Técnicas Astronómicas

Observatorio Virtual, Grandes Sondeos

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En esta clase

- ¿Qué es el VO?
- ¿Cómo acceder? ¿cómo buscar?
    - Ejemplos de herramientas para acceso a datos del VO
- ¿Qué buscar?
    - Sistemas Fotométricos asociados a sondeos en diferentes regiones del Espectro
    - Un breve recuento de grandes sondeos públicos

Observatorio Virtual *(VO=Virtual Observatory)*

- El "Observatorio Virtual" es un concepto, no un lugar específico o único

- Se refiere a los recursos en línea que proveen acceso a datos astronómicos como bases de datos, páginas web, servidores grandes donde se compilan los datos de misiones espaciales, sondeos grandes, telescopios, proyectos

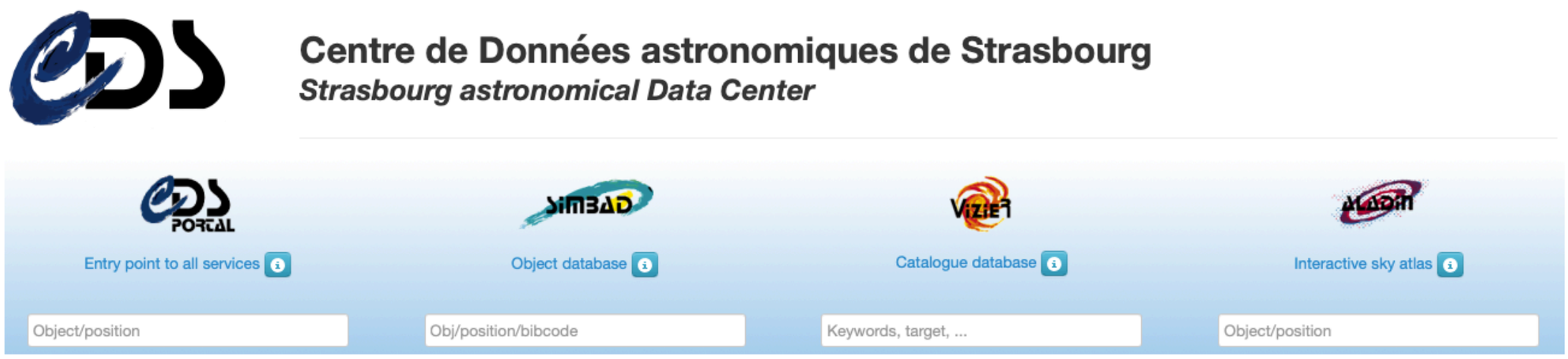
- Se ha definido una serie de estándares que brindan cierto grado de homogeneidad y permiten compartir/acceder a los datos en el VO desde diferentes herramientas

  - Protocolos de Acceso a Imágenes, a Espectros, Cone Search, …

¿Cómo acceder? ¿cómo buscar?

Herramientas para Acceder al VO

- ¿Cómo acceder a servicios VO?
- Hay numerosas herramientas para acceder a los diferentes servicios, vamos a ver algunas
  - Agregadores web: ej. VizieR / SIMBAD y Aladin (CDS - Centre de Donnees de Strasbourg)
  - Aplicaciones: ej. Topcat
  - Repositorios de Observatorios o Instituciones: ej. MAST, Gaia Archive, …
  - Todo esto se puede hacer programáticamente por ej. en Python (astroquery)



VizieR

- Web: Acceso a catálogos de Sondeos grandes, tablas de datos publicadas en artículos

Portal Simbad VizieR Aladin X-Match Other Help

VizieR

VizieR home . Photometry viewer . Query VizieR using TAP . X-match tables . Query images/spectra

Search Criteria

Preferences
max: 50
HTML Table
All columns
Compute

Mirrors
CDS, France

Find catalogs among 21382 available

Clear Find...

Expand search

Catalog, author's name, word(s) from title, description, etc. e.g.: AGN, Veron, I/239, or bibcodes...

Search for catalogs by column descriptions *(UCD)*

Search for catalogs containing additional data

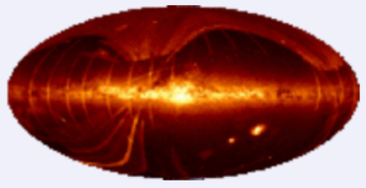
Wavelength	Mission	Astronomy
Radio	TESS	Gravitational_lensing
Millimeter	UIT	Gravitational_wave
IR	ULYSSES	GRB
optical	WISE	HII_regions
UV	WMAP	Intergalactic_medium
EUV	WUPPE	Interstellar_Medium
X-ray	XMM	Magnetic_fields

Search by Position across 23509 tables

Target Name (resolved by Sesame) or **Position**: Target dimension:

Clear J2000 2 arcmin Go!

NB: The epoch used for the query is the original epoch of the table(s) Radius Box size



More about VizieR

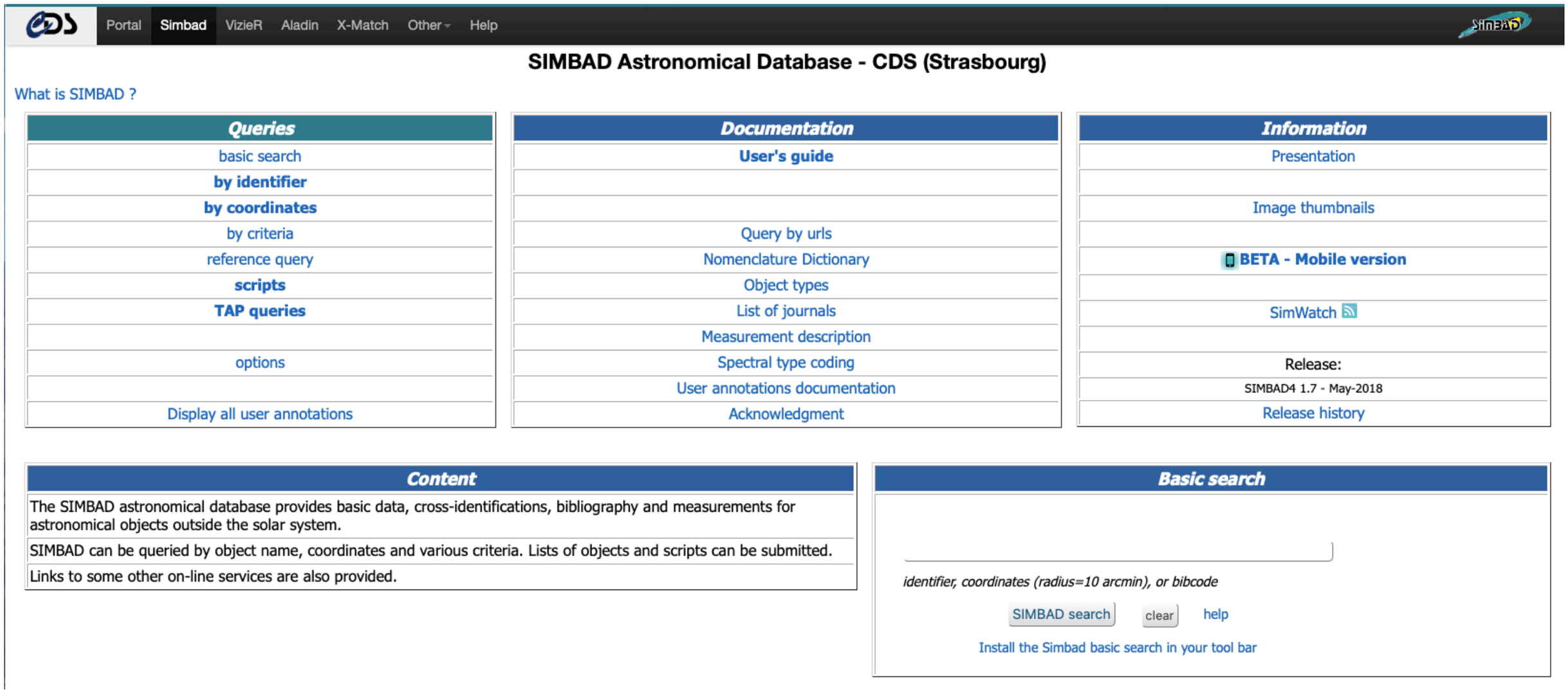
Find Catalogs

Tools related to VizieR

- **Catalogue collection** : Search VizieR catalogues available via various services (FTP, VizieR, TAP, ...)
- **CDS Portal** : Access CDS data including VizieR, Simbad and Aladin using the CDS portal
- **Spectra, images in VizieR** : Search Spectra, images in VizieR
- **Photometry viewer** : Plot photometry (sed) including all VizieR
- **TAP VizieR** : query VizieR using ADQL (a SQL extension dedicated for astronomy)
- **CDS cross-match service** : fast cross-identification between any 2 tables, including VizieR catalogues, SIMBAD

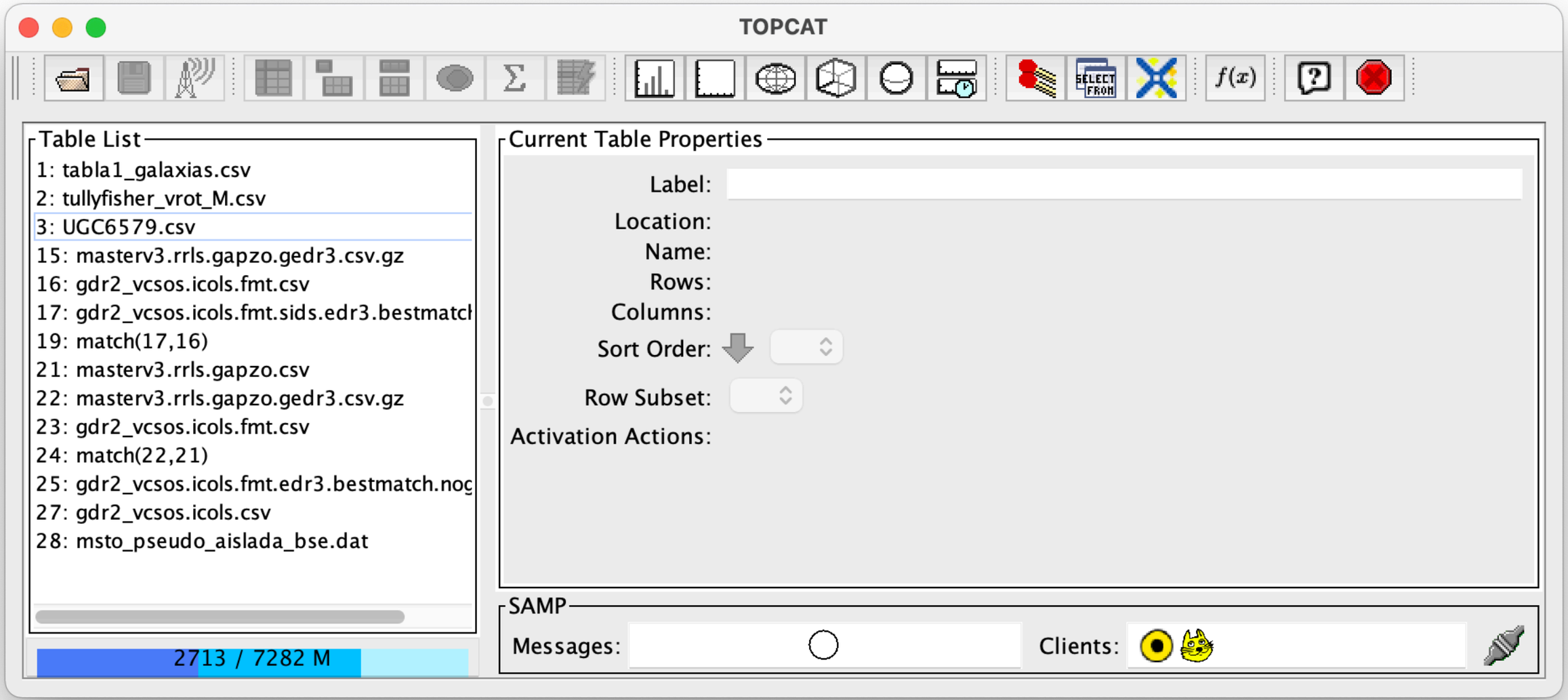
SIMBAD

- Web: Búsqueda de toda la información disponible en la literatura para objetos individuales



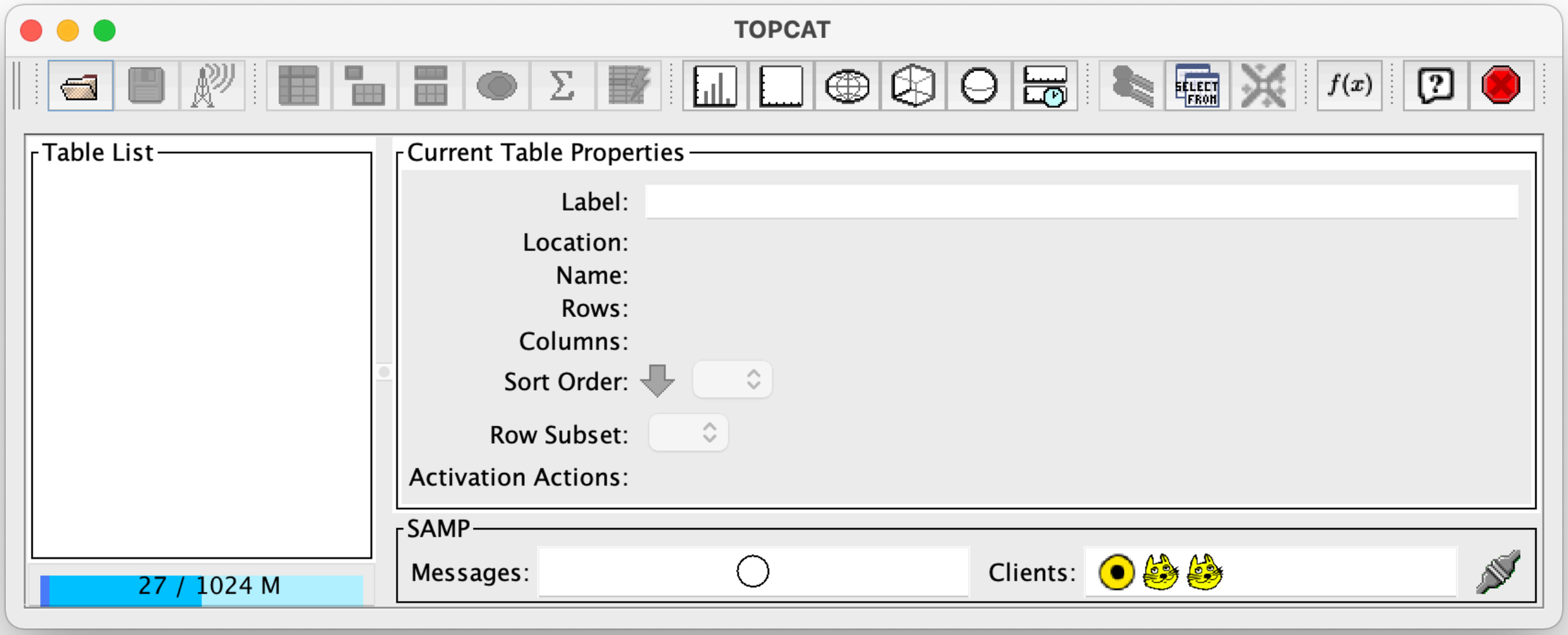
TOPCAT

- Es una aplicación java (programa) para manejo de tablas y catálogos astronómicos
- Cuenta con varias formas de acceder a datos de VO
- **De esto se tratará la clase del próximo lunes (tipo taller)**



Topcat

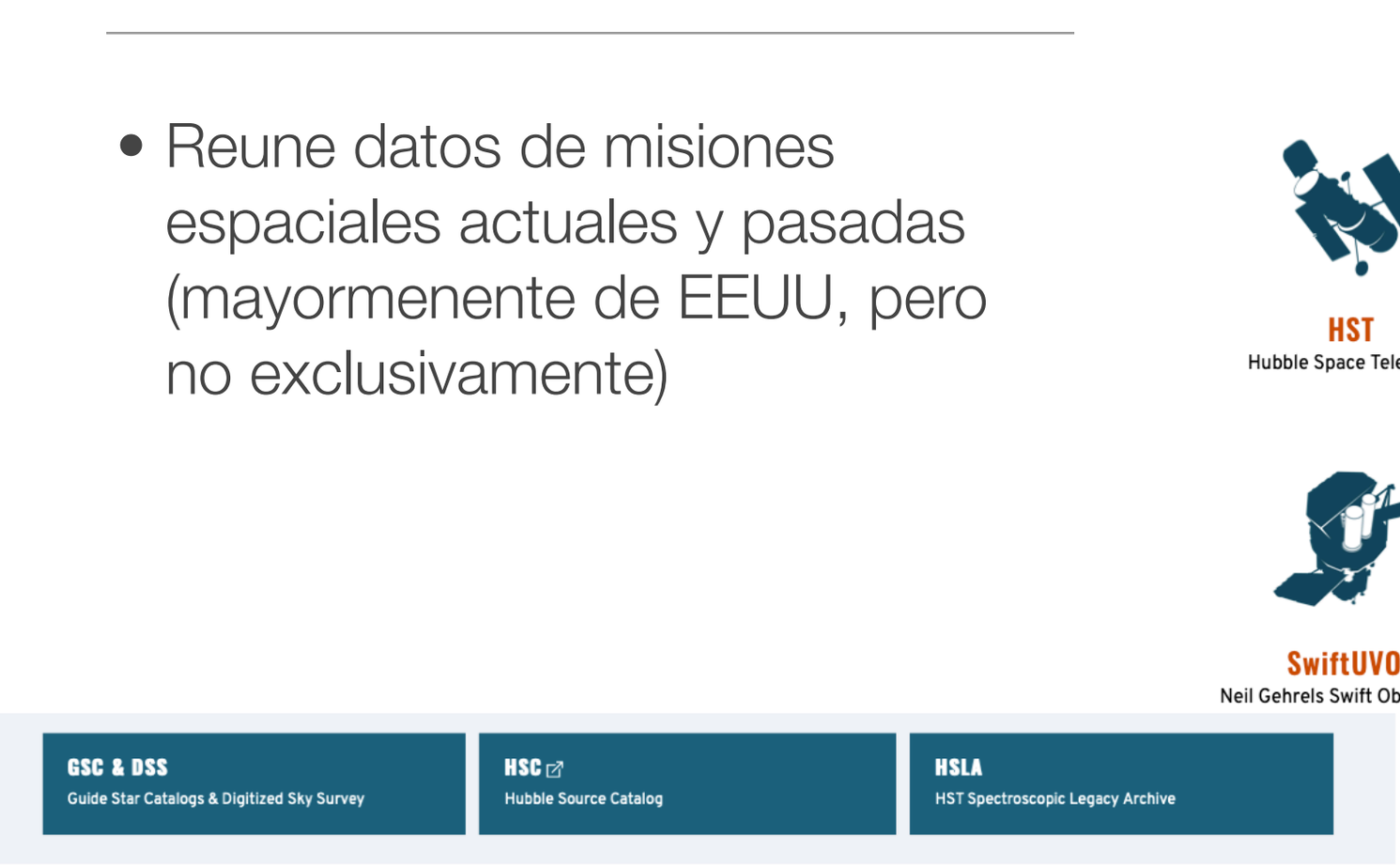
- Al hacer doble click en el archivo topcat-full.jar les saldrá esta ventana
- Si no aparece / da error es que no tienen instalado Java (es lo único que necesita)



Antes del lunes 8: Instalar Topcat (consultas por email/Slack)

MAST: Mikulski Archive Space Telescopes

- Reune datos de misiones espaciales actuales y pasadas (mayormenente de EEUU, pero no exclusivamente)



- Contiene datos procesados (Catálogos) + imágenes y espectros crudos/reducidos

- ‘Éste es sólo un ejemplo, otros observatorios tienen repositorios similares

¿*Qué* buscar?

Algunos sondeos públicos de gran cobertura

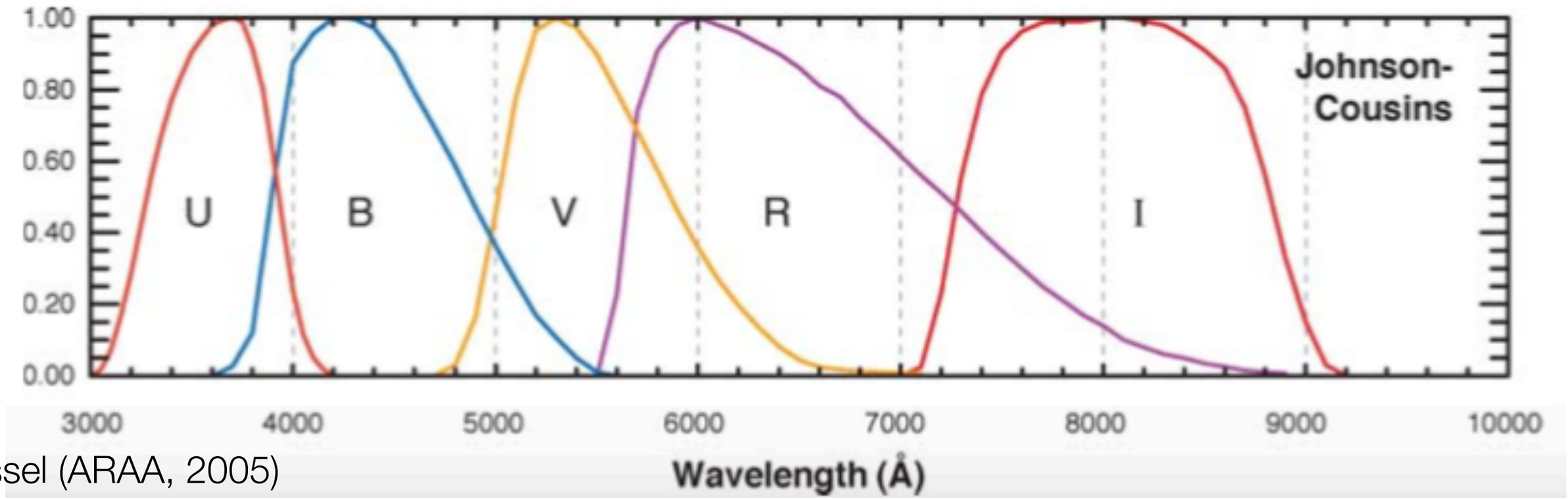
- Cercano Infrarrojo: (NIR) 2MASS
- Mediano Infrarrojo (MIR): AllWISE
- Ópticos:
    - SDSS: SDSS, SEGUE, APOGEE, ManGa
    - PanSTARRS-1, DeCAM
- Astrométricos (Óptico): UCAC 4., USNO B1, Hipparcos, **Gaia**
- Variabilidad: Catalina (CRTS), ASAS, SkyMapper, Gaia
- Futuro Inmediato: LSST, SDSS-V

Ojo: diferentes sondeos usan, además de diferentes filtros, diferentes sistemas fotométricos…

Definición de los sistemas estándar de magnitudes

Magnitudes Vega

- Sistema Johnson: UBVRIJHK
  - Se *define* de manera que Vega (Alpha Lyrae) tiene colores =0 y V=0.03 mag
  - Hayes & Lathan (1975) calibraron el flujo de Vega: 3500 Jansky @ 5556 Angstrom
  - Para calibrar UBVRI en este sistema se usan los Estándares de Landolt (1992, 2007)
  - Para calibrar JHK se puede usar el catálogo 2MASS, que está calibrado uniformemente a este sistema



Bessel (ARAA, 2005)

Magnitudes Vega

- Dado el flujo en el filtro X (UBVRIJHK) integrado en longitud de onda, la magnitud (en sistema Vega) en el filtro X se calcula como:

$$\mathrm{mag}_\lambda = -2.5\log(f_\lambda) - 21.1 - \mathrm{zp}(f_\lambda)$$

	U	B	V	R	I	J	H	K	Kp	L	L*
λ_{eff}	0.366	0.438	0.545	0.641	0.798	1.22	1.63	2.19	2.12	3.45	3.80
f_ν	1.790	4.063	3.636	3.064	2.416	1.589	1.021	0.640	0.676	0.285	0.238
f_λ	417.5	632	363.1	217.7	112.6	31.47	11.38	3.961	4.479	0.708	0.489
$zp(f_\lambda)$	0.770	-0.120	0.000	0.186	0.444	0.899	1.379	1.886	1.826	2.765	2.961
$zp(f_\nu)$	-0.152	-0.602	0.000	0.555	1.271	2.655	3.760	4.906	4.780	6.775	7.177

ojo, error en la tabla publicada

f_ν (10^{-20} ergs cm^{-2} sec^{-1} hz^{-1})
f_λ (10^{-11} ergs cm^{-2} sec^{-1} Å^{-1})
$\mathrm{mag}_\lambda = -2.5 \log (f_\lambda) - 21.100 - zp(f_\lambda)$
$\mathrm{mag}_\nu = -2.5 \log (f_\nu) - 48.598 - zp(f_\nu)$

Bessell (1998)

- o, análogamente si el flujo está integrado en frecuencia

$$\mathrm{mag}_\nu = -2.5\log(f_\nu) - 48.598 - \mathrm{zp}(f_\nu)$$

ver notas de O'Connell en http://web.ipac.caltech.edu/staff/fmasci/home/astro_refs/magsystems.pdf

Magnitudes AB

- Se *define* de manera que si el flujo monocromático Fν es medido en erg/(s cm^2 Hz) la magnitud es

$$m(AB) = -2.5 \log F_\nu - 48.6$$

- donde la constante está elegida tal que m(AB)=V para una fuente de espectro plano (*uniforme) en frecuencia*

- En el sistema AB una fuente de espectro plano en frecuencia tiene colores nulos

conversión entre los sistemas Vega y AB

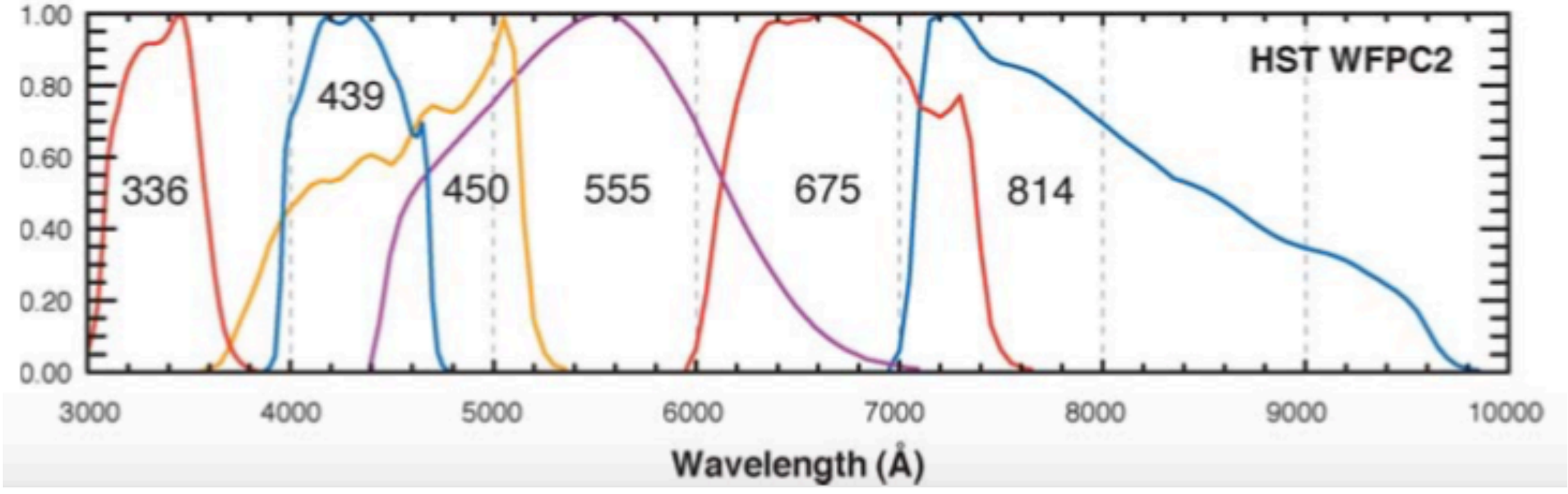
```
 V   =   V(AB) + 0.044   (+/- 0.004)
 B   =   B(AB) + 0.163   (+/- 0.004)
Bj   =  Bj(AB) + 0.139   (+/- INDEF)
 R   =   R(AB) - 0.055   (+/- INDEF)
 I   =   I(AB) - 0.309   (+/- INDEF)
 u'  =  u'(AB) + 0.0
 g'  =  g'(AB) + 0.0
 r'  =  r'(AB) + 0.0
 i'  =  i'(AB) + 0.0
 z'  =  z'(AB) + 0.0
Rc   =  Rc(AB) - 0.117   (+/- 0.006)
Ic   =  Ic(AB) - 0.342   (+/- 0.008)
```

