A 5D map of the nearest clusters

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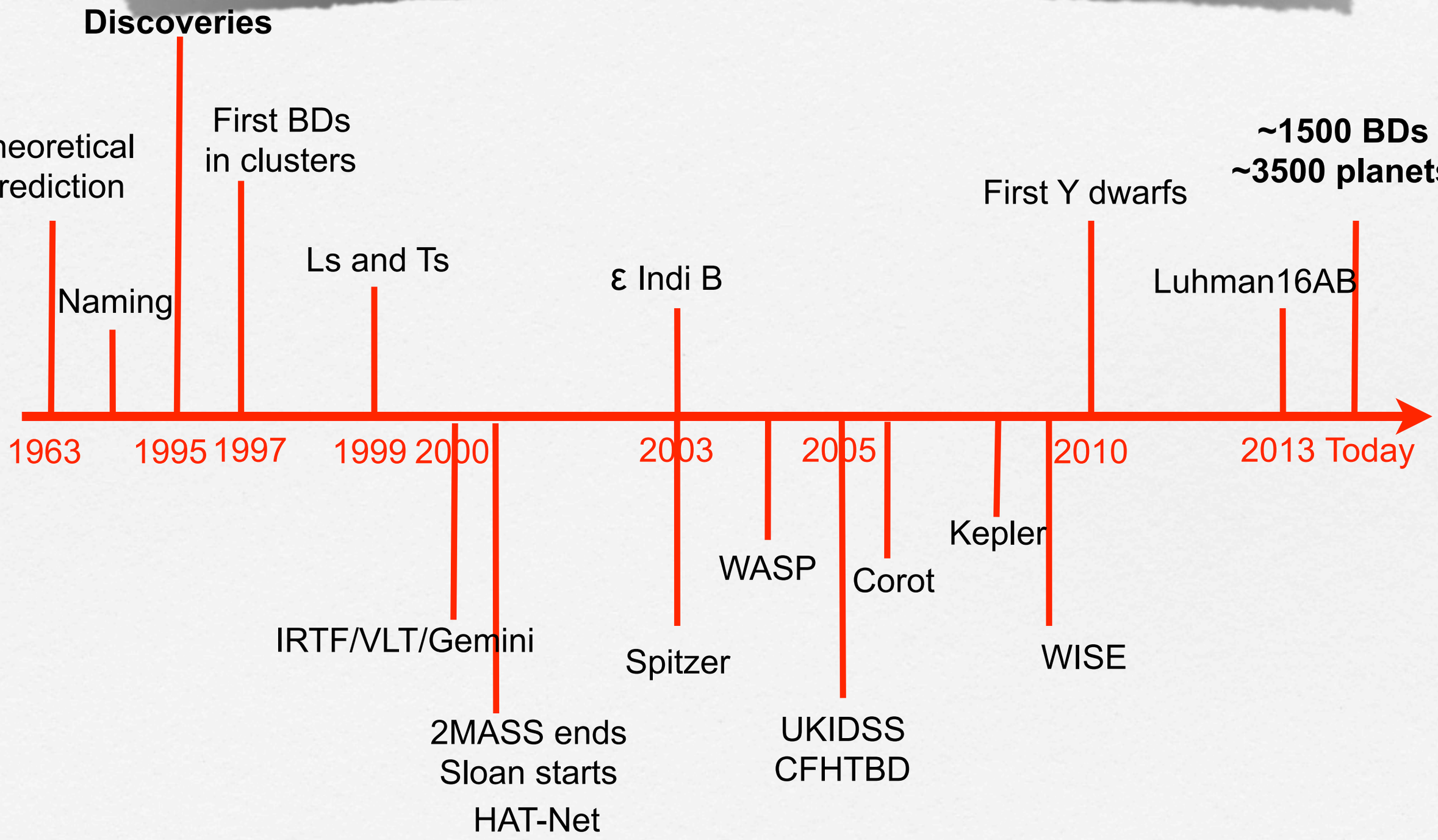
Seminar @ Brno, CZ

Friday 10 May 2019

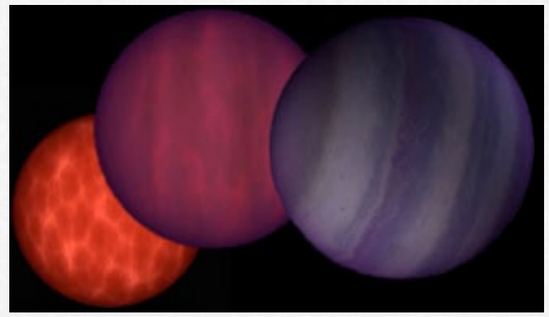
Part 1

Brown dwarfs & Exoplanets

A short history of BDs and Planets

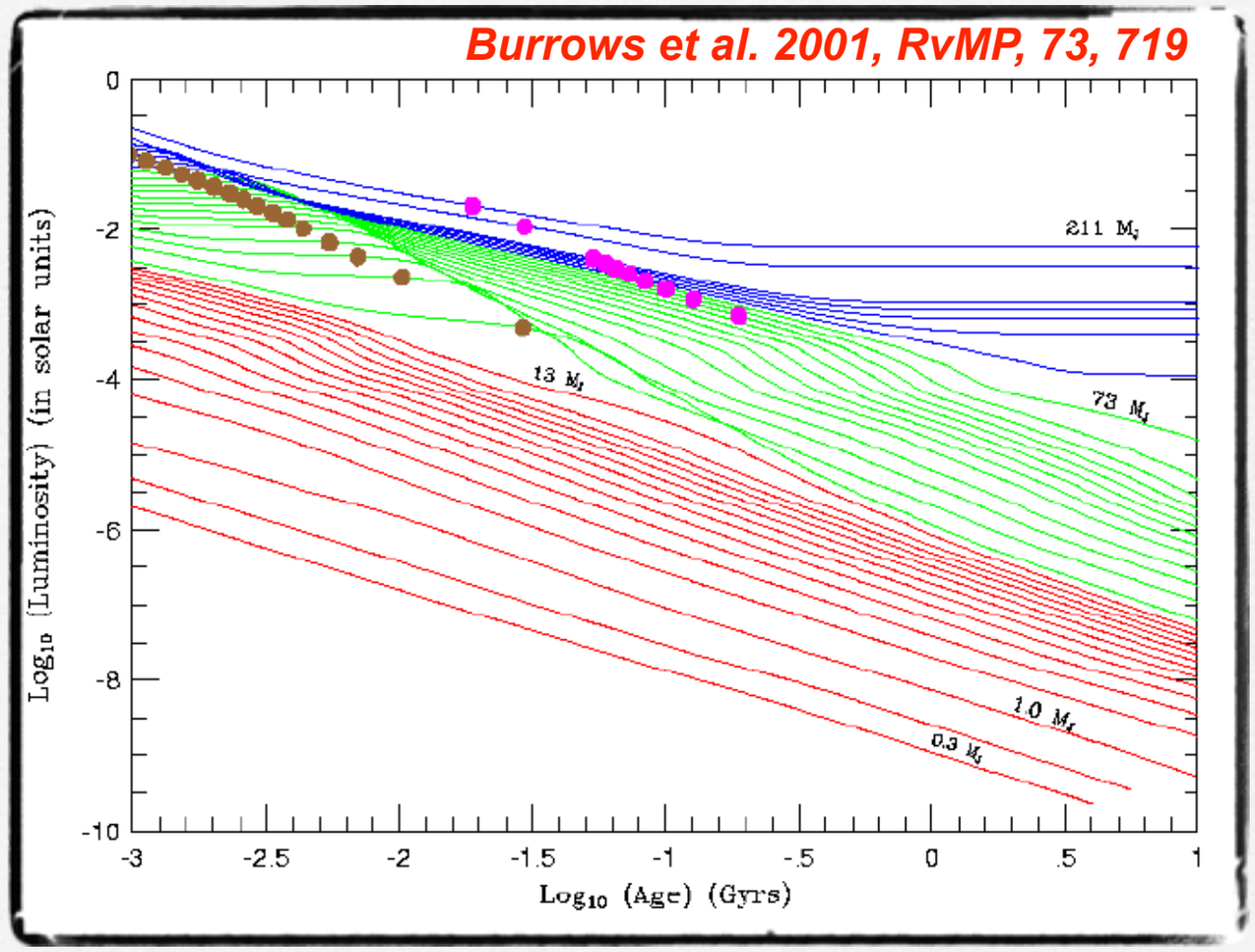


Brown Dwarfs (BDs)



1) Definition:

a) Objects with substellar masses unable to burn hydrogen in their cores
b) Masses below 0.075 $M_{\odot}$
c) Temperatures below ~2000K
d) Spectral types M, L, T y Y
e) Link between low-mass stars and planetary-mass objects



2) Observations:

a) The nearest: Luhman16AB @ 2 pc
b) ~1500 BDs known in the field
c) Many BDs in clusters > M6

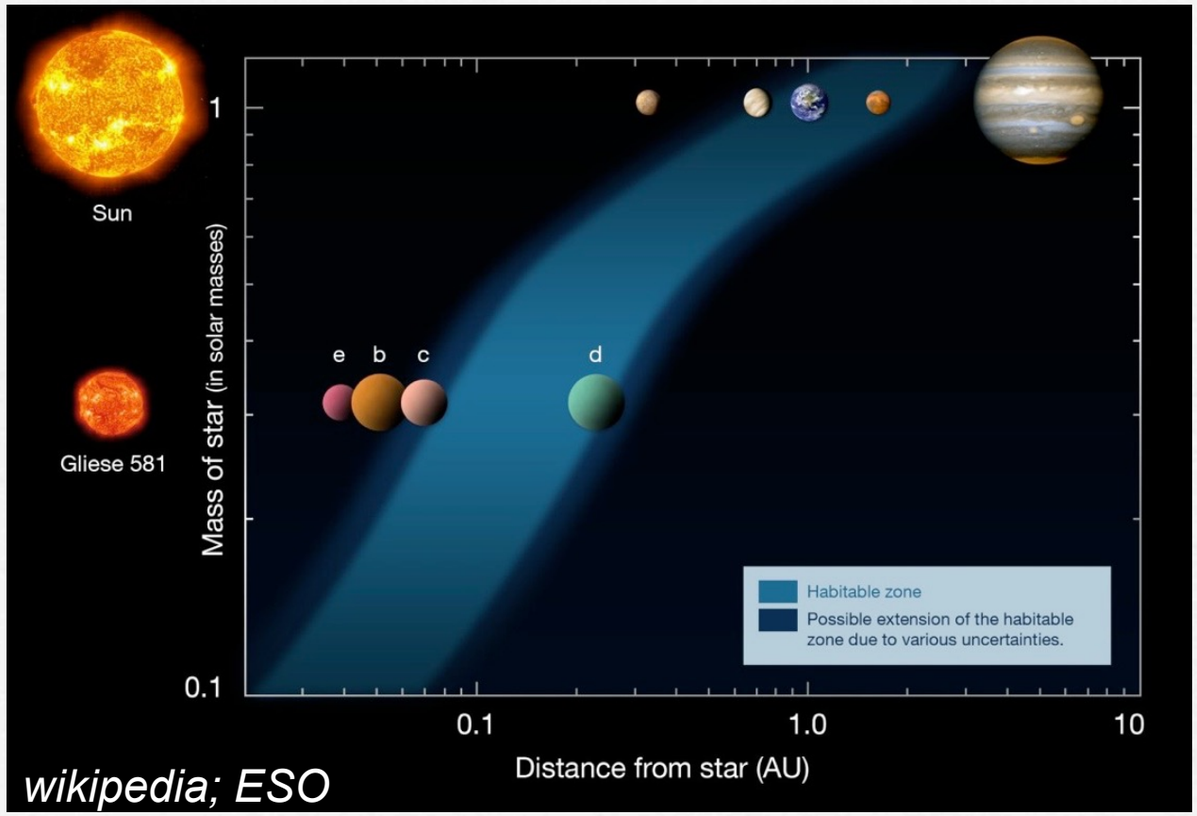
3) Open questions:

a) What is the closest brown dwarf?
b) How do physical properties of brown dwarf change with age?
c) Is there a mass limit for the formation of isolated BDs and planetary-mass objects?

Exoplanets

1) Definition:

a) Planet orbiting a star different from our Sun, outside our Solar system
b) 51 Peg b, first RV planet
c) Temperatures below ~2000K



2) Detection methods:

a) Radial velocity (RV)
b) Transits
c) Microlensing
d) Astrometry
e) Direct imaging, photometry

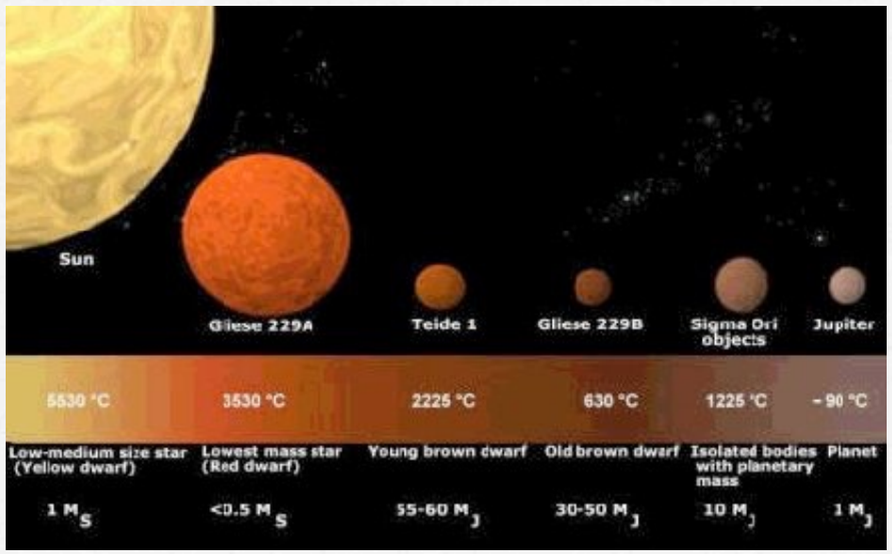
3) Open questions:

a) What is the frequency of multiple systems with planets?
b) How do planet properties evolve with time?
c) Do other Earths exist in the habitable zone?

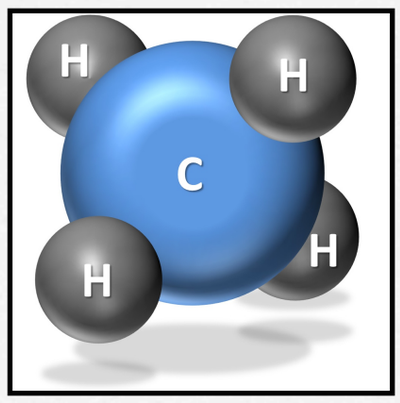
Brown Dwarfs and exoplanets

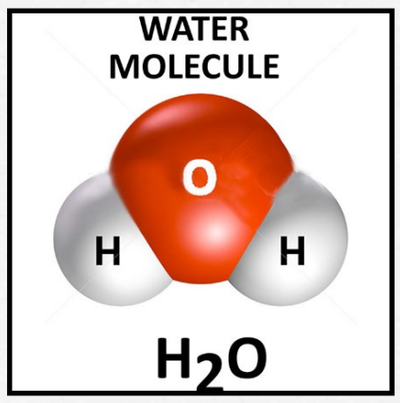
1) Temperatures

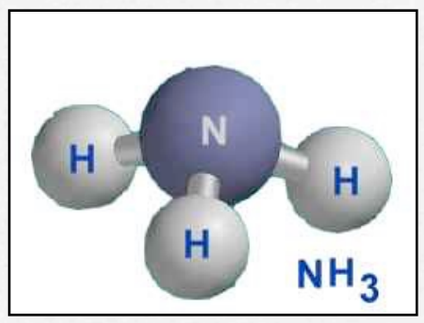
2) Radii



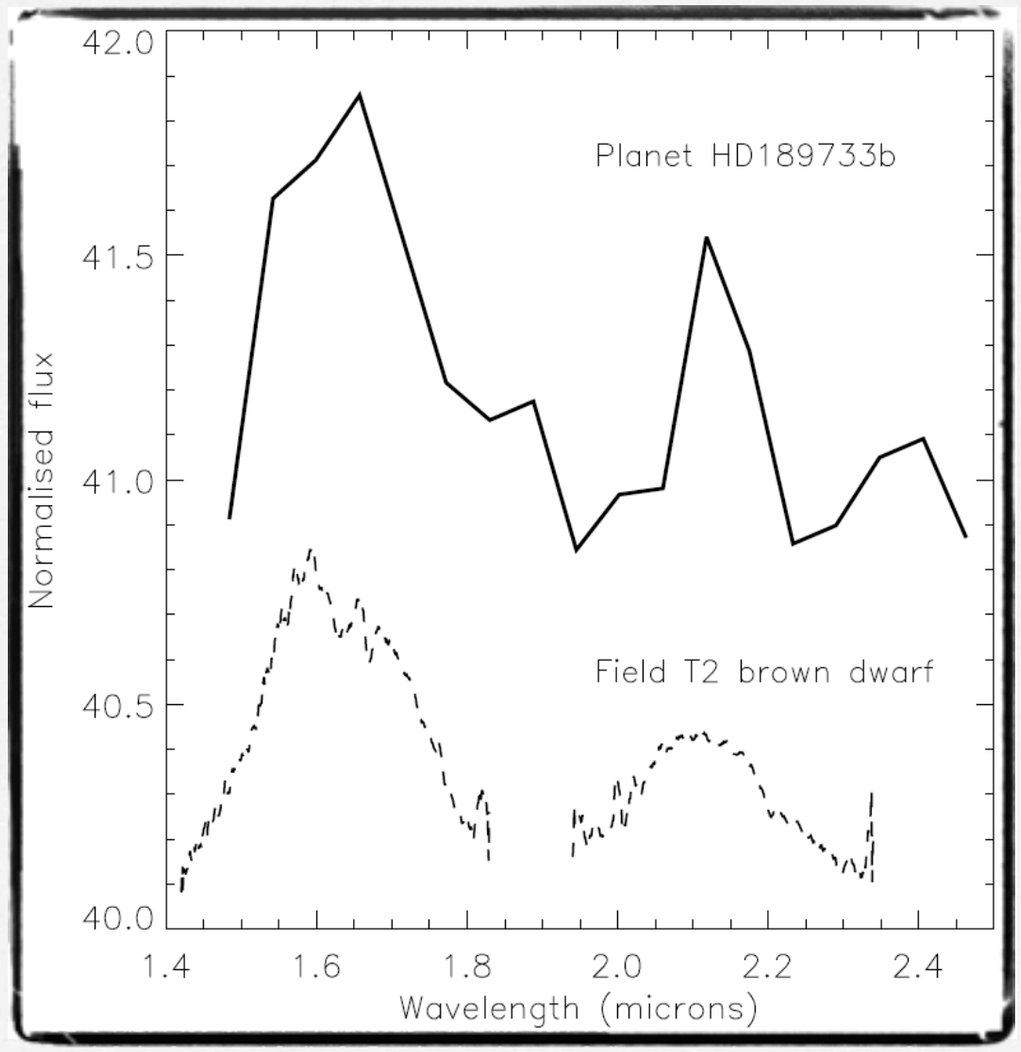
3) Composition







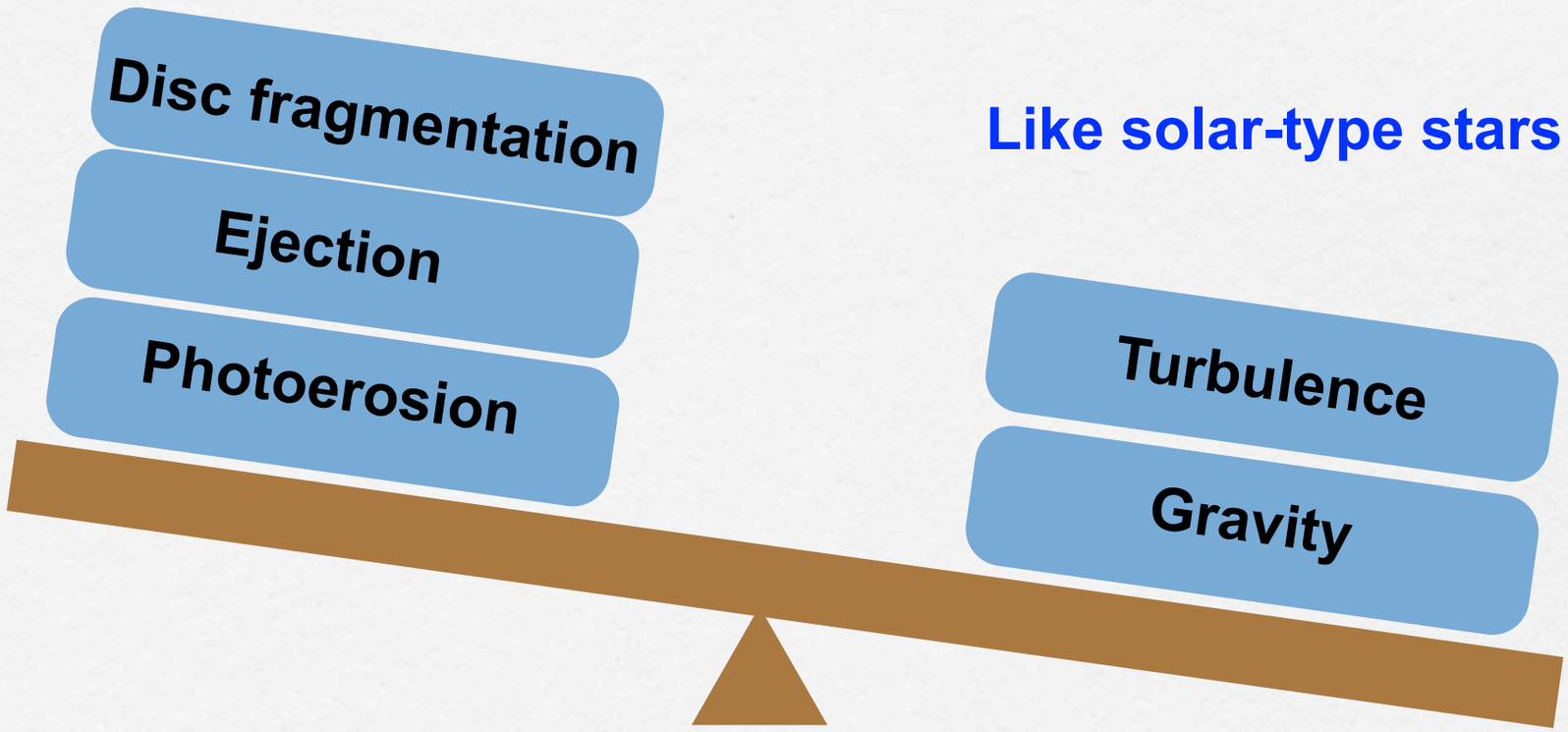
4) SEDs



Formation mechanisms

How do BDs fit in our vision of star formation?

