IA self-calibration, indirect detection, and what's next?

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DESC - Pittsburg PA(12/5/13)

- How does the self-calibration work?
- How can principles used by self-calibration inform simulations (& direct detection) of IA (cross-)correlations?
- What's next for both?

Weak gravitational lensing (cosmic shear)

$$\gamma_i^{obs} \equiv \gamma_i + I_i$$

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$$\langle \gamma_i^{obs} \gamma_j^{obs} \rangle = \langle (\gamma_i + I_i)(\gamma_j + I_j) \rangle = \langle \gamma_i \gamma_j \rangle + \langle I_i \gamma_j \rangle + \langle \gamma_i I_j \rangle + \langle I_i I_j \rangle$$

= GG + IG + GI + II

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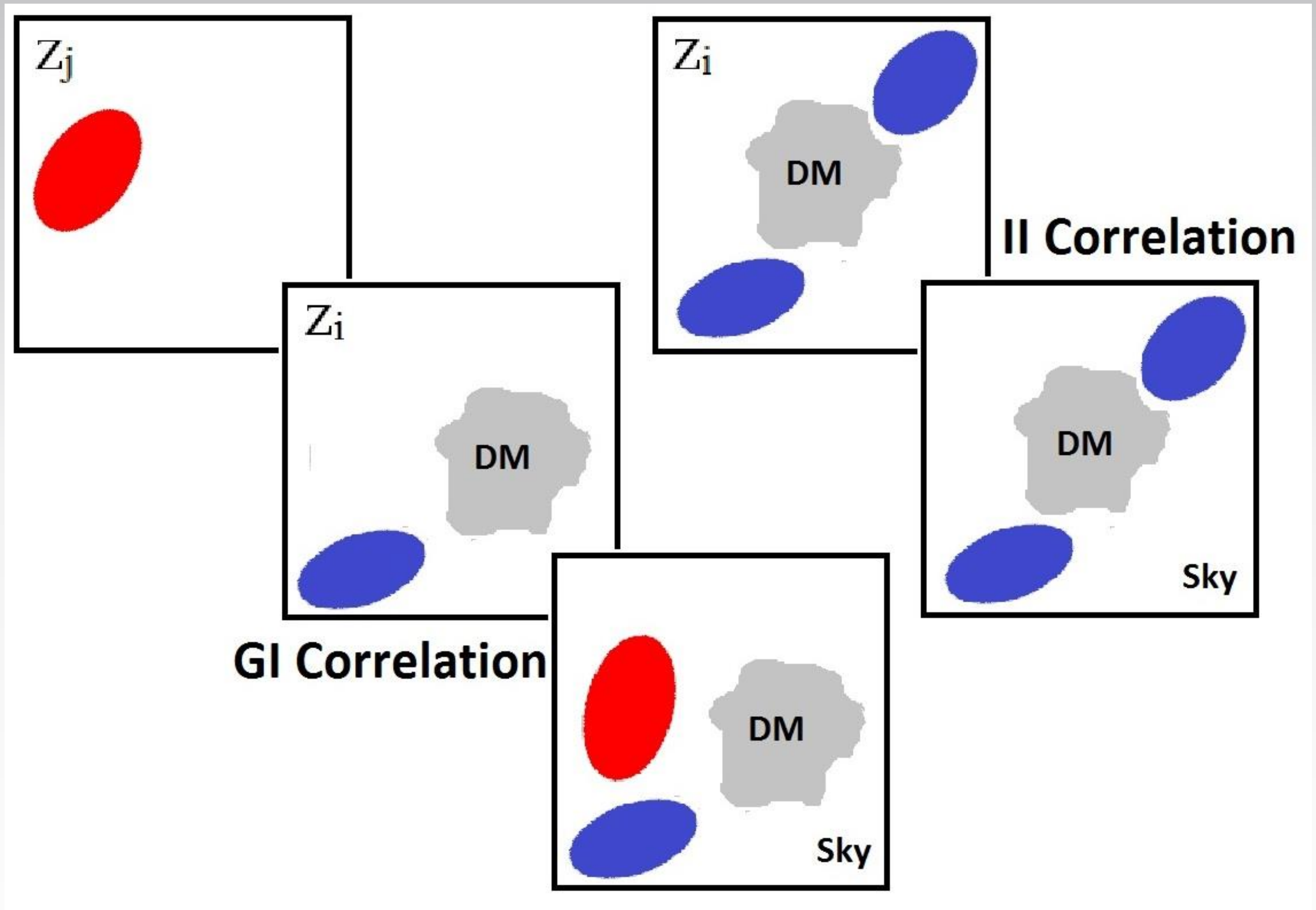
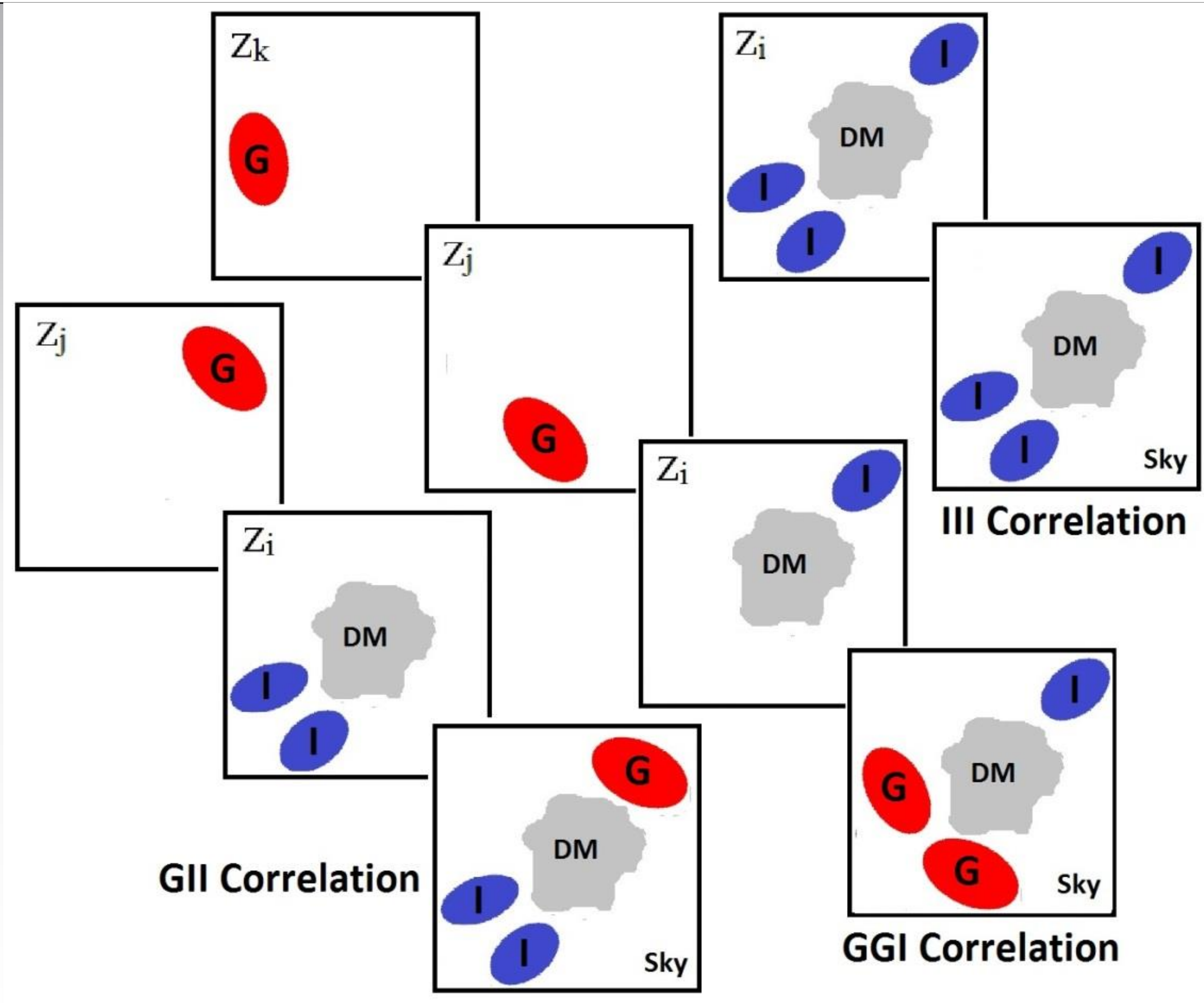
$$= \quad \mathrm{GG} + \mathrm{IG} + \mathrm{GI} + \mathrm{II}$$