Frei & Gunn (1994)

Sistema STMAG

- Se define como el sistema AB pero tal que una fuente de espectro *plano en longitud de onda* tiene colores nulos

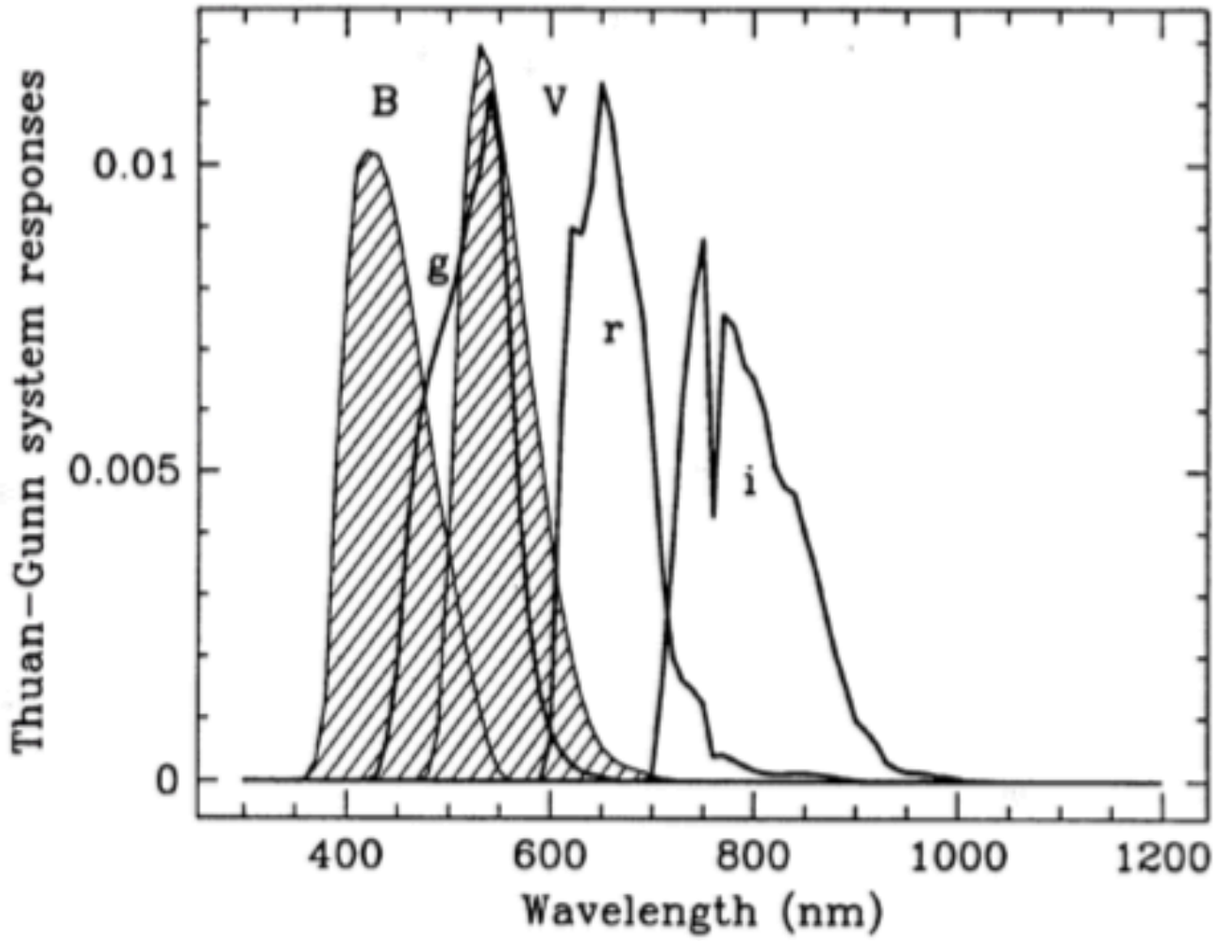
- Usado para el sistema de filtros del Telescopio Espacial Hubble.
- Los sistemas AB y STMAG se llaman monocromáticos

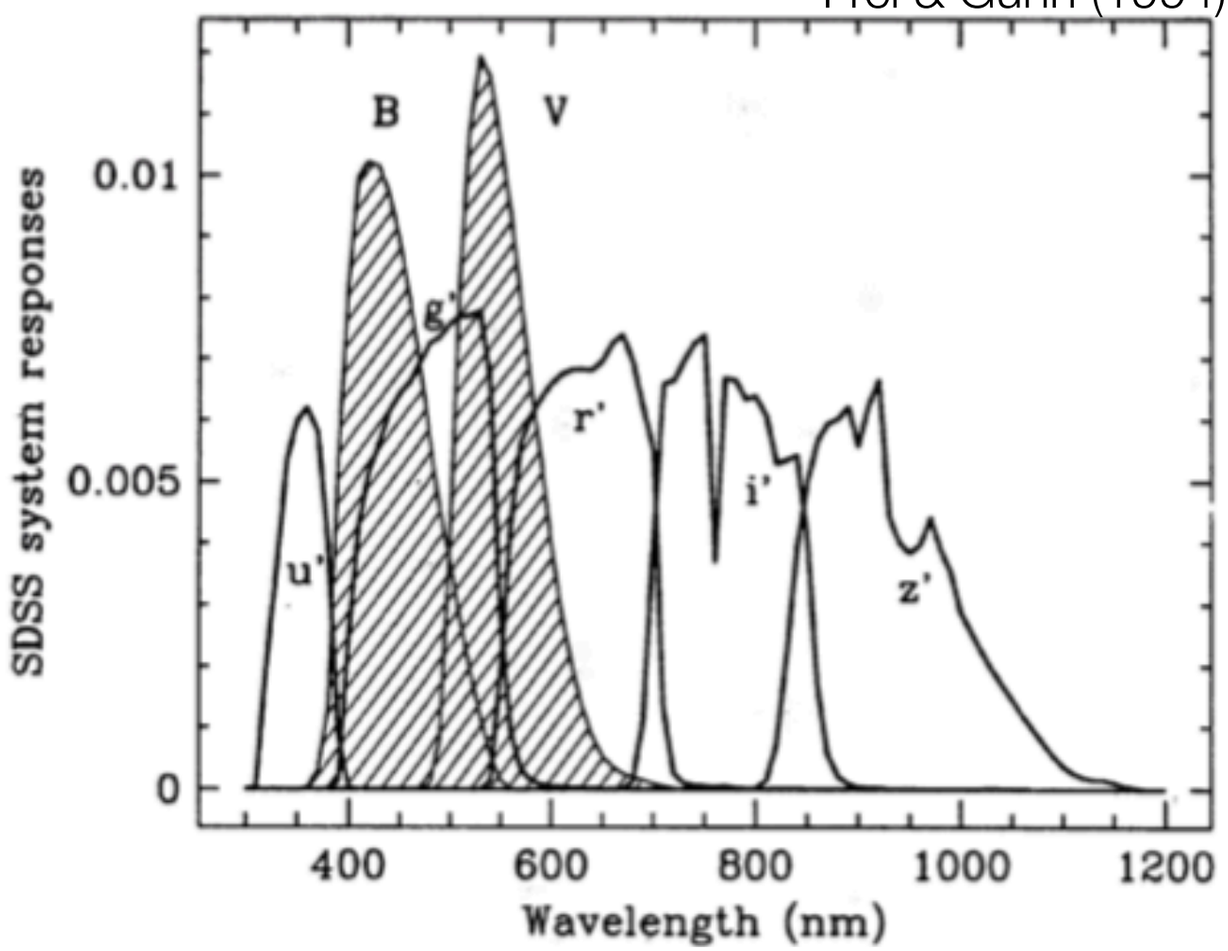


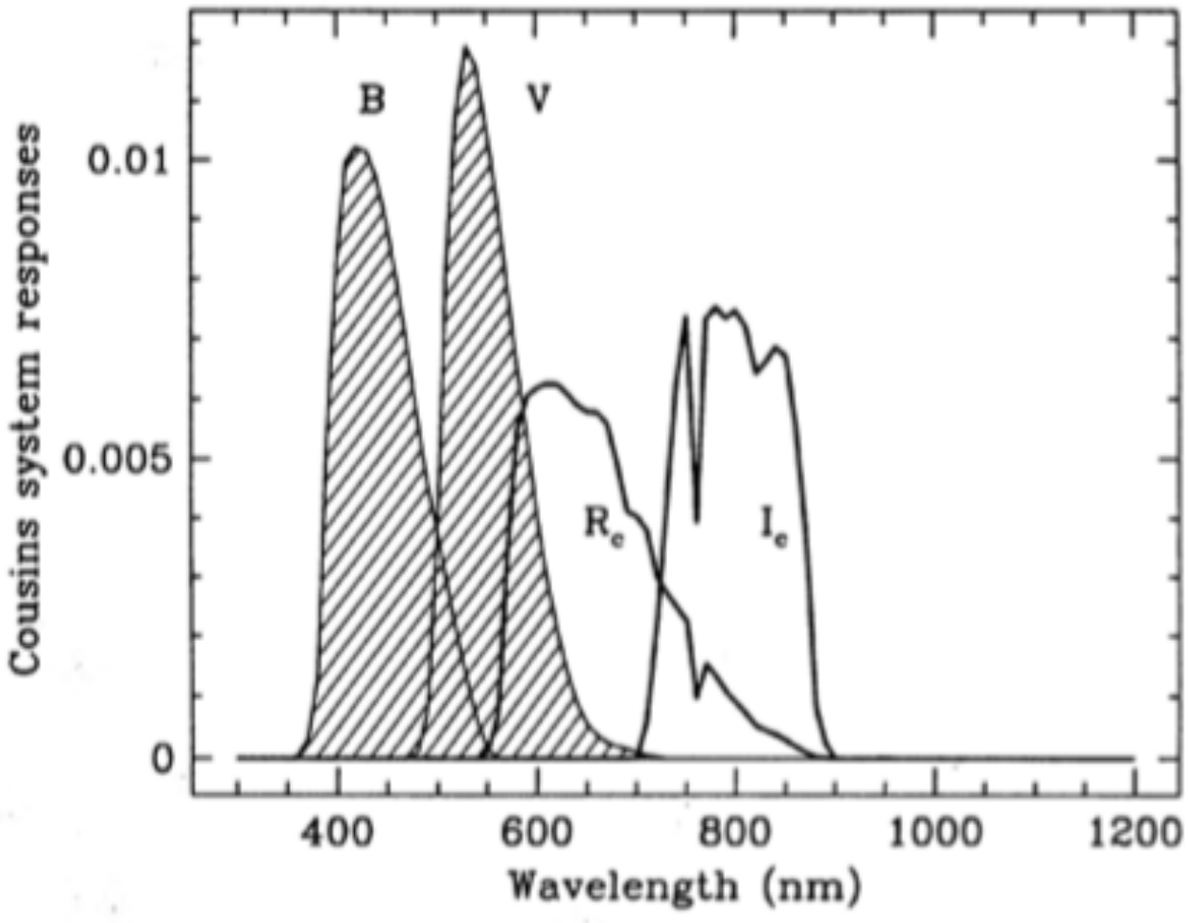
$$m_\lambda(\lambda) \equiv -2.5 \log_{10} F_\lambda(\lambda) - 21.1$$

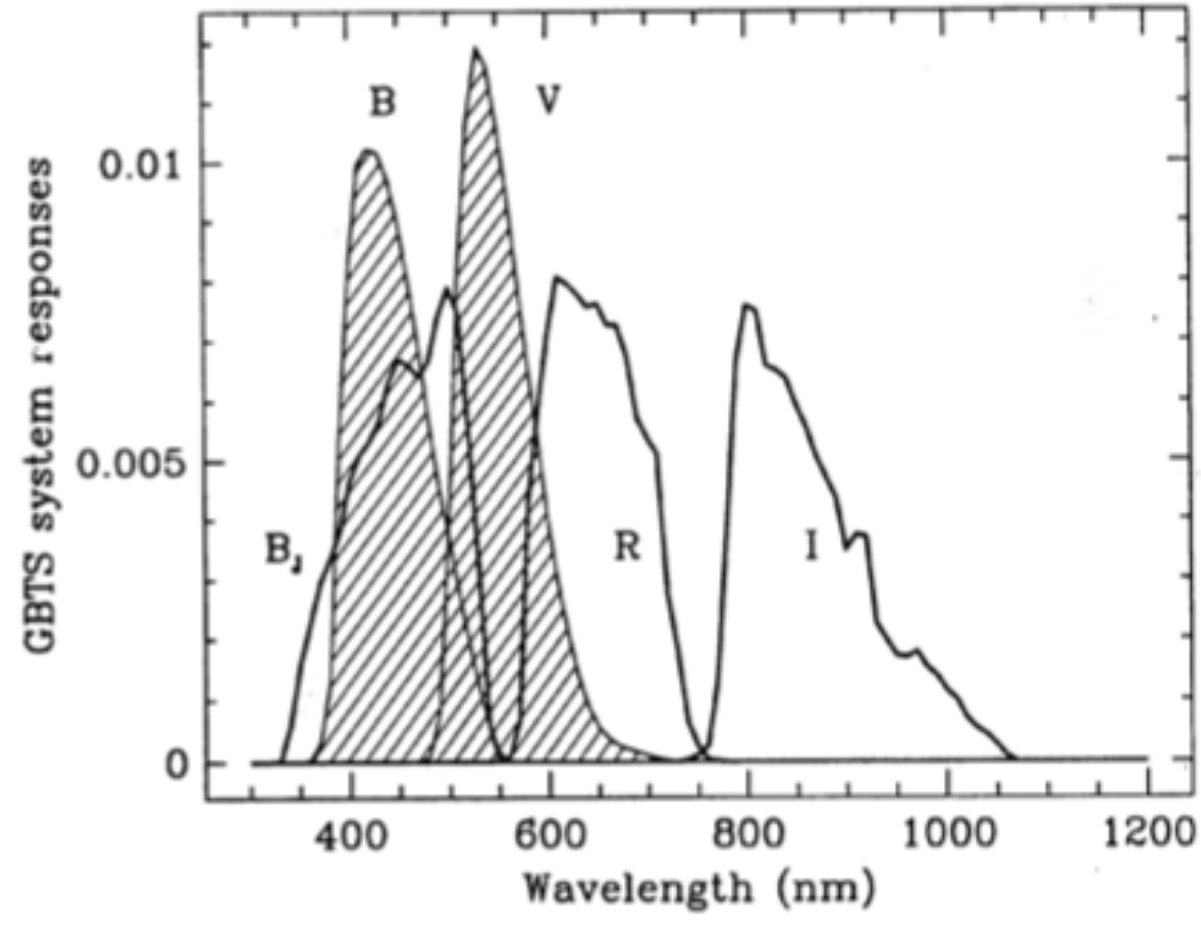
Bessel (ARAA, 2005)

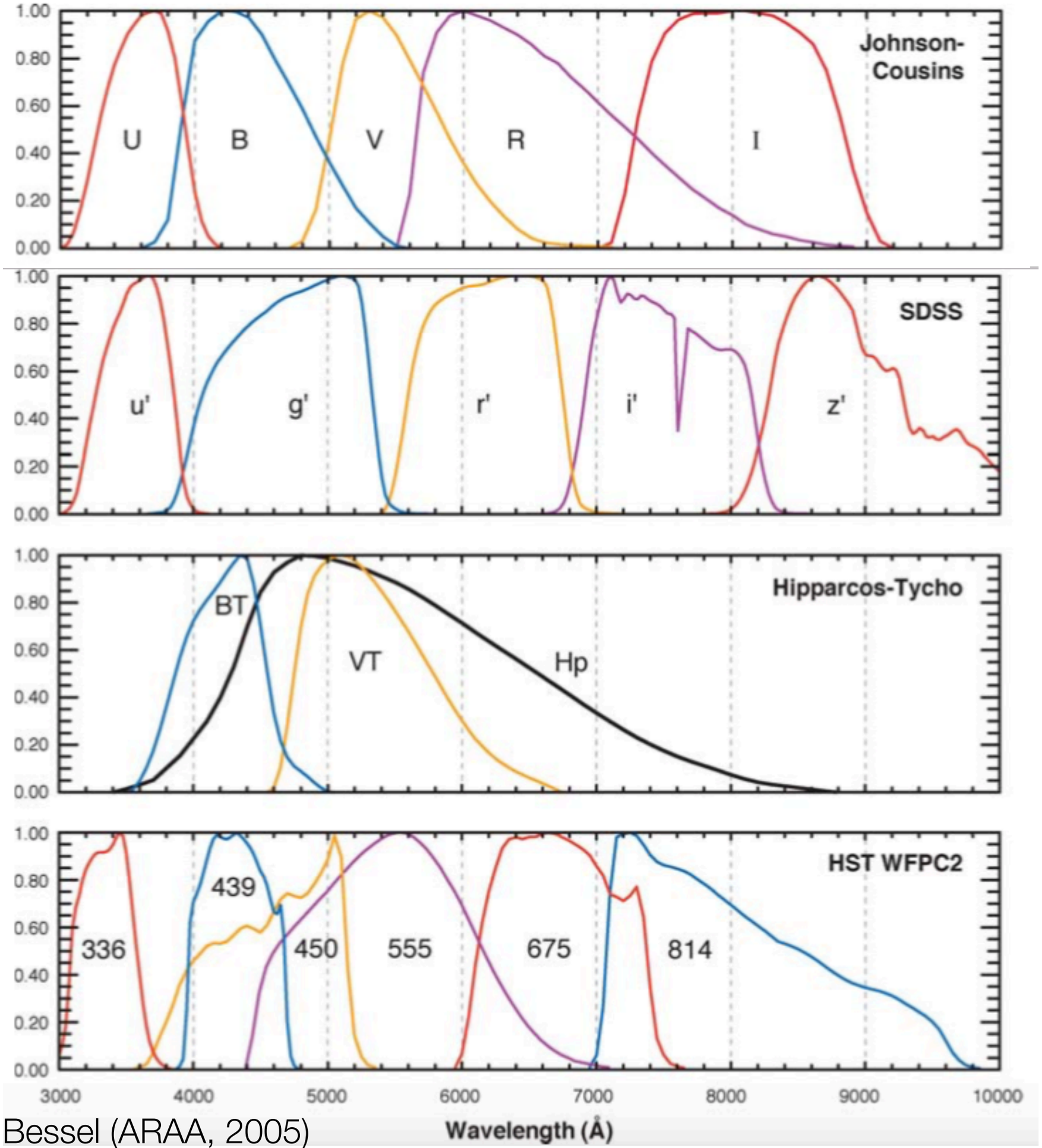
Frei & Gunn (1994)







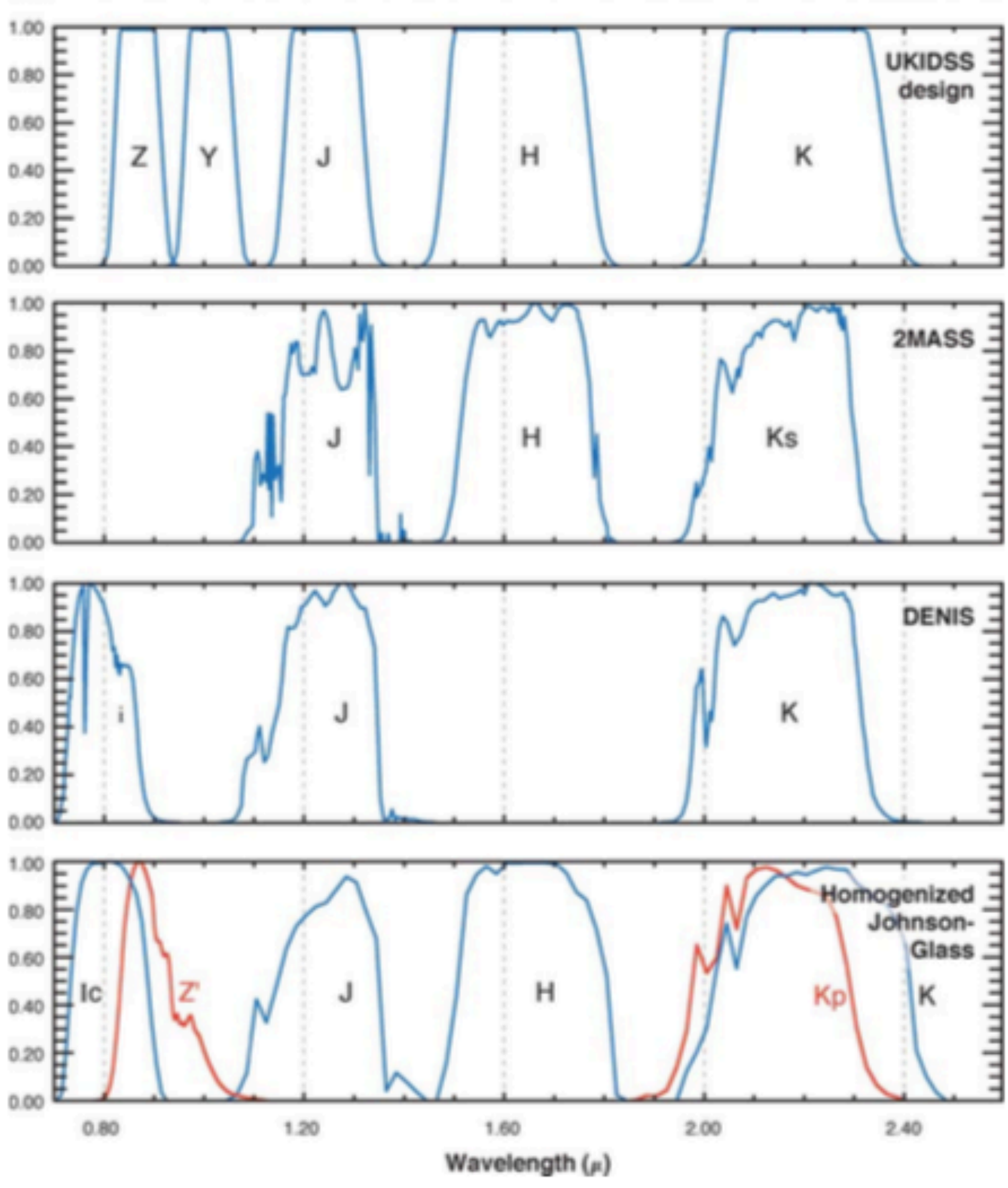




Bessel (ARAA, 2005)

Infrarojo

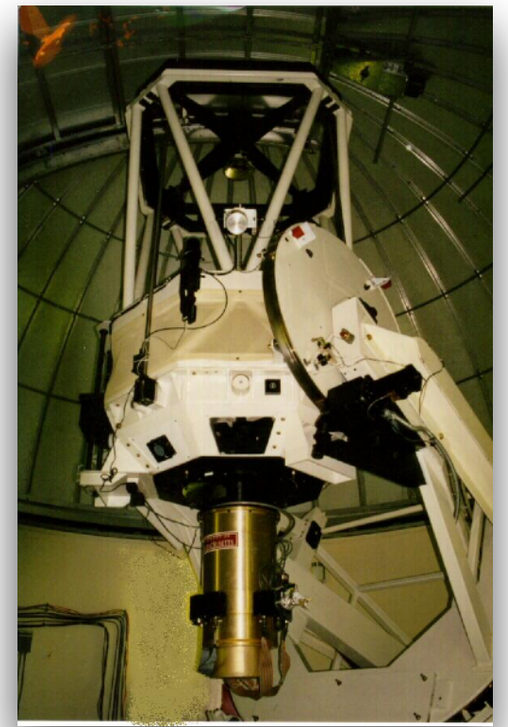
- 2MASS
- DENIS
- UKIDSS

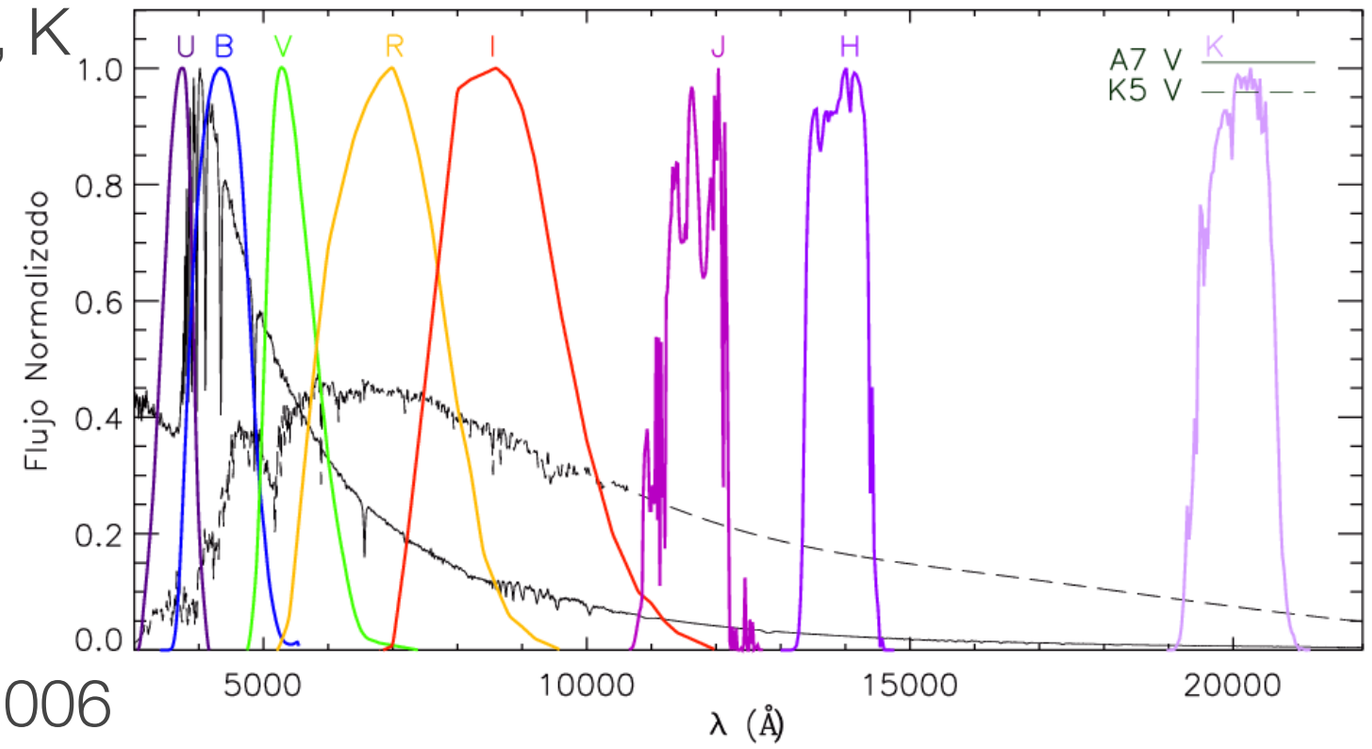


Sondeos (algunos ejemplos de los principales)

2MASS: Two-Micron All Sky Survey

- Hecho con dos Telescopios (1.3 meter Cassegrain Ecuatoriales) y cámaras idénticos ubicados en: F. L. Whipple Observatory en Mt. Hopkins, Arizona, EEUU y en Cerro Tololo Inter-American Observatory, La Serena, Chile.
- 1997-2001, catálogo 2MASS All-Sky Data Release publicado en 2003
- 470 millones de objetos puntuales + 1.6 millones de objetos extendidos
- Bandas J, H, K

