Stellar and Substellar Members in the Coma Berenices Star Cluster

Wen Ping **Chen** & S. Y. "Tony" **Tang**

NCU/Astronomy

Collaborators:

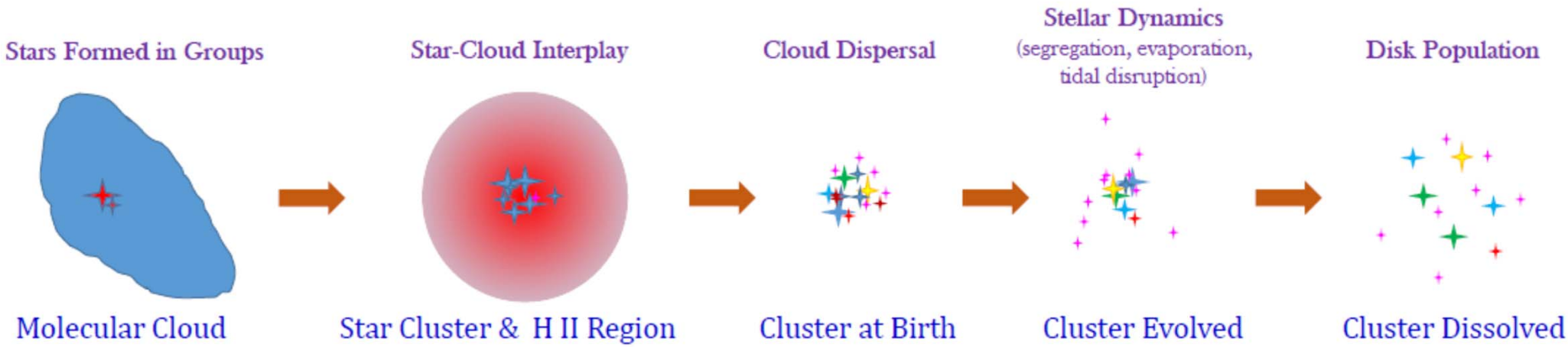
P. S. Chiang, C. Y. Chen (NCU),

Jessy Jose, Greg Herczeg (KIAA)

APRIM 2017 @ Taipei

Dynamical Evolution of a Star Cluster

- (Initial) Molecular clouds are clumpy and filamentary; so are the youngest star clusters.
- (Internal) Gas dispersal (stellar winds, SN explosions) + Mutual gravitational interaction between members → spherical shape (relaxation), with more massive stars concentrating more toward the center (mass segregation). Lowest-mass members are vulnerable to ejection out from the system (stellar evaporation).
- (External) Eventually Galactic perturbations (tidal forces, differential rotation) distort and rip apart the star clusters. Then-members supply the Galactic disk population.
- A recently dissolved system in the solar neighborhood may be recognized as a moving (star) group.



$$\tau_{\rm cr} = \frac{D}{v} \qquad N_{\rm cr} = \frac{0.1\,N}{\ln N} \qquad \tau_{\rm relax} = \tau_{\rm cr} \cdot N_{\rm cr} \qquad \tau_{\rm evap} \approx 100\,\tau_{\rm relax}$$

Massive stars "sink" to center

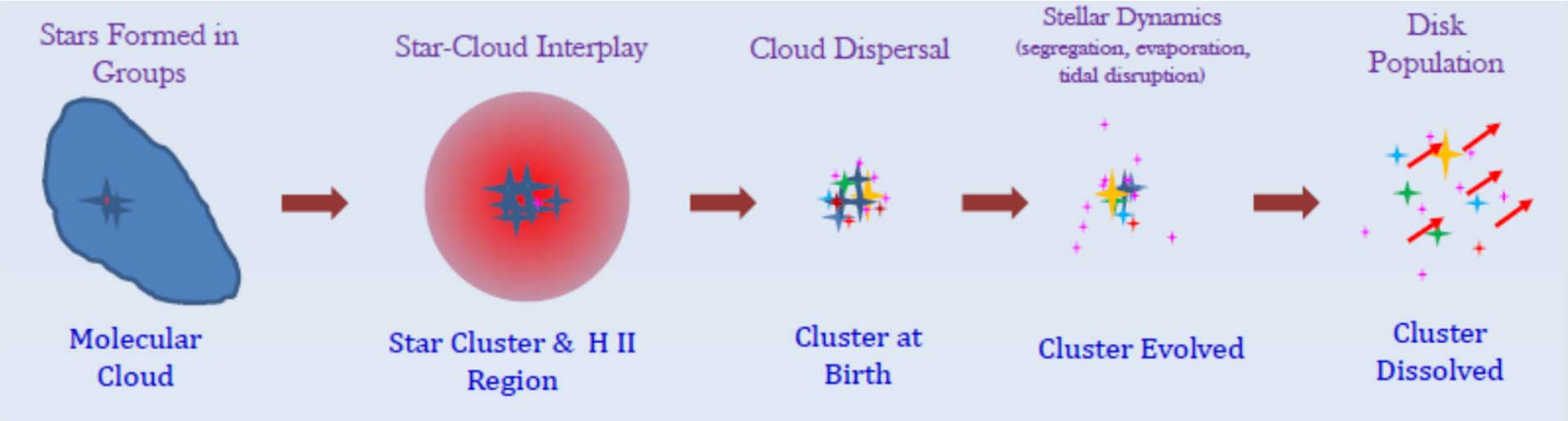
Cluster disintegrates

Spitzer (1988); Shu (1984); Binney & Tremaine (1987)

For a typical GC, $\tau_{\rm relax} \approx 10^8 \sim 10^9$ yr … **most GCs have been relaxed.**

For a typical OC, $\tau_{\rm relax} \approx 10^6 \sim 10^7$ yr … **young OCs are being relaxed.**

Dissolved Star Clusters

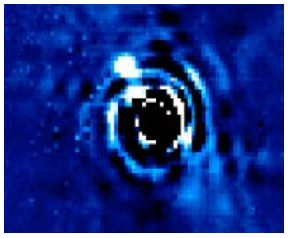


Recently dissolved star clusters recognizable if young and in the solar neighborhood → **stellar moving groups**

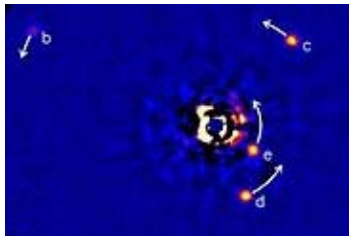
Then-members share the same space volume and motion, (and chemical abundance, age, etc.)