$$\langle \gamma_i^{obs} \gamma_j^{obs} \gamma_k^{obs} \rangle = \langle (\gamma_i + I_i)(\gamma_j + I_j)(\gamma_k + I_k) \rangle$$

$$= \mathrm{GGG} + \mathrm{GGI} + \ldots + \mathrm{GII} + \ldots + \mathrm{III}$$

Intrinsic alignment of galaxies (IA)

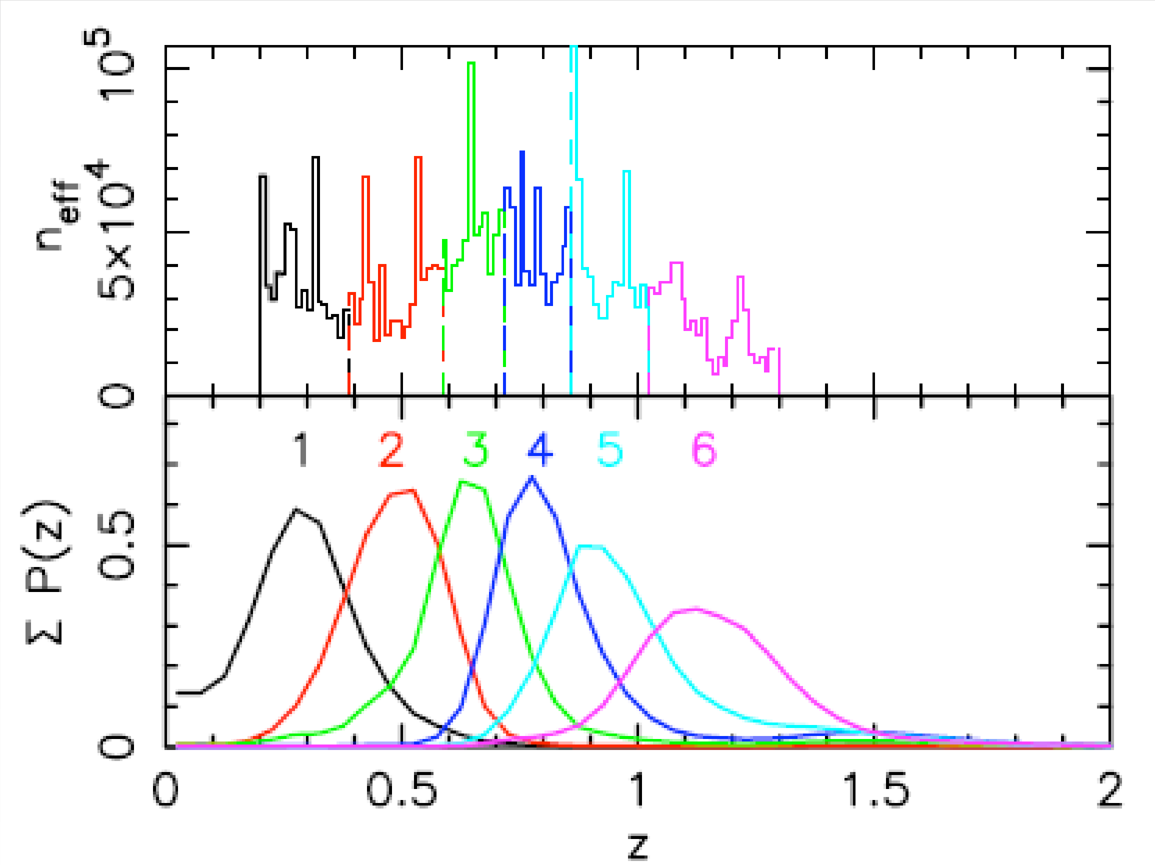




Z_k
G
Z_i
I
DM
I
I
Z_j
G
Z_j
G
I
DM
I
I
Sky
III Correlation
Z_i
I
DM
Z_i
DM
I
I
G
DM
I
I
Sky
GII Correlation
I
G
DM
G
Sky
GGI Correlation

