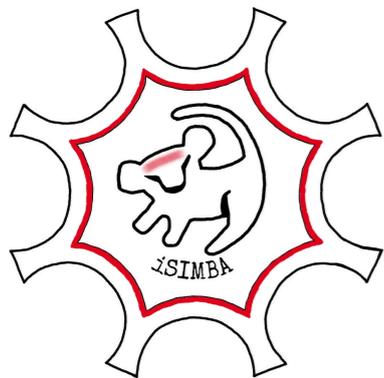


BASTA: the BAYesian STellar Algorithm

Víctor Silva Aguirre

A. Justesen, J. Mosumgaard, C. Sahlholdt, A. Stokholm,
E. Knudstrup, K. Verma, M. Winther, S. Cassisi, and A. Serenelli



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The BAYesian STellar Algorithm

iSIMBA > BASTA > Details



BASTA

Bayesian STellar Algorithm

Star 0 Fork 0 SSH git@gitlab.com:iSIMBA/BASTA.git

Files (14.2 MB) Commits (721) Branches (8) Tags (31) Readme Changelog Contribution guide

master BASTA / History Find file Web IDE



Updated info

Jakob Rørsted Mosumgaard authored 2 days ago

62381ba7

Name	Last commit	Last update
bast	Add lines	4 days ago
docs	Updated names to match examples	3 months ago
.gitignore	Added F2PY to .gitignore	a year ago
BASTAbuild	Changed name from restart to resume	11 months ago
BASTArun	Fit mixed modes using a matching algorithm	a week ago



The BAYesian STellar Algorithm

The rationale behind BASTA



The BAYesian STellar Algorithm

The rationale behind BASTA

- Create the most versatile pipeline for stellar properties determination



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- Fast and flexible in its input: fit any observation available (spectroscopy, photometry, astrometry, asteroseismology) and predict stellar properties



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The Bayesian STellar Algorithm

The rationale behind BASTA

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- Made for the space-based era, where thousands of stars are fitted and not all have the same data available
- Bayesian scheme: calculate joint PDF, report median and (16,84) percentiles, use of priors and weights, etc.



The BAYesian STellar Algorithm

Pipeline widely applied for:

- Exoplanet characterisation e.g., Silva Aguirre et al. 2015, MNRAS
Lundkvist et al. 2016, Nat.Com.
- Asteroseismic fitting e.g., Chaplin et al. 2014, ApJS
Silva Aguirre et al. 2017, ApJ
- Galactic archaeology e.g., Casagrande et al 2016, MNRAS
Silva Aguirre et al. 2018, MNRAS
- Gyrochronology van Saders et al. 2016, Nature
- Cluster studies e.g., Lund et al. 2016, MNRAS
Stello et al. 2016, ApJ
- Parallaxes e.g., Silva Aguirre et al. 2012
Huber et al. 2017



The BAYesian STellar Algorithm

Level of precision



The BAYesian STellar Algorithm

Level of precision

- Seismology:



The BAYesian STellar Algorithm

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 - Radii and distances: ~2%



The BAYesian STellar Algorithm

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The BAYesian STellar Algorithm

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The BAYesian STellar Algorithm

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- Gaia:
 - Even better (we have hit grid resolution)



The BAYesian STellar Algorithm

Grids of models: standard



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- Models freely available: BaSTI isochrones and BaSTI evolutionary tracks



The Bayesian STellar Algorithm

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- Sampling in mass currently $\sim 0.05\text{-}0.1 M_{\text{sun}}$



The BAYesian STellar Algorithm

Grids of models: unique



The BAYesian STellar Algorithm

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- Produce tailor-made grids of evolutionary tracks with GARSTEC and MESA (extensible to any code)



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The BAYesian STellar Algorithm

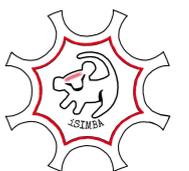
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- Sobol grids: quasi-random number generator to select combination of parameters at a given input physics



The BAYesian STellar Algorithm

Grids of models: flexible



The BAYesian STellar Algorithm

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The BAYesian STellar Algorithm

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$M=0.65;1.8 @ 0.01 M_{\text{sun}}$
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 $DY/DZ = 1.4$
Fixed ove, ml



The BAYesian STellar Algorithm

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The BAYesian STellar Algorithm

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 $Y_i= 0.15;0.40@0.02$
 $ML= 1.5;2.2@0.1$



The BAYesian STellar Algorithm

Grids of models: solar model



The BAYesian STellar Algorithm

Grids of models: solar model

- Ensure consistency between the solar Δv as given by observations and the “solar model” in the grid



The BAYesian STellar Algorithm

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- Ensure consistency between the solar $\Delta\nu$ as given by observations and the “solar model” in the grid
- Basically scales the input $\Delta\nu$ values by the fraction between the observed solar $\Delta\nu$ of the pipeline and that of the “solar model”



The BAYesian STellar Algorithm

Grids of models: solar model

- Ensure consistency between the solar Δv as given by observations and the “solar model” in the grid
- Basically scales the input Δv values by the fraction between the observed solar Δv of the pipeline and that of the “solar model”
- If the grids do not have diffusion, one solar property cannot be reproduced (e.g., age)



The BAYesian STellar Algorithm

Grids of models: general considerations



The BAYesian STellar Algorithm

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- Once your grid is computed and processed, there are ~160 properties that can be fitted/extracted



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The BAYesian STellar Algorithm

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The BAYesian STellar Algorithm

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The BAYesian STellar Algorithm

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- Standardised visual output to easily interpret results
- Possibility of store full PDFs of your fits for each star

The Bayesian STellar Algorithm

Grids of models: general considerations

BASTA
0.15.1

Search docs

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Description of library parameters

Fitting model parameters to data

Fitting to individual frequencies or frequency ratios

Technical documentation

[Docs](#) » Description of library parameters

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Description of library parameters

The following table lists all of the parameters included in the model libraries. The column named **In** indicates which libraries contain the given parameter. The keys are G for Garstec, B for Basti, and S for the solar models. The solar model parameters are the same for both Garstec and Basti libraries.

Name	Unit	In	Description
name	None	G	Name of the model fgong-file
modnum	None	G	Model number from Garstec.
Gconst	cm3/gs2	G,B,S	Gravitational constant.
LPhot	solar	G,B,S	Photospheric luminosity.
radPhot	solar	G,B,S	Photospheric radius.
radTot	solar	G,S	Total radius.
massini	solar	G,B	Initial mass.
massfin	solar	G,B,S	Final mass. This is the mass at the current age.
age	Myr	G,B,S	Age.
Teff	K	G,B,S	Effective temperature.
rho	g/cm3	G,B,S	Mean density.
logg	log10(cm/s2)	G,B,S	Surface gravity.
FeH	dex	G,S	Surface iron abundance [Fe/H] (equal to MeH in the case of no ...)
MeH	dex	G,B,S	Surface metallicity [M/H].
alphaFe	dex	G,B,S	Alpha enhancement.
FeHini	dex	G	Initial [Fe/H]
MeHini	dex	G	Initial [M/H]



The Bayesian STellar Algorithm

Scaling relations

$$\left(\frac{\rho}{\rho_{\odot}} \right) \simeq \left(\frac{\langle \Delta v_{nl} \rangle}{\langle \Delta v_{nl} \rangle_{\odot}} \right)^2$$

$$\left(\frac{g}{g_{\odot}} \right) \simeq \left(\frac{v_{\max}}{v_{\max, \odot}} \right) \left(\frac{T_{\text{eff}}}{T_{\text{eff}, \odot}} \right)^{0.5}$$

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Scaling relations: corrections



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Scaling relations: corrections

- 4 different versions of the scaling relations available:



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The BAYesian STellar Algorithm

Scaling relations: corrections

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 - $\Delta\nu$ and ν_{\max} corrected following Sharma et al. 2016

The BAYesian STellar Algorithm

Main sequence stars: frequencies



The Bayesian STellar Algorithm

Main sequence stars: frequencies

- Fit individual frequencies using Kjeldsen et al. 2008 or Ball & Gizon 2014



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The BAYesian STellar Algorithm

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- Fit frequency ratios using 5-point differences



The BAYesian STellar Algorithm

Main sequence stars: frequencies

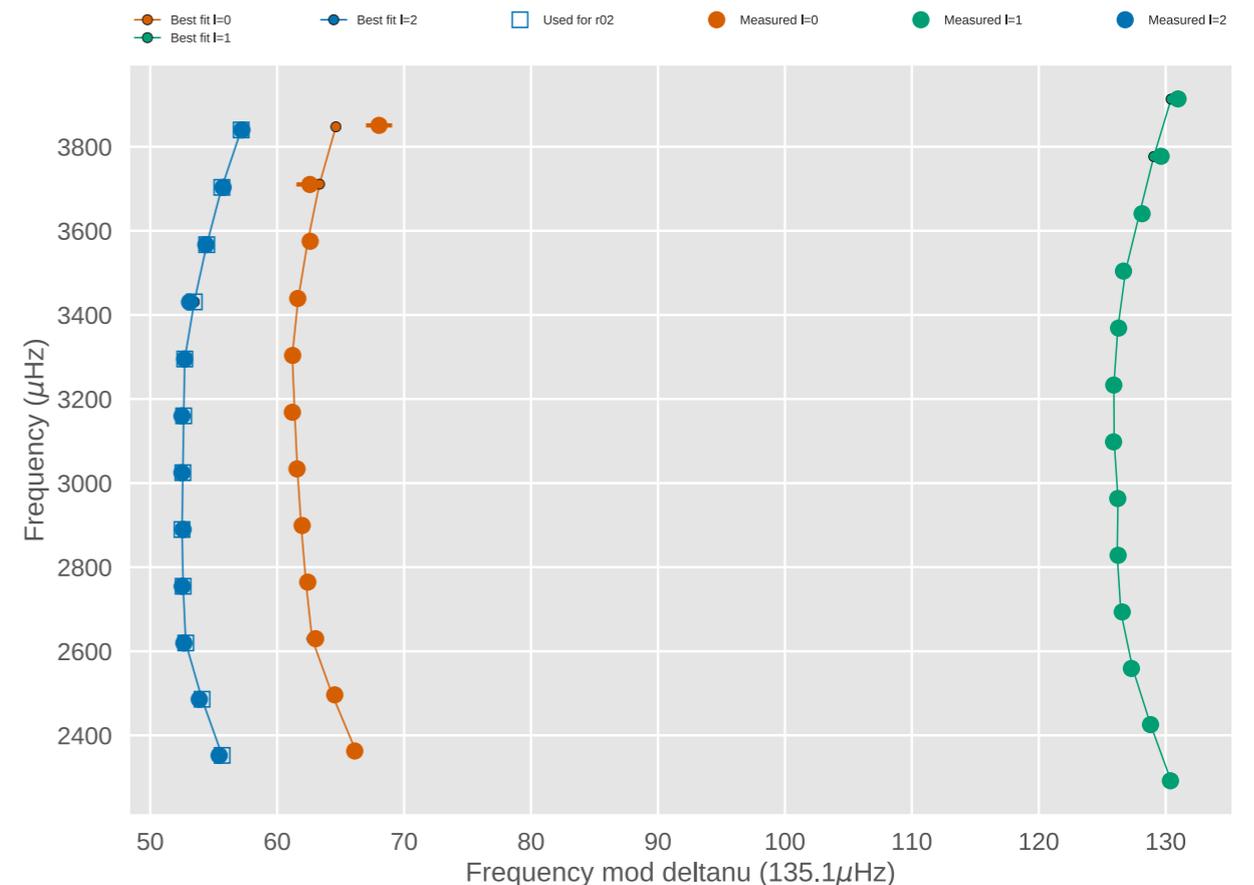
- Fit individual frequencies using Kjeldsen et al. 2008 or Ball & Gizon 2014
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The Bayesian STellar Algorithm

