BANYAN: Searching for young objects in the Solar neighborhood

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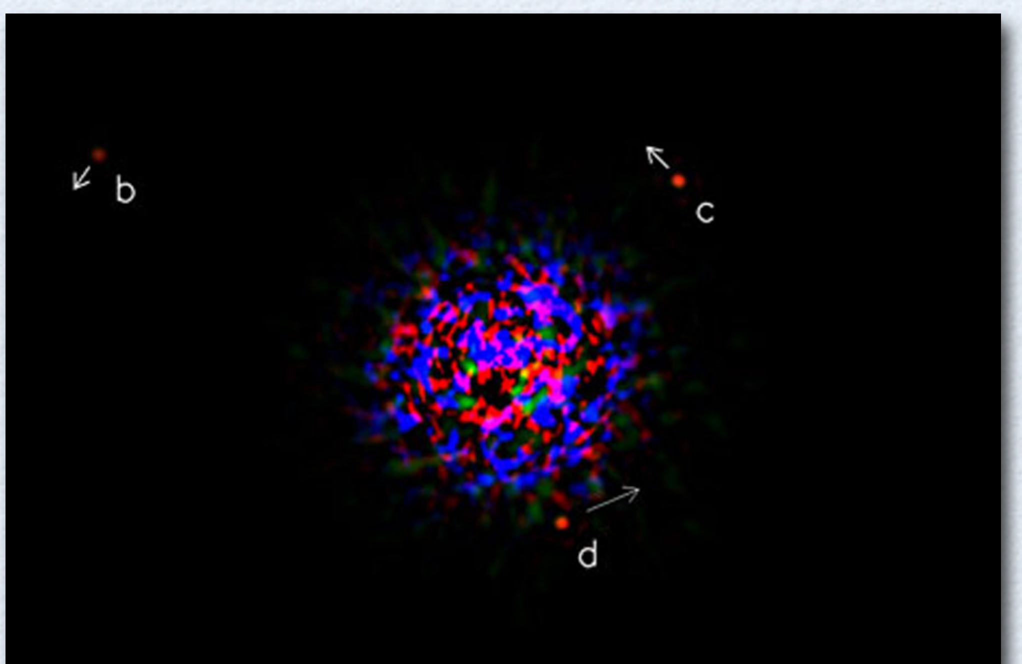
Gaia and the unseen, March 25th 2014

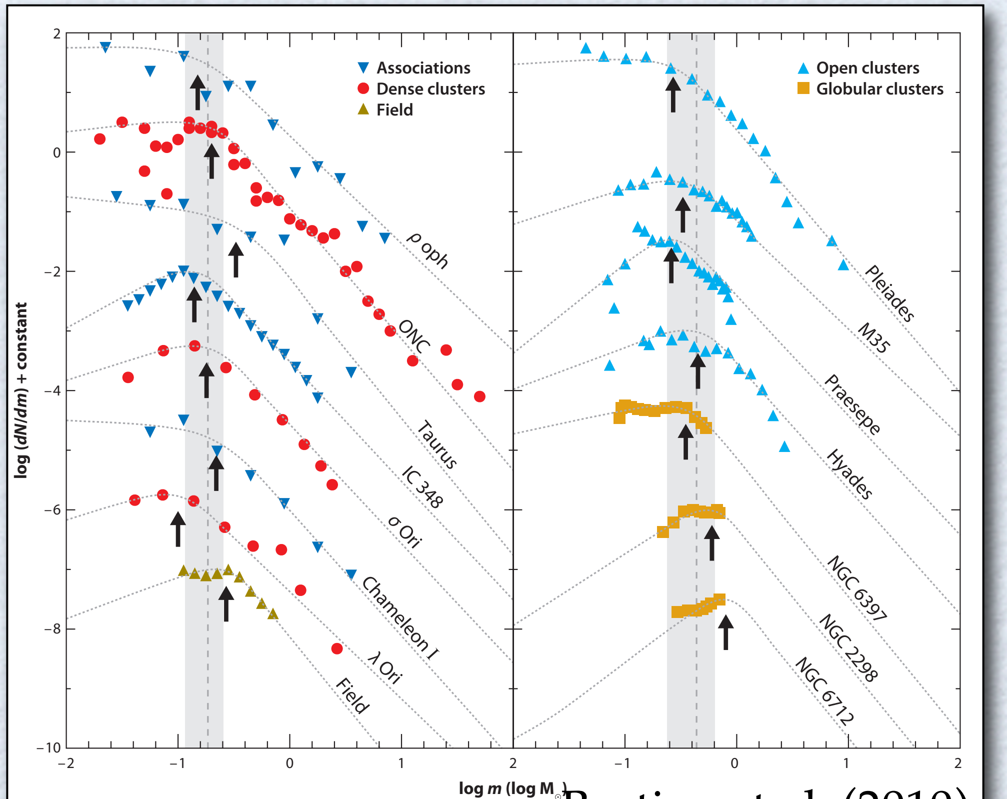
BANYAN-I: Malo et al. (2013)
BANYAN-II: Gagne et al. (2014)

Why searching for young objects near the Sun?

- Confirm the shape of the initial mass function
- Powerful exoplanet imaging
- Knowledge of the distance (Hipparcos, CTIOPI, others studies)
- Understanding the formation mechanisms and stellar evolution
- Undertanding the complex relation between luminosity-mass-age



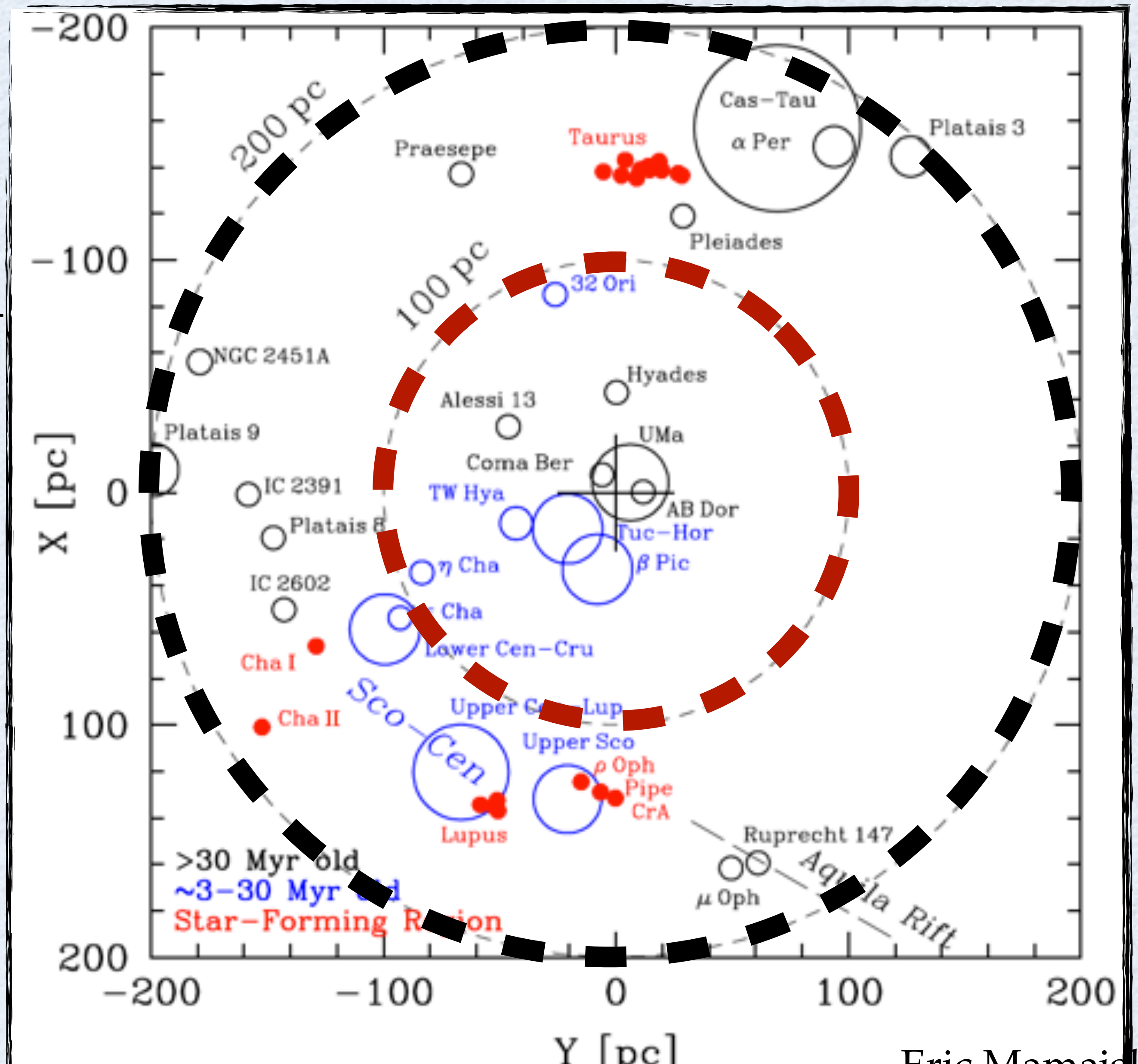
Marois et al. (2008)



Bastian et al. (2010)

The Solar neighborhood: Nearby young kinematic group members

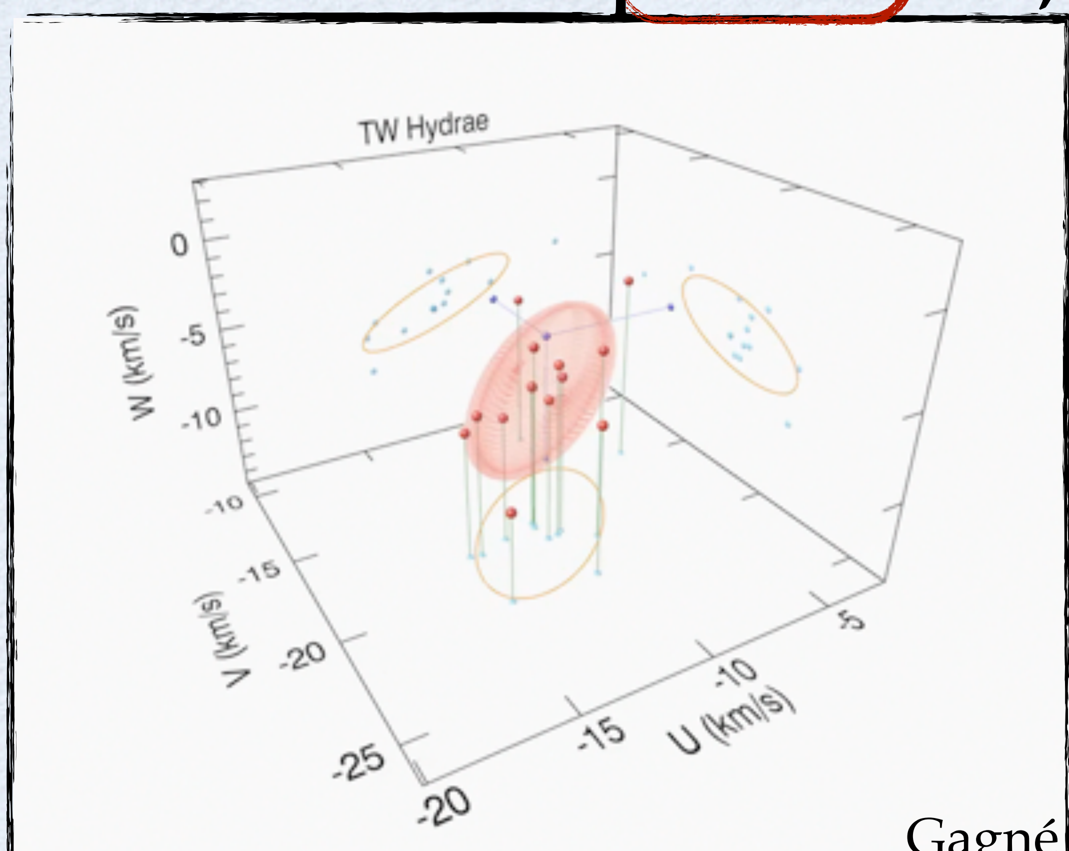
- 100 pc region centered on the Sun
- 7 groups within 100 pc and <120 Myr
- T-Tauri, B9-M5 dwarfs and brown dwarfs (total of 184 members)
    - Member definition:?
- Share similar kinematics, luminosity & signs of youth



