Testing Generic Predictions of Dark Energy

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Outline

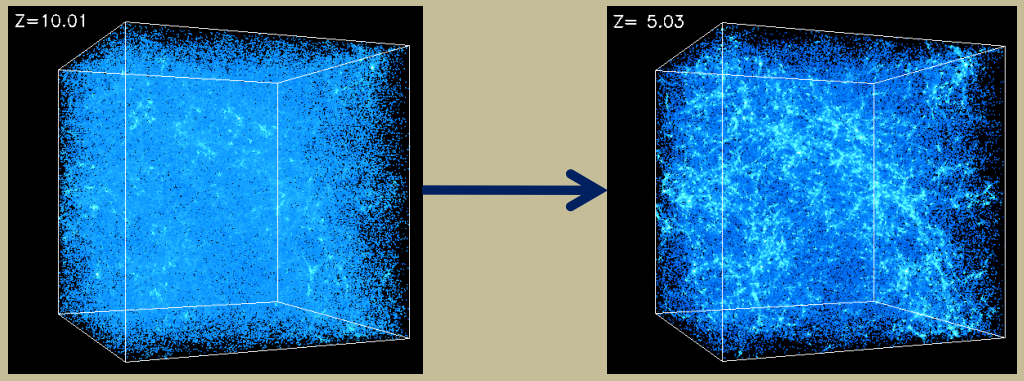
- Goals:
  1) Identify *general features* of broad *classes* of dark energy models
  2) Make *observable predictions* that provide tests of the model classes

- Methods for predicting the growth history of large-scale structure from measurements of cosmological distances

- Current predictions for two classes of dark energy models:
  - ➢ cosmological constant
  - ➢ dynamical scalar field (quintessence)

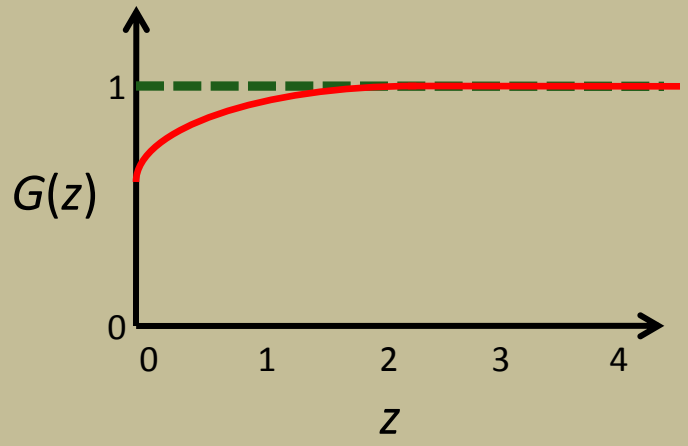
- Applications and extensions

Growth Predictions

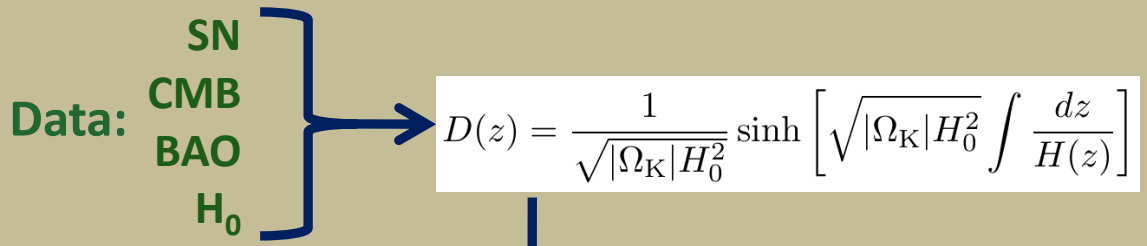


Growth of dark matter density fluctuations (simulations by A. Kravtsov)

$$G(z) = \frac{1+z}{1+z_{\rm MD}} \frac{\delta(z)}{\delta(z_{\rm MD})}$$



Growth Predictions



Best fit dark energy model → ***H(z)***

$$G'' + \left(4 + \frac{H'}{H}\right) G' + \left[3 + \frac{H'}{H} - \frac{3}{2}\Omega_m(z)\right] G = 0$$

(also $G/G(z{=}0)$, f, γ, H, D, ...)

