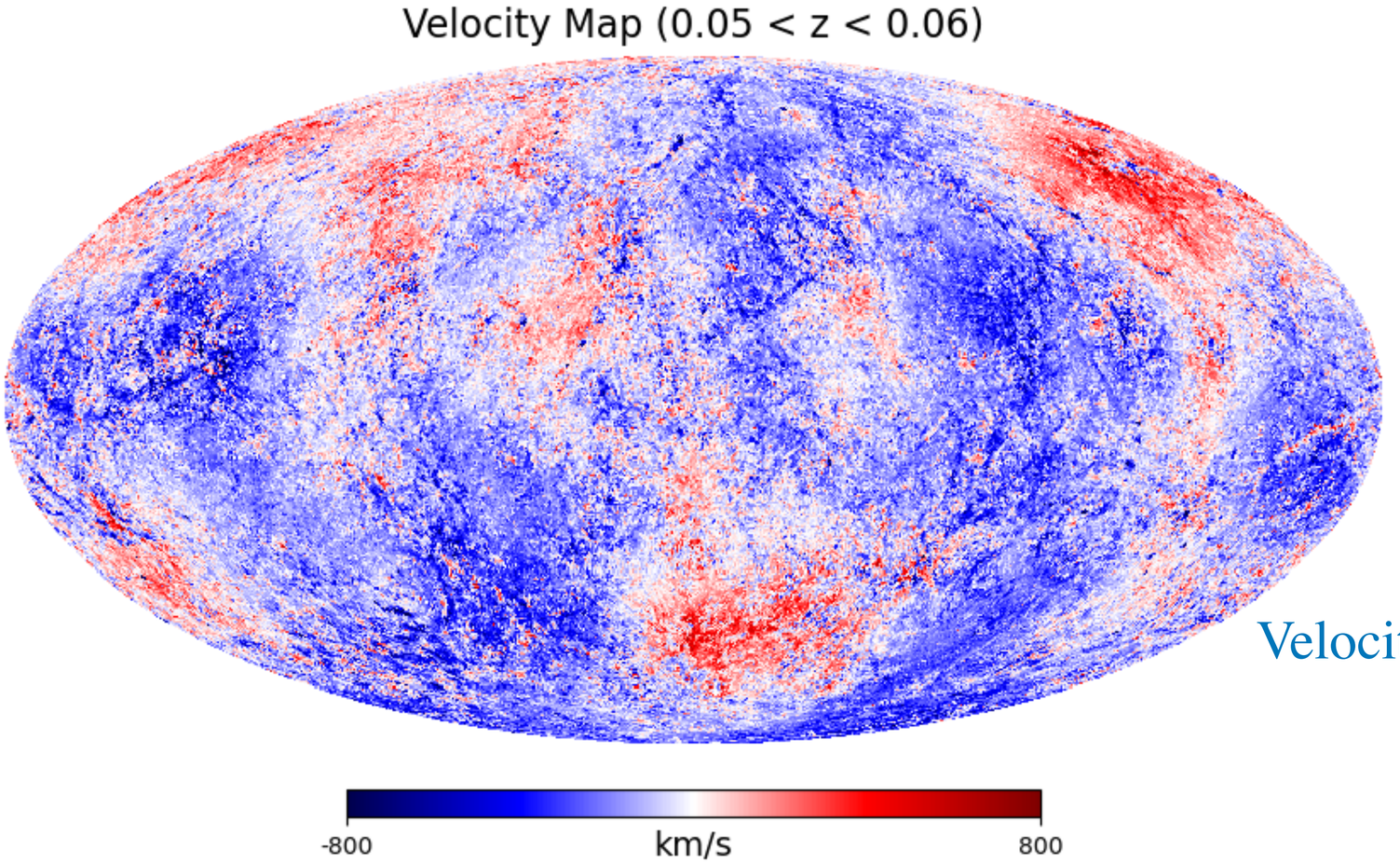
$f\sigma_8$ with SNIa from the ZTF DR2.5 Pipeline status

Rafael Kebadian and the CPPM team - LPNHE 2026

$f\sigma_8$



Growth rate of linear perturbations

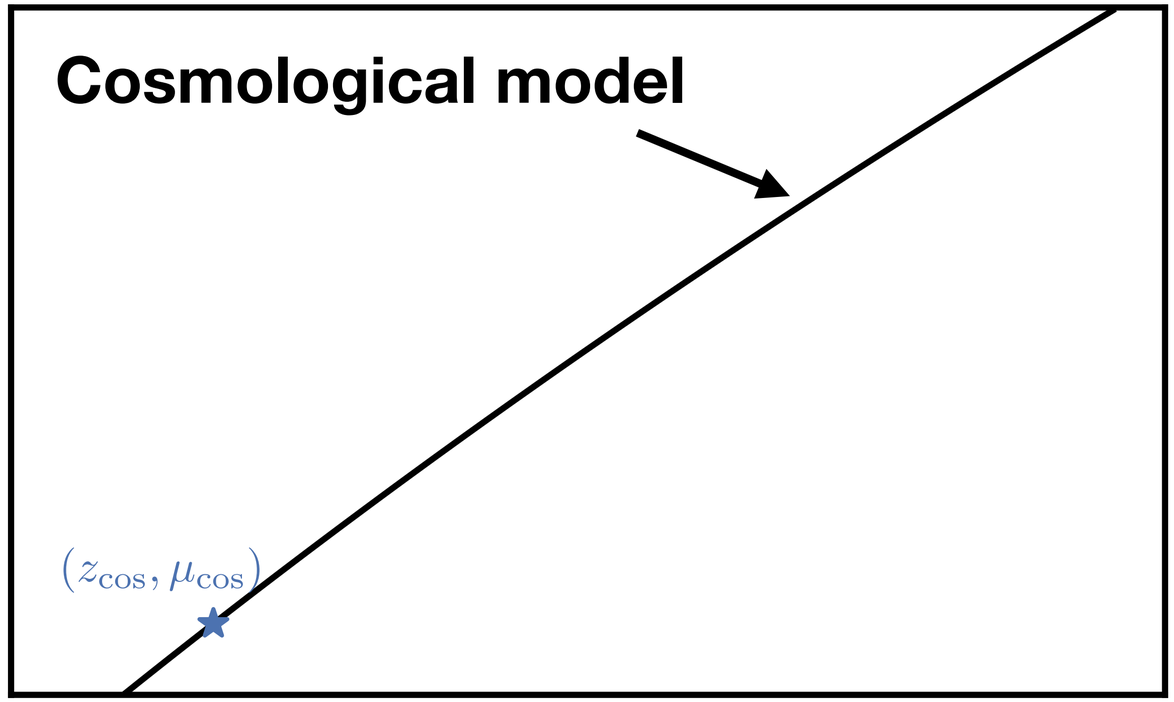
$$\nabla \cdot \vec{v}(\vec{r}) \propto f\sigma_8$$

