A spectroscopic survey of faint Local Group satellites

Searching for the least massive galaxies

Nicolas Martin (MPIA, Heidelberg), Rodrigo Ibata (Strasbourg), Scott Chapman & Mike Irwin (Cambridge), Geraint Lewis (Sydney)

MNRAS, accepted, astro-ph 0705.4622
+ Ibata et al. (2006), MNRAS 373, L70

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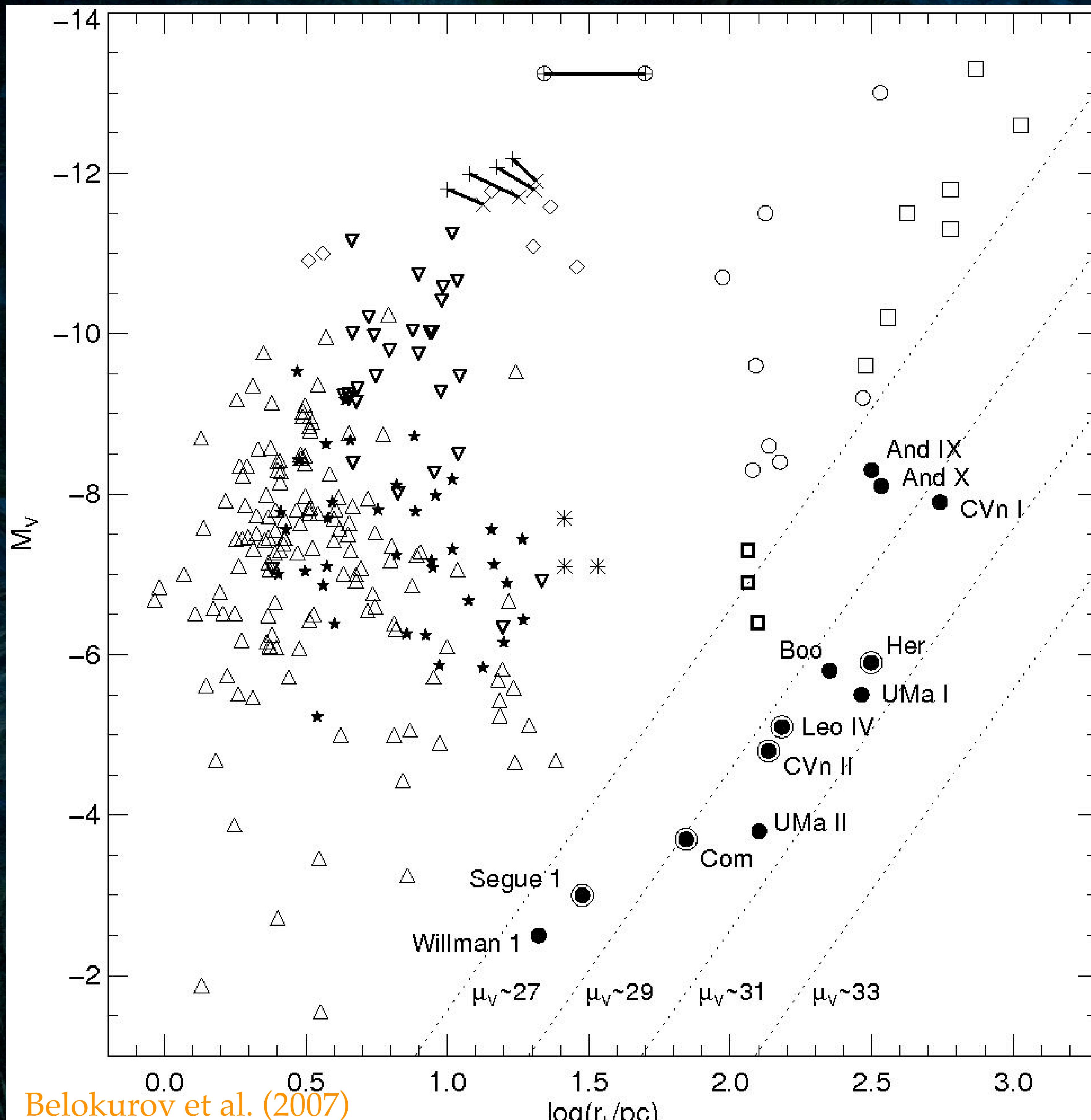
What can we learn from a spectroscopic survey?

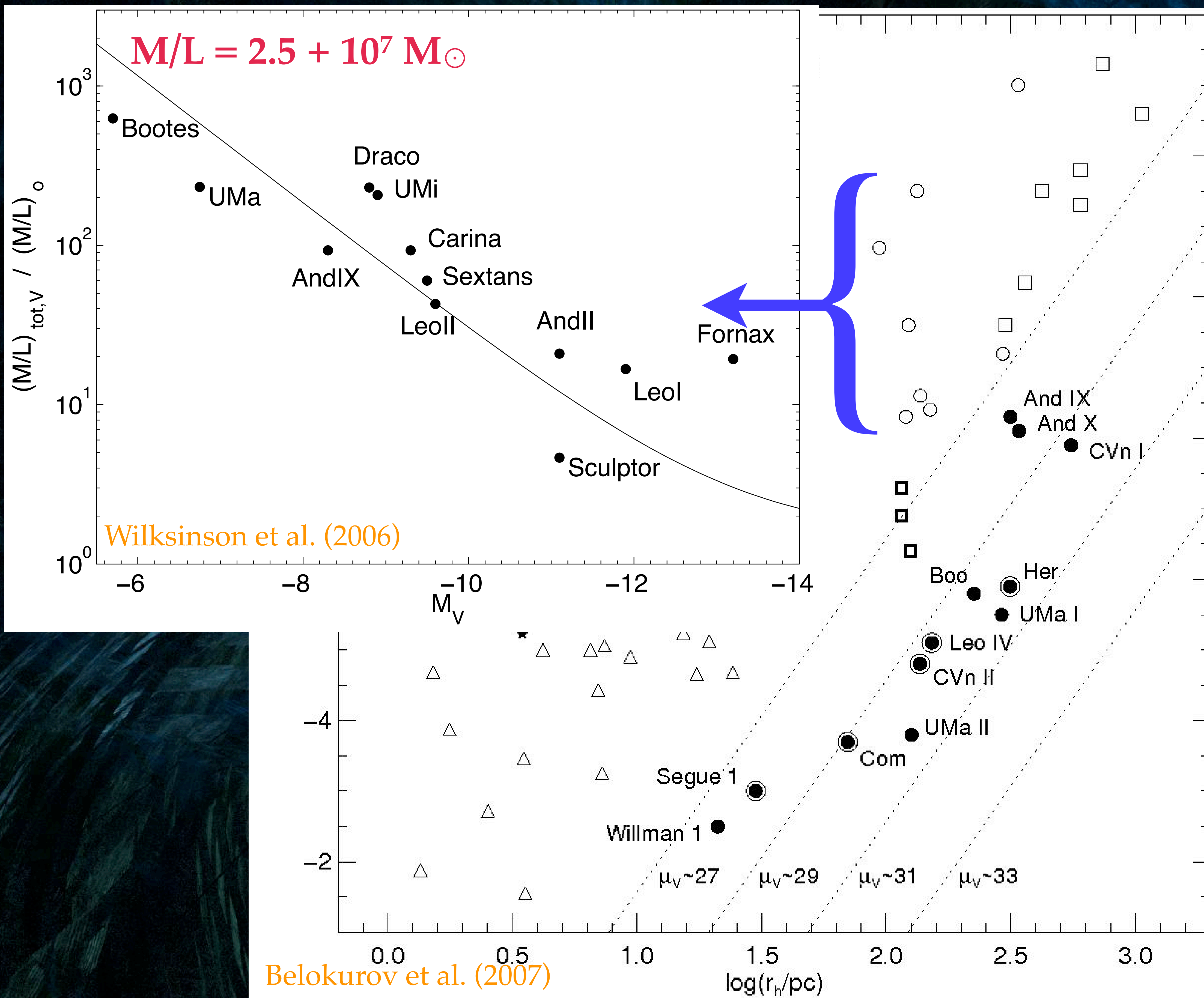
- Radial velocity ➙ first hint of the orbit of the dwarfs (and extreme cases)
- Spectroscopic metallicities
- Velocity dispersion ➙ *instantaneous mass estimate of the system*
  - Illingworth (1976) $M = 167\, r_c\, \mu\, \sigma_0^2$ μ~8 (Mateo 1998)
  - *caveats:*
    - r_c not determined for faint dwarfs ➙ $r_c \sim r_{hb}$ (true within ±25%)
    - Assuming spherical and virialized systems
    - Tidal heating could increase σ but not in the center of the dwarf (Piatek & Pryor, 1995)
    - Binaries?

Faint SDSS satellites

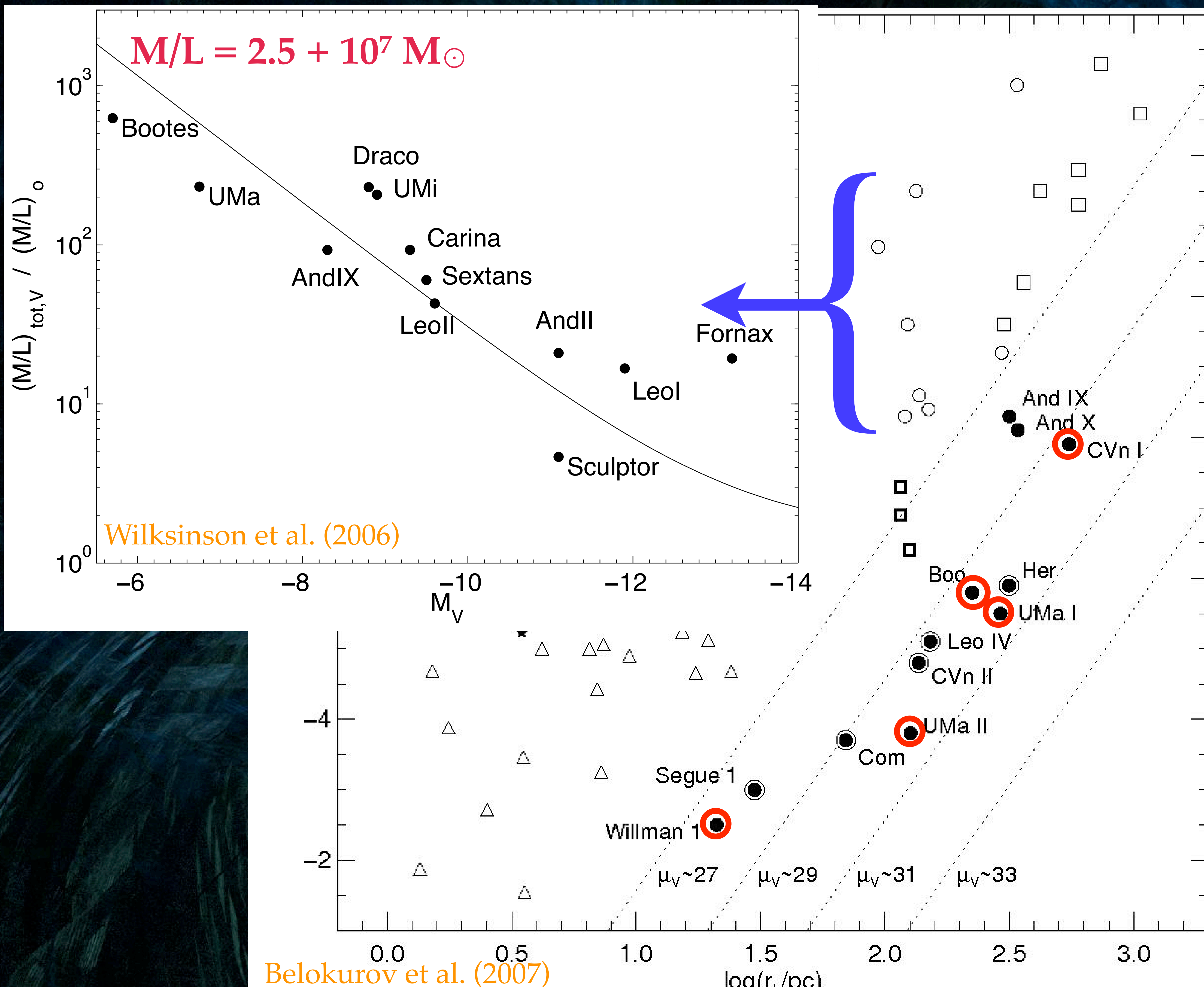


Belokurov et al. (2007)

