1D model atmosphere CLV calculations

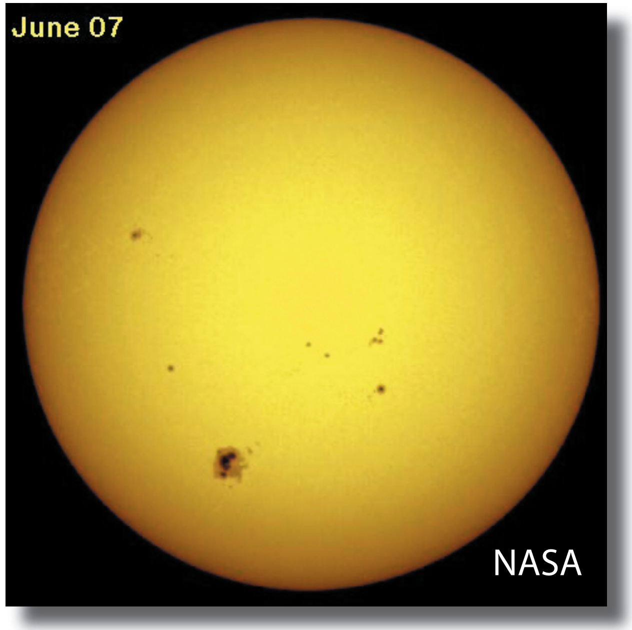
Bertrand Plez
LUPM, Université de Montpellier & CNRS

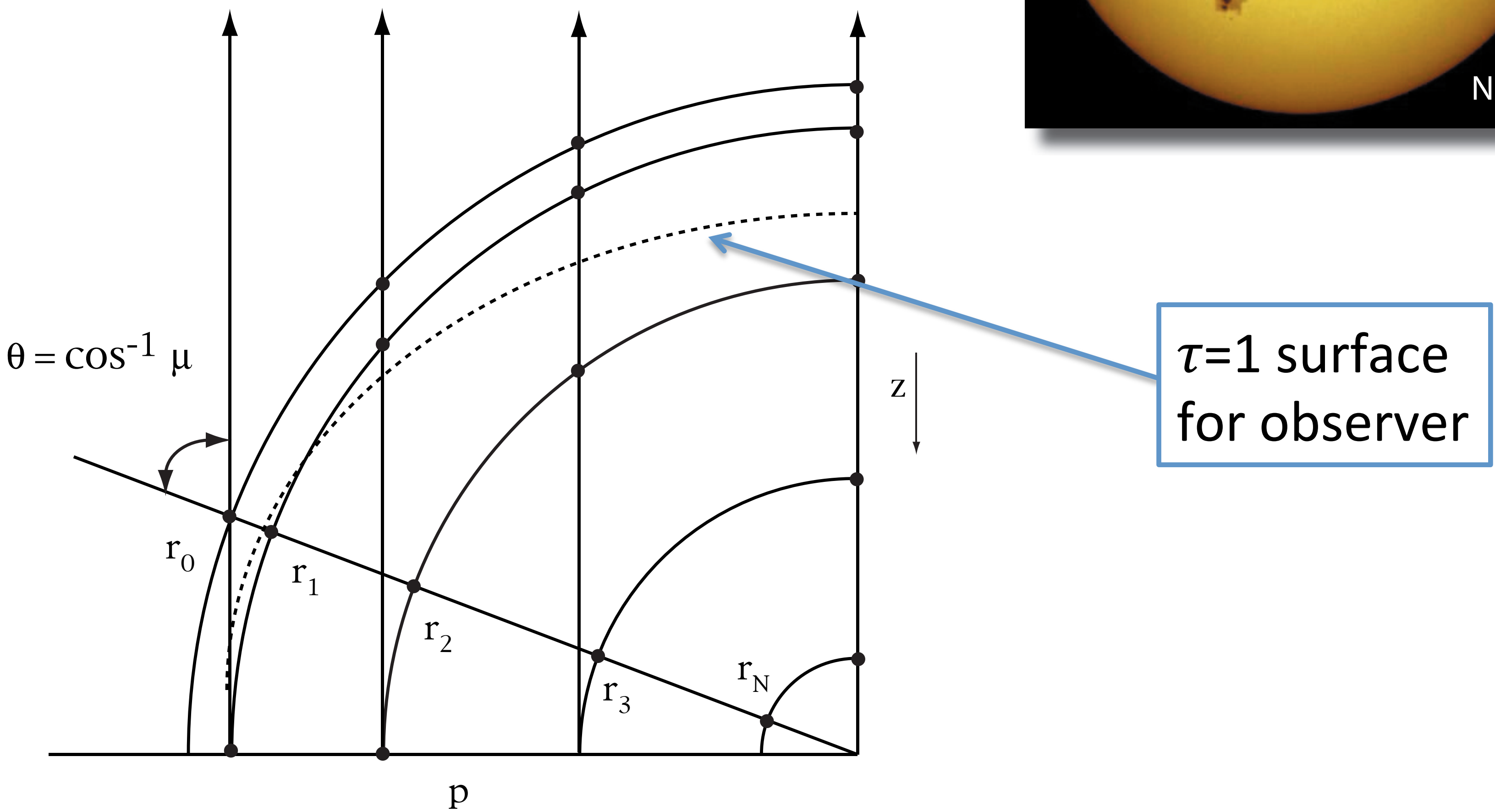
PLATO CLV workshop
IAA-CSIC
Granada 26-27/02-2019

Limb darkening

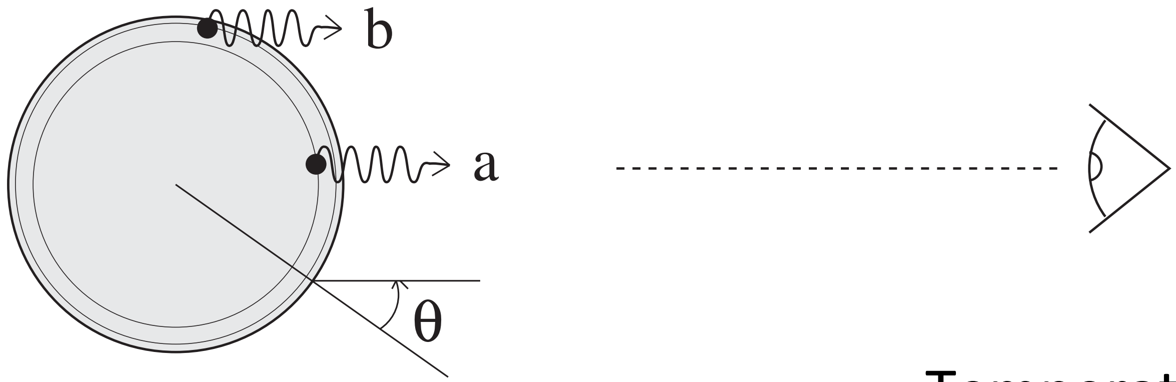
Eddington Barbier approximation:

$$I(\mu) \cong S(\tau=1)$$



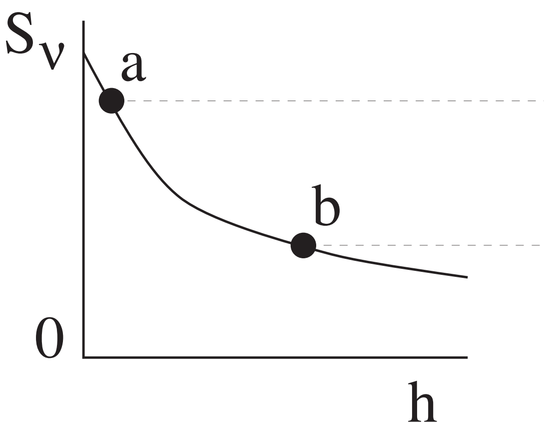


Limb darkening

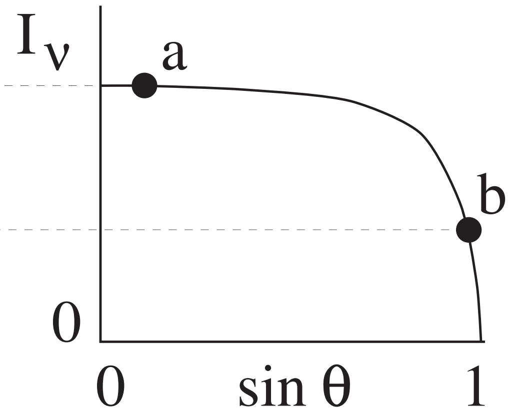


$I(\mu) \cong S(\tau=1)$

Temperature gradient
=> limb darkening



source function as a function of depth



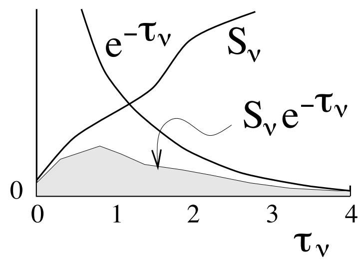
center to limb intensity profile

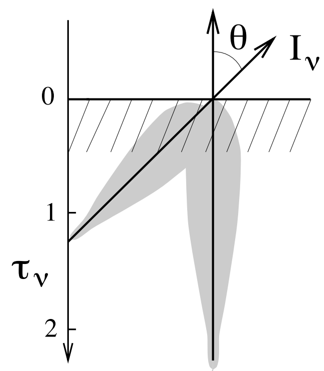
R. Rutten

Actually, it is a little more complicated

Emergent intensity: $$I_\nu^+(\tau_\nu\!=\!0,\mu) = \int_0^\infty S_\nu(t_\nu)\,\mathrm{e}^{-t_\nu/\mu}\,\mathrm{d}t_\nu/\mu.$$

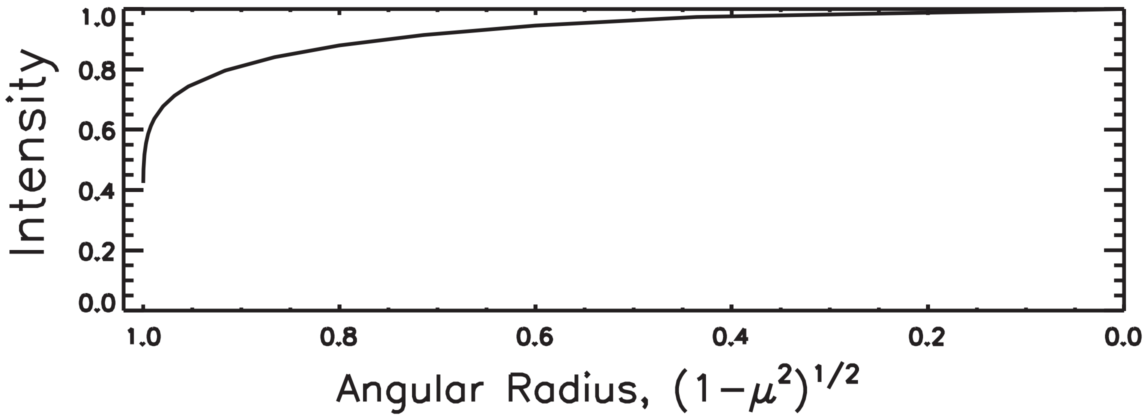
=> weighted average of source function along line of sight

