Spectroscopy of Very Low Mass Stars and Brown Dwarfs in the LOSFR.

Enlarging the census down to the planetary mass domain in C69

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collaborating with
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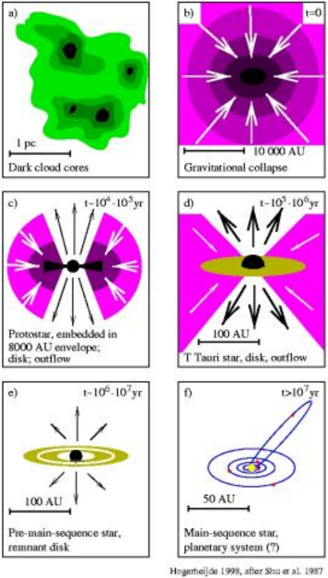
ESO, Garching

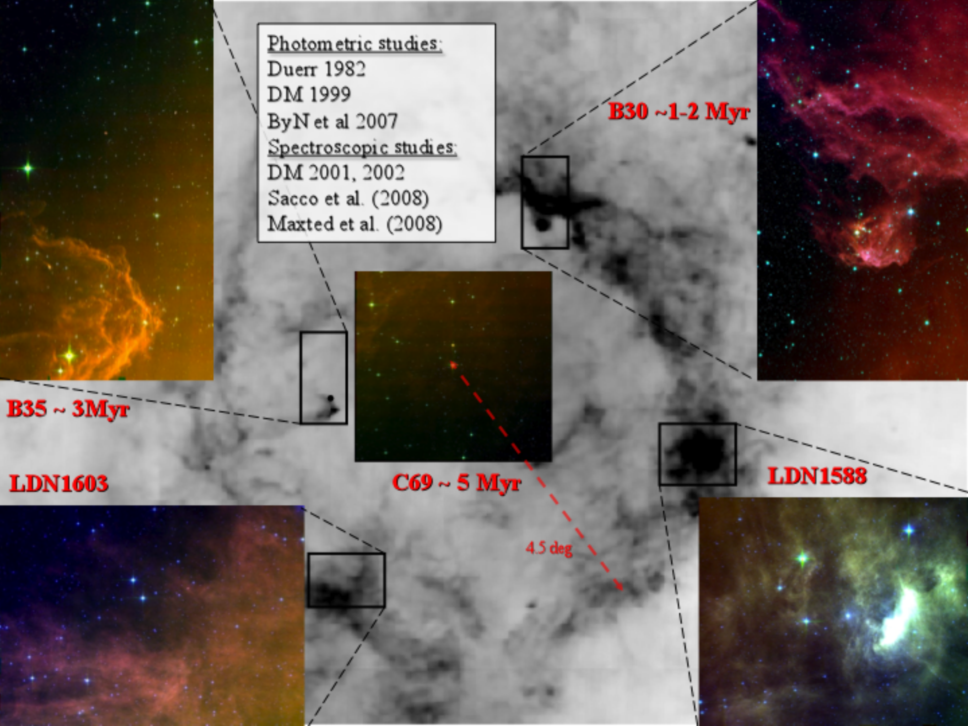
October 24, 2011

Outline

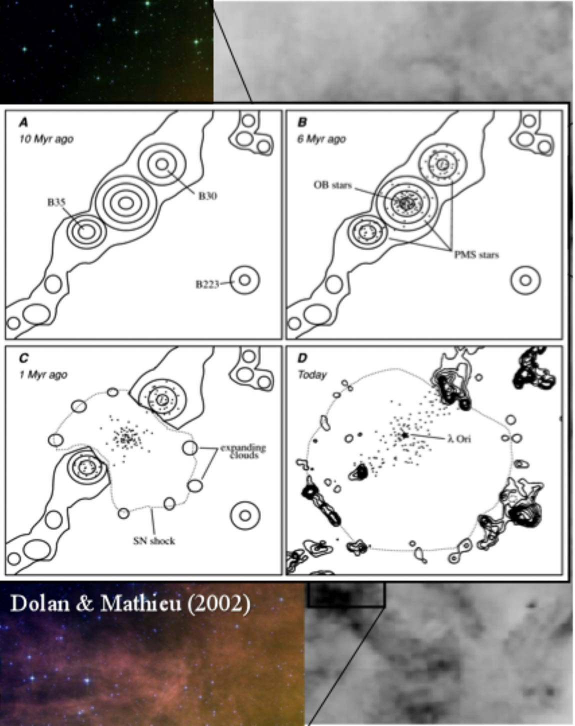
Low mass SF Theory



- Turbulent fragmentation *(Padoan & Nordlund, 2002, Hennebelle & Chabrier, 2008, Chabrier & Hennebelle, 2011)*:
  density enhancements → decrease the Jeans mass
- Ejection scenario *(Reipurth & Clarke 2001)*: stellar embryos ejected before accreting enough mass for H burning.
- Photoevaporation *(Whitworth & Zinnecker 2004)*: winds from massive nearby stars → lost envelopes of protostellar cores.
- Disk fragmentation *(Goodwin & Whitworth, 2007 and Stamatellos et al 2007)*:
  scaled up version of planets.



Photometric studies:
Duerr 1982
DM 1999
ByN et al 2007
Spectroscopic studies:
DM 2001, 2002
Sacco et al. (2008)
Maxted et al. (2008)
B30 ~1-2 Myr
B35 ~ 3Myr
C69 ~ 5 Myr
LDN1603
LDN1588
4.5 deg



A. ~8–10 Myr ago, the λ Ori region was composed of a starless, roughly linear string of dense molecular clouds.

B. Over the next few Myr, stars began to form in the densest portions of this cloud chain. 6 Myr ago, a dozen OB stars formed near λ Ori's present-day position while low-mass stars formed in all productive areas of the star-forming complex.