Strength of predictions depends on:

- quality of data
- dark energy parameters and priors
- redshift
- which observable (e.g. growth relative to today or to MD epoch?)

Forecasts: Mortonson, Hu, & Huterer, PRD 79, 023004 (2009), arXiv:0810.1744

Current data: Mortonson, Hu, & Huterer, PRD in press (2010), arXiv:0912.3816

Data

SN: Union compilation (Kowalski et al. 2008)

distances to 307 Type Ia SNe at $z \lesssim 1$

CMB: WMAP5 (Komatsu et al. 2009)

distance to $z = 1100$, matter density $\Omega_m h^2$

BAO: SDSS (Eisenstein et al. 2005)

4% distance at $z = 0.35$

H_0: SH0ES measurement with HST (Riess et al. 2009)

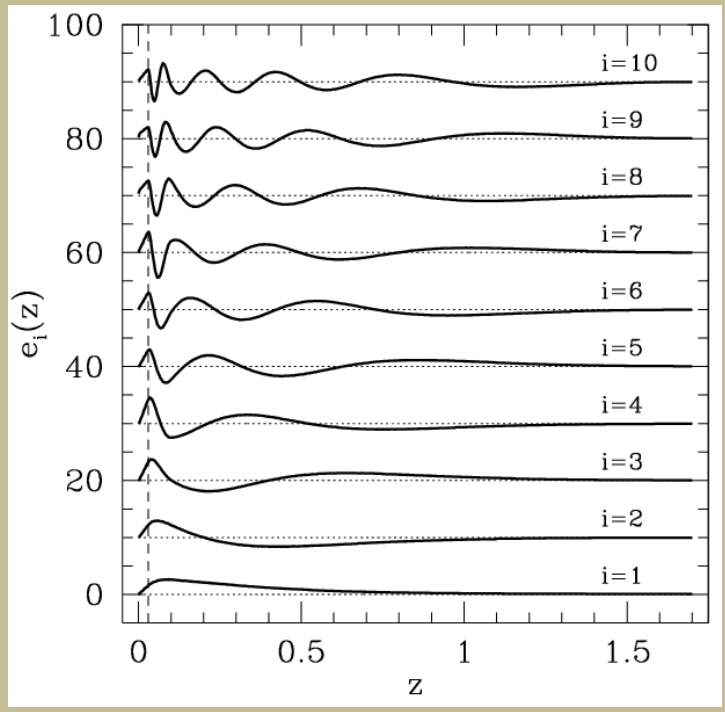
5% Hubble constant from SNe at $z < 0.1$

Parametrization

Dark energy

- cosmological constant (**ΛCDM**): ***w* = −1**

- scalar field (**quintessence**): **−1 < *w*(*z*) < 1**
  - **low *z***:
    complete set of basis functions for *w*(*z*)
  - **high *z*** (early dark energy):
    constant effective equation of state, w_∞

