# The DRS Interferometer

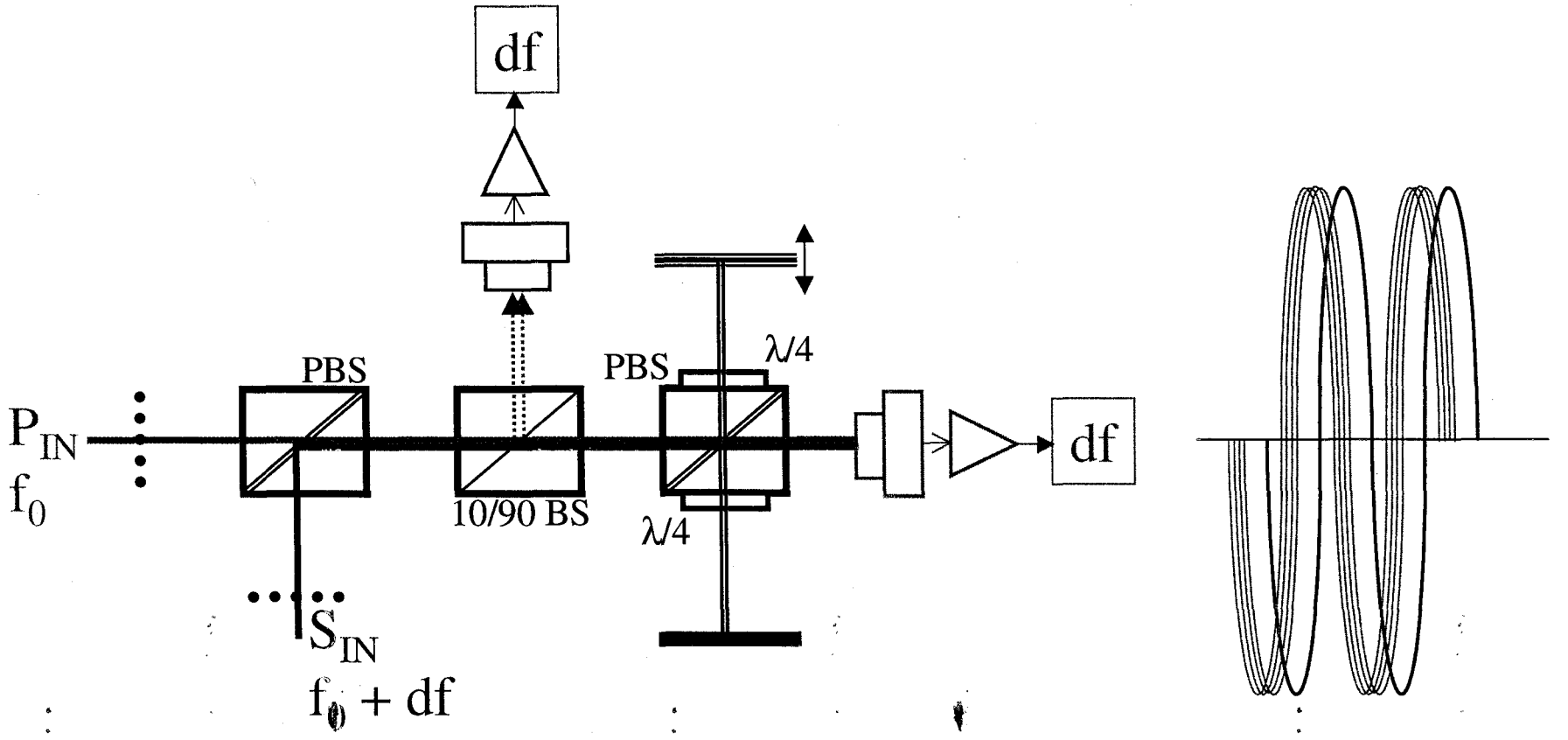
A. Kuhnert

October 19th, 2001

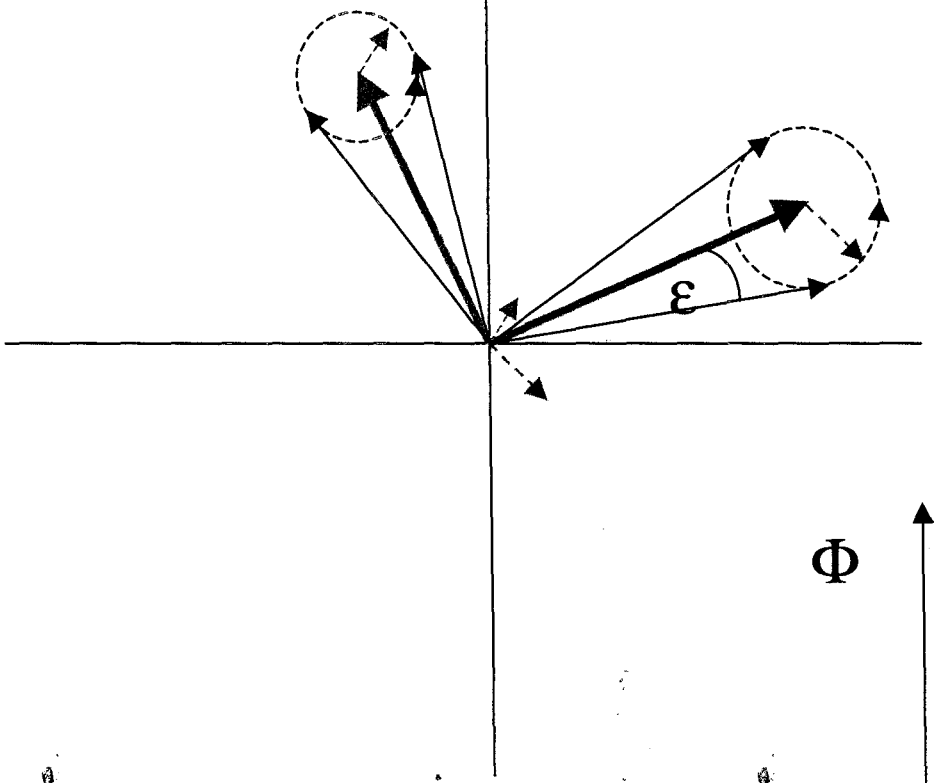
# Why an interferometer

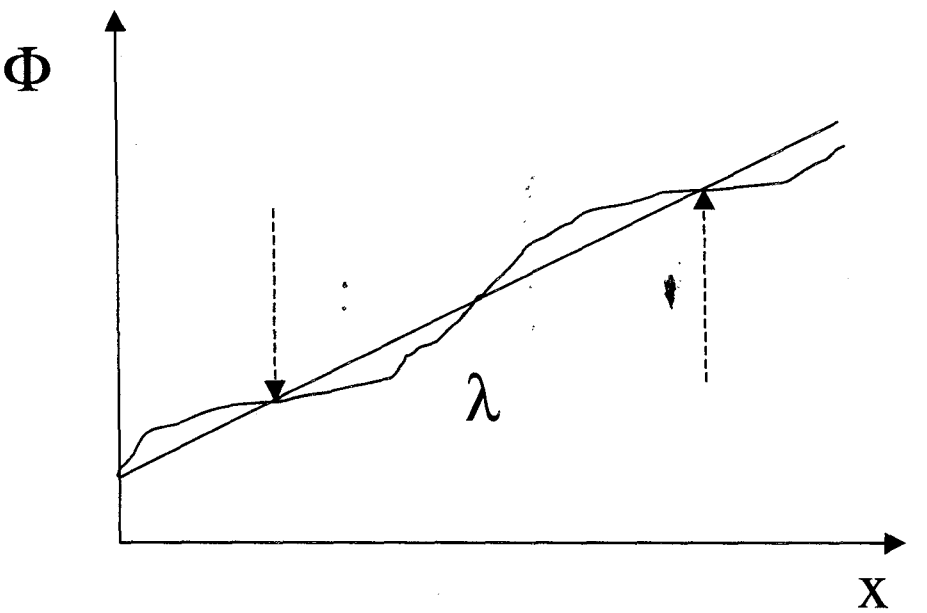
- Independent sensor for test mass separation.
- It's optical, does not interfere with test masses.
- Accelerometer sensor noise of ~1 nm/√Hz allows to measure ~$3*10^{-14}$ m/s$^2$/√Hz @ 1 mHz.
- Interferometer noise/non-linearity of 10 pm/√Hz allows to measure that accelerometer performance up to 10 mHz.

