# Ground-based observations for Gaia (GBOG)

**Ulrike Heiter**

**Uppsala University**

gaia



# A selection of GBOG programmes:

- **Astrometry**
  - Gaia satellite tracking (GBOT)
  - Reference frame alignment
- **Photometry**
  - Spectrophotometric standard stars
- **Spectroscopy**
  - Radial velocity standard stars
  - Reference stars for astrophysical parameters
- **Ecliptic Poles Catalogue**

# GBOG programmes

- **Astrometry**
  - **Gaia satellite tracking (GBOT)**
  - Reference frame alignment
- **Photometry**
  - Spectrophotometric standard stars
- **Spectroscopy**
  - Radial velocity standard stars
  - Reference stars for astrophysical parameters
- **Ecliptic Poles Catalogue**

# Ground-based optical tracking (GBOT) of the Gaia satellite

- Gaia global astrometry precision aim = up to 7µas for brightest stars –> need to take into account relativistic aberration, which is proportional to **satellite velocity** relative to the barycentre of the solar system
- Velocity **must be known with 2 mm/s precision** –> requirement in position is 150 m per day, which corresponds to about 21 mas at L2

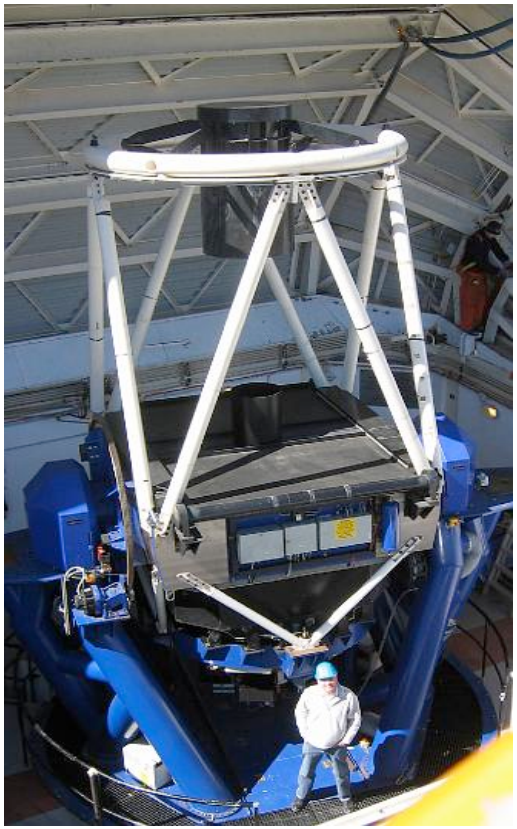
# Ground-based optical tracking (GBOT) of the Gaia satellite

- Would need more than one radio tracking station, but this is too expensive –> use one radio station and a small network of optical telescopes
- **GBOT programme (Altmann et al.)**:
  ~6 telescopes will obtain daily astrometric measurements of Gaia, with precision of 10 mas in position

# Ground-based optical tracking (GBOT) of the Gaia satellite

- **Telescope requirements**
  - 1 to 2m aperture, for short exposures of fast moving R = 18 mag source
  - Optimum size of detector pixels
  - Large field of view to include enough astrometric reference stars
- **Participating observatories**
  - Liverpool Telescope, Las Cumbres Optical Global Telescope network, possibly others

# Ground-based optical tracking (GBOT) of the Gaia satellite



Liverpool Telescope

LCOGT:
existing 2m-telescopes

1m- and 40cm-telescopes under construction

# Ground-based optical tracking (GBOT) of the Gaia satellite

- **Telescope tests**: observations of asteroids, the Planck satellite (also at L2), Milky Way test field, to assess feasibility and precision
- **Current status**: ongoing tests, and development of data-reduction pipeline

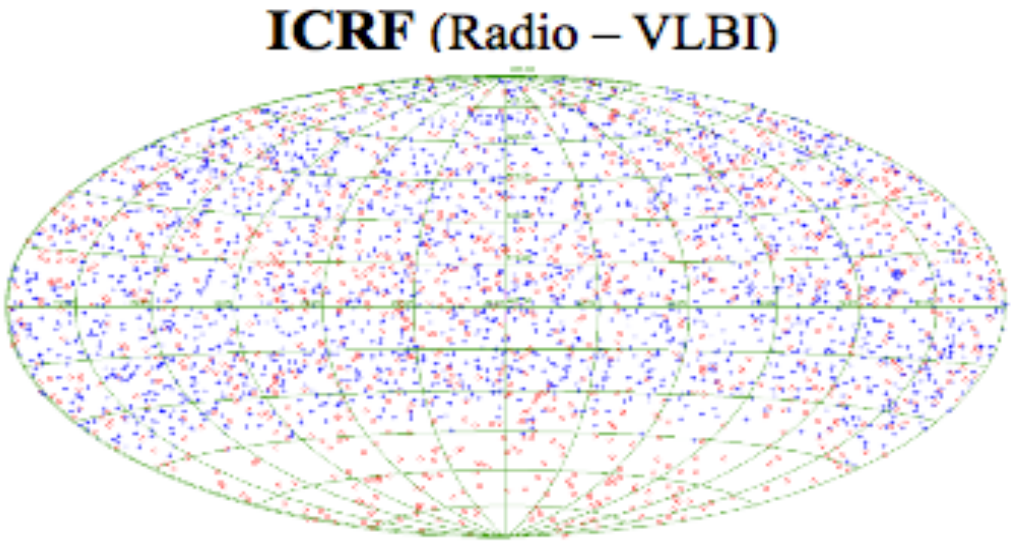
# GBOG programmes

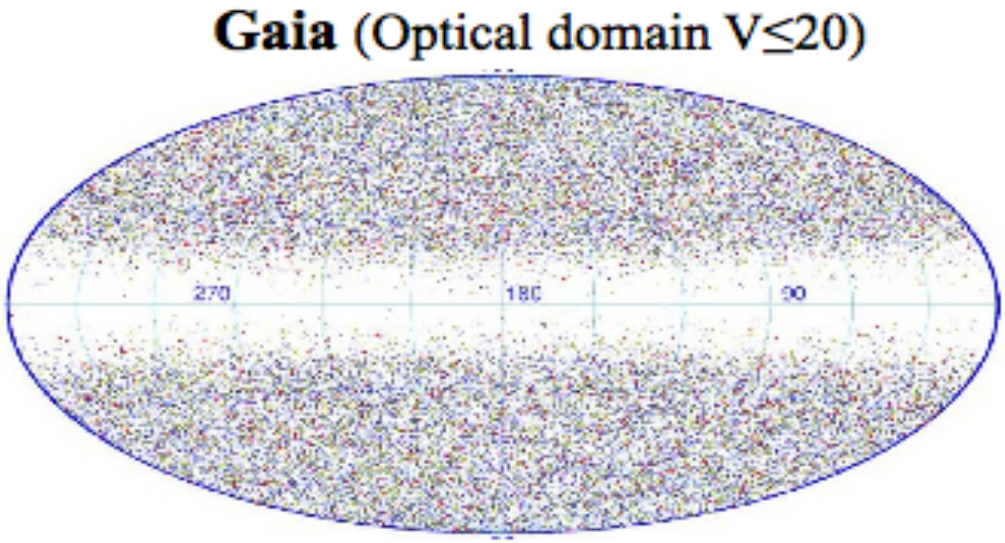
- **Astrometry**
  - Gaia satellite tracking (GBOT)
  - **Reference frame alignment**
- **Photometry**
  - Spectrophotometric standard stars
- **Spectroscopy**
  - Radial velocity standard stars
  - Reference stars for astrophysical parameters
- **Ecliptic Poles Catalogue**

# Reference frame alignment

- **Current reference frame** for astrometry, space navigation, and geodynamics = ICRF2 (International Celestial Reference Frame), based on coordinates of ~3400 extragalactic **radio** sources measured with VLBI (Very Long Baseline Interferometer), with position accuracy up to 60 µas
- **Gaia** will define new reference frame based on **optical** coordinates of ~10000 quasars, with similar accuracy

