# Does a Radius Measurement from Interferometry Complement Oscillation Frequencies ?

Orlagh L. Creevey(1+,2,3), Mario J.P.F.G. Monteiro(1), Travis Metcalfe(2), Timothy M. Brown(2)

(1)CAUP, Porto, Portugal; (2)HAO/NCAR Boulder, CO, USA; (3)IAC, La Laguna, Tenerife, Spain; + Visitor @ CAUP

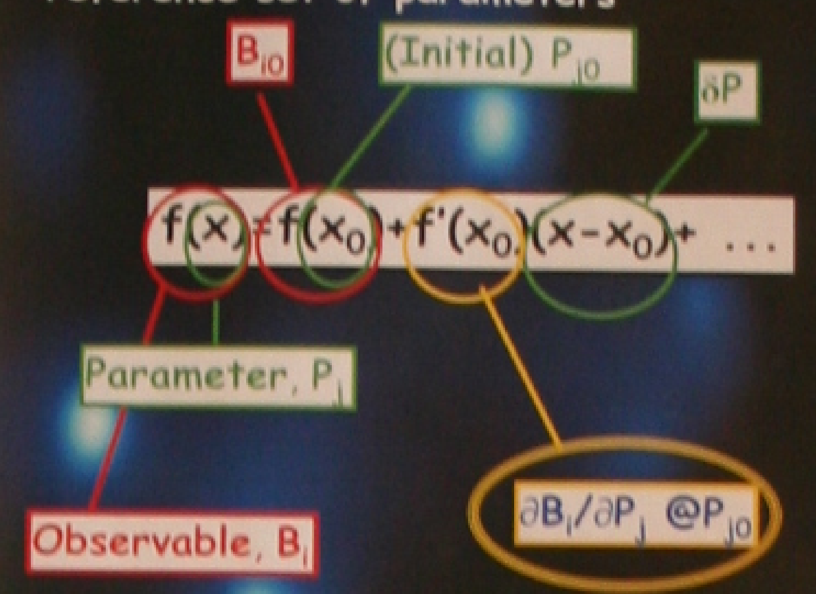
## 1. Introduction

Recent studies have shown that an independent radius measurement using interferometry allows us to measure the radius of a star with a precision of about 1% for the brightest stars (Pijpers et al. 2003) and it has been suggested that we could obtain a precision of up to 4% for most stars. Our interest is exploring how this radius measurement can complement oscillation frequency information. Can this radius measurement determine the mass of the star? And if it can, can we then use the frequencies to probe the physics of the star? How important is the radius for determining other parameters such as Age and Chemical Composition? And what is the effect on the derived errors?

Our study follows that presented in Brown et al. (1994) and Miglio and Montalban (2005). We use the information obtained from the derivatives of each of the observables with respect to each of the parameters to approach this study. We use the ASTEC/ADIPLS codes for stellar structure and evolution, and pulsation frequencies (Christensen-Dalsgaard 1982).

## 2. Mathematical Background

From the Taylor Series Expansion... we can always linearize any function or model in the neighbourhood of a reference set of parameters




$P_j$ : Mass (M), Age($\tau$), Hydrogen (X), Metallicity (Z), mixing-length parameter ($\alpha$)

$B_i$ : Radius (R), Teff (T), Luminosity (L) Magnitudes (V), Colours (V-R), Frequencies ($\nu$), Frequency separations($\Delta\nu$, $\delta\nu$)

Given real observations $O_i$ with errors $\sigma_i$ we can find the solution by using the following:

$P_{real} = \delta P + P_{j0}$ where

$\delta P = VW^{-1}U^T \delta B$ (Eqn 1)

$\delta B = (B_{i0} - O_i)/\sigma_i$

$\partial B_i/\partial P_j \; \sigma_i^{-1}$ → Singular Value Decomposition → $UWV^T$

Even with no observations, we can always study the relationship between the parameters and observables :

Significance of each observable for the determination of the parameters

$S_j = ( \sum_i U_{ji} )^2$ (Eqn 2)

