Title: Tidal Alignments & Large Scale Structure

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Abstract: TBA

Tidal Alignments
&
Large Scale Structure

Christopher Hirata

Perimeter, 30 Apr 2010

C.H., MNRAS 399:1074 (2009) – Redshift space distortion

Elisabeth Krause & C.H., 1004.3611 – Bispectrum

Outline

1. Growth of Structure
2. Tidal Alignments & Effects on LSS
3. Formalism & Models
4. Redshift Space Distortions
5. Bispectrum

The Growth of Structure

- The discovery of cosmic acceleration motivates an independent check of general relativity on cosmological scales.
  - More than just w.
- The principal test we have available is the growth of linear perturbations:
  - Growth function $G(t)$: $[\delta\rho/\rho \propto G]$ In GR, smooth DE:

$$\ddot{G} + 2H\dot{G} + \tfrac{3}{2}\Omega_m(t)H^2G = 0$$

  - Growth rate $f(t)$:

$$f = \frac{\dot{G}}{HG}$$

Tests of Growth?

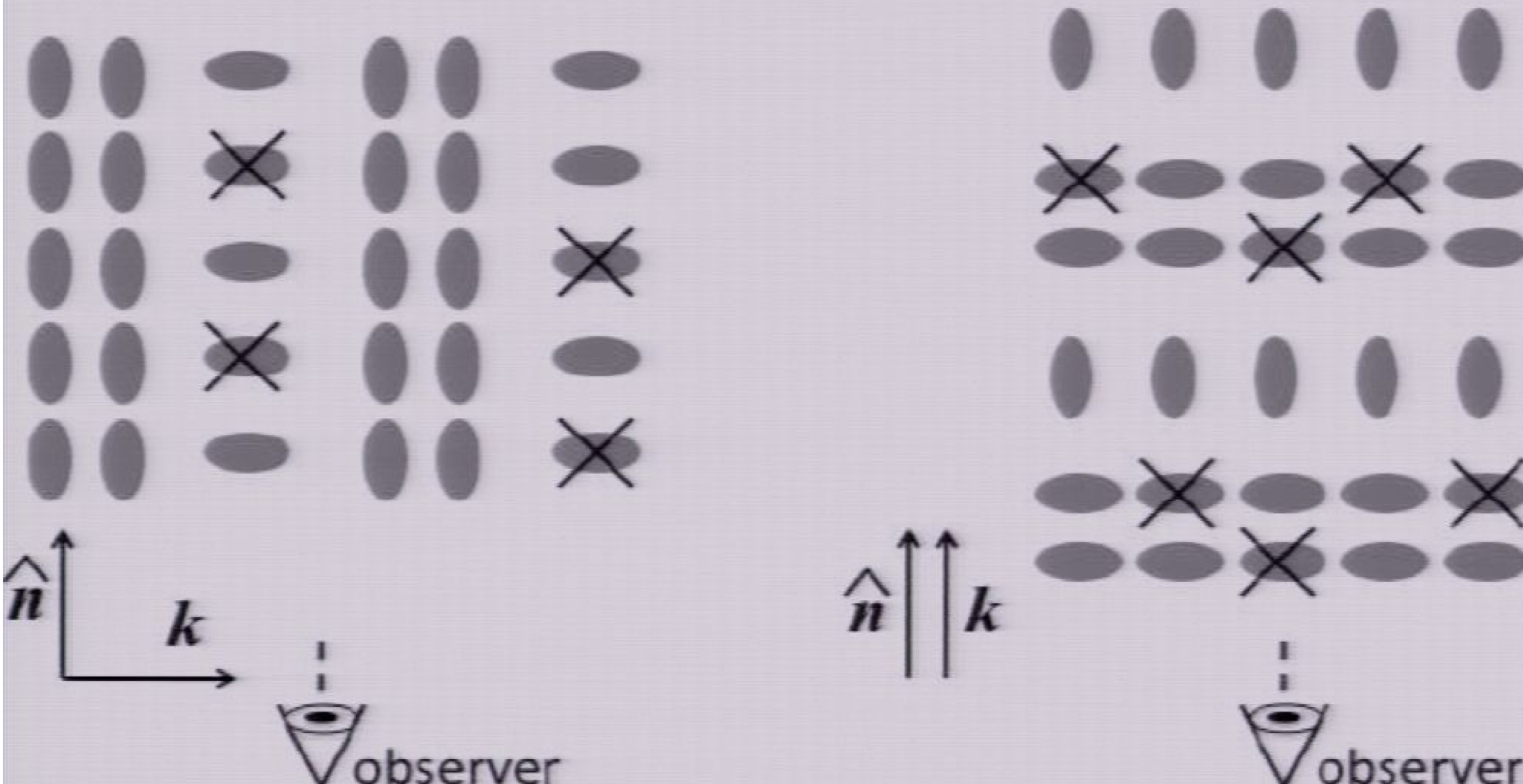
• Weak lensing	$(\nabla\nabla\Psi)$
• ISW	$(\partial\Psi/\partial t)$
• Clusters	(virialized massive halos)
• Redshift space distortions	$(\nabla\mathbf{v})$
• Galaxy bispectrum	(nonlinear evolution)

Tidal Alignments

- Galaxy orientation determined by:
  - Triaxiality (ellipticals)
  - Disk angular momentum (spirals)
- Both affected by large-scale tidal fields – somehow:
  - Affects principal axes of collapse of halo
  - Tidal torquing of infalling baryons
- Clearly an issue for weak lensing. Much effort by community on this.

- BUT when combined with orientation-dependent selection biases: Also an issue for large scale structure!

Example: Redshift Space Distortions



Hirata 200

Formalism

- A galaxy's orientation is described by a matrix $\mathbf{Q} \in SO(3)$, or equivalently the 3 Euler angles (θ,ϕ,ψ).
- The observer looks at the galaxy along the line-of-sight unit vector $\mathbf{n} \in S^2$.
- The probability of observing the galaxy is modulated by a function Y of the line of sight in the galaxy frame:

