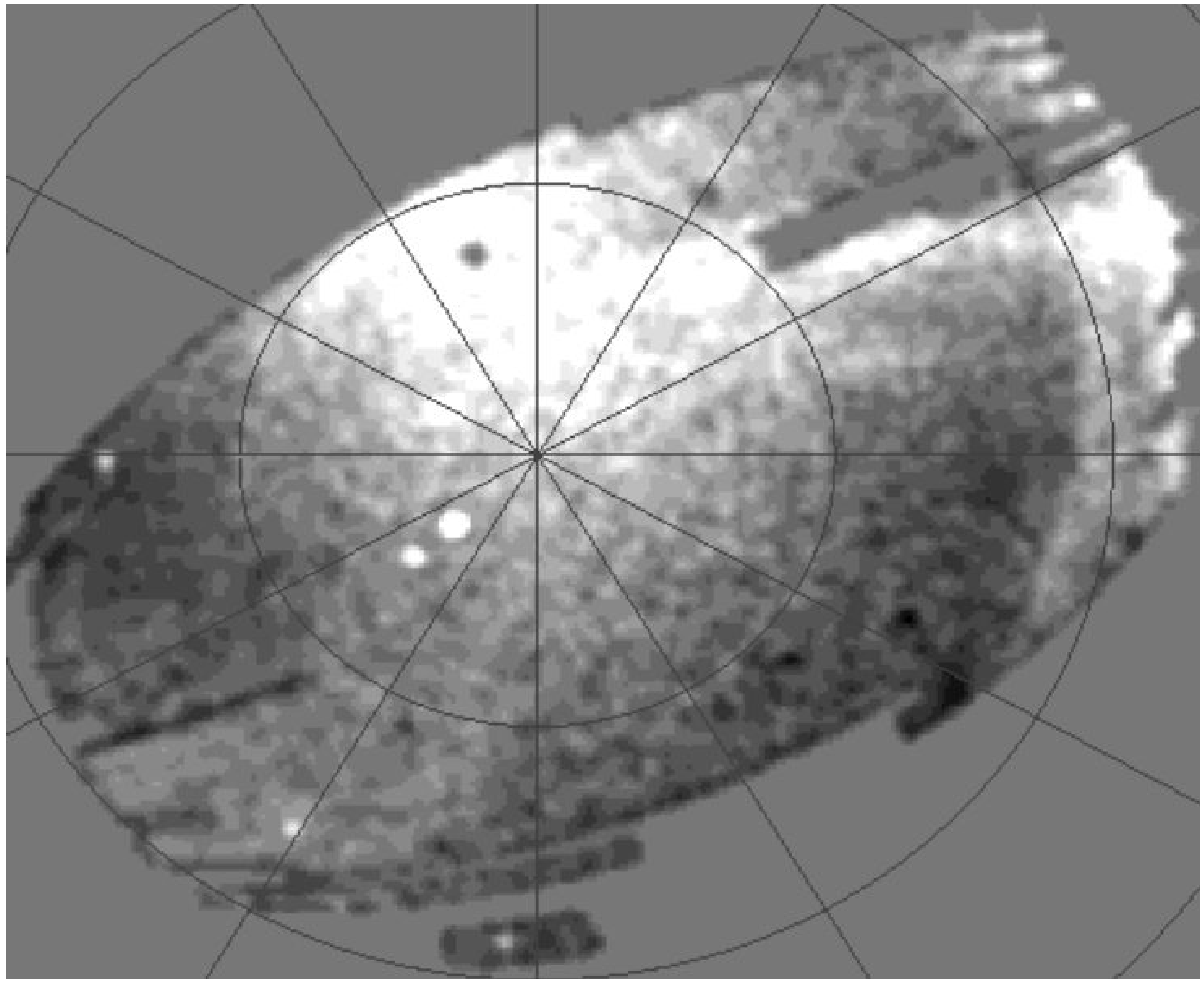
Studying Milky Way structure using stellar populations



Jelte de Jong (Max-Planck-Institut für Astronomie, Heidelberg)

H-W. Rix, E. Bell, D. Butler, N. Martin, D. Zucker, V. Belokurov, A. Dolphin

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Overview
- CMD fitting
- Canis Major
- Halo substructure

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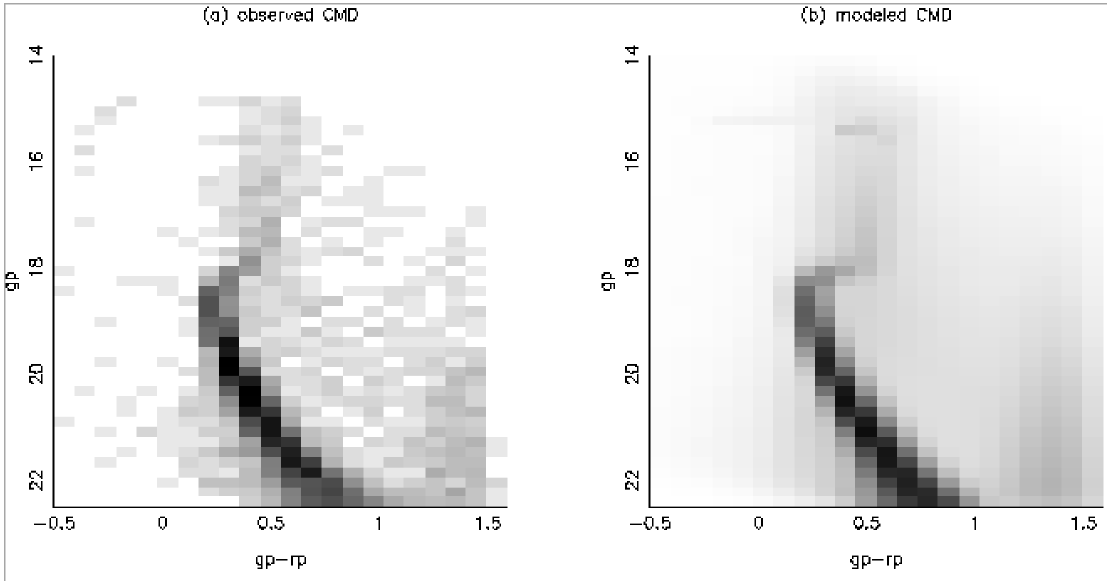
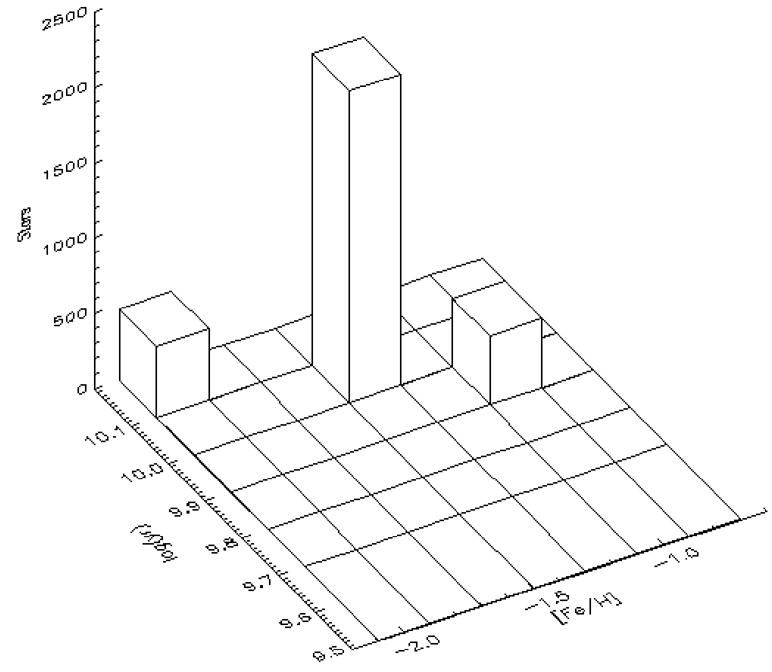
CMD fitting techniques

