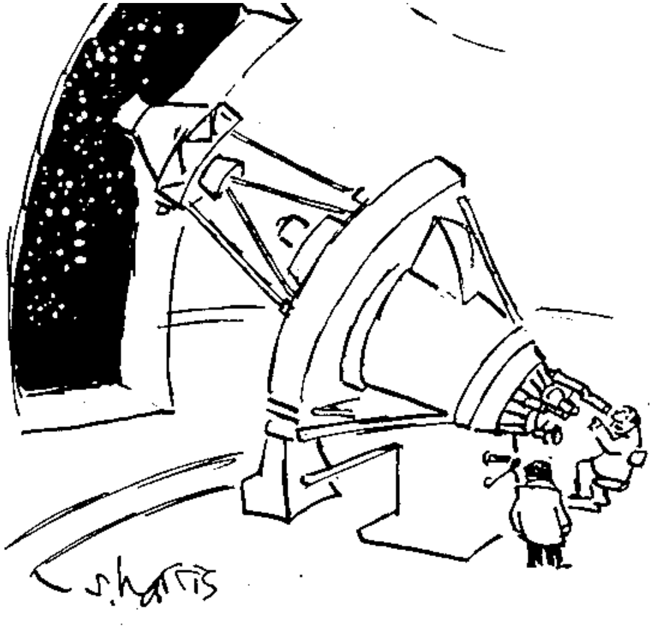
Accuracy of T_{eff} determination

Pasadena – November 8th 2006



"Actually they all look alike to me."

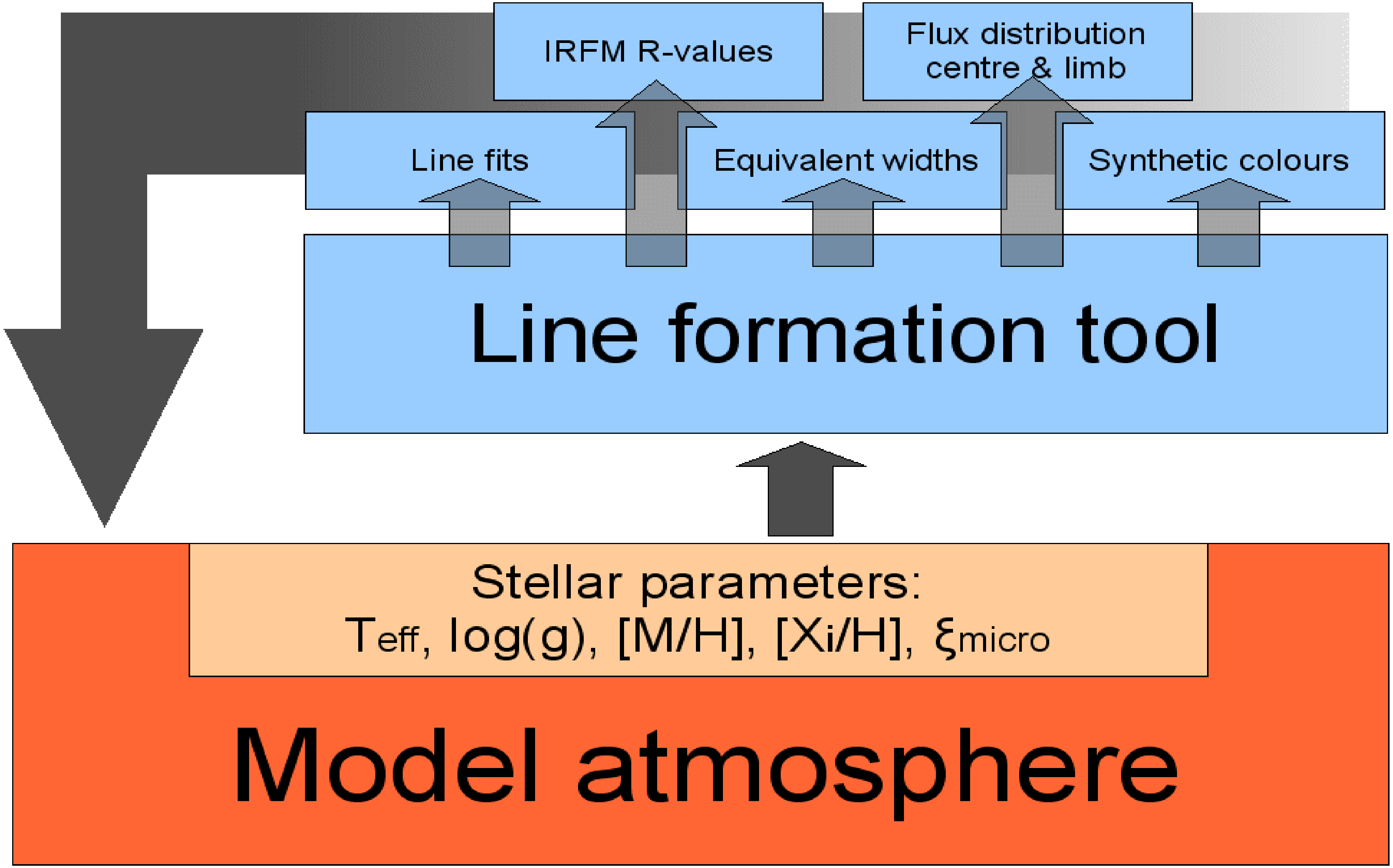
How accurately can we determine stellar parameters: The case of T_{eff}