So far 9 MGs known, all within 150 pc and with ages 10–100 Myr (young and nearby)

Known Moving Groups



β Pic in BPMG
Lagrange et al. 2009



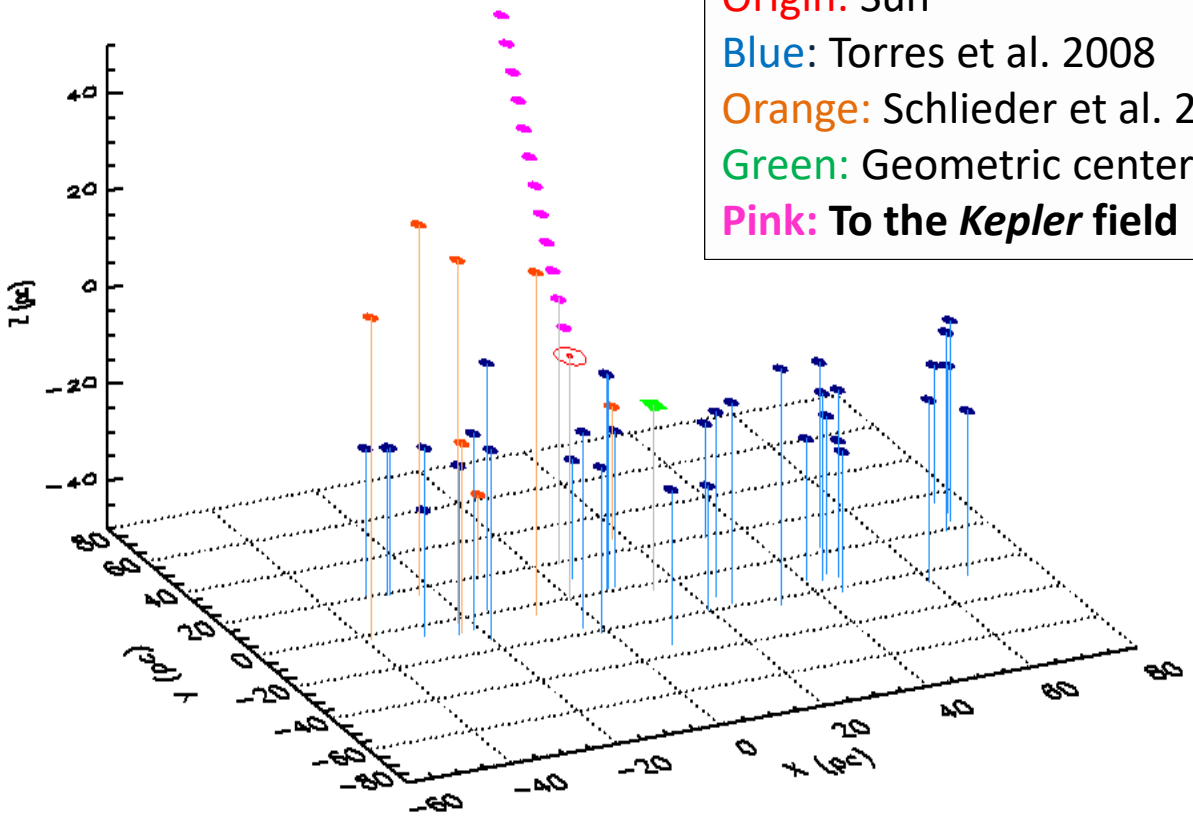
HR 8799 in Columba
Marois et al. 2010

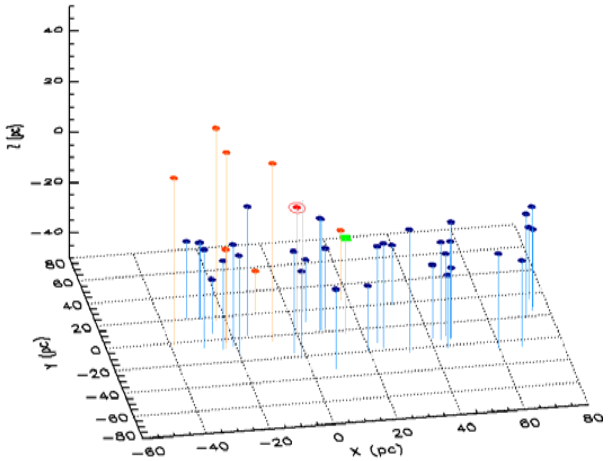
Known nearby moving groups, adapted from Torres et al. (2008)						
Name	D^T [pc]	Age^M [Myr]	U^T [kms^{-1}]	V^T [kms^{-1}]	W^T [kms^{-1}]	N^T
Pictoris (BP)	$40\pm18^{T,S}$	12-22	-10.1±2.1	-15.9±0.8	-9.2±1.0	$55^{T,S}$
AB Doradus (AB Dor)	$51\pm29^{T,S}$	50-120	-6.8±1.3	-27.2±1.2	-13.3±1.6	$97^{T,S}$
Tucana/Horologinm (Tuc-Hor)	48±7	10-40	-9.9±1.5	-20.9±0.8	-1.4±0.9	44
TW Hydrae (TWH)	59 ± 22^{D}	8-20	-10.5±0.9	-18.0±1.5	-4.9±0.9	31^{D}
Columba (Col)	82±30	10-40	-13.2±1.3	-21.8±0.8	-5.9±1.2	41
Carina (Car)	85±35	10-40	-10.2±0.4	-23.0±0.8	-4.4±1.5	23
Argus (Arg)	106±51	30-50	-22.0±0.3	-14.4±1.3	-5.0±1.3	64
Chamaeleontis (Cha)	108±9	$\sim6^{T}$	-11.0±1.2	-19.9±1.2	-10.4±1.6	30^{M2}
Octans (Oct)	141±34	$\sim20^{T}$	-14.5±0.9	-3.6±1.6	-11.2±1.4	15

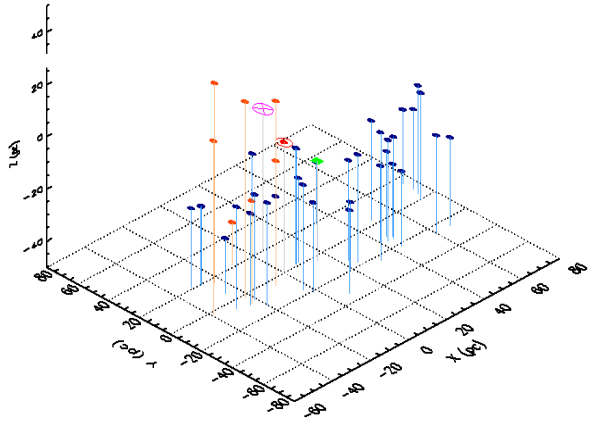
D: Ducourant et al. 2014, M: Malo et al. 2013 , M2: S: Schlieder et al. 2012, T: Torres et al. 2008, M2: Murphy et al. 2013

Known members of the BPMG

Origin: Sun
Blue: Torres et al. 2008
Orange: Schlieder et al. 2012
Green: Geometric center
Pink: **To the *Kepler* field**

