Spettrofotometria: calibrazione assoluta

INAF - Osservatorio Astronomico Bologna

SPSS - DU13	FTE	
E. Pancino (manager)	0.5	
G. Altavilla	1.0	TD
M. Bellazzini	0.2	
A. Bragaglia	0.1	
G. Cocozza	1.0	AR
L. Federici	0.1	
S. Galleti	1.0	AR
S. Marinoni (ASDC+OARM)	0.2	AR
S. Ragaini	0.5	AR
TOTALE	**4.6**	

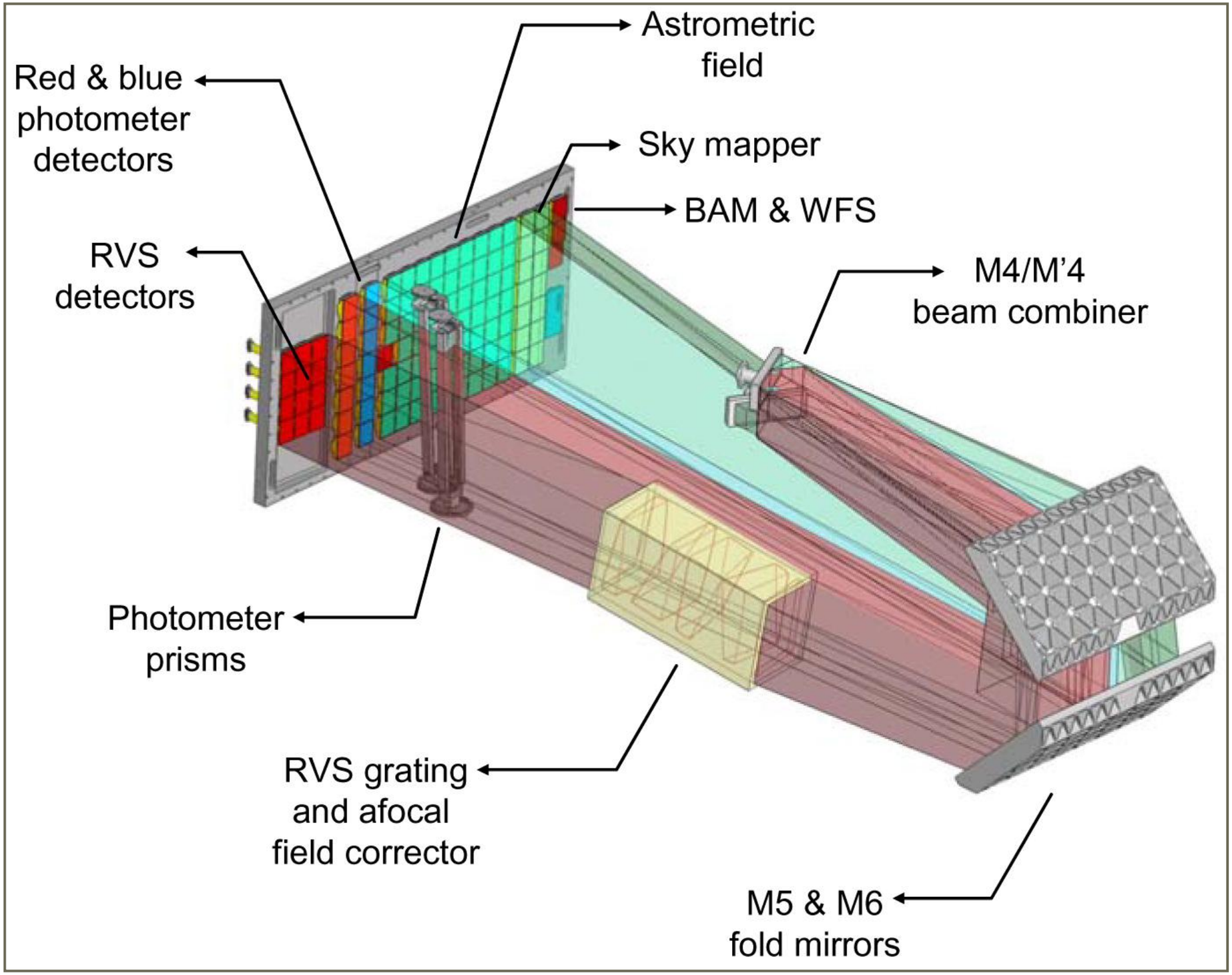
Model - DU14	FTE	
C. Cacciari (manager)	0.5	
M. Bellazzini	0.1	
P. Montegriffo	0.9	
S. Ragaini	0.5	AR
TOTALE	**2.0**	