IA Self-calibration

- Information in survey: galaxy density (g) and shape (G+I)
- Redshift bin tomography (photo-z measurements)



Heymans et al. 2013

IA Self-calibration

- Information in survey: galaxy density (g) and shape (G+I)
- Redshift bin tomography (photo-z measurements)

Now we build correlations…

$$
\begin{aligned}
C_{ij}^{(1)}(\ell) &\approx C_{ij}^{GG}(\ell) + C_{ij}^{IG}(\ell), \\
C_{ii}^{(2)}(\ell) &= C_{ii}^{gG}(\ell) + C_{ii}^{gI}(\ell), \\
C_{ii}^{(3)}(\ell) &= C_{ii}^{gg}(\ell).
\end{aligned}
$$

$$B_{ijk}^{(1)}(\ell_1,\ell_2,\ell_3) \approx B_{ijk}^{GGG}(\ell_1,\ell_2,\ell_3) + B_{ijk}^{IGG}(\ell_1,\ell_2,\ell_3) + B_{ijk}^{IIG}(\ell_1,\ell_2,\ell_3).$$

$$B_{iii}^{(2)}(\ell_1,\ell_2,\ell_3) = B_{iii}^{Ggg}(\ell_1,\ell_2,\ell_3) + B_{iii}^{Igg}(\ell_1,\ell_2,\ell_3).$$

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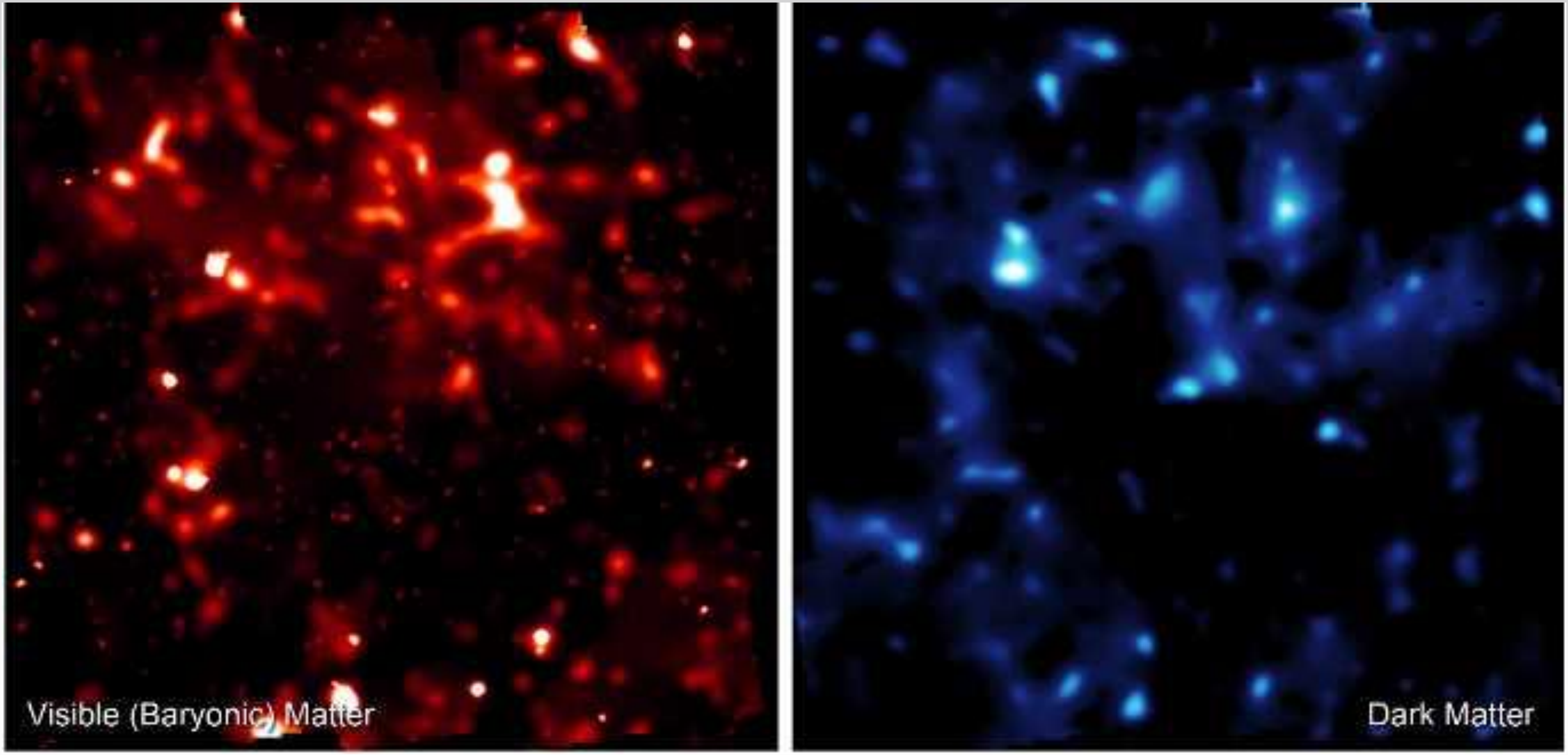
$$B_{iii}^{(3)}(\ell_1,\ell_2,\ell_3) = B_{iii}^{ggg}(\ell_1,\ell_2,\ell_3).$$

IA Self-calibration

- Information in survey: galaxy density (g) and shape (G+I)
- Redshift bin tomography (photo-z measurements)



$$\delta_g(\boldsymbol{x};\chi) = b_{g,1}(\chi)\delta_m(\boldsymbol{x};\chi) + \frac{b_{g,2}(\chi)}{2}\delta^2(\boldsymbol{x};\chi) + O(\delta^3).$$

