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Magnetic Activity in Low Mass Stars
... Does it Depend on Rotation?

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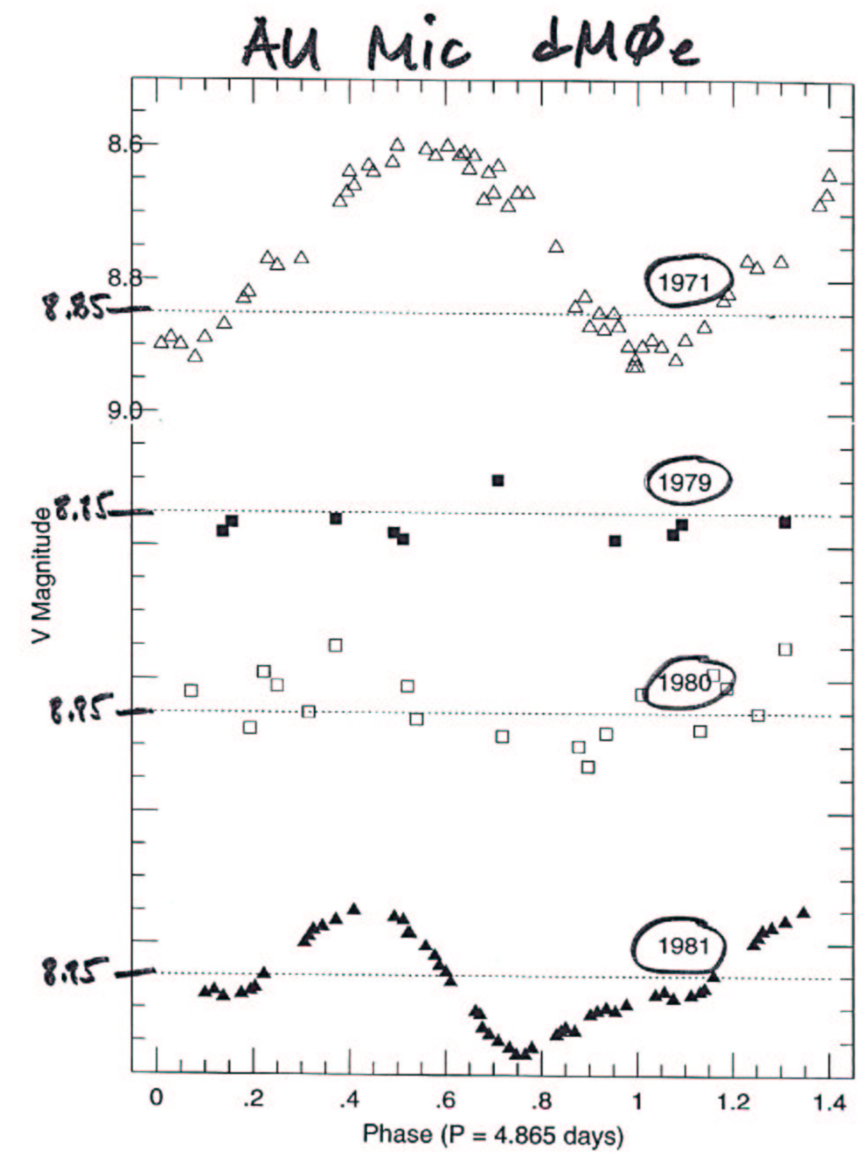
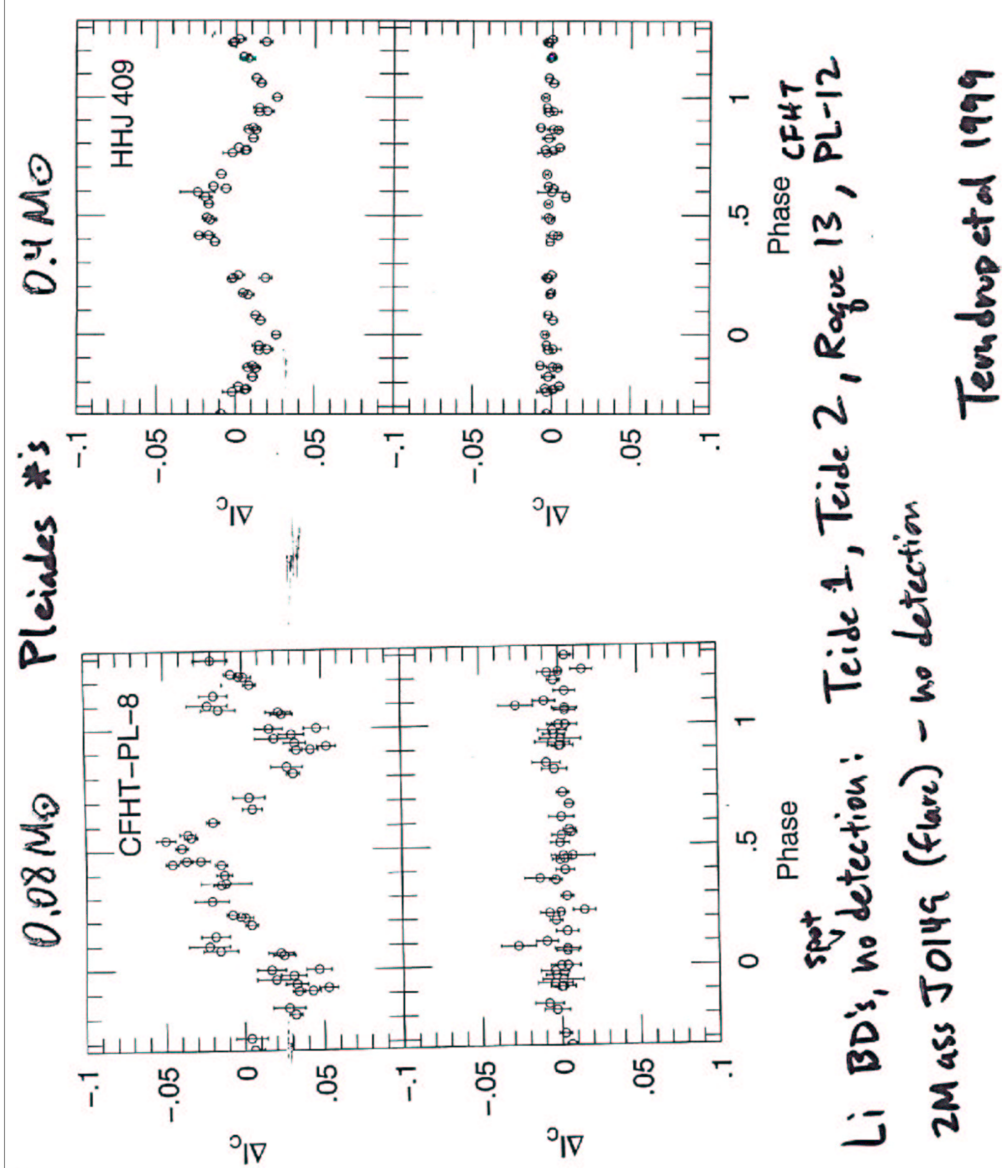
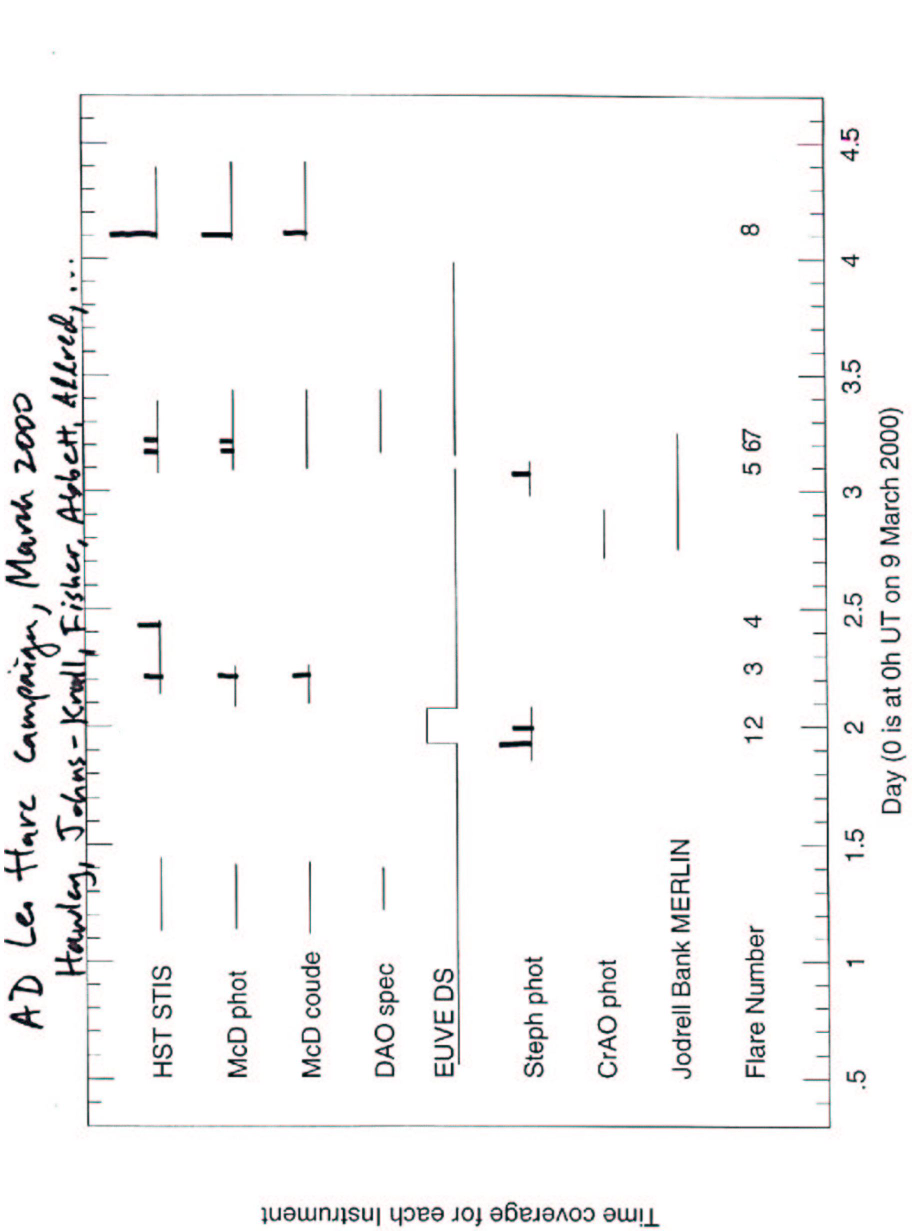
Magnetic Activity Properties of Low Mass Dwarfs

Feature	Solar-type	early-mid M	late M - L
Magnetic fields B, filling factor	yes 1000G, 1%	yes 3000G, 50%	? ?
spots	yes	few (low amp)	only young? (weather?)
cycles	yes	no?	?
flares	yes weak	yes strong	yes only?
chromospheric radiation	Ca II, Mg II	Hα	Hα?
radio, Xrays, UV (corona, TR)	yes weak	yes strong	yes flare only?
fraction with persistent activity	small	increasing -> all	decreasing -> none (do have flares!)
activity strength	weak	strong, large scatter	weakening -> none
age behavior	decays with time	lasts longer at lower masses	? (correlates with T?)
rotation dependence	correlated	weak/none threshold? "saturated"?	none fast rotation inhibits?
dynamo	shell	turbulent	turbulent -> none (primordial?)



