



Leibniz
Universität
Hannover



MAX PLANCK INSTITUTE
FOR GRAVITATIONAL PHYSICS
(ALBERT EINSTEIN INSTITUTE)



MODELLING LOW-FREQUENCY CONTROL NOISE FOR THE EINSTEIN TELESCOPE AND DERIVING A REQUIREMENTS MATRIX

ET Symposium, ISB/ANM session

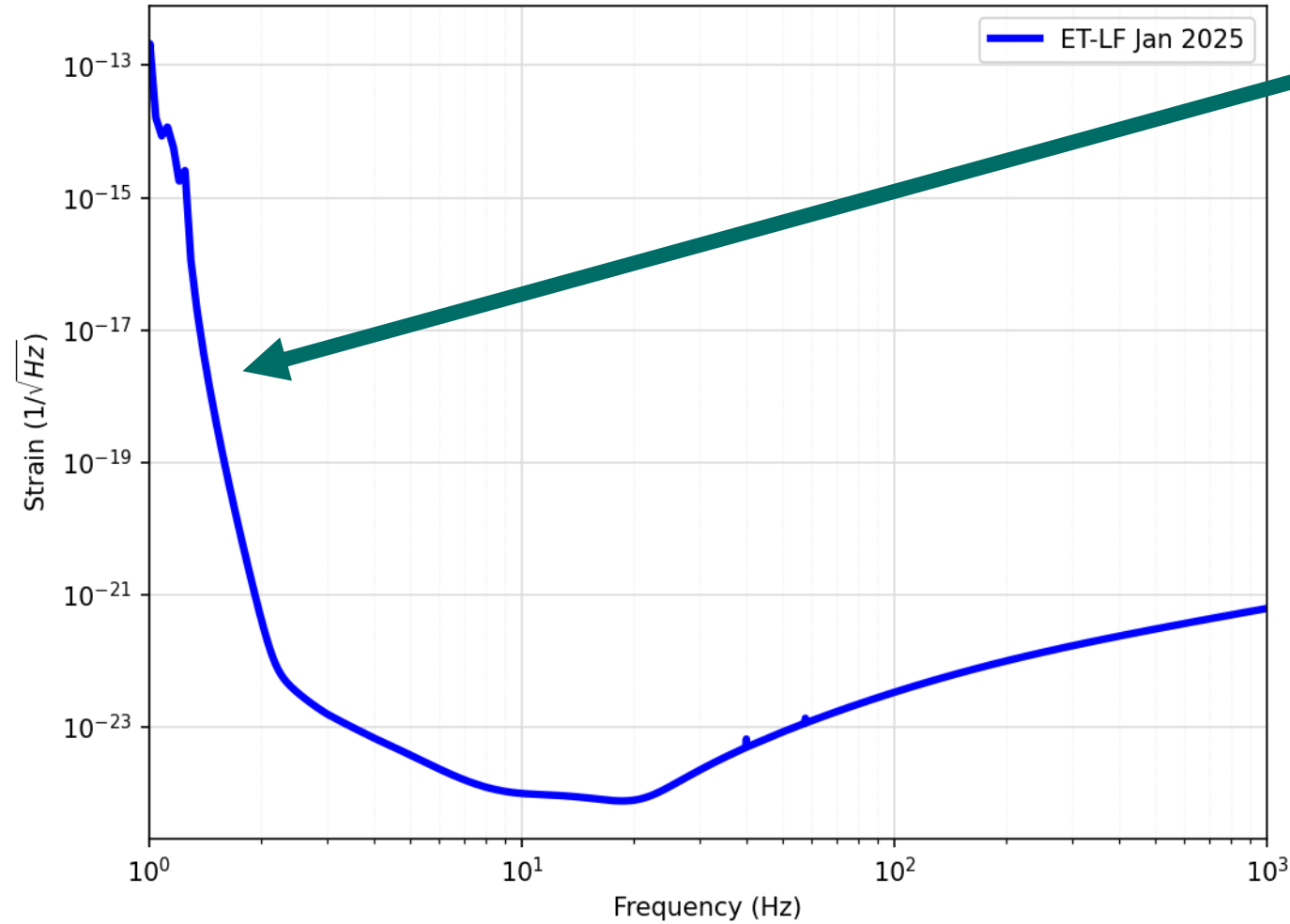
Artem Basalaeu (AEI Hannover, 10 m Prototype)
on behalf of ET LF Control Noise WP

ET-0264A-25, ET-0327A-25

27 May 2025



LOW-FREQUENCY NOISE WALL



Very steep here!
Can we actually
achieve this?

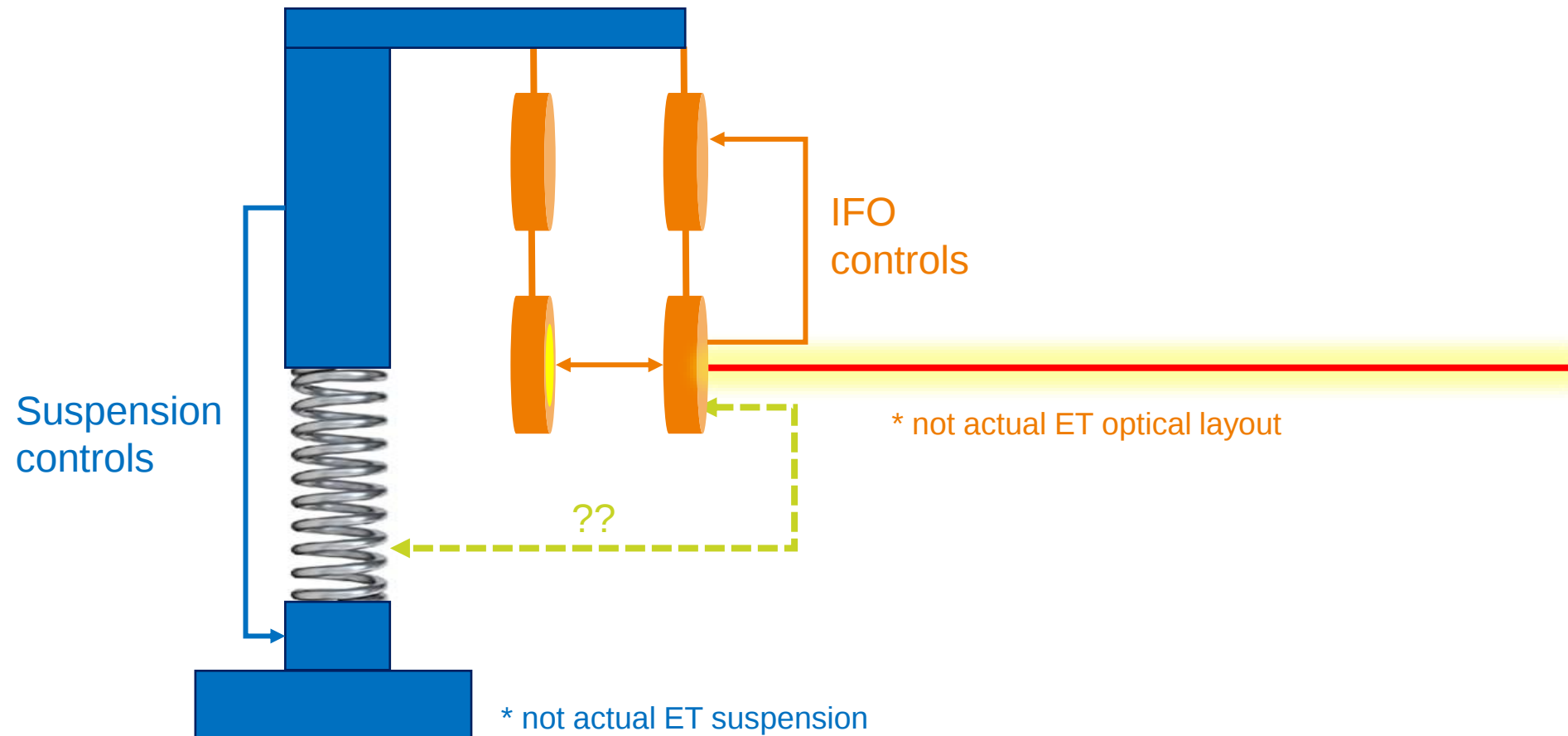
We don't know:
complex
interplay of
requirements

