X-Shooter Characterization of YSOs selected with Gaia DR2

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- Identifying the new members of Lupus I cloud
- Our motivation for a deeper investigation of this region
- Criteria for selecting new members of Lupus I
- Role of Gaia DR2
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- Conclusions

Collaborators: J. M. Alcala', A. Frasca, S. Desidera, G. Beccari, et al. (INAF + ESO Garching)

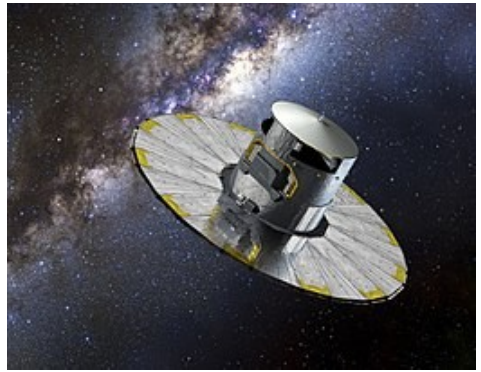
X-Shooter Characterization of New Wide Companions of Known Stellar Systems

Wide companions (1000au-1pc) are important

- Benchmarks for studying stellar/planet evolution (multiplicity statistics, dynamical environment of stars w/wo planets, w/wo disks)
- Constraining the age of the associated stellar system

Selected based on their similar kinematic properties to the central star (Gaia DR2) that is already a member of a stellar association

Characterizing unknown objects belonging to a stellar association is important



- New members will be identified
- We can constrain the age of the association more accurately
- Disk fraction of the association can be studied

X-Shooter

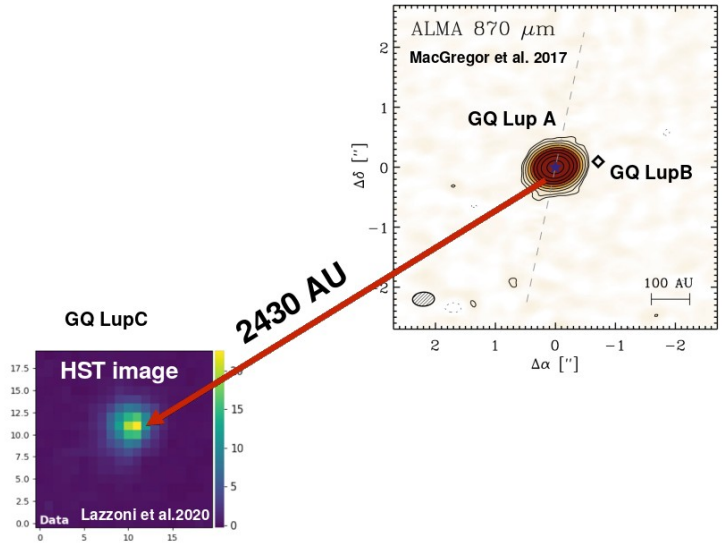
- The first 2nd generation instrument of the ESO Very Large Telescope (VLT)
  - Very efficient
  - Single-target
  - Intermediate-resolution spectrograph
    (R ~ 4000−17,000, depending on wavelength and slit width)
  - In a single exposure, covers the spectral range from 300 to 2500 nm

Wavelength range	300-2500 nm split over 3 arms
UV-Blue arm	Range: 300-550 nm in 11 orders
Resolution:	4500 (1" slit)
Detector:	4k x 2k E2V CCD
Visual-red arm	Range: 550-1000 nm in 14 orders
Resolution:	7000 (1" slit)
Detector:	4k x 2k MIT/LL CCD
Near-IR arm	Range: 1000-2500 nm in 16 orders
Resolution:	4500 (1" slit)
Detector:	2k x 1k Hawaii 2RG
Slit length	12"
Beam separation	Two high efficiency dichroics
Atmospheric dispersion compensation	In the UV-Blue and Visual-red arms
Integral field unit	1.8" x 4" reformatted into 0.6" x 12"

