

Galaxy Alignment

Misleading Myths, Miserable Mistakes & Mirky Mysteries



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Two Types of Alignment

Alignment between orientations of neighbouring galaxies

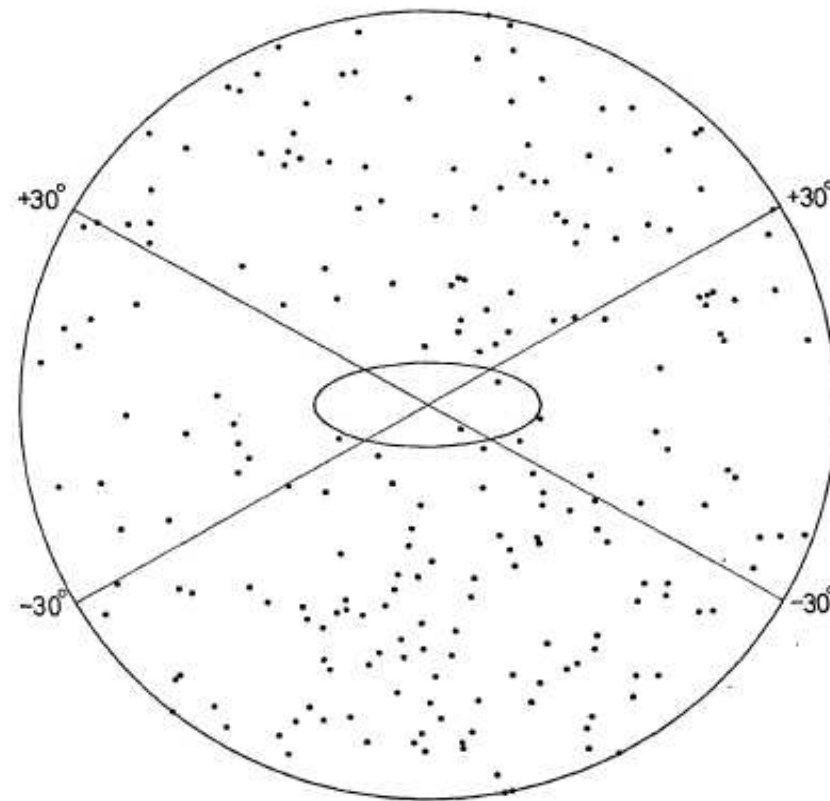
- Important for weak lensing studies
- Of interest for galaxy formation
- Not the topic of this talk

Alignment between orientation of 'central' galaxy and distribution of 'satellites'

- Potentially important for galaxy-galaxy lensing
- Of interest for galaxy formation
- The topic of this talk
- Rich history; full of Myths, Mistakes & Mysteries

The Holmberg Effect

ARKIV FÖR ASTRONOMI. Bd 5 nr 20



(Holmberg 1969).

Fig. 3. Combined distribution of 218 galaxies in 58 survey areas around spiral systems of class A (edgewise orientation). The ellipse shows the average size of the central system.

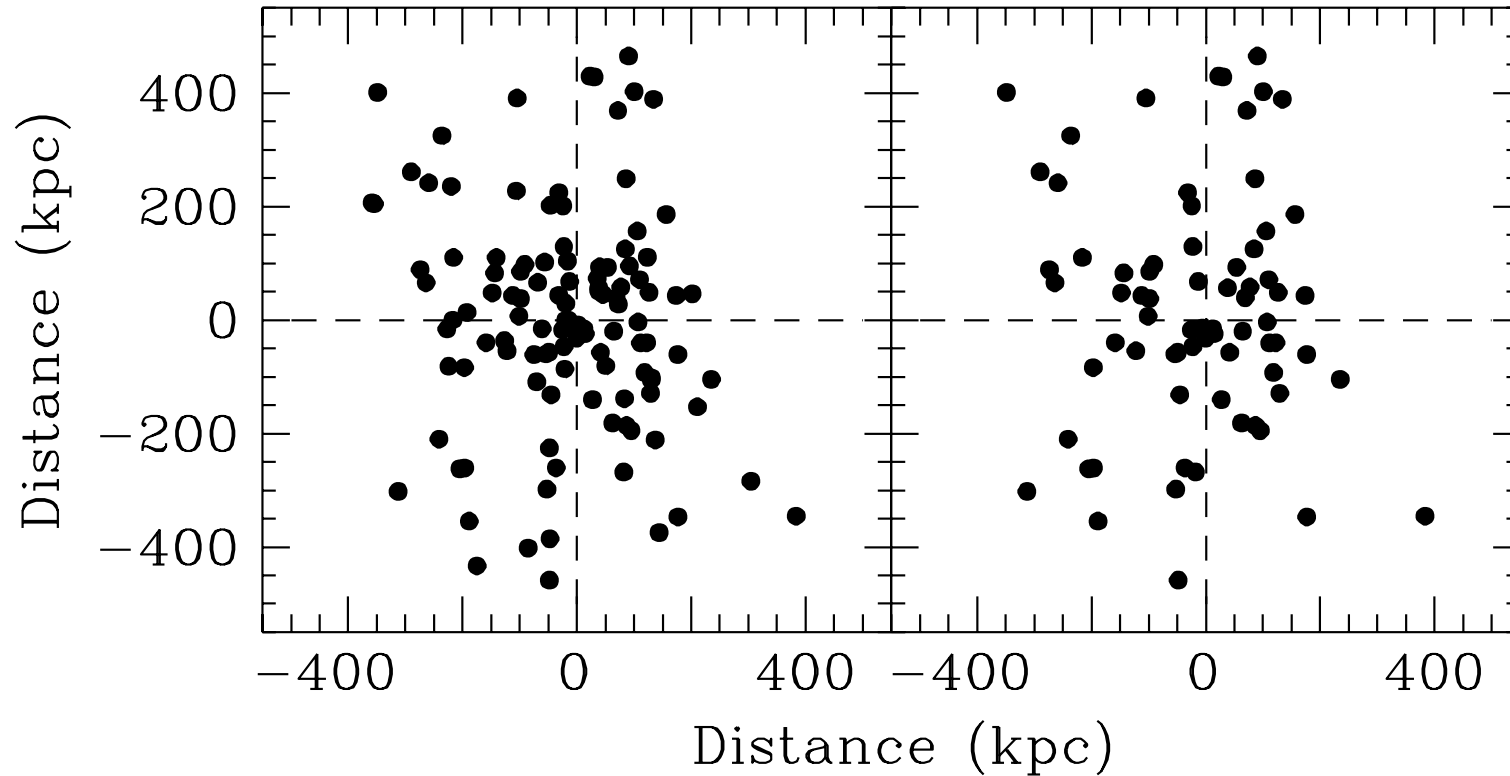
Holmberg Effect: Satellite galaxies are preferentially located along the minor axis of disk galaxies

