# New concepts for calibrating Non-common path aberrations (NCPA) in adaptive optics and coronagraph systems

François Hénault

Institut de Planétologie et d'Astrophysique de Grenoble
Université Grenoble-Alpes
Centre National de la Recherche Scientifique
BP 53, 38041 Grenoble – France

# Plan of presentation

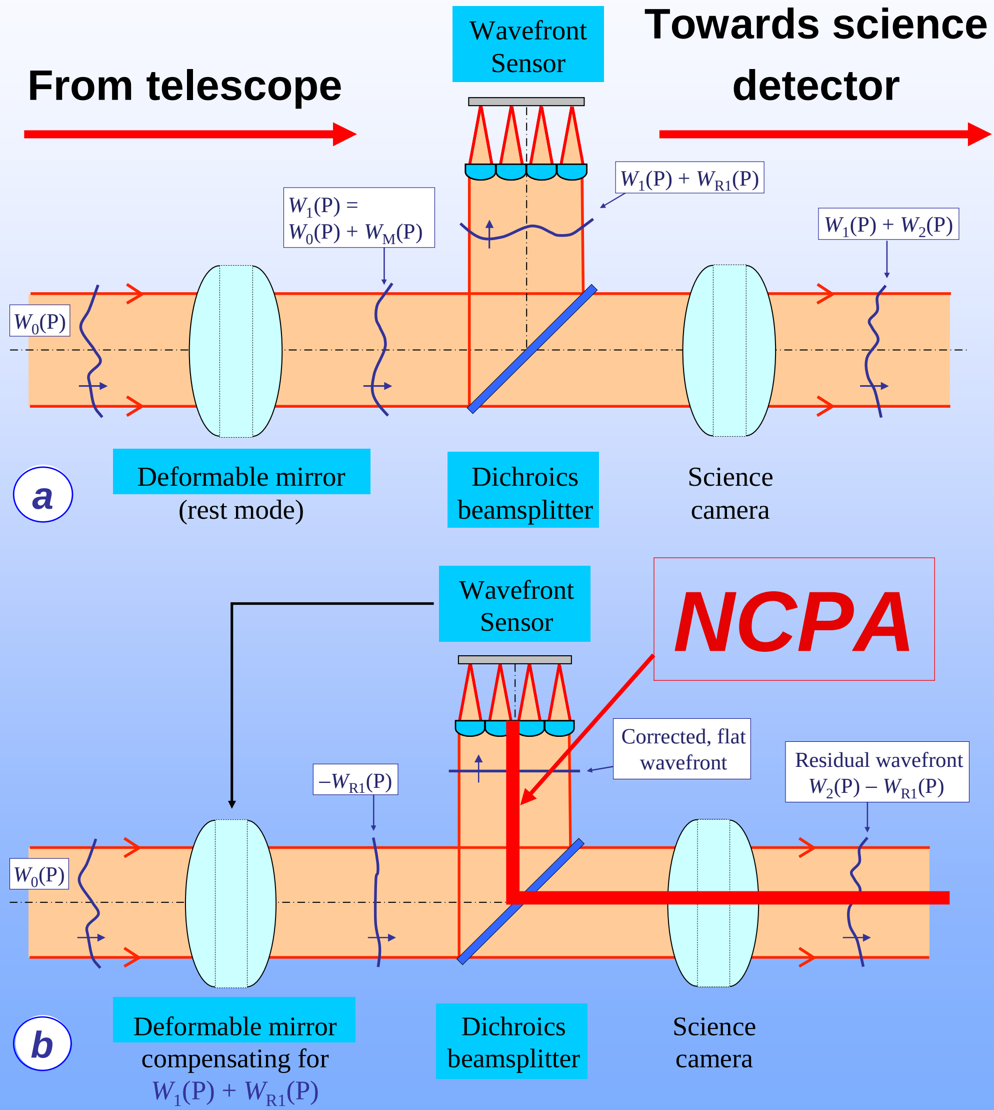
- Introducing the NCPA problem
- Alternative concept – Interferometric arrangement
  - General principle
  - Application to imaging or spectroscopic instruments
  - Application to coronagraphs
- Preliminary requirements of dichroics plates
  - Radiometric characteristics
  - Image quality
- Choice of wavefront sensors
- Conclusion

# Introducing the NCPA problem

- AO systems are typically made of three basic components
  - Deformable Mirror (DM)
  - Dichroics beamsplitter
  - Wavefront Sensor (WFS)
- In close loop WFS measure nearly flat wavefronts, but NCPA arise from different aberrations along the science and WFS arms (in red):

$$NCPA(\mathrm{P}) = W_2(\mathrm{P}) - W_{\mathrm{R}1}(\mathrm{P})$$

- **Solution 1**: Pushing the WFS and beamsplitter arm as close as possible to science detector



