MAX-PLANCK-GESELLSCHAFT

Achim Gandorfer
Max Planck Institute for Solar System Research
on behalf of the Sunrise Team

Solar-C science meeting, Takayama, Nov.2013

Kiepenheuer-Institut für Sonnenphysik

SOLAR AND ASTROPHYSICS LAB


Bild hochgeladen von
bei www.ciao.de

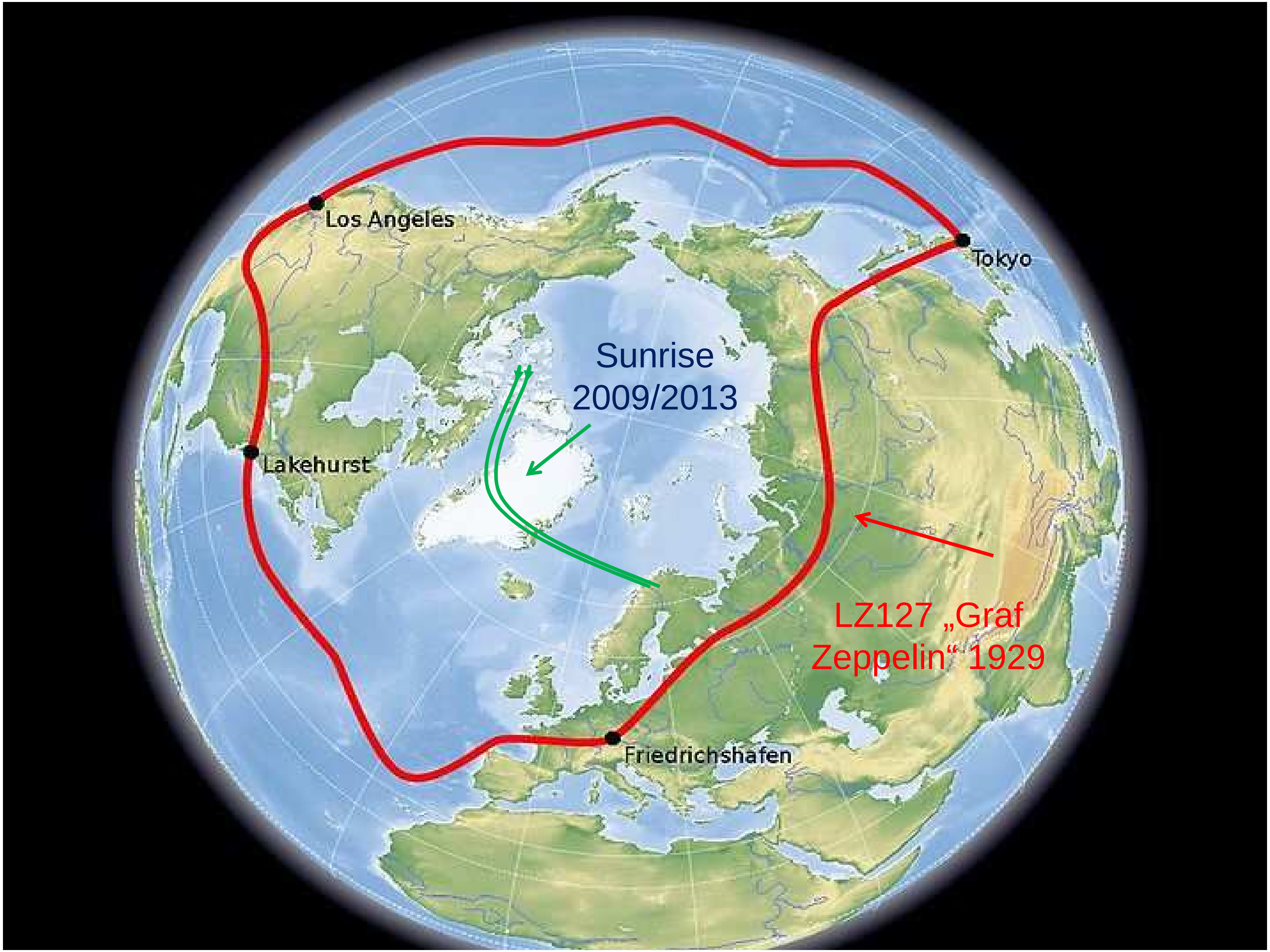
Flying from Germany to Japan 1929

Launch of Sunrise in ESRANGE, Sweden

8th June 2009


Asociación AstroInnova - Proyecto Daedalus
Sunrise II Mission
IRIS - Cameras 1, 2 & 3


Proyecto



Los Angeles
Tokyo
Lakehurst
Friedrichshafen
Sunrise
2009/2013
LZ127 „Graf
Zeppelin“ 1929

Who is SUNRISE?

S.K. Solanki (PI),
P.Barthol (PM),
A. Gandorfer (PS),
Max-Planck-Institut für Sonnensystemforschung, Katlenburg-Lindau

M. Knölker (Co-I)
High Altitude Observatory, Boulder, USA

V. Martínez-Pillet (Co-I)
Instituto de Astrofísica de Canarias, Teneriffa, Spanien und das IMaX Team

W. Schmidt (Co-I)
Kiepenheuer Institut für Sonnenphysik, Freiburg i. Br.

A.M. Title (Co-I)
Lockheed-Martin Solar and Astrophysics Laboratory, Palo Alto, USA

What is Sunrise?

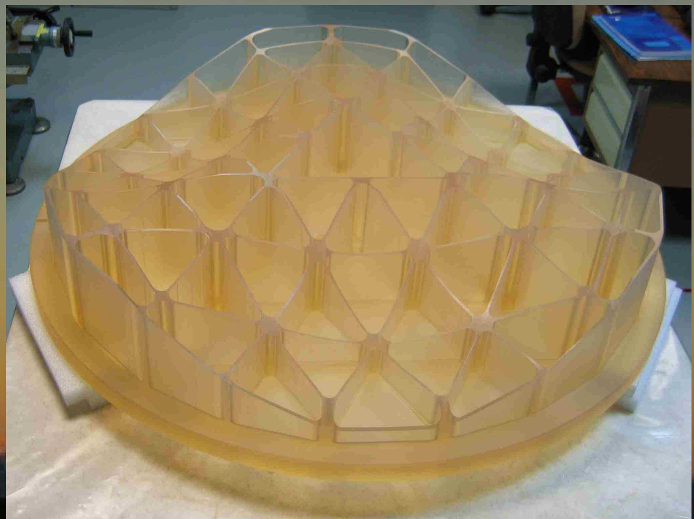
Sunrise

- is a 1-m aperture telescope (biggest solar telescope to leave the ground)
- operates in the stratosphere
- carries two science instruments working in UV and visible
- to provide UV images, Doppler maps, and vectormagnetograms of unprecedented quality

