Constraining the origin of high metallicity in planet host stars

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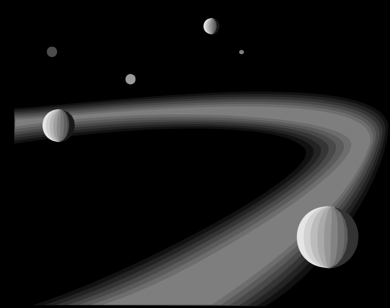

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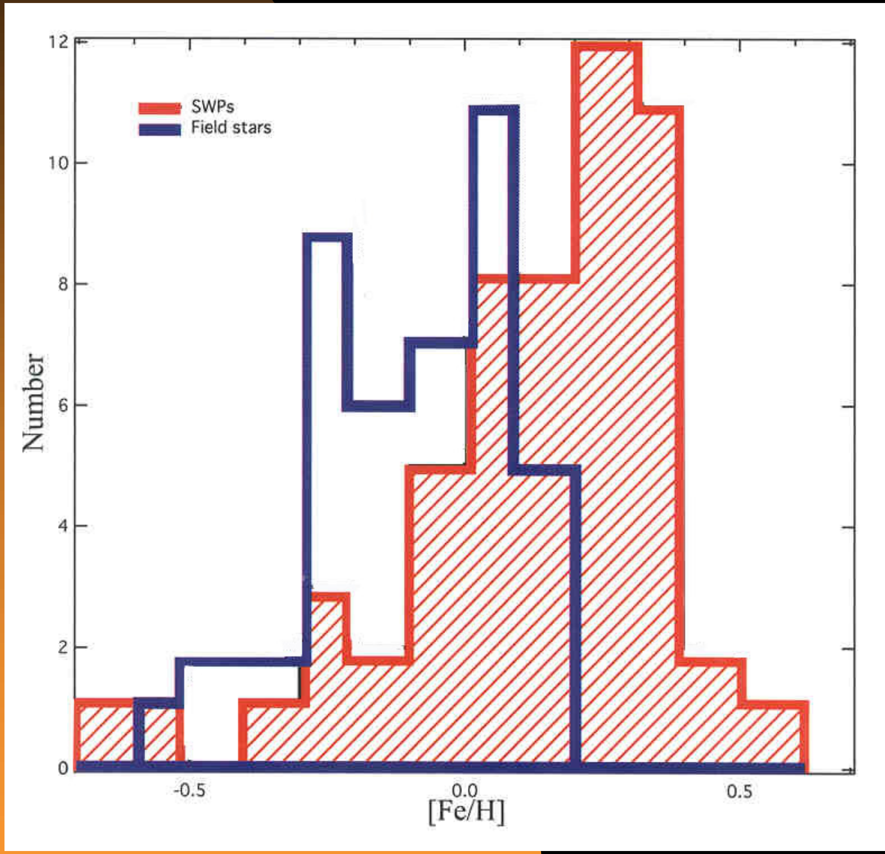
Scope of the Problem

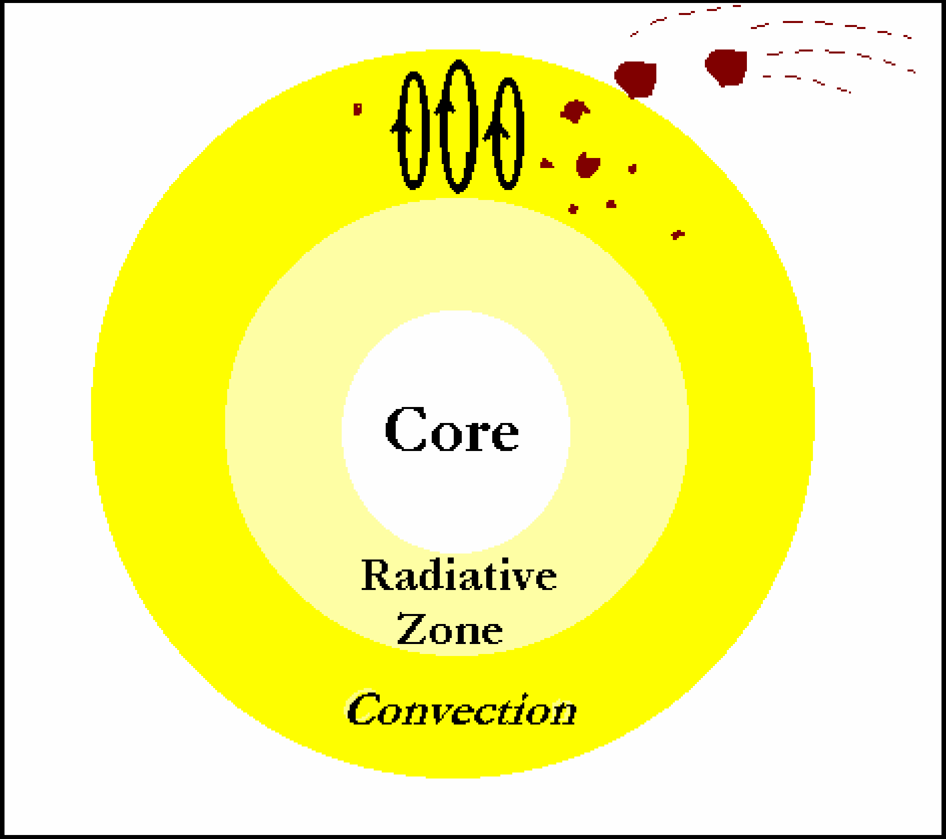
Metallicity distributions



Gonzalez (2003)

- Since 1995, over 150 extrasolar planets have been discovered via radial velocity and transit methods-- data are now statistically significant.
- One of the most intriguing trends has been the relatively high *metallicities* of stars with planets: Is this effect primordial, or is it due to infalling material??

