SUMMARY LECTURE

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How to do this summary

I have found four models in the literature for doing conference summaries:

1. *The Literal Summary.*
   One summarizes all that has been presented, preferably interspersed with comments as "of particular interest was...".
2. *The Historical Perspective.*
   One places all (or some) presentations within a historical background, preferably implying that science progresses smoothly in well-planned, orderly fashion.
3. *The Future Perspective.*
   One points out the way to go, preferably in overly optimistic vein.
4. *The personal Impressions.*
   One concedes lack of wisdom to forego balanced summarizing, prefering to discuss primarily one's own interests.

Which model to choose here? Literal summarizing seems superfluous for the oral presentations. They are printed in the preceding pages, each is effectively a summary of work published elsewhere, and many have an author's summary already. It won't be useful to summarize them here once more, but some perspective may be worthwhile.

The poster presentations, on the other hand, are not printed in this volume, obeying current IAU (or Kluwer) policy. The policy may be wise since many posters describe work that will eventually be published in regular journals anyhow; nevertheless, it might be better to have one-page abstracts for these and somewhat more space (though refereed) for those that describe new instruments, new techniques and new methods not easily detailed in journal papers. Symposium proceedings would then possess the added flavour of showing who is doing what, where, and how. This is particular useful for PhD studies and students and for meetings with strong East-West overtones: probably, there were surprises here for you as there were for me in discovering research and researchers I was not aware of before.

There were more than 100 posters, many of them excellent; they should be summarized here. However, I have studied only a minority in detail and that holds probably for

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the majority of you as well, indicating that the non-reading of posters poses a larger problem than their non-publishing. We had two specific poster sessions plus the breaks; not enough, I fear, for full merit.

And then the video movies. These are neither printed nor posted, only shown; they are virtually impossible to summarize since they must be seen. Nevertheless, they have constituted a prime ingredient of this meeting; their showing showing that solar physics has entered the video clip era, not only in California where the Hollywood heritage is strongest, but also here at Kiev and elsewhere.

Video movies must be seen to be believed. The same holds for equations and diagrams, but the equations and the diagrams in these proceedings can be studied over and over whereas you and I have only a fleeting remembrance of what we thought (or were told) to see in the movies, and other readers of this volume have none. Movies may be a necessary step in the gleaning of useful information out of the complex manifold offered by the Sun, with the very important advantage of utilizing the superb pattern analysis capabilities of human vision, but ultimately, more formal descriptions are needed. Perhaps video storage will replace printed language, math and diagrams in future but until then, moviemakers must face the problem that showing a movie and publishing results are not the same thing at all.

So much for Summary Model 1. It leaves me with the task to summarize all poster and video presentations and to place these and the talks into perspective. Then, there are Summary Models 2–4. These are attractive too. Let me try them all on you.

How to divide the subject

The next question to be answered before I start summarizing is how to divide the subject. This is not obvious either; there are many possibilities:

1. Evolutionary: *past – present – future.*
   This is the standard order for any research article: first review the preceding work, then give the new stuff and end with predictions. The last item lacks too often. There have been classical examples of predictions in solar physics, as Parker's solar wind and Ulrich's p-modes, and we have seen a few gastronomical ones here too such as siphon flows, dynamo rolls and a missing piece of Napolitan cake, but in general solar physics seems a field in which the object produces unpredicted surprises.
2. Geographically: *West – Western Europe – Eastern Europe – East.*
   This division neglects our single participant from the southern hemisphere; permissably, I feel, since he has given his own Conference Summary already. What is wrong in this division is that it is linear whereas international astronomy runs in circles. The most interesting display of that fact were the Big Bear–Huairou movies shown by Sara Martin, the two video magnetographs working in tandem at an 11–hour difference to produce round-the-clock coverage of active regions. They demonstrate that not only helioseismology gains from worldwide observing networks. The LEST Foundation, already the most international of astronomical telescope-building consortia, might solve its location dilemma by building two Large Earth-based Solar Telescopes: Mauna Kea and La Palma are 9 hours apart. A Large Eastern Solar Telescope at (or preferably in) Lake Baikal would then complete the circle.

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3. Spectrally: *X-ray – UV – visual – IR – radio.*
The old division in techniques is less evident nowadays. This conference was primarily visual, mainly because that is where $\tau = 1$ in the photosphere and because the $\lambda = 1.6$ μm promise has not yet been fulfilled. X-ray means flares and radio means coronal instabilities which we have not discussed; the existence of this conference, the first IAU Symposium on the photosphere, signifies a come-back of optical studies. To quote the Conference Rationale:

> "The photosphere is the interface between the solar interior and the outside, and is the layer of the Sun that is best accessible to observations. The photosphere transforms the energy generated in the solar interior and emits it into the corona and the heliosphere. It makes all the radiative, dynamical, and magnetic processes that transfer solar energy into space available to our detailed observations".

