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Sensor Fusion Possibilities in High-Contrast Imaging

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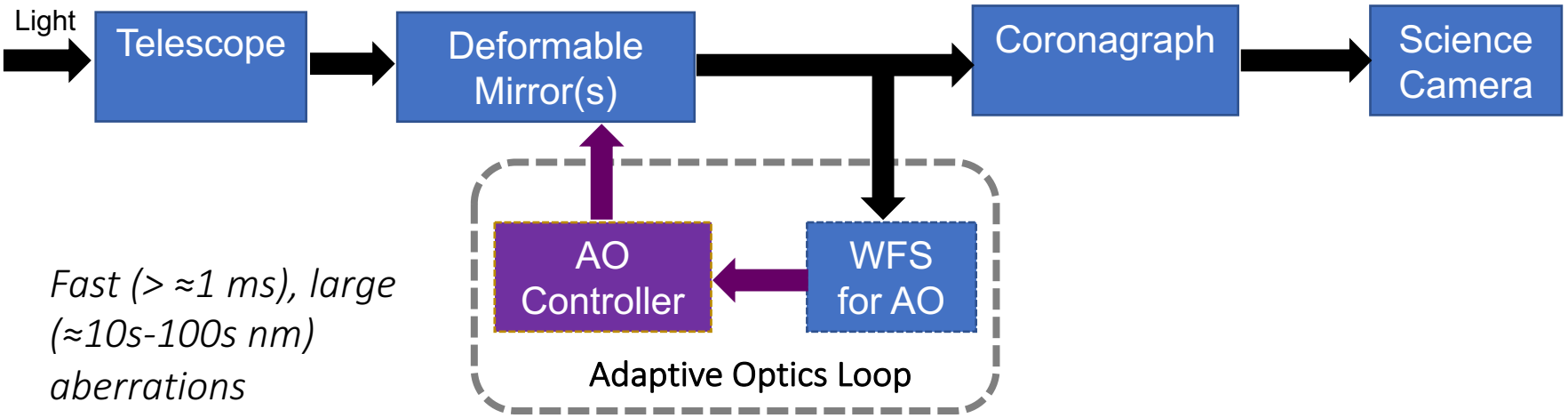
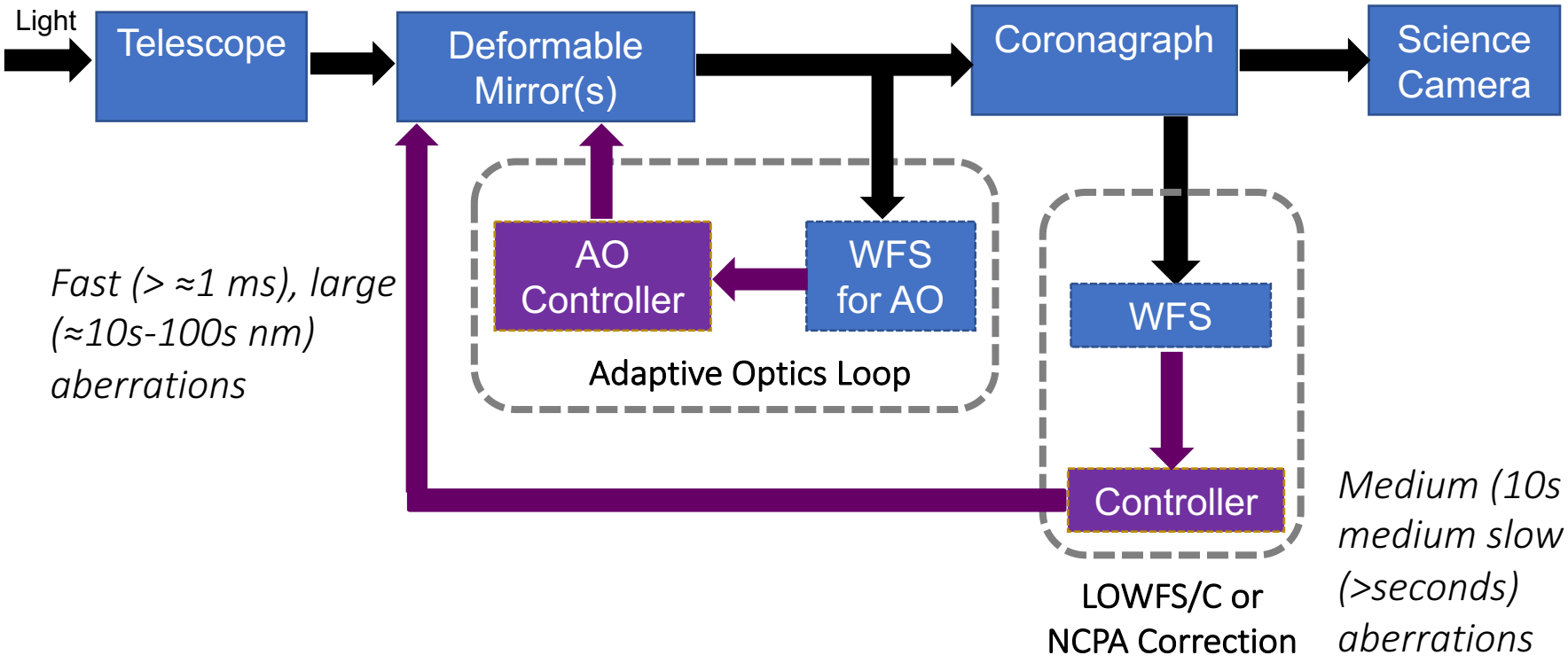
Wavefront Correction Loops

