Theia : *the new Astrometry frontier*

Alberto Krone-Martins (U. Lisboa, Portugal)
on behalf of the Theia collaboration

arXiv:1707.01348

THEIA : *the new Astrometry frontier*

- **Driving questions**
  - > 80% of the matter in the Universe seems to be Dark Matter...
    but what is Dark Matter?

arXiv:1707.01348

THEIA : *the new Astrometry frontier*

- **Driving questions**
  - > 80% of the matter in the Universe seems to be Dark Matter...
    but what is Dark Matter?
  - It seems that there should be some habitable exo-Earths around our neighbour Sun-like stars... *but... where are these habitable exo-Earths? And how is the architecture of these systems?*

arXiv:1707.01348

THEIA : *the new Astrometry frontier*

- **Driving questions**

  - > 80% of the matter in the Universe seems to be Dark Matter...
    but what is Dark Matter?

  - It seems that there should be some habitable exo-Earths around our neighbour Sun-like stars... *but... where are these habitable exo-Earths? And how is the architecture of these systems?*

  - We know that there are neutron stars and black holes around there...
    but... what is the behaviour of matter in Nature's densest environments?

arXiv:1707.01348

THEIA : *the new Astrometry frontier*

What is the nature of Dark Matter?

Which nearby Solar-like stars have Earth-like planets in their habitable zones? And what is the architecture of the systems?

What is the behaviour of matter in Neutron Stars and around Black Holes?

arXiv:1707.01348

THEIA : *the new Astrometry frontier*

What is the nature of Dark Matter?

Which nearby Solar-like stars h
like planets in their habitable z
what is the architecture of the

Kinematical and dynamical effects

What is the behaviour of matter in Neutron Stars and around Black Holes?

arXiv:1707.01348

THEIA : *the new Astrometry frontier*

What is the nature of Dark Matter?

Which nearby Solar-like stars h
like planets in their habitable z
what is the architecture of the

Kinematical a
dynamical
effects

Astrometry

What is the behaviour of matter in Neutron Stars and around Black Holes?

arXiv:1707.01348

THEIA : *the new Astrometry frontier*

What is the nature of Dark Matter?

Which nearby Solar-like stars h
like planets in their habitable z
what is the architecture of the

Kinematical a
dynamical
effects

Astrometry

What is the behaviour of matter in Neutron Stars and around Black Holes?

arXiv:1707.01348

THEIA : *the new Astrometry frontier*

What is the nature of Dark Matter?

Which nearby Solar-like stars h
like planets in their habitable z
what is the architecture of the

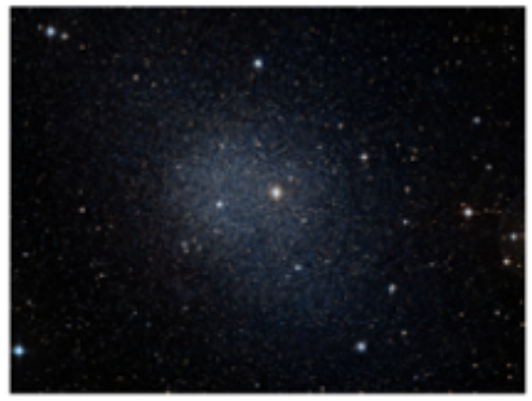
Kinematical a
dynamical
effects

Astrometry

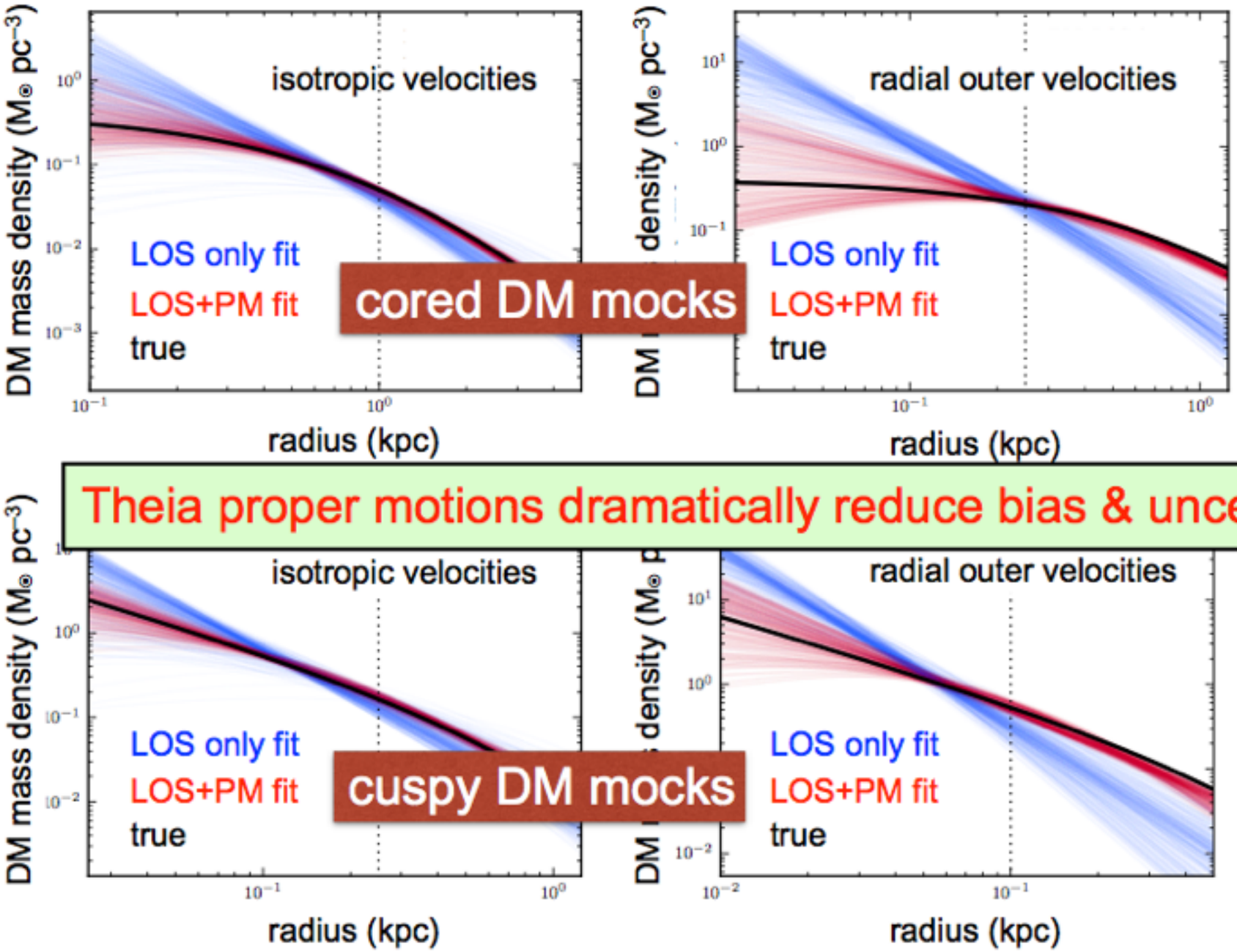
What is the behaviour of matter in Neutron Stars and around Black Holes?

arXiv:1707.01348

Dark Matter (DM) in dwarf Spheroidal (dSph) galaxies



Mass-orbit modeling (Jeans equation) of mock dSph galaxies → DM density profiles



dSph = DM-dominated velocity dispersion:
$\sigma_v \approx 10$ km/s

Theia proper motions
→ $\Delta v = 3$ km/s

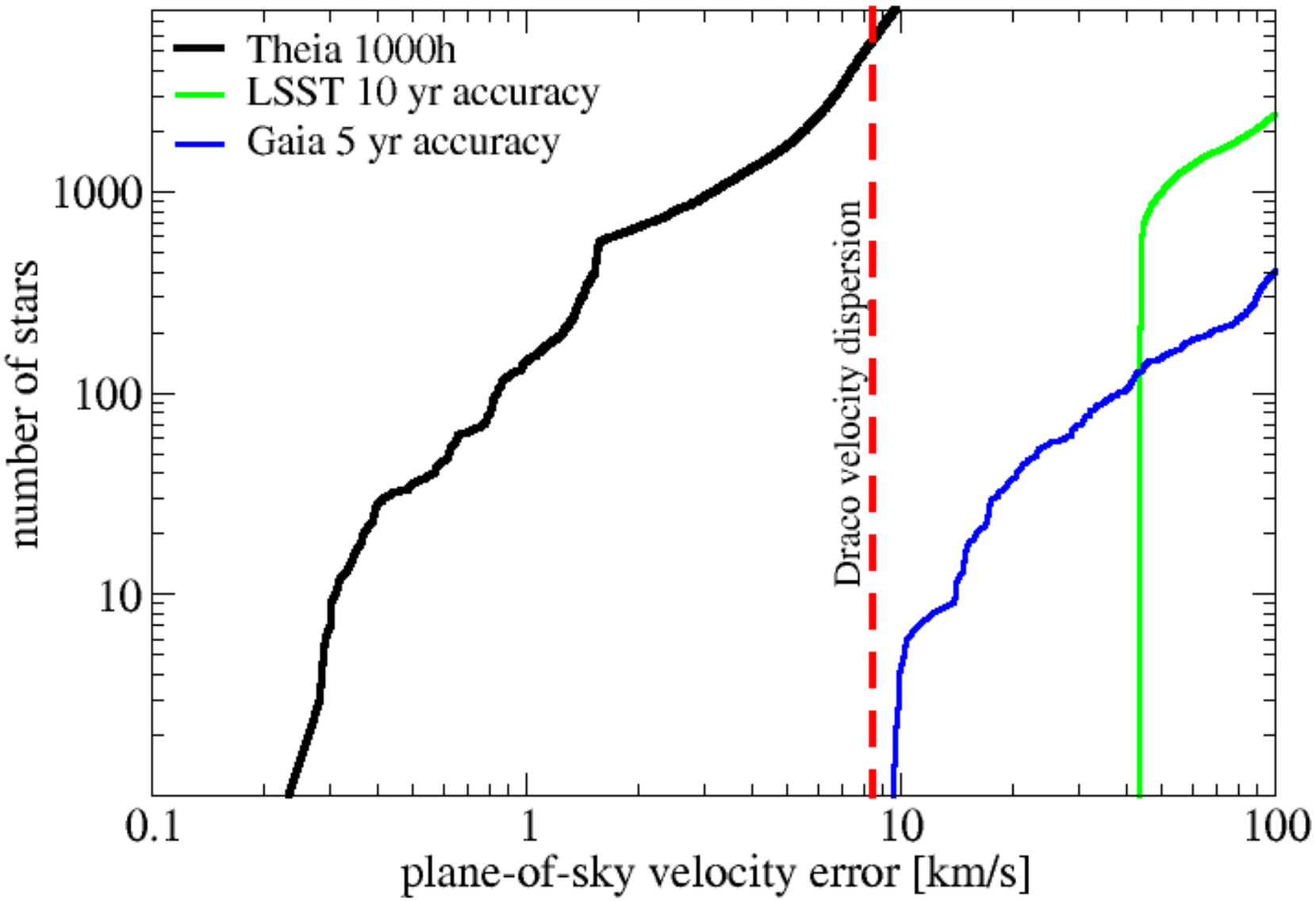
Theia proper motions dramatically reduce bias & uncertainty on inner DM slope!

If cores found in ~all dSphs:
case for interacting DM

calibration of DM annihilation x-section
from γ-ray obs of dSph galaxies

arXiv:1707.01348

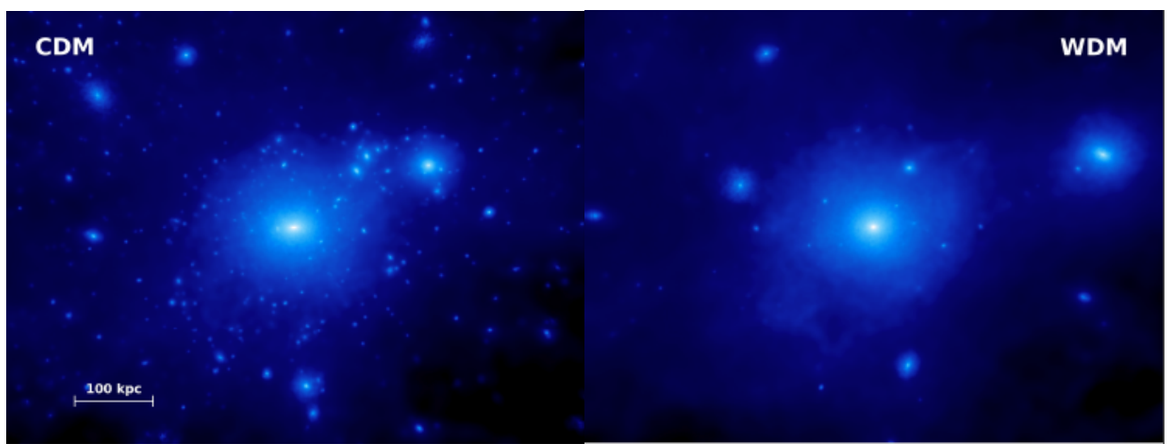
Dark Matter (DM)
in dwarf Spheroidal (dSph) galaxies



arXiv:1707.01348

Theia : *the new Astrometry frontier*

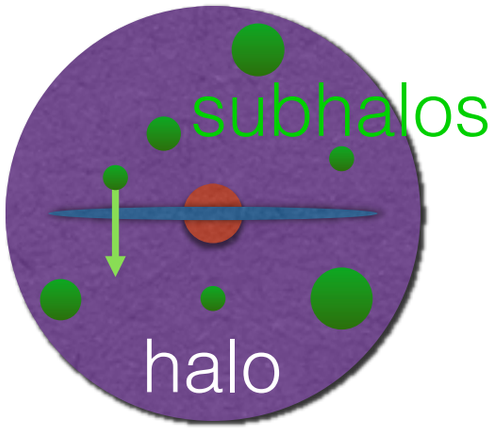
- **Dark Matter:**
  - Low mass galaxies ($10^{8\text{-}9}M_{sun}$) dominated by DM
  - Core-like structure if self-interacting DM or baryonic feedback
  - Satellites and subhalos ($10^{6\text{-}8}M_{sun}$) should be **rare** if warmer DM particles

