Growth rate of structure measurement with ZTF SNIa

Maximum likelihood method

Rafael Kebadian

Maximum likelihood method

$$\mathscr{L}(\mathbf{p}, \mathbf{p}_{\mathrm{HD}}) = (2\pi)^{-\frac{n}{2}} \,|\, C(\mathbf{p}, \mathbf{p}_{\mathrm{HD}}) \,|^{-\frac{1}{2}} \exp\left[-\frac{1}{2}\mathbf{v}^{\top}(\mathbf{p}_{\mathrm{HD}}) C(\mathbf{p}, \mathbf{p}_{\mathrm{HD}})^{-1} \mathbf{v}(\mathbf{p}_{\mathrm{HD}})\right]$$

$$\mathbf{p} = f\sigma_8, \sigma_u, \sigma_v$$

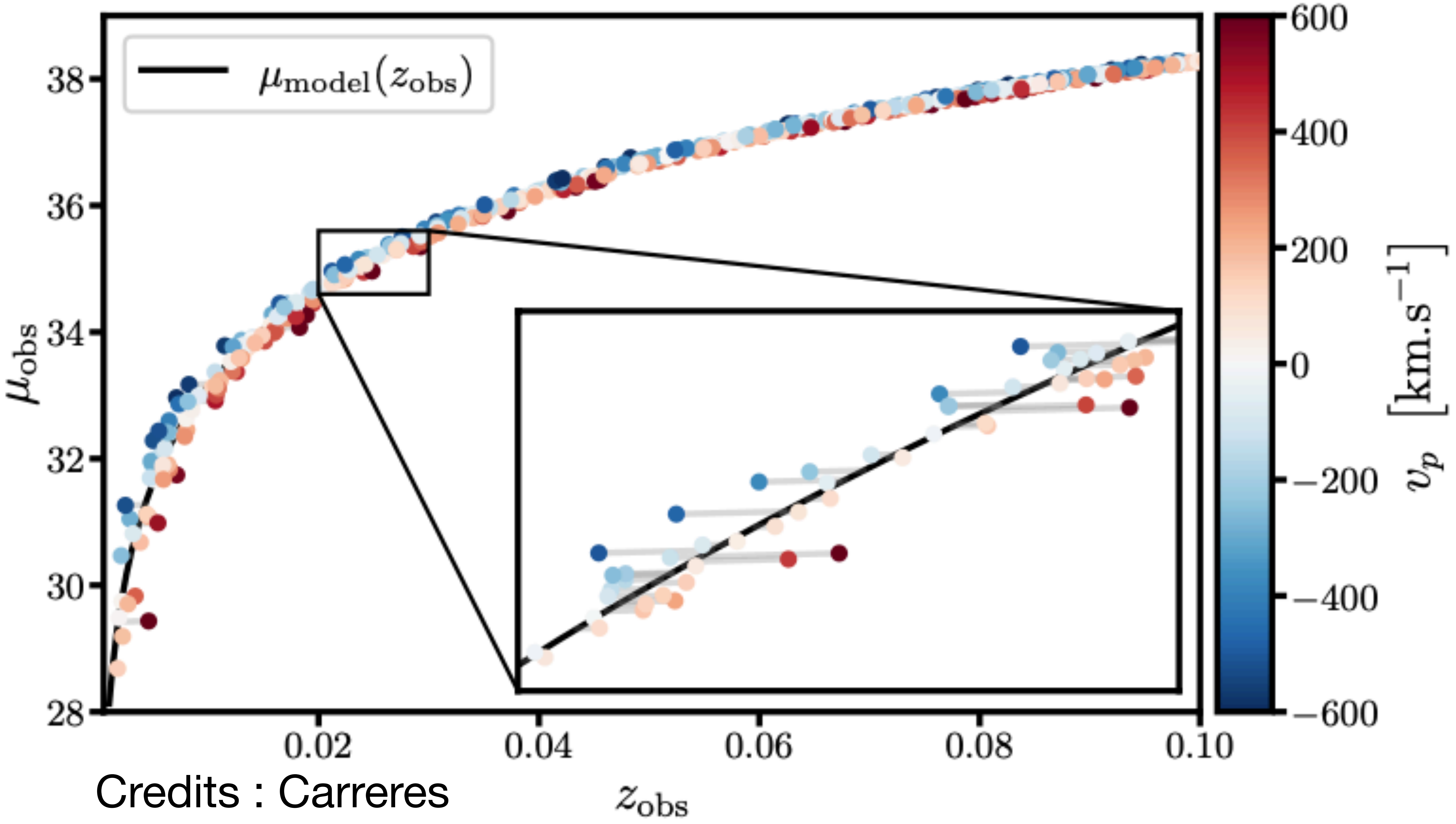
Cosmological parameters

$$\mathbf{p}_{\mathrm{HD}} = \alpha, \beta, \sigma_{int}, M_0$$

Hubble Diagram parameters

Maximum likelihood method

$$\mathscr{L}(\mathbf{p}, \mathbf{p}_{\mathrm{HD}}) = (2\pi)^{-\frac{n}{2}} \,|\, C(\mathbf{p}, \mathbf{p}_{\mathrm{HD}}) \,|^{-\frac{1}{2}} \exp\left[-\frac{1}{2}\mathbf{v}^{\top}(\mathbf{p}_{\mathrm{HD}}) C(\mathbf{p}, \mathbf{p}_{\mathrm{HD}})^{-1} \mathbf{v}(\mathbf{p}_{\mathrm{HD}})\right]$$