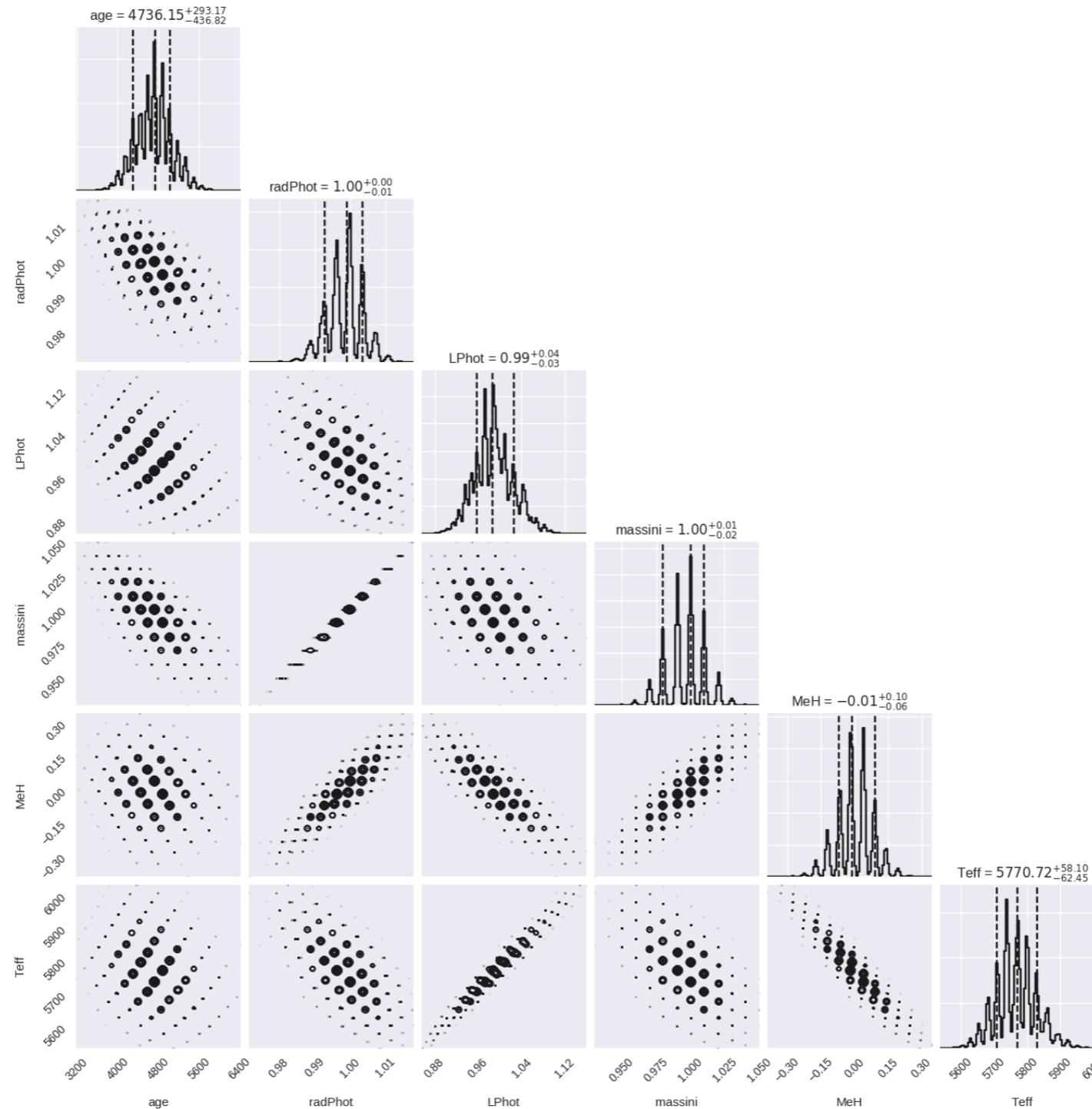
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The Bayesian STellar Algorithm

Main sequence stars: frequencies



The BAYesian STellar Algorithm

Main sequence stars: glitches



The BAYesian STellar Algorithm

Main sequence stars: glitches

- Fit frequencies directly using 3 components: one smooth and two oscillatory



The Bayesian STellar Algorithm

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- Allows extraction of the base of the convection envelope and amplitude of helium signature



The Bayesian STellar Algorithm

Main sequence stars: glitches

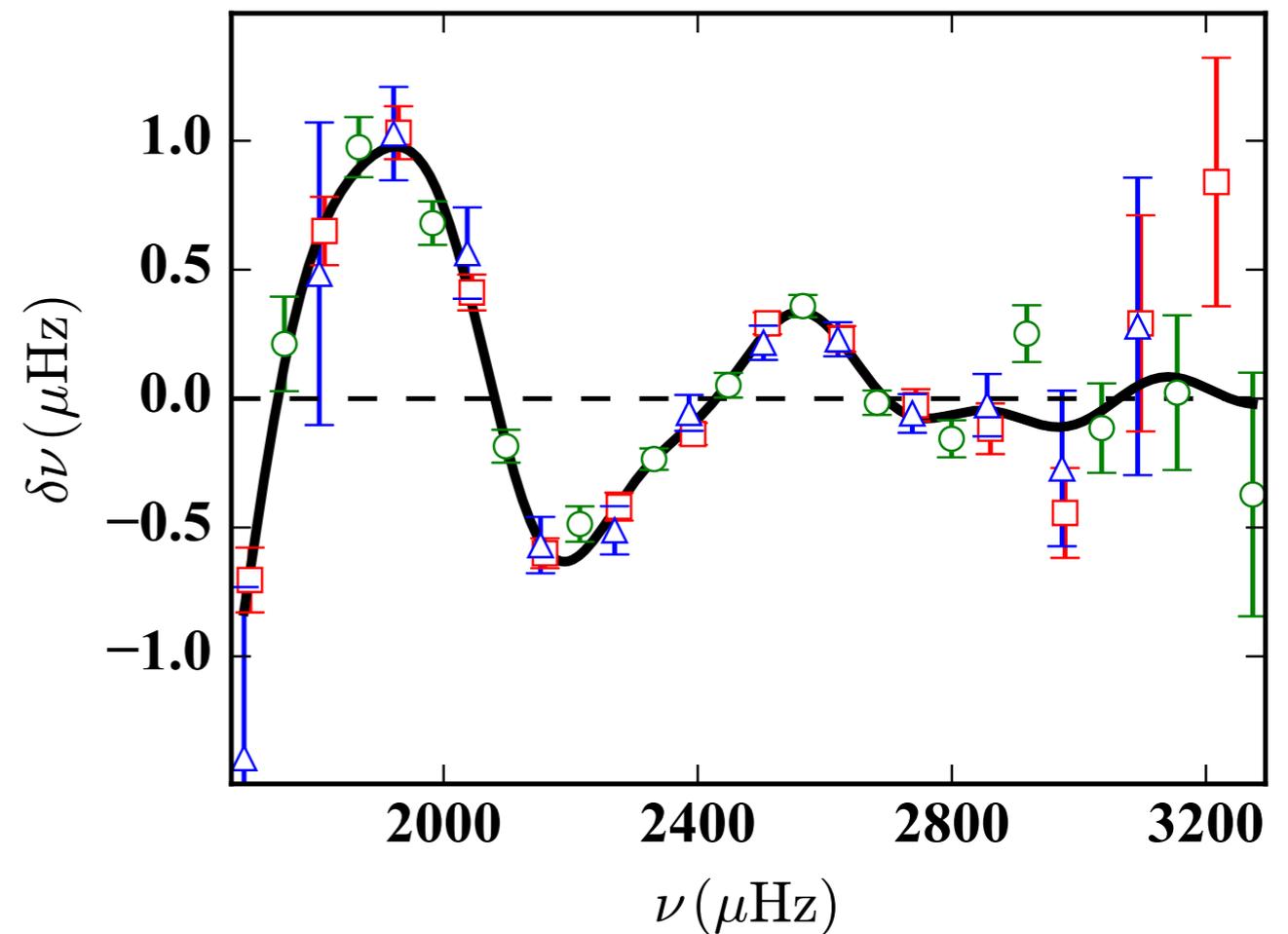
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- Used for determining surface abundances in 36 LEGACY stars (Verma et al. 2018, in prep)



The Bayesian STellar Algorithm

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Verma et al. 2014, 2018

The BAYesian STellar Algorithm

Mixed modes in subgiants

Stokholm et al. 2018, in prep



The BAYesian STellar Algorithm

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- BASTA automatically identifies mixed modes present in the observed frequencies

Stokholm et al. 2018, in prep



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Stokholm et al. 2018, in prep



The BAYesian STellar Algorithm

Mixed modes in subgiants

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- Current grid sampling is adequate to follow mixed-modes evolution

