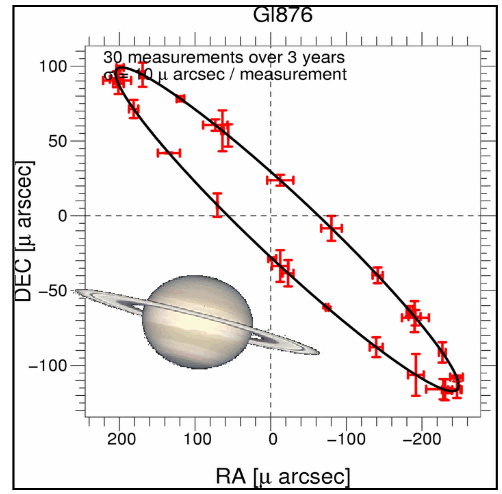
# Towards high-precision astrometry - Differential Delay Lines for PRIMA@VLTI

IMT (Neuchâtel, CH)
EPFL (Lausanne, CH)
ASTRON (Dwingeloo, NL)
MPIA Heidelberg
Observatoire de Genève
University of Leiden/NOVA





R. Launhardt[1], D. Queloz[2], Th. Henning[1], A. Quirrenbach[3], & consortium

[1] Max Planck Institute for Astronomy, Heidelberg, Germany

[2] Observatoire de Genève, Switzerland

[3] University of Leiden, The Netherlands

# The PRIMA-DDL/AOS Consortium:

***Observatoire de Genève:***

M. Fleury
C. Maire
F. Pepe
D. Queloz
D. Ségransan
D. Sosnowska
L. Weber

***IMT (Neuchâtel, CH):***

R. Dandliker
O. Scherler

***Collaborators from ESO:***

P. Ballester
F. Delplancke
F. Dérie
A. Glindemann

***MPIA Heidelberg:***

H. Baumeister
P. Bizenberger
T. Henning
R. Launhardt
J. Setiawan
K. Wagner

***EPFL (Lausanne, CH):***

H. Bleuler
D. Gillet
P. Mullhaupt
L. Sache
R. Wüthrich

***University of Leiden/NOVA:***

E. Bakker
S. Frink
S. Hekker
W. Jaffe
J. de Jong
R. le Poole
A. Quirrenbach
R. Tubbs

***ASTRON (Dwingeloo, NL):***

H. Hanenburg
J. Pragt
F. Rigal
L. Venema

# Overview:

## Goal

Perform **Astrometric Planet Search Program**

with 10µas accuracy at PRIMA@VLTI (2007-2010)