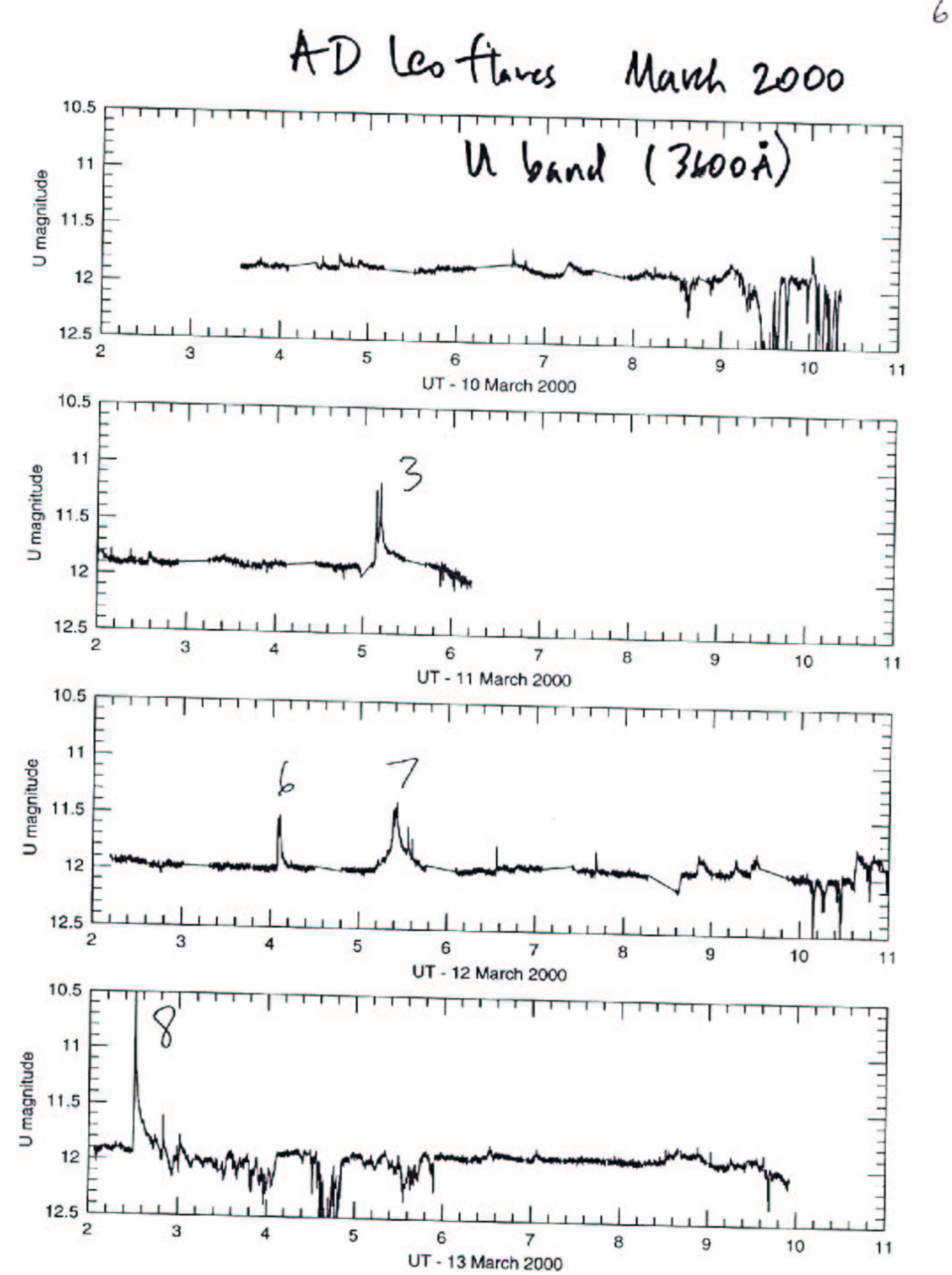
Rodono et al 1986

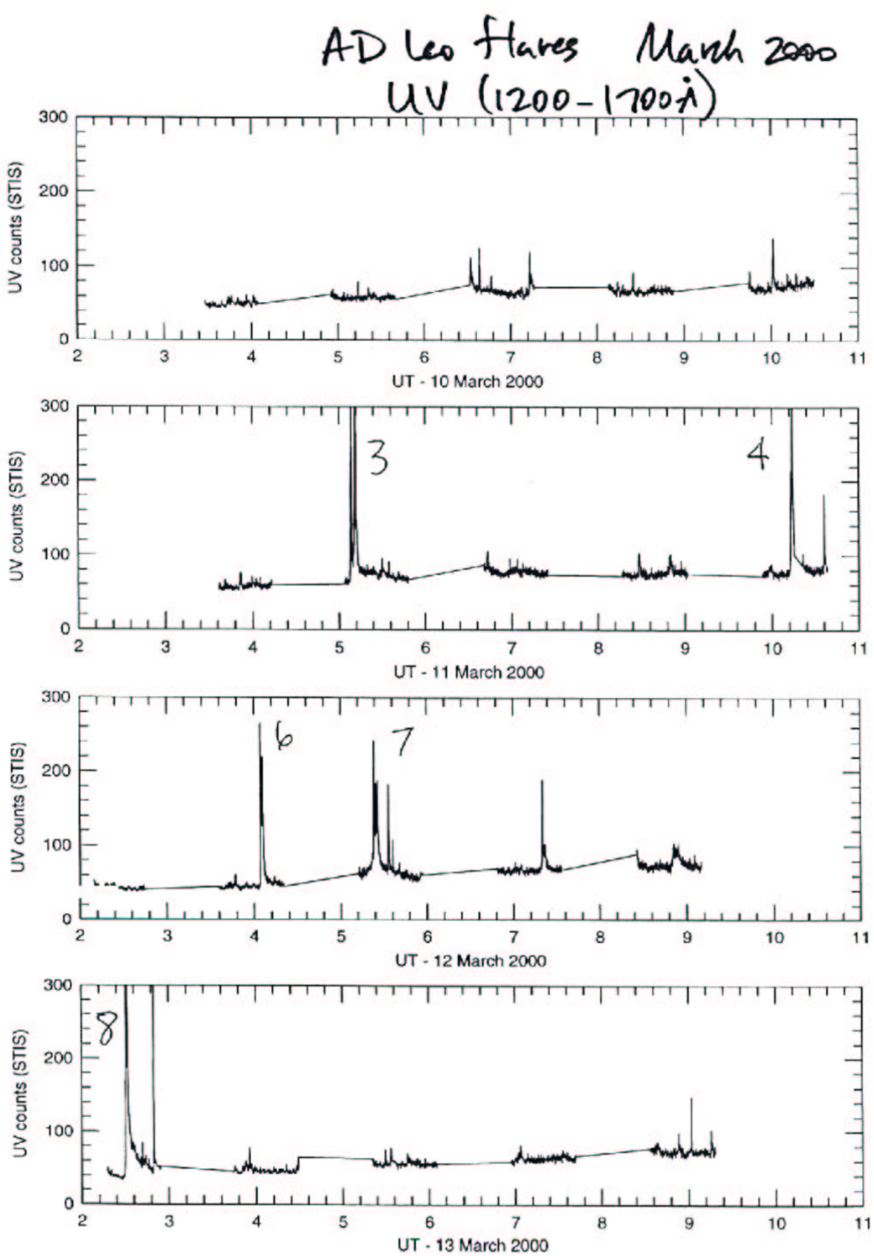


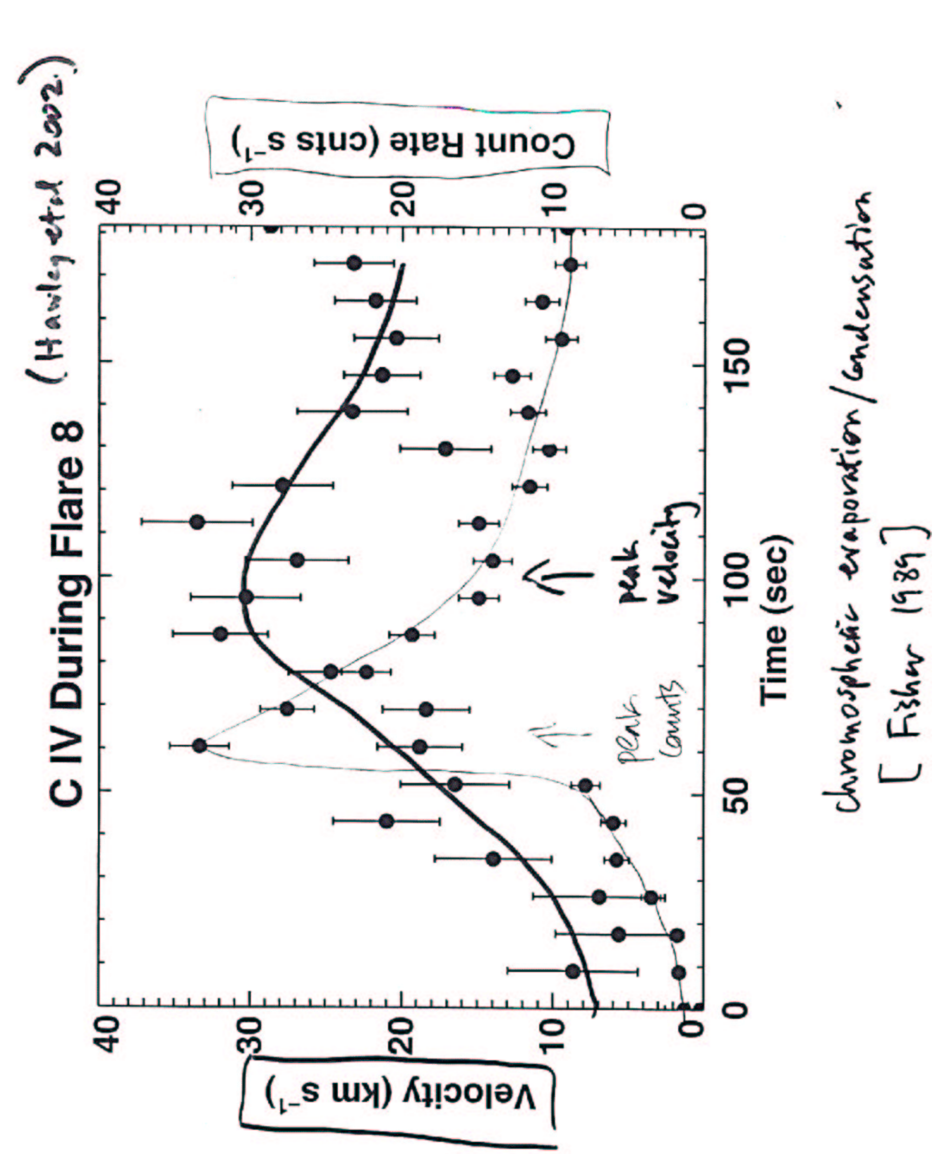

AD Leo Flare Campaign, March 2000
Hawley, Johns-Krull, Fisher, Abbett, Allred, ...
HST STIS
McD phot
McD coude
DAO spec
EUVE DS
Steph phot
CrAO phot
Jodrell Bank MERLIN
Flare Number
1 2
3
4
5 6 7
8
Day (0 is at 0h UT on 9 March 2000)
Time coverage for each instrument

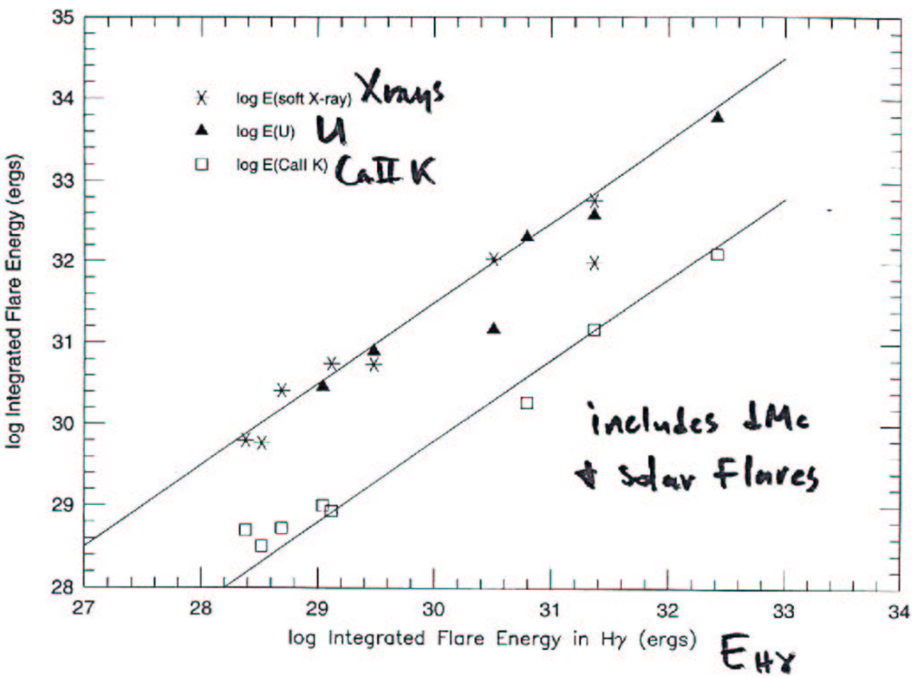
5

6


AD Leo flares March 2000
U band (3600Å)
U magnitude
UT - 10 March 2000
UT - 11 March 2000
UT - 12 March 2000
UT - 13 March 2000
3
6
7
8


AD Leo flares March 2000
UV (1200–1700Å)
UV counts (STIS)
UT - 10 March 2000
UT - 11 March 2000
UT - 12 March 2000
UT - 13 March 2000
3
4
6
7
8


C IV During Flare 8
(Hawley et al 2002)
Count Rate (cnts s⁻¹)
Velocity (km s⁻¹)
Time (sec)
peak velocity
peak counts
chromospheric evaporation/condensation
[Fisher 1989]

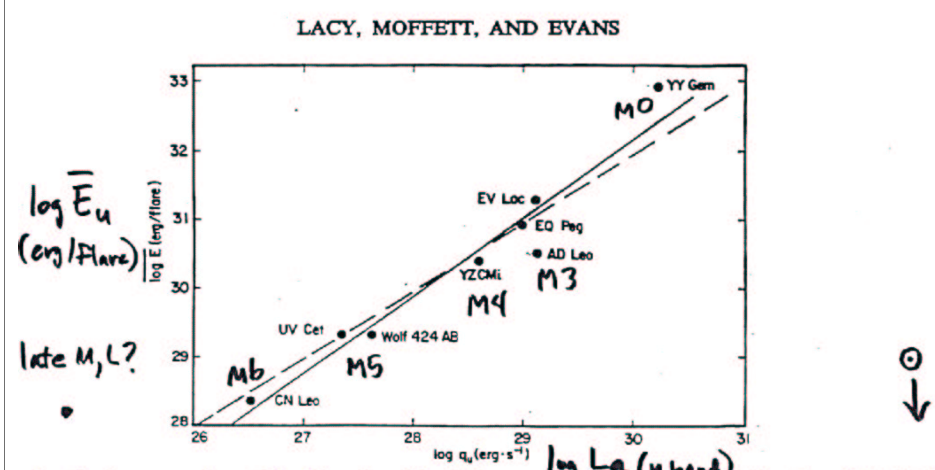


$E_u \sim E_x$

$E_{H\gamma} \sim E_{CaII\,K}$

$E_{H\gamma} \sim 0.05\, E_u$

Hawley + Pettersen 1991



Mean log flare energy through the *U*-bandpass (⟨log *E*⟩) versus quiescent luminosity (q_u). Equations of the fitted lines = (1.15 ± 0.12) log q_u − (2 ± 3) (*solid line*) and ⟨log *E*⟩ = log q_u + (2.0 ± 0.7) (*dashed line*).