Stokholm et al. 2018, in prep



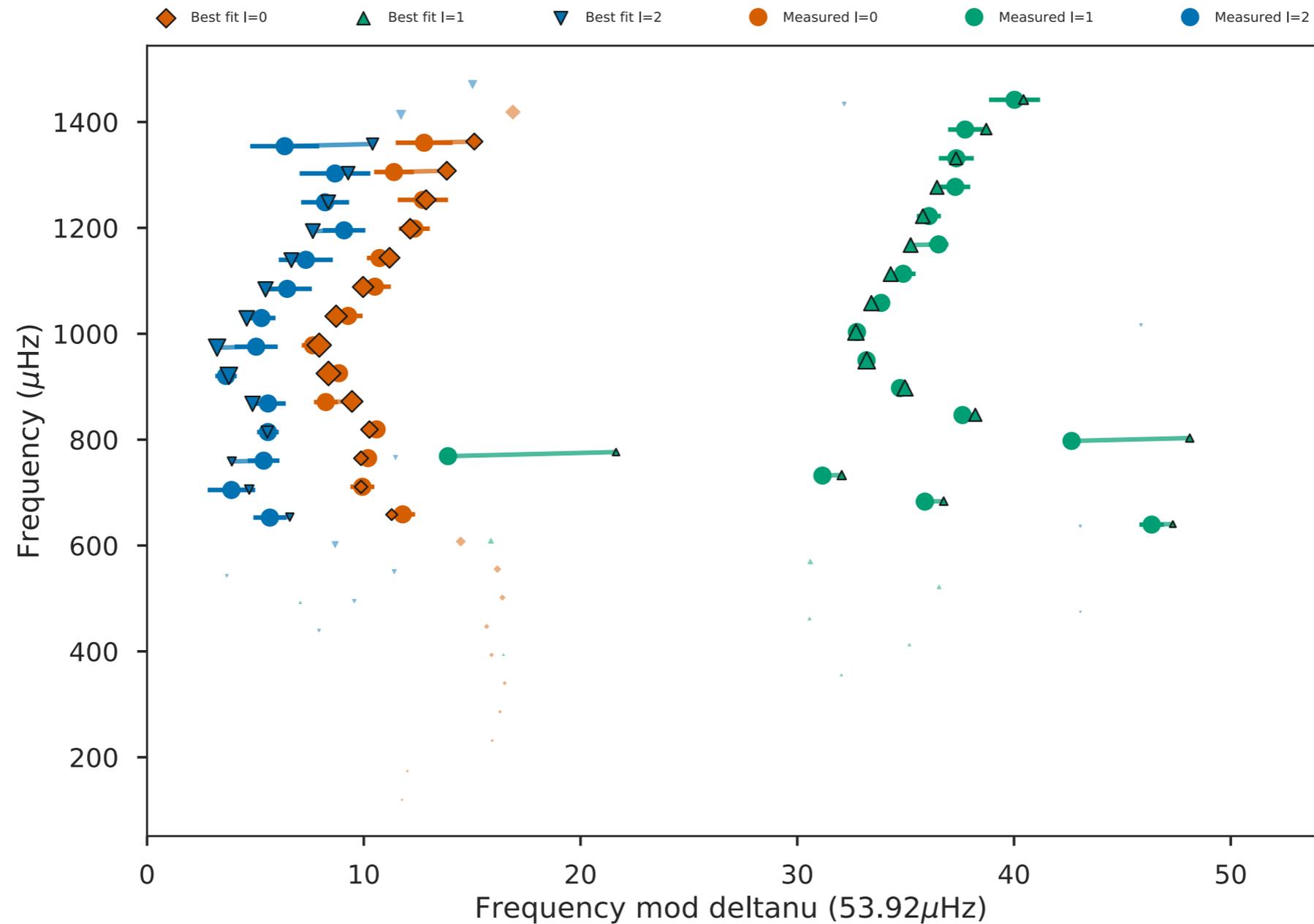
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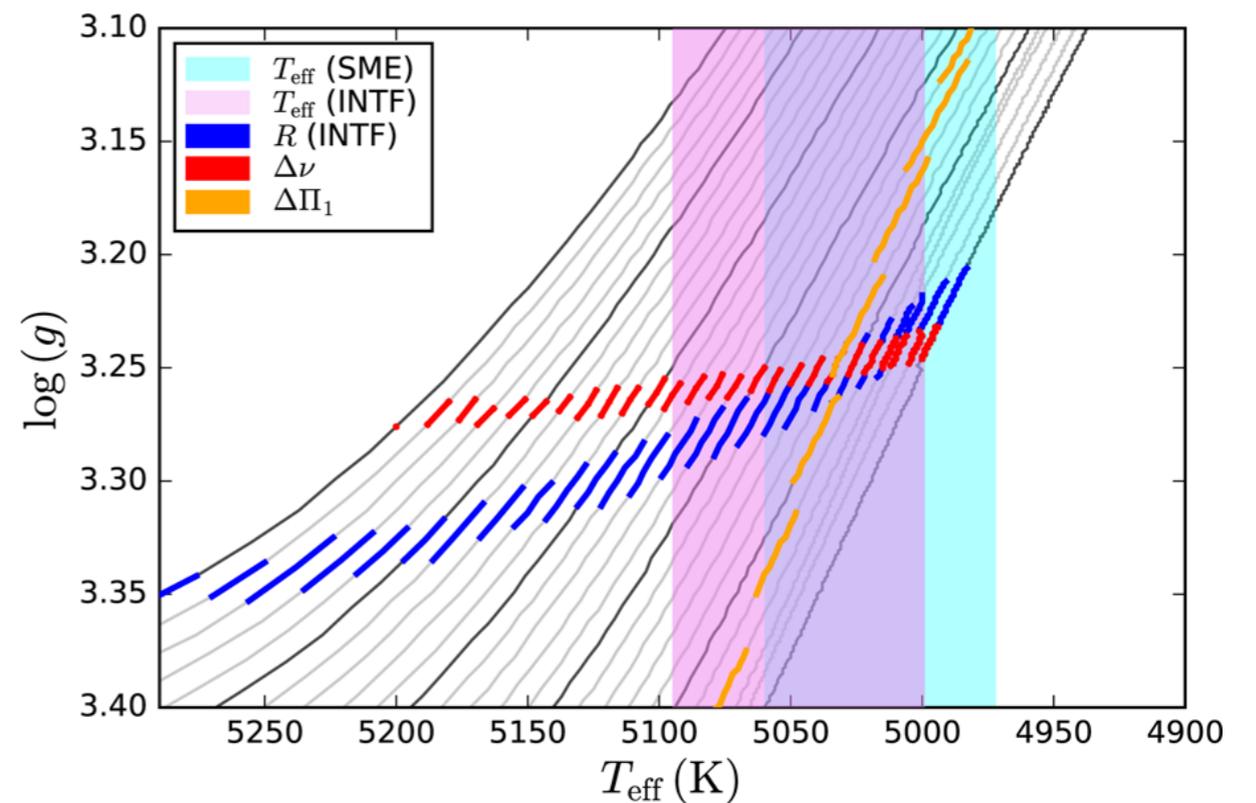
The Bayesian STellar Algorithm

Mixed modes in subgiants



The Bayesian STellar Algorithm

Period spacing

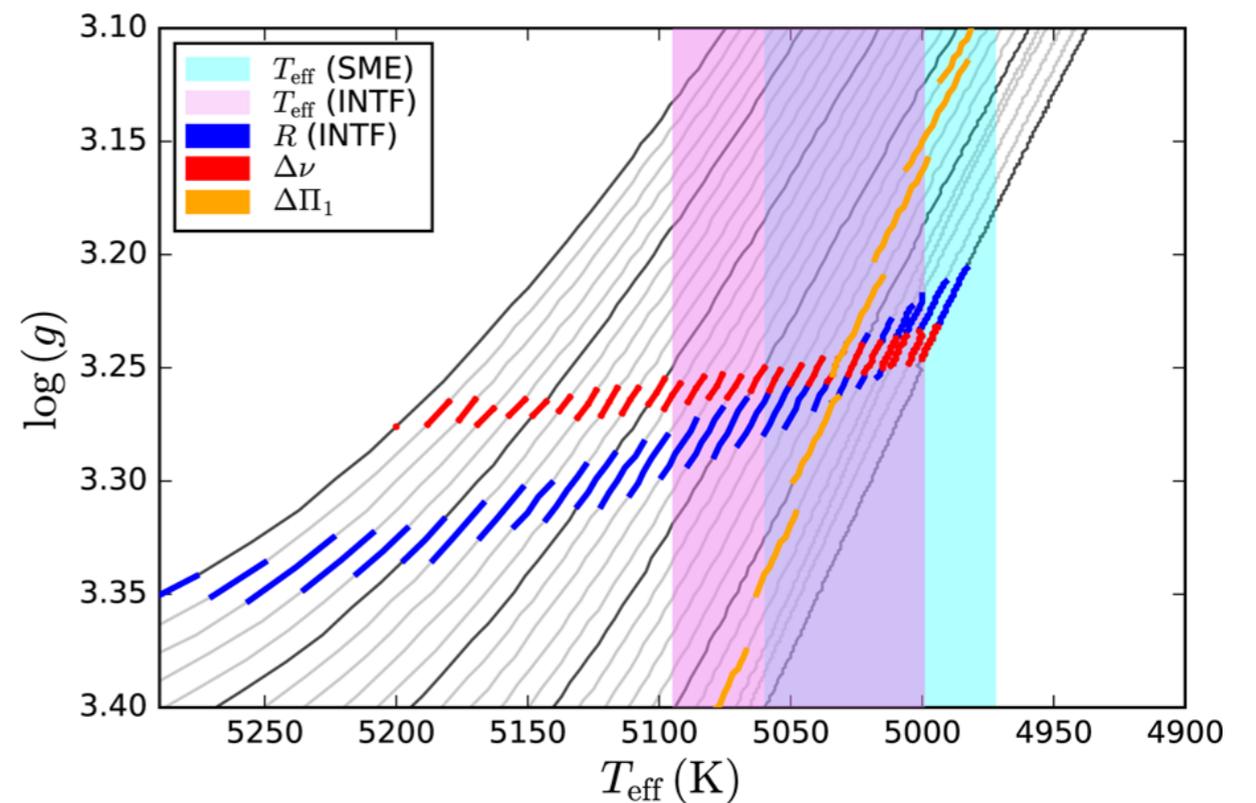


Hjørringgaard et al. 2017, MNRAS

The BAYesian STellar Algorithm

Period spacing

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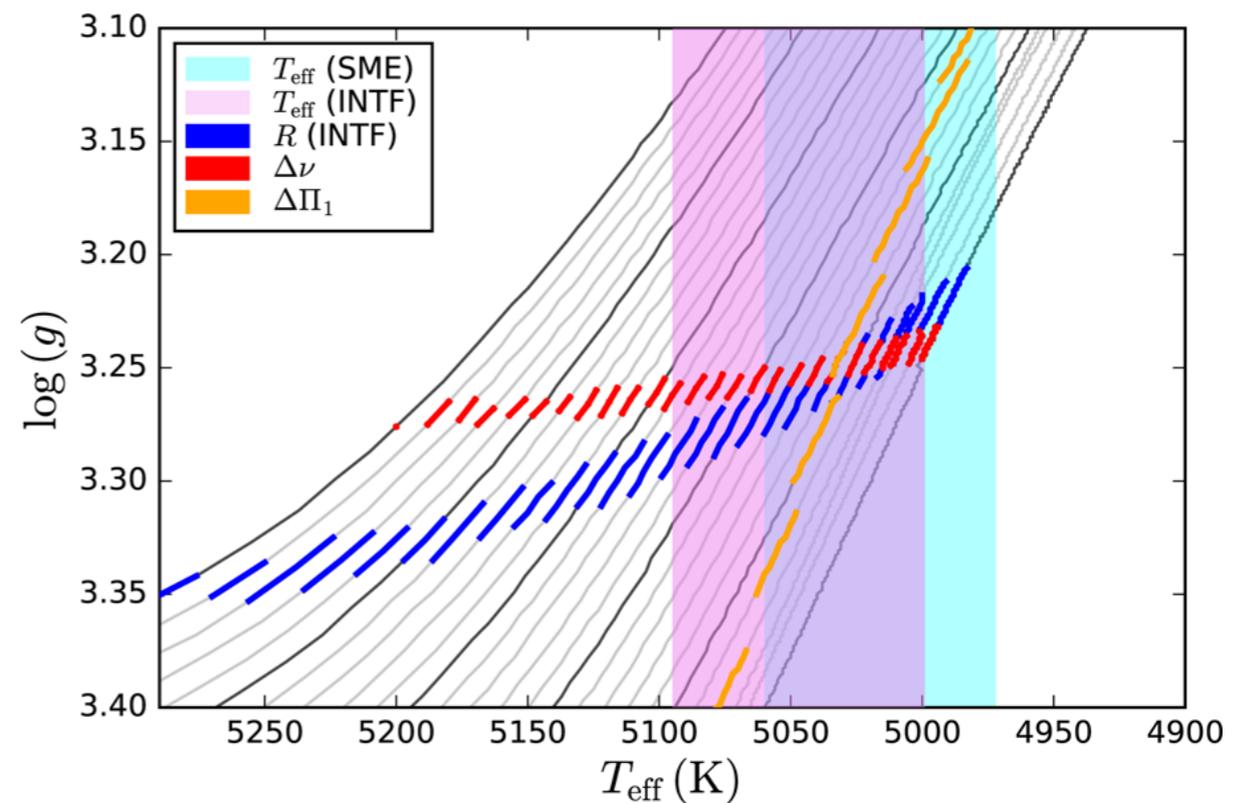