# Reference frame alignment




The 2 frames need to be linked

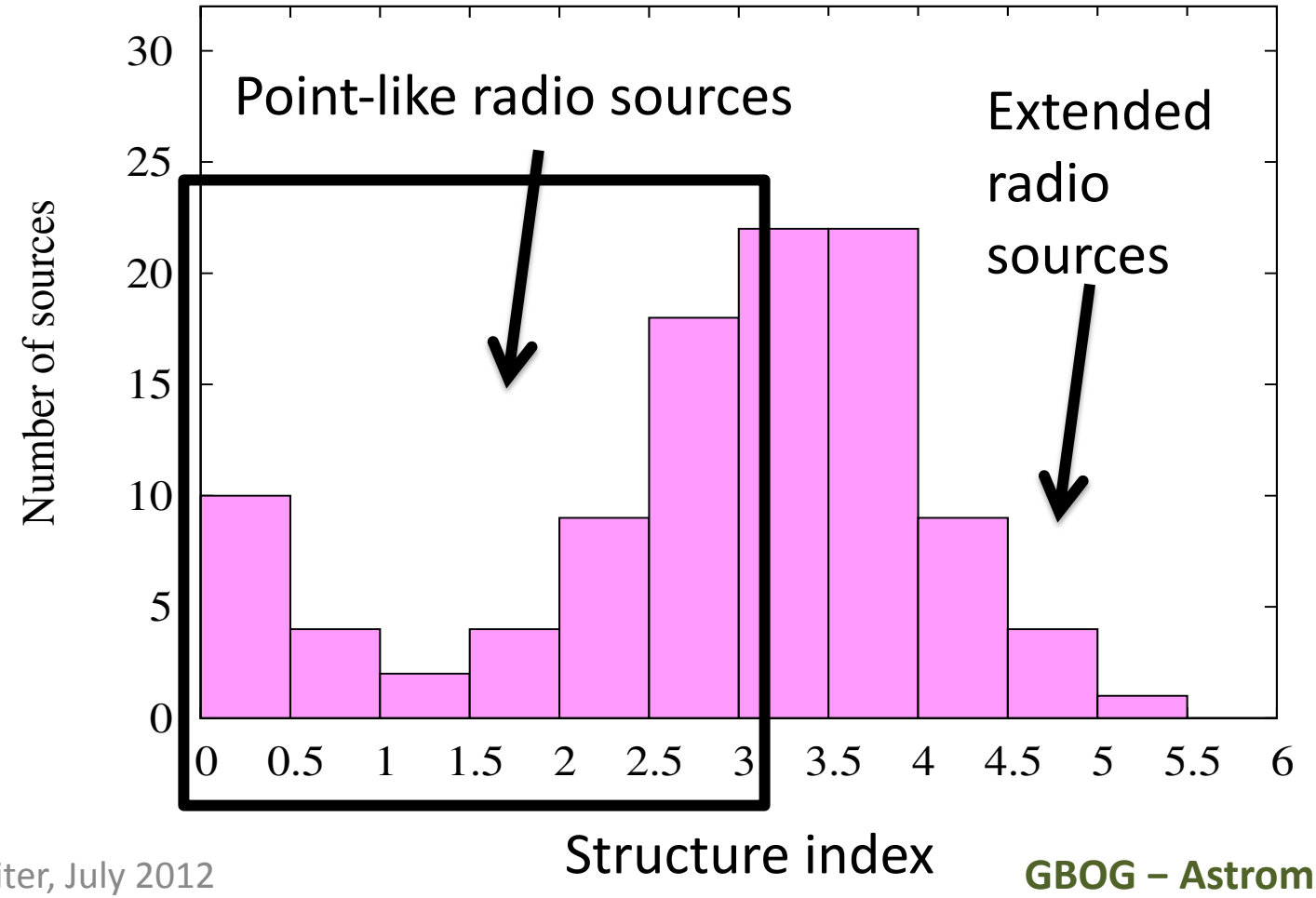
- to ensure continuity of the fundamental celestial reference frame
- to register optical & radio positions with the highest accuracy

# Reference frame alignment

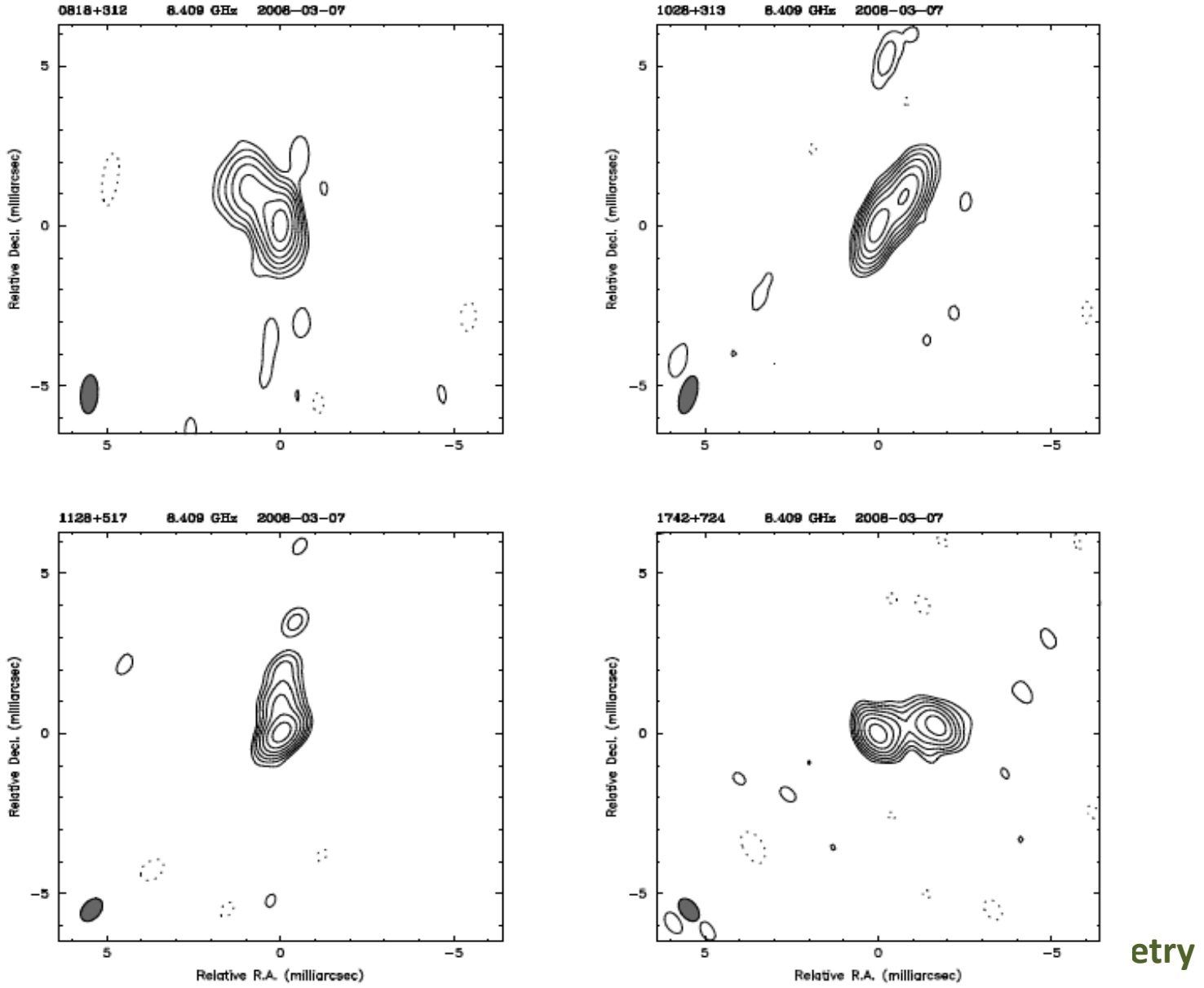
- **Programme for accurate alignment (Bourda et al.)**: need several hundreds of common sources, with uniform sky coverage, and
  1. accurate Gaia positions –> optically bright (V ≤ 18)
  2. accurate VLBI position –> radio point sources
- The ~300 ICRF2 defining sources fulfill 2., but only 50% fulfill 1. –> search for new radio-optical link sources –> **~400 candidate sources** (fulfilling 1.) selected from radio and optical quasar catalogs and imaged with VLBI

# Reference frame alignment

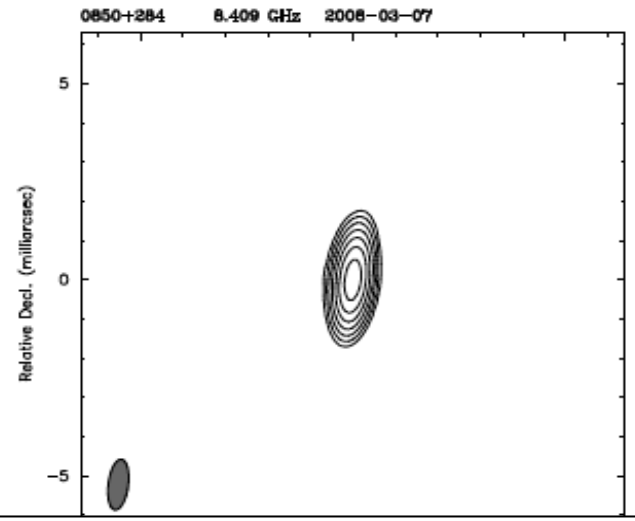
- About 50% of candidates found to fulfill 2.

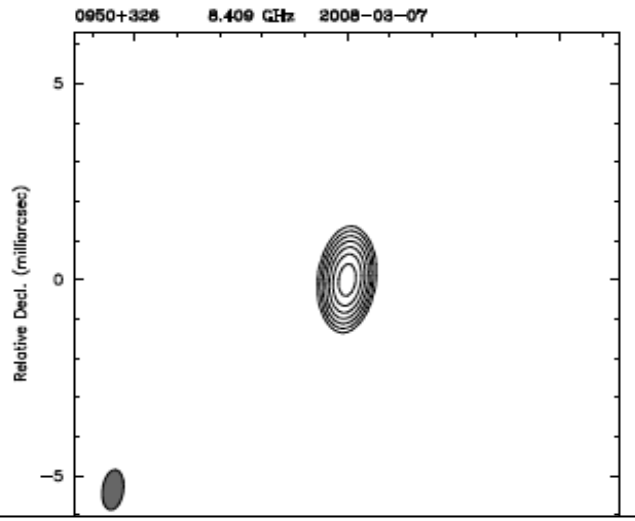


# Bad sources

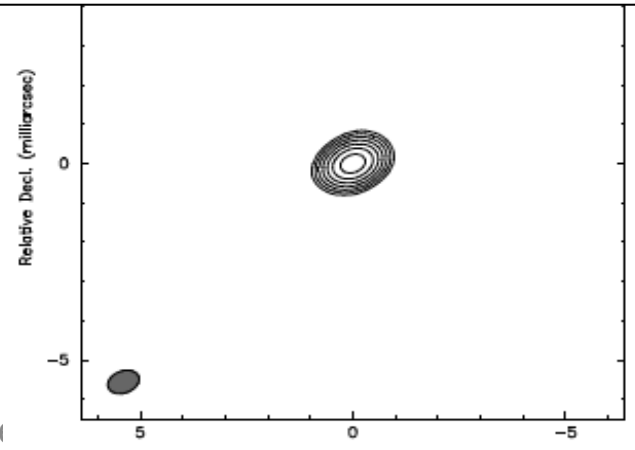

0818+312 8.409 GHz 2006-03-07
1028+313 8.409 GHz 2006-03-07
1128+517 8.409 GHz 2006-03-07
1742+724 8.409 GHz 2006-03-07
Relative Decl. (milliarcsec)
Relative R.A. (milliarcsec)
5
0
-5

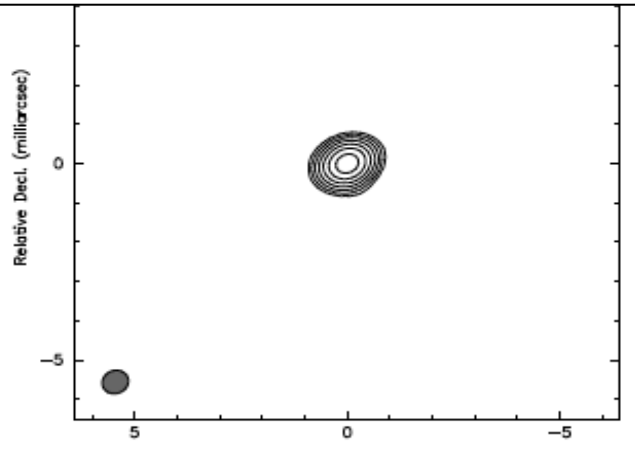
# Good sources




Next step: VLBI astrometry to obtain positions to better than 100 µas.



