Building complete censuses and studying disk evolution to understand how brown dwarfs form

A. Bayo

ESO-Chile Fellow

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M. Morales-Calderón, J.R. Stauffer
B. Stelzer
C. Melo

ESAC

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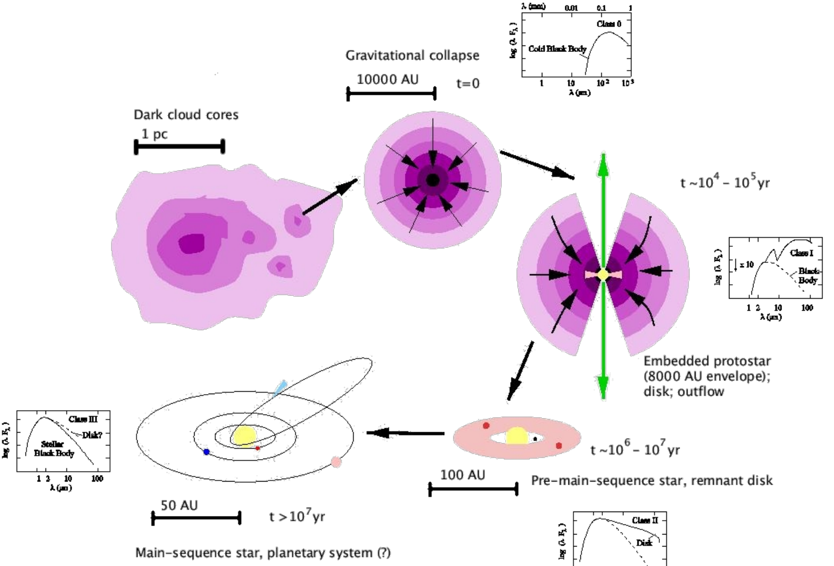
Low mass SF Theory (I)



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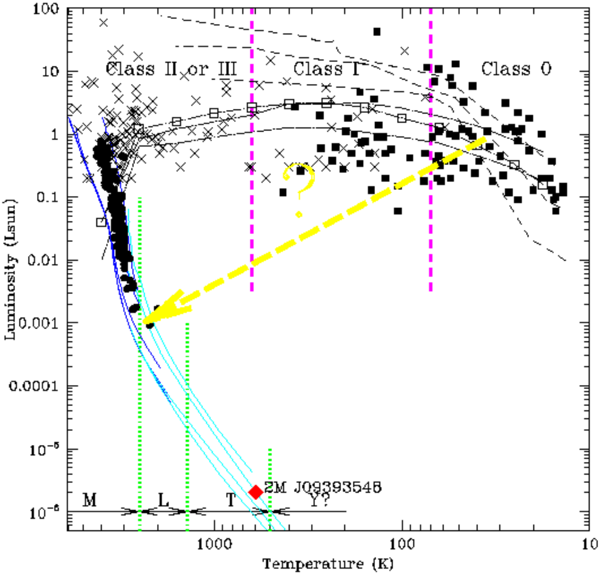

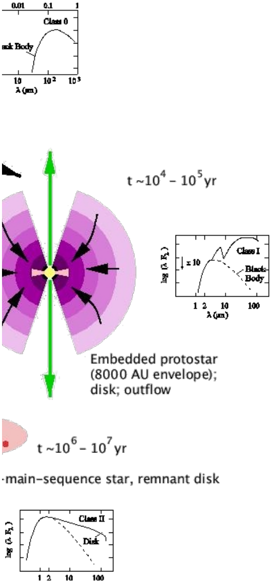

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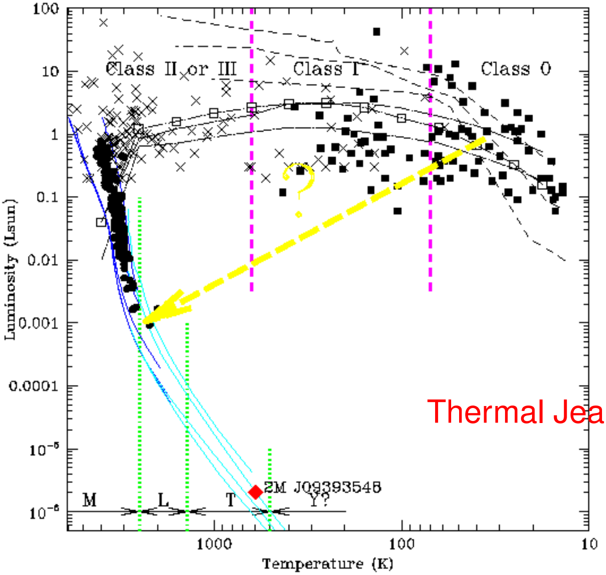

Thermal Jeans mass $\sim 1\ M_{\odot}$

Low mass SF Theory (II)

Turbulent fragmentation *(Padoan & Nordlund, 2002; Hennebelle & Chabrier, 2008)*: density enhancements → decrease the Jeans mass

Ejection scenario *(Reipurth & Clarke 2001)*: distribution of BDs different than stars?

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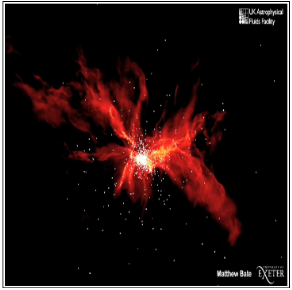

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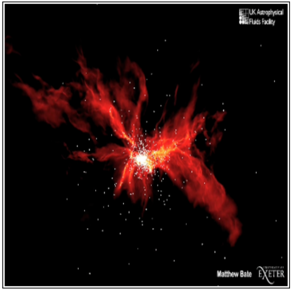

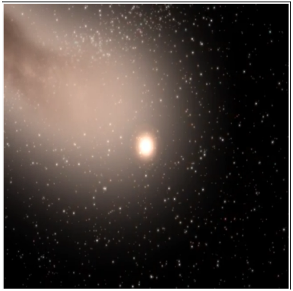

Ejection scenario *(Reipurth & Clarke 2001)*: distribution of BDs different than stars?

