Tidal Alignments as a Contaminant of the galaxy Bispectrum

Elisabeth Krause, with Chris Hirata

Hirata 2009, Krause & Hirata 2010

Cosmology from galaxy clustering

- Measure spatial/angular galaxy distribution

  ↓ Galaxy bias & other magic

- Relate to matter distribution

  ↓ Compare to models, pert. theory

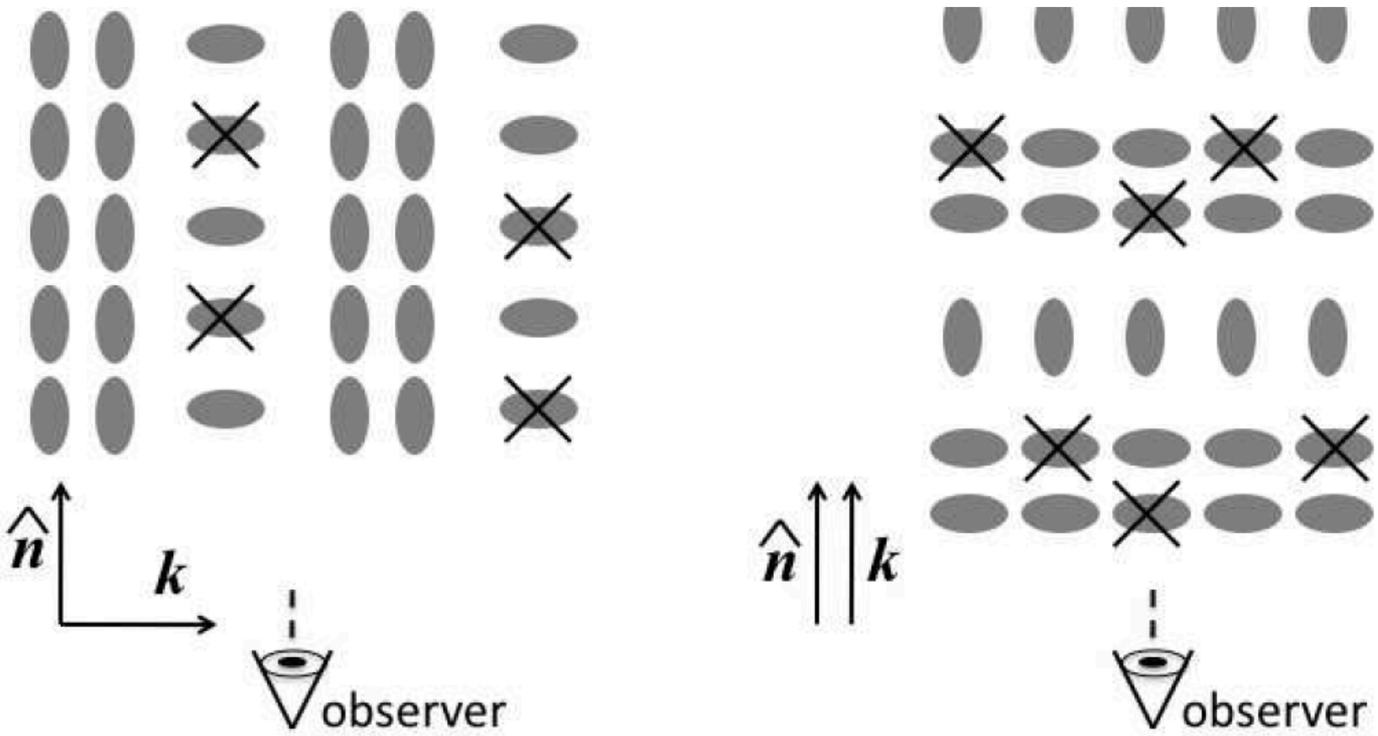
- Constrain growth of structure, cosmology

growth function, non-linear evolution, $\nabla \mathbf{v}$

Tidal Alignments

- Galaxy orientation determined by
  - Triaxiality (ellipticals)
  - Disk angular momentum (spirals)
- Both affected by large-scale tidal fields
  - affects principal axes of collapsing region
  - Tidal torquing
- When combined with orientation dependent selection bias, issue for LSS observations!

Tidal Alignments



from Hirata 2009

- Clustering in radial Fourier modes appears suppressed
- May introduce systematic offset to LSS observables!

