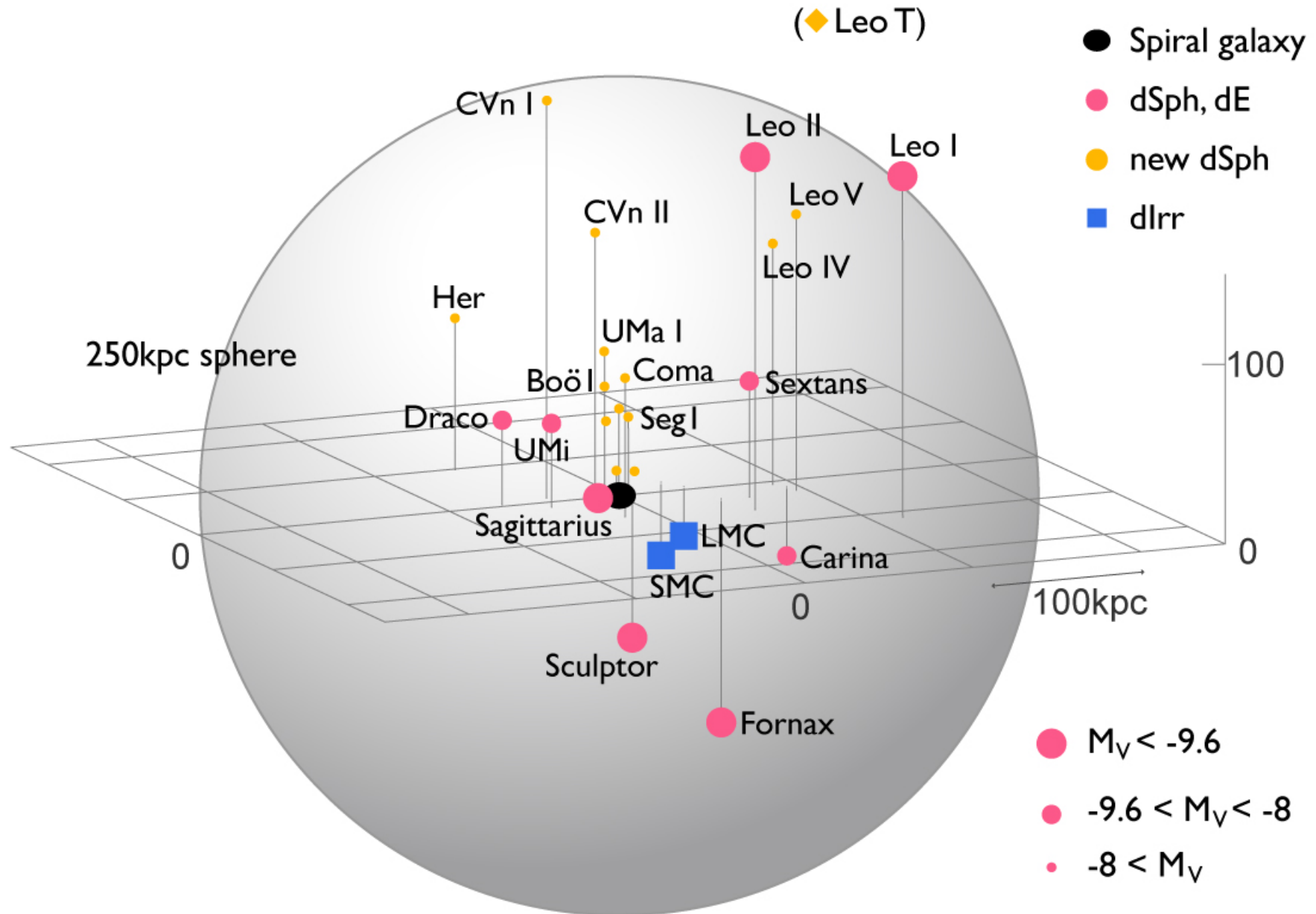


Galaxy Formation Conference, Durham
19 July, 2011

The Stellar Populations of Ultra Faint Dwarf Galaxies

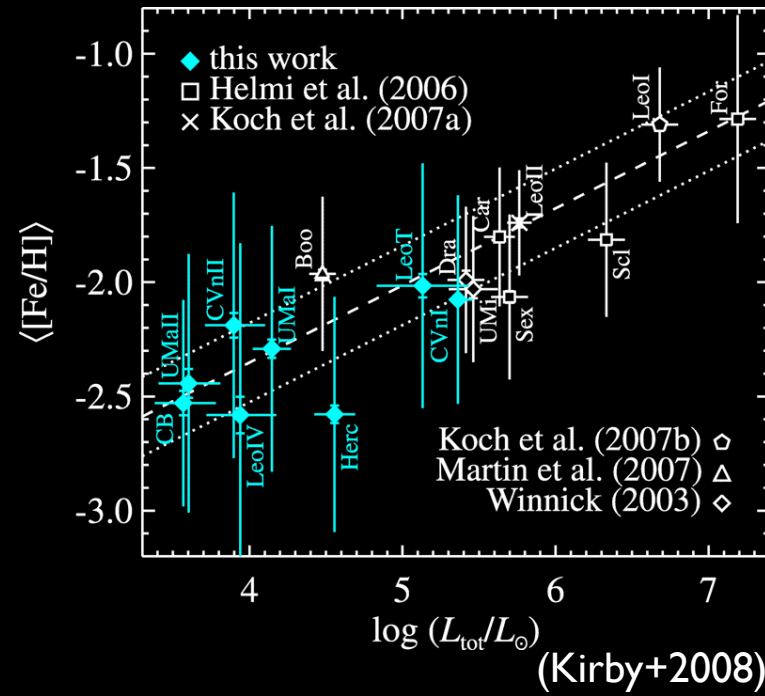
Sakurako Okamoto
Kavli Institute of Astronomy and Astrophysics, Peking University

dwarf satellites around the Milky Way



dwarf satellites around the Milky Way

Name	M _v [mag]	D [kpc]	[mag]	[Fe/H]	log (L _{tot} /L _⊙)	Age	Metallicity
Sgr / Fornax	-13.4 / -13.0	24 / 138	25.1	-1.2	4.7	old?	simple?
Leo I / Sculptor	-11.9 / -10.7	250 / 79	22.1	-1.5	4.4	old?	simple?
Leo II / Carina	-9.6 / -9.3	204 / 105	24.1	-1.8	4.1	old?	simple?
Sextans	-9.5	93		-2.2	5.8	old?	simple?
Draco	-9.1	83		-2.5	5.5	old?	simple?
Ursa Minor	-8.9	64		-2.8	5.2	old?	simple?
CVn I	-7.8	220		-2.2	4.5	old?	simple?
UMa I	-6.8	97		-2.5	4.2	old?	simple?
Her	-6.0	140		-2.8	4.8	old?	simple?
Boo I	-6.0	66		-2.5	4.5	old?	simple?
Leo IV	-4.9	160		-2.8	4.1	old?	simple?
CVn II	-4.9	150		-2.5	4.5	old?	simple?
UMa II / Coma	-3.8/-3.7	30 / 44		-2.8	4.2	old?	simple?
Boo II,,,	-2.3	42		-2.8	4.8	old?	simple?
LeoT	-7.0	420		-2.8	5.2	young? old?	Extended?



bright

faint

Subaru/Suprime-Cam observation of UFDs & Draco, UMi, Sextans

Targets : **Ursa Major I** (S05B-006 / PI: N.Arimoto)

Bootes I (S08A-022 / PI: S.O.)

