Planet Host Stars: Params & More

Lijiang – May 15\textsuperscript{th} 2007

“Actually they all look alike to me.”

Planet host stars, parameters and element abundances.
Our collaboration: The team

- Prof. ZHAO Gang and group: *NLTE-element abundances*

- Prof. Lyudmila MASHONKINA: *NLTE-element abundances, Hydrogen in NLTE*

- Prof Thomas GEHREN: *NLTE-element abundances*

- Dr. Frank GRUPP: *Model atmospheres, stellar parameters, instrument development*
Planet host stars: Outline

- Model atmospheres – the **backbone** of it all
- Methods of determining stellar parameters
  - \( T_{\text{eff}} \), \( \log(g) \), \([M/H] \), etc.
- Error sources:
  - Models: atmospheres
  - Line formation
- What can be done
- What should be improved
Model atmospheres: Backbone (1)

Line formation tool

Stellar parameters:
$T_{\text{eff}}, \log(g), [M/H], [X/H], \xi_{\text{micro}}$

Model atmosphere
Model atmospheres: Backbone (2)

• There are different approaches to model atmosphere calculation:
  - 1D hydrostatic models: ATLAS, MARCS, MAFAGS
  - 3D hydrodynamic models: 3D (Nordlund)
  - Empirical models (for the sun): Holweger-Müller, Maltby ...

• In this talk: 1D, plane parallel, LTE, opacity sampling – MAFAGS-OS (A&A 420, 289-305)
  - OS (MARCS, ATLAS12) ↔ ODF (ATLAS9)

• In this talk: F & G-type stars
Model atmospheres: Backbone (3)

- MAFAGS-OS
  - Optimized for A, F and G stars
  - Arbitrary element mixture possible due to OS
    - e.g. new CNO abundances of Asplund et al.
  - New, more accurate bound-free data for Fe I, Mg I & Al I (up to 1000 times larger than hydrogenic approx.)
  - 45' - 4h computation time
Model atmospheres: Backbone (4)

- Solar flux well reproduced
- Solar colors agree well
Stellar parameters: $T_{\text{eff}}$

• F and G-type stars
  – Infrared Flux Method, IRFM
  – Balmer lines
  – Theoretical colors
  – Empirical colors
  – Ionization equilibrium
  – Excitation equilibrium
Stellar parameters: $T_{\text{eff}}$ - IRFM

- InfraRed Flux Method
  - Compares the ratio of IR-Colors to total flux between:
    - Theoretical model (model atmosphere flux distribution)
    - Measurement
  - As $F \approx T_{\text{eff}}^4$ this provides $T_{\text{eff}}$
  - Fewer opacity sources in the IR
    → often said to be ”model independent” ?!
Stellar parameters: $T_{\text{eff}}$ – Balmer lines

- $T_{\text{eff}}=6000\text{K}$
- $\Delta T_{\text{eff}}=100$
- $\Delta \log(g)=0.2$

→ Good $T_{\text{eff}}$ indicator

→ Detailed spectral information
Stellar parameters: $T_{\text{eff}}$ – Balmer lines

- $\Delta \log(g) = 0.2$ Dex
- $\Delta T_{\text{eff}} = 100K$
Stellar parameters: $T_{\text{eff}}$ – Colors

- Colors: $\Delta = 0.01 \text{Mag}$
- U-B can not be used for A & F-type stars
- Best models meet solar colors within 0.03 Mag... (ODF 0.08 Mag)
Stellar parameters: $\log(g)$

- F and G-type stars
  - Strong line method
  - Ionization equilibria
  - Main sequence fitting
  - Colors
Stellar parameters: \( \log(g) \) - Strong

- Strong lines of eg. Mg, Fe, Ca are very pressure and therefore \( \log(g) \) sensitive.
  - Measure element abundance using “weak” lines.
  - Use strong lines of the same element to measure \( \log(g) \).
- Mg-b lines together with Mg 5711Å work well.
- If there is significant NLTE at work we are in trouble.
Stellar parameters: $\log(g)$ - IonEqui