$$P \propto 1 + \Upsilon(\mathbf{Q}\hat{\mathbf{n}}),$$

$$\int_{S^2} \Upsilon(\hat{\mathbf{m}})\, d^2\hat{\mathbf{m}} = 0.$$

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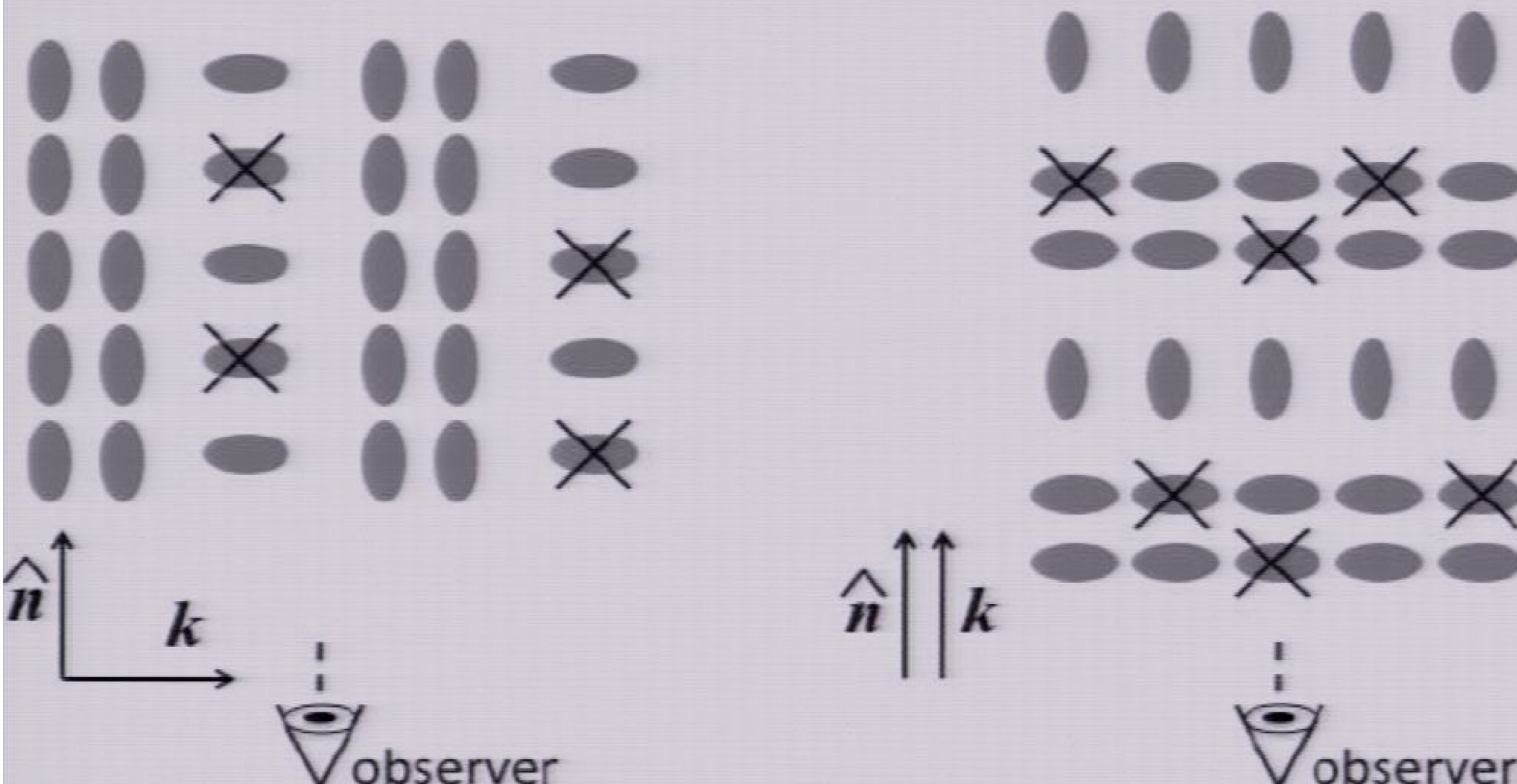

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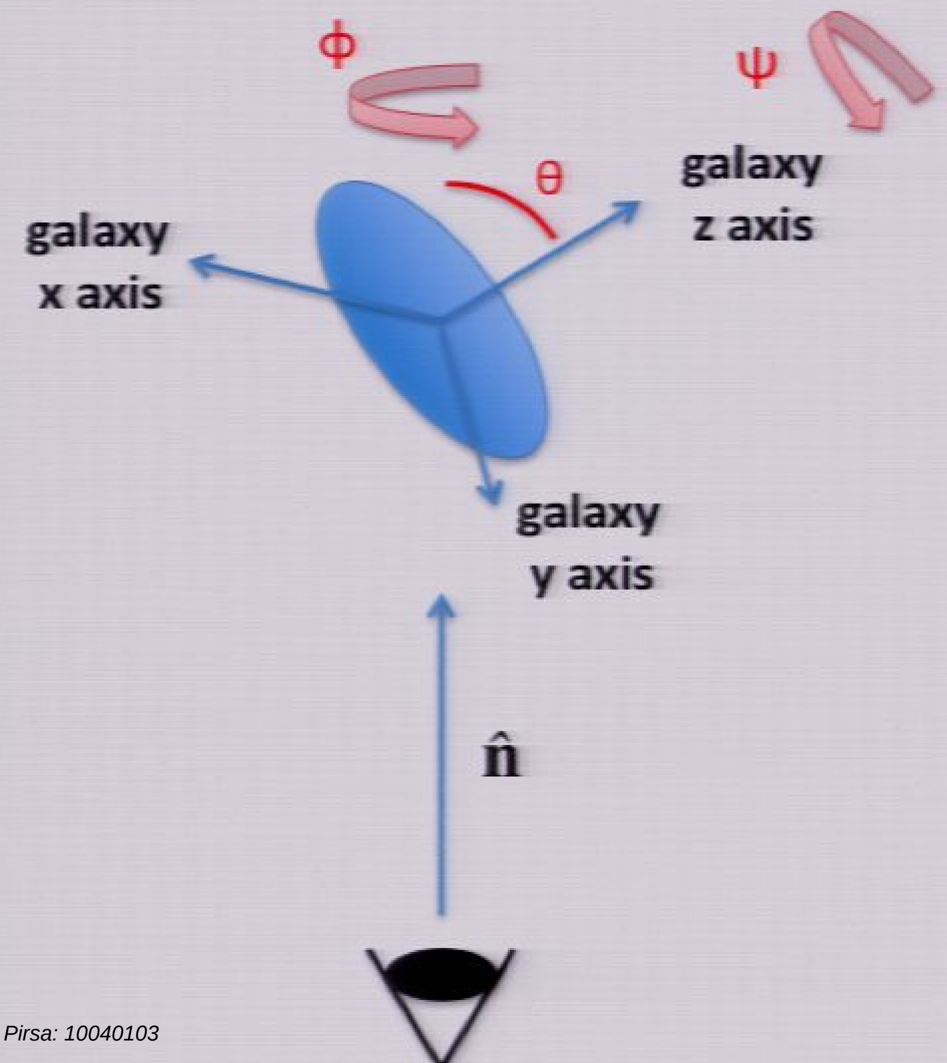
In Pictures



$$P \propto 1 + Y(\mathbf{Q}\hat{\mathbf{n}}),$$

$$\int_{S^2} Y(\hat{\mathbf{m}})\, d^2\hat{\mathbf{m}} = 0.$$

For an axisymmetric galaxy:

- *P* does not depend on ψ
- Y does not depend on longitude of **Qn**.

