Asteroseismology with Pulsating White Dwarf Stars

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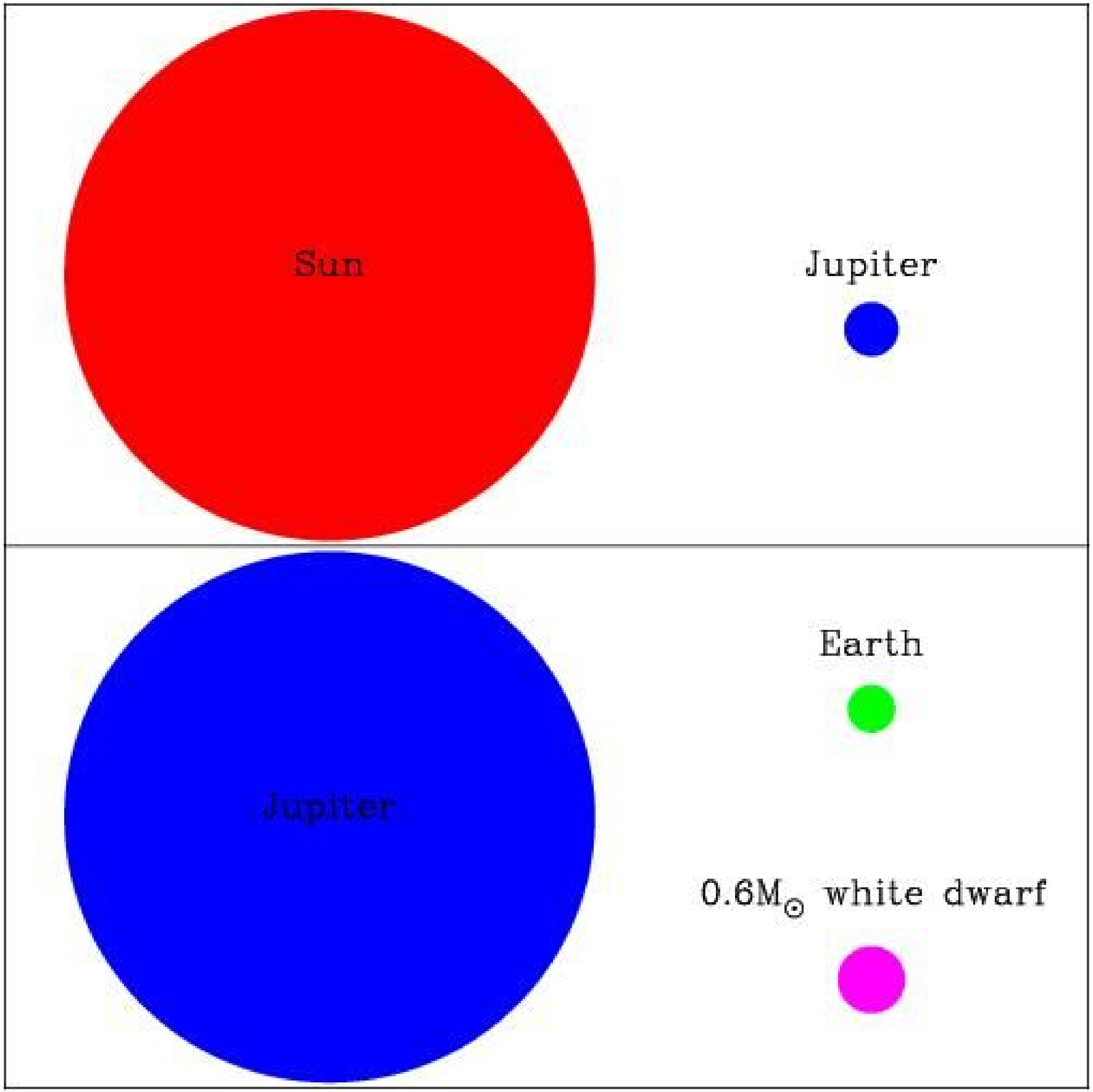
Talk Format

- white dwarfs and WD models
- asteroseismology: pulsating WDs : DAVs and DBVs
- WD issues – (1) core composition (C/O)?, (2) cooling rate (plasmon neutrino cooling flux and core crystallization), (3) WDs as galactic time pieces, (4) WD structure
- time-series photometry (3 channel photometer vs CCDs --> frame-transfer CCD photometer)
- the DBV EC20058-5234 (discovered 1994, WET run in 1997, observed regularly since the by DJS)
- example light curves and DFTs (Mt John, WET and Magellan 6.5-m telescope
- prewhitened DFTs and false alarm probability

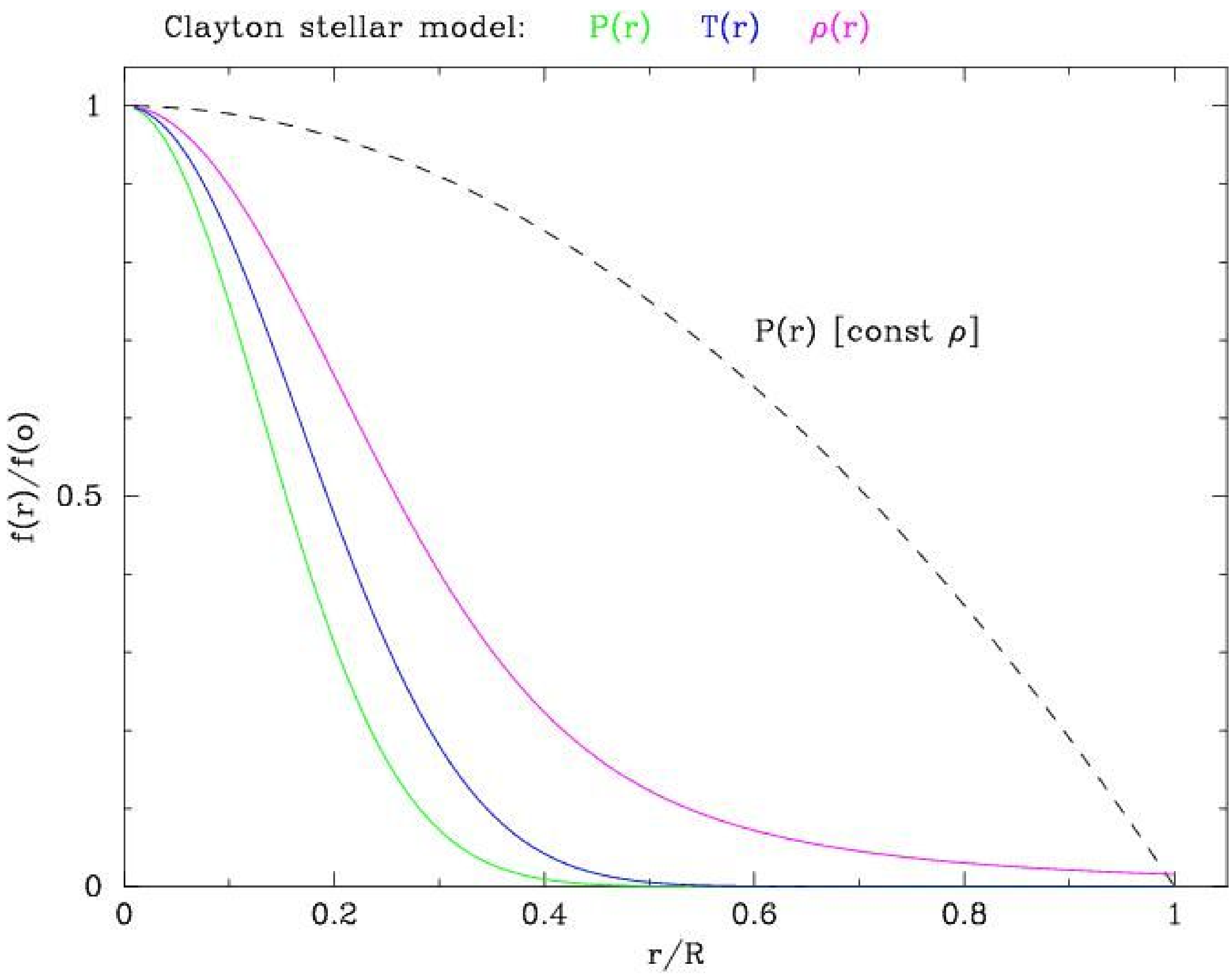
white dwarfs

- Almost 99% stars eventually become WDs
- Energy producing nuclear reactions have ceased
- WDs slowly cool to observational oblivion by emitting photons from surface, and in hotter stages plasmon neutrinos directly from hot core
- WD models are relatively simple – a C/O (?) core, an atmosphere & a degenerate electron gas
- hydrogen (DA) versus helium (DB) atmosphere white dwarfs

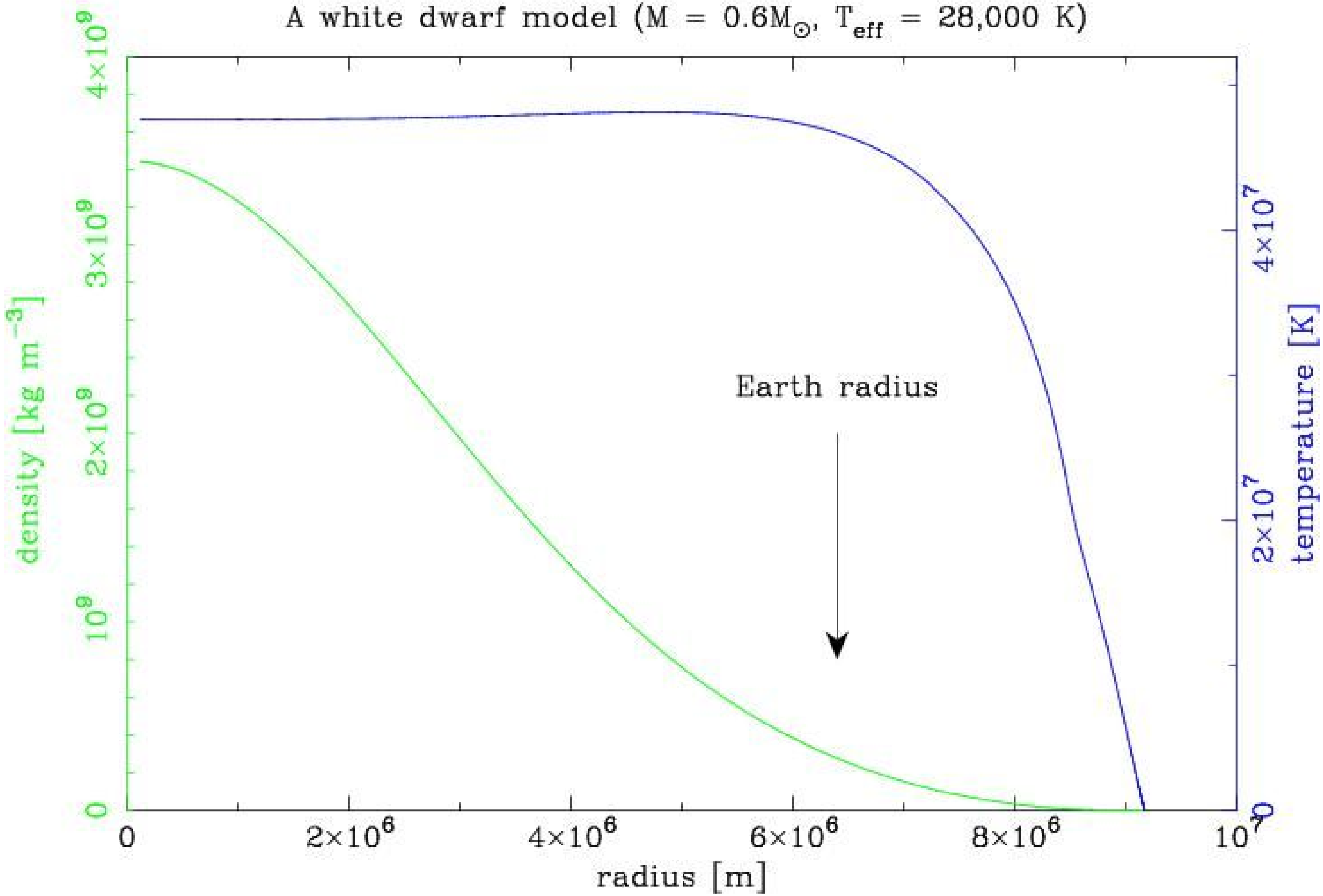
Comparison of size of a WD with other objects



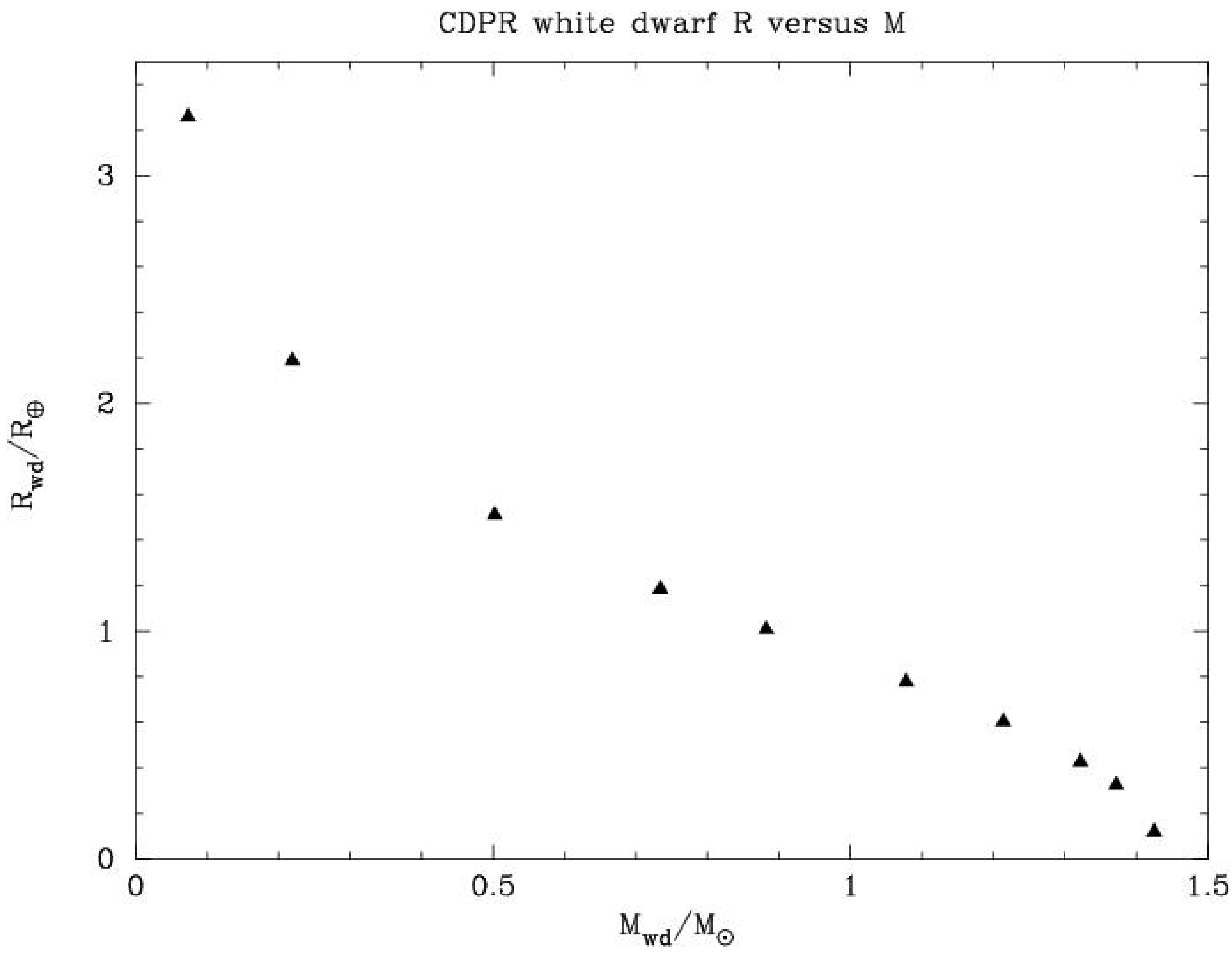
Simple stellar model of a nuclear burning star