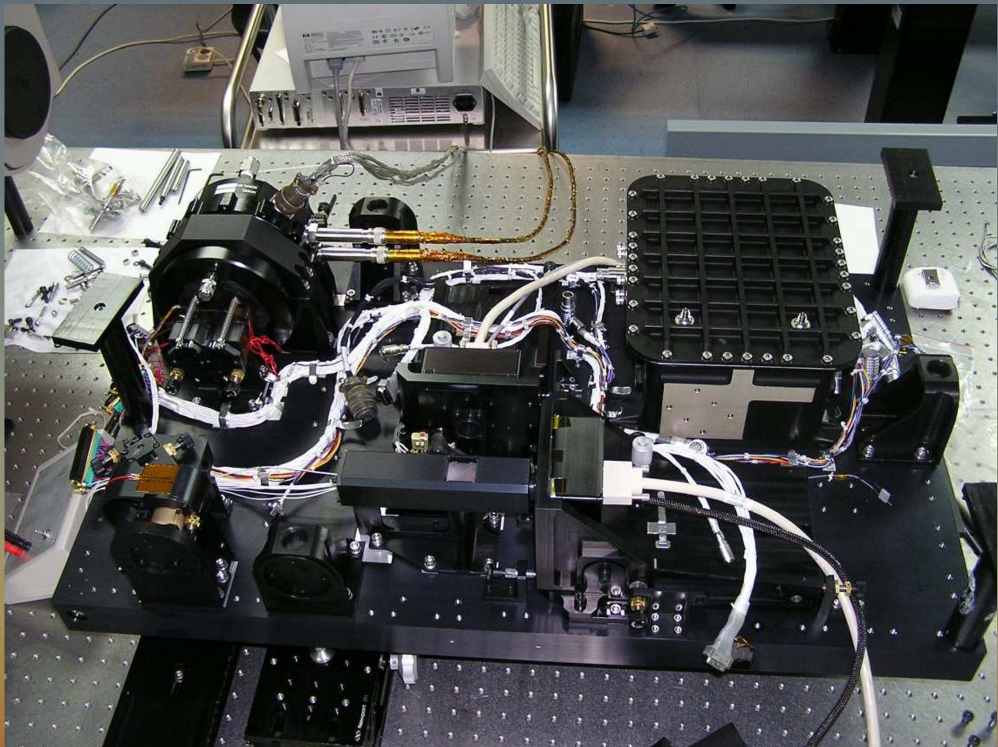
Barthol et al., 2011, Sol. Phys. 268,1

Sunrise balloon-borne solar observatory

- Gregory telescope, 1-m aperture (biggest solar telescope to leave the ground) (Barthol et al. 2010)
- 2 science instruments:
  - SUFI, UV filter imager (Gandorfer et al. 2010)
  - IMAX, Imaging Magnetograph Experiment: vectormagnetograms in Fe I 525.02 nm (Landé g=3) (Martínez Pillet et al. 2010)
  - Both instruments observe simultaneously thanks to clever light distribution unit
- Correlating wavefront sensor (Berkefeld et al. 2010)
- Protective and stabilizing gondola



IMaX Imaging Magnetograph eXperiment
(Martínez Pillet et al., 2011, Sol.Phys. 268, 57)



vectormagnetograms and Doppler maps in Fe I 525.02 nm (Landé g=3)

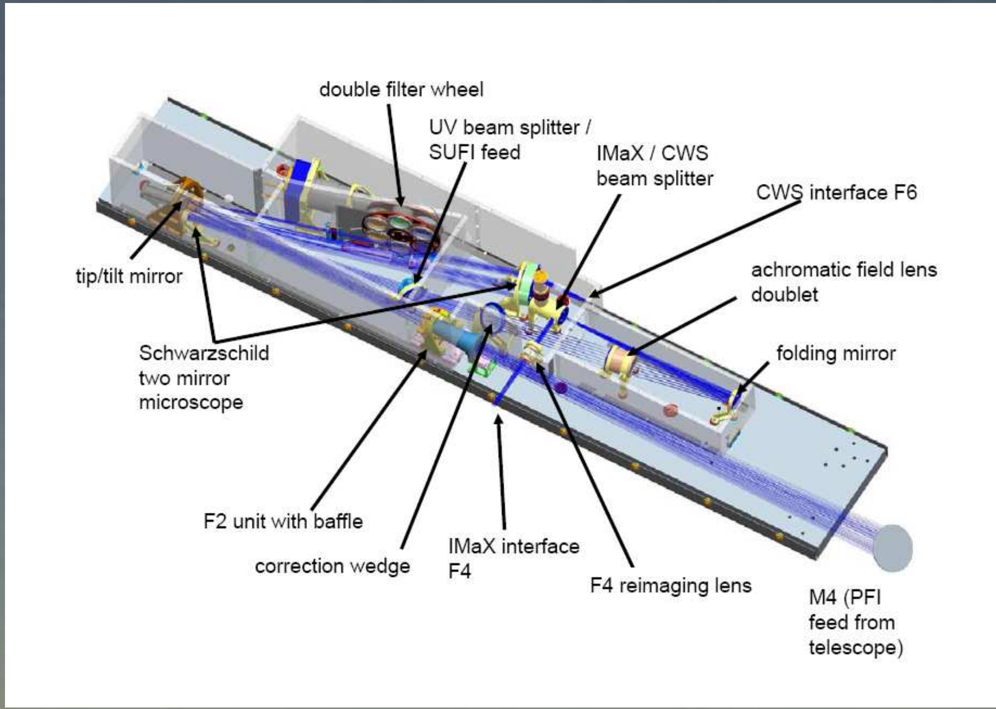
33s cadence

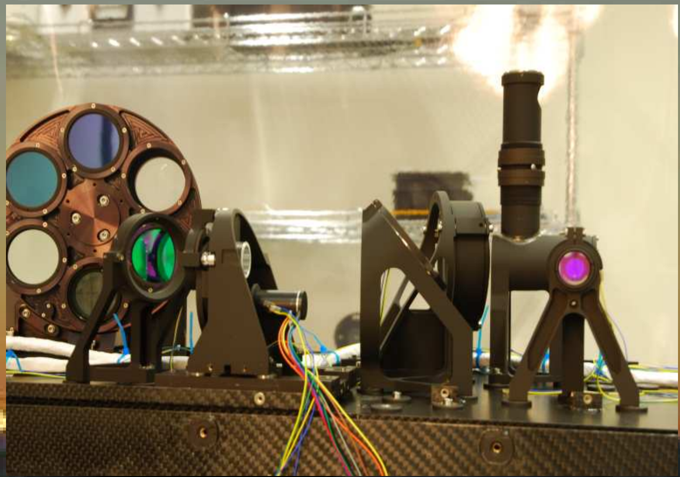
50“x50“ FoV

0.15“ resolution

S/N ~ 1000

SuFI Sunrise Filter Imager (Gandorfer et al. 2011, Sol.Phys. 268, 35)





214nm, 300nm, 312nm, CN, Ca II H

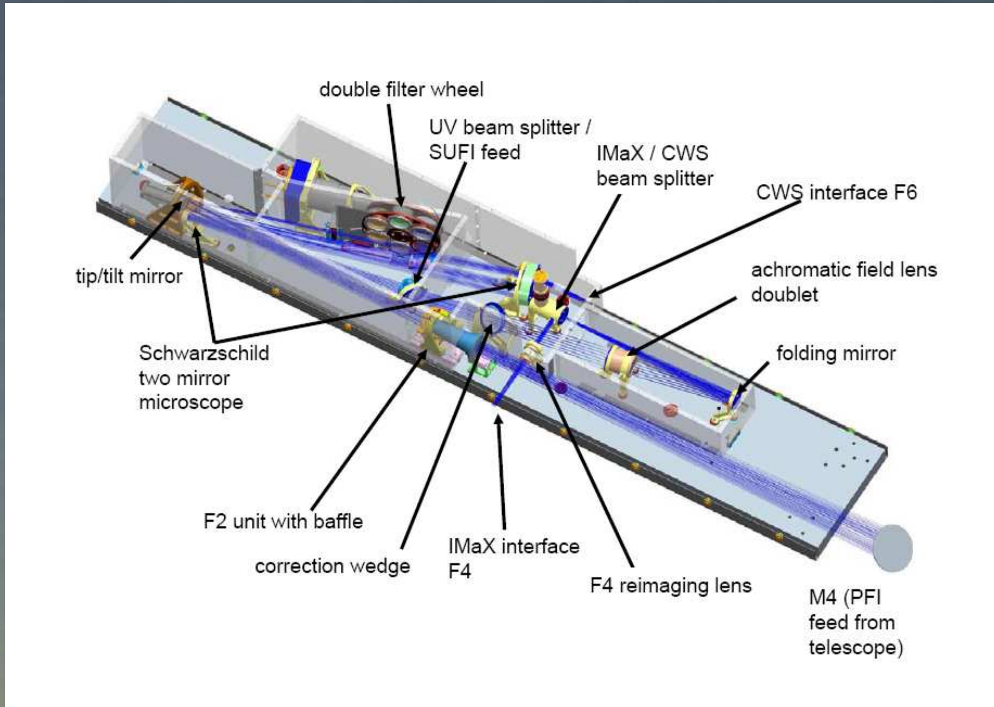
1s max cadence (fixed wavelength)

8sec (all wvlgths excluding 214nm)

30sec including 214

14“x40“arcsec

0.15“



SuFI Sunrise Filter Imager

new for 2013 flight:

214nm, 300nm, Ca II H (0.18nm), Ca II H (0.11nm), Mg II k (0.48nm)