# GBOG programmes

- **Astrometry**
  - Gaia satellite tracking (GBOT)
  - Reference frame alignment
- **Photometry**
  - **Spectrophotometric standard stars**
- **Spectroscopy**
  - Radial velocity standard stars
  - Reference stars for astrophysical parameters
- **Ecliptic Poles Catalogue**

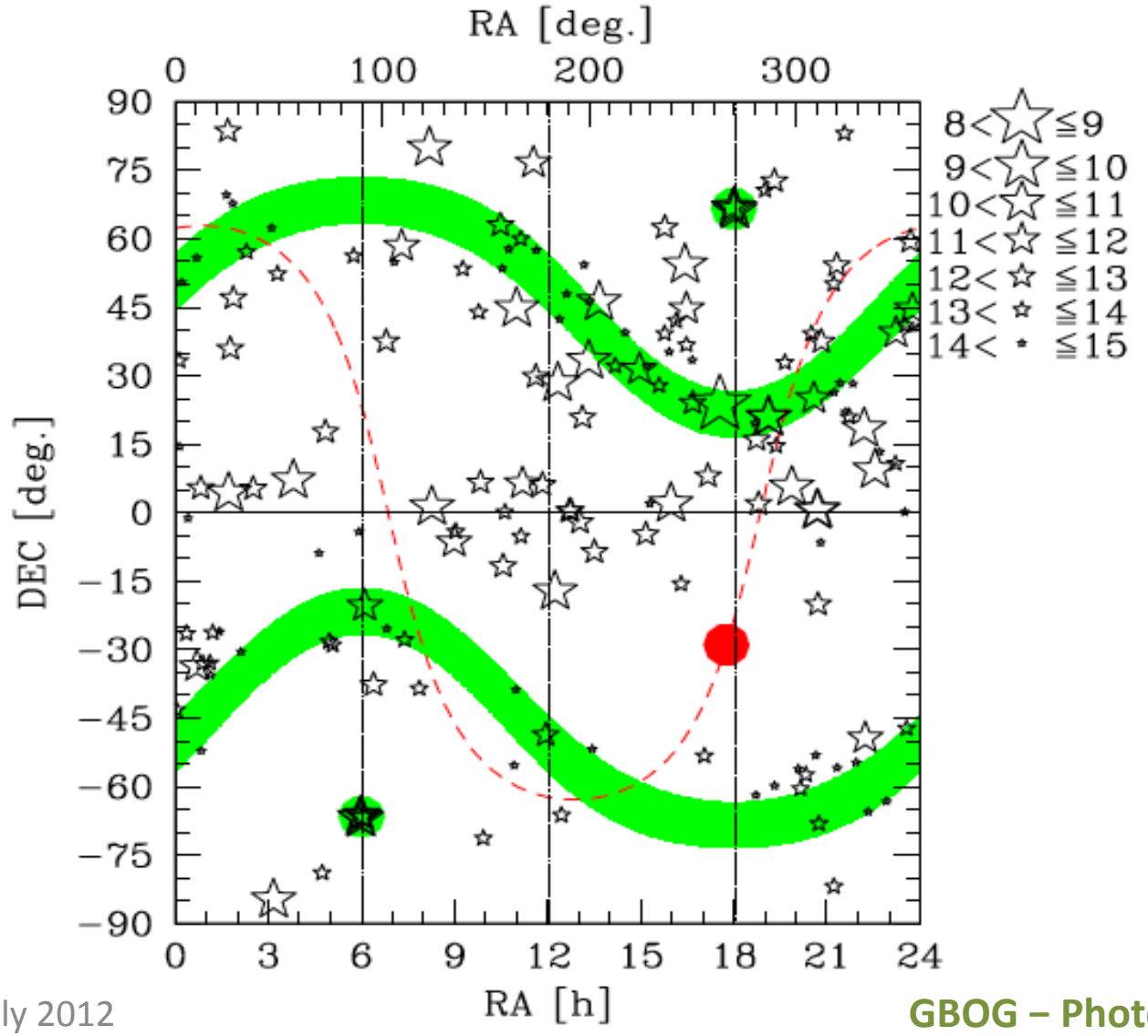
# Spectrophotometric standard stars

- Gaia aims to provide **spectrophotometry on a physical flux scale** accurate to a few percent
- **Flux calibration is difficult** due to observing method (objects moving across large focal plane) and radiation damage
- Flux calibration model **requires large set of calibration stars** (~200) with known absolute fluxes (330 to 1050 nm)

# Spectrophotometric standard stars

- **SPSS programme (Pancino et al.)**: Ground-based observations of candidate SPSS
  - to establish **flux constancy** on short and long term
  - to produce **flux tables accurate to a few percent**, using absolute photometry and relative spectro-photometry based on 3 HST calibrators tied to Vega flux calibration
- Using **6 observatories** at ESO, in Italy, Spain, Mexico

# Spectrophotometric standard stars



# Spectrophotometric standard stars

- **Current status**
  - **Observations** are more or less completed, more than 400 nights since 2007
  - **Data reduction and analysis** ongoing, following strict protocols and procedures, to ensure homogeneity
- **Side result**: A widely used HST flux calibrator was found to be variable (possible delta Scuti star)

# GBOG programmes

- **Astrometry**
  - Gaia satellite tracking (GBOT)
  - Reference frame alignment
- **Photometry**
  - Spectrophotometric standard stars
- **Spectroscopy**
  - **Radial velocity standard stars**
  - Reference stars for astrophysical parameters
- **Ecliptic Poles Catalogue**

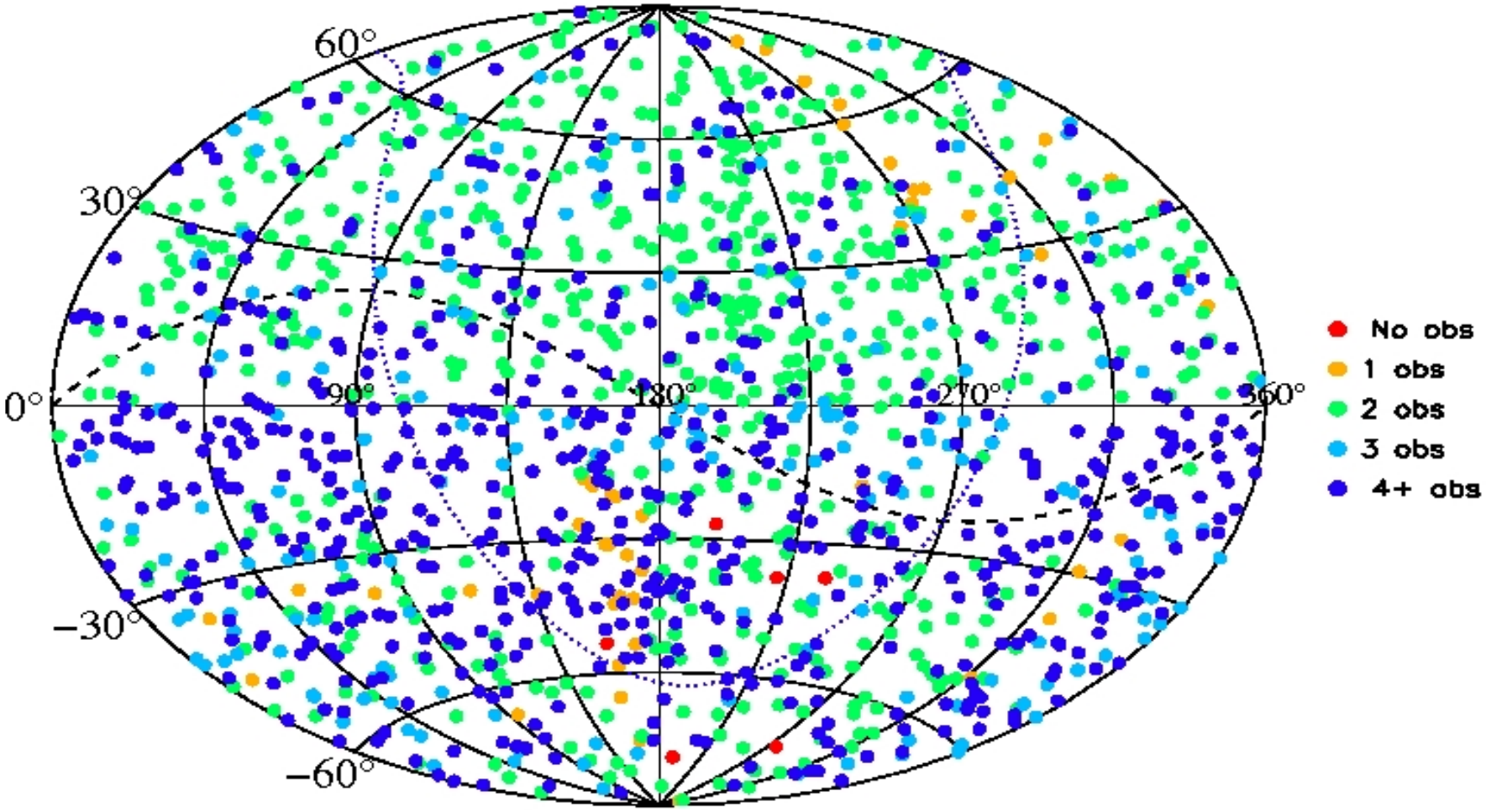
# Radial velocity standard stars

- **Absolute calibration of Gaia radial velocity** (RV) measurements with 1 km/s accuracy requires ~1000 RV standard stars, with
  - RV known and stable with accuracy of <300m/s
  - Homogeneous distribution over whole sky
  - Magnitude range: 6 < V < 10
- **Problem** with RV standard stars in existing catalogues: many are too bright and most of them are in the northern hemisphere