Anisotropic galaxy selection

- A galaxy's orientation is described by a matrix **Q** $\in$SO(3), or equivalently the 3 Euler angles
- Observer looks at the galaxy along the line-of-sight unit vector **n** $\in S^2$
- Describe galaxy appearance by expressing observer's line-of-sight in galaxy frame: **Qn**
- Probability P of observing a galaxy is modulated by a function *Y* of the line of sight in the galaxy frame:

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

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

Effect on Observed Galaxy Density

- Number density of observed galaxies depends on distribution of their orientation $P(\mathbf{Q}|\mathbf{x})$:

$$N \propto \int_{SO(3)} P(\mathbf{Q}\,|\,\mathbf{x})\left[1+Y(\mathbf{Q}\hat{\mathbf{n}},\mathbf{x})\right]\,d^3\mathbf{Q}$$

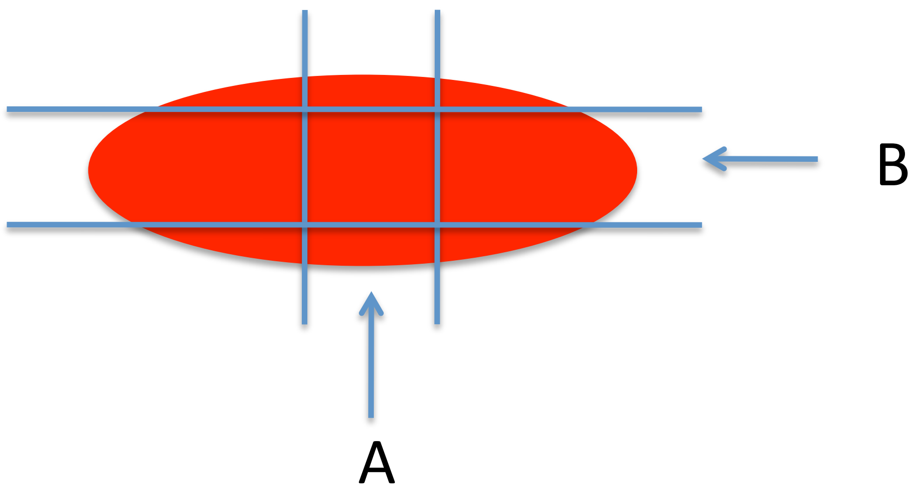
$$= 1 + \boxed{\int_{SO(3)} P(\mathbf{Q}\,|\,\mathbf{x})Y(\mathbf{Q}\hat{\mathbf{n}},\mathbf{x})\;d^3\mathbf{Q}}$$

$\varepsilon(\boldsymbol{n}|\boldsymbol{x})$

- Effect non-zero if BOTH
  - Intrinsic alignments: $P(\mathbf{Q}|\mathbf{x})$ not uniform
  - Anisotropic galaxy selection: $Y(\mathbf{Qn,x}) \neq 0$

Models for ε – Luminous Red Galaxies

- LRGs known to be aligned with stretching axis of the tidal field (Binggeli 1982)
- If aperture magnitudes are used to select LRGs, bias for selecting galaxies viewed down the long axis (B)
- Not a problem if model magnitudes used and galaxy optically thin



Models for ε – LRGs II

- LRGs alignment expected to be linear in tidal field, hence from symmetry only possibility:

$$\varepsilon(\hat{\mathbf{n}} \mid \mathbf{x}) = A_1 n_i n_j \left(\nabla_i \nabla_j \nabla^{-2} - \frac{1}{3} \right) \delta_{\mathrm{m}}(\mathbf{x})$$

- Coefficient A_1 product of
  - Anisotropic selection (from models, survey specific)
  - Intrinsic alignment amplitude: ellipticity – LSS correlation (from observations – SDSS, Hirata et al 2007)

Models for ε -Spiral 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 (only anisotropic part contributes)
- Expected to be quadratic in tidal field - anisotropic moment of inertia itself induced by tidal field
- At tree level, predict

$$\varepsilon(\hat{\mathbf{n}} \mid \mathbf{x}) = A_2 n_i n_j \left(T_{ik} T_{jk} - \frac{1}{3} T^2 \delta_{ij} \right)$$

Models for ε - A_2

- Selection based on broad band/ emission line flux
- Spiral galaxies dimmer if viewed edge on (dust)
- Use geometric emission/extinction models to estimate anisotropic selection
- No measurements for intrinsic alignment strength yet - use tidal torque theory

