Gaia parallax accuracies

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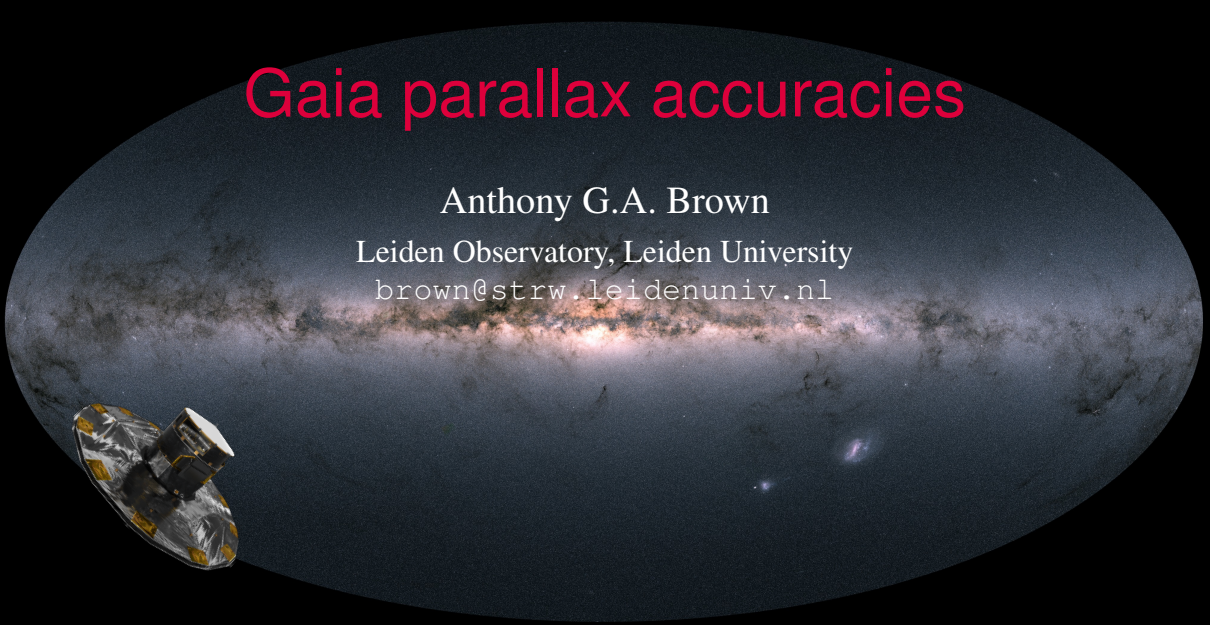
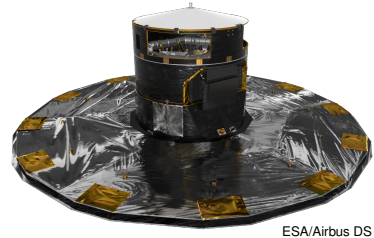


ESA/Gaia/DPAC

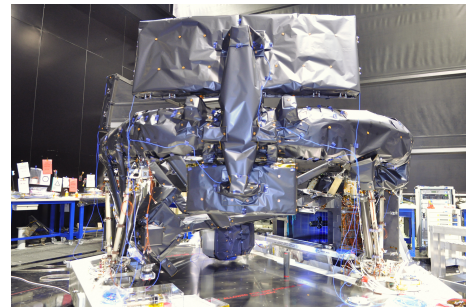
Gaia summary

- Astrometry and spectrophotometry for >1 billion objects
- Radial velocities for >100 million objects
- Survey
  - Complete to $G = 20.7$ ($V = 20$–22)
  - Observing programme: autonomous on-board detection and unbiased
  - Quasi-regular time-sampling over 5 years (~ 70 observations)
- Launch December 2013
- 5 years of operations at L2