NOTE: Holmberg's analysis restricted to projected distances $r_p \lesssim 50$ kpc

Subsequent studies by Hawley & Peebles (1975), Sharp, Lin & White (1979) and MacGillivray et al. (1982) were unable to confirm Holmberg effect.

More History...

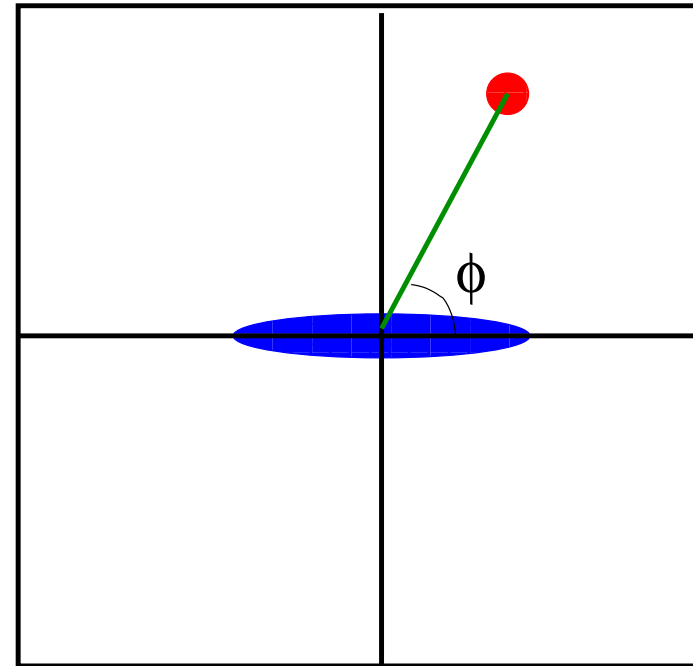
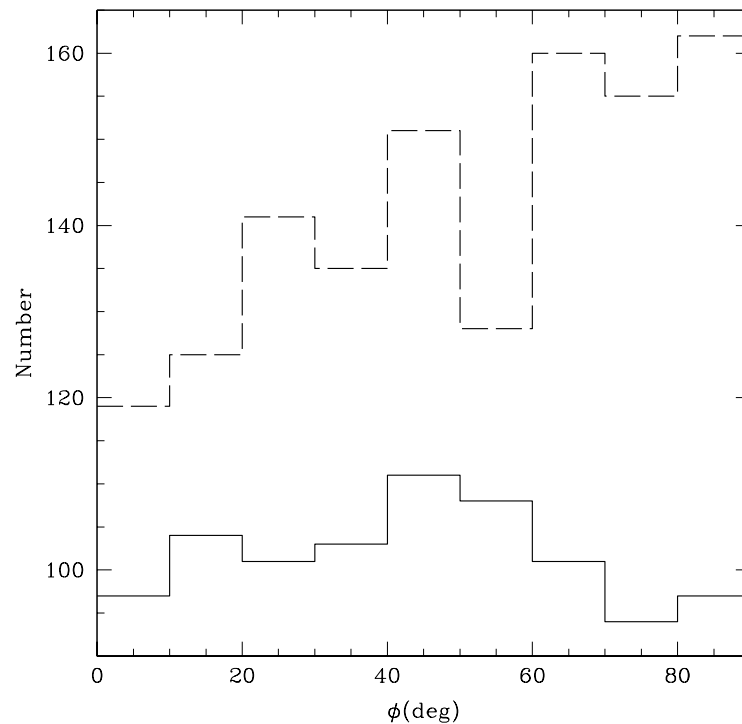
Zaritsky et al. (1997): study of spatial, projected distribution of **72** satellites around **48** isolated disk galaxies:



- Significant detection of **Holmberg effect** for $300 \text{ kpc} < r_p < 500 \text{ kpc}$.
- No significant alignment detected for $r_p \lesssim 50 \text{ kpc}$...

Alignment in 2dFGRS

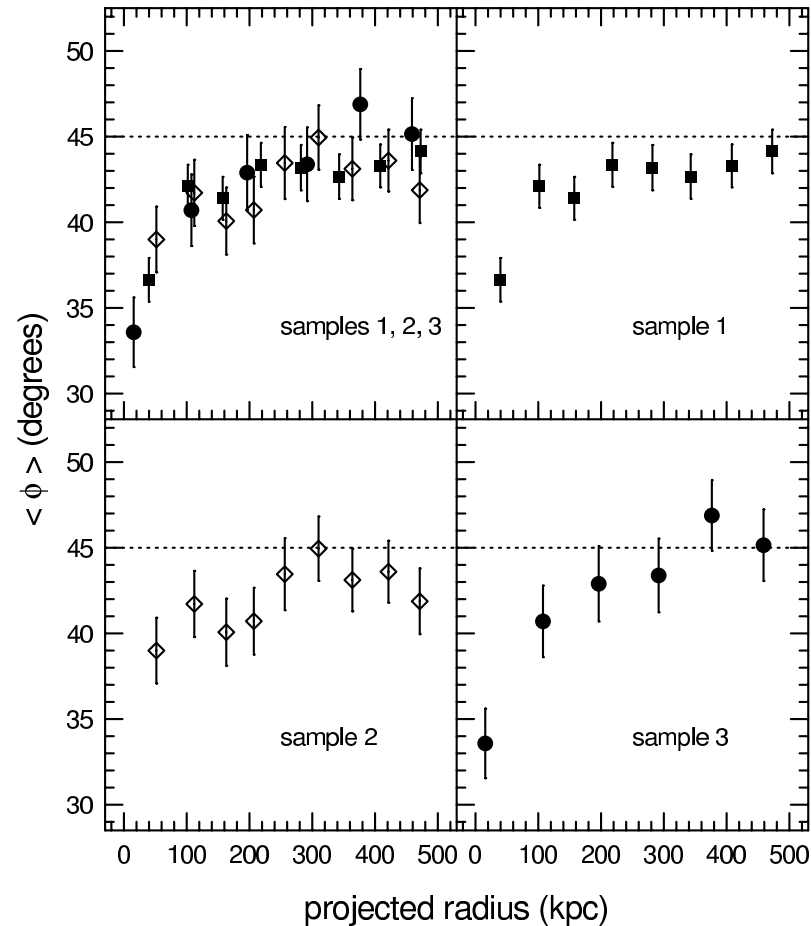
Sales & Lambas (2005): alignment between isolated galaxies (all types) and satellites ($r_p < 500$ kpc) in **2dFGRS**.