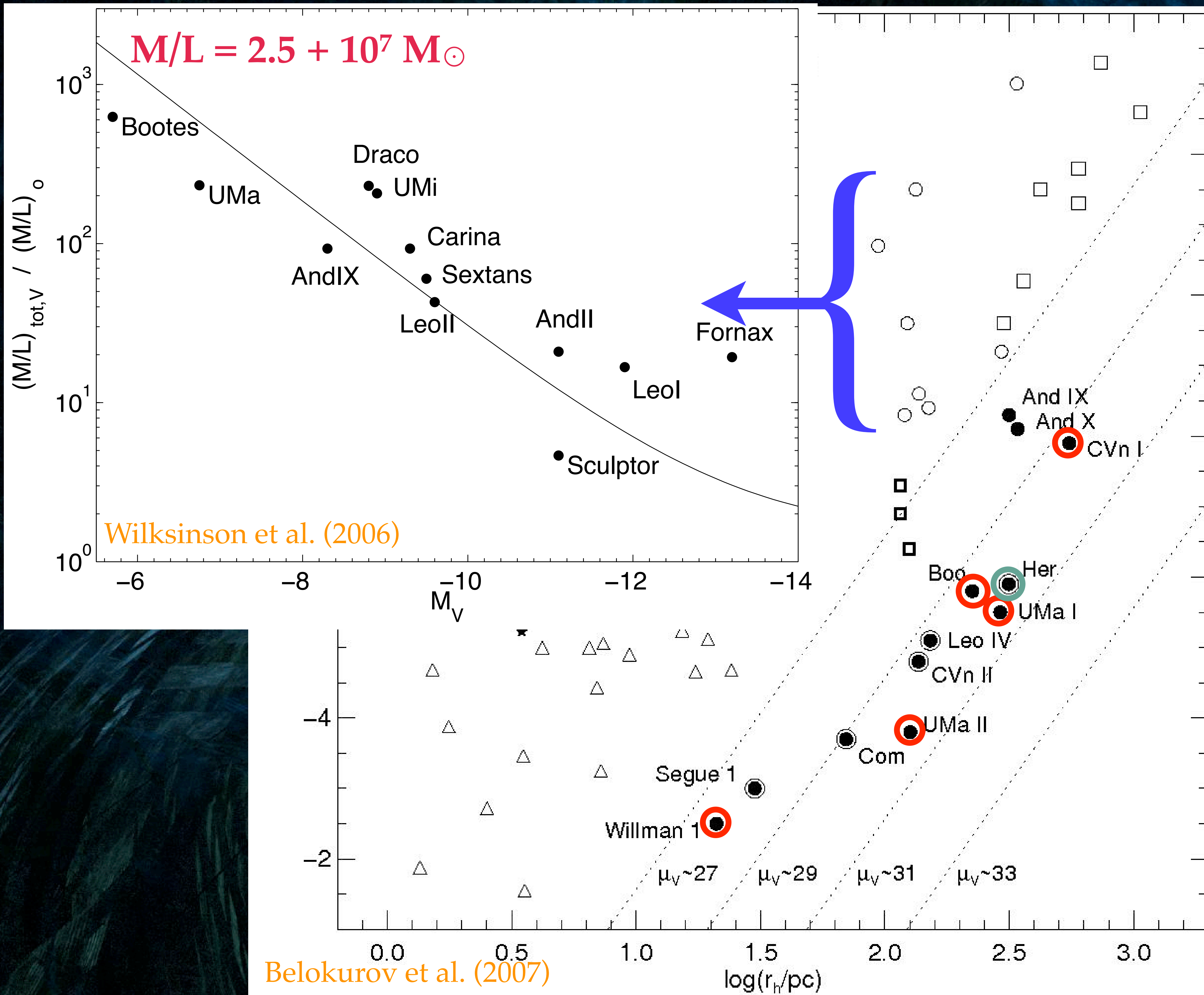
Faint SDSS satellites



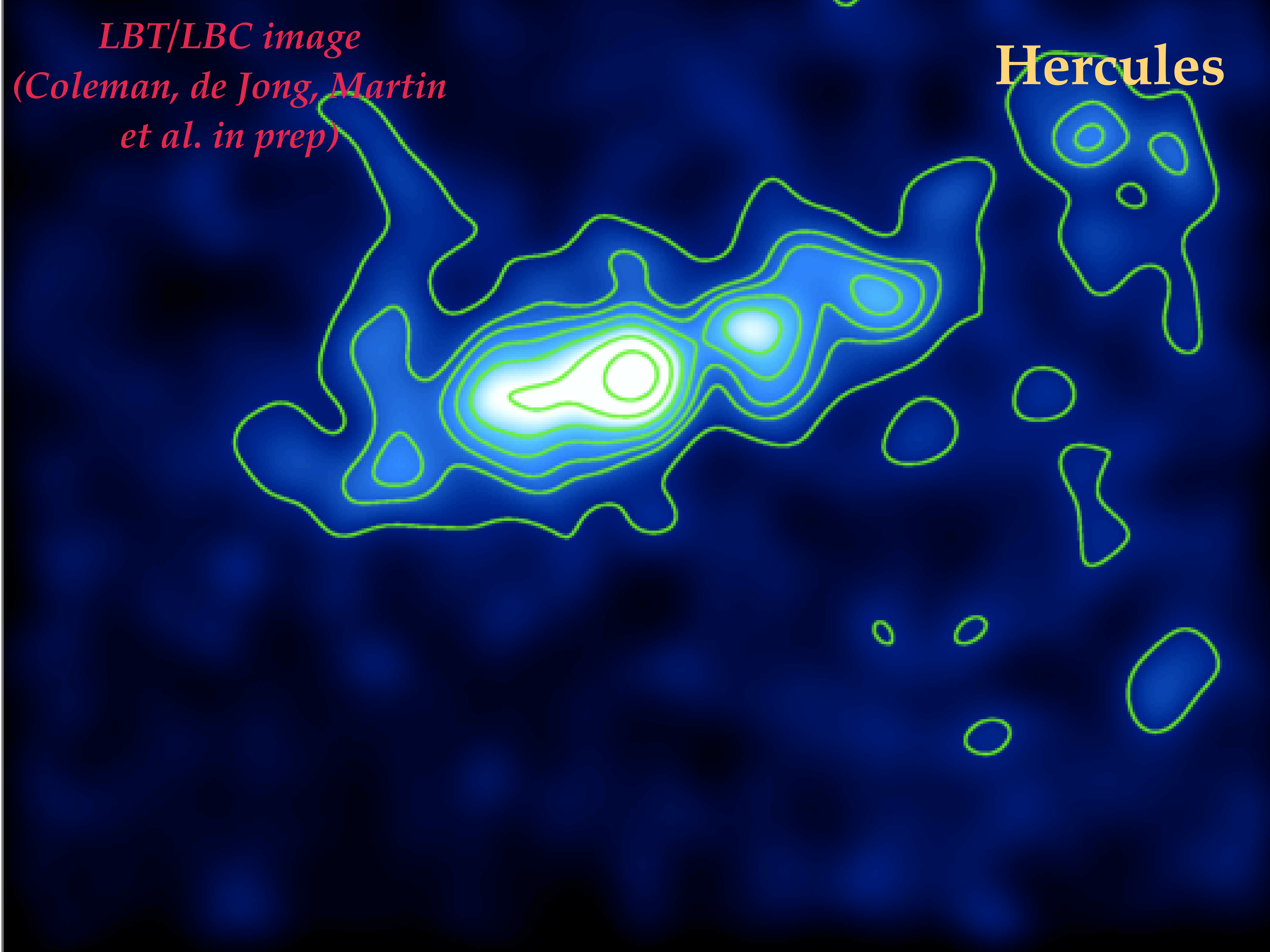
Faint SDSS satellites



Faint SDSS satellites




LBT/LBC image
(Coleman, de Jong, Martin
et al. in prep)
Hercules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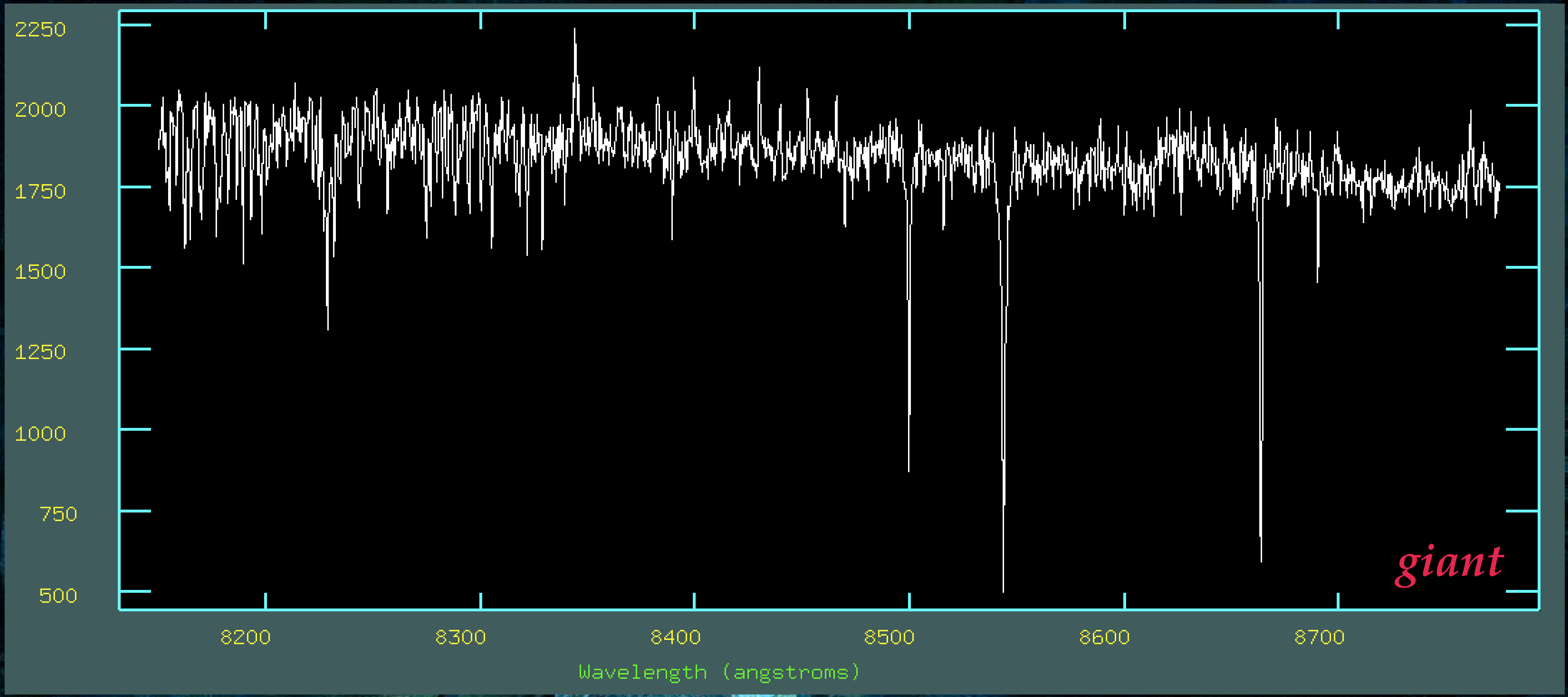
Hercules

Data

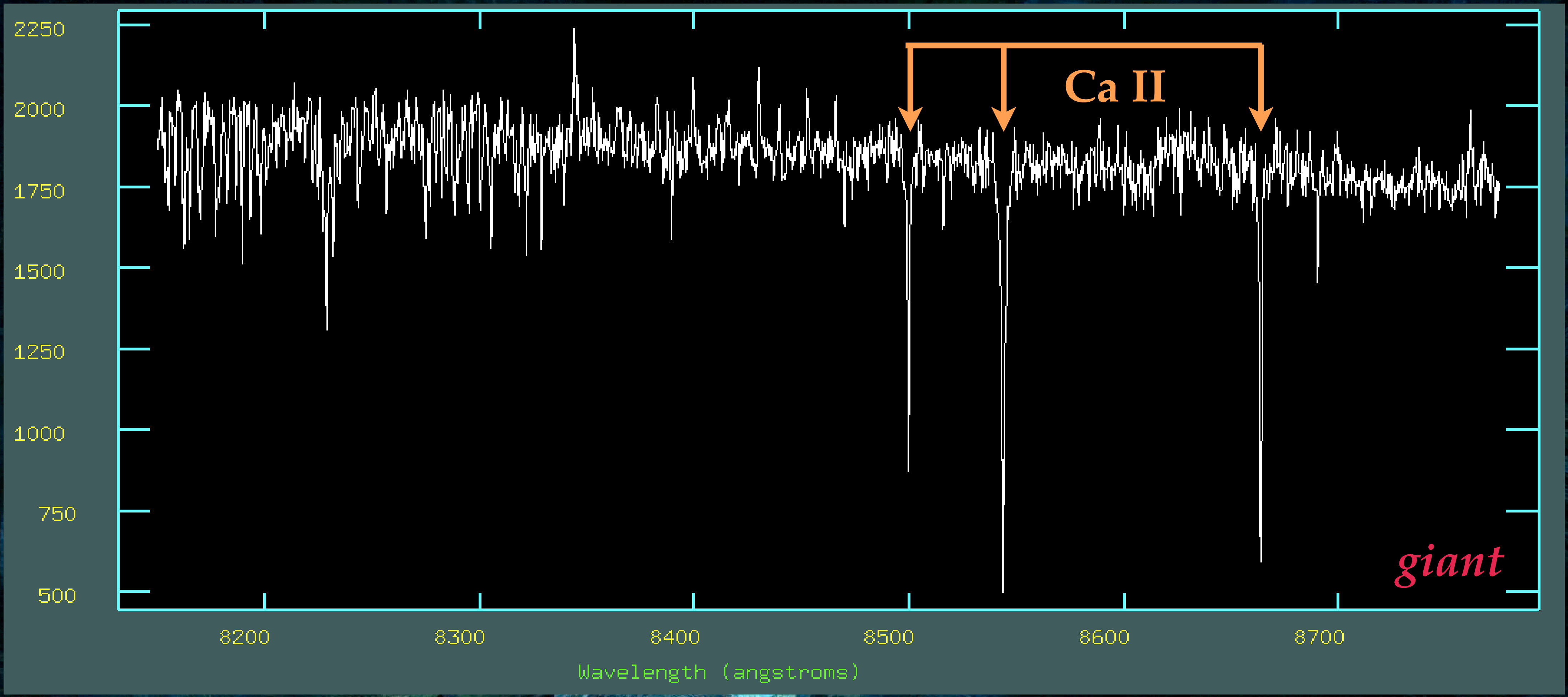


- DEIMOS multi-object spectrograph on Keck
- 1h exposures with HR grating → 6500-9000 Å, 1Å resolution spectra ($2<S/N<60$)
- 20 – 150 targets (red giant branch, sub-giant branch and turn-off stars) depending of faintness of satellite
- Calibration lamps observed between each observation to cope with slight rotation of spectrograph → *uncertainties 1-2 km/s*
- Calcium triplet → $[Fe/H] = -2.66 + 0.42[\Sigma Ca + 0.64(V - V_{HB})]$

$$\Sigma Ca = 0.5 EW_{\lambda 8498} + 1.0 EW_{\lambda 8542} + 0.6 EW_{\lambda 8662}$$

- Na doublet, gravity sensitive to discriminate dwarfs (Galactic foreground stars) from *giants*

Data



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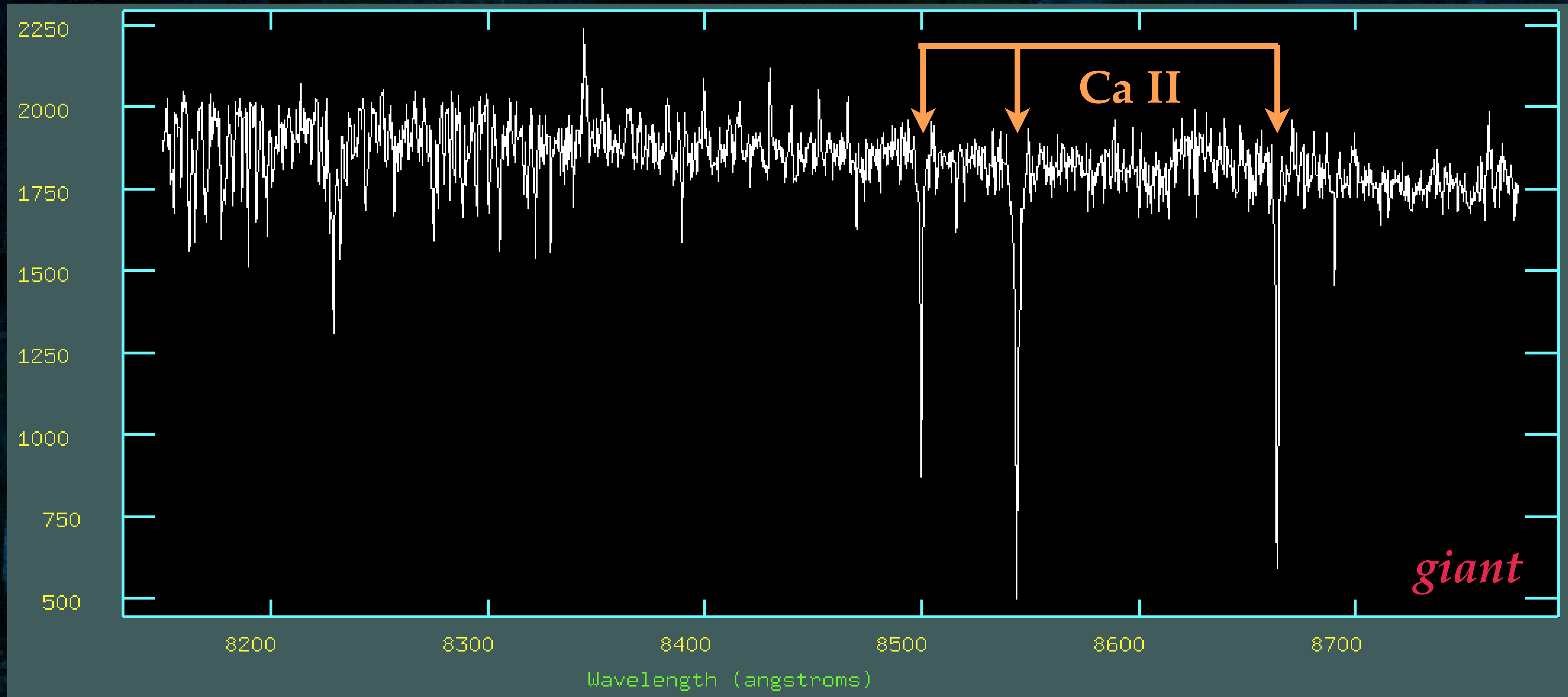
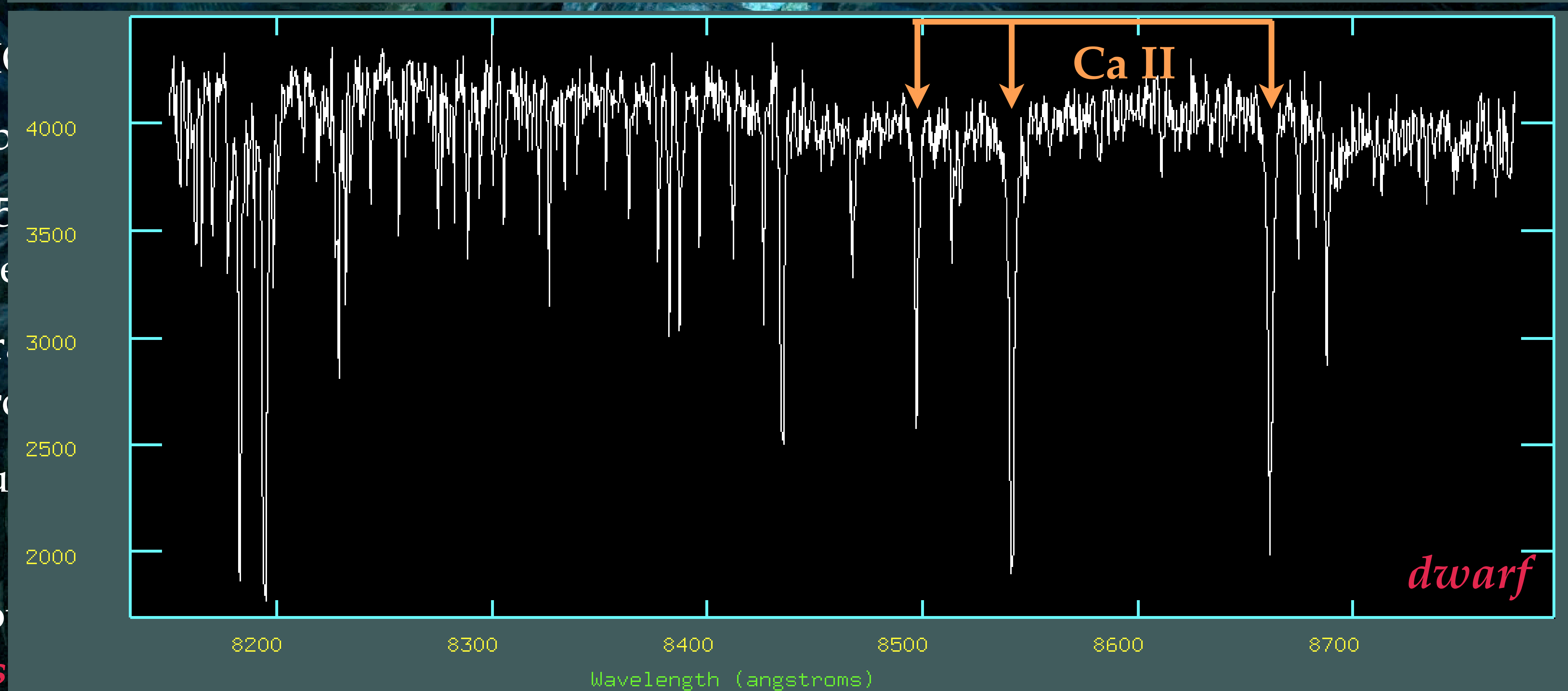
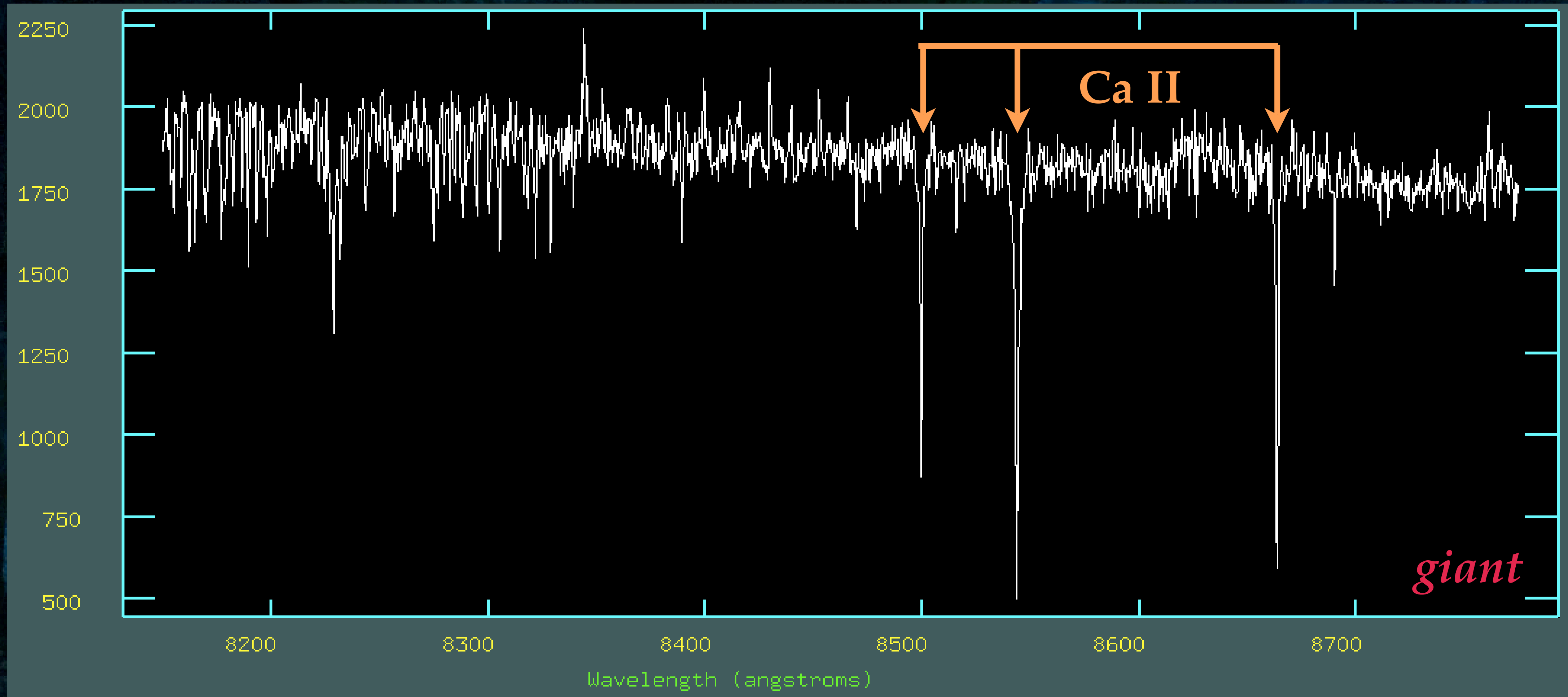
Data

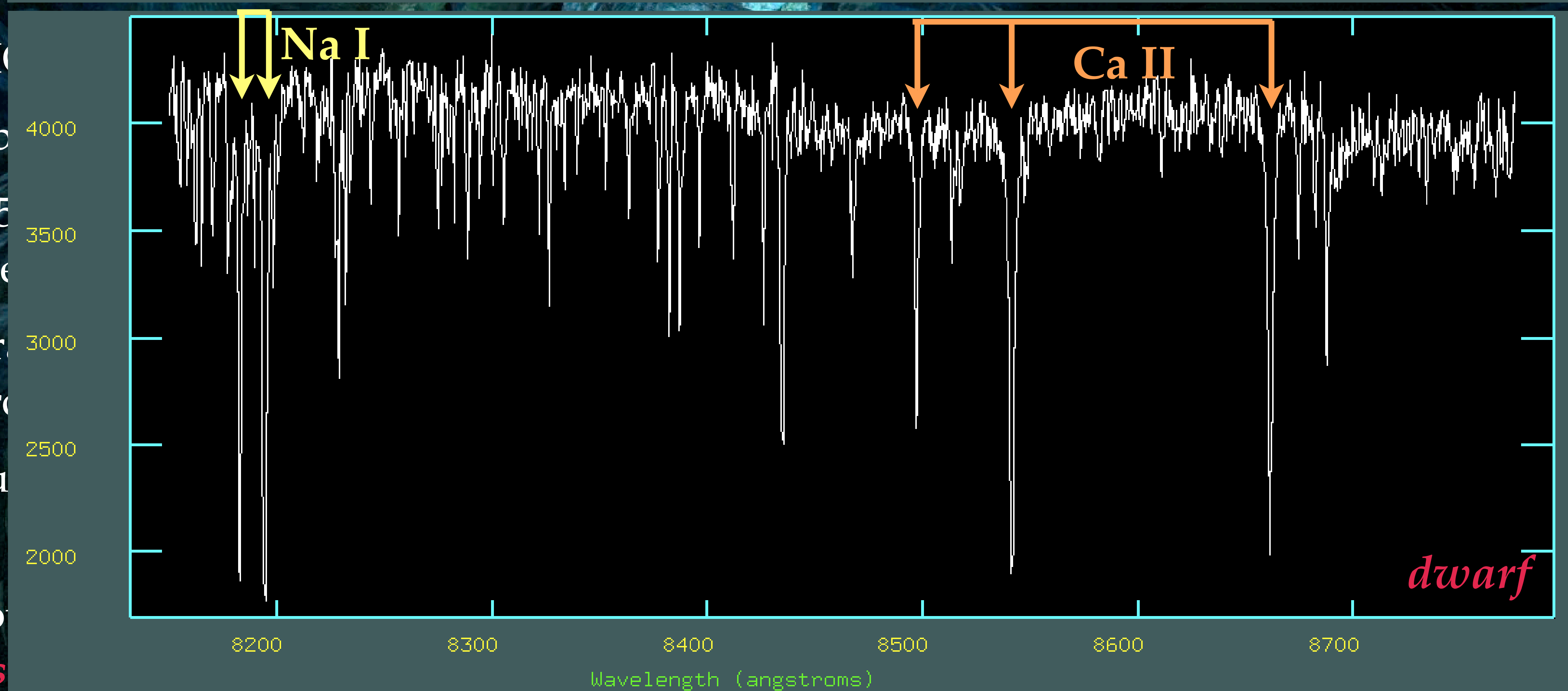




- DEIM
- 1h exp
- 20 – 15
  faintne
- Calibr
  spectr
- Calciu
- Na do
  giants

Data





- DEIM
- 1h exp
- 20 – 15
  faintne
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  giants