Optical astronomy flourishes in general, and the solar and nighttime developments are strikingly similar. While the longest and the shortest waves exhibit the more spectacular phenomena more obviously, optical imaging, spectrometry, photometry and polarimetry often provide the diagnostics that are required to identify the underlying processes. The LEST and OSL projects are direct counterparts to ESO's VLT and to Space Telescope; SOHO's seismometers resemble HIPPARCOS in obtaining very basic information from a mathematical transformation of a year's data gathering.

In general, there is a transition from doing discoveries with newly-opened non-optical eyes to multispectral interpretation for which spatial resolution is an essential requirement. Spatial resolution is the next observational frontier, using satellite VLBI and optical interferometry from space. For solar physics too: the Abstract Book lists an interesting poster by Damé *et XVII al.* (which I couldn't find though, neither poster nor Damé) describing a Space Station proposal called SUN comprising a non-redundant 4-telescope array giving 10 km resolution on the Sun.

4. Height: *core – convection zone – photosphere – T-min region – chromosphere – corona.*
This meeting on the photosphere covered much additional depth by including convection and dynamos. It covered less additional height, presumably because the photosphere suffers more from below than from above, and in keeping with the current inward-looking trend crowned by helioseismology.

This trend does not imply that all things chromospheric and coronal are now fully understood. Although valuable concepts like loop scaling laws, magnetic helicity, electrodynamical circuits, Alfvén wave heating and magnetic reconnection scenarios have been developed, definitive outer-atmosphere success stories are yet lacking. Deeper down, the granulation does constitute a new and important solar physics success. It indicates, as stressed by Durrant in the preceding pages, that numerical simulation is the way to go and that this way may well lead upwards again, progressing to the larger MHD complexity and instability of the outer atmosphere. Here is a see-saw oscillation: from equating solar physics with the photosphere when optical spectrometry was its prime diagnostic, up to the outer atmosphere when radio and space astronomy came in, down to the surface and digging even deeper now with spatial, Fourier and numerical resolution, back up again in future, perhaps eventually down again to get the dynamo. Damped or unstable?

5. Scale: *granulation – mesogranulation – supergranulation – giant cell – torsion wave*
   or: *filigree – intranetwork field – network – active region – activity complex.*
   Different or the same? The most interesting aspect of these scale sequences is their existence—mesogranulation now firmly established from the SOUP cork movies, but giant cells still questionable. Tarbell mentioned that the magnetic structures seen in an active region display cell sizes ranging as a self-similar set, "straight from Mandelbrot's book". One might have expected such behaviour for all of the surface phenomena, the photosphere being made of turbulent gases, and Muller's claim that the smaller scales possess a Kolmogorov spectrum is still in discussion, but it isn't the case in general. Why?

   Nordlund stressed topology as the key item of the hydrodynamical simulations, the granular scales dominant just at the surface (though not for all other stars as shown by Dravins) but finger-like downdrafts repeatedly connecting in larger and larger patterns deeper down. Noticing simulation behaviour which resembles solar behaviour does in itself not explain the latter, but simulation behaviour is, in contrast to solar behaviour, fully understandable—although having a nice simulation is one thing and understanding it is quite another: simulations require extensive interpretation with clever diagnostics just as observations do. But they do permit physical experimentation, and so deliver a vital element to bridge the gap between noticing patterns and understanding them. The solar hydrodynamical scales are now clearly attackable; the magnetohydrodynamical ones should follow when massive parallelism brings the required orders of magnitude improvement in computer power.

   Topology is also a key item in understanding the larger-scale patterns of magnetic activity. Petrovay's suggestion that differential drag causes typical spot group morphologies asks for simulatory confirmation; more in general, the topological nature of the activity cycle remains the major constraint to dynamo theory, not to be lost out of sight while helioseismology delivers the internal rotation.

   Whether the dynamo itself requires full simulation eventually is yet unclear. Hoyng concluded that dynamo theory is now in a stage of reappraisal and renewed reconnoitring, leaving linear mean field theory to try out new ideas and possibilities in order to admit multiple periods and finite phase memories. Numerical experimentation will be worthwhile to study nonlinearities because the fields are dominated by motions and the motions are dominated by nonlinear advection terms. In particular, Ruzmaikin eloquently explained the globally stochastic nature of the solar MHD generator by putting a strange attractor in its phase space. Evaluation of that concept for any but the simplest nonlinear models requires much computation; however, such studies will be interesting even if it turns out in the end that the Sun works differently.

6. Period: *sec – min – hour – day – month – year – cycle.*
   Why are millisecond radio bursts and 22-year cycles harder to grasp then 5-minute oscillations and 10-minute granules? Perhaps because your attention span, listening now to me, is of minute duration too?

   One use of video techniques, for observations and simulations alike, is to transform solar time scales to our physiological ones to obtain better appreciation. We haven't seen the Greenwich sunspot data speeded up to a few minutes yet; it might prove interesting.