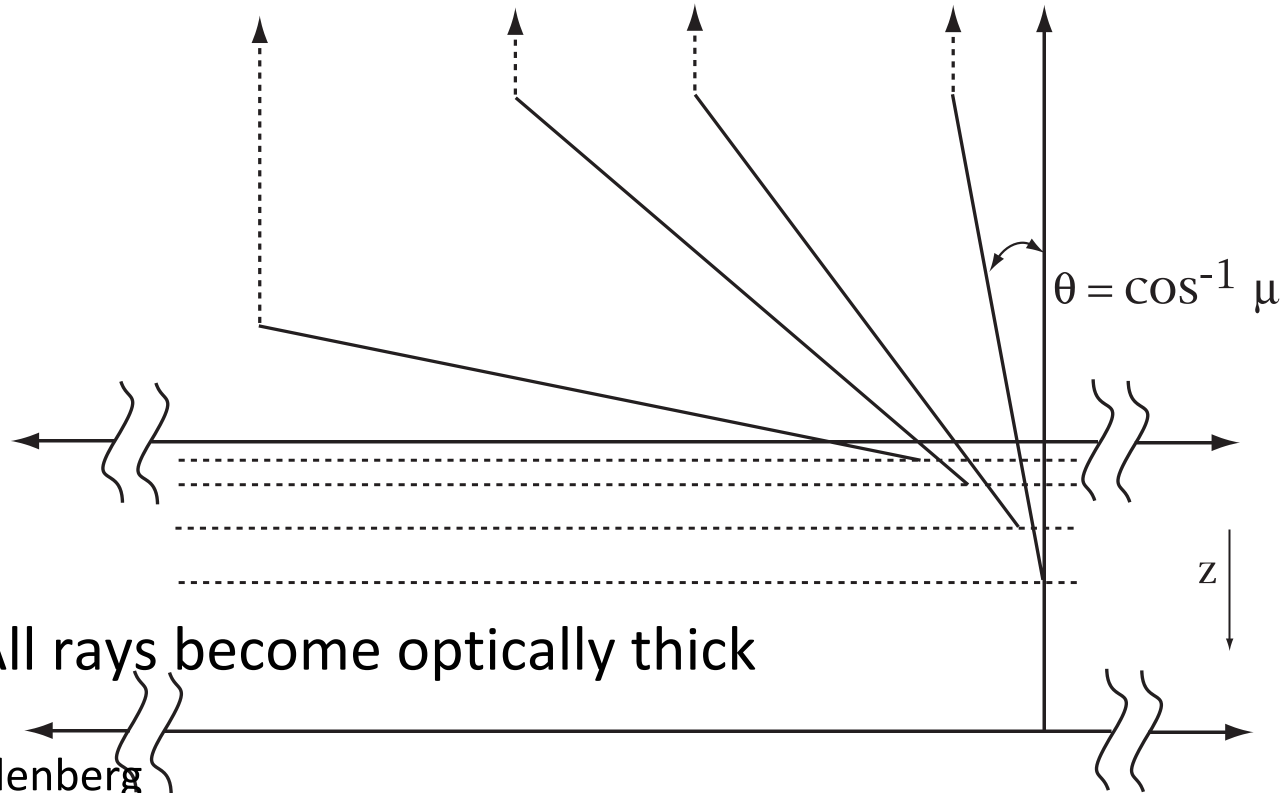




Formally very simple, but S can depend on I at other depths (e.g., scattering)

Plane-parallel atmosphere





All rays become optically thick

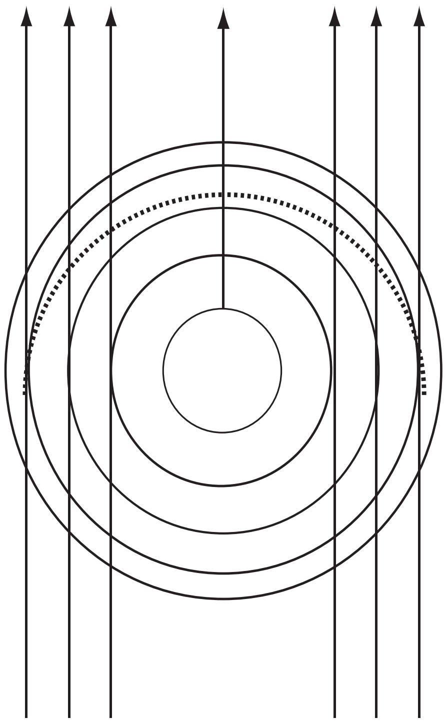
Jason Aufdenberg

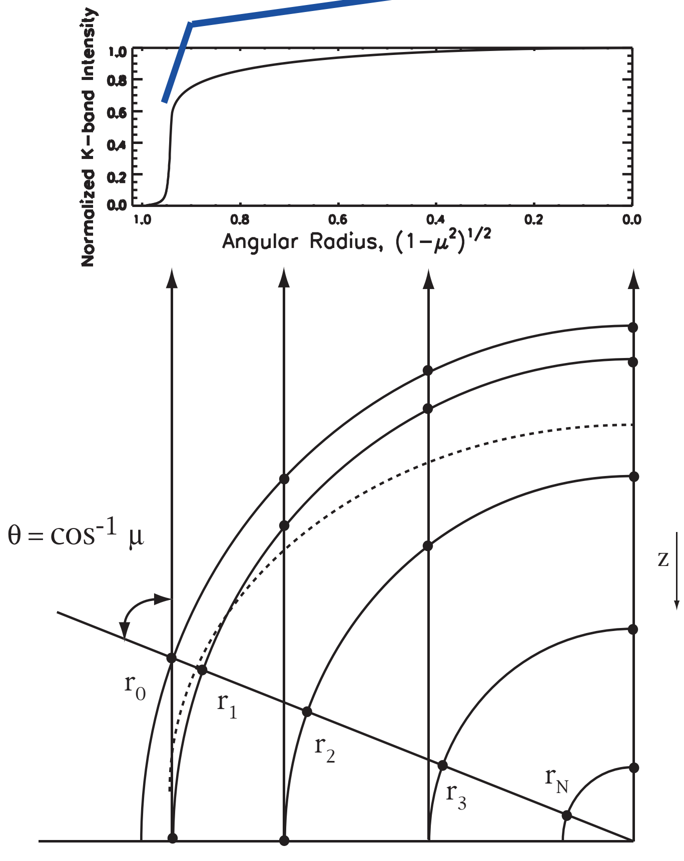
Spherically symetric atmosphere

Some rays are optically thin

=> drop-off

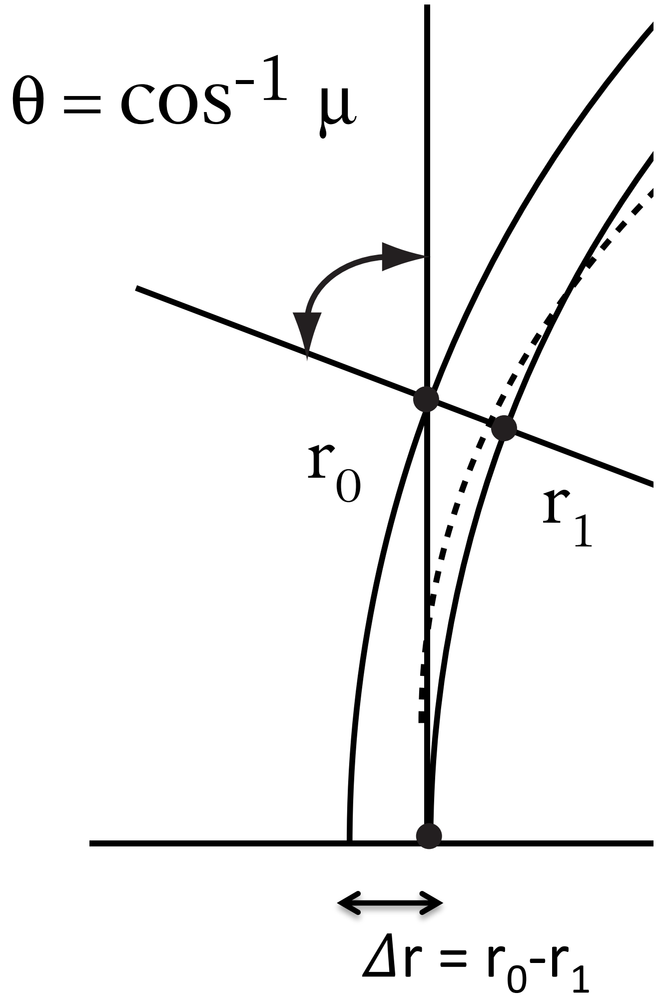
b) spherical case





Jason Aufdenberg

Importance of sphericity



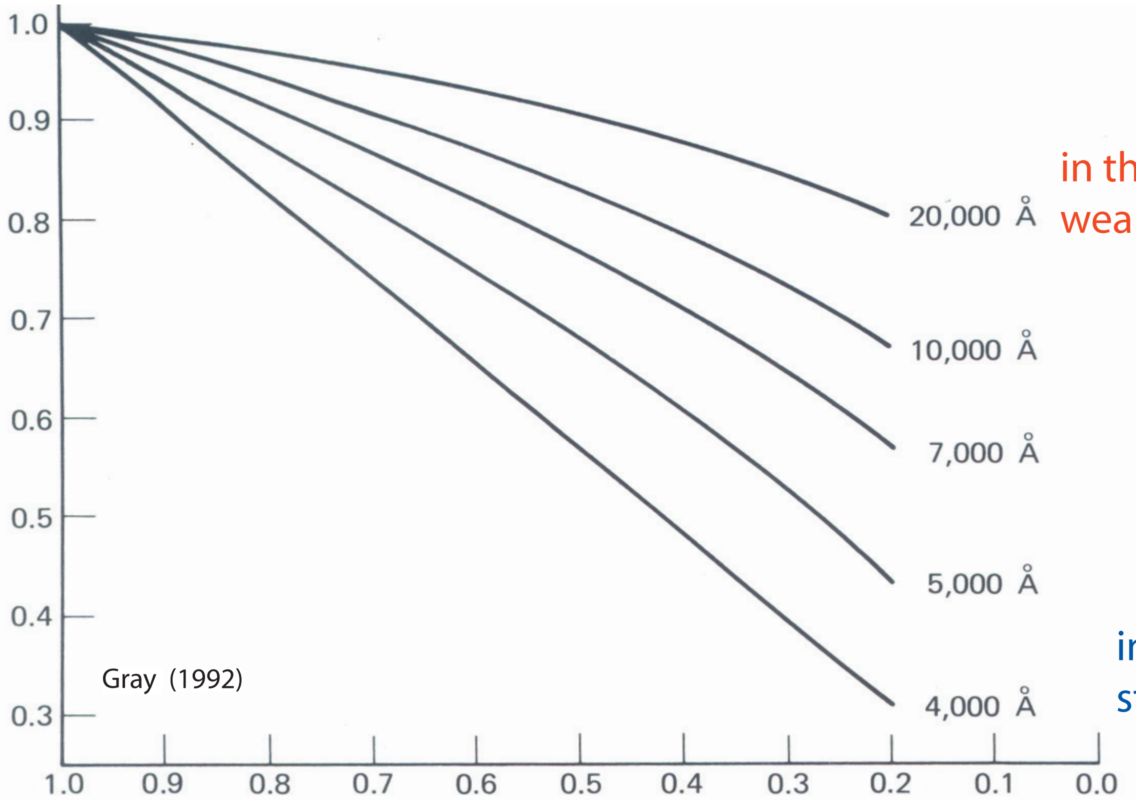
Critical angle for which ray crosses atmosphere at τ=1:
$\sin\theta_c = r_1/r_0$

$\Rightarrow \mu_c = (1-r_1/r_0)^{1/2} \approx (2\,\Delta r/r_0)^{1/2}$

$\Delta r/r_0$	μ_c	
0.1	0.45	(red giant)
0.01	0.14	
0.001	0.045	(solar case)