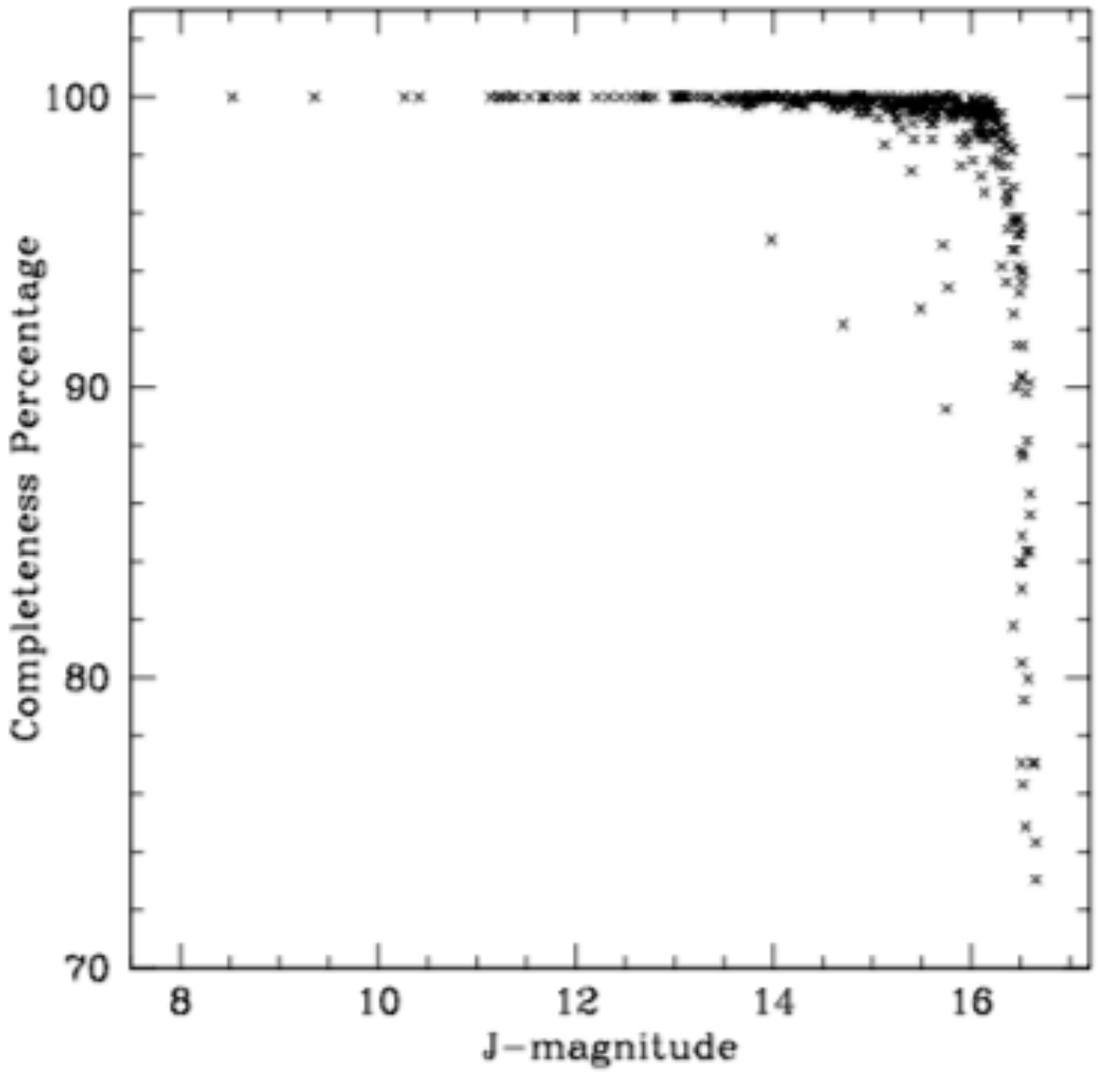


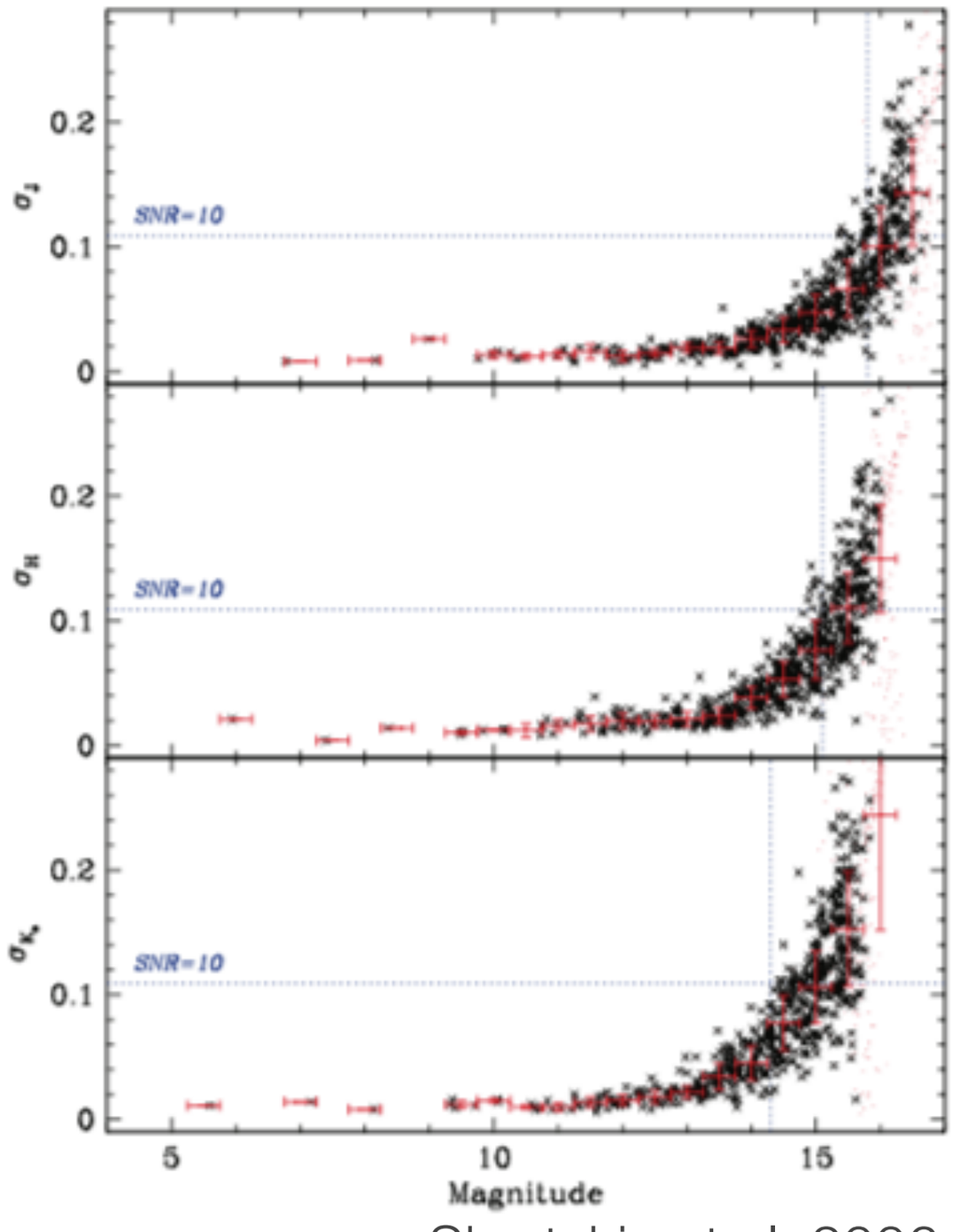


Skrutskie et al. 2006

2MASS: Two-Micron All Sky Survey

		Magnitude Limits	
Band	**Wavelength (μm)**	**Point Sources (SNR=10)**	**Extended Sources**
J	1.25	15.8	15.0
H	1.65	15.1	14.3
K_s	2.17	14.3	13.5

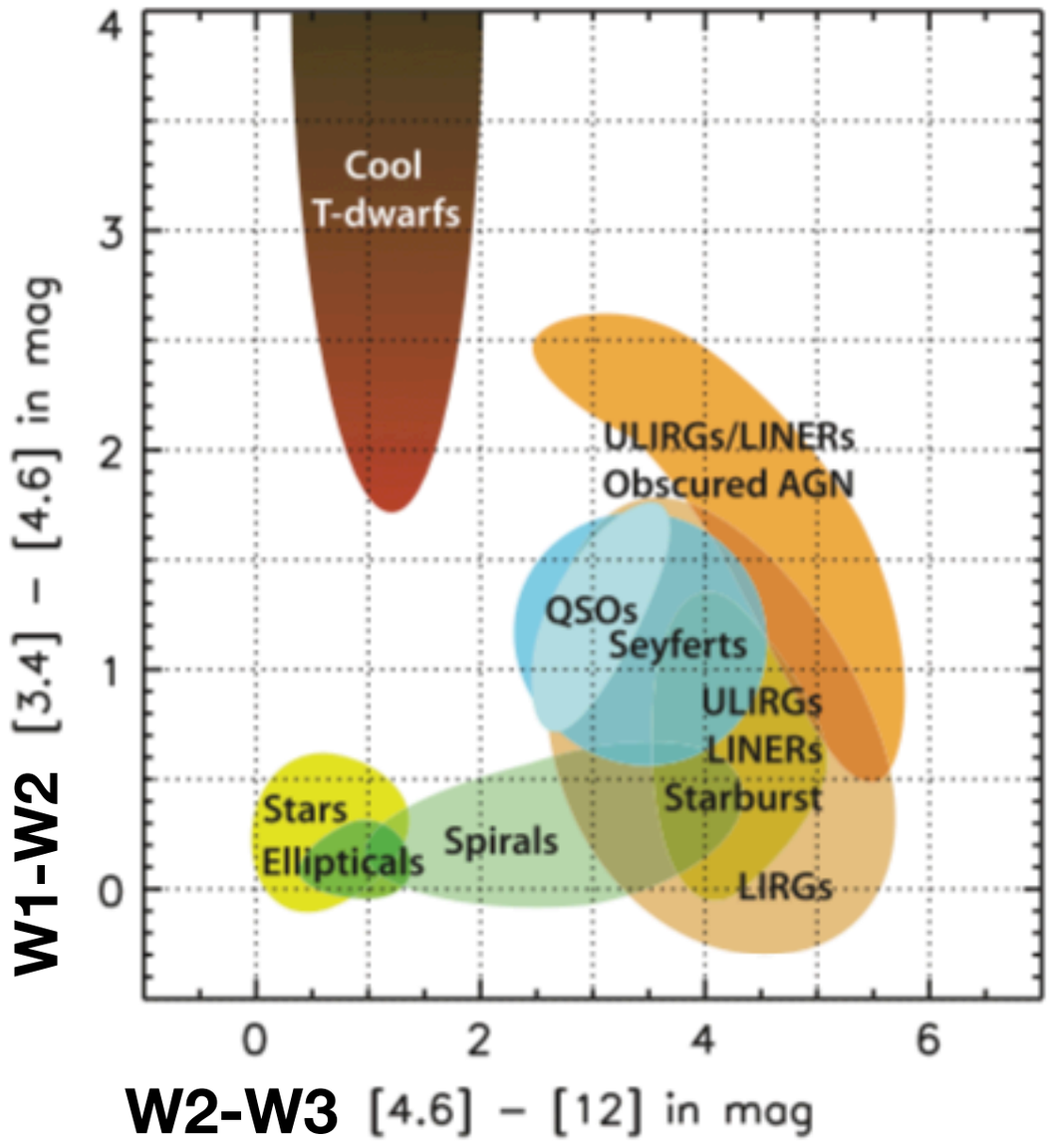


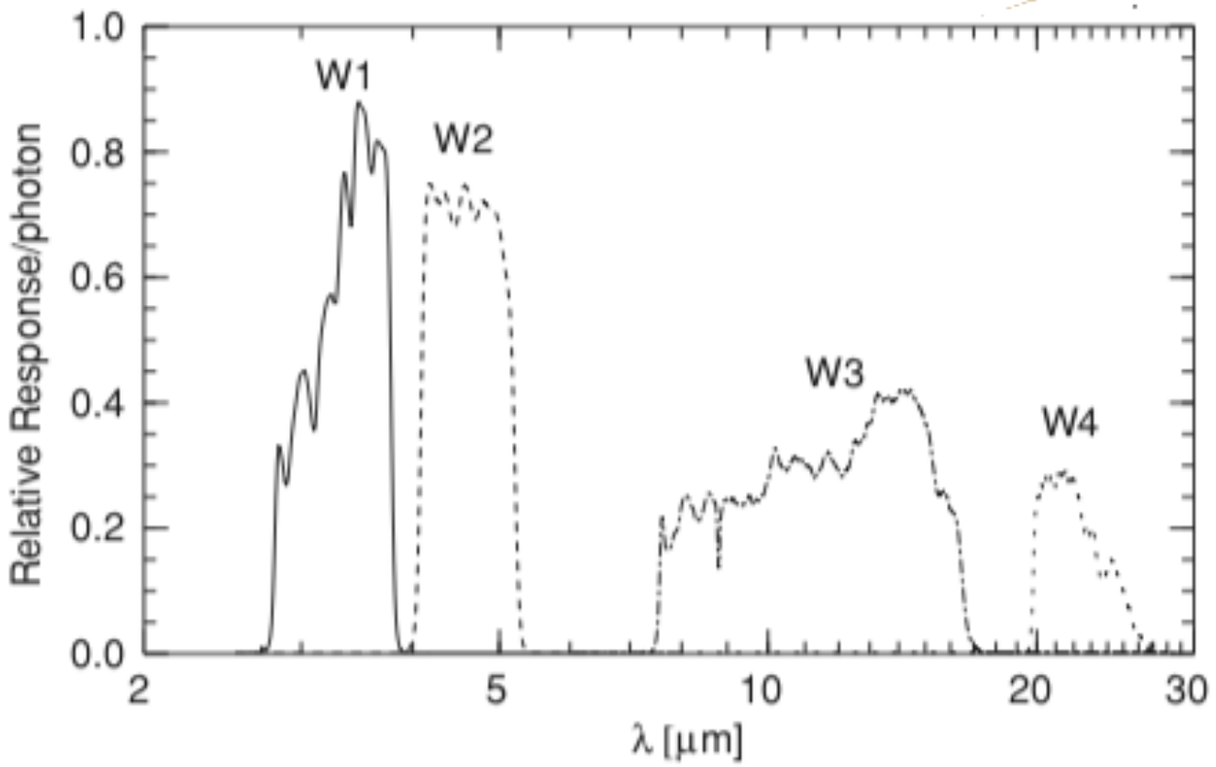


Skrutskie et al. 2006

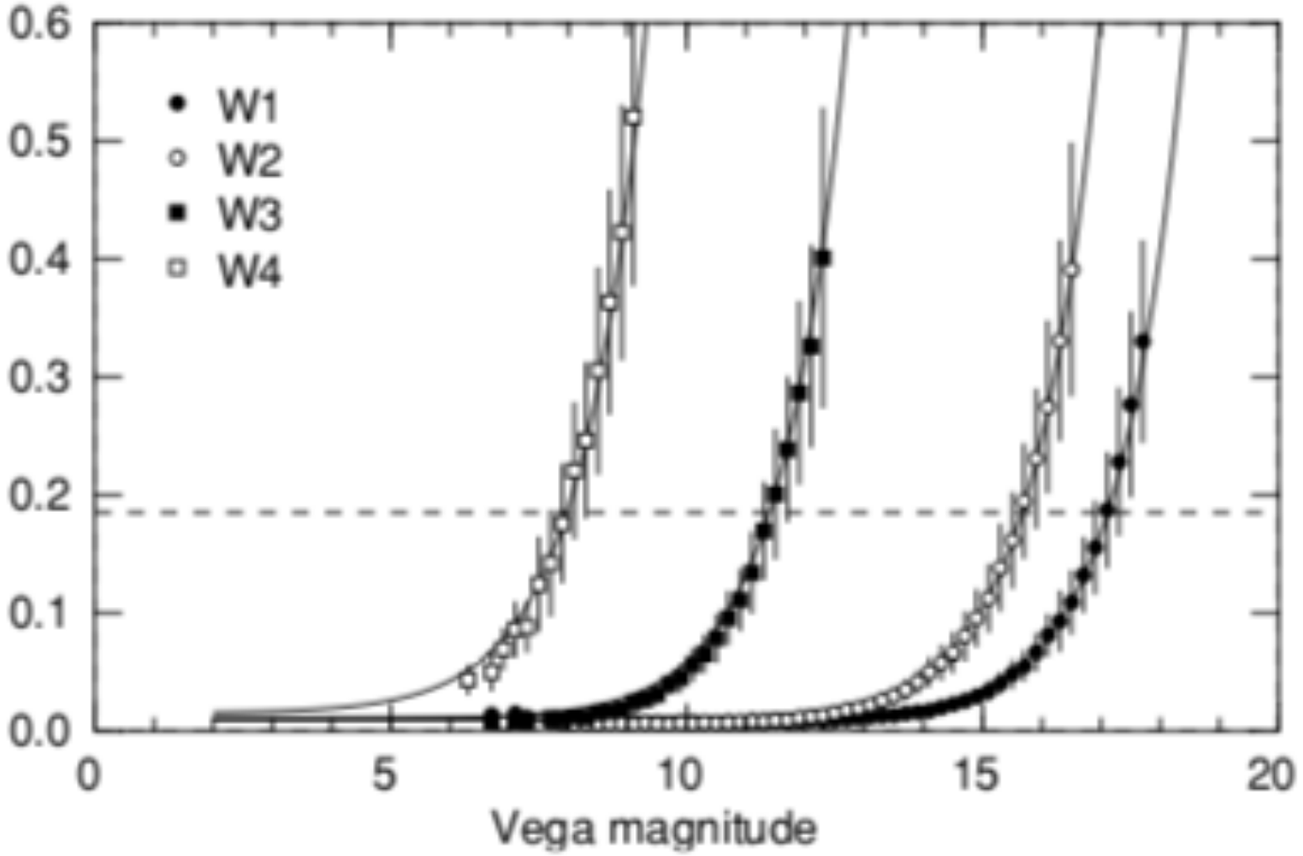
WISE: Wide-field Infrared Explorer at IPAC

- AllWISE: Catálogo final de todo el sondeo WISE (2013)
- 747 millones de objetos en todo el cielo



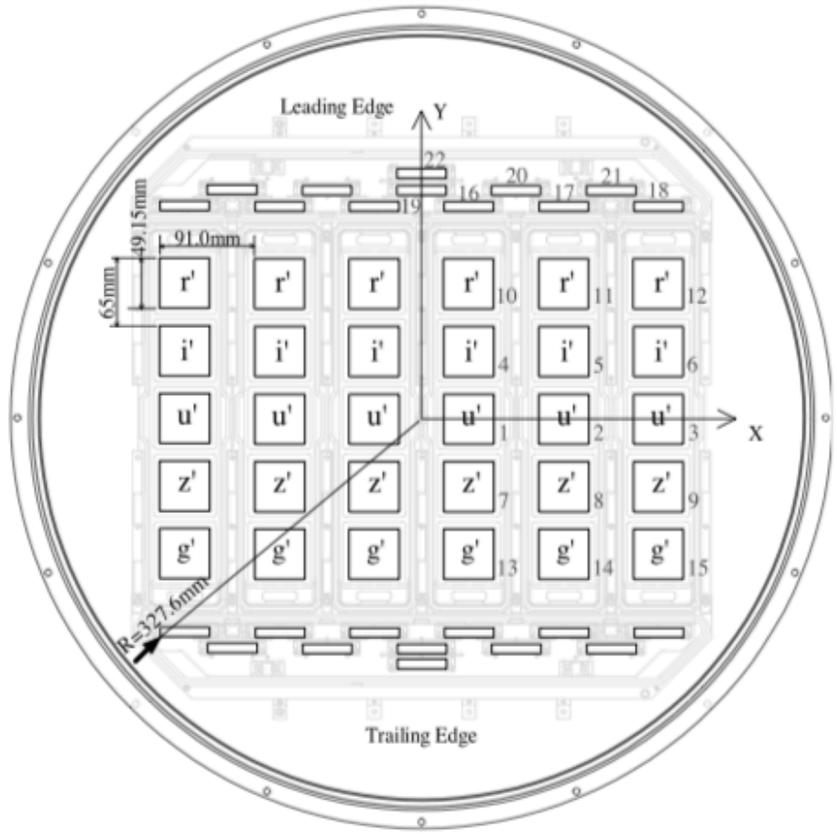


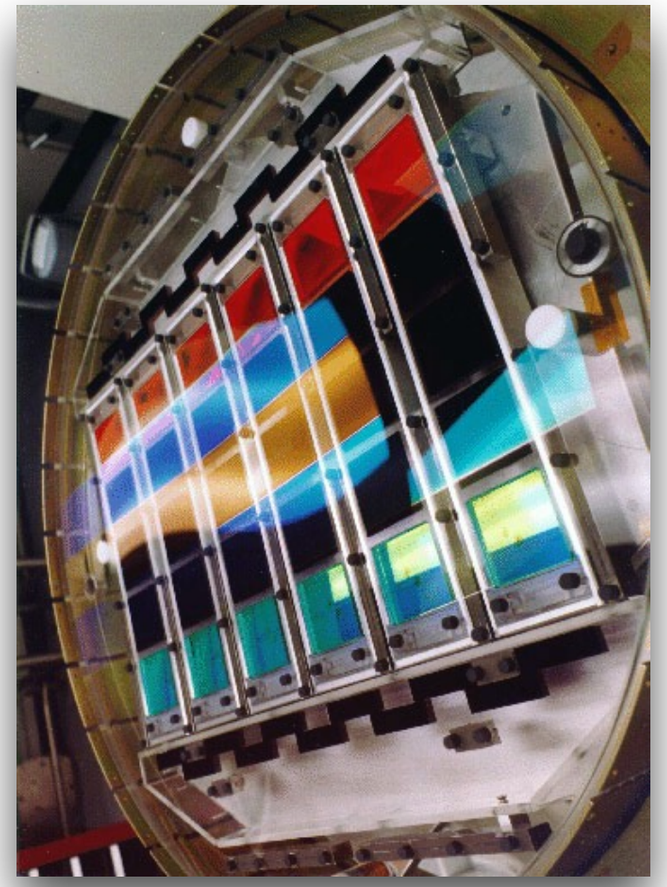
Wright et al. 2010



SDSS: Sloan Digital Sky Survey

- Sondeo iniciado en 2000 (SDSS-I), actualmente va por la etapa IV
- SDSS I-III: Sloan Foundation 2.5m Telescope at Apache Point Observatory, Nuevo Mexico, EEUU
- SDSS IV: +Telescopio 2.5m DuPont en Las Campanas, Chile



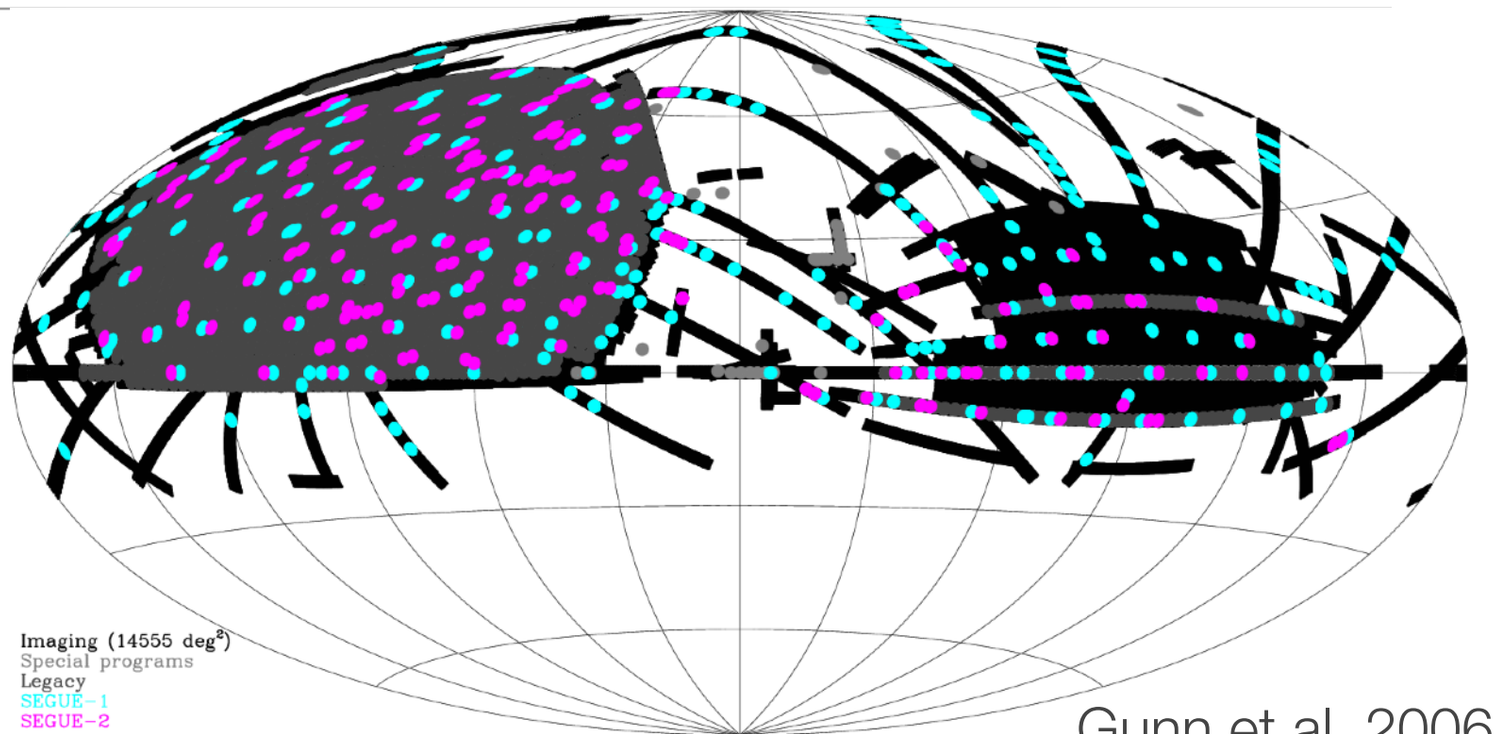


Gunn et al. 2006

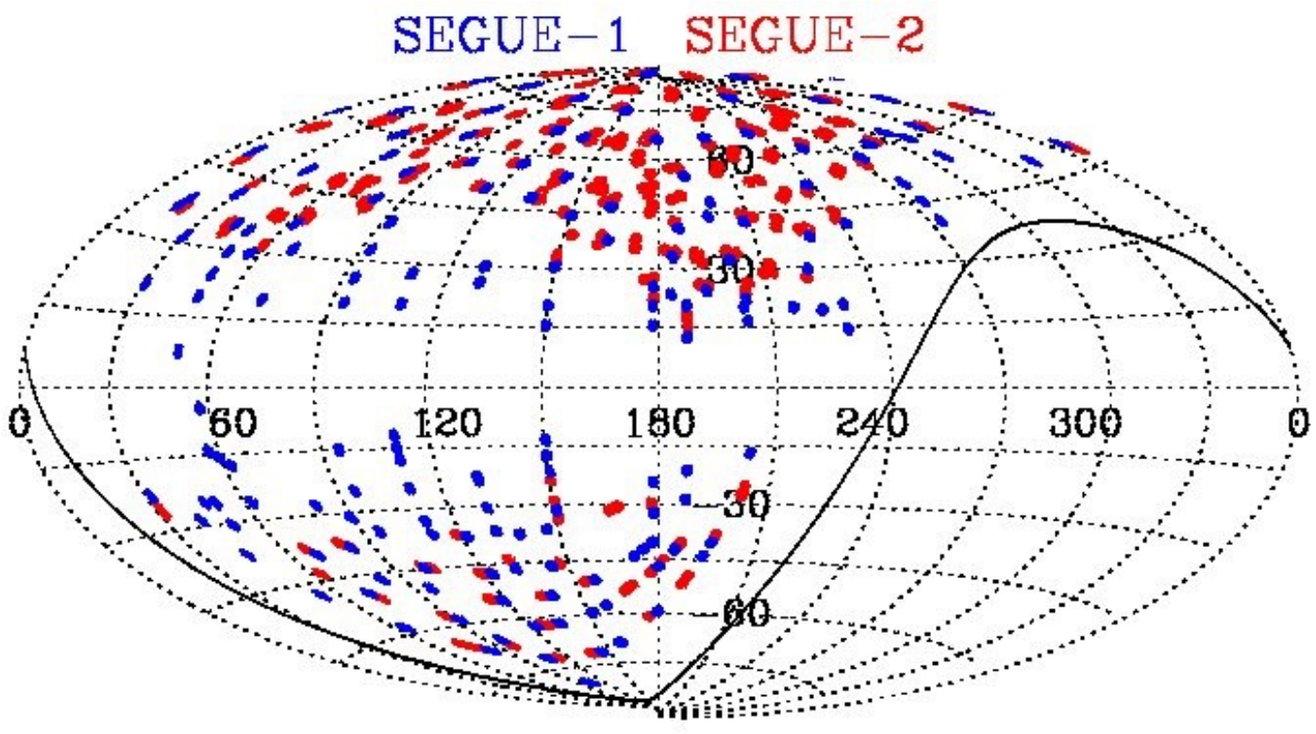
- Tiene dos partes: el sondeo directo (fotometría ugriz) y el espectroscópico (λ~ 3000 a 8000 Å)
- Inicialmente el sondeo espectroscópico SDSS-I observó galaxias mayoritariamente
- En etapas posteriores se hicieron diferentes sondeos con distintos objetivos científicos y con nuevos instrumentos