Differences with stars



Like solar-type stars

Do BDs share the same formation mechanism as VLM stars?

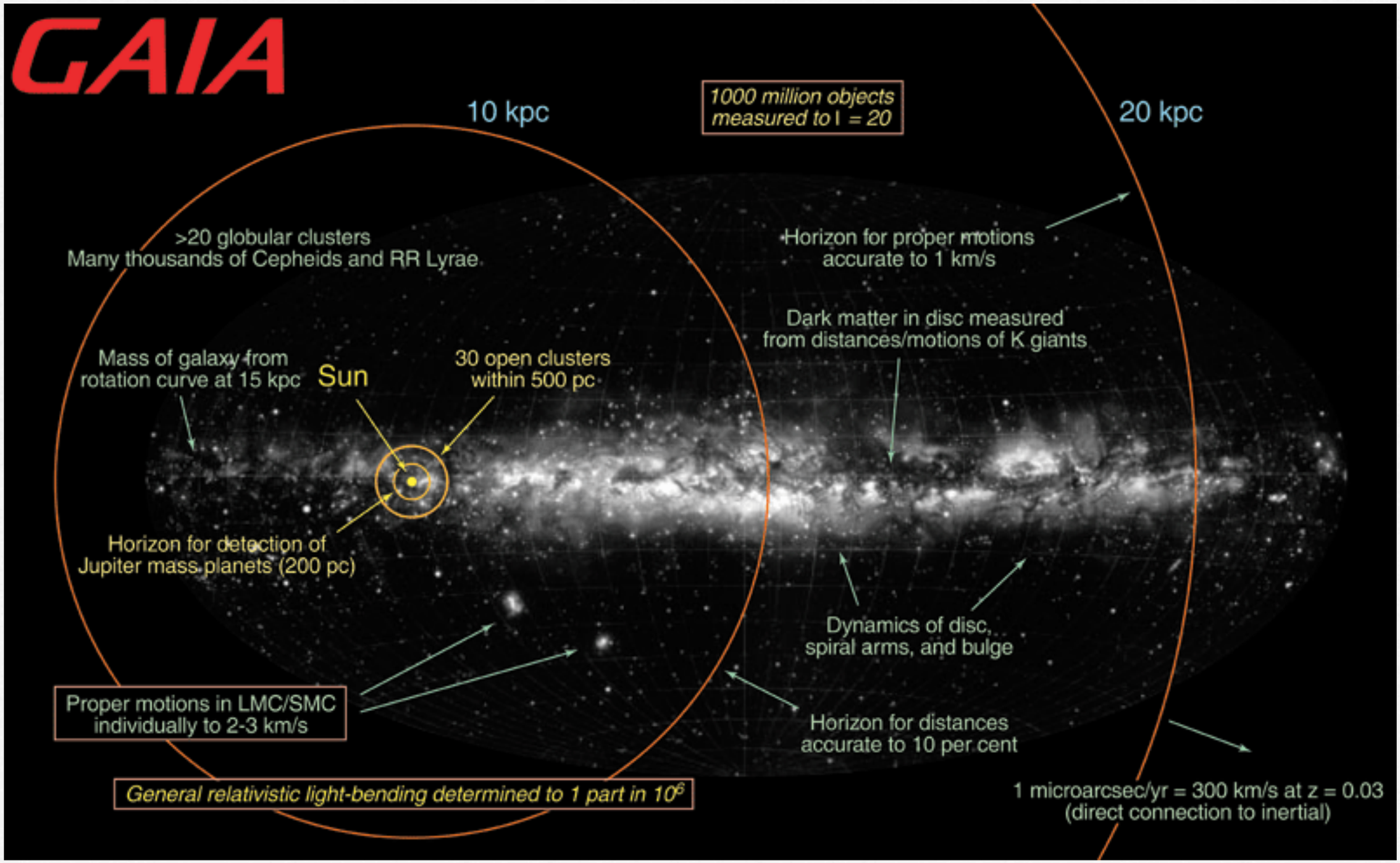
Part 2

Open clusters & *Gaia*

gaia

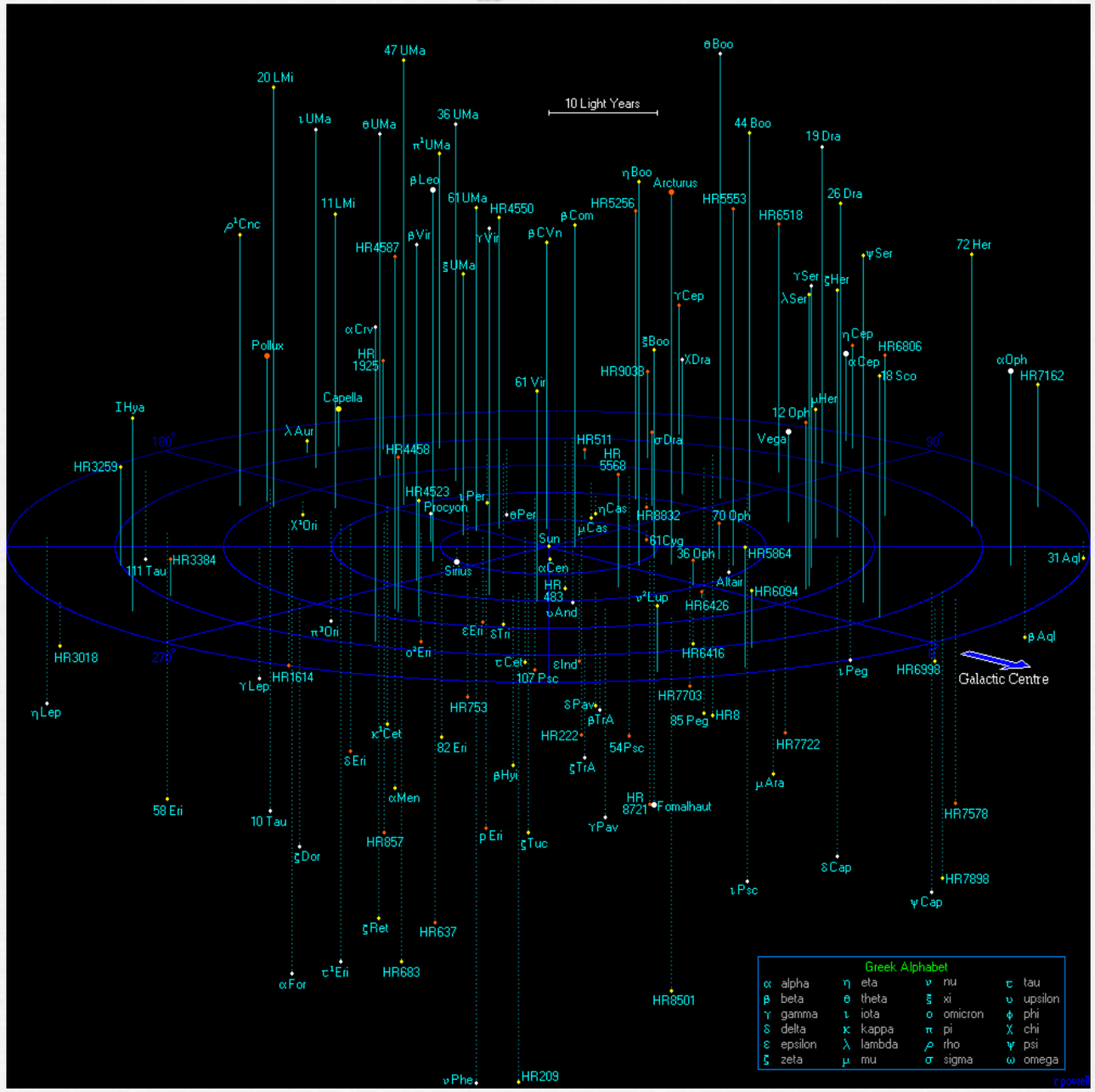
The *Gaia* mission

gaia



Lift-off of *Gaia*

Goal of the project



A 3D map of the nearest clusters from high-mass stars down brown dwarfs

The method

With the availability of the full 6D positional and velocity information from *Gaia*, we are in a position to examine membership based solely on spatial and kinematic criteria.

Perryman et al. (1998)

The method also works when the velocity information (=RV) is missing, which is the case for *Gaia* sources with G >~ 13 mag

Include

1) **assign preliminary membership**
2) **determine preliminary center of mass**
3) **examine motion + residuals for each object**
4) **refine membership criteria**

+ Statistical treatment of the *Gaia* parallaxes *Luri et al. (2018)*

+ Photometry from large-scale surveys: 2MASS, SDSS, WISE, …

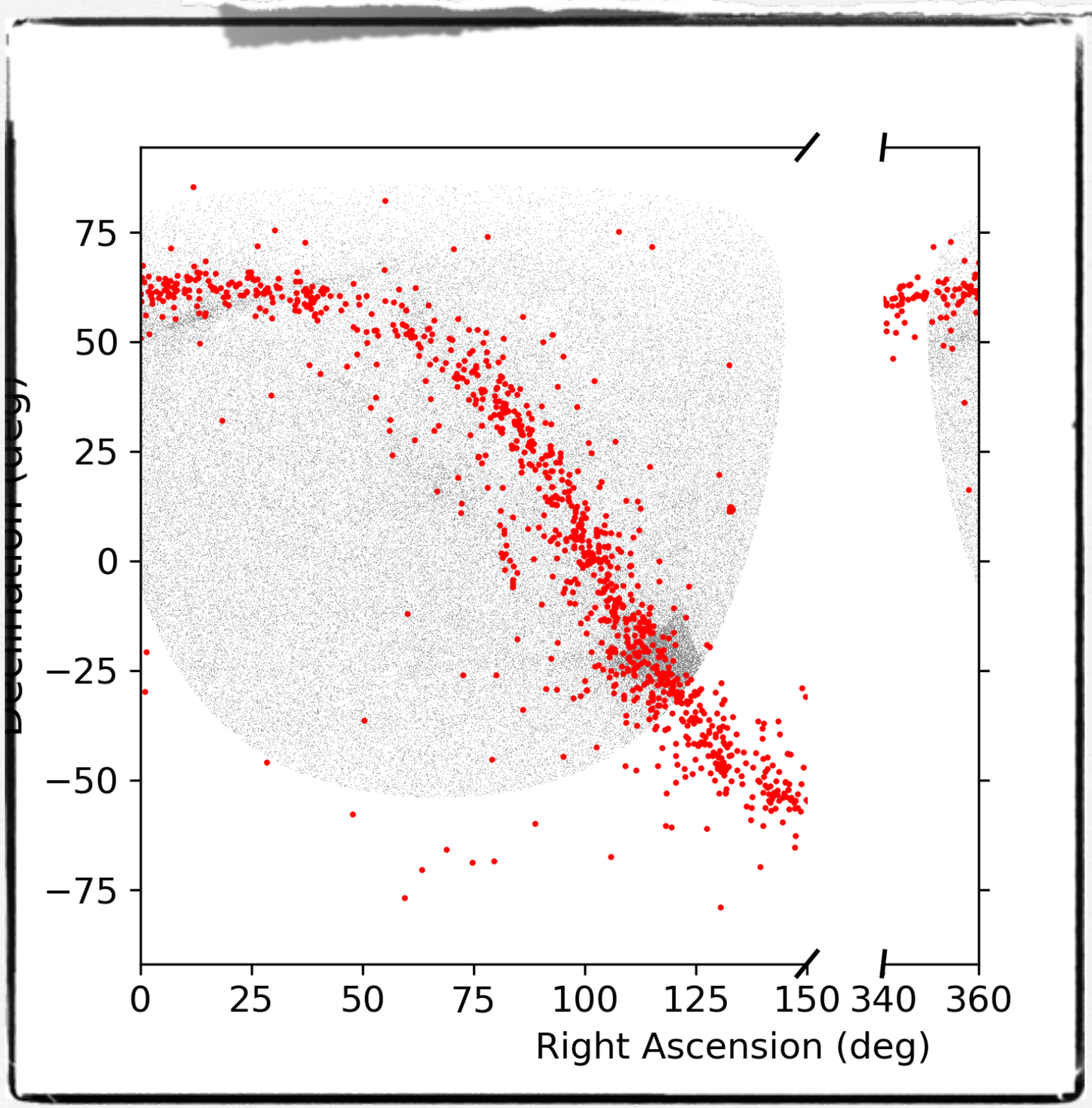
The Hyades

The Hyades. Copyright Jerry Lodriguss/AstroPix.com. Used with permission.

The Hyades cluster

- ➔ **Names:** Hyades, M25; Collinder 25; Caldwell 40
- ➔ **d = 46.34 pc** with tidal radius of ~10 pc
- ➔ Mean **proper motion** in the **74-140 mas/yr** range
- ➔ **Mean RV of ~40 km/s**
- ➔ **Age** of about **650+/-100 Myr from various methods**
- ➔ About **850 known members** pre-Gaia
- ➔ 10 brown dwarfs confirmed spectroscopically
- ➔ **Metallicity** close to solar
- ➔ Many pencil-beam and wide-scale surveys

Main parameters of the cluster



Distance: 47.03 pc

Mean velocity: 46.34 km/s

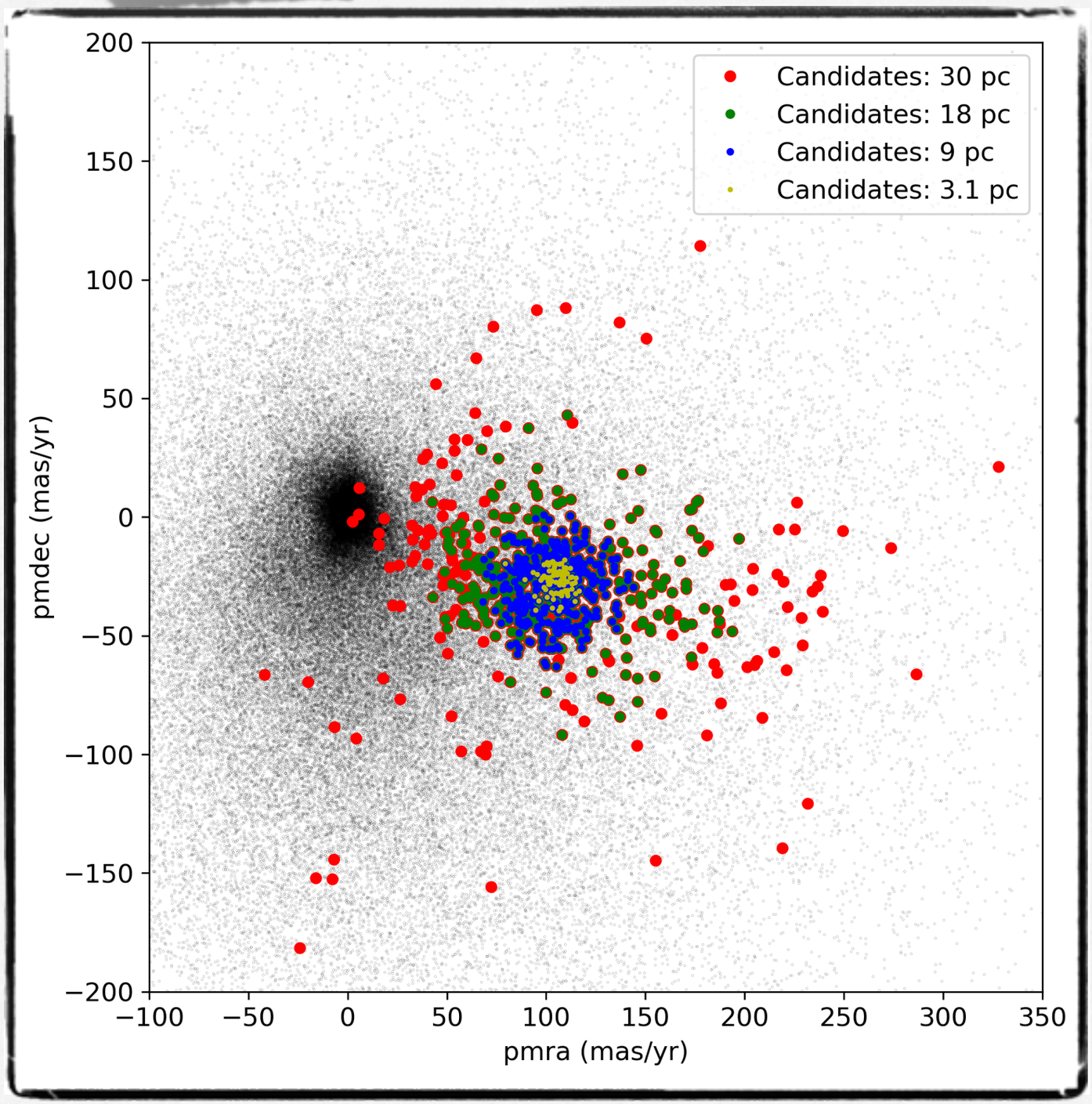
Barycenter: coordinates

-43.83, 0.42, -17.05 pc

Barycenter: velocities

-42.14, -19.26, -1.12 km/s

The Hyades seen by *Gaia* DR2: PM



All sources in 70 degrees

Gaia selection

Within 3.1 pc

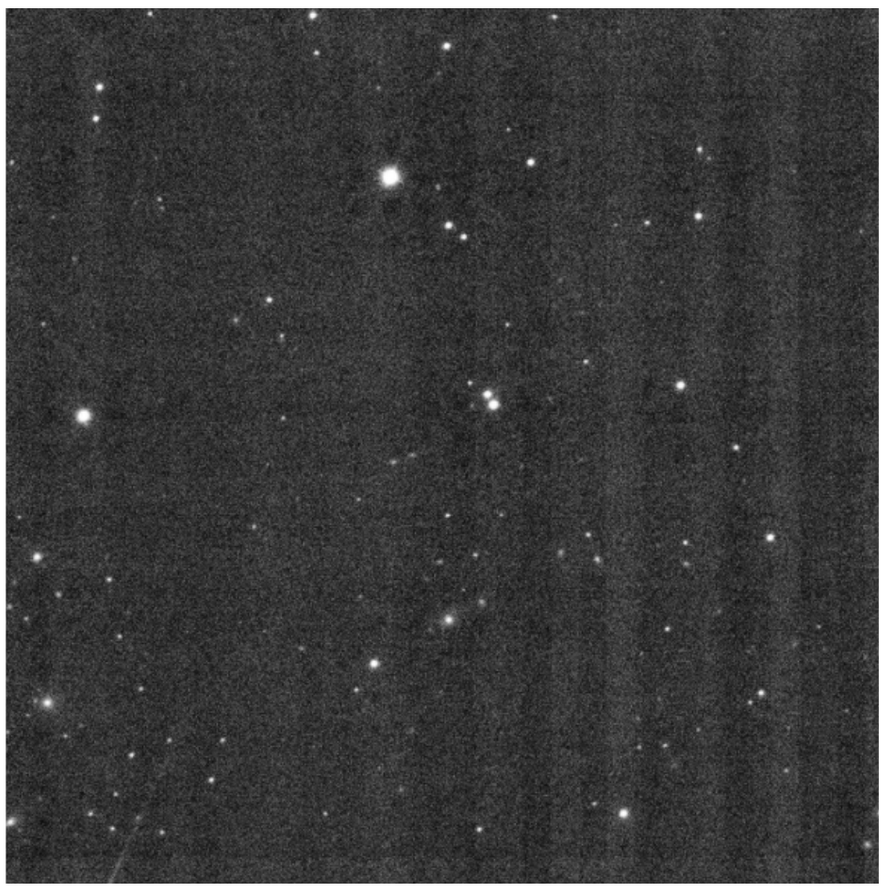
Within 9 pc

Within 18 pc

Within 30 pc

Ground-based parallaxes

Observations of 8 Hyades L+T dwarfs with the IO:I infrared camera on the Liverpool 2-m robotic telescope in La Palma.