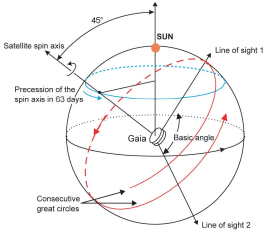
- Second data release April 25 2018
- Photometric alerts started in 2014
- Alerts on new solar system objects started end 2016

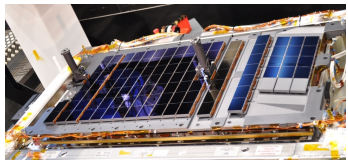


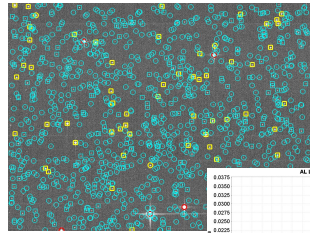
ESA/Airbus DS

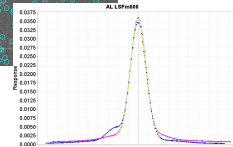


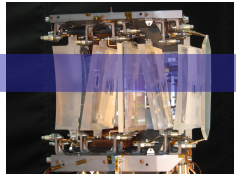
Gaia instruments and measurements

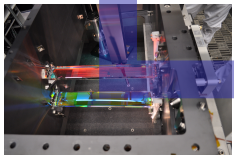


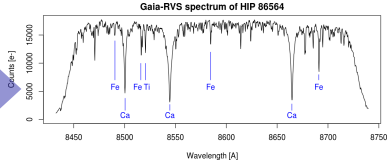


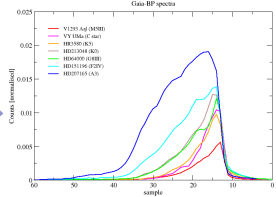


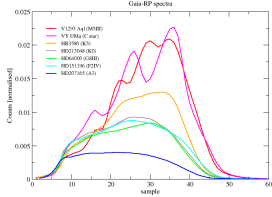




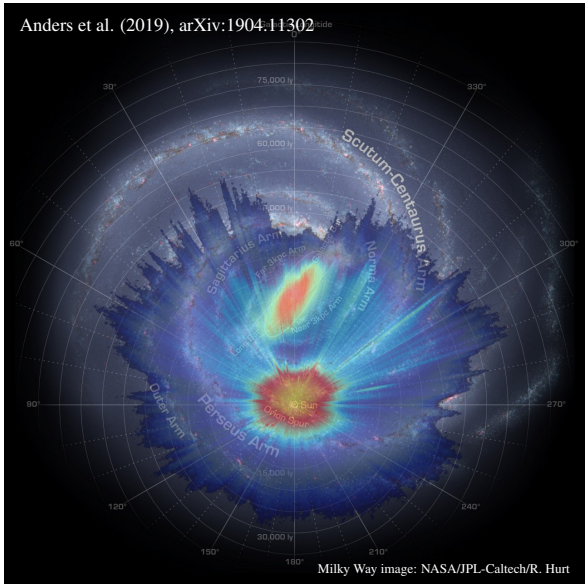


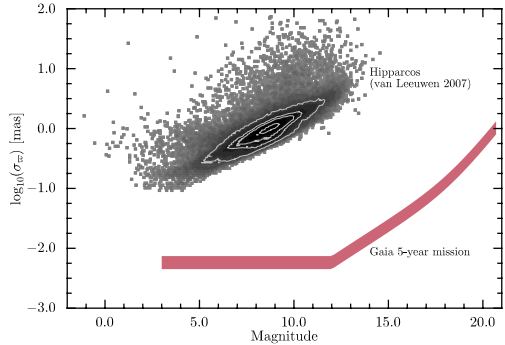






Current reach, expected performance





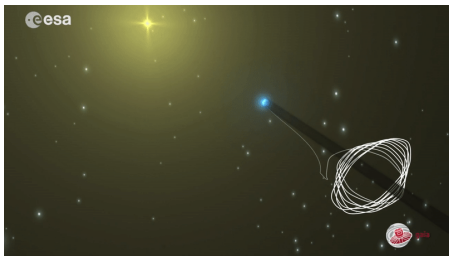
Mission numbers

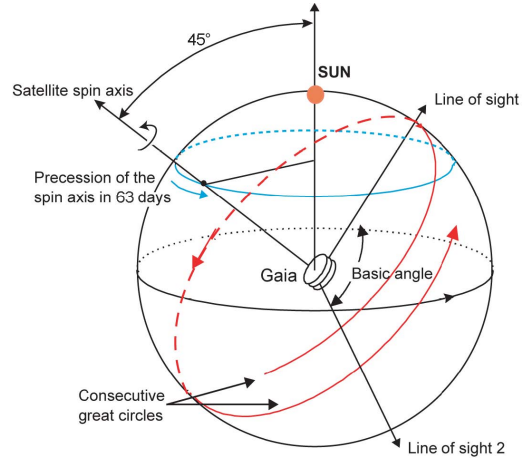
Gaia status as of 2019-07-16T15:47:47 (TCB)	
Satellite distance from Earth (in km)	1 502 661
No. of days having passed since 25 July 2014	1 818