- Total Sample: ~ 1500 primaries and ~ 3000 satellites
- Strong, highly significant detection of **Holmberg effect**, but only for satellites with $|\Delta V| < 160 \text{ km s}^{-1}$...
- Alignment strength largest for **red primaries** and **red satellites**

Alignment in SDSS

Brainerd (2005): similar primary-satellite selection criteria as **Sales & Lambas** but applied to **SDSS**.

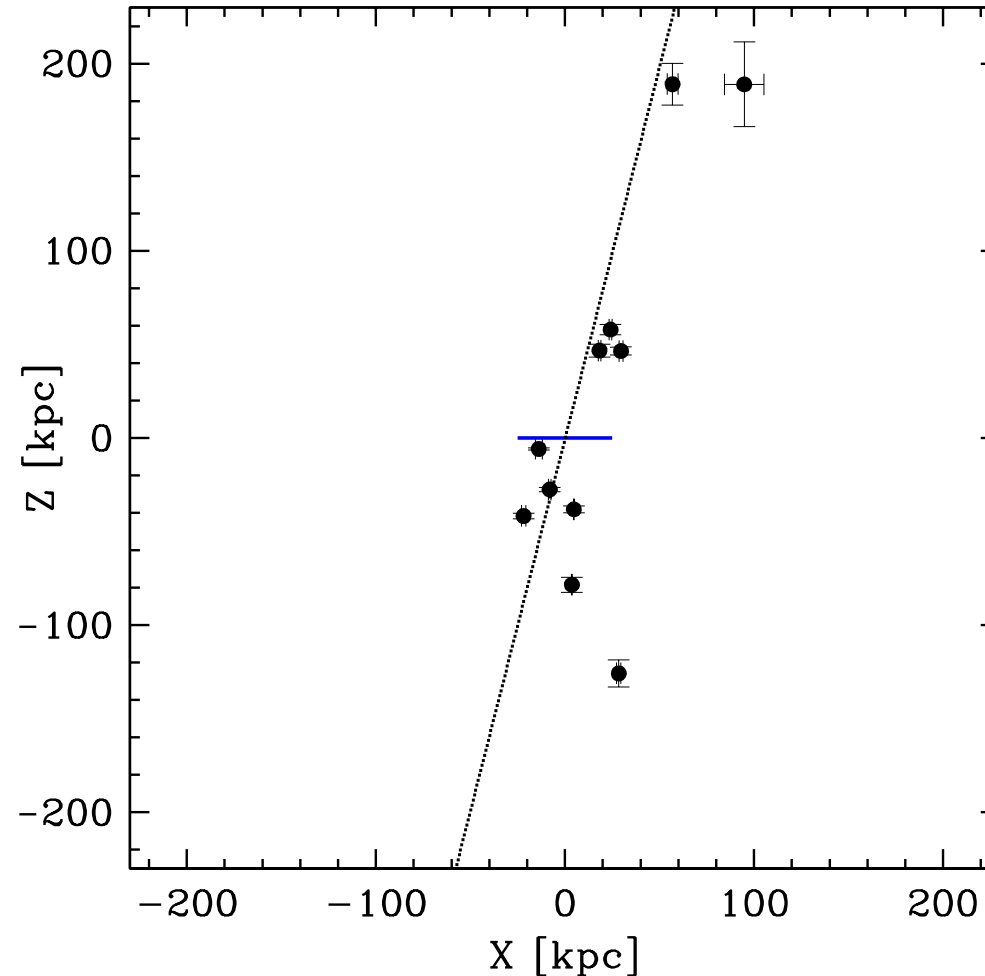


Total Sample: ~ 2000 primaries and ~ 3300 satellites.

Alignment along MAJOR AXIS: Inverse of Holmberg Effect

Holmberg and the MW...

Even our own Milky Way reveals a **Holmberg Effect**...



(Kroupa, Theis & Boily 2005).

Distribution of the **innermost eleven MW satellites** with respect to the orientation of the MW disk (blue line)

Alignment in SDSS Groups I

We study alignment of **satellites** with orientation of **central** galaxy using **SDSS galaxy groups**

Galaxy groups obtained with new, halo-based group finder of **Yang, Mo, vdB & Jing (2005)**, applied to **NYU-VAGC** of **DR2**