NASA, ESA, R. Massey

IA Self-calibration

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C^{(1)}_{ij}(\ell) &\approx C^{GG}_{ij}(\ell) + C^{IG}_{ij}(\ell), \\
C^{(2)}_{ii}(\ell) &= C^{gG}_{ii}(\ell) + C^{gI}_{ii}(\ell), \\
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\end{aligned}
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$$B^{(1)}_{ijk}(\ell_1,\ell_2,\ell_3) \approx B^{GGG}_{ijk}(\ell_1,\ell_2,\ell_3) + B^{IGG}_{ijk}(\ell_1,\ell_2,\ell_3) + B^{IIG}_{ijk}(\ell_1,\ell_2,\ell_3).$$

$$B^{(2)}_{iii}(\ell_1,\ell_2,\ell_3) = B^{Ggg}_{iii}(\ell_1,\ell_2,\ell_3) + B^{Igg}_{iii}(\ell_1,\ell_2,\ell_3).$$

$$B^{(2)}_{iii}(\ell_1,\ell_2,\ell_3) = B^{GGg}_{iii}(\ell_1,\ell_2,\ell_3) + B^{GIg}_{iii}(\ell_1,\ell_2,\ell_3) + B^{IIg}_{iii}(\ell_1,\ell_2,\ell_3).$$

$$B^{(3)}_{iii}(\ell_1,\ell_2,\ell_3) = B^{ggg}_{iii}(\ell_1,\ell_2,\ell_3).$$

IA Self-calibration

$$C_{ij}^{IG}(\ell) \approx \frac{W_{ij}}{b_1^i(\ell)\Pi_{ii}} C_{ii}^{Ig}(\ell),$$

$$\begin{aligned} B_{ijk}^{IGG}(\ell_1,\ell_2,\ell_3) \quad &\approx \quad \frac{W_{ijk}}{(b_1^i)^2\Pi_{iii}} B_{iii}^{Igg}(\ell_1,\ell_2,\ell_3) - \frac{b_2^i}{(b_1^i)^2}\frac{W_{ijk}}{\omega_{ii}\Pi_{ii}} \\ &\times \left[C_{ii}^{Ig}(\ell_1)C_{ii}^{GG}(\ell_2) + C_{ii}^{GG}(\ell_2)C_{ii}^{Ig}(\ell_3) + \frac{\omega_{ii}}{b_1^i\Pi_{ii}} C_{ii}^{Ig}(\ell_1)C_{ii}^{Ig}(\ell_3) \right]. \end{aligned}$$

IA Self-calibration

$$C_{ij}^{IG}(\ell) \approx \frac{W_{ij}}{b_1^i(\ell)\Pi_{ii}} C_{ii}^{Ig}(\ell),$$

$$\begin{aligned} B_{ijk}^{IGG}(\ell_1,\ell_2,\ell_3) \quad &\approx \quad \frac{W_{ijk}}{(b_1^i)^2\Pi_{iii}} B_{iii}^{Igg}(\ell_1,\ell_2,\ell_3) - \frac{b_2^i}{(b_1^i)^2}\frac{W_{ijk}}{\omega_{ii}\Pi_{ii}} \\ &\quad \times \left[C_{ii}^{Ig}(\ell_1)C_{ii}^{GG}(\ell_2) + C_{ii}^{GG}(\ell_2)C_{ii}^{Ig}(\ell_3) + \frac{\omega_{ii}}{b_1^i\Pi_{ii}} C_{ii}^{Ig}(\ell_1)C_{ii}^{Ig}(\ell_3)\right]. \end{aligned}$$

$$\begin{aligned} C_{ij}^{(1)}(\ell) &\approx C_{ij}^{GG}(\ell) + C_{ij}^{IG}(\ell), \\ C_{ii}^{(2)}(\ell) &= C_{ii}^{gG}(\ell) + C_{ii}^{gI}(\ell), \\ C_{ii}^{(3)}(\ell) &= C_{ii}^{gg}(\ell). \end{aligned}$$

IA Self-calibration

$$C_{ij}^{IG}(\ell) \approx \frac{W_{ij}}{b_1^i(\ell)\Pi_{ii}} C_{ii}^{Ig}(\ell),$$

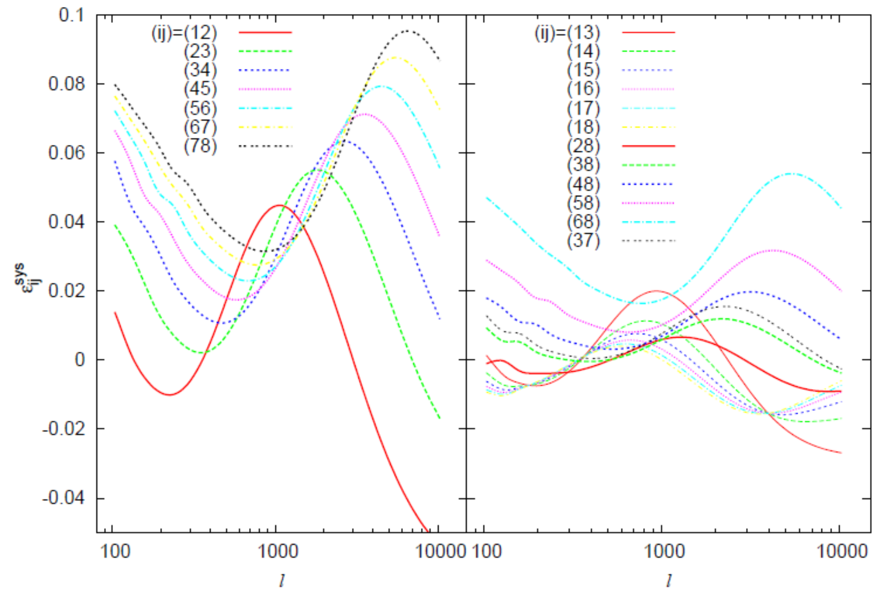
$$\begin{aligned} B_{ijk}^{IGG}(\ell_1,\ell_2,\ell_3) \quad \approx \quad & \frac{W_{ijk}}{(b_1^i)^2\Pi_{iii}} B_{iii}^{Igg}(\ell_1,\ell_2,\ell_3) - \frac{b_2^i}{(b_1^i)^2}\frac{W_{ijk}}{\omega_{ii}\Pi_{ii}} \\ & \times \left[C_{ii}^{Ig}(\ell_1)C_{ii}^{GG}(\ell_2) + C_{ii}^{GG}(\ell_2)C_{ii}^{Ig}(\ell_3) + \frac{\omega_{ii}}{b_1^i\Pi_{ii}} C_{ii}^{Ig}(\ell_1)C_{ii}^{Ig}(\ell_3) \right]. \end{aligned}$$

