CS14 - A Session on the Thorny Issue of Stellar Ages

Eric Mamajek - 2006

KITP Workshop → Alyssa's Intro on Monday 5.11
"what is the best way to measure stellar ages?"

IAU 258: The Ages of Stars

David Soderblom - 2008

Ages diagnostics cool stars

- HR diagram (theoretical isochrones)
- Asteroseismology (interior structure)
- Li-depletion boundary in clusters (evol. tracks)
- Rotation & activity (R'_{HK}, P_{rot}, V_{eq})
- Kinematics
- Age of companion/group members (e.g. white dwarf cooling, high-mass evolved siblings)
- Uranium-Thorium cosmochronology
- Others…

Ages & age spreads in young clusters and associations: Status report

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Collaborators: P. Sestito, V. d'Orazi, S. Manzi - Arcetri
G. Sacco, R. Pallavicini - Palermo
W-.J. De Wit – Leeds Univ.

SCIENTIFIC QUESTION

Does the observed spread in luminosity in HR diagrams of young clusters and associations correspond to a real spread in age?

↓

Duration of the star formation process

> Alternative approach: use of lithium to determine nuclear ages

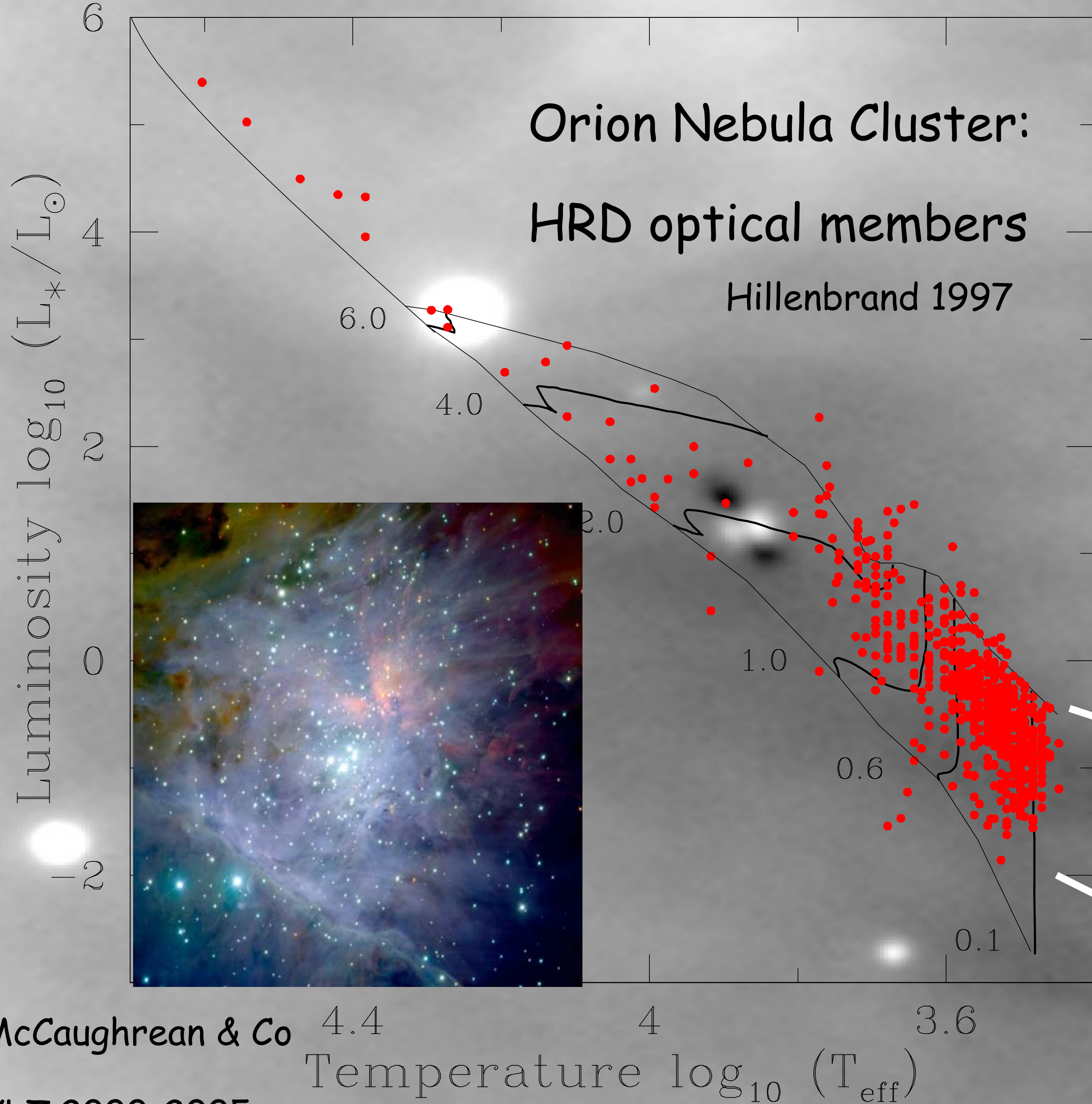
> Avoid SFR → young clusters: most stars form in clusters

> Find new PMS (10-50 Myr) clusters

SFH of clusters & associations

- SF only occurs above threshold
  N_{th} (SF>4 mag) >>N(HI→H_2~0.5 mag)
  function of local conditions (G_o, x_e, …)
- SF starts at low rates & increases in time
- SF accelerates with e-folding times
  t~1-3x10^6 yr, followed by decelaration
- SF occurs over an extended time period:
  age spread

(Palla & Stahler 2000, 2003)



McCaughrean & Co

VLT 2000-2005

Fast or slow?

Most stars formed ~1-2 Myr ago

Notice the large ΔL~10

↓

t-spread: real or not?

SFH of clusters & associations

- *Age spread (~10 Myr) >dynamic time (<2 Myr)*

- *Is spread real? Two camps…*

  yes → slow, quasi-static, B-T driven SF
  low SFE due to rapid deceleration

  no → rapid, dynamic SF
  low SFE in shells/filaments

- *In both cases, most of SF occurs in a short time in one case there is a tail of older stars → hunt!*

fast or slow?
how to decide?