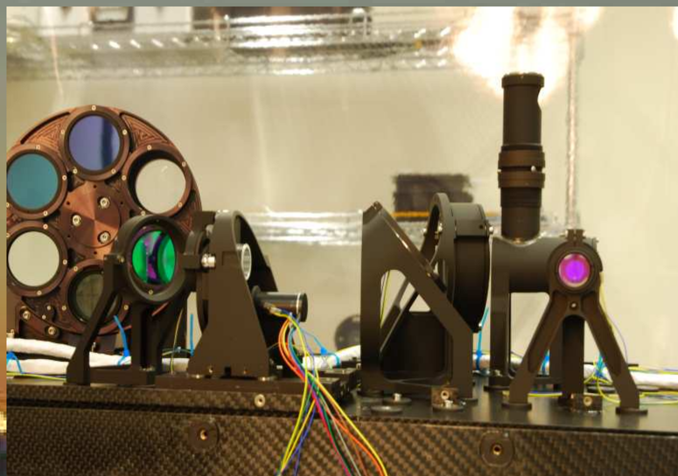
1s max cadence (fixed wavelength)

8sec (all wvlgths excluding 214nm and 280nm)

60sec including 214

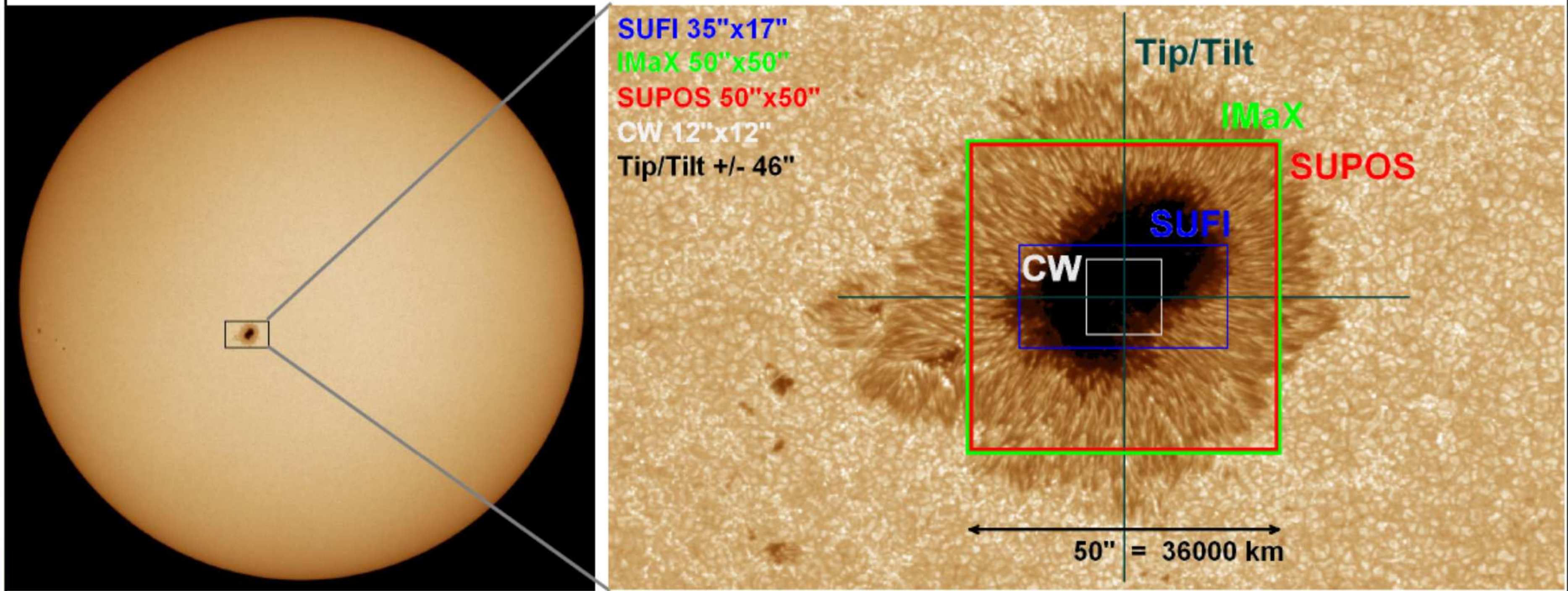
14“x40“arcsec

0.15“ except Mg II k



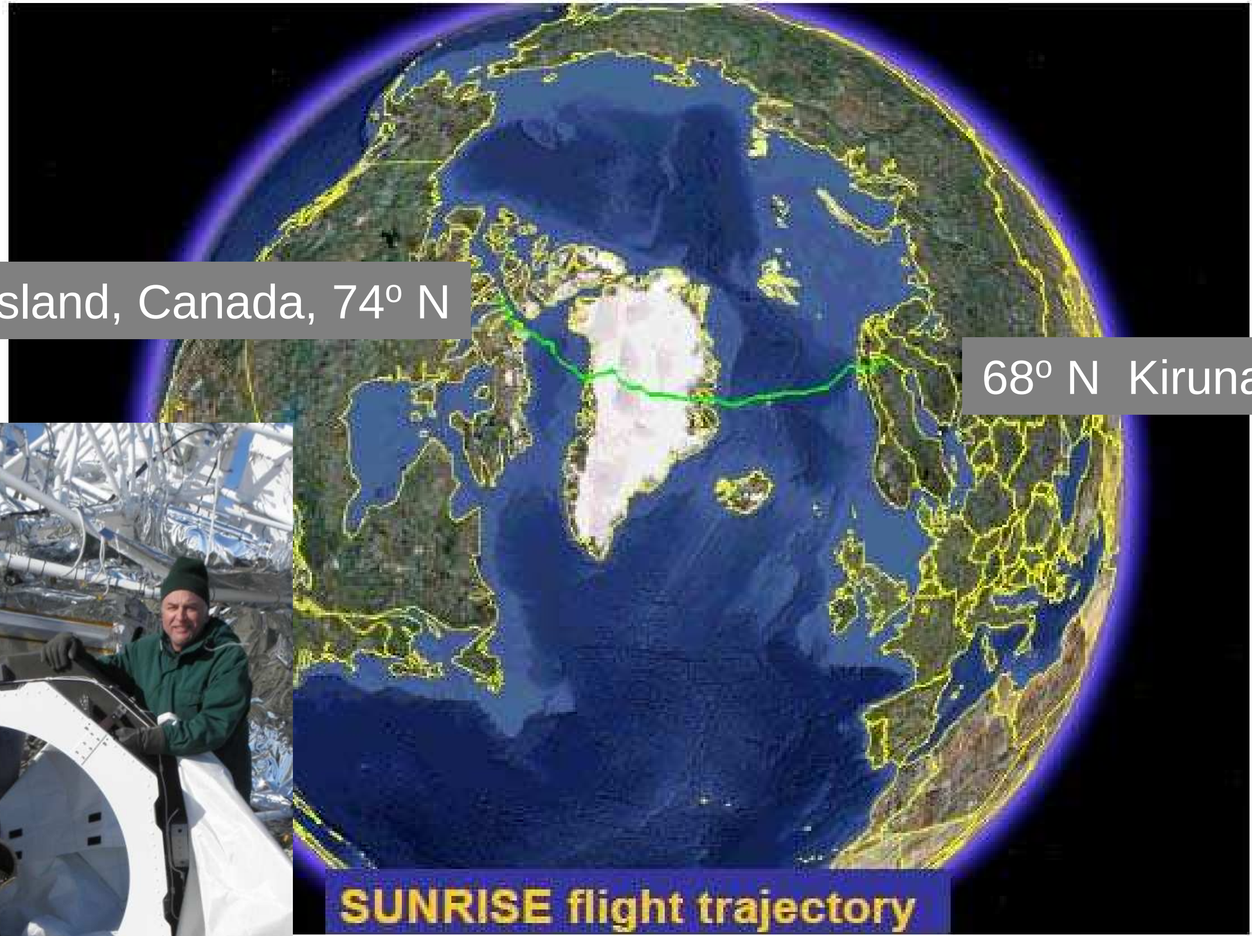
Field Of View of the Sunrise Instruments

(See Document SUN-MPS-TN-GEN-008)



	Sunrise Field Of Views	Sunrise Field Of Views	16 Mar. 2007	Max-Planck-Institut für Sonnensystemforschung
		Doc.: SUN-MPS-TN-GEN-014	Issue: Draft	
		Author: T.Riethmüller	Revision: a	

First flight path (duration ~6 days)