Velocity field

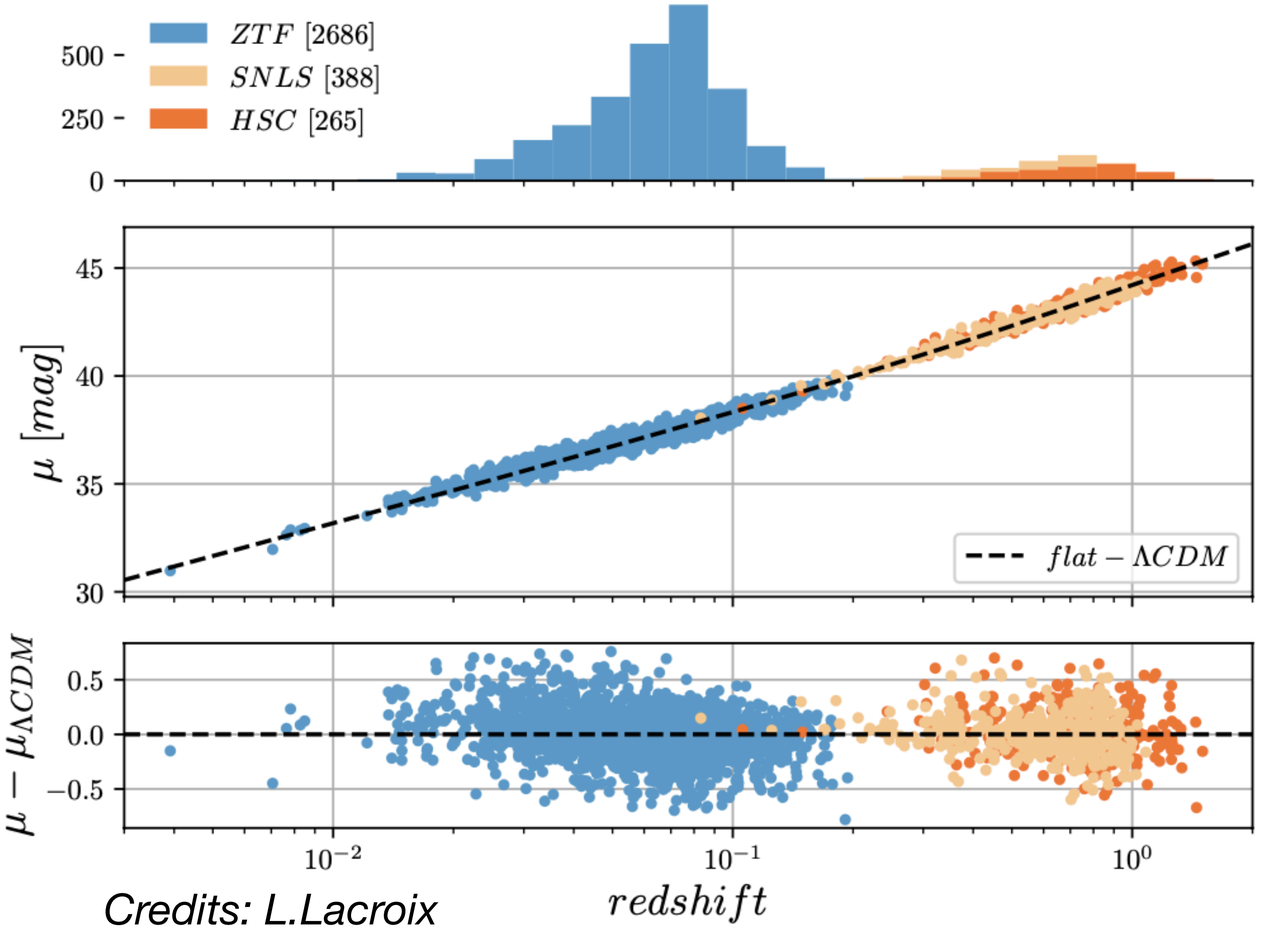
Amplitude of the matter fluctuations

Peculiar velocities

$$(1 + z_{obs}) = (1 + z_{cos})(1 + \frac{v_p}{c})$$



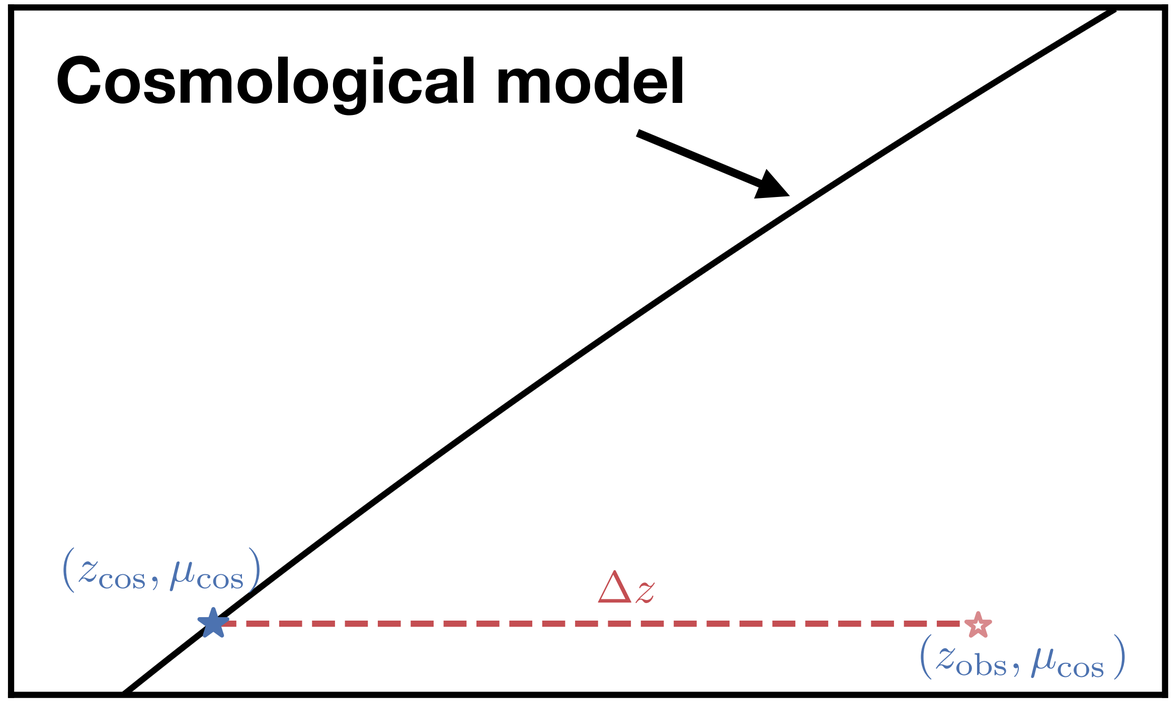
Credits: B.Carreres



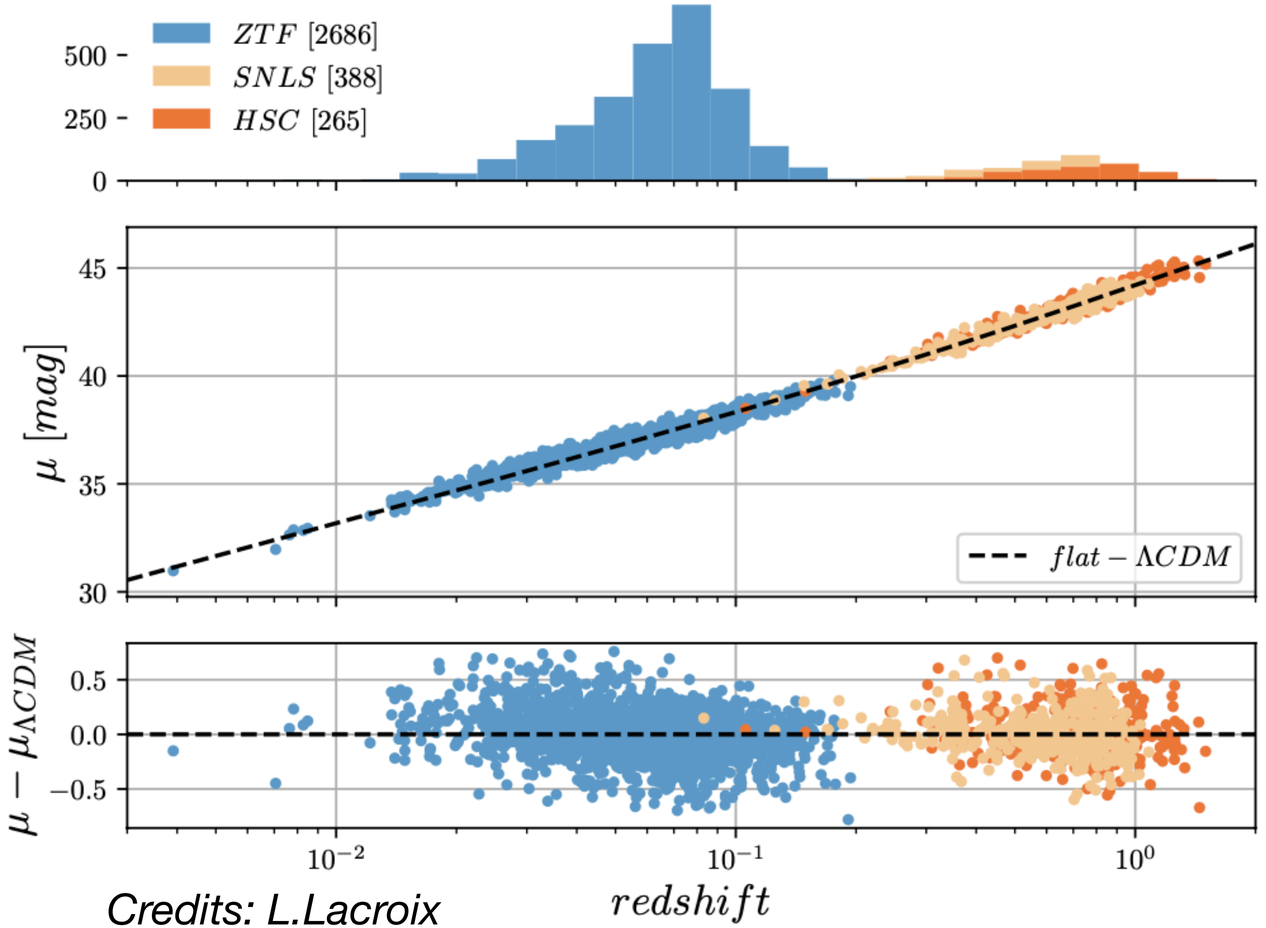
Credits: L.Lacroix

Peculiar velocities

$$(1 + z_{obs}) = (1 + z_{cos})(1 + \frac{v_p}{c})$$



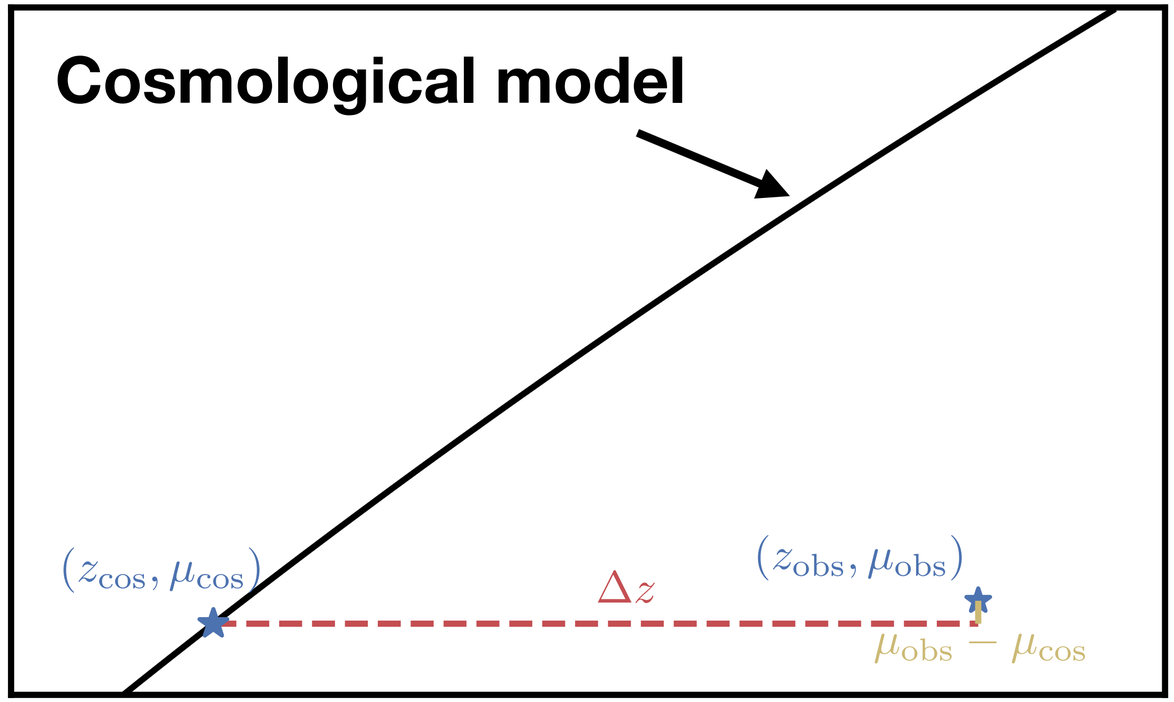
Credits: B.Carreres



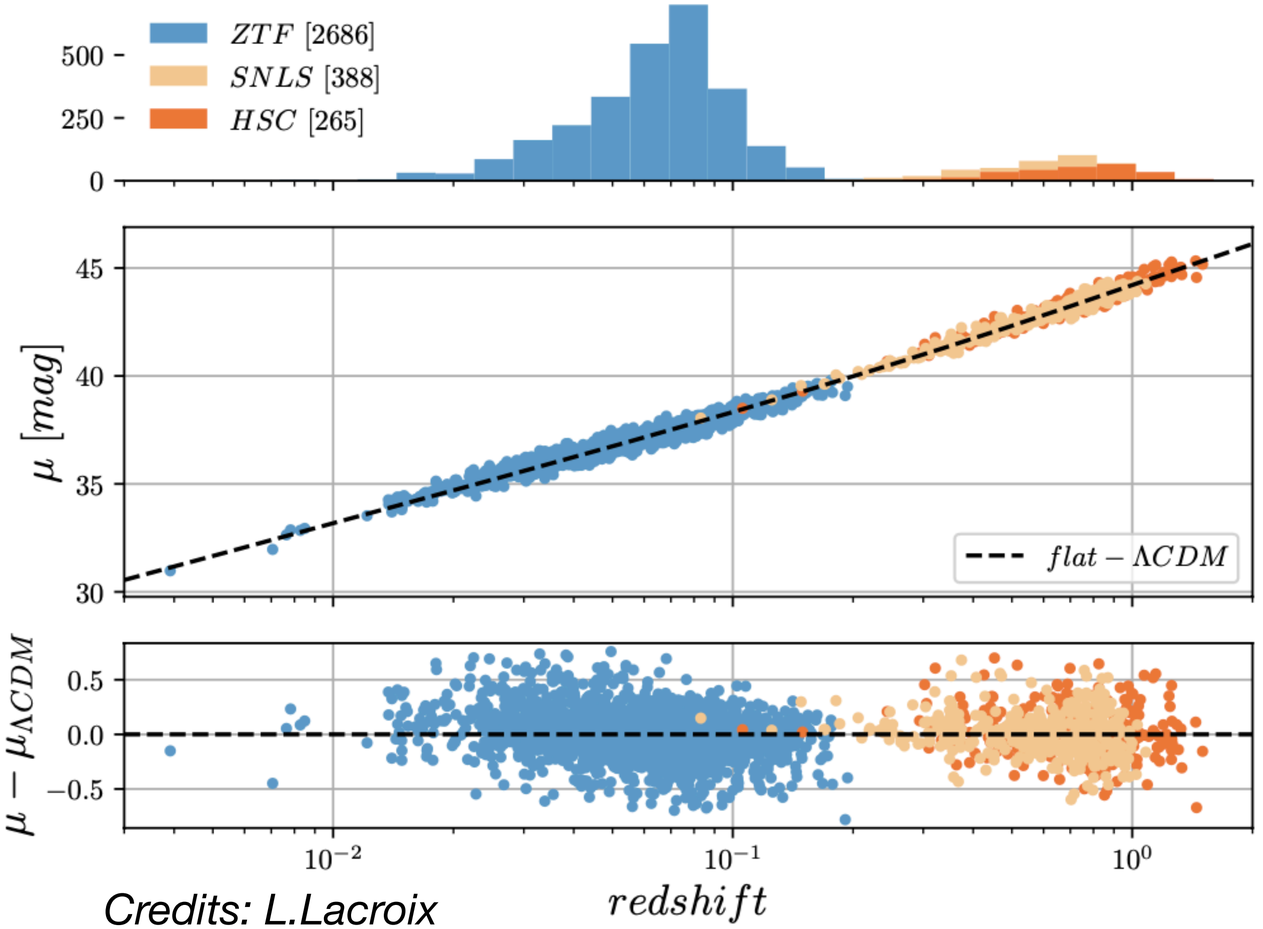
Credits: L.Lacroix

Peculiar velocities

$$(1 + z_{obs}) = (1 + z_{cos})(1 + \frac{v_p}{c})$$



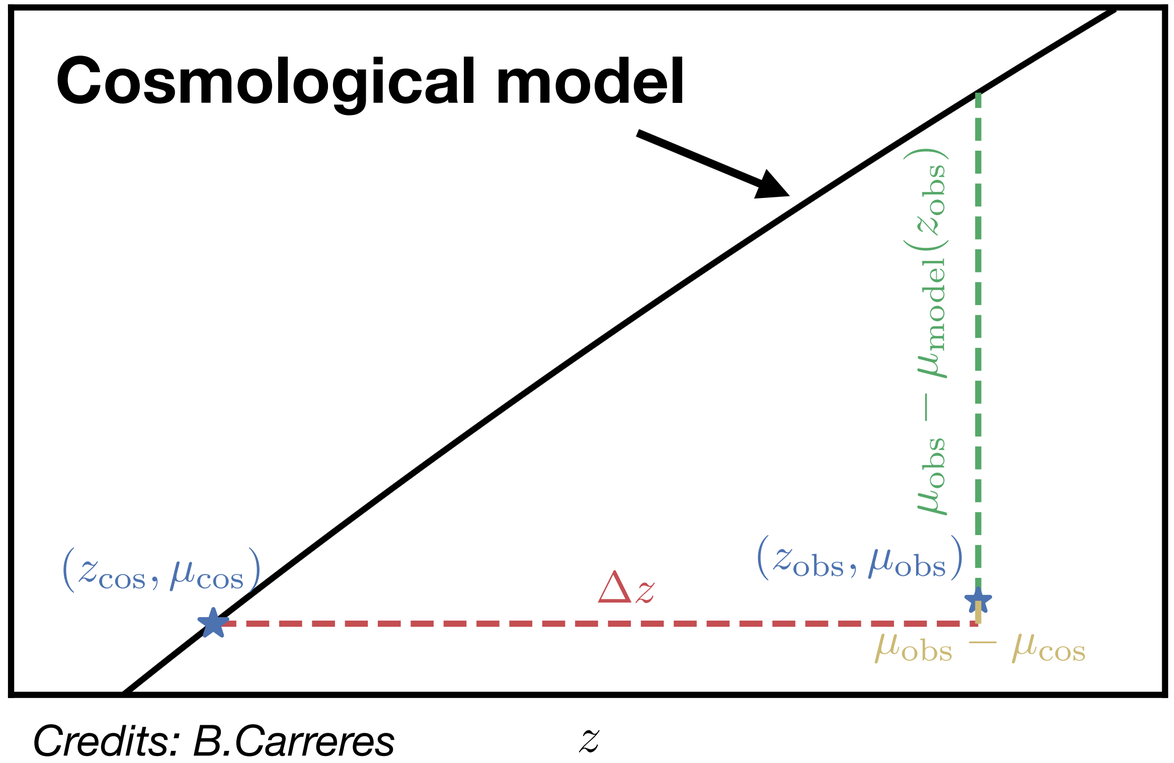
Credits: B.Carreres



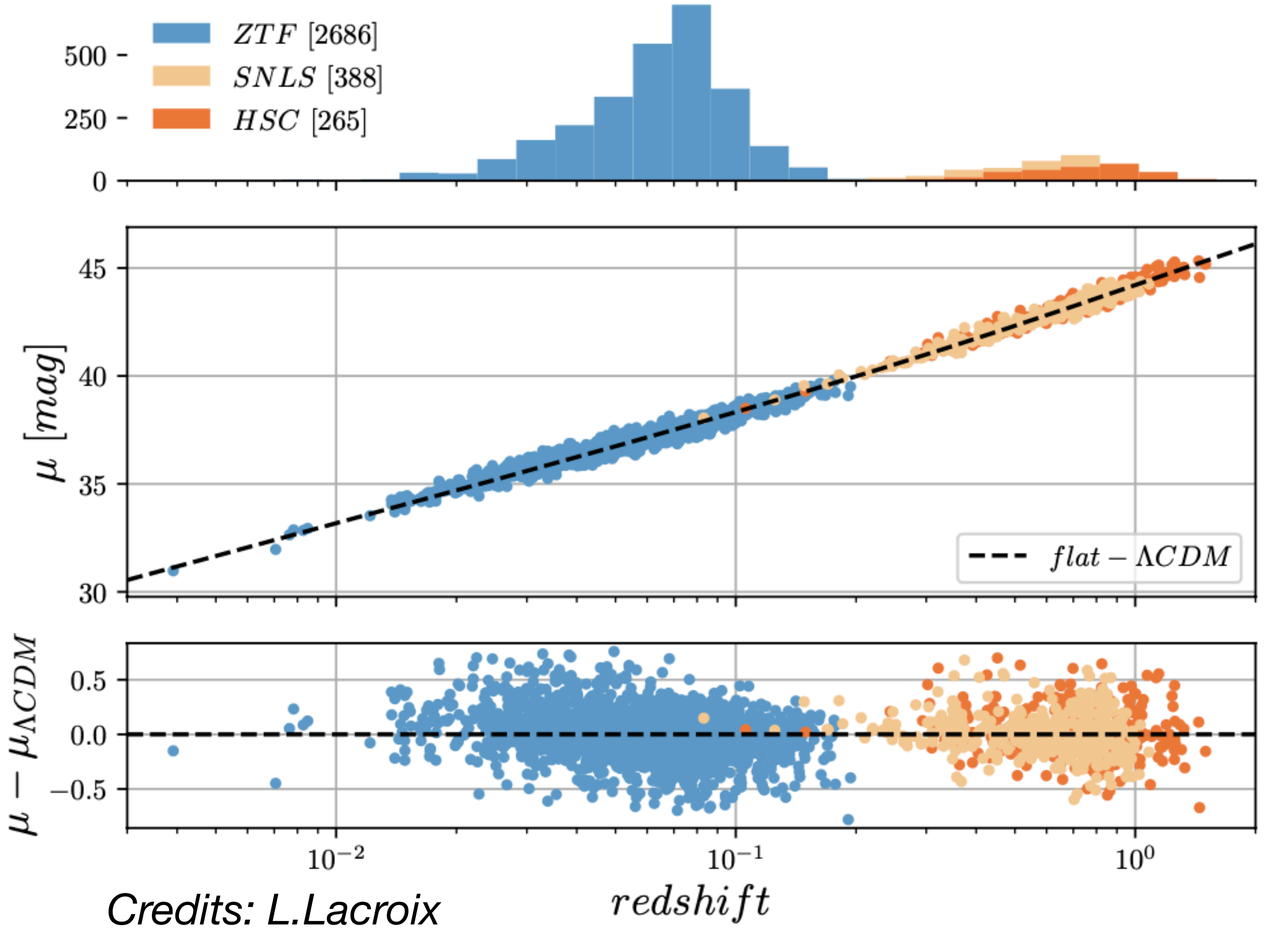
Credits: L.Lacroix

Peculiar velocities

$$(1 + z_{obs}) = (1 + z_{cos})(1 + \frac{v_p}{c})$$



Credits: B.Carreres



Credits: L.Lacroix

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

$f\sigma_8$ likelihood

$$\mathscr{L}(f\sigma_8, \Theta, \Theta_{\rm HD}) = (2\pi)^{-n/2} \, | \, C(f\sigma_8, \Theta, \Theta_{\rm HD}) \, |^{-1/2}$$
$$\times \exp \left[-\frac{1}{2} \, \mathbf{v}^{\rm T}(\Theta_{\rm HD}) \, C^{-1}(f\sigma_8, \Theta, \Theta_{\rm HD}) \, \mathbf{v}(\Theta_{\rm HD}) \right]$$

$$\Theta = \sigma_u, \sigma_v$$

Damping term
RSD effect

Non-linear
motions

$$\Theta_{HD} = \alpha, \beta, \sigma_{int}, M_0$$

Hubble Diagram parameters

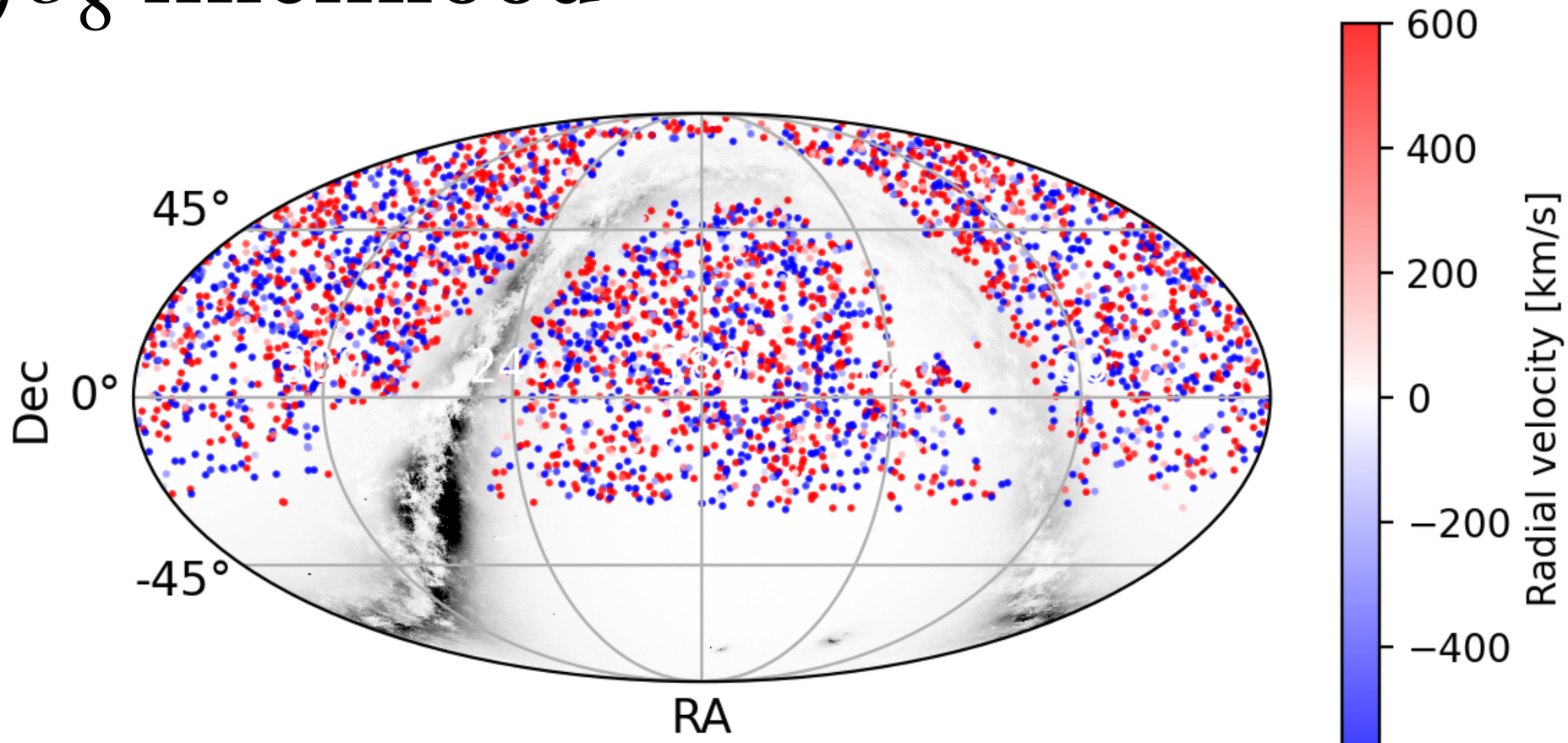
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$$\times \exp \left[-\frac{1}{2} \, \mathbf{v}^{\rm T}(\Theta_{\rm HD}) \, C^{-1}(f\sigma_8, \Theta, \Theta_{\rm HD}) \, \mathbf{v}(\Theta_{\rm HD}) \right]$$

$$C_{ij}(\Theta, \Theta_{\rm HD}) = C_{ij}^{vv}(f\sigma_8, \sigma_u) + \sigma_v^2 + \sigma_{\hat{v},ij}^2(\Theta_{\rm HD})$$

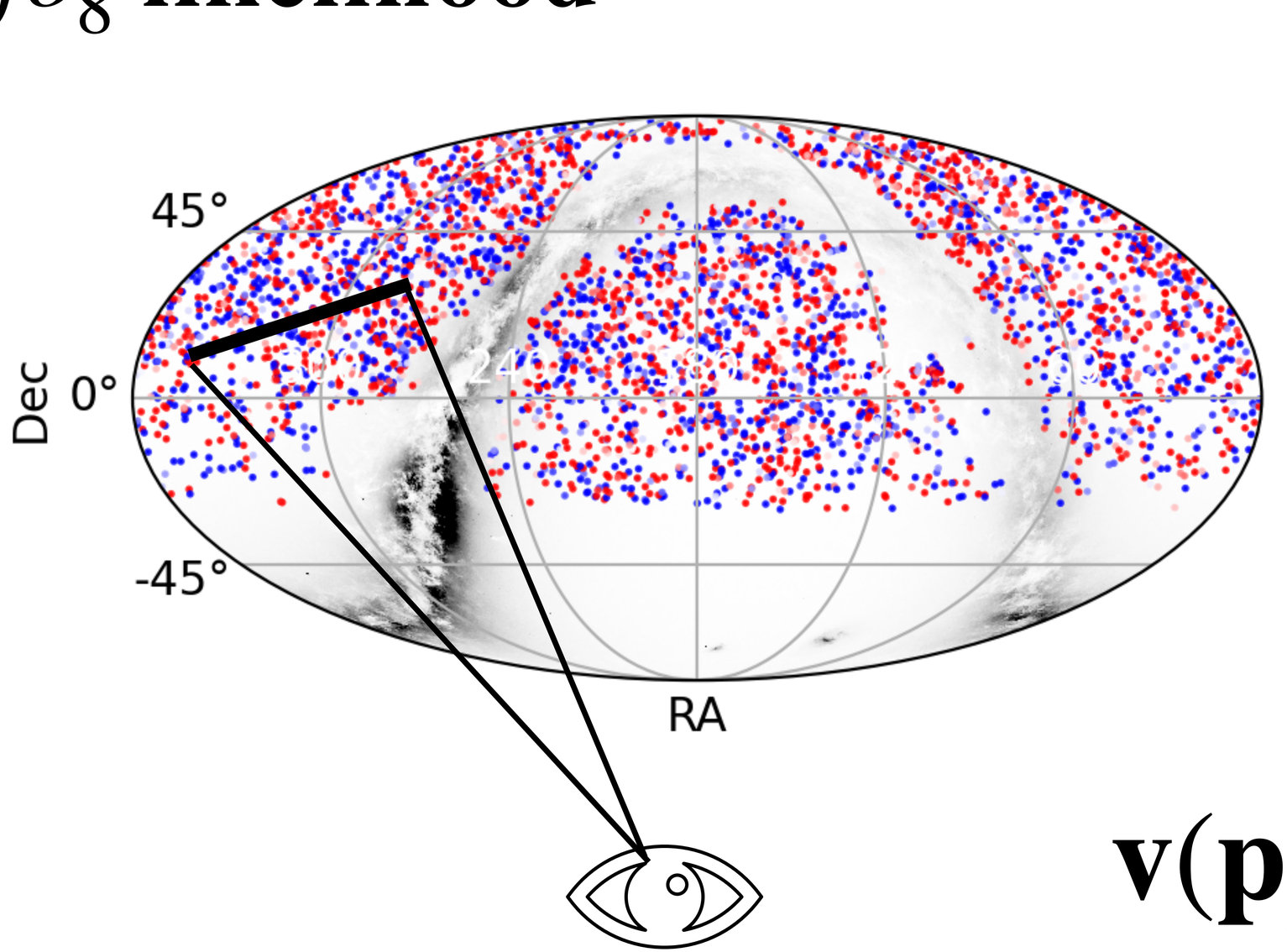
$$C_{ij}^{vv} = \frac{H_0^2 \left(f\sigma_8\right)^2}{2\pi^2 \left(f\sigma_8\right)_{\rm fid}^2} \int_0^{+\infty} f_{\rm fid}^2 P_{\theta\theta}(k) D_u^2(k) W_{ij}(k; r_i, r_j) \, {\rm d}k$$