# Radial velocity standard stars

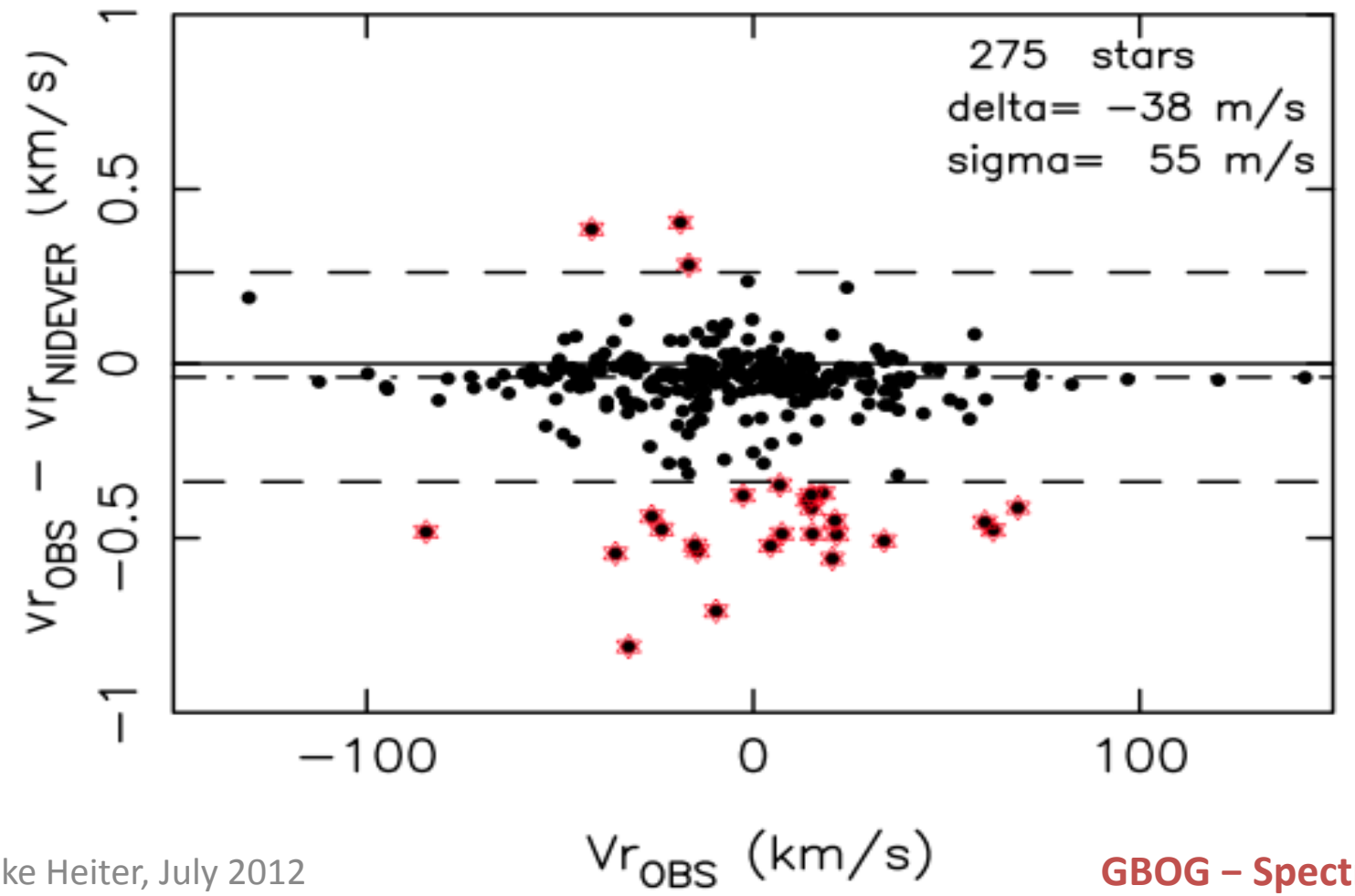
- **GBOG programme (Crifo et al.)**: Selection of ~1400 candidate RV standard stars from 3 RV catalogues and monitoring (at least 2 observations) with echelle spectrographs
- **Instruments** used: SOPHIE, NARVAL, CORALIE, and archive data from HARPS and ELODIE
- **Link of data** from different instruments via **asteroids** and IAU standard stars
- **Preliminary results**: ~8% of candidates exhibit RV variations and should be rejected

# Radial velocity standard stars



# Radial velocity standard stars

Comparison to RV catalogue by Nidever et al. (2002)



# GBOG programmes

- **Astrometry**
  - Gaia satellite tracking (GBOT)
  - Reference frame alignment
- **Photometry**
  - Spectrophotometric standard stars
- **Spectroscopy**
  - Radial velocity standard stars
  - **Reference stars for astrophysical parameters**
- **Ecliptic Poles Catalogue**

# AP reference stars

- Gaia astrophysical parameter determinations will be based on model spectra for RP/BP and RVS resolution/wavelength range
- Need to estimate systematic errors due to deviation of model spectra from real spectra
- **GBOG programme (Heiter et al.)**: Calibration stars with $6 < V < 13$ and high-resolution ground-based spectra

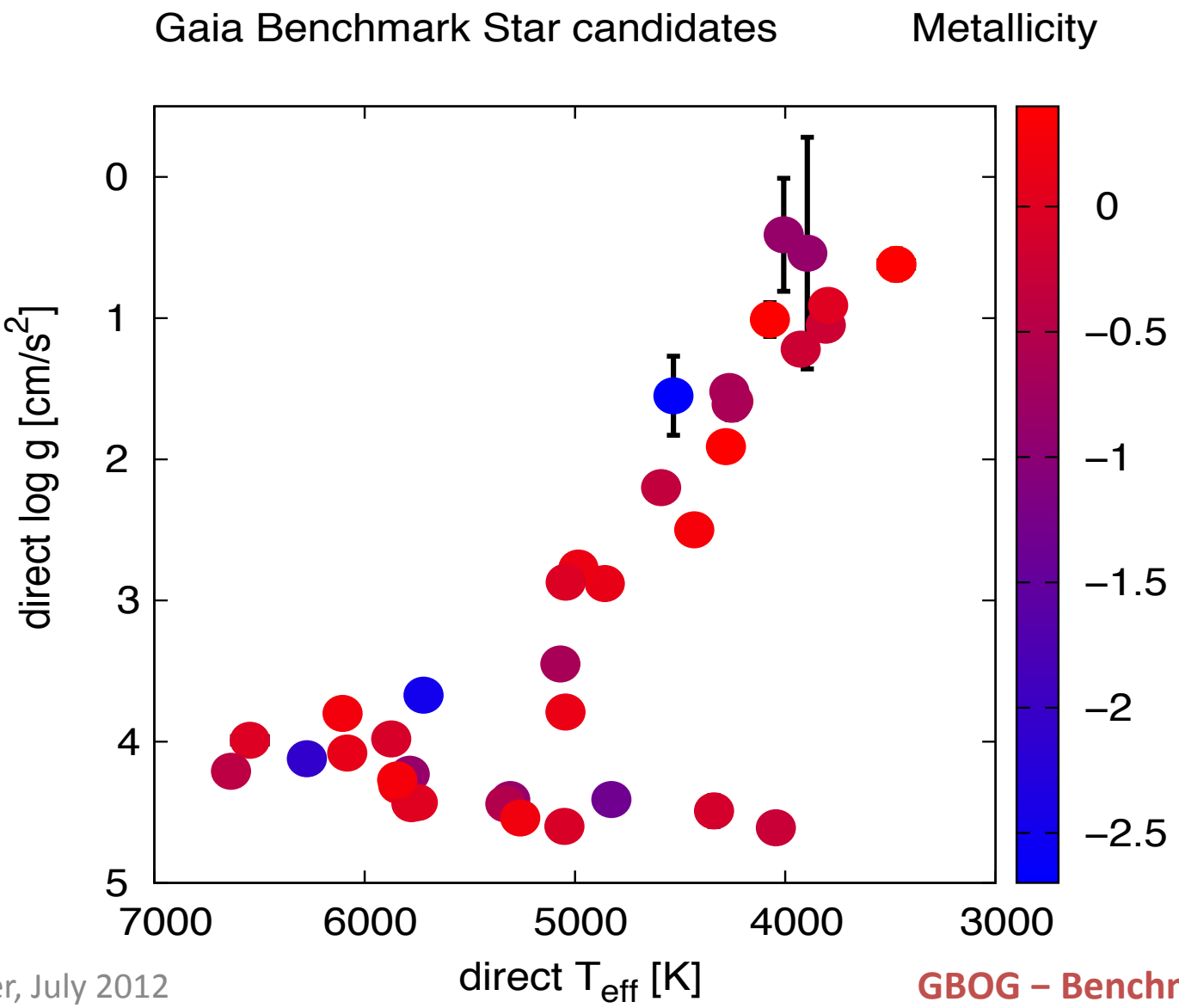
# AP reference stars

- Data for >1000 stars available in **archives** of ESO and french telescopes, supplemented by **new observations** with NARVAL
- Goal: Homogeneous and accurate determination of astrophysical parameters, calibrated with benchmark stars