Field-of-view is 6.3 arcmin squared

Pixel scale is 0.18 arcsec

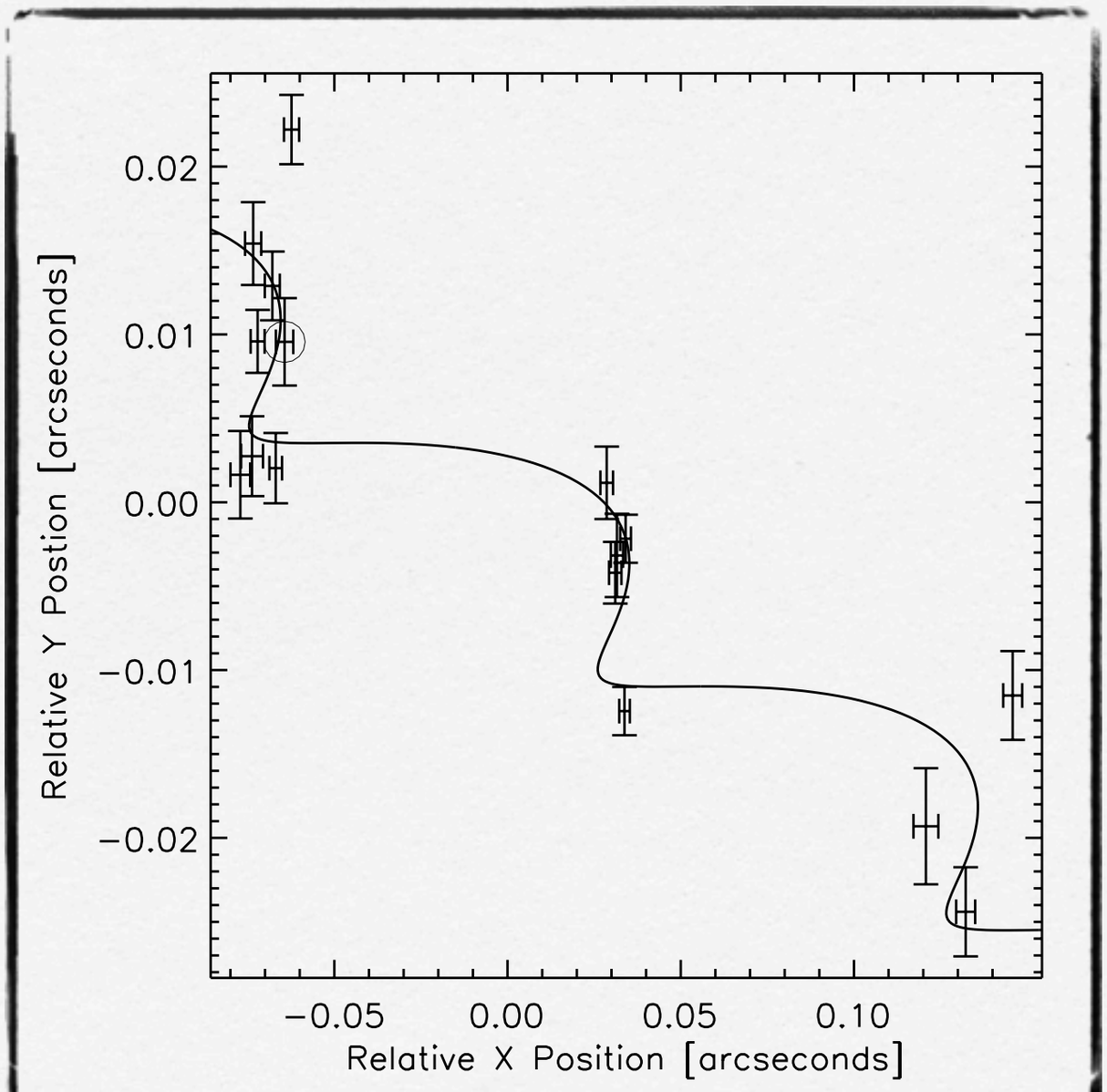
Imaging in *H*-band

9-point dither of 10s repeated 7 times

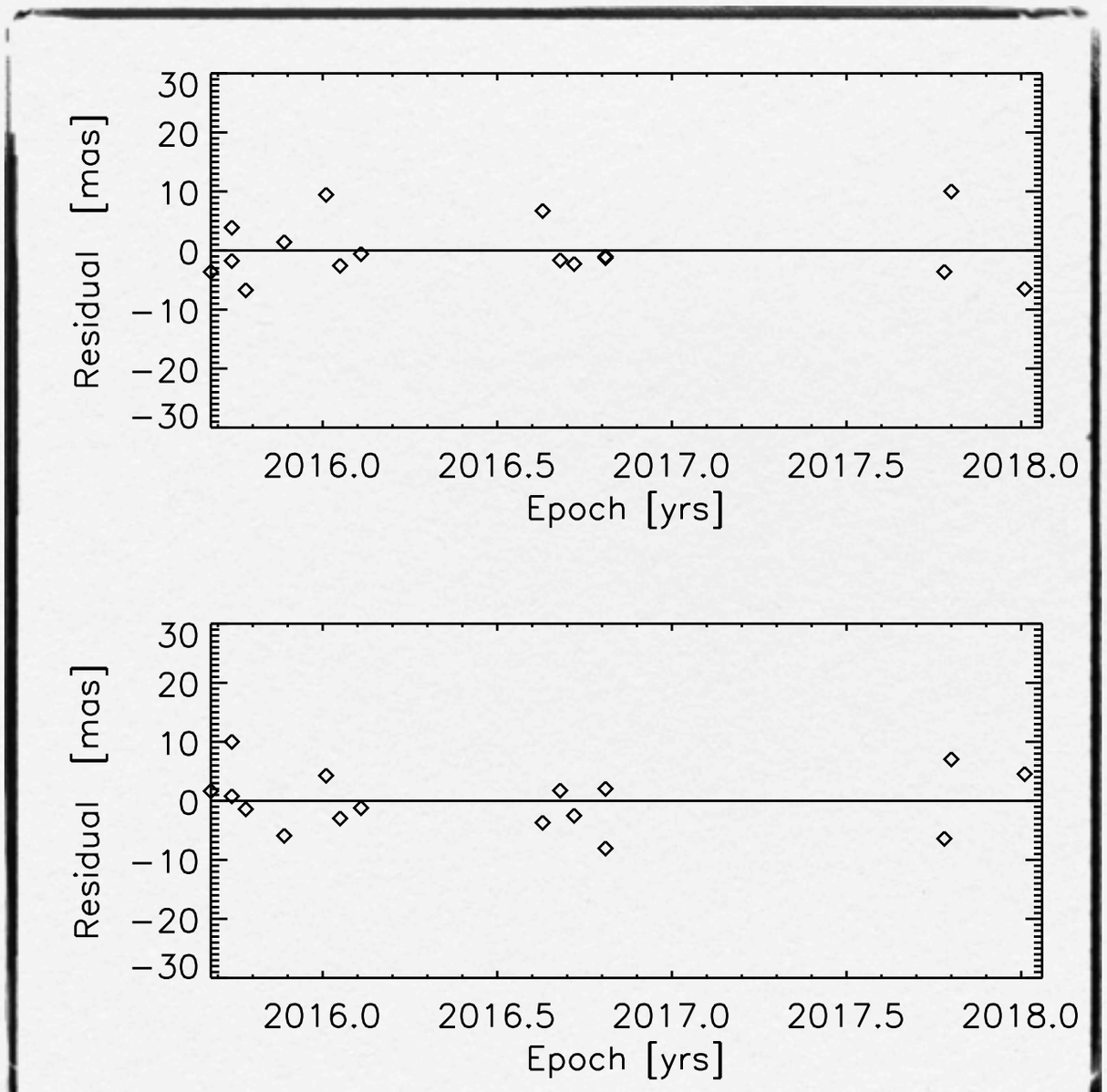
About 12 epochs obtained per object between August 2015 and January 2018

Ground-based parallaxes: results

Relative positions => Trig. Plx



Residuals vs time

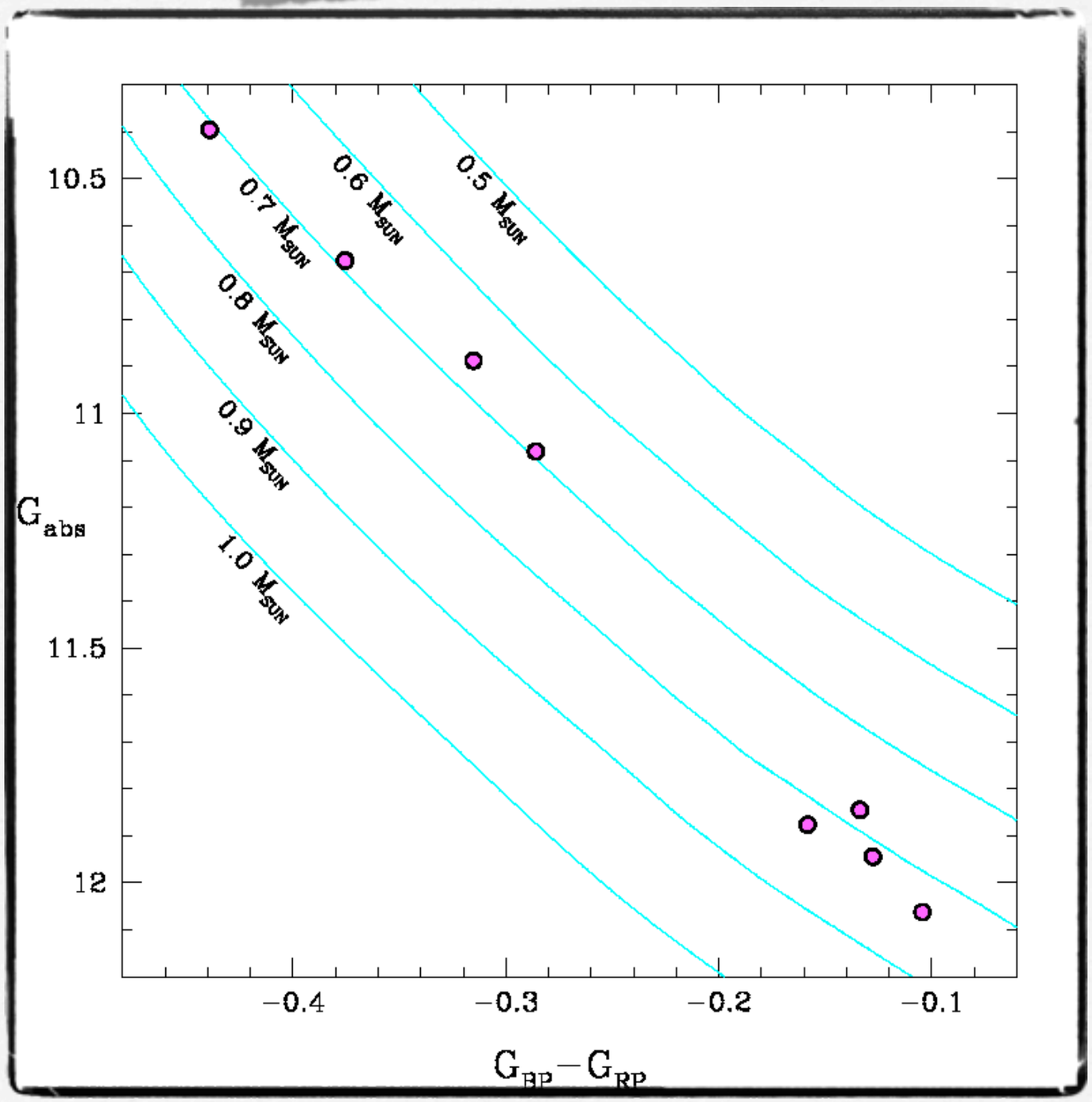


Ground-based parallaxes: table

Table 1. *Top:* Hyades late-M and early-L confirmed spectroscopically with *Gaia* proper motion and distances. Note: Hya05 (M3) and Hya07 (M5) are not listed below because they were rejected as spectroscopic members of the Hyades based on their optical spectra (Lodieu et al. 2014b). *Bottom:* Ground-based proper motions and parallaxes derived from our astrometric follow-up with the IO:I instrument on the Liverpool telescope. Spectral types are derived from optical spectra (Lodieu et al. 2014b; Martín et al. 2018).

Name	RA	dec	SpT	SourceID	Plx	pmRA	pmDEC	*H*
	hh:mm:ss.ss	dd:′:″			mas	mas/yr	mas/yr	mag
Hya01	04:20:24.50	+23:56:13.0	M8.5	1490897609326484 48	22.6480 ±0.4575	130.178±0.876	−28.598±0.660	13.85
Hya03	04:10:24.01	+14:59:10.3	L0.5	3311691879984803072	17.3183±1.5853	107.981±2.747	−11.185±2.612	14.78
Hya04	04:42:18.59	+17:54:37.3	M9.5	3409343115420601728	—	—	—	14.97
Hya06	04:22:05.22	+13:58:47.3	M9.5	3310992904122021120	18.2032±0.9181	89.391±1.612	−17.657±1.307	14.81
Hya08	04:58:45.75	+12:12:34.1	L0.5	3295377360811741184	24.2448±0.9774	85.748±2.536	−16.008±1.265	14.55
Hya02	03:52:46.40	+21:12:32.8	L1.5	—	17.67±1.99	116.43±2.02	−26.90±1.51	14.81
Hya09	04:46:35.40	+14:51:26.0	L2.0	—	20.55±2.47	76.27±2.87	−17.69±1.48	15.29
Hya10	04:17:33.97	+14:30:15.4	L3.5	—	28.48±3.87	120.20±3.59	−12.912±5.50	15.43
Hya11	03:55:42.00	+22:57:01.0	L3.0	—	39.06±16.30	138.12±13.20	−19.44±8.95	15.05
Hya12	04:35:43.02	+13:23:44.8	L4.0	—	24.09±2.11	100.17±1.92	−15.13±1.96	15.77
HyaL5	04:18:35.00	+21:31:26.7	L5.0	—	25.79±2.91	141.53±2.65	−45.74±2.26	16.26
CFHT-Hy-20	04:30:38.80	+13:09:56.6	T2.0	—	30.75±3.01	140.31±2.94	−14.46±3.16	15.93
CFHT-Hy-21	04:35:43.02	+13:23:44.8	T1.0	—	33.49±12.70	82.13±9.81	−15.47±8.61	15.33

The Hyades: Age from WD



10 “classical” WDs (known)

3 out of 10 are binaries

von Hippel et al. (1998)

27 New WD candidates

Schilbach & Roeser (2012)

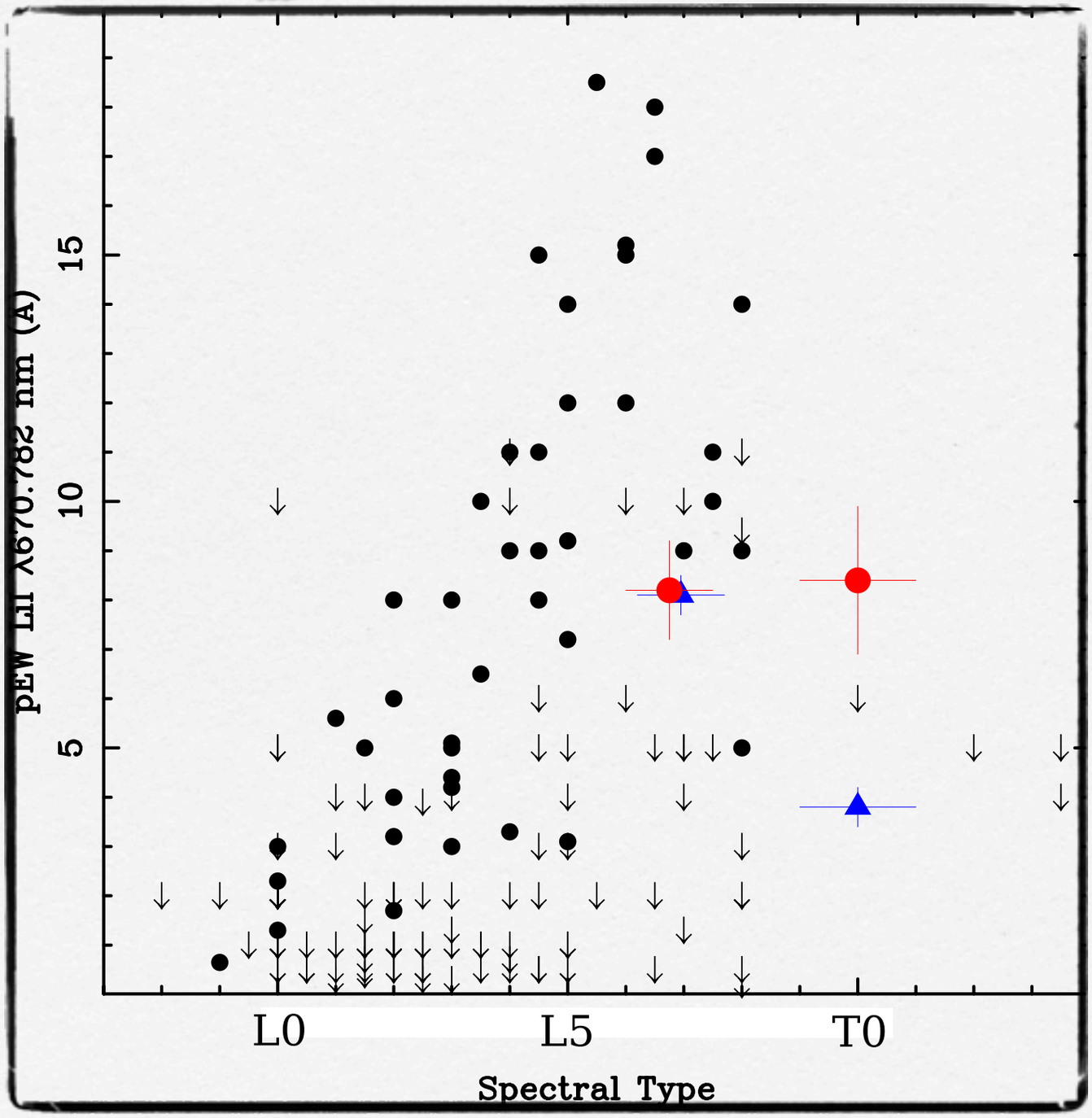
9 confirmed WDs

3 WD binaries confirmed

8 pure hydrogen single WDs for age determination

==> Age = 640 (+67-49) Myr

The Hyades: Age from LDB



Lithium detected in absorption in the two faintest L dwarfs: L3.5 + L4.0

Martin et al. (2018)