Consortium proposes to ESO

## Agreement with ESO

Build **D**ifferential **D**elay **L**ines

and provide

**A**strometric **O**peration and **S**oftware tools (2004-2007)

## Science preparation

Target star characterization

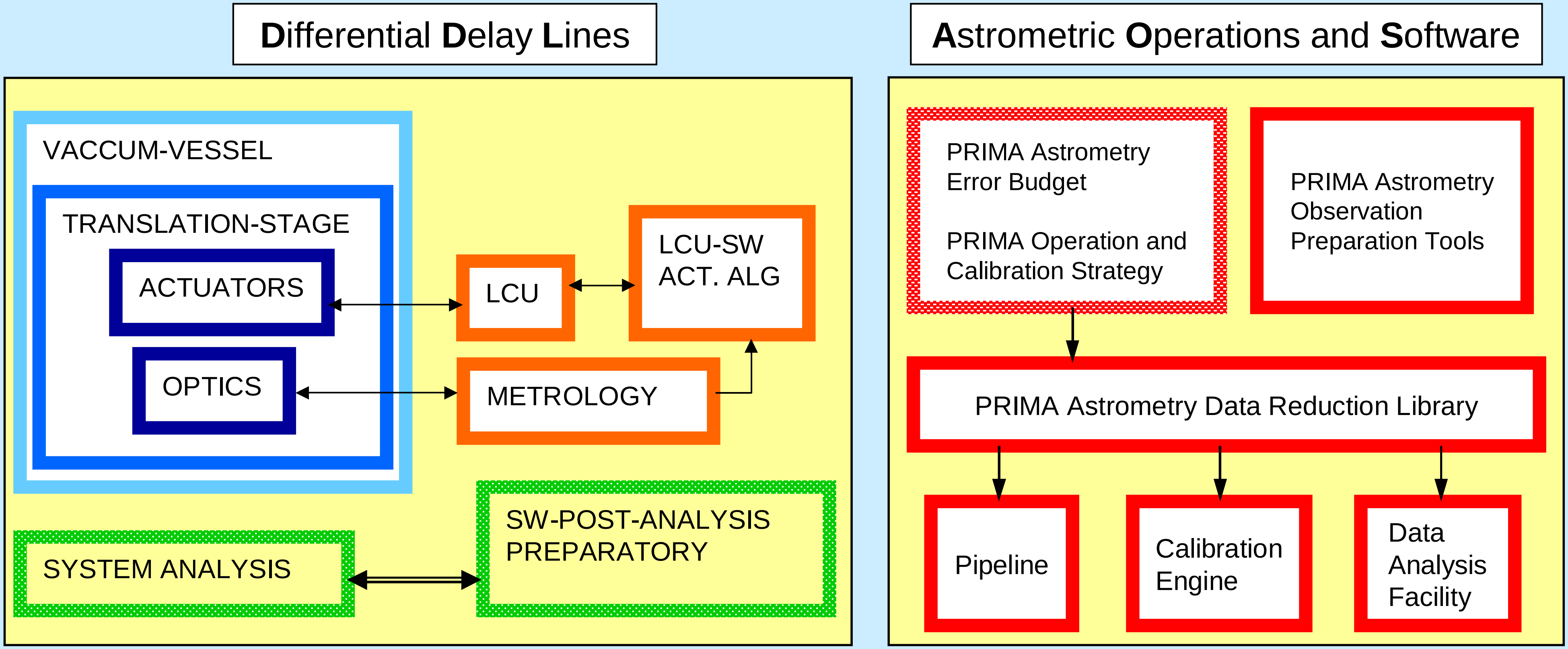
Modelling

Preparatory observations

## Reward

Observing time with 2 ATs

# The Project:



Differential Delay Lines
VACCUM-VESSEL
TRANSLATION-STAGE
ACTUATORS
OPTICS
LCU
LCU-SW
ACT. ALG
METROLOGY
SYSTEM ANALYSIS
SW-POST-ANALYSIS
PREPARATORY
Astrometric Operations and Software
PRIMA Astrometry
Error Budget
PRIMA Operation and
Calibration Strategy
PRIMA Astrometry
Observation
Preparation Tools
PRIMA Astrometry Data Reduction Library
Pipeline
Calibration
Engine
Data
Analysis
Facility

# Measurement Principle:

- **Interferometric differential astrometry** with a **dual-star interferometer:** Two small fields (primary and secondary star) from each of the two telescopes are sent as separate beams through the delay lines.

- The **delay difference between the two telescopes** is corrected for with the **main delay lines**. Primary and secondary beams from each telescope travel together through one main delay line.

- The **delay difference between the two fields** (for each telescope) is taken out with additional short-stroke **differential delay lines**.

- **Zero-order fringes** for both target and reference are observed on **fringe sensing units** (FSUs).