Science data collected since 2014-07-25	
Volume (in GB)	68 123
No. of object transits through the focal plane	129 705 110 100
No. of astrometric CCD measurements	1 278 521 799 553
No. of photometric CCD measurements	258 759 786 958
No. of spectroscopic CCD measurements	25 125 452 190
No. of object transits through the RVS instrument	8 394 259 584

Five years go by quickly!

- End of nominal mission reached on July 16 2019
- Orbit manoeuvre executed on 16th to ensure avoidance of eclipse of the sun by the earth for next 6 years
- Scan law slightly altered to optimize Jupiter light bending observations
- Change of spin-axis precession for one year (not scanning direction)
  - break certain degeneracies in astrometric solution





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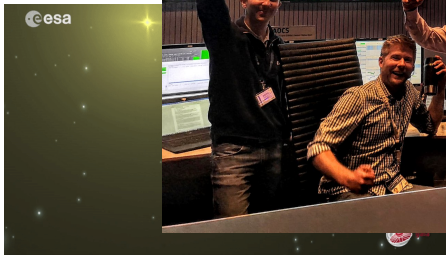
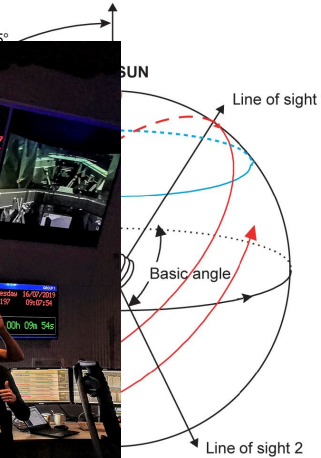
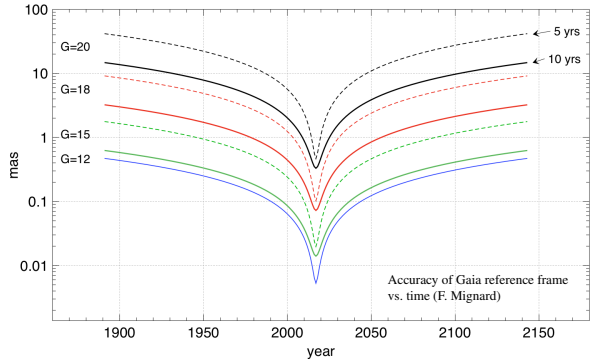