# Heterodyne Interferometer

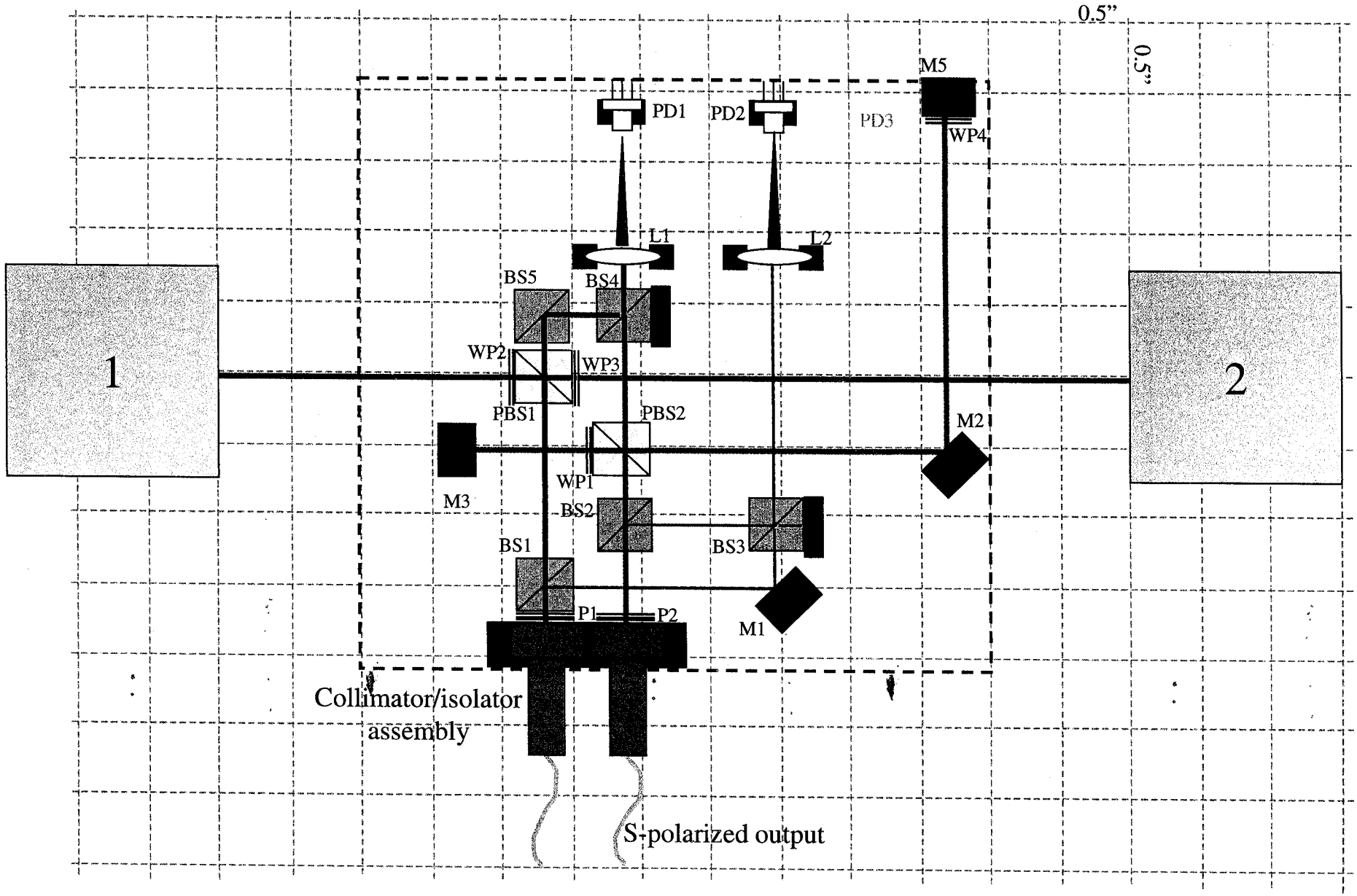


# Heterodyne Interferometer Non-linearity