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The BAYesian STellar Algorithm

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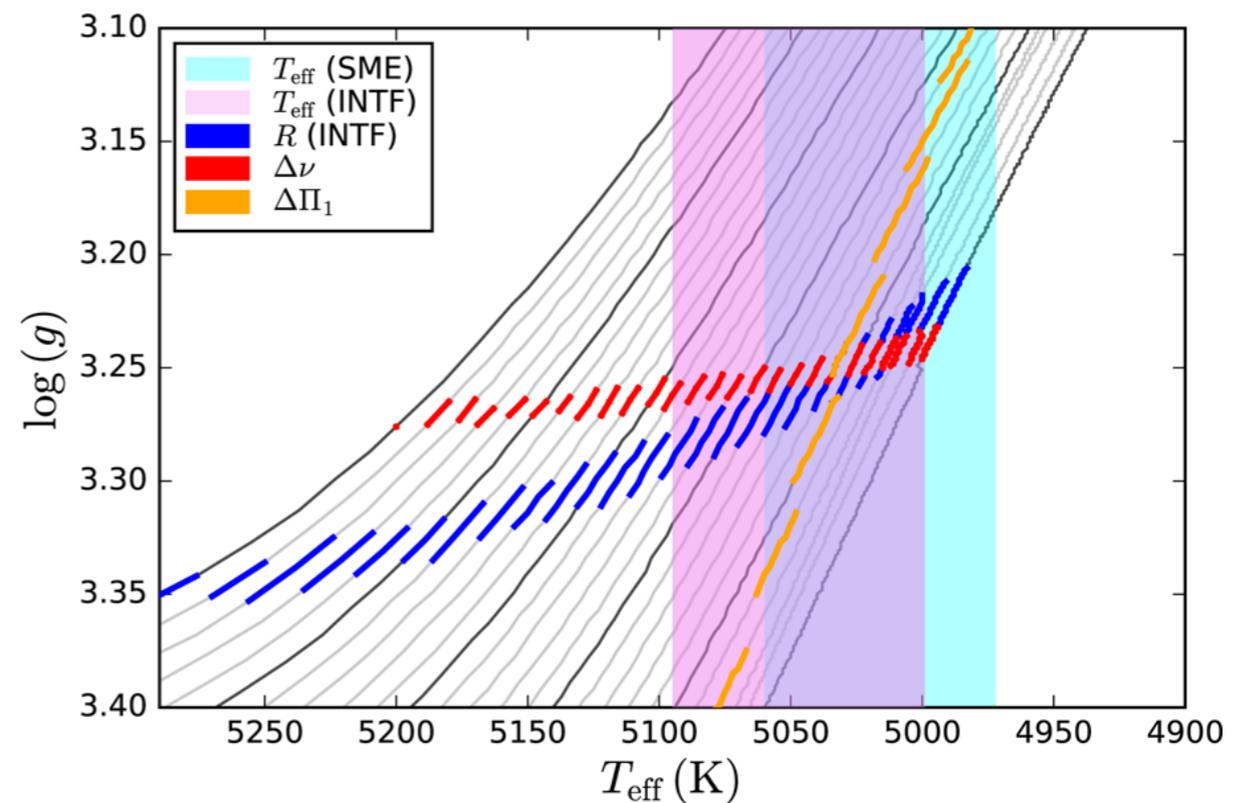


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The Bayesian STellar Algorithm

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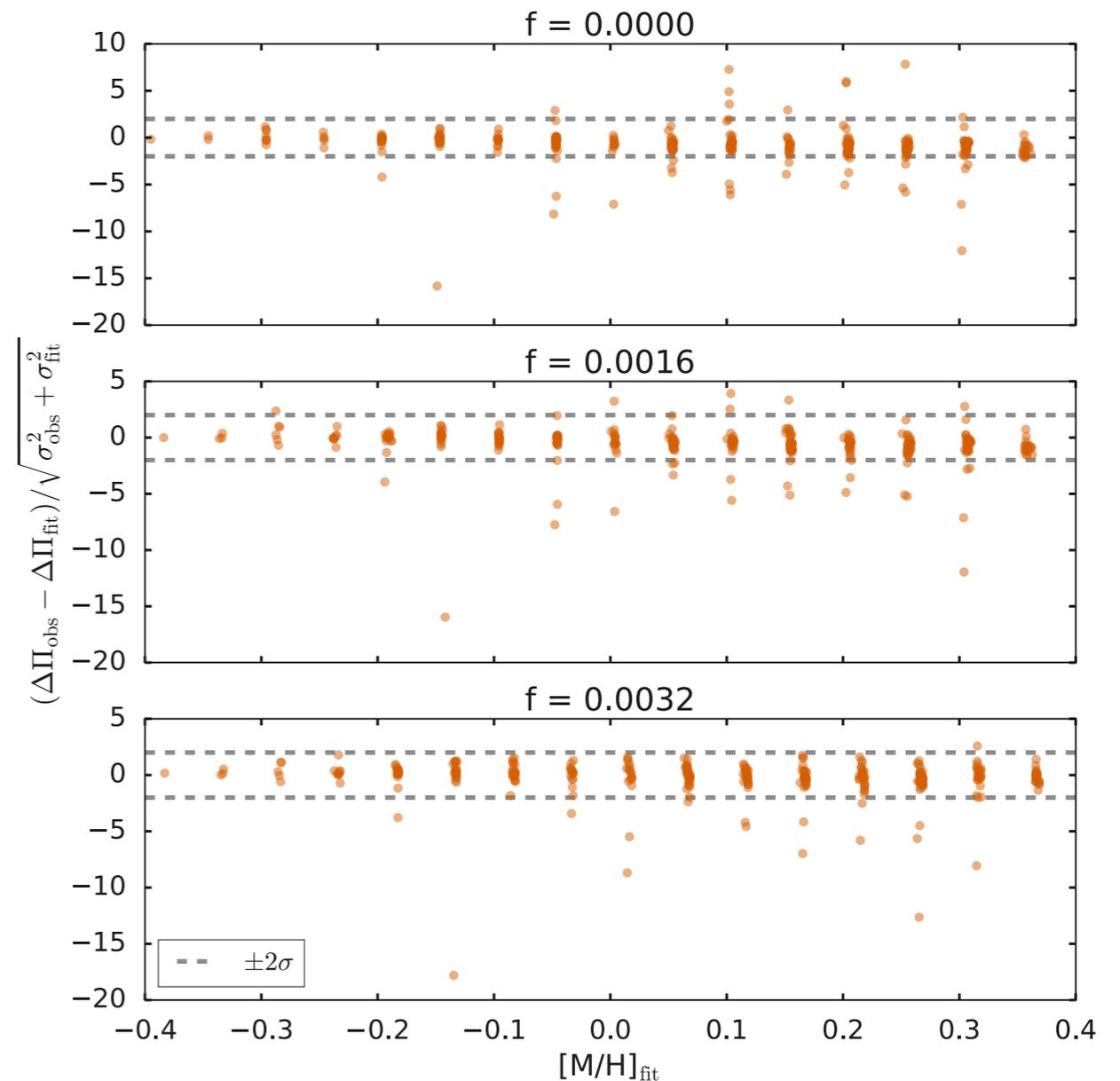


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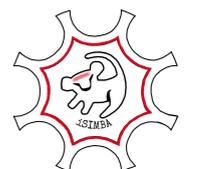
The BAYesian STellar Algorithm

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Winther et al. 2018, in prep



The BAYesian STellar Algorithm

Photometry, spectroscopy, astrometry



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Photometry, spectroscopy, astrometry

- Fit to photometric measurements in many bands



The BAYesian STellar Algorithm

Photometry, spectroscopy, astrometry

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The BAYesian STellar Algorithm

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The BAYesian STellar Algorithm

Photometry, spectroscopy, astrometry

- Fit to photometric measurements in many bands
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- Use of Green et al. 2018 3D extinction map
- Absorption coefficients from Schlafly & Finkbeiner (2011)
- Fit Gaia parallaxes (plus one magnitude)



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Photometry: ~110 filters

Photometric system	Calibration	Passbands	Zero-points
<i>UBVRIJHKLM</i>	Vegamag	Bessell & Brett (1988); Bessell (1990)	Bessell et al. (1998)
<i>HST-WFPC2</i>	Vegamag	SYNPHOT	SYNPHOT
<i>HST-WFC3</i>	Vegamag	SYNPHOT	SYNPHOT
<i>HST-ACS</i>	Vegamag	SYNPHOT	SYNPHOT
2MASS	Vegamag	Cohen et al. (2003)	Cohen et al. (2003)
DECam	ABmag	DES collaboration	0
<i>Gaia</i>	Vegamag	Jordi et al. (2010) ^a	Jordi et al. (2010)
<i>JWST-NIRCam</i>	Vegamag	<i>JWST</i> User Documentation ^b	SYNPHOT
SAGE	ABmag	SAGE collaboration	0
Skymapper	ABmag	Bessell et al. (2011)	0
Sloan	ABmag	Fukugita et al. (1996)	Dotter et al. (2008)
Strömgren	Vegamag	Maíz Apellániz (2006)	Maíz Apellániz (2006)
VISTA	Vegamag	ESO	González-Fernández et al. (2017)