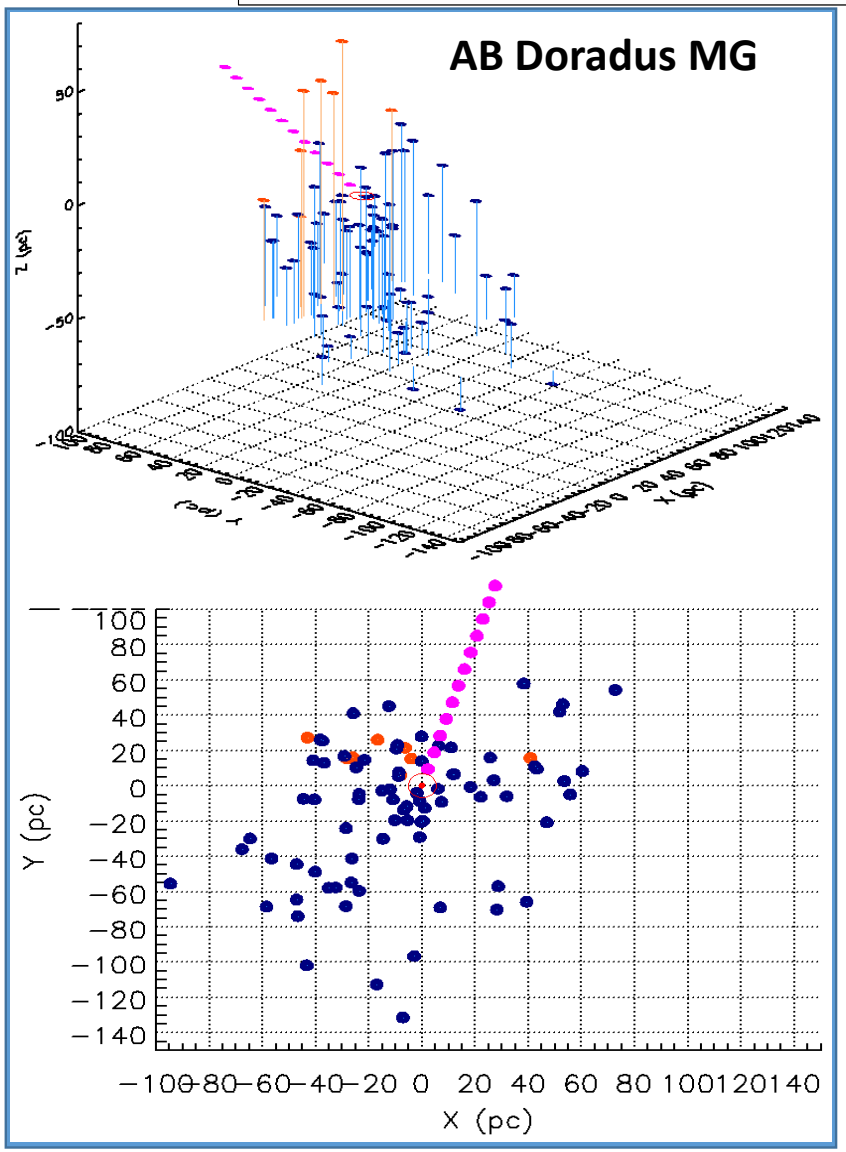


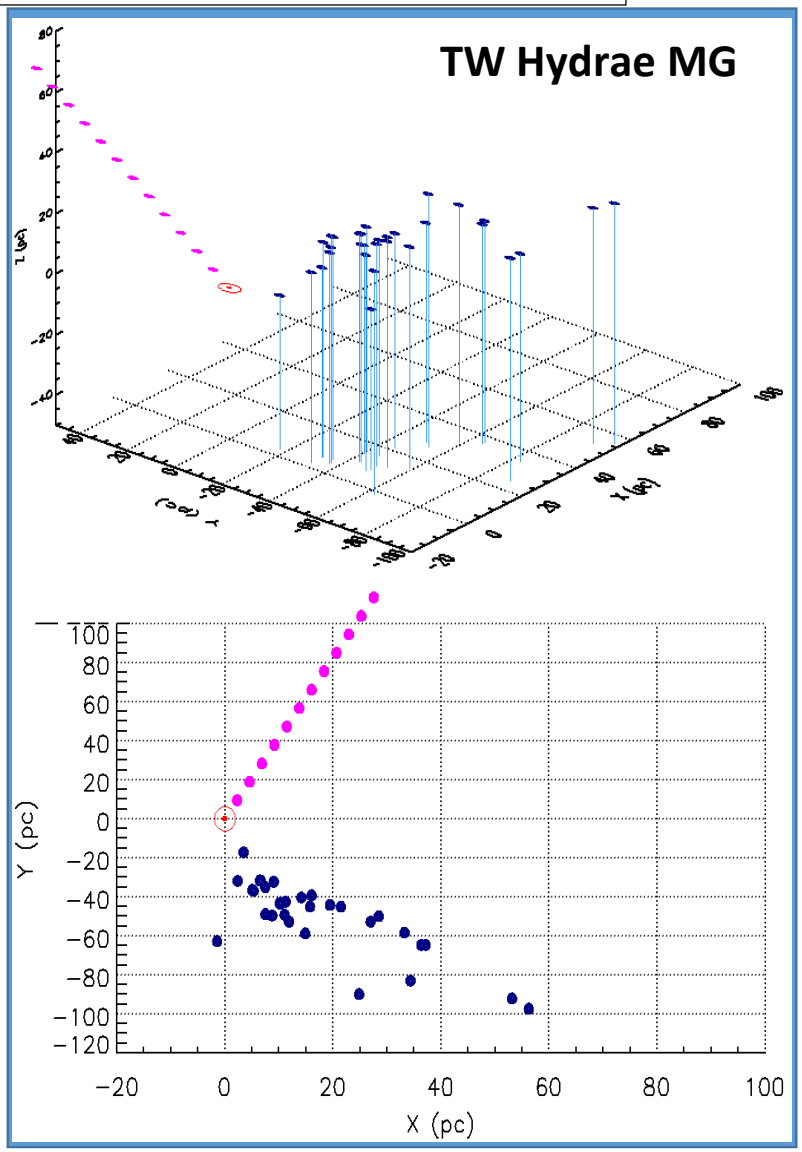




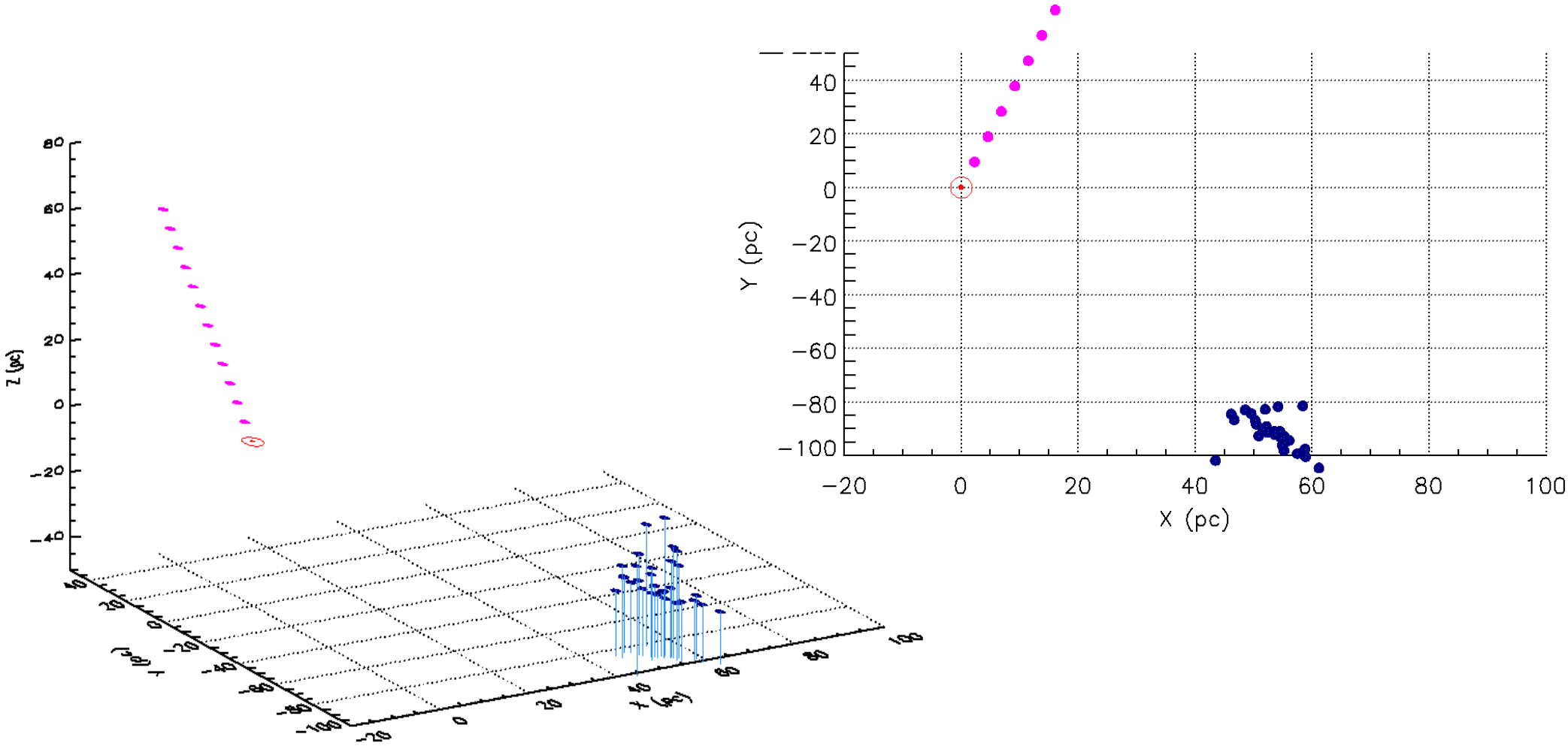
... in Galactic Coordinates with respect to the Sun