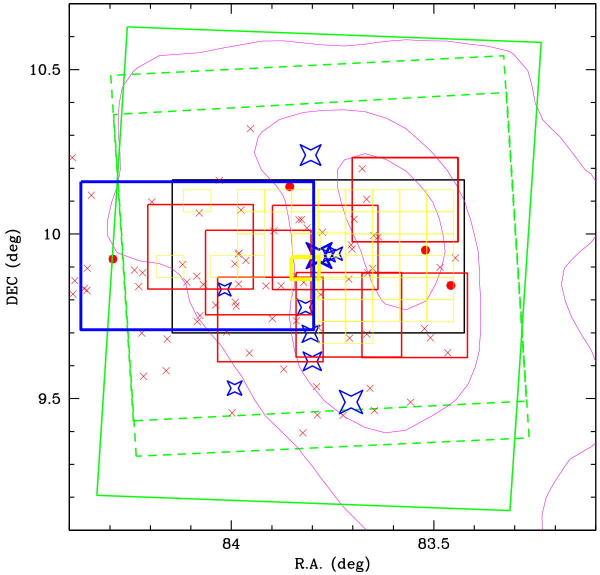
C. ~1 Myr ago, one of the O stars became a supernova. The blast quickly dispersed all of the parent core, creating the molecular ring, the large HII region, and the nearby HI structures.

D. Today we see the fossil distribution of young stars within the molecular ring, as well as the remnants of the B30 and B35 clouds within the ionized region.

Aims

- Spectroscopically confirm the lowest mass members of the three associations (including Brown Dwarfs and IPMOS).
- Build complete census for the three regions.
- Relate properties of individual sources (acc. rates, etc.) with three different environments (ages).
- Build a very complete IMF for Collinder 69 from $\sim$ 20 $M_\odot$ down to the planetary mass domain (shared mechanism of formation for low mass domain?).
- “Test" the Supernova hypothesis.

Photometric and X-ray surveys



CFHT (optical)

IRAC & MIPS (MIR)

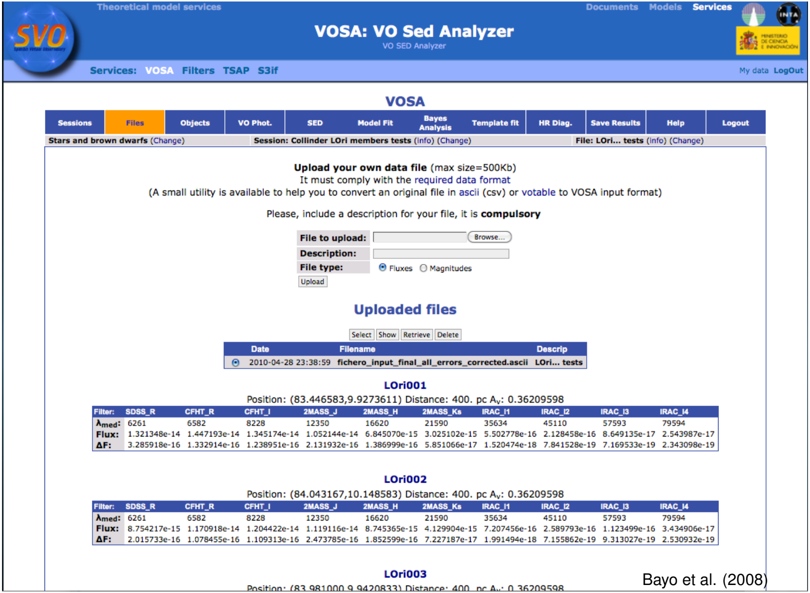
Omega200 (NIR)

Ingrid (NIR)

Suprime-Cam (optical)

XMM-Newton (X-rays)

SED analysis



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SVO

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Stars and brown dwarfs (Change) Session: Collinder LOri members tests (info) (Change) File: LOri... tests (info) (Change)

Upload your own data file (max size=500Kb)
It must comply with the required data format
(A small utility is available to help you to convert an original file in ascii (csv) or votable to VOSA input format)

Please, include a description for your file, it is **compulsory**

File to upload: Browse...
Description:
File type: Fluxes Magnitudes
Upload

Uploaded files

Select Show Retrieve Delete

Date	Filename	Descrip
2010-04-28 23:38:59	fichero_input_final_all_errors_corrected.ascii	LOri... tests

LOri001

Position: (83.446583,9.9273611) Distance: 400. pc A_v: 0.36209598

Filter:	SDSS_R	CFHT_R	CFHT_I	2MASS_J	2MASS_H	2MASS_Ks	IRAC_I1	IRAC_I2	IRAC_I3	IRAC_I4
λmed:	6261	6582	8228	12350	16620	21590	35634	45110	57593	79594
Flux:	1.321348e-14	1.447193e-14	1.345174e-14	1.052144e-14	6.845070e-15	3.025102e-15	5.502778e-16	2.128458e-16	8.649135e-17	2.543987e-17
ΔF:	3.285918e-16	1.332914e-16	1.238951e-16	2.131932e-16	1.386999e-16	5.851066e-17	1.520474e-18	7.841528e-19	7.169533e-19	2.343098e-19