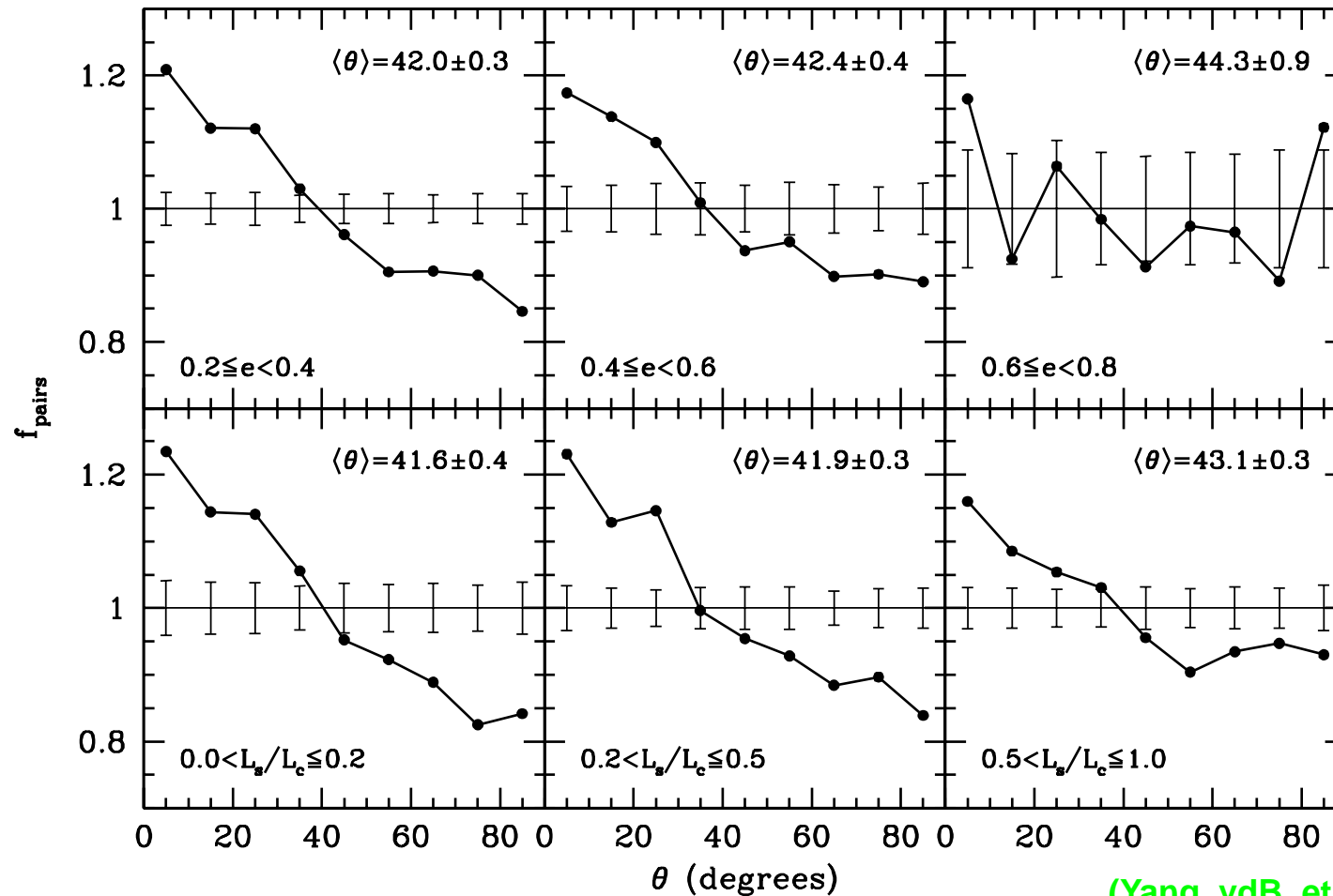
Total of **53,229** groups with **39,086** unique central-satellite pairs; order of magnitude more than any previous study

We study alignment within groups; we only probe only out to R_{vir}

Count $N(\theta)$ from groups, and from 100 realizations in which orientation of centrals is randomized. Compute $f_{\text{pairs}}(\theta) = N(\theta) / \langle N_R(\theta) \rangle$

To access **significance** we compare $f_{\text{pairs}}(\theta)$ to $\sigma_R(\theta) / \langle N_R(\theta) \rangle$, and we also compute $\langle \theta \rangle$ and σ_θ

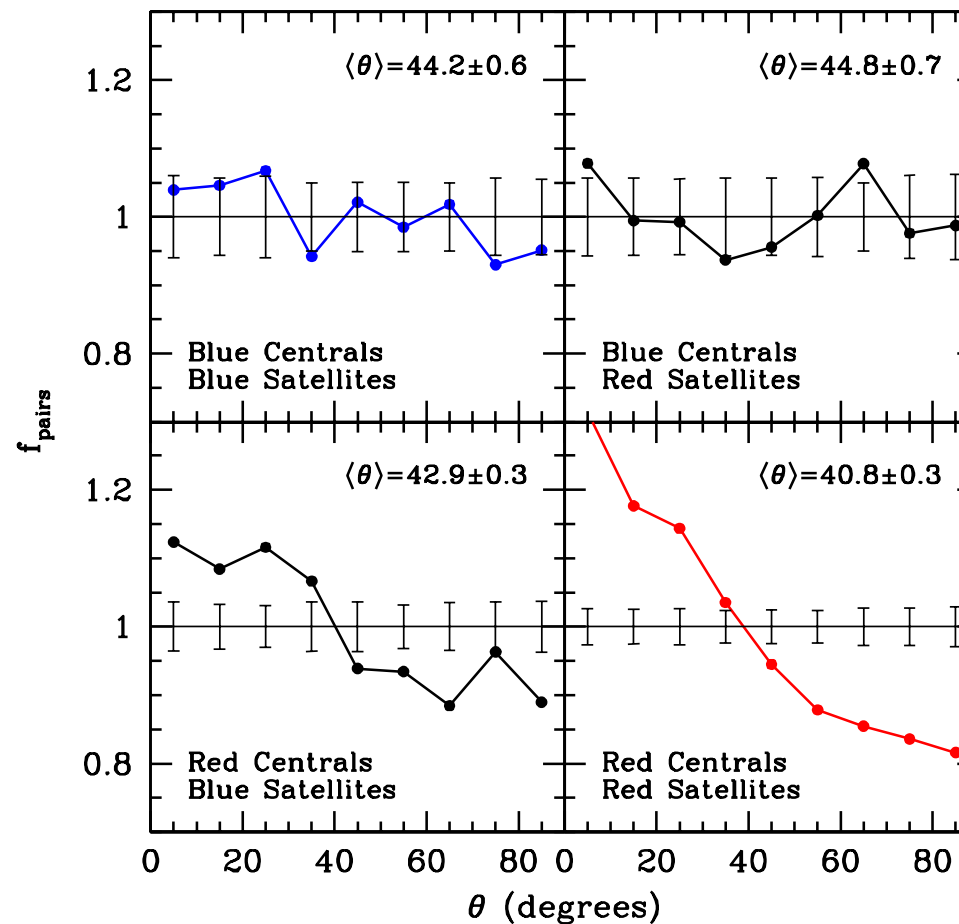
Alignment in SDSS Groups II



(Yang, vdB, et al. 2006).