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Disk fragmentation *(Goodwin & Whitworth, 2007; Stamatellos et al 2007)*: scaled up version of planets

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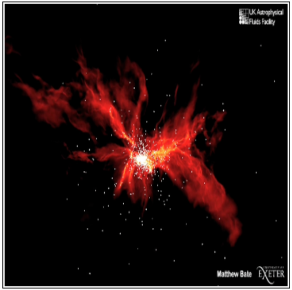

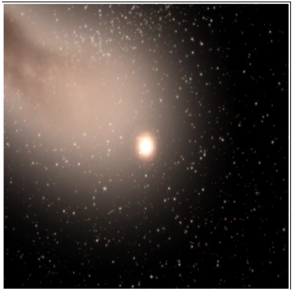

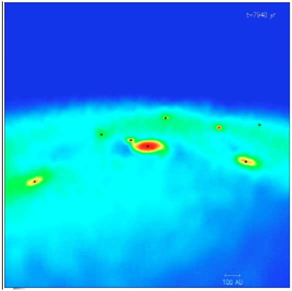

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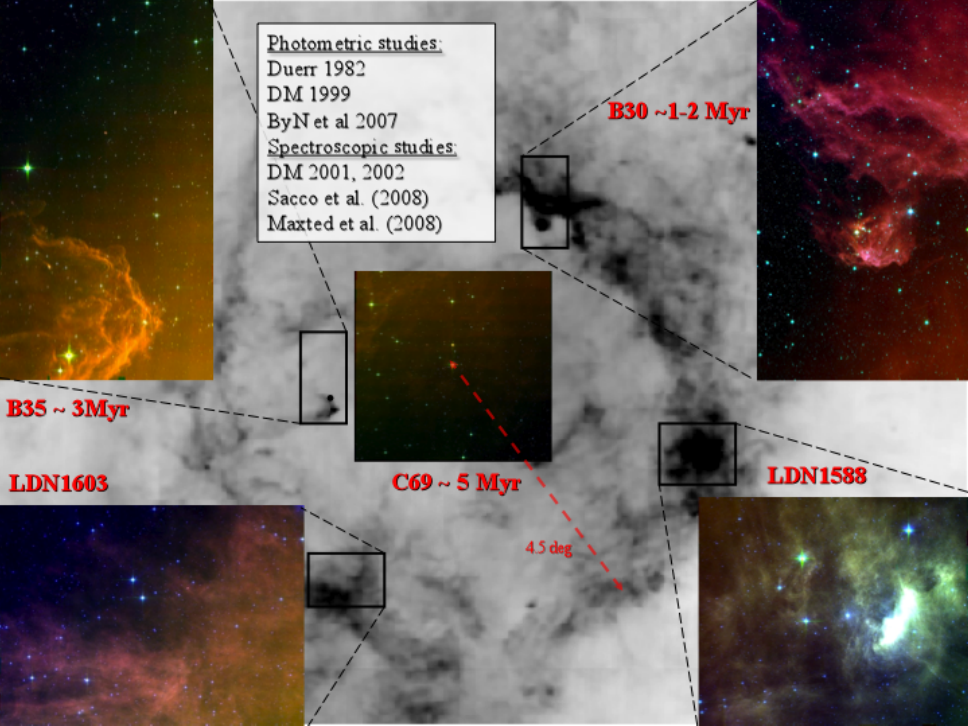
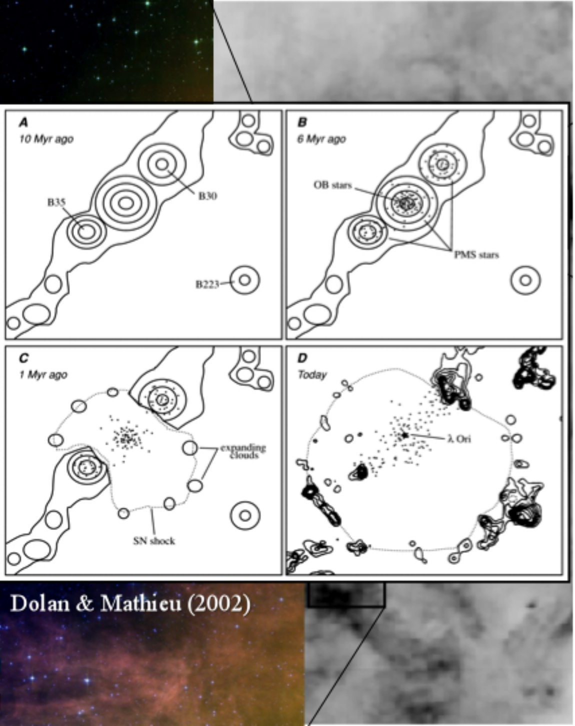


Photometric studies:
Duerr 1982
DM 1999
ByN et al 2007
Spectroscopic studies:
DM 2001, 2002
Sacco et al. (2008)
Maxted et al. (2008)
B30 ~1-2 Myr
B35 ~ 3Myr
LDN1603
C69 ~ 5 Myr
LDN1588
4.5 deg



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.

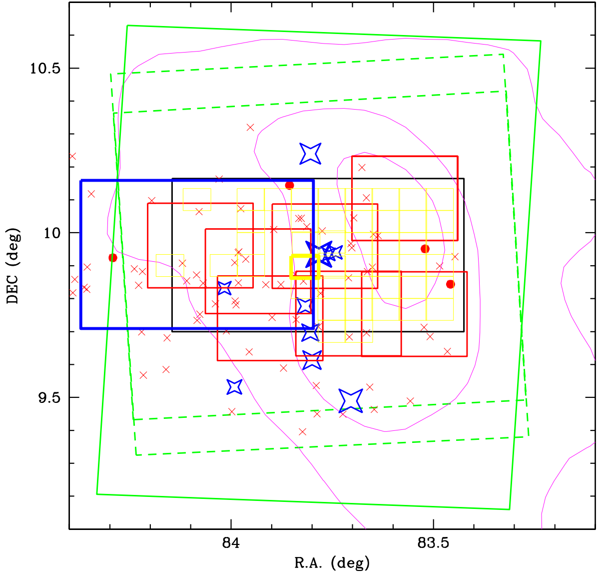
C. ~1 Myr ago, one of the O stars became a supernova. The blast quickly dispersed all of the parent core, creating the molecular ring, the large HII region, and the nearby HI structures.

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?).
- Study the disk properties and their dependence with mass.
- “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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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
λ_{med}:	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
λ_{med}:	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, 2012b)

SED analysis

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

Coordinates | Distances | Extinction

Object coordinates

This option allows you to query Sesame VO service to search for object coordinates using the object name.

Take a look to the corresponding Help Section and Credits Page for more information.