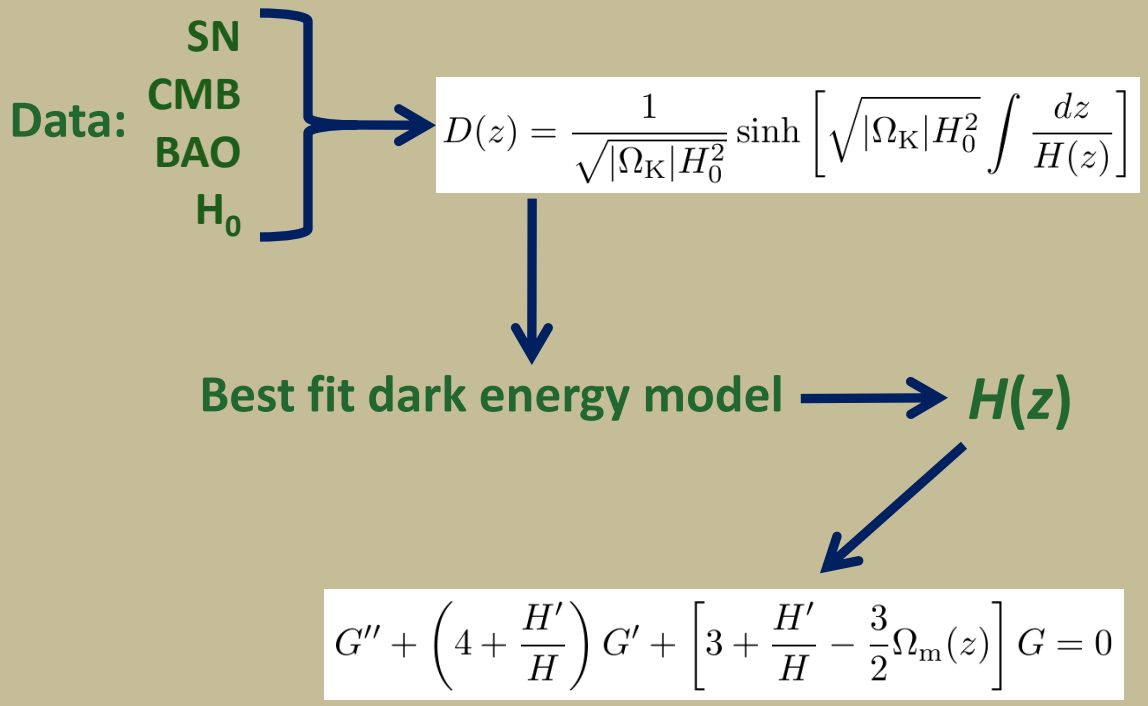


Curvature

- flat ($\Omega_K = 0$)
- nonflat ($\Omega_K \neq 0$)

