GaiaNIR

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GaiaNIR photometric system

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& UB team

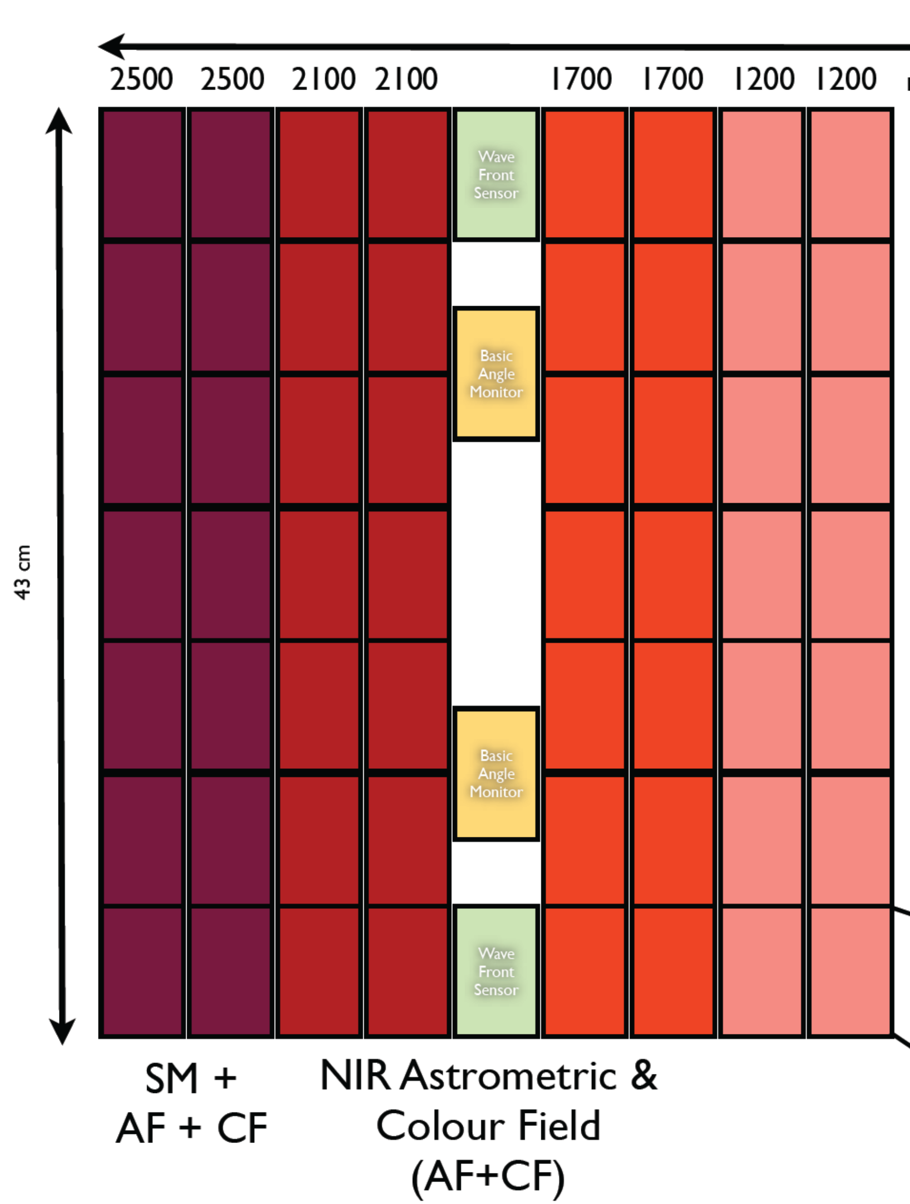
Photometry

- Chromatic corrections of the astrometric observations.
- All-sky NIR survey at the mmag accuracy level → less extinction-limited CMDs.
- Astrophysical classification (stars, galaxy, quasars, etc.).
- Astrophysical parameterisation (interstellar reddening, effective temperatures of stars, surface gravities, chemical abundances, photometric redshifts of quasars, …).
- Photometric distances for distant sources (when large parallax relative error).
- Multiwavelength variability of sources.

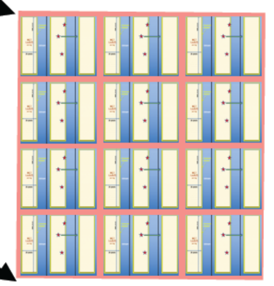
Gaia vs GaiaNIR

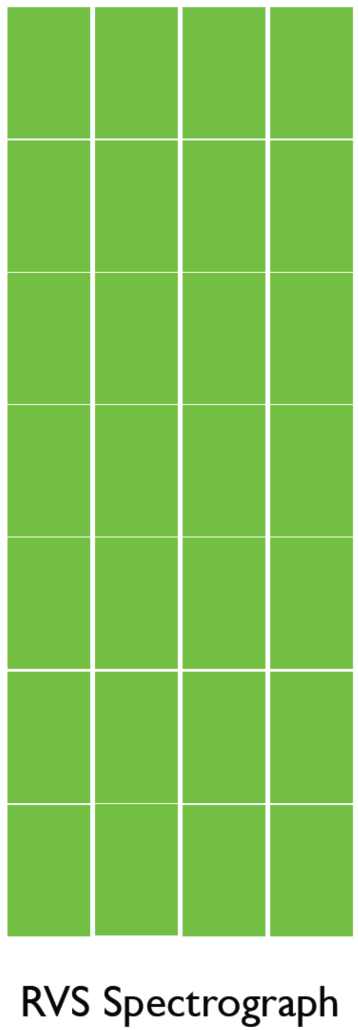
GaiaNIR Focal Plane

D. Hobbs (IAU, 2022)



- Four filters
- 2 CCD strips/filter
- The first band must cover the complete wavelength range (unfiltered light)



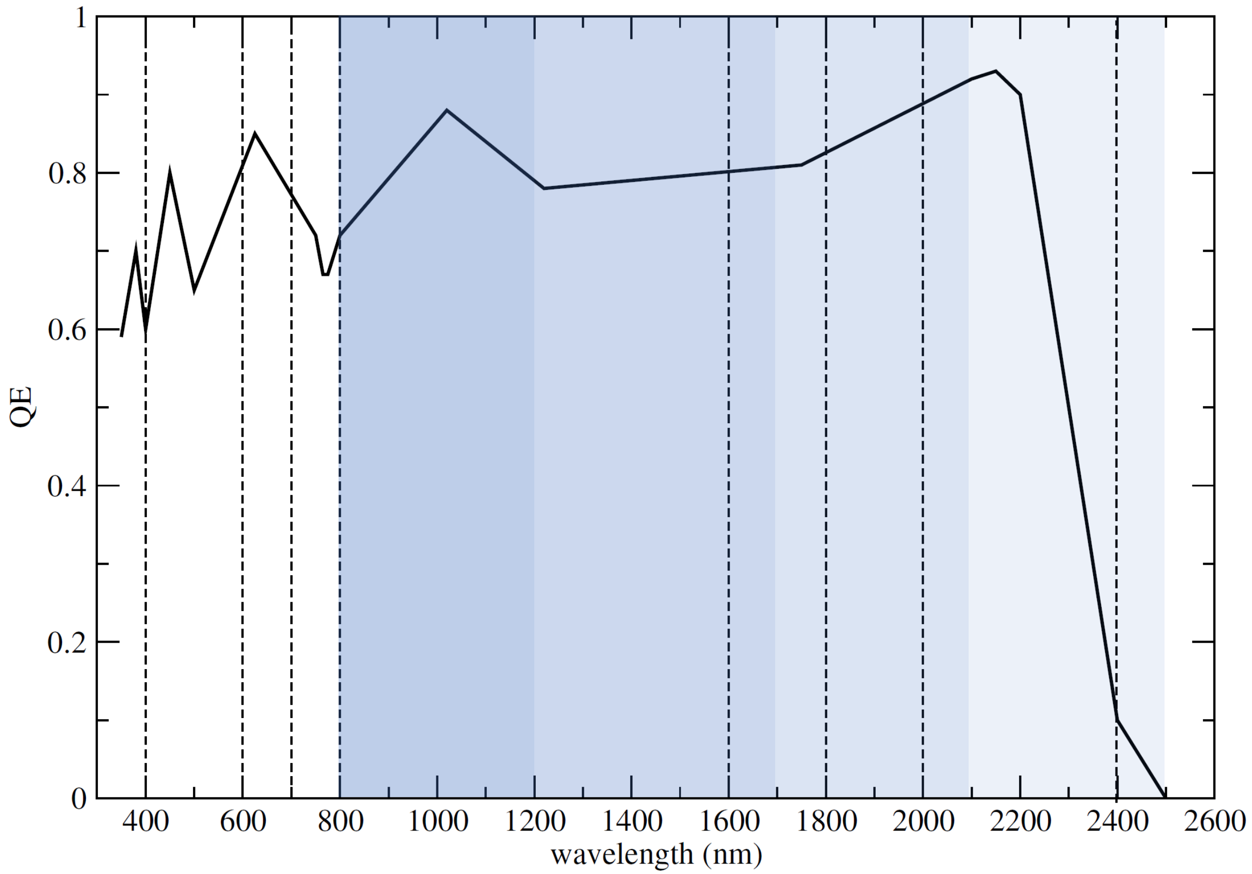


Instrument

GN-TN-UB-CJ-001 (05/07/2017)

- 16 HgCdTe detectors (14 are now foreseen)
- Vertical lines are passband limits options assumed by CJ-001
  - 400-1600, 400-1800, 400-2000, 400-2400
  - 600-1600, 600-1800, 600-2000, 600-2400
  - 700-1600, 700-1800, 700-2000, 700-2400
  - 800-1600, 800-1800, 800-2000, 800-2400

Blue rectangles show the passbands limits proposed by D. Hobbs (IAU, 2022)



Colour-colour relationships

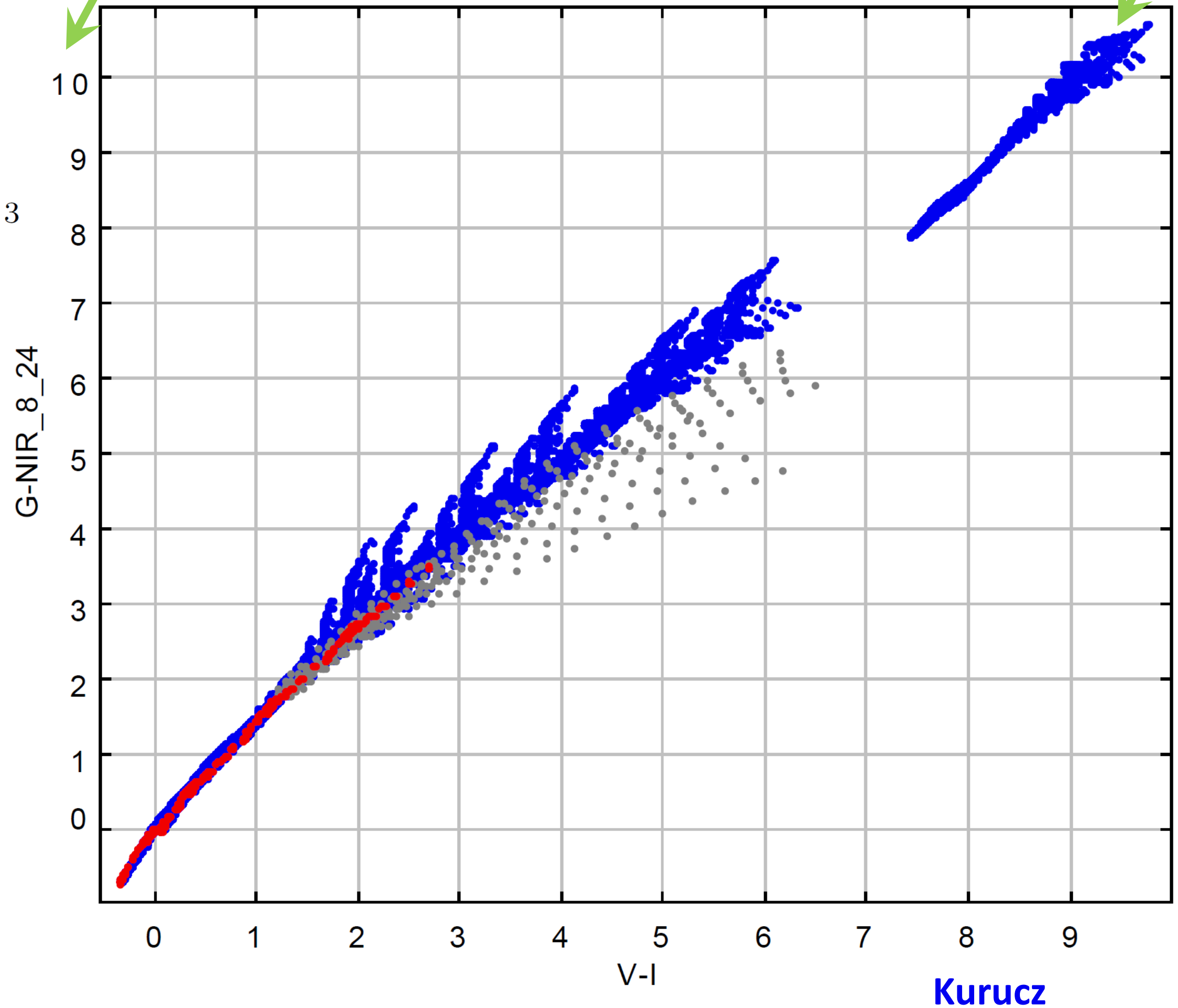
G-NIR = f(V-I) for disc & halo sky directions (GUMS)