LOri002

Position: (84.043167,10.148583) Distance: 400. pc A_v: 0.36209598

Filter:	SDSS_R	CFHT_R	CFHT_I	2MASS_J	2MASS_H	2MASS_Ks	IRAC_I1	IRAC_I2	IRAC_I3	IRAC_I4
λmed:	6261	6582	8228	12350	16620	21590	35634	45110	57593	79594
Flux:	8.754217e-15	1.170918e-14	1.204422e-14	1.119116e-14	8.745365e-15	4.129904e-15	7.207456e-16	2.589793e-16	1.123499e-16	3.434906e-17
ΔF:	2.015733e-16	1.078455e-16	1.109313e-16	2.473785e-16	1.852599e-16	7.227187e-17	1.991494e-18	7.155862e-19	9.313027e-19	2.530932e-19

LOri003

Position: (83.981000,9.9420833) Distance: 400. pc A_v: 0.36209598

Bayo et al. (2008)

SED analysis

Bayo et al. (2008)

SED analysis

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Stars and brown dwarfs (Change) **Session: Collinder LOri members tests** (info) (Change) **File: LOri... tests** (info) (Change)

Object data

LOri001
LOri002
LOri003
LOri004
LOri005
LOri006
LOri007
LOri008
LOri009
LOri010
LOri011
LOri012
LOri013
LOri014
LOri015
LOri016
LOri017
LOri018
LOri019
LOri020
LOri021
LOri022
LOri023
LOri024
LOri025
LOri026
LOri027
LOri028

LOri029

Position: (83.855667,10.144083) Distance: 400. pc A_V: 0.36209598

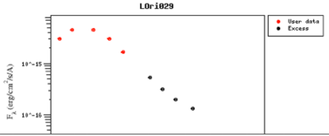
Data for this object:

		Final		User		VO		
Filter	λ_{med}	Flux	ΔF	Flux	ΔF	Flux	ΔF	
CFHT_R	6582	3.079827e-15	2.836626e-17	3.079827e-15	2.836626e-17	---	---	Delete
CFHT_I	8228	4.579084e-15	4.217492e-17	4.579084e-15	4.217492e-17	---	---	Delete
2MASS_J	12350	4.538110e-15	1.086736e-16	4.538110e-15	1.086736e-16	---	---	Delete
2MASS_H	16620	3.085872e-15	7.673922e-17	3.085872e-15	7.673922e-17	---	---	Delete
2MASS_Ks	21590	1.670090e-15	2.922599e-17	1.670090e-15	2.922599e-17	---	---	Delete
IRAC_I1	35634	5.347884e-16	1.477675e-18	5.347884e-16	1.477675e-18	---	---	Delete
IRAC_I2	45110	3.148220e-16	8.698853e-19	3.148220e-16	8.698853e-19	---	---	Delete
IRAC_I3	57593	1.968669e-16	1.087927e-18	1.968669e-16	1.087927e-18	---	---	Delete
IRAC_I4	79594	1.322863e-16	3.655205e-19	1.322863e-16	3.655205e-19	---	---	Delete
MIPS_M1	238442	2.027081e-17	1.306907e-19	2.027081e-17	1.306907e-19	---	---	Delete

Excess detected from **IRAC_I1**. Points with larger wavelength will not be considered in model fit.

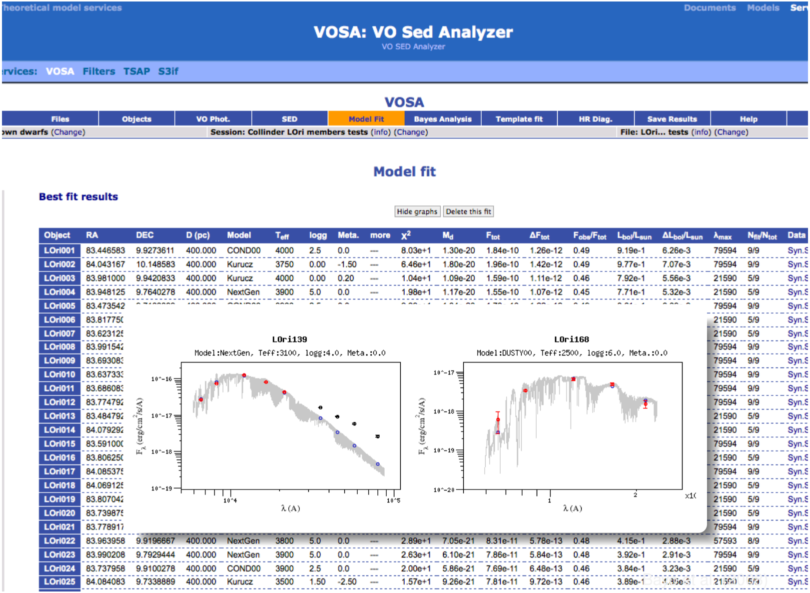
You can manually specify where excess starts.