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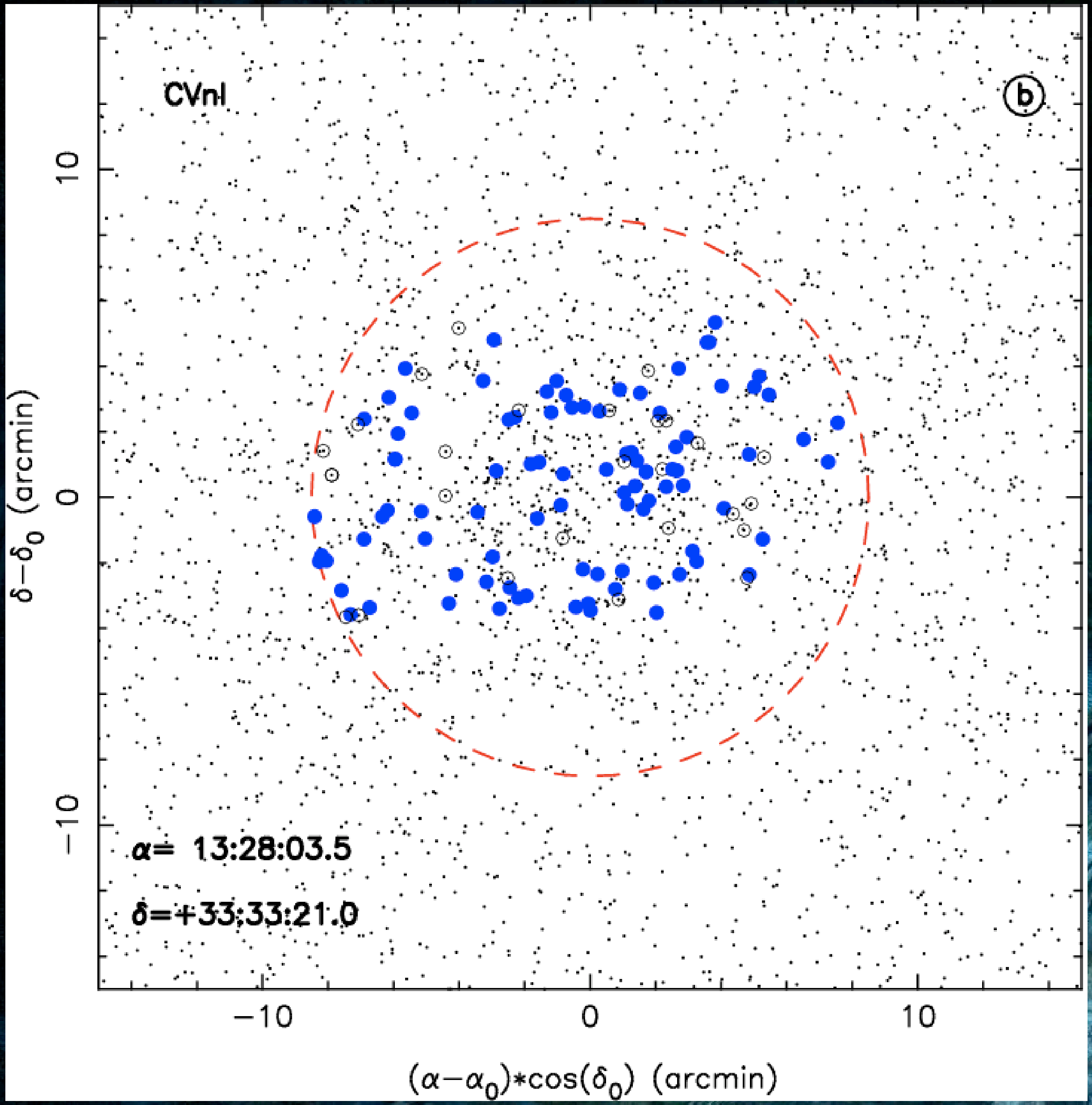
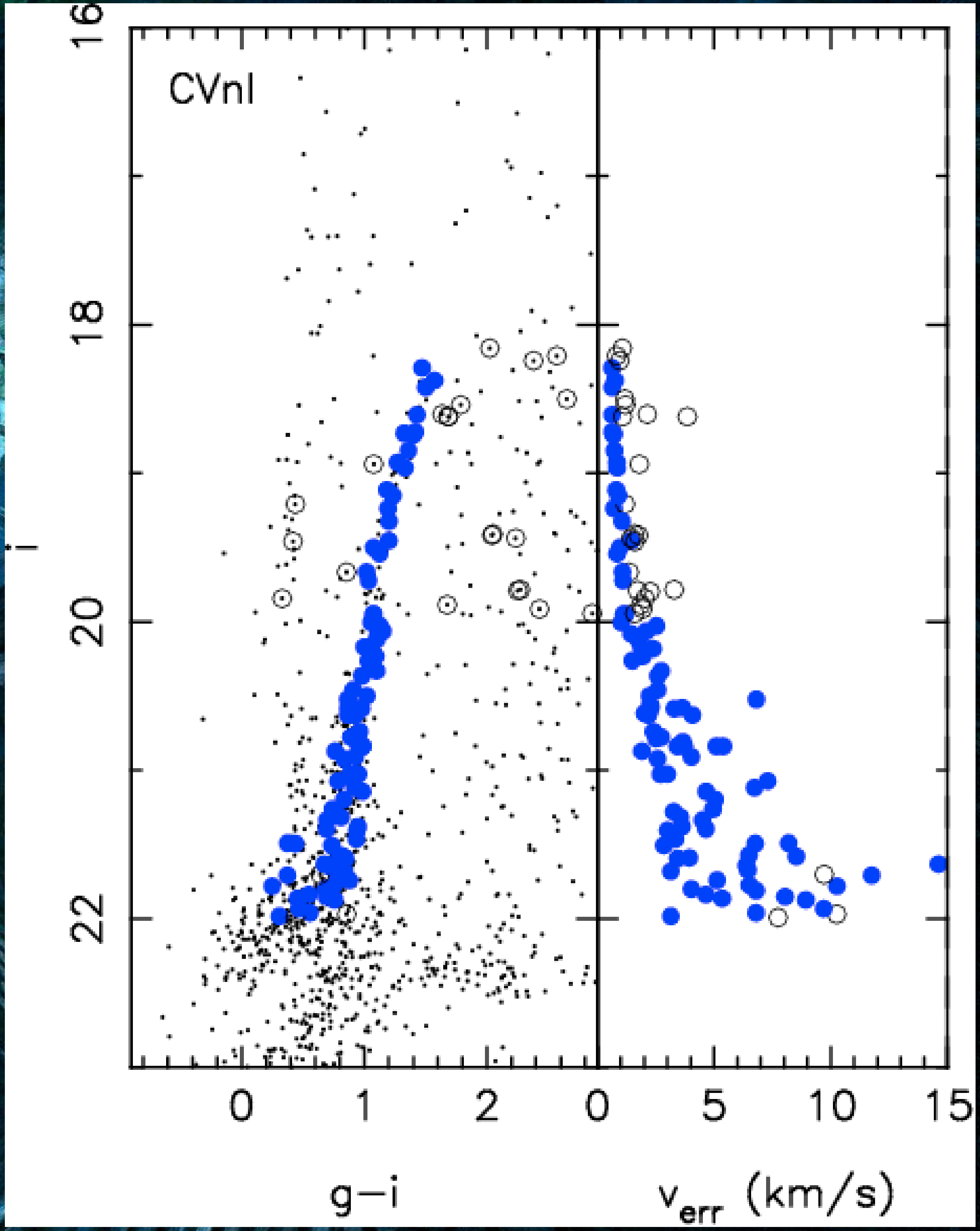
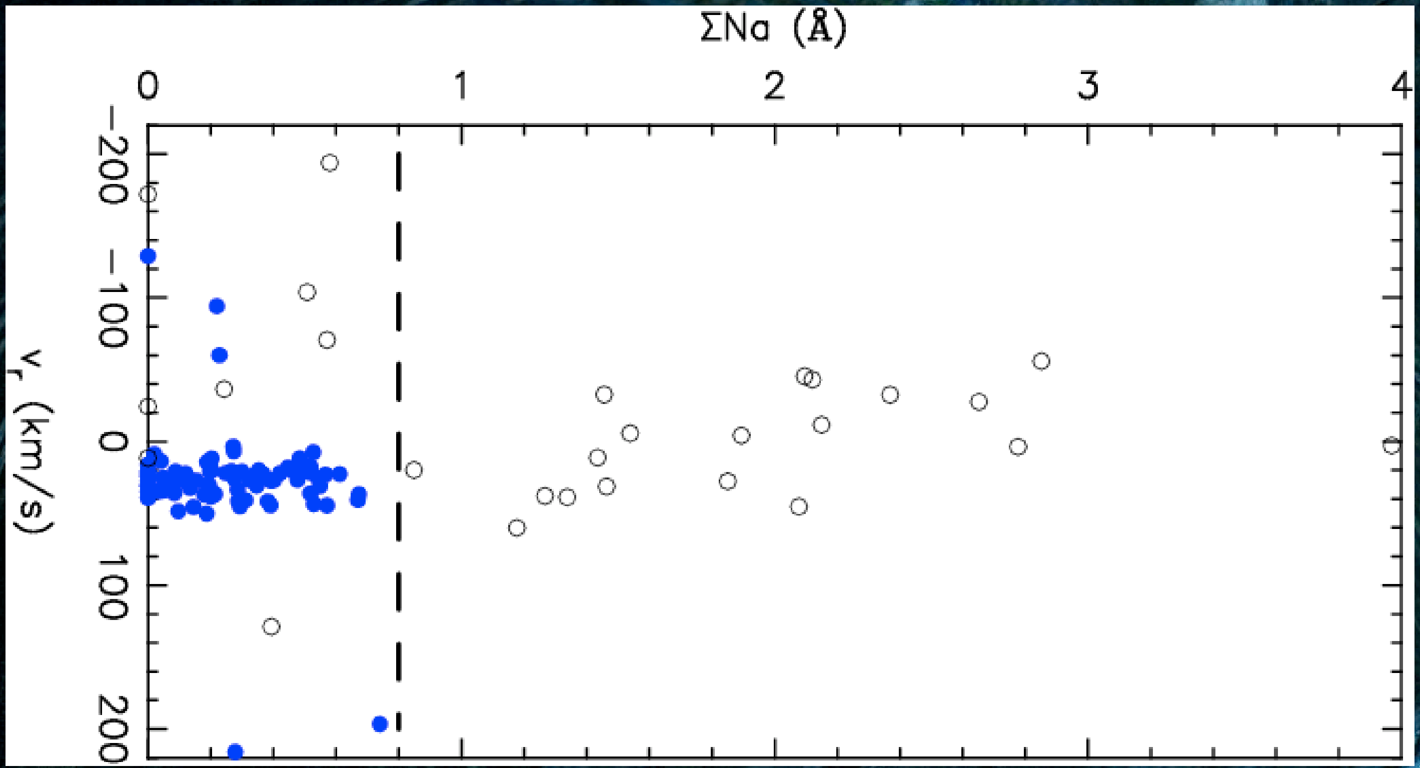
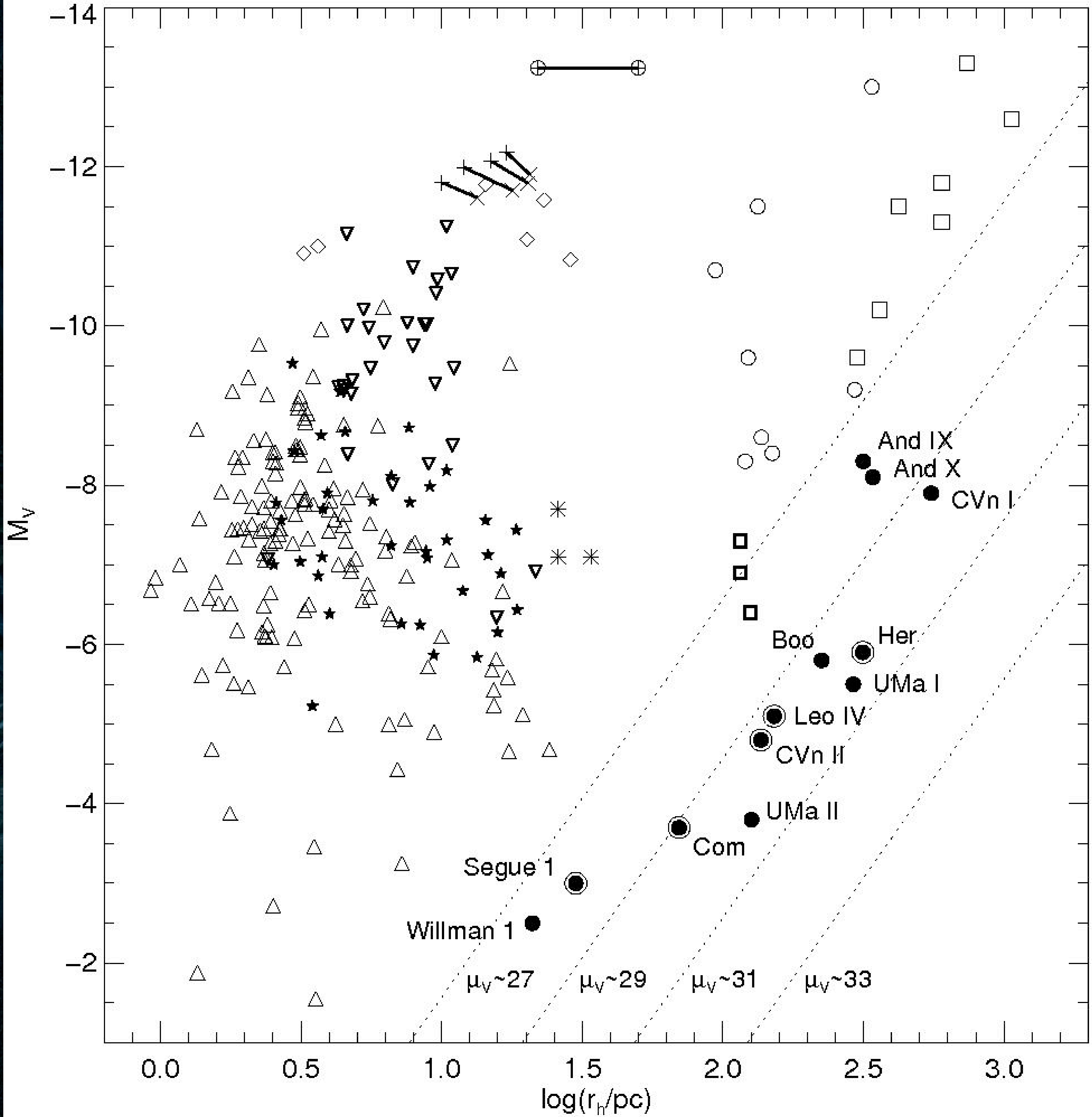
Canes Venatici I

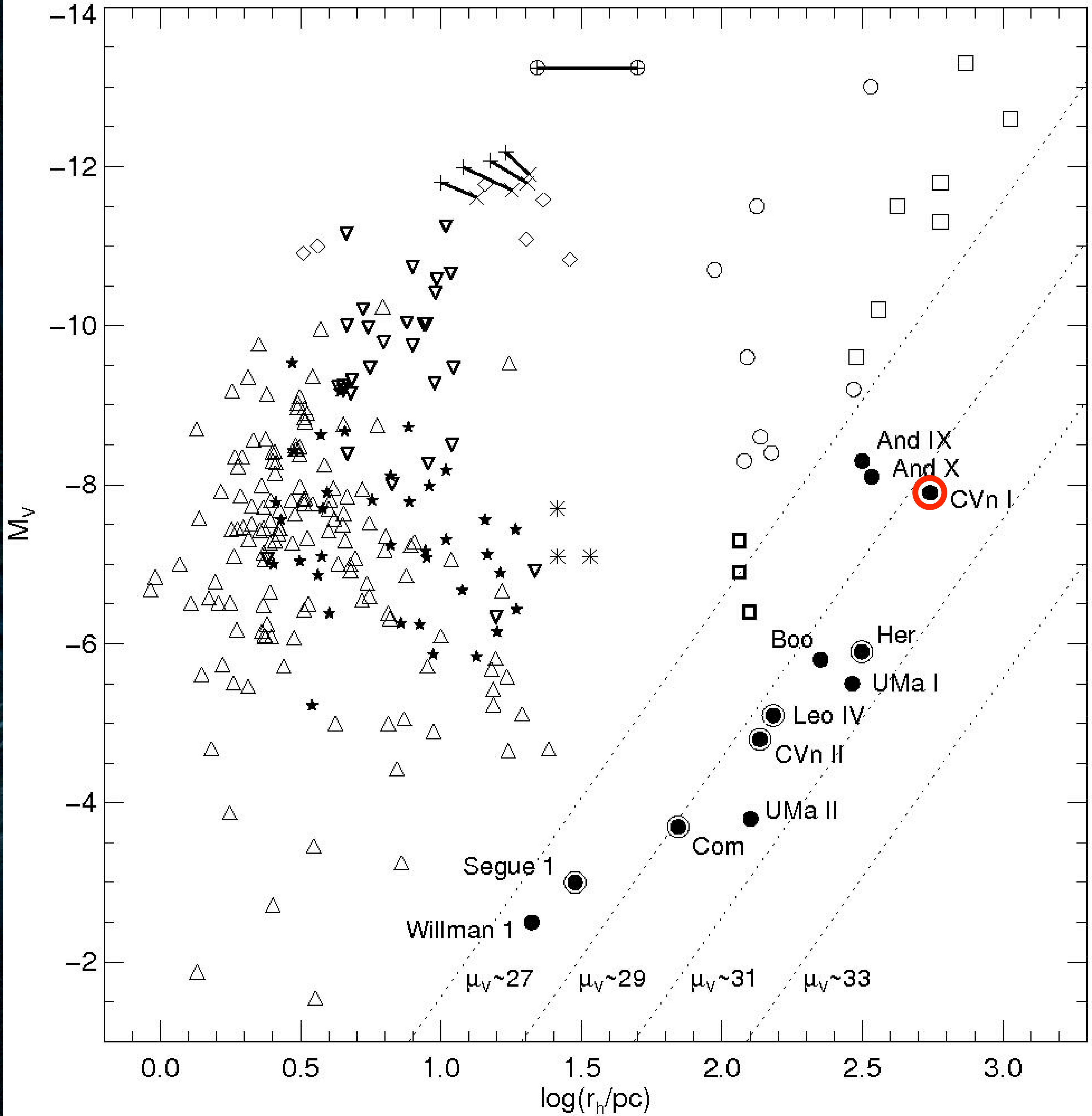








And IX
And X
CVn I
Boo
Her
UMa I
Leo IV
CVn II
UMa II
Com
Segue 1
Willman 1
μV~27
μV~29
μV~31
μV~33
MV
log(rh/pc)