Example: M13
(SDSS DR5, Adelman-McCarthy, 2007, ApJS, subm.)
MATCH
(Dolphin, 2001, MNRAS, 332, 91)



Fitting of observed CMDs of e.g. globular clusters or dwarf galaxies, allows measurement of distance, star formation history and metallicity evolution



The Milky Way: a whole different ball game

Current WFI's and “all-sky” surveys (SDSS, 2MASS, ...) enable study of stellar populations in the Milky Way, but...

- Stars with greatly varying ages and metallicities all along the line of sight
- Even for restricted structures, large contamination

CMD-fitting and the use of stellar populations must be taken to a completely different regime

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The Milky Way: a whole different ball game

Two examples:

- Canis Major stellar overdensity
- Halo substructure in SDSS data

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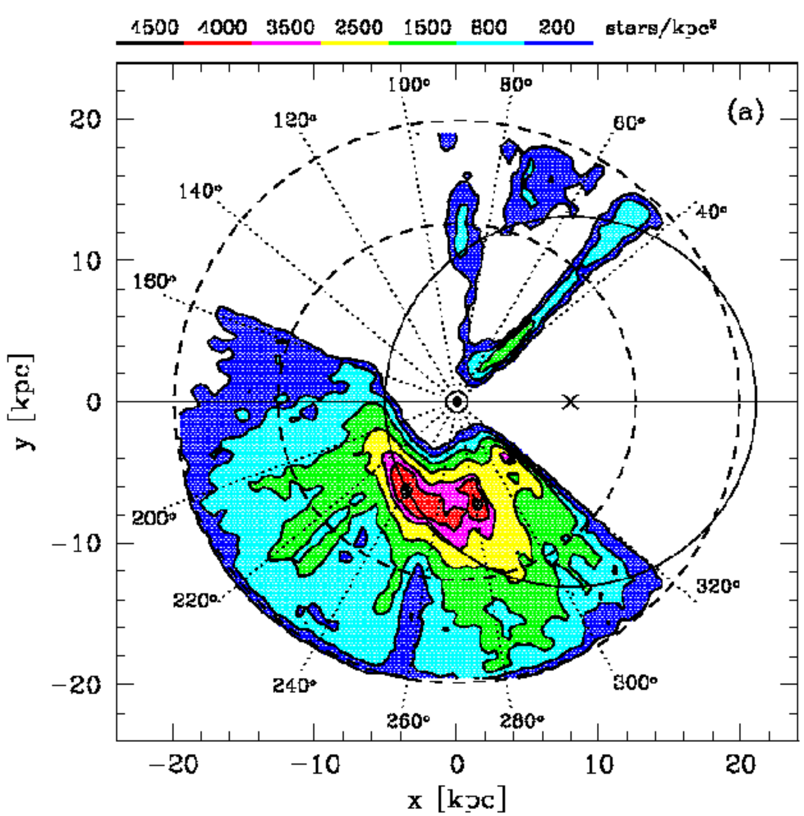
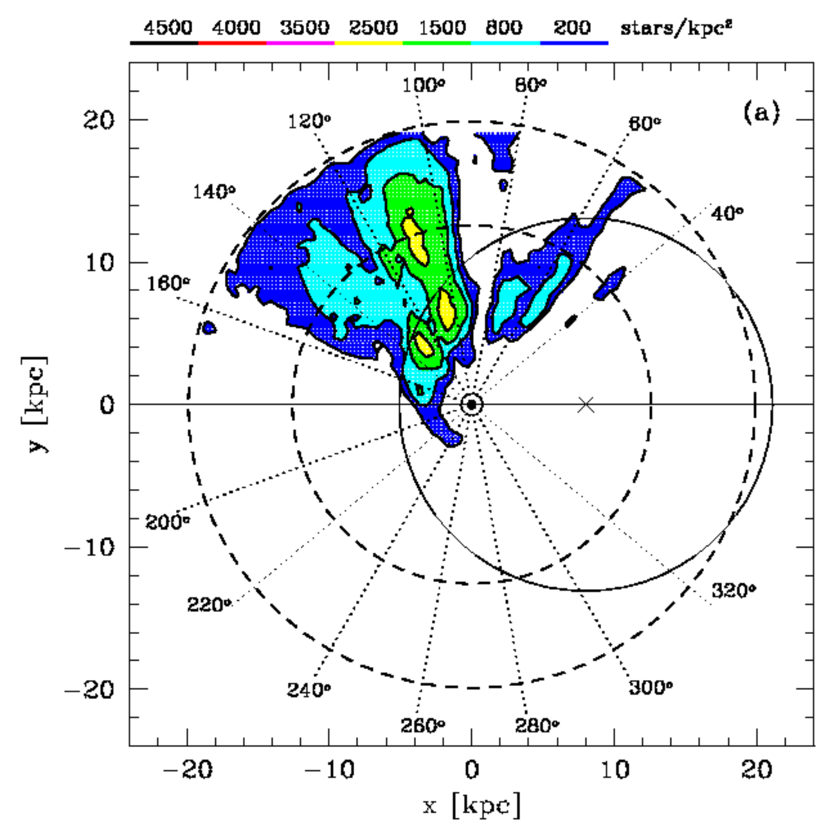
Introduction to Canis Major

Discovered by Martin et al. (2004, MNRAS, 348, 12) using 2MASS M-giants

Largest substructure at low Galactic latitudes



ρ(south) – ρ(north)



ρ(north) – ρ(south)

2MASS RC stars (Bellazzini et al. 2006, MNRAS, 366, 865)

