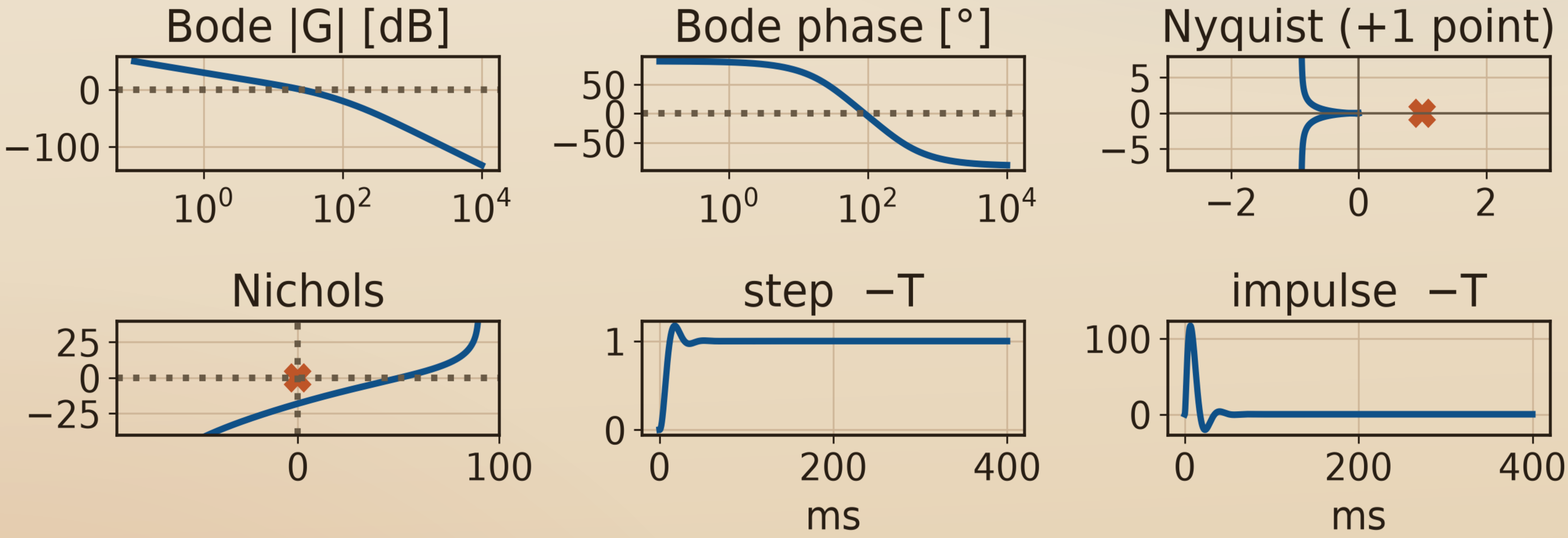
Day 4 — Noise & ASC

17 JULY · RANA, EVAN

Build the **full noise budget** of a locked loop — and meet **ASC** as a hierarchy of angular loops.

