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Astrophysical Tests of Fundamental Physics

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MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR

The Quest for Scalar Fields

- The fields of Nature:
 - Observed particles are described by Fermi spinors
 - Gauge forces are described by boson vector fields
 - Einstein gravity uses only a 2-tensor (the metric)
 - Is there anything else (such as fundamental scalar fields)?
- Scalar fields have long been part of the standard model of particle physics (cf. the Higgs particle).
- Recent developments suggest that they could be equally important in astrophysics and cosmology.
- ***Yet neither side has so far produced definitive experimental or observational evidence for them...***



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Hints of New Physics

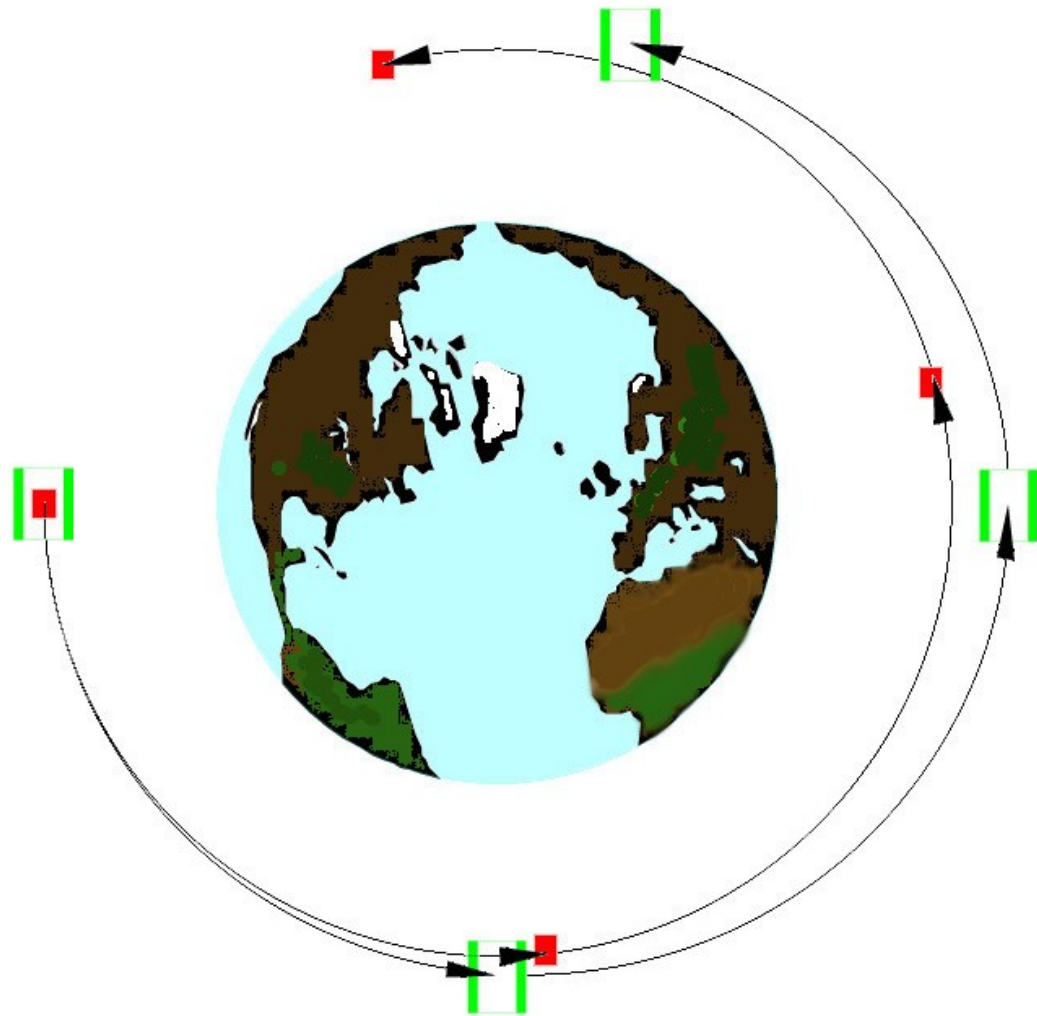