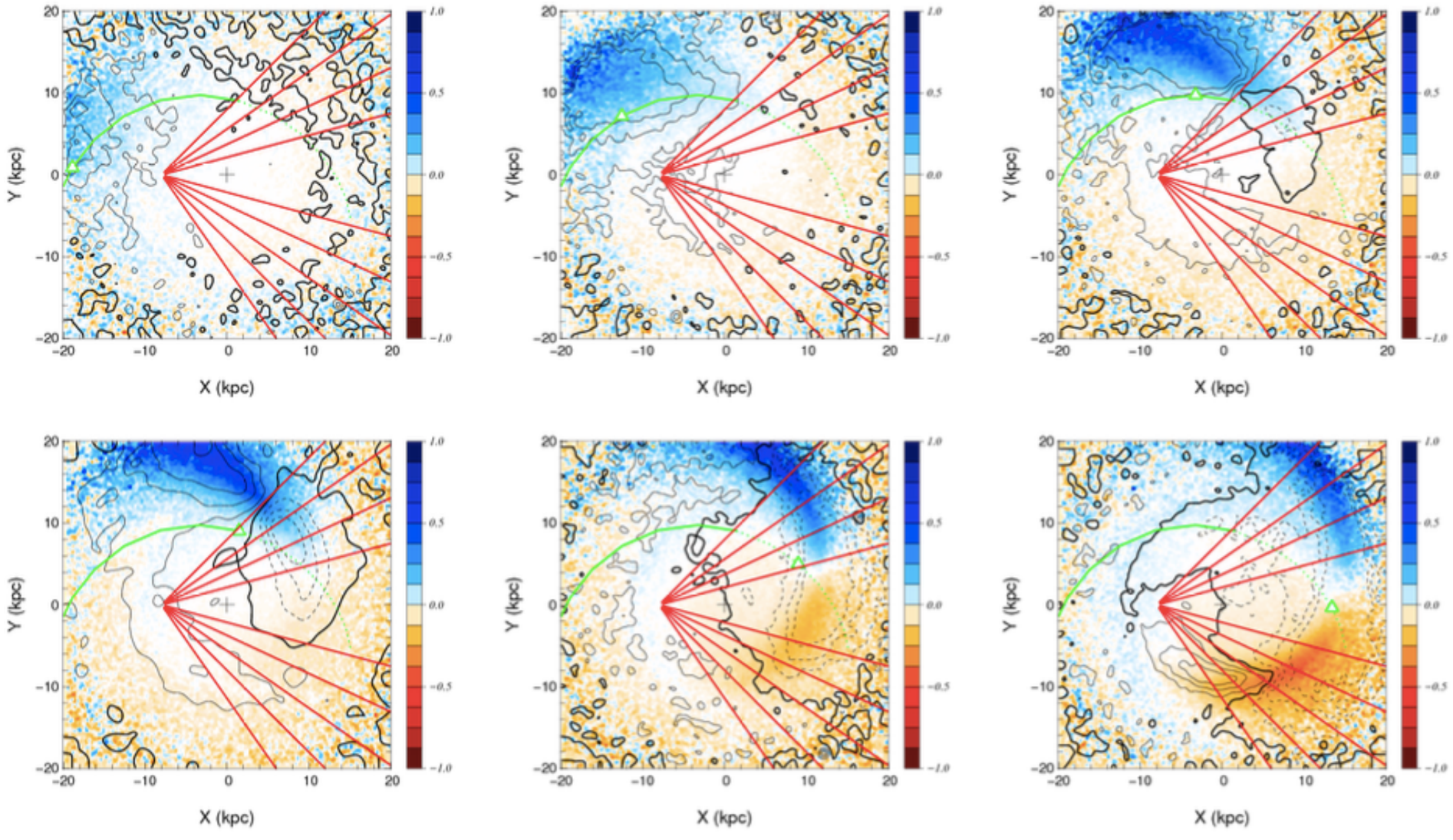


Mass of the smallest DM halos

arXiv:1707.01348

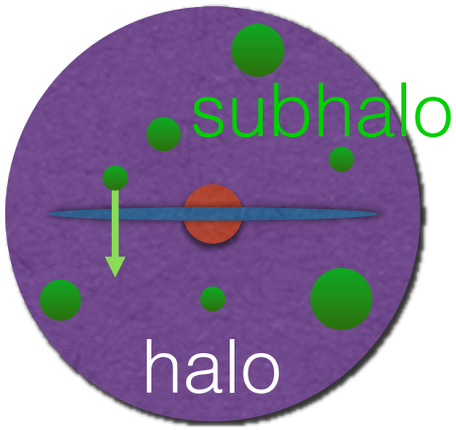
Theia : *the new Astrometry frontier*



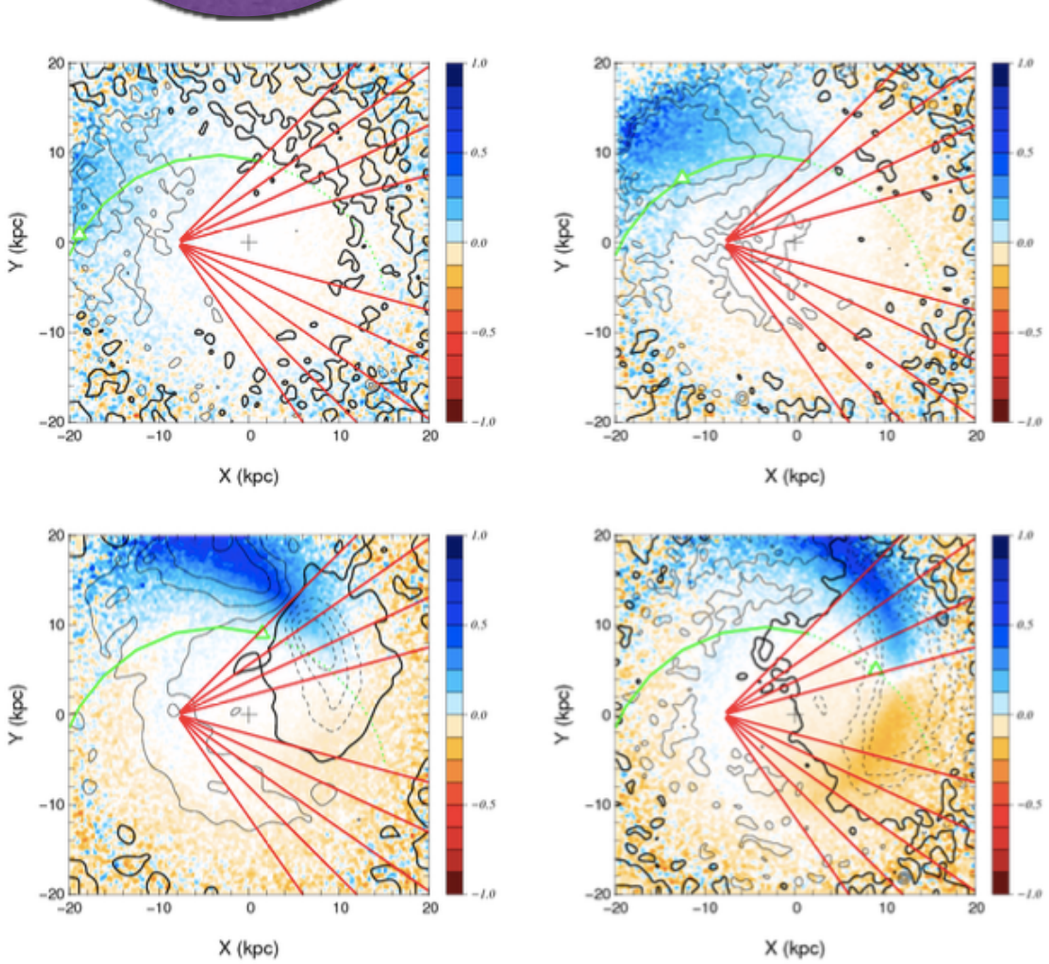


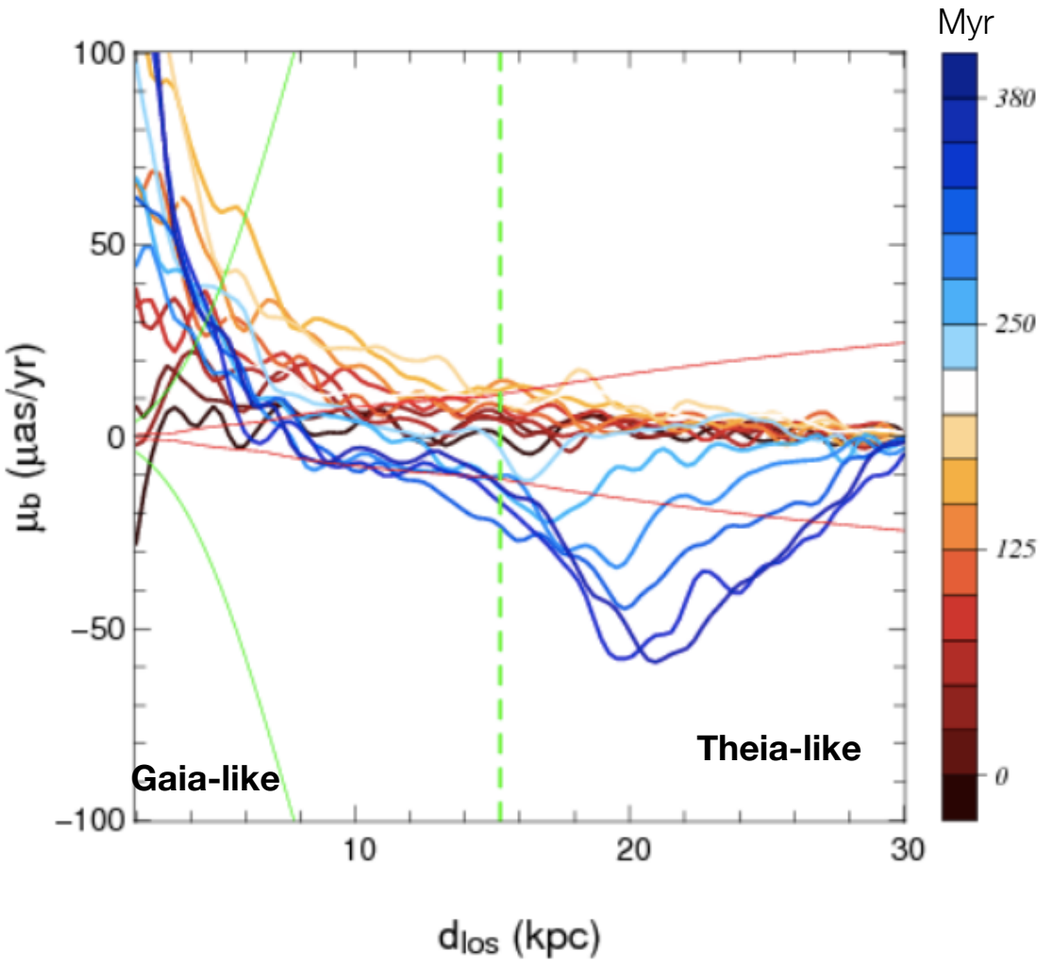
arXiv:1707.01348

Theia : *the new Astrometry frontier*



- Different DM particles : different spectrum of small amplitude, large-scale correlated, perturbations (need at least 3σ!)

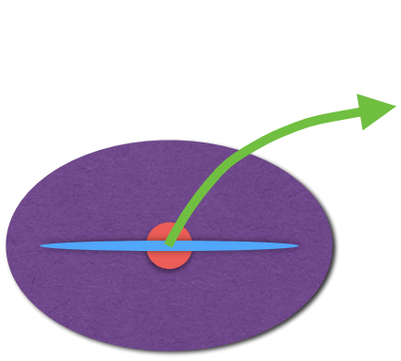




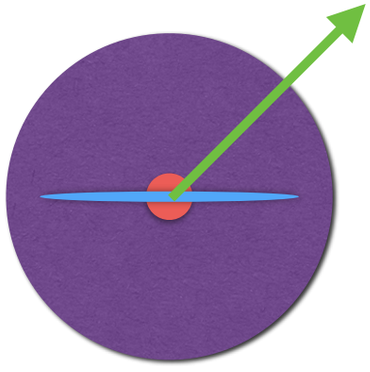
arXiv:1707.01348

Theia : *the new Astrometry frontier*

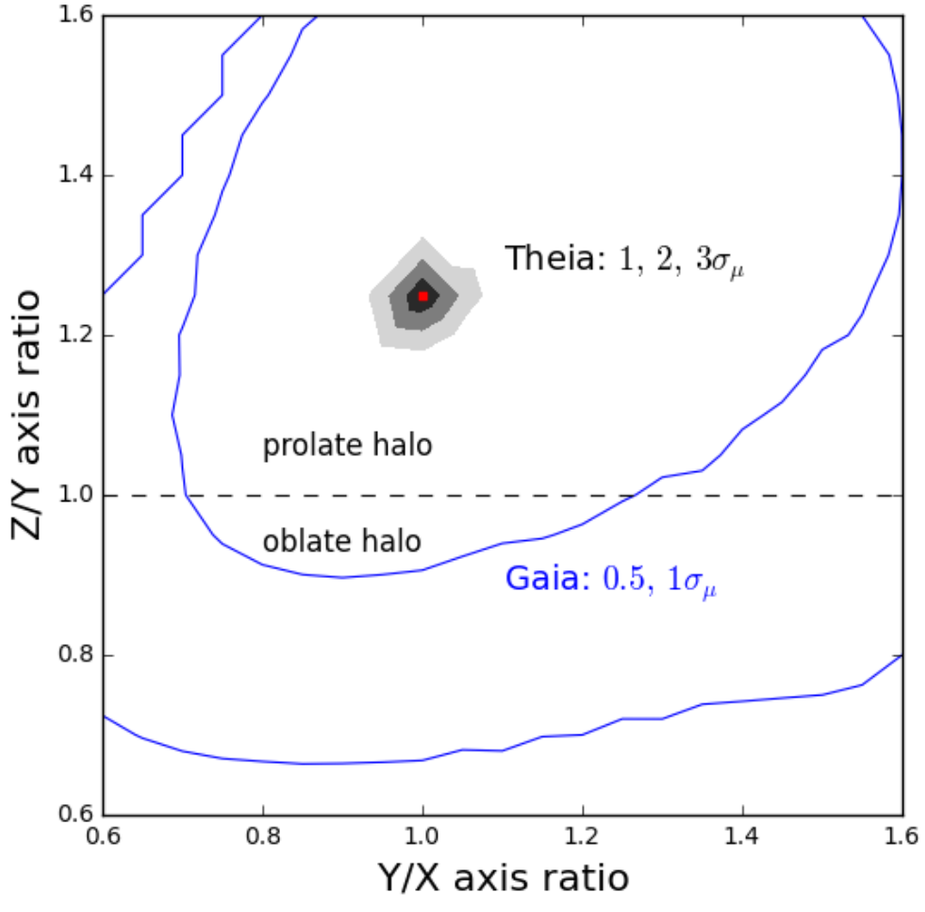
- **Dark Matter Halo shape**
  - Different DM particles : different halo shapes (need at least 3σ!)
  - Hyper Velocity Stars <u>at the Halo</u> : infeer the DM particle behaviour



oblate



spherical



arXiv:1707.01348

THEIA : *the new Astrometry frontier*

What is the nature of Dark Matter?

Which nearby Solar-like stars h
like planets in their habitable

Kinematical a
dynamical
effects

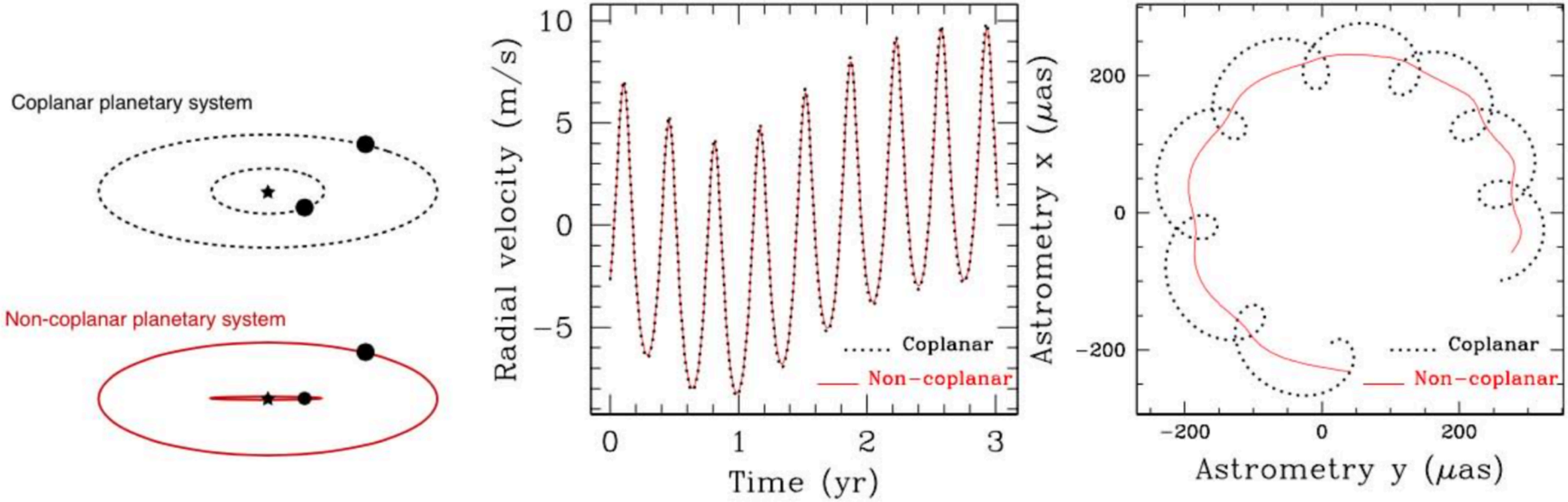
Astrometry

What is the behaviour of matter in Neutron Stars and around Black Holes?

arXiv:1707.01348

Theia : *the new Astrometry frontier*

- **Astrometry:**
  - Not strongly affected by stellar activity;
  - No sin (i) effect on the mass;

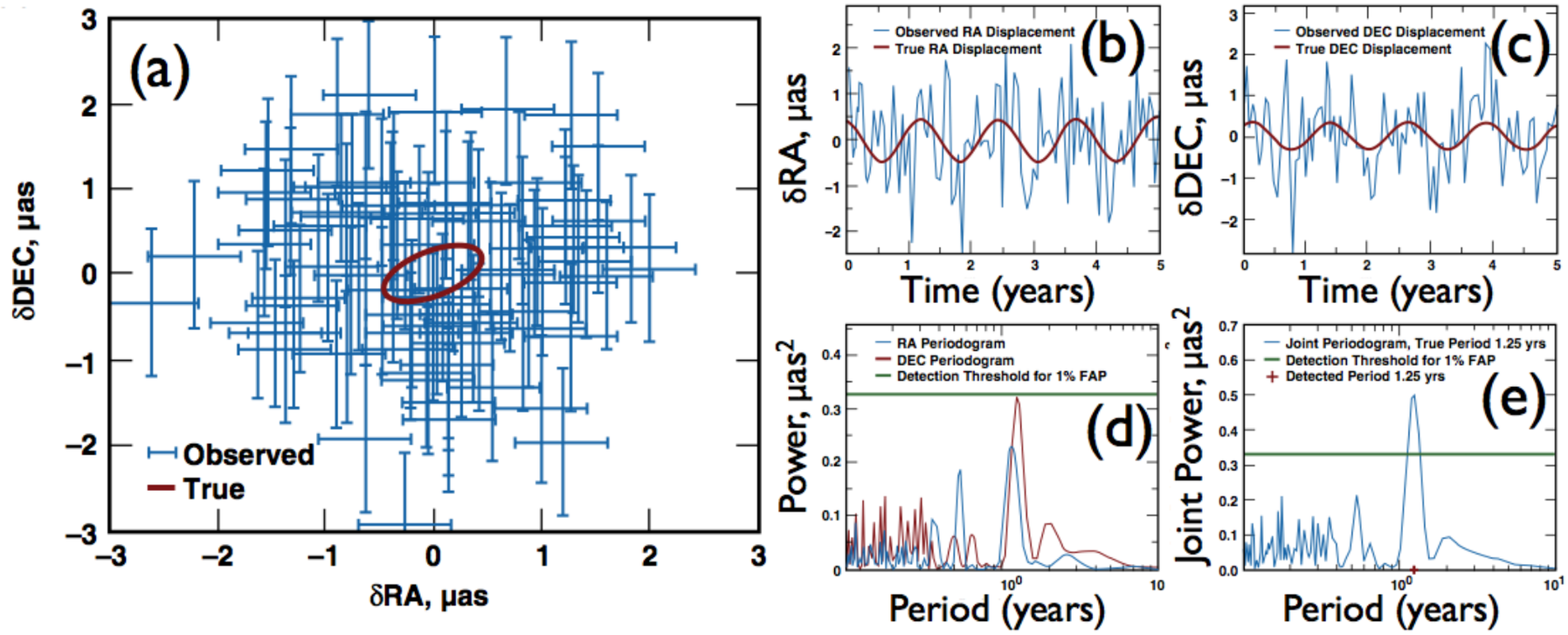


arXiv:1707.01348

Theia : *the new Astrometry frontier*

- **Astrometry:**
  - Not strongly affected by stellar activity;
  - No sin (i) effect on the mass;
  - Full characterisation of the system masses and orbital information.

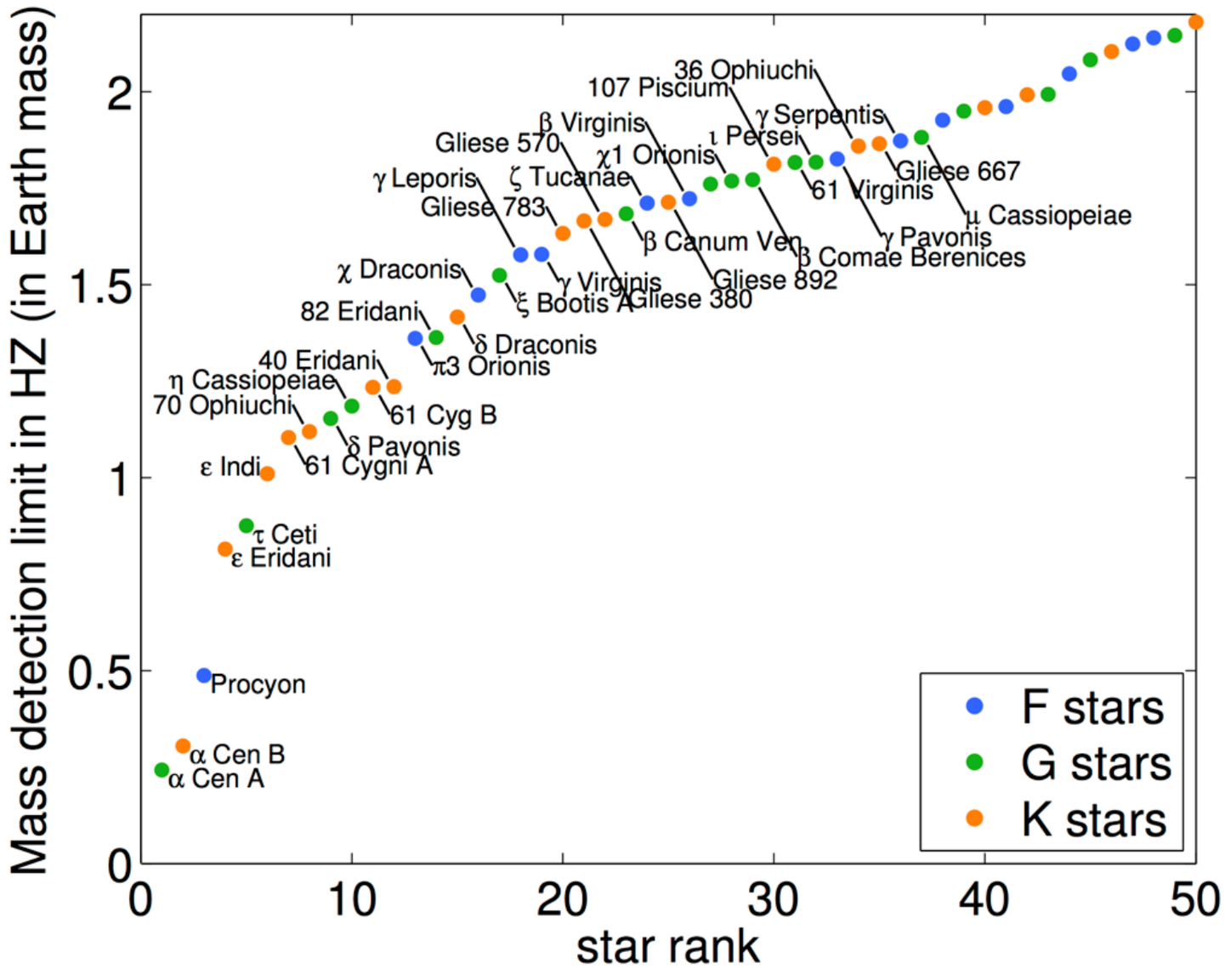
very simplistic way to perform a detection of a 1.5 MEarth planet at the HZ of a Sun at 10pc



arXiv:1707.01348

THEIA : *the new Astrometry frontier*

- Nearby, habitable, exoplanets around FGK stars

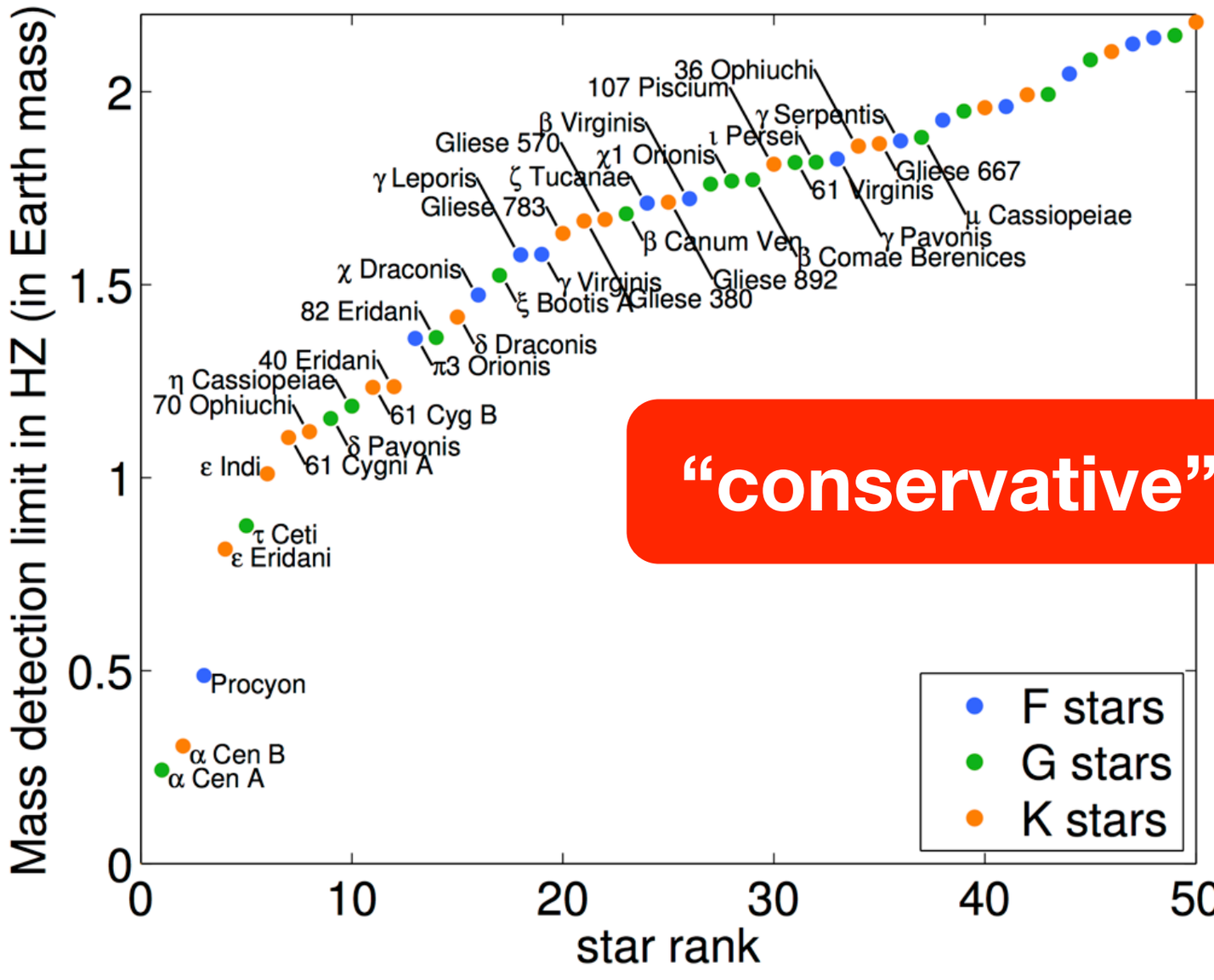


Theia will unambiguously detect habitable Exo-Earths around our nearest FGK stars