Effect on Observed Galaxy Density

- The number density of galaxies observed depends on the statistics of their orientation:

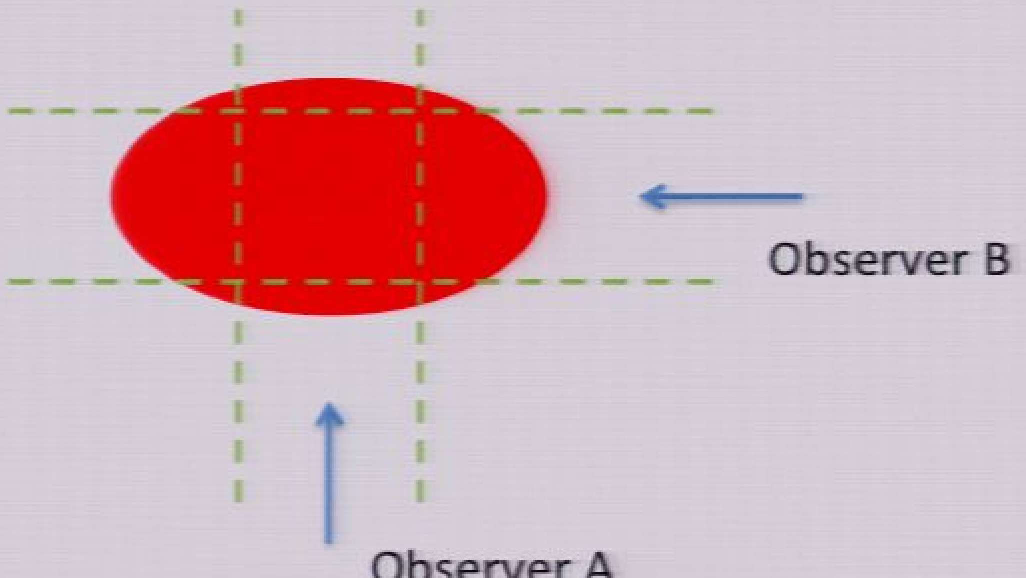
$$N \propto \int_{SO(3)} P(\mathbf{Q} \mid \mathbf{x})[1 + \Upsilon(\mathbf{Q}\hat{\mathbf{n}})] d^3\mathbf{Q}$$

$$= 1 + \underbrace{\int_{SO(3)} P(\mathbf{Q} \mid \mathbf{x}) \Upsilon(\mathbf{Q}\hat{\mathbf{n}}) d^3\mathbf{Q}}_{\varepsilon(\hat{\mathbf{n}} \mid \mathbf{x})}.$$

- Effect nonzero if BOTH:
  - Intrinsic alignments: $P(\mathbf{Q}|\mathbf{x})$ not uniform.
  - Anisotropic selection: $\Upsilon(\mathbf{Qn}) \neq 0$.

Model I: Luminous Red Galaxies

- LRGs are known to be aligned with the stretching axis of the tidal field (Binggeli 1982).
- If aperture magnitudes are used to select LRGs, there is a bias in favor of looking down the long axis.
- Of course, if an accurate model is used to fit the galaxy and it is optically thin, then the model magnitude leads to no such effect.

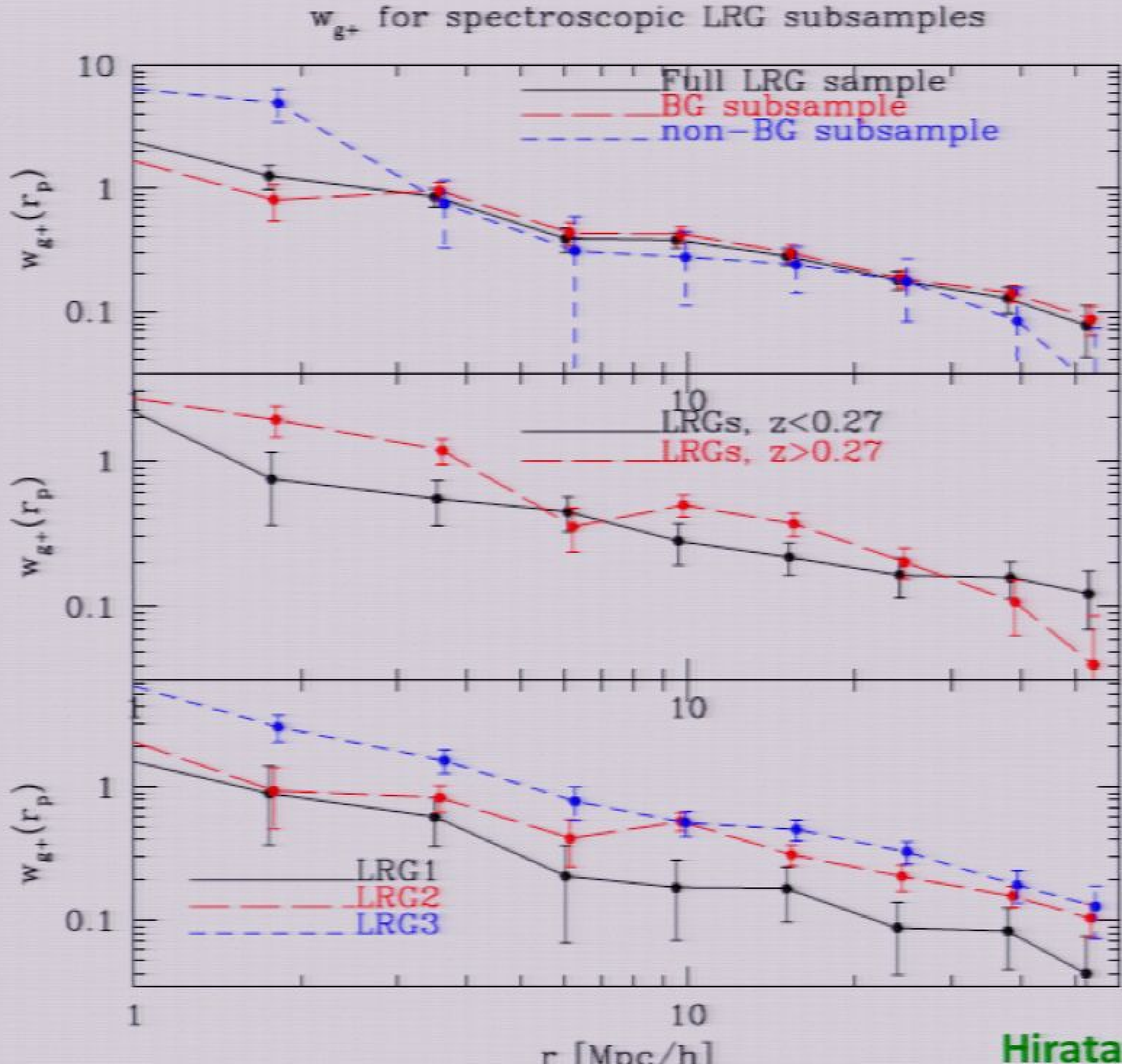


Model I, continued

- LRGs alignments are expected to be linear in the tidal field. The only possibility is then:

$$\varepsilon(\hat{\mathbf{n}}\,|\,\mathbf{x}) = A_1 n_i n_j \left(\nabla_i \nabla_j \nabla^{-2} - \tfrac{1}{3}\right)\delta_m(\mathbf{x}).$$