Hidalgo et al. 2018, ApJ

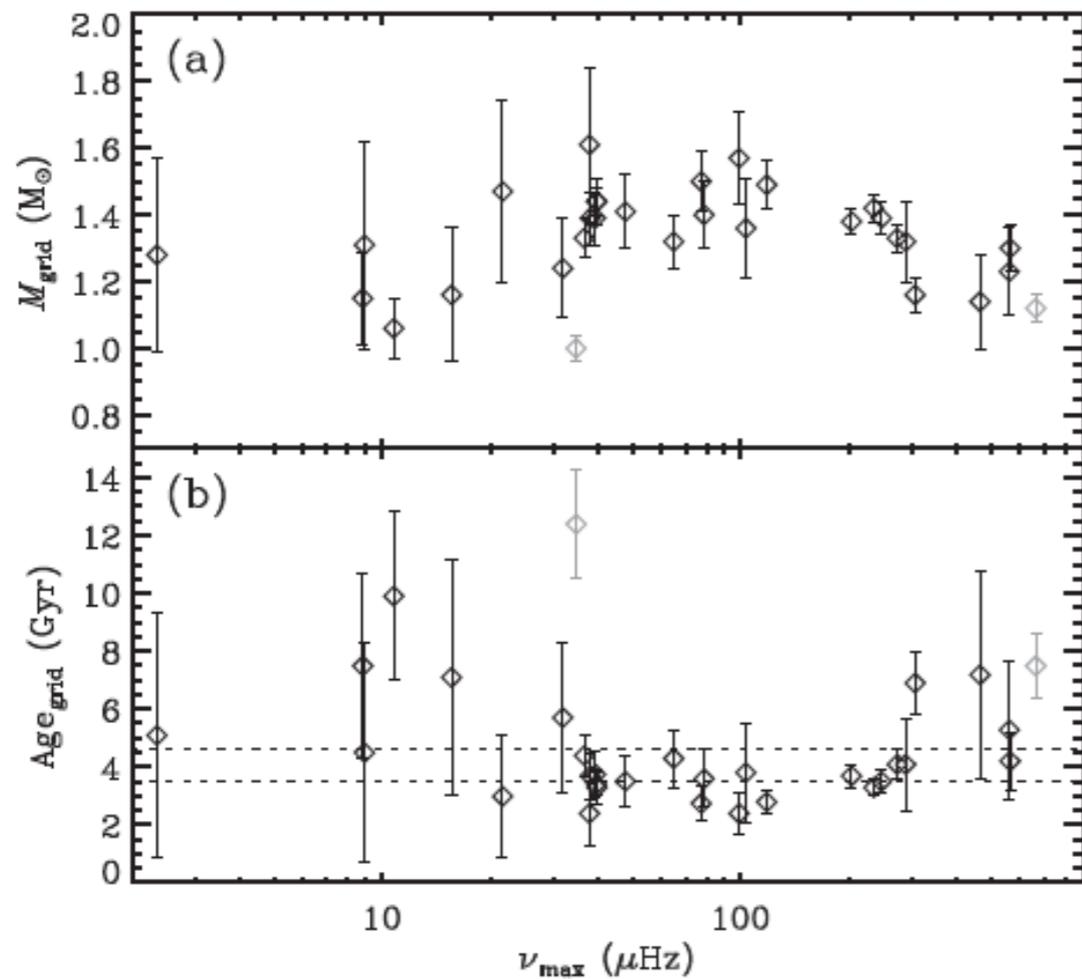


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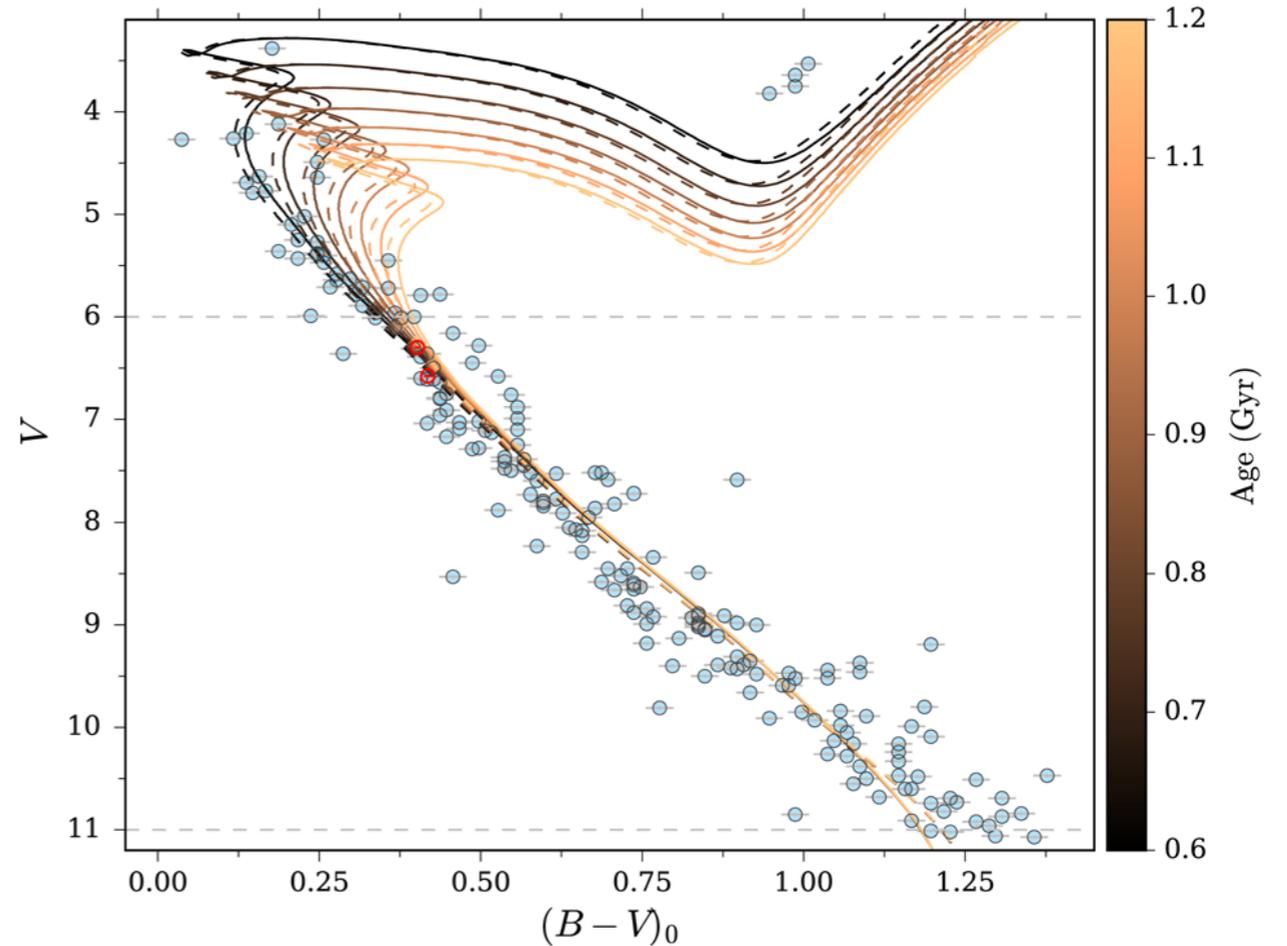
Photometry, spectroscopy, astrometry