SDSS: Sloan Digital Sky Survey

- Sondeos dentro de SDSS:
- SEGUE: Sloan Extension for Galactic Understanding (2004-2008)
  - g<19
  - ~240.000 estrellas
- APOGEE (2011-2020)
- ManGa
  - sondeo de galaxias con espectrografía IFU (óptico)
- eBOSS (Baryon acoustic Oscillations Spec. Survey)
  - sondeo de galaxias lejanas en microondas



Gunn et al. 2006



APOGEE: APO Galaxy Evolution Experiment

- Espectros estelares en el cercano infrarojo, banda H
- H<12

APOGEE-2 Technical Details

☆ Bright-time observations at APO and LCO

☆ Duration: Fall 2014 – Fall 2020

☆ Fiber Complement: 300 fibers per 7 deg^2 plate (APO) (LCO)

☆ Wavelength Range: 1.51-1.70 μm

☆ Spectral Resolution: R~22,500

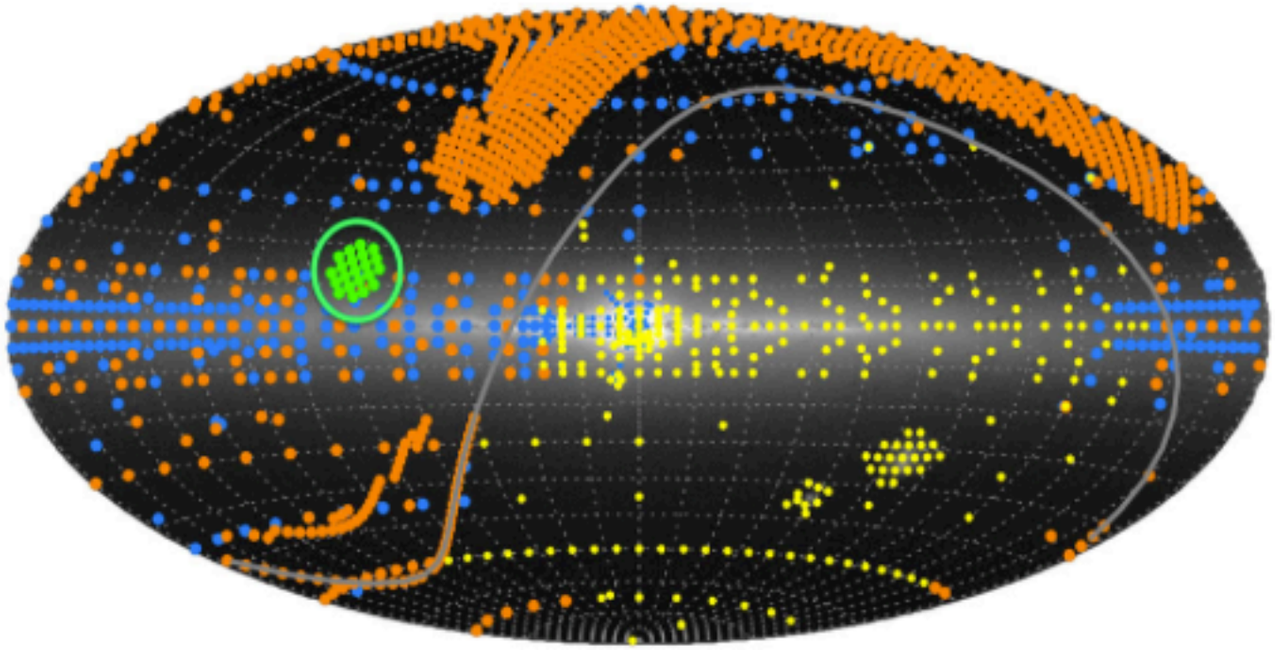
☆ Sample Size: 300,000 stars

☆ Signal-to-Noise Goal: S/N > 100

☆ Radial Velocity Precision: ~200 m/s

☆ Element Abundance Precision: ~0.1 dex for 20 species

ahora viene SDSS-V



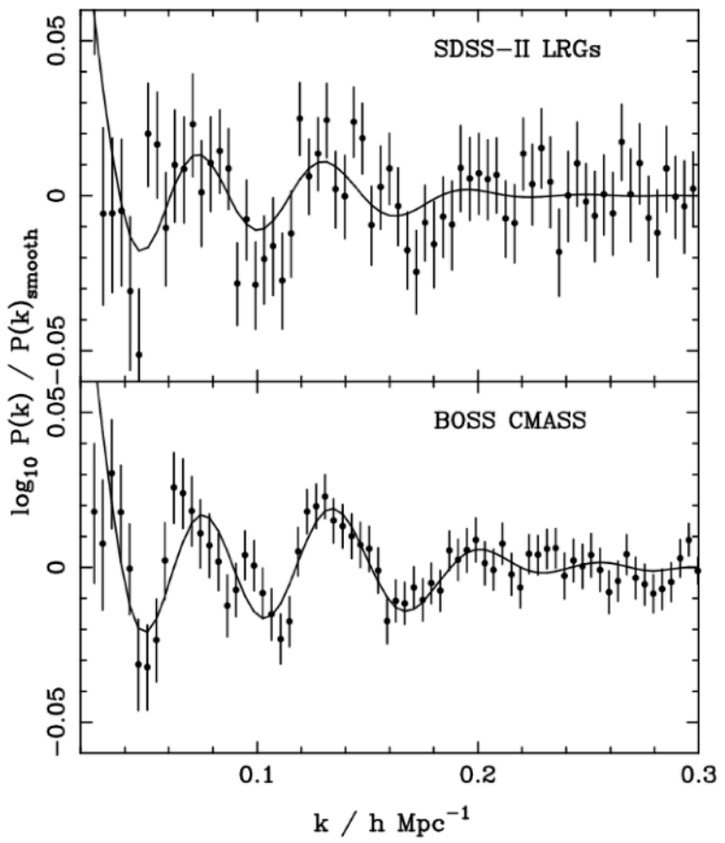
The APOGEE-2 survey footprint, overlaid on an infrared image of the Milky Way. Each dot shows a position where APOGEE obtains at least 250 stellar spectra. *Image credit: P. M. Frinchaboy and SDSS/APOGEE, 2MASS (background image)*

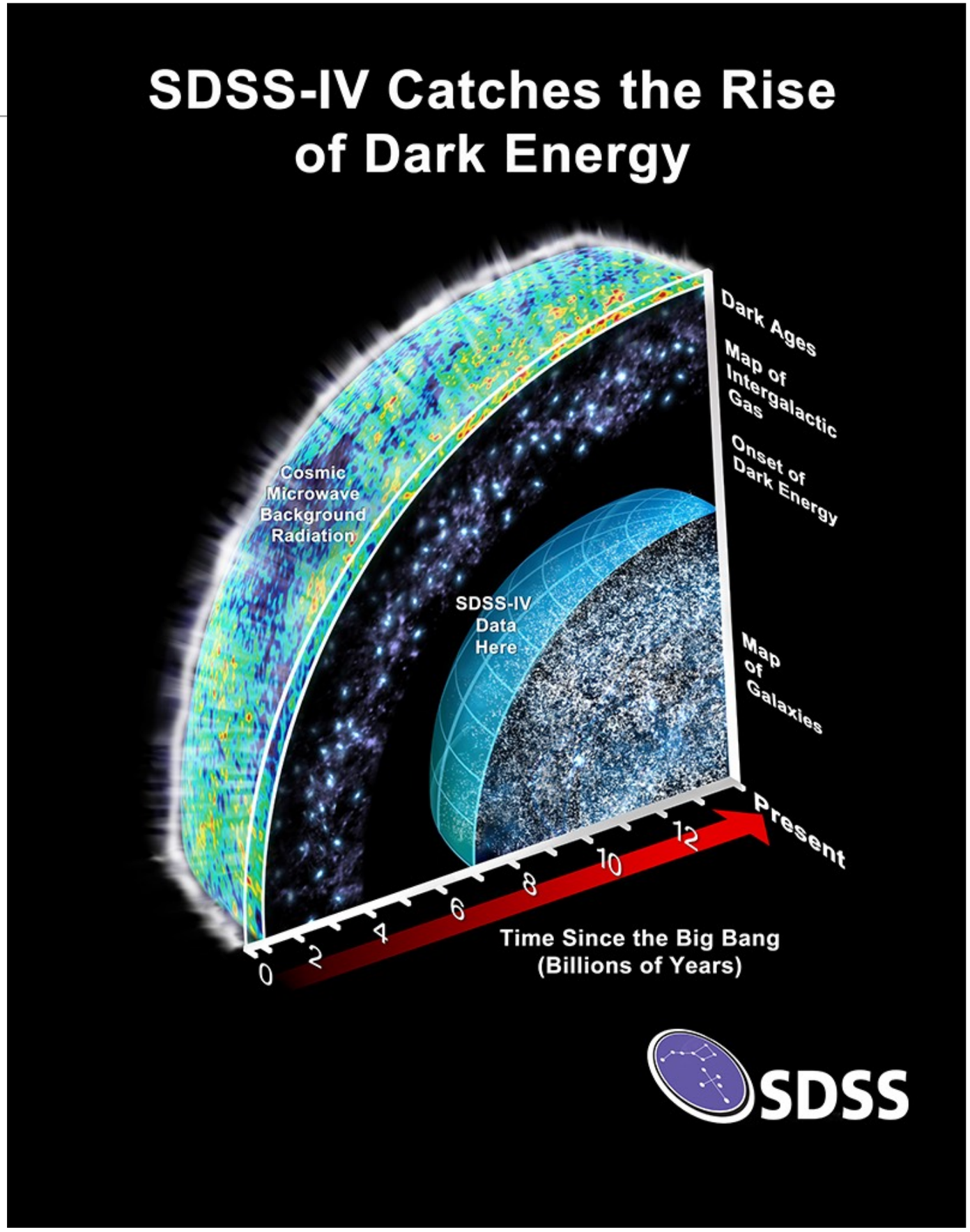
- Se publican datos en “Data Releases”
- El último liberado es el DR16, el “actual" DR17 tiene acceso sólo para los miembros del consorcio por un par de años, luego se hace público

Crédito: SDSS DR16 webpage

e-BOSS

- Objetivo: Distribución espacial de galaxias a alto redshift
- Oscilaciones Bariónicas Acústicas a través del espectro de potencia (o de la 2-point c.f.) de galaxias
- Como las BAO del CMB pero con galaxias -> independiente





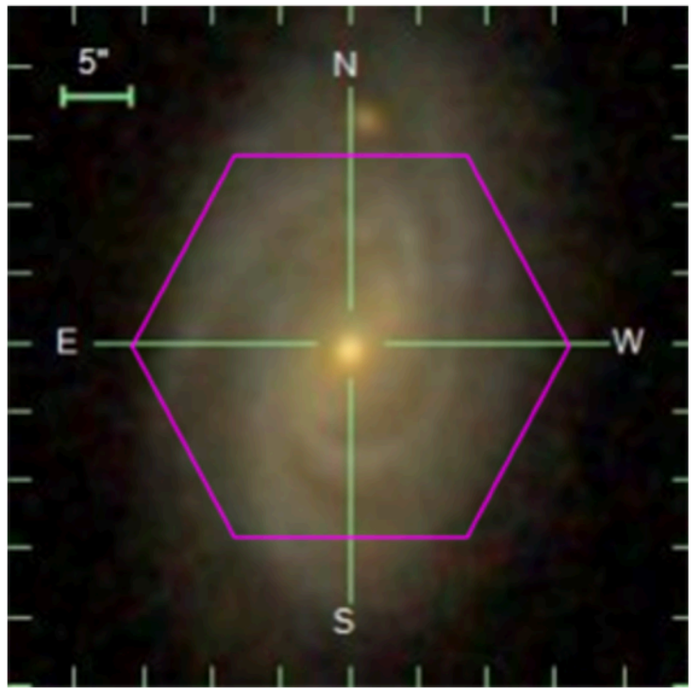
Crédito: SDSS DR16 webpage

Sondeos IFU=Integral Field Unit Spectrograph

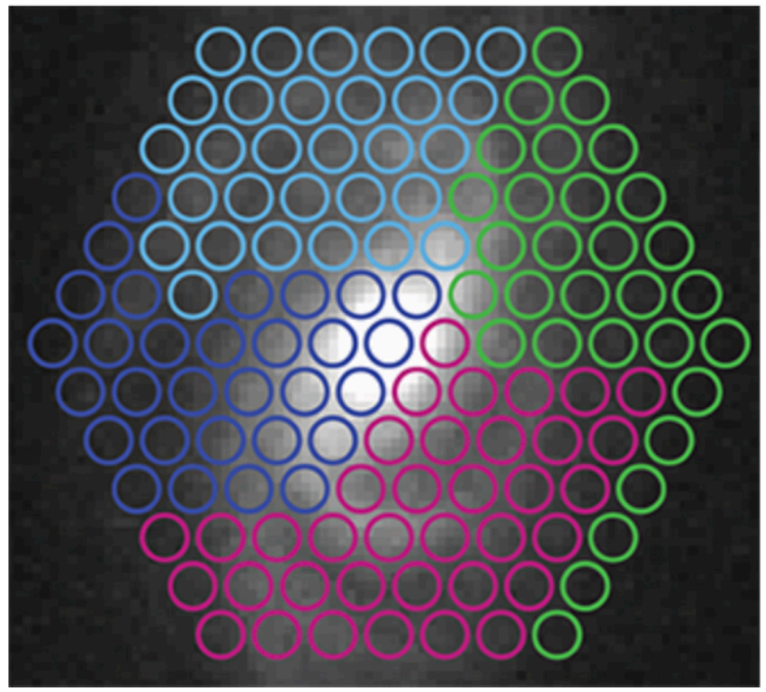
- Sondeos ***espectrales*** de galaxias con resolución ***espacial***

- **MaNGa** - SDSS IV

- CALIFA, SAMI…



A face-on spiral galaxy seen by MaNGA – the red hexagon shows the coverage of the MaNGA IFU instrument



The same spiral galaxy, now showing circles for the individual IFU fibers

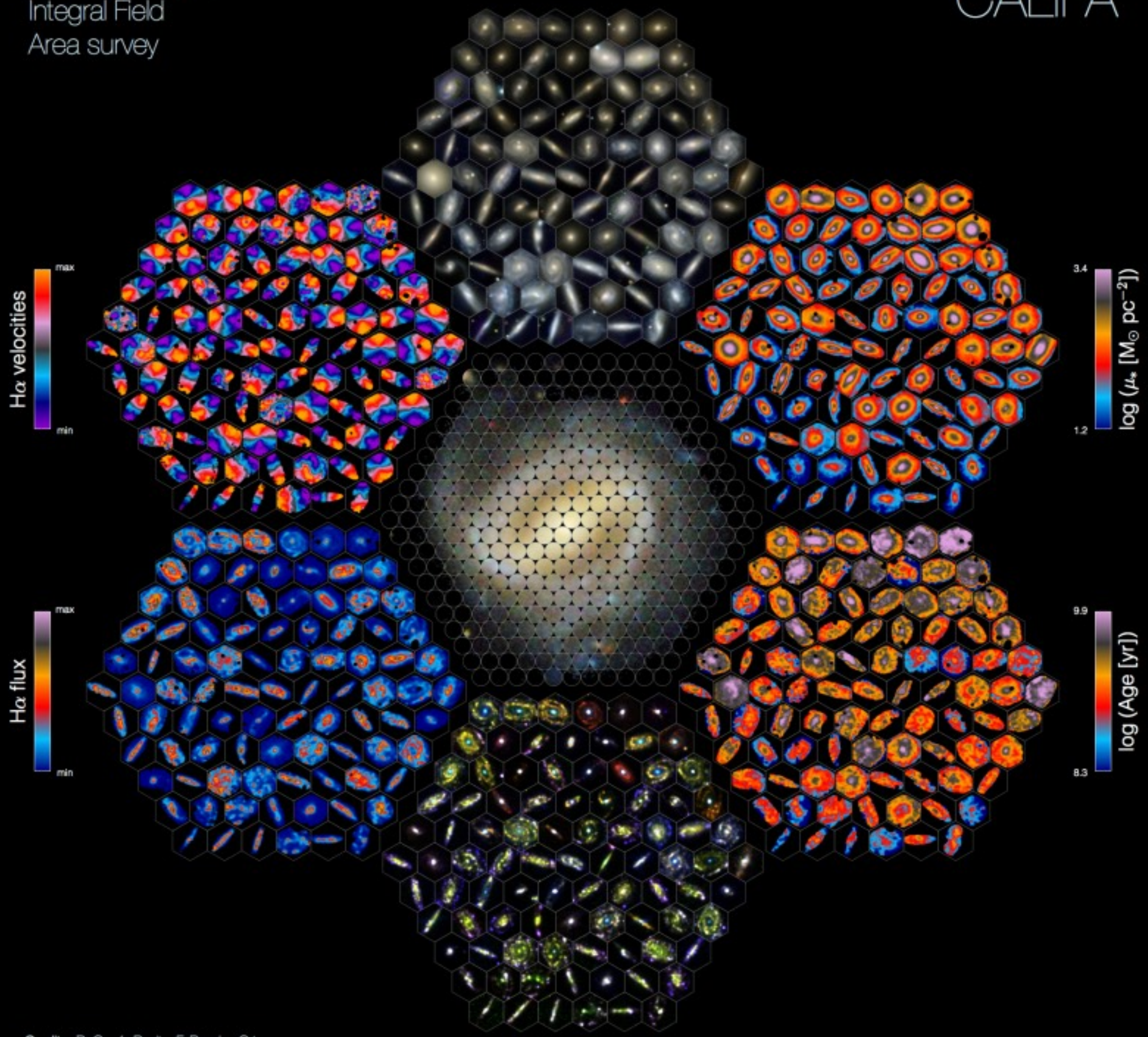
Specification	MaNGA	SAMI	CALIFA	Atlas3D
Sample Size	10,000	3,400	600	260
Selection	$M > 10^9 M_\odot$	$M > 10^{8.2} M_\odot$	45" $< D_{25} <$ 80"	E/S0 $M > 10^{9.8} M_\odot$
Radial coverage	$1.5r_e$ (2/3), $2.5r_e$ (1/3)	1-2r_e	>2.5r_e	<1r_e
S/N at 1r_e	15-30	10-30	~30	15
Wavelength range(Å)	3600-10300	3700-7350	3700-7500	4800-5380
Instrumental resolution	50-80 km/s	75/28 km/s	85/150 km/s	105 km/s
Input Spaxel Size	2.0″	1.6‴	2.7″	1″
Input Spaxels per object	$<3\times127$[1]	3×61	3×331	1,431
Spatial FWHM	2″	2″	2.5″	1.5″
Telescope size	2.5m	3.5m	3.5m	4.2m

Sebastian Sanchez + CALIFA 2014

Calar Alto Legacy
Integral Field
Area survey

6900 Å 5250 Å 4100 Å

CALIFA



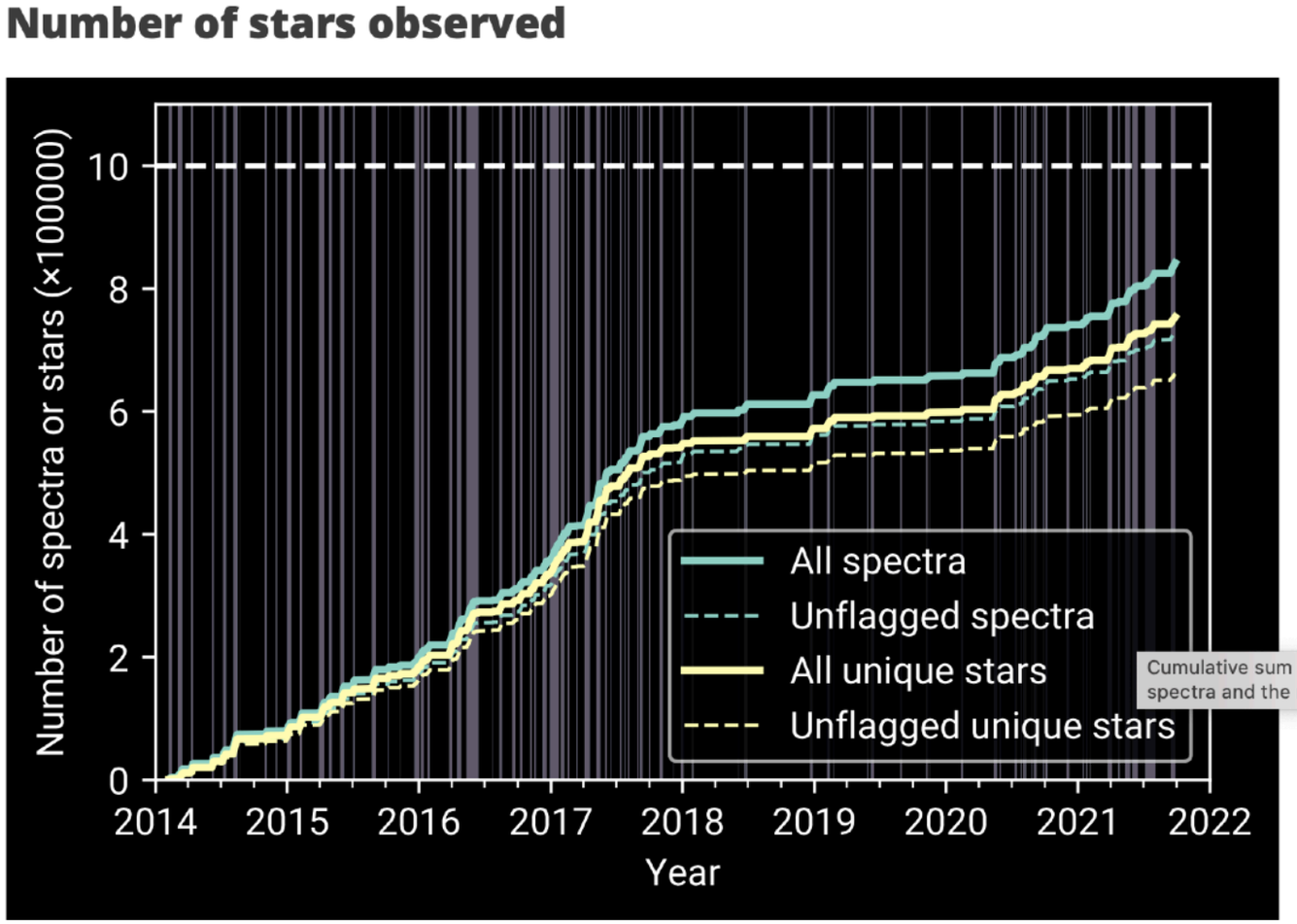
Hα [NII] 6584 Å [OIII] 5007 Å

Credits: R. García-Benito, F. Rosales-Ortega, E. Pérez, C.J. Walcher, S.F. Sánchez & the CALIFA team

Centro Astronómico Hispano Alemán

Sondeos de Abundancias Químicas y/o Vradiales

- Estos son sondeos de espectros (estelares) de muy alta resolución (R>30.000)
- Abundancias:
- GALAH
- Gaia ESO
- WEAVE
- Algunos sondeos de Velocidades radiales:
  - RAVE, LAMOST y 4MOST



GALAH has acquired 841941 spectra from 754032 stars. The cumulative sum with time for the number of spectra and the number of stars. Unflagged refers to those targets where there is no problem noted with the reduction. The vertical grey stripes indicate observing nights.

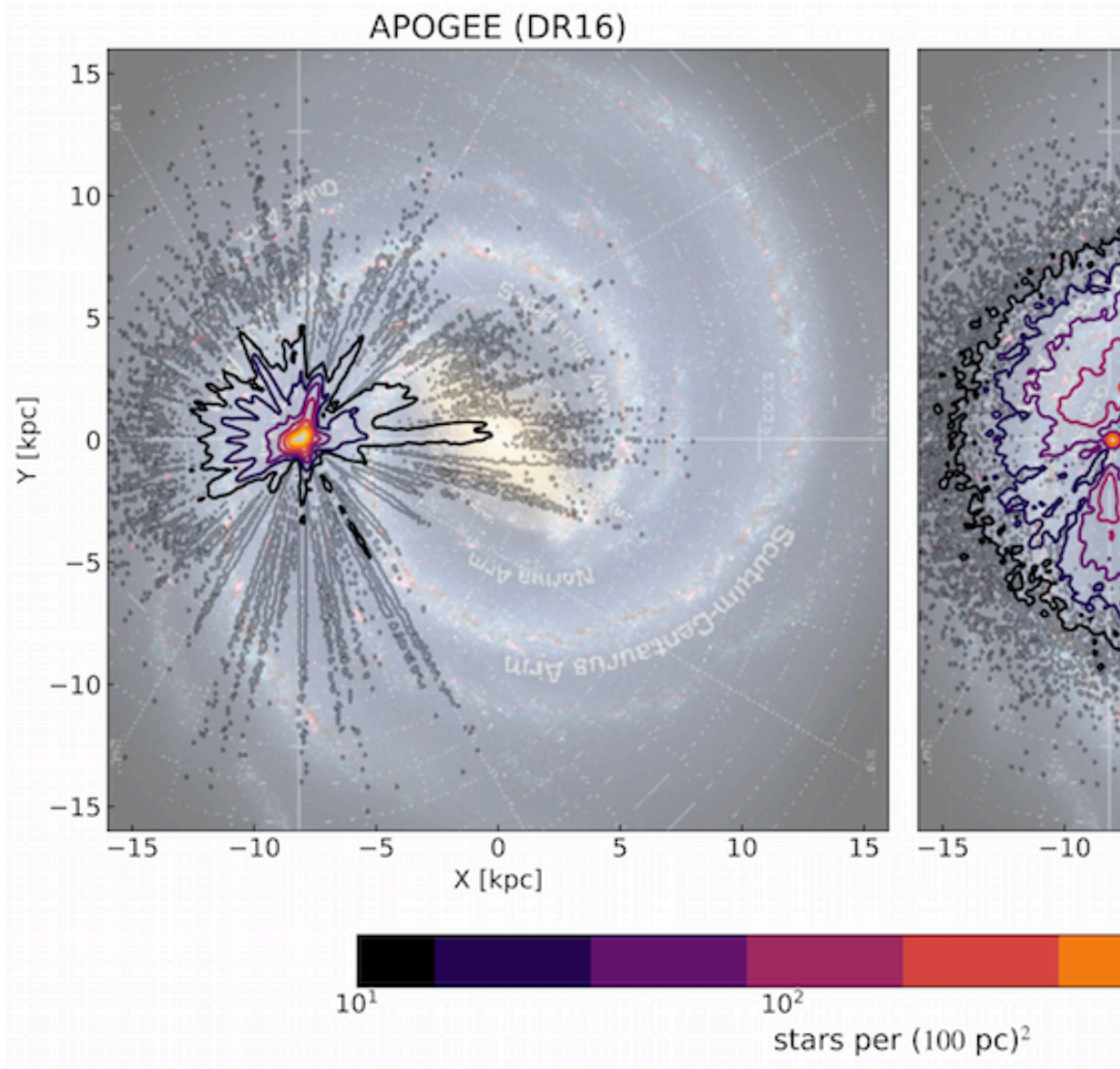
- Abundancias medidas por GALAH: Li, C, O, Na, Mg, Al, Si, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Rb, Sr, Y, Zr, Mo, Ru, Ba, La, Ce, Nd, Sm, and Eu. Buder *et al.* (2021)

Próximo: SDSS V - Milky Way Mapper

- Galactic Genesis, Stellar Astrophysics, and Stellar System Architecture.