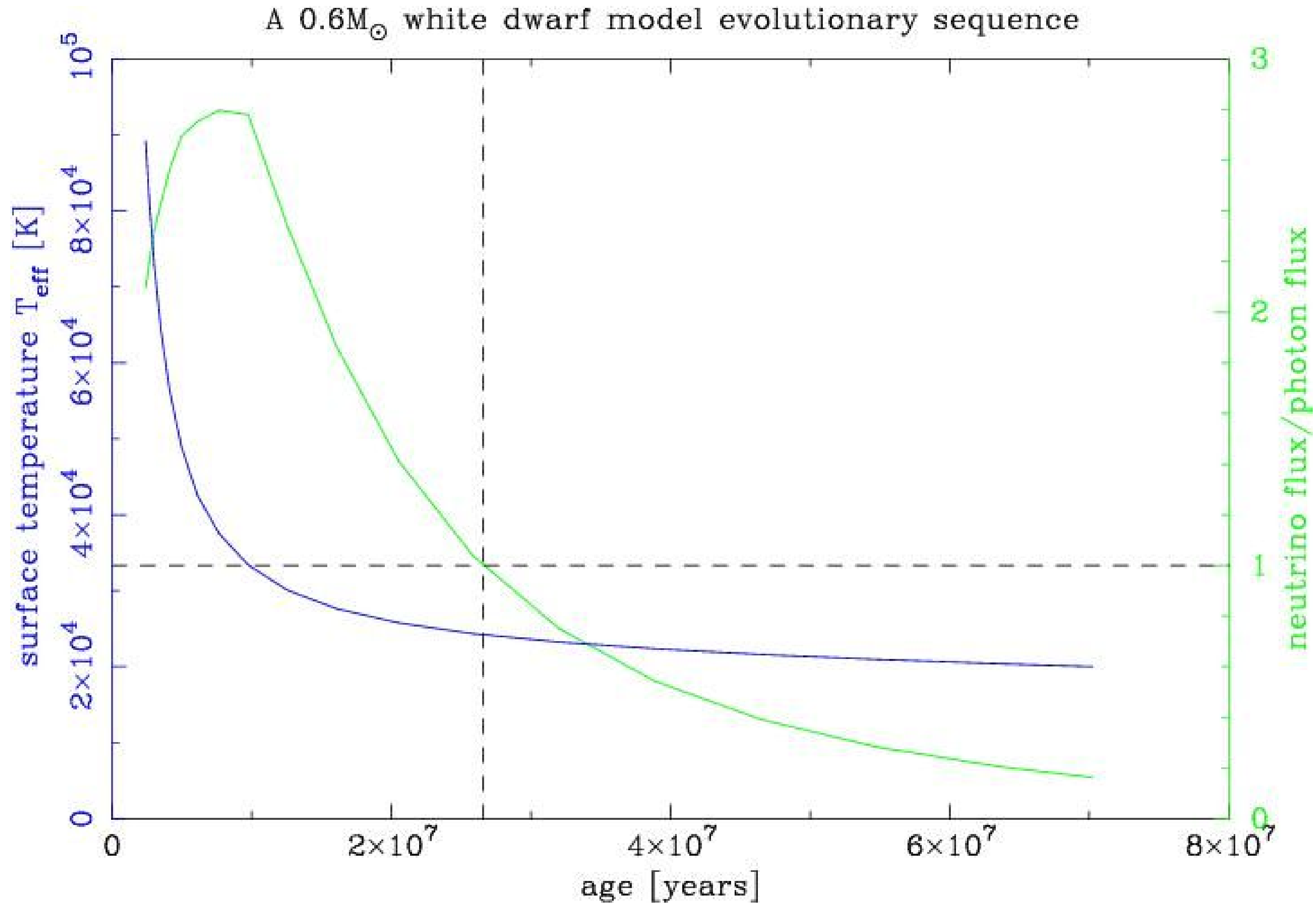
A white dwarf stellar model



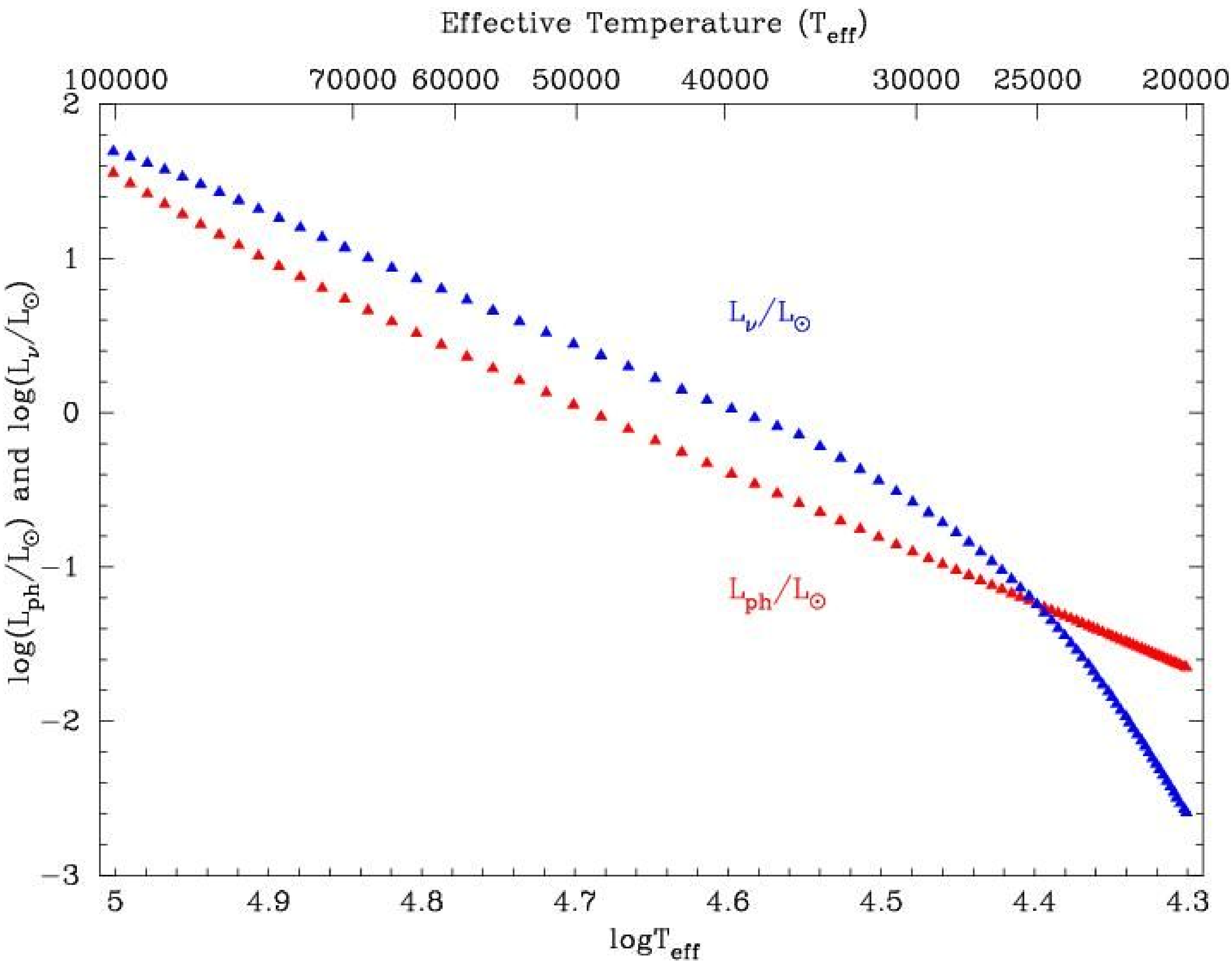
Completely degenerate (cold) white dwarf models
R vs M (Chandrasekhar's theory)



White dwarf model evolutionary sequence

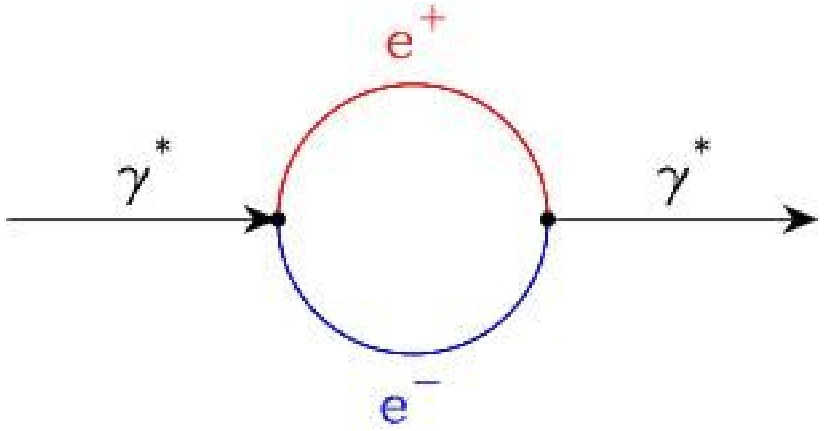


WD cooling flux: photons versus neutrinos

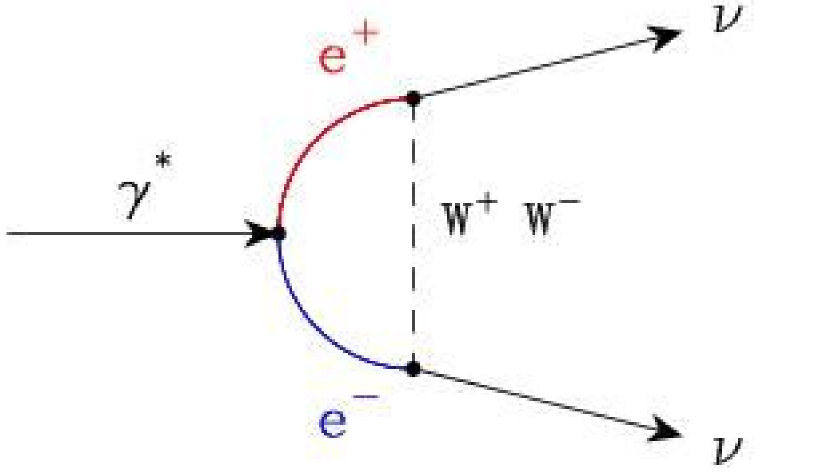


Neutrino generation in dense WD plasmas via decay of plasmons (massive photons) [electroweak theory]

plasmons continuously create virtual electron positron pairs which recombine back into photons almost all the time.



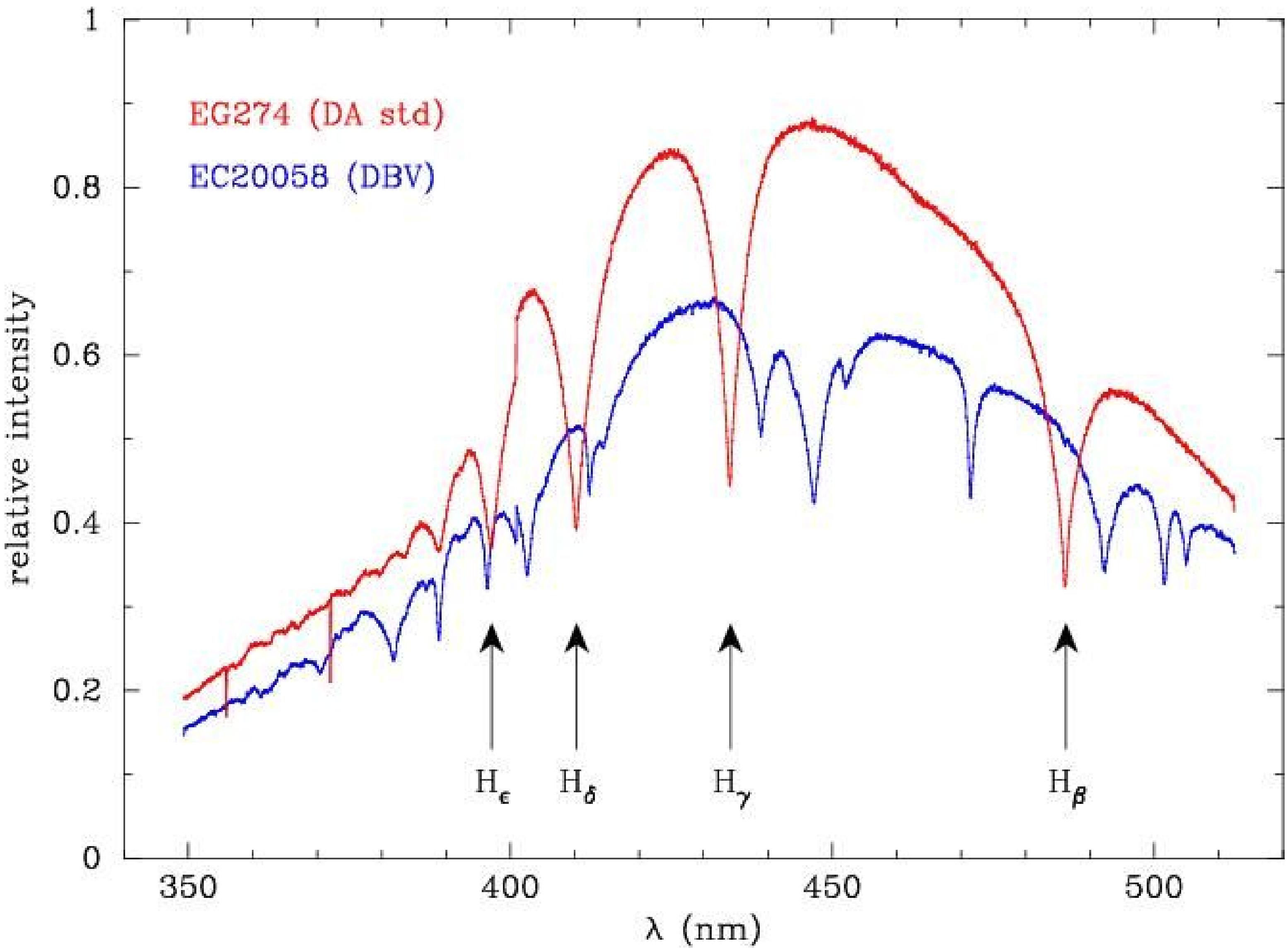
Occasionally e+, e- pairs exchange a W boson, creating a real neutrino/antineutrino pair, which escapes the core (carrying energy)



Pulsating white dwarfs

- [Very hot (DOV) prewhite dwarfs: Teff > 100,000 K]
- Hot helium atmosphere DBVs – Teff ~ 25,000 K
- Cooler hydrogen atmosphere DAVs – Teff ~ 12,000 K
- nonradial gravity modes driven by buoyancy forces in partial ionization zones near surface.
- DAVs accidentally discovered in the late 1960s
- DBVs discovered after a targeted search in early 1980s

Magellan 6.5-m spectroscopy of 2 WDs
DA (H atmosphere) & DB (He atmosphere)



Observing the pulsating white dwarfs

- frequencies with periods in the range ~ 100s – 1000 s. Rich array of pulsation modes gives many possible frequencies --> multiperiodic pulsators.
- Need high-speed time -series photometry techniques.
- Suitable instrumentation (need comparison & sky)
  - two/three channel P/M photometer
  - CCD (preferably frame-transfer) photometer.