arXiv:1707.01348

Theia : *the new Astrometry frontier*

- Nearby, habitable, exoplanets around FGK stars



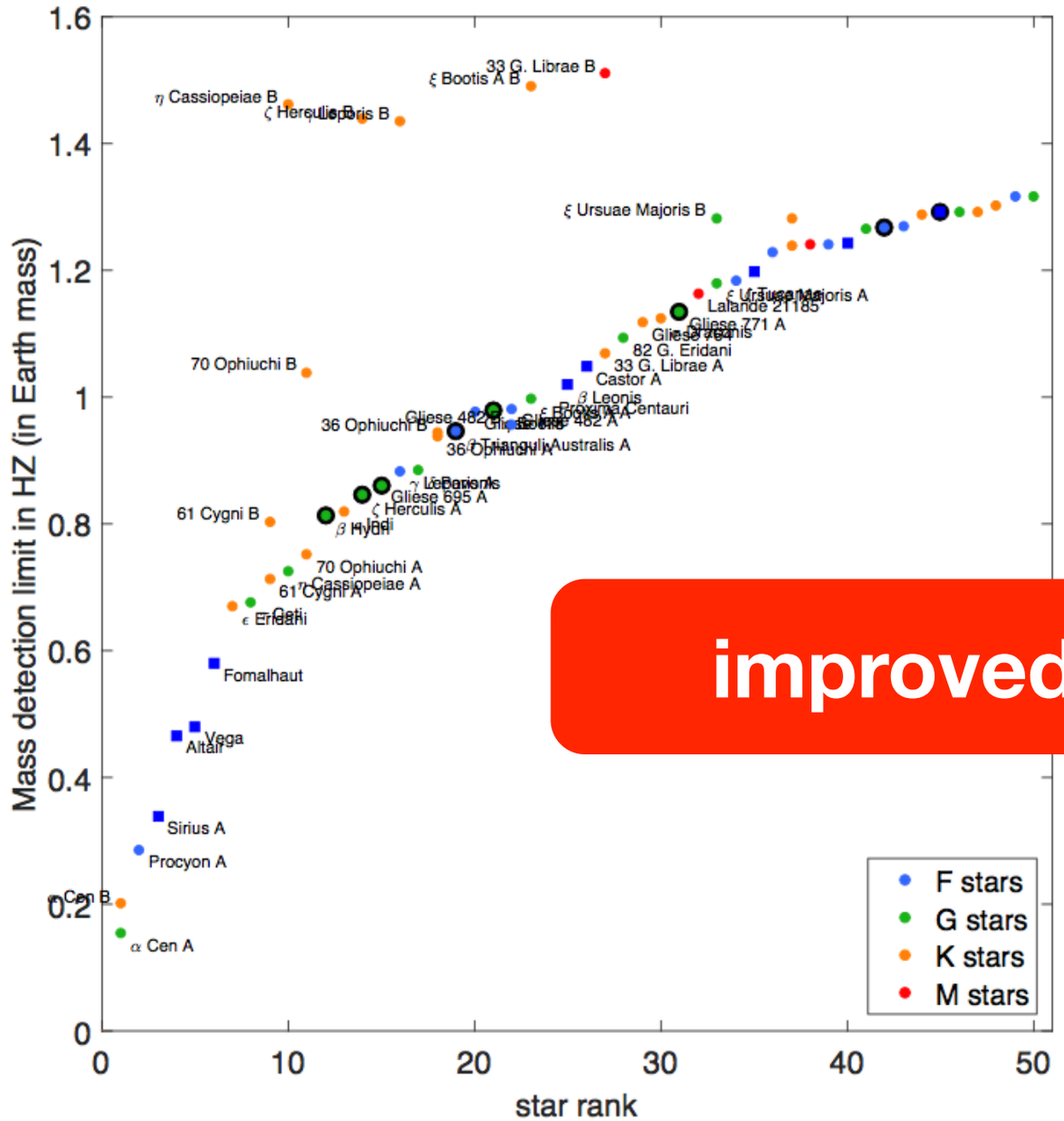
“conservative” technique

Theia will unambiguously detect habitable Exo-Earths around our nearest FGK stars

arXiv:1707.01348

Theia : *the new Astrometry frontier*

- Nearby, habitable, exoplanets around FGK stars



improved technique

arXiv:1707.01348

THEIA : *the new Astrometry frontier*

What is the nature of Dark Matter?

Which nearby Solar-like stars h
like planets in their habitable

Kinematical a
dynamical
effects

Astrometry

What is the behaviour of matter in Neutron Stars and around Black Holes?

arXiv:1707.01348

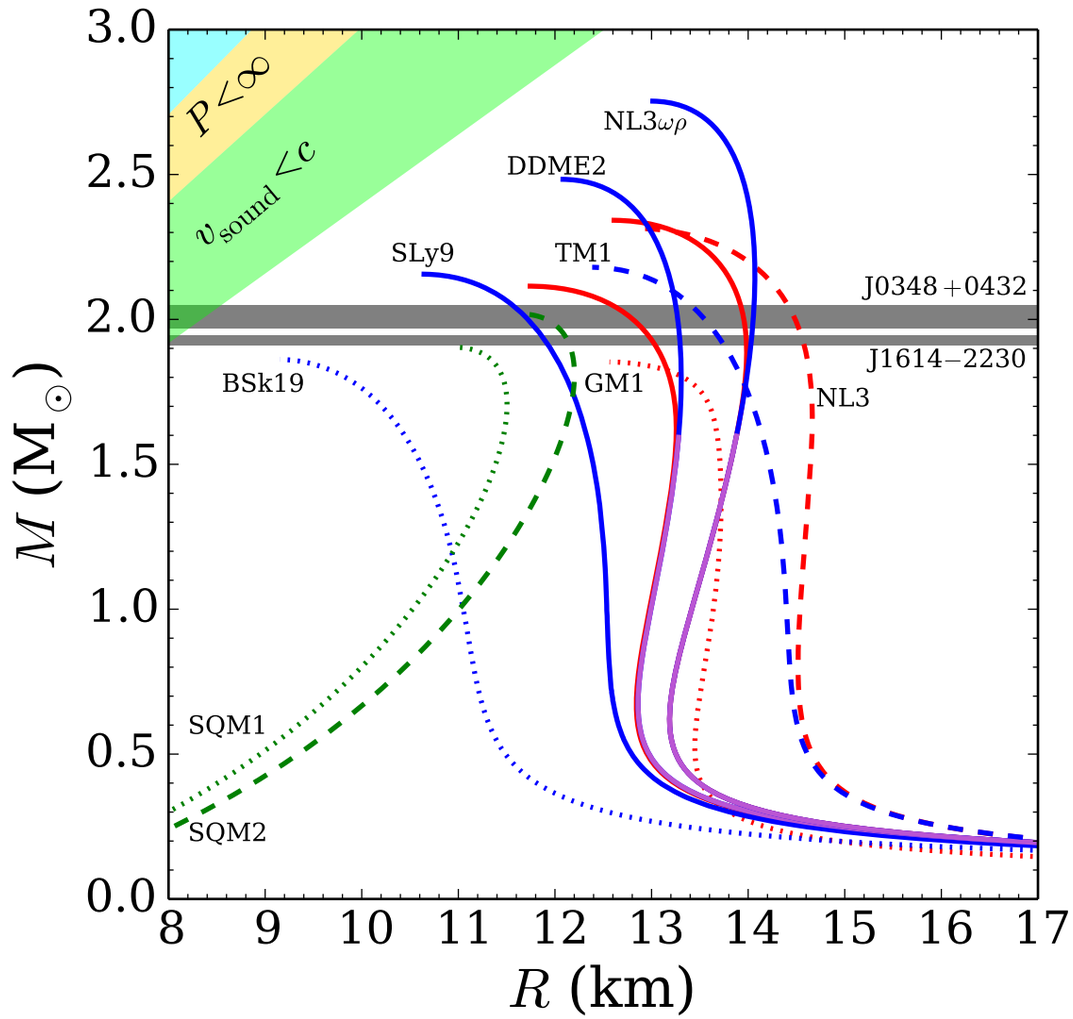
Theia : *the new Astrometry frontier*

- EOS is still not well constrained in NS-like environments

- Nothing appears to rule out quark or strange stars, but we haven't observed them yet.

  - Determination of masses of Neutron Stars in binary systems;

  - Determination of very precise distances via parallax.



arXiv:1707.01348

Theia : *the new Astrometry frontier*

- EOS is still not well constrained in NS-like environments

- Nothing appears to rule out quark or strange stars, but we haven't observed them yet.

  - Determination of masses of Neutron Stars in binary systems;

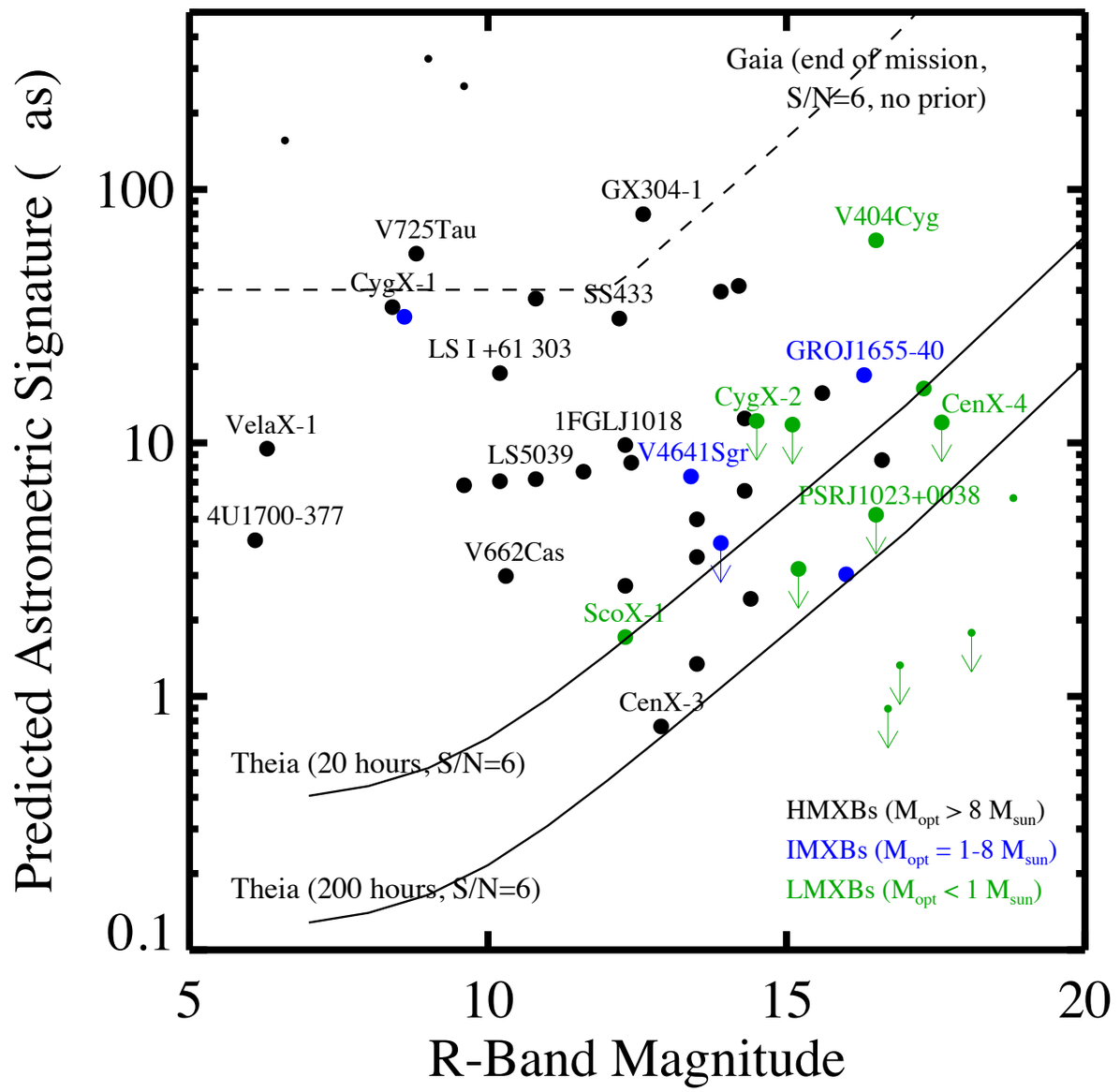
  - Determination of very precise distances via parallax.

- Proper motions and orbital determination of Black Hole binaries: formation of the systems, accretion disc warping and signatures of the shadow.

arXiv:1707.01348

THEIA : *the new Astrometry frontier*

- Extreme astrophysical objects



Theia will probe matter at the most extreme conditions in nature.

arXiv:1707.01348

THEIA : *the new Astrometry frontier*

What is the nature of Dark Matter?

Which nearby Solar-like stars h
like planets in their habitable

Kinematical a
dynamical
effects

Astrometry

What is the behaviour of matter in Neutron Stars and around Black Holes?

arXiv:1707.01348

THEIA : *the new Astrometry frontier*

What is the nature of Dark

Which nearby Solar-like stars
like planets in their habitabl

What is the behaviour of matte
Stars and around Black H

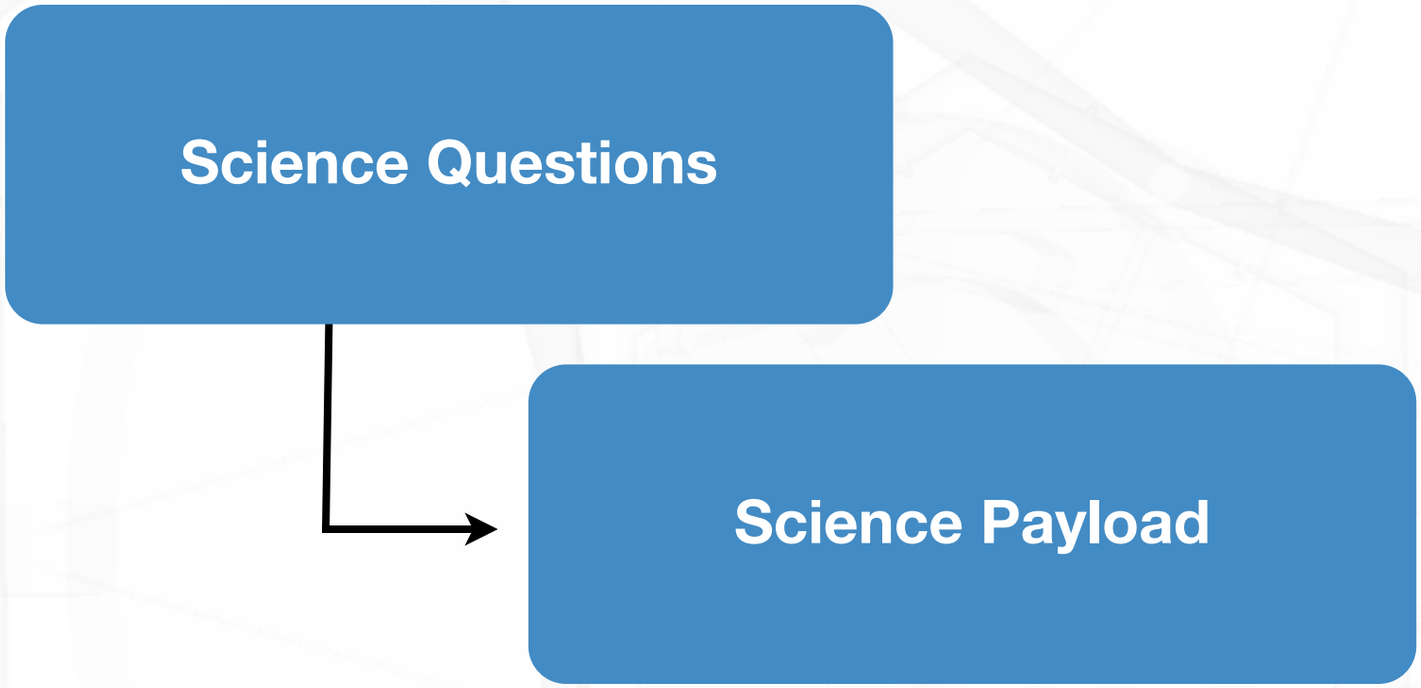
Kinematical a
dynamical
effects

Astrometry

0.15 uas to 10 uas (R~5–20, but extending to fainter)
strictly differential measurements in a large FoV