[et-sensitivity-
curves in git](#)





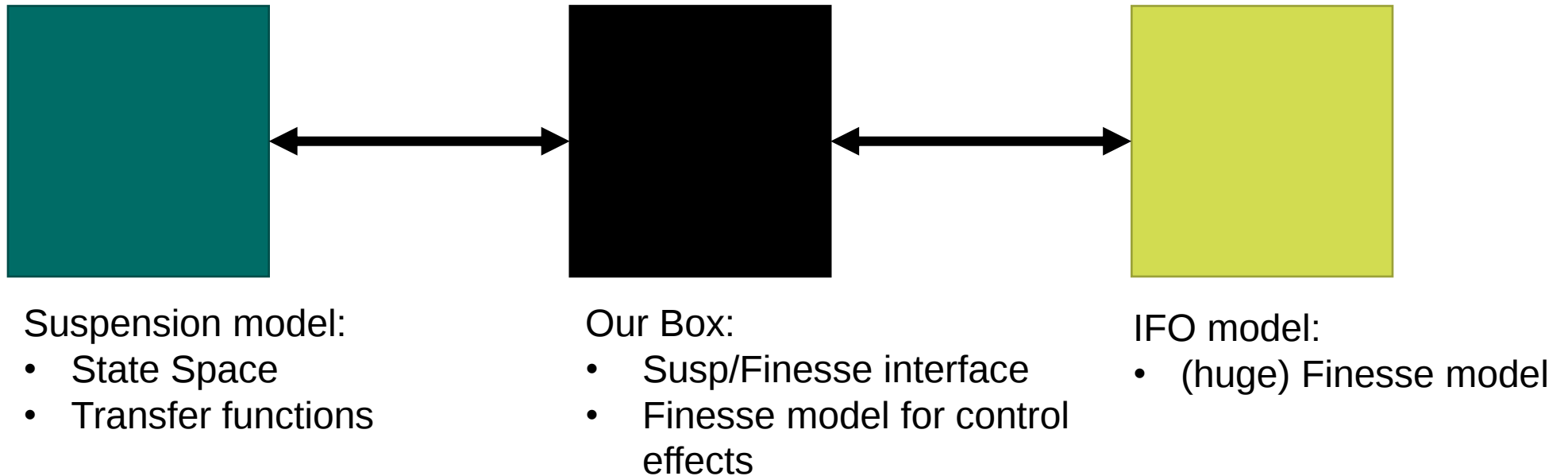
CONTROLS (ESPECIALLY LF) ARE UNIQUELY AFFECTED BY INTERPLAY OF NOISES IN TWO REALMS: OPTICS AND MECHANICS





HOW TO TACKLE THIS INTERFACE WITHOUT “SIMULATING EVERYTHING”?

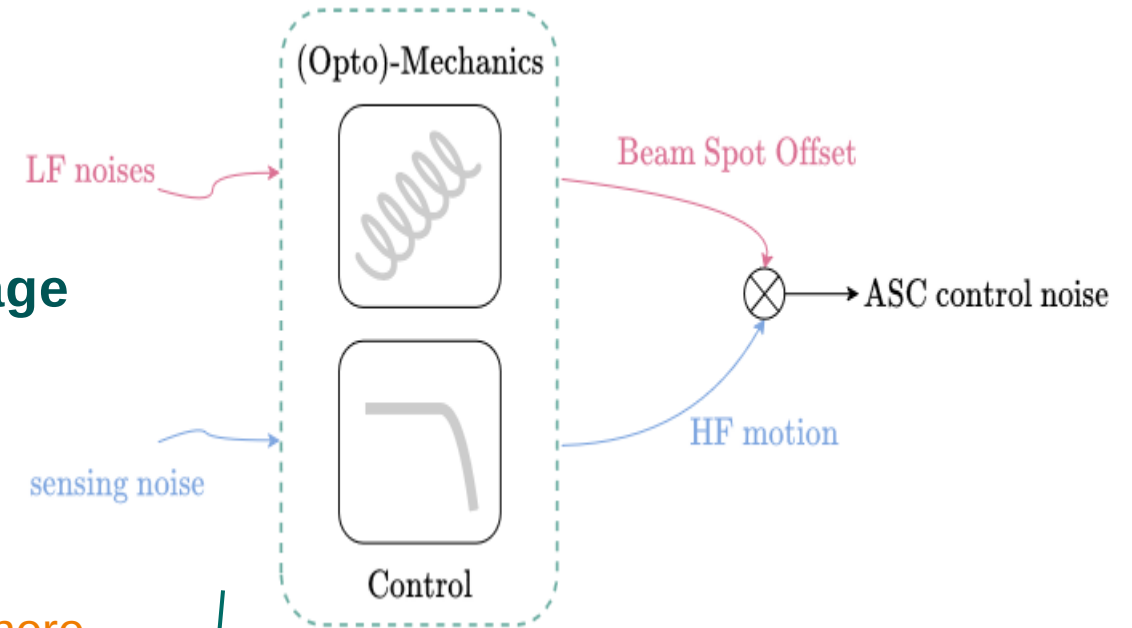
- If we can make simulation **modular**, we can also better **integrate** with other groups and **work in parallel**
- Requirements **flow** between modules and in some cases **loop** in several iterations