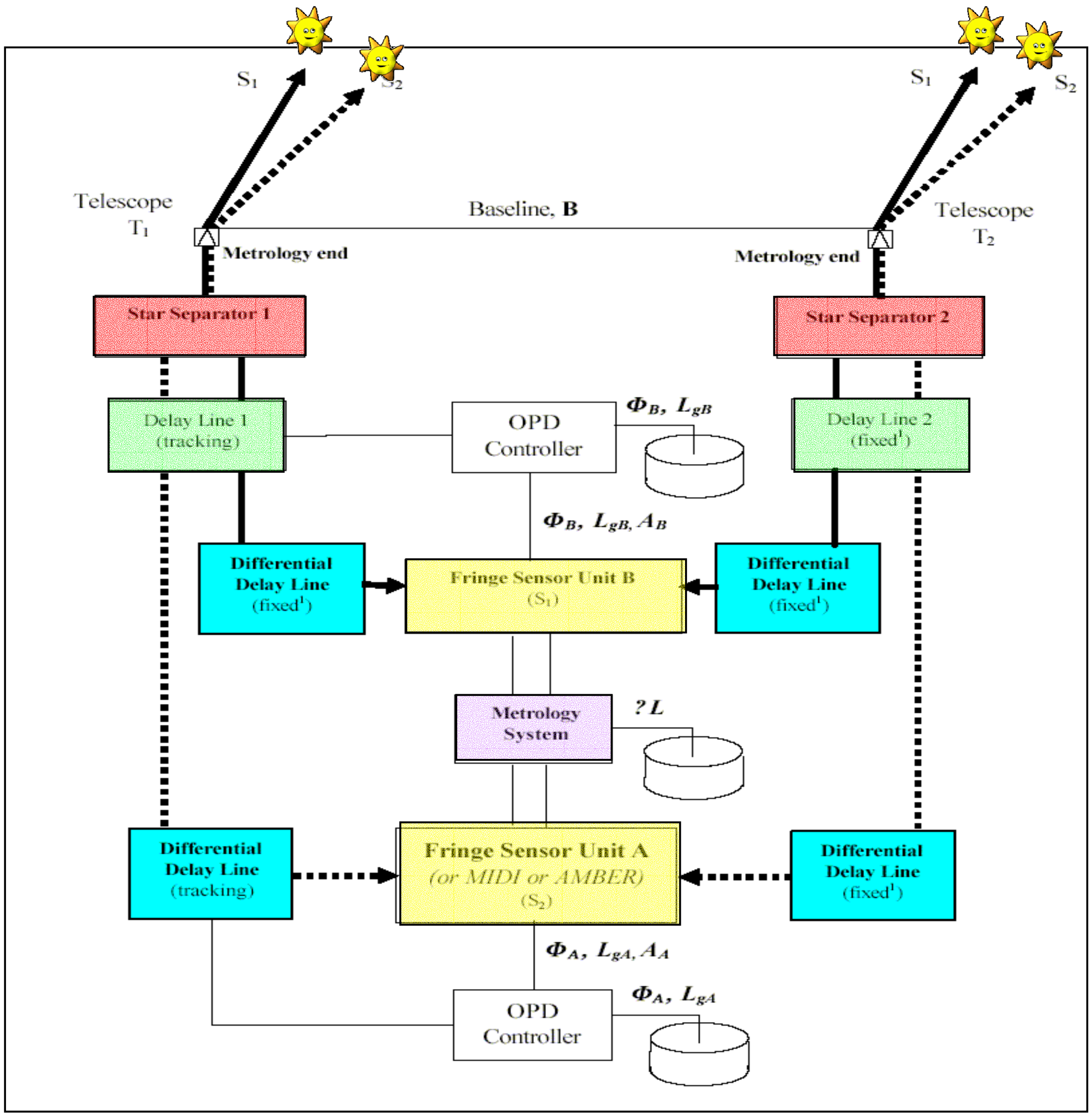
- An internal end-to-end laser **metrology** system monitors the delay difference within the interferometer and to controls the delay lines.

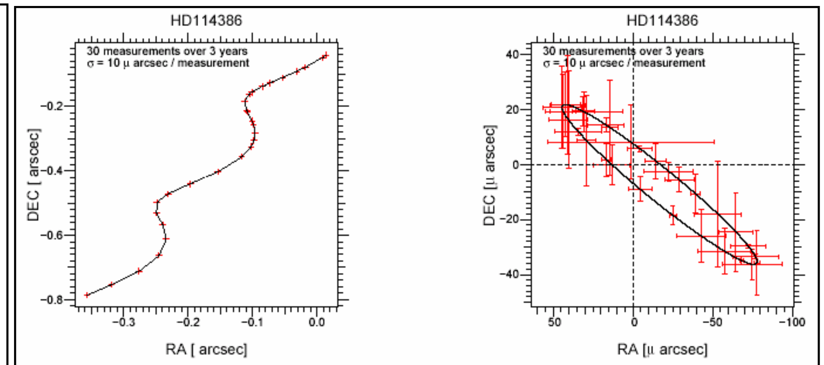
- The external **delay difference $\Delta D$ between target and reference** (the *Observable*) is measured from the internal delay difference $\Delta D_{int}$ (from metrology) and the offset between the zero order fringes on both FSUs. It is directly related to the **angular offset vector between the two stars** projected on the baseline $B$:
$\Delta D = \Delta D_{int} + D_{FSU1} - D_{FSU2} = B (\cos \theta_1 - \cos \theta_2)$

- **Astrometric data point:** 1-D angular offset (projected on the baseline) between target and reference star at time $t$.