Apply excess from IRAC_I1



Bayo et al. (2008)

SED analysis



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own dwarfs (Change) Session: Collinder LOri members tests (info) (Change) File: LOri... tests (info) (Change)

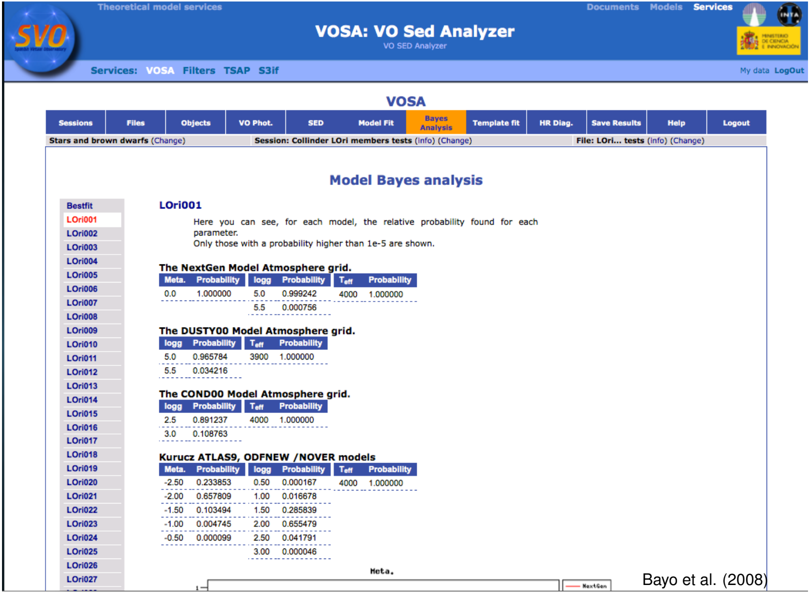
Model fit

Best fit results

Hide graphs Delete this fit

Object	RA	DEC	D (pc)	Model	T_{eff}	logg	Meta.	more	χ^2	M_d	F_{tot}	ΔF_{tot}	F_{obs}/F_{tot}	L_{bol}/L_{sun}	$\Delta L_{bol}/L_{sun}$	λ_{max}	N_{fit}/N_{tot}	Data
LOri001	83.446583	9.9273611	400.000	COND00	4000	2.5	0.0	---	8.03e+1	1.30e-20	1.84e-10	1.26e-12	0.49	9.19e-1	6.26e-3	79594	9/9	Syn.S
LOri002	84.043167	10.148583	400.000	Kurucz	3750	0.00	-1.50	---	6.46e+1	1.80e-20	1.96e-10	1.42e-12	0.49	9.77e-1	7.07e-3	79594	9/9	Syn.S
LOri003	83.981000	9.9420833	400.000	Kurucz	4000	0.00	0.20	---	1.04e+1	1.09e-20	1.59e-10	1.11e-12	0.46	7.92e-1	5.56e-3	21590	5/9	Syn.S
LOri004	83.948125	9.7640278	400.000	NextGen	3900	5.0	0.0	---	1.98e+1	1.17e-20	1.55e-10	1.07e-12	0.45	7.71e-1	5.32e-3	21590	5/9	Syn.S
LOri005	83.473542															79594	9/9	Syn.S
LOri006	83.81775															21590	5/9	Syn.S
LOri007	83.62312															21590	5/9	Syn.S
LOri008	83.99154															79594	9/9	Syn.S
LOri009	83.69308															79594	9/9	Syn.S
LOri010	83.63733															79594	9/9	Syn.S
LOri011	83.68608															79594	9/9	Syn.S
LOri012	83.77479															79594	9/9	Syn.S
LOri013	83.48479															21590	5/9	Syn.S
LOri014	84.07929															21590	5/9	Syn.S
LOri015	83.59100															79594	9/9	Syn.S
LOri016	83.80625															21590	5/9	Syn.S
LOri017	84.08537															79594	9/9	Syn.S
LOri018	84.06912															21590	5/9	Syn.S
LOri019	83.80704															21590	5/9	Syn.S
LOri020	83.73987															21590	5/9	Syn.S
LOri021	83.778917															79594	9/9	Syn.S
LOri022	83.963958	9.9196667	400.000	NextGen	3800	5.0	0.0	---	2.89e+1	7.05e-21	8.31e-11	5.78e-13	0.48	4.15e-1	2.88e-3	57593	8/9	Syn.S
LOri023	83.990208	9.7929444	400.000	NextGen	3900	5.0	0.0	---	2.63e+1	6.10e-21	7.86e-11	5.84e-13	0.48	3.92e-1	2.91e-3	79594	9/9	Syn.S
LOri024	83.737958	9.9100278	400.000	COND00	3900	2.5	0.0	---	2.00e+1	5.86e-21	7.69e-11	6.48e-13	0.46	3.84e-1	3.23e-3	21590	5/9	Syn.S
LOri025	84.084083	9.7338889	400.000	Kurucz	3500	1.50	-2.50	---	1.57e+1	9.26e-21	7.81e-11	9.72e-13	0.46	3.89e-1	4.85e-3	21590	5/9	Syn.S

SED analysis



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Stars and brown dwarfs (Change) Session: Collinder LOri members tests (info) (Change) File: LOri... tests (info) (Change)

Model Bayes analysis

Bestfit
LOri001
LOri002
LOri003
LOri004
LOri005
LOri006
LOri007
LOri008
LOri009
LOri010
LOri011
LOri012
LOri013
LOri014
LOri015
LOri016
LOri017
LOri018
LOri019
LOri020
LOri021
LOri022
LOri023
LOri024
LOri025
LOri026
LOri027

LOri001

Here you can see, for each model, the relative probability found for each parameter.
Only those with a probability higher than 1e-5 are shown.

The NextGen Model Atmosphere grid.