The possibility of Stellar "Pollution"



- From disk dynamics- transport of both dust and larger rocky objects toward the central star is likely
- Evidence from possible abundance anomalies in Li content of stars? **(Israelian et al. 2003)**
- At present, unknown as to whether large planets or smaller metal-rich rocks and dust are more efficient polluters

Current Status of the Metallicity Problem

- The hypothesis that observed metal enhancements are primordial seems to be favored by the lack of trend in metallicity vs. stellar mass as well as studies of open cluster abundances

BUT…

- This relies on assumptions about how material is distributed after falling into a star and is primarily based on statistics
- It would be nice to find a definitive test for pollution, to provide constraints for planet formation theories and migration models

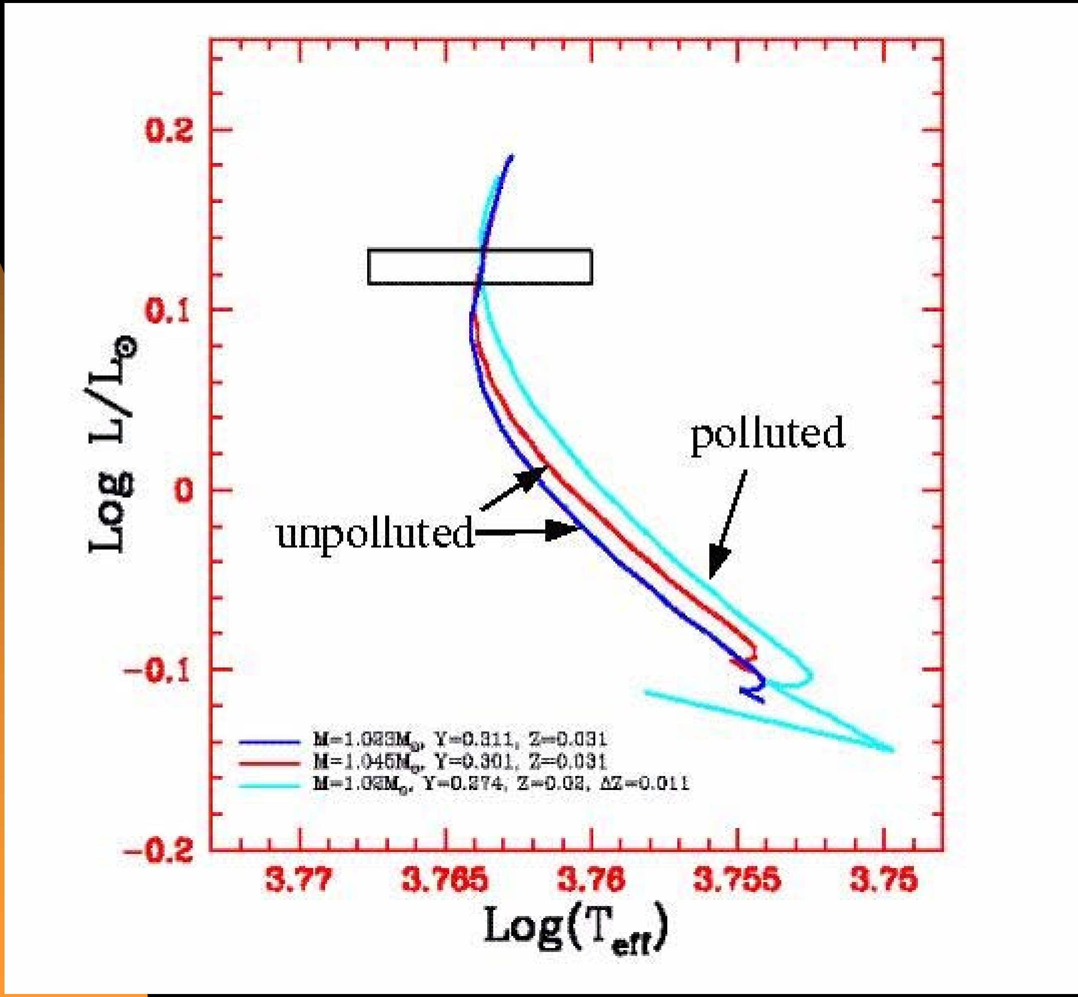
→ Are there any *direct* probes of pollution?

Constraining Pollution via Stellar Evolution Models

- We have altered the Princeton Stellar Evolution Code to allow for non-uniform metallicity distributions in stars and study the evolution of stars with contaminated convection zones
- Main Results: Polluted stars have lower temperatures and larger radii than unpolluted stars of the same interior composition (Cody & Sasselov 2005)
- Problem: Further constraints (e.g., stellar mass) are needed to distinguish polluted stars from unpolluted ones

Evolutionary Track Degeneracies

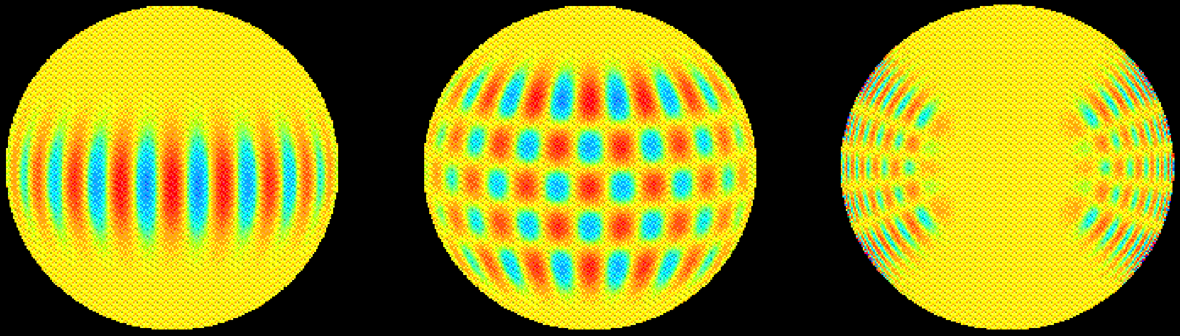
Example: 51 Pegasi



Constraining Pollution via Non-radial Stellar Oscillations

- Stars exhibit three-dimensional oscillations (small!); pulsation modes are characterized by *spherical harmonics,* Y_{lm}, radial components with *n* nodes, and frequencies ν_{nl}
- Oscillations frequencies are excellent probes into the stellar interior; they could help distinguish between polluted and unpolluted stars (Bazot & Vauclair 2004)
- In particular, the metallicity gradient expected at the base of the convection zone is a useful distinguishing feature of polluted models