$$\mathrm{colour} = a_0 + a_1(V-I) + a_2(V-I)^2 + a_3(V-I)^3$$

disk: colour	a_0	a_1	a_2	a_3	σ
G – NIR_4_16	-0.0953	0.8002	0.0043	-0.0012	0.11
G – NIR_4_18	-0.1067	0.8911	0.0016	-0.0009	0.14
G – NIR_4_20	-0.1119	0.9532	0.0021	-0.0009	0.15
G – NIR_4_24	-0.1156	1.0168	0.0041	-0.0010	0.16
G – NIR_6_16	-0.0704	1.2242	-0.0899	0.0050	0.10
G – NIR_6_18	-0.0829	1.3027	-0.0906	0.0052	0.13
G – NIR_6_20	-0.0884	1.3545	-0.0885	0.0051	0.14
G – NIR_6_24	-0.0928	1.4071	-0.0846	0.0049	0.14
G – NIR_7_16	-0.0767	1.3797	-0.1207	0.0069	0.10
G – NIR_7_18	-0.0887	1.4528	-0.1211	0.0071	0.13
G – NIR_7_20	-0.0937	1.5003	-0.1185	0.0070	0.14
G – NIR_7_24	-0.0976	1.5481	-0.1141	0.0068	0.14
G – NIR_8_16	-0.0861	1.5112	-0.1443	0.0083	0.10
G – NIR_8_18	-0.0976	1.5799	-0.1447	0.0085	0.13
G – NIR_8_20	-0.1019	1.6238	-0.1420	0.0084	0.14
G – NIR_8_24	-0.1051	1.6676	-0.1373	0.0082	0.14
G – J2MASS	-0.0761	1.6967	-0.1713	0.0089	0.08
G – H2MASS	-0.1362	2.0820	-0.2031	0.0113	0.19
G – K2MASS	-0.1232	2.2214	-0.1975	0.0110	0.17

10 magnitudes fainter for Gaia than for Gaia-NIR!!

A_V=20 mag



Kurucz

NextGen ([M/H]>-1)

White dwarfs

GN-TN-UB-CJ-001

Zeropoints and limiting magnitudes

GN-TN-UB-CJ-001

- VEGAMAG zeropoint
- G - NIR = 0 for an A0V type star (see Jordi et al 2010).
- Table shows magnitudes at which 1 e-/s is detected (zeropoint) and magnitudes at which the same amount of e-/s are detected as with G=21 mag.

Detector	$1\,e^-/s$	magnitude equivalent to $G = 21$
G	25.6085	21.00000
NIR_4_16	25.9055	21.29700
NIR_4_18	25.9447	21.33620
NIR_4_20	25.9746	21.36610
NIR_4_24	26.0078	21.39930
NIR_6_16	25.3194	20.71091
NIR_6_18	25.3864	20.77790
NIR_6_20	25.4354	20.82690
NIR_6_24	25.4895	20.88100
NIR_7_16	25.0801	20.47160
NIR_7_18	25.1630	20.55450
NIR_7_20	25.2230	20.61450
NIR_7_24	25.2883	20.67980
NIR_8_16	24.8475	20.23900
NIR_8_18	24.9492	20.34070
NIR_8_20	25.0218	20.41323
NIR_8_24	25.1000	20.49150

Galactic pole: (l,b)=(0,89), r<0.68°

Photometry simulations

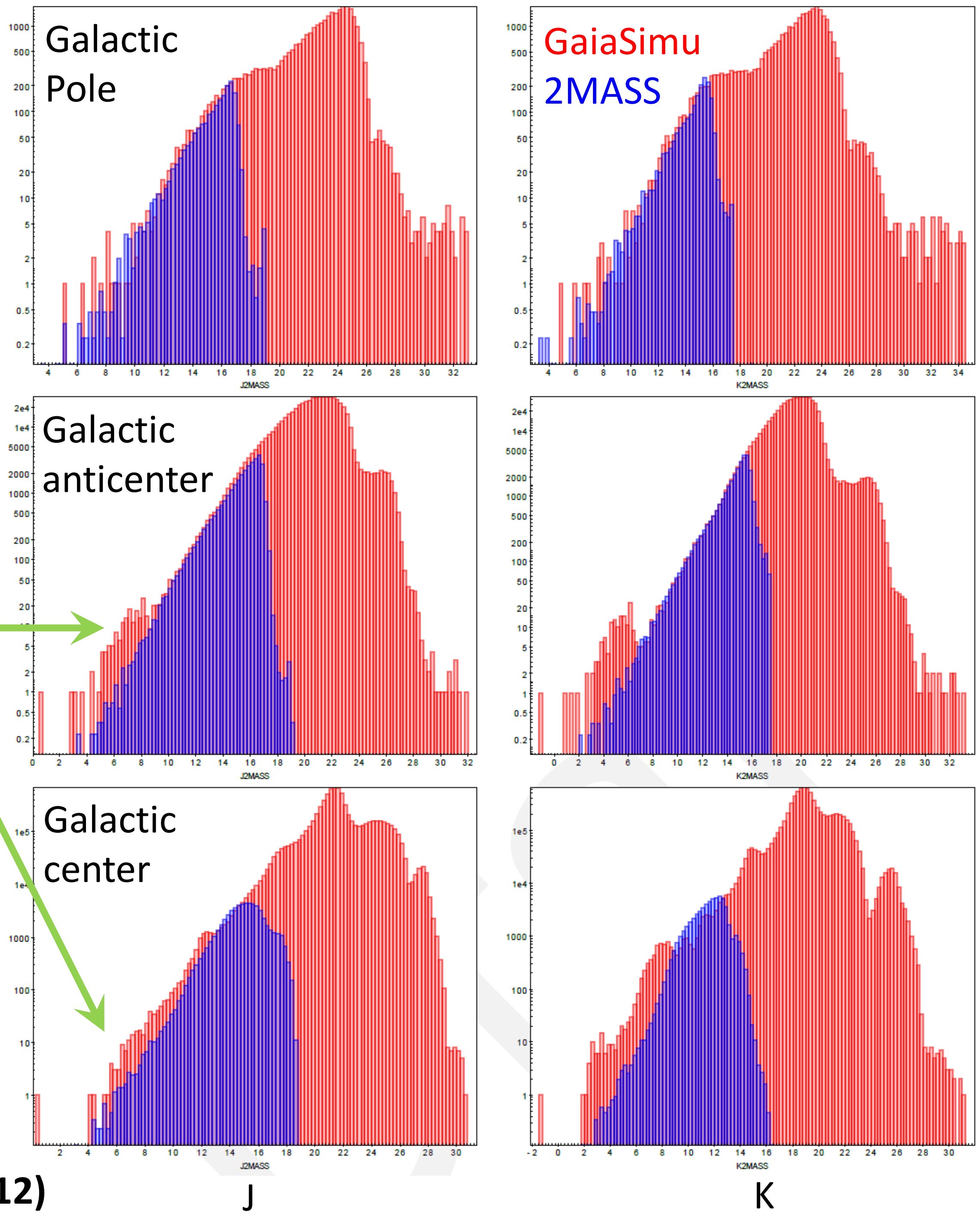
Galactic anticenter: (l,b)=(180,0), r<0.68°

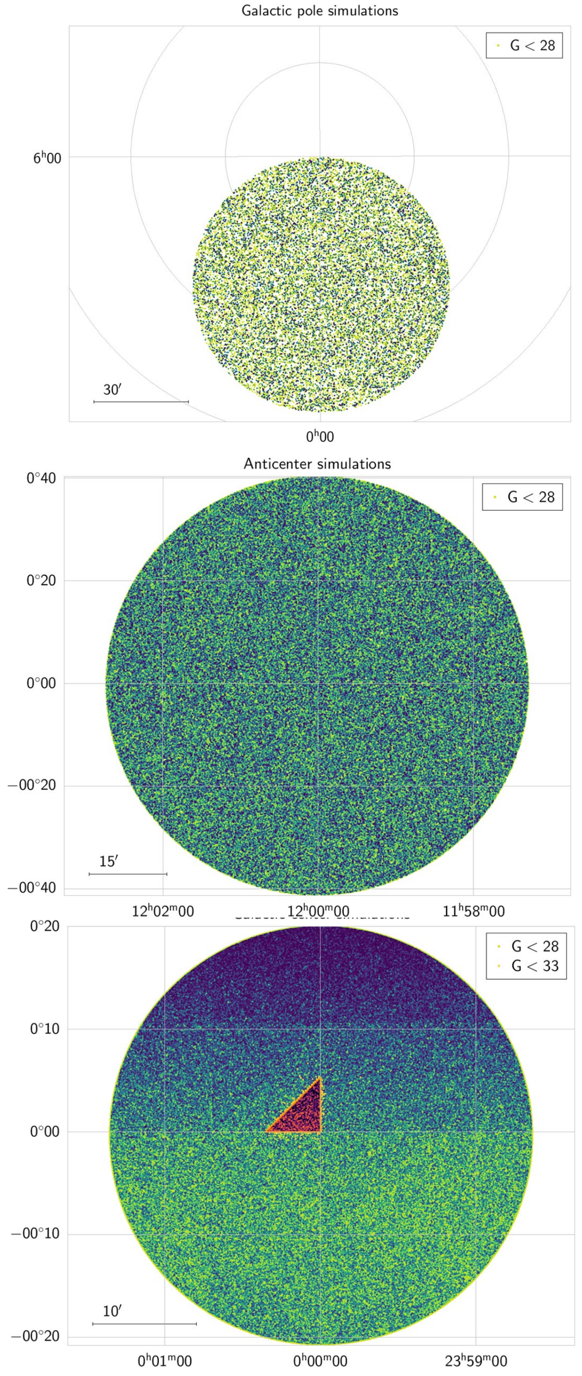
Good general agreement.
Excess of bright sources in our simulations with respect to 2MASS observations

We consider stars in multiple systems as detectable

Galactic center 1: (l,b)=(0,0), r<0.34°
Galactic center 2: (l,b)=(0,0), r<0.0253°

