Δλ !

INTRINSIC LINESHIFTS IN ASTRONOMICAL SPECTRA

$$\Delta\lambda\,!$$

Dainis Dravins

Lund Observatory, Sweden

... and the Solar-Intergalactic Connection

ESO Santiago, January 2008

$\Delta\lambda$!

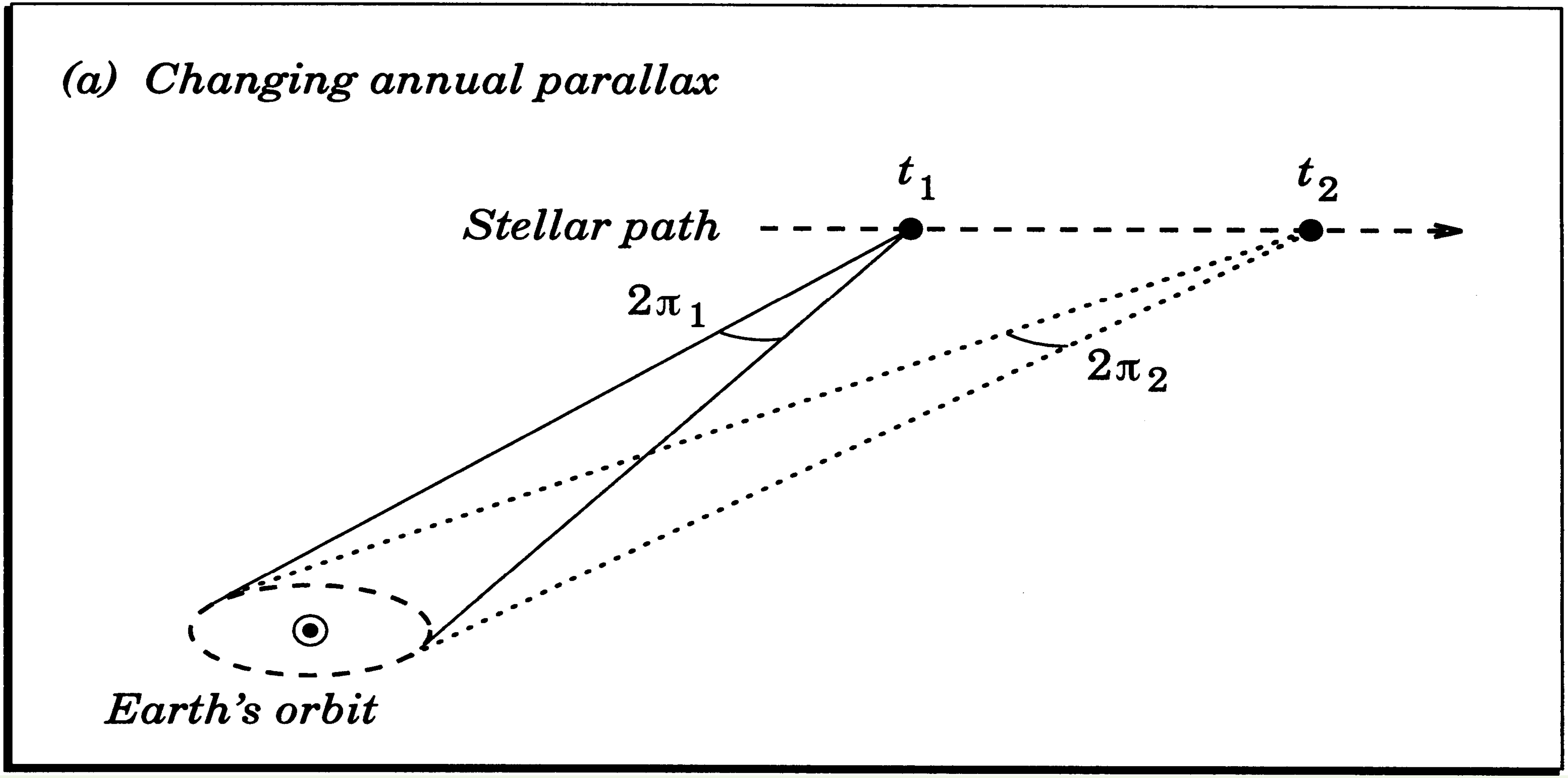
"***Wavelength Shift***"

can be much more than just

"***Radial Velocity***"

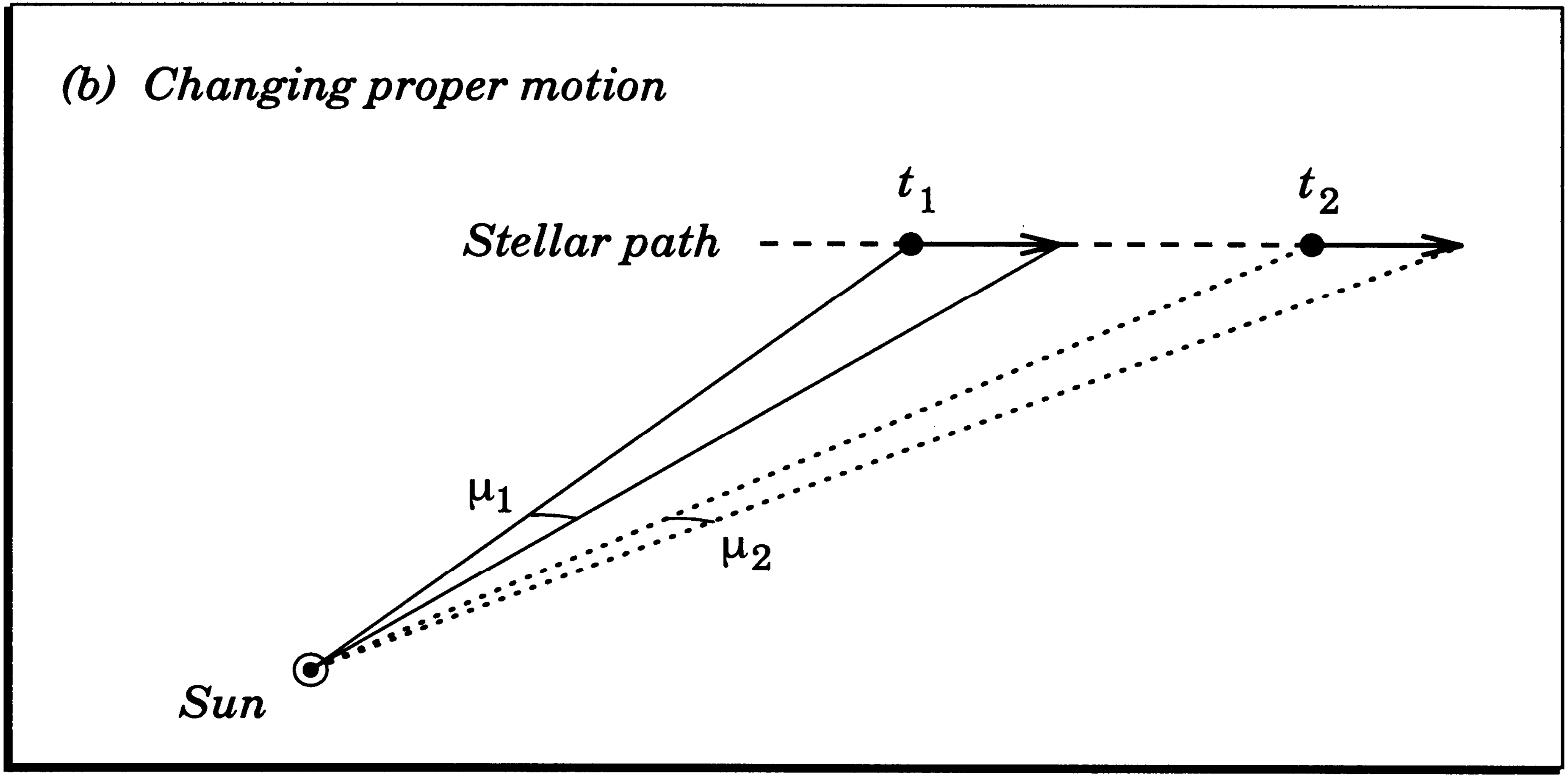
Measuring true radial motion without using spectroscopy

Astrometric radial velocities I



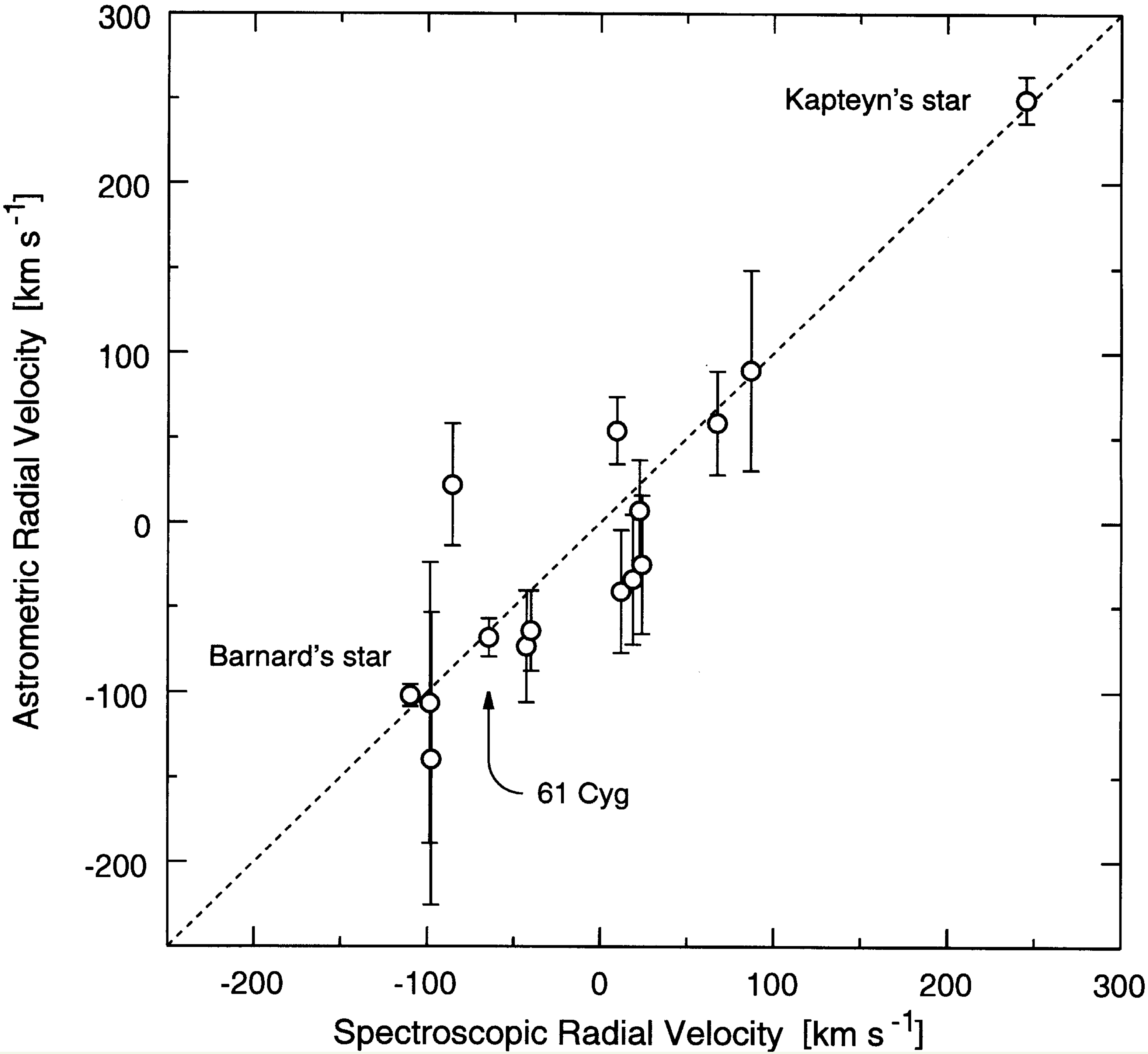
Dravins, Lindegren & Madsen, *A&A* **348**, 1040

Astrometric radial velocities II

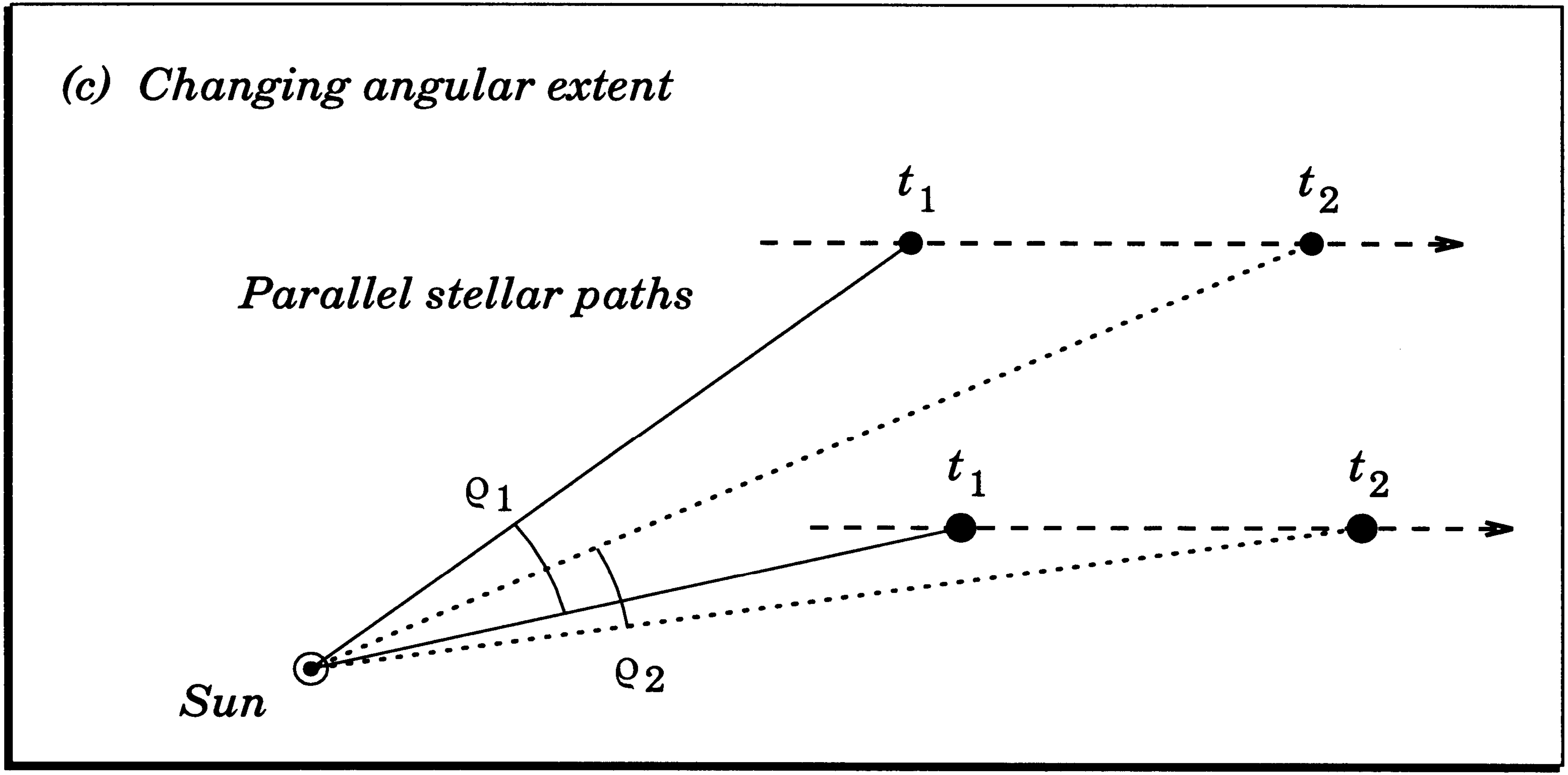


Astrometric radial velocities from perspective acceleration

Dravins, Lindegren & Madsen, A&A 348, 1040



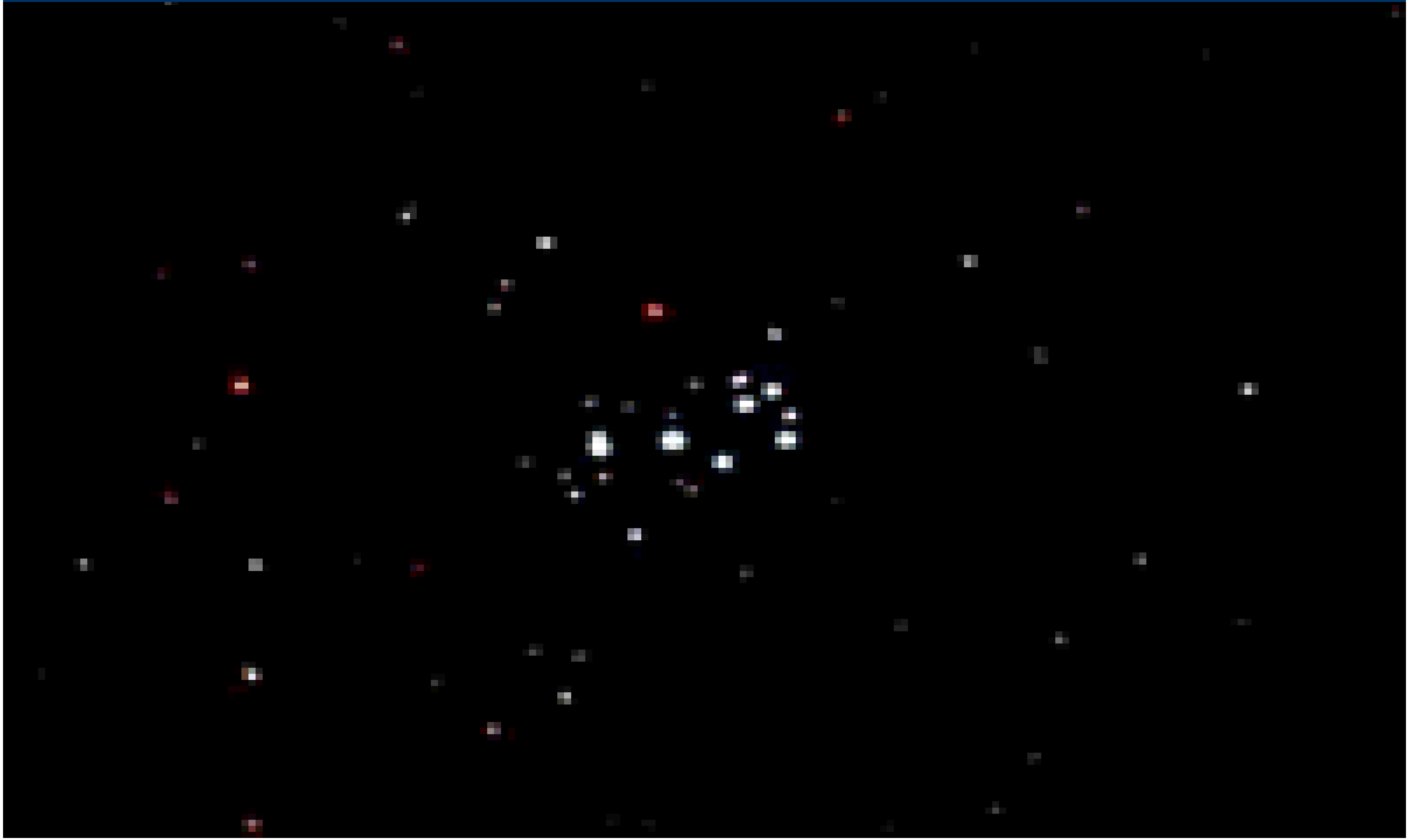
Astrometric radial velocities III



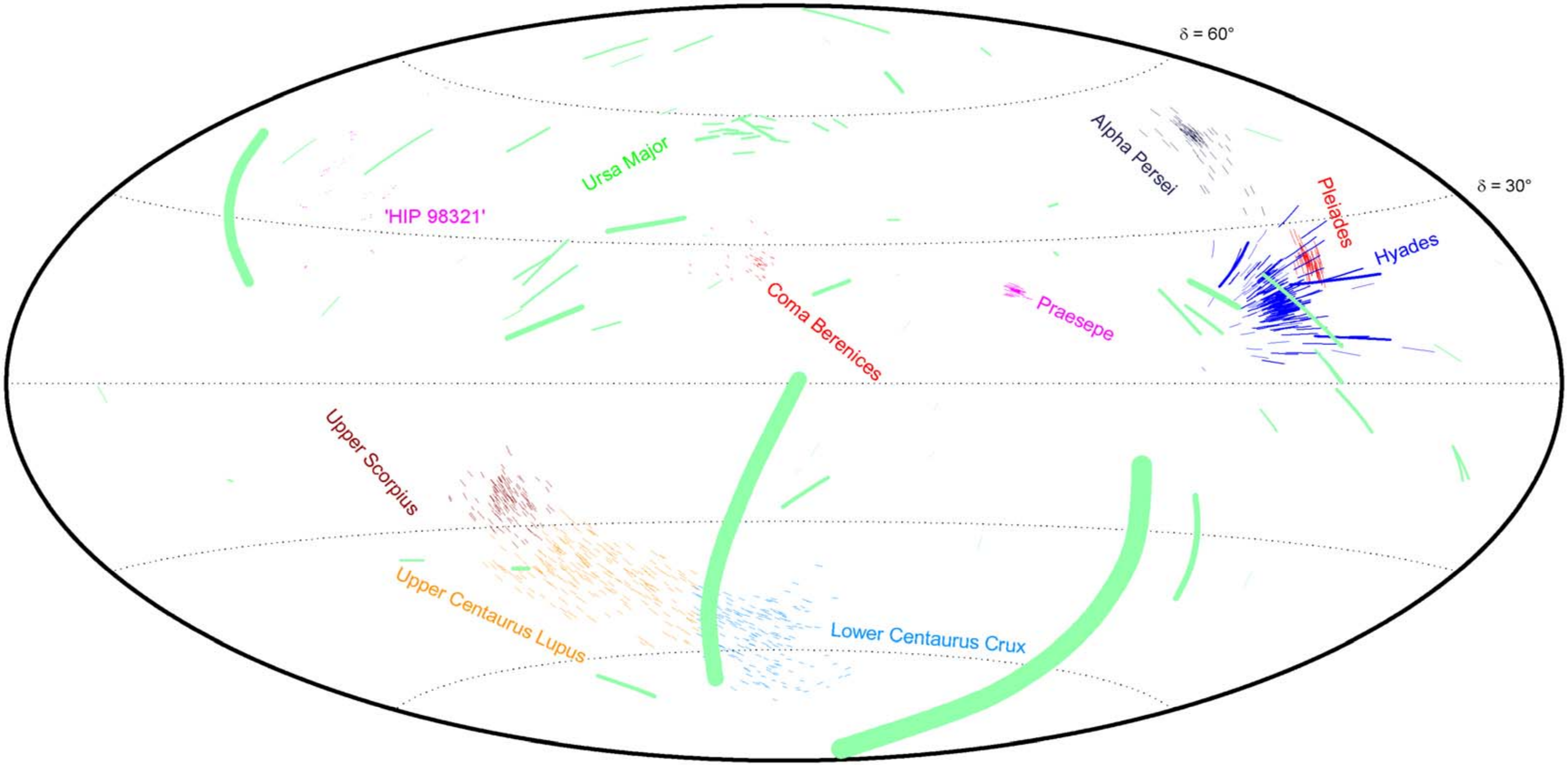
Dravins, Lindegren & Madsen, *A&A* 348, 1040