7. Observed features: *granule – exploding granule – vortex – BP – FBP – NBP – XRBP – K_{2v}BP – 160 nm BP – jet – grain – bomb – prominence – p-mode – ridge – torsional mode – butterfly – filigree – knot – pore – spot – umbra – umbral dot – penumbra – EFR – EAR – facula – plage – arch – rosette – ribbon – spicule, etc. etc.*
These and a host of others make up solar dermatology, with terminological fashions such as "grain" replacing "mottle" and "mottle" replacing "flocculus". These features are interesting to most of us, but many non-solar astronomers hate them since they wouldn't see them on their object if it has them which they hope it doesn't, regretting Galileo's announcement of blemishes on what should have remained a perfect sphere.

Of course, Dravins' computer granules and Saar's inferred magnetic regions make stars look more like the Sun and may make astronomers like the Sun more; nevertheless, solar morphological detail is not of obvious interest to others. That is quite understandable (who would be oenologist without savouring a vintage wine from time to time?) but leaves us with the need to explain why solar surface detail needs to be explained using expensive telescopes and supercomputers. Such defense is not yet required of galaxy baggers and other morphologists in our feature-prone science, though "clumpiness" being a current buzz word in galactic and extragalactic research implies that fine-scale structuring becomes important elsewhere too.

In the long run, solar physics gains from having to explain now already why studying structural detail is worthwhile, because that pressure forces more emphasis on physical understanding. That should make solar physics a path finder in the transition from phenomenological to process description and from scenario to self-consistent modelling. All fields of astrophysics have to make this transition at some time or other; it goes with the succession of the second observational revolution (the opening up of the electromagnetic spectrum to discover violent nonthermal behaviour) by the third, consisting of getting the resolution necessary to see what is going on. Solar physics is again at an advantage sitting so close to its scene: the physical scales at which many a solar process occurs are in reach.

8. Not-observed features: *fluxtubes – flux sheets – current sheets – magnetic loops – CO clouds – flare kernels – siphon flows – giant cells – circuits – mirror currents – proton beams – g-modes – oblateness, etc. etc.*
Again a host of phenomena, but invented rather than observed. That makes them much more interesting! For example, granules may be a current breakthrough but fluxtubes attract more attention. They are much more atractive to theorize on, presenting an elegant concept with pleasant geometry offering tractability to many a specialist in hydrodynamics, radiative transfer and magnetohydrodynamics, and they are also easily sold to non-solar theoretical astrophysics for use in other objects were they are also not observed. Accretion disks, for example, now produce tube and loop and circuit papers (typically by former solar tube and loop and circuit persons) but no granule or spicule papers.

The reason is, of course, that tubes, loops and circuits are modelling concepts rather than morphological features. Concepts have wider applicability the more abstract they are and the less constrained they are by observations; perhaps it is unfortunate that Solanki and Keller produce such detailed empirical fluxtube models from FTS observations now, and perhaps the attractivity of fluxtubes will wane when the properties of actual magnetic field concentrations will be further constrained by LEST and OSL and SUN. On the other hand, the fluxtube concept does produce firm and detailed predictions open for observational verification, such as Schüssler's illumination heating; it will be nice to find out whether and how the tiny strong-field fluxtubes do all the things they are currently supposed to do, such as heating the corona and, perhaps, the chromosphere.

One thing they appear to do indeed is exist. Tarbell's high-resolution magnetograms dissolve the plage in an active region into unipolar clusters of small grains, arranged in cells of many sizes. The pixels are yet bigger than the modeller's tubes, but the overall graininess is unmistakable.

One thing they appear not to do is to sit in bipolar clusters in quiet-sun cell interiors and parade unresolvedly as weak polarization. I hesitated whether to list *intranetwork fields* under the "observed features" or not, but now Sara Martin's movie shows patches of unipolar intranetwork field steadily travelling to the network boundaries, the coherency of this motion proving their existence at least to me. In the margin of Tarbell's magnetograms there are quiet cell interiors which do not show anything strongly polarized. These observations together with those from Kitt Peak indicate that intranetwork fields do exist and consist primarily of intrinsically weak fields arranged in patches measuring a few arcseconds, not as strong thin tubes. This issue is of obvious importance, as is the question whether there are areas in the photosphere truly without magnetic field.

So now we have already an eightfold way of dividing our subject matter. And there are more: *Sun – solar-like stars – non-solar-like stars – non-stars* for example, or *analytical theory – numerical theory – theoretical interpretation – observational interpretation – observation – instrumentation*, and others.

Which division to follow here? I take the easy way out; realising that the scientific organisers of this meeting have had the same problem already, it seems easiest to copy their solution by just following the order of the Abstract Book[1]. That implies there are 181 presentations to summarize, beginning with the invited review of Avrett and ending with the poster of Bonaccini *et al.* Quite a list, let me begin quickly.