GAS: dense core chemistry
HI → H_2 indicates t≥2-3 Myr (Li & Goldmsith 2005)

STARS: age spreads in PMS clusters:
diagnostics from Li-depletion →
test based on nuclear physics independent of HRD

Lithium as a secure age indicator for low mass PMS stars

1. Li is burned at the relatively low temperature of ~3 MK

2. Properties of low mass ($M < 0.5\ M_{sun}$) stars during PMS contraction:

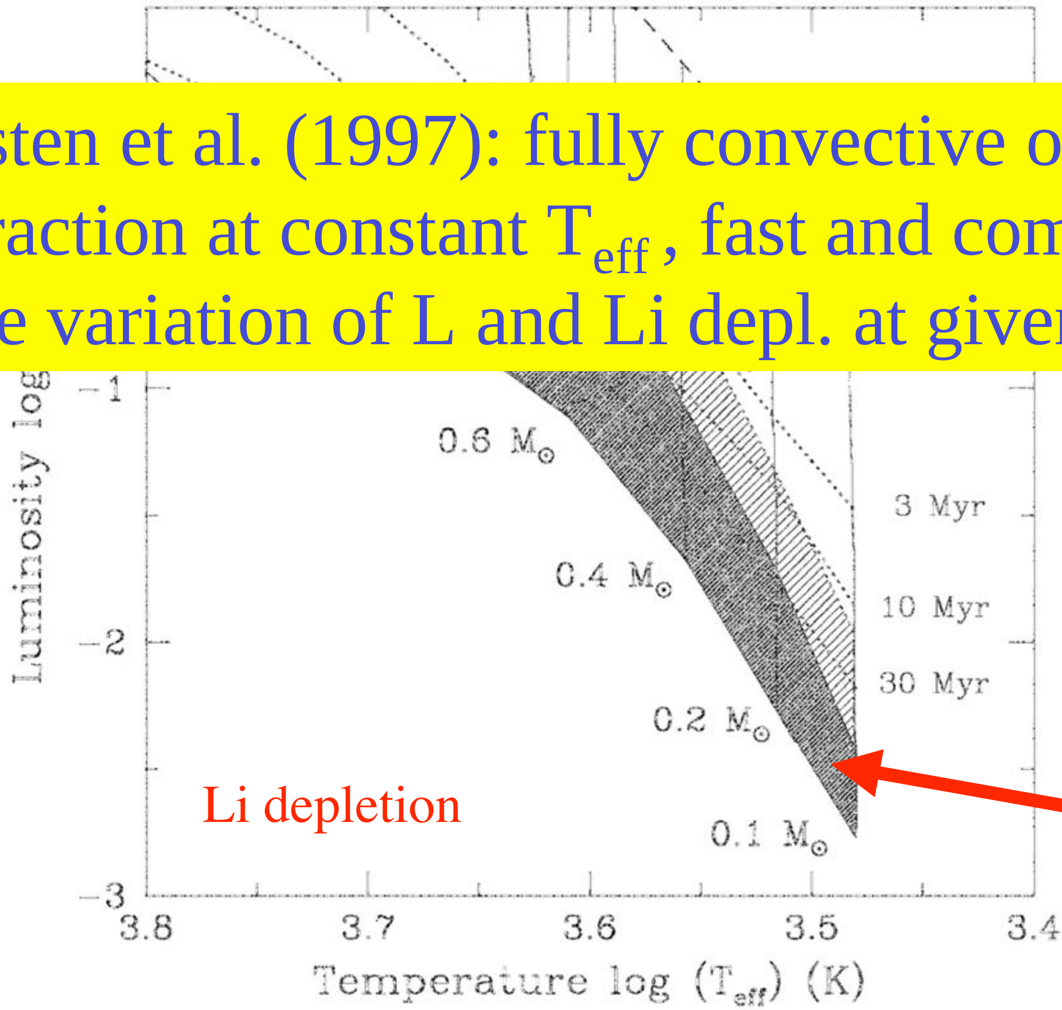
i. fully convective (surface material readily mixed with interior + little uncertainty in physics and depletion history)

ii. core temperatures increase as they contract to the MS eventually reaching 3 MK

iii. the higher mass stars reach that temperature first

Using the lithium line at 6708 Å as a diagnostic of depletion history in very young clusters

Bildsten et al. (1997): fully convective objects, gravitational contraction at constant T_{eff}, fast and complete mixing.
Time variation of L and Li depl. at given age.



up to 1/10 of the initial value

Complete depletion

LI TEST ON YOUNG CLUSTERS USING VLT/FLAMES

ONC: 84 + 57 high probability members

σ Ori: 98 cluster candidates

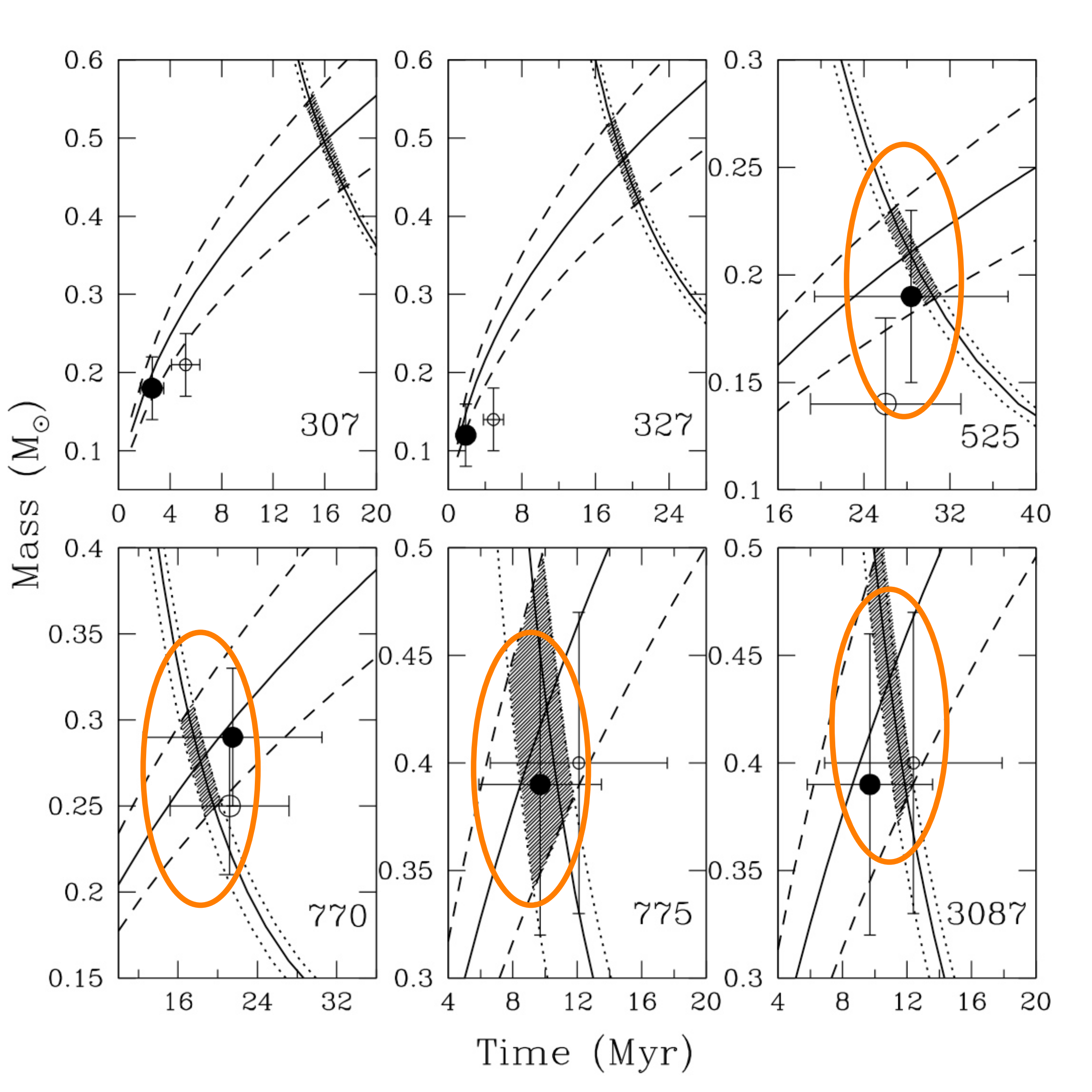
Upper Scorpius: 41 candidates

PMS cluster IC4665 (30-100 Myr): 168 candidates

IC 2602, NGC 2632: ~100 candidates each

Comparing isochronal and Li-depletion ages

PMS



4 stars:
M & age are fully consistent (5%!):

