Calibrating asteroseismology scaling relation by CHARA observation on Gaia binaries

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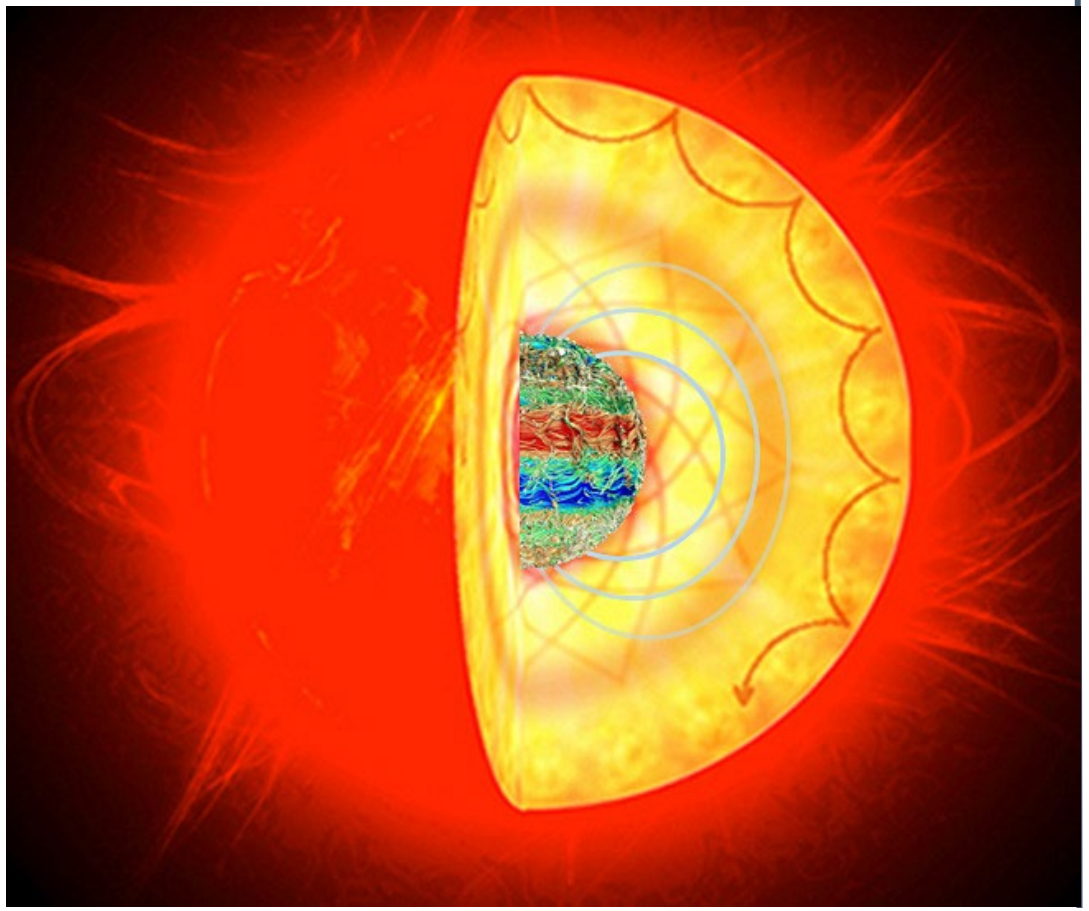
Asteroseismology

- Asteroseismology: Study the internal structure of a star by their oscillations

- Much potential to provide mass measurements
- Depend on scaling relations

$$\frac{M}{M_\odot} = \left(\frac{\nu_{\max}}{\nu_{\max_\odot}}\right)^3 \left(\frac{\Delta\nu_\odot}{\Delta\nu}\right)^4 \left(\frac{T_{\rm eff}}{T_{\rm eff,\odot}}\right)^{\frac{3}{2}}$$