1.1 Avrett's review

Avrett started his review by showing his familar diagram that specifies the height of formation of various spectral features throughout the solar atmosphere. That diagram is often used for openers, but usually only to show where one's diagnostic comes from before one discards one-dimensional modelling to proceed with inhomogeneous explanations of observed or not-observed features. In this era of realistic 3D simulation, 1D standard modelling drops out of fashion. Over half a century of plane-parallel explanations of the solar spectrum is seen as enough of a good thing, spectroscopy not being regarded as a proper science in its own anymore but rather as a necessary tool. Personally, I do not agree to that view at all; in general, we shouldn't forget that here lies a strong link with stellar astrophysics—the oldest and strongest solar-stellar connection.

[1] E.A. Gurtovenko (Editor), 1989, *Solar Photosphere: Structure, Convection and Magnetic Fields*, Naukova Dumka, Kiev, 65 kopecks (or 3 abstracts per kopeck; a bargain compared with this volume)

Solar-stellar perspective

Let us digress to solar-stellar connections for a moment. There are more than one:

1. *Stellar abundance determination.*
   The oldest one, dating back to the time in which the whole of astrophysics consisted primarily of solar spectrum analysis. Unsöld's 1955 bible[2] is still the basis of what we now call the classical theory of stellar atmospheres. Although Kurucz and Gustafsson's Uppsala group have put this classical edifice on modern computer footing, it still rests on the assumptions of spherical symmetry, hydrostatic equilibrium, radiative or convective equilibrium, and usually LTE notwithstanding Mihalas' book. In the meantime, solar physics has lost interest in the constitution of its matter (some years ago, Zwaan and I terminated a 50-year Utrecht tradition with the ultimate paper on the solar curve of growth), but stellar abundance determination remains a large field, alive and well, in which many astrophysicists use the solar spectrum for guidance. It behooves us to supply them with the information they require; the solar group here in Kiev sets a good example. (Another good example is the Kurucz *et al.* NSO Atlas Nr. 1; so would, if they existed, Nrs. 2 and higher be.)
2. *Stellar activity.*
   Cool-star magnetic activity constitutes what is termed "THE solar-stellar connection" at the moment. It started long ago with the work of O.C. Wilson, Bappu and Sivaraman, but it became a hot topic only after EINSTEIN demonstrated that the topic is hot indeed. In the meantime the amazing sharpness of the flux-flux relations has shown that dynamos work in similar fashion in different stars, and pioneers as Schrijver have returned to the Sun to find out how. Some stars deviate, though. There are also stellar flares which differ much from solar flares, but not enough not to have another connection.
3. *Stellar convection.*
   Dravins' presentation of the Dravins–Nordlund stellar granulation simulations gave ample evidence of another blossoming connection. It started with Dravins' and Gray's bisector studies, and has progressed very quickly to the desirable stage in which observations and simulations are compared, and that, also desirable, by various groups (including the Kiev one) using different approaches and different numerical methods. Who would have predicted that the smallest surface features on unresolved stars, the star itself smaller than a solar granule on our sky, would be the first to reach this happy state?
4. *Stellar interiors.*
   Helioseismology presents another obvious solar-stellar connection in the making. The GONG and SOHO projects are bound to produce results of interest to stellar evolutionaries; asteroseismology does not seem too farfetched. Again—who would have predicted such rich diagnostics of the invisible layers so far below the surface? This is not a yes/no matter of a few missing neutrinos: the oscillation spectrum contains thousands of lines with measurable frequencies, splittings and amplitudes, and hope-

[2] unfortunately like Luther's in German

fully g-modes as well.

5. *Stellar dynamos.*
   Elsewhere I have pessimistically predicted that helioseismology may lead to another solar physics bout of ghettosis by producing too much structural detail again, this time not on the outer but on the inner surface of the convection zone. Let me be optimistic here. The activity connection shows dynamos working in other cool stars. Rotational modulation, circular and linear polarization, asteroseismology, bisector monitoring and other stellar measurement techniques may well deliver the evidence necessary to constrain possible realizations of dynamos to realistic ones. The solar dynamo is perhaps too deep to fathom; knowing more about others will help.

Solar perspective

Returning to Avrett's review, it is clear that all 1D spectrum interpretation is of direct interest to our stellar colleagues. It is important for them to know whether 1D stratification, hydrostatic equilibrium, radiative equilibrium, LTE and opacity distribution functions are acceptable shortcuts, and that can be checked more easily for the Sun than elsewhere.

Amazingly, these shortcuts seem to become more and more acceptable for the solar photosphere. Even NLTE has gone away—the recent change of the upper photosphere in the Harvard models from the cool HSRA dip back to the gentle slope of the classical Holweger-Müller model largely reduces the NLTE departures found before. The change also led Ayres to move his cool CO clouds to larger height, above the temperature minimum where they do not bother anyone anymore. We now have an 1D upper photosphere in hydrostatic equilibrium and nearly in radiative equilibrium, which explains the continuum pretty well from the near-UV to the IR, which reproduces the wings of the Ca II H & K lines and which fits most visual lines in classical manner assuming LTE, as is clear from the Kiev fits to 2000 lines reported by Gurtovenko.