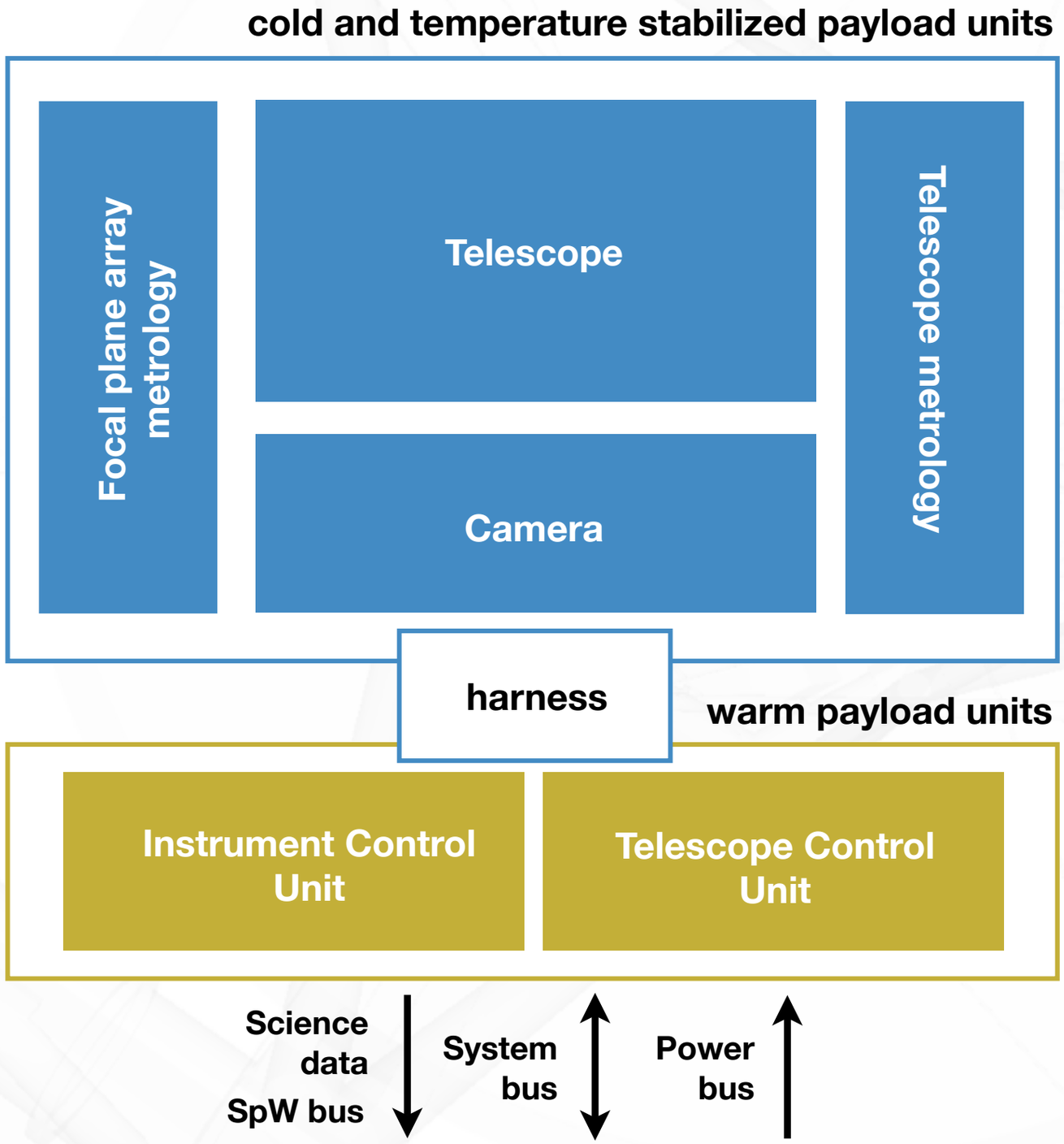
arXiv:1707.01348

THEIA : *the new Astrometry frontier*



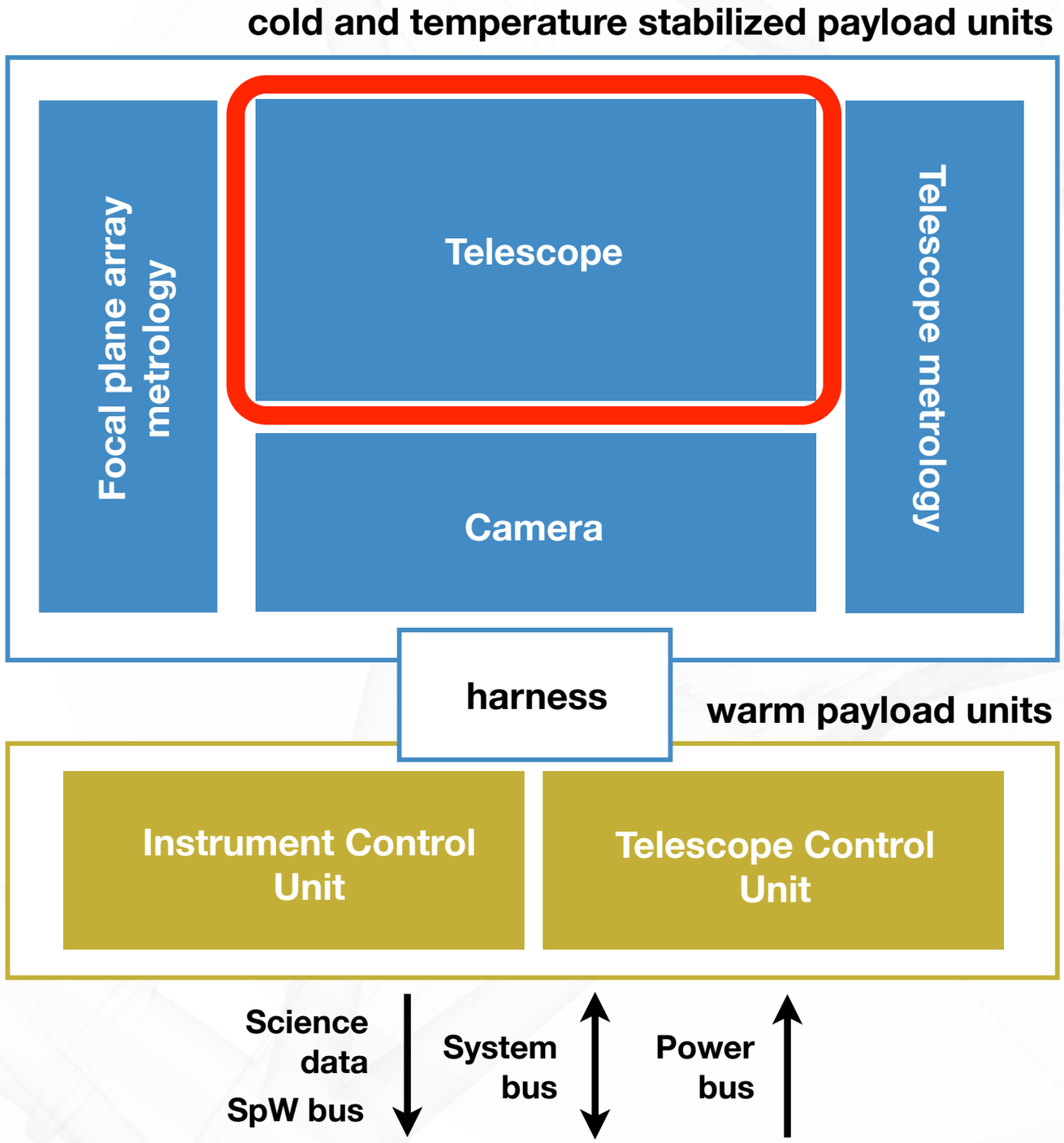
arXiv:1707.01348

THEIA : *the new Astrometry frontier*



arXiv:1707.01348

THEIA : *the new Astrometry frontier*

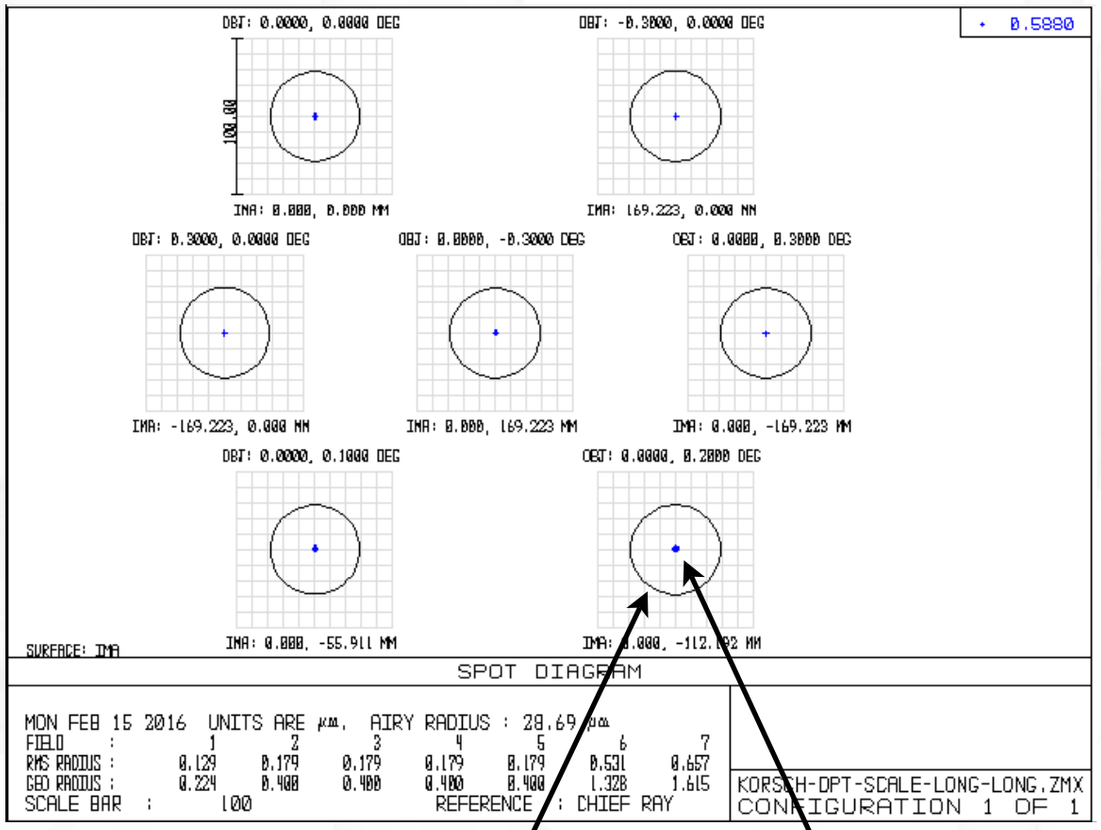


arXiv:1707.01348

THEIA : *the new Astrometry frontier*

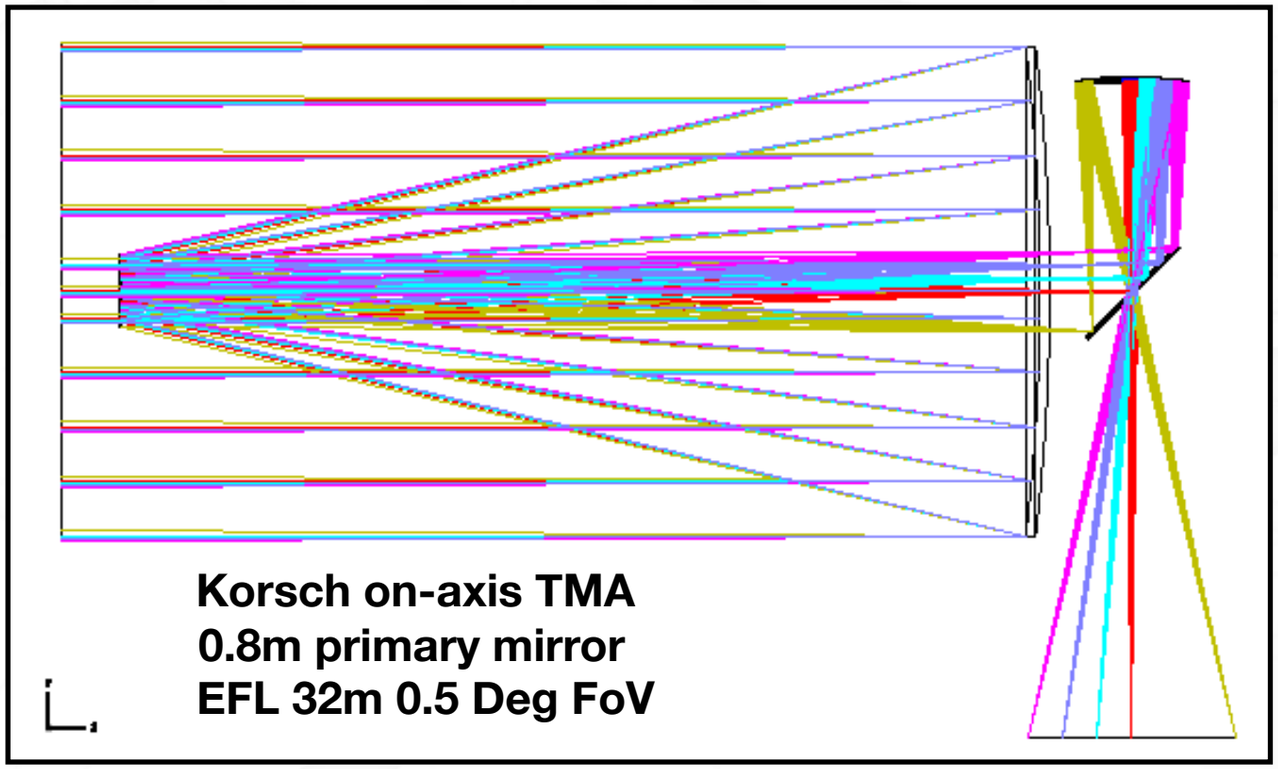
Overview of the optical design

Korsch TMA :: no aberrations up to third order



Airy disk

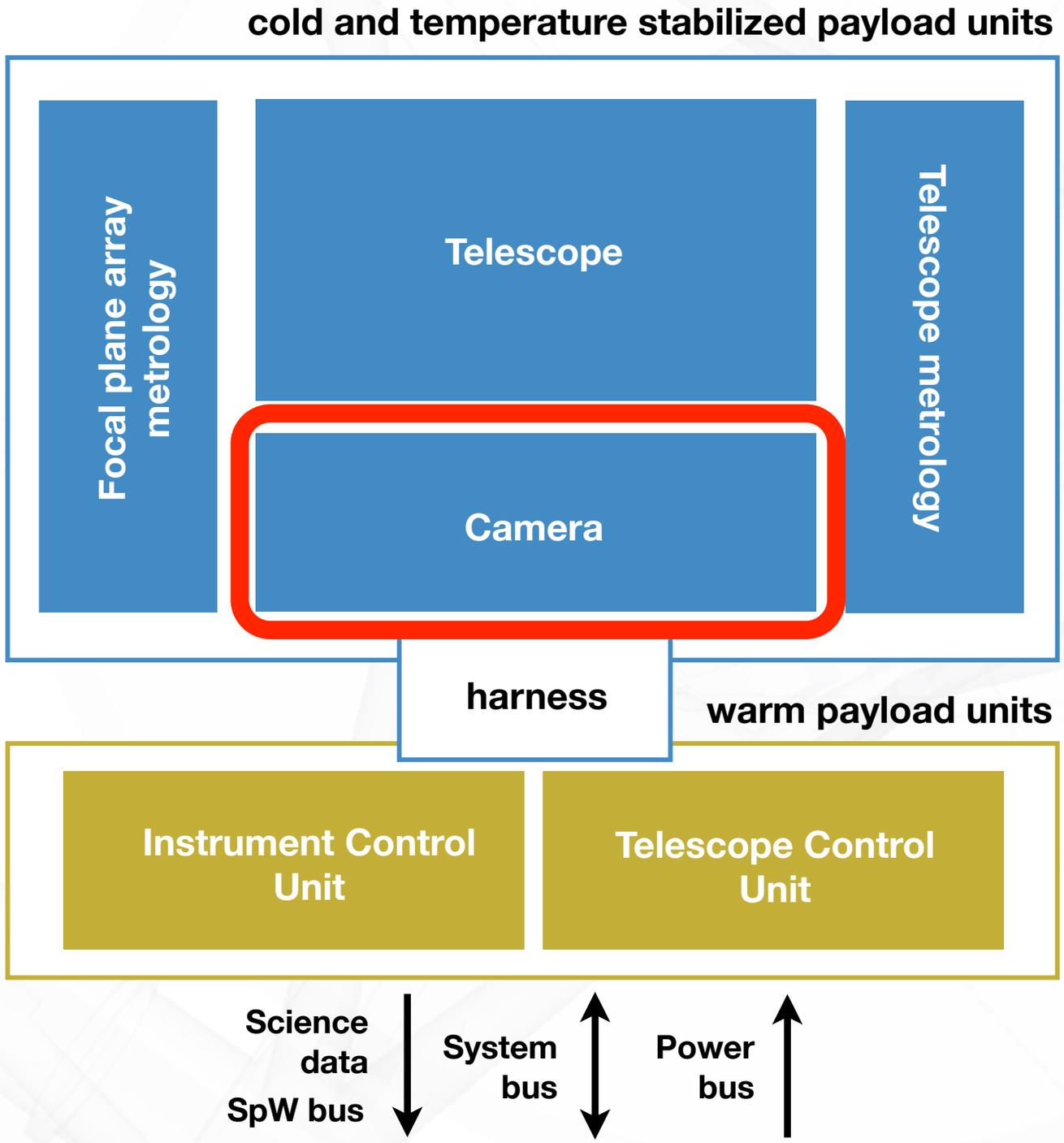
Optical Aberrations



Korsch on-axis TMA
0.8m primary mirror
EFL 32m 0.5 Deg FoV

arXiv:1707.01348

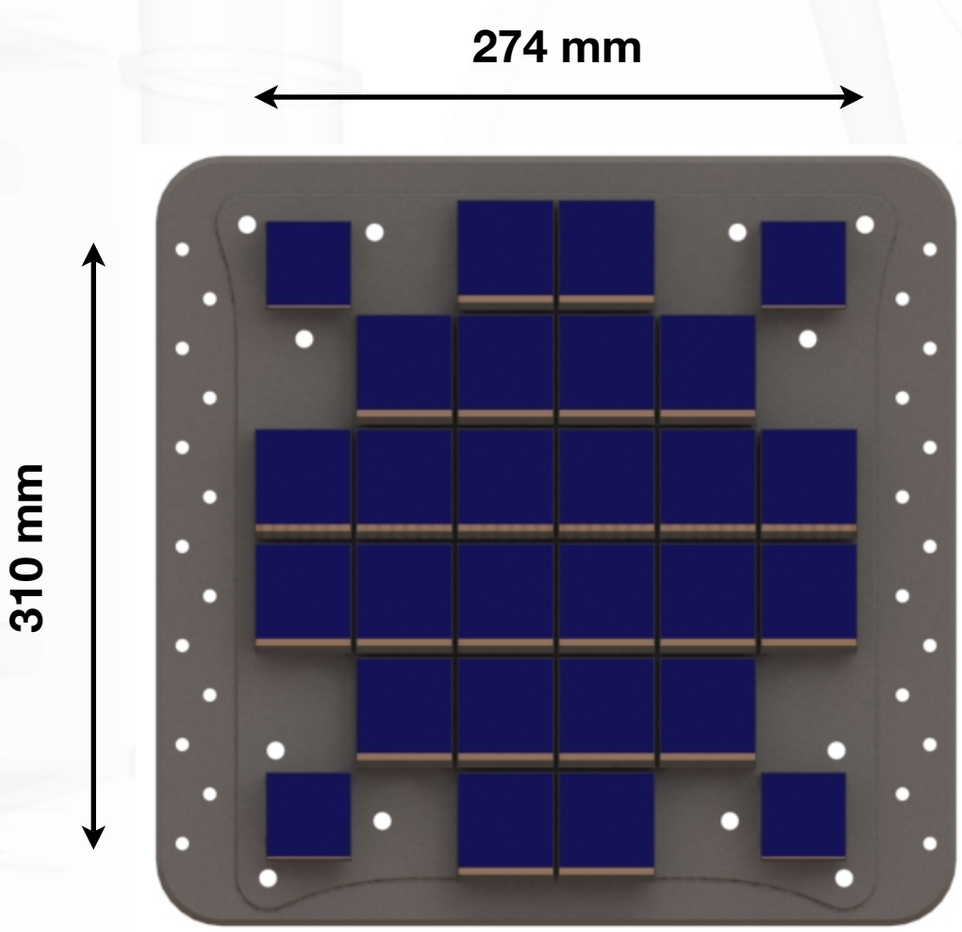
THEIA : *the new Astrometry frontier*



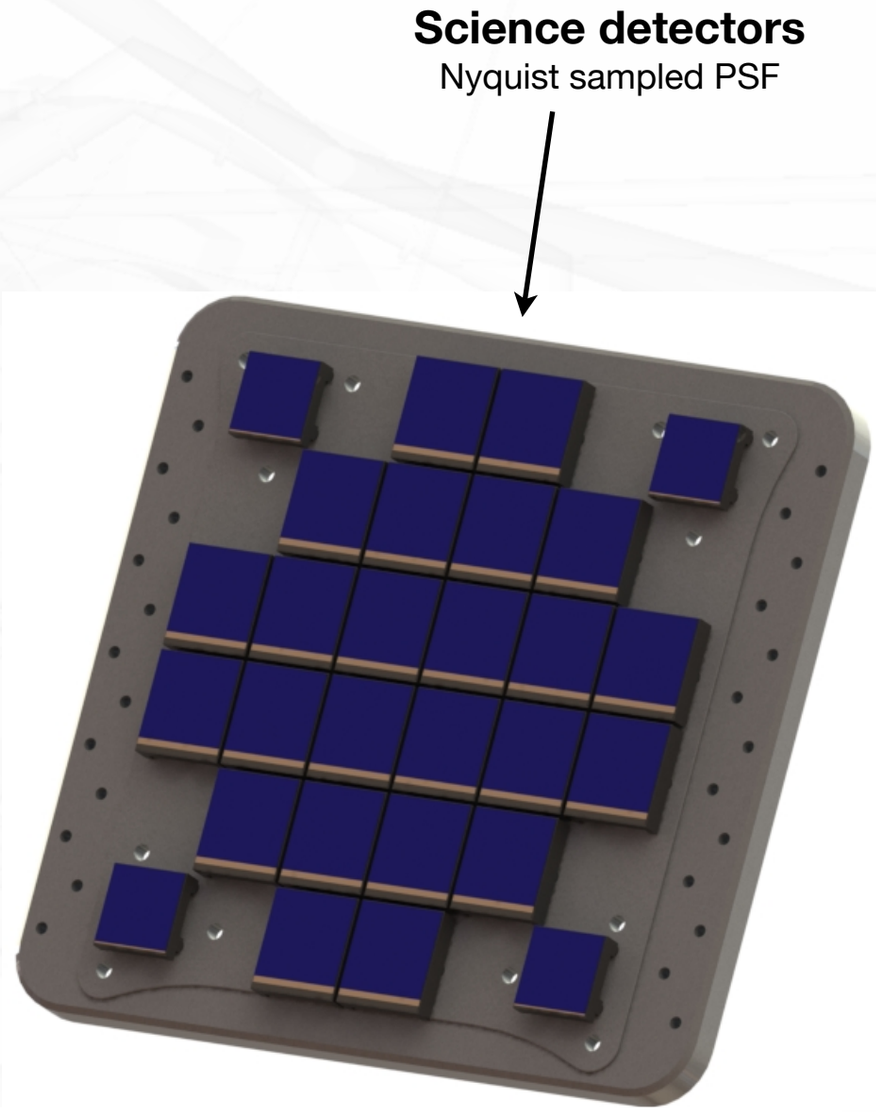
arXiv:1707.01348

Theia : *the new Astrometry frontier*

Theia::FPA-I-3b



SiC FPA Detector Plate



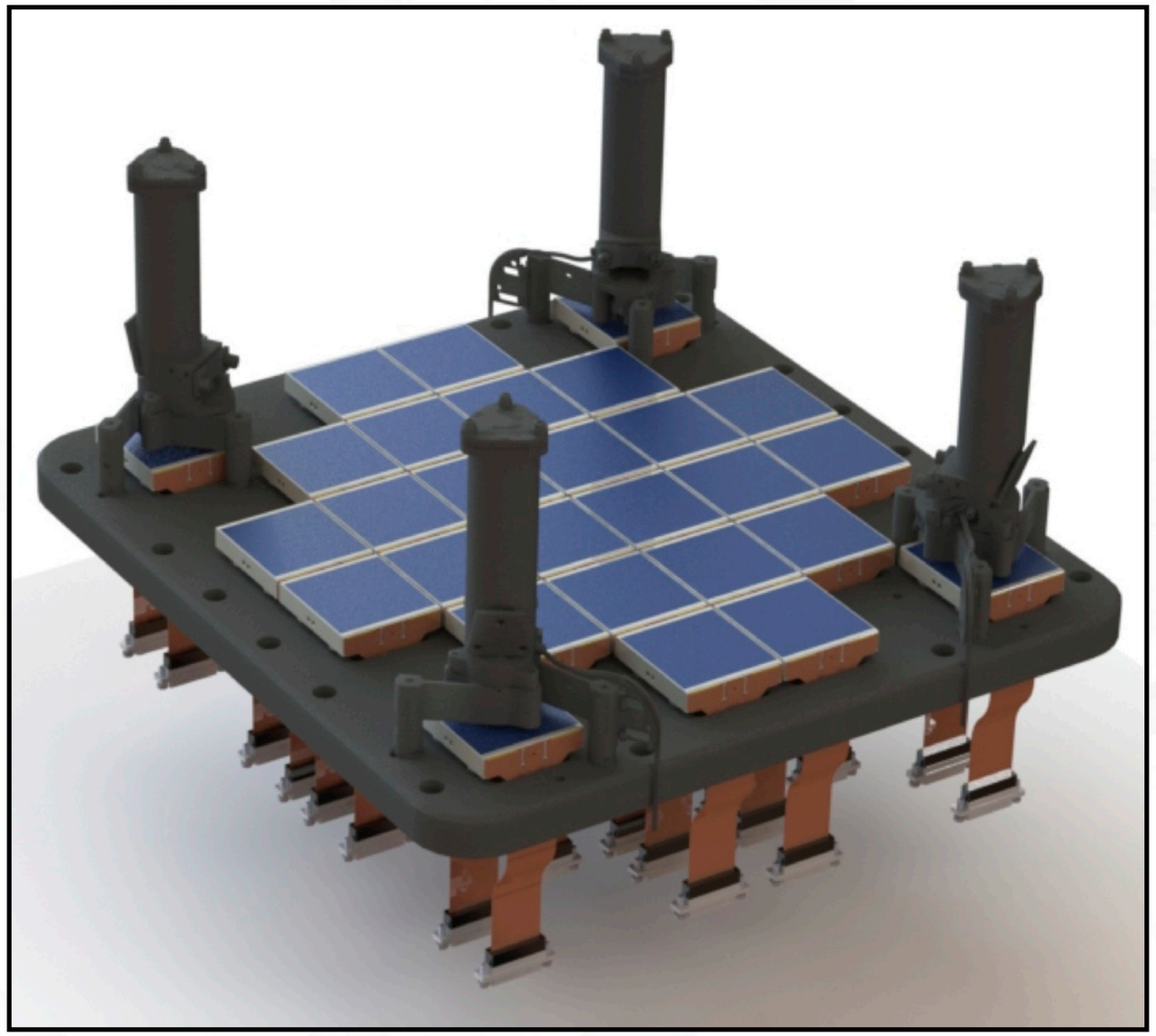
6x6 Elliptical FoV Science Array of 4k vs. 4k Detectors

