

Characterising stars with AIMS and SPInS

D. R. Reese
July 1, 2022



Laboratoire d'Études Spatiales et d'Instrumentation en Astrophysique

Introduction

- AIMS = Asteroseismic Inferences on a Massive Scale
 - goal: obtain probability distribution functions (PDFs) for stellar properties, from a set of classic (T_{eff} , $\log g$, $[M/H]$) and seismic constraints
- SPInS = Stellar Parameters INferred Systematically
 - basically the same as AIMS without the seismic constraints
 - can be seen as a spin-off of AIMS

AIMS website

The screenshot shows the GitLab interface for the AIMS project. The browser address bar displays `https://gitlab.com/sasp/aims`. The left sidebar contains navigation options: AIMS, Project information, Repository, Issues (7), Merge requests (1), CI/CD, Deployments, Packages & Registries, Monitor, Analytics, Wiki, and Snippets. The main content area features a notification about free tier open source projects, the project name AIMS with Project ID 13903026, and a star count of 0. It also shows 6 Commits, 5 Branches, 5 Tags, -4718771 Bytes Project Storage, and 5 Releases. A pipeline status bar indicates 'passed' and 'coverage 82.00%'. Below this, there are buttons for 'Find file', 'Download', and 'Clone'. A release section highlights 'Release version 2.0.0' by Steven Hale, authored 1 year ago, with a 'Verified' badge and commit ID '5a84d960'. A table lists files and their last commit: 'doc' with 'Release version 2.0.0' from 1 year ago. A maintenance notice is visible in the bottom right corner.

Activities | Navigateur Web Firefox | juin 30 22:55

SASP / AIMS - GitLab

← → ↻ `https://gitlab.com/sasp/aims` 133% ☆

⚙ Most Visited | 📁 My bookmarks | 📁 Work | 📁 Email | 📁 Music | 📁 Language | 📁 Friends | 📁 System | 📁 Church | 📁 Banks | 📁 Creation | 📁 Paris tour | 📁 Photo books | 📁 Egypt | 📁 Other Bookmarks

🔑 Menu | 🔍 Search GitLab | 📄 Sign in / Register

A AIMS

📁 Project information

📄 Repository

📄 Issues 7

🔗 Merge requests 1

🔗 CI/CD

🔗 Deployments

📦 Packages & Registries

📄 Monitor

📊 Analytics

📄 Wiki

✂ Snippets

⏪ Collapse sidebar

SASP > AIMS

🔔 **Changes to free tier open source projects** ✕

Before July 1, 2022, all free tier public open source projects must [enroll in the GitLab for Open Source Program](#) to continue to receive GitLab Ultimate benefits.

For more information, see the [FAQ](#).

A AIMS 🌐

Project ID: 13903026 📄

☆ Star 0

🔗 6 Commits | 🌿 5 Branches | 🏷 5 Tags | 💾 -4718771 Bytes Project Storage | 📄 5 Releases

pipeline passed | coverage 82.00%

master | aims

Find file | 📄 | Clone

👤 **Release version 2.0.0** Verified ✓ 5a84d960 📄

Steven Hale authored 1 year ago

📄 README | 📄 GNU GPLv3 | 📄 CI/CD configuration

Name	Last commit
📁 doc	Release version 2.0.0

1 year ago

🔔 Scheduled maintenance on the database layer will take place on 2022-07-02. We expect GitLab.com to be unavailable for up to 2 hours starting from 06:00 UTC. Kindly follow our [status page](#) for updates and read more in our [blog post](#). ✕

<https://gitlab.com/sasp/aims>

SPInS website

Reese Daniel > SPInS

SPInS Project ID: 1481 ☆ Star 0

49 Commits 2 Branches 2 Tags 147.2 MB Project Storage 2 Releases

The Stellar Parameters INferred Systematically (SPInS) characterises stars based on classic constraints. It has been derived from the AIMS code. For more details, see <https://dreese.pages.obspm.fr/spins>

master spins Find file Clone

Added emcee and ptmcee version numbers to output README file 40a00f79
Reese Daniel authored 4 weeks ago

README GNU GPLv3 CI/CD configuration

Name	Last commit	Last update
doc	Updated documentation on requirements	1 month ago
.gitignore	Added .gitignore file	1 month ago
.gitlab-ci.yml	Updated documentation installation	1 month ago
COPYING	Initial commit	2 years ago

<https://gitlab.obspm.fr/dreese/spins>

Some history – AIMS

- 2015: initial version written during my postdoc in Birmingham
 - written in python in order to make it easier for others to contribute to the code
- 2016: tutorial on AIMS with Mikkel Lund
 - various parts of the code are translated to Fortran to speed up calculations
- 2019: publication of Rendle et al. (2019, MNRAS 484, 771)
- 2021: inclusion of age parameter (in addition to physical age)
- 2019, 2022: inclusion of seismic indicators based on WhoSGIAd method (Farnir et al. 2019)
 - method based on Gram-Schmidt orthogonalisation

AIMS – contributors

- Daniel R. Reese
- Andrea Miglio
- Benoît D. C. P. Herbert
- Ben Rendle
- Gael Buldgen
- Guy R. Davies
- Martin Farnir
- Martin W. Long
- Mikkel N. Lund
- Tiago L. Campante

Some history – SPInS

- 2018: initial version written for the 5th International Young Astronomer's School (Paris)
 - derived from AIMS
 - included a physical age and an age parameter from the start
- 2020:
 - official release
 - improved treatment of age
 - possibility of handling multiple systems
 - publication of Lebreton & Reese (2020, A&A 642, 88)
- Main contributors: Daniel R. Reese & Yveline Lebreton

Flowchart

Analytical priors & Observational constraints:

- seismic: ν_i , r_{02} , r_{01} , r_{10} , $\Delta\nu$
- classical: T_{eff} , L , $[M/H]$, ...
- error bars and correlations

Grid of models

- n-dimensional ($n \geq 3$)
- pre-computed pulsation frequencies
- optional surface effects

AIMS = “Asteroseismic Inference on a Massive Scale”

- unstructured linear interpolation
- MCMC approach with parallel tempering (via the python EMCEE package, Foreman-Mackey et al. 2013)

Estimated properties

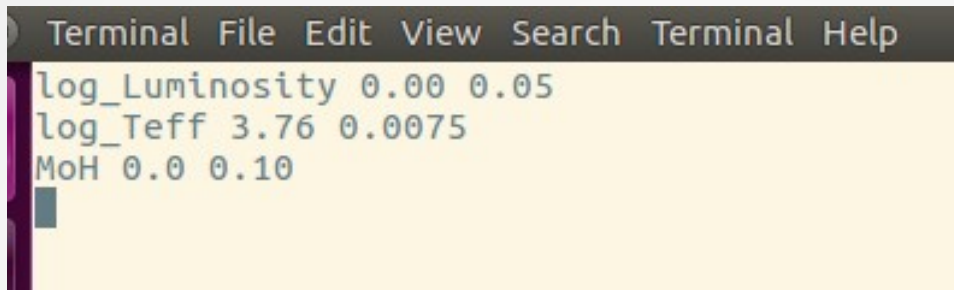
- probability distribution functions for different parameters

Representative models

- provides coefficients for interpolating acoustic structure
- allows inversions

Observational constraints

- classic constraints (typically Gaussians)

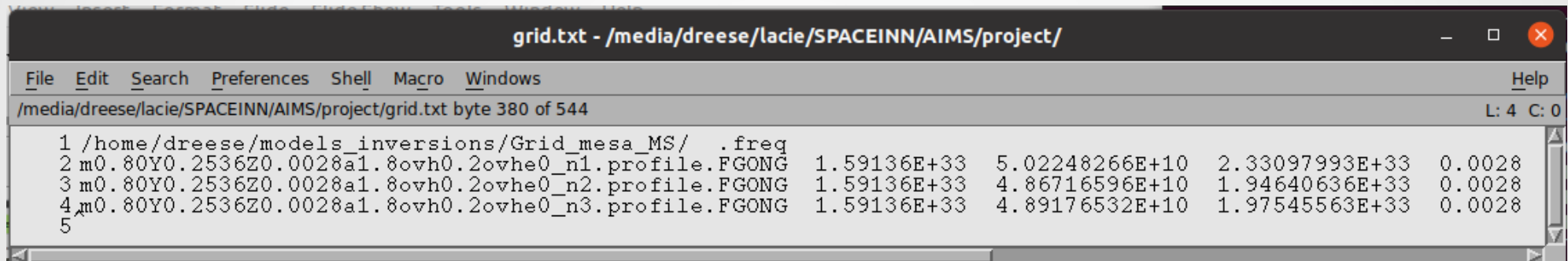


```
Terminal File Edit View Search Terminal Help
log_Luminosity 0.00 0.05
log_Teff 3.76 0.0075
MoH 0.0 0.10
```

- may apply elementary functions (e.g. log)
- may also specify other distributions (uniform, truncated gaussian)
- seismic constraints (AIMS only)
 - individual frequencies with ℓ and with or without n
 - error distributions are assumed to be Gaussian and independent
 - frequency combinations (e.g. separations/ratios) are calculated subsequently and correlations are calculated analytically