# Benchmark stars

- **Parameters**
  - ***Direct*** $T_{eff}$ and log g from angular diameter, bolometric flux, parallax, mass
  - ***Spectroscopic*** $T_{eff}$, log g, **abundances** from ~10 previously published high-resolution studies per star, and in future from our own studies
- **Purpose**: test and improve model spectra, calibrate parameters of AP reference stars
- **40 candidate benchmark stars**

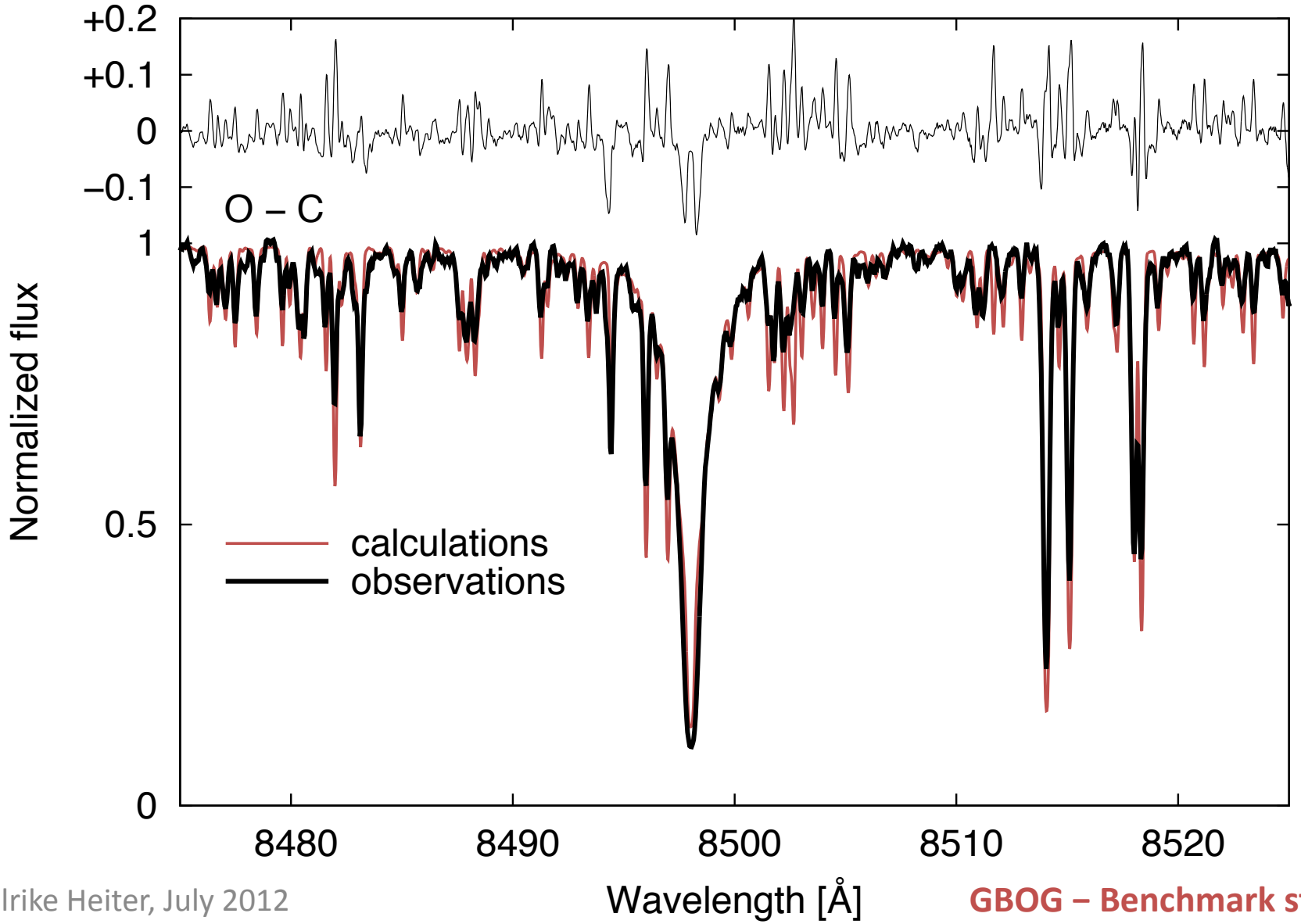
# Candidate benchmark stars



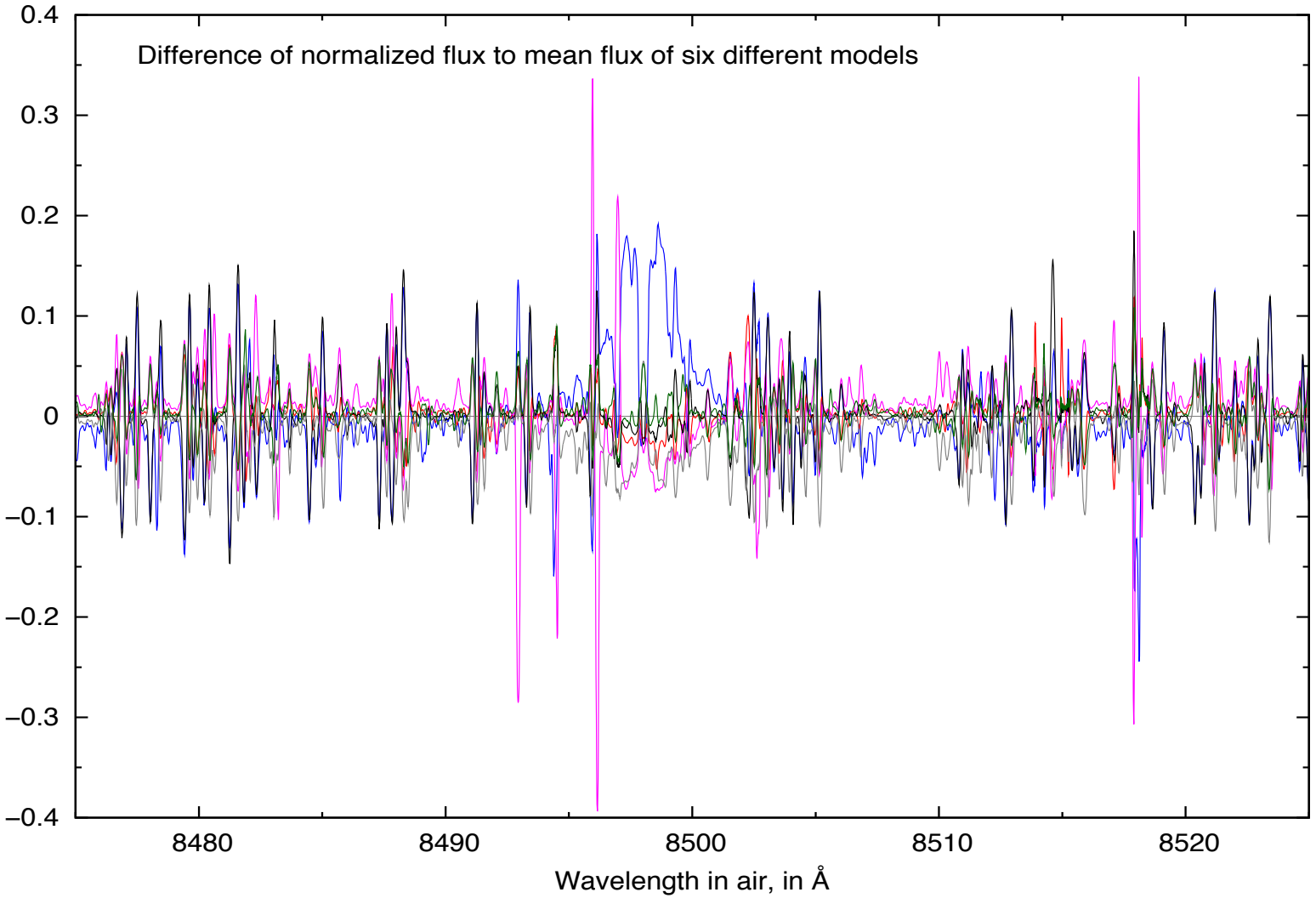
# Observations of benchmark stars

- **GBOG programme (Heiter et al.)**: High-resolution (R = 80000 – 160000) optical/near-IR spectra obtained with NARVAL, HARPS, SARG, and supplemented with archive spectra
- Spectra of two cool giants ($T_{eff}$ ~3900 K) recently analysed by 14 different groups
- **Resulting parameters** cluster around "true" values: **$T_{eff}$ ~100 K, log $g$ ~0.5 dex, [Fe/H] ~0.4 dex**
- Differences mainly due to **atomic and molecular line data and analysis method**