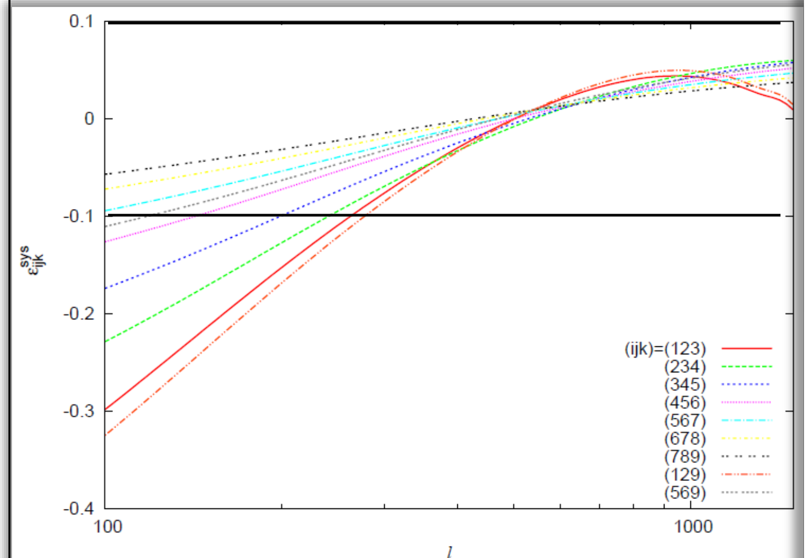
$$\hat{C}_{ii}^{Ig}(\ell) = \frac{C_{ii}^{(2)}|_S(\ell) - Q_2(\ell)C_{ii}^{(2)}(\ell)}{1 - Q_2(\ell)},$$

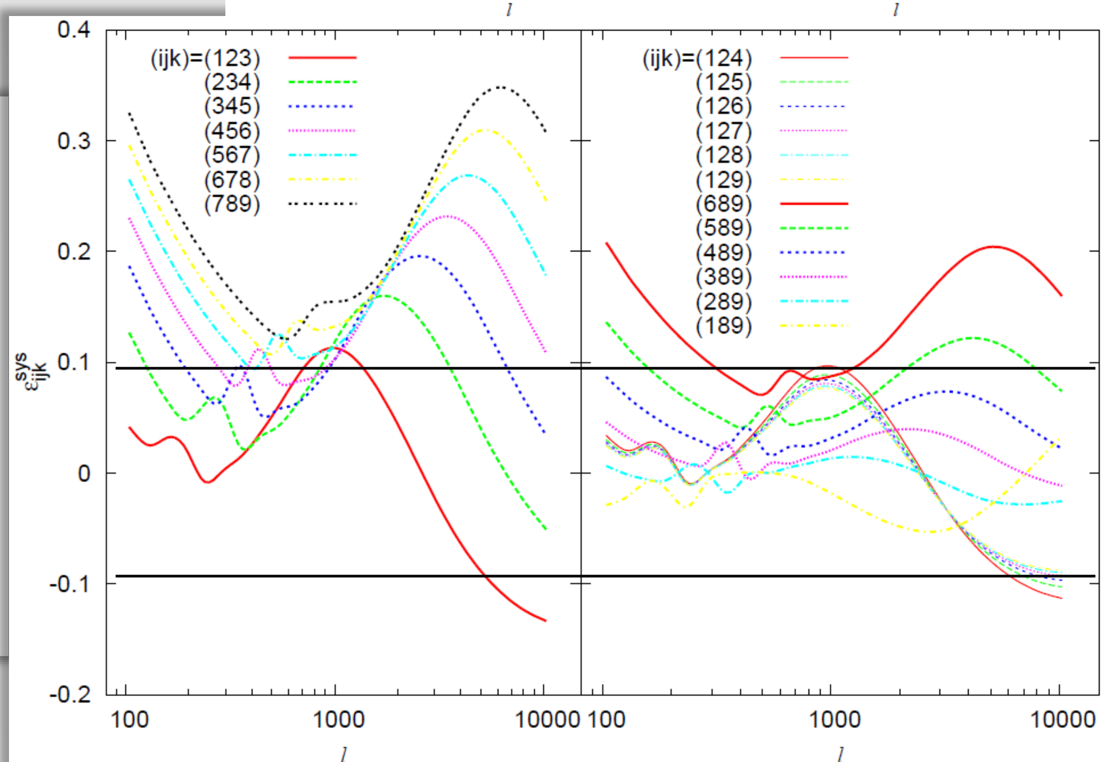
$$\begin{aligned} C_{ij}^{(1)}(\ell) \quad & \approx \quad C_{ij}^{GG}(\ell) + C_{ij}^{IG}(\ell), \\ C_{ii}^{(2)}(\ell) \quad & = \quad C_{ii}^{gG}(\ell) + C_{ii}^{gI}(\ell), \\ C_{ii}^{(3)}(\ell) \quad & = \quad C_{ii}^{gg}(\ell). \end{aligned}$$

IA Self-calibration

How accurate is it?