The instruments

R ~ 80 – 20

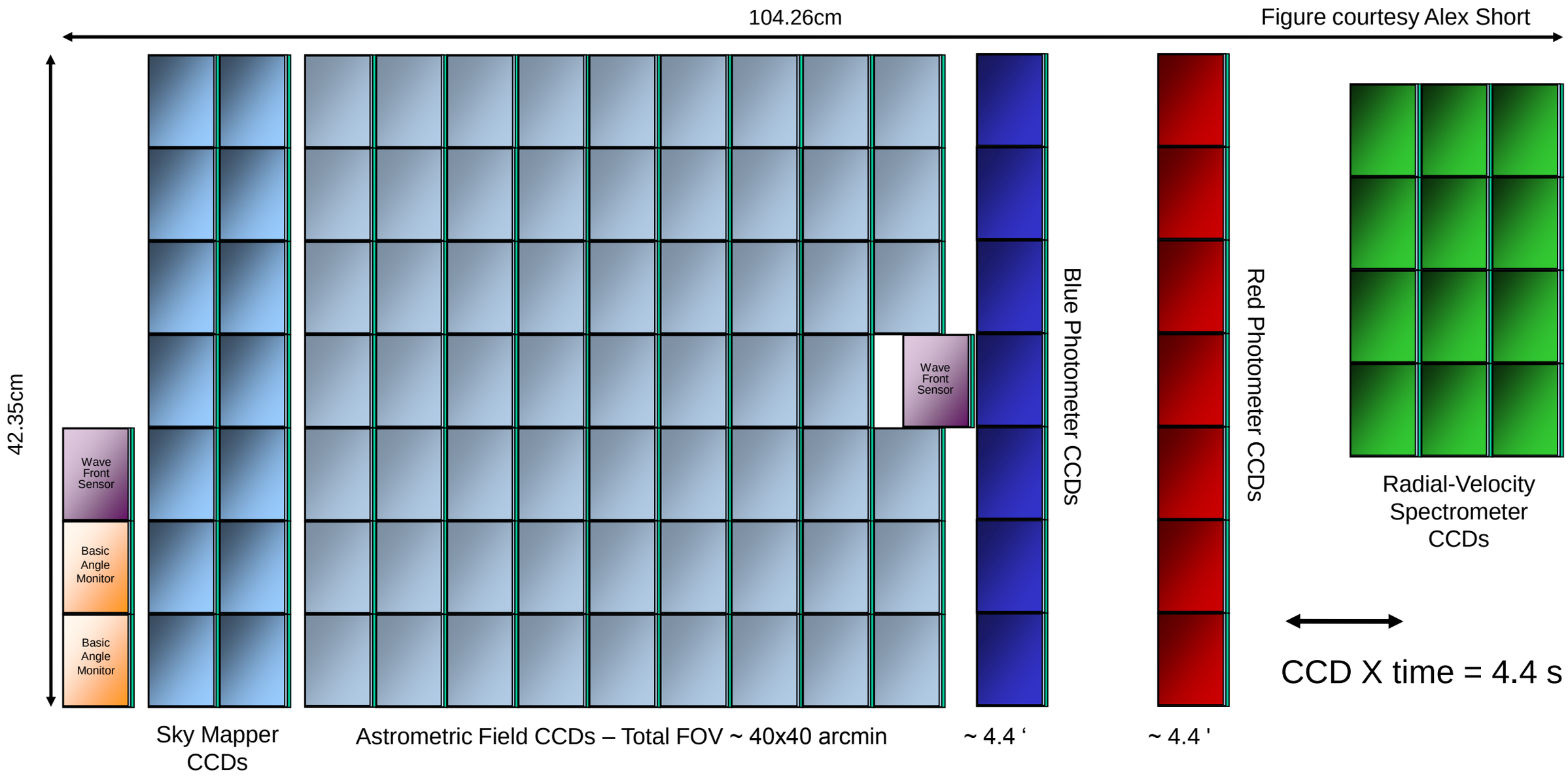
R ~ 90 – 70

Slitless spectroscopy on Ca triplet (847–874 nm) Resolution ~11,000



Figures courtesy EADS-Astrium

Focal Plane



Total field:
- active area: 0.75 deg^2
- CCDs: 14 + 62 + 14 + 12
- each CCD: 4500x1966 px (TDI)
- pixel size = 10 µm x 30 µm
  = 59 mas x 177 mas

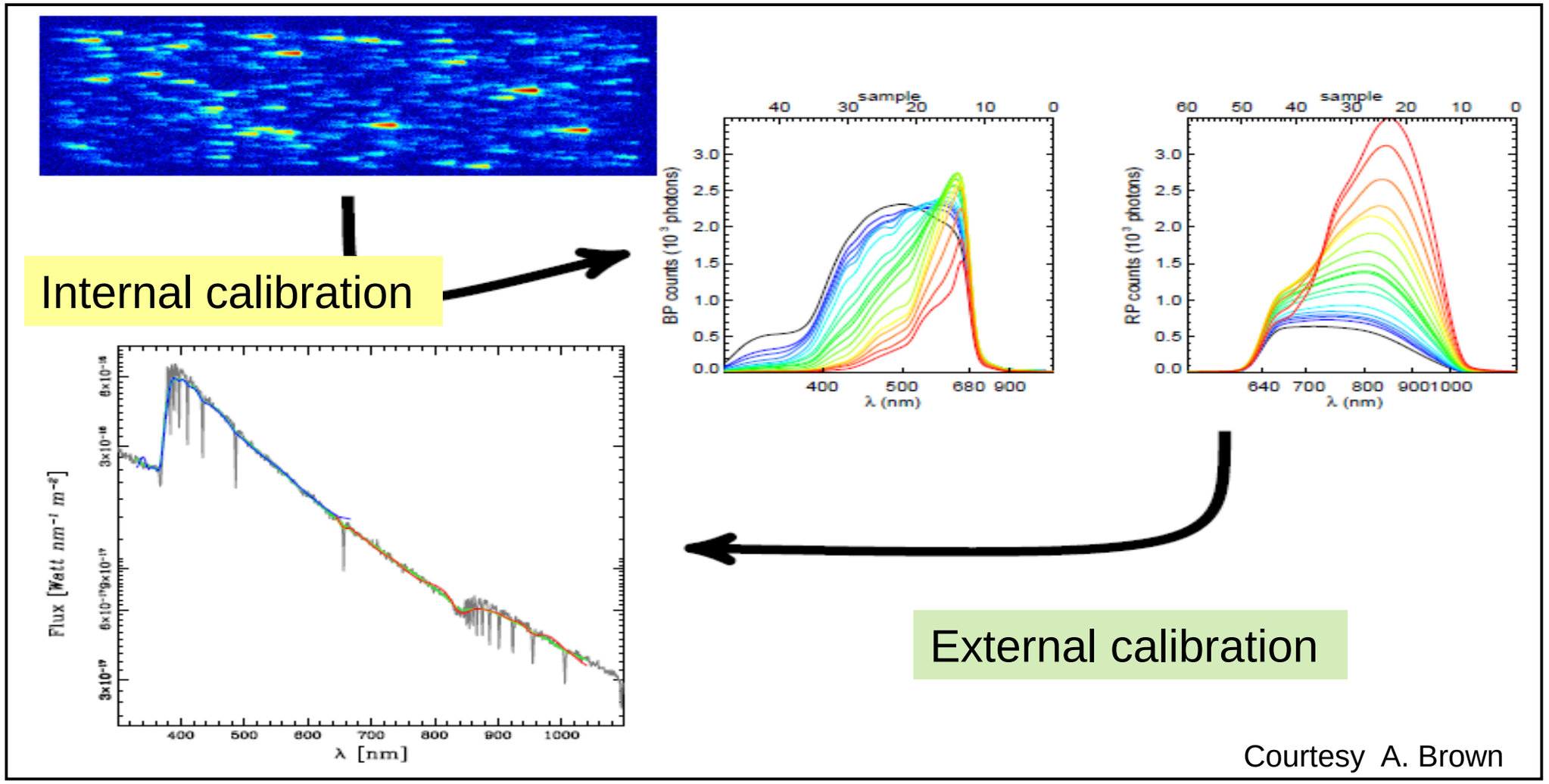
Sky mapper:
- detects all objects to 20 mag
- rejects cosmic-ray events
- FoV discrimination

Astrometry:
- total detection noise: 6 e$^-$

Photometry:
- spectro-photometer
- blue and red CCDs

Spectroscopy:
- high-resolution spectra
- red CCDs

Gaia spectro-photometric system



Courtesy A. Brown

- same principle as classical spectrophotometry calibration
- much more complex instrument model: characterize 62 CCD (AF) + 7 (BP) +7(RP)
  ➔ mean *internal* instrument ➔ mean *external* instrument