Origin: Sun, Blue: Torres et al. 2008 (AB Dor), Ducourant et al. 2014 (TWH),
Orange: Schlieder et al. 2012, Pink: the *Kepler* field





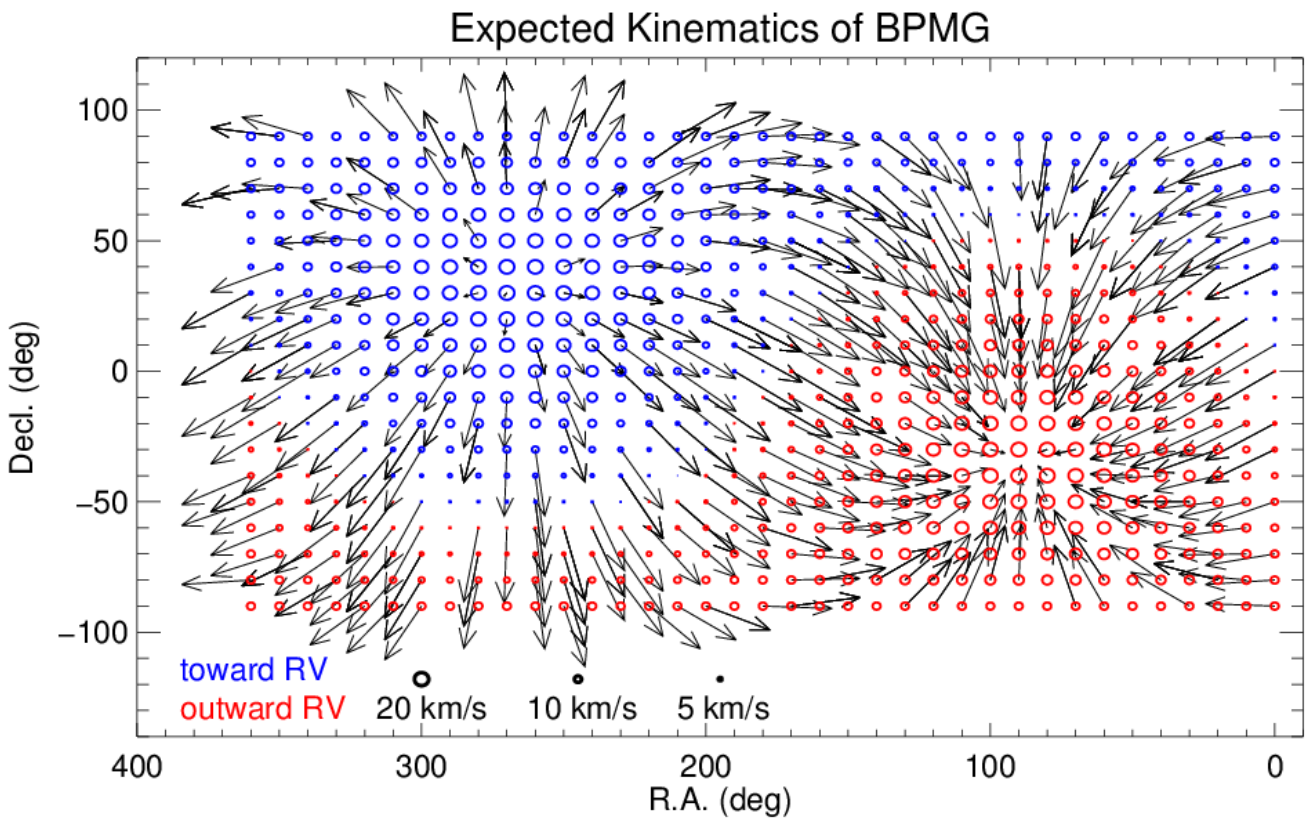
Cha MG as a controlled sample for false positives



Member candidacy

Consistent distance, RV (variable for binaries), and tangential velocities (PM + distance)

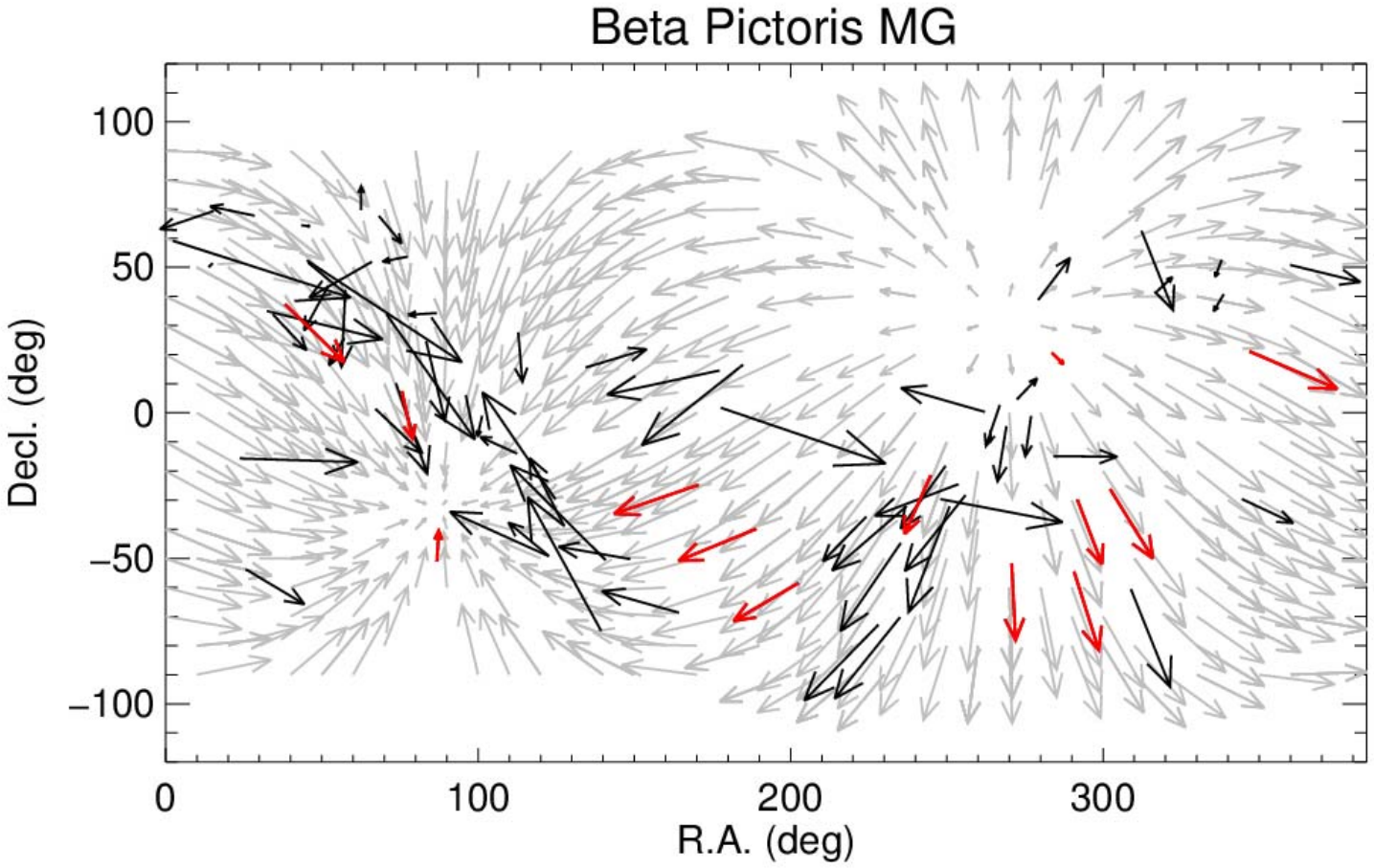
Stellar youth ($v \sin i$, X rays, emission spectra, etc.)