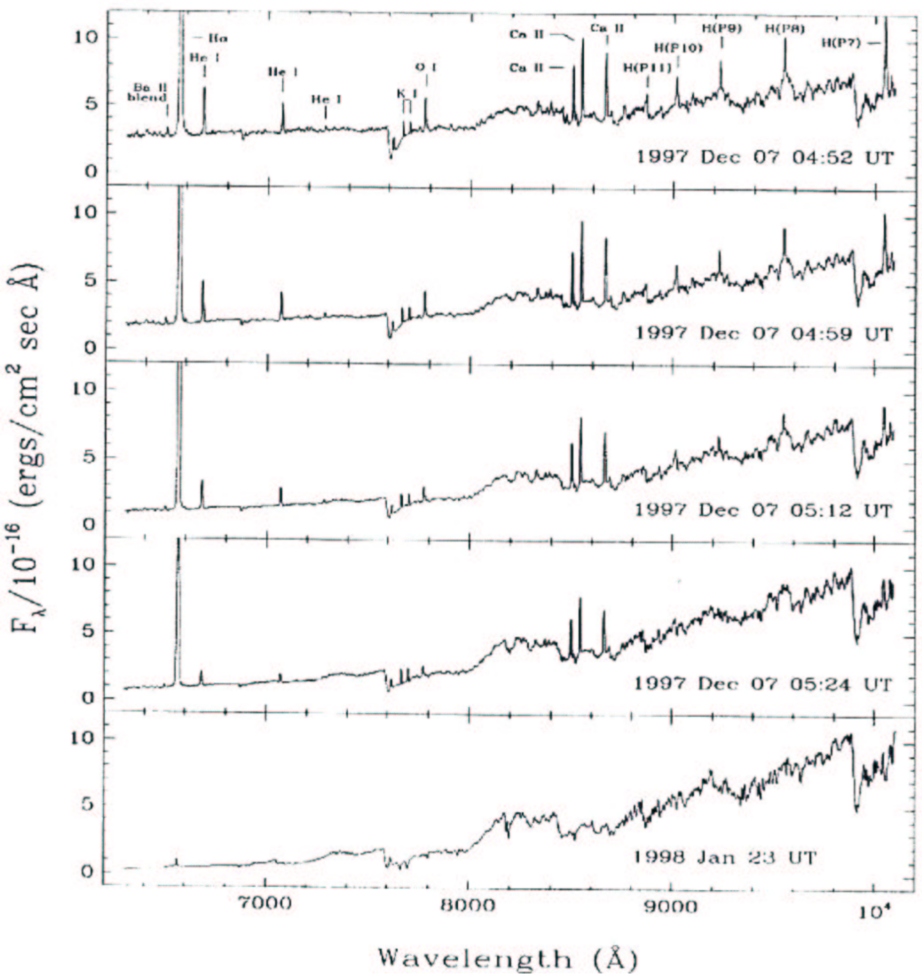
$E(\text{flare}) \sim 100\,(L_{quiet})$

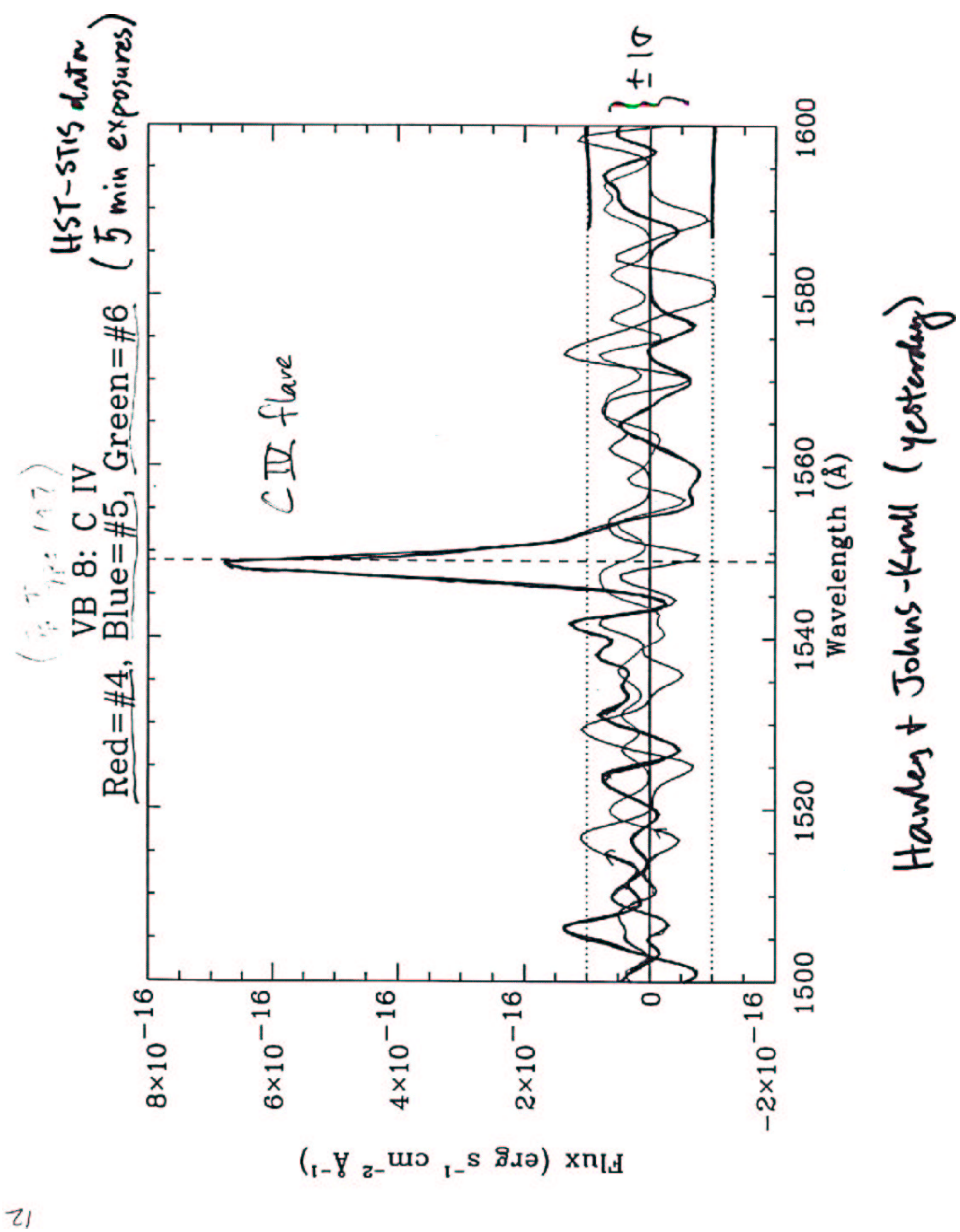
Liebert	2MASSJ0149	Hα ≳ 100 x quiet	(M9.5)
Fleming	VB10	Xrays ≳ 100 x quiet	(M8)

2M0149 dM9.5 Hα flare (Keck)

Fig. 2 Liebert et al (1999) CITED IN TEXT | HI-RES IMAGE (399kb) |

The four initial Keck II digital spectra of 2M0149, observed on 1997 December 7, ordered by increasing time from the top; the bottom panel is one of several similar spectra taken at later times (see text) when the object was observed in quiescence. Detected emission lines from Table 1 are labeled in the top frame. The Hα line in all but the bottom spectrum is truncated in the plot.





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Radio flare (8.46 GHz)

2M0036 – L3.5

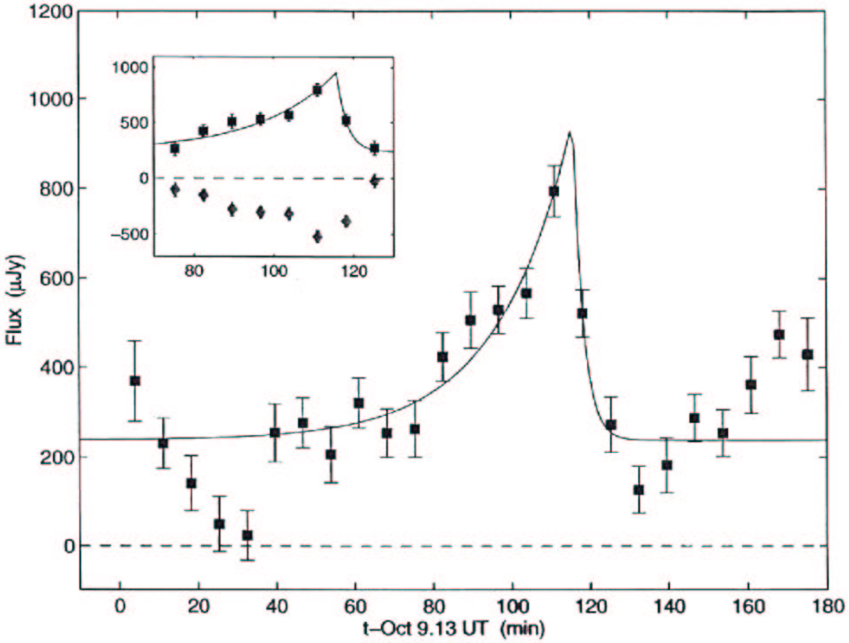

FIG. 3.— Lightcurve of the 8.46 GHz emission from 2MASS 0036+18 on 2001, Oct 9.13 UT, with 25 6.5-min bins. We find a flare and persistent emission, which appears to be strongly variable. The steep decline in flux during the first twenty minutes of the observation, and the shallow rise during the last sixty minutes possibly signal two additional strong flares. The solid line is an exponential model. The inset shows the circularly polarized flux (diamonds) and the total flux (squares). The fraction of circular polarization near the peak of the flare is ≈ −65%. The negative values indicate left-handed circular polarization (see Table 3).

Berger (2002)

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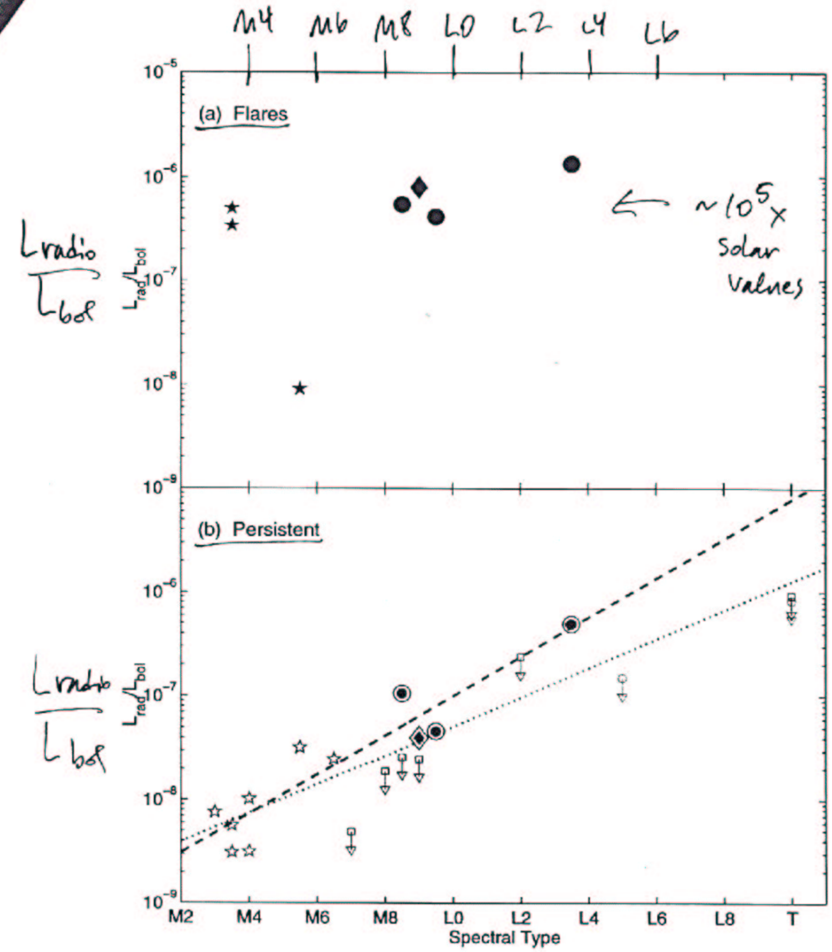

FIG. 6.— (a) Ratio of radio to bolometric luminosities for detected flares from M and L dwarfs. Symbols are as in Figure 5. With the exception of Proxima Centauri (M5.5), the radio activity appears to cluster around $\log(L_{rad,f}/L_{bol}) \approx -6$. This possibly indicates a saturation effect. (b) Ratio of radio to bolometric luminosities for persistent emission from the detected sources, and upper limits which are similar to or lower than these detections. The dashed line is a linear fit to the detections, while the dotted line includes the upper limits. In both cases there is an increase in $\log(L_{rad,q}/L_{bol})$ with spectral type. The same ratio for Hα emission drops significantly beyond M7. These observations indicate that the radio and Hα emission are probably uncorrelated at the bottom of the main sequence. The upper limits that violate the relation, and have measured rotational velocities, have $v\sin i < 10$ km sec^{-1}. This result is discussed in detail in §6 and Figure 7.