VUW 3 channel P/M tube photometer at Mt John (NZ)

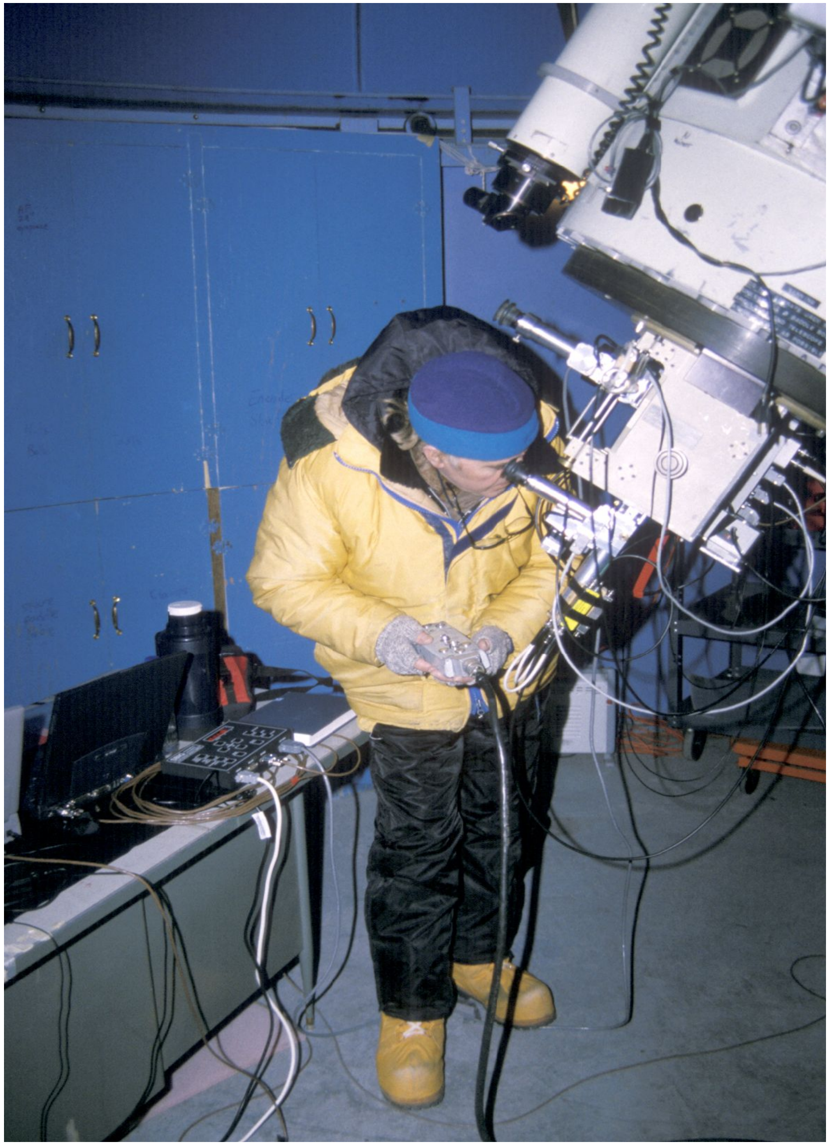
Mt John 1.0-m telescope (NZ South Island)

Mt John and snow

Mt John and more snow

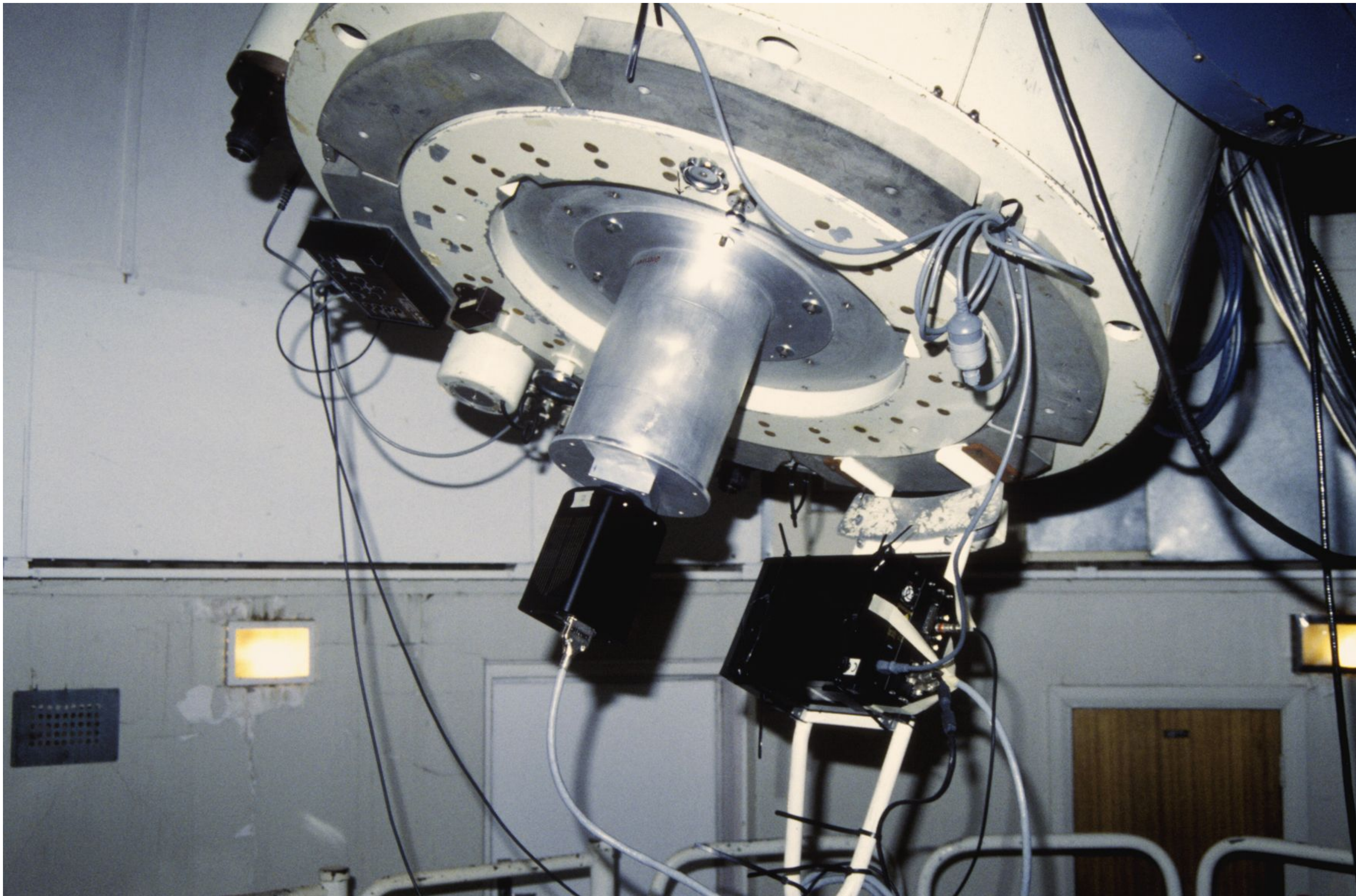
The 3 channel photometer is reasonably portable

The 3 channel photometer on the U of H 0.6-m telescope at Mauna Kea Observatory, Hawaii

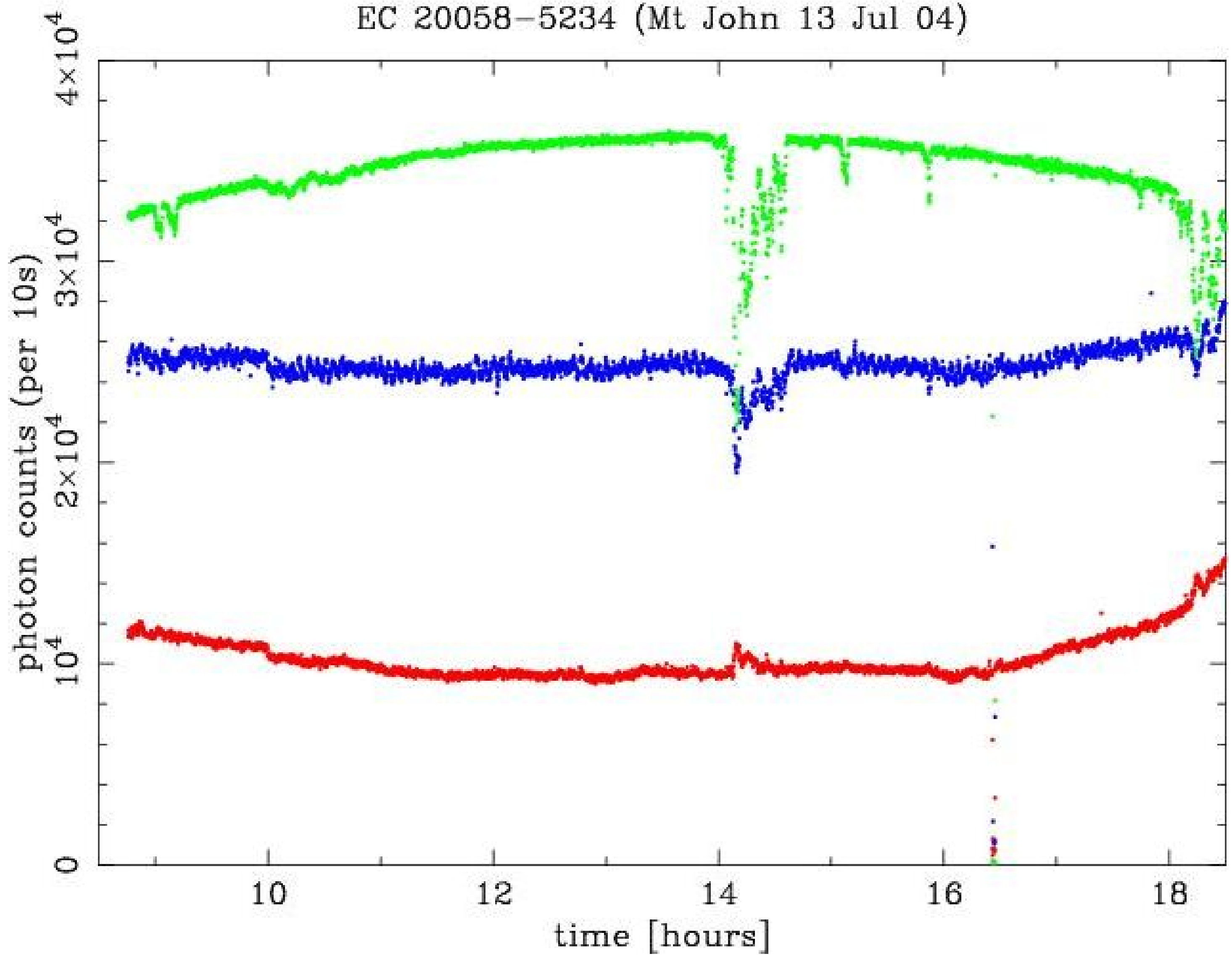


You need to be suitable dressed in the 0.6-m dome

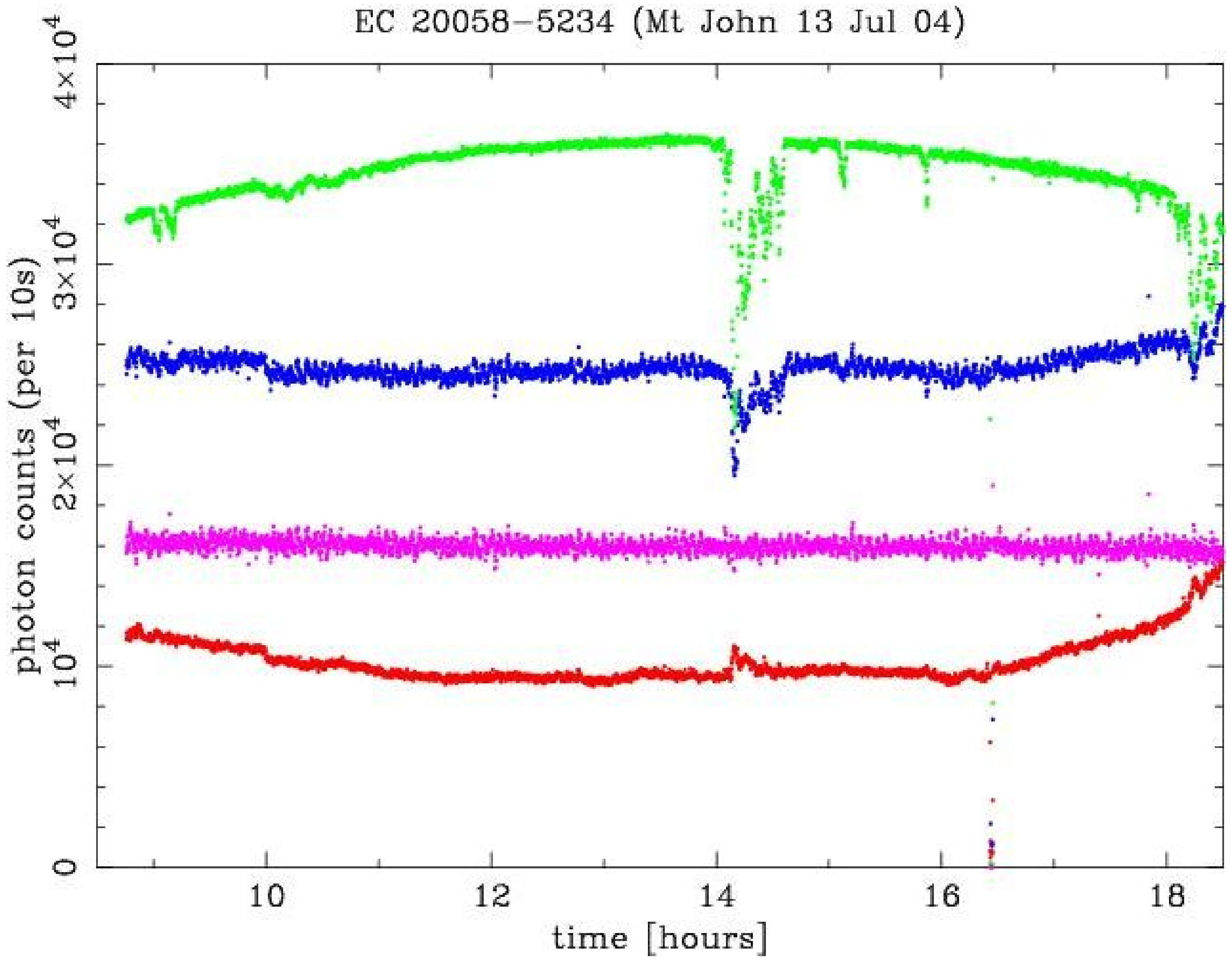
My new toy on the 40-in telescope, SSO (Australia)
A 1k x 1k frame transfer CCD photometer