2MASS (Skrutskie+2006): SNR=10 for J<15.8, H<15.1, Ks<14.3



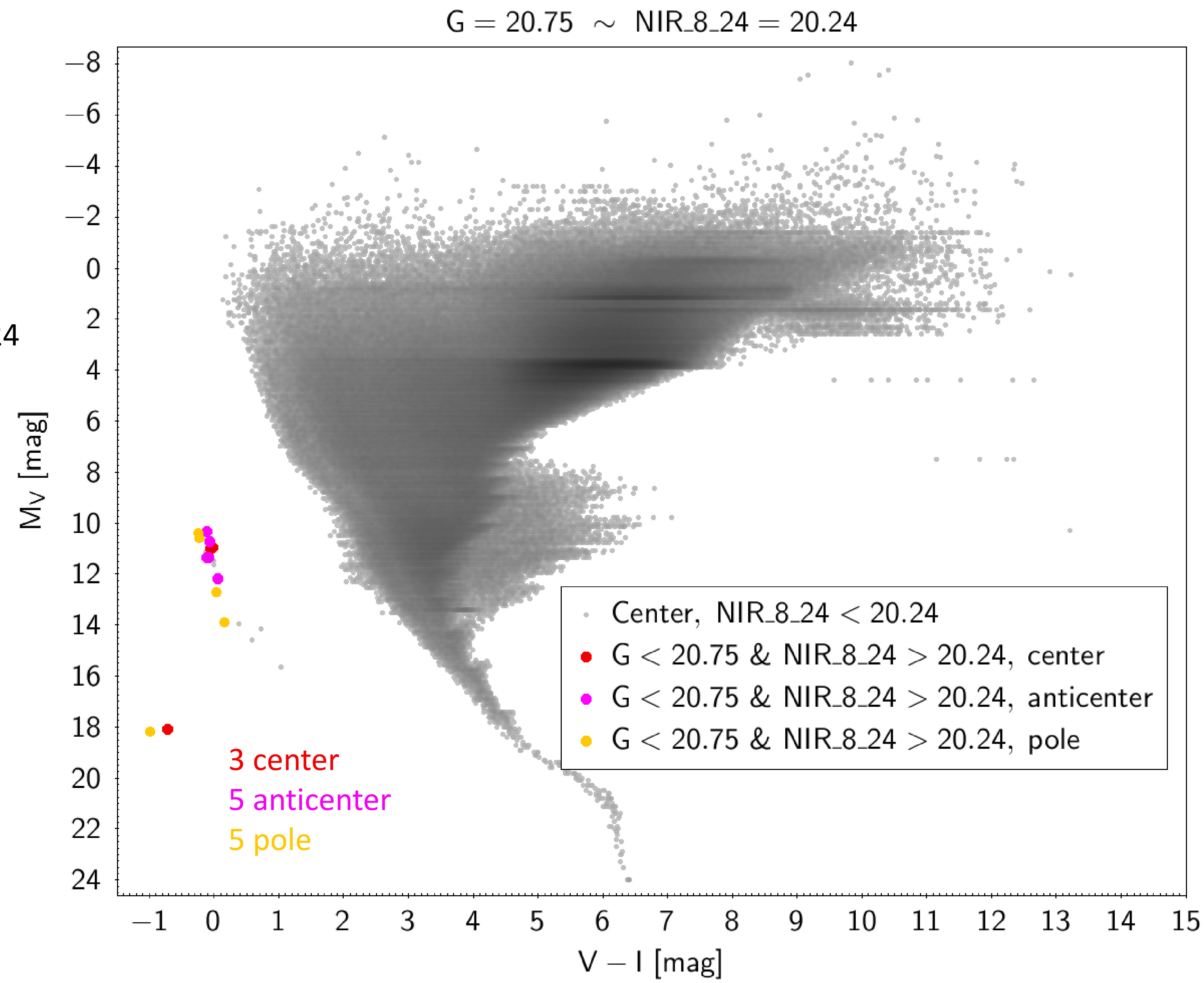


Besançon Galaxy Model (Robin et al 2012)

Overlap with Gaia

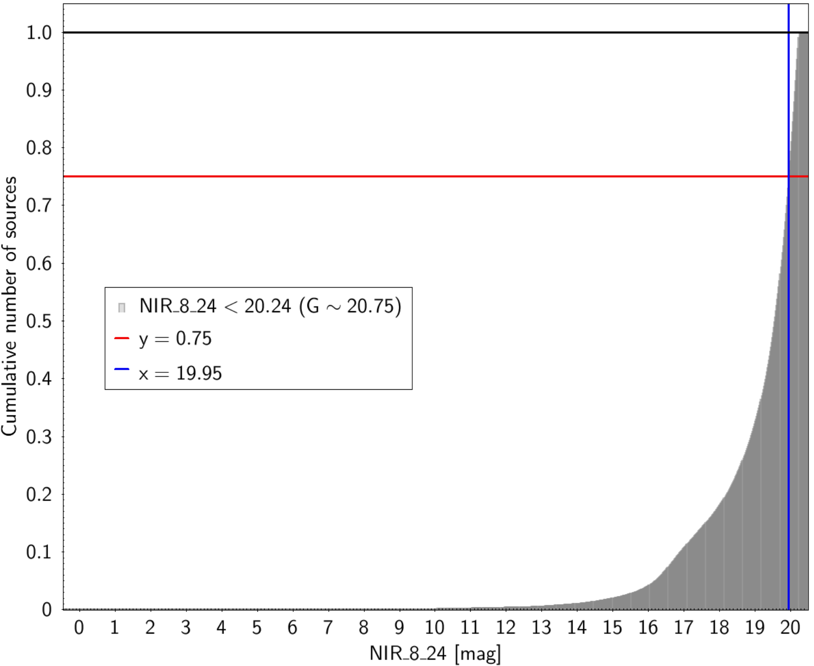
G=21 corresponds to NIR_8_24=20.49

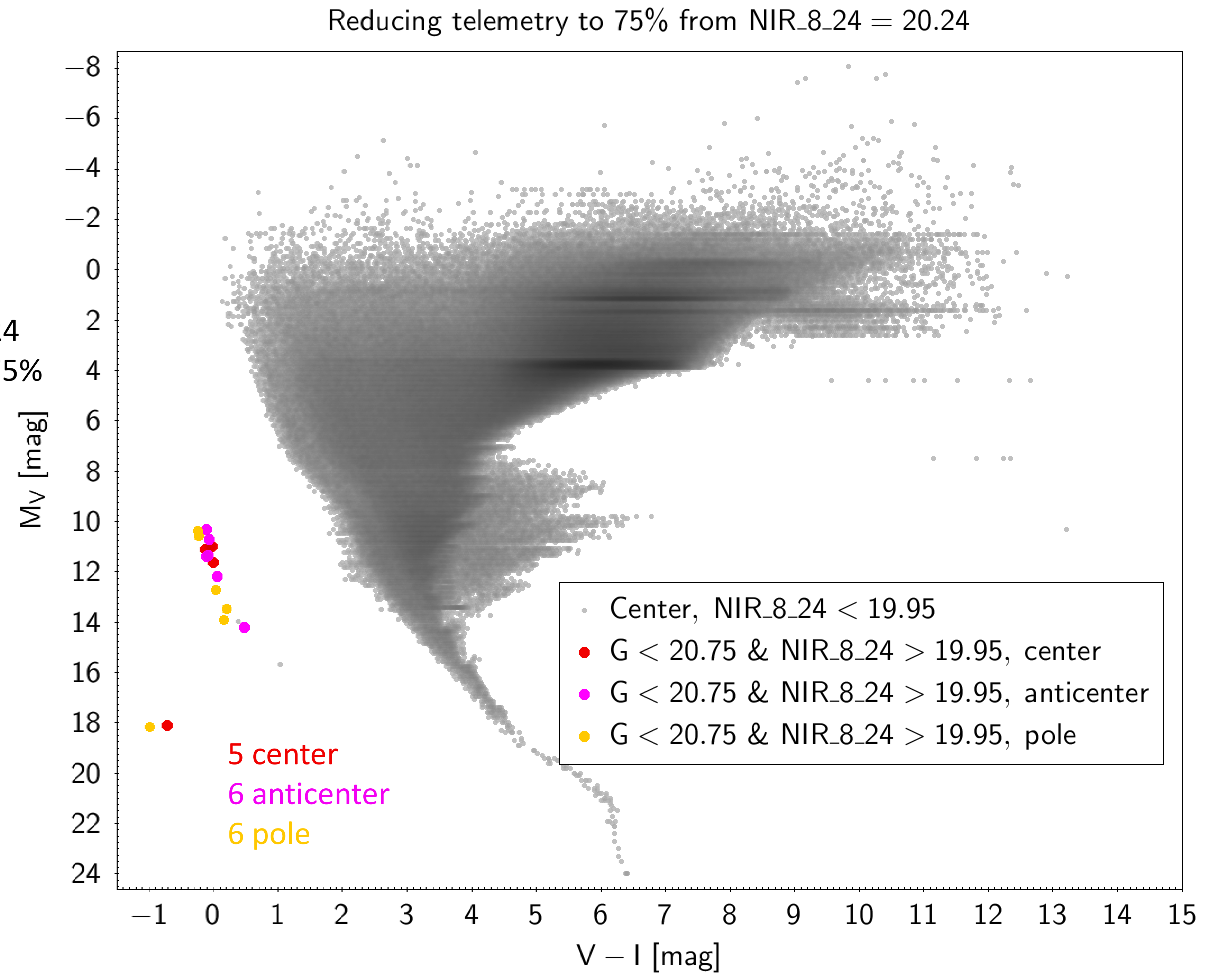
G=20.75 corresponds to NIR_8_24=20.24



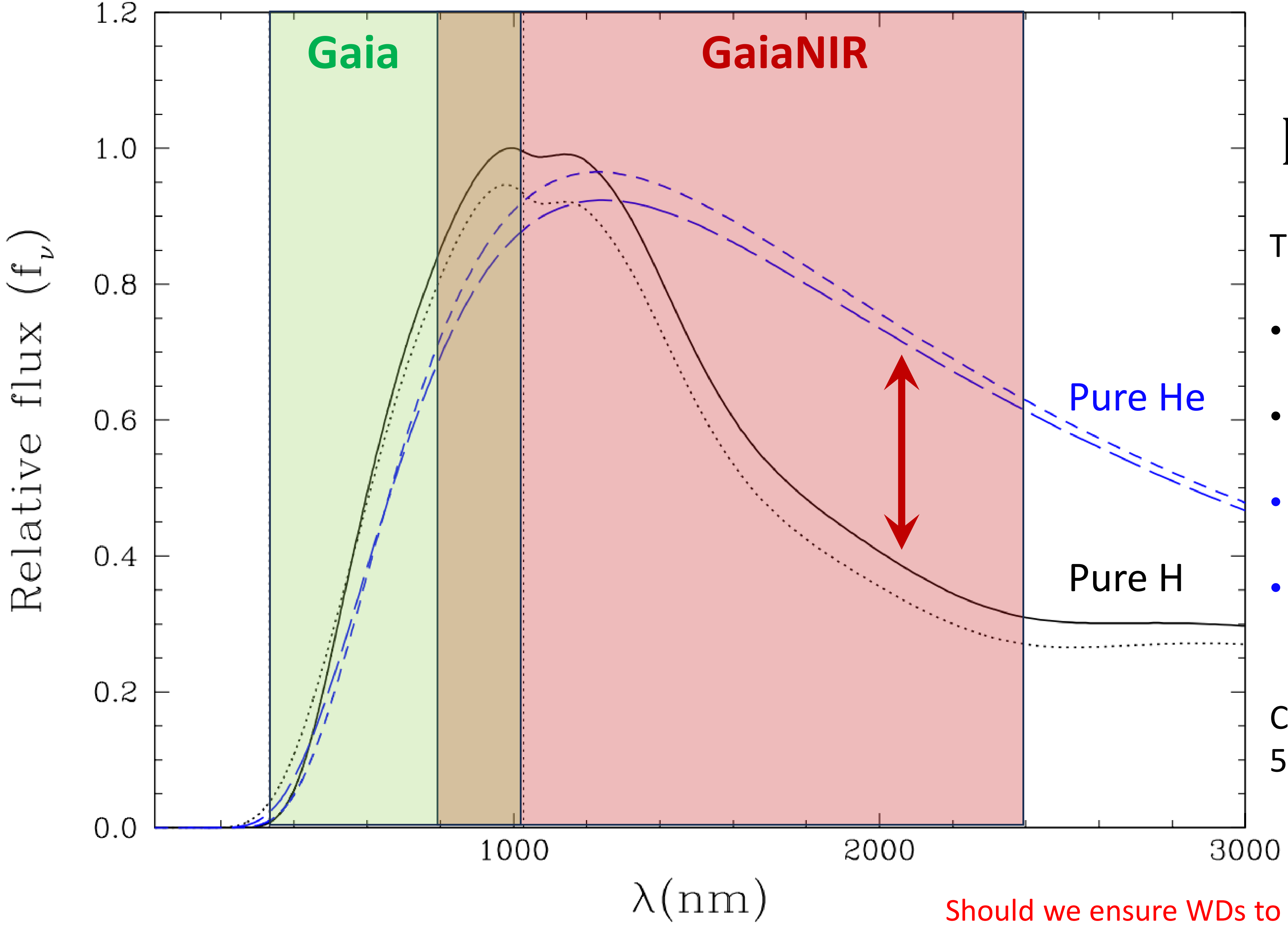
Overlap with Gaia

G=21 corresponds to NIR_8_24=20.49
G=20.75 corresponds to NIR_8_24=20.24
NIR_8_24<19.95 reduces telemetry to 75%