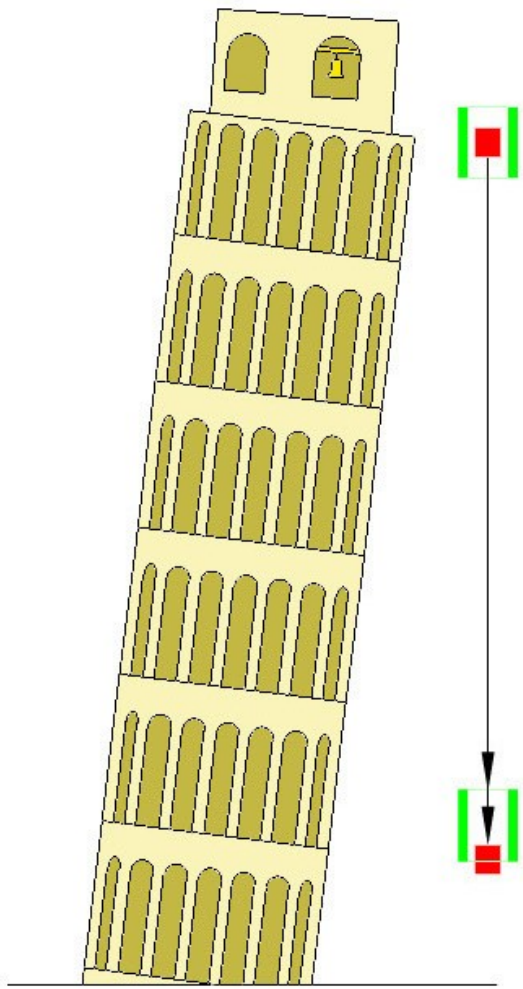
- Three firmly established facts that the standard model of particle physics can't explain:
 - **Neutrino masses:** Most important recent result in particle physics, needs new ad-hoc conservation law or phenomena beyond current framework.
 - **Dark matter:** no object in SM can account for the amount of dark matter required by observations (and baryons or massive neutrinos can't do it).
 - **Size of baryon asymmetry:** A mechanism for BAU does exist, but fails quantitatively given the measured values of the parameters controlling it.
- It's precisely our confidence in the standard model that leads us to the expectation that there must be new physics beyond it.
- All have obvious astrophysical and cosmological implications!
- ***Progress in fundamental particle physics increasingly depends on progress in cosmology.***