Canes Venatici I (S08A-022)

Canes Venatici II (S08A-022)

Leo IV (S08A-022)

Hercules (S09B-068 / PI: M. Grossi)

Leo T (S08A-022)

+ each control fields (S08A-022)

Draco 5 fields (S08A-022)

Sextans 26 fields, (S05B-006)

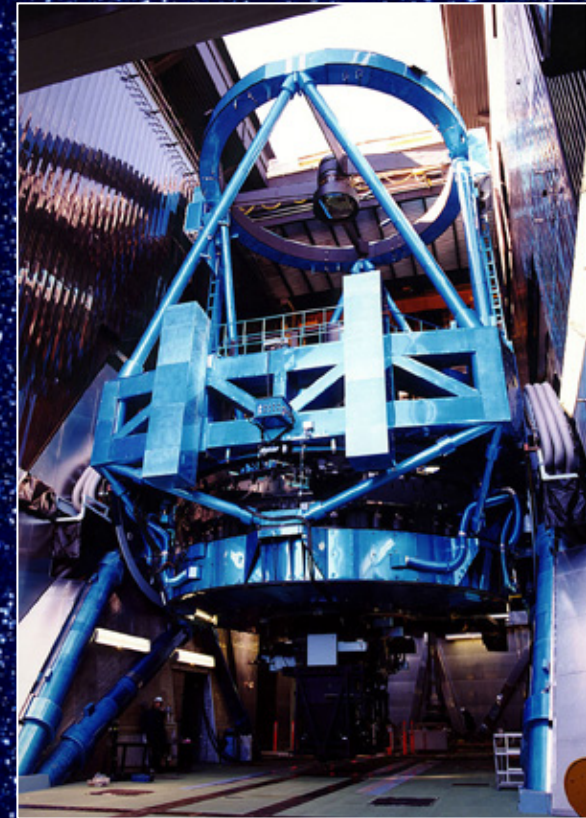
Ursa Minor 2 fields (S09B-068)

Band, exp-time :

V (10s / 600s~)

Ic (30s / 3000s~)

Seeing : 0.7~1.0''

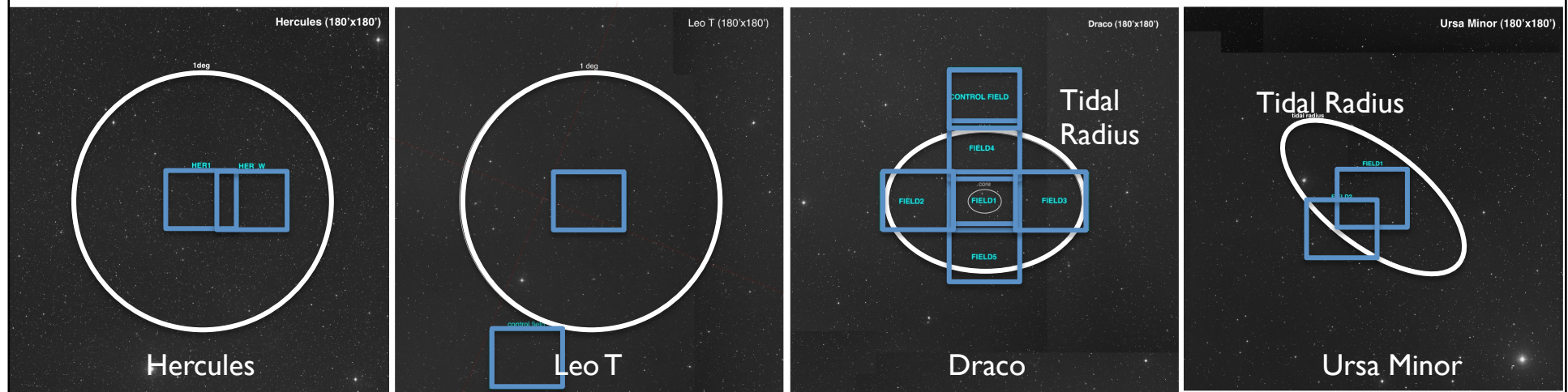
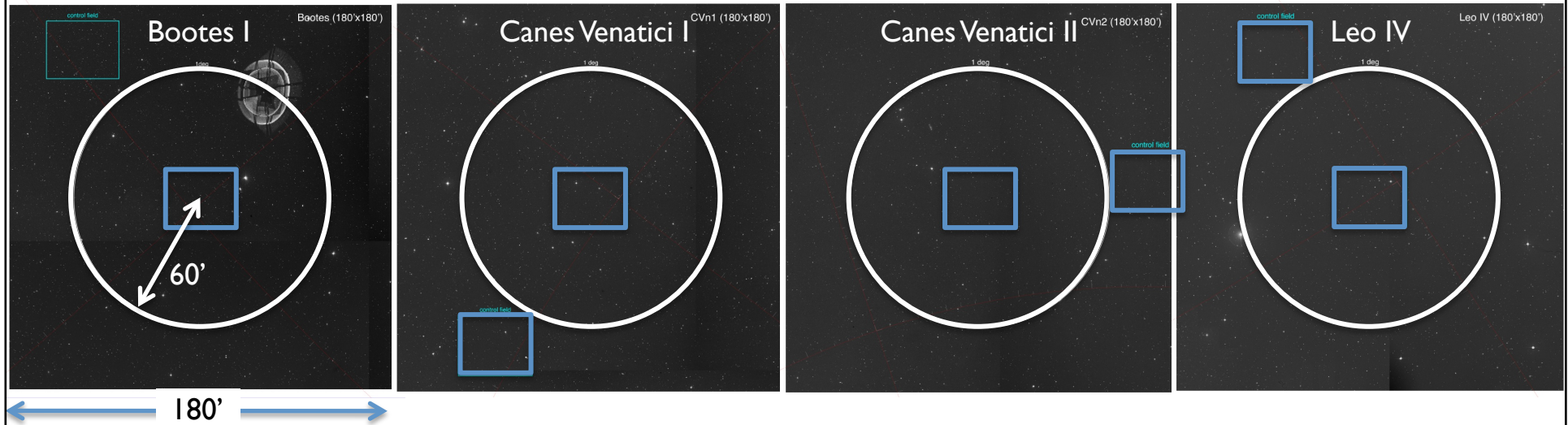


Suprime-Cam :