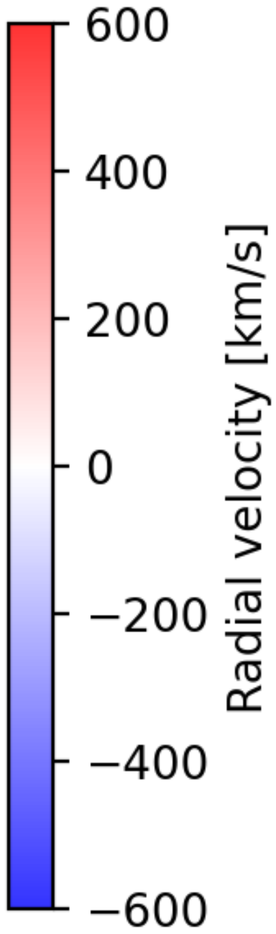
$f\sigma_8$ likelihood



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

$f\sigma_8$ likelihood





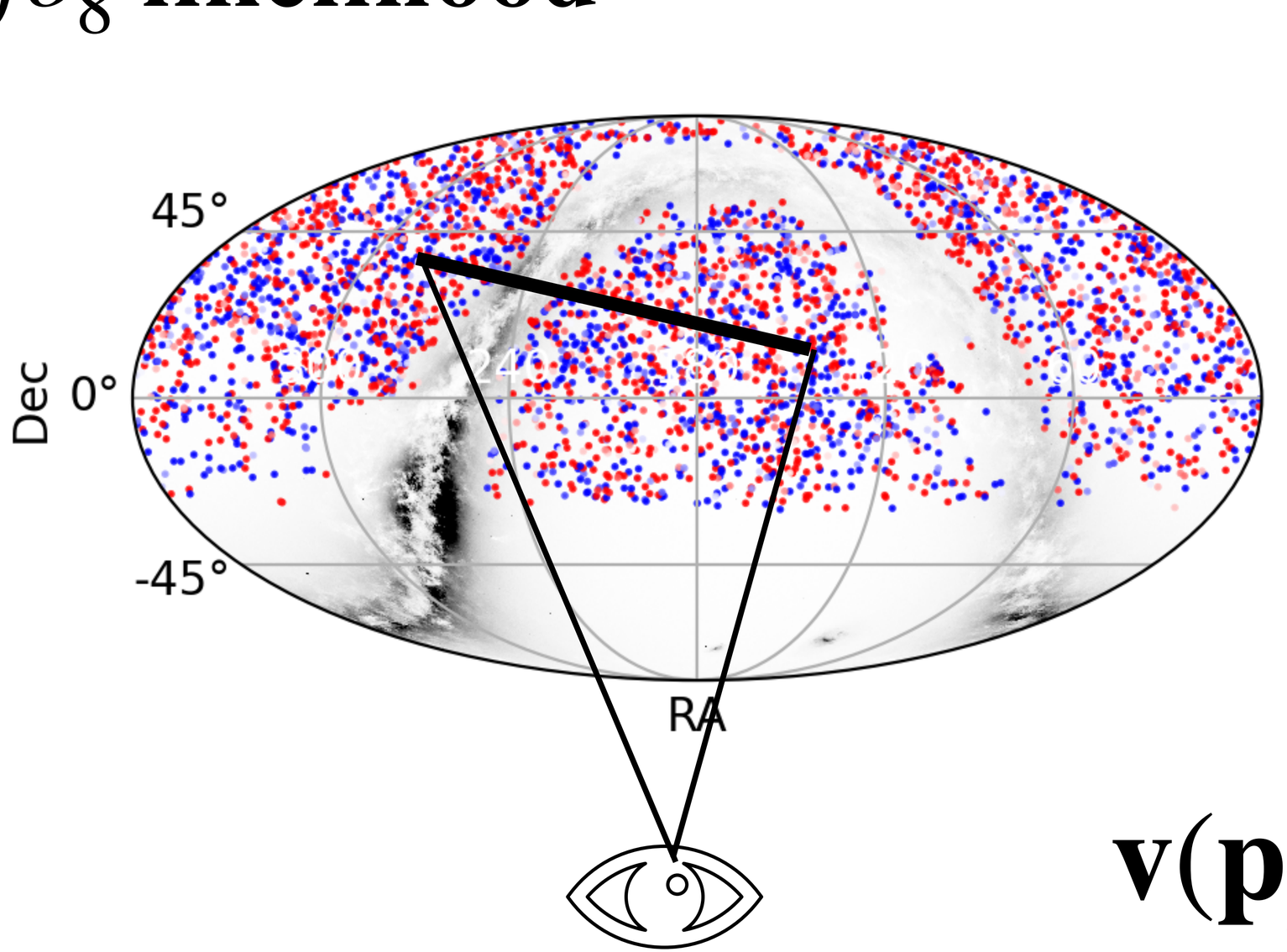


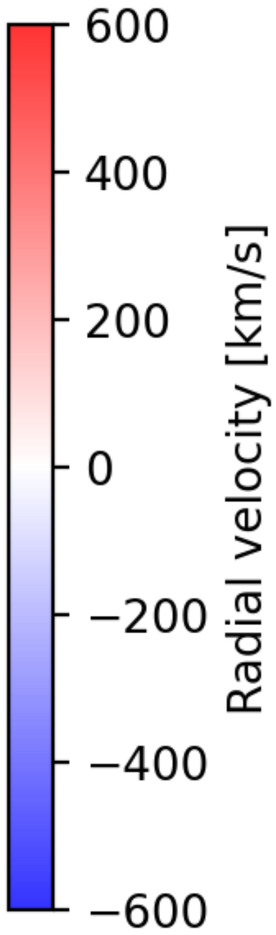
Developped by Corentin Ravoux, Bastien Carreres, Damiano Rosselli

Theoretical velocity covariance

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

$f\sigma_8$ likelihood





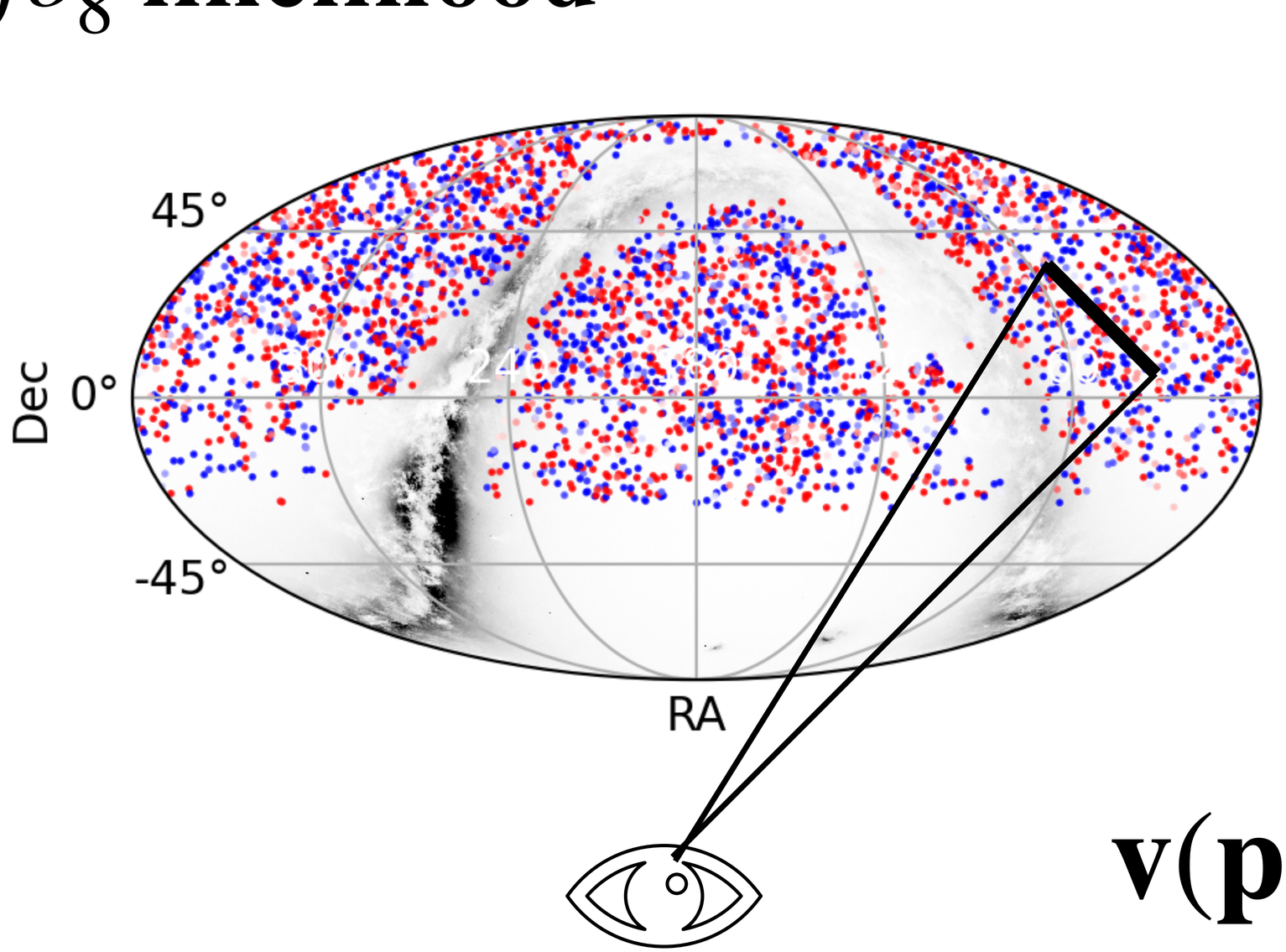


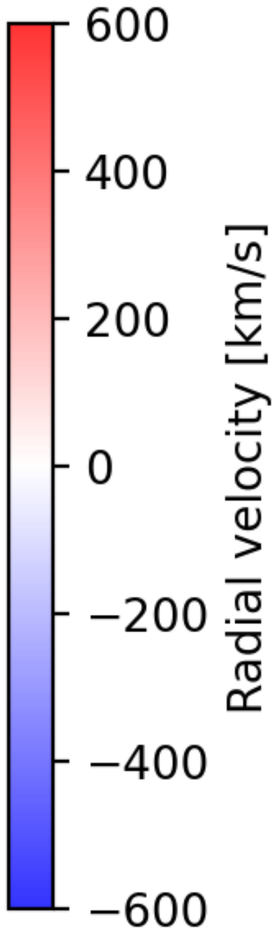
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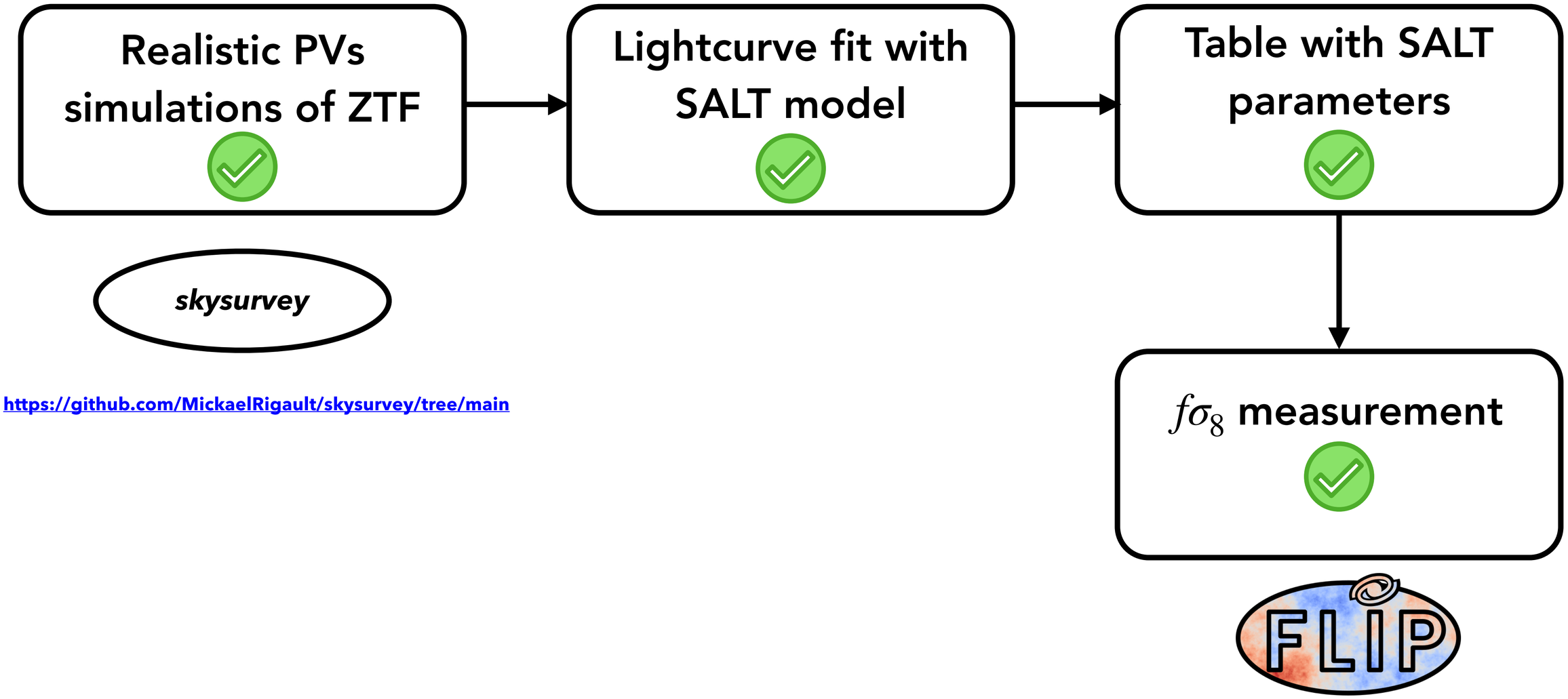


Developped by Corentin Ravoux, Bastien Carreres, Damiano Rosselli

Theoretical velocity covariance

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

Status of the pipeline



https://github.com/MickaelRigault/skysurvey/tree/main

https://github.com/corentinravoux/flip/tree/main

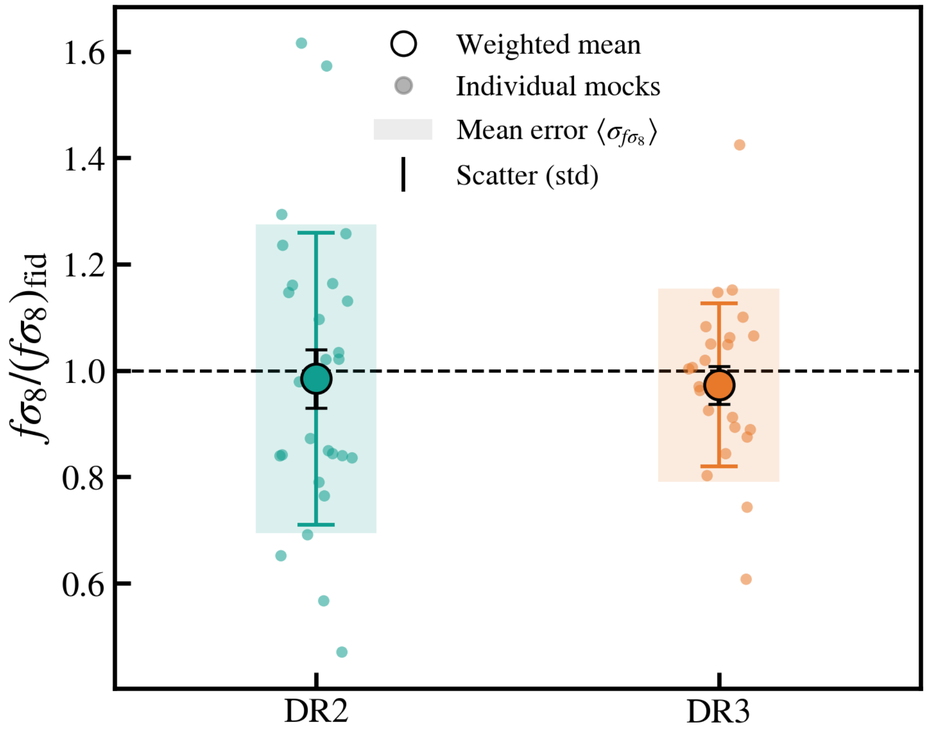
Status of the pipeline

Realistic PVs simulations of ZTF

Lightcurve fit with SALT model

Table with SALT parameters

$f\sigma_8$ measurement



Status of the pipeline

Already ready to :

- From a **table with SALT parameters** and their errors we can **measure** $f\sigma_8$ on simulations.
- Including a **non-diagonal matrix** is ready (NaCl).
- **Anisotropic systematic analysis**

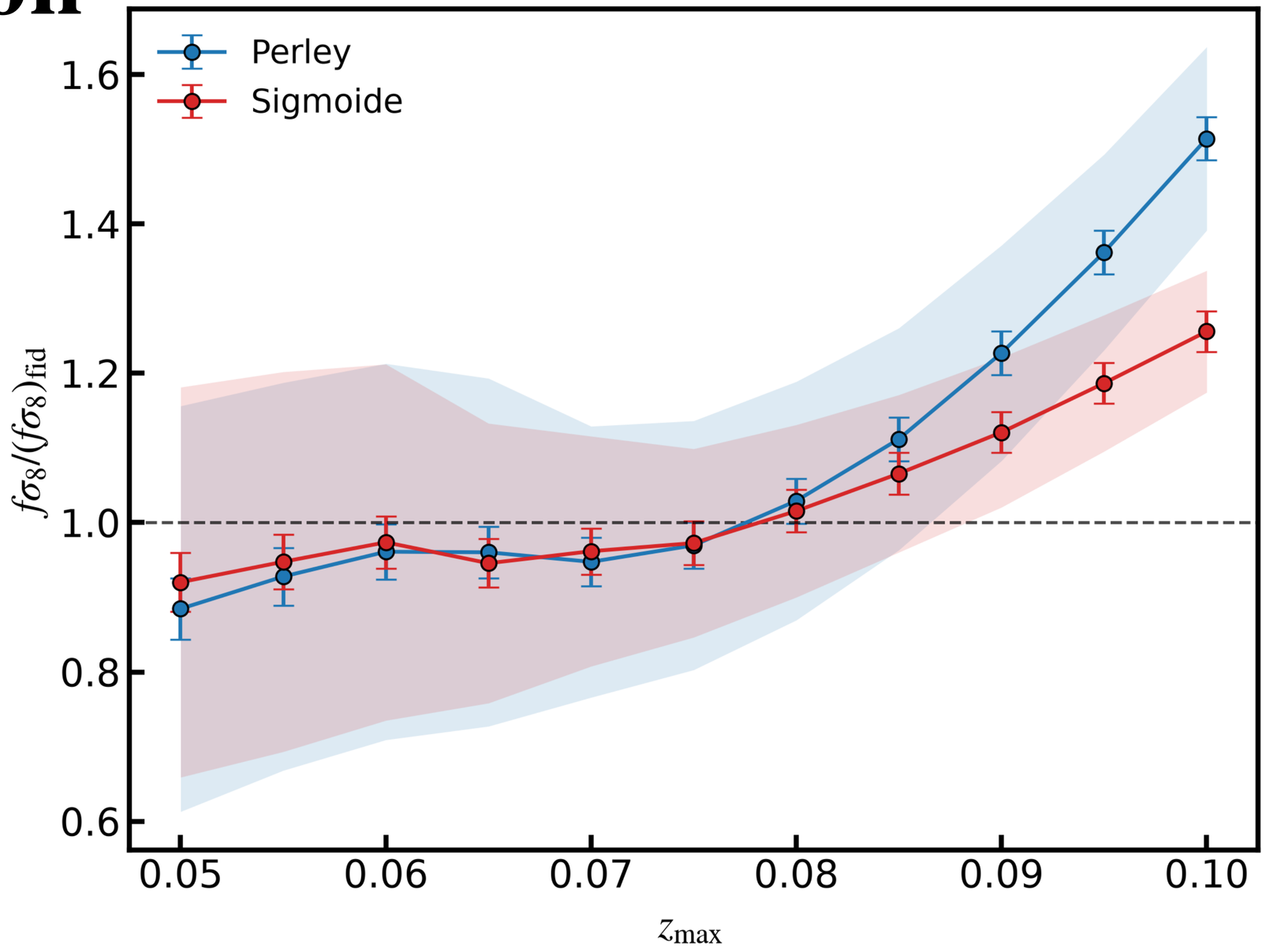
To do :

- Test the effect of the inclusion of **redshift uncertainties**
- Add the **mass step** (not simulated yet but already included in FLIP)
- Test the $f\sigma_8$ **blinding** on $w_0 w_a$ analysis
- Test the pipeline on **real blinded data**.