- Assume homologous structure to the Sun

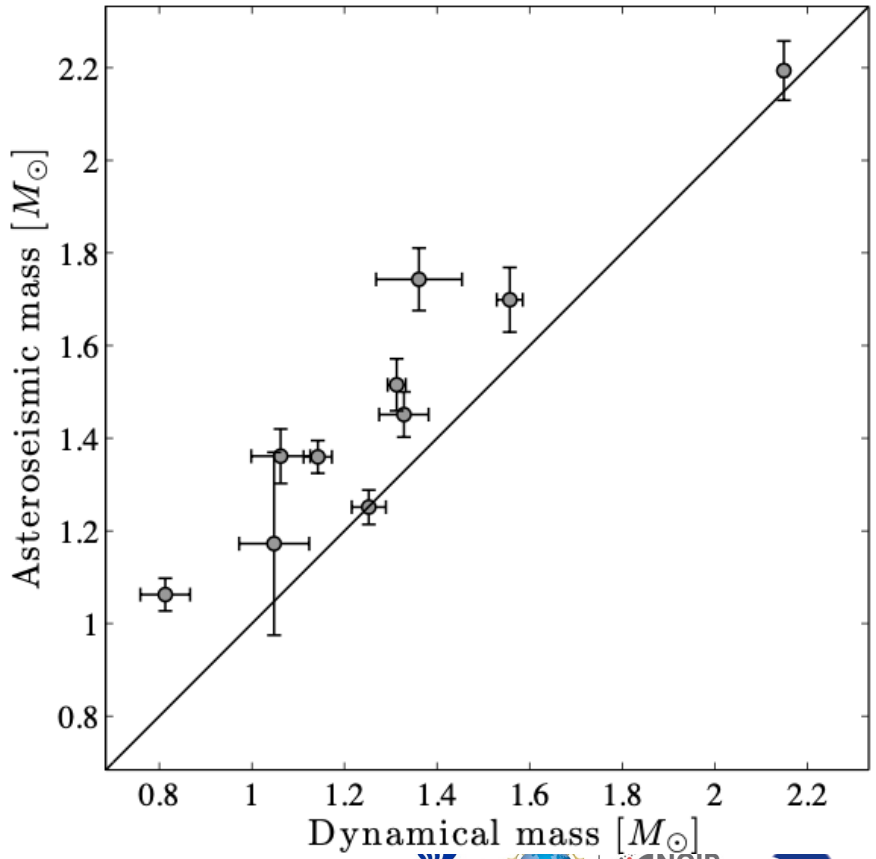


García+ 2015

Asteroseismology

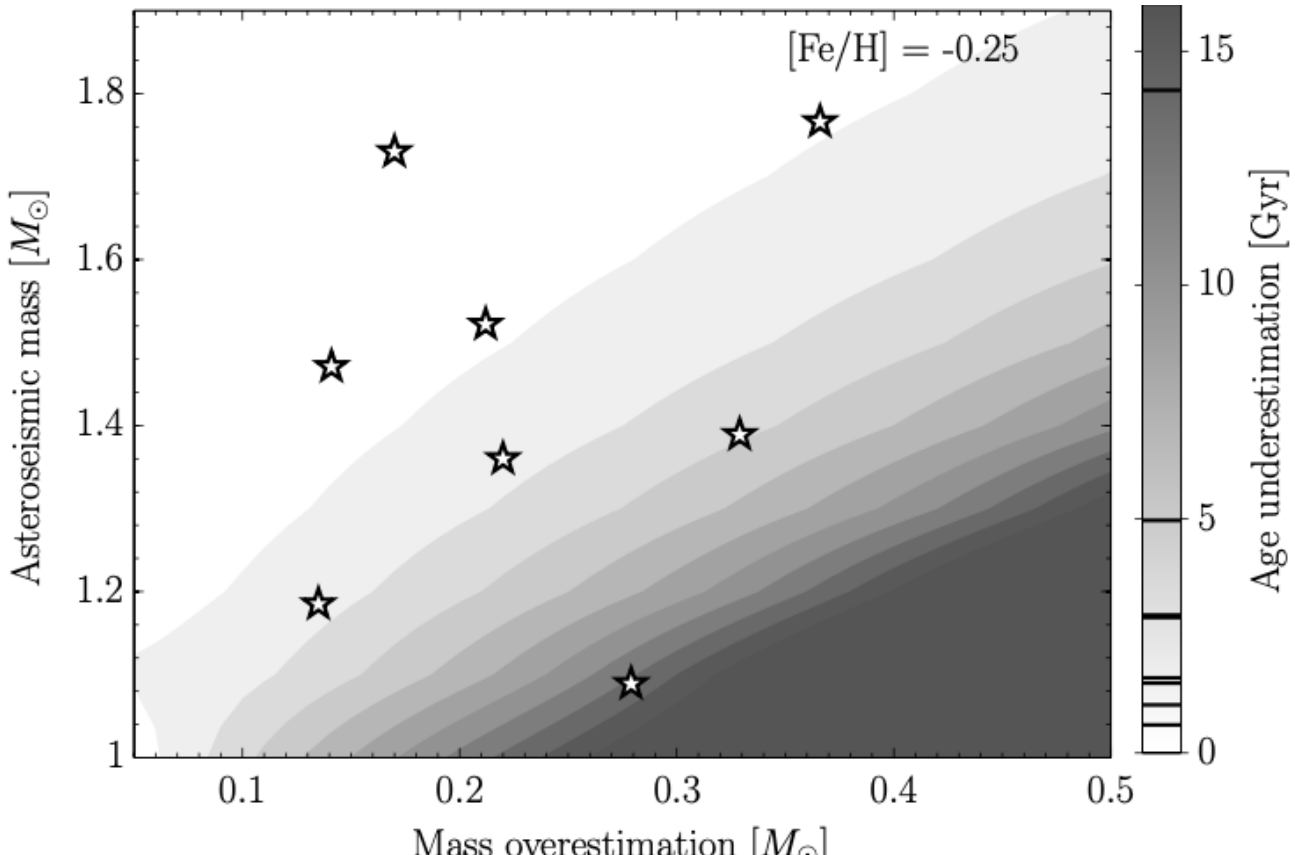
- Asteroseismology overestimate red-giant masses ~15% (Gaulme+ 2016)
- Mass overestimation leads to age underestimation
- Overpredict the number of high mass stars

Dynamical mass vs Asteroseismic mass



Gaulme+ 2016

Mass overestimation leads to age underestimation from up to 14 Gyr



Calibrating Asteroseismology

- Requires model-independent mass to calibrate

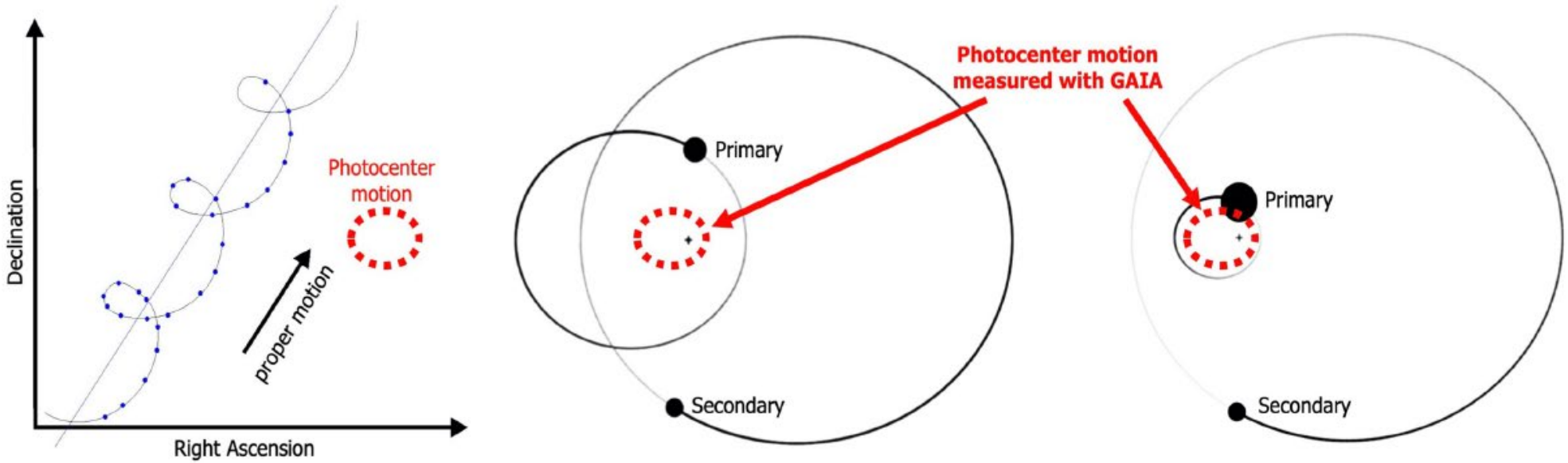
- 17 eclipsing binaries hosting oscillating red giants known
- No targets at other evolutionary phase than the RGB
- Require long time monitoring, not efficient

Gaia+Interferometry offers opportunity for more efficient model-independent mass!

Binary stars with Gaia

- Gaia DR3: First release of non-single star catalogue in 2022 June
- Limited angular resolution of 0.1”
- Photocenter orbits face stellar flux ratio/separation degeneracy