Limb-darkening in the continuum

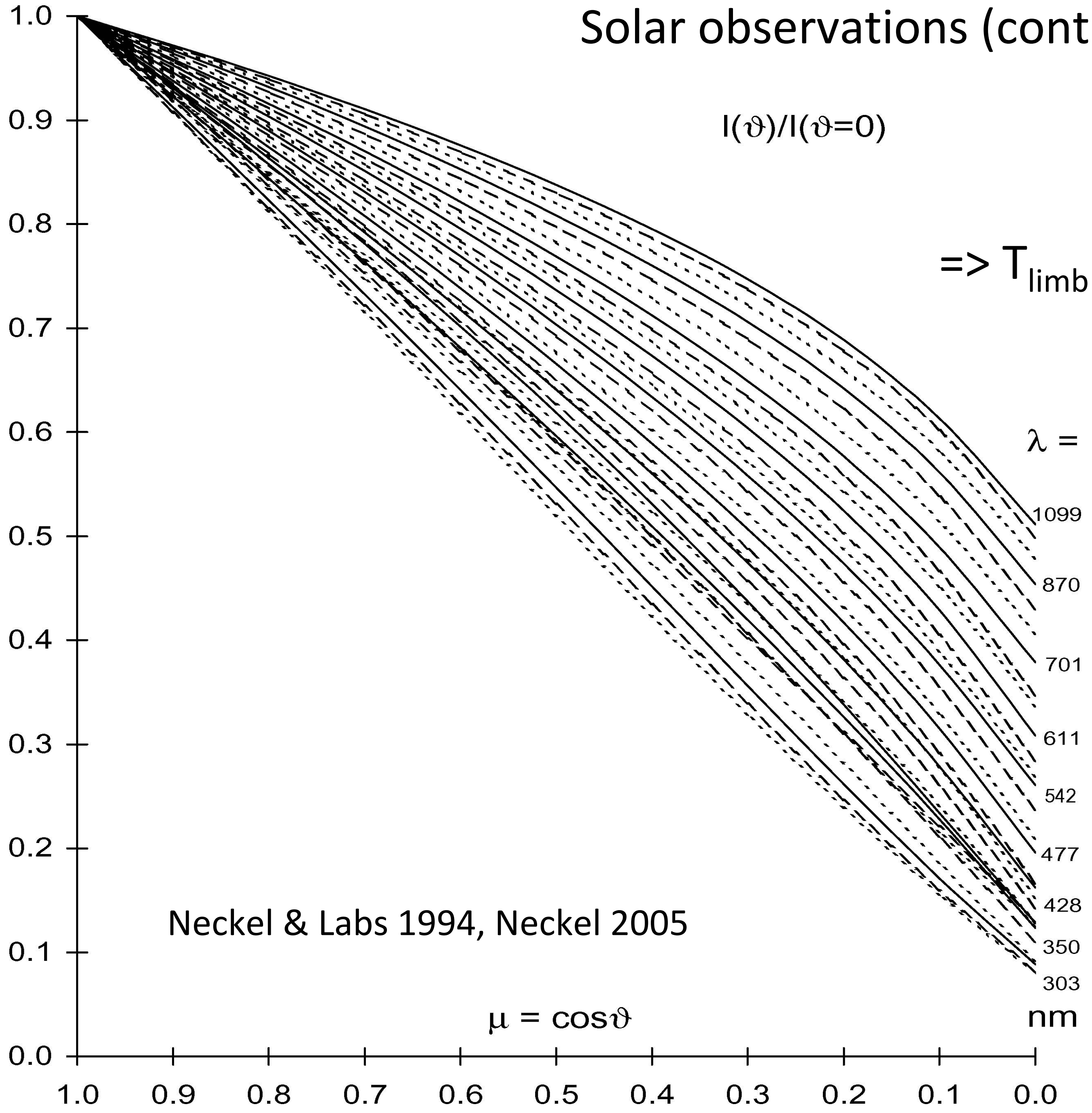
Stronger T-dependence of Planck function in the blue
=> stronger limb-darkening



in the red:
weaker limb darkening

in the blue:
stronger limb darkening

Solar observations (continuum)



=> T_{limb} = 4746K

Calculations

MARCS models + line lists + Turbospectrum

PP or SPH

continuum and line spectrum

spectral resolution > 100 000

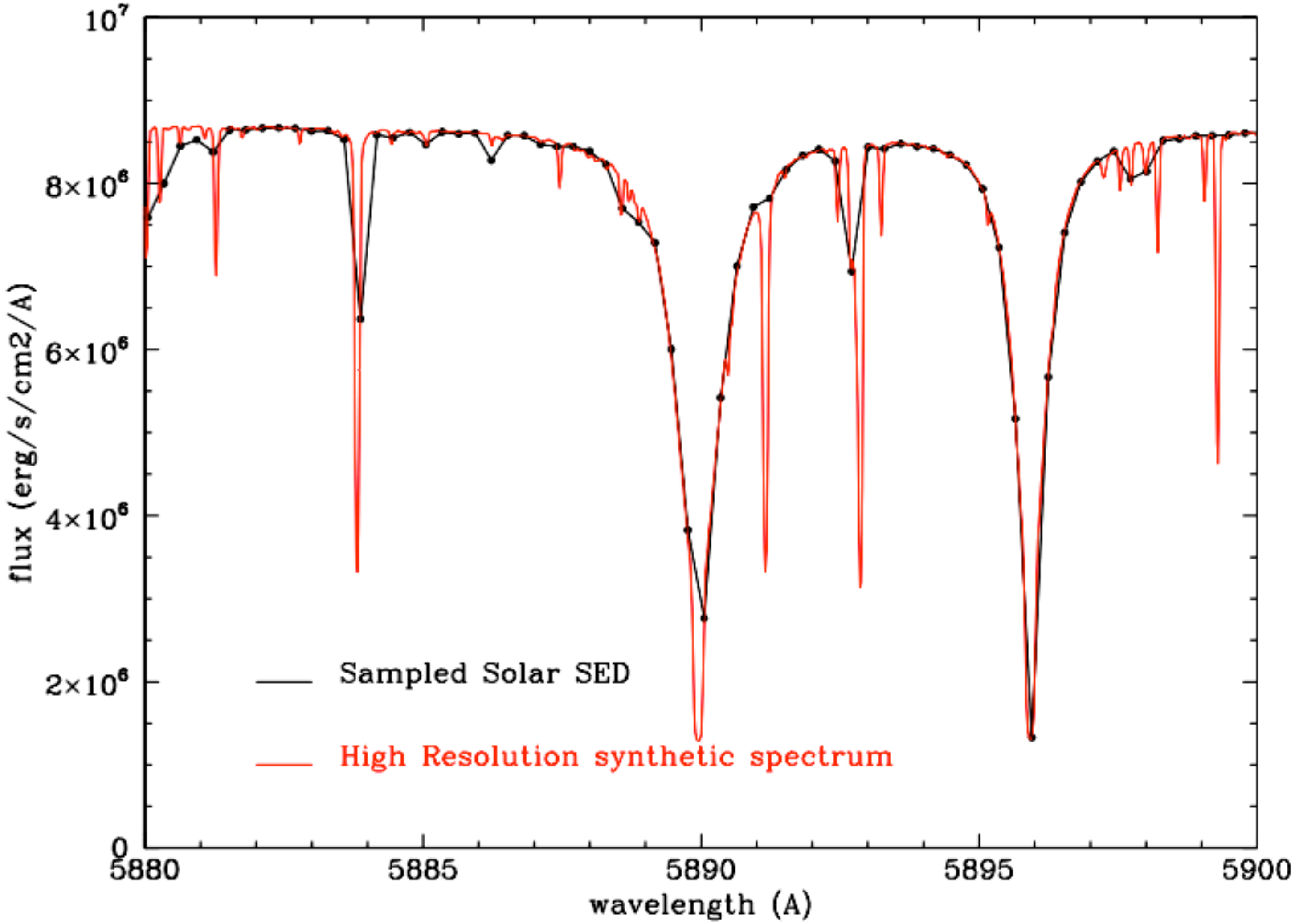
μ=0.1, 0.2, …, 1.0

MARCS 2008

- Opacity Sampling (OS) 108000 points
- updated continuous opacities
- updated line opacities, e.g. H_2O, atomic lines with Anstee, Barklem et al.'s collisional broadening, and better H I lines (Barklem & Piskunov, 2003), ...
- more than 10^4 models
- note on computing time :
  - Gustafsson & Nissen 1972 : 25mn for a PP model with 148 λ (25 Balmer lines)
  - 2008 : 10mn for a SPH model with 108000 λ (>10^8 lines)

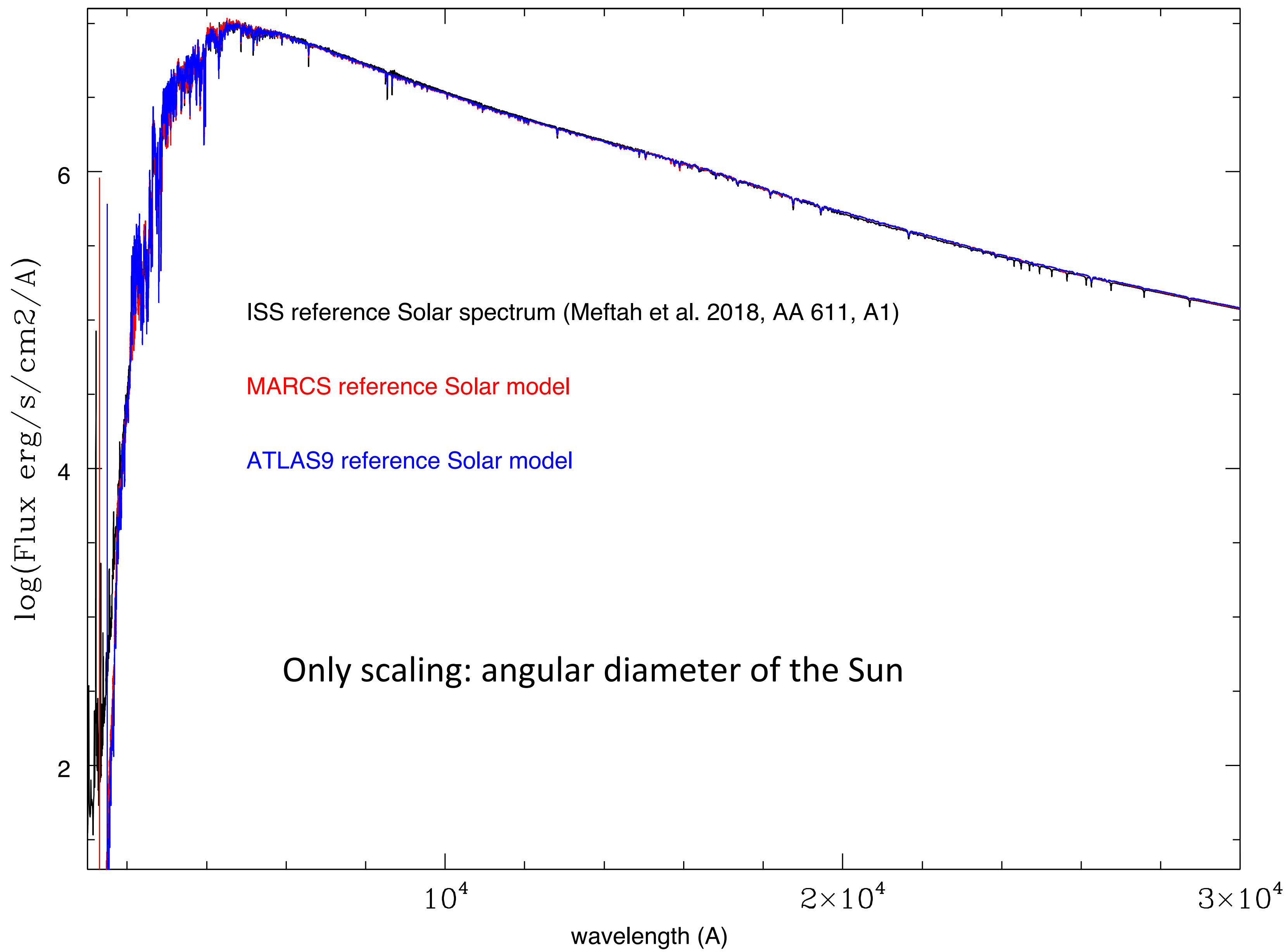
  - NB: 2019: a few minutes on this laptop