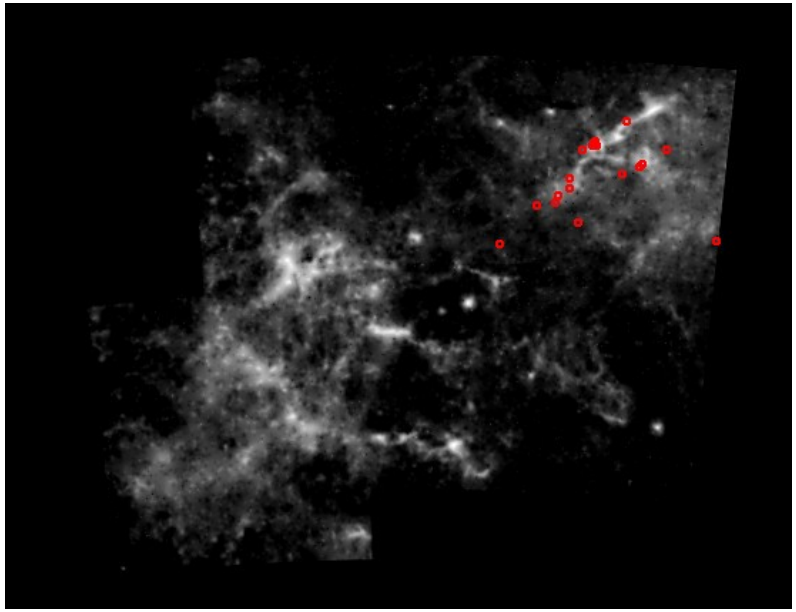
GQ Lup's new wide companion candidate, GQ Lup C

Alcala', Majidi, Desidera, et al. 2020 (A&A)

- a wide (projected separation ~16".0, or 2400 AU) companion of the GQ Lup A-B system
- a bonafide low-mass (~0.15 M $\odot$) young stellar object (YSO) with stellar and accretion/ejection properties typical of Lupus YSOs of similar mass
- with kinematics consistent with that of the GQ Lup A-B system
- the disk of the target was resolved on the HST images (Lazzoni et al. 2020)
- (roughly aligned with the disk of the GQ Lup)
  ** Both of them are roughly aligned with the Lupus I dust filament containing GQ Lup.
- Not-conclusive: a possible scenario for the formation of the triple system is that GQ Lup A and C formed by fragmentation of a turbulent core in the Lup I filament, while GQ Lup B (BD companion of GQ Lup A at 0".7), formed in-situ by the fragmentation of the circumprimary disc
  -- The recent discoveries that stars form along cloud filaments would favor the scenario of turbulent fragmentation for the formation of GQ Lup A and C.