- Galactic Genesis: The Galactic Genesis (GG) program will produce the first spectroscopic stellar map that is contiguously and densely sampled across the entire sky, with a focus on the low Galactic latitudes

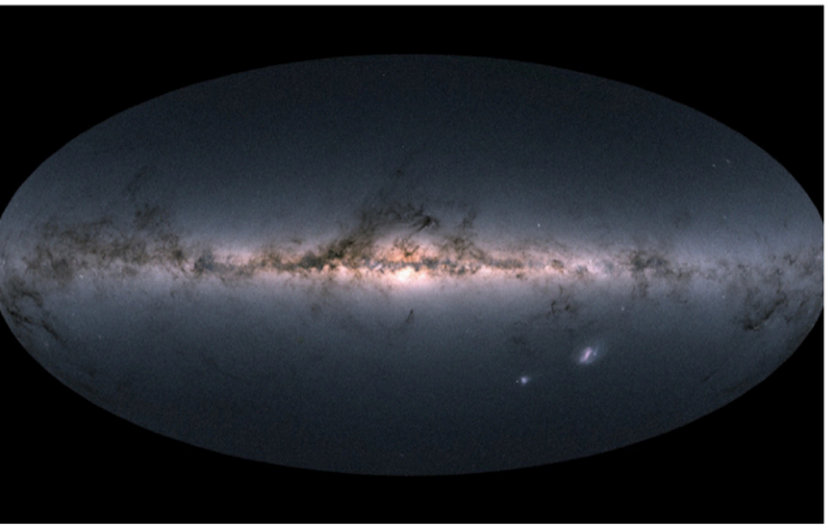
- Stellar Astrophysics (SA) and Stellar System Architecture (SSA) programs take advantage of the panoptic spectral capabilities of SDSS-V to measure mass, age, chemical composition, internal structure, rotation, and the presence of companions for vast samples of stars across the color-magnitude diagram



Próximamente: SDSS V

SDSS-V

MILKY WAY MAPPER



A time-domain, optical+IR spectroscopic survey of Milky Way stars of all types. *Image credit: ESA/Gaia/DPAC*

Program Head: **Jennifer Johnson**
(The Ohio State University)

LOCAL VOLUME MAPPER

An optical, integral-field spectroscopic survey of the Milky Way and its galactic neighbors. *Image credit: NASA, ESA/A. Nota*

Program Head: **Niv Drory**
(University of Texas at Austin)

BLACK HOLE MAPPER

An optical time-domain spectroscopic survey of quasars and X-ray sources. *Image credit: ESO/M. Kornmesser*

Program Head: **Scott Anderson**
(University of Washington)

star formation and ISM

Próximamente: LSST en el Vera Rubin Obs

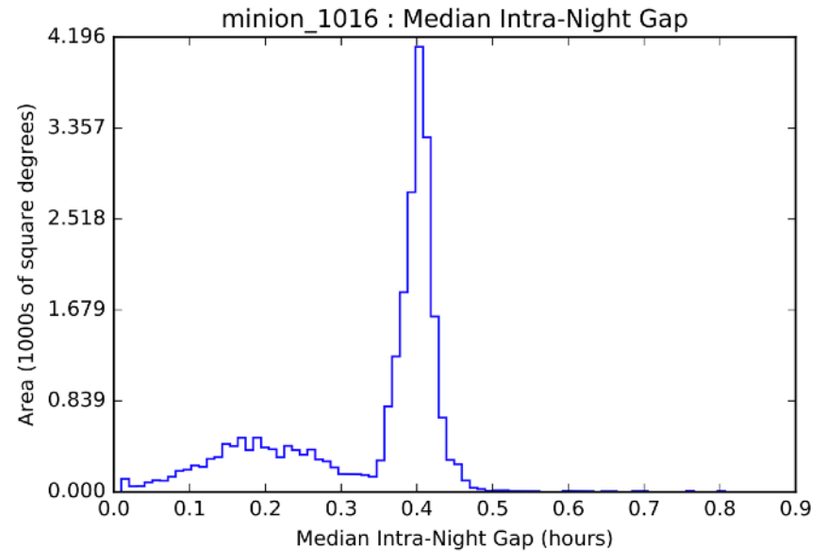
- Legacy Survey of Space and Time *(ugriz)*
- **Multiépoca con alta Profundidad Fotométrica**
- Main survey: Sondeo de 18000 sqdeg, 10yr
- Deep Drilling Field: alta cadencia
- Campo de ~**3º x 3º** (comparar con GTC-10m 7.8’ x 7.8’)

Domo del LSST (Cerro Pachón, Chile)

- Algunos objetivos científicos:
  - Naturaleza de la energía y materia oscuras
  - Inventario del Sistema Solar (censo de cuerpos menores)
  - Fenómenos transientes en el óptico
  - Mapeo de la Vía Láctea

LSST: Cadencia

- cada cuánto se observa la misma zona del cielo? Cuántas repeticiones?



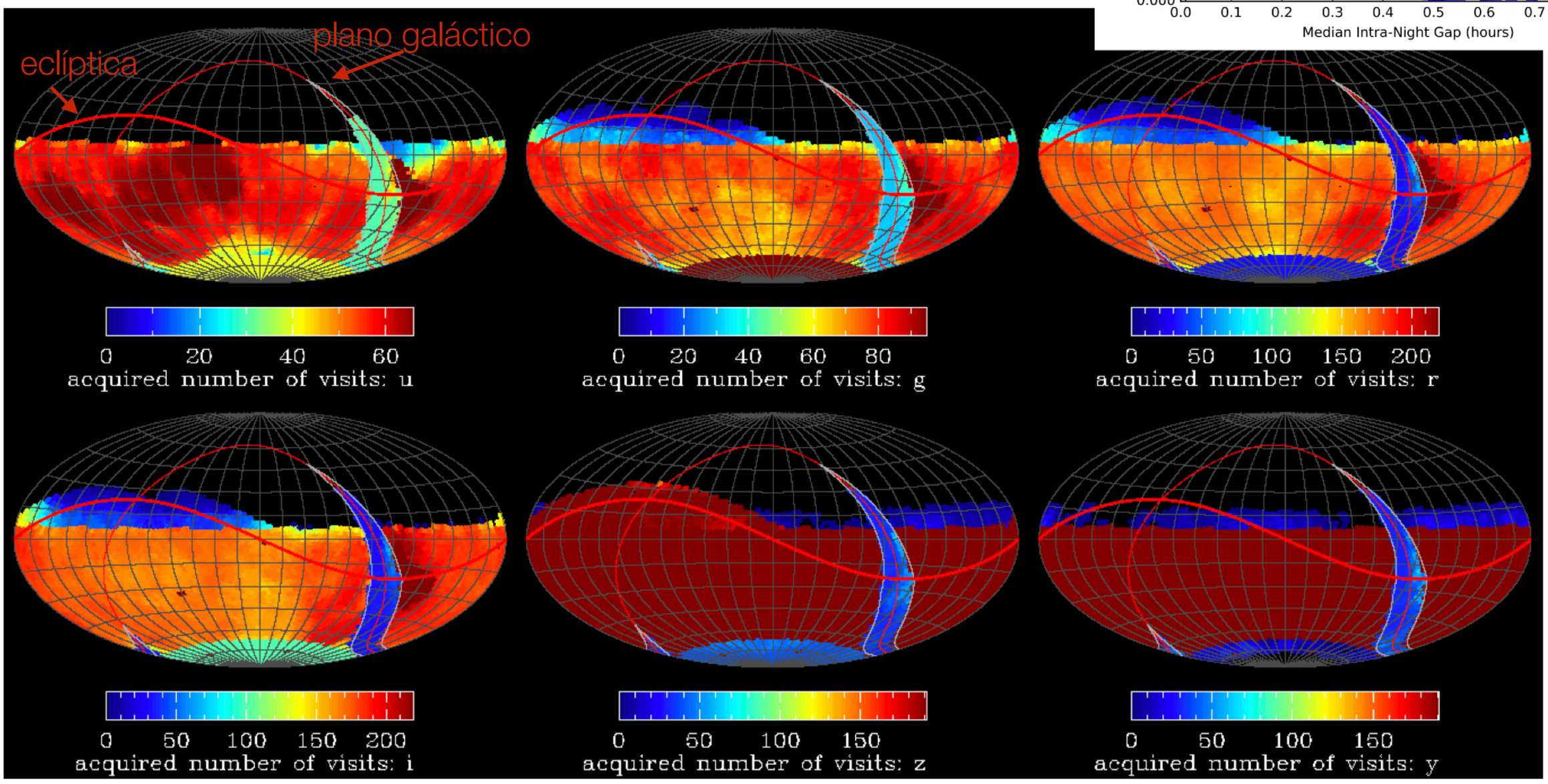


Figure 3.1: The number of visits in one realization of a simulated ten-year survey in all six LSST filters, shown in Equatorial coordinates. The project goals are to have 56, 80, 180, 180, 164, and 164 visits in the u, g, r, i, z, y filters, respectively, over 20,000 deg^2 of sky. One of the deep-drilling field is apparent at $\alpha = 90°, \delta = -32°$.

LSST - Profundidad Fotométrica

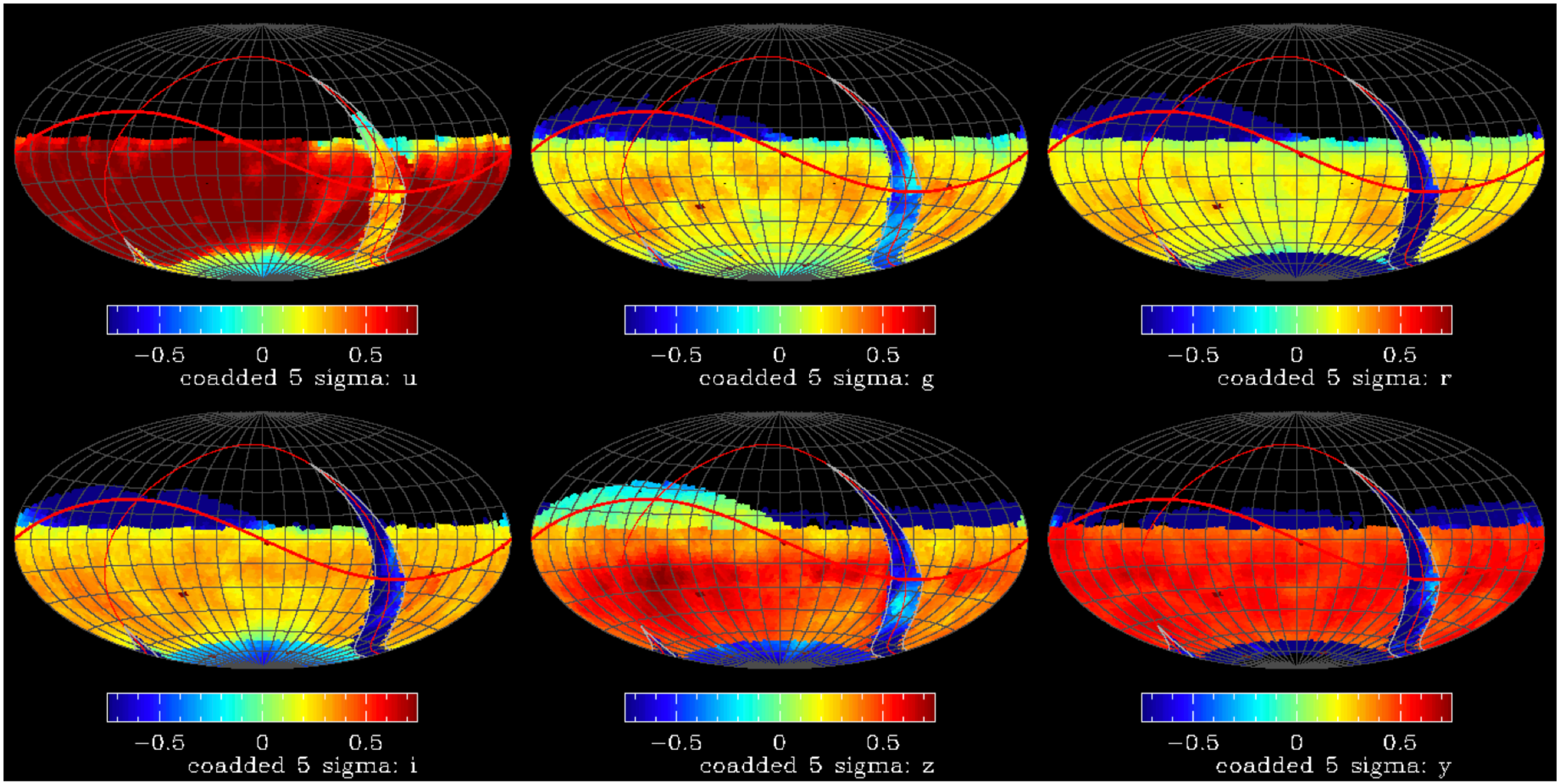
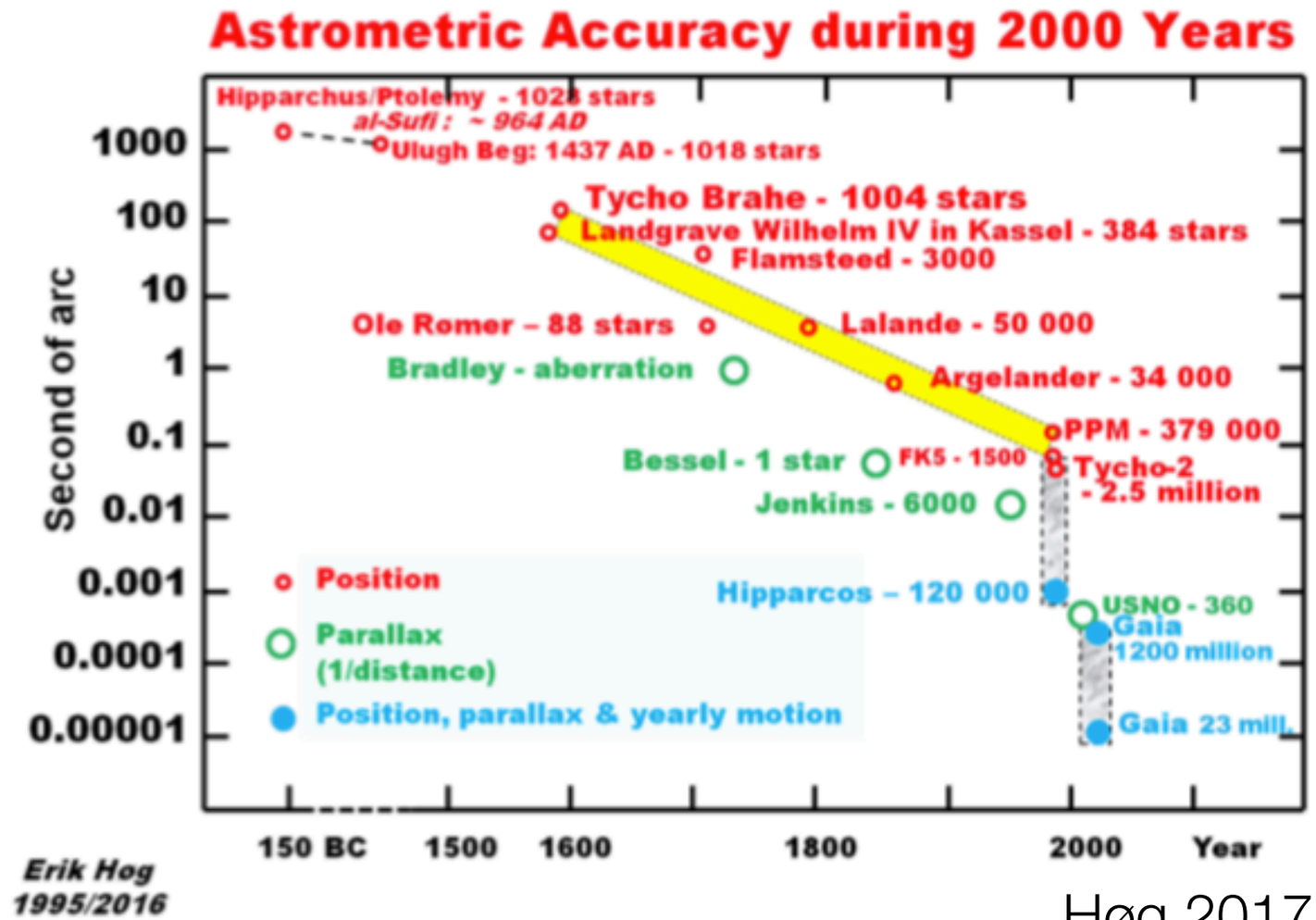


Figure 3.2: The 5σ stacked point-source depth of the simulated ten-year survey shown in Figure 3.1. The scale in each panel shows the depth of the stack relative to the fiducial values of 25.8, 27.0, 27.2, 27.0, 25.7, and 24.4 in u, g, r, i, z, y respectively.

Astrométricos

Astrométricos

- USNO B1:
  - Digitalización de las placas fotográficas tomadas por varios sondeos 1949-2002 (mayoritariamente POSS - Palomar Observatory Sky Survey)
    - V<20
- UCAC-5:
  - USNO CCD Astrometric Catalogue
    - V<14
- PPMXL: USNO (1ra época) + 2MASS (2da época)



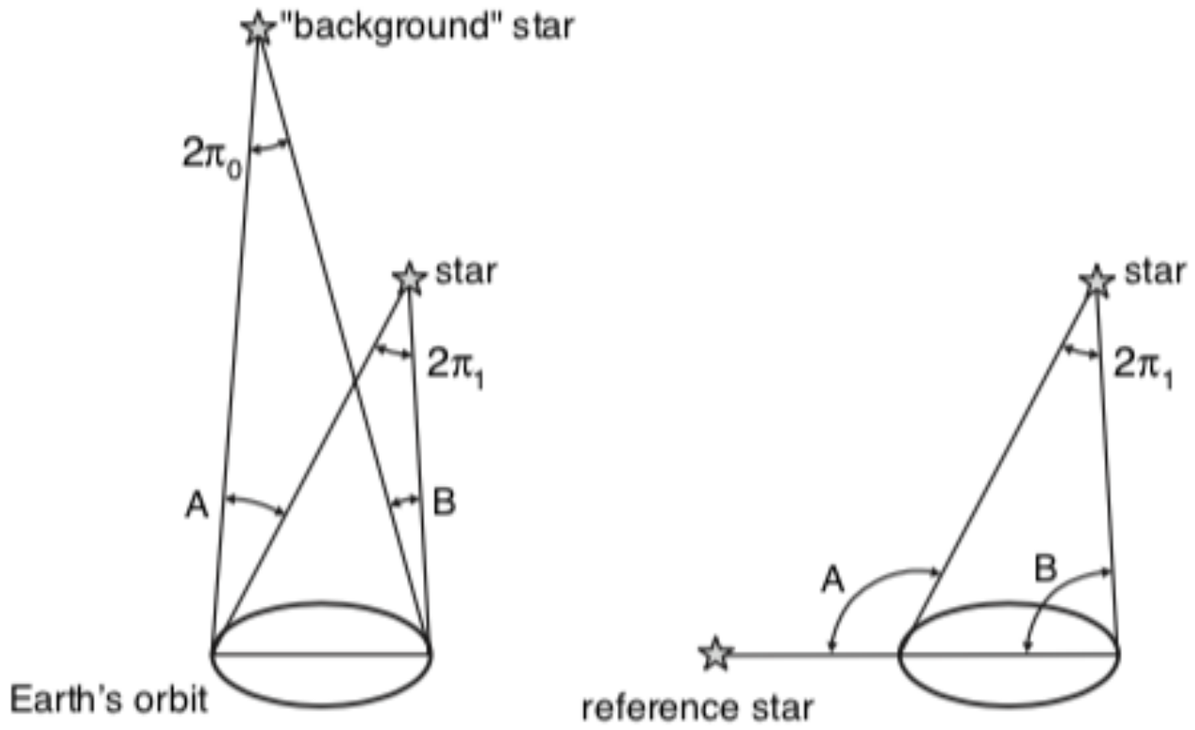
Høg 2017

Høg 2008

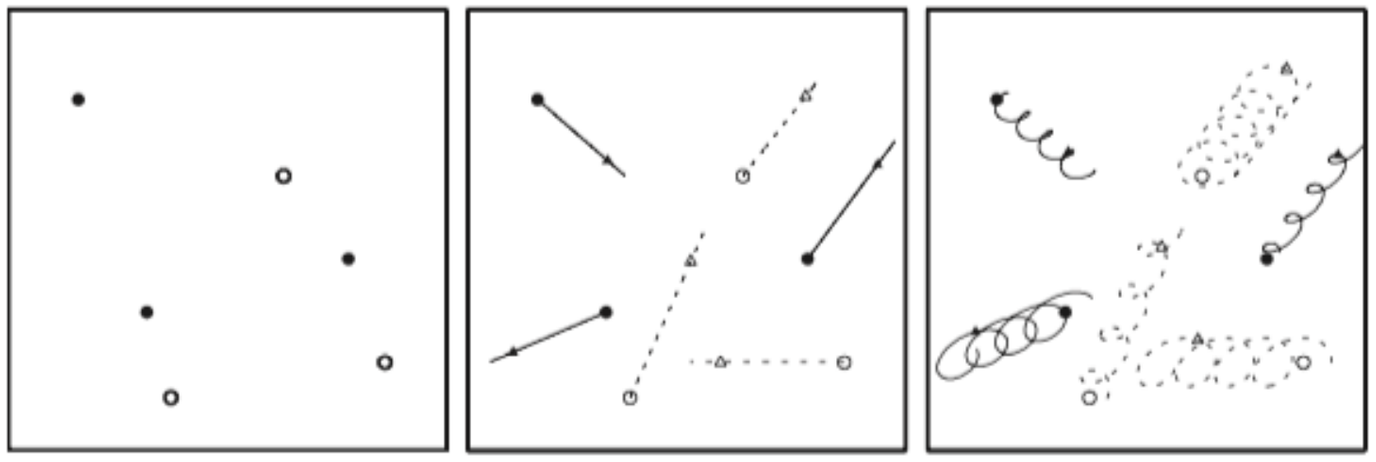
llegamos hasta aquí…

Hipparcos

- Órbita Geoestacionaria 1989-1993. Catálogo final publicado en 1997
- 118.218 estrellas hasta V=12.4
- Completitud: V=7-9.3 (depende del tipo espectral y la latitud galáctica)



- Precisión astrométrica:
- paralaje: 0.97 mas
- movimiento propio: 0.8 mas/año
- B, V



Perryman 2009

Hipparcos

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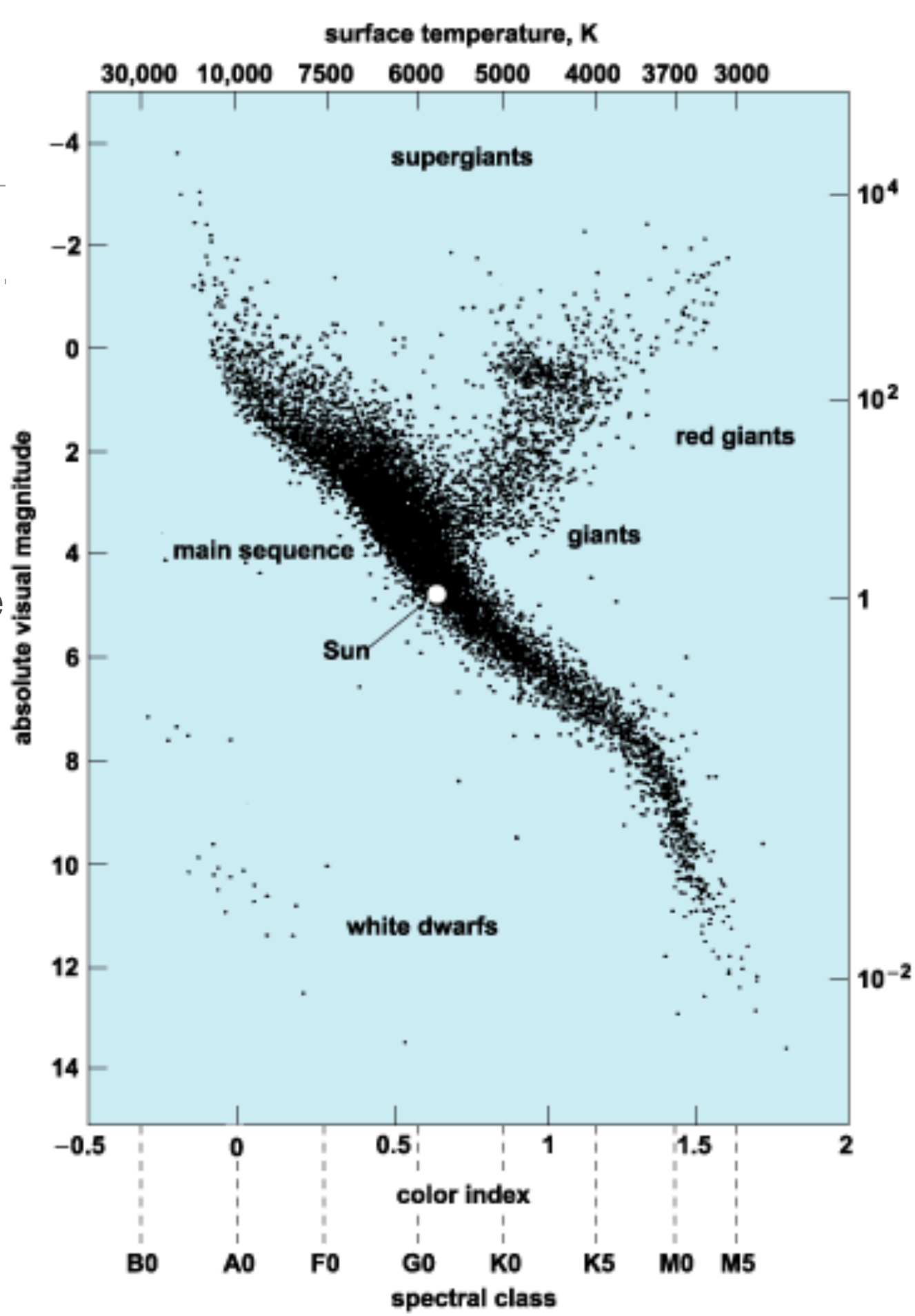
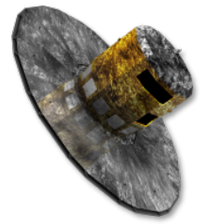


