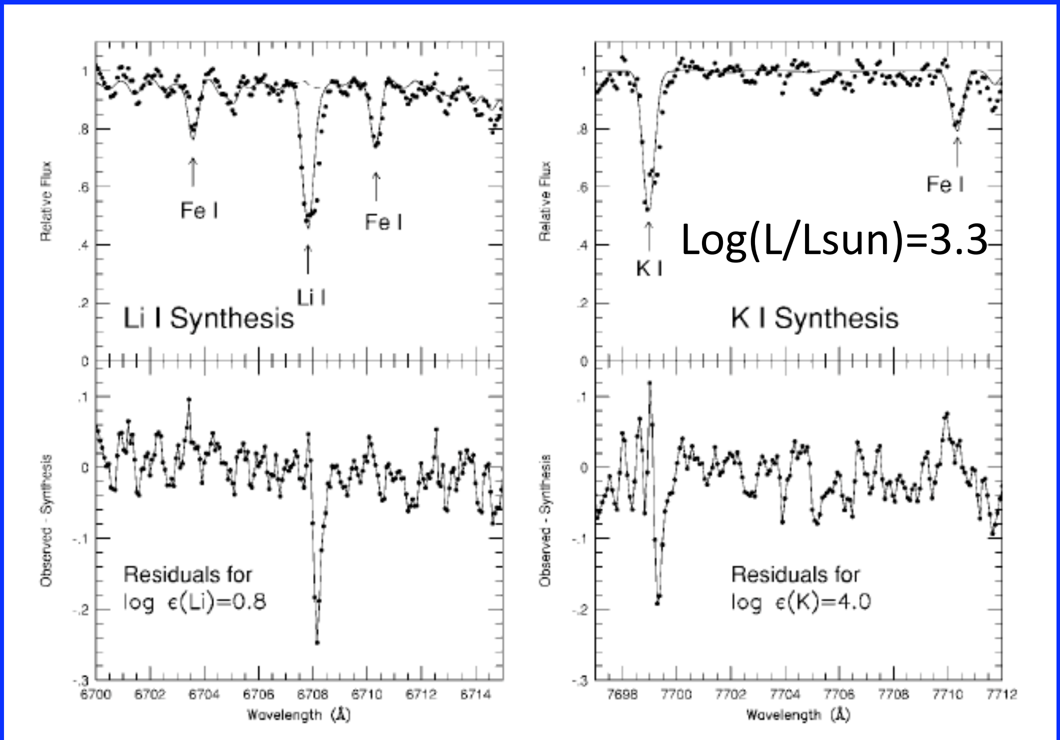
Properties of the Li-rich Red Giants

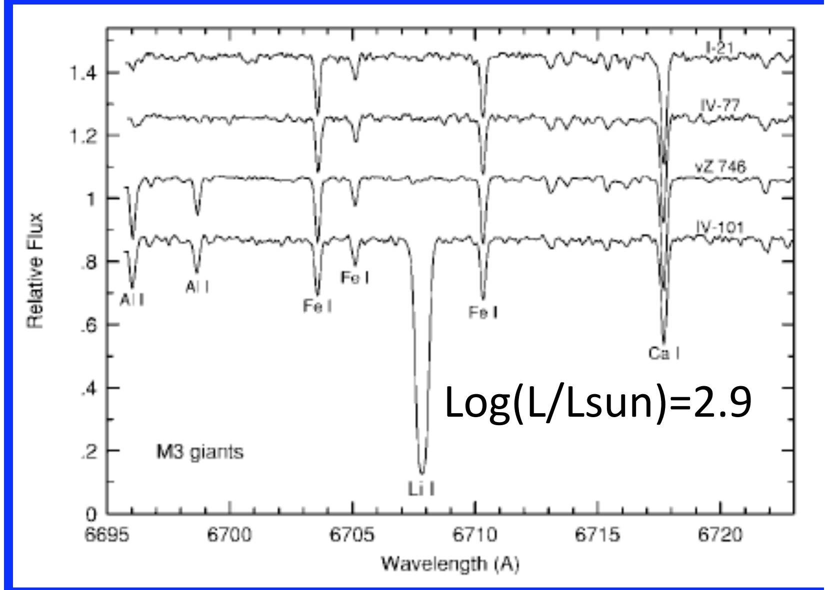
- Brown et al. (1989):
  ~1% of G-K giants.
- Fekel & Balachandran (1993):
  A significant fraction of Li-rich giants are rapid rotators.
- de la Reza et al. (1996):
  Circumstellar dust from IRAS colors.
- Charbonnel & Balachandran (2000): Possible association of the Li-rich giants with the Luminosity Bump.
- Lagarde et al. (2009)