- Very significant **major axis alignment** detected; again opposite to **Holmberg** effect, but in agreement with **Brainerd (2005)**
- Alignment stronger around **less** elongated primaries
- Weak trend that alignment is stronger for **fainter** satellites

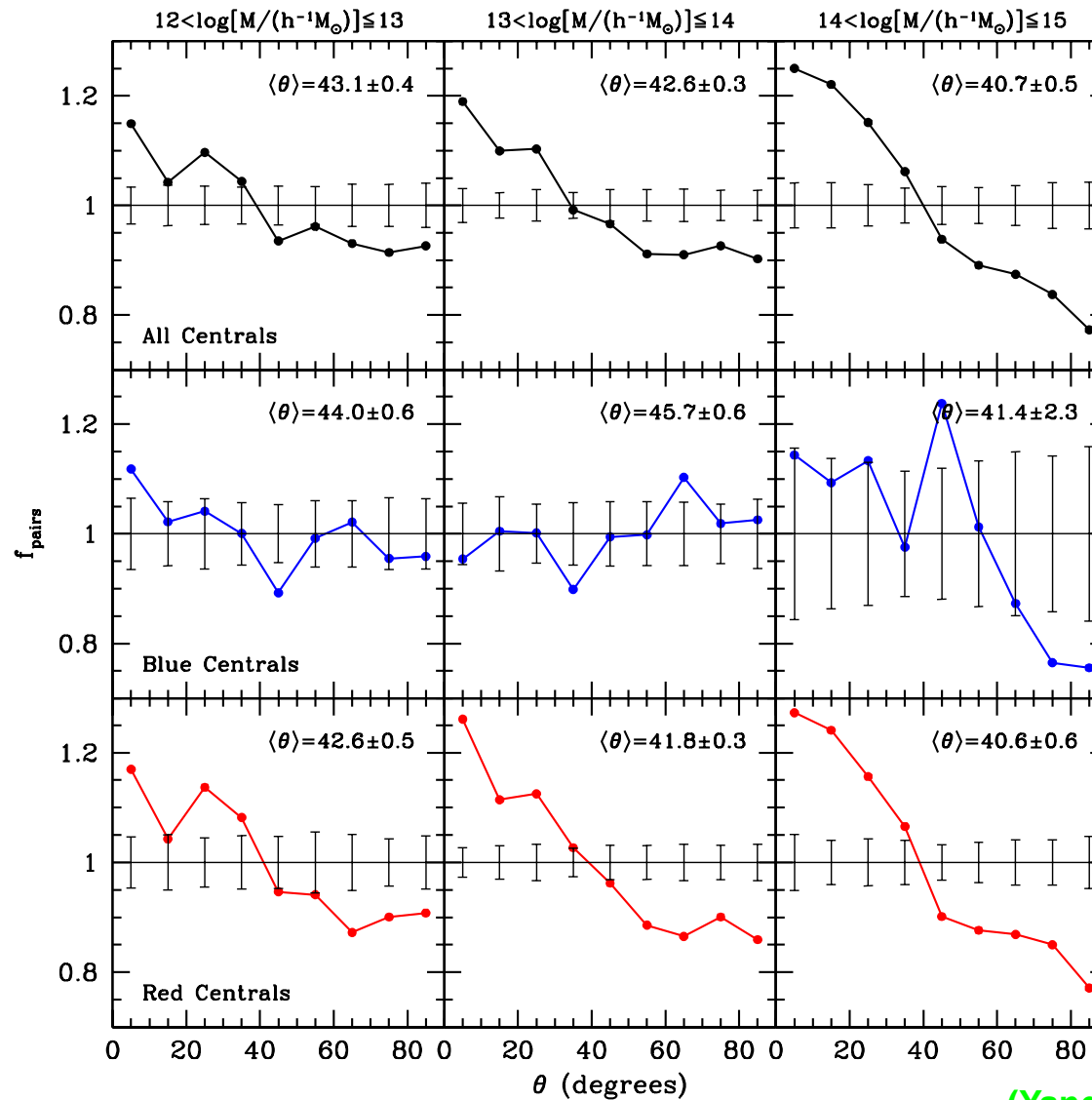
Colour Dependence



(Yang, vdB, et al. 2006).

- Blue primaries show no alignment with either red or blue satellites.
- Red primaries reveal strong alignment with blue satellites and even more so with red satellites.
- Color-trends as in Sales & Lambas (2005), but along major axis....