Grid of models

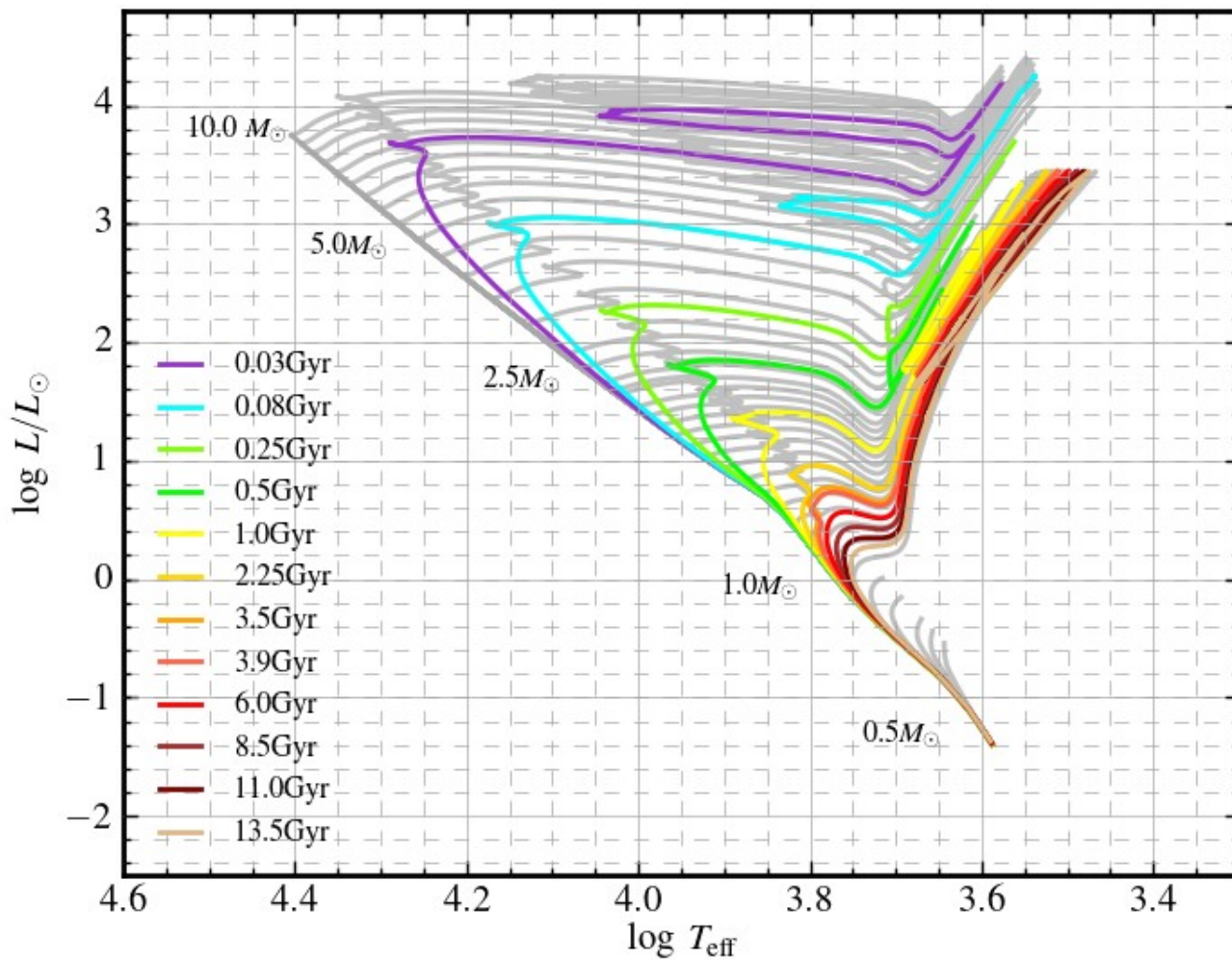
- made of evolutionary tracks characterised by a set of parameter (e.g. M, X, Y)
 - model parameters read from list file by AIMS/SPInS
 - AIMS/SPInS will reconstruct the evolutionary tracks



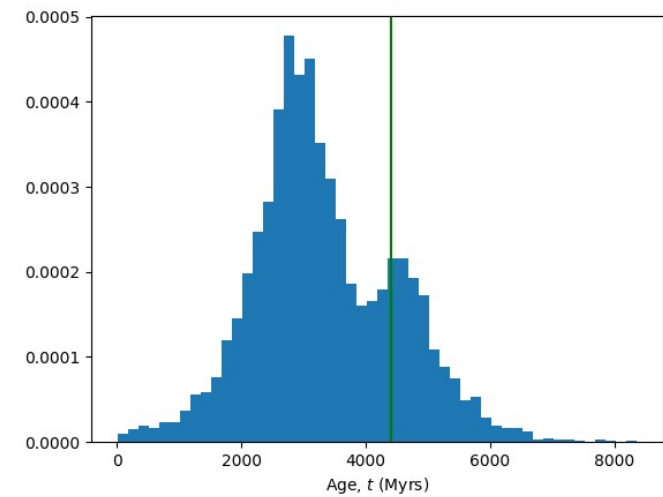
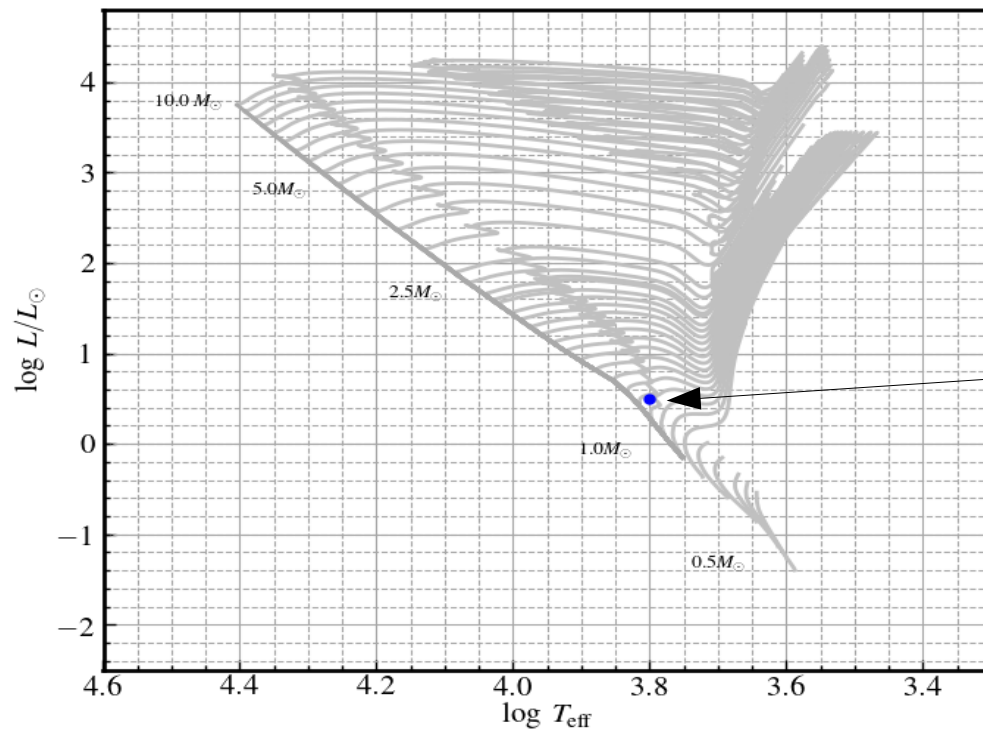
```
grid.txt - /media/dreese/lacie/SPACEINN/AIMS/project/
File Edit Search Preferences Shell Macro Windows Help
/media/dreese/lacie/SPACEINN/AIMS/project/grid.txt byte 380 of 544 L: 4 C: 0
1 /home/dreese/models_inversions/Grid_mesa_MS/ .freq
2 m0.80Y0.2536Z0.0028a1.8ovh0.2ovhe0_n1.profile.FGONG 1.59136E+33 5.02248266E+10 2.33097993E+33 0.0028
3 m0.80Y0.2536Z0.0028a1.8ovh0.2ovhe0_n2.profile.FGONG 1.59136E+33 4.86716596E+10 1.94640636E+33 0.0028
4 m0.80Y0.2536Z0.0028a1.8ovh0.2ovhe0_n3.profile.FGONG 1.59136E+33 4.89176532E+10 1.97545563E+33 0.0028
5
```

- *for AIMS only*: model frequencies stored in individual files (their paths are specified in the list file)
- a first run is necessary to generate a binary grid file with all of the models parameters, frequencies, and grid tessellation (see interp.)

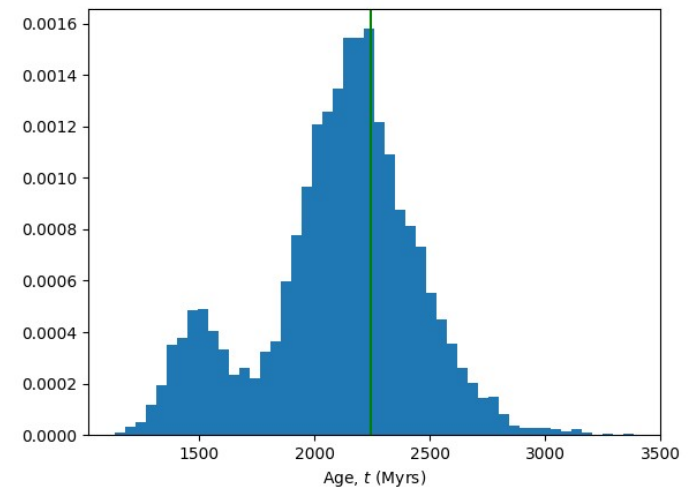
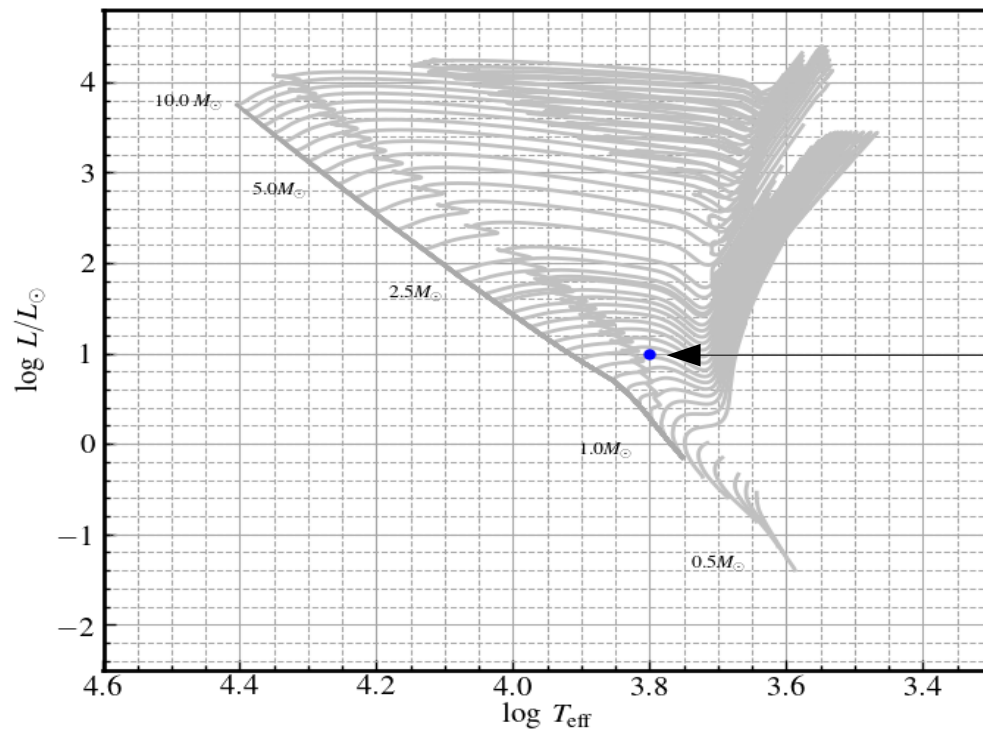
A Bayesian approach