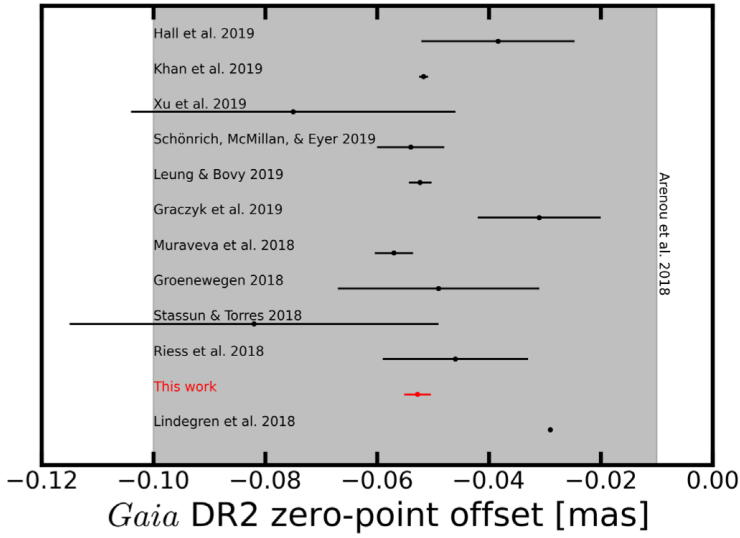
Gaia extension

- Nominal Gaia mission ended on July 16 2019 after 5 years of measurements
- Hardware in good shape, only limiting factor is micro-propulsion fuel
  - mission can continue to end-2024
- Proposal submitted to ESA for 5 year extension
  - approved to end 2020, preliminary approval to end 2022, submit proposal for 2023–2024 in 2020

- Parallaxes, photometry, radial velocities improve by 40% with respect to DR4
- Proper motions improve by factor of 2.8 with respect to DR4
  - Improvement of more complex motions (e.g., planets) up to factors of 20
- Accurate tangential motions over 22.6× larger volume

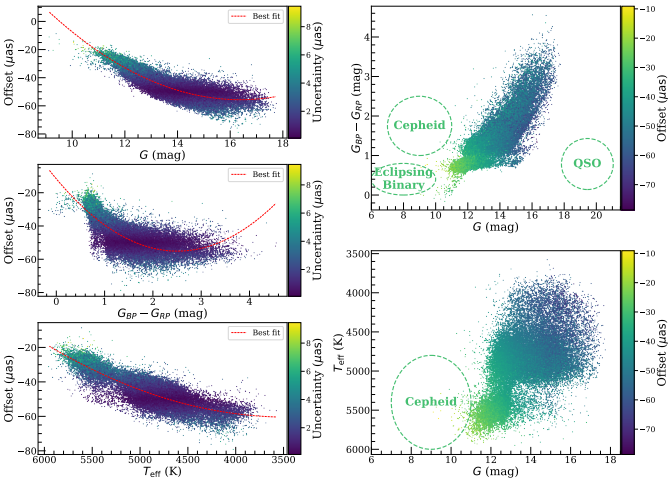


Parallax zero point estimates for Gaia DR2



Zinn et al. (2019)

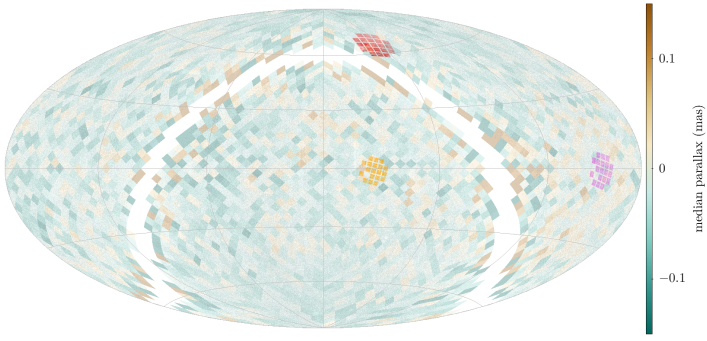
Parallax zero point estimates for Gaia DR2



Leung & Bovy: arXiv:1902.08634

- Simultaneous calibration of spectro-photometric distances and the Gaia DR2 parallax zero-point
- Illustrates variation with apparent brightness and colour
- Shows the importance of investigating the zero-point specifically for the sample of sources your are interested in
- See also Arenou et al.