White dwarfs



T=4000K, logg=8.0

- Pure-H solid: with Lyman-α opacity
- Pure-H dotted: without Lyman-α opacity
- Pure He medium dashed: Bergeron+1995
- Pure He long dashed: Kowalski+2007

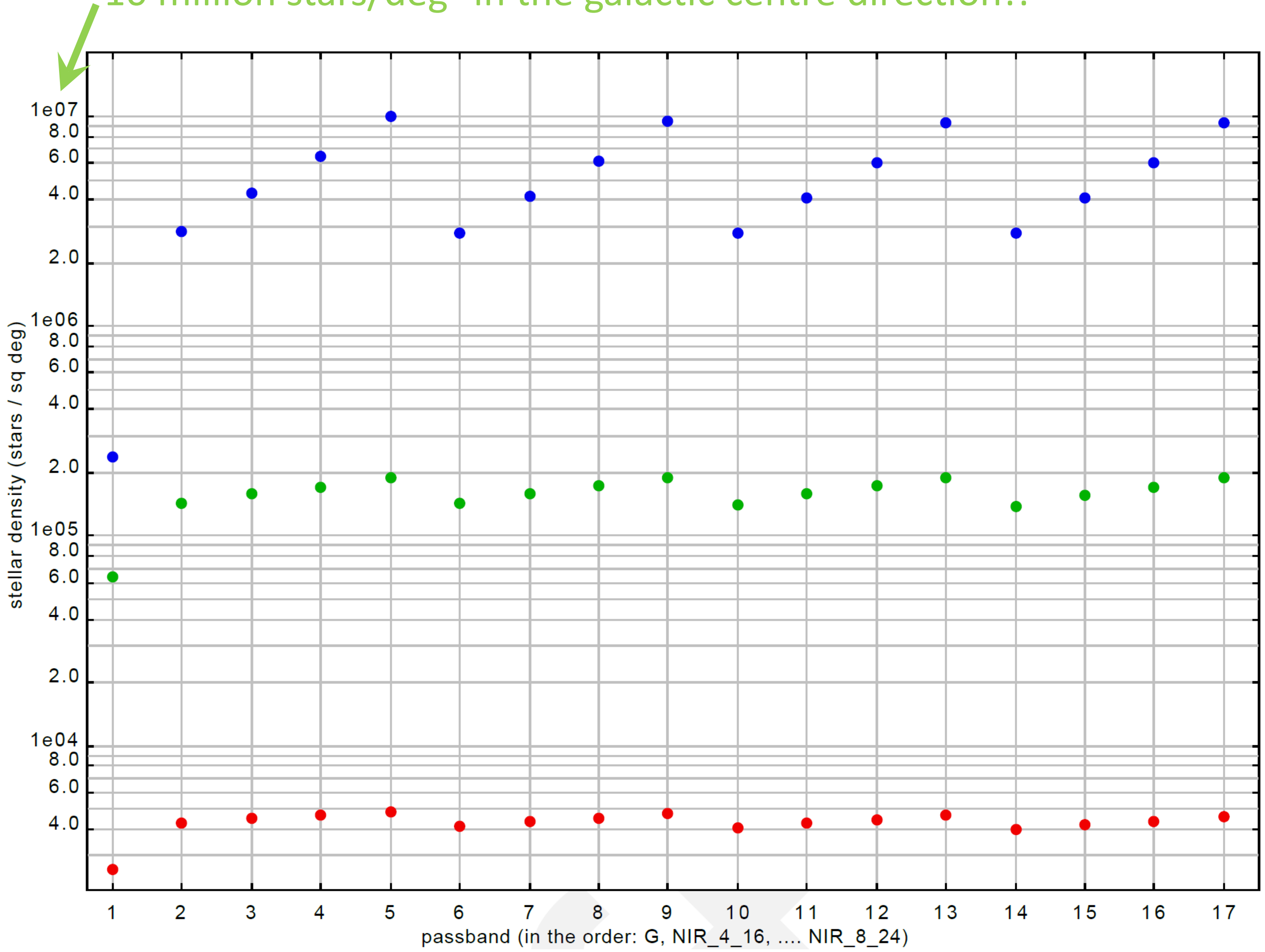
Carrasco et al (2014), A&A 565, A11, 16

Should we ensure WDs to be detectable with GaiaNIR?

Stellar density (stars/deg^2)

(l, b)	Galactic pole (0, 89)	Galactic anticentre (180, 0)	Galactic centre (0, 0)
G	2529	63 118	234 701
NIR_4_16	4225	139 979	2 762 126
NIR_4_18	4436	155 756	4 227 884
NIR_4_20	4592	169 042	6 342 556
NIR_4_24	4795	185 001	9 751 422
NIR_6_16	4075	140 104	2 722 041
NIR_6_18	4302	156 714	4 077 687
NIR_6_20	4449	170 308	6 008 123
NIR_6_24	4643	186 774	9 273 894
NIR_7_16	3984	138 836	2 724 441
NIR_7_18	4216	155 842	4 040 296
NIR_7_20	4384	169 737	5 959 973
NIR_7_24	4572	186 465	9 218 208
NIR_8_16	3900	136 420	2 727 783
NIR_8_18	4103	153 929	4 023 110
NIR_8_20	4297	168 160	5 904 245
NIR_8_24	4487	185 263	9 145 361

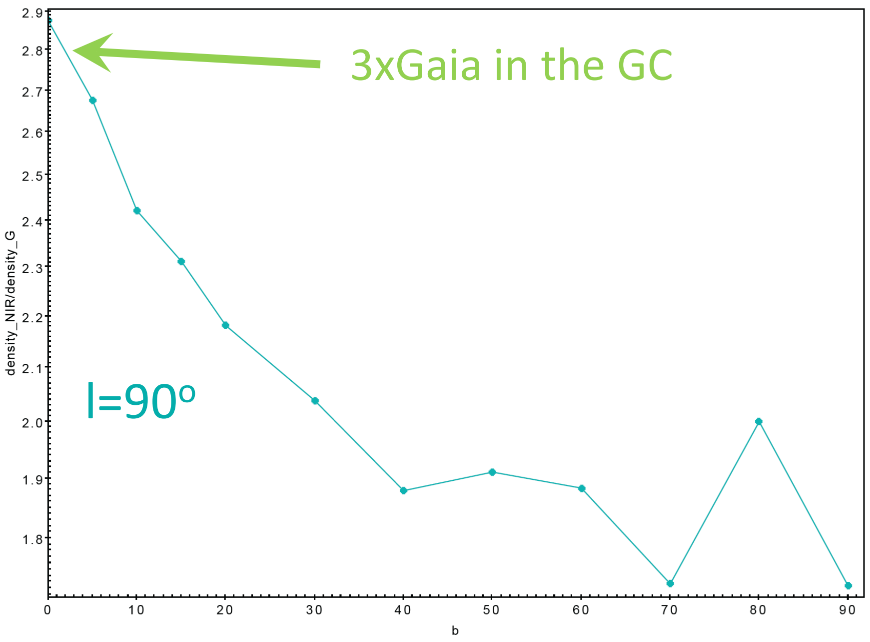
10 million stars/deg^2 in the galactic centre direction!!