Gaia spectro-photometric calibration

Integrated photometry

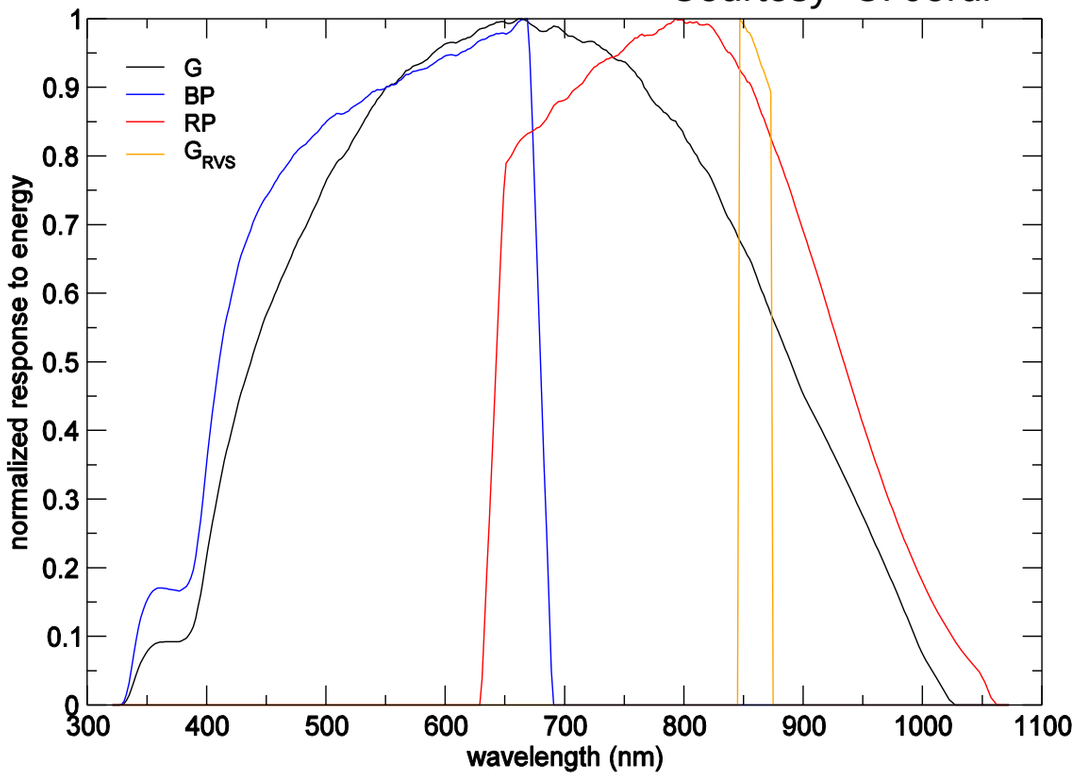
Spectro-photometry

G: luce bianca (AF)
330 – 1030 nm

G_{BP} : banda blu
330 – 690

G_{RP} : banda rossa
630 –1080

Courtesy C. Jordi



BP: **R = 80 – 20**
disp 4-32 nm/px

RP: **R = 90 – 70**
disp 7-15 nm/px

Internal calibration: corrects relative instrument response **variations wrt mean instrument ➔ fluxes and SEDs in internal flux and pseudo-wavelength scales**

External calibration: **ties mean instrument response to absolute flux and wavelenght scales**

Internal & external calibration goals

- ***Internal*** calibration means removing following effects using to model:

  -- geometry (e.g. CCD misalignment)
  -- CCD response variations *(*QE, flat-fielding, etc.)
  -- dispersion curve variations (spectra only)
  -- PSF/LSF variations (spectra only)
  -- effects of gates
  -- across-scan (AC) flux loss
  -- other effects (varying full well capacity, background non-uniformity, contamination, CTI, etc.)
  -- all of the above as a function of FoV and AC coordinate

a few millions of non-variable stars as internal standards

- ***External*** calibration removes remaining effects using to model**:**

  -- **dispersion & LSF & wavelength absolute calibration (spectra)**
  -- **mean instrument response in absolute flux scale (photometry & spectra)**

~ 200 flux-calibrated spectro-photometric standard stars (SPSS)

External calibration model – integrated photometry

Goal: derive true filter response R(λ) using SPSS data

For each one of the ~ 200 SPSS

$$f_{obs} = \int_0^{\infty} R(\lambda) \cdot S(\lambda)\ d\lambda$$

f_{obs} : internally calibrated integrated flux in any of G/BP/RP bandpass

S(λ): tabular flux data points (**SED**) at some λ-sampling

R(λ): G/BP/RP bandpass (i.e. **instrument response**, same λ-sampling as SED), i.e. convolution of: telescope & camera optics, mirror reflectivity & attenuation, CCD characteristics (QE, FWC, etc.), filter coating, prism transmissivity, etc.