Gaia

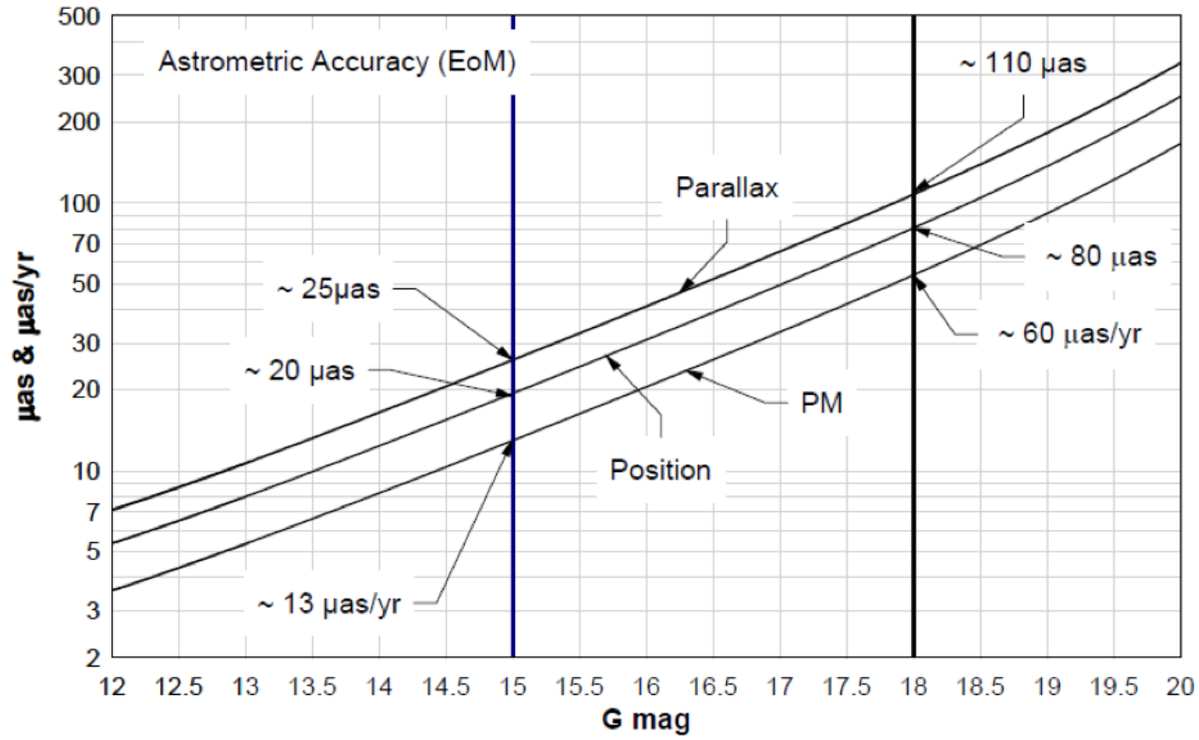
The Gaia Mission: A Short Summary

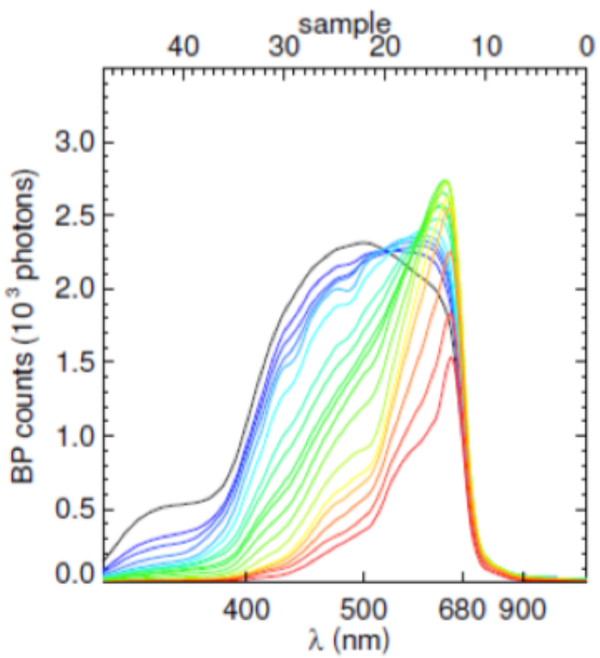


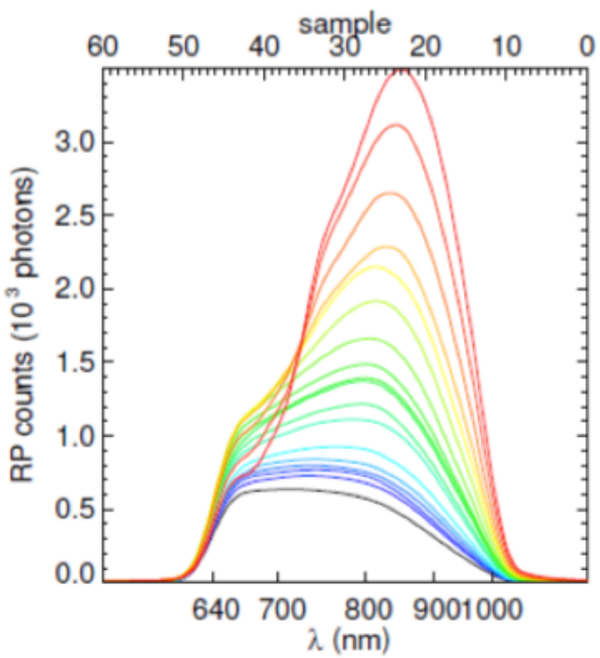
Launched: December 2013
Latest Data Release: E-DR3 12/2020
Mission Span: 5 years + 5yr extension
Orbit: Around L2

- Sondeo *all-sky, todo el cielo,* <u>completo</u> para todos los objetos hasta G=20 (V~20-22)

- Fotometría G + espectros de baja dispersión en 2 bandas BP, RP (y fotometría BP, RP)







- Velocidades radiales hasta G=16
  - Espectros Alta-Resolución (RVS) alrededor de Ca II Triplet (8500Å)

- Multi-época: de ~80 a 200 tránsitos por objecto (final de misión nominal)

ESA Gaia Science Performance Website + deBruijne (2012)

Photometric band-passes: G, BP, and RP

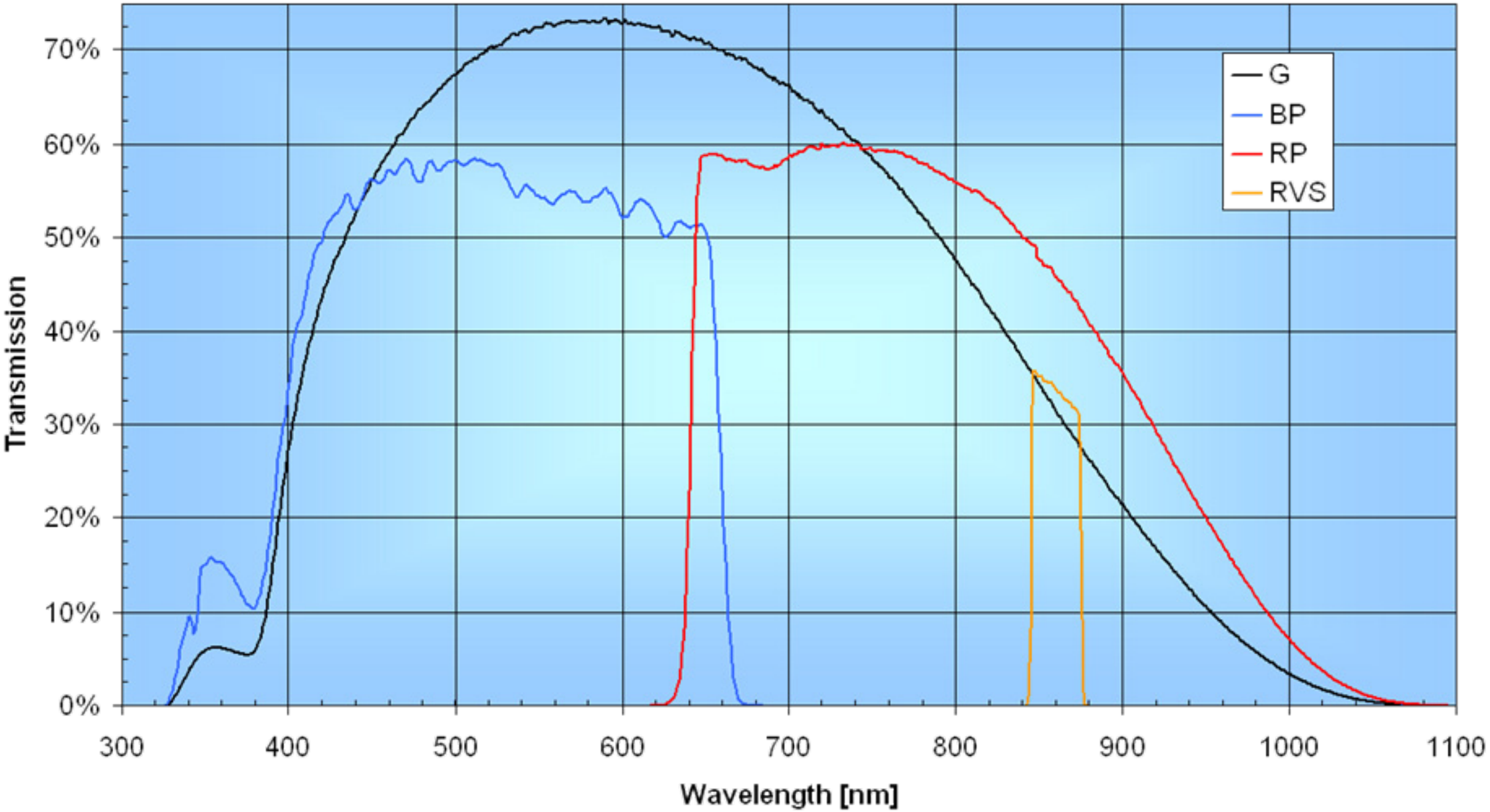
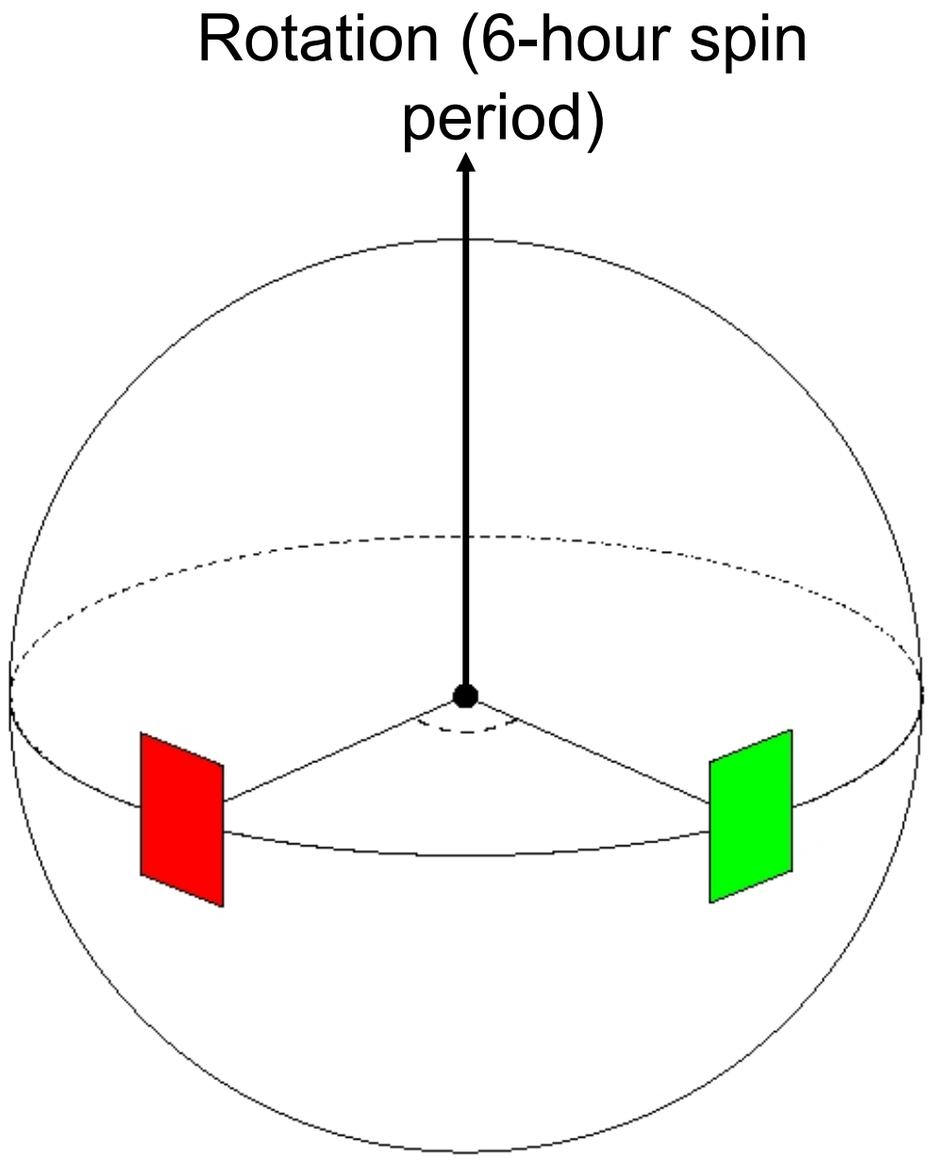


Figure from http://www.rssd.esa.int/index.php?project=GAIA&page=Science_Performance (see also 2012arXiv1201.3238De Bruijne)

Gaia's "secret"



1. Make simultaneous measurements in two fields separated by a large angle
   (Two 1.45m telescopes)
2. Scan along a great circle through both fields

3. Make one-dimensional measurements, along scan

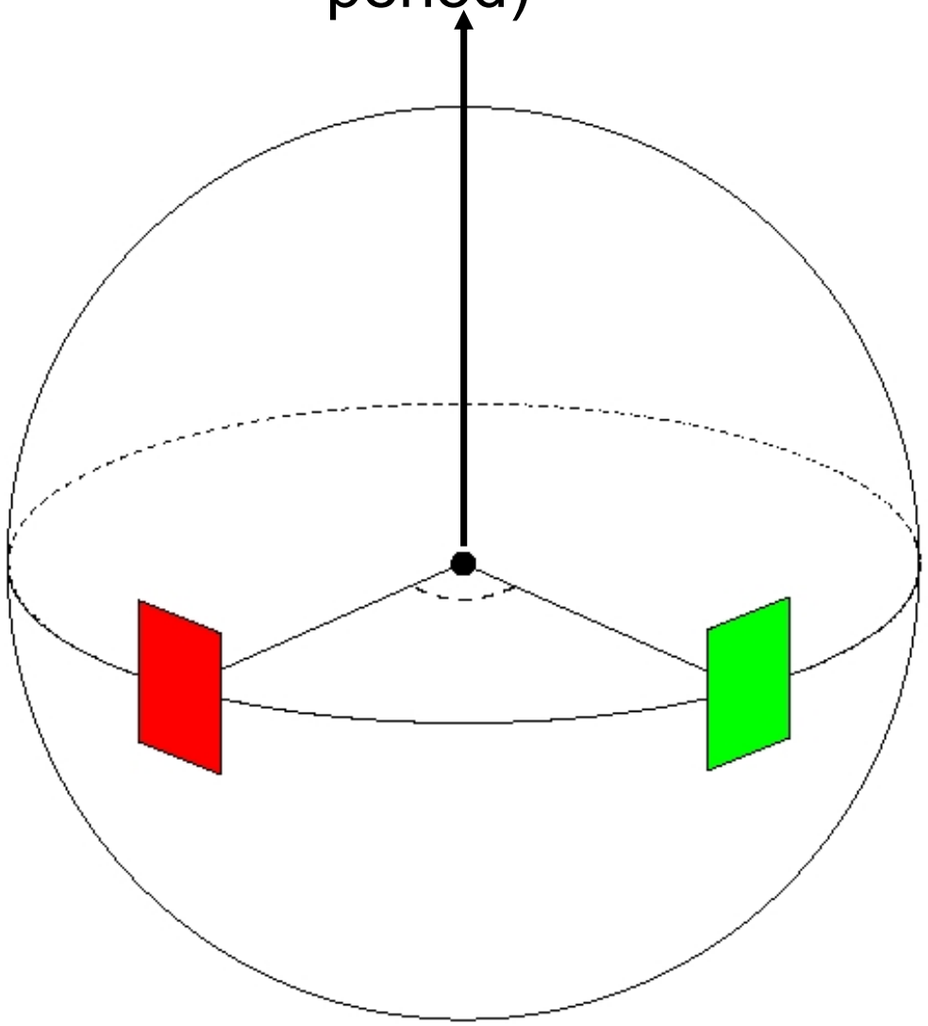
4. The 'basic angle' between the two fields must be "perfectly" stable ⇒ observe from space

Sky scanning with two viewing directions ⇒ global accuracy

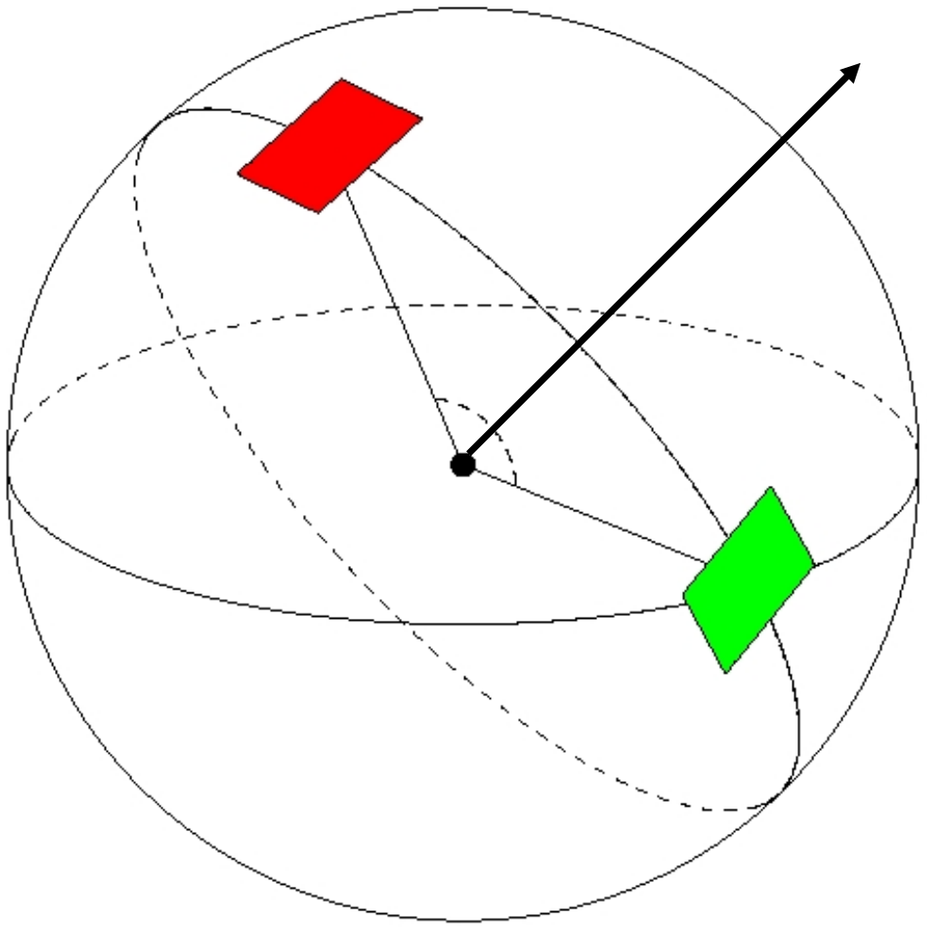
Figure courtesy of Jos de Bruijne

Measurement principle

Rotation (6-hour spin period)



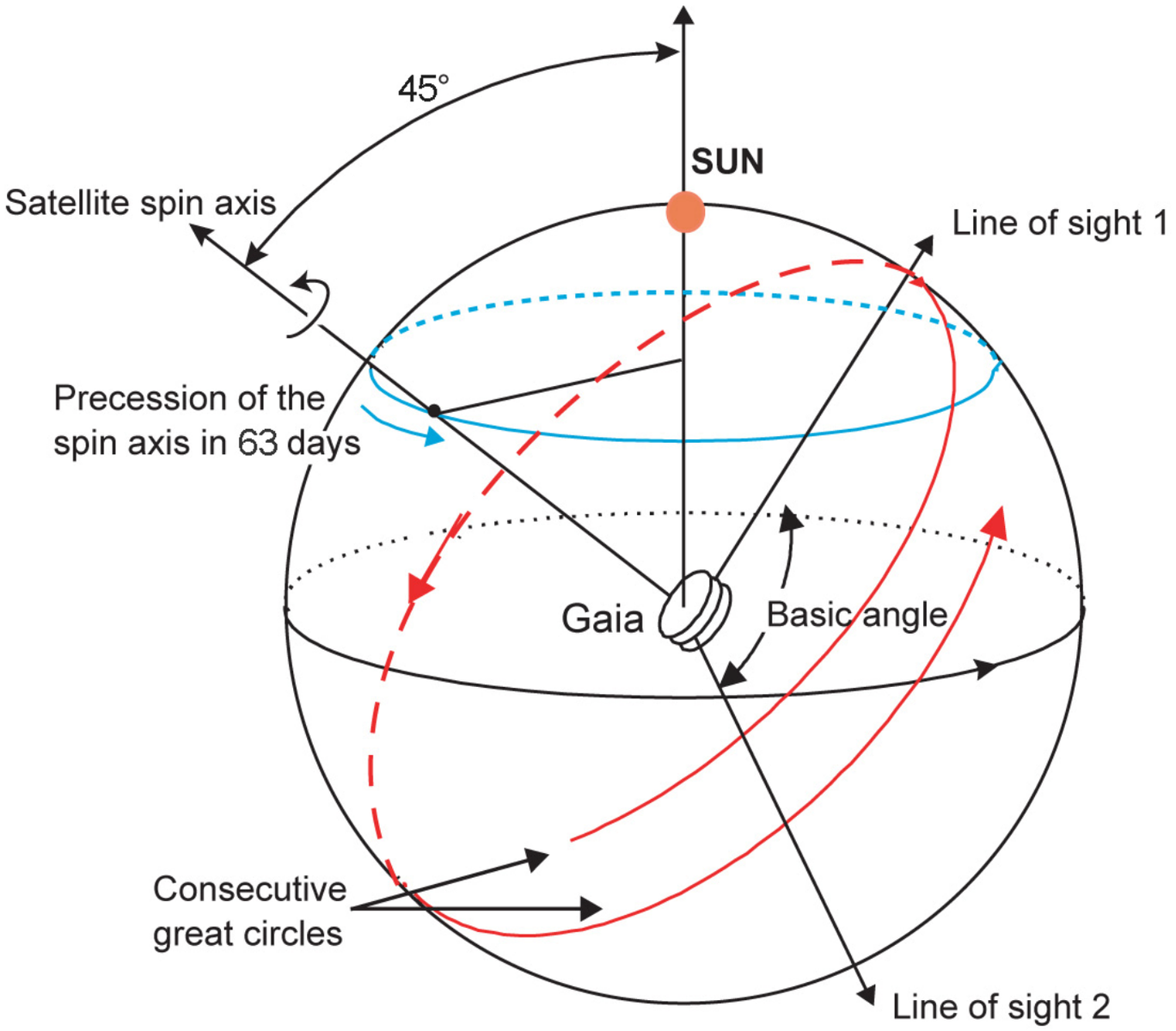
Precession of spin axis (63-day period)



Each star is seen, on average, 14 times per year
(70 times in 5 years)

Figure courtesy of Jos de Bruijne

Sky-scanning principle



Make the spin axis revolve at a constant angle ξ from the Sun

Spin axis:	45° to Sun
Scan rate:	60 arcsec s^{-1}
Spin period:	6 hours
Precession:	63-day period
Transits:	70 in 5 years
Coverage:	100% every 6 months

Figure courtesy of Jos de Bruijne

End-of-mission number of transits

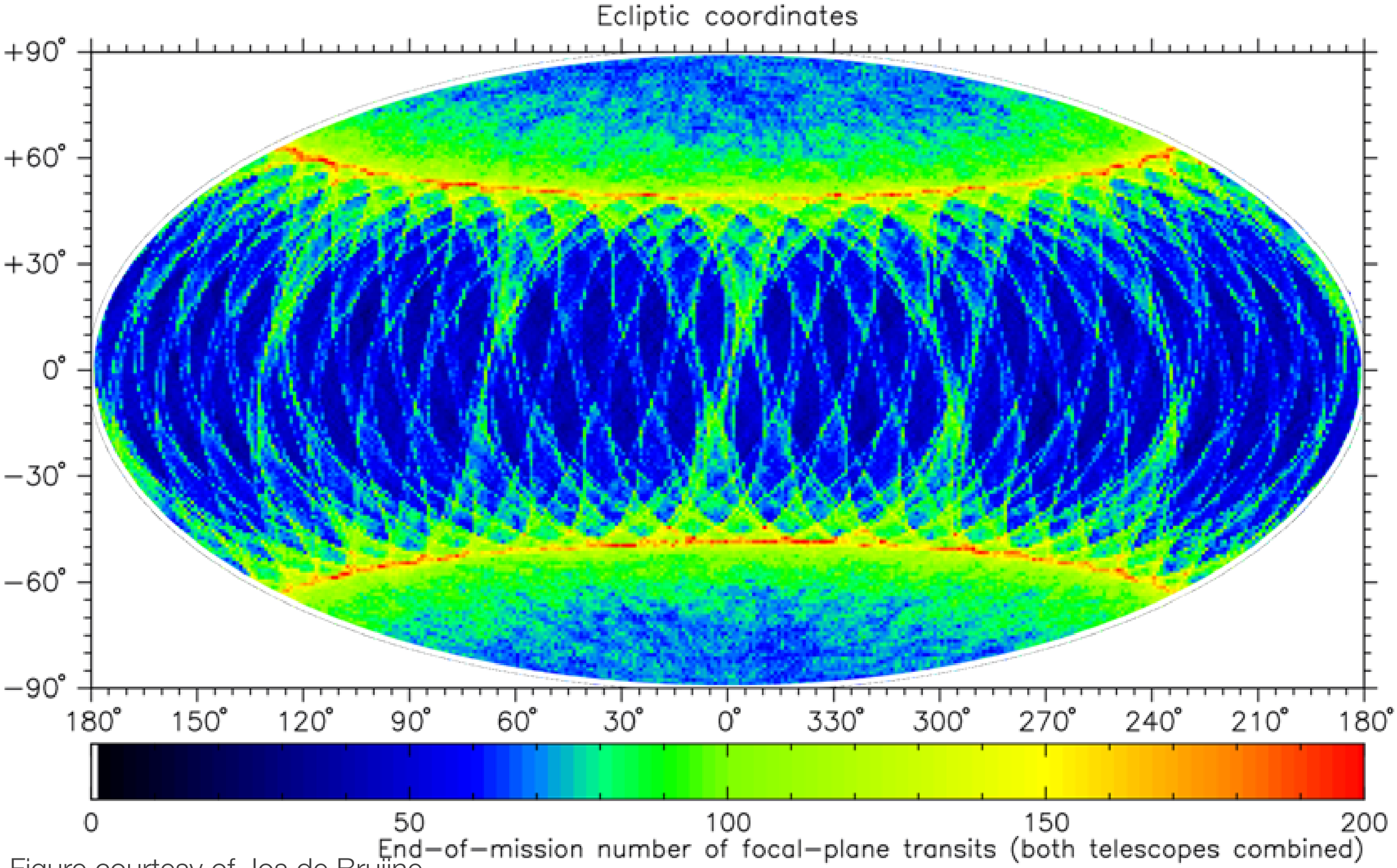
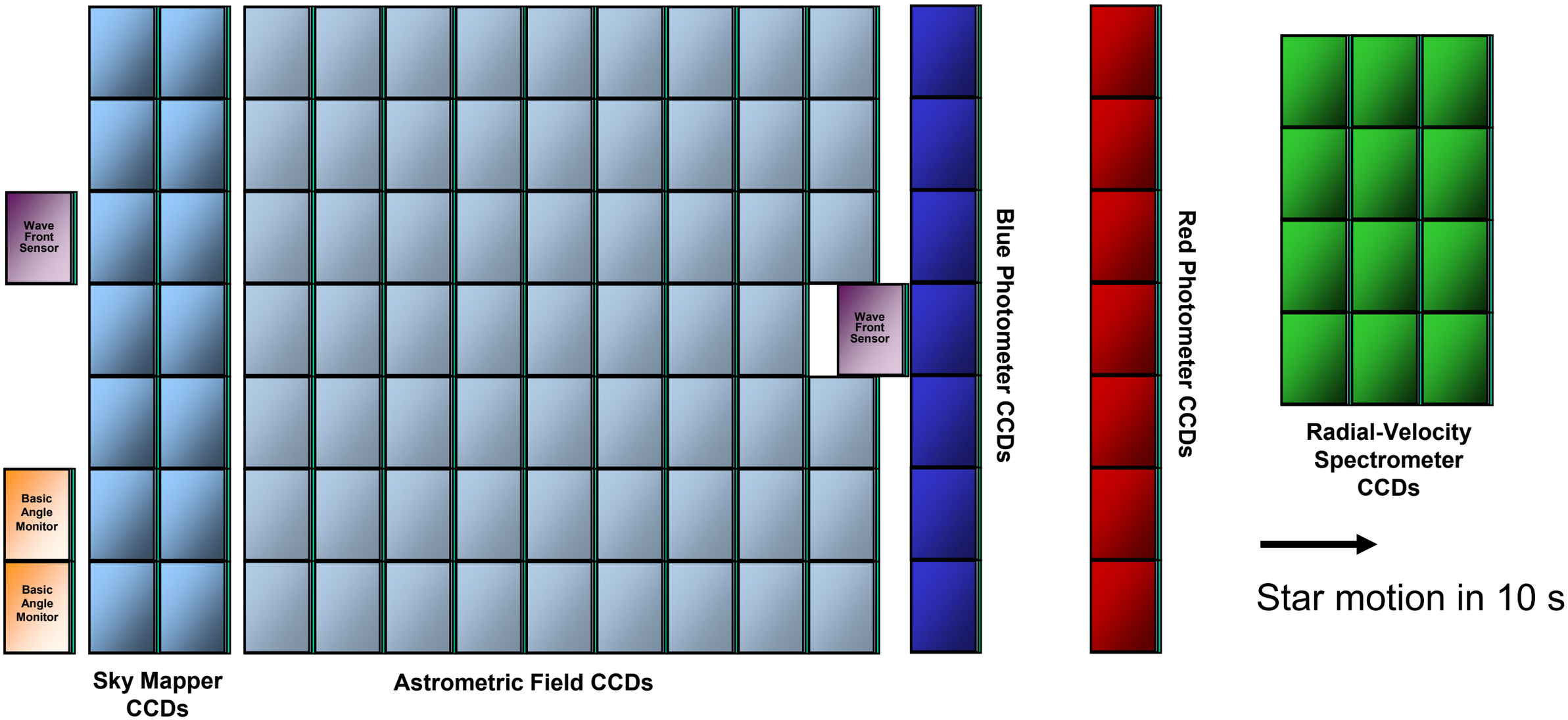