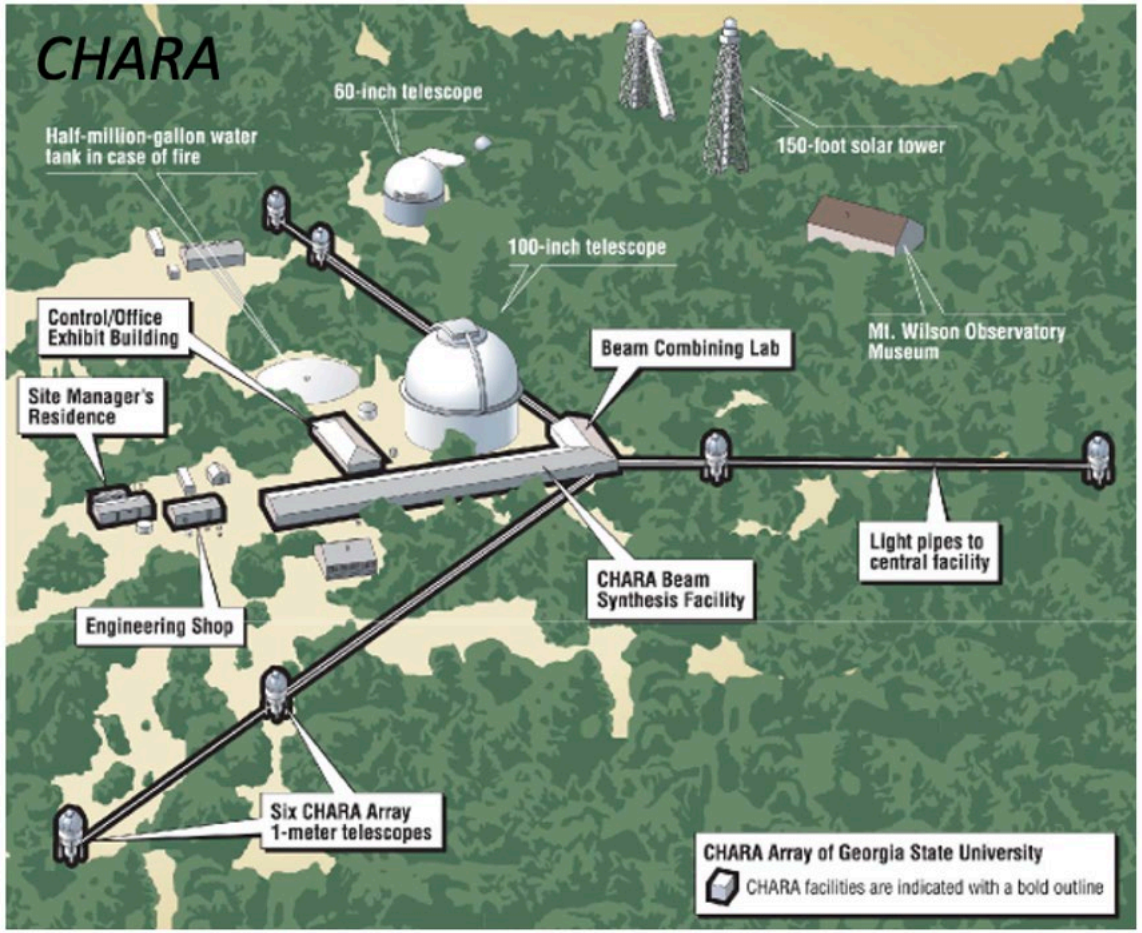
→ Incomplete orbital parameters: no position no dynamical mass



Binary stars with Gaia and interferometry

- Interferometry could break the degeneracy with **a single pointing ~ 30 mins**

- Gaia photocenter + Interferometry → Dynamical masses, precision ages and full 3D orbits for both components in more efficient way

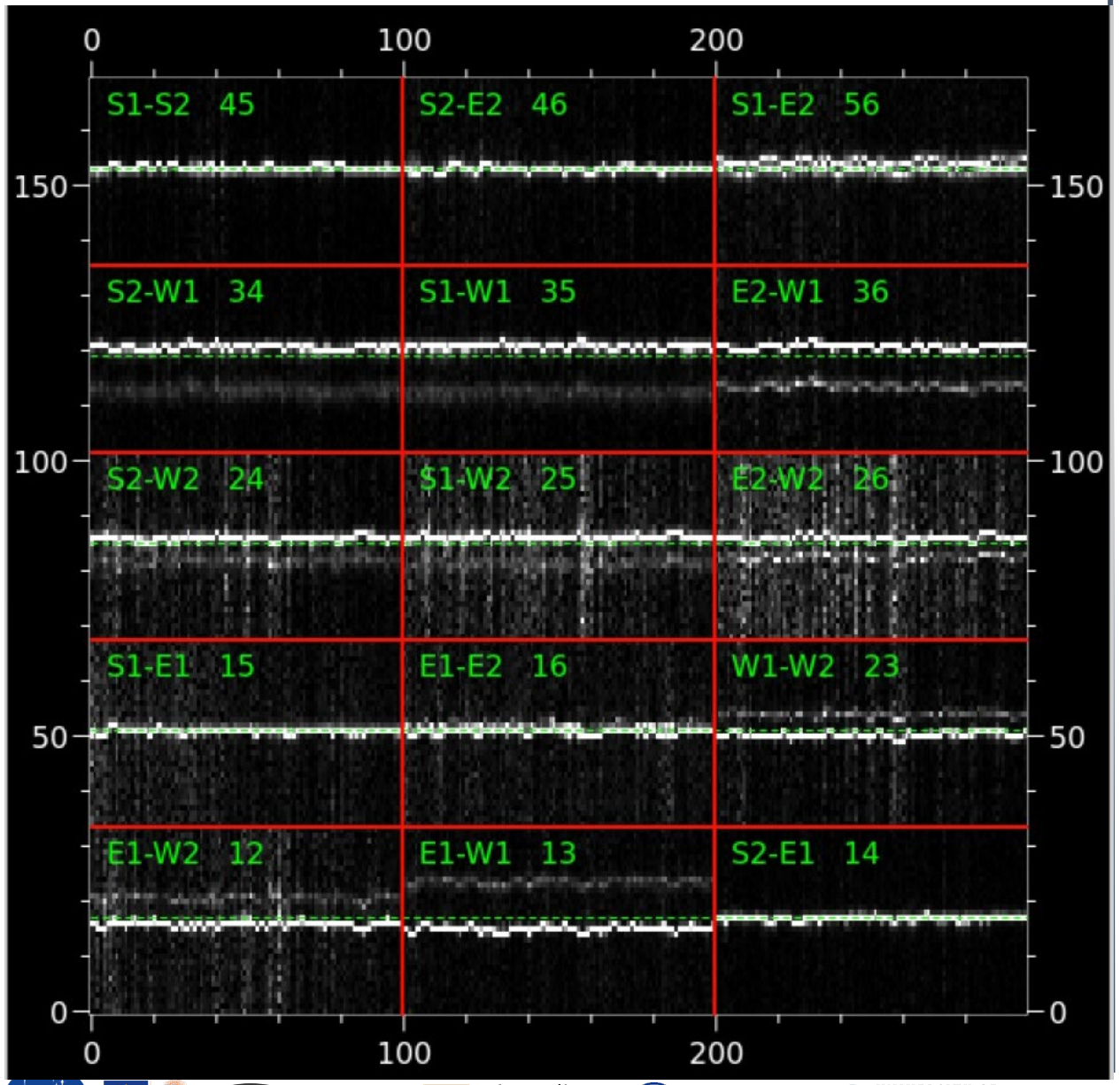


Observation

- Data sequence on CHARA
  - 10 minutes data + 5-10 minutes calibration frames
  - Calibrator source every ~3-4 targets