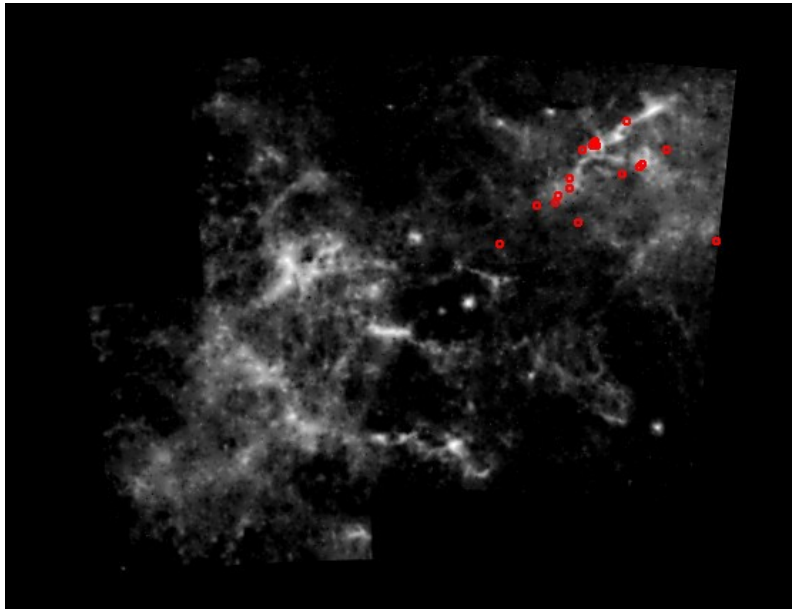


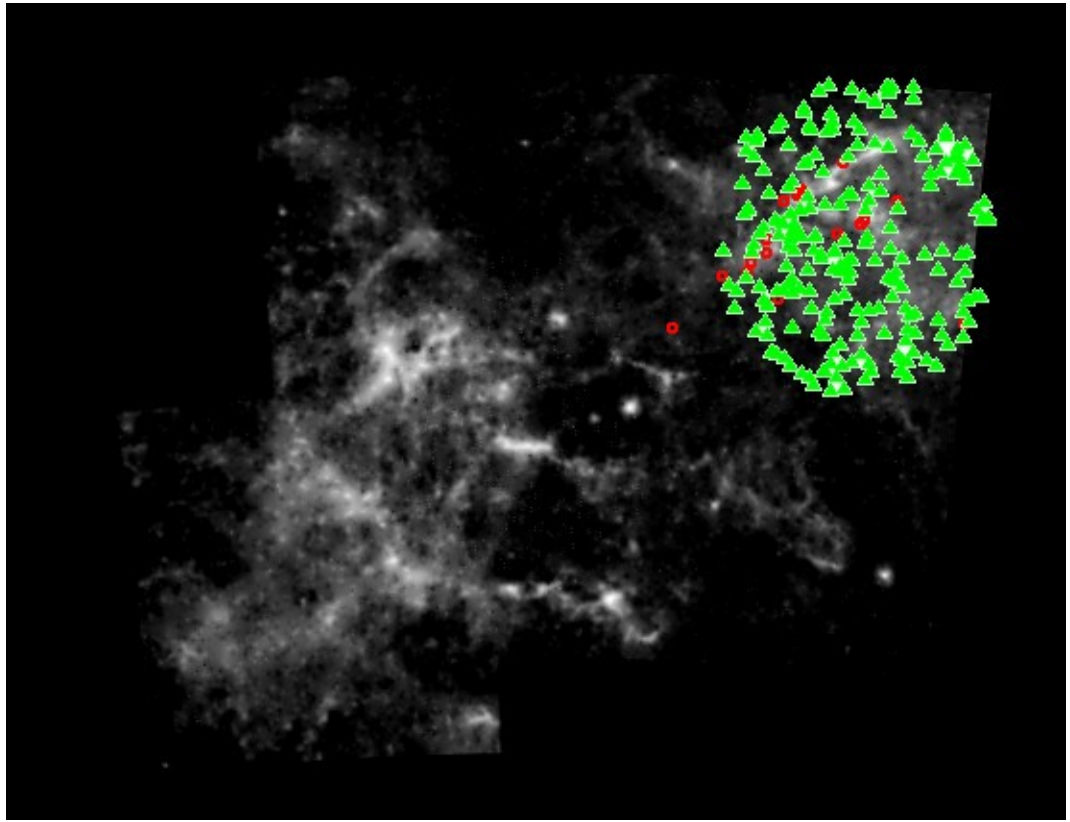
X-Shooter characterization of new members of Lupus I selected with Gaia DR2



5 < parallax < 8 (mas)
-21 < pmra < -10 (mas/yr)
- 27 < pmdec < -18 (mas/yr)

X-Shooter characterization of new members of Lupus I selected with Gaia DR2





5 < parallax < 8 (mas)
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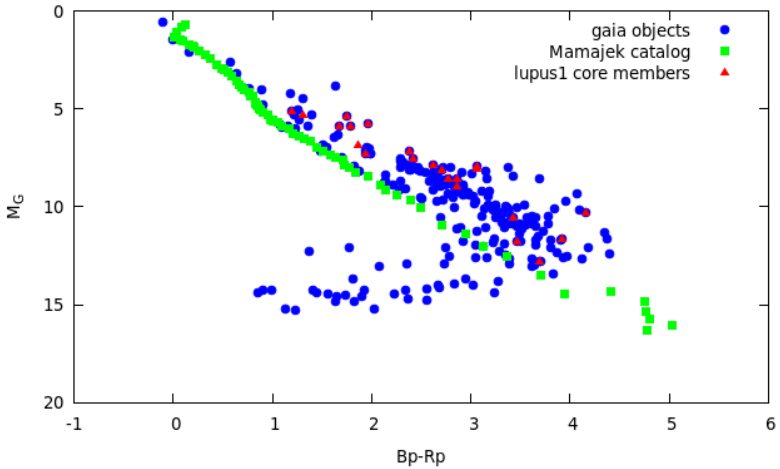
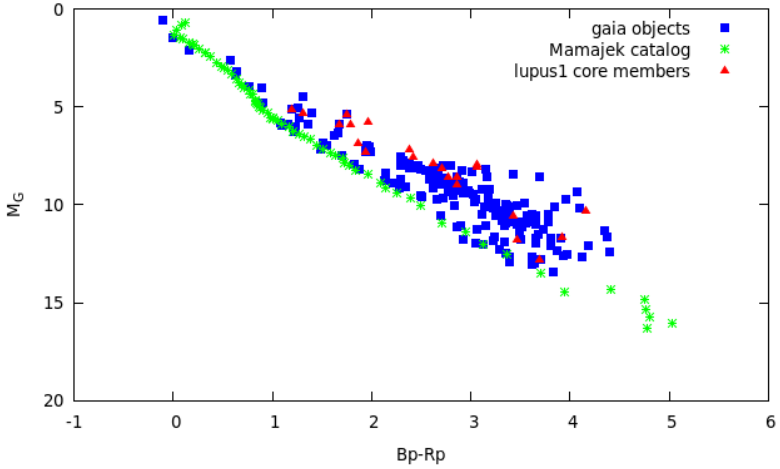
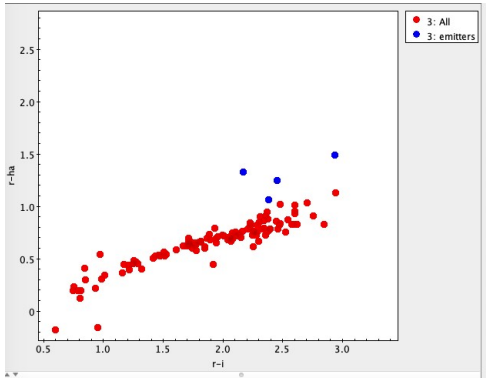
** 247 objects