Covariance Matrix

$C_{jk} = \sum_i V_{ji} V_{ki} / W_{ii}^2$ (Eqn 3)

## 3. Significance of the Observables

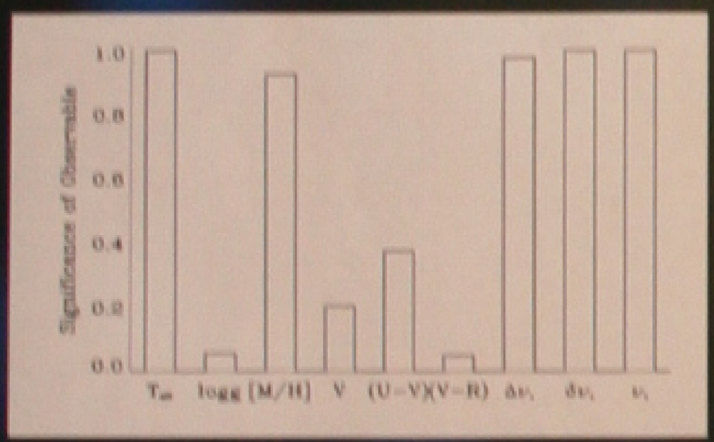


Figure 1: Significance of each of these 9 observables for determining the parameters of the star.

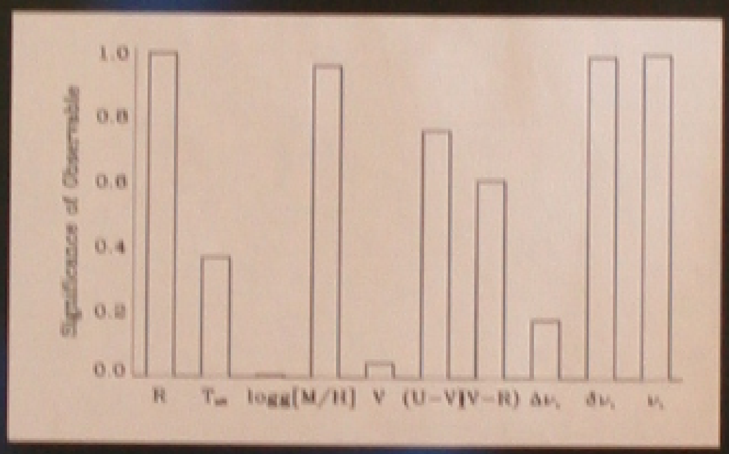


Figure 2: The addition of a radius meausurement changes the importance of the observables

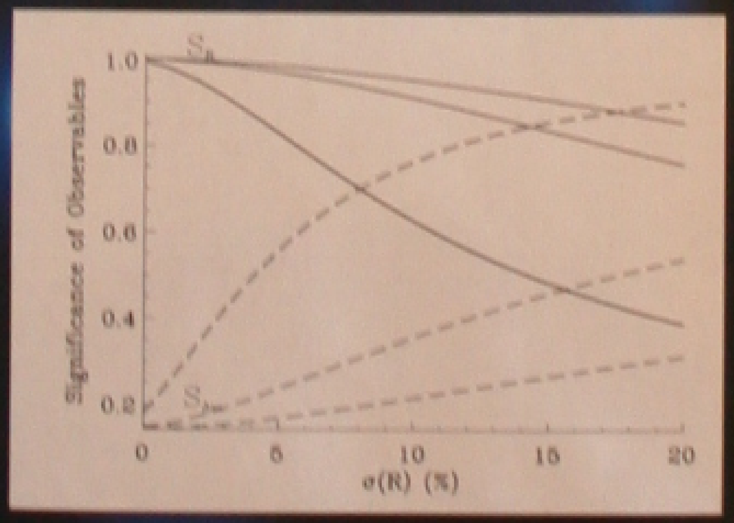


Figure 3: Change in importance of R and $\overline{\Delta\nu}$ as the error on R increases, the other lines show the same but for larger frequency errors.