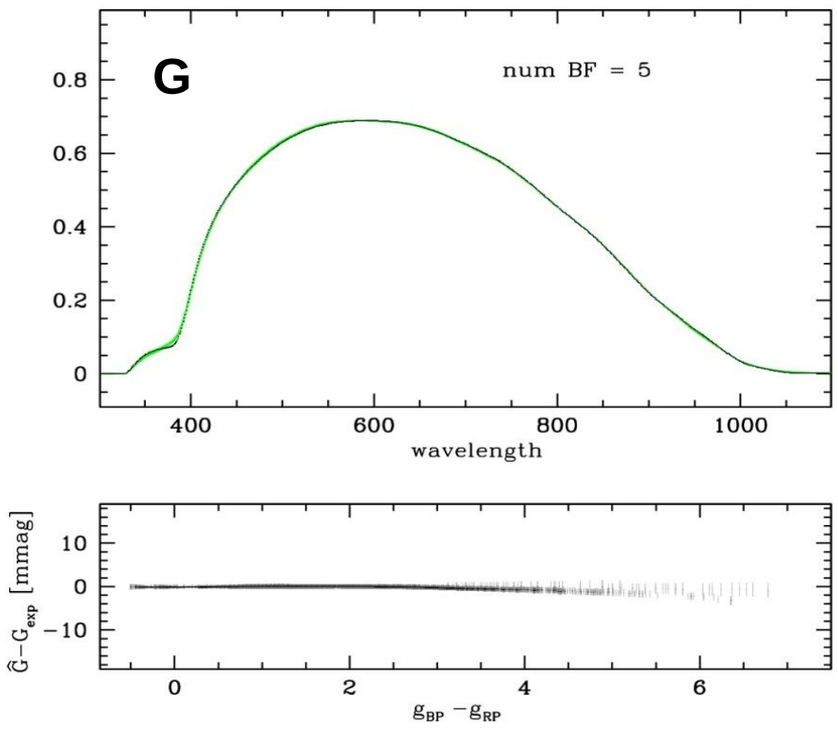
undersampling ➔ decrease dimensions

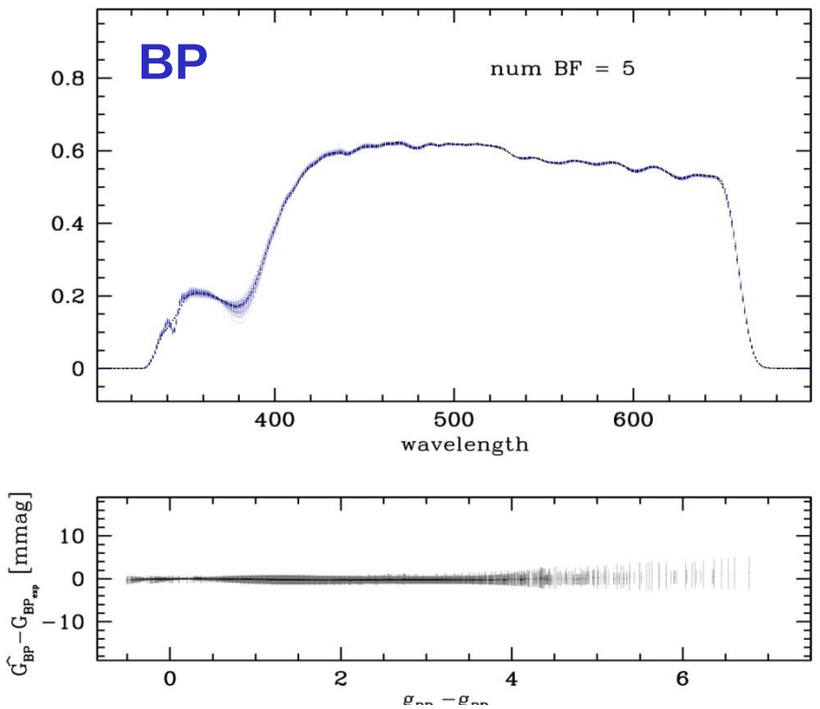
➔ parametrize R(λ) shape as linear combination of ***n*** optimal basis functions derived via PCA method

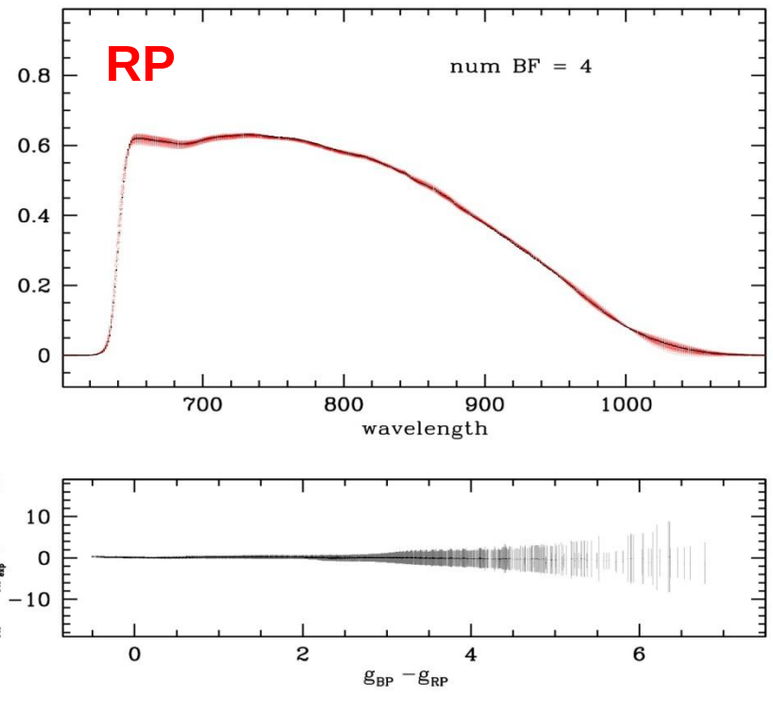
$$R(\lambda) = \sum_{i=0}^{n} b_i\ B_i(\lambda) \qquad n \sim 4\text{-}5$$

External calibration model – integrated photometry

Goal: derive true filter response R(λ) using SPSS data







- **re-define photometric system on SPSS**
- **no color equation, calibrate only flux zero-point**

Calibration model **R(λ)** applied to a large sample of test stars with Montecarlo simulations

reliable and robust calibration model

final expected accuracy ≤ 1-2%

External calibration model definition - BP/RP spectra

Goal: derive true SED shape & absolute flux S(λ) using SPSS data

Mean (internally calibrated) spectra $\mathbf{f_{obs}(u)}$ can be modelled as

$$f_{obs}(u) = \int_0^\infty R(\lambda) \cdot L_\lambda(u - u_0(\lambda)) \cdot S(\lambda)\, d\lambda$$