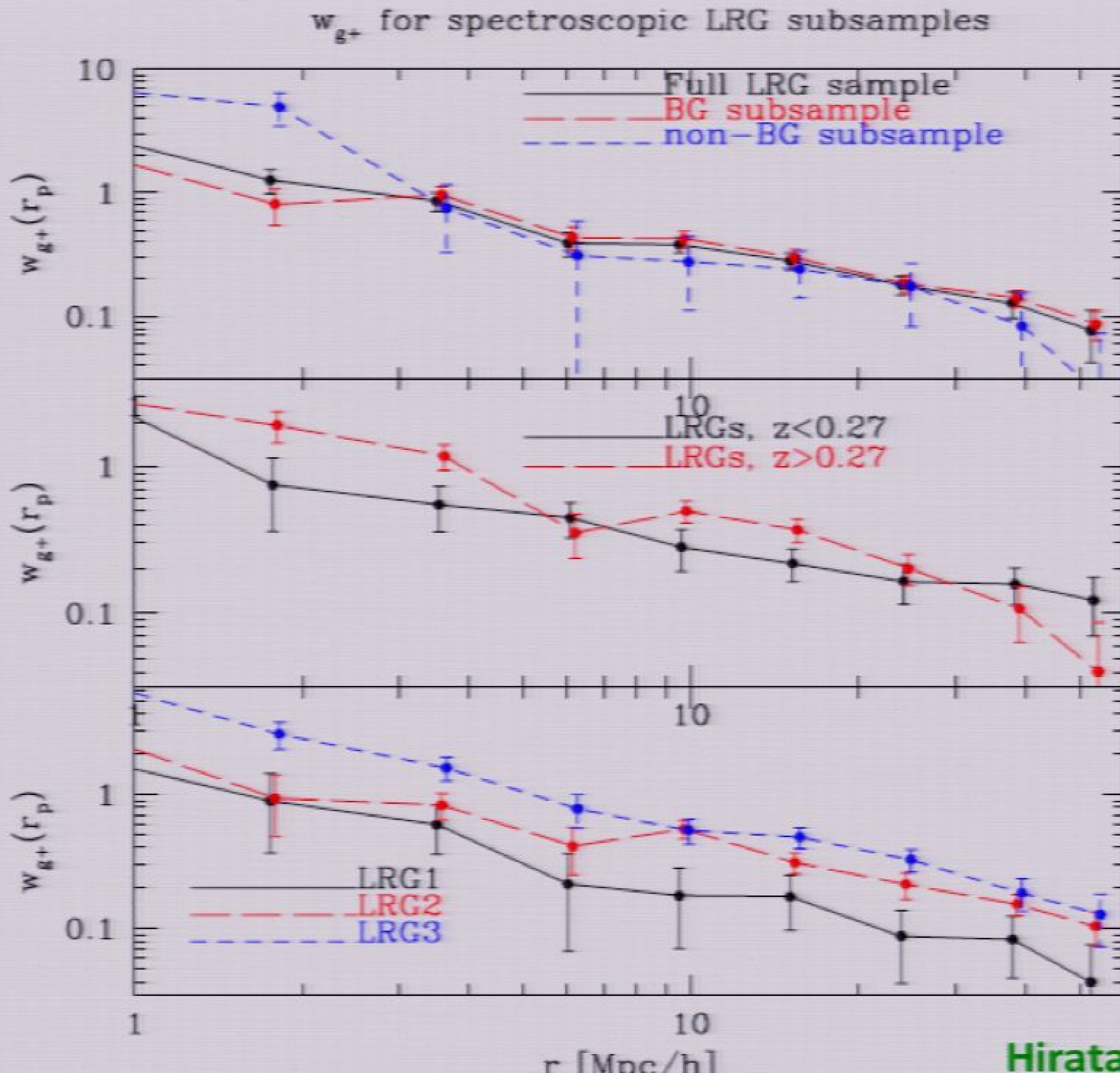
- The coefficient A_1 is the product of:
  - Anisotropic selection (take from theory)
  - Intrinsic alignment amplitude, i.e. ellipticity-LSS correlation (take from observations – SDSS)
  - Theory predicts an ellipticity-density correlation function with the same power-law slope, $w_p(r_p) \sim r_p^{-0.7}$, as the matter or galaxy correlation functions. This is indeed seen!



Hirata et al 2007

Model II: Disk Galaxies

- Spin-up by tidal torques: $\Gamma_i = \varepsilon_{ijk} T_{jl} I_{kl}$.
  - T = tidal tensor
  - I = moment of inertia tensor of collapsing galaxy (note: only anisotropic part contributes)
- Expected to be quadratic in tidal field since the moment of inertia tensor is itself induced by the tidal field.
- Predict: $\varepsilon(\hat{\mathbf{n}} \mid \mathbf{x}) = n_i n_j \left[A_1 T_{ij} + A_2 \left(T_{ik} T_{jk} - \frac{1}{3} T^2 \delta_{ij} \right) + \ldots \right]$
- At tree level, first term is A_2. [Note: on large scales, the A_1 term should exist, see Hui & Zhang 2002.]



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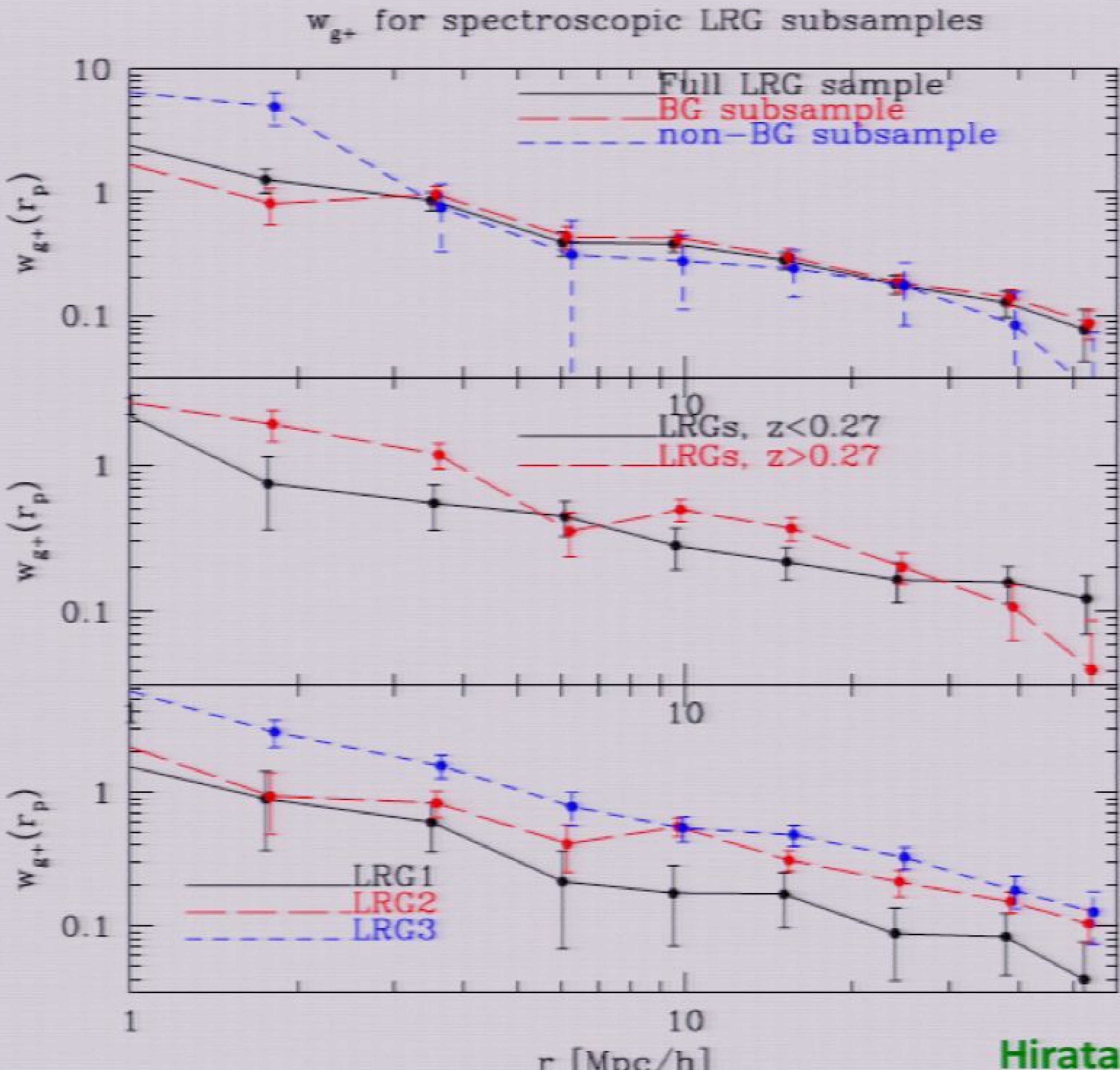