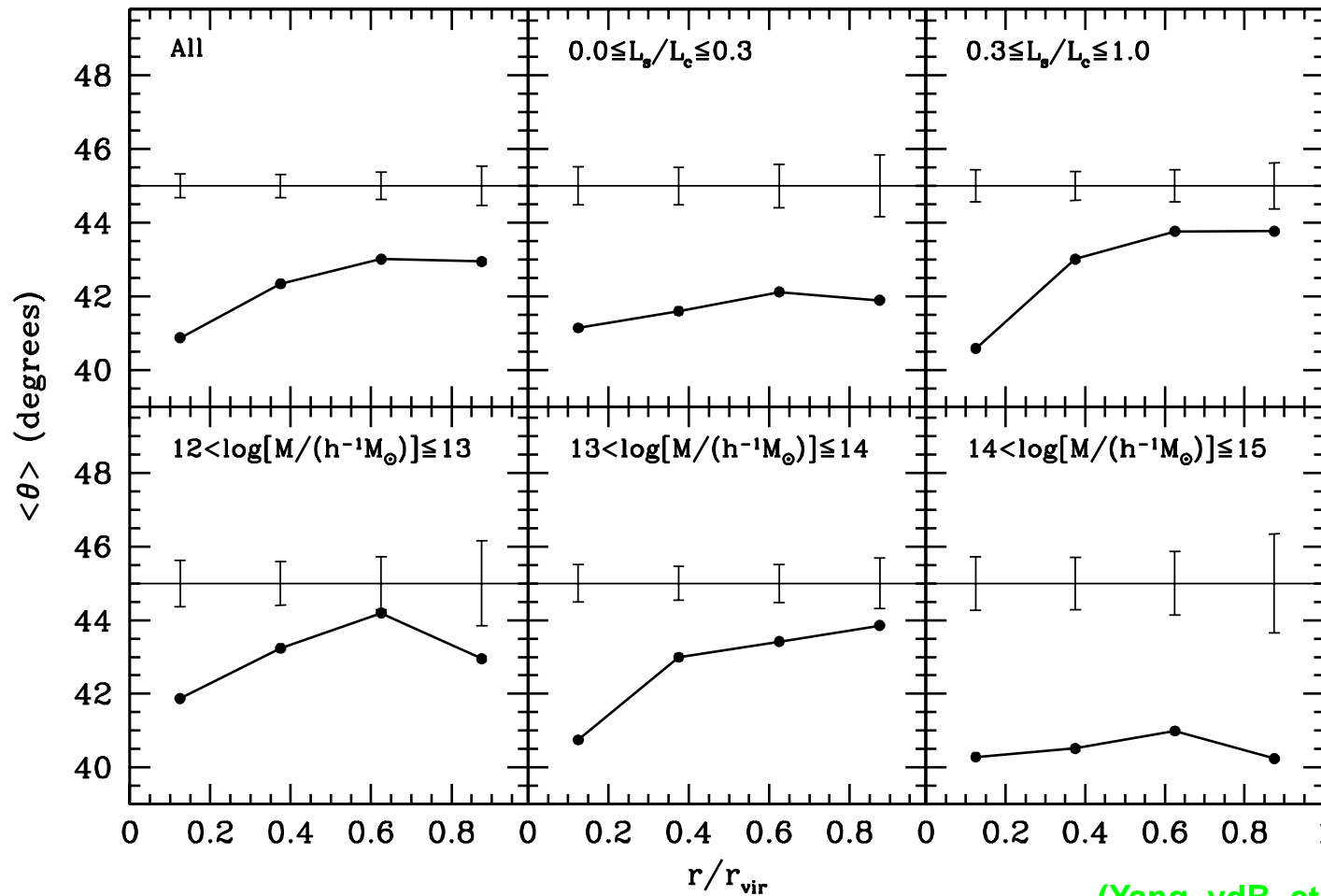
Halo Mass Dependence



(Yang, vdB, et al. 2006).

Alignment stronger in more massive haloes.

Radial Dependence



(Yang, vdB, et al. 2006).

Alignment is stronger at smaller halo-centric radii.

Overview

WHO OR WHAT	RESULT
Holmberg (1969)	Minor axis alignment for $r_p < 50$ kpc
Zaritsky et al. (1997)	Minor axis alignment for $300 \text{ kpc} < r_p < 500 \text{ kpc}$ No alignment for $r_p < 50$ kpc
Sales & Lambas (2005)	Minor axis alignment in 2dFGRS for $r_p < 500$ kpc
Brainerd (2005)	Major axis alignment in SDSS for $r_p \lesssim 300$ kpc
Milky Way	Planar, minor axis alignment of eleven satellites
Yang et al. (2006)	Major axis alignment in SDSS for $r_p \lesssim r_{\text{vir}}$ for red centrals No alignment for blue centrals Alignment stronger in more massive haloes Alignment stronger at smaller halo-centric radii

Who or What is going Wrong and Why?

How Observers confuse Theorists

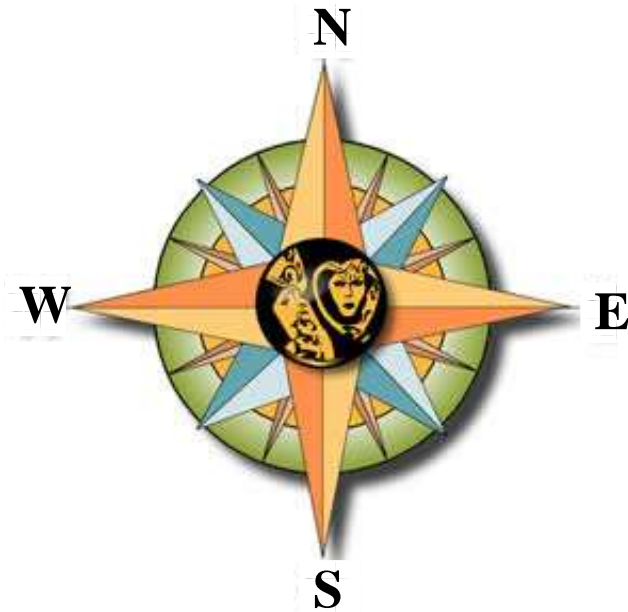
In the **2dFGRS** the major axes of the galaxies are defined as:

“...measured in degrees clockwise from East to West...”