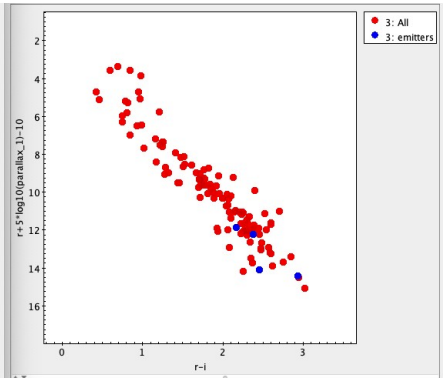
X-Shooter characterization of new members of Lupus I selected with Gaia DR2



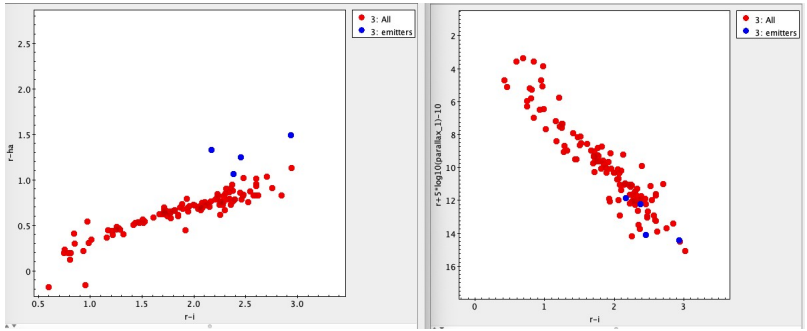


CMD (186 objects) +
OmegaCAM (H_α)

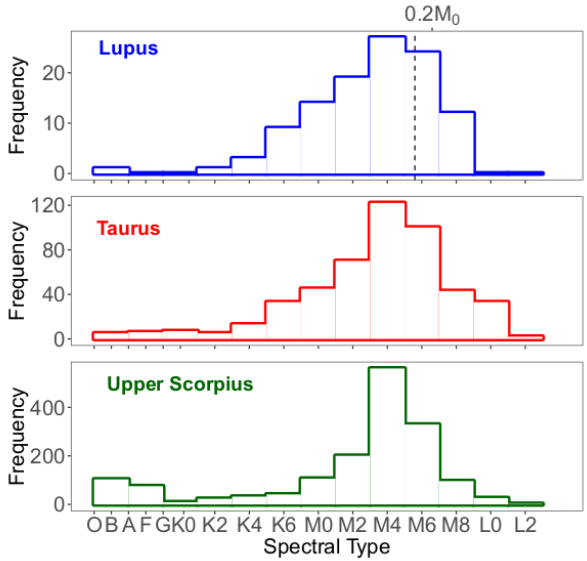




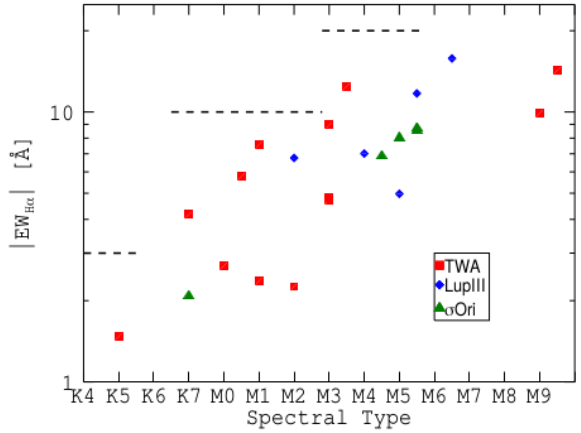
X-Shooter characterization of new members of Lupus I selected with Gaia DR2