Berger (2002)

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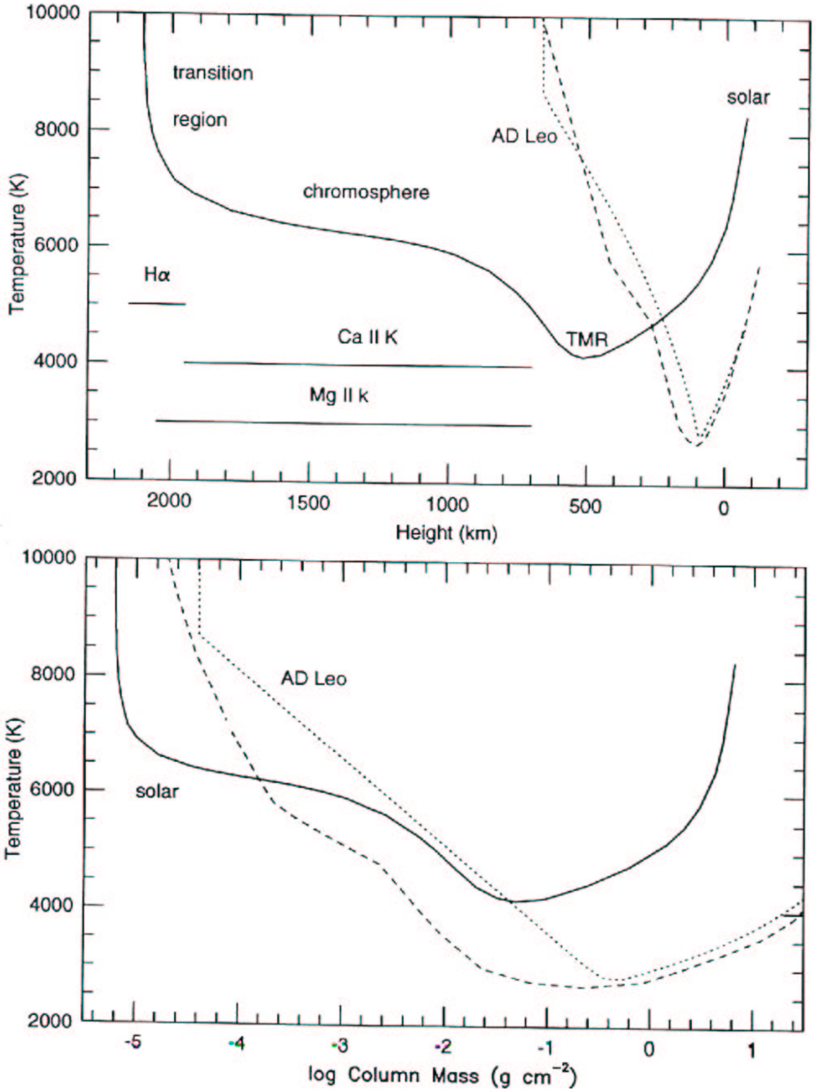
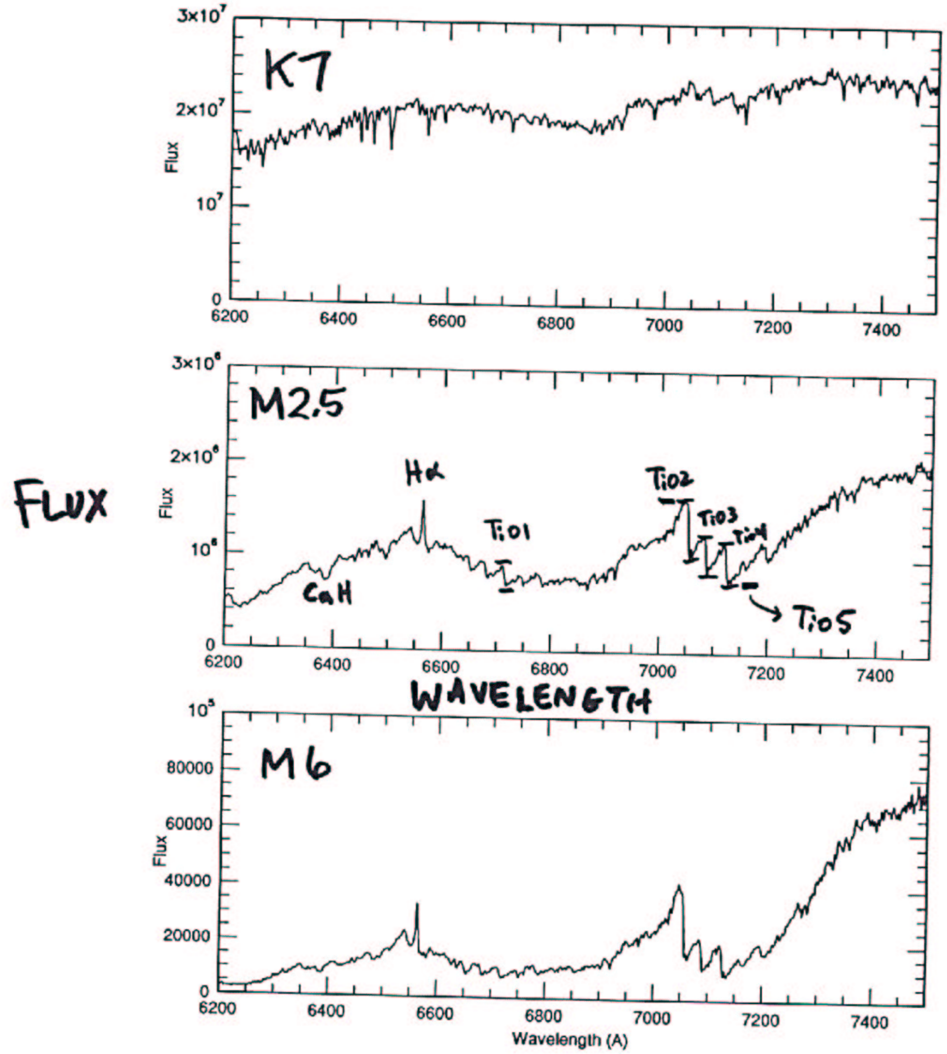

transition
region
chromosphere
AD Leo
solar
Hα
Ca II K
Mg II k
TMR
Temperature (K)
Height (km)
AD Leo
solar
log Column Mass (g cm^{-2})

16


FLUX
K7
M2.5
Hα
TiO1
TiO2
TiO3
TiO4
TiO5
CaH
WAVELENGTH
M6
Flux
Wavelength (A)

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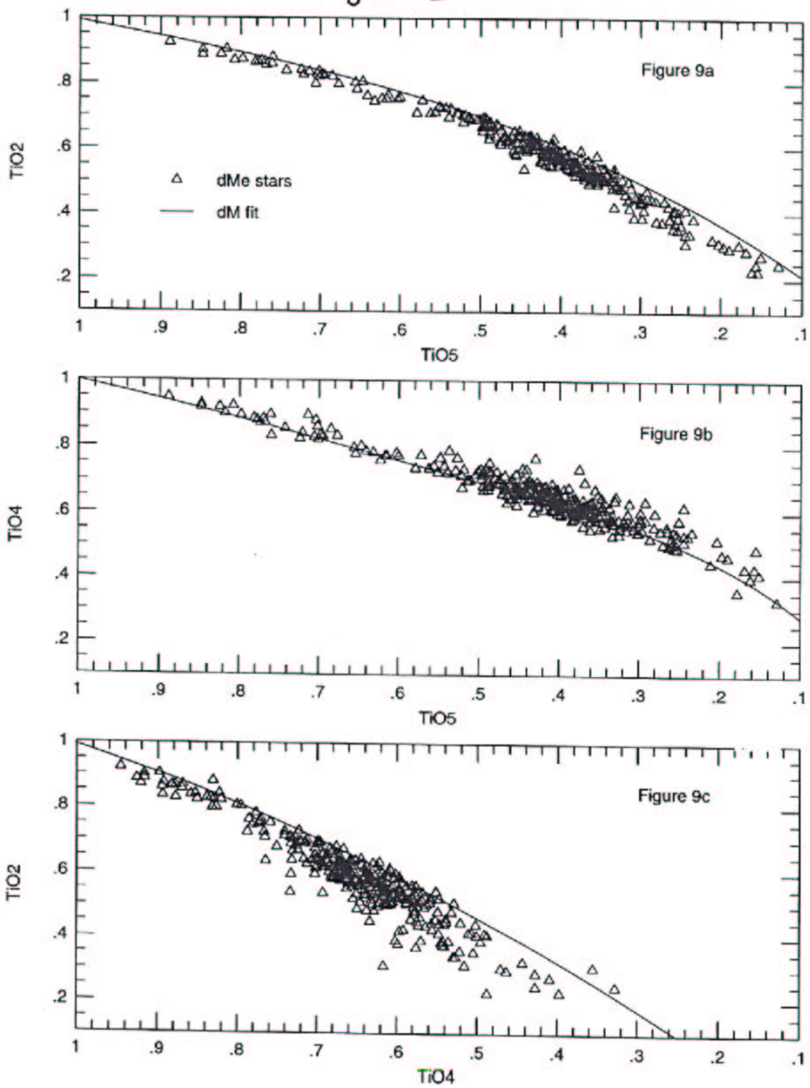
Activity Effects on TiO (7050) subbands

Figure 3



Hawley et al 1996 (PMSU2)