Selection function

Perley : selection function on observed magnitude

Sigmoide : selection function on the simulated magnitude

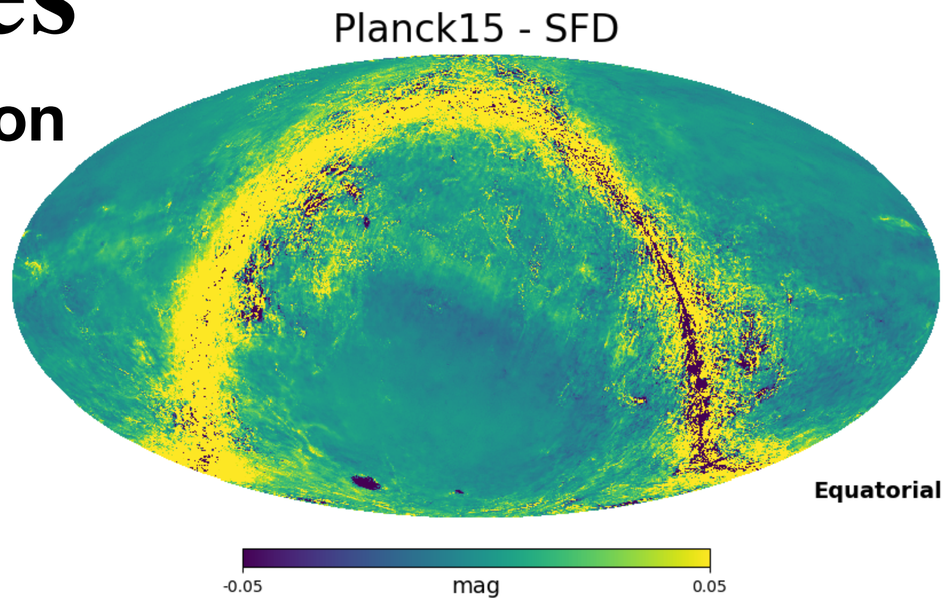


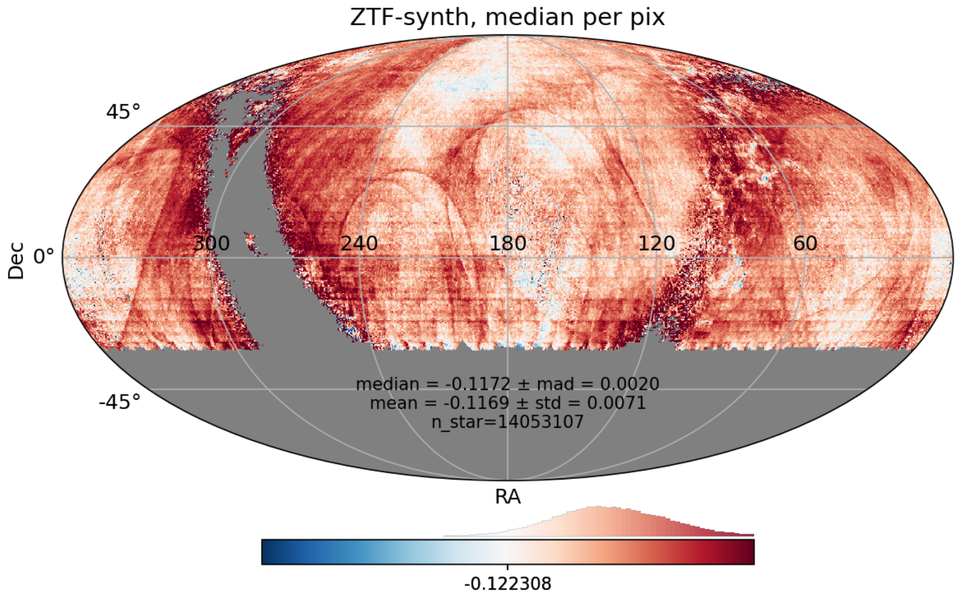
Anisotropic systematic studies

Baseline = SFD + F99(RV = 3.1) + perfect calibration

Systematics tested :

- **Milky way maps**
  - Scaling the SFD dust map (+-5%)
  - Planck dust map
- **Milky way color law**
  - CCM89
  - Changing RV value
- **Calibration**
  - Ubercal residuals
  - Filters



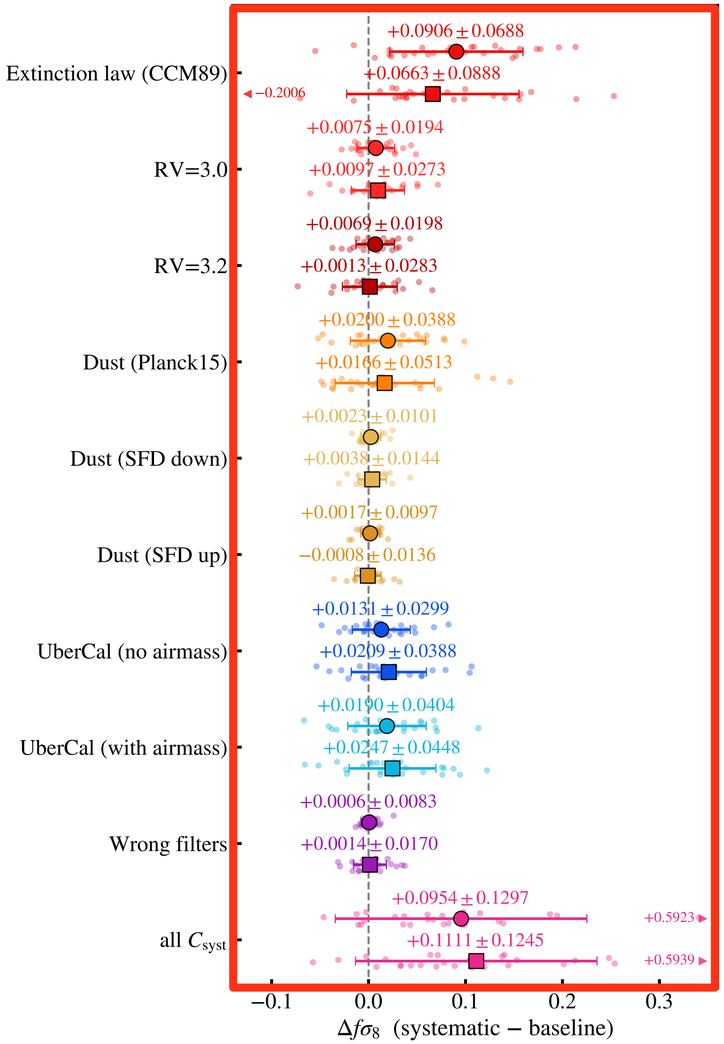


Anisotropic systematic studies

$$\mathscr{L}(f\sigma_8, \Theta, \Theta_{\rm HD}) \propto \exp\left[-\frac{1}{2}\,\mathbf{v}^{\rm T}(\Theta_{\rm HD})\,C^{-1}(f\sigma_8, \Theta, \Theta_{\rm HD})\,\mathbf{v}(\Theta_{\rm HD})\right]$$

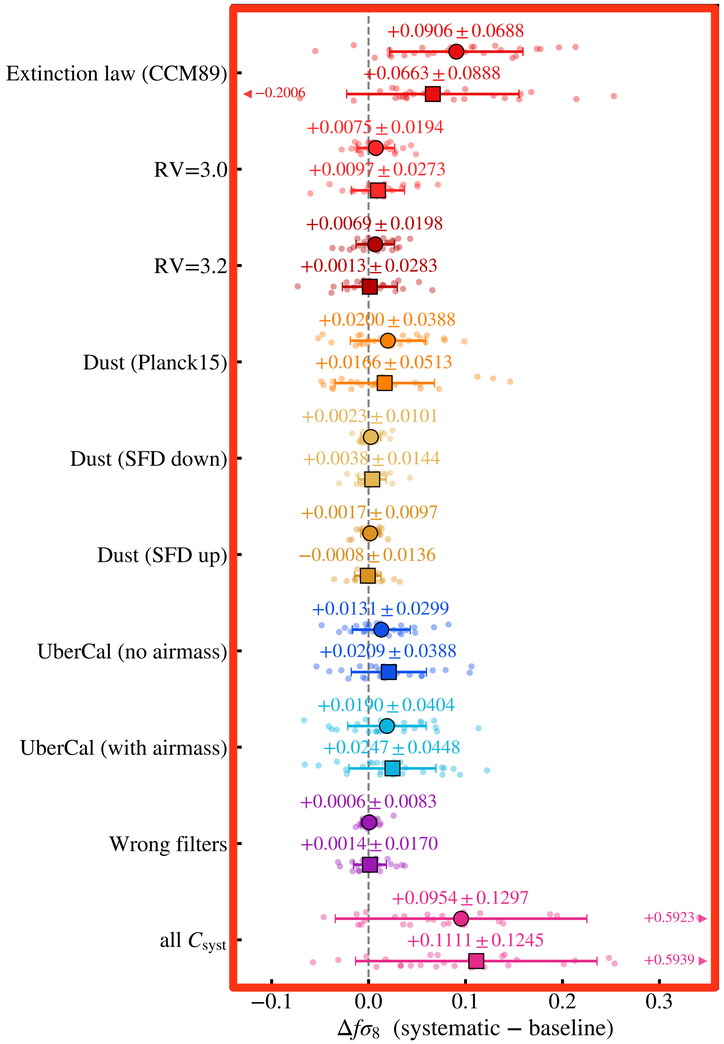
Systematic shift

$$\left(\mathbf{v}+\mathbf{s}\right)^{\rm T} C^{-1} \left(\mathbf{v}+\mathbf{s}\right)$$



Anisotropic systematic studies

$$\mathscr{L}(f\sigma_8, \Theta, \Theta_{\rm HD}) \propto \exp\left[-\frac{1}{2}\,\mathbf{v}^{\rm T}(\Theta_{\rm HD})\,C^{-1}(f\sigma_8, \Theta, \Theta_{\rm HD})\,\mathbf{v}(\Theta_{\rm HD})\right]$$



Systematic shift

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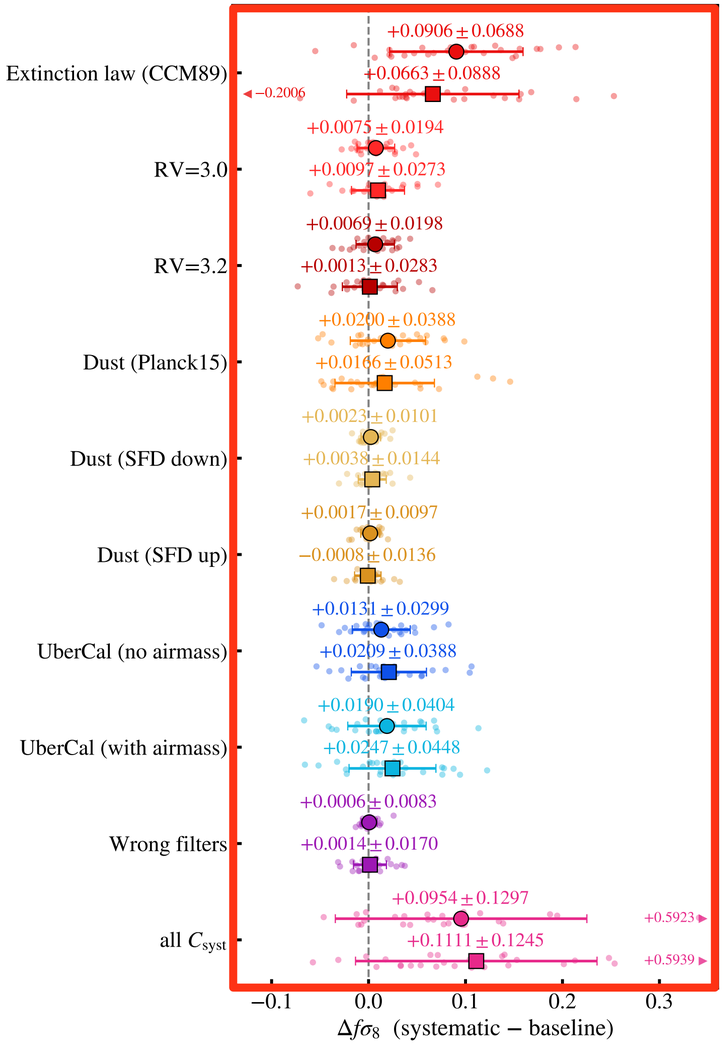
$$C_{syst} = \Delta\mu\Delta\mu^{\dagger} \text{ with}$$
$$\Delta\mu = \mu_{syst} - \mu_{baseline}$$

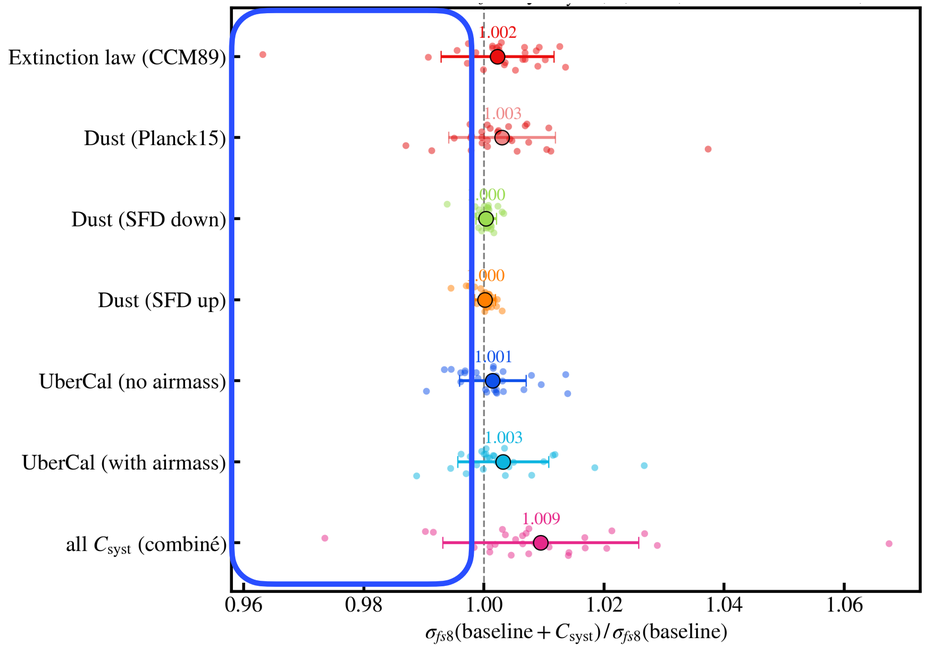
Systematic SNIa analysis

$$\mathbf{v}^{\rm T}\left(C+C_{\rm syst}\right)^{-1}\mathbf{v}$$

Anisotropic systematic studies

$$\mathscr{L}(f\sigma_8, \Theta, \Theta_{\rm HD}) \propto \exp\left[-\frac{1}{2}\,\mathbf{v}^{\rm T}(\Theta_{\rm HD})\,C^{-1}(f\sigma_8, \Theta, \Theta_{\rm HD})\,\mathbf{v}(\Theta_{\rm HD})\right]$$





Systematic shift

$$\left(\mathbf{v}+\mathbf{s}\right)^{\rm T} C^{-1} \left(\mathbf{v}+\mathbf{s}\right)$$

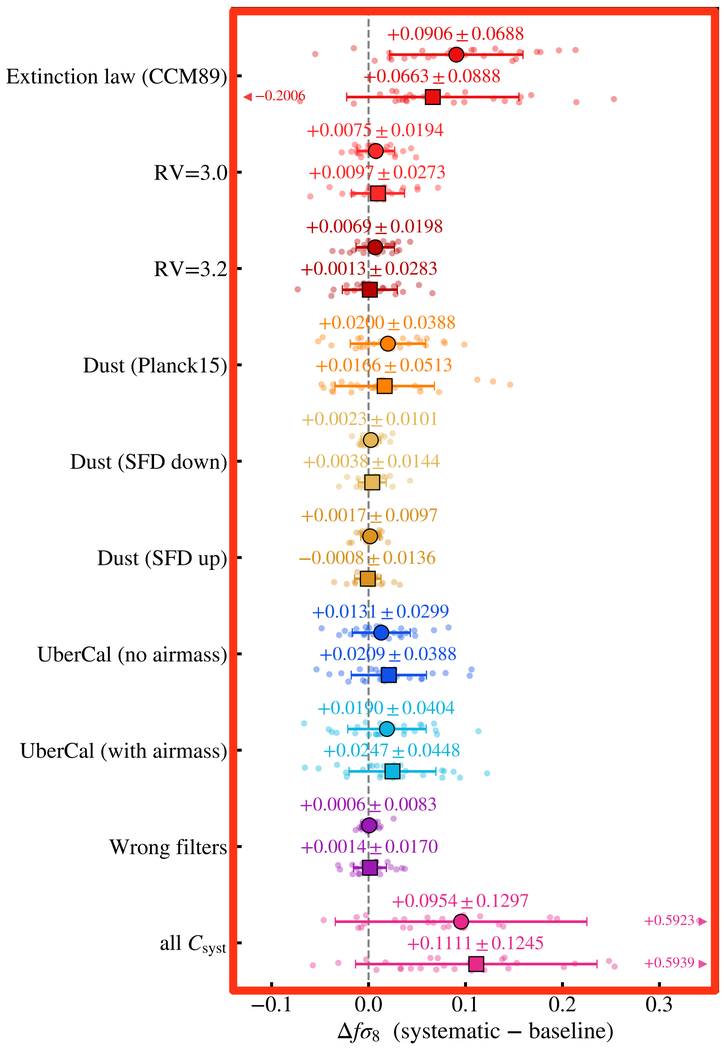
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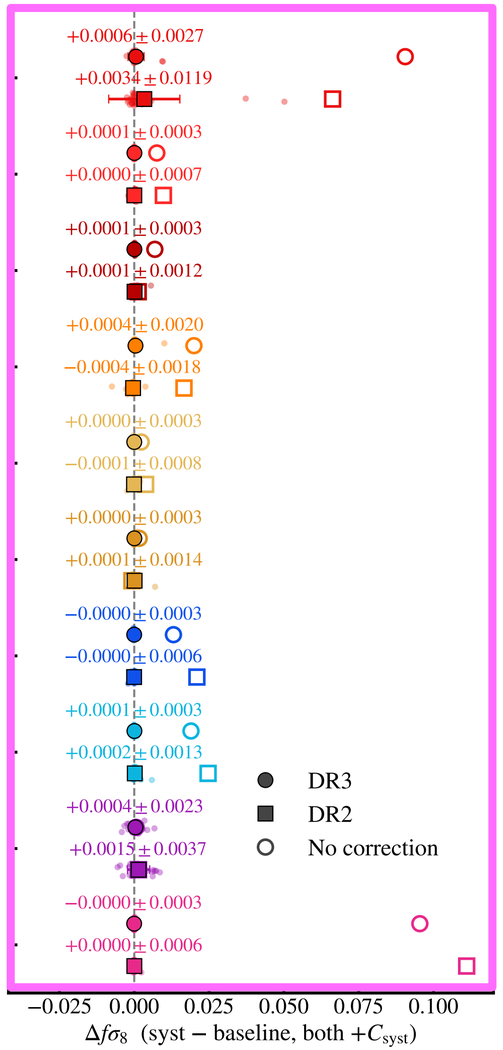
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Systematic shift

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Systematic SNIa analysis

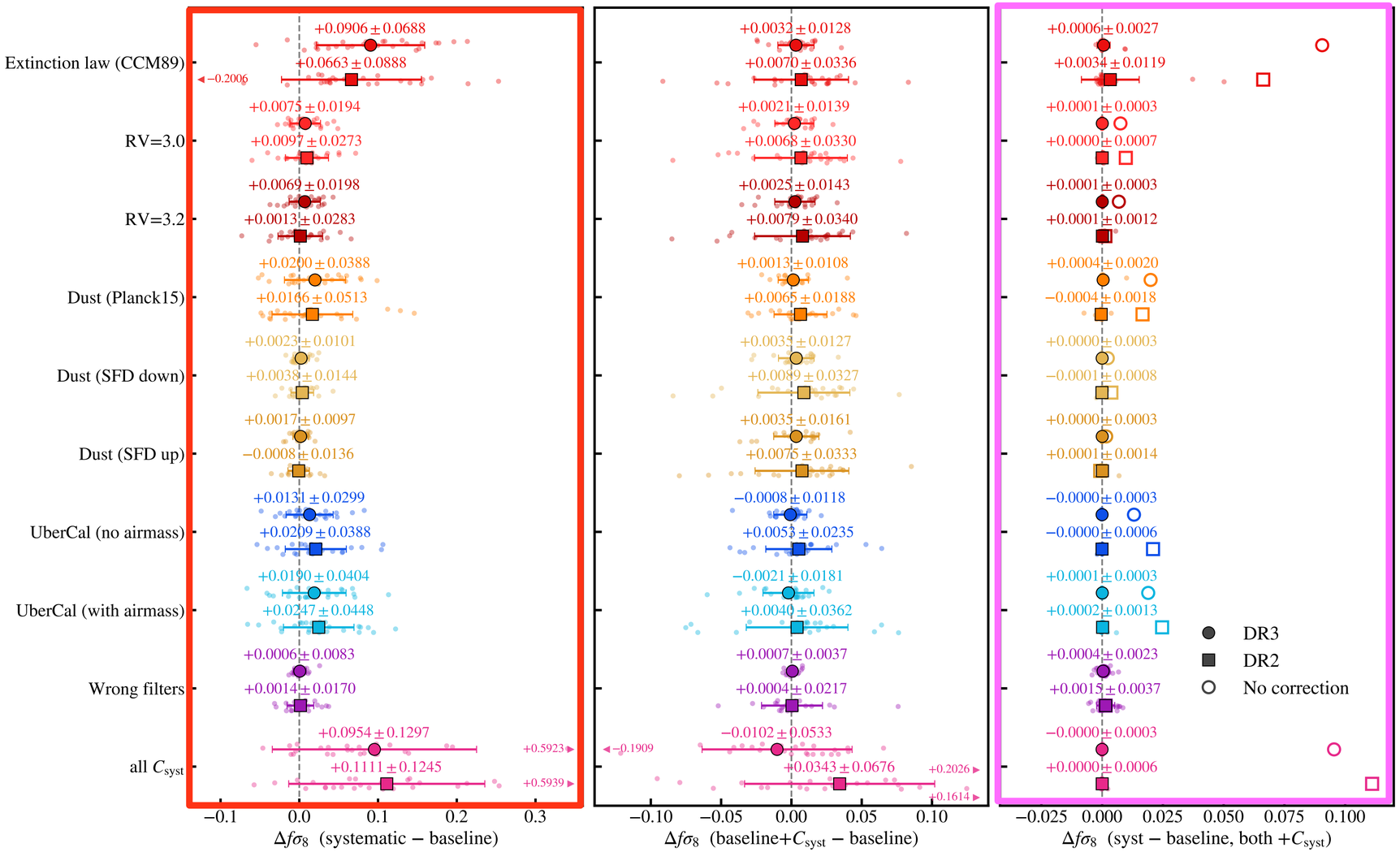
$$\mathbf{v}^{\rm T}\left(C+C_{\rm syst}\right)^{-1}\mathbf{v}$$

Mode deprojection

$$\mathbf{v}^{\rm T}\left(C+\lambda\, C_{\rm syst}\right)^{-1}\mathbf{v}, \lambda \to \infty$$

Anisotropic systematic studies

$$\mathscr{L}(f\sigma_8, \Theta, \Theta_{\rm HD}) \propto \exp\left[-\frac{1}{2}\,\mathbf{v}^{\rm T}(\Theta_{\rm HD})\,C^{-1}(f\sigma_8, \Theta, \Theta_{\rm HD})\,\mathbf{v}(\Theta_{\rm HD})\right]$$



Systematic shift

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Systematic SNIa analysis

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Mode deprojection

$$\mathbf{v}^{\rm T}\left(C+\lambda\, C_{\rm syst}\right)^{-1}\mathbf{v}, \lambda \to \infty$$