Search for Obj. Coordinates

	Final		User Data		Sesame	
Object	RA (deg)	DEC (deg)	RA (deg)	DEC (deg)	RA (deg)	DEC (deg)
LOri001	83.446583	9.9273611	??	??	??	??
LOri002	84.043167	10.148583	??	??	??	??
LOri003	83.981000	9.9420833	??	??	??	??
LOri004	83.948125	9.7640278	??	??	??	??
LOri005	83.473542	9.7188889	??	??	??	??
LOri006	83.817750	9.9216111	??	??	??	??
LOri007	83.623125	9.8163056	??	??	??	??
LOri008	83.991542	9.9091111	??	??	??	??
LOri009	83.693083	10.109889	??	??	??	??
LOri010	83.637333	10.144750	??	??	??	??
LOri011	83.686083	9.8993056	??	??	??	??
LOri012	83.774792	9.8688333	??	??	??	??
LOri013	83.484792	9.8990833	??	??	??	??
LOri014	84.079292	10.064111	??	??	??	??
LOri015	83.591000	10.070694	??	??	??	??
LOri016	83.806250	9.9234722	??	??	??	??
LOri017	84.085375	9.8720278	??	??	??	??
LOri018	84.069125	9.8468889	??	??	??	??
LOri019	83.807042	9.9413333	??	??	??	??
LOri020	83.739875	9.7687500	??	??	??	??
LOri021	83.778917	9.8160556	??	??	??	??

Bayo et al. (2008, 2012b)

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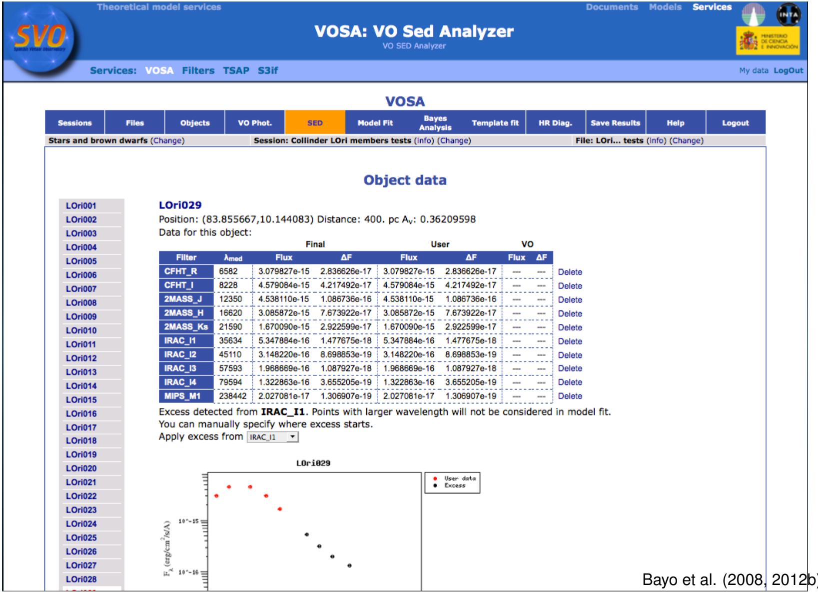

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Stars and brown dwarfs (Change) Session: Collinder LOri members tests (info) (Change) File: LOri... tests (info) (Change)

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, 2012b)

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Model fit

Best fit results

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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	9.7188889	400.000	COND00	3900	2.5	0.0	---	9.39e+1	1.34e-20	1.73e-10	1.22e-12	0.49	8.61e-1	6.09e-3	79594	9/9	Syn.S
LOri006	83.817750	9.9216111	400.000	Kurucz	4000	0.50	0.50	---	5.29e+0	9.78e-21	1.42e-10	1.07e-12	0.46	7.07e-1	5.32e-3	21590	5/9	Syn.S
LOri007	83.623125	9.8163056	400.000	NextGen	4000	5.5	0.0	---	2.50e+0	8.76e-21	1.27e-10	9.46e-13	0.45	6.33e-1	4.72e-3	21590	5/9	Syn.S
LOri008	83.991542	9.9091111	400.000	Kurucz	4000	0.50	-2.50	---	4.63e+1	1.00e-20	1.43e-10	1.10e-12	0.49	7.13e-1	5.49e-3	79594	9/9	Syn.S
LOri009	83.693083	10.109889	400.000	NextGen	4000	3.5	0.0	---	1.32e+1	8.29e-21	1.18e-10	8.44e-13	0.48	5.90e-1	4.21e-3	79594	9/9	Syn.S
LOri010	83.637333	10.144750	400.000	NextGen	4200	5.0	0.0	---	4.25e+1	6.54e-21	1.14e-10	8.37e-13	0.48	5.67e-1	4.17e-3	79594	9/9	Syn.S
LOri011	83.686083	9.8993056	400.000	Kurucz	3750	0.00	-0.50	---	1.62e+1	1.20e-20	1.33e-10	1.04e-12	0.49	6.62e-1	5.19e-3	79594	9/9	Syn.S
LOri012	83.774792	9.8688333	400.000	Kurucz	4000	2.50	0.50	---	6.91e+1	8.76e-21	1.23e-10	8.96e-13	0.47	6.12e-1	4.47e-3	79594	9/9	Syn.S
LOri013	83.484792	9.8990833	400.000	NextGen	3900	4.5	0.0	---	2.10e+1	8.85e-21	1.18e-10	8.37e-13	0.45	5.86e-1	4.17e-3	21590	5/9	Syn.S
LOri014	84.079292	10.064111	400.000	Kurucz	3750	4.00	-2.00	---	8.59e-1	9.25e-21	1.04e-10	7.53e-13	0.46	5.17e-1	3.75e-3	21590	5/9	Syn.S
LOri015	83.591000	10.070694	400.000	Kurucz	4000	2.50	0.00	---	2.29e+1	7.61e-21	1.10e-10	7.93e-13	0.49	5.50e-1	3.95e-3	79594	9/9	Syn.S
LOri016	83.806250	9.9234722	400.000	Kurucz	3500	2.50	-2.50	---	6.85e+0	1.12e-20	9.51e-11	7.21e-13	0.46	4.74e-1	3.60e-3	21590	5/9	Syn.S
LOri017	84.085375	9.8720278	400.000	NextGen	4200	5.0	0.0	---	8.44e+0	5.13e-21	8.91e-11	6.13e-13	0.48	4.44e-1	3.06e-3	79594	9/9	Syn.S
LOri018	84.069125	9.8468889	400.000	Kurucz	3500	2.00	-2.50	---	1.67e+1	1.04e-20	8.88e-11	6.49e-13	0.47	4.43e-1	3.24e-3	21590	5/9	Syn.S
LOri019	83.807042	9.9413333	400.000	COND00	3900	2.5	0.0	---	1.49e+1	6.57e-21	8.64e-11	6.54e-13	0.46	4.31e-1	3.26e-3	21590	5/9	Syn.S
LOri020	83.739875	9.7687500	400.000	NextGen	3600	5.0	0.0	---	1.34e+1	9.52e-21	9.16e-11	7.59e-13	0.44	4.57e-1	3.79e-3	21590	5/9	Syn.S
LOri021	83.778917	9.8160556	400.000	Kurucz	3750	2.50	-2.50	---	1.92e+1	6.86e-21	7.69e-11	5.95e-13	0.50	3.83e-1	2.97e-3	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	[illegible]	21590	5/9	Syn.S