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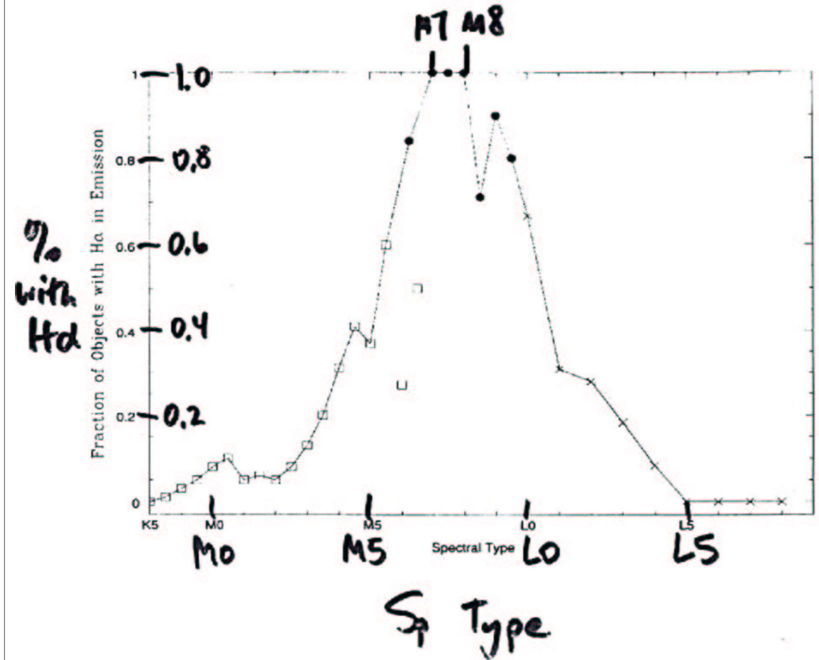
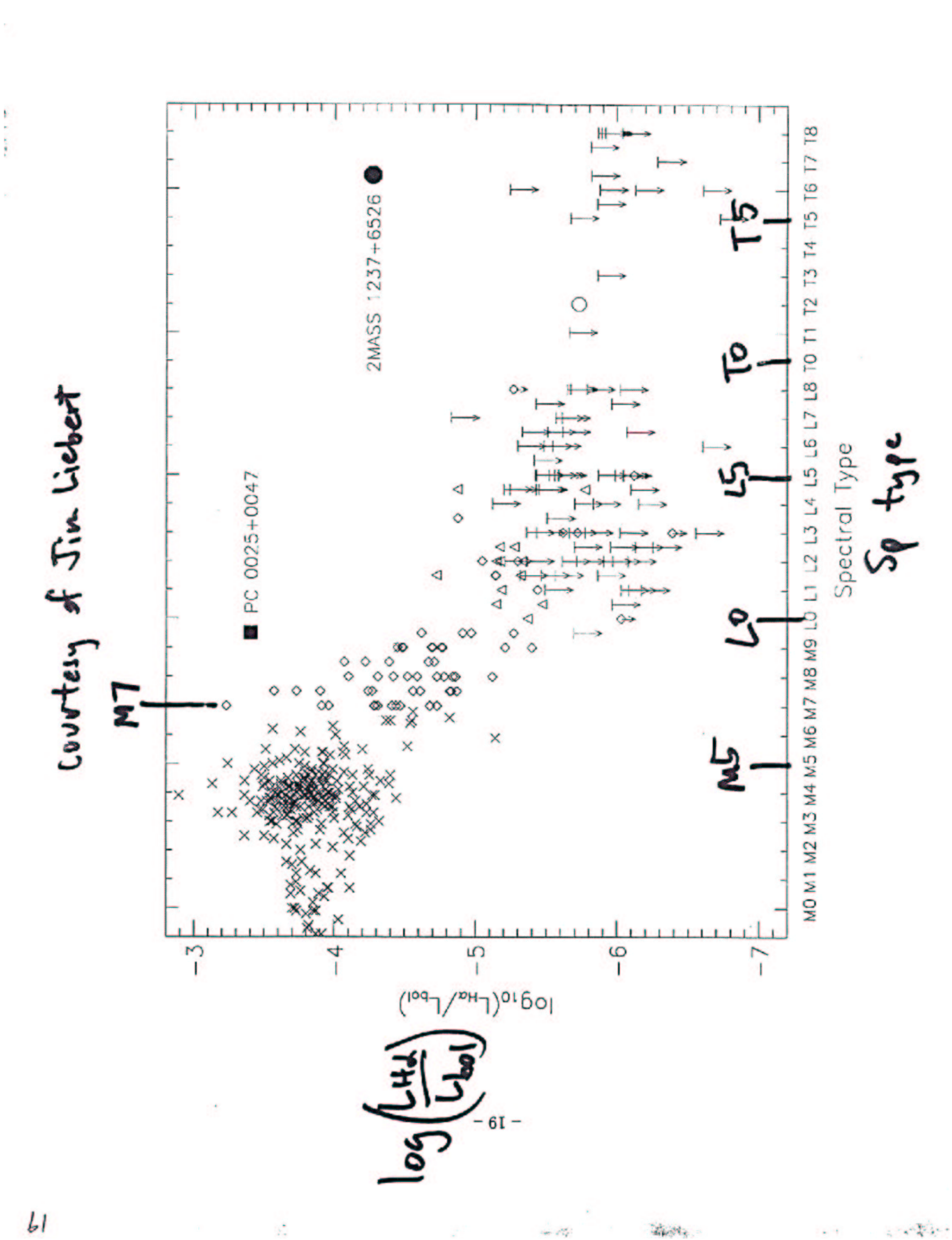