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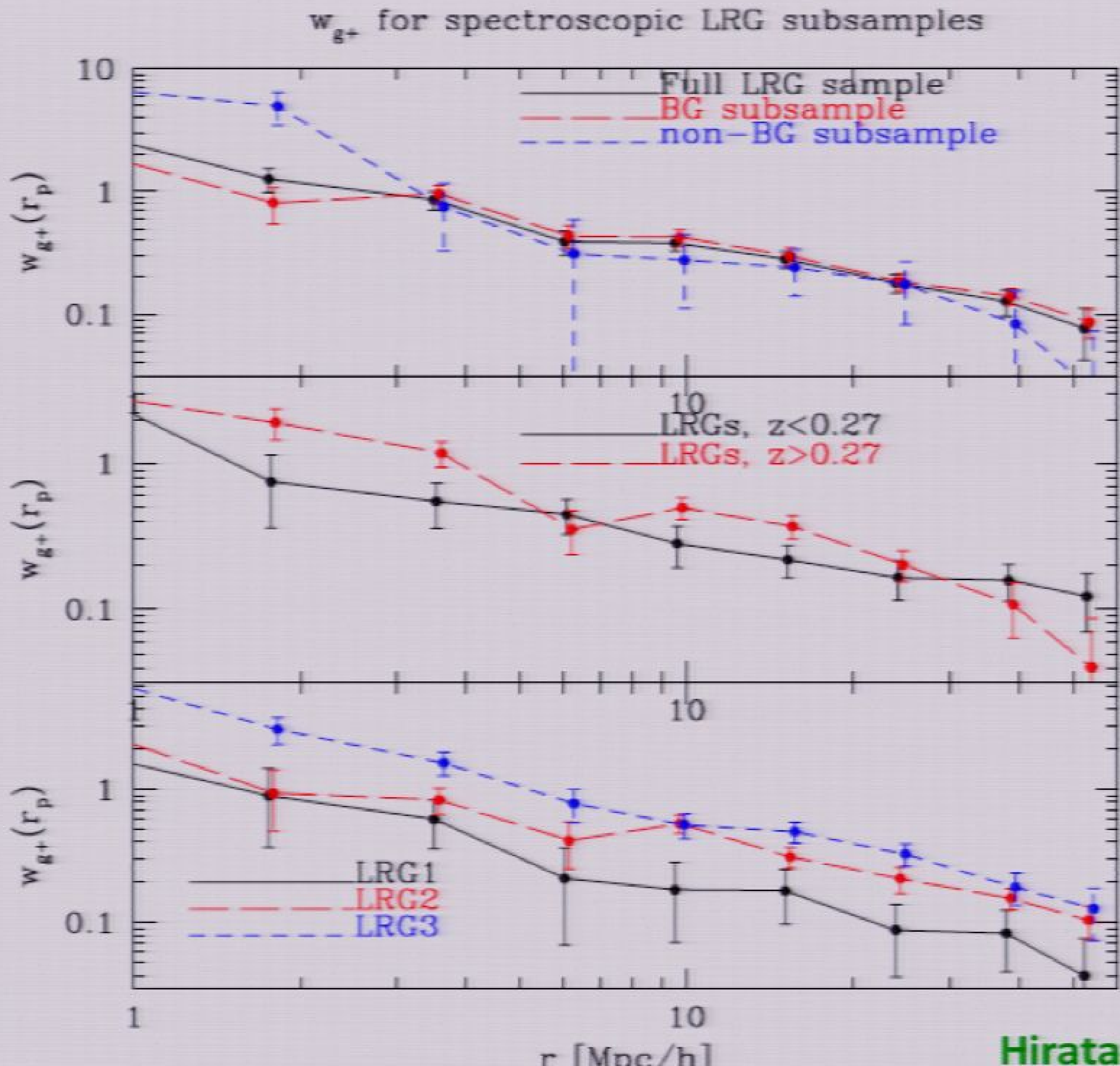

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Model II, continued

- Disk galaxies are dimmer if viewed edge-on due to dust extinction.
- Leads to anisotropic selection if one imposes a broadband or line flux selection.
- This is an order-unity effect:
  - Giovanelli et al 1994 estimate $F \propto \left|\cos^{0.41\pm0.03} i\right|$ in I band for nearby spirals
  - For cumulative LF ~ F^{-2}, $N \propto \left|\cos^{0.82} i\right|$, although may be different for high z, rest frame UV continuum, emission lines, etc.

Model II, continued

- Can set an upper limit on A_1 from:
  - Anisotropic selection (take from theory)
  - Linear intrinsic alignment amplitude, i.e. ellipticity-LSS correlation (take from observations – SDSS, Hirata et al 2007) – upper limit only.
- Don't have a measurement of the quadratic contribution to intrinsic alignments, needed to get A_2
  - Someone should do this!
  - In the mean time: take a guess from the simplest versions of tidal torque theory. (We get A_2 of order unity ...)