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Best fit results

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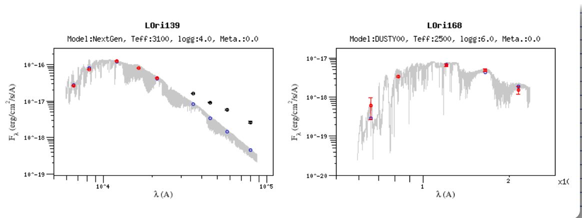
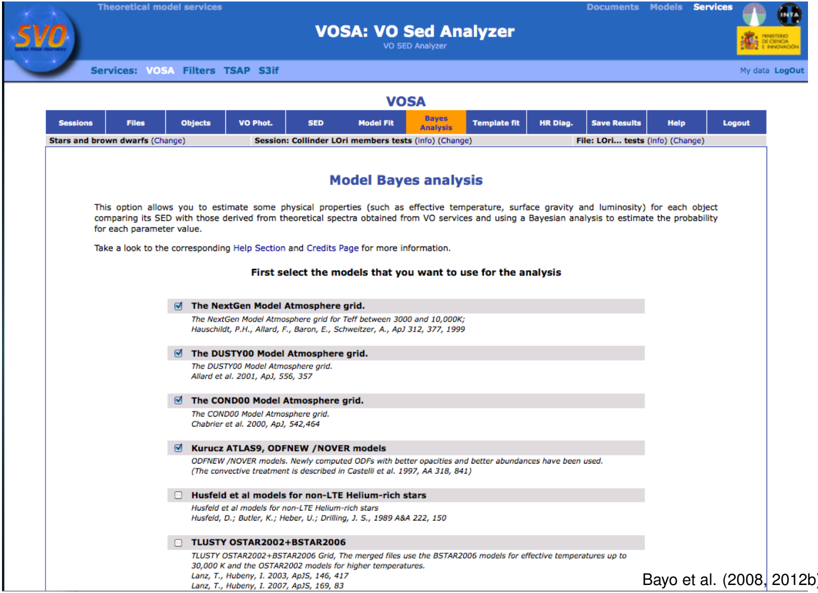
LOri001	83.446583	9.9273611	400.000	COND00	4000	2.5	0.0	---	8.03e+1	1.30e-20	1.84e-10	1.26e-12	0.49	9.19e-1	6.26e-3	79594	9/9	Syn.S
LOri002	84.043167	10.148583	400.000	Kurucz	3750	0.00	-1.50	---	6.46e+1	1.80e-20	1.96e-10	1.42e-12	0.49	9.77e-1	7.07e-3	79594	9/9	Syn.S
LOri003	83.981000	9.9420833	400.000	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



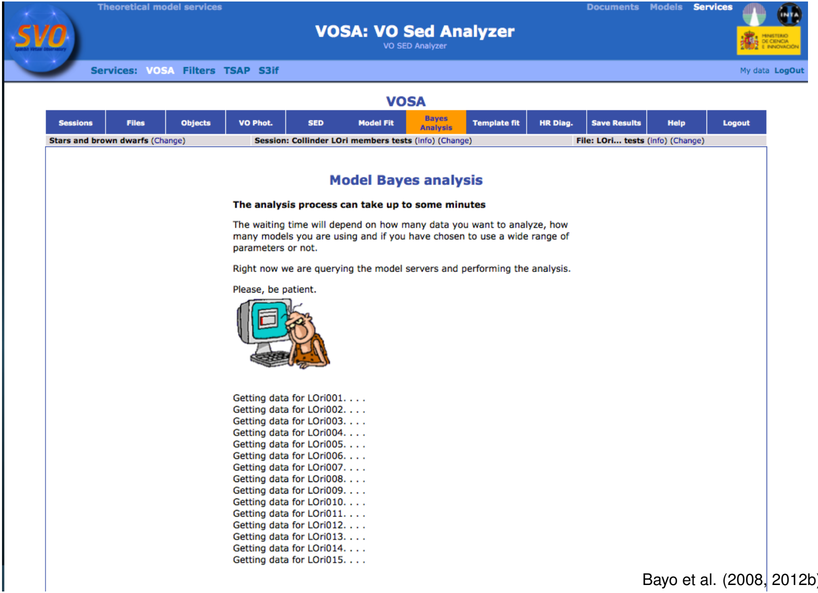
Bayo et al. (2008, 2012b)

SED analysis



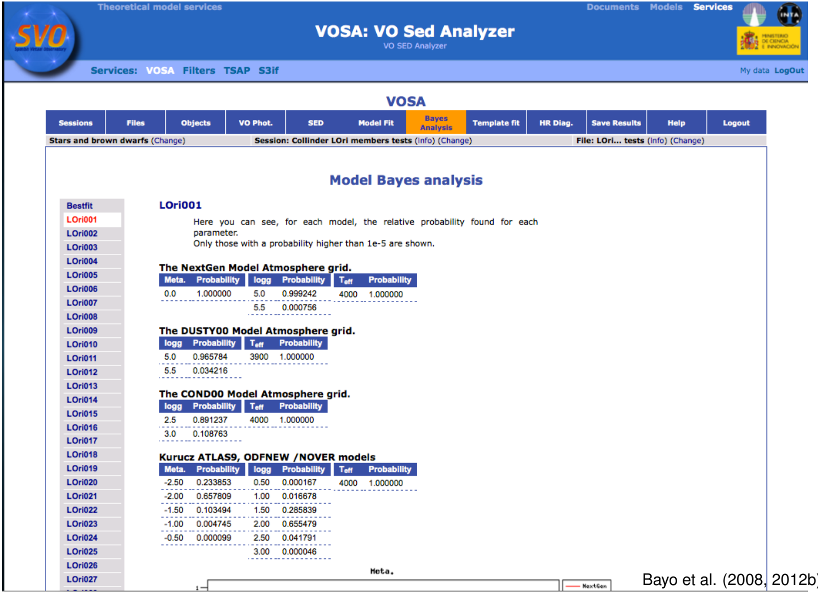
Bayo et al. (2008, 2012b)

SED analysis



Bayo et al. (2008, 2012b)

SED analysis



Theoretical model services · Documents · Models · Services

VOSA: VO Sed Analyzer

VO SED Analyzer

Services: VOSA Filters TSAP S3if · My data LogOut

VOSA

Sessions | Files | Objects | VO Phot. | SED | Model Fit | Bayes Analysis | Template fit | HR Diag. | Save Results | Help | Logout

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.