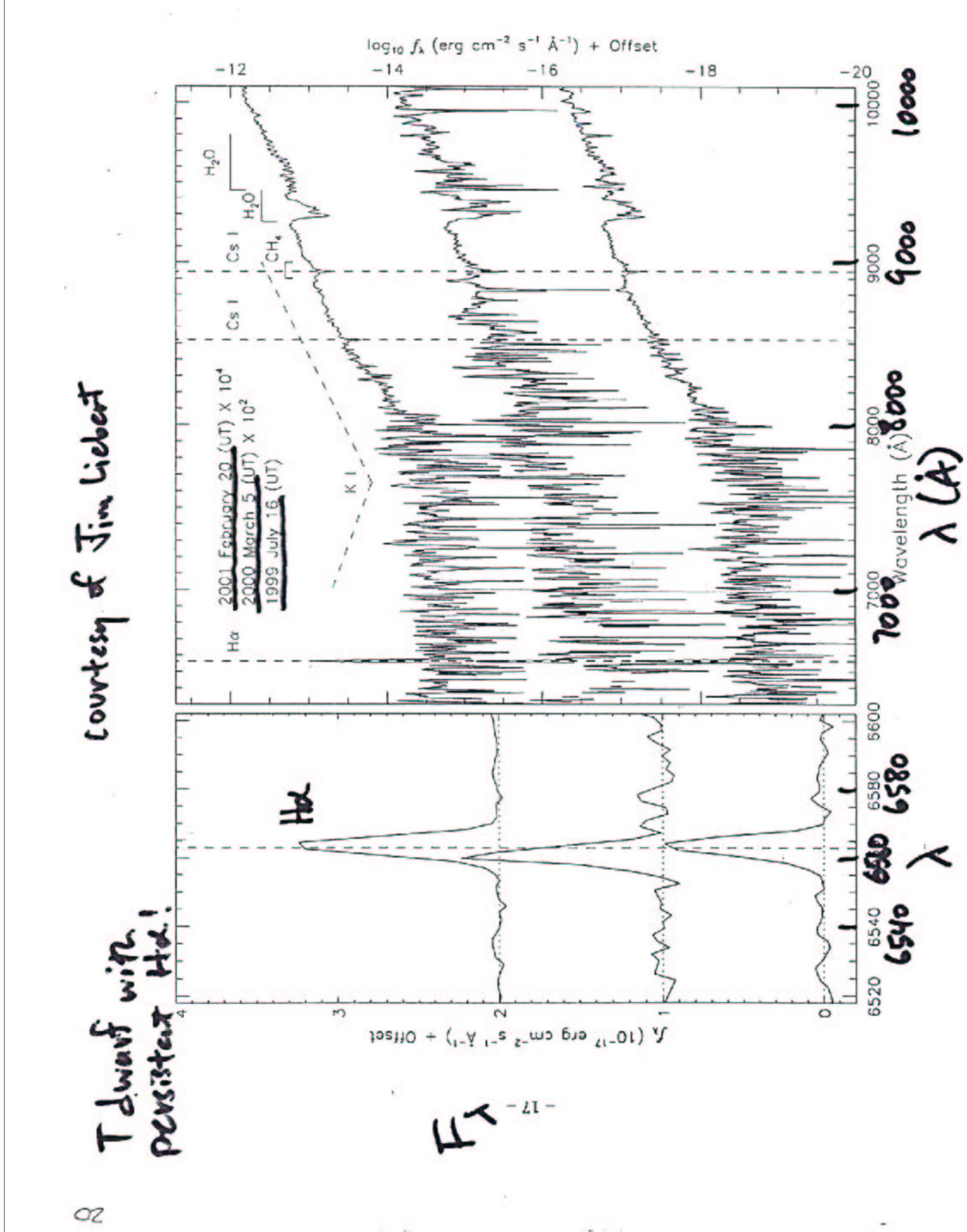
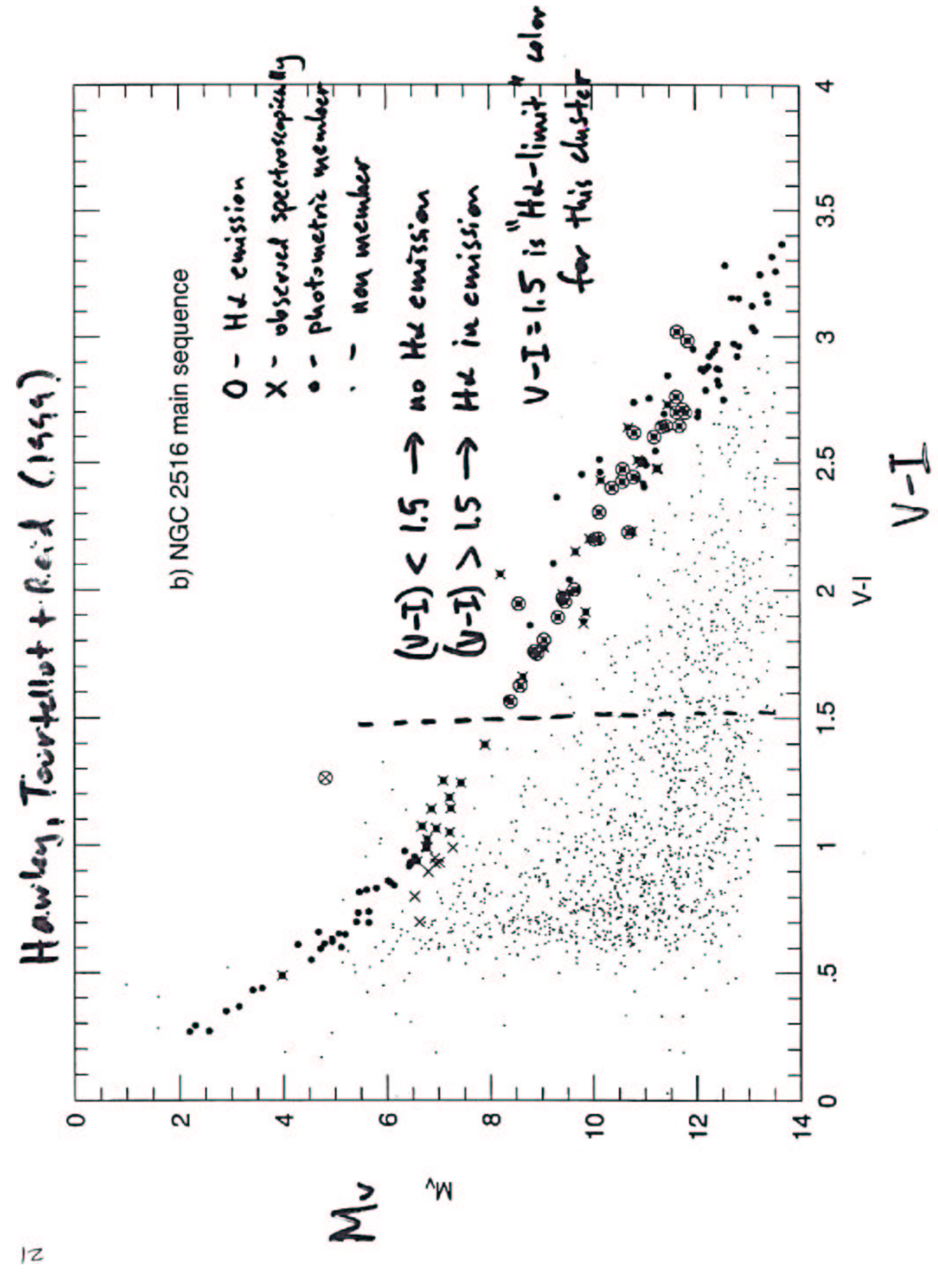
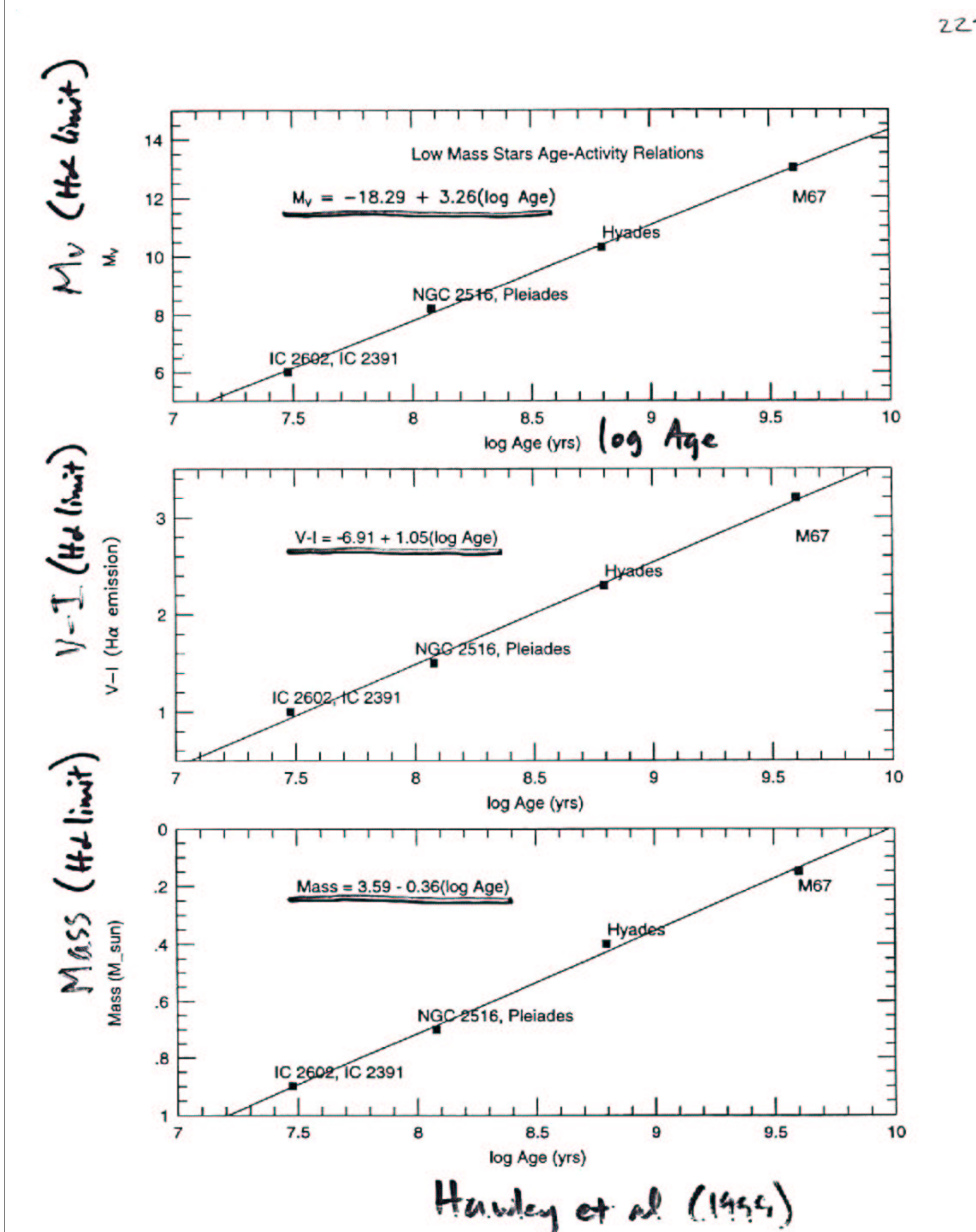


