Accretion Rates of the Very Small

(But extremely numerous)

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The Paper

"Accretion in Young Stellar/Substellar Objects"

James Muzerolle, Lynne Hillenbrand, Nuria Calvet, Cesar Briceno, and Lee Hartmann

2003 ApJ, 592, 266

Outline

- Why study these objects?
- Data set & observations
- How to determine whether accretion is occurring
- Modeling to ascertain mass accretions
- Results & discussion

Why So Small?

- Understanding of accreting protoplanetary disks limited to T Tauri stars thus far ($M \sim 0.5\ M_\odot$)
  - Finding accretion rates of smaller objects should lead to better understanding of how disks work
- Stellar mass functions predict that more low mass stars form than high mass stars
- Problem: small YSOs and brown dwarfs are difficult to detect

Anatomy of a Sample

- Selected very low mass (VLM) objects from various star forming regions
  - Taurus, IC 348, σ Ori, Upper Sco, ρ Oph
- Target
  - Spectral type M5 or later
  - Ages no more than ~10 Myr old
- Actual selection (45 objects)
  - Spectral types: M4-M8.5
  - Ages < 10 Myr

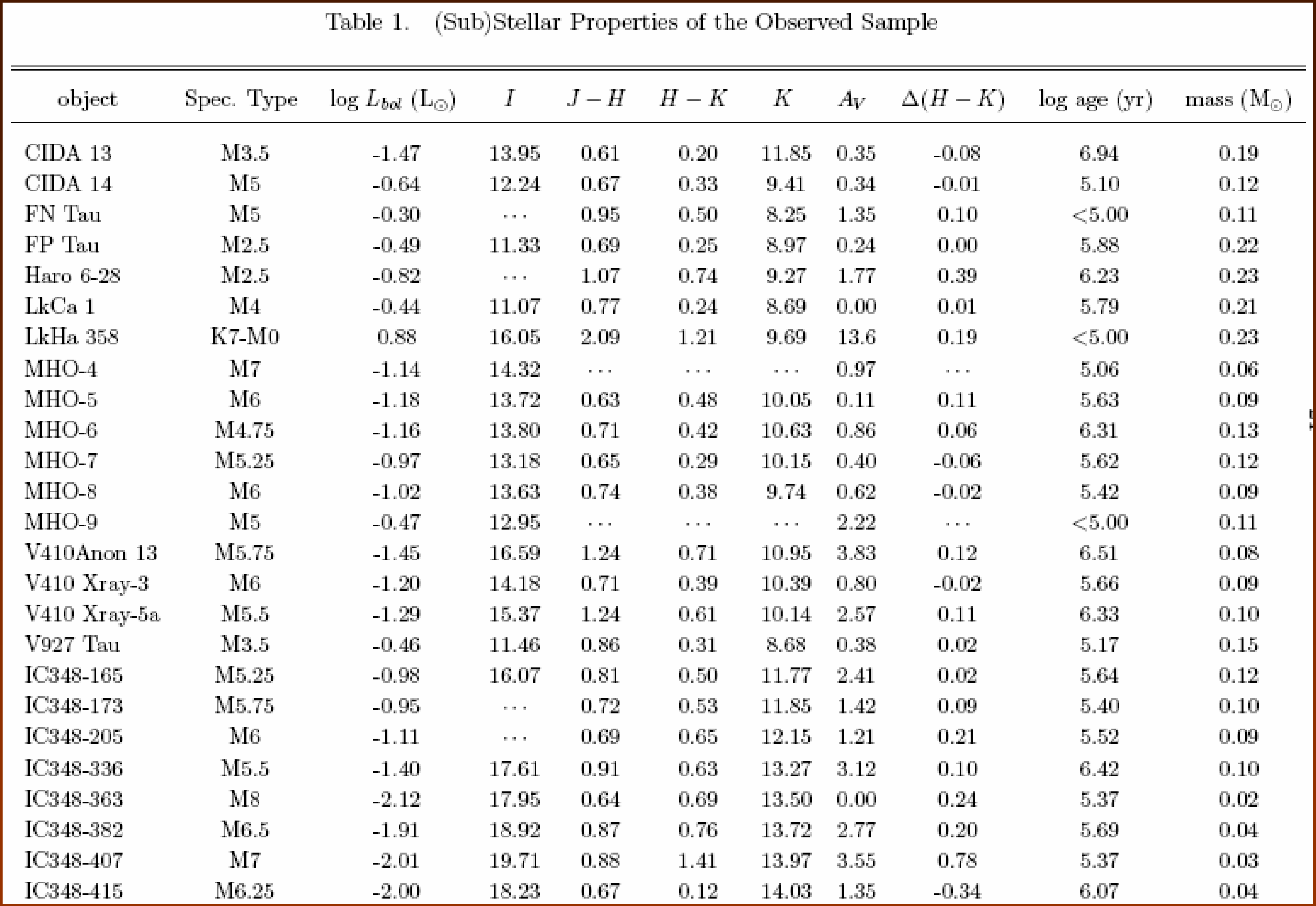


Table 1. (Sub)Stellar Properties of the Observed Sample

object	Spec. Type	log L_{bol} ($L_\odot$)	I	$J-H$	$H-K$	K	A_V	$\Delta(H-K)$	log age (yr)	mass ($M_\odot$)
CIDA 13	M3.5	-1.47	13.95	0.61	0.20	11.85	0.35	-0.08	6.94	0.19
CIDA 14	M5	-0.64	12.24	0.67	0.33	9.41	0.34	-0.01	5.10	0.12
FN Tau	M5	-0.30	···	0.95	0.50	8.25	1.35	0.10	<5.00	0.11
FP Tau	M2.5	-0.49	11.33	0.69	0.25	8.97	0.24	0.00	5.88	0.22
Haro 6-28	M2.5	-0.82	···	1.07	0.74	9.27	1.77	0.39	6.23	0.23
LkCa 1	M4	-0.44	11.07	0.77	0.24	8.69	0.00	0.01	5.79	0.21
LkHa 358	K7-M0	0.88	16.05	2.09	1.21	9.69	13.6	0.19	<5.00	0.23
MHO-4	M7	-1.14	14.32	···	···	···	0.97	···	5.06	0.06
MHO-5	M6	-1.18	13.72	0.63	0.48	10.05	0.11	0.11	5.63	0.09
MHO-6	M4.75	-1.16	13.80	0.71	0.42	10.63	0.86	0.06	6.31	0.13
MHO-7	M5.25	-0.97	13.18	0.65	0.29	10.15	0.40	-0.06	5.62	0.12
MHO-8	M6	-1.02	13.63	0.74	0.38	9.74	0.62	-0.02	5.42	0.09
MHO-9	M5	-0.47	12.95	···	···	···	2.22	···	<5.00	0.11
V410Anon 13	M5.75	-1.45	16.59	1.24	0.71	10.95	3.83	0.12	6.51	0.08
V410 Xray-3	M6	-1.20	14.18	0.71	0.39	10.39	0.80	-0.02	5.66	0.09
V410 Xray-5a	M5.5	-1.29	15.37	1.24	0.61	10.14	2.57	0.11	6.33	0.10
V927 Tau	M3.5	-0.46	11.46	0.86	0.31	8.68	0.38	0.02	5.17	0.15
IC348-165	M5.25	-0.98	16.07	0.81	0.50	11.77	2.41	0.02	5.64	0.12
IC348-173	M5.75	-0.95	···	0.72	0.53	11.85	1.42	0.09	5.40	0.10
IC348-205	M6	-1.11	···	0.69	0.65	12.15	1.21	0.21	5.52	0.09
IC348-336	M5.5	-1.40	17.61	0.91	0.63	13.27	3.12	0.10	6.42	0.10
IC348-363	M8	-2.12	17.95	0.64	0.69	13.50	0.00	0.24	5.37	0.02
IC348-382	M6.5	-1.91	18.92	0.87	0.76	13.72	2.77	0.20	5.69	0.04
IC348-407	M7	-2.01	19.71	0.88	1.41	13.97	3.55	0.78	5.37	0.03
IC348-415	M6.25	-2.00	18.23	0.67	0.12	14.03	1.35	-0.34	6.07	0.04