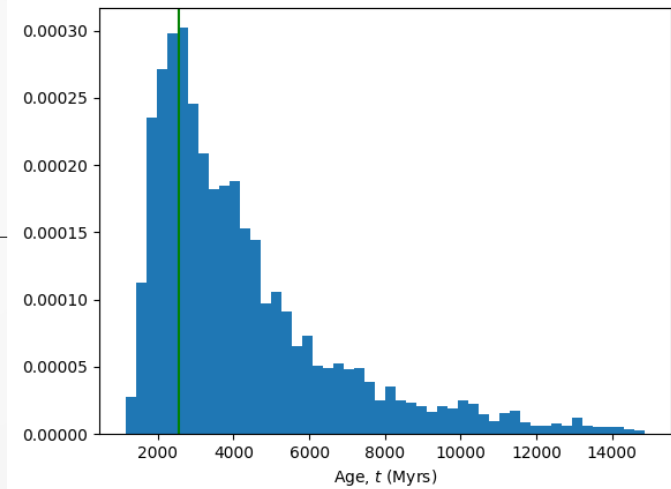
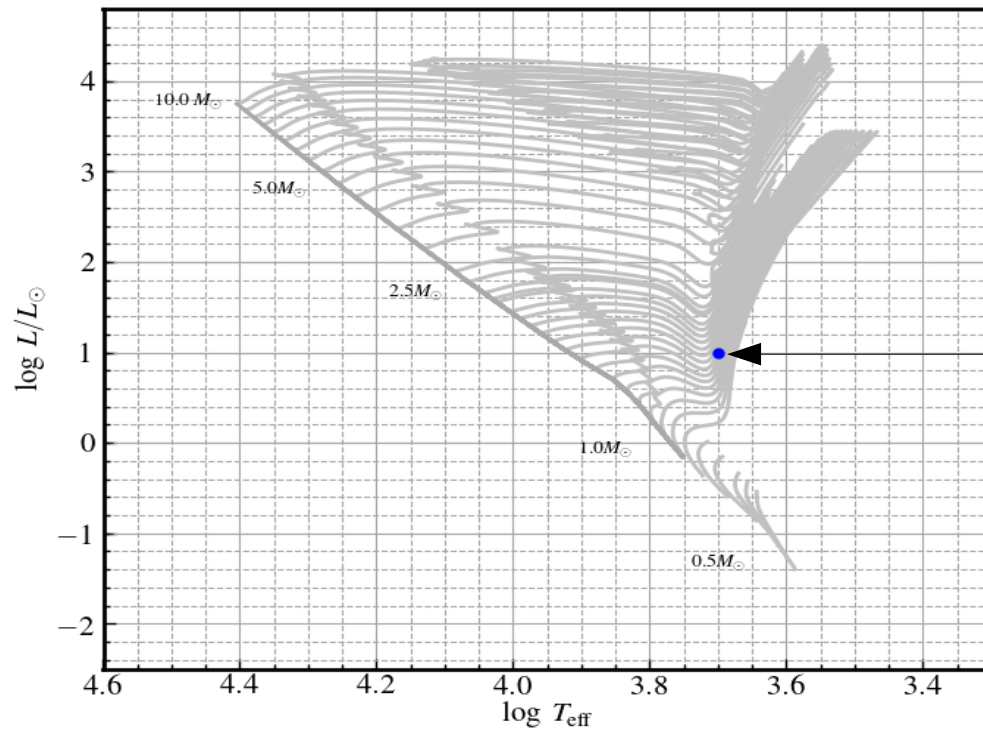
A Bayesian approach



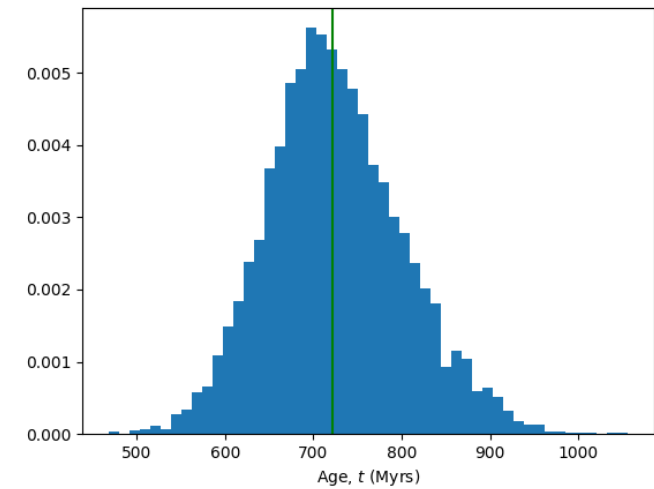
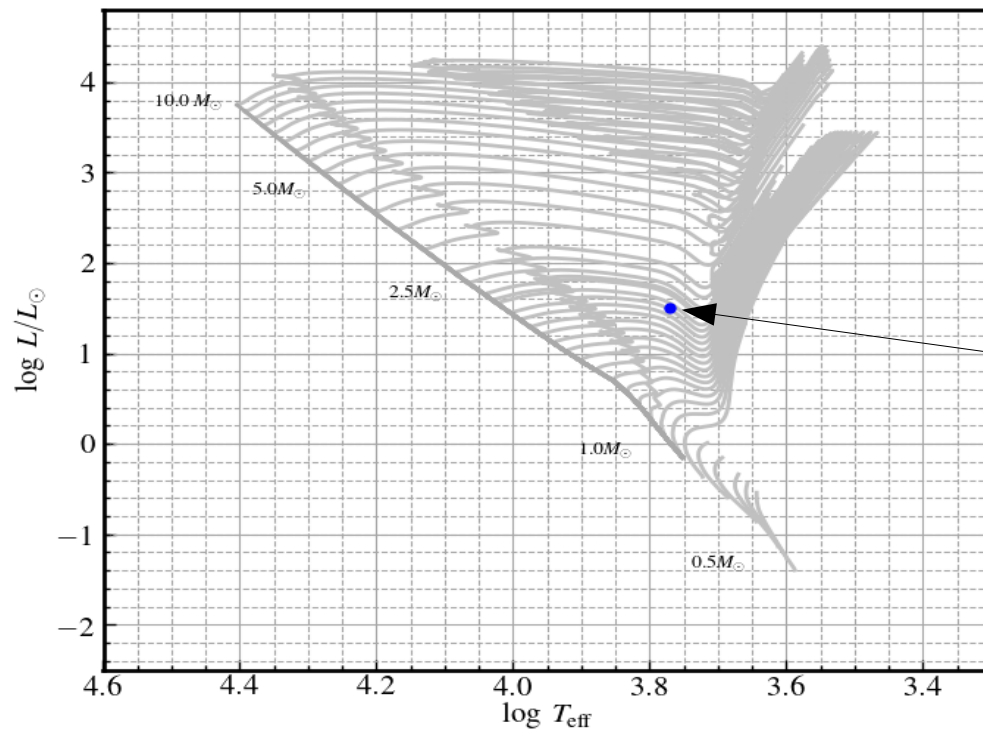
A Bayesian approach



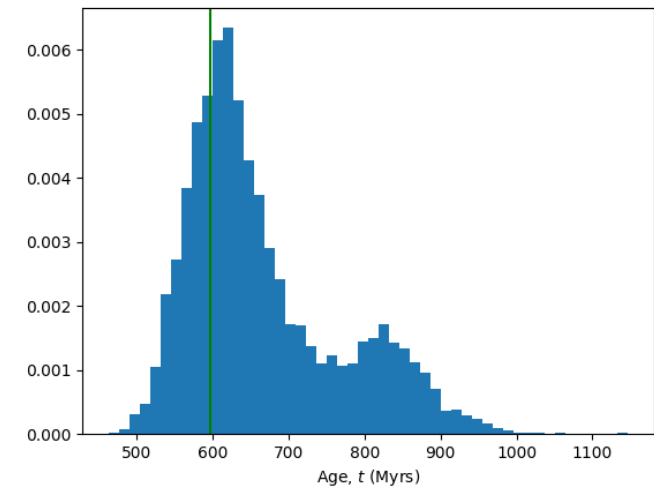
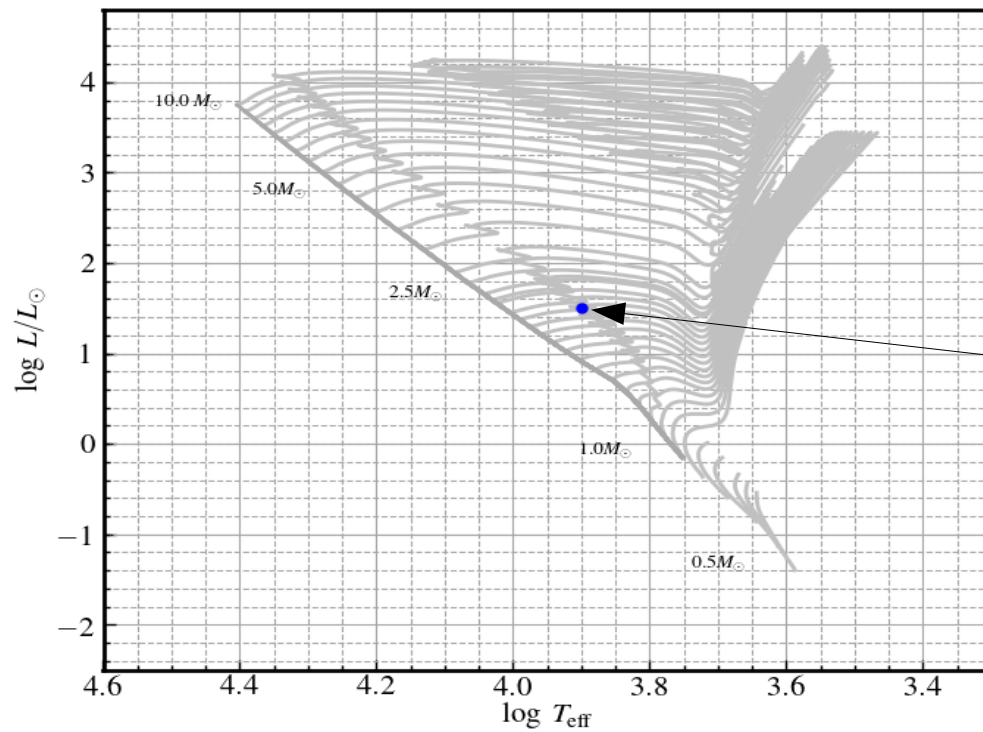
A Bayesian approach