- Ionization equilibria
  - Ionization equilibrium depends on electron pressure and therefore on $\log(g)$.
  - Very unequal partners, often 98% vs. 2%.
    Small changes in number $\rightarrow$ large changes in ratio.
  - Ionization is in most cases NLTE affected.
  - NLTE effects from other elements affect the test partners by their contribution to electron pressure.
  - In general: Results insecure by at least 0.2 Dex.
Stellar parameters: \( \log(g) \) - Evolution

- Binarity?
- Membership?
- Field stars?
Stellar parameters: Abundances

- Line fitting (LTE & NLTE)
- Equivalent width (LTE & NLTE)
Stellar parameters: Abundances

- [Fe/H] often used as “general metallicity”
- [$\alpha$/Fe] with $\alpha$=O, Ne, Mg, Si, S & Ca overabundant in metal poor stars
  - O is important opacity contributor
  - $\alpha$-elements are important electron donators
- Determined by individual line fits.
- EW is an integrated number that tells few about the quality of a fit.
- SME - “spectroscopy made easy” ...
Stellar parameters: Abundances

- Li (NLTE)
  - Significant “scatter”
  - Is this real?

Chen, Nissen, Benoni, Zhao (2001)
Stellar parameters: Error sources

- Model
  - Computational limitations (≈10K for 1D models)
  - Opacity data
  - Treatment of convection
  - Solar element abundances (C,N,O, .. Ne,..Fe)
  - Balmer line broadening
  - LTE vs. NonLTE
  - ...

- Observation
  - High resolution spectroscopy (noise, normalization)
  - Photometry (standards, system transformation ...)

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Slide 20
Error sources: Model atmospheres

More UV-opacity → Flux redistribution to the red
Error sources: Resonance broad.

- There are concurrent theories of resonance broadening for Balmer lines

\[ \Delta T \approx 70 \text{K} \]
Error sources: LTE vs. NLTE (1)

- NLTE / LTE difference
- As large as 0.5 Dex
- Too large to tell anything about chemical evolution

What can be done (1)

- Mel111, age determination
What can be done (2)

- Mel111 distance: Hipparcos vs. spectroscopic
- Note the error-bars
What can be done (3)

- Pleiades distance: Hipparcos vs. spectroscopic
- Now spectro. is even better!
Summary:

- We are able to determine stellar parameters with reasonable accuracy
  - Using Balmer lines for effective temperatures
  - Broad lines (Mg-b) for log(g)
  - Fe for metallicity
  - Mg for $\alpha$-element enhancement

- We can determine good NLTE abundances

- LTE is a real danger – remember, $\Delta$(LTE,NLTE) may reach 0.5 Dex
Planet host stars: Rocky planets

- Rocky planets consist of Fe, O, Si, Mg, ...
- So these elements should miss in the stars that have formed rocky planets
- Very precise measurements needed (effect is small)
  - Best parameters
  - NLTE analysis
  - Main-sequences of OC
What should be improved

- Modern telescopes and spectrographs increased observational quality dramatically.
- Model insecurities today level observational errors → need to improve on theory!
- Theory needs to keep pace with >VLT projects.
  - NLTE for hydrogen Balmer lines
  - NLTE for Mg-b lines (and all other elements)
  - Better tests of the atmospheric models
  - Better instruments that allow for good continuum rectification and continuous spectra
Planet host stars: Parameters

- Thanks to the organizers of the conference!
- If anybody needs MAFAGS atmospheric models, feel free to contact me.
- We need large telescopes dedicated to spectroscopy!

Thank you for your attention!
A few words on differential analysis...

- Differential analysis require:
  - Comparable physics throughout the model
    - Comparable temperature structure
    - Comparable pressure structure
    - Comparable flux structure (photo-ionization)
    - Comparable convective structure
A few words on differential analysis...
Error sources: Solar abundances

CNO changed
## Total error budget: Contributors (Sun)

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<tr>
<th>Category</th>
<th>IRFM</th>
<th>U-B</th>
<th>B-V</th>
<th>Balmer</th>
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</table>
Total error budget: The $T_{\text{eff}}$ error bar

Neither Gaussian error propagation nor total sum are the real thing! (e.g. Balmer line broadening) It is a “budget” and it depends on the science how much you “spend”.

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<td>Balmer</td>
<td>±90 K</td>
<td>±190 K</td>
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Model insecurities $\geq$ observational insecurities. Better observations VLT/ELT need better models!