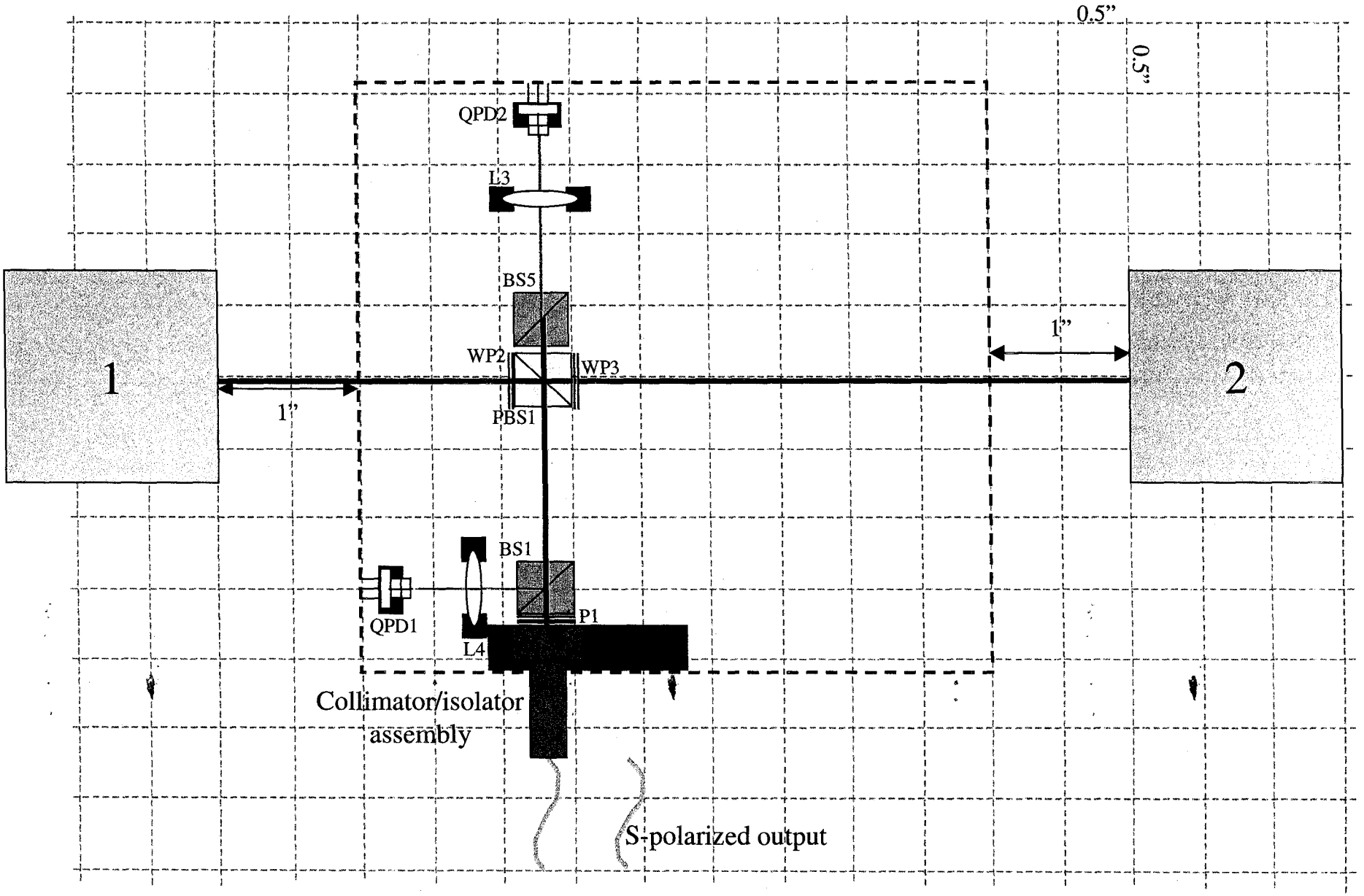


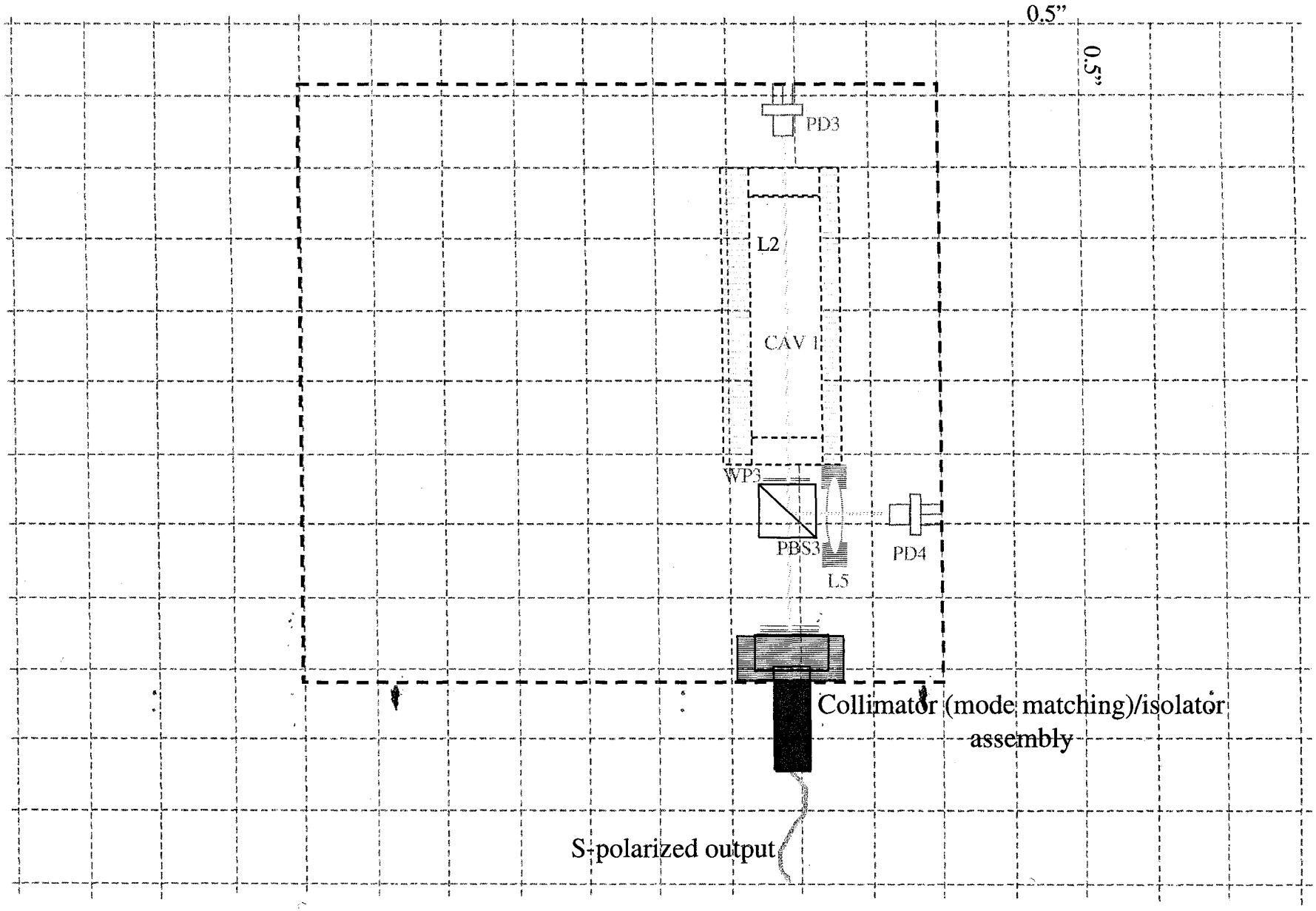
# Basic Heterodyne Interferometer for DRS