in F and G type stars

T_{eff} determination: Outline

- Model atmospheres – the backbone of all methods
- Methods of determining effective temperatures
- Error sources:
  - **Models: atmospheres / line formation**
  - Observation
- Error budget
- Outlook (checking our atmospheric models)

Model atmospheres: Backbone (1)



Model atmospheres: Backbone (2)

- There are different approaches to model atmosphere calculation:
  - 1D hydrostatic models: ATLAS, MARCS, MAFAGS
  - 3D hydrodynamic models: 3D
  - 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)

Methods of T_{eff} determination

- F and G-type stars
  - Infrared Flux Method, IRFM
  - Balmer lines
  - Theoretical colors
  - Empirical colors
  - Ionization equilibrium
  - Excitation equilibrium

Error sources

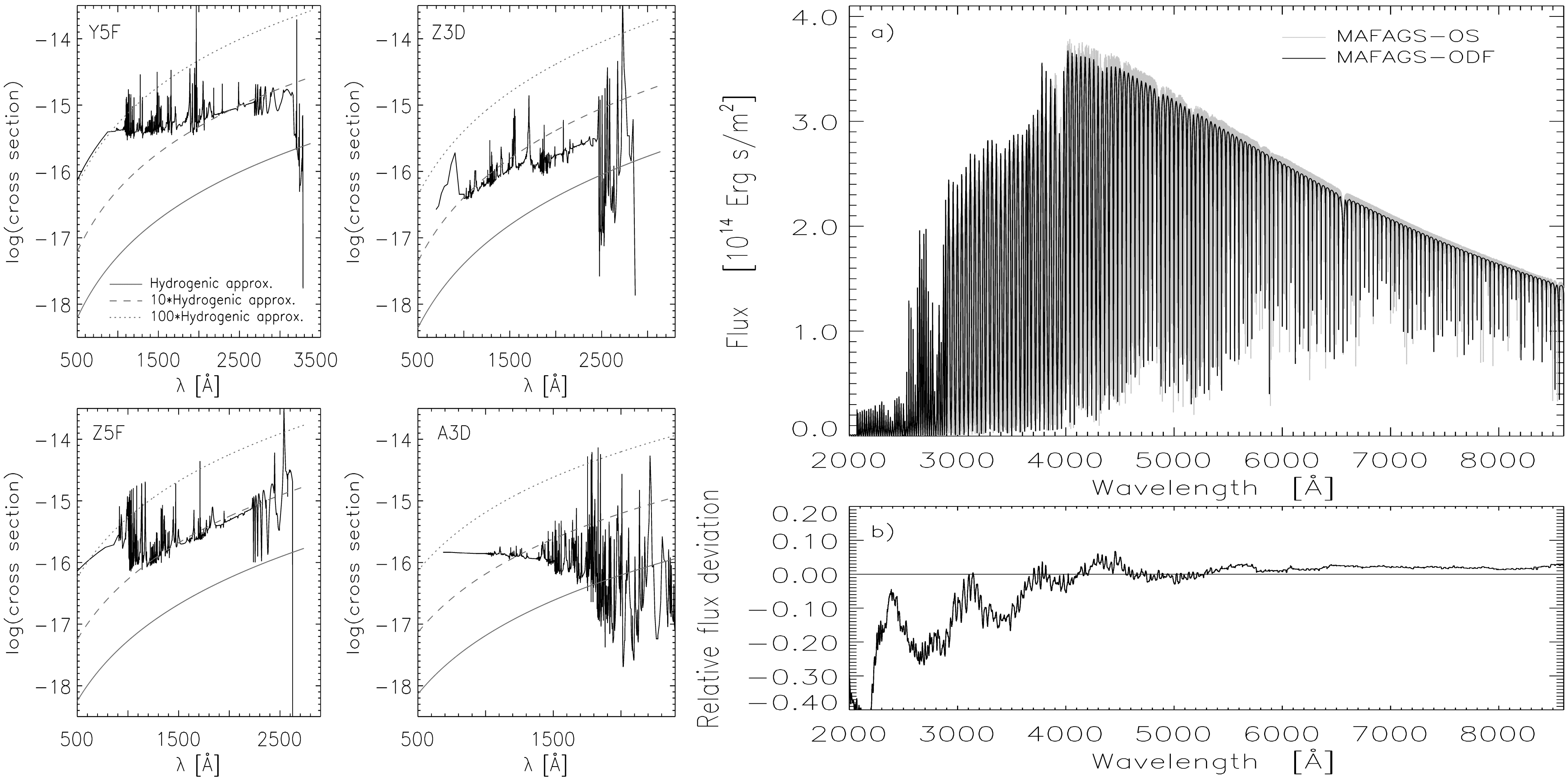
- Model
  - Computational limitations (≈10K for 1D models)
  - Opacity data
  - Treatment of convection
  - Solar element abundances
  - Balmer line broadening
  - LTE vs. NonLTE
  - ...
- Observation
  - High resolution spectroscopy (noise, normalization)
  - Photometry (standards, system transformation ...)

Error sources: Opacity data (1)

- Line opacity (bound-bound)
  - Blindly use large atomic databases

  → OS instead of ODF
- Continuous opacity
  - Bound free cross sections (ionization)
    → Calculated instead of hydrogenic data Fe,Mg,Al
  - Free-free cross sections (photon scatter)

Error sources: Opacity data (2)



More UV-opacity → Flux redistribution to the red

Error sources: Opacity data (3)

- Flux is redistributed
  → IRFM and colors affected
- Temperature structure changed
  → Balmer lines affected

	Sun	Sun [M]=-2
IRFM	±60 K	±20 K
U-B / B-V	±170/45 K	±35/45 K
Balmer	±50 K	±20 K

Error sources: Convection

- 1D hydrostatic
  - Böhm-Vitense mixing length theory
  - Canuto & Mazzitelli theory
  - → α-parameter insecure by ≈±0.15