Scalar Fields in Cosmology

- Scalar fields play a key role in most paradigms of modern cosmology, yielding *inter alia*
 - Exponential expansion of the early universe (inflation)
 - Relics of cosmological phase transitions (cosmic defects)
 - Dynamical dark energy powering current acceleration phase
 - Varying fundamental couplings
- ***Even more important than each of these paradigms is the fact that they usually don't occur alone – this will be crucial for future consistency tests!***

To Couple or Not To Couple

- Any scalar field couples to gravity.
- It couples to nothing else if a global symmetry $\phi \rightarrow \phi + \text{const.}$ acts to suppress couplings to the rest of the Lagrangian.
 - If so, only derivatives and derivative couplings survive.
- Quantum gravity effects don't respect global symmetries, and there's no unbroken global symmetries in string theory.
- *Scalars in the theory will couple to the rest of the world (in any manner not prevented by symmetry principles).*

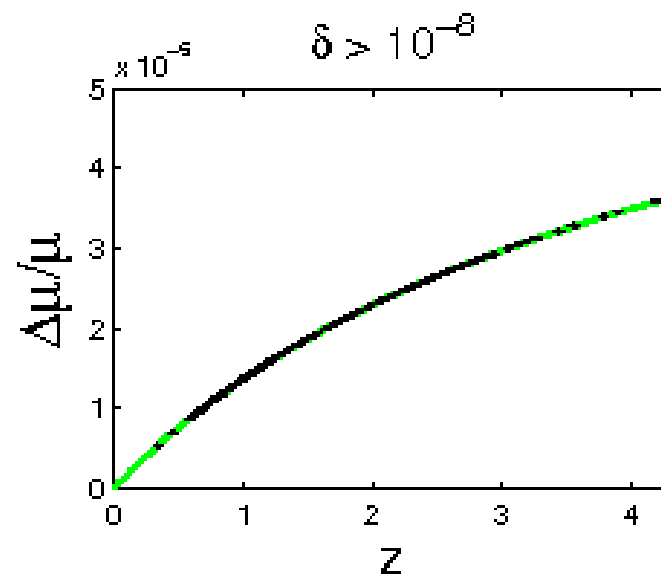
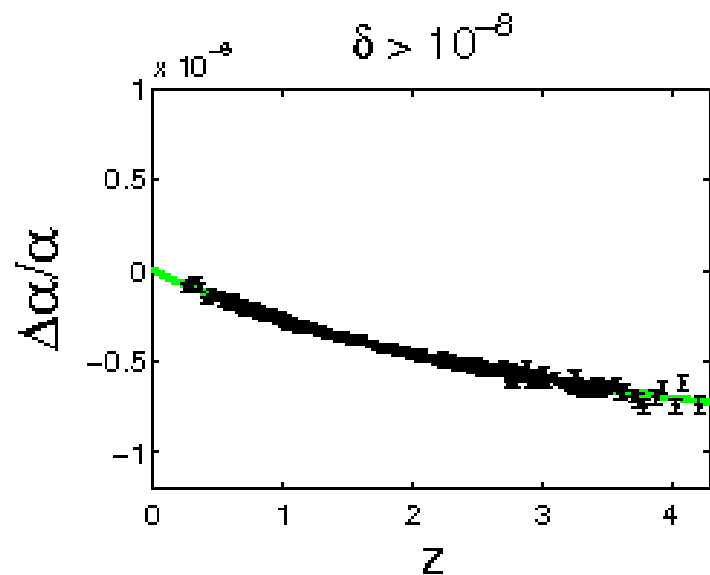
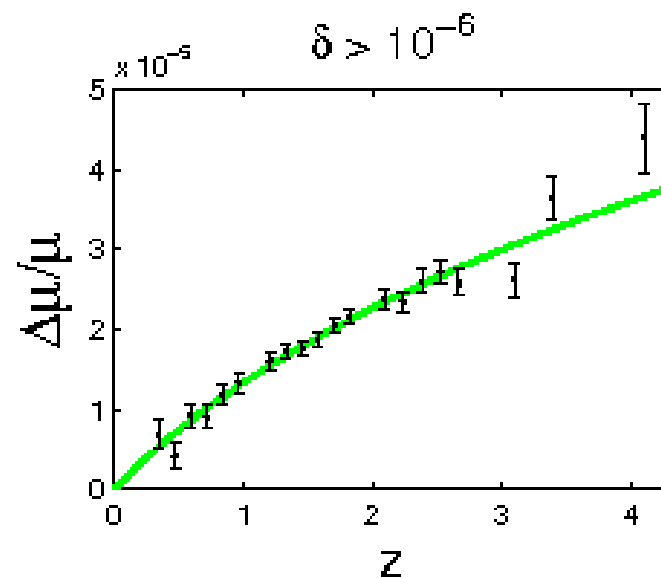
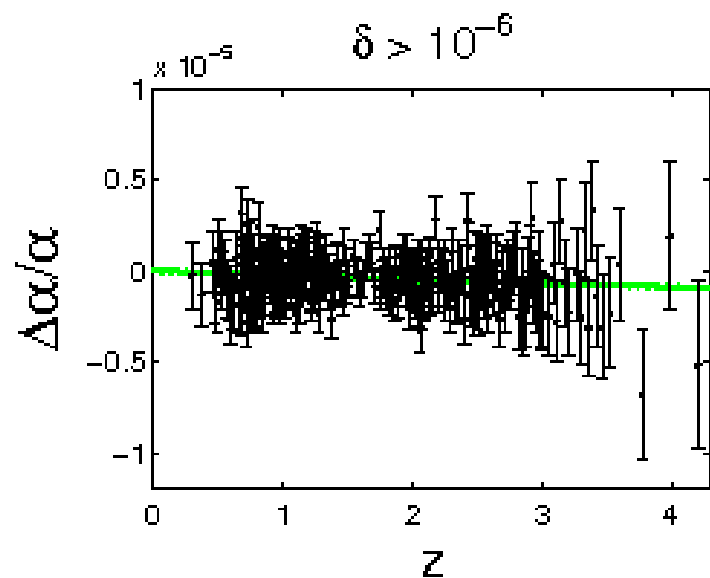