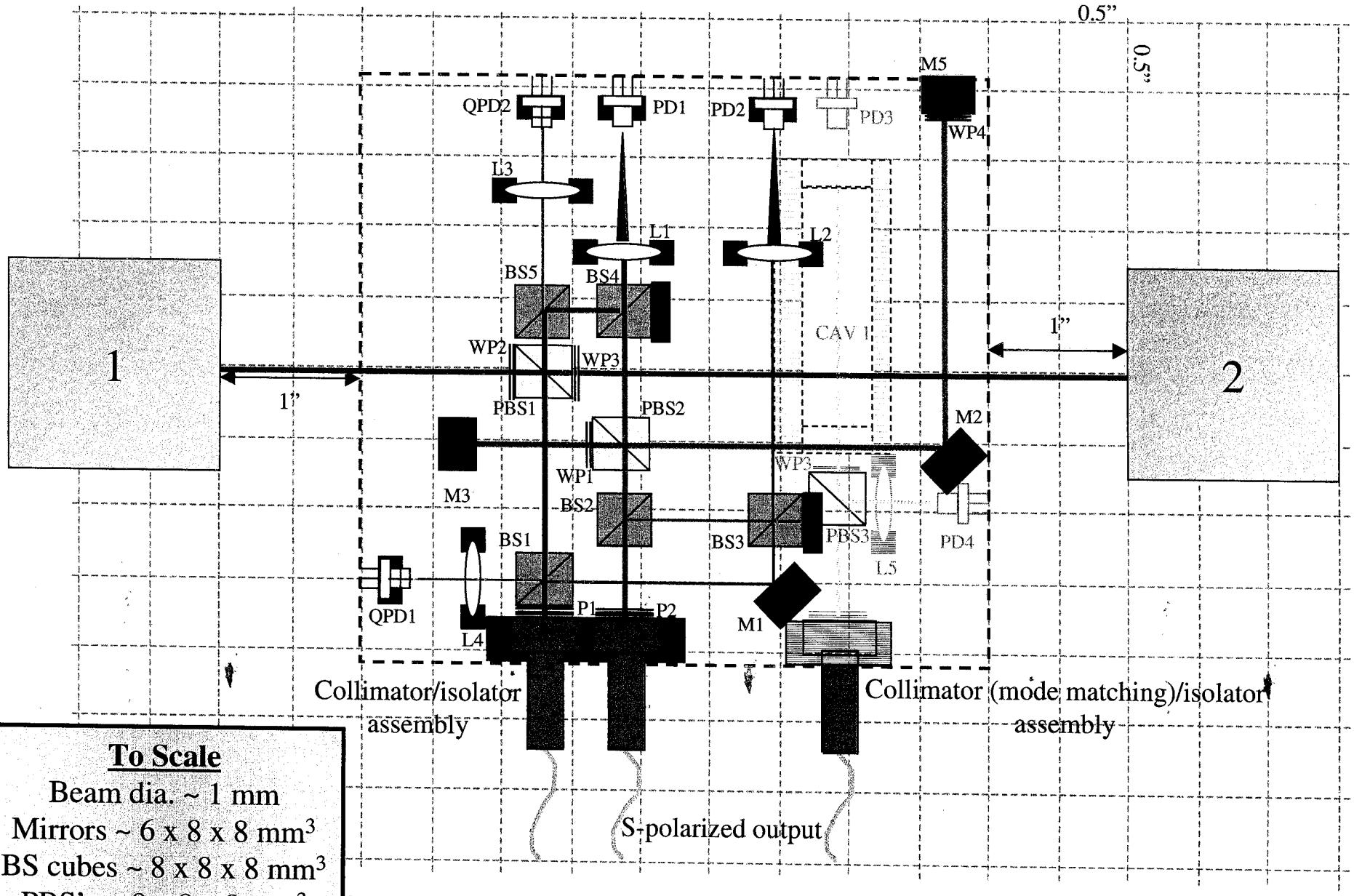
# Test Mass Alignment sensors



# Frequency Stabilization Reference Cavity



# BASELINE DESIGN




**To Scale**

Beam dia. ~ 1 mm

Mirrors ~ 6 x 8 x 8 $mm^3$

BS cubes ~ 8 x 8 x 8 $mm^3$

PBS's ~ 8 x 8 x 8 $mm^3$

# Some numbers...

- Measurement and reference optical paths are equal within 1 mm,

  $\Phi = 2\pi/\lambda * OPD = 2\pi * \nu/c * OPD$

  $d\Phi = 2\pi * d\nu/c * OPD$, e.g. $d\nu$=10 GHz and OPD=1mm => $d\Phi \sim 3.3*10^{-2} * 2\pi$

  => $\mathbf{d\Phi} \sim 7*10^{-2} * \pi$.

  We need to suppress frequency noise to <1 MHz/√Hz @ 1 mHz to achieve $7*10^{-6}$ of a fringe = 5 pm/√Hz. *(NOTE: $dL/L = d\nu/\nu$ => $dL = d\nu/\nu * L$ < 1 MHz/√Hz /227.5 THz * 1 mm < 5 pm/√Hz)*

- Reference cavity is also in $10^{-6}$ °K/√Hz @ 1 mHz environment, with ULE CTE ~ $10^{-8}$/°K it follows that cavity is stable to $10^{-14}$ /√Hz, i.e. a 5 cm long cavity w/ FSR=3 GHZ is stable to ~1 Hz /√Hz @ 1 mHz.

# and more numbers...

- Proof mass distance stable to ~ 1 nm (~1/600 of a fringe) => let's assume we'll have ~1 nm periodic non-linearity: => max. slope of non-linearity ~ 6 $nm_{PP}$/330 nm => 18 pm/ nm; worst case we'll get ~20 pm non-linearity over 1 nm motion.
  **<u>Q: Over what time scale do masses drift, i.e. is non-linearity out of signal band?</u>**

# and even more…

- Measurement and reference optical paths in glass are equal within the dimensional differences of the BSs, PBSs (~100 μm), soak temperature sensitivity then is: CTE(BK7)*Δdim*ΔT ~ $10^{-5}$/°K*$10^{-4}$m*$10^{-6}$ °K/√Hz =$10^{-15}$ m/√Hz, i.e. there is room. We might use ULE for all optics since the optical bench is ULE.