Sampling of opacities and fluxes

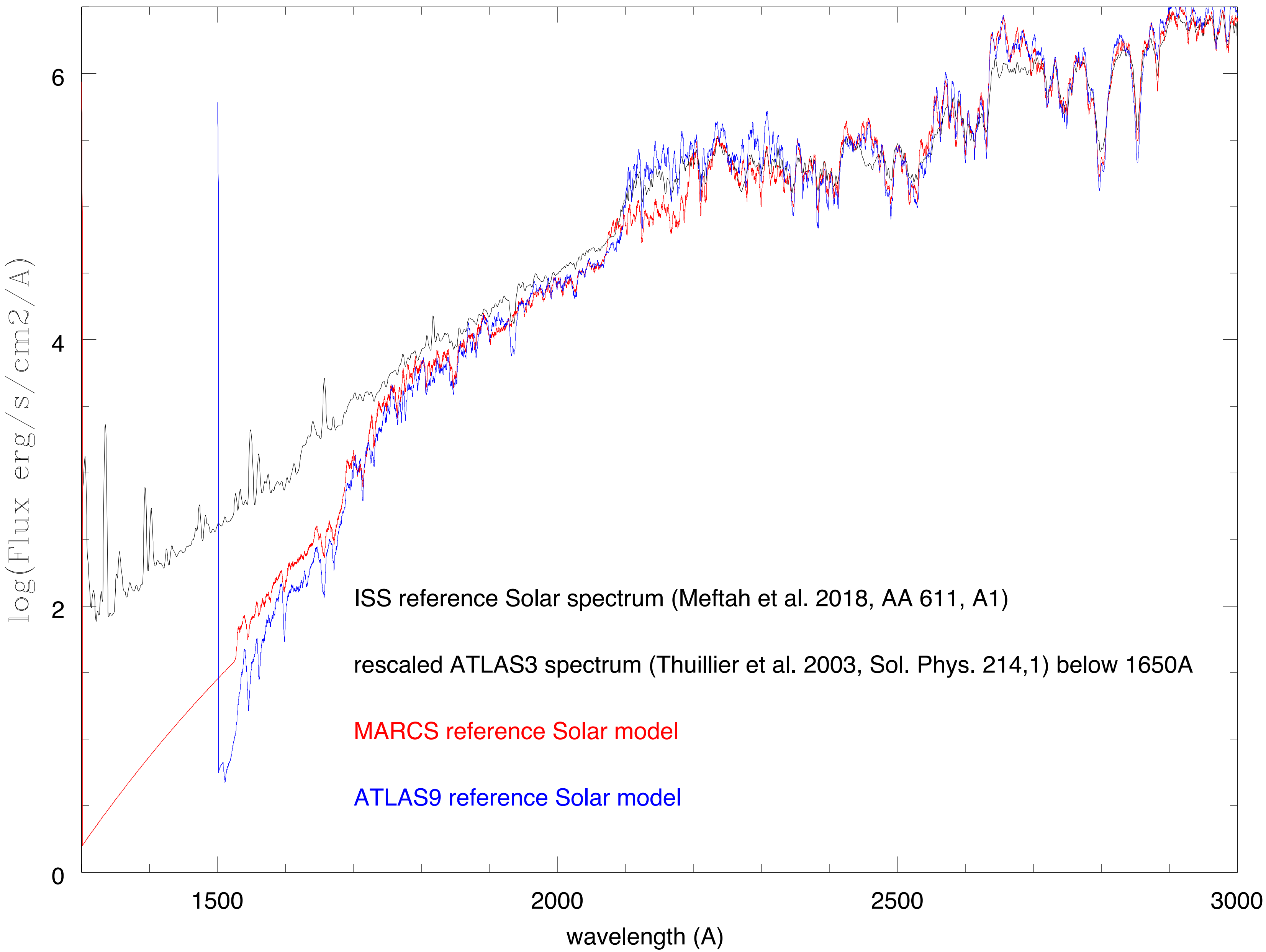


A sampled SED **is not** a high resolution spectrum smoothed to lower resolution !