Velocity patterns & eigenfuctions of various pulsation modes (Gough et al. 1996)



Density & Sound Speed Gradients → Oscillatory Signature

- It has been shown (Gough 1990) that discontinuities in a derivative of the sound speed in a star contribute an additional oscillatory component to the oscillation frequencies: $\nu' = \nu_o + A\sin(2(2\pi\nu_{nl}\tau + \phi))$

  where τ is acoustic depth, Φ is a phase
- This component should be best seen in the *2nd differences*: $\delta_2\nu = \nu_{n+1,l} - 2\nu_{nl} + \nu_{n-1,l}$
- Analogous scenario: add a small "perturbation" to a string (e.g., a bead); when plucked, the resonant frequencies no longer fall in linearly spaced harmonics

Spreading of metals below the convection zone

- If we pollute the convection zone only, we expect the material at the base to be Rayleigh-Taylor unstable, and metals will seep downward .

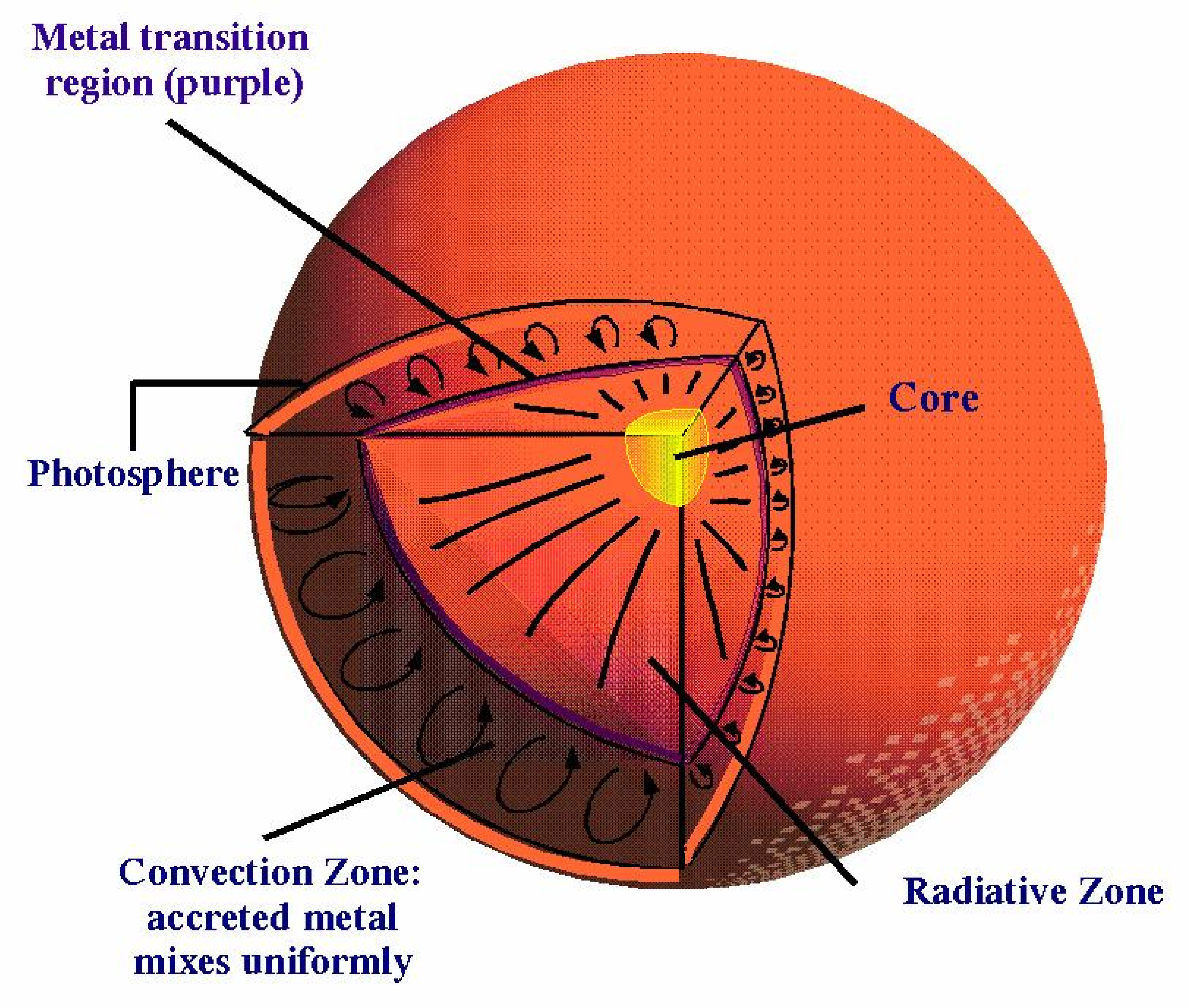
- To account for this, we spread the metals downward at the convection zone base, according to the neutral stability criterion:

$$\frac{d\rho}{dr} = \left(\frac{d\rho}{dr}\right)_{ad}$$

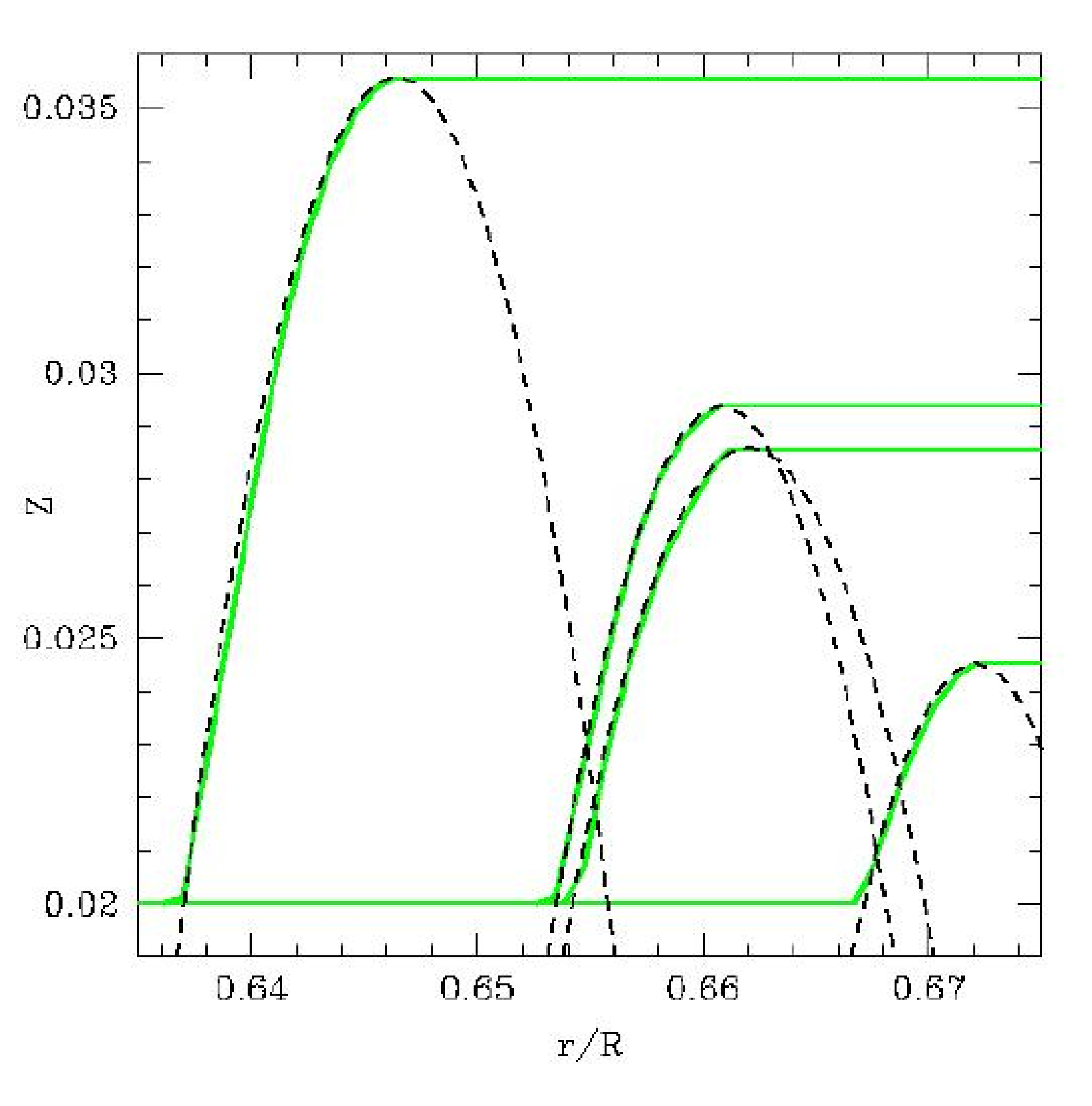
- The resulting metal profile still has a steep gradient, but is more parabolic in shape.

- *How does this affect observations of stars with pollution? – Could it wash out an oscillatory signal?*

