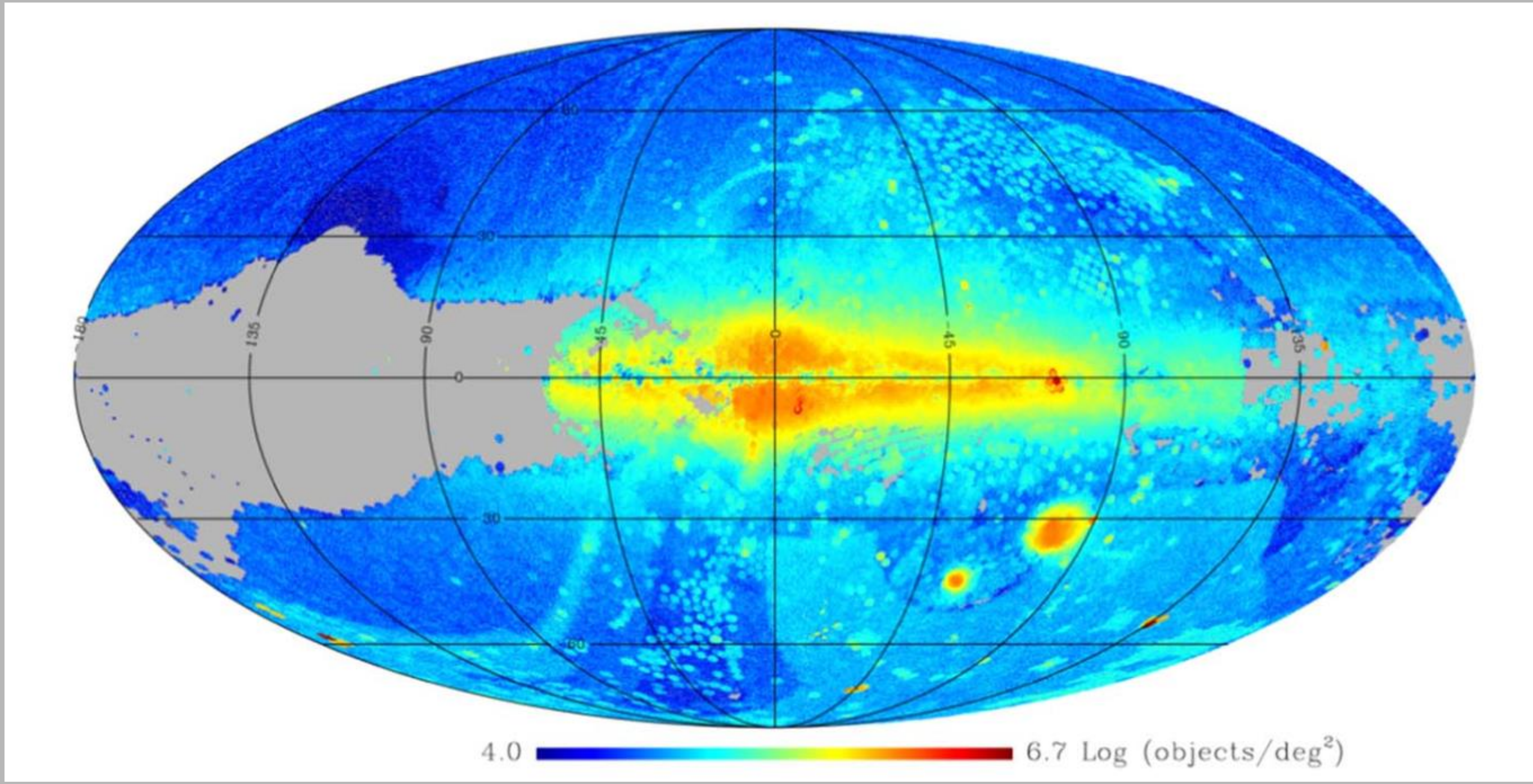
The variable sky with the NOIRLab Source Catalog (NSC)

POL MASSANA
Postdoc

Collaborators: David Nidever, Brett Meerdink, Neel Vadodaria, Clara Martínez-Vázquez, Kathy Vivas

NSC DR2

- ~410,000 exposures
- 68 billion individual source measurements
- 3.9 billion unique objects
- 7-year baseline for DECam data



Nidever et al. 2021

Check out **David Nidever's poster**!