Pleiades from Hipparcos

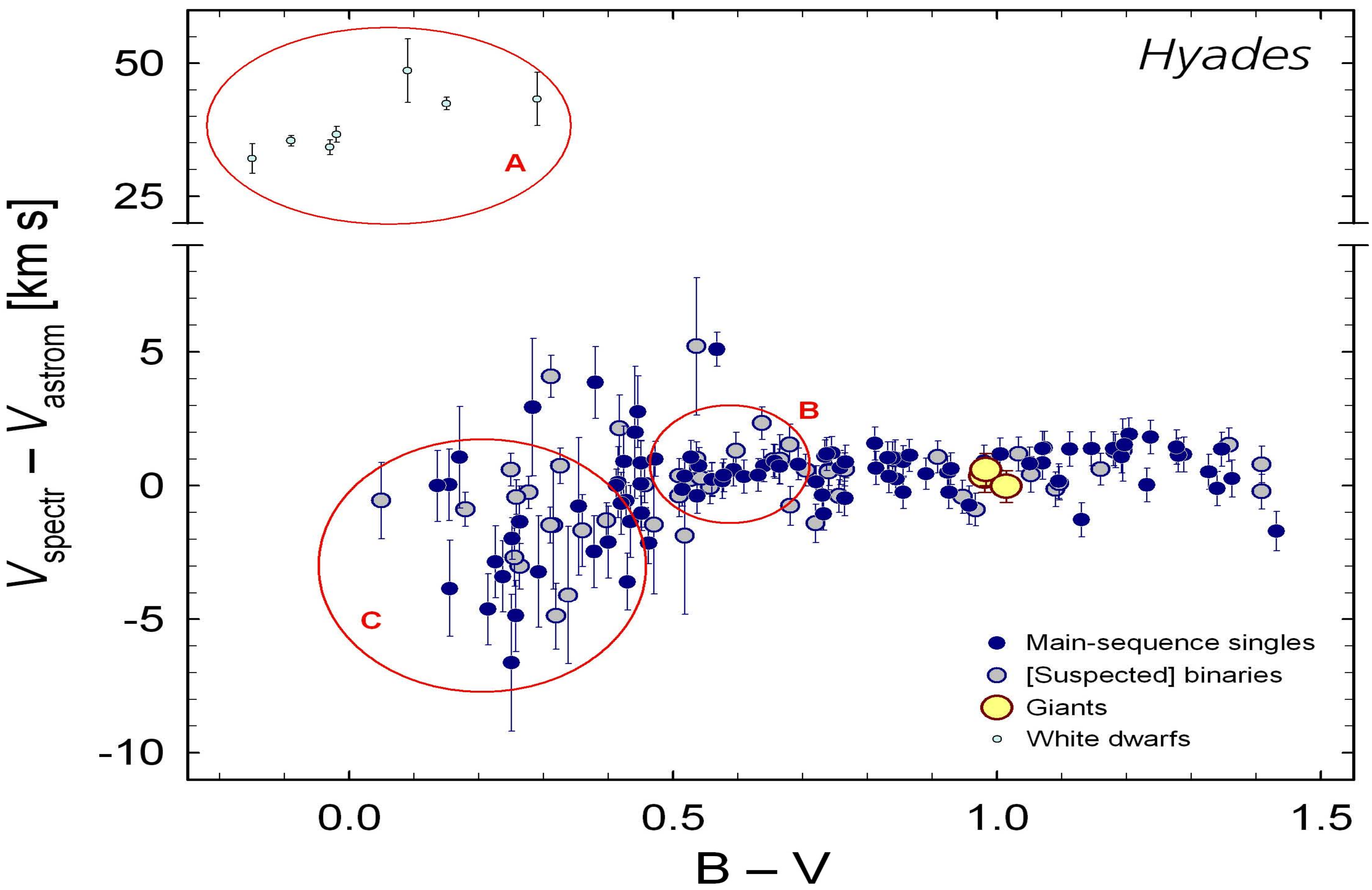
Proper motions over 120,000 years



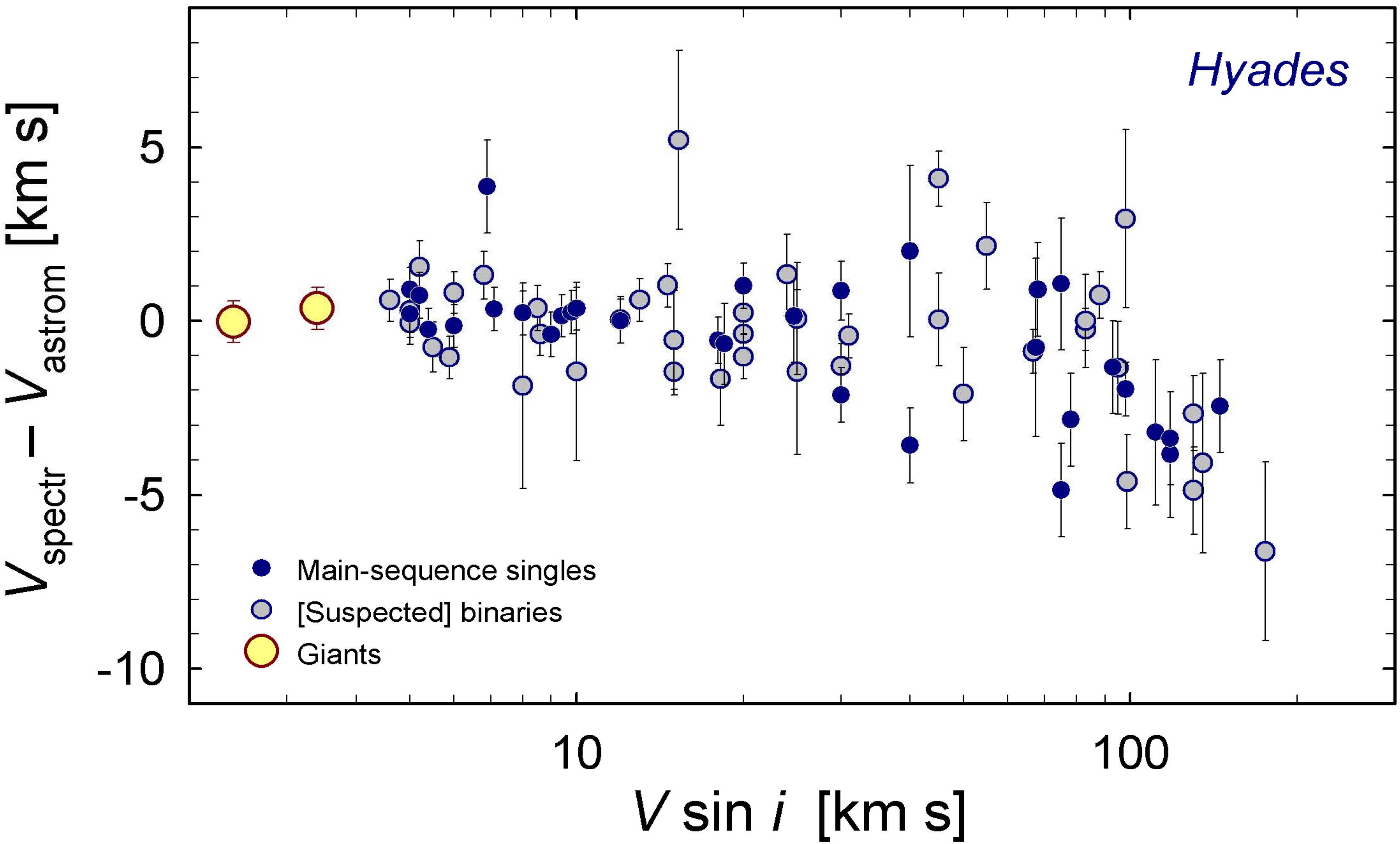
STARPATHS (200,000 y)



Madsen, Dravins & Lindegren, *A&A* **381**, 446



Hyades lineshifts *Madsen, Dravins & Lindegren, A&A 381, 446*

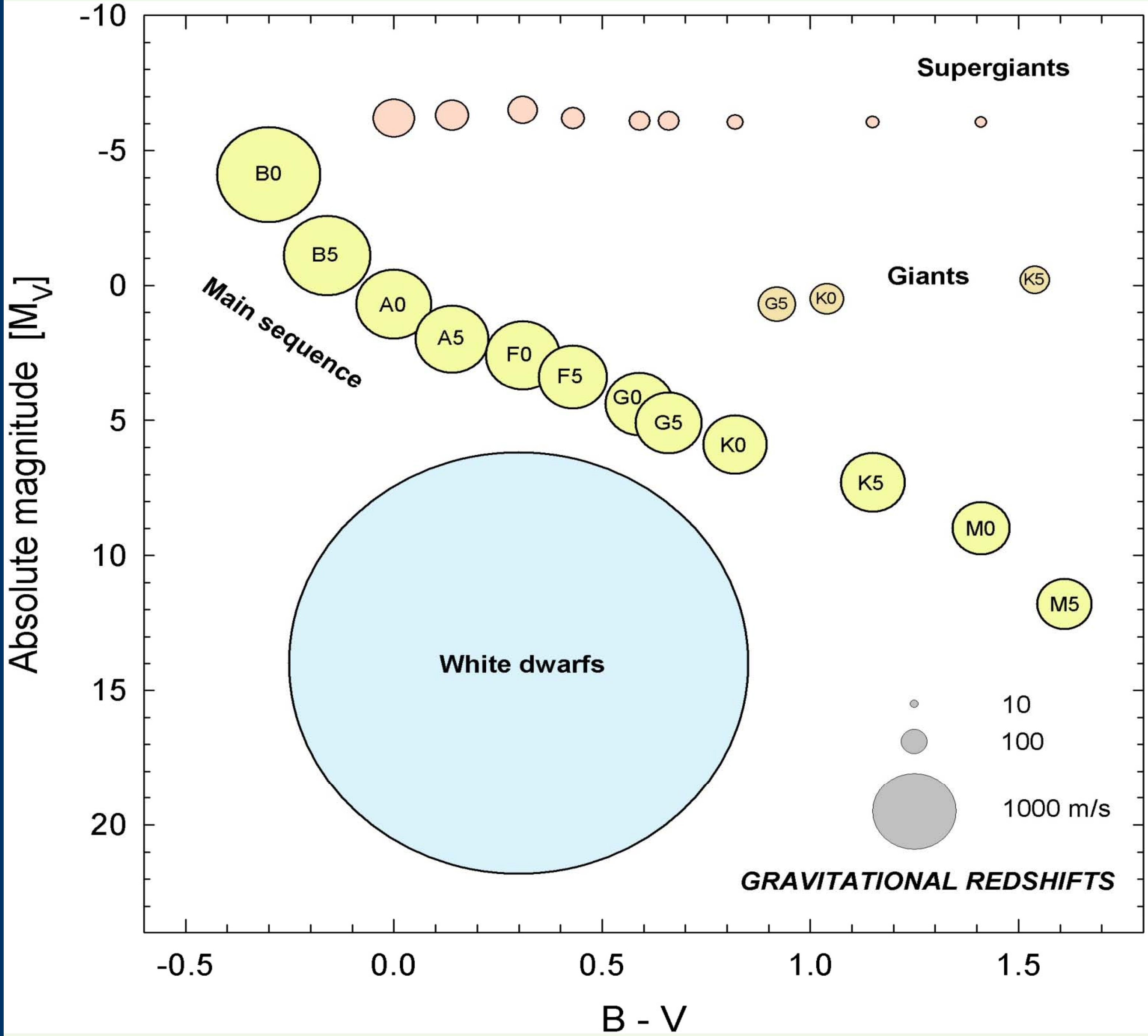


Lineshift & stellar rotation

*Madsen, Dravins & Lindegren, A&A **381**, 446 & Dravins, IAU Symp. **215**, 27*

What causes wavelength shifts?

Gravitational redshifts



D. Dravins

IAU Symp. 210

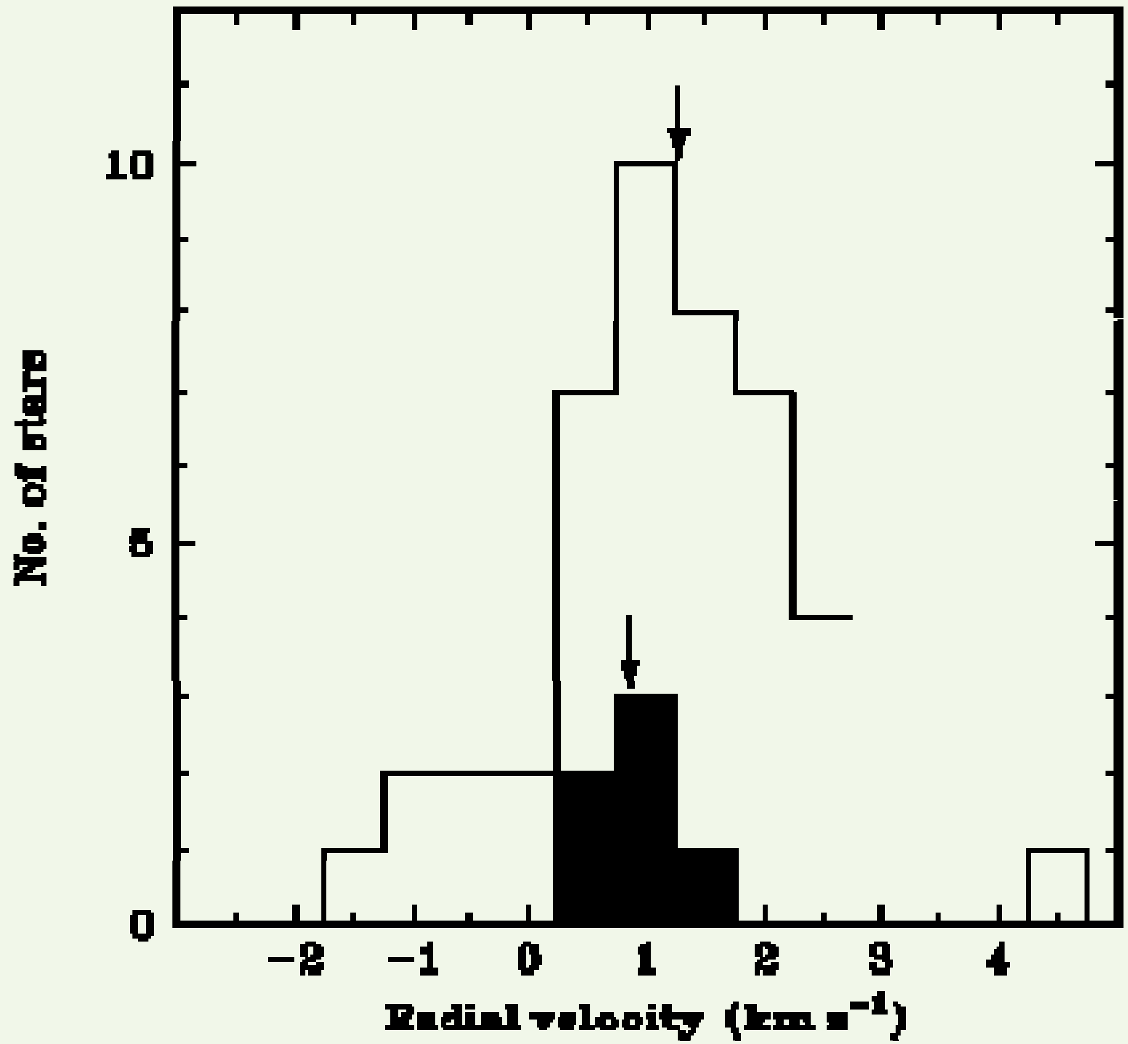
Gravitational redshifts in NGC3680 open cluster?

GIANTS vs. DWARFS

B.Nordström, J.Andersen, M.I.Andersen

Critical tests of stellar evolution in open clusters. II. Membership, duplicity, and stellar and dynamical evolution in NGC3680

A&A **322**, 460 (1997)



Radial velocities in NGC3680

Open curve: All member stars

Solid: Single giants

Gravitational redshifts in M67 open cluster?

GIANTS vs. DWARFS

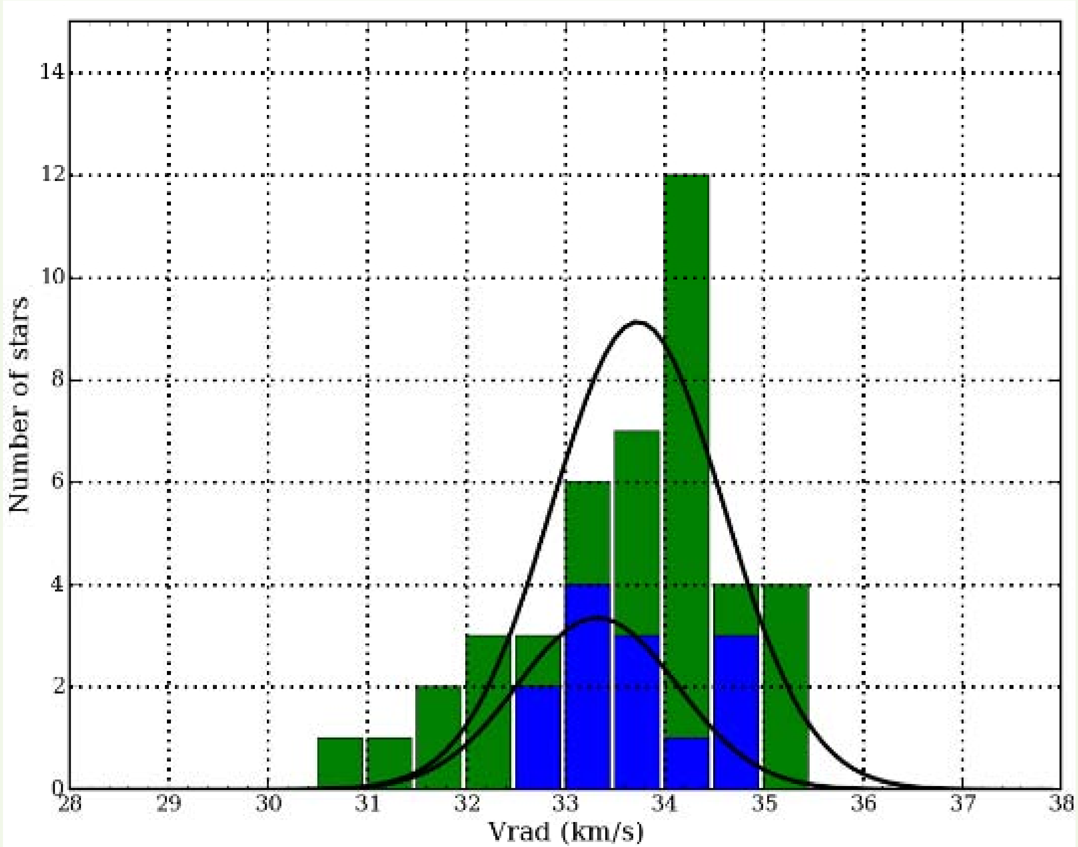
FEROS observations from

C.H.F.Melo, L.Pasquini, J.R.De Medeiros

Accurate Vsin i measurements in M 67: The angular momentum evolution of 1.2 M_{Sun} stars

A&A **375**, 851, 2001

(& C.Melo, private comm.)

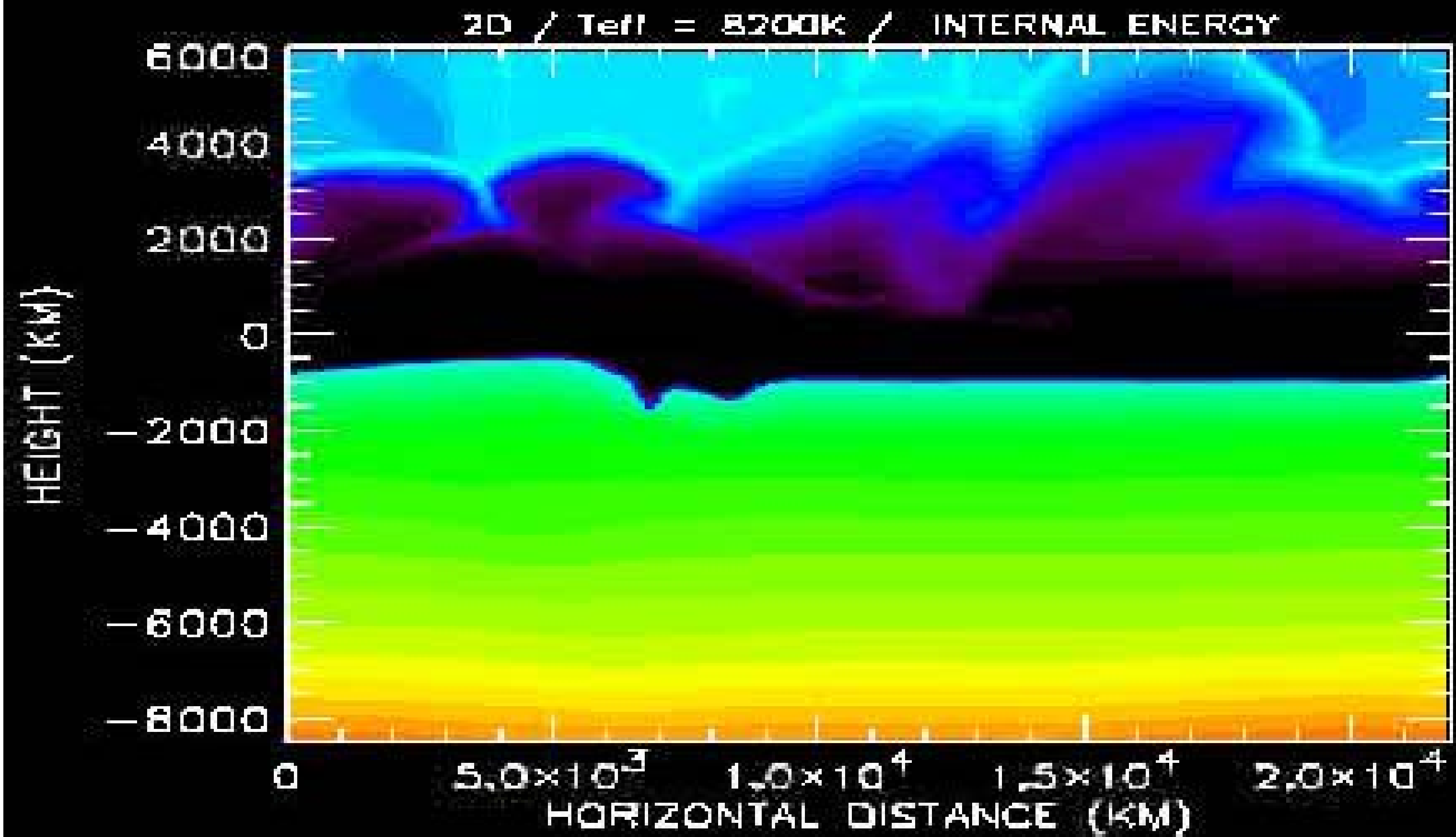


Radial velocities for stars in M67

Green: Main-sequence

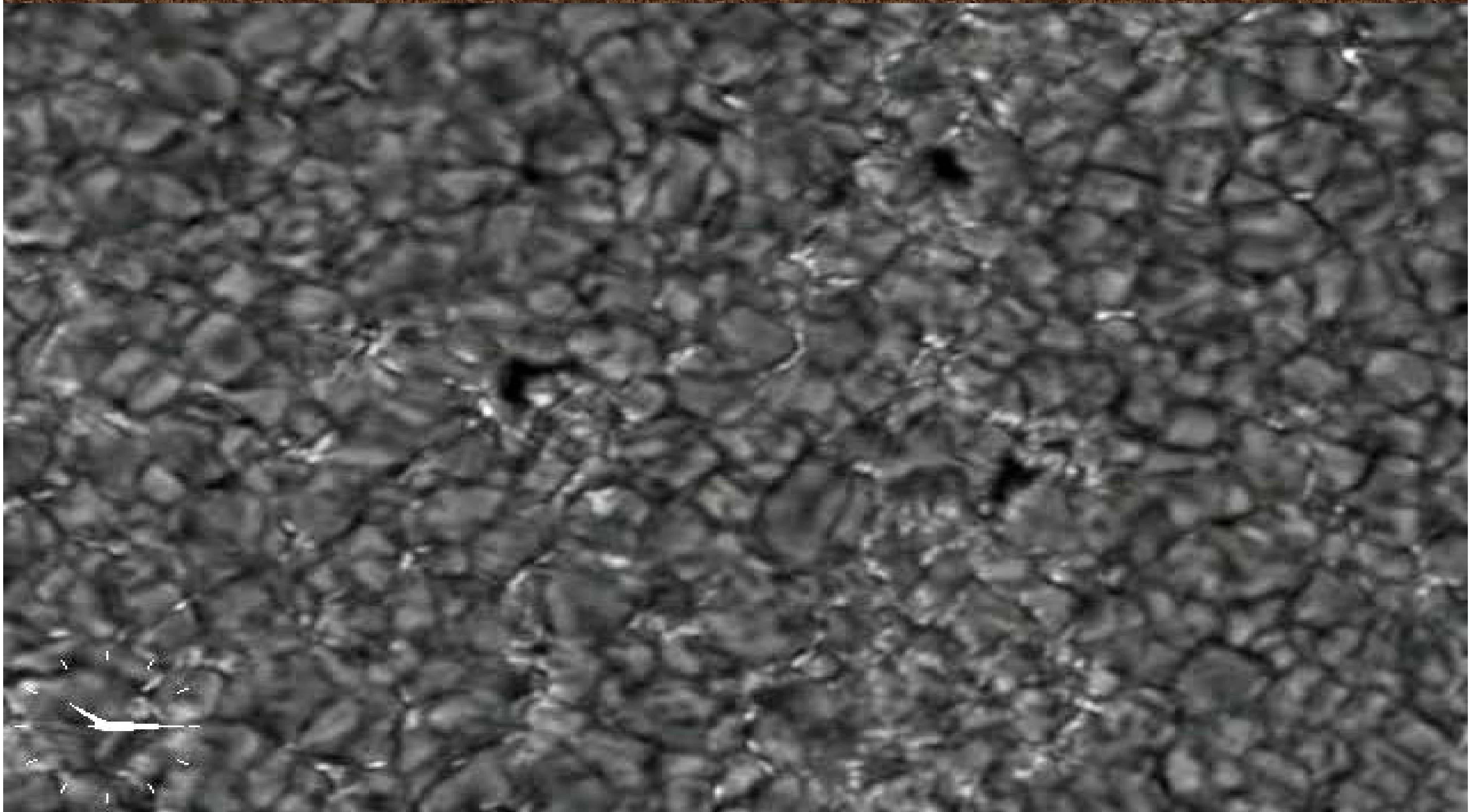
Blue: Giants

ATMOSPHERIC SHOCKWAVES (A-type star)