Baseline : Optical (350-950nm) but NIR option (Int. participation if ESA mission)

arXiv:1707.01348

THEIA : *the new Astrometry frontier*

Theia::FPA-I-3b



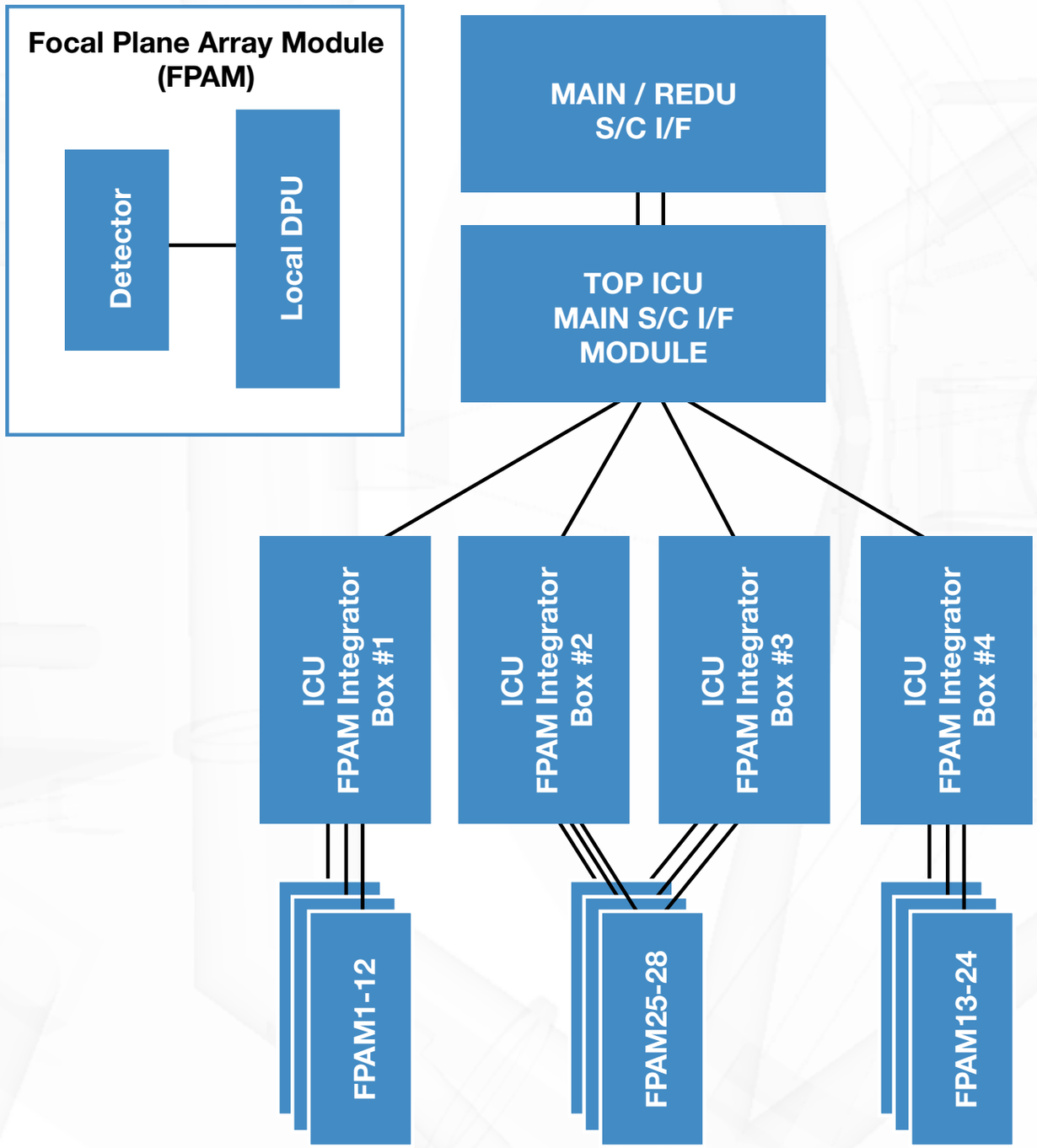
6x6 Elliptical FoV Science Array of 4k vs. 4k Detectors

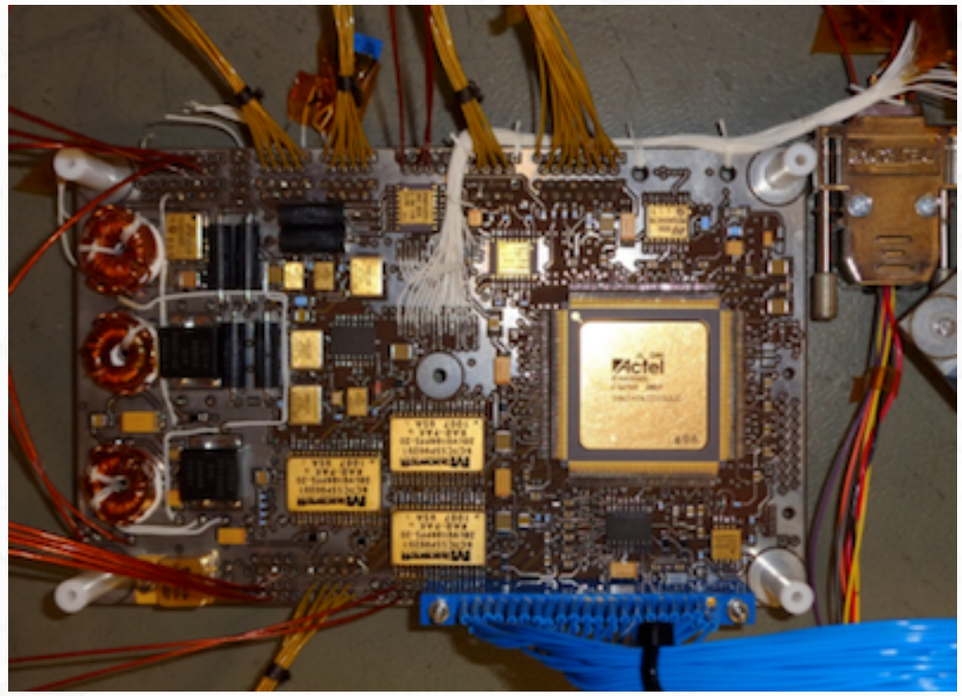
Baseline : Optical (350-950nm) but NIR option (Int. participation if ESA mission)

λ/1000 SH WFS: optical surfaces deformations

arXiv:1707.01348

THEIA : *the new Astrometry frontier*

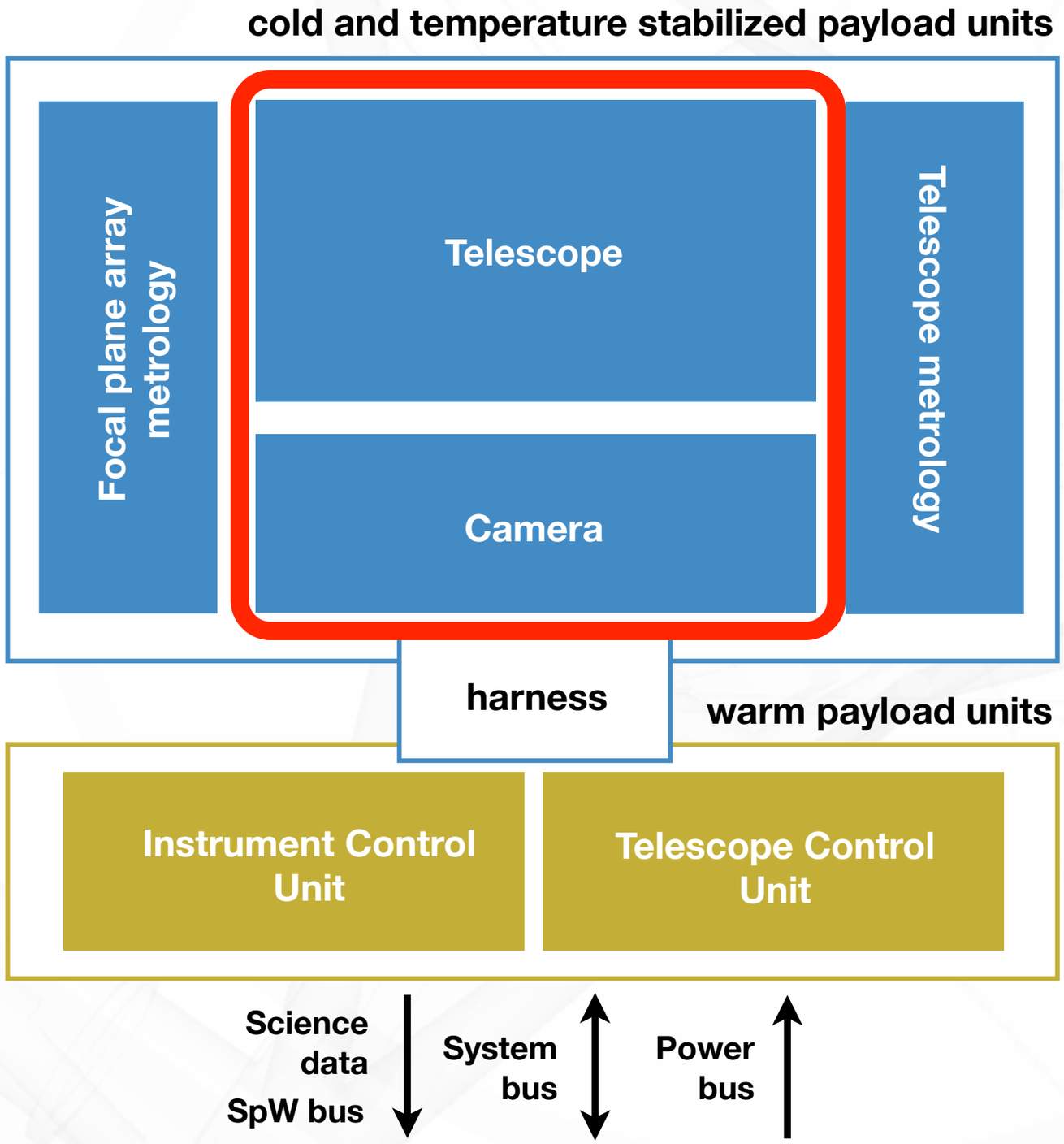




~ 1 GB/frame, 1 frame/minute (Dark Matter)
FPGA-based on board processing

arXiv:1707.01348

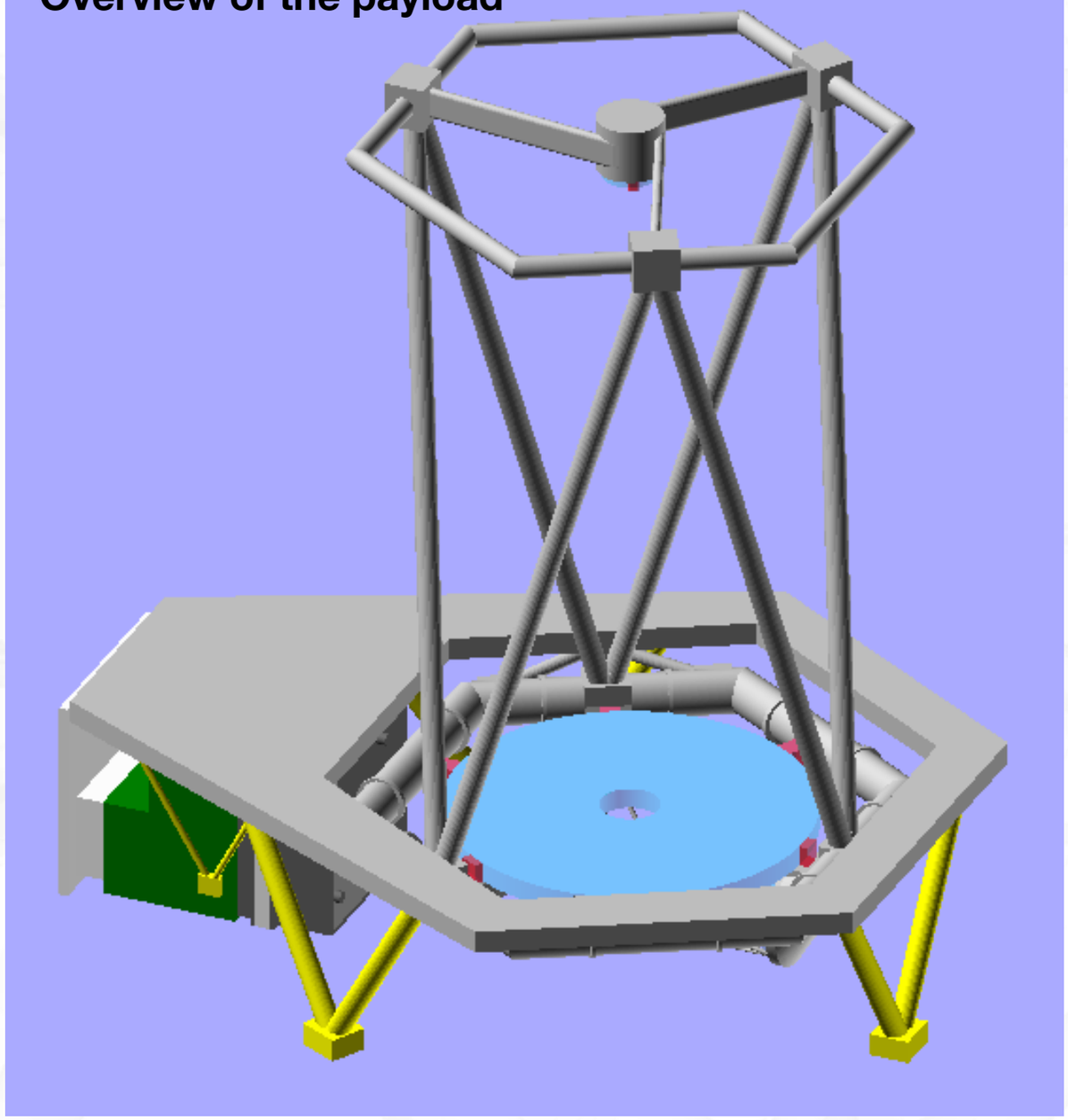
THEIA : *the new Astrometry frontier*



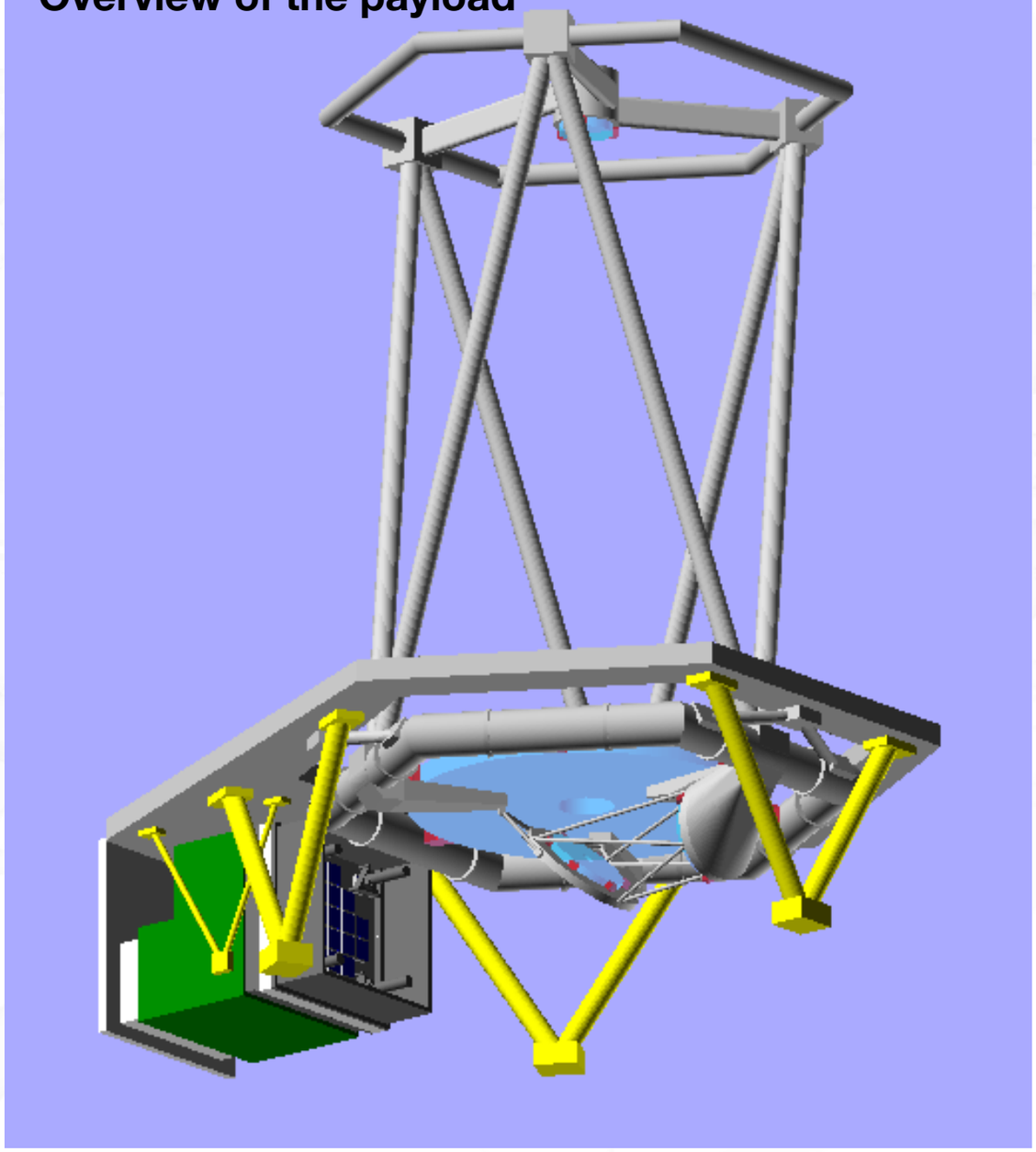
arXiv:1707.01348

THEIA : *the new Astrometry frontier*

Overview of the payload



Overview of the payload



Korsch on-axis TMA
0.8m primary mirror
EFL 32m

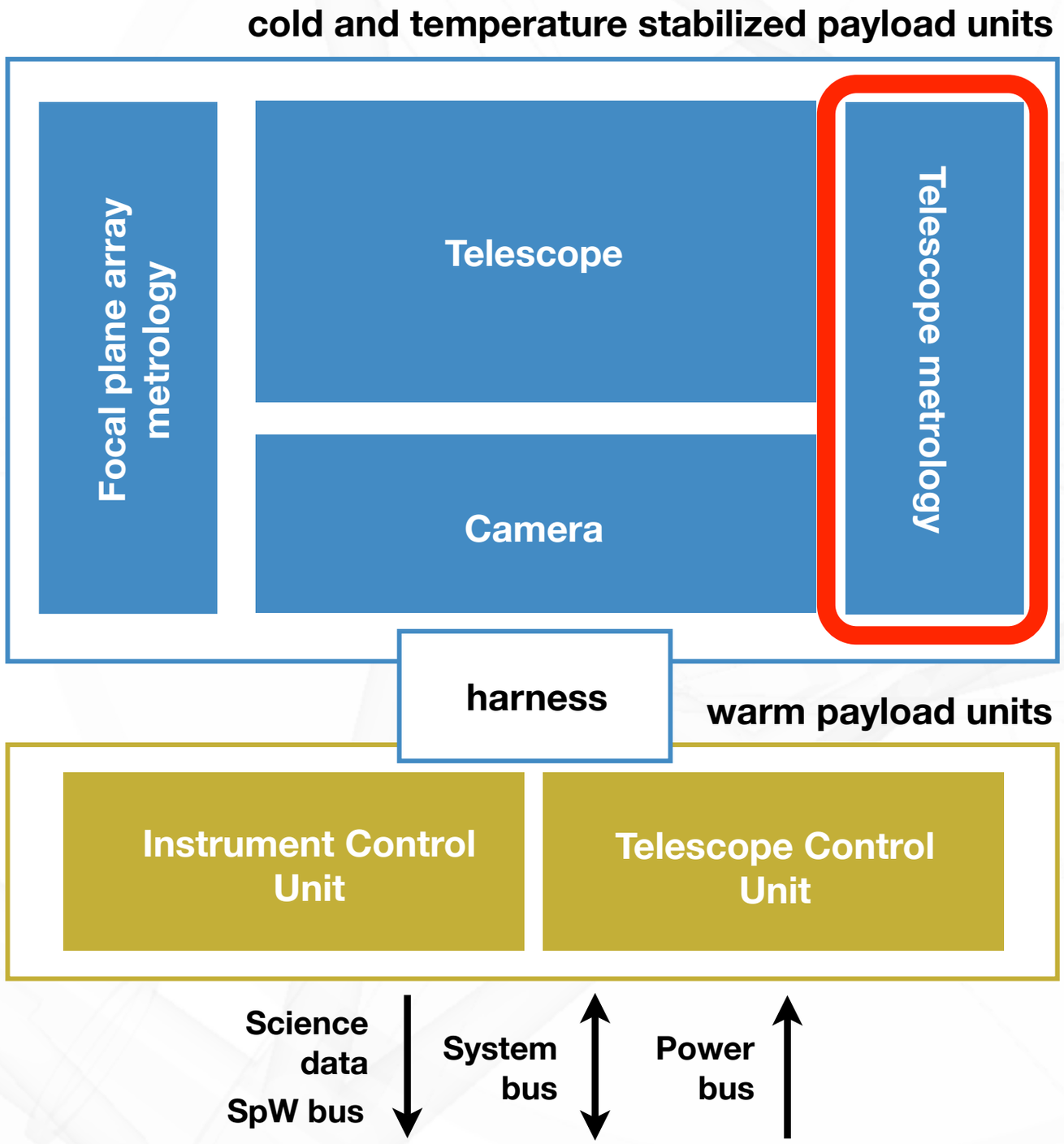
Optics: Zerodur, ULE or Sitall
Structures: SiC or Si3N4
Rigid Hexapod configuration