Gray: Expected PMs at 40 pc with member tangential velocities

Black: 75 nearby sources with debris disks (Liu+14 by Hipparcos and AKARI/FIS)

Red: consistent tangential velocities (PMs + Hipparcos parallaxes)



Coma Berenices = Coma Star Cluster

- Melotte 111; RA=12:25, DE=26:06 (J2000)
- 90 pc; 600 Myr (Tsvetkov 1989)
- Poorly studied because of large sky coverage (5 deg); members difficult to distinguish from field
- 60 member candidates by 2MASS/USNO (Casewell et al. 2006)
- 82 low-mass candidates, including 5 possible BDs, by optical and 2MASS, but no kinematic constraints (Melnikov & Eislöffel 2012)
- A few more K and early-M members by SDSS/APOGEE (RV) (Terrien et al. 2014)

Our data

- UKIDSS Galactic Cluster Survey, ZYJHKs, 78.5 square deg; J=11.0 to 19.8 mag, so 1.4 to 0.05 $\mathcal{M}_\odot$ members, supplemented by 2MASS (140 square deg) for the bright sample; but UKIDSS spatially incomplete
- URAT1 proper motions for bright stars
- UKIDSS DR10 proper motions for faint stars

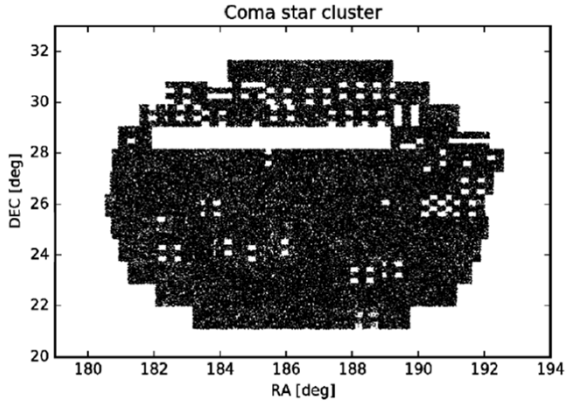


Figure 1. UKIDSS/GCS sources toward the Coma cluster with ZYJK1 photometric measurements. No data are available in the blank regions due to poor image quality judged by the UKIDSS quality control pipelines.

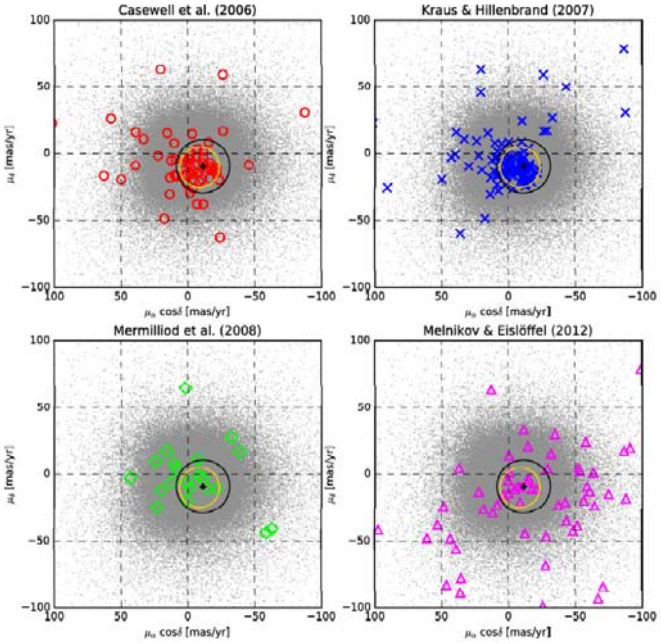
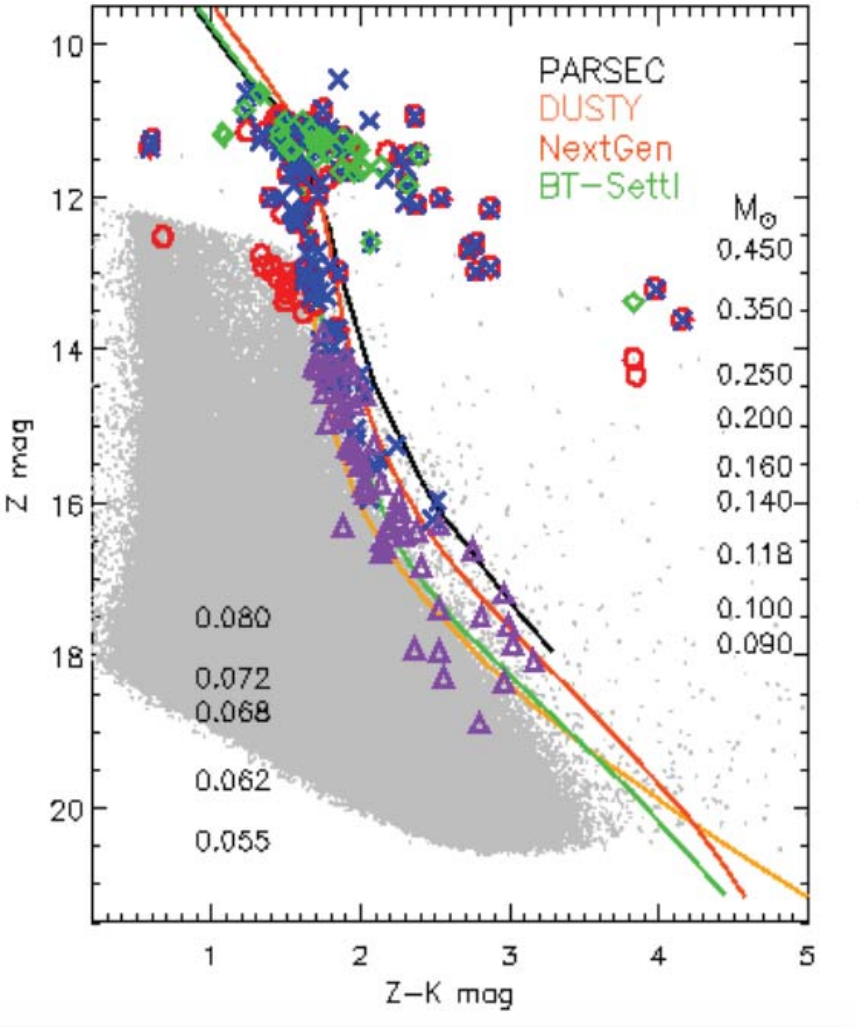
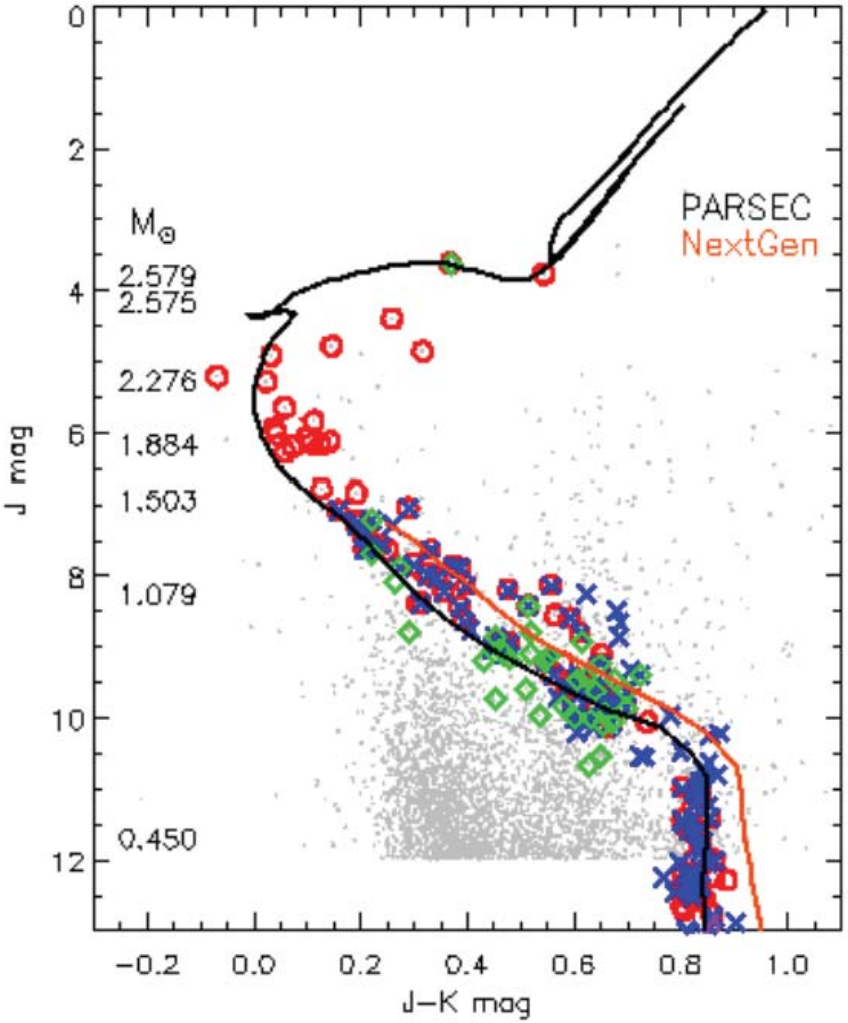