Meta.	Probability	logg	Probability	T_{eff}	Probability
0.0	1.000000	5.0	0.999242	4000	1.000000
		5.5	0.000756		

The DUSTY00 Model Atmosphere grid.

logg	Probability	T_{eff}	Probability
5.0	0.965784	3900	1.000000
5.5	0.034216		

The COND00 Model Atmosphere grid.

logg	Probability	T_{eff}	Probability
2.5	0.891237	4000	1.000000
3.0	0.108763		

Kurucz ATLAS9, ODFNEW /NOVER models

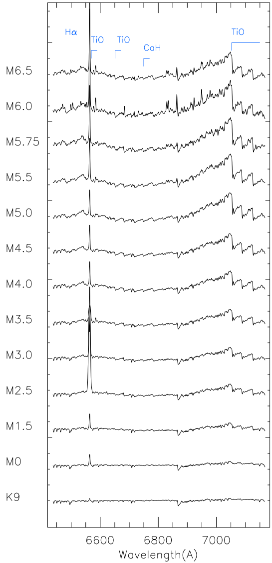
Meta.	Probability	logg	Probability	T_{eff}	Probability
-2.50	0.233853	0.50	0.000167	4000	1.000000
-2.00	0.657809	1.00	0.016678		
-1.50	0.103494	1.50	0.285839		
-1.00	0.004745	2.00	0.655479		
-0.50	0.000099	2.50	0.041791		
		3.00	0.000046		

Bayo et al. (2008)

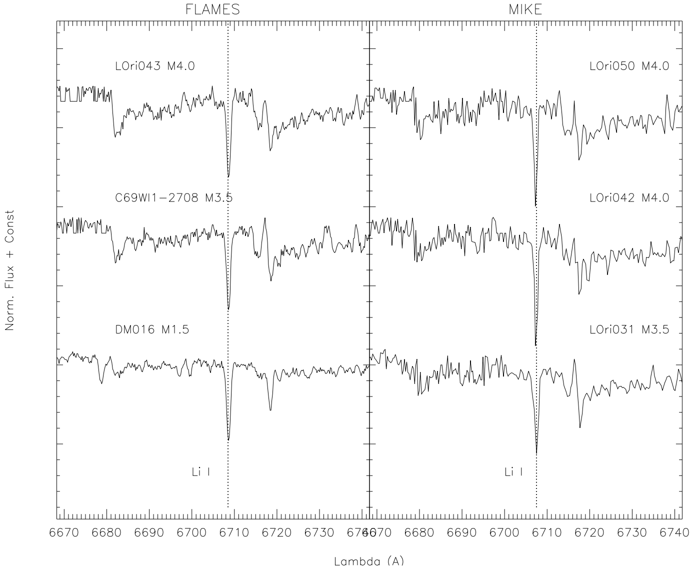
Spectroscopic follow-up

Spectroscopic confirmation of candidates

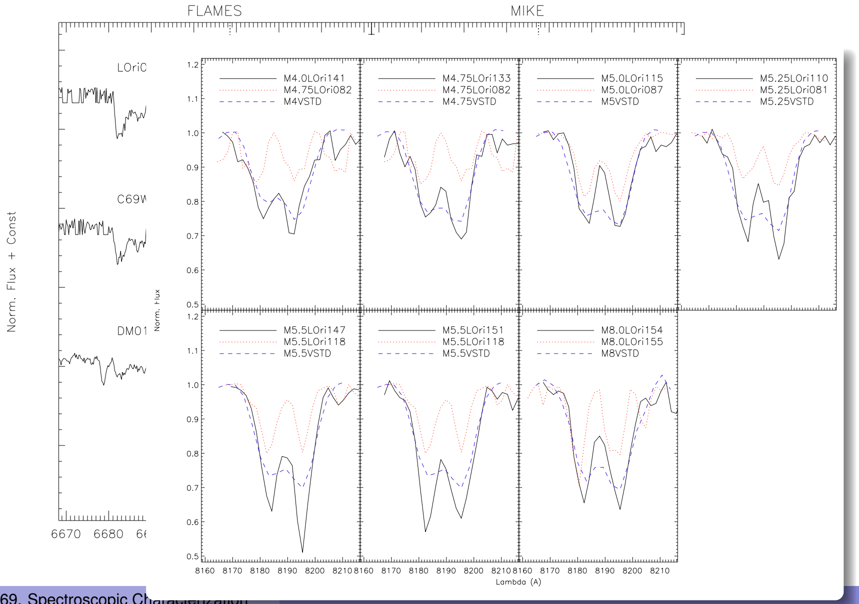
- Alkali lines ⇒ youth indicators
- Emission lines ⇒ activity and accretion