Mission duration : 4yr (built for 8 yrs)

TheiaM5-PM-Iteration-3d

arXiv:1707.01348

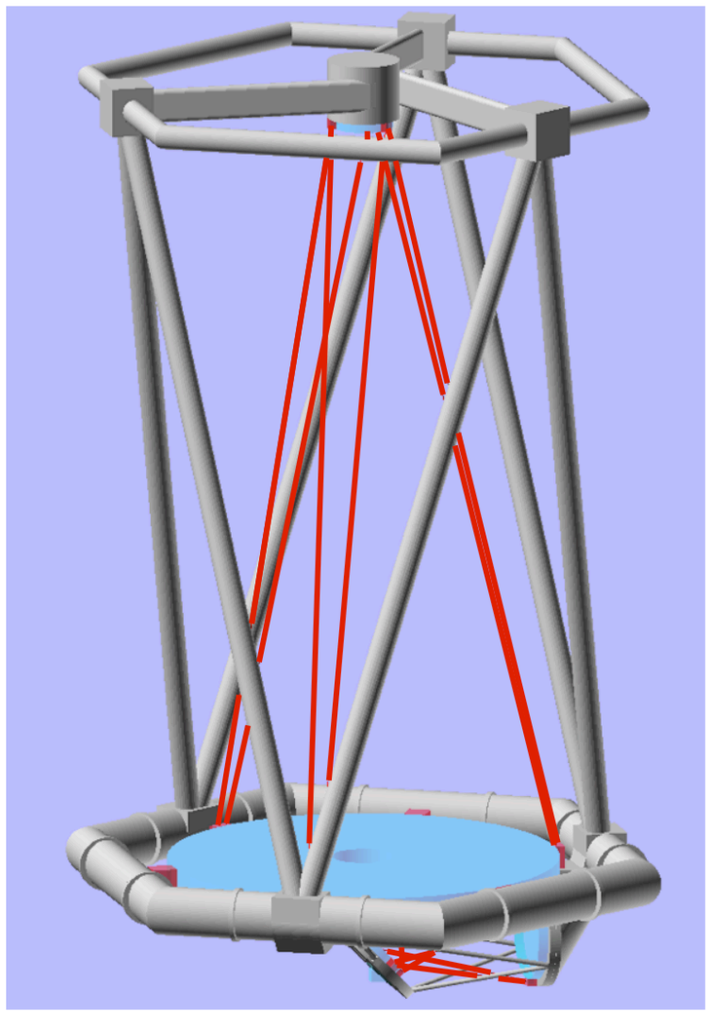
THEIA : *the new Astrometry frontier*



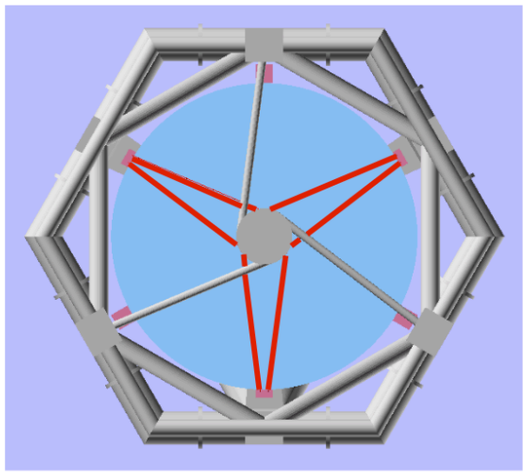
arXiv:1707.01348

THEIA : *the new Astrometry frontier*

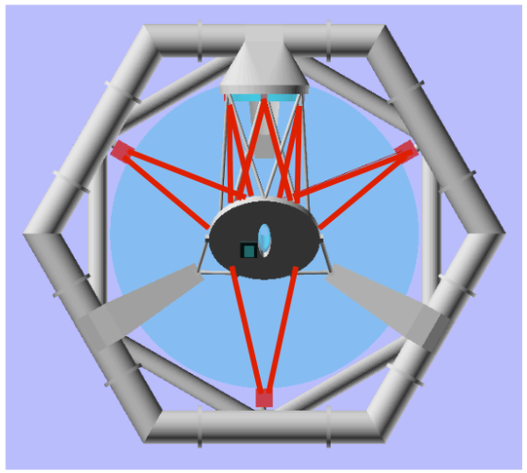
Lesson from Gaia :: Monitor, monitor, monitor



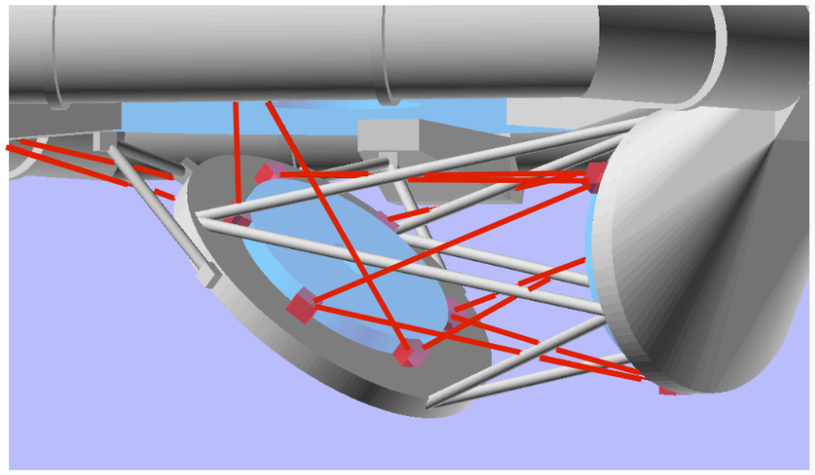
angular



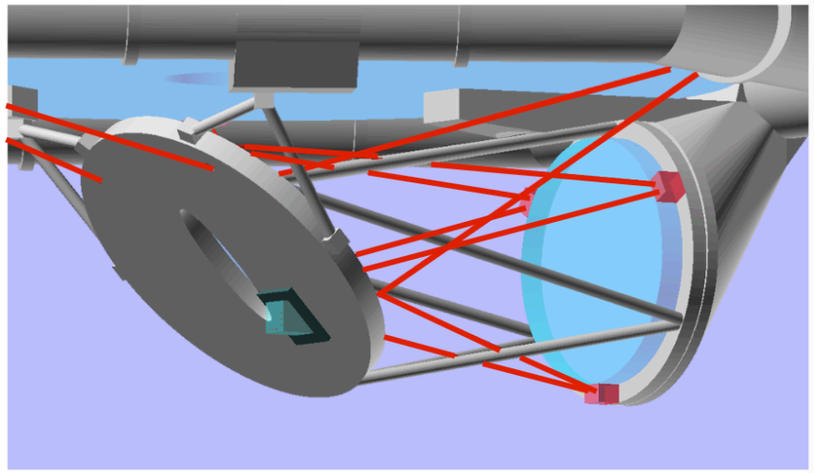
top



bottom



M3

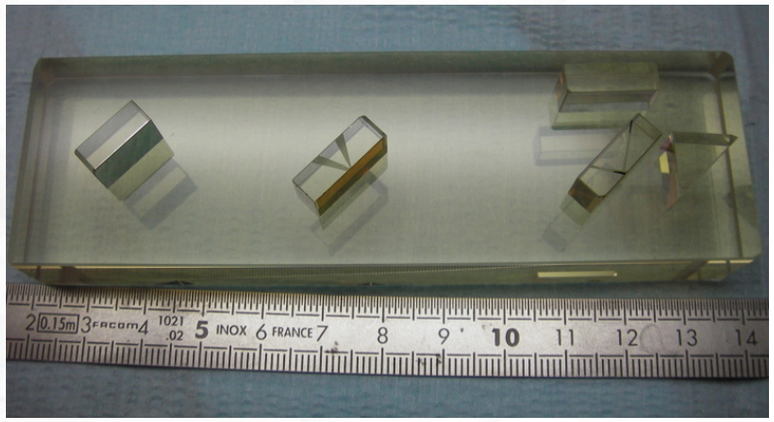


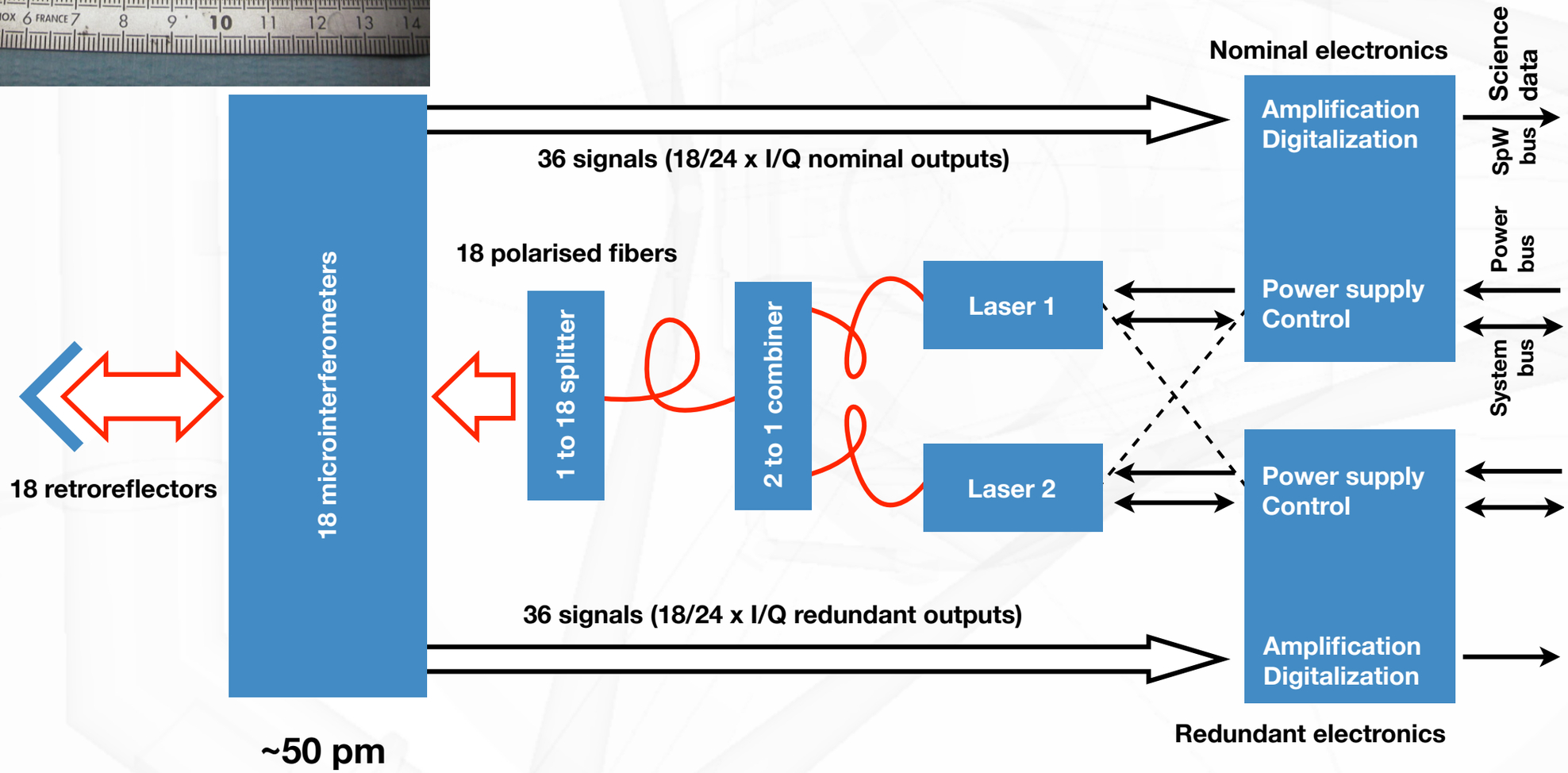
M4

Independent linear interferometers : monitoring for corrections on ground.

arXiv:1707.01348

THEIA : *the new Astrometry frontier*

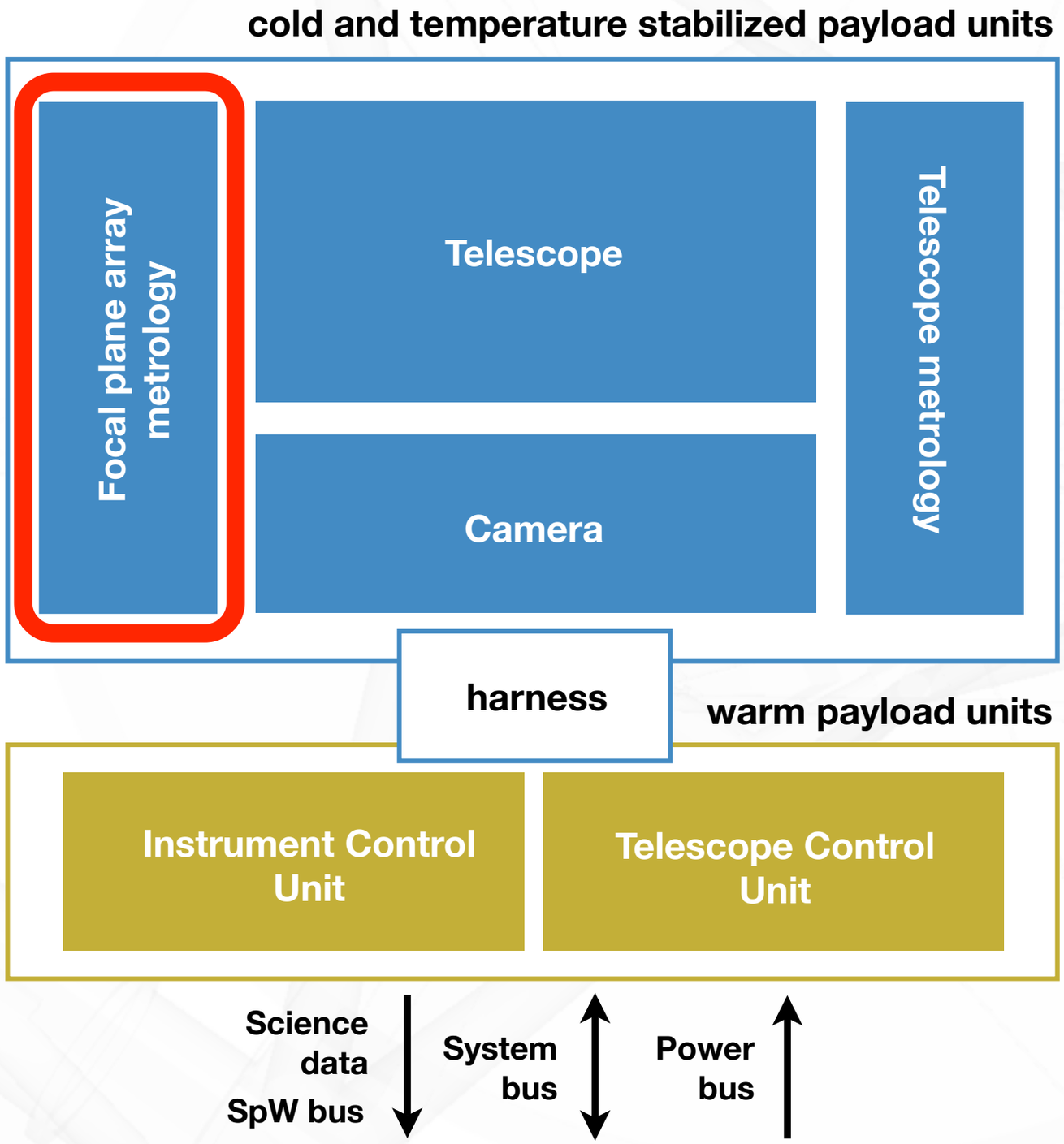




Independent linear interferometers : monitoring for corrections on ground.

arXiv:1707.01348

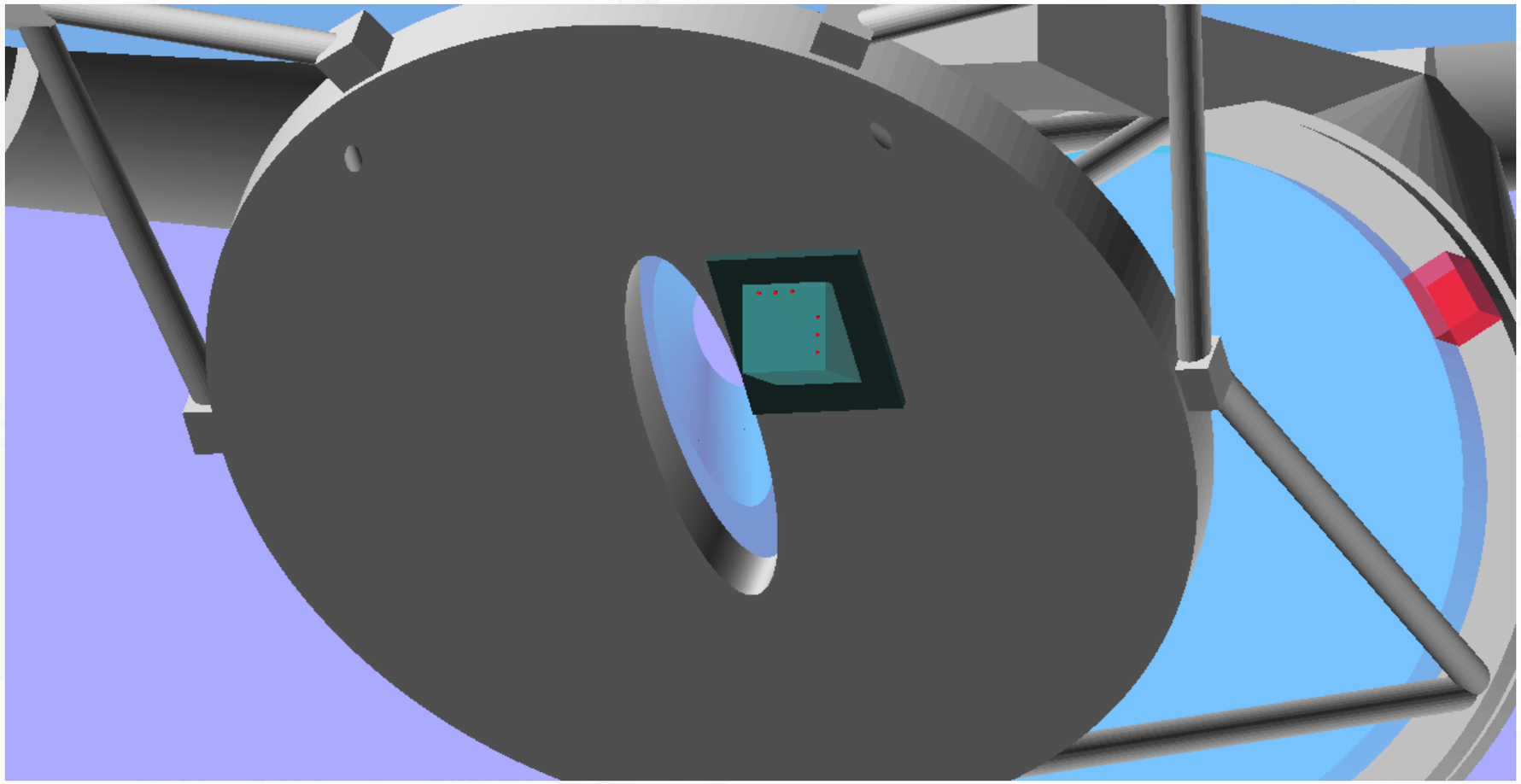
THEIA : *the new Astrometry frontier*



arXiv:1707.01348

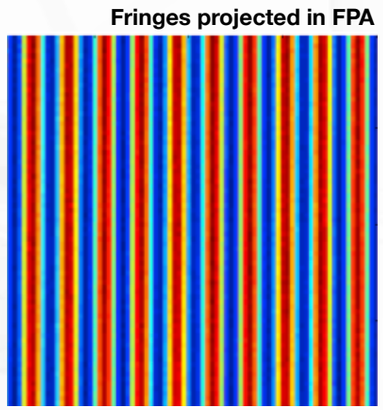
THEIA : *the new Astrometry frontier*

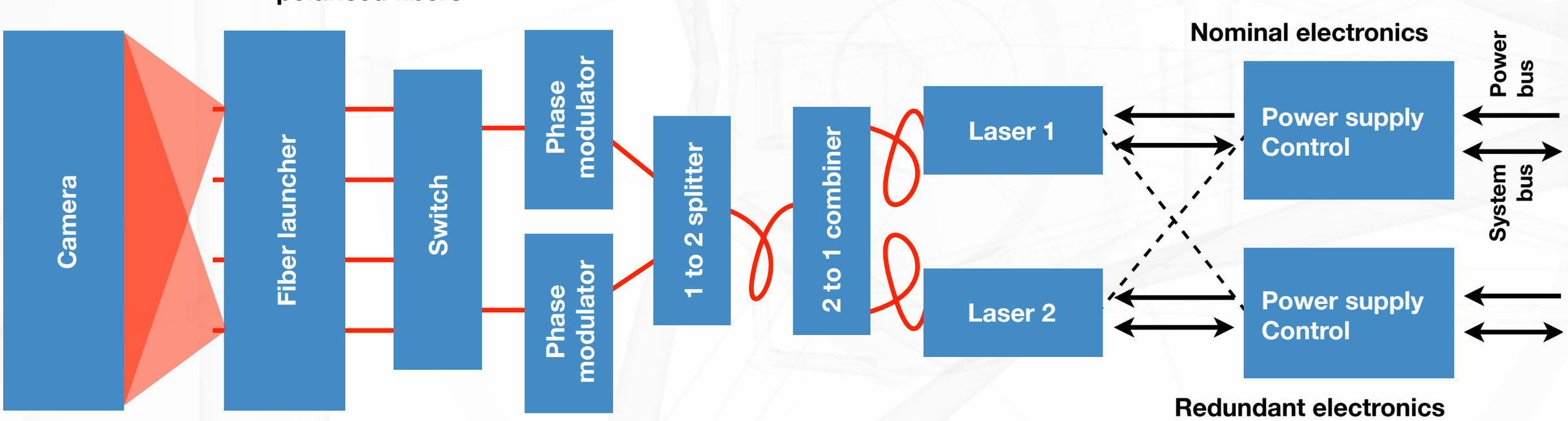
Lesson from Gaia :: Monitor, monitor, monitor