Li: M~0.43 M_0 t~12 Myr
HR: M~0.39 M_0 t~10Myr

Li: M~0.20 M_0 t~25 Myr
HR: M~0.20 M_0 t~25 Myr

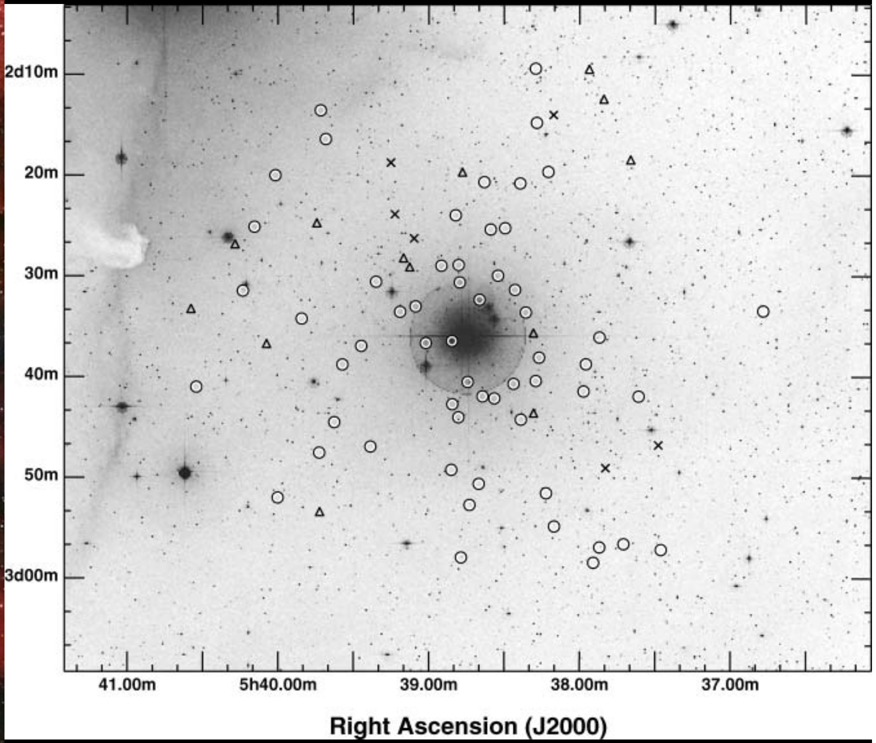
2 stars: inconsistency

$t_{HRD} < t_{Li}$

Orion Cluster did not form in a single, rapid burst…

Palla et al. 2005, 2007

The case for Sigma Orionis 1-3 Myr

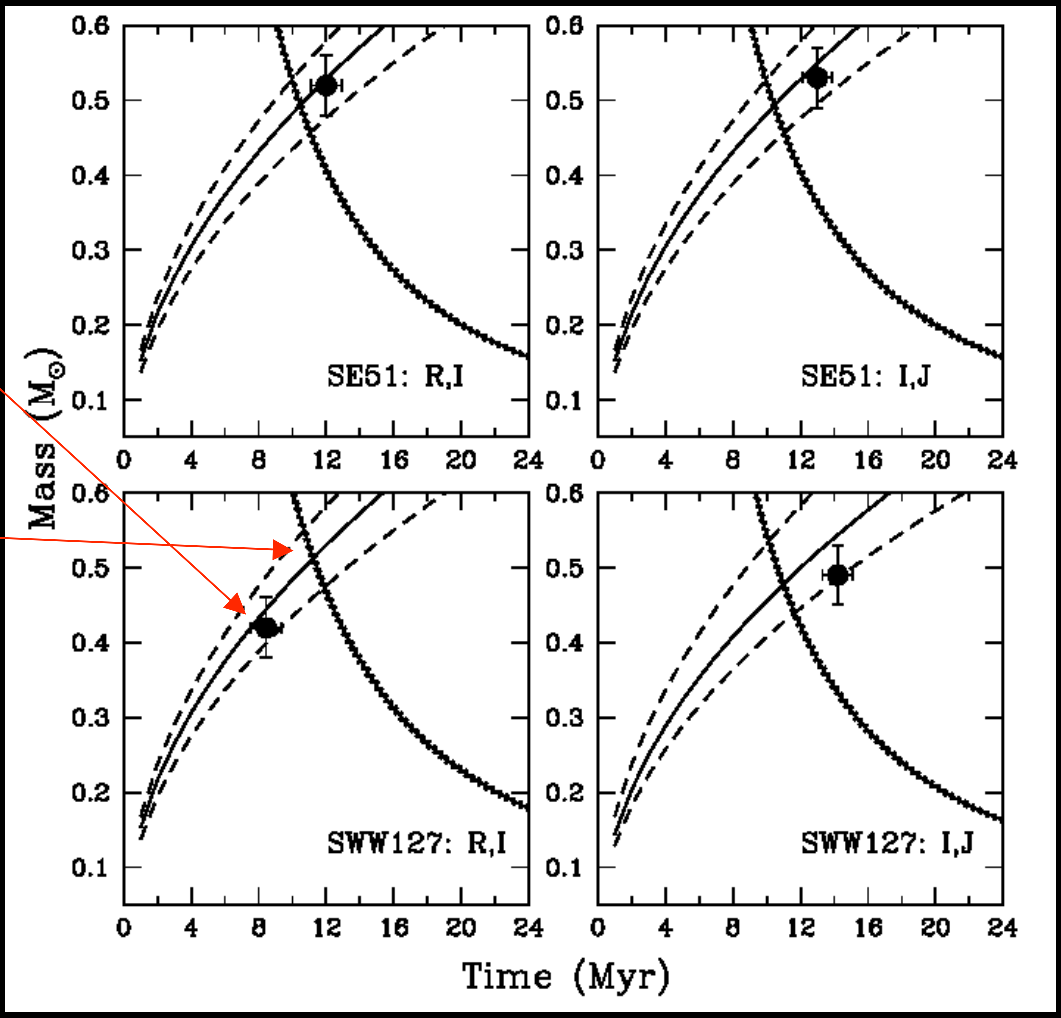


σ Ori: age spread

Using photometry and pms models

Using Li abundance

Star formation process starts more than 10-15 Myr ago