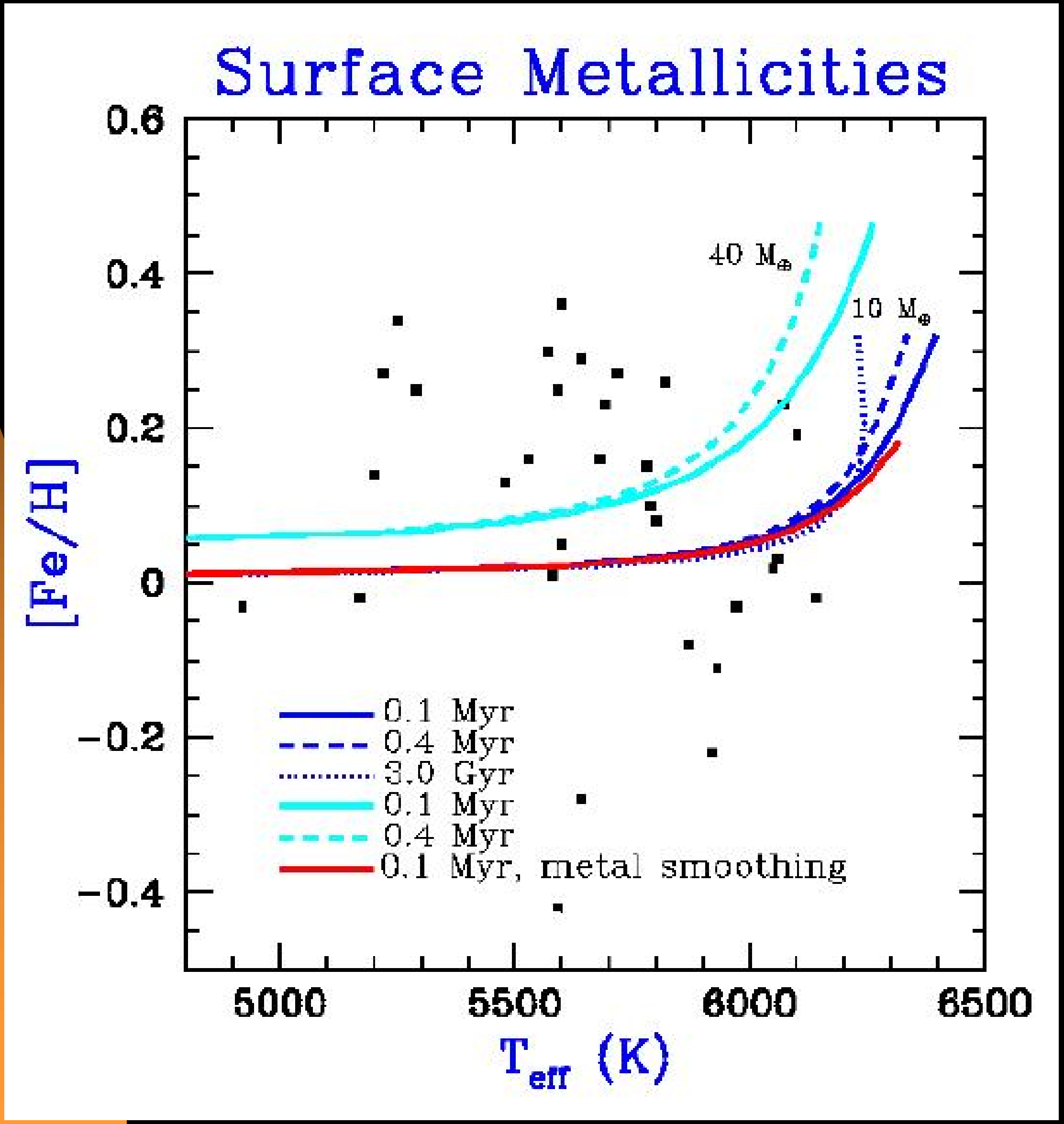
Spreading of metals below the convection zone



Metallicity Profiles



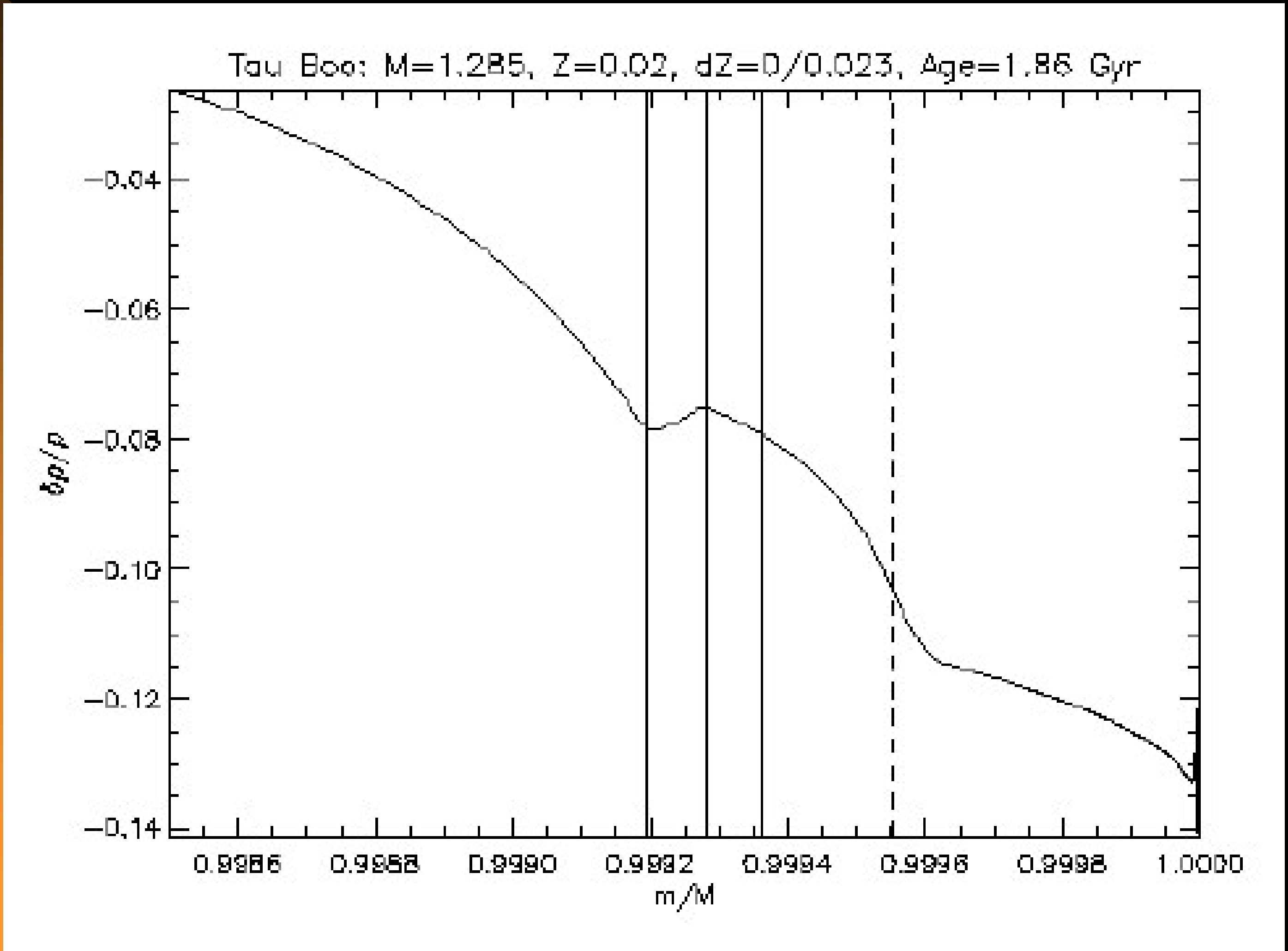
Spreading: Effect on Surface Metallicities