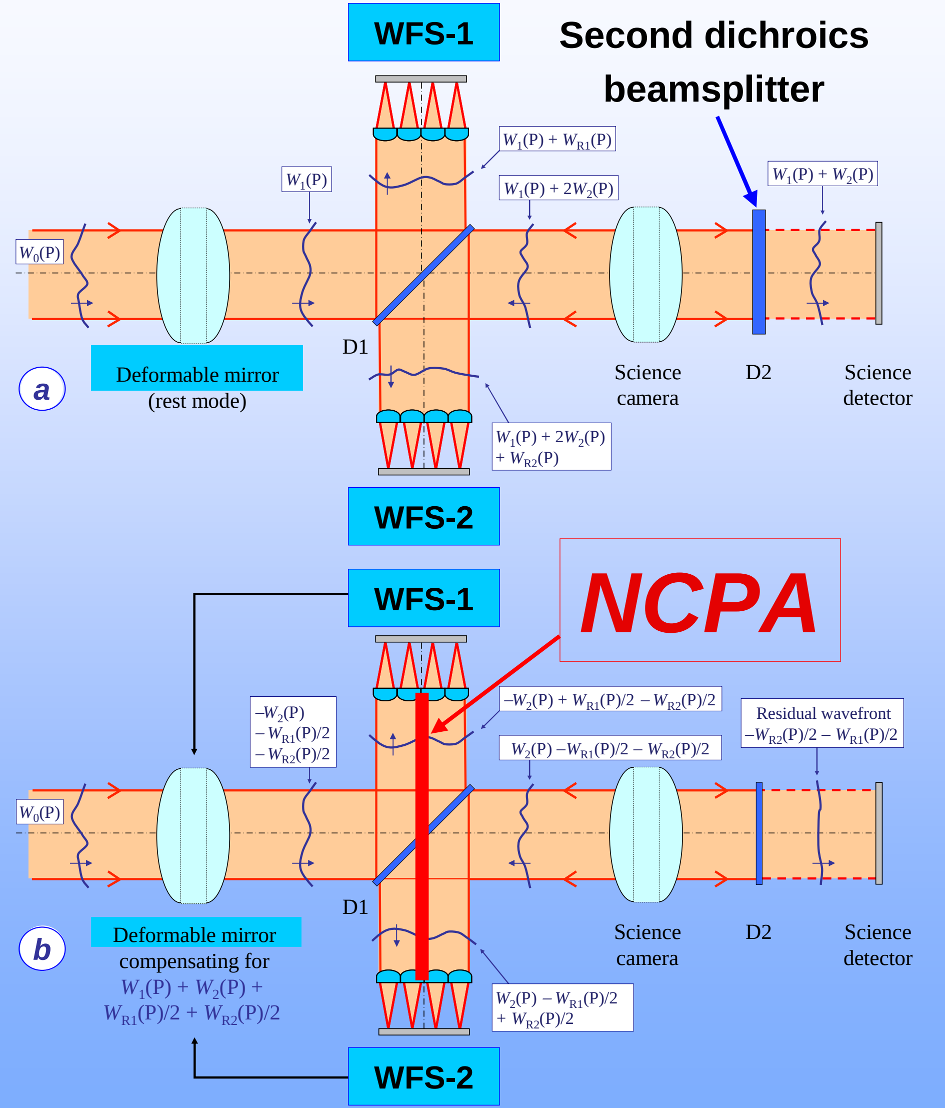
# Alternative concept – General principle

- **Principle**: Adding a second dichroics beamsplitter D2 and a second wavefront sensor WFS-2
  - D2 is located as close as possible to science detector
  - It reflects part of the beam back through the system
  - That beam is measured by WFS-2
- The error signal is the arithmetical mean of both measured wavefronts:

$$\varepsilon(\mathrm{P}) = [W_{\mathrm{M1}}(\mathrm{P}) + W_{\mathrm{M2}}(\mathrm{P})]/2$$