Gizis et al (2000)


Courtesy of Jim Liebert
PC 0025+0047
2MASS 1237+6526
M0 M1 M2 M3 M4 M5 M6 M7 M8 M9 L0 L1 L2 L3 L4 L5 L6 L7 L8 T0 T1 T2 T3 T4 T5 T6 T7 T8
Spectral Type
Sp type
M5
M7
L0
L5
T0
T5
log10(LHα/Lbol)
−3
−4
−5
−6
−7
– 19 –
19


Courtesy of Jim Liebert
log10 fλ (erg cm−2 s−1 Å−1) + Offset
2001 February 20 (UT) × 10^4
2000 March 5 (UT) × 10^2
1999 July 16 (UT)
Hα
Cs I
Cs I
CH4
H2O
H2O
K I
Wavelength (Å)
7000
8000
9000
10000
Hα
T dwarf with persistent Hα!
fλ (10−17 erg cm−2 s−1 Å−1) + Offset
6520
6540
6560
6580
6600
– 17 –
20


Hawley, Tourtellot + Reid (1999)
b) NGC 2516 main sequence
O - Hα emission
X - observed spectroscopically
• - photometric member
. - non member
(V-I) < 1.5 → no Hα emission
(V-I) > 1.5 → Hα in emission
V-I = 1.5 is "Hα-limit" color for this cluster
V-I
M_V
12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Low Mass Stars Age-Activity Relations
$M_V = -18.29 + 3.26(\log Age)$
M67
Hyades
NGC 2516, Pleiades
IC 2602, IC 2391
Mv (Hα limit)
log Age (yrs)
log Age
V-I = -6.91 + 1.05(log Age)
V-I (Hα limit)
V−I (Hα emission)
Mass = 3.59 - 0.36(log Age)
Mass (Hα limit)
Mass (M_sun)
Hawley et al (1999)

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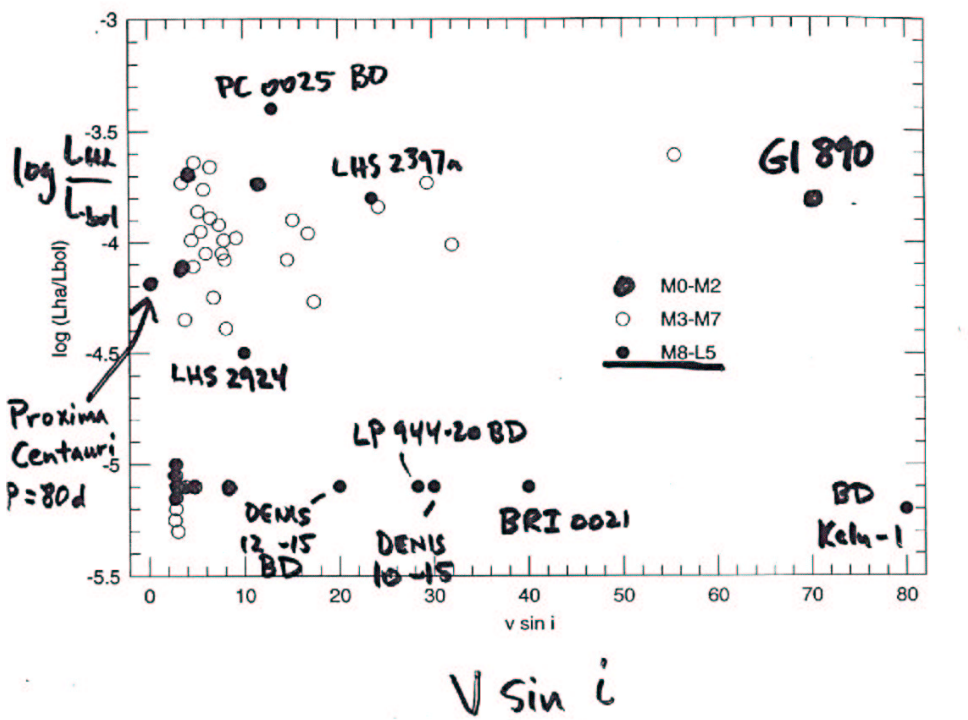

M0-M7 no correlation with v sin i (threshold?)