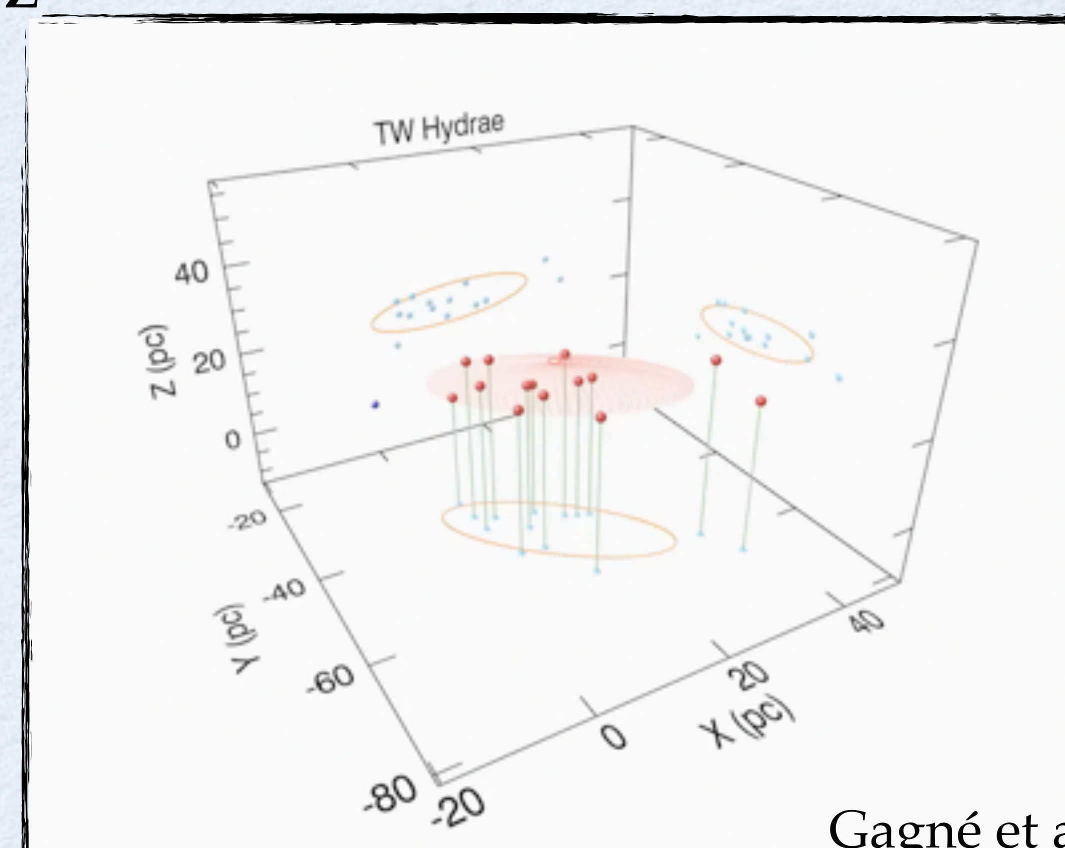
Eric Mamajek

Global properties of known members: kinematics

- Share same Galactic Space velocities (UVW)
  - Projection of the member's motion in the Galactic plane (Johnson & Soderblom, 1987)
  - $\alpha + \delta + \mu_\alpha + \mu_\delta + \mathrm{RV} + \mathrm{parallax} = U,V,W + \sigma_{UVW}$
- Share same Galactic positions (XYZ)
  - $\alpha + \delta + \mathrm{parallax} = X, Y, Z + \sigma_{XYZ}$

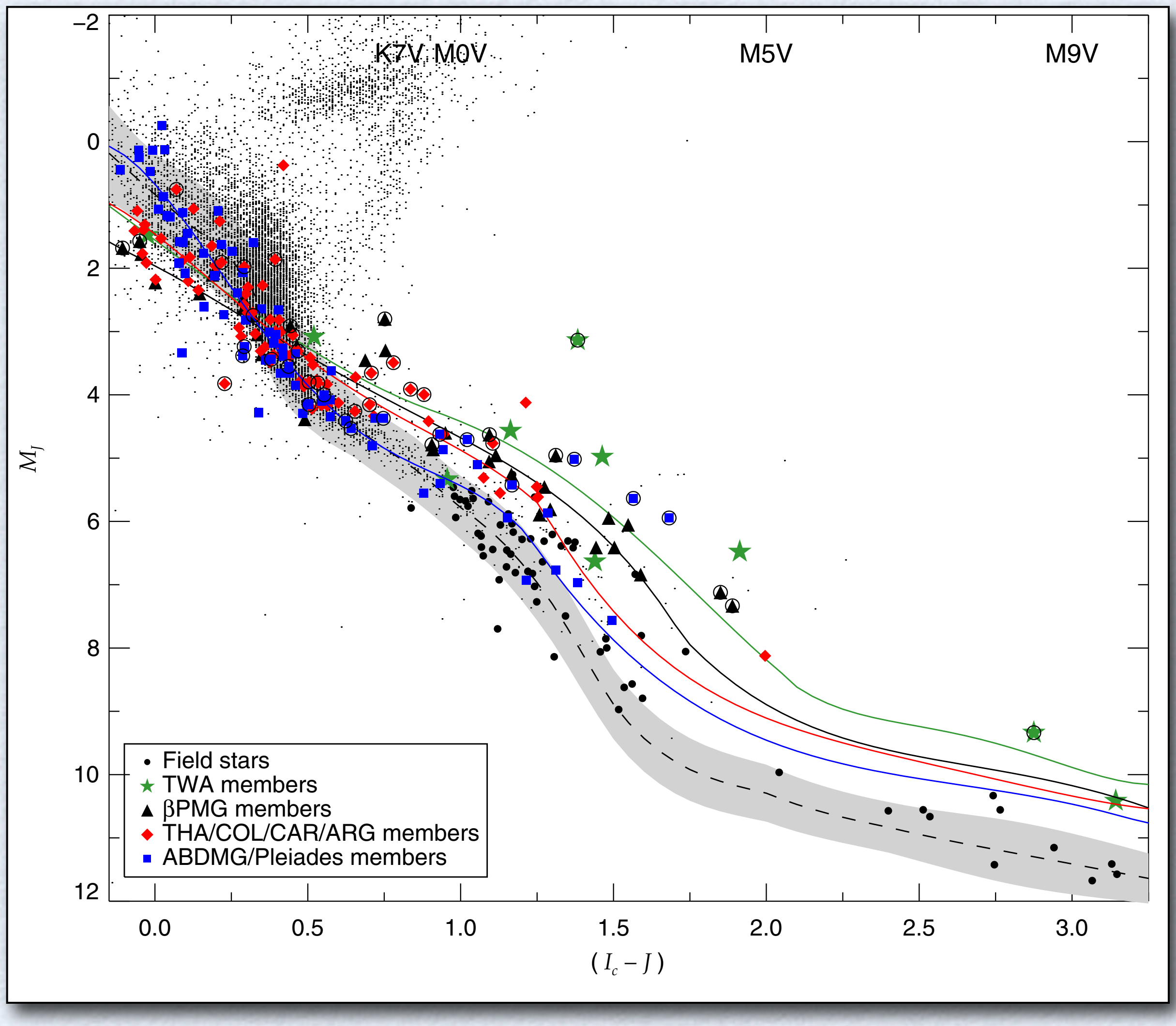


Gagné et al. (2014)