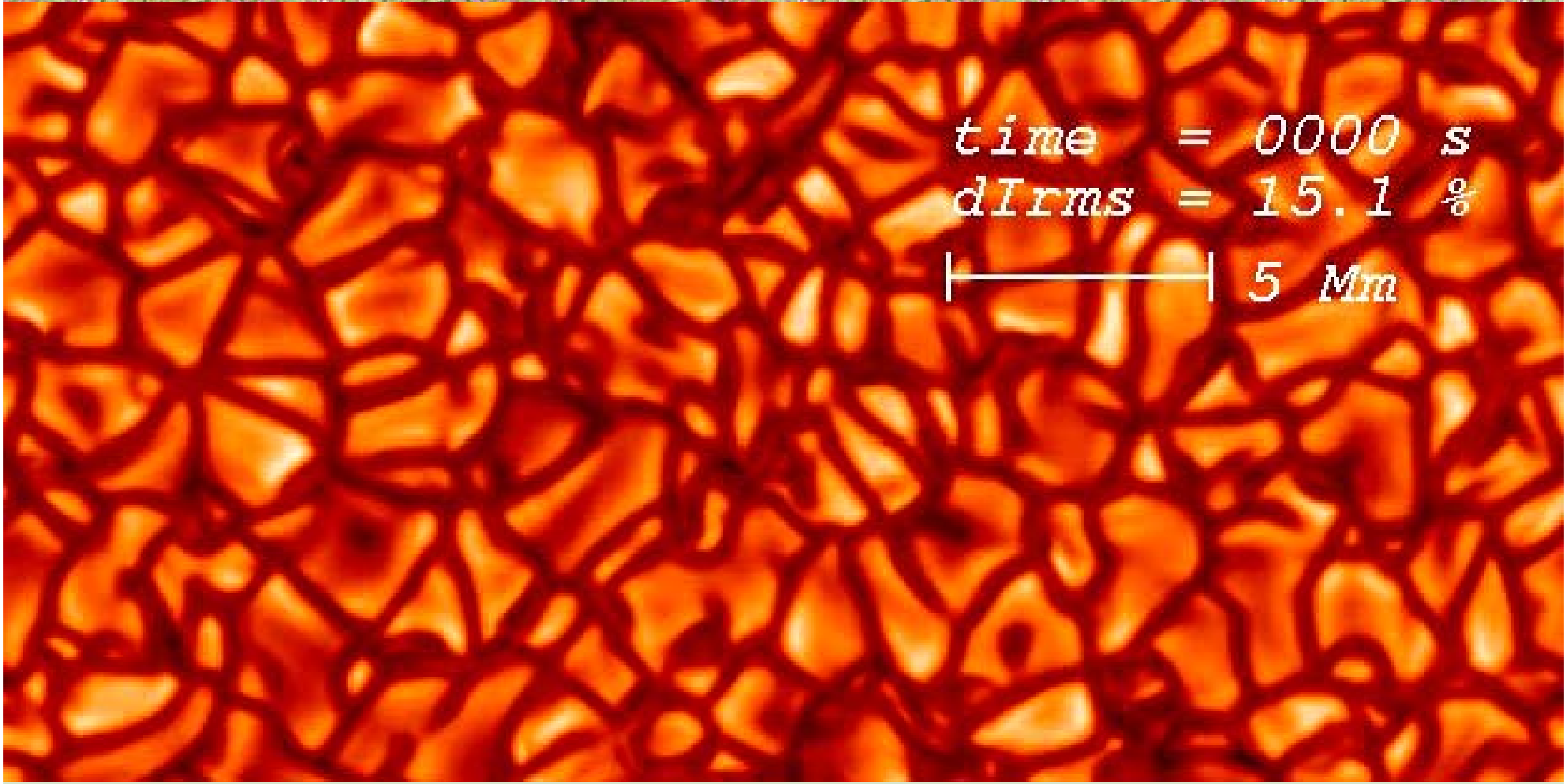
Hartmut Holweger (Kiel)

OBSERVED SOLAR GRANULATION



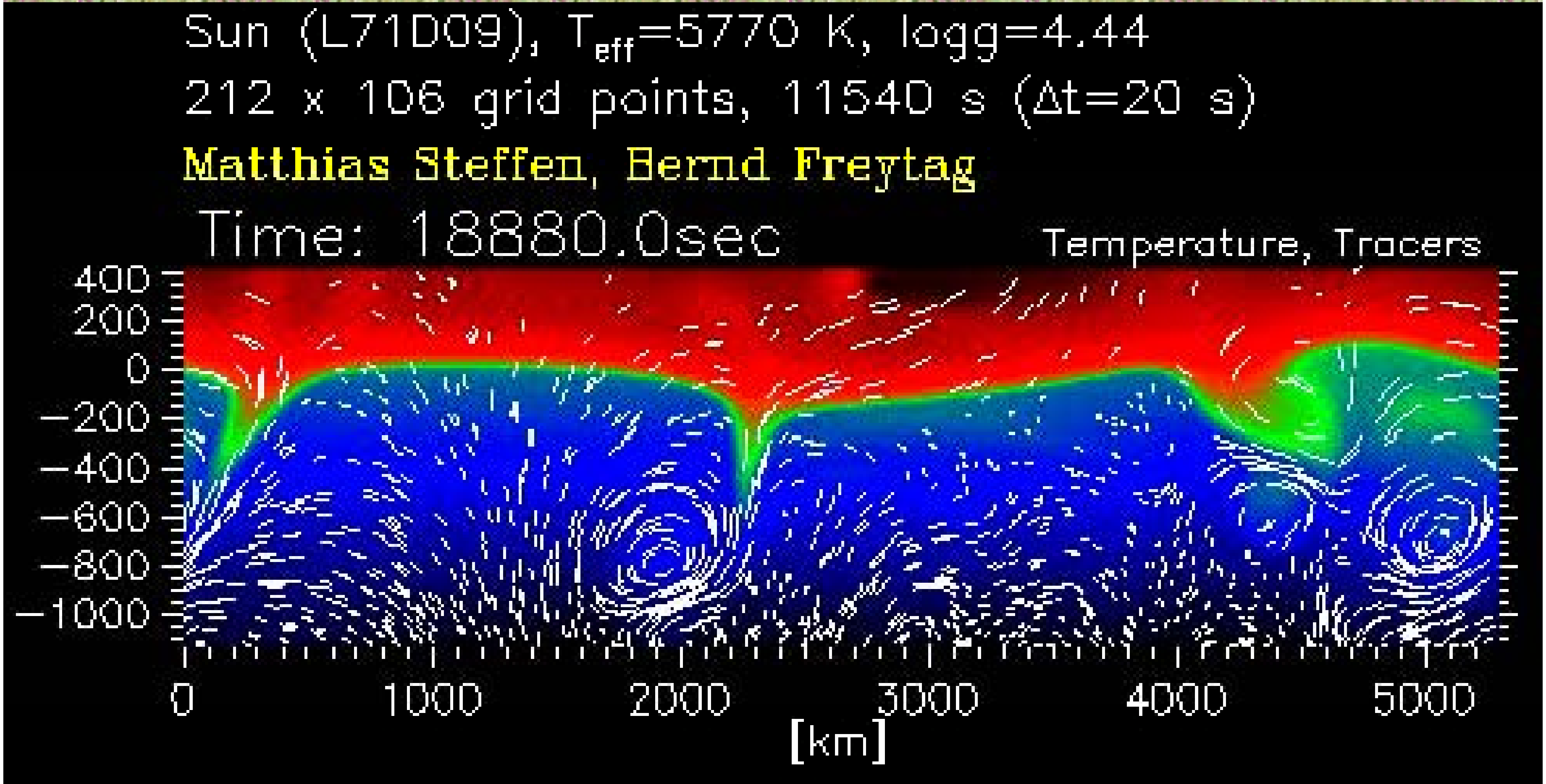
Dutch Open Telescope (La Palma)

MODELED STELLAR GRANULATION



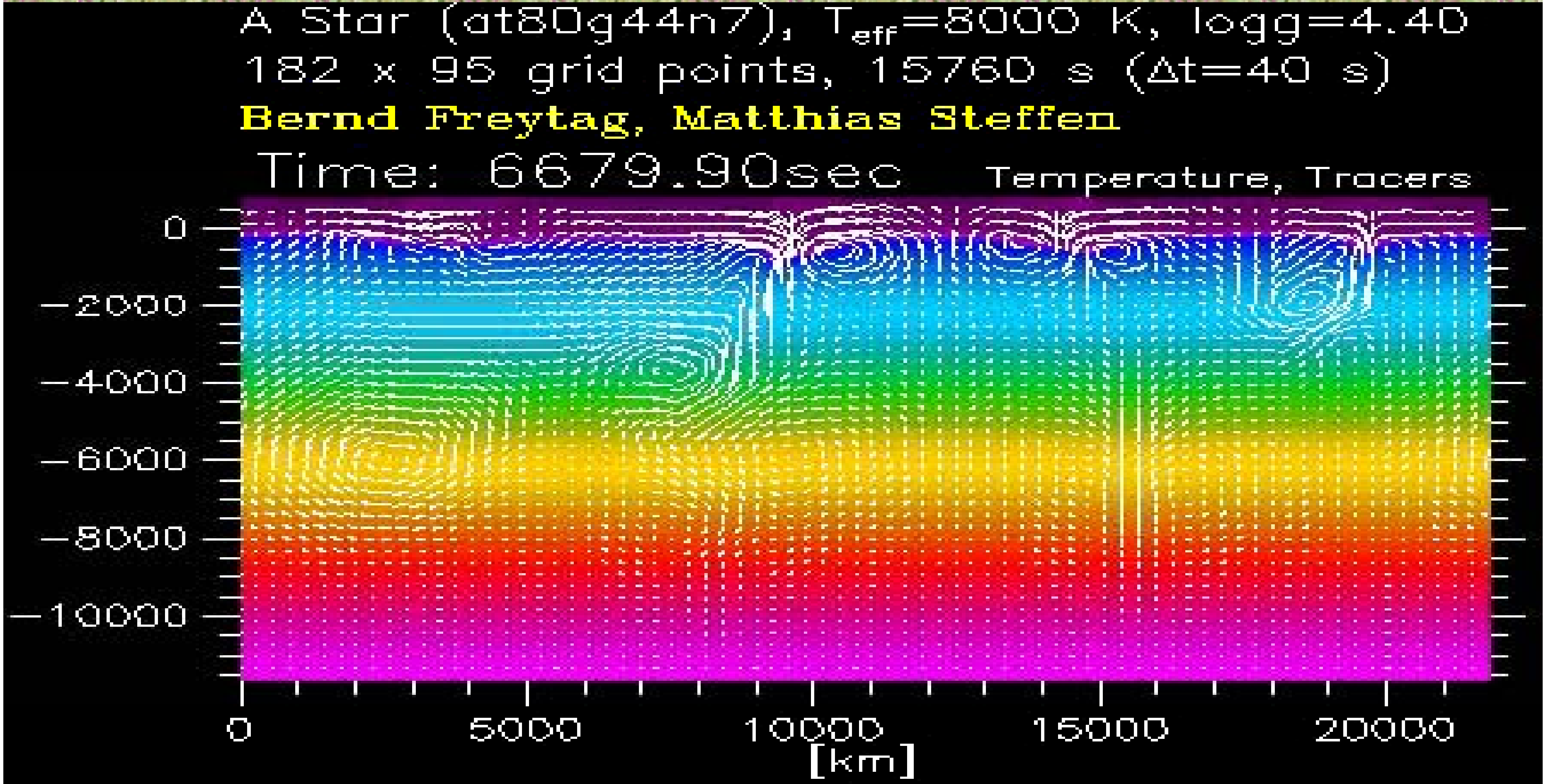
Hans-Günter Ludwig (Lund/Paris)

STELLAR CONVECTION (Sun)



Matthias Steffen (Potsdam) & Bernd Freytag (Uppsala)

STELLAR CONVECTION (A-star)



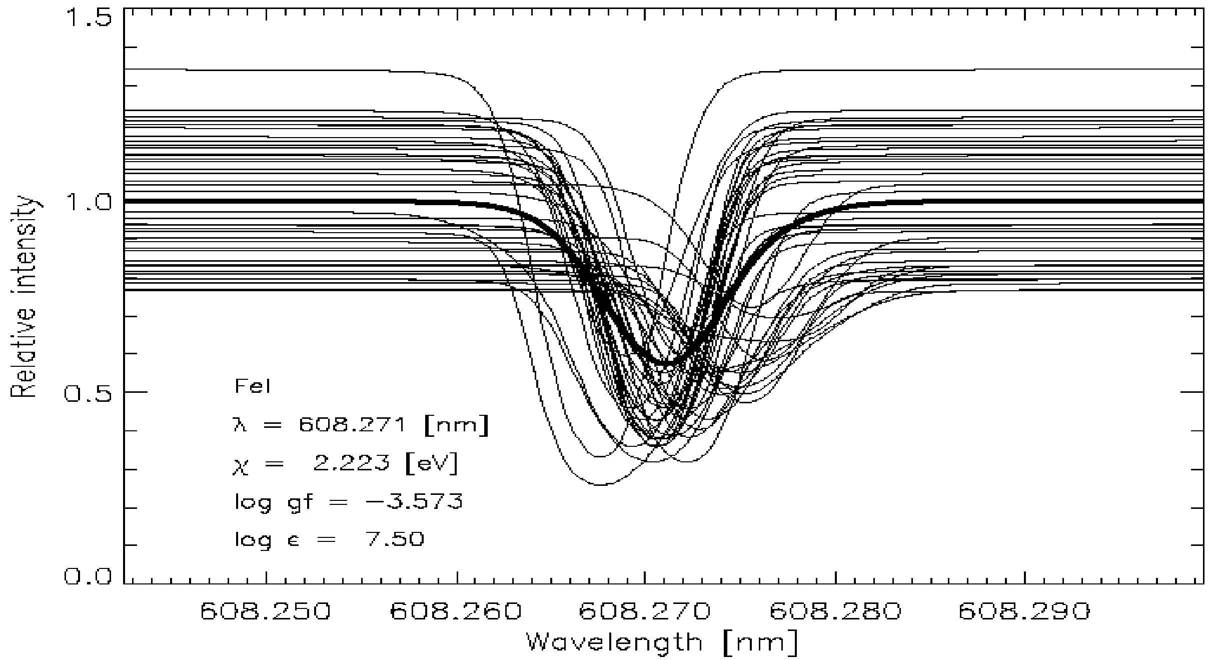
Bernd Freytag (Uppsala) & Matthias Steffen (Potsdam)

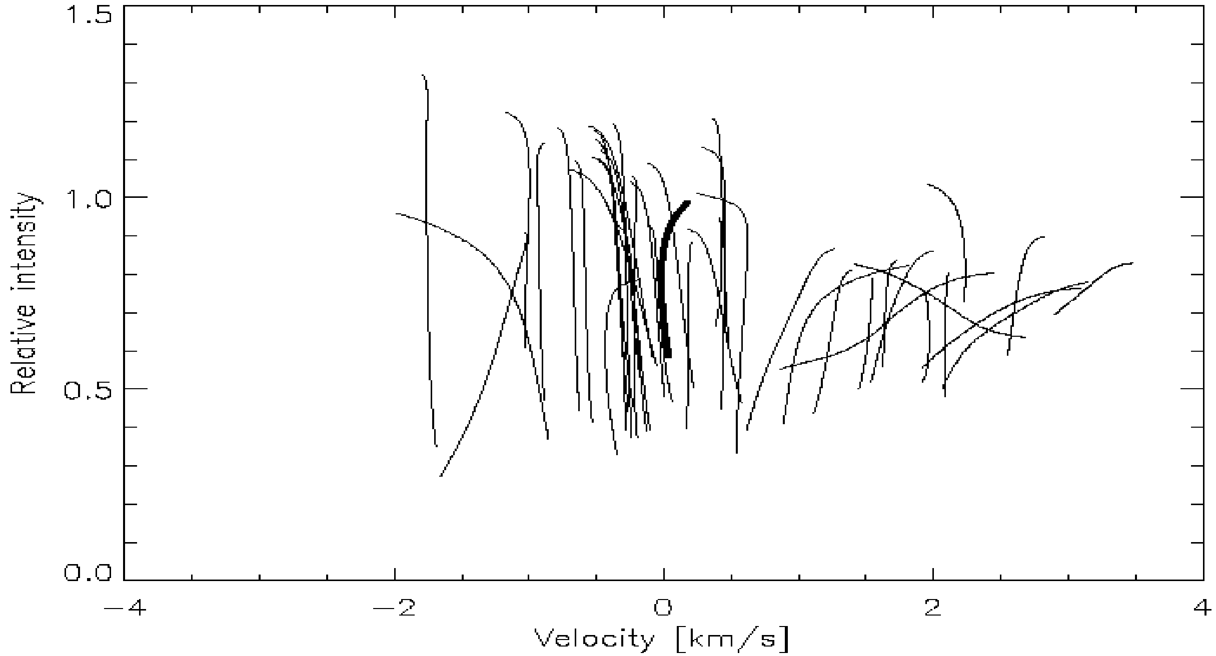
Solar line formation

Spatially resolved line profiles & bisectors of solar granulation (modeled)

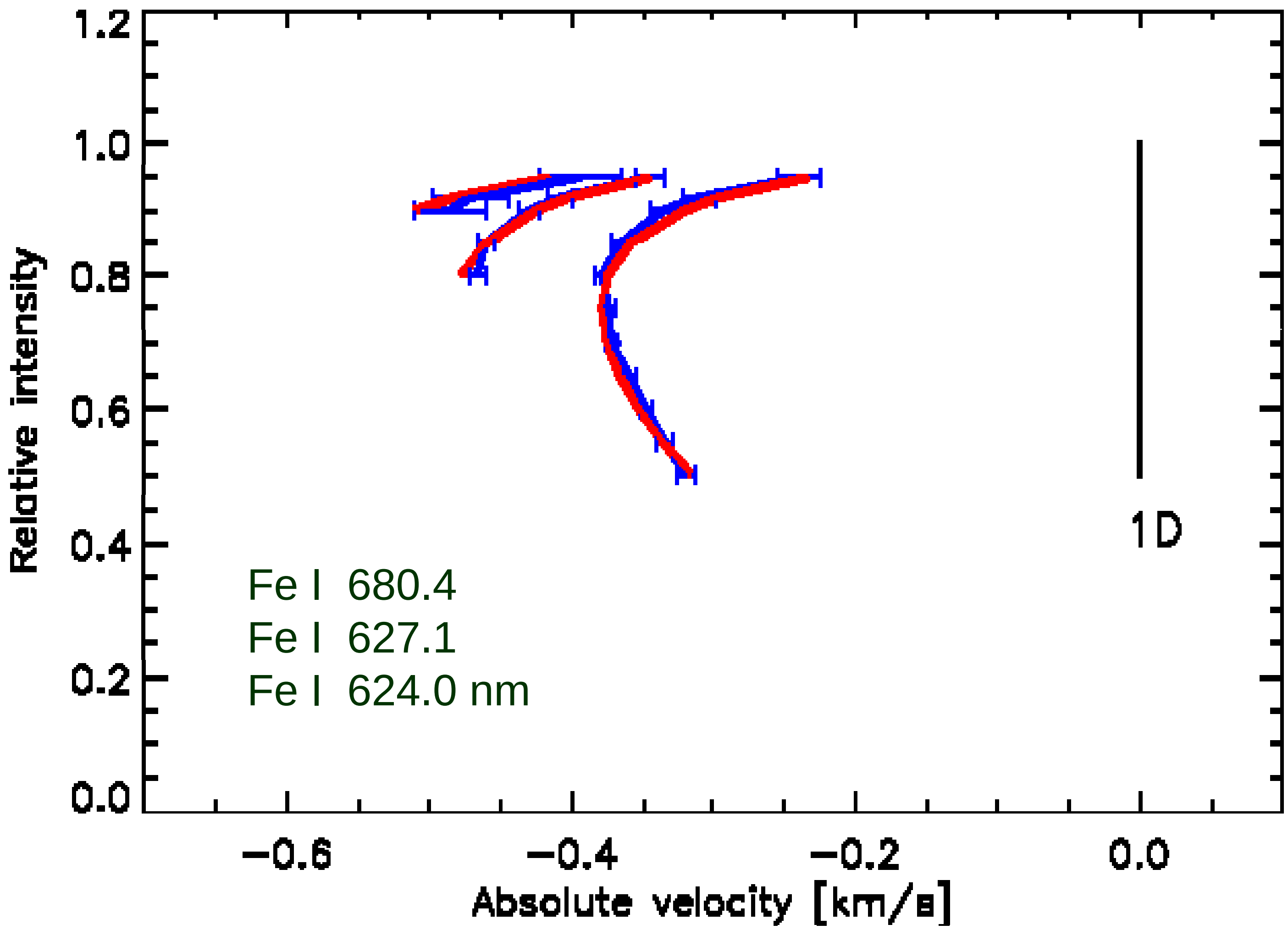
M.Asplund, Å.Nordlund, R.Trampedach, C.Allende Prieto, R.F.Stein:

Line Formation in Solar Granulation. I. Fe Line Shapes, Shifts and Asymmetries, *Astron.Astrophys.* **359**, 729





BISECTORS & SHIFTS: Line-strength

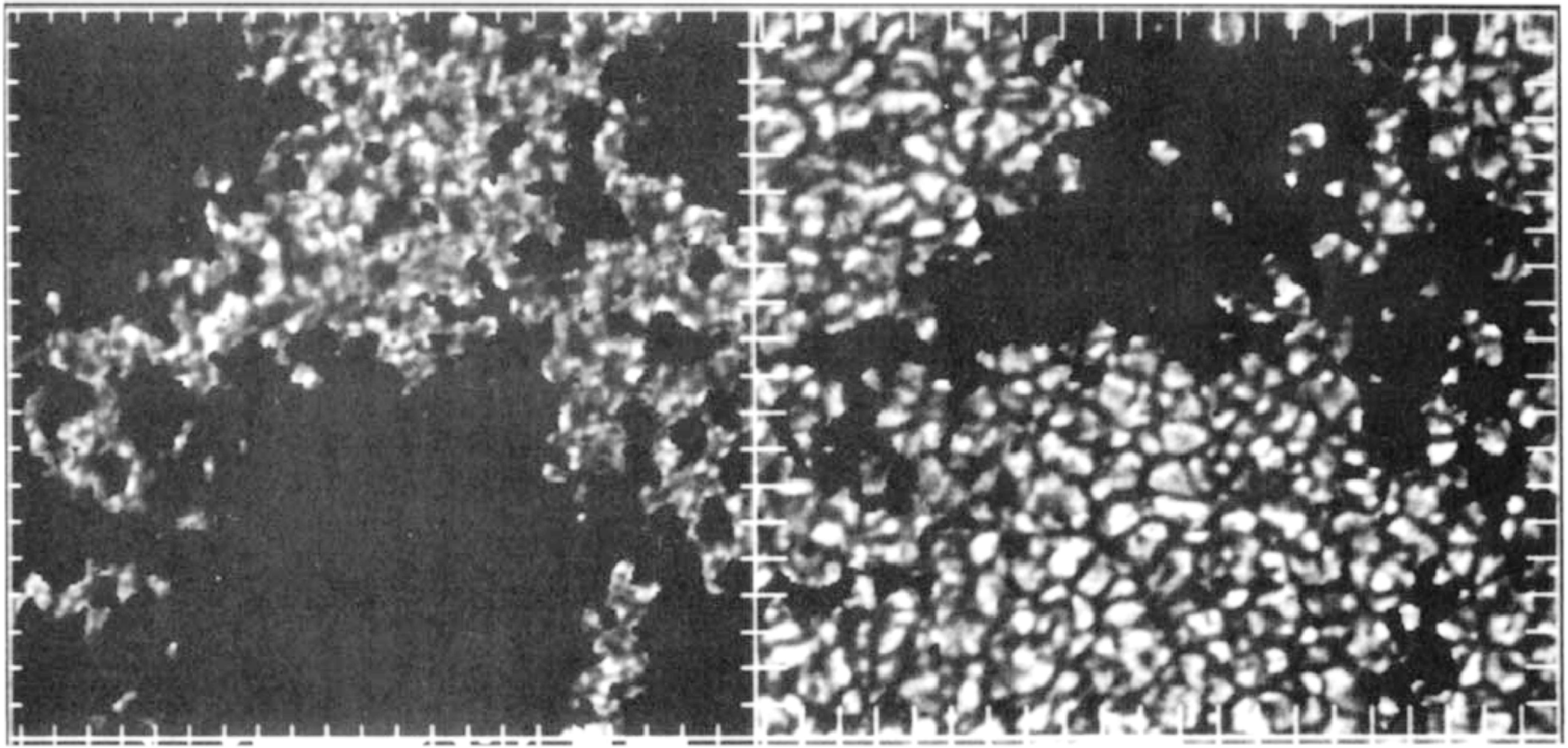


Predicted (solid) and observed bisectors for differently strong solar lines; 3-D hydrodynamic modeling on an absolute velocity scale. (Classical 1D models produce vertical bisectors at zero absolute velocity.)