Galaxy Bispectrum

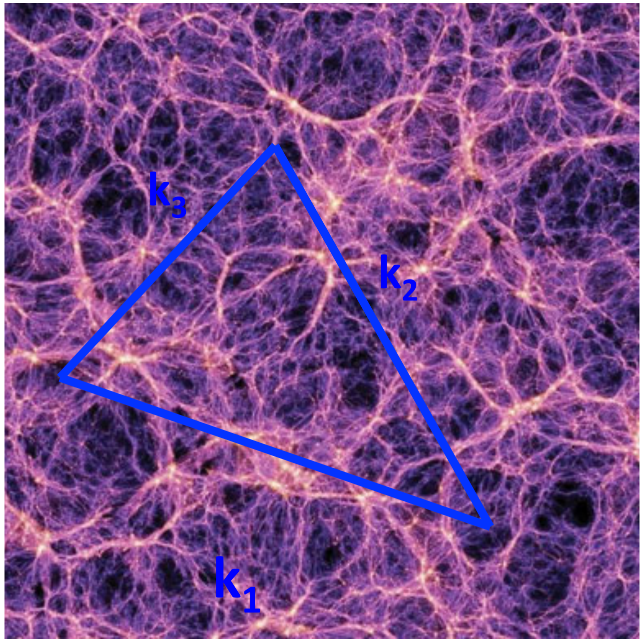
- On quasilinear scales, expand galaxy density

$$\delta_{\mathrm{g}}(\mathbf{x}) = b_1\delta_{\mathrm{m}}(\mathbf{x}) + \frac{1}{2}b_2\delta_{\mathrm{m}}^2(\mathbf{x})$$

- This results in a bispectrum (3 point clustering), in real space it is given by

$$\left\langle \tilde{\delta}_{\mathrm{g}}(\mathbf{k}_1)\tilde{\delta}_{\mathrm{g}}(\mathbf{k}_2)\tilde{\delta}_{\mathrm{g}}(\mathbf{k}_3)\right\rangle \equiv (2\pi)^3 B_{\mathrm{g}}(k_1,k_2,k_3)\delta_{\mathrm{D}}(\mathbf{k}_1+\mathbf{k}_2+\mathbf{k}_3)$$

$$B_{\mathrm{g}}(k_1,k_2,k_3) = 2b_1^2\left(b_1F_2(\mathbf{k}_1,\mathbf{k}_2) + \frac{1}{2}b_2\right)P(k_1)P(k_2) + 2\ \text{perm.}$$



- Can break degeneracies between b_1, σ_8 (Fry 1994, Verde et al 2001)

Contaminated Bispectrum

- Models for ε give tidal alignment modulated galaxy density

$$1+\delta_{\mathrm{g}}^{\mathrm{obs}}(\mathbf{x}) = \left[1+\delta_{\mathrm{g}}(\mathbf{x})\right]\left[1+\varepsilon(\hat{\mathbf{n}}\mid\mathbf{x})\right]$$

- Calculate Bispectrum

$$\left\langle \tilde{\delta}_{\mathrm{g}}^{\mathrm{obs}}(\mathbf{k}_1)\tilde{\delta}_{\mathrm{g}}^{\mathrm{obs}}(\mathbf{k}_2)\tilde{\delta}_{\mathrm{g}}^{\mathrm{obs}}(\mathbf{k}_3)\right\rangle$$

- Tidal alignments introduce systematic offsets!
- For angular clustering of LRGs (linear alignment model, transverse modes) this amounts to rescaling

$$b_1 \rightarrow b_1 - \frac{1}{3}A_1, \quad b_2 \rightarrow b_2 - \frac{2}{3}A_1 b_2$$