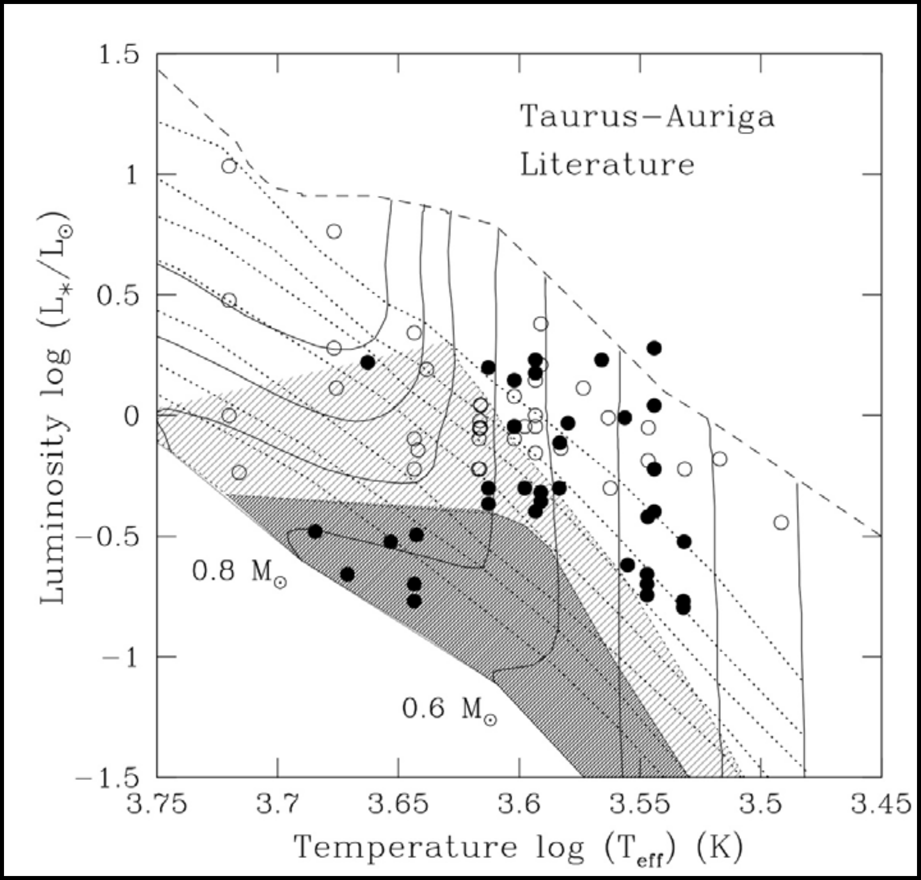


Sacco et al. 2007, A&A, 462, L23

Taurus-Auriga: re-assessment of Li

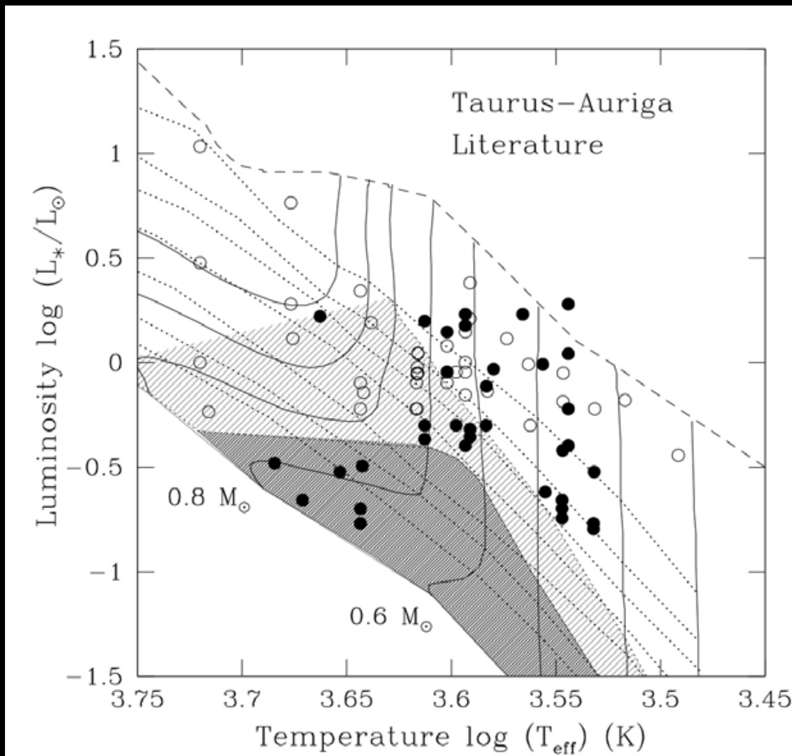
Basri et al. 1991
Martin et al. 1993
Magazzù et al. 1994…

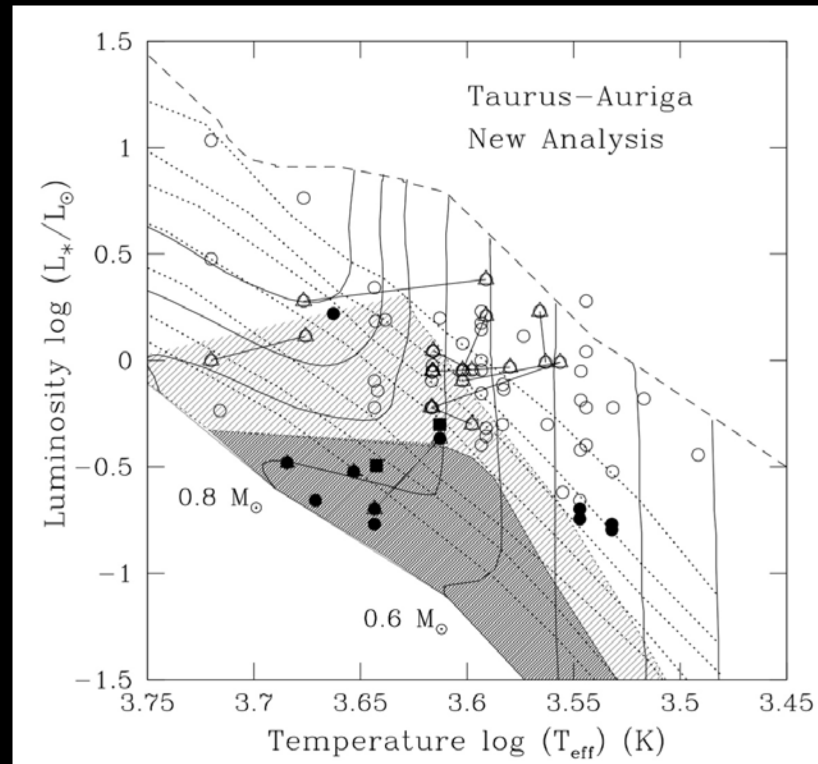
70 cTTS & wTTS
→many with Li=Li(IS)
→several with depleted Li by factor of 2-100
→inconsistent HRD location



Need: Homogeneous updated Li analysis – Membership & location -→ surprises?