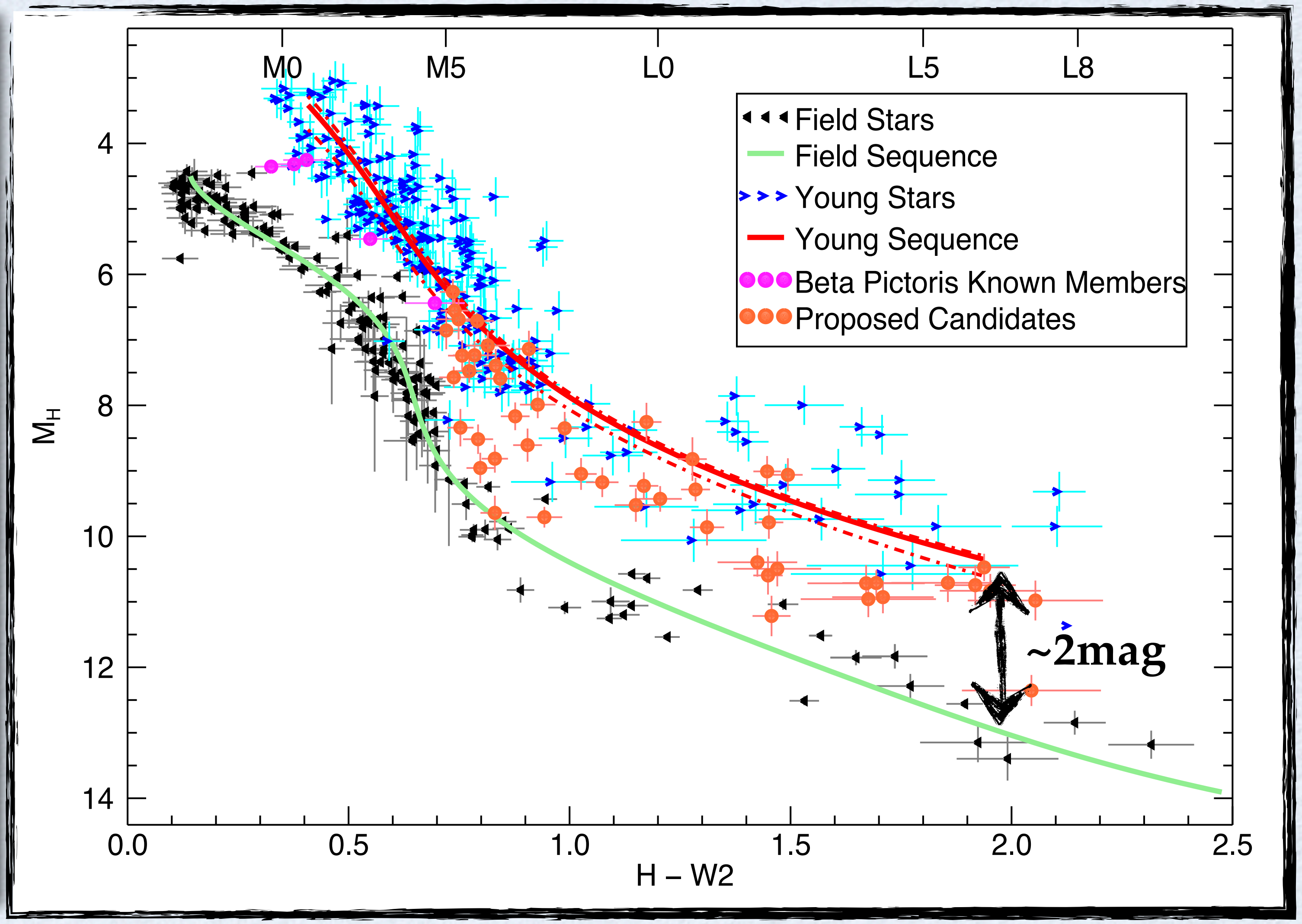


Gagné et al. (2014)

Global properties of known members: luminosity



BANYAN-I

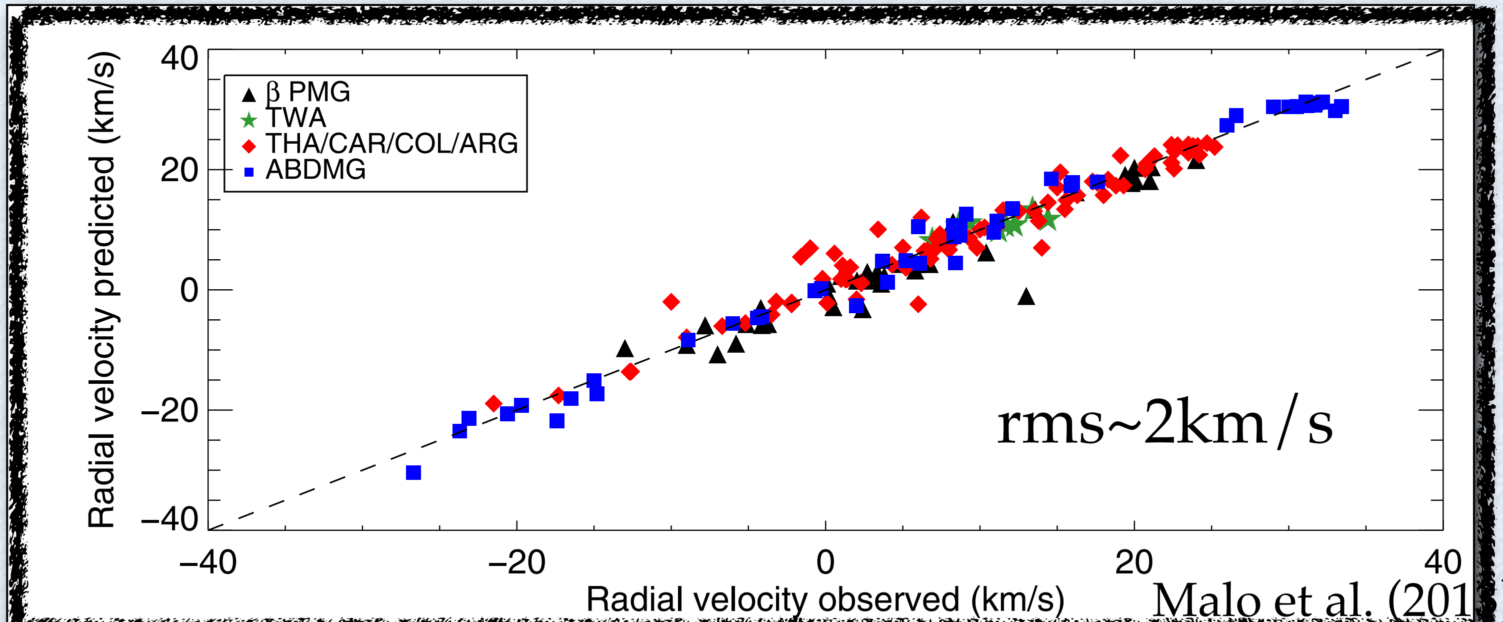


BANYAN-II

Finding new members: Kinematic model

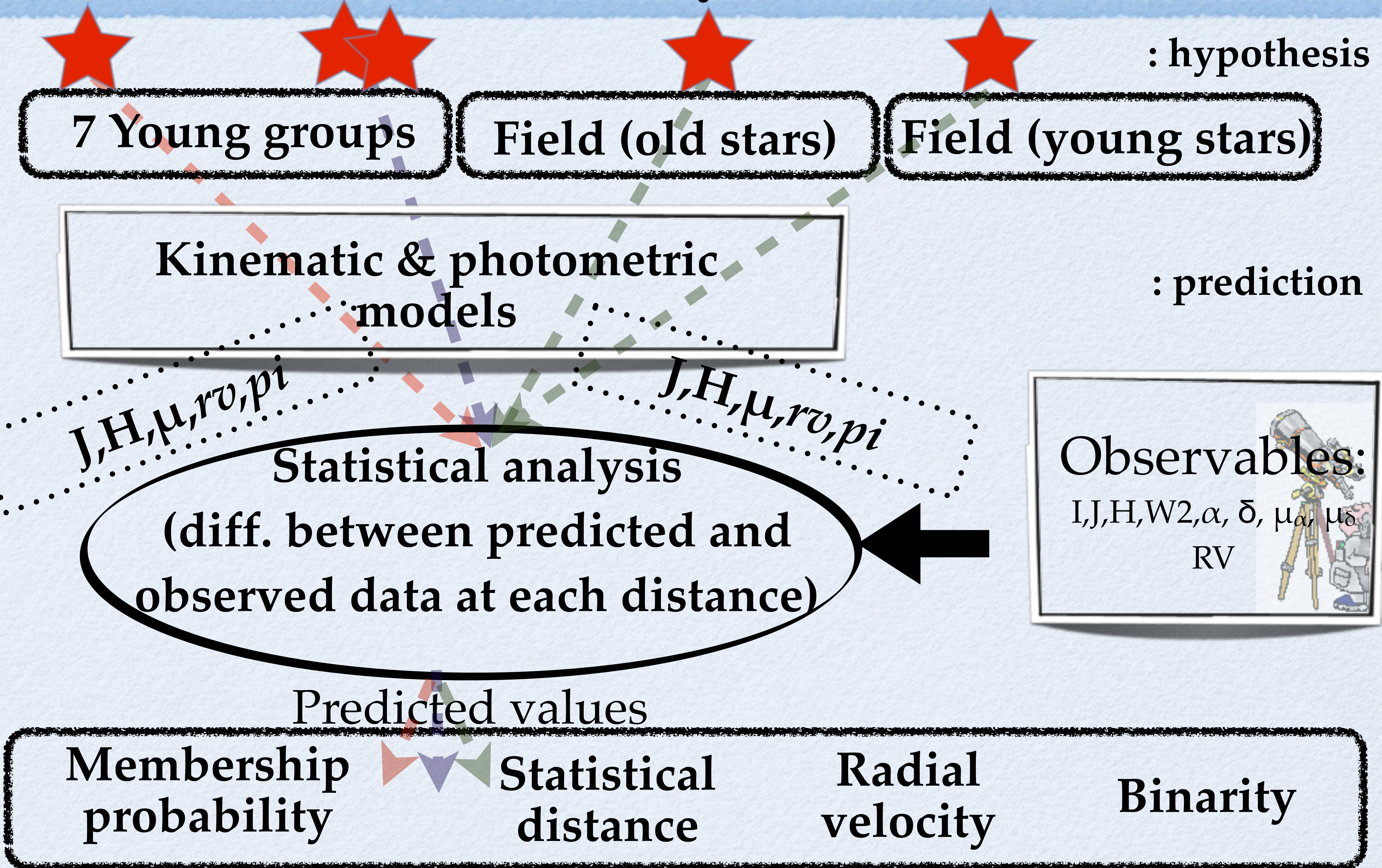
- UVW + σ_{UVW} + α + δ + parallax + $\sigma_{parallax}$ -> RV + σ_{RV}+ μ_{α} + μ_{δ}
- We need good precision on RV measurements (< 1km/s)

Name of Group	UVW (km s^{-1})	σ_{UVW} (km s^{-1})	XYZ (pc)	σ_{XYZ} (pc)
β Pictoris (βPMG)	−10.94, −16.25, −9.27	2.06, 1.30, 1.54	9.27, −5.96, −13.59	31.71, 15.19, 8.22
Tucana-Horologium (THA)	−9.88, −20.70, −0.90	1.51, 1.87, 1.31	11.39, −21.21, −35.40	19.29, 9.17, 5.39
AB Doradus (ABDMG)	−7.12, −27.31, −13.81	1.39, 1.31, 2.16	−2.37, 1.48, −15.62	20.03, 18.83, 16.59
Columba (COL)	−12.24, −21.32, −5.58	1.03, 1.18, 0.89	−27.44, −31.32, −27.97	13.79, 20.55, 15.09
Carina (CAR)	−10.50, −22.36, −5.84	0.99, 0.55, 0.14	15.55, −58.53, −22.95	5.66, 16.69, 2.74
TW Hydrae (TWA)	−9.87, −18.06, −4.52	4.15, 1.44, 2.80	12.49, −42.28, 21.55	7.08, 7.33, 4.20
Argus (ARG)	−21.78, −12.08, −4.52	1.32, 1.97, 0.50	14.60, −24.67, −6.72	18.60, 19.06, 11.43
Field stars	−10.92, −13.35, −6.79	23.22, 13.44, 8.97	−0.18, 2.10, 3.27	53.29, 51.29, 50.70