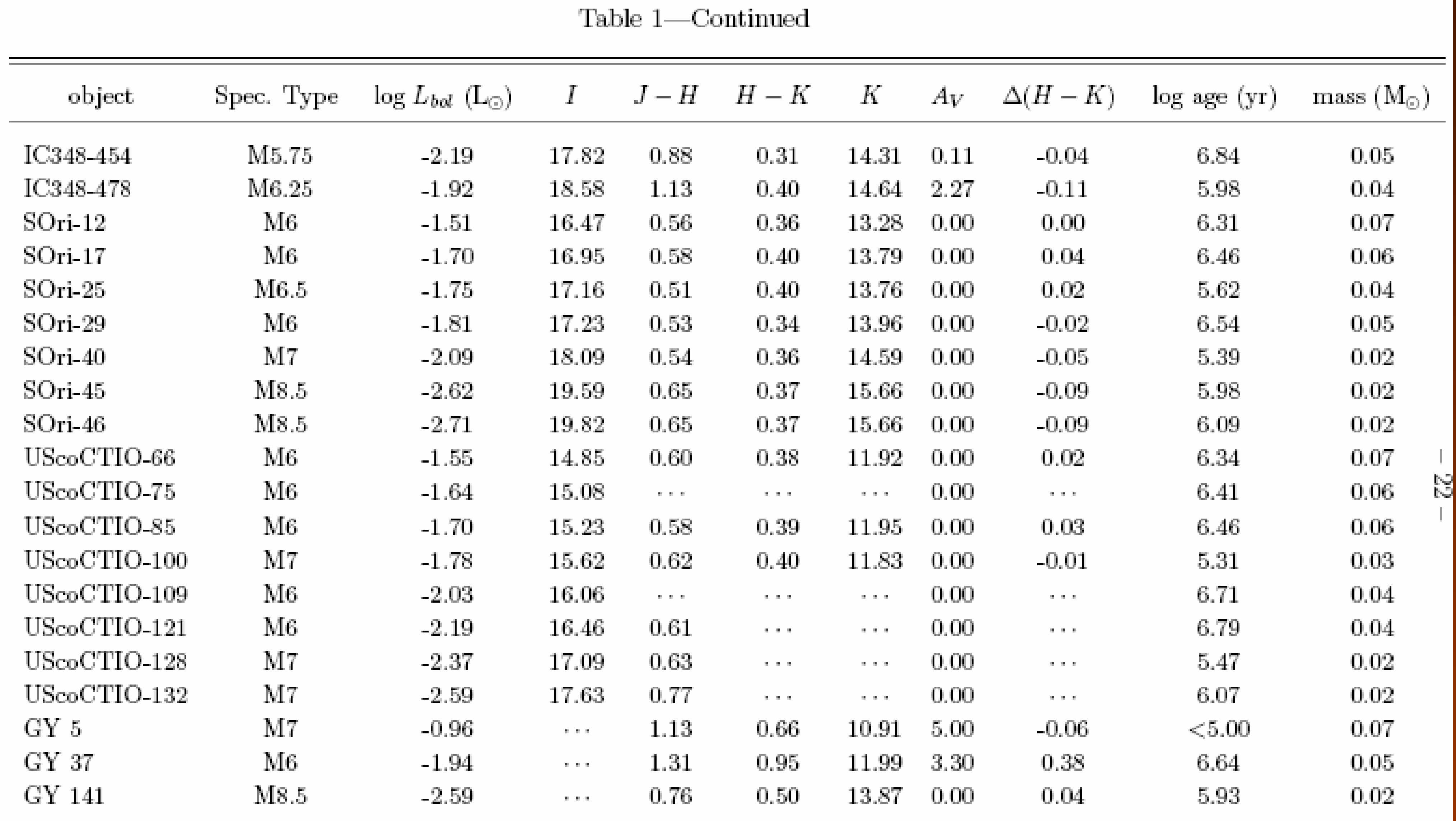


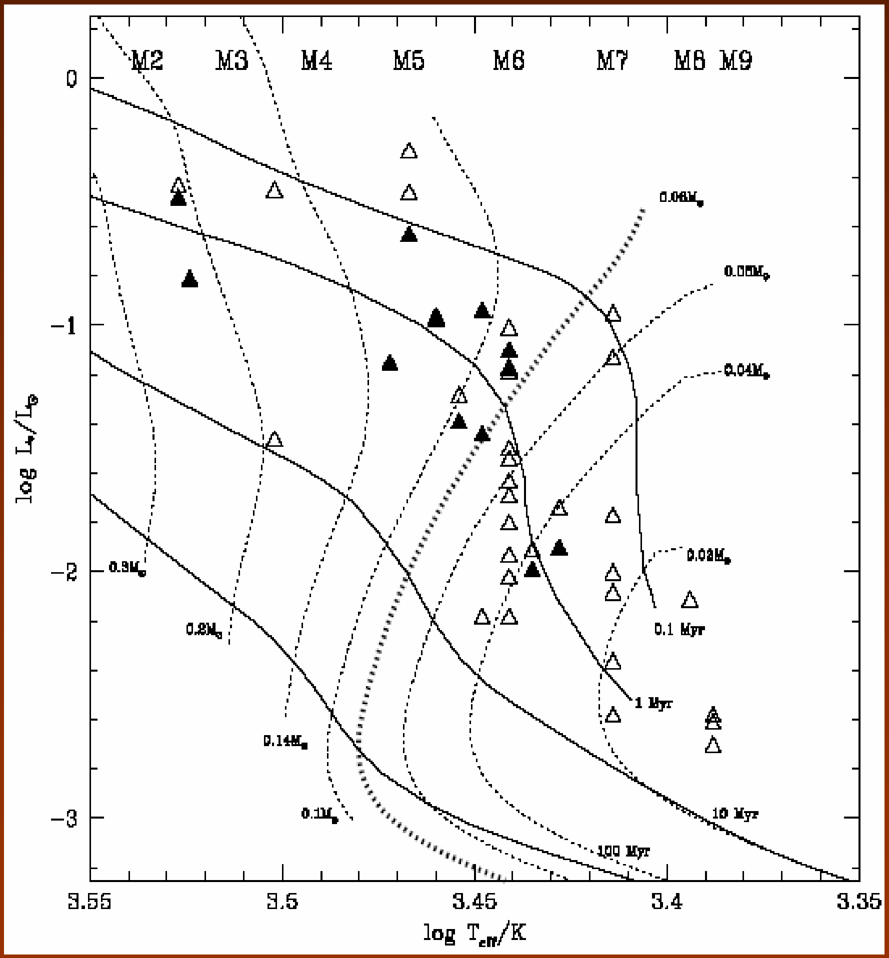
Table 1—Continued

object	Spec. Type	log L_{bol} ($L_\odot$)	I	$J-H$	$H-K$	K	A_V	$\Delta(H-K)$	log age (yr)	mass ($M_\odot$)
IC348-454	M5.75	-2.19	17.82	0.88	0.31	14.31	0.11	-0.04	6.84	0.05
IC348-478	M6.25	-1.92	18.58	1.13	0.40	14.64	2.27	-0.11	5.98	0.04
SOri-12	M6	-1.51	16.47	0.56	0.36	13.28	0.00	0.00	6.31	0.07
SOri-17	M6	-1.70	16.95	0.58	0.40	13.79	0.00	0.04	6.46	0.06
SOri-25	M6.5	-1.75	17.16	0.51	0.40	13.76	0.00	0.02	5.62	0.04
SOri-29	M6	-1.81	17.23	0.53	0.34	13.96	0.00	-0.02	6.54	0.05
SOri-40	M7	-2.09	18.09	0.54	0.36	14.59	0.00	-0.05	5.39	0.02
SOri-45	M8.5	-2.62	19.59	0.65	0.37	15.66	0.00	-0.09	5.98	0.02
SOri-46	M8.5	-2.71	19.82	0.65	0.37	15.66	0.00	-0.09	6.09	0.02
UScoCTIO-66	M6	-1.55	14.85	0.60	0.38	11.92	0.00	0.02	6.34	0.07
UScoCTIO-75	M6	-1.64	15.08	···	···	···	0.00	···	6.41	0.06
UScoCTIO-85	M6	-1.70	15.23	0.58	0.39	11.95	0.00	0.03	6.46	0.06
UScoCTIO-100	M7	-1.78	15.62	0.62	0.40	11.83	0.00	-0.01	5.31	0.03
UScoCTIO-109	M6	-2.03	16.06	···	···	···	0.00	···	6.71	0.04
UScoCTIO-121	M6	-2.19	16.46	0.61	···	···	0.00	···	6.79	0.04
UScoCTIO-128	M7	-2.37	17.09	0.63	···	···	0.00	···	5.47	0.02
UScoCTIO-132	M7	-2.59	17.63	0.77	···	···	0.00	···	6.07	0.02
GY 5	M7	-0.96	···	1.13	0.66	10.91	5.00	-0.06	<5.00	0.07
GY 37	M6	-1.94	···	1.31	0.95	11.99	3.30	0.38	6.64	0.05
GY 141	M8.5	-2.59	···	0.76	0.50	13.87	0.00	0.04	5.93	0.02

Mass and Age Ranges

- Ages range from 0.1 Myr to 8 Myr
- Masses range from 0.02 to 0.14 $M_\odot$
    - Spans stellar/substellar boundary

Figure 1:



Observations

- Keck II – ESI echellette spectrograph
  - Wavelengths covered: 3900-11000 Å
  - Resolution: 37.5 km s^{-1}
- Keck I – HIRES echelle spectrograph
  - Wavelengths covered: 6320-8730 Å
  - Resolution: 8.8 km s^{-1}

Radial & Rotational Velocities

- *v* sin *i* values found from HIRES data (Keck I)
  - Rotational velocities range from 8 to 35 km s^{-1}
- Radial velocities determined from both data sets
  - Range: -38.9 to 55.8 km s^{-1}

Are they really VLM YSOs?

- Membership in respective clusters verified
  - Color magnitude diagrams
  - Lithium abundances
  - Radial velocities
- 6 stars with questionable resumes tossed out
  - Also have weakest Hα emission
  - Emission lines resemble main-sequence dwarfs