Figure courtesy of Jos de Bruijne

Figure from http://www.rssd.esa.int/index.php?project=GAIA&page=Science_Performance – Ecliptic coordinates

Focal plane

Figure courtesy Alex Short

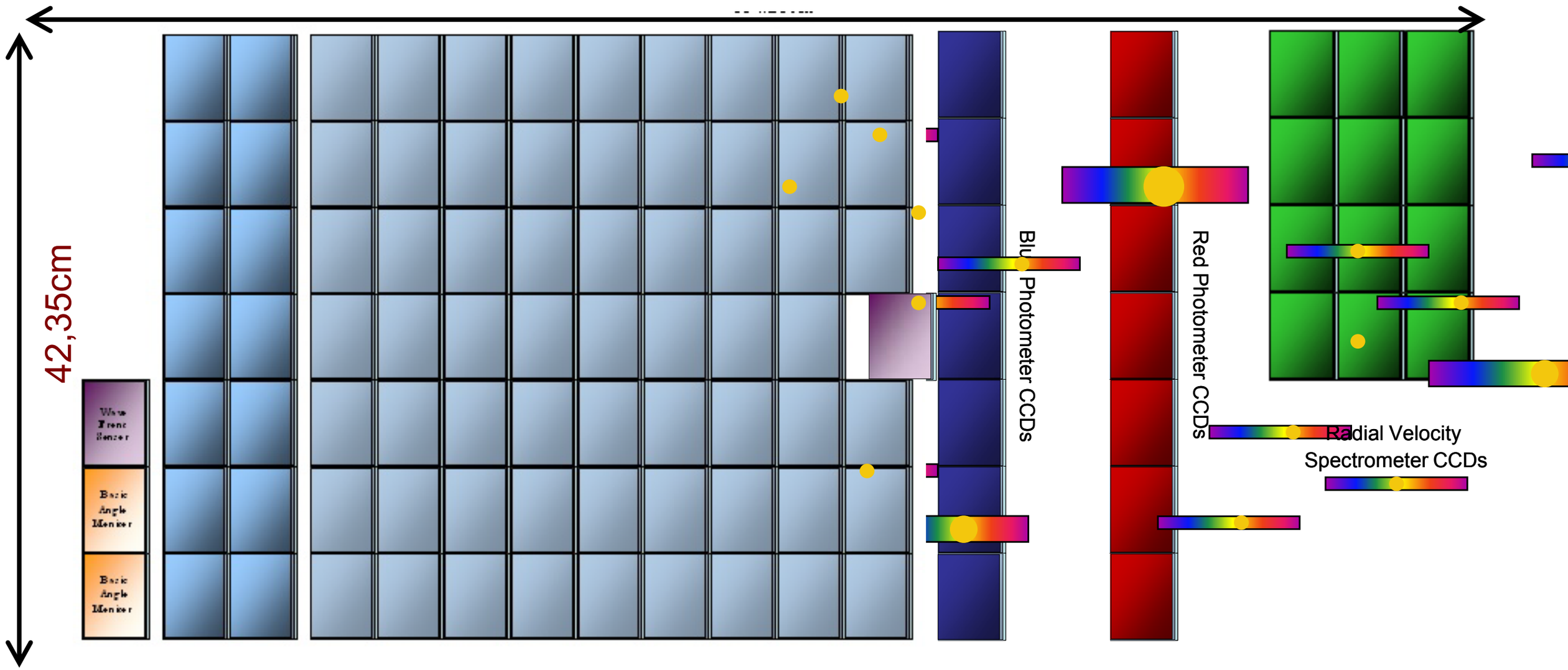


Total field:

- Area: 0.75 deg^2
- Size: 104 $\times$ 42 cm^2
- Number of CCDs: 106 (938 million pixels)
- CCDs: 4500 $\times$ 1966 pixels, operated in TDI mode

Scanning Space Astrometry:

to transform positional information into timing data



Time Delay Integration (TDI mode) 4.4 s/ CCD

Example (AF2)

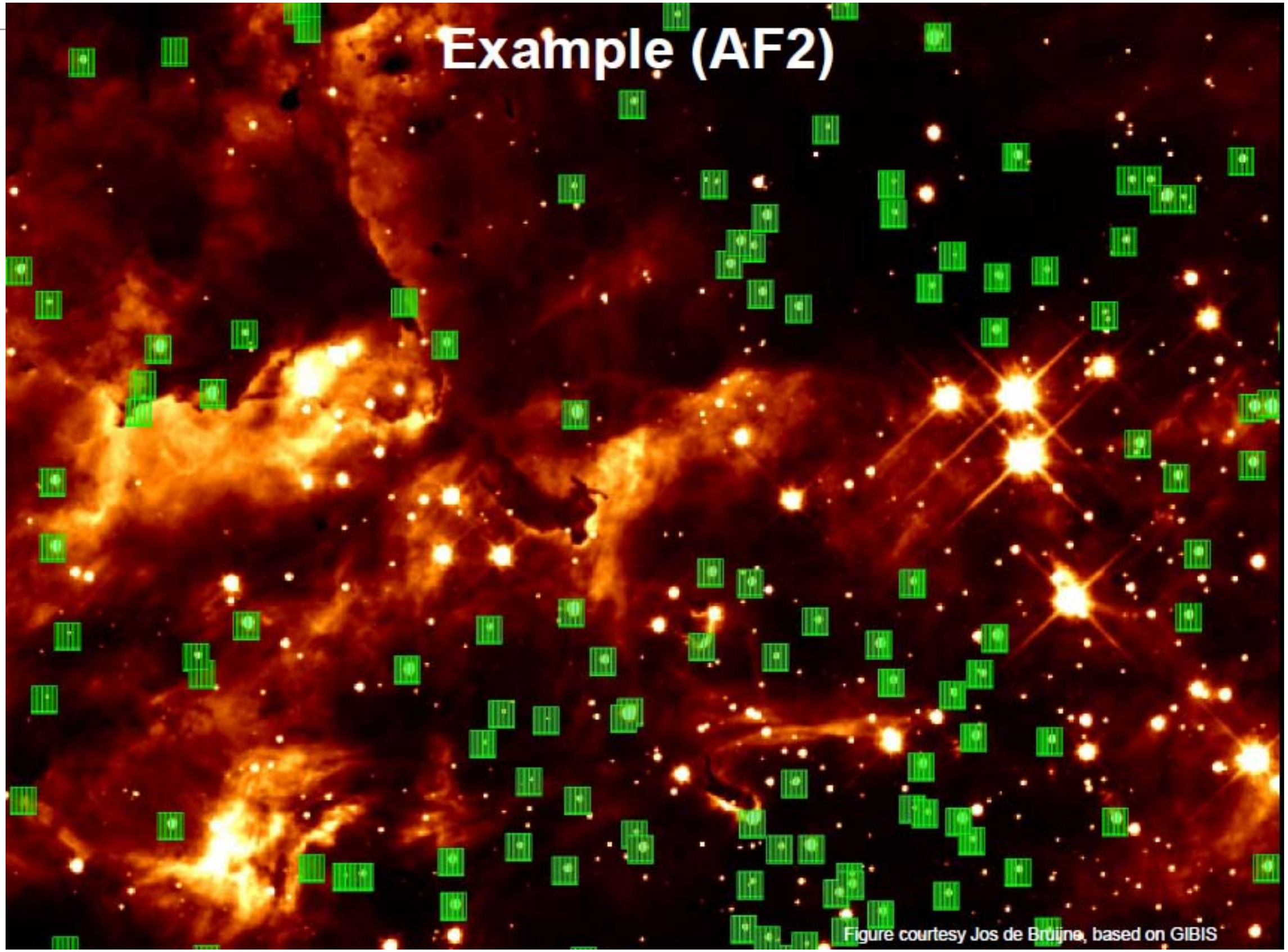
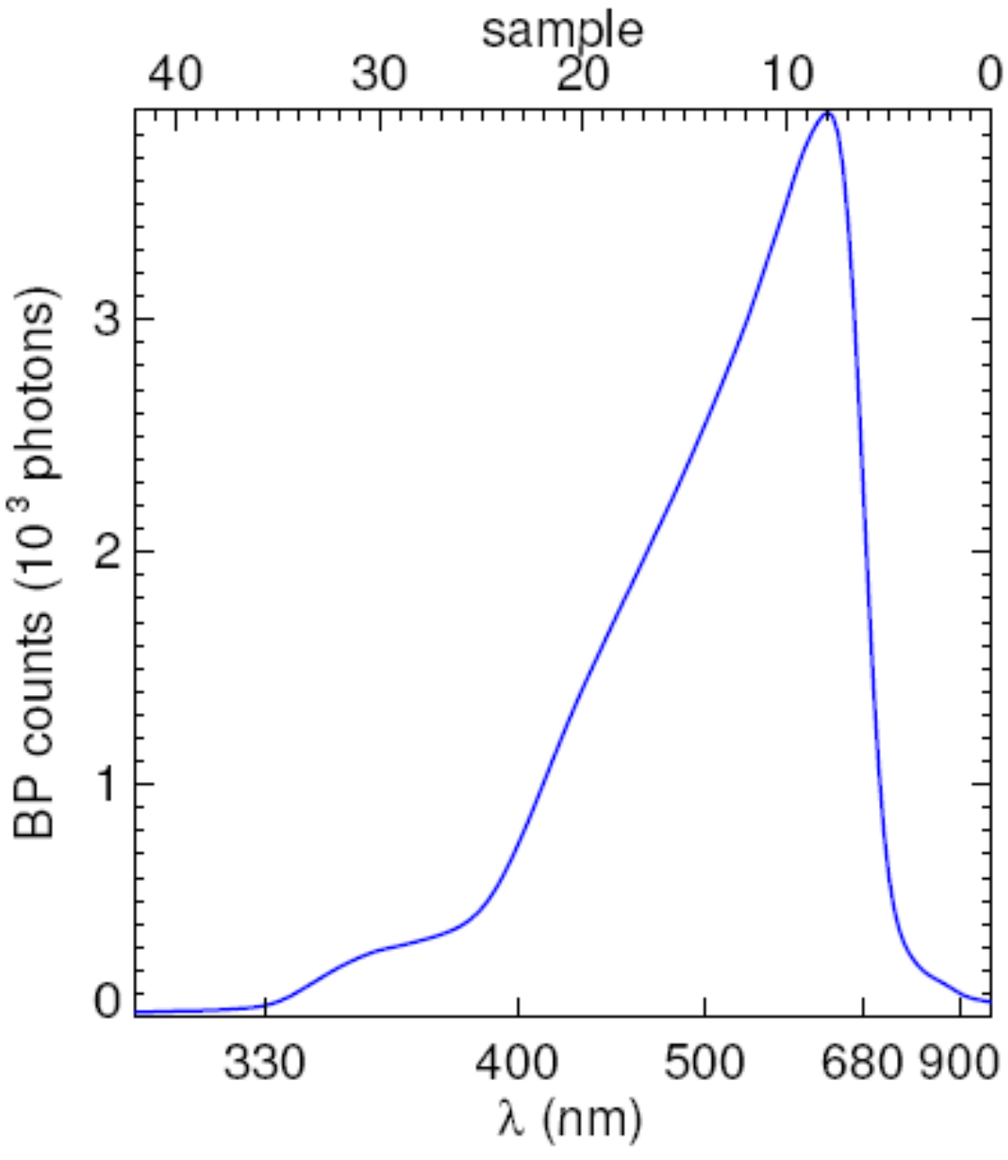


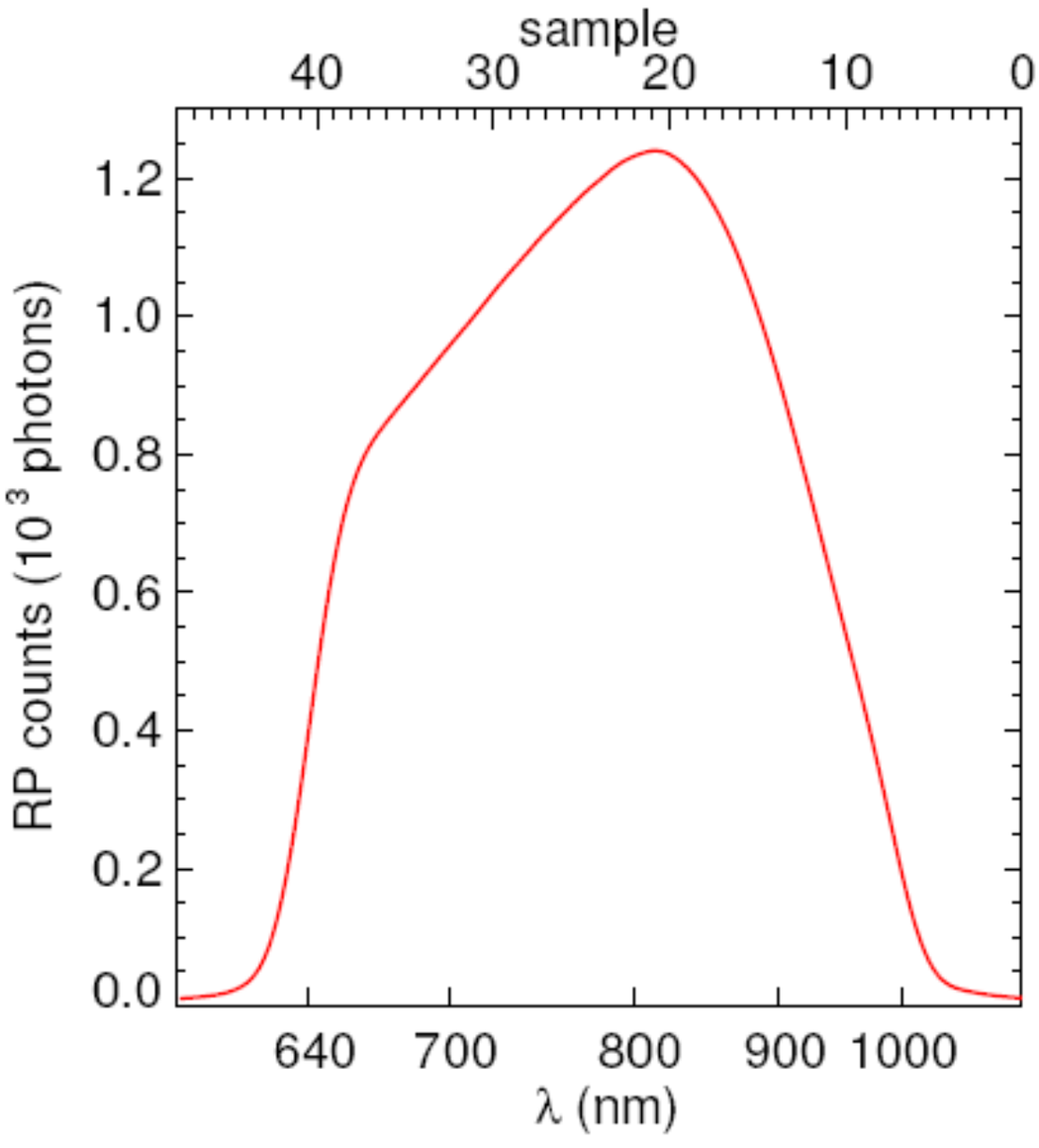
Figure courtesy Jos de Bruijne, based on GIBIS

Example BP and RP spectra

Espectros de fuente plana (para ver la curva de transmisión de BP/RP)



BP has red edge leading

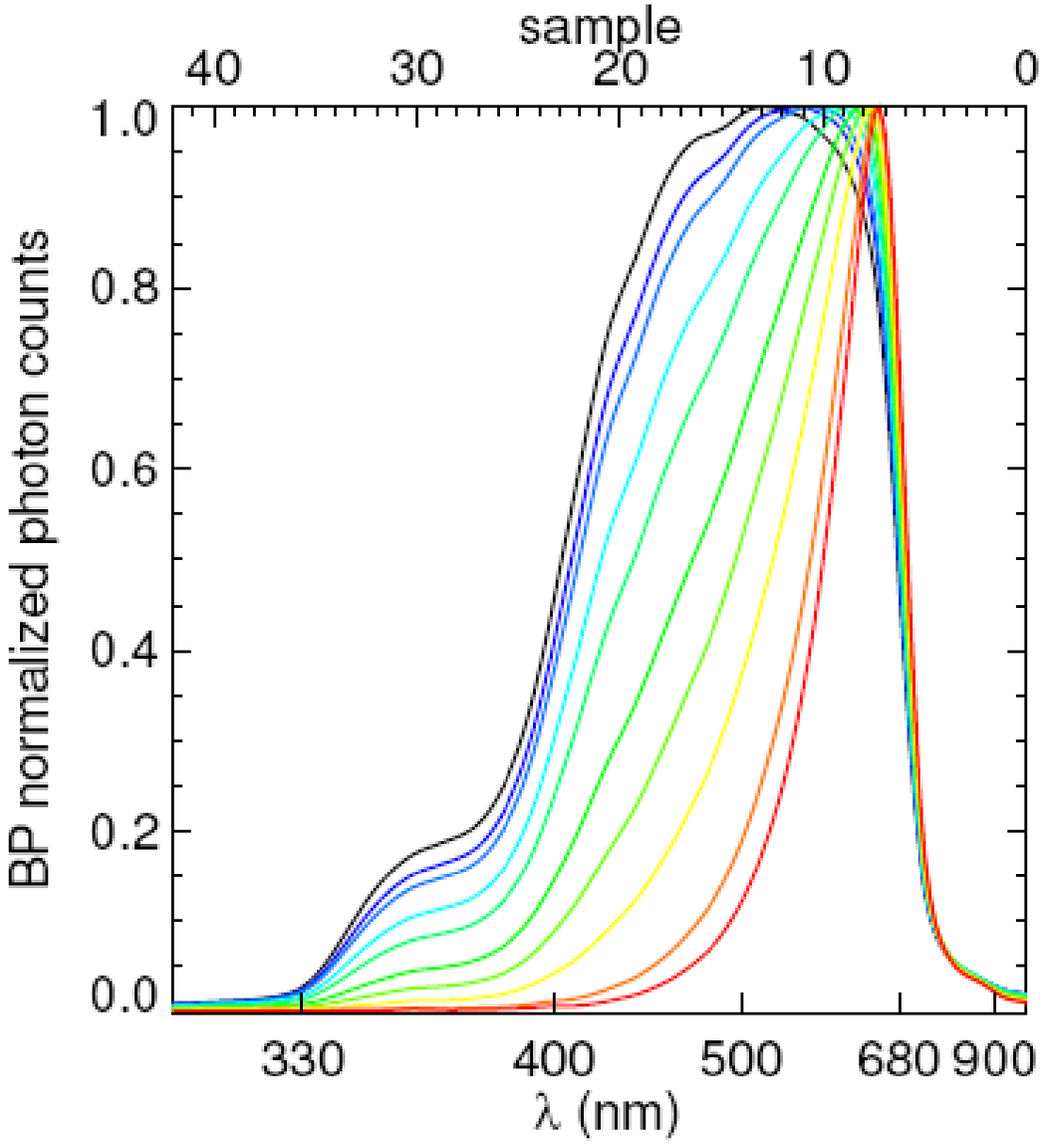


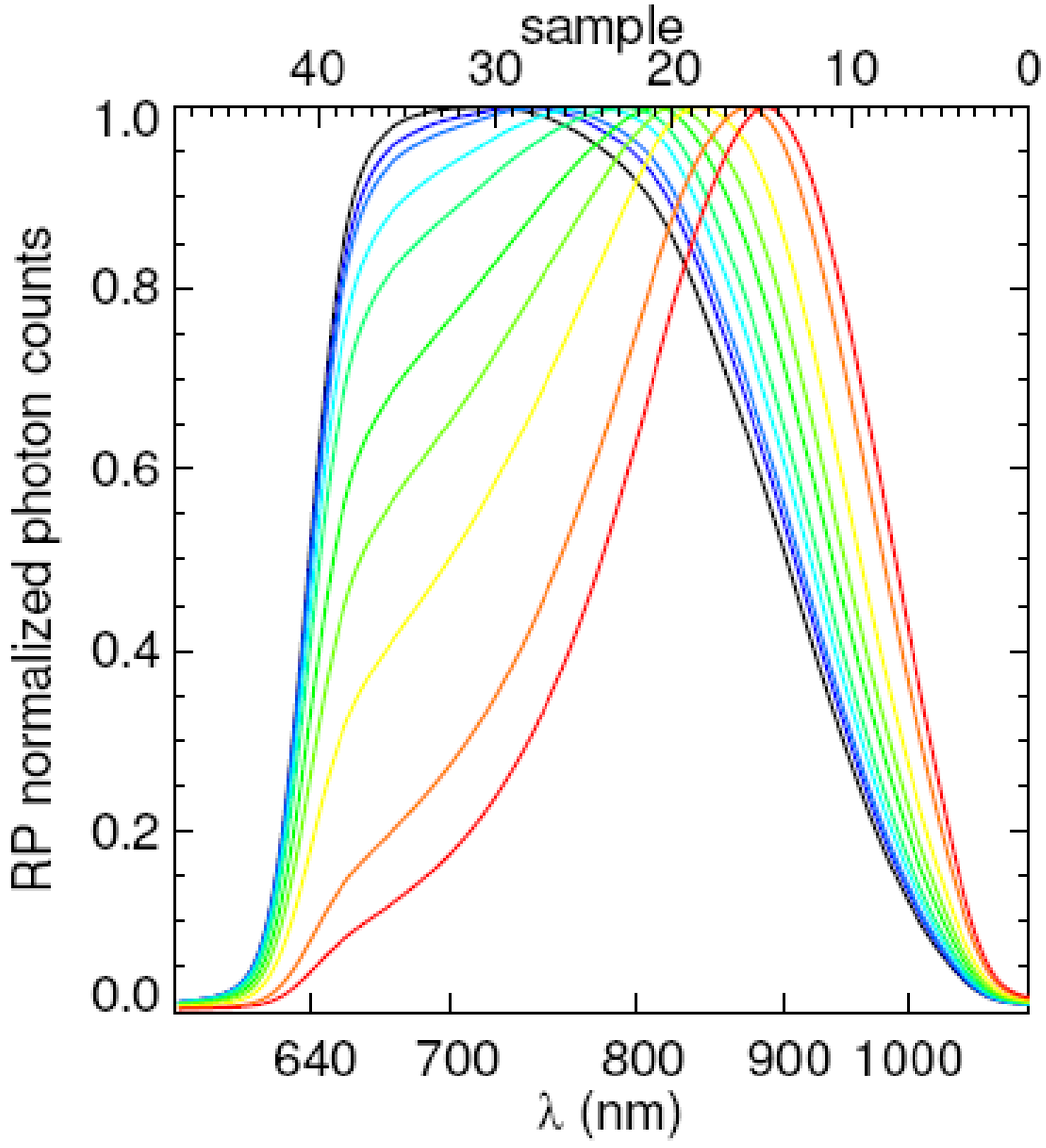
RP has blue edge leading

Figures courtesy Anthony Brown

Example BP and RP spectra

Blue dwarf with varying extinction



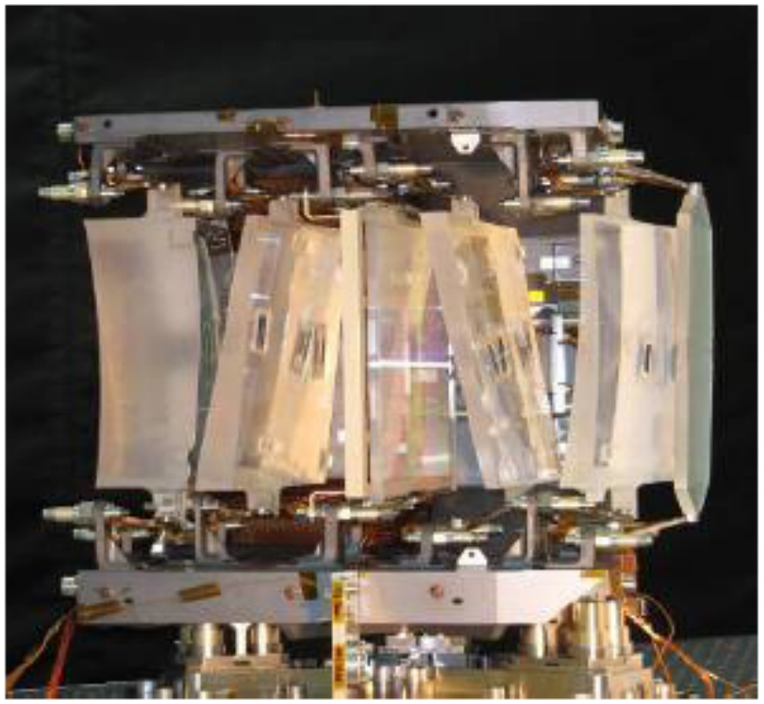


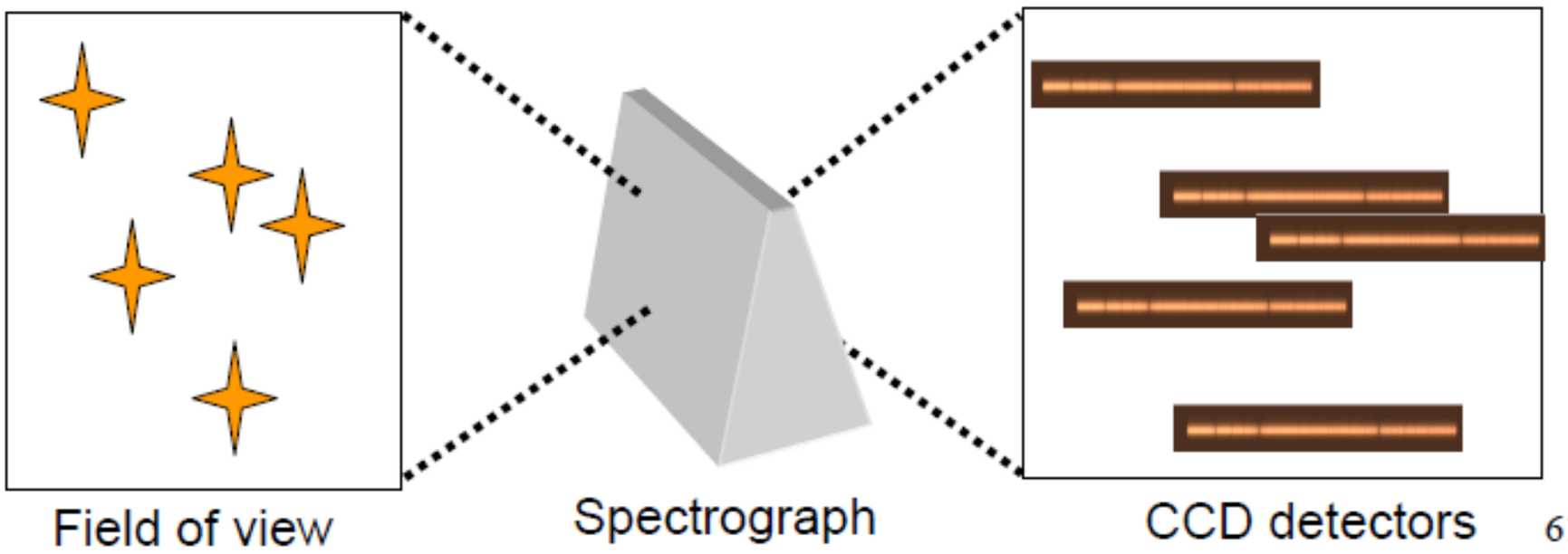
Figures courtesy Anthony Brown

High-resolution spectroscopy

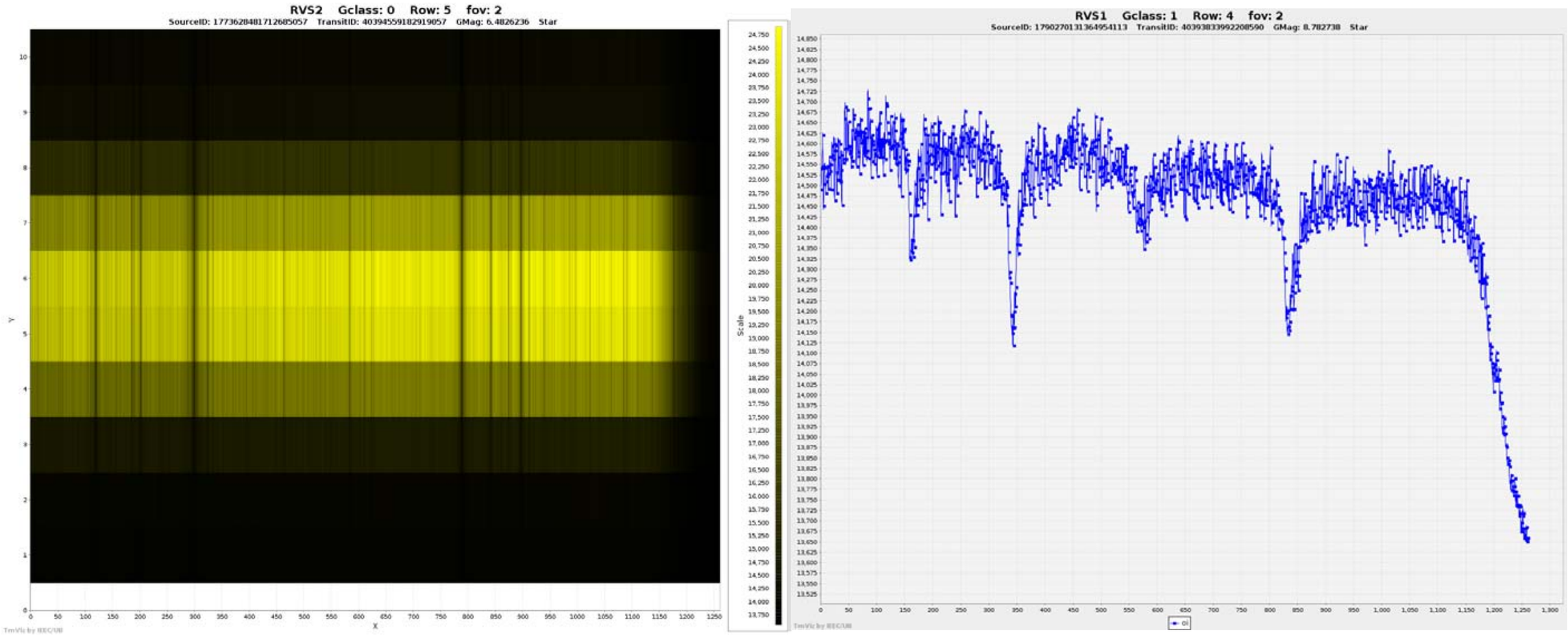
- Grating-based, integral-field spectrograph
  - Resolving power 11,500
  - Spectral sampling 0.027 nm pixel^{-1}
  - Wavelength range 847 – 874 nm
  - Limiting magnitude ~17 mag
- Covers 4 CCD rows ⇒ 40 transits over 5 years
- Along-scan dispersion with 1260-pixel spectra
- Red-enhanced CCDs operated in TDI mode