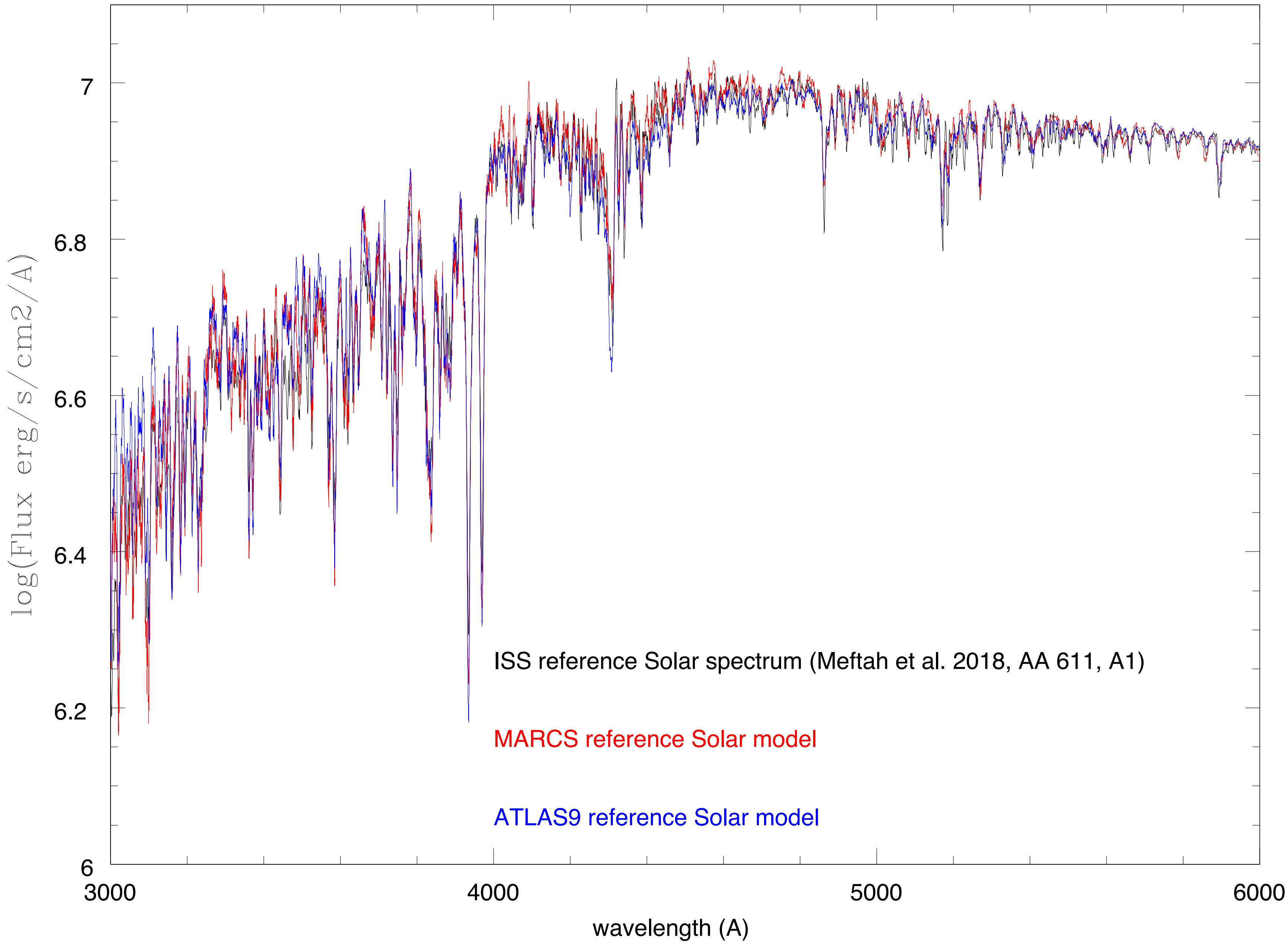
MARCS Solar model: the flux spectrum



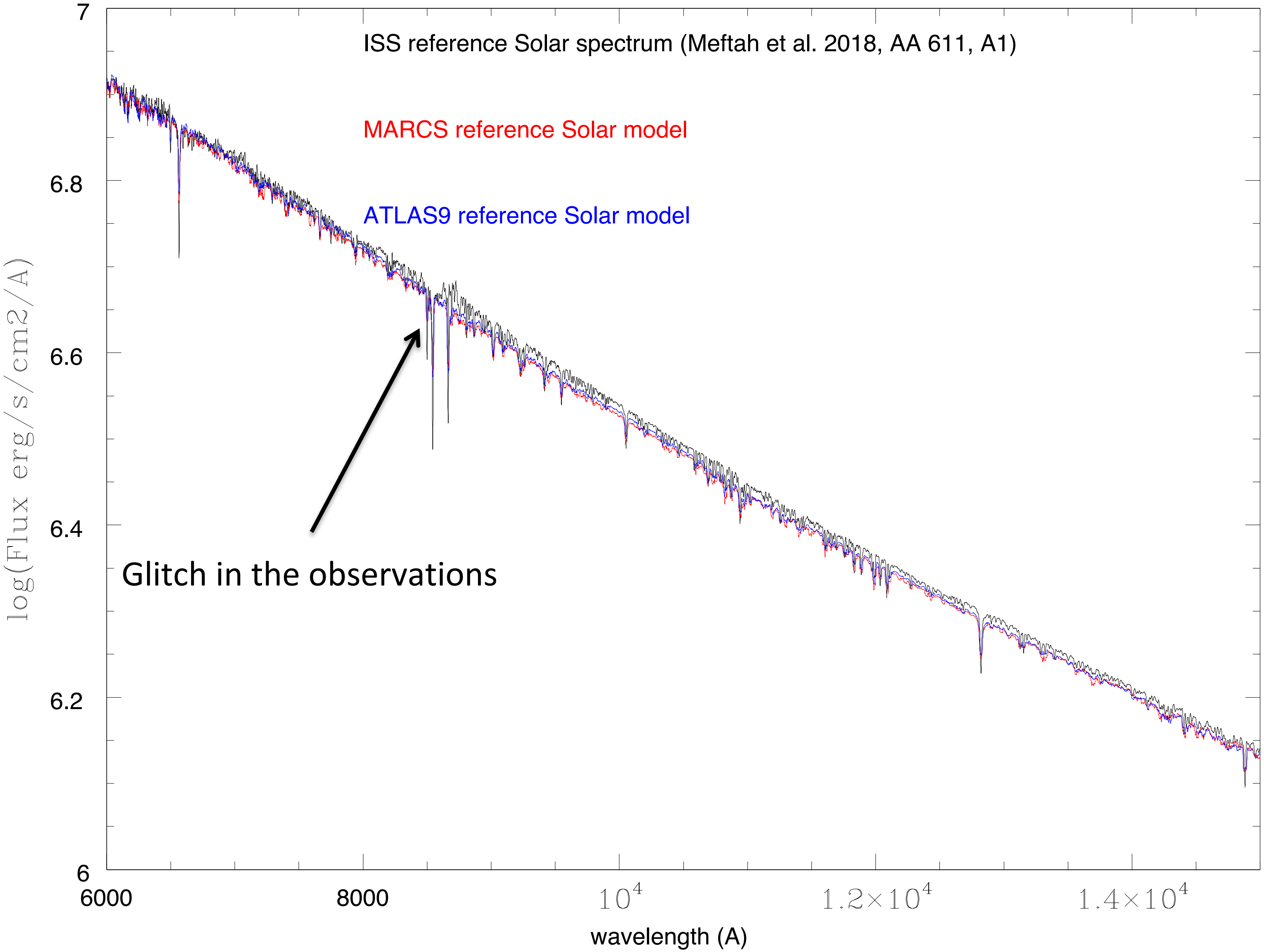
MARCS solar flux spectrum



MARCS solar flux spectrum



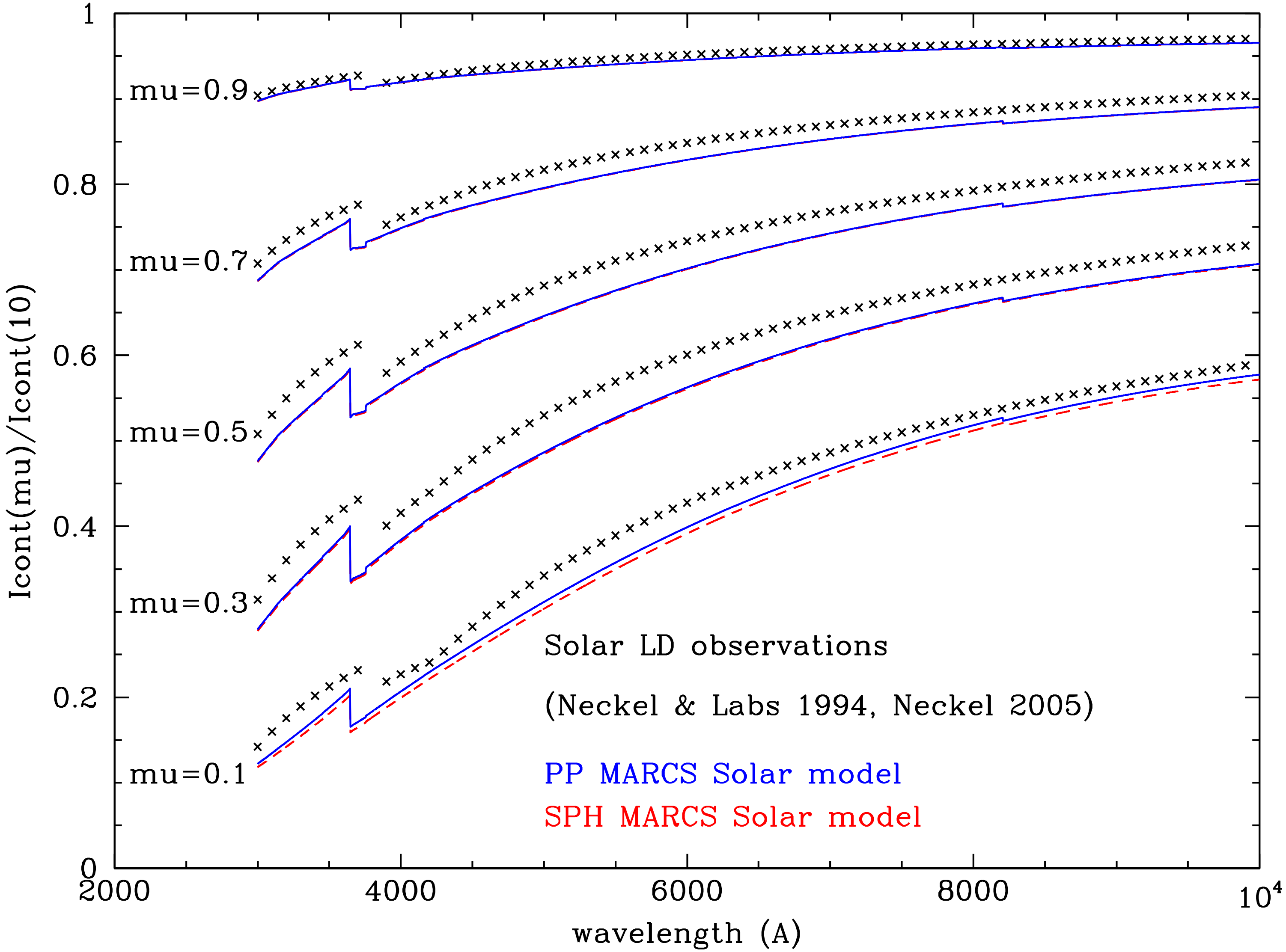
MARCS solar flux spectrum



The comparison to solar flux, although not perfect is quite good.
This can probably be improved with better line lists.
We are working on it.

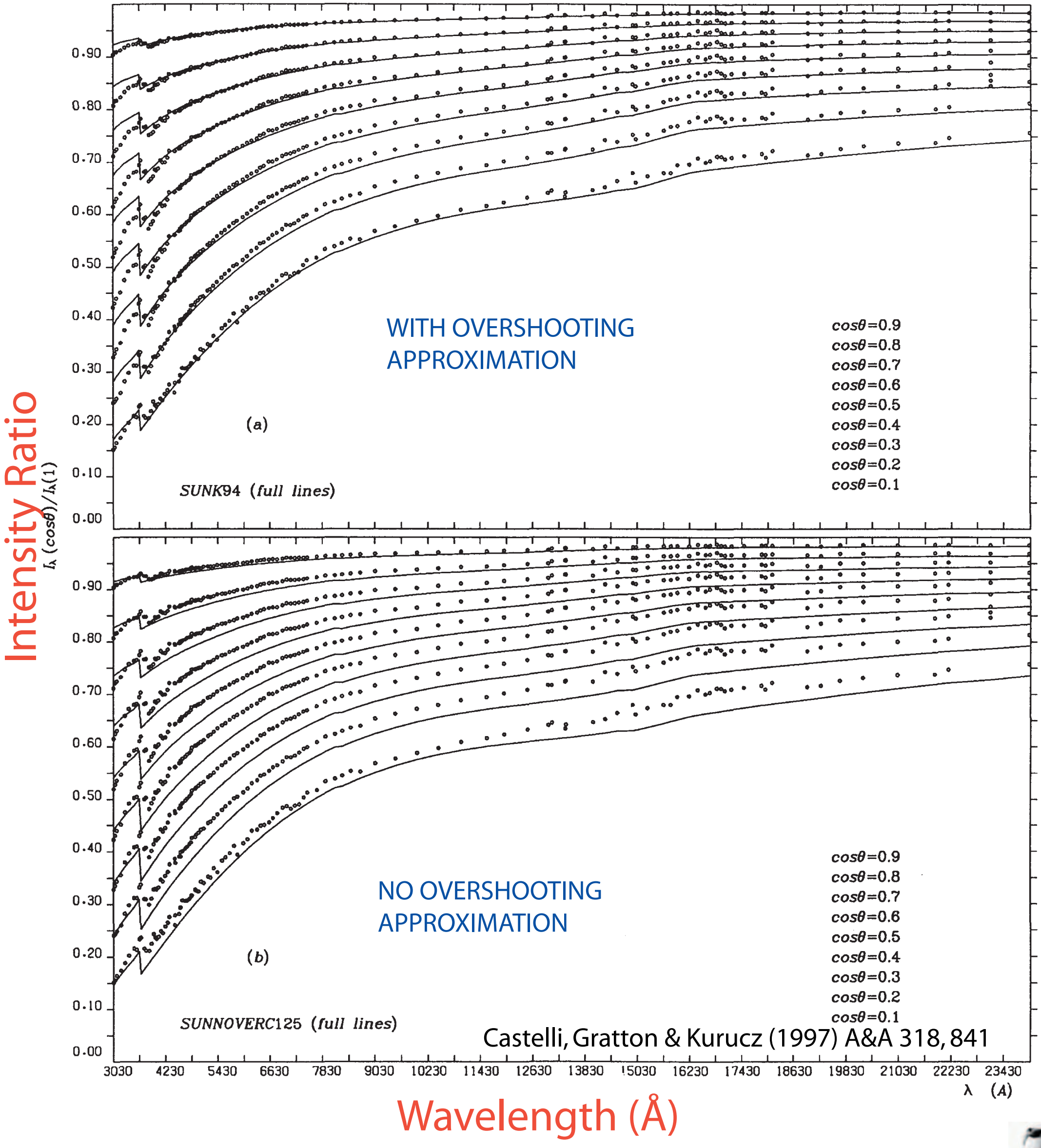
And now, a more difficult matter: intensities

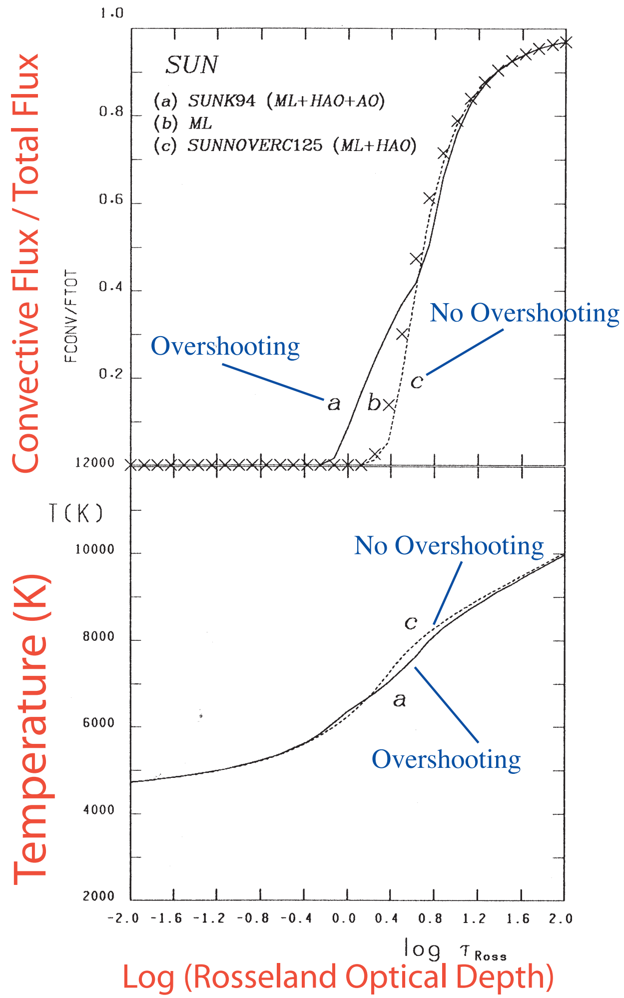
Solar continuum Limb-Darkening



⇒ the thermal gradient of 1D models is too steep between τ=1 and τ=0.1

Fiddling with convection in 1D models could partially do the trick. But this is not the way we want to do it.