M67

Hyades



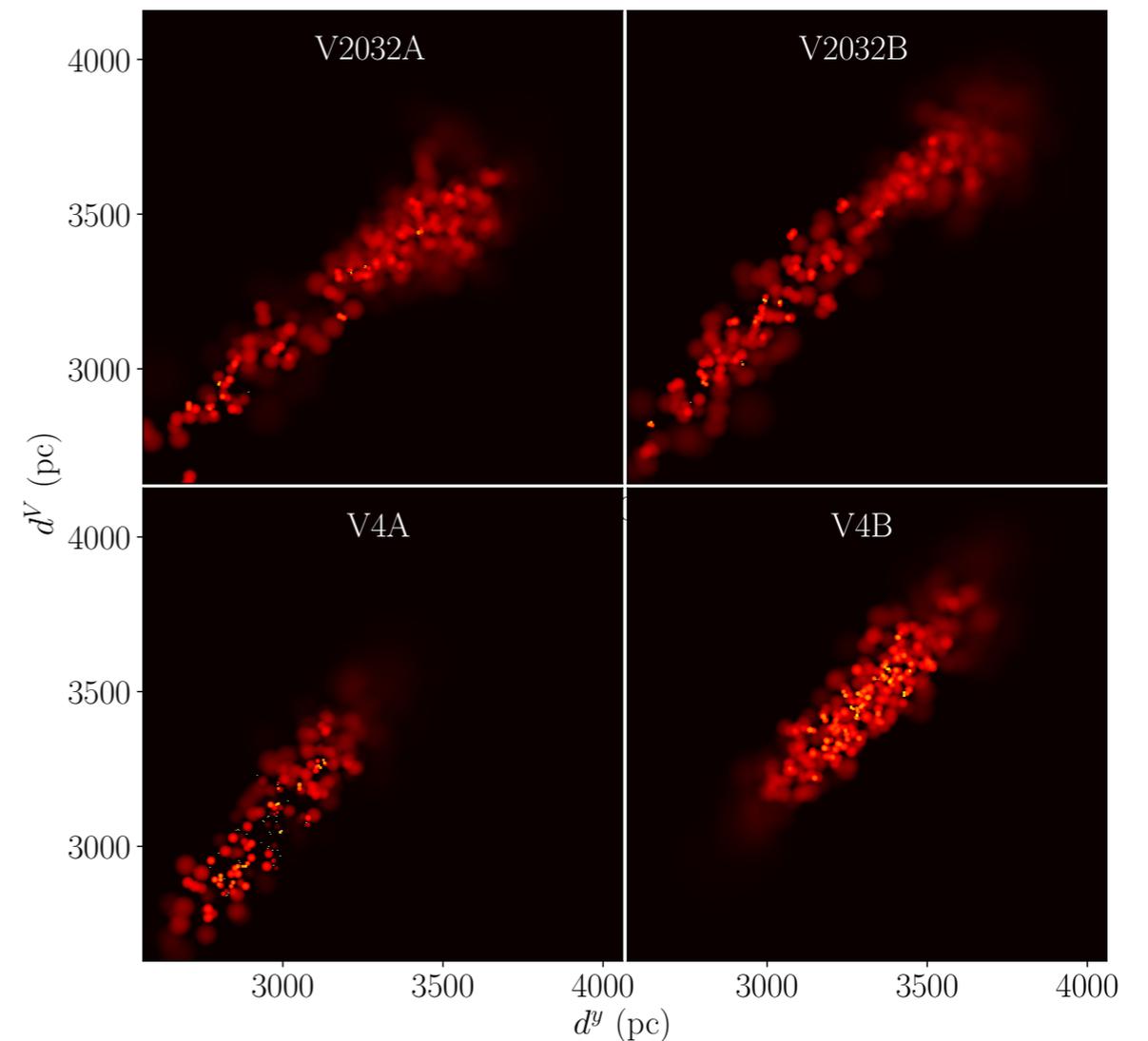
Stello et al. 2017, ApJ



Lund et al 2016, MNRAS

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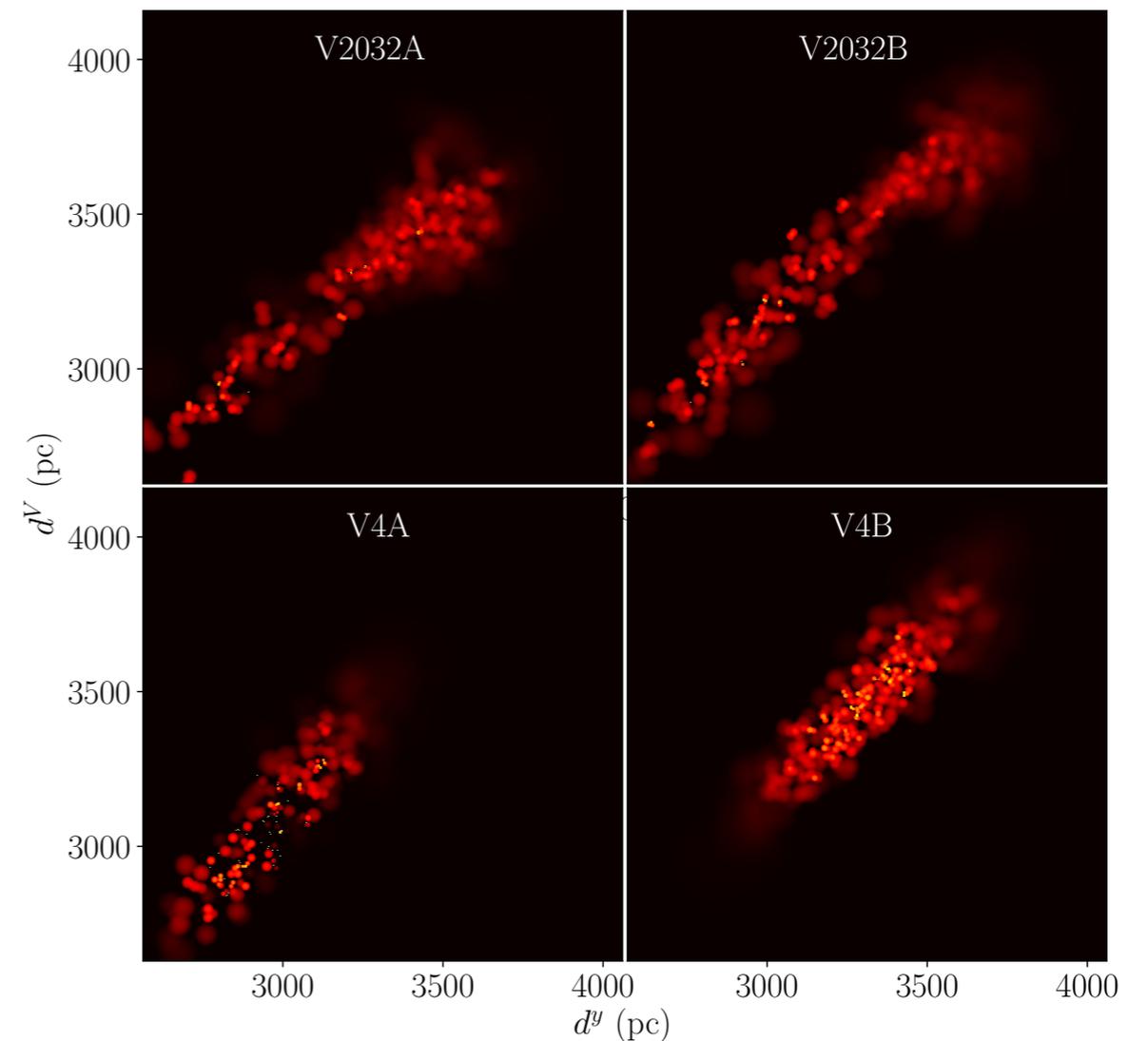
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Photometry, spectroscopy, astrometry

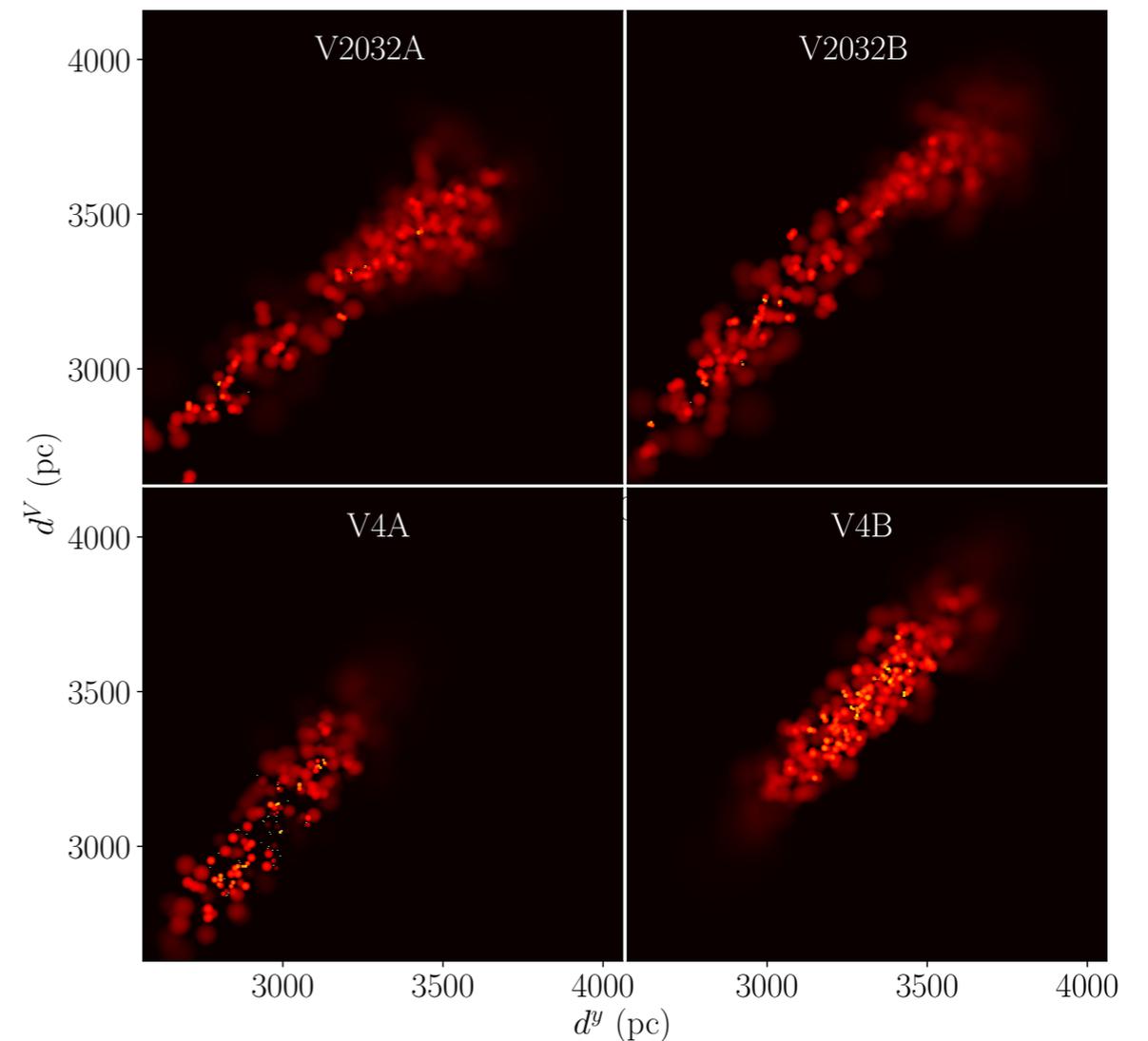
- Binaries in NGC2506



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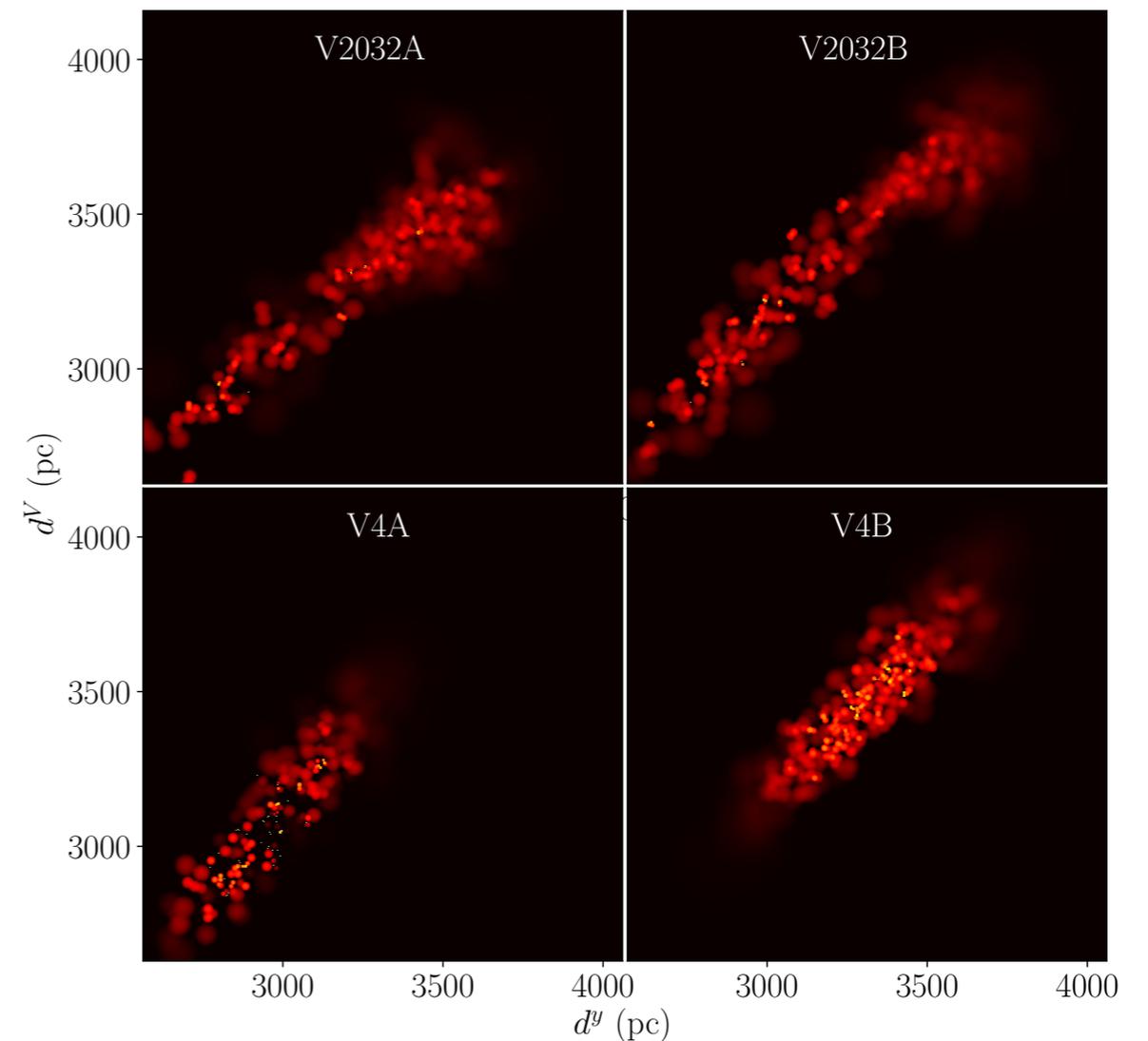
- Binaries in NGC2506
- Fitting masses and radii from binary solution, spectroscopic parameters, and two magnitudes