Figure courtesy IOF, Selex Galileo, Boostec, and EADS Astrium



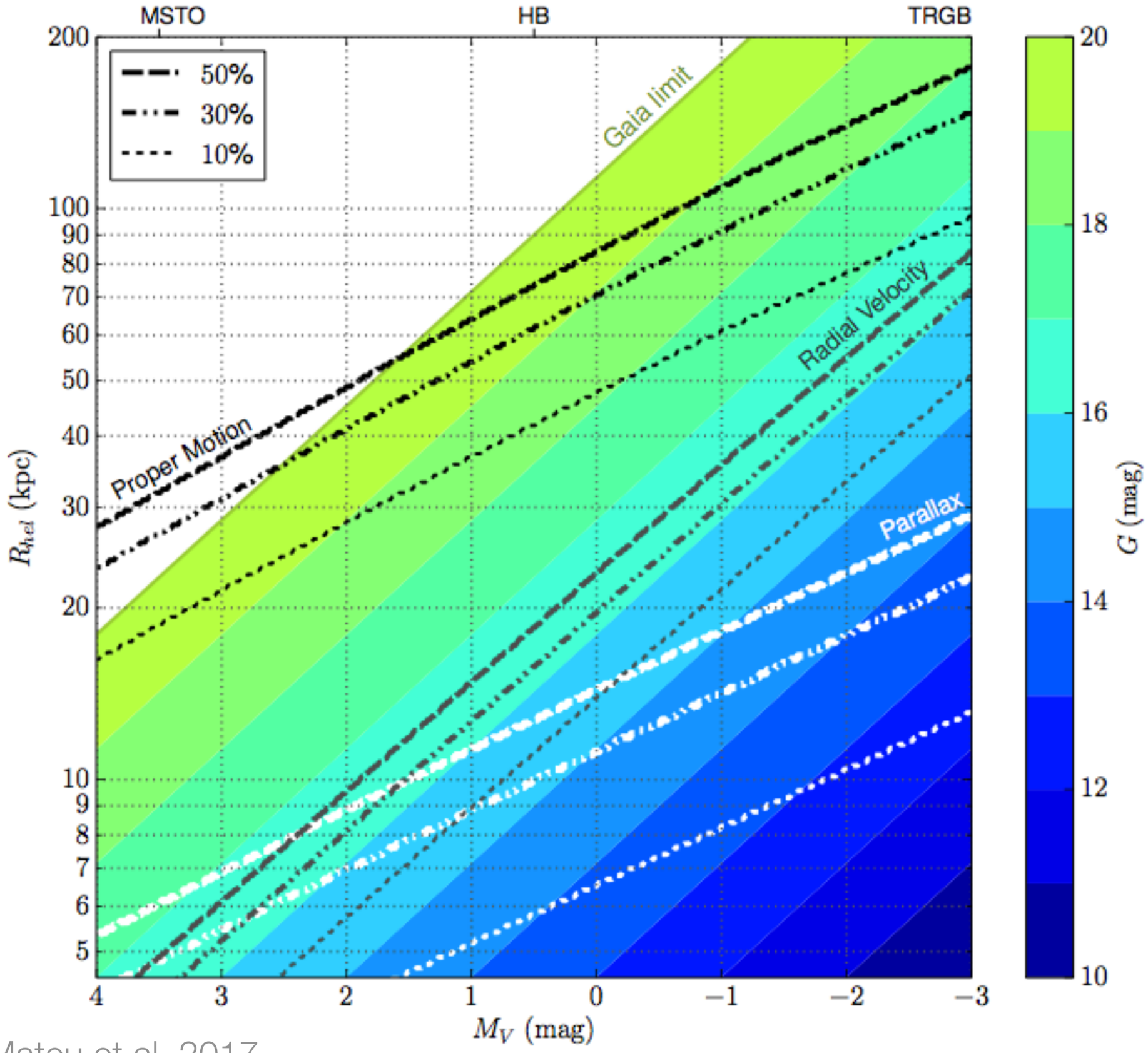


High-resolution spectroscopy (RVS)



Transit spectra G= 8.7

Desempeño de Gaia (tiempo nominal de misión 5 años)



adaptado de Mateu et al. 2017

¿Cuánto de la Vía Láctea está observando Gaia?

- La Vía Láctea tiene ~10^{10} estrellas
- **Gaia observará >1% de *todas* las estrellas en la Galaxia**
- El volumen cubierto ***depende del tipo de estrella que se use*** (trazador)
- **Paralajes trigonométricos** con precisión del 30% **hasta ~20 kpc** (para estrellas brillantes)
- Para distancias mayores necesitamos usar distancias fotométricas (también llamados "paralajes fotométricos")

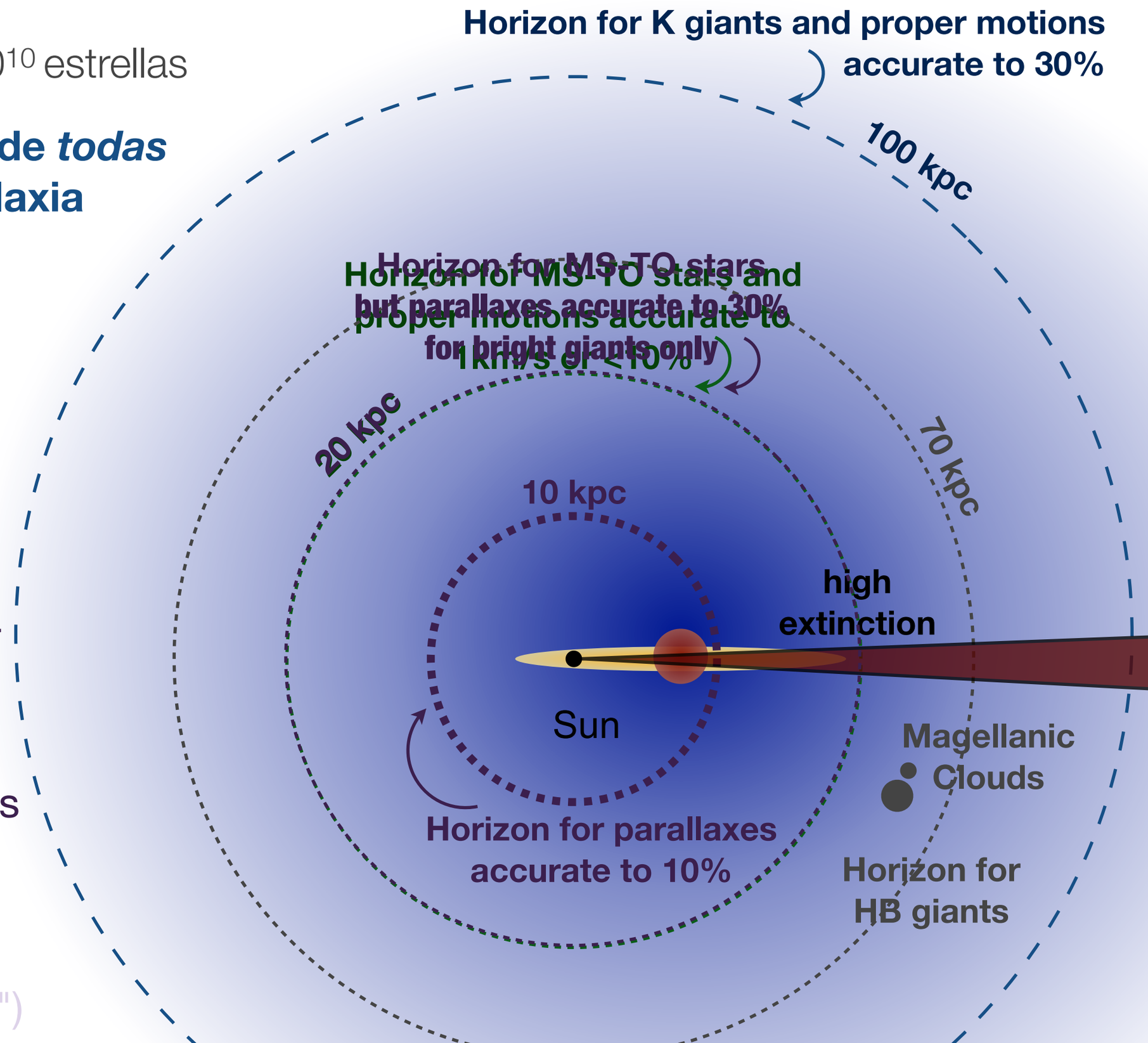


Diagrama Color-Magnitud de Gaia

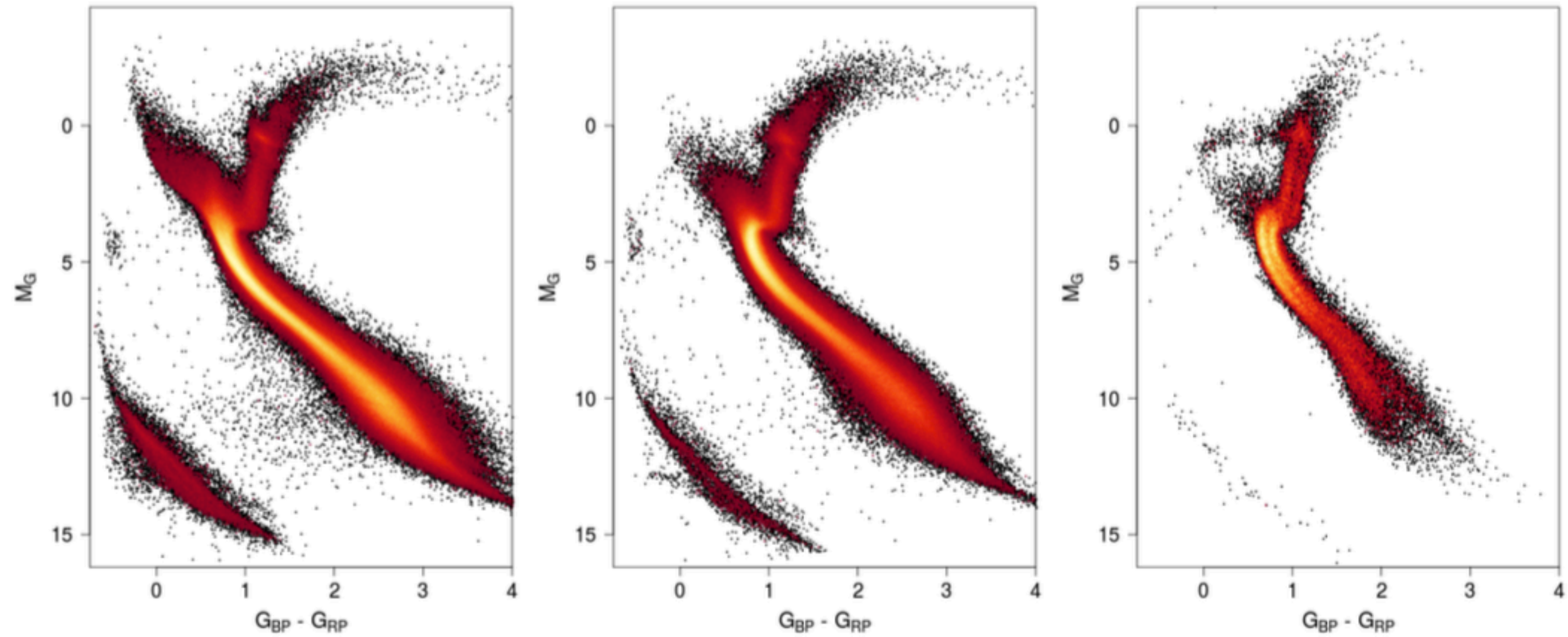


Fig. 21. *Gaia* HRDs with kinematic selections based on the tangential velocity: a) V_T<40 km s^{-1} (1,893,677 stars), b) 60<V_T<150 km s^{-1} (1,303,558 stars), and c) V_T>200 km s^{-1} (64,727 stars).

Babusiaux et al. 2018

Transit-level integrated photometry

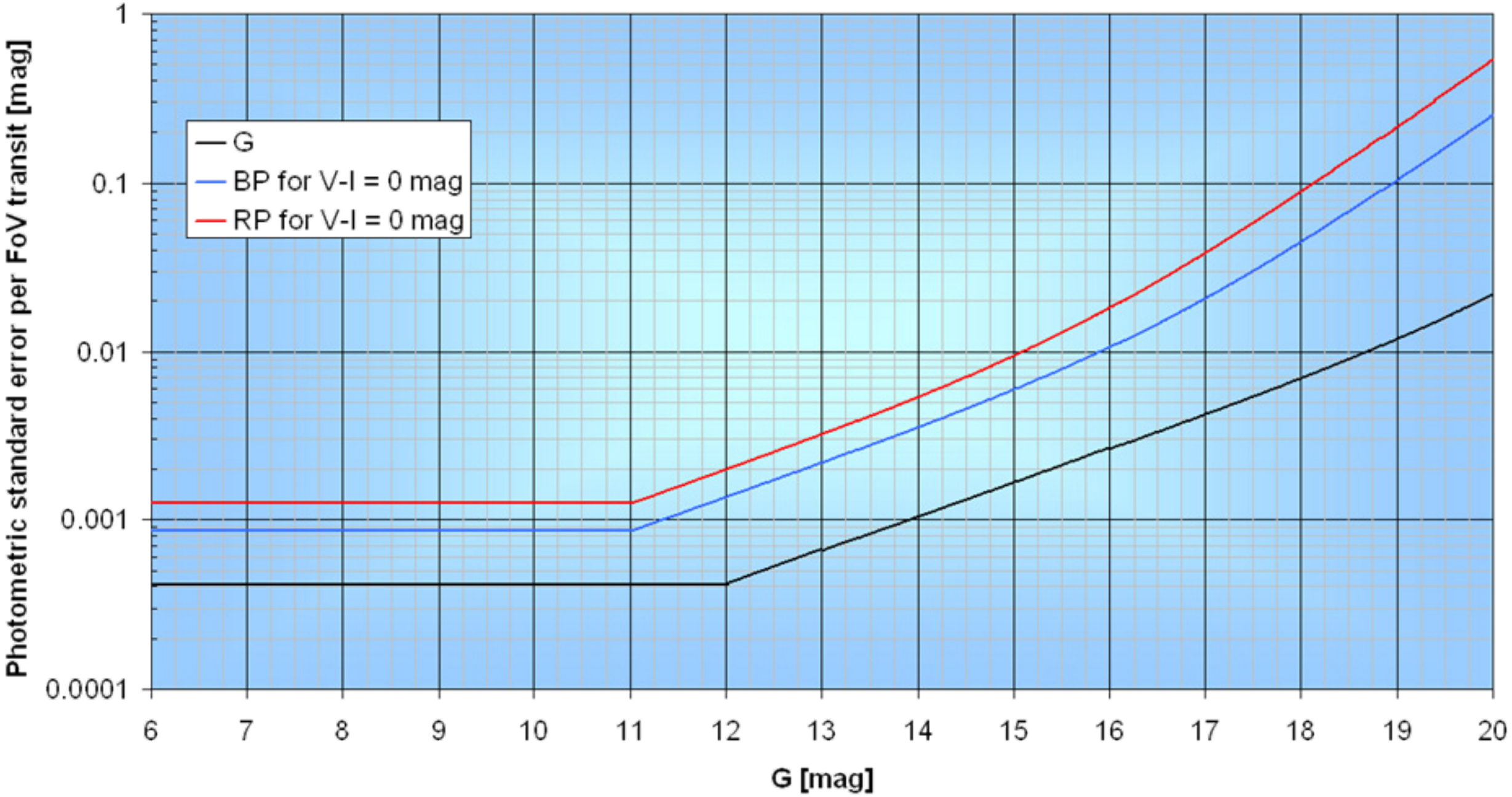


Figure from http://www.rssd.esa.int/index.php?project=GAIA&page=Science_Performance (see also 2012arXiv1201.3238De Bruijne)

Transit-level integrated photometry

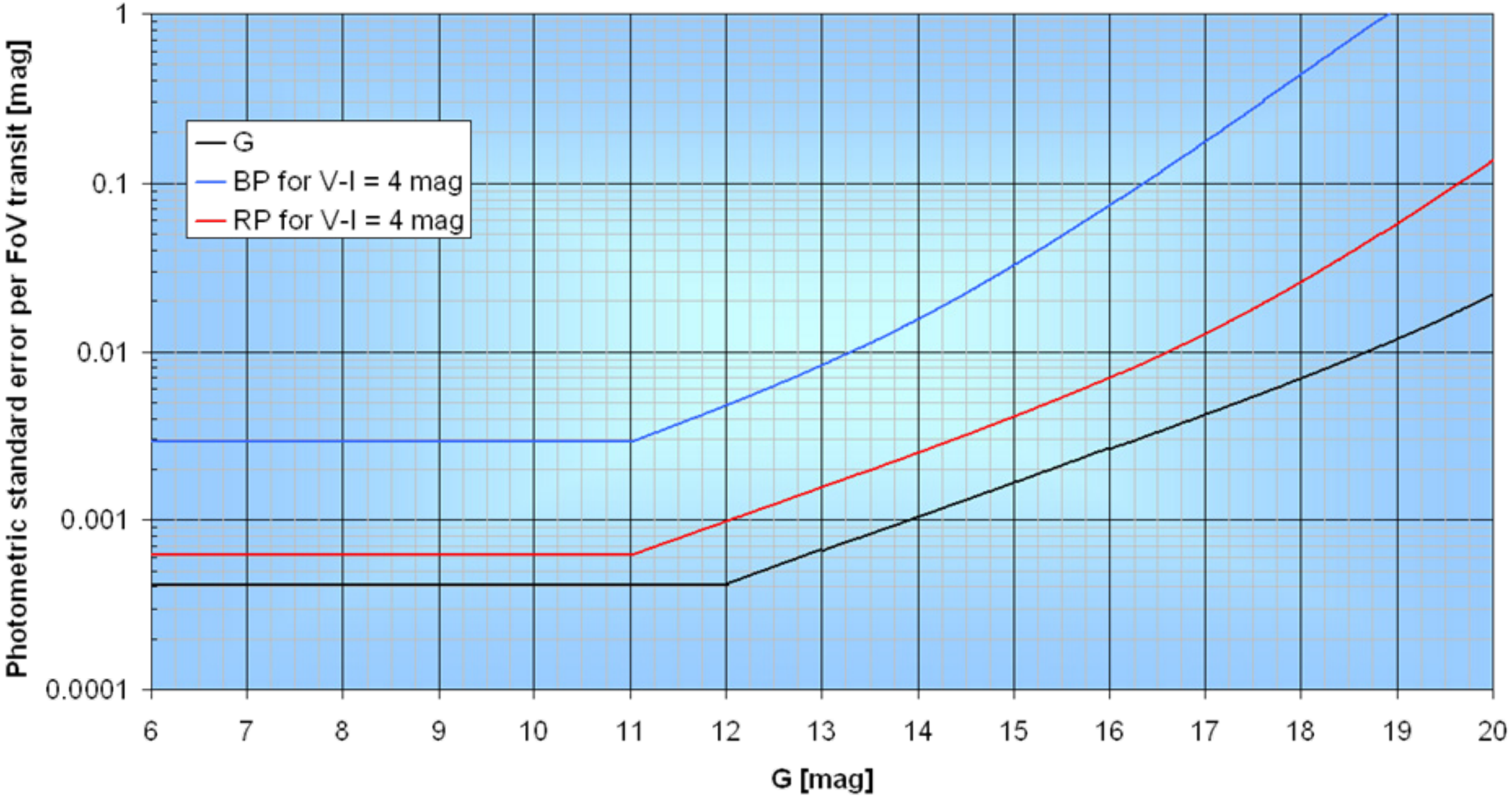
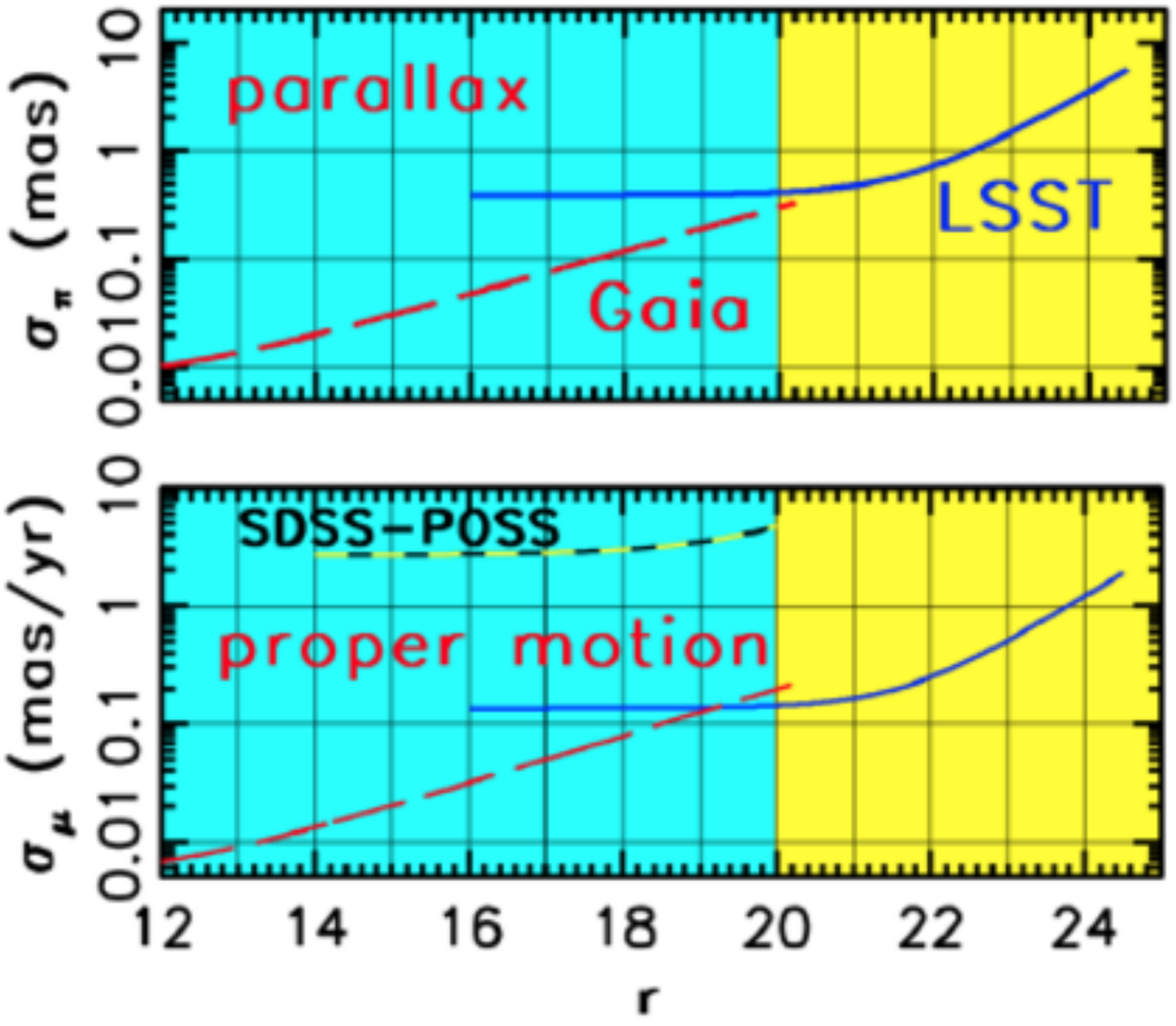
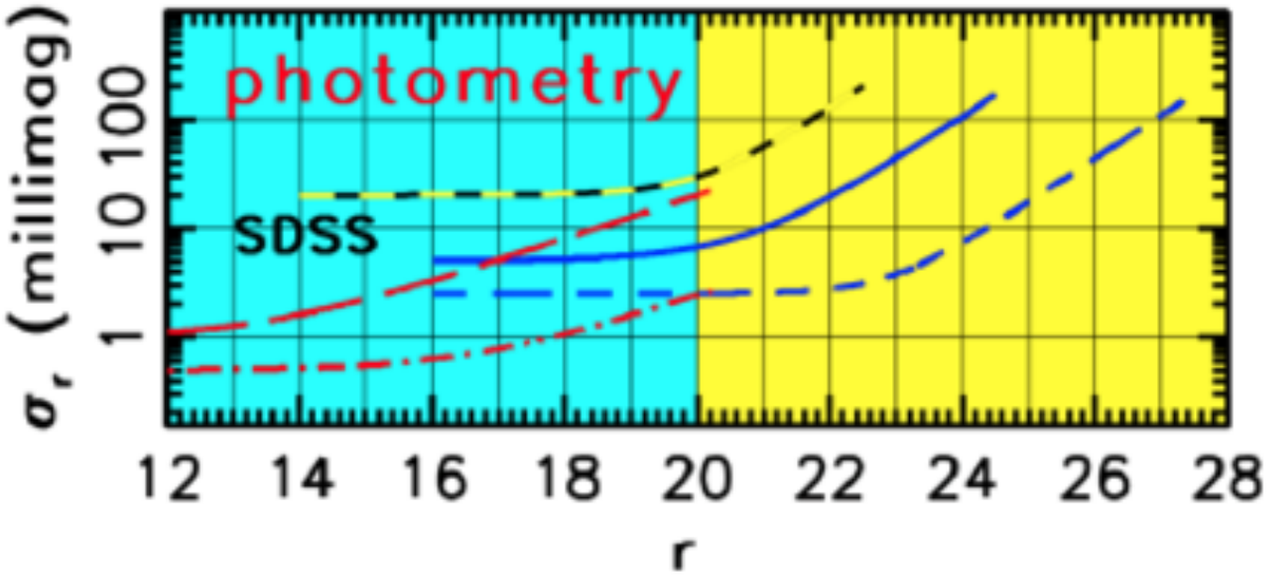


Figure from http://www.rssd.esa.int/index.php?project=GAIA&page=Science_Performance (see also 2012arXiv1201.3238De Bruijne)

y lo que viene…





Eyer et al. 2012