# Summary

- Heterodyne interferometer used as independent, non-interfering test mass separation sensor.
- Interferometer performance: ~10 pm/√Hz @ 1 mHz limited by non-linearity and pointing fluctuations (compared to 1 nm/√Hz @ 1 mHz for accelerometer noise)

# The DRS Interferometer

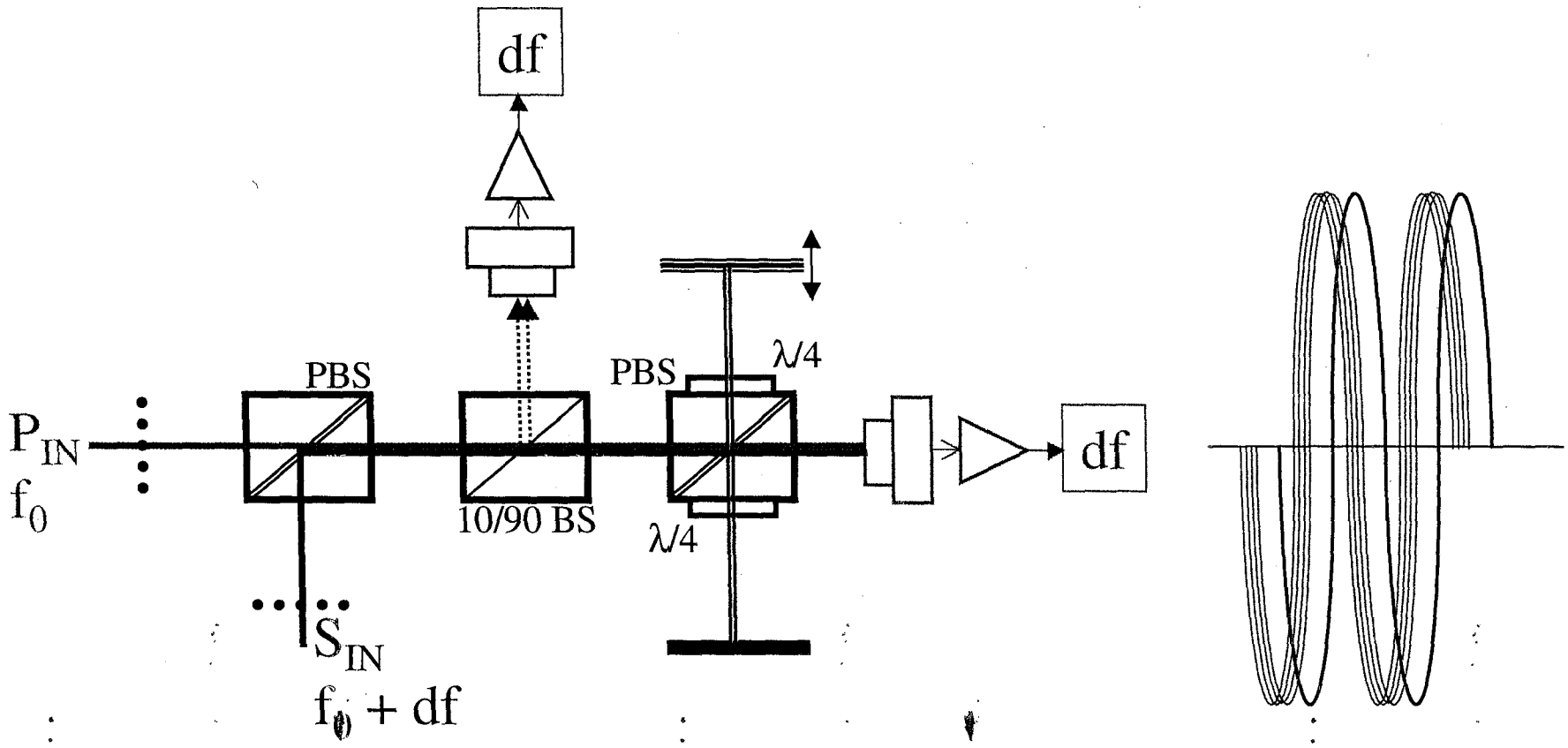
A. Kuhnert

October 19th, 2001

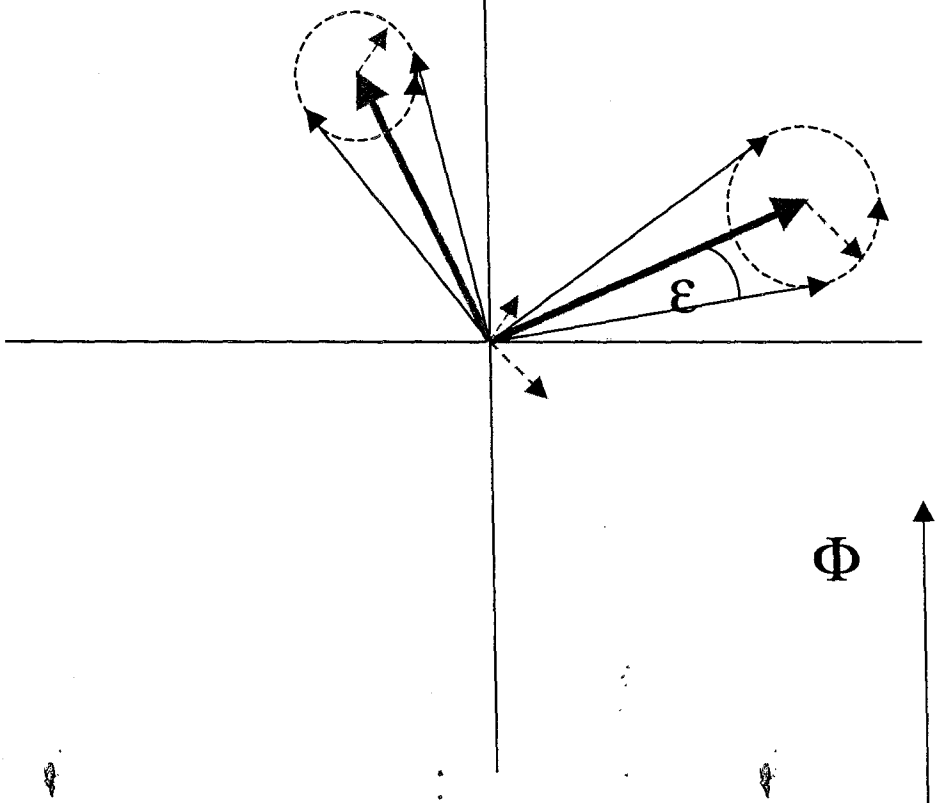
# Why an interferometer

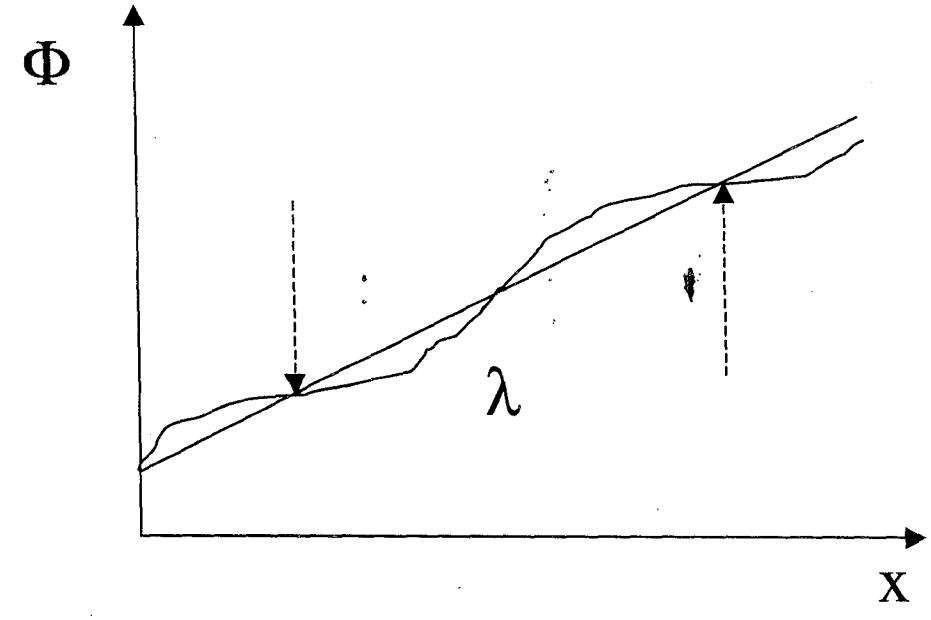
- Independent sensor for test mass separation.
- It's optical, does not interfere with test masses.
- Accelerometer sensor noise of ~1 nm/√Hz allows to measure ~$3*10^{-14}$ m/s$^2$/√Hz @ 1 mHz.
- Interferometer noise/non-linearity of 10 pm/√Hz allows to measure that accelerometer performance up to 10 mHz.