	Sun	Sun [M]-2
IRFM	±10 K	±10 K
U-B / B-V	±10/5 K	±30/15 K
Balmer	±30 K	±50 K

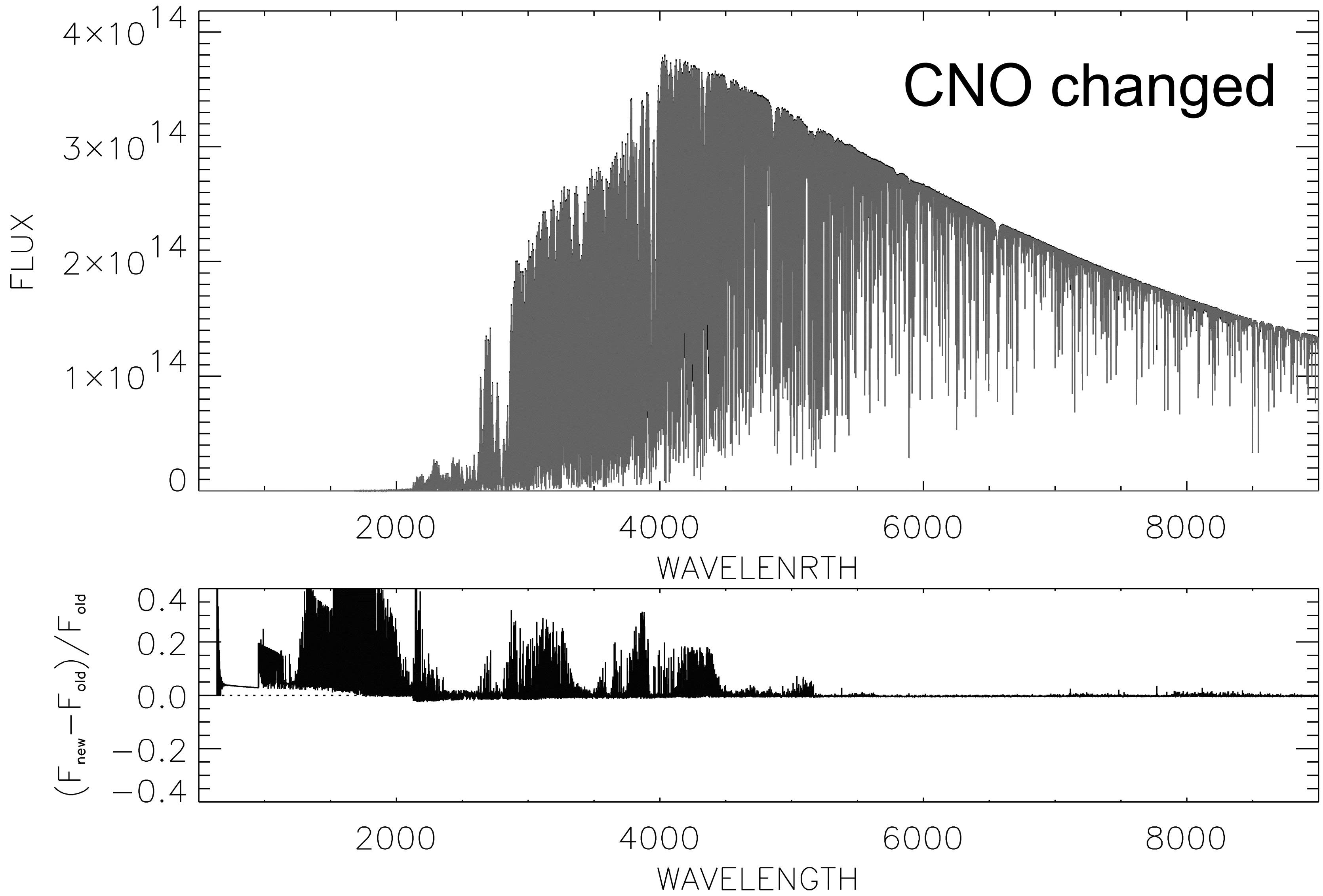
- **3D hydrodynamics (Nordlund et al.) ??**

Error sources: Solar abundances (1)

- CNO abundances decreased in recent studies.
- Ne has no notable influence on solar *atmosphere*.
- Fe insecure by at least 0.03 dex.