Somerset Island, Canada, 74º N

68º N Kiruna, Sweden

lost hours after launch. No images until recovery

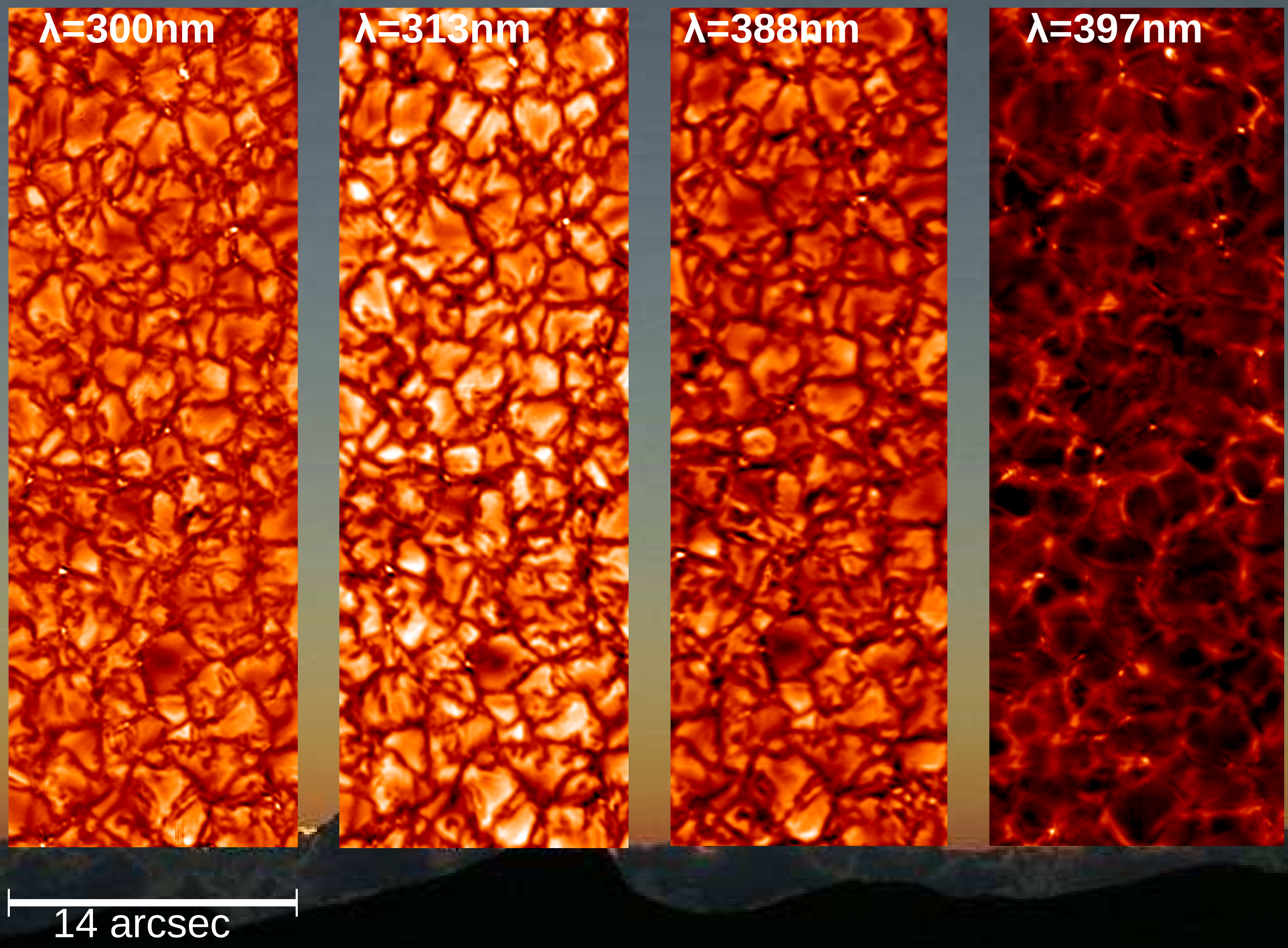
as recovered with all major systems intact

Sunrise 1 Data

Sun was VERY quiet during first flight: no sunspots, no pores

➔ Sunrise 1 results all refer to quiet Sun

PD Reconstructed SUFI Images



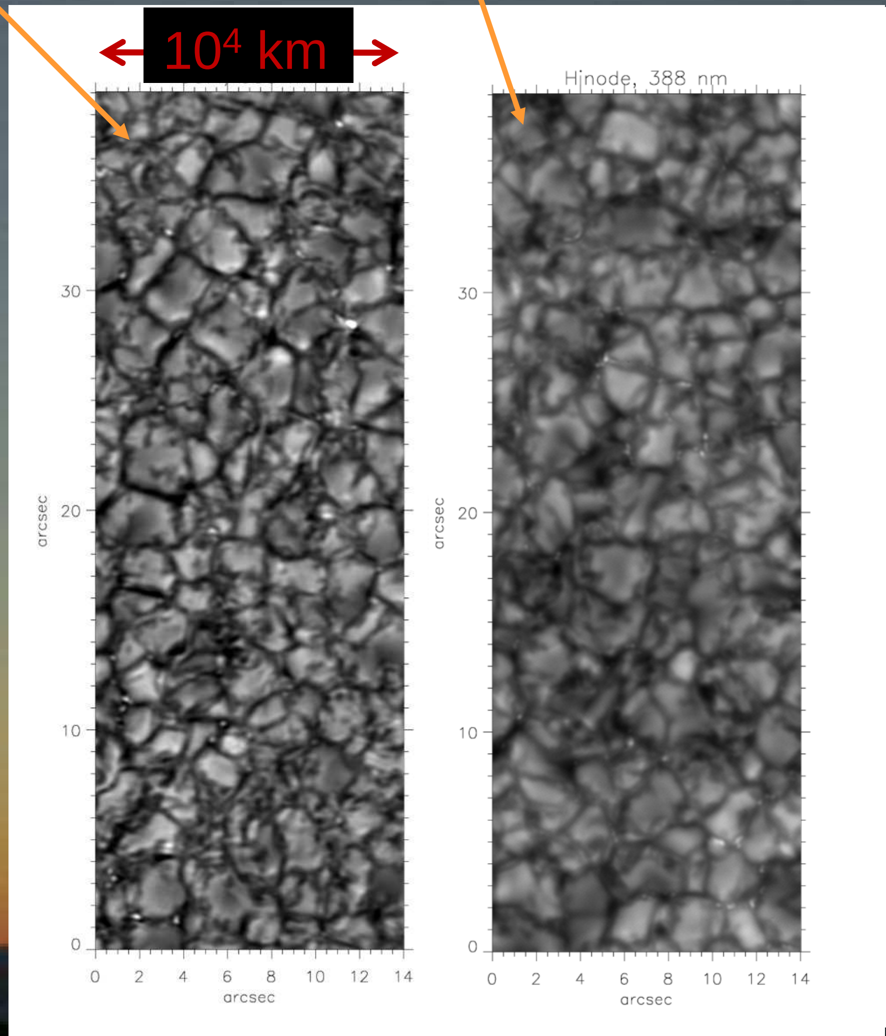
Comparison Sunrise with Hinode data

Sunrise: SUFI 388 nm (filter width 0.8 nm)

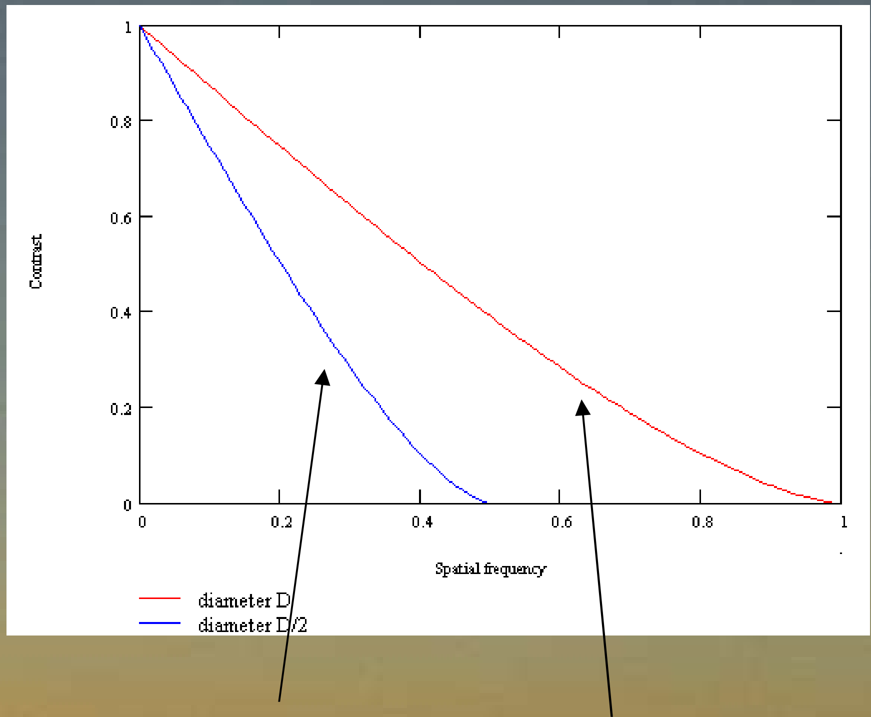
Hinode: BFI 388 nm (filter width 0.7 nm)