Taurus-Auriga





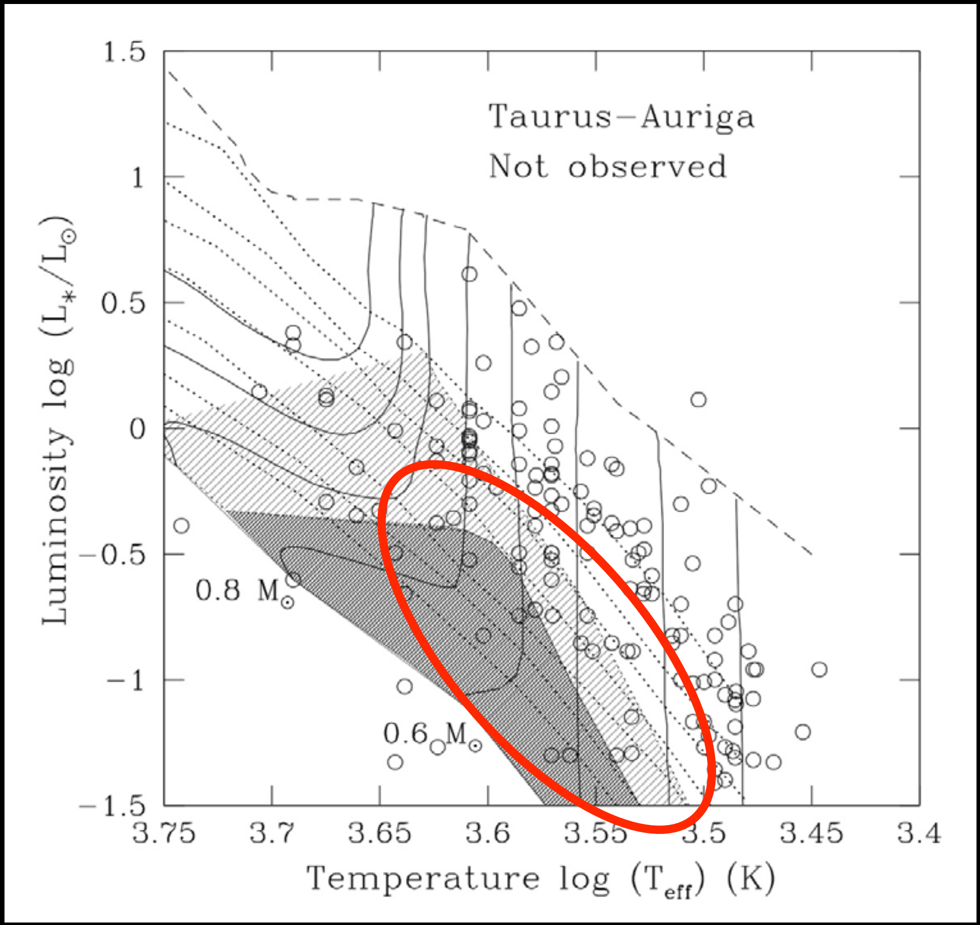
Filled dots: Li-depleted stars - Empty dots: undepleted stars

Result: most stars have n(Li)=initial consistent with HRD position
Li-depleted stars ~ in the correct Li-depletion region

Sestito, Palla & Randich 2007, in prep.

Taurus-Auriga

"Complete" population of Tau-Aur: stars without Li-abundance determination → sample of candidate Li-depleted stars

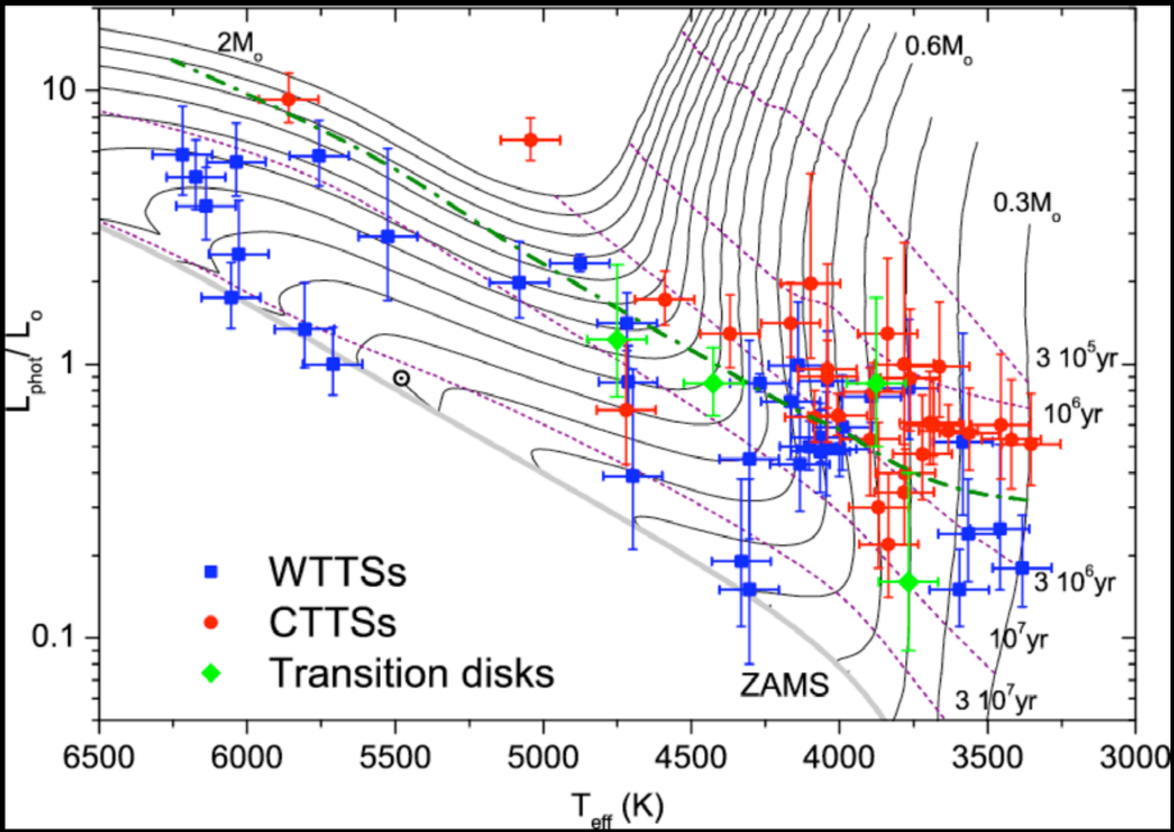


Sestito, Palla & Randich 2007, in prep.