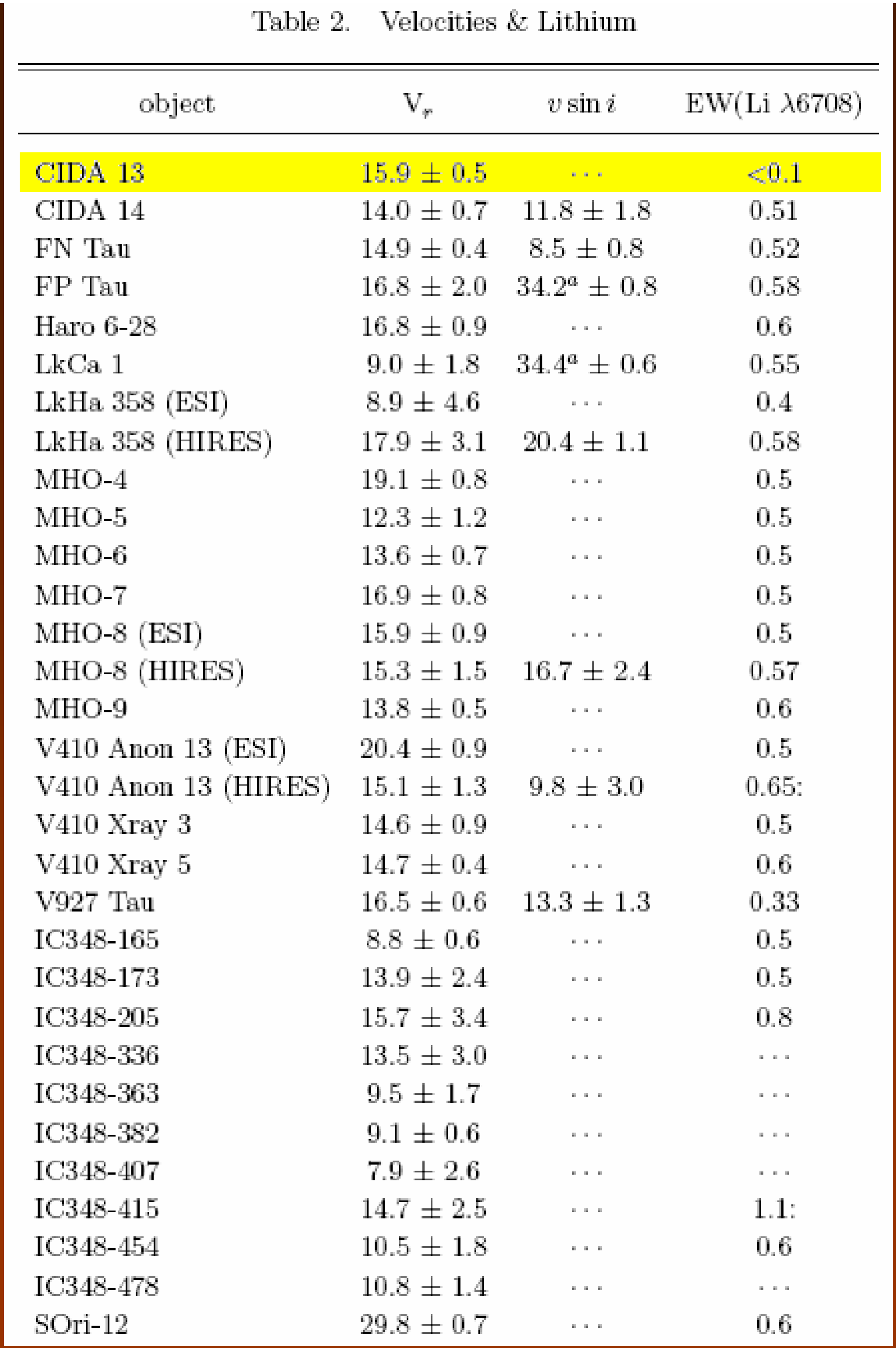


Table 2. Velocities & Lithium

object	V_r	$v \sin i$	EW(Li λ6708)
CIDA 13	15.9 ± 0.5	···	<0.1
CIDA 14	14.0 ± 0.7	11.8 ± 1.8	0.51
FN Tau	14.9 ± 0.4	8.5 ± 0.8	0.52
FP Tau	16.8 ± 2.0	34.2[a] ± 0.8	0.58
Haro 6-28	16.8 ± 0.9	···	0.6
LkCa 1	9.0 ± 1.8	34.4[a] ± 0.6	0.55
LkHa 358 (ESI)	8.9 ± 4.6	···	0.4
LkHa 358 (HIRES)	17.9 ± 3.1	20.4 ± 1.1	0.58
MHO-4	19.1 ± 0.8	···	0.5
MHO-5	12.3 ± 1.2	···	0.5
MHO-6	13.6 ± 0.7	···	0.5
MHO-7	16.9 ± 0.8	···	0.5
MHO-8 (ESI)	15.9 ± 0.9	···	0.5
MHO-8 (HIRES)	15.3 ± 1.5	16.7 ± 2.4	0.57
MHO-9	13.8 ± 0.5	···	0.6
V410 Anon 13 (ESI)	20.4 ± 0.9	···	0.5
V410 Anon 13 (HIRES)	15.1 ± 1.3	9.8 ± 3.0	0.65:
V410 Xray 3	14.6 ± 0.9	···	0.5
V410 Xray 5	14.7 ± 0.4	···	0.6
V927 Tau	16.5 ± 0.6	13.3 ± 1.3	0.33
IC348-165	8.8 ± 0.6	···	0.5
IC348-173	13.9 ± 2.4	···	0.5
IC348-205	15.7 ± 3.4	···	0.8
IC348-336	13.5 ± 3.0	···	···
IC348-363	9.5 ± 1.7	···	···
IC348-382	9.1 ± 0.6	···	···
IC348-407	7.9 ± 2.6	···	···
IC348-415	14.7 ± 2.5	···	1.1:
IC348-454	10.5 ± 1.8	···	0.6
IC348-478	10.8 ± 1.4	···	···
SOri-12	29.8 ± 0.7	···	0.6

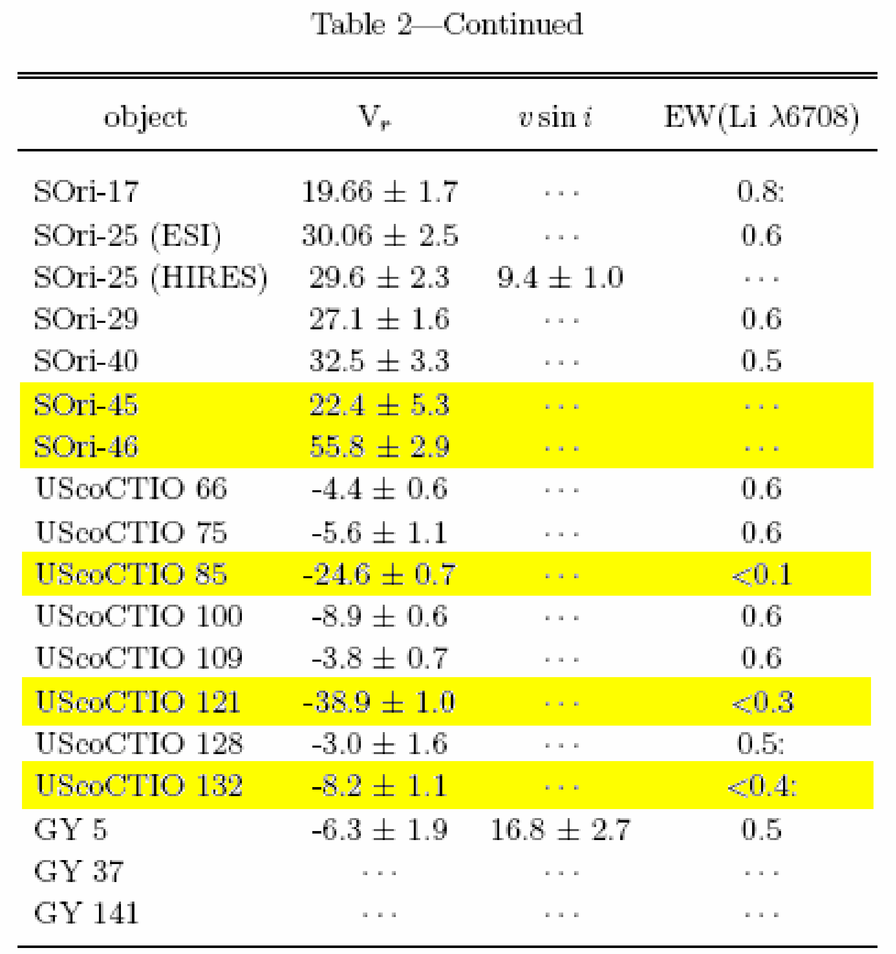


Table 2—Continued

object	V_r	$v \sin i$	EW(Li λ6708)
SOri-17	19.66 ± 1.7	···	0.8:
SOri-25 (ESI)	30.06 ± 2.5	···	0.6
SOri-25 (HIRES)	29.6 ± 2.3	9.4 ± 1.0	···
SOri-29	27.1 ± 1.6	···	0.6
SOri-40	32.5 ± 3.3	···	0.5
SOri-45	22.4 ± 5.3	···	···
SOri-46	55.8 ± 2.9	···	···
UScoCTIO 66	-4.4 ± 0.6	···	0.6
UScoCTIO 75	-5.6 ± 1.1	···	0.6
UScoCTIO 85	-24.6 ± 0.7	···	<0.1
UScoCTIO 100	-8.9 ± 0.6	···	0.6
UScoCTIO 109	-3.8 ± 0.7	···	0.6
UScoCTIO 121	-38.9 ± 1.0	···	<0.3
UScoCTIO 128	-3.0 ± 1.6	···	0.5:
UScoCTIO 132	-8.2 ± 1.1	···	<0.4:
GY 5	-6.3 ± 1.9	16.8 ± 2.7	0.5
GY 37	···	···	···
GY 141	···	···	···

Emission Lines

- A number of emission lines' strengths are listed for each object in sample
- 2 main-sequence dM stars included for comparison (Gl 406 & LHS 2351)
- Most VLM objects have emission line profiles that tend to be narrow, resemble dMe stars and WTTS
- 13 have broader Hα emission resembling CTTSs
- Active VLM objects have emissions characteristic of 0.5 $M_{\odot}$ CTTS

Table 3. Emission Lines

object	Hα 10% width	Hα	Hβ	Hγ	Hδ	He I λ5876	[OI] λ6300	[OI] λ6363	Ca II λ8498^a	Ca II λ8542^a	Ca II λ8662^a	accretor?	instrument
CIDA 13^c	77	-1.6	-2.0	-2.0	-2.0	-0.4	<-0.1	<-0.1	<-0.1	<-0.6	<-0.6	n	ESI
CIDA 14	289	-34	···	···	···	···	···	<-0.1	<-0.2	···	<-0.1	y	HIRES
FN Tau	195	-22	···	···	···	···	···	<-0.2	-0.9	···	-0.7	n	HIRES
FP Tau	418	-32	···	···	···	···	···	<-0.1	-0.1	···	-0.1	y	HIRES
Haro 6-28	347	-48	-30	-25	-25	-2.2	-1.2	-0.3	-0.2	-0.3	-0.1	y	ESI
LkCa 1	178	-3.9	···	···	···	···	···	<-0.1	-0.1	···	<-0.1	n	HIRES
LkHα 358	502	-63	-22^b	···	···	-1.9	-15	-4.1	-6.3	-6.6	-5.1	y	ESI
LkHα 358	477	-62	···	···	···	···	···	-2.2	-9.1	···	-7.8	y	HIRES
MHO-4	116	-43	-56	-35	-25	-4.3	1.2:	<-0.1	-0.4	-0.5	-0.1	n	ESI
MHO-5	154	-60	-44	-29	-19	-3.3	-4.0	-0.9	-0.4	-0.5	-0.1	y	ESI
MHO-6	309	-25	-13	-11	-8.6	-1.7	-1.4	-0.3	<-0.1	<-0.1	<-0.1	y	ESI
MHO-7	116	-9.0	-7.5	-3.6	-3.0	-0.5	<-0.1	<-0.1	<-0.1	<-0.1	<-0.1	n	ESI
MHO-8	115	-18	-17	-11	-5.5	-1.4	<-0.1	<-0.1	<-0.2	<-0.1	<-0.1	n	ESI
MHO-8	128	-14	···	···	···	···	···	<-0.1	<-0.2	···	<-0.2	n	HIRES
MHO-9	116	-3.5	-4.3	-2.8	-2.4	-0.5	<-0.2	<-0.1	<-0.1	<-0.3	<-0.2	n	ESI
V410 Anon 13	270	-29	-20^b	-9^b	···	-12.8^b	-0.8	<-0.5	<-0.1	<-0.1	<-0.1	y	ESI
V410 Anon 13	248	-27	···	···	···	···	···	<-0.4	<-0.3	···	<-0.1	y	HIRES
V410 Xray-3	116	-20	-23	-18	-10	-2.4	<-0.2	<-0.1	<-0.1	<-0.2	<-0.1	n	ESI
V410 Xray-5a	154	-19	-22	-15^b	···	-2.1	<-0.5	<-0.2	-0.2	-0.3	<-0.1	n	ESI
V927 Tau	290	-7.0	···	···	···	···	···	<-0.1	<-0.1	···	<-0.1	n	HIRES
IC348-165	347	-54	-28	-24^b	···	-2.4	-0.3:	-0.2	-0.3:	-0.4	-0.4:	y	ESI
IC348-173	347	-86	-50	-10^b	-35^b	-7.5	-2.2:	-0.4	-0.8	-1.6	-0.7	y	ESI
IC348-205	270	-105	-74^b	···	···	<-1.5^b	<-0.5	<-0.7	-1.1	-1.8	-0.9	y	ESI
IC348-336	309	-121	-42^b	-20^b	···	-6.4^b	<-2.8:	<-1.1:	-0.2	-0.4	<-0.1	y	ESI
IC348-363	117	-13	···	···	···	···	<-21:	<-1.0	<-0.1	<-0.1	<-0.1	n	ESI
IC348-382	232	-70	···	···	···	···	···	···	-0.6	-0.9	-0.3:	y	ESI
IC348-407	155	-24	···	···	···	···	···	···	<-0.7	-0.7:	<-1.1	n	ESI
IC348-415	272	-152	-40^b	···	···	···	<-4.0:^{b}	<-1.3	-2.8	-4.7	-2.6	y	ESI