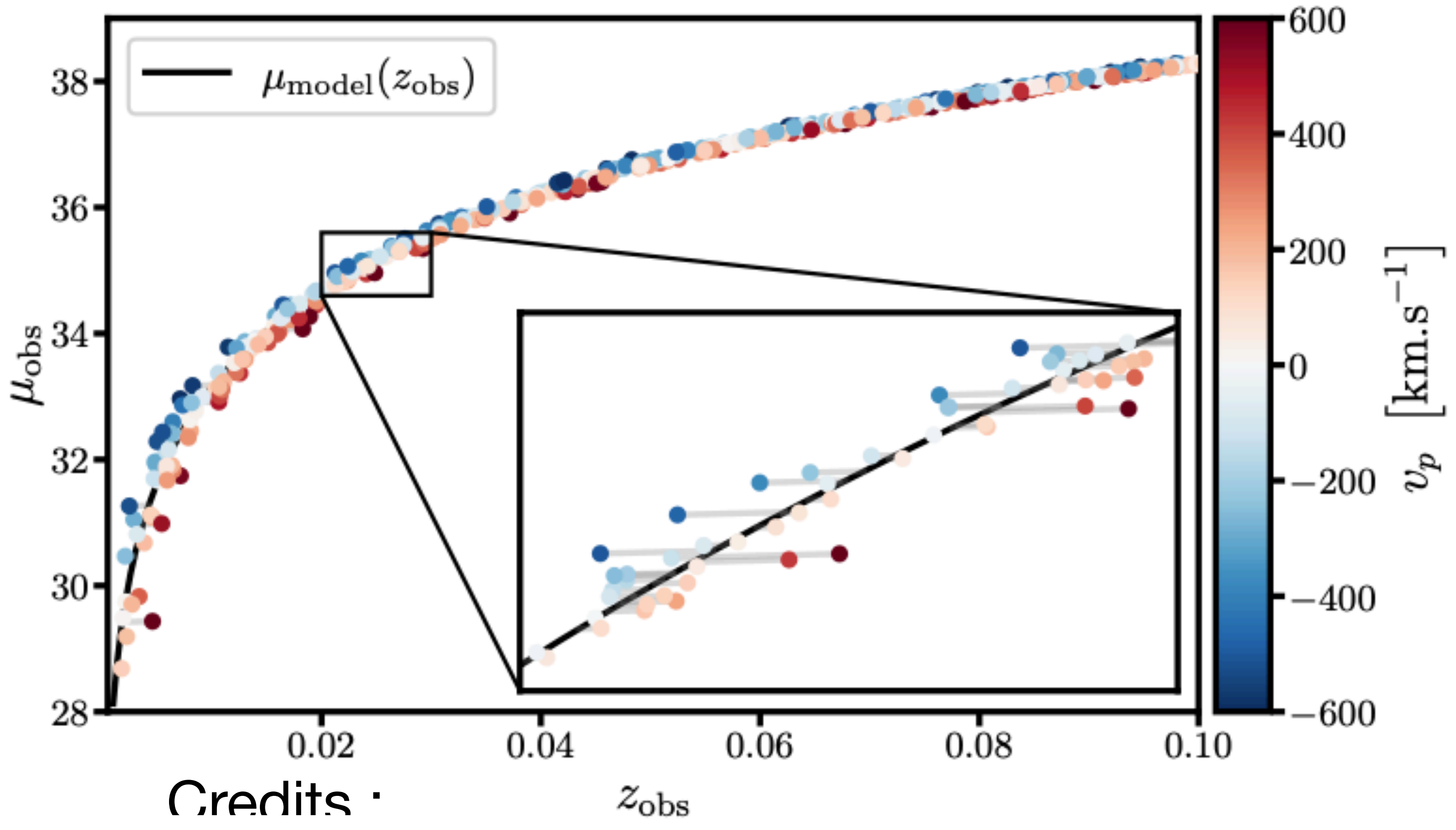
Credits : Carreres

$$\mathbf{v}(\mathbf{p}_{\mathrm{HD}}) \propto \Delta\mu_i(\mathbf{p}_{\mathrm{HD}})$$

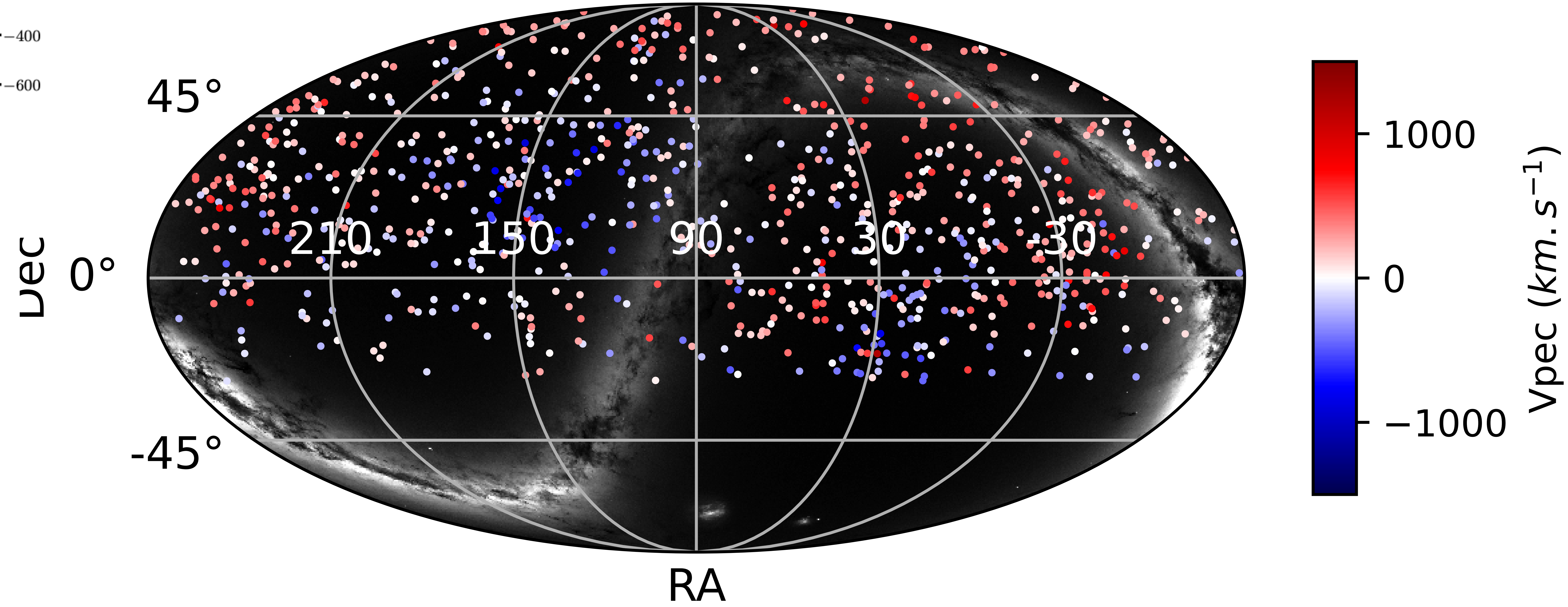
$$\mathbf{v}(\mathbf{p}_{\mathrm{HD}}) = \frac{\ln(10)c}{5}\left(\frac{(1+z_i)c}{H(z_i)r(z_i)} - 1\right)^{-1} \Delta\mu_i(\mathbf{p}_{\mathrm{HD}})$$