At the same time, Nordlund's simulations indicate that the spatial and temporal variations should be very large throughout the photosphere. Are the simulations wrong in producing too much inhomogeneity? Or is the averaging such that, fortuitously, the spatially and temporally averaged spectrum can well be described with a 1D atmosphere even while large deviations actually occur?

I don't know the answer to this important question, but I conclude that, either way, the photosphere is nice to abundance determiners. This leads me to formulate a new principle here. Let me call it the "Principle of Solar Communicativity" although I won't object if you call it "Rutten's Law" henceforth[3]. Actually, it consists of two principles:

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[3] although R.G.M. Rutten may object. Yes, there are two of us. He is René and I am Rob.

Detail Is Beautiful

Detail Must Be Optimally Displayed

A thought experiment will clarify its meaning. Imagine a solar terrestrial physicist, sitting on a cool CO cloud above the photosphere. (Sunspots are also suitable locations for organic chemistry, but they live too briefly to produce DNA molecules whereas the CO clouds have been in the literature for years already and don't seem to go away at all.) She has her telescope trained on a structure on the third planet which, in its center, consists of rectangular granules and dark intergranular lanes. The lanes are bordered at regular intervals by the socalled "intergranular features" for which the following model has been derived: a globular infrared-emitting cloud, which shows a half-orbit modulation from optical thick to optical thin, crowns a vertical tube which is present during the full orbit and which seems firmly anchored in the co-rotating black matter at the $\tau = 1$ level. Our physicist now studies a peculiar fine structure in the IR globule. It appears and disappears in a single pulse during a short segment of each orbit. It consists of clumps which seem randomly distributed over the globule. Each clump is small and possesses a high vertical wavenumber signature. She wonders what they are.

We know. They are the blossoms of the chestnut trees that border the streets here in Kiev. The chestnuts make Kiev one of the most beautiful cities on earth. We know that they are beautiful. We appreciate their beauty especially when they show blossomy detail, as they do now. And we know and appreciate that they have been carefully arranged for optimal display. We take it for granted that a plane-parallel city would not have the beauty of a chestnut-lined one; we savour such morphological surface detail without objection; we love adorning simple structures with surface detail to keep ourselves happy and solar terrestrial physicists as well.

The Sun does exactly the same. Clear proof is its singing. Why should the Sun excite tens of thousands of modes in a beautiful harmonic chord if not for the beauty of it, and to keep terrestrial solar physicists happy? Another proof is its magnetic field. To quote Leighton, without magnetic field the Sun would be as boring as the nighttime astronomers believe it is. Configured in strong-field tubes rather than a weak-field dipole, that field is clearly designed to optimize the amount of beautiful detail displayed to terrestrial astrophysicists.

In fact, the Principle of Solar Communicativity underlies all that the Sun displays to us. A short list of solar terrestrial action items illustrates the solar perspective:

- emit far too few neutrino's, just enough to prove that their detector works;
- sing loudly, to show them internal structure;
- show interesting hydrodynamics with minimal interference from magnetic fields;
- show surface structures at different scales that map different depths;
- have beauty spots;
- have a 1.6 μm opacity dip for Koutchmy;
- have tubes for MHD physicists;
- have loops for plasma physicists;
- have prominences for radiative-transfer-in-slabs specialists;

The Principle of Solar Communicativity. There is a benign presence in the Sun gracefully offering magnetostatic fluxtubes to terrestrial astrophysicists to grasp and to hold on to for dear life—illustration by M.P. Ryutova.

- have flares big enough to be spectacular but small enough for safety;
- hide a dynamo as a real brain teaser;
- vary everything on time scales from TV-rates to career lengths;
- have a cycle in step with NASA's planning cycle;
- have a supermaximum when funding is poor, to get on Time Magazine;
- obey Parker's wind theory;
- have a moon for eclipses, such that they occur in interesting faraway places;
- attract comets for tail chasing.

In particular, for Avrett the Principle of Solar Communicativity implies that the Sun cooperates by emitting continua that are very well modellable: the Sun is not a box of Pandora; its genes beget continuaty.

1.2 Title's review

The second entry in the Abstract Book is the invited review by Title. How does the Principle of Solar Communicativity apply to him and his LPARL coworkers, measuring Fe I 6303 with SOUP at the superb vacuum refractor of the Swedish Solar Observatory on La Palma? Let us again do a thought experiment. Imagine yourself to be a bunch of iron atoms somewhere in the photosphere, all set to jump the 6303 Å transition. You are aware there is quite a variety of rather quaint characters interested in you; how do you optimally provide beautiful detail to:

- oscillator strengtheners and plane-parallel layer layers;
- NLTE radiative transfreaks and magneto-optical affectionists;
- k-ω plodders and helioseismologists;
- granulation morphologists and bisectarians;
- convective blueshifters and limbshifters;
- compressible and incomprehensible 2D and 3D simulators;
- fluxtube FTS ETH highschoolers and fluxtube MHD PHD students;
- magnetic field pattern recognizers and self-similar setters;
- activity cyclists and torsional surfers?