# Heterodyne Interferometer

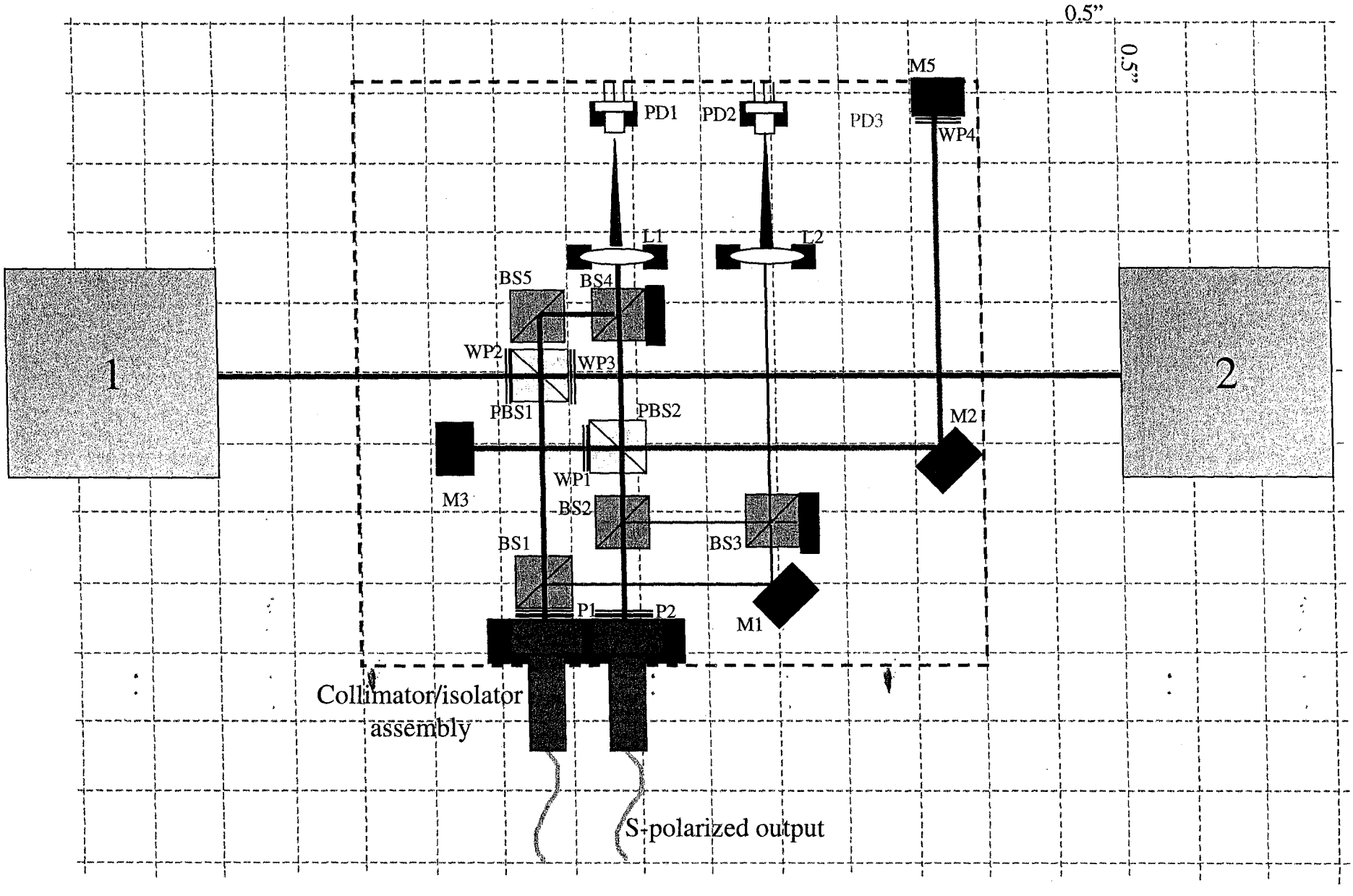


# Heterodyne Interferometer Non-linearity