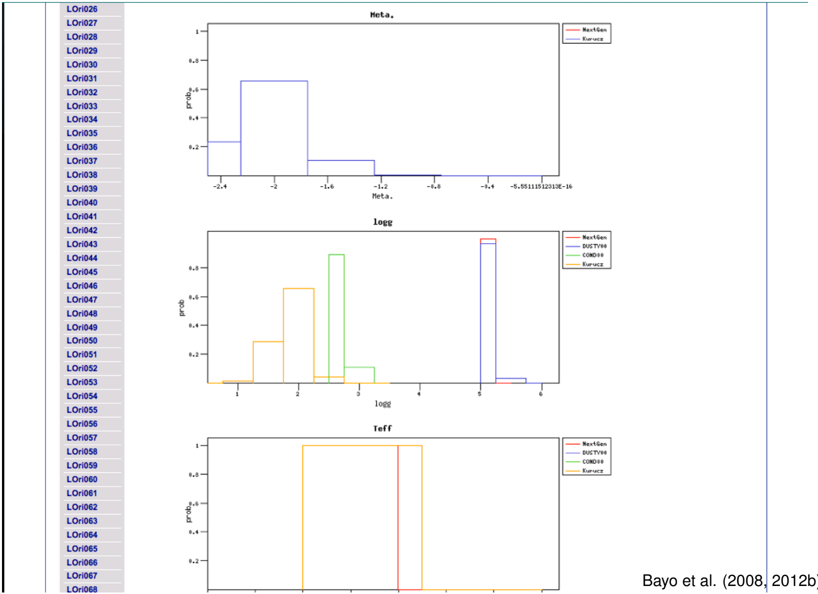
logg	Probability	T_{eff}	Probability
2.5	0.891237	4000	1.000000
3.0	0.108763		

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, 2012b)

SED analysis

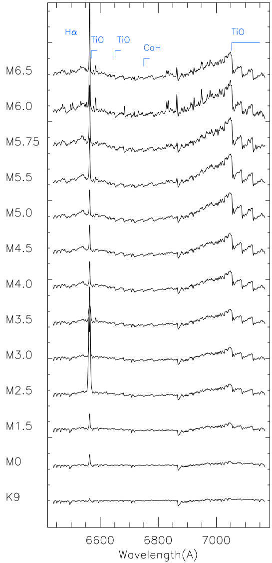


Bayo et al. (2008, 2012b)

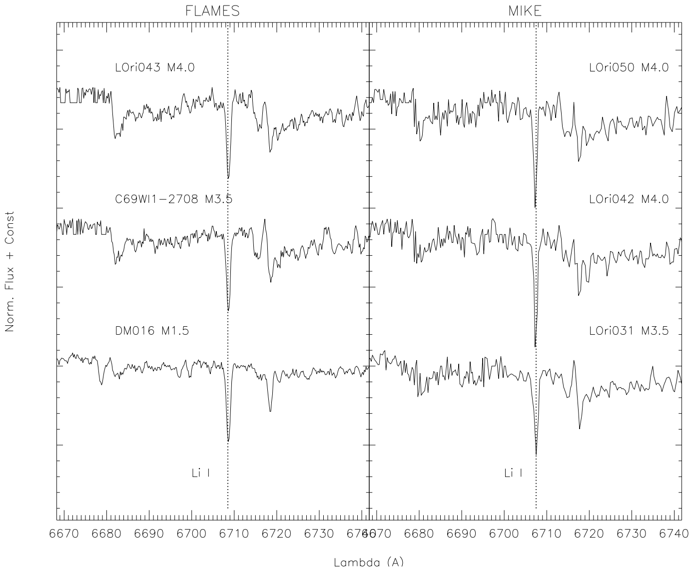
Spectroscopic follow-up

Spectroscopic confirmation of candidates

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



Alkali: signpost of youth



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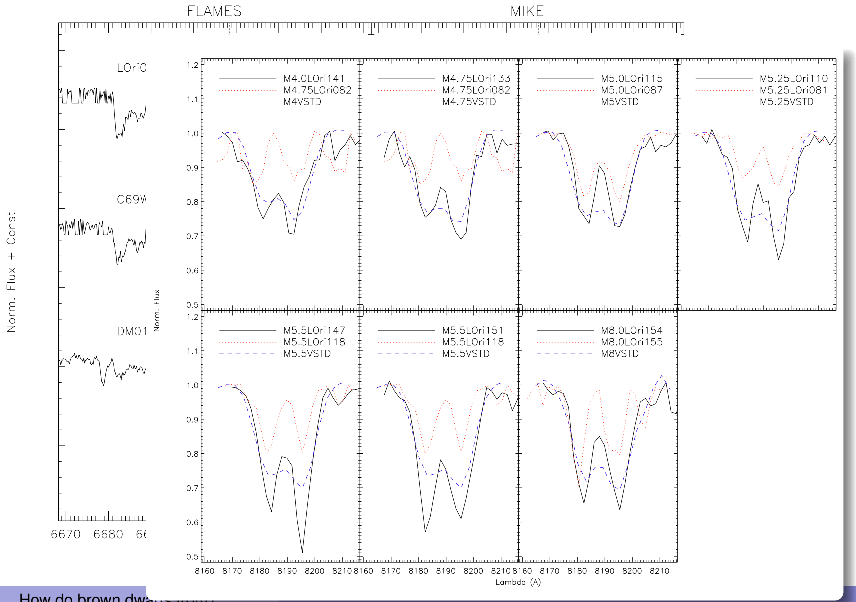