Case Study: From α (and μ) to w

- Scalar field yielding dark energy must give varying couplings. They can be used to reconstruct $w(z)$ [Nunes & Lidsey 2004].
 - Analogous to reconstructing the 1D potential for the classical motion of a particle, given its trajectory
- Will complement and easily be competitive with standard methods.
- Key Advantages:
 - ***Direct probe of Grand Unification and fundamental physics***
 - ***Directly distinguishes Λ from dynamical field (no false positives)***
 - ***Huge z lever arm, probes otherwise inaccessible z range where scalar field dynamics is expected to be fastest (deep matter era)***
 - ***Cheaper, ground-based (~100 good nights on VLT, Keck, LBT, ...)***
 - ***We can start now!***

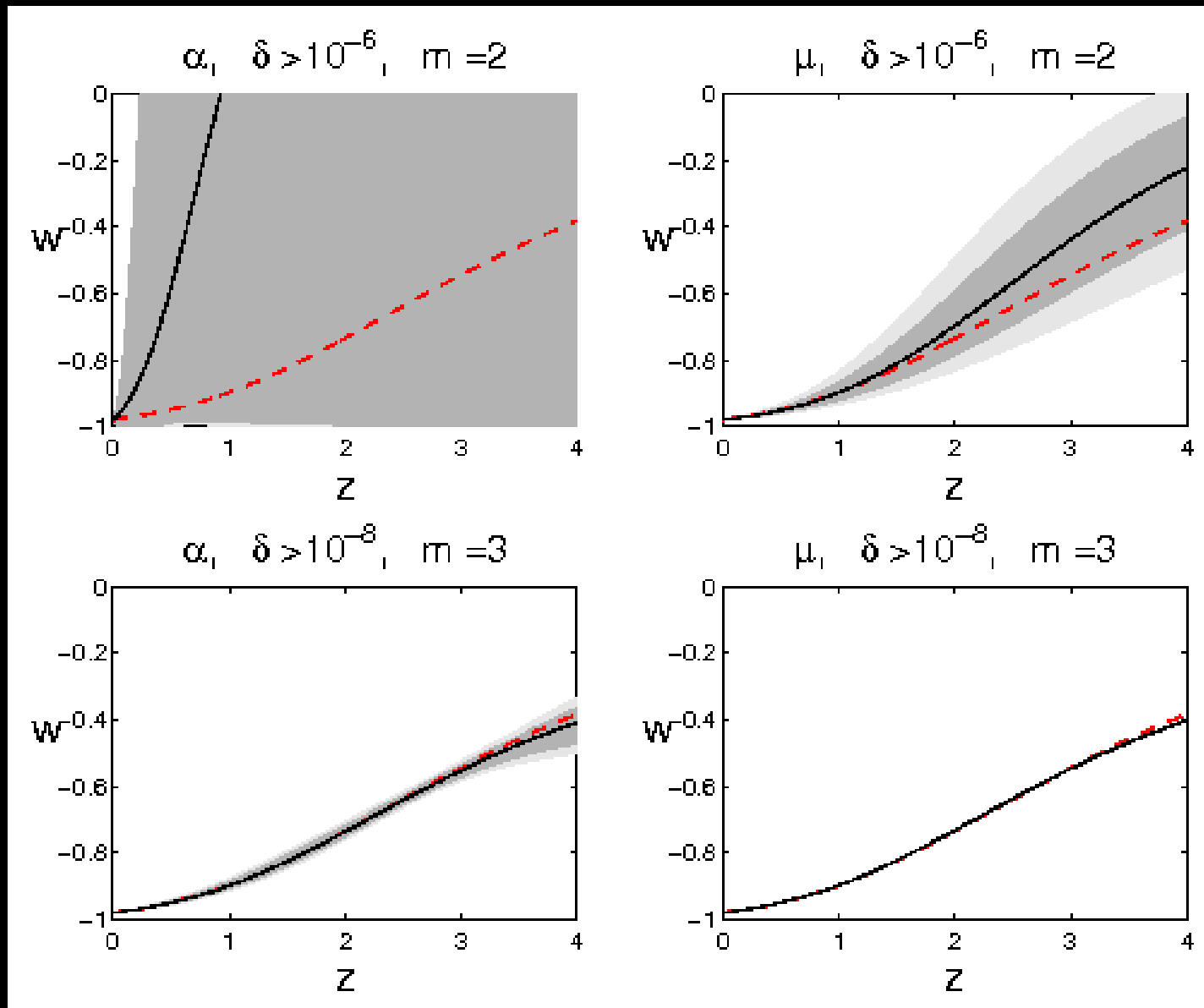
Data: Soon vs. CODEX