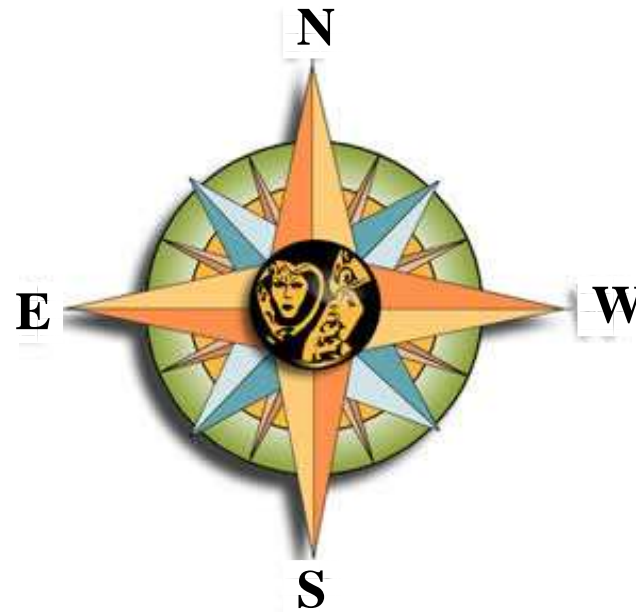
How Observers confuse Theorists

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Normal People

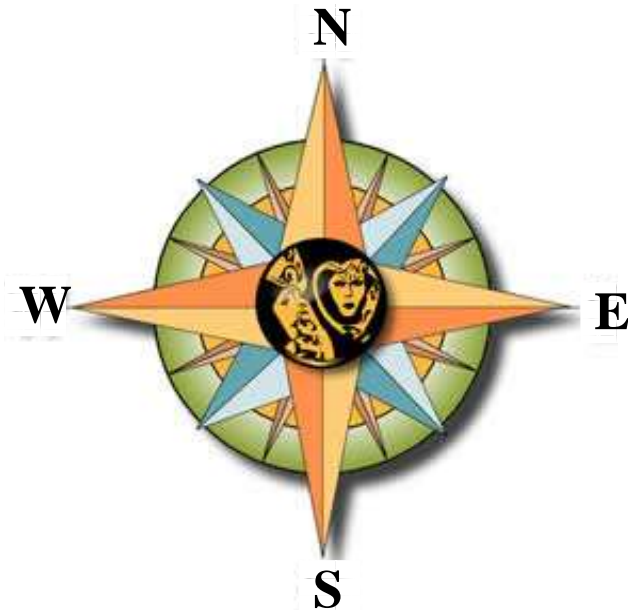


Observers

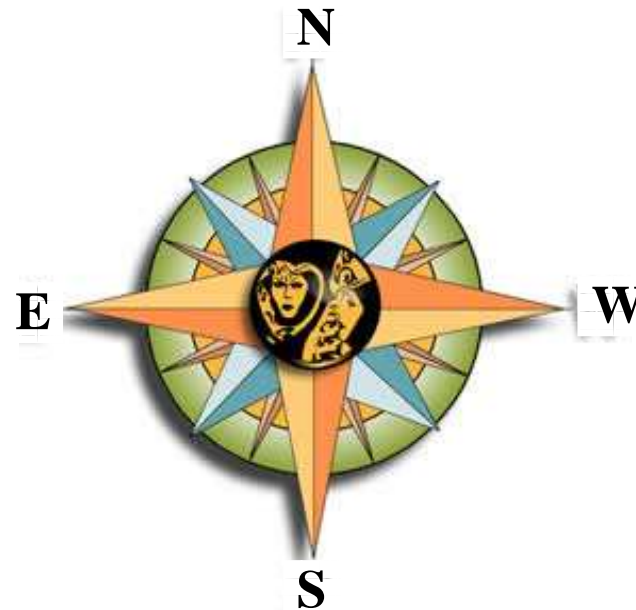
How Observers confuse Theorists

In the **2dFGRS** the major axes of the galaxies are defined as:

“...measured in degrees clockwise from East to West...”



Normal People



Observers

- Our tests show that this definition is made by **normal person**.
- Sales & Lambas are **observers** \Rightarrow misinterpretation of orientation angles.

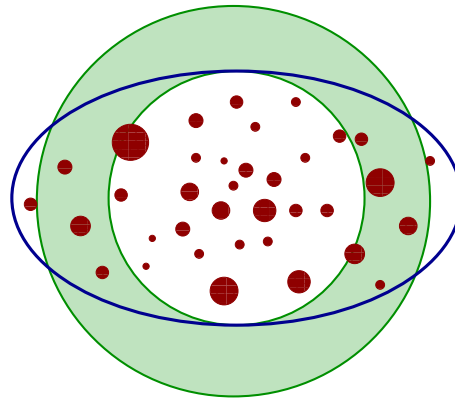
Miserable Mistake: When Sales & Lambas say **“minor”**
they mean **“major”**, and vice versa.

Mirky Mysteries

Numerical simulations have shown that:

- Dark Matter Haloes are not spherical
- Dark Matter Subhaloes trace dark matter distribution
- More massive haloes are less spherical
- Angular momentum axis of dark matter halo along its minor axis

(e.g. Warren et al. 1992; Bullock 2002; Jing & Suto 2002; Bailin & Steinmetz 2005)



Therefore, **alignment** occurs naturally if **satellites** reside in subhaloes, and **central galaxies** are aligned with principal axes of halo

- Consistent with fact that alignment is stronger in more massive haloes
- Major axis of elliptical aligned with that of dark matter halo
- Angular momentum axis of spirals **NOT** aligned with that of DM halo