And IX
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CVn I
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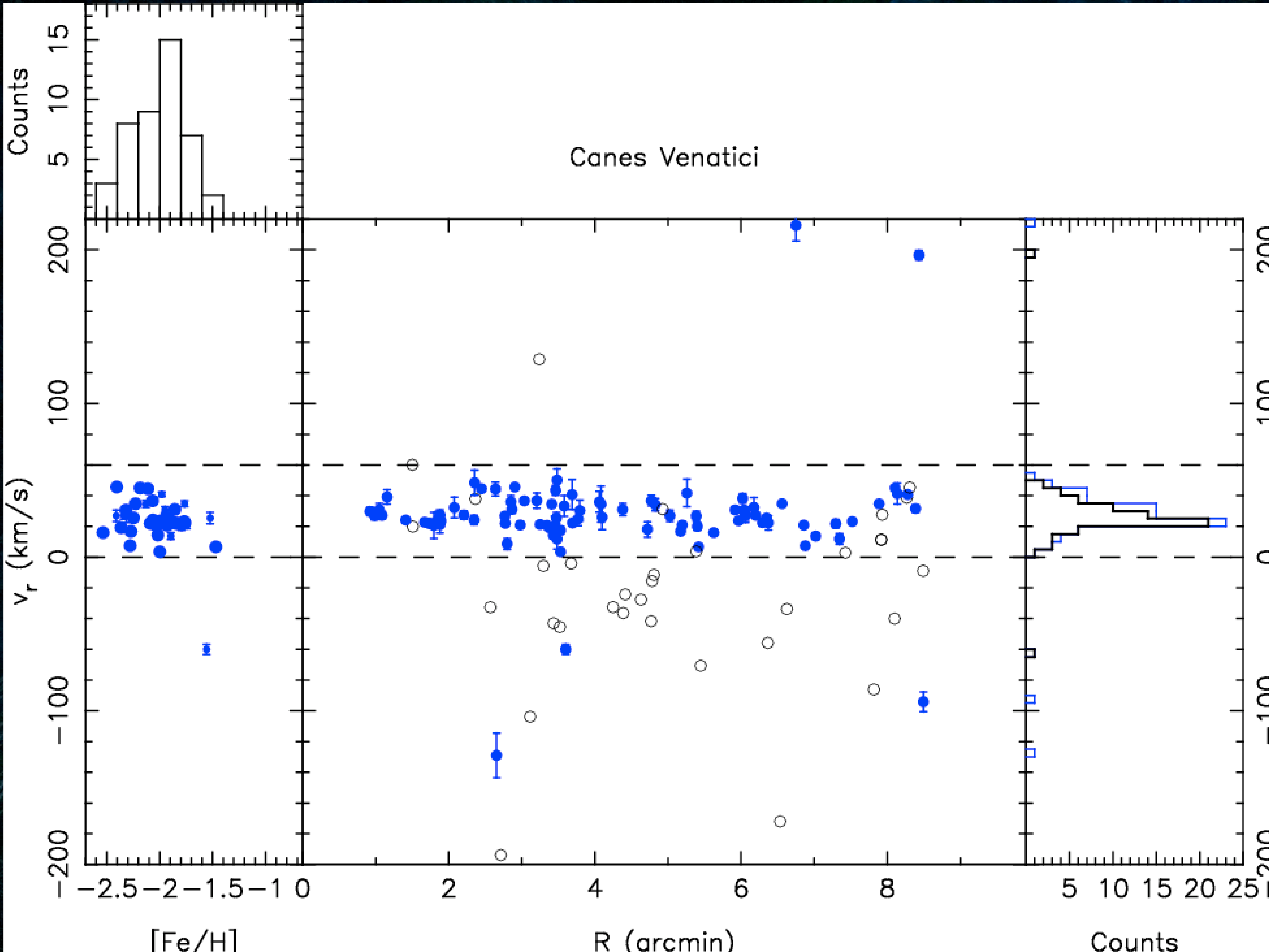
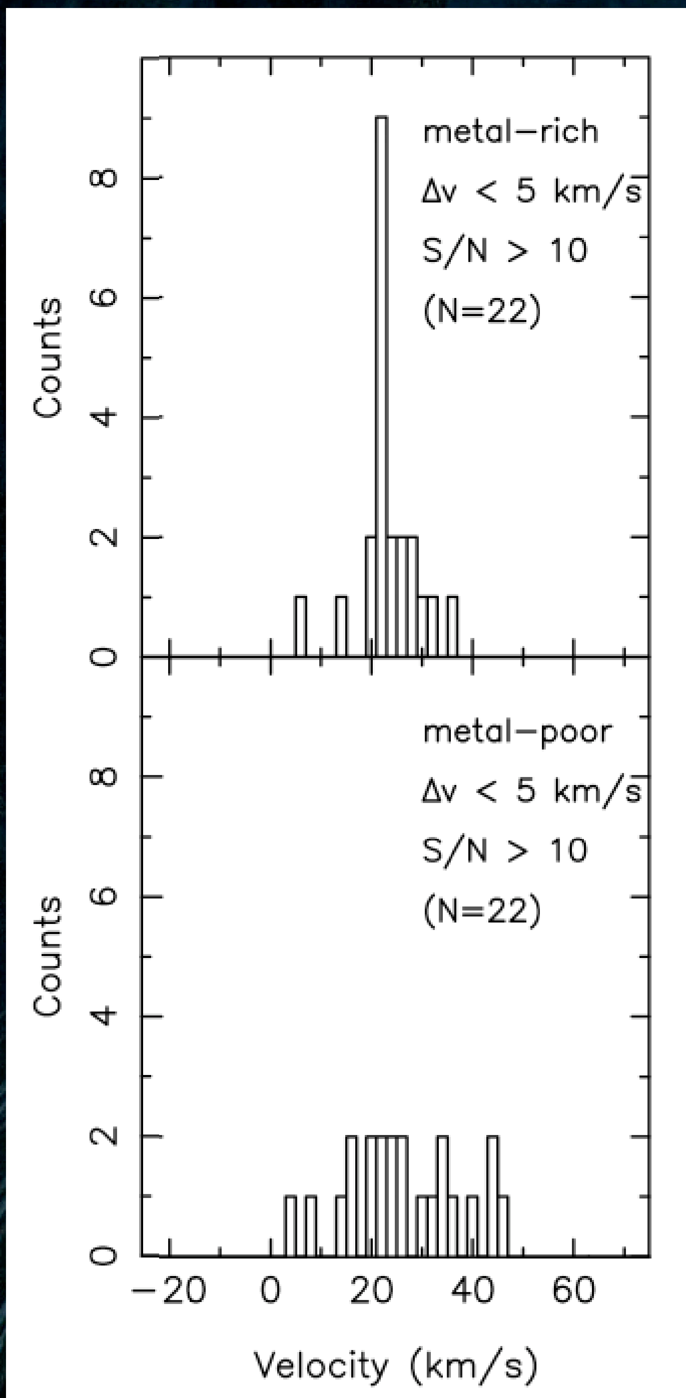
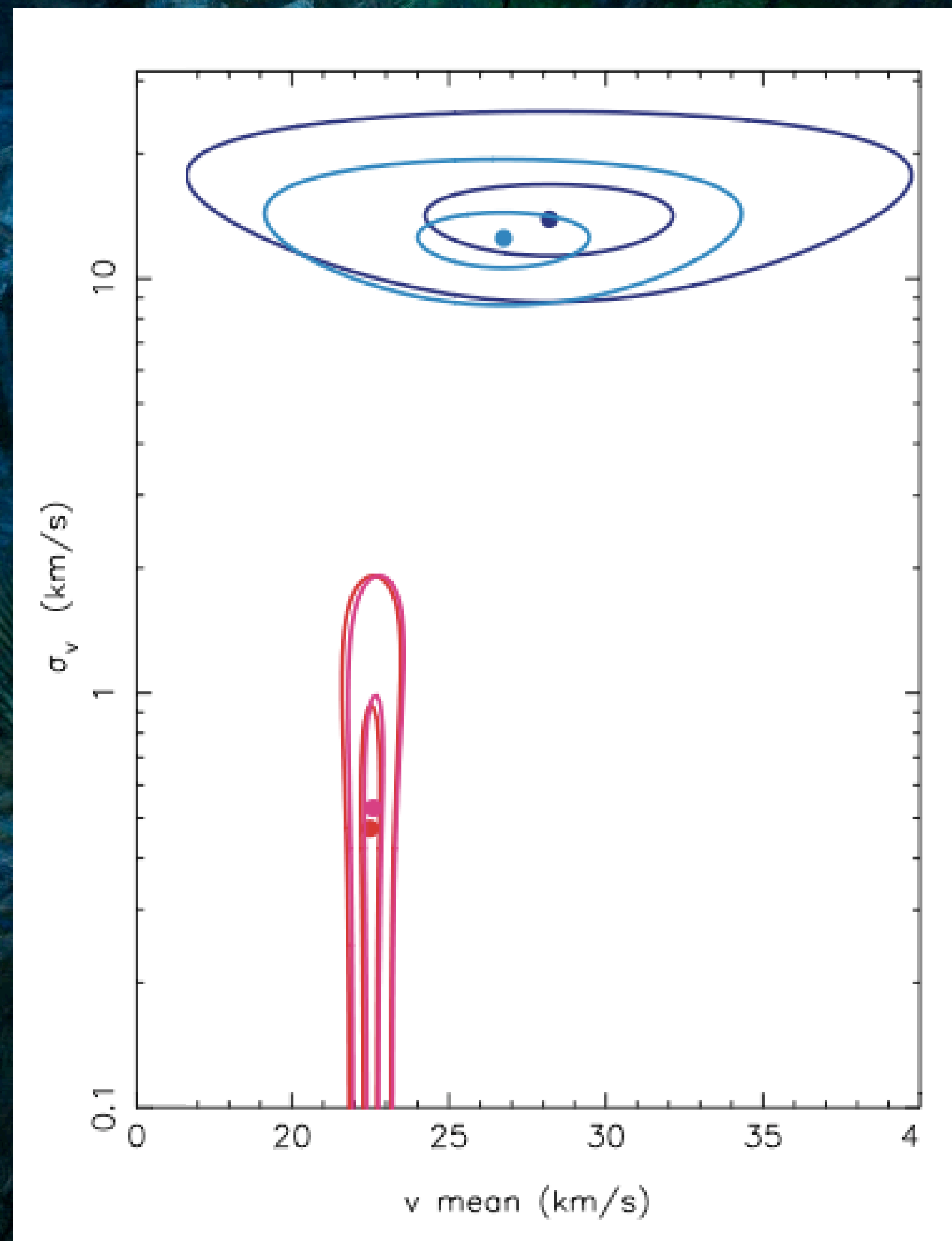
Segue 1
Willman 1
μ_V~27
μ_V~29
μ_V~31
μ_V~33
M_V
$\log(r_h/pc)$



Canes Venatici
Counts
5
10
15
v_r (km/s)
200
100
0
−100
−200
−2.5
−2
−1.5
−1
[Fe/H]
0
2
4
6
8
R (arcmin)
5
10
15
20
25
Counts

The Canes Venatici I case





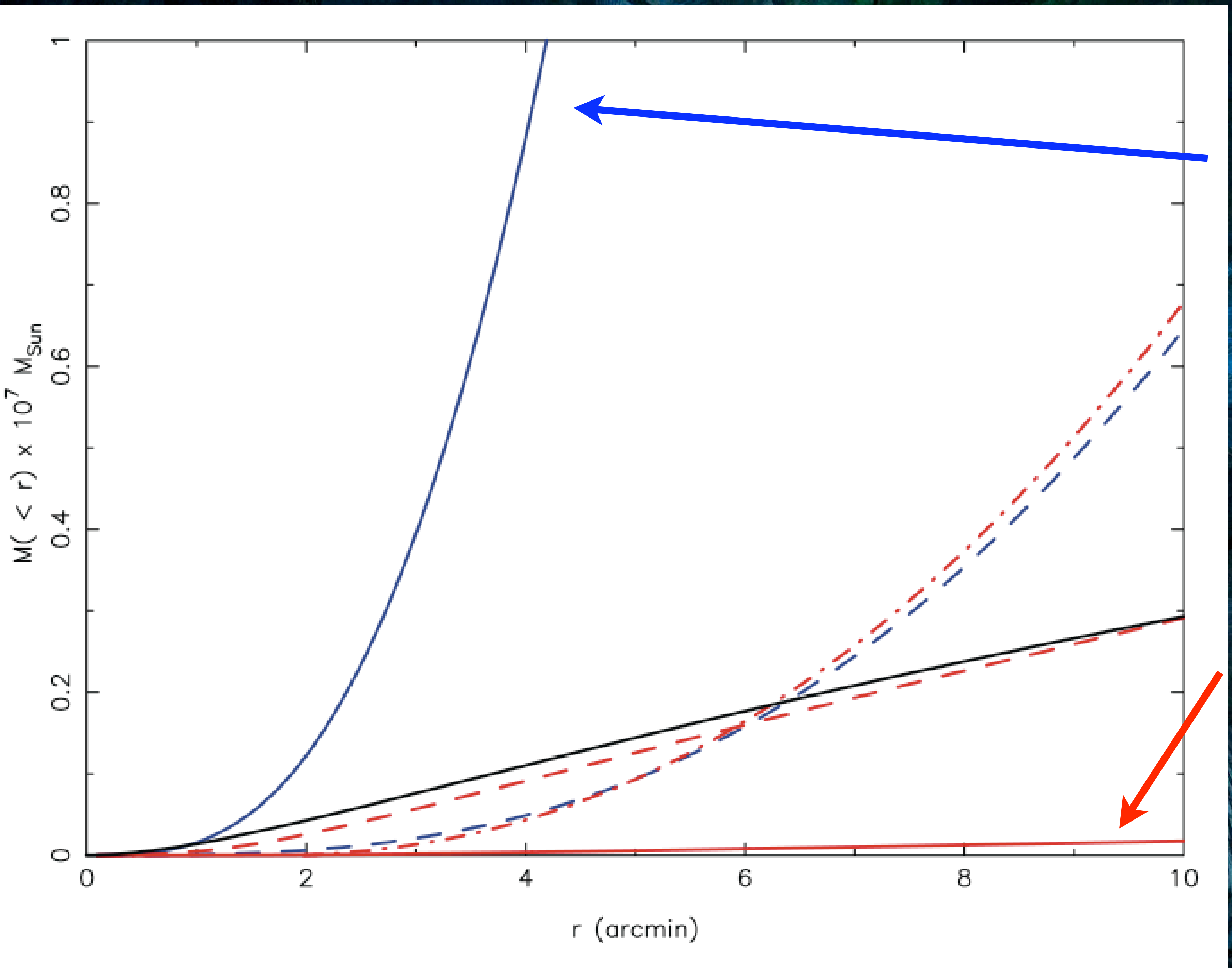
Metal-poor, hot extended component

- $-2.5 \lesssim [Fe/H] \lesssim -2.0$
- $r_{hb} = 500 \pm 135$ pc
- $\sigma = 13.9_{-2.5}^{+3.2}$ km/s

Metal-rich, cold component

- $-2.0 \lesssim [Fe/H] \lesssim -1.5$
- $r_{hb} = 230 \pm 65$ pc
- $\sigma = 0.5 \pm 0.5$ km/s
- $\sigma < 1.9$ km/s at 99% conf

The Canes Venatici I case



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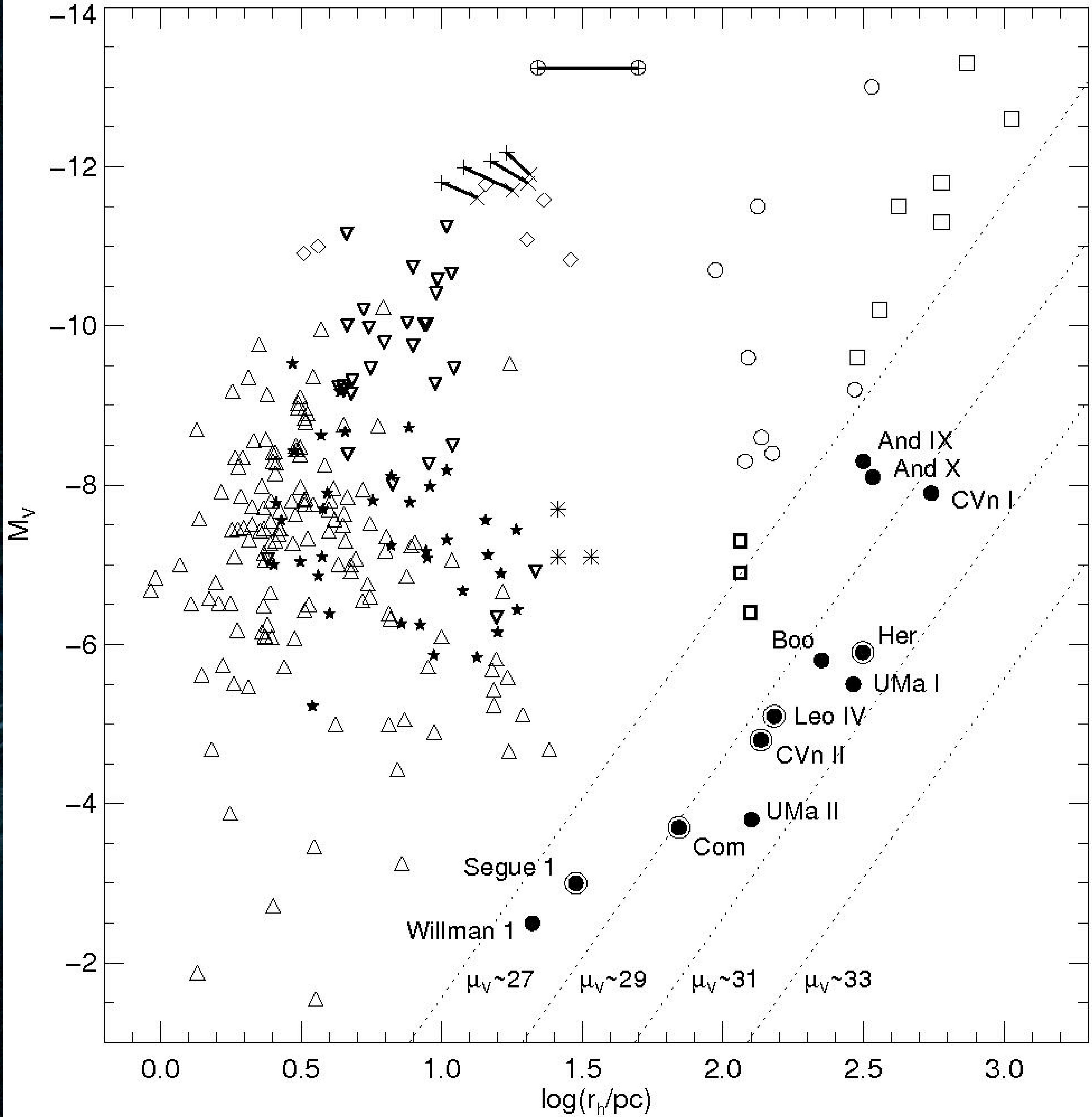