M8-L5 anti-correlation " ?

Hawley et al (1999, 2000)

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Mohanty + Basri (2002)

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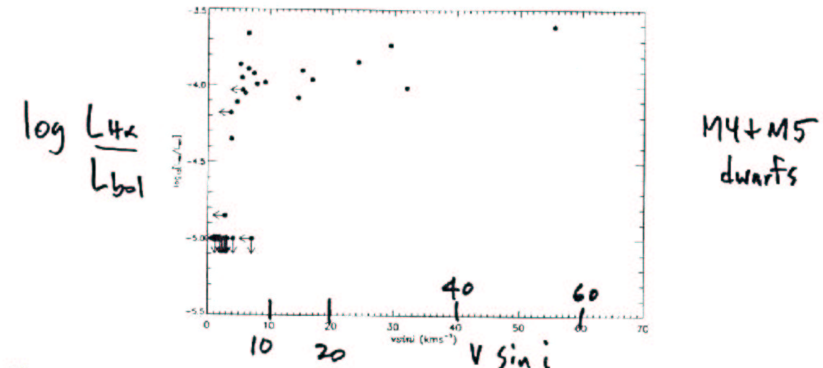

Fig. 1.— $L_{H\alpha}/L_{bol}$ versus $v \sin i$ for M4 and M5 dwarfs (from Delfosse et al., 1998). Upper limits in Hα emission and $v \sin i$ marked by arrows (though actual equatorial velocity may be higher)

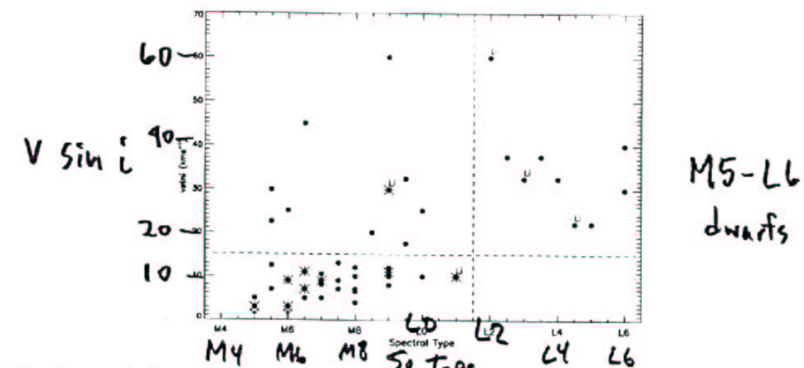

Fig. 2.— $v \sin i$ versus Spectral Type, for M5 to L6 dwarfs. Overlapping objects marked with spines. Horizontal line is at 15 km s^{-1} , below which we define objects as slow rotators. Vertical line marks spectral type L1.5, above which all objects rotate rapidly. 'Li' marks objects with Lithium; these are confirmed brown dwarfs.

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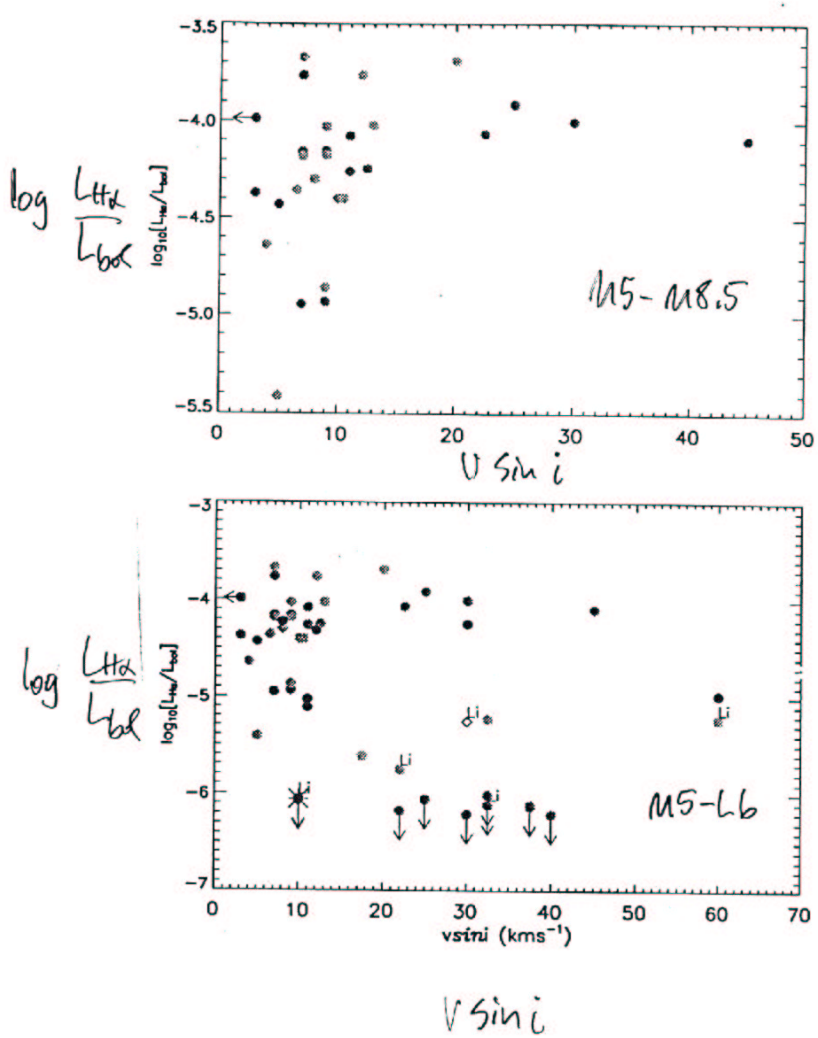
"threshold ~10 km/s?" "saturation"?



Mohanty + Basri (2002)

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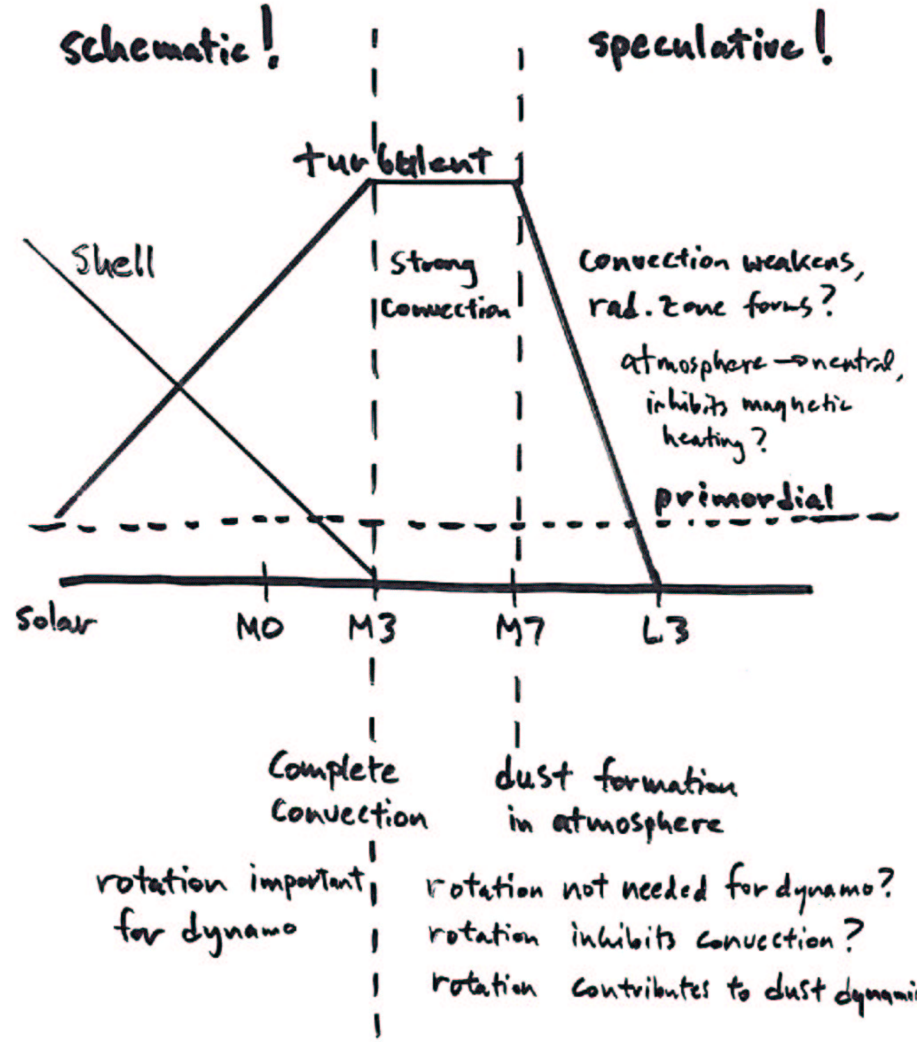

Questions

- what causes activity effects on TiO bands + colors?
- is Hα best diagnostic for late M-L dwarfs?
  → need chromospheric models
- why does activity last longer at lower mass (M3-M7 range)? [Answer is NOT rotation!]
  → need turbulent dynamo theory
- does dust formation inhibit convection and/or form radiative zone, preventing field from reaching surface? [M8-L range]
  → need atmosphere calculations, incorporate turbulent dynamo
  Or atmosphere becomes neutral, preventing heating?
- is there an age effect in late M - early L dwarf activity? Difference between stars + brown dwarfs? Or just depends on T of atmosphere?
  → need more data
- primordial or acoustic fields important?