Left: GII self-calibration systematic error

Right: GGI self-calibration systematic error

IA Self-calibration

Is there a residual error?

$$
\begin{aligned}
\left(\Delta B^{IIg}_{iii}\right)^2 = \frac{4\pi^2}{\ell_1\ell_2\ell_3\Delta\ell_1\Delta\ell_2\Delta\ell_3 f_{sky}} \Big\{ & \left(C^{\rm GG}+C^{\rm II}\right) C^{\rm Gg}C^{\rm Gg}K_1 \\
& + C^{\rm GG}\Big[\left(C^{\rm GG}+2C^{\rm II}\right)\left(C^{\rm gg}+C^{\rm gg,N}a_1\right)+2C^{\rm Ig}C^{\rm Ig} \\
& + C^{\rm Gg}C^{\rm Ig}K_2 + C^{\rm IG}\left(C^{\rm gg}K_3+C^{\rm gg,N}K_4\right)+C^{\rm GG,N}\left(C^{\rm gg}K_5+C^{\rm gg,N}K_6\right)\Big] \\
& + C^{\rm IG}\Big[C^{\rm IG}\left(C^{\rm gg}K_7+C^{\rm gg,N}K_8\right)+C^{\rm Gg}C^{\rm Gg}K_9+C^{\rm Gg}C^{\rm Ig}K_{10} \\
& + C^{\rm GG,N}\left(C^{\rm gg}K_{11}+C^{\rm gg,N}K_{12}\right)\Big] \\
& + C^{\rm GG,N}\Big[C^{\rm GG,N}\left(C^{\rm gg}c_1+C^{\rm gg,N}e_1\right)+C^{\rm Ig}C^{\rm Ig}K_5+C^{\rm II}\left(C^{\rm gg}K_5+C^{\rm gg,N}K_6\right) \\
& + C^{\rm Gg}C^{\rm Gg}K_{13}+C^{\rm Gg}C^{\rm Ig}K_{14}\Big]\Big\}.
\end{aligned}
$$

IA Self-calibration

Is there a residual error?

$$\Delta B^{IGG}_{ijk} = \frac{W_{ijk}}{(b_1^i)^2\Pi_{iii}}\left(2m_i\Delta m_i B^{GGG}_{iii} + m_i^2 B^{GGG}_{iii}\Delta B^{GGG}_{iii}\right) - \frac{b_2^i W_{ijk}}{(b_1^i)^3\Pi^2_{ii}}\left(2\frac{W_{ij}}{\omega_{ii}}+1\right)\left(\Delta m_i C^{GG}_{ii} + m_i C^{GG}_{ii}\Delta C^{GG}_{ii}\right)^2.$$

$$\begin{aligned}\Delta f^M_{ijk} &< \frac{W_{ijk}}{(b_1^i)^2\Pi_{iii}}\left(2\left|m_i\Delta m_i\right| + m_i^2\left|\frac{\Delta B^{GGG}_{iii}}{B^{GGG}_{iii}}\right|\right) - \frac{b_2^i W_{ijk}}{3Q_k(b_1^i)^3\Pi^2_{ii}}\left(2\frac{W_{ij}}{\omega_{ii}}+1\right)\left(\left|\Delta m_i\right| + \left|m_i\frac{\Delta C^{GG}_{ii}}{C^{GG}_{ii}}\right|\right)^2 \\ &< O(10^{-4})\left[\left(2\left|m_i\frac{\Delta m_i}{0.1}\right| + m_i^2\left|\frac{\Delta B^{GGG}_{iii}/B^{GGG}_{iii}}{10\%}\right|\right) + \left(\left|\frac{\Delta m_i}{0.1}\right| + \left|m_i\frac{\Delta C^{GG}_{ii}/C^{GG}_{ii}}{10\%}\right|\right)^2\right].\end{aligned}$$

IA Self-calibration

- Potential to turn 10-20% systematic bias into a 1-2% error
- Benefits:
  - Doesn't throw away any lensing signal
  - IA model independent
  - Isolates true IA signal (study of structure formation, cosmology)

But what about II/III…

$$
\begin{aligned}
C_{ij}^{(1)}(\ell) &\approx C_{ij}^{GG}(\ell) + C_{ij}^{IG}(\ell), \\
C_{ii}^{(2)}(\ell) &= C_{ii}^{gG}(\ell) + C_{ii}^{gI}(\ell), \\
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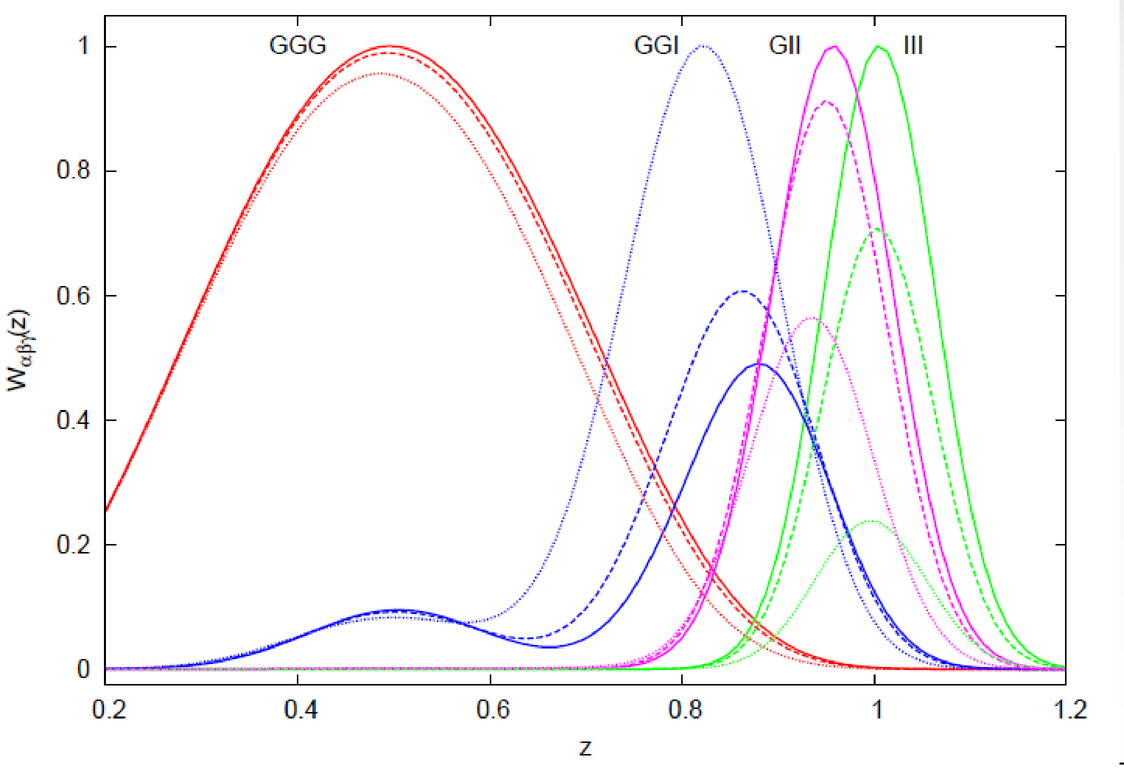
\end{aligned}
$$