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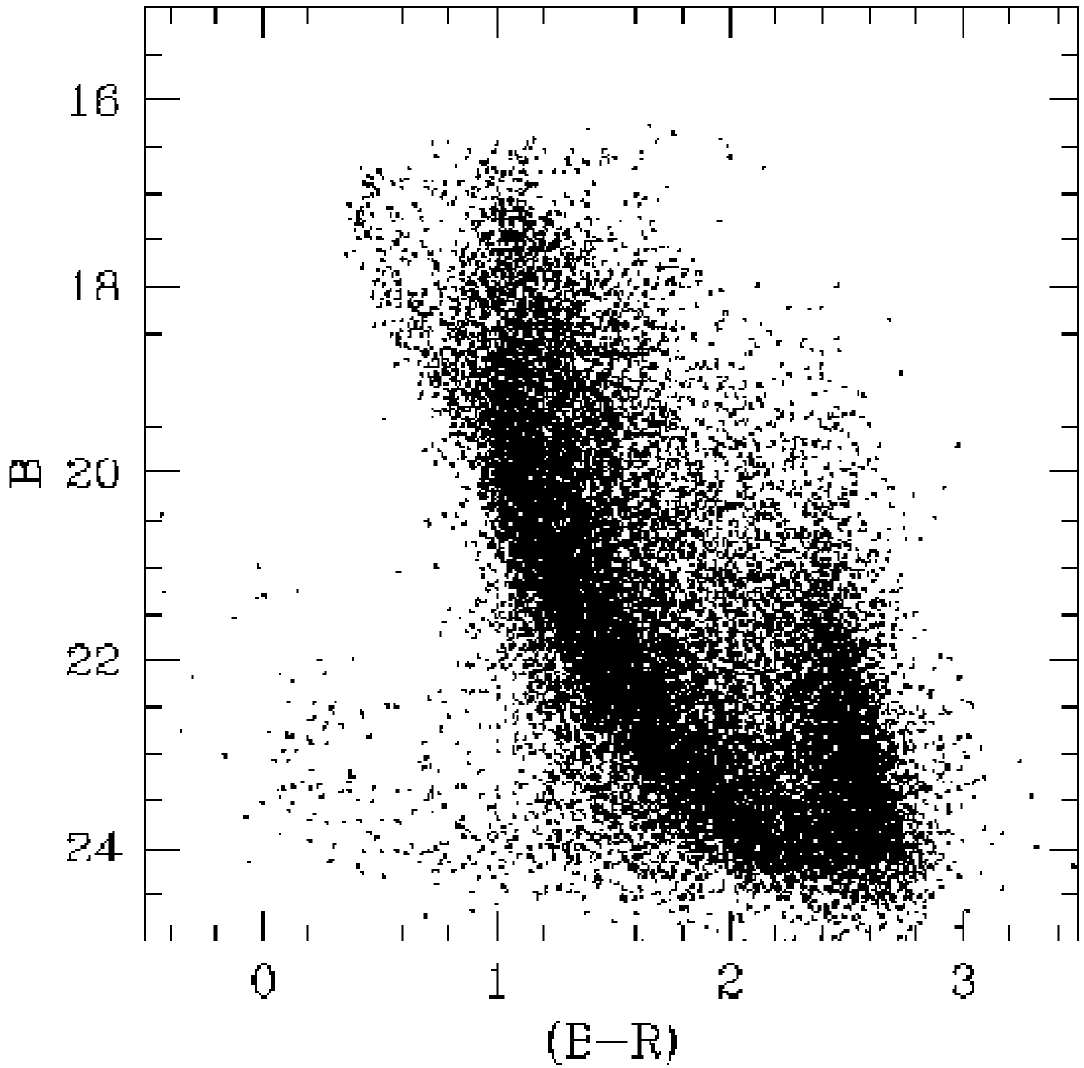
Introduction to Canis Major

Deep photometry shows narrow main sequence, and two clearly separate populations
(e.g. Martinez-Delgado et al. 2005, ApJ, 633, 205; Bellazzini et al. 2005, MNRAS, 354, 1263)



(Martinez-Delgado et al. 2005)

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Dragged in or kicked out?

- **Accreted** dwarf, progenitor Low Latitude stream
  (e.g. Martin et al. 2004, Martinez-Delgado et al. 2005, Bellazzini et al. 2006)

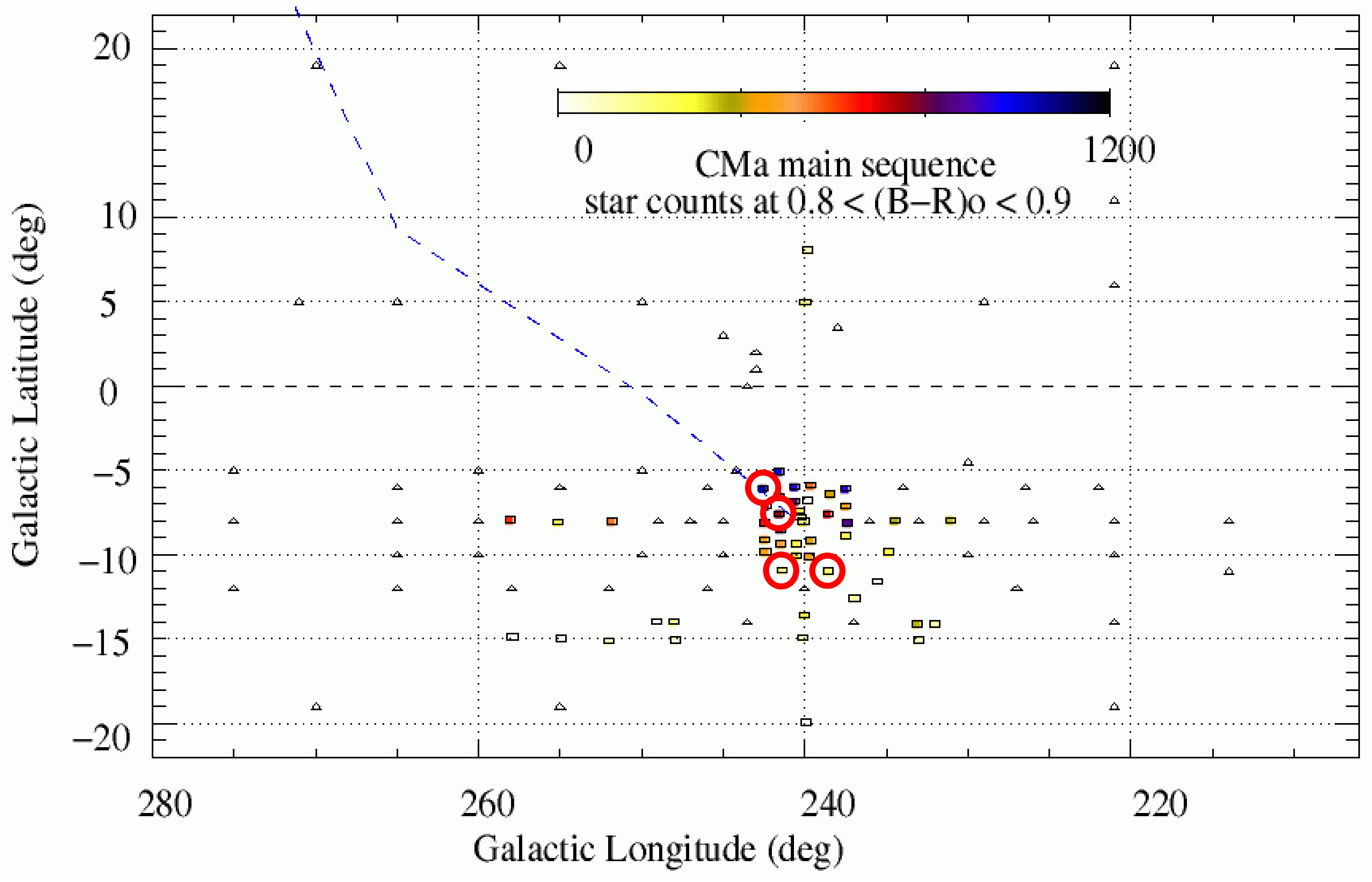
- Produced by **warp** and **flare** of outer disk crossing the line-of-sight (e.g. Momany et al. 2004, 2006)

- Old MS stars belong to local **spiral arm**, young stars part of outer **spiral arm** (Carraro et al. 2005, Moitinho et al. 2006)

Is CMa overdensity intrinsic (sub)structure, or is it coming from outside?