Maximum likelihood method

$$\mathscr{L}(\mathbf{p}, \mathbf{p}_{\mathrm{HD}}) = (2\pi)^{-\frac{n}{2}} \, | \, C(\mathbf{p}, \mathbf{p}_{\mathrm{HD}}) \, |^{-\frac{1}{2}} \exp \left[-\frac{1}{2} \mathbf{v}^{\top}(\mathbf{p}_{\mathrm{HD}}) C(\mathbf{p}, \mathbf{p}_{\mathrm{HD}})^{-1} \mathbf{v}(\mathbf{p}_{\mathrm{HD}}) \right]$$

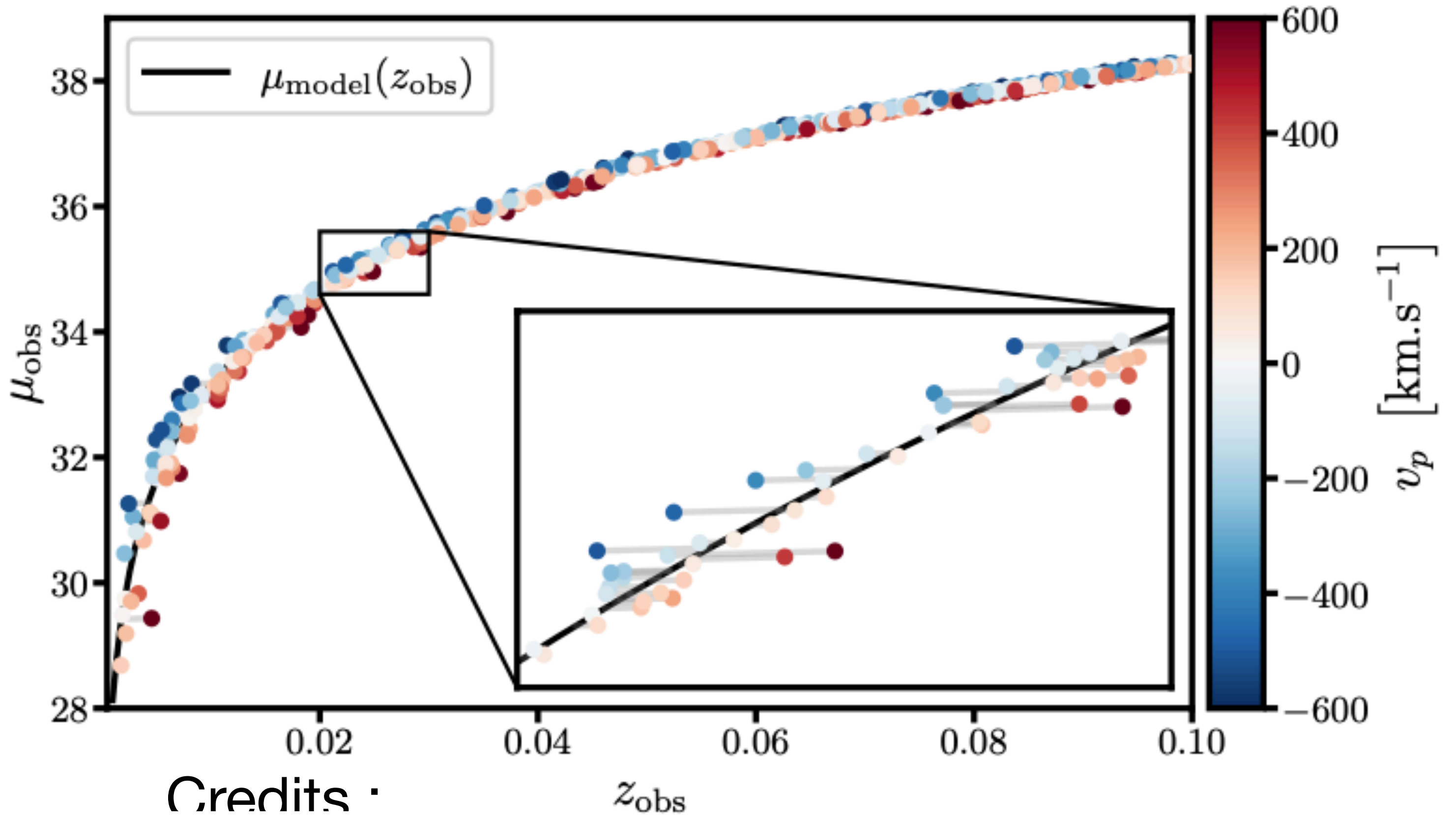


True N-body velocities

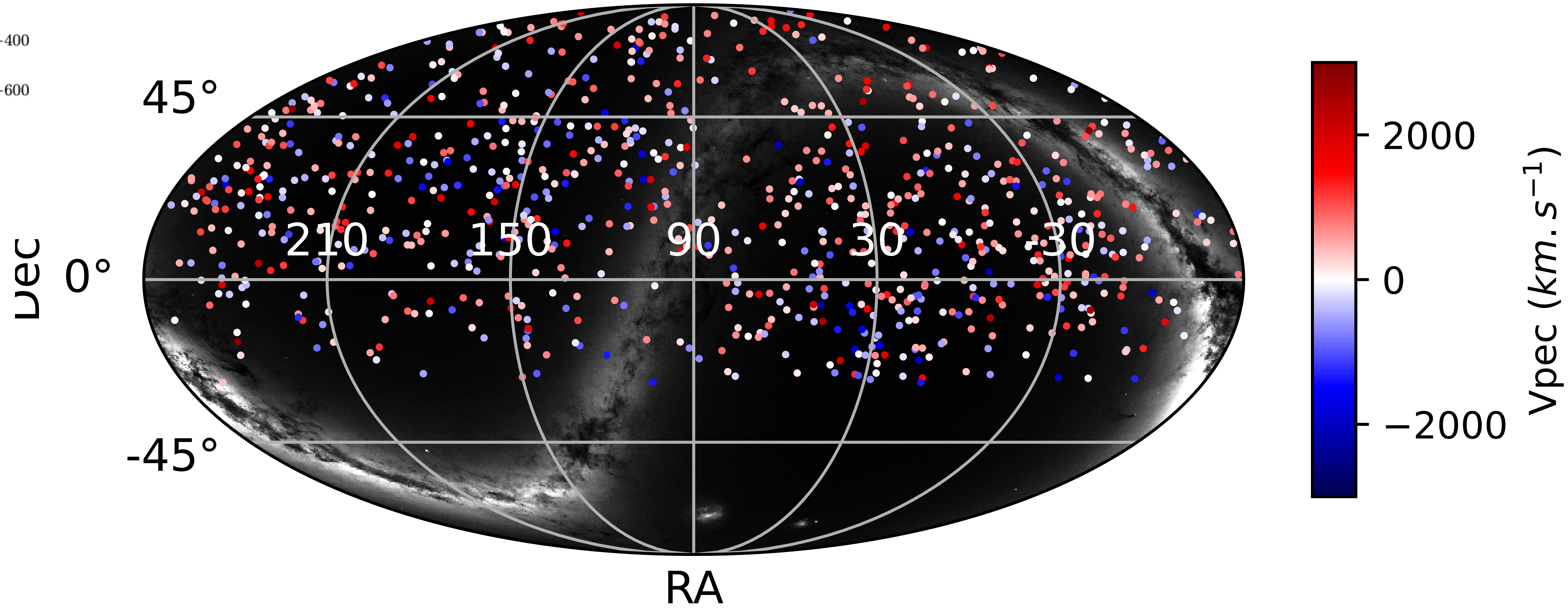


Maximum likelihood method

$$\mathscr{L}(\mathbf{p},\mathbf{p}_{\mathrm{HD}}) = (2\pi)^{-\frac{n}{2}}\,|\,C(\mathbf{p},\mathbf{p}_