Self-calibration of IA auto-correlations

- Use distinct separation dependence of IA and shear signal

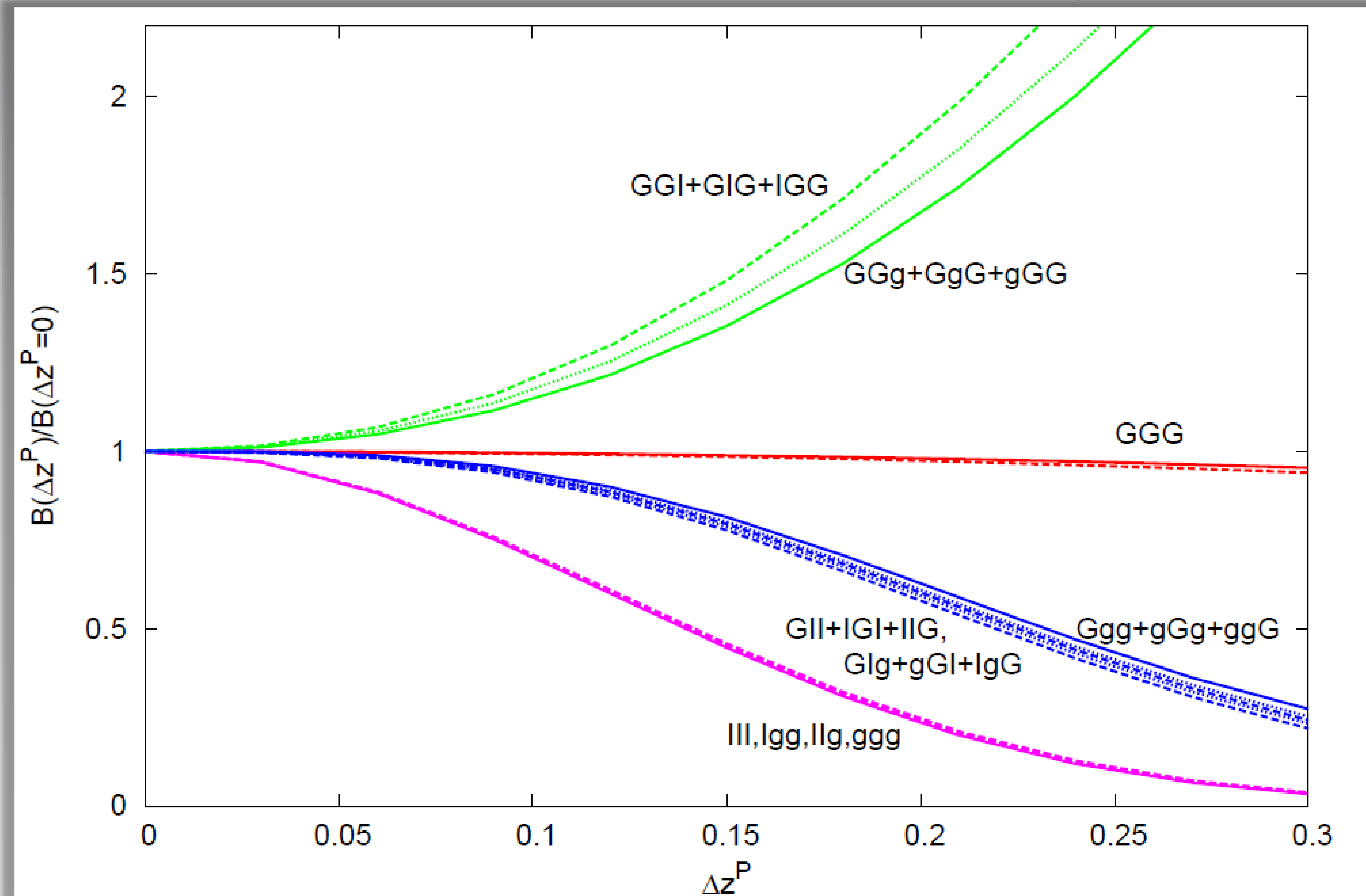
$$B^{\alpha\beta\gamma}(\ell; z_1^P, z_2^P, z_3^P) = \int_0^{\chi} \frac{W^{\alpha\beta\gamma}(\chi'; \chi_1, \chi_2, \chi_3)}{\chi'^4} B_{\alpha\beta\gamma}(k; \chi') d\chi',$$

$$\begin{aligned} W^{\alpha\beta\gamma}(z(\chi); z_1^P(\chi_1), z_2^P(\chi_2), z_3^P(\chi_3)) &\equiv W^{\alpha}(z, z_1^P) W^{\beta}(z, z_2^P) W^{\gamma}(z, z_3^P), \\ W^G(z, z^P) &= \int_0^{\infty} W_L(z', z) p(z'|z^P) dz', \\ W^I(z, z^P) &= W^g(z, z^P) = p(z|z^P), \end{aligned}$$



Self-calibration of IA auto-correlations

- Use distinct separation dependence of IA and shear signal



Self-calibration of IA auto-correlations

- Use distinct separation dependence of IA and shear signal
- Build relationships between IA-shear and gal. density-shear

III

$$B^{III}(\ell; z_1^P, z_2^P, z_3^P) = A_{III}(\ell; z_1^P, z_2^P, z_3^P) B^{ggg}(\ell; z_1^P, z_2^P, z_3^P),$$

$$\begin{aligned} B^{IIg}(\ell; z_1^P, z_2^P, z_3^P) &= A_{IIg}(\ell; z_1^P, z_2^P, z_3^P) B^{ggg}(\ell; z_1^P, z_2^P, z_3^P), \\ B^{Igg}(\ell; z_1^P, z_2^P, z_3^P) &= A_{Igg}(\ell; z_1^P, z_2^P, z_3^P) B^{ggg}(\ell; z_1^P, z_2^P, z_3^P). \end{aligned}$$