Are the old and young stars co-spatial and co-moving, or are they only coinciding in projection?

MPIA Wide Field Imager survey



(Butler et al., 2007, AJ, 133, 2274)

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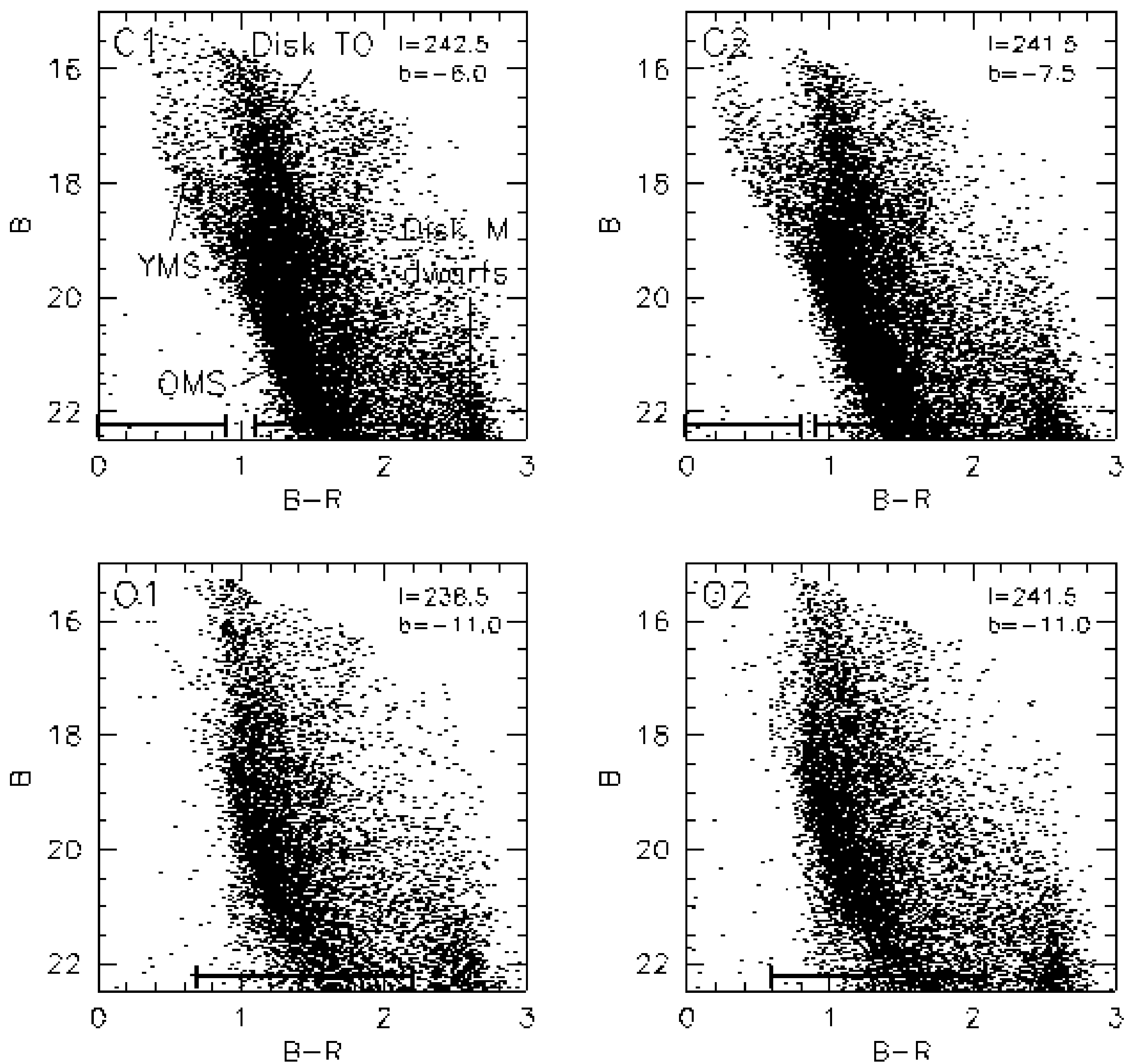

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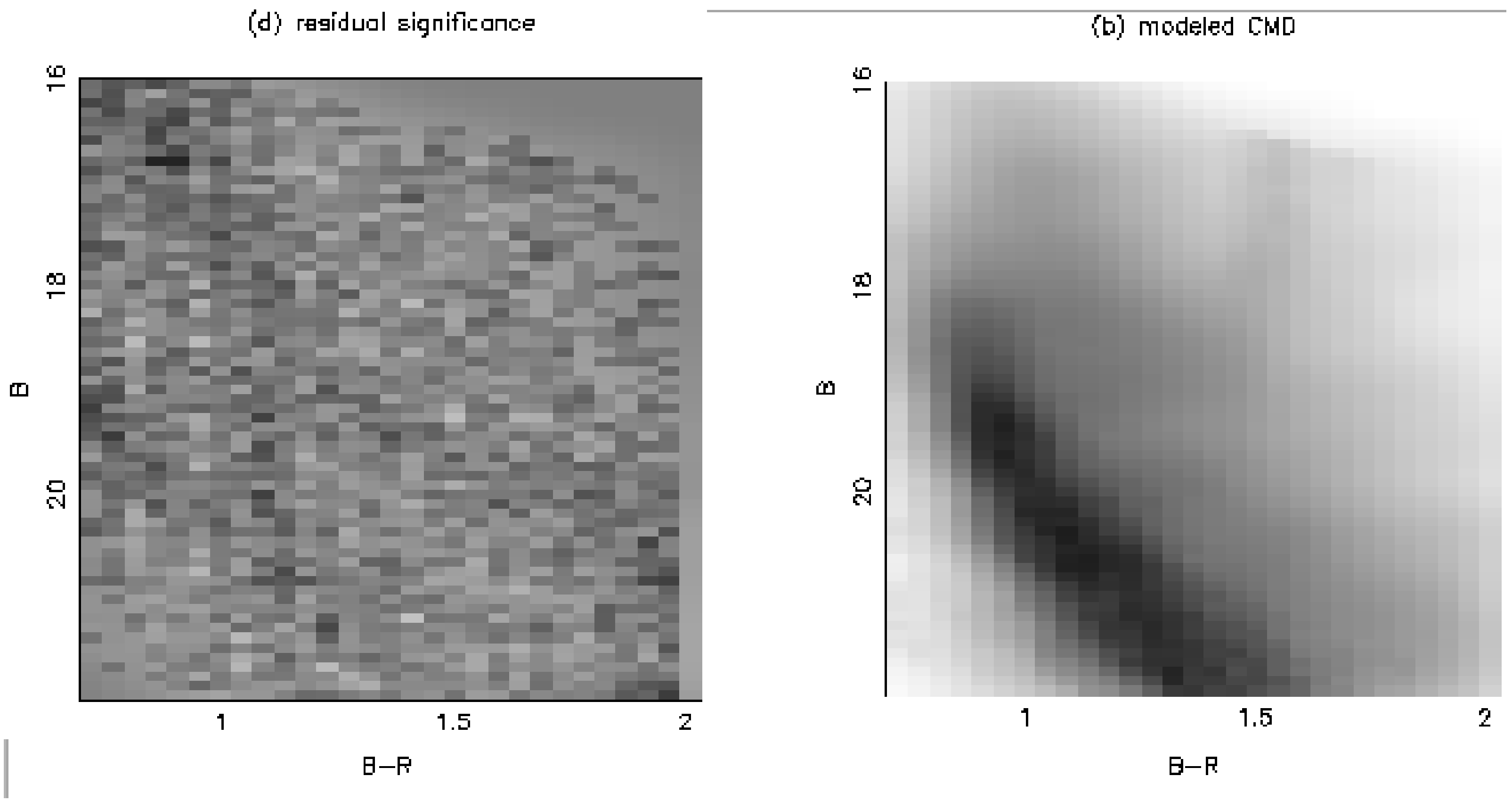
CMa Old Main Sequence fitting