{\mathrm{HD}})\,|^{-\frac{1}{2}}\exp\left[-\frac{1}{2}\mathbf{v}^{\top}(\mathbf{p}_{\mathrm{HD}})C(\mathbf{p},\mathbf{p}_{\mathrm{HD}})^{-1}\mathbf{v}(\mathbf{p}_{\mathrm{HD}})\right]$$



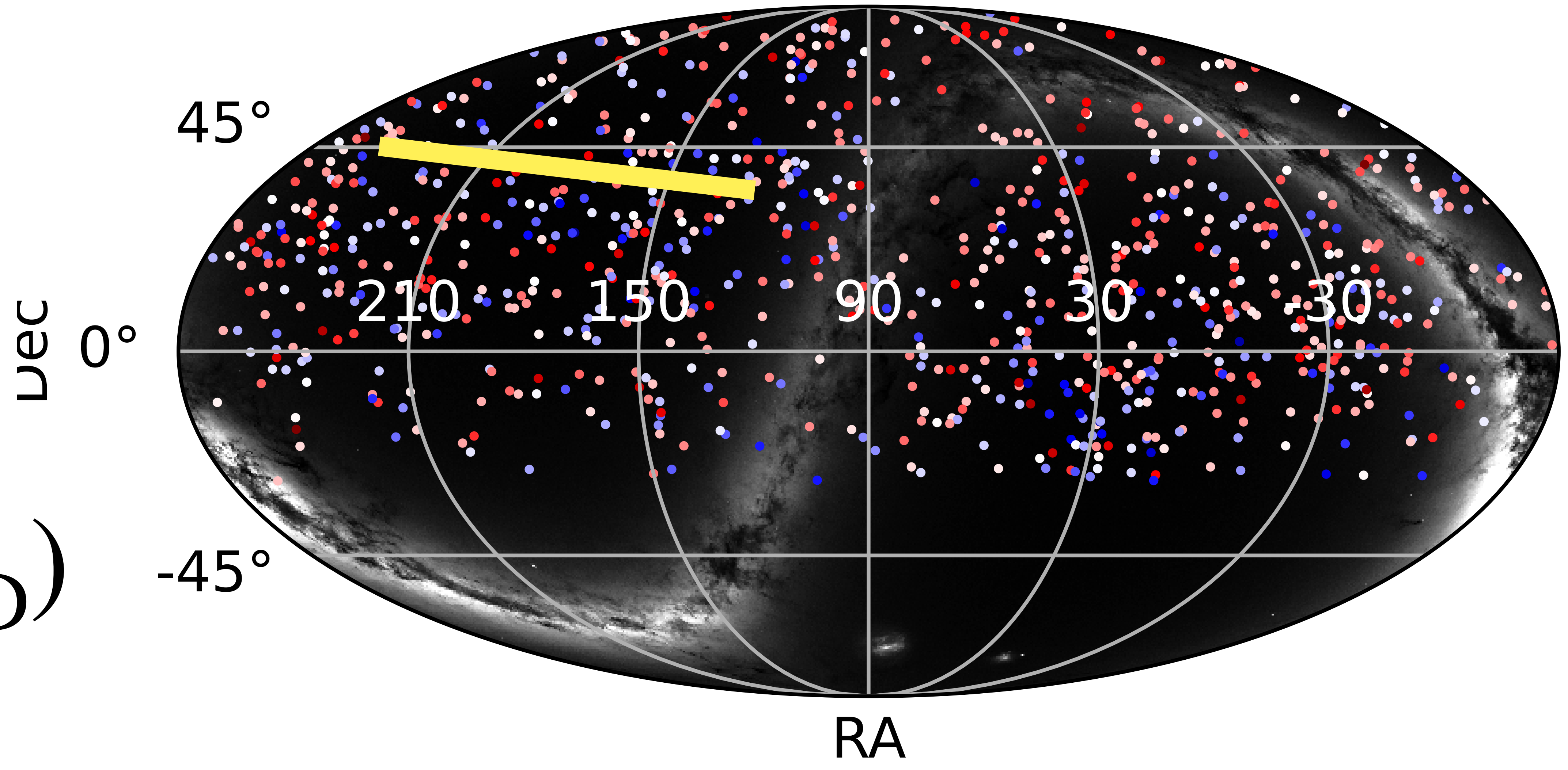
Estimated velocities



Maximum likelihood method

$$\mathscr{L}(\mathbf{p}, \mathbf{p}_{\mathrm{HD}}) = (2\pi)^{-\frac{n}{2}} |C(\mathbf{p}, \mathbf{p}_{\mathrm{HD}})|^{-\frac{1}{2}} \exp\left[-\frac{1}{2}\mathbf{v}^{\top}(\mathbf{p}_{\mathrm{HD}}) C(\mathbf{p}, \mathbf{p}_{\mathrm{HD}})^{-1} \mathbf{v}(\mathbf{p}_{\mathrm{HD}})\right]$$