OmegaCAM (H_α)
– FOV limitation
– EW_(H_α) > 10 Ang



Galli et al. 2020



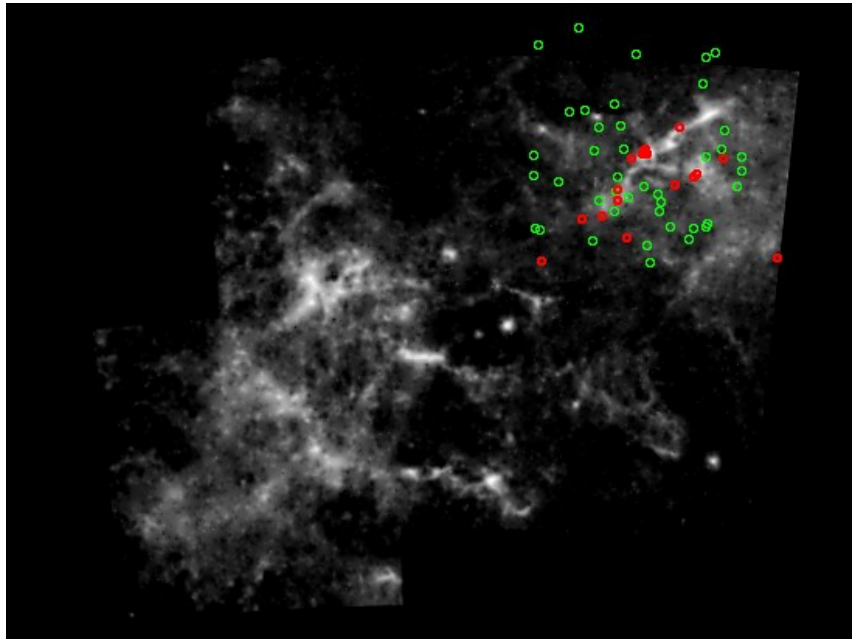
Manara et al. 2013

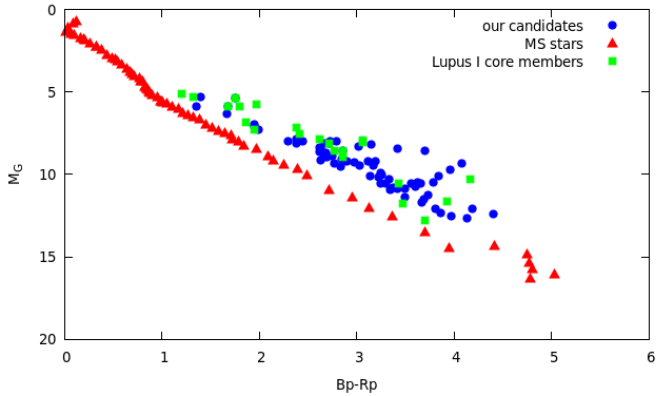
X-Shooter characterization of new members of Lupus I selected with Gaia DR2

– CMD (more consistent with Lupus I core members)
– Closer/further with respect the filaments of Lupus I
– Showing H_α excess in OmegaCAM

43 objects proposed to 105.20P9.001 ESO observing run (filler program)

** We only got 12 observed eventually with X-Shooter





X-Shooter characterization of new members of Lupus I selected with Gaia DR2

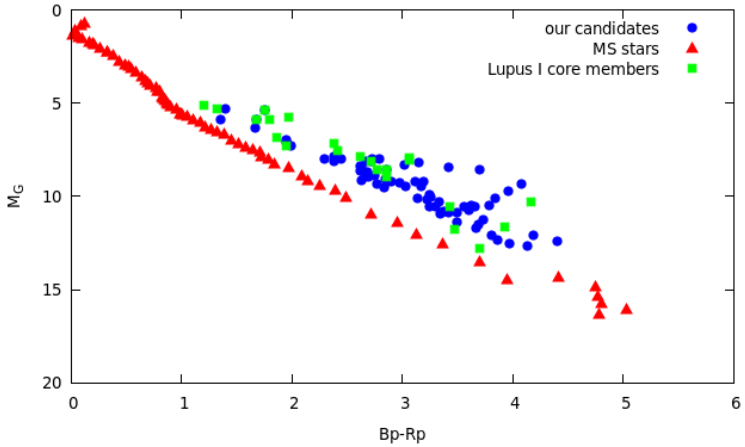
Our main motivation for full characterization of the targets
- Asses their physical properties + RV + v sin i
- Age determination is important (2MASS J1815-3249)

