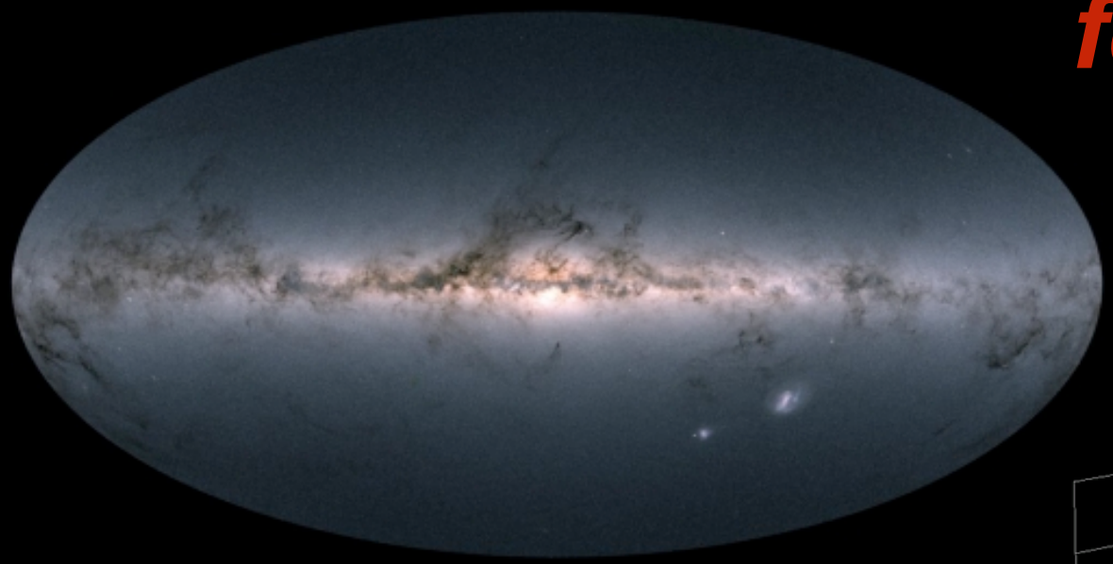
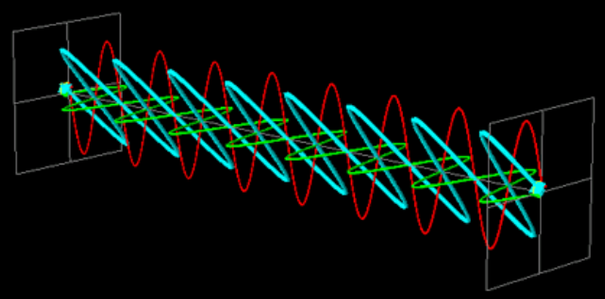
Alain Smette, Stefano Bagnulo, Frans Snik
Nick Cox, Olivier Hainaut,
Damien Hutsemekers, Antonio Mario Magalhaes

VST: the first large survey telescope for optical polarimetry



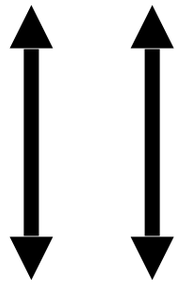


many thanks to
Alberto Cellino, Tolis Christou, Maxime Devogele,
Gavin Ramsay, Paolo Tanga

WHY POLARIMETRY?

Everything that breaks the symmetry in a radiative source or between the source and the observer produces polarisation

Imaging polarimetry



Linear polarisation from scattering

ELECTRON SCATTERING

DUST SCATTERING

SURFACE SCATTERING

POLARIMETRY @ VST

Broadband or narrow band **linear polarimetry** of (scattered) light

+

large field of view

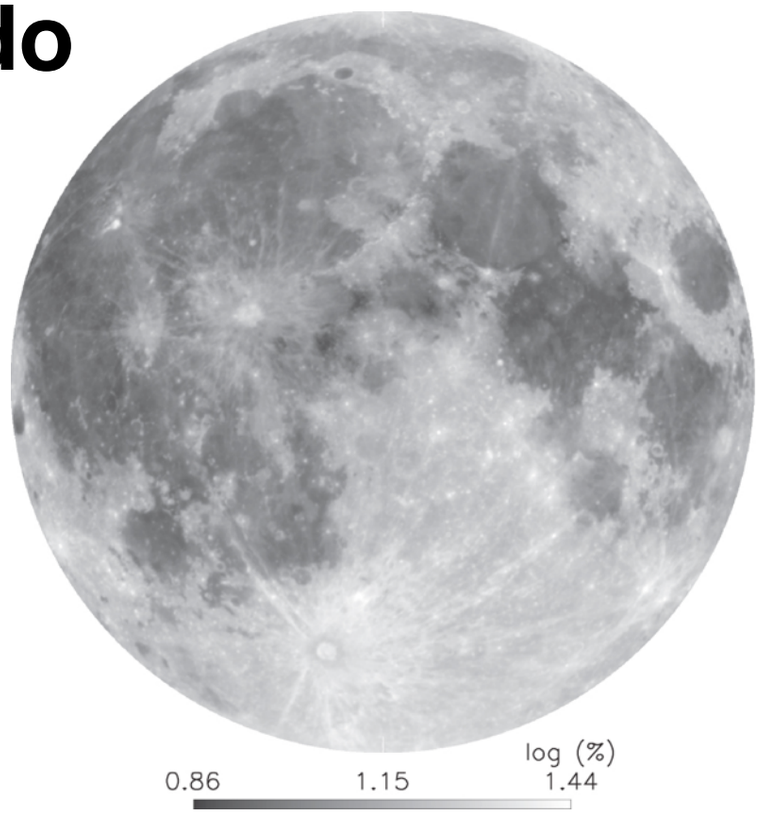
hence

1) Extended sources

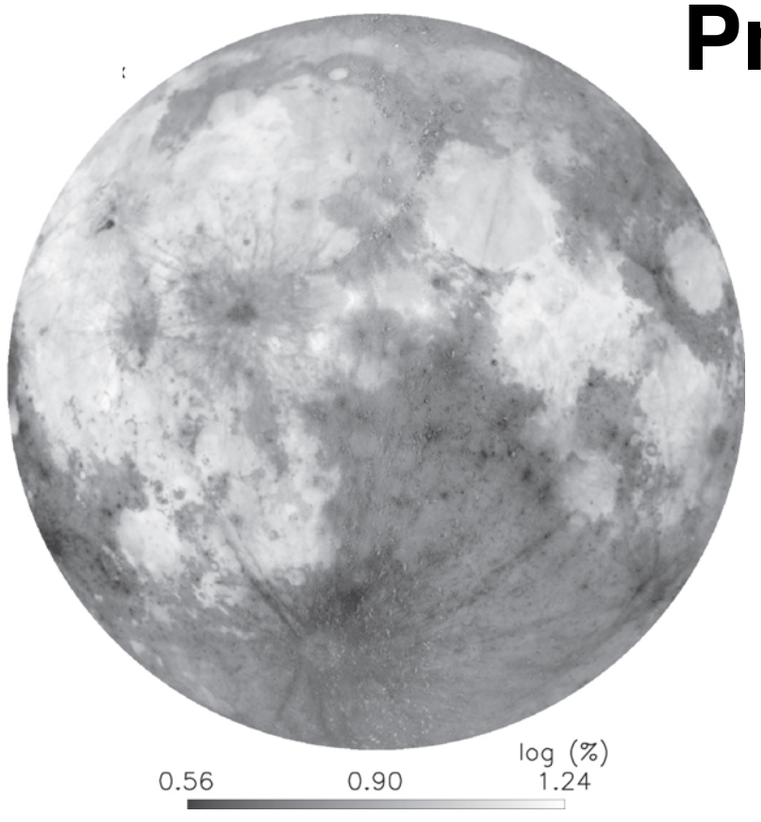
2) Several sources within a 1deg x 1deg FoV

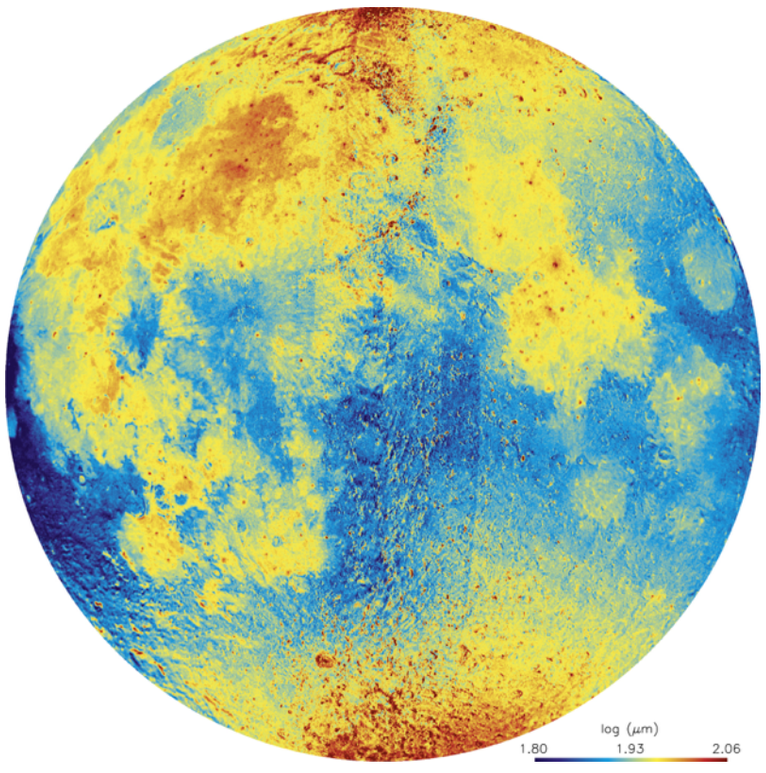
3) Transients with no accurate coordinates

Albedo



Pmax

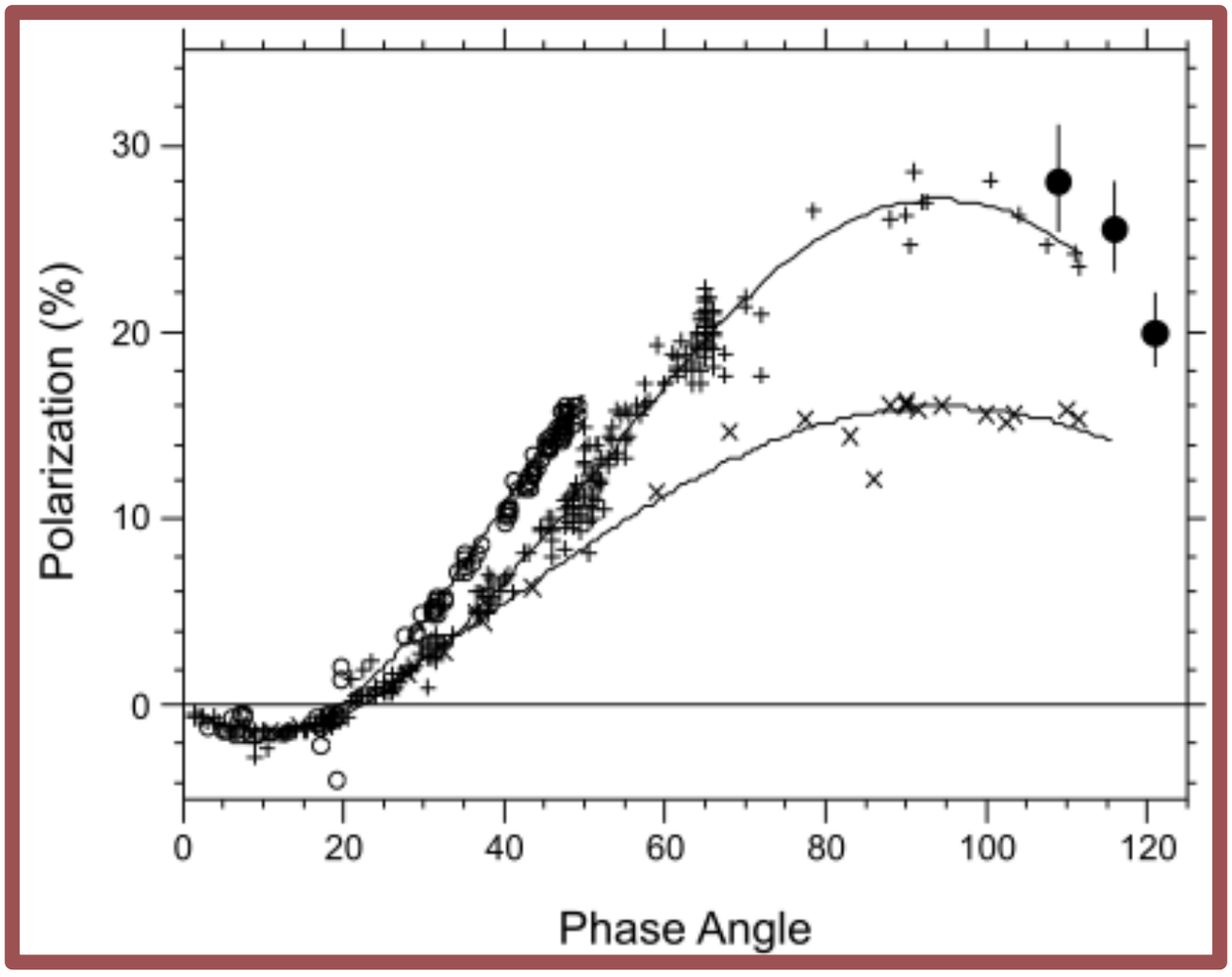




Jeong et al. (2015)

