Title: Detecting scalar field with extreme mass ratio inspirals

Speakers: Nicola Franchini

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Abstract: I will present extreme mass ratio inspirals (EMRIs), during which a small body spirals into a supermassive black hole, in gravity theories with additional scalar fields. No-hair theorems and properties of known theories that manage to circumvent them introduce a drastic simplification to the problem: the effects of the scalar on supermassive black holes, if any, are mostly negligible for EMRIs in vast classes of theories. I will show how to exploit this simplification to model the inspiral perturbatively and demonstrate that the scalar charge of the small body leaves a significant imprint on gravitational wave emission. This result is particularly appealing, as this imprint is observable with LISA, rendering EMRIs promising probes of scalar fields.

Detecting scalar fields with extreme mass ratio inspirals

Nicola Franchini – Sissa, Trieste

24th Capra meeting 2021

8 Jun 2021 – Online ☹

Based on the works made in collaboration with Andrea Maselli, Susanna Barsanti, Leonardo Gualtieri, Thomas Sotiriou and Paolo Pani - To appear soon

European Research Council
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ERC-2018-COG GRAMS 815673

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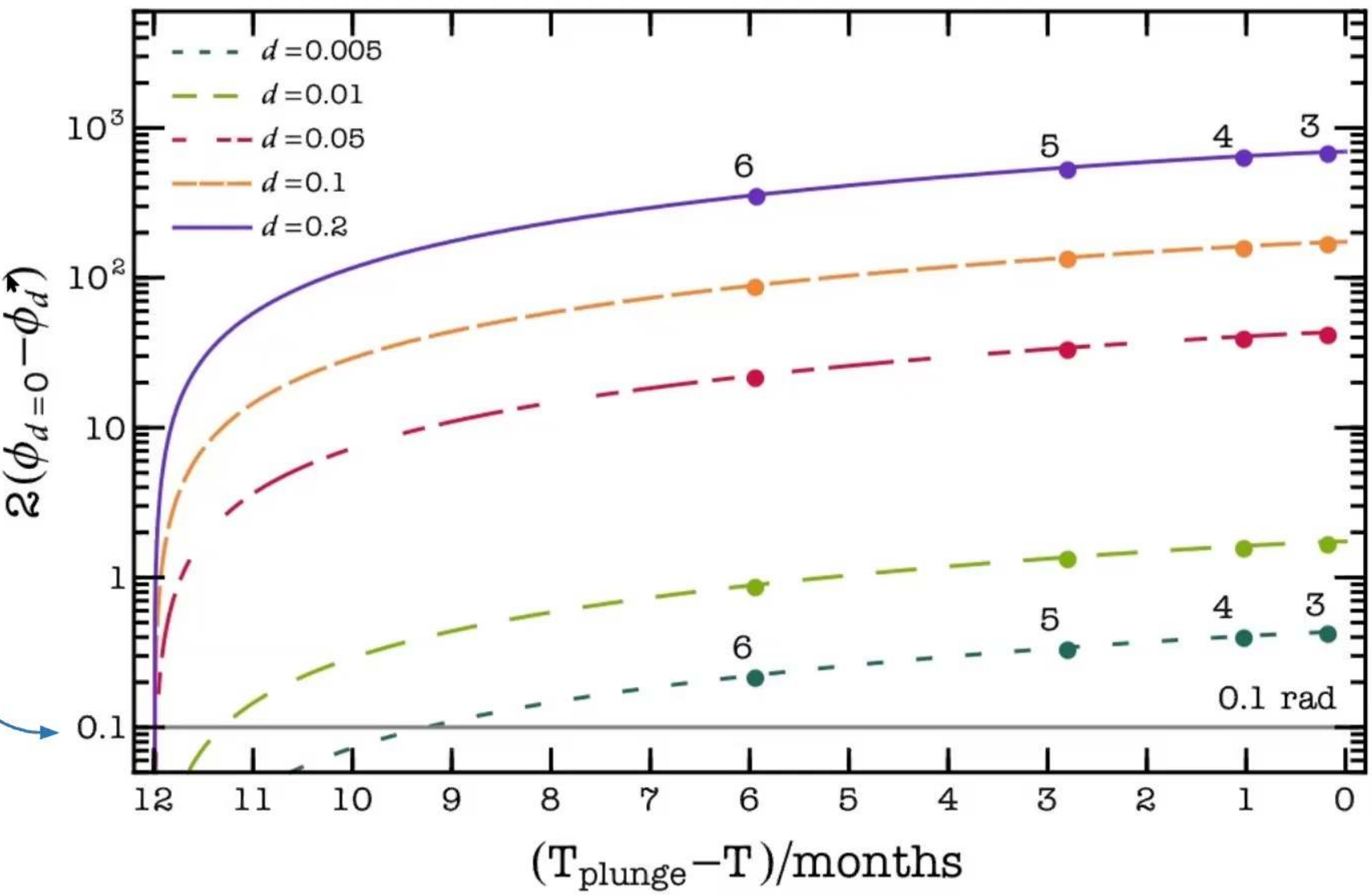
Let’s take it back from here...