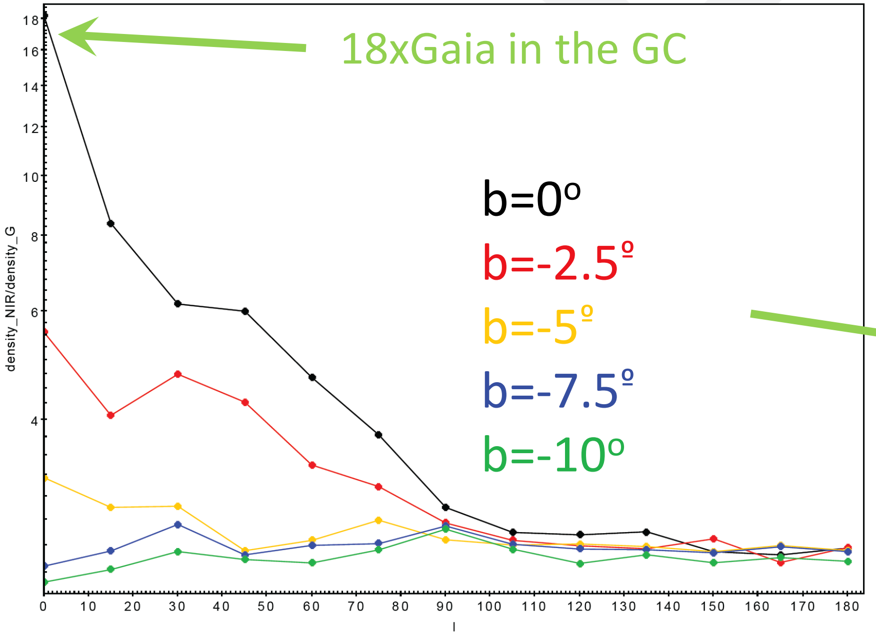


G=21 mag was considered

Stellar density dependency with sky position

Variation with galactic latitude

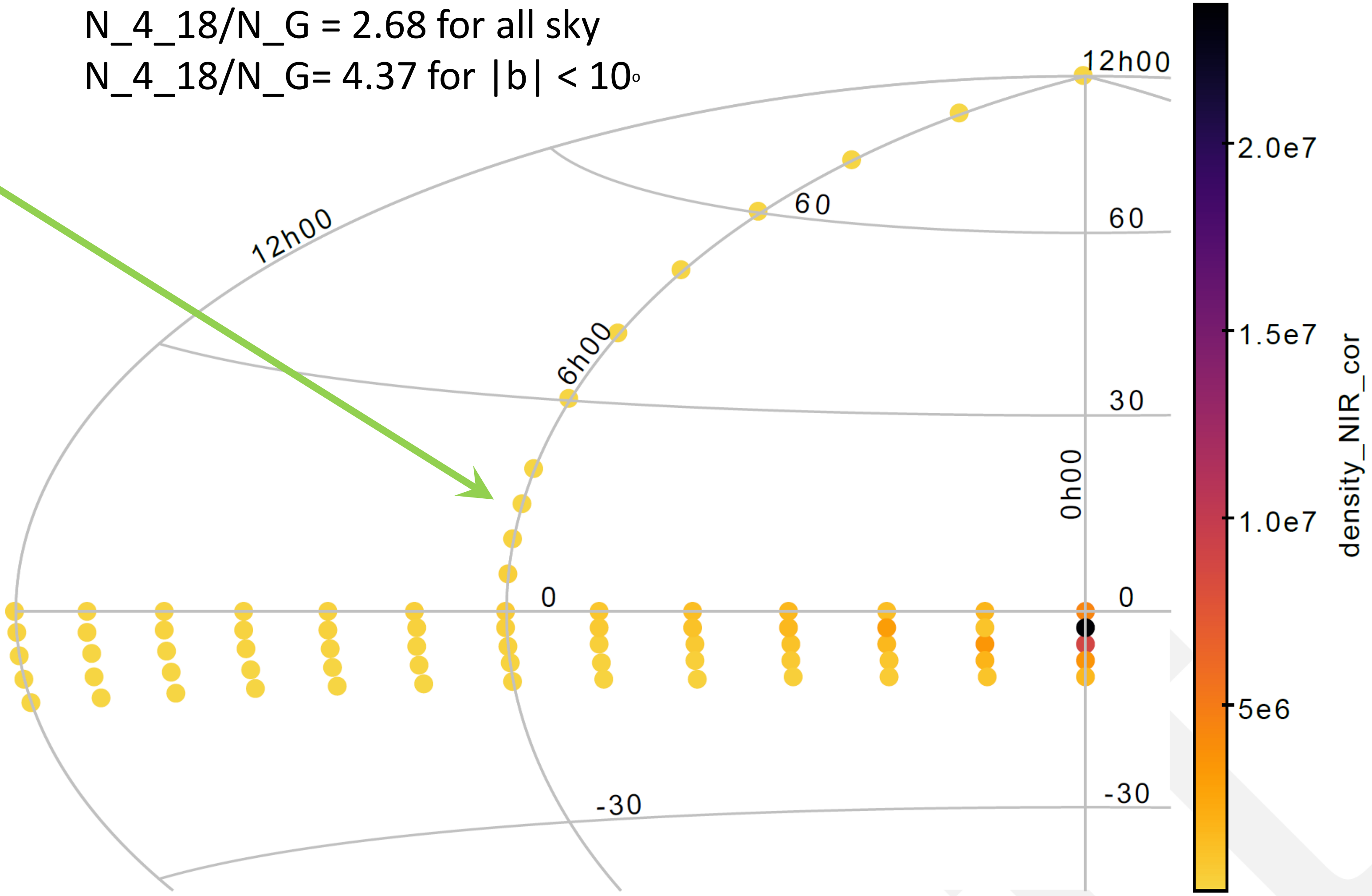




Variation with galactic longitude

N_4_18/N_G = 2.68 for all sky

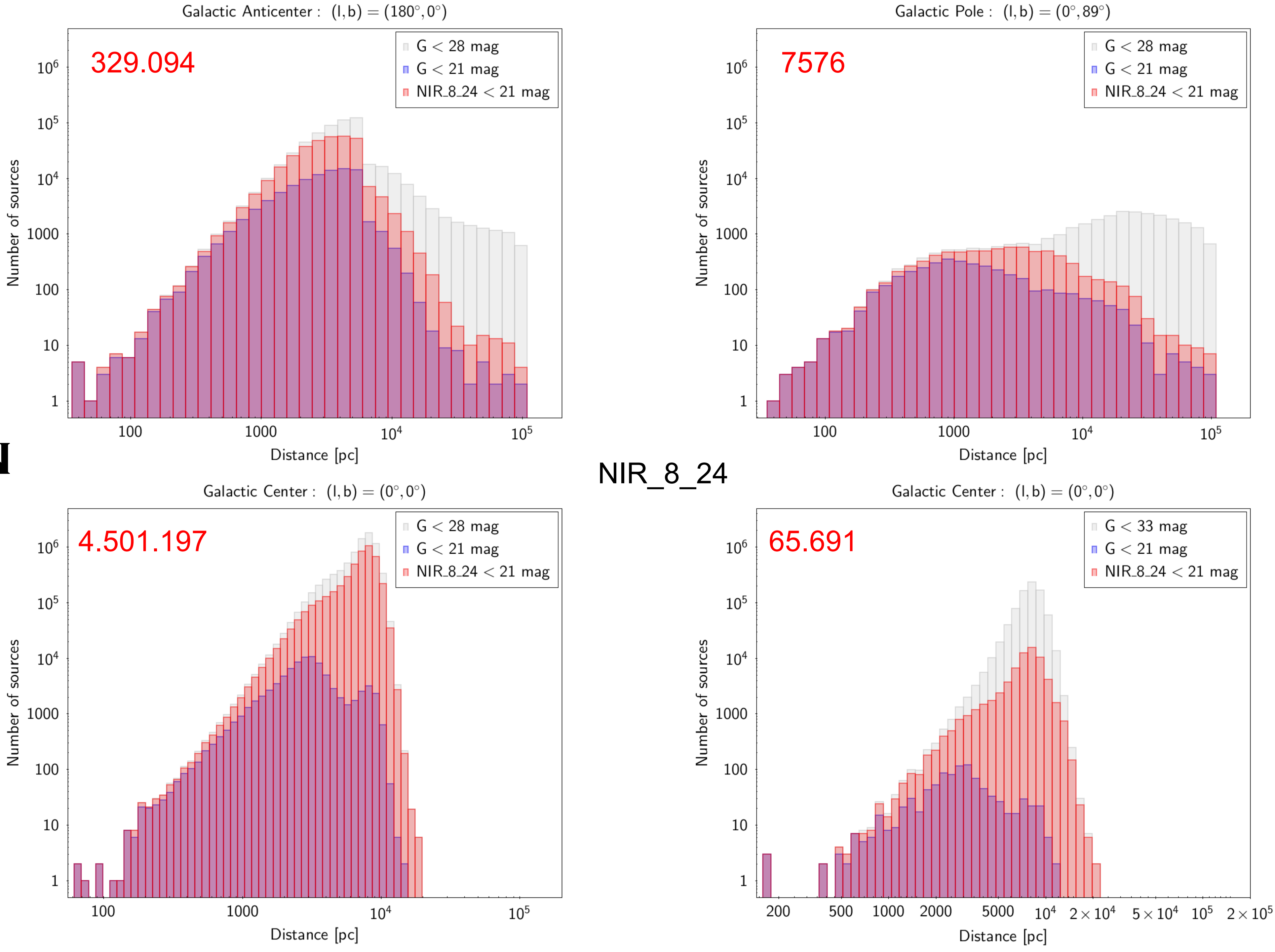
N_4_18/N_G= 4.37 for |b| < 10º



More overlapping with Gaia → Combined long-term proper motion

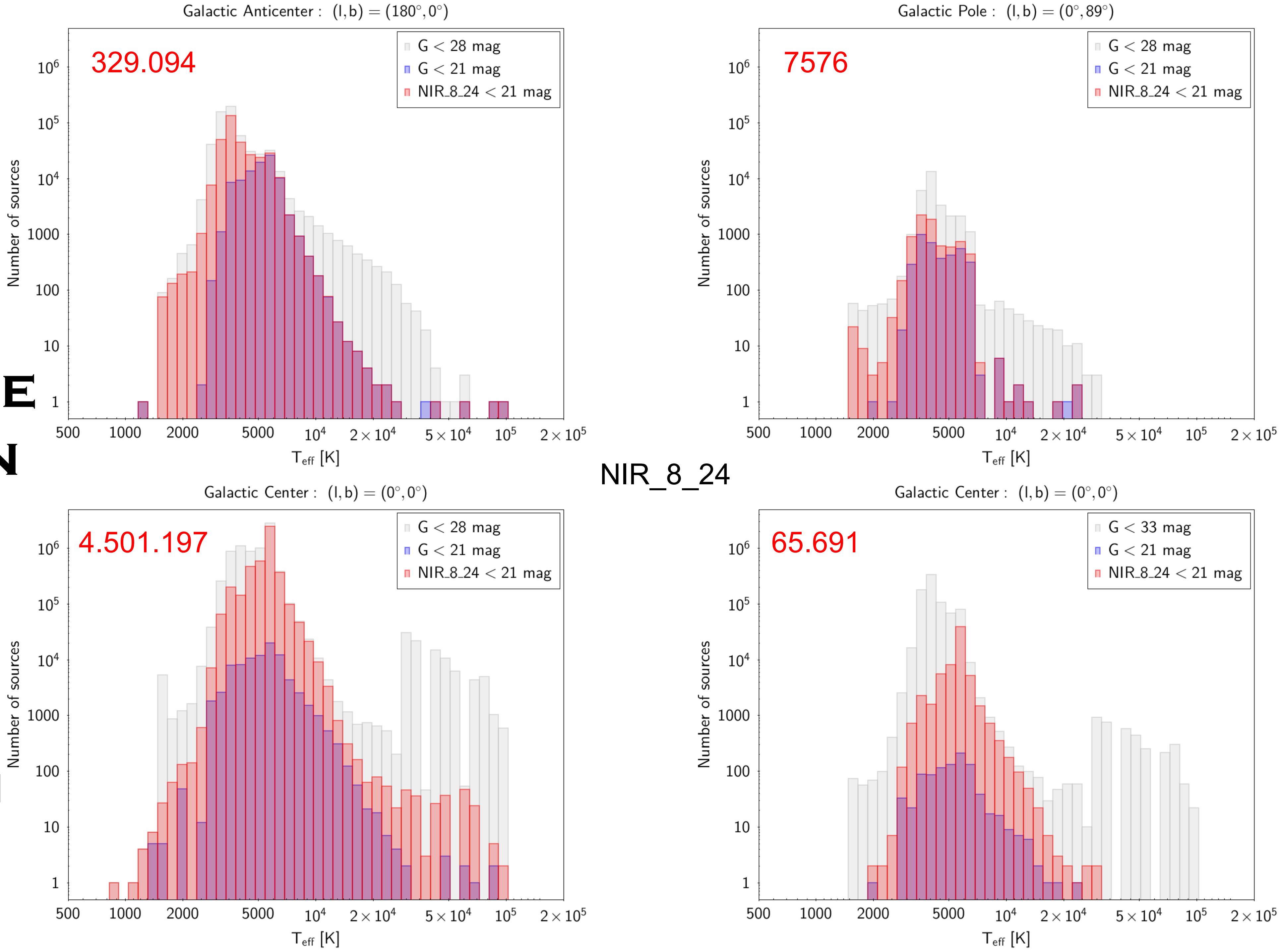
Less overlapping with Gaia → New sources added not previously studied

Distance distribution



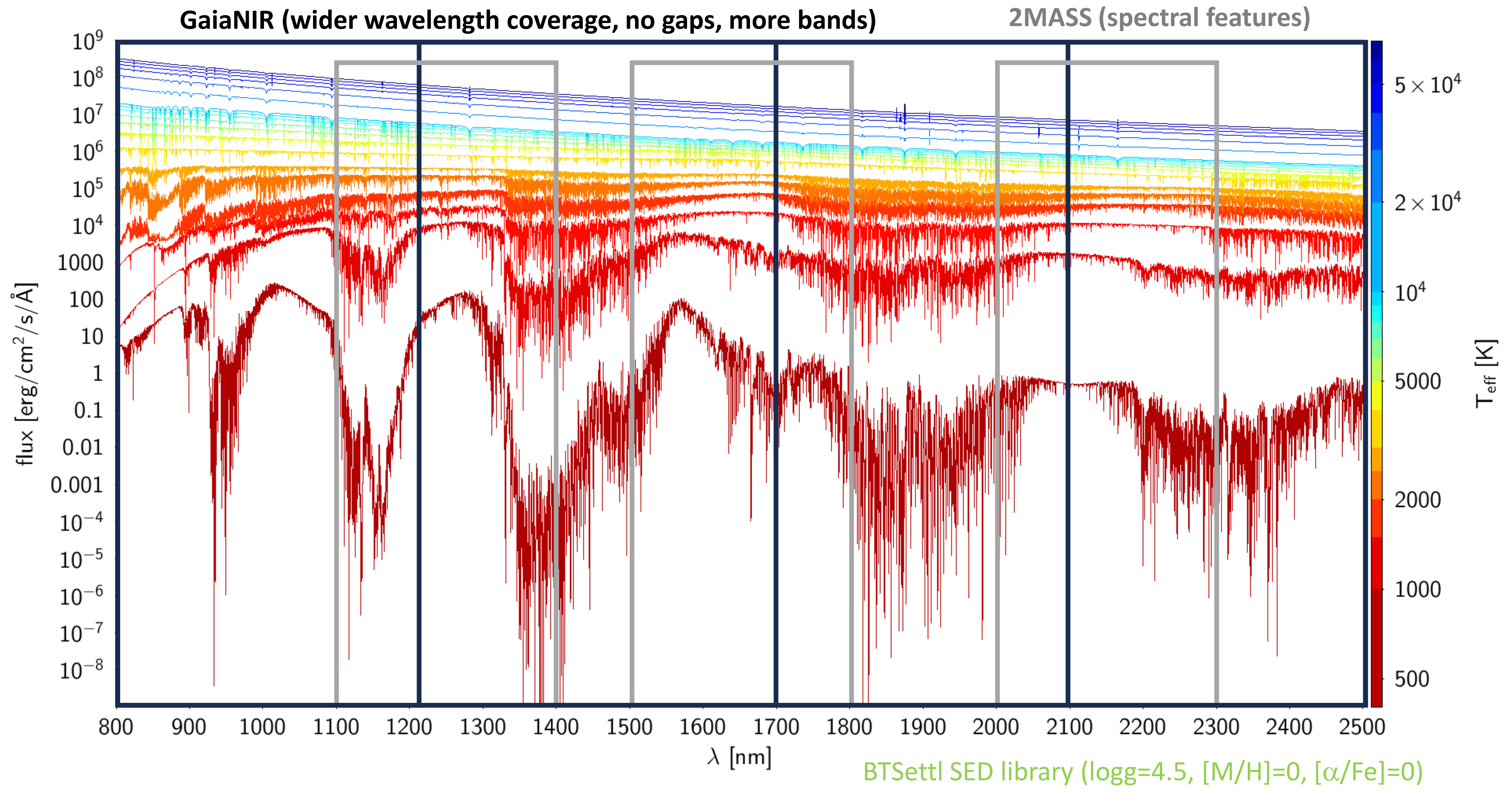
With GaiaNIR we add more distant sources