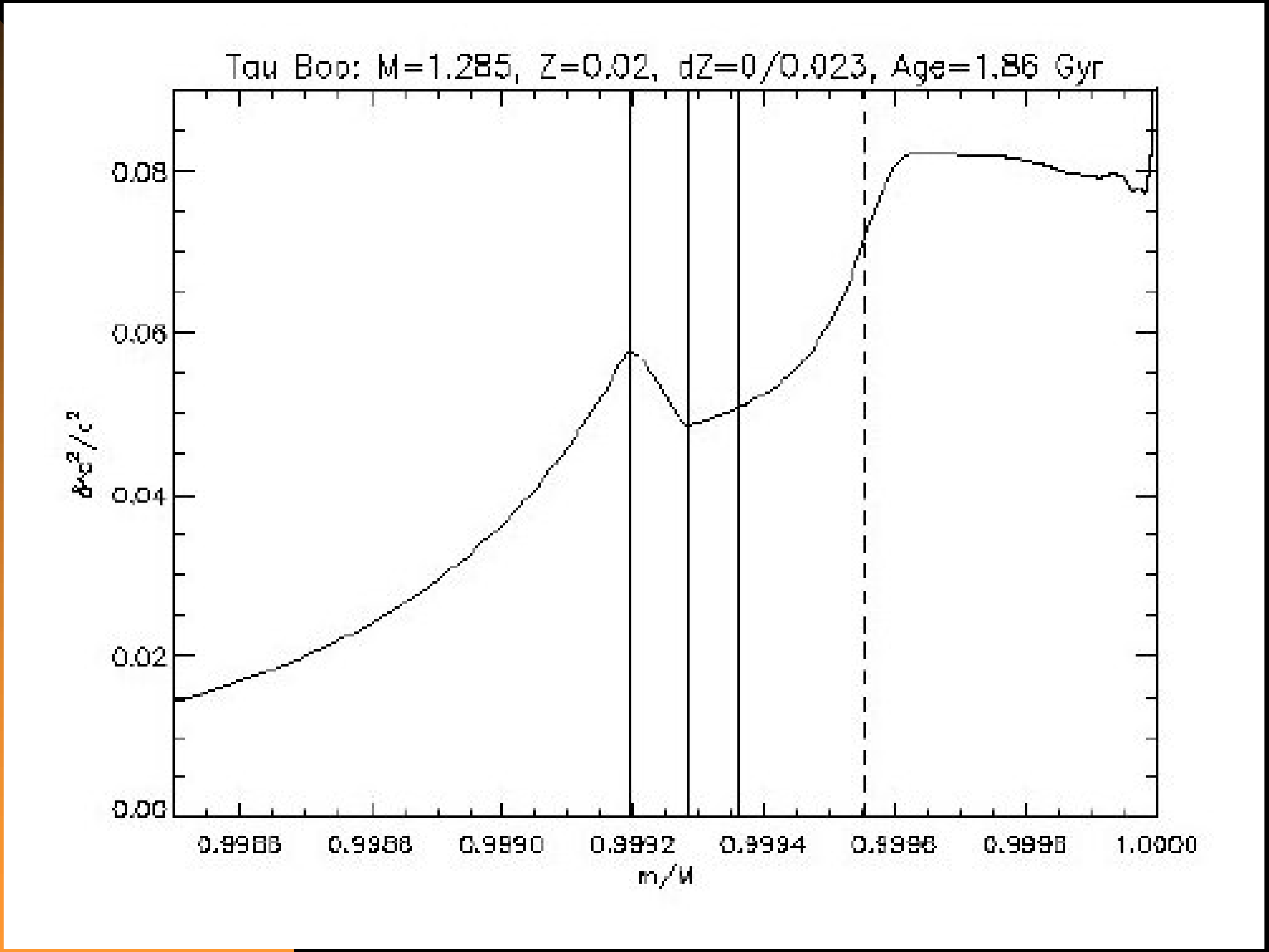
Seismological Models

- We have computed a number of polluted and unpolluted stellar evolution tracks to match the temperature and luminosity of metal-rich stars 51 Pegasi and τ Bootis
- The resulting stellar structure models are input into a non-radial pulsation code, kindly provided by J. Christensen-Dalsgaard
- We computer the expected oscillation frequencies for polluted and unpolluted models, and derive from these the large and small separation and second differences