Covariance: $\langle v_r(\vec{x}_i) v_r(\vec{x}_j)\rangle = C(\vec{x}_i, \vec{x}_j) \equiv C_{ij}$



$$C_{ij}(\mathbf{p}, \mathbf{p}_{\mathrm{HD}}) = C_{ij}^{vv}(f\sigma_8, \sigma_u) + \sigma_v^2 + \sigma_{\hat{v},ij}^2(\mathbf{p}_{\mathrm{HD}})$$

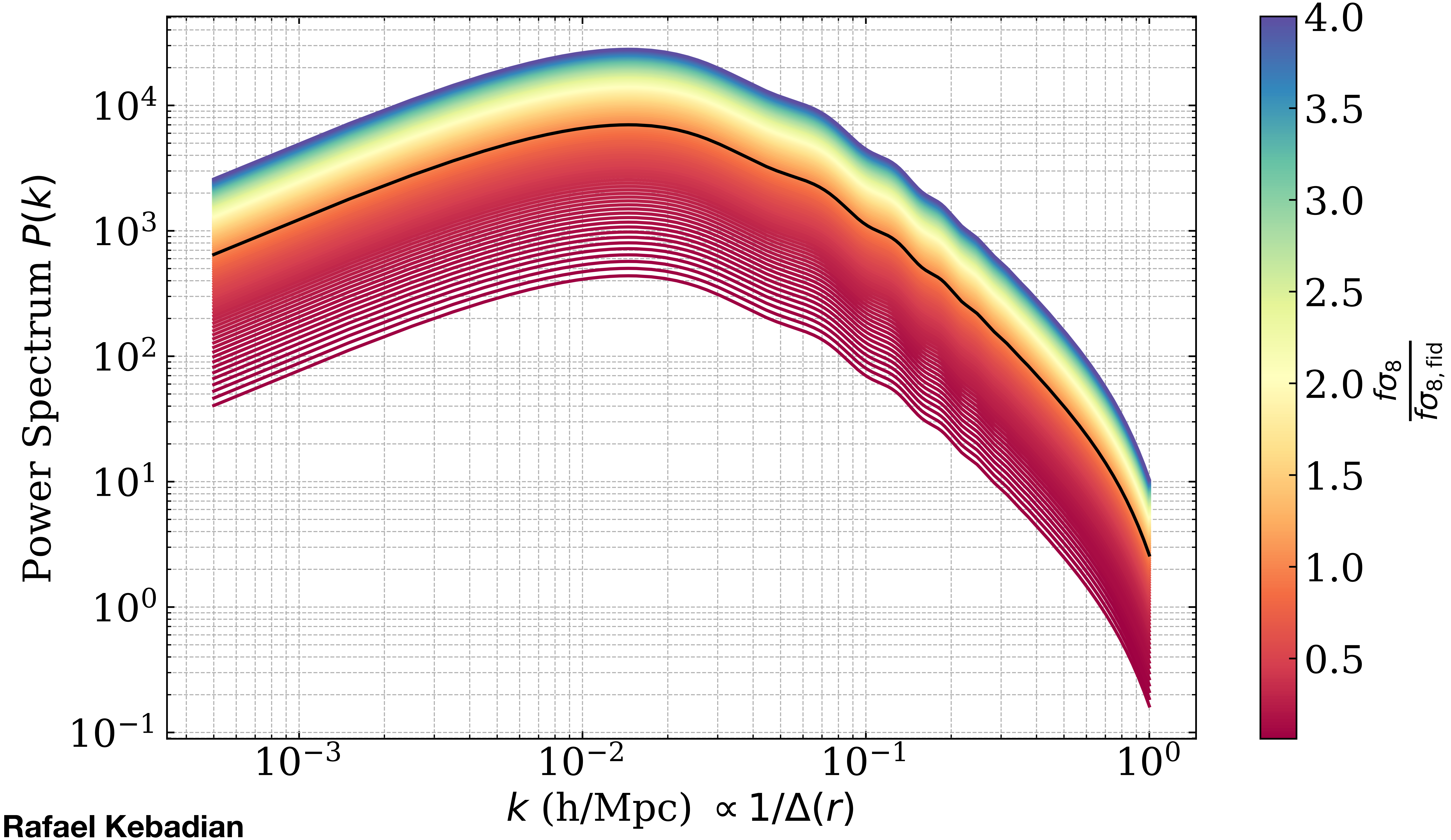
$$C_{ij}^{vv} = \frac{H_0^2 \left(f\sigma_8\right)^2}{2\pi^2 \left(f\sigma_8\right)^2_{\mathrm{fid}}} \int_0^{+\infty} f_{\mathrm{fid}}^2 P_{\theta\theta}(k) D_u^2(k) W_{ij}(k; r_i, r_j)\, \mathrm{d}k$$

Maximum likelihood method

$$C_{ij}^{vv} = \frac{H_0^2 \left(f\sigma_8\right)^2}{2\pi^2 \left(f\sigma_8\right)^2_{\mathrm{fid}}} \int_0^{+\infty} f_{\mathrm{fid}}^2 P_{\theta\theta}(k) D_u^2(k) W_{ij}(k; r_i, r_j)\, \mathrm{d}k$$