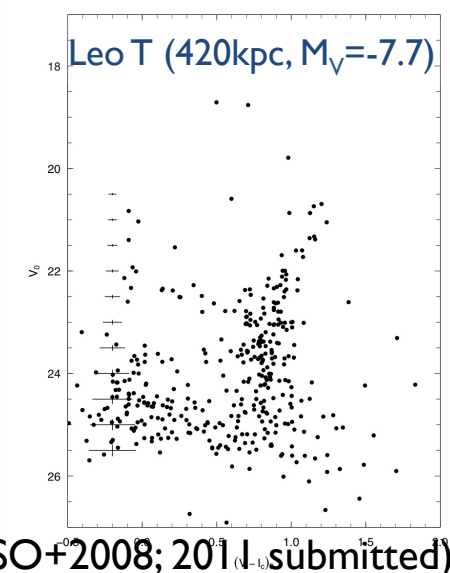
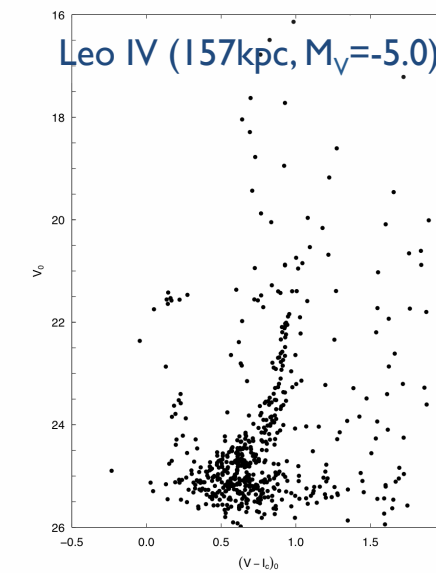
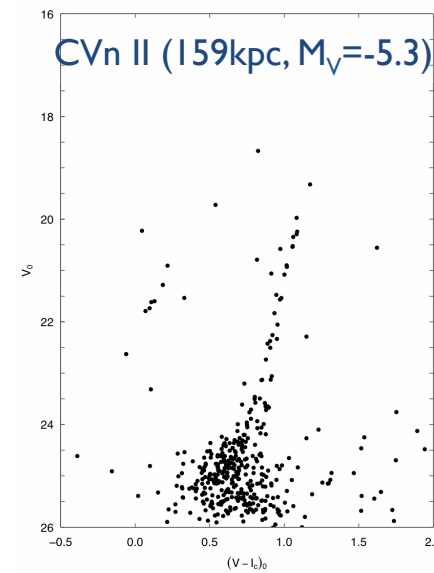
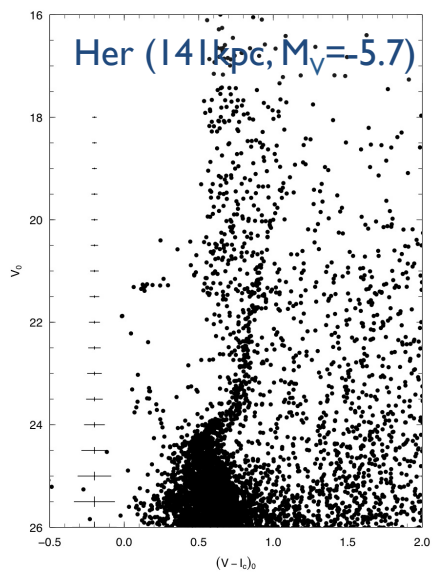
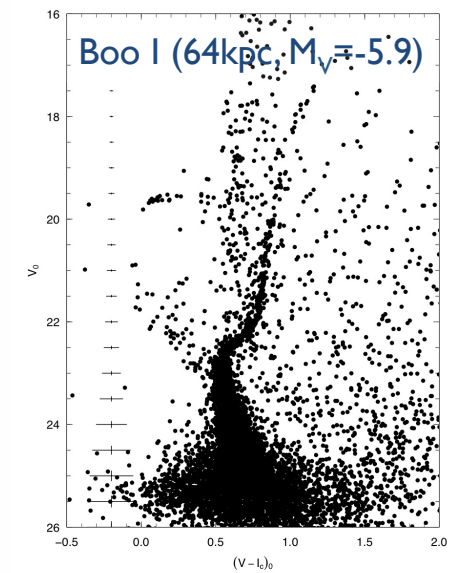
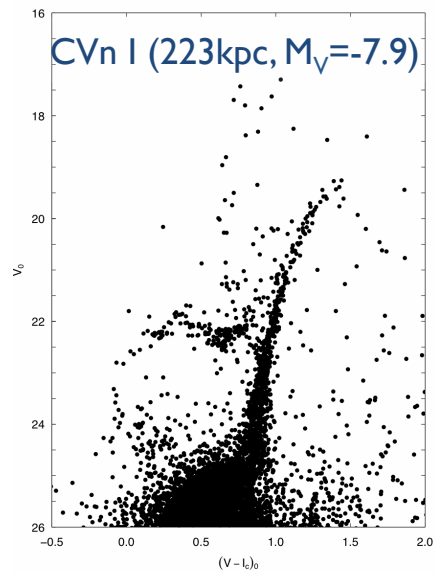
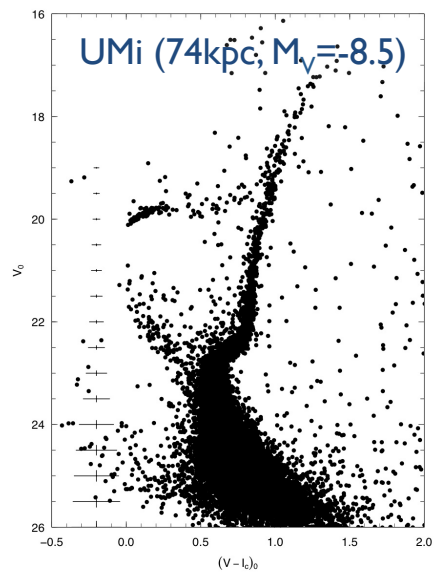
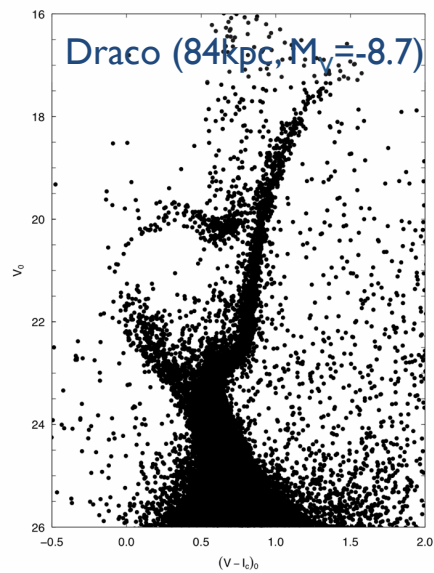
FoV = 34' x 27'

pixel scale = 0.202''