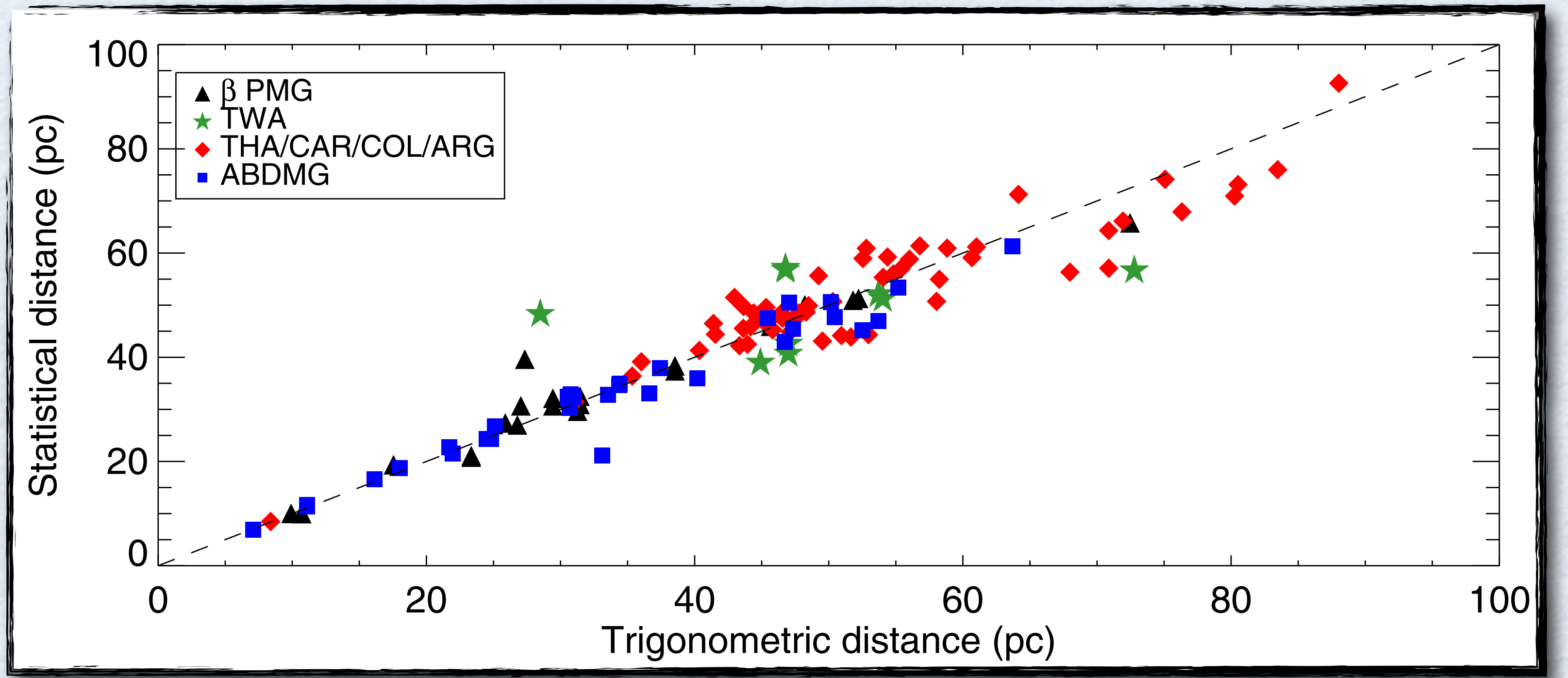
Malo et al. (201)

BANYAN: combinaison of empirical models and statistical analysis



A powerful method to predict distance

- **Application to the previous known members**
- **Correlation between parallax and our statistical distance within 10%**
- **Over-luminosity prediction (binary)**



Malo et al. (2013)

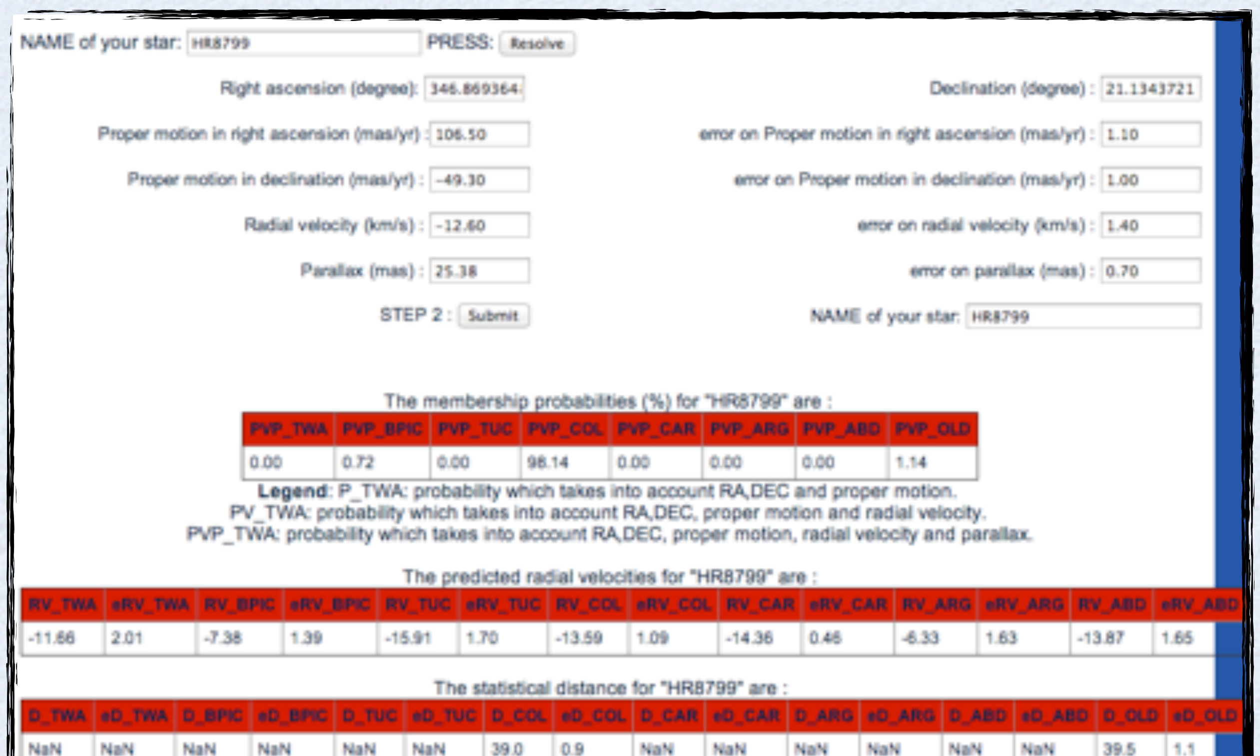
Application to stars and brown dwarf sample

- 1104 K5-M5 dwarfs
  - 1061 from Riaz et al. (2006)
  - 43 from previous studies
  - Showing X-ray, Hα or UV emission
- Brown dwarf sample
  - Cross-correlation WISE+2MASS
  - 360,000 objects with $\mu > 10$ mas/yr

Results for cool stars sample

- **LMS: 247 candidate members with 51 ambiguous members**
- **BDs: 300 candidate members**

Name	βPMG			TWA			THA			COL			CAR			ARG			ABDMG			Field		
	P	P_v	$P_{v+\pi}$	P	P_v	$P_{v+\pi}$	P	P_v	$P_{v+\pi}$	P	P_v	$P_{v+\pi}$	P	P_v	$P_{v+\pi}$	P	P_v	$P_{v+\pi}$	P	P_v	$P_{v+\pi}$	P	P_v	$P_{v+\pi}$
J00171443-7032021	0.0	…	…	0.0	…	…	99.2[b]	…	…	0.0	…	…	0.0	…	…	0.0	…	…	0.5	…	…	0.3	…	…
J00172353-6645124	99.9	99.9	…	0.0	0.0	…	0.0	0.0	…	0.0	0.0	…	0.0	0.0	…	0.4	0.0	…	0.1	0.0	…	0.0	0.0	…



NAME of your star: HR8799 PRESS: Resolve

Right ascension (degree): 346.869364 Declination (degree) : 21.1343721

Proper motion in right ascension (mas/yr) : 106.50 error on Proper motion in right ascension (mas/yr) : 1.10

Proper motion in declination (mas/yr) : -49.30 error on Proper motion in declination (mas/yr) : 1.00

Radial velocity (km/s) : -12.60 error on radial velocity (km/s) : 1.40

Parallax (mas) : 25.38 error on parallax (mas) : 0.70

STEP 2 : Submit NAME of your star: HR8799

The membership probabilities (%) for "HR8799" are :

PVP_TWA	PVP_BPIC	PVP_TUC	PVP_COL	PVP_CAR	PVP_ARG	PVP_ABD	PVP_OLD
0.00	0.72	0.00	98.14	0.00	0.00	0.00	1.14

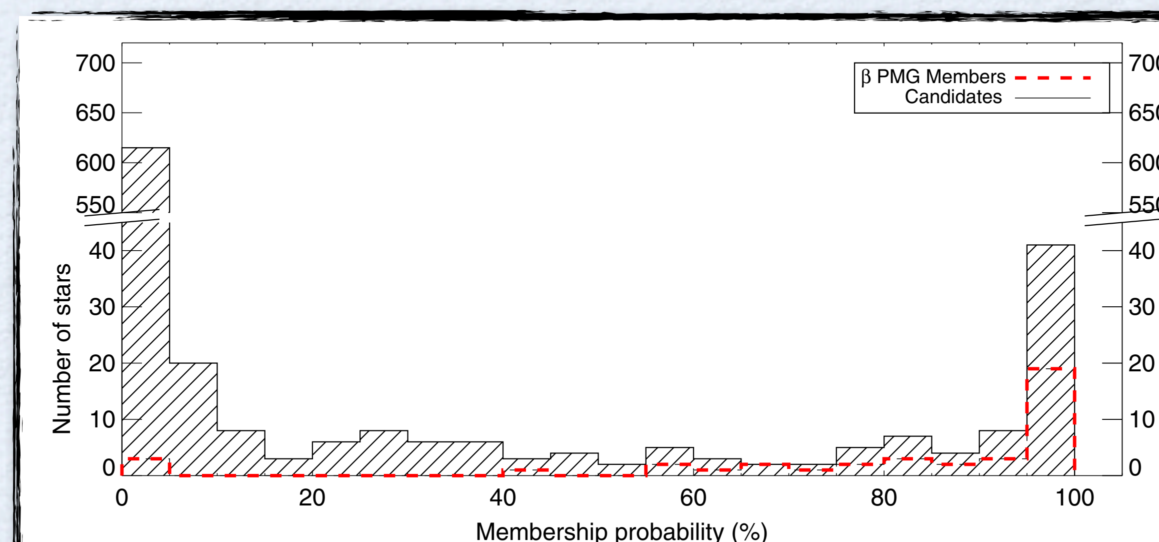
Legend: P_TWA: probability which takes into account RA,DEC and proper motion.
PV_TWA: probability which takes into account RA,DEC, proper motion and radial velocity.
PVP_TWA: probability which takes into account RA,DEC, proper motion, radial velocity and parallax.