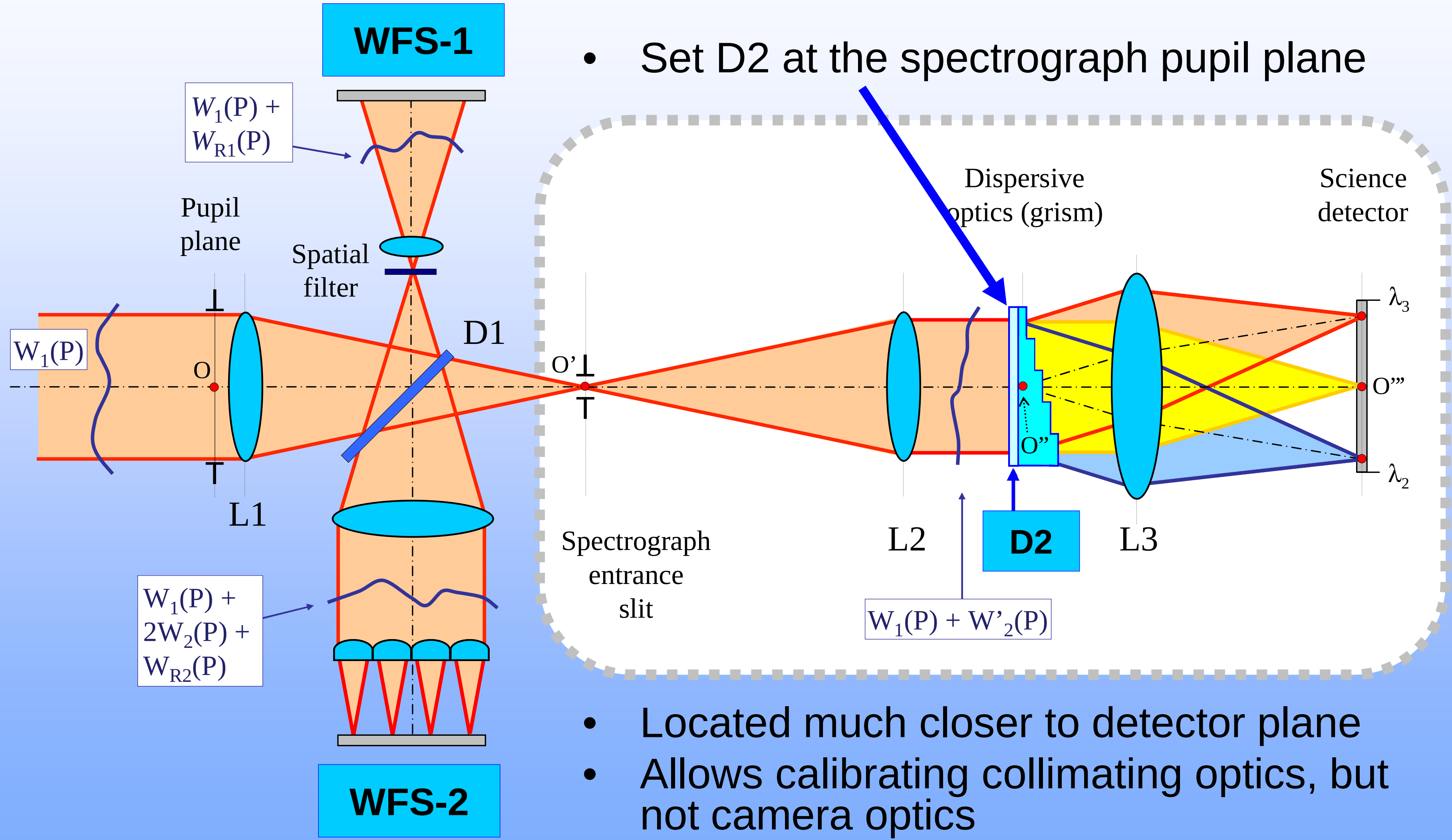
- NCPA errors are minimized as:

$$NCPA(\mathrm{P}) = -[W_{\mathrm{R1}}(\mathrm{P}) + W_{\mathrm{R2}}(\mathrm{P})]/2$$



# Application to spectroscopic instruments (1/2)

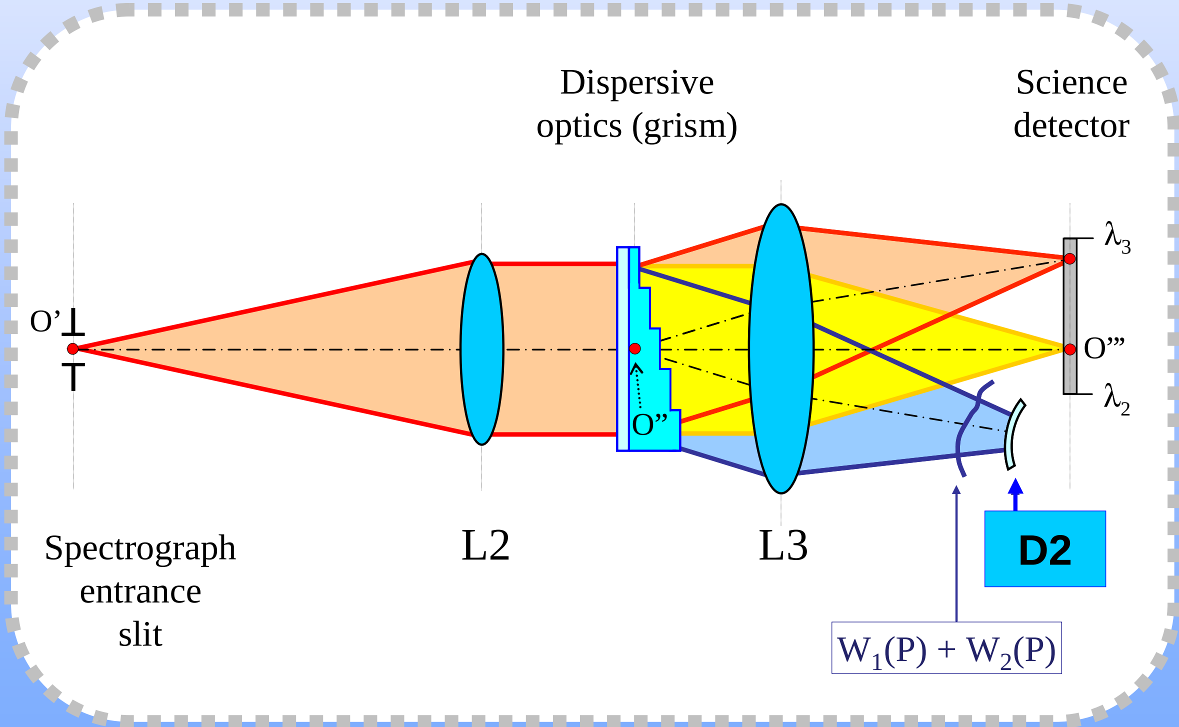
- Set D2 at the spectrograph pupil plane