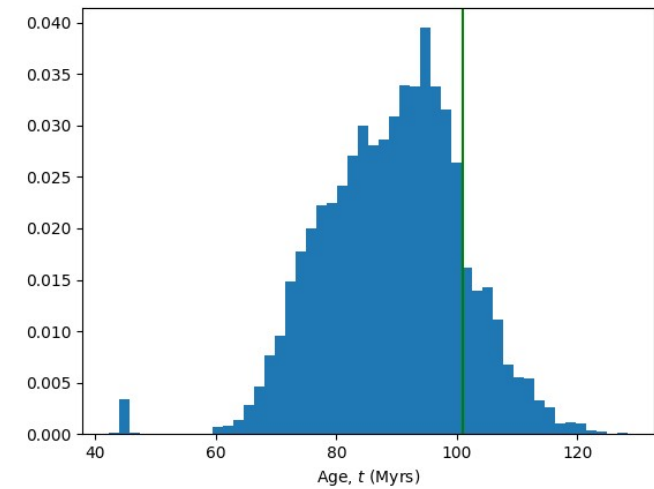
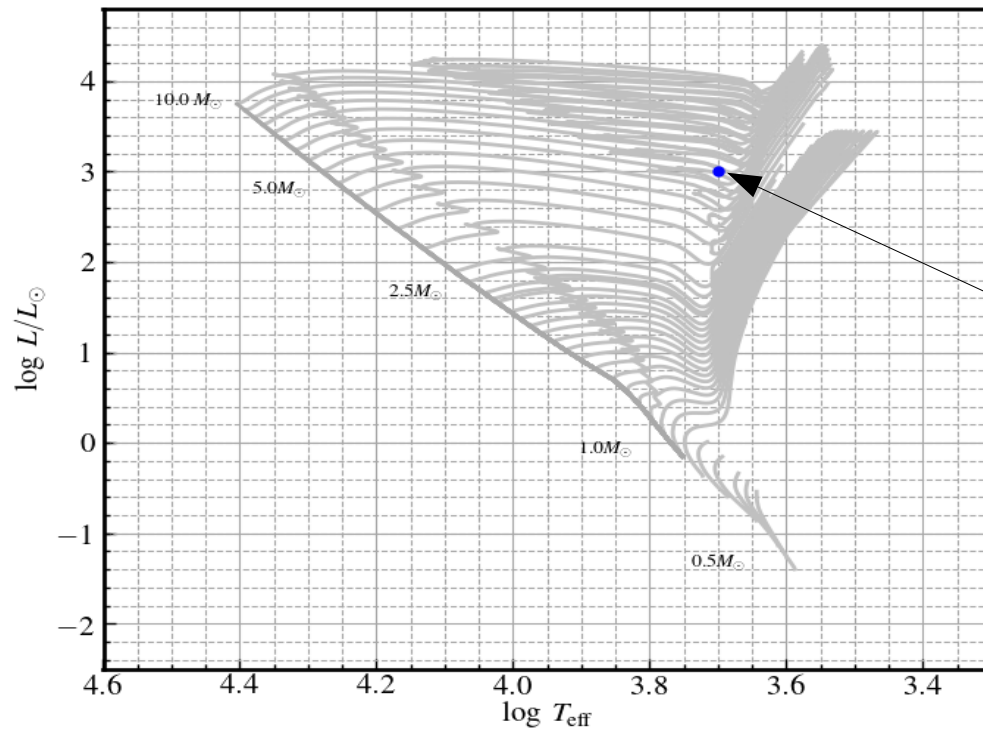
A Bayesian approach



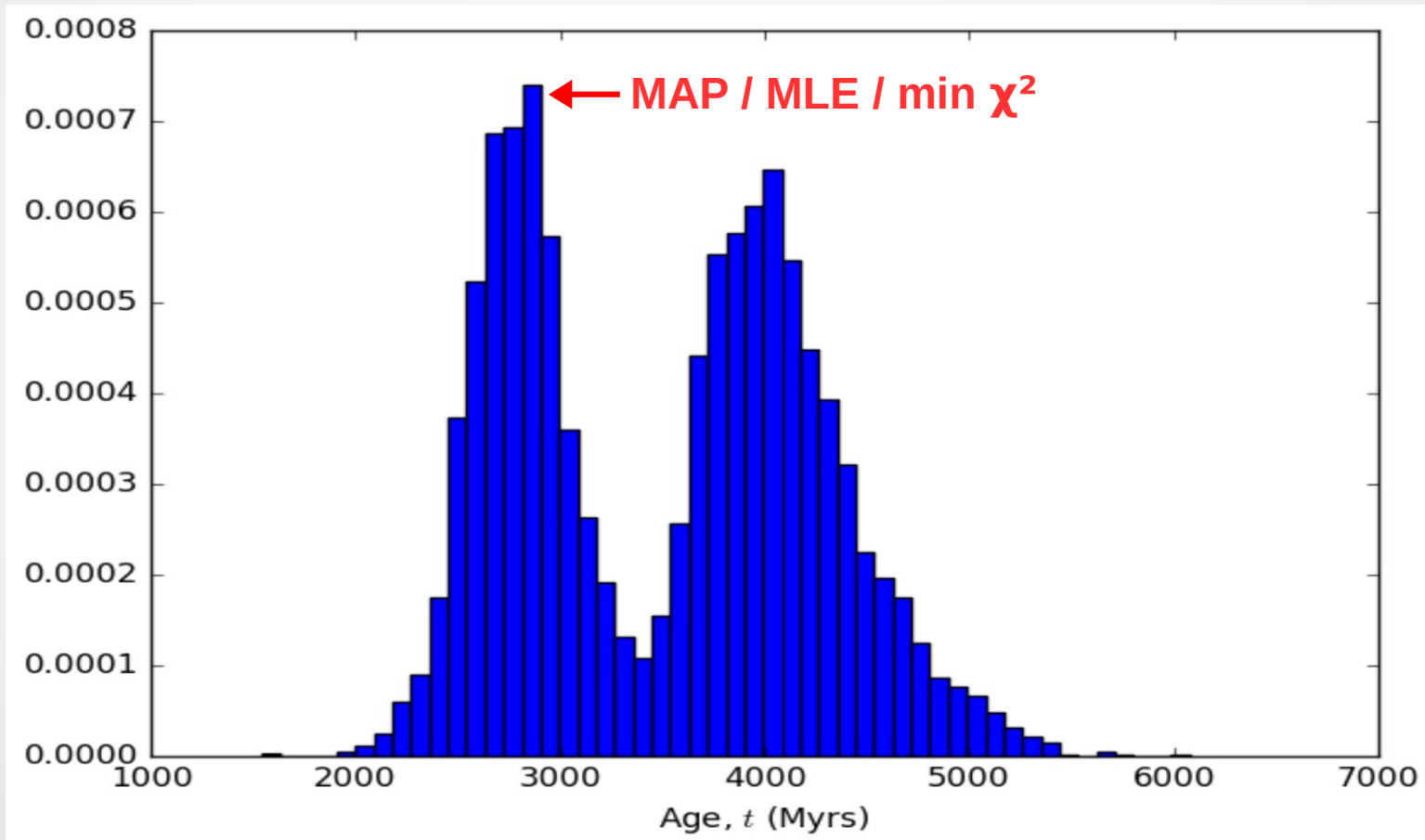
A Bayesian approach



A Bayesian approach



A Bayesian approach

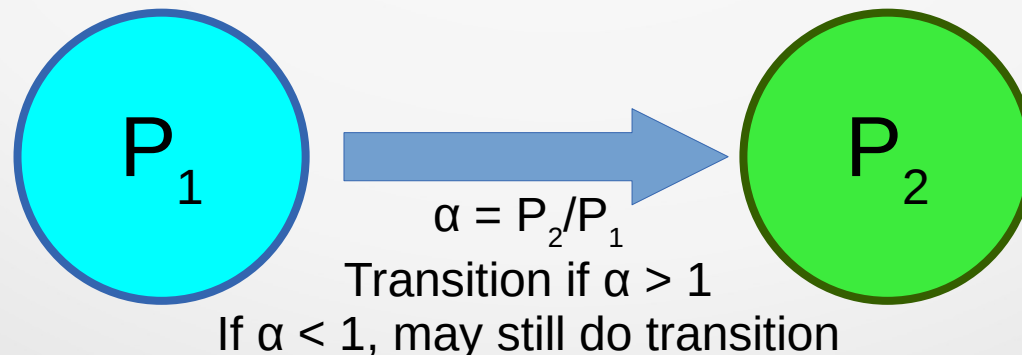


A Bayesian approach

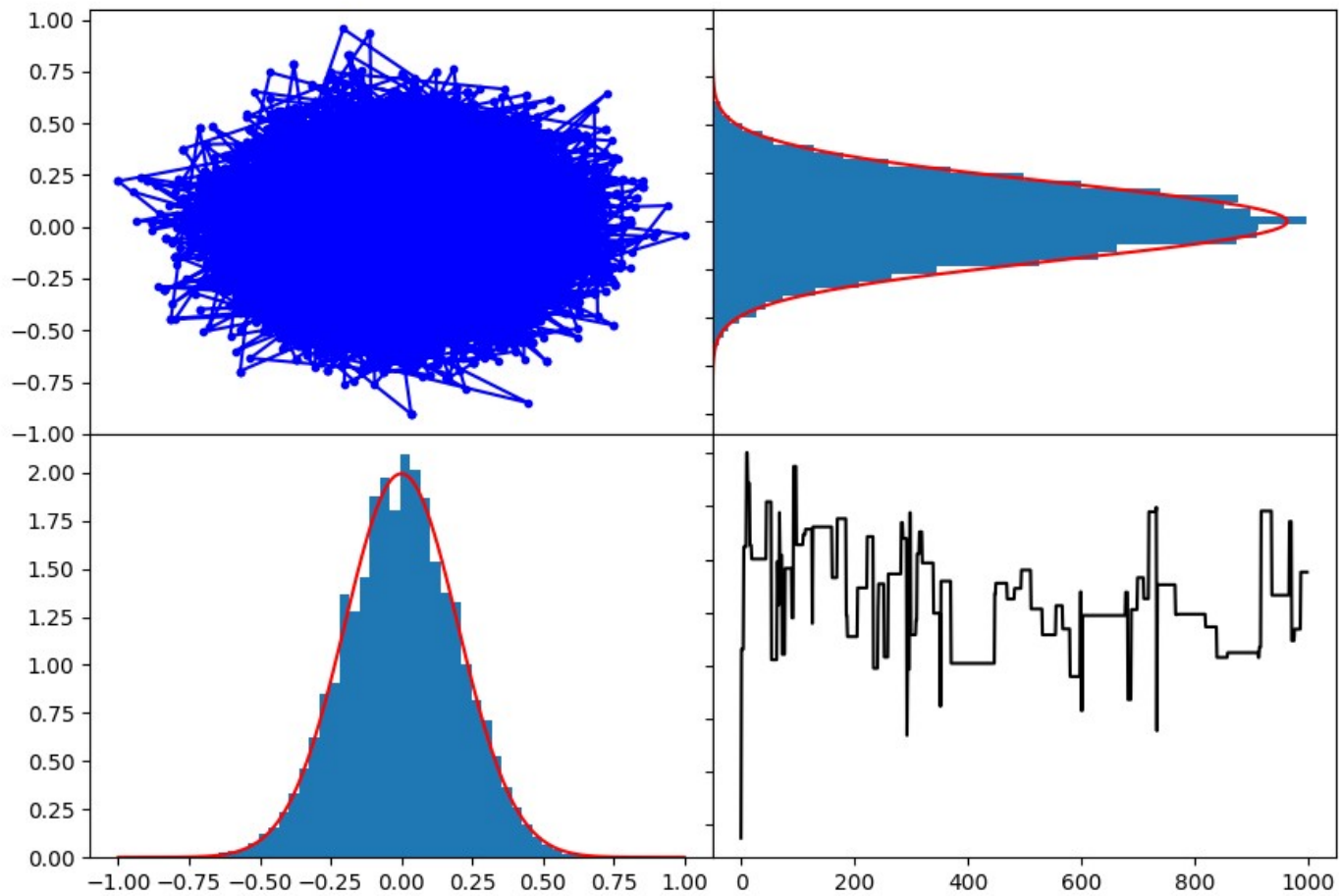
- Bayes' theorem: $P(model|data) \propto \underbrace{P(data|model)}_{\text{Likelihood function}} \underbrace{P(model)}_{\text{Prior}}$
- Priors: initial mass function (IMF), metallicity distribution function (MDF), star formation rate (SFR)
- Likelihood function: observational constraints