Taurus-Auriga

* Individual parallaxes for many stars of Tau-Aur, members of same kin. group: 94 stars/systems with same spatial velocity - 67 stars with kin. parallax (Bertout & Genova 2006; d=139±12 pc)

- Bertout et al. 2007: determine stellar parameters for 72 stars
- Study of relationship between CTTS & WTTS: different ages →CTTS younger

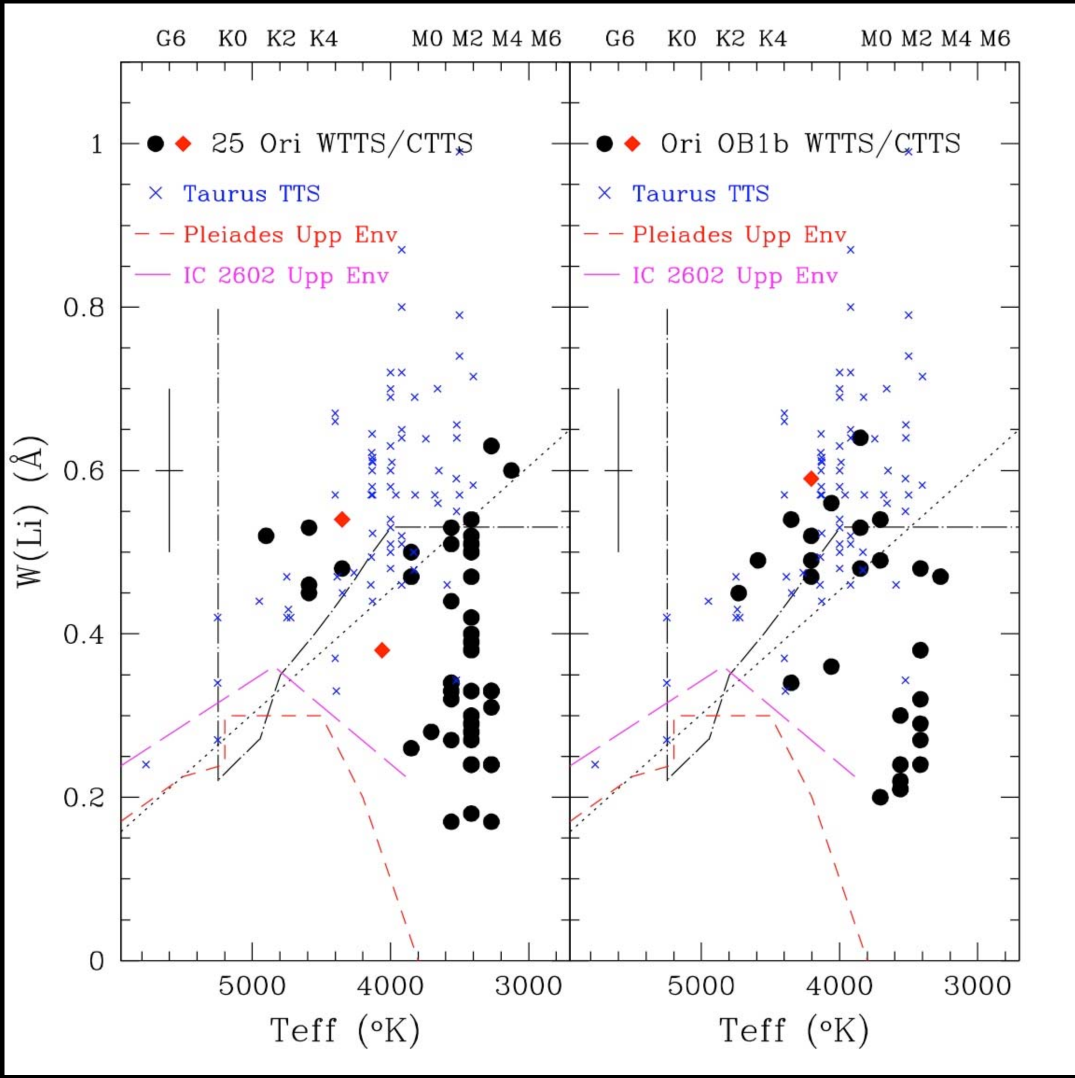


Evolution from CTTS to WTTS when the disk is fully accreted: average disk lifetime:
$4\times10^6\ (M/M_0)^{0.75}$ yr

Age spread confirmed complete down to M=0.4 M for t<5 Myr

Bertout, Siess & Cabrit 2007, A&A Lett.

25 Ori



Briceno et al. 07:
North of ONC
Distinct group
Age: ~10 Myr

Substantial spread of EW(Li)