Figure 2. UKIDSS/GCS Proper motion vector plots for members identified by (a) Casewell et al. (2006), (b) Kraus & Hillenbrand (2007), (c) Mermilliod et al. (2008), and (d) Melnikov & Eislöffel (2012). In each case, the black circle marks a radius 20 mas yr^{-1} centered at $(\mu_\alpha \cos\delta, \mu_\delta) = (-11, 21, -9.16)$ mas yr^{-1}, whereas the yellow circle has a radius 15 mas yr^{-1} centered at $(\mu_\alpha \cos\delta, \mu_\delta) = (-8.5, -10.0)$ mas yr^{-1}, within which we selected faint candidates.

UKIDSS/GCS



2MASS

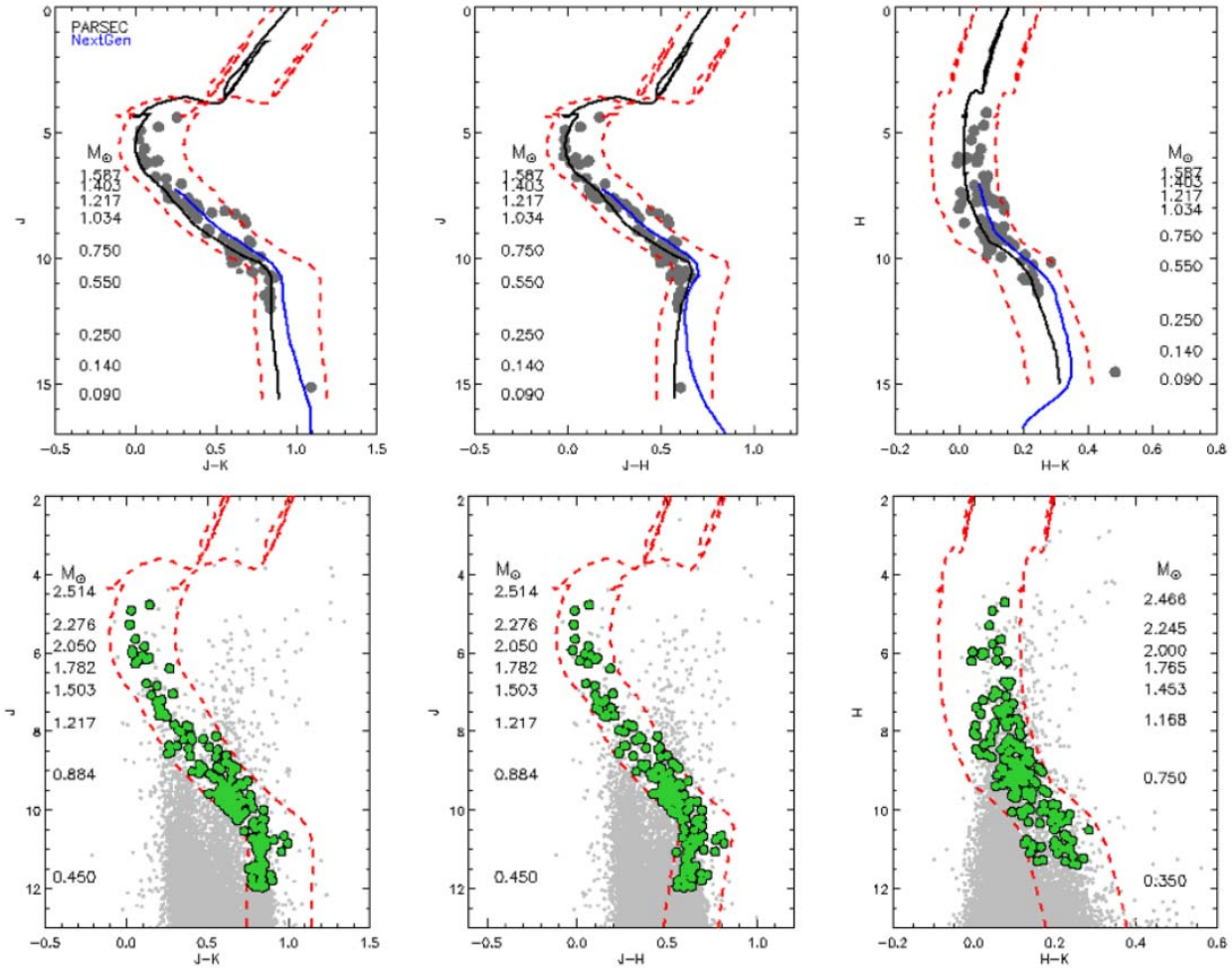


Casswell+06 Kraus & Hillenbrand 07 Mermilliod+08 Melnikov & Eislöffel 12 $J_{2MASS} < 12$ mag or $J_{GCS} > 12$ mag

What Colors to diagnose?