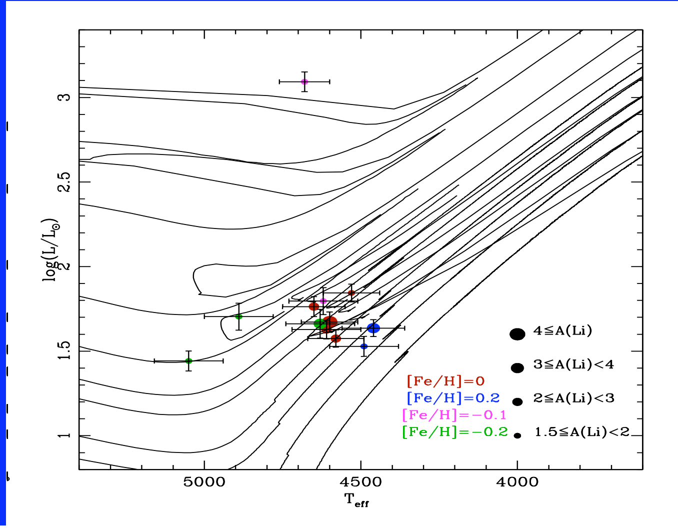


Lithium-rich Red Giants are in Globular Clusters, too!





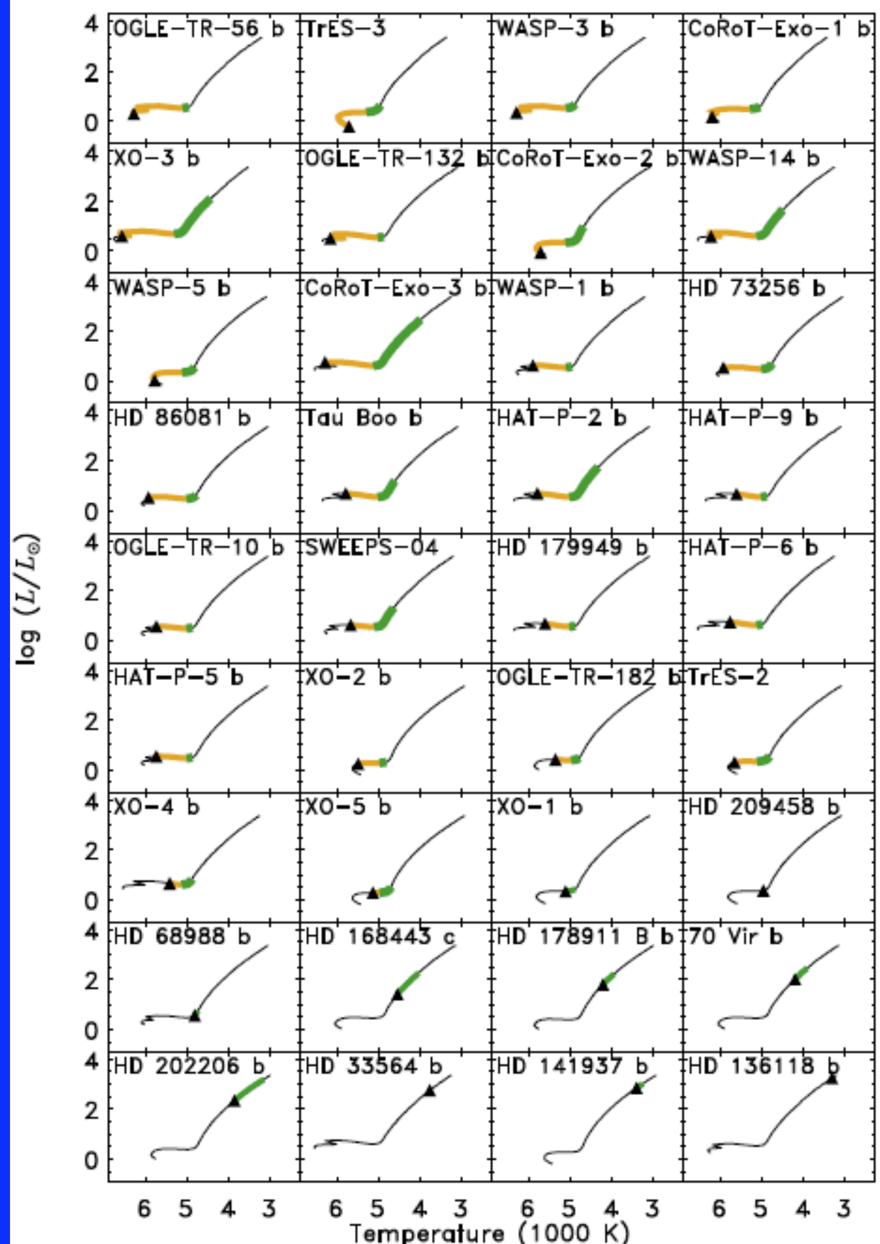
- Carney, Fry, & Gonzalez (1998): M5 (Log[L/Lsun]=3.1)
- Smith, Shetrone, & Keane (1999): NGC362
- Kraft et al. (1999): M5