Same grey scale

Note that the two images were not taken simultaneously (different granules), but both refer to quiet Sun at $\mu = 1$



MTF curves (circular, unobscured entrance apertures of different sizes)

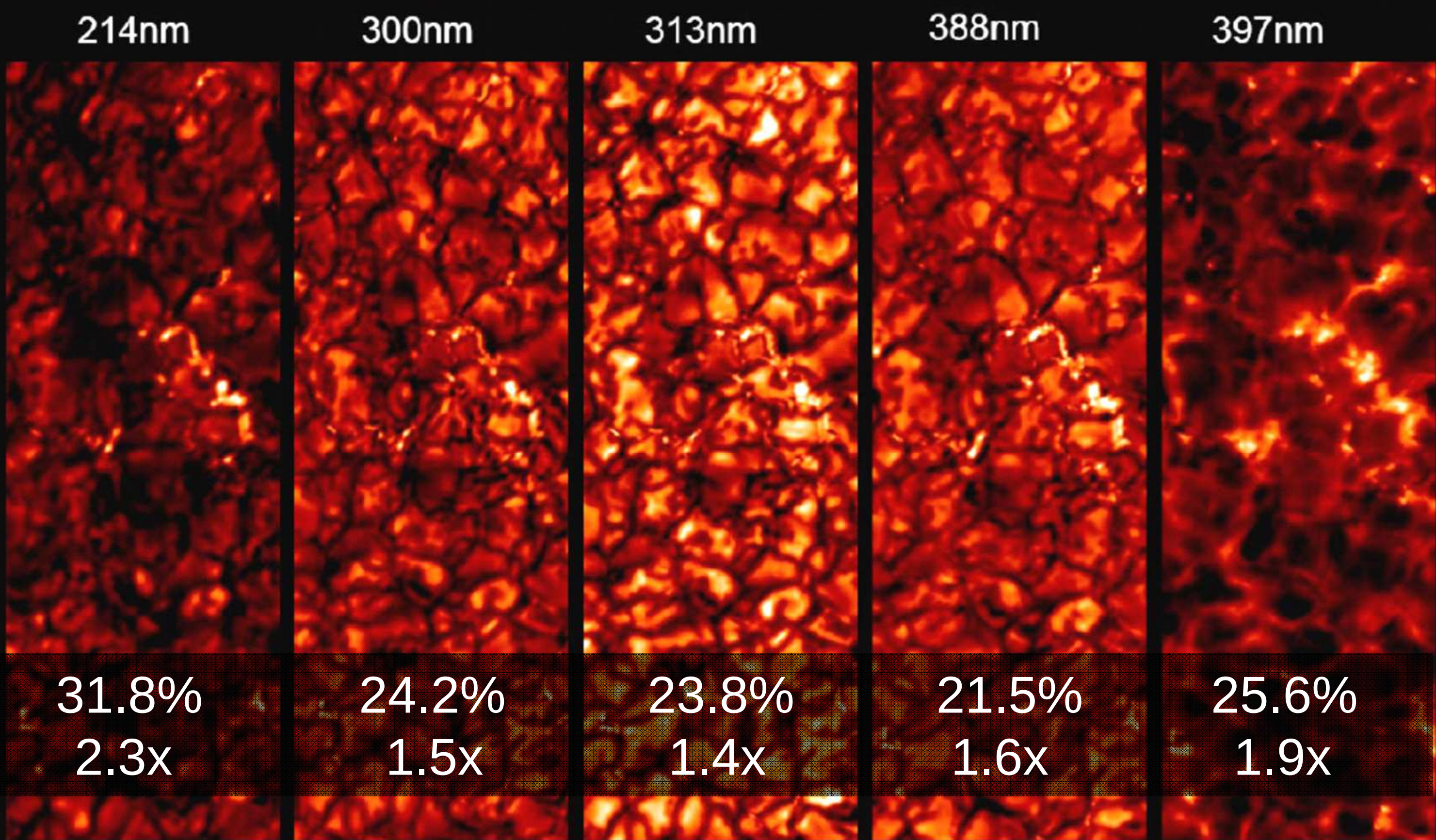


Hinode-size (D=50cm); Sunrise-size (D=1m)

if both telescopes are perfect, the larger telescope will provide higher contrast images AT ALL SPATIAL FREQUENCIES!

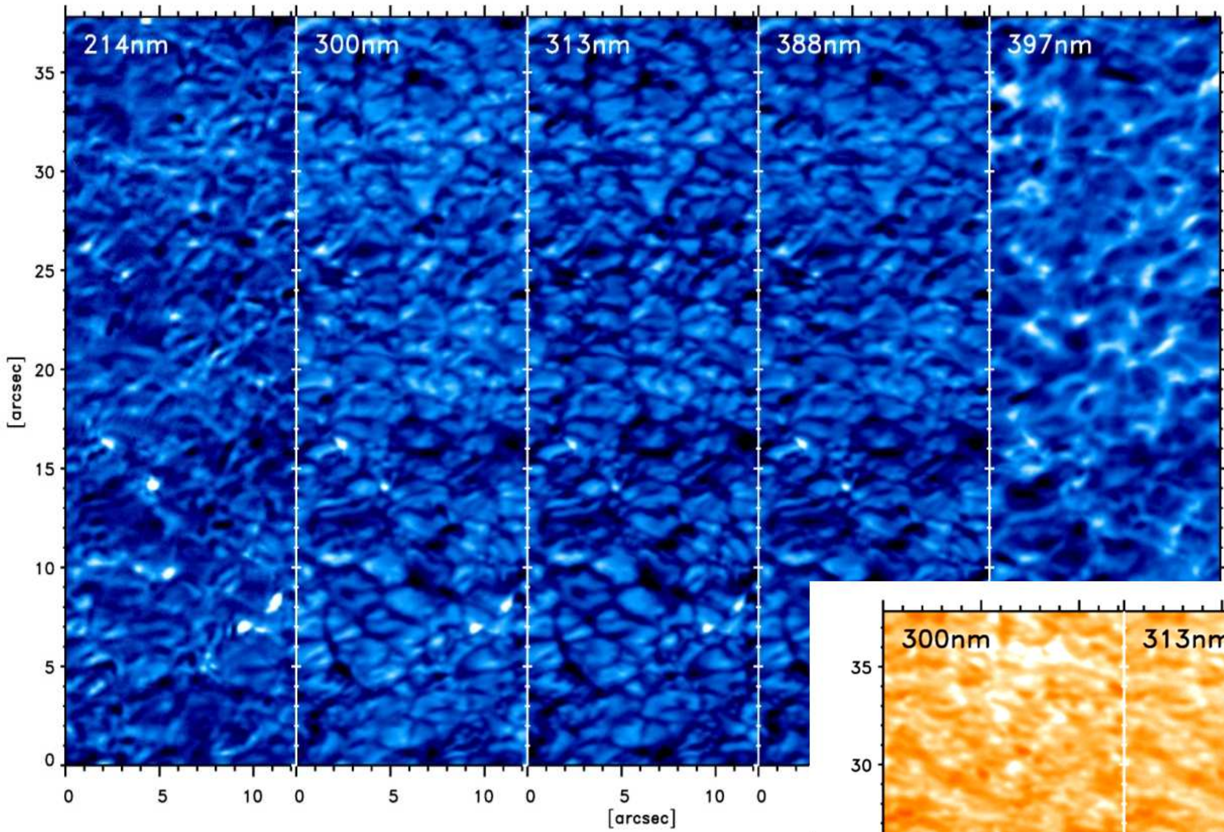
Data: SuFI

300-388nm: granulation with BPs, 214nm: more structured granules, prominent BPs, 397nm: reversed granulation, waves, BPs; more diffuse than other WLs