Sestito et al. 2008

The L … rs

• Stars with 0.1–0.4 M … -20 Myr (fully convective objects), w …

• Li abundance is indi …

sharp transition (L … sters

different degree c …

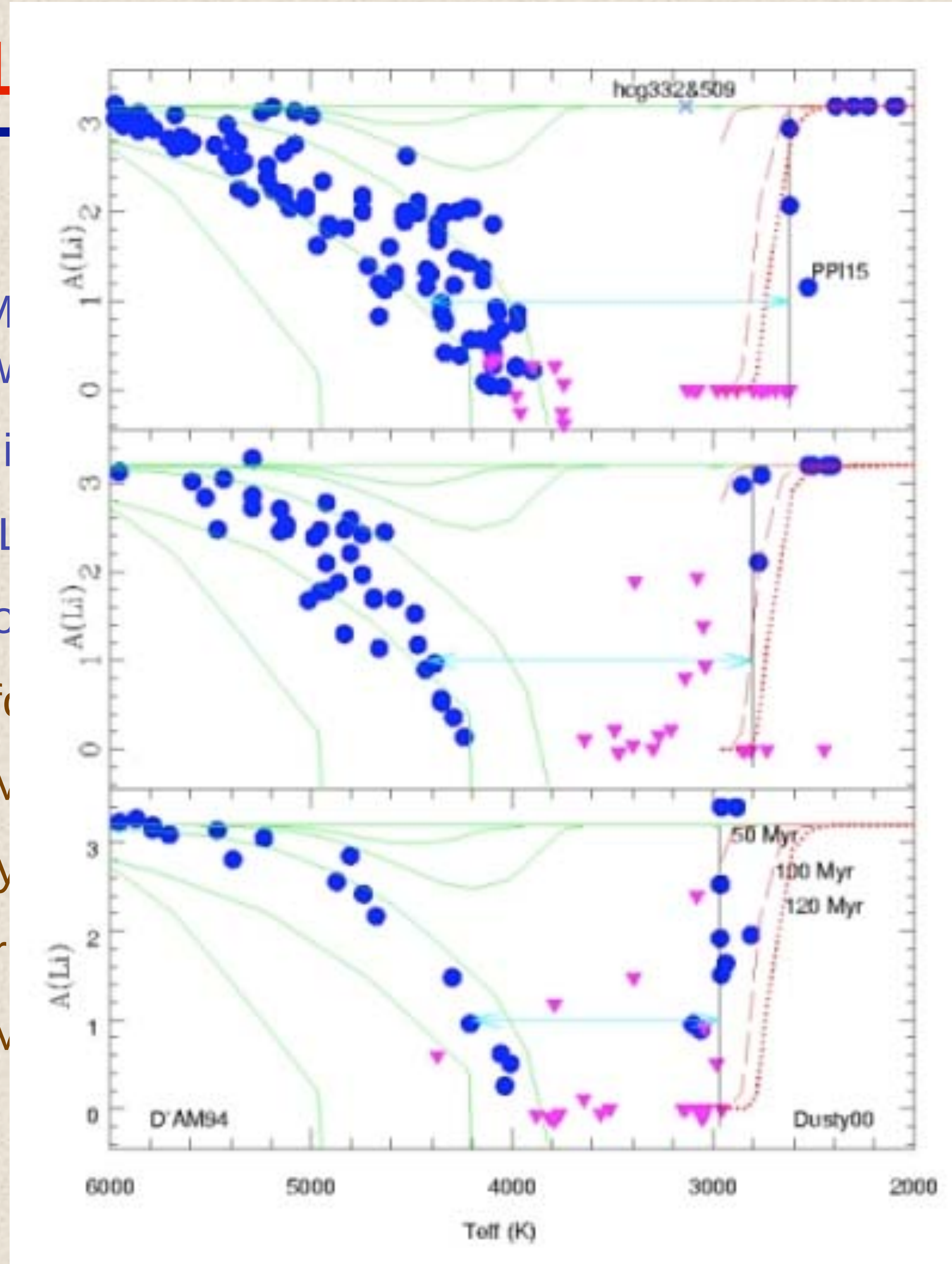
• Until recently, LDB fo …

e.g. Pleaides - 125 M …

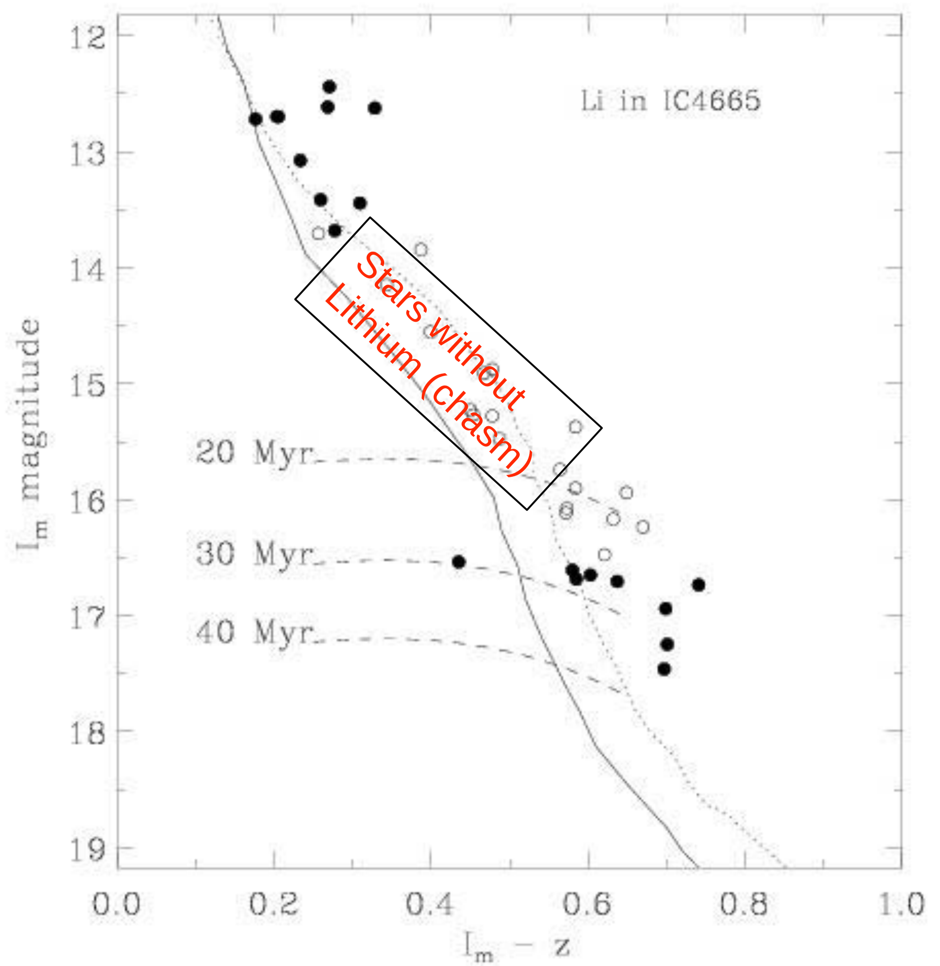
alpha Per - 87 My …

IC 2391 – 48 Myr …

NGC 2547 – 40 M …



IC4665: LDB



Litihium depletion boundary (LDB) in IC4665: I=16.5

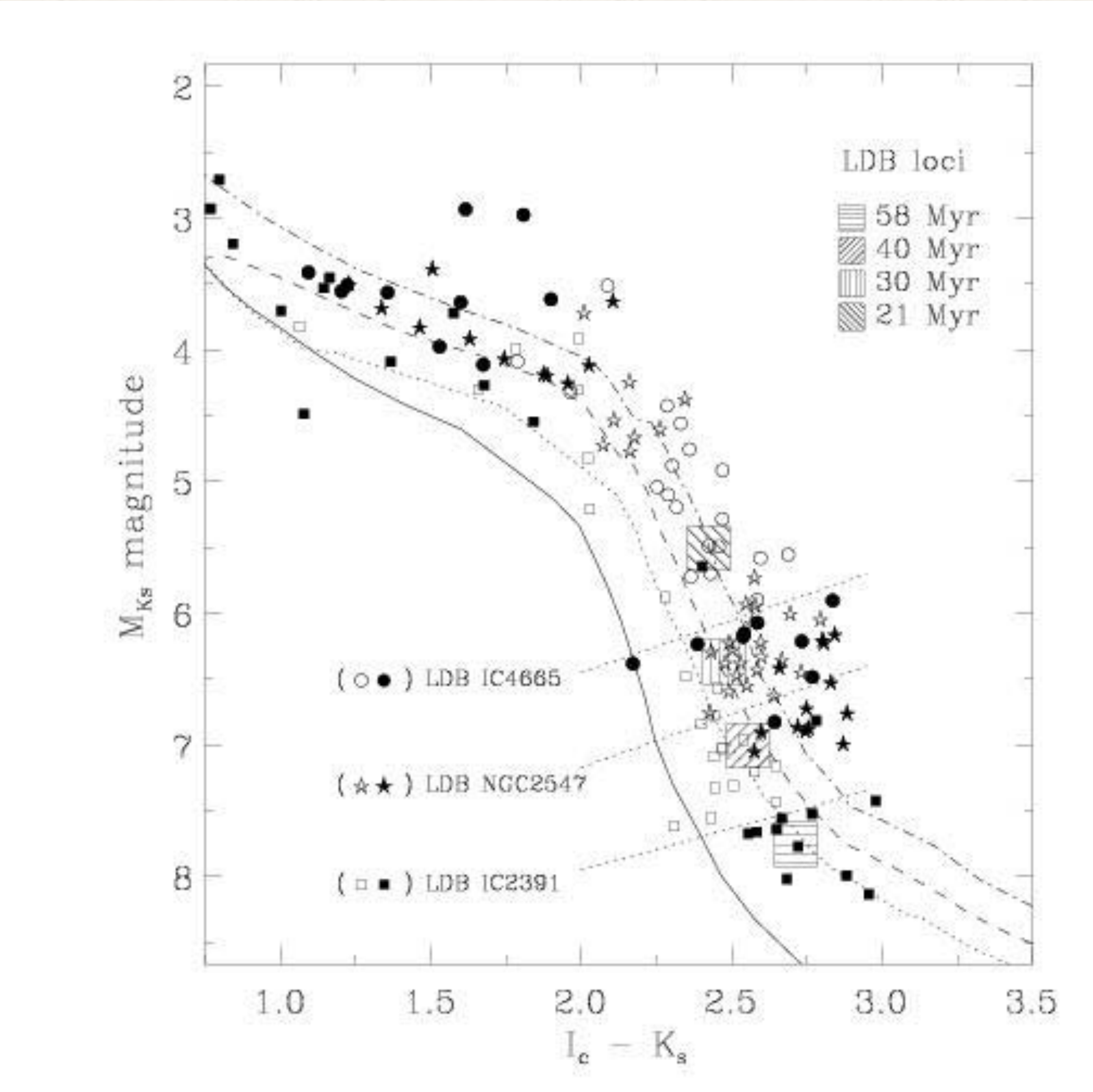
Age: 27±5 Myr → youngest PMS cluster

LDB & TO age: consistent! also NGC 2547

IC4665 is a confirmed PMS cluster

Manzi et al. (2007 A&A in press)