==> Age (LDB) = 650 +/-70 Myr

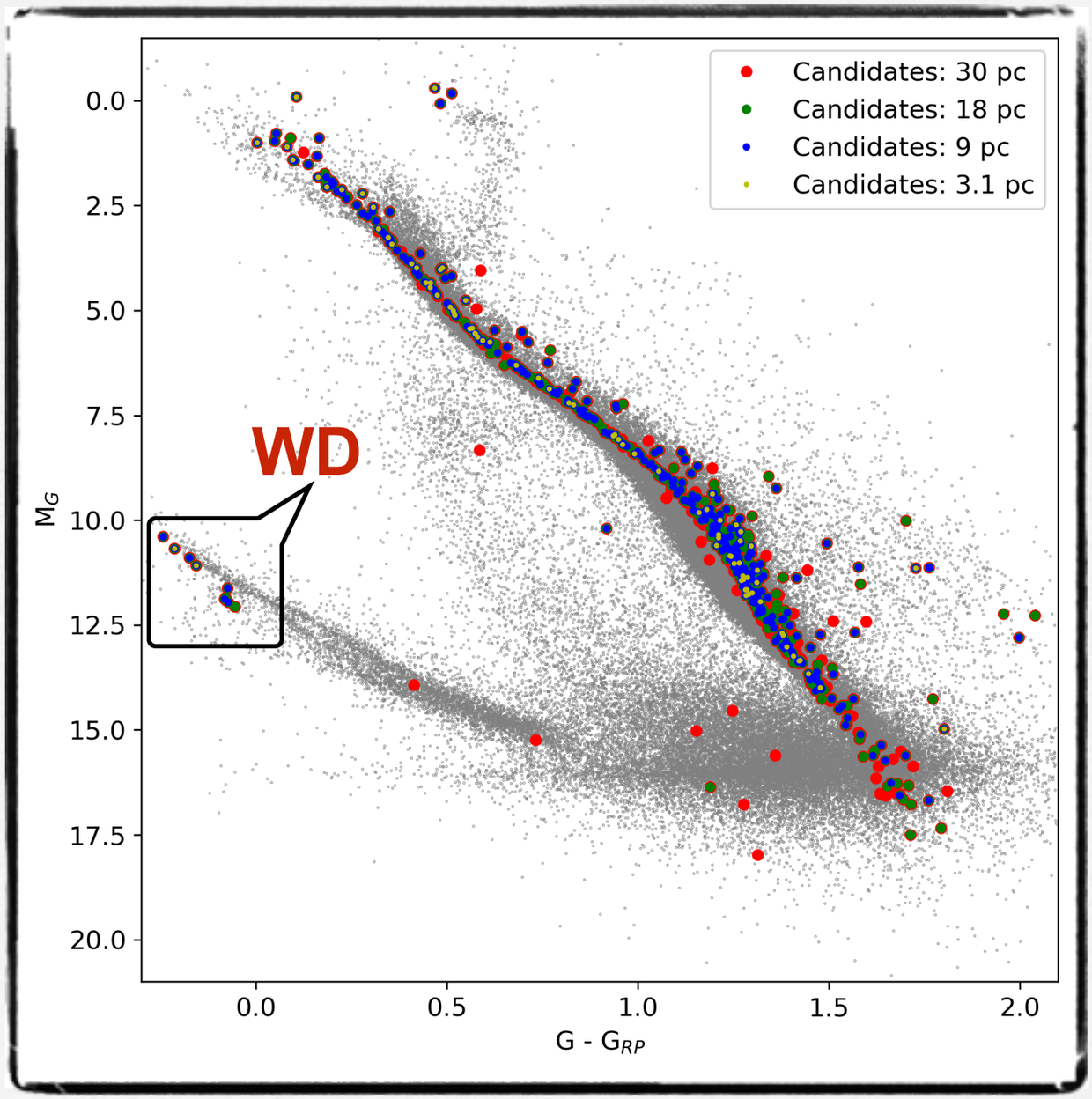
Lithium also in absorption in the faintest L5 member

Lodieu et al. (2018)

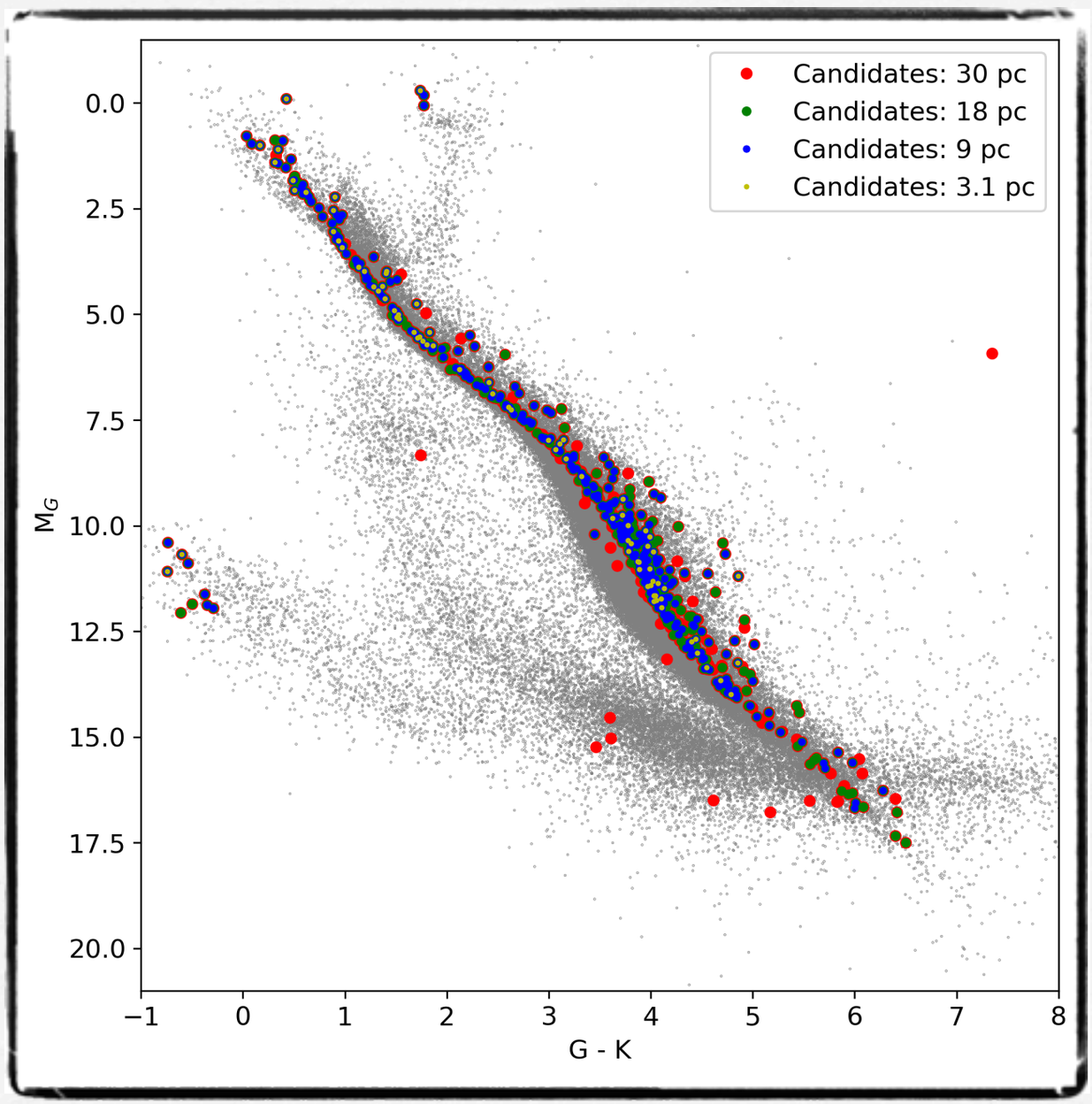
==> Age (LDB) = 580-775 Myr

Colour-magnitude diagrams

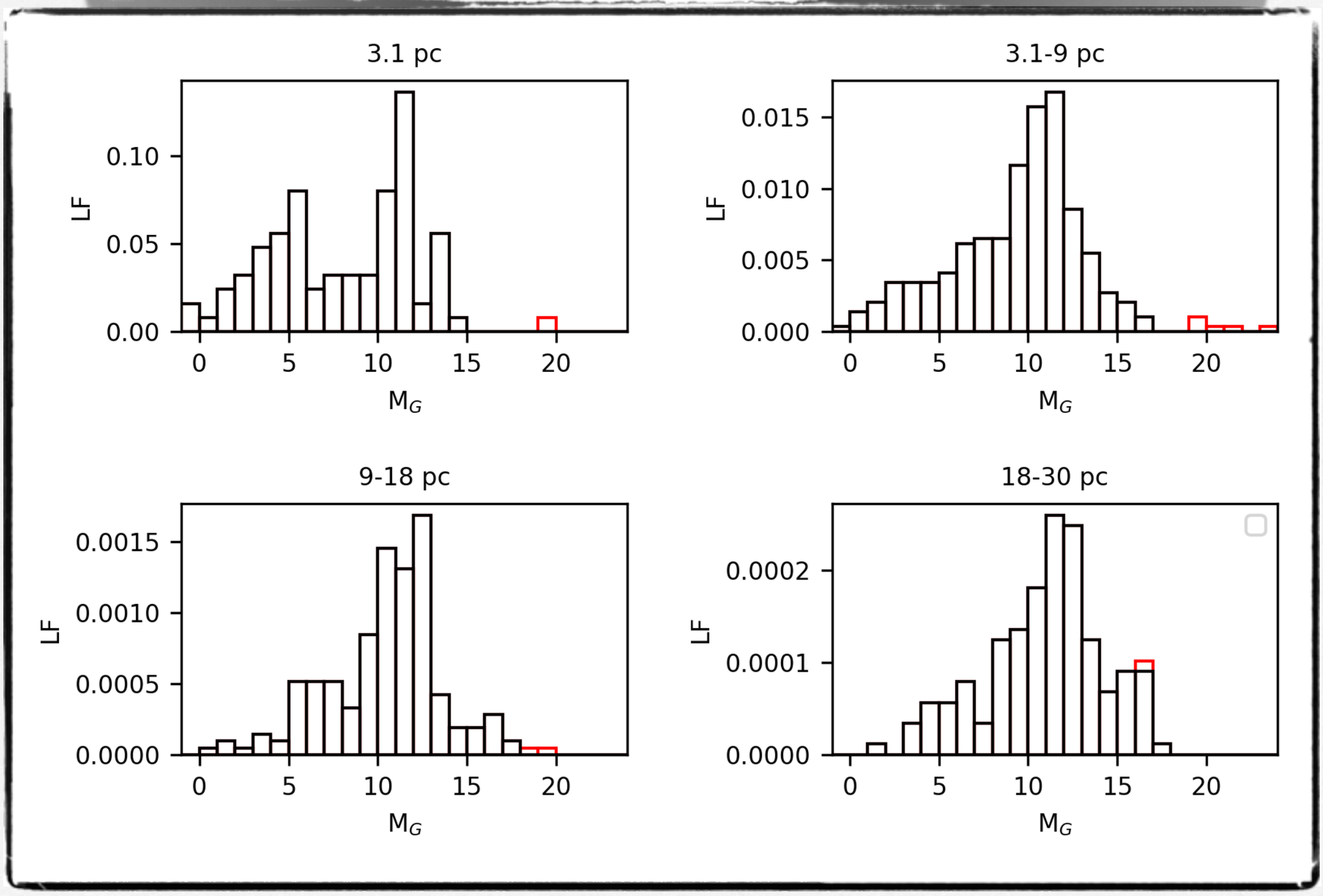
(G-Rp, M_G) CMD



(G-K, M_G) CMD

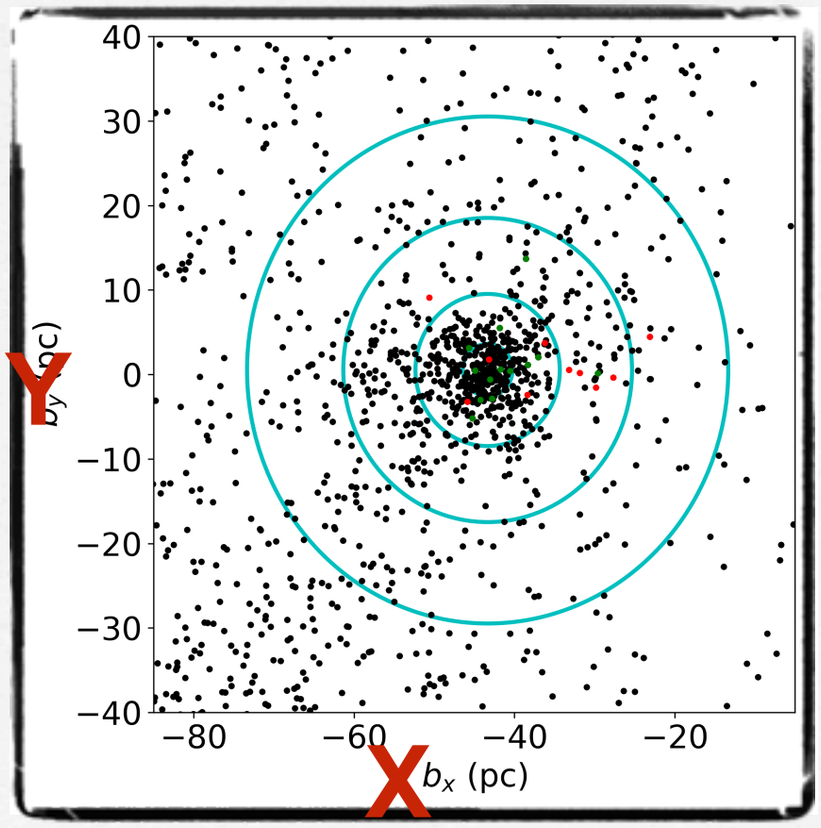


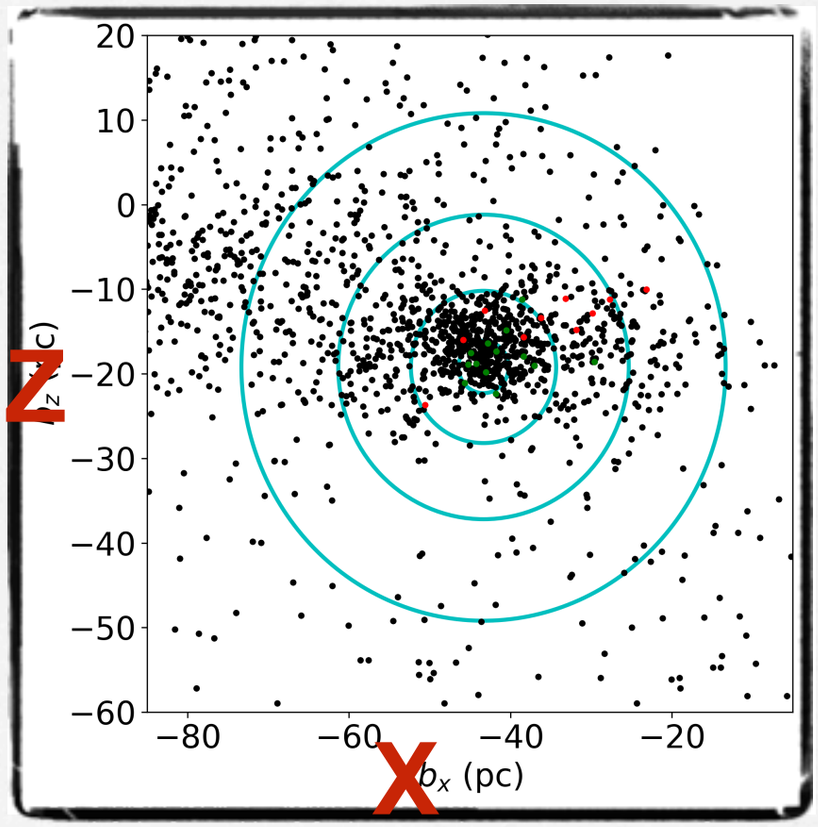
The luminosity function

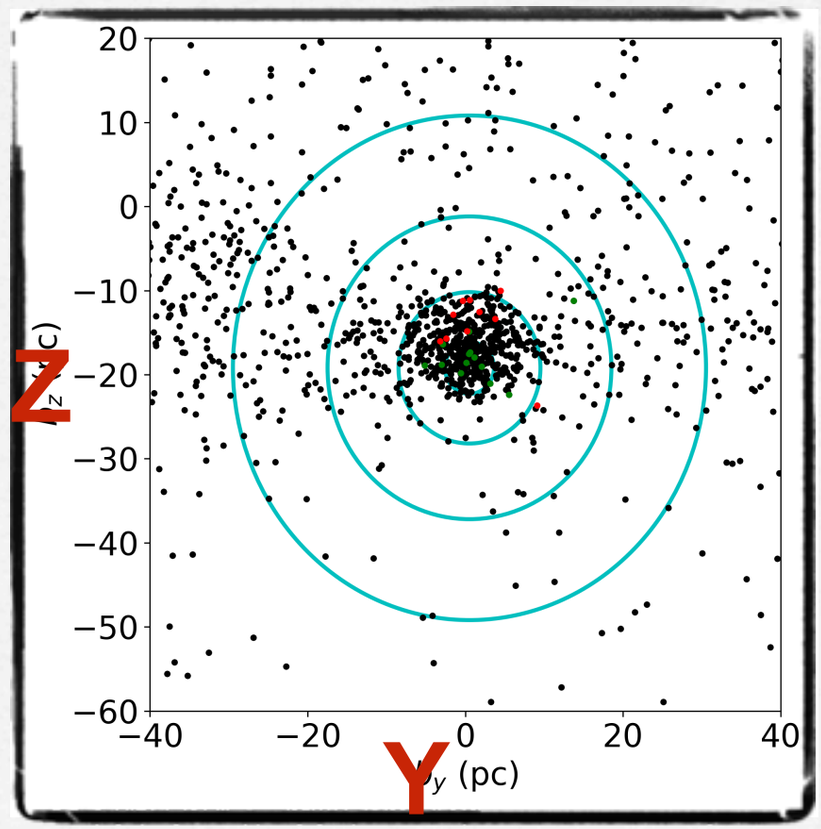


Distribution in space

Galactic coordinates in 3D space for *Gaia* members and 10 brown dwarfs with 4 annuli drawn in cyan: 3.1, 9, 18, and 30 pc