# Example model fit for benchmark star



# Differences between 6 models



# GBOG programmes

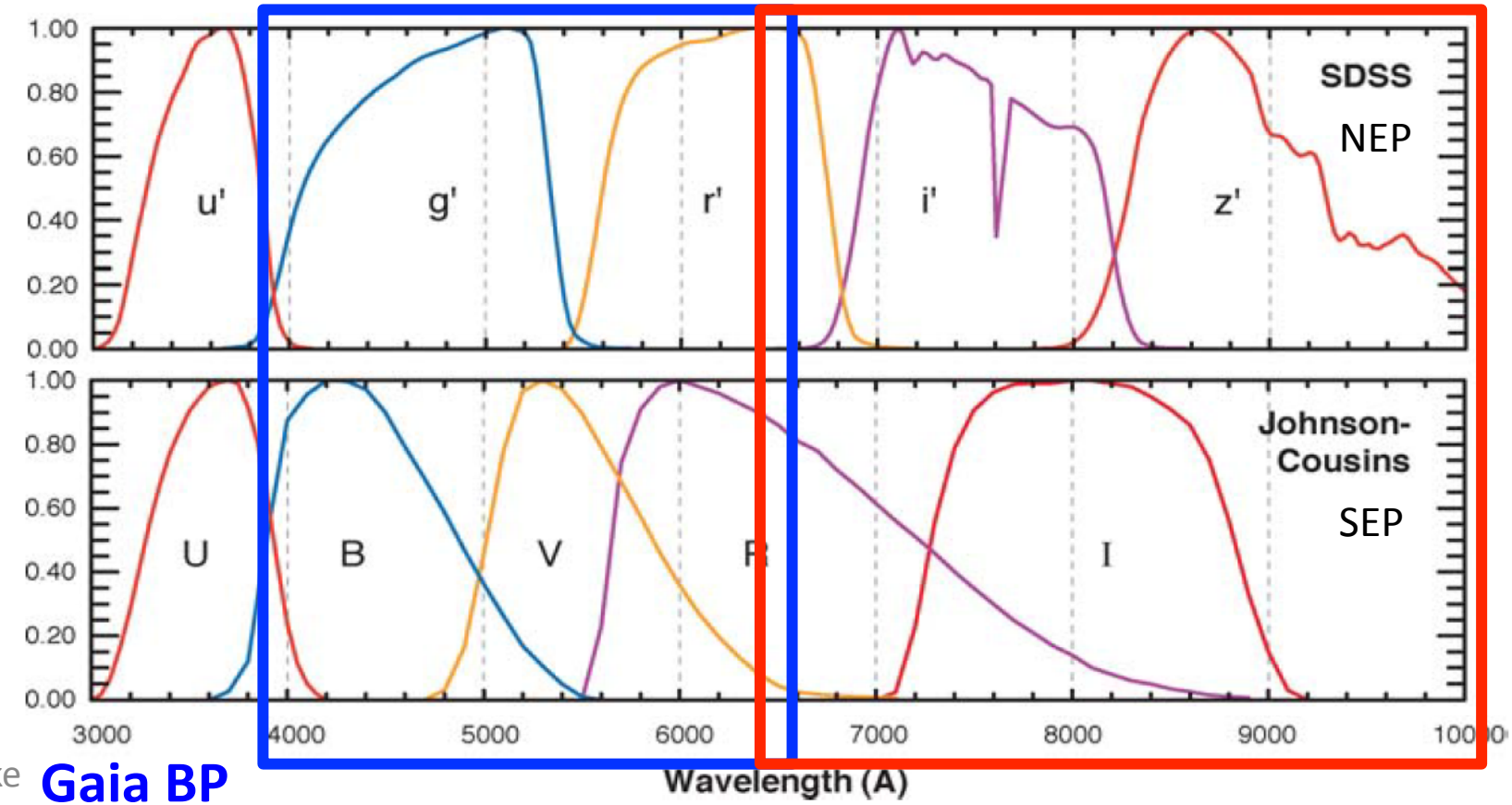
- **Astrometry**
  - Gaia satellite tracking (GBOT)
  - Reference frame alignment
- **Photometry**
  - Spectrophotometric standard stars
- **Spectroscopy**
  - Radial velocity standard stars
  - Reference stars for astrophysical parameters
- **Ecliptic Poles Catalogue**

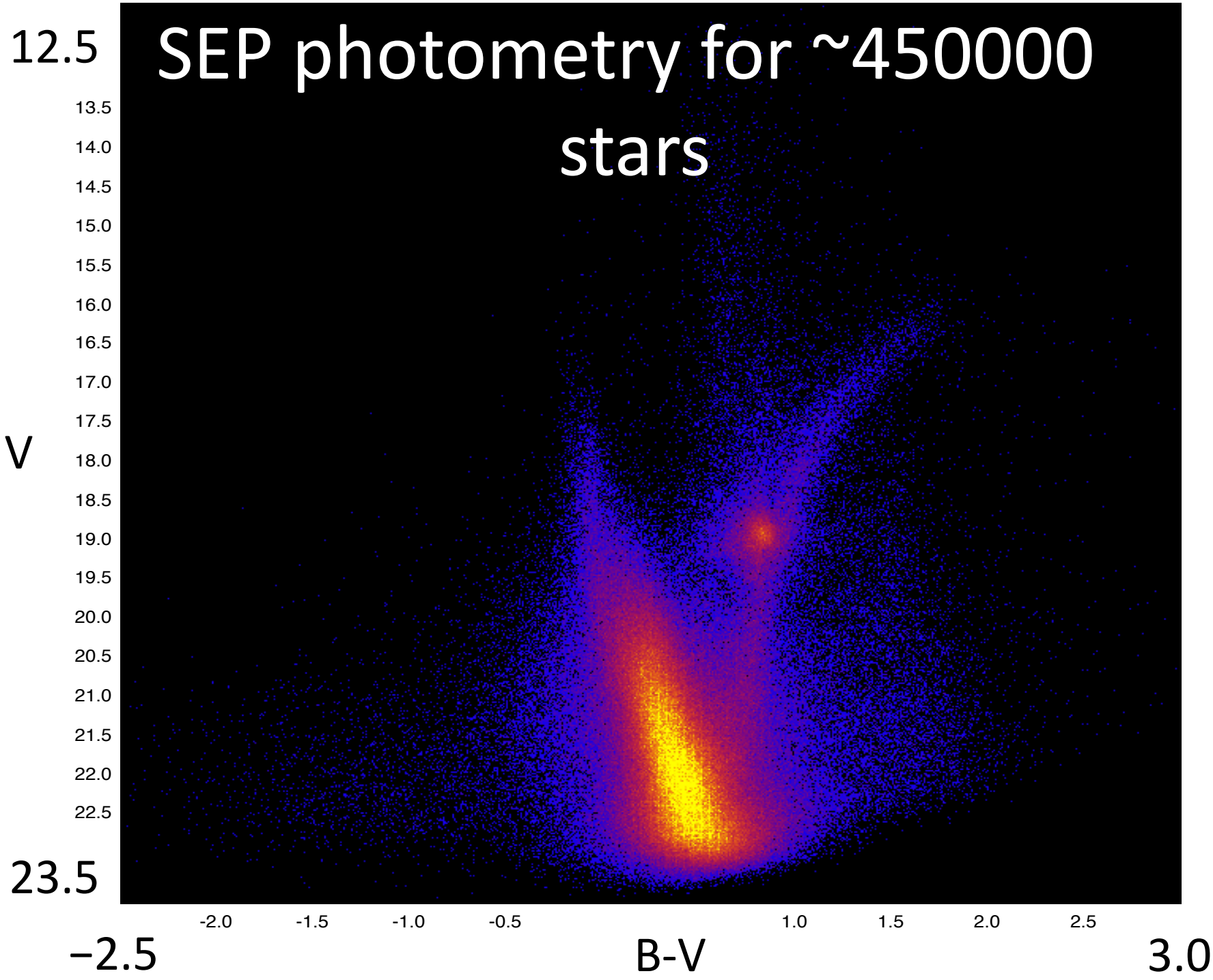
# Ecliptic Poles Catalogue

- **Gaia commissioning phase** (first few weeks): intense observations of two one-square-degree fields at ecliptic poles for initial testing and calibration
- **Ecliptic poles catalogue (Altmann et al.)**: astrometric, photometric, and spectroscopic measurements from ground for all sources observed by Gaia