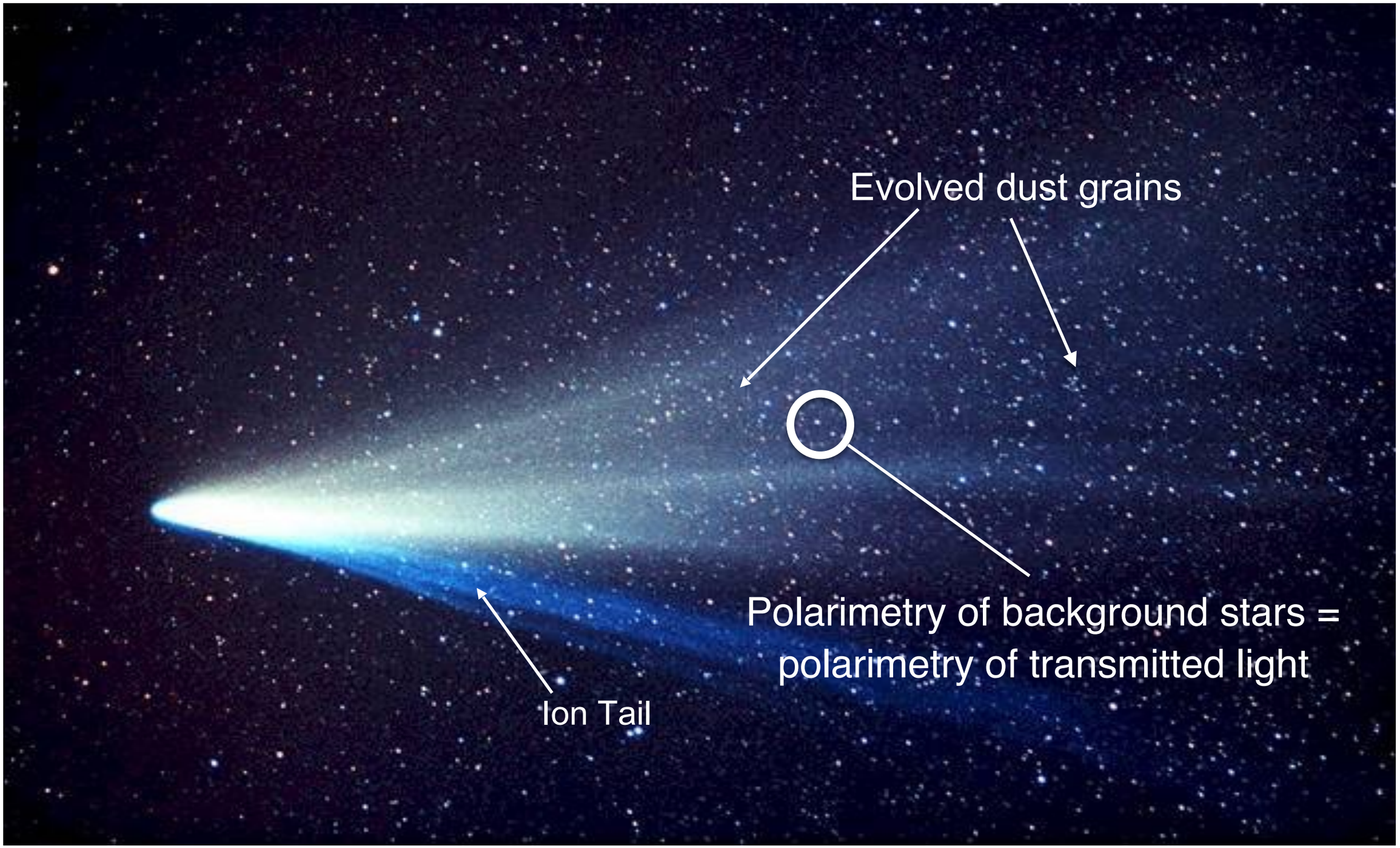
- A median grain size map of the regolith of the Moon has been constructed from albedo and polarimetric maps
- Median grain size appears a monotonically increasing function of selenographic latitude β
- High spatial resolution grain size maps may be used to select sites and activities of future lunar landing missions.

COMETS POLARISATION CURVES



Kiselev et al. (2015)

COMETS: DUST GRAIN EVOLUTION

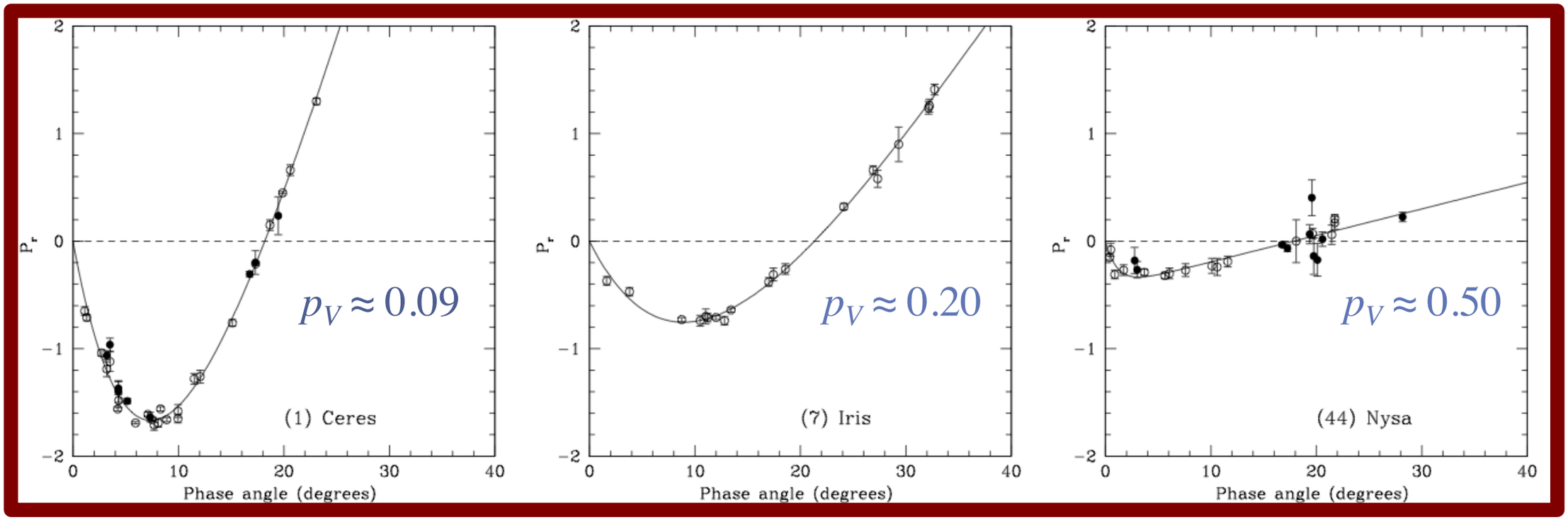


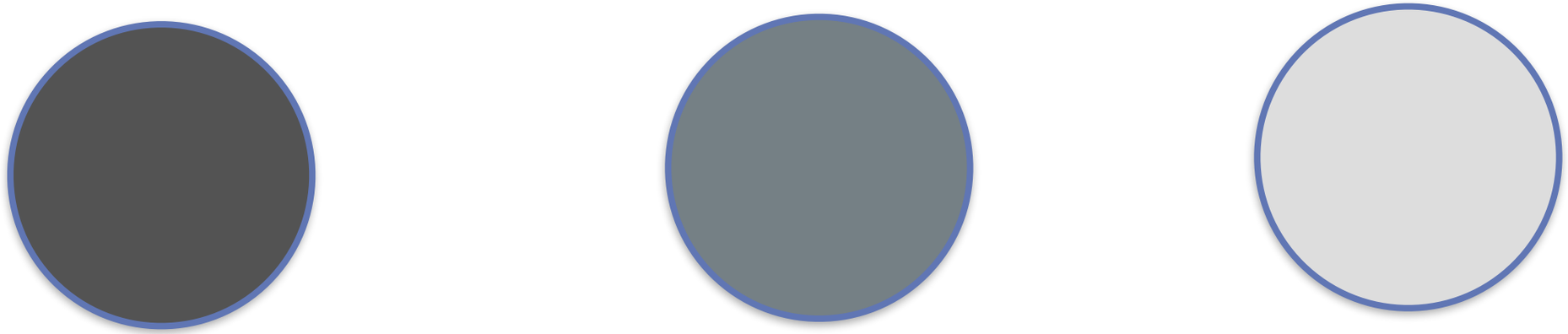
ASTEROIDS POLARIMETIC CURVES:
ALBEDO + SURFACE STRUCTURE & COMPOSITION

C-type (carbonaceous)
low albedo (0.03 – 0.10)
large amount of carbon

S-type (silicaeous)
albedo ~ 0. 1- 0.2
iron- or magnesium silicates

E-type
albedo : 0.25 – 0.60
(enstatite ($MgSiO_3$) achondrite)



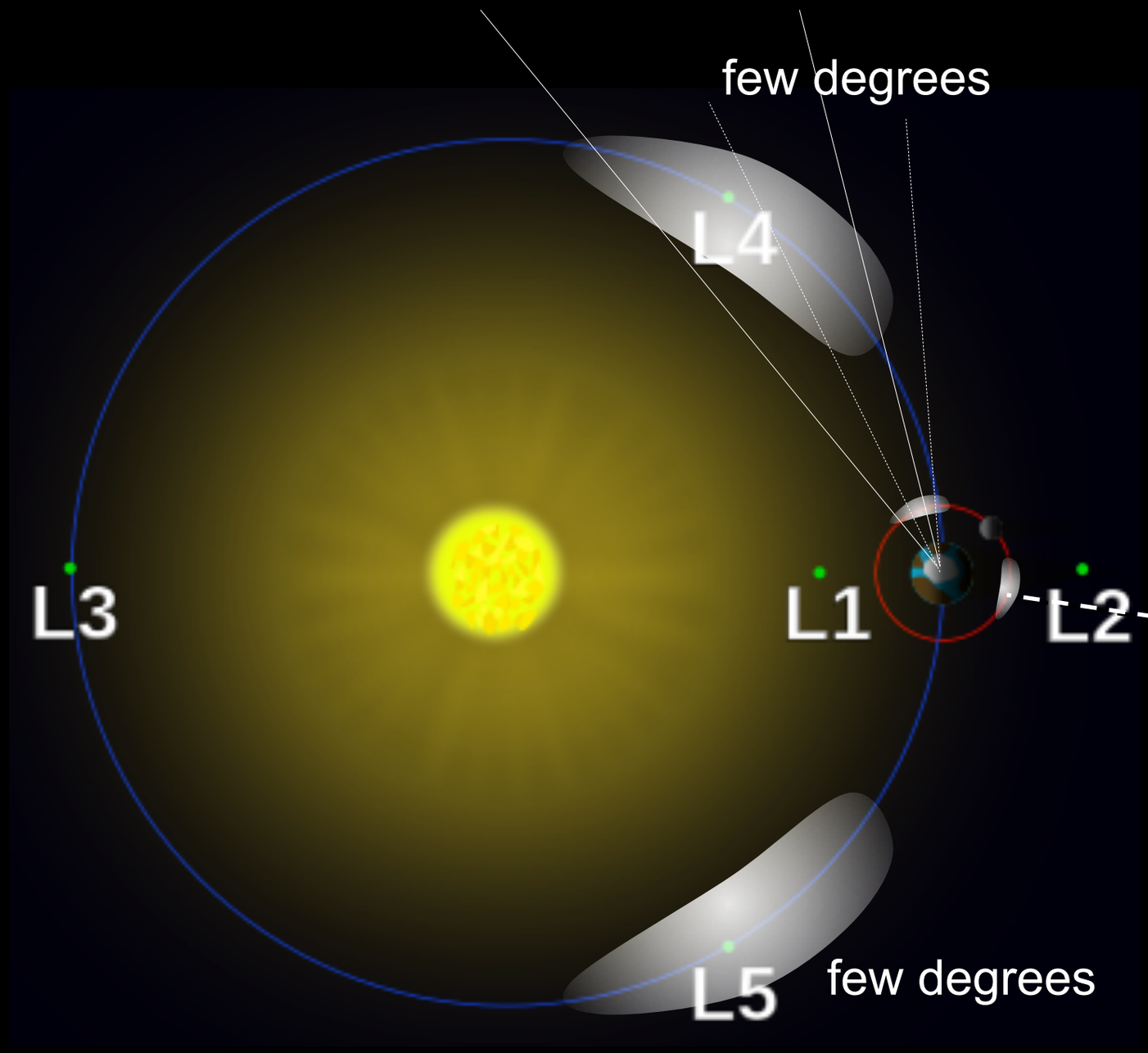


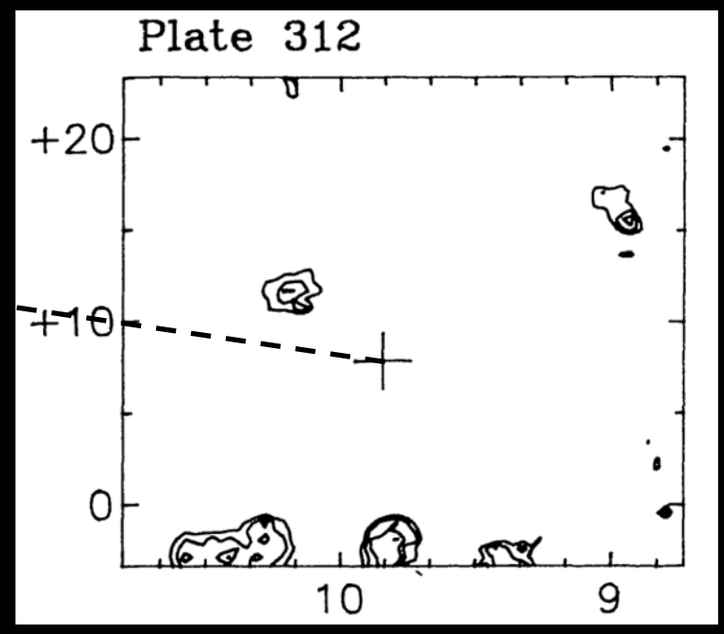
500h survey of a 60ºx1º ecliptic band —>
sampling of the polarimetric curves of 3000 asteroids

- sampling varying from 1 to 6 points
- magnitude limit *V*=21
- *P* uncertainties between 0.1% and 1%

This may lead to a 10x increase in the size of the database of asteroid polarimetric measuremens