Recent observations of the solar CLV

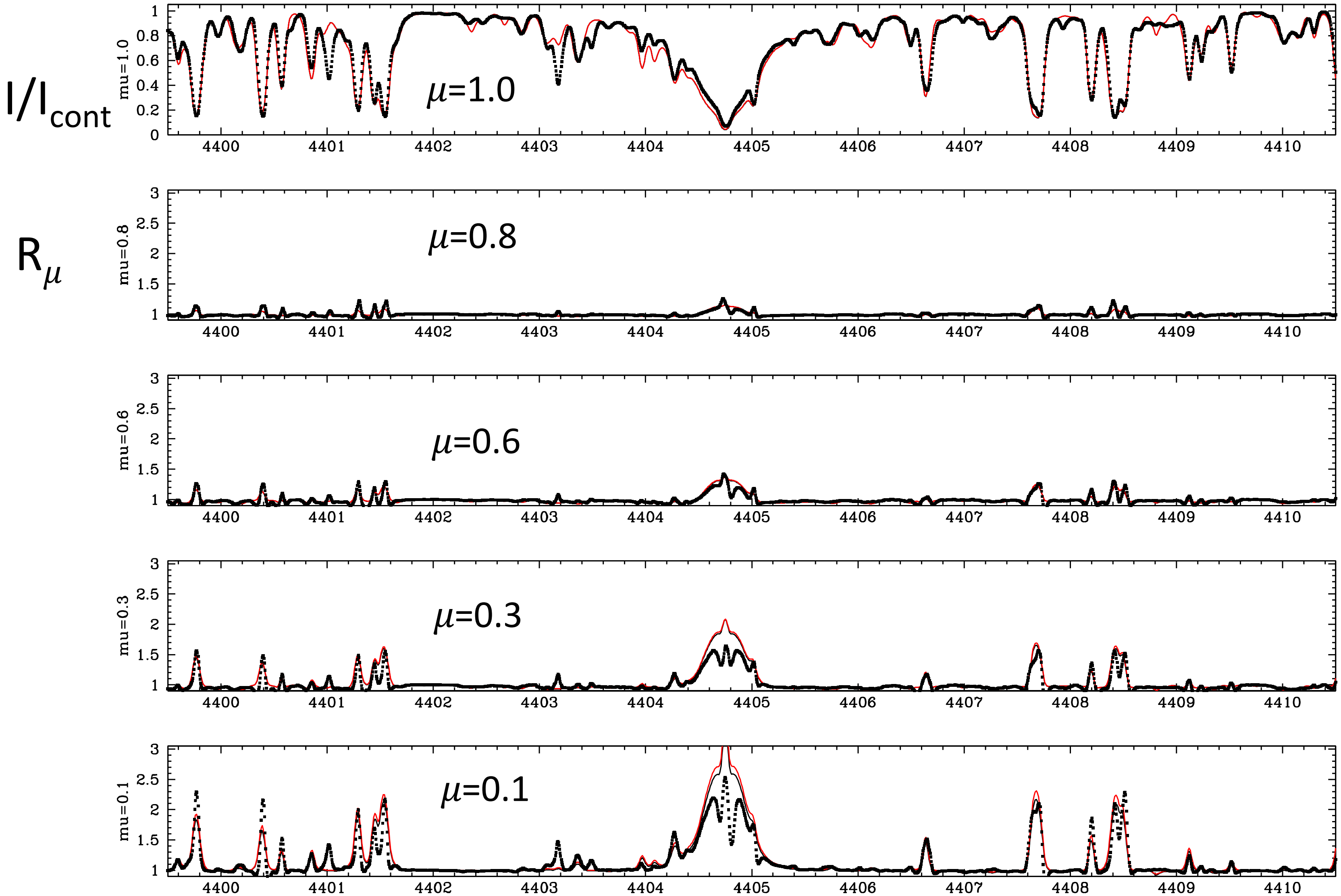
Ramelli et al. 2017, arXiv 1708.03284 IRSOL (Locarno)

Intensities at 10 angles: mu=0.1, 0.2, …., 1.0

439 − 666 nm, full resolution

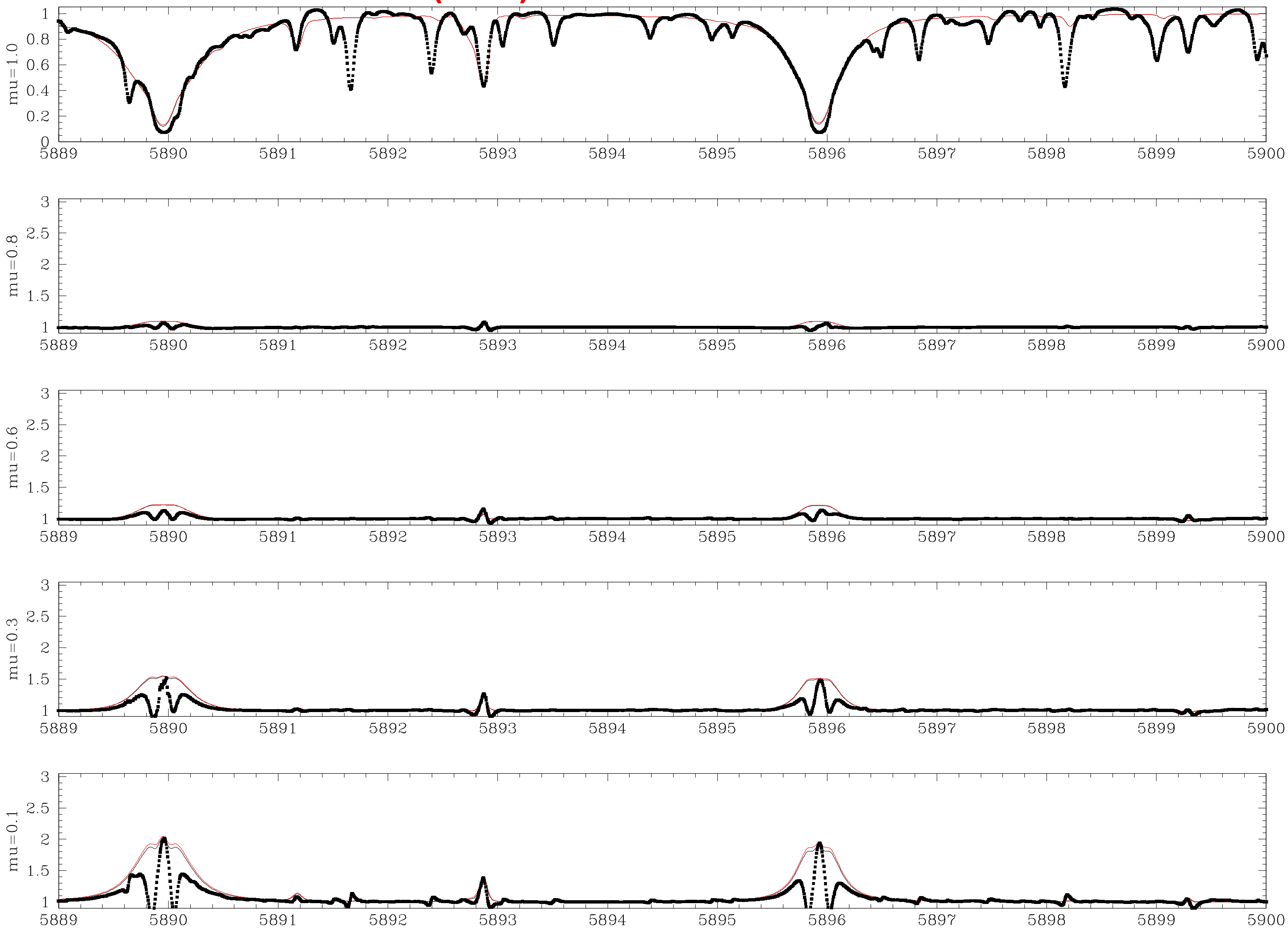
Normalized to continuum AND divided by I/I_{cont} at disk center

Continuum-normalized intensity observations (black) vs MARCS models (red)



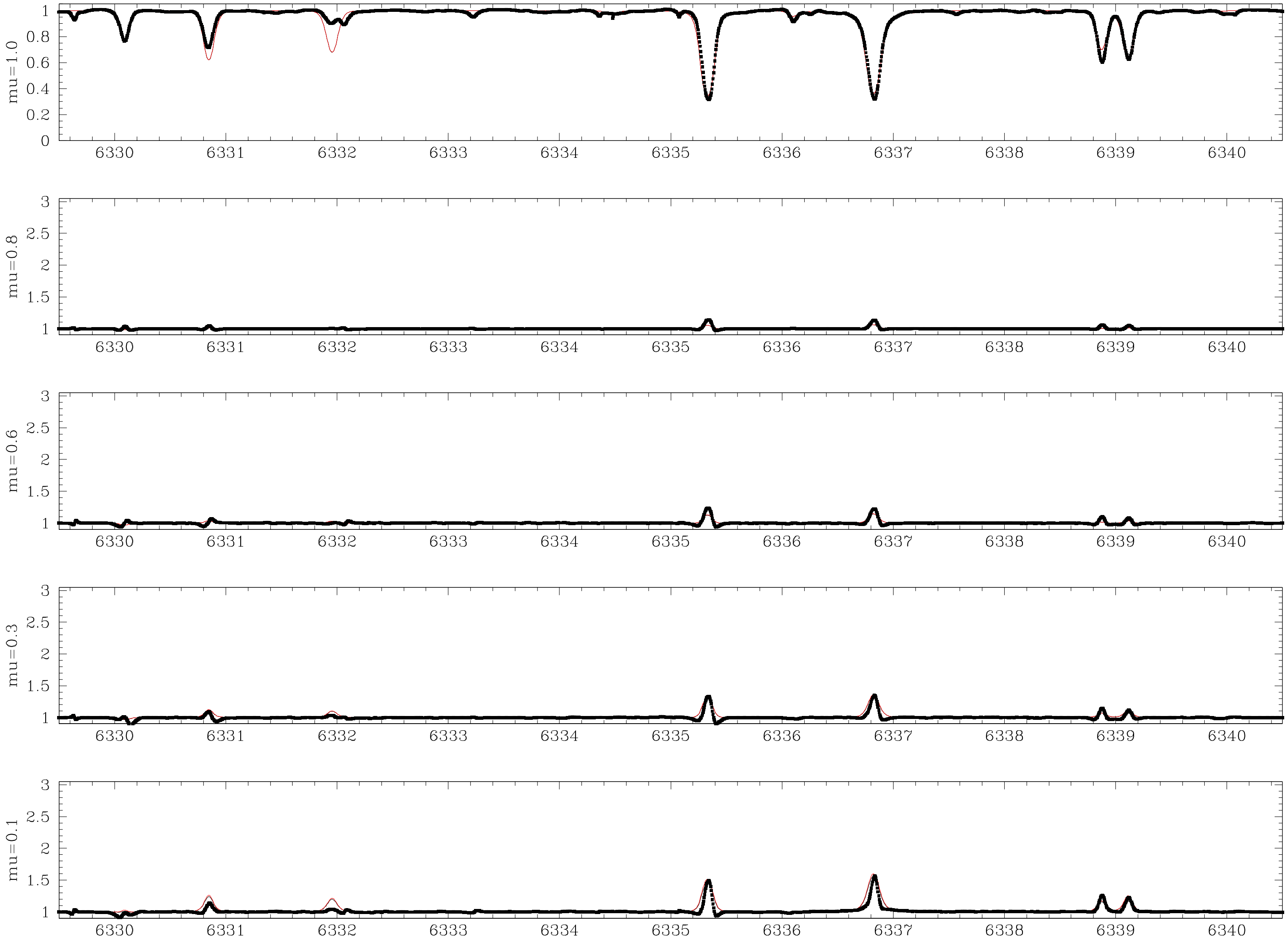
The data for this analysis have been provided in electronic form by IRSOL as a compilation by Setzer et al. (2017)

Continuum-normalized intensity observations (black) vs MARCS models (red)