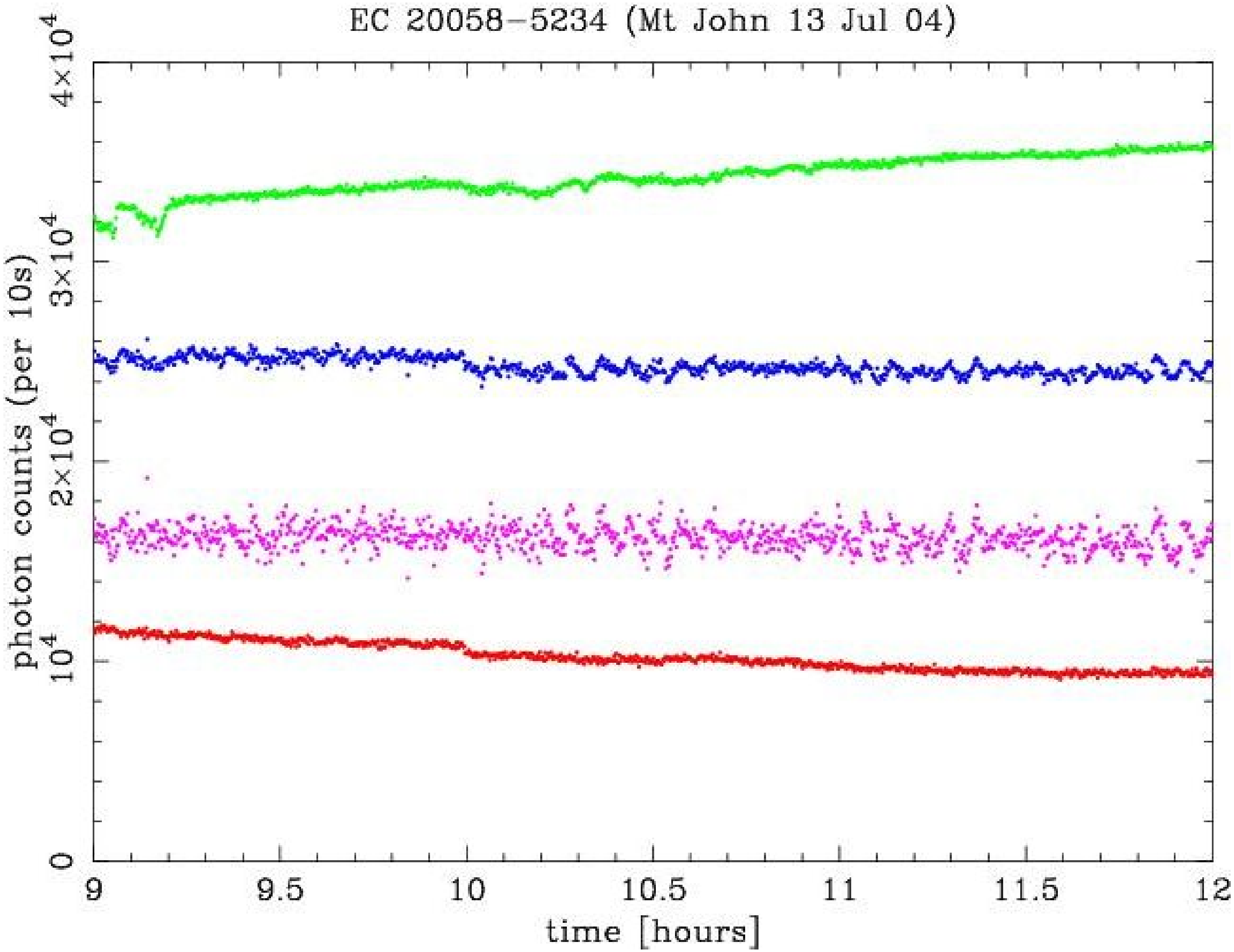
3 channel data obtained on Mt John 1-m



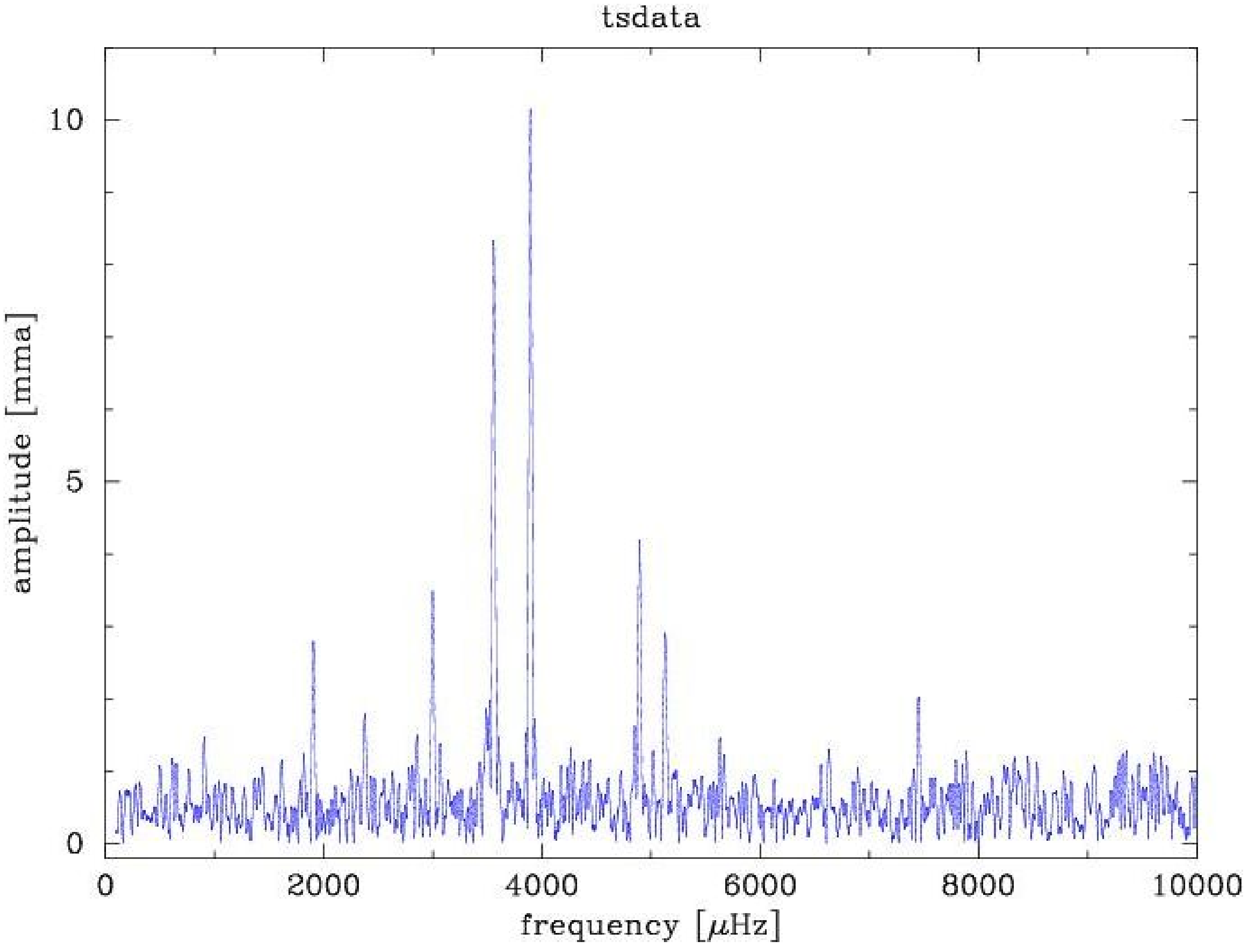
The quick-look reduced light curve (mauve)



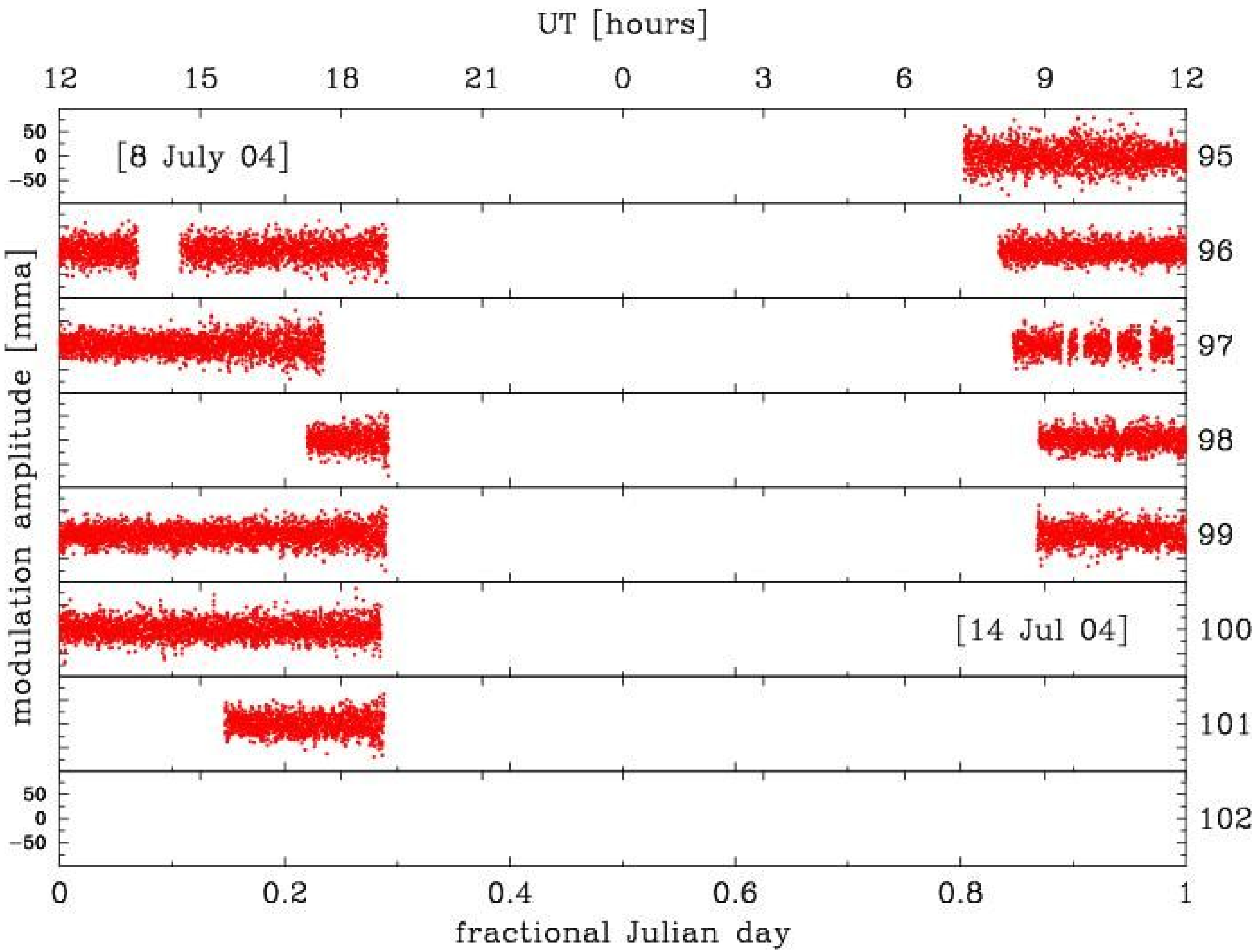
An expanded 3 hour segment of the light curve showing the variations – beats (at least 2 freq)



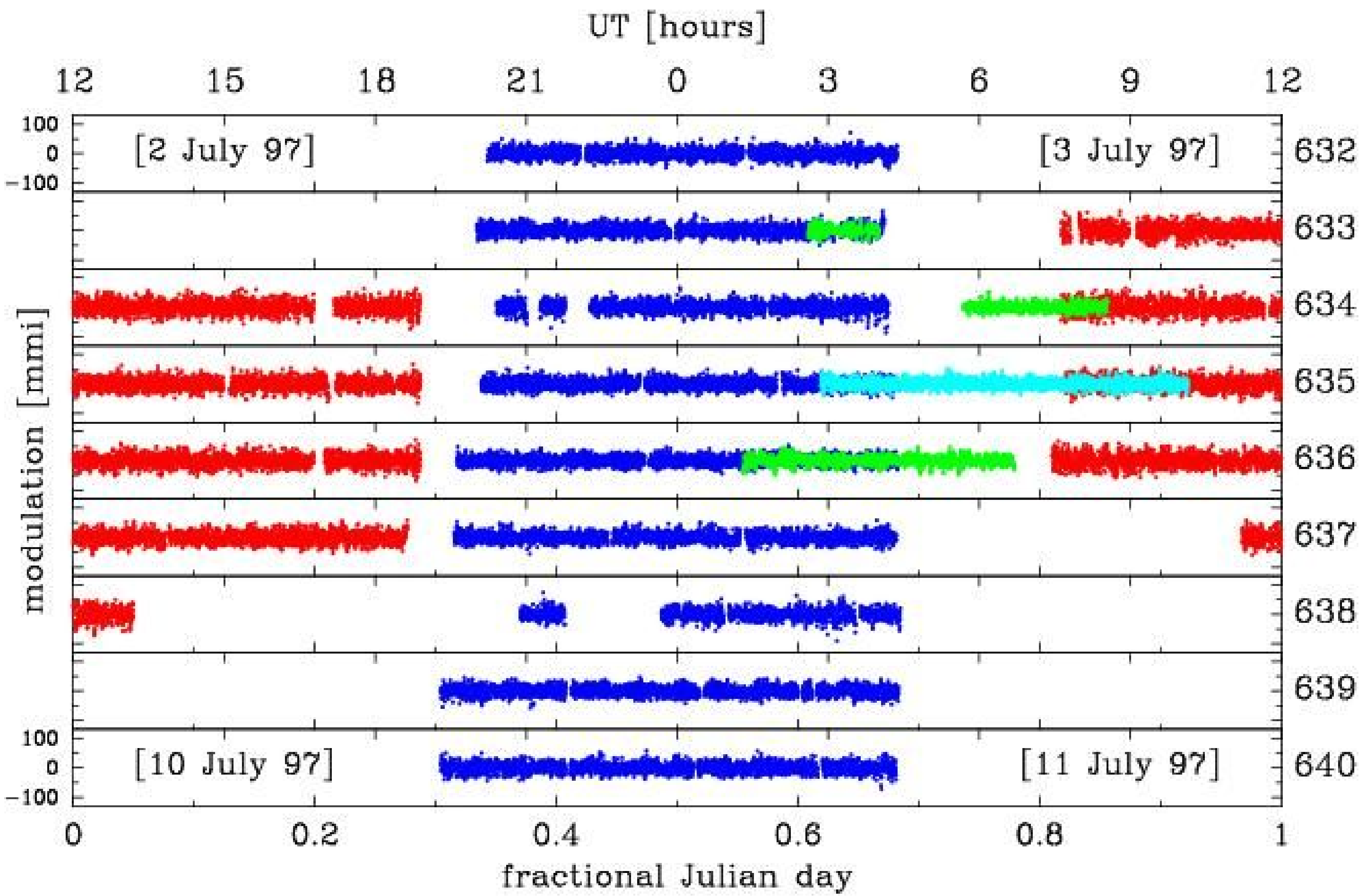
A Discrete Fourier Transform (DFT) of the light curve