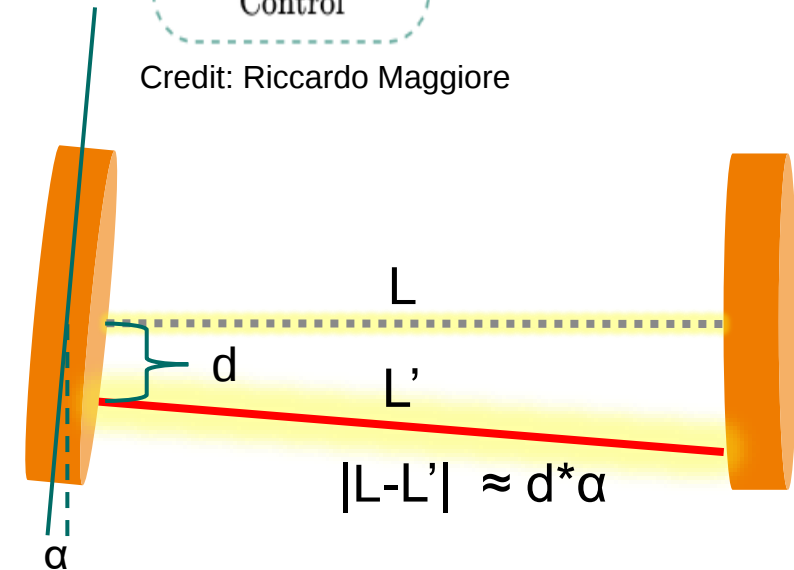


WHERE TO START

- Tackle potentially the **worst offender: angular sensing and control (ASC)**
 - Build up one **cavity model** with **realistic last stage suspension**
 - **Assume some value** for beam spot RMS and sensing noise, **see how they interact**
 - Do this for pitch
-
- Do this for yaw
 - Include effects of **longitudinal sensing noise (LSC)**
 - Build up more **realistic IFO model**/take “official” model – this is a big one!
 - Is **Finesse the right tool?** Check results esp. for pitch

