Astrometric Gravitation Probe (AGP)

Riva, A., on the behalf of AGP team

Rome, Nov 20th 2018

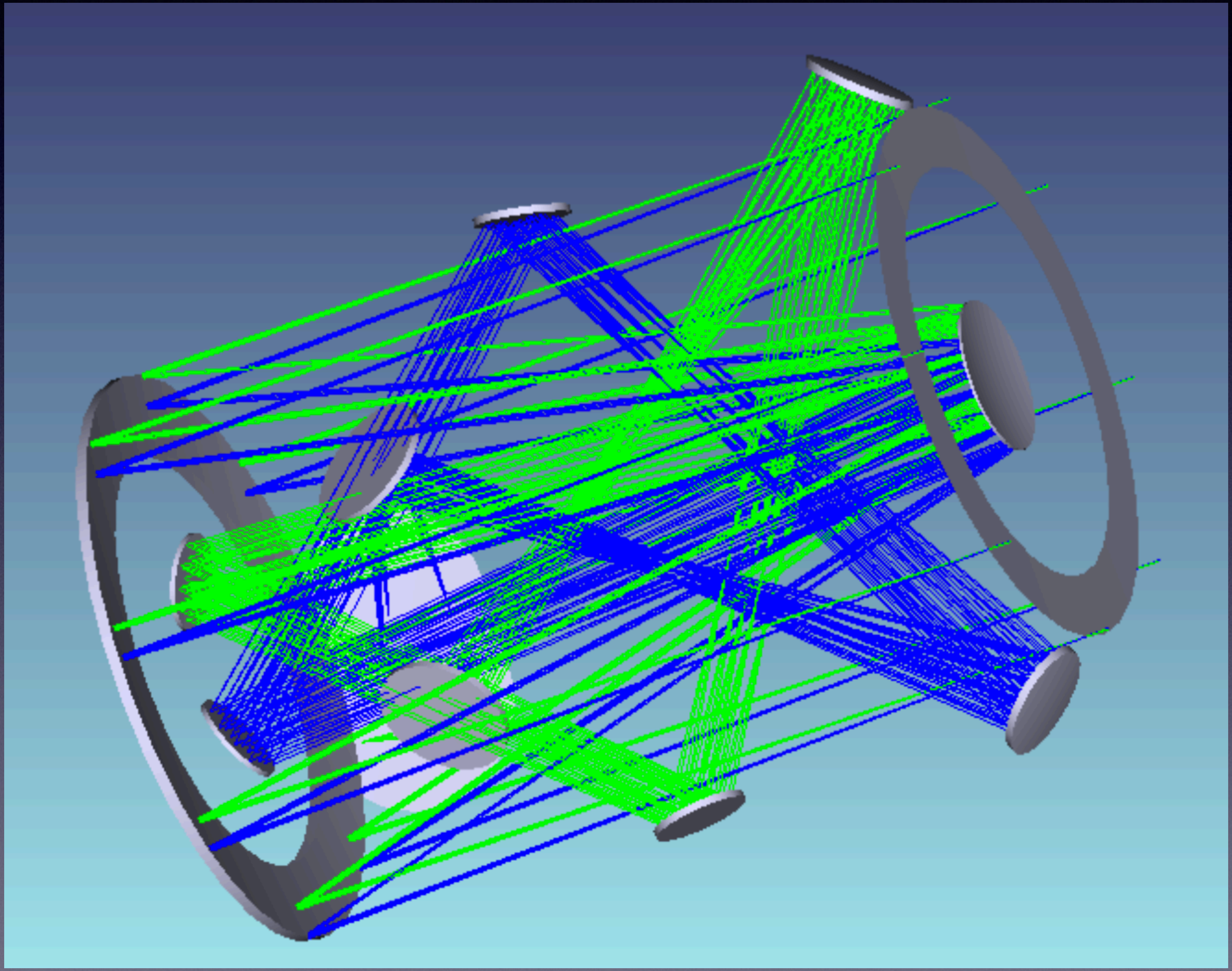
Final message

- Let’s enhance the “sparse pupil” technique research activities

Overview

- AGP Mission
- Science goals
- Scientific requirements
- Measurement principles
- Instrument design
- Performances

What's AGP?



AGP: Astrometric Gravitation Probe

Astrometry = measurement of apparent star position

Gravitation = Tests in weak field (solar system)

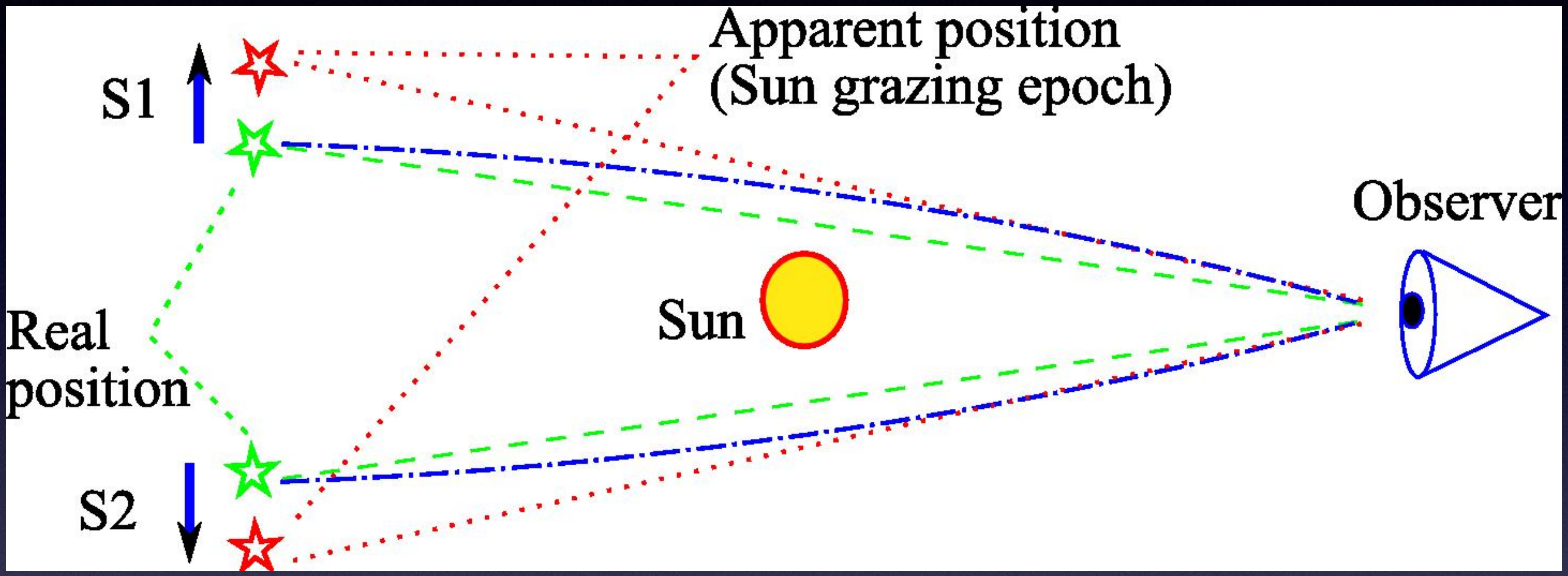
1) Light deflection close to the Sun
2) High precision dynamics in Solar System

Probe = Medium size space mission

Mission design driver:
Light bending around the Sun @ sub-μas level

Proposed in ESA M4 call and 2015 Call for Ideas

AGP concept: Dyson-Eddington-Davidson experiment (1919)



A space mission in the visible range to achieve

- long permanent artificial eclipses
- no atmospheric disturbances, low noise

Differential measurement for
systematic error control

AGP Mission Profile

Baseline launcher:	Vega
Sun-Synchronous orbit (SSO, i=99.48°), elevation:	1000 (1500) km
Useful mass (satellite + payload):	1140 (1000) kg
Spacecraft dry mass (incl. payload and propulsion systems)	~ 800 kg
Payload mass	~ 300 kg
In-orbit operations	3-5 years
fields of view	16' x 16'
Effective Focal Length	~ 25 m
Telescope primary diameter:	1.15 m
Effective Fizeau pupil diameter:	1.10 m
	lightweight mirror zerodur or SiC
Payload envelope:	2.1 m diameter x 1.5 m height
Detector:	CCD mosaic @ -20 C
Main science focal plane:	8 x 4 CCDs - 2kx4k
Auxiliary (pointing) focal plane:	1 x 2 CCDs - 2kx4k

AGP Science goals

Characterisation of weak field gravity in the Solar System

- Deflection of light in the solar system
- Non-linearity of gravity, preferred frame
- Relativistic effects of oblate and moving giant planets
- Solar system dynamics [High precision ephemerides]

AGP Science goals

Characterisation of weak field gravity in the Solar System

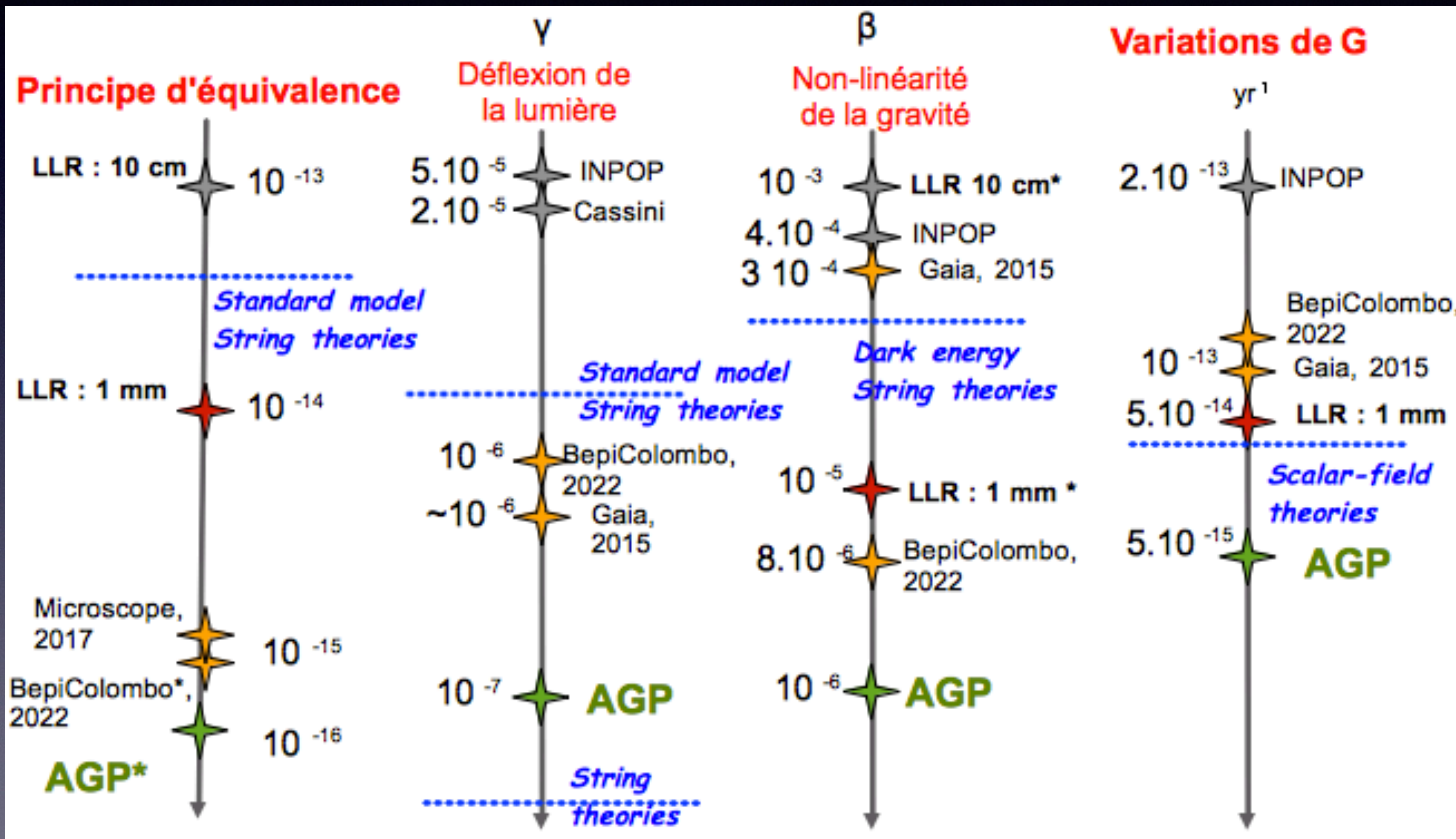
- ➢ Deflection of light in the solar system
- ➢ Non-linearity of gravity, preferred frame
- ➢ Relativistic effects of oblate and moving giant planets
- ➢ Solar system dynamics [High precision ephemerides]

- Detection of dilaton
- Limits on Lorentz invariance
- Preferred frame detection
- Anisotropy of light deflection
- Test of Equivalence Principle

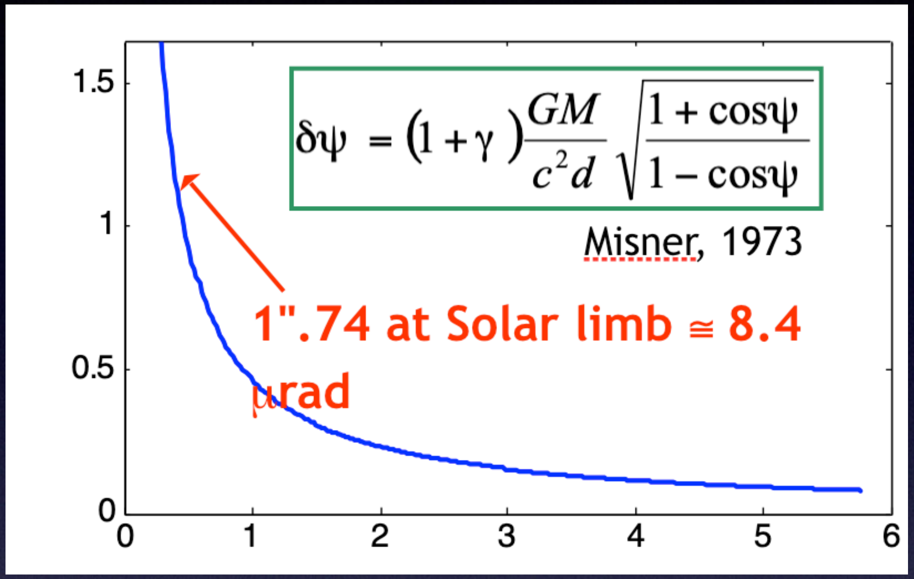
→ **Exclusion / validation of alternative theories of gravity**

Crosta and Mignard, 2006
Colladay, Kostelecký, 1998
Kostelecký, 2004
Kostelecký, Russell,2014
A. Hees et all., 2015

Science goals summary



AGP scientific requirements driven by light deflection case



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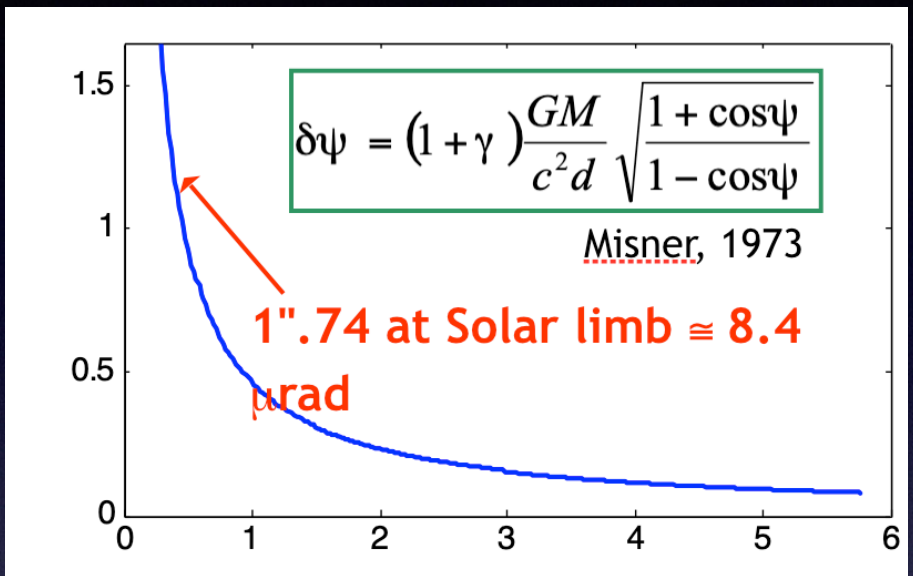