With P. Avelino, N. Nunes, K. Olive, PRD74, 083508



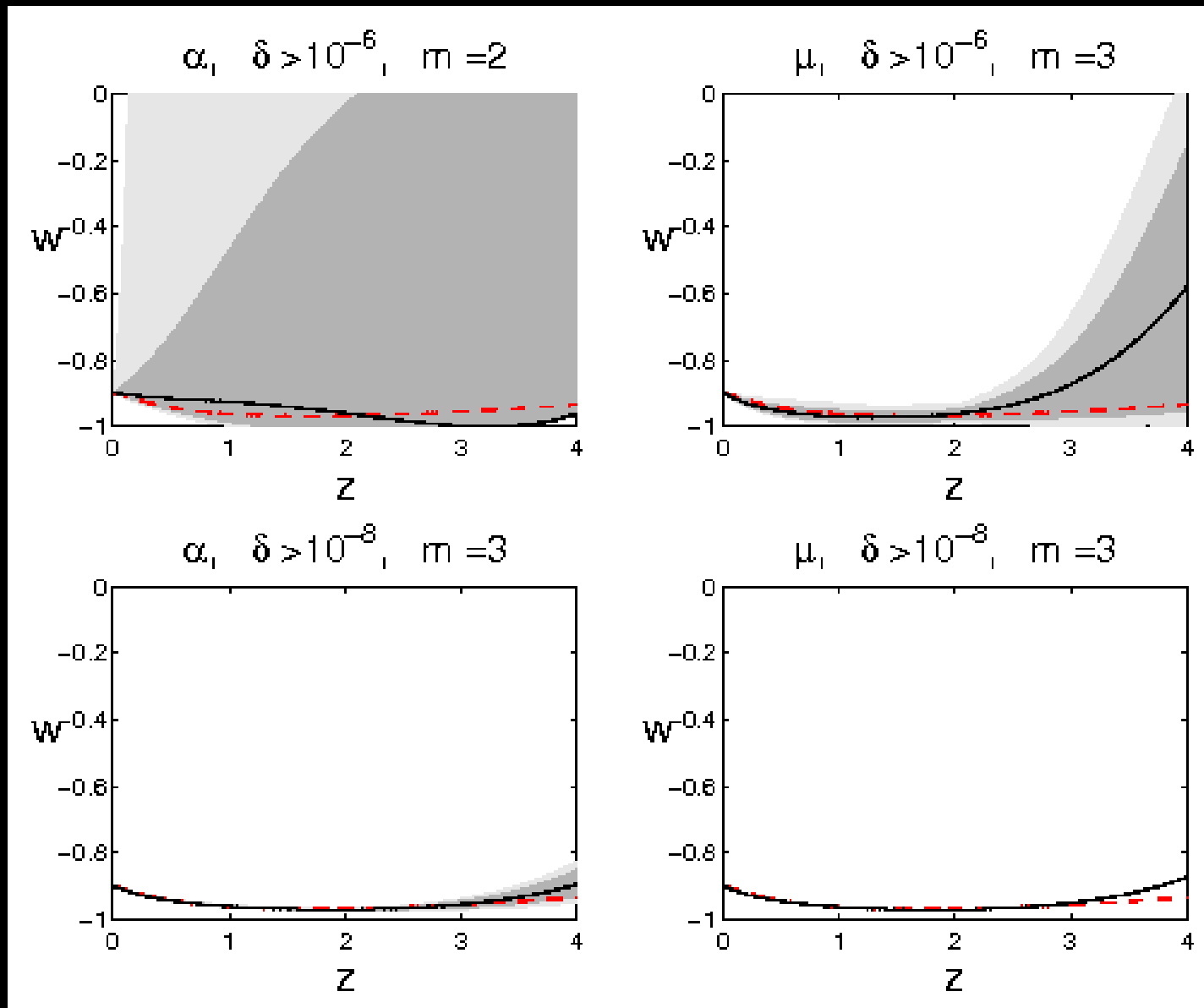
Reconstruction: Soon vs. CODEX

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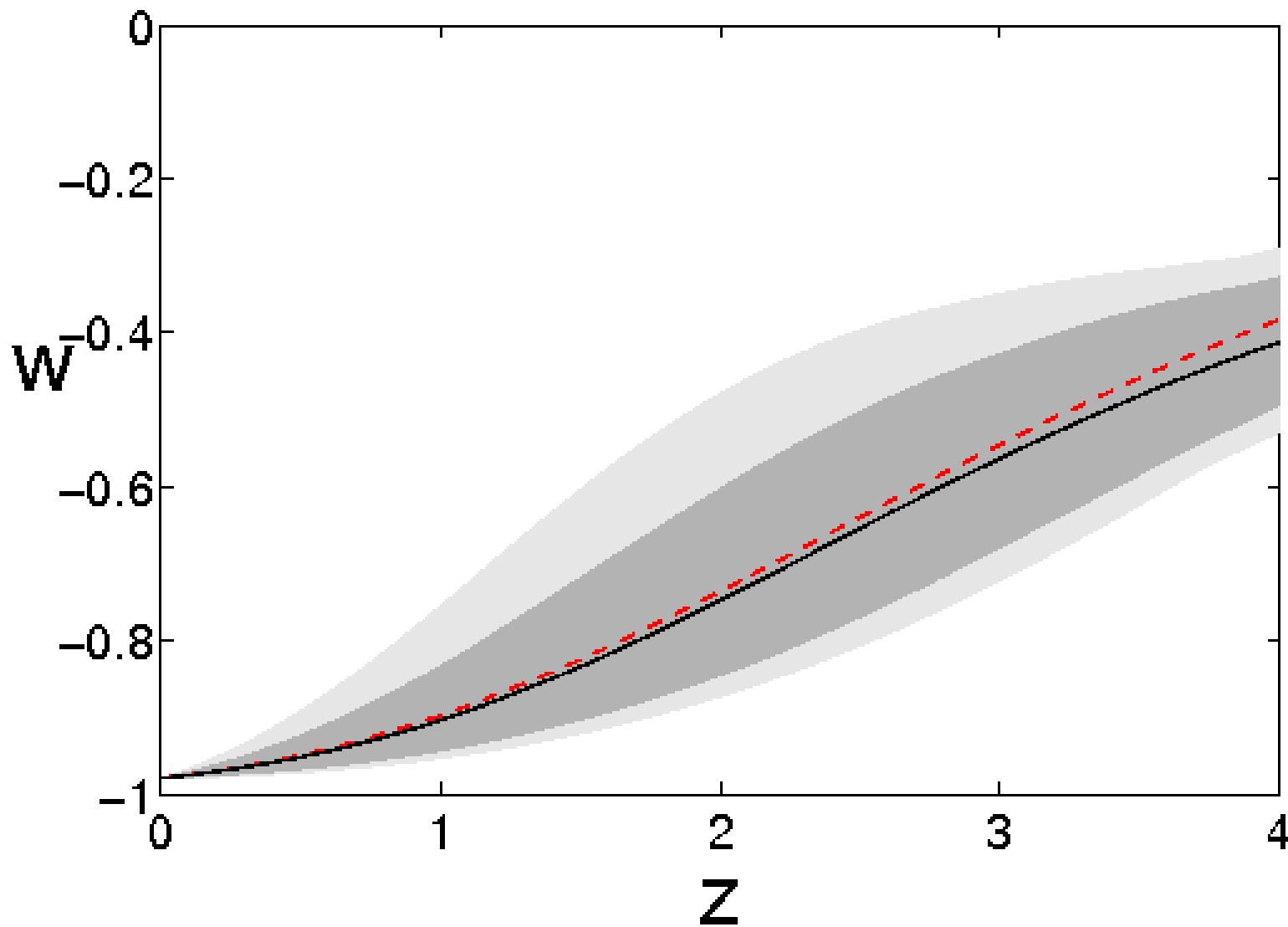
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Reconstruction: ESPRESSO

$$\alpha + \mu, \quad \delta = 10^{-6}, \quad m = 3$$





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