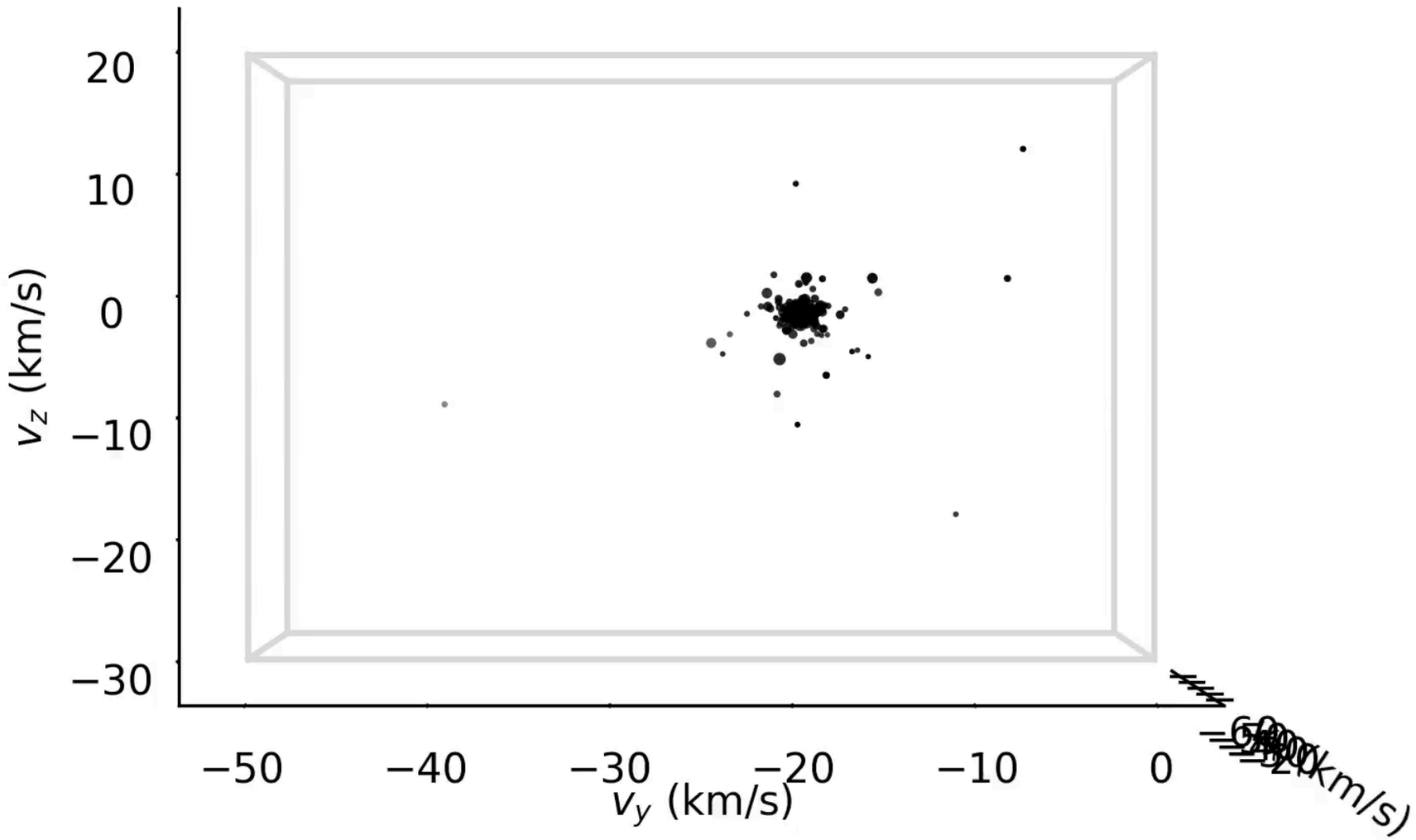






3D velocities

281 Hyades member with *Gaia* RV with G=5.6-13.6 mag



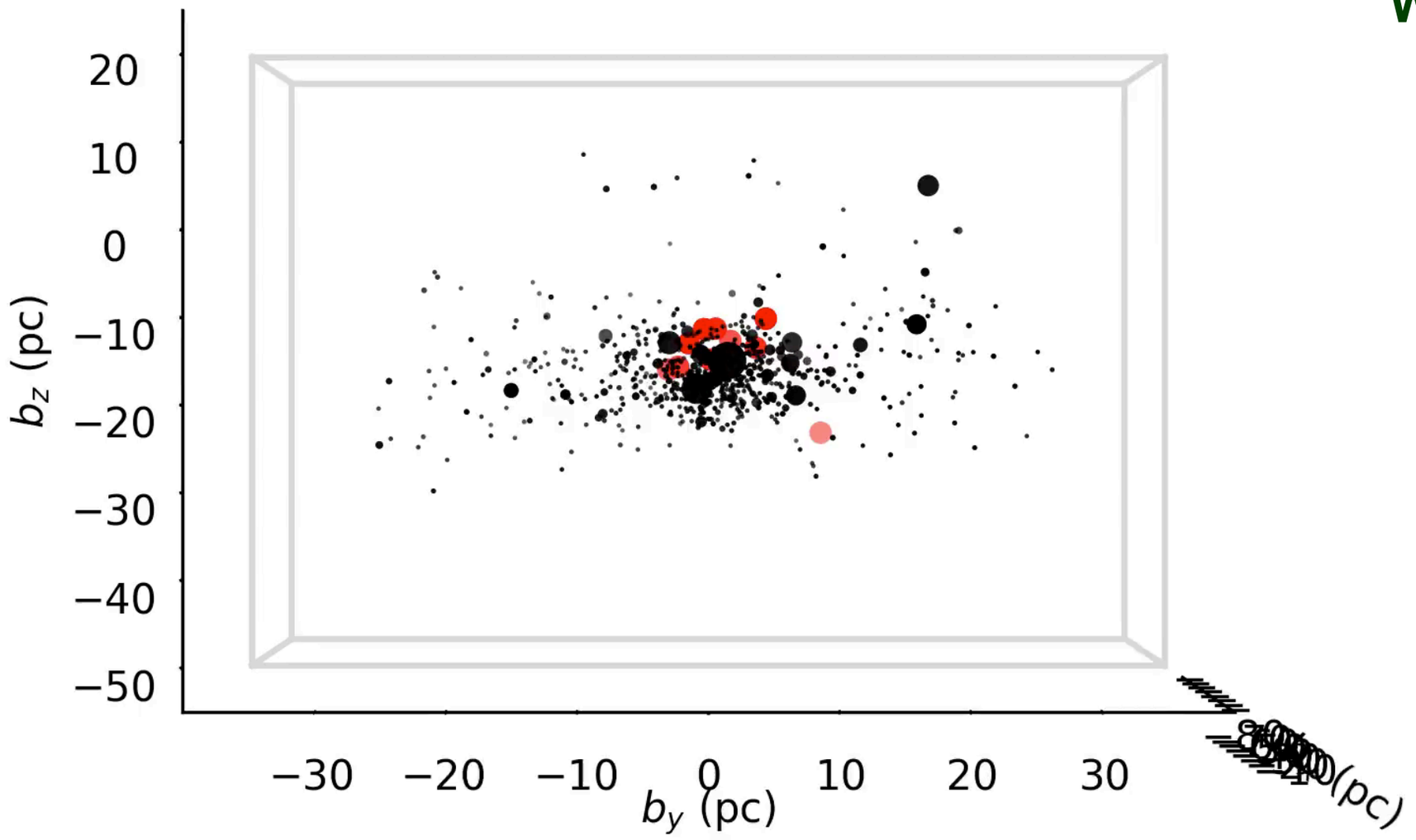
Movie: travelling in the Hyades

Size of the black symbols represent masses

Stars

BDs

WDs



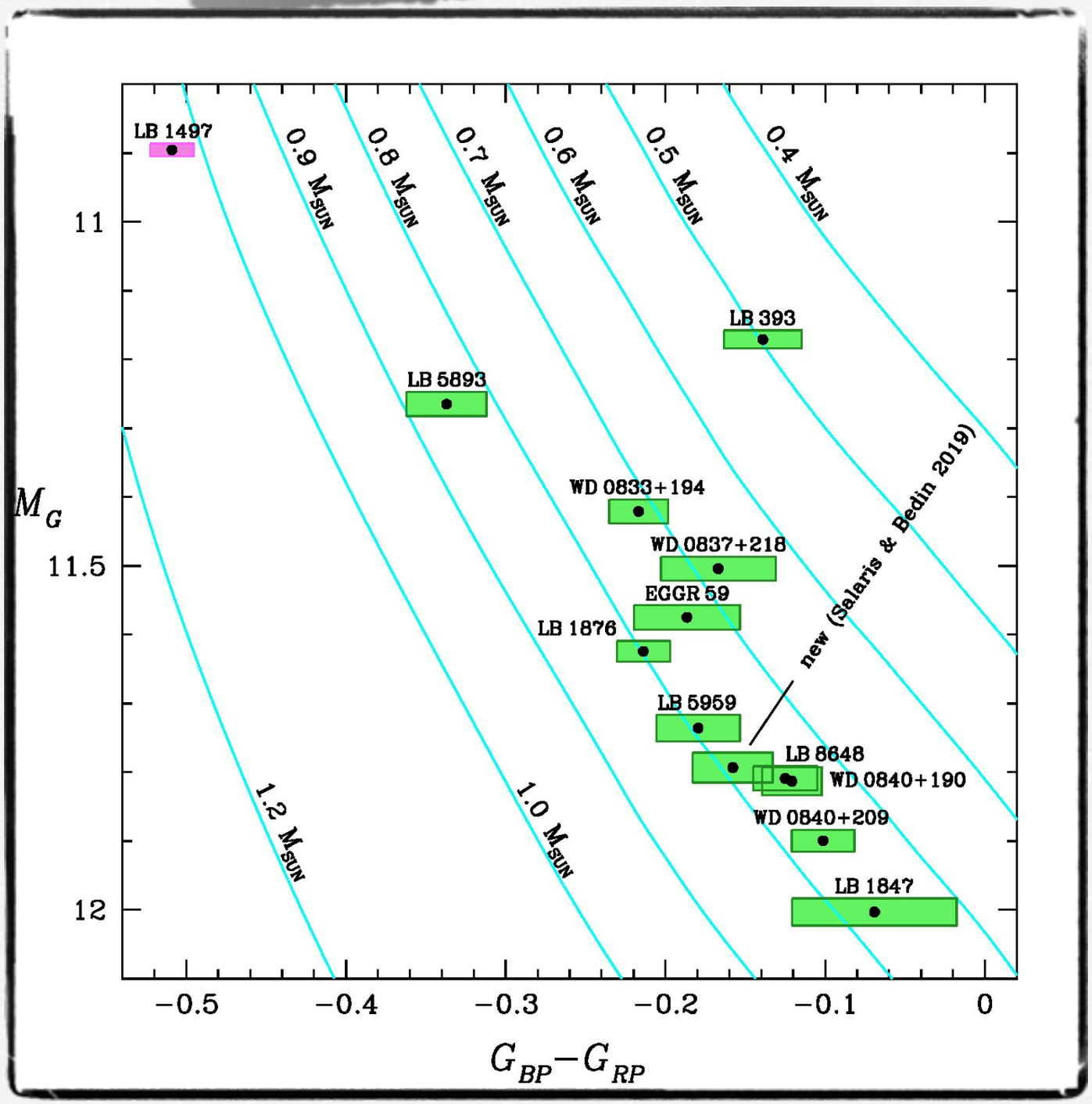
Lodieu et al. (2019, A&A, 623, 35)

Praesepe

The Praesepe cluster

- ➔ **Names:** Praesepe
- ➔ **d ~ 180 pc** with tidal radius of ~10 pc
- ➔ Mean **proper motion** in the **32 mas/yr** range
- ➔ **Mean RV of ~36 km/s**
- ➔ **Age** of about **590-660 Myr from various methods**
- ➔ About **1100 known members** pre-Gaia
- ➔ No brown dwarfs confirmed spectroscopically yet
- ➔ **Metallicity** close to solar
- ➔ Many pencil-beam and wide-scale surveys

Praesepe: Age from WDs



11 known pre-Gaia WD
1 new WD
5 WDs within tidal radius

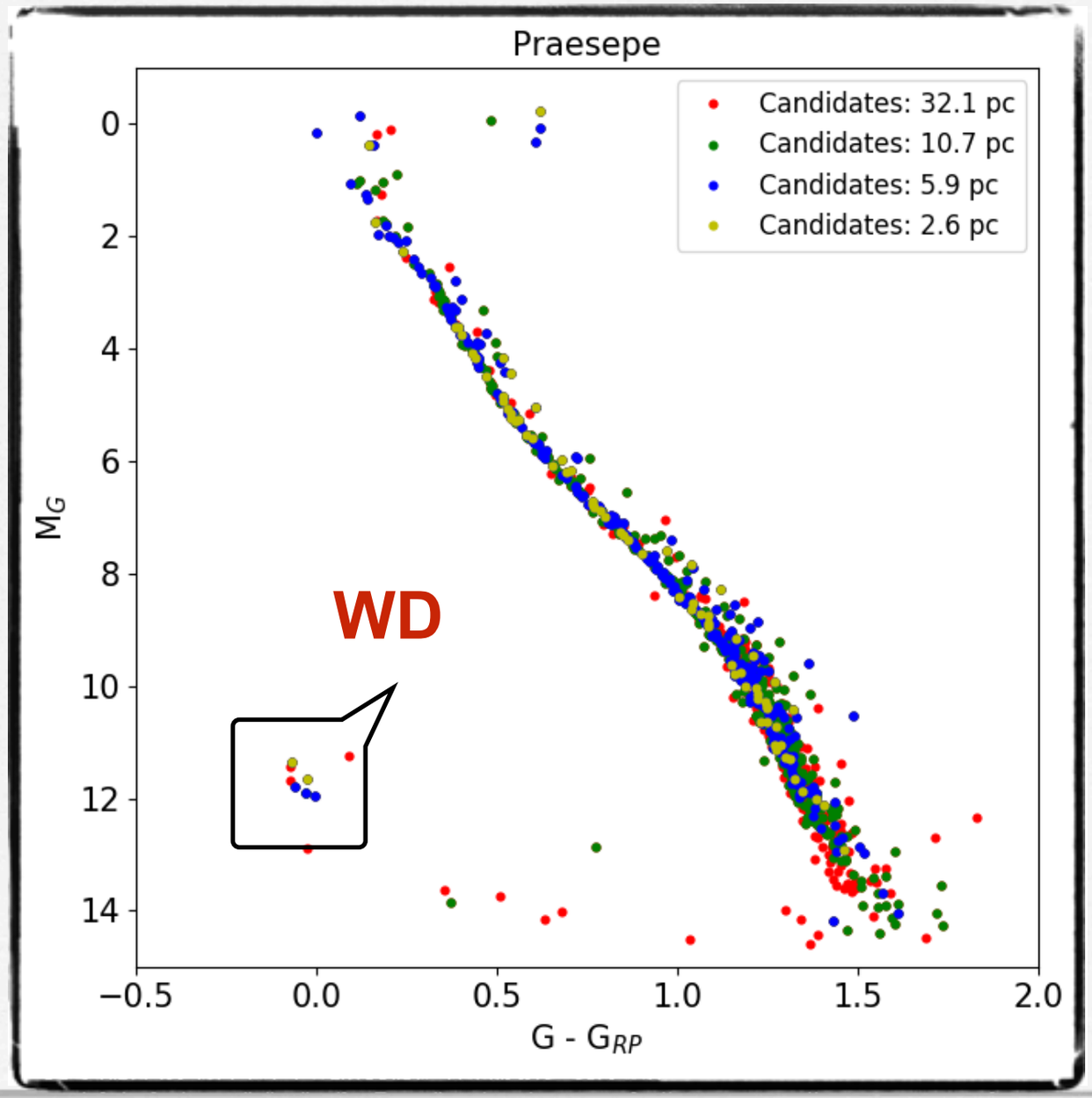
Ages

10 WDs: 673 (+55-39) Myr
8 WDs: 699 (+65-46) Myr
4 WDs: 705 (+76-54) Myr

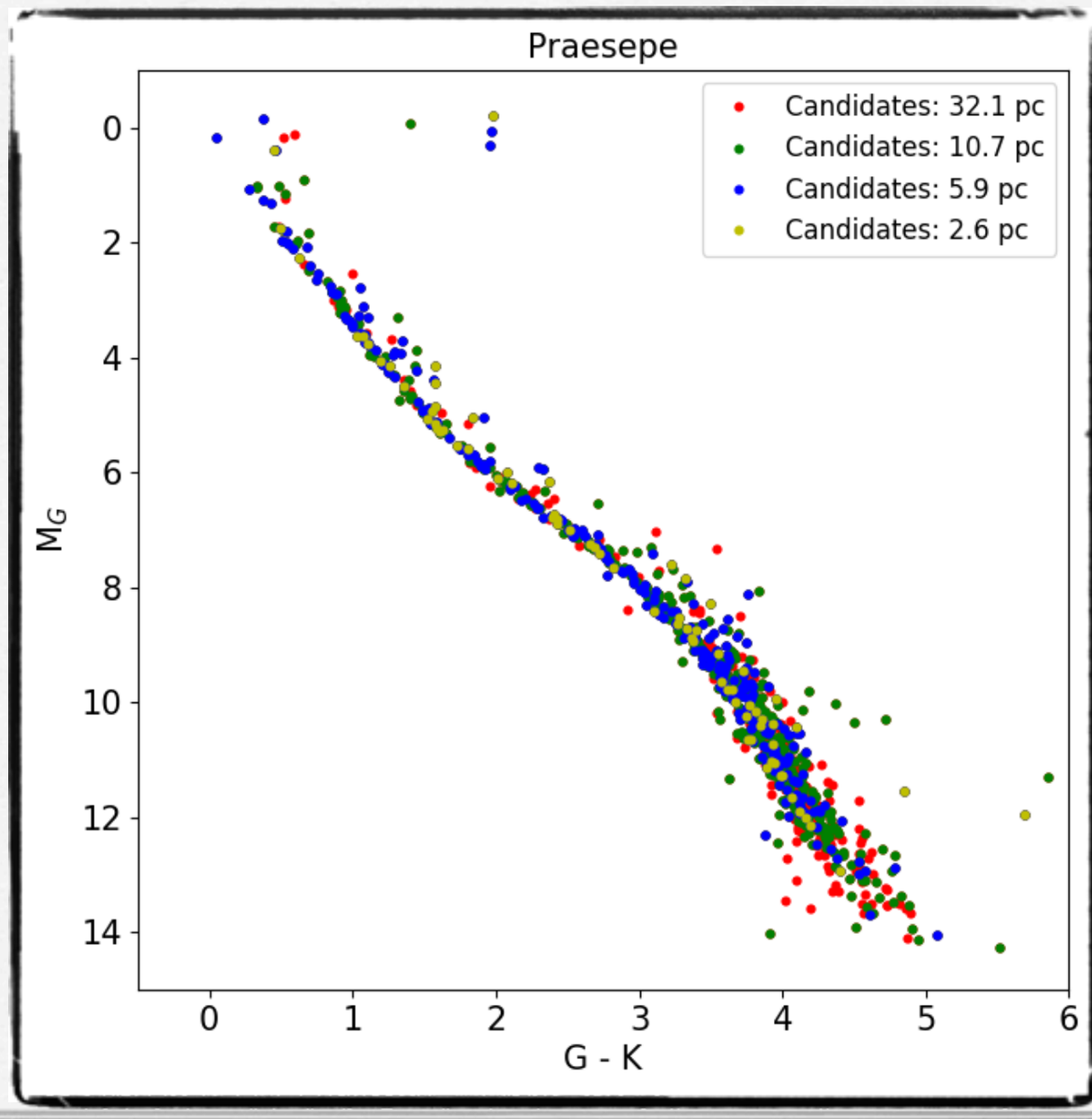
Role of reddening
705 Myr -> 815 Myr (+17%)