Redshift Space Distortions

- In the linear regime limit, the observed number density fluctuation of galaxies becomes:

$$\delta_g^{obs}(\hat{\mathbf{n}} \mid \mathbf{x}) = b\delta_m(\mathbf{x}) + \frac{1}{aH}(\hat{\mathbf{n}}\cdot\nabla)(\hat{\mathbf{n}}\cdot\mathbf{v})(\mathbf{x}) + \varepsilon(\hat{\mathbf{n}} \mid \mathbf{x})$$

$$= b\delta_m(\mathbf{x}) + f\nabla_i\nabla_j\nabla^{-2}\delta_m(\mathbf{x}) + A_1 n_i n_j\left(\nabla_i\nabla_j\nabla^{-2} - \tfrac{1}{3}\right)\delta_m(\mathbf{x})$$

- In Fourier space: [where μ = **k•n**]

$$\delta_g^{obs}(\mathbf{k}) = \left[b - \frac{A_1}{3} + (f + A_1)\mu^2\right]\delta_m(\mathbf{k}).$$

- The new term exactly mimics RSD even on linear scales! Origin of both: sensitivity to tidal field.

Examples

- LRGs:
  - Cut at $M_r^{0.0} = -22.5$, assume isophotal magnitude cut at $3r_{eff.}$ Use Hirata et al 2007 amplitude for intrinsic alignments (@ z=0.3).
  - $A_1 \sim -0.024$ (4% contamination).
- Disk galaxies:
  - Use anisotropic selection model with flux ~ $\cos^{0.4} i$, cumulative LF ~ $1/F^2$. Intrinsic alignments: use upper limit on linear alignment coefficient from Hirata et al. 2007.
  - $|A_1| \leq 0.039$ (6% contamination).
  - But unconstrained at high z (BigBoss, JDEM/Euclid, etc.) although see Mandelbaum et al 2009.

A Note on Lyman-α Emitters

- Zheng et al 2010 find a strongly anisotropic clustering pattern for z=5.7 LAEs opposite to linear RSD.
  - Same macrophysical effect: an anisotropic selection effect determined by the tidal forces on a galaxy.
  - This is exactly degenerate with β in the linear regime since the tidal field is the lowest-order feature of large scale structure to which a galaxy can be sensitive. (All others have additional powers of k.)

  - Very different microphysics: Escape of Lyman-α radiation along directions of high velocity gradient. Zheng et al 2010 aligns the surrounding IGM whereas Hirata 2009 aligns the galaxy itself.

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Bispectrum

- On quasilinear scales, galaxy density is traditionally expanded:

$$\delta_g(\mathbf{x}) = b_1\delta_m(\mathbf{x}) + \tfrac{1}{2}b_2\delta_m^2(\mathbf{x}) + \ldots$$

- This results in a bispectrum. The real space bispectrum (observed for transverse Fourier modes) is:

$$B_g^\perp(k_1,k_2,k_3) = 2b_1^2 Z_2^\perp(\mathbf{k}_1,\mathbf{k}_2)P(k_1)P(k_2) + 2\text{ perm.}$$
$$Z_2^\perp(\mathbf{k}_1,\mathbf{k}_2) = b_1F_2(\mathbf{k}_1,\mathbf{k}_2) + \tfrac{1}{2}b_2.$$

- Can break degeneracy between b_1, σ_8 since the F_2 term scales as $\sigma_8^4 b_1^3$. (e.g. Fry 1994, Verde et al 2001, …)
- Must ultimately calibrate against N-body mocks.

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Intrinsic Alignments & Bispectrum

- Corrections from both linear and quadratic intrinsic alignment terms.
- Linear terms (A_1):

$$\Delta B_g^{\mathrm{I.A.1}}(\boldsymbol{k}_1, \boldsymbol{k}_2, \boldsymbol{k}_3) = \left[2\left(b_1^2 A_1 - b_1 \frac{A_1^2}{3} + \frac{A_1^3}{27}\right) F_2(\boldsymbol{k}_1, \boldsymbol{k}_2) - b_1 \frac{A_1}{3}\right] P(k_1)P(k_2) + 2\ \mathrm{perm.}$$

- Correction is merely a rescaling of the bias parameters:

$$b_1 \to b_1 - \frac{A_1}{3}, \quad b_2 \to b_2 - \frac{2}{3} A_1 b_1$$

No bias in σ_8!

Intrinsic Alignments & Bispectrum

- Quadratic terms (A_2):

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- Has quadrupolar term. Lowest effect is on the bispectrum:

$$\Delta B_{\mathrm{g}}^{\mathrm{QA},\perp}(\boldsymbol{k}_1, \boldsymbol{k}_2, \boldsymbol{k}_3) = \frac{2}{3} A_2 b_1^2 \left[\frac{2}{3} - \left(\hat{\boldsymbol{k}}_1 \cdot \hat{\boldsymbol{k}}_2 \right)^2 \right] P(k_1) P(k_2) + 2 \text{ perm.}$$

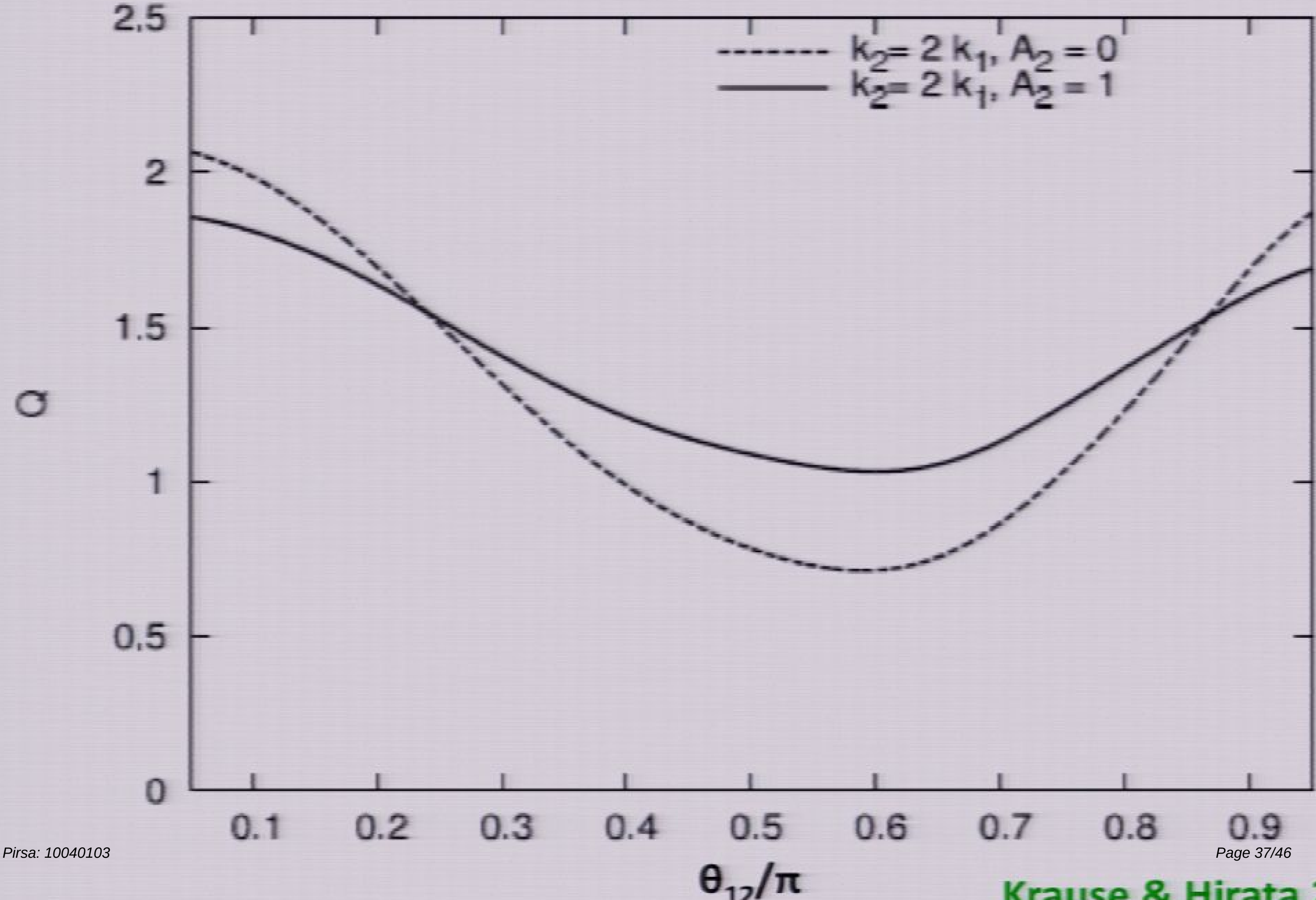
- Compare to F_2 term:

$$F_2(\mathbf{k}_1, \mathbf{k}_2) = \frac{5}{7} + \frac{\mathbf{k}_1 \cdot \mathbf{k}_2}{2 k_1 k_2} \left(\frac{k_1}{k_2} + \frac{k_2}{k_1} \right) + \frac{2}{7} \left(\frac{\mathbf{k}_1 \cdot \mathbf{k}_2}{k_1 k_2} \right)^2 .$$

Intrinsic Alignments & Bispectrum

- Quadratic intrinsic alignment term contaminates the galaxy bispectrum …
- But the contamination is not of the same configuration dependence as the nonlinear-evolution bispectrum and hence is in principle separable.

Galaxy Bispectrum, Sides of k = 0.05, 0.1 h/Mpc



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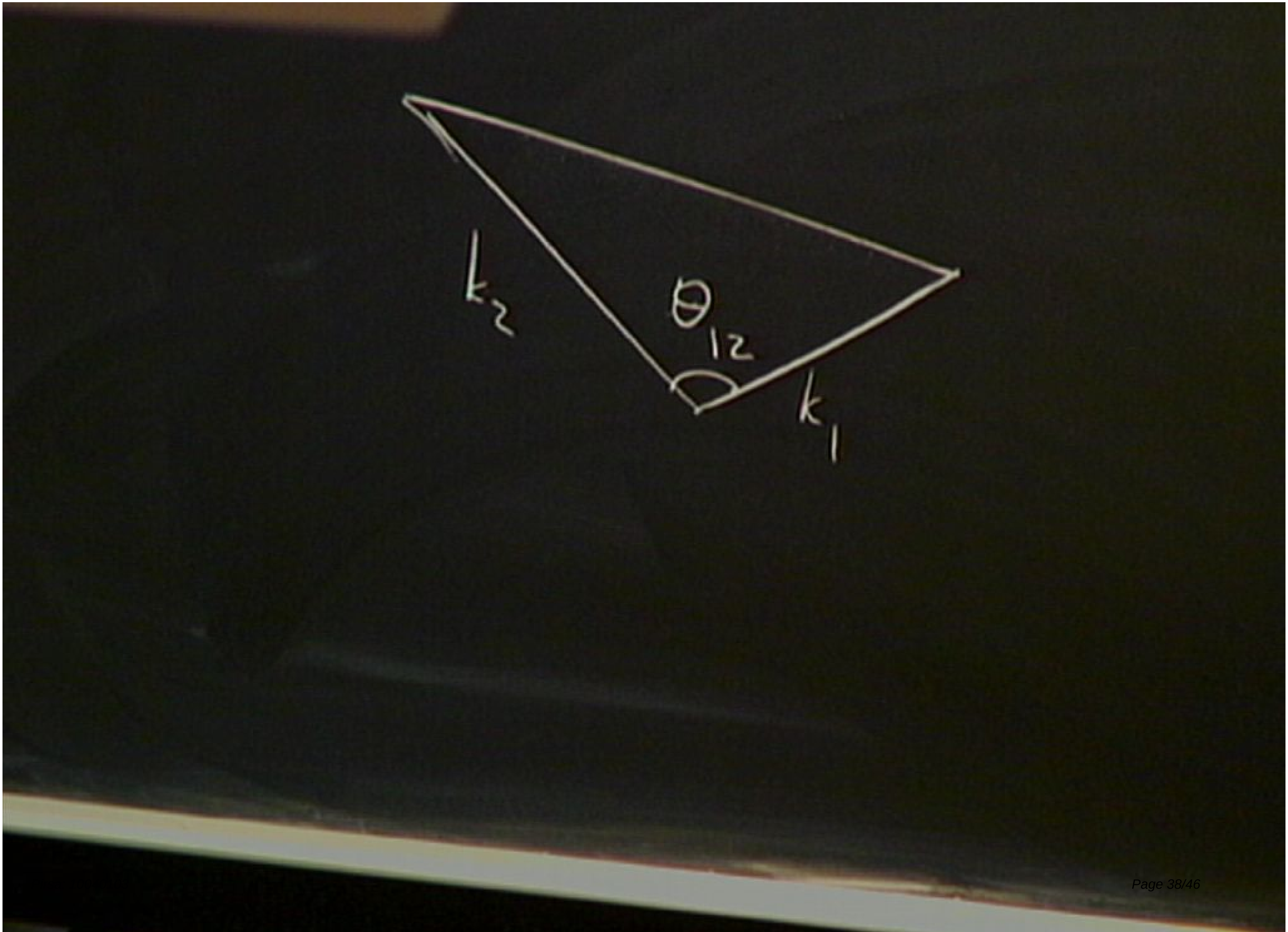
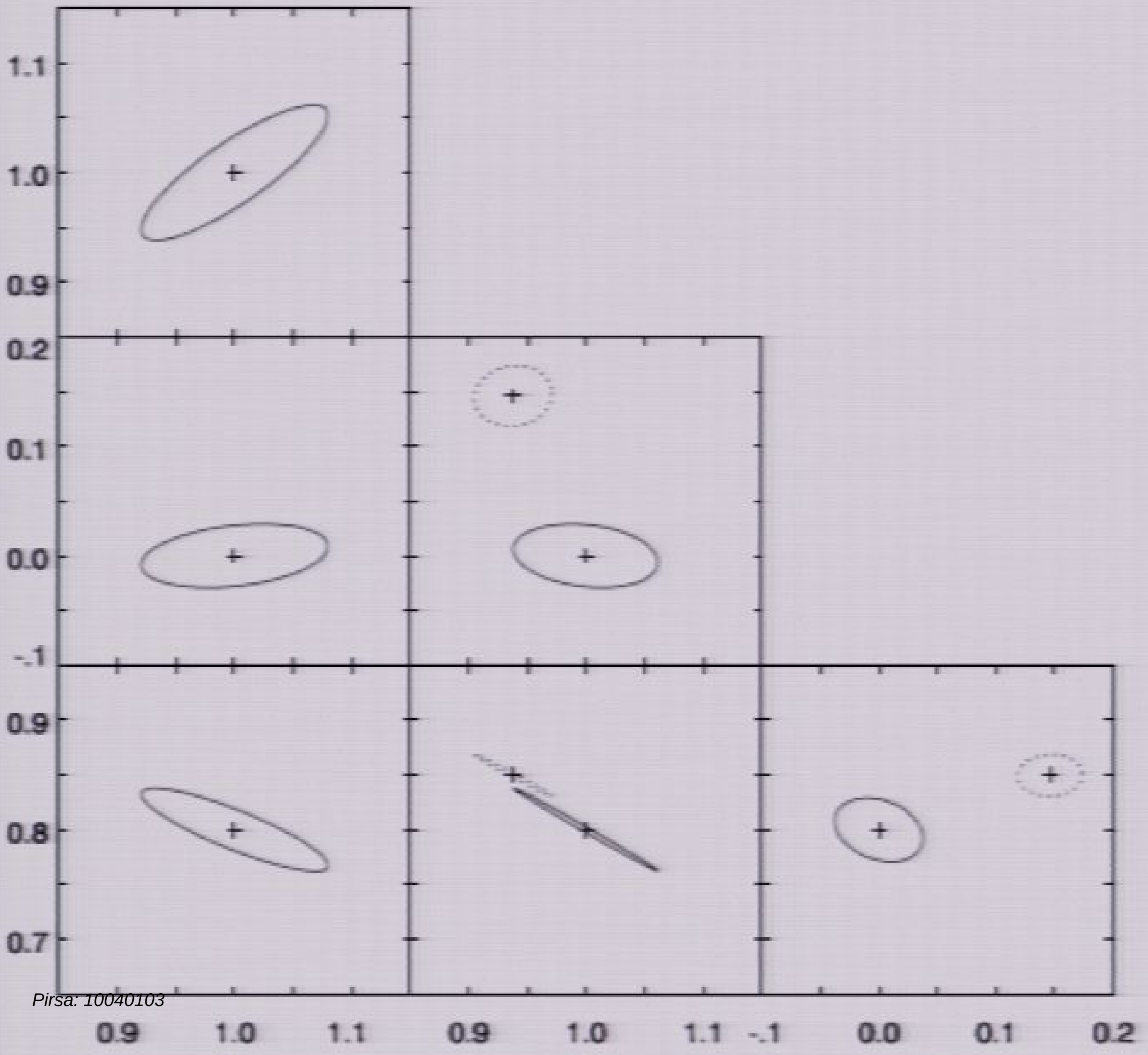