arXiv:1707.01348

Theia : *the new Astrometry frontier*

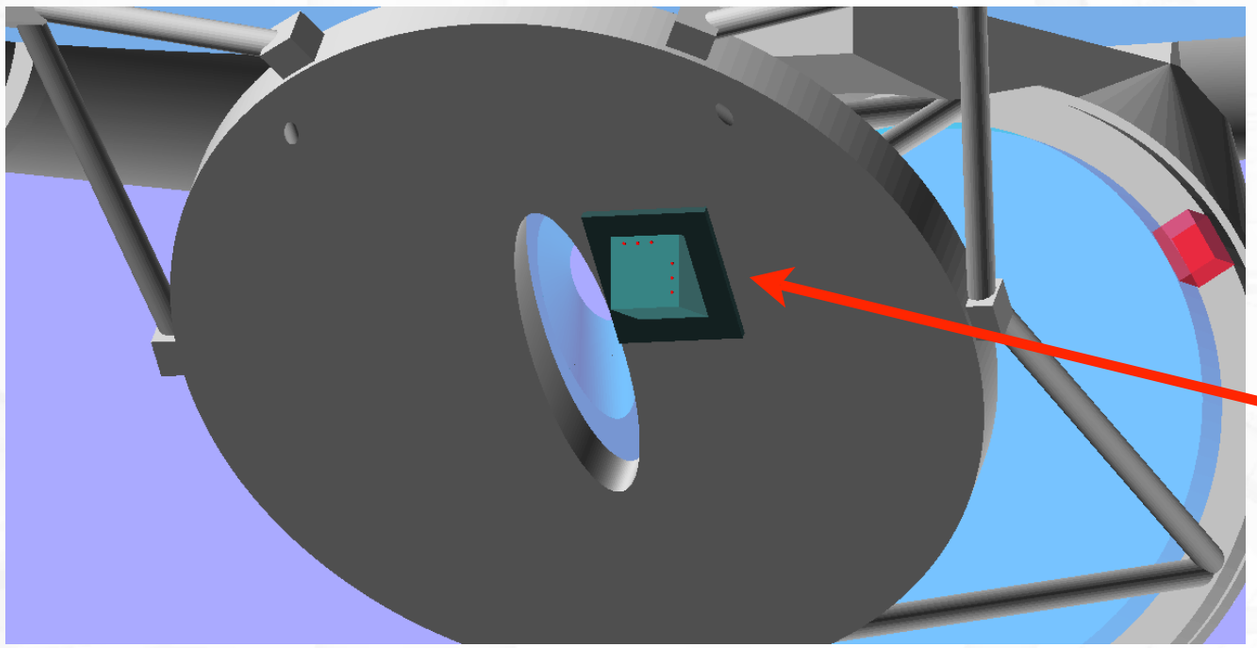




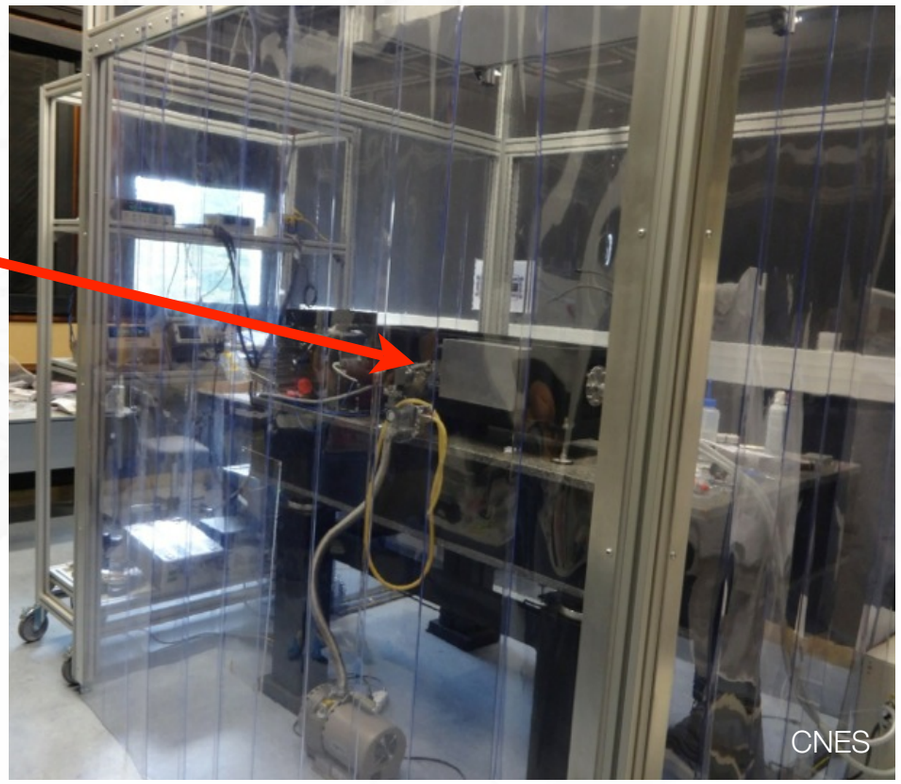
arXiv:1707.01348

THEIA : *the new Astrometry frontier*

Lesson from Gaia :: Monitor, monitor, monitor

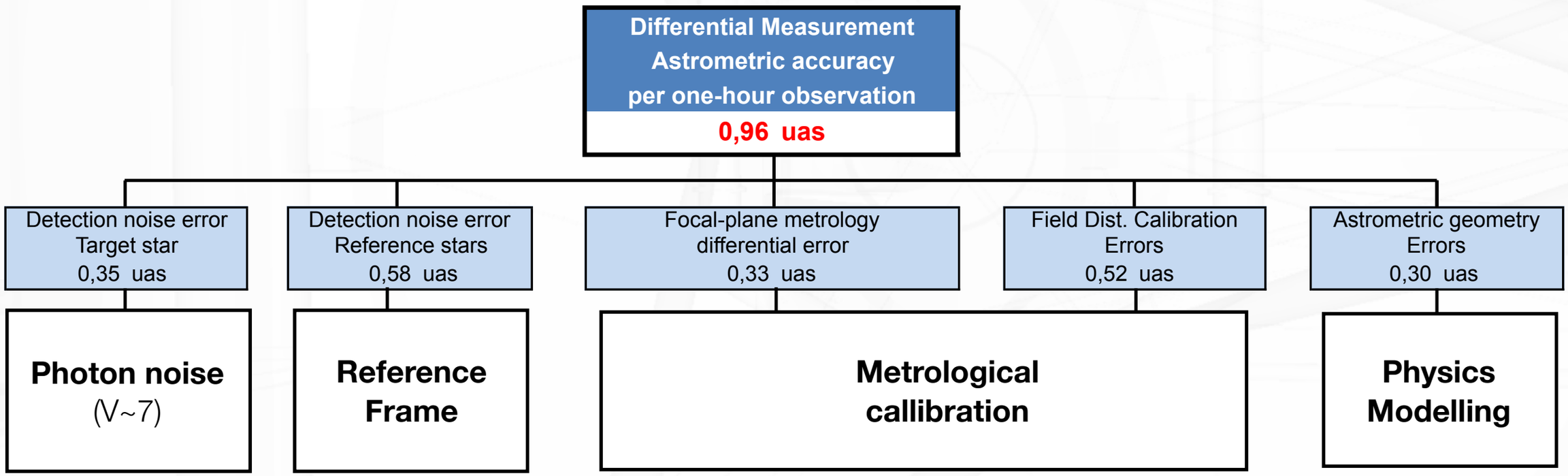


Interferometric FPA callibration
Prototype @ IPAG
reached 5x10^{-5} pixel size



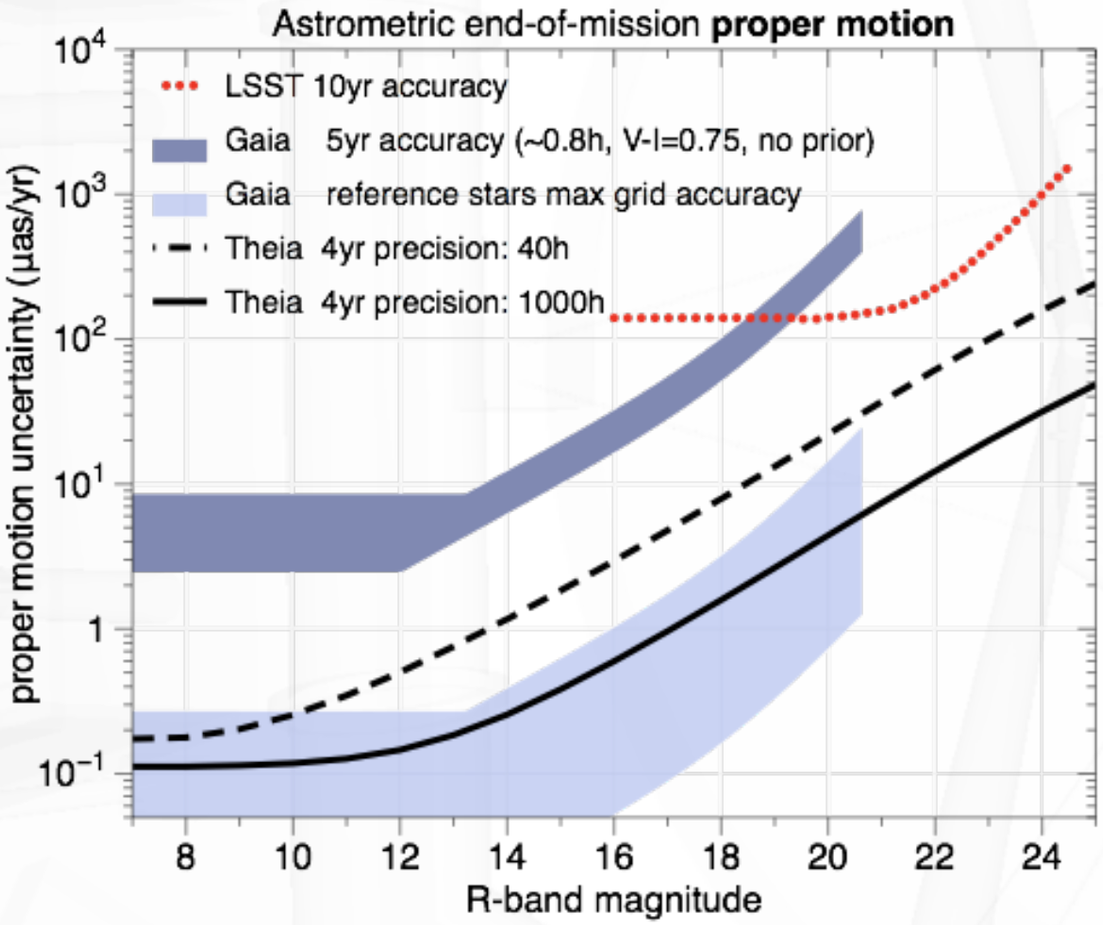
arXiv:1707.01348

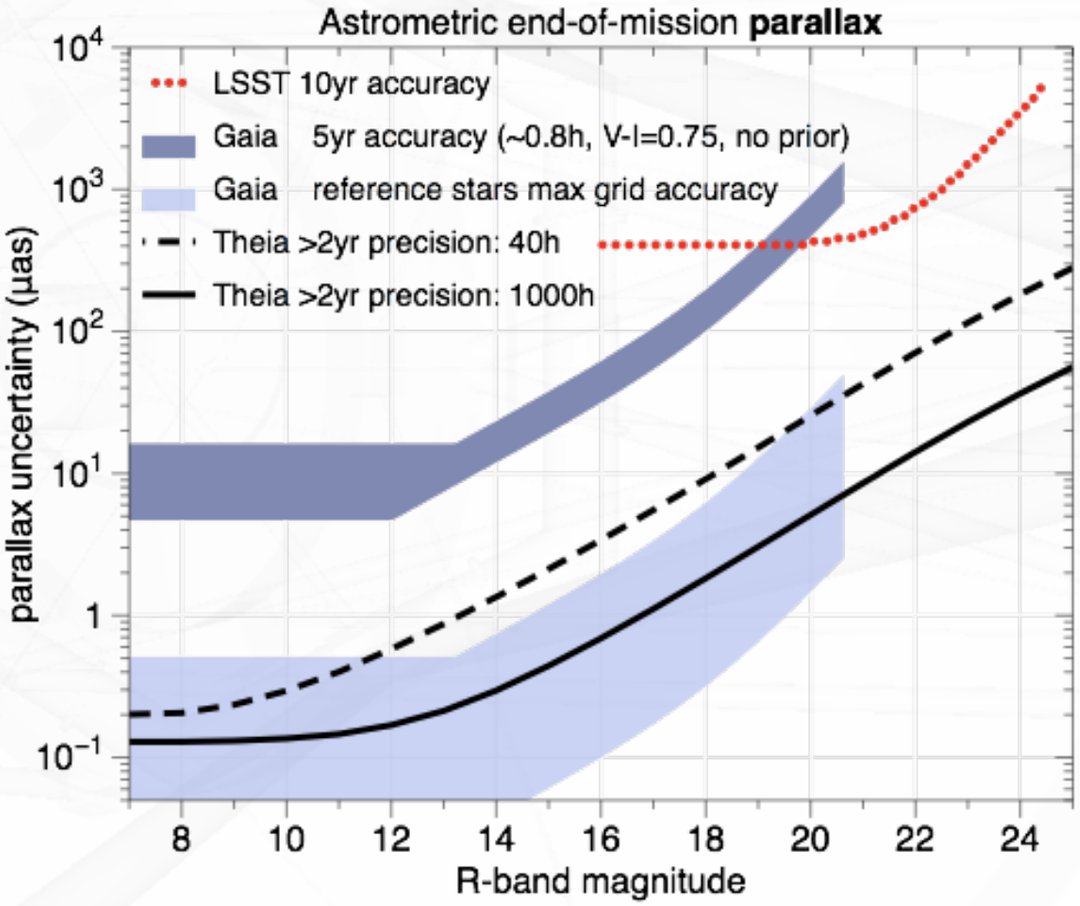
THEIA : *the new Astrometry frontier*



arXiv:1707.01348

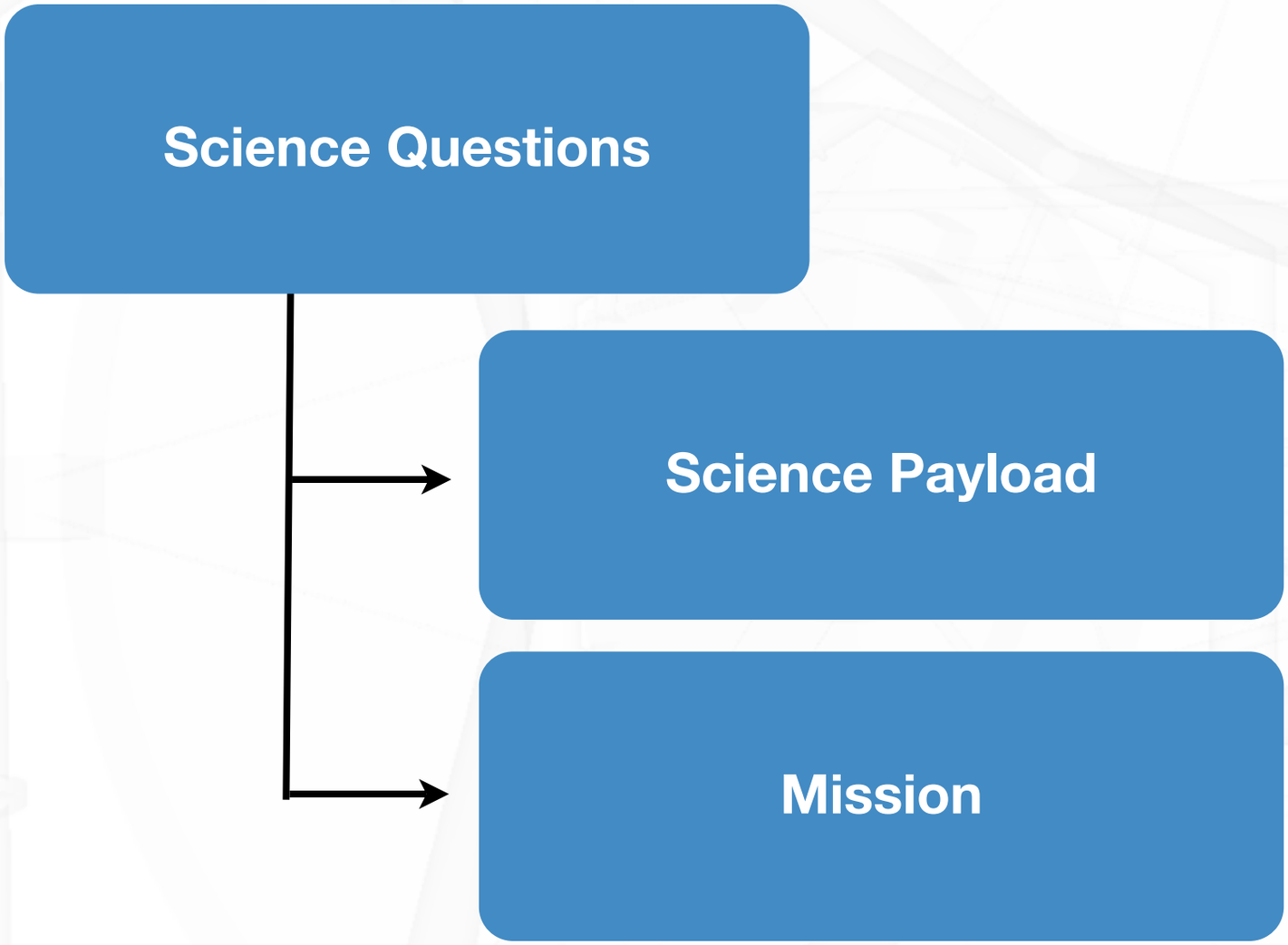
Theia : *the new Astrometry frontier*





arXiv:1707.01348

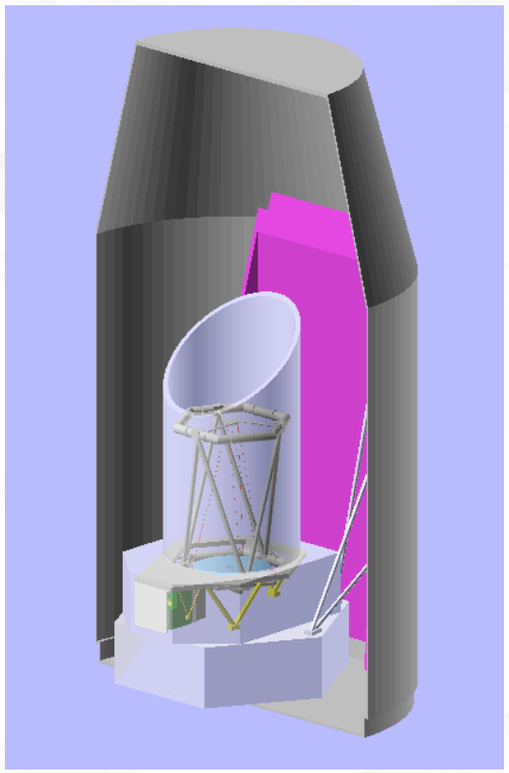
THEIA : *the new Astrometry frontier*



arXiv:1707.01348

THEIA : *the new Astrometry frontier*

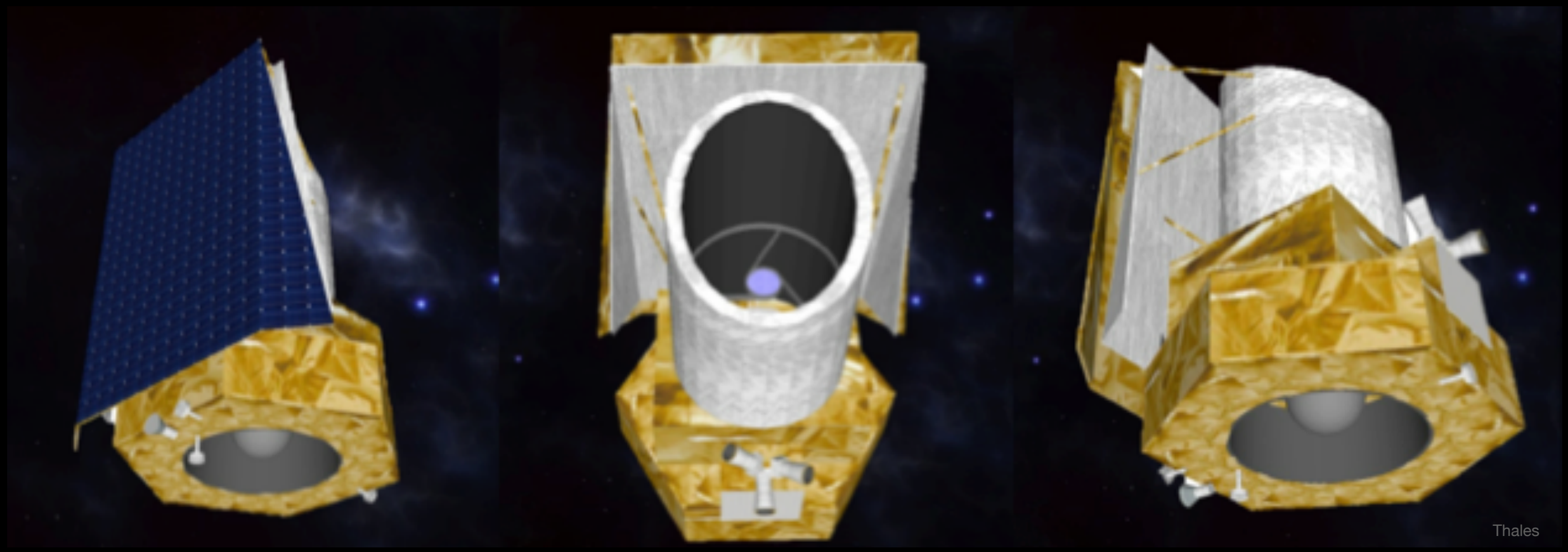
- **ESA-led, ESA-operated mission with consortium funded payload**
  ("standard" ESA mission) : 536M€ (inc. 10% Cont) + 51.5M€ (inc. 15% Cont)
- Ariane 6.02 launch, Large Lissajous at L2
- Spacecraft dry mass with margin: 1063 kg. Total launch Mass: 1325 kg



Soyuz Fairing 936S

arXiv:1707.01348

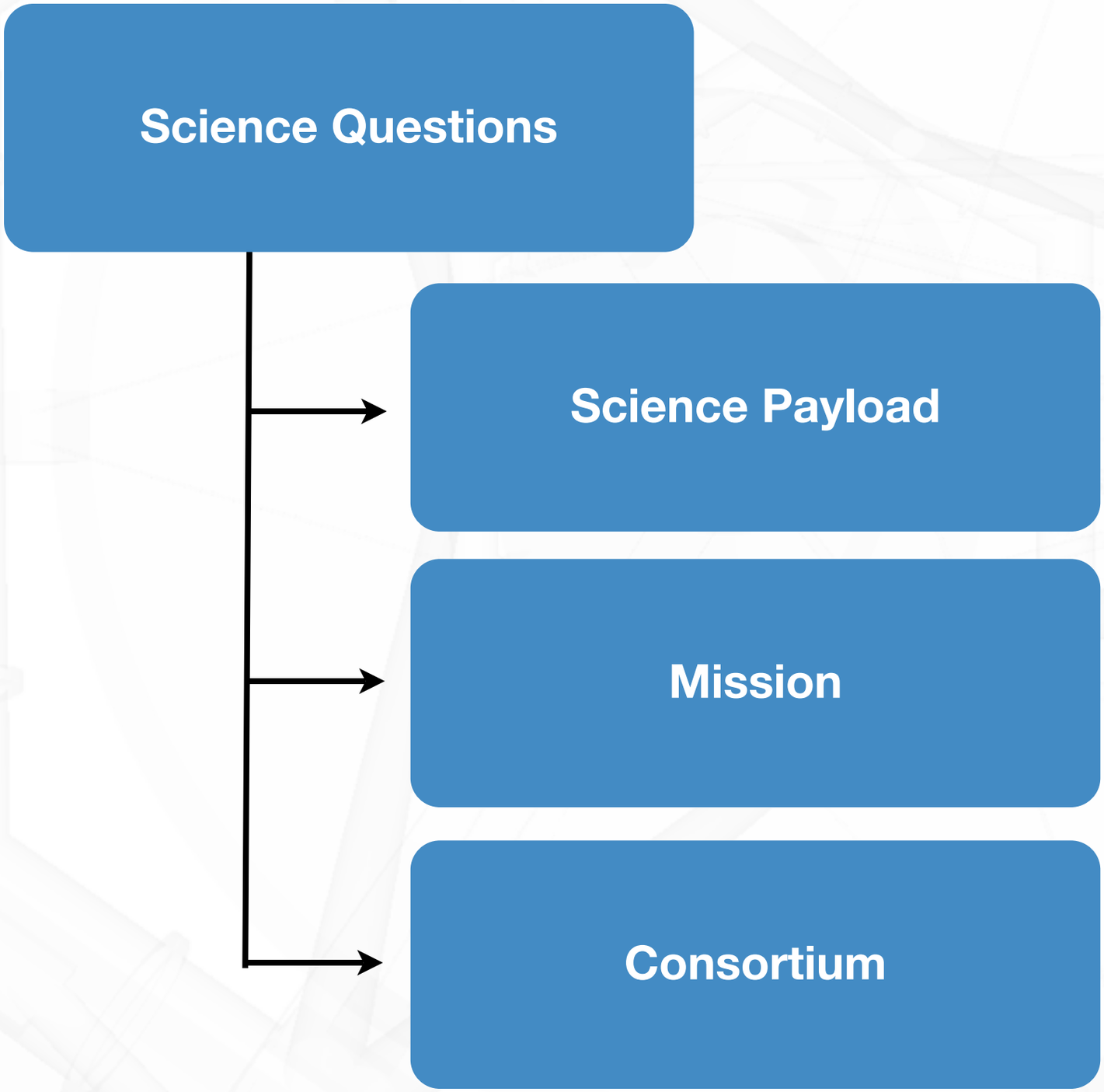
Theia : *the new Astrometry frontier*



Thales

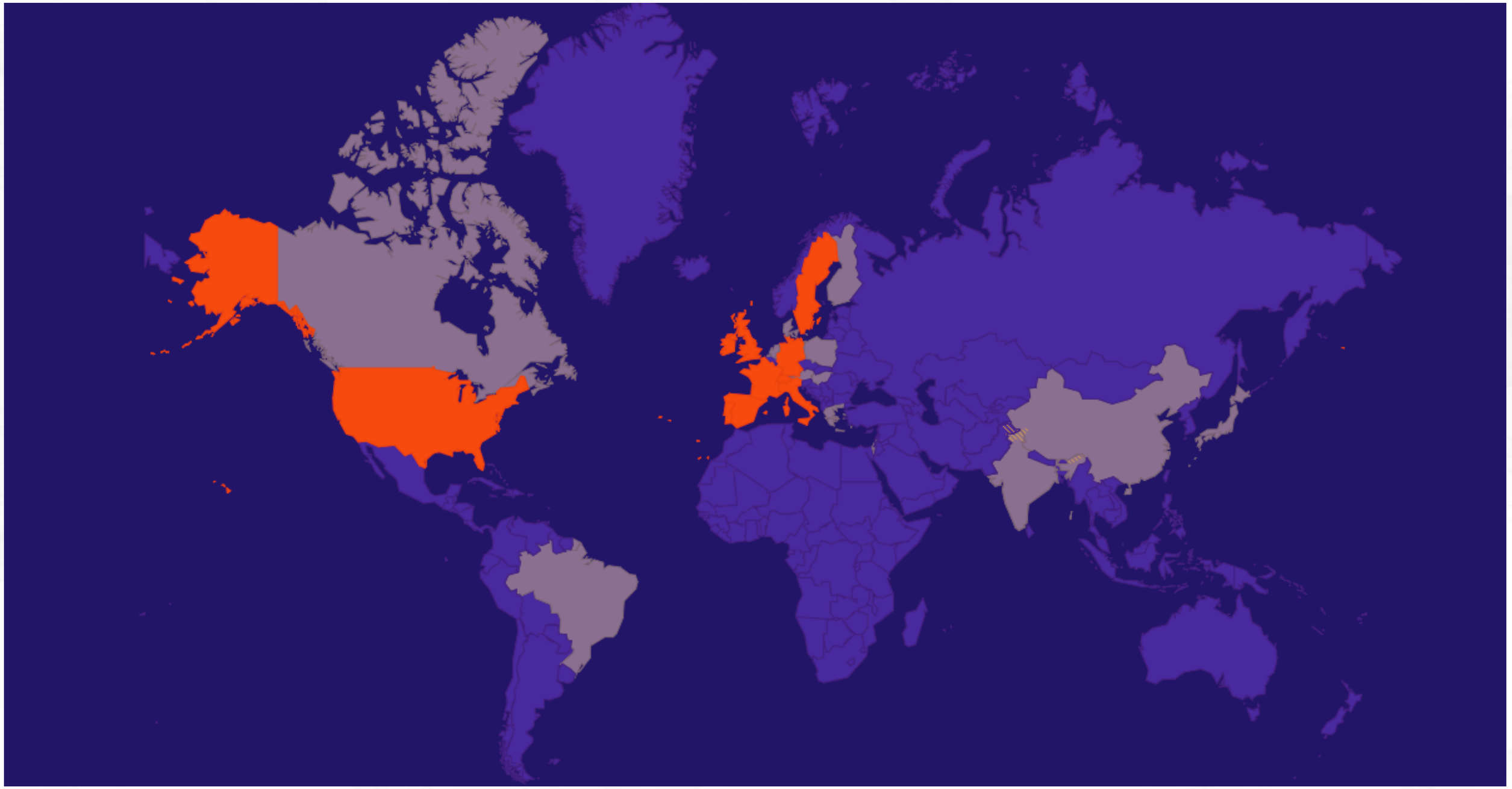
arXiv:1707.01348

THEIA : *the new Astrometry frontier*



arXiv:1707.01348