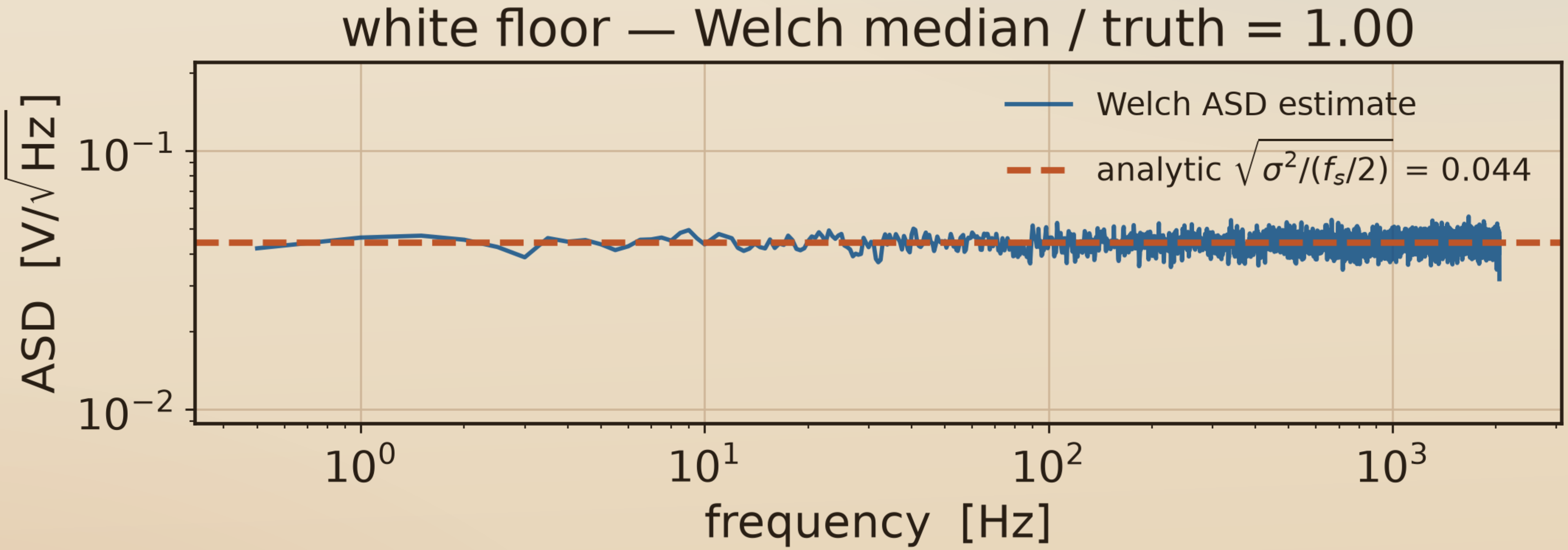
Reading a loop — five views of one G

One **signed** open-loop gain $G(j\omega) = -k/\left[s(1+s/\omega_1)(1+s/\omega_2)\right]$ — the servo is inverting — drawn five ways. Each makes one question easy: **Bode** (where the gain is, where phase runs out) · **Nyquist** (the definitive stability test — encirclements of $+1$) · **Nichols** (a gain change is a vertical slide) · **step** (overshoot ↔ phase margin) · **impulse** (ringdown ↔ Q).