Using equation (2), figure (1) shows how the significance of each of the observables compare to each other in the case of just having those 9 observables. In particular the oscillation frequencies (the mean large and small frequency separation + an individual frequency) are important for the determination of the parameters of the star. Figure 2 shows the same graph but including a radius measurement. Note how $\overline{\Delta\nu}$ is no longer important. As we make the error on the radius worse, the radius becomes less important for the determination of the parameters, meanwhile $\overline{\Delta\nu}$ increases in significance (Figure 3).

## 4. Determination of the Parameter Errors

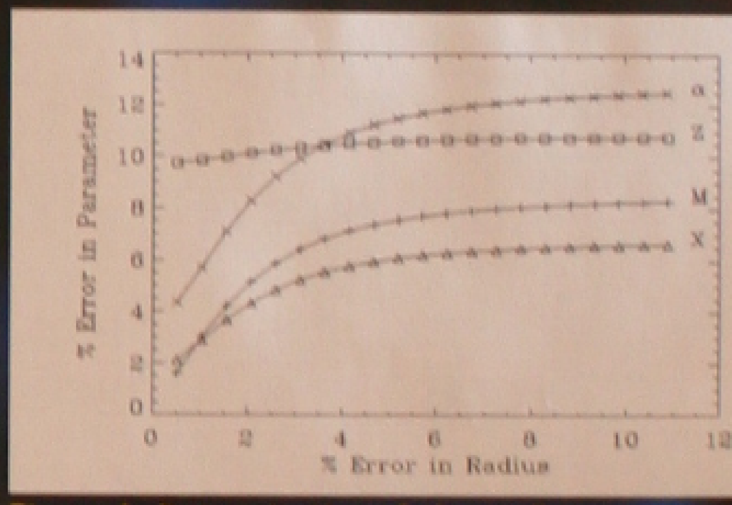


Figure 4: Determination of the stellar parameters as a function of radius error.

We assume a real case scenario, the observables we have are R, T, [M/H] + a set of $\Delta\nu$ and $\delta\nu$ for a range of values of n. With an expected error on T of 100K, of .05 on [M/H] and an error on the frequency of 0.5μHz (Corot expected error), we show how well we can determine each of the parameters of the star as a function of radius error. We see that it is only when we reach a precision of radius of about 4% or less, the error on each of the parameters begins to decrease notably. It is in this region where the radius becomes the important observable. This trend changes as we worsen the frequency errors. The error on the age is much larger.

## 5. How well can we recuperate the mass?

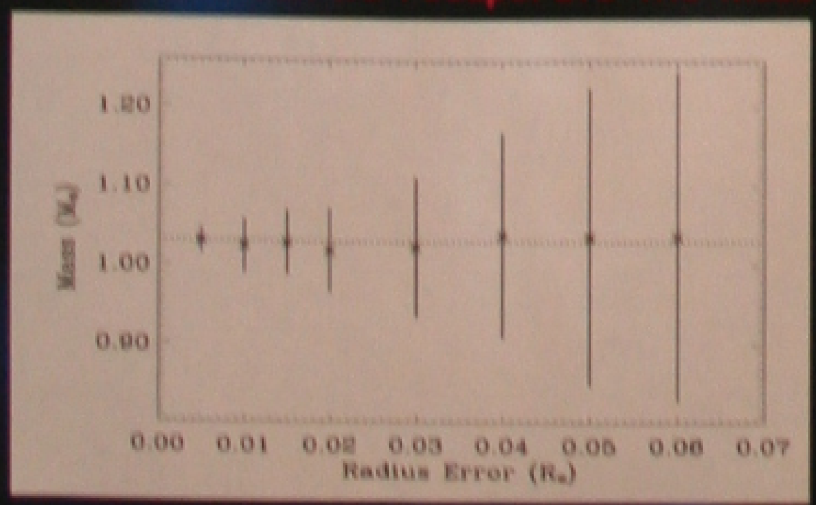


Figure 5: How well we can recuperate the mass of the star using just R,T,[M/H] and $\overline{\Delta\nu}$, $\overline{\delta n}$

We simulated observations by adding gaussian errors to the expected observables of a particular model with M=1.03M⊙. We used just 5 observables (see caption). Using Equation 1 we obtained the $\delta P$ that should return the real parameters. Our $P_{j0}$ all had masses of ~.9M⊙. Figure 5 shows how well we recuperate M as a function of increasing R error. At a precision of ~1%, we can estimate the mass to within 2%. Figure 6 shows just the precision (standard deviation) of the simulations (black) with the theoretical error from equation 3 (red). The theory and the simulations agree. Figure 7 shows the same as 6 but for the precision obtained for X.