k_2
θ_{12}
k_1

Effects on Parameters: Bispectrum of Photo-z Galaxy Surve



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Conclusions

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- In particular, has implications for measuring the growth of structure:
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  - Bispectrum: not exactly degenerate in quasilinear regime, can simultaneously fit out albeit with some increase in error bars.
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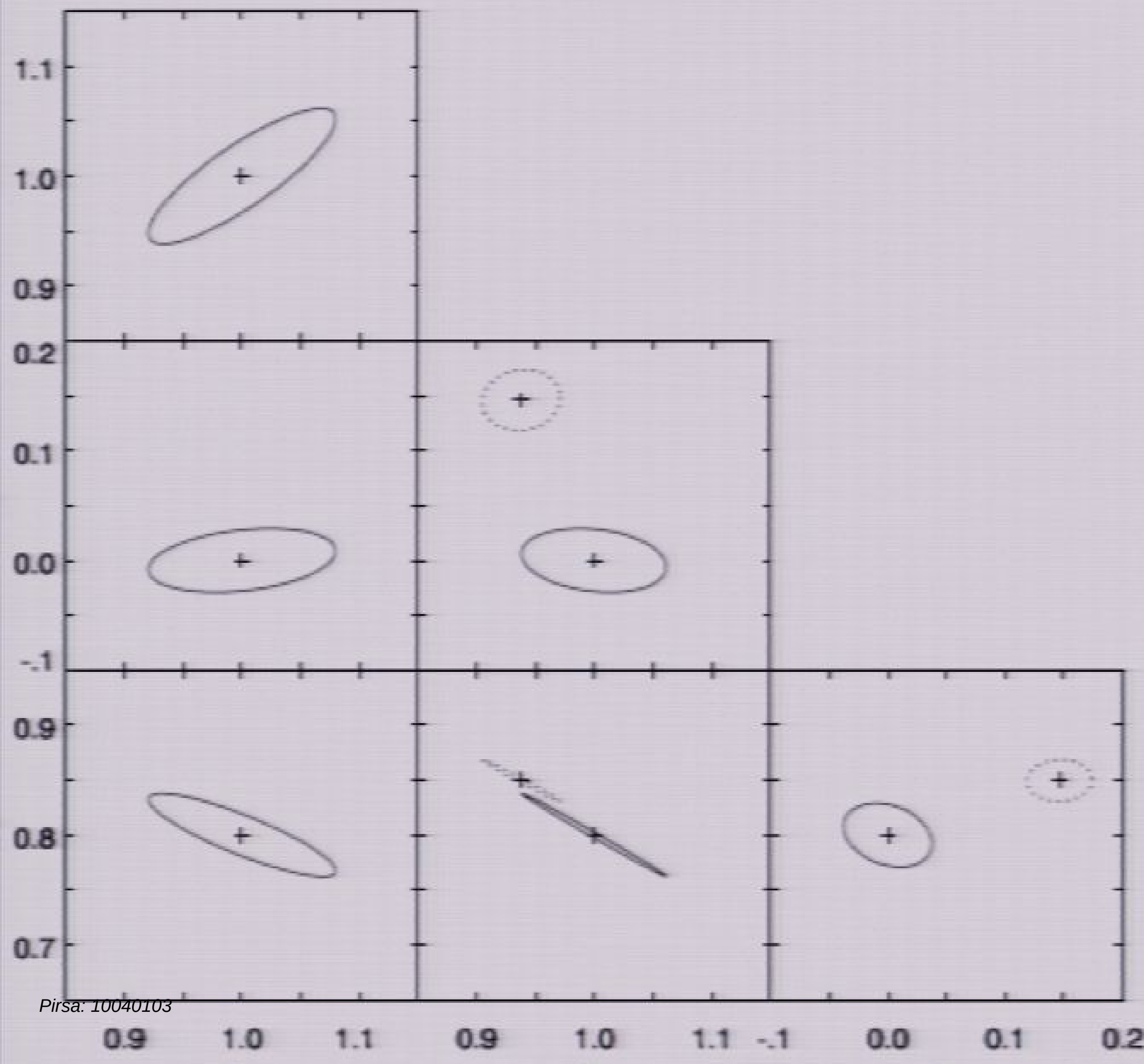

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