The MCMC algorithm

- MCMC = Monte Carlo Markov Chain
- one approach: Metropolis-Hastings algorithm
 - explores the model parameter space so as to
 - spend little time in unlikely regions
 - spend a lot of time in likely regions
 - the distribution of explored points corresponds to PDF



The MCMC algorithm



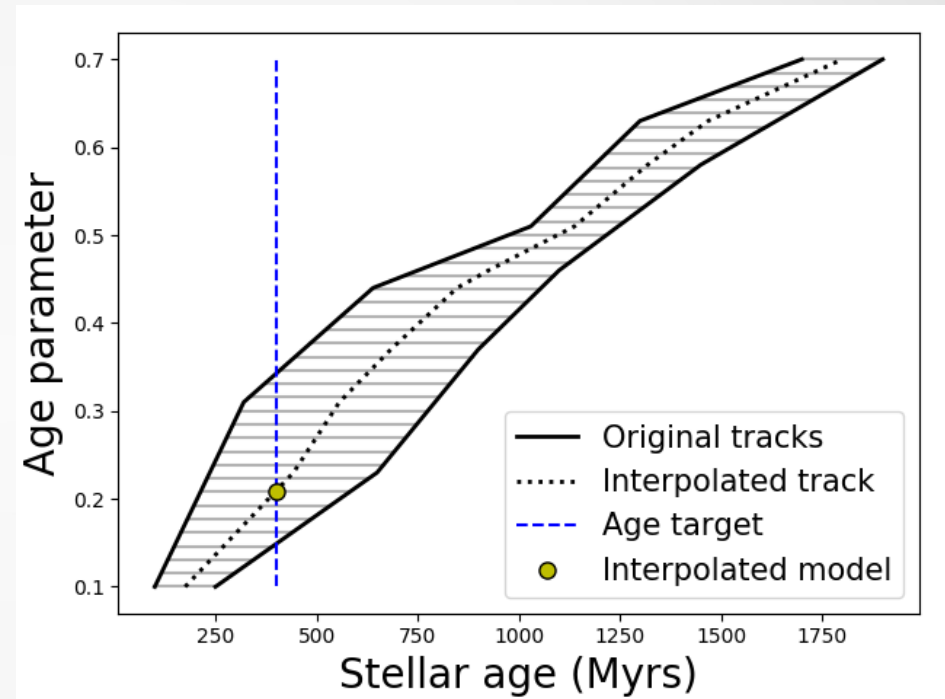
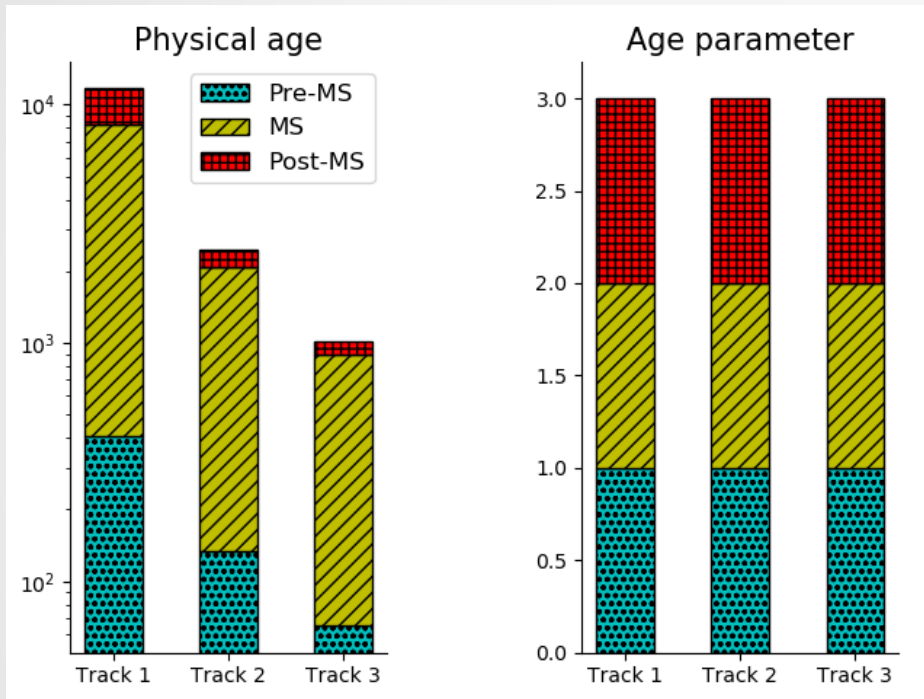
Model interpolation

- two parts
 - age interpolation
 - track interpolation

Age interpolation

- AIMS/SPInS uses 2 age parameters:
 - the physical age, t
 - the equivalent age parameter, τ (corresponds to evolutionary stage)
- MCMC according to age, t
 - this avoids introducing unwanted priors on age
 - components of multiple systems typically have the same *physical age*
- interpolation according to τ
 - this enables combining models at equivalent evolutionary stages when interpolating across tracks

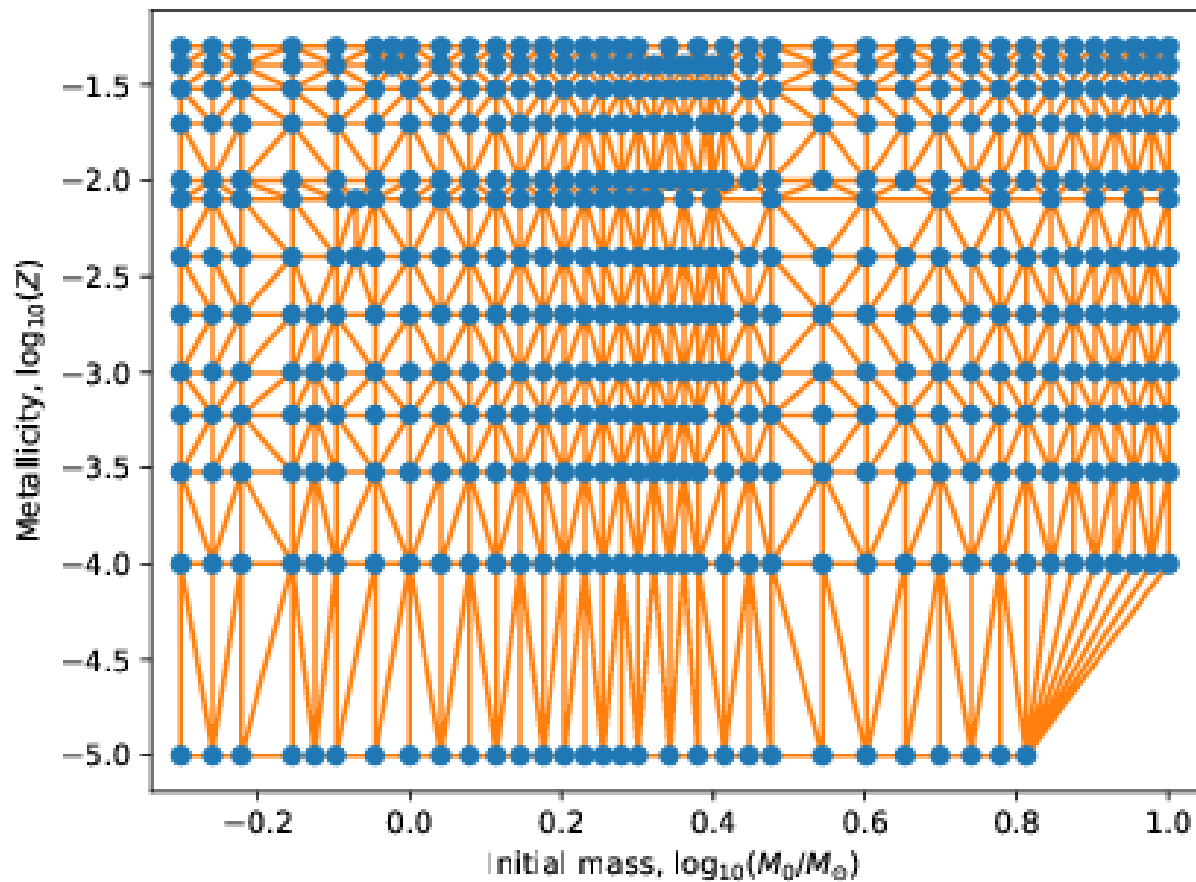
Age interpolation



- AIMS/SPInS is constantly going back and forth between t and τ
 - need for efficient algorithm