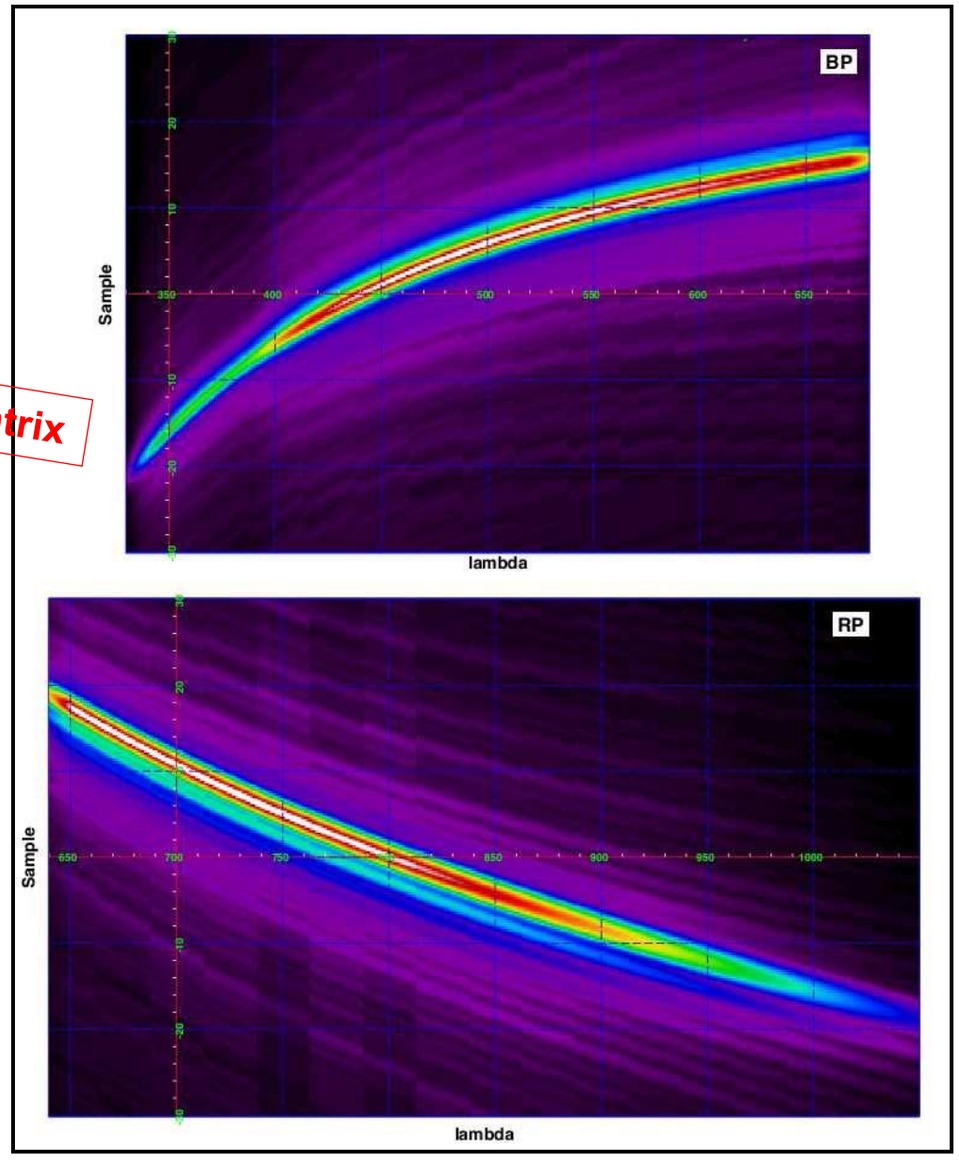
instrument response matrix

R(λ): filter response function, i.e. same as for integrated photometry

L(λ): effective monochromatic LSF

u_0(λ): dispersion function

u: AC pixel coordinate



LSF

Shape of photometric band R(λ)

External calibration model implementation - BP/RP spectra

$$f_{obs}(u) = \int_0^{\infty} R(\lambda) \cdot L_\lambda(u - u_0(\lambda)) \cdot S(\lambda)\ d\lambda$$

R(λ): modelled by linear combination of basis functions – same as for integrated photometry

L(λ): modelled by linear combination of **specific** basis functions

$$L_\lambda(u) = H_{0,\lambda}(u) + \sum_{n=1}^{N} h_n(\lambda) \cdot H_{n,\lambda}(u)$$

$$h_n(\lambda) = \sum_{i=0}^{I} q_{ni} \left(\frac{\lambda - \lambda_0}{\lambda_0} \right)^i$$

u_0(λ): modelled by a polynomial function

solve for all SPSS ➔ calibration model

$$S(\lambda) = \begin{cases} (f_{\lambda_0}, f_{\lambda_1}, ..., f_{\lambda_n}) & External\ calibrators \\ \sum_{\delta=0}^{N_\delta} b_\delta\ B_\delta(\lambda) & all\ other\ sources \end{cases}$$

External calibration model implementation - BP/RP spectra

$$f_{obs}(u) = \int_0^\infty R(\lambda) \cdot L_\lambda(u - u_0(\lambda)) \cdot S(\lambda)\ d\lambda$$

R(λ): modelled by linear combination of basis functions – same as for integrated photometry

L(λ): modelled by linear combination of **specific** basis functions

u_0(λ): modelled by a polynomial function

$$L_\lambda(u) = H_{0,\lambda}(u) + \sum_{n=1}^{N} h_n(\lambda) \cdot H_{n,\lambda}(u)$$

$$h_n(\lambda) = \sum_{i=0}^{I} q_{ni} \left(\frac{\lambda - \lambda_0}{\lambda_0} \right)^i$$

solve for all SPSS ➔ calibration model

$$S(\lambda) = \begin{cases} (f_{\lambda_0}, f_{\lambda_1}, ..., f_{\lambda_n}) & External\ calibrators \\ \sum_{\delta=0}^{N_\delta} b_\delta\ B_\delta(\lambda) & all\ other\ sources \end{cases}$$

apply calibration model ➔ calibrated SEDs

Final expected accuracy ~ 1-3%
Work in progress

Spectro-Photometric Standard Stars (SPSS)

Goal: provide the grid of SPSS (homogeneous flux scale, 1-3% accuracy)

SPSS candidates

- **three pillars** from CALSPEC, V ~ 11.5 to 13.5, **calibrated on Vega**
- **~ 50 primary standards,** ~ 9 ≤ V ≤ ~ 14 across the sky
- **~ 200 secondary standards,** ~ 9 ≤ V ≤ ~ 15 across the sky
- **all spectral types**, from bluest (e.g. WDs) to reddest (late types, reddened)
- initial sample of **~ 350 SPSS candidates**
- *possible addition ~200 bright (6.0 ≤ V ≤ 10.5) stars from NGSL for calibration of gated observations*

Observing campaign (in **GBOG)** started in 2007 at various sites:

TNG (La Palma, Canary Islands): spectroscopy, photometry
NTT (ESO, LaSilla) - spectroscopy, photometry
CAHA (Calar Alto, Spain): spectroscopy, photometry
1.5m (San Pedro Martir, Mexico): spectroscopy, photometry
REM (**(ESO, LaSilla):** variability monitoring
CASSINI (Loiano, Italy): spectroscopy, variability monitoring

→ **Interesting science being produced from variability monitoring**

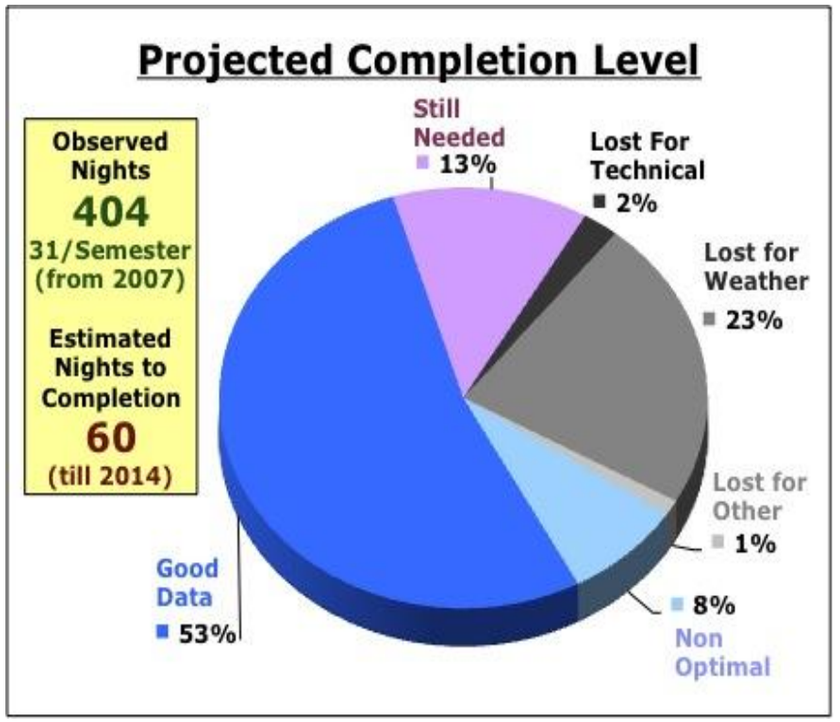
SPSS: status of observations and data processing

More than **400 nights already observed + 60** to complete survey ≤ 2014
SPSS sample: initial 350 stars, current 250 stars

GES awarded 240 + 60 nights, ~ 300 Co-Is !