→ **New abundances**
  → **Changed opacities**
    → **Changed atmospheric structure and flux!**

Error sources: Solar abundances (2)



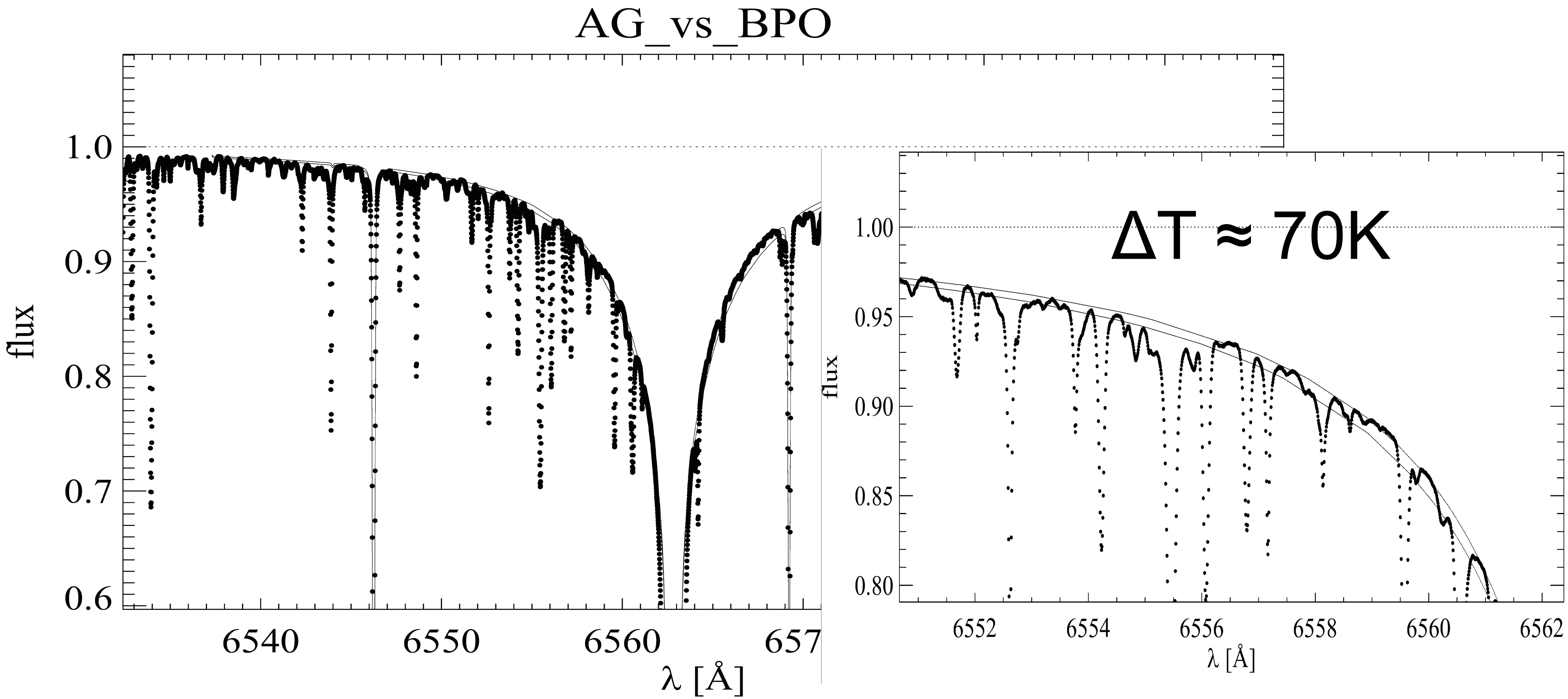
Error sources: Solar abundances (3)

- CNO abundances decreased (1D value)
- Fe = 7.50 (1D value)