$M = 10^6 M_\odot$

$\chi = 0.9$

$\mu = 10 M_\odot$

Detectability for a signal of SNR = 30



Are we really able to measure scalar charges down to 0.005 with LISA?

This is optimistic, but there is a lot that we can say

Waveform generation

Flux radiated by the binary

$$\dot{E} = \dot{E}_{\rm GR} + d^2\,\dot{E}_{\rm scal}$$

Universal, theory independent relation

Recall Susanna's talk

Adiabatic evolution of the inspiral in circular orbits

$$\frac{dr}{dt} = \dot{E}\frac{dr}{dE_{\rm orb}} \qquad \frac{d\Phi}{dt} = \omega_p$$

Keplerian frequency

Waveform generation

Quadrupole approximation, TT gauge for metric perturbation
Analytic kludge

$$h_{ij}^{\mathrm{TT}} = \frac{2}{D}\left(P_{il}P_{jm} - \frac{1}{2}P_{ij}P_{lm}\right)\ddot{I}_{lm}$$

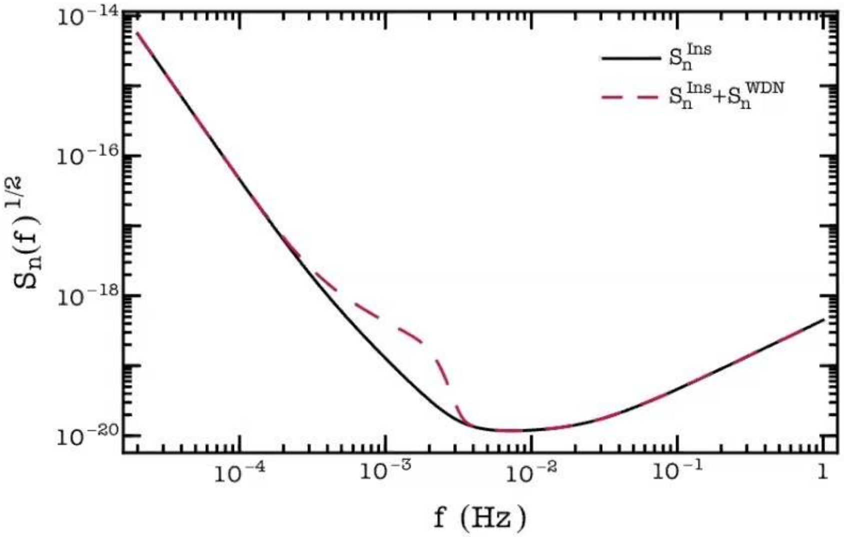
→ Quadrupole moment

$$I_{ij} = \mu z^i(t) z^j(t)$$

→ Location of the secondary. Depends on $r(t)$ and $\Phi(t)$

Barack, Cutler (2004)
Huerta, Gair (2011)
Canizares, Gair, Sopuerta (2012)

Waveform comparison



Robson, Cornish, Liu (2019)