All these terrestrial solar physicists are going to study the iron line that you are about to cause, and each of them will use that line in his own particular way for his own particular purpose. It is your task to provide all of them with the beautiful detail that each of them requires to write an interesting paper on his subject, not once but over and over again.

That task is not easy. Nevertheless, the Sun accomplishes it. All these people are here and have new results to show and tell. That implies that any solar signal is a mixture containing diagnostics for all of these diverse interests simultaneously. Title said in his introduction:

> "The Sun is a very complicated structure—it has turbulent convection, a whole family of wave motions, magnetic structures *etc.* It is easy to fall into the trap of looking only at those aspects that you can model simplifiedly"

which is an essential point to be taken very seriously, by observers and theoreticians alike.

Solar physics may be part of physics but in many respects it resembles biology, being less reductionist than physics. Our object, the solar photosphere, obeys a rather simple set of basic equations and offers nothing special to those who desire to reduce nature to a few fields and particles; its interest rather lies in the beautiful detail that nature is able to generate out of those simple equations, much richer than Eddington's "cloud-bound physicist" might ever have predicted. To study that rich detail, we cannot stick a thermometer in the photosphere and measure the isolated effect of a single controlled parameter change; we have to take our object as it is, holistically, with only limited experimentation possible through simulation.

Thus, Title's warning must be heeded. Interpreting solar surface phenomena is complicated because the Sun tries to satisfy all of us at the same time. Your message is there, but there are many more messages on the same information carrier; clear reception requires sharp listening to pick your message out of the noise made by the others.

The problem becomes larger when the observing is better. The more data, the less *a priori* selection towards a preconceived idea. This is particularly clear in the LPARL observations. In one of last year's runs the SOUP was used to obtain images of 512×512 pixels, cycling through the Fe I 6303 magnetic line in left and right circular polarization, the continuum and the Ni I 6768 velocity line in 4 wavelengths, one cycle per 50 sec for 2.5 hours, over 2 Gigabyte in total. It takes sophisticated processing to transform such data into Dopplergrams, magnetograms, continuum images and line-center images: gain and dark corrections, reordering, derotation, reregistration, destretching *etc.*, 30 hours computer time per sequence. And that is only the beginning. The previous SOUP analyses have shown how cleverly such data sets must be attacked to distill interesting information: 3D Fourier filtering, local correlation tracking and cork sprinklers were required to isolate the flow fields discussed by Title. Future data sets will be even more comprehensive; the poster by Bonaccini *et al.* describes instrumentation for 2D imaging in 41 wavelengths, effectively giving 2D spectrometry.

Clearly, the Principle of Solar Communicativity has a corollary: there is so much beautiful detail optimally displayed by the Sun that much ingenuity is required for full appreciation. We need new ways of analysing data, not only video clips but also new display formats, analysing techniques (as the multivariate approach in the poster by Caccin *et al.*) and cork-like inventions.

A new display format was displayed by Deubner. Not content with having put the ridges in the k-ω diagram already, he now changed that diagram into a 3D one by adding phase, specifying power per spatial and temporal Fourier component per phase shift between intensity and velocity, both per line and between lines formed at different heights. He so produced clear evidence of gravity waves and new k-ω phase ridges; there is much to be learned from such phase diagrams and from corresponding predictions by Marmolino and Severino (including their missing piece of phase cake).

This indicates that the new LPARL data may fruitfully be analysed for intensity and velocity phase behaviour, and that 4D rather than 3D Fourier analysis may be the next trick to try. The same suggestion applies to simulation results. In Deubner's words[4]:

> "To our knowledge there are no theoretical predictions available yet about phase relations in that brackish regime between fresh convection and the overshoot layers salted with all kinds of waves. We strongly encourage our

[4]F.-L. Deubner, 1989, *Astron. Astrophys.* **216**, 259

colleagues working on three-dimensional simulation of compressible convection to extract the temporal phase information from their models, since we feel that it bears extraordinary diagnostic potential."

There is another lesson in the paper from which this quote was taken: it re-analyzed data taken 17 years ago. Is it not worthwhile to sprinkle corks on digitized older data, such as the beautiful balloon sequences that were taken by Karpinsky *et al.* already before the Spectrostratoscope, Pic du Midi and La Palma high-resolution imaging? That might recover the supergranulation, too large to fit on a CCD.