Take home message

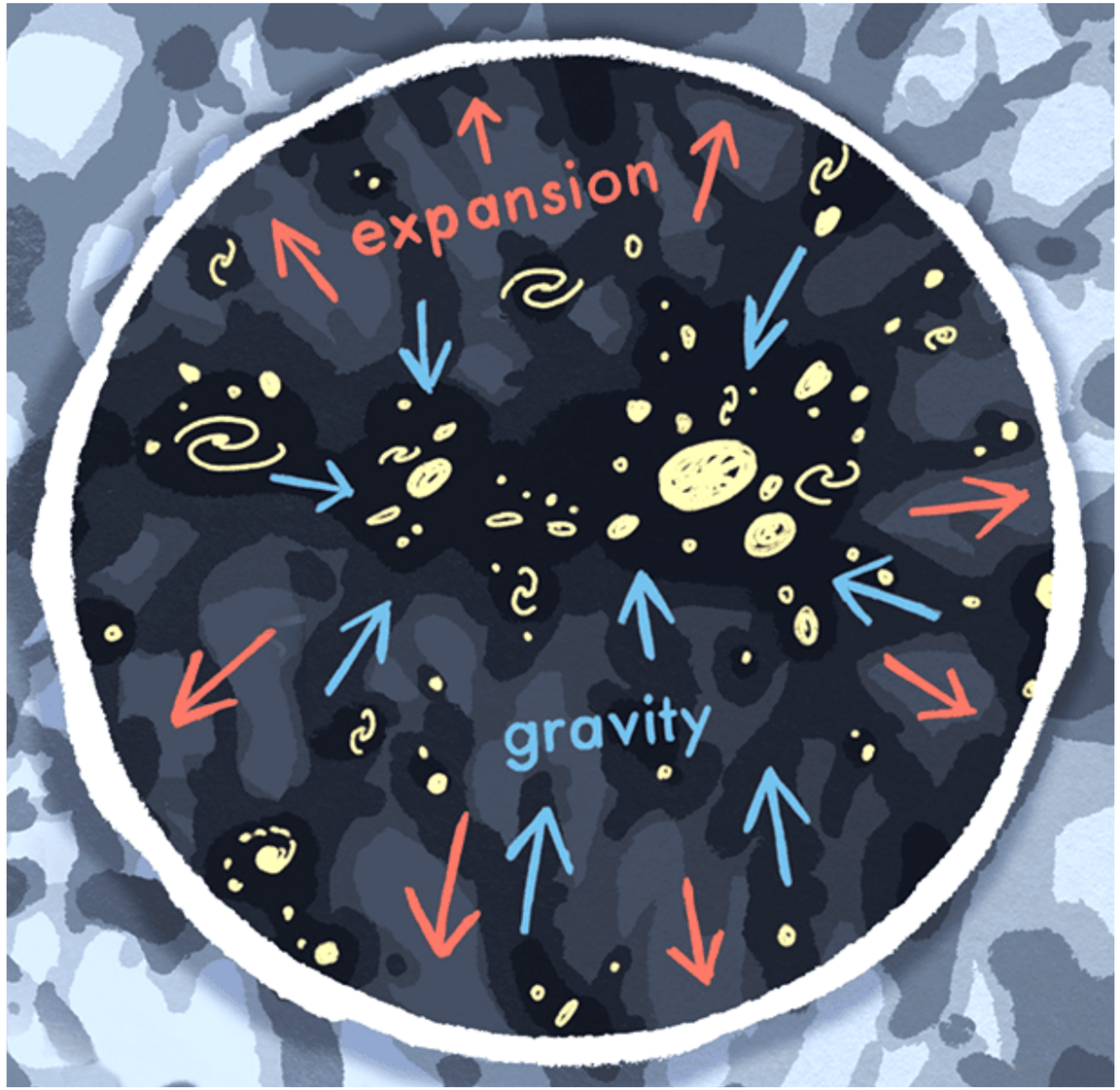
- **The pipeline is ready to be tested on the data**
- **Anisotropic systematic studies**
- **Method to debias the systematic effect on $f\sigma_8$ (?)**
- **First draft of the paper finished soon**

Peculiar velocities correction for the $w_0 w_a$ analysis

- **Add the C_{vv} to the total covariance**
- **Correct the z_{obs} via velocity reconstruction from an external galaxy density catalog (2M++, DESI)**

Back up slides

$f\sigma_8$



Growth rate of
linear perturbations

$$\nabla \cdot \vec{v}(\vec{r}) \propto f\sigma_8$$

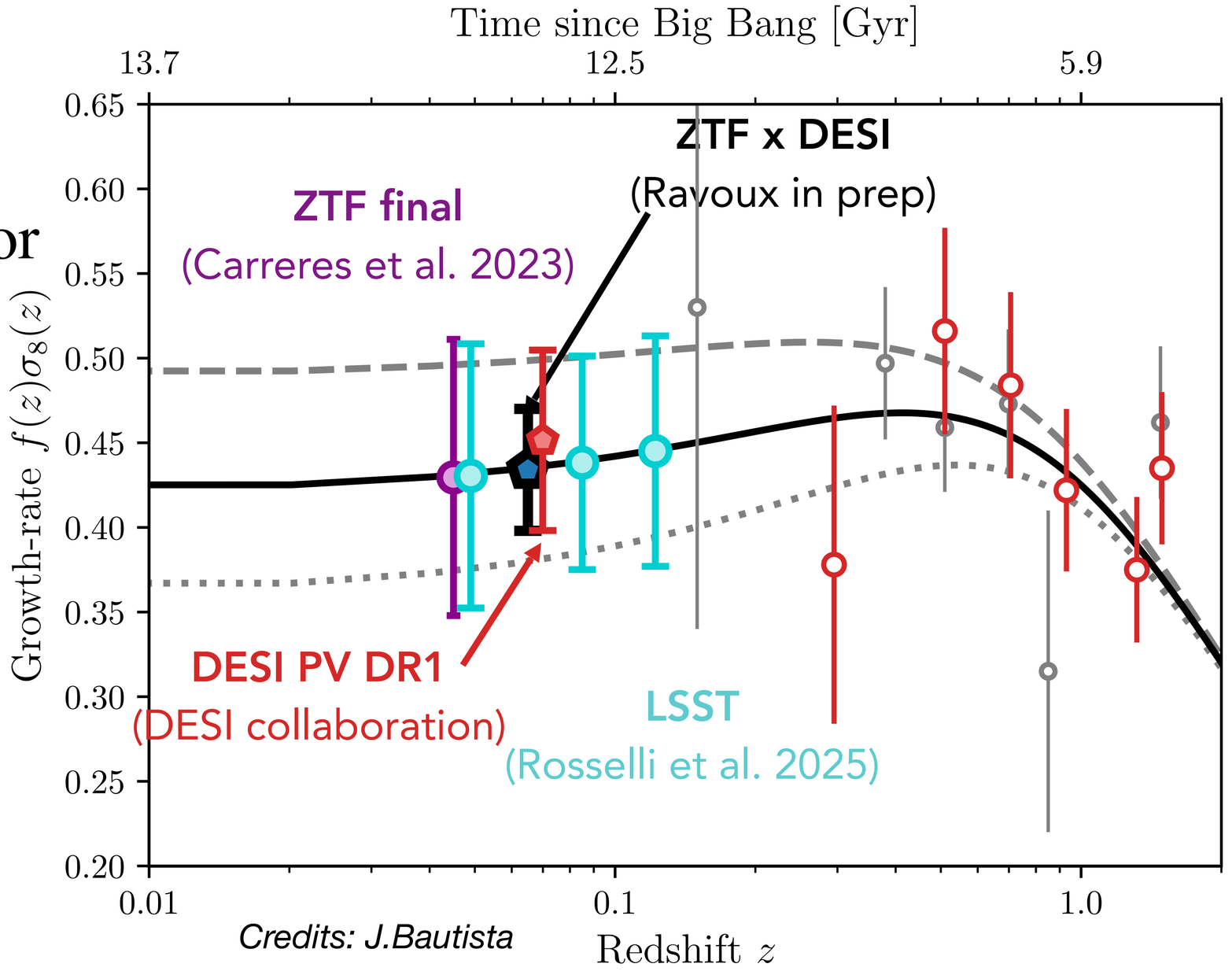
Velocity field

Amplitude of the matter
fluctuations

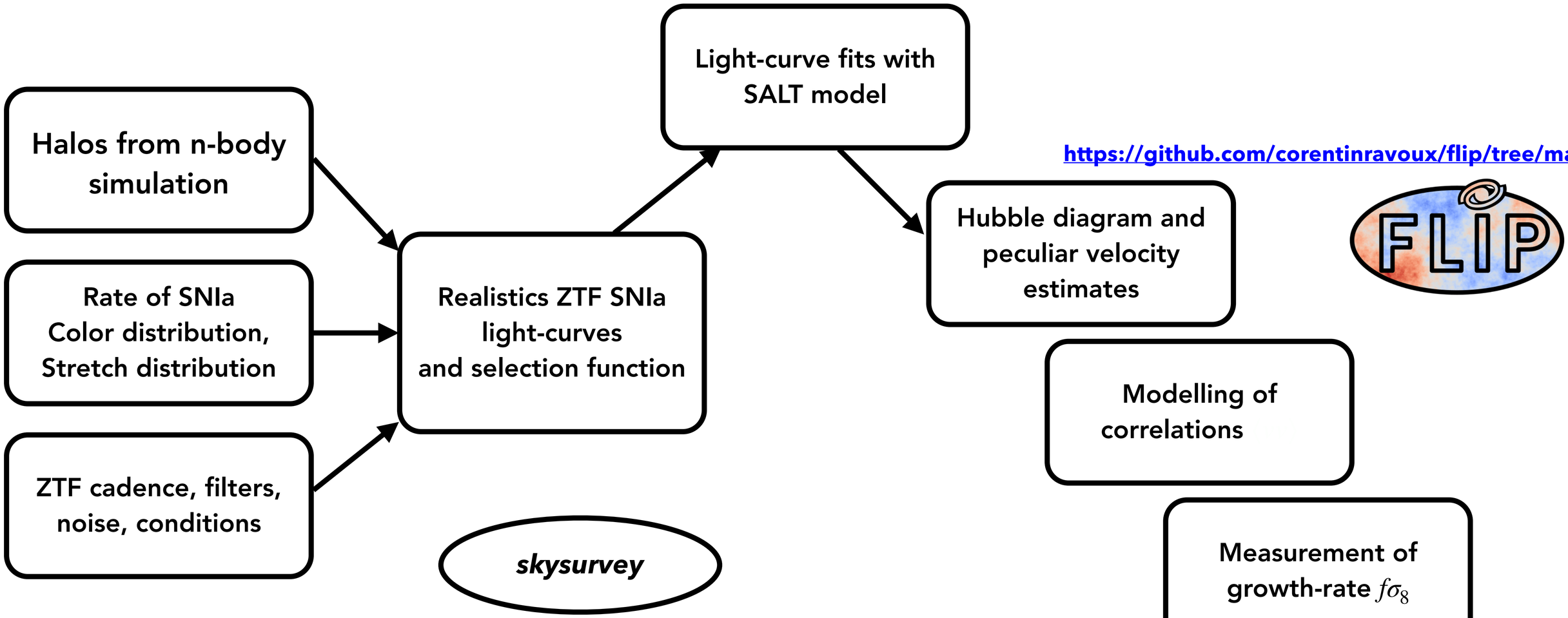
Forecast

$f\sigma_8$

- Competitve measurement for low redshift
- Method works on realistic simulations
- Systematics are on the way to be under control
- Stay tuned for the data



$f\sigma_8$ pipeline

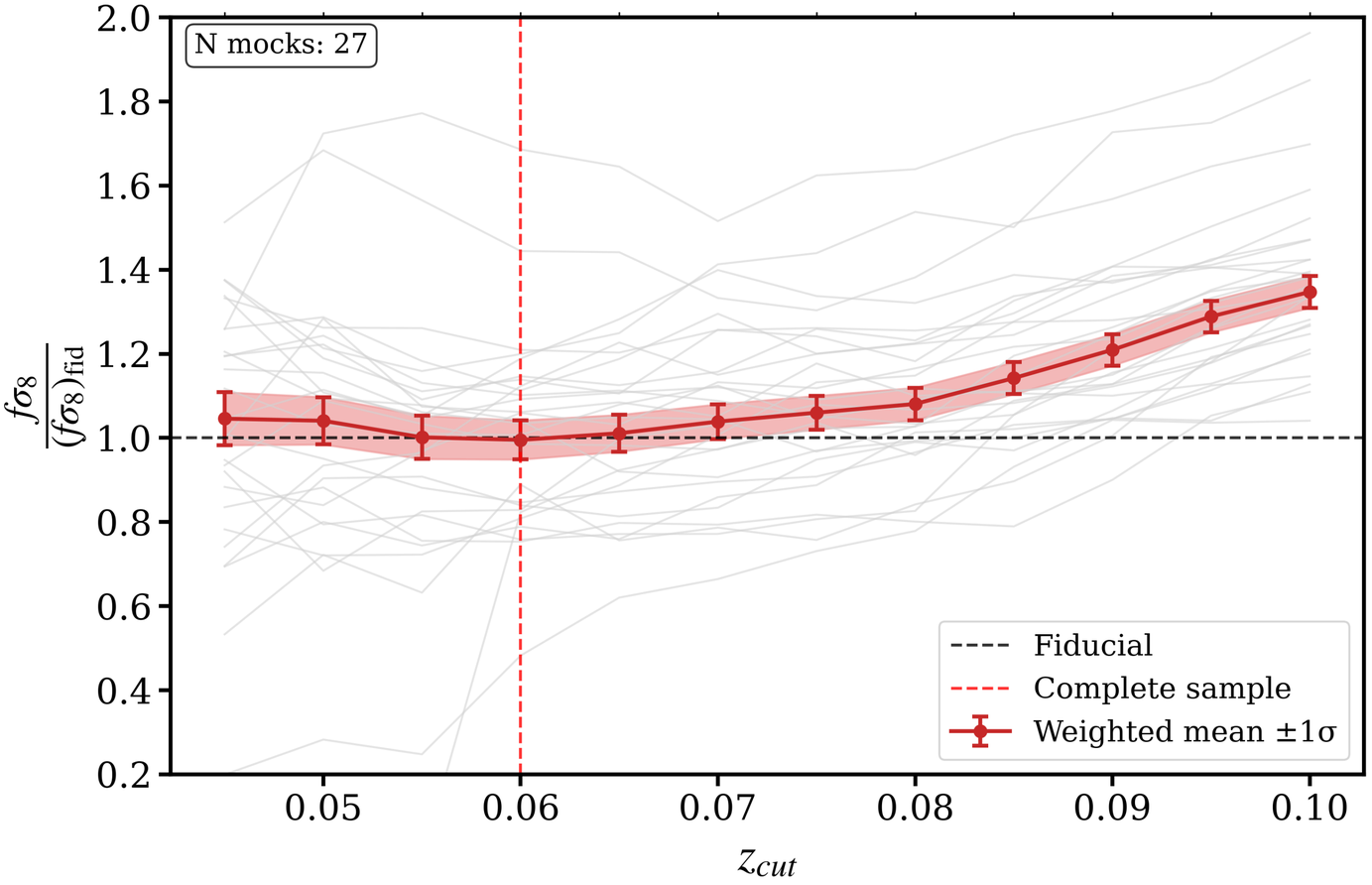


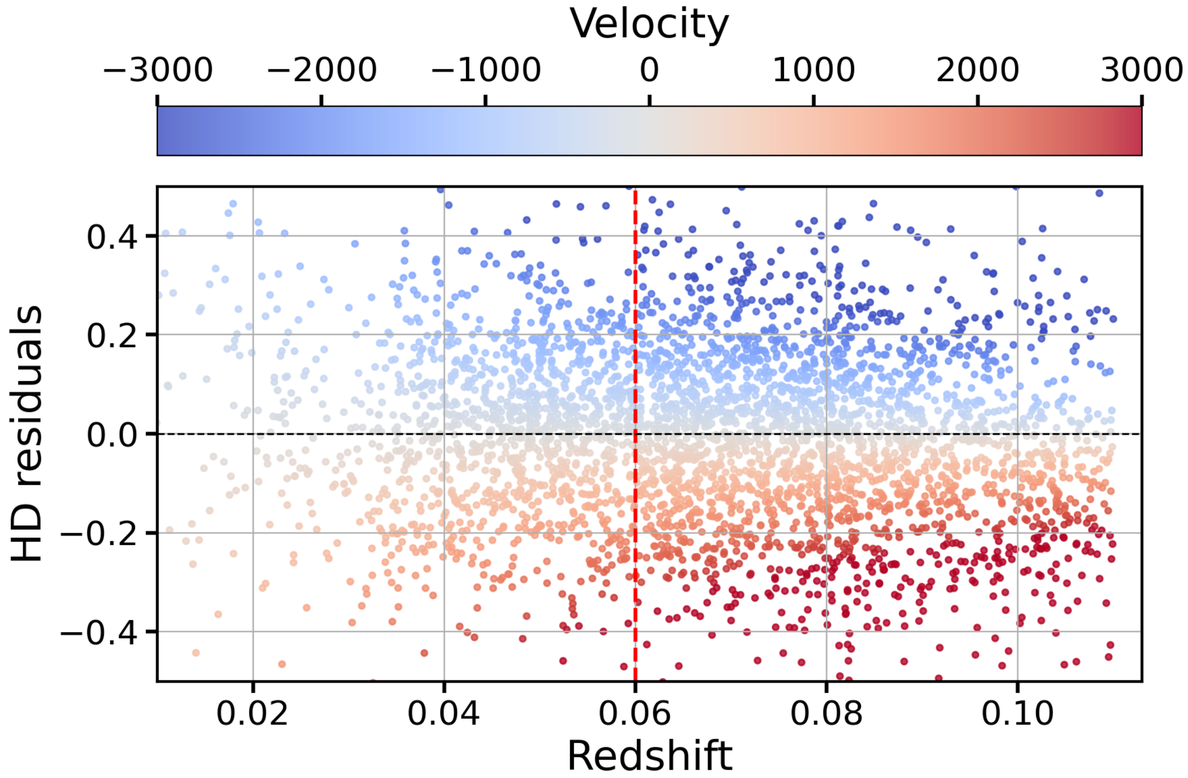
https://github.com/corentinravoux/flip/tree/main

https://github.com/MickaelRigault/skysurvey/tree/main

$f\sigma_8$ results

$f\sigma_8$ biased for $z_{cut} > 0.06$ due to Malmquist bias

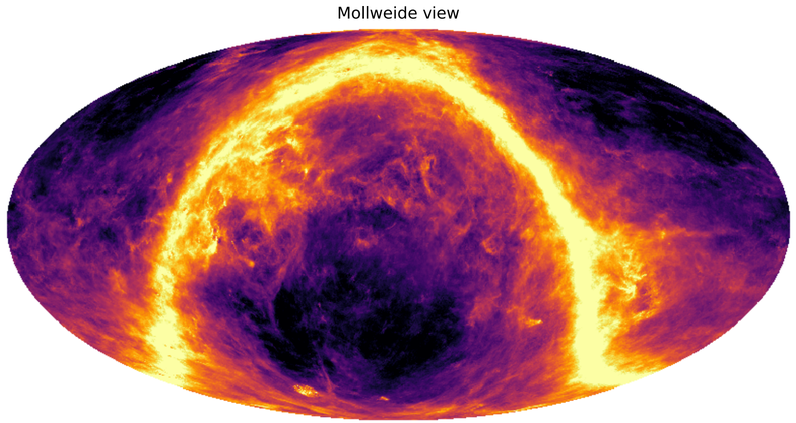




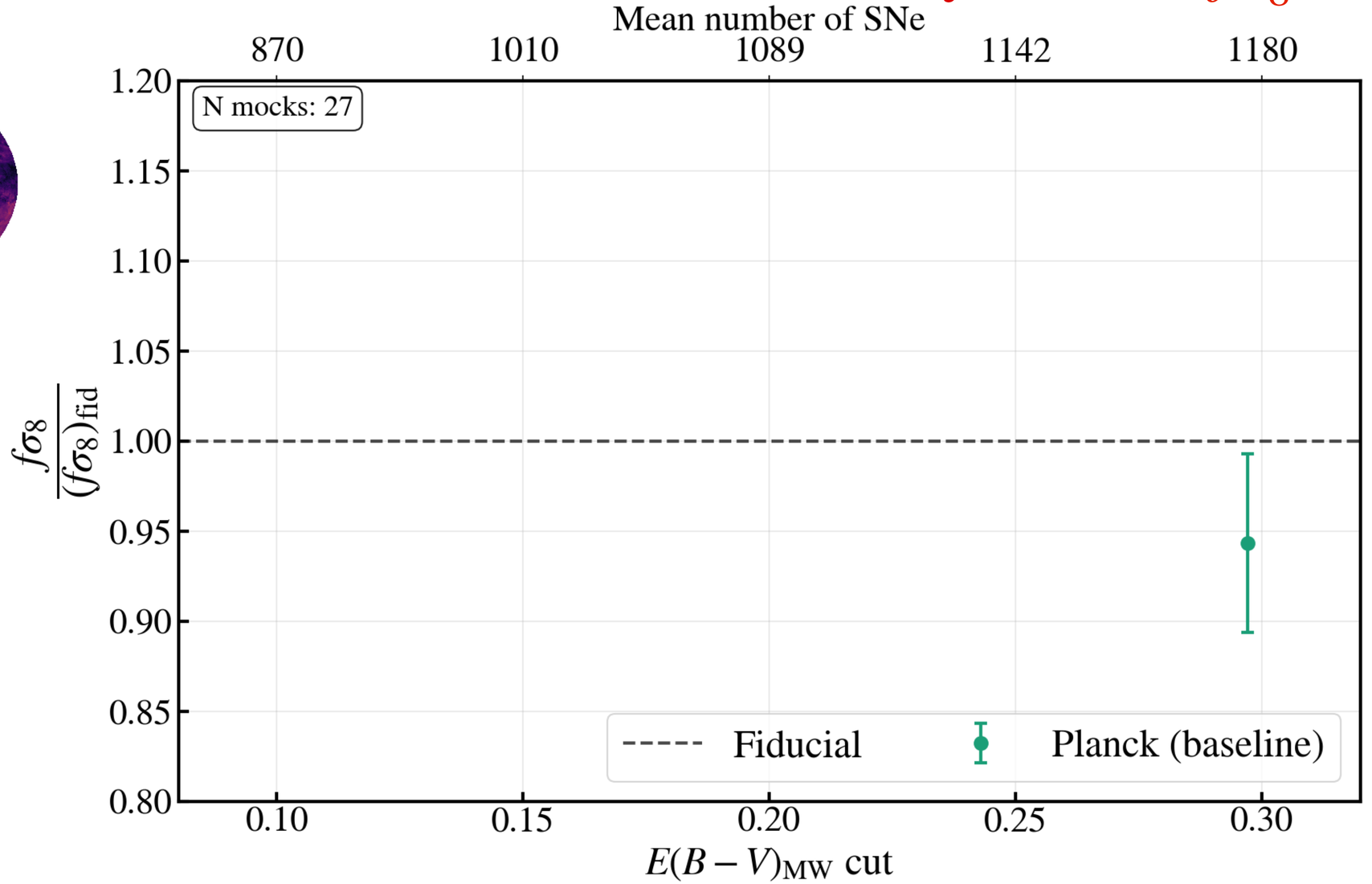
$$\mathbf{v}(\mathbf{p}_{\rm HD}) \propto \Delta\mu_i(\mathbf{p}_{\rm HD})$$