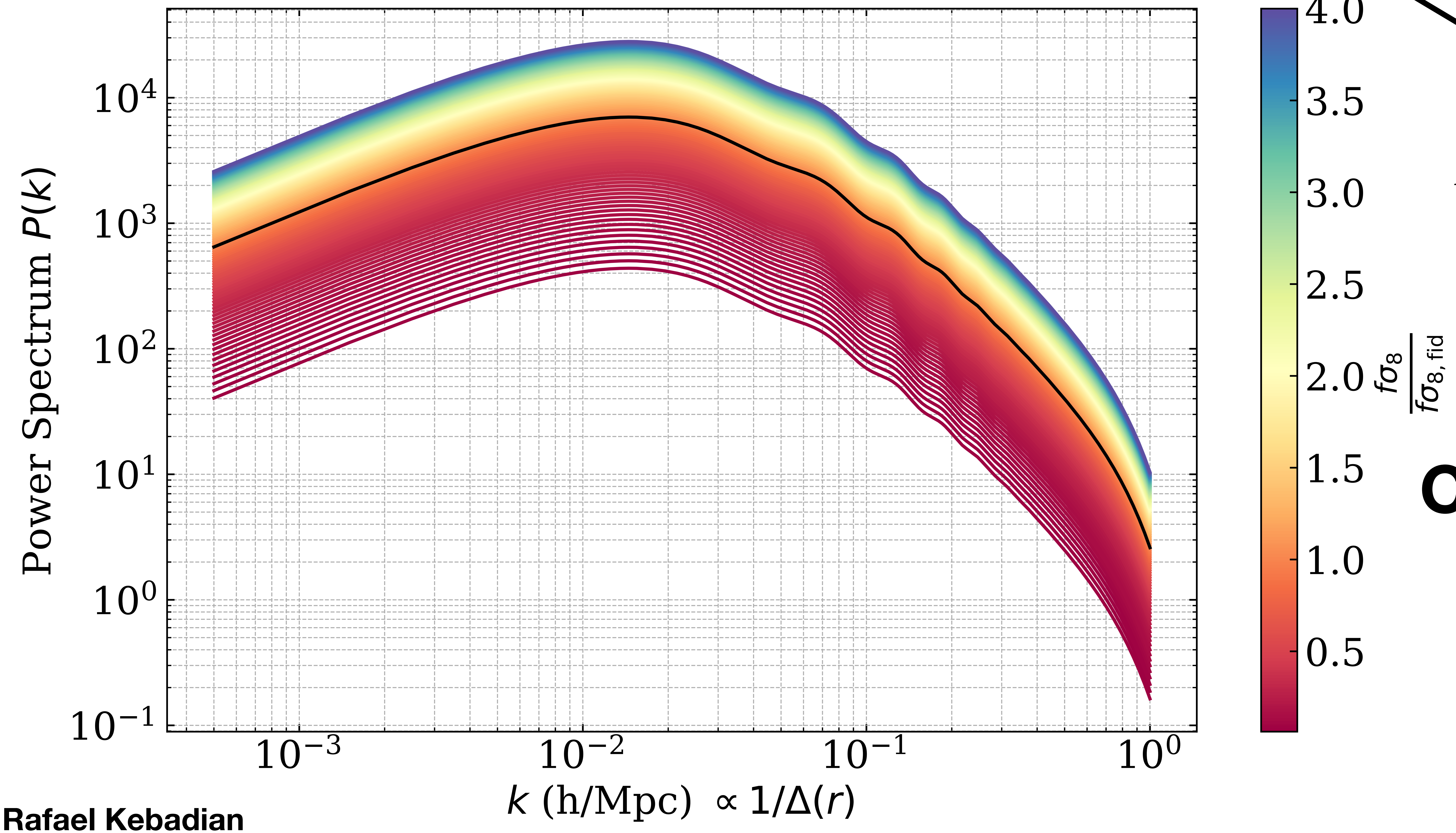
Maximum likelihood method

$$C_{ij}^{vv} = \frac{H_0^2 \left(f\sigma_8\right)^2}{2\pi^2 \left(f\sigma_8\right)^2_{\mathrm{fid}}} \int_0^{+\infty} f_{\mathrm{fid}}^2 P_{\theta\theta}(k) D_u^2(k) W_{ij}(k; r_i, r_j)\, \mathrm{d}k$$



Maximum likelihood method

$$C_{ij}^{vv} = \frac{H_0^2 \left(f\sigma_8\right)^2}{2\pi^2 \left(f\sigma_8\right)_{\text{fid}}^2} \int_0^{+\infty} f_{\text{fid}}^2 P_{\theta\theta}(k) D_u^2(k) W_{ij}(k; r_i, r_j)\, \mathrm{d}k$$