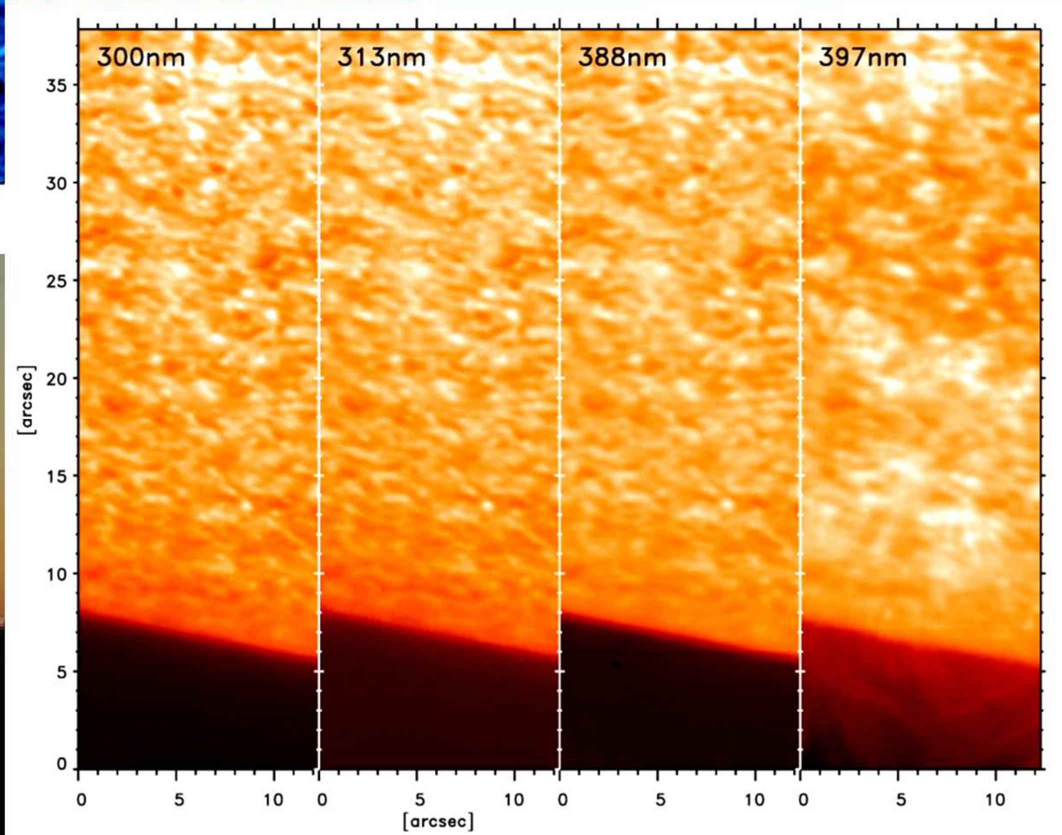


	214nm	300nm	313nm	388nm	397nm
SUFI RMS:	31.8%	24.2%	23.8%	21.5%	25.6%
BP contrast:	2.3x	1.5x	1.4x	1.6x	1.9x
MHD RMS:	?	25.5%	22.0%	20.0%	?

Hirzberger et al. 2010, ApJ 723, L154; Riethmüller et al. 2010, ApJ 723, L169



SUFI CLV



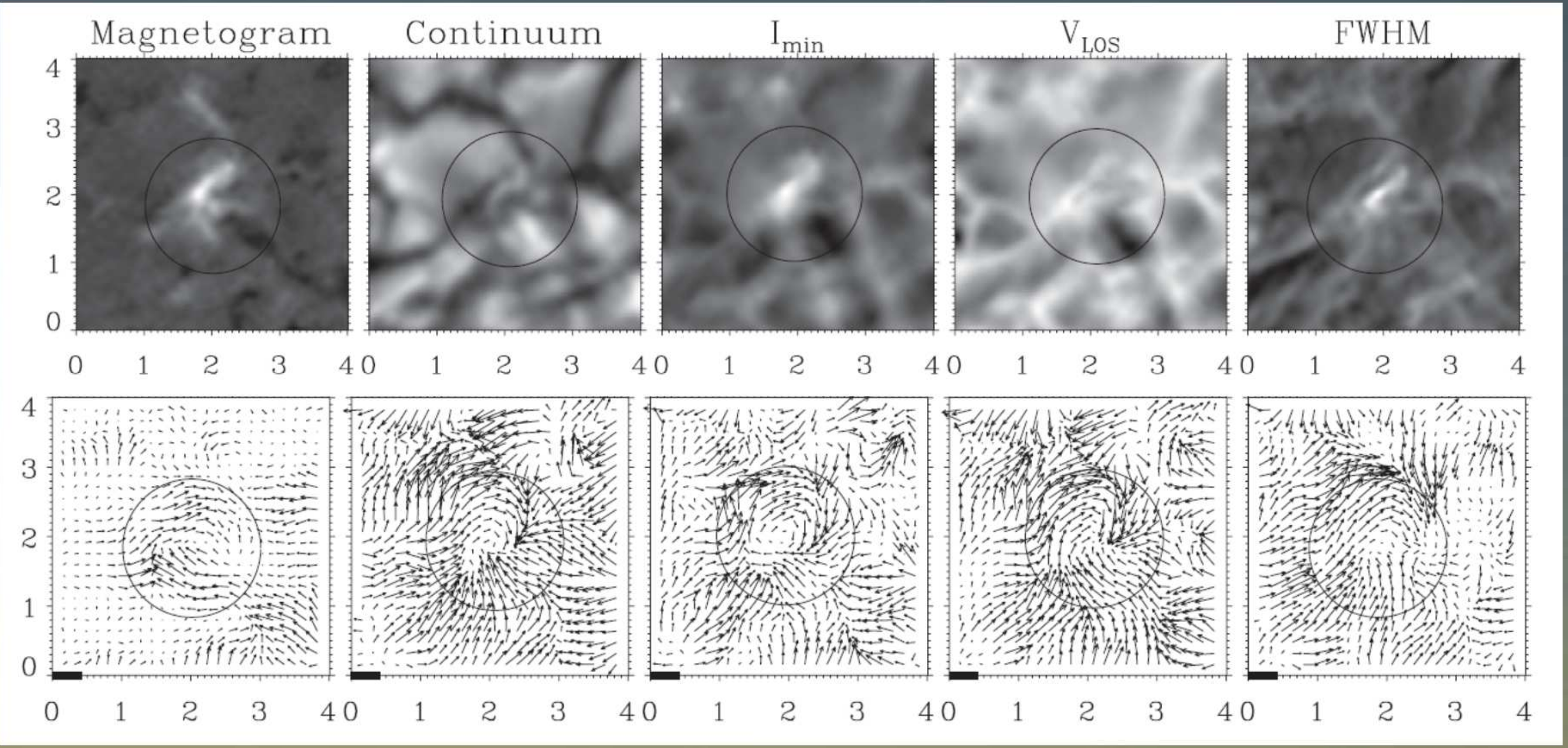
214nm displays signs of increasing inverse granulation away from disk centre

Granules (or convective features at limb are distinctly smaller. → sub-structure of granules better visible at limb

Sunrise 1 Data

velocities, flows, and waves...