	Sun	Sun [M]-2
IRFM	±15 K	±5 K
U-B / B-V	±30/20 K	±30/10 K
Balmer	±15 K	±5 K

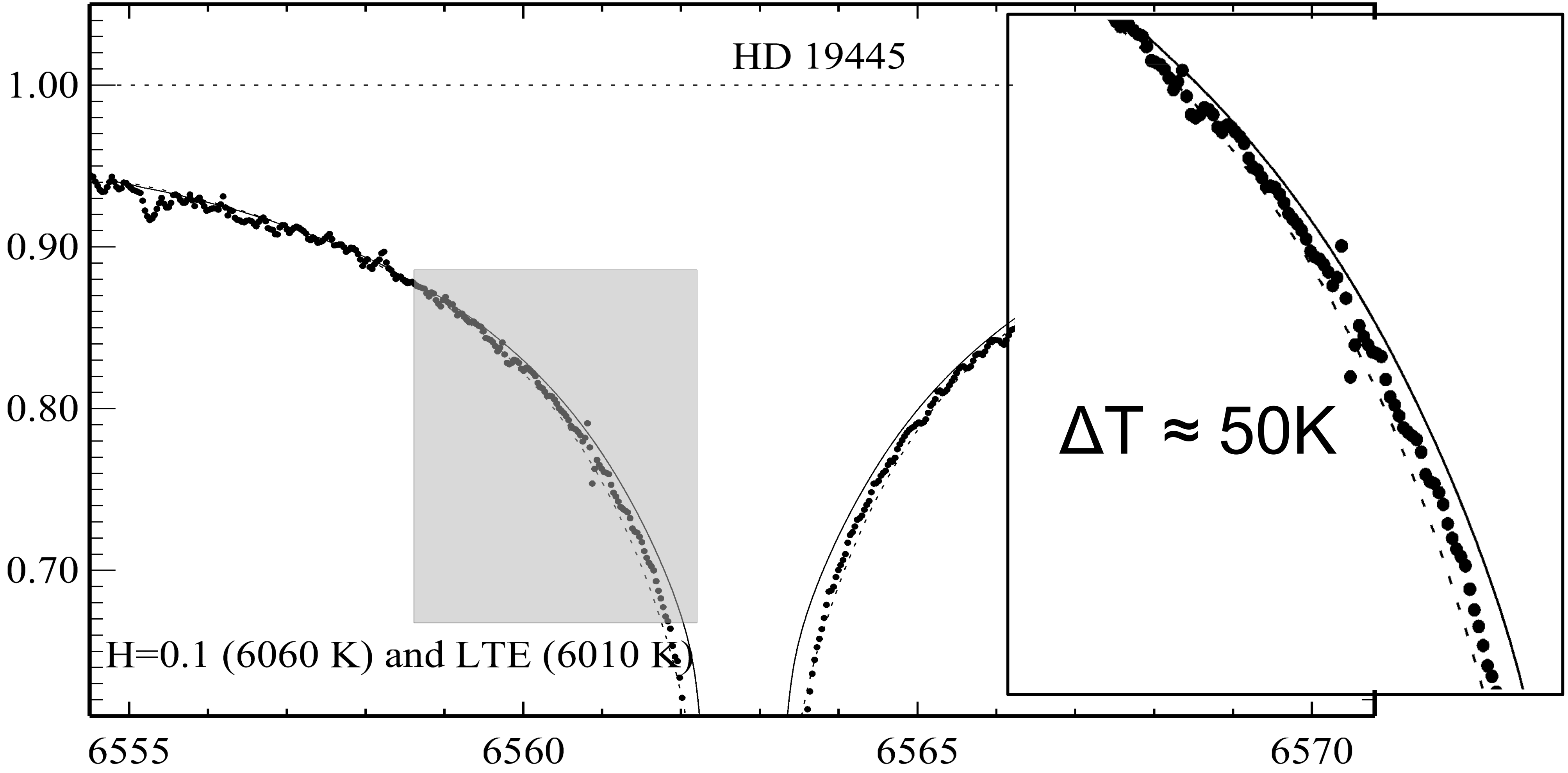
Error sources: Balmer lines (1)

- There are concurrent theories of resonance broadening for Balmer lines



Error sources: Balmer lines (2)

- NLTE in metal poor stars (HD19445)



Total error budget: Contributers (Sun)

	IRFM	U-B	B-V	Balmer
Computation	10	10	10	10
ODF→OS(bf-cross)	60	170	55	50
Convection (1D)	10	10	5	30
CNO	15	40	20	15
Fe	30	30	25	25
Balmer				60

Total error budget: The T_{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”.