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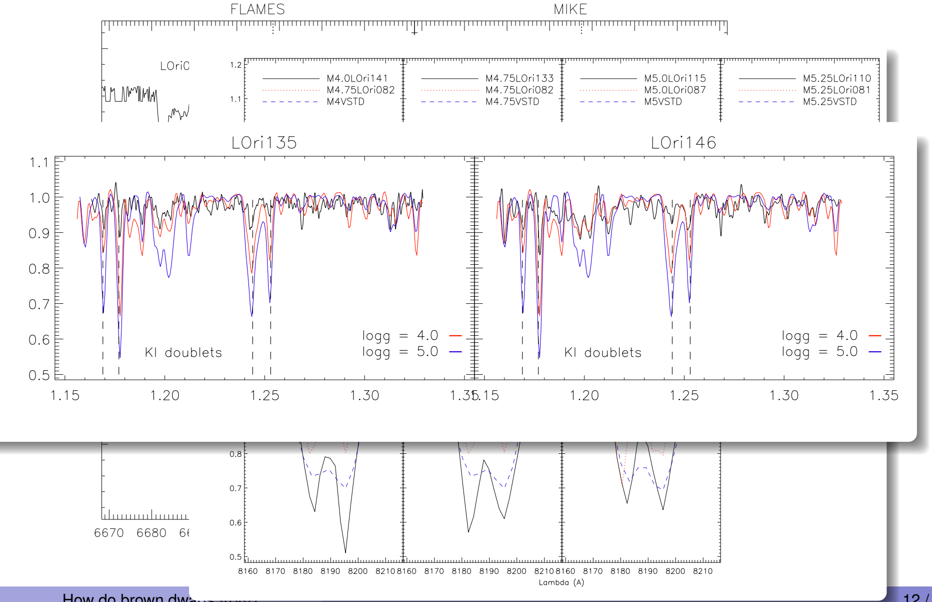
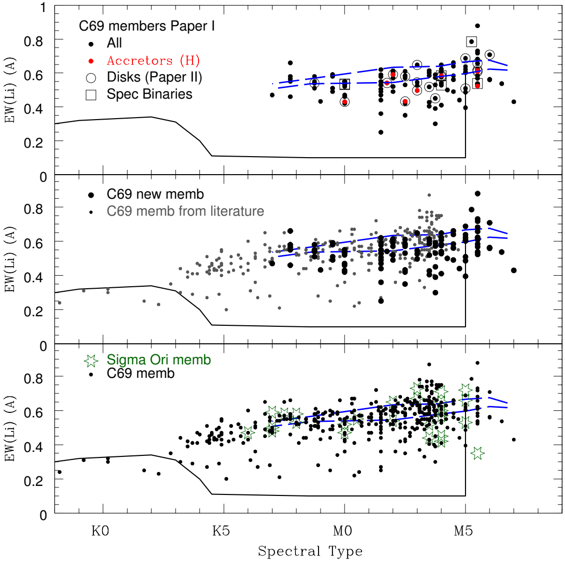


The youth of C69

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



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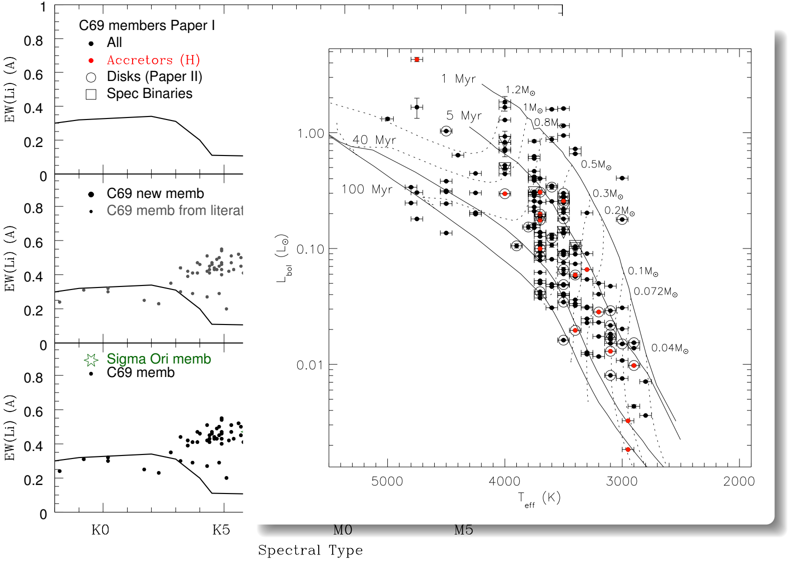
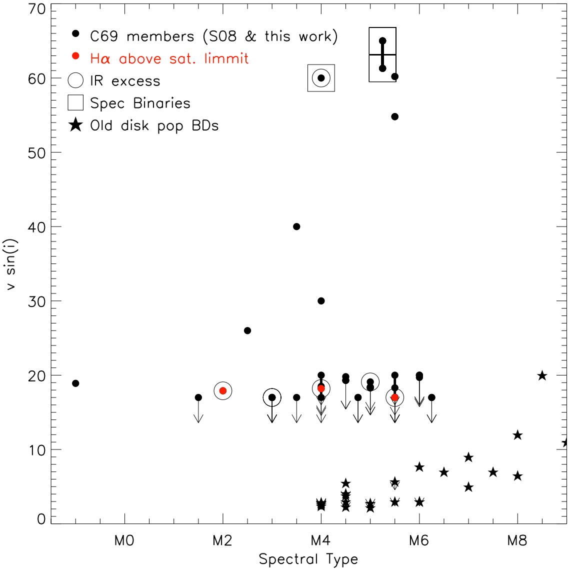
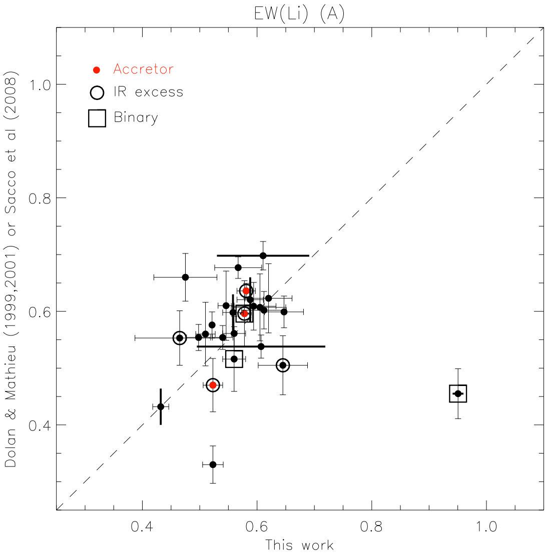


The youth of C69 (II)



- Faster rotators than old BDs.
- Disk locking?

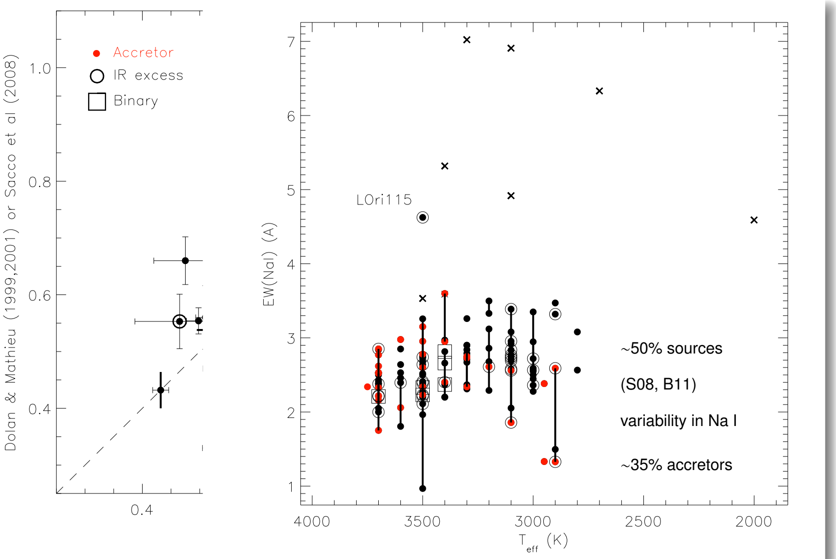
Variability: alkali



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

All Active stars (Xrays or Hα variability)