Subaru/Suprime-Cam observation of UFDs & Draco, UMi

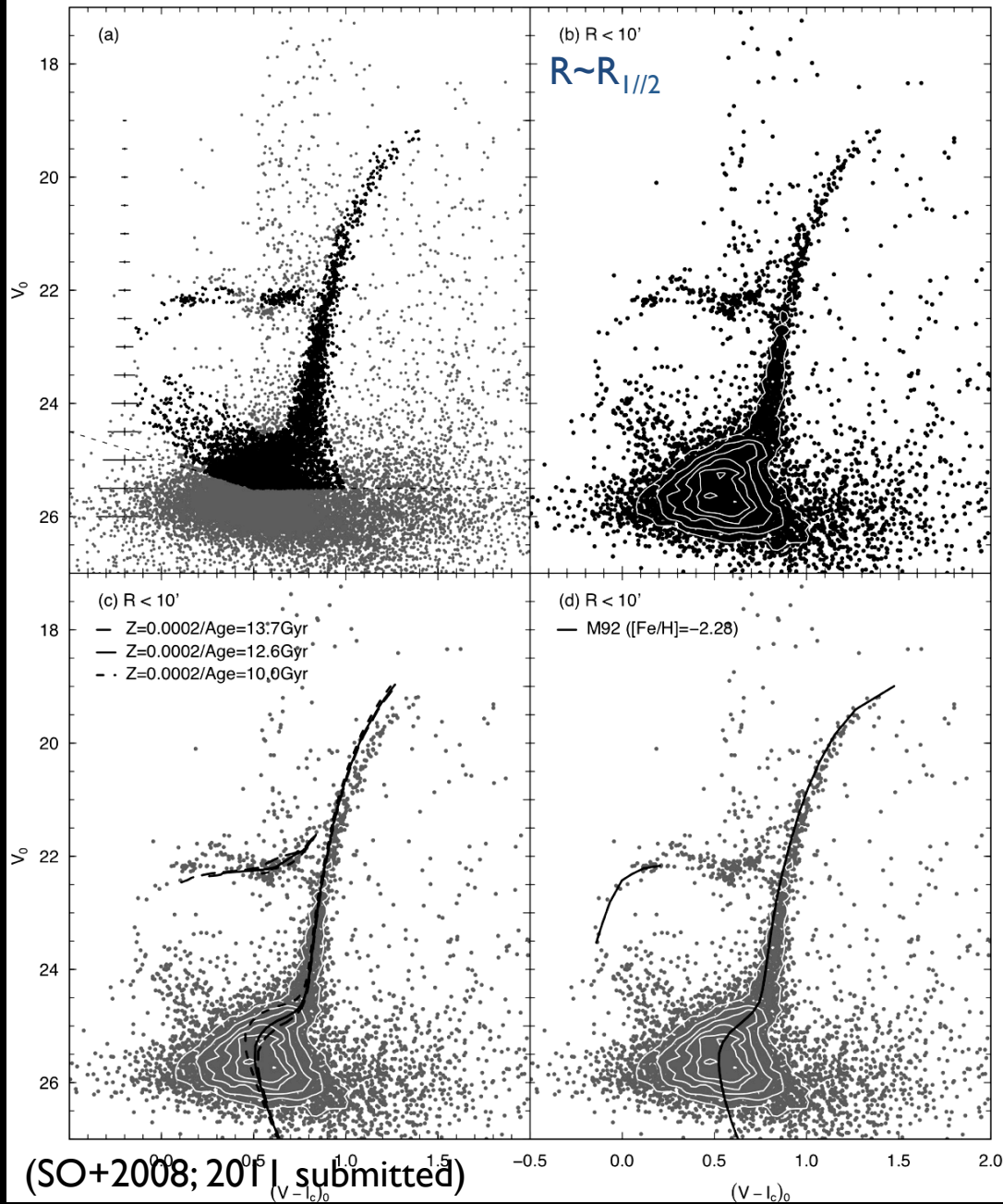


CMDs within $R_{1/2}$



(SO+2008; 2011 submitted)

CVn I



Distance = 223 ± 8 kpc

ellipticity = 0.30

$R_C = 363 \pm 26$ pc

$R_T = 3.5 \pm 0.8$ kpc

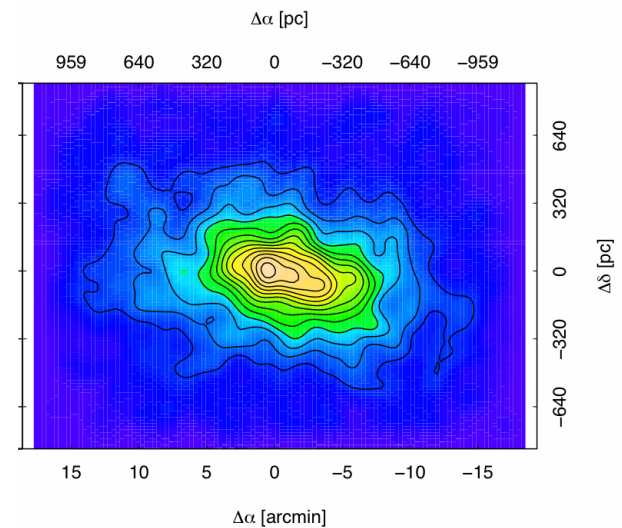
$R_{1/2} = 596 \pm 25$ pc

$M_V = -7.93 \pm 0.2$

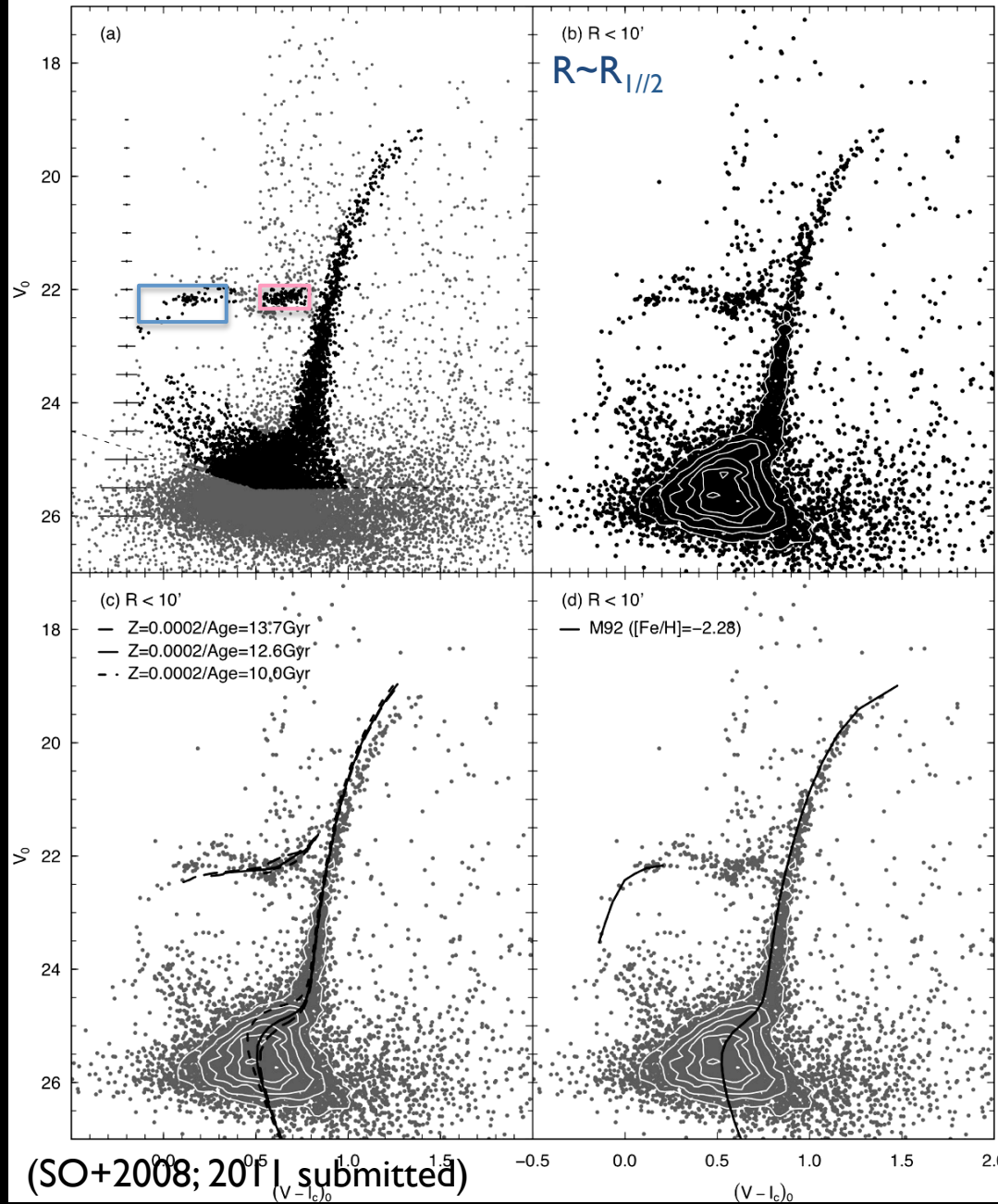
$\mu_0 = 27.5 \pm 0.2$

$[\text{Fe}/\text{H}] = -2.08$ (by Kirby+2008)