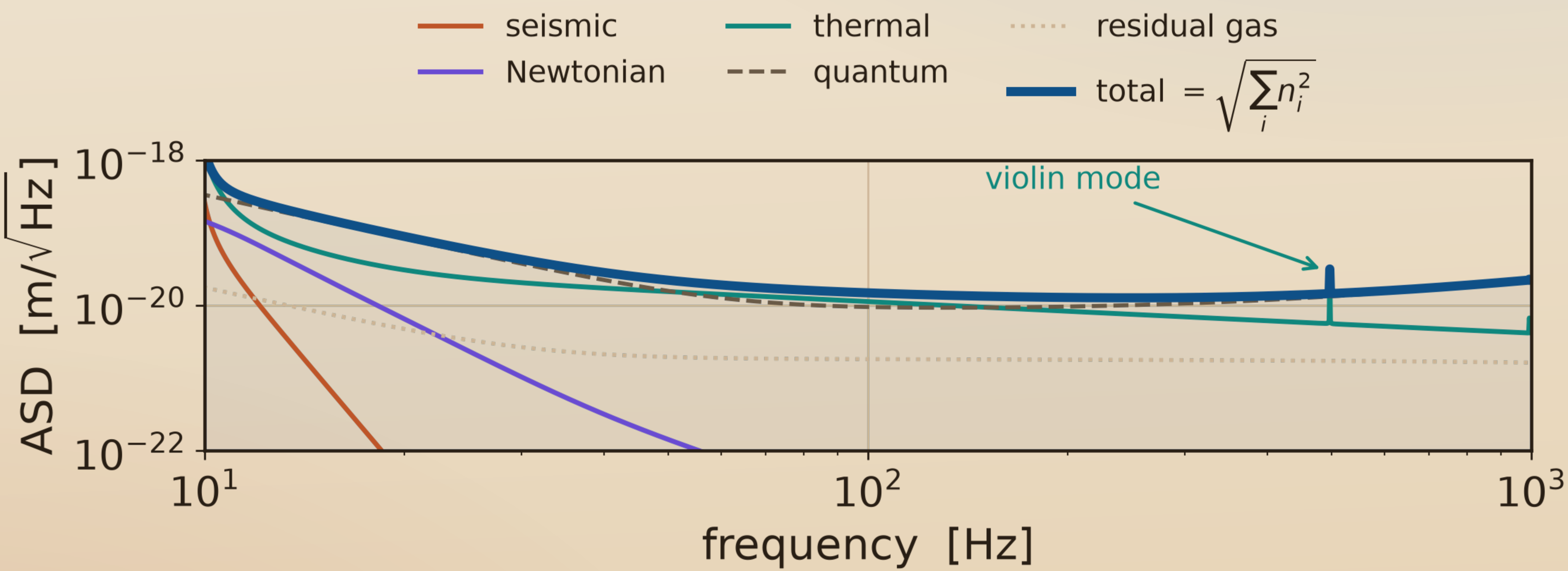
PSD vs ASD — the dimension check

Pin the units before the budget. **PSD** $S_x(f)$: $[\mathrm{signal}]^2/\mathrm{Hz}$, integrates to the variance ($\sigma^2 = \int S_x\, df$). **ASD** = $\sqrt{S_x}$: $[\mathrm{signal}]/\sqrt{\mathrm{Hz}}$. Variance is what adds — so **say PSD-or-ASD before you write a** $\sqrt{\ }$**.**



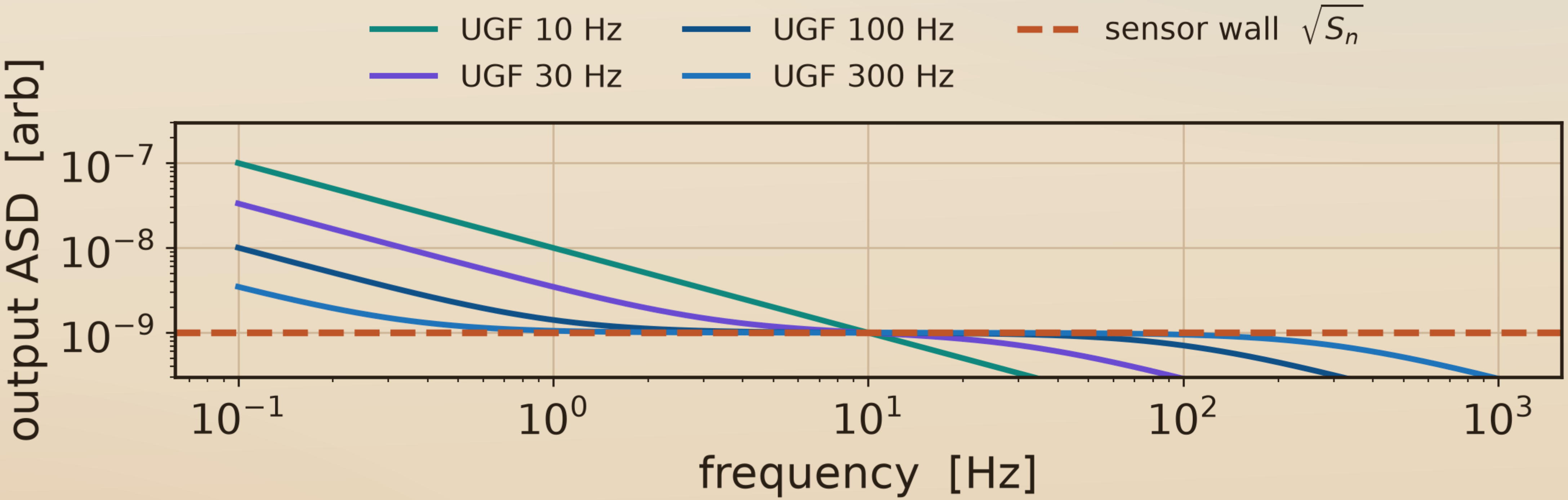
The noise budget

Enumerate the terms, propagate each through the loop, sum in quadrature — the top curve is what you fight.