Temperature distribution



With GaiaNIR we add colder and reddened sources

Optimisation of the photometric system



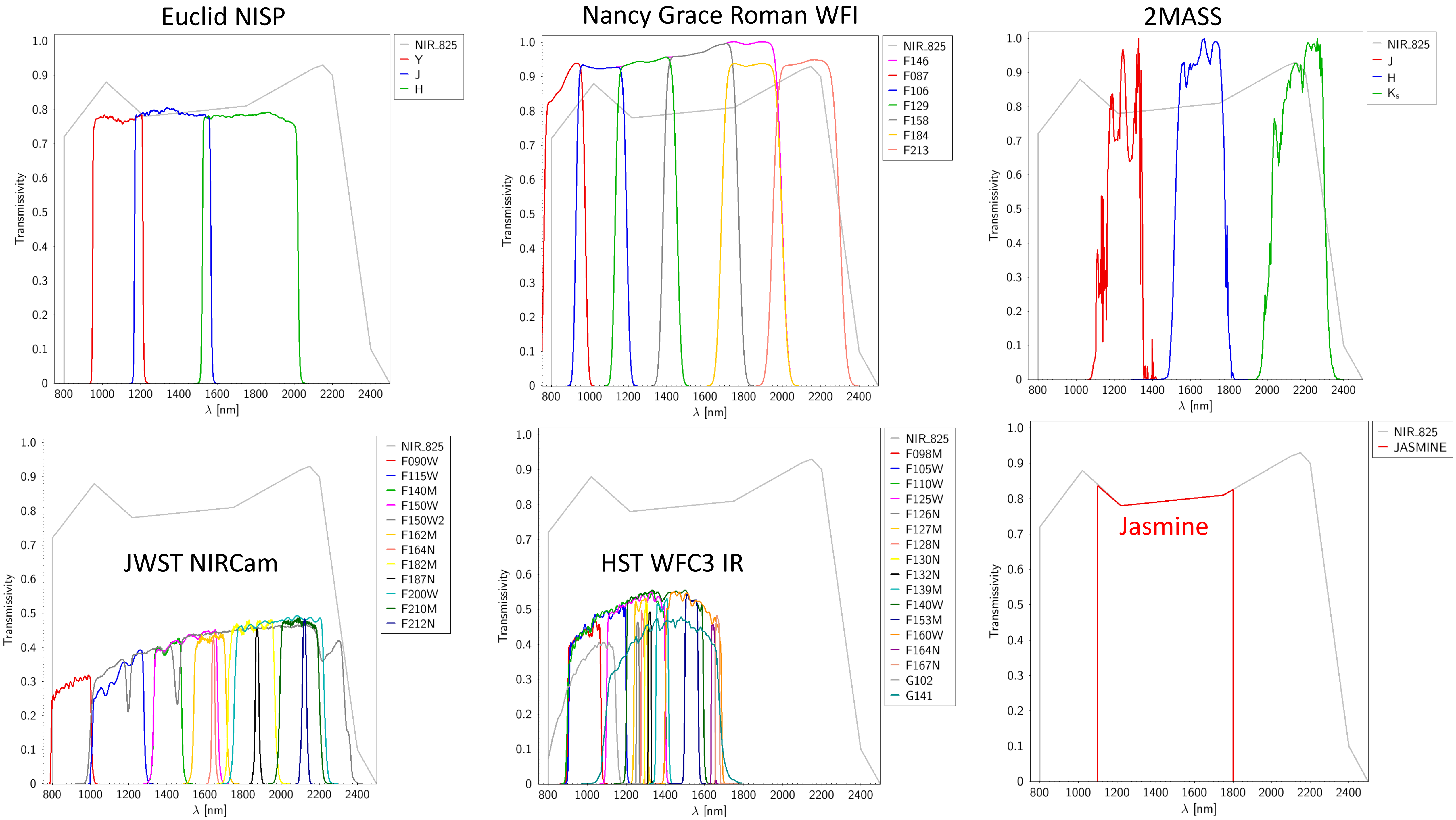
GaiaNIR (wider wavelength coverage, no gaps, more bands)
2MASS (spectral features)
flux [erg/cm²/s/Å]
λ [nm]
800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400 2500
T_eff [K]
5×10⁴ 2×10⁴ 10⁴ 5000 2000 1000 500
BTSettl SED library (logg=4.5, [M/H]=0, [α/Fe]=0)

Key Scientific goals

- Key type of sources to be studied? Galactic populations?
- Key astrophysical parameters to be recovered for each population? Stellar parameters? QSO photometric redshift? BD? WD? Exoplanets? Asteroids? RR Lyrae?
- Precission needed?
- Infrared spectral information to be recovered? Spectral libraries for simulations? Extinction law?
- Any restrictions from centroid determination (No gaps? Overlapping?)

IR photometric catalogs

Survey	Sky coverage	Wavelength range (μm)	Faint limit	Angular resolution (arcsec)
GaiaNIR	All sky survey	0.8-2.5	21 (TBD)	10^{-9} (TBD)
JASMINE	Galactic bulge	1.1-1.7 (H_W + JH)	15	0.535
2MASS	All sky survey	1.05-2.4 (JHK_s)	H=15.4	0.8-10.9
VVV	Galactic bulge	0.8-2.4 ($ZYJHK_S$)	H=17.3	0.6
AllWISE	All sky survey	2-30 ($W_1W_2W_3W_4$)	H=14.5	6-12
DENIS	South=20000 deg^2	iJK	K=12	3
UKIDSS	North=7500 deg^2	YJHK	K=18.4	0.9
VISTA VHS	South=18000 deg^2	YJK	K=18.4	0.7
Nancy Roman	All sky pointing	0.5-2.3	28 (1h)	0.1
JWST	All sky pointing	0.6-2.3 (NIRCam)	26-29	0.07
Euclid	1/3 of the sky	0.92-2.02 (YJH)	24.5	0.3
HST WFC3	All sky pointing	0.85-1.7	J=27 (1h)	0.1



Euclid NISP
NIR_825
Y
J
H
Nancy Grace Roman WFI
NIR_825
F146
F087
F106
F129
F158
F184
F213
2MASS
NIR_825
J
H
Ks
JWST NIRCam
NIR_825
F090W
F115W
F140M
F150W
F150W2
F162M
F164N
F182M
F187N
F200W
F210M
F212N
HST WFC3 IR
NIR_825
F098M
F105W
F110W
F125W
F126N
F127M
F128N
F130N
F132N
F139M
F140W
F153M
F160W
F164N
F167N
G102
G141
NIR_825
JASMINE
Jasmine
Transmissivity
λ [nm]

JWST NIRCam FILTERS

F090W - General purpose
F115W - General purpose
F140M - Cool stars, H_2O, CH_4
F150W - General purpose
F150W2 - Blocking filter for F162M, F164N, and DHS
F162M - Cool Stars, off-band for H_2O
F164N - [FeII]
F182M - Cool stars, H_2O, CH_4
F187N - Pa-alpha
F200W - General purpose
F210M - H_2O, CH_4
F212N - H_2

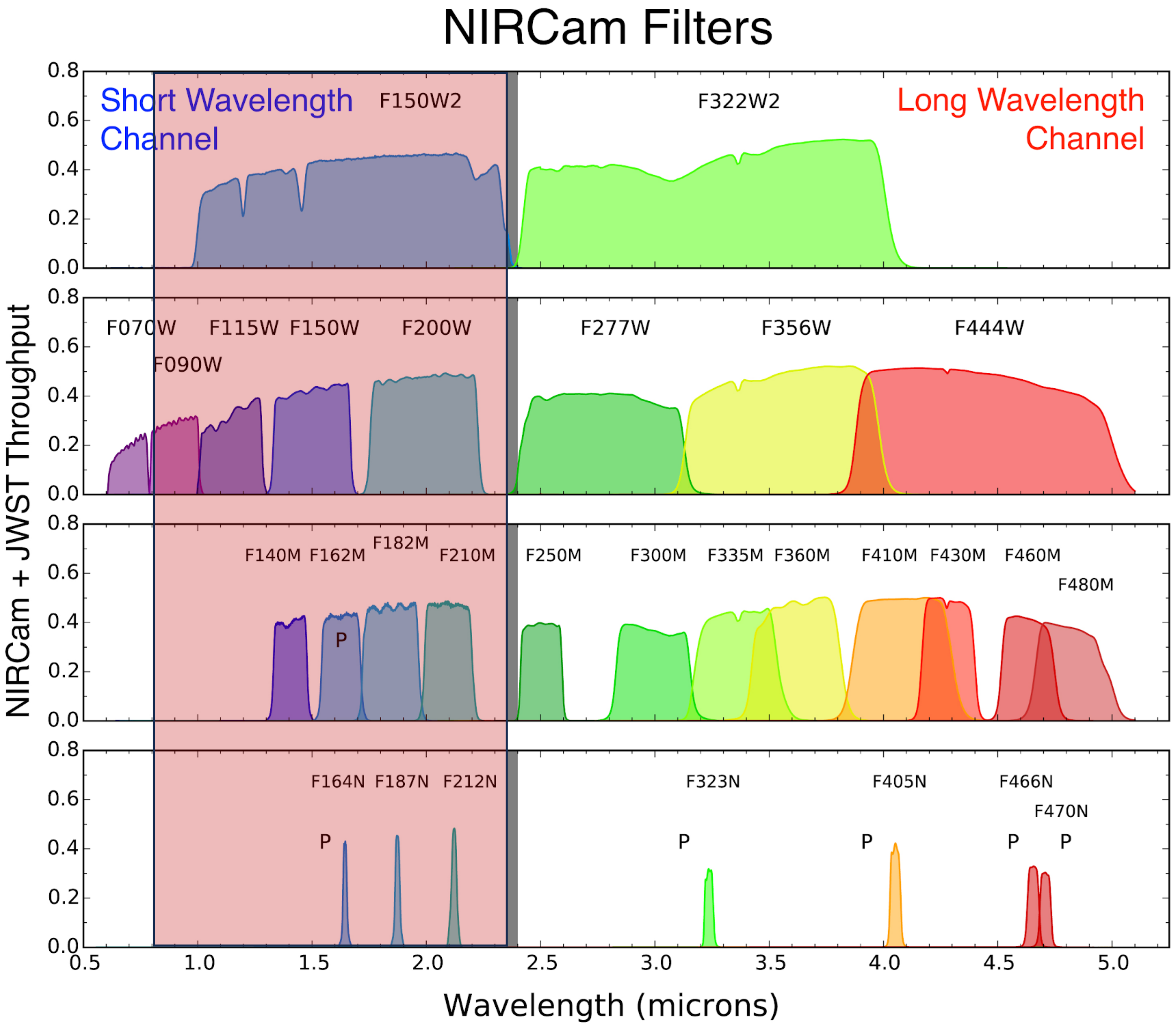


Figure of merit

i	=	index for the different ST
j	=	index for the different filters in a given PS
k	=	index for the different AP for which a PS is optimized
p_k	=	AP k (defining the vector $\boldsymbol{p}$)
ϕ_{ij}	=	normalized flux of ST i in filter j

See Gaia PWG technical reports:

GAIA–LL–047 → PWG–AB–003 → UB-PWG-028, UB-PWG-029

Covariance matrix

$$\mathbf{C}_{\boldsymbol{\phi}} = \mathrm{diag}(\epsilon_j^{-2})$$

Sensitivity matrix

$$\mathbf{S}_i = \begin{bmatrix} \partial\phi_{i1}/\partial p_1 & \cdots & \partial\phi_{i1}/\partial p_K \\ \vdots & \ddots & \vdots \\ \partial\phi_{iJ}/\partial p_1 & \cdots & \partial\phi_{iJ}/\partial p_K \end{bmatrix}_{\boldsymbol{p}\,=\,\boldsymbol{p}_i}$$

Prior matrix (can include parallax)

$$\mathbf{B} = \mathrm{diag}(\sigma_{k,\,\mathrm{prior}}^{-2})$$

Posterior covariance

$$\mathbf{C}_{\boldsymbol{p},\,\mathrm{post}} = \left(\mathbf{B} + \mathbf{S}^{\mathrm{T}}\mathbf{C}_{\boldsymbol{\phi}}^{-1}\mathbf{S}\right)^{-1}$$