M.Asplund, Å.Nordlund, R.Trampedach, C.Allende Prieto, R.F.Stein: Line formation in solar granulation. I. Fe line shapes, shifts and asymmetries, *Astron.Astrophys.* **359**, 729 (2000)

Effects of magnetic fields

MAGNETIC & NON-MAGNETIC GRANULATION

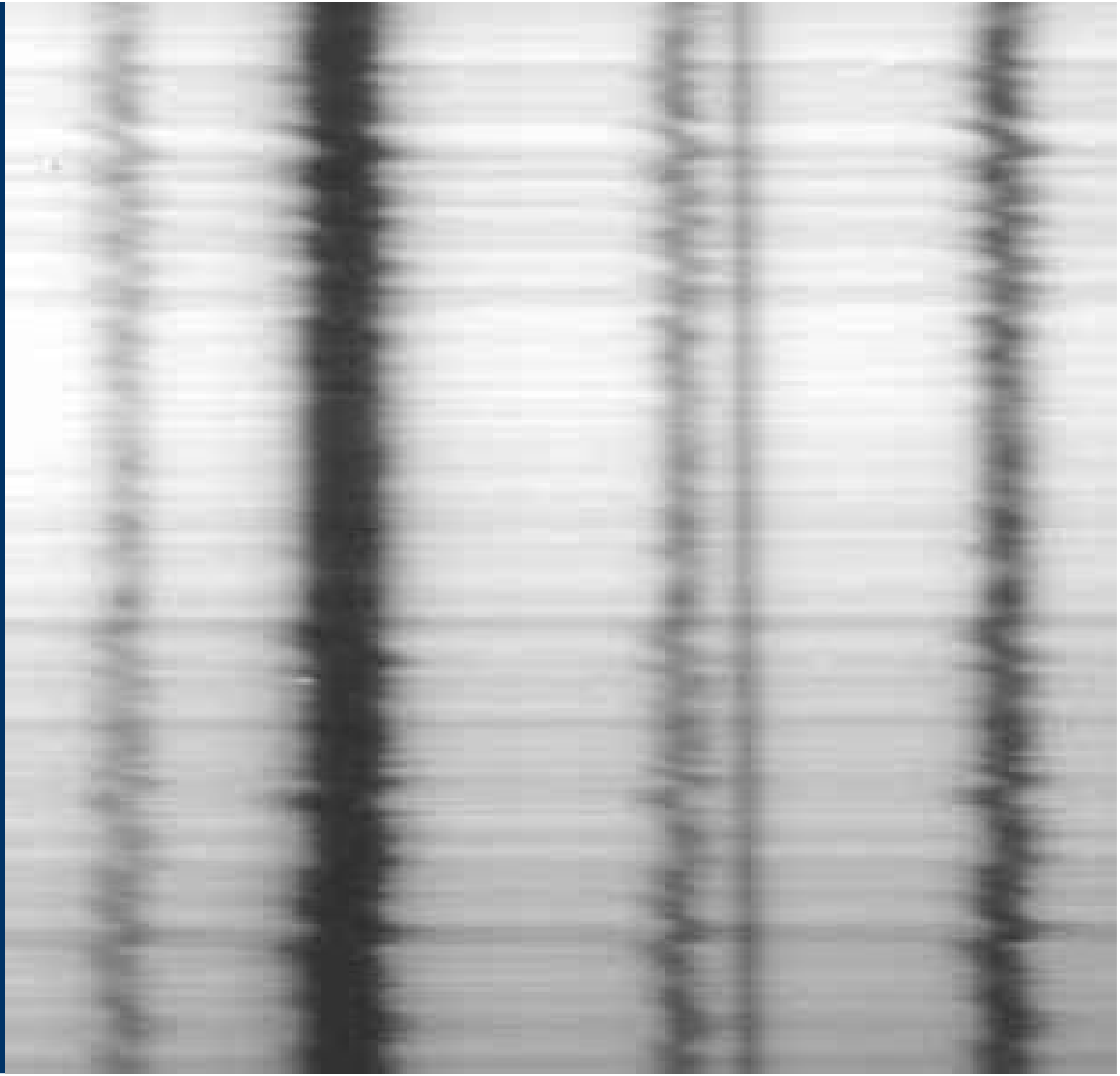


Difference in solar granulation between magnetic and non-magnetic regions. Continuum images of the same area, blackened out (left) where the average field strength is less than 75 G, and (right) where the field strength is larger than 75 G. (Swedish Vacuum Solar Telescope, La Palma)

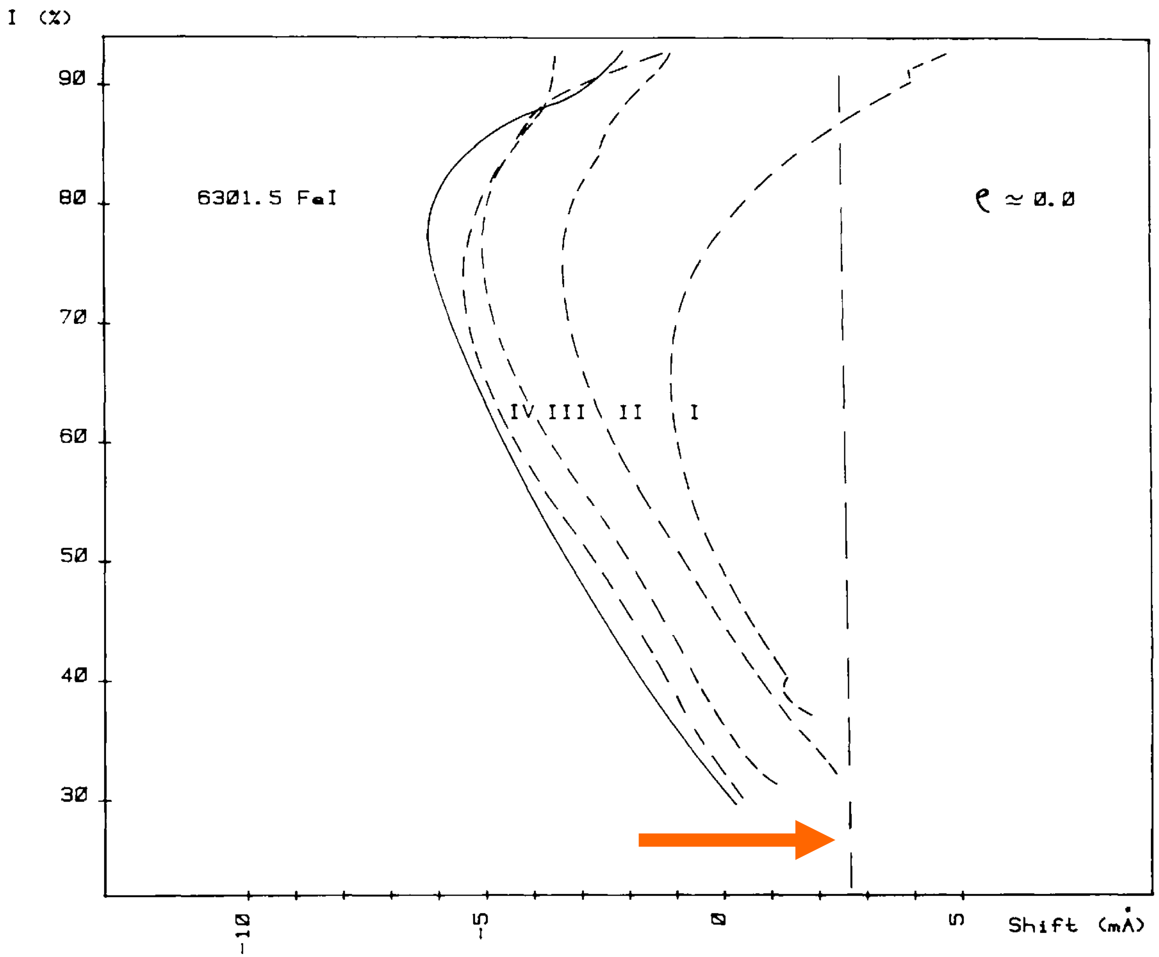
H.C.Spruit, Å.Nordlund, A.M.Title: Solar Convection, *Ann.Rev.Astron.Astrophys.* **28**, 263 (1990)

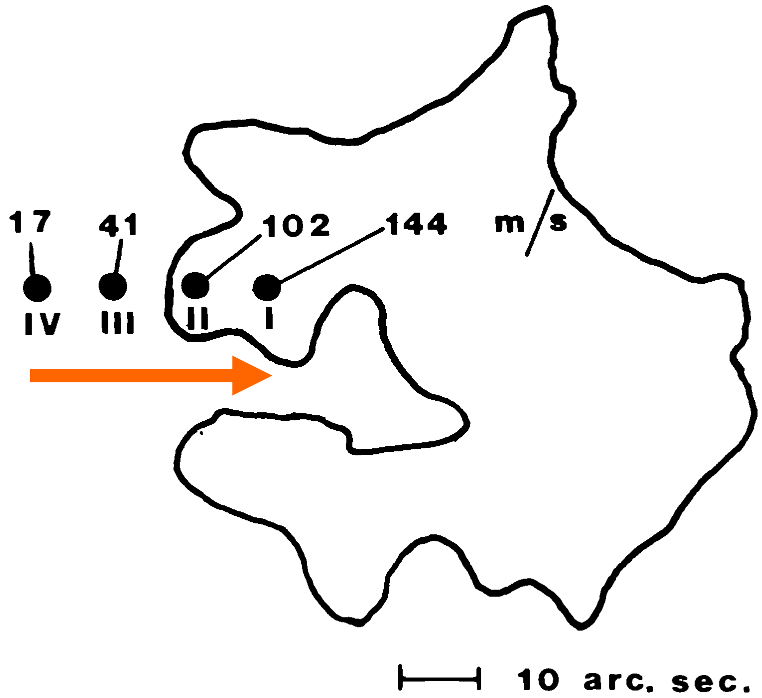
"Wiggly" spectral lines of solar granulation

"Wiggly" spectral lines in the solar photosphere inside and outside a region of activity, reflecting rising and sinking motions in granulation (wavelength increases to the right). The central part crosses a magnetically active region with reduced velocity amplitudes. (W.Mattig)



MAGNETIC & NON-MAGNETIC BISECTORS



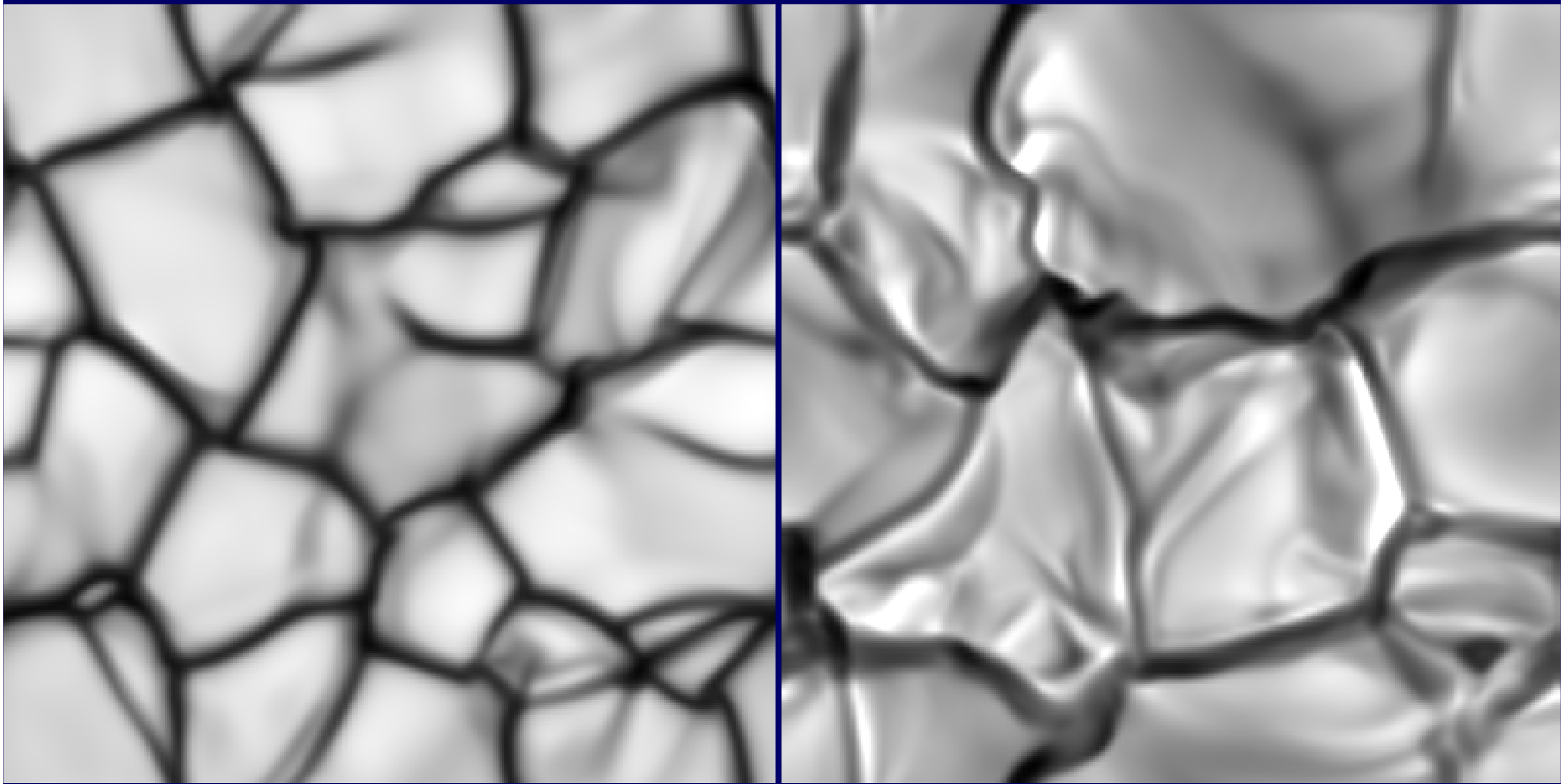


Line bisectors gradually closer to an active region (dashed), compared to that of the quiet Sun. Positions relative to the Ca II K plage are indicated.

F.Cavallini, G.Ceppatelli, A.Righini, *Astron.Astrophys.* **143**, 116 (1985)

Stellar line formation

STELLAR CONVECTION – White dwarf vs. Red giant



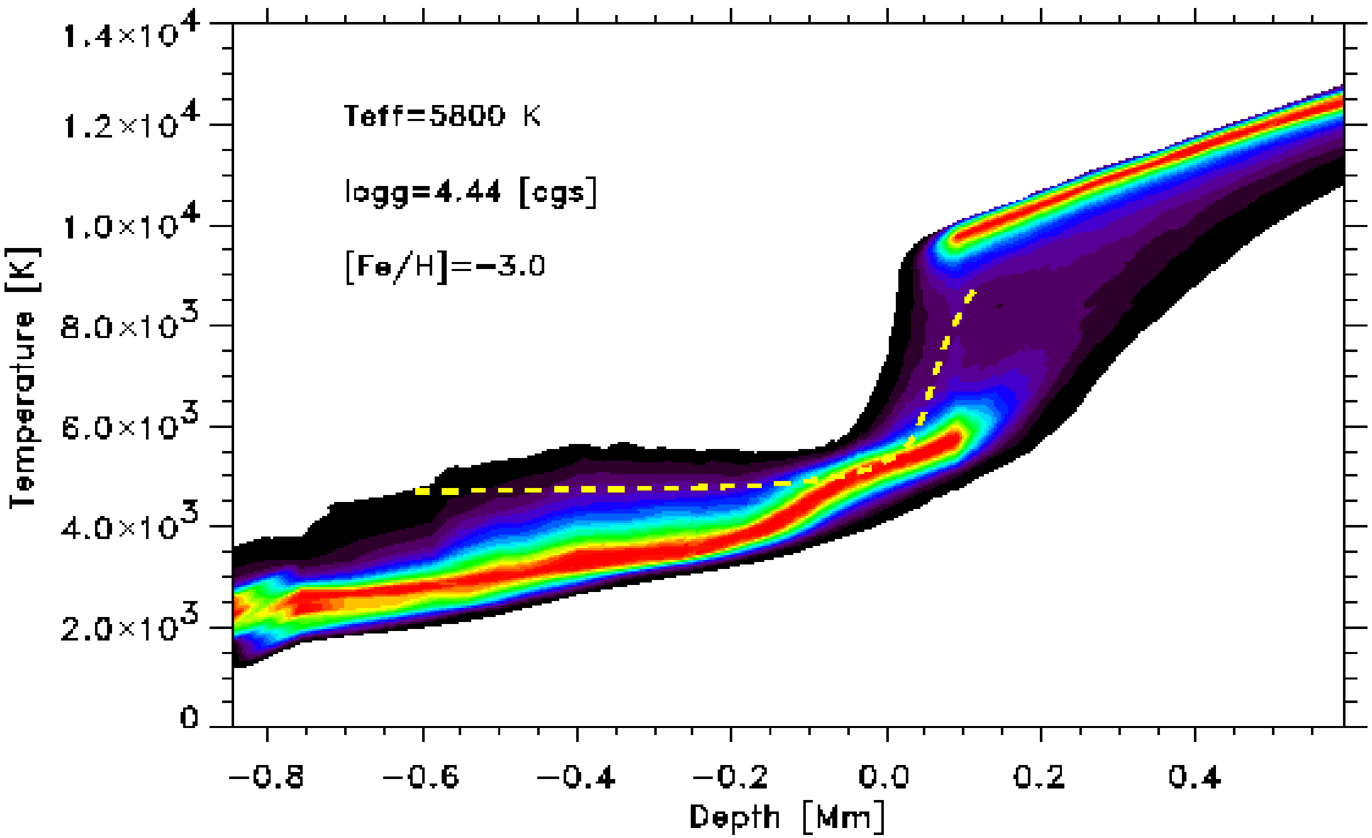
Snapshots of emergent intensity during granular evolution on a 12,000 K white dwarf (left) and a 3,800 K red giant. Horizontal areas differ by dozen orders of magnitude: 7x7 km^2 for the white dwarf, and 23x23 R_{Sun}^2 for the giant. (Ludwig 2006)

3-D MODELS OF METAL-POOR STARS

Surface layers much cooler in 3-D than in 1-D

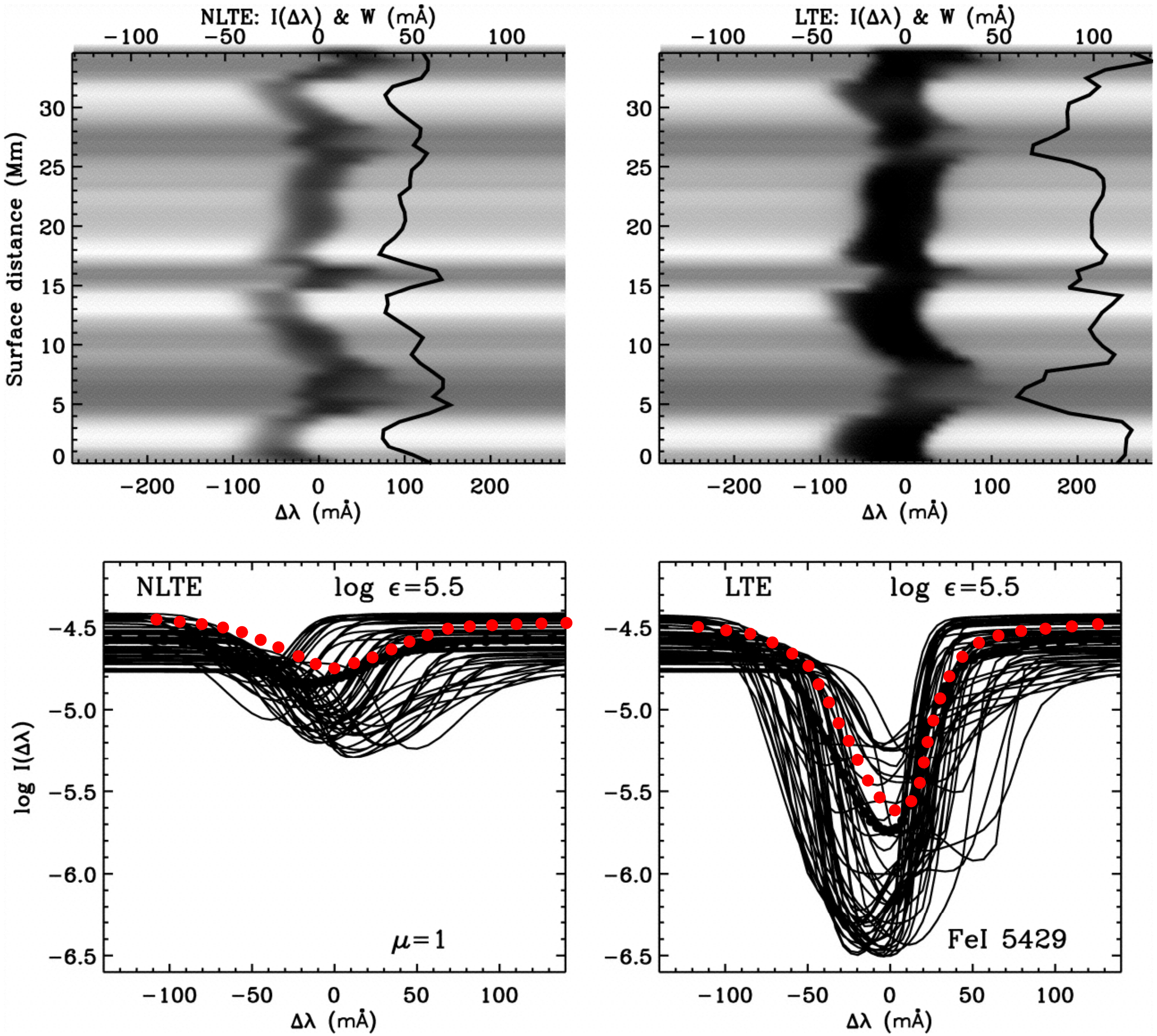
Expansion cooling dominates over radiative heating

Effect of lines opposite to that in 1-D models



"Wiggly" spectral lines of stellar granulation

(modeled)

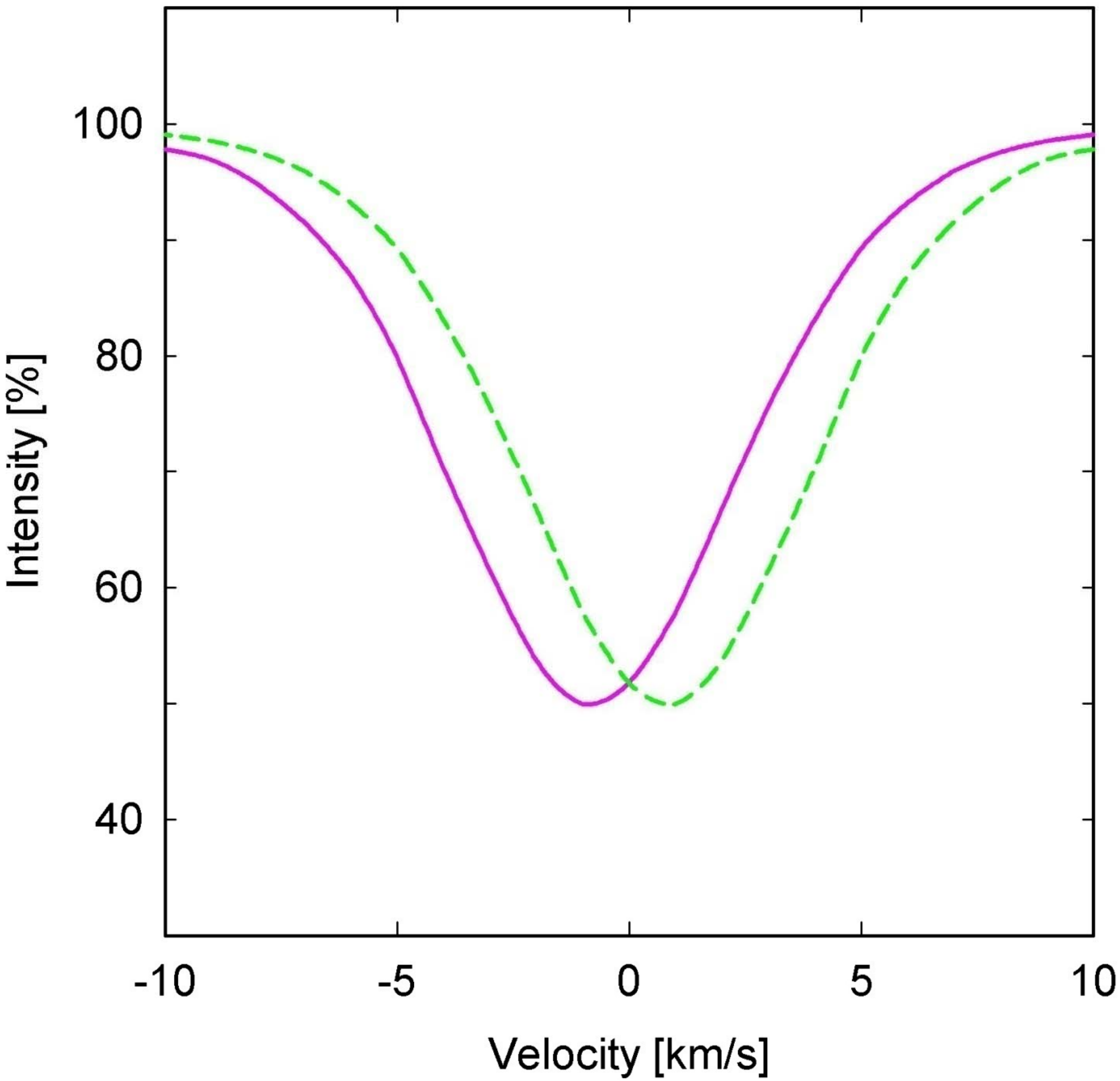


Disk-center Fe I profiles from 3-D hydrodynamic model of the metal-poor star HD 140283 in NLTE and LTE.
Top: Synthetic "wiggly-line" spectra across stellar surface. Curves show equivalent widths W along the slit. Bottom: Spatially resolved profiles; average is red-dotted.
N.G.Shchukina, J.Trujillo Bueno, M.Asplund, *Astrophys.J.* **618**, 939 (2005)