Age ~ 12.6 Gyr



CVn I



Distance = 223 ± 8 kpc

ellipticity = 0.30

$R_C = 363 \pm 26$ pc

$R_T = 3.5 \pm 0.8$ kpc

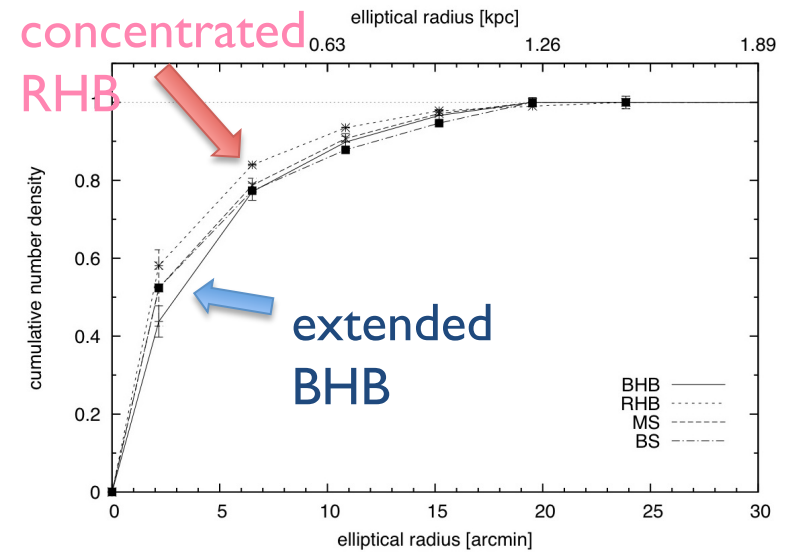
$R_{1/2} = 596 \pm 25$ pc

$M_V = -7.93 \pm 0.2$

$\mu_0 = 27.5 \pm 0.2$

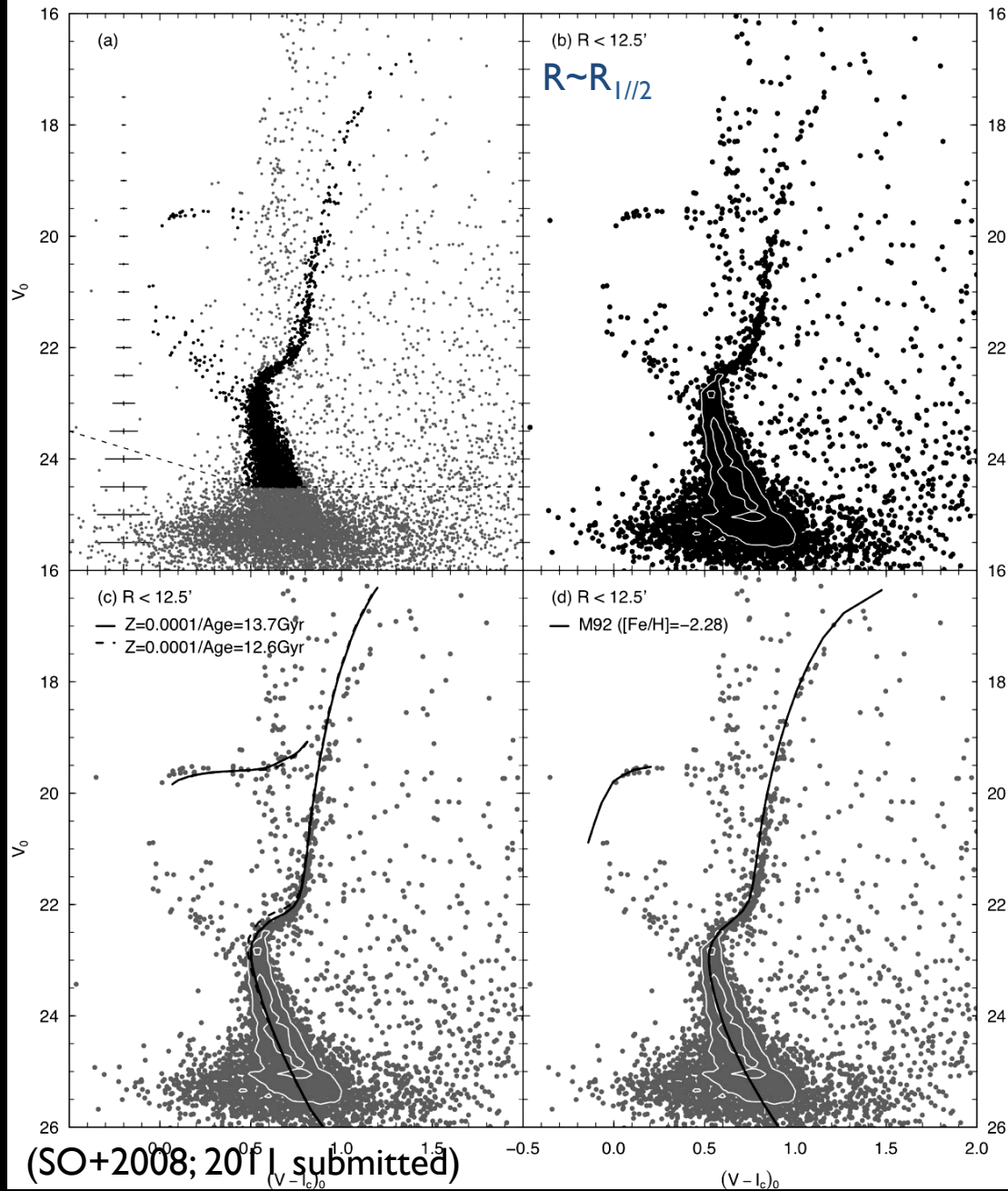
$[\text{Fe}/\text{H}] = -2.08$ (by Kirby+2008)

Age ≈ 12.6 Gyr



(SO+2008; 2011 submitted)

Bootes I



Distance = 65 ± 3 kpc

ellipticity = 0.22

$R_C = 194 \pm 17$ pc

$R_T = 0.7 \pm 0.1$ kpc

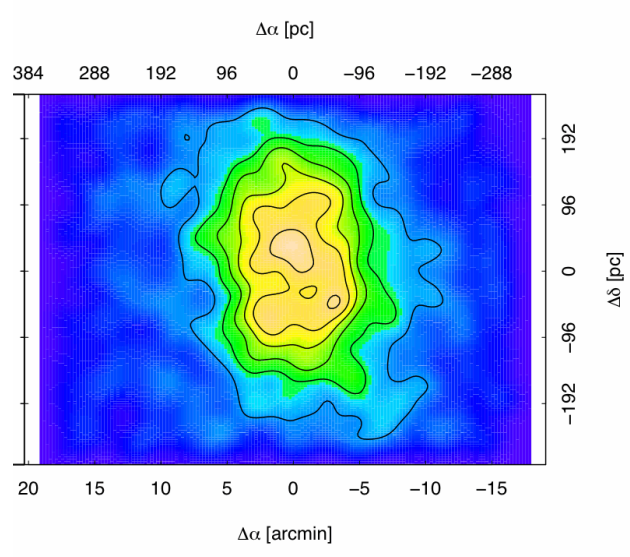
$R_{1/2} = 235 \pm 6$ pc

$M_V = -5.9 \pm 0.2$

$\mu_0 = 27.8 \pm 0.6$

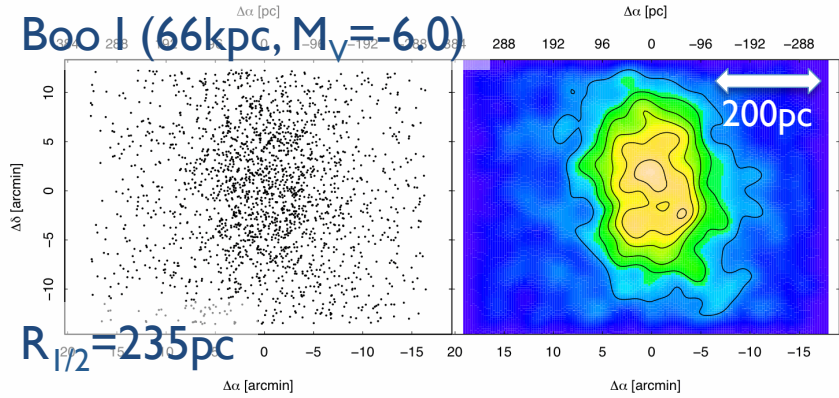
$[\text{Fe}/\text{H}] = -2.5$ (by Norris+2008)