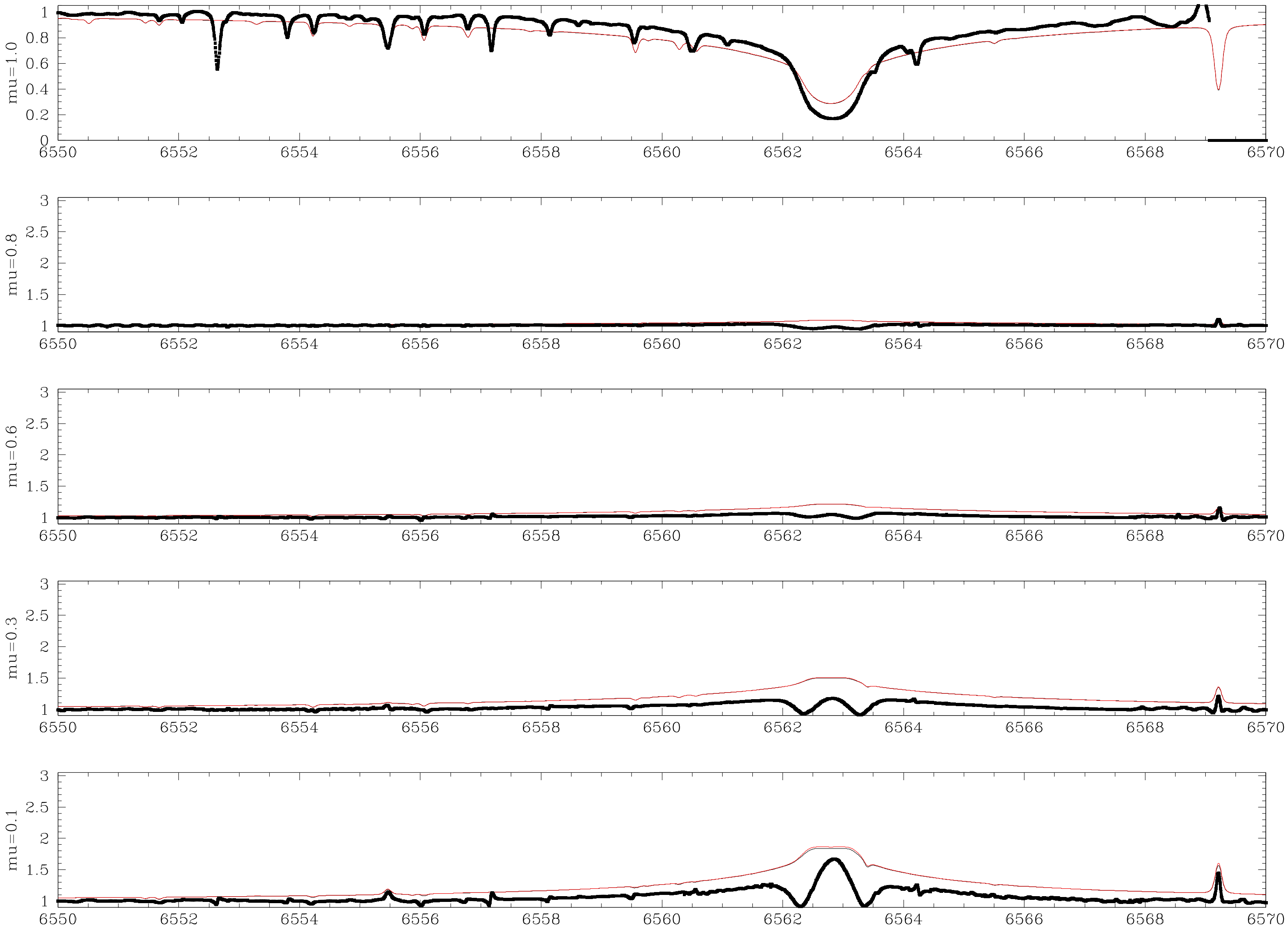
The data for this analysis have been provided in electronic form by IRSOL as a compilation by Setzer et al. (2017)

Continuum-normalized intensity observations (black) vs MARCS models (red)



The data for this analysis have been provided in electronic form by IRSOL as a compilation by Setzer et al. (2017)

Continuum-normalized intensity observations (black) vs MARCS models (red)



The data for this analysis have been provided in electronic form by IRSOL as a compilation by Setzer et al. (2017)

Recall, these observations were
normalized to continuum AND divided by I/I_{cont} at disk center

Ramelli et al. suggest using as best estimate for the absolute intensity:

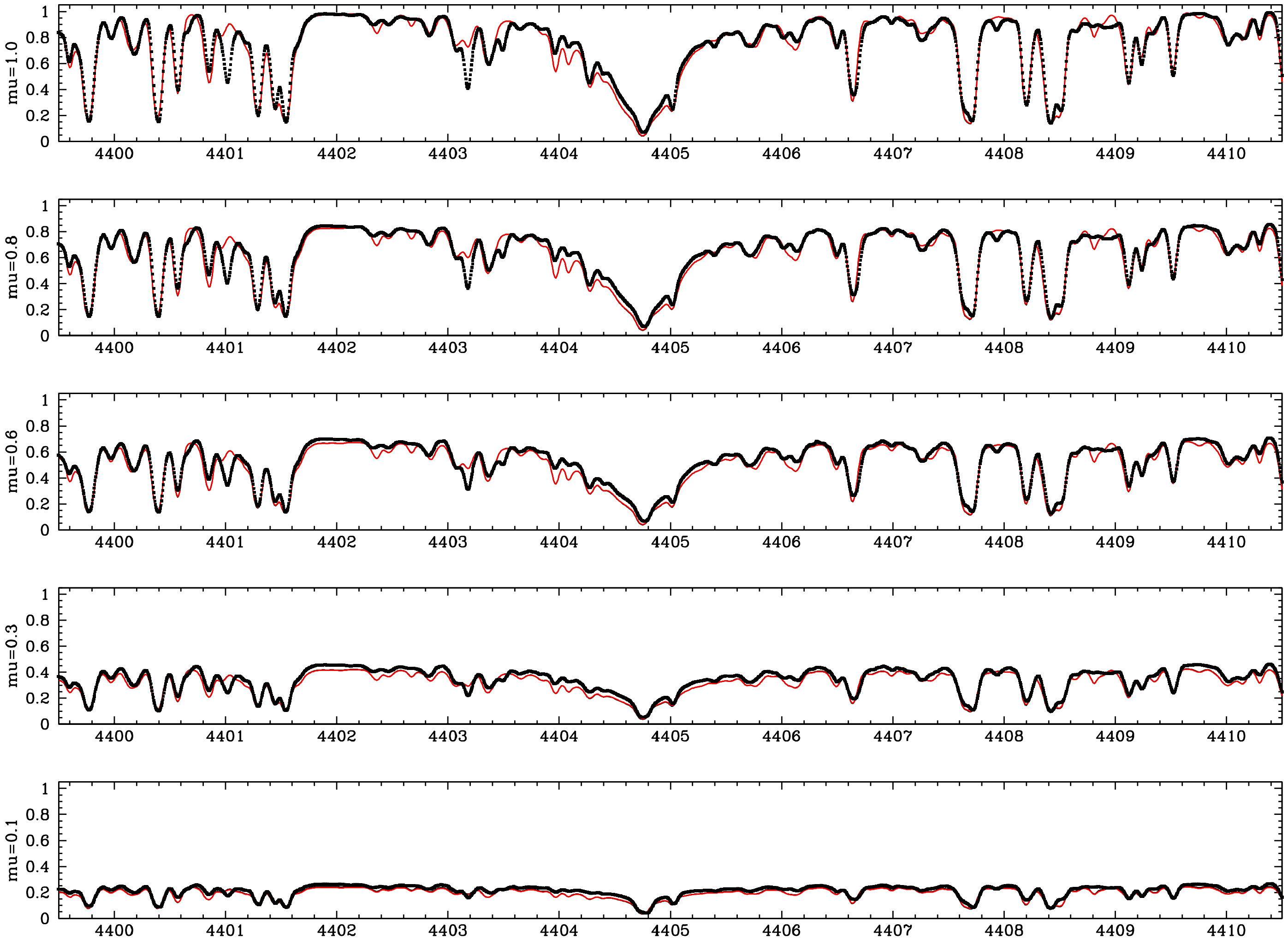
IRSOL measurements

$$I_\mu(\lambda) = R_\mu(\lambda) \cdot I_\lambda^N(\mu) \cdot I_c^{FTS}(\lambda)$$

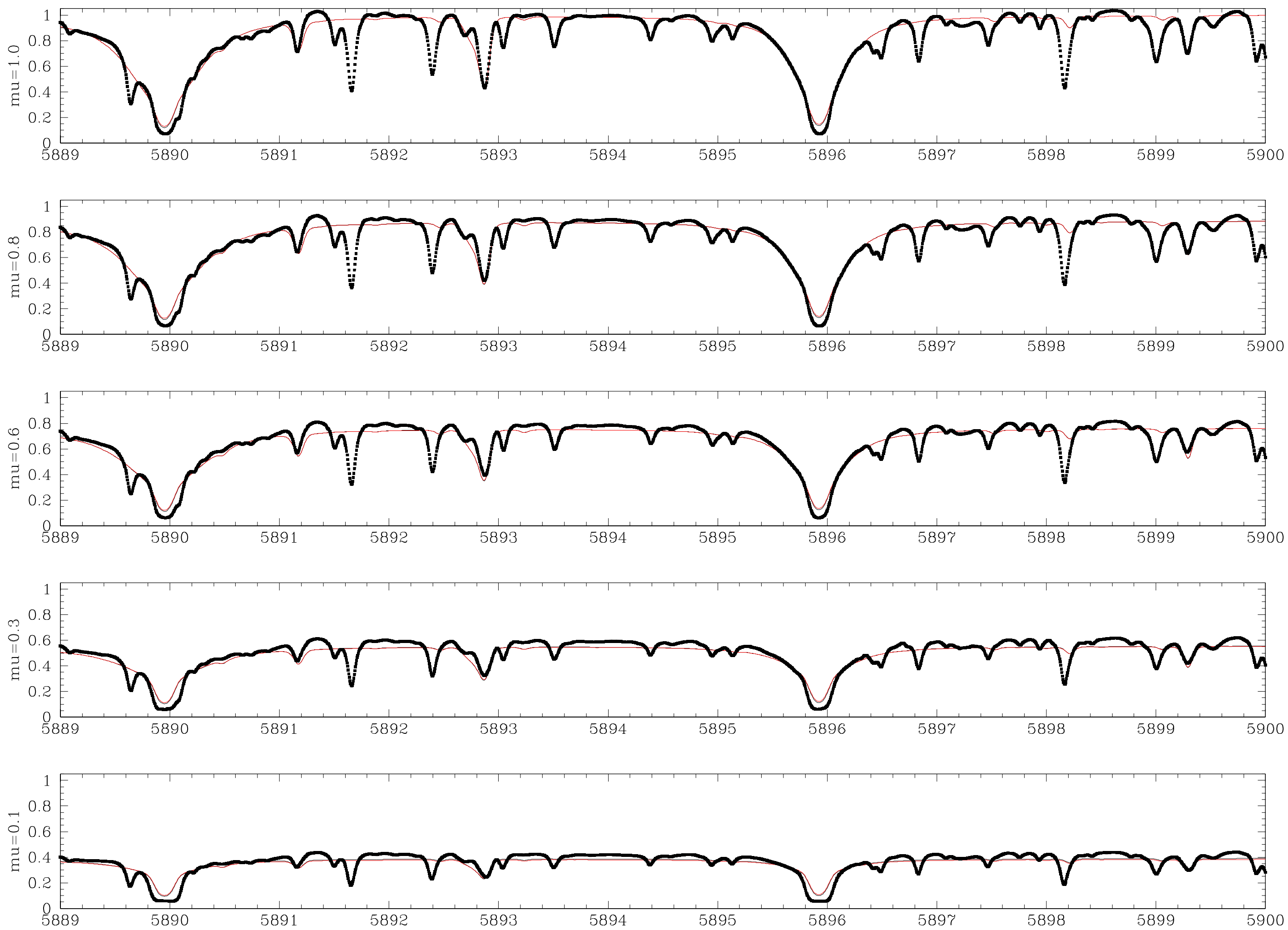
Neckel & Labs
continuum CLV (1994)

Kurucz et al. disk center
intensity (1984)