The predicted radial velocities for "HR8799" are :

RV_TWA	eRV_TWA	RV_BPIC	eRV_BPIC	RV_TUC	eRV_TUC	RV_COL	eRV_COL	RV_CAR	eRV_CAR	RV_ARG	eRV_ARG	RV_ABD	eRV_ABD
-11.66	2.01	-7.38	1.39	-15.91	1.70	-13.59	1.09	-14.36	0.46	-6.33	1.63	-13.87	1.65

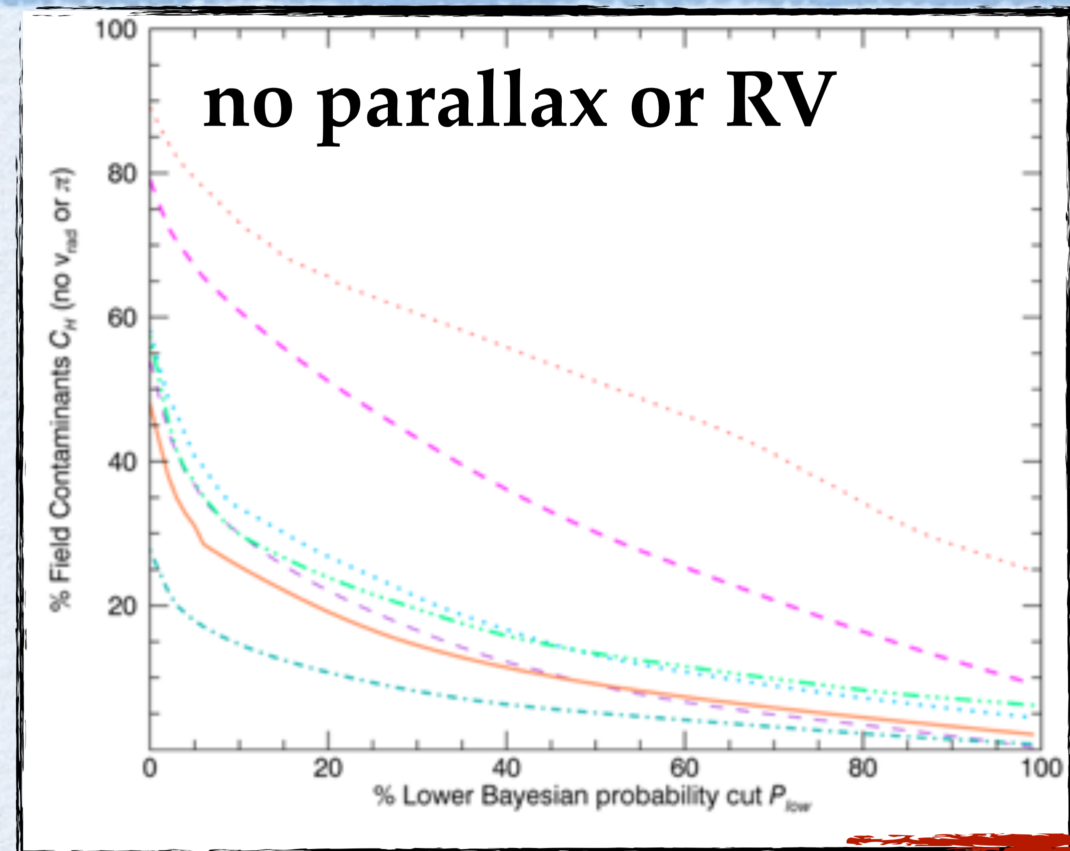
The statistical distance for "HR8799" are :

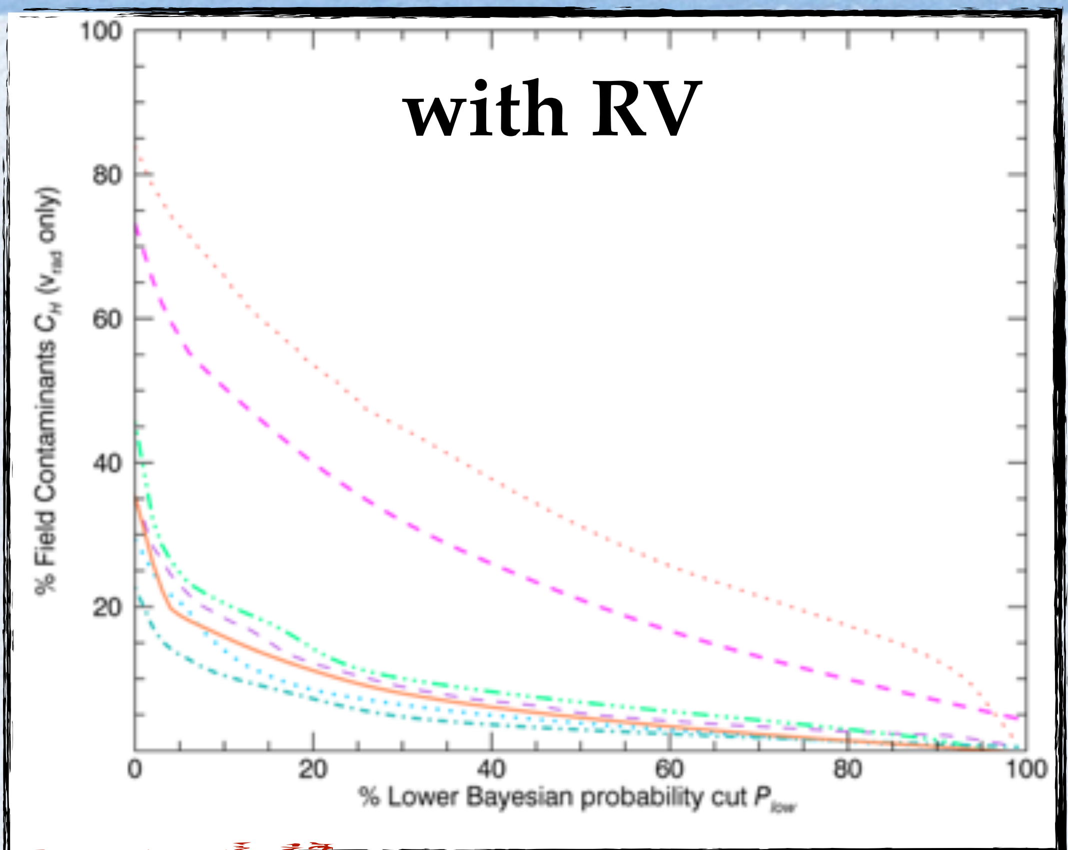
D_TWA	eD_TWA	D_BPIC	eD_BPIC	D_TUC	eD_TUC	D_COL	eD_COL	D_CAR	eD_CAR	D_ARG	eD_ARG	D_ABD	eD_ABD	D_OLD	eD_OLD
NaN	NaN	NaN	NaN	NaN	NaN	39.0	0.9	NaN	NaN	NaN	NaN	NaN	NaN	39.5	1.1

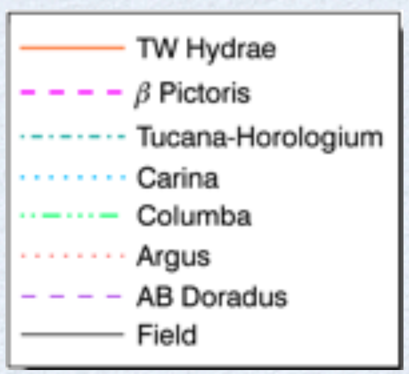


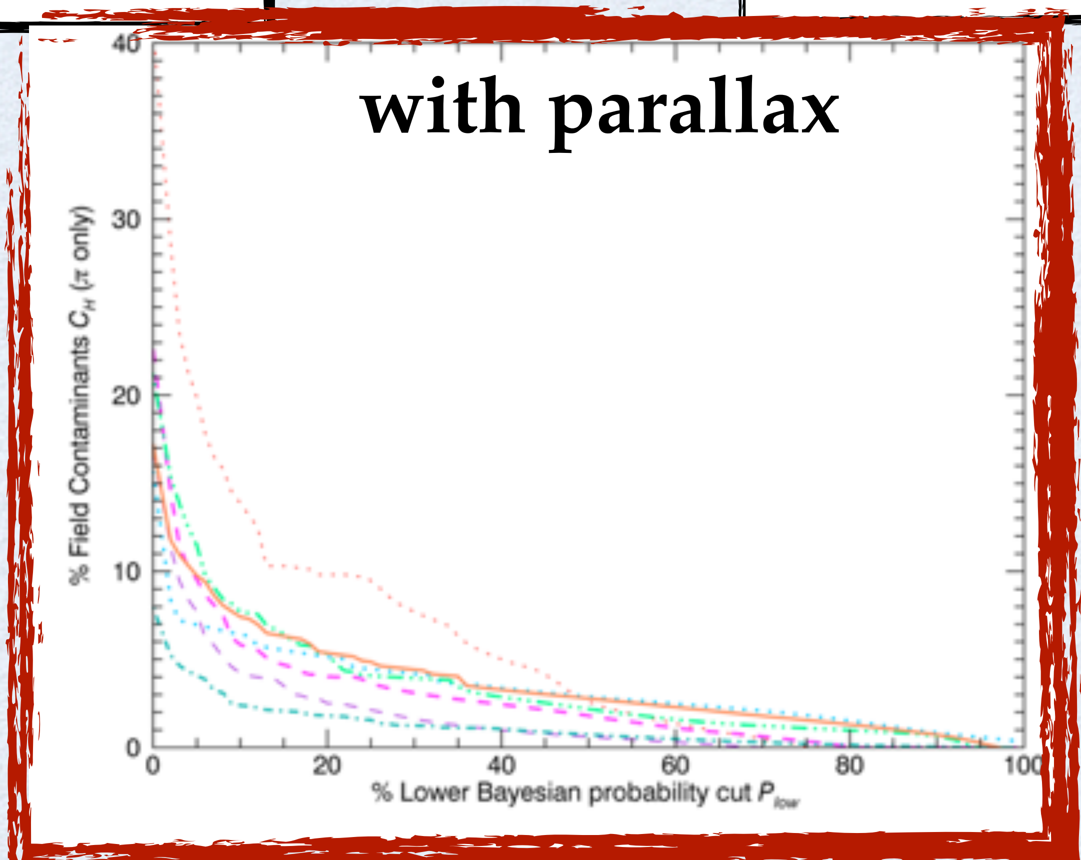
BANYAN webtools: www.astro.umontreal.ca/~malo/banyan.php or https://sites.google.com/site/mbderg/