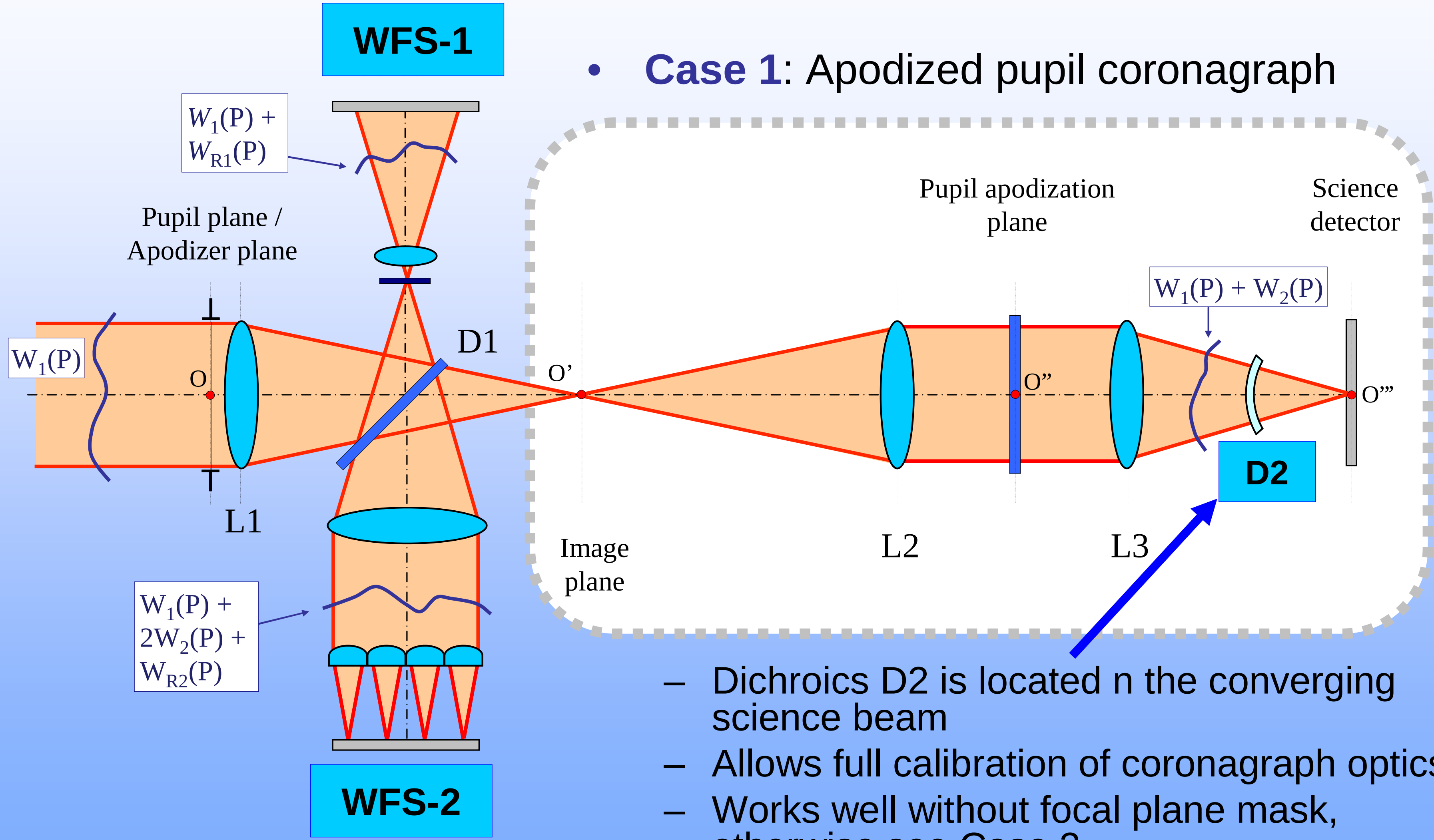

- Located much closer to detector plane
- Allows calibrating collimating optics, but not camera optics

# Application to spectroscopic instruments (2/2)

- Set dichroics D2 in the science converging beam, very close to the science detector
- D2 could be replaced with a small mirror or tooling ball
- Critical issues: limited spectral range, chromatic NCPA in camera optics