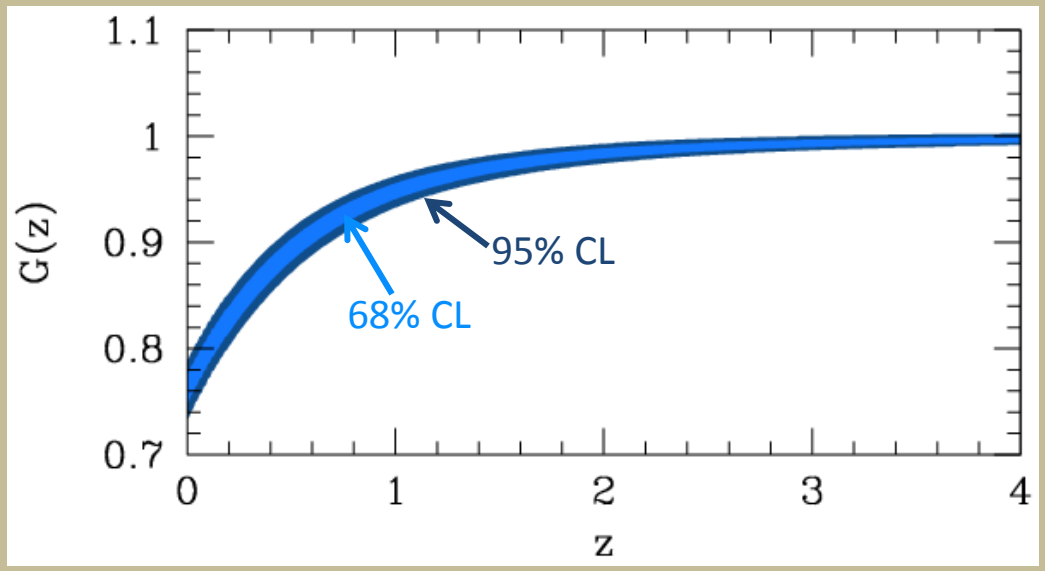
Gravity – assume GR

Growth Predictions



ΛCDM predictions

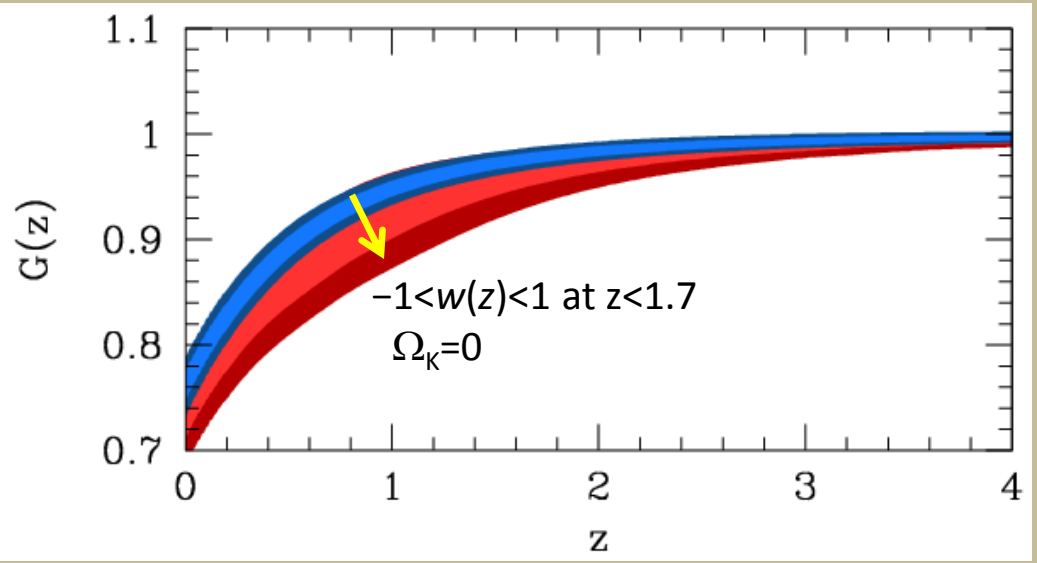
With current SN, CMB, BAO, and H_0 constraints, growth is predicted with ≲ 2% precision (including curvature).



Mortonson, Hu, & Huterer, PRD in press (2010), arXiv:0912.3816

Quintessence predictions

For more general quintessence models of dark energy, growth can be suppressed relative to ΛCDM ($w > -1$) but can't be larger by more than $\sim 2\%$.



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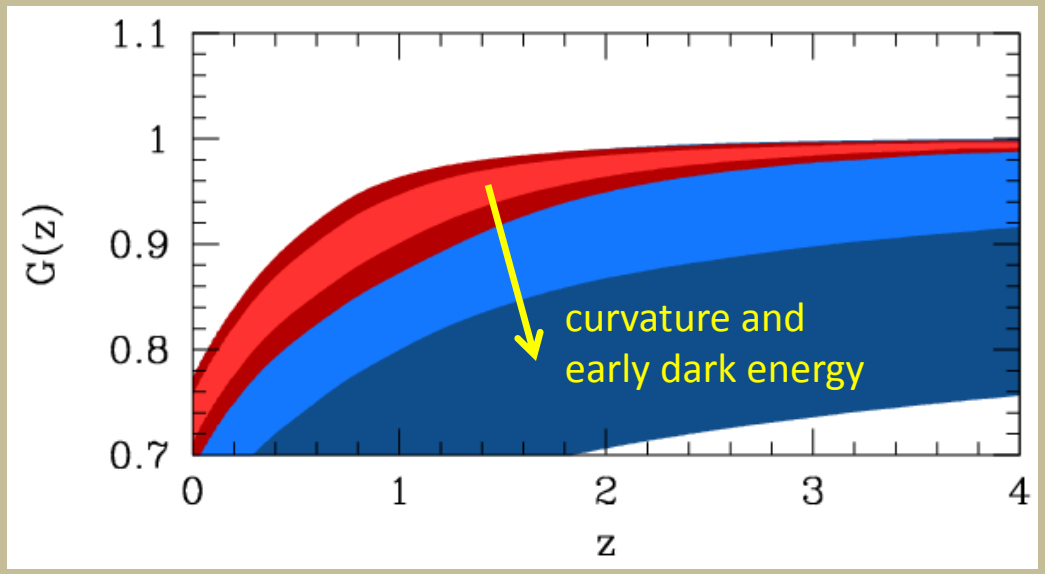