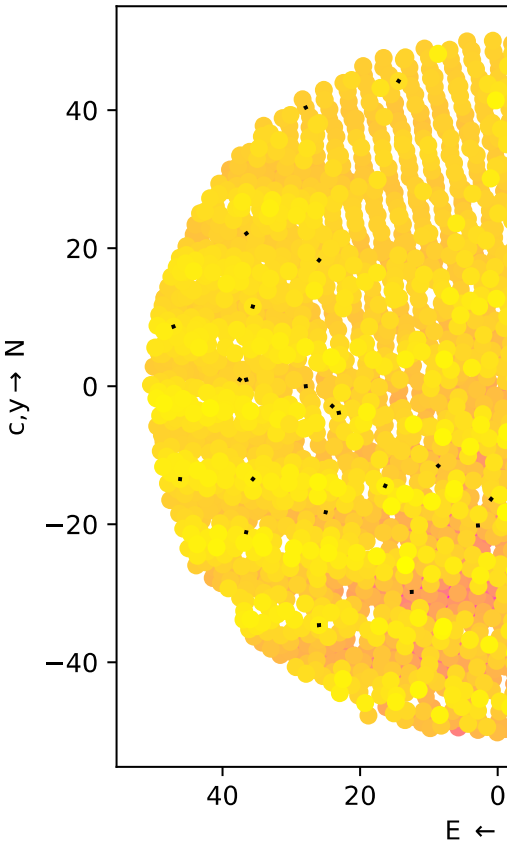
- Data sequence on VLTI
  - SCI+CAL within 1 hour
  - Longer integration on SCI

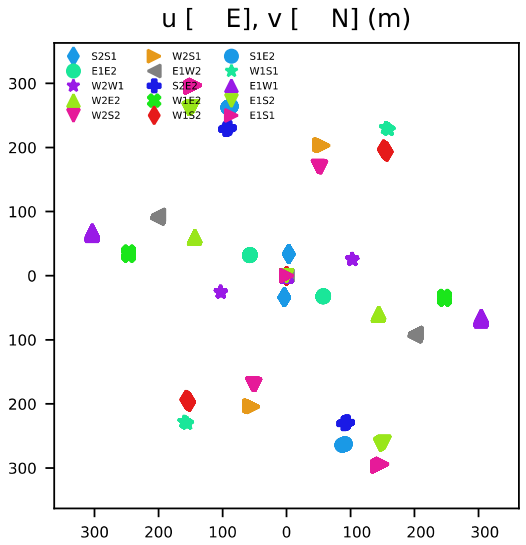
Fringes on a Binary Star with CHARA/MIRC-X:

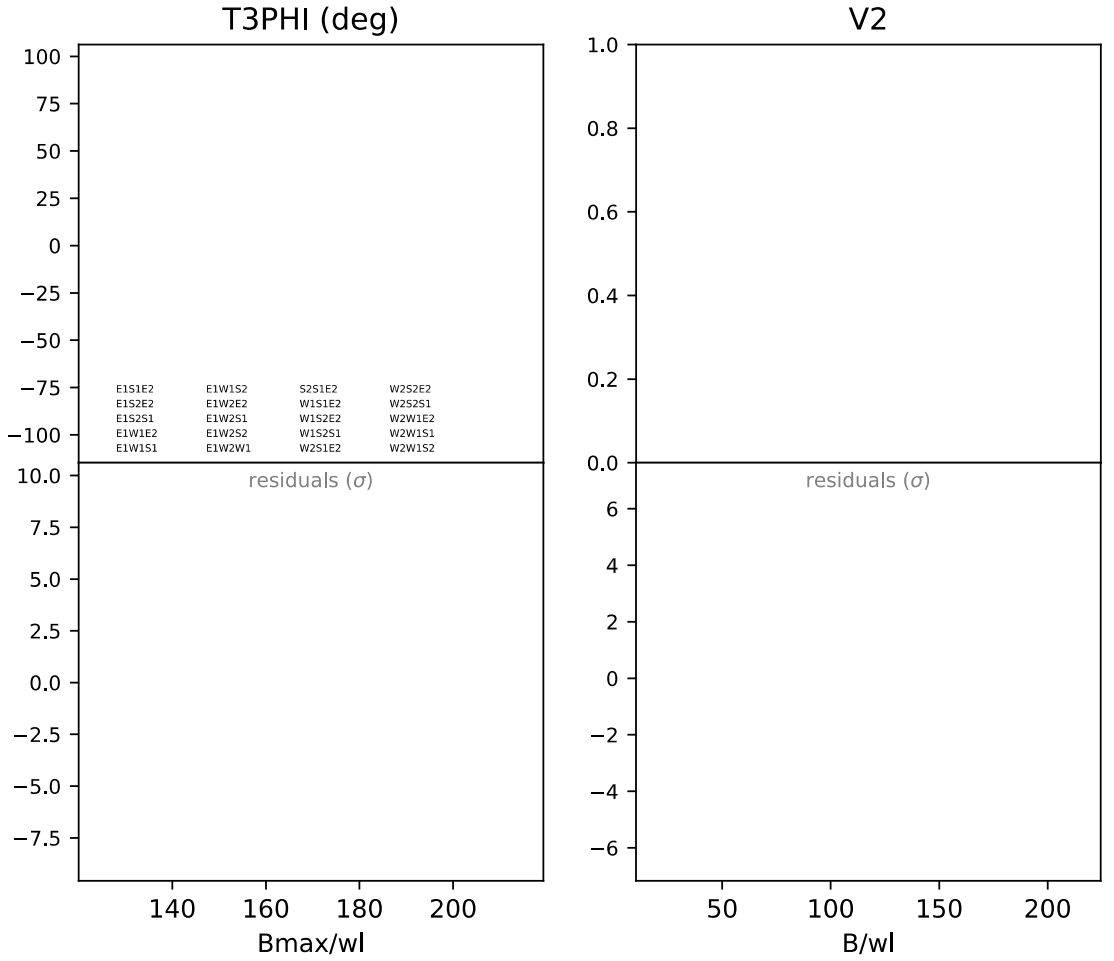


Methodology

- PMOIRED for model fitting (Antoine Mérand)