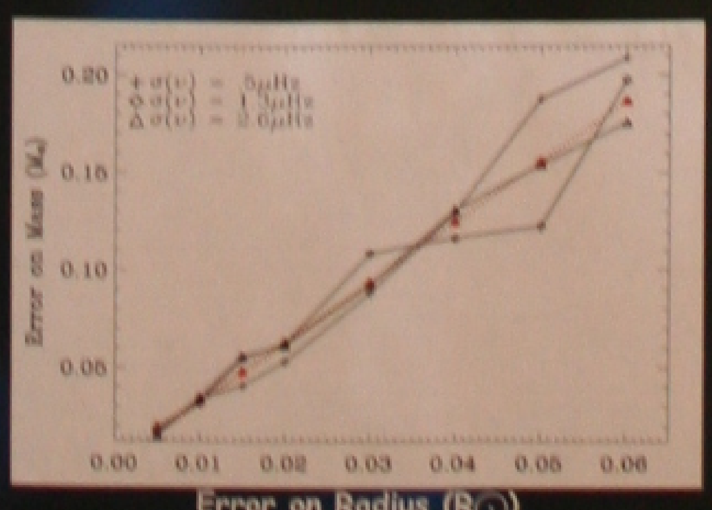
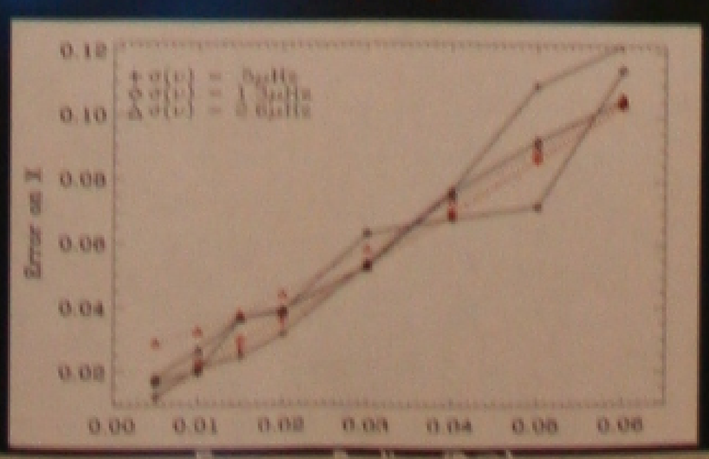


Figure 6: Comparison between the theoretical errors (red) on the mass determination and those resulting from the simulations (black).

Figure 7 : Same as Figure 6, but for the determination of the hydrogen abundance.



## 6. Preliminary Conclusions

- The radius is important for the determination of stellar parameters (Figure 2).
- The size of each of the observational errors will dictate how important they become. In particular we noted how the $\overline{\Delta\nu}$ had little role to play when we had a good radius determination (Figure 2 & 3).
- Given the expected error on frequency that Corot will obtain, we need to know the radius to a precision of 4% or less in order for this observable to be important (Figure 4).
- If we obtain an error on radius to 1%, simulations predict that we should be able to recuperate the mass of the star to within 2% while just using direct inversions (Figure 5).
- Simulations reproduce the expected error predicted by theory (Figure 6 & 7).

### References

Brown et al. 1994, ApJ, 427, 1013
Christensen-Dalsgaard, 1982, MNRAS, 199, 735
Pijpers et al. 2003, A&A, 346, 586
Miglio & Montalbán, 2005, A&A, 441, 615

Background Image Credit:
NASA/CXC/Northwestern U./C.Law & F.Yusef-Zadeh