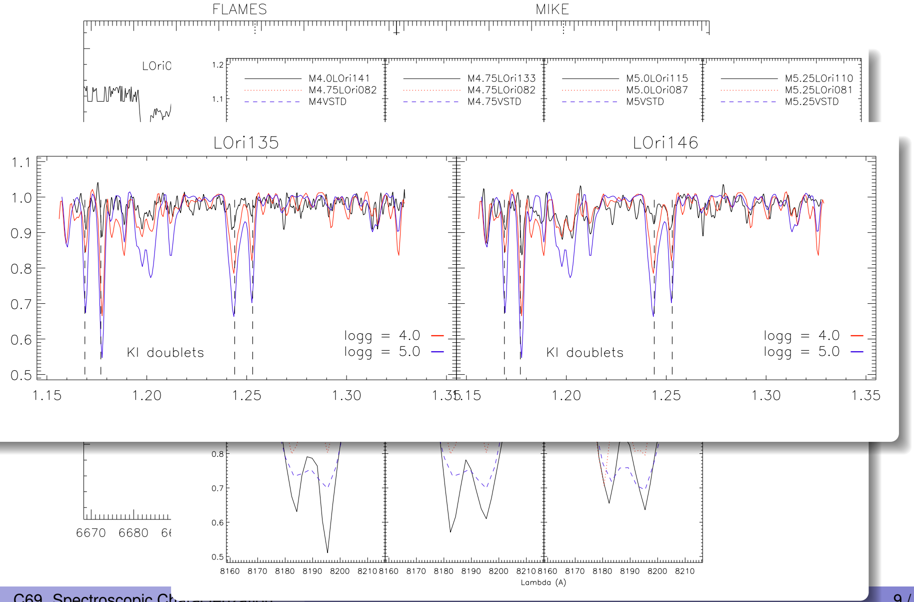
Alkali: signpost of youth



Alkali: signpost of youth

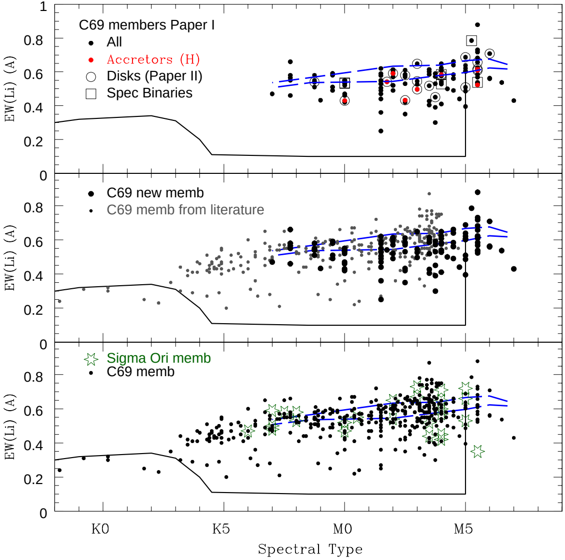


Alkali: signpost of youth



The youth of C69

C69: More than 30 new members (~175 spect. confirmed members)



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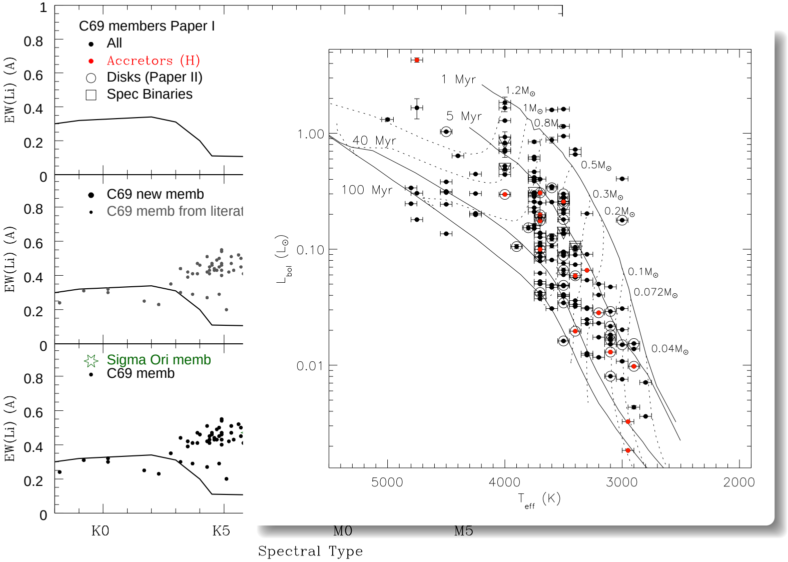
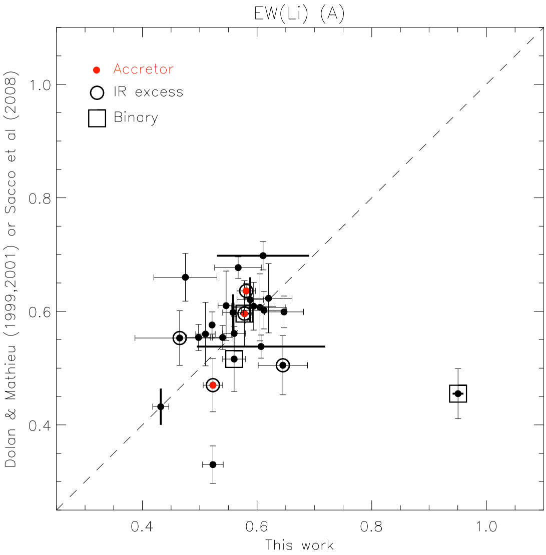


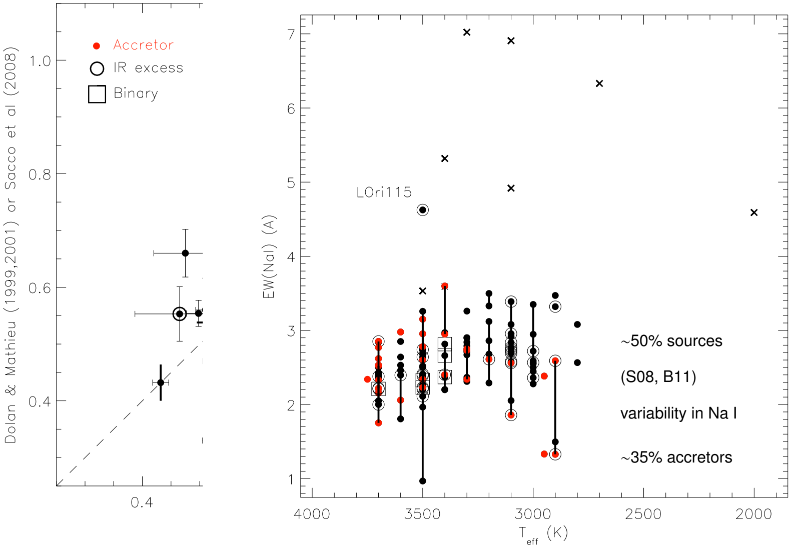
Alkali variability



~30% sources (DM, S08, B11) variability in Li I

All Active stars (Xrays or Hα variability)