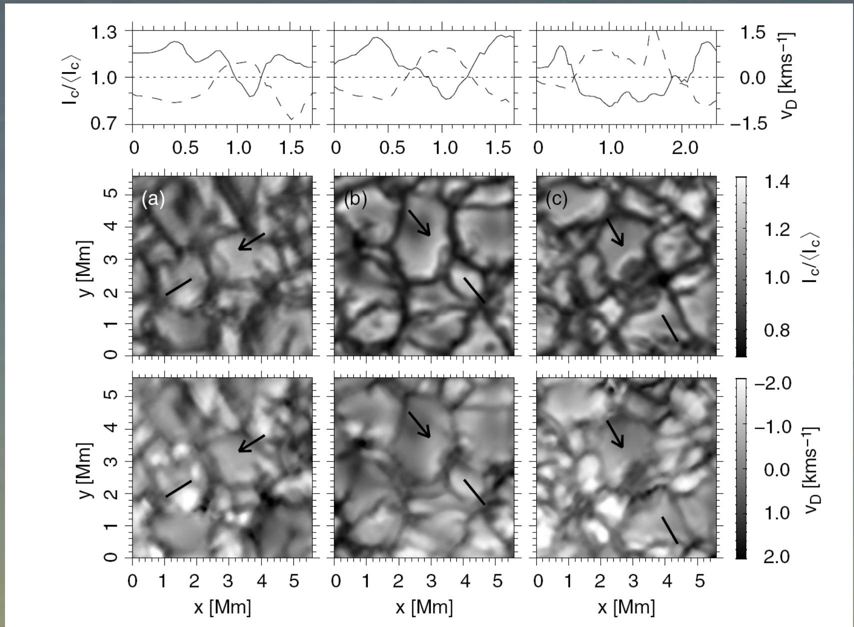
Vortices in granulation



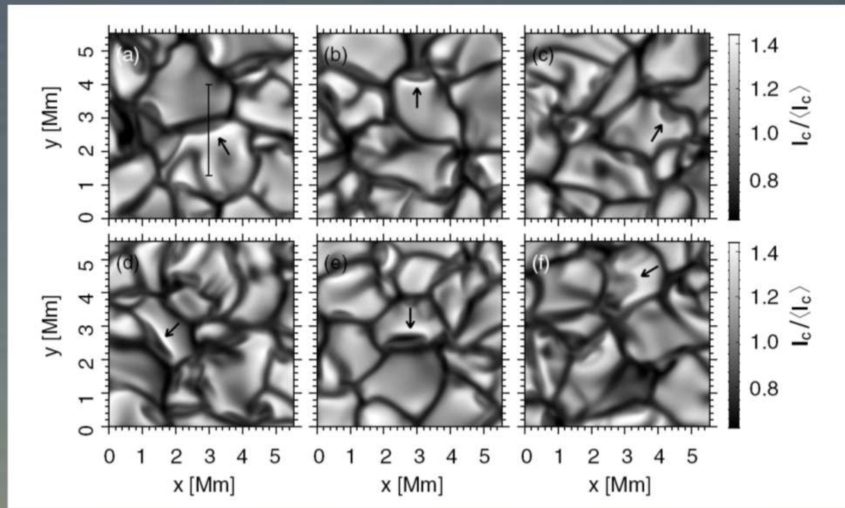
Bonet et al., 2010, ApJ 723, L139

3.1 × 10^{-3} vortices Mm^{-2} $minute^{-1}$, a factor of ~1.7 larger than previous estimates.

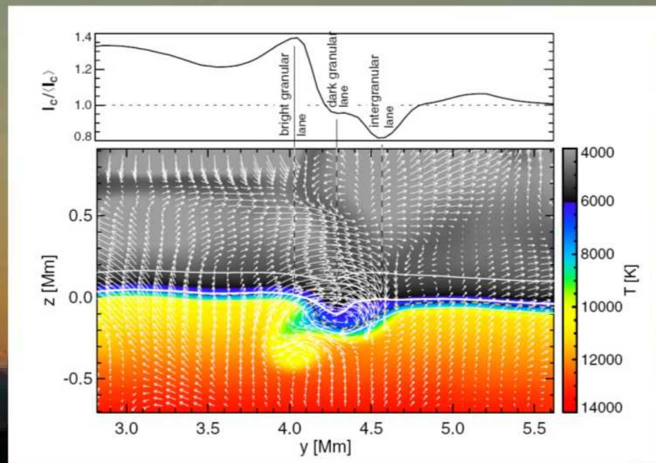
Horizontal vortices



IMaX intensity and Doppler data



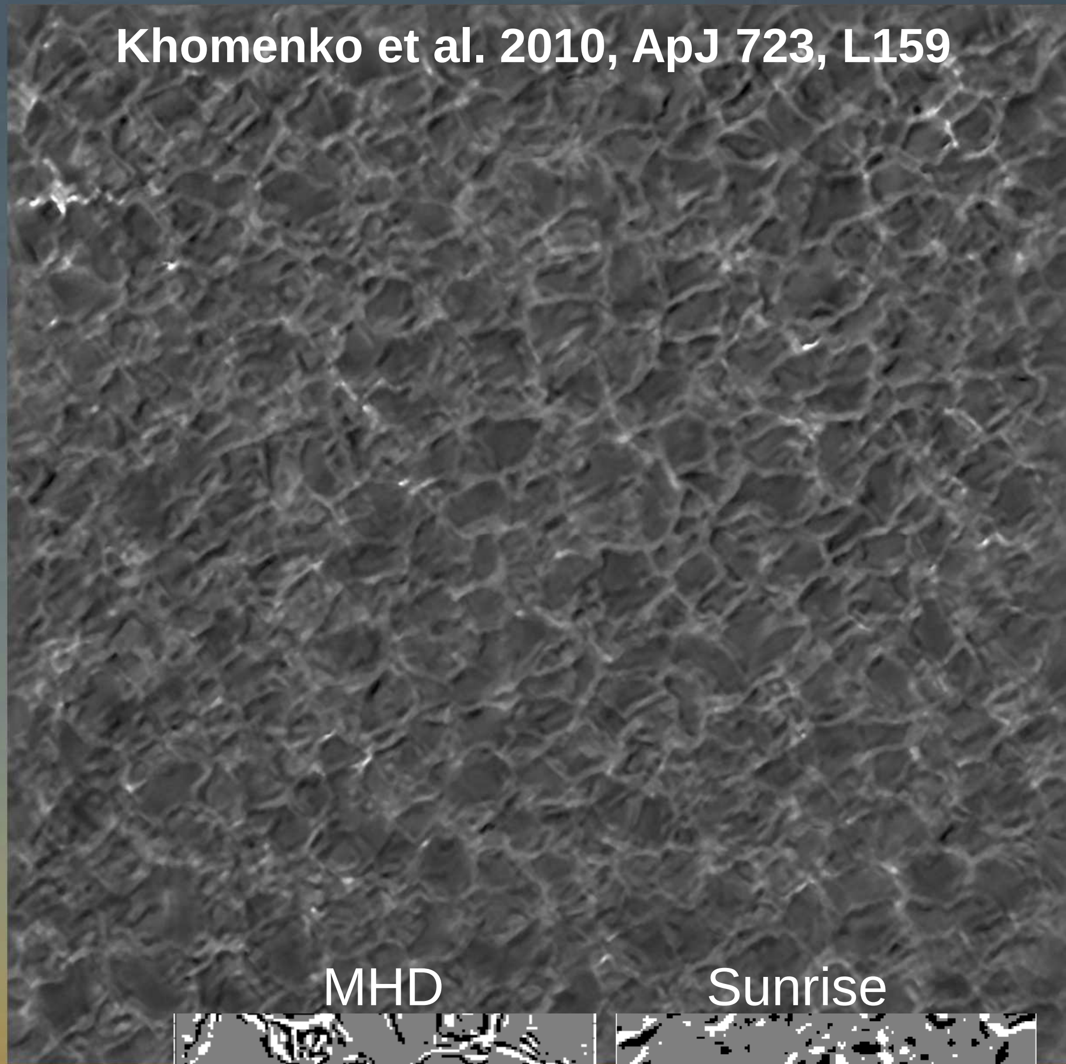
numerical simulation

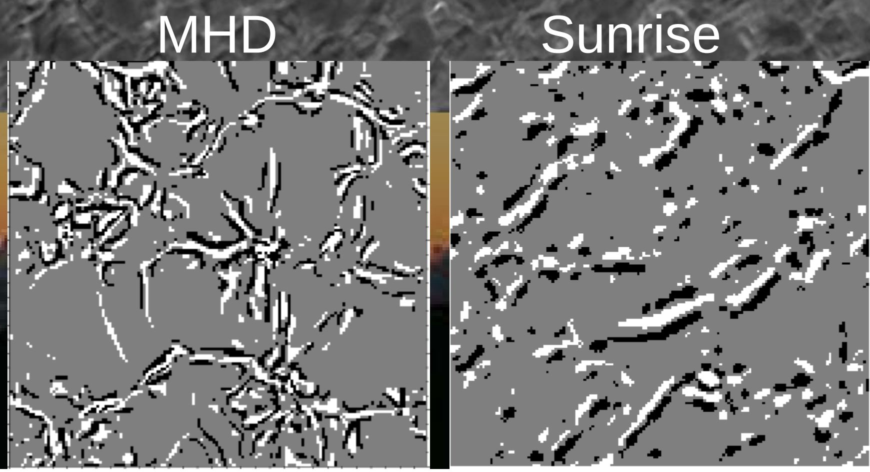


Steiner et al., 2010, ApJ 723, L180

Where the granular flows bend

- Intergranular lanes show large line width (bright)
- Small line width at the granular/intergranular borders (dark lanes)
- MHD simulations: low width where granular flows bend over (low velocity gradient)