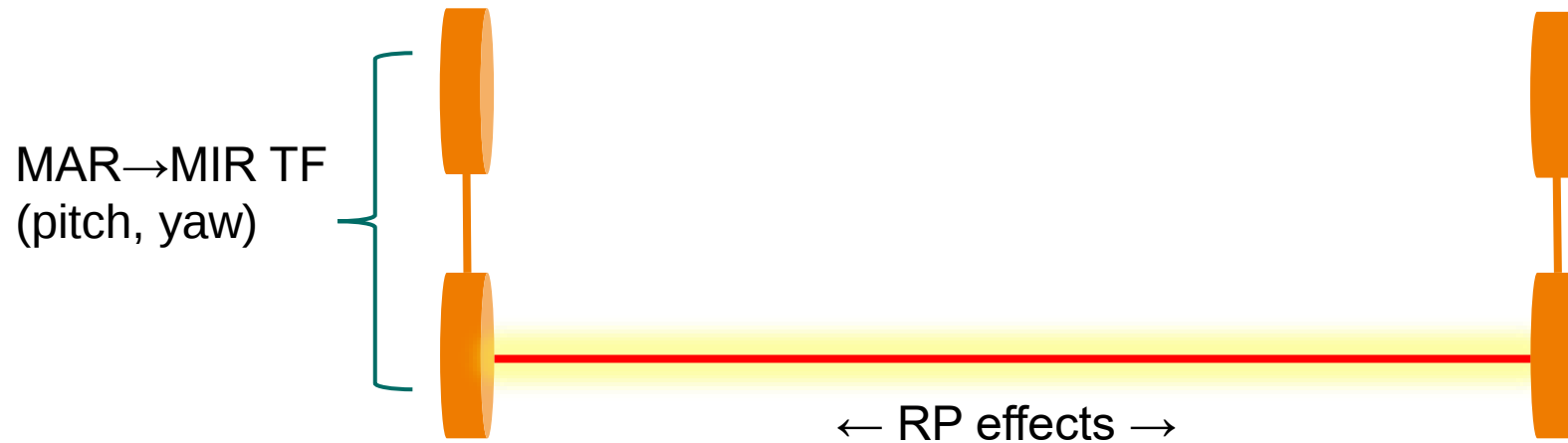


Credit: Riccardo Maggiore





OUR CURRENT MODEL

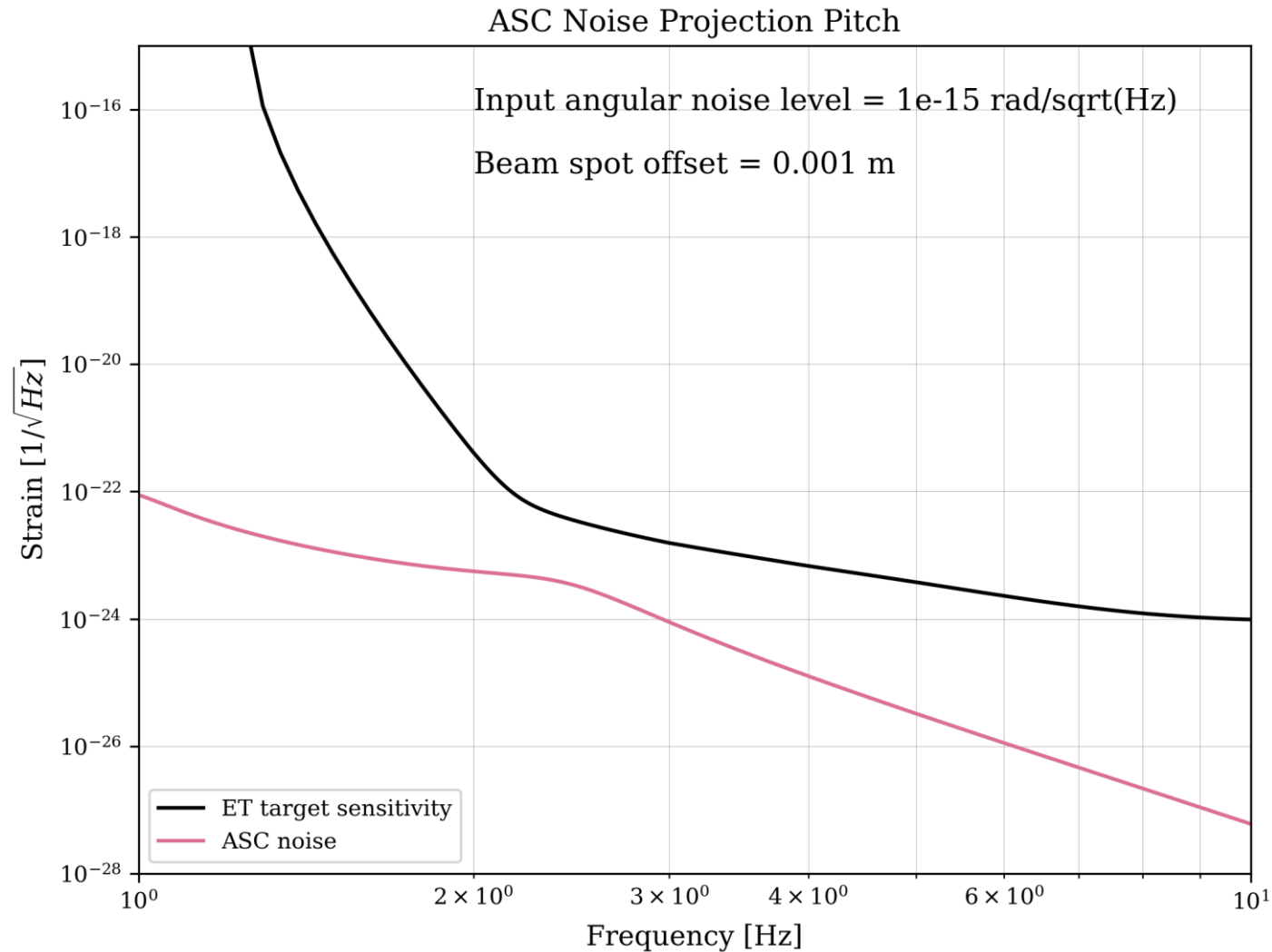


Our model is accessible
in [ET gitlab](#) 

- Realistic marionette → mirror TF extracted from state space suspension model and ported to Finesse
- Mirrors response to tilts is calculated with radiation pressure effects
- Two variables: **static beam offset** and **input tilt**
- Fix one, vary the other to get max allowed: get **requirements matrix**