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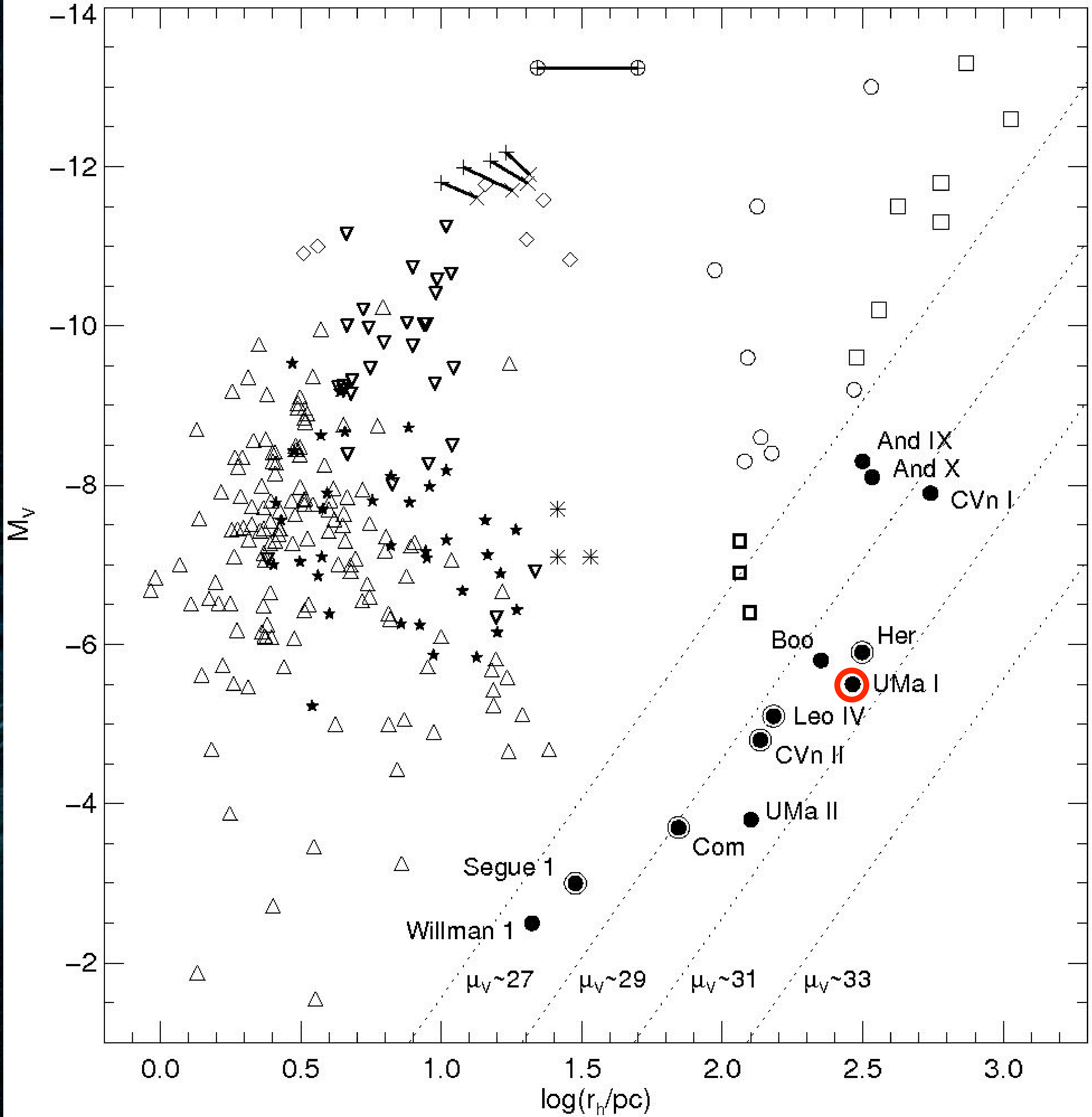
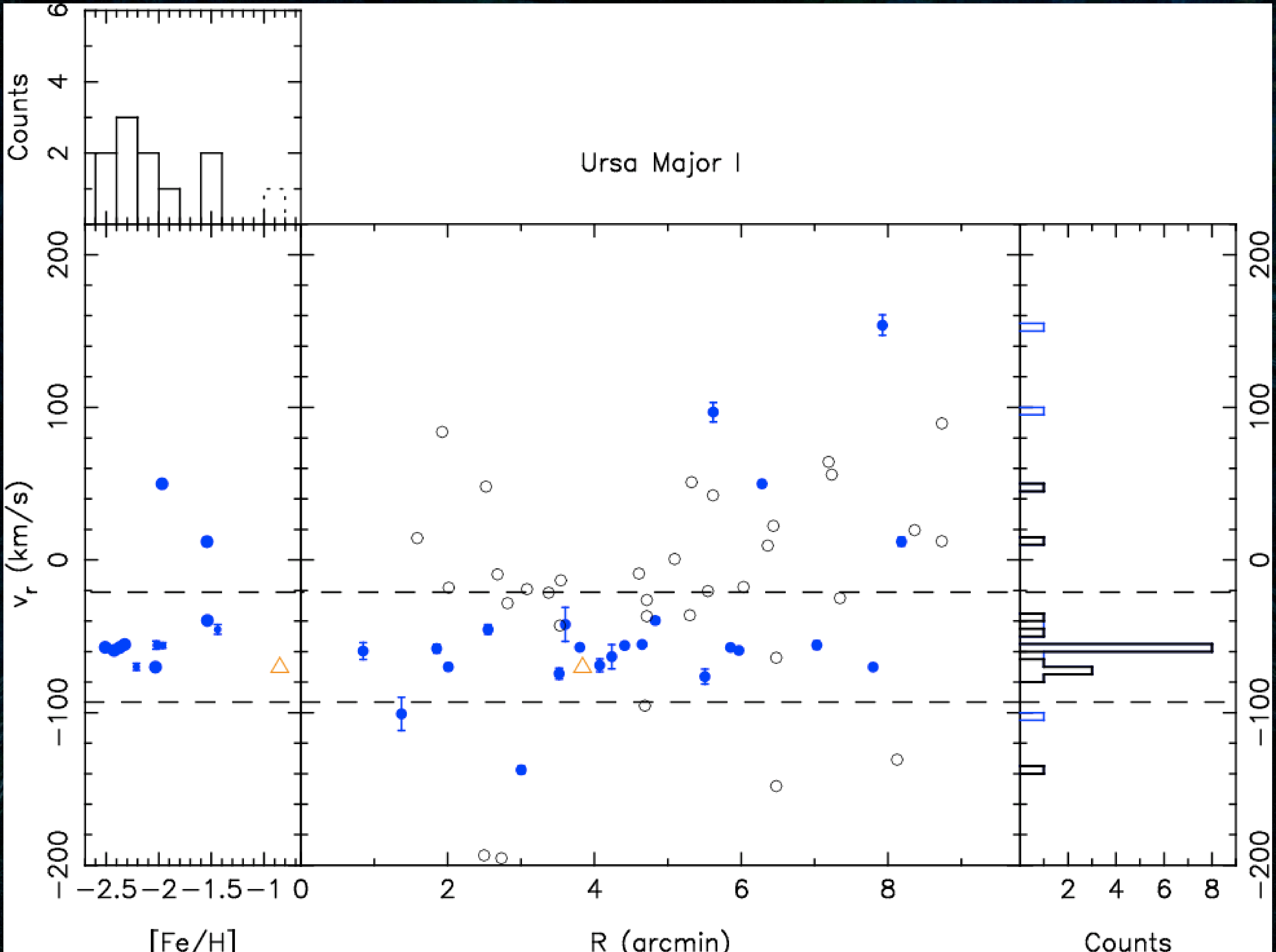


M_V
$\log(r_h/pc)$
And IX
And X
CVn I
Boo
Her
UMa I
Leo IV
CVn II
UMa II
Com
Segue 1
Willman 1
μ_V~27
μ_V~29
μ_V~31
μ_V~33



Ursa Major I
Counts
[Fe/H]
R (arcmin)
Counts
v_r (km/s)
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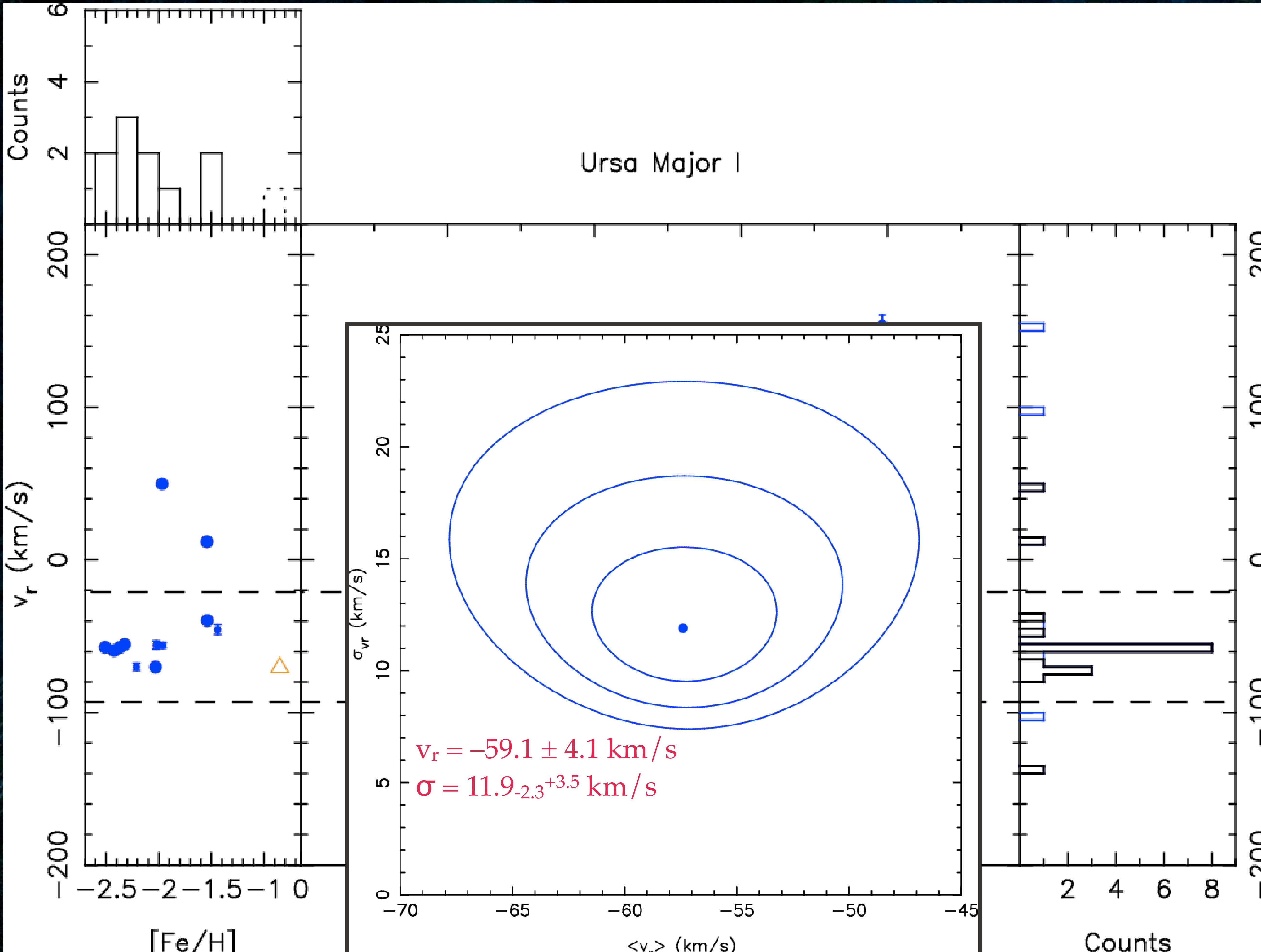
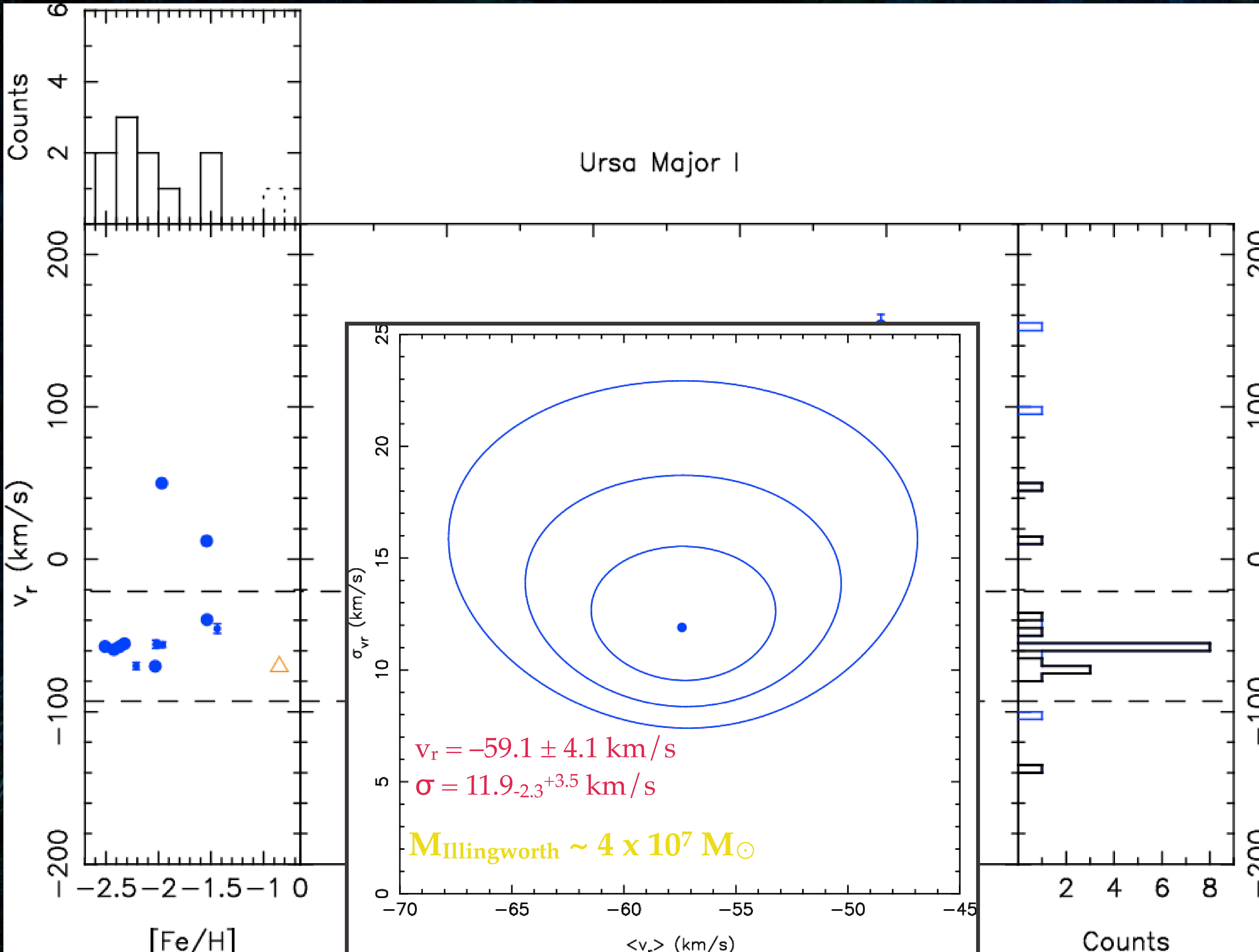
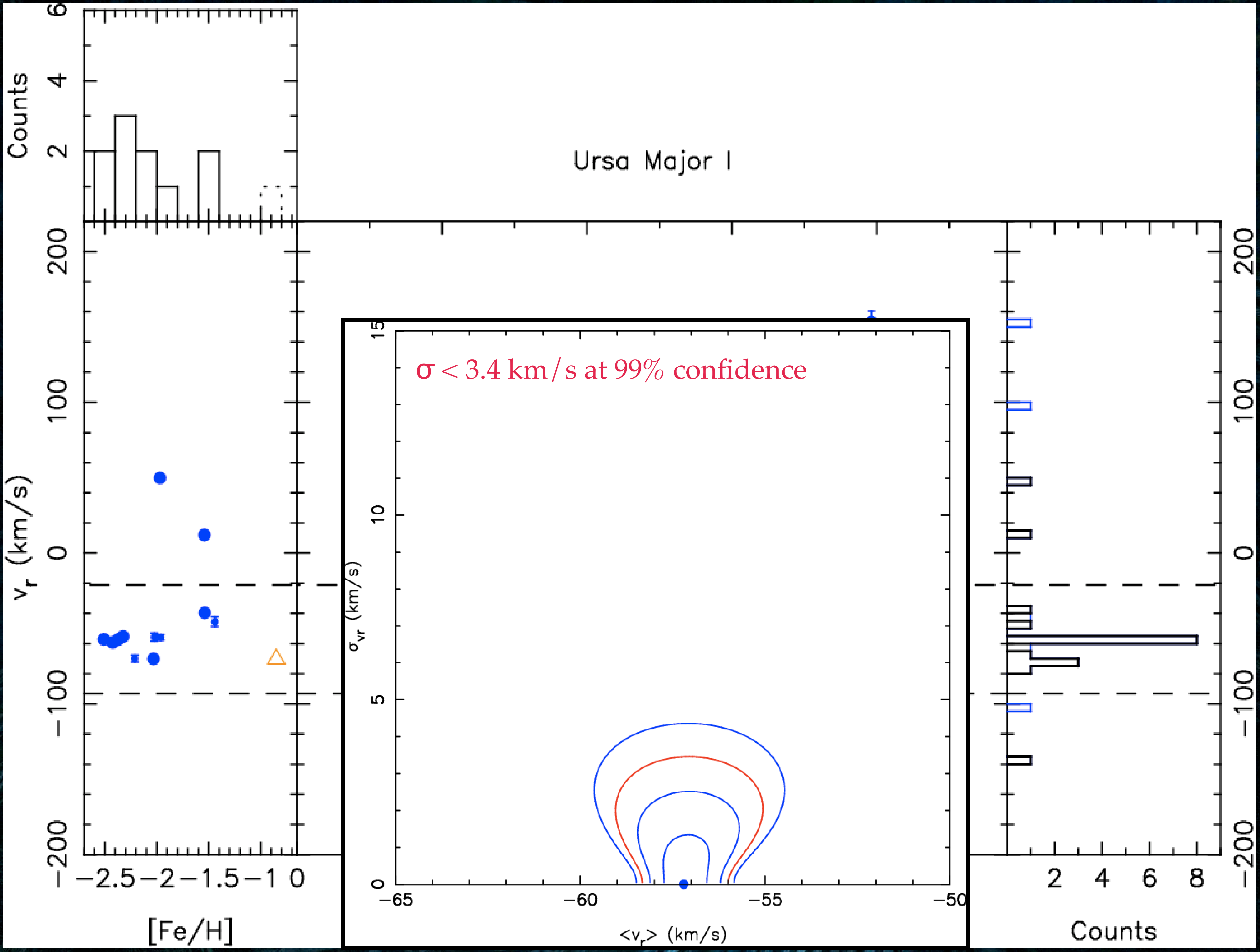
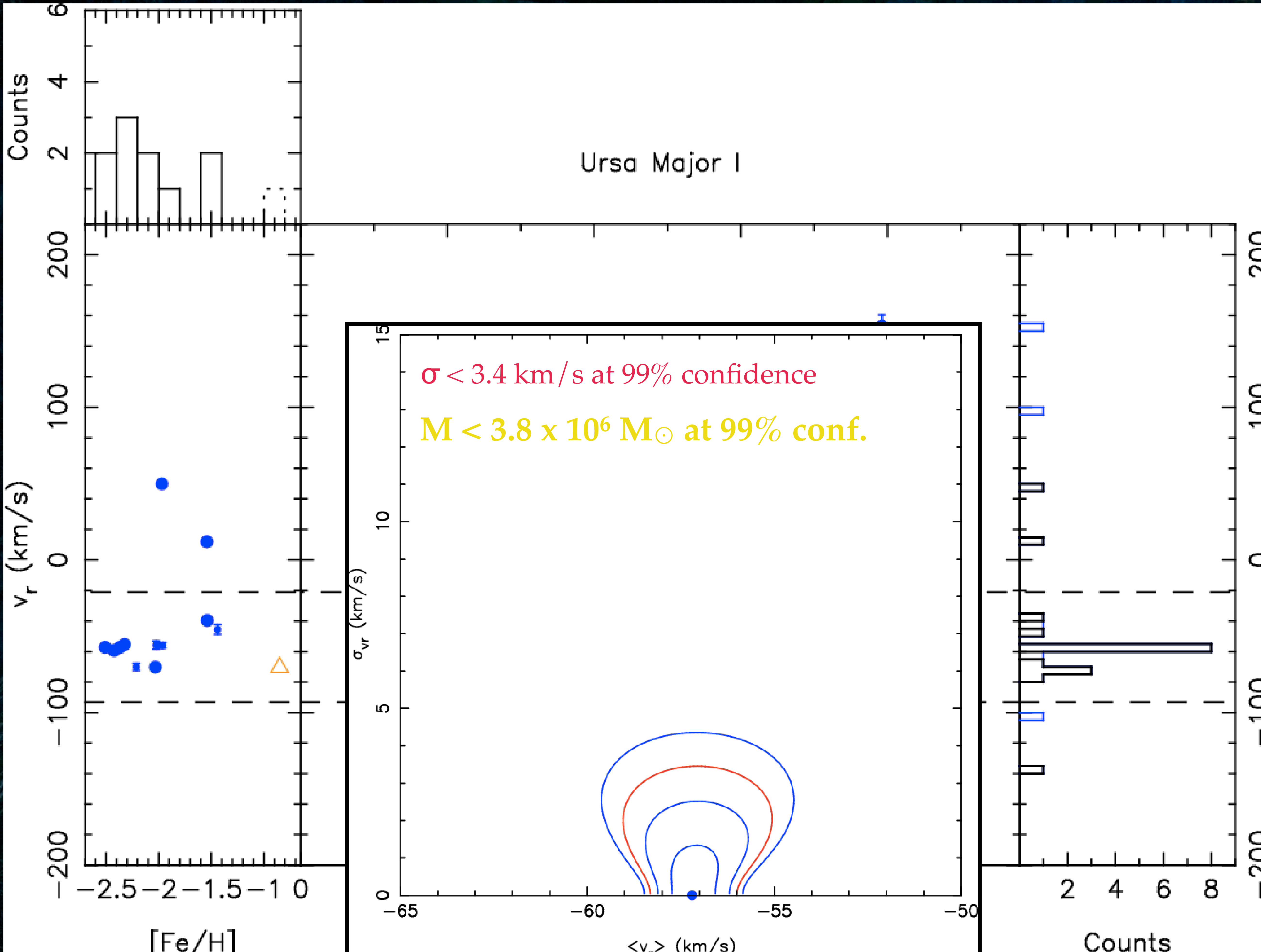