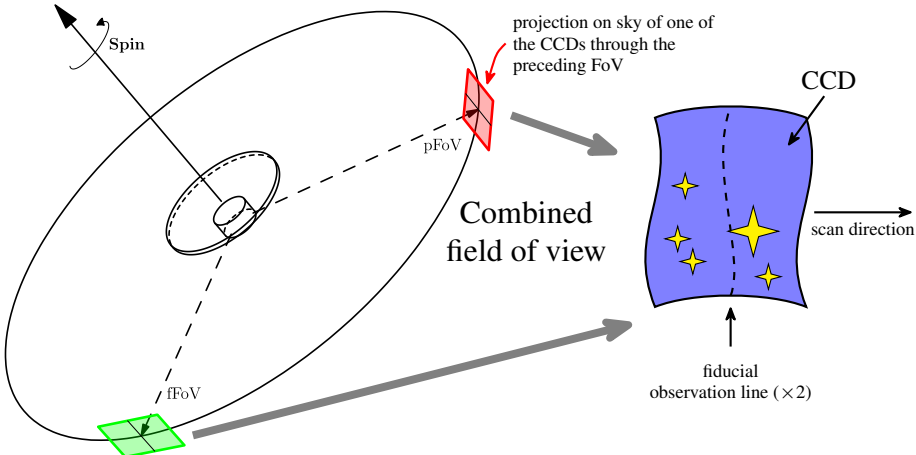
Parallax zero point estimates for Gaia DR2



Khan et al.: arXiv:1904.05676

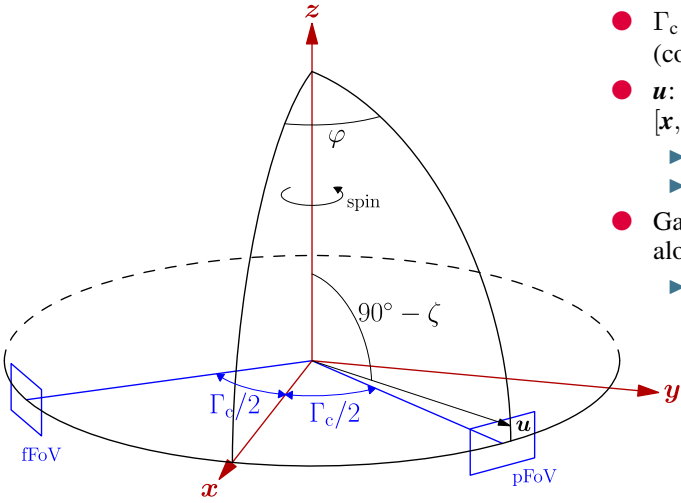
- Comparison of asteroseismic and Gaia DR2 parallaxes in Kepler field and two K2 fields
  - Kepler RGB/ RC: -51.7 ± 0.8 μas/ -47.9 ± 0.9 μas
  - K2-C3 red giants: -6.4 ± 3.8 μas
  - K2-C6 red giants: -16.9 ± 2.4 μas
- Spatial variations consistent with mean QSO parallaxes