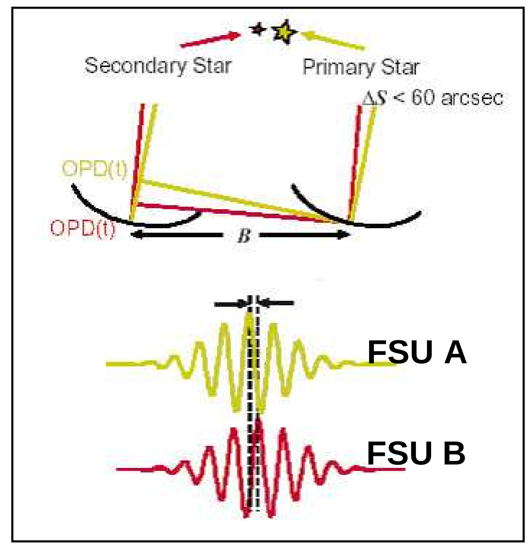
- **Astrometric data series:** 1-D angular offsets projected on different relative baseline orientations at different times.

- **Science result:** Planetary orbit and mass from reflex motion of host star, derived from fitting the residuals after global astrometric solution to parallax and proper motion of both target and reference star. The reference star will usually be at a much larger distance than the target star, so that the planetary signal can be assigned to the target star.




parameters retrieved from a global fit on the astrometric measurements for HD114386. For this simulation we assumed *i*=84deg, W=25deg, and 30 measurements spread over 3 years and evenly distributed over the orbital phase.