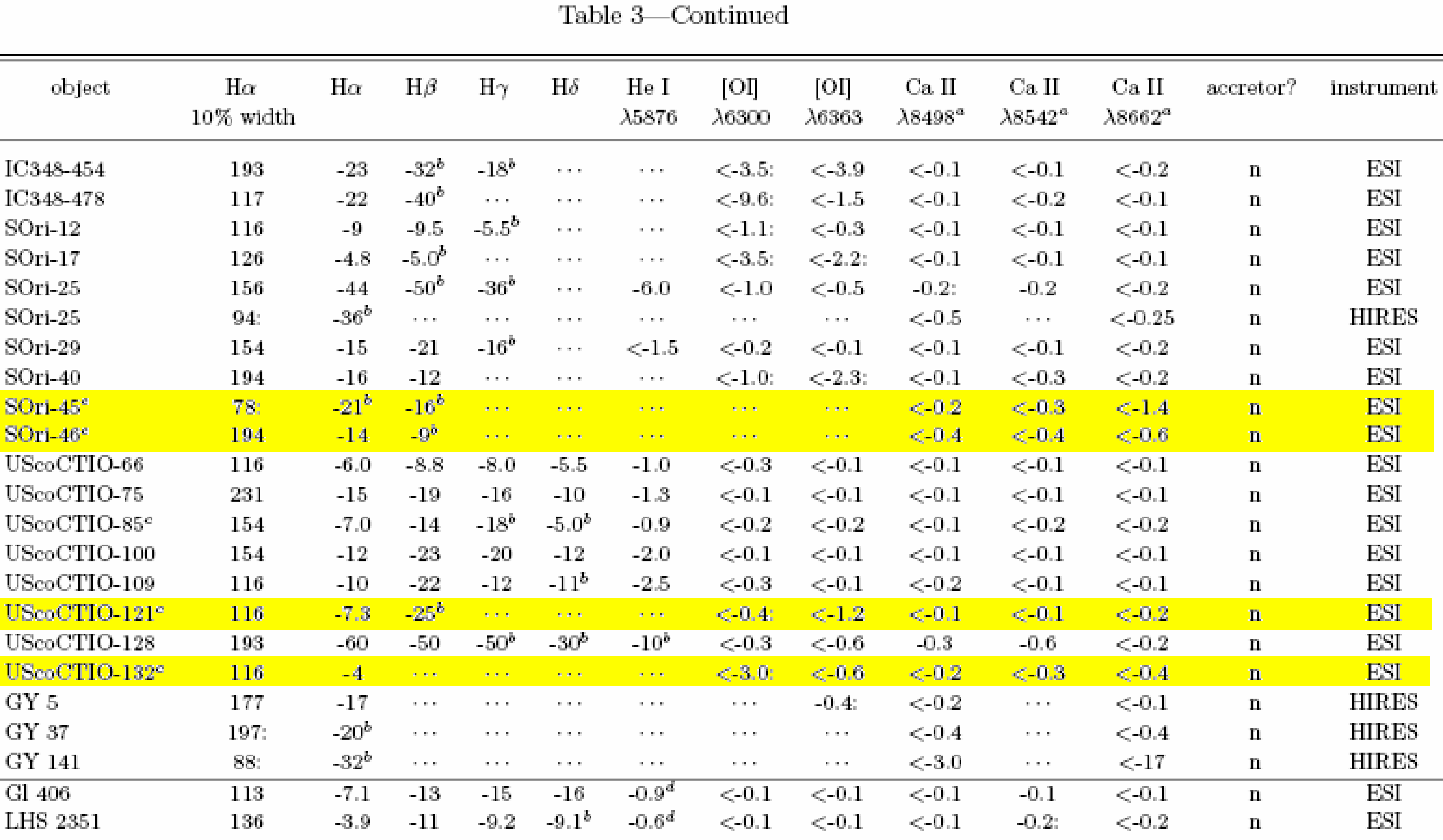


Table 3—Continued

object	Hα 10% width	Hα	Hβ	Hγ	Hδ	He I λ5876	[OI] λ6300	[OI] λ6363	Ca II λ8498^a	Ca II λ8542^a	Ca II λ8662^a	accretor?	instrument
IC348-454	193	-23	-32^b	-18^b	···	···	<-3.5:	<-3.9	<-0.1	<-0.1	<-0.2	n	ESI
IC348-478	117	-22	-40^b	···	···	···	<-9.6:	<-1.5	<-0.1	<-0.2	<-0.1	n	ESI
SOri-12	116	-9	-9.5	-5.5^b	···	···	<-1.1:	<-0.3	<-0.1	<-0.1	<-0.1	n	ESI
SOri-17	126	-4.8	-5.0^b	···	···	···	<-3.5:	<-2.2:	<-0.1	<-0.1	<-0.1	n	ESI
SOri-25	156	-44	-50^b	-36^b	···	-6.0	<-1.0	<-0.5	-0.2:	-0.2	<-0.2	n	ESI
SOri-25	94:	-36^b	···	···	···	···	···	···	<-0.5	···	<-0.25	n	HIRES
SOri-29	154	-15	-21	-16^b	···	<-1.5	<-0.2	<-0.1	<-0.1	<-0.1	<-0.2	n	ESI
SOri-40	194	-16	-12	···	···	···	<-1.0:	<-2.3:	<-0.1	<-0.3	<-0.2	n	ESI
SOri-45^c	78:	-21^b	-16^b	···	···	···	···	···	<-0.2	<-0.3	<-1.4	n	ESI
SOri-46^c	194	-14	-9^b	···	···	···	···	···	<-0.4	<-0.4	<-0.6	n	ESI
UScoCTIO-66	116	-6.0	-8.8	-8.0	-5.5	-1.0	<-0.3	<-0.1	<-0.1	<-0.1	<-0.1	n	ESI
UScoCTIO-75	231	-15	-19	-16	-10	-1.3	<-0.1	<-0.1	<-0.1	<-0.1	<-0.1	n	ESI
UScoCTIO-85^c	154	-7.0	-14	-18^b	-5.0^b	-0.9	<-0.2	<-0.2	<-0.1	<-0.2	<-0.2	n	ESI
UScoCTIO-100	154	-12	-23	-20	-12	-2.0	<-0.1	<-0.1	<-0.1	<-0.1	<-0.1	n	ESI
UScoCTIO-109	116	-10	-22	-12	-11^b	-2.5	<-0.3	<-0.1	<-0.2	<-0.1	<-0.1	n	ESI
UScoCTIO-121^c	116	-7.3	-25^b	···	···	···	<-0.4:	<-1.2	<-0.1	<-0.1	<-0.2	n	ESI
UScoCTIO-128	193	-60	-50	-50^b	-30^b	-10^b	<-0.3	<-0.6	-0.3	-0.6	<-0.2	n	ESI
UScoCTIO-132^c	116	-4	···	···	···	···	<-3.0:	<-0.6	<-0.2	<-0.3	<-0.4	n	ESI
GY 5	177	-17	···	···	···	···	···	-0.4:	<-0.2	···	<-0.1	n	HIRES
GY 37	197:	-20^b	···	···	···	···	···	···	<-0.4	···	<-0.4	n	HIRES
GY 141	88:	-32^b	···	···	···	···	···	···	<-3.0	···	<-17	n	HIRES
Gl 406	113	-7.1	-13	-15	-16	-0.9^d	<-0.1	<-0.1	<-0.1	-0.1	<-0.1	n	ESI
LHS 2351	136	-3.9	-11	-9.2	-9.1^b	-0.6^d	<-0.1	<-0.1	<-0.1	-0.2:	<-0.2	n	ESI

Accretion?

- Two primary methods for determining whether accretion is present
  - Veiling
  - Hα emission-line profiles
- Secondary indicators
  - Balmer, Ca II lines
  - [O I], [S II] lines

Hα Emission

- For T Tauri stars, Hα EW = 10 Å is dividing line between weak-lined and classical
- But equivalent width is dependent on continuum flux
  - Lower continuum ➔ higher EW
- Instead, use 10% line widths
  - Define 200 km s^{-1} as lower limit for accretion
- Also use symmetric vs. asymmetric shapes

Hα Emission

- 10 objects meet both criteria
- 7 objects meet one
  - 4 others have broad Hα lines but are symmetrical
  - 3 objects have asymmetric Hα but are relatively narrow
  - 3 of 7 “maybes” probably are accretors (based on other emission features; i.e. Balmer lines, Ca II triplet)

