# Local few-hundred-megaparsec Hubble–Lemaître analysis with minimal model dependence

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# Overview

- context: FLRW interpretation of data is over restrictive
- aim: infer cosmological line element @few 100 Mpc with many fewer assumptions
- method:
  - theory: "quiet universe" assumption – Heinesen & Macpherson 2022 ArXiv:2111.14423
  - data: Rubin–LSST + spectro followup 4MOST + DESI

# Assumptions – details

- Lorentzian spacetime
  - $\forall \mathbf{x}$ tangent $@\mathbf{x} =$ Minkowski spacetime
- geometrical optics
- Etherington's reciprocity theorem — $d_{\mathrm{L}} = (1+z)^2 d_{\mathrm{A}}$
- congruence of light paths from emitters to observer
- negligible caustics
- convergence of $d_{\mathrm{L}}$ in $z$

$\Rightarrow$ roughly speaking, not too far from FLRW for $z \ll 1$

# Cosmographic parameters

- observational aim: determine $\mathfrak{H}_{\rm o}, \mathfrak{Q}_{\rm o}, \mathfrak{R}_{\rm o}, \mathfrak{J}_{\rm o}$ from SNe Ia
- $d_L = d_L^{(1)} z + d_L^{(2)} z^2 + d_L^{(3)} z^3 + \mathcal{O}(z^4)$

where $d_L^{(1)} = f(\mathfrak{H}_{\rm o})$,

$d_L^{(2)} = f(\mathfrak{H}_{\rm o}, \mathfrak{Q}_{\rm o})$,

$d_L^{(3)} = f(\mathfrak{H}_{\rm o}, \mathfrak{Q}_{\rm o}, \mathfrak{R}_{\rm o}, \mathfrak{J}_{\rm o})$

  - variation over sky – dipoles, quadrupoles

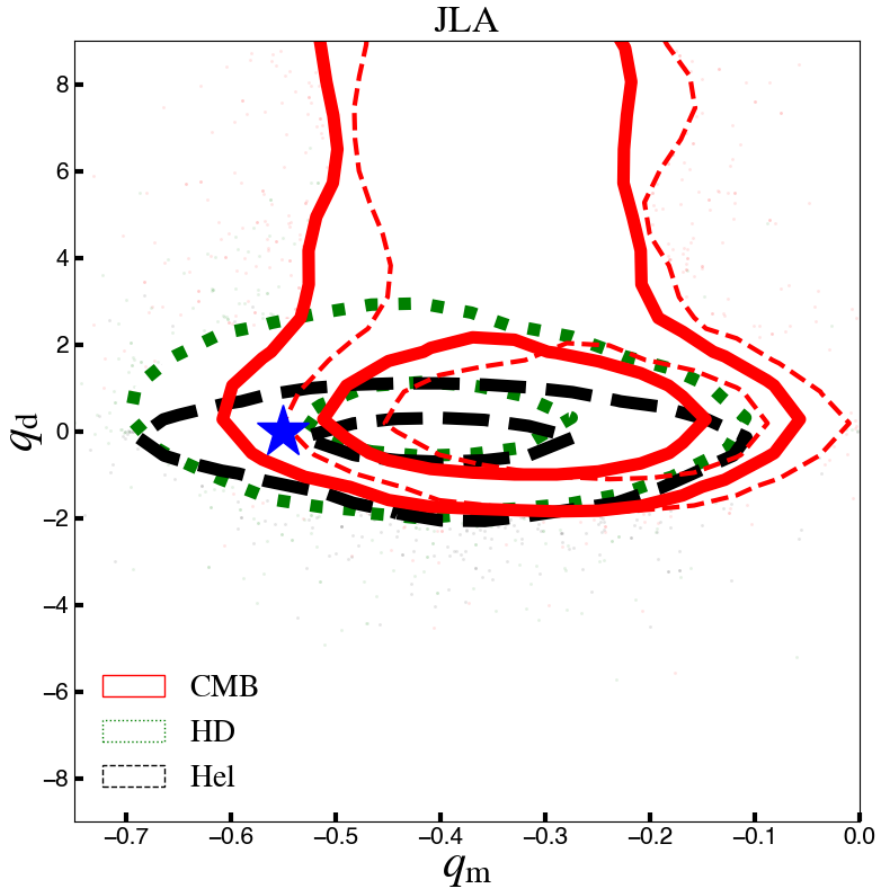
# Cosmographic predictions (HM2022)

- $\mathfrak{H}_{\rm o}$ dipole $= 0$
- $\mathfrak{Q}_{\rm o}$ dipole: $\overset{1}{\mathfrak{q}}_{\mu} \propto D_{\mu}\theta \propto D_{\mu}\rho$ – aligned with matter spatial-gradient
  - ($\mathfrak{R}_{\rm o}$ – fully dependent on $\mathfrak{H}_{\rm o}, \mathfrak{Q}_{\rm o}, \mathfrak{J}_{\rm o}$)
- $\mathfrak{J}_{\rm o}$ dipole: $\overset{1}{\mathfrak{j}}_{\mu} \propto D_{\mu}\theta \propto D_{\mu}\rho$ – aligned with $\mathfrak{Q}_{\rm o}$ dipole and matter spatial-gradient