Achieved error for AP k and ST i

$$\sigma_{ik,\mathrm{post}} = [\mathbf{C}_{\mathbf{p},\mathrm{post}}]_{kk}$$

$$f(x) = \left(1 + x^{2n}\right)^{-1/n}$$

$$n = 3$$

FoM for ST i

$$Q_i = \sum_k w_k f(\sigma_{ik,\mathrm{post}}/\sigma_{ik,\mathrm{goal}})$$

Global FoM

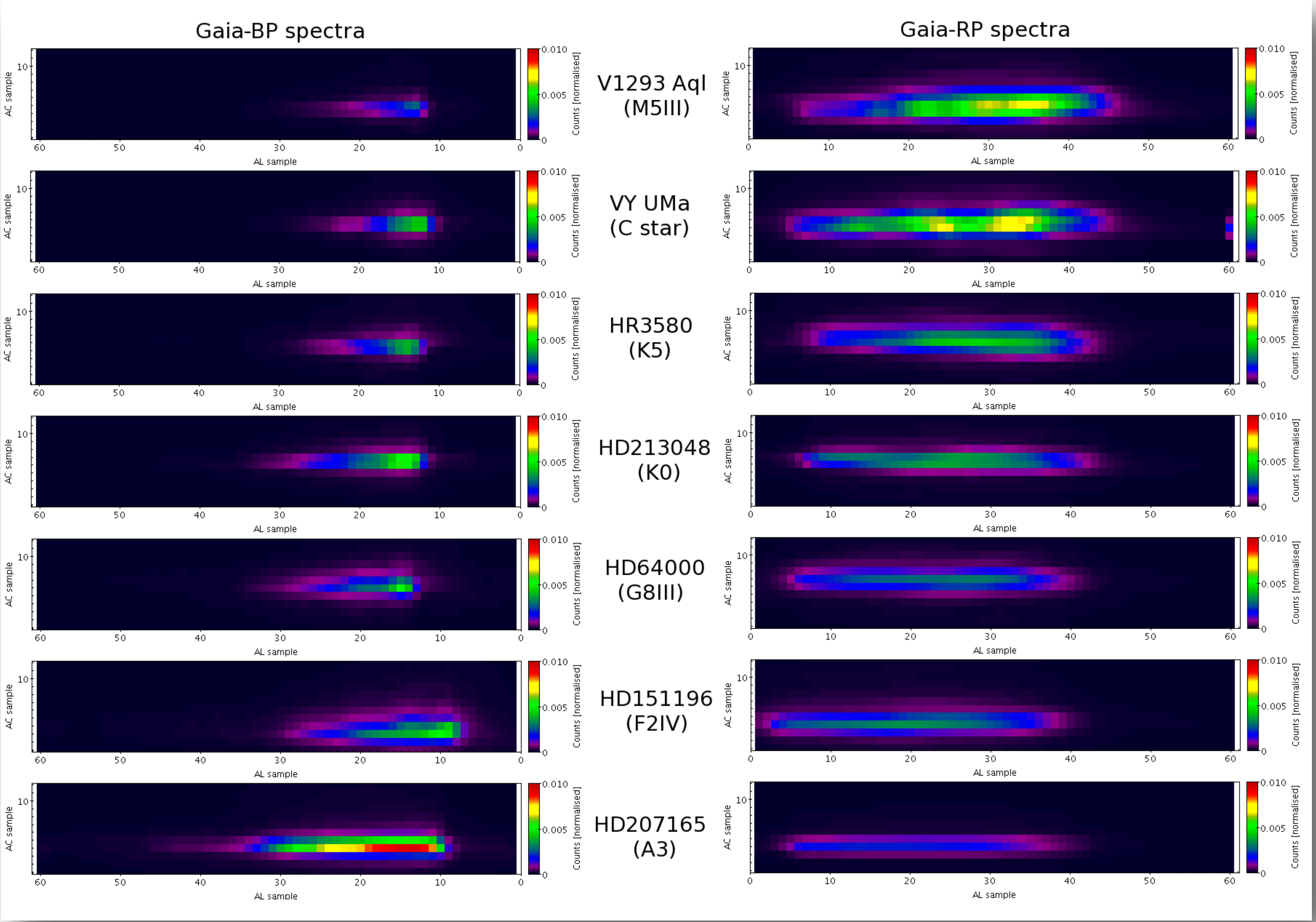
$$Q = \sum_i w_i Q_i$$

Normalised FoM

$$\widehat{Q} = \frac{Q}{\sum_i w_i}$$

Filters or spectrophotometry?

Spectrophotometry as in Gaia?



Filters or spectrophotometry?

- Spectrophotometry provides better nominal spectral resolution elements, but…
- Passbands provide clearer wavelength information (no contamination from neighbouring wavelengths due to LSF).
- Spectrophotometry provides lower angular resolution in crowded fields (more blending) which is more critical in the IR.
- More background contributions in spectra.
- Photometric passbands get better SNR for faint sources (more stars are detected).

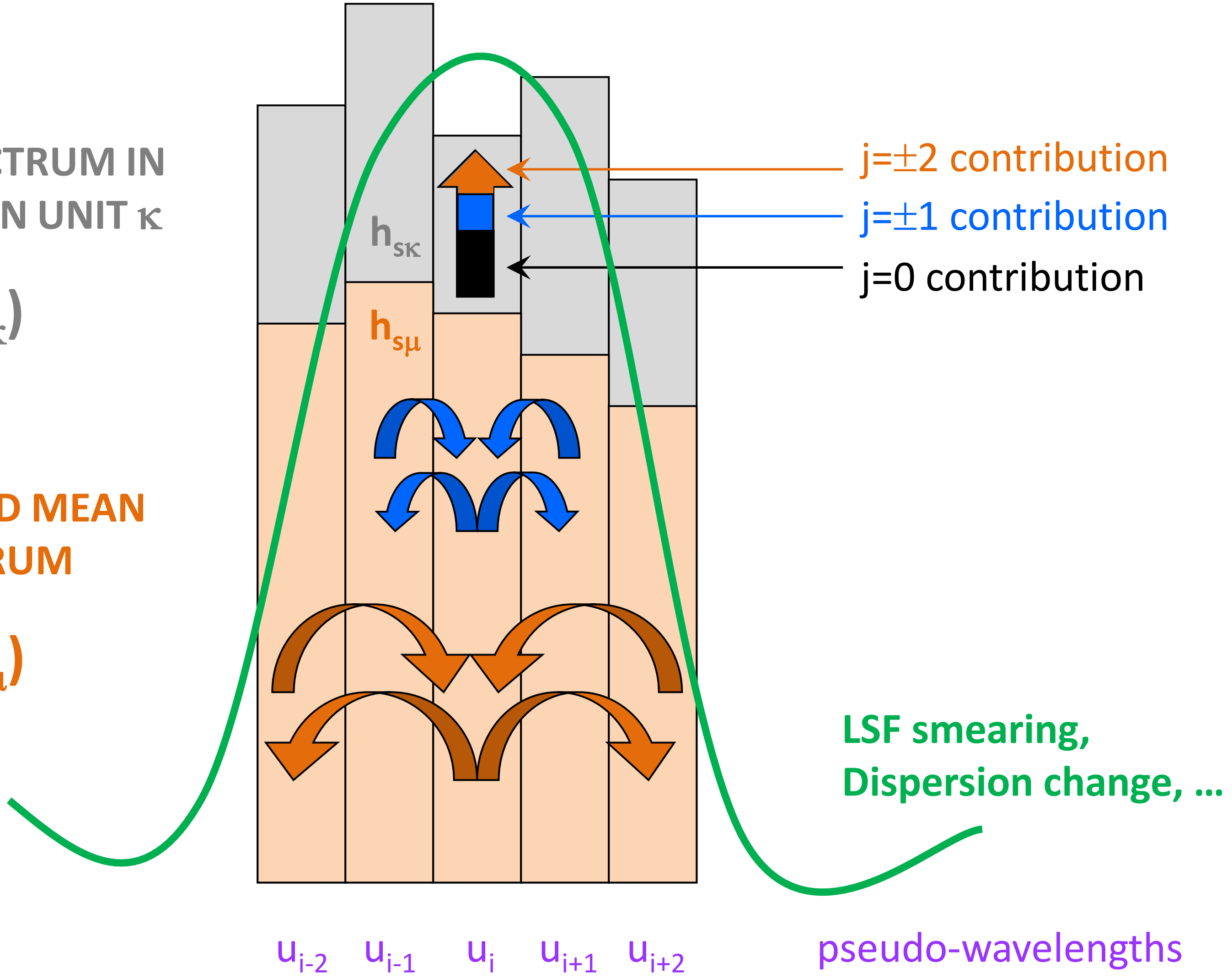
Neighbours influence (J=2 case)

EPOCH SPECTRUM IN CALIBRATION UNIT κ

($h_{s\kappa}$)

RESAMPLED MEAN SPECTRUM

($h_{s\mu}$)



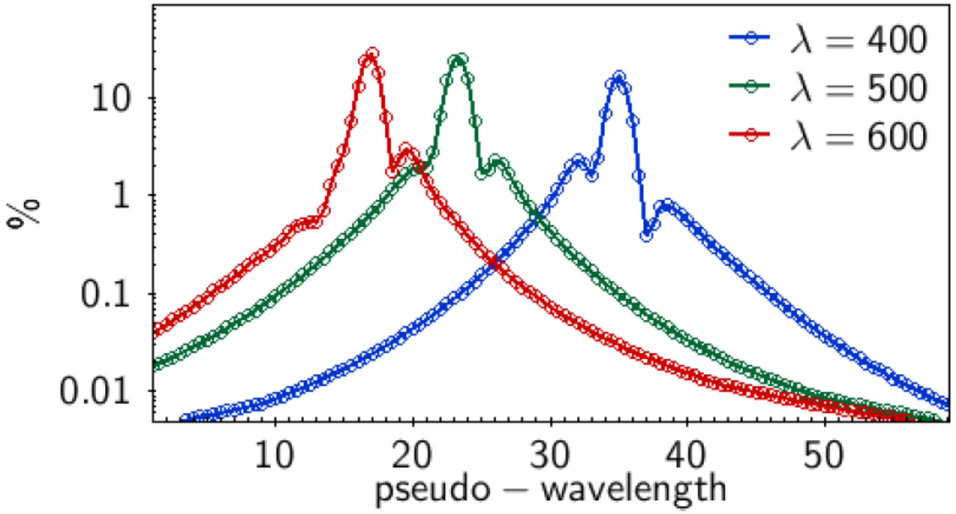
$$h_{s\kappa}(u_i, x_i, 0, 0, G_{\mathrm{BP}} - G_{\mathrm{RP}}, 0) \approx$$
$$\approx \sum_{j=-J}^{J} A_\kappa(u_i, u_{i+j}, x_i) \cdot h_{s\mu}(u_{i+j})$$

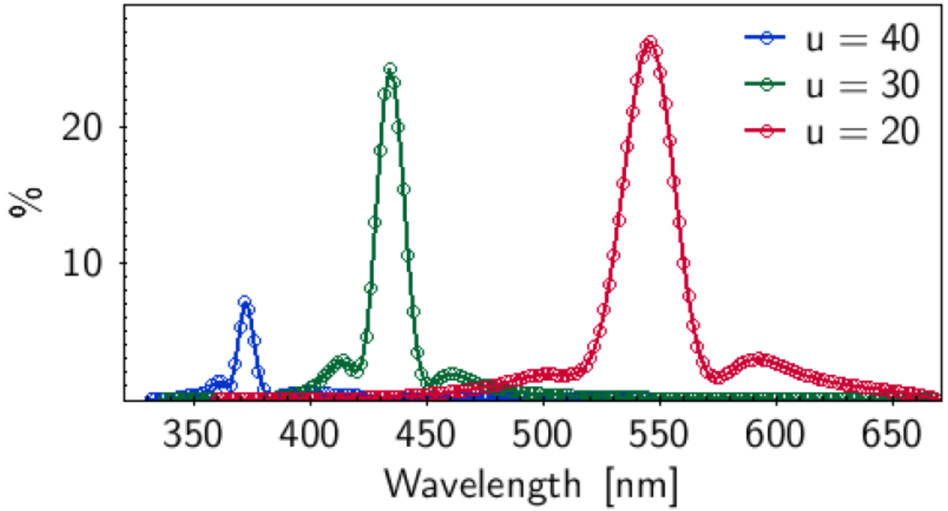
Carrasco et al (2021)