Can Sub-stellar Ingestion Affect Rotation or Lithium?

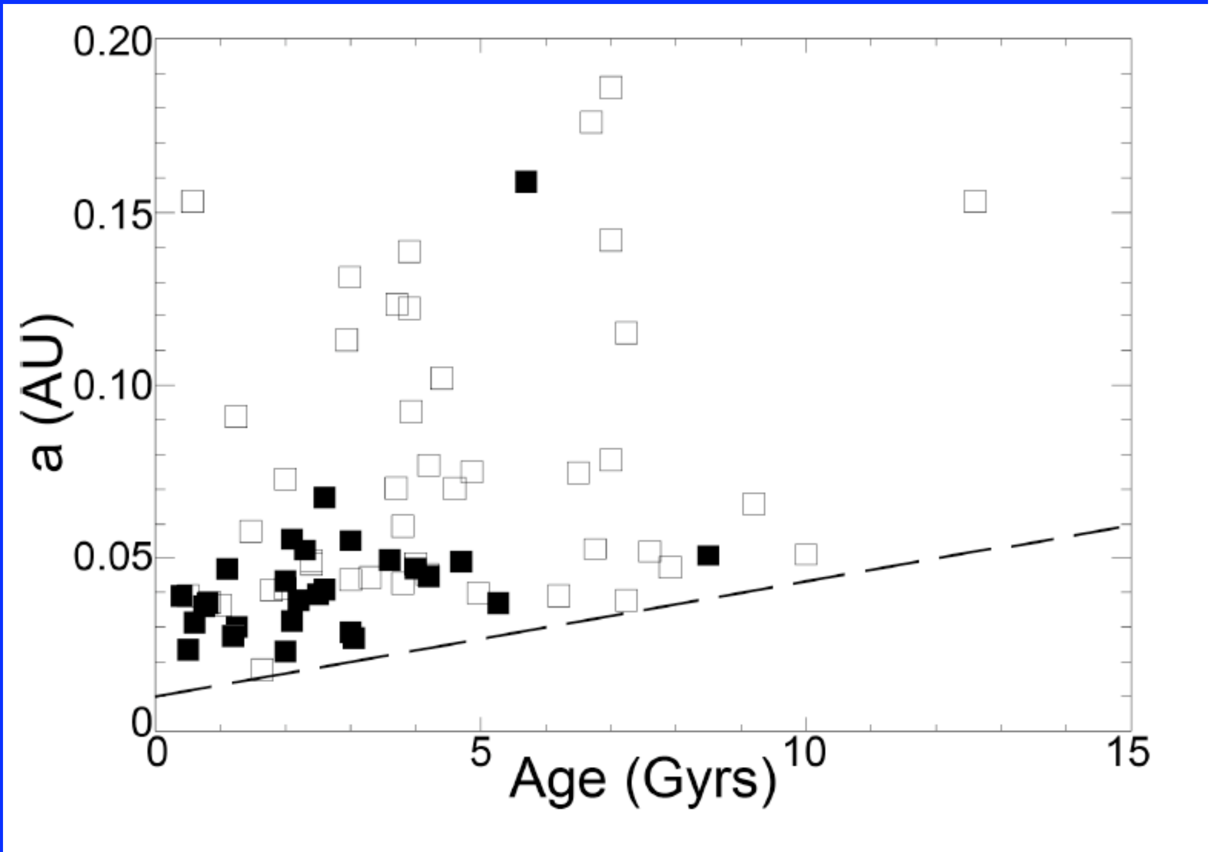
- Carlberg et al. (2009): Modelling rotation from assimilation.