Age ~ 13.7 Gyr

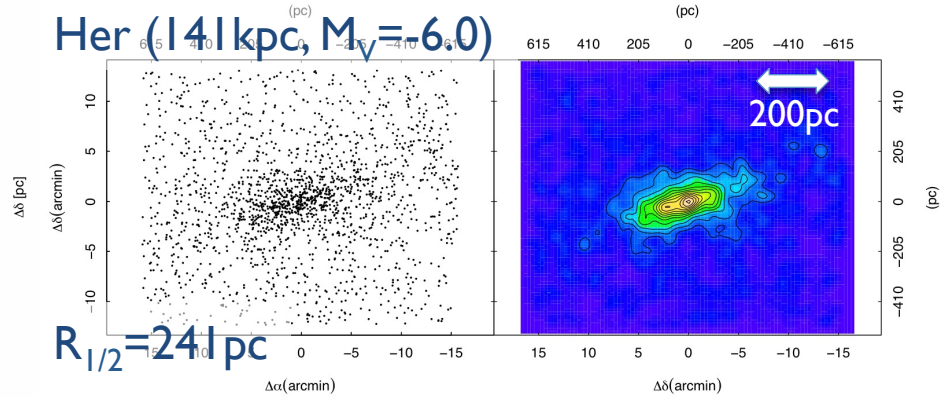


Spatial Distributions of UFDs

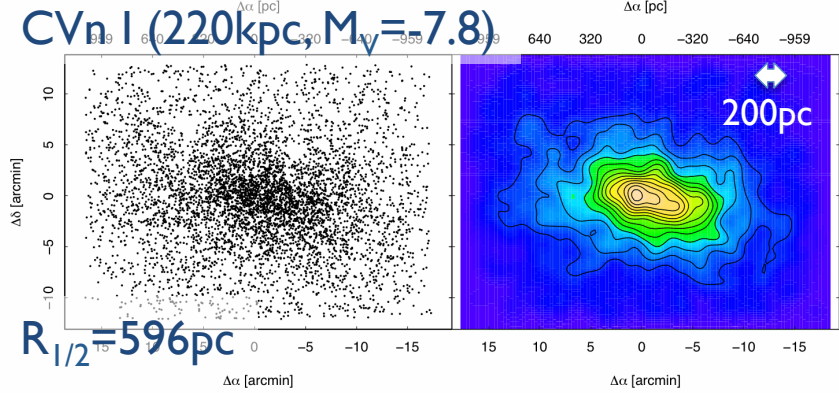
Boo I (66kpc, $M_V = -6.0$)



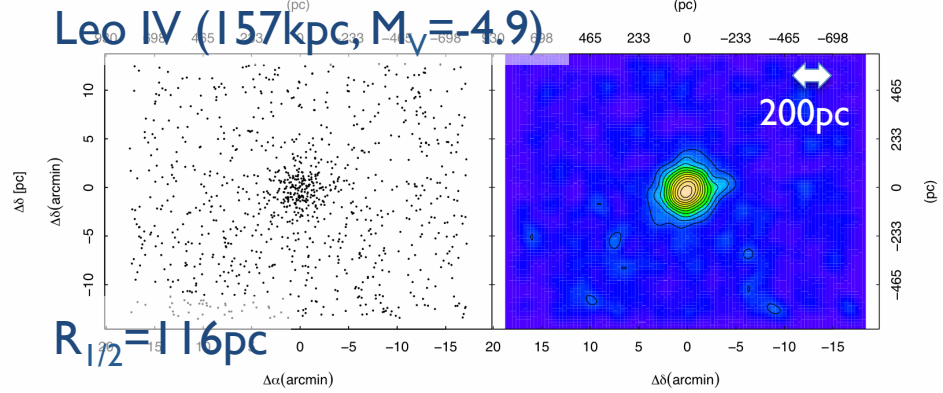
Her (141kpc, $M_V = -6.0$)



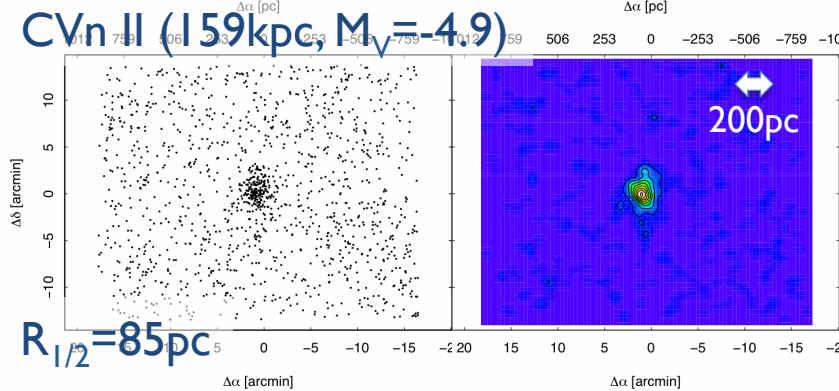
CVn I (220kpc, $M_V = -7.8$)



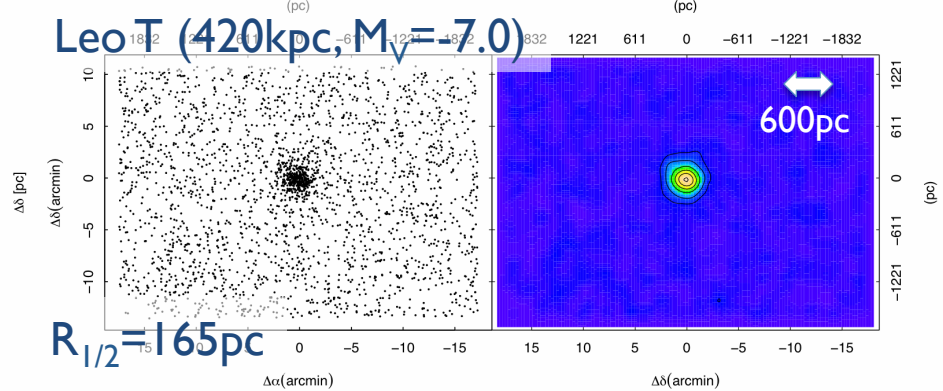
Leo IV (157kpc, $M_V = -4.9$)