2. Historical perspective

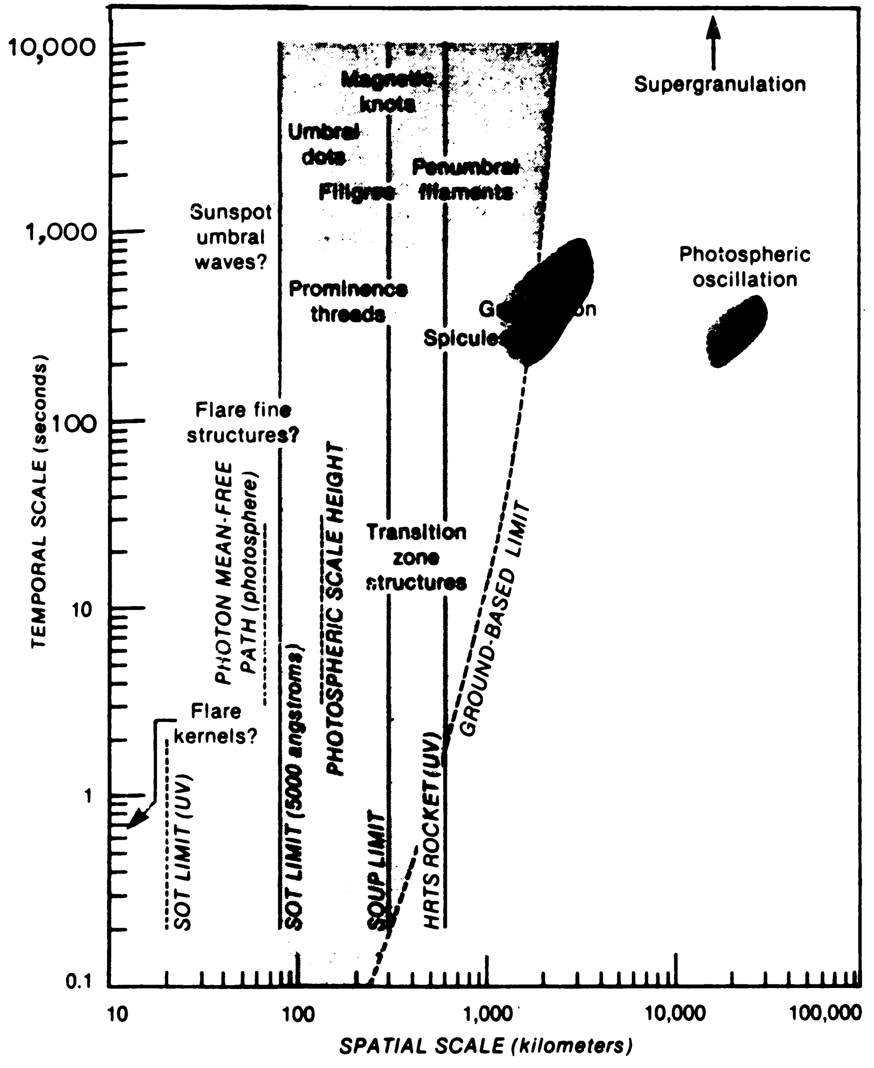
I am running out of summary spacetime, speaking time and printing space. Further literal summarizing of all the remaining 179 contributions in Abstract Book order is out of the question; let me apologize to all of you whom I won't mention (and also to those whom I did mention), and skip all other presentations by jumping to Summary Model 2.

Our history is summarized in this list of solar IAU Symposia:

Nr	Year, Place & Title
6	1956 Stockholm — *Electromagnetic Phenomena in Cosmical Physics*
9	1958 Paris — *Paris Symposium on Radio Astronomy*
12	1960 Varenna — *Aerodynamic Phenomena in Stellar Atmospheres*
16	1961 Cloudcroft — *The Solar Corona*
22	1963 München — *Stellar and Solar Magnetic Fields*
35	1967 Budapest — *Structure and Development of Solar Active Regions*
43	1970 Paris — *Solar Magnetic Fields*
56	1973 Surfers Paradise — *Chromospheric Fine Structure*
57	1973 Surfers Paradise — *Coronal Disturbances*
71	1975 Praha — *Basic Mechanisms of Solar Activity*
86	1979 Maryland — *Radiophysics of the Sun*
91	1979 Cambridge Mass. — *Solar and Interplanetary Dynamics*
102	1982 Zürich — *Solar and Stellar Magnetic Fields*
123	1986 Aarhus — *Advances in Helio- and Asteroseismology*
138	1989 Kiev — *Solar Photosphere: Structure, Convection and Magnetic Fields*

At first solar physics was quite cosmical, in keeping with the IAU's roots in the International Union for Cooperation in Solar Research. Later, solar physics became more restrictive. Numbers 22, 43 and 102 indicate that we will have a definitive meeting called *Stellar Magnetic Fields* in the year 2000; the last one on that topic because it will exhaust its title possibilities.

But while we discuss solar and/or stellar magnetic fields throughout the years, the world around us changes. Here in Kiev, with this Symposium embedded between the second and the final rounds of the election of a Kiev representative to the new USSR Congress, that change is outspoken. Magnetic-field discussing solar physicists play only a minor role in world politics, even if they write letters to superpower presidents as we have done; nevertheless, they belong to an exceptionally internationally-oriented community in which cooperation across time zones and borders is the rule and not an exception.