Contamination





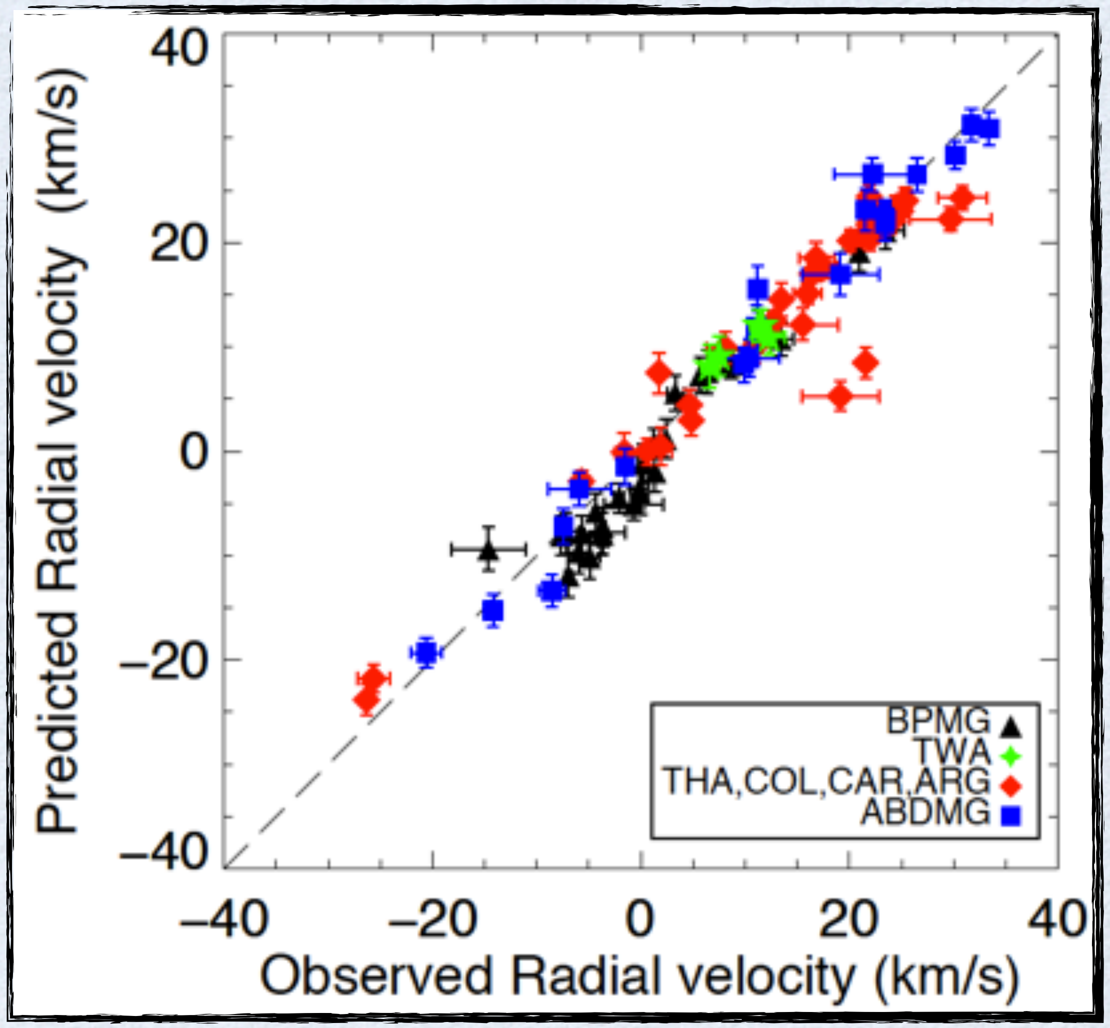




Gagné et al. (2014)

Radial velocity follow-up for candidates members

- Radial velocity measurements with a precision less than 1 km/s
  - ESPaDOnS (CFHT)
    - λ = 390-1050 nm
    - R=68,000 or 81,000
  - CRIRES (VLT)
    - λ = 1.552-1.559 μm
    - R= 50,000
  - PHOENIX (GEMINI)
    - λ = 1.552-1.558 μm
    - R=52,000



Malo et al. (accepted)

- 219 measurements -> 130 dwarfs with confirmed RV

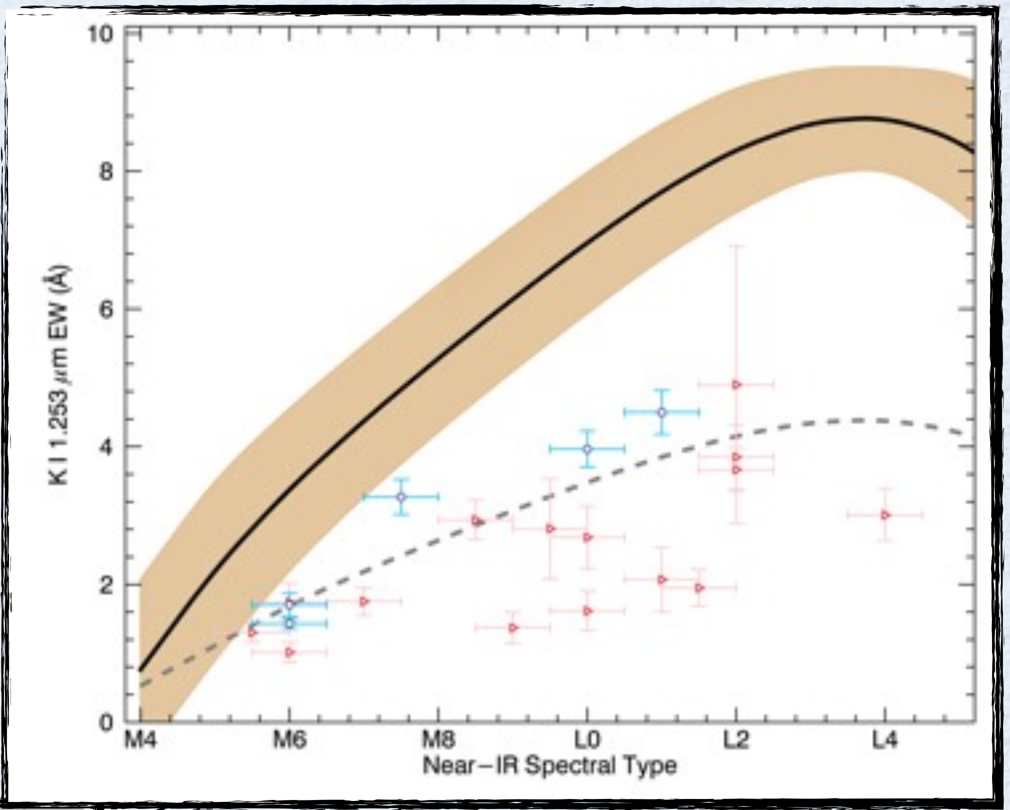
Parallax confirmation

- **15 stars from CTIOPI (A. Riedel)**
- **5 stars from Shkolnik et al. (2012)**
- **3 objects from Weinberger et al. (2013a), Faherty et al. (2013b), Liu et al. (2013a) (Gagné et al. (2014)**

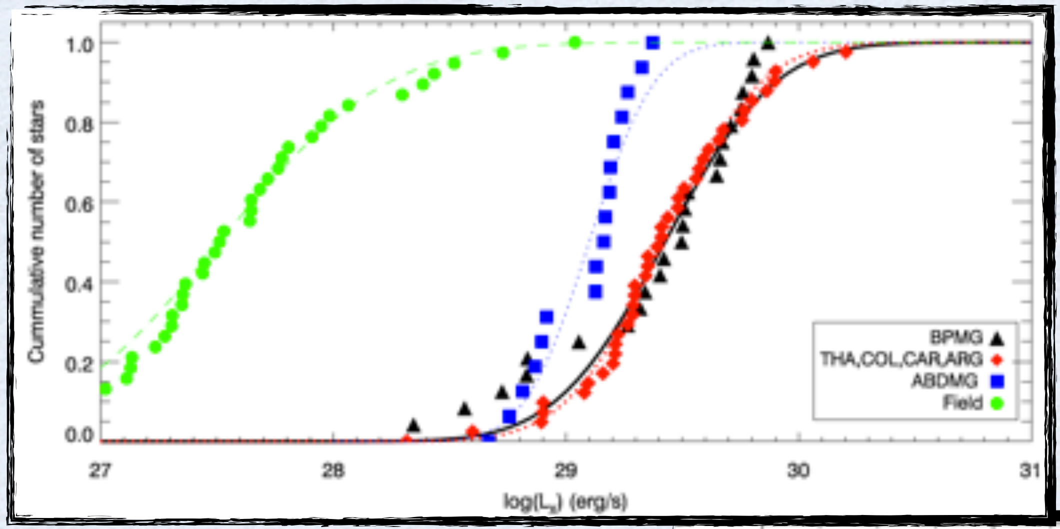
Name	d_s [c] (pc)	d_π [d] (pc)	P_v [a] (%)	$P_{v+\pi}$ [a] (%)	Group
J00503319+2449009	22.5 ± 1.3	11.8 ± 0.7[f]	99.99[b]	0.00	
J01034210+4051158	33.5 ± 1.6	29.9 ± 2.0	95.64	96.67	ABDMG
J01112542+1526214	20.5 ± 1.5	21.8 ± 0.8[e]	99.99[b]	99.99[b]	β PMG
J01351393-0712517	35.5 ± 3.1	37.9 ± 2.4	99.99[b]	99.99[b]	β PMG
J01365516-0647379	21.1 ± 1.7	24.0 ± 0.4	99.99	99.99	β PMG
J04141730-0906544	28.7 ± 1.9	23.8 ± 1.4	99.99	99.99	ABDMG
J04522441-1649219	16.0 ± 1.2	16.3 ± 0.4	99.99[b]	99.99[b]	ABDMG
J05015881+0958587	38.4 ± 3.9	24.9 ± 1.3[e]	99.99[b]	99.99[b]	β PMG
J05064946-2135038	21.9 ± 4.4	19.2 ± 0.5[e]	99.99[b]	99.99[b]	β PMG
J05064991-2135091	22.4 ± 0.7	19.2 ± 0.5[e]	4.35	99.99	β PMG
J05254166-0909123	21.8 ± 1.5	20.7 ± 2.2	99.99[b]	99.99[b]	ABDMG
J06091922-3549311	22.5 ± 4.5	21.3 ± 1.4[g]	99.99[b]	99.99[b]	ABDMG
J10121768-0344441	12.5 ± 0.0	7.9 ± 0.1[f]	0.14	0.00	
J14142141-1521215	16.2 ± 1.2	30.2 ± 4.5[f]	99.41	96.92	β PMG
J20434114-2433534	44.8 ± 3.2	28.1 ± 3.9	99.99[b]	99.99[b]	β PMG
J21212873-6655063	32.0 ± 2.0	30.2 ± 1.3[f]	99.99	99.99	β PMG
J21521039+0537356	29.0 ± 1.7	30.5 ± 5.3[f]	99.99[b]	99.99[b]	ABDMG
J23205766-0147373	29.6 ± 1.5	41.0 ± 2.7	96.16[b]	99.99[b]	ARG
J23301341-2023271	13.5 ± 0.6	16.2 ± 0.9[f]	75.69[b]	99.21[b]	COL