Anisotropic Systematics

Angular correlation in the sky can bias $f\sigma_8$

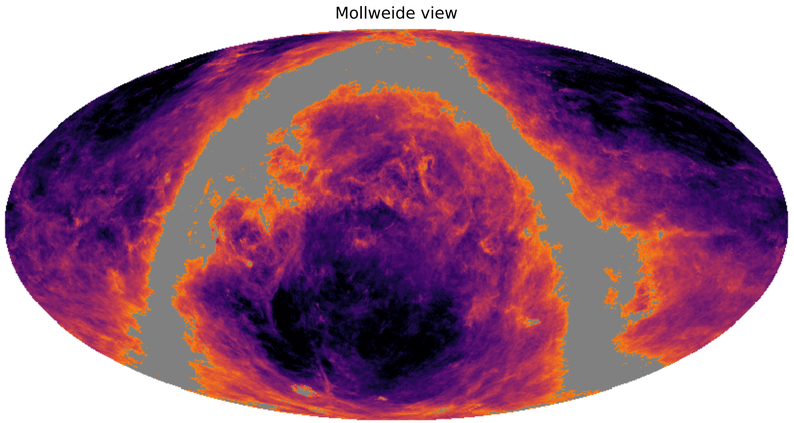


Effect of the Milky way dust

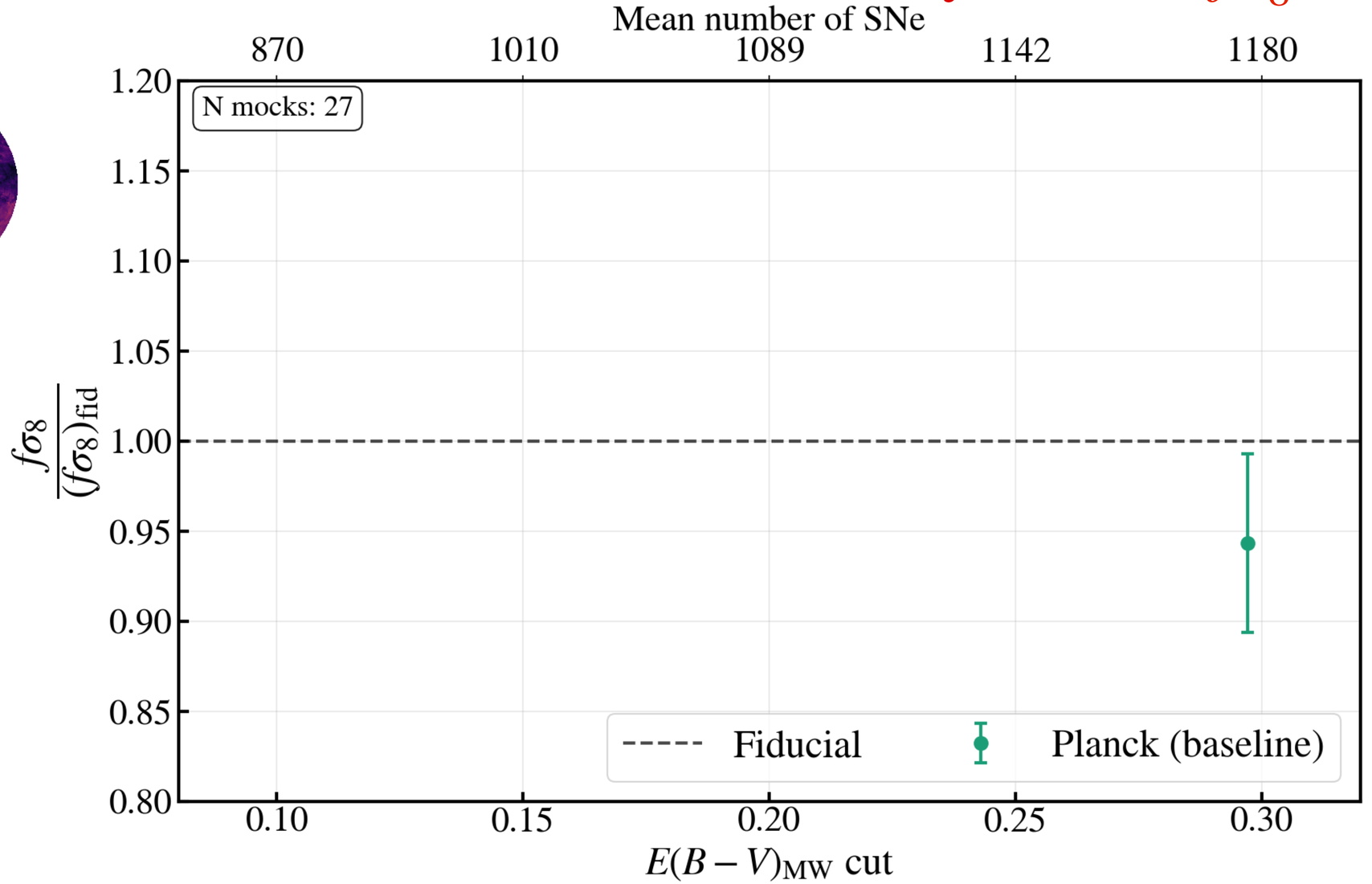


Anisotropic Systematics

Angular correlation in the sky can bias $f\sigma_8$

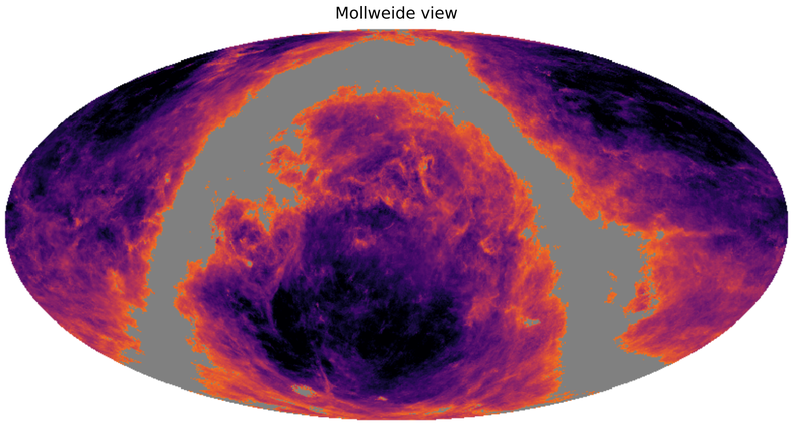


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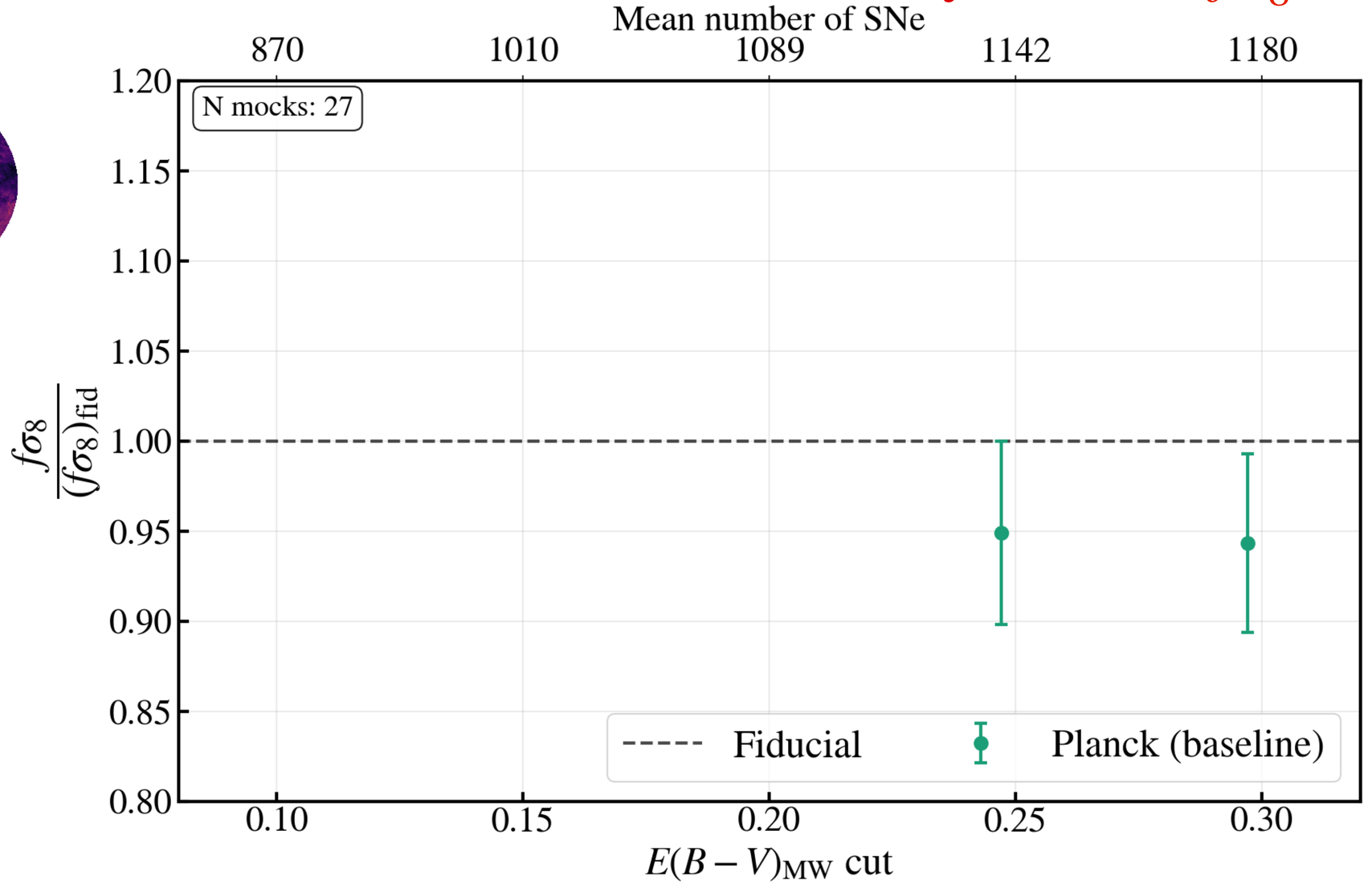


Anisotropic Systematics

Angular correlation in the sky can bias $f\sigma_8$

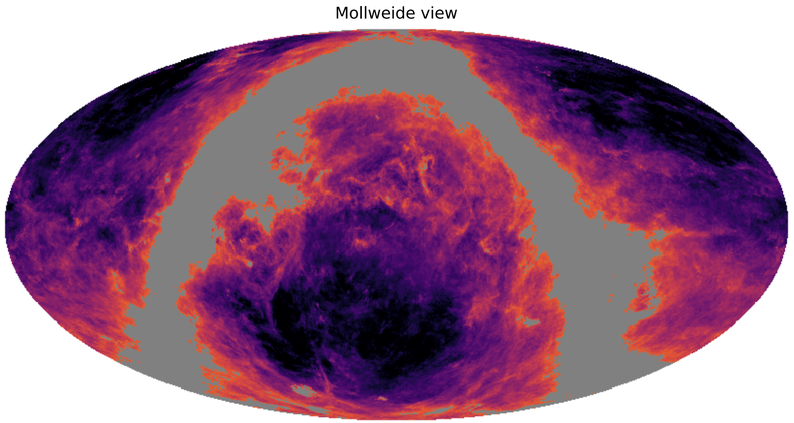


Effect of the Milky way dust

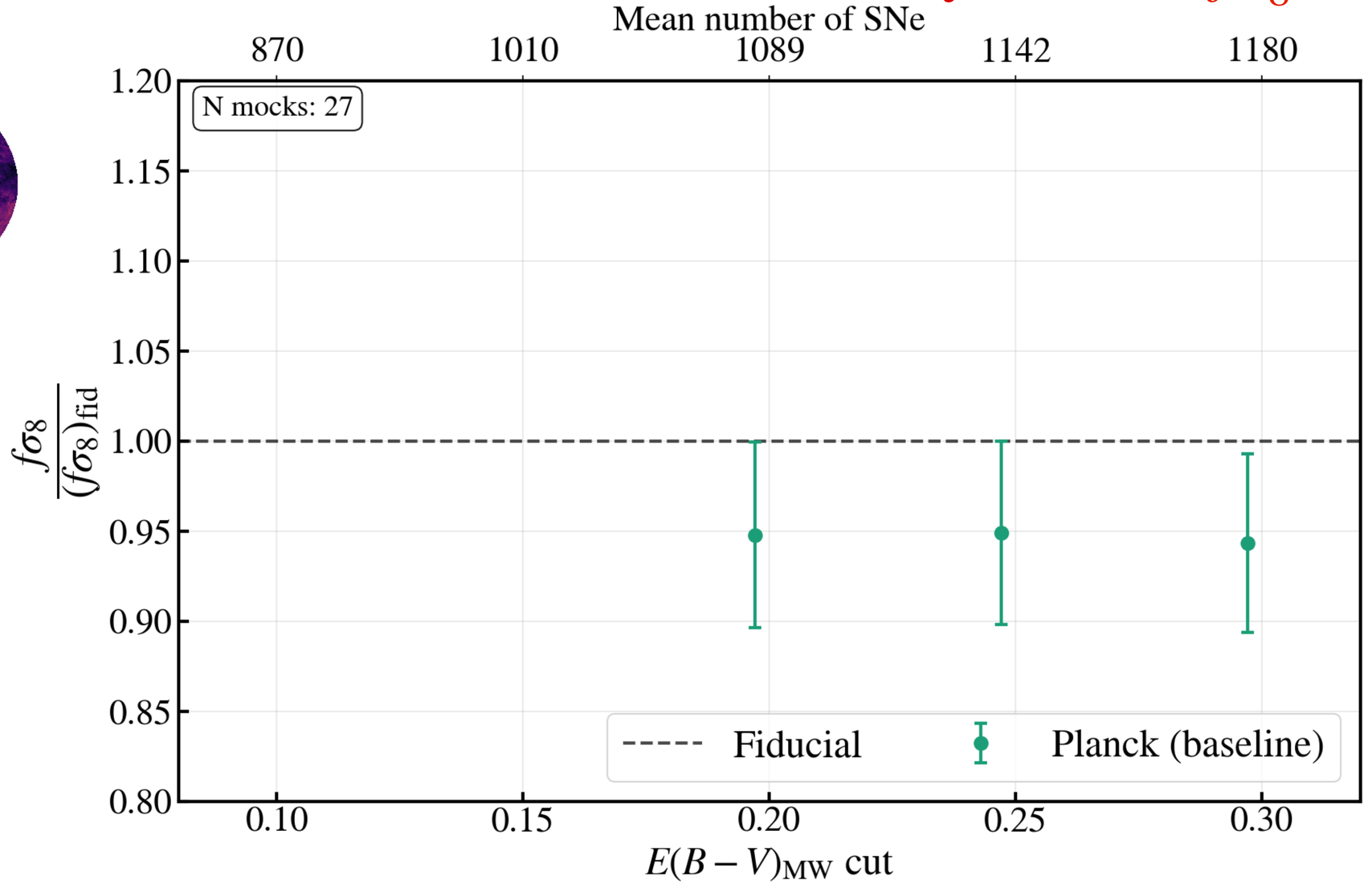


Anisotropic Systematics

Angular correlation in the sky can bias $f\sigma_8$

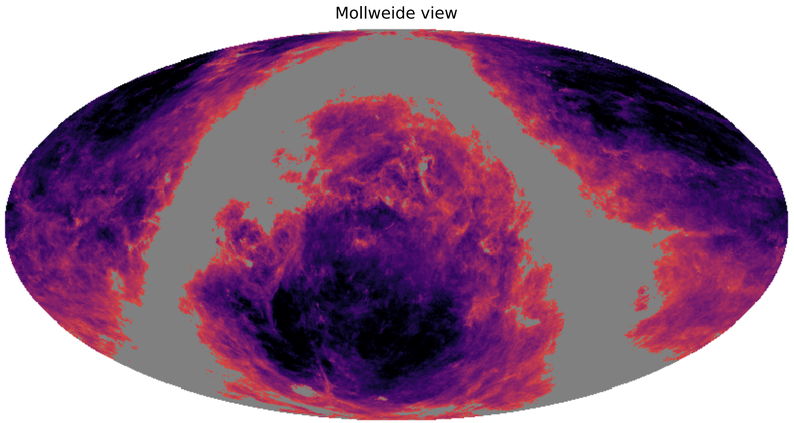


Effect of the Milky way dust

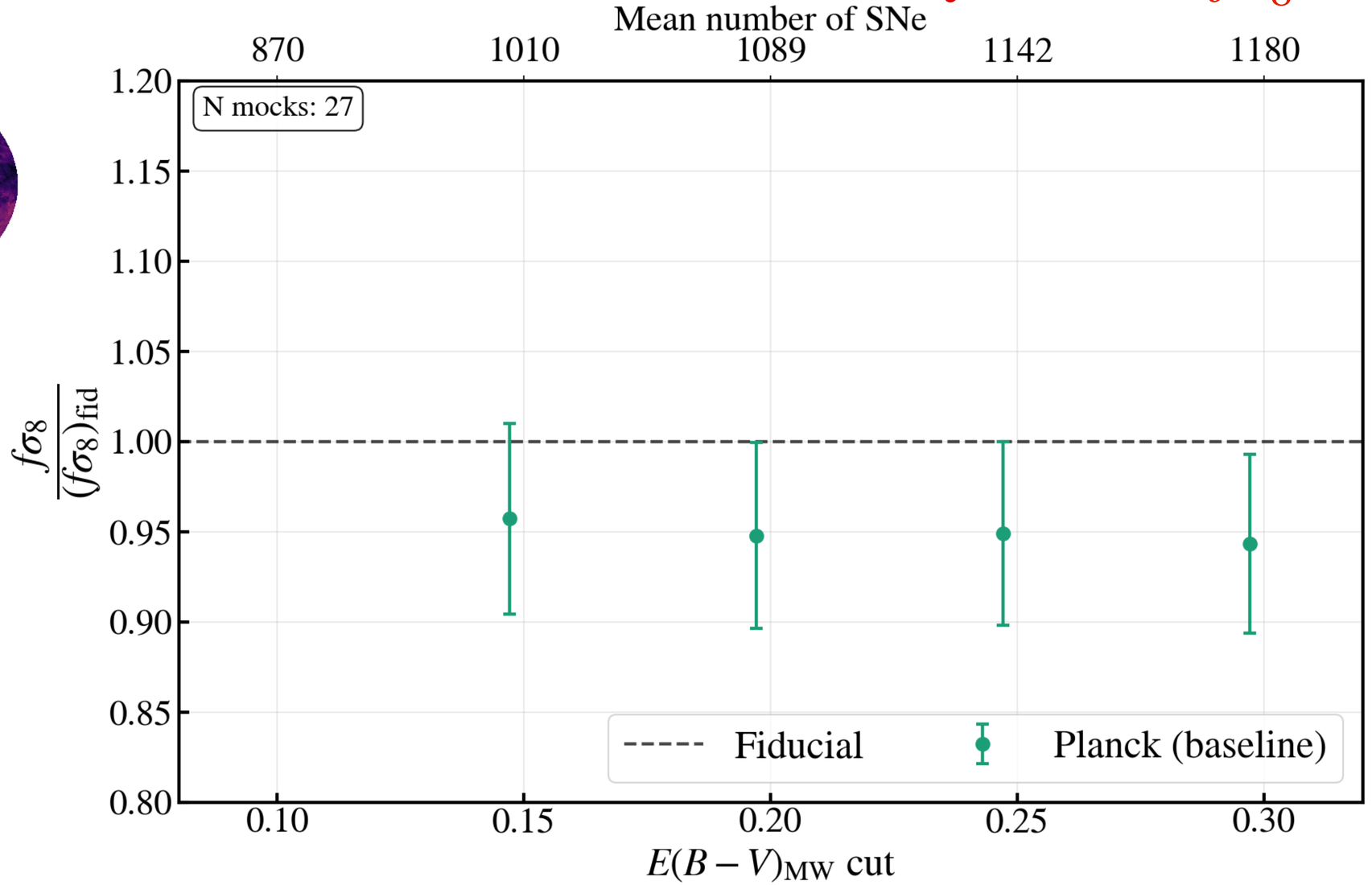


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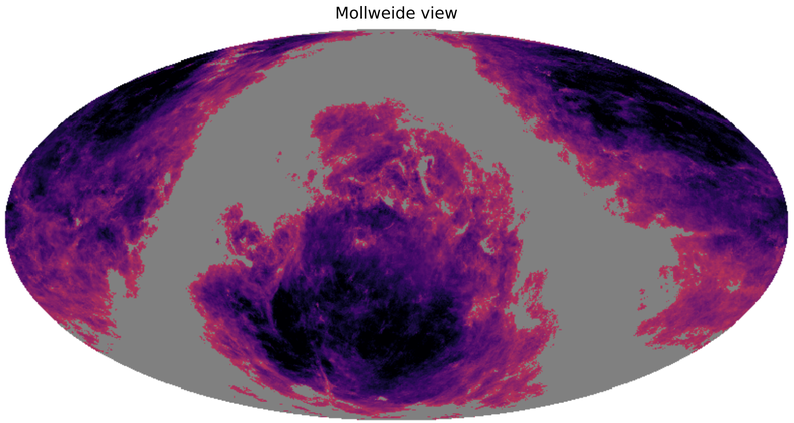