Using MATCH (Dolphin 2001, MNRAS, 332, 91) we compare how well single component populations fit the data



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CMa Old Main Sequence fitting

	Central	Outer
Ages (Gyr)	3 – 6	3 – 6
m–M (mag)	14.4 ± 0.1	14.3 ± 0.3
Los σ (mag)	0.42 ± 0.06	0.42 ± 0.07
[Fe/H]	–1.0 ± 0.3	–0.6 ± 0.3

Intermediate age population

[Fe/H] agrees with spectroscopy (Martin et al. in prep)

Distance ~ 7.5 kpc with l.o.s. FWHM of ~3.5 kpc

(de Jong et al. 2007, ApJ, 662, 259)

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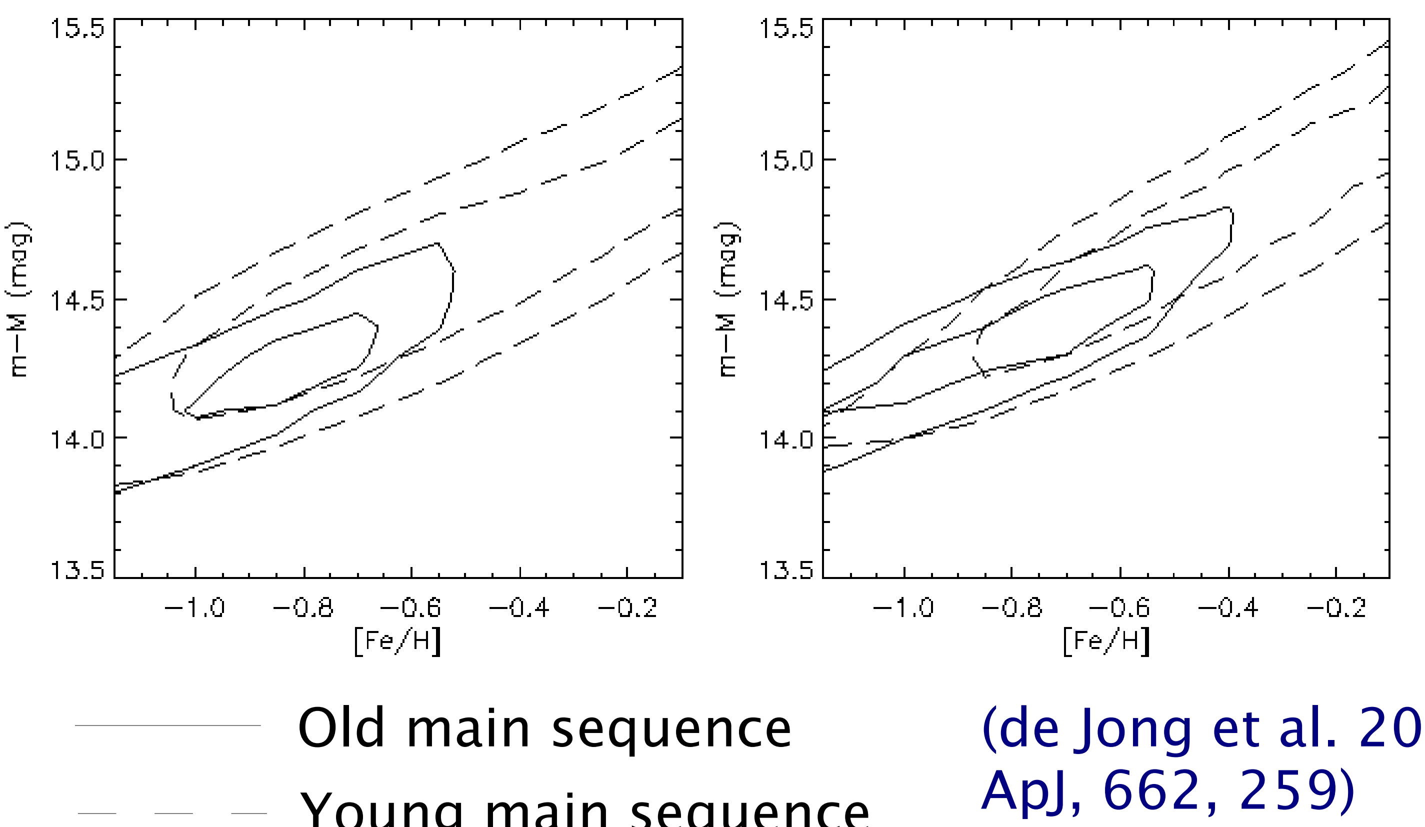
CMa Young Main Sequence fitting

Ages 0.25-2 Gyr, but metallicity and distance cannot be determined due to strong degeneracy between these paremeters:



(de Jong et al. 2007, ApJ, 662, 259)

Summary of CMa results

(de Jong et al. 2007, ApJ, 662, 259)

CMa Old Main Sequence:

- CMD–fitting: D ~ 7.5 kpc, l.o.s. FWHM ~ 3.5 kpc,
  Ages ~ 3–6 Gyr, [Fe/H]~−1.0

CMa Young Main Sequence:

- Ages 250 Myr – 2 Gyr
- can be co–spatial with old stars if same [Fe/H], otherwise located behind the OMS

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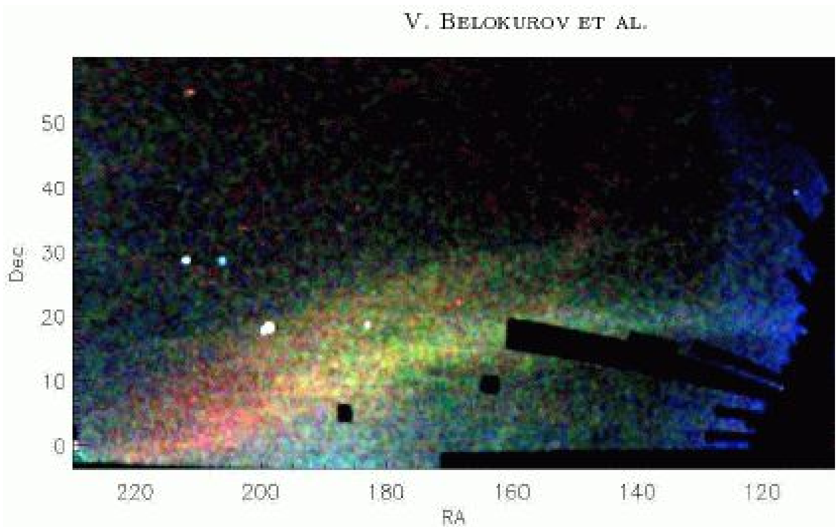
Stellar halo substructure