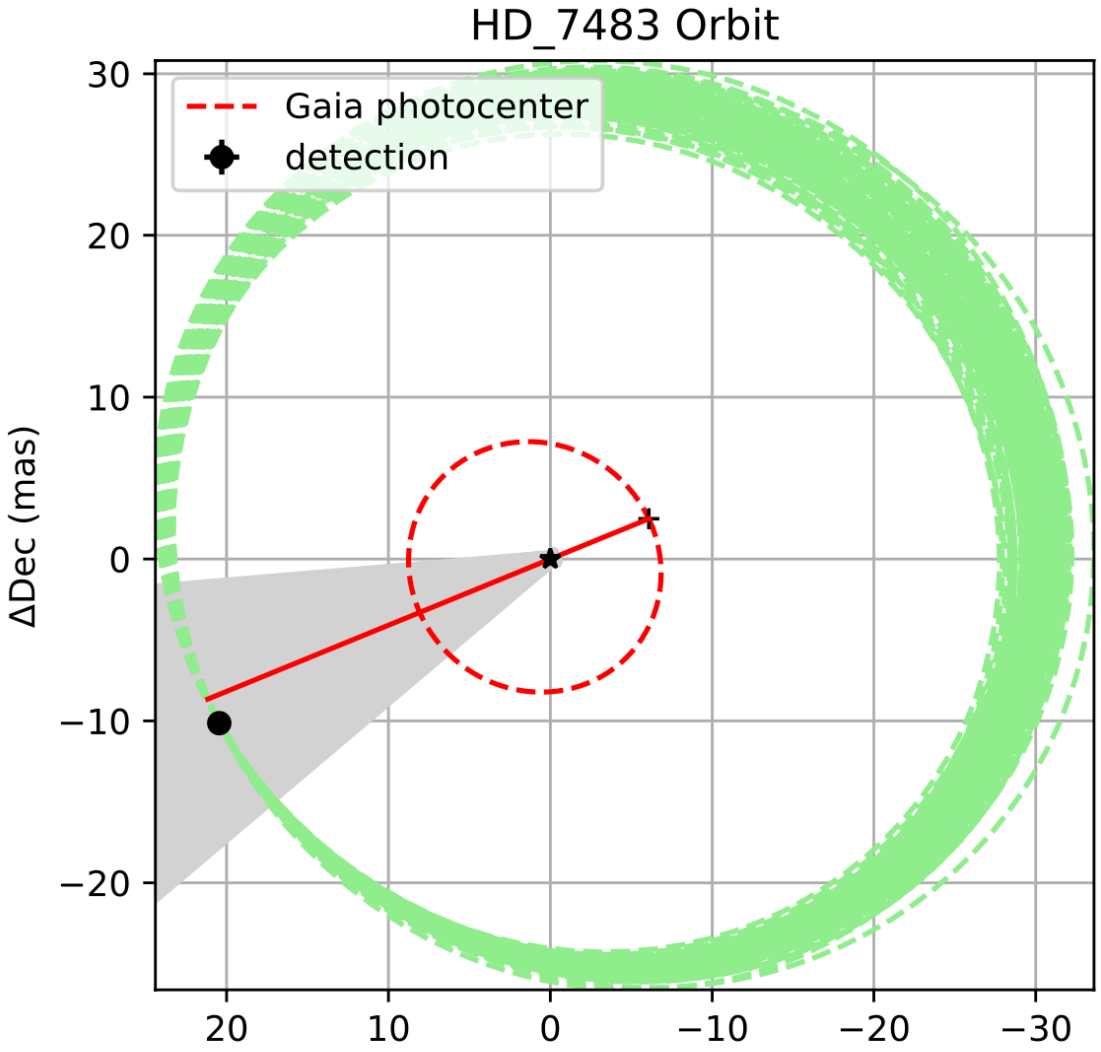


χ2 grid map for detection

Observables along with the best-fit model and residuals

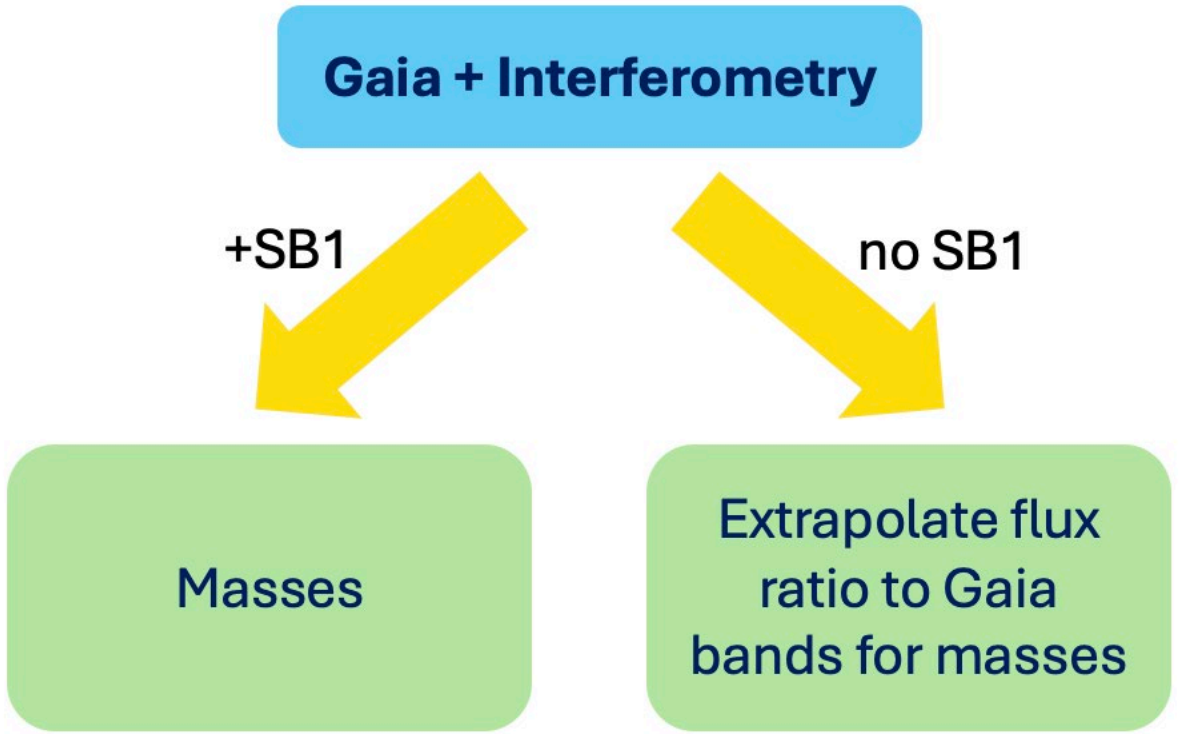
Methodology

- Gaia photocenter orbit → 'shape' of the orbit
- Interferometry → semi-major axis and flux ratio, 'scale' of the orbit