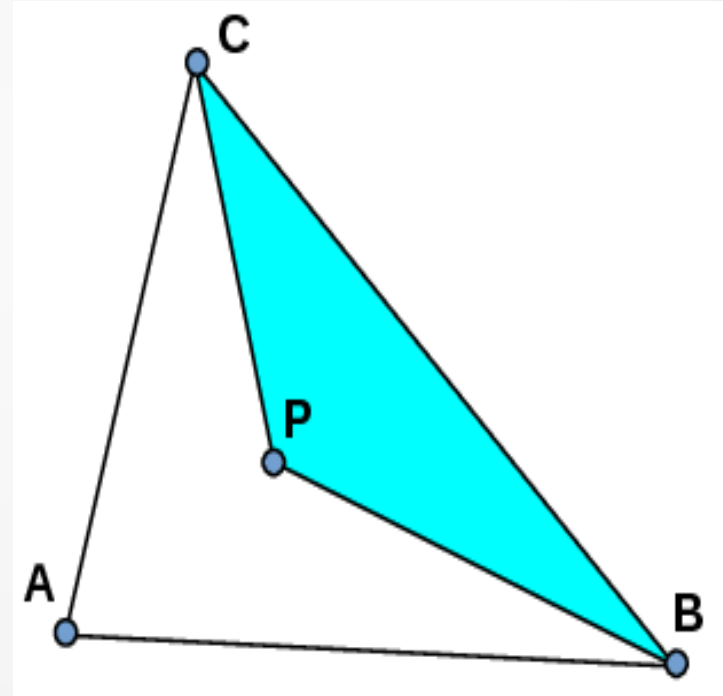
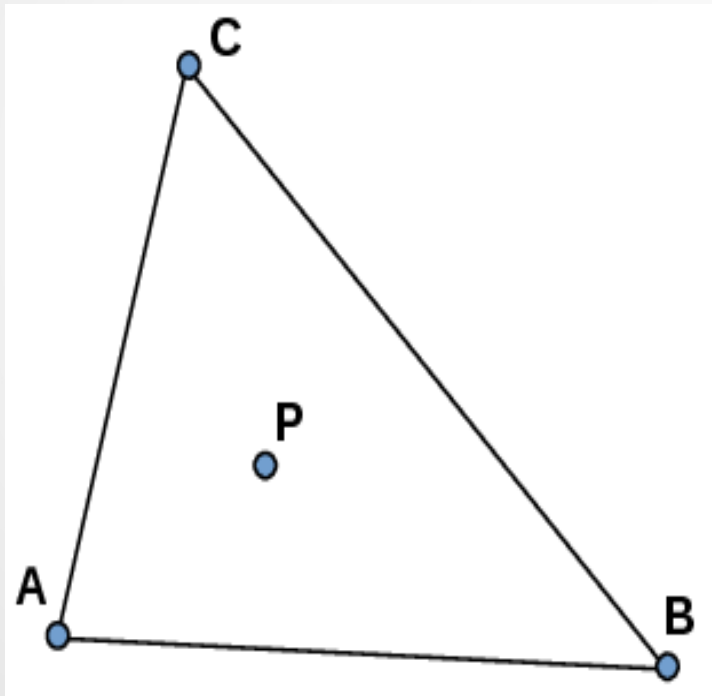
Track interpolation

- apply a Delaunay tessellation



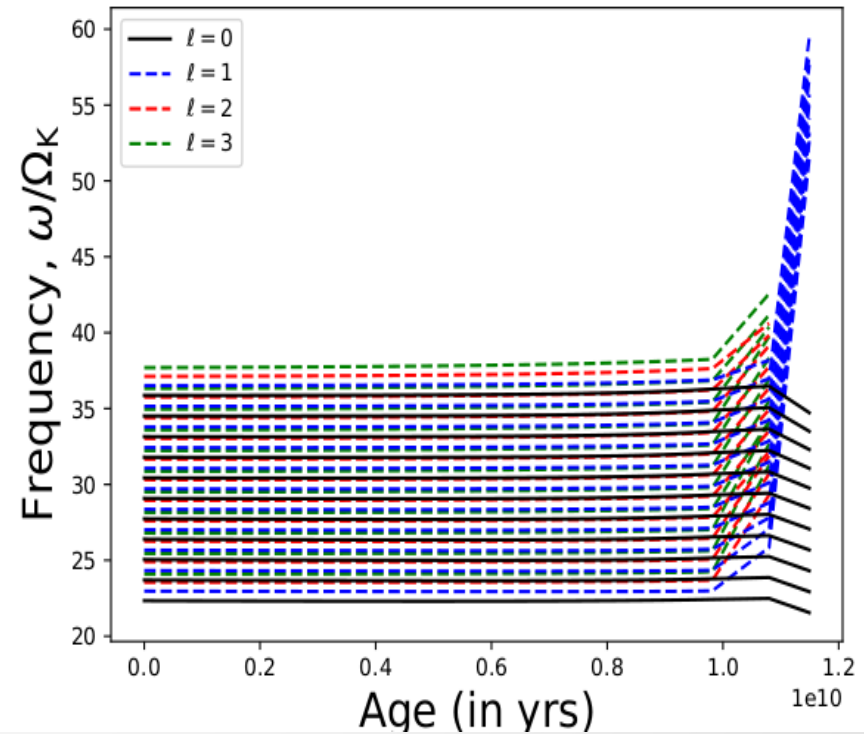
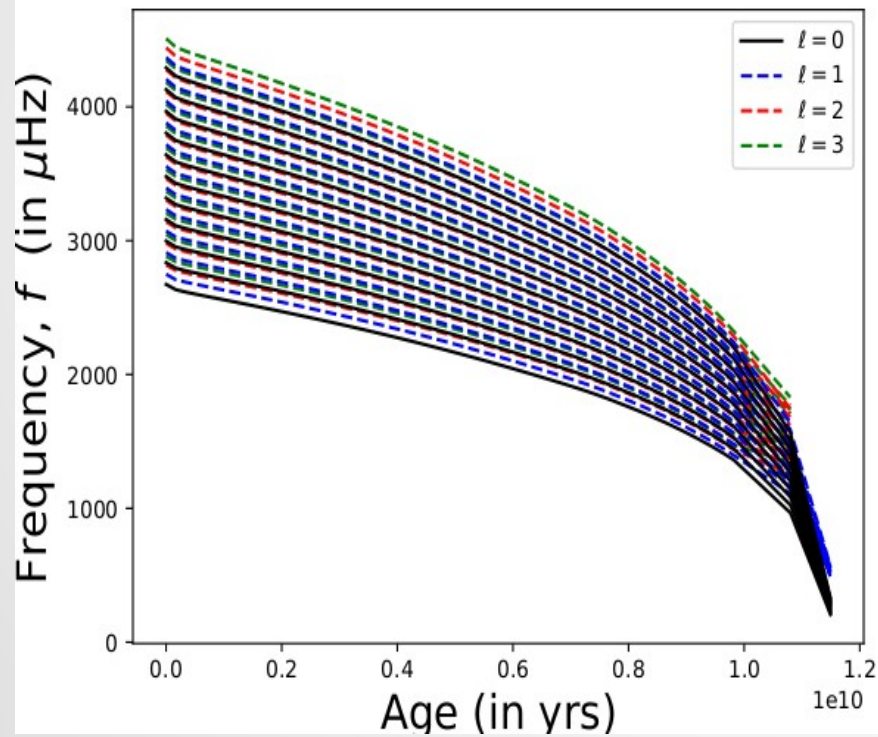
Track interpolation

- calculate linear integration weights within selected simplex



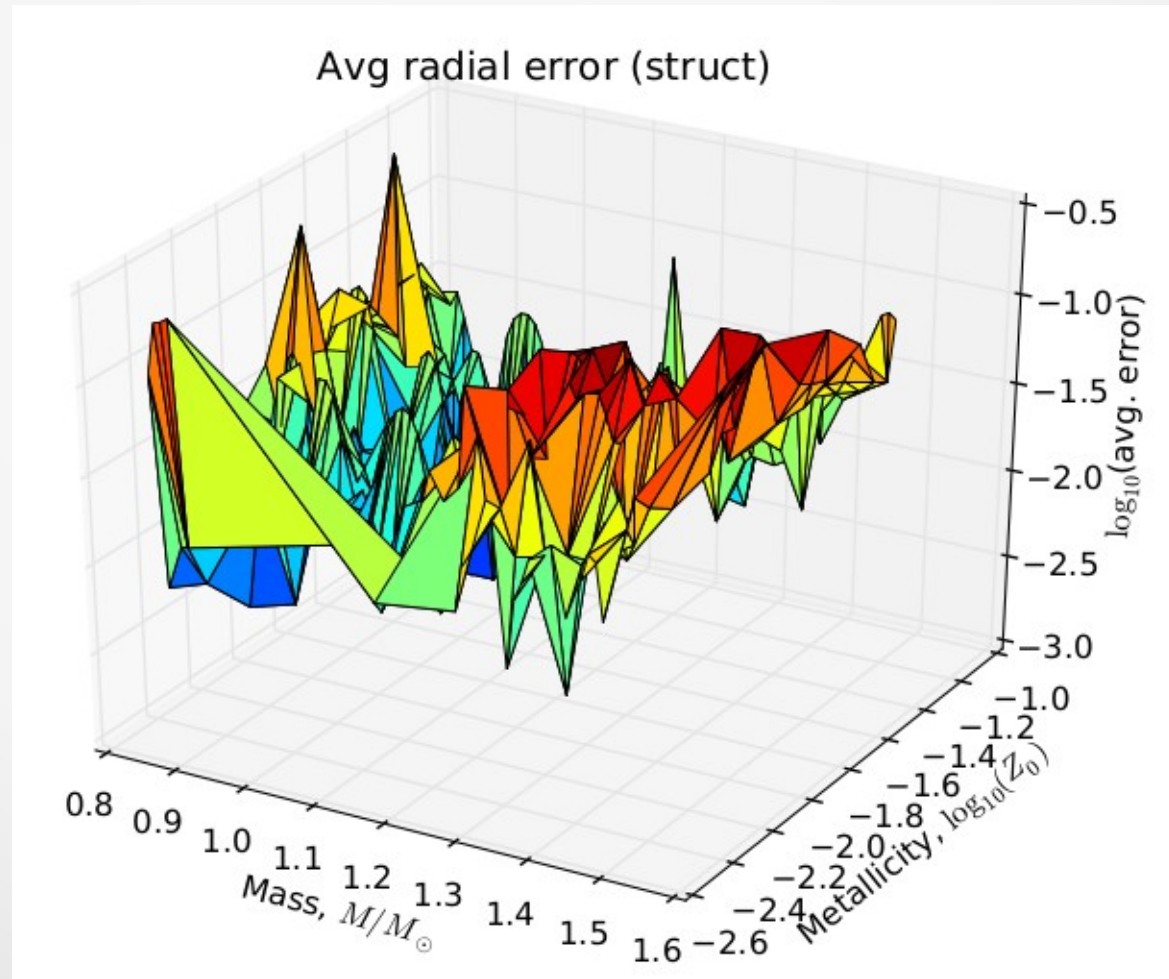
Frequency interpolation (AIMS only)