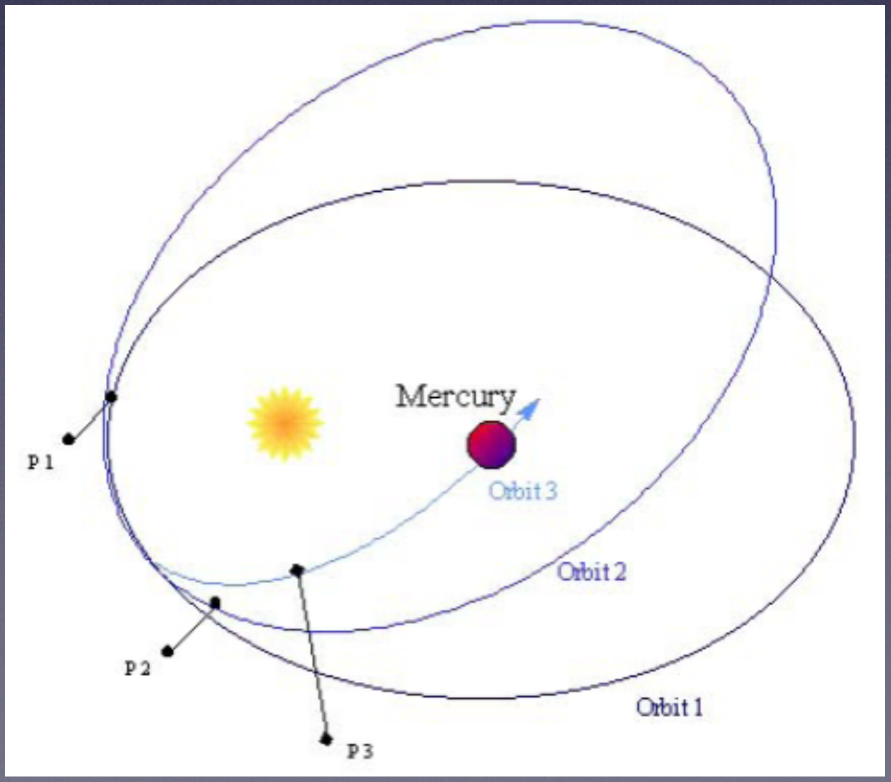
Measurement precision required:

→ Final collective accuracy (α,δ) : 0.1 to 0.01 µas

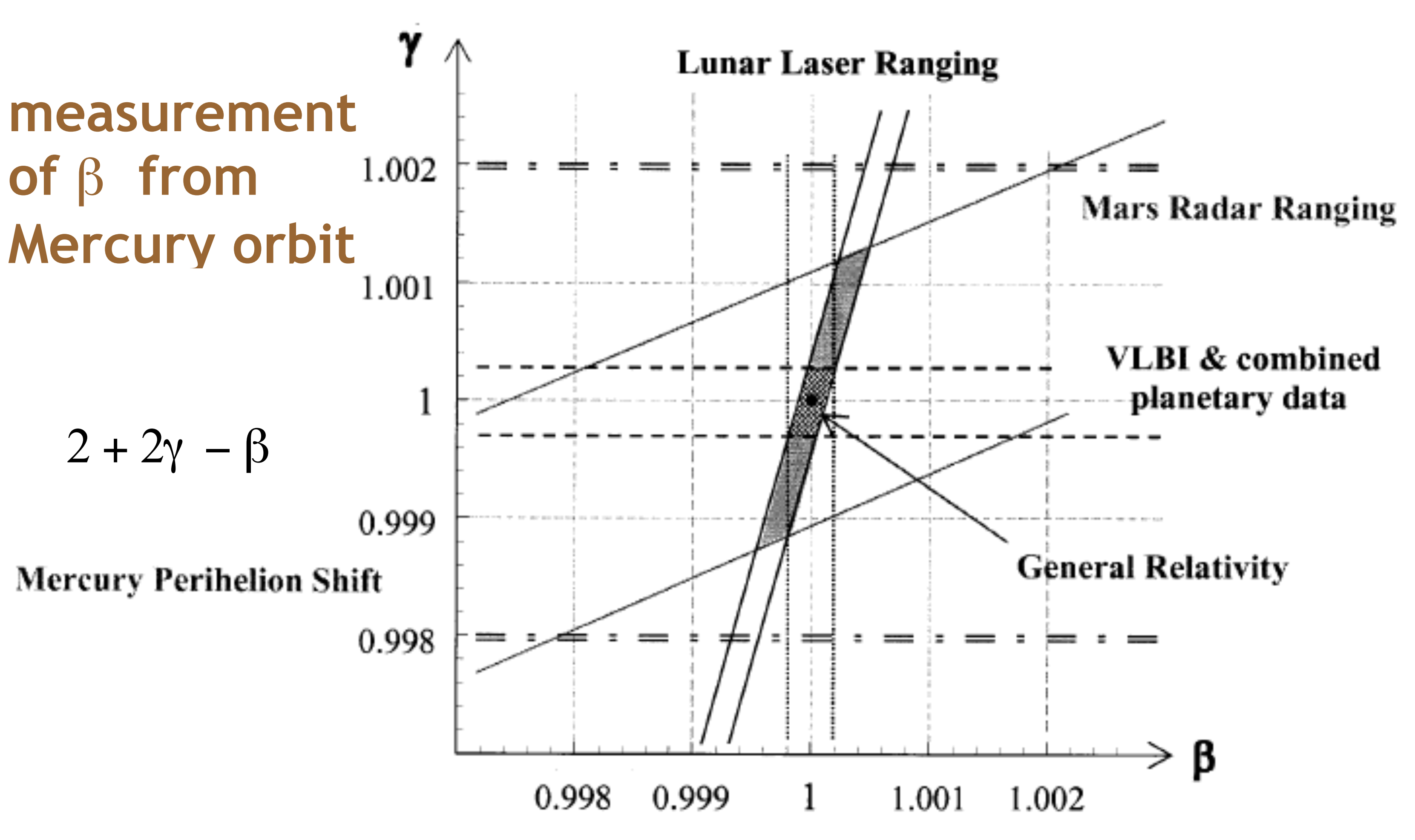
1 µas (α,δ) for Mercury

→ Individual precision: σ_{star}~ 100 to 10 µas

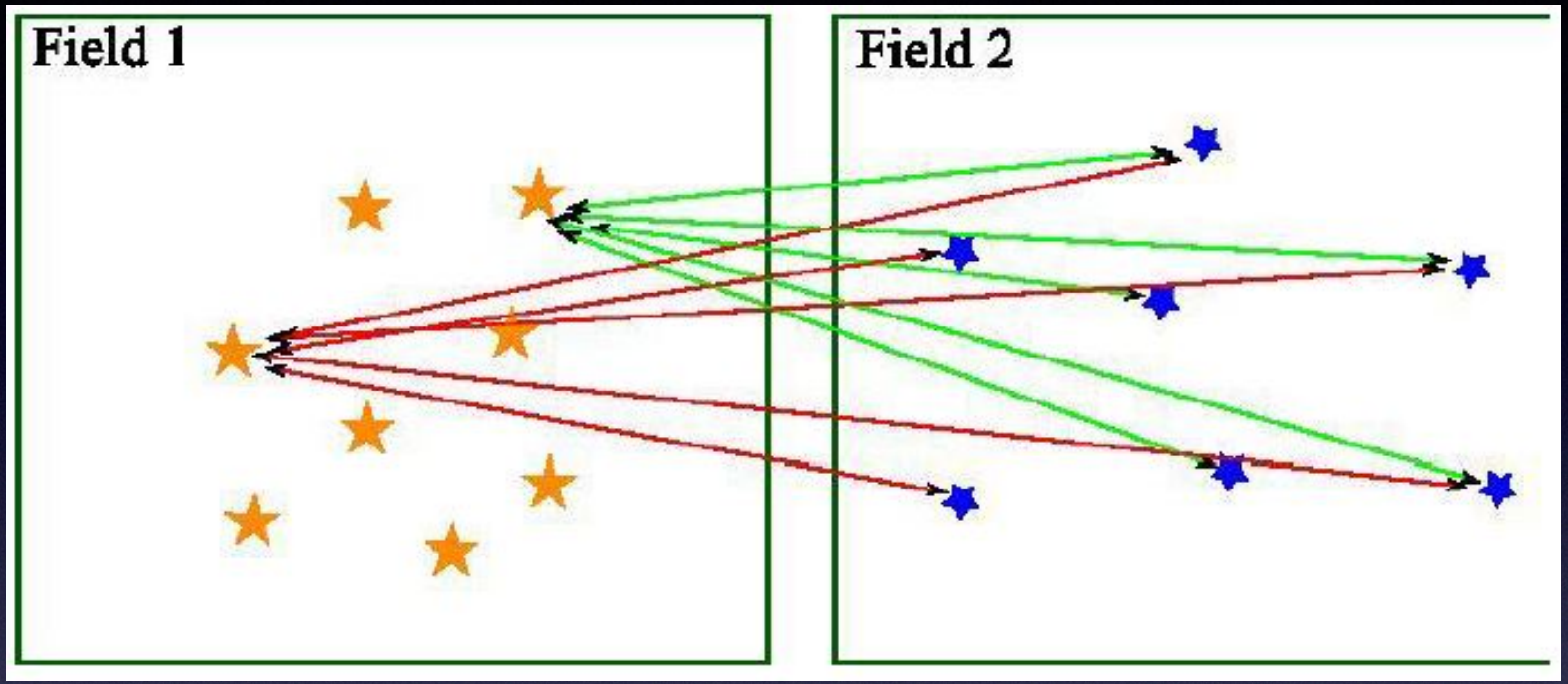
Complementary GR tests:

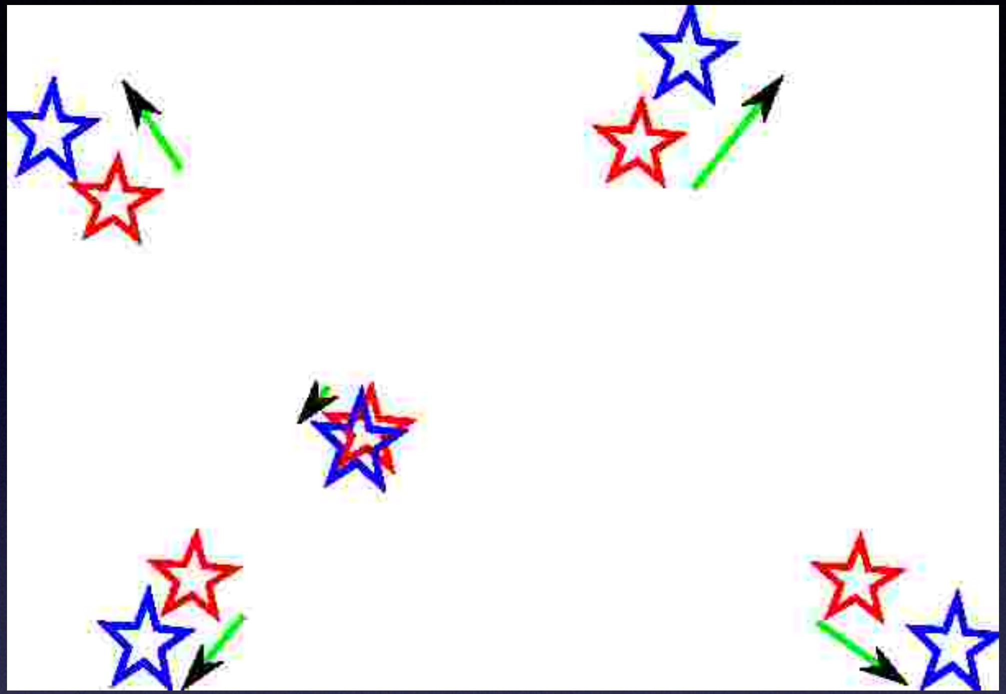


measurement of β from Mercury orbit



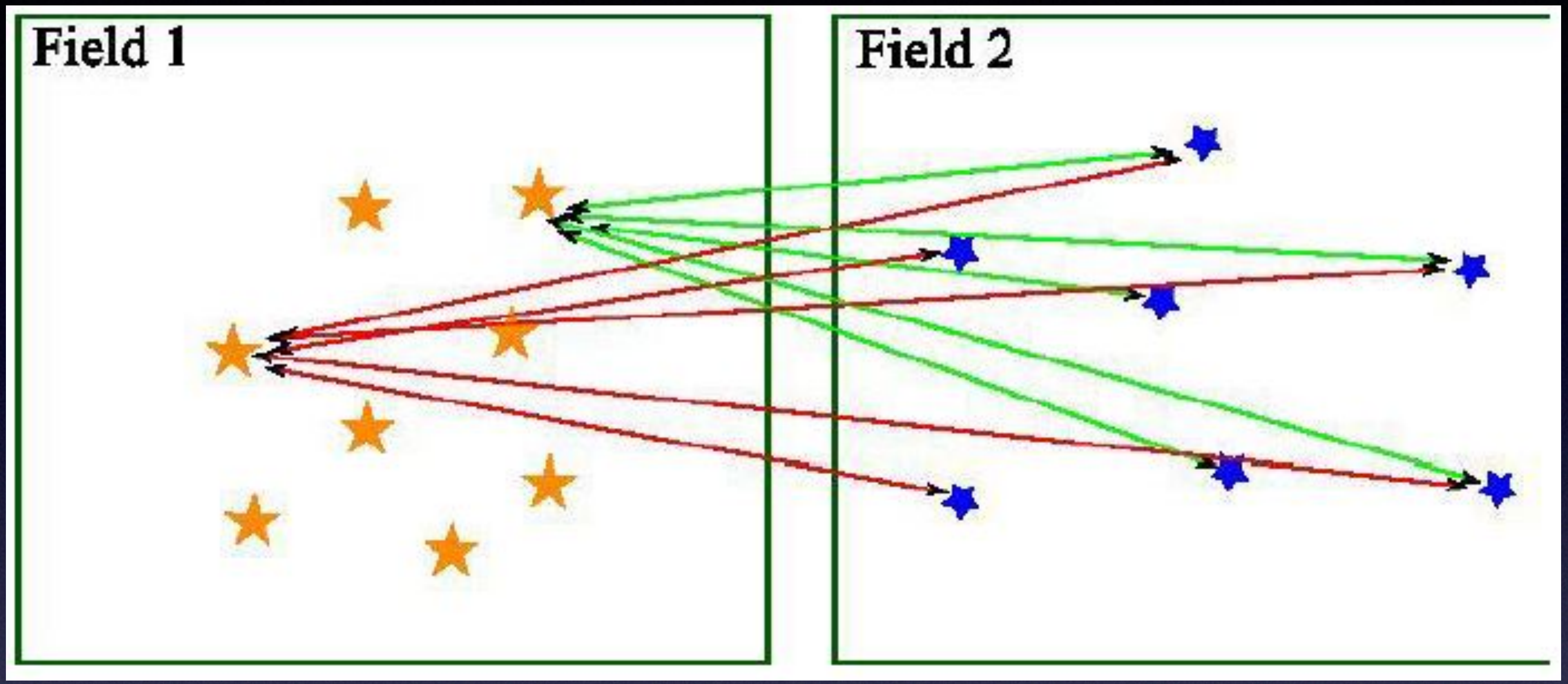
Fully differential measurement

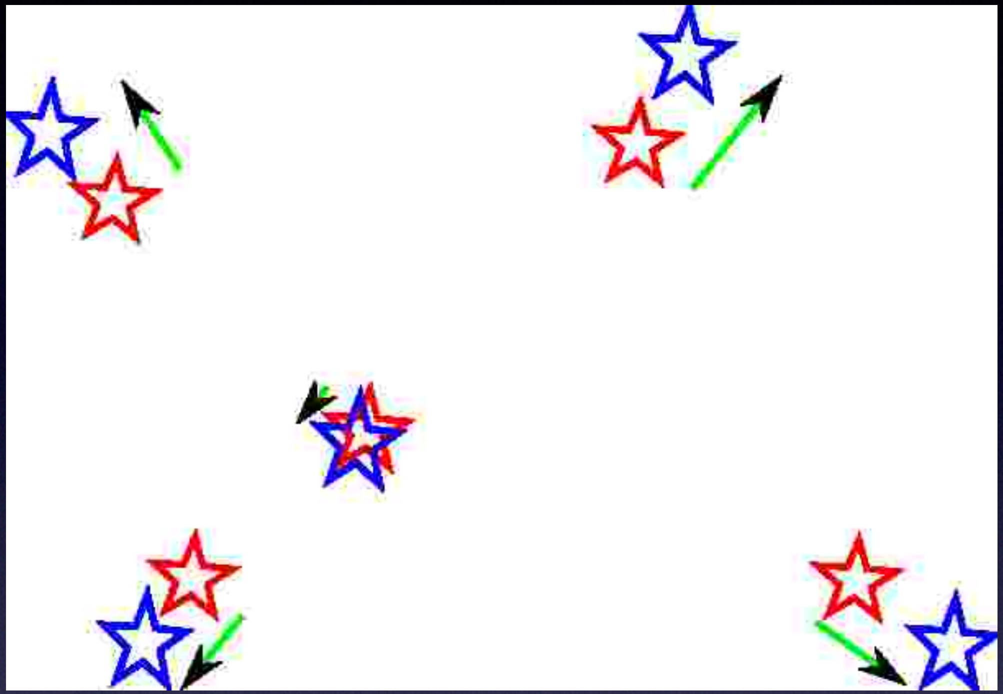




Measurement of angular separation of stars between fields

Fully differential measurement





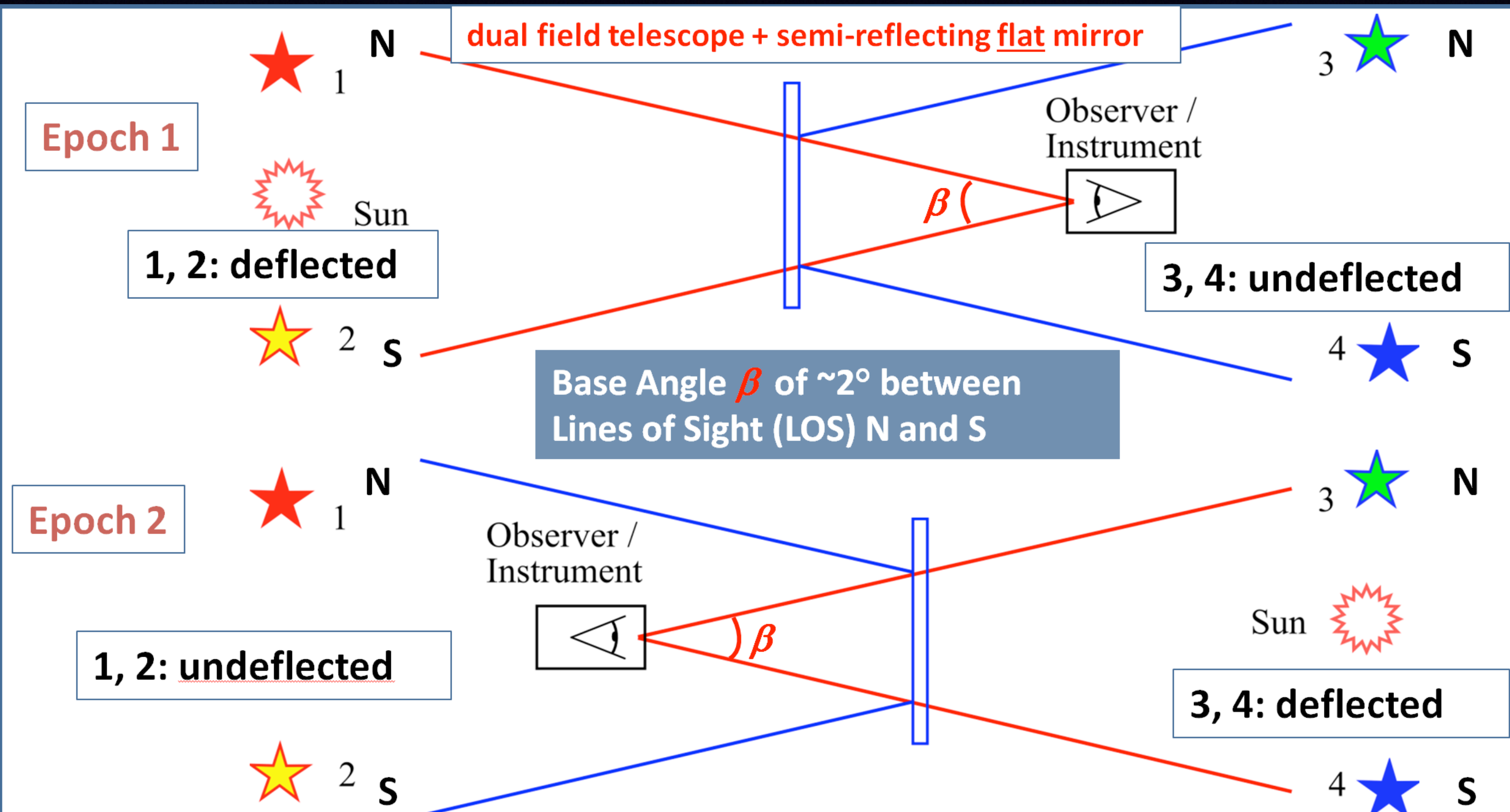
Measurement of angular separation of stars between fields

Different **collective** effects on field images from

- instrument evolution (focal length, distortion)
- deflection (field displacement)

⇒ simple calibration of MULTIPLICATIVE terms

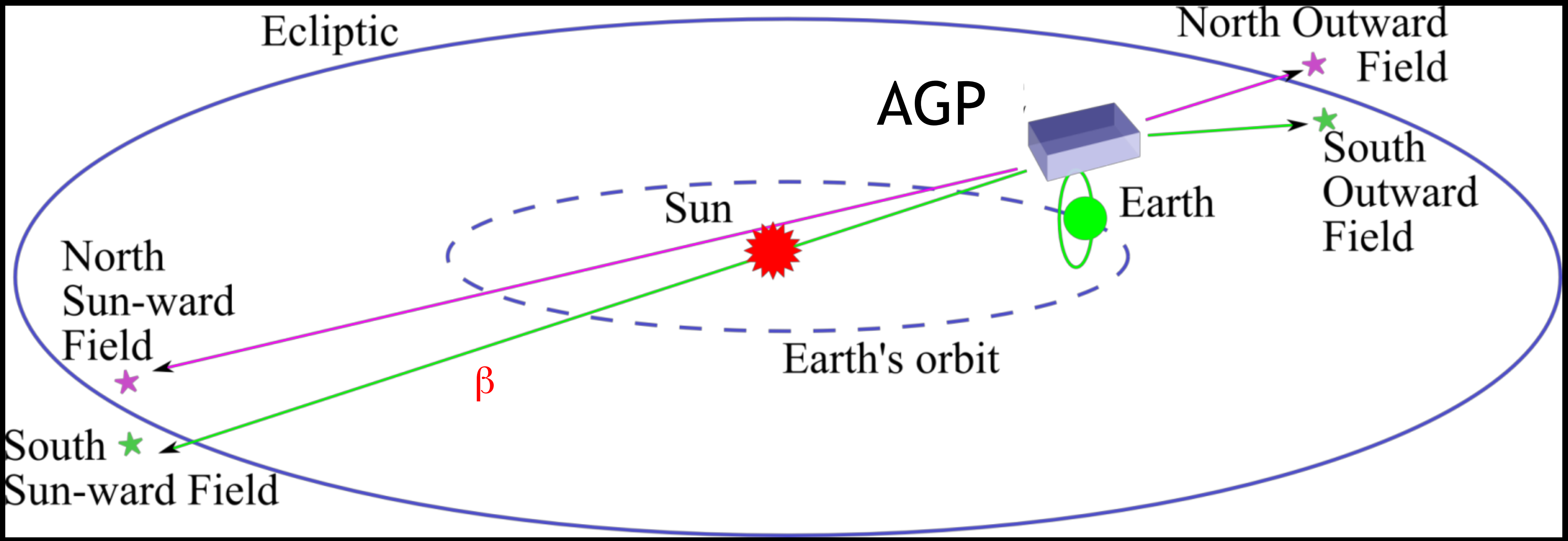
Principle

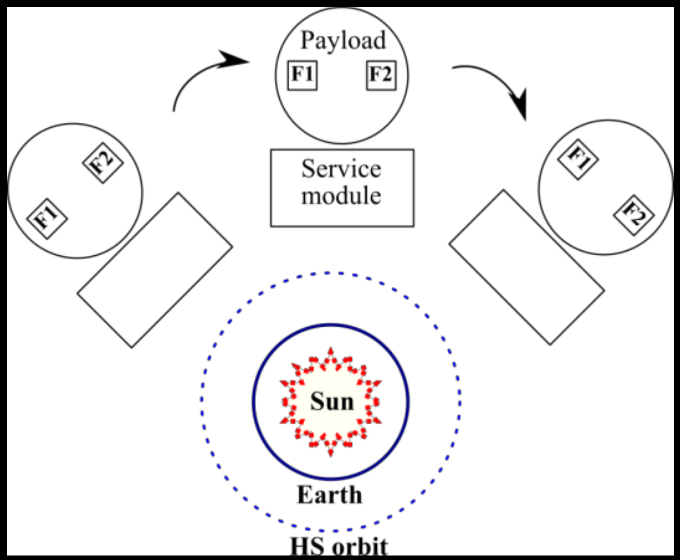


dual field telescope + semi-reflecting flat mirror
Epoch 1
1
N
Sun
1, 2: deflected
2
S
3
N
Observer / Instrument
β
3, 4: undeflected
4
S
Base Angle β of ~2° between Lines of Sight (LOS) N and S
Epoch 2
1
N
Observer / Instrument
β
1, 2: undeflected
2
S
3
N
Sun
3, 4: deflected
4
S

AGP Observation Strategy

Multiple field telescope on Helio-synchronous orbit @ h=1000 km

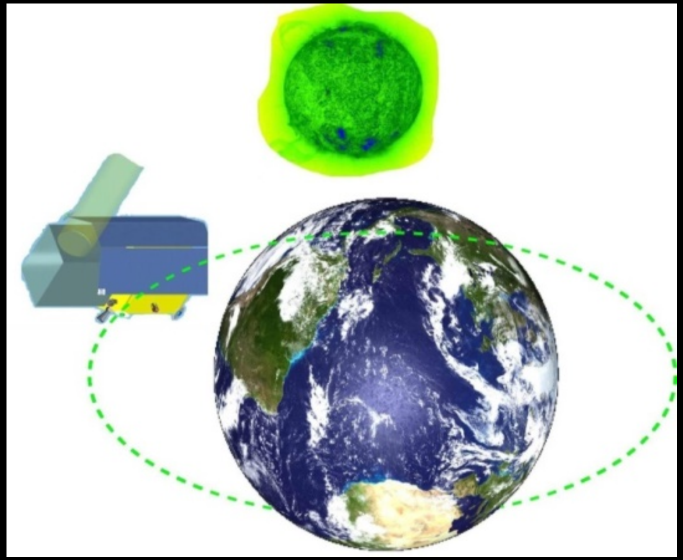




- 105 minute period
- Satellite spin with orbit period

100% observing time

Stable energy supply + *thermal environment*



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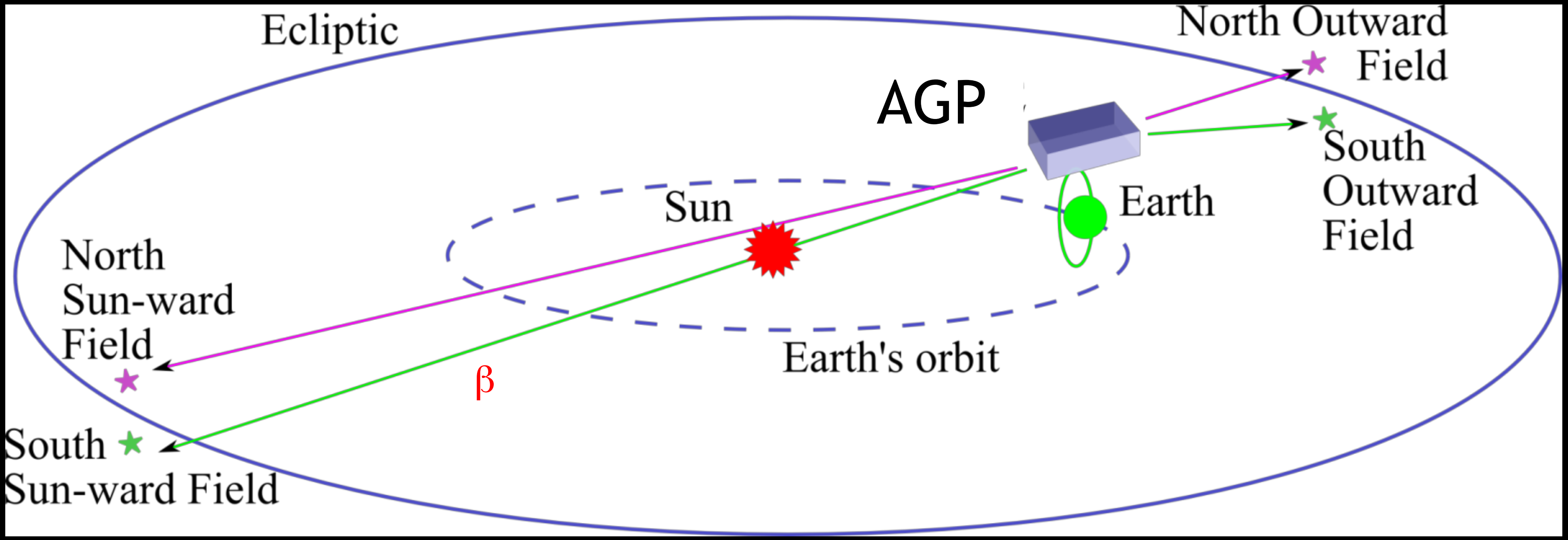

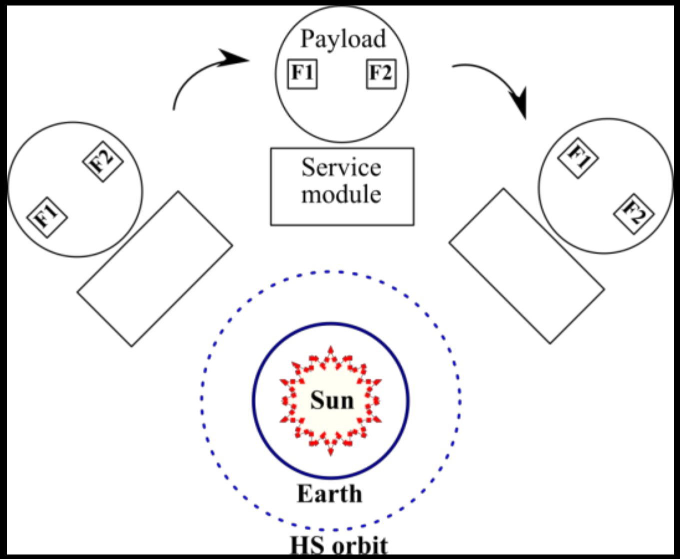

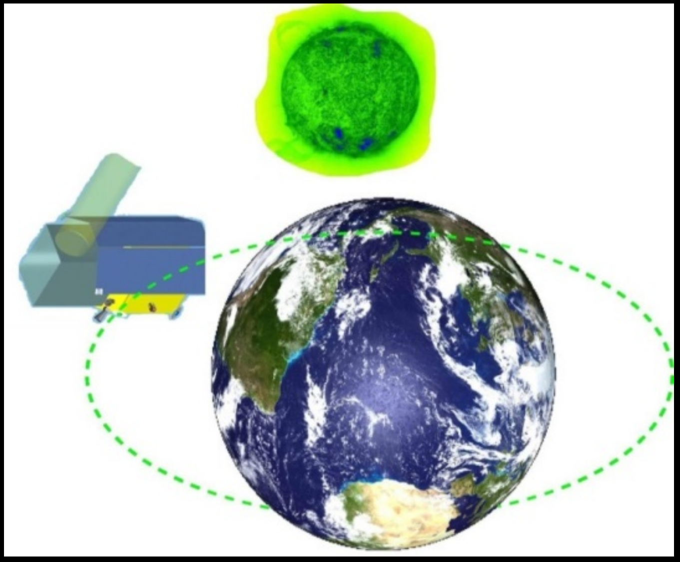

- 105 minute period
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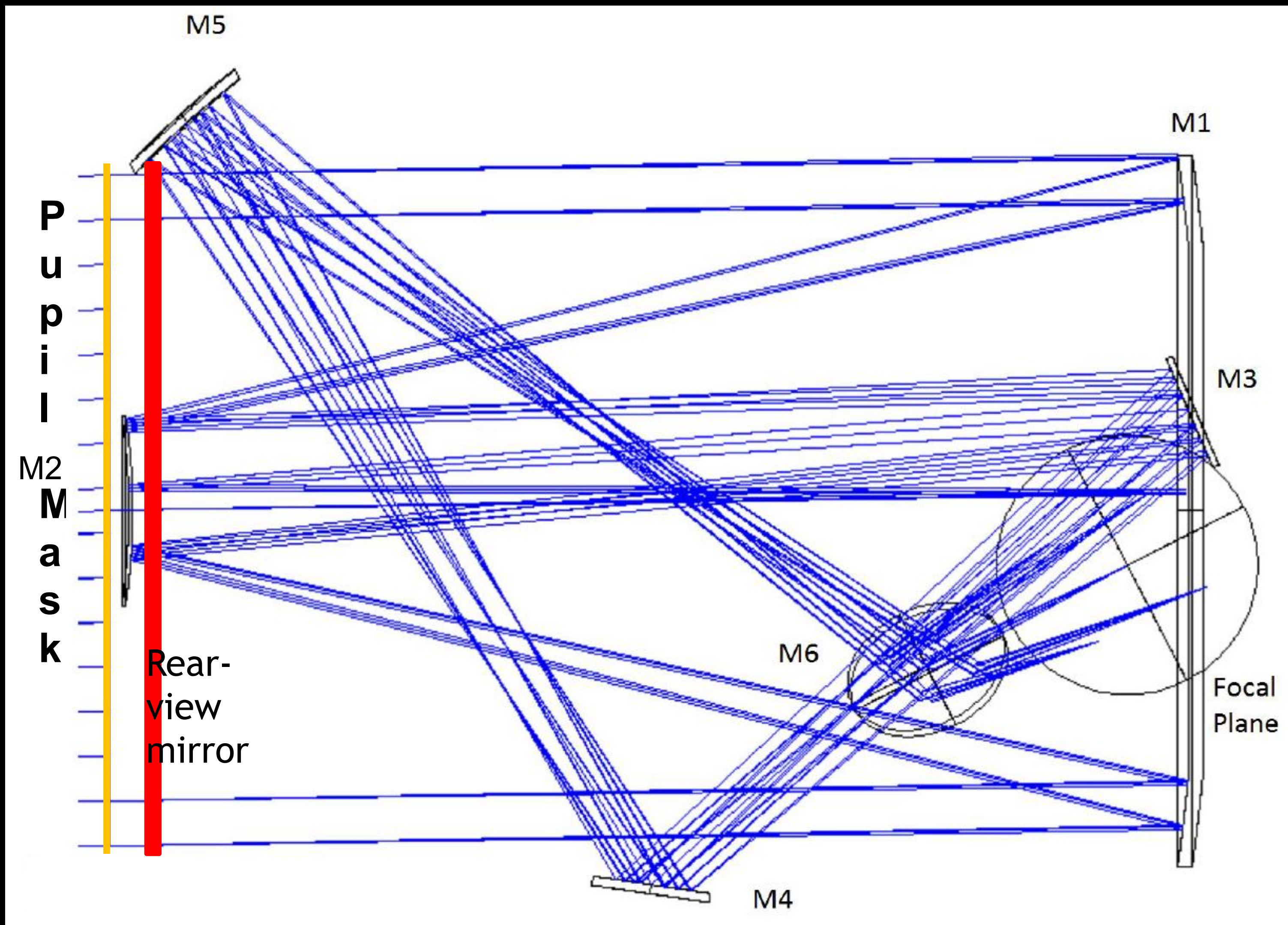
100% observing time