A multi-night run on EC20058 at Mt John (NZ)



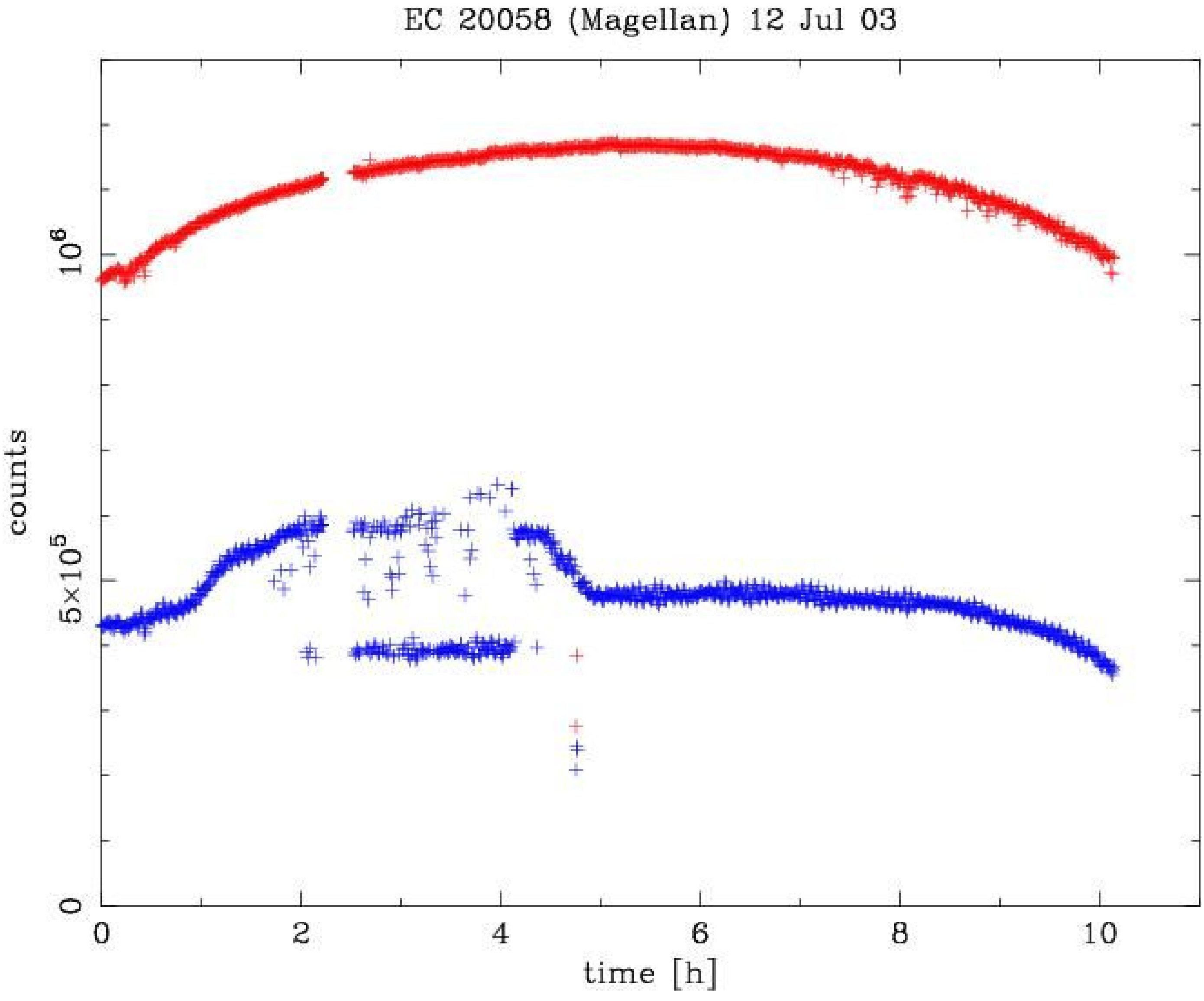
A Whole Earth Telescope run on EC20058
SAAO (blue), Mt John (red), CTIO (cyan), Brazil (green)



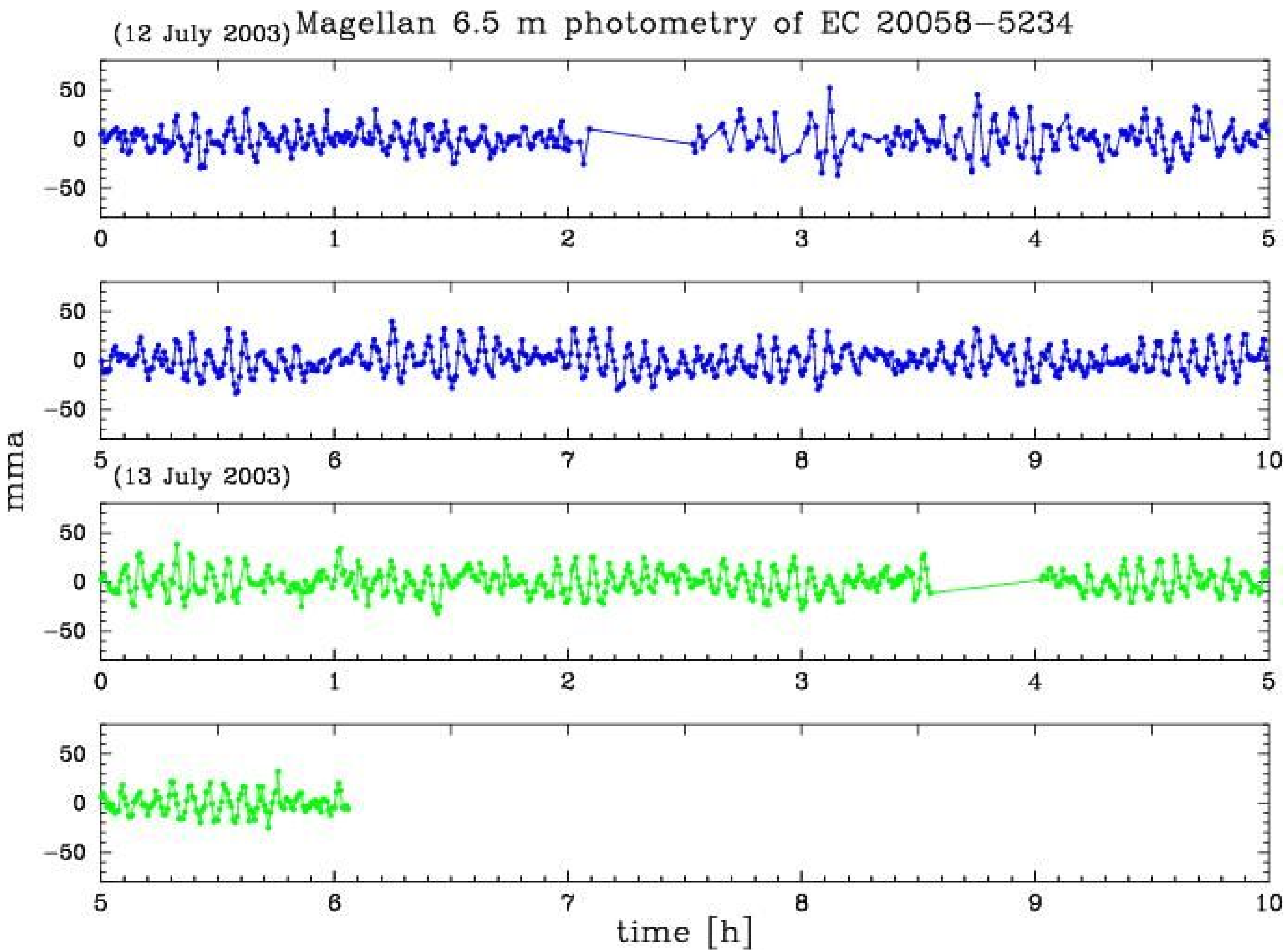
The twin Magellan 6.5-m telescopes in Chile
Las Campanas (near La Serena)

A view of the ESO La Silla site from Magellan

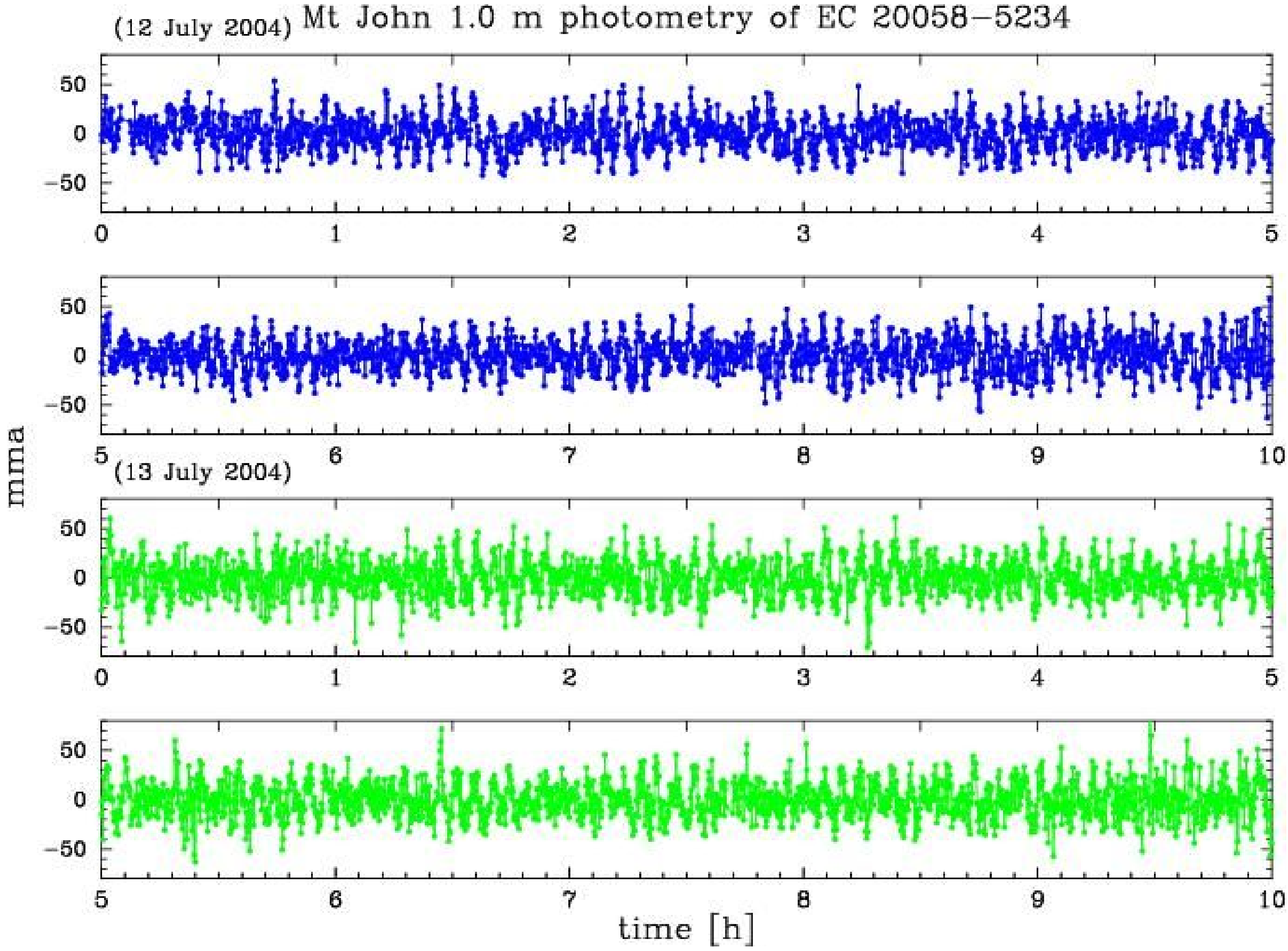
Time-series photometry of EC20058 with Magellan
No frame transfer CCD: (6.5-m --> 0.67*6.5-m)



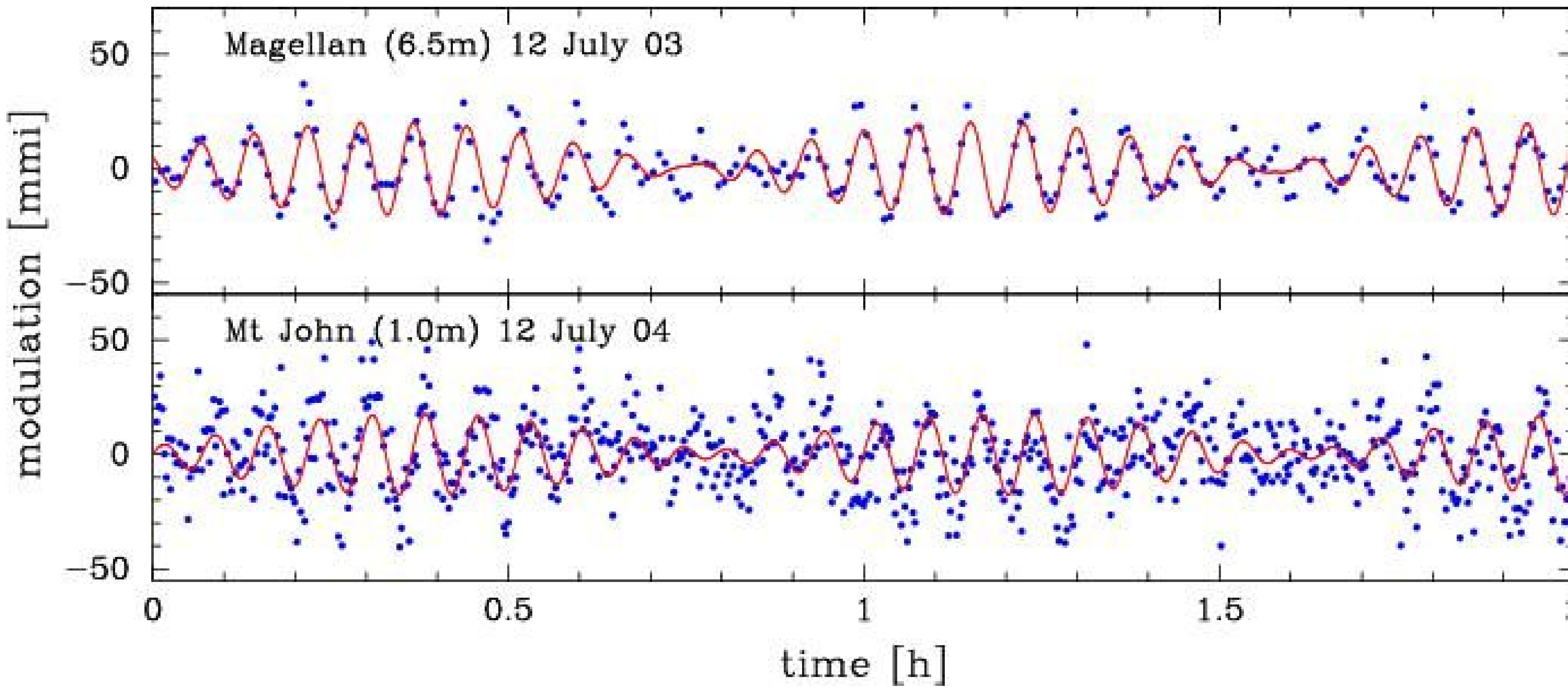
Two nights of Magellan 6.5-m reduced photometry