Effect of the Milky way dust

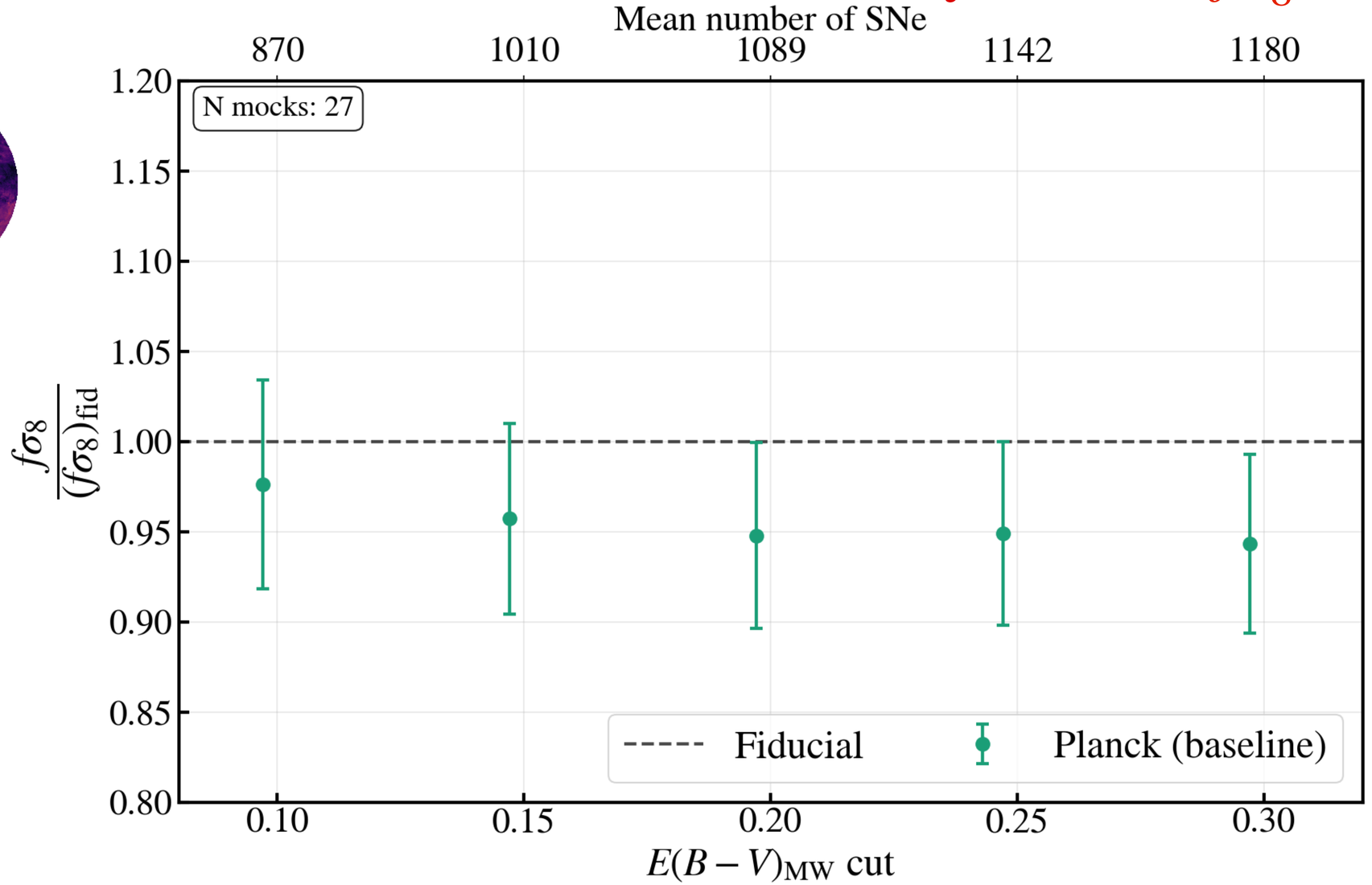


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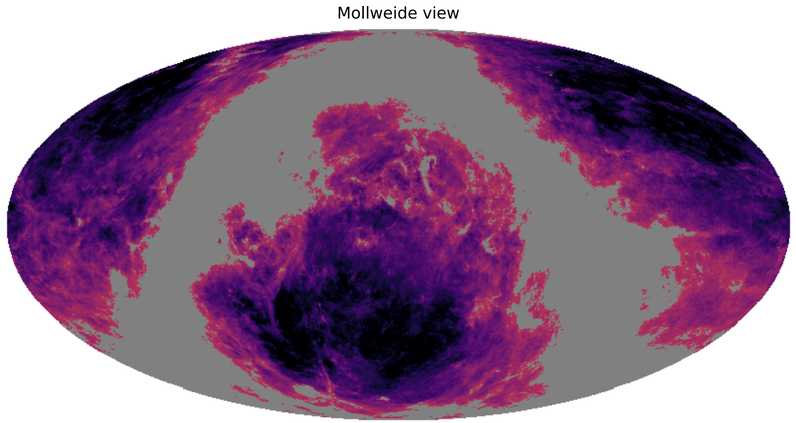


Effect of the Milky way dust

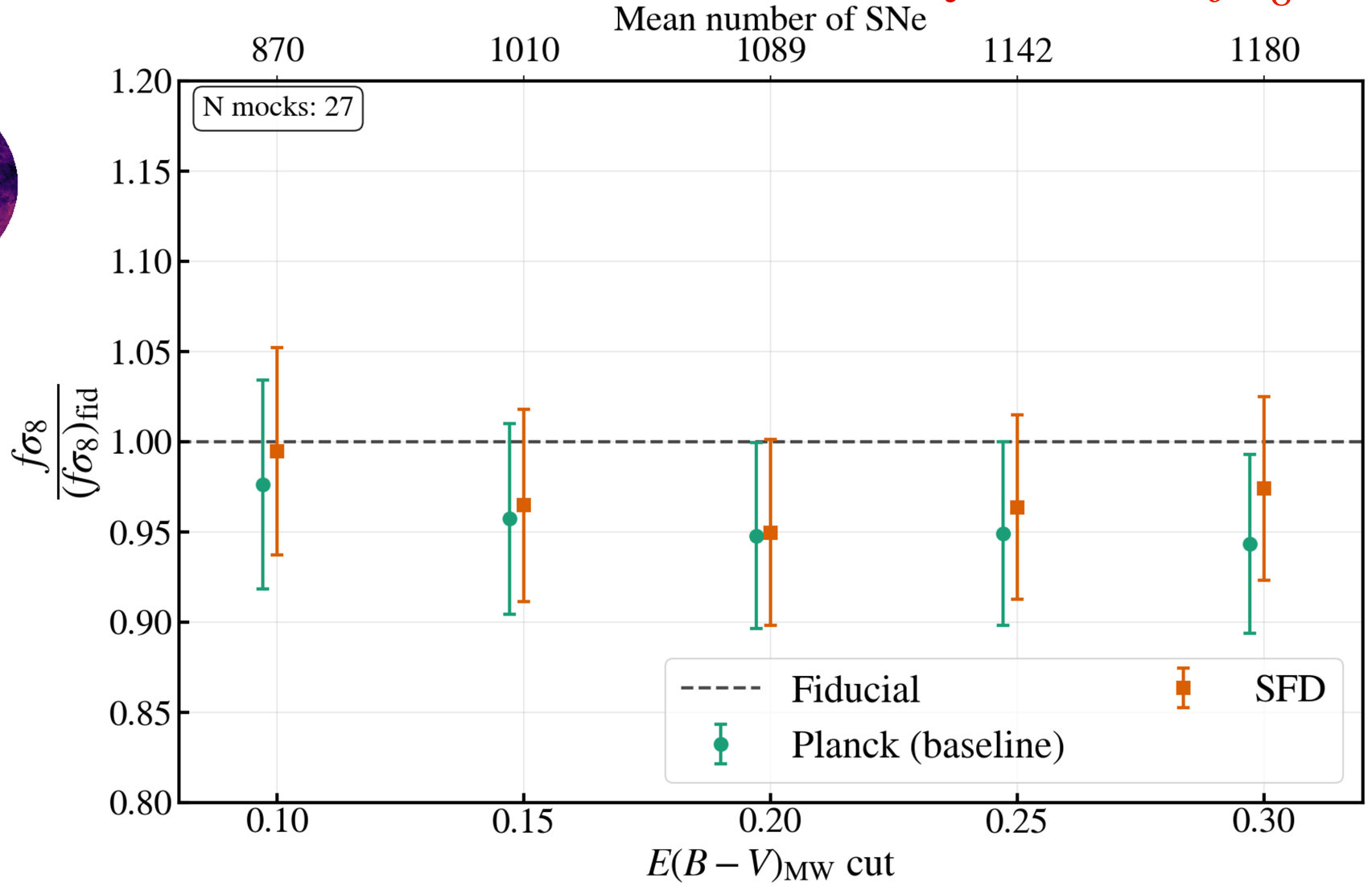


Anisotropic Systematics

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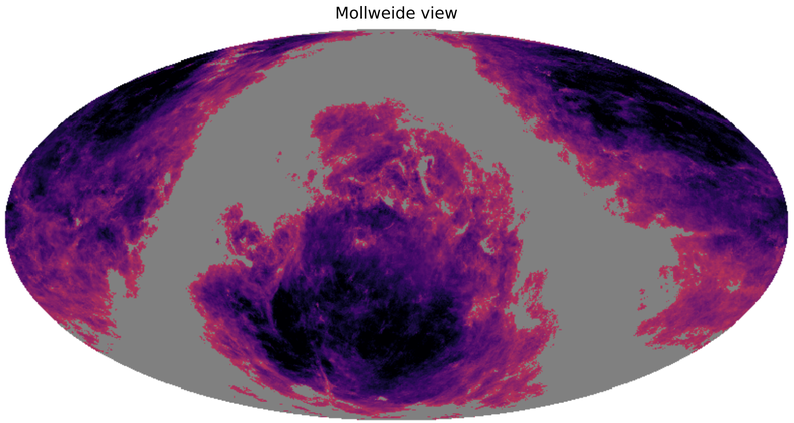