Stable energy supply + *thermal environment*

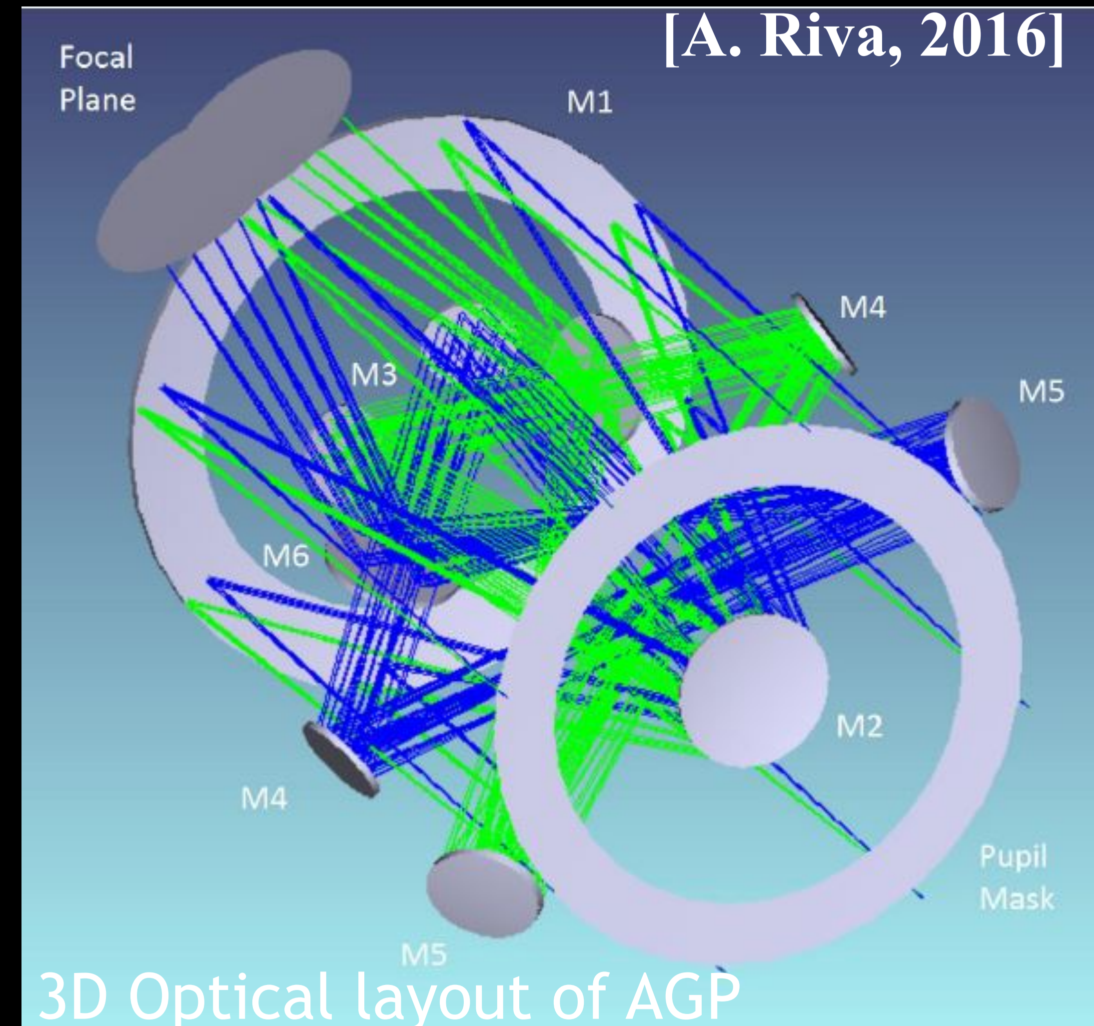
System rationale: preserve satellite orientation vs. Earth (nearly stable thermal environment, filtered by service module)

Science rationale: average instrument response among channels (strenghten calibration) by field rotation

AGP Instrument design

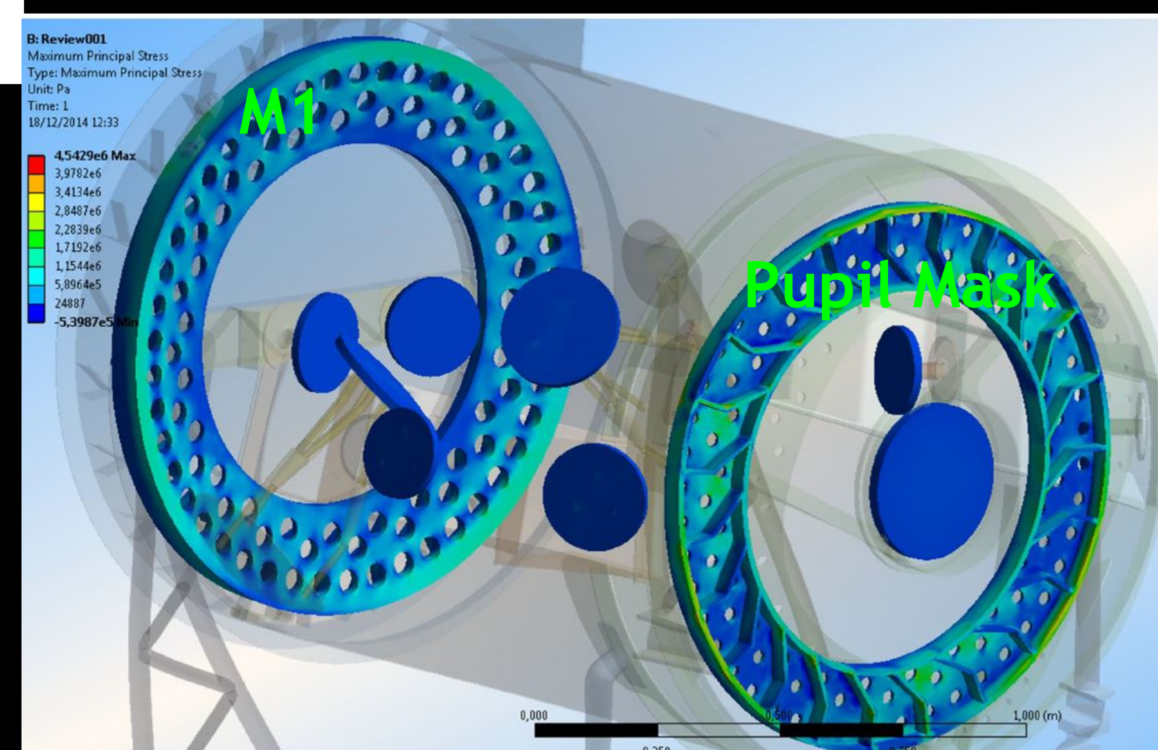


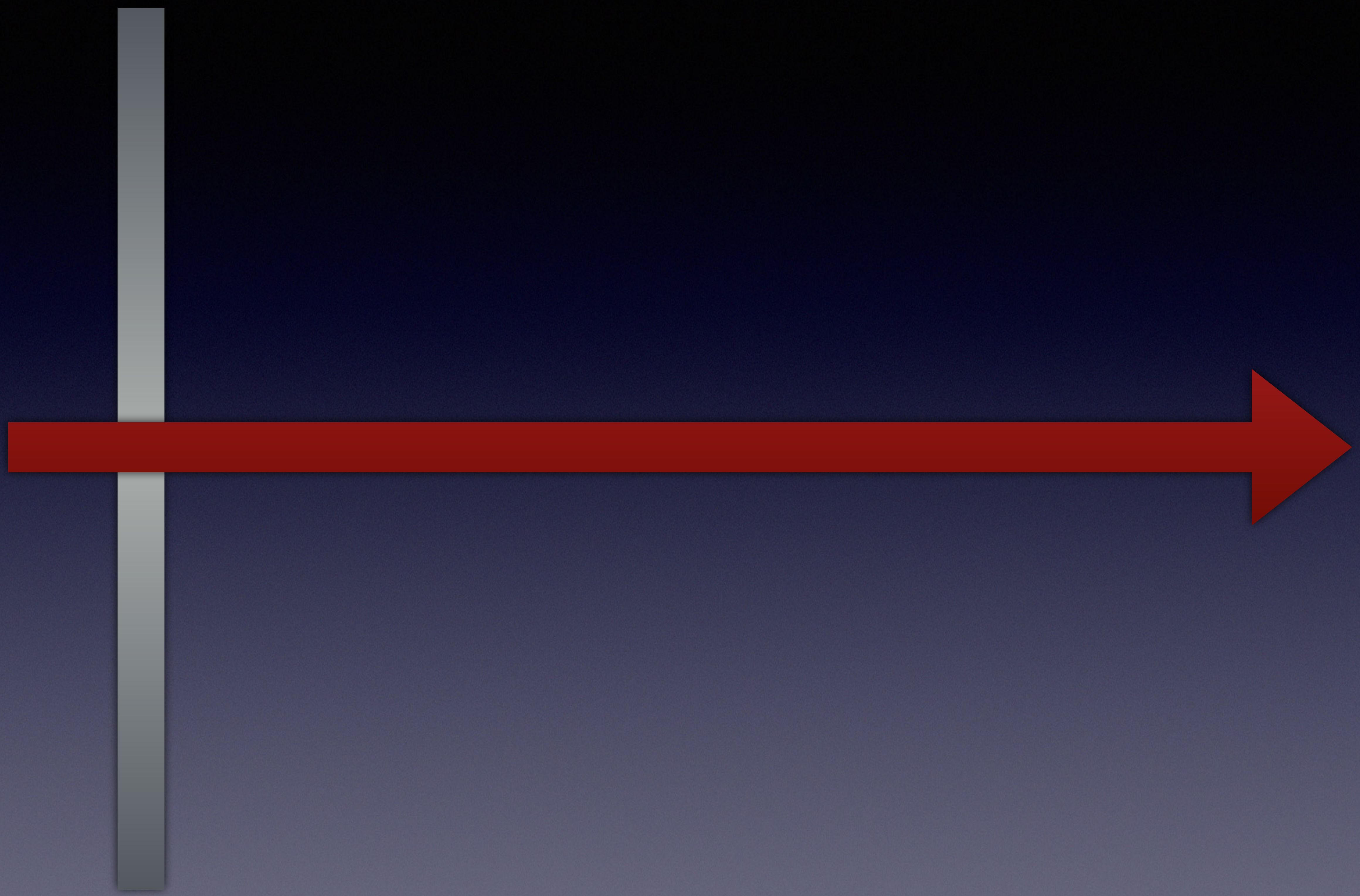
Optical layout of AGP for the single channel