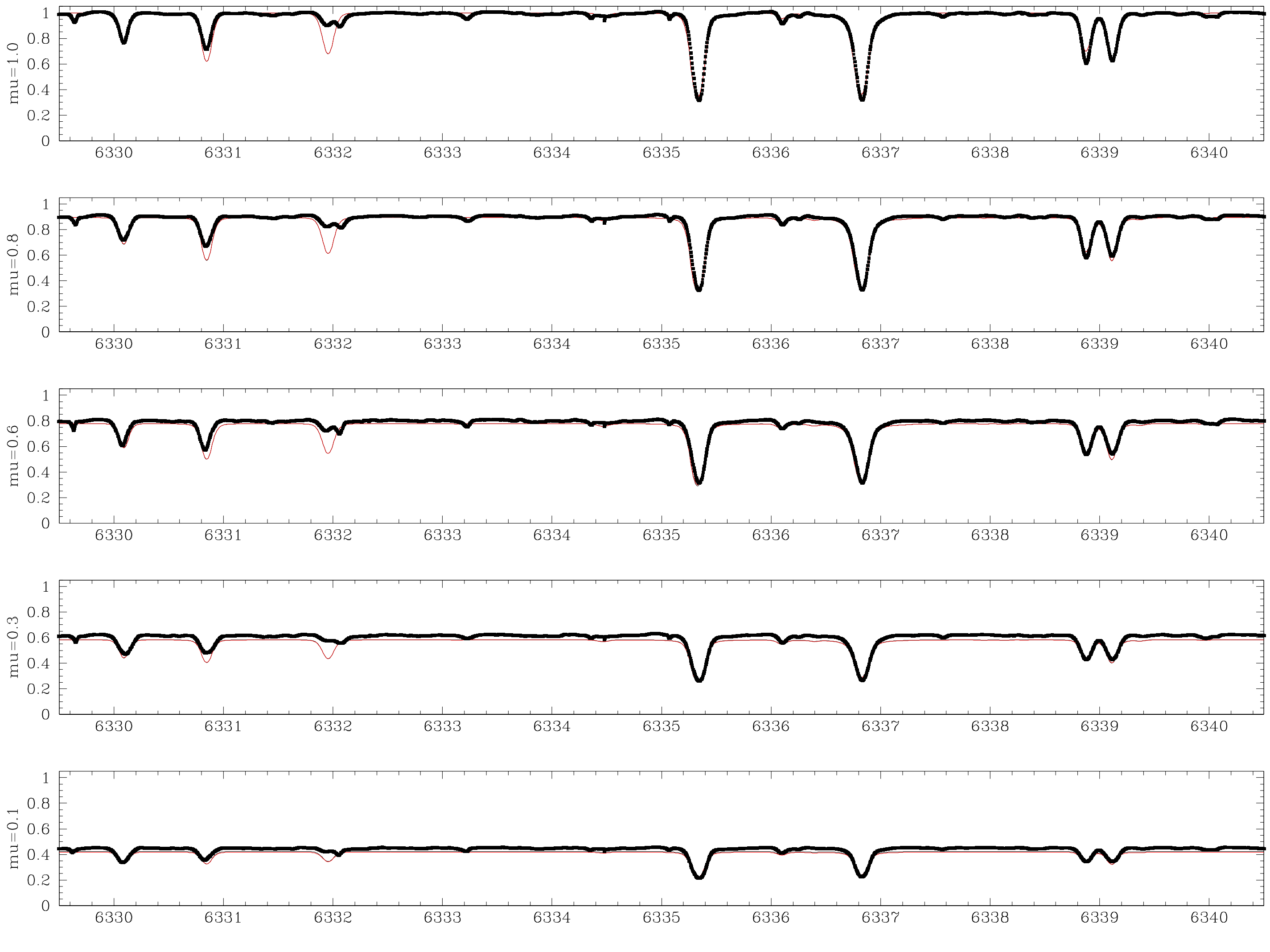
So, another way of looking at it:
scale observations using Neckel & Labs continuum CLV measurements



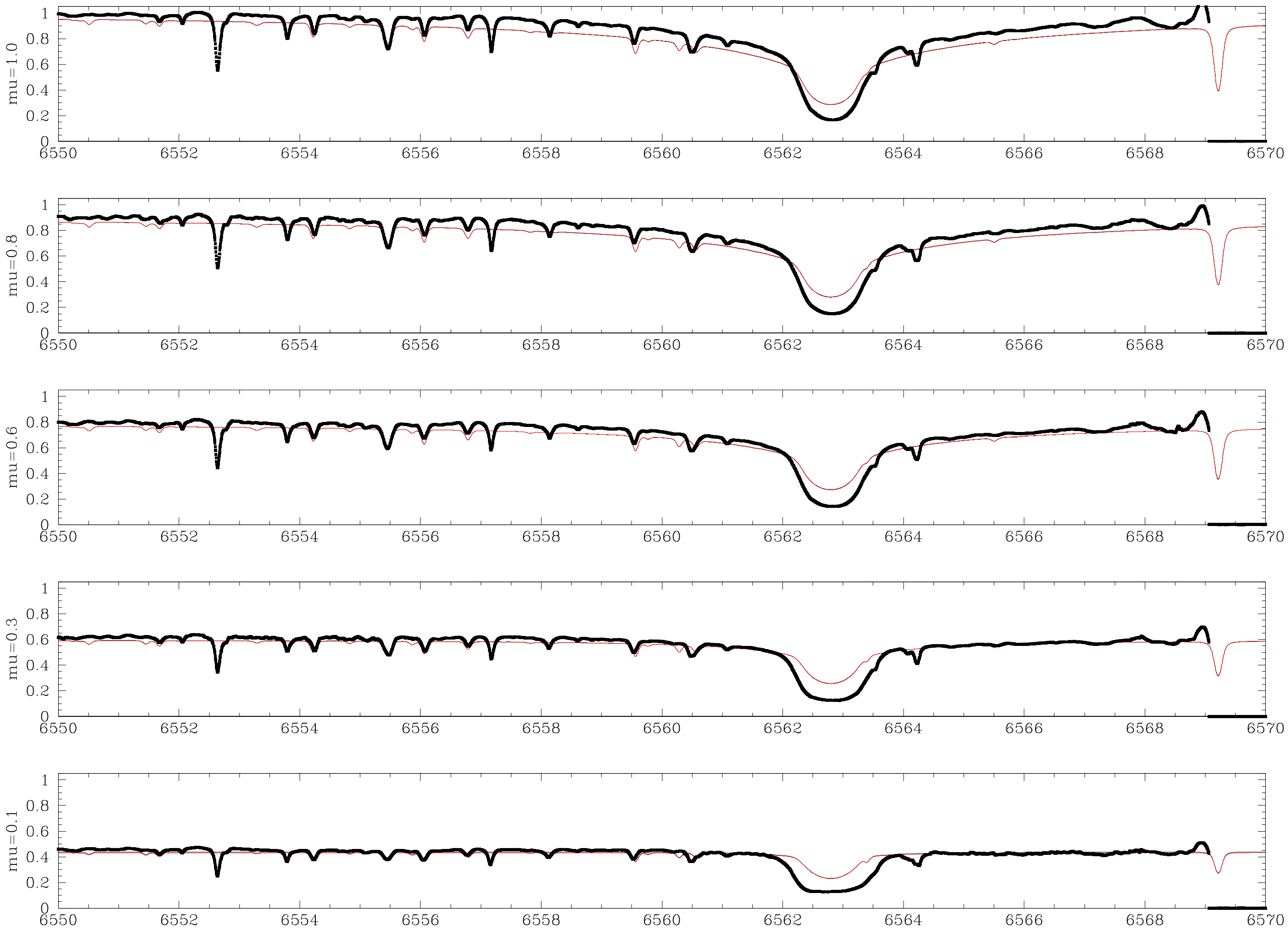
Observations scaled using Neckel & Labs continuum CLV measurements



Observations scaled using Neckel & Labs continuum CLV measurements

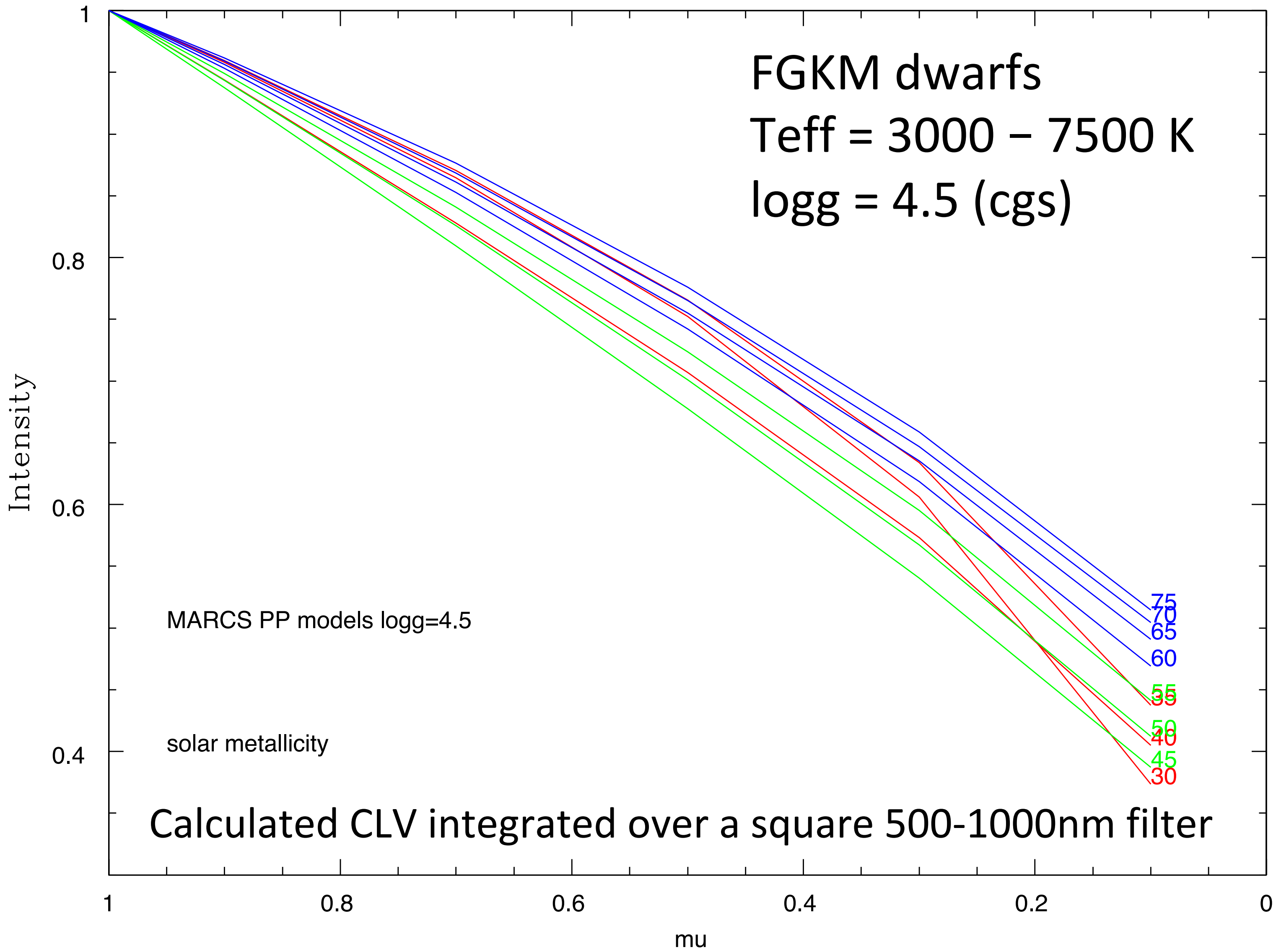


Observations scaled using Neckel & Labs continuum CLV measurements



Hα requires a chromosphere and NLTE

PLATO will integrate the flux in the 500-1000nm window



Some conclusions, thoughts, and questions

- 1D models do not perform optimally for CLV.
  As is well known, CLV is a stringent test of the temperature gradient accuracy!

- 3D models perform better

- While 1D models are inexpensive, 3D models demand large ressources: only sparse grids can be computed

$\Rightarrow$ map 3D CLVs on 1D counterparts and interpolate?
$\Rightarrow$ Or maybe Stagger grid is already sufficient to directly interpolate?

- Little reliable data exist to test our models, beyond the Sun.

$\Rightarrow$ Need more from interferometry, transits, binaries,…