Alkali variability



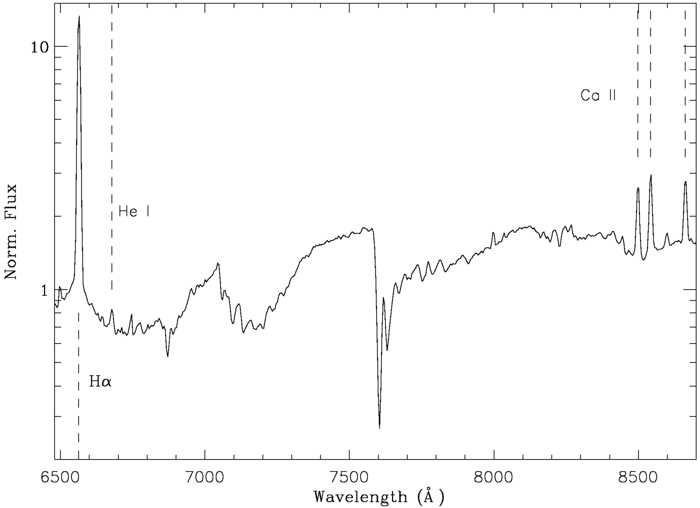
~50% sources

(S08, B11)

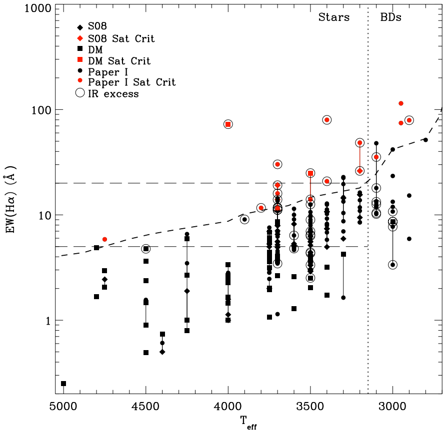
variability in Na I

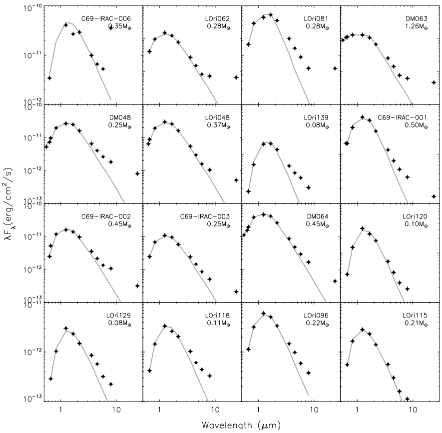
~35% accretors

Activity and accretion through emission lines



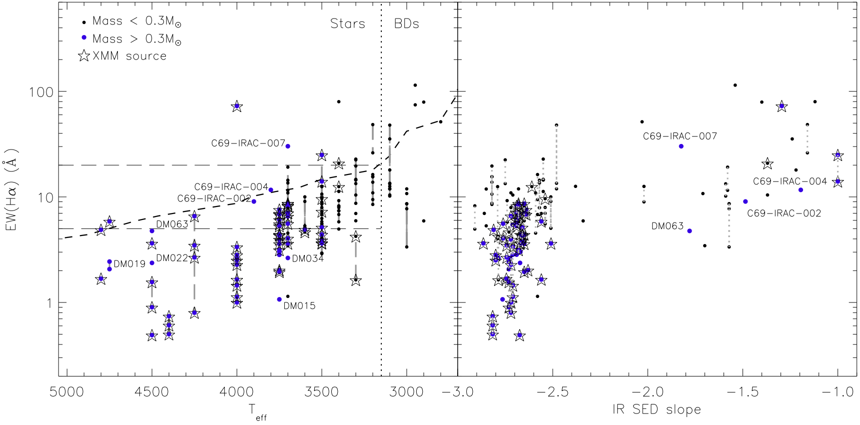
Distinguishing between accretion and activity





Saturation criteria Barrado y Navascués & Martin (2003)

Distinguishing between accretion and activity



Saturation criteria Barrado y Navascués & Martin (2003)

Disks Properties and distribution

Disk and diskless populations unevenly distributed ⇒ Not consistent with SN hypothesis.