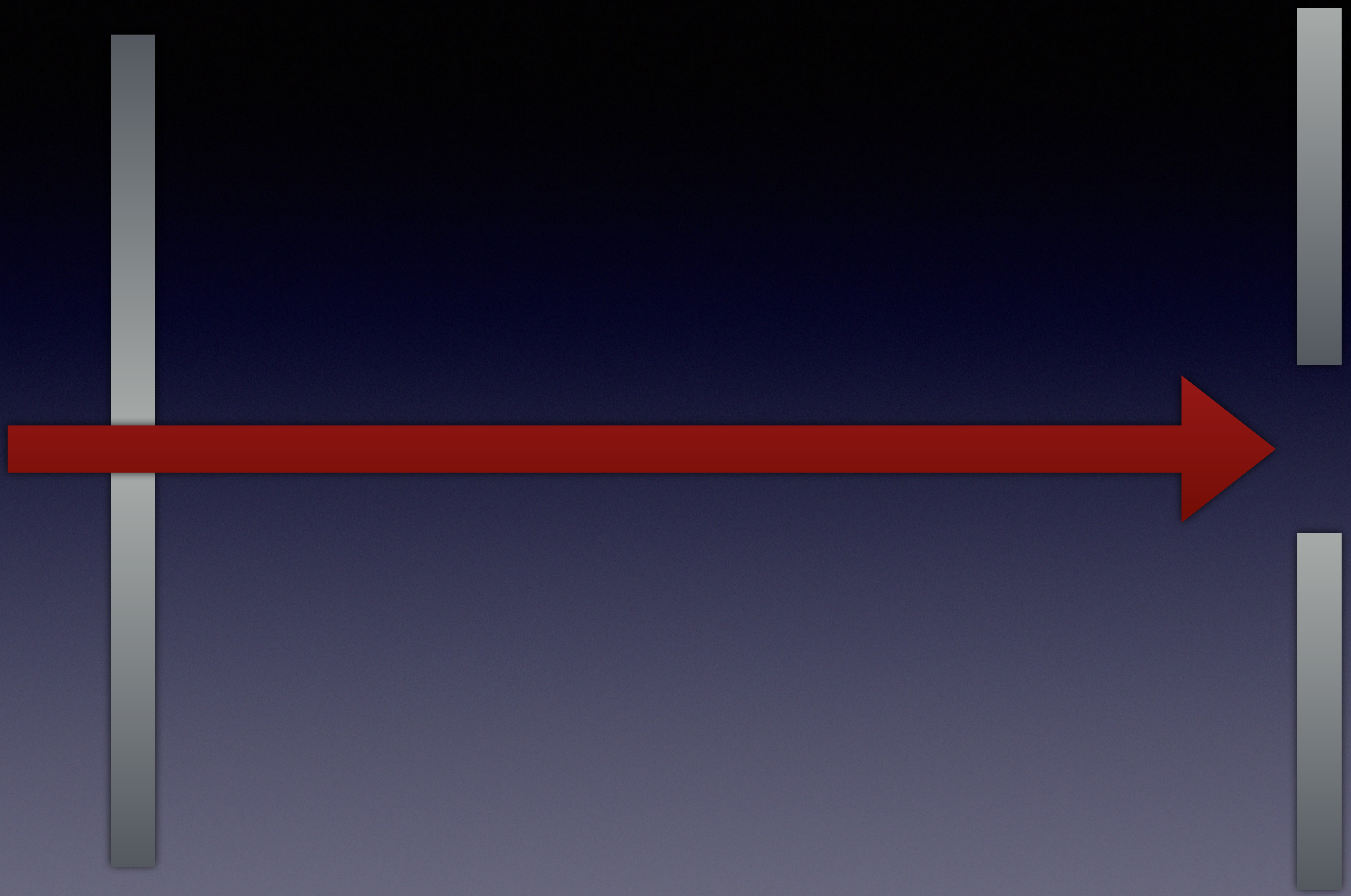


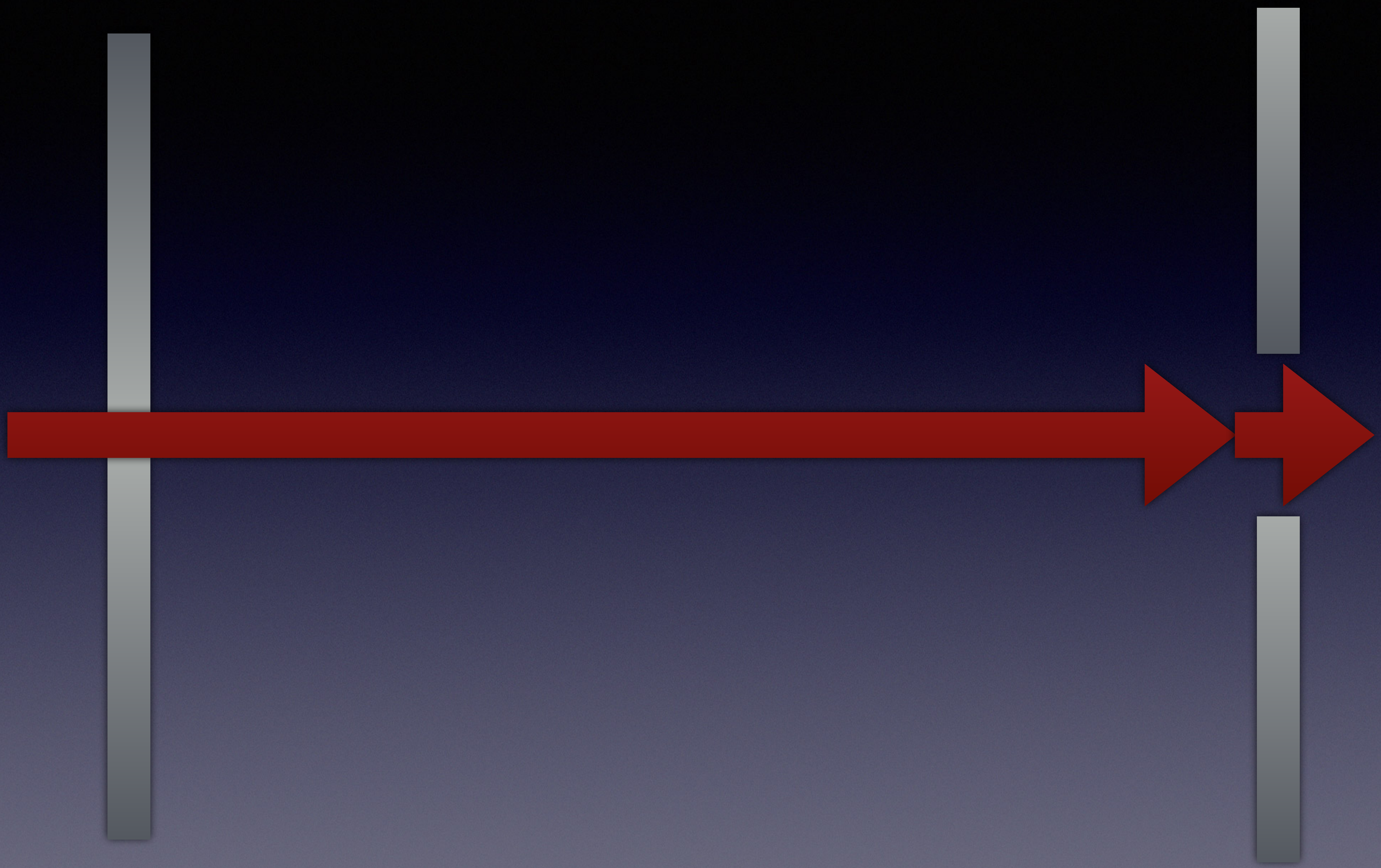
3D Optical layout of AGP

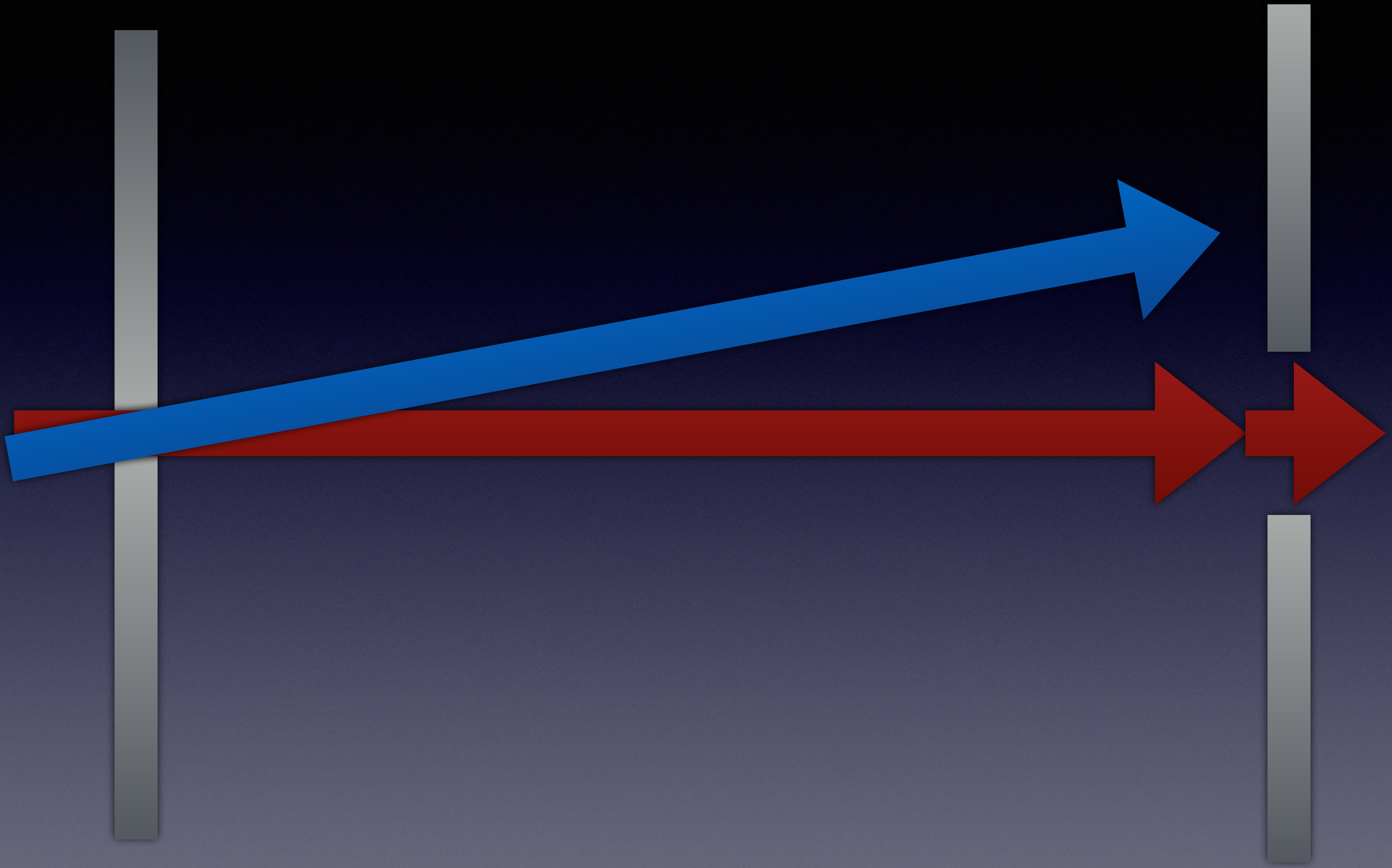
Element	Diameter	Radius	Conic	Distance to next element
Mask	1080.00	flat	0	1750.00
M1	1148.26	-4367.56181	-0.99265207	-1730.00
M2	309.08	-1045.77804	-1.65031622	1760.00
M3	200.00	flat	0	-1000.00
M4	180.00	flat	0	1650.00
M5	220.00	-1340.96793	-0.71077101	-1280.00
M6	240.00	flat	0	860.00