NSC DR3

- Increase of over 40% in DECam exposures
- Longer baseline by ~3-4 years (depends on images being public)
- Improved, iterative source extraction
- PSF photometry

Coming (potentially) in the later part of the year!

NSC stellar variability

Goals

- Create an automated pipeline to detect and classify variable stars.
- Release a catalogue of variables detected by the NSC.
- Derive P-L relations for the main types of variables (Cepheids and RRL).

Good preparation for Rubin!

Current work in progress

- **Deriving new P-L relations for Cepheids and RR Lyraes with NSC bands (me!)**
  - This presentation!
- **Test different period estimating techniques (Brett Meerdink, grad student)**
  - Lomb-Scargle is one of the standard methods, but there are better and faster ways.
  - Testing how well they work with lower epochs and how adding more bands can help.
  - Methods being tested:
    - Period04 (Lenz & Breger 2005)
    - Conditional entropy (Graham et al. 2013)
    - Analysis of variance (Hartman & Bakos 2016)
- **Machine learning techniques to classify stellar variables (Neel Vadodaria, grad student)**
  - One main issue will be discerning eclipsing binaries from other more useful standard candles.

Leavitt

We are building up a Python library (`leavitt`) with useful tools to download and analyze variable star data in the NSC.

David will be doing a demo of some of the currently implemented capabilities **tomorrow at 16:15**.

There are two main ways to initialize a `Variable` object.

1. Using the NSC ID (objectid) of a star. We'll do that here. This performs a synchronous query to the DataLab catalog.
2. Giving it a TimeSeries object.

[ ]:
```
star = Variable('150537_4644')
```

This object now has an attribute called `timeseries` which contains the timeseries data.

[ ]:
```
star.timeseries
```

Now, we can perform a Lomb-Scargle multiband to find the period of the star (it may take a while). This is a RRc star with a period of 0.3367 days.

[ ]:
```
frequency, power = star.ls_mb_periodogram()
period, error = star.get_period(frequency, power)
```

The period and errors are stored in the new variables, but also a new attribute called `period` that stores the period only.

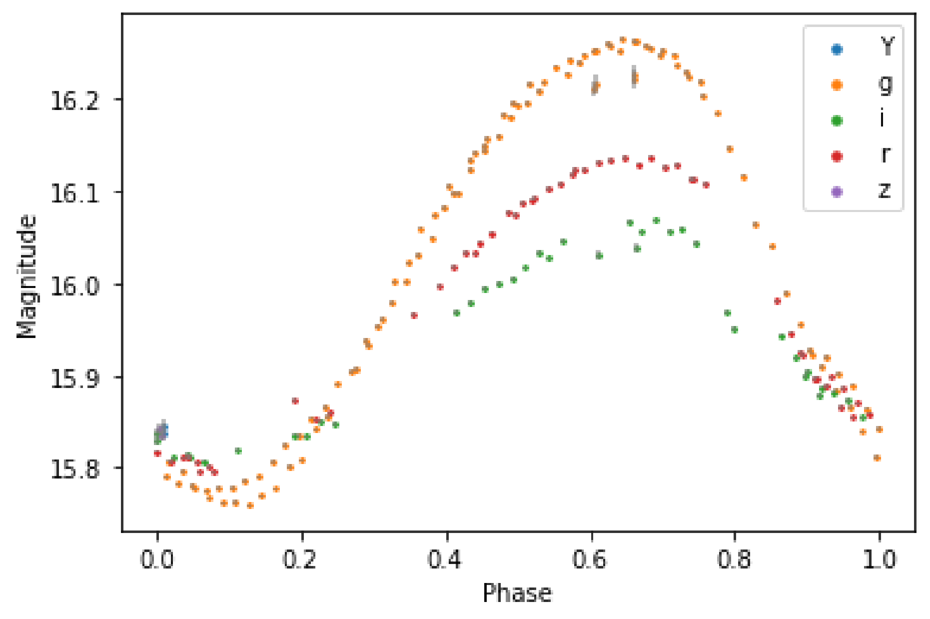
[20]:
```
print('{:.5f} +/- {:.5f} days'.format(period.value,error.value))
print('{:.5f} days'.format(star.period.value))
```

```
0.33667 +/- 0.00004 days
0.33667 days
```

We can now get the data to construct a phased lightcurve.