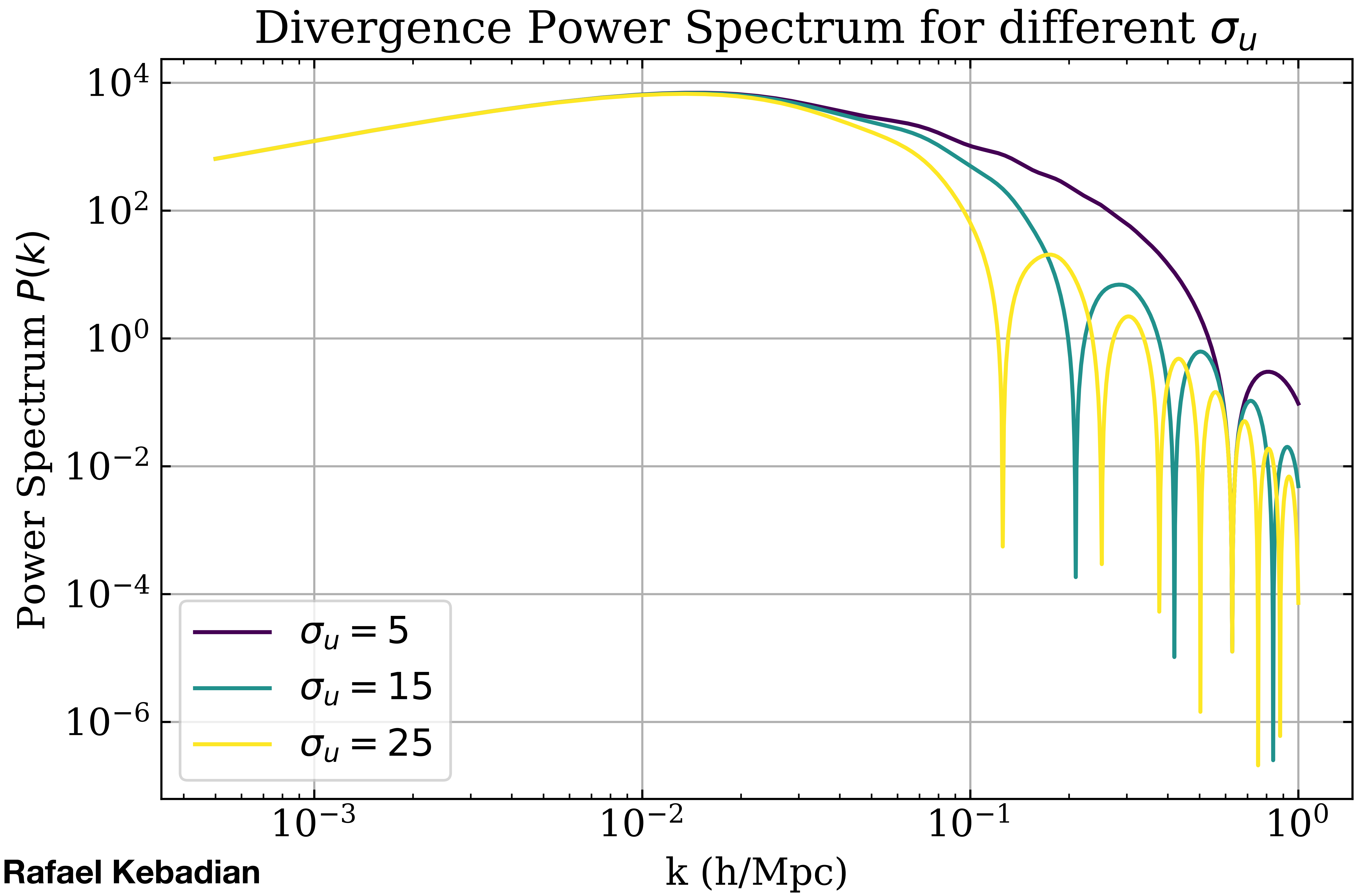


$$D_u(k, \sigma_u) = \frac{\sin(k\sigma_u)}{k\sigma_u}$$

Correction for non-linear effects

Maximum likelihood method

$$C_{ij}^{vv} = \frac{H_0^2 \left(f\sigma_8\right)^2}{2\pi^2 \left(f\sigma_8\right)^2_{\rm fid}} \int_0^{+\infty} f_{\rm fid}^2 P_{\theta\theta}(k) D_u^2(k) W_{ij}(k; r_i, r_j)\, \mathrm{d}k$$

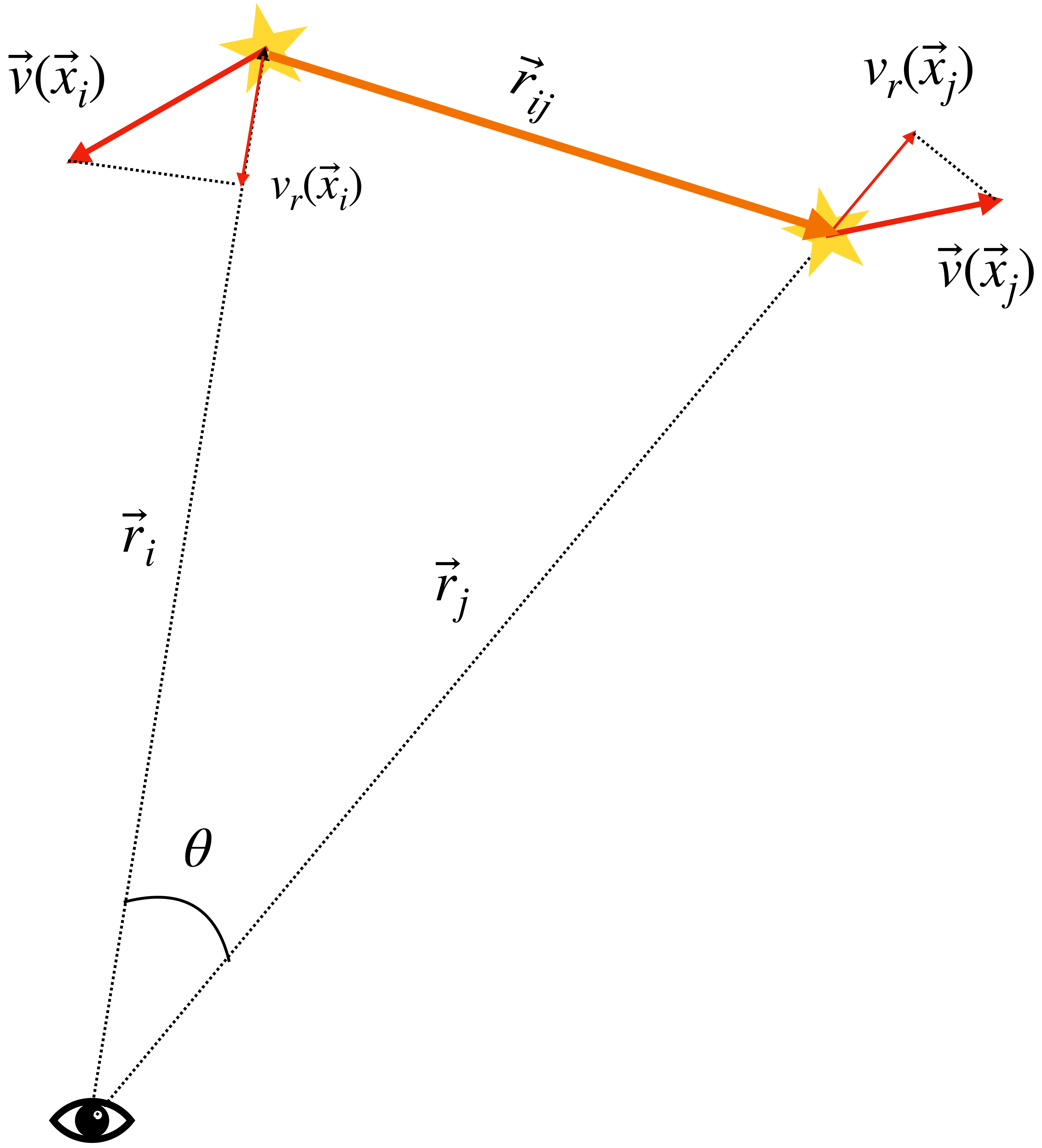


$$D_u(k, \sigma_u) = \frac{\sin(k\sigma_u)}{k\sigma_u}$$

Correction for non-linear effects

Maximum likelihood method

$$C_{ij}^{vv} = \frac{H_0^2 \left(f\sigma_8\right)^2}{2\pi^2 \left(f\sigma_8\right)_{\rm fid}^2} \int_0^{+\infty} f_{\rm fid}^2 P_{\theta\theta}(k) D_u^2(k) W_{ij}(k; r_i, r_j)\, \mathrm{d}k$$