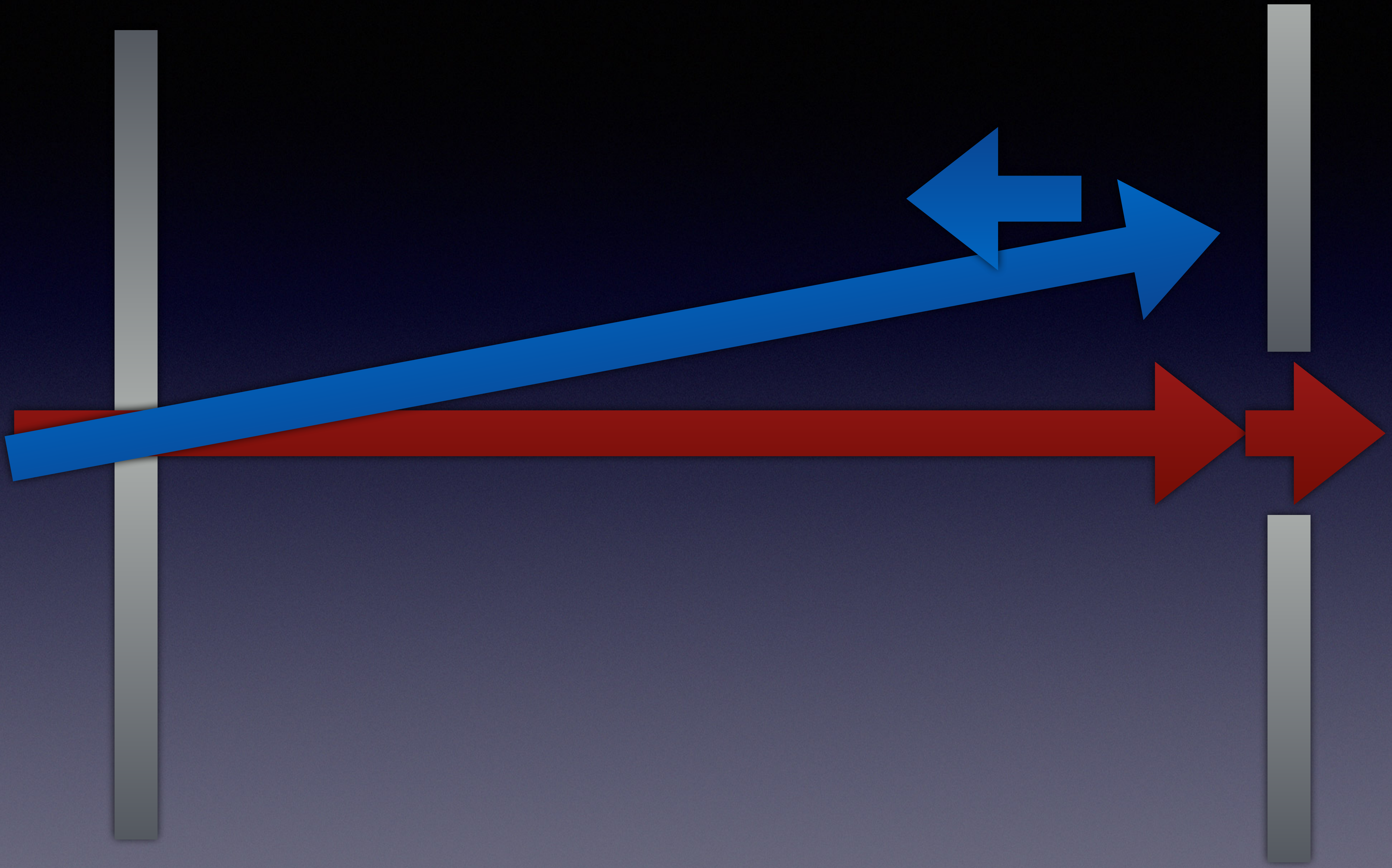


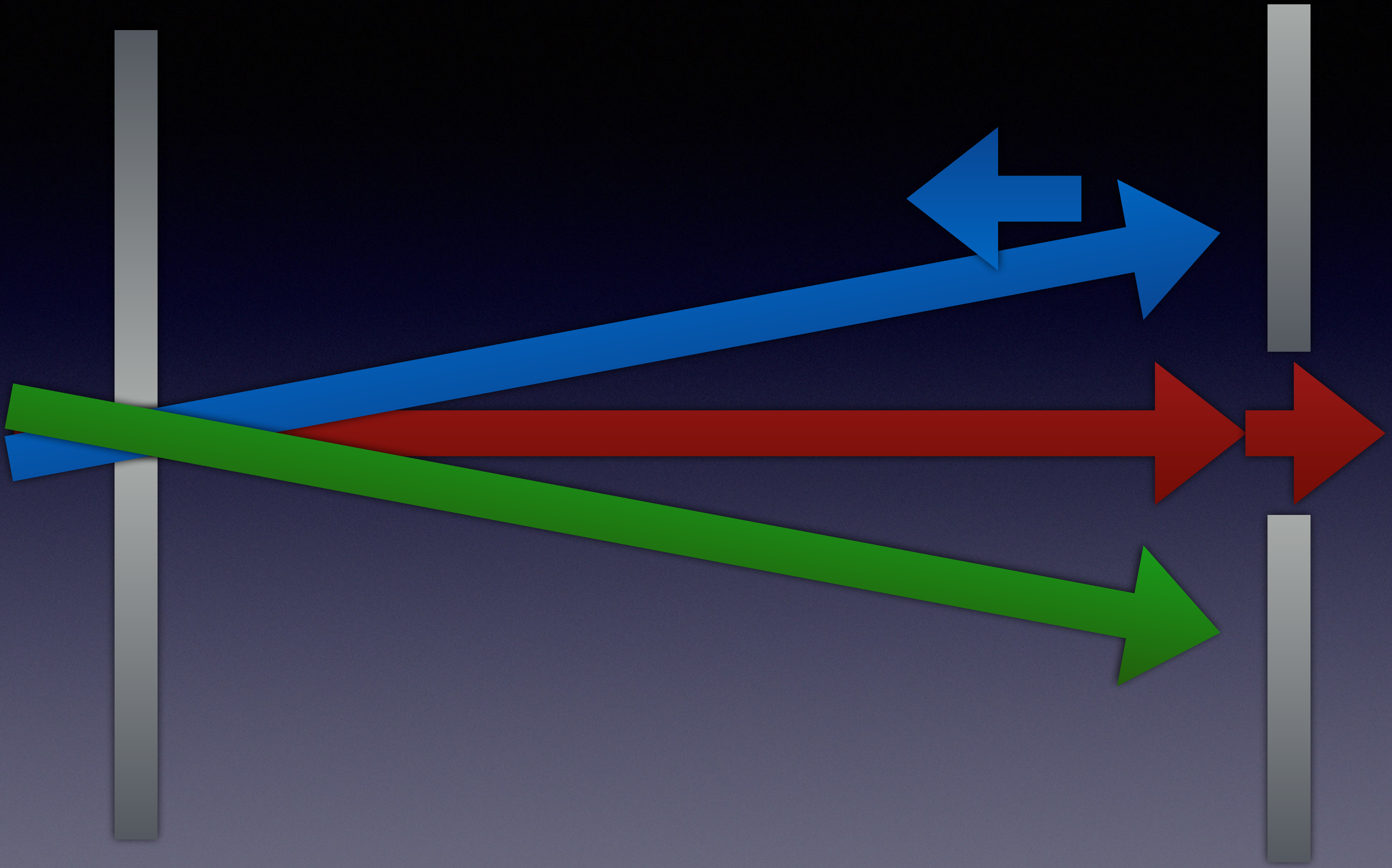


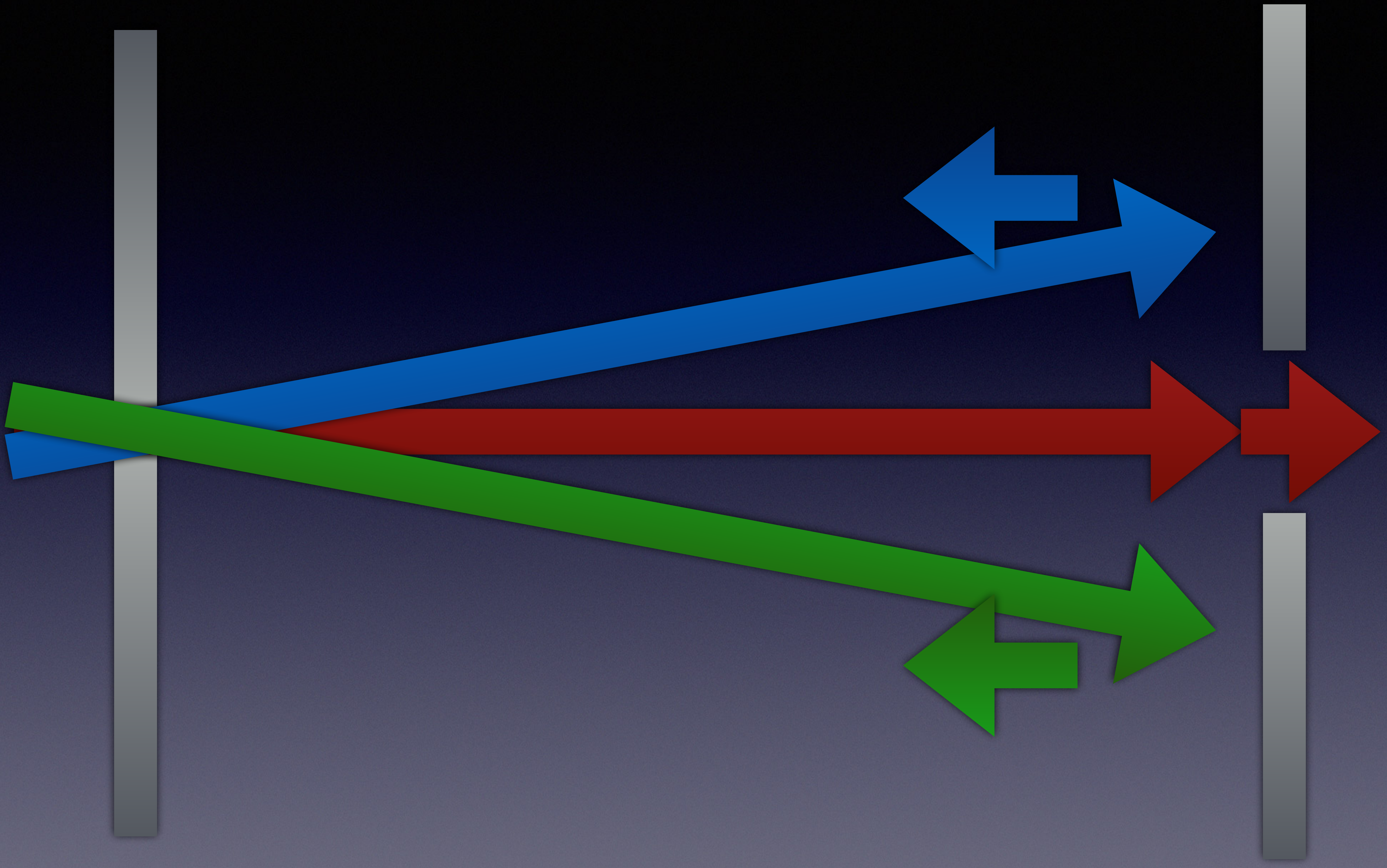


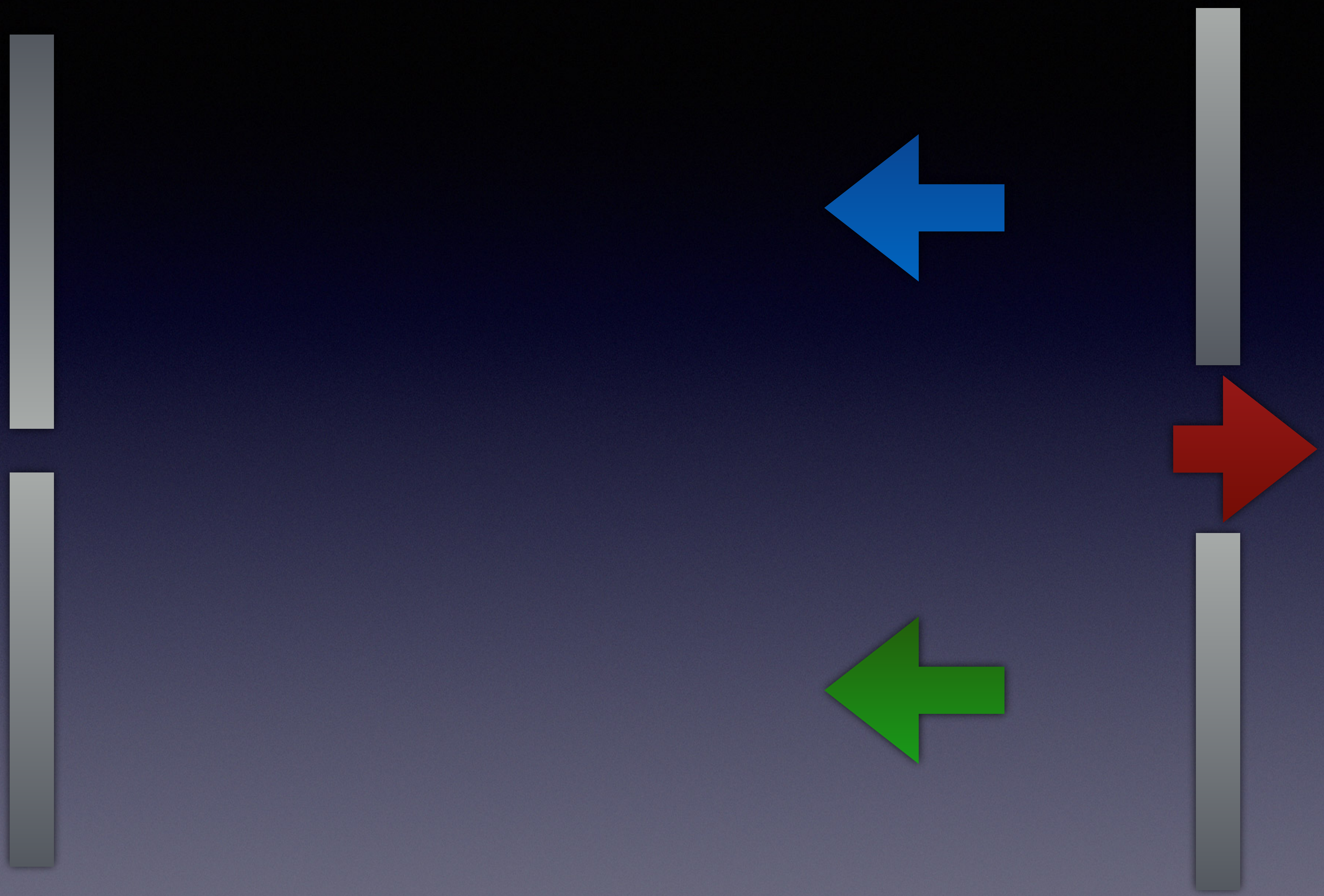


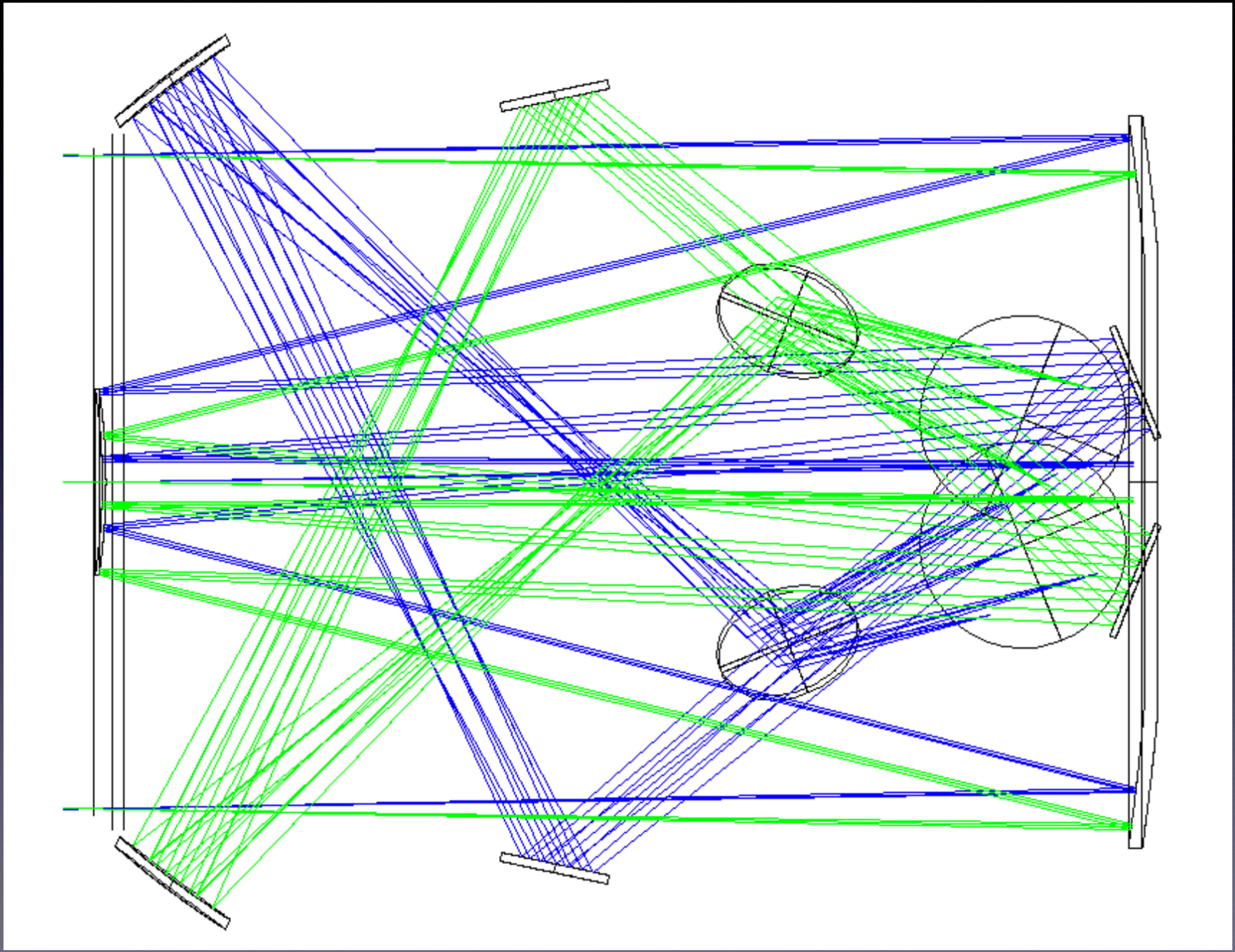


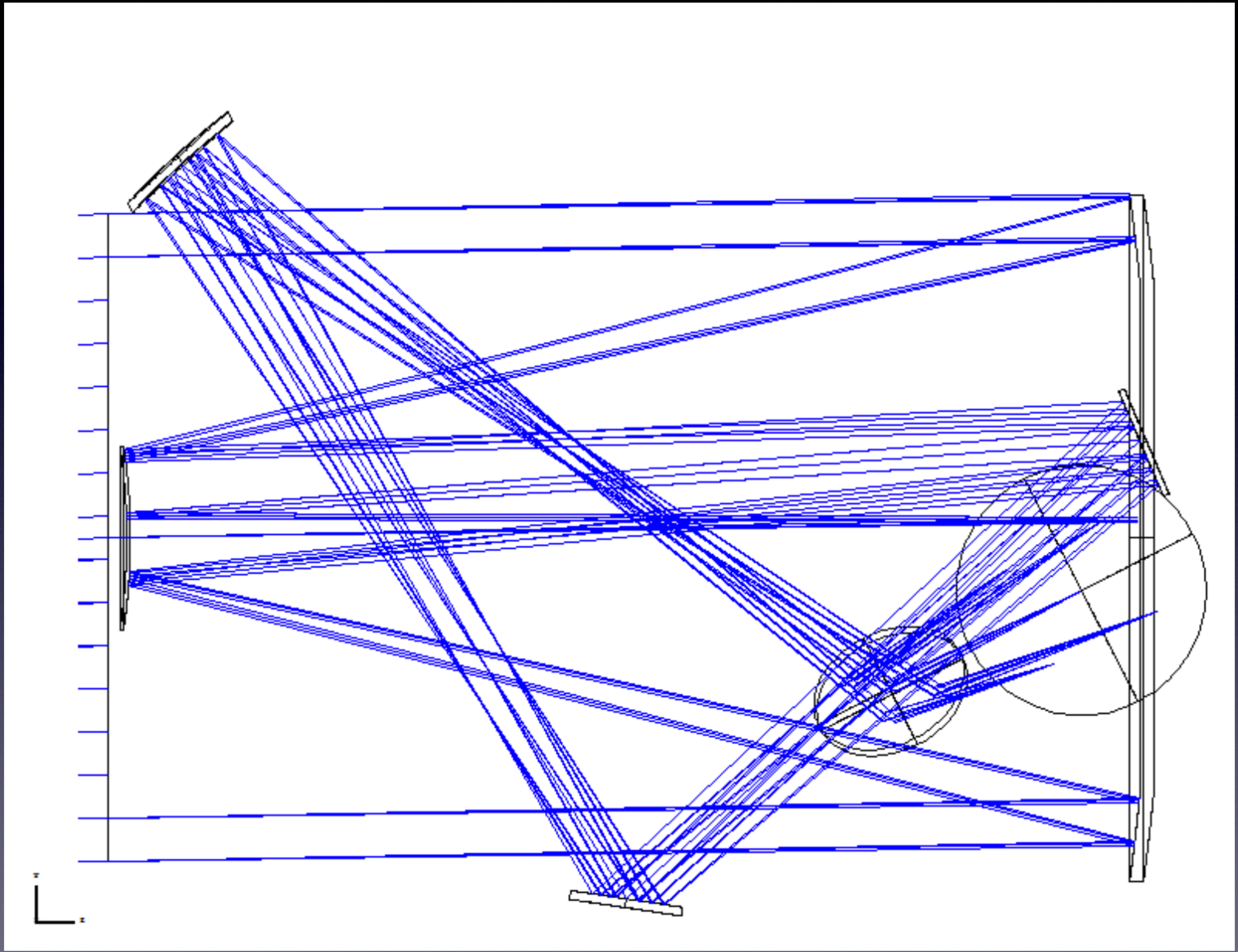




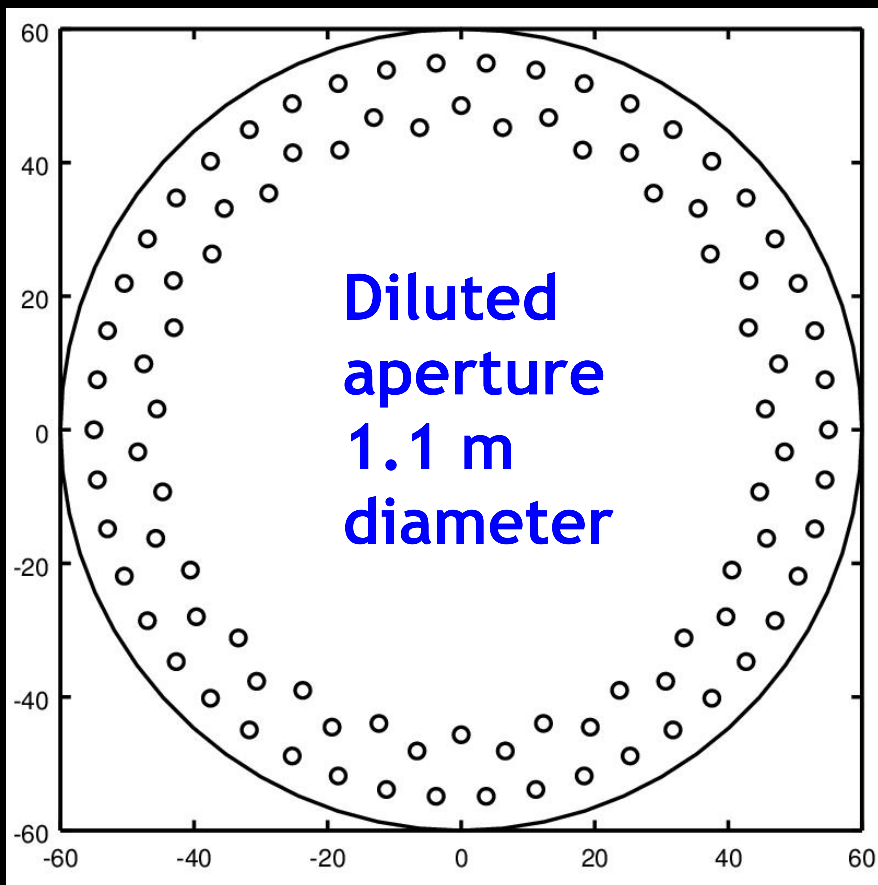




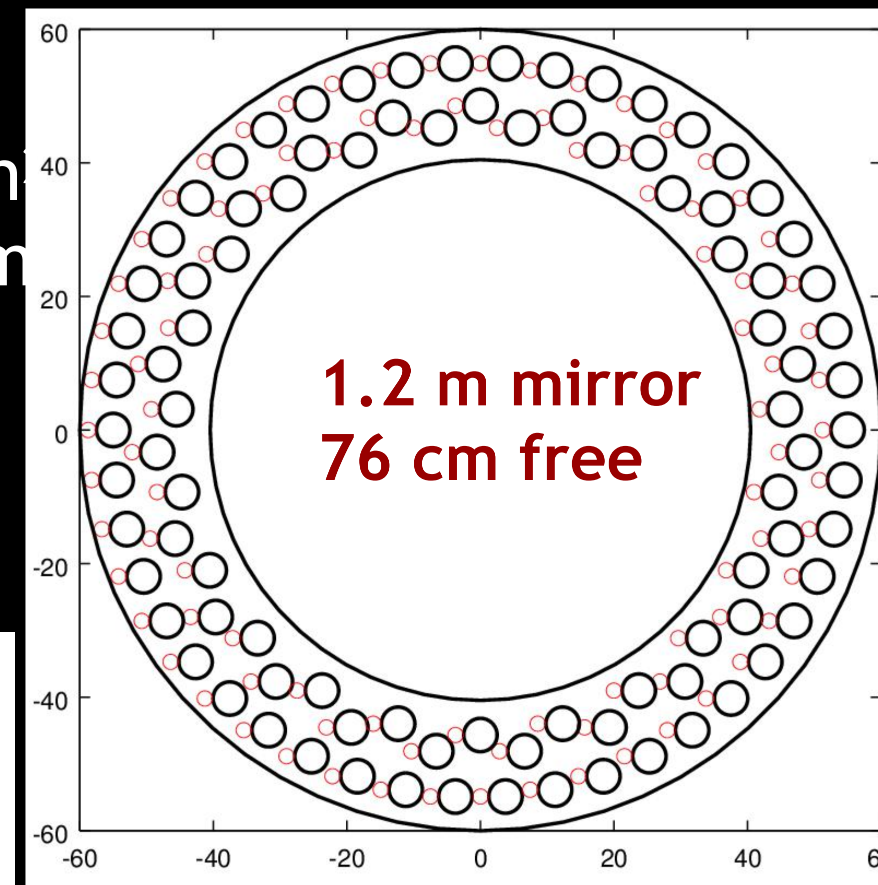




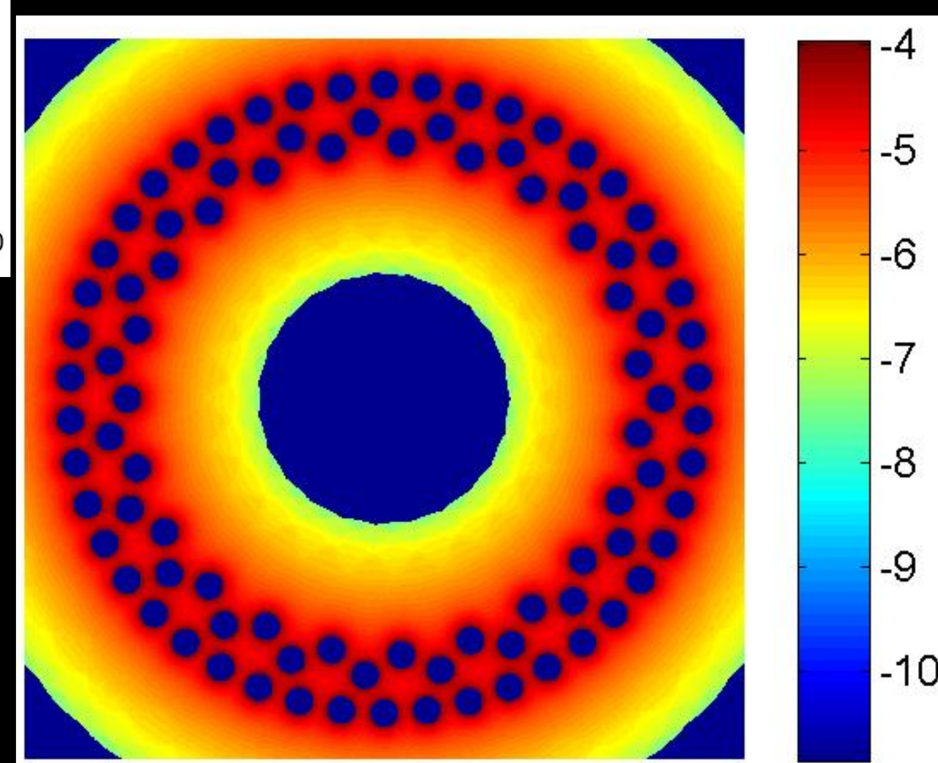
Coronagraphic system – multiple inverted occulter



Collecting area
Sun direction: 375 cm