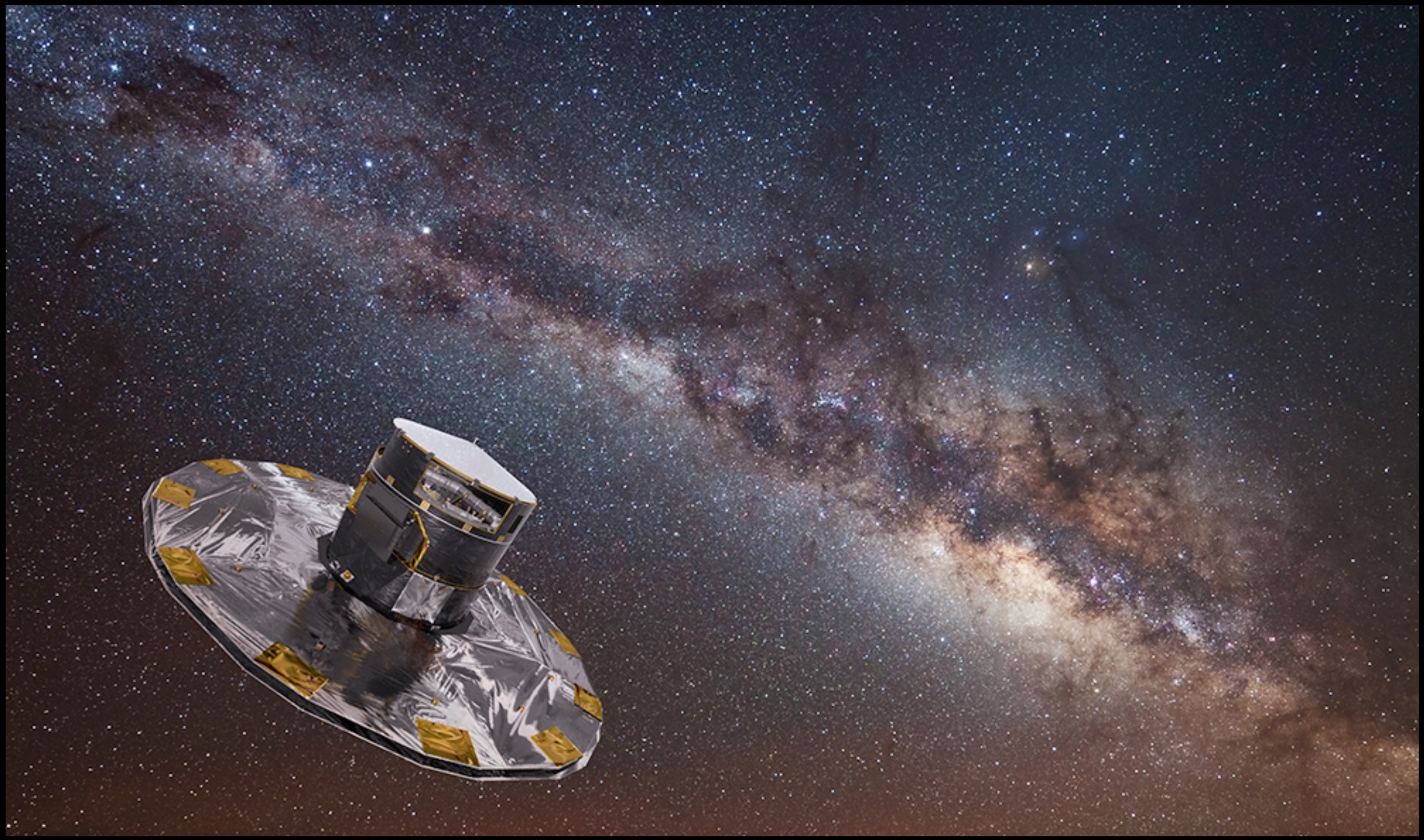
KORDYLEWSKY CLOUDS & ZODIACAL LIGHT



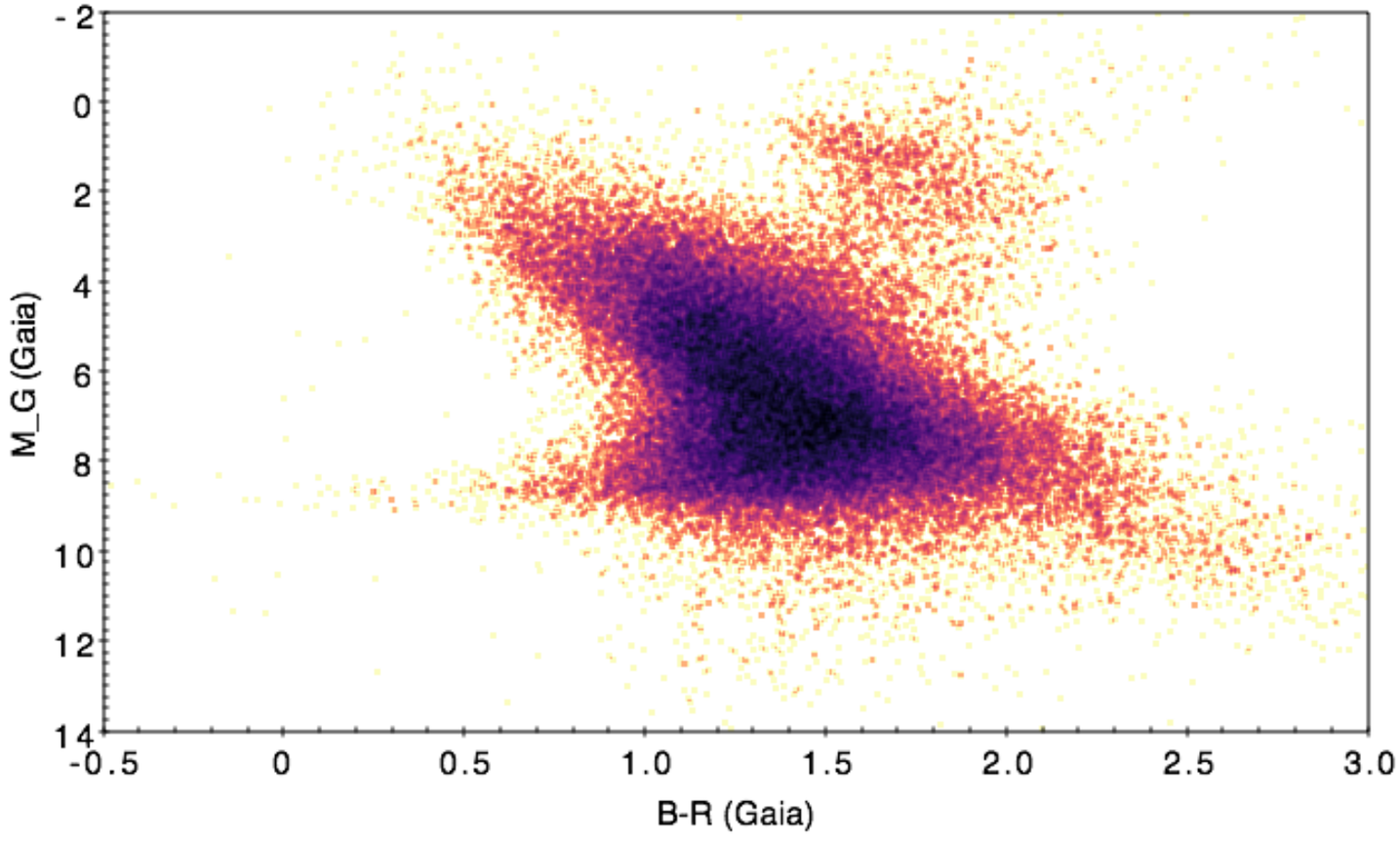


Winiarski (1989)

- Detect, image and characterize L4/5 dust clouds in scattered light.
- Monitor dynamics.
- Expand to mapping/characterizing of zodiacal dust along ecliptic.
- Consequences for exo-Earth imaging?



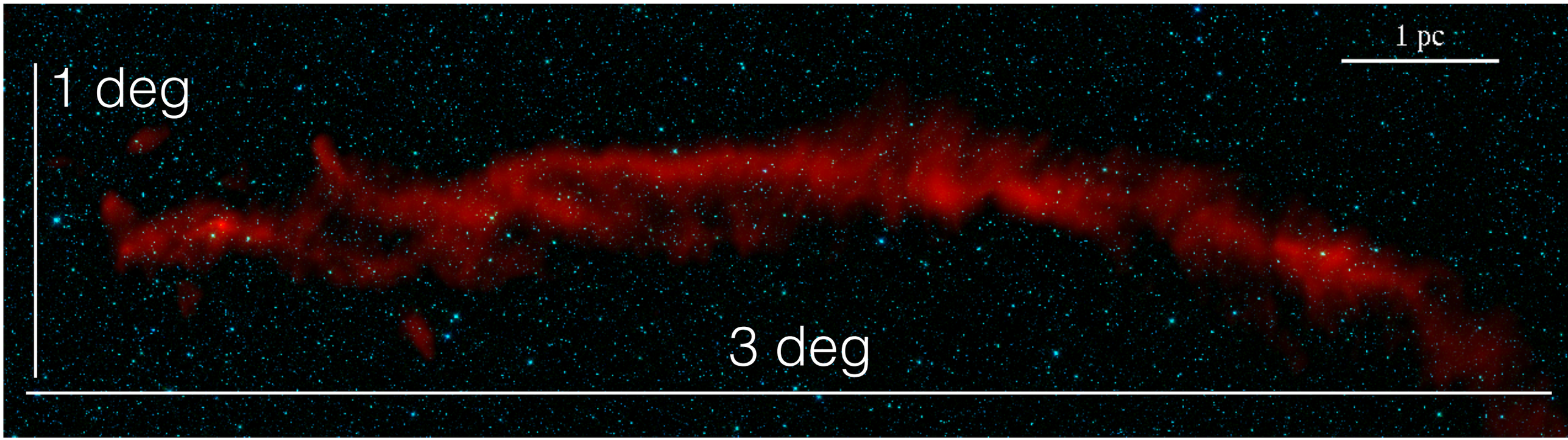
STELLAR POLARIMETRY + GAIA



Macfarlane et al. 2015

OmegaPOL will add another dimension to the HR diagram!

STAR FORMING REGIONS



Credit: 2MASS/SPIRE/Cox

The Musca molecular cloud filament is a nearby (~200pc) low-mass star forming region

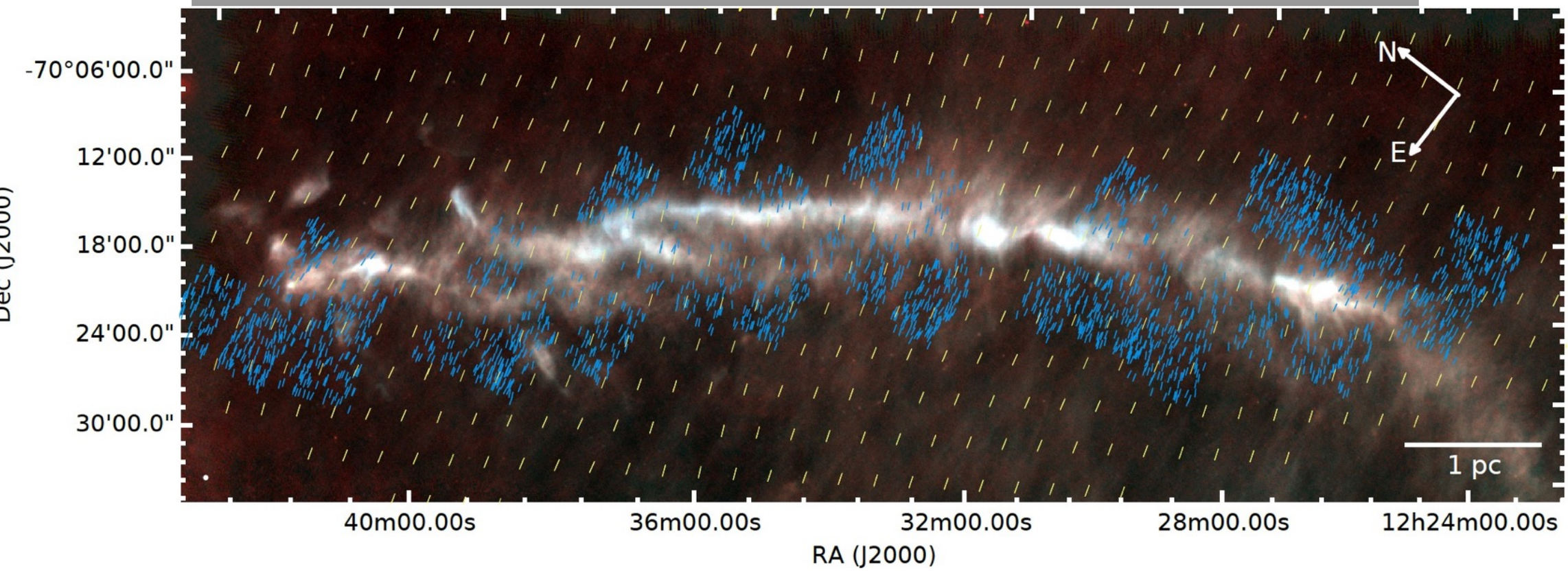
Red = Herschel/SPIRE 250 μm

Blue/Green = 2MASS J+K background stars

Magnetic field in molecular clouds/ filaments: Impact on star-formation?

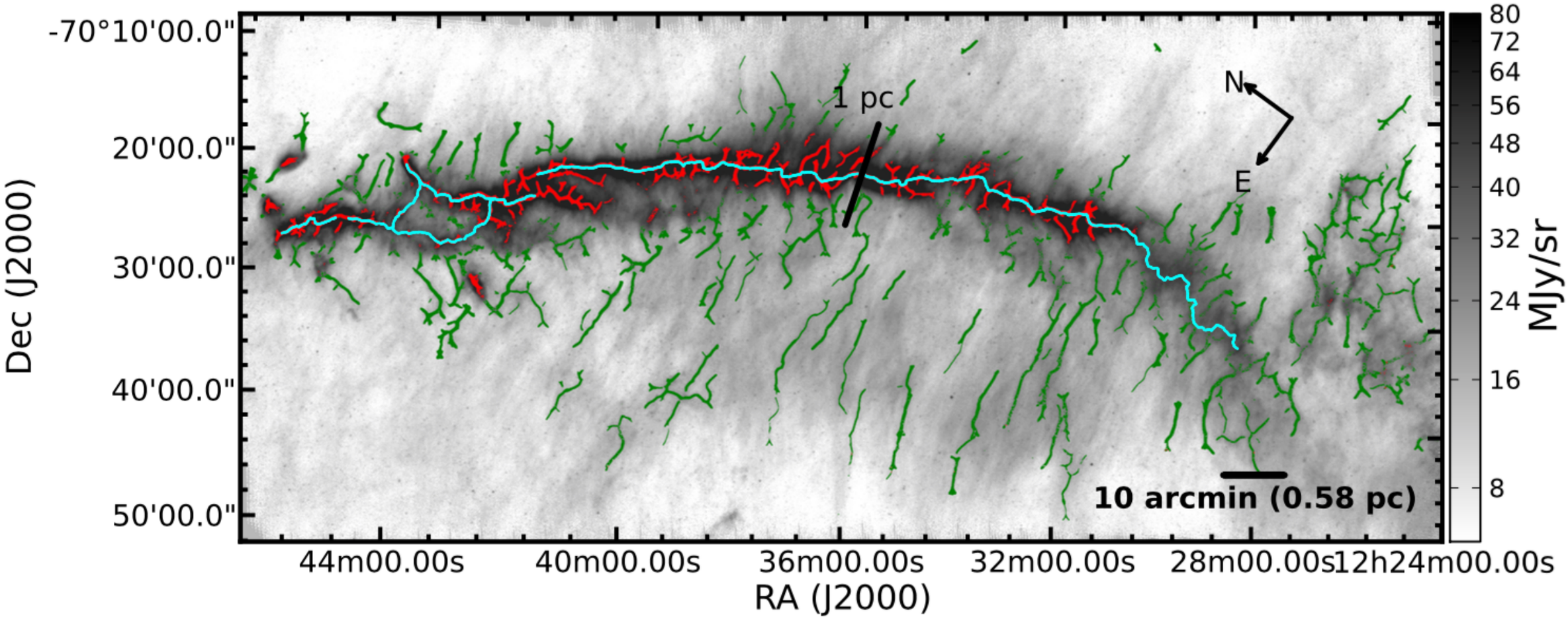
B-field from starlight polarization (Pereyra & Magalhaes 2004)