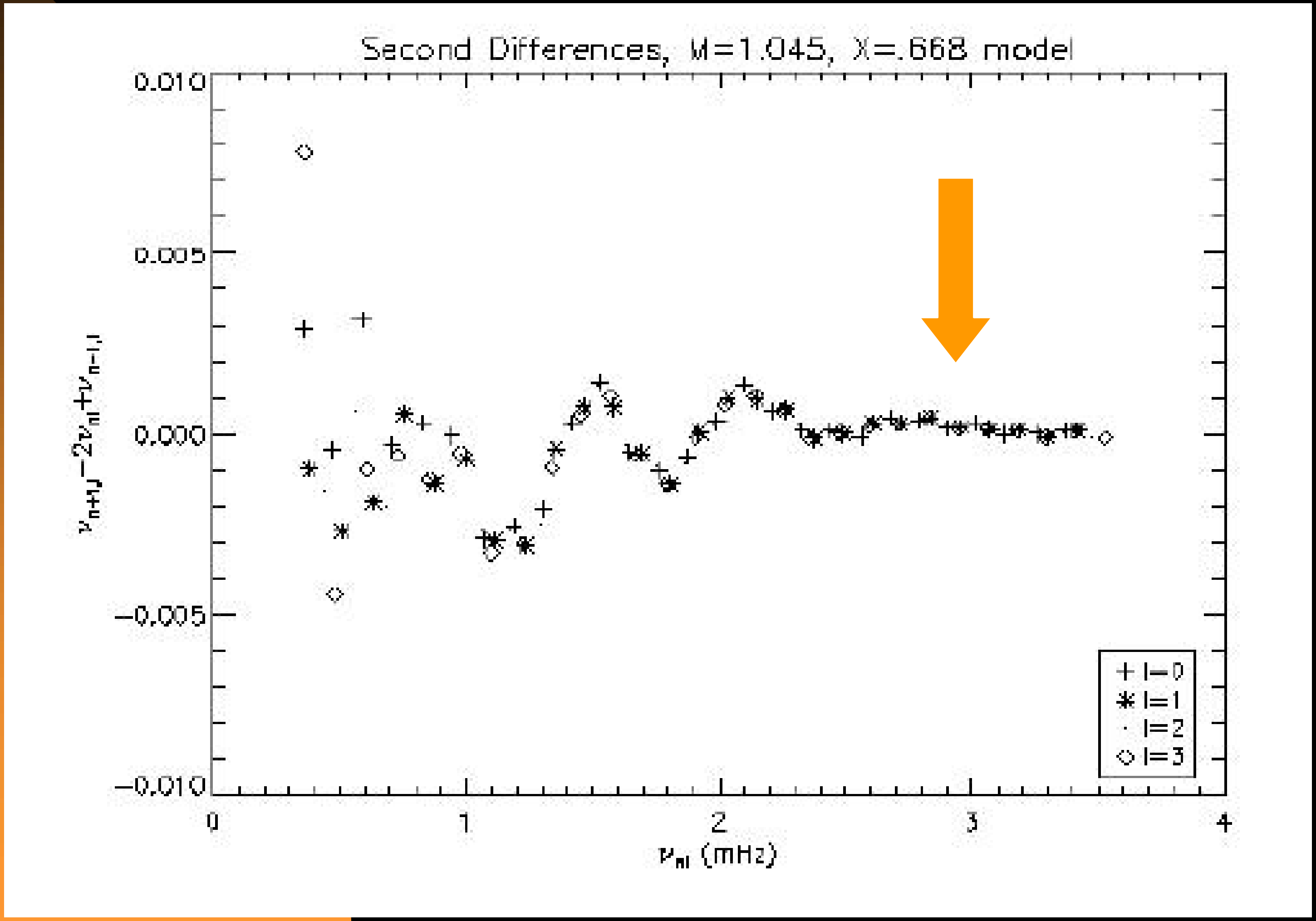
Density Perturbation due to Pollution



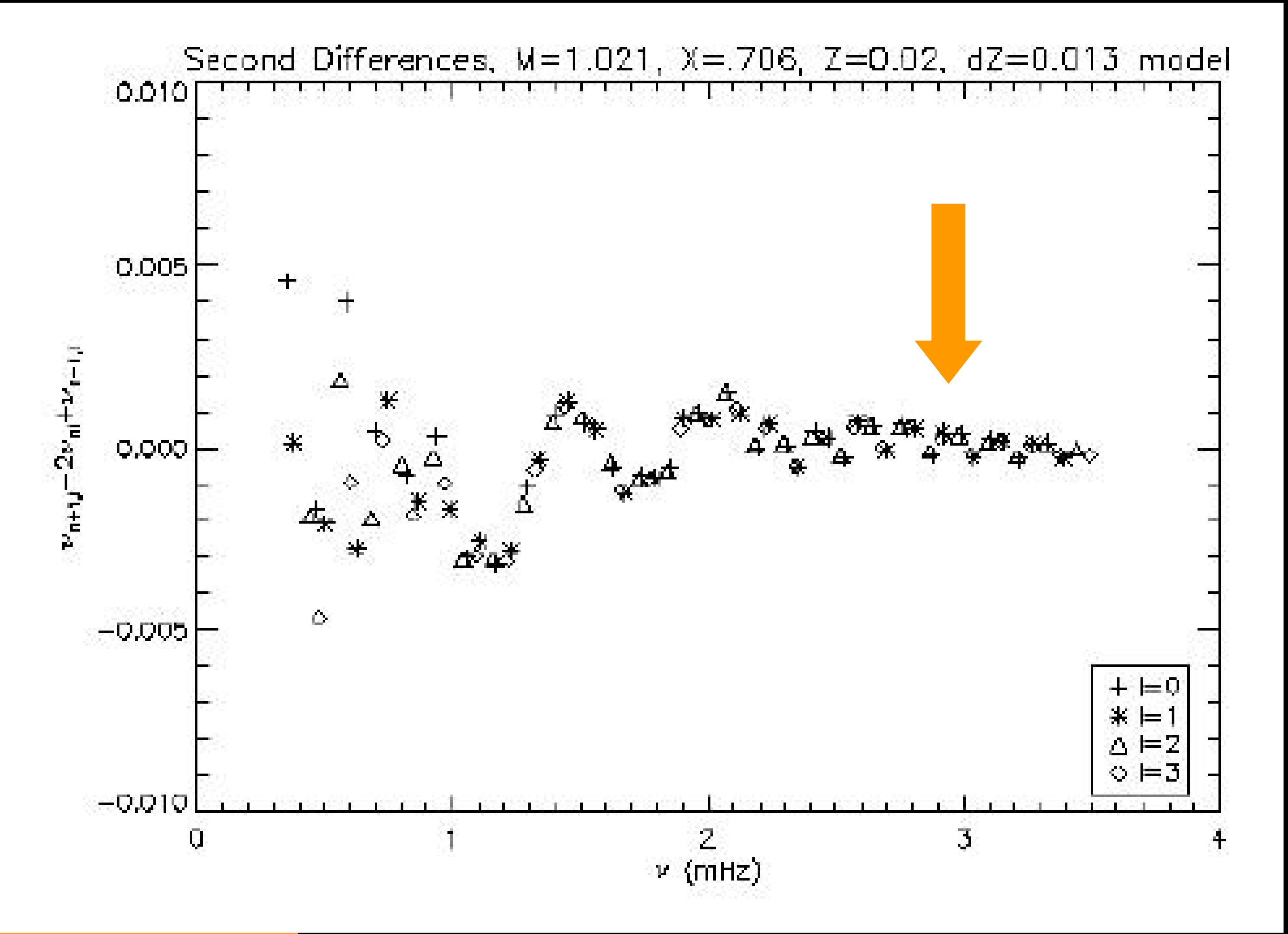
Sound Speed Perturbation due to Pollution