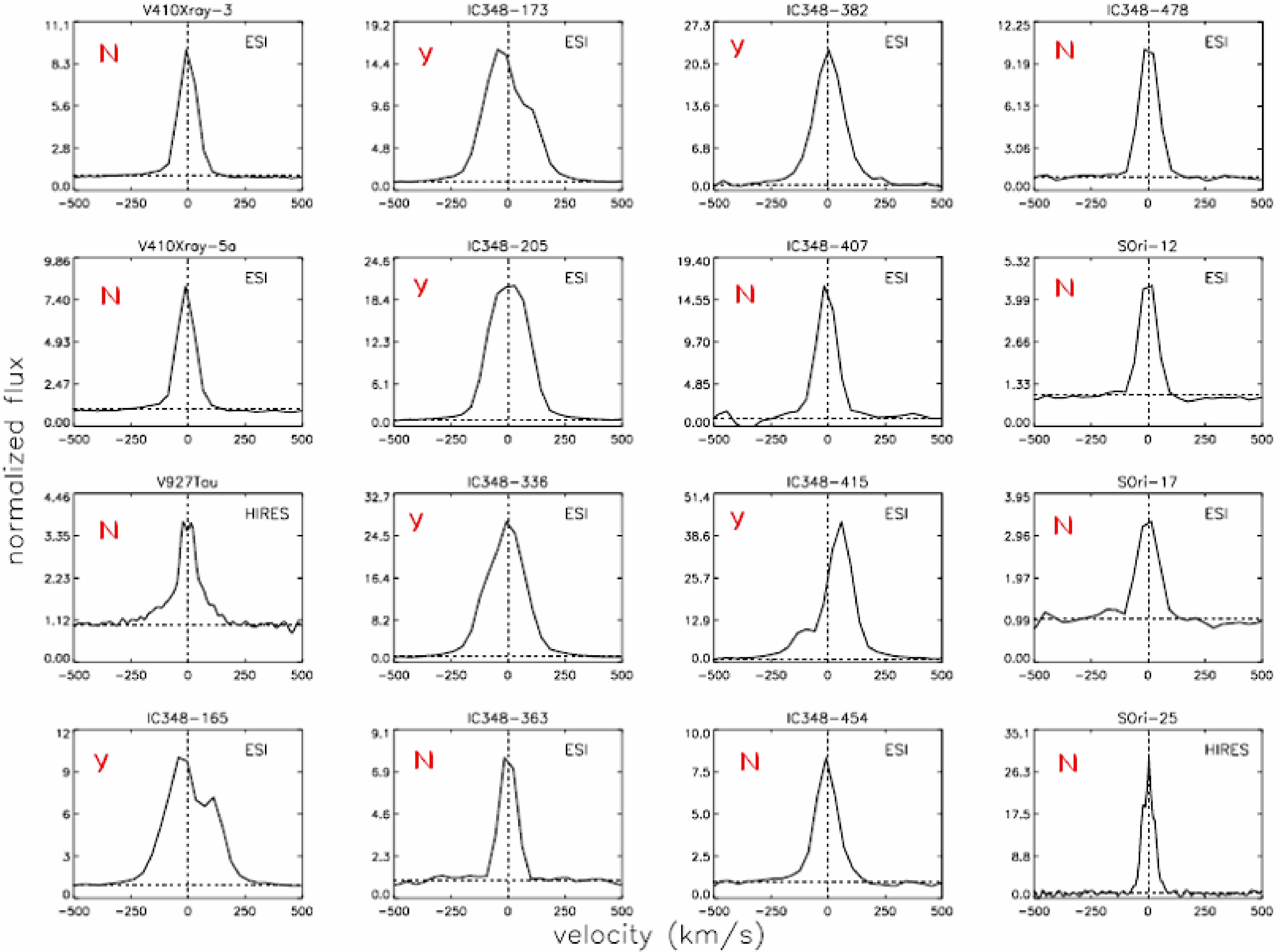
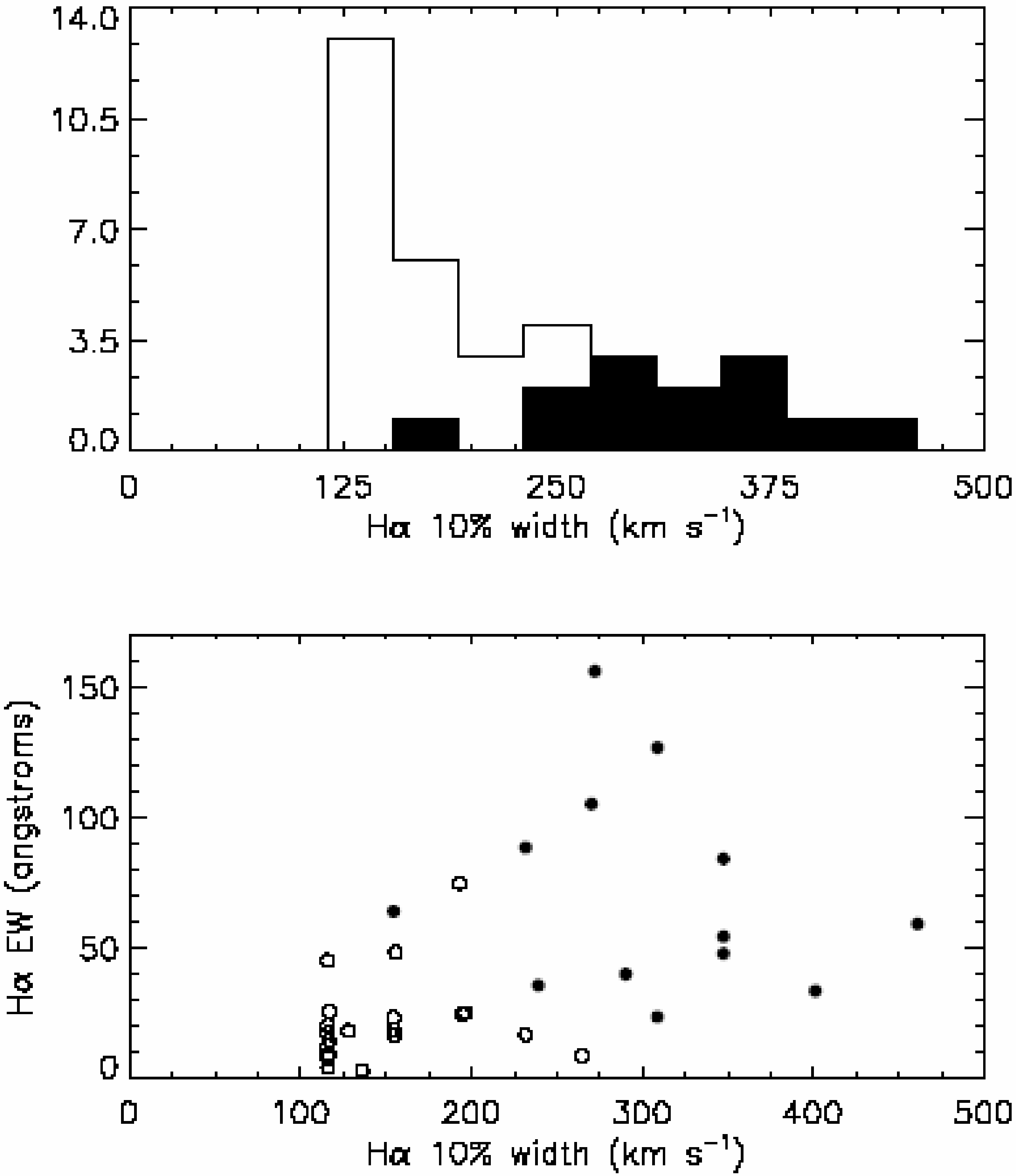

normalized flux
velocity (km/s)
V410Xray-3
N
ESI
11.1
8.3
5.6
2.8
0.0
IC348-173
y
ESI
19.2
14.4
9.6
4.8
0.0
IC348-382
y
ESI
27.3
20.5
13.6
6.8
0.0
IC348-478
N
ESI
12.25
9.19
6.13
3.06
0.00
V410Xray-5a
N
ESI
9.86
7.40
4.93
2.47
0.00
IC348-205
y
ESI
24.6
18.4
12.3
6.1
0.0
IC348-407
N
ESI
19.40
14.55
9.70
4.85
0.00
SOri-12
N
ESI
5.32
3.99
2.66
1.33
0.00
V927Tau
N
HIRES
4.46
3.35
2.23
1.12
0.00
IC348-336
y
ESI
32.7
24.5
16.4
8.2
0.0
IC348-415
y
ESI
51.4
38.6
25.7
12.9
0.0
SOri-17
N
ESI
3.95
2.96
1.97
0.99
0.00
IC348-165
y
ESI
12
9
6
3
0
IC348-363
N
ESI
9.1
6.9
4.6
2.3
0.0
IC348-454
N
ESI
10.0
7.5
5.0
2.5
0.0
SOri-25
N
HIRES
35.1
26.3
17.5
8.8
0.0
-500
-250
0
250
500

Figure 3:


14.0
10.5
7.0
3.5
0.0
0
125
250
375
500
Hα 10% width (km s^{-1})
150
100
50
0
Hα EW (angstroms)
0
100
200
300
400
500
Hα 10% width (km s^{-1})

Veiling

- The process:
  - Mass accretes onto the star via magnetospheres and undergoes an accretion shock, giving off continuum flux
- Quantified by measuring excess continuum flux and comparing to photospheric continuum

  $r_\lambda = F_{\lambda,ex} / F_{\lambda,cont}$

  - Use objects determined to not have mass accretion as continuum templates
- Expect little veiling for lower mass stars