B-field from Planck IR polarised emission



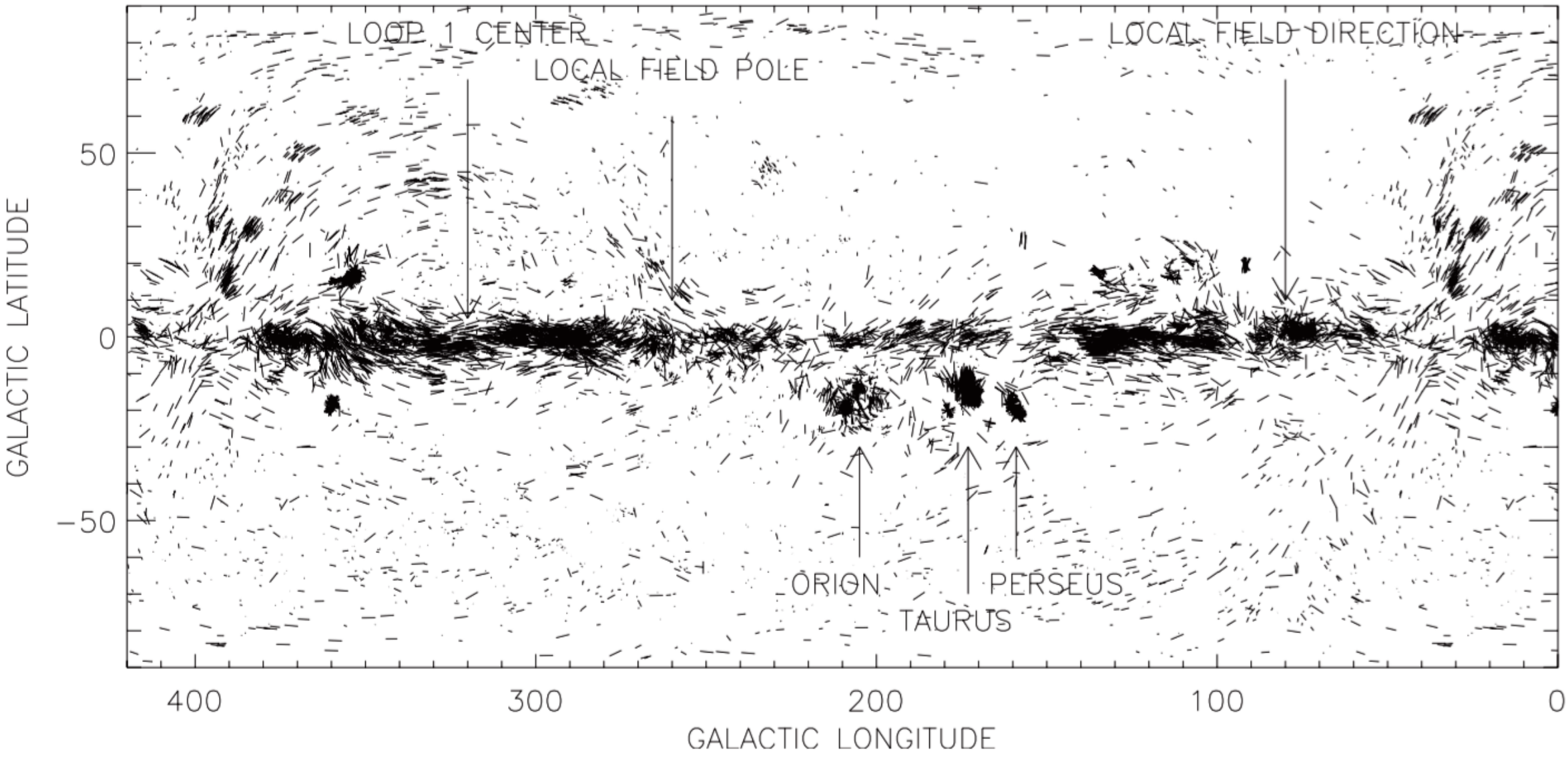
Polarimetry tells us that the magnetic field is perpendicular to the longer direction of the filament

Magnetic field in molecular clouds/ filaments: Impact on star-formation?



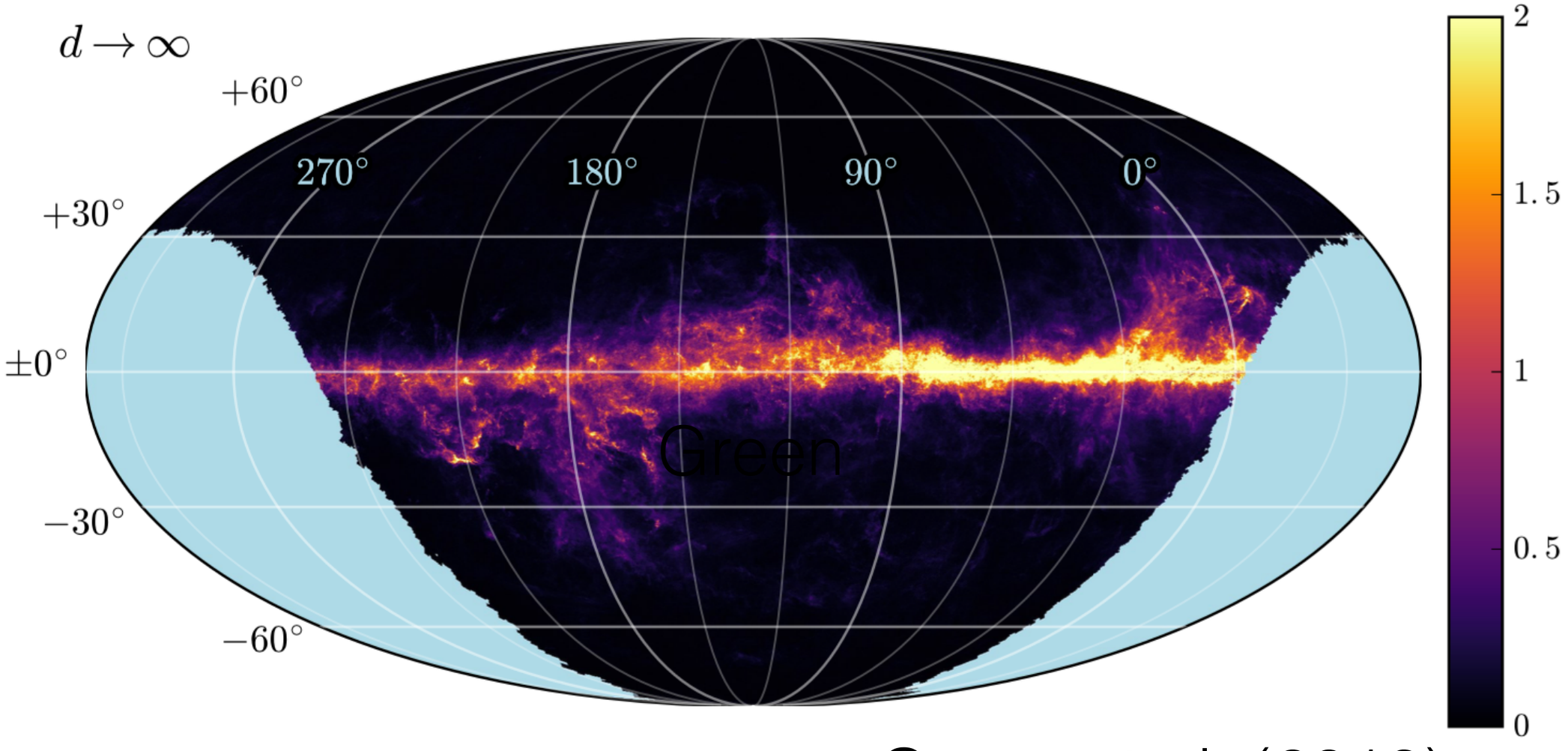
Cox et al. (2016) have found faint low density structures, or “striations” parallel to the magnetic field and locally oriented close to perpendicular to the high-density main filament …

POLARIMETRY OF THE ISM



Heiles & Crutcher (2005)
based on ~ 10000 stars

POLARIMETRY OF THE ISM



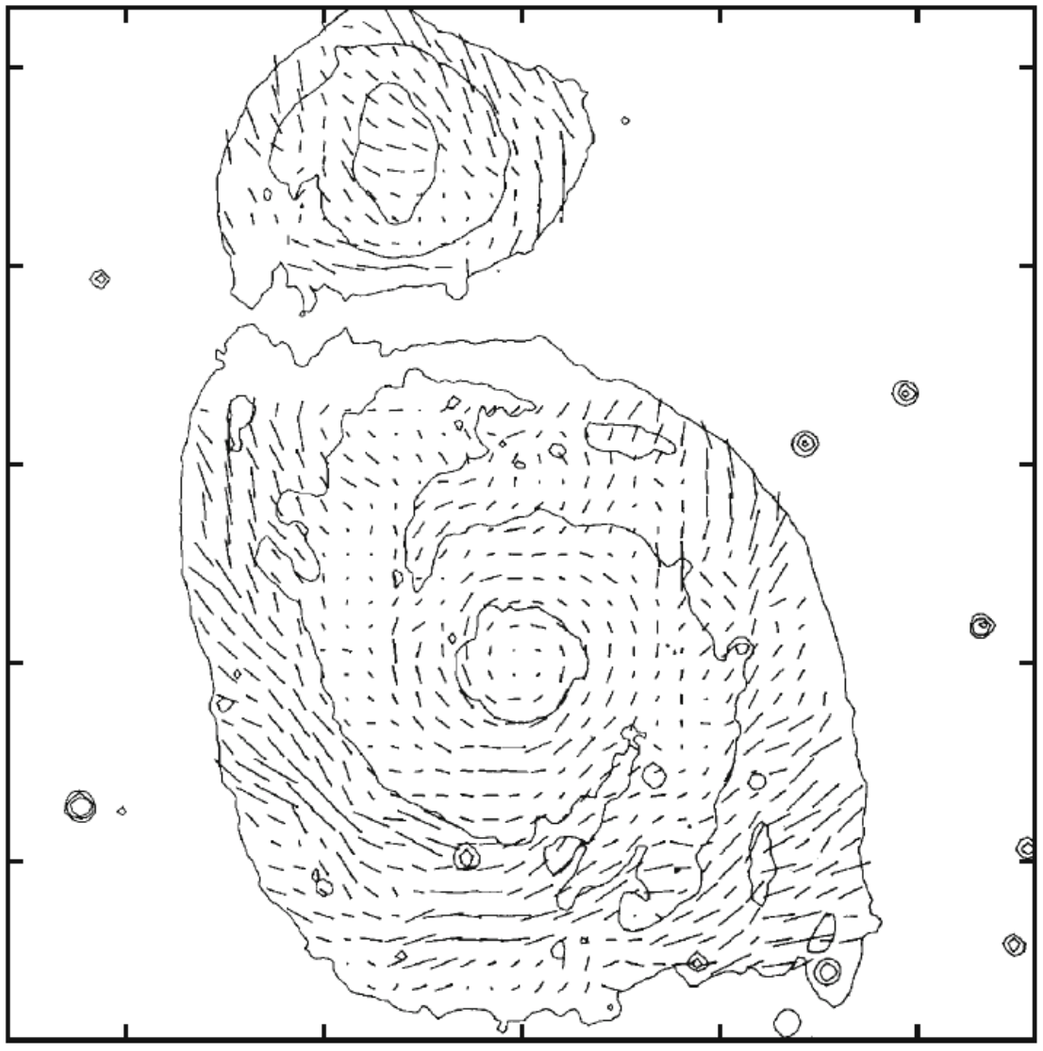
Green et al. (2018)

Extinction map from Pan-STARRS1 and 2MASS photometry of 8×10^8 stars

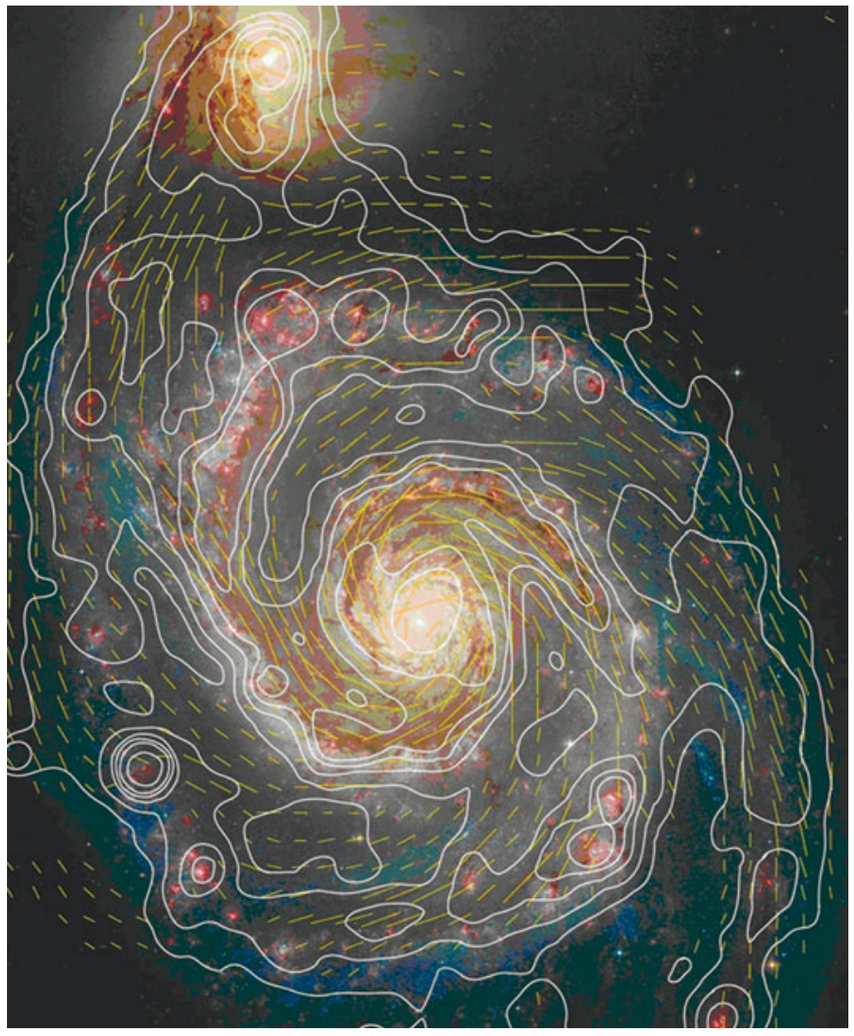
Combined with the distance from **GAIA**, and polarization from **OmegaPOL**,

—> **3D map** of the magnetic field and of the dust grain size and composition.