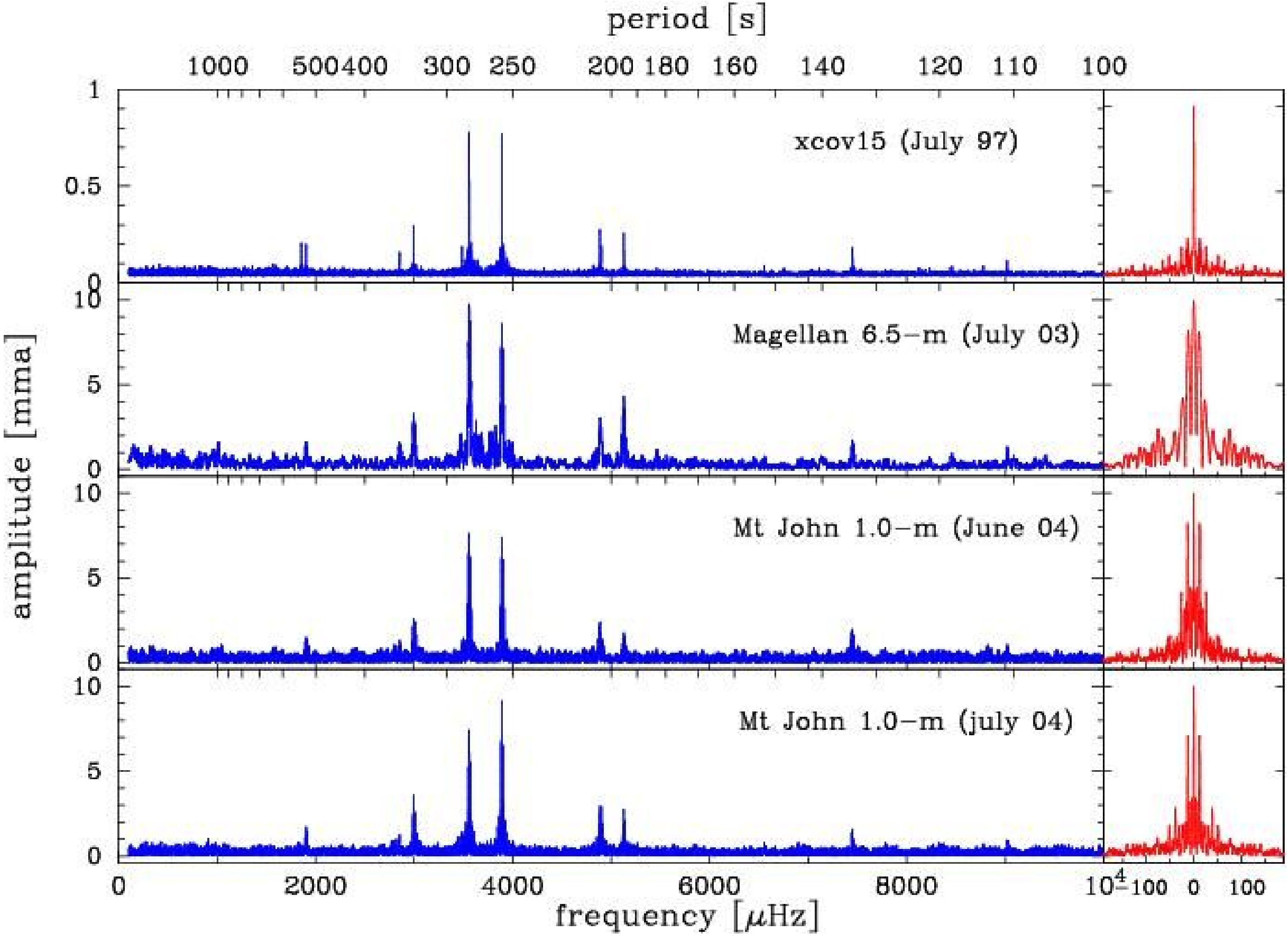
Mt John (1.0m) versus Magellan (4.2-m)



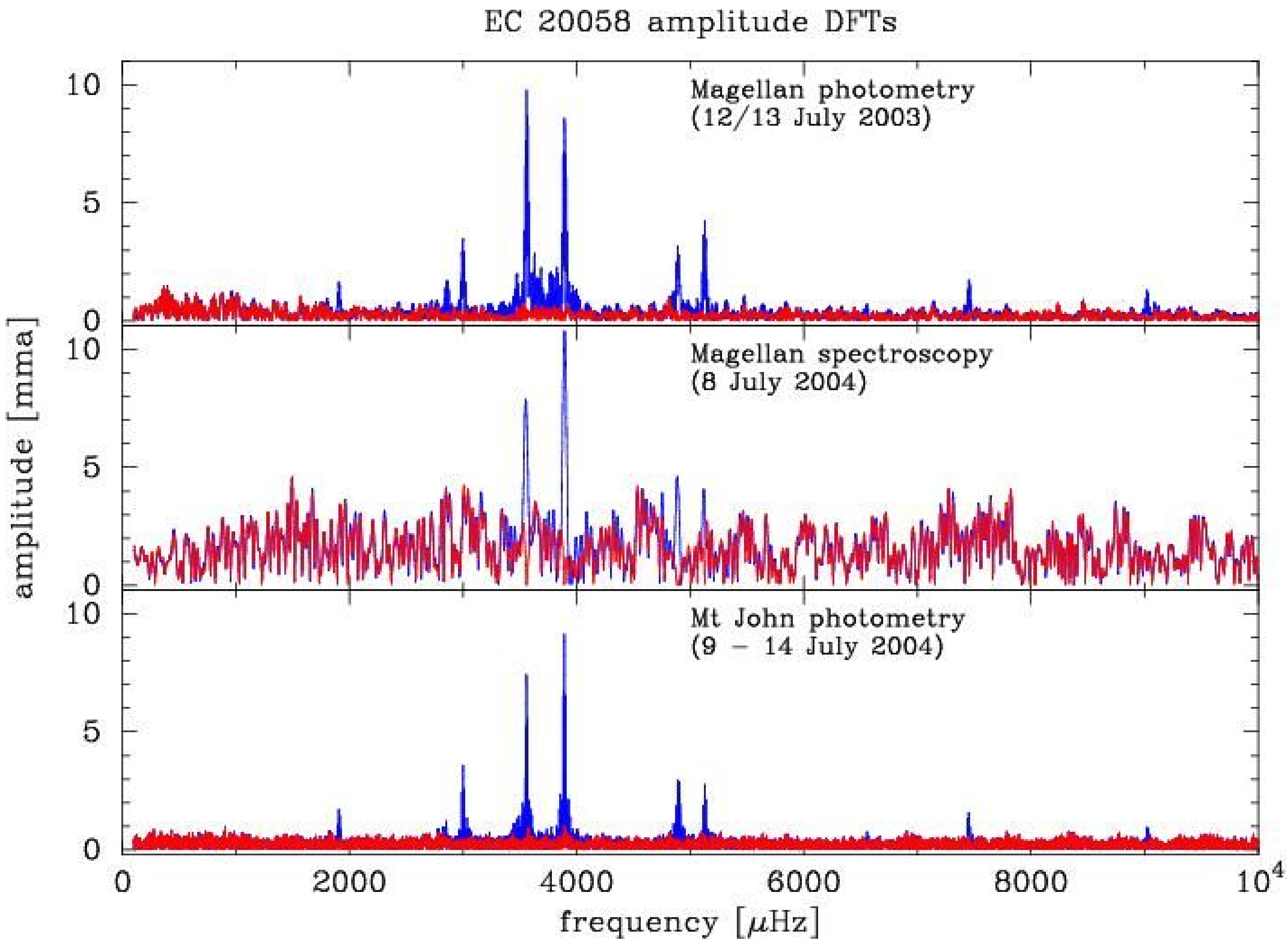
2 hour data segements showing two frequency fits



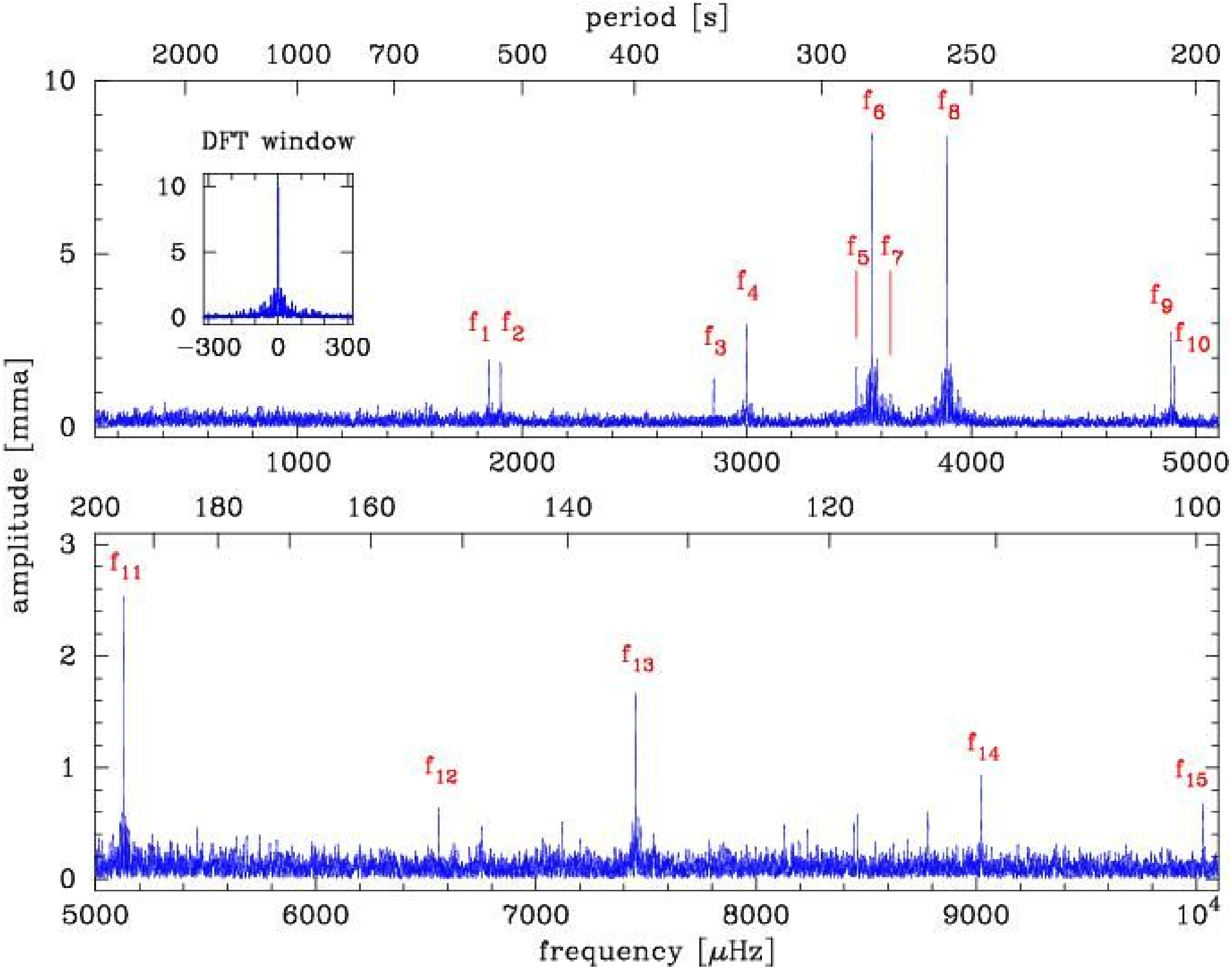
DFTs of EC20058 photometry – 4 data sets