Inner product between two templates

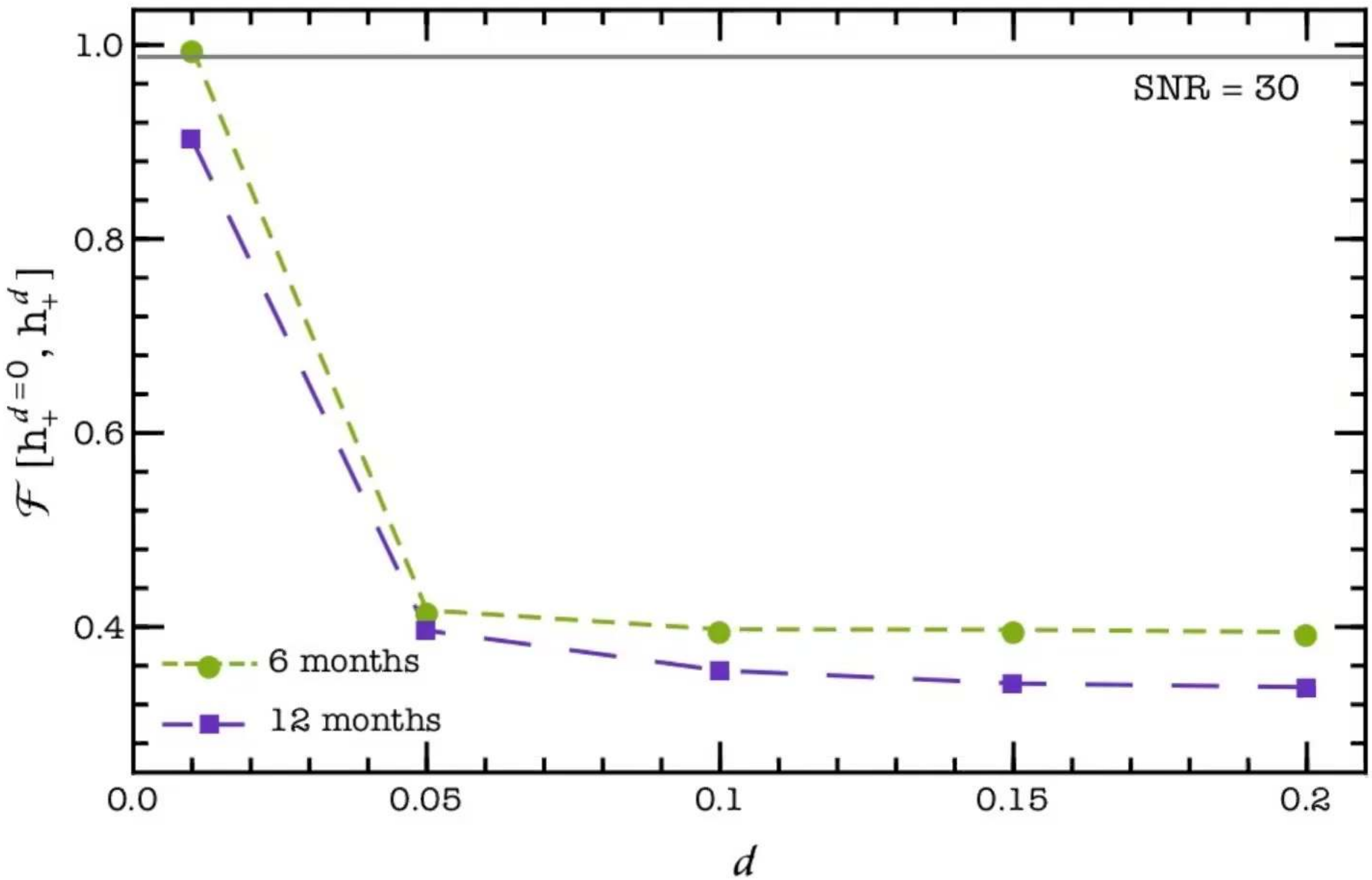
$$\langle h_1 | h_2 \rangle = 4\Re \int_0^{f_{\rm ISCO}} \frac{\tilde{h}_1(f)\tilde{h}_2^*(f)}{S_n(f)} df$$

Faithfulness: comparison between two templates

$$\mathcal{F}[h_1, h_2] = \max_{\{t_c, \phi_c\}} \frac{\langle h_1 | h_2 \rangle}{\sqrt{\langle h_1 | h_1 \rangle \langle h_2 | h_2 \rangle}}$$

Lindblom, Owen, Brown (2008)

Waveform comparison



LISA potential capability to distinguish faithfulness

Parameter estimation

The strain measured by the detector depends on 11 parameters

$$\vec{\theta} = (M, \mu, \chi, D, \theta_s, \phi_s, \theta_l, \phi_l, r_0, \Phi_0, d)$$

Parameter estimation

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Masses of primary and secondary BH, spin of the primary

Parameter estimation

The strain measured by the detector depends on 11 parameters

$$\vec{\theta} = (M, \mu, \chi, D, \theta_s, \phi_s, \theta_l, \phi_l, r_0, \Phi_0, d)$$