Take into account the "geometry" of the sample

The pipeline

Inputs

Table of **SN parameters** (x0, x1, c) and their **covariance matrix**

Options

Fit the Hubble Diagram and cosmology in two step

Fit the HD with a likelihood and then fix $\alpha, \beta, \sigma_{int}, M_0$ for the $f\sigma_8, \sigma_v$ fit

Fit jointly the Hubble Diagram and $f\sigma_8$

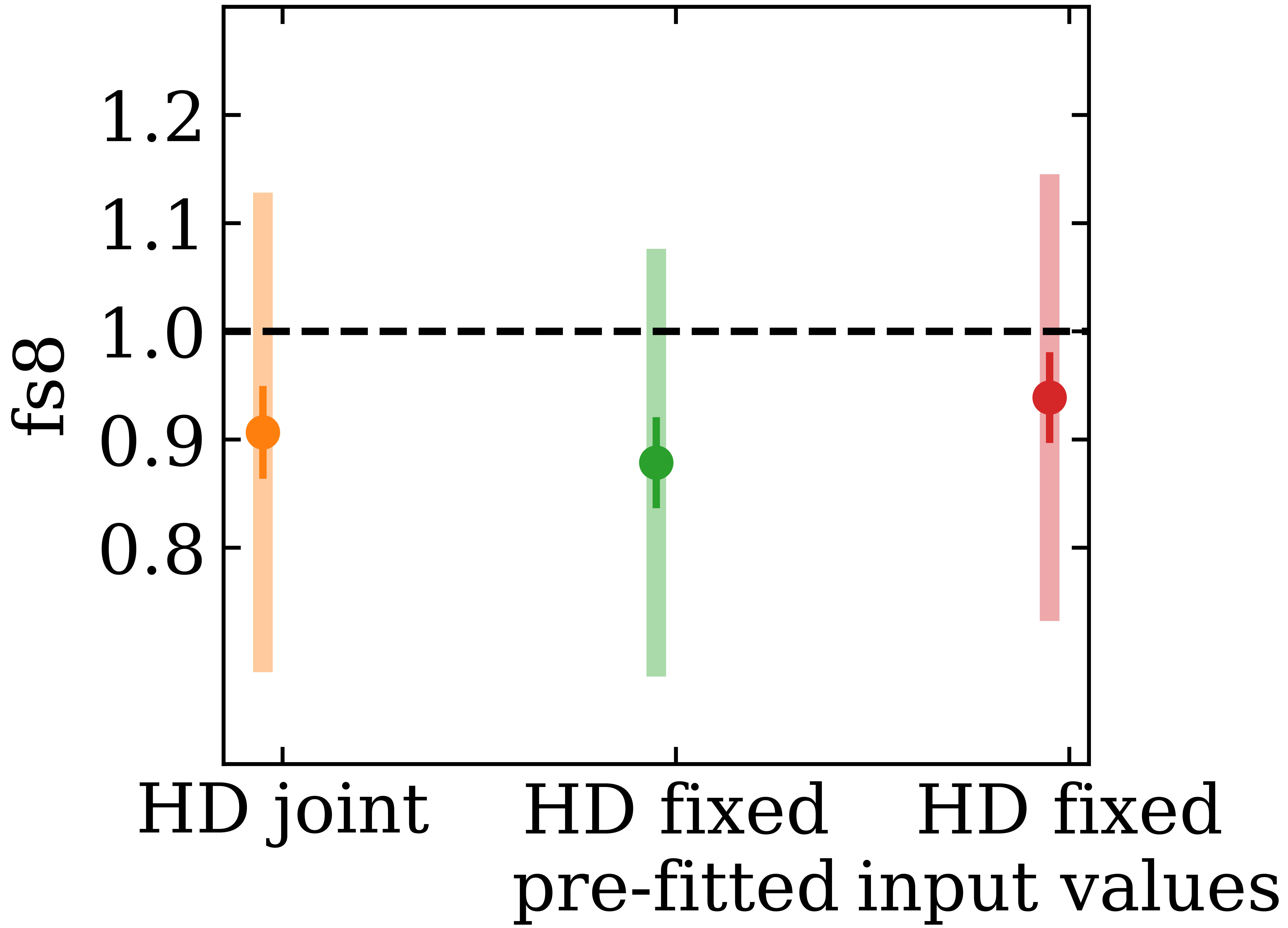
Fit jointly $\alpha, \beta, \sigma_{int}, M_0$ and $f\sigma_8, \sigma_v$

Outputs

$\alpha, \beta, \sigma_{int}, M_0, f\sigma_8, \sigma_v$

and their **errors**

The pipeline



Conditions

- **No σ_u fit**
- Old DR2 mocks
- BTS selection function

The pipeline

To do (for now) :

- Add the **covariance between each SN** from NaCl
- Add the σ_u fit
- MCMC fit option
- Everything is already in FLIP

Any ideas ?

What's next ?

- Include 3D simulations to the DCs
- Check systematics :
  - Selection function
  - Tracer velocity bias (A + B model)
  - Color dependent scattering
  - Ubercal residuals
  - Ideas ?

- NaCl training and effects on $f\sigma_8$
- Edriss ?

Thanks for your attention

Preliminary

Testing the impact of a mis-calibration.
First approach: add delta_mag directly to m_b
More realistically we could do this for each band and change LC's and rerun SALT/nacl