External instrument matrix

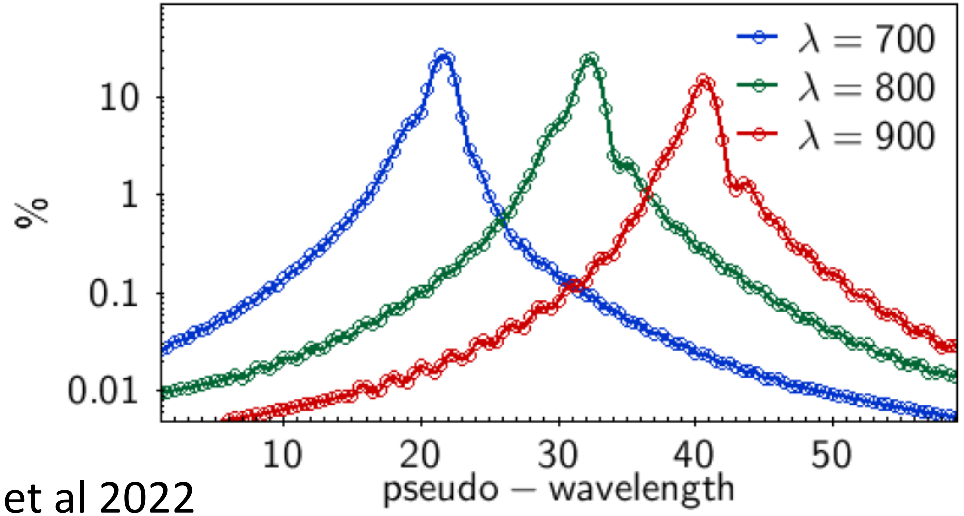
Column (monochromatic LSF) ***Row (λ contribution in a pixel)***

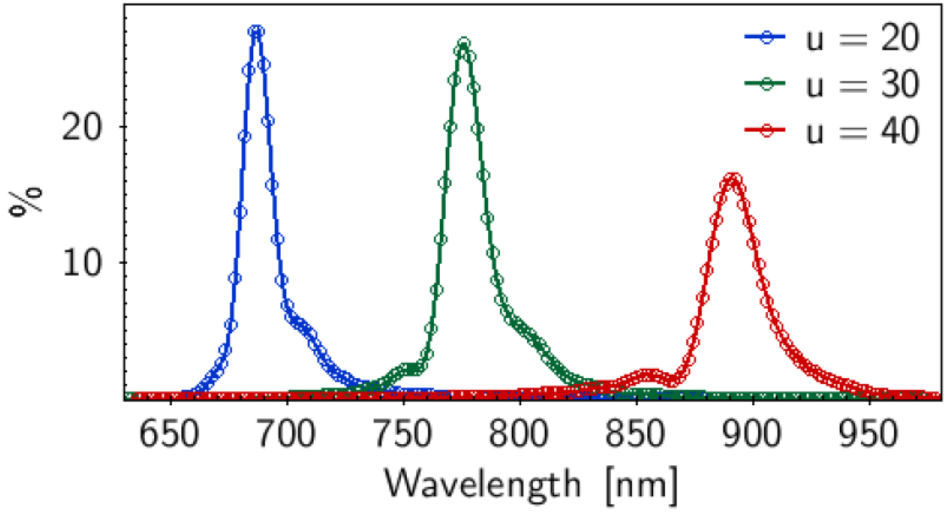
BP





RP

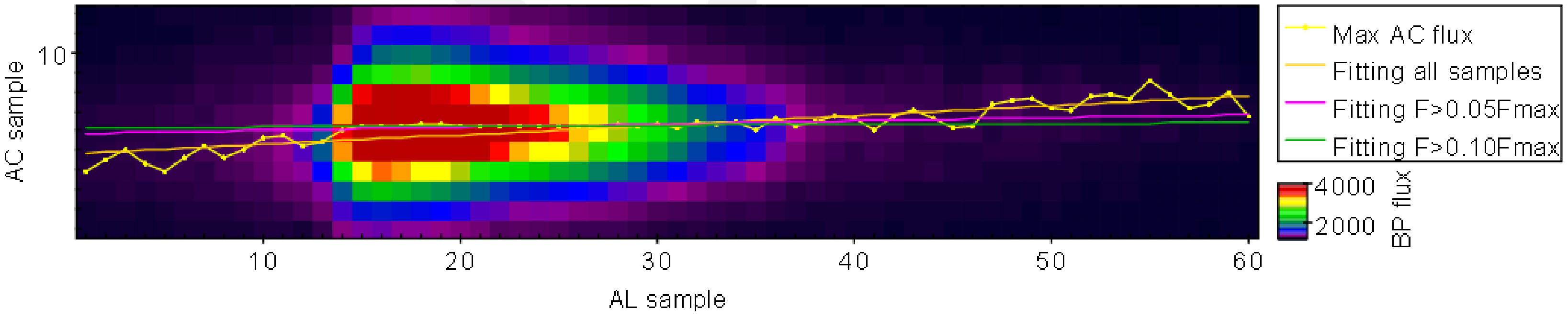


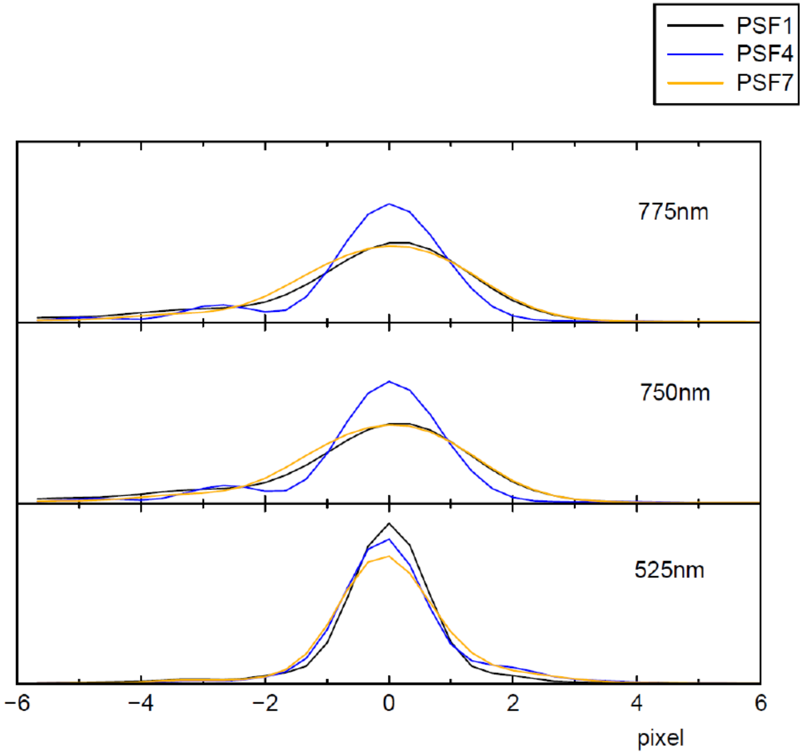


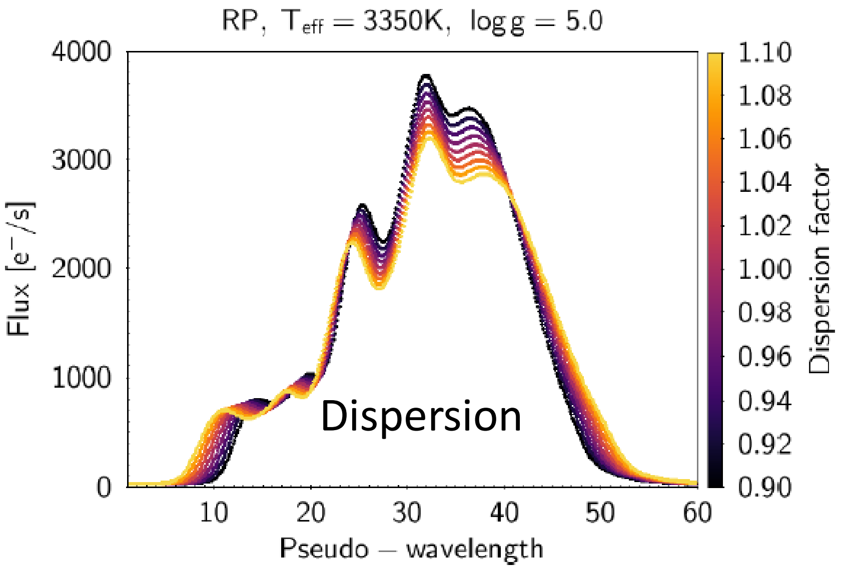
Montegriffo et al 2022

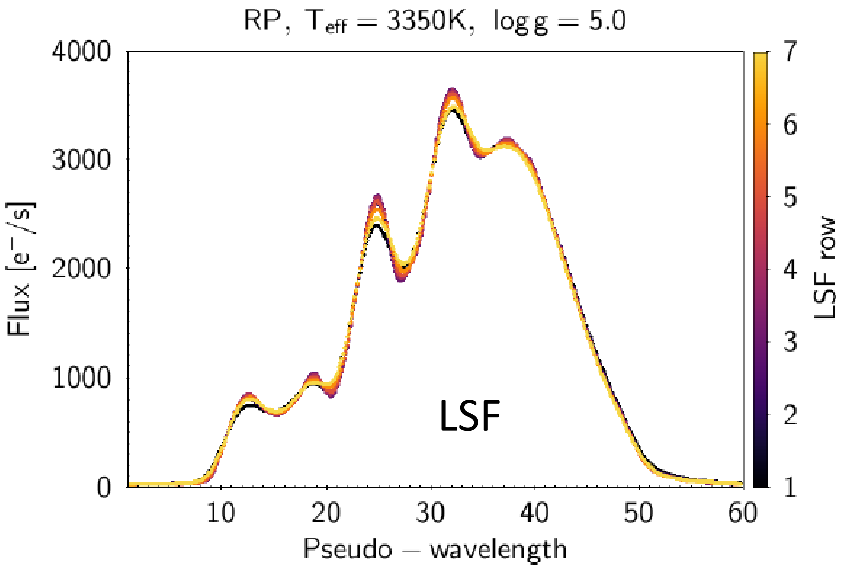
LSF, Dispersion & tilts

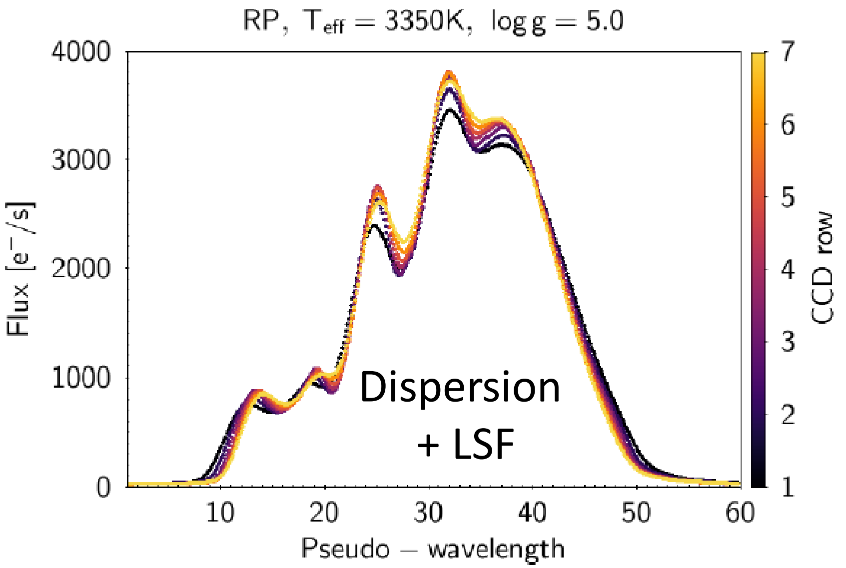
JMC-016











Carrasco et al (2021)

Future developments

- Improve the Galaxy model to the infrared type of sources (extinction, low mass stars, large distance extension, …).
- Definition of a list of key scientific targets (KST) for GaiaNIR
- Optimisation of the filters to the spectral features present in the KST
- Test for the scientific benefit of extending GaiaNIR to shorter wavelengths (400 nm vs 800 nm?).
- Study of spectrophotometry.

GaiaNIR

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THANK YOU