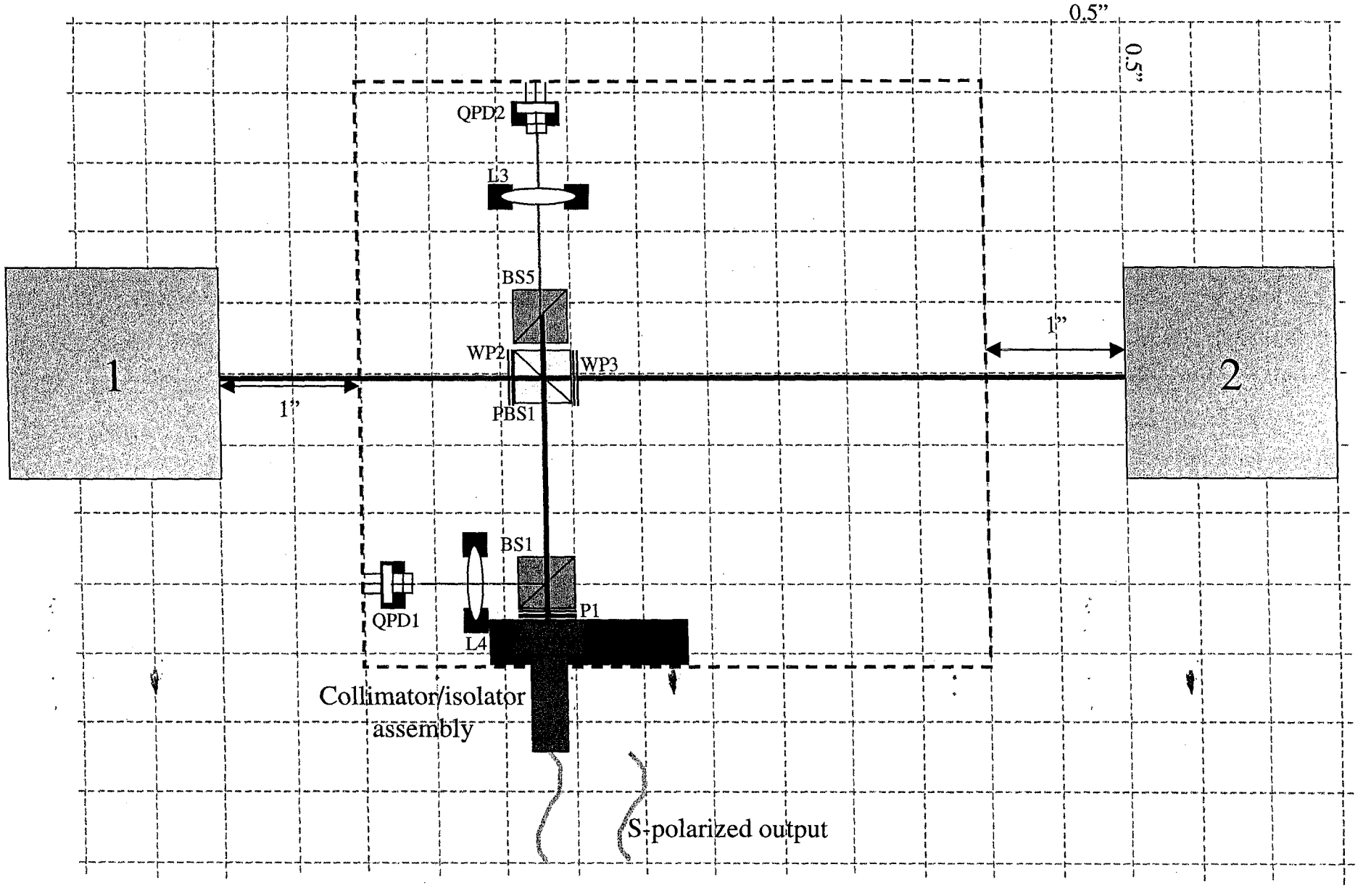


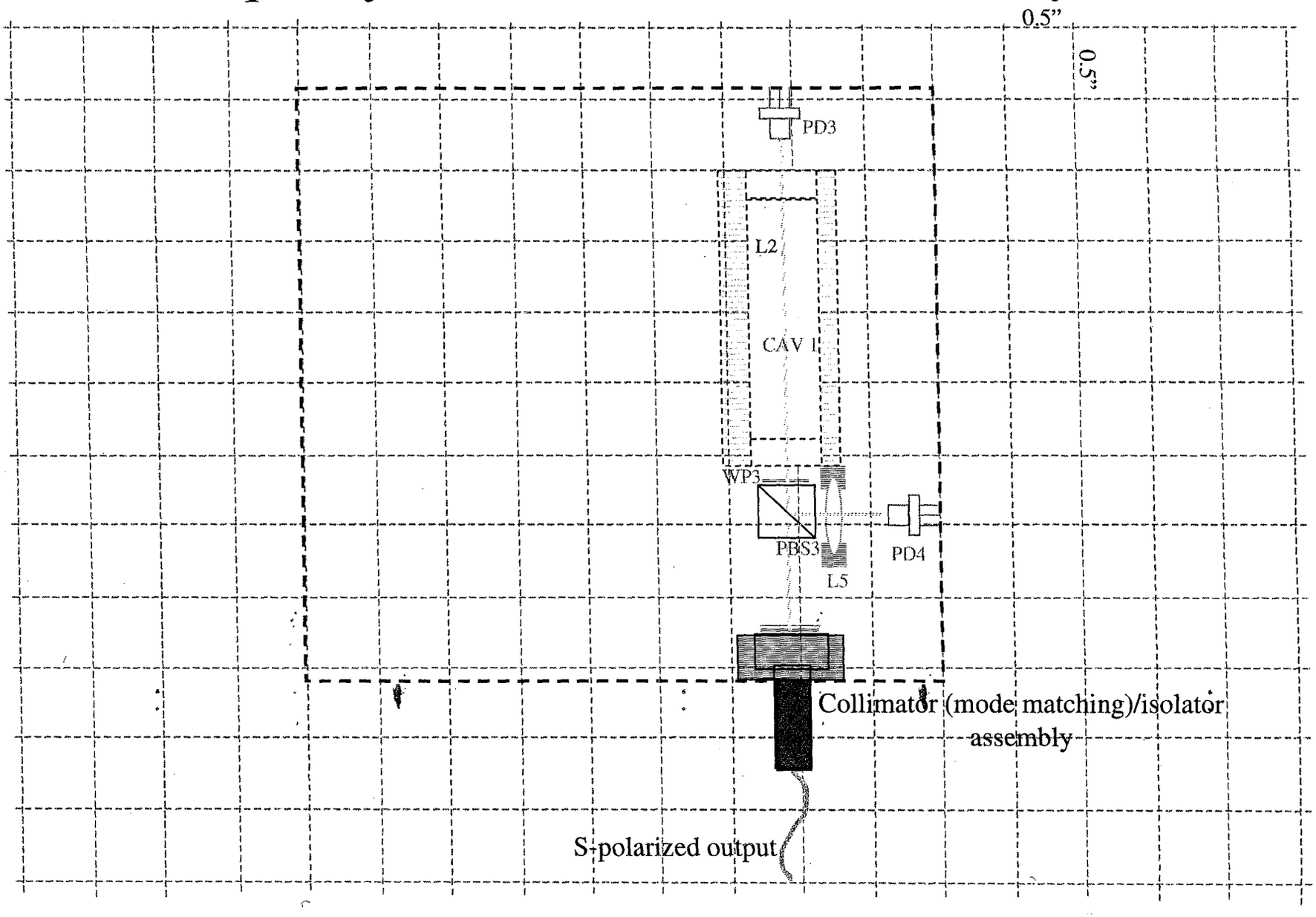
# Basic Heterodyne Interferometer for DRS