M51



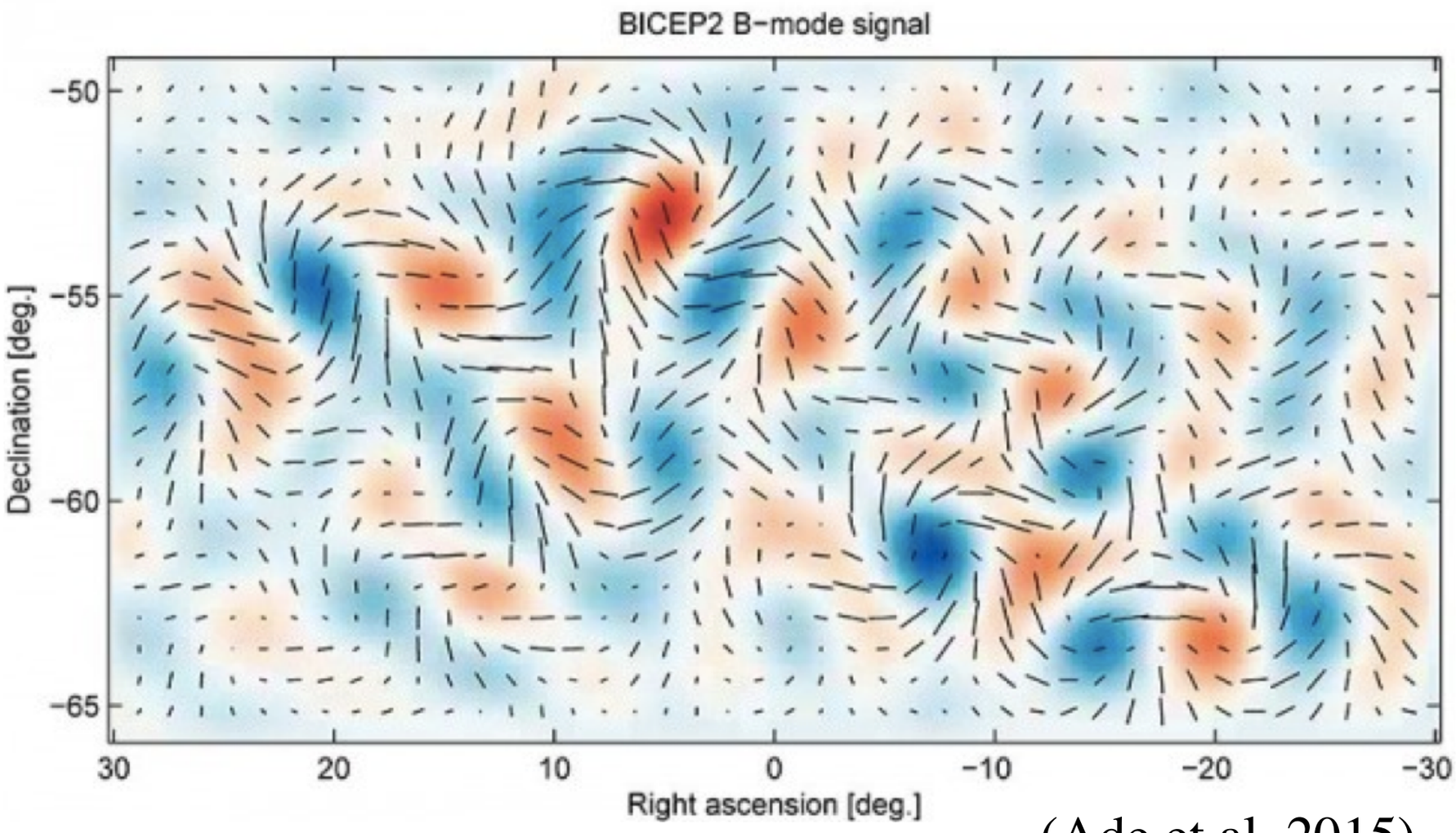
E-vectors of the optical polarization of diffuse light which trace the spiral magnetic field orientation (Scarrott et al. 1987).



Total radio-intensity (contours) and B-vectors at 3.6 cm (Fletcher et al. 2011).

"… the polarization vector in the optical range and the magnetic field vectors in the radio range are partly aligned, but deviate by up to 60° in some regions (Beck et al. 1987). Again a mixture of anisotropic scattering and Davis-Greenstein mechanism *[= selective extinction of magnetically aligned dust grains]* could explain this result." (Fendt et al. 1996)

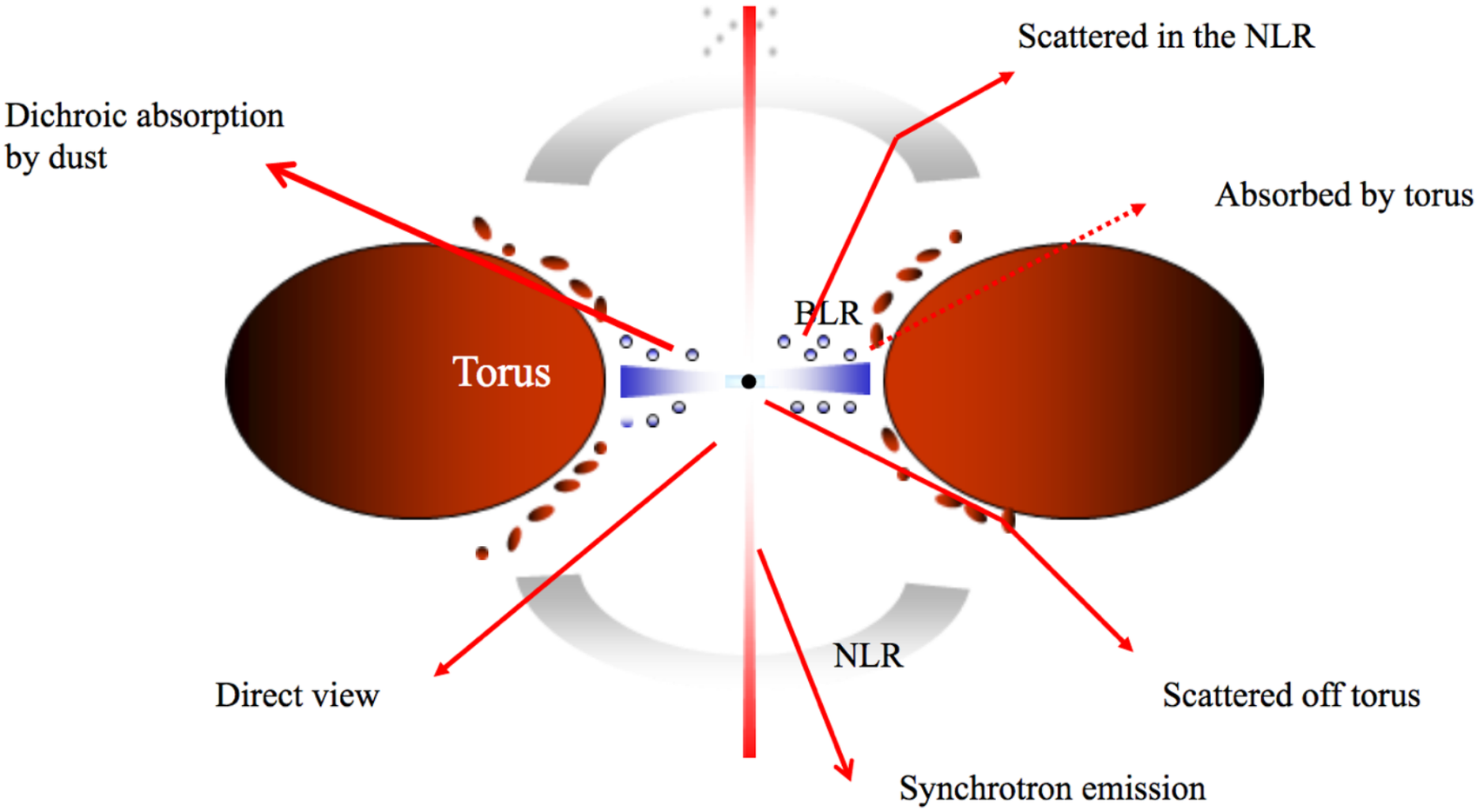
POLARIMETRY OF CMB



(Ade et al. 2015)

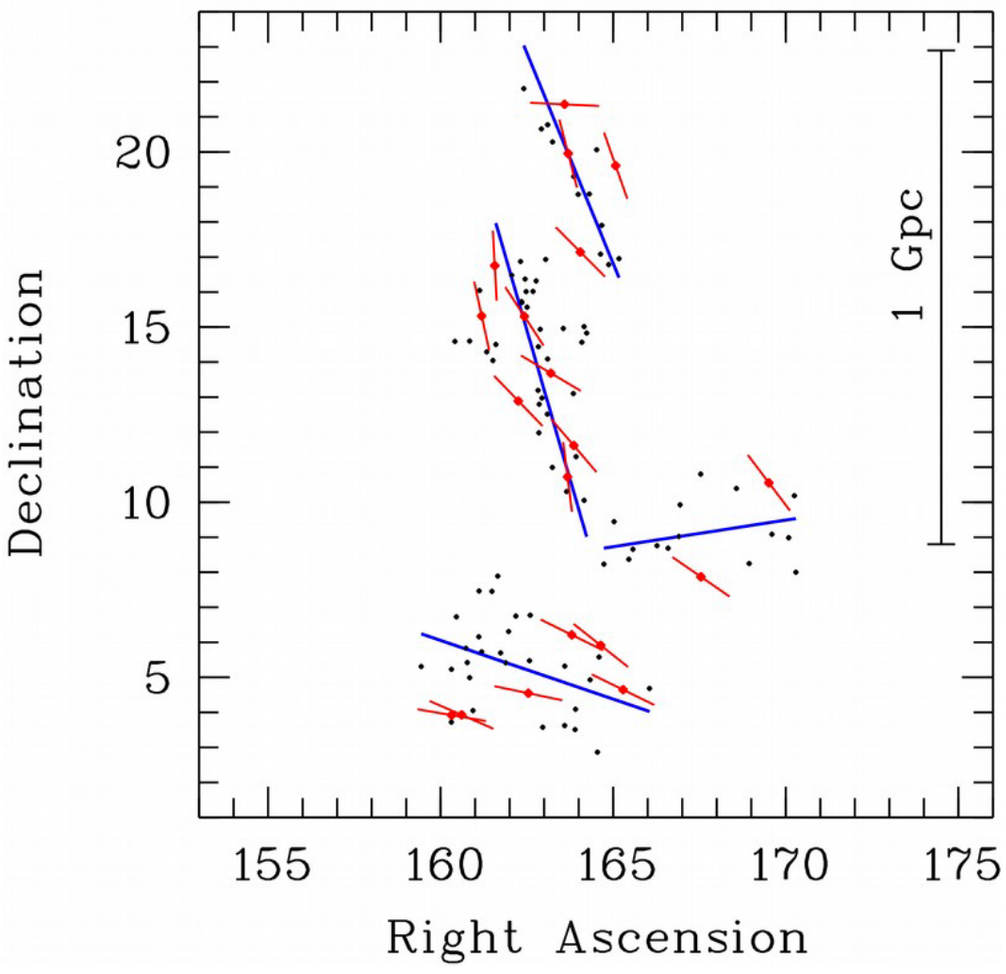
Optical polarimetry with OmegaPOL —>
higher spatial resolution + **better dust grain characterisation** =
better predictions of the foreground microwave polarisation from dust
importance of proper estimation of dust emission in the ISM

POLARIMETRY OF AGNs



- AGN polarization is related to the electron and dust scattering geometry
- **The polarization position angle is an indicator of orientation and inclination of objects too distant to be spatially resolved**

POLARIMETRY OF AGNs



Hutsemékers et al. (2014)

The directions of AGN morphological axes as probed by measurements of polarisation position angle **show structures from 100 Mpc to ~ 500 Mpc** (confirmed by the discovery of large-scale alignments of radio jets)

"Correlations in quasar axes over such extreme scales would constitute a serious anomaly for the cosmological principle."

Polarimetry over a wide field-of-view would bring significant progress:

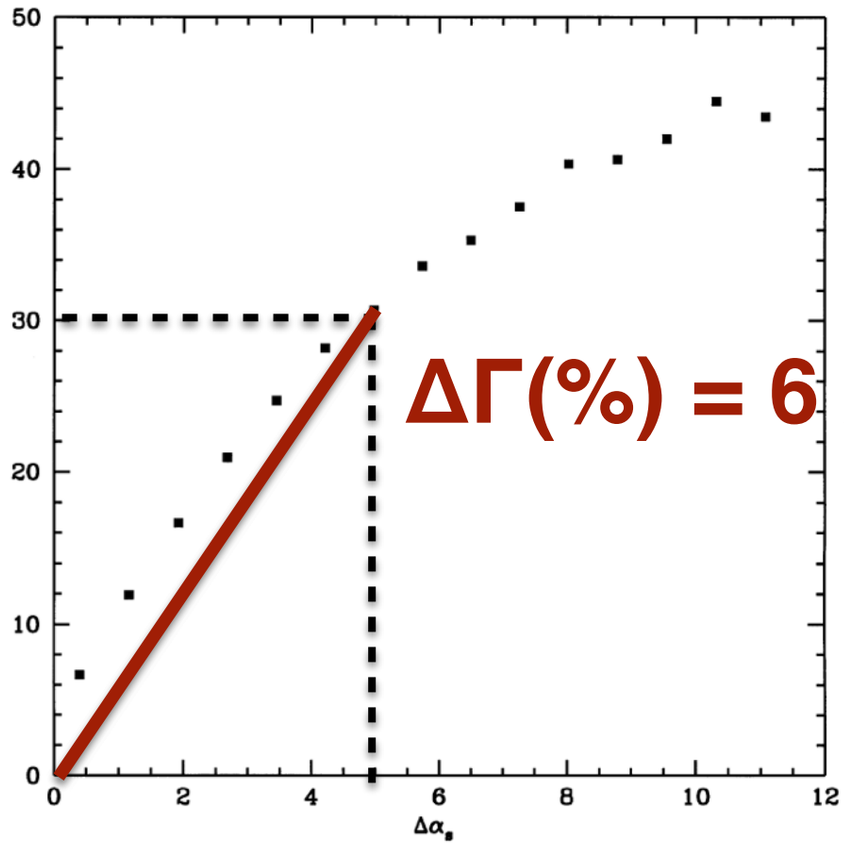
VST would be 20 times more efficient than EFOSC/FORS2

400 deg^2 survey (400 h) —> homogeneous measurements for 10,000 quasars

POLARIMETRY AND WEAK LENSING

- **Light polarization is not affected by gravitational lensing** (e.g., Schneider et al. 1992)
- **Polarisation position angle gives the intrinsic orientation of the galaxy** (in fact, a discrepancy between the perpendicular to the symmetry of the galaxy and the orientation of the polarisation, is a signature of a lensed galaxy)
- Typical spiral galaxy: polarisation from Thompson+Rayleigh+dust scattering integrated over the entire disk **1-10%** and ~ sin^2i
- Integrated polarization of weakly lensed galaxies provides constraints on lens models, and in particular:
- the error on **ratio Γ between shear γ and convergence terms only depends on the error on polarisation position angle**

POLARIMETRY AND WEAK LENSING



ΔΓ(%)