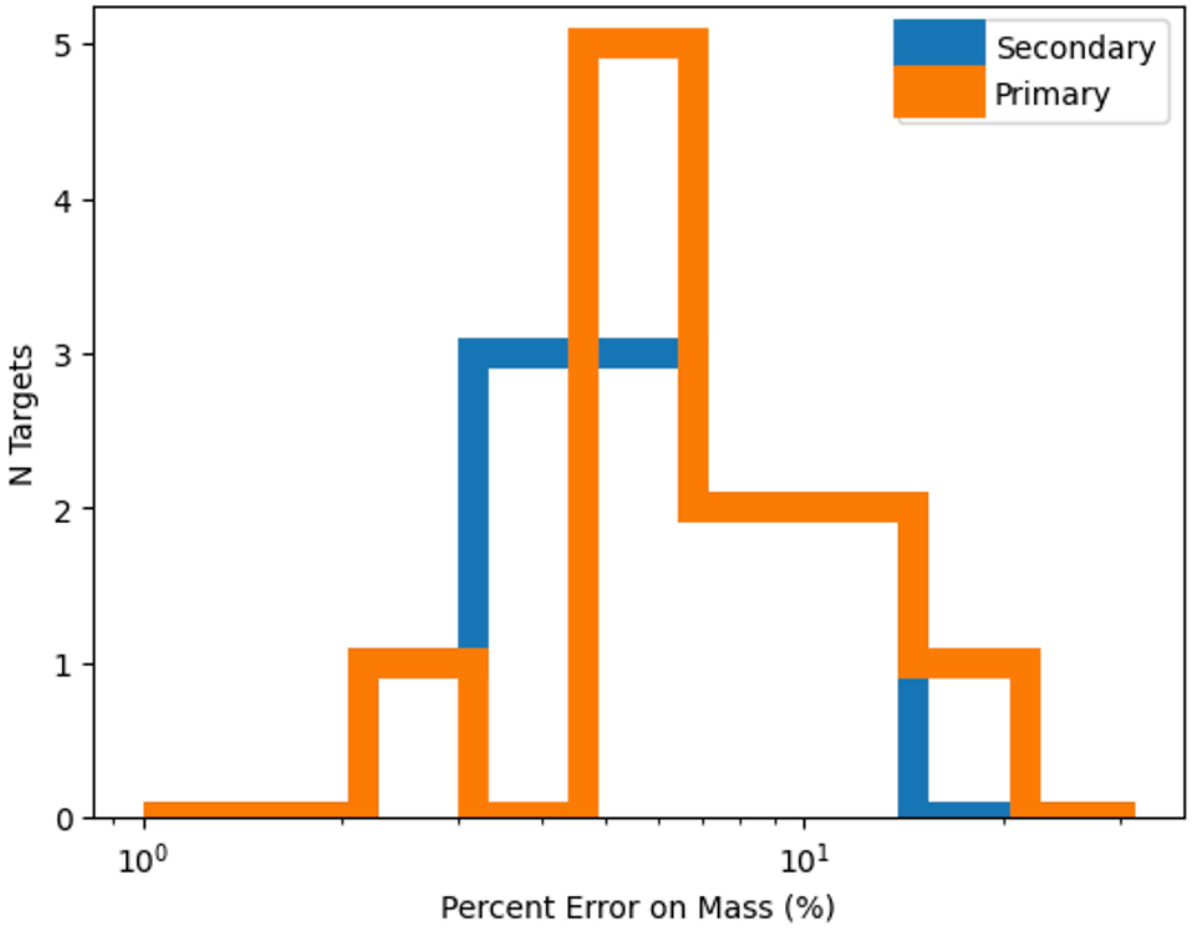


P=704.71±1.59 d e=0.14±0.02

- Non-linear least squares fitting for χ2 minimization
- Explore posterior distributions with MCMC routine



Statistics for Pilot Study



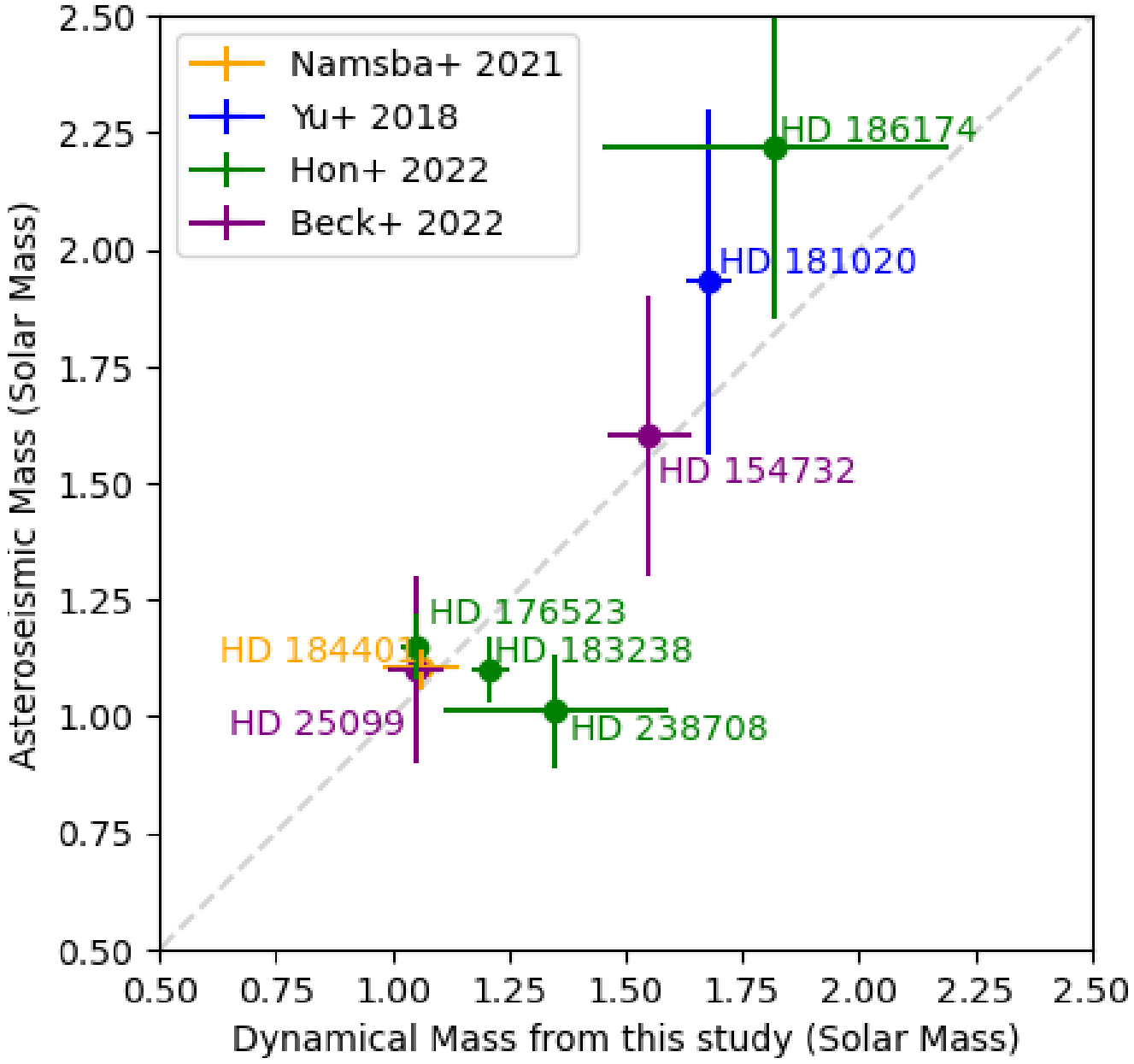
Current typical mass uncertainty ~ 4%-5%

Potential improvement on precision:

- Gaia DR4 (2026)
- J band on VLTI Asgard/BIFROST (2026) and CHARA (2025)
- Improved modelling
- Quantifying observational bias