Astrometric observations with Gaia



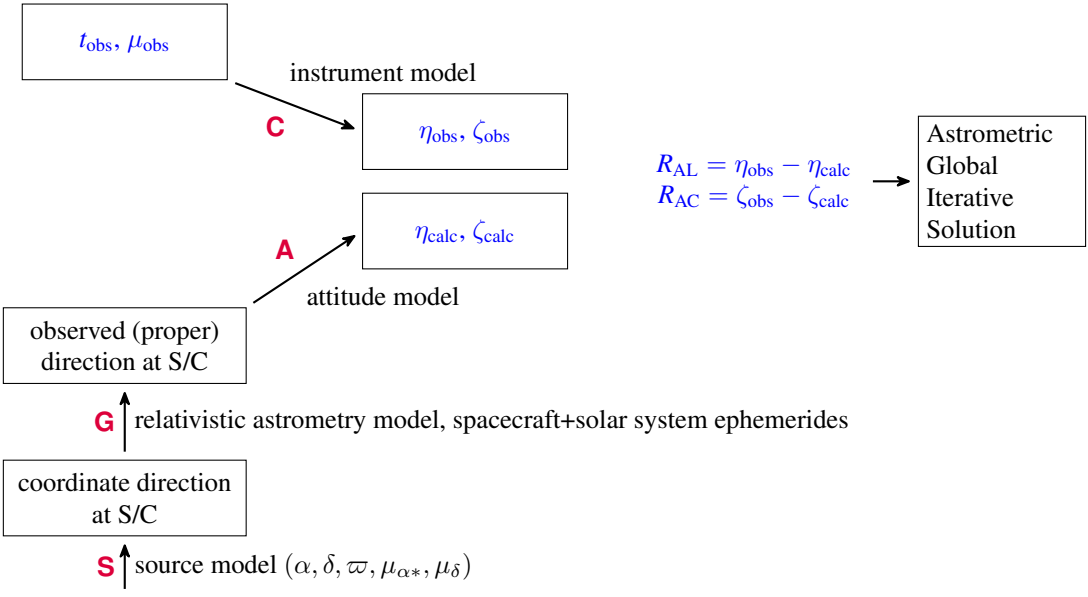
$\Rightarrow$ 'observation time' $t_{\rm obs}$
$+$AC pixel coordinate $\mu_{\rm obs}$

Astrometric modelling in terms of field angles (η, ζ)



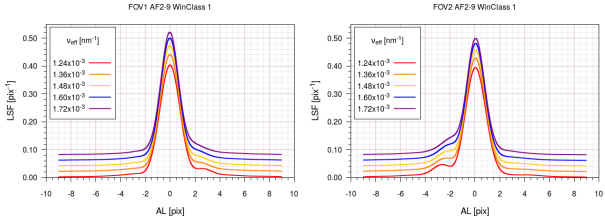
- Γ_c: basic angle between two fields of view (conventional value)
- $\boldsymbol{u}$: observed direction to source in S/C frame $[\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{z}]$
  - specified by instrument angles φ, ζ
  - $-\pi \leq \varphi < \pi$, $-\pi/2 \leq \zeta \leq \pi/2$
- Gaia astrometry is modelled in terms of along and across-scan 'field angles' η, ζ
  - $f = \mathrm{sign}(\varphi)$, $\eta = \varphi - f\Gamma_c/2$

Astrometric modelling in terms of field angles (η, ζ)



Limitations on accurate determination (η, ζ)

- PSF model limitations
  - dependency on time, colour, focal plane position, etc
  - bright images more sensitive to PSF model inadequacies, exacerbated by saturation
  - will be fixed in future data releases (DR3+)
- NOTE: for DR2 no colour dependent PSF employed; for DR3 only mean colour accounted for
  - important limitation for parallaxes of variable stars