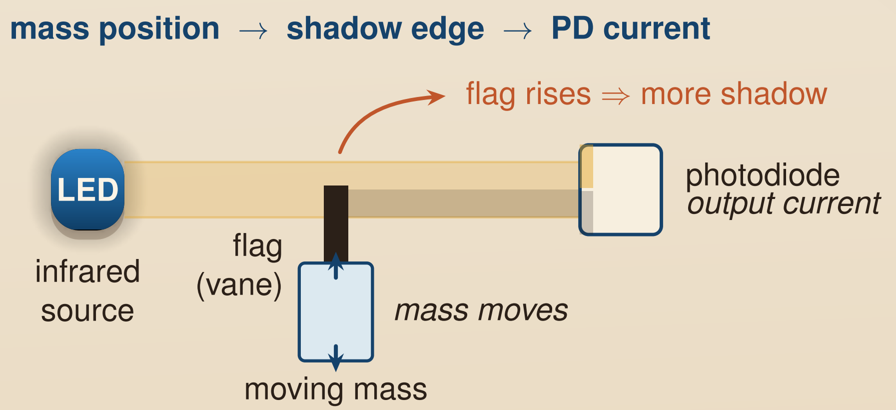
The wall

In-band $T \approx 1$, so the output floor sits at the sensor ASD $\sqrt{S_n}$. Raising the loop gain pushes the crossover to higher frequency — it **widens** the sensor-noise-limited band, it does not lower the floor.

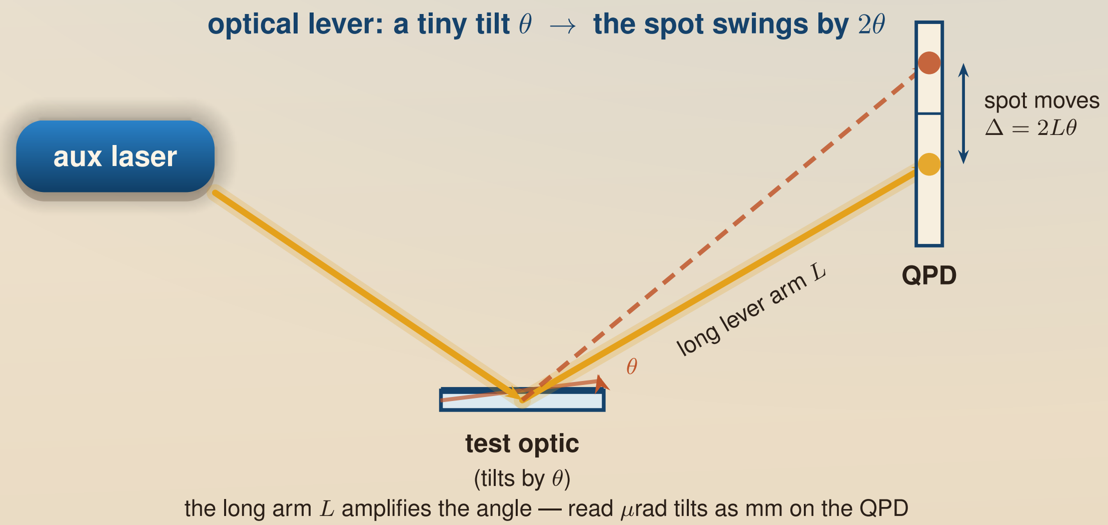


Illustrative shapes. This afternoon's Tier-3 makes the same trade a Pareto front: past $T \to 1$, more ASC gain buys no floor — only wider band and less stability.