Scalar charge of the secondary

Parameter estimation

Fisher matrix

Poisson, Will (1995)
Vallisneri (2008)

$$\Gamma_{ij} = \left\langle \frac{\partial h}{\partial \theta_i} \middle| \frac{\partial h}{\partial \theta_j} \right\rangle_{\theta=\hat{\theta}}$$

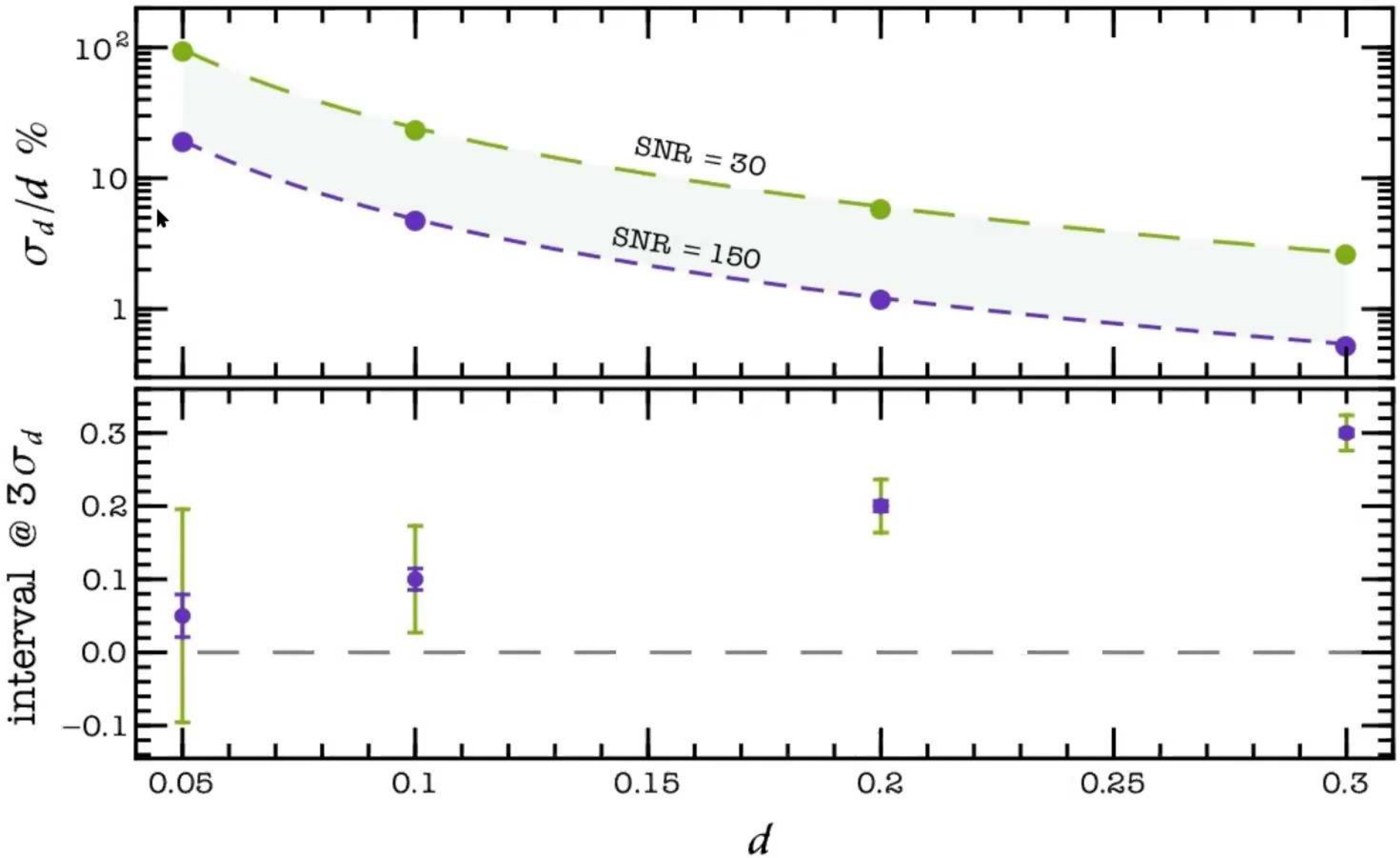
True values

Statistical errors

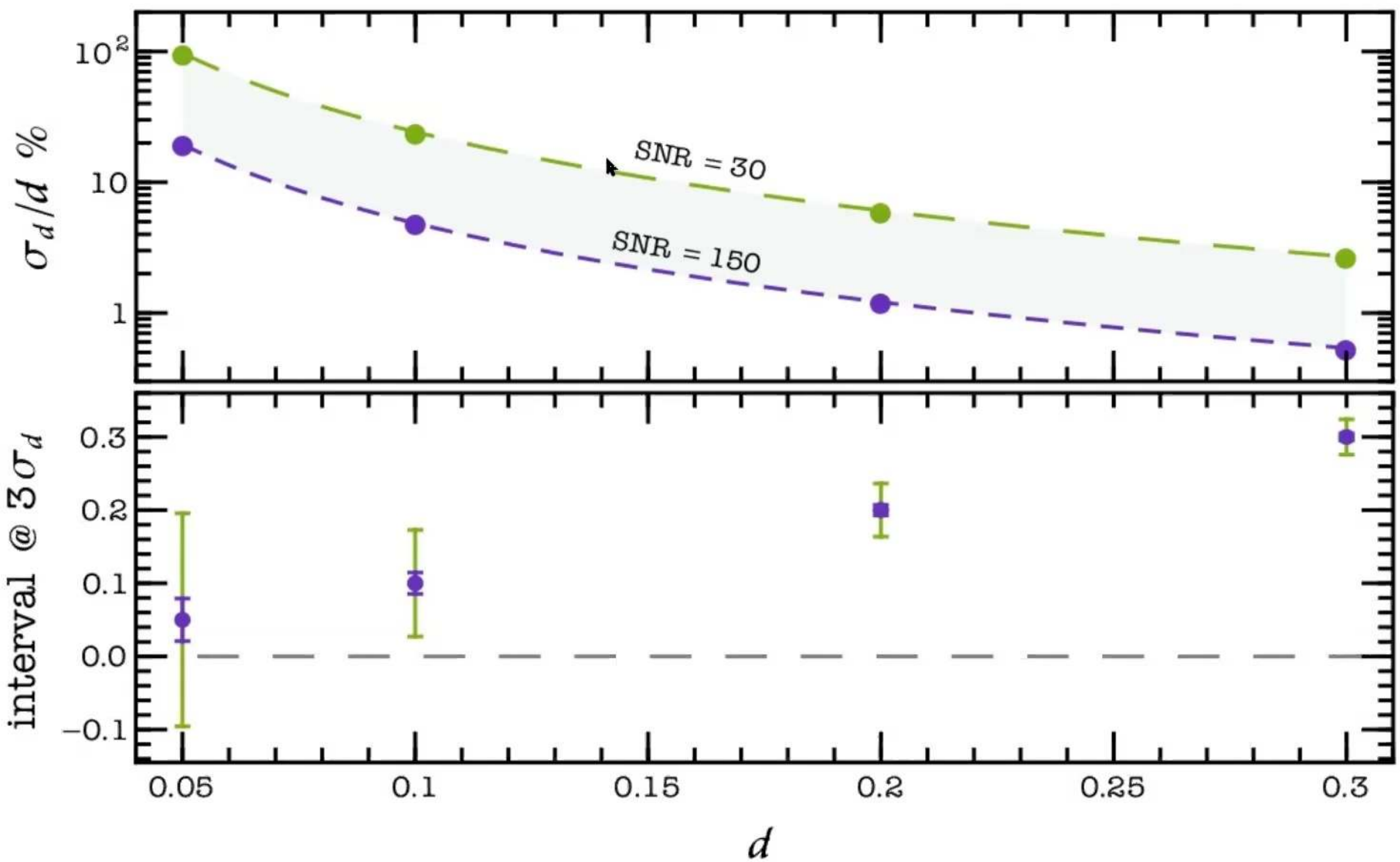
$$\mathbf{\Sigma} = \mathbf{\Gamma}^{-1} \longrightarrow \sigma_i = \Sigma_{ii}^{1/2}$$

$$\vec{\theta} = (M, \mu, \chi, D, \theta_s, \phi_s, \theta_l, \phi_l, r_0, \Phi_0, d)$$

Parameter estimation



Parameter estimation



Conclusions

- First attempt to perform a rigorous estimation of the measurability of beyond GR effects with EMRIs
- We can constrain a charge d=0.01 with ~10% error making conservative assumptions. Larger charges get smaller errors, down to 1%!
- The procedure is theory agnostic, but can be traced back to specific theories if there is a mapping between d and the fundamental coupling