<1%

GII

$$B^{GII} + B^{IGI} + B^{IIG} \approx A_{GII} \left[B^{Ggg} + B^{gGg} + B^{ggG} \right].$$

$$B^{GIg} + B^{gGI} + B^{IgG} \approx A_{GIg} \left[B^{Ggg} + B^{gGg} + B^{ggG} \right].$$

<3-5%

GGI

$$B^{GGI} + B^{GIG} + B^{IGG} \approx A_{GGI} \left[B^{GGg} + B^{GgG} + B^{gGG} \right].$$

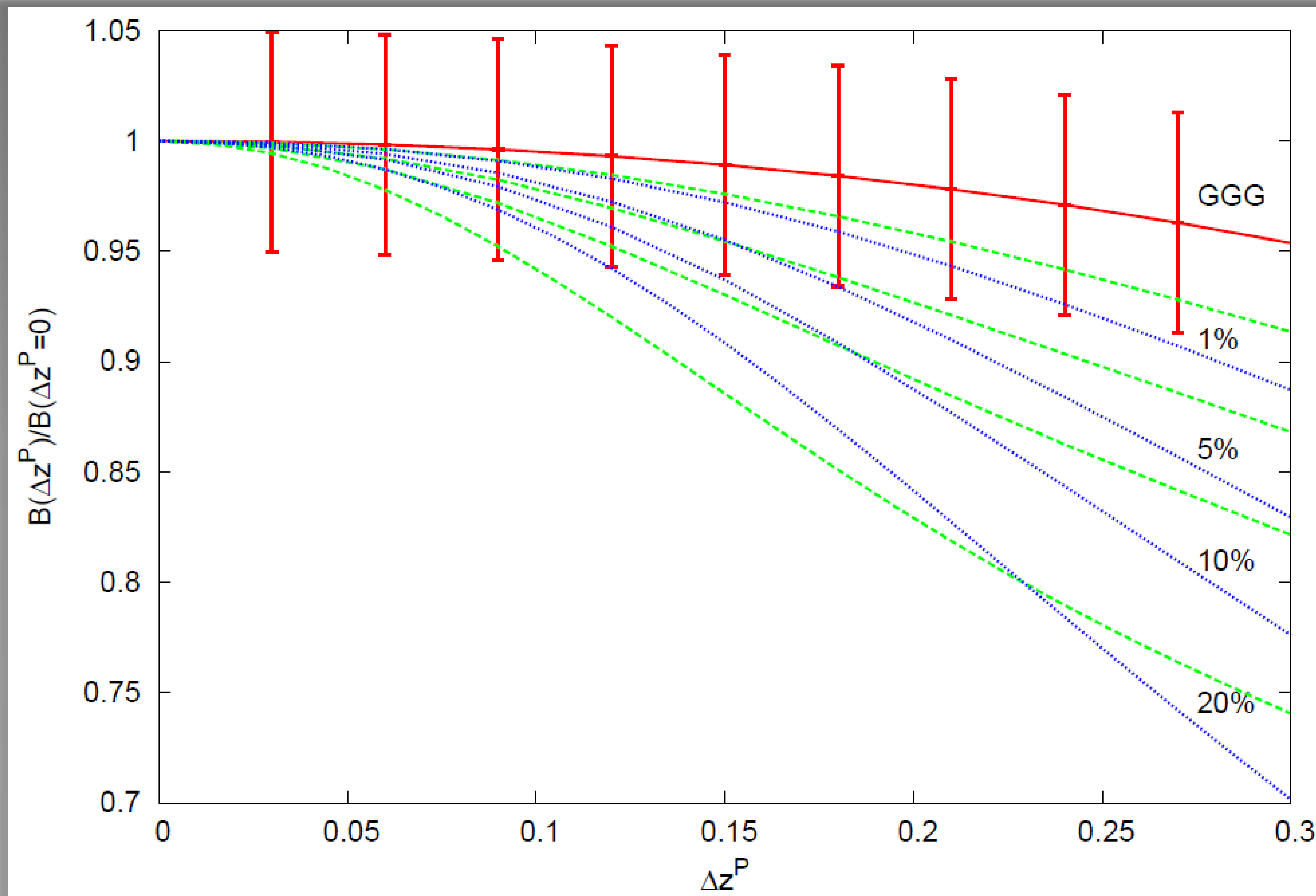
<10-20%

GGG

$$\begin{aligned} \frac{B^{GGG}(\Delta z^P)}{B^{GGG}(\Delta z^P = 0)} &\approx 1 - f_{GGG}(\Delta z^P)^2, \\ f_{GGG} &\equiv \frac{\partial^2 B^{GGG}(\Delta z^P)/\partial(\Delta z^P)^2|_0}{B^{GGG}(\Delta z^P = 0)}. \end{aligned}$$

<1%

Self-calibration of IA auto-correlations



IA Self-calibration

- IA has distinct z-separation dependence unique from lensing signal
  - Again use complementary information to build scaling relationships
  - Marginalize over parameters to constrain magnitude of GGG, GGI, GII, III
- Benefits:
  - Doesn't throw away any lensing signal
  - Weakly IA model dependent
  - Isolates true IA signal (study of structure formation, cosmology) including II/III

How can we use these principles?

- The self-calibration provides an indirect measurement of the IA signal
- The self-calibration identifies three useful properties of IA/shear on large scales…
  - Separation and geometric dependencies of the two signals
  - Scaling relations between different observables
  - Estimators for isolating IA signals in some observables (both photo-z and spec-z)
- Self-calibration / simulations / direct measurements / etc must agree
  - Each provide consistency tests for the others

What's next?

- The self-calibration is well-developed analytically
  - Promising efficiency at isolating IA (too promising?)
  - Primary benefits over other methods useful here – little stat. loss, preserved IA
- But does it work in a realistic environment?
  - This is the key question for IA mitigation through SC in LSST
- First step: Utilize the SC in a semi-realistic simulation with IA included
  - Initial toy model of IA ok?