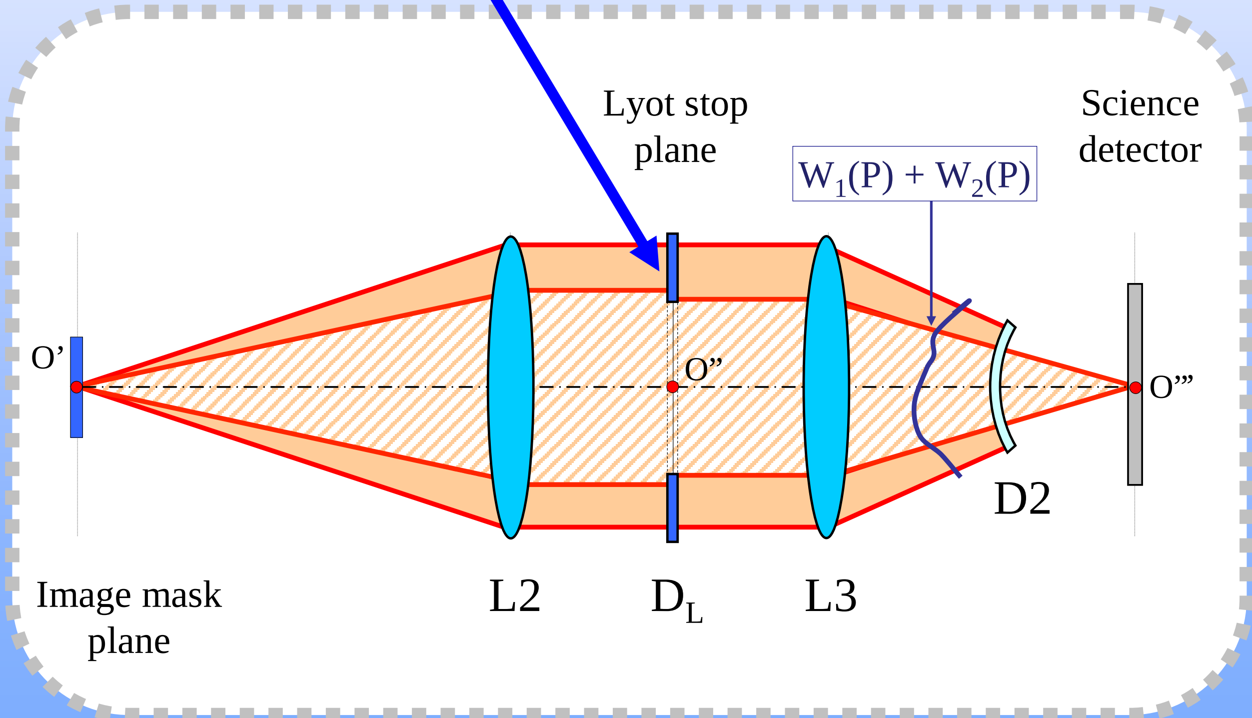
# Application to coronagraphs (1/2)




- **Case 1**: Apodized pupil coronagraph
  - Dichroics D2 is located n the converging science beam
  - Allows full calibration of coronagraph optics
  - Works well without focal plane mask, otherwise see Case 2

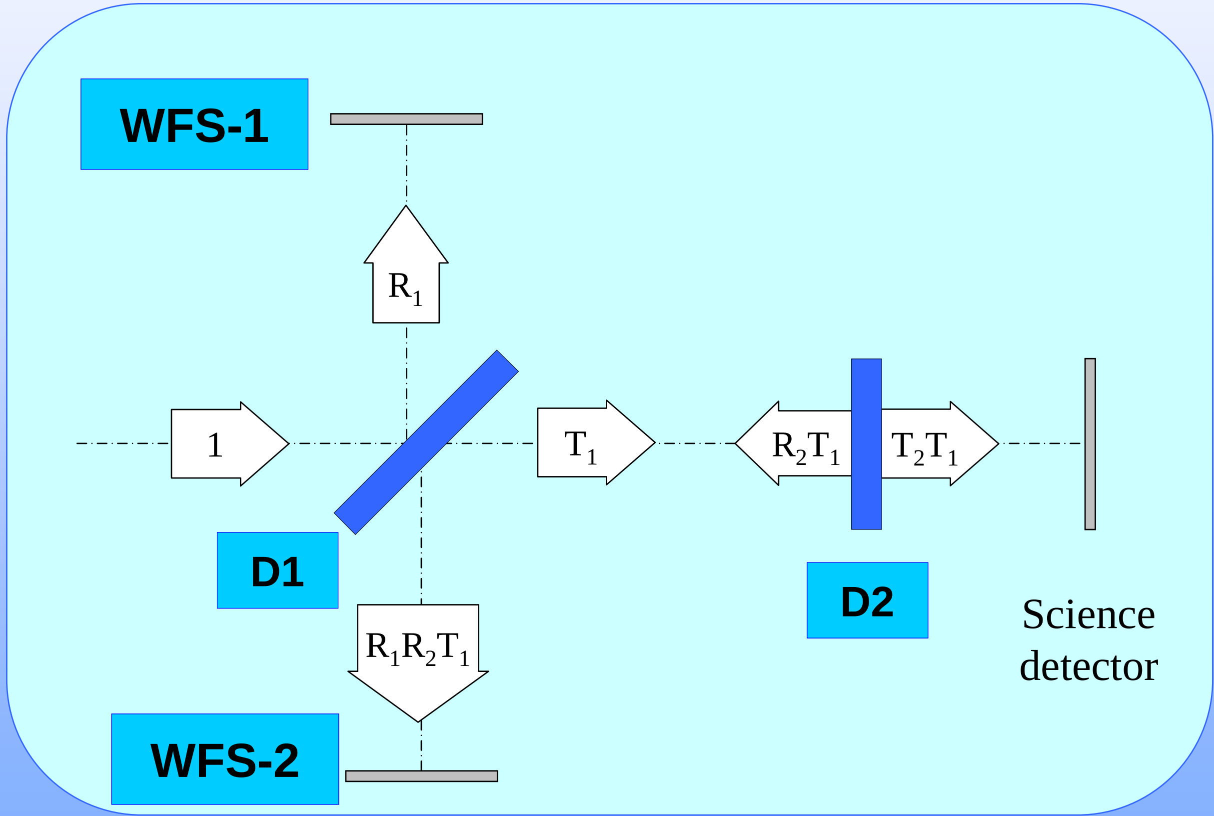
# Application to coronagraphs (2/2)