Colour and time dependent PSF models. Credits ESA/Gaia/DPAC/CU3

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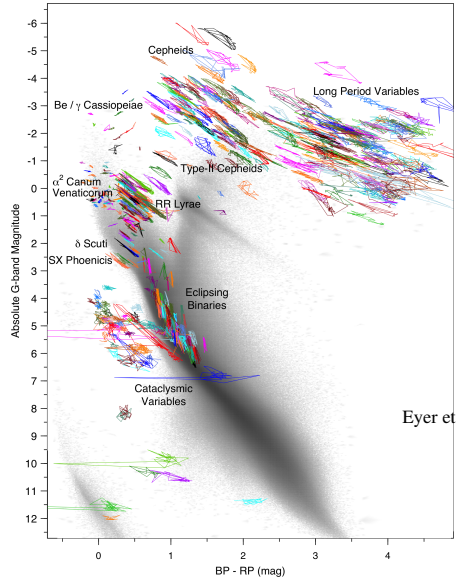
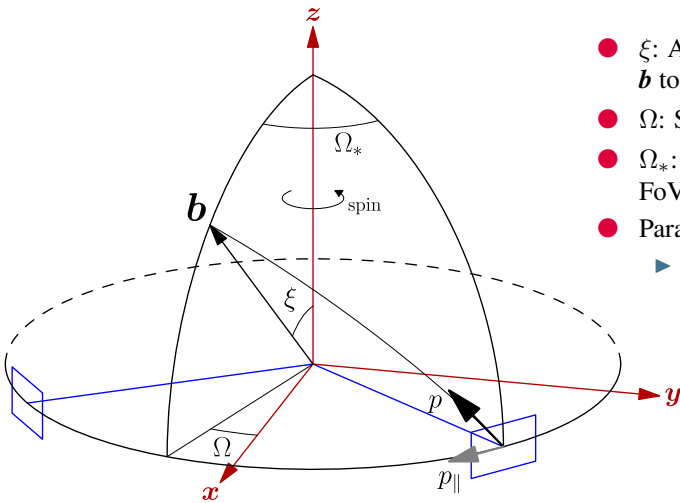


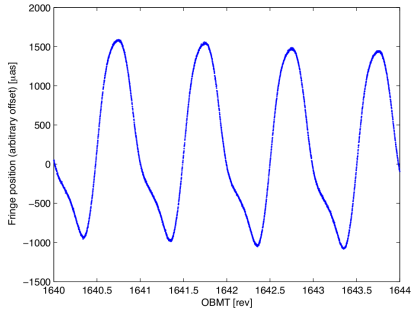
Eyer et al. (2019)

Parallax as seen by Gaia

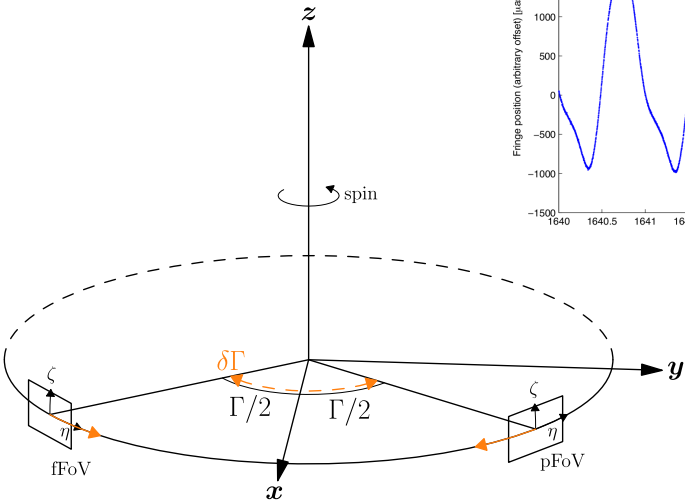


- ξ: Angle between S/C spin axis and direction $\boldsymbol{b}$ to solar system barycentre ($\sim 45°$)
- Ω: Spin phase of S/C
- Ω_*: 'Spin phase' of star observed in preceding FoV
- Parallax displacement along scan direction
  - $p_\parallel = -\varpi \sin\Omega_* \sin\xi$

Basic angle variations and the parallax zero point

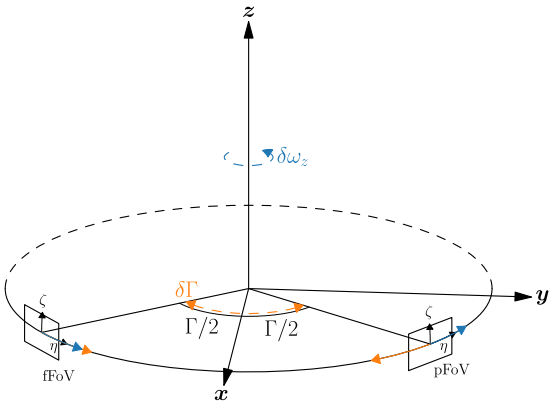


$\delta\Gamma(t)$ as measured by on-board metrology device (Lindegren et al. 2016)