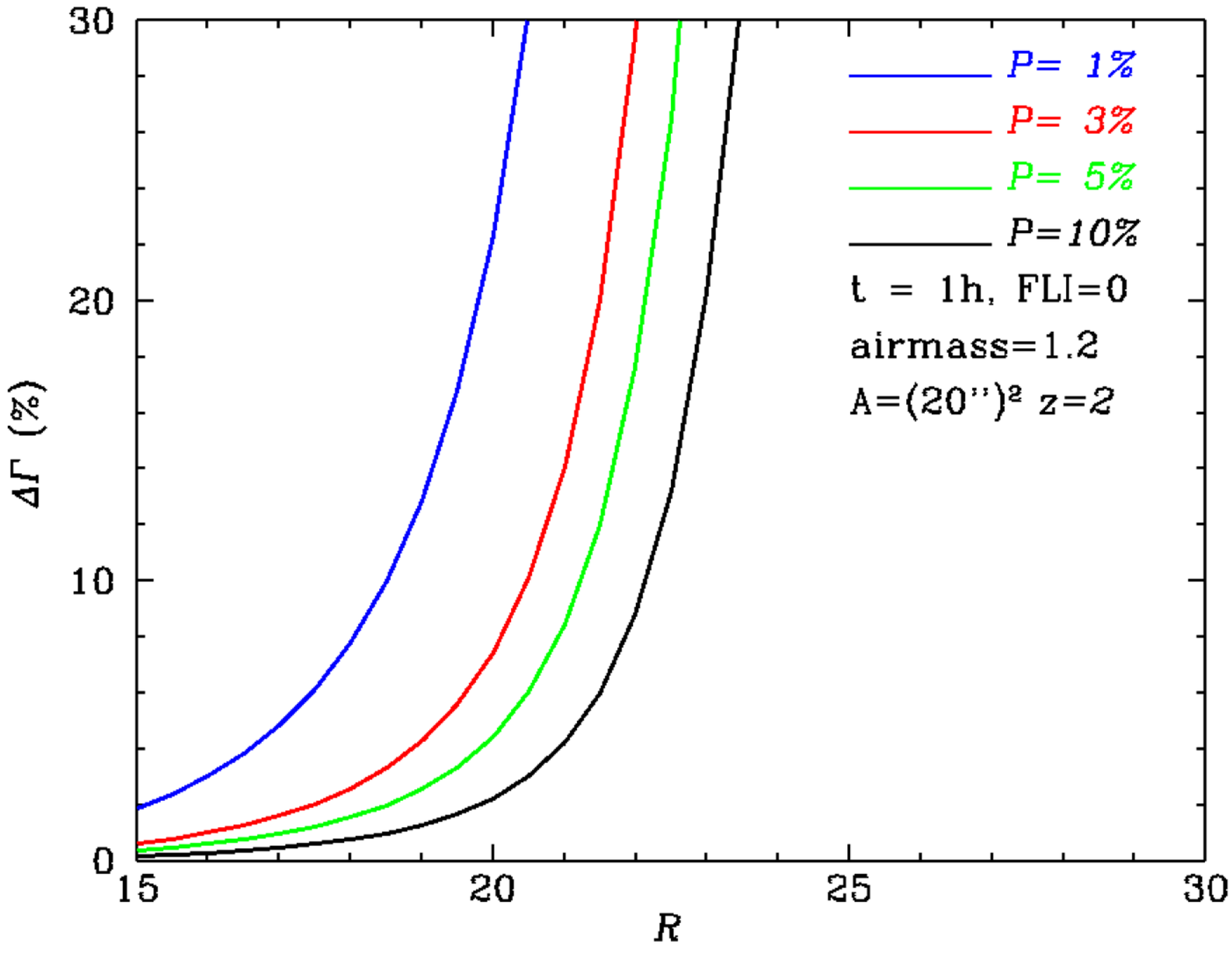
ΔΓ(%) = 6 Δα (DEG)

Audit & Simmons (1999)