Wavefront Correction Loops

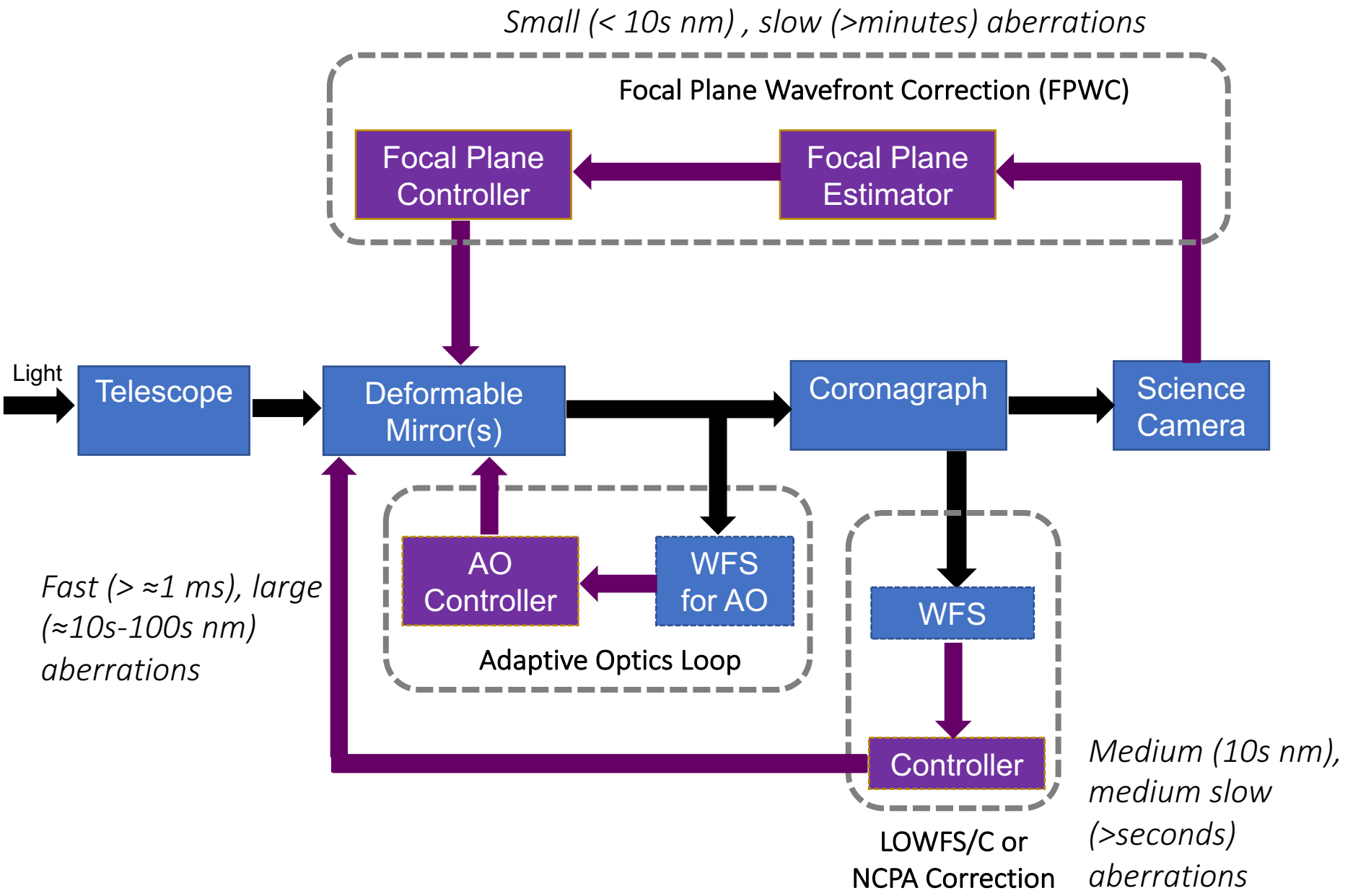


Fast (> ≈1 ms), large (≈10s-100s nm) aberrations

Wavefront Correction Loops

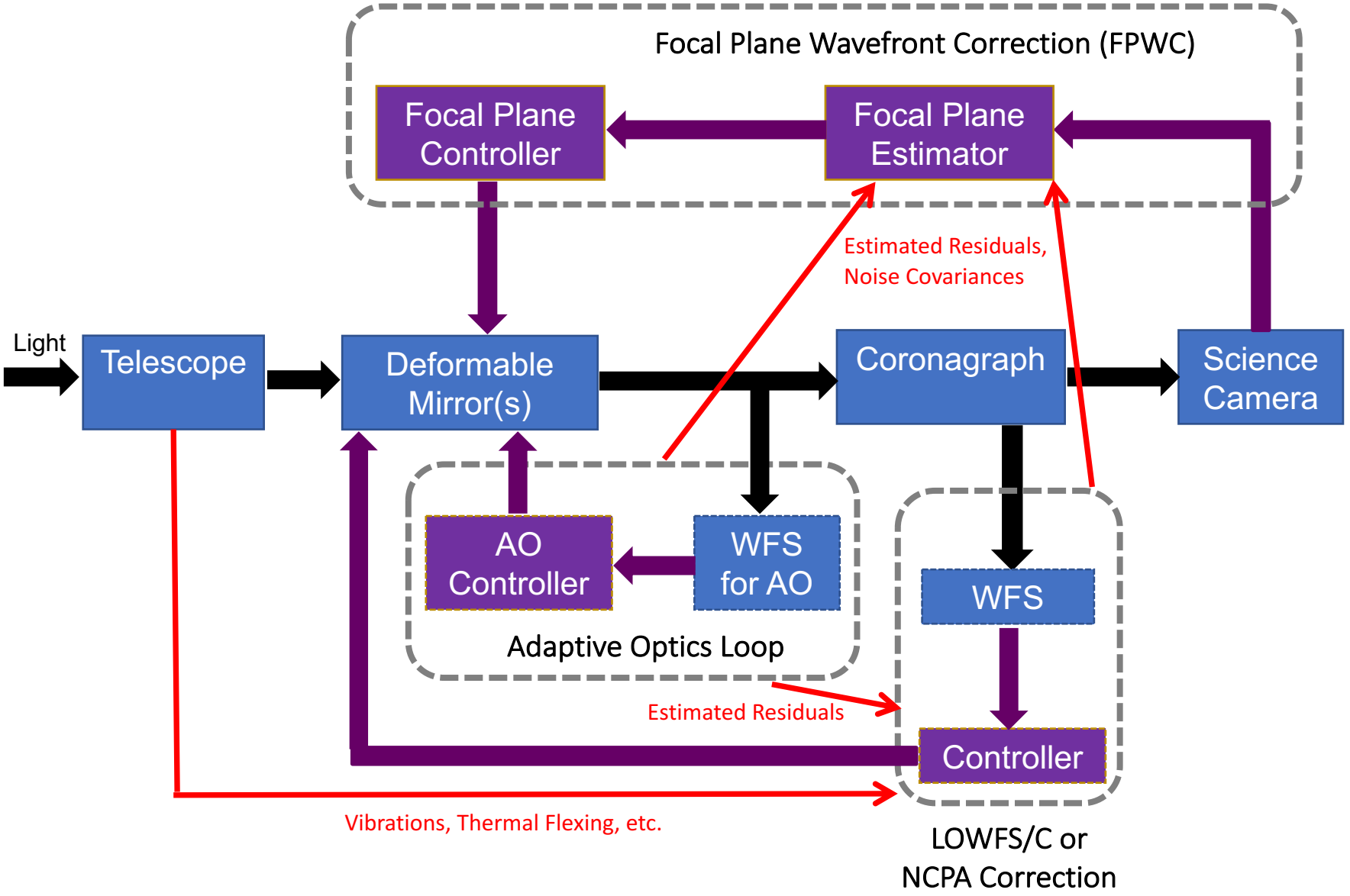


Wavefront Correction Loops



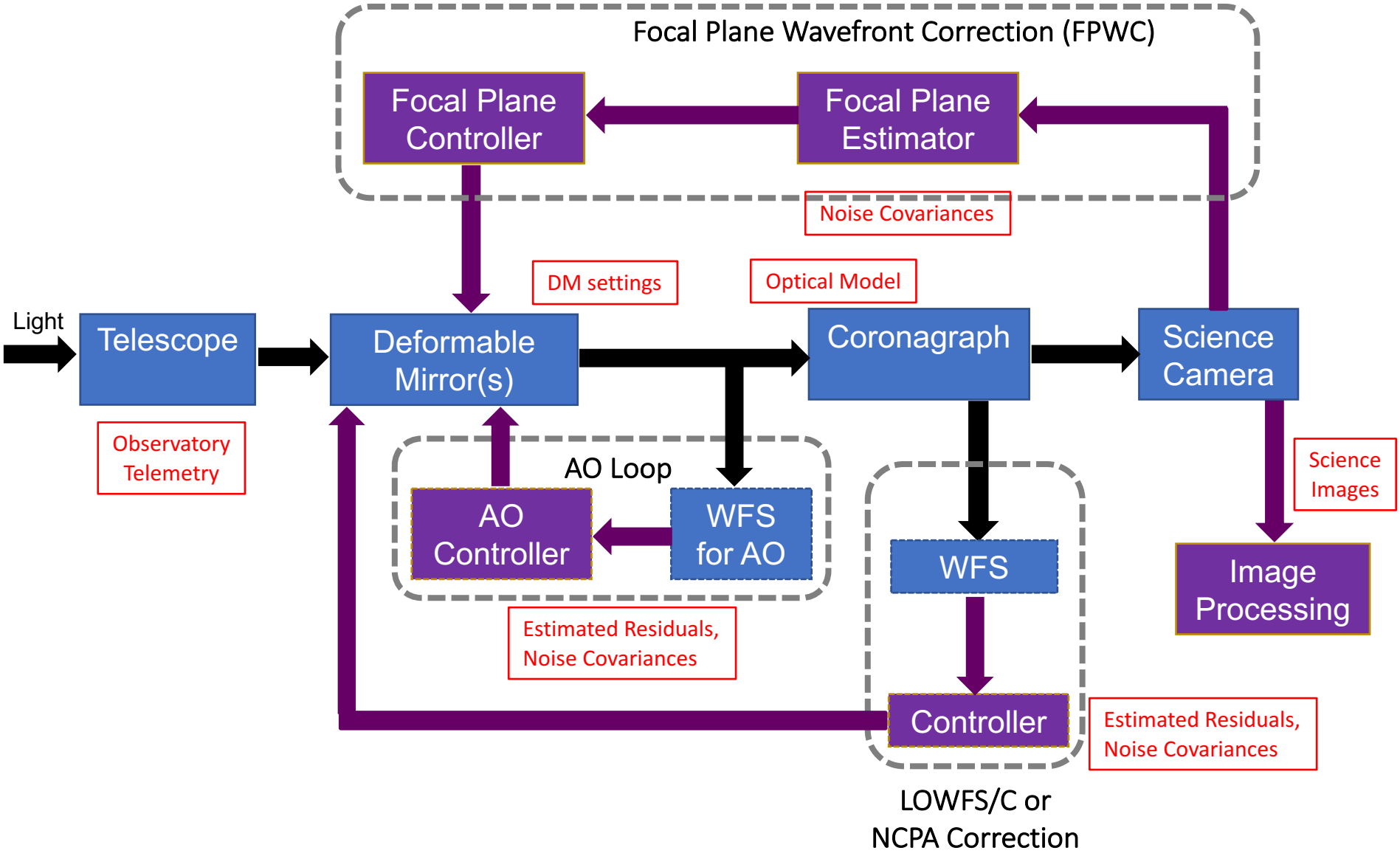
Sensor Fusion

→ Connect the correction loops

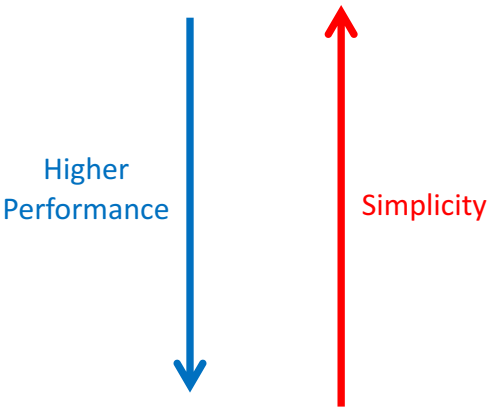


Post-Processing with More Measurements

- Many of the same sensor fusion strategies apply for post processing, except:
  - Speed is not a driver in algorithm choice
  - More complicated, more robust algorithms can be used.



Real-Time Correction



Possible Strategies