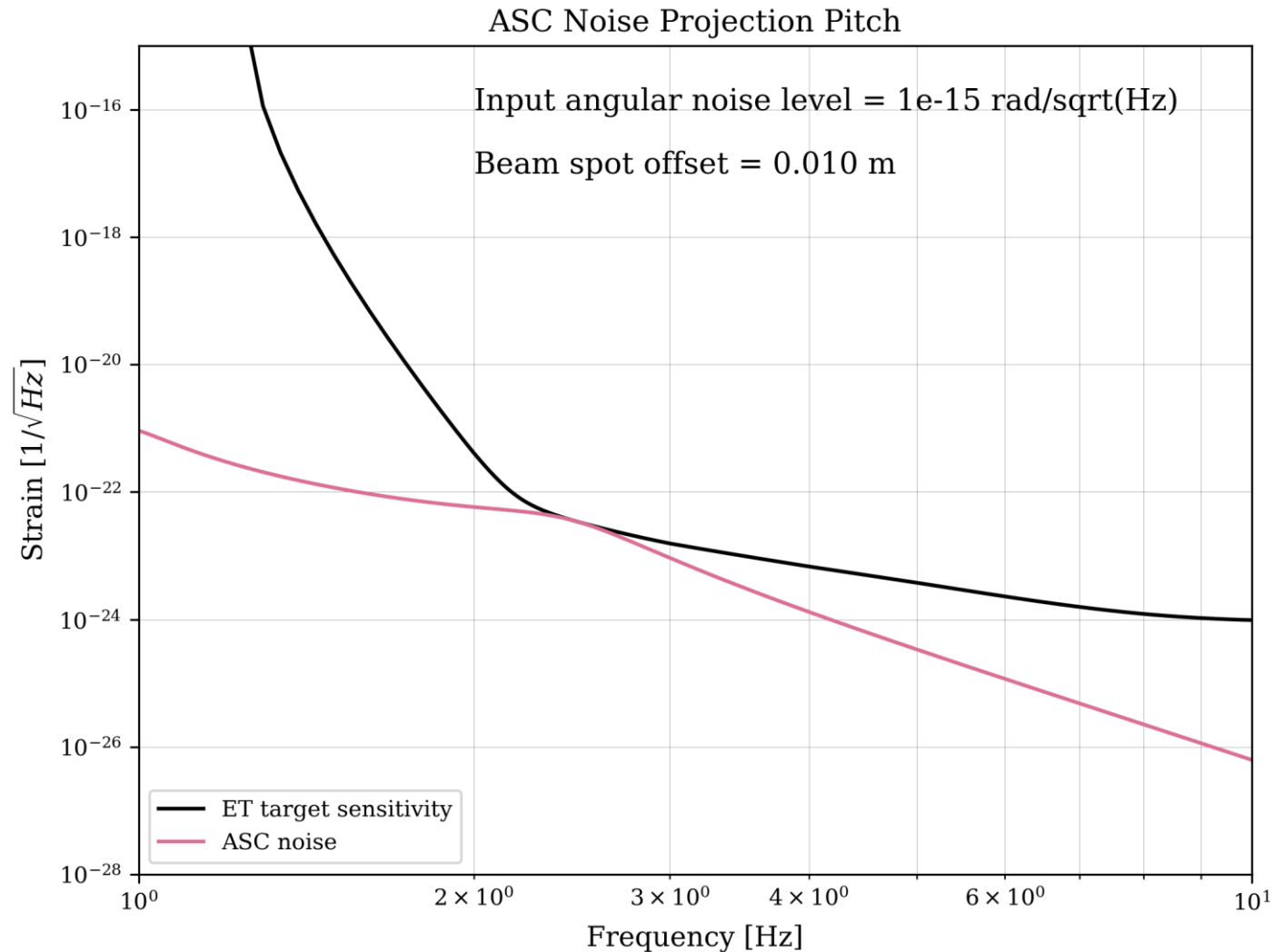
PRELIMINARY RESULTS



- Tilt sensing noise and beam spot offset are at ~low levels



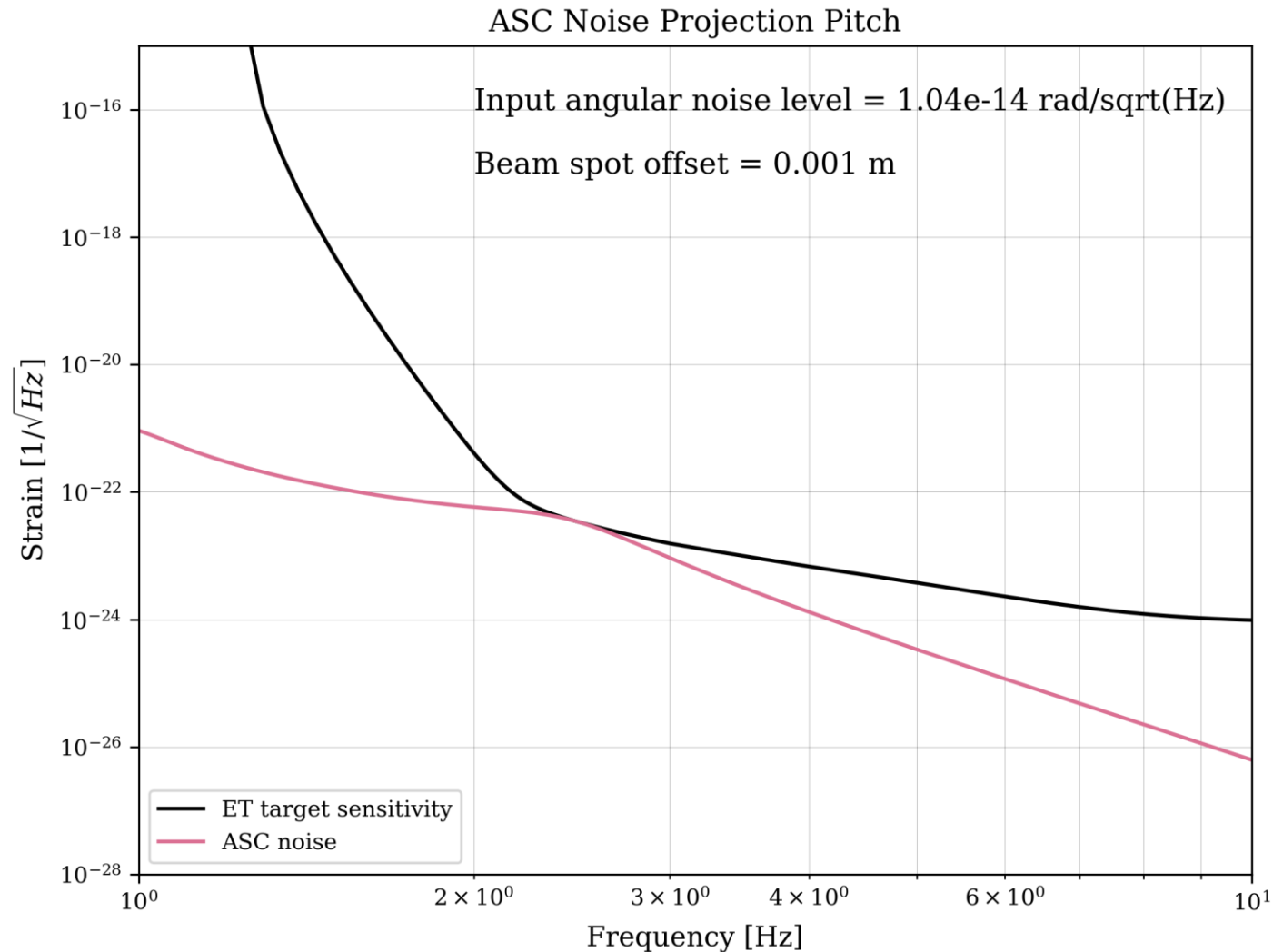
PRELIMINARY RESULTS



- Tilt sensing noise is fixed at low level, find maximum tolerable beam spot offset before exceeding ET sensitivity



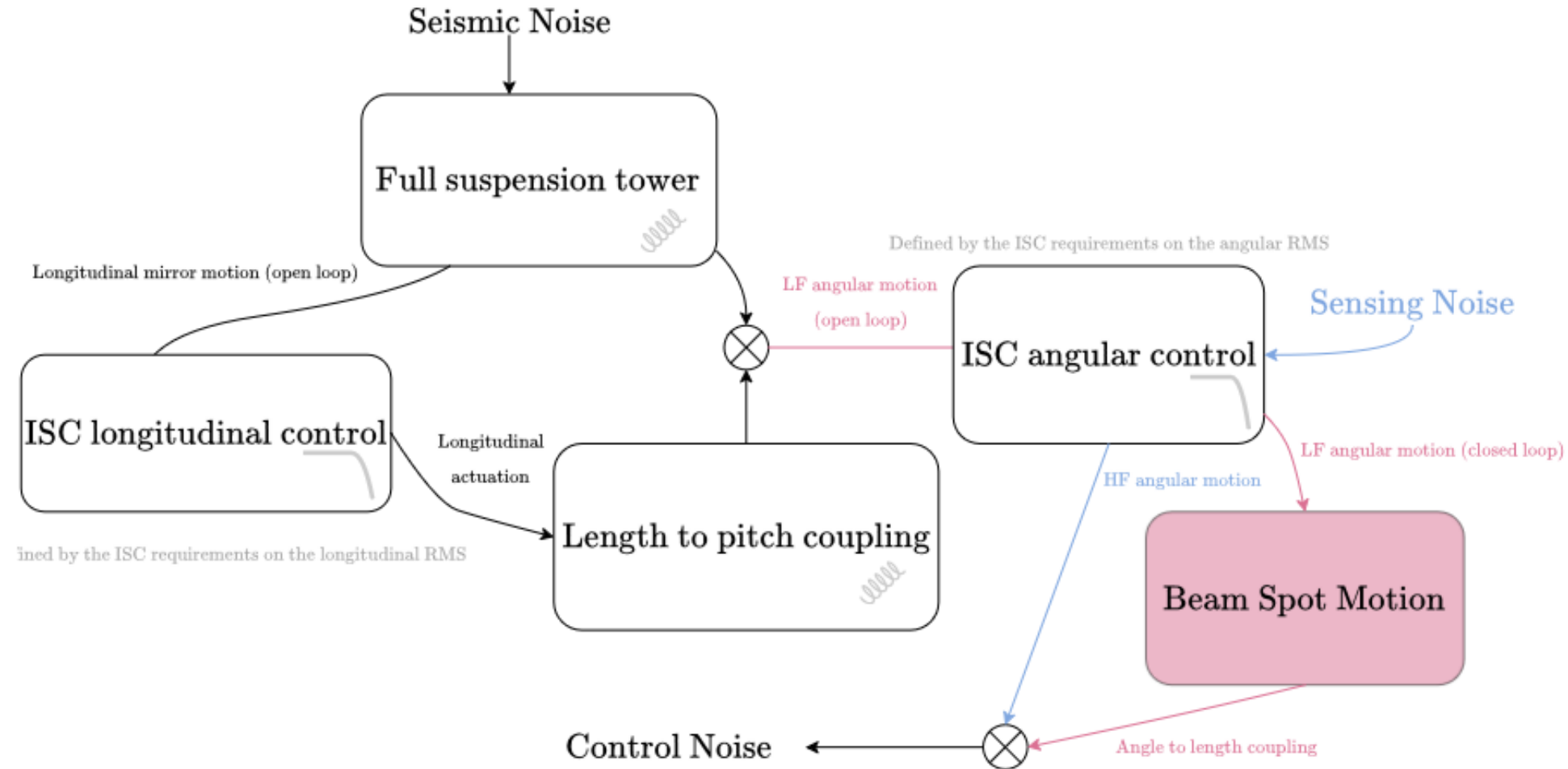
PRELIMINARY RESULTS



- Beam spot offset is fixed at low level, find maximum tolerable tilt noise input at marionette before exceeding ET sensitivity