Question:

Hierarchical build-up of stellar halos clearly happens

- Is it icing on the cake?
  - Minor addition to halo mostly built up before
- Or is it the cake?
  - Major addition to halo

Use SDSS:
~8000 sq.deg. to r=22.5
~52.000.000 stars



(Belokurov et al. 2006, ApJ, 642, L137)

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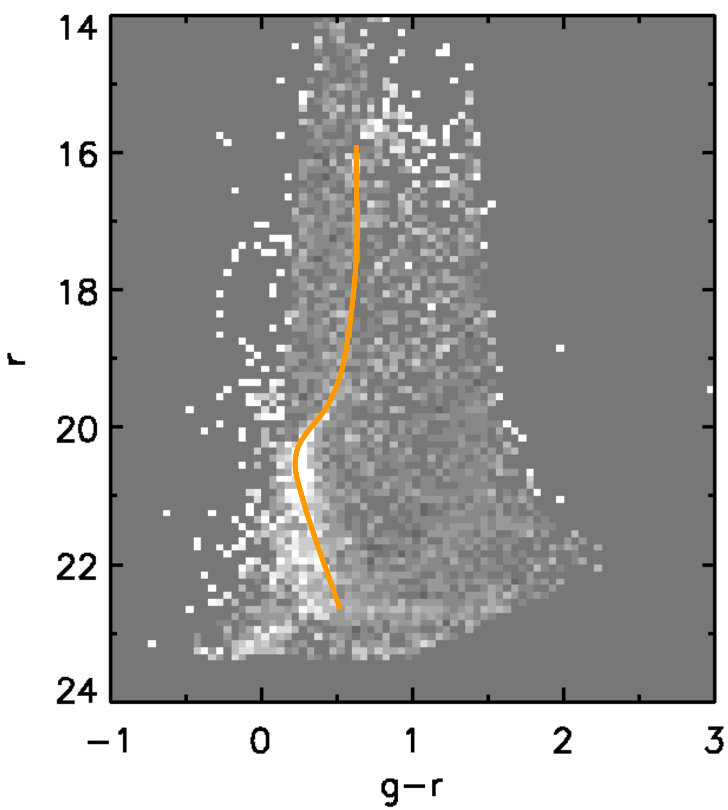
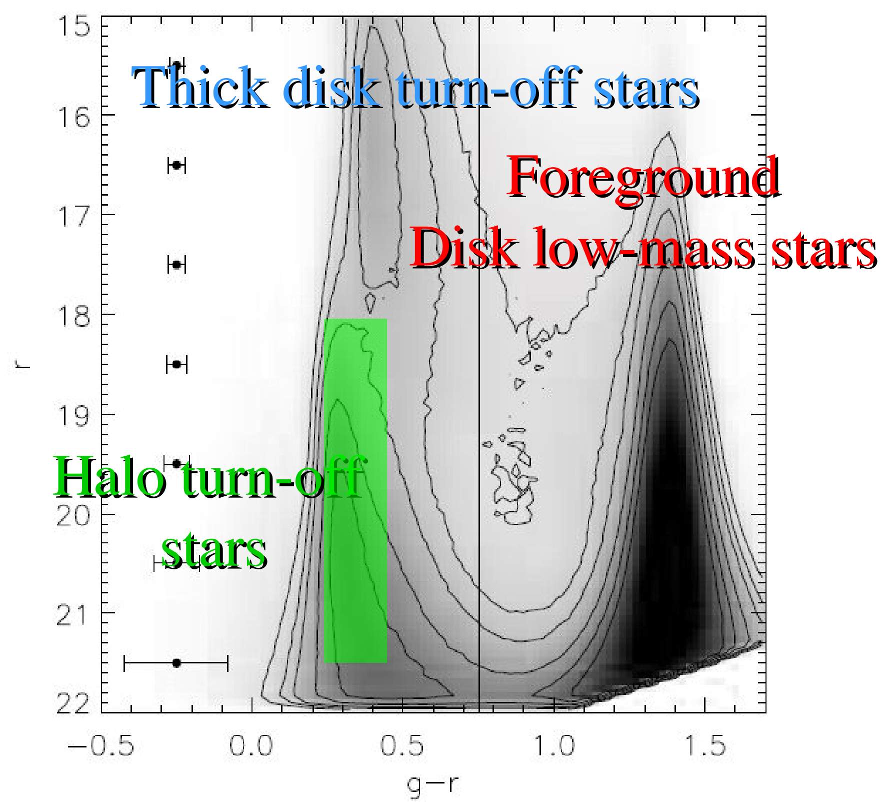
Stellar halo substructure

Use main-sequence turn-off stars as 'standard candle'
(~4 million color selected stars)

Pal 5:



All SDSS:



(Bell et al. 2007, arXiv:0706.0004)

Stellar halo substructure

Fit oblate and triaxial halos to MSTO stellar density, $\rho(D,\alpha,\delta)$

Results:

- 'best' halo fit is $\sim r^{-3}$, between $5<r_{gc}/\mathrm{kpc}<40$; perhaps shallower inside 20kpc and steeper outside
- Oblate c/a = 0.6+/-0.1

- Is smooth model a good fit?
  - RMS of data around model; take off Poisson in quadrature from RMS

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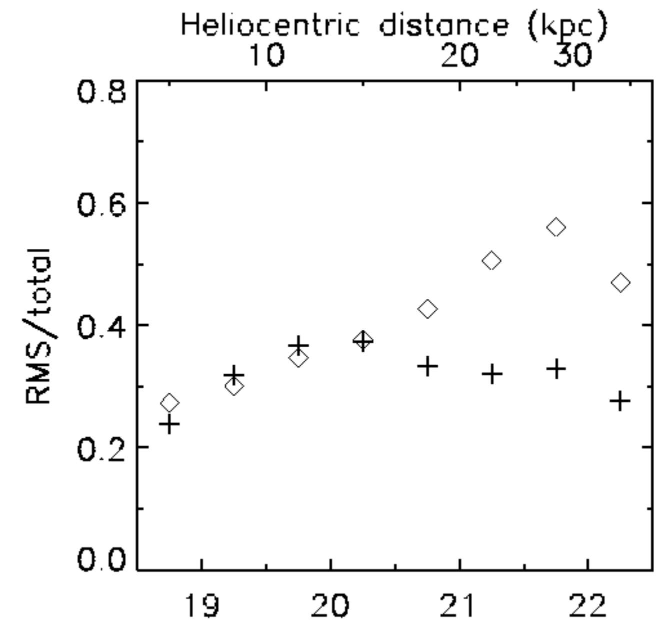
Stellar halo substructure

Results:

- ‘best’ halo fit is $\sim r^{-3}$, between $5<r_{gc}/\mathrm{kpc}<40$; perhaps shallower inside 20kpc and steeper outside
- Oblate c/a = 0.6+/−0.1
- BUT, smooth model is a RMS/total > 0.4
- Indications of more
- structure at larger radii