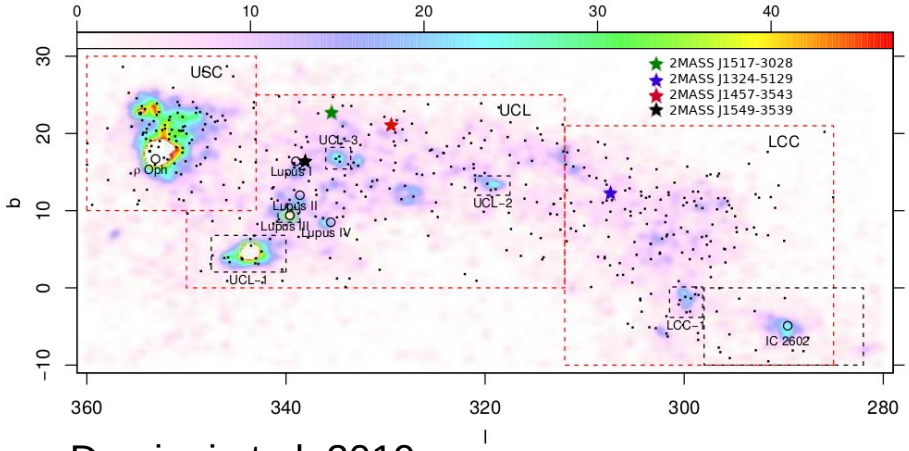
Problem
– Disentangling the members of the UCL (~15 Myr) and Lupus I (~ 2 Myr)

Membership criteria for young, star-forming regions
- Consistent kinematic properties and RV
- Age
- Containing Lithium

Majidi et al. 2020

Name	parallax (mas)	μ_α (mas/yr)	μ_δ (mas/yr)	RV (km/s)
2MASS J1815-3249	13.12±0.054	1.07±0.095	−52.74±0.078	−20.1±2.0
V4046Sgr	13.81±0.064	3.49±0.11	−52.75±0.087	−6.94±0.16
GSC 7396-00759	13.99±0.052	3.08±0.10	−52.64±0.08	−6.10±0.5





Damiani et al. 2019

X-Shooter characterization of new members of Lupus I selected with Gaia DR2

Not always this straightforward

Membership criteria for young, star-forming regions
– Consistent kinematic properties and RV
– Age (Lupus ~ 2 Myr)

** AKC2006 18 and AKC2006 19 in Lupus I (Frasca et al. 2017)

Name	α (J2000) (h:m:s)	δ (J2000) (d:m:s)	ϖ (mas)	$\mu_{\alpha*}$ (mas/yr)	μ_δ (mas/yr)	RV (km/s)	Prob %	age Myr
AKC2006 18	15 41 40.81	–33 45 18.86	6.69(0.35)	–18.84(0.33)	–22.06(0.27)	9.10(2.30)	95.3	8.3
AKC2006 19	15 44 57.89	–34 23 39.36	6.54(0.14)	–18.94(0.089)	–22.75(0.06)	9.60(2.10)	97.0	8.0

– Containing Lithium : Sz 94 in Lupus III cloud (Frasca et al. 2017)

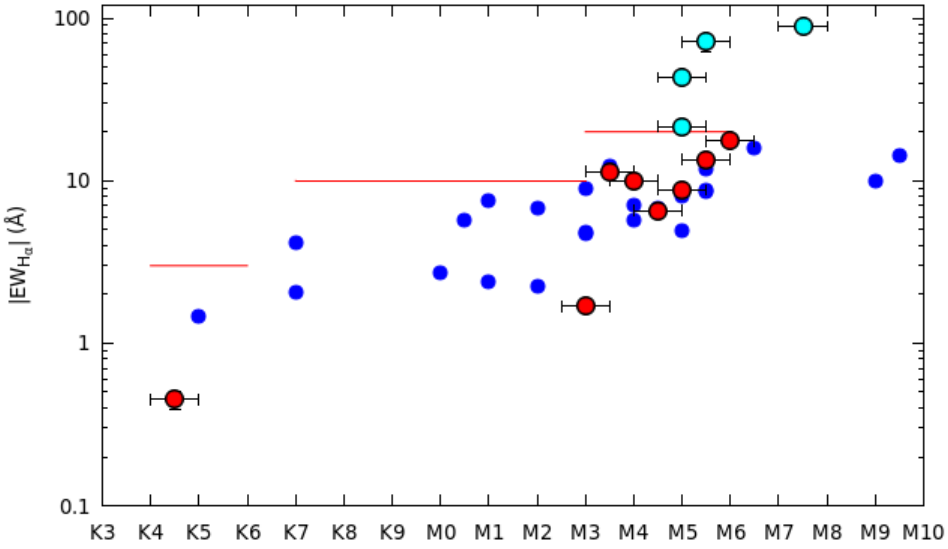
** Assessing all the physical properties of the targets is important and then decide on a target's membership