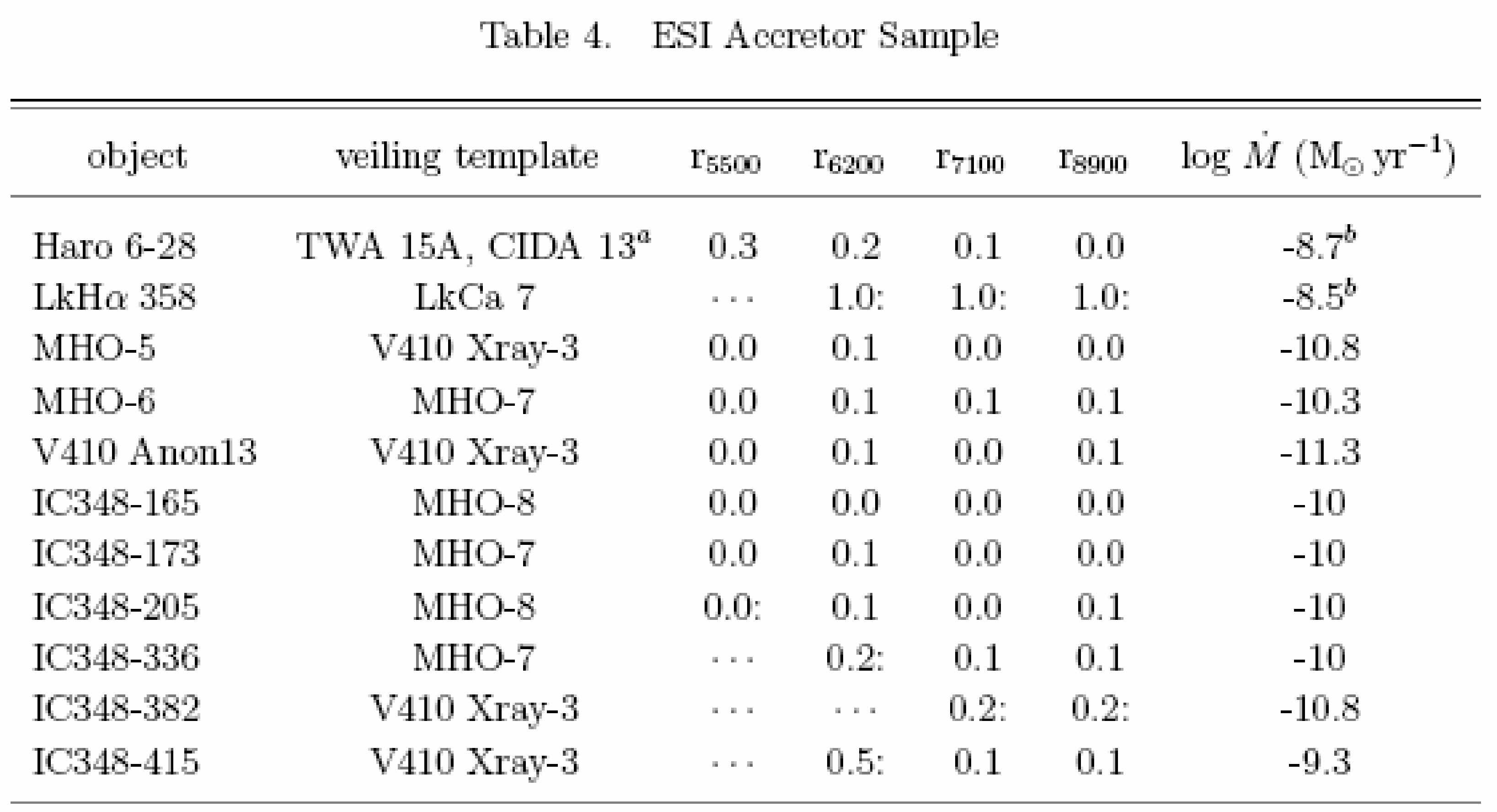


Table 4. ESI Accretor Sample

object	veiling template	r_{5500}	r_{6200}	r_{7100}	r_{8900}	$\log \dot{M}$ ($M_\odot$ yr^{-1})
Haro 6-28	TWA 15A, CIDA 13[a]	0.3	0.2	0.1	0.0	-8.7[b]
LkHα 358	LkCa 7	· · ·	1.0:	1.0:	1.0:	-8.5[b]
MHO-5	V410 Xray-3	0.0	0.1	0.0	0.0	-10.8
MHO-6	MHO-7	0.0	0.1	0.1	0.1	-10.3
V410 Anon13	V410 Xray-3	0.0	0.1	0.0	0.1	-11.3
IC348-165	MHO-8	0.0	0.0	0.0	0.0	-10
IC348-173	MHO-7	0.0	0.1	0.0	0.0	-10
IC348-205	MHO-8	0.0:	0.1	0.0	0.1	-10
IC348-336	MHO-7	· · ·	0.2:	0.1	0.1	-10
IC348-382	V410 Xray-3	· · ·	· · ·	0.2:	0.2:	-10.8
IC348-415	V410 Xray-3	· · ·	0.5:	0.1	0.1	-9.3

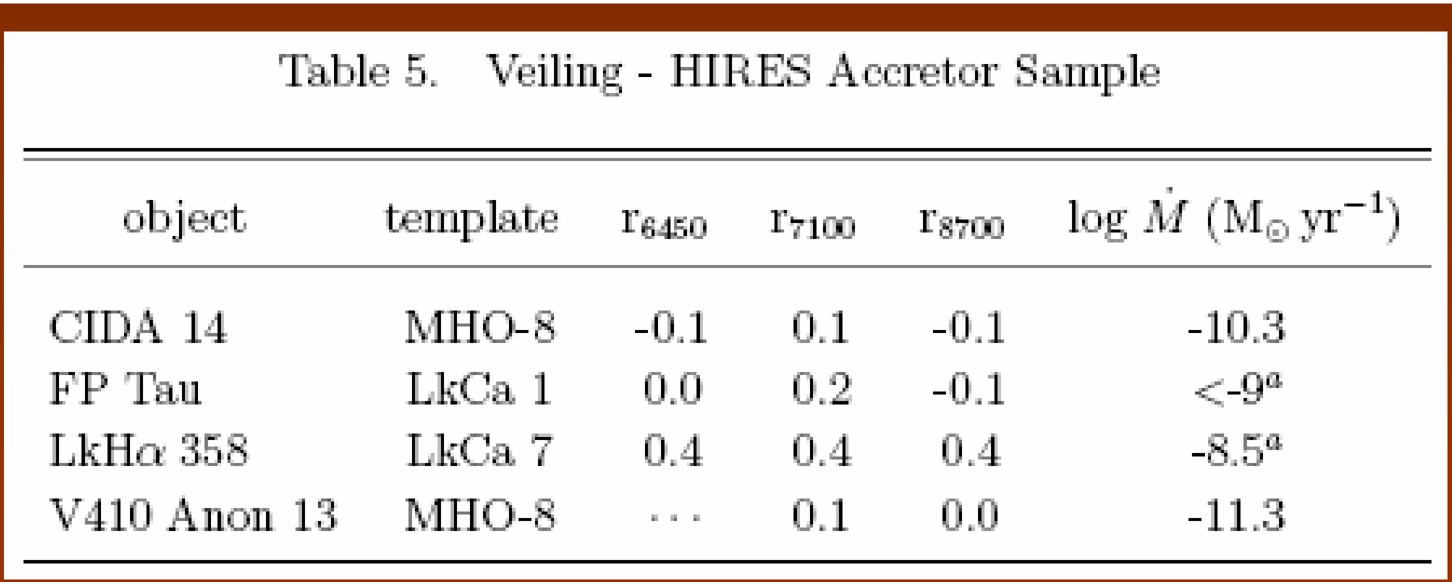


Table 5. Veiling - HIRES Accretor Sample

object	template	r_{6450}	r_{7100}	r_{8700}	$\log \dot{M}$ ($M_\odot$ yr^{-1})
CIDA 14	MHO-8	-0.1	0.1	-0.1	-10.3
FP Tau	LkCa 1	0.0	0.2	-0.1	$<$-9[a]
LkHα 358	LkCa 7	0.4	0.4	0.4	-8.5[a]
V410 Anon 13	MHO-8	· · ·	0.1	0.0	-11.3

Continuum Excess Models

- Picked 2 generic stars that compare to sample
  - M5: $T = 2900$ K, $M_* = 0.12\ M_\odot$, $R_* = 1.2\ R_\odot$
  - M6: $T = 2800$ K, $M_* = 0.05\ M_\odot$, $R_* = 0.5\ R_\odot$
- Selected accretion energy fluxes of log F = 10, 11, 12 (corresponding to TTS)
- Calculated emission from shock for mass accretions of 10^{-10}, 10^{-9}, $10^{-8}\ M_\odot\ \mathrm{yr}^{-1}$
- Finally, computed veiling ratio r_λ over wavelength regime of observations

Figure 4:

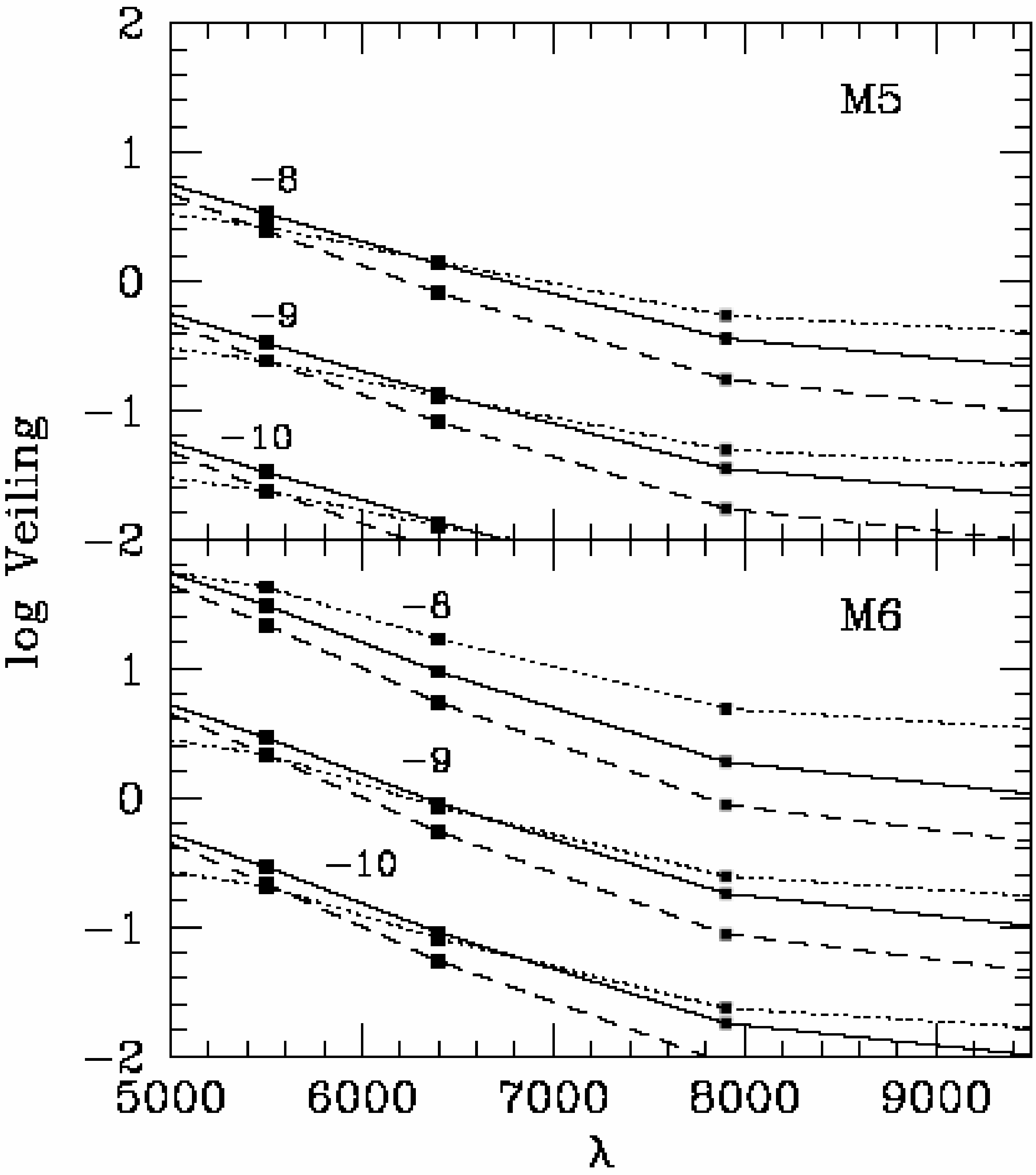
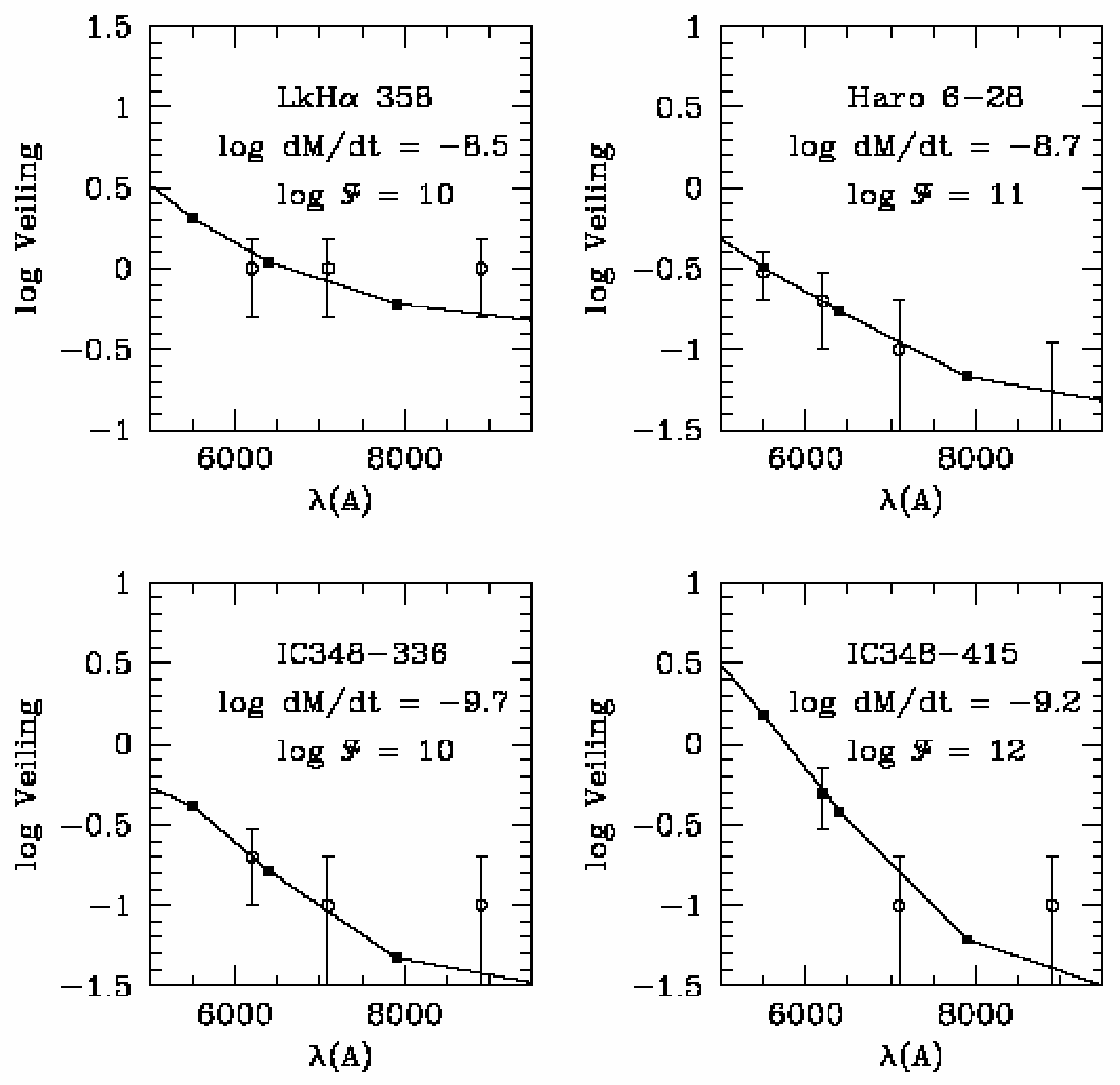

M5
M6
−8
−9
−10
−8
−9
−10
log Veiling
2
1
0
−1
−2
1
0
−1
−2
5000
6000
7000
8000
9000
λ

Figure 5:



LkHα 358
log dM/dt = −8.5
log ℱ = 10
Haro 6−28
log dM/dt = −8.7
log ℱ = 11
IC348−336
log dM/dt = −9.7
log ℱ = 10
IC348−415
log dM/dt = −9.2
log ℱ = 12
log Veiling
λ(A)
6000
8000
1.5
1
0.5
0
−0.5
−1
−1.5

Hα Emission Models

- Model parameters: M_*, R_*, R_{mag}, T_{max}, i, dM/dt
  - Adopted $M_* = (0.05,0.15)\ M_\odot$, $R_* = (0.5,1.0)\ R_\odot$, $R_{mag} = 2.2\text{-}3\ R_*$, $T_{max} = 12000$ K
  - i, dM/dt varied to fit
    - i: 0 - 90°
    - dM/dt: $10^{-12} - 10^{-9}\ M_\odot\ yr^{-1}$
- Rotation effects ignored (no significant effects expected for $v_{rot} < 20$ km s^{-1})
- To avoid problems with T_{max}, accretors earlier than M5 not modeled

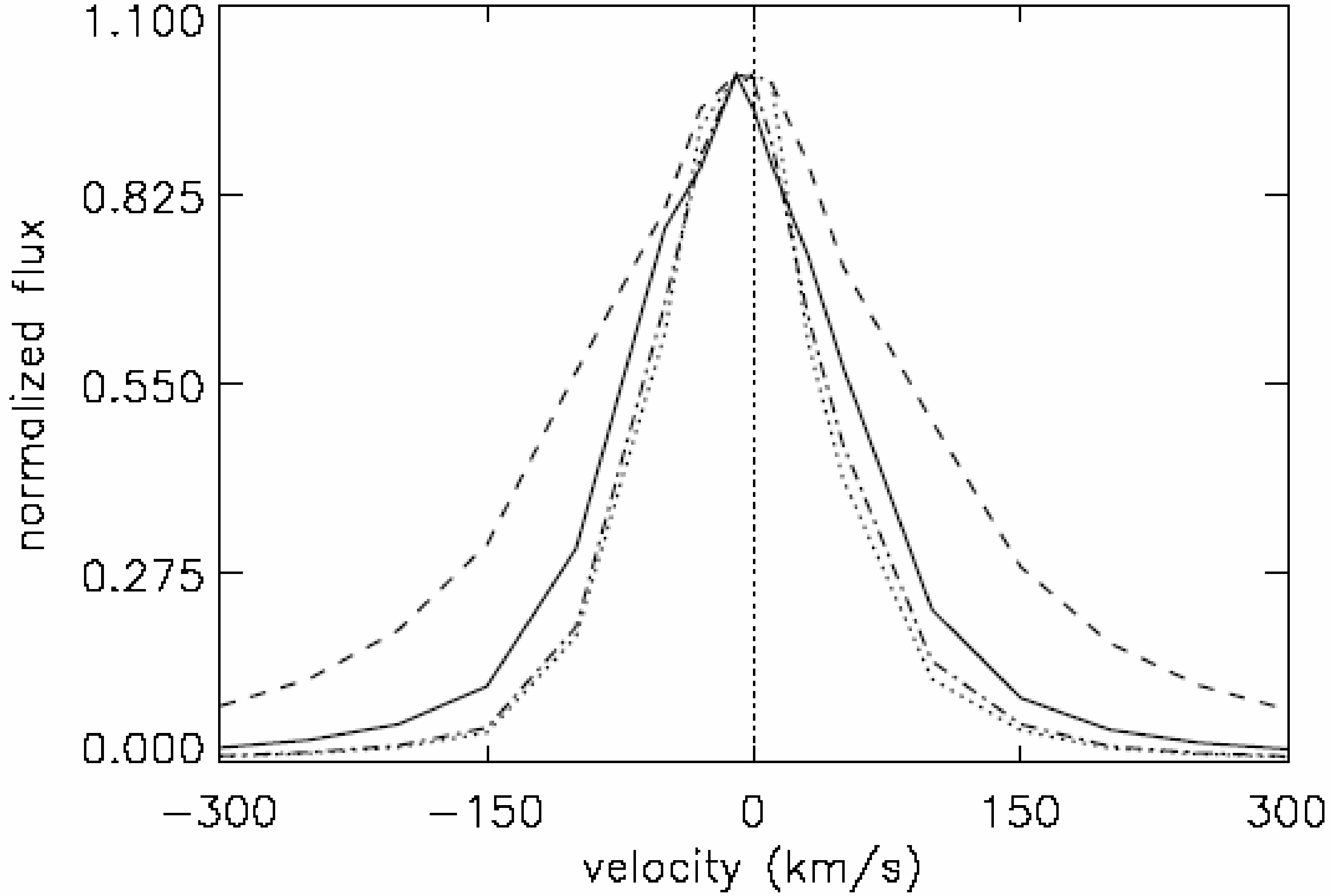


Fig. 6.— Model Hα profiles, as a function of magnetospheric density and temperature. All models calculated with $M_* = 0.05\,\mathrm{M}_\odot$, $R_* = 0.5\,R_\odot$, $i = 60°$, and $R_{mag} = 2.2 - 3\ R_*$. Solid line: $\dot{M} = 10^{-9}\,\mathrm{M}_\odot\,\mathrm{yr}^{-1}$, $T_{max} = 8000\ K$. Dashed line: $\dot{M} = 10^{-9}\,\mathrm{M}_\odot\,\mathrm{yr}^{-1}$, $T_{max} = 10,000\ K$. Dot-dashed line: $\dot{M} = 10^{-10}\,\mathrm{M}_\odot\,\mathrm{yr}^{-1}$, $T_{max} = 10,000\ K$. Dotted line: $\dot{M} = 10^{-10}\,\mathrm{M}_\odot\,\mathrm{yr}^{-1}$, $T_{max} = 12,000\ K$.