- **Case 2**: Phase mask coronagraph (or apodized pupil coronagraoh with focal plane mask)
  - Requires oversized optics after image plane phase mask
  - Requires a “dichroic Lyot stop” in pupil plane



# Preliminary requirements of dichroics plates

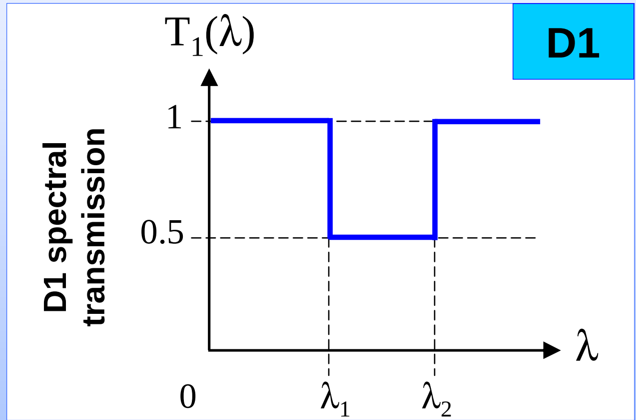
- Simplified radiometric budget



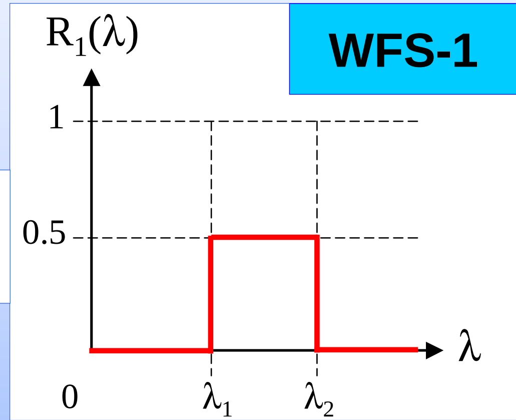
# Preliminary requirements of dichroics plates

- Radiometric characteristics

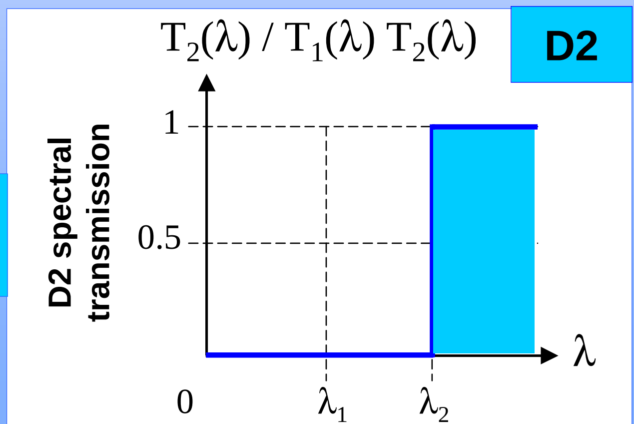
| | |
|---|---|
| WFS spectral range | $[\lambda_1 - \lambda_2]$ |
| Science spectral range | $> \lambda_2$ |