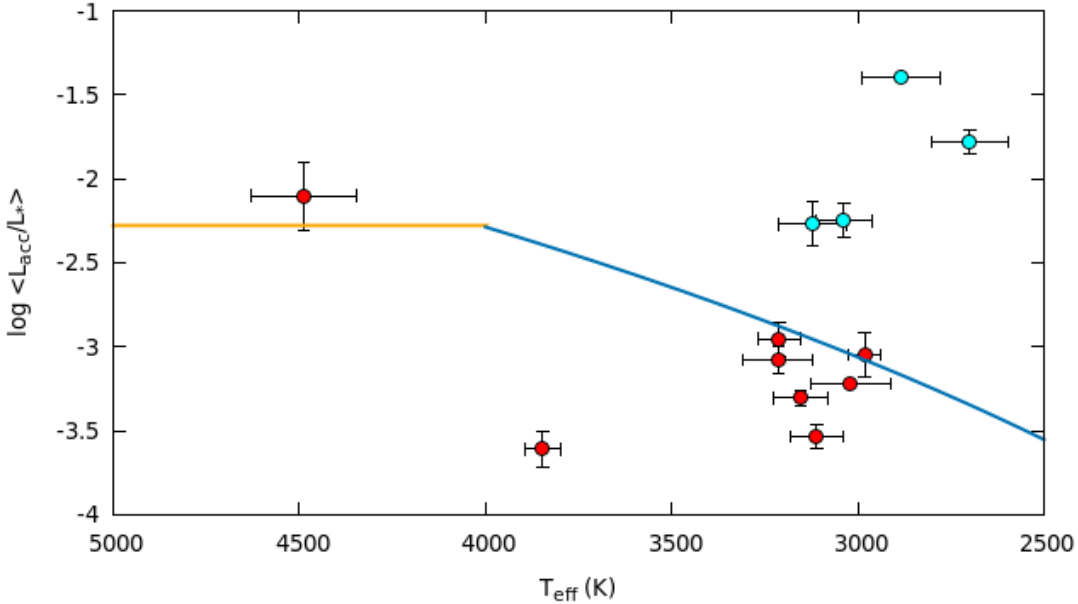
X-Shooter characterization of new members of Lupus I selected with Gaia DR2

Name	Age (Myr)	Membership (UCL/Lup I)	Active (yes/no)	Accreting (yes/no)	Contains Li I (yes/no)	Rotation (F/S)	A_v (mag)	Conclusion
2MASS J	11	Lup I	yes	no	yes	S	0	Genuine member of Lup I
Sz	1	Lup I	yes	yes	yes	S	0.5	Genuine Lup I member + wide companion candidate
TYC 733	5	Lup I	yes	no	yes	S	0.7	Genuine member of Lup I + wide companion candidate
2MASS J	9	?	yes	yes	no	S	1.75	Unresolved binary (?) + wide companion candidate
2MASS J	8	Lup I	yes	no	yes	S	0.5	New member of Lup I
2MASS J	0.7	Lup I	yes	yes	?	S	0.75	Genuine member of Lup I
2MASS J	9.5	Lup I	yes	yes	yes	S	0	New member of Lup I
UCAC4 2	4	Lup I	yes	no	yes	S	0.5	Genuine member of Lup I
Gaia DR	8	Lup I	yes	no	yes	F	0	New member of Lup I
2MASS J	2	Lup I	yes	no	no	F	0	Genuine member of Lup I
UCAC4 2	8	UCL	yes	no	no	S	0	New member of UCL
Gaia DR	9	?	yes	no	no	F	0	?