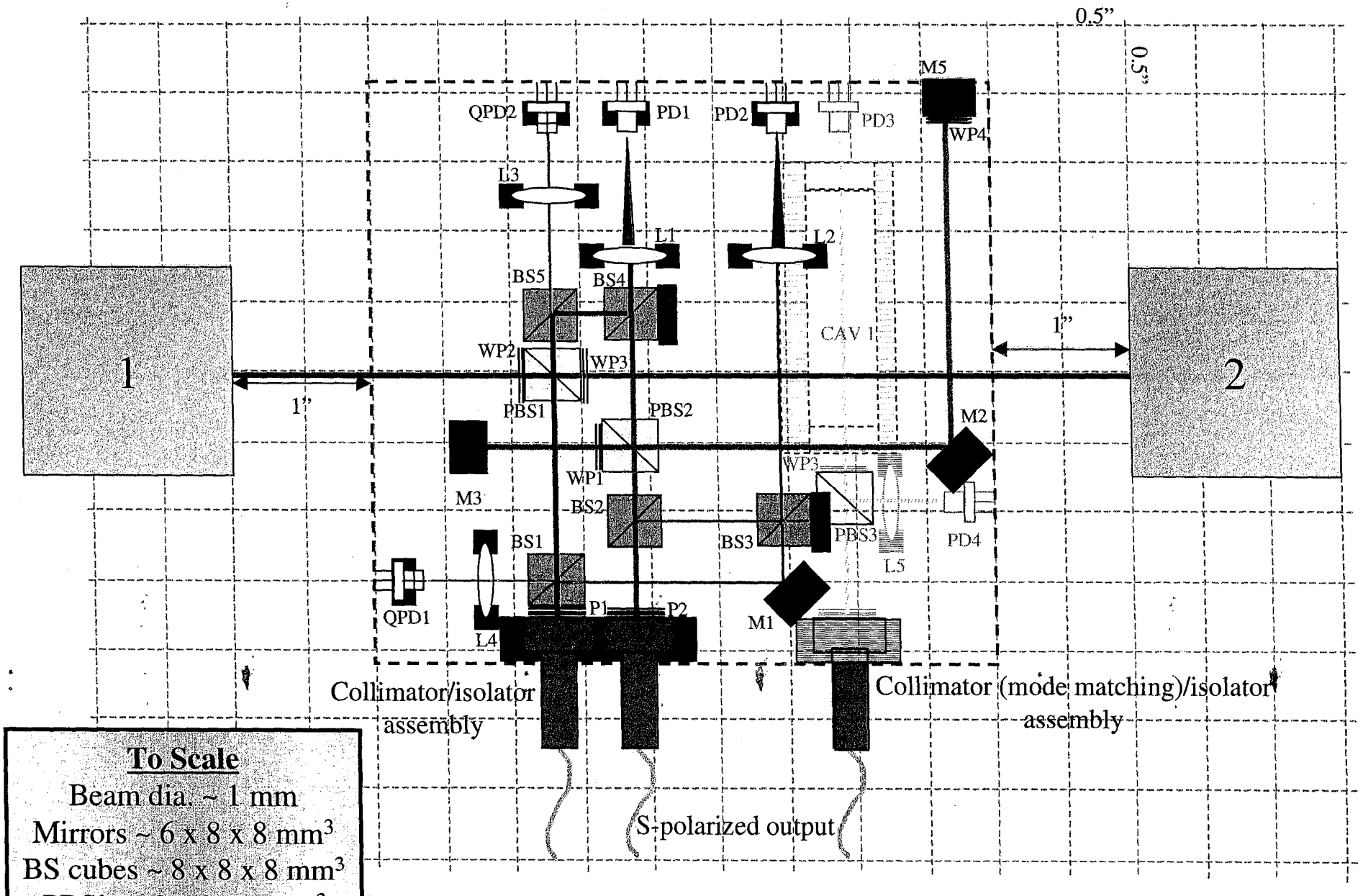
# Test Mass Alignment sensors



# Frequency Stabilization Reference Cavity



# BASELINE DESIGN




**To Scale**

Beam dia. ~ 1 mm

Mirrors ~ 6 x 8 x 8 $mm^3$

BS cubes ~ 8 x 8 x 8 $mm^3$

PBS's ~ 8 x 8 x 8 $mm^3$

# Some numbers...

- Measurement and reference optical paths are equal within 1 mm,

  $\Phi = 2\pi/\lambda * OPD = 2\pi * \nu/c * OPD$

  $d\,\Phi = 2\pi * d\nu/c * OPD$, e.g. $d\nu$=10 GHz and OPD=1mm => $d\,\Phi \sim 3.3*10^{-2} * 2\pi$

  => $\mathbf{d\,\Phi} \sim 7*10^{-2} * \pi$.

  We need to suppress frequency noise to <1 MHz/√Hz @ 1 mHz to achieve $7*10^{-6}$ of a fringe = 5 pm/√Hz. *(NOTE: $dL/L = d\nu/\nu$ => $dL = d\nu/\nu * L$ < 1 MHz/√Hz /227.5 THz * 1 mm < 5 pm/√Hz)*

- Reference cavity is also in $10^{-6}$ °K/√Hz @ 1 mHz environment, with ULE CTE ~ $10^{-8}$/°K it follows that cavity is stable to $10^{-14}$/√Hz, i.e. a 5 cm long cavity w/ FSR=3 GHZ is stable to ~1 Hz/√Hz @ 1 mHz.

# and more numbers...

- Proof mass distance stable to ~ 1 nm (~1/600 of a fringe) => let's assume we'll have ~1 nm periodic non-linearity: => max. slope of non-linearity ~ 6 $nm_{PP}$/330 nm => 18 pm/ nm; worst case we'll get ~20 pm non-linearity over 1 nm motion.
  **<u>Q: Over what time scale do masses drift, i.e. is non-linearity out of signal band?</u>**

# and even more…

- Measurement and reference optical paths in glass are equal within the dimensional differences of the BSs, PBSs (~100 μm), soak temperature sensitivity then is: CTE(BK7)*Δdim*ΔT ~ $10^{-5}$/°K*$10^{-4}$m*$10^{-6}$ °K/√Hz =$10^{-15}$ m/√Hz, i.e. there is room. We might use ULE for all optics since the optical bench is ULE.

# Summary

- Heterodyne interferometer used as independent, non-interfering test mass separation sensor.
- Interferometer performance: ~10 pm/√Hz @ 1 mHz limited by non-linearity and pointing fluctuations (compared to 1 nm/√Hz @ 1 mHz for accelerometer noise)