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Overview
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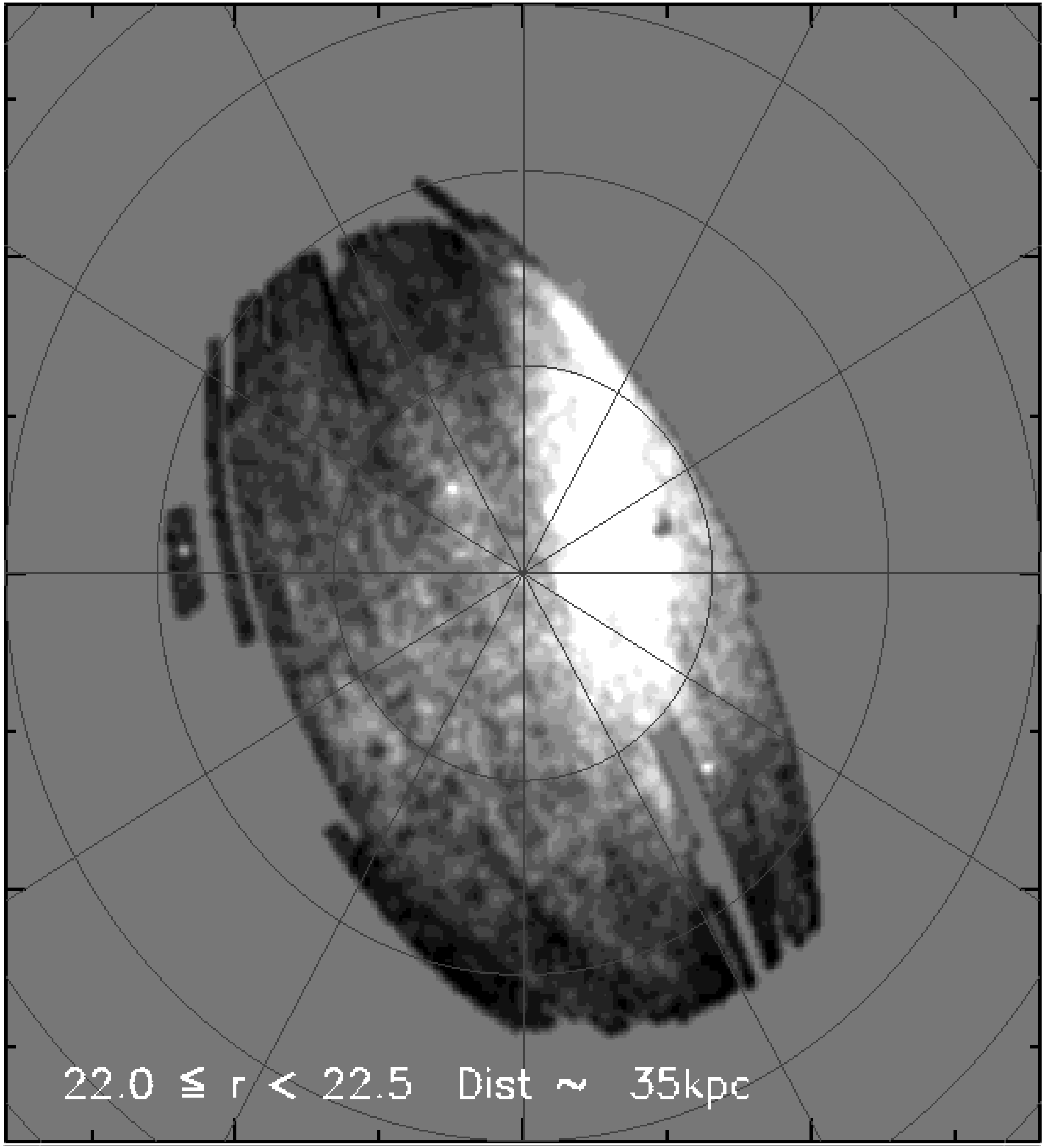

Residuals

black=−60%
white=+60%

(Bell et al. 2007)

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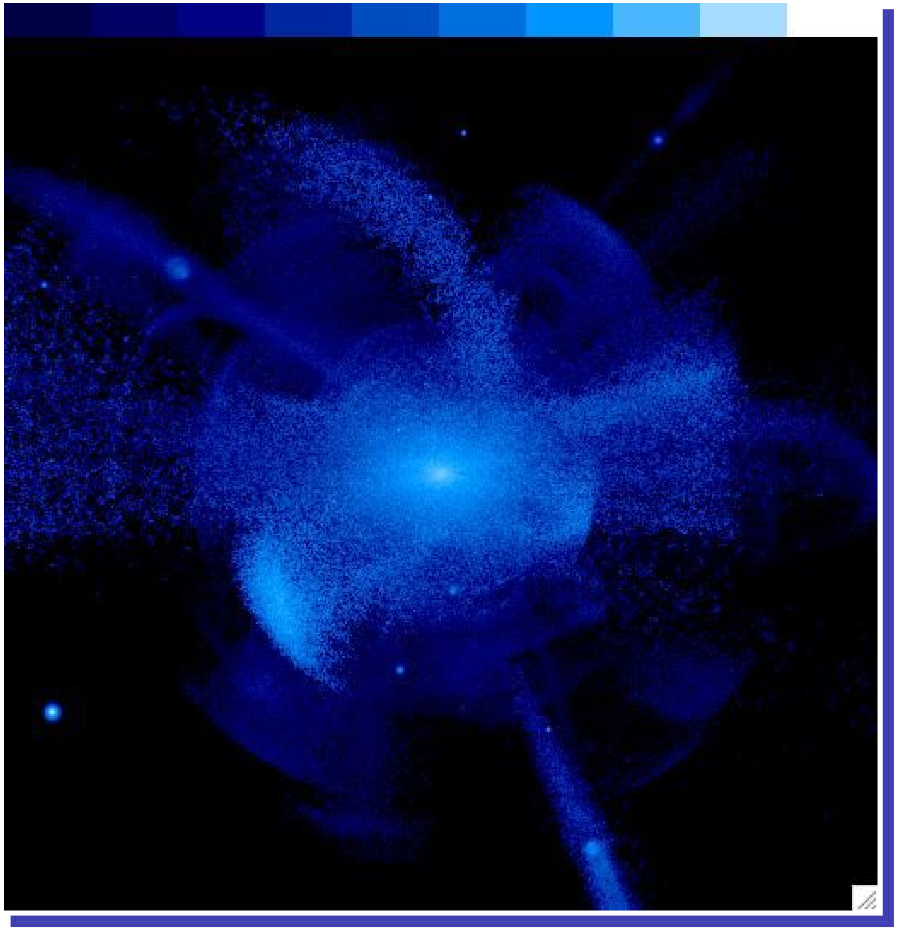
Comparison with simulations

Simulated stellar halos from Bullock & Johnston (2005, ApJ, 635, 931)



Accretion of N–body dwarf galaxies following cosmological merger histories
(i.e. halos purely built up through accretion)

Models capable of creating halos similar to that of the MW?