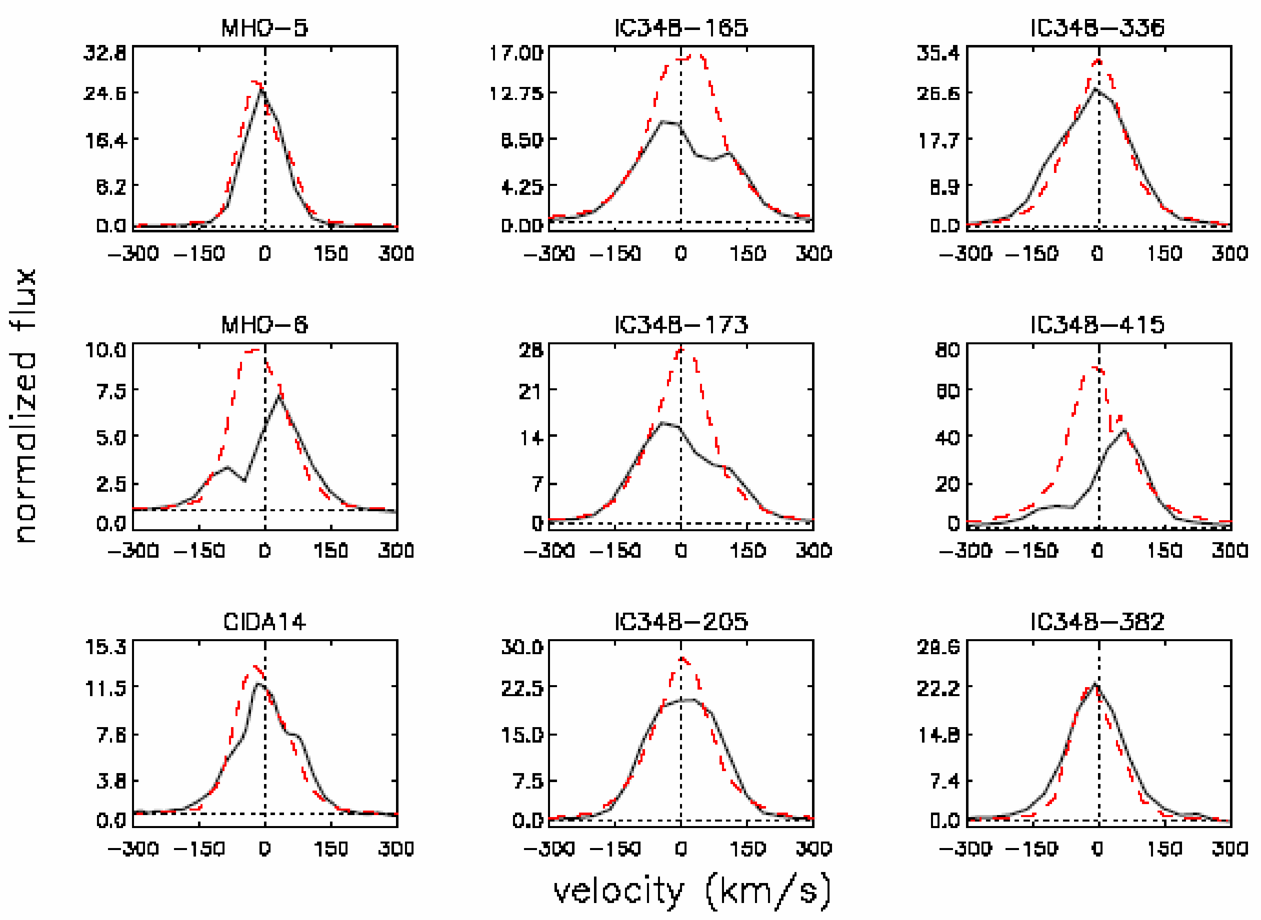


Figure 7

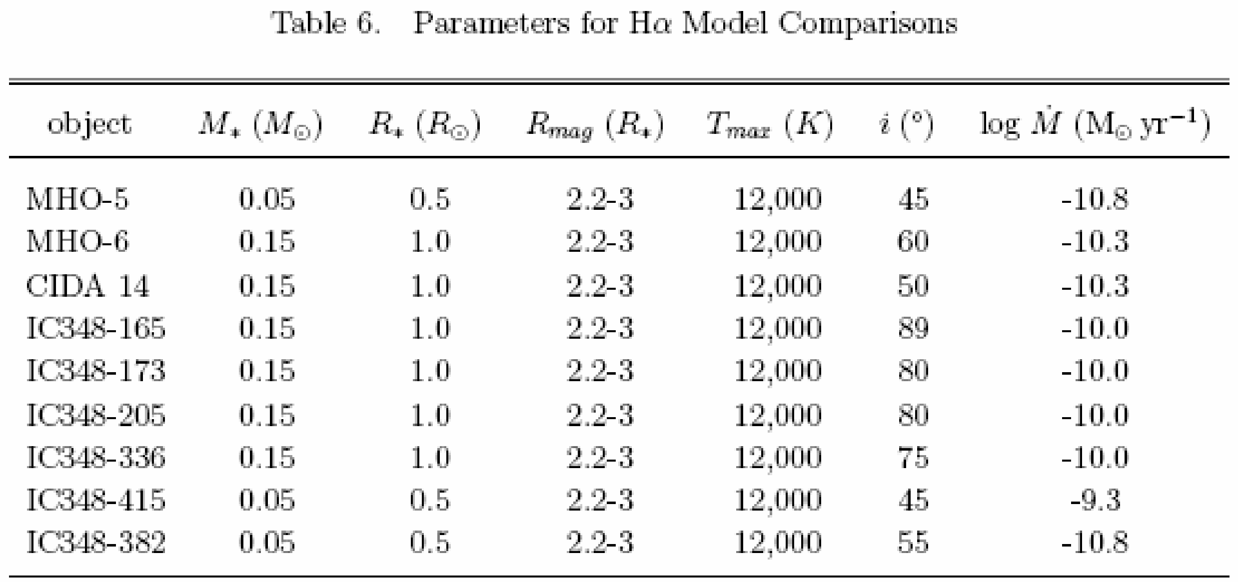


Table 6. Parameters for Hα Model Comparisons

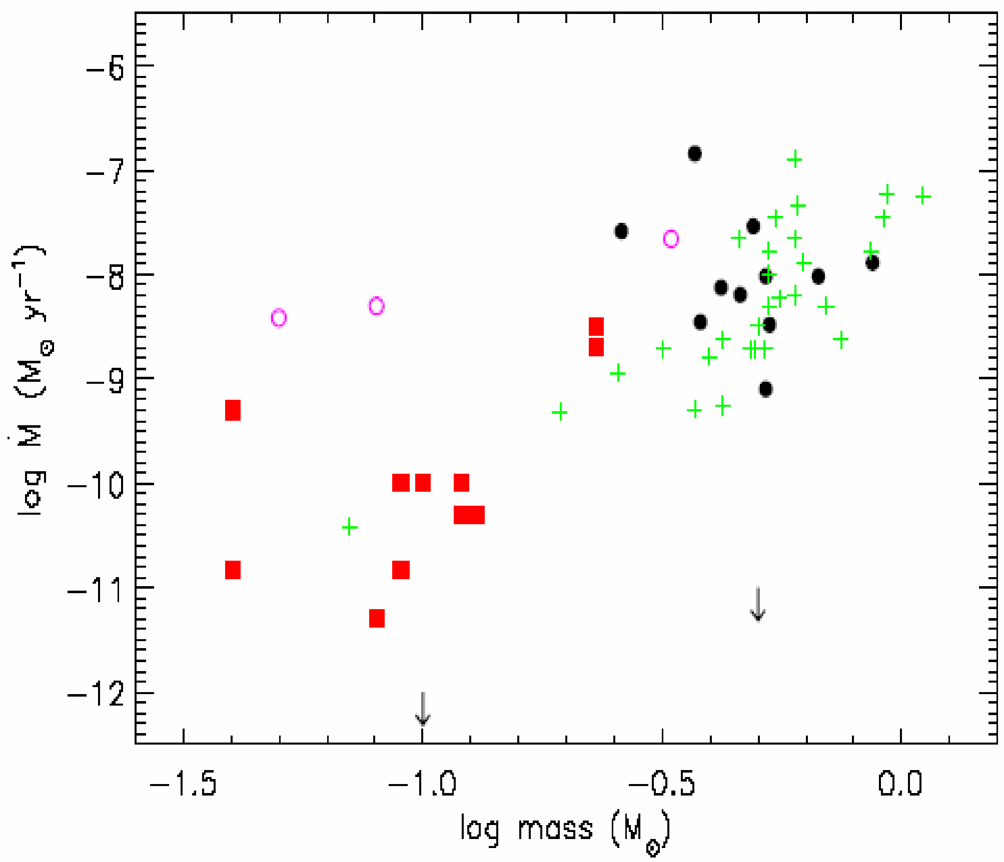
object	M_* ($M_\odot$)	R_* ($R_\odot$)	R_{mag} (R_*)	T_{max} (K)	i (°)	log $\dot{M}$ ($M_\odot$ yr^{-1})
MHO-5	0.05	0.5	2.2-3	12,000	45	-10.8
MHO-6	0.15	1.0	2.2-3	12,000	60	-10.3
CIDA 14	0.15	1.0	2.2-3	12,000	50	-10.3
IC348-165	0.15	1.0	2.2-3	12,000	89	-10.0
IC348-173	0.15	1.0	2.2-3	12,000	80	-10.0
IC348-205	0.15	1.0	2.2-3	12,000	80	-10.0
IC348-336	0.15	1.0	2.2-3	12,000	75	-10.0
IC348-415	0.05	0.5	2.2-3	12,000	45	-9.3
IC348-382	0.05	0.5	2.2-3	12,000	55	-10.8

Discussion

- ~30% of sample deemed to be accreting
  - Similar to studies of higher mass TTS
- Near-infrared excess suggests disks with small inner holes
  - Other possibilities include spots or cooler companions
- Magnetospheric accretion models fit accretors well over large range of masses
- Combining these results with literature values, correlation between *M* and *dM/dt* can be examined

M vs. dM/dt

- Potential problems
  - Masses are based on evolutionary tracks
  - Very low accretion rates would yield undetectable Hα emission
  - Veiling could mask objects with higher accretion rates



Discussion

- Why a M vs. dM/dt relationship?
  - Accretion is thought to be dependent on disk density, viscosity
  - Balbus-Hawley instability (viscosity model) requires ionized gas to operate efficiently
  - X-rays?
- M vs. dM/dt relation found here is for narrow age range (1 – 3 Myr)

Discussion

- Location of accretors dependent on cluster age
  - IC 348 & Taurus star forming regions are about 1-3 Myr – all 13 VLM accretors found
  - σ Ori & Sco-Cen associations are older (3-8 Myr) and have none
- Similar fraction of VLM objects in Taurus are accretors compared to TTS (~50%)

Questions?

My last journal club talk
. . . *sniff* *sniff*