Praesepe: CMDs

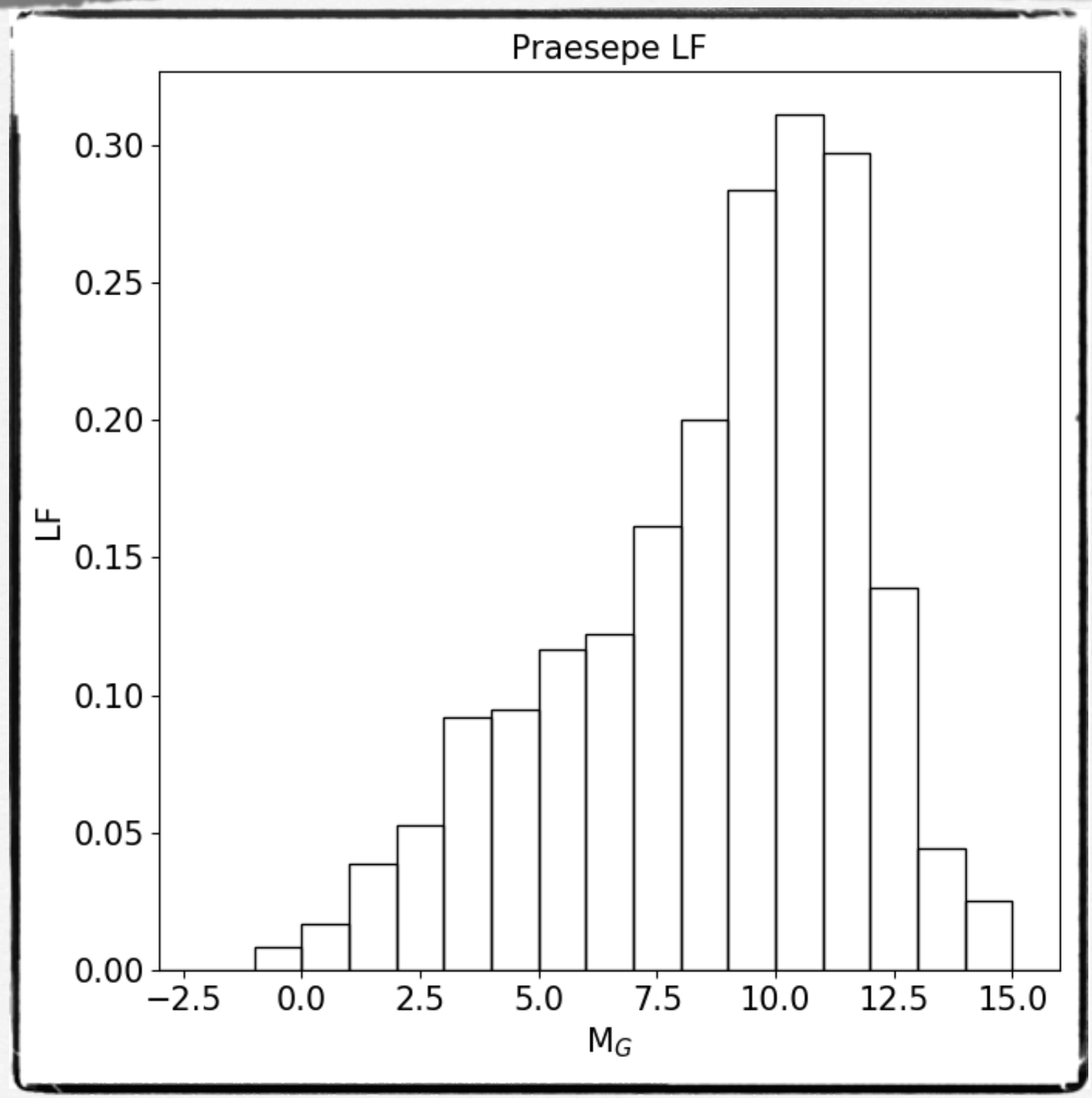
(G-Rp, M_G) CMD



(G-K, M_G) CMD

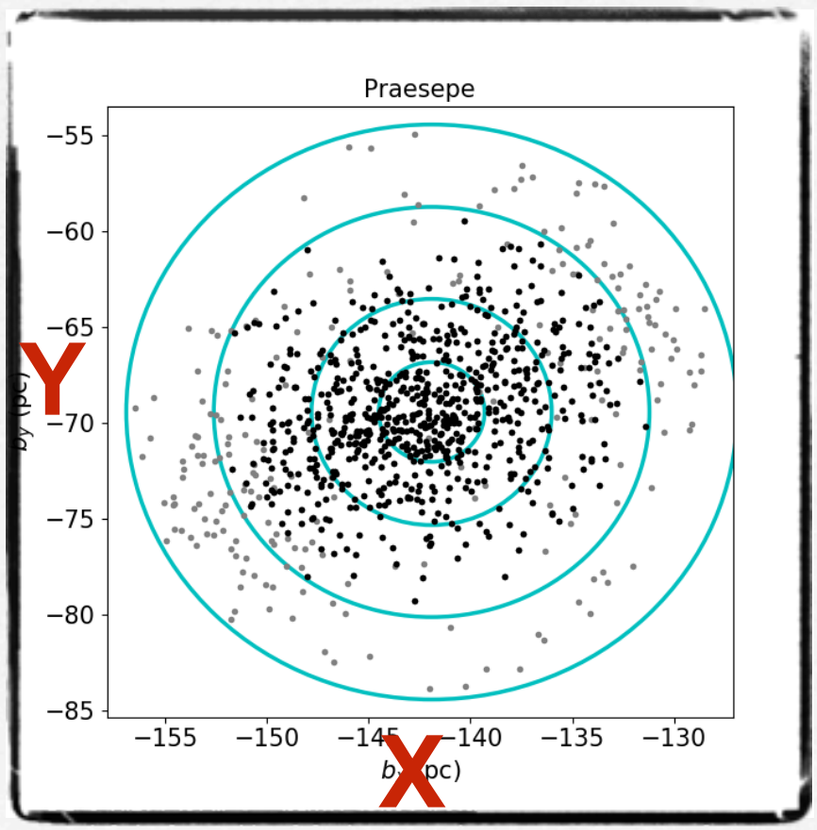


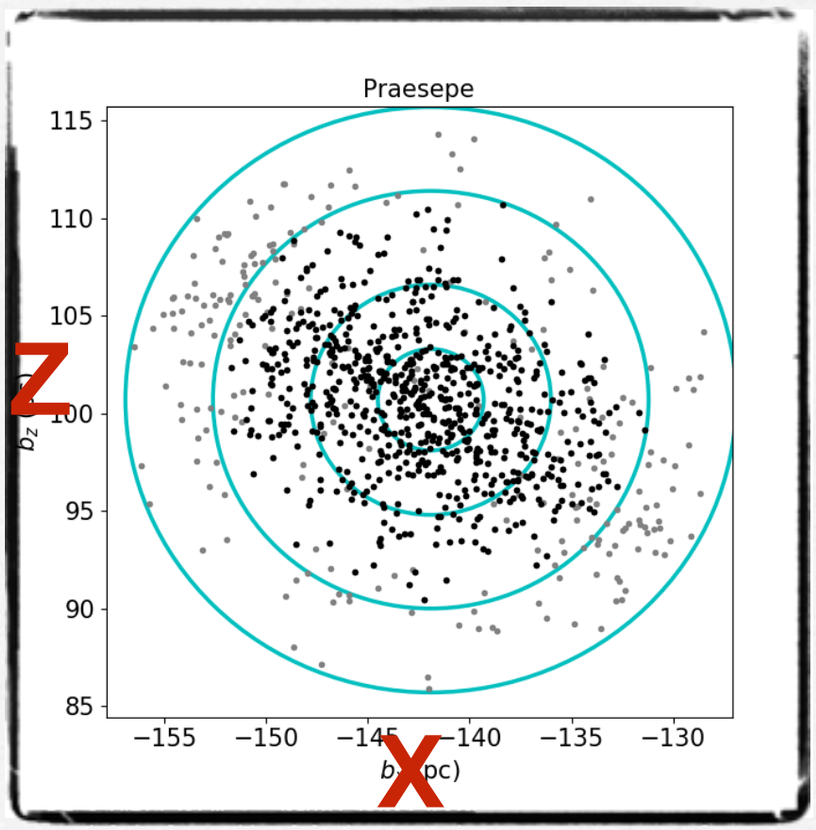
Praesepe: Luminosity function

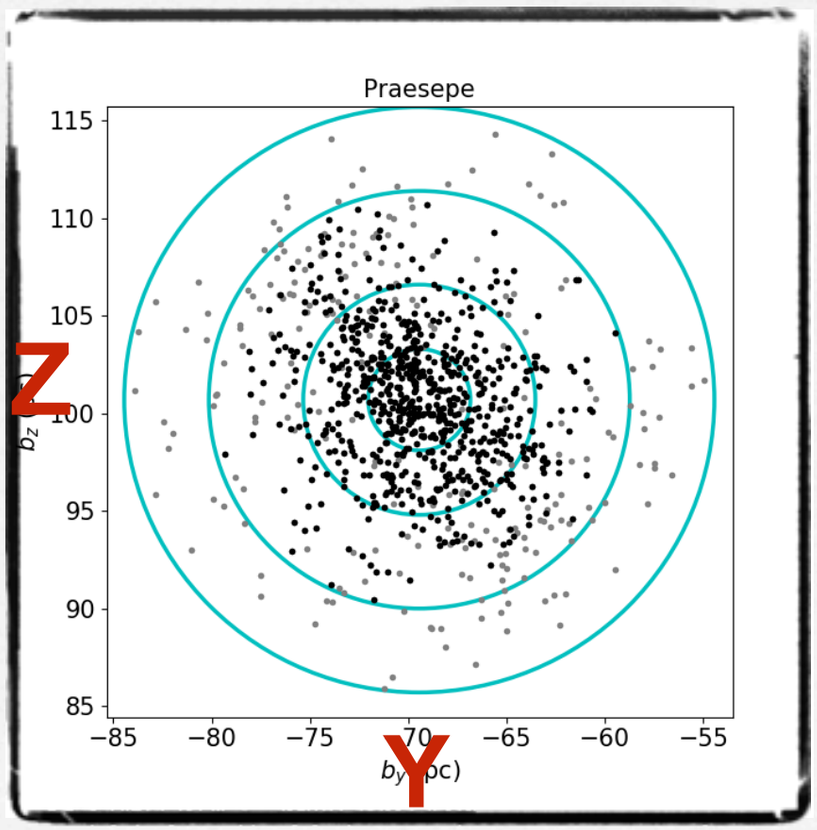


Praesepe: Distribution in space

Galactic coordinates in 3D space for *Gaia* members with 4 annuli drawn in cyan: 2.6, 5.9, 10.7, and 32.1 pc

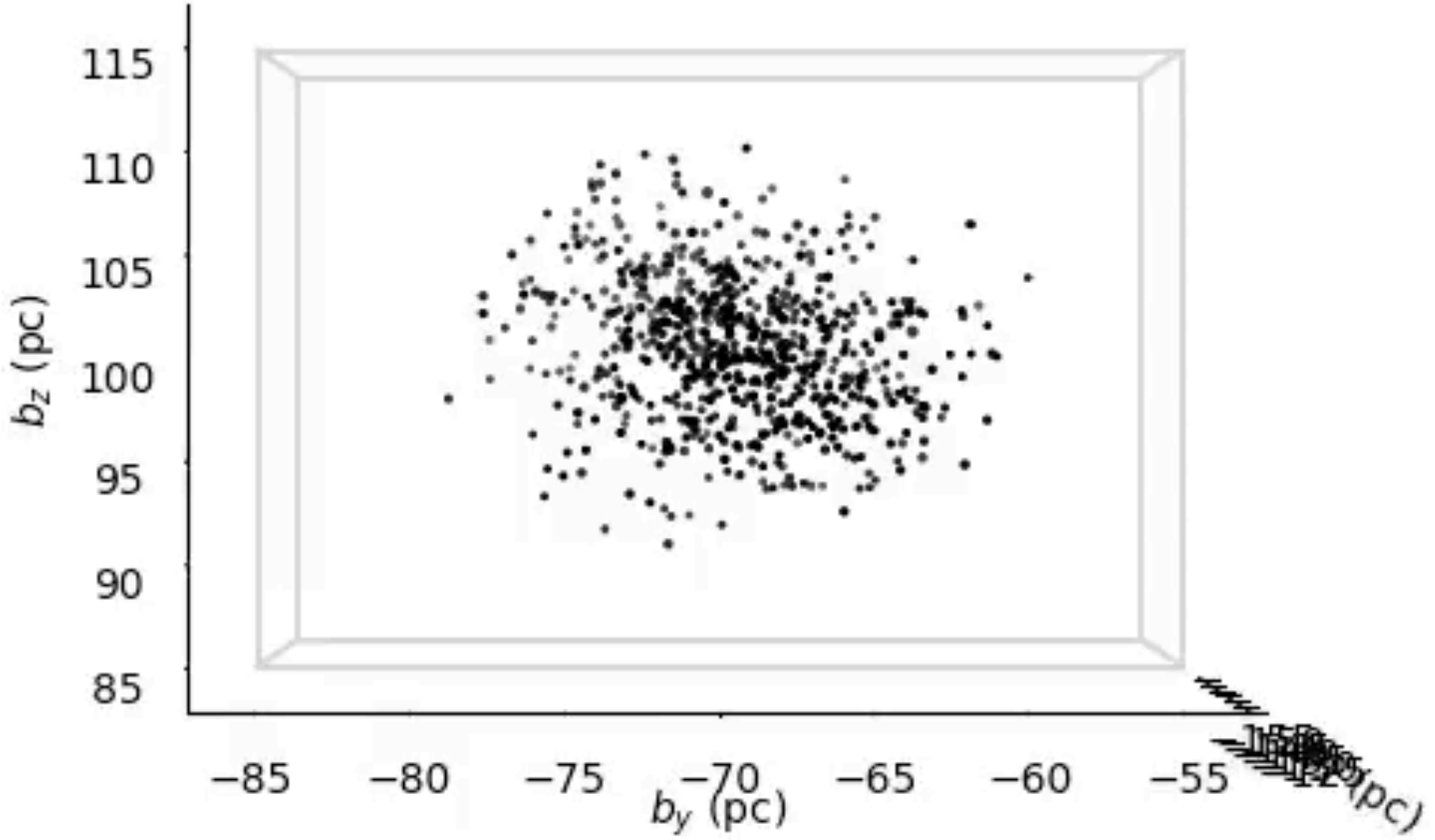






Movie: travelling in the Praesepe

Size of the black symbols represent masses **Stars**



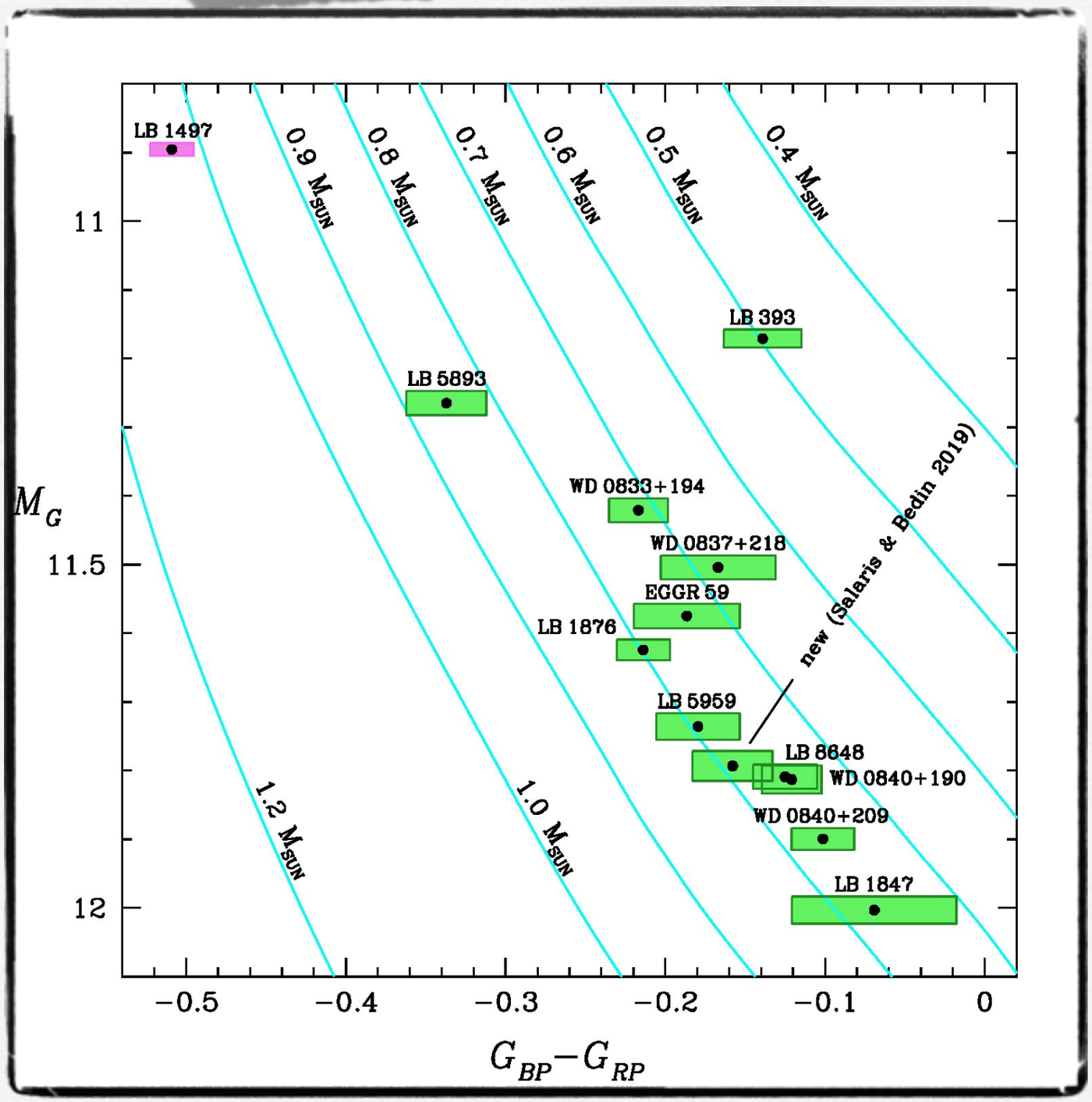
Lodieu et al. (2019, A&A, subm)

The Pleiades

The Pleiades cluster

- ➔ **Names:** Pleiades
- ➔ **d ~ 130 pc** with tidal radius of ~10 pc
- ➔ Mean **proper motion** in the 50 **mas/yr** range
- ➔ **Mean RV of ~11 km/s**
- ➔ **Age** of 120-130 **Myr from various methods**
- ➔ More than **1000 known members** pre-Gaia
- ➔ First brown dwarf ever confirmed: Teide 1
- ➔ **Metallicity** close to solar
- ➔ Many pencil-beam and wide-scale surveys

The Pleiades: Age from WD



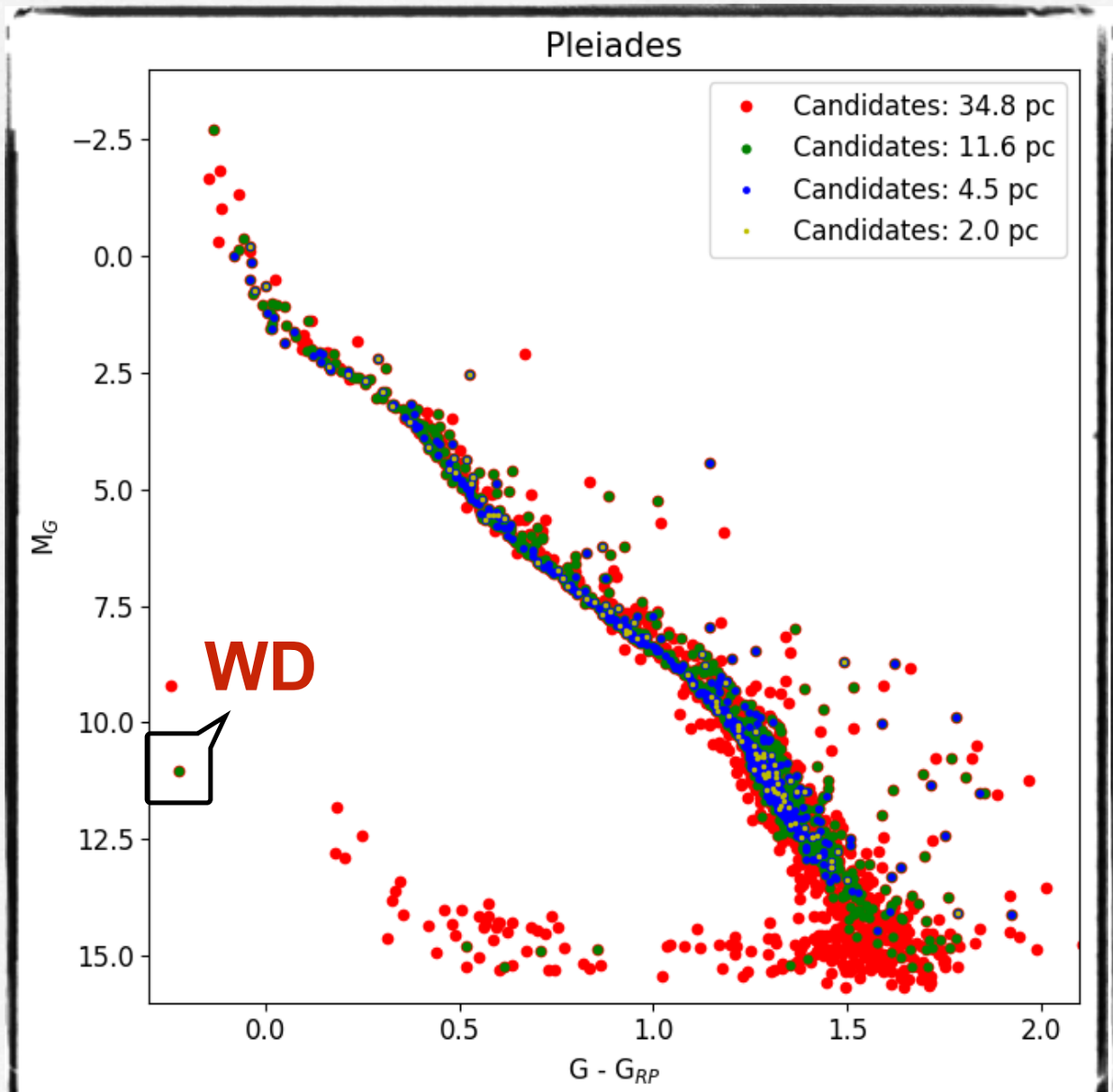
1 known pre-Gaia WD
1 possible WD rejected