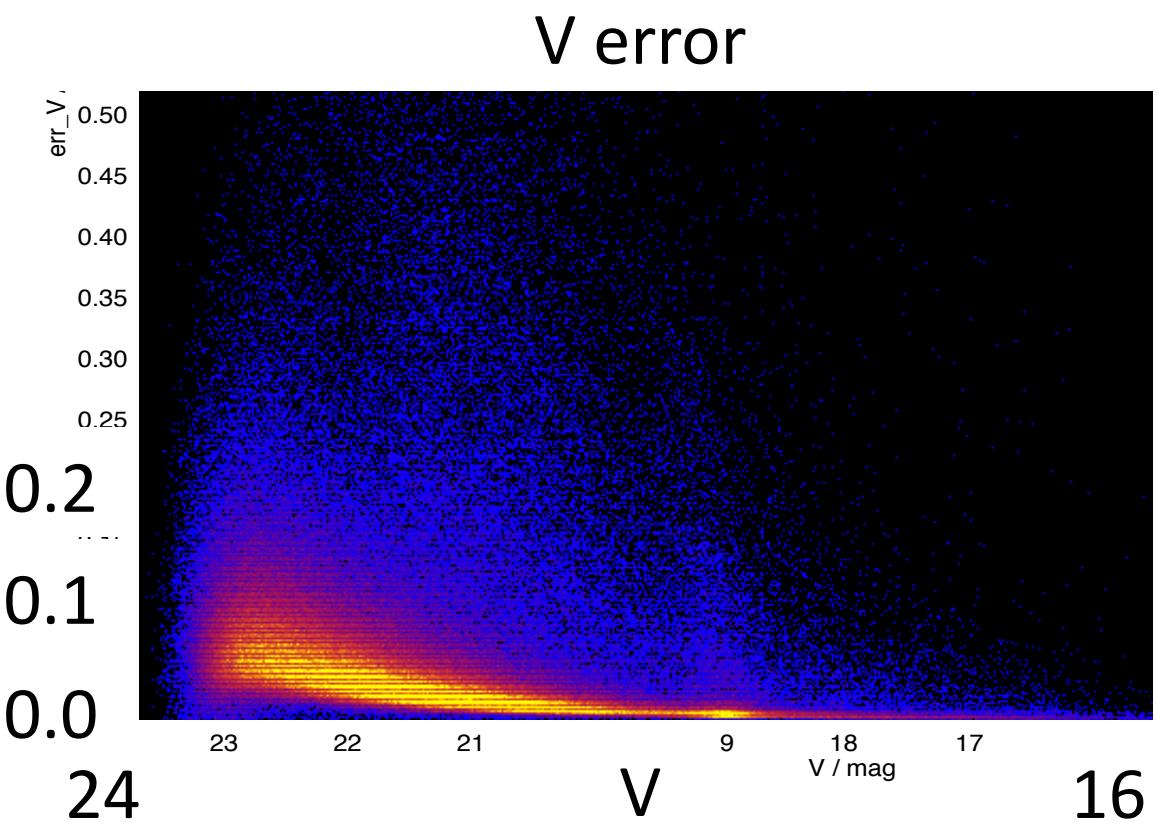
# EPC – Imaging at two epochs

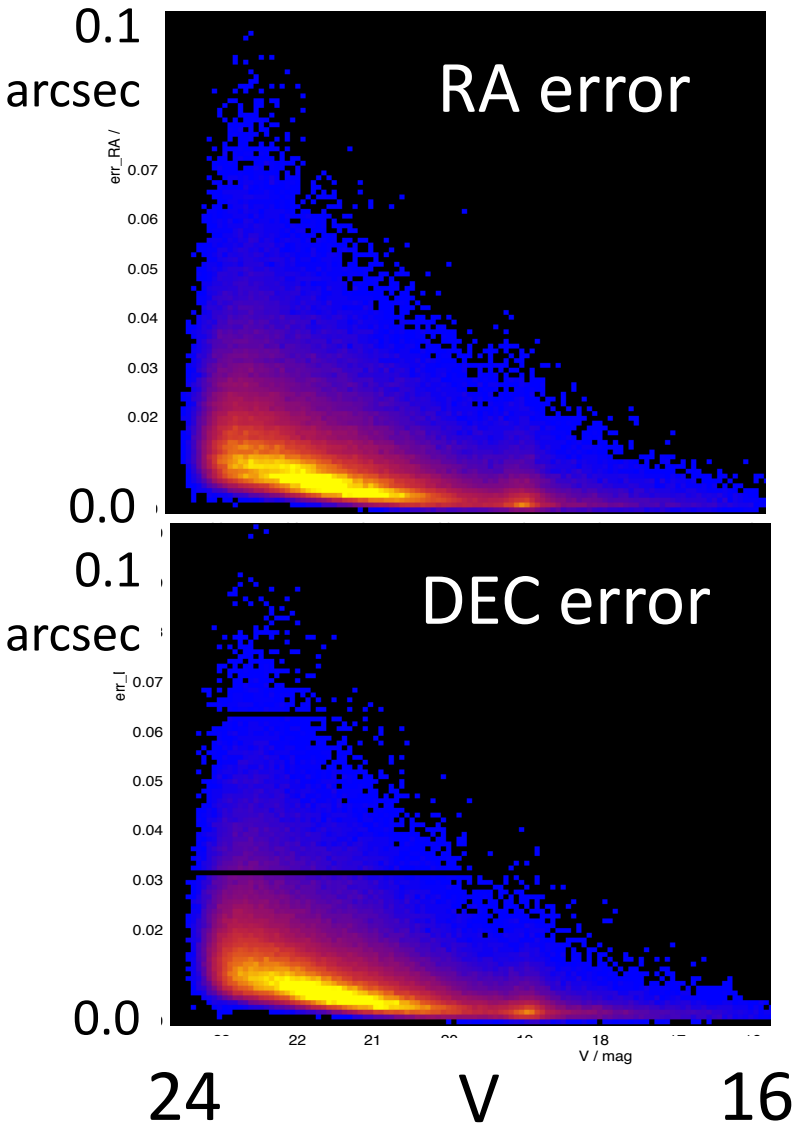
- North (NEP): CFHT 3.6m telescope on Hawaii
- South (SEP): MPIA 2.2m telescope at La Silla

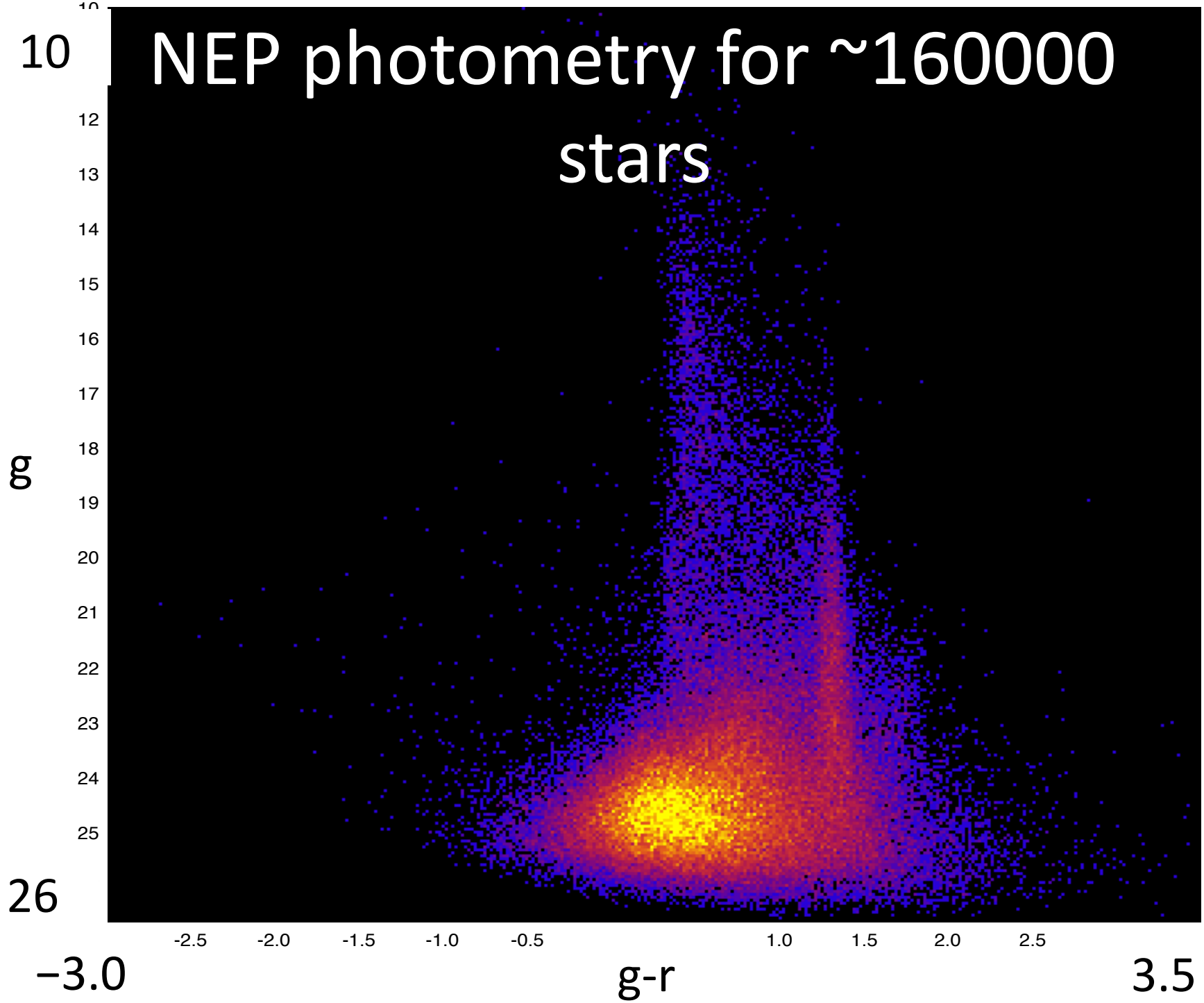


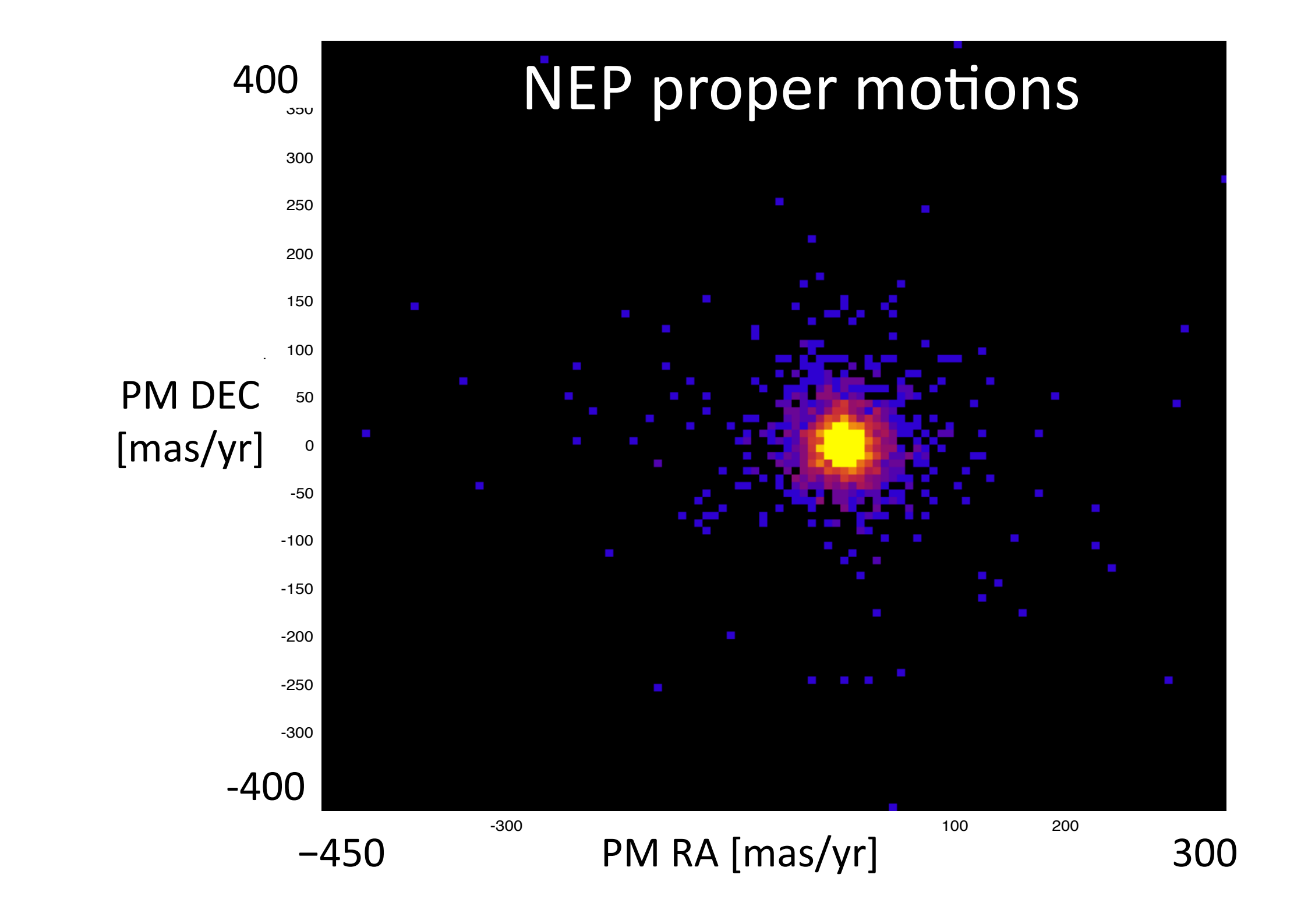

SEP photometry for ~450000 stars
12.5
13.5
14.0
14.5
15.0
15.5
16.0
16.5
17.0
17.5
V
18.0
18.5
19.0
19.5
20.0
20.5
21.0
21.5
22.0
22.5
23.5
-2.0
-1.5
-1.0
-0.5
1.0
1.5
2.0
2.5
−2.5
B-V
3.0