Variability: alkali



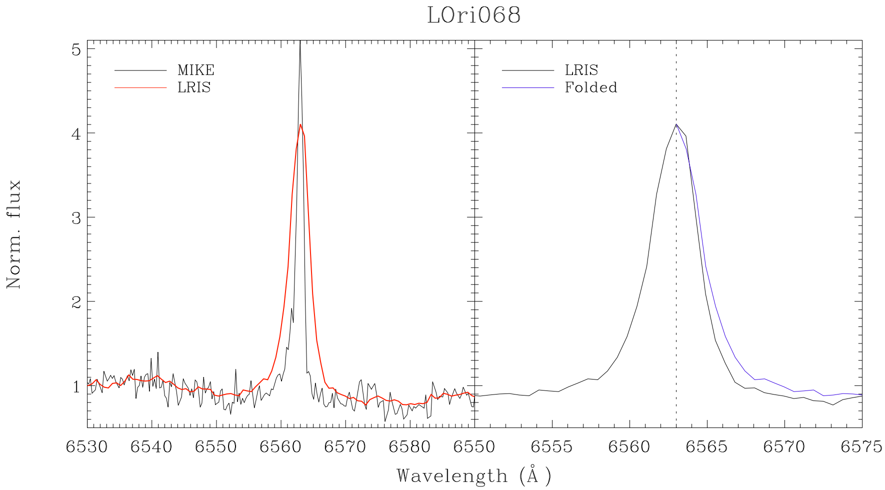
~50% sources

(S08, B11)

variability in Na I

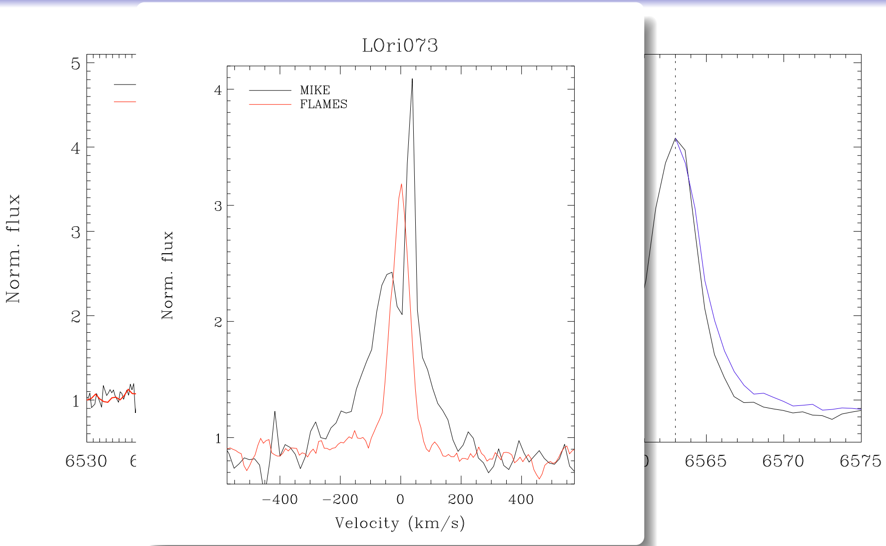
~35% accretors

Variability: Hα



Asymmetry in the “flared" state. Mass movement

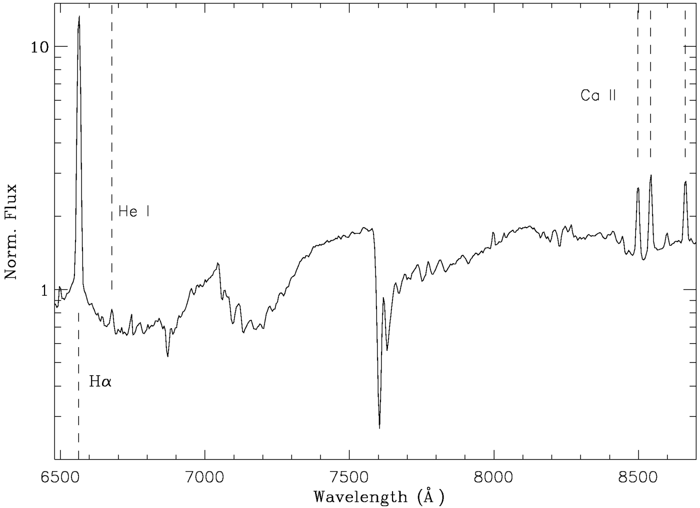
Variability: Hα



Asymmetry in the “flared” state. Mass movement

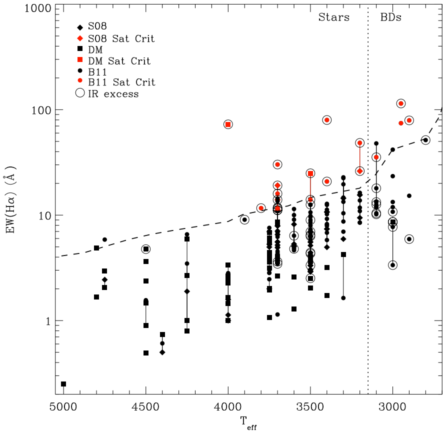
Presence of winds

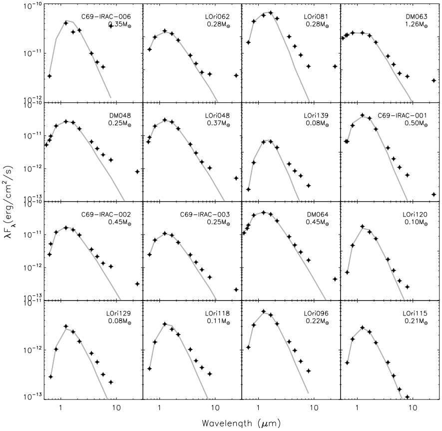
Activity and accretion through emission lines



Distinguishing between accretion and activity

~65% disk-harboring non-accretors





Saturation criteria Barrado y Navascués & Martin (2003)