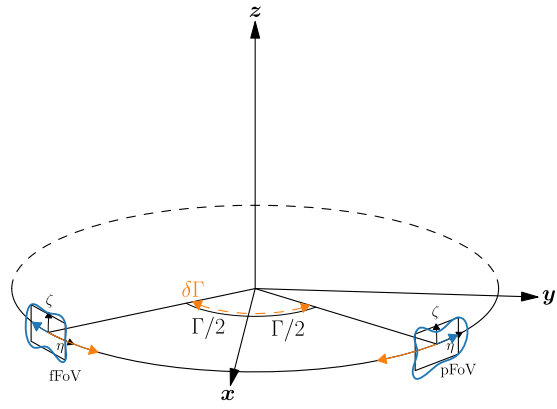


- $\delta\Gamma = \sum_{k\geq 0} a_k \cos(k\Omega) + b_k \sin(k\Omega)$
- Coefficient a_1 is only one almost degenerate with parallax zero point
- See Butkevich et al. (2017)

Interacting degeneracies



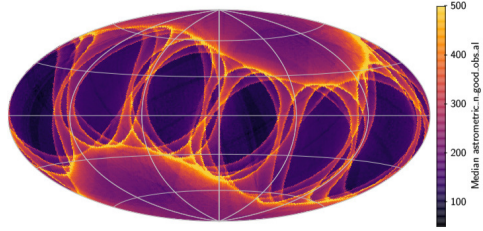
Shifts in η due to combined change of z-attitude and basic angle

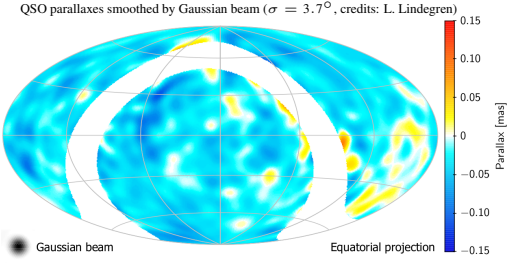


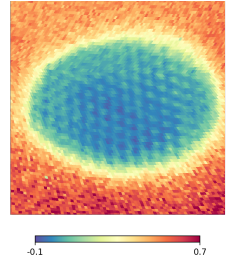
Shifts in η due to combined change of optical distortion and basic angle

Systematics projected on the sky

- Combinations of attitude and calibration errors (including basic angle and instrument model) can be (mis-)interpreted as changes to astrometric source parameters
  - attitude modelling harder for bright stars
- Filtered through scanning law this could explain patterns seen in systematics







Median parallaxes LMC region (Arenou et al. 2017)

Developments to reduce systematic errors

Accuracy (η, ζ)

- Improvements in PSF models
  - including treatment of CTI effects
- Take source epoch colour into account
- Iterate between AGIS and image location process

Self-calibration to reduce impact of AGIS degeneracies

- Characterize in detail which attitude/basic angle variations are degenerate with source parameters
- Design self-calibration models to avoid the above null-space
- Improve geometric calibration model of instrumental variations on time scales $<$ 6h

Stay tuned for next data releases...

...and keep investigating/calibrating the zero-point(s)!

Your papers are the best argument for an extended Gaia mission

Gaia 👍

- Please acknowledge the work by DPAC and ESA in your papers!
  - helps us argue the case for continued funding of the data processing
  - `https://gea.esac.esa.int/archive/documentation/credits.html`
- Communicate your Gaia results
  - `https://www.cosmos.esa.int/web/gaia/communicating-your-results`