	Quadratic	Total
IRFM	±70 K	±125 K
U-B / B-V	±180/65 K	±260/115 K
Balmer	±90 K	±190 K

Model insecurities ≥ observational insecurities.
Better observations VLT/ELT need better models!

How can we improve on this situation?

- Solar flux distribution (center and limb) is a great test for the model. (3D ??, A&A 420)
- Balmer lines probe a significant fraction of the stellar atmosphere. (3D ??, A&A 426)
- Currently there is only the sun – because the sun is the only main-sequence star with “known” parameters.

... but ...

How can we improve on this situation?

...but...

- VLT-I measurement of τ Cet
  → another main sequence star with "known" parameters.
  → More such measurements urgently needed.

- Open Cluster main sequences as tests for atmospheric modeling (simultaneous to stellar evolution testing).

Accuracy of T_{eff} determination

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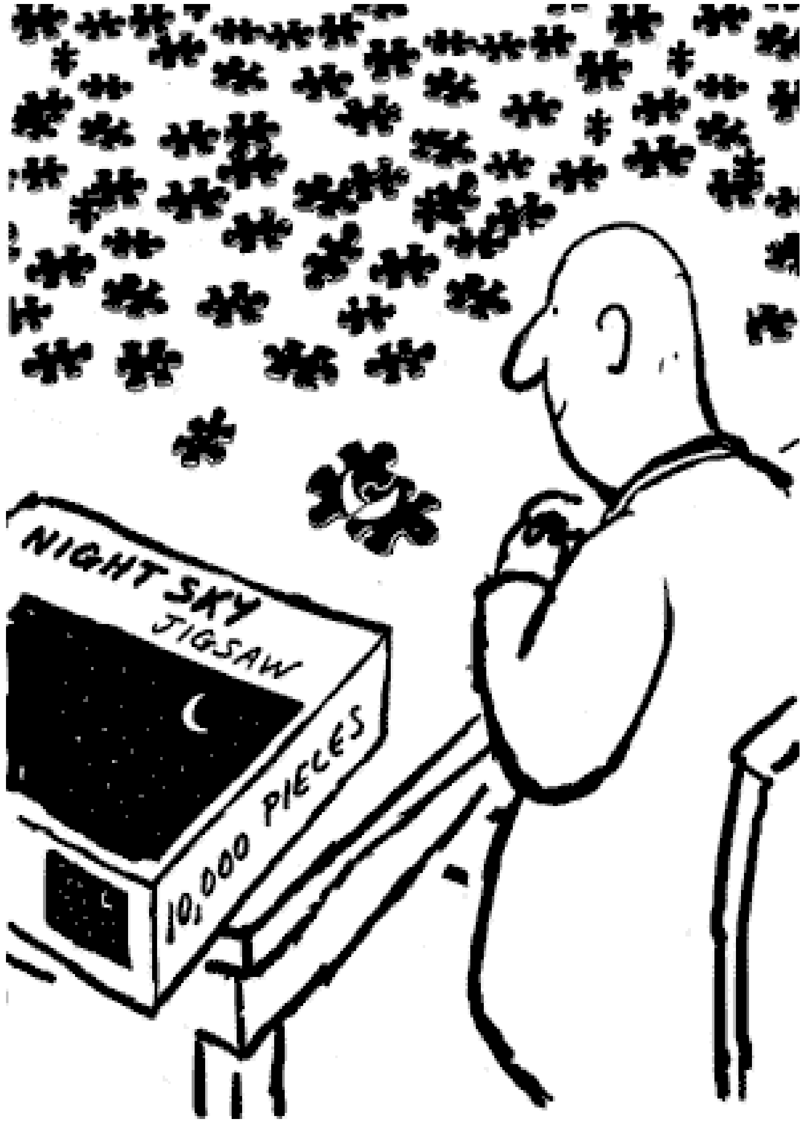

Thank you for your attention!

A few words on differential analysis...

- Differential analysis requires:
  - Comparable physics throughout the model
    - Comparable temperatures throughout the model
    - Comparable atmospheric structure
    - Comparable flux structure (photo-ionization)
    - Comparable convective structure

A few words on differential analysis...