Stellar disk fraction 28.5%

Sub-stellar disk fraction

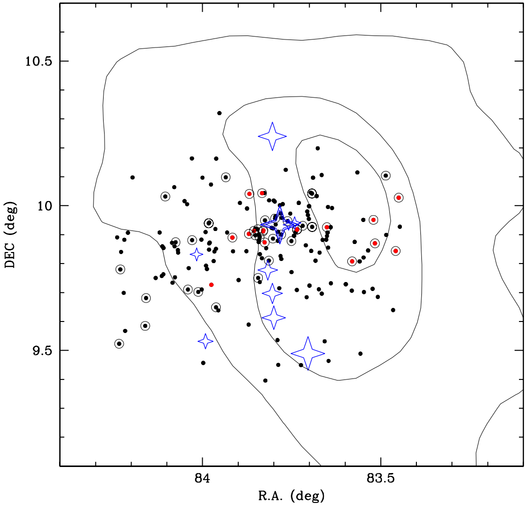
>30%

- Barrado y Navascués et al. (2004) 40%
- Scholz et al. (2007) 37.9% for Upper-Sco

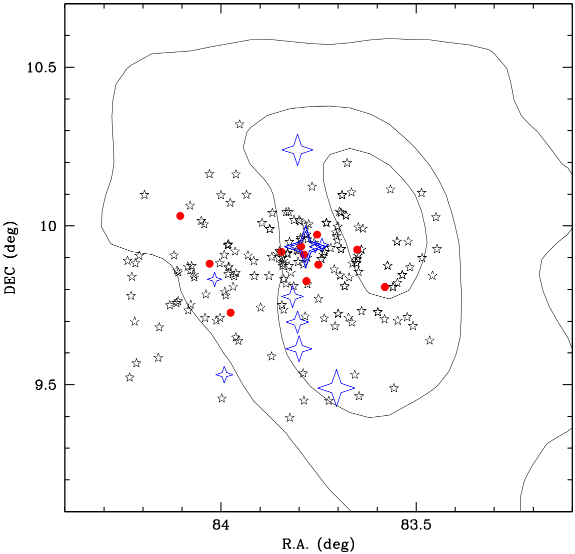
Accretors fraction

sub-stellar 18%

- Scholz et al. (2007) 31% for Upper Sco (low-mass and sub-stellar)



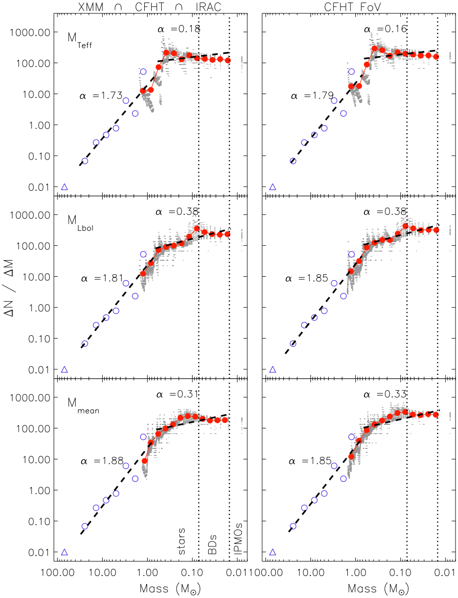
Spatial distribution of the members



Homogeneous distribution of both BDs and stars

⇒ Caveats to ejection scenario

IMF of Collinder 69



$$R_{SS} = \frac{N(0.02 \le M/M_\odot \le 0.08)}{N(0.08 \le M/M_\odot \le 10)}$$

Briceño et al. (2002)

Collinder 69 ⇒ 0.06

∼ Taurus

Briceño et al. (2002)

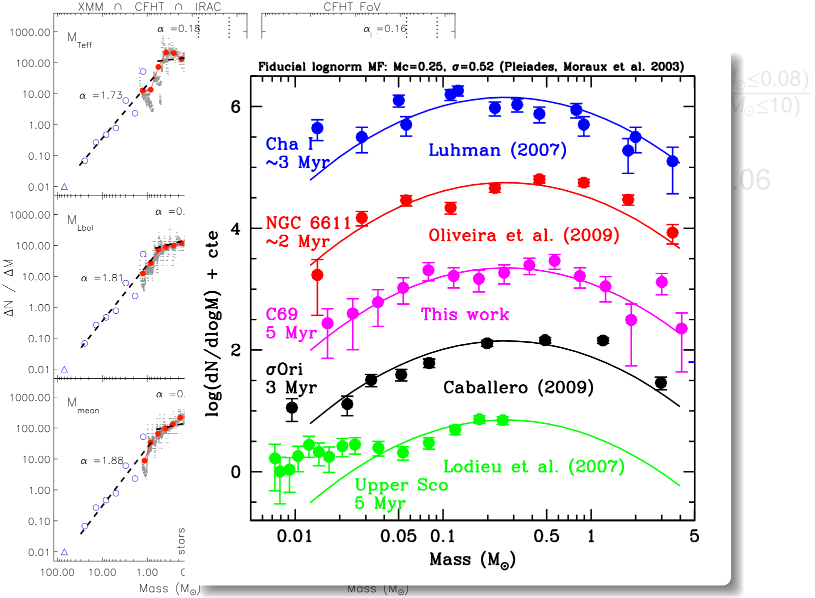
< Taurus

revised by Guieu et al (2006)

< ONC

Kroupa et al. (2003)

IMF of Collinder 69



Conclusions

- Complete census of ~175 spectroscopicaly confirmed members plus 60 photom. probable members.
- Physical parameters derived for the spectroscopic sample: Spectral Type, Hα and Li I equivalent width, accretion rates, etc.
- Age study: upper limit of 20 Myr, optimal 5 Myr.
- One of the most complete spectroscopic IMF reported so far (from $\sim$20 $M_{\odot}$ down to 20 $M_{\rm Jup}$; the photometric reaches $8_{\rm Jup}$)
- No evidence of mass segregation (caveats on ejection scenario for BD formation)
- Study of the disks properties: Not consistent with SN scenario

Bayo et al. (2011)

THANK YOU!!!