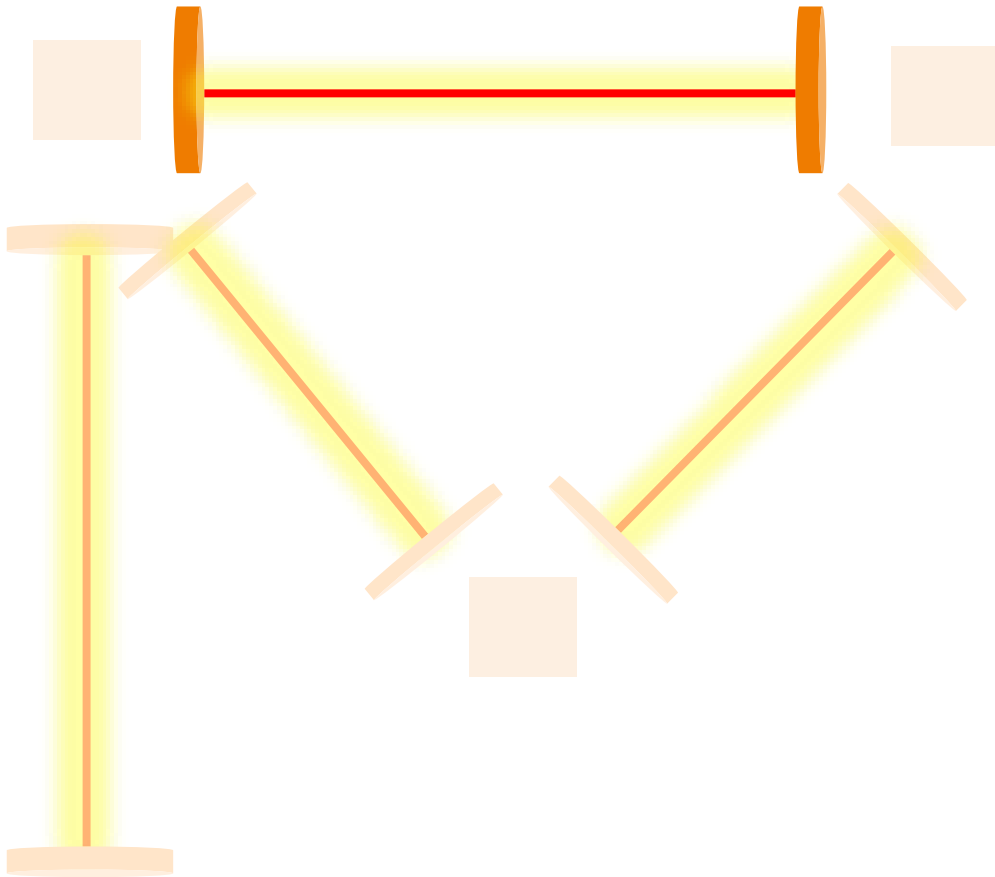
WHERE NEXT? LSC NOISE



Credit: Riccardo Maggiore, Jonathan Perry

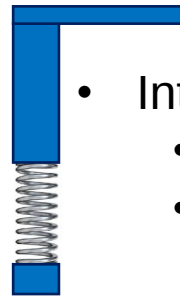


WHERE NEXT? IFO, SUSPENSIONS MODELS



Previously studied case of Virgo [[Maggiore et al 2024](#)]

- Angular noise is not simply multiplied by static offsets
beam offsets – they act as mirror tilts in actual model
- Interaction with IFO Division:
 - Virgo work made possible by **available official model** `finesse.virgo` – we need `finesse.et`!
 - **Sensing matrix**: use good guess from them, provide feedback, iterate

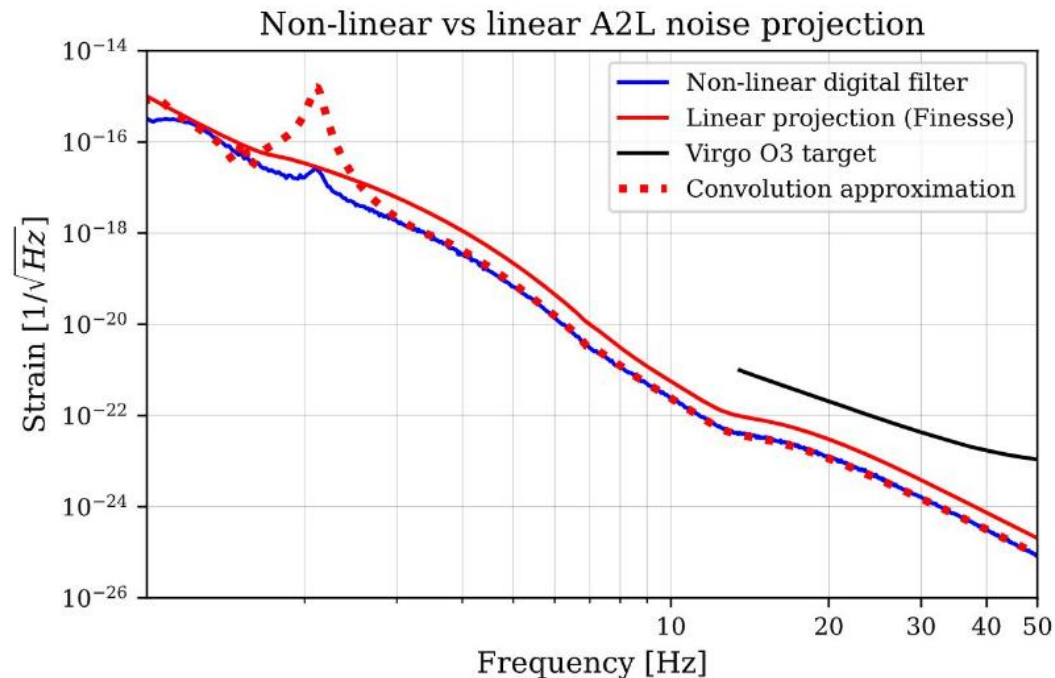


- Interaction with Suspensions Division:
 - Marionette → mirror TF – is it enough??
 - Angular RMS guess



FINESSE MODELLING – IS IT ENOUGH FOR US?

- Does Finesse underestimate ASC noise, however complex the model?
- Perhaps yes! Because ASC is nonlinear. Looking into time-domain simulation and “in-between”



The case of Virgo. Credit: Jonathan Perry, GWADW presentation [[ET-0234A-25](#)]



CONCLUSIONS

Note with more information:
[ET-0327A-25](#)

- Low-frequency control noise of ET is a hard problem
- We can only solve it by **working together** and adopting **modular approach** with clearly defined responsibilities of WPs
- LF Control Noise WP is at the **interface between Suspension and Optics**
- First step: tackle ASC noise with Finesse model with realistic suspension, **produce requirements matrix** (first result shown)
- Next: further develop the model in cooperation with Suspension and IFO Divisions, **iterate on requirements**
- In parallel explore limits of our tools: e.g. is Finesse sufficient for, generally, non-linear problem of LF controls?