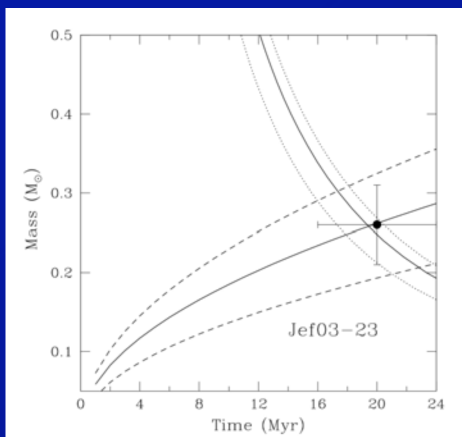
IC4665: comparison with PMS clusters

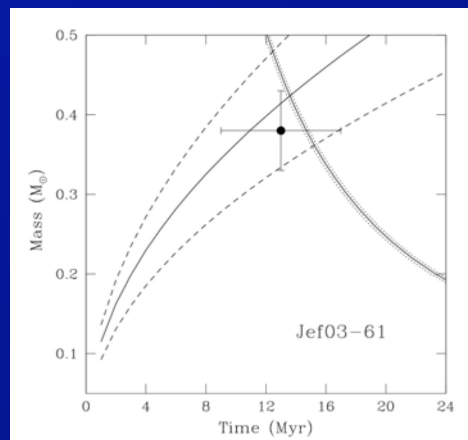


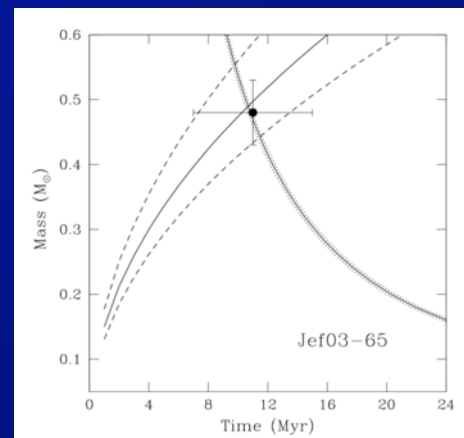
The LDB moves towards fainter magnitudes
and the cluster sequence moves to the left as the age increases

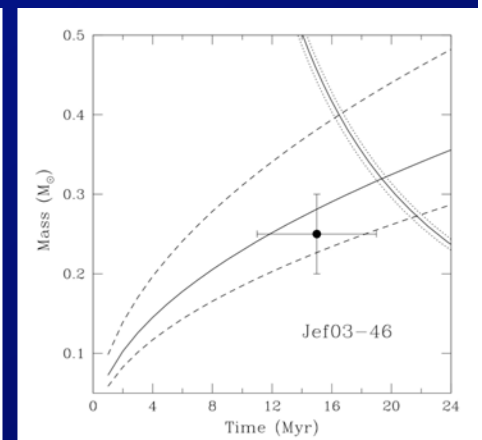
NGC 2547

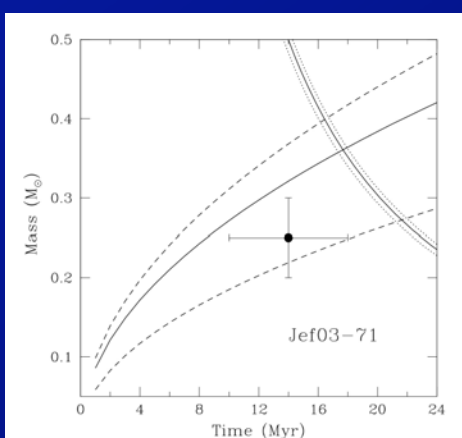
Can we determine the age spread in the Li chasm?
Li-partially depleted stars with known (Teff,L)

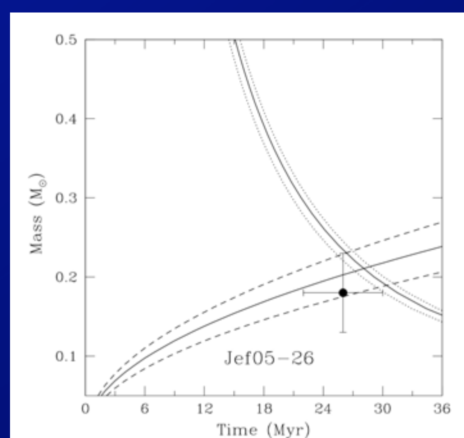


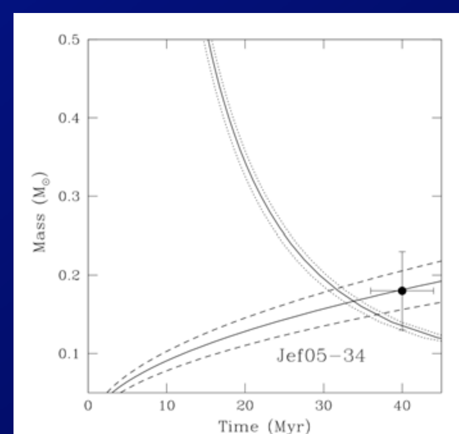


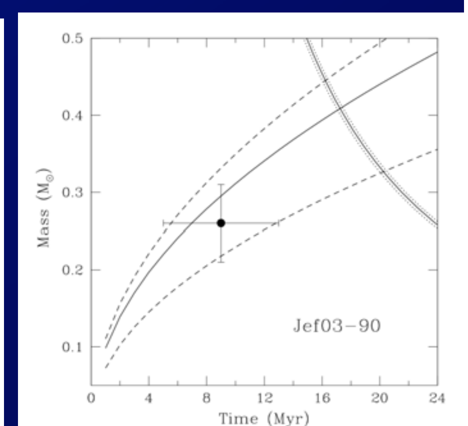












Some ideas on why star formation is slow

→ *SFR per unit free fall time <<1 at $n \sim 10^5$ cm-3 (Krumholz & Tan)*

→ *unbound GMC/collapsing cluster models: small mass fraction is bound & protocluster collapse globally (MacLow, Klessen, Clark, Bonnell, Vazquez-Semadeni…): SFR too high*

→ *SFR determined by large-scale gravitational instability in a galactic disk (Li, Tasker & Bryant)*

→ *B models: star forming clouds are magnetically subcritical (Shu, Tassis & Mouschovias, Li…)*

→ *Virialized turbulent clouds (Tan, Krumholz, McKee)*

→ *Quasi-static contraction of turbulent clouds (Huff, Stahler)*