# Analysis aim

- find best fit monopoles, dipoles and quadrupoles of $\mathfrak{H}_{\rm o}, \mathfrak{Q}_{\rm o}, \mathfrak{R}_{\rm o}, \mathfrak{J}_{\rm o}$ in $d_{\rm L}(z)$ relation
- cf Dhawan+2022
  - Pantheon + JLA
  - no significant dipole, quadrupole detected in $\mathfrak{H}_{\rm o}$, $\mathfrak{Q}_{\rm o}$ in CMB frame after accounting for peculiar velocities

# Dhawan+2022: deceleration moments




Dhawan+2022 – JLA

$\Omega_{\rm o}$ dipole $q_{\rm d}$ vs monopole $q_{\rm m}$

**Heliocen** **CMB** **HD = pec vel corr.**

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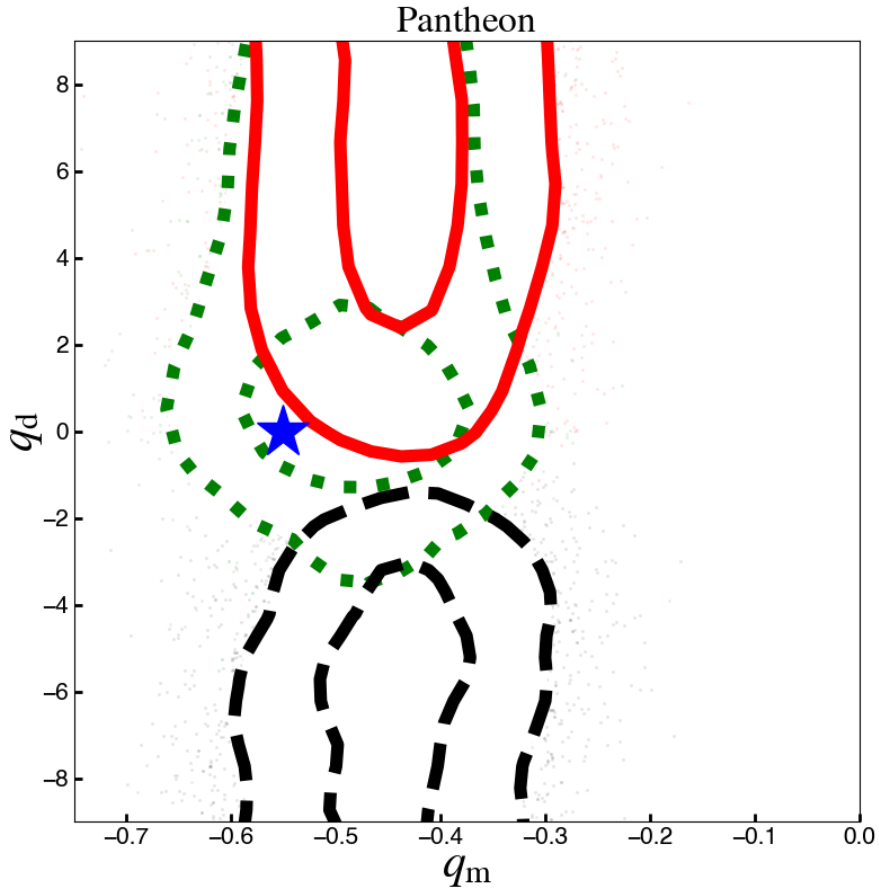


Dhawan+2022 – Pantheon

$\mathfrak{Q}_{\rm o}$ dipole $q_{\rm d}$ vs monopole $q_{\rm m}$

**Heliocen** **CMB** **HD = pec vel corr.**

# Caveats

- how much will non-uniform, non-$4\pi$ sky coverage bias the results?
- can the full selection functions (sky $\rightarrow$ Rubin $\rightarrow$ redshifts) be modelled accurately?

# Conclusion

- beyond-FLRW modelling – "cosmography" – has recently made significant progress – HM2022
- Rubin + 4MOST + DESI SNe Ia data will be ideal for the few-hundred Mpc scale
- aim: upper bounds or detections of the monopoles, dipoles and quadrupoles of $\mathfrak{H}_{\rm o}, \mathfrak{Q}_{\rm o}, \mathfrak{R}_{\rm o}, \mathfrak{J}_{\rm o}$
- HM2022 prediction: detection of $\mathfrak{Q}_{\rm o}, \mathfrak{R}_{\rm o}, \mathfrak{J}_{\rm o}$ dipoles aligned with matter spatial-gradient