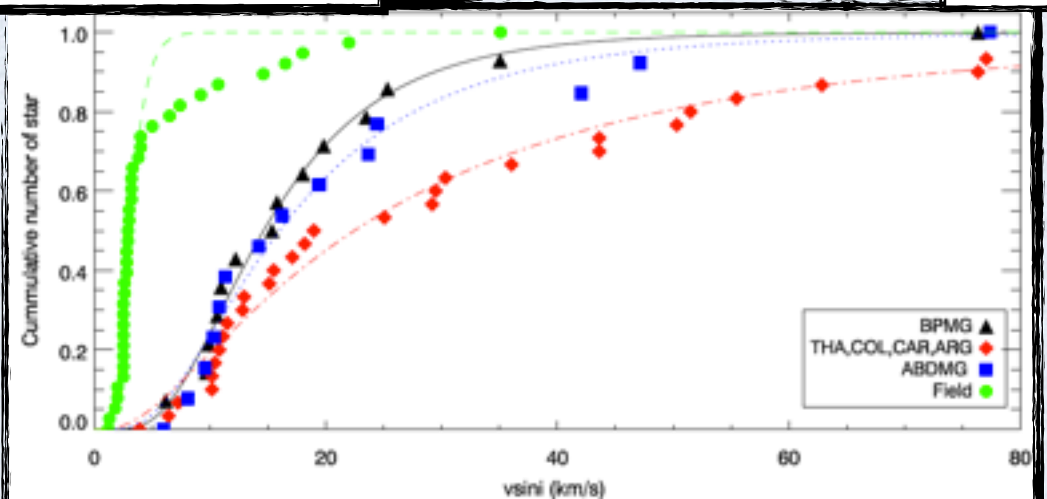
Signs of youth confirmation

- Chromospheric and coronal activity (Hα, X-ray, UV)
- Stellar rotation
- Surface gravity (*H*-band, NaI, KI)
- Lithium abundance /LDB



Gagné et al. (inprep)



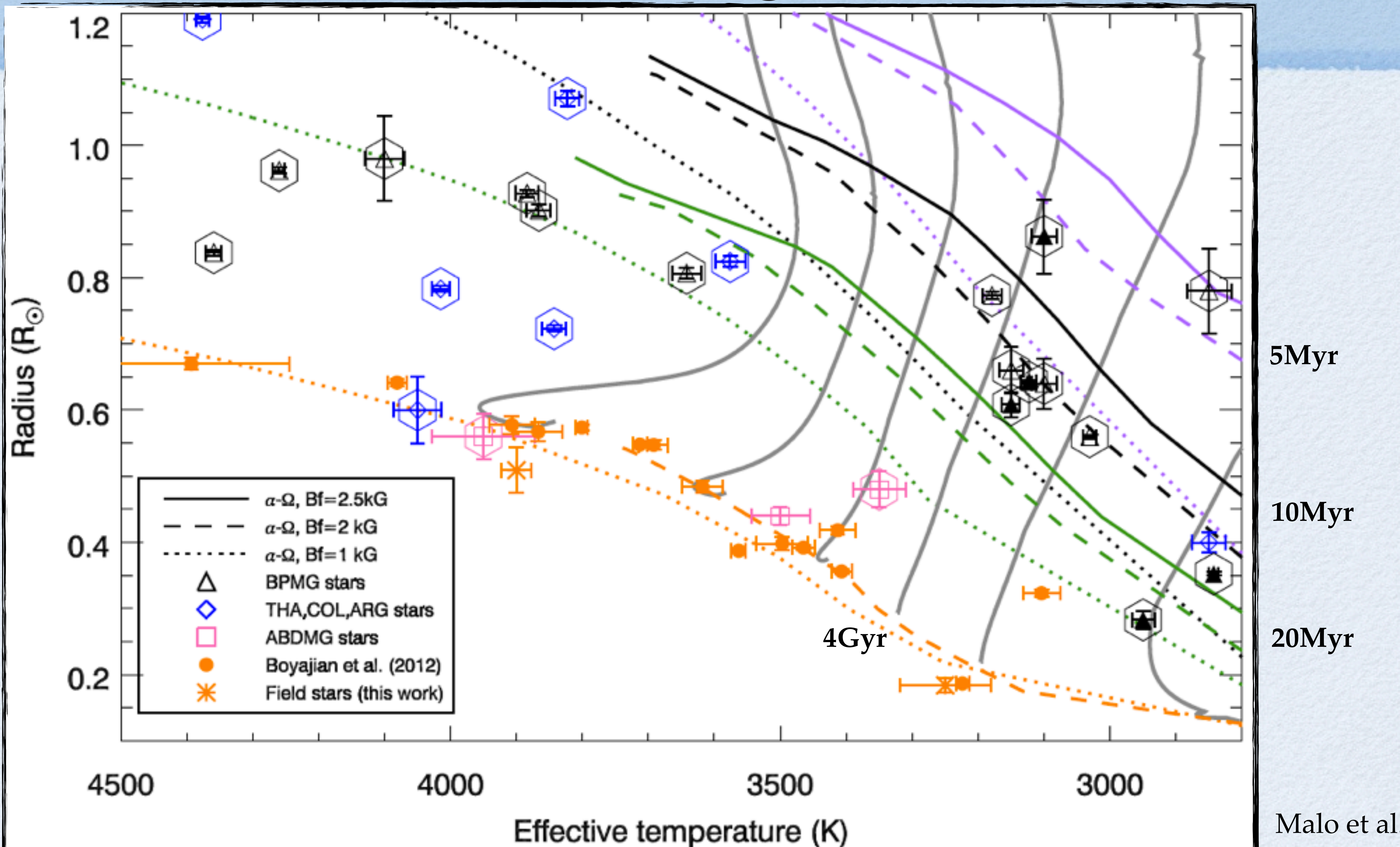


Malo et al. (accepted)

Full membership & age confirmation with Gaia?

- Most complete census (last 10 yrs): Riedel et al. (2014), Rodriguez et al. (2014), Malo et al. (2013), Gagné et al. (2014), Kraus et al. (2014)
- Gaia + Gaia-ESO survey:
  - $\alpha + \delta + \mu_\alpha + \mu_\delta$ + RV + parallax = U,V,W + σ_{UVW}
  - $\alpha + \delta$ + parallax = X, Y, Z + σ_{XYZ}
  - Youth indicators
- Two things are missing for the age confirmation:
  - Interferometric radii measurements -> L_{bol}
  - Magnetic field measurements

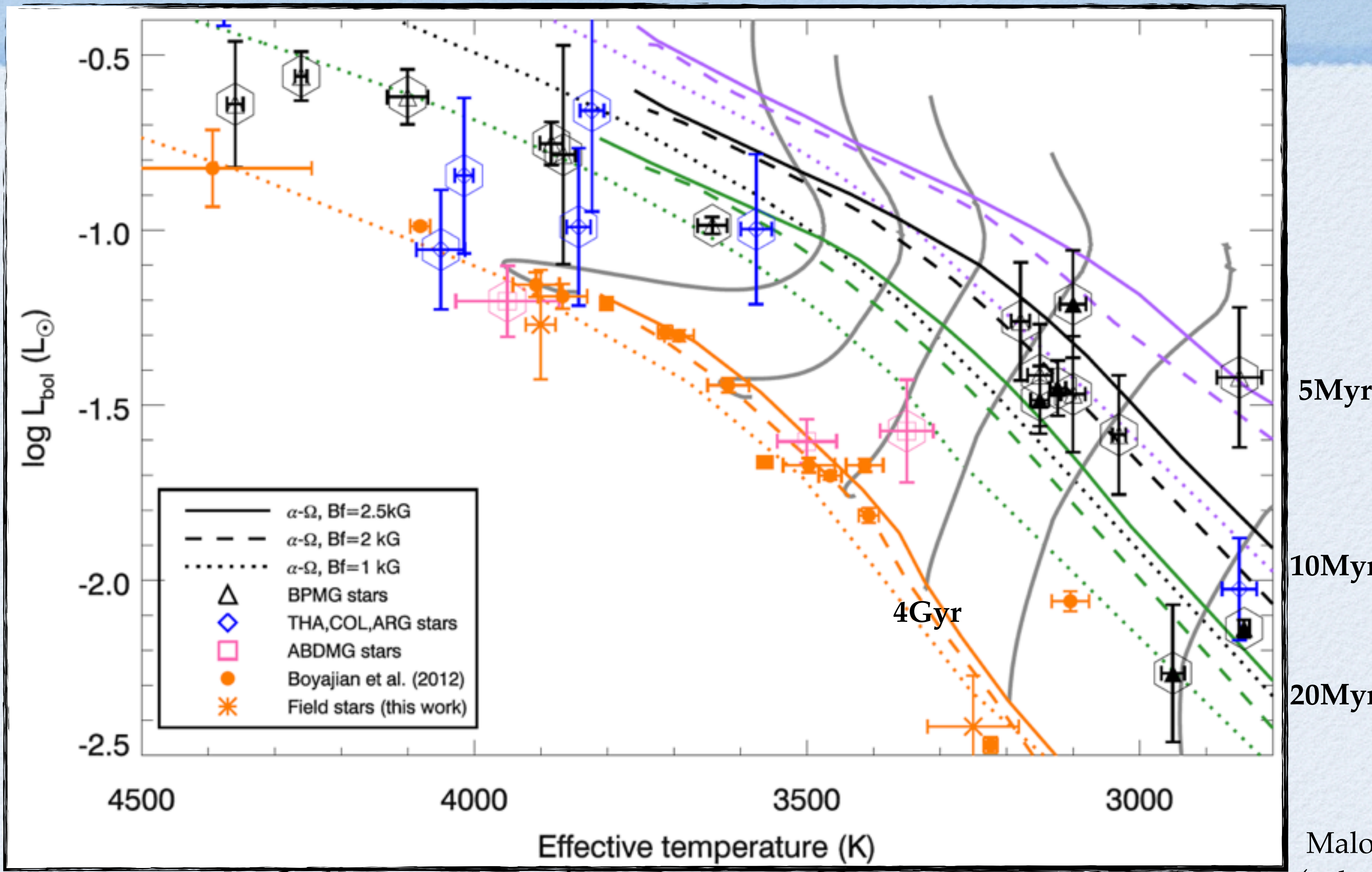
Radii diagram



Malo et al. (submitted)

- $<Bf>$ for old M dwarfs = ~2.0 kG (Reiners 2012)
  - Dartmouth Magnetic evolutionary models (Feiden et al. 2013)

Hertzsprung-Russell diagram



Malo et al. (submitted)