CHANGING STELLAR PARADIGMS

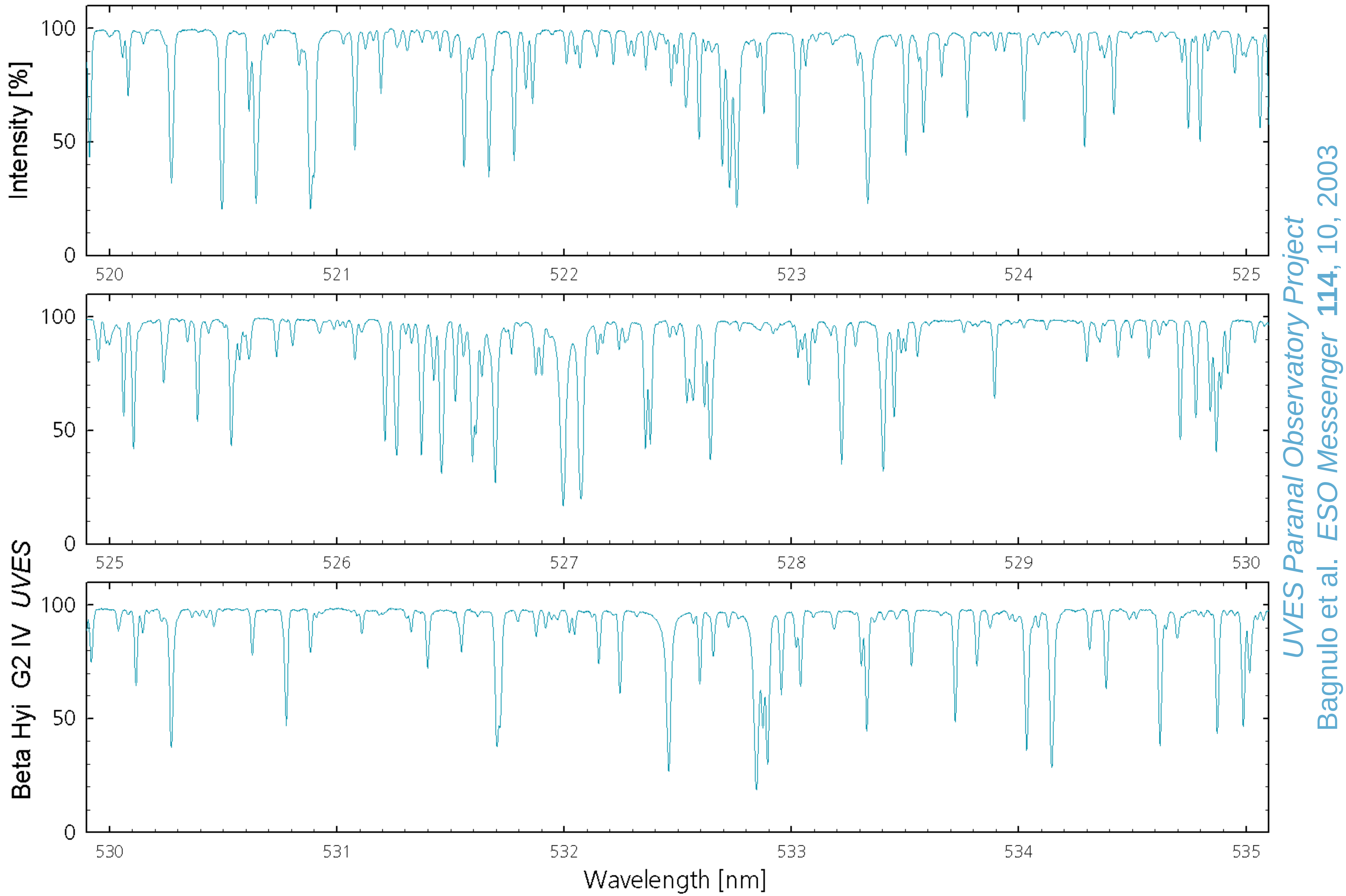
- **RECENT PAST:** "Inversion" of line profiles; *"any part of a profile corresponds to some height of formation"*
- Adjustable parameters, e.g., "*micro-*" & "*macro-turbulence*"
- **NOW:** Stellar line profiles reflect statistical distribution of lateral inhomogeneities across stellar surfaces
- Not possible, *not even in principle*, to "invert" observed profiles into exact atmospheric parameters
- Confrontation with theory through "*forward modeling*": numerical simulations of radiation-coupled stellar hydrodynamics, and computation of observables

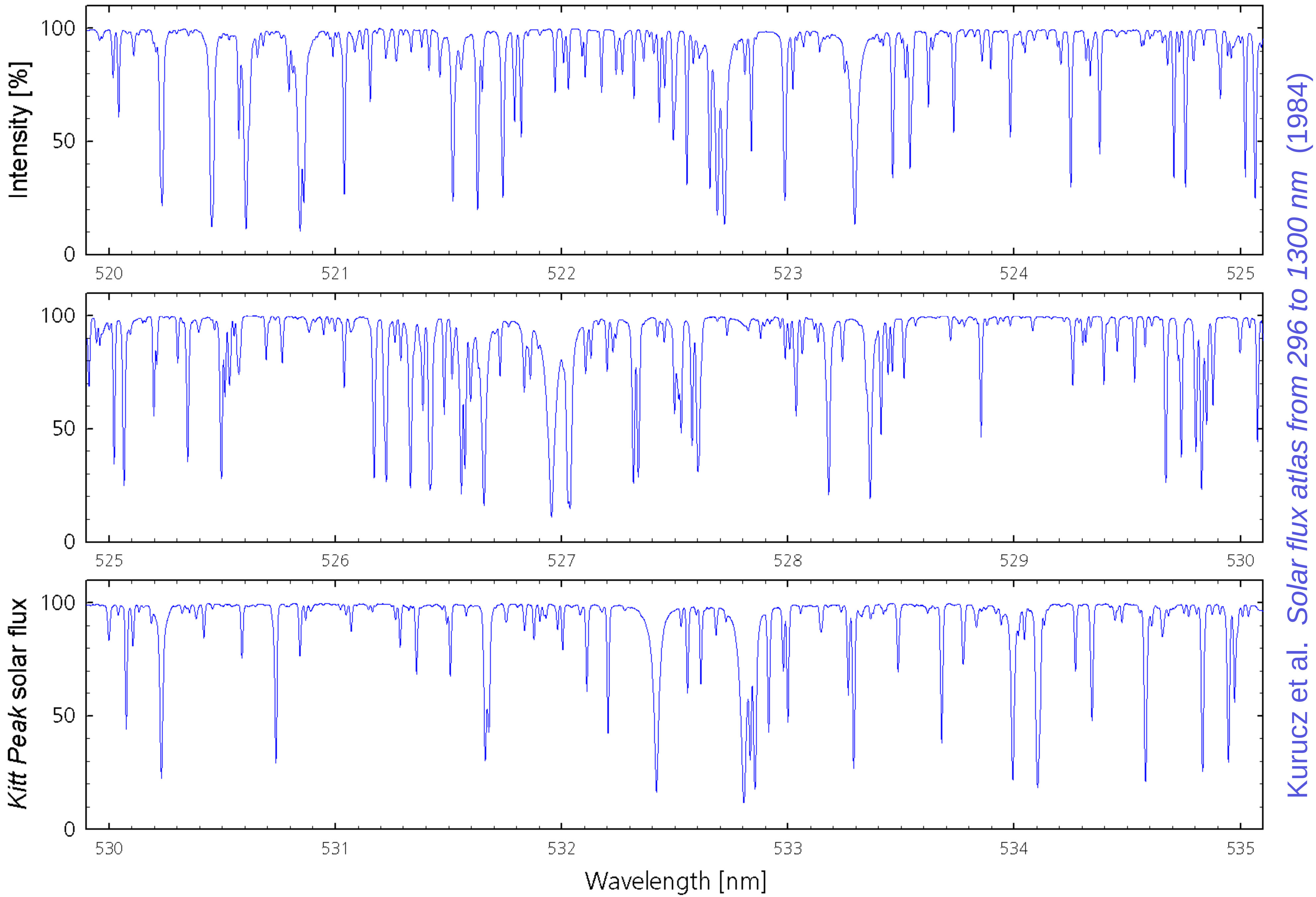
Limits to information content of stellar spectra?



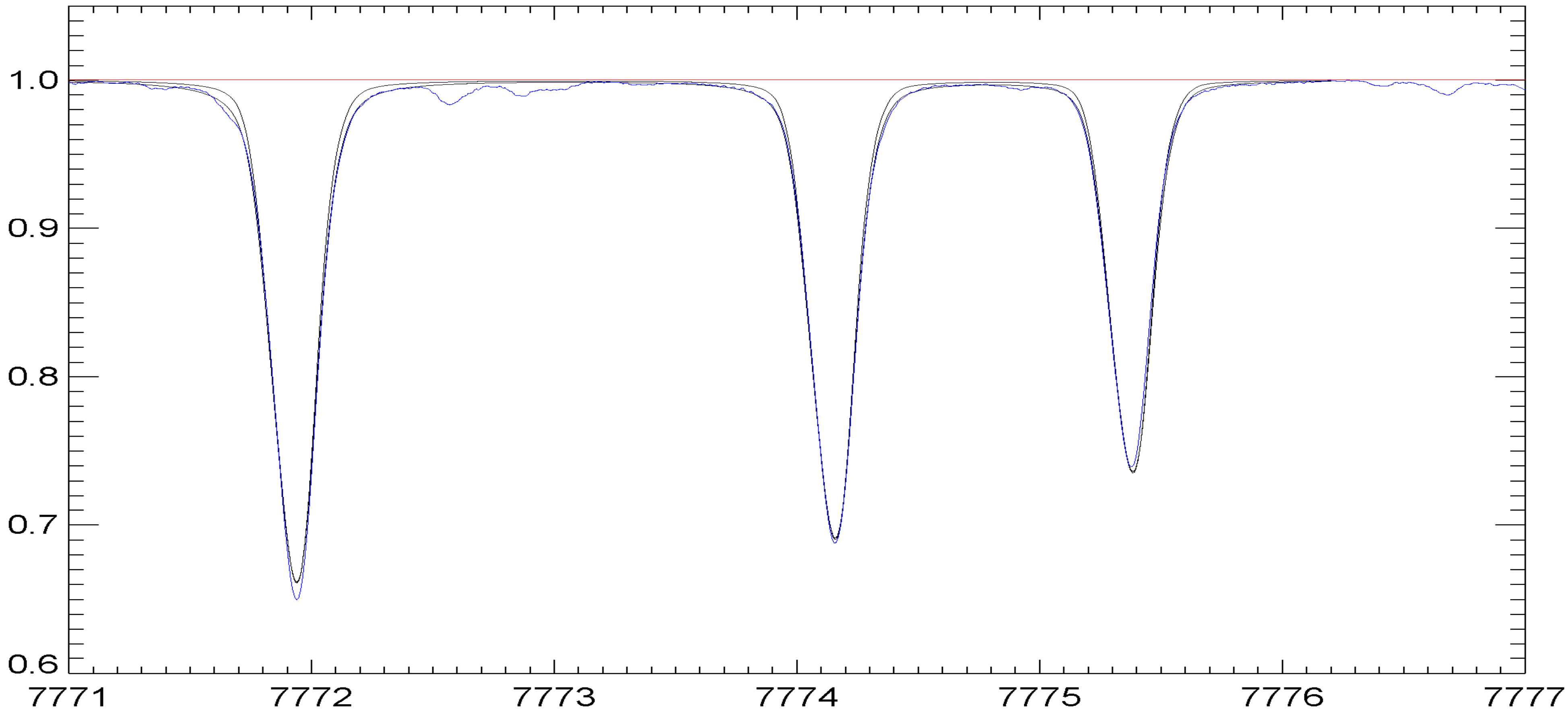
"Beta Hydri" [G2 IV] Synthetic Fe I line & mirror profile

Dravins, Lindegren, Nordlund & VandenBerg, *ApJ* **403**, 385


Intensity [%]
Beta Hyi G2 IV UVES
Wavelength [nm]
100
50
0
520
521
522
523
524
525
526
527
528
529
530
531
532
533
534
535
UVES Paranal Observatory Project
Bagnulo et al. ESO Messenger 114, 10, 2003

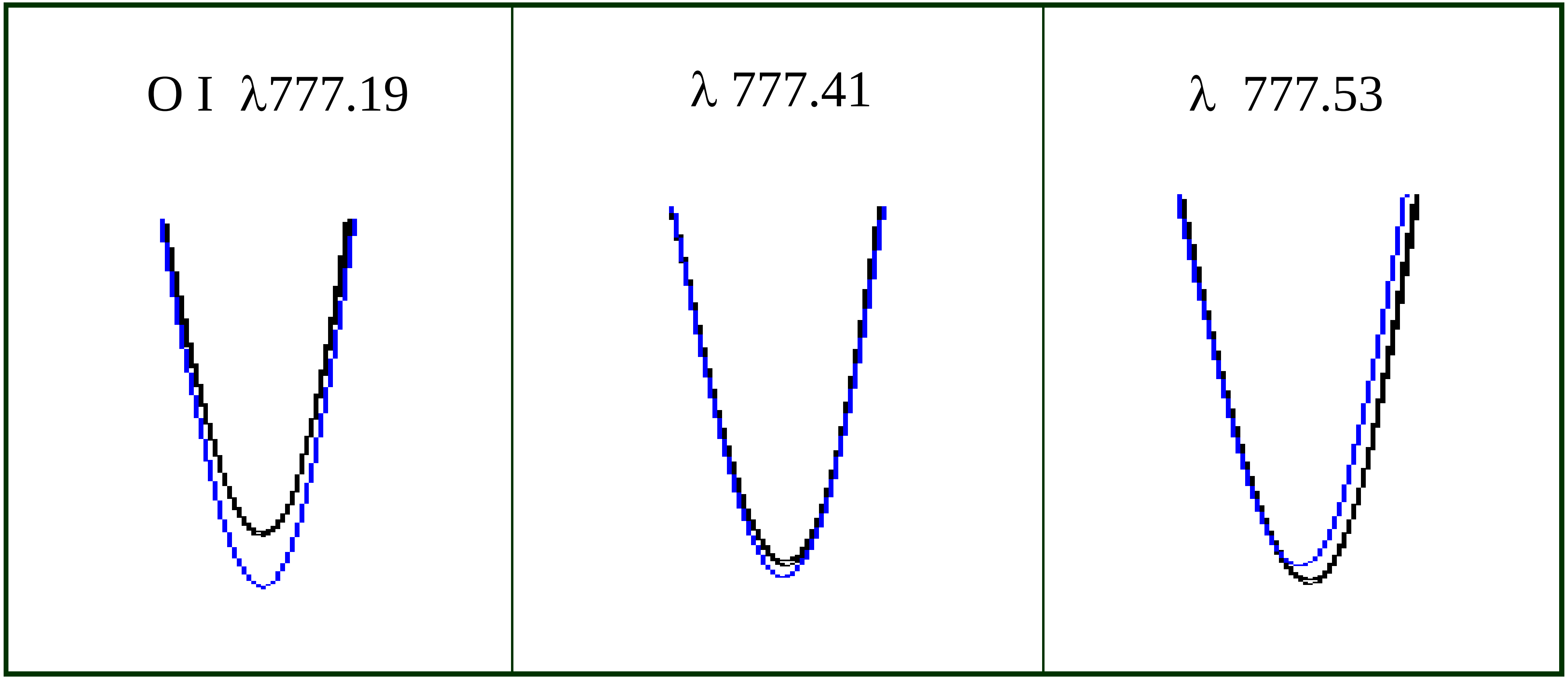

Intensity [%]
100
50
0
520
521
522
523
524
525
526
527
528
529
530
531
532
533
534
535
Wavelength [nm]
Kitt Peak solar flux
Kurucz et al. *Solar flux atlas from 296 to 1300 nm* (1984)

MODELING SPECTRA (not only single lines)



LTE solar 3-D spectra, assuming [O]=8.86 for two different van der Waals damping constant (black lines).
Blue line: observed disk center FTS spectrum by Neckel ("Hamburg photosphere"), slightly blueshifted.

O I LINE PROFILES & SHIFTS



LTE solar 3-D hydrodynamic spectra, assuming [O]=8.86, for two different damping constants (black lines).
Blue line: observed disk center FTS spectrum, slightly blueshifted.

Integrated sunlight

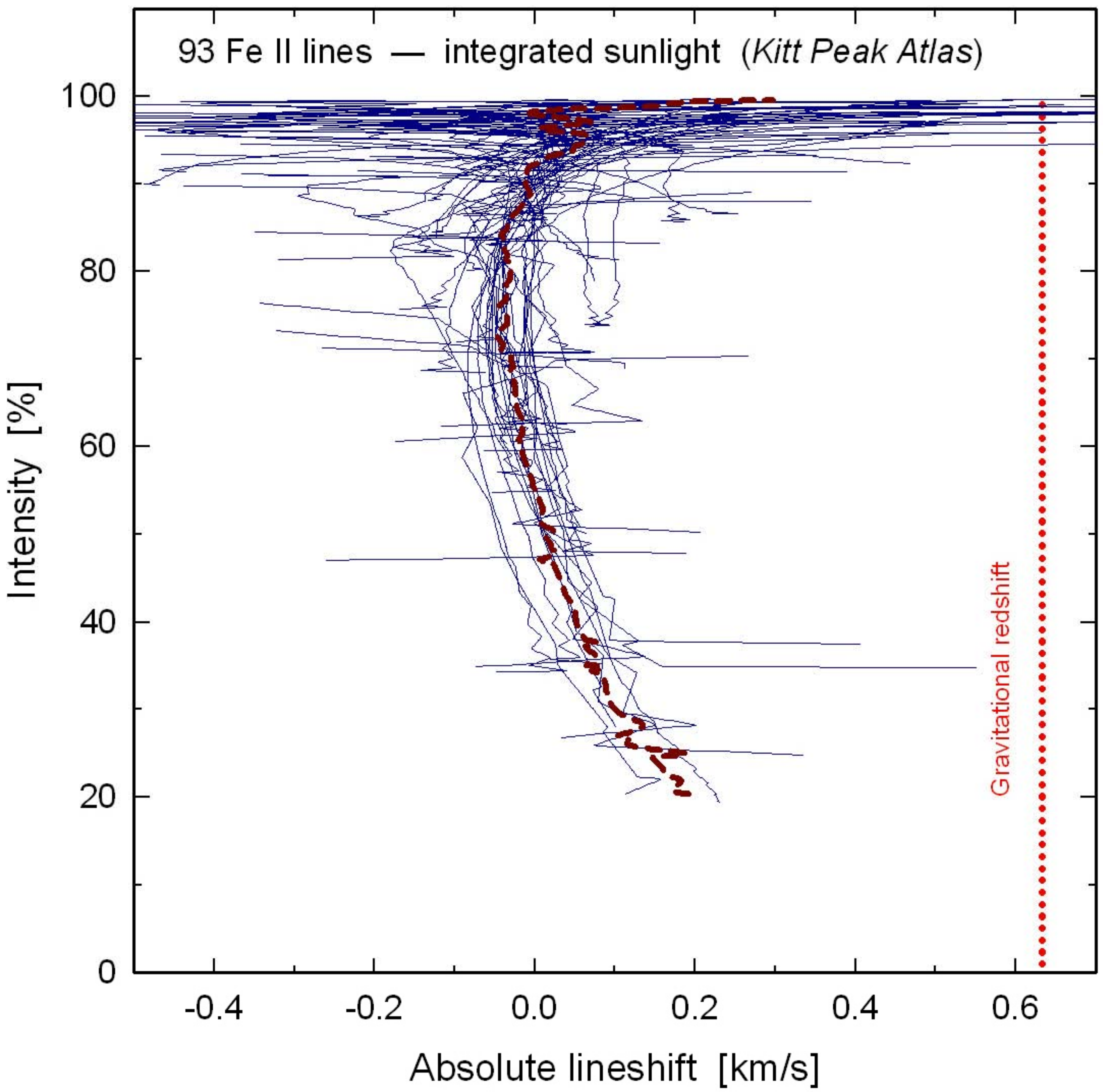
93 Fe II bisectors

Solar spectra:

Kurucz et al.:
Solar Flux Atlas from 296 to 1300 nm

Laboratory wavelengths:

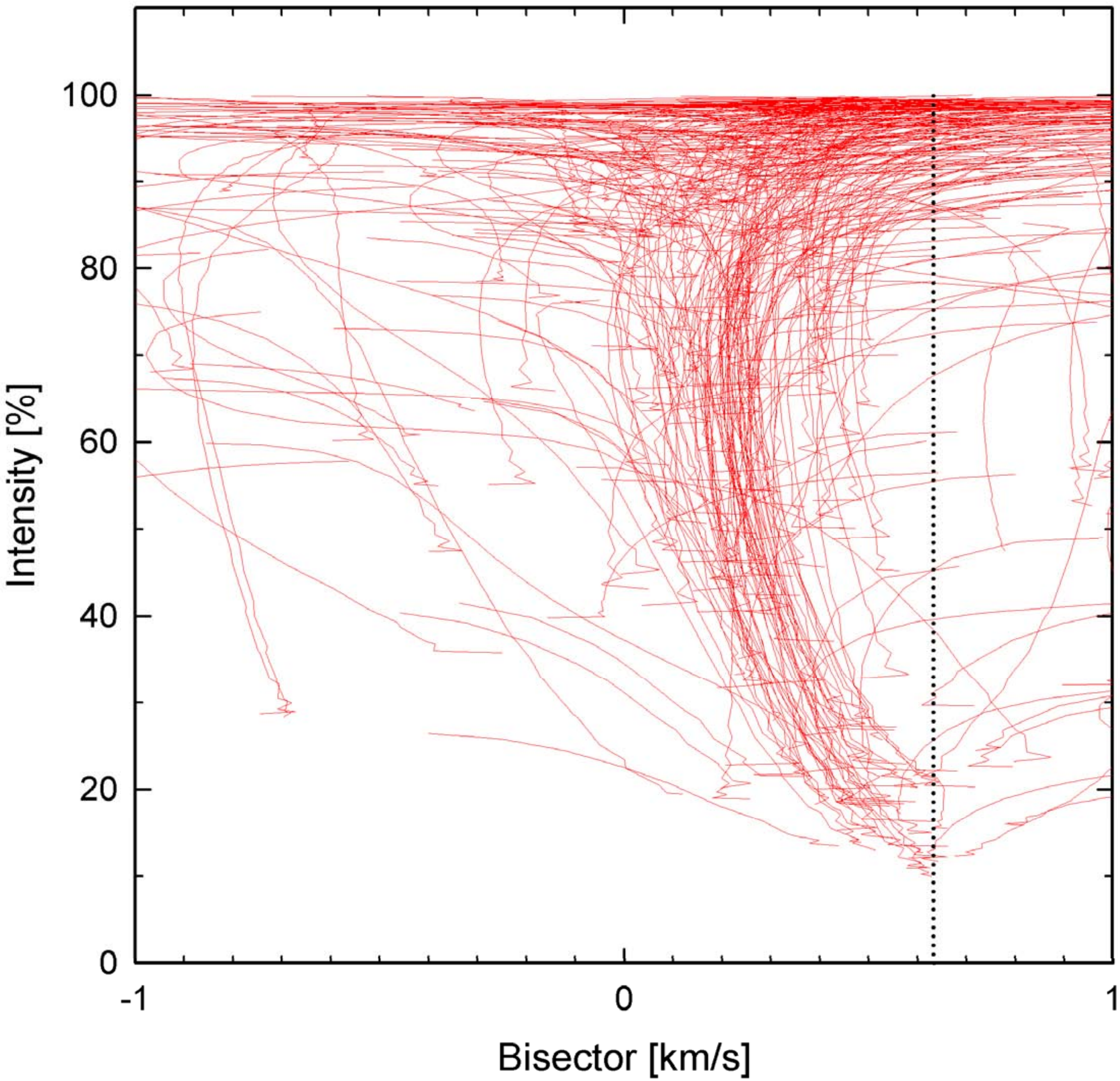
S.Johansson (Lund)



429 Ti I bisectors at solar disk center

Solar data:
"Hamburg photosphere"
H. Neckel, Solar Phys.
***184**, 421*

Laboratory wavelengths:
P. Forsberg, Phys.Scr.
***44**, 446*
U. Litzén (Lund)