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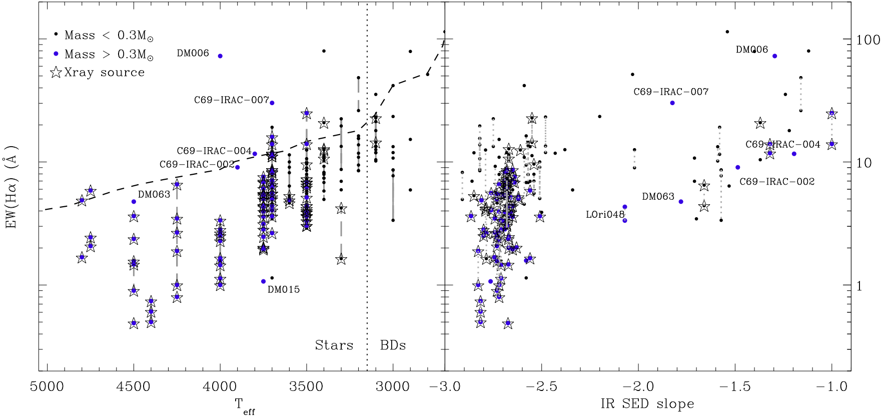
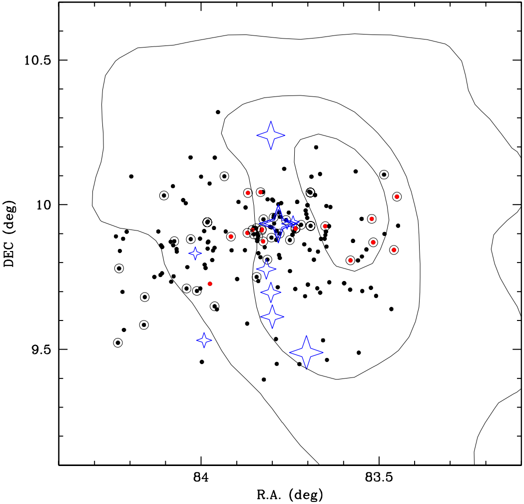


Saturation criteria Barrado y Navascués & Martin (2003)

Disks Properties and distribution

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

- Dichotomy at $M_* \sim 0.6 M_\odot$
- Stellar disk fraction 26.3%
- Sub-stellar disk fraction <58%
  - Barrado y Navascués et al. (2004) 40%
  - Scholz et al. (2007) 37.9% for Upper-Sco
- Acc. frac. sub-stellar 30–43%
  - Scholz et al. (2007) 31% for Upper Sco (low-mass and sub-stellar)



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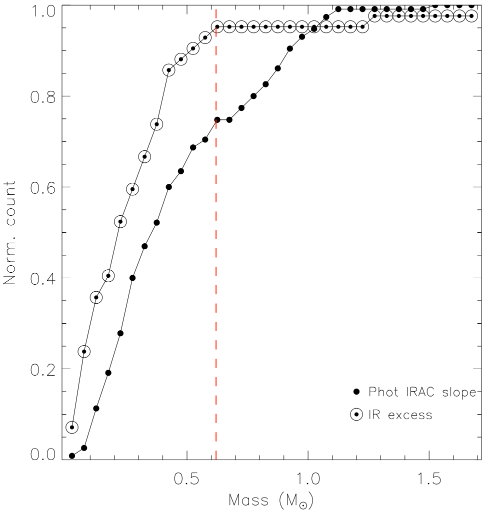

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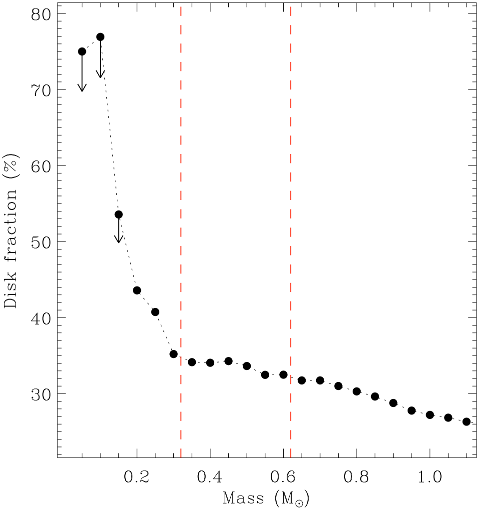
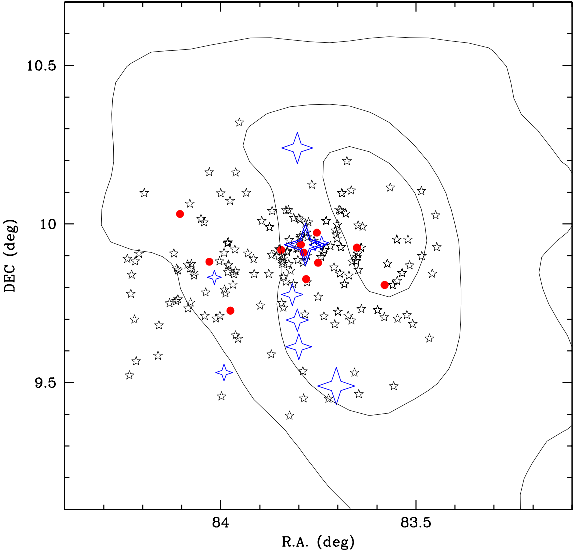


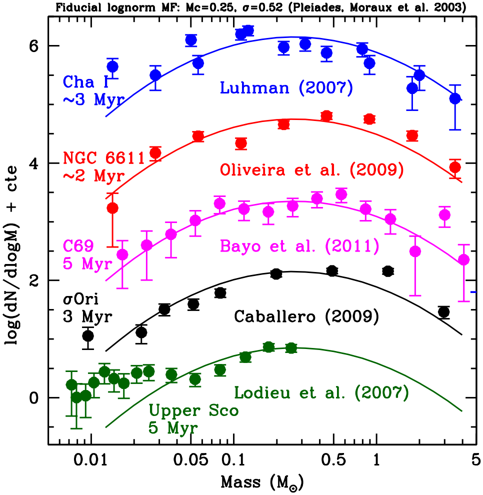
Spatial distribution of the members



Homogeneous distribution of both BDs and stars

⇒ Caveats to ejection scenario

IMF of Collinder 69



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

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)

Summary

- Complete census of $\sim$175 spectroscopicaly confirmed 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.
- vsin(*i*) estimation and relation with disk presence.
- Variability on absorption and emission lines.
- Study of the disks distrib: Not consistent with SN scenario.
- Complete study on disk fraction dependence on mass.
- No evidence of mass segregation (caveats on ejection scenario for BD formation)
- One of the most complete spectroscopic IMF reported so far (from $\sim$20 $M_\odot$ down to 20 M_{Jup}.

Barrado y Navascués et al. (2004, 2007, 2011) Bayo et al. (2011, 2012a)

THANK YOU!!!

Remember to use the right tool....