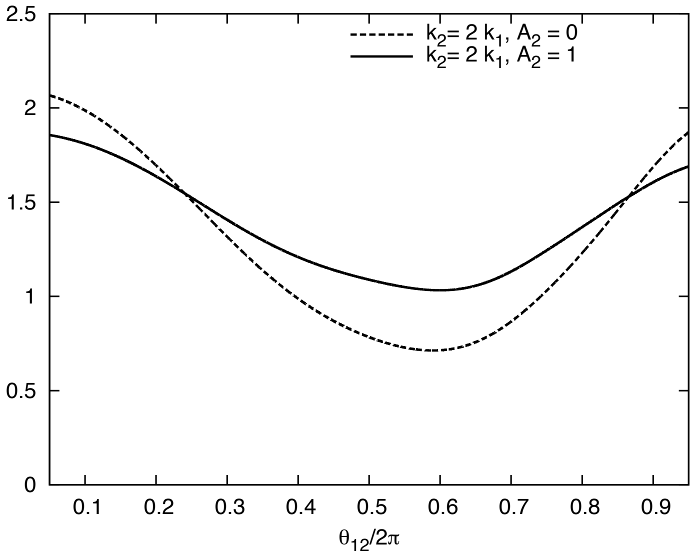
Contaminated Bispectrum – QA

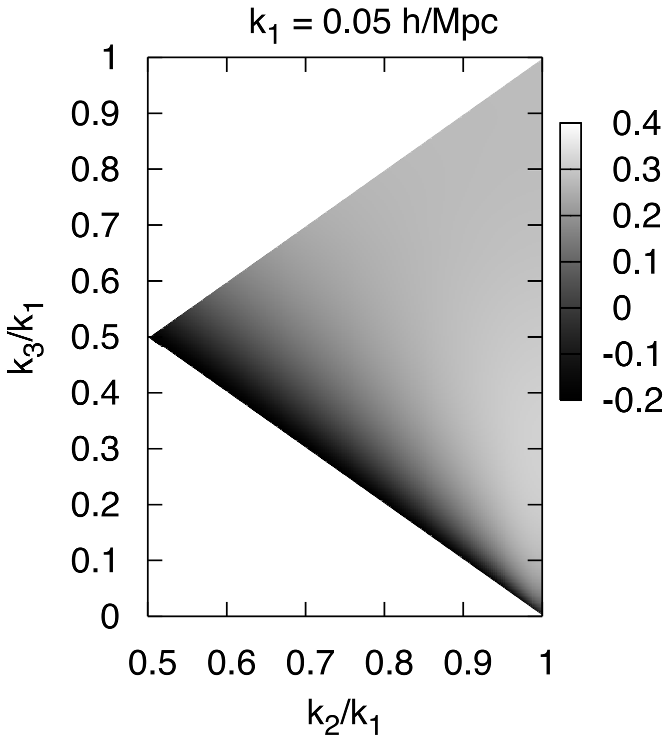
- Quadratic alignment has quadrupolar term, lowest order effect on (transverse) Bispectrum is

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

- Characteristic shape dependence

$$Q_{\rm g} = \frac{B_{\rm g}\left(k_1,k_2,k_3\right)}{P_{\rm g}(k_1)P_{\rm g}(k2) + \ 2\ \text{perm.}}$$





Parameter Bias: Technique

- Characteristic shape dependence of QA contamination not easily recast as bias rescaling
- Instead use Fisher matrix analysis for DES like angular galaxy clustering observations

$$\Delta p_\alpha = \langle \hat{p}_\alpha \rangle - p_\alpha^{\mathrm{fid}} = \left(\mathcal{F}^{-1}\right)_{\alpha\beta} \left[\Delta\vec{\mathcal{P}}^t \, \mathrm{Cov}^{-1}\left(\vec{\mathcal{P}},\vec{\mathcal{P}}\right) \frac{\partial \vec{\mathcal{P}}}{\partial p_\beta} + \Delta\vec{\mathcal{B}}^t \, \mathrm{Cov}^{-1}\left(\vec{\mathcal{B}},\vec{\mathcal{B}}\right) \frac{\partial \vec{\mathcal{B}}}{\partial p_\beta} \right],$$

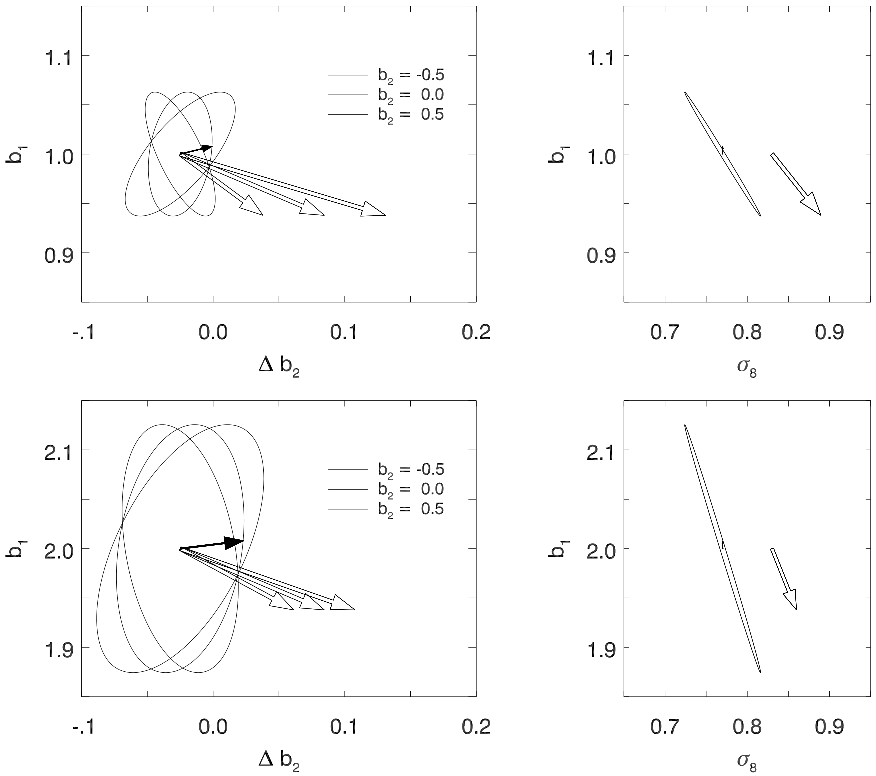
$$\mathcal{F}_{\alpha\beta} = \frac{\partial \vec{\mathcal{P}}^t}{\partial p_\alpha} \mathrm{Cov}^{-1}\left(\vec{\mathcal{P}},\vec{\mathcal{P}}\right) \frac{\partial \vec{\mathcal{P}}}{\partial p_\beta} + \frac{\partial \vec{\mathcal{B}}^t}{\partial p_\alpha} \mathrm{Cov}^{-1}\left(\vec{\mathcal{B}},\vec{\mathcal{B}}\right) \frac{\partial \vec{\mathcal{B}}}{\partial p_\beta}$$