# SEP data precision



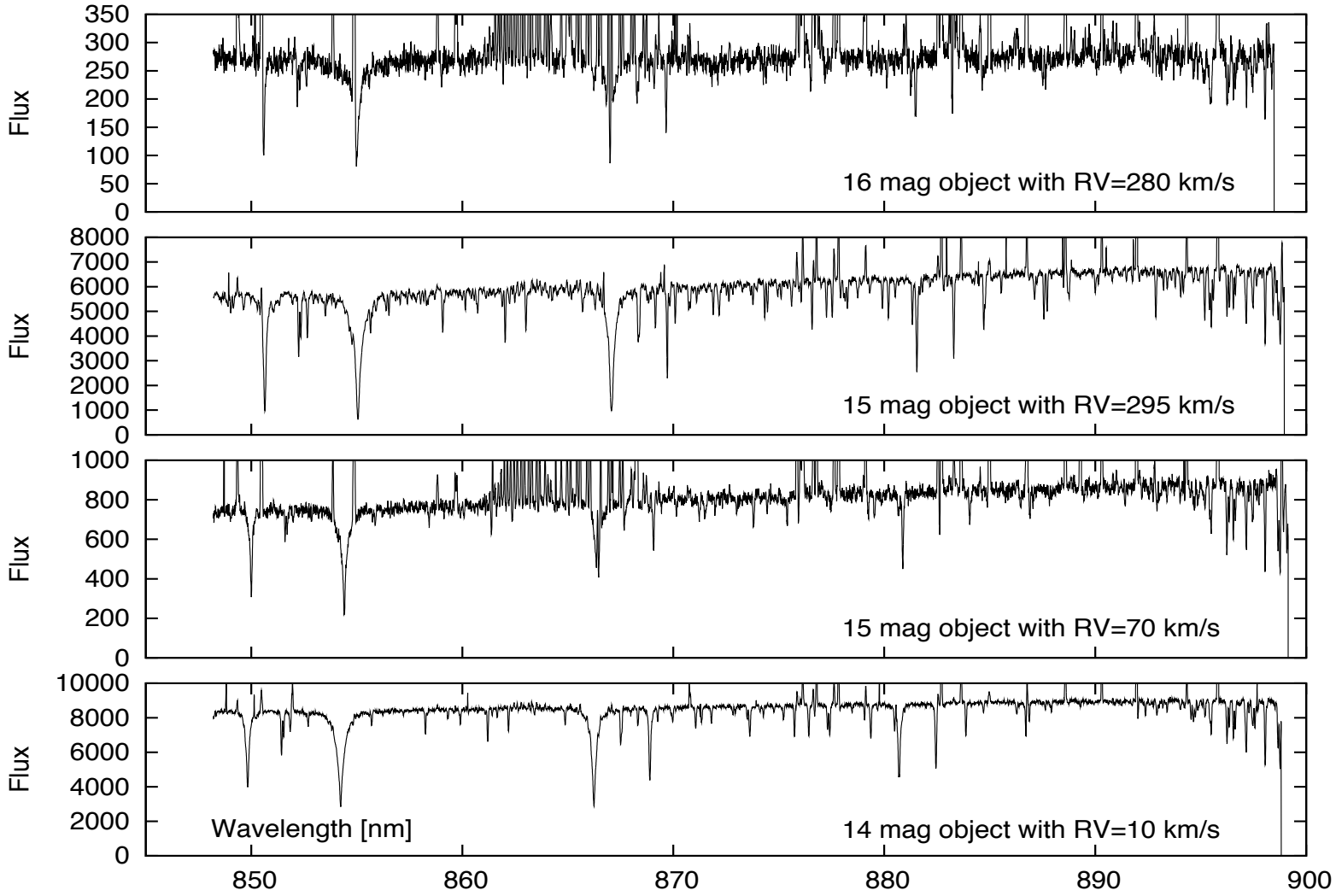

NEP photometry for ~160000 stars
10
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
g
-2.5
-2.0
-1.5
-1.0
-0.5
1.0
1.5
2.0
2.5
−3.0
g-r
3.5


NEP proper motions
400
350
300
250
200
150
100
50
0
-50
-100
-150
-200
-250
-300
-400
PM DEC
[mas/yr]
-450
-300
100
200
300
PM RA [mas/yr]

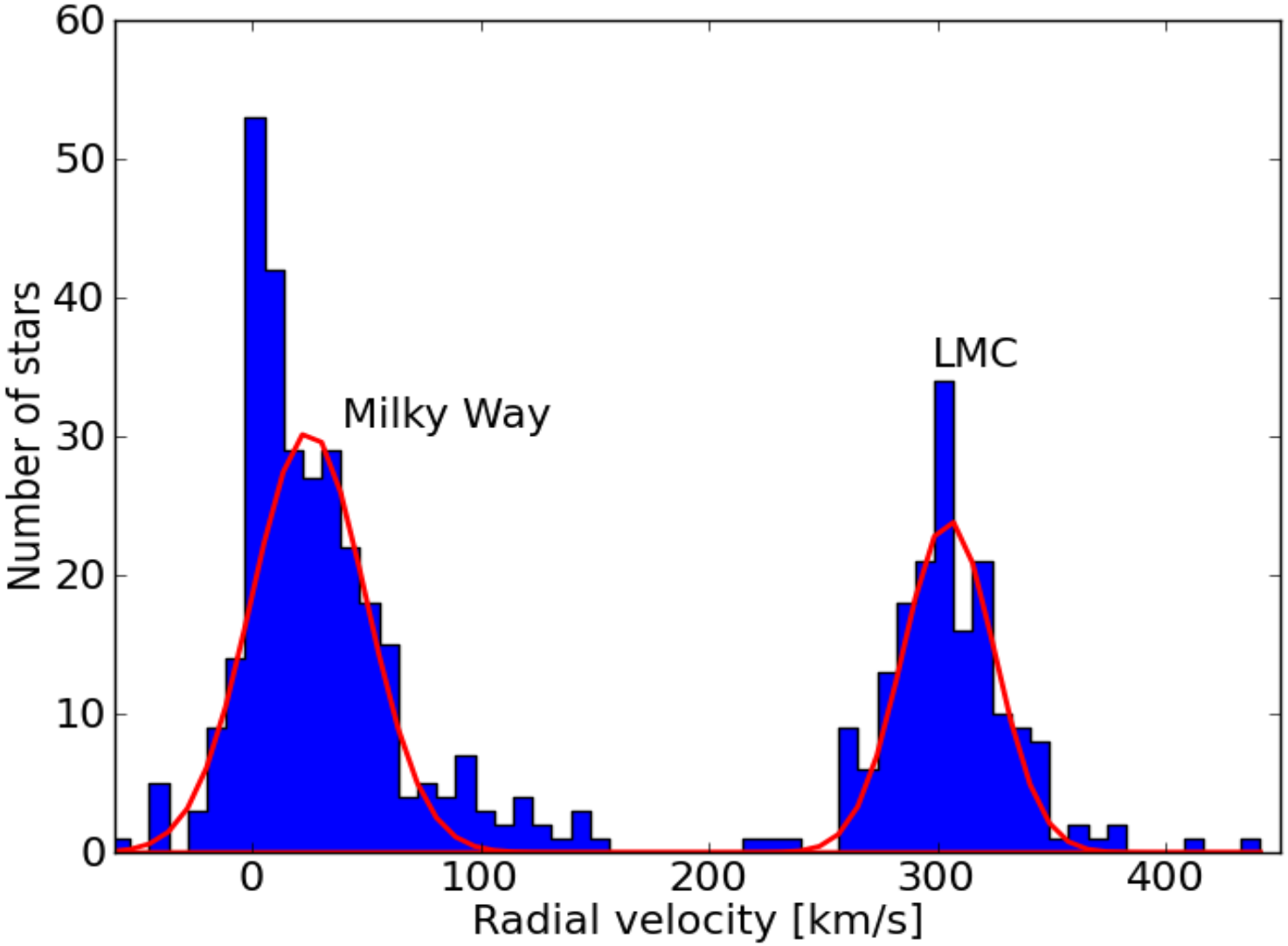
# Spectroscopy for **SEP** field

- Spectra for **about 500 stars** (0.1%) obtained at VLT with **FLAMES**
  - Short blue wavelength range with R~6000
  - Gaia-RVS wavelength range with R~16000
  - 50 spectra centered at 860 nm with R~47000
- **Data reduction** – need to remove spectral lines caused by Earth's atmosphere (not in pipeline)
- **Data analysis** – radial velocity (RV) determination and abundance analysis

# Example RVS range spectra for **SEP**



# Preliminary RVs for **SEP** field



# The End