THEIA : *the new Astrometry frontier*

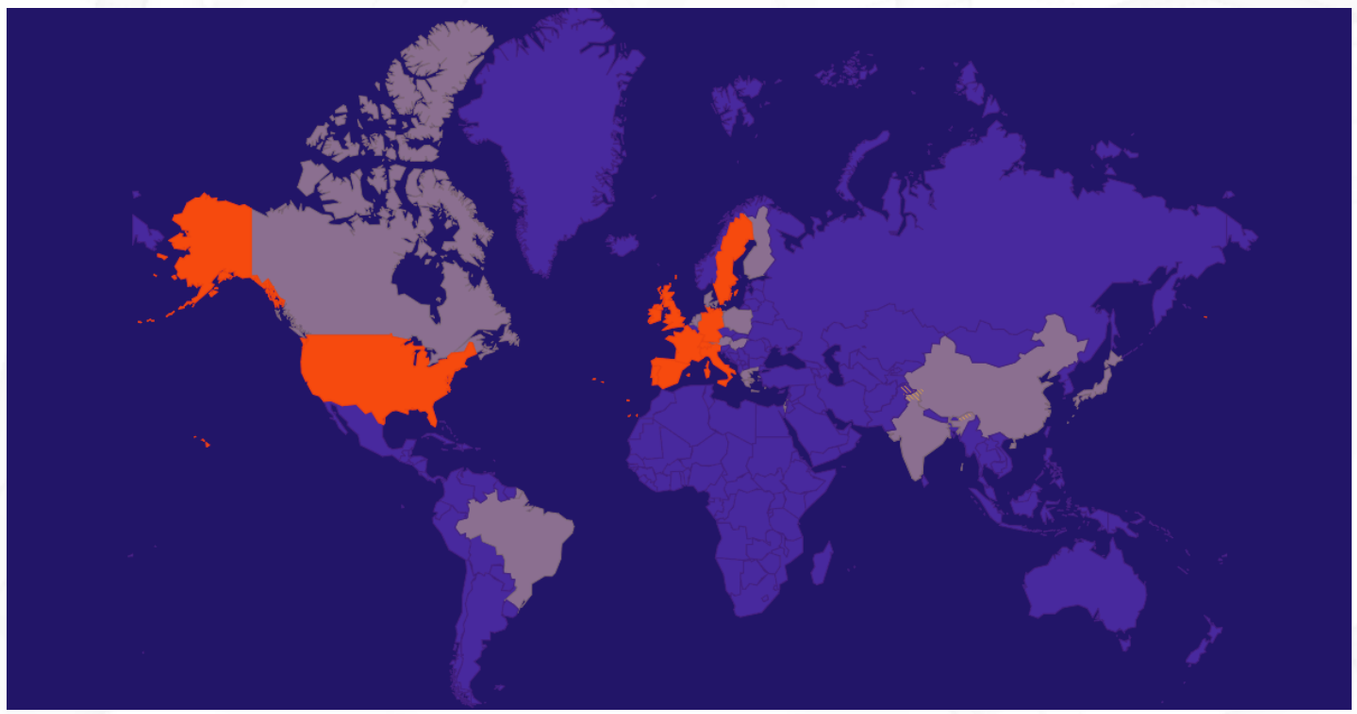


arXiv:1707.01348

Theia : *the new Astrometry frontier*

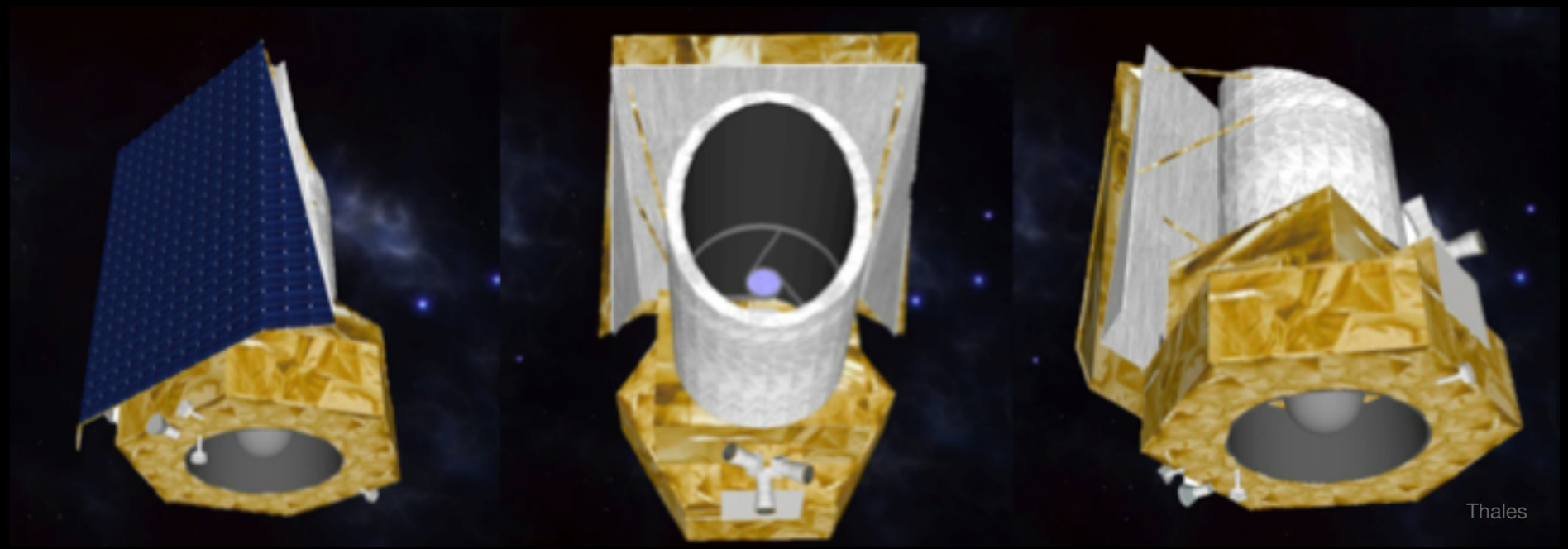
- The core team includes members from the UK (Durham-PI Inst.), France, Italy, Germany, Sweden, Spain, Switzerland and Portugal (USA if int. part.).
- Additional contributions from Austria, Denmark, Finland, Greece, Hungary, The Netherlands and Poland.
- Participants from seven countries outside Europe: Brazil, Canada, China, India, Israel, Japan and USA ("non-enabling" contribution).

- **22 countries**
- **> 200 Researchers**
- **~70 contributors to the proposal**



arXiv:1707.01348

Theia : *the new Astrometry frontier*

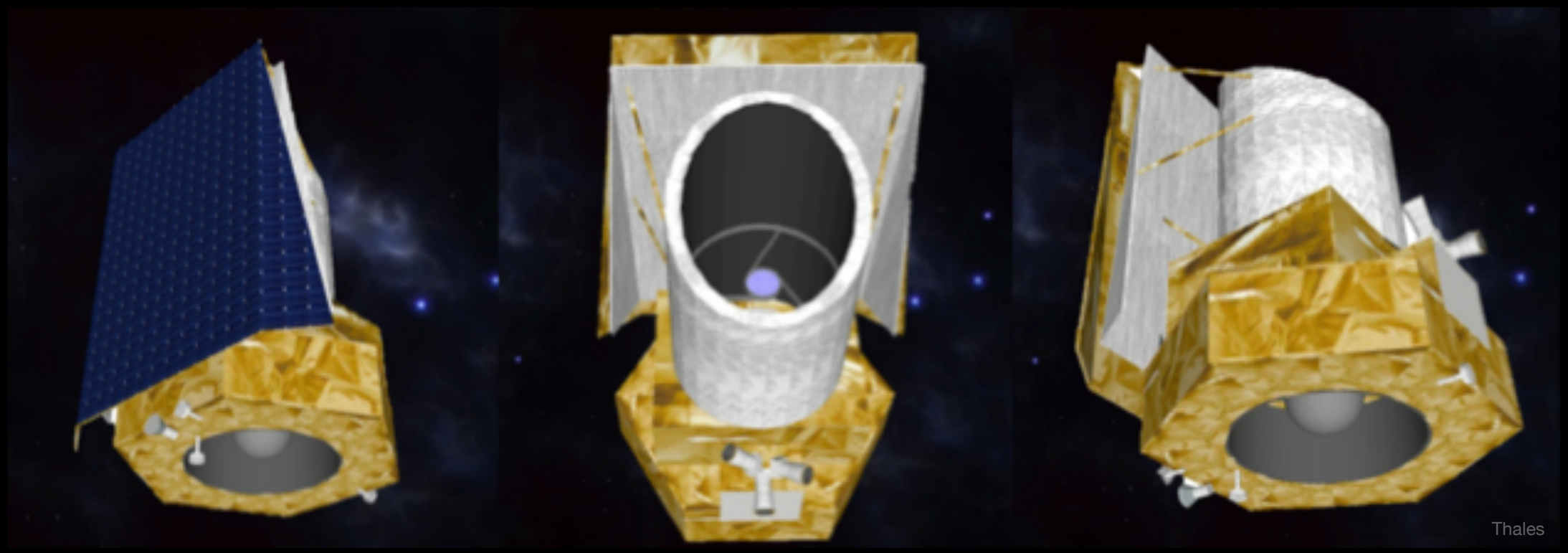


A mission concept designed:

- **To be the 1st to probe small-scale properties of Dark Matter**
- **To be the 1st to reliably probe the shape of MW DM halo**
- **To be the 1st to detect habitable exo-Earths around FGK stars unambigously and to probe their systems architectures**
- **To significantly improve the knowledge of Neutron Star EOS and of matter around Black Holes**
- **Plus : ~15% open time & serendipitous discoveries**

arXiv:1707.01348

Theia : *the new Astrometry frontier*



Tack *you all, but specially*

Tack *Lennart, for providing inspiration and wisdom to several generations!*