Effect of the Milky way dust

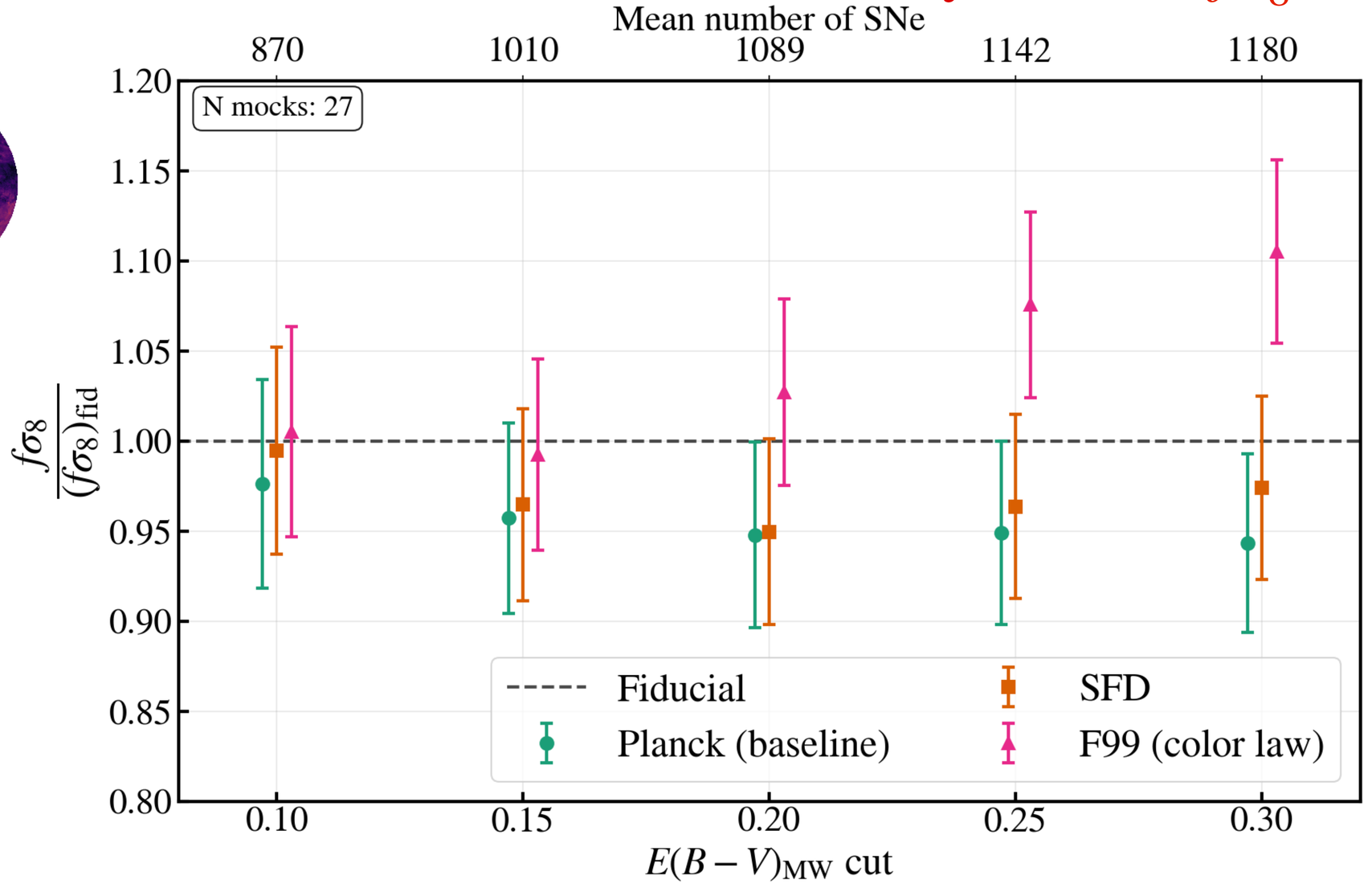


Anisotropic Systematics

Angular correlation in the sky can bias $f\sigma_8$



Effect of the Milky way dust



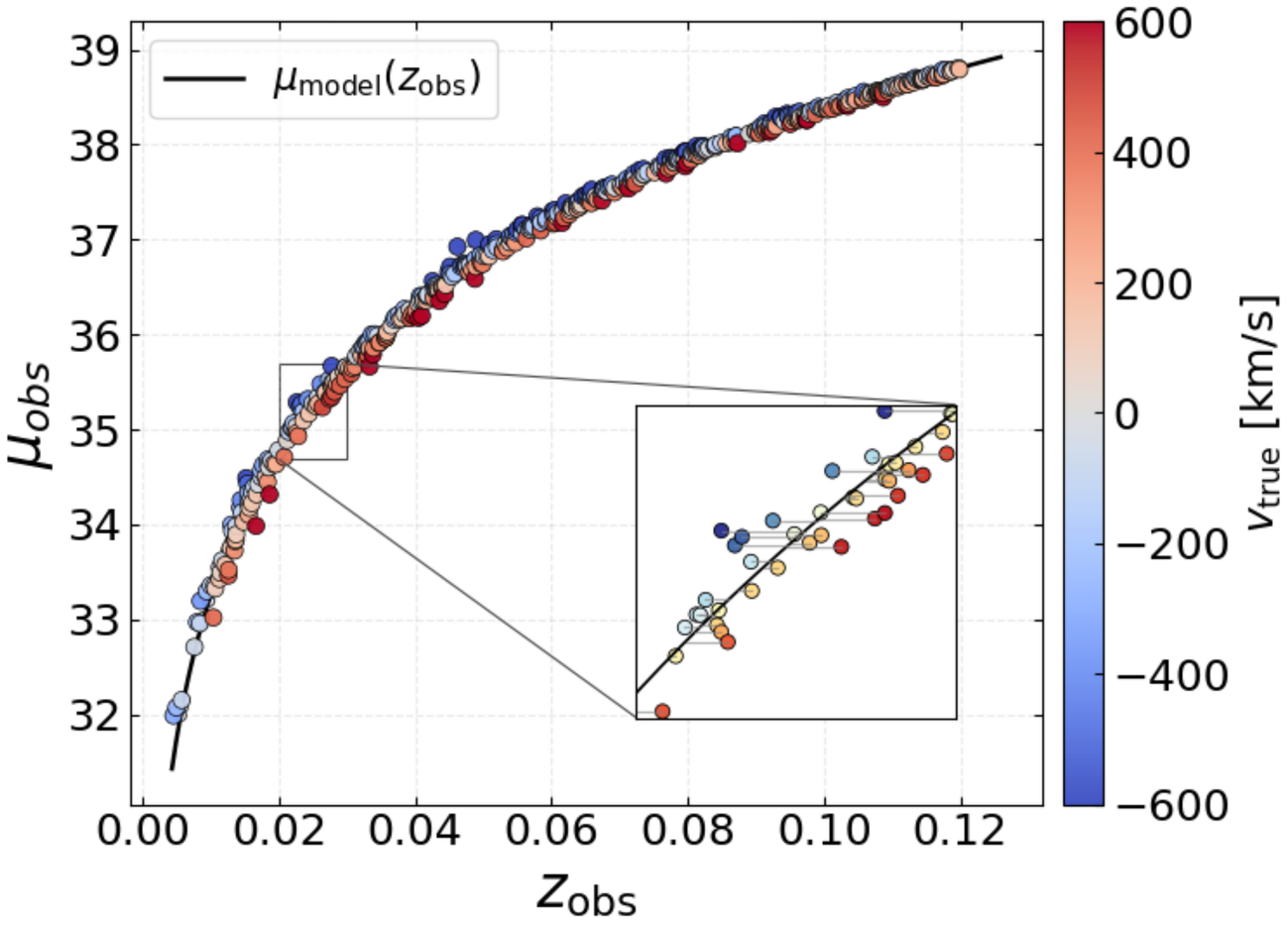
$f\sigma_8$ pipeline

Likelihood

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

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

Hubble Diagram parameters

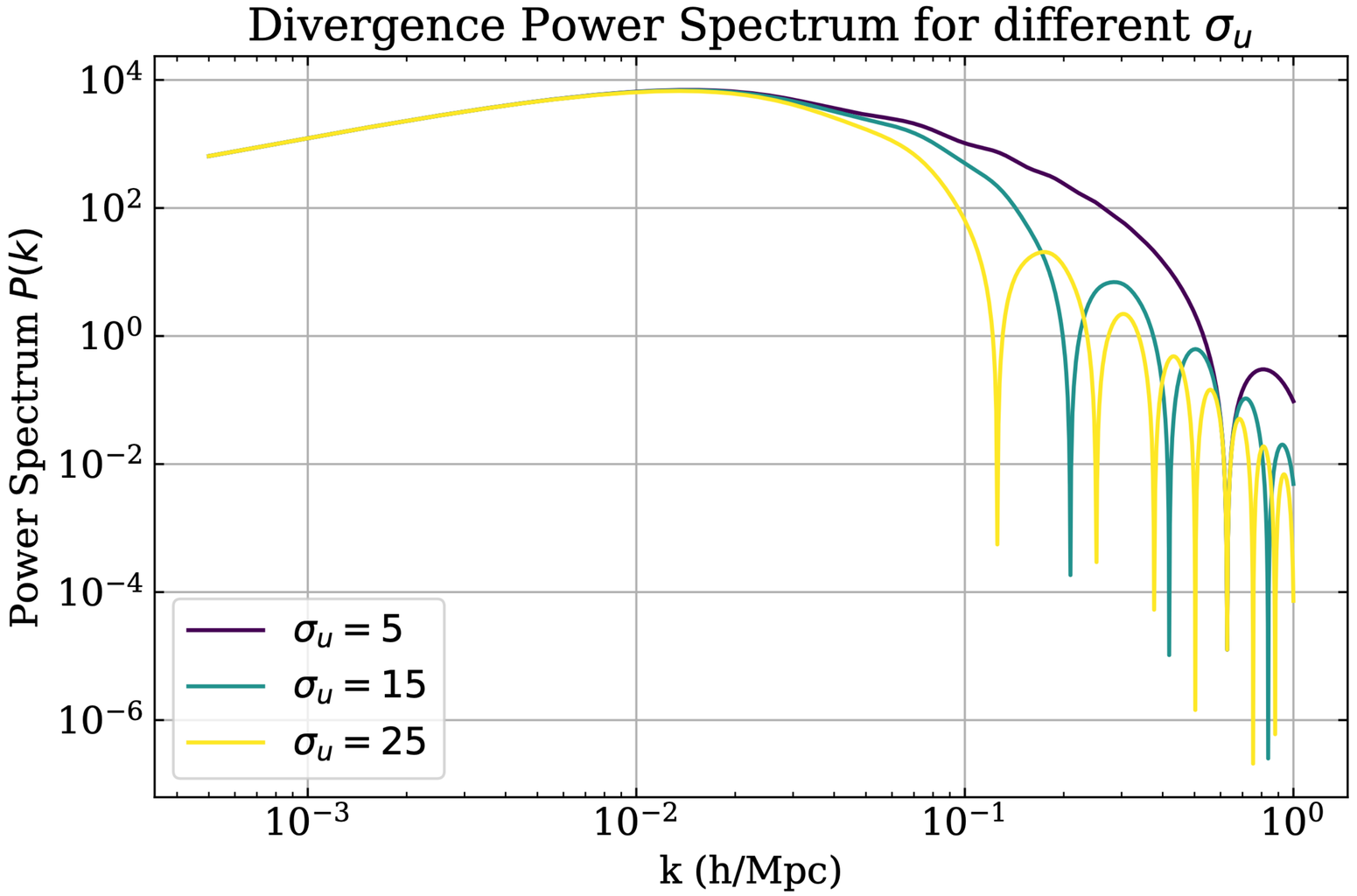


$$\mathbf{v}(\mathbf{p}_{\rm HD}) \propto \Delta\mu_i(\mathbf{p}_{\rm HD})$$

$$(1 + z_{obs}) = (1 + z_{cos})(1 + \frac{v_p}{c})$$

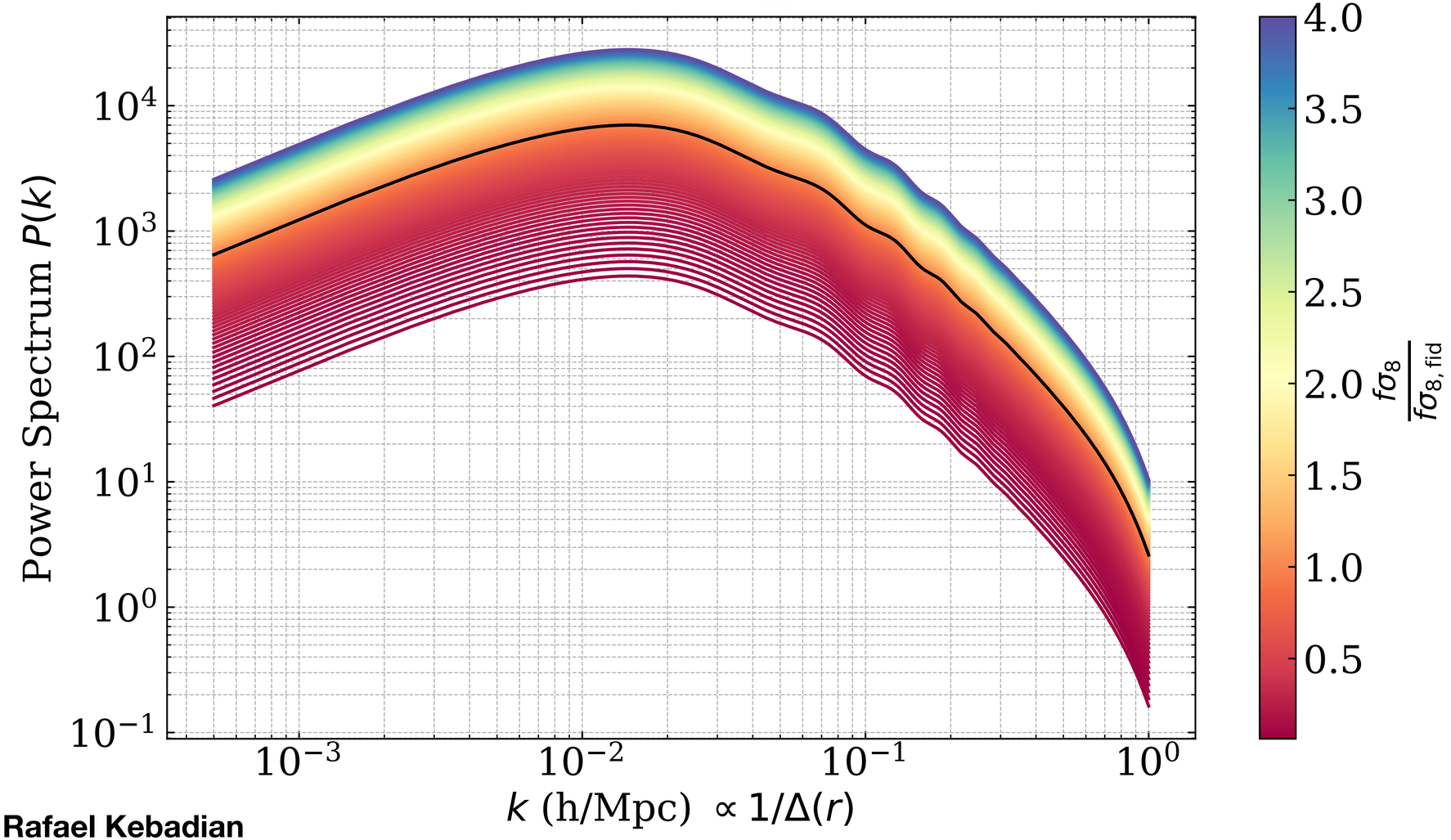
Back up slides

σ_u



Maximum likelihood method

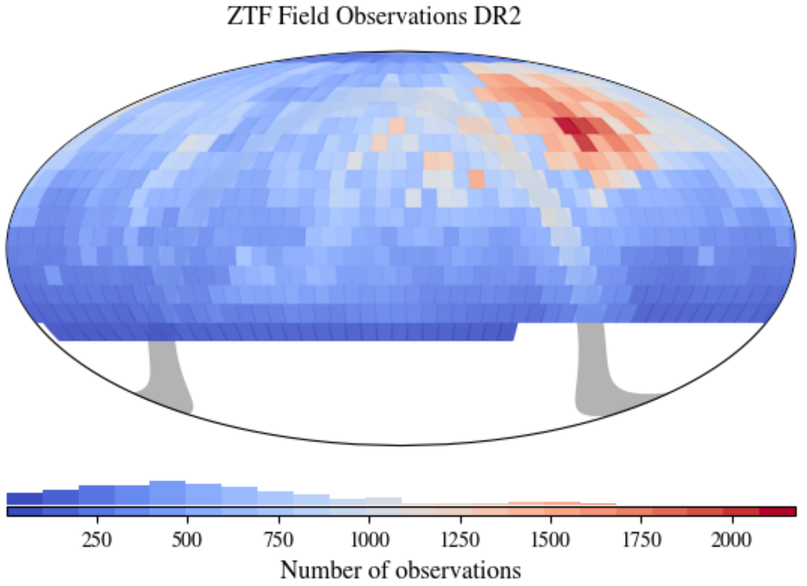
$$C_{ij}^{vv} = \frac{H_0^2 \left(f\sigma_8\right)^2}{2\pi^2 \left(f\sigma_8\right)^2_{\rm fid}} \int_0^{+\infty} f_{\rm fid}^2 P_{\theta\theta}(k) D_u^2(k) W_{ij}(k; r_i, r_j)\, {\rm d}k$$

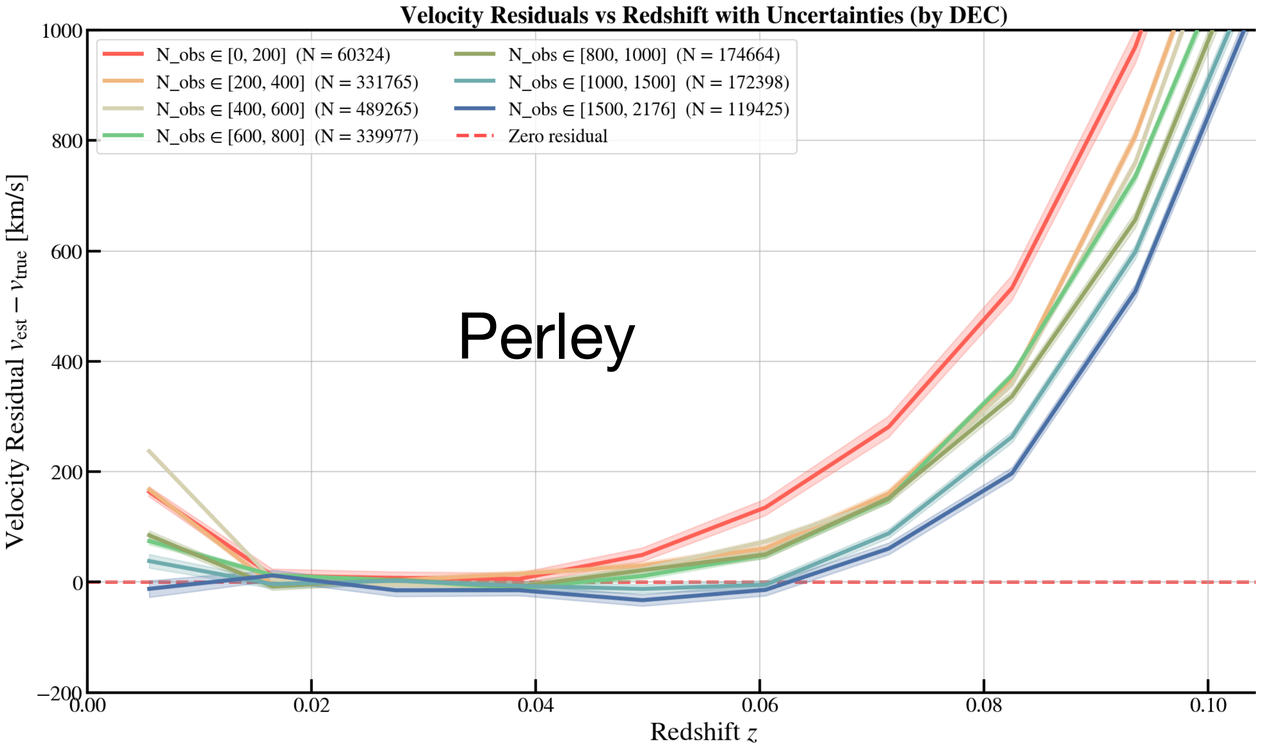


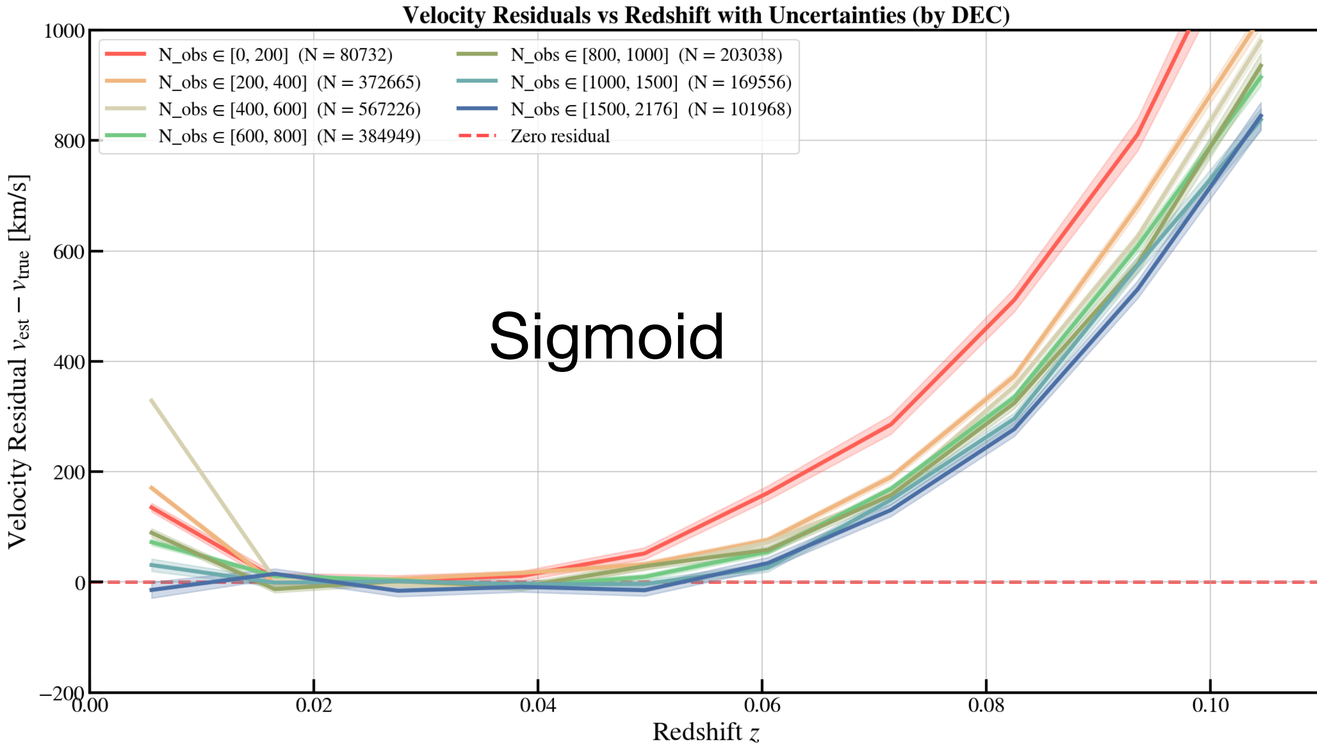
Rafael Kebadian

Selection function

500 DR2 sample in the same Uchuu box



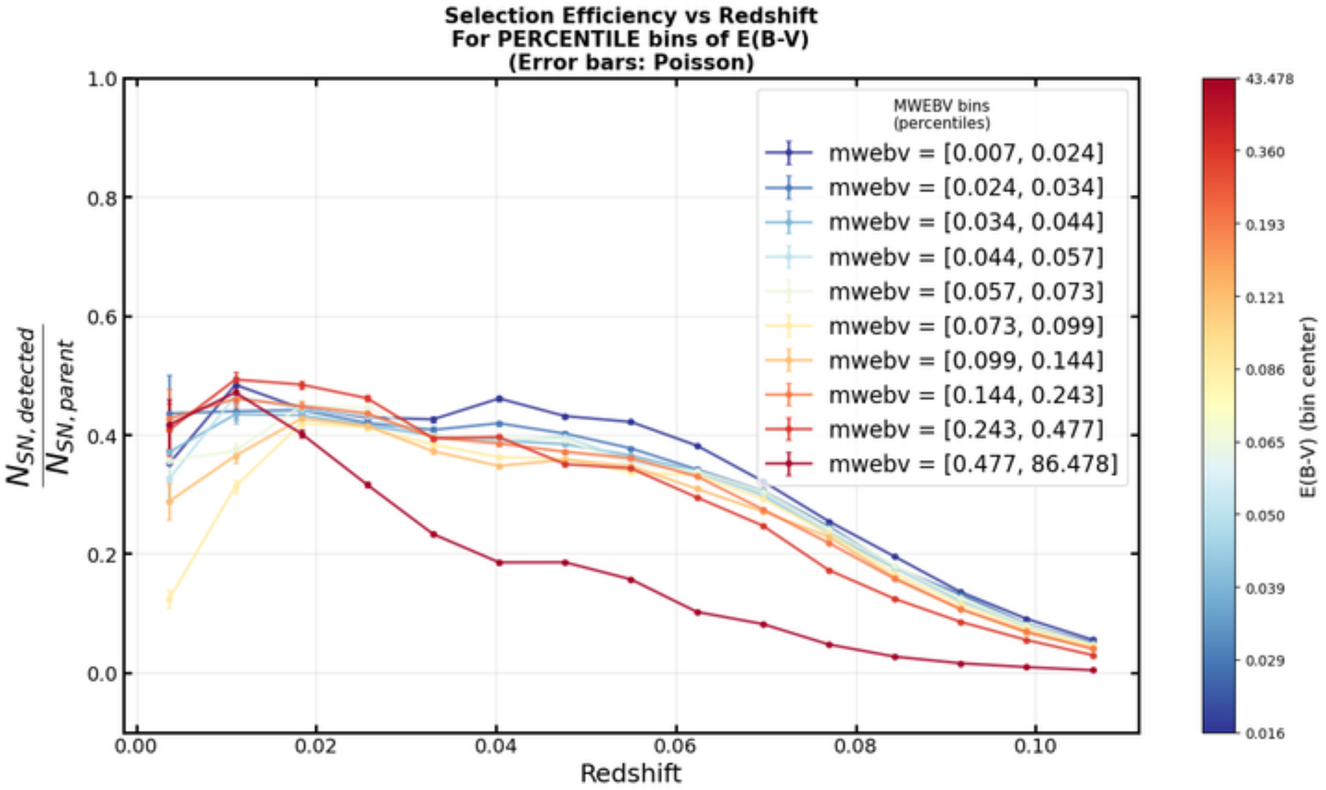


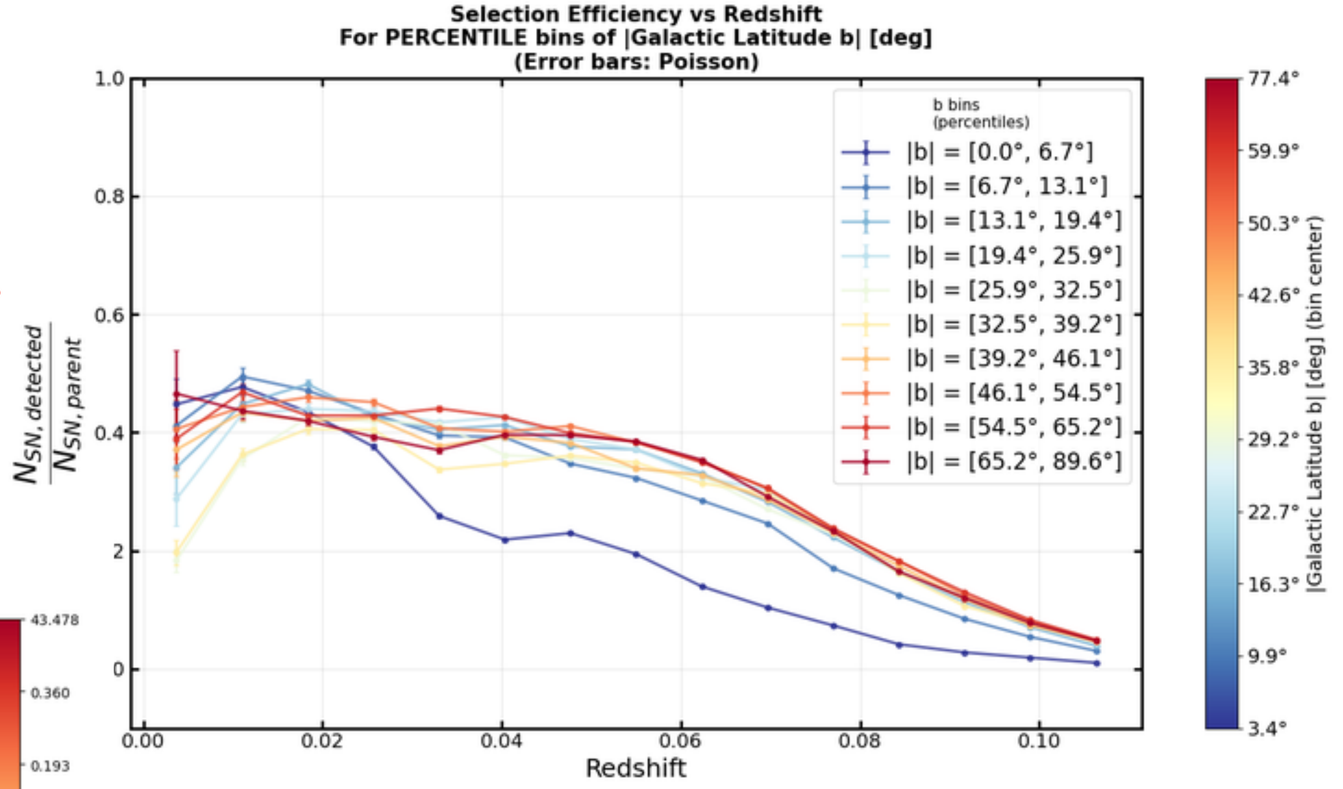


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Observation strategy

Preliminary !





Back up slides

Observation strategy

Preliminary !