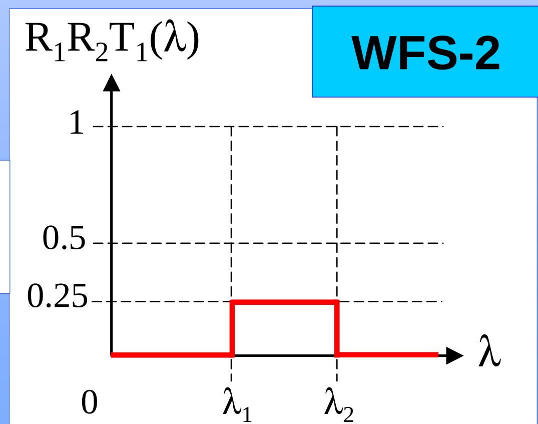

WFS-1 cannel




Science cannel



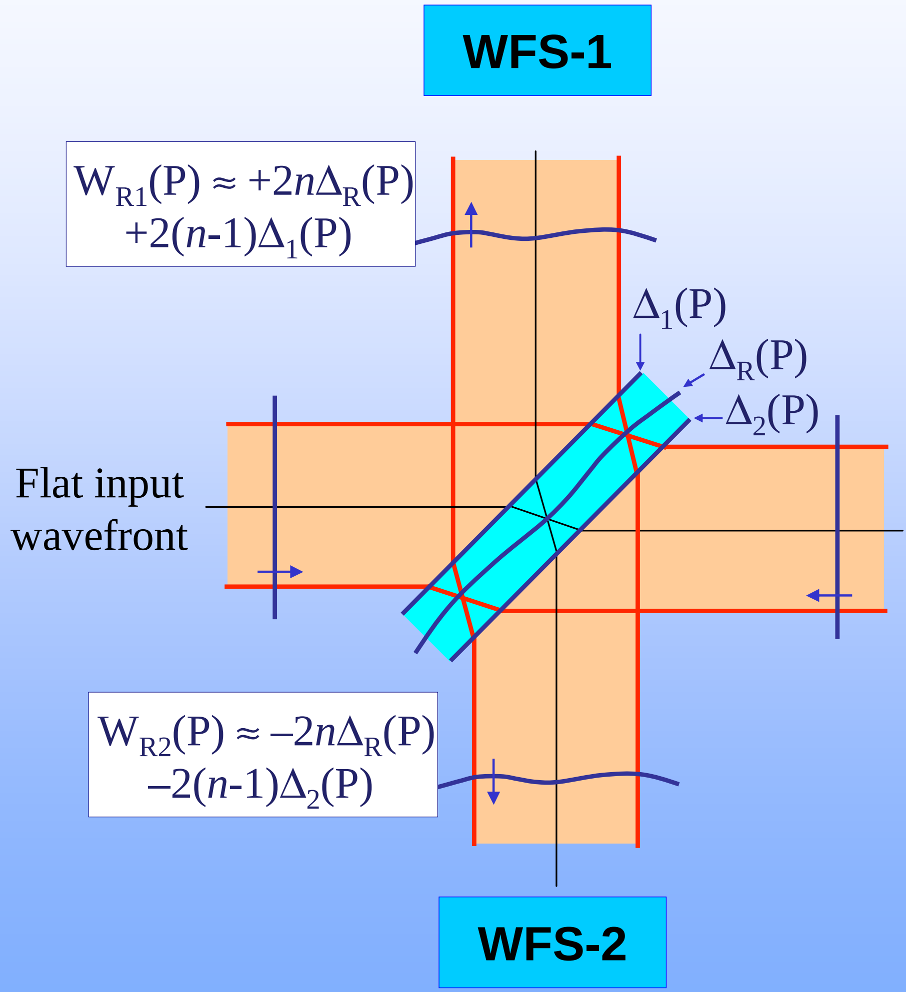

WFS-2 cannel



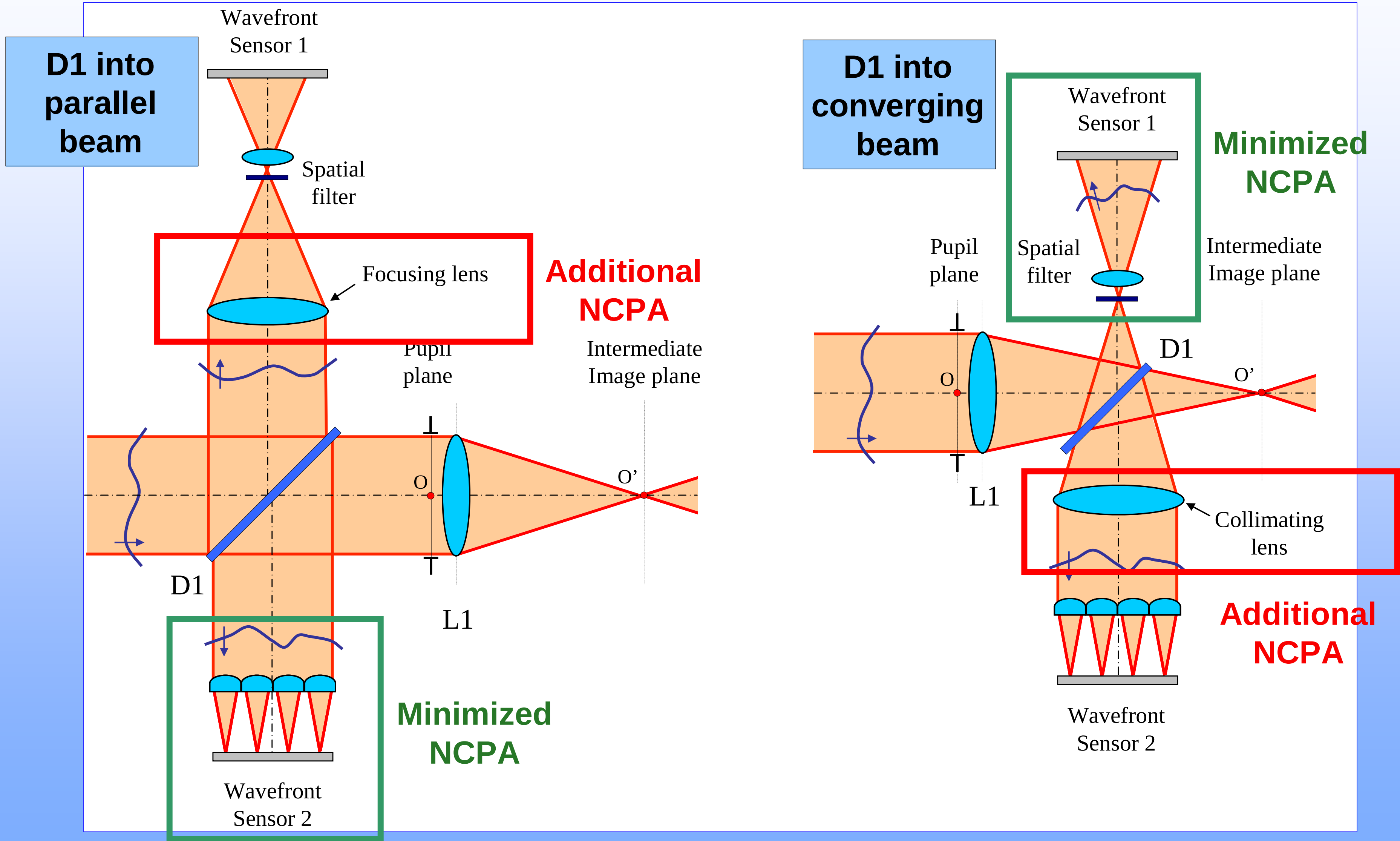
# Image quality requirements

- D2 requirements are similar to those of an interferometer caliber (typically < $\lambda/40$ RMS)
- D1 requirements are relaxed due to the symmetric WFS-1 / WFS-2 configuration
  - NCPA only depend on dichroics plate parallelism (flatness errors of D1 reflective surface are cancelled)

$$NCPA(\mathrm{P}) \approx (n(\lambda)-1)[\Delta_2(\mathrm{P})-\Delta_1(\mathrm{P})]$$



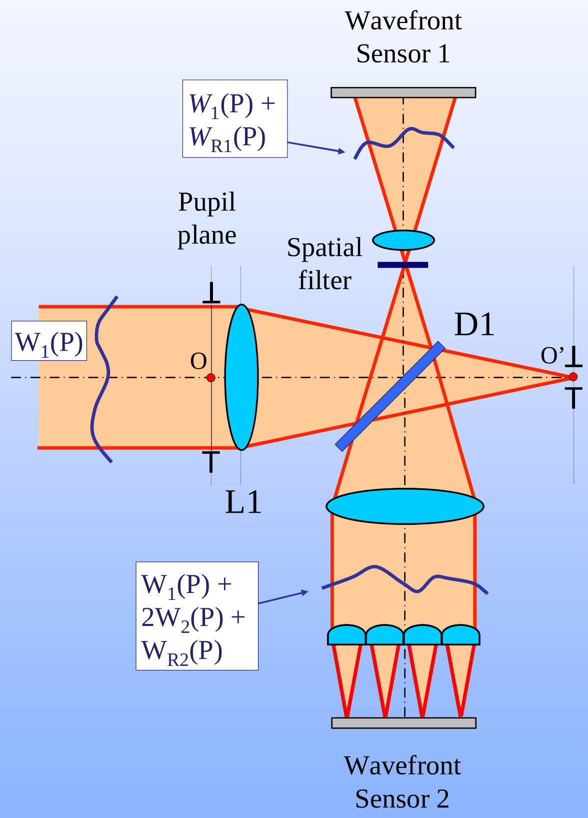
# Pupil of image plane wavefront sensors ?



# Conclusion

- NCPA are one of the last issue to be solved in adaptive optics, especially when looking for extra-solar planets with a coronagraph
- Better NCPA calibration can be achieved using a pseudo-interferometer arrangement, including:
  - A second beamsplitter located closer to the science detector
  - Two wavefront sensors operating simultaneously
  - Error signal equal to the arithmetical mean of both measured WFEs
- The concept seems to be applicable to most spectroscopic and coronagraph instruments (although with increasing difficulties)
- Specific radiometric and image quality requirements are applicable to both dichroic beamsplitters, but none of them seem unfeasible

# Many thanks for your attention




# Questions ?