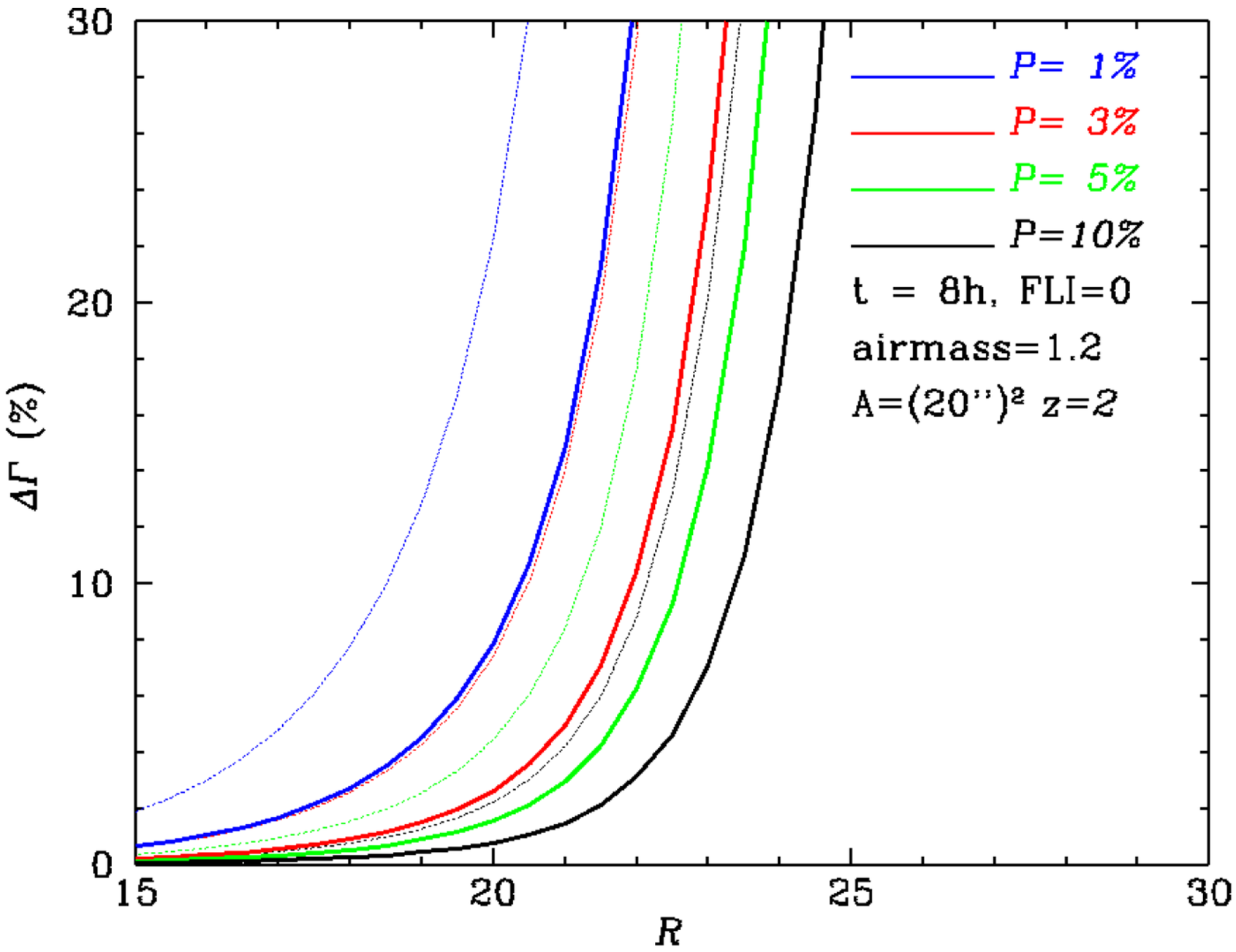
Γ=γ/κ

Δγ ~ ΔΓ

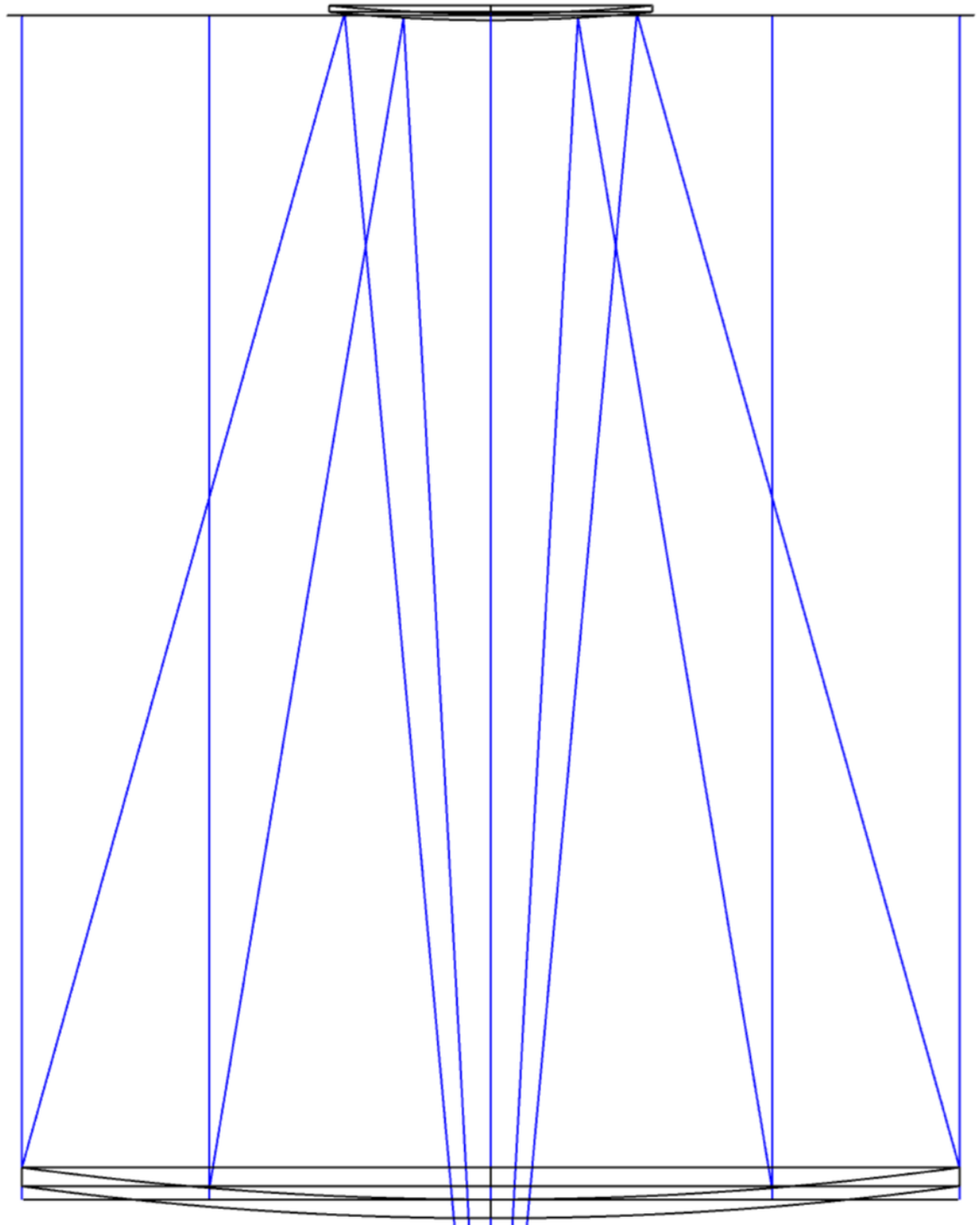
POLARIMETRY AND WEAK LENSING



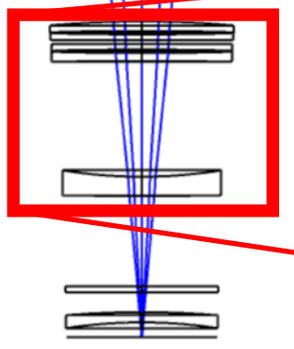
POLARIMETRY AND WEAK LENSING

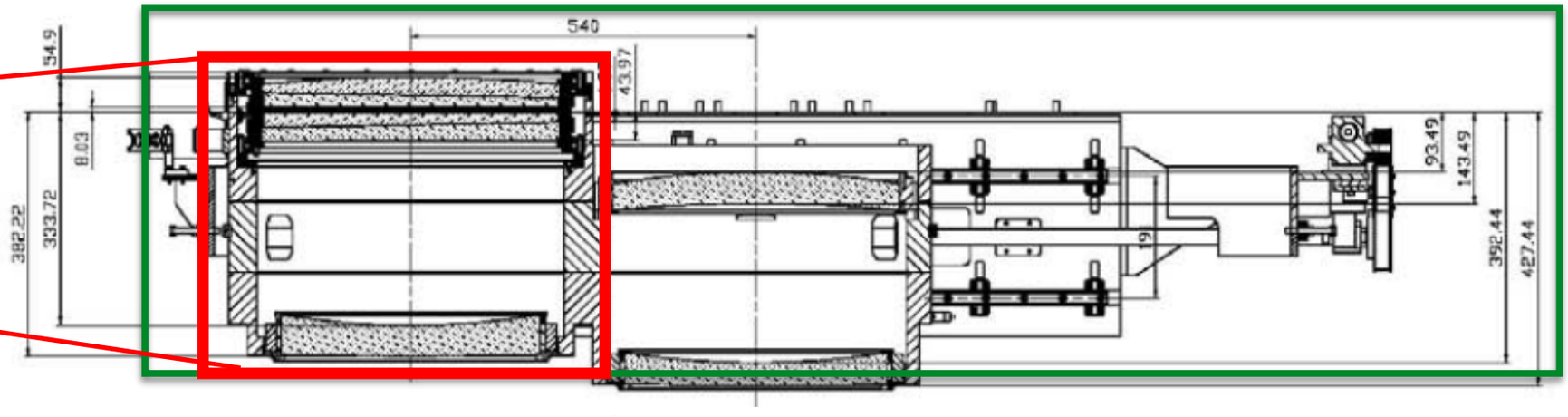


ADC unit switch



ADC+1-lens corrector

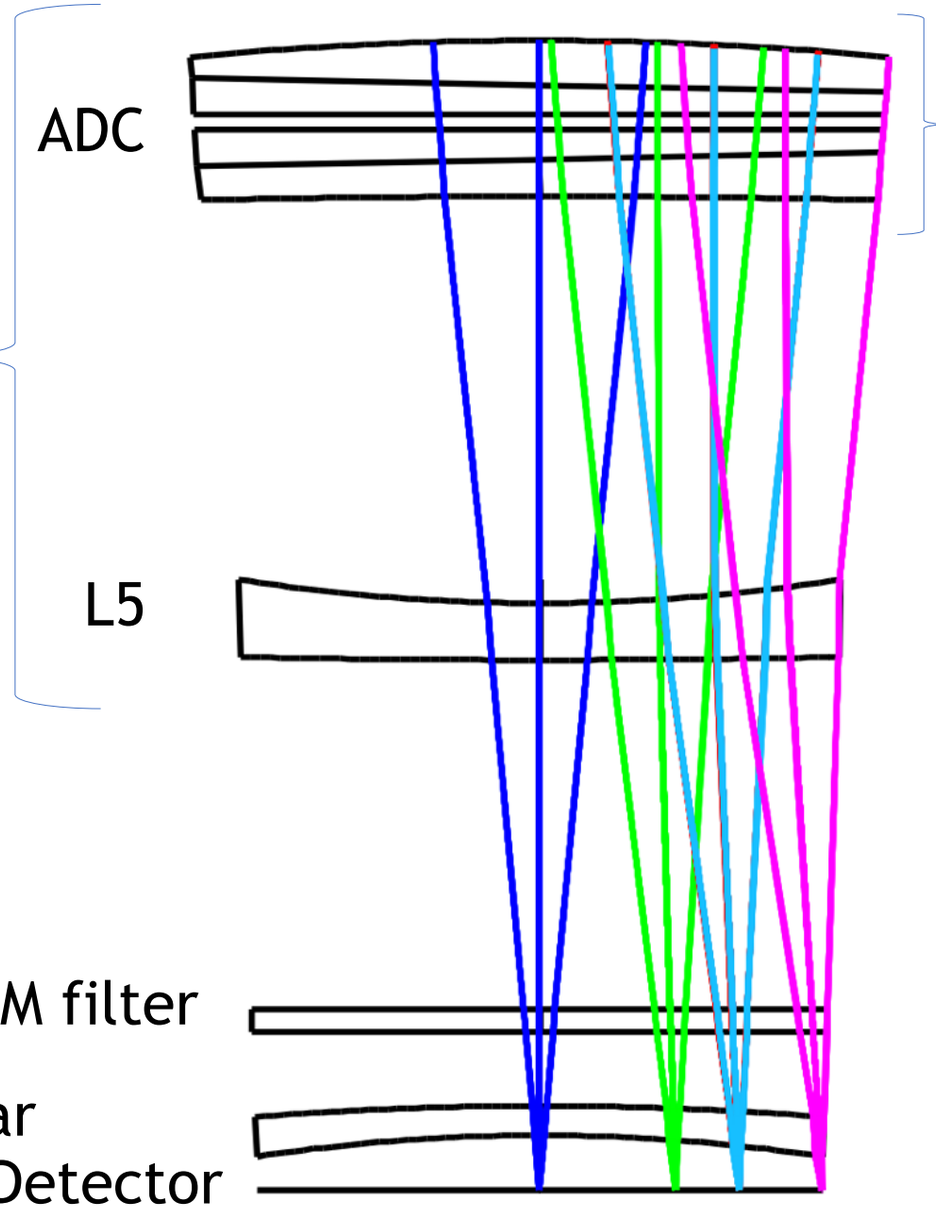




2-lens corrector

DETAILS OF THE ADC UNIT

ADC + 1-lens corrector

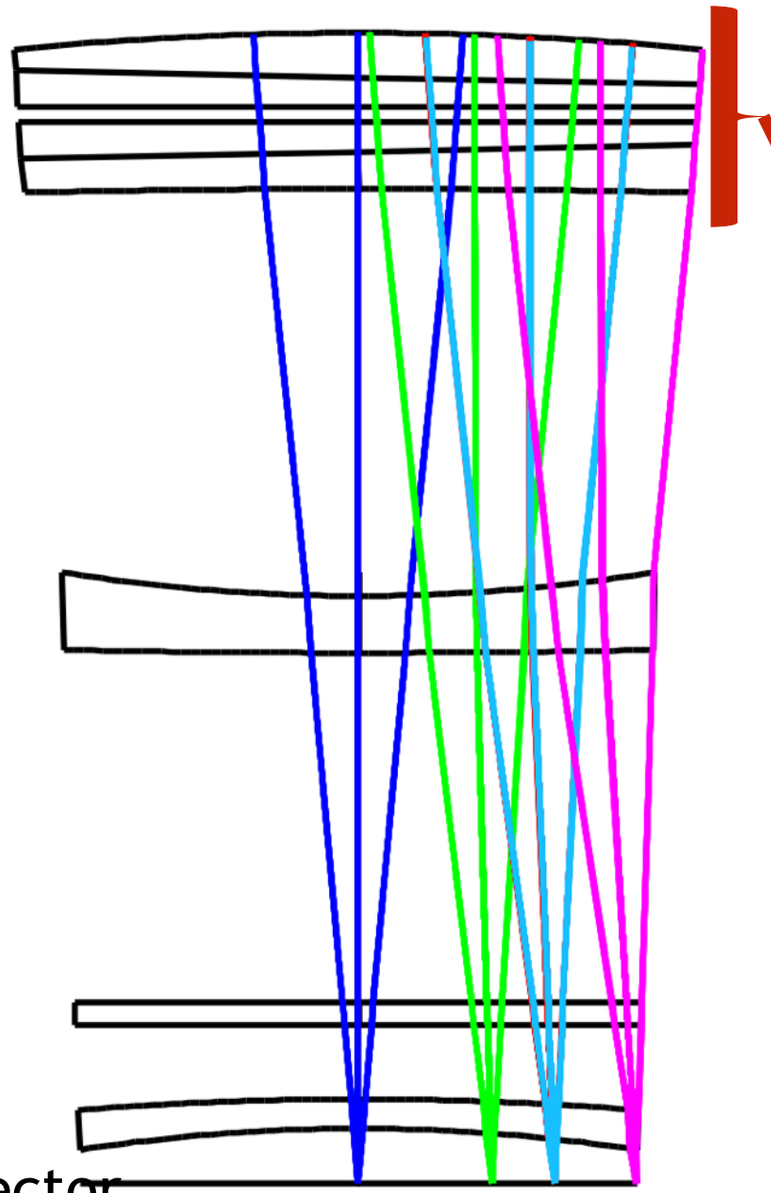


From top to detector:

- Prism #1
  - Surface 1: *R = 2 511.9 mm*
  - Surface 2: plan, tilted 1.03 deg
- Prism #2
  - Surface 2: plan, tilted 1.03 deg
  - Surface 3: plan
- air gap of 10 mm
- Prism #3:
  - Surface 4: plan
  - Surface 5: plan, tilted -1.03 deg
- Prism #4:
  - Surface 5: plan, tilted -1.03 deg
  - Surface 6: *R = 10 000 mm*

DETAILS OF THE ADC UNIT

ADC + 1-lens correct or

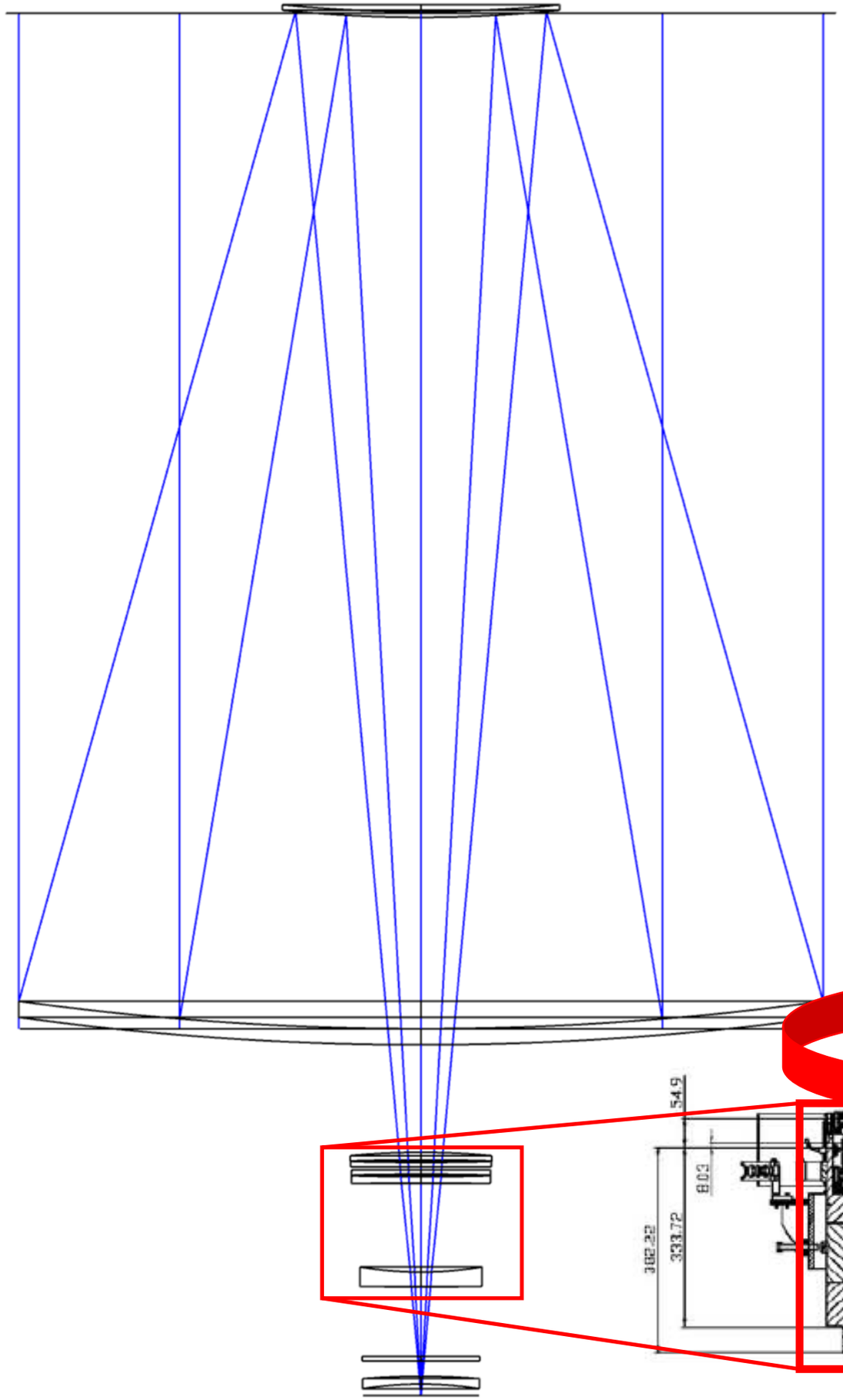


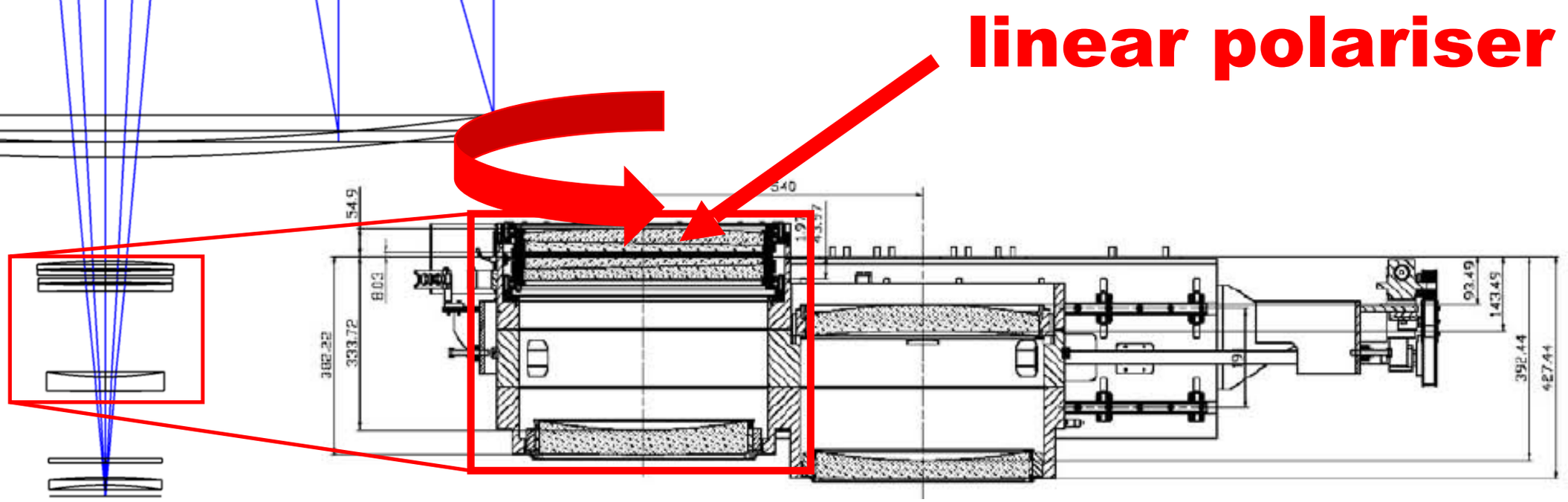
From top to detector:

- Prism #1
  - Surface 1: *R = 2 511.9 mm*
  - Surface 2: plan, tilted 1.03 deg
- Prism #2
  - Surface 2: plan, tilted 1.03 deg
  - Surface 3: plan
- air gap of 10 mm
- Prism #3:
  - Surface 4: plan
  - Surface 5: plan, tilted -1.03 deg
- Prism #4:
  - Surface 5: plan, tilted -1.03 deg
  - Surface 6: *R = 10 000 mm*

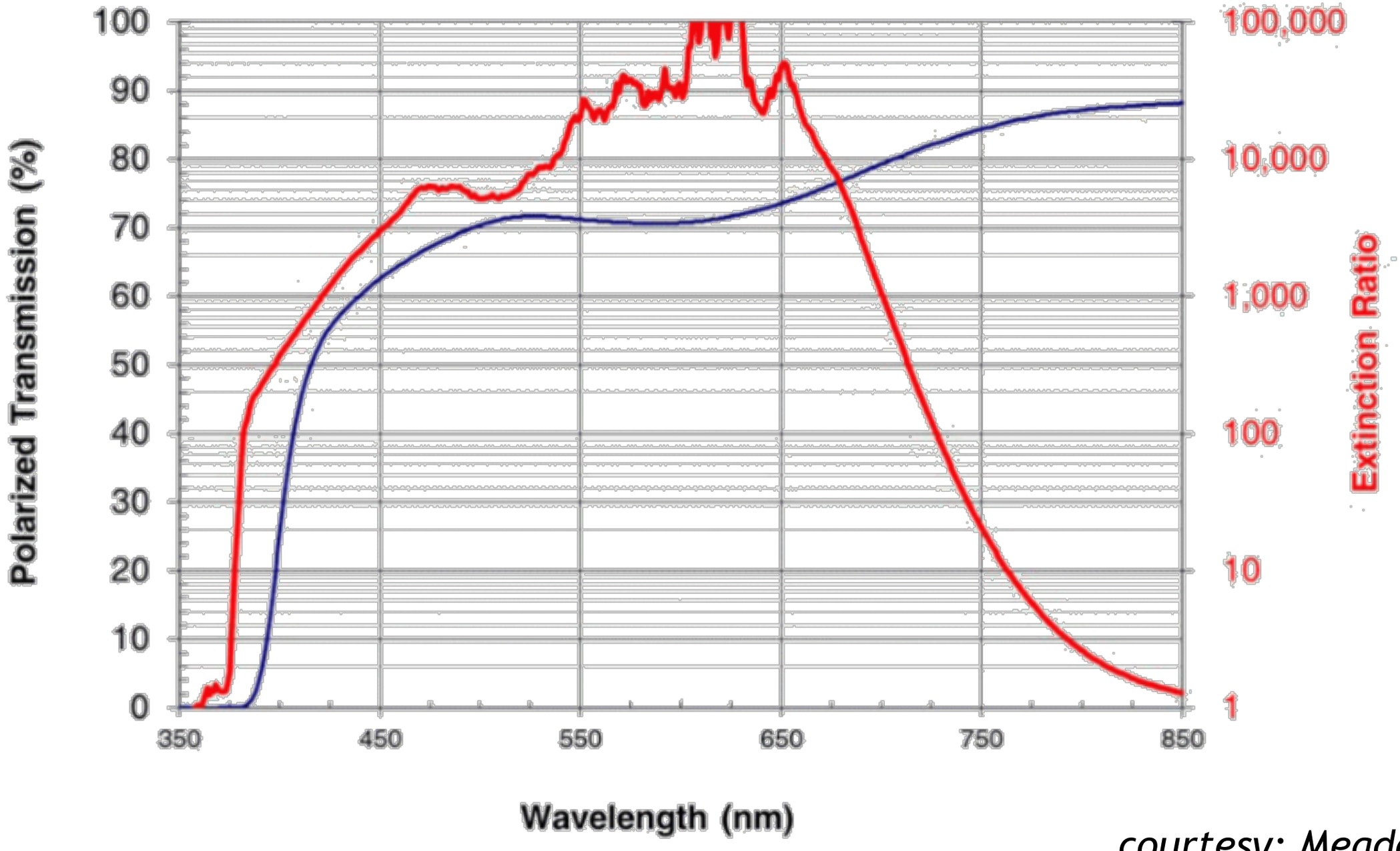
Can rotate:

- angular position accuracy of 8.6”
- speed > 0.5°/s (45 s to rotate 90°).