- spectroscopy ~ 94% done, ~ 50% reduced, to be completed by end 2013
- photometry ~ 70% done, ≤ 40% reduced, expected completion by 2014
- variability monitoring ~ 90% done, expected completion by June 2014

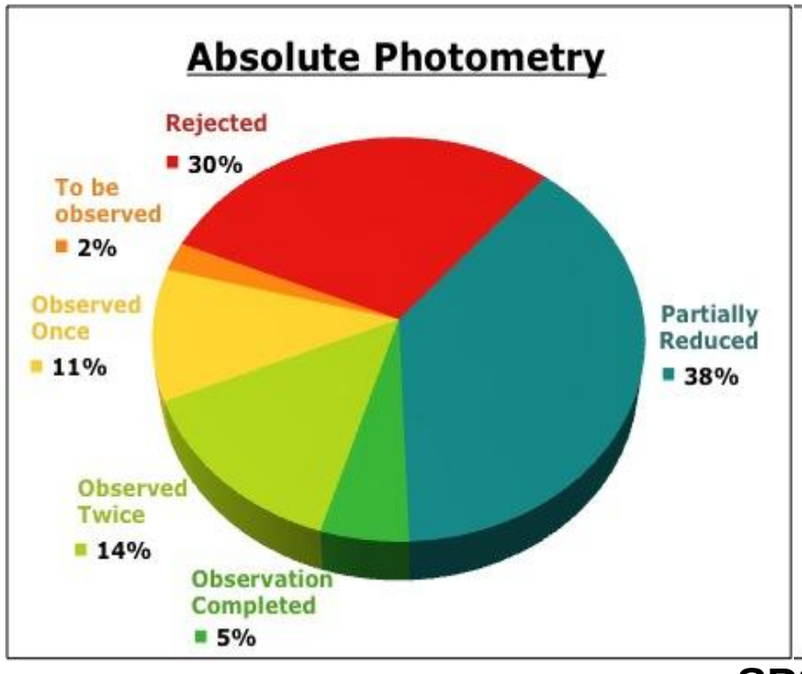
Observations

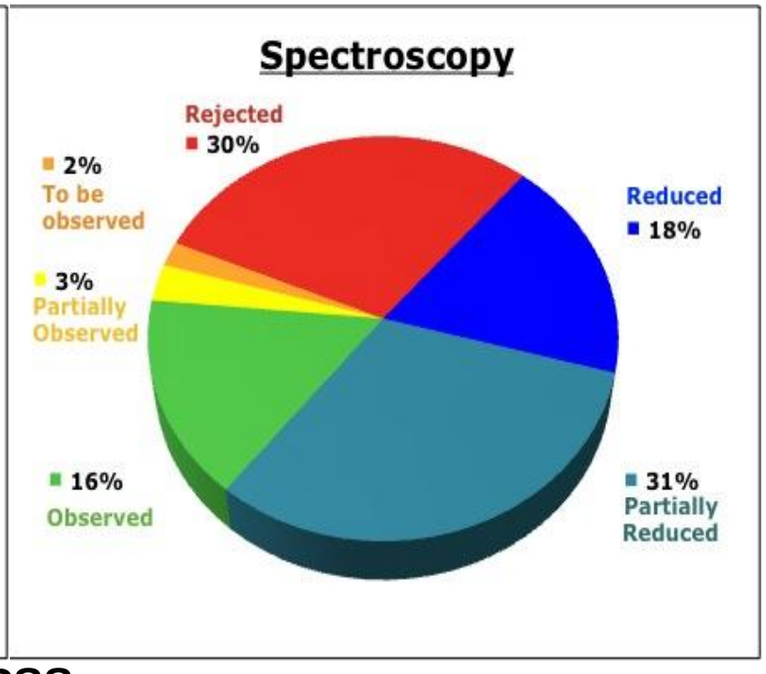


Pre-launch release
~ 100 SPSS

- ❑ non-optimal flux accuracy – initial calibration
- ❑ test calibration pipeline

Improvement → eom





SPSS

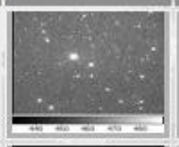
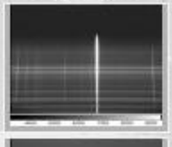
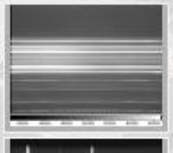
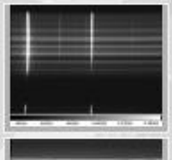
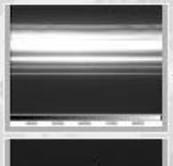
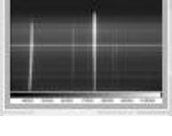
ASDC-SPSS archive & database

- Raw data: calibration, science, tests for instruments characterization **~ 10^5 frames in 410 nights**
- Reduced data: various intermediate data reduction levels
- Data products: photometric catalogues and long term light curves, absolute photometry, night quality parameters, synthetic magnitudes, **flux tables (stored also in Main DataBase)**
- Auxiliary data: filters and grisms characterization, reference data

Foreseen Releases

- DPAC only: dynamic, DU13 people working space
- Public: static, one for each Gaia Data Release

Web interface for data access and retrieval

					G_TEL	G_INST	G_RUNTYP	G_RUNID	G_NIGHT	G_SKY	G_ID	FILE_THUMB	G_TYPE	G_RAhms	G_DECdms	G_DATE	G_UT	G_HJD	G_EXPT	G_EFFAM	G_SEEING
1			File Download		CAHA2.2	CAFOS	M	001	2007-10-31	Clear	1		Pillar	05:06:10.31	+52:48:31.46	2007-10-31	22:04:25	2454405.42345234	10	1.511271	1.54
2			File Download		CAHA2.2	CAFOS	M	001	2007-10-31	Clear	1		Pillar	05:06:06.69	+52:48:42.52	2007-10-31	22:18:33	2454405.43668268	600	1.432132	1.54
3			File Download		CAHA2.2	CAFOS	M	001	2007-10-31	Clear	1		WaveLamp	05:08:47.64	+52:47:58.49	2007-10-31	22:33:58	2454405.44390024	1.5	1.403048	
4			File Download		CAHA2.2	CAFOS	M	001	2007-10-31	Clear	1		Pillar	05:06:10.04	+52:48:37.76	2007-10-31	23:03:27	2454405.46786456	600	1.28563	1.54
5			File Download		CAHA2.2	CAFOS	M	001	2007-10-31	Clear	1		WaveLamp	05:06:10.19	+52:48:36.90	2007-10-31	23:17:20	2454405.47405121	3	1.261966	
6			File Download		CAHA2.2	CAFOS	M	001	2007-10-31	Clear	1		Pillar	05:06:08.32	+52:48:31.46	2007-11-01	02:22:06	2454405.60582424	600	1.038576	1.4

Thank you !