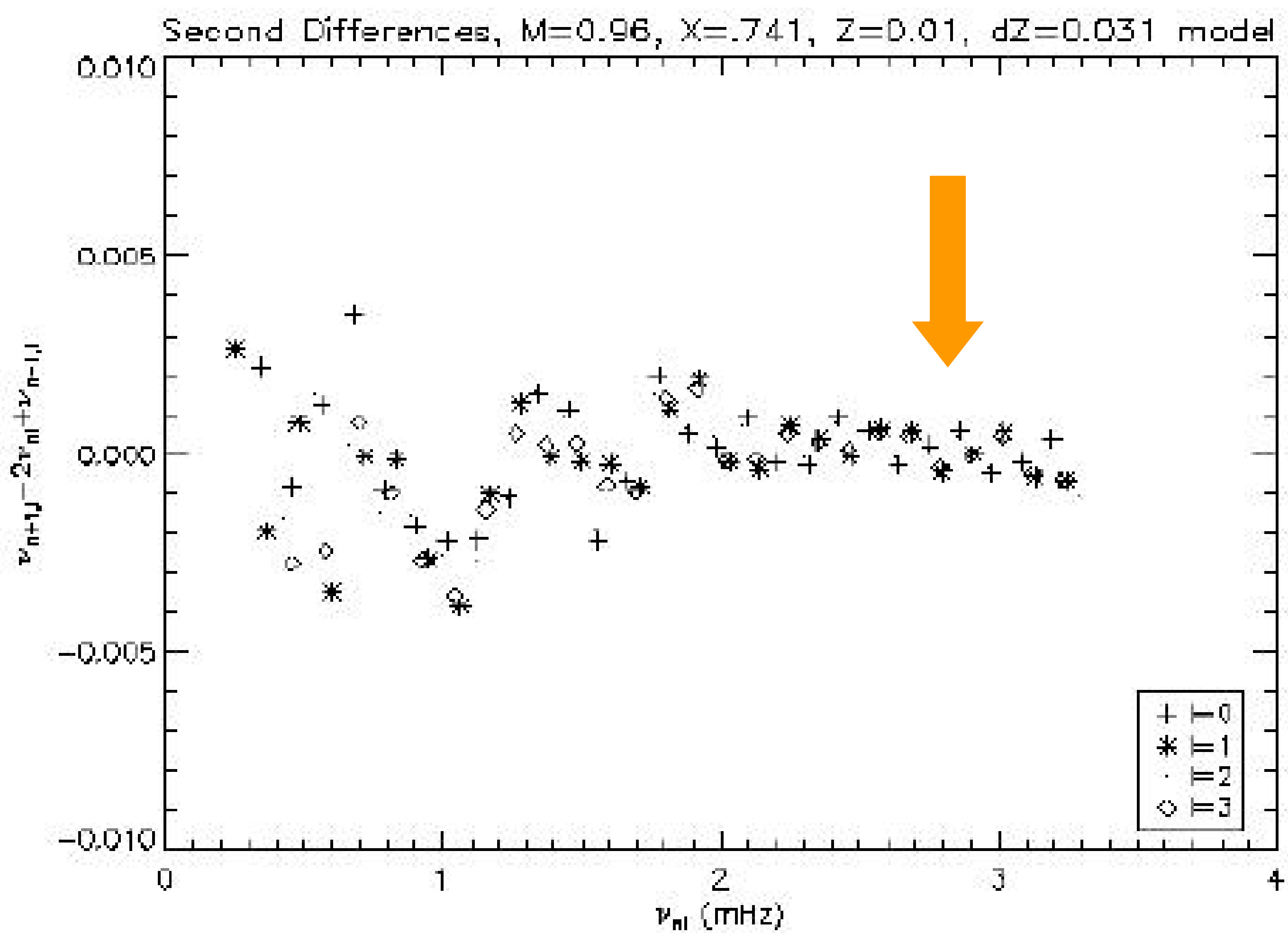
$\delta_2\nu$: 51 Pegasi, Unpolluted



$\delta_2\nu$: 51 Pegasi, Polluted



$\delta_2\nu$: 51 Pegasi, More Pollution



Observational Prospects

- P-mode pulsations have now been observed in a quite a few stars; instruments with the ability probe to the sensitivity level of pollution effects are becoming available

- The Microvariability and Oscillations of Stars (MOST) mission is in the process of observing 51 Peg and τ Boo for p modes ; sensitivity is expected to reach 1 μHz for measurements of the second differences

- The Convection Rotation and Planetary Transits (COROT) mission, to be launched in 2006, should also contribute valuable oscillation data

Conclusions & Further Questions

- We have shown that metal pollution introduces a characteristic oscillatory component in the second differences of p-mode frequencies.
- These predictions should be verifiable in the near future with p-mode data from both the MOST and COROT missions.
- If pollution seems likely, further modeling is needed to identify the contributors– what might be the expected trends in disk size, density and number of planets vs. amount of material that falls onto the star?