Ursa Major I
Counts
[Fe/H]
v_r (km/s)
σ_vr (km/s)
<v_r> (km/s)
Counts
$v_r = -59.1 \pm 4.1$ km/s
$\sigma = 11.9_{-2.3}^{+3.5}$ km/s



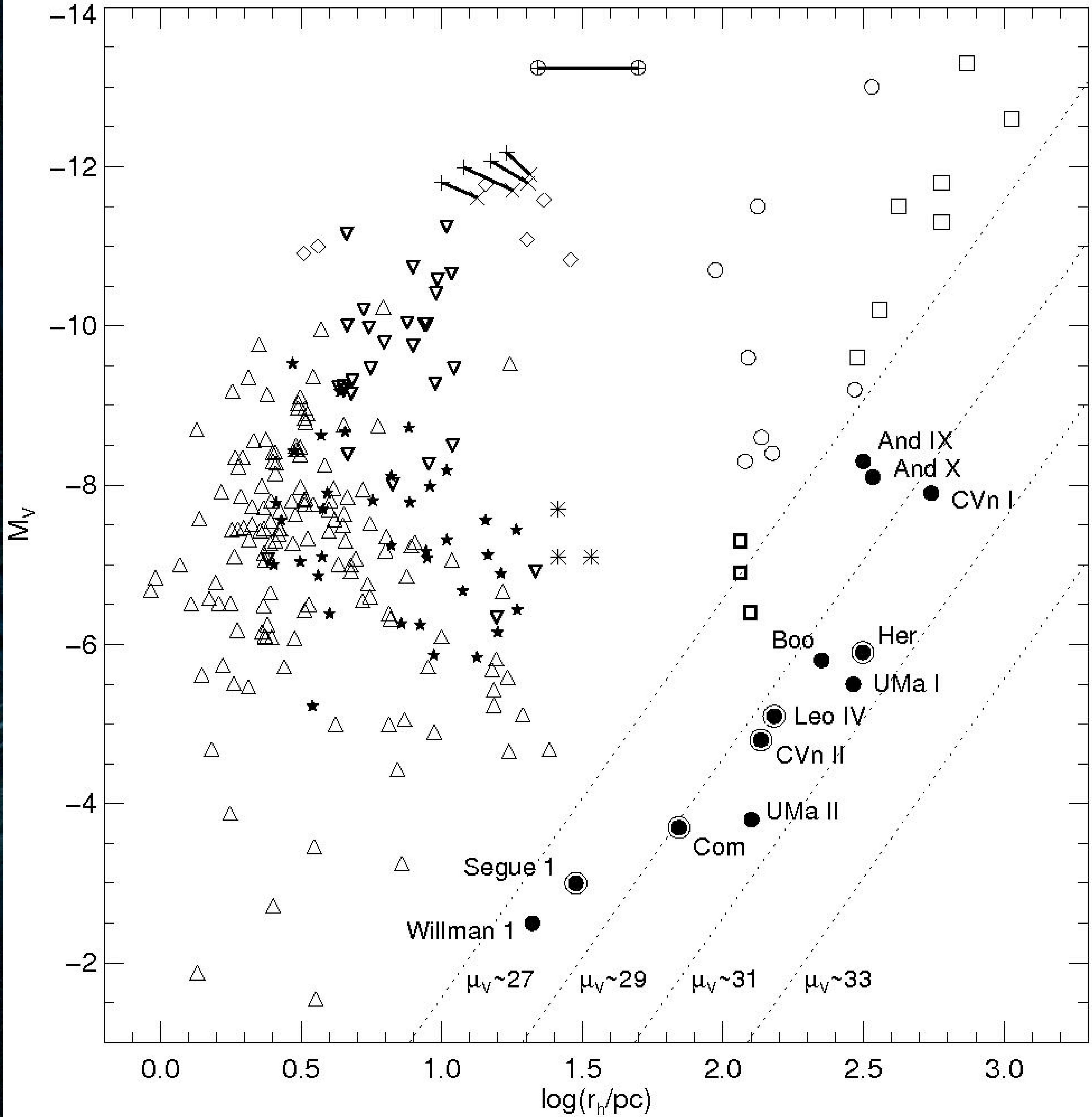
Ursa Major I
Counts
[Fe/H]
v_r (km/s)
σ_vr (km/s)
<v_r> (km/s)
Counts
v_r = –59.1 ± 4.1 km/s
σ = 11.9_-2.3^+3.5 km/s
M_Illingworth ~ 4 x 10^7 M⊙



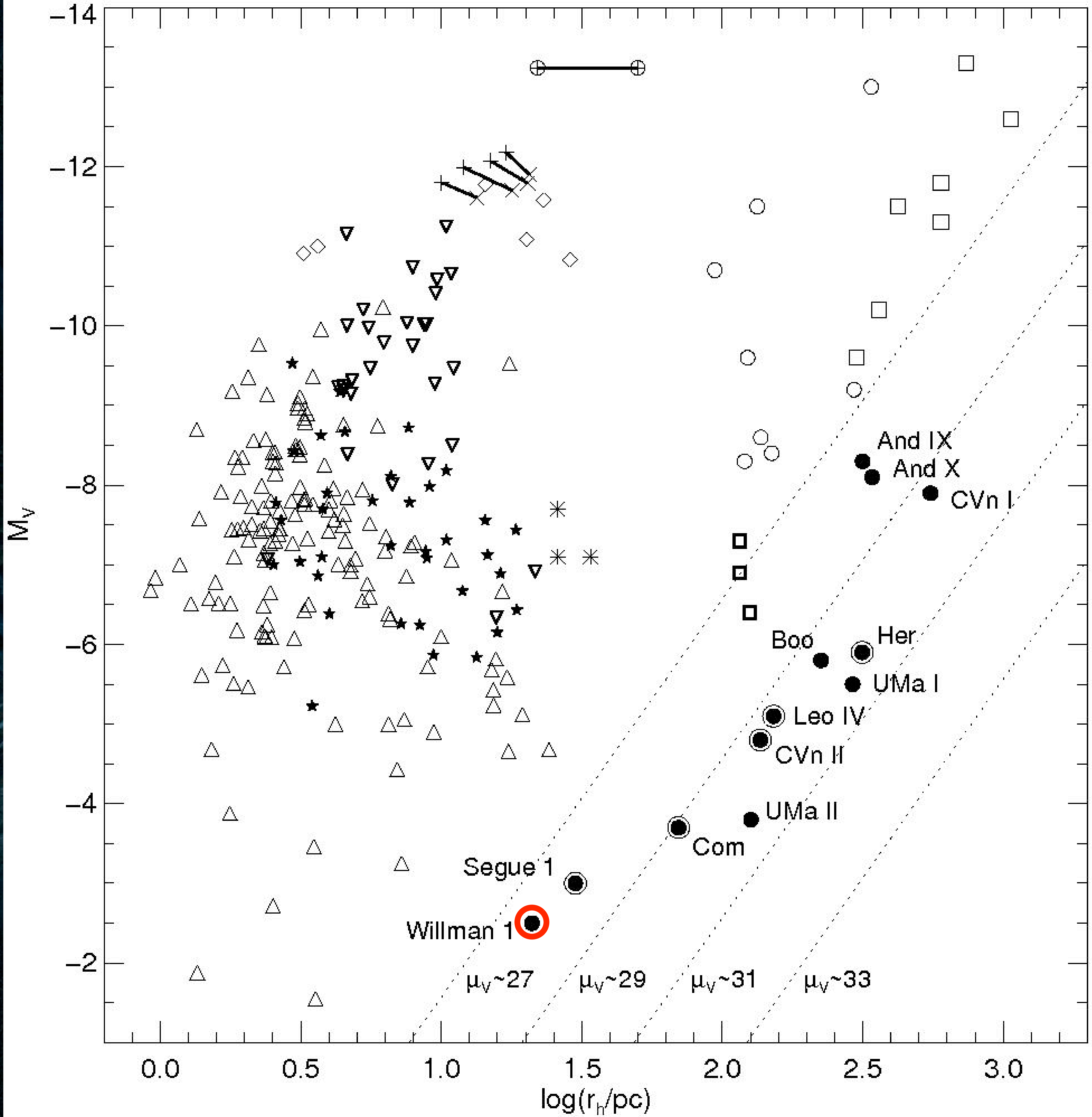
Ursa Major I
σ < 3.4 km/s at 99% confidence
Counts
[Fe/H]
v_r (km/s)
σ_{vr} (km/s)
$\langle v_r \rangle$ (km/s)
Counts



Ursa Major I
σ < 3.4 km/s at 99% confidence
M < 3.8 x 10⁶ M⊙ at 99% conf.
Counts
[Fe/H]
v_r (km/s)
σ_vr (km/s)
<v_r> (km/s)

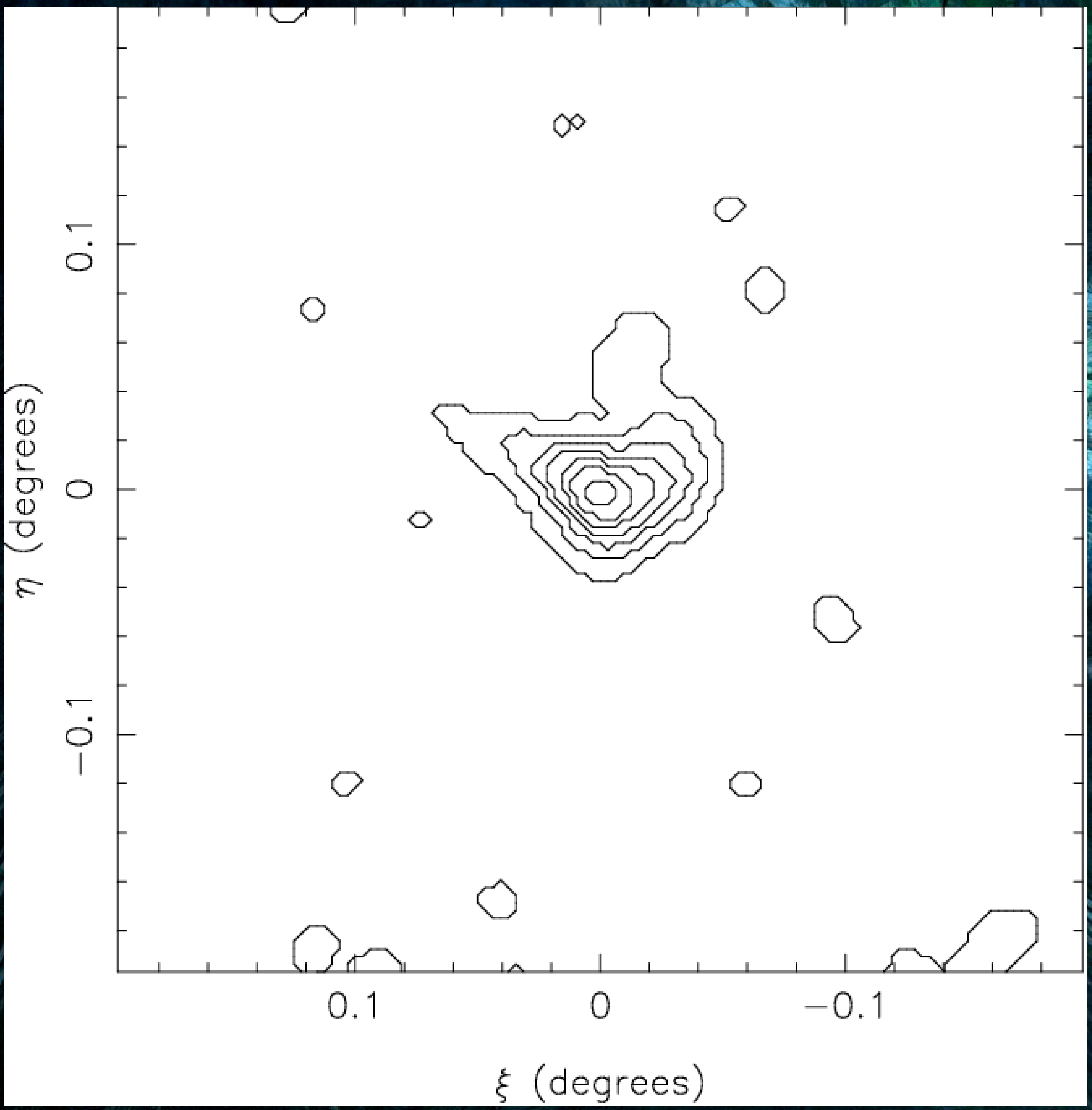


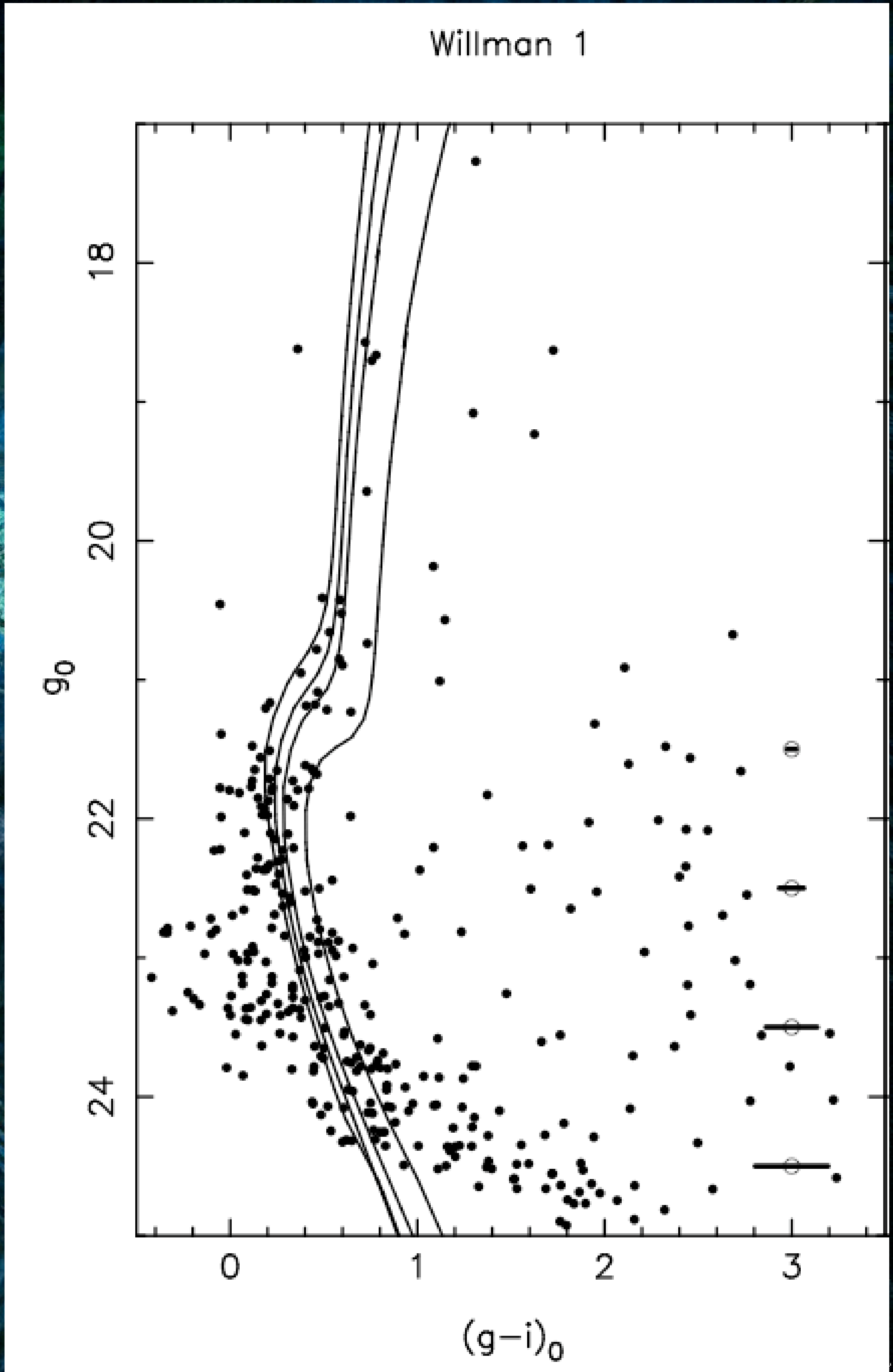
M_V
log(r_h/pc)
And IX
And X
CVn I
Boo
Her
UMa I
Leo IV
CVn II
UMa II
Com
Segue 1
Willman 1
μ_V~27
μ_V~29
μ_V~31
μ_V~33



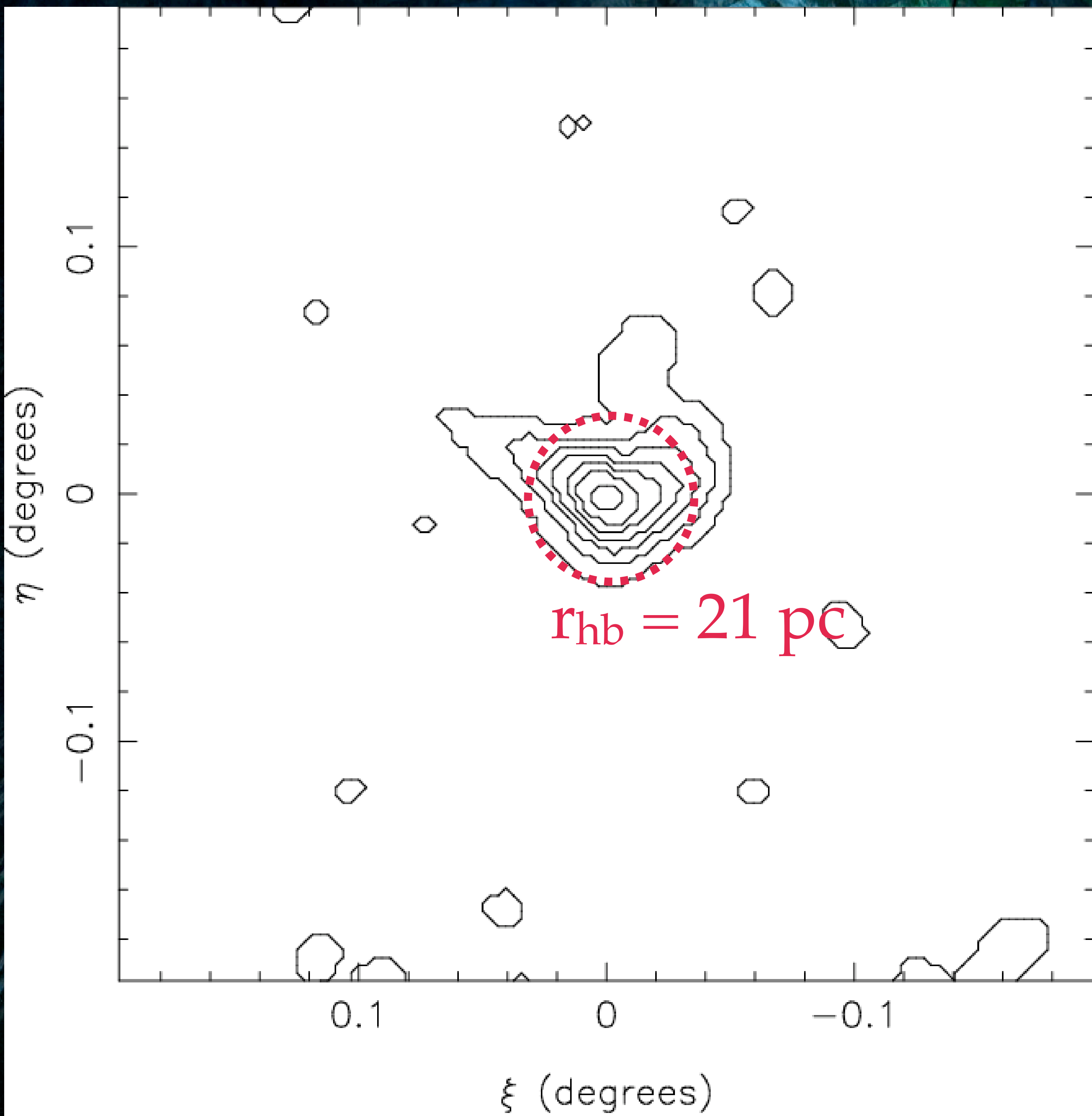
And IX
And X
CVn I
Boo
Her
UMa I
Leo IV
CVn II
UMa II
Com
Segue 1
Willman 1
μ_V~27
μ_V~29
μ_V~31
μ_V~33
M_V
$\log(r_h/pc)$