POLAROID MATERIAL



courtesy: Meadowlark

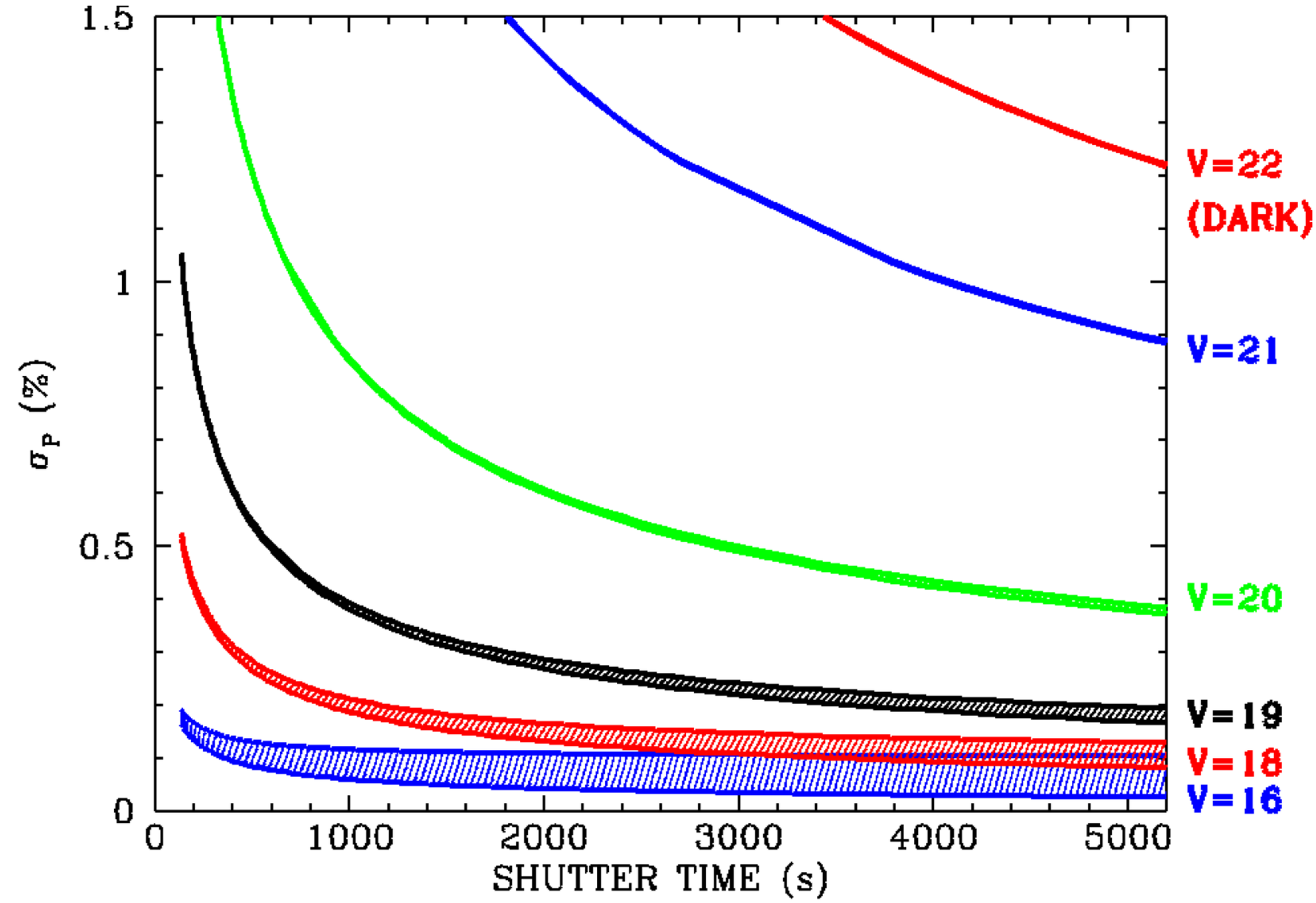
- available up to 62 cm in diameter
- sufficiently uniform performance over the 30-cm footprint

IMPLEMENTATION

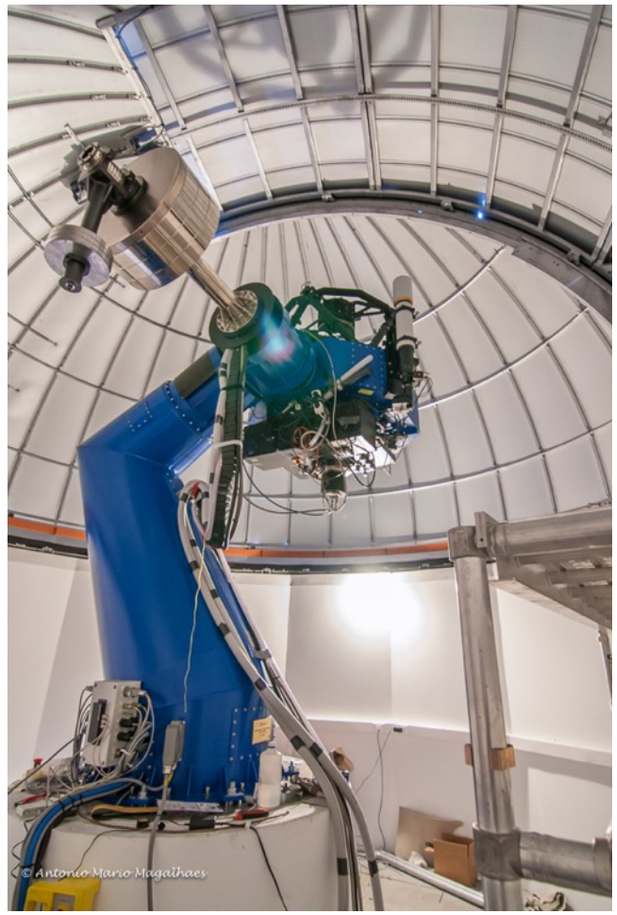
- **Easy upgrade and simple operations**
  - Uses existing insertion + rotation mechanism (with sufficient rotation accuracy)
  - Quadruplets of exposures [0º,90º] and [45º,135º] or triplet [0º,60º, 120º]
  - Can be moved out for other OmegaCAM operation
- **Rotating polarizer single-beam system:**
  - Spurious polarization signals can be created by variable seeing and sky transmission
- **Accurate calibration:**
  - Using **Gaia catalogue**, make use of many unpolarized stars in the field as a zero-point reference
  - Expected “polarimetric sensitivity”: ~10^{-3} (factor of 10 better than simple-minded single-beam system), **OR BETTER**

Performance simulations based on existing data later this year

FLI=0.5, airmass=1.5, A-type star in Johnson V



SOUTH POL @ CERRO TOLOLO

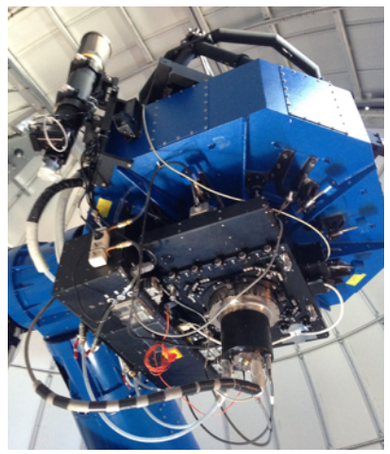


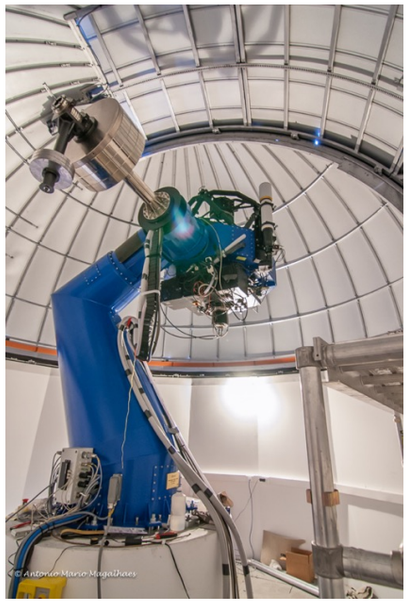
d: 0.84m

FoV: 1.7º x 1.7º

σ = 0.1% at V=15

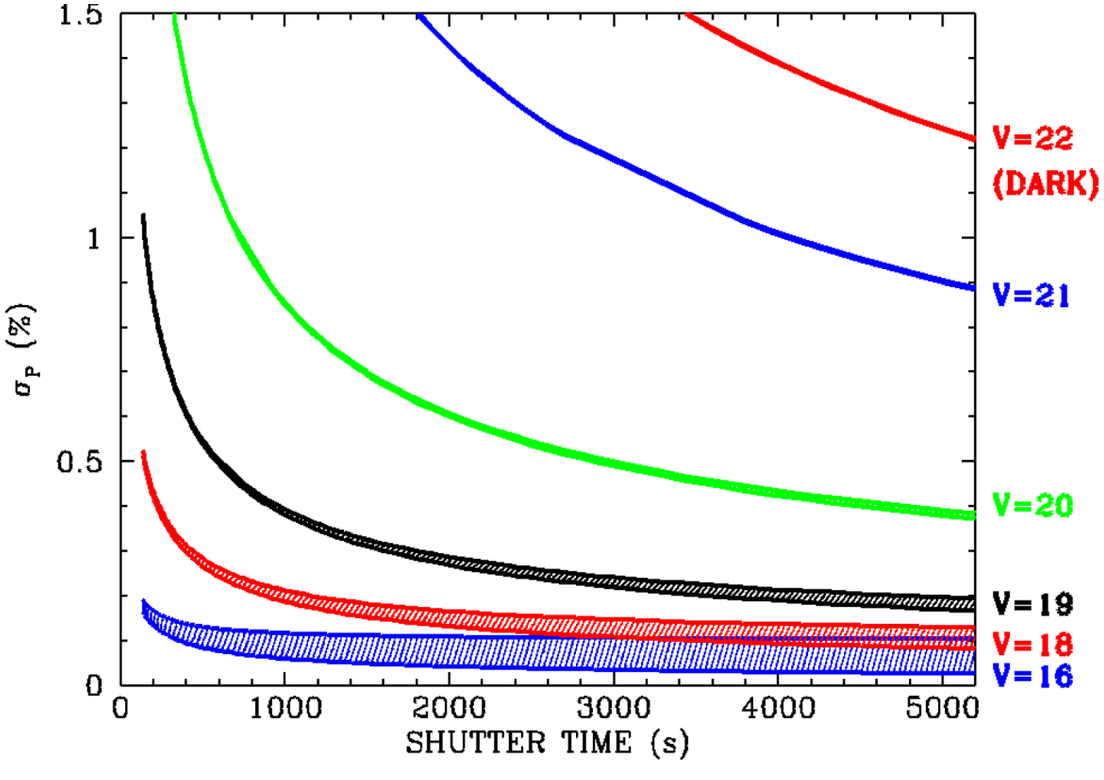
All sky survey in 2 years

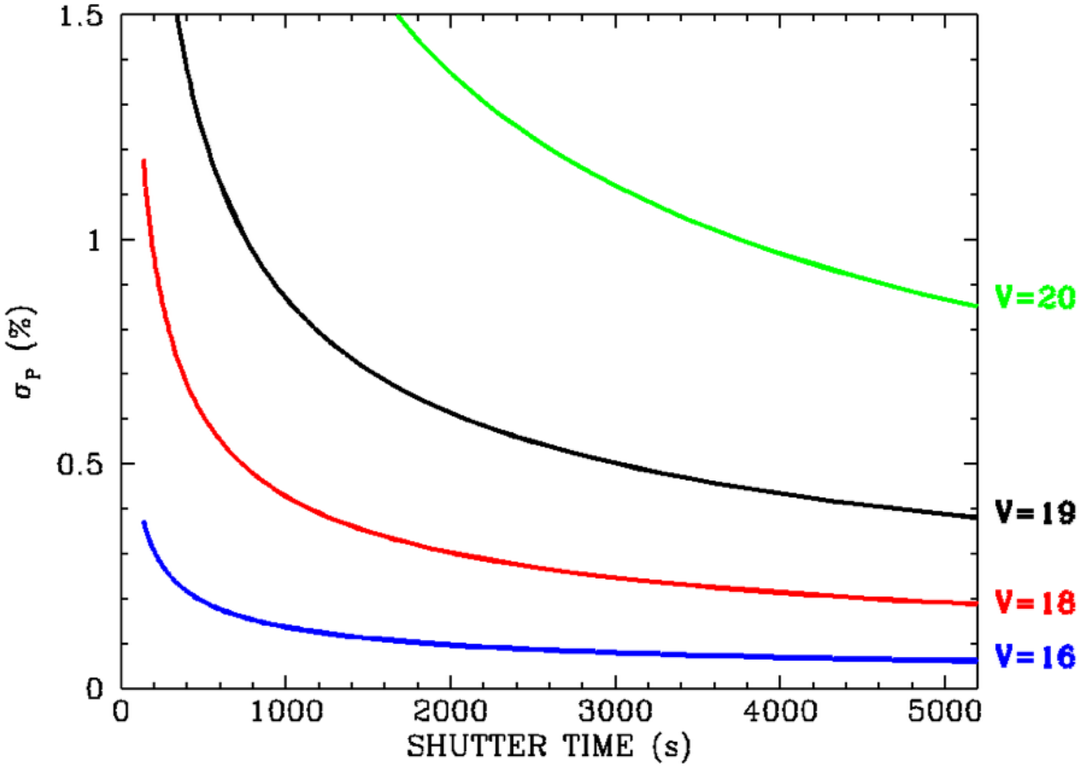




calibrate

validate





SOUTH POL may be used to calibrate / validate OmegaPOL data

No need for major intervention

SUMMARY OF SCIENCE CASES

- **Comets:**
  - Provide insights into the composition of different layers or regions within and on the comet
  - Indication of comet history
- **Asteroids:**
  - composition, structure of surface; survey allows statistical characterization
  - measurement of albedo => sizes
- Extended study of Kordylewski clouds, **zodiacal light**
  - ExoEarth imaging and exodiacal light
  - Role of magnetic fields in **star forming regions** + dust features
- **Magnetic fields and dust grains** in MW, LMC, SMC, and other external galaxies
  - Current best MW map is based on ~ 10,000 stars. Omprovement in angular resolution and structure would be several order of magnitudes.
  - 3-D map of dust grain size and orientation
  - Help to disentangle CMB polarisation
- **AGN:** 20 times more efficient than current telescopes
  - 400 deg^2 (400 h): 10,000 quasars could be homogeneously measured
  - Polarization dependence on types and redshift
  - Correlation of polarization position angles with large scale structures
- Polarization as a proxy of orientation: determination of **weak lensing** parameters