Payload and Telescope

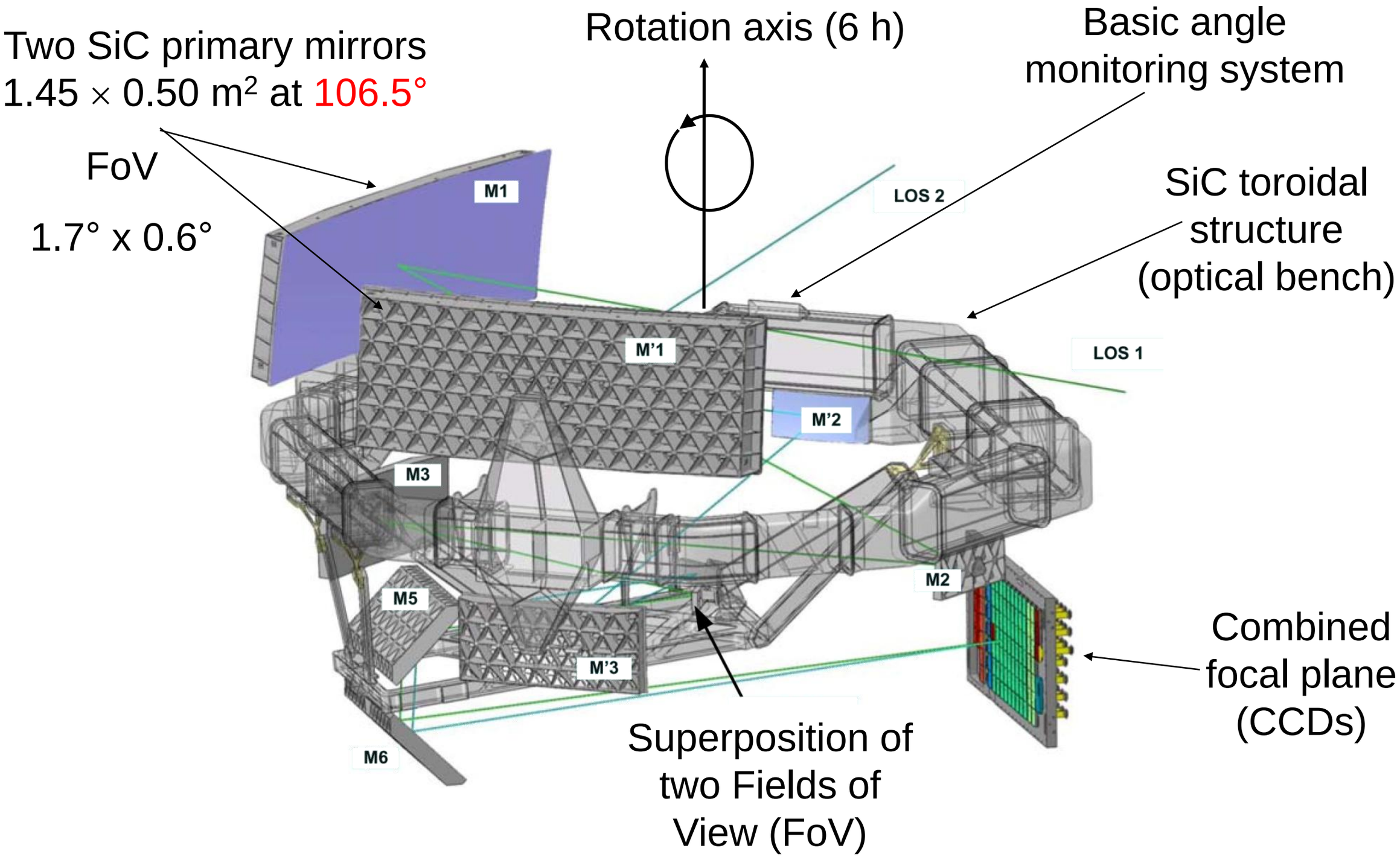
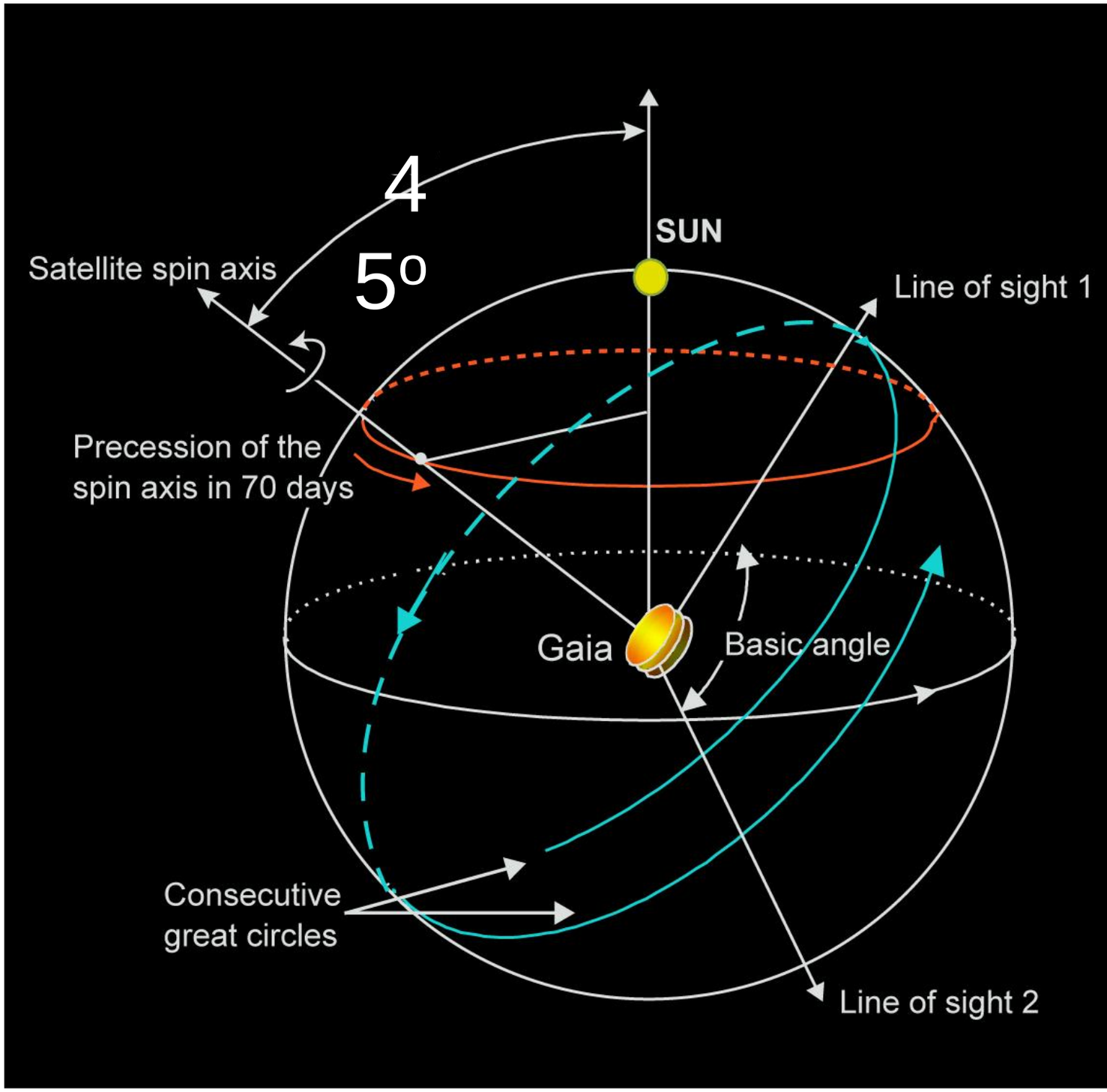