Age for E(B-V) = 0.045
1 WD: 132 (+26-27) Myr

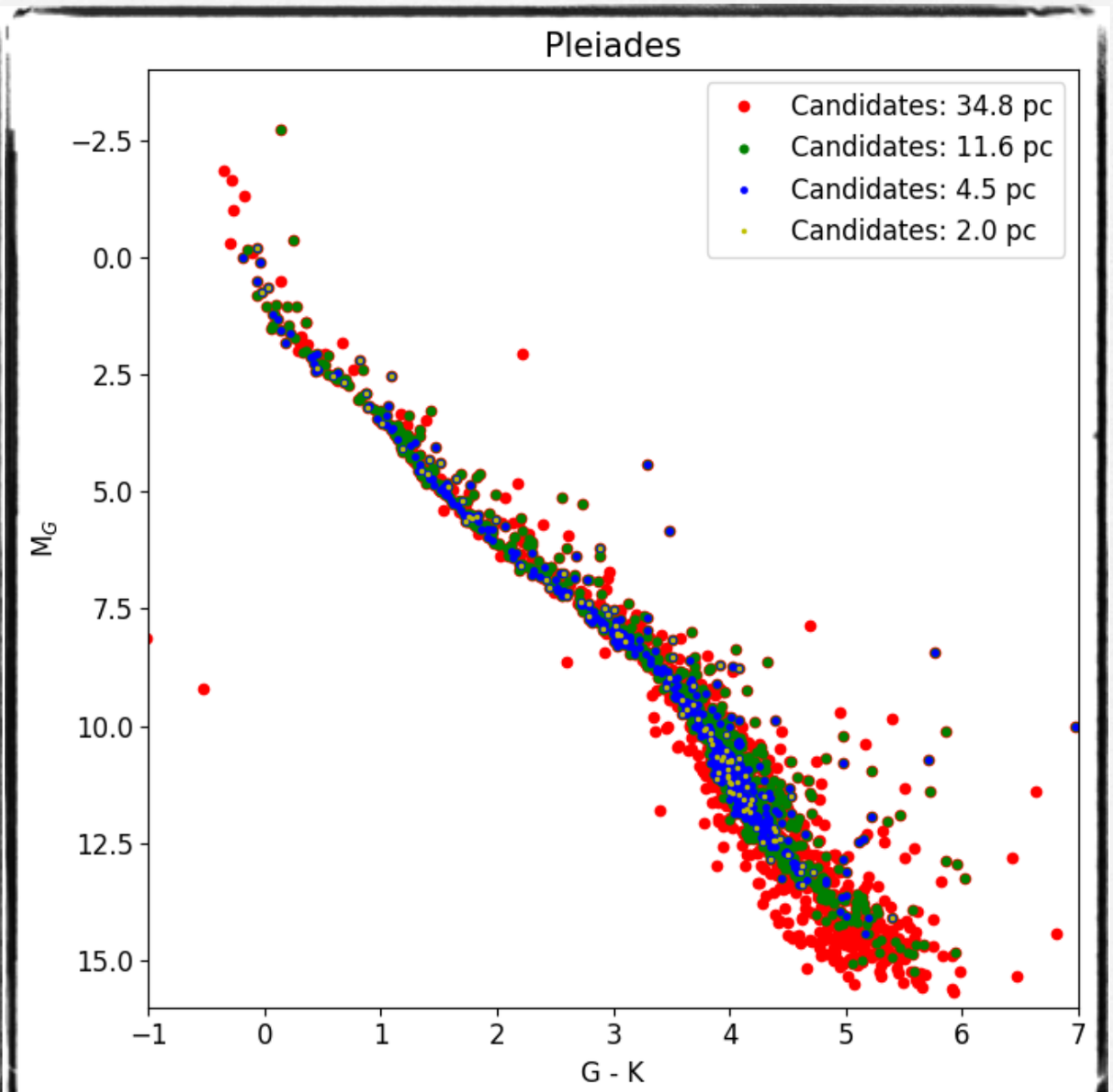
Role of reddening
132 Myr -> 174 Myr (+32%)

The Pleiades: CMDs

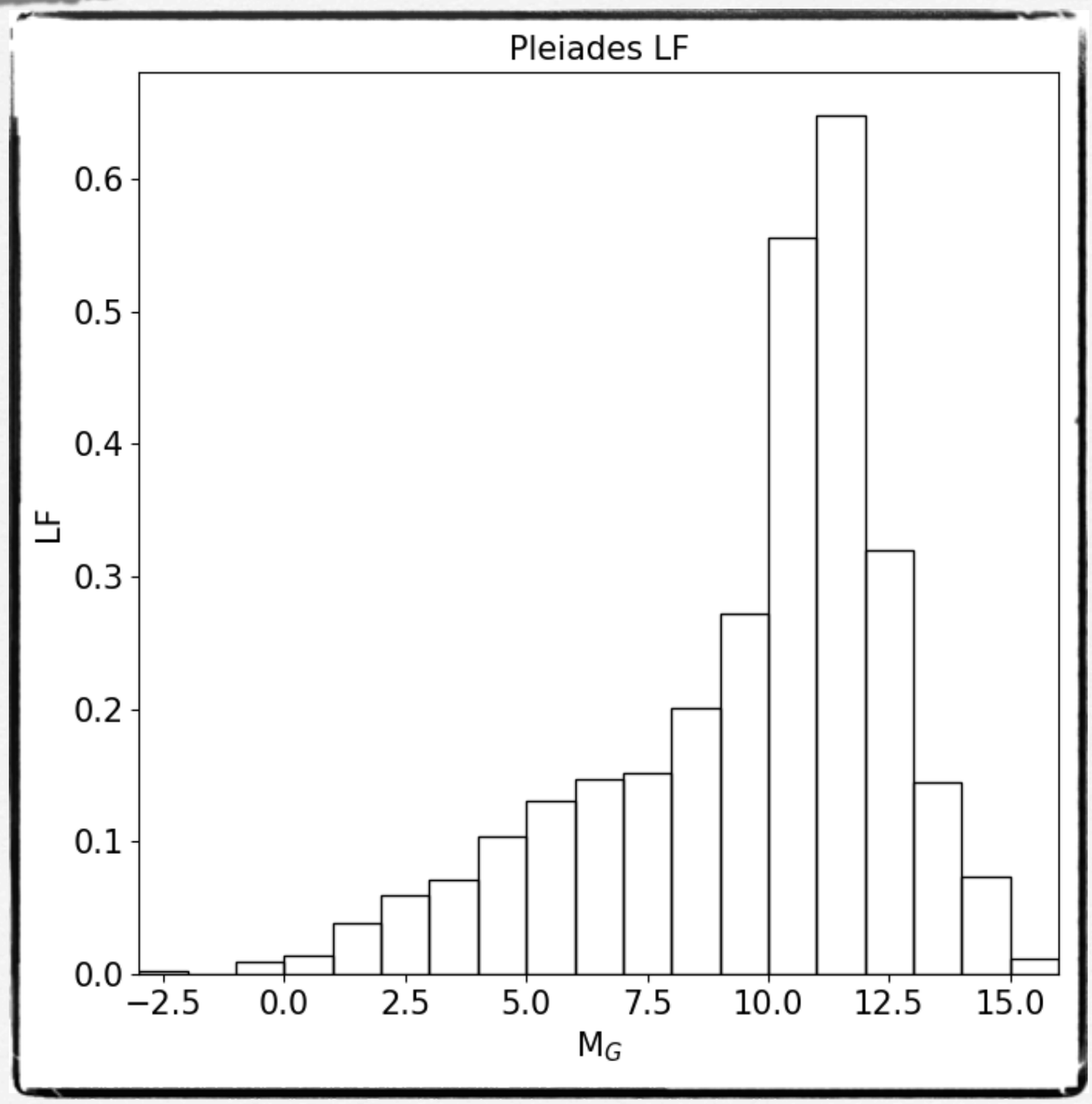
(G-Rp, M_G) CMD



(G-K, M_G) CMD

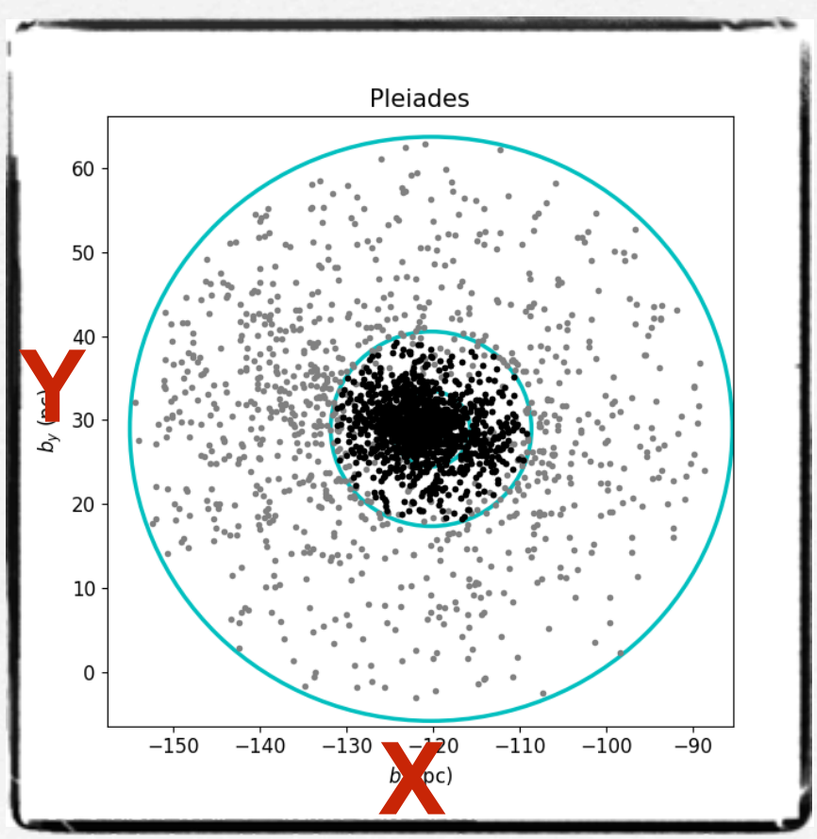


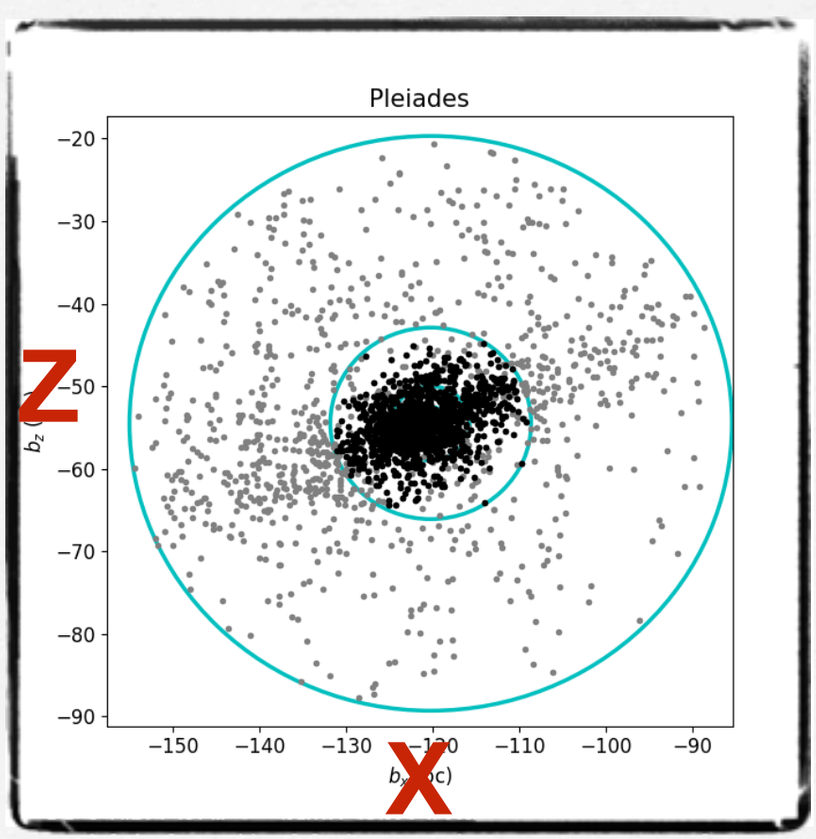
The Pleiades: Luminosity function

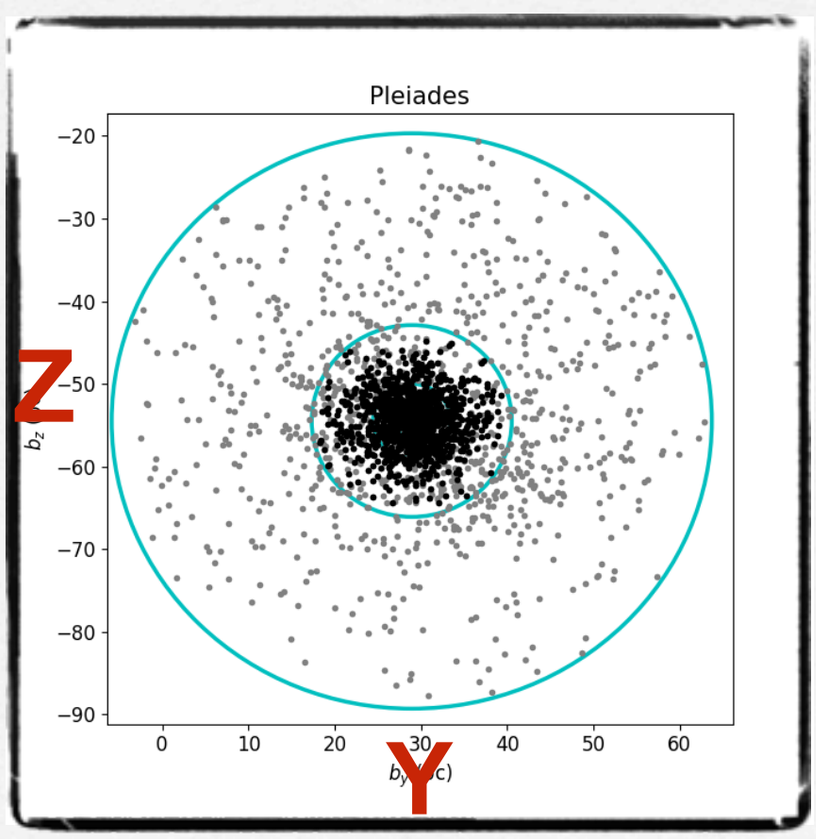


The Pleiades: Distribution in space

Galactic coordinates in 3D space for *Gaia* members with 4 annuli drawn in cyan: 2.0, 4.5, 11.6, and 34.8 pc

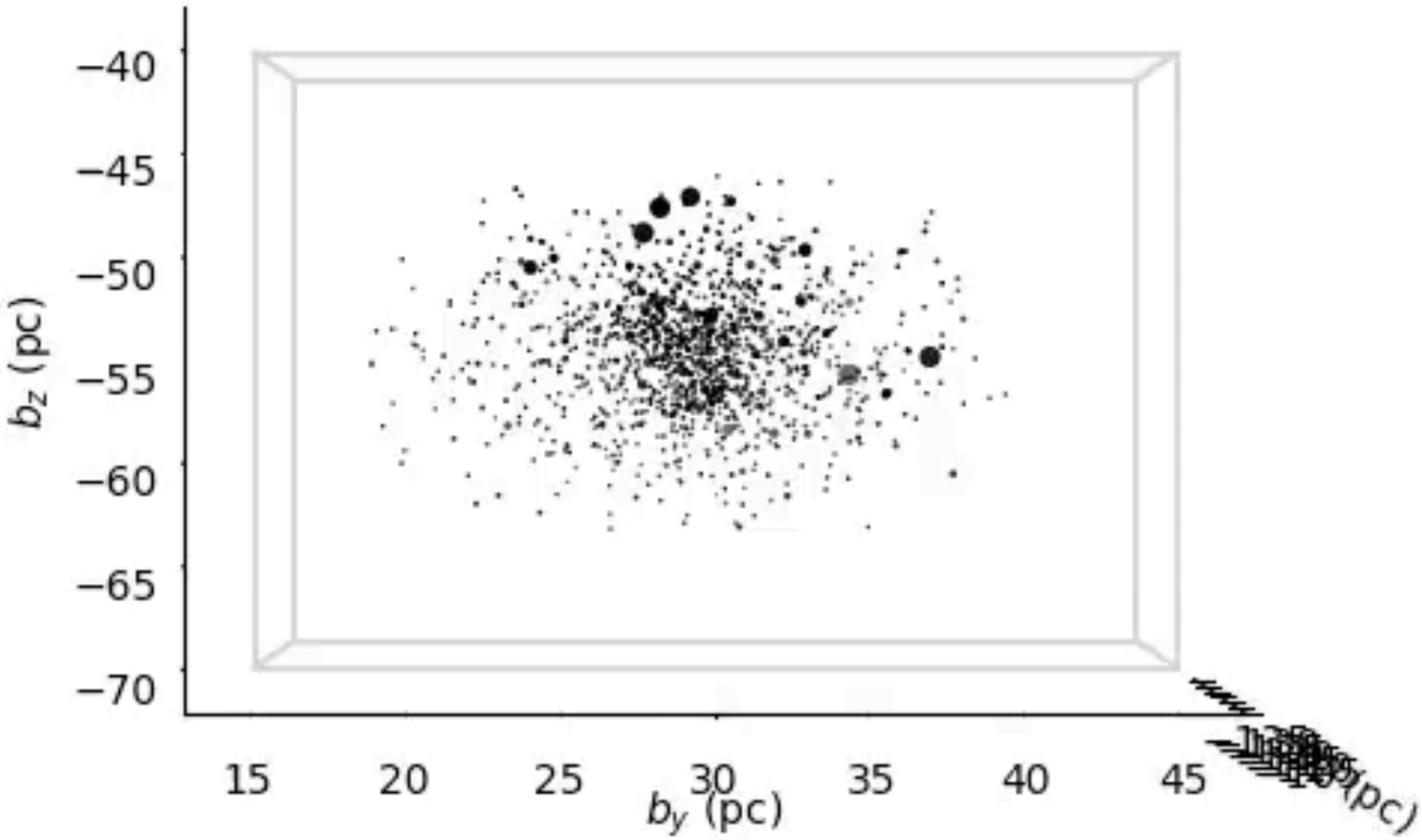






Movie: travelling in the Pleiades

Size of the black symbols represent masses **Stars**



Lodieu et al. (2019, A&A, subm)