10,000
1,000
100
10
1
0.1
TEMPORAL SCALE (seconds)
10
100
1,000
10,000
100,000
SPATIAL SCALE (kilometers)
Supergranulation
Magnetic knots
Umbral dots
Penumbral filaments
Filigree
Sunspot umbral waves?
Photospheric oscillation
Prominence threads
Spicules
Flare fine structures?
PHOTON MEAN-FREE PATH (photosphere)
PHOTOSPHERIC SCALE HEIGHT
Transition zone structures
GROUND-BASED LIMIT
Flare kernels?
SOT LIMIT (UV)
SOT LIMIT (5000 angstroms)
SOUP LIMIT
HRTS ROCKET (UV)

The spirit of frankness, mutual respect and constructive cooperation in which we run our business of understanding the physics which the Sun tries to teach us sets an example which we ourselves do not, perhaps, fully appreciate but which has important value, especially in this city where the awareness of the dangers embedded in physical knowledge is larger than anywhere else. In that historical perspective, the timing and location of this meeting have been significant. I hope that, looking back from the future, we will be happy to mark it as a turning point within and outside solar physics.

3. Future perspective

I base my predictions for the future on a graph made by Dunn, Harvey and Milkey over a decade ago to sell the SOT project which then became the HRSO project which then became the OSL project, and which we will eagerly await for years yet to come. This long delay is very unfortunate. NASA's Orbiting Solar Laboratory is for solar physics what Space Telescope is for nighttime astronomy: not just another space project to be advertised overly loudly but the required next step for nearly all interests in the whole field, a general purpose observatory located where it belongs, above the atmosphere. It should have flown its maidenflight long ago. In keeping with the letter sent from this meeting to Presidents Bush and Gorbachev I note that a very small fraction of the funds misspent on space militarization would have sufficed for space solarization.

However, solar physics does not compete directly with the military for funds but rather with non-solar colleagues who do not regard solar detail as beautiful yet; we must teach that principle by displaying what we do. There is enough to show, but the showing can be better. To quote Beckers[5], who recently had a look at granulation after leaving solar physics a decade ago: "The story of this exciting research should be made very visible so that our other astronomy colleagues can enjoy it as well".

Apart from the SOT-to-OSL name change, there are other changes necessary in the graph that do mark significant progress. The groundbased limit should be shifted and tilted a bit. Its lower part shifts to the left thanks to the good seeing of the Canary Islands. The shift is larger higher up because active mirroring, image grabbing, correlation tracking and destretching result in much longer high-quality time series, connecting periods of good seeing over hours rather than minutes. Hopefully, the realisation of a LEST with adaptive optics will produce a yet larger leftward shift all over. The graph must also be extended upwards since the Big Bear–Huairou magnetographs have already produced uninterrupted movies of over seventy hours. Let us hope there is no turning point now in this cooperation. Finally, there is a new feature to be entered: mesogranulation, at a few thousand kilometers and a few thousand seconds firmly to the right of the groundbased limit.

The area to the right marks the domain where we should see things properly already—and therefore understand them too. That is not altogether true because there are only two resolutions plotted here; temporal Fourier resolution, for example, is missing. Nevertheless, the photospheric oscillation is indeed understood; that was the first success story of modern solar physics. The granulation breakthrough also obeys this graph although

[5] J.M. Beckers, 1989, in R.J. Rutten and G. Severino (Eds.): *Solar and Stellar Granulation*, NATO ASI C-263, p. 613, Kluwer, Dordrecht

its essential resolution (simulation computer resources) is also missing.

Any graduate student can now see what subject he should choose for thesis project, depending on whether he prefers quick success or to spend a long career on a single problem. Mesogranulation is the next to go, then follow penumbrae and spicules (amazingly so), after that transition zone structures, and only then come the tiny strong-field concentrations (knots and filigree) of interest to tube and sheet modellers. This graph indicates that it will take some time before these are properly observed, but that may work out well; neutron stars also waited thirty years after their invention before showing themselves, giving time for thought. Perhaps such maturing is part of the Principle too.

4. Personal Impressions

I have found this a very interesting and inspiring conference. Speaking for the other participants as well, I gratefully thank the organisers for taking on and completing so successfully a task that undoubtedly must have brought much more work and problem solving than we can guess and, probably, than they themselves envisaged. Let me assure them that their work was worthwhile.

I sincerely believe that we are at a turning point in solar physics, progressing from riddles to answers. That belief was strengthened here, thanks to the excellent scientific program. We may also be at a turning point in international relationships. This conference, the first solar IAU Symposium in the USSR, exhibited a strong and lively spirit of unrestrained international exchange and cooperation, to which the splendid social program contributed substantially. On behalf of all participants, many thanks for the science and the hospitality presented to us!