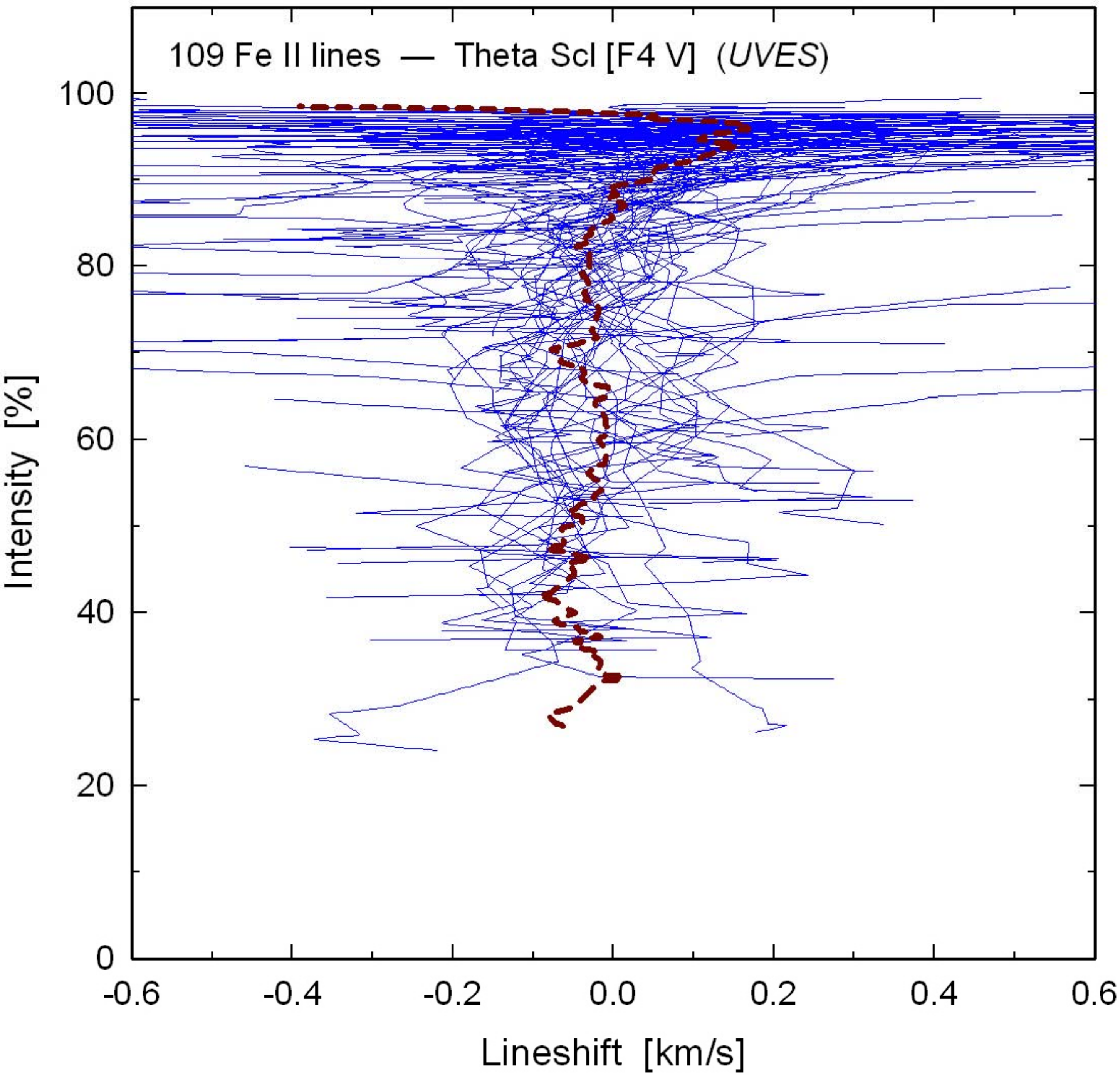
Theta Scl [F4 V]

109 Fe II bisectors

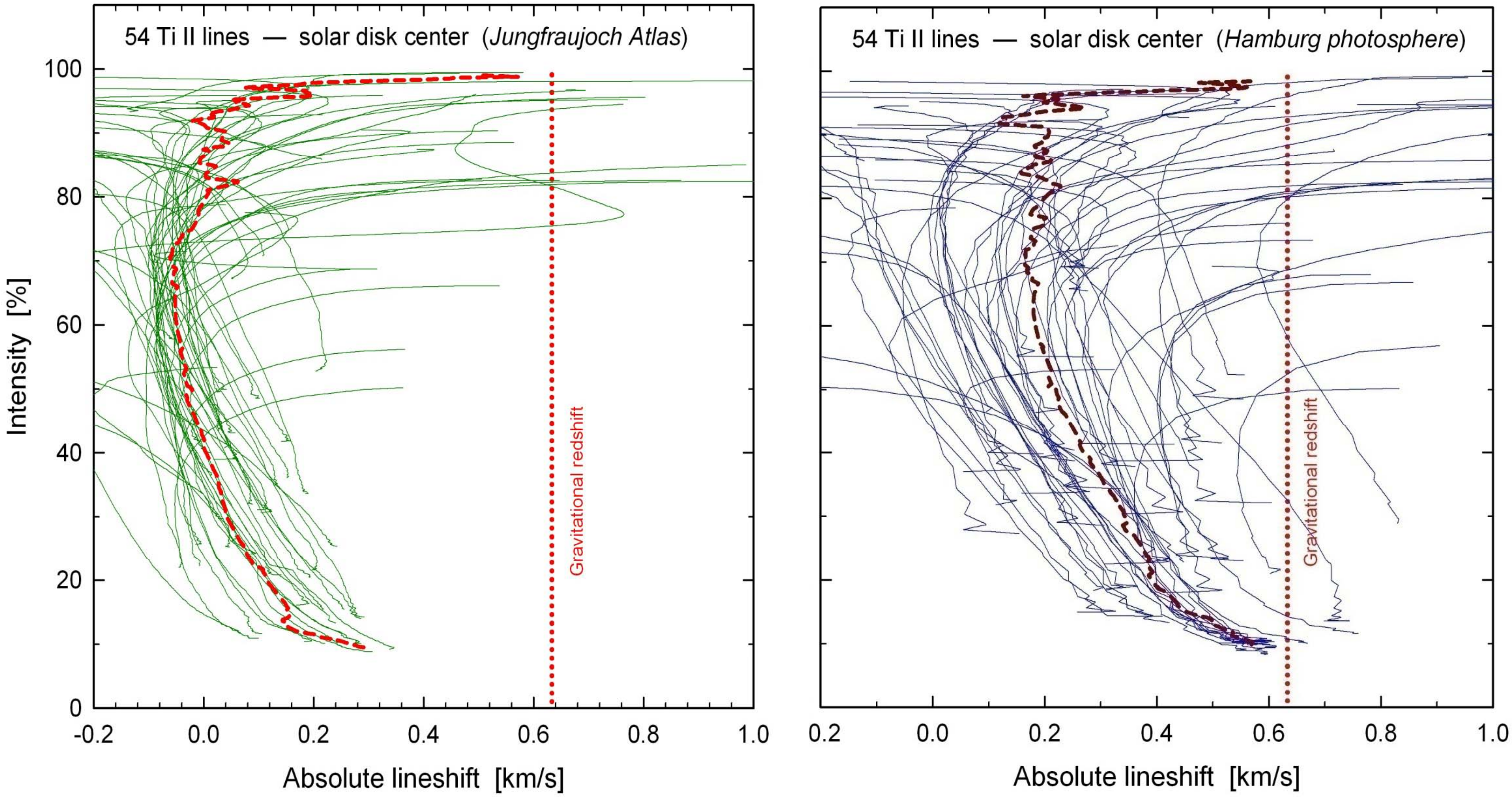
Stellar spectra:
ESO VLT / UVES
Paranal Observatory Project

This F-type star displays a "blueward hook" of its [average] bisector quite close to the continuum.

Laboratory wavelengths:
S.Johansson (Lund)

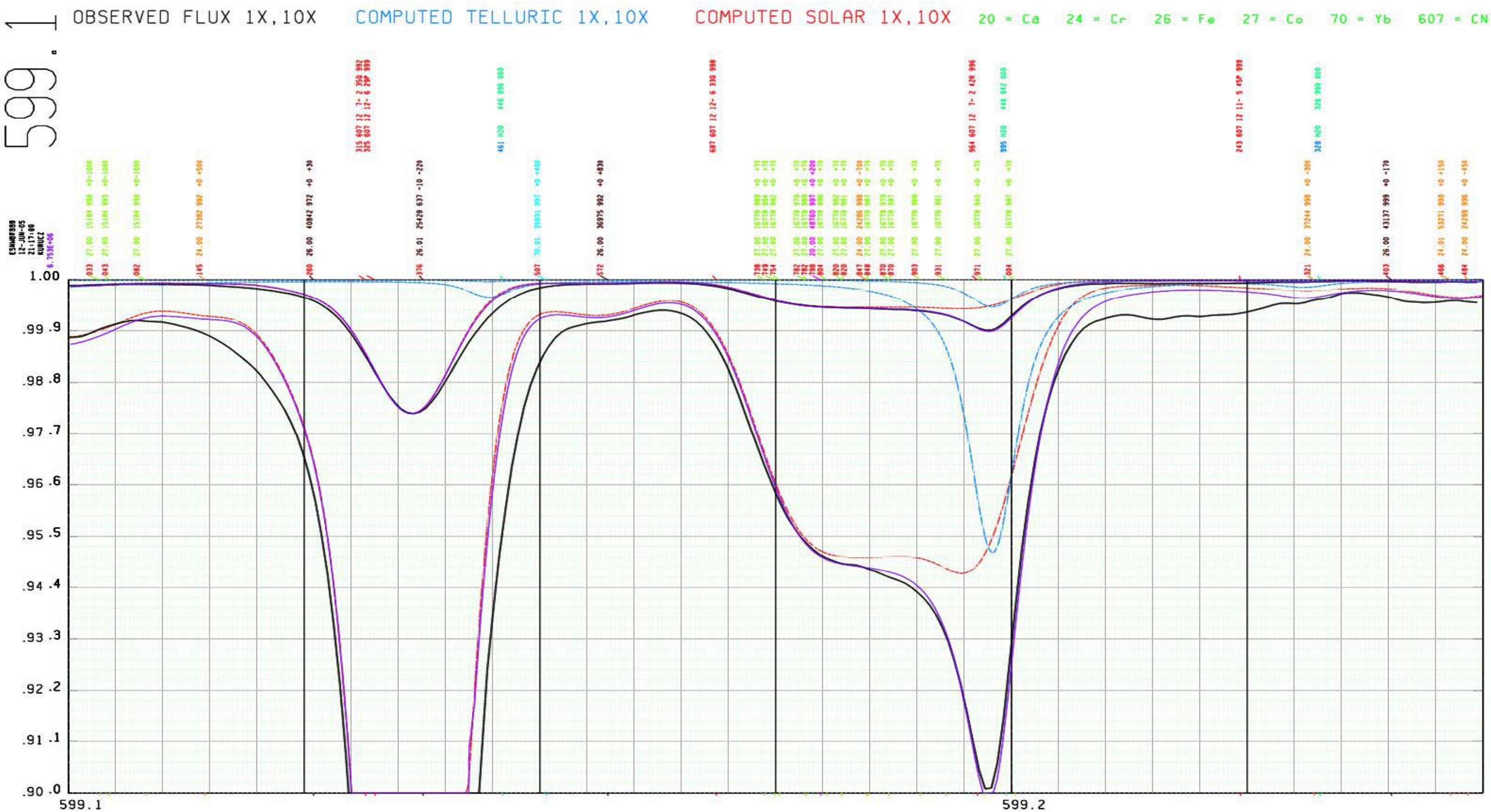


Limits from wavelength noise ?



Bisectors of 54 Ti II lines at solar disk center from Jungfraujoch Atlas (grating spectrometer; left); and as recorded with the Kitt Peak FTS . Bisectors have similar shapes but differ in average lineshift, and scatter about their average.

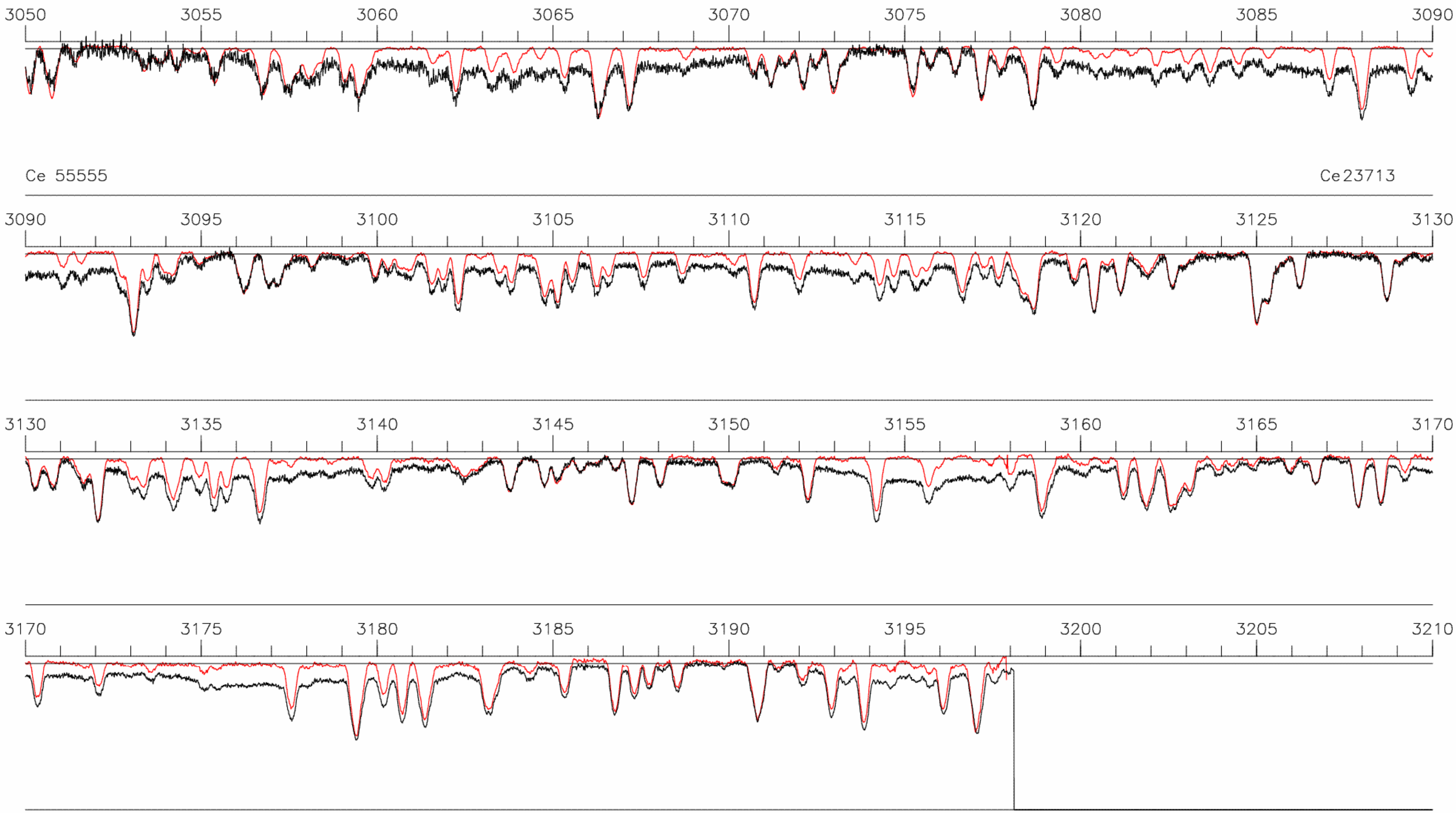
Limits from telluric absorption ?



Spectrum calculation in a relatively empty spectral region of the Solar Flux Atlas.
Telluric, synthetic, and observed spectra at normal, and 10× scale.

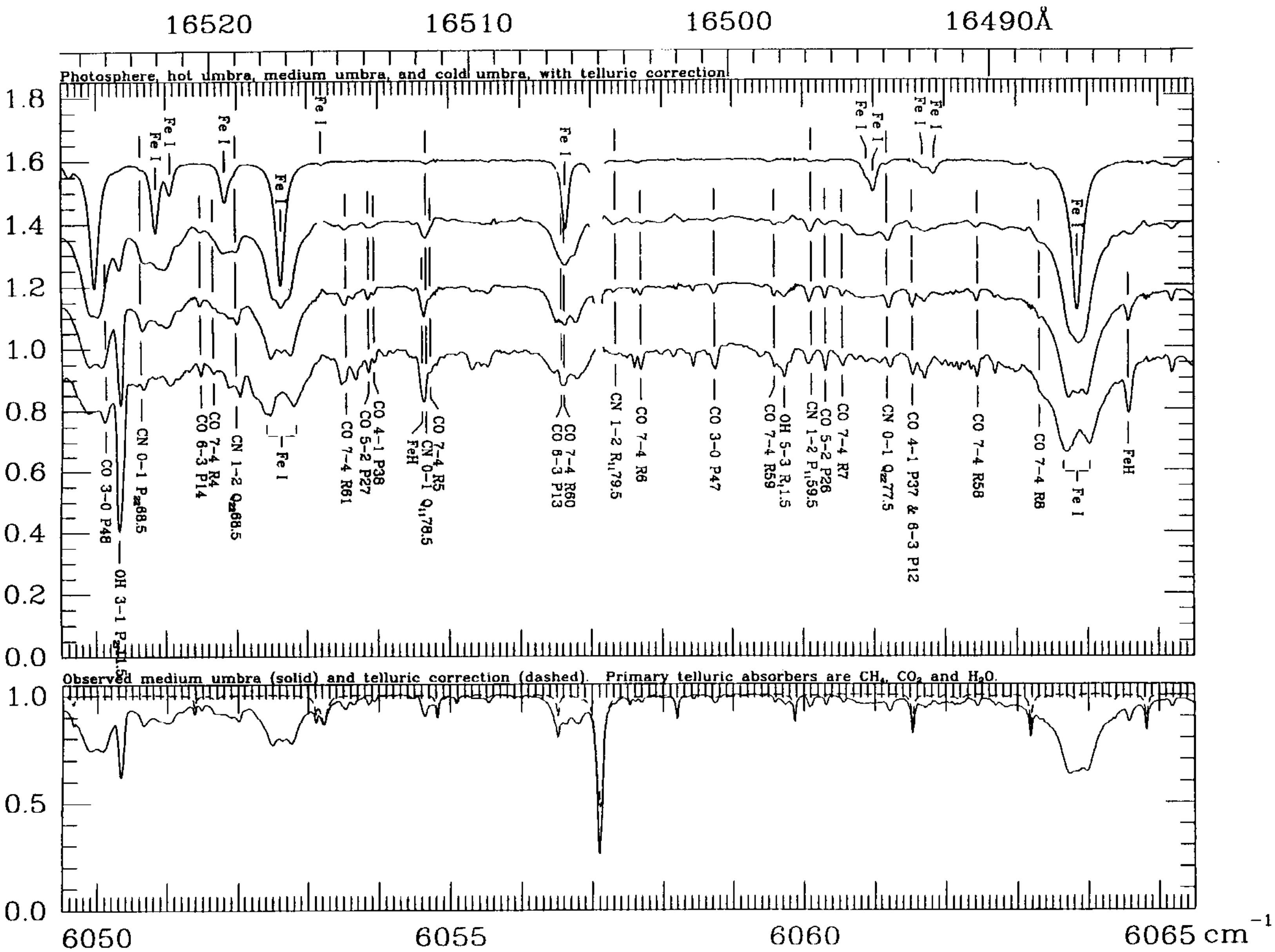
R.Kurucz: New Atlases for Solar Flux, Irradiance, Central Intensity, and Limb Intensity, *Mem.Soc.Astr.It.Suppl.* **8**, 189 (2005)

Limits from telluric absorption ?



Spectrum of *Sirius* (A1 V) from space (R.Kurucz; Hubble Space Telescope), and from the ground (E.Griffin; Mt.Wilson), showing atmospheric ozone absorption in near-UV.

Limits from lack of spectral lines ?



Top sequence (telluric-corrected):

Disk-center photosphere

Hot umbra

Medium umbra

Cold umbra

Bottom:

Medium umbra (uncorrected; solid)

Telluric correction (dashed)

L.Wallace, K.Hinkle & W.C.Livingston: Sunspot Umbral Spectra in the Region 4000 to 8640 cm^{-1} (1.16 to 2.50 μm); 2001

"ULTIMATE" INFORMATION CONTENT OF STELLAR SPECTRA ?

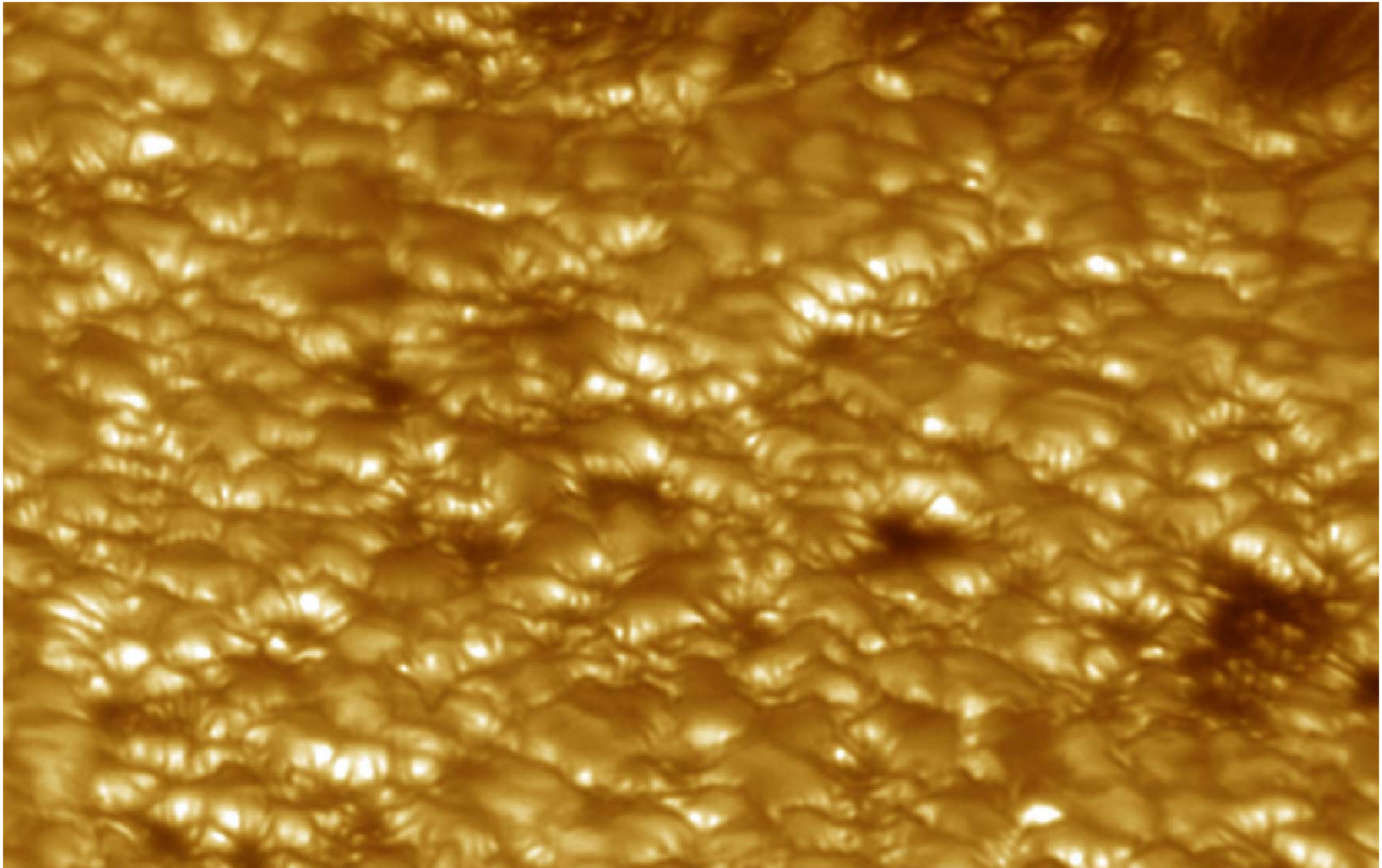
3-D models predict detailed line shapes and shifts

… but …

their predictions may not be verifiable due to:

- Uncertain laboratory wavelengths
- Absence of relevant stellar lines
- Blends with stellar or telluric lines
- Data noisy, low resolution, poor wavelengths
- Line-broadening: rotation, oscillations

Spatially resolved stellar surfaces



Solar granulation near the limb (upward on image)

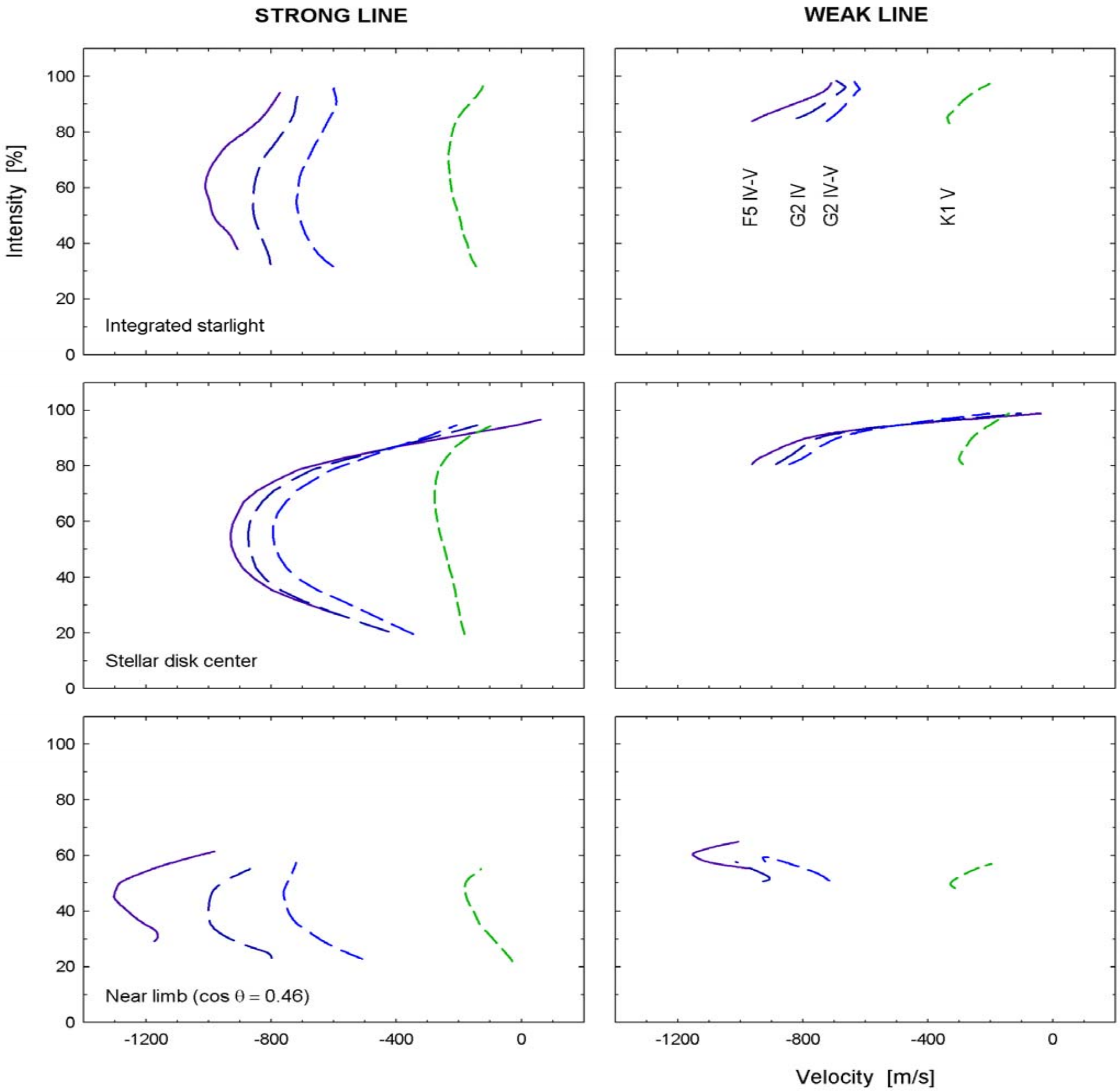
Filtergram at 488 nm; Swedish 1-m Solar Telescope on La Palma (G.Scharmer & M.G.Löfdahl)

SPATIALLY RESOLVED STELLAR SPECTROSCOPY

Future observational challenges include...