- non-dimensional frequencies are interpolated along tracks



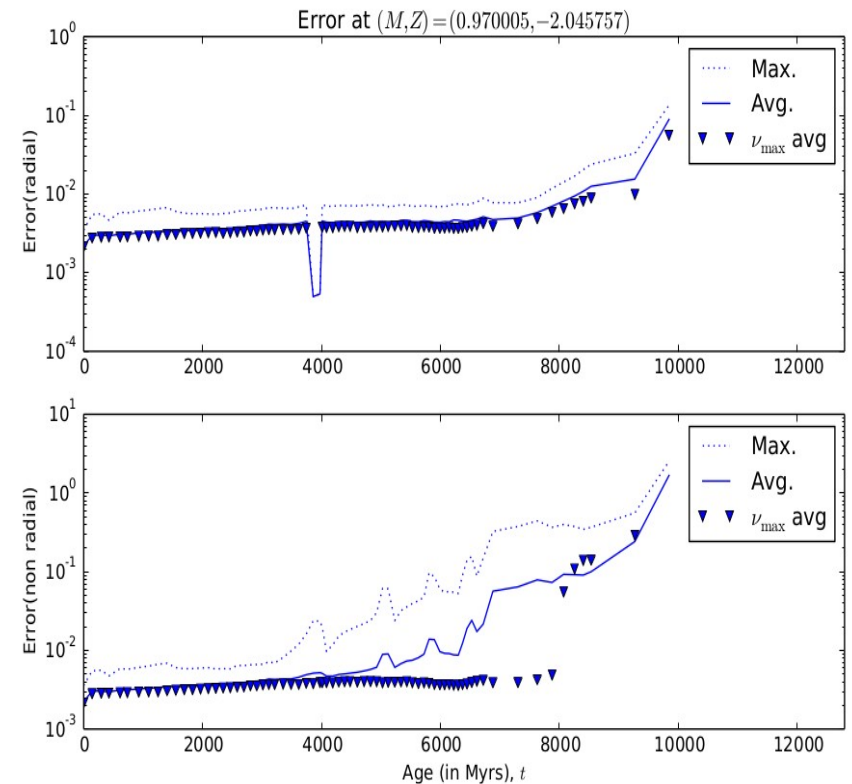
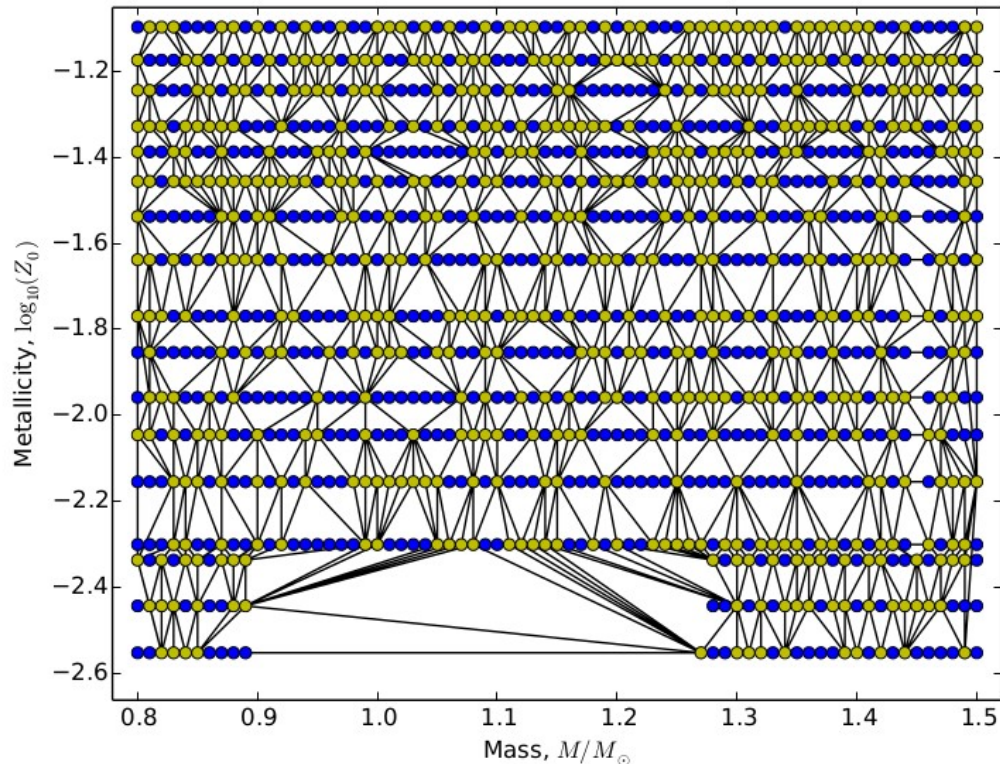
Accuracy of the interpolation

- internal tests may be applied to analyse interpolation accuracy

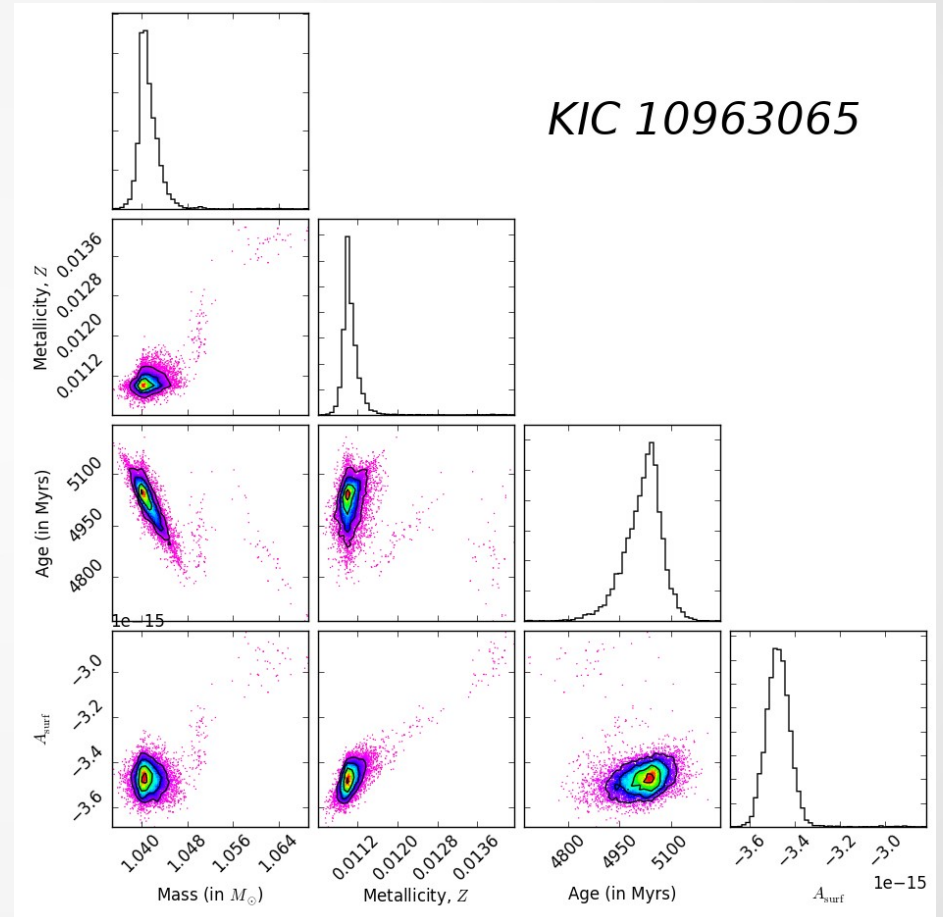
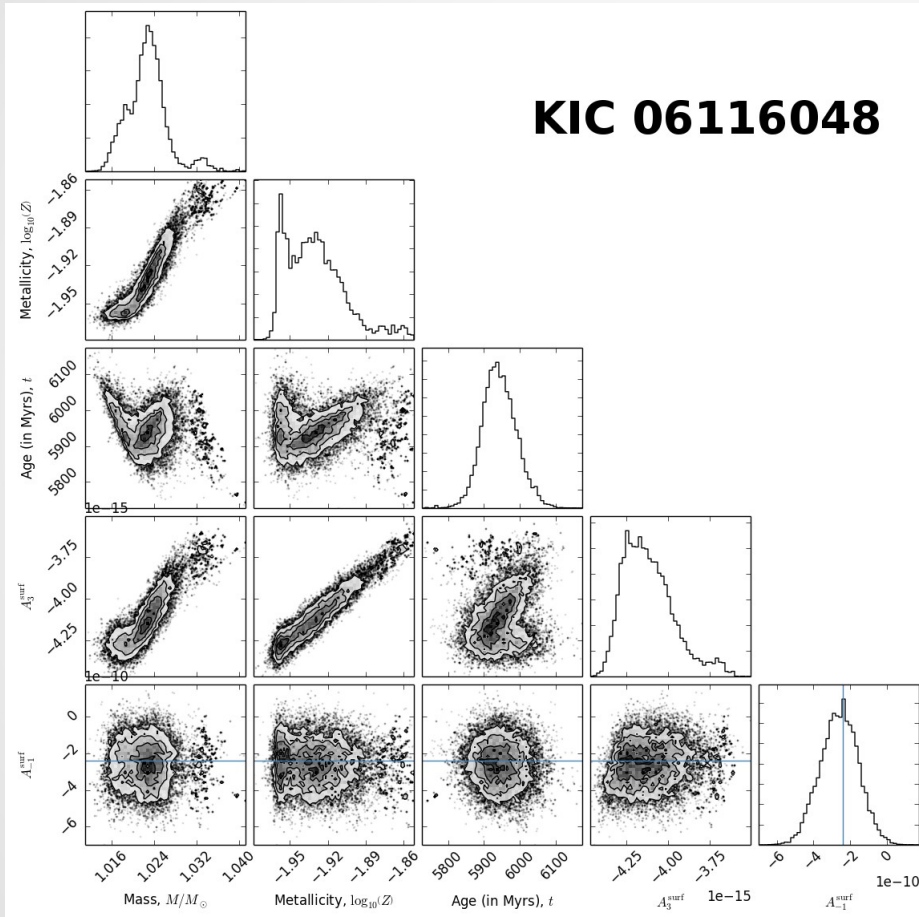