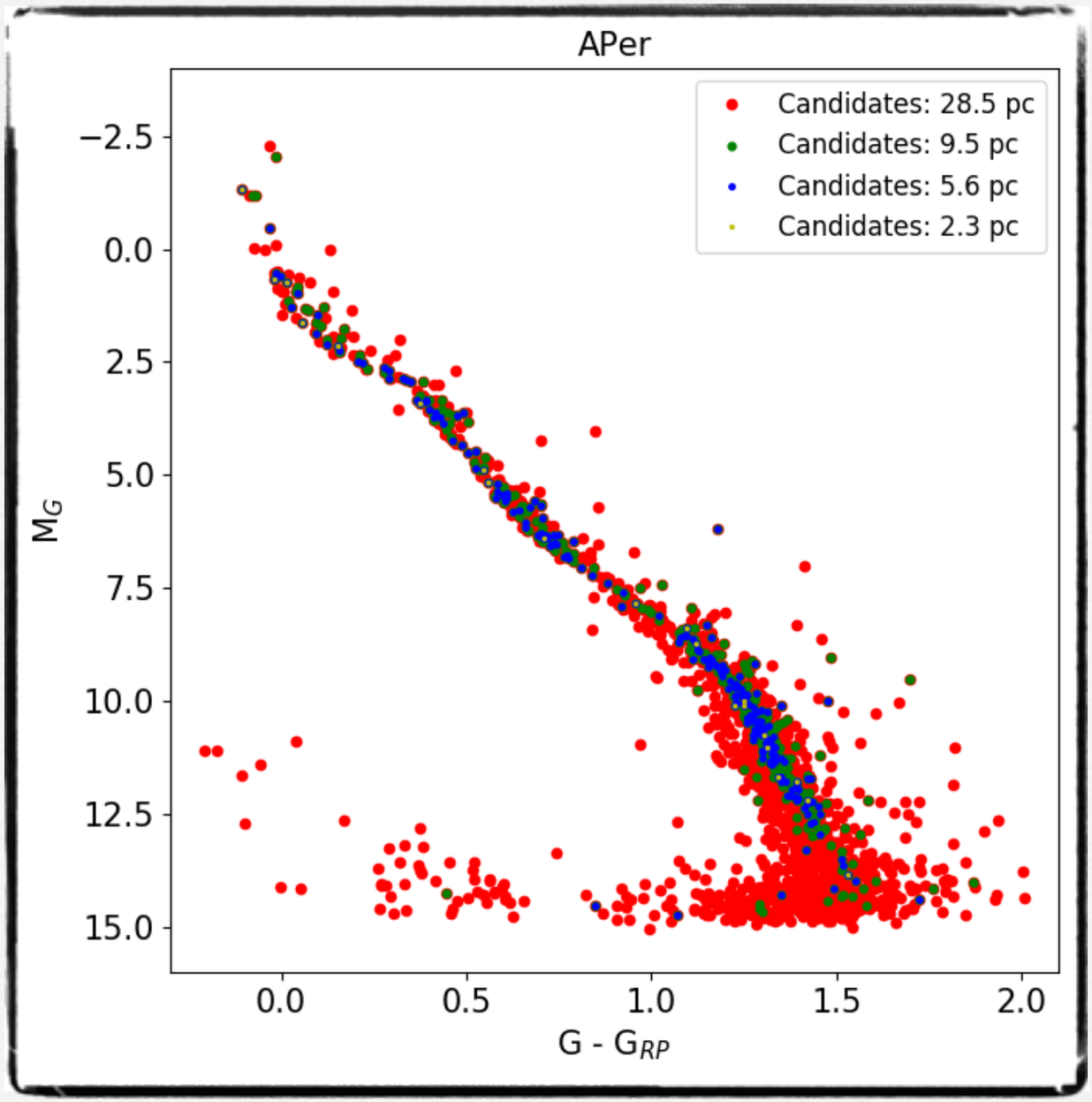
Alpha Persei

The Alpha Persei cluster

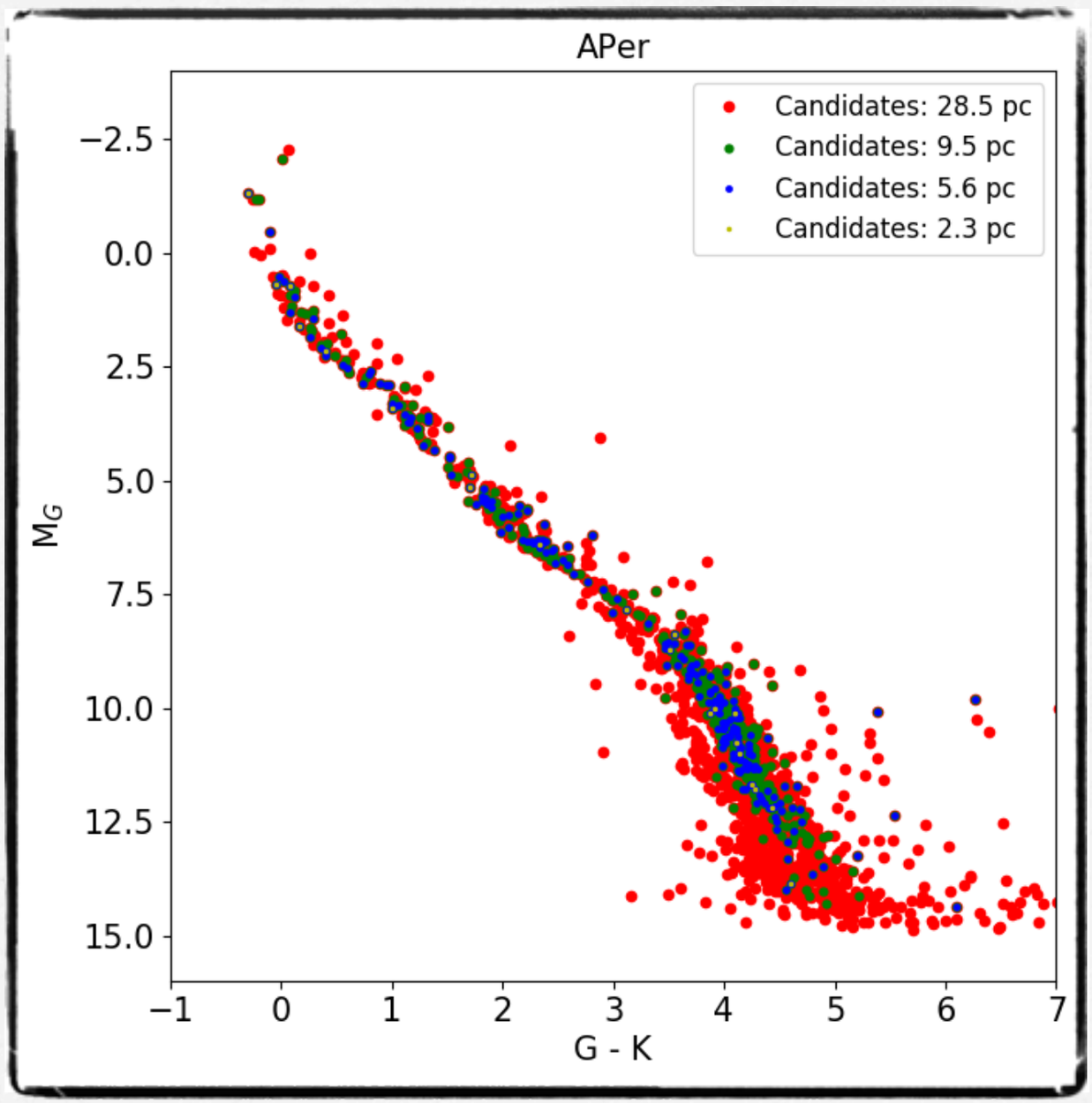
- ➔ **Names:** Alpha Persei
- ➔ **d ~ 170 pc** with tidal radius of ~10 pc
- ➔ Mean **proper motion** in the **25 mas/yr** range
- ➔ **Mean RV of ~4.5 km/s**
- ➔ **Age** of 80-90 **Myr** from **LDB**
- ➔ About **700 known members** pre-Gaia
- ➔ No brown dwarfs confirmed spectroscopically yet
- ➔ **Metallicity** close to solar
- ➔ Some pencil-beam and wide-scale surveys

Alpha Persei: CMDs

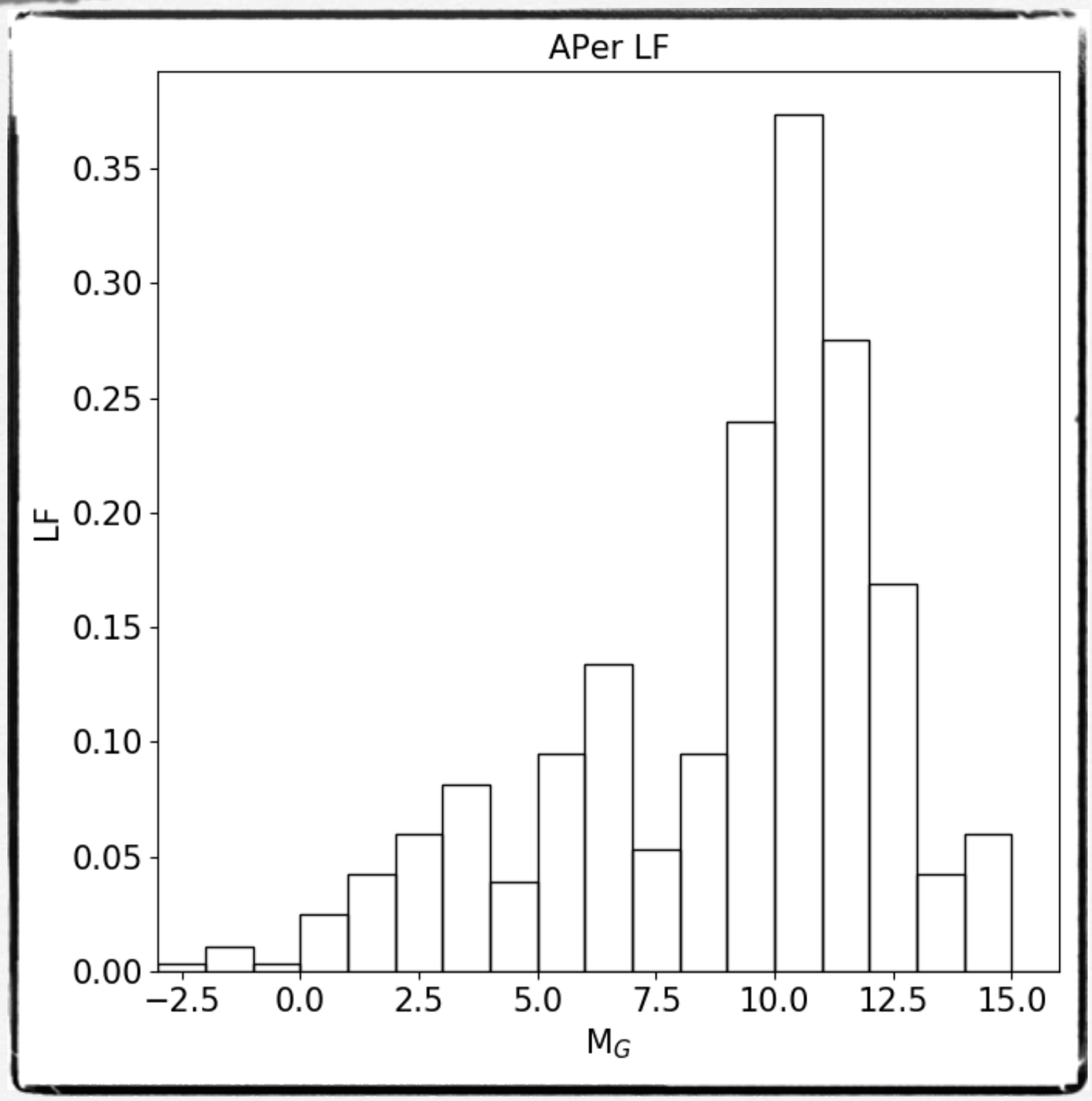
(G-Rp, M_G) CMD



(G-K, M_G) CMD

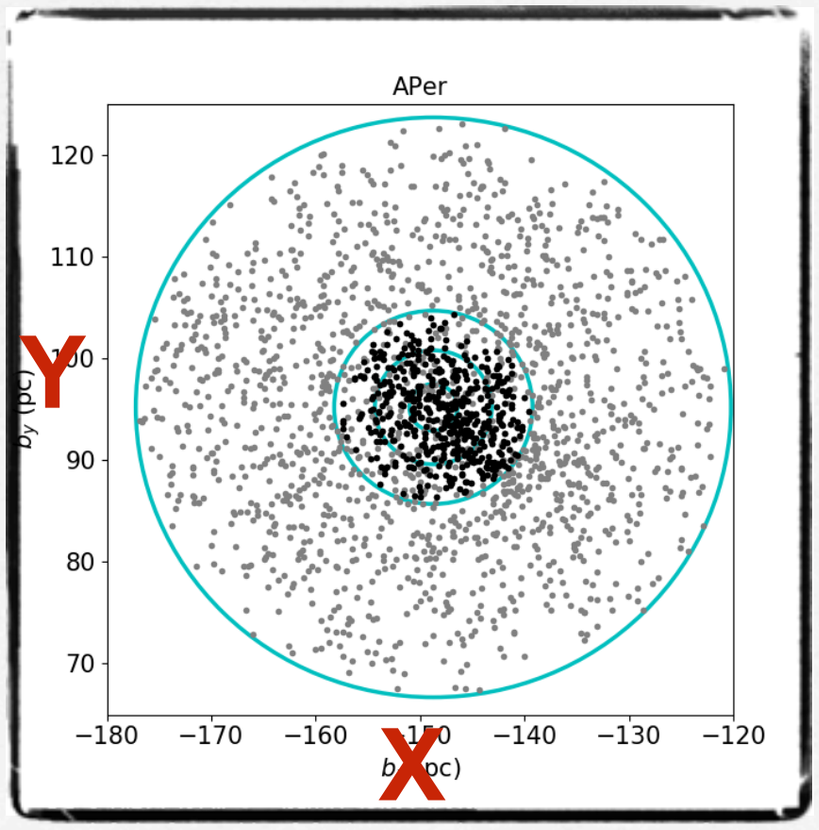


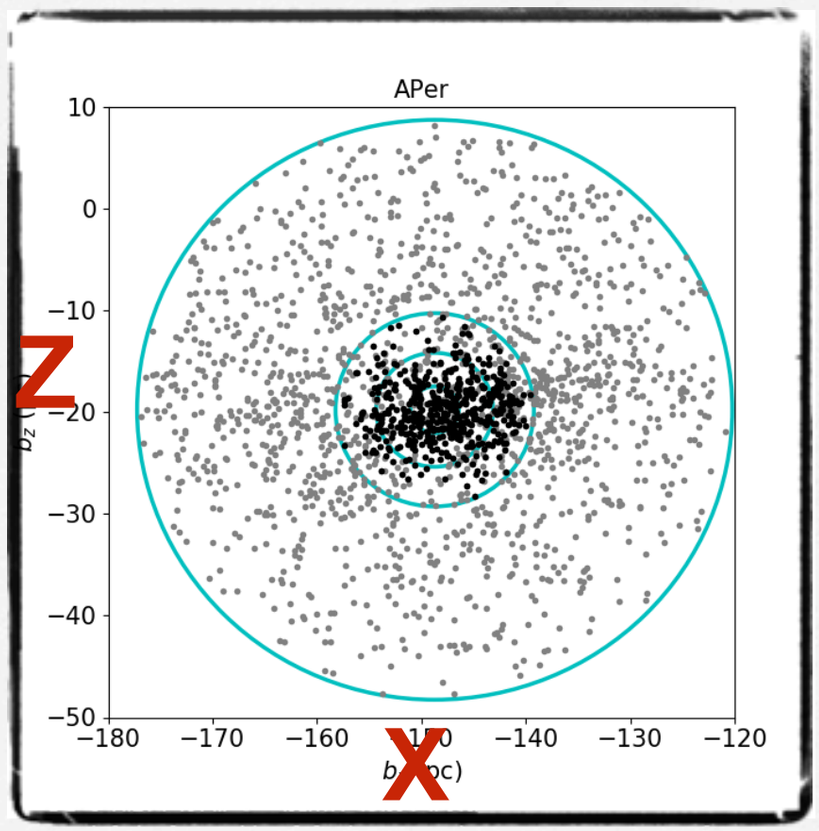
APer: luminosity function

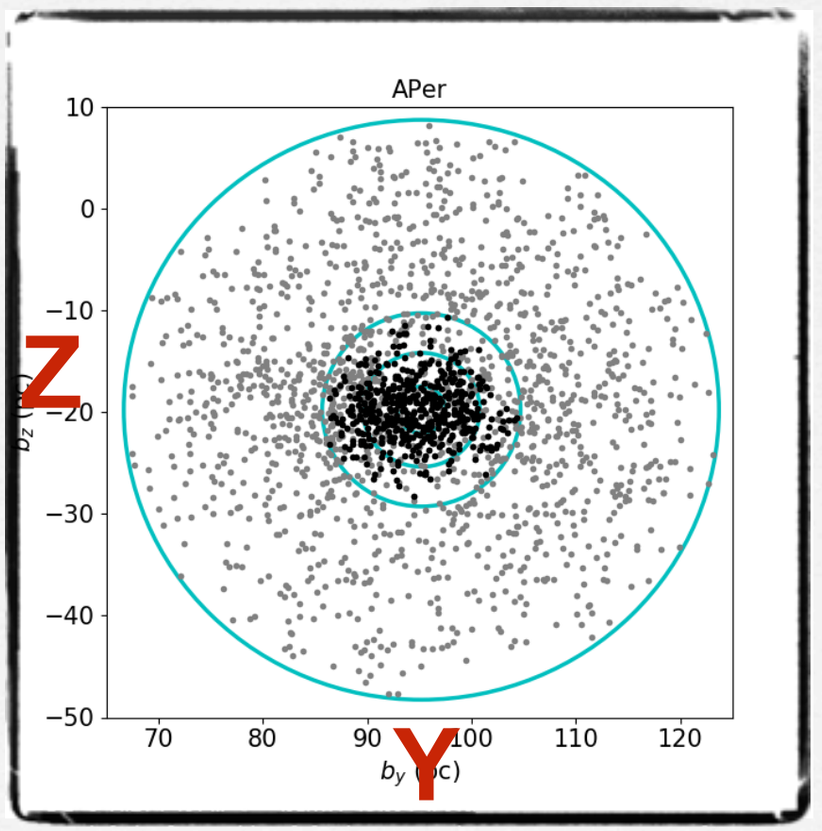


APer: Distribution in space

Galactic coordinates in 3D space for *Gaia* members with 4 annuli drawn in cyan: 2.3, 5.6, 9.5, and 28.5 pc

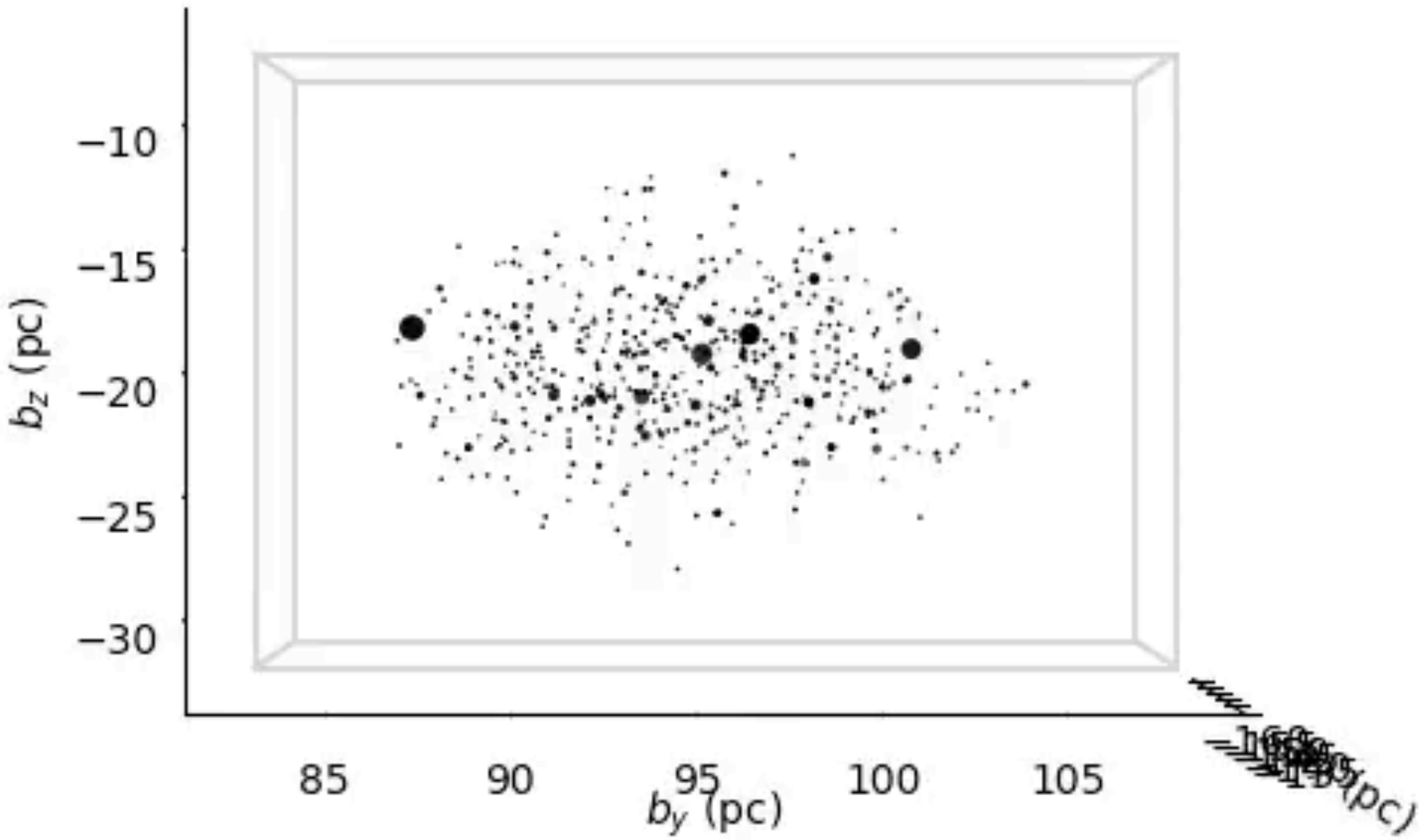






Movie: travelling in Alpha Persei

Size of the black symbols represent masses **Stars**



Lodieu et al. (2019, A&A, subm)

Conclusions

Updated census of members from *Gaia* DR2
Updated distances, radii, mean positions and velocities
==> First 3D map of the Hyades, Praesepe, Pleiades, APer

381, 721, 1248, 546 members in the Hyades, Praesepe, Pleiades, and Alpha Persei
10 Hyades brown dwarfs not detected by *Gaia* DR2

The Hyades and Praesepe suffered mass segregation
Tidal tail structure in the Hyades and Pleiades

More details in Lodieu et al. (2019a, 2019b)

Video: El cielo de Canarias

http://vimeo.com/23205323