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- ...
- ~~PROFIT!~~ ET TDR



THANK YOU!



BACKUP





OPTICS MODEL & CONTROL

```
# OPTICS - Creating a model of ETX arm cavity
base = finesse.Model()
base.parse(
    """
    l l1 P=32.3450455 # to get 18000W circulating within the arm cavity

    # ET arm cavity
    m ITM T=7000e-6 L=37.5u Rc=-5580
    m ETM T=6u L=37.5u Rc=5580

    link(l1, ITM, 10k, ETM) # setting 10Km long arm cavity

    cav cav1 ITM.p2.o # set the eigenmode

    modes(maxtem=1)
    """
)

# Linking the mechanical plant to the optics
mirrors = ('ITM', 'ETM') # mirrors to link suspensions to
for mir in mirrors:
    sus_tmp = SuspensionTFPlant(
        f'{mir}_sus', # name (appears as e.g., model.ETM.mech.ETM_sus)
        inputs,      # input nodes
        outputs,     # output nodes
        mechanical_plant, # 2D array of control.TransferFunction between inputs and outputs
        {
            'mir': base.get(f'{mir}.mech'), # connects to ETM.mech
        }
    )
base.add(sus_tmp)
```

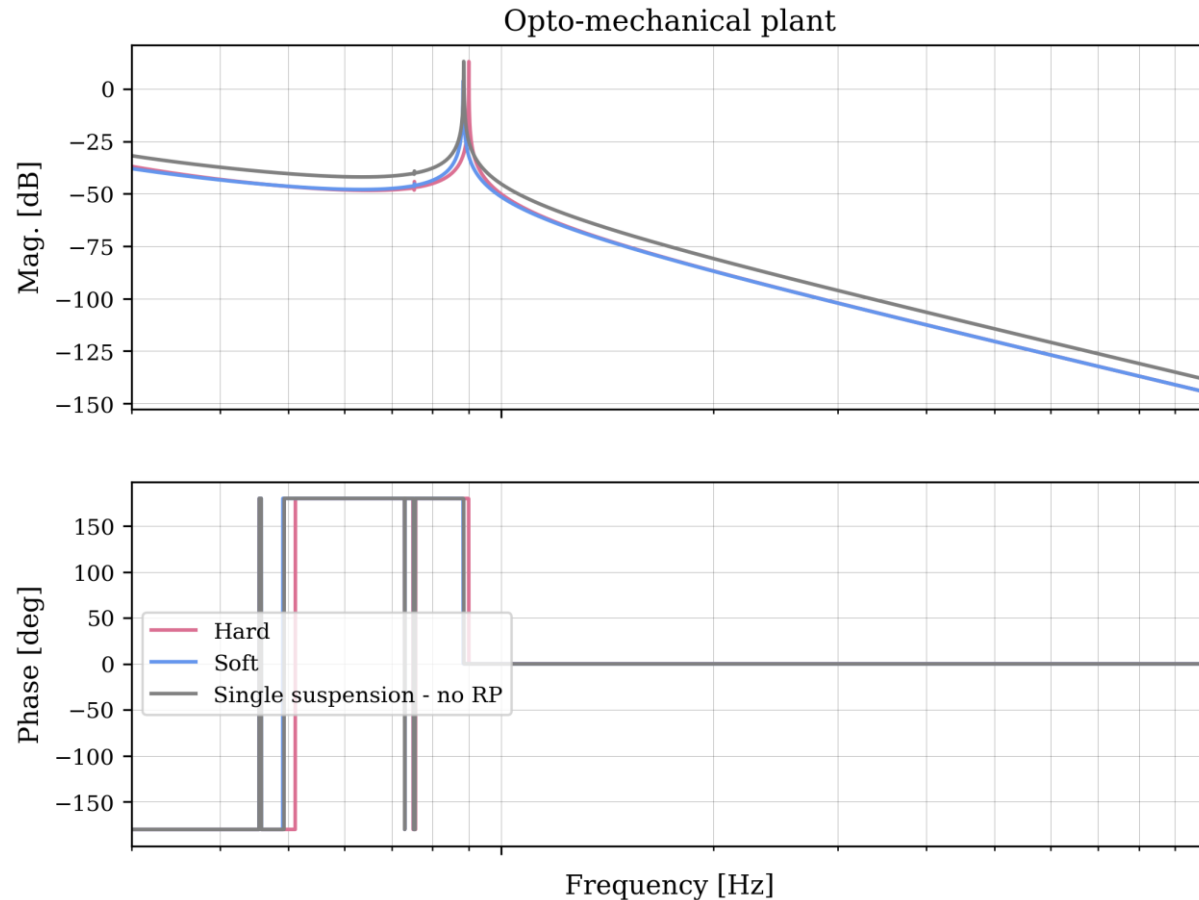
```
# # CONTROL
model.parse(
    """
    # driving values
    var driv_hard_ITM -0.5
    var driv_hard_ETM -0.5
    var driv_soft_ITM 0.5
    var driv_soft_ETM -0.5

    # sensing values
    var sens_ITM_hard -0.5
    var sens_ETM_hard -0.5
    var sens_ITM_soft 0.5
    var sens_ETM_soft -0.5
    """
)

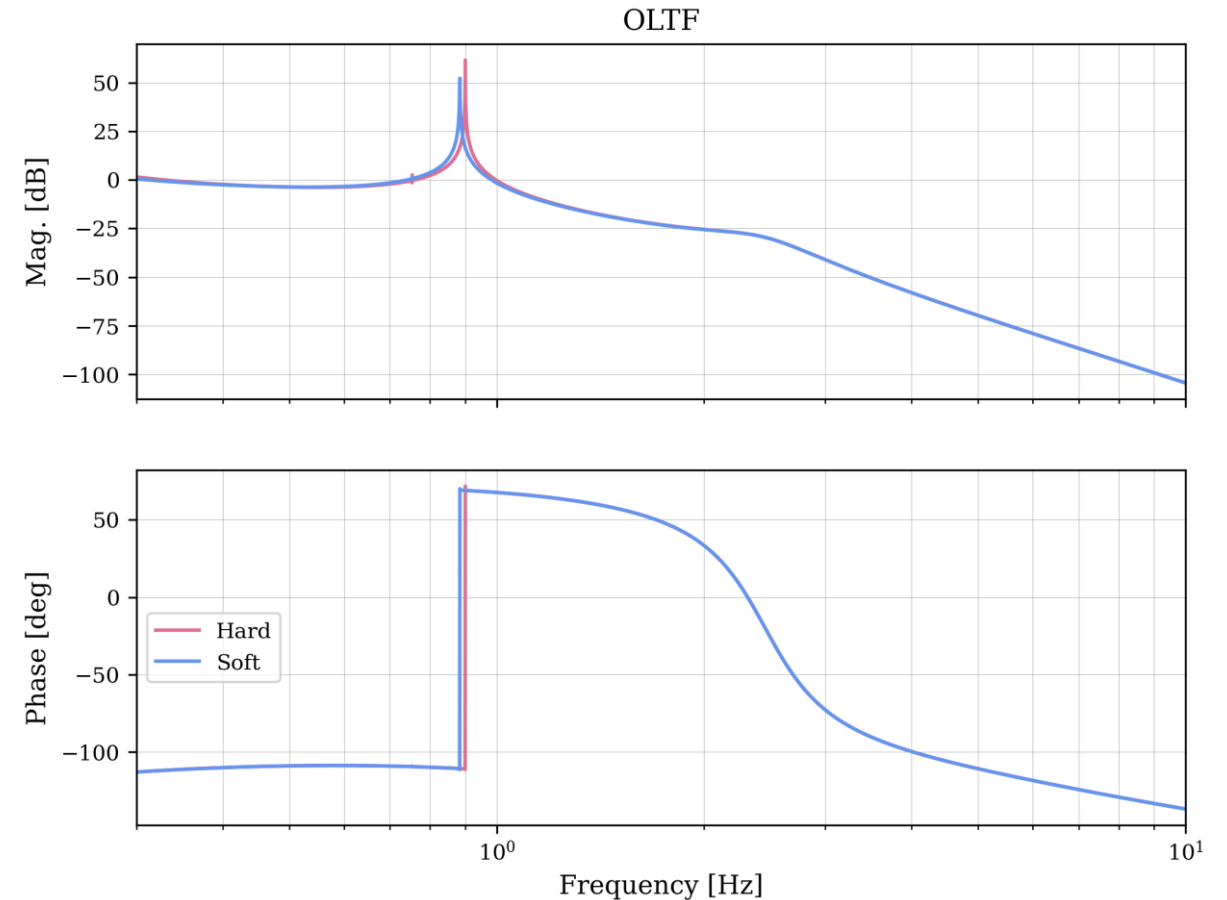
# z, p, k for control filters -- Source M.v.Dael
z = [-0.62855655] # zeroes
p = [-50.20934212, -2.60171545+15.1712101j, -2.60171545-15.1712101j] # poles
k = 493500.0 # gain
```