The Bayesian STellar Algorithm

Photometry, spectroscopy, astrometry

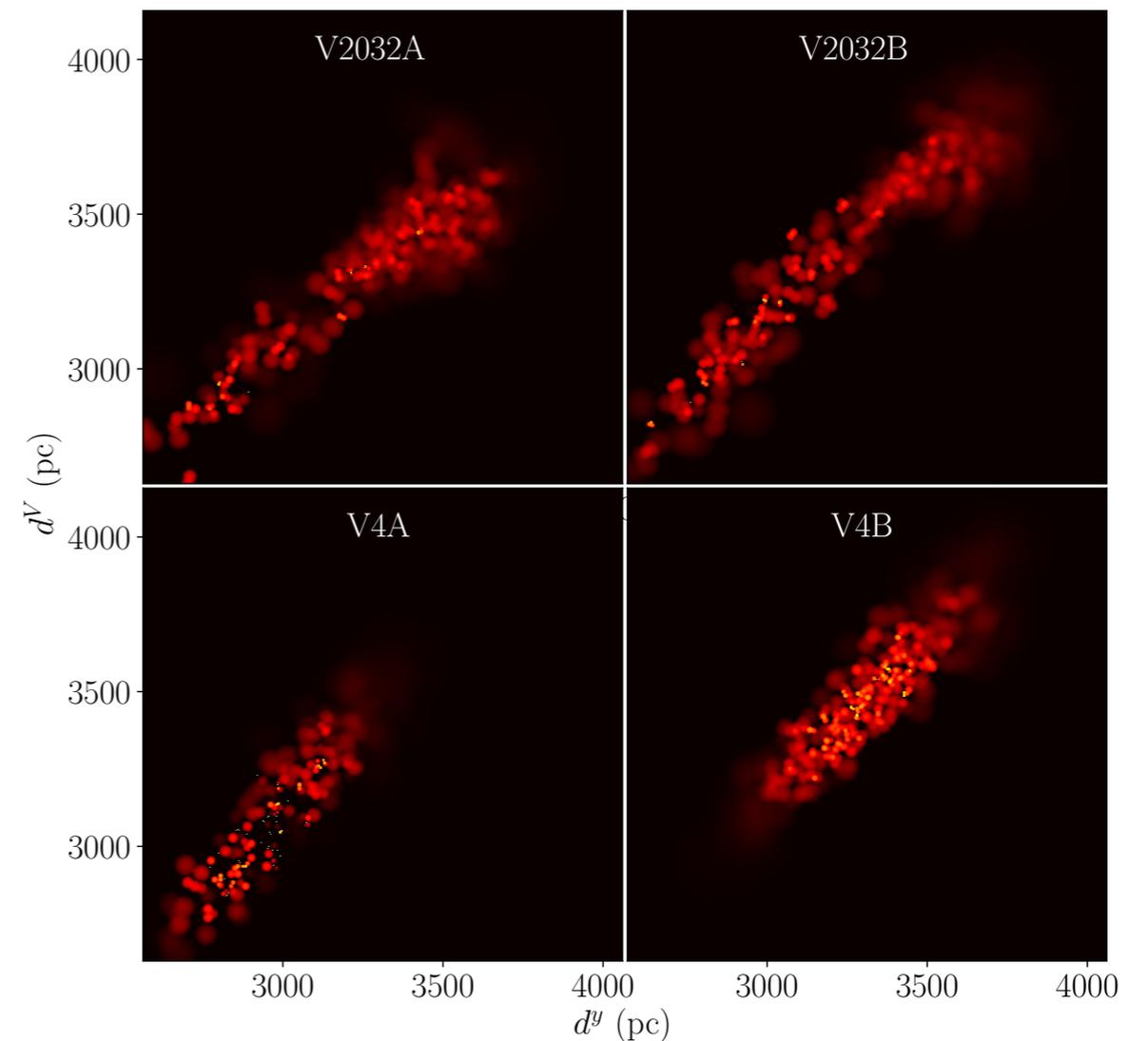
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- Weighted average of the four distances: (3300 ± 70) pc.



The BAYesian STellar Algorithm

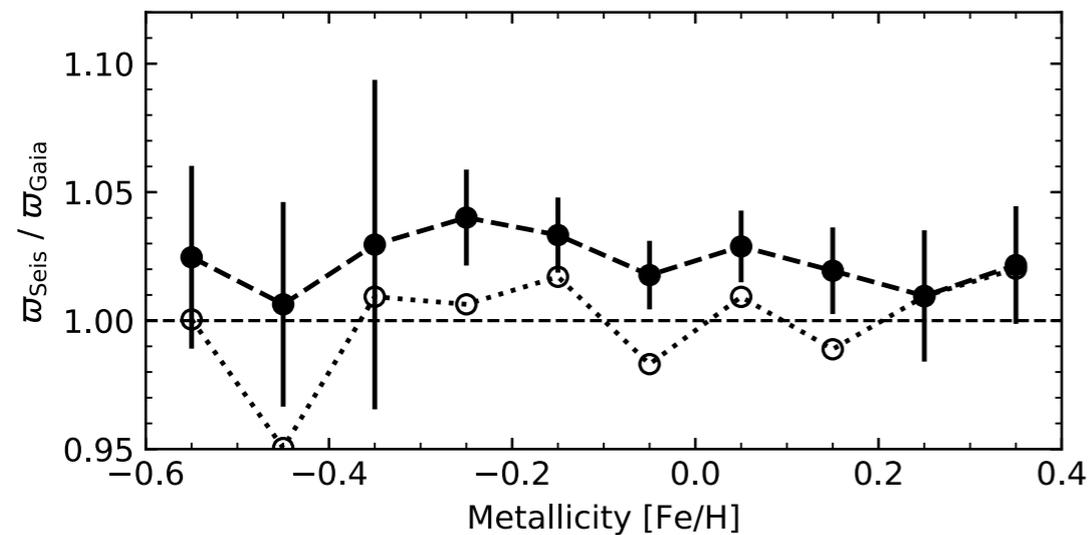
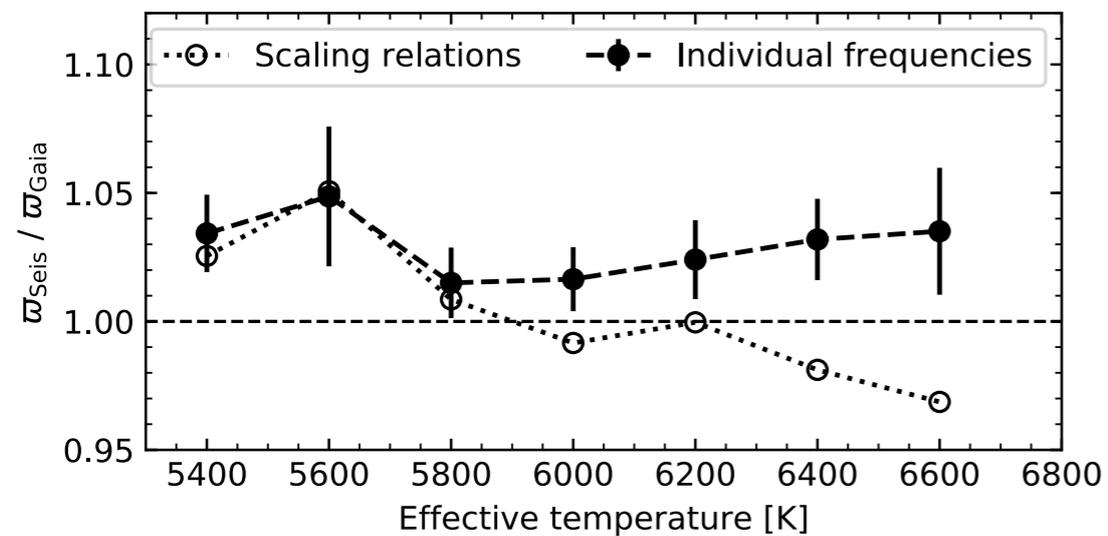
Photometry, spectroscopy, astrometry