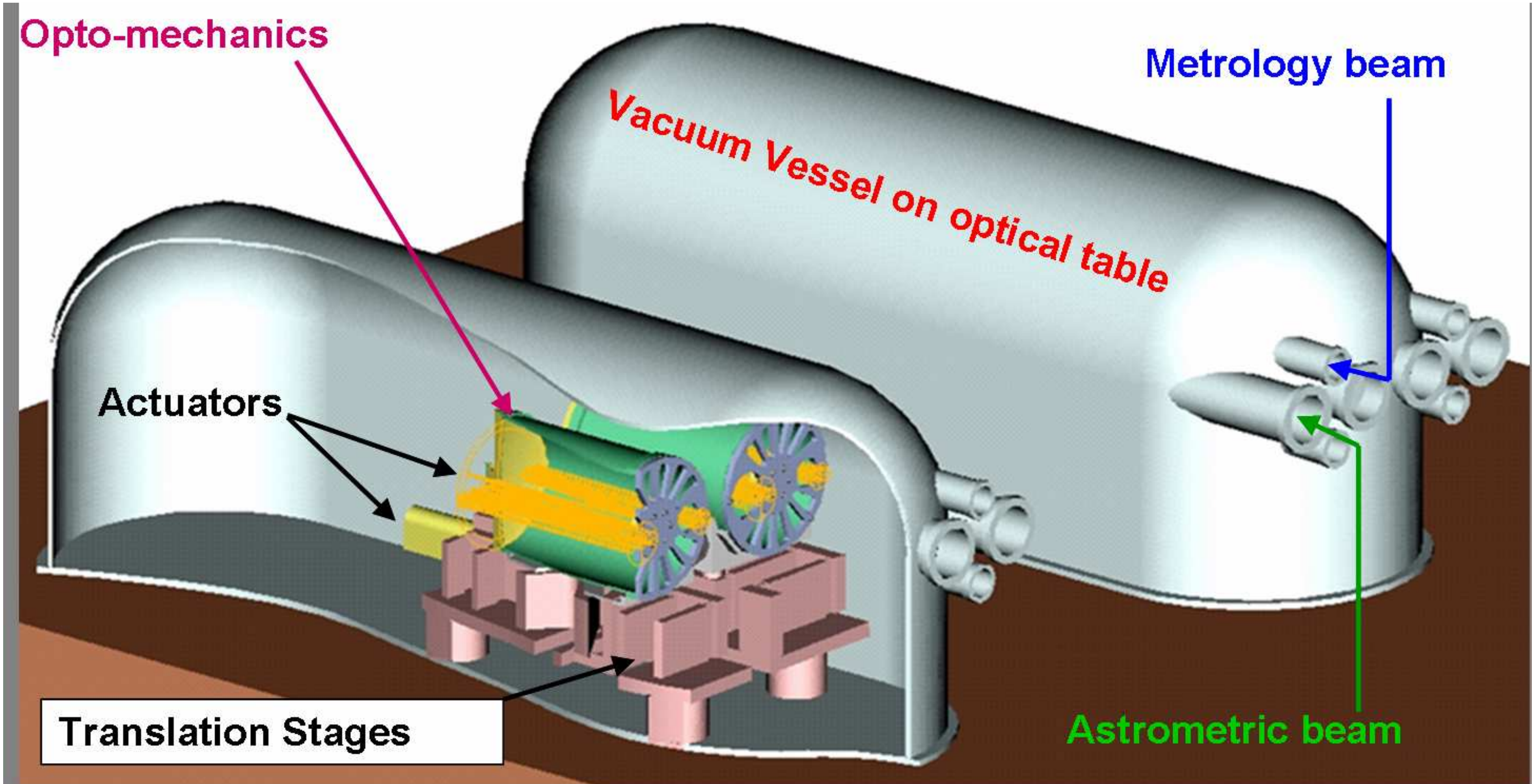


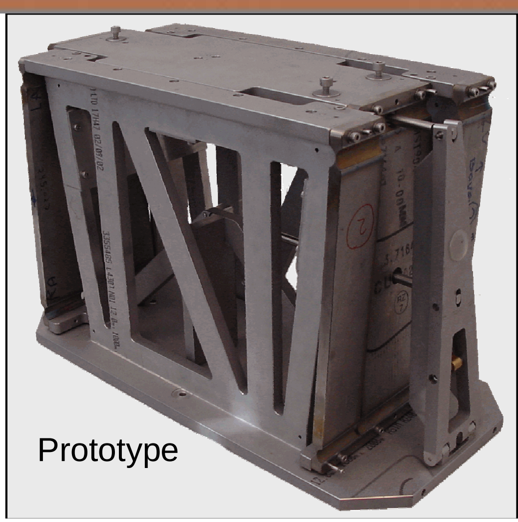
# Technical Concept Design:

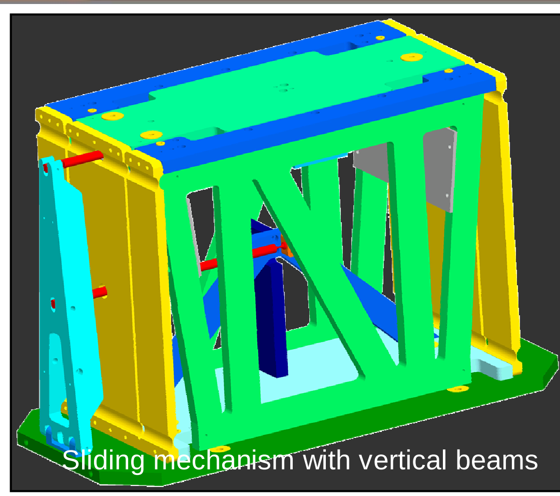
- **Accuracy requirements/tolerances:** Stroke: 70mm, Resolution: 2nm, Angular alignment <0.3arcsec
- **Vacuum vessel:** One vessel covers two DDLs, Size: ≈1m × 480mm × 500mm (l×w×h), Windows optimized for K-band
- **Translation Stage:** Two-stage parallel beam sliders with blade spring hinges
- **Actuators:** Two-stage actuator system (linear motor + piezo, possibly with active tilt control)

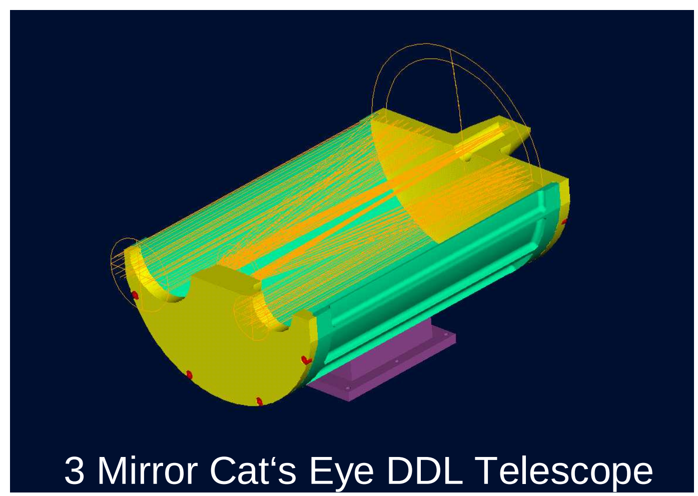
| Actuator | Range | Accuracy | Freq. resp. |
|---|---|---|---|
| Main | +/- 35 mm | 100 nm | 15 Hz |
| Fine | +/- 2 µm | 1 nm | 200 Hz |