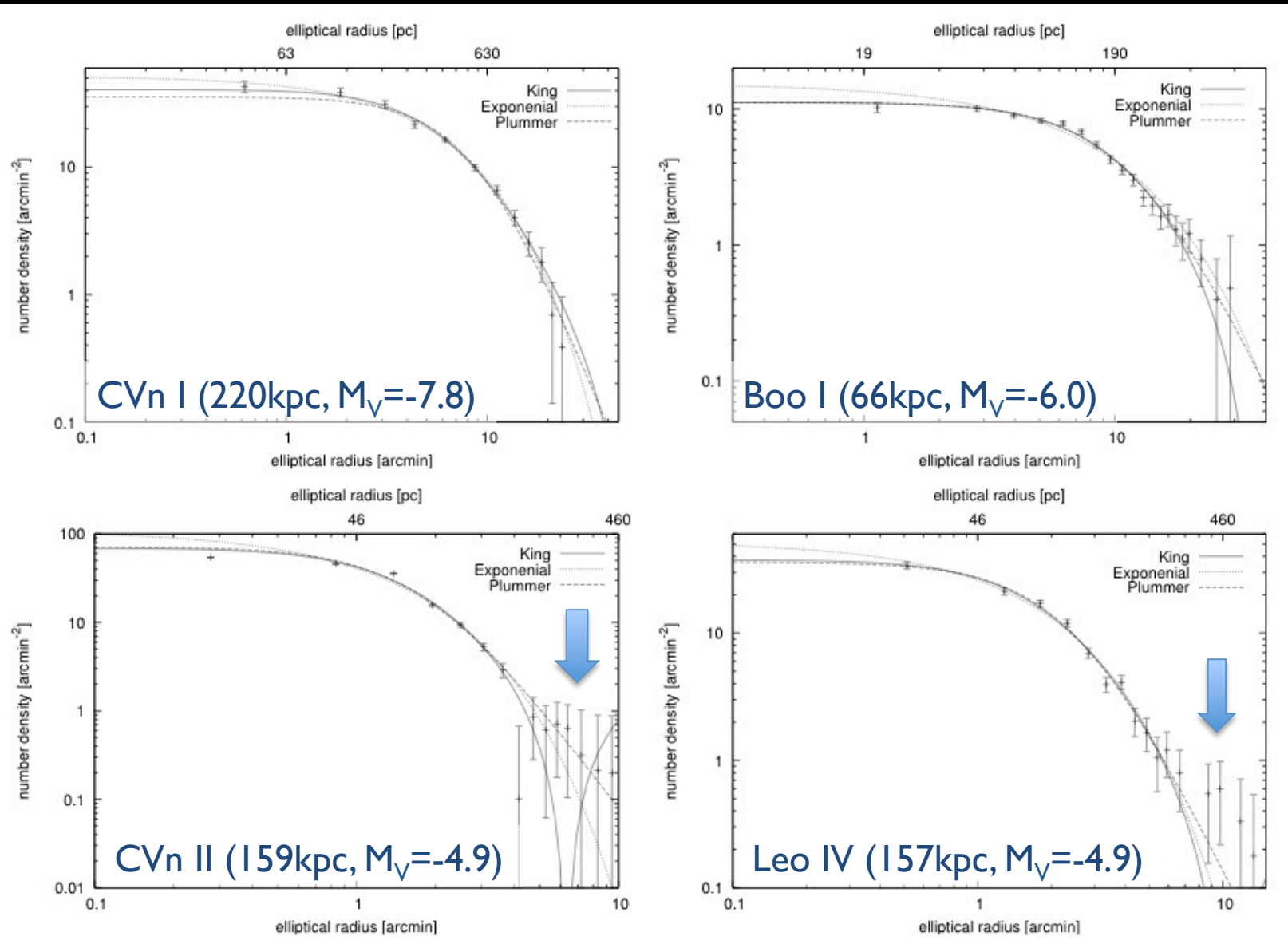
CVn II (159kpc, $M_V = -4.9$)



Leo T (420kpc, $M_V = -7.0$)