Five ways to sense angle — local



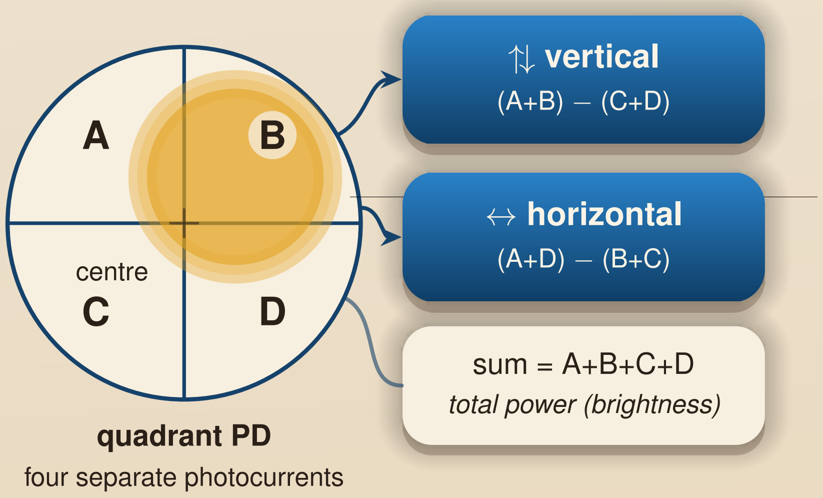
OSEM · ~1e-9 rad/√Hz



optical lever · ~1e-10 rad/√Hz

Five ways to sense angle — global cavity

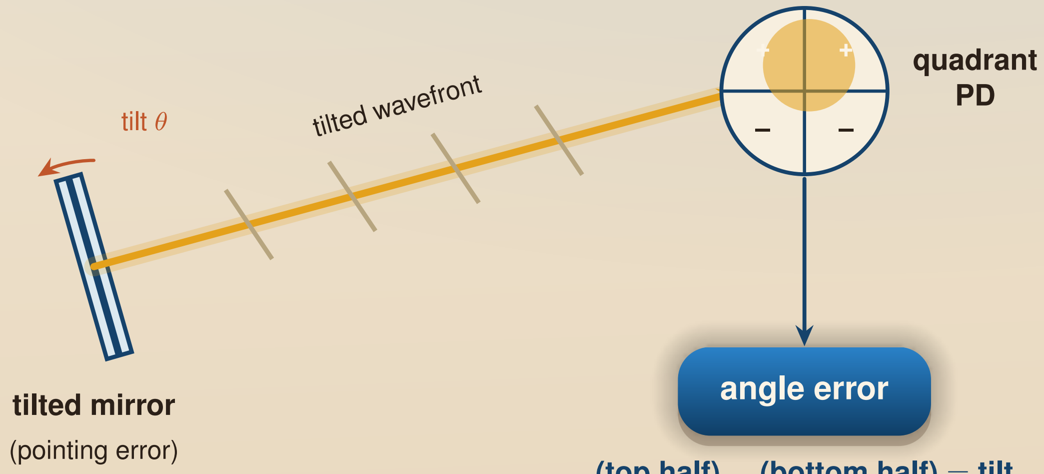
one spot, four currents → where the beam sits