Anti-Sun direction: 1500 cm



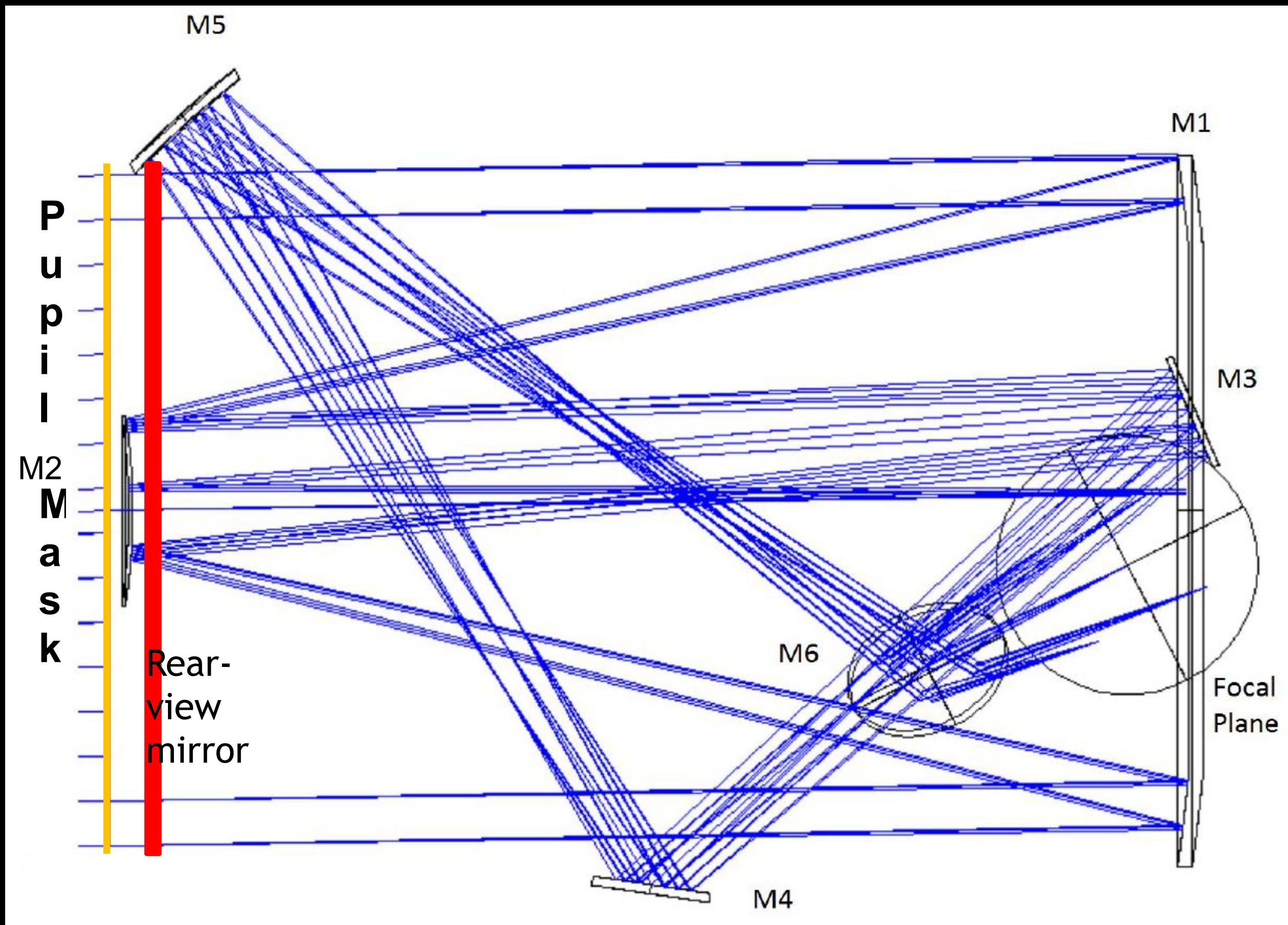
Diffraction on primary mirror [log units]



Background on focal plane: ~10^{-7} B_{Sun}

[F. Landini, 2016]

AGP Instrument design



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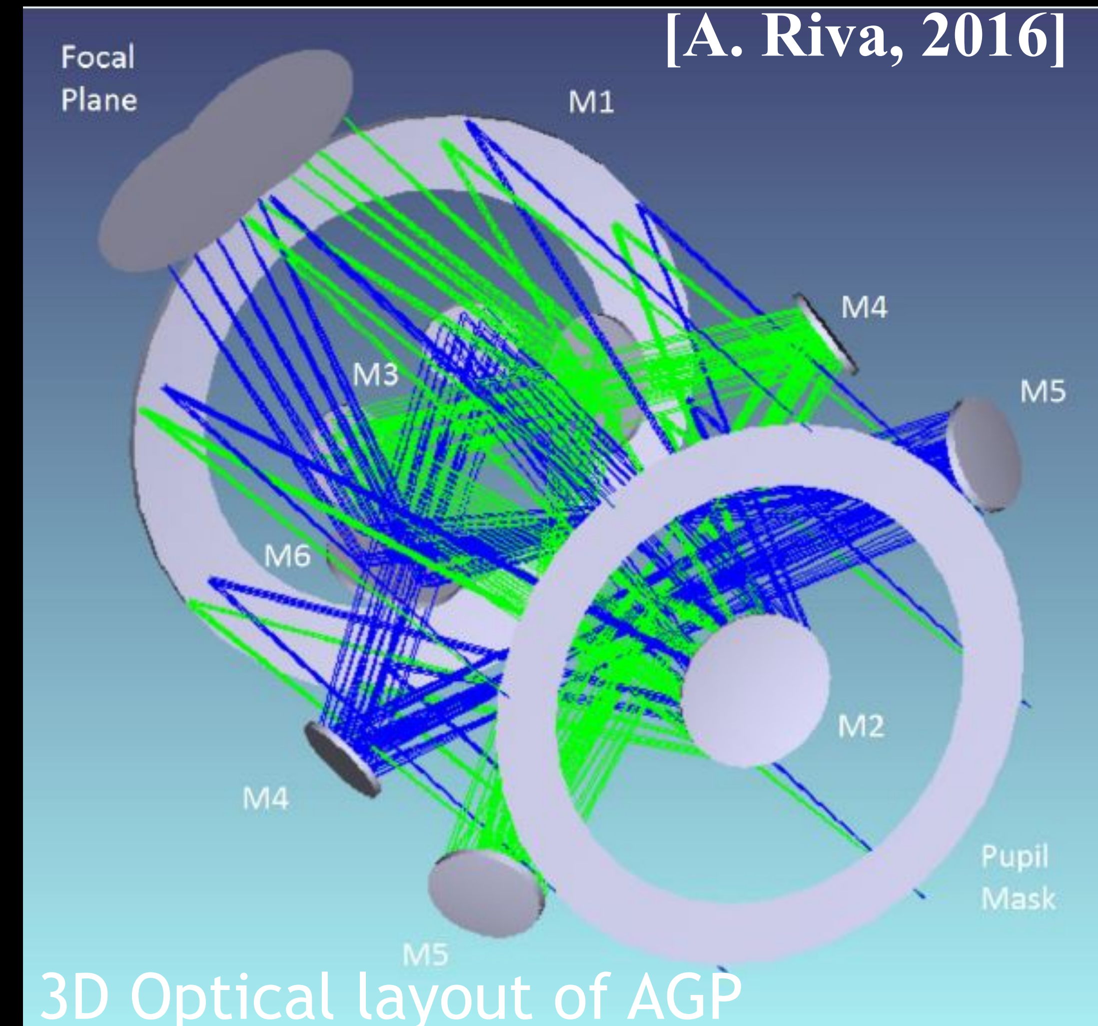

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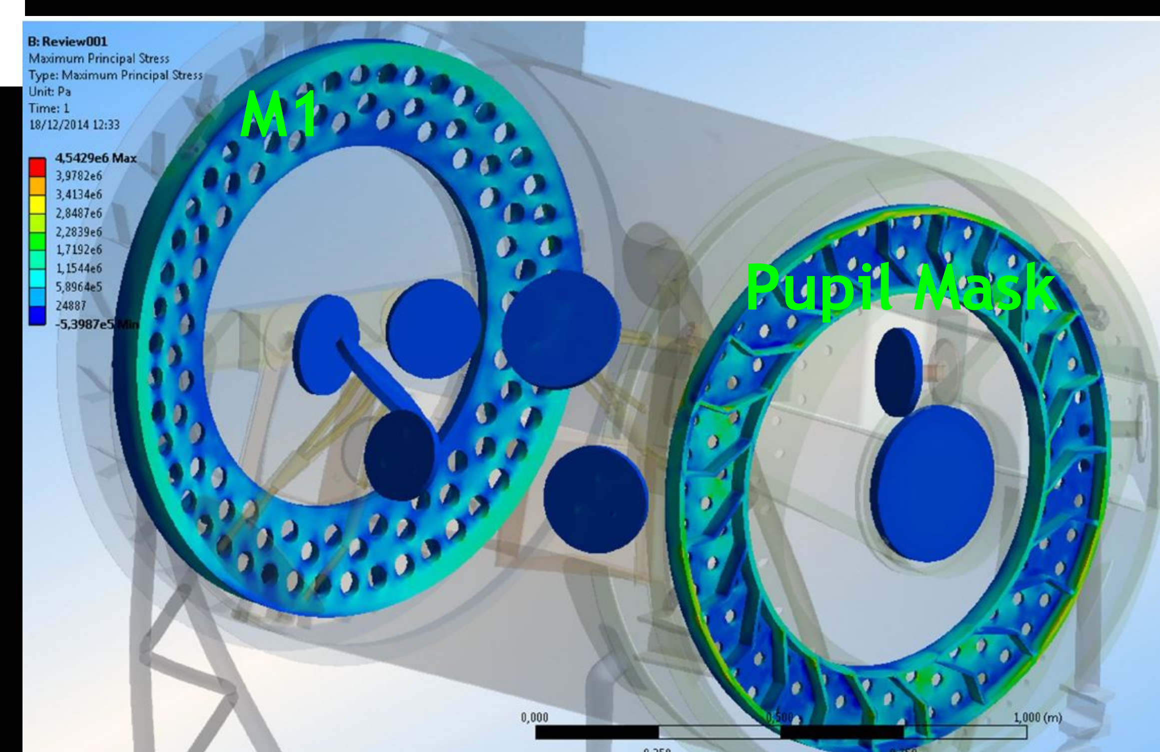
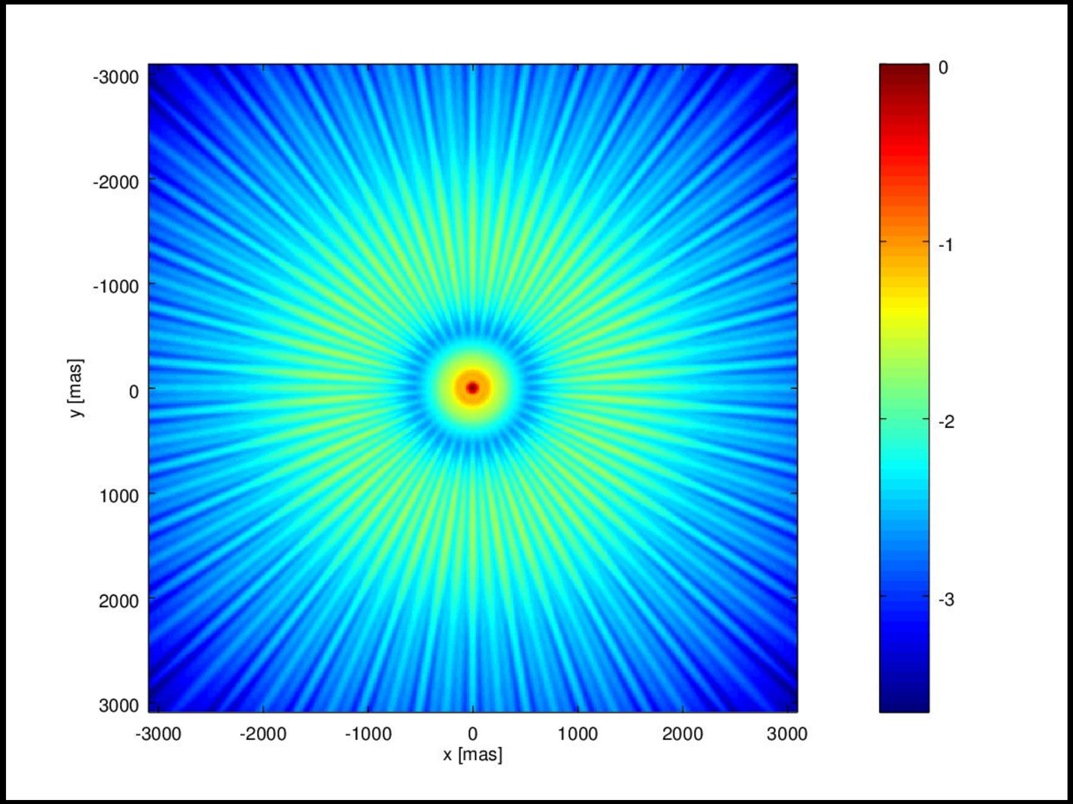
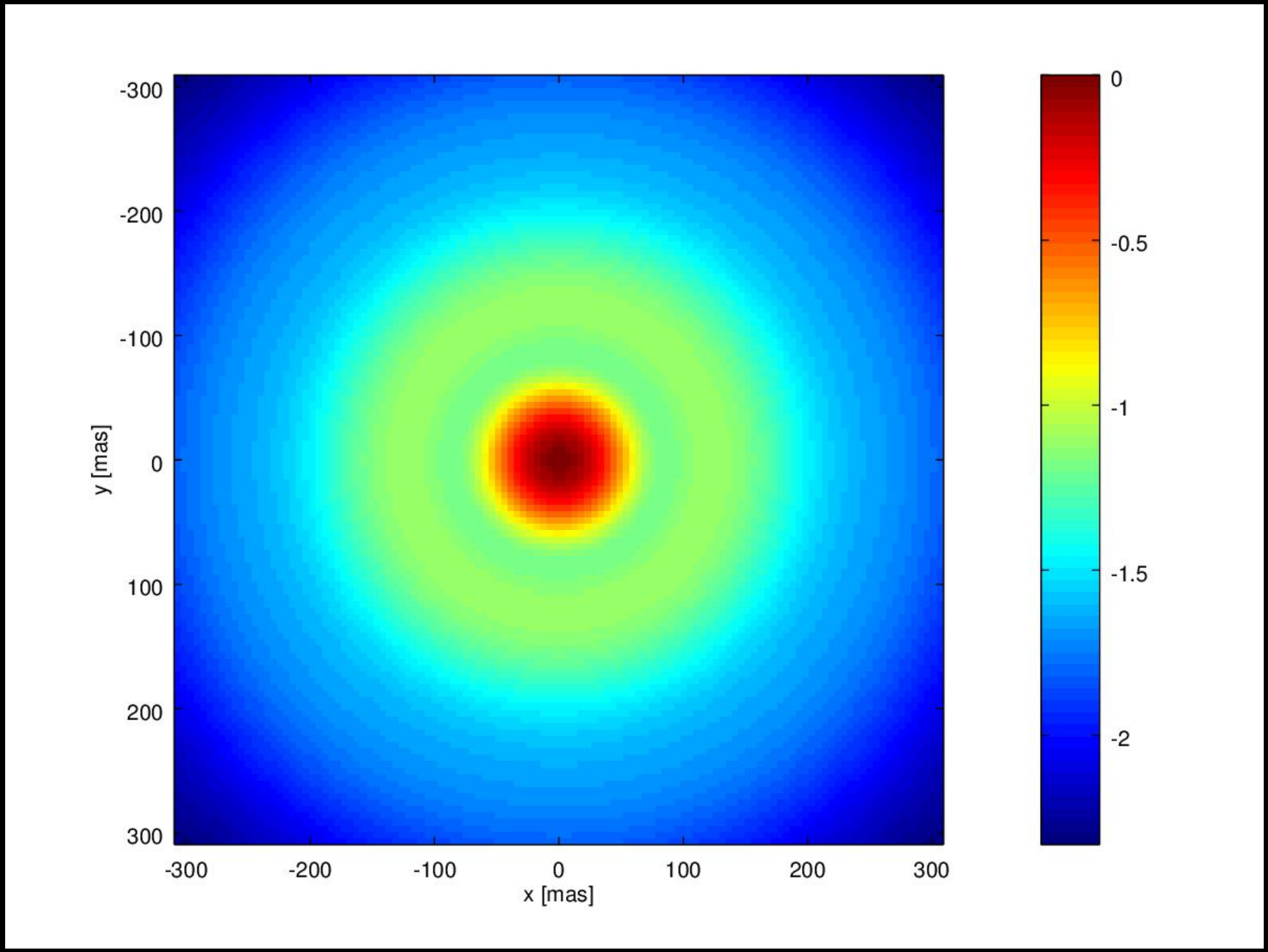