- **Optics:** 3-Mirror cat‘s eye optical system
- **Internal metrology:** based on a commercially available laser interferometer, 1nm resolution
- **Translation control:** Control loop using two actuators (in open loop) and a single metrology
- **DDL control:** HW and SW, to ensure the correct position of the DDLs


Opto-mechanics
Metrology beam
Vacuum Vessel on optical table
Actuators
Translation Stages
Astrometric beam


Prototype


Sliding mechanism with vertical beams


3 Mirror Cat‘s Eye DDL Telescope

# Astrometric Planet Search:

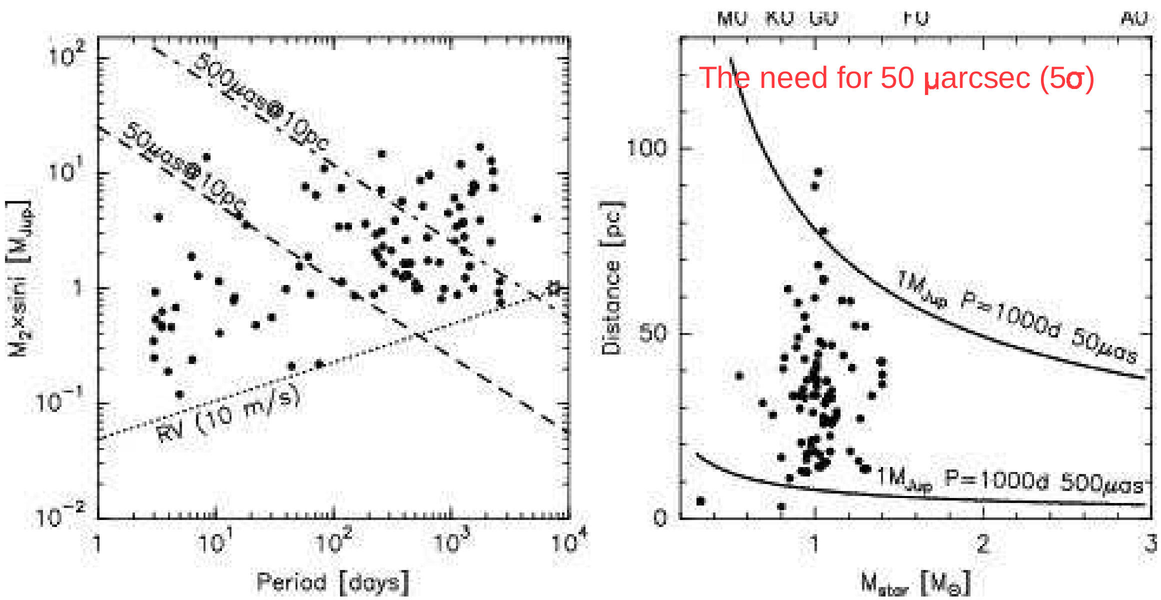
**Goals:**

- Derive *sin i* (i.e, measure mass) for all known RV planets accessible to PRIMA
- Confirm RV hints for long-period planets
- Inventory of planets around stars of different mass and age
(*PMS stars and MS stars > 1.4 $M_{Sun}$ are not accessible to RV method).
*Observe stars around which full orbit of a 1 $M_{Jup}$ planet within 3 yr would be detectable*
- Search for multiple planetary systems with masses decreasing from inside out and measure relative inclination of orbits *( $\rho$ ~ a, RV ~ a-0.5 )*

**Challenges and Strategy:**

- A reference star within the anisoplanatic angle is needed (optimimum < 10arcs)
***Solution:*** *Careful selection and preparatory observations*
- The baseline vector has to be known to < 50μm (on 200m)
***Solution:*** *Good strategy plus long-term (years) trend analysis and correction*
- Required differential OPD stability (and resolution) < 5nm
***Solution:*** *Instrumental accuracy, error analysis, chromatic corrections, vacuum in DDLs*
- Astronomical astrometric noise from target and reference star < 10μarcs
***Solution:*** *Pre-selection, preparatory observations, and modeling of each target/ref. star*
- Parallax and proper motion are $10^4$ times larger than planet signal and are not known to the required accuracy
***Solution:*** *Global solution for parallax, proper motion, and planets has to be derived*

# Planet search discovery space




Dots represent all know RV planets/host stars. Asterisk = Jupiter

**PRIMA-DDL Kick-off meeting in Geneva, Feb. 2004**