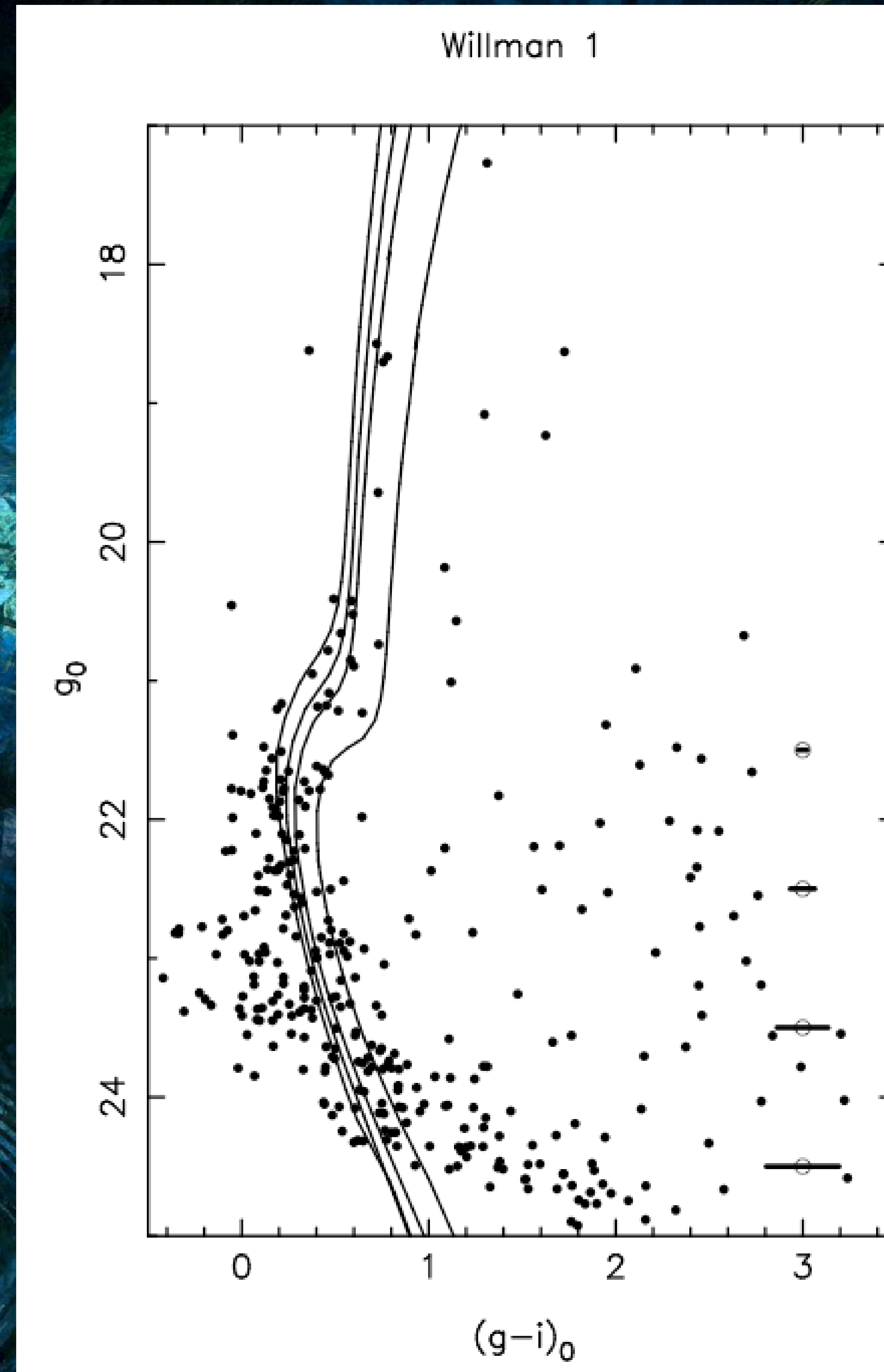
Willman 1, the INT/WFC view



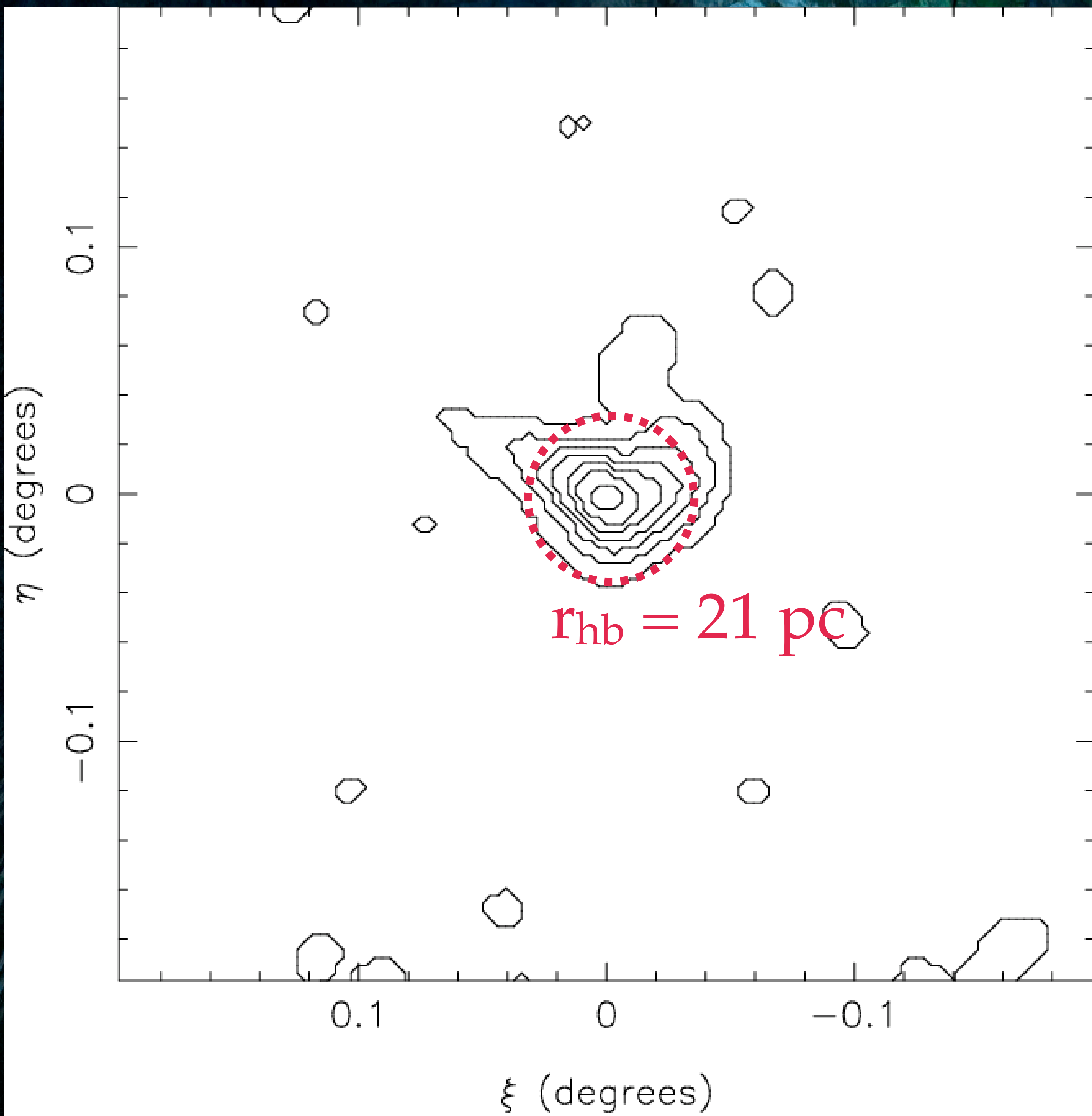


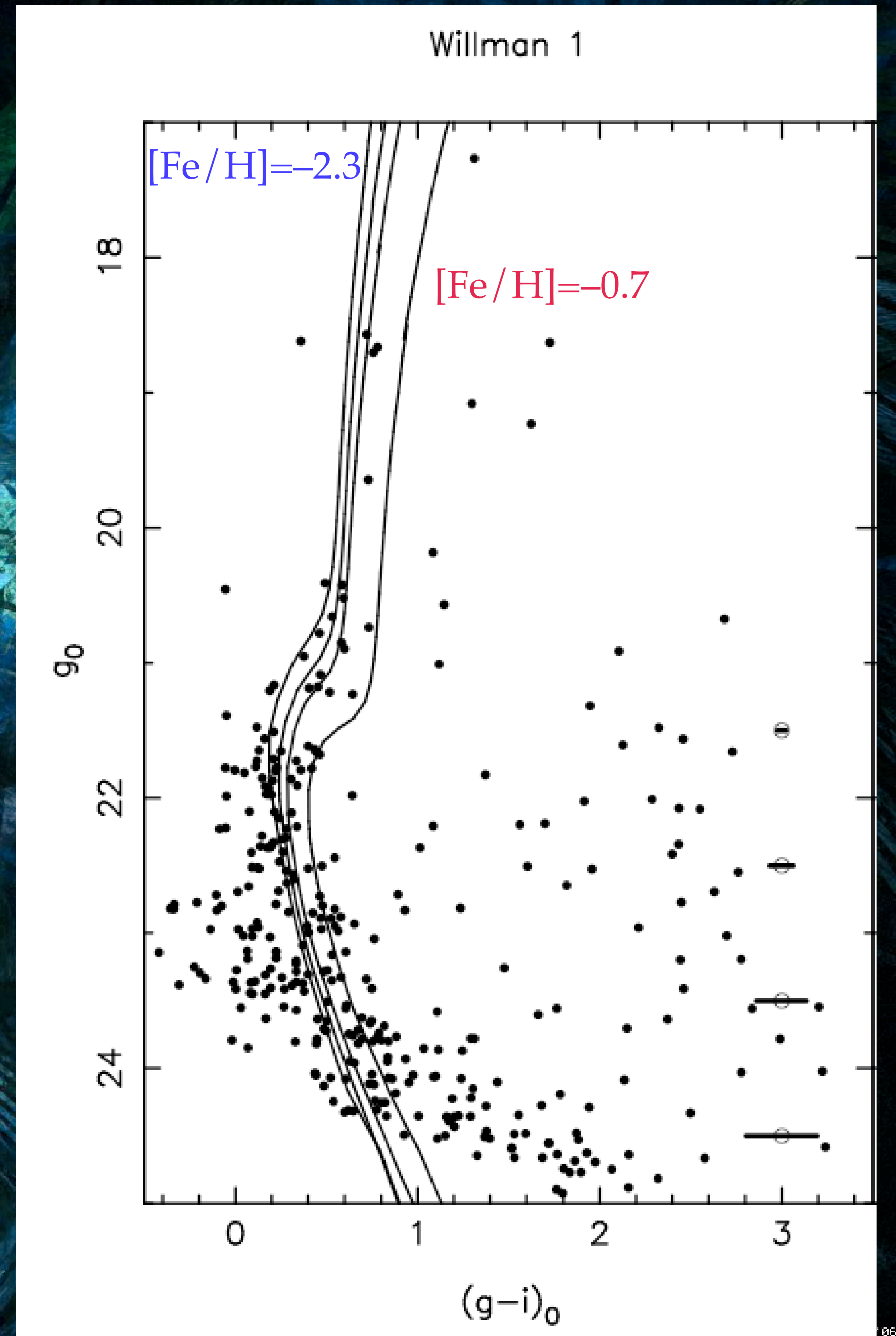
Willman 1, the INT/WFC view

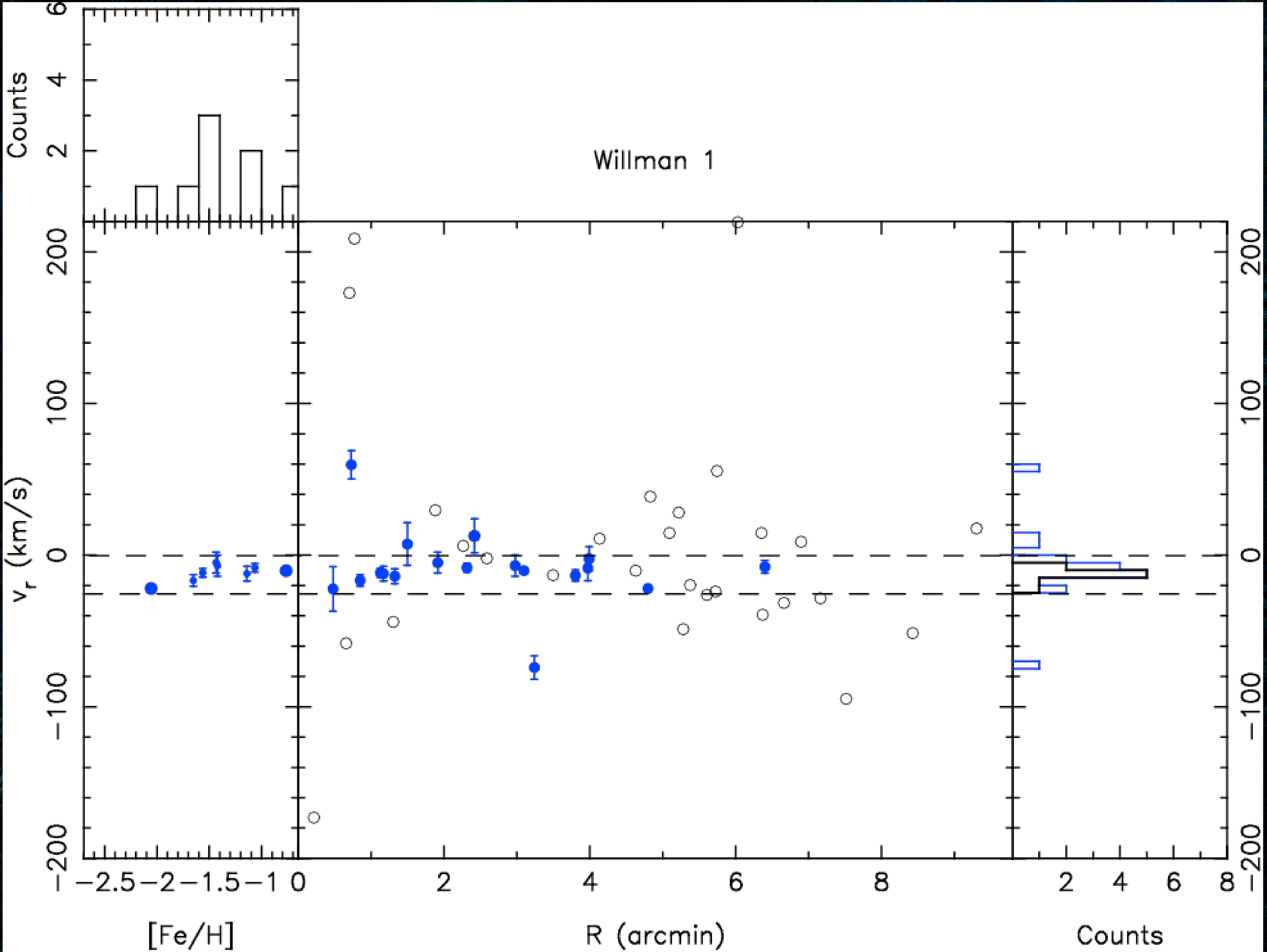




Willman 1, the INT/WFC view







Willman 1
Counts
v_r (km/s)
[Fe/H]
R (arcmin)
Counts
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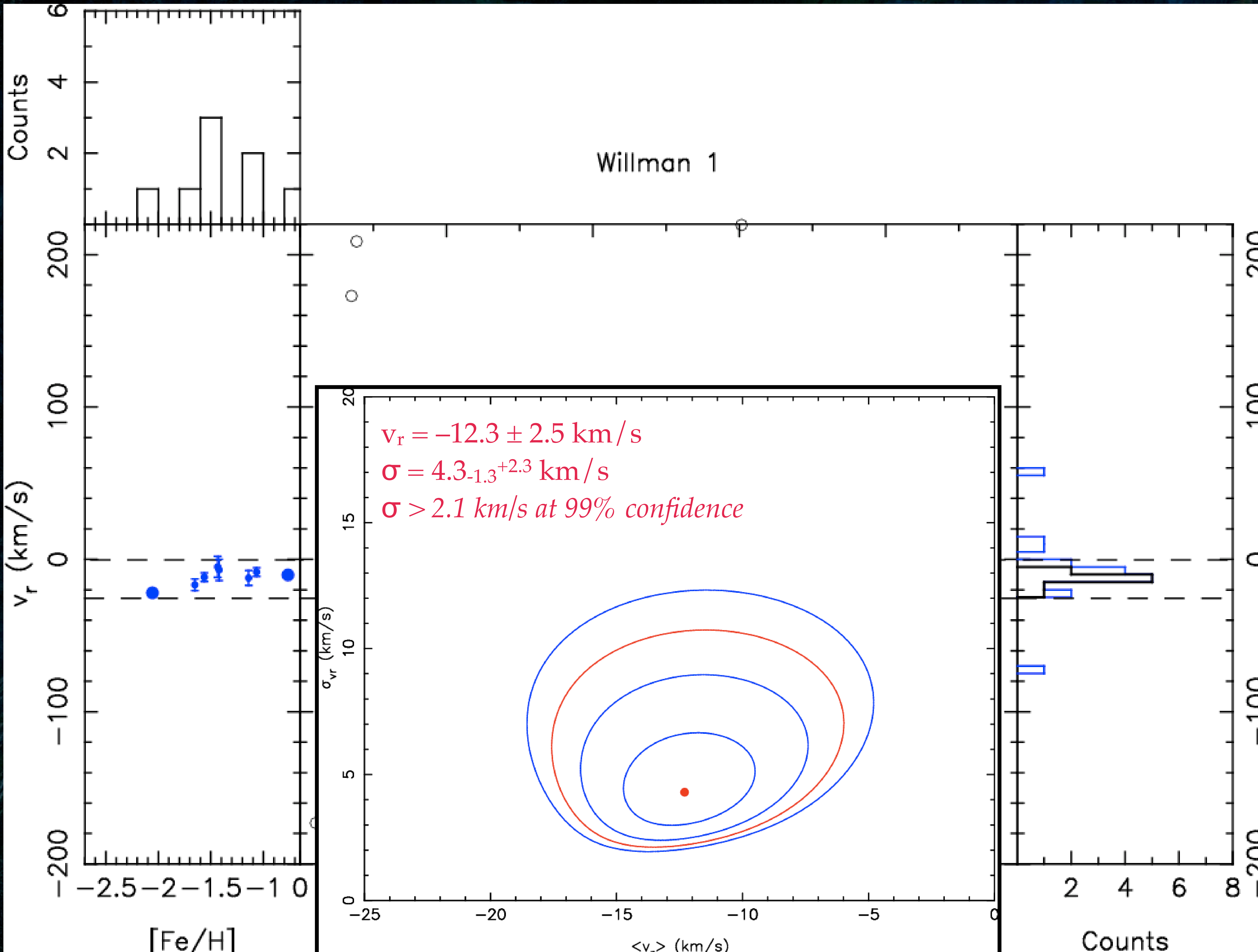
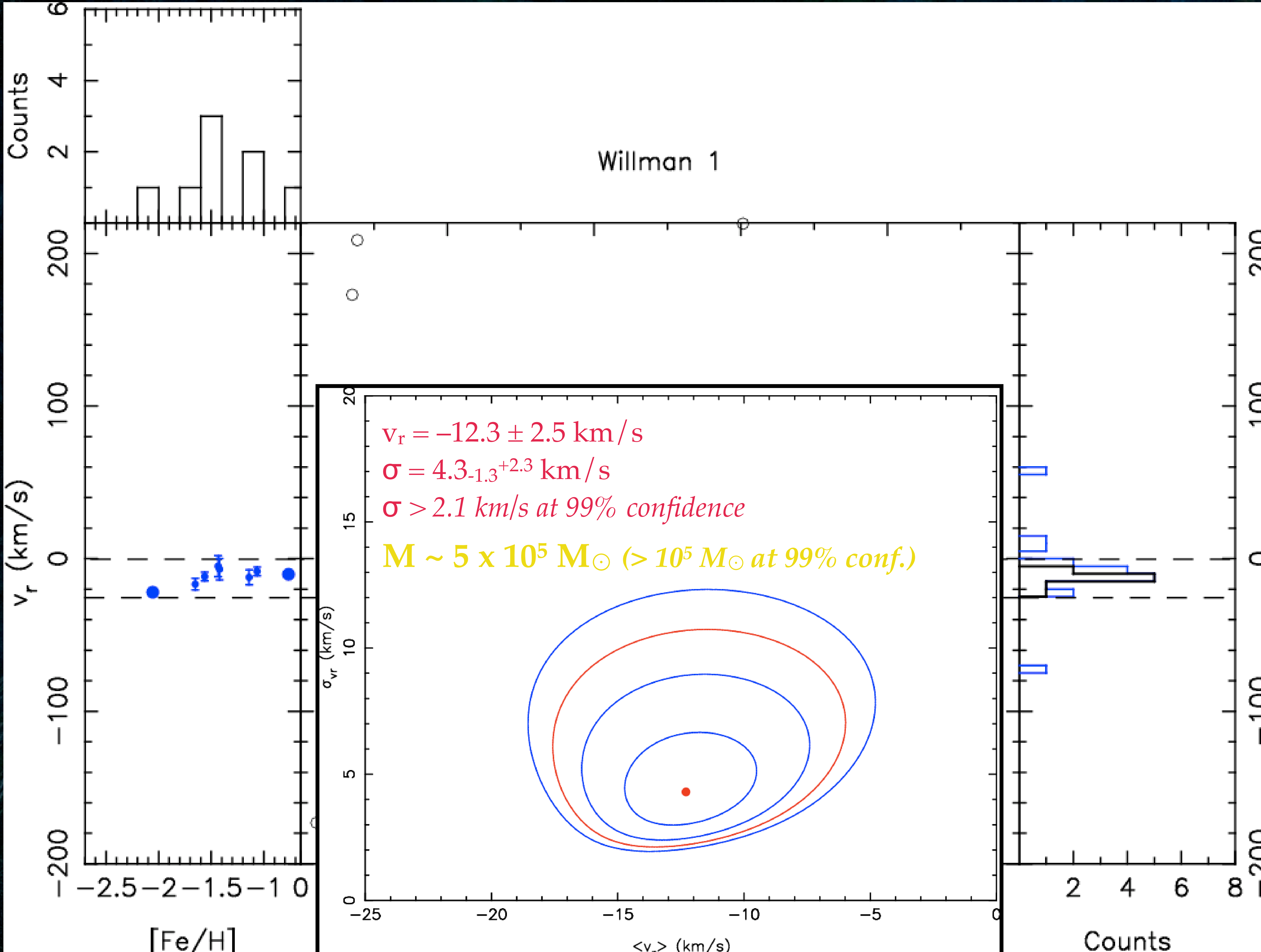
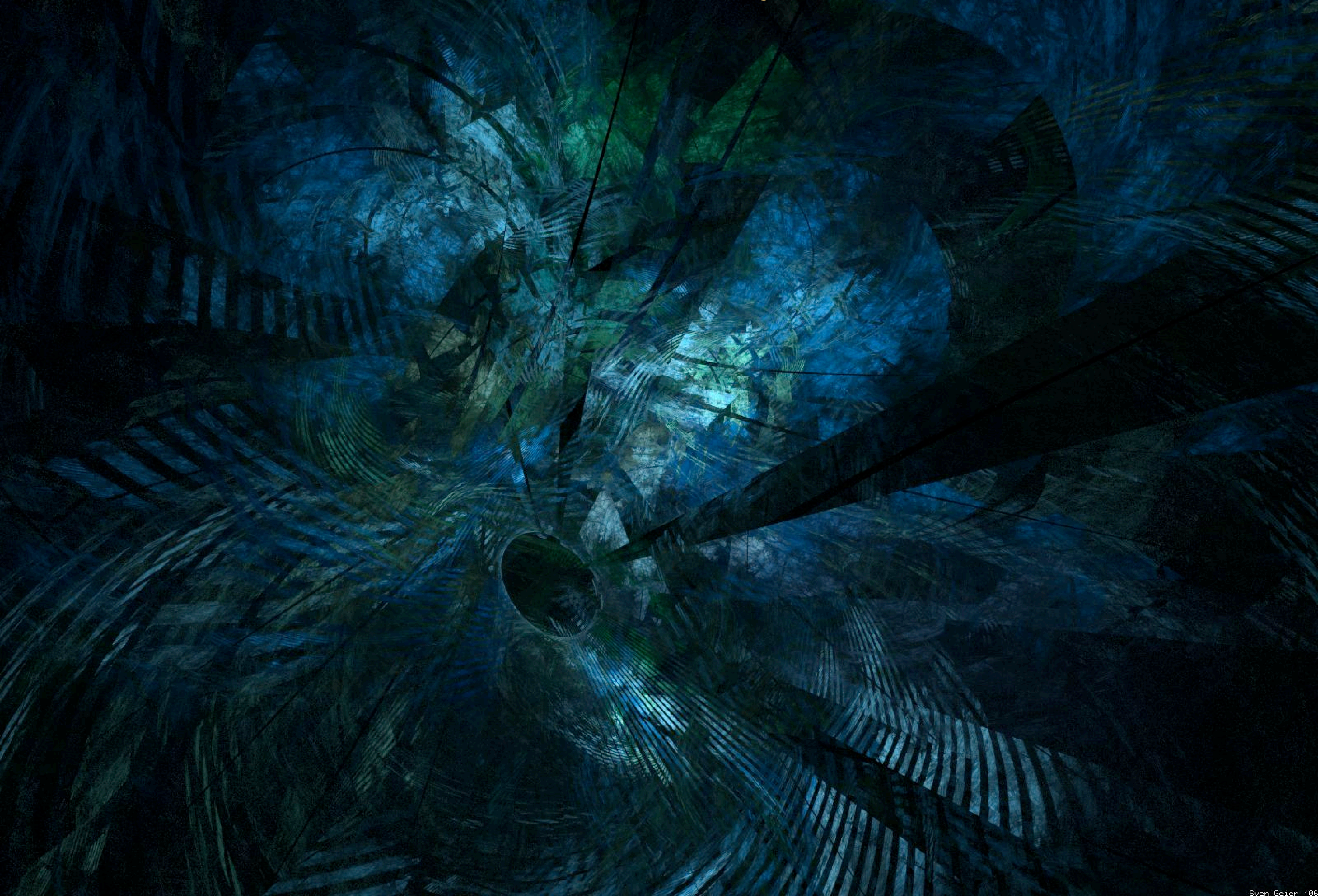

Willman 1
vr = −12.3 ± 2.5 km/s
σ = 4.3-1.3+2.3 km/s
σ > 2.1 km/s at 99% confidence
Counts
vr (km/s)
[Fe/H]
σvr (km/s)
<vr> (km/s)
Counts



Willman 1
Counts
[Fe/H]
v_r (km/s)
Counts
σ_vr (km/s)
<v_r> (km/s)
v_r = −12.3 ± 2.5 km/s
σ = 4.3 -1.3 +2.3 km/s
σ > 2.1 km/s at 99% confidence
M ~ 5 x 10^5 M☉ (> 10^5 M☉ at 99% conf.)

Summary



Summary

	Boo
v_r (km/s)	99.0 ± 2.1
σ_{vr} (km/s)	$6.5_{-1.4}^{+2.0}$
Mass ($M_\odot$)	***1.3×10^7***
median [Fe/H]	–2.1

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Summary

	Boo	CVn I (cold)	CVn I (hot)
v_r (km/s)	99.0 ± 2.1	22.5 ± 0.5	26.5 ± 1.5
σ_{vr} (km/s)	$6.5_{-1.4}^{+2.0}$	0.5 ± 0.5	$13.9_{-2.5}^{+3.2}$
Mass ($M_\odot$)	***1.3 x 10^7***	***~1.1 x 10^6***	***~1.3 x 10^8***
median [Fe/H]	–2.1	~ –1.7	~ –2.1

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Summary

	Boo	CVn I (cold)	CVn I (hot)	UMa I
v_r (km/s)	99.0 ± 2.1	22.5 ± 0.5	26.5 ± 1.5	–57.0 ± 3.5
σ_{vr} (km/s)	$6.5_{-1.4}^{+2.0}$	0.5 ± 0.5	$13.9_{-2.5}^{+3.2}$	$11.9_{-2.3}^{+3.5}$ *
Mass ($M_\odot$)	*1.3×10^7*	*$\sim 1.1 \times 10^6$*	*$\sim 1.3 \times 10^8$*	*4.7×10^7* *
median [Fe/H]	–2.1	~ –1.7	~ –2.1	~ –2.1

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Summary

	Boo	CVn I (cold)	CVn I (hot)	UMa I	UMa II
v_r (km/s)	99.0 ± 2.1	22.5 ± 0.5	26.5 ± 1.5	–57.0 ± 3.5	–115 ± 5
σ_{vr} (km/s)	$6.5_{-1.4}^{+2.0}$	0.5 ± 0.5	$13.9_{-2.5}^{+3.2}$	$11.9_{-2.3}^{+3.5}$ *	$7.4_{-2.8}^{+4.5}$