[21]:
```
phase = phase_fold(star.timeseries['time'],period)
```

[22]:
```
plot_phased_lightcurve(phase, star.timeseries['mag_auto'],mags_errs=star.timeseries['magerr_auto'],filters=star.timeseries['filter'])
```



github.com/NideverAstroResearch/leavitt

Leavitt

We want to add:

- More period estimating techniques
- Template fitting for RR Lyraes and Cepheids
- More ways to plot and represent data
- In the long run, we want to add our methods for finding and classifying the different stellar types.

github.com/NideverAstroResearch/leavitt

Period-luminosity relations

Method

- We use the ***Gaia* DR3 variable set** for our calibration.
- We also require that stars have a minimum of 10 measurements in each g, r and i bands.
- We focus on δ Cepheids, RRLab and RRLc. As classified by *Gaia*.

- There are **enough RR Lyrae that we can use parallaxes to derive its distances** and make a truly independent calibration of the P-L relation
- For **Cepheids**, there are not enough common sources between the two catalogues with reliable parallaxes, therefore **we use the *Gaia* P-L relations to get their distances**.

RR Lyraes

RRLab

LMC: 12884

SMC: 1991

Rest of the sky: 12380

Total: 27255

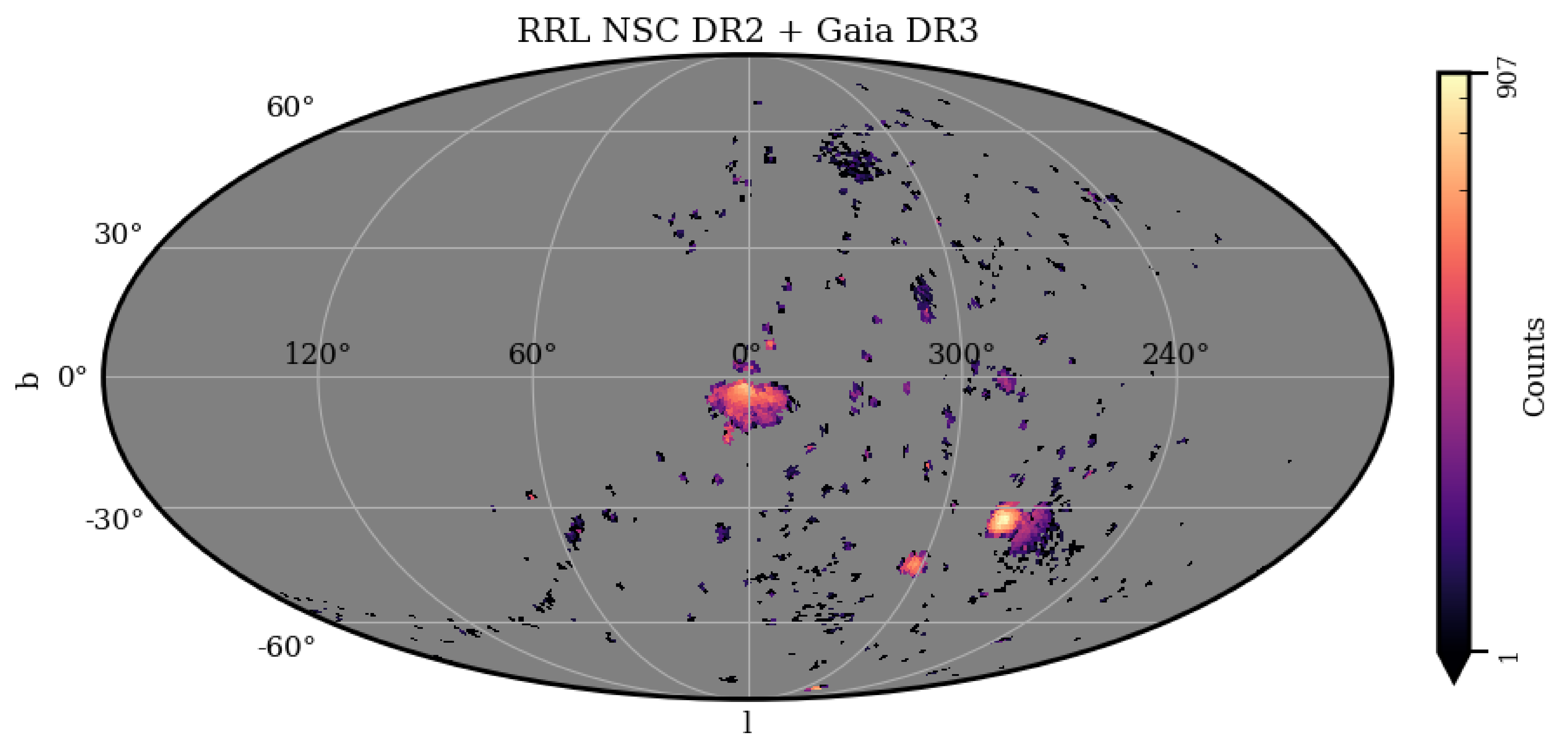
RRLc

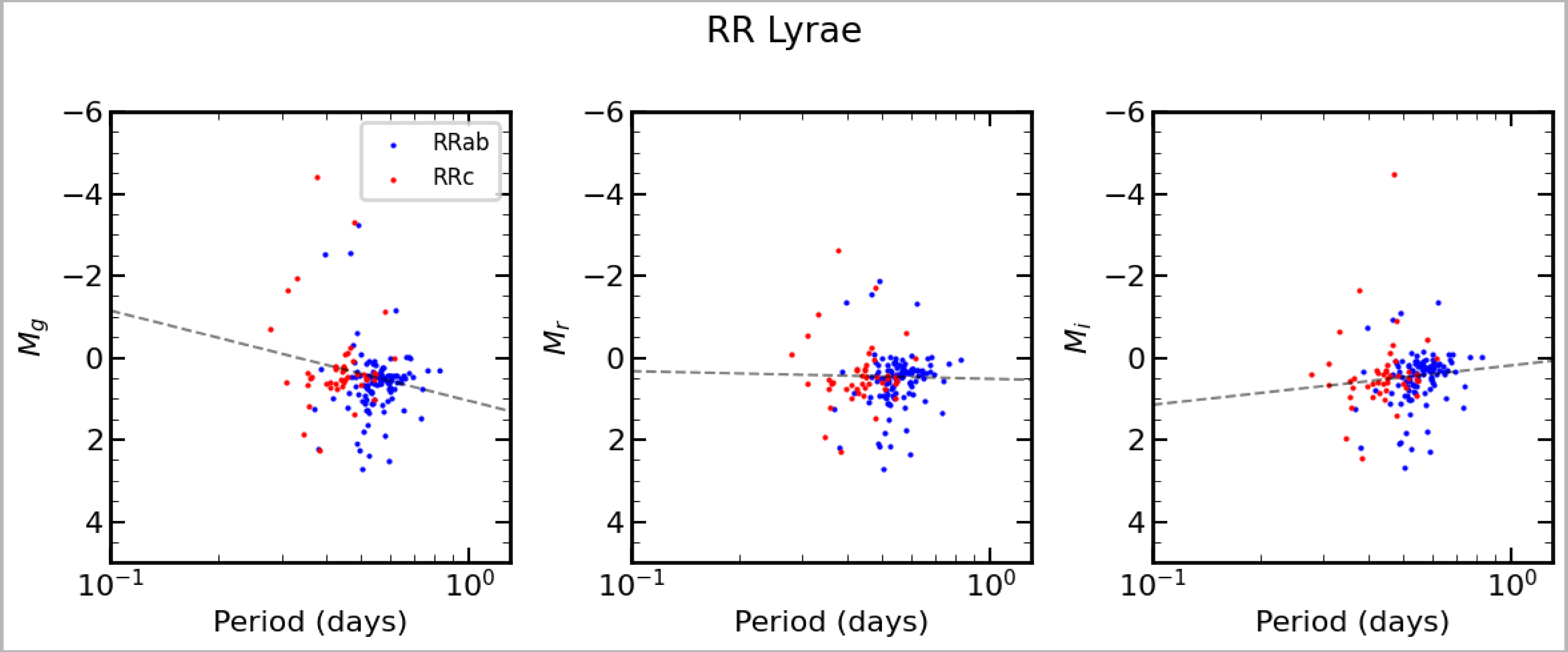
LMC: 4946

SMC: 446

Rest of the sky: 6262

Total: 11654





$$M = a + b\log(P)$$

	a	b
g	1.055	2.204
r	0.517	0.189
i	0.188	-0.963

PRELIMINARY!