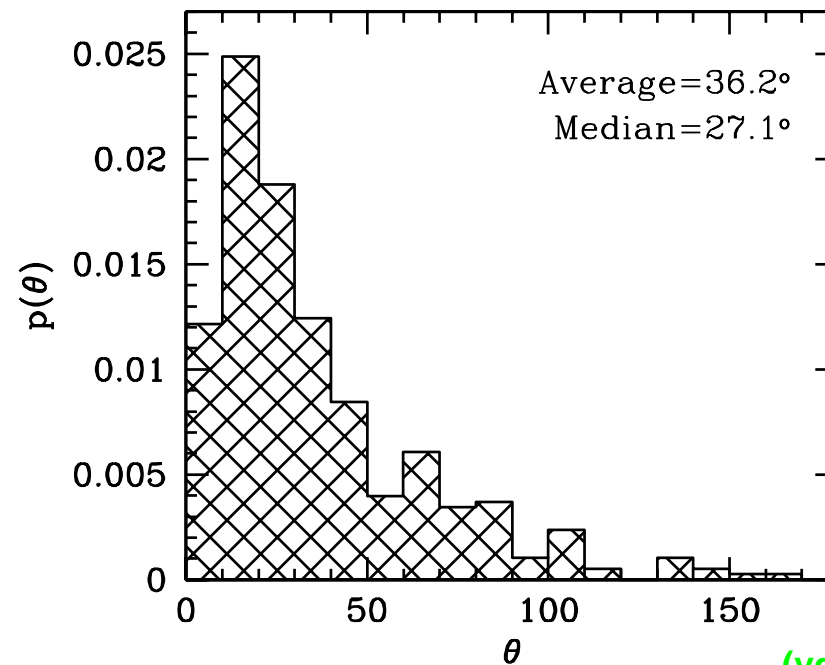
Angular Momentum Alignment

Dark Matter: Angular momentum axis aligned with minor axis

(e.g., Warren et al. 1992; Dubinski 1992; Porciani et al. 2002)

Hot Gas: Angular momentum axis only mildly aligned with that of dark matter

(vdB et al. 2002; Chen et al. 2003; Sharma & Steinmetz 2005)



(vdB et al. 2002, ApJ, 576, 21)

Cold Gas: Angular momentum axis of disk poorly aligned with that of dark matter without gas

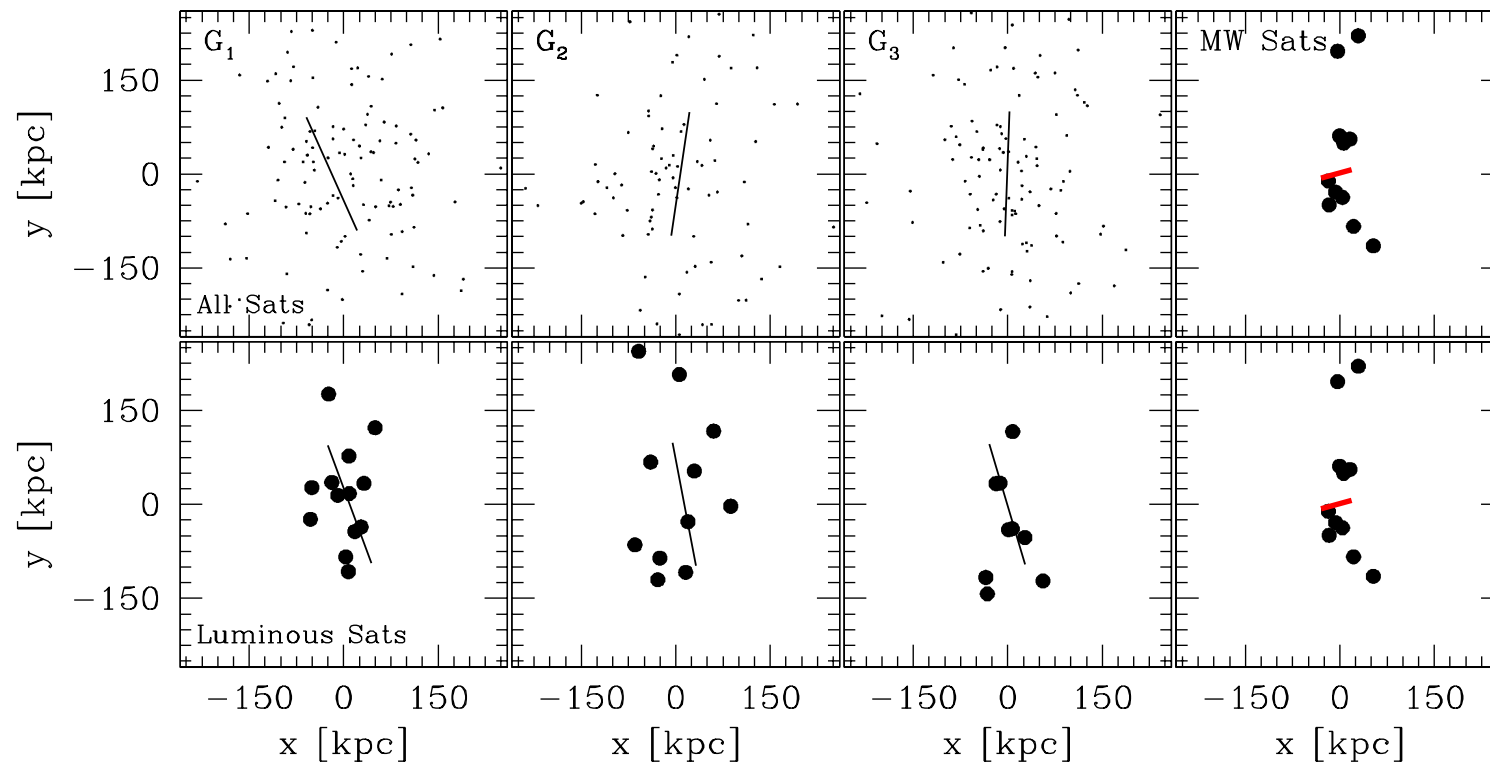
(Bailin et al. 2005)

Disk Formation still not properly understood

and what about the Milky Way?

Kroupa et al. (2005) claimed that this planar distribution is inconsistent with CDM, since it significantly deviates from **isotropic** distribution.

However, **Zentner et al. (2005)** showed that an **isotropic** distribution of satellites is **NOT the correct null-hypothesis**: DM subhaloes are distributed **anisotropically**, and preferentially aligned with the **major axis** of the triaxial halo.



Angular momentum of disk along major axis of halo???

Summary

- Holmberg effect is a **Myth**
- Orientation of **Red Centrals** strongly aligned with satellites
- Orientation of **Blue Centrals** not aligned with satellites
- Alignments most likely reflection of **asphericity** of dark matter haloes
- Naturally explains why alignment is stronger in more massive haloes
- Orientation of **ellipticals** apparently aligned with dark matter halo
- Orientation of **spirals** apparently not aligned with dark matter halo
- Galaxy Formation still harbors **mirky mysteries**