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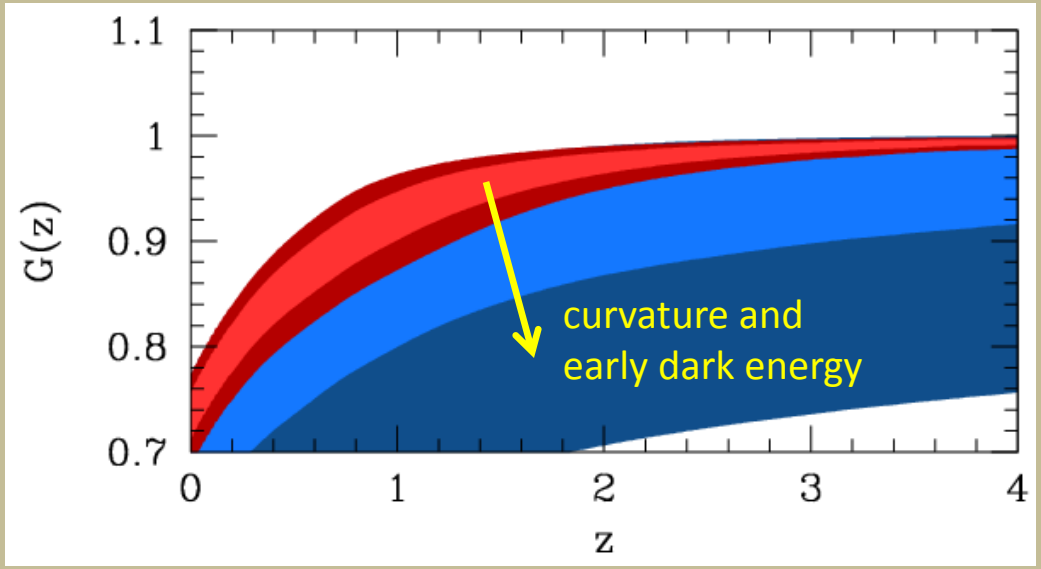
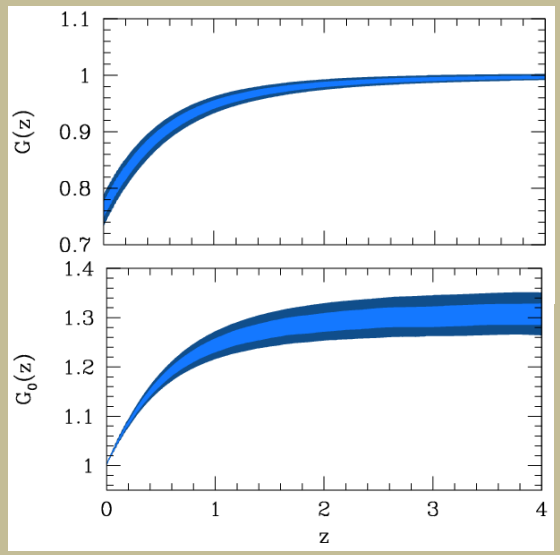


One-sided expansion of predictions due to quintessence prior:
relative to ΛCDM ($w = -1$), a quintessence model can only have larger w, so dark energy density can only increase with redshift.

Mortonson, Hu, & Huterer, PRD in press (2010), arXiv:0912.3816

Applications

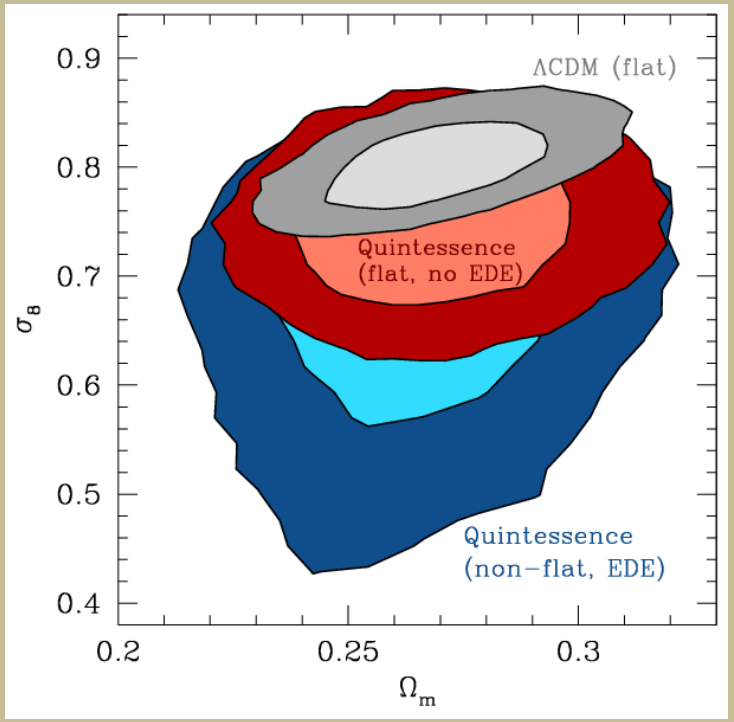
- Combine predictions with independent growth measurements
- Narrow predictions ⟶ test dark energy models
  - ➢ falsification of ΛCDM
    (suppressed growth could indicate quintessence)
  - ➢ falsification of quintessence
    (increased growth by more than a few %)
- Broad predictions ⟶ constrain model parameters
  e.g., measure growth relative to $z = 0$ to constrain Ω_K
  [Mortonson, PRD 80, 123504 (2009), arXiv:0908.0346]