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- Gaia: (3340 ± 80) pc



The Bayesian STellar Algorithm

Photometry, spectroscopy, astrometry

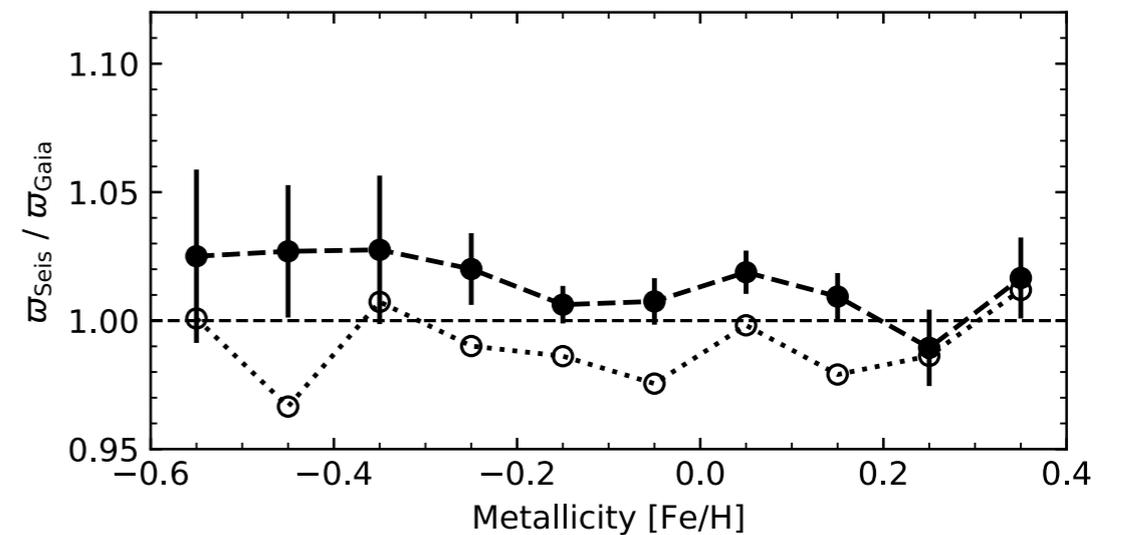
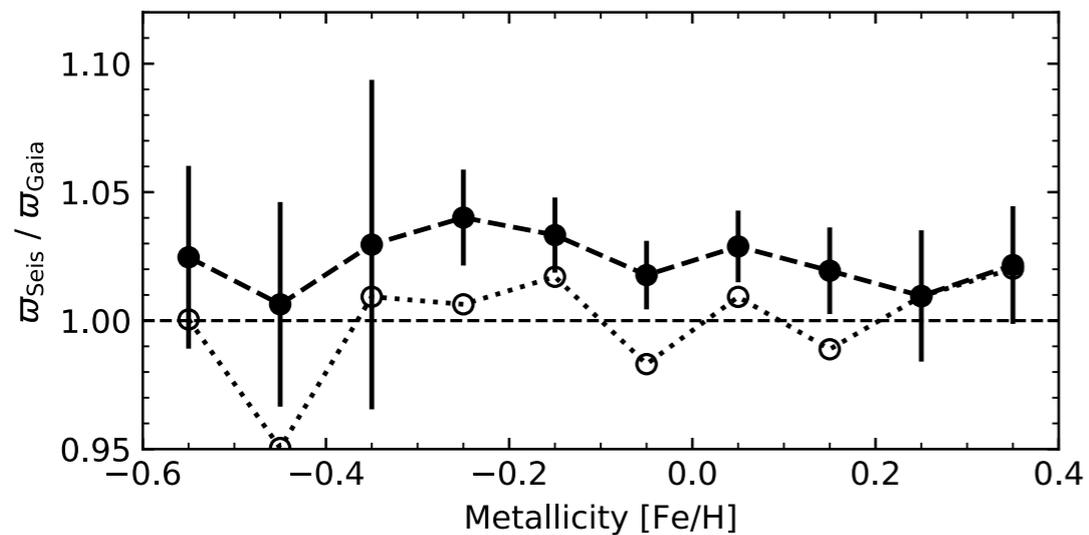
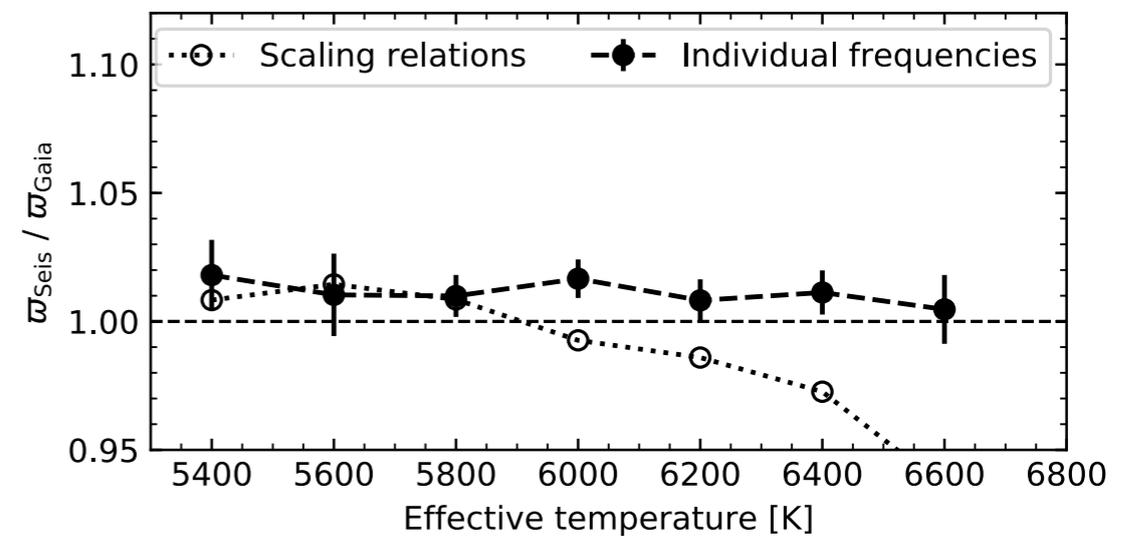
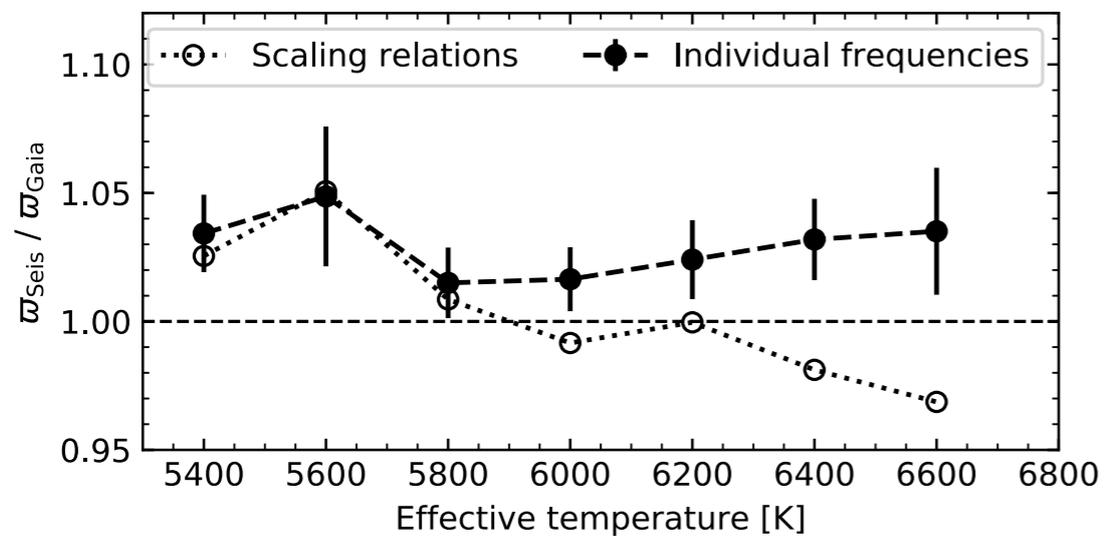


Sahlholdt et al. 2018, MNRAS



The Bayesian STellar Algorithm

Photometry, spectroscopy, astrometry



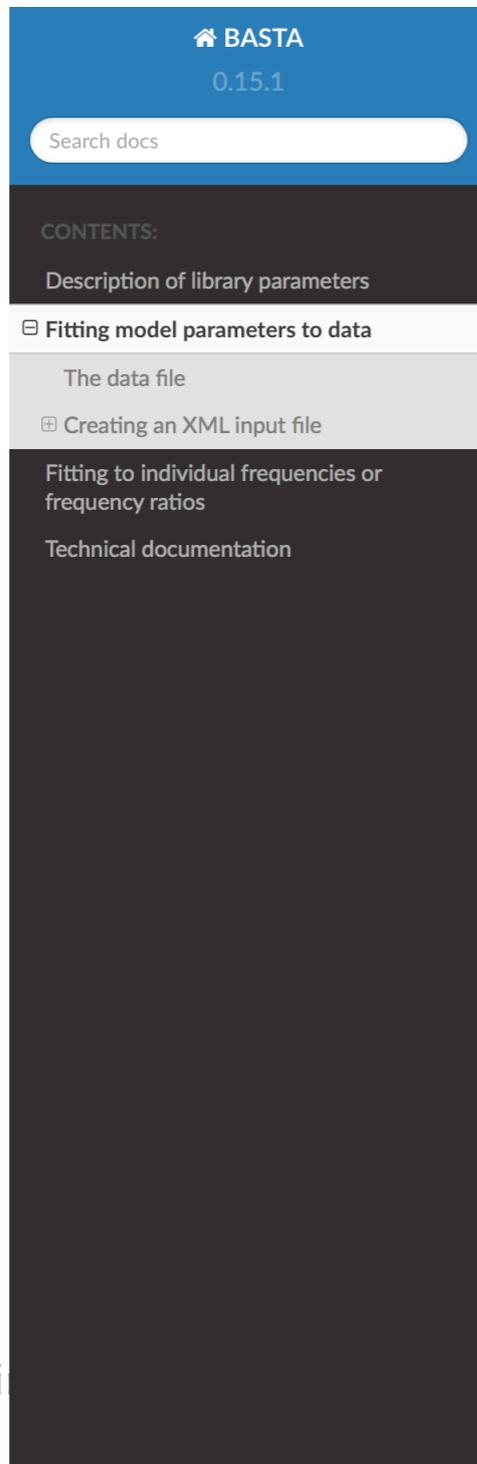
Sahlholdt et al. 2018, MNRAS

Sahlholdt et al. 2018, in prep



The Bayesian STellar Algorithm

Documentation



The screenshot shows the BASTA documentation website. At the top, it says 'BASTA 0.15.1'. Below that is a search bar labeled 'Search docs'. A 'CONTENTS:' section lists several topics: 'Description of library parameters', 'Fitting model parameters to data' (which is expanded to show 'The data file' and 'Creating an XML input file'), 'Fitting to individual frequencies or frequency ratios', and 'Technical documentation'.

Docs » Fitting model parameters to data

[View page source](#)

Fitting model parameters to data

The process of fitting stellar models to observations using BASTA can be divided into a few simple steps:

1. Collect the relevant data in a plain text data file.
2. Create an XML input file which specifies the desired settings and contains the information from the data file.
3. Run BASTA on the XML input file (`BASTArun input.xml`).

In the following, the components involved in this process are described further.

The data file

The values and uncertainties of the parameters to be used in the fit must be supplied in the form of a text file. This file must also contain the stellar identifications (usually placed in the first column).

For example, to fit two stars using ν_{\max} , $\Delta\nu$, T_{eff} and $[\text{Fe}/\text{H}]$, the file may look like the following:

```
# EPIC      numax  enumax   dnu  ednu    teff  eteff      feh      efef
211403248  305.50   2.95  21.45  0.09  4963.73  80.27    0.063    0.034
211403356   10.75   0.15   1.66  0.04  4391.44  97.07   -999.9990 -999.9990
```

Here the number `-999.9990` is used as a placeholder for a missing value (BASTA must be informed of this value, see below). Any missing parameter will be skipped in the fit.

Creating an XML input file

With the data file ready, the BASTA function `xmltools.create_xml()` can be used to generate an XML input file. To make things simpler, the example `M67_input` provides the script `m67_generate_xml_input.py` which acts as a template for specifying the necessary settings. The XML input file specifies which stellar library is used and the parameters BASTA should fit, as well as the parameters outputted and plotted. The input file also specifies which bayesian weights or priors



The Bayesian STellar Algorithm

Tutorials



The BAYesian STellar Algorithm

Upcoming developments



The BAYesian STellar Algorithm

Upcoming developments

- Test the Gaia parallax fitting (non-gaussian PDFs)



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- Test of sampling for subgiants and red giants



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- Test of sampling for subgiants and red giants
- Input PDFs instead of value and gaussian uncertainties
- Finish documentation, tutorials, and paper

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The BAYesian STellar Algorithm

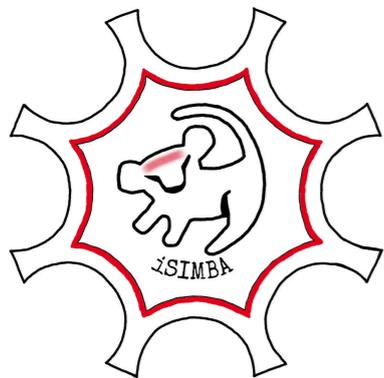
Upcoming developments

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- Test of sampling for subgiants and red giants
- Input PDFs instead of value and gaussian uncertainties
- Finish documentation, tutorials, and paper
- Parallelise runs for large number of targets
- A web interface?

BASTA: the BAYesian STellar Algorithm

Víctor Silva Aguirre

A. Justesen, J. Mosumgaard, C. Sahlholdt, A. Stokholm,
E. Knudstrup, K. Verma, M. Winther, S. Cassisi, and A. Serenelli



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