A. Correction loops operate independently.

B. Faster loops feed slower loops expected error envelopes (covariances).
   A. Covariances are easier to know than actual dynamic residuals.

C. Loops feed each other expected dynamics and covariances.
   - AO, NCPA, & LOWFSC loop fitting errors fed to FPWC.
   - Telescope telemetry fed to LOWFSC or AO loop for predictive control, feed-forward, or notch filtering.

Real-Time Correction

Kalman Filter

- New estimate made from optimally combining
  - New measurements
  - Previous estimate
  - Dynamic system model
  - Noise and model uncertainties
- Kalman filters already used individually for:
  - AO: sensing part of LQG, used at several observatories
  - FPWC: at Princeton and JPL

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Multirate Kalman Filter

- Updates estimate with sensors running at different speeds.
- *Difficulties* in our case:
  - Sensor speeds are orders of magnitude apart:
    - AO ~ 0.001 s
    - LOWFSC or NCPA ~ 1-10s
    - FPWC ~ 10-1,000s
  - Some measurements are not directly related
  - Some states measured not linearly related

➢ How to combine measurement data?

Sensor Fusion in Direct Imaging

AO + NCPA

- Both measure pupil plane phase
  - NCPA measurement is post—AO correction
- AO residuals will change during NCPA sensing
  - Depending on NCPA measurement scheme, time-varying AO-residuals might not average out to zero net effect
  - Multirate, dynamic Kalman filter for NCPA loop could help decrease errors from AO residuals

(AO &/or NCPA) + FPWC

- Different measurements: pupil plane phase and focal plane E-field
  - Not linearly related, but small (<≈10nm) pupil plane phases can be treated as imaginary and propagated to focal plane.
  - Multirate Kalman filter can be used for the linear approximations.
  - Nonlinear filter necessary for generic treatment
    - Much slower and less stable.