Parameter Bias: Results

- DES survey size + radial selection function
- Angular clustering of galaxies with 0.4 <z<0.6

solid arrows: Linear Alignment

open arrows: Quadratic Alignment



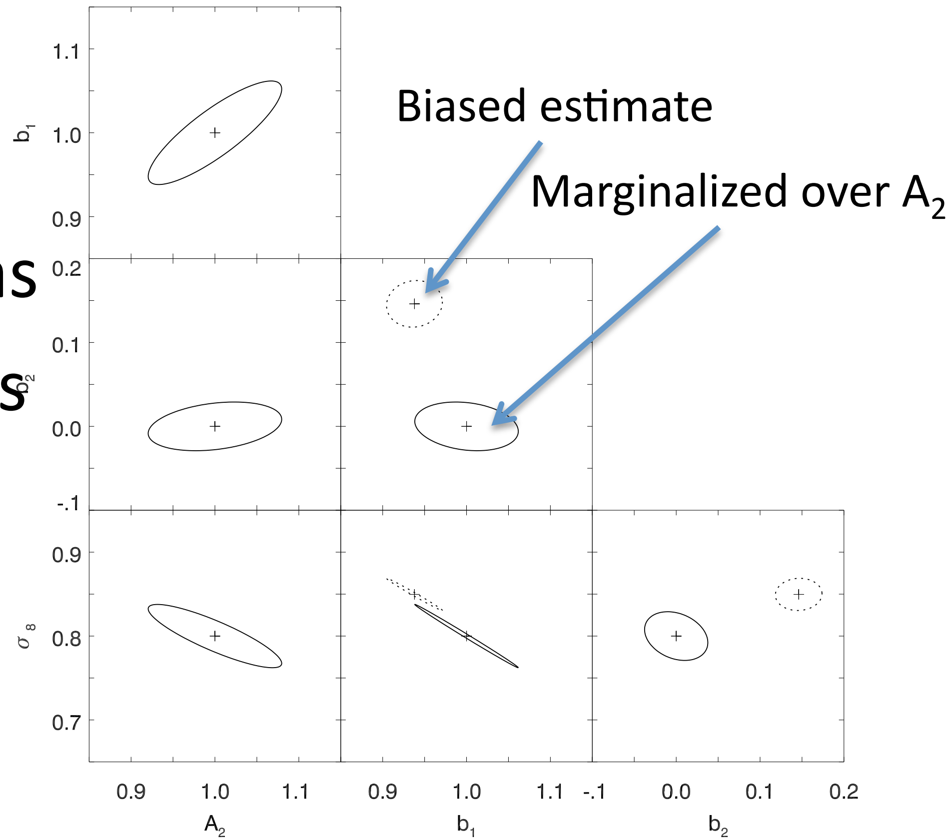
- QA introduces relevant offset in bias estimates

Removal of QA contamination

- Include QA contamination in Bispectrum model, marginalize over A_2

- Can remove paramter bias

  at cost of larger error bars



Conclusions

- Tidal galaxy alignments combined with anisotropic galaxy selection effects can affect LSS observables
- Has implications for measuring growth of structure, galaxy bias parameters
  - mimics red shift space distortions in linear regime
  - LA not important for Bispectrum; given a model for shape dependence, QA contamination may be fit out
- Cures: Judicious galaxy selection? Modeling?