- Center-to-limb changes of line profiles
- Center-to-limb changes of line shifts
- Center-to-limb changes of time variablity
- Changes across stellar active regions

Same spectral line in different stars



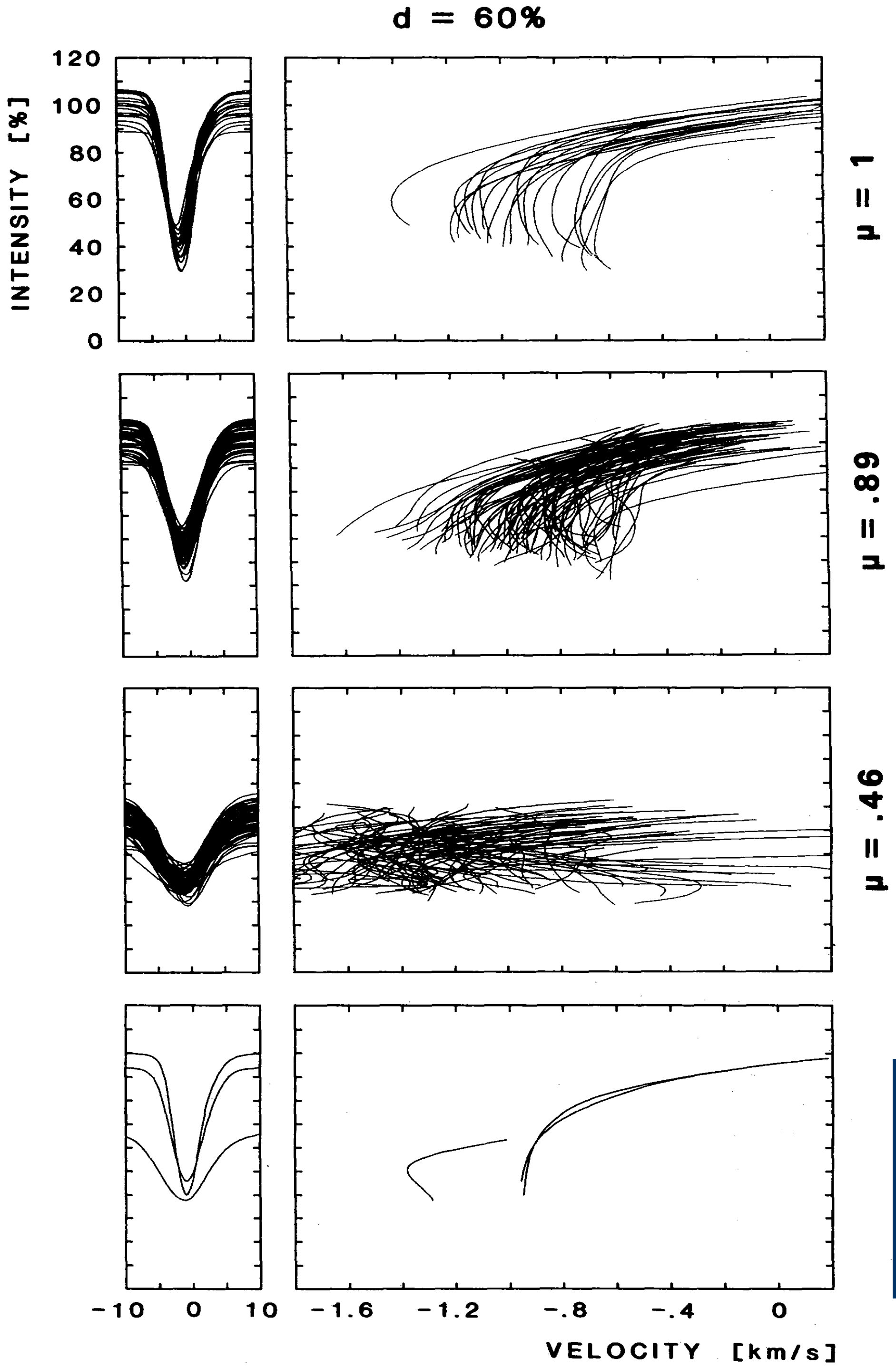
Adapted from

Dravins & Nordlund, A&A 228, 203

Center-to-limb line-profile changes in Procyon

Evolution of spatially averaged line profiles and bisectors in the Procyon model, leading to the global averages.

Time variability increases toward the limb, and the limb effect has opposite sign from that on the Sun.



D.Dravins & Å.Nordlund
Stellar Granulation IV.
Line Formation in
Inhomogeneous
Stellar Photospheres
A&A **228**, 84

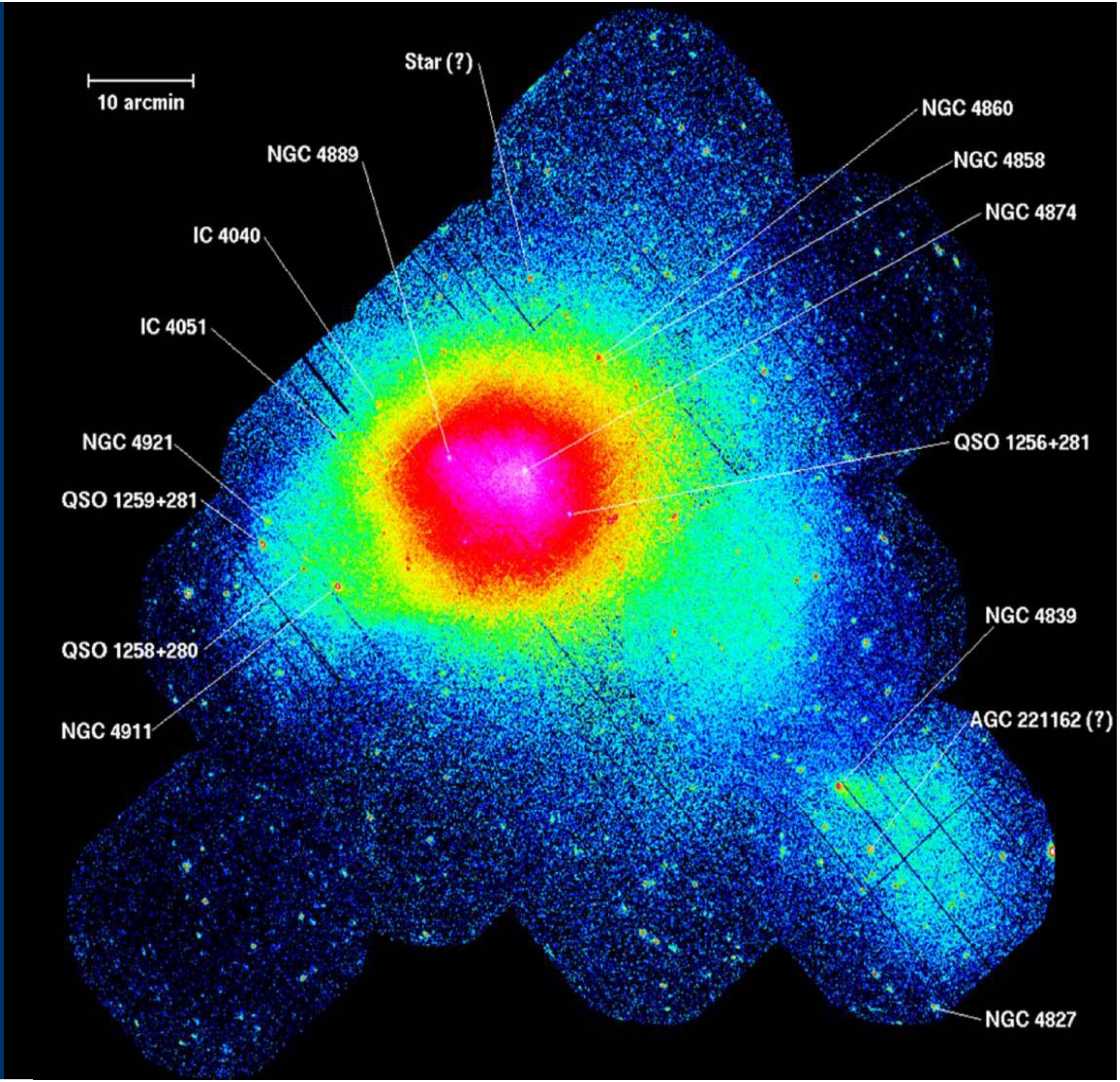
Intergalactic convection

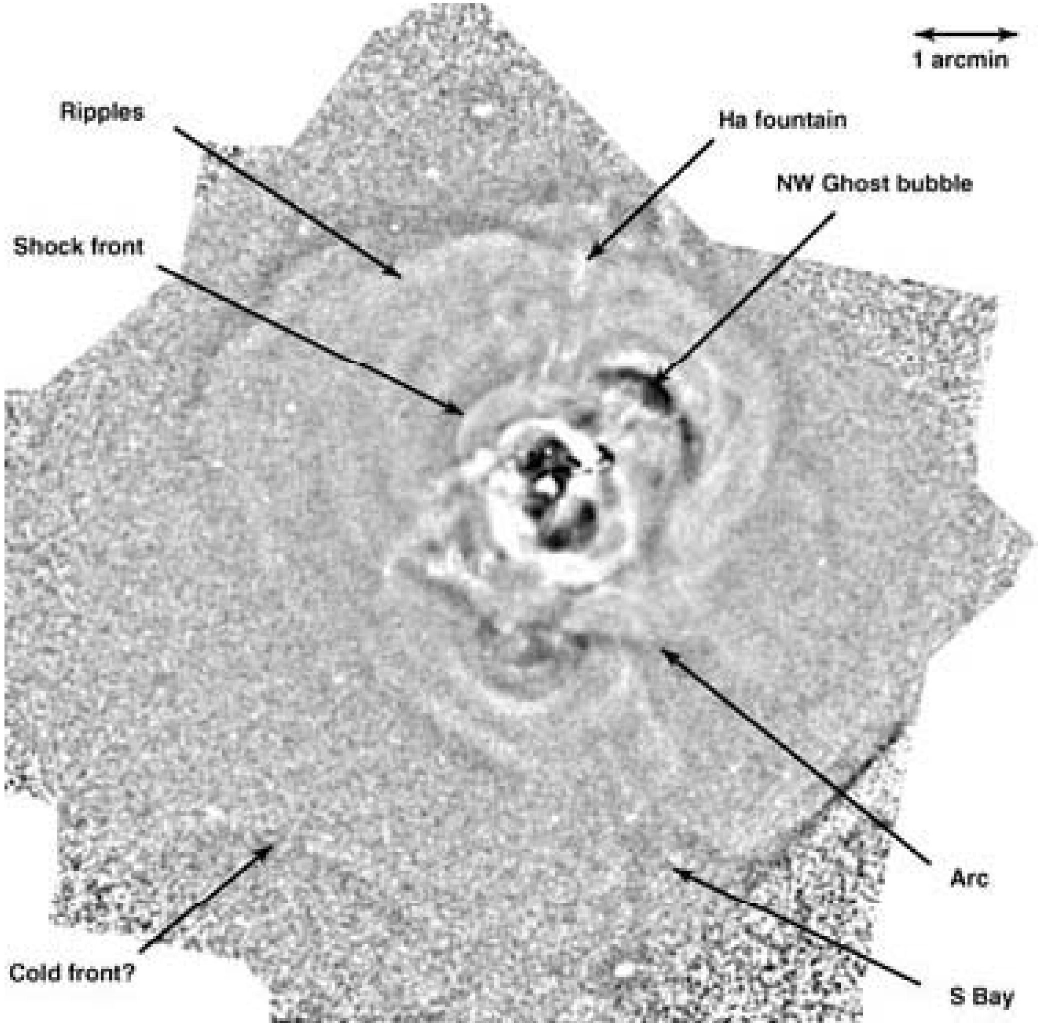
GALAXY CLUSTERS

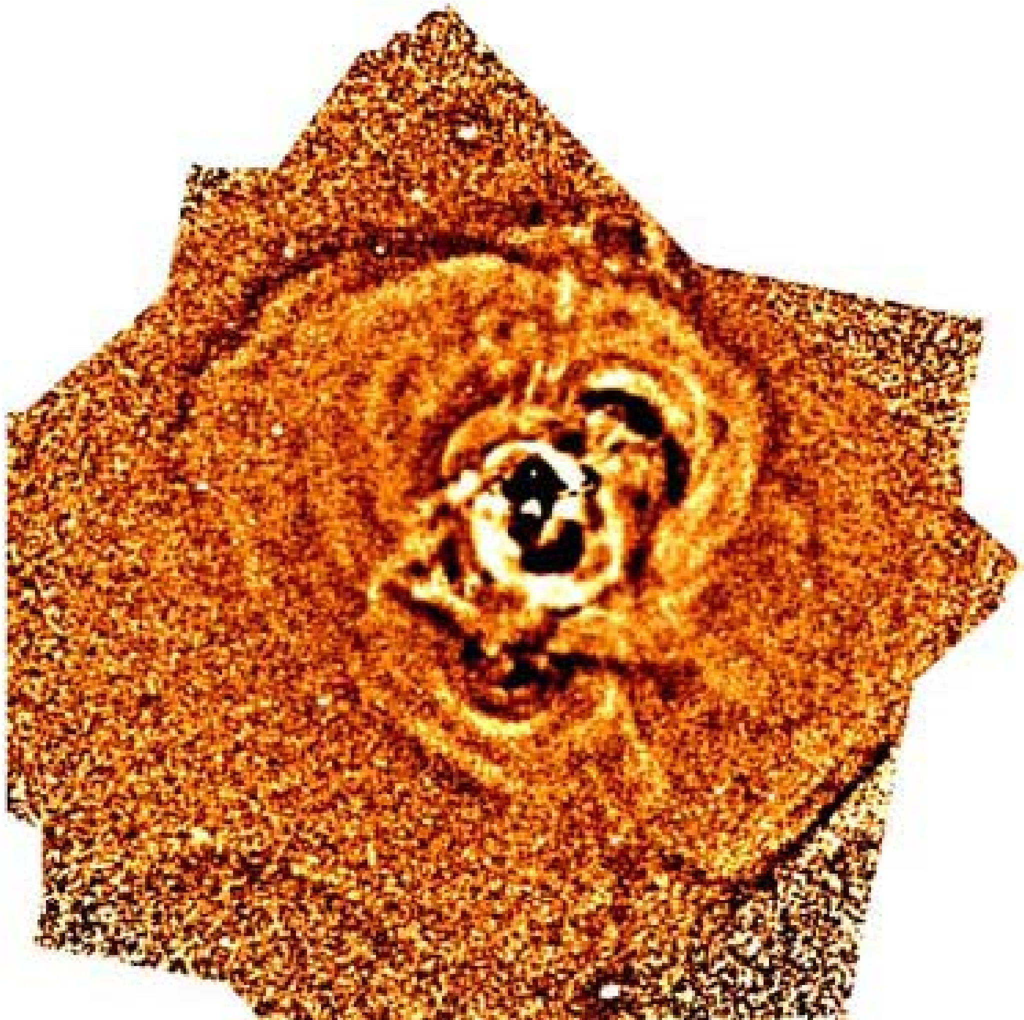
XMM/Newton X-ray image of the Coma galaxy cluster

Lower right: X-ray emission from the merging-galaxy group NGC 4839

(Max-Planck Institute for Extraterrestrial Physics)







Perseus galaxy cluster in 0.3–7 keV X-rays (900 ks exposure with *Chandra*)

Unsharp masking shows inner cavities containing radio lobes, and outer ghost cavities.
Sound waves (weak shocks) are visible as circular ripples.

A.C.Fabian, J.S.Sanders, G.B.Taylor, S.W.Allen, C.S.Crawford, R.M.Johnstone, K.Iwasawa
A very deep Chandra observation of the Perseus cluster: shocks, ripples and conduction
MNRAS **366**, 417 (2006)

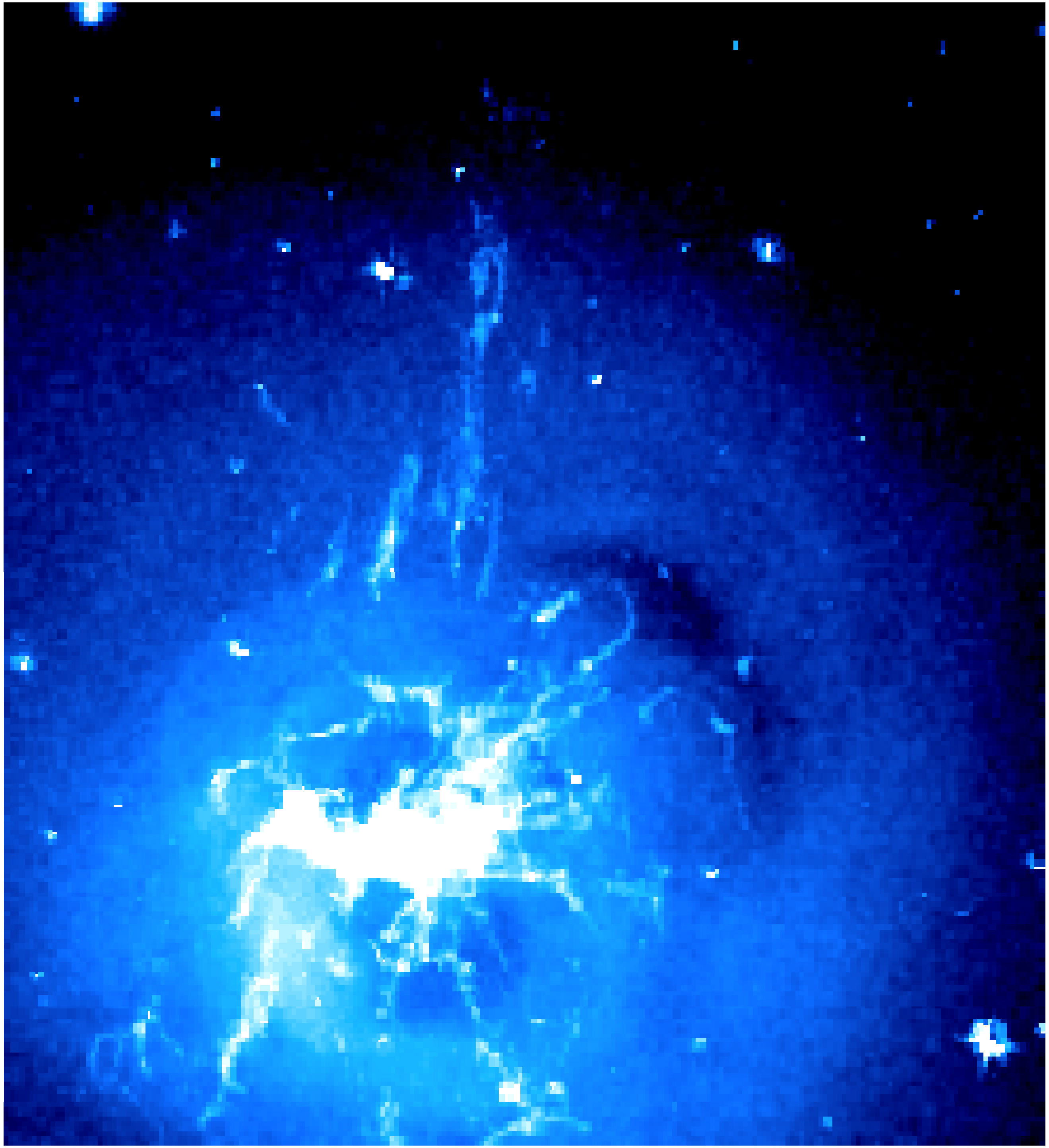
INTERGALACTIC CONVECTION

Perseus cluster core in X-rays (Chandra), overlaid with Hα image (WYIN)

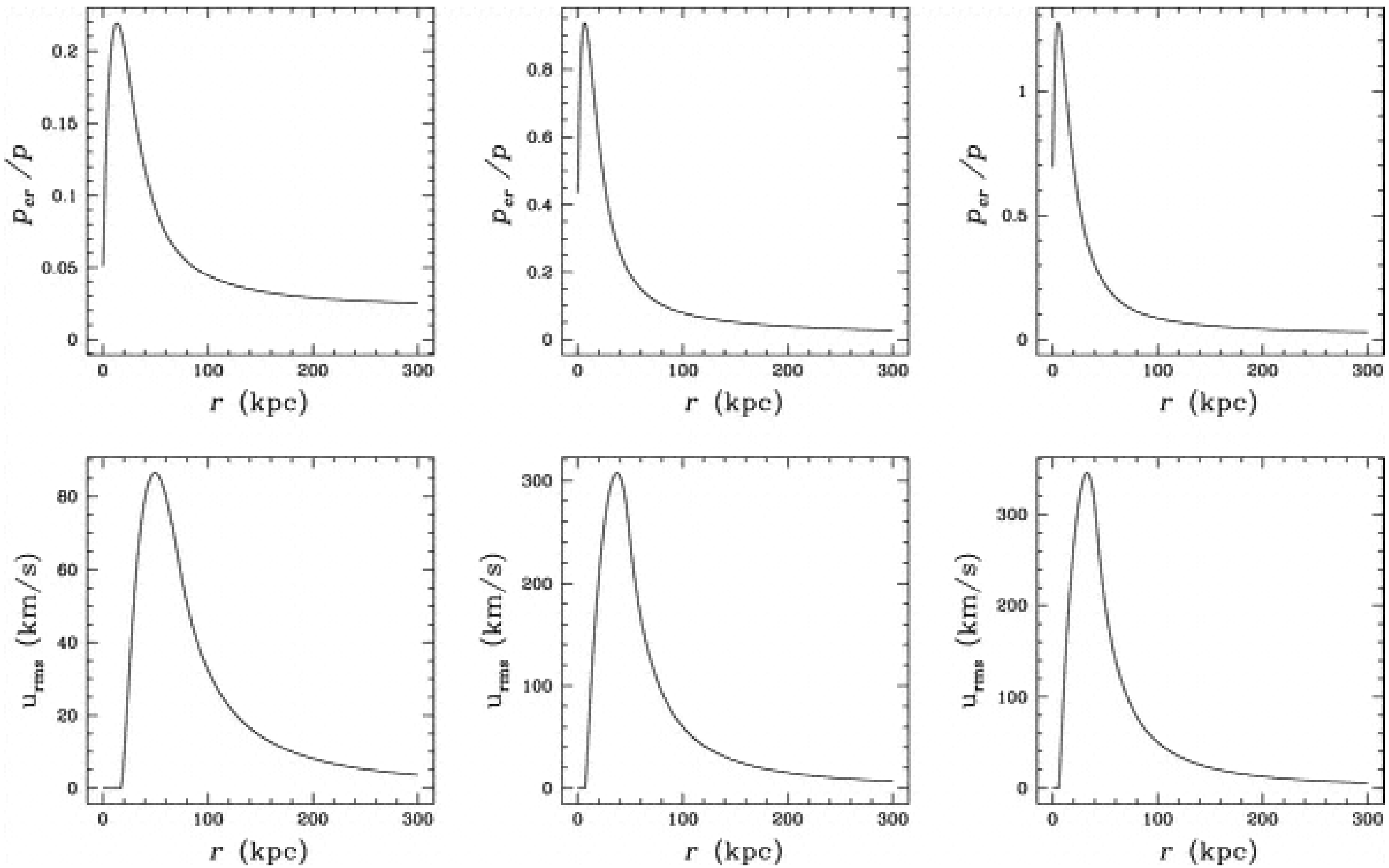
Arc-shaped Hα filaments suggest vortex-like flows

Image is 4.3 arcmin (96 kpc) on the side

Reynolds et al.: Buoyant radio-lobes in a viscous intracluster medium, *MNRAS* **357**, 242 (2005)