OPTO-MECHANICAL PLANT



```
ys_hard = om_plant['sensor_hard.p2', 'ctrl_hard.p2'] # output, input  
ys_soft = om_plant['sensor_soft.p2', 'ctrl_soft.p2']  
ys_susp = sus_plant['ITM_sus.mir.pitch', 'ITM_sus.mar.F_pitch']
```

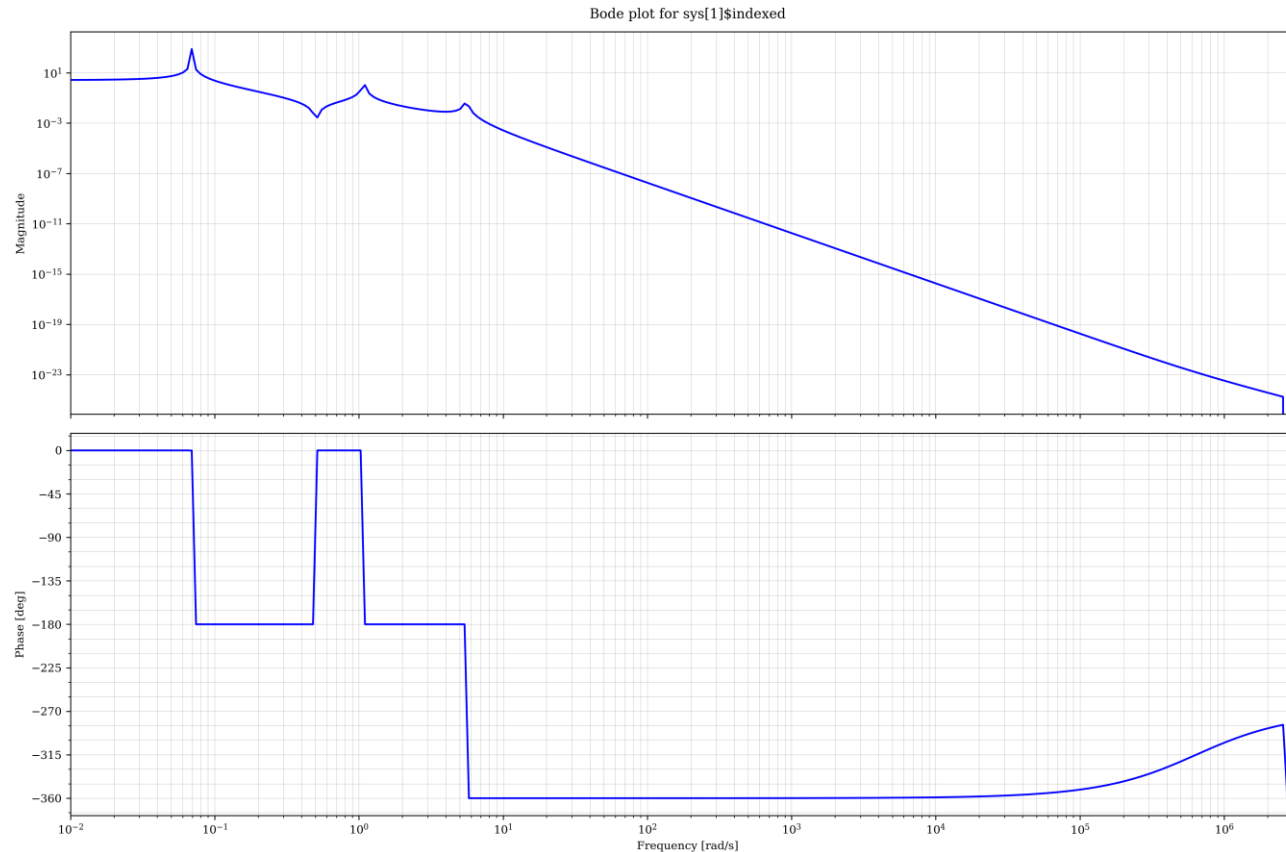


```
ys_hard = oltf['sensor_hard.p2', 'ctrl_hard.p1']  
ys_soft = oltf['sensor_soft.p2', 'ctrl_soft.p1']
```



SUSPENSION MODEL

Marionette torque in pitch $\rightarrow$ mirror pitch transfer function



Notes about this model:

- **Author: Robin Cornelissen**
- Ref: ET-0592A-24, live doc: <https://www.overleaf.com/read/bgcyqqrtrdmc#03d933>
- Produced with Femto
- The model, especially the parameters, are not final.
 - E.g. mirror mass went through several iterations; a value of 211 kg was used here

Model is converted to
SuspensionTFPlant
for Finesse