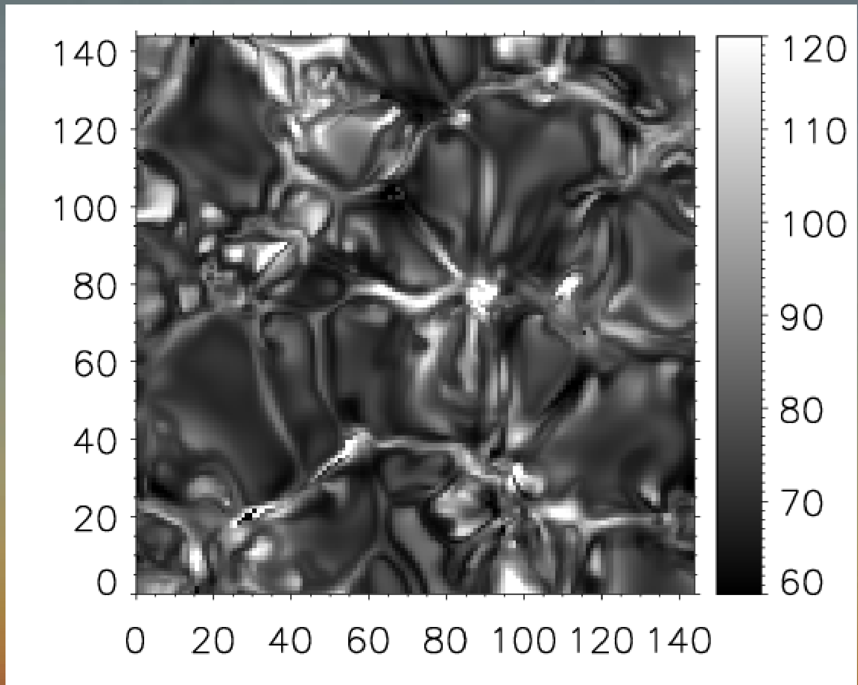




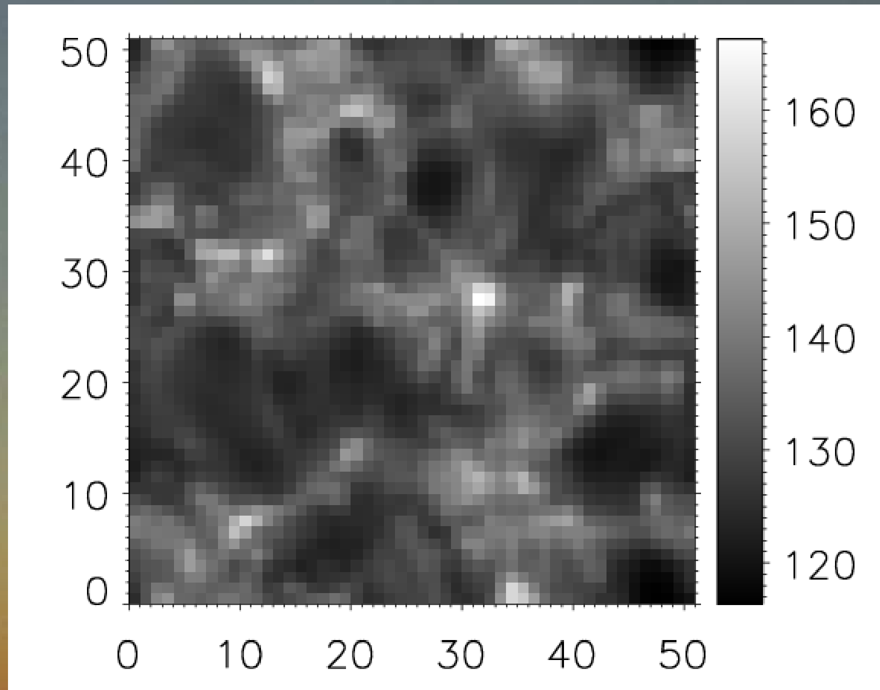
Important: this narrowing of spectral lines can only be seen if spatial resolution is sufficiently high

MHD <B>=30 G, mixed polarity

FWHM of FeI 5250 Stokes I, binned to IMaX (after restoration) resolution



FWHM of FeI 6301 Stokes I, degraded to HINODE resolution

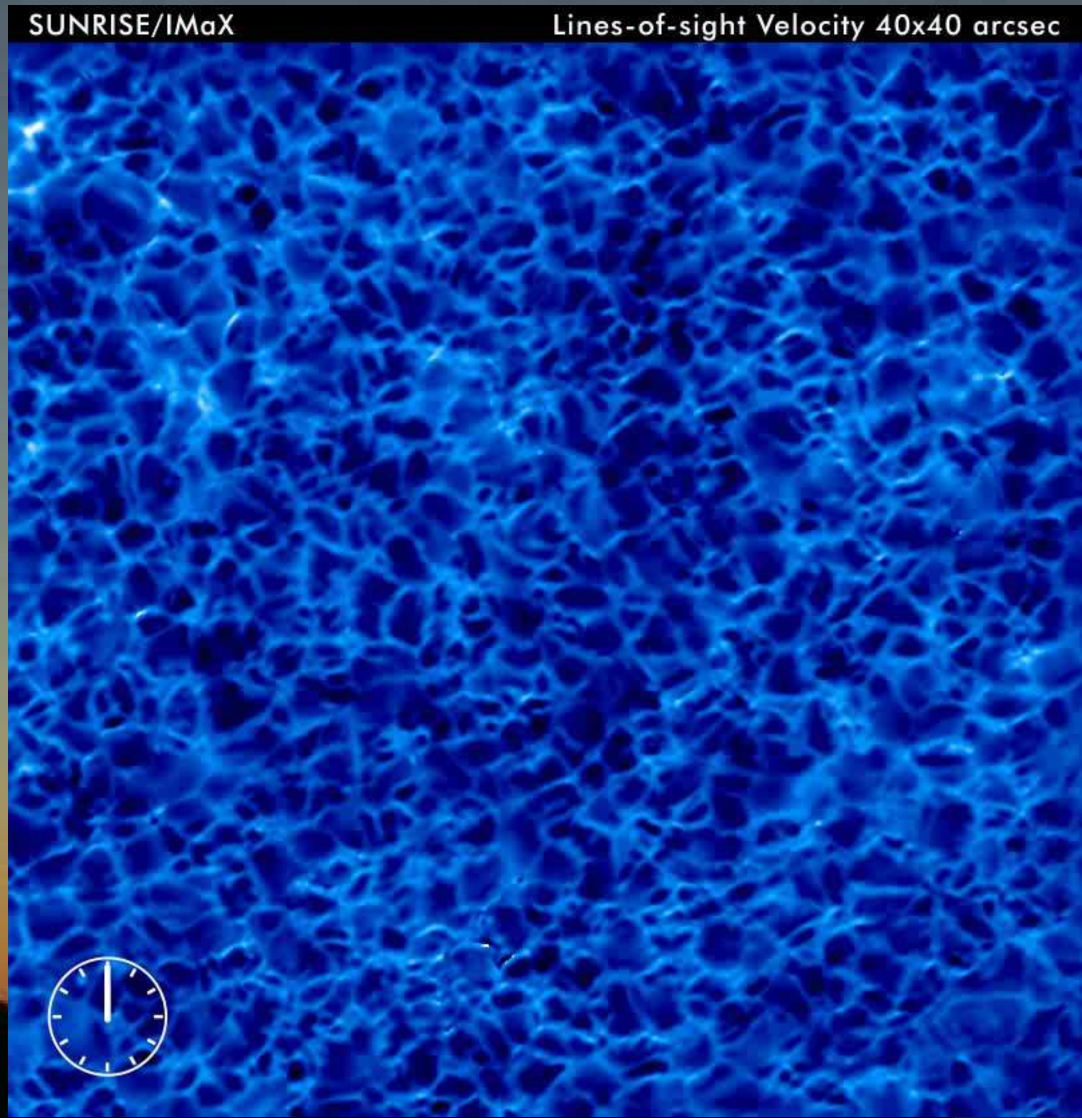


Dark lanes do not appear at HINODE resolution

Elena Khomenko, Instituto de Astrofisica de Canarias

IMAX data: velocity movie