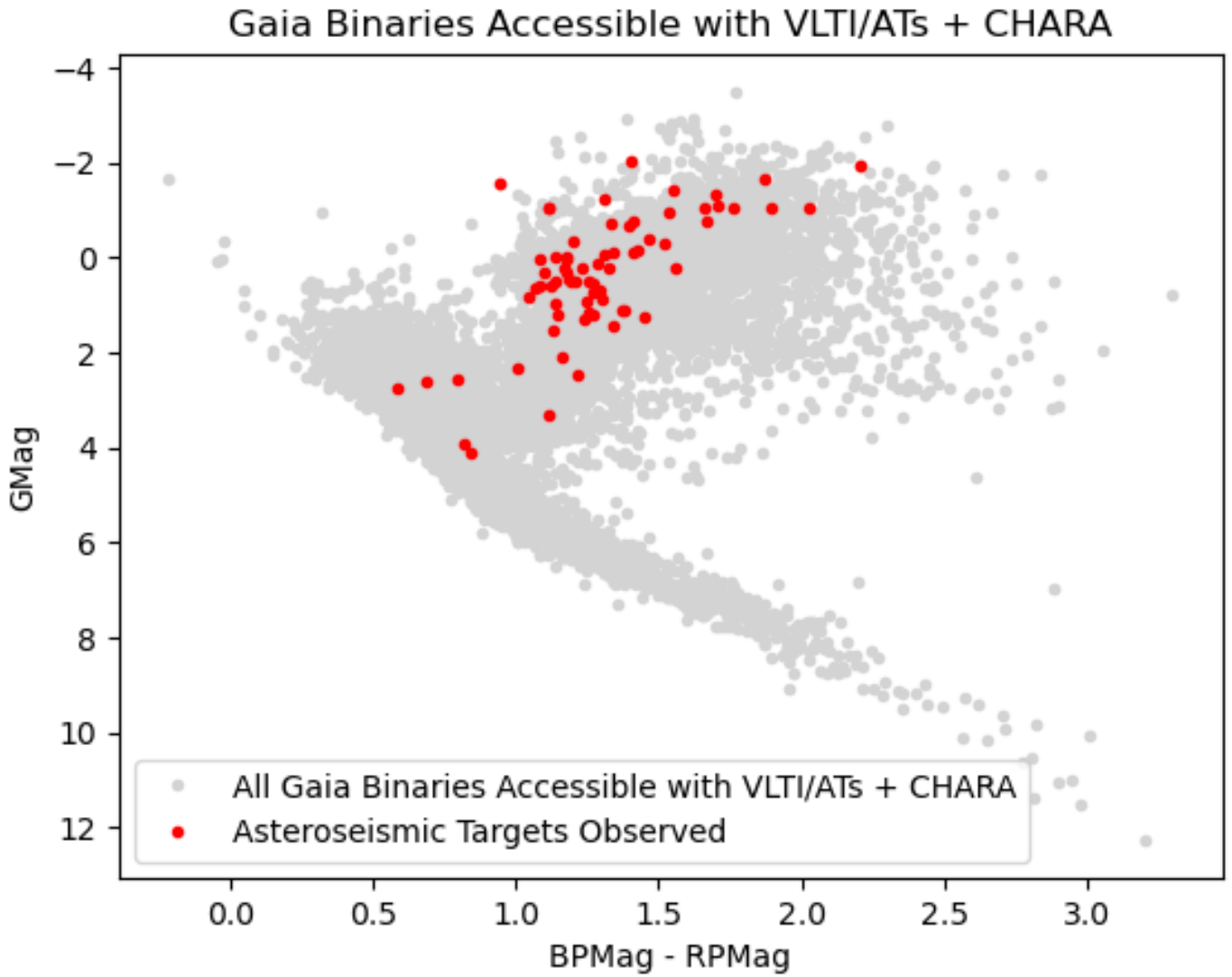
Aim to 2% in the end

Dynamical Mass vs Asteroseismic Mass



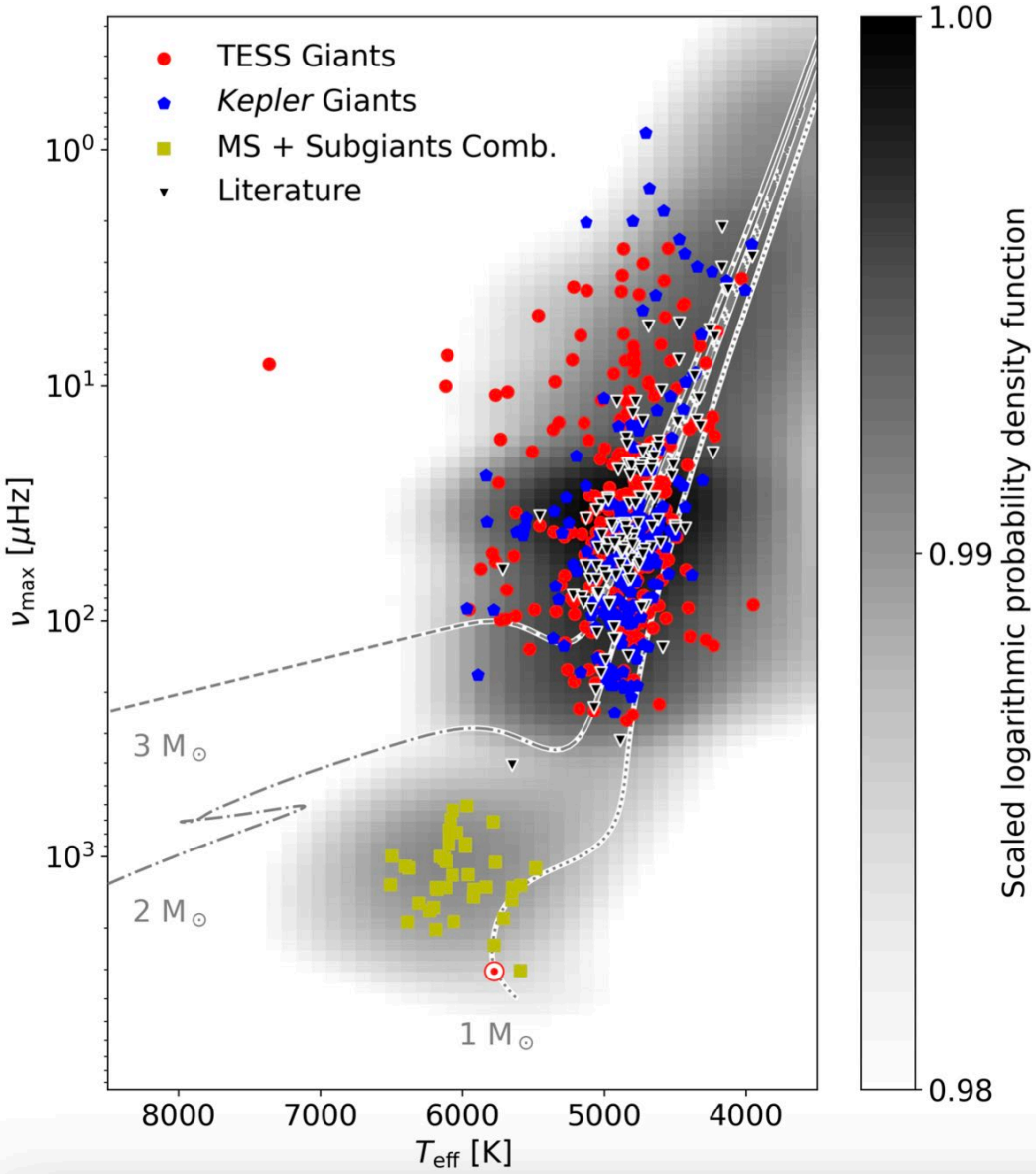
Lu+ 2025 (in prep)