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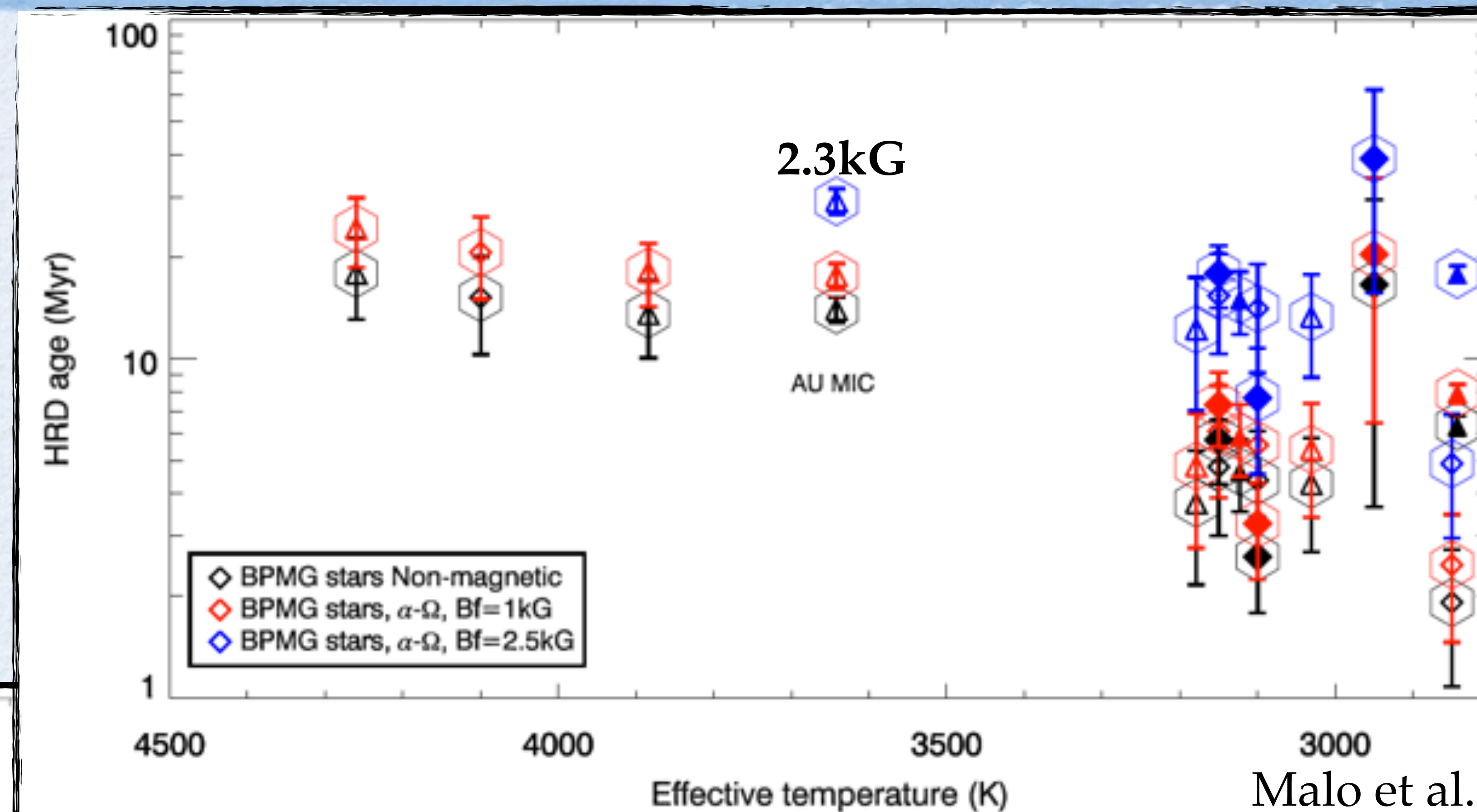
    - Dartmouth Magnetic evolutionary models (Feiden et al. 2013)

Age determination, example for βPMG



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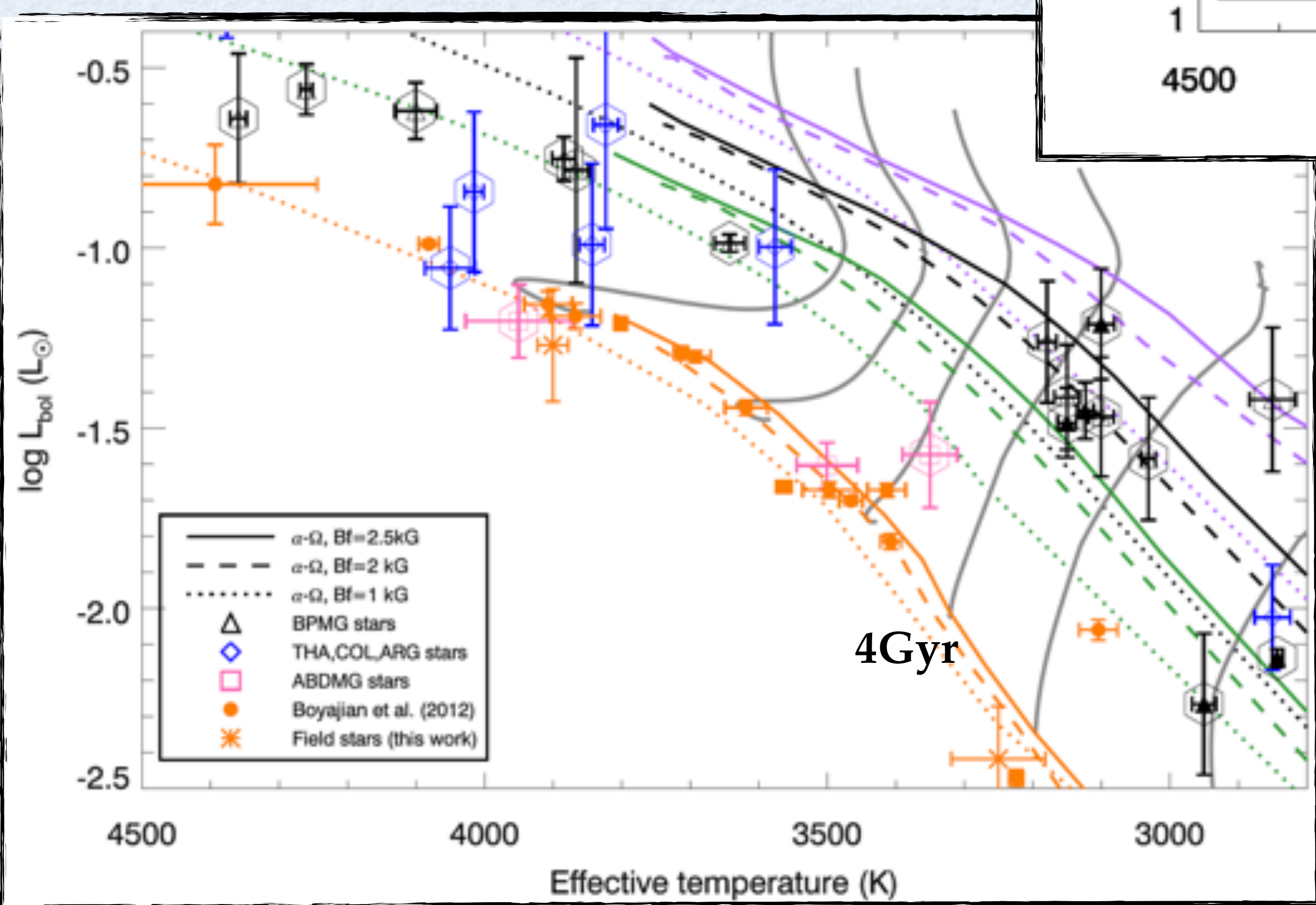


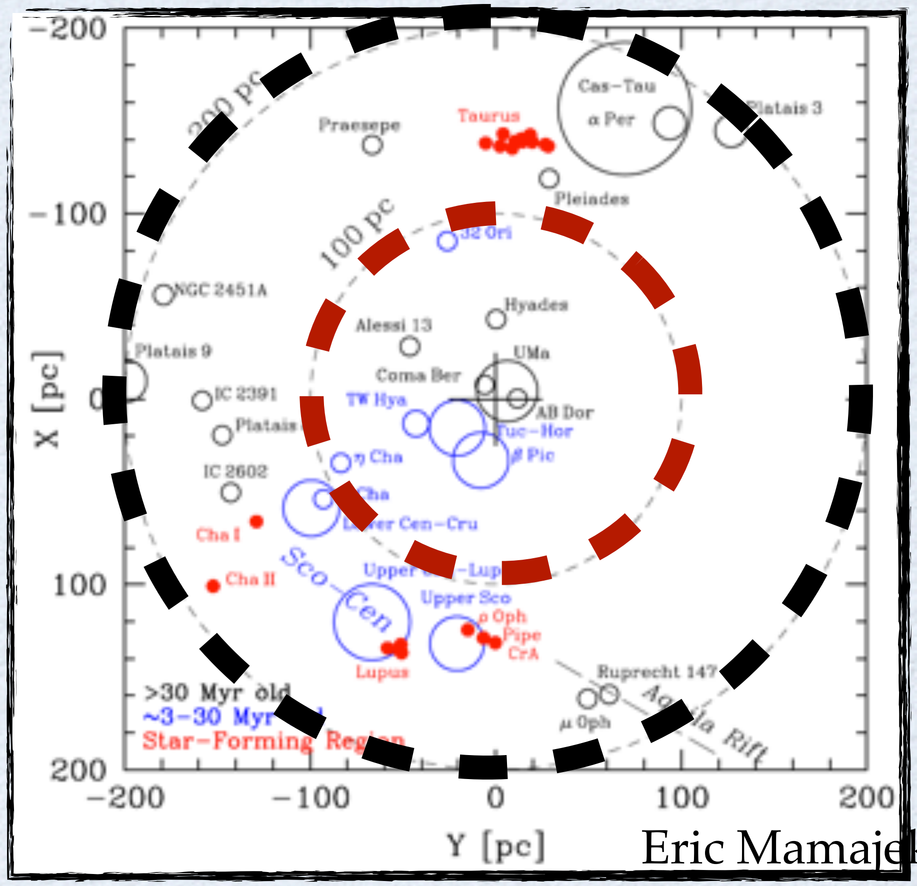
5Myr

10Myr

20Myr

Next steps

- Currently the main limitation of the BANYAN tool is the number of well known associations (good parallaxes).
- Waiting for parallax to model the other associations farther than 100 pc.
- Magnetic field measurements
  - Zeeman splitting effects
  - SPIRou/CFHT (first light 2017)
    - spectro-polarimeter, R=70,000; ƛ=0.98-2.35 microns
- GRACES: 270m fiber between Gemini-North and ESPaDOnS-CFHT ->RV



For more information, see our poster