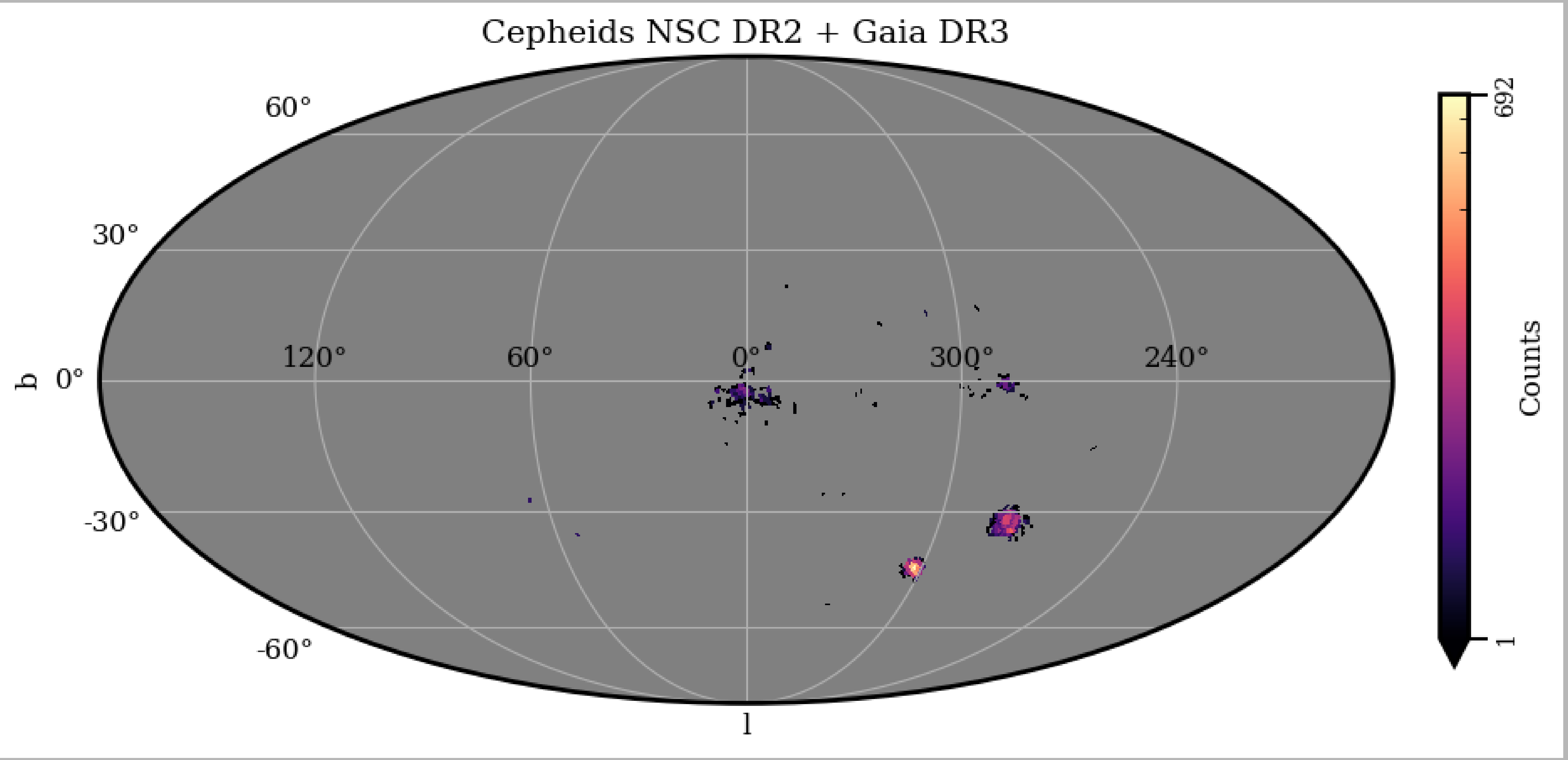
δ Cepheids

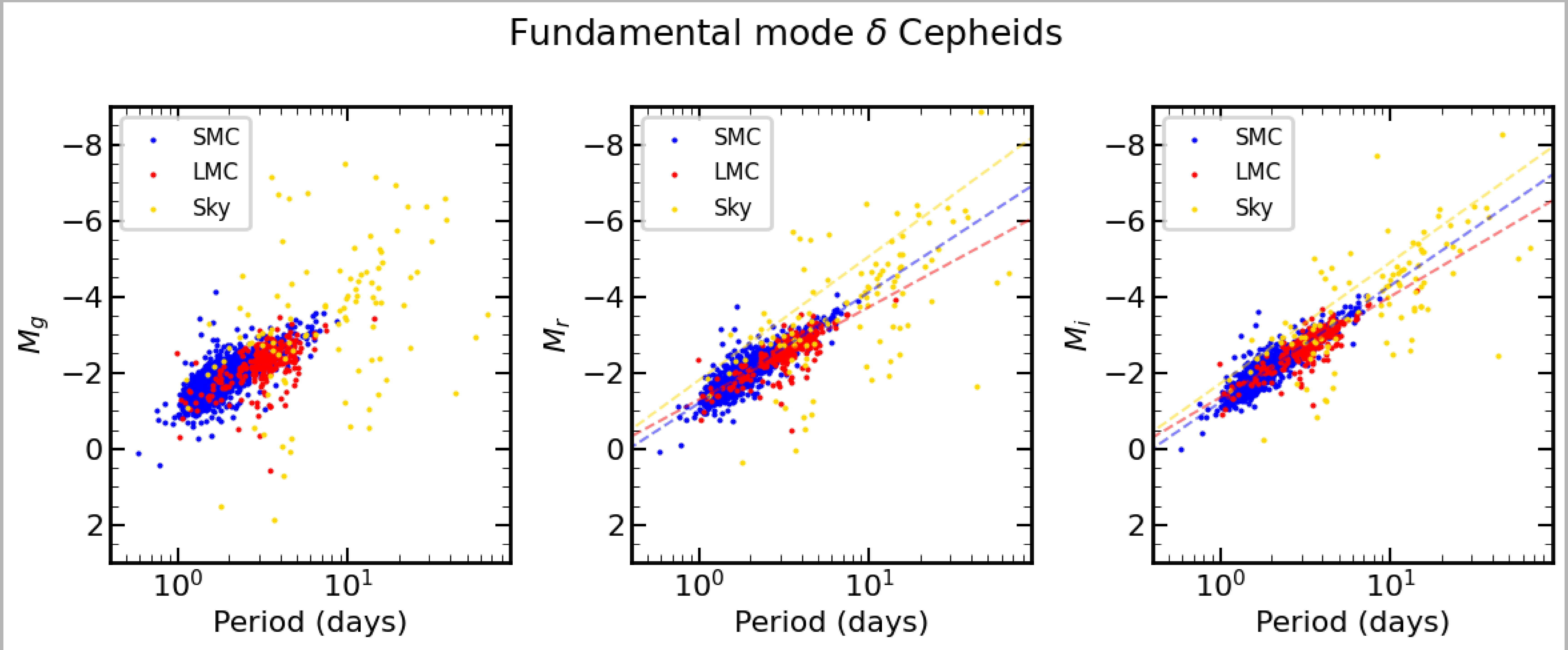
<u>Fundamental δ Cepheids</u>

LMC: 260
SMC: 1358
Rest of the sky: 115
Total: 1733

<u>First overtone δ Cepheids</u>

LMC: 435
SMC: 1109
Rest of the sky: 55
Total: 1599



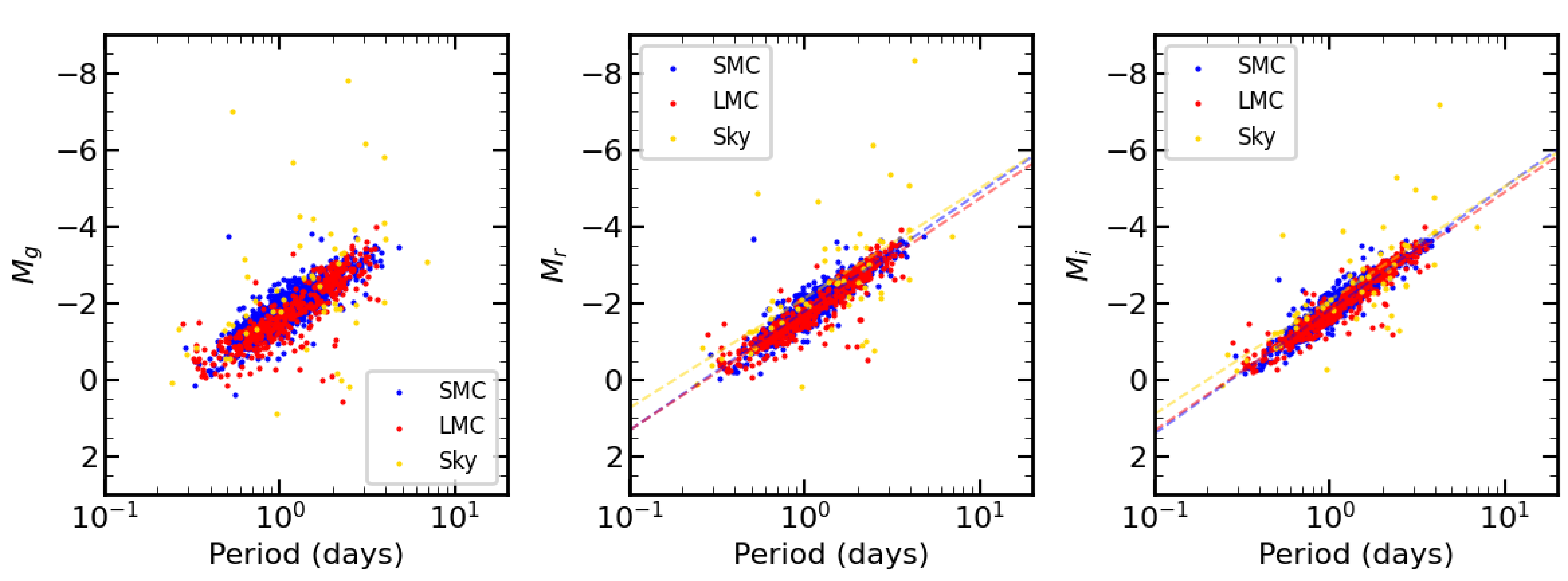


$$M = a + b\log(P)$$

	LMC		SMC		Sky	
	a	b	a	b	a	b
r	-1.292	-2.433	-1.197	-2.919	-1.803	-3.257
i	-1.349	-2.649	-1.221	-3.063	-1.711	-3.184

PRELIMINARY!

First overtone δ Cepheids



$$M = a + b\log(P)$$

	LMC		SMC		Sky	
	a	b	a	b	a	b
r	-1.701	-3.023	-1.785	-3.105	-2.127	-2.865
i	-1.780	-3.111	-1.812	-3.219	-2.067	-2.969

PRELIMINARY!

Future work

- Refine the selection to get more Cepheids for which we can use parallax as a distance estimator
- Improve the template fitting to find better mean magnitudes for the variables
- Extend the analysis to find P-W relations using DECam filters
- Repeat analysis with DR3

Conclusions

- NSC offers a unique opportunity to study variable stars with its many epochs.
- DR3 will offer much more complete and robust data in 2025 onwards.
- Several projects are underway so that in future releases of the NSC we can detect and classify variable sources reliably.
- We are working with NSC DR2 to characterise the main types of variable stars.
- We are ready to provide P-L relations for Cepheids and RRL.

Thank you!