AGP Instrument design

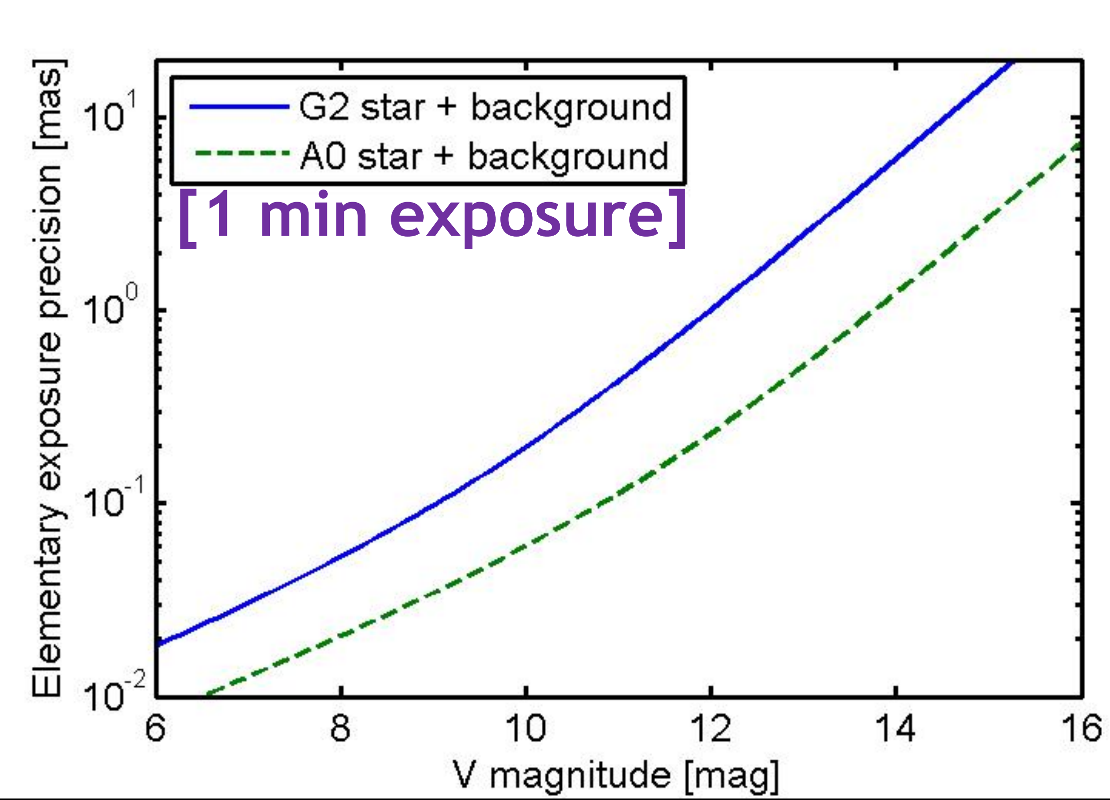
AGP Point Spread Function for a solar-type star





Zoomed in the central region

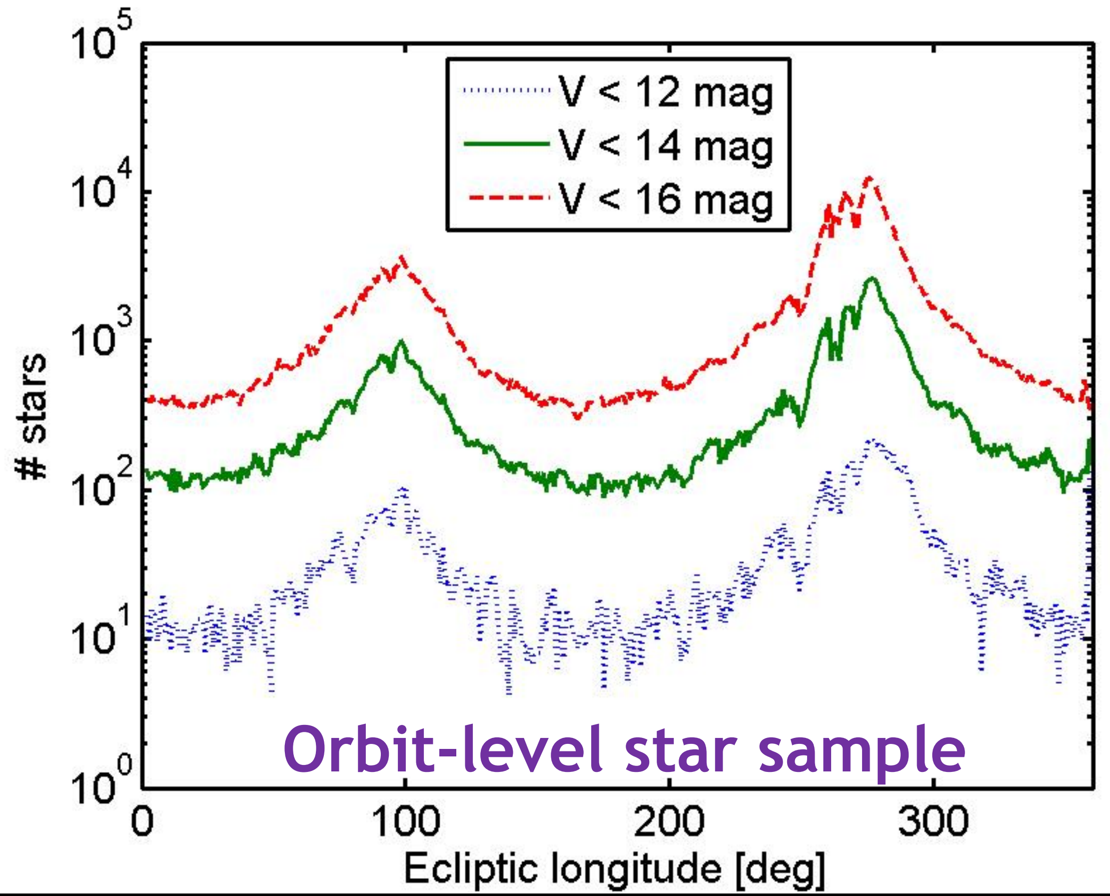
Individual location error and orbit-level performance

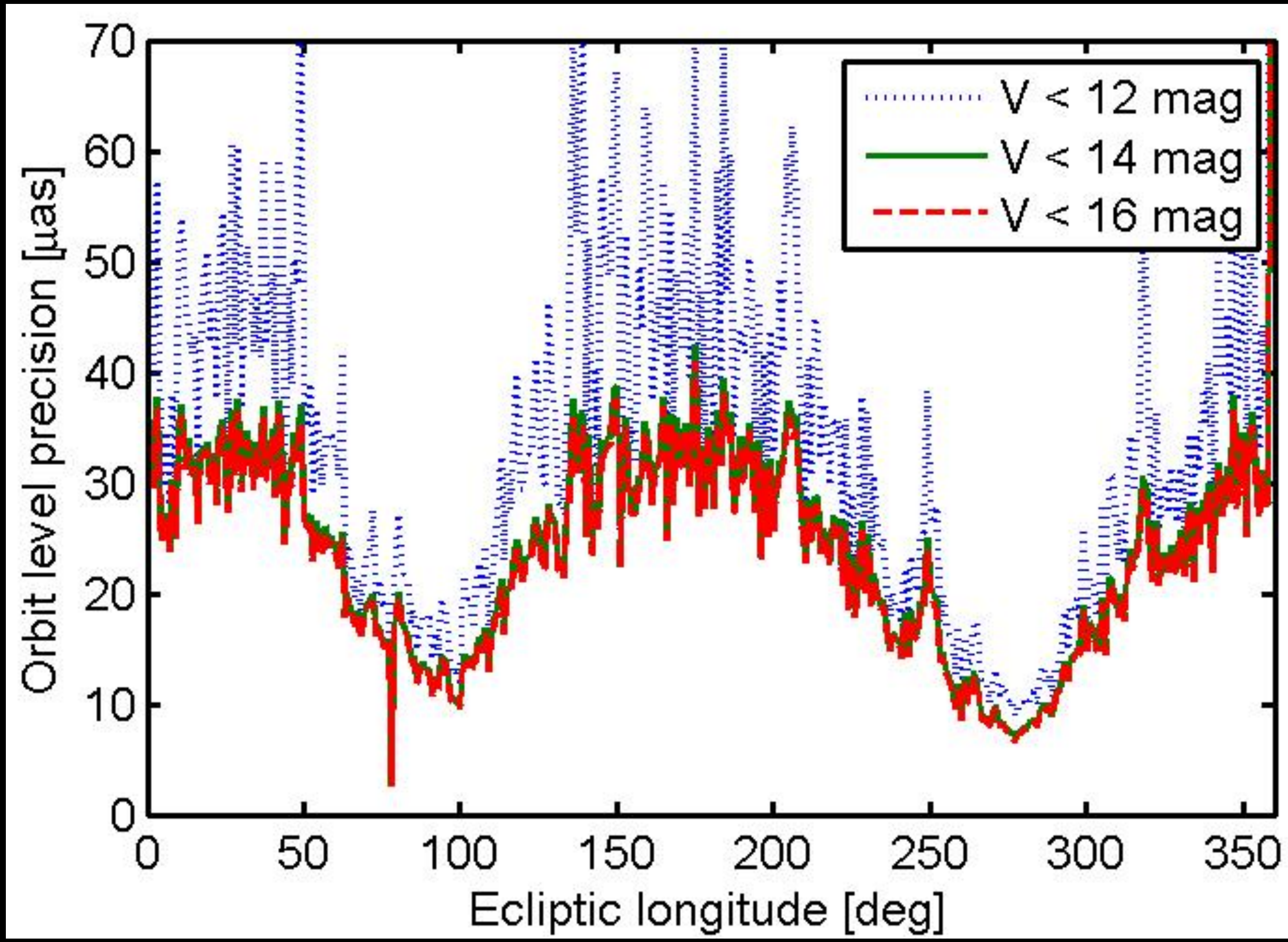


Observation close to Sun → trade-off PSF accuracy / background / deflection

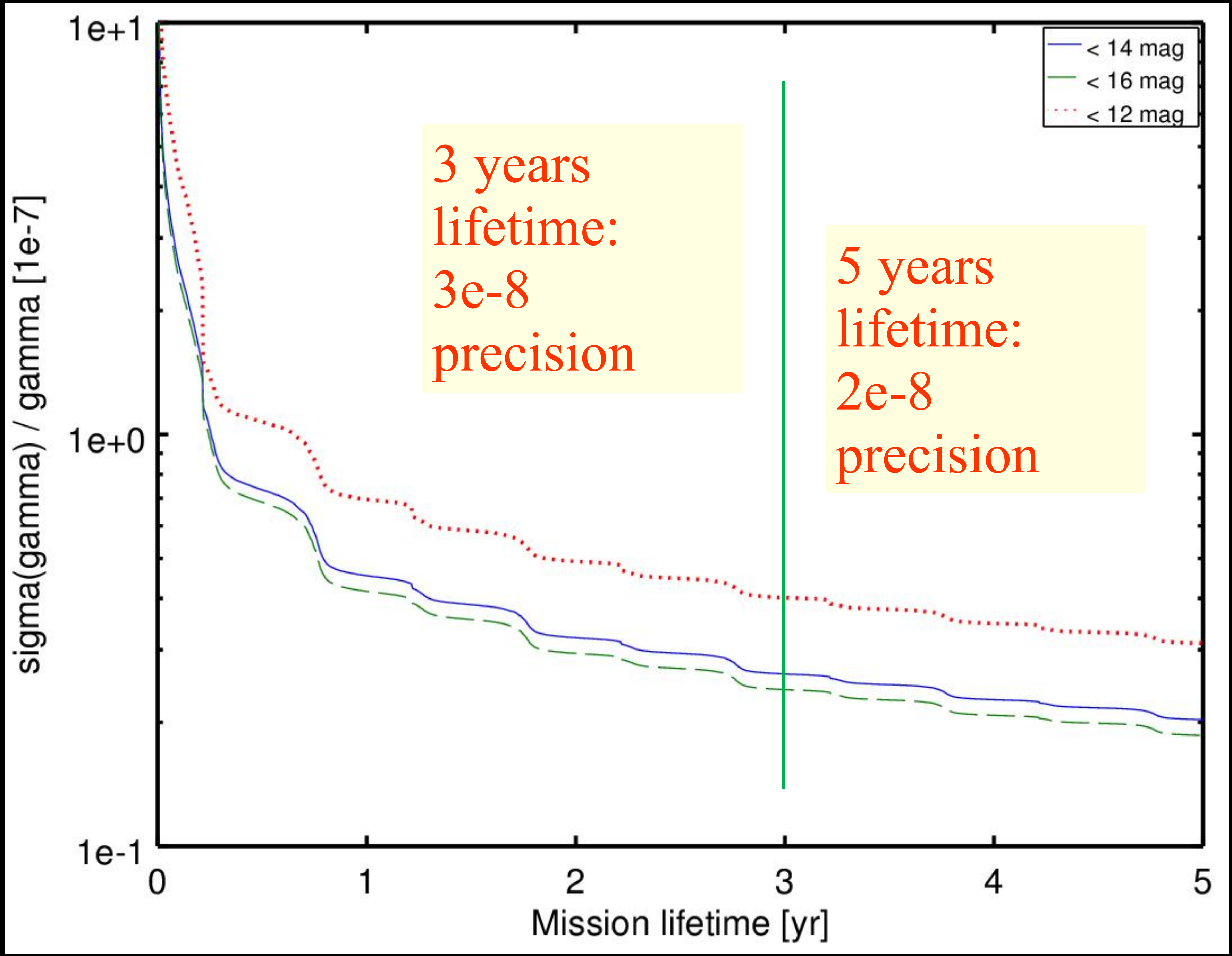
Measurement focused on bright stars V<16

10^3-10^4 stars with cumulated precision ~30 µas / orbit (+metrology/calibration)





Mission performance on light deflection



Deflection measurements averaged over ~5000 orbits/year

Simultaneous estimate of star and planet astrometric parameters

Years of mission	$obs.n. \times 10^{-7}$	$\sigma_\beta / \beta \times 10^6$
1	9.5	5.5
2	19.8	3.9
3	28.4	3.2
4	38.8	2.8
5	47.8	2.5

Tab. 1 – Accuracy for β and total number of observations throughout the mission lifetime.

Performance factors: ~D^2, $FoV^{3/2}$, $t^{1/2}$

…but performance on orbits scales as time^{3/2}: factor >2

Final message

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