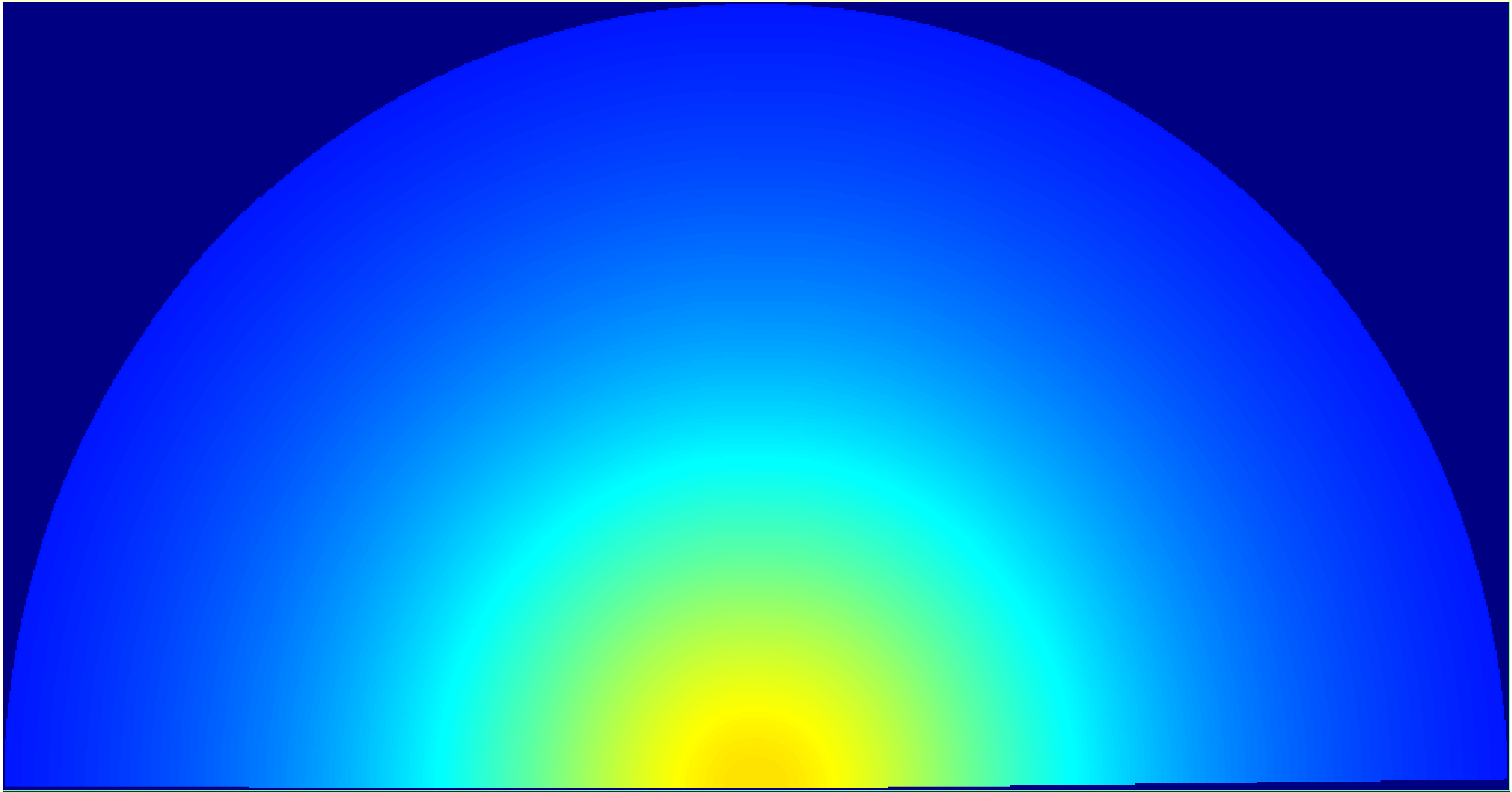
INTERGALACTIC CONVECTION



Cosmic-ray pressure divided by the plasma pressure and the rms turbulent velocity in model solutions for the Virgo Cluster (left), the Perseus Cluster (middle), and Abell 478 (right)

B.D.G.Chandran: AGN-driven Convection in Galaxy-Cluster Plasmas, *Astrophys.J.* **632**, 809 (2005)

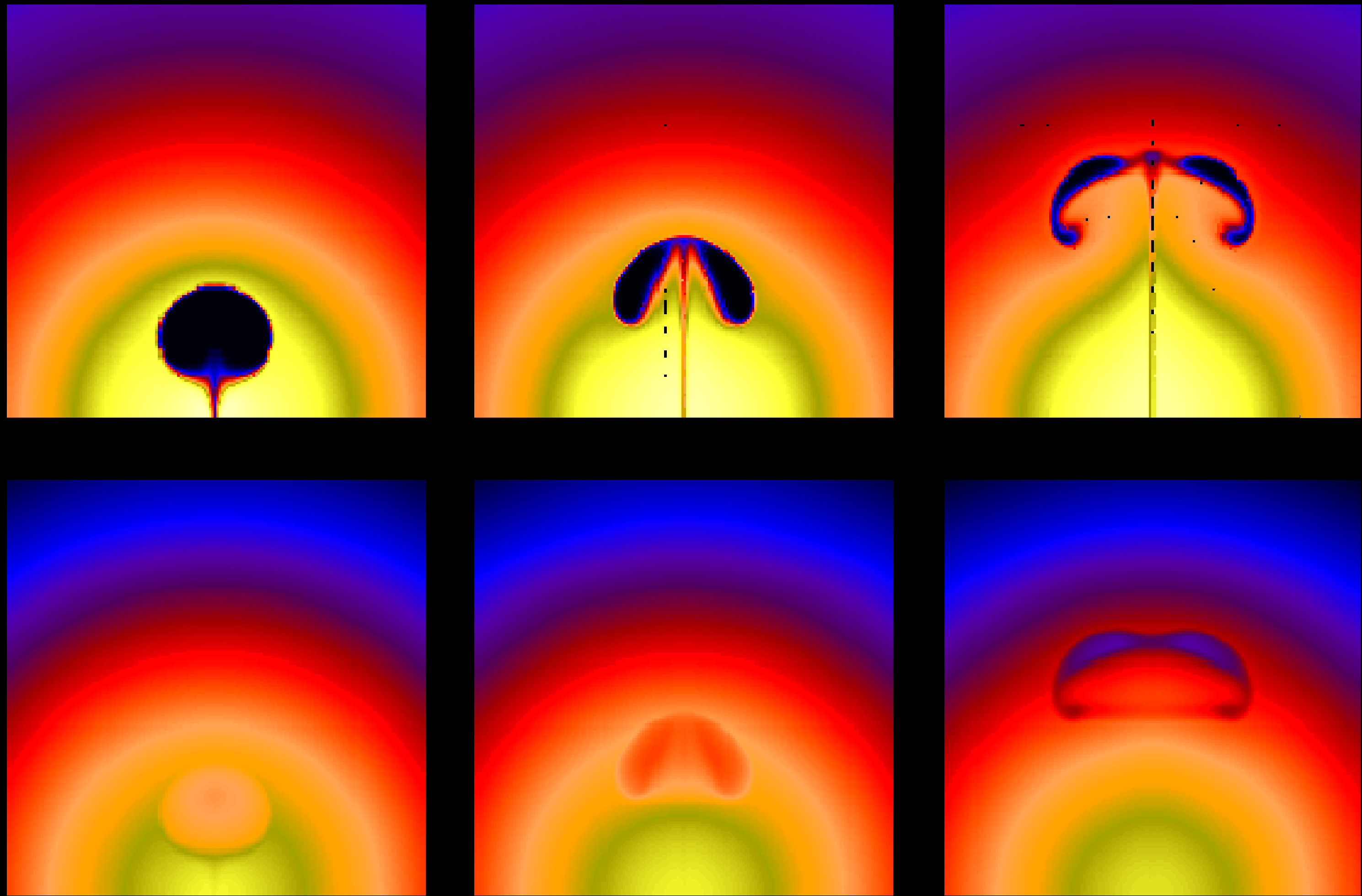
INTERGALACTIC CONVECTION



Density map (inner 254 kpc of simulation): 3-D hydrodynamic simulations of jetted active galaxies responding to accretion of an intracluster-medium atmosphere.

J.C.Vernaleo, C.S.Reynolds: AGN Feedback and Cooling Flows: Problems with Simple Hydrodynamical Models - Astrophys.J. ***645****, 83 (2006)*

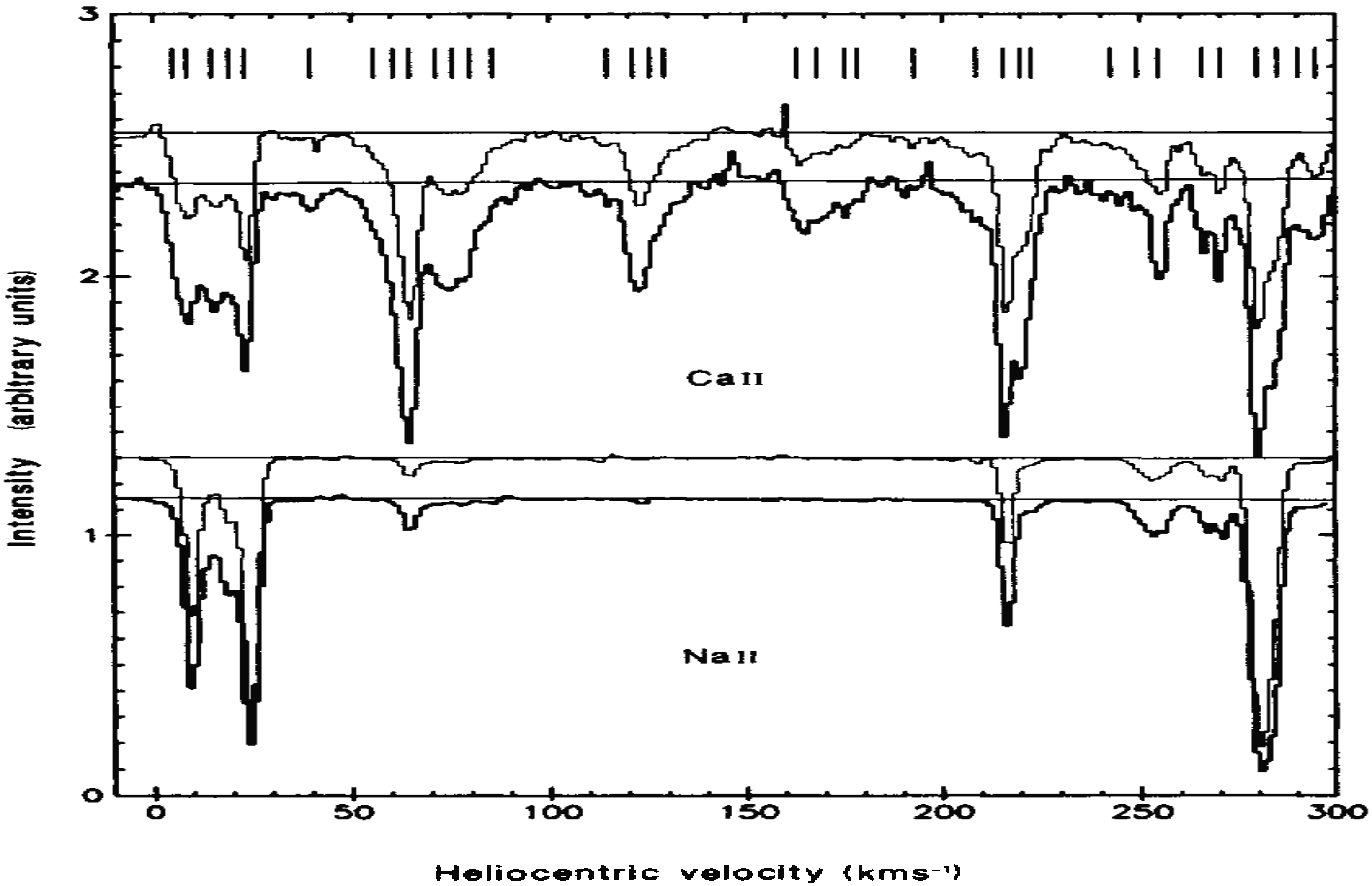
INTERGALACTIC CONVECTION



Density slices (top) and simulated X-ray brightness maps (bottom) at three times. Arrows indicate fluid velocity. Viscosity stabilizes the bubble, allowing a flattened buoyant "cap" to form. X-ray brightness and inferred velocity field in Per-A can be reproduced.

Reynolds et al.: Buoyant radio-lobes in a viscous intracluster medium, *MNRAS* **357**, 242 (2005)

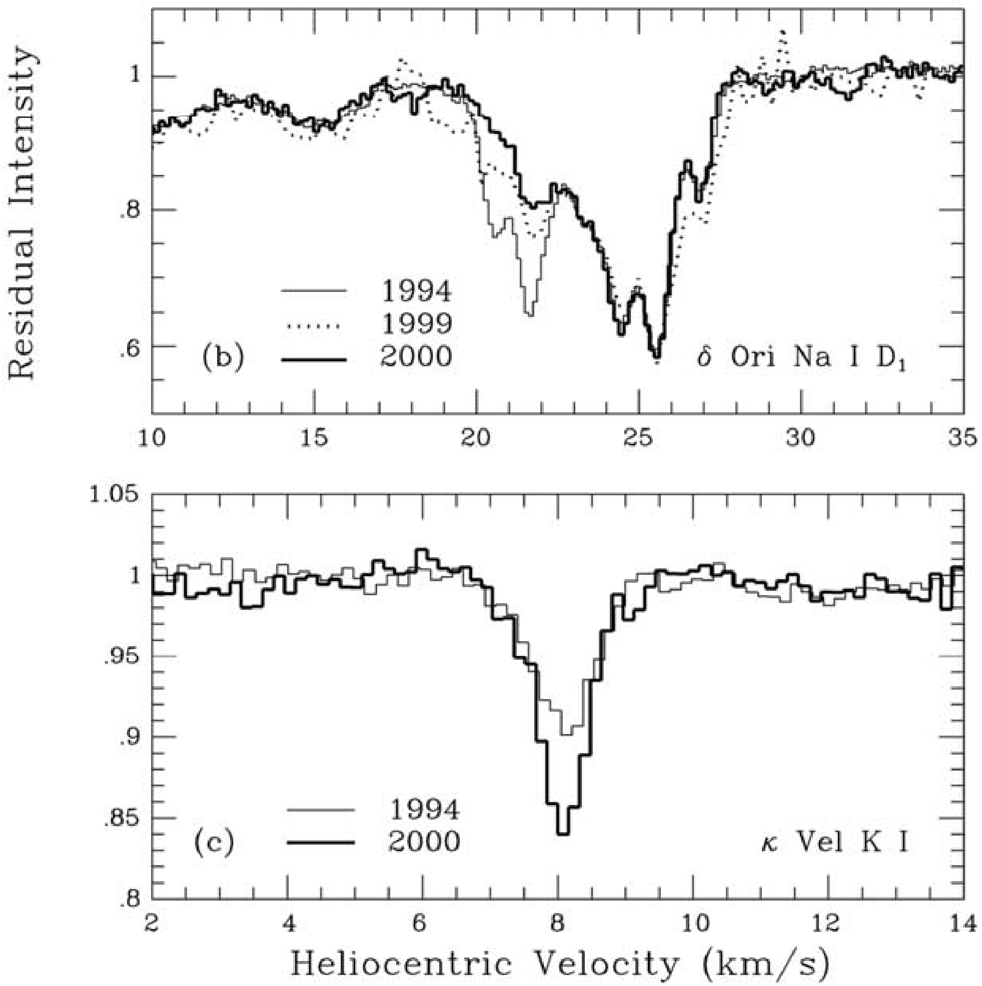
INTERGALACTIC SPECTRAL LINES



Ca II K & H lines (above); Na I D1 & D2 lines (below). 35 identified components are marked.

P.Andreani & A.Vidal-Madjar: The Intergalactic Medium towards Supernova 1987A, *Nature* **333**, 432 (1988)

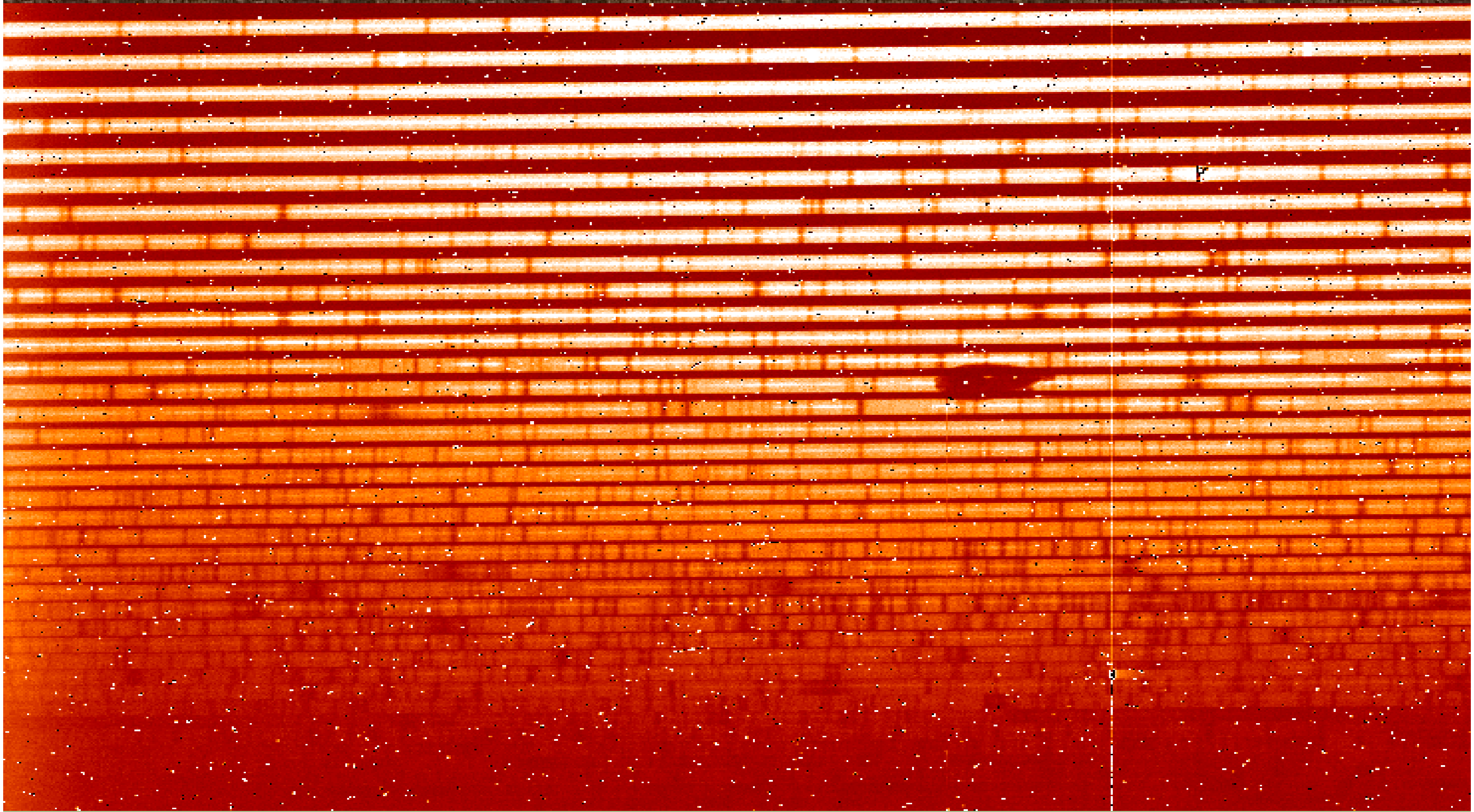
INTERSTELLAR LINE VARIABILITY



Variable interstellar lines, observed with AAT/UHRF, R = 940,000, also resolving the hyperfine structure of Na I D_1 (separation 1.08 km/s). Variation over years imply scales on 10-100 AU.

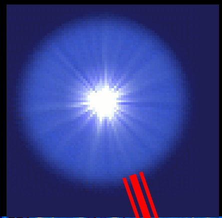
I.A.Crawford: Variable Interstellar Absorption Lines: A Brief Review, *Astrophys.Space Sci.* **285**, 661 (2003)

INTERGALACTIC SPECTRAL LINES

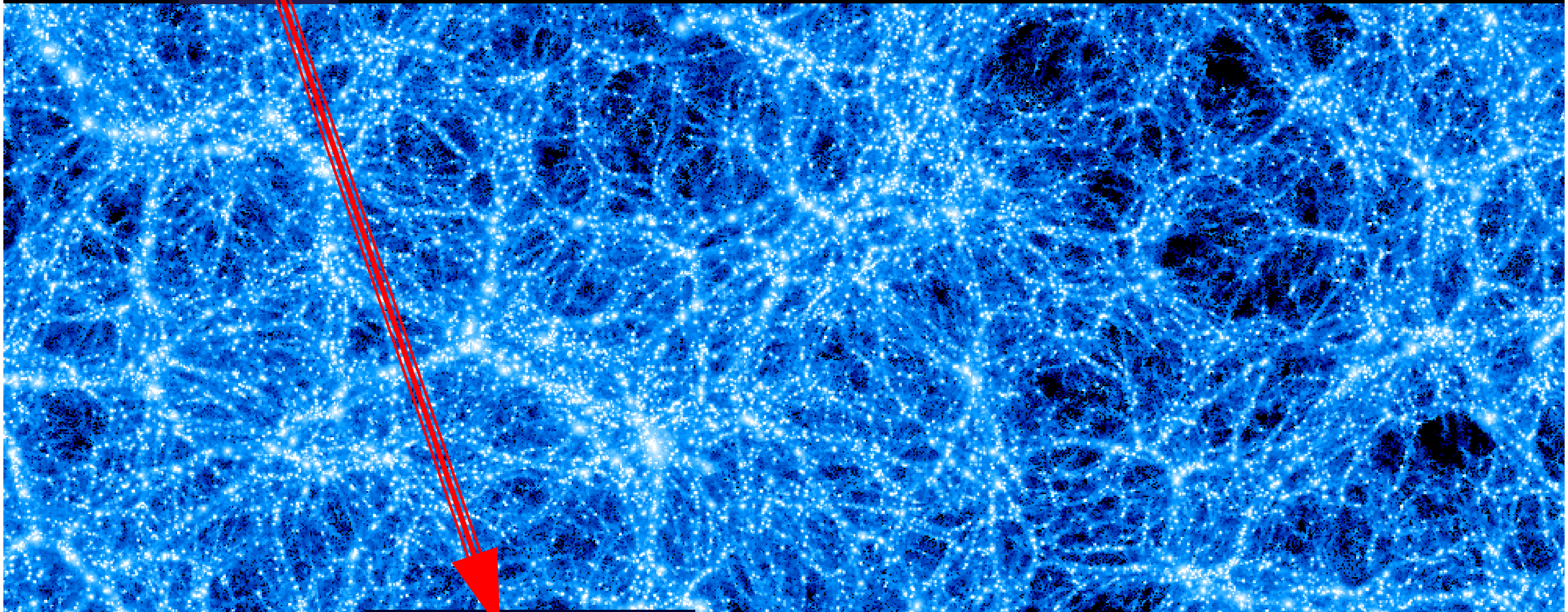


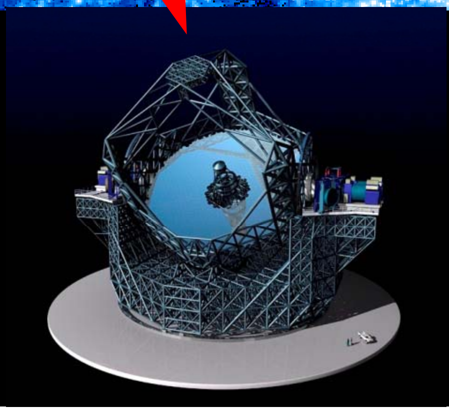
Spectra of $z > 2$ quasar, recorded with Keck *HIRES* spectrograph (A.S.Cowie, Univ.of Hawaii)

QSO



OBSERVING THE INTERGALACTIC MEDIUM





Cosmological 3-D hydrodynamic simulation (512^3 gas & 512^3 dark). Density map; each bright point is a group of galaxies evolved within a cold-dark-matter cosmology. Image width = 400 Mpc. (James Wadsley)

LINESHIFTS FROM INTERGALACTIC CONVECTION ?

INTERGALACTIC LINE ASYMMETRIES AND SHIFTS; ANALOGIES AND DIFFERENCES TO STELLAR CONVECTION:

- Plausible amount: 1 % of “turbulent” broadening, ≈ 1 km/s ?
- Lines closer to cluster center gravitationally more redshifted
- Need line synthesis from 3-D hydrodynamic models !
- Mapping depth structure from multiple line components
- Mapping lateral structure from secular time changes ?
- Need ESPRESSO- or CODEX-like instrumentation !

- **Line-formation physics must be understood before inferring possible variation of fine-structure or other “constants”!**

PRECISION SPECTROSCOPY IN ASTROPHYSICS !!

Despite recent progress, intergalactic, stellar (and even solar) spectra have many limitations, precluding, e.g., more detailed verification of 3-D hydrodynamic models. Needs for the next instrument generation include:

- *Absolute* wavelength calibration to 10 m/s
- Spectral resolving power reaching 1,000,000
- Photometric random-noise S/N > 3,000
- Space-based spectra in the visual of some stars, enabling calibration of telluric absorption
- Spectroscopy across resolved stellar surfaces

THE
END