- Lithium abundances would be affected—depends on ratio of planet mass to convective envelope mass, or chemical fractionation.



Tidal Decay and Ingestion Occurs

- Jackson et al. (2009)
- Model tidal evolution.
- Note Age – minimum semi-major axis relation.



Beryllium (or Boron) can Provide Constraints to the Lithium-rich Phenomenon

- Castilho et al. (1999): Beryllium abundances in two Li-rich K-giants.
- Beryllium is depleted as predicted by stellar evolution.
- Melo et al. (2005): Beryllium in 7 Li-rich giants. Same result.

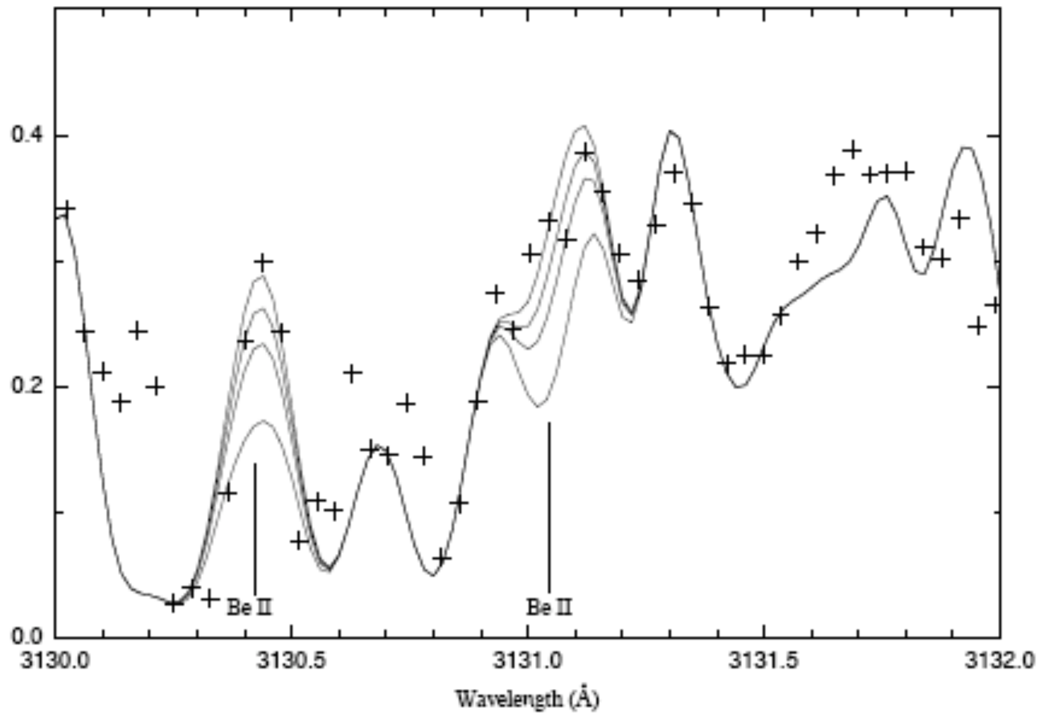


Fig. 7. HD 787: Observed spectrum (+ + +) and synthetic spectra (—–) computed with Be abundances: logN(Be) = –0.4, 0.0 (best fit), 0.4 and 1.2.

Summary/Conclusions

- Evolution along the RGB—first dredge-up followed by extra-mixing at the Luminosity Bump. Lithium created/destroyed. Lithium is a sensitive probe, more so than Beryllium or Boron. In a perfect world, we'd have all 3.
- AGB and Hot-Bottom Burning. Lithium is again a monitor. Conversion of C-stars to S-stars, primary ^{14}N.
- The Lithium-rich Giants. Still a mystery. Internal versus external processes. Could be a complex mixture.

Summary II

- RGB/AGB mixing processes + nucleosynthesis.
- BBN, Cosmic Rays, New Physics (?).
- Main-Sequence star microphysics.
- Connections to exo-planets.
- With Lithium, Beryllium, and Boron we have it all; we can be at one with Nature.

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- With Lithium, Beryllium, and Boron we have it all; we can be at one with Nature.
- “I am at two with Nature” –Woody Allen
- So… “We are at three with Nature” - LiBeB