Comparison of 3 DFTs of EC20058 photometry



An expanded DFT of the WET data

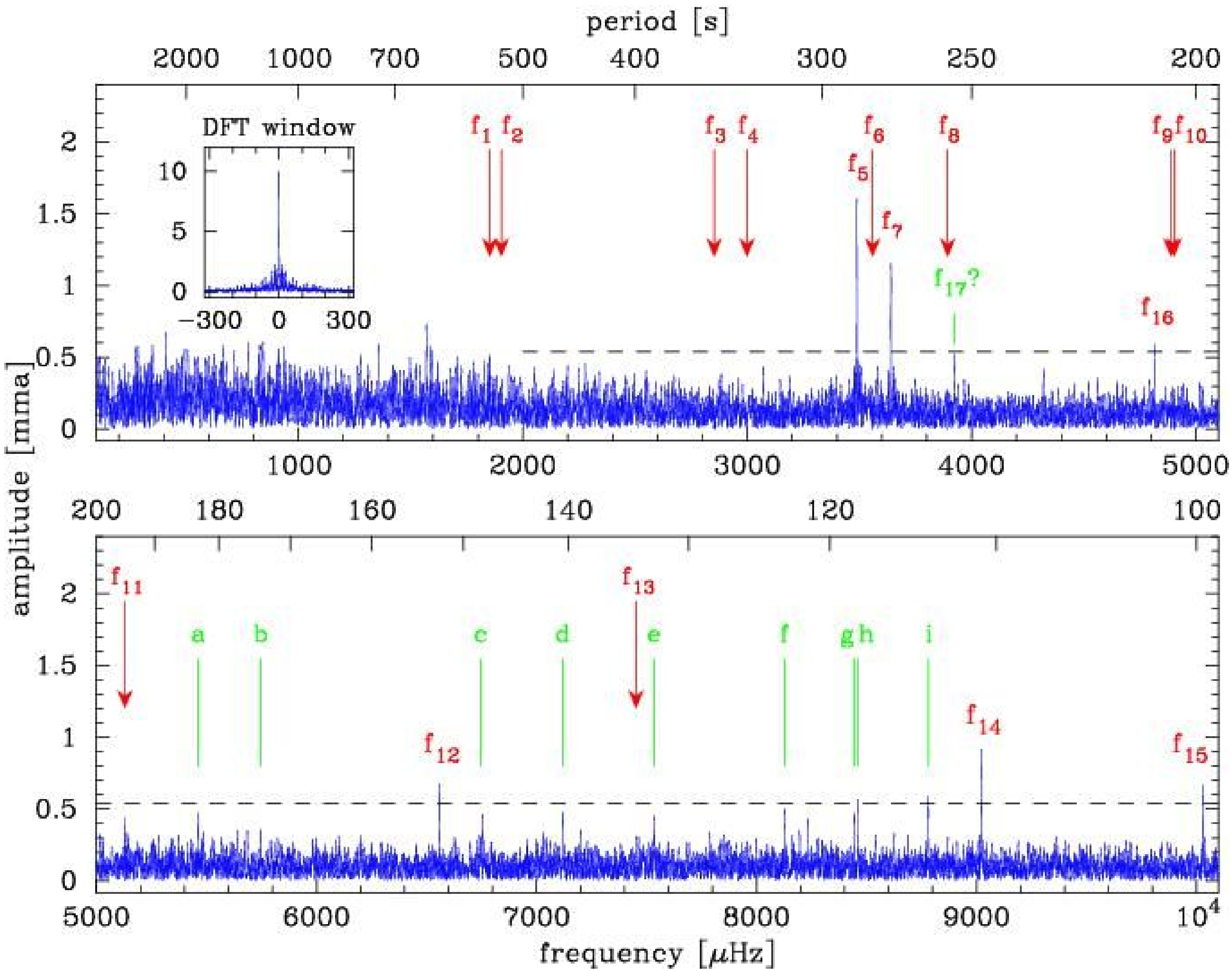


(1) Prewhitening of DFTs

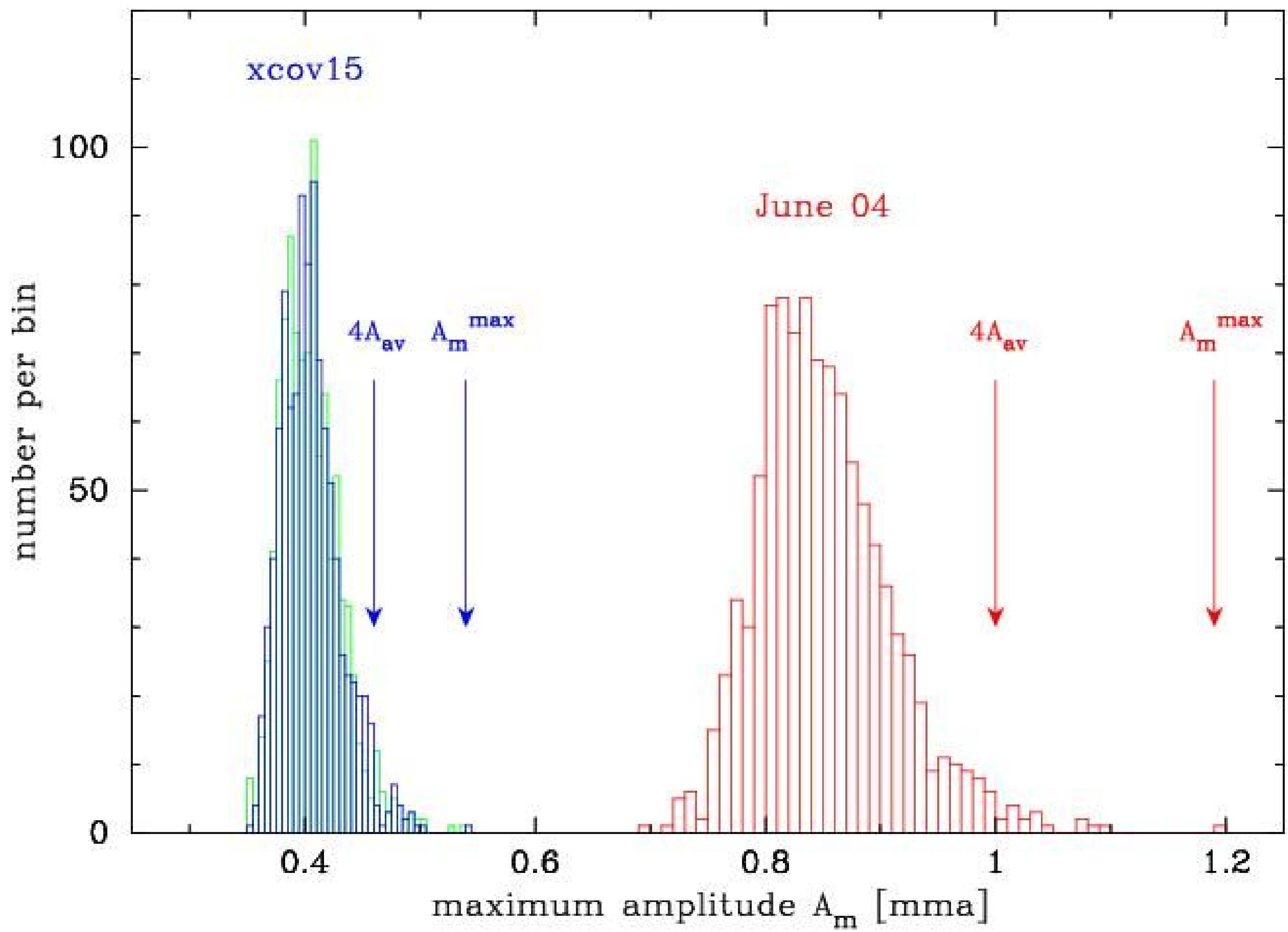
(2) the false alarm probability for spurious peaks

- The technique of prewhitening a DFT involves subtracting LSQ fitted sinusoids from the data and calculating another DFT. Either use successive LSQ fits or simultaneous ones
- Reality of a peak in the DFT specified by the false alarm probability. Can estimate this using Monte Carlo techniques - calculate DFTs of successively randomised data sets and select highest peak for each DFT

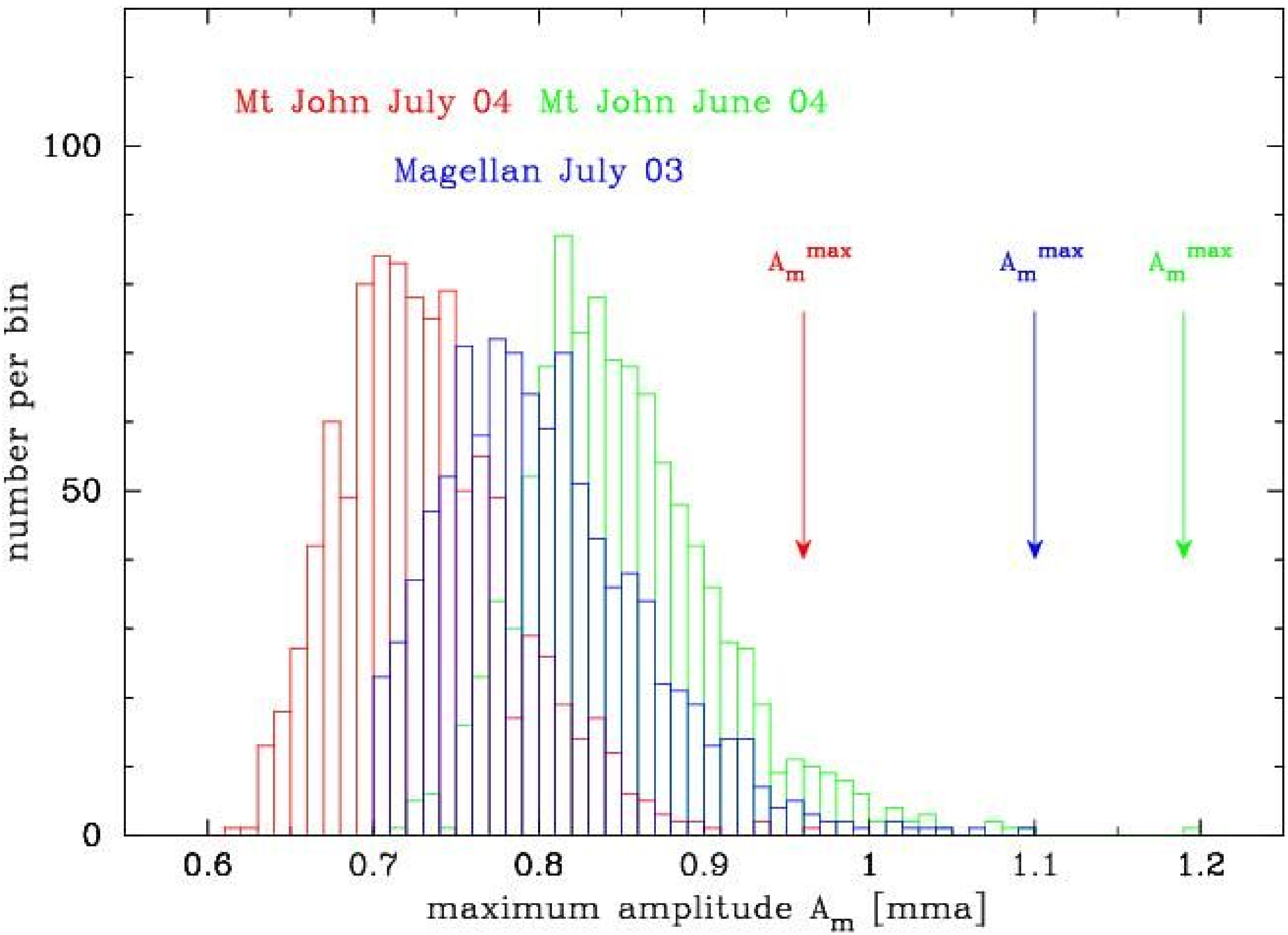
WET data prewhitened by 14 frequencies



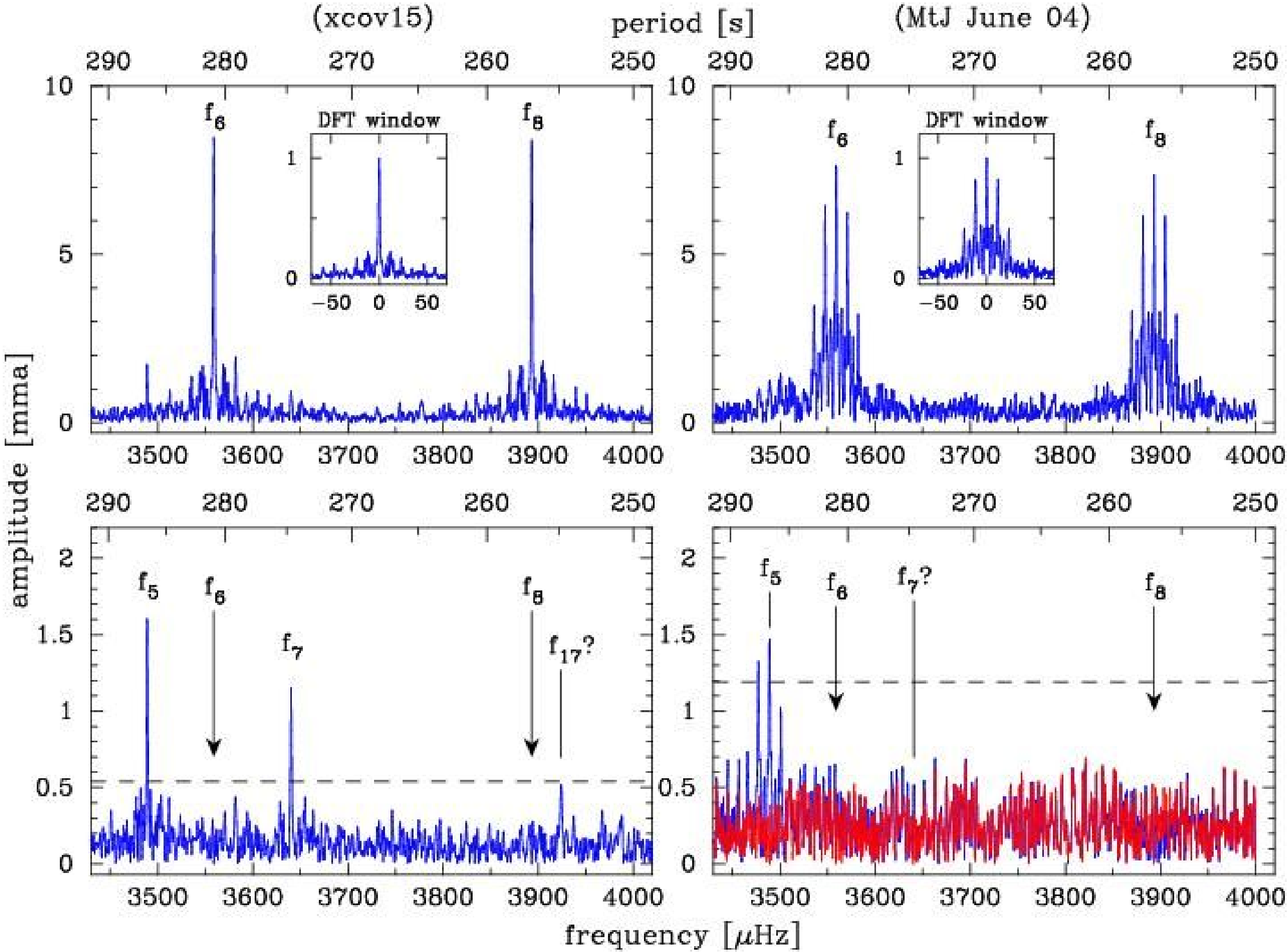
Histograms depicting the maximum peak height in 1000 successively randomised data sets