Accuracy of the interpolation

- internal tests may be applied to analyse interpolation accuracy

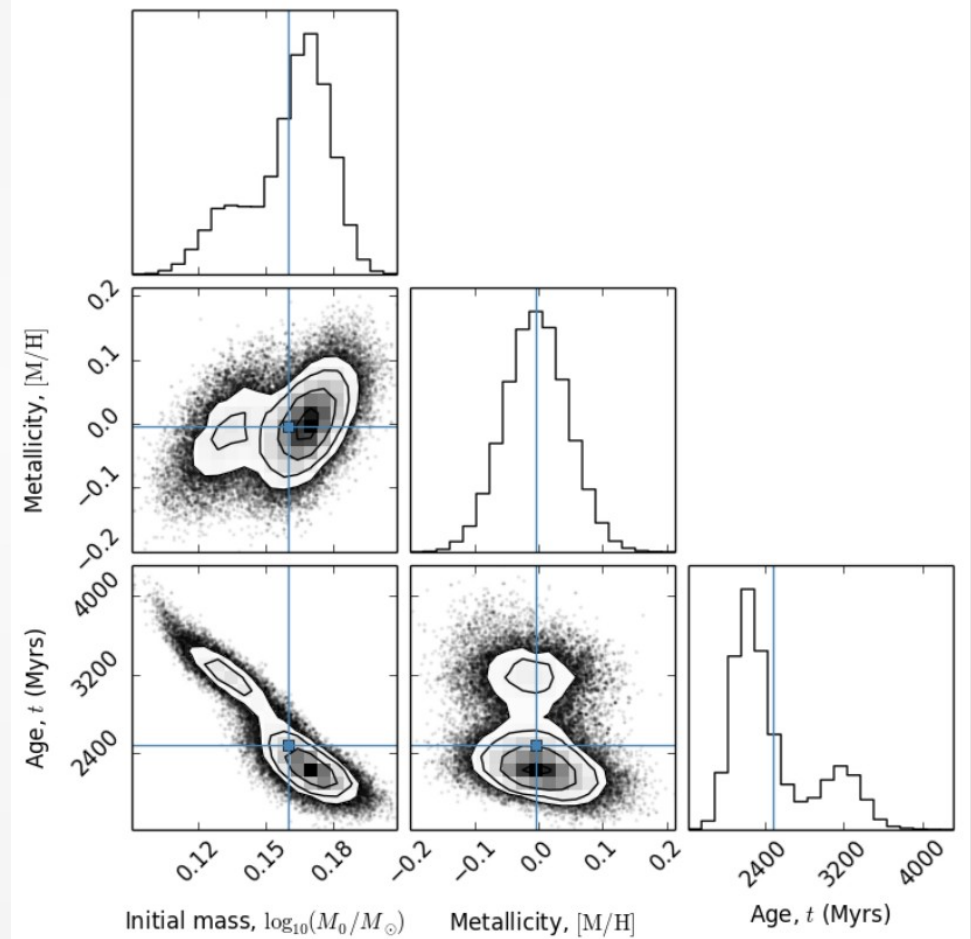
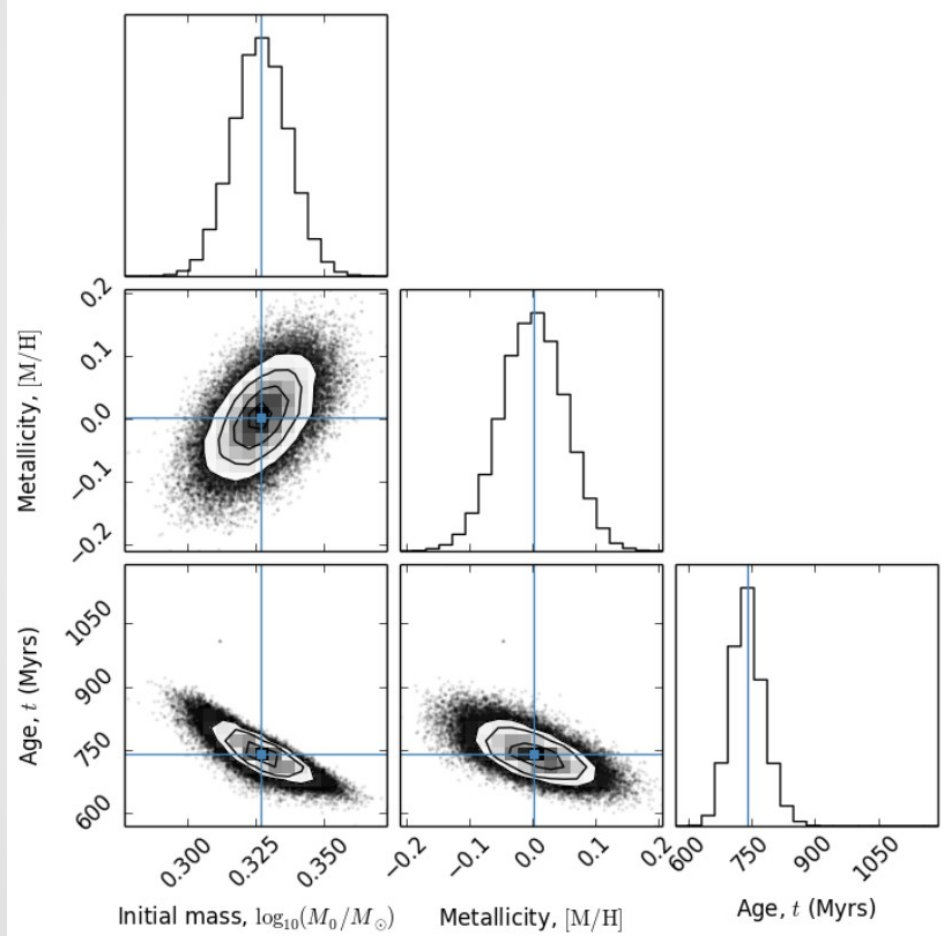


Some results with AIMS



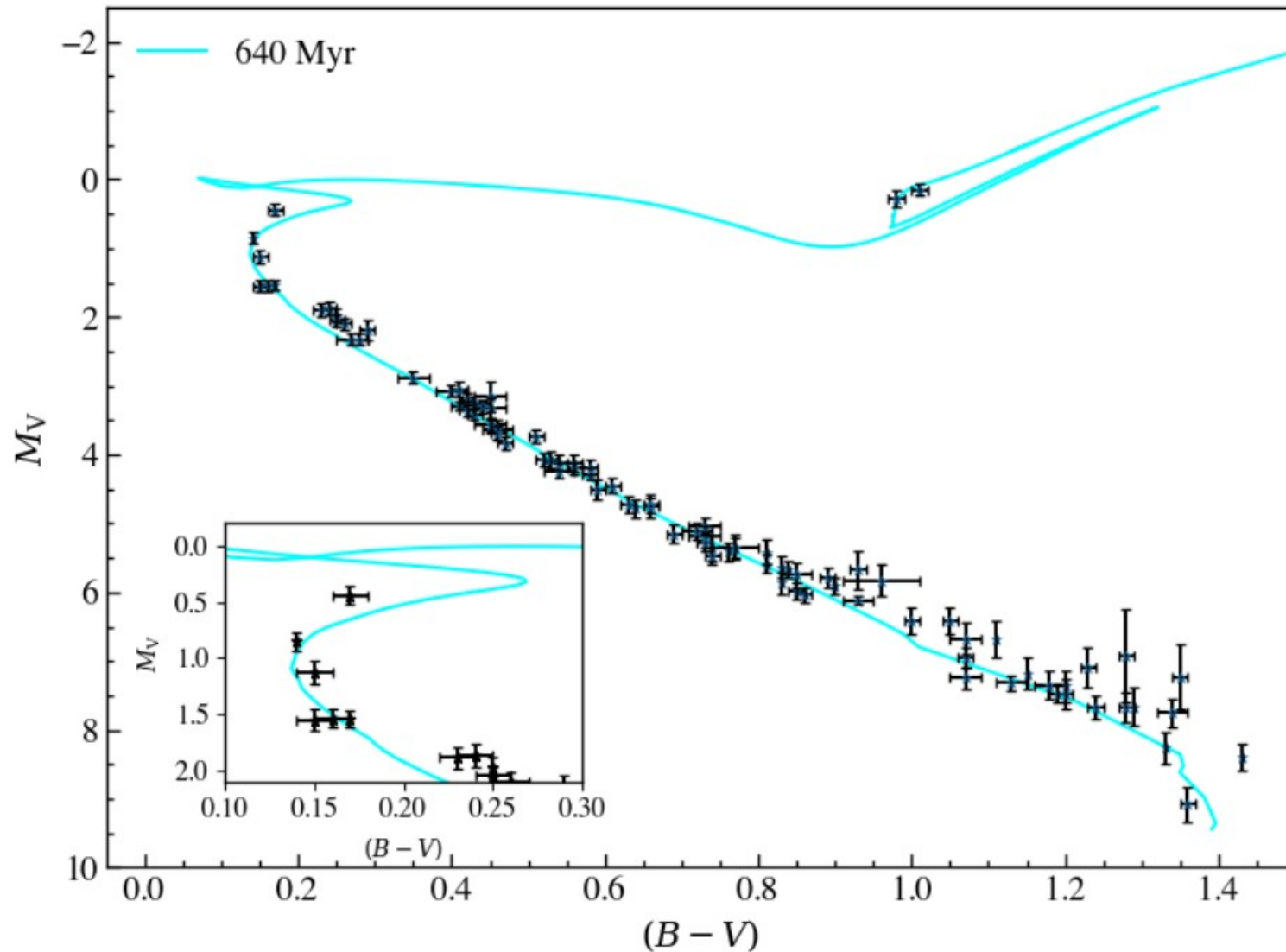
Solutions obtained with AIMS for Kepler LEGACY stars (Lund et al. 2017, Silva Aguirre 2017) – solutions are sometimes multimodal

Some results with SPInS



Results for some artificial stars

Some results with SPInS



Best fitting isochrone obtained with 92 stars from the Hyades cluster

Conclusion & perspectives

- AIMS and SPInS are helping to characterise stars and improve our understanding of various effects, e.g.:
 - AIMS: internal systematic effects and surface effects (Nsamba et al. 2018)
 - SPInS starting to be used extensively for the FLAME work package for Gaia and various other groups
- future improvements
 - automatic stopping criterion for the MCMC sampler
 - possibility of isolating separate modes in multimodal solutions
 - extend AIMS to handle multiple systems
 - extend AIMS to handle rotating stars