The bright sample
is vastly enlarged …

Known members/candidates



Our candidates (J < 12, URAT1 PM within 15 mas yr^{-1})

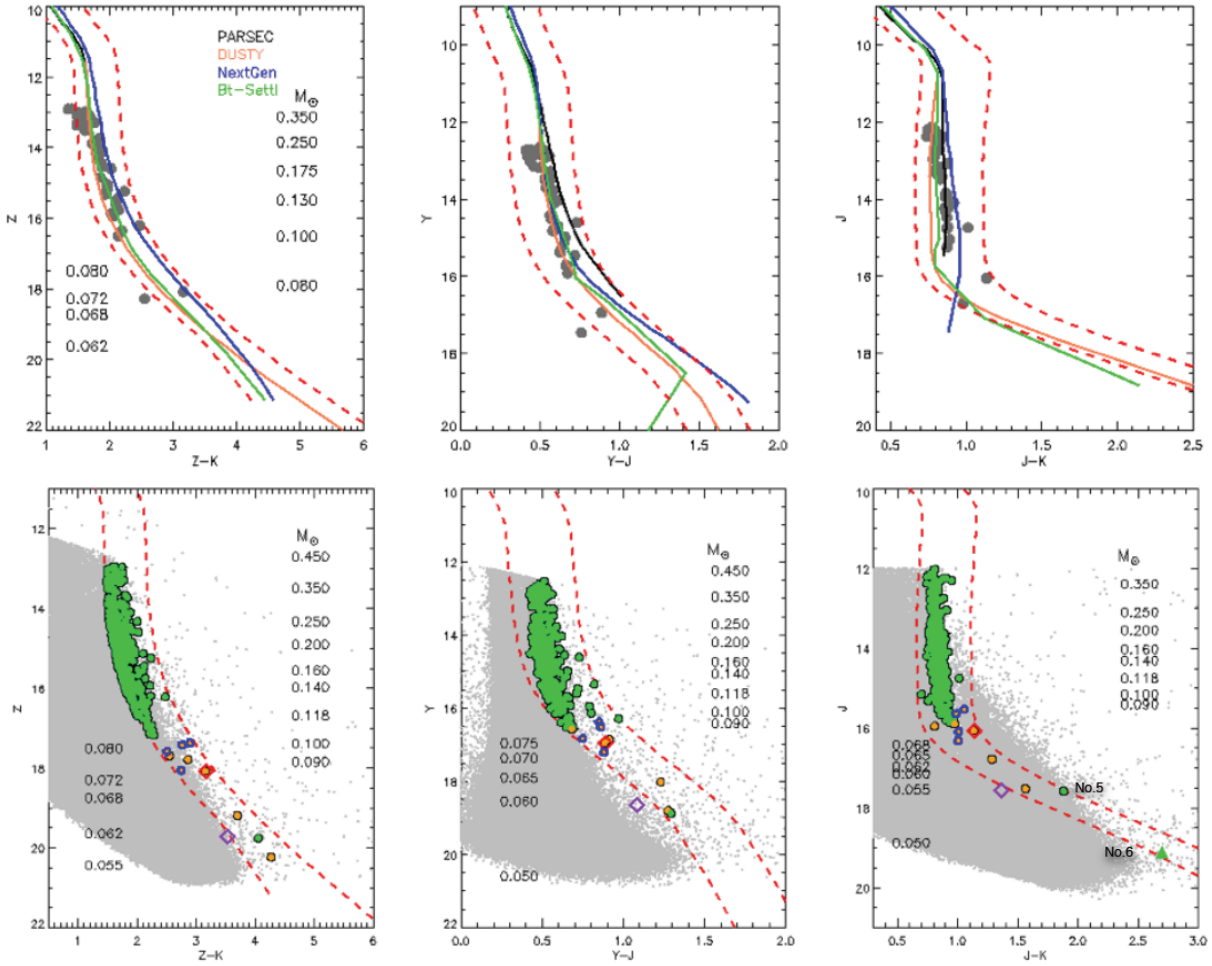
… and so is the faint sample

- Z vs $Z-K$ good for cool BDs
- J vs $J-K$ not as useful, except for very red BDs too faint at Z

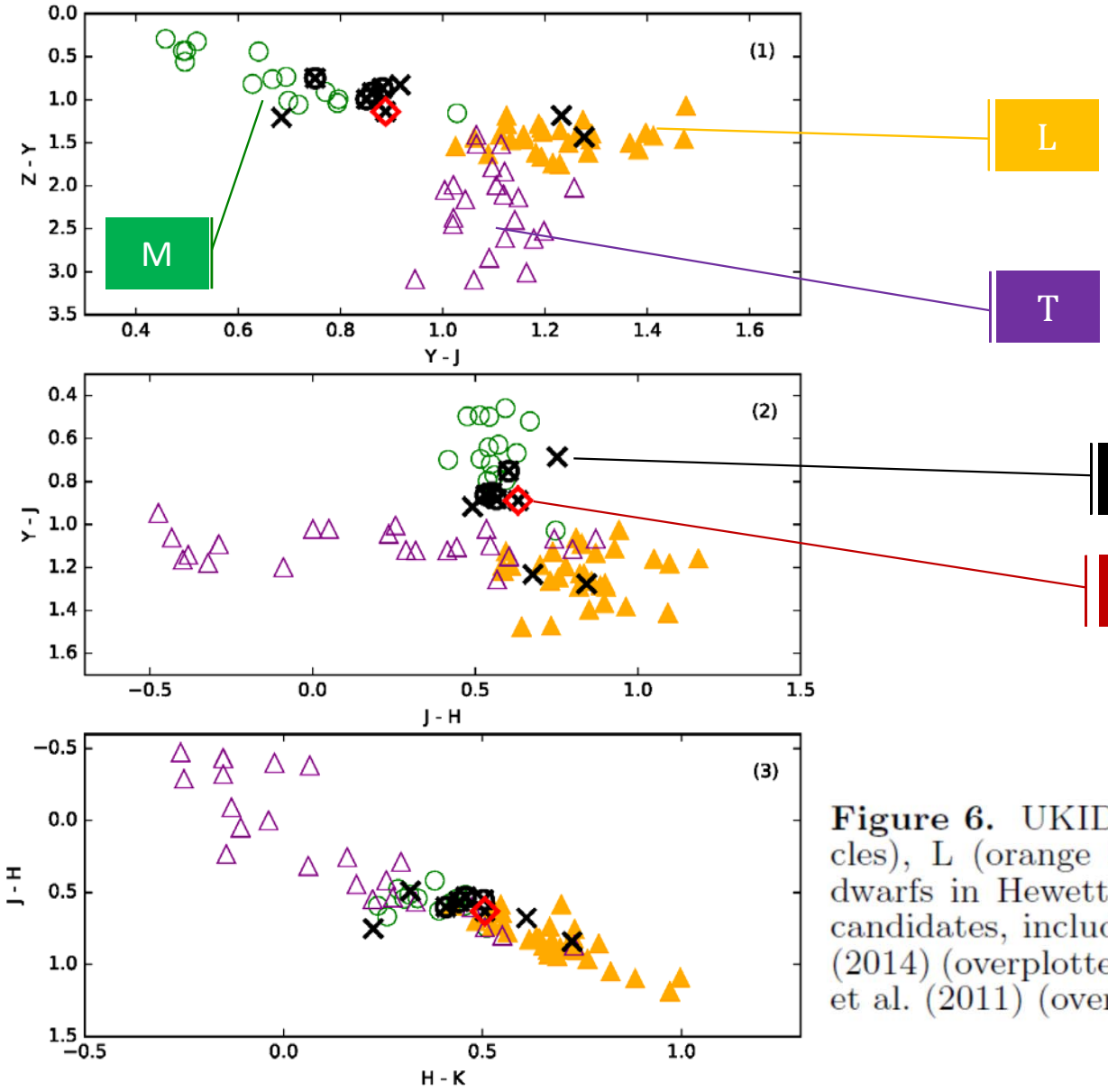
· photerr < 0.2 mag
∘ Our BD candidates
∘ Sp M stars (West+11) 4 in our list
◊ BDs (Casswell+14) one is our candidate (M9), one is not (L1)