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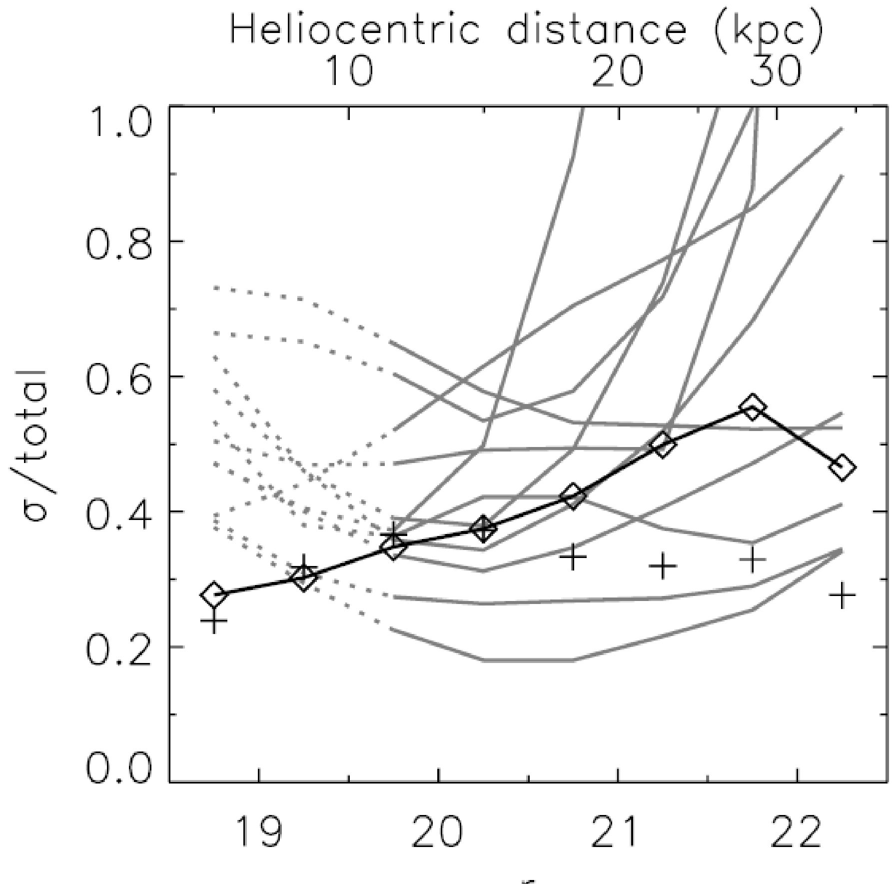
Comparison with simulations

Convert model particles to stellar mass distribution, turn this into stellar luminosity distribution and distribution of MSTO stars

View simulation from solar position through SDSS field-of-view and follow same fitting procedure as with SDSS data



Large scatter, several models have similar amount of substructure

(Bell et al. 2007, arXiv:0706.0004)

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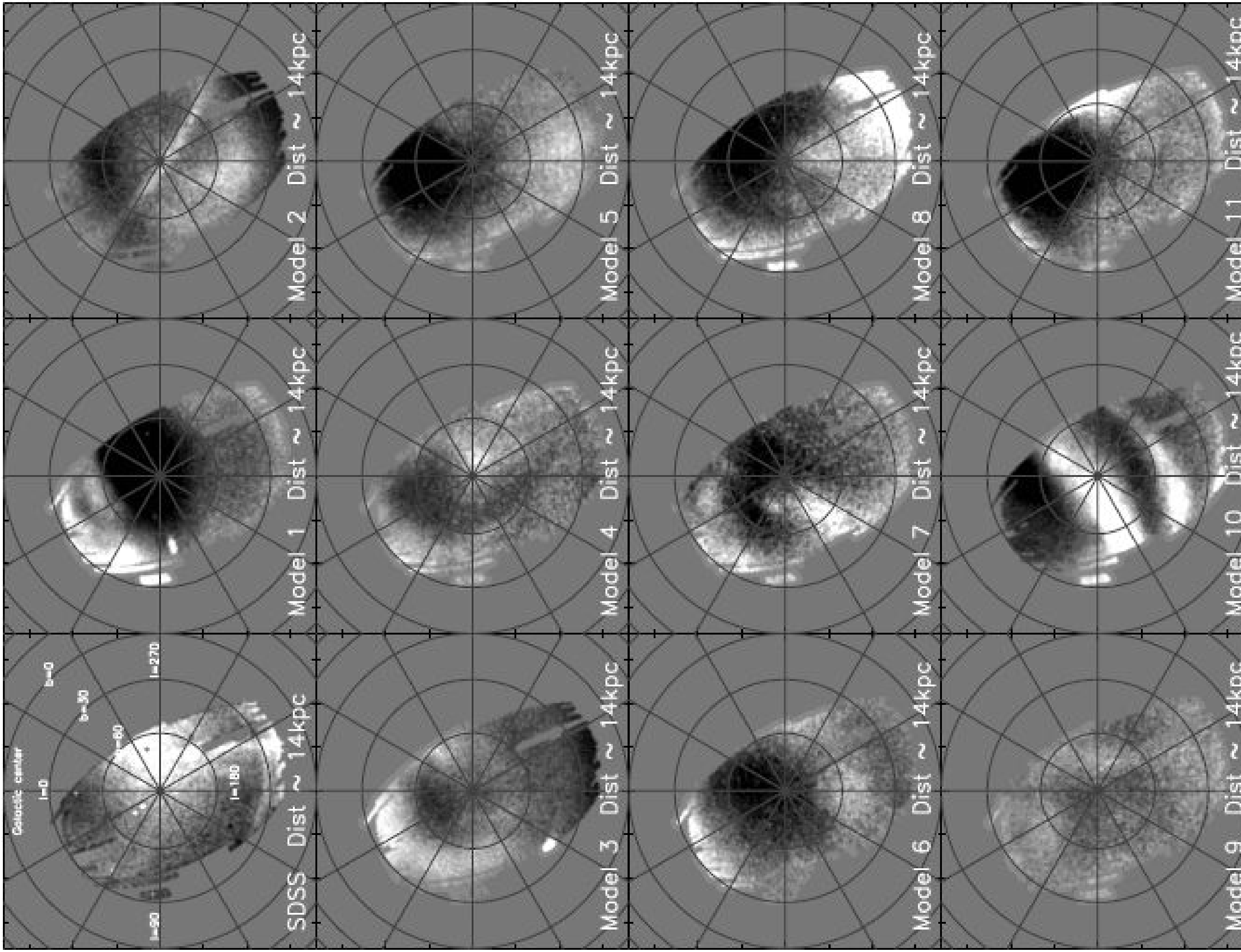

(Bell et al. 2007, arXiv:0706.0004)

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Summary of halo substructure results

(Bell et al. 2007, arXiv:0706.0004)

- SDSS is a powerful tool in understanding halo structure
- Results so far:
  - r^{-3} halo at <~40kpc
  - c/a ~ 0.6 ; M ~ 5e8 Msun
  - Smooth halo poor fit: RMS/total ~ 0.4
- Simulated halos show considerable scatter in properties, but properties and degree of sub-structure of MW halo match those of 'typical' halo built up purely by accretion
- Seems likely that significant fraction of halo has been accreted from satellite galaxies