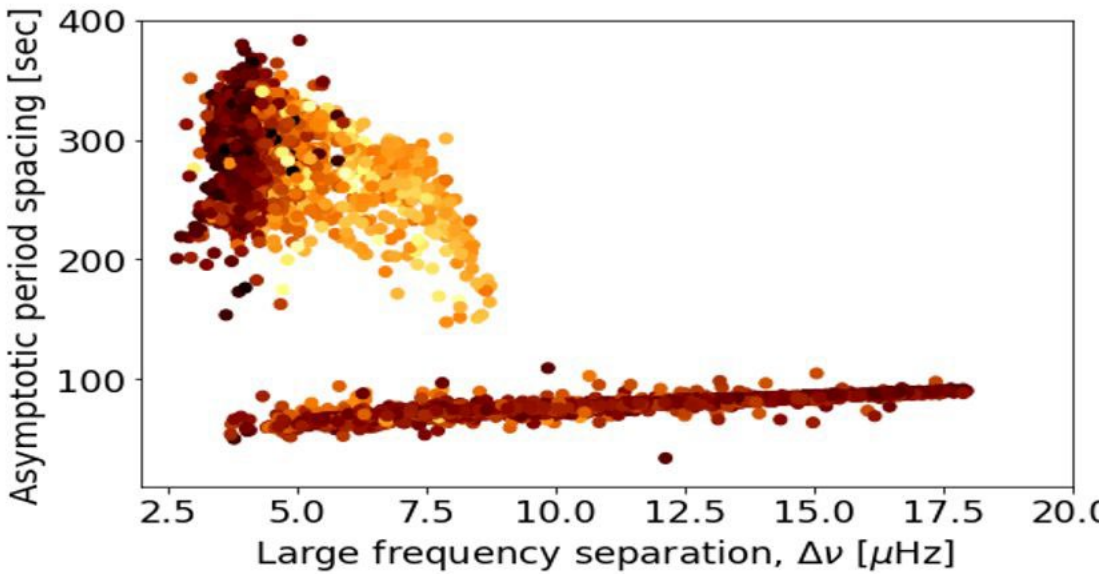
Overview of the Survey



- Record 70 so far, more to come
- Our method: main sequences, red clumps, subgiants
- CHARA: ONLY interferometer for MS and Kepler field
- Revise scaling relations
- Compare different correction methods
- Update published seismic masses
- Calibrate evolutionary track and models

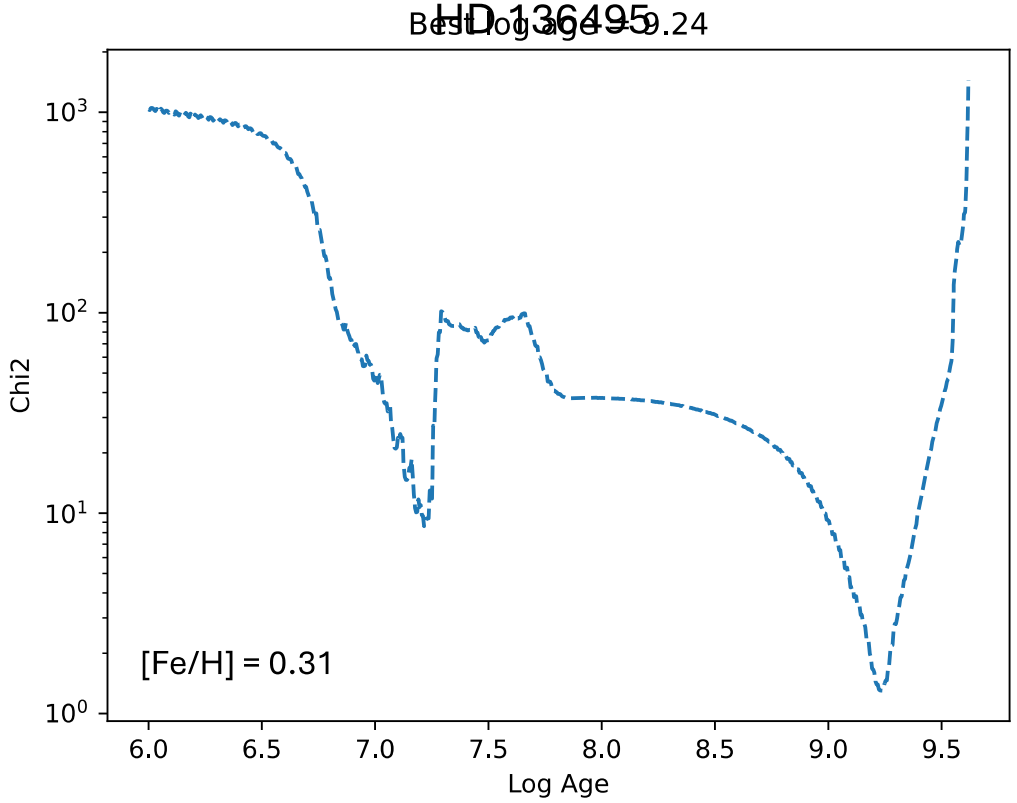
Definition of Evolutionary Stages

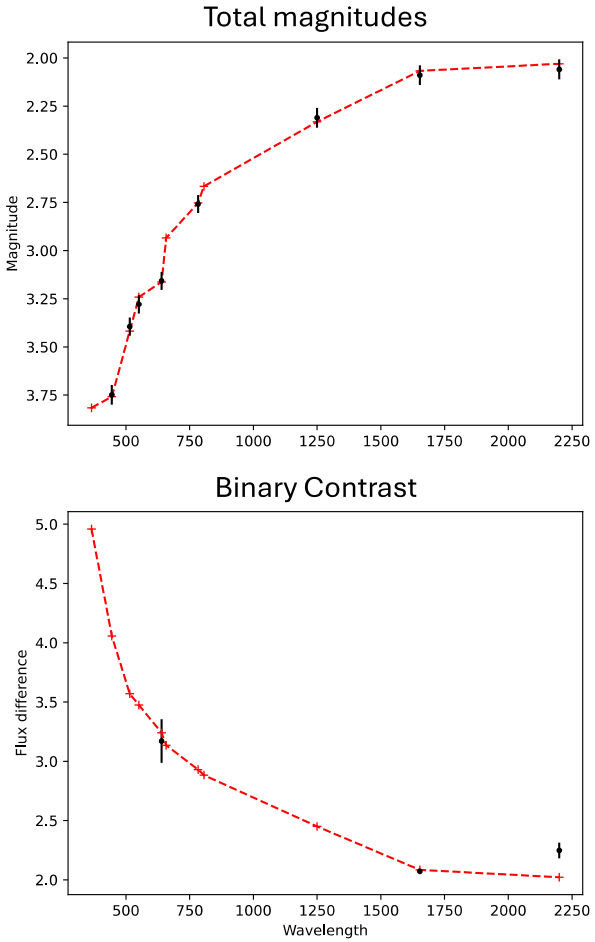




- $\Delta\nu$: Large frequency separation
- ν_{max} : Frequency of maximum amplitude
- $\Delta\Pi$: Asymptotic period spacing

Next Step: Age Estimation





- Use MIST to generate model magnitudes and flux ratio
- Use measured flux ratio and literature unresolved magnitude to grid over the age and metallicity

Summary

- Asteroseismology provides stellar mass measurements – **need calibration**!
- Currently only 17 eclipsing binaries with oscillating red giants known
- Model-independent masses with larger spread in period and evolutionary stage are required for calibration
- **Interferometry+Gaia provide model-independent mass within 30 mins**
- Increase the sample size and expand to other evolutionary phases
- Age estimation based on observation
- CHARA plays an important role in this study