Mass ($M_\odot$)	***1.3×10^7***	***$\sim 1.1 \times 10^6$***	***$\sim 1.3 \times 10^8$***	***4.7×10^7*** *	***$0.4\text{-}0.9 \times 10^6$***
median [Fe/H]	–2.1	~ –1.7	~ –2.1	~ –2.1	~ –1.7 *

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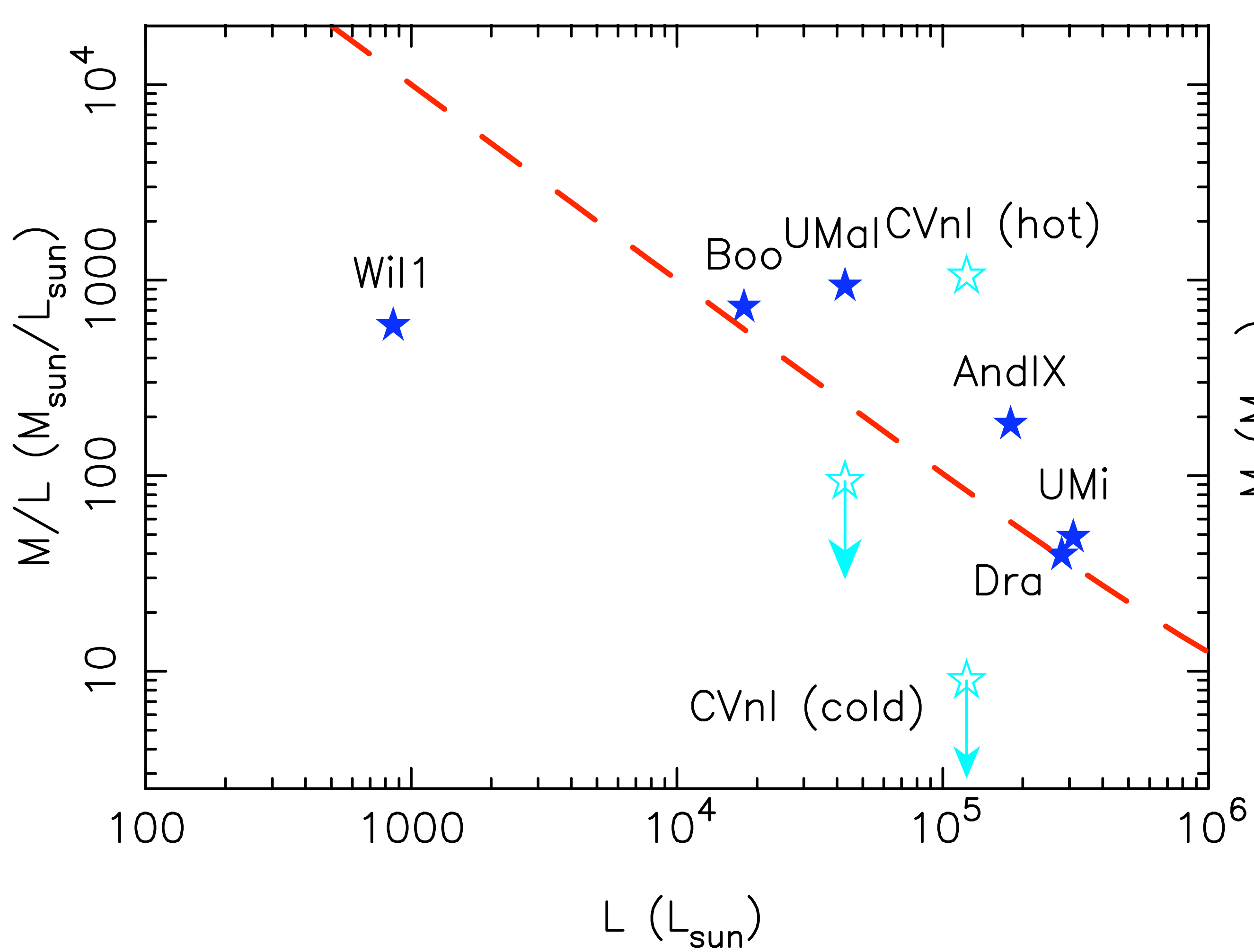
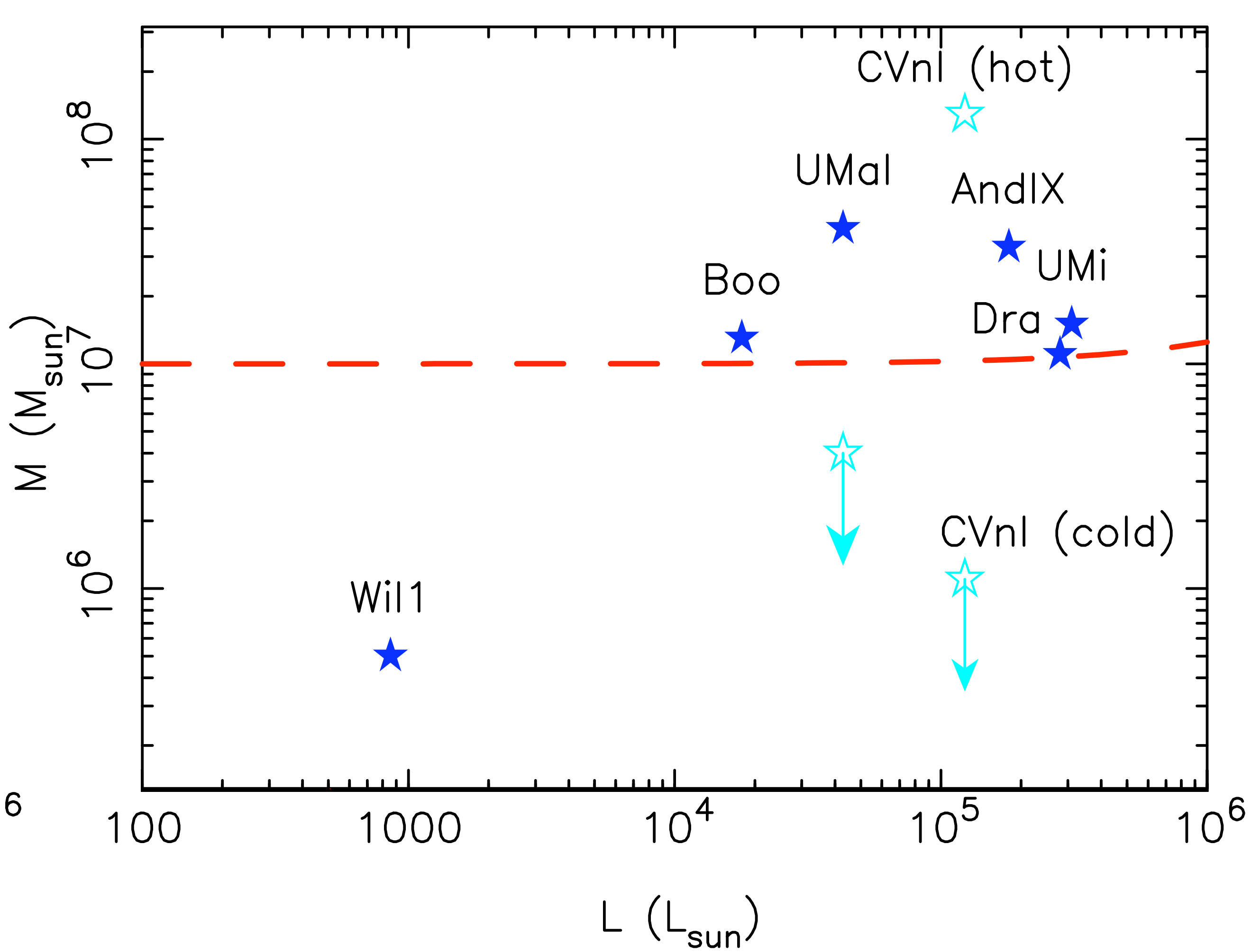
Summary

	Boo	CVn I (cold)	CVn I (hot)	UMa I	UMa II	Wil 1
v_r (km/s)	99.0 ± 2.1	22.5 ± 0.5	26.5 ± 1.5	–57.0 ± 3.5	–115 ± 5	–12.3 ± 2.5
σ_{vr} (km/s)	$6.5_{-1.4}^{+2.0}$	0.5 ± 0.5	$13.9_{-2.5}^{+3.2}$	$11.9_{-2.3}^{+3.5}$ *	$7.4_{-2.8}^{+4.5}$	$4.3_{-1.3}^{+2.3}$
Mass ($M_\odot$)	*1.3×10^7*	*$\sim 1.1 \times 10^6$*	*$\sim 1.3 \times 10^8$*	*4.7×10^7* *	*$0.4\text{-}0.9 \times 10^6$*	*5×10^5*
median [Fe/H]	–2.1	~ –1.7	~ –2.1	~ –2.1	~ –1.7 *	–1.5

Summary

	Boo	CVn I (cold)	CVn I (hot)	UMa I	UMa II	Wil 1
v_r (km/s)	99.0 ± 2.1	22.5 ± 0.5	26.5 ± 1.5	–57.0 ± 3.5	–115 ± 5	–12.3 ± 2.5
σ_{vr} (km/s)	$6.5_{-1.4}^{+2.0}$	0.5 ± 0.5	$13.9_{-2.5}^{+3.2}$	$11.9_{-2.3}^{+3.5}$ *	$7.4_{-2.8}^{+4.5}$	$4.3_{-1.3}^{+2.3}$
Mass ($M_\odot$)	*1.3×10^7*	*$\sim 1.1 \times 10^6$*	*$\sim 1.3 \times 10^8$*	*4.7×10^7* *	*$0.4\text{-}0.9 \times 10^6$*	*5×10^5*
median [Fe/H]	–2.1	~ –1.7	~ –2.1	~ –2.1	~ –1.7 *	–1.5





References

- Belokurov V. et al. 2007, *ApJ* 658, 337
- Coleman M., de Jong J., Martin N., Rix H.-W., Sand D., Bell E., Olszewski E., Hippelein H., 2007, *ApJL* submitted
- Ibata R, Chapman S., Irwin M., Lewis G. & Martin N., 2006, *MNRAS* 373, L70
- Illingworth G., 1976, *ApJ* 204, 73
- Martin N., Ibata R., Chapman S., Irwin M. & Lewis G., 2007, *MNRAS* accepted, astro-ph/0705.4622
- Mateo M., 1998, *ARA&A* 36, 435
- Piatek S. & Pryor C., 1995, *AJ* 109, 1071
- Wilkinson M., Kleyna J., Gilmore G., Evans W., Koch A., Grebel E., Wyse R. & Harbeck D., 2006, *The Messenger* 124, 25