divide by the sum ⇒ position, independent of laser power

QPD · ~1e-12 rad/√Hz

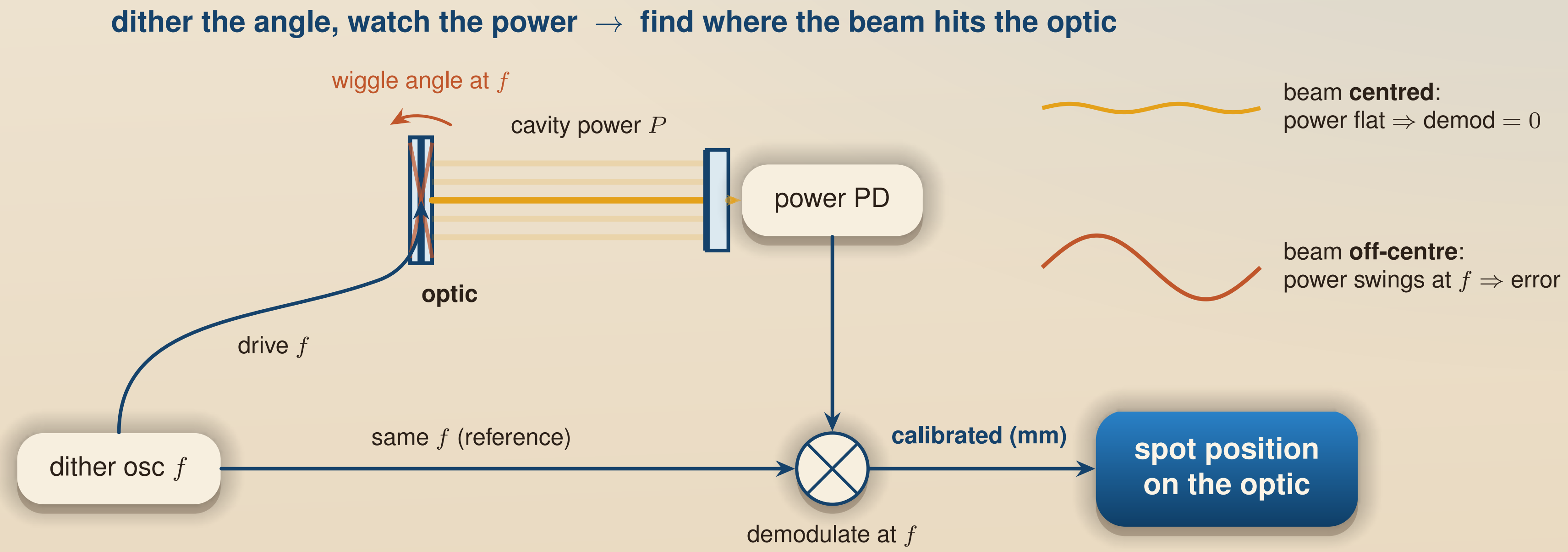
mirror tilt → wavefront tilt → spot shifts on the QPD