Figure courtesy EADS-Astrium

Sky Scanning Principle



Spin axis 45º to Sun
Scan rate: 60 arcsec/s
Spin period: 6 hours

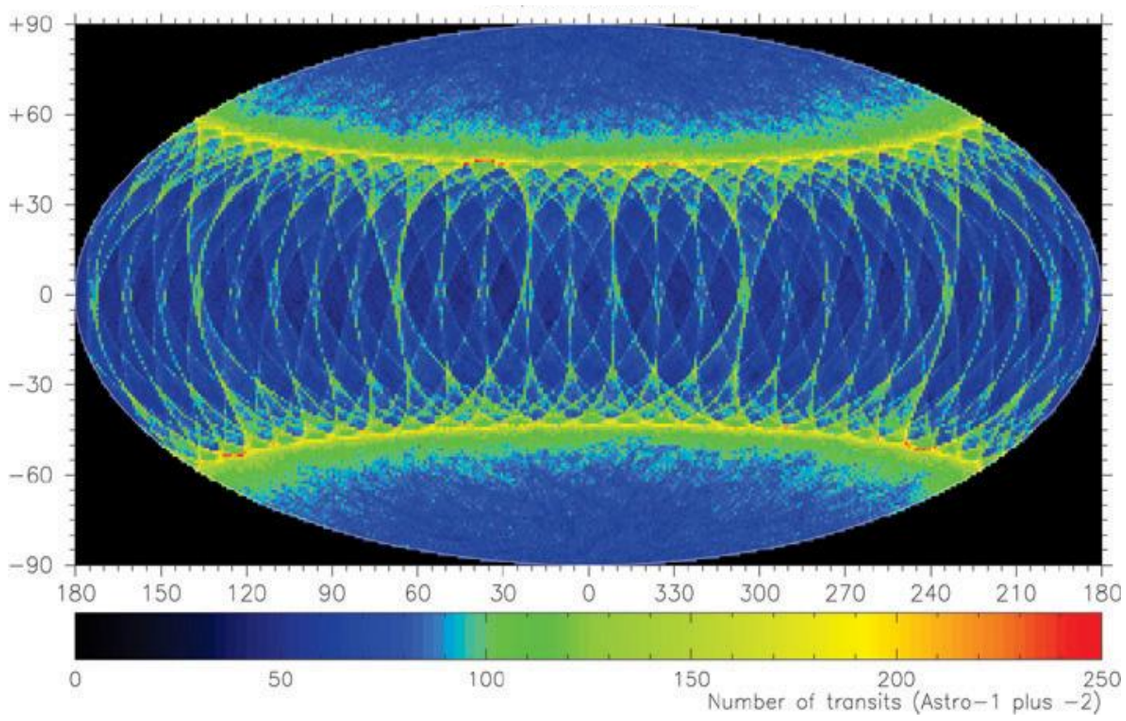
➔ less transits per FoV than Hipparcos (2.13 hr spin period)

➔ higher spatial resolution in focal plane (~ 0.1 arcsec)

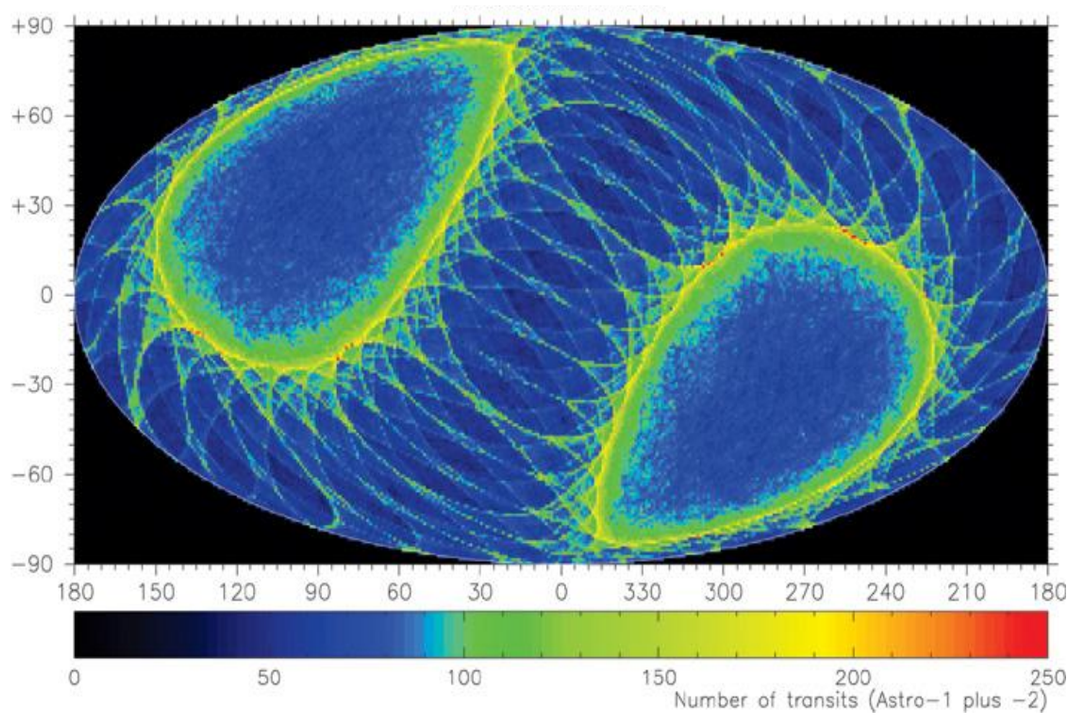
Figure courtesy Karen O'Flaherty

Transit maps

Ecliptic coordinates



Galactic coordinates



End of mission (5+1 yr) average (max) number of transits: about 80 (240)

Figure courtesy Karen O'Flaherty