– Only 1 UCL member + 2 unknown (but interesting) targets
– Ages older than 2 Myrs
– 1 new member without Lithium
– 4 accretors (1 escaped OmegaCAM catalog) + the rest chormospherically-dominant

X-Shooter characterization of new members of Lupus I selected with Gaia DR2

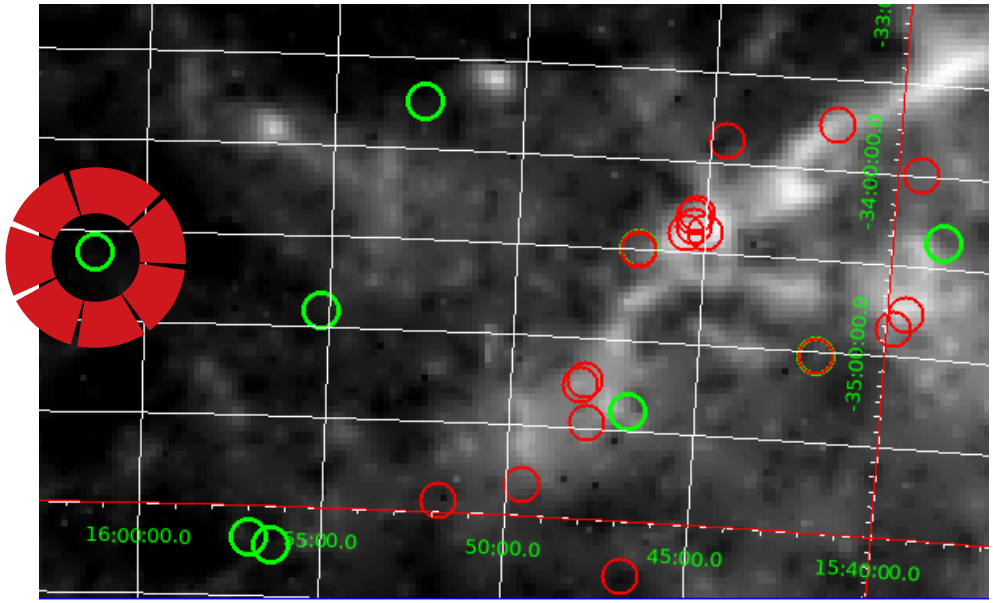




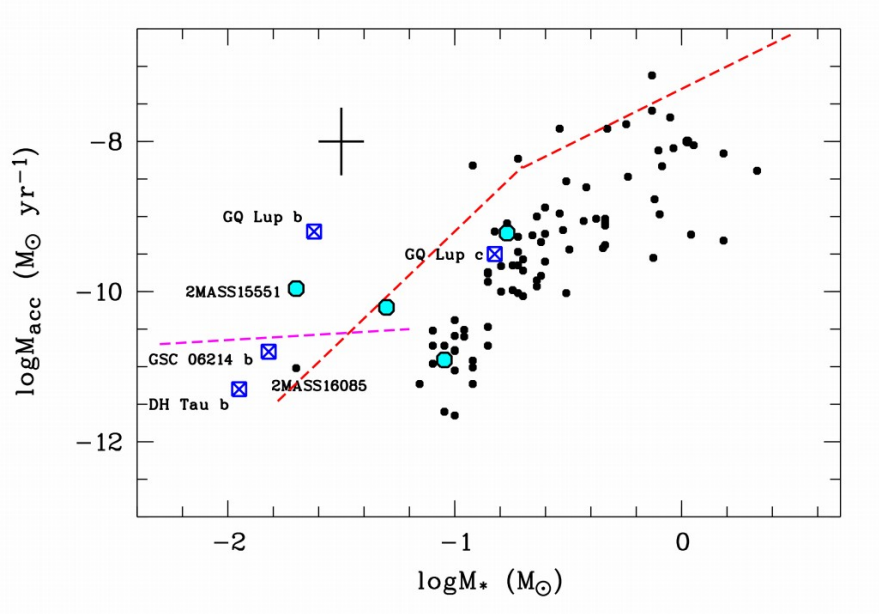
Cyan dots are accretors
Red dots are chormospherically-dominant objects

+ new member : K-type object with H_α in absorption

X-Shooter characterization of new members of Lupus I selected with Gaia DR2



Green circles are our targets
Red circles are Lupus I core members



Red line: Vorobyov & Basu (2009), based on modelling self-regulated accretion by gravitational torques in self-gravitating disks. Magenta line: the prediction of disk fragmentation model by Samatellos & Herczeg (2015).

Conclusions

– Lupus I has more (interesting) members that are yet unknown (new conclusion)
– In order to find these members, various surveys and follow-up programs are required due to the wide variety of Lupus members (old conclusion)
– Gaia catalogs are essential for conducting follow-up programs on finding new members of stellar associations (reminder?)

Future plans

– Resolving the disks of our targets with other instruments (SED + photometry)
– Continuing the search for the unknown members of Lupus complex

Thank You!