- Deviations from general relativity
  Growth measurements can test for modifications to GR, but there could be degeneracies between modified gravity and dynamical dark energy since both can produce a wide range of growth histories for the same well-measured expansion history.

Future work

- Compute predictions that are closer to the observational quantities (e.g., *dN*/*dM*, cluster counts, WL, ...)
- Introduce scale dependence (massive ν, DE clustering, ...)



Summary

- Current measurements of cosmological distances strongly constrain the growth history of ΛCDM models ($\lesssim$ 2% deviations allowed).

- More general quintessence models have a wide range of growth histories, especially when curvature and early dark energy are included, but significant departures from ΛCDM are only allowed in one direction.

- Growth predictions provide multiple paths for testing a variety of general dark energy models, and provide important information about the robustness of growth-based tests of modified gravity.

- Upcoming CMB, SN, and BAO data sets will make more precise growth predictions and enable even sharper tests of dark energy models.

Forecasts

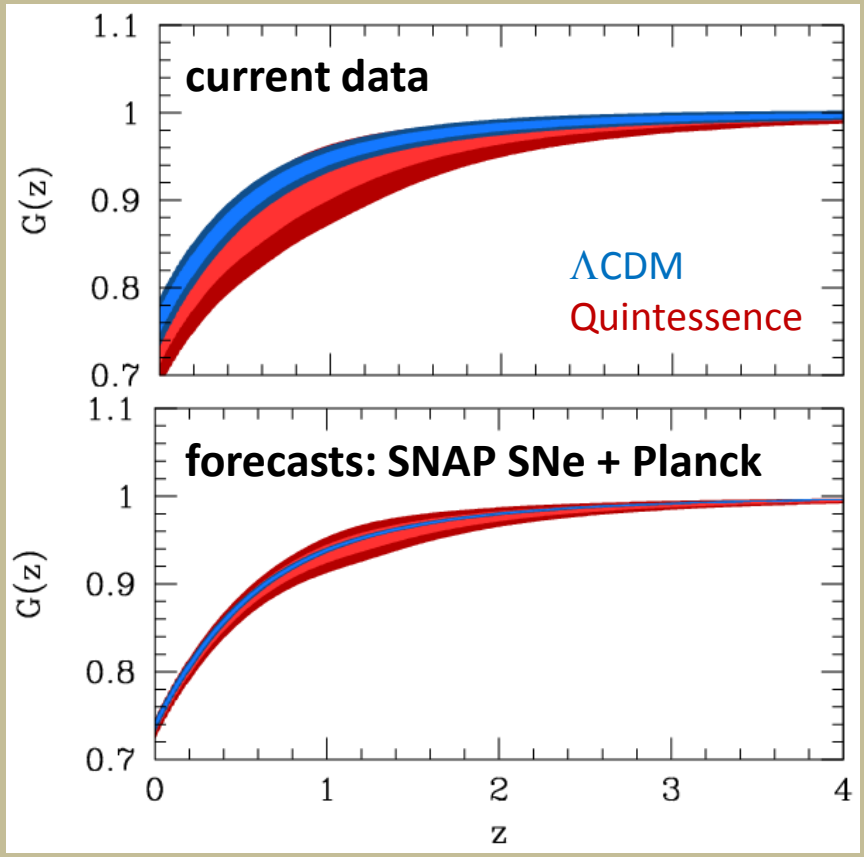


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Figure of merit for improvement in quintessence $w(z)$ parameters:

$$\text{FoM} = (\det \mathbf{C})^{-1/2}$$