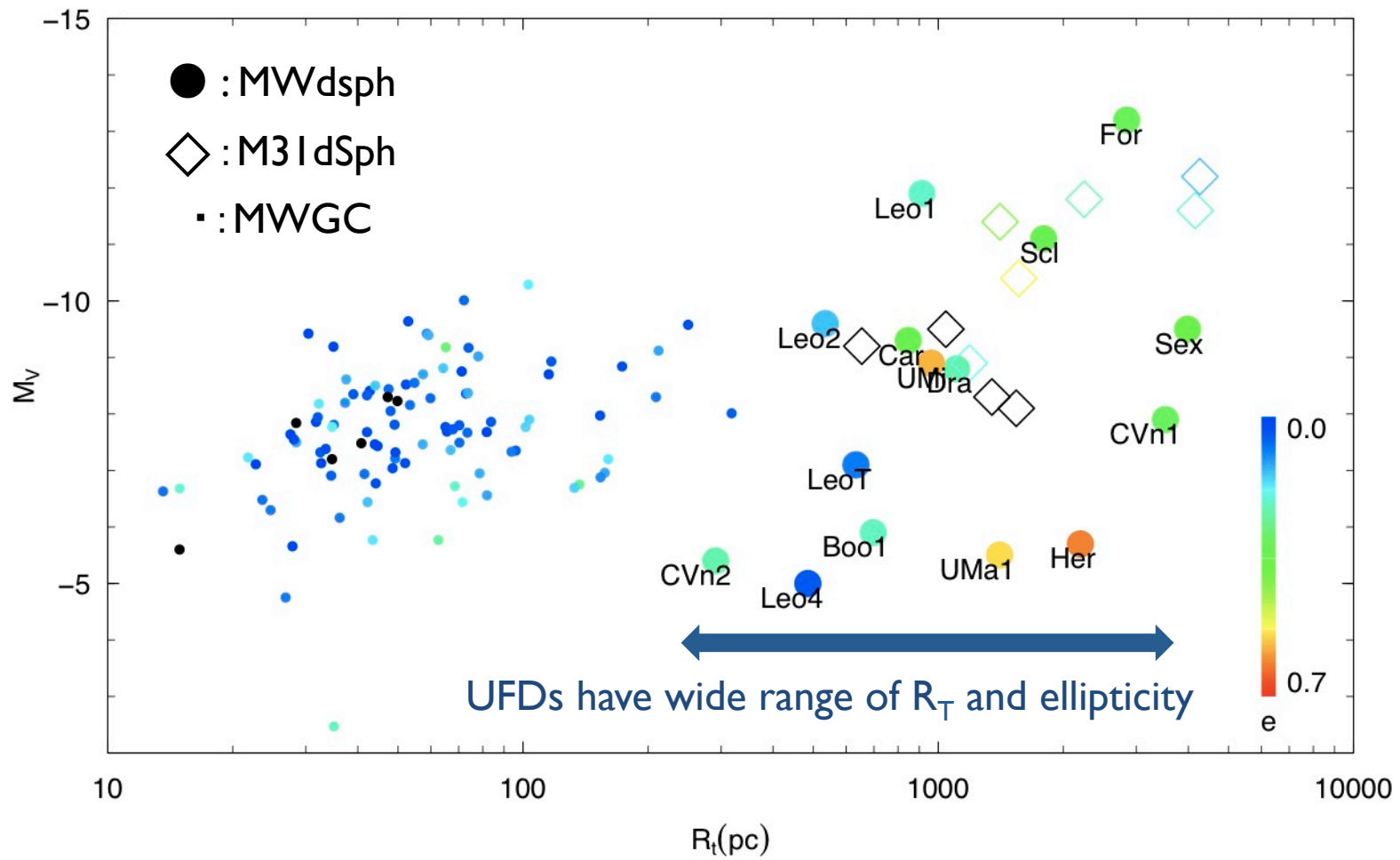


Spatial Distributions of UFDs

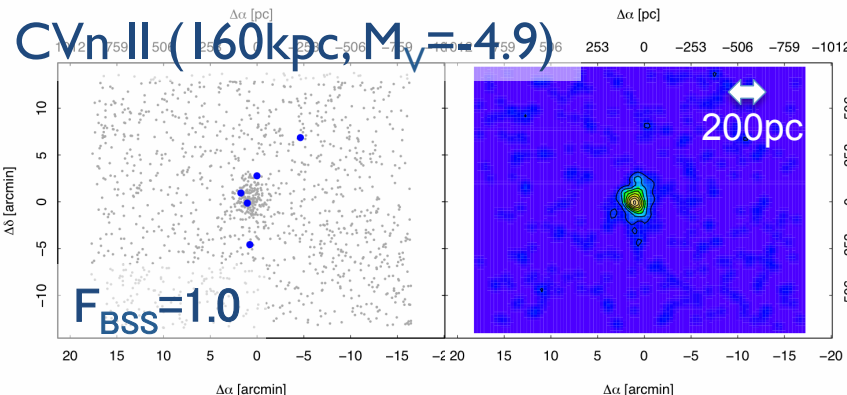
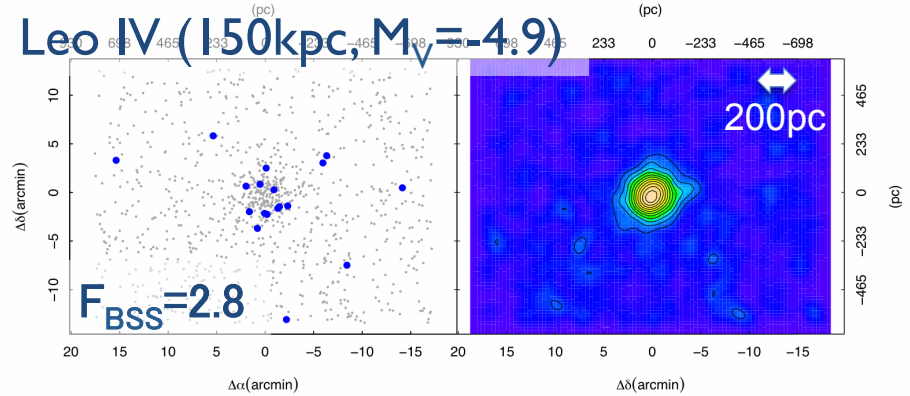
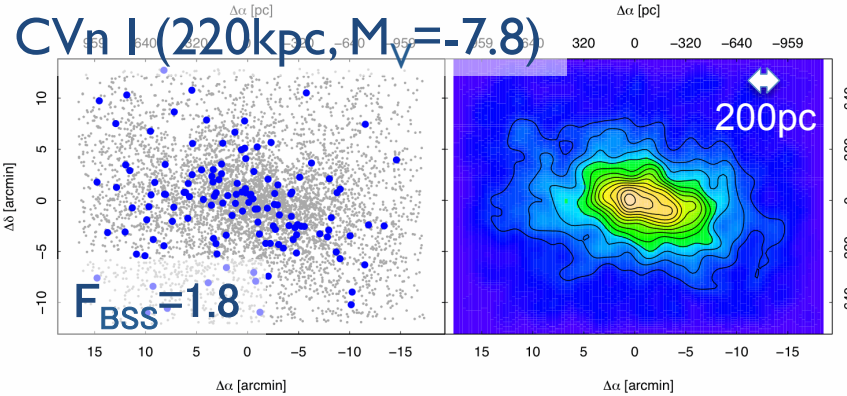
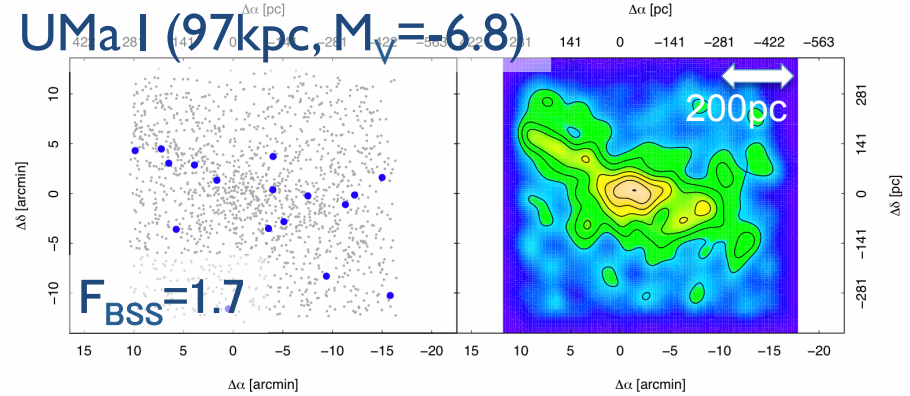
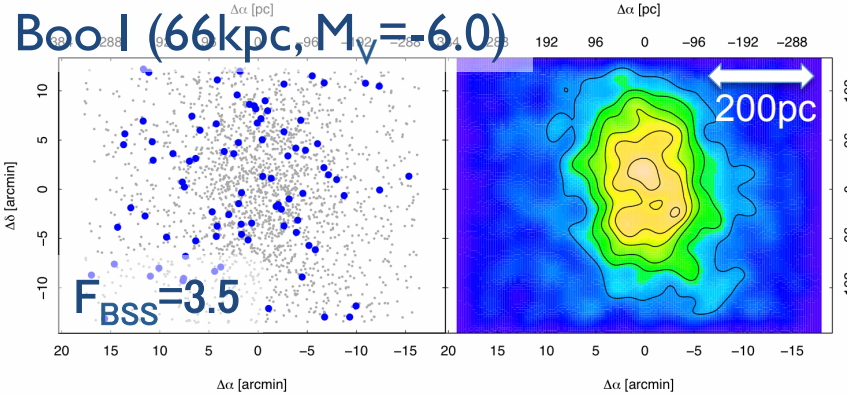


(SO+2008; 2011 submitted)

Tidal radius of UFDs



Blue Straggler Distributions of UFDs



numerous BS candidate in the UFDs

higher frequency than MWGC
(c.f. $F_{BSS,GC} \sim 0.3$)

dwarf satellites around the Milky Way

Name	M_V [mag]	D [kpc]	μ_0 [mag/arcsec ²]	Population	SFH
Sgr / Fornax Leo I / Sculptor Leo II / Carina	-13.4 / -13.0 -11.9 / -10.7 -9.6 / -9.3	24 / 138 250 / 79 204 / 105	25.4 / 23.4 22.4 / 23.7 24.0 / 25.5	inter-age ~ old	Extended or Episodic SF
Sextans Draco Ursa Minor	-9.5 -9.1 -8.9	93 83 64	26.2 25.3 25.5	old+	Extended (a few Gyr)
CVn I	-7.8	220	27.5	old+	simple?
UMa I Her Boo I Leo IV CVn II	-6.8 -6.0 -6.0 -4.9 -4.9	97 140 66 160 150	29.5 27.2 27.8 29.5 28.2	purely old	simple
UMa II / Coma Boo II	-3.8/-3.7 -2.3	30 / 44 42	- / - 27.7	old?	simple?
LeoT	-7.0	420	27.7	young-old	Extended

bright



faint

Star Formation in UFDs

All UFDs (except for CVn I) are the purely-old & metal-poor, and brighter dSphs (Draco, Sextans, CVn I) have complex pop.

UFDs had stopped their SF earlier than bright dSphs.



Gas was removed more efficiently in the progenitor of UFDs

- external effect to remove gas from UFD
 - ✓ re-ionization Shallower potential ?
 - ✓ tidal effect and ram pressure of Milky Way (unlikely...)
 - Accreted at quite early and same epoch ?
 - If so, how they keep such a elongate/distorted shape for a long time ??
- internal effect
 - ✓ SNe feedback Shallower potential ?

Conclusions

- ✓ The fainter UFDs ($M_V > -7$; Boo, UMa, Her, LeoIV, CVnII) show a purely old and metal-poor population.
- ✓ The brighter UFDs ($M_V = -7.8$; CVn I) dSph shows the different spatial distribution of each evolutionally phases (BHB, RHB, RGB,,), as classical dSphs. (e.g. more centrally concentrated metal-rich RHB).
- ✓ The UFDs show the irregular shape, suggesting that strong tidal effect from M.W. The UFDs have wide range of tidal radius.
- ✓ The stellar population of the brighter classical dSphs (Sextans, Draco, UMi) have the spatial gradient.

The UFDs do not have the same stellar pop as bright dSph,
but have older population.