(top half) − (bottom half) = tilt

WFS · ~1e-13 rad/√Hz

Five ways to sense angle — dither

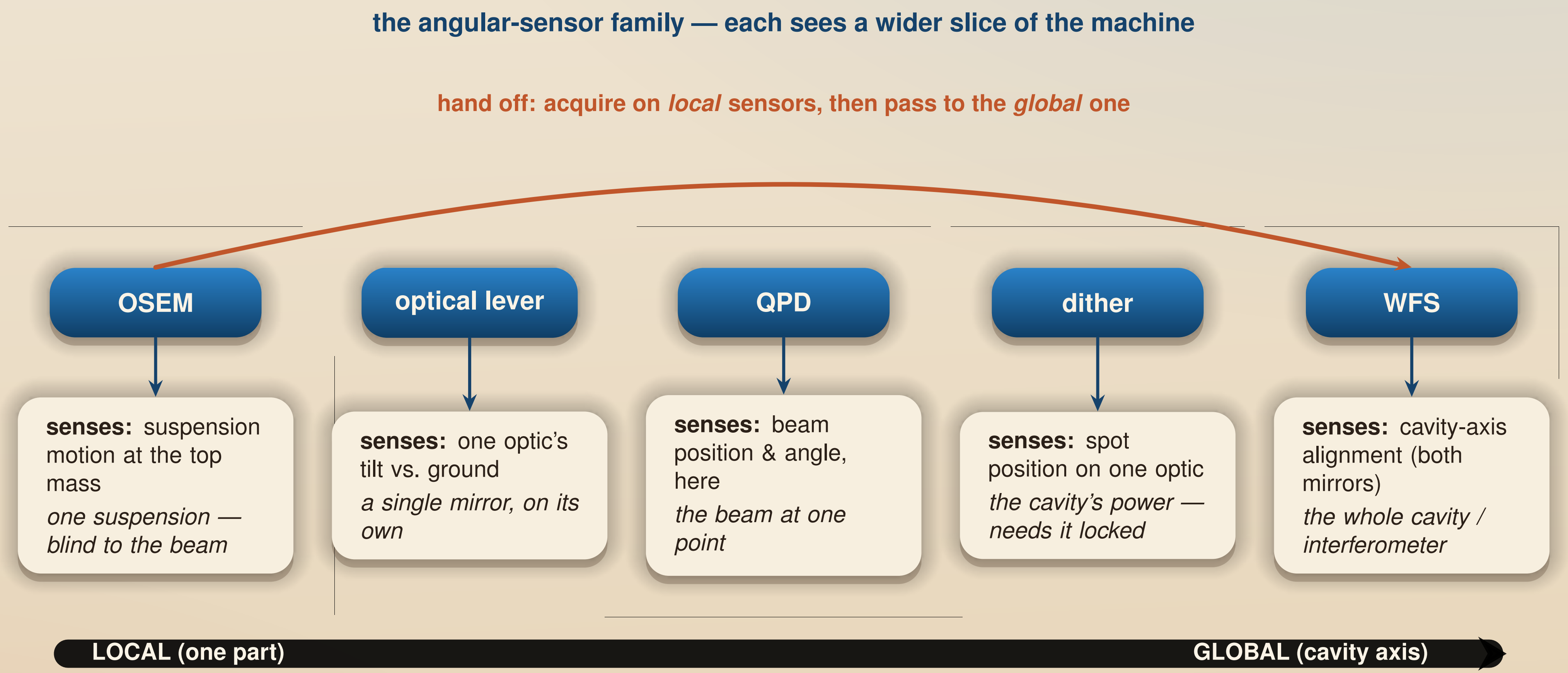


dither · calibrated spot

The five span ~4 decades of angular sensitivity, OSEM (~1e-9 rad/√Hz) to WFS (~1e-13) — each injecting its own noise through its T.

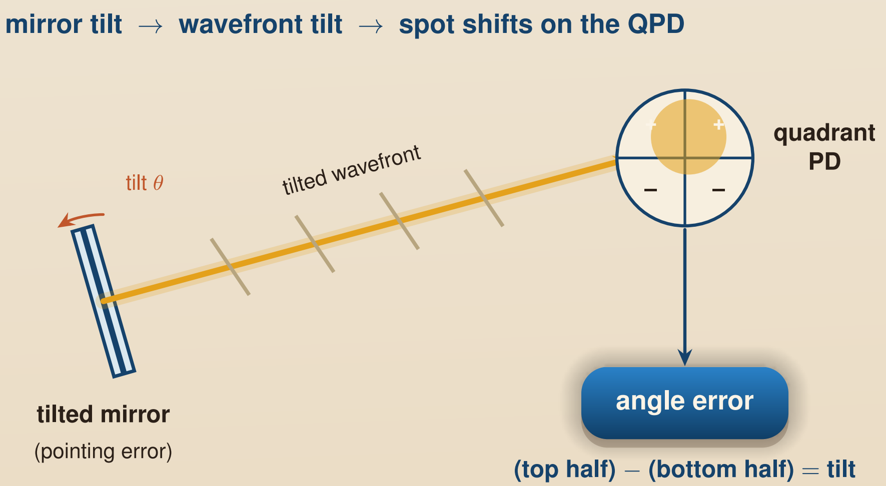
Sensitivities illustrative, order-of-magnitude — the local→global trend, not calibrated floors.

The sensor hierarchy



All five: **local** (OSEM, optical lever) → **global cavity** (QPD, **dither**, WFS). Acquire alignment on the local sensors, then **hand off to WFS in lock** for the low-noise regime; dither needs the cavity locked but reports one optic. (Full sensor table in `curriculum.pdf`.)

Day 4 · afternoon



Angular loop: tilt → tilted wavefront → spot moves on the QPD → angle error.

Thread A — noise budget `twin`

Build the budget of Wednesday's locked loop and hunt the limiting noise.

Thread B — angular loop `twin`

Tune it; budget its WFS sensor noise through T.

INJECTED DISCREPANCY

A **noisy WFS** sits above the model. Measure non-destructively, localize the excess to the sensor, let the budget make the keep/fix call.

`Deliverable · length-loop budget + localized noisy-WFS diagnosis with a keep/fix call`

NAME THE MOVE

Pick the loop with the lowest sensor-noise budget; hand off as the state changes.