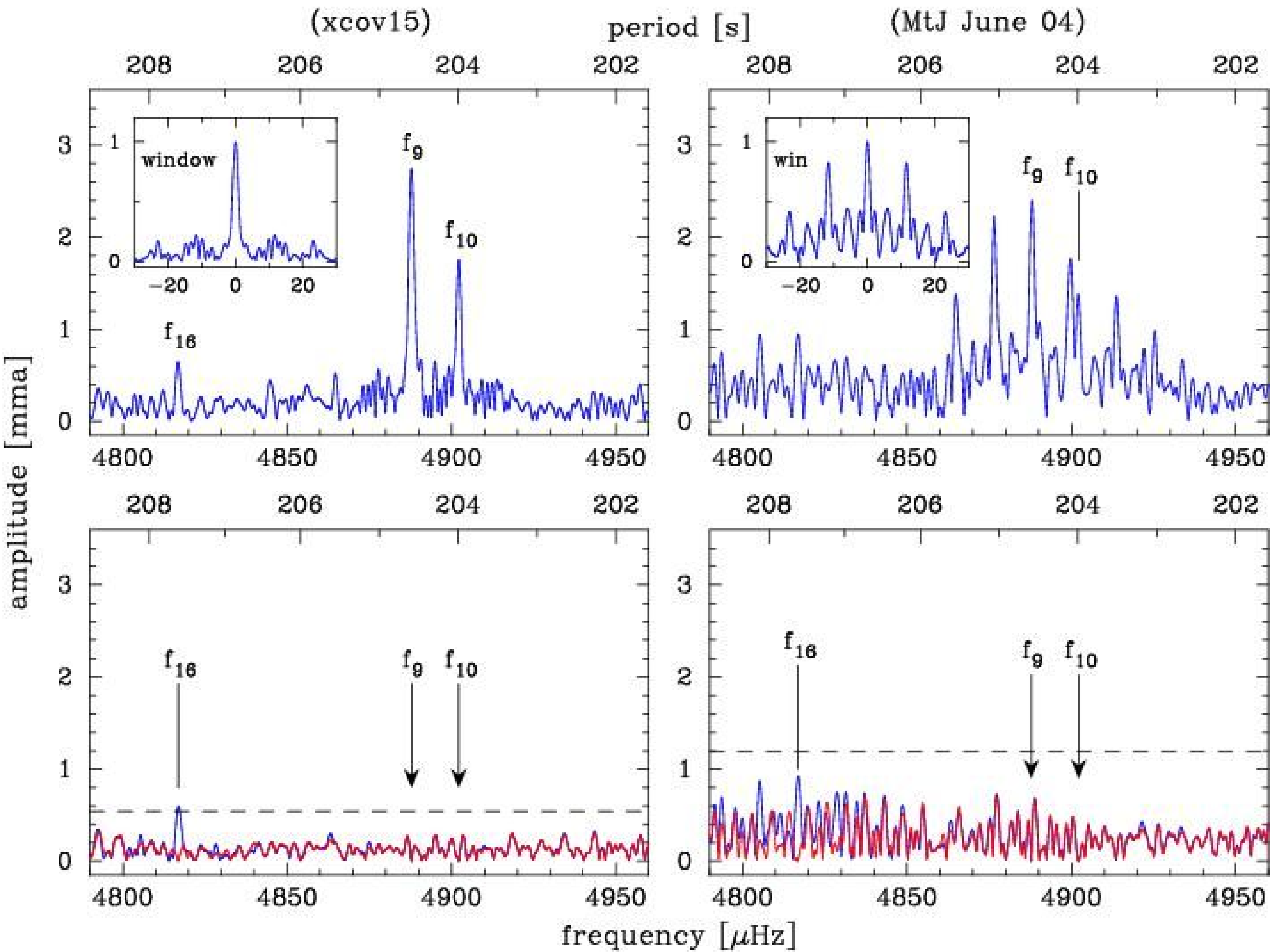
Monte Carlo false alarm probabilities for Magellan (2 nights) versus Mt John (6/7 nights)



expanded DFT near 256s & 280s periods
WET multi-site data vs Mt John single-site data

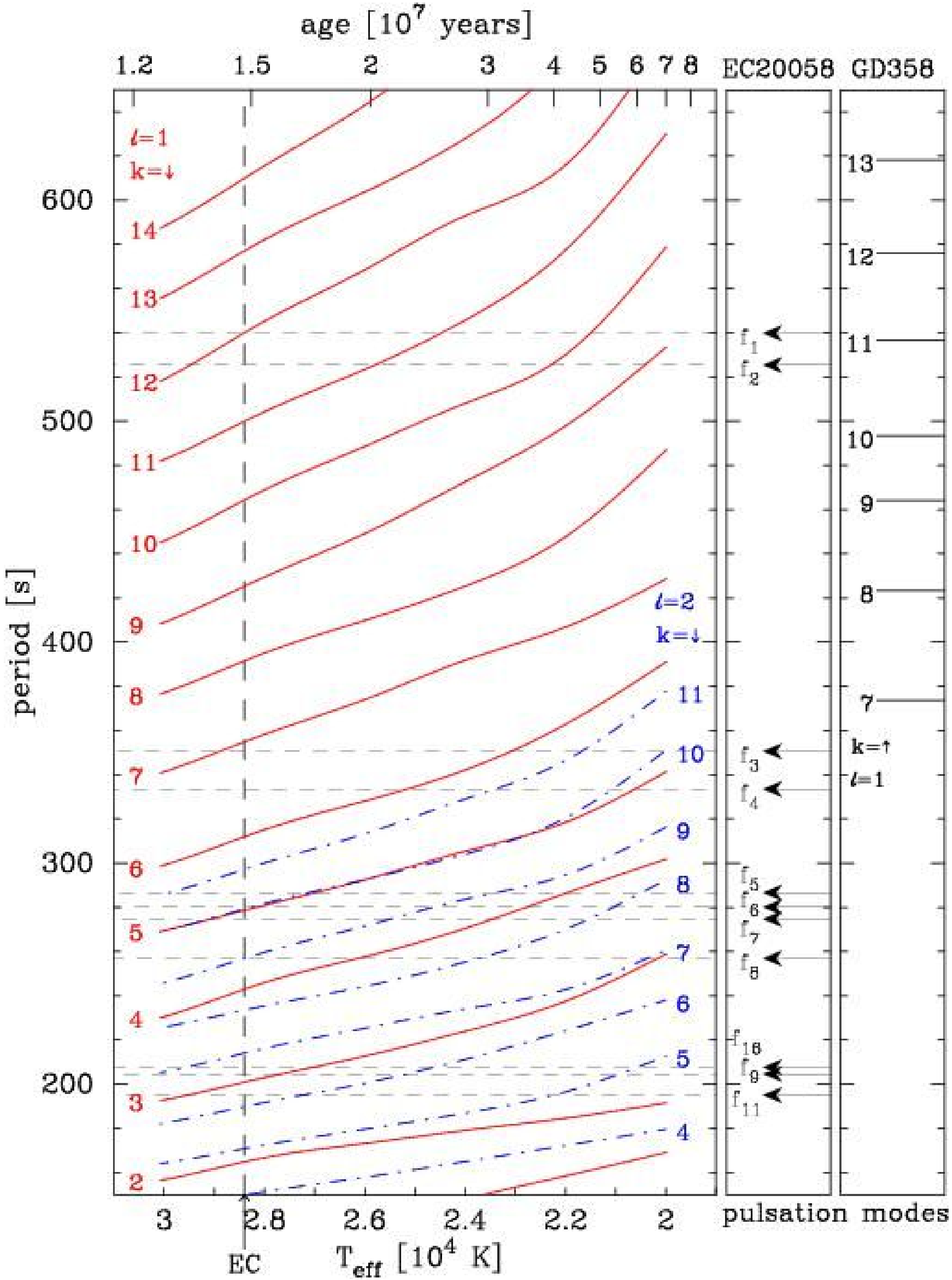


DFT of the 204s period region (WET vs Mt John)

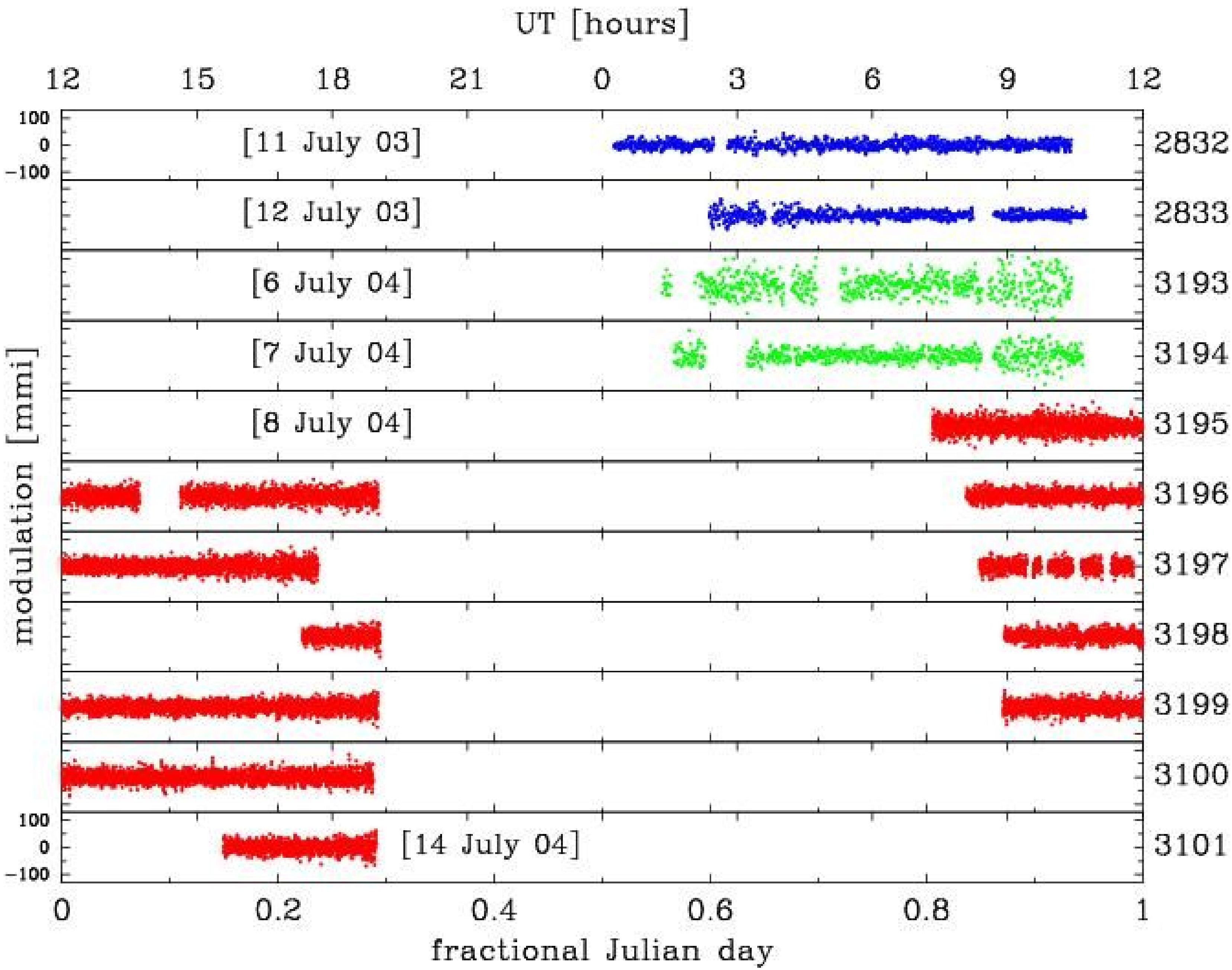


WD model frequencies versus Teff

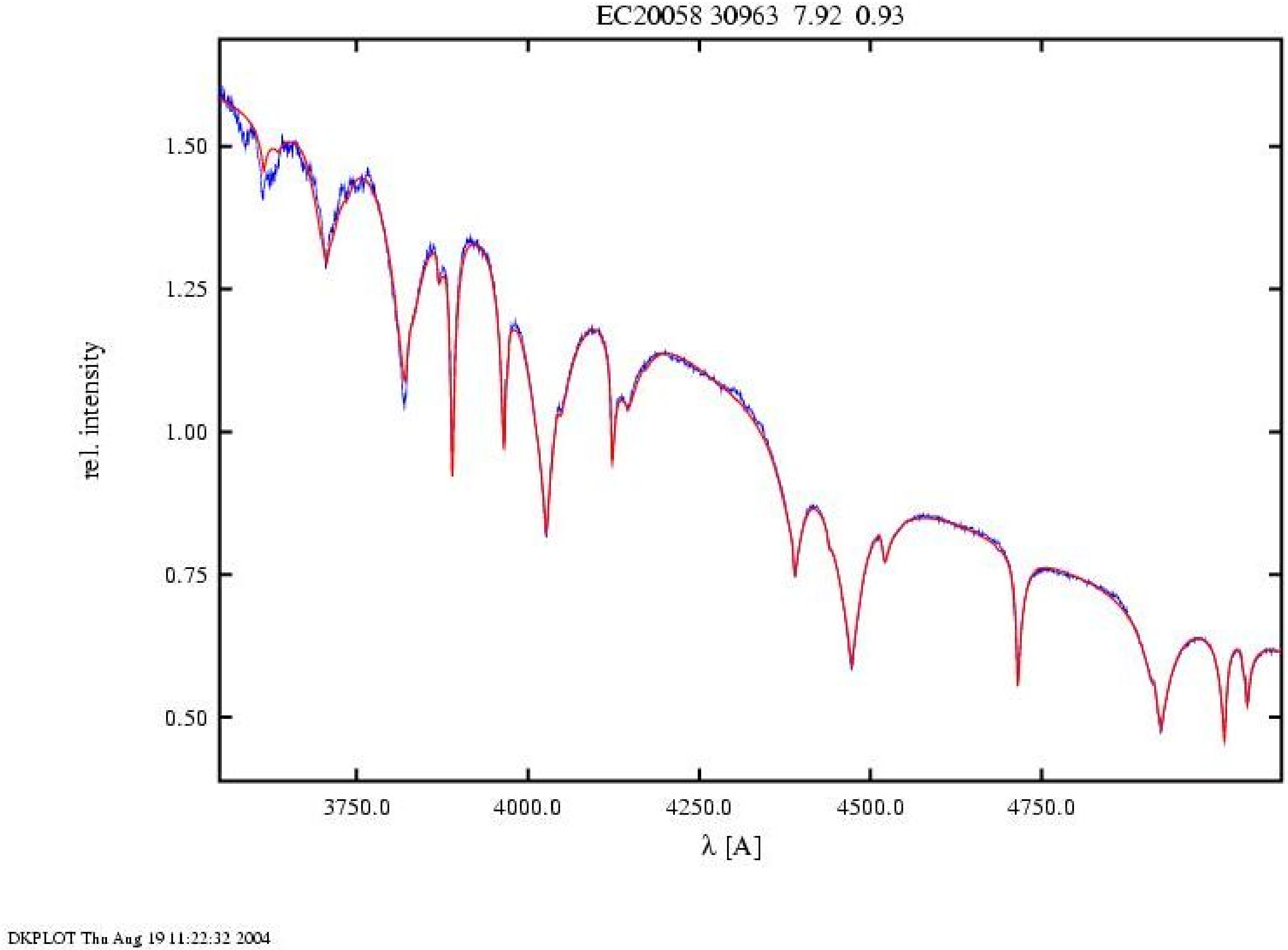
Matching the observed frequencies to those predicted by a model enables model params to be constrained



Magellan 6.5-m time-series photometry and spectroscopy



Atmospheric model fitting to obtain Teff and g (Detlev Koester)



Summary

- Asteroseismology provides only way to peer beneath stellar surface of white dwarfs.
- The more detected pulsation modes there are the better the constraints on the models --> better meaurements
- Pulsating WDs are often sufficiently multiperiodic that multi-site campaigns are needed to decipher frequencies
- For hot DBV white dwarf EC20058-5234 hope to obtain an indirect measurement of presence of neutrino flux --> a low energy test of electroweak theory
- For massive cooler DAV white dwarfs, aim to test theory of core crystallization