No. 6 not detected at Z

Known members/candidates



Our candidates (J > 12, UKIDSS PM within 15 mas yr^{-1})



Our candidates have UKIDSS colors consistent with BDs in the field.

Figure 6. UKIDSS two-color diagrams of the M (green open circles), L (orange filled triangles), and T (purple open triangles) dwarfs in Hewett et al. (2006). The black crosses represent our candidates, including the M9 member reported by Casewell et al. (2014) (overplotted with a red diamond), and the M dwarfs in West et al. (2011) (overplotted with black open circles).

Our brown dwarf candidates

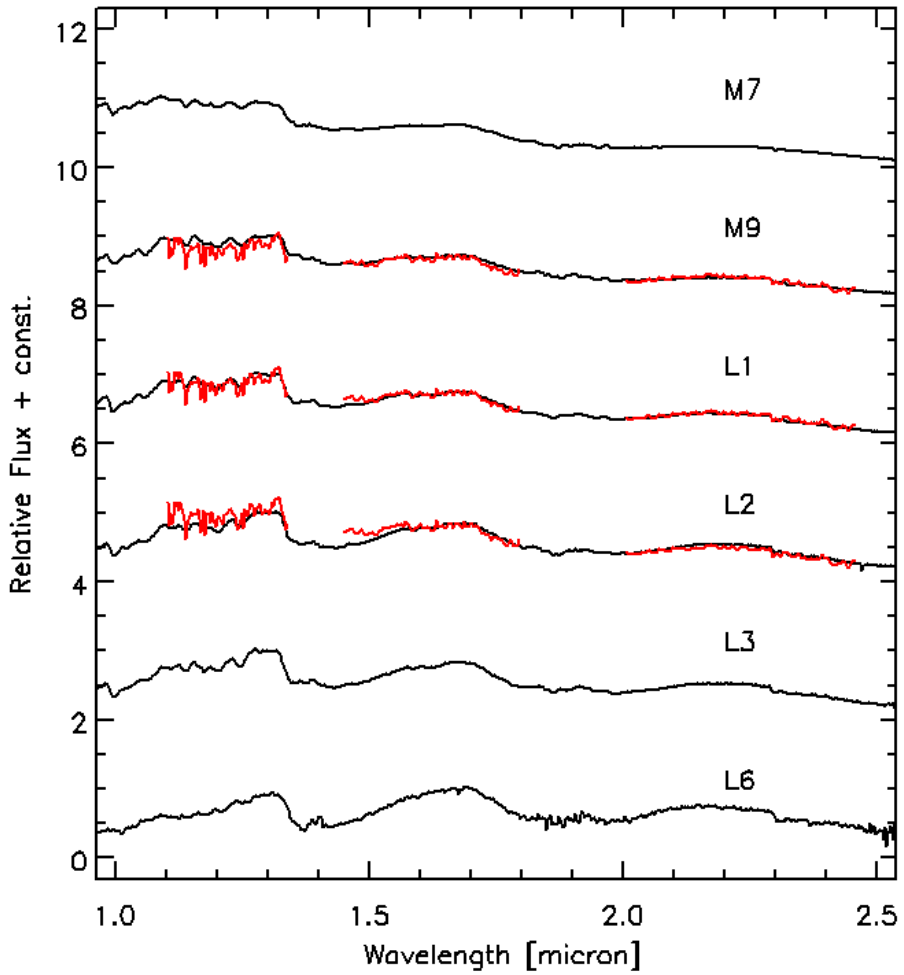
Table 1
Very Low-mass Candidates of the Coma Star Cluster

No.	R.A. [deg]	Decl. [deg]	Z [mag]	Y [mag]	J [mag]	H [mag]	K1 [mag]	$\mu_\alpha \cos\delta$ [mas yr^{-1}]	μ_δ [mas yr^{-1}]	Estimated SpT	Measured SpT
1			18.0680	17.2021	16.3201	15.7545	15.3133	-11.3	-5.8	M7	M8[a]
2			17.3756	16.3825	15.5315	14.9799	14.4771	-4.9	-2.0	M7	M8[a]
3			17.5872	16.8390	16.0885	15.4859	15.0781	-10.2	-22.9	M7	M8[a]
4			17.4297	16.5134	15.6511	15.1188	14.6610	-3.5	-12.2	M7	M9[a]
5			18.0889	16.9529	16.0646	15.4329	14.9268	-13.5	-5.3	M9	M9[b]
6			17.7934	16.5876	15.9029	15.1508	14.9253	-13.0	2.1	M5	
7			17.7026	16.8755	15.9585	15.4668	15.1479	-3.0	-7.7	M5	
8			19.2019	18.0187	16.7868	16.1094	15.4987	1.4	-8.5	L2	L1.5[c]
9			20.2402	18.8068	17.5300	16.6876	15.9625	-13.0	-1.0	...	L8
10			19.7604	18.8839	17.5882	16.8063	15.7036	-9.4	-3.0	...	...
11			($\sim$ 22.5)	($\sim$ 21.1)	19.1199	17.4459	16.4182	-7.3	-4.6	...	...

[a] West et al. (2011)
[b] Casewell et al. (2014)
[c] This work.

SED spectral typing by least-squares fitting to *iz* (SDSS), *YJHK* (UKIDSS), through *W1/W2* photometry (Skrzypek+15)

An L dwarf member in the Coma Ber star cluster



Palomar/TripleSpec

Tang+17

Conclusions

- Coma Ber dissolving, or bound with many uncatalogued members
- A total of 11 brown dwarf candidates have been identified, on the basis of proper motions, near-infrared magnitudes/colors, and spectral energy distributions, in the nearby Coma Berenices star cluster. Four are possible newly found.
- One L1.5 is confirmed by Palomar spectra, the first and coolest member for this cluster.
- Our sample excludes a few spectroscopic BDs previously found.
- J versus J-K not as discriminating as Z versus Z-K for cool (L or perhaps T) dwarfs.

- Most known brown dwarfs and planet-mass objects are in the field, so have aged ↔ exoplanets
- To study their formation and early evolution → a young sample
- Brighter when younger. But even the nearest SFRs fall far.
- Strategy:

☐ Wide-field IR molecular "line imaging" (methane or water) surveys for candidates, e.g., with CFHT/WIRCam

Large mirrors to confirm, e.g., with Gemini/VLT/Subaru

☐ Next: Wide-field imaging by 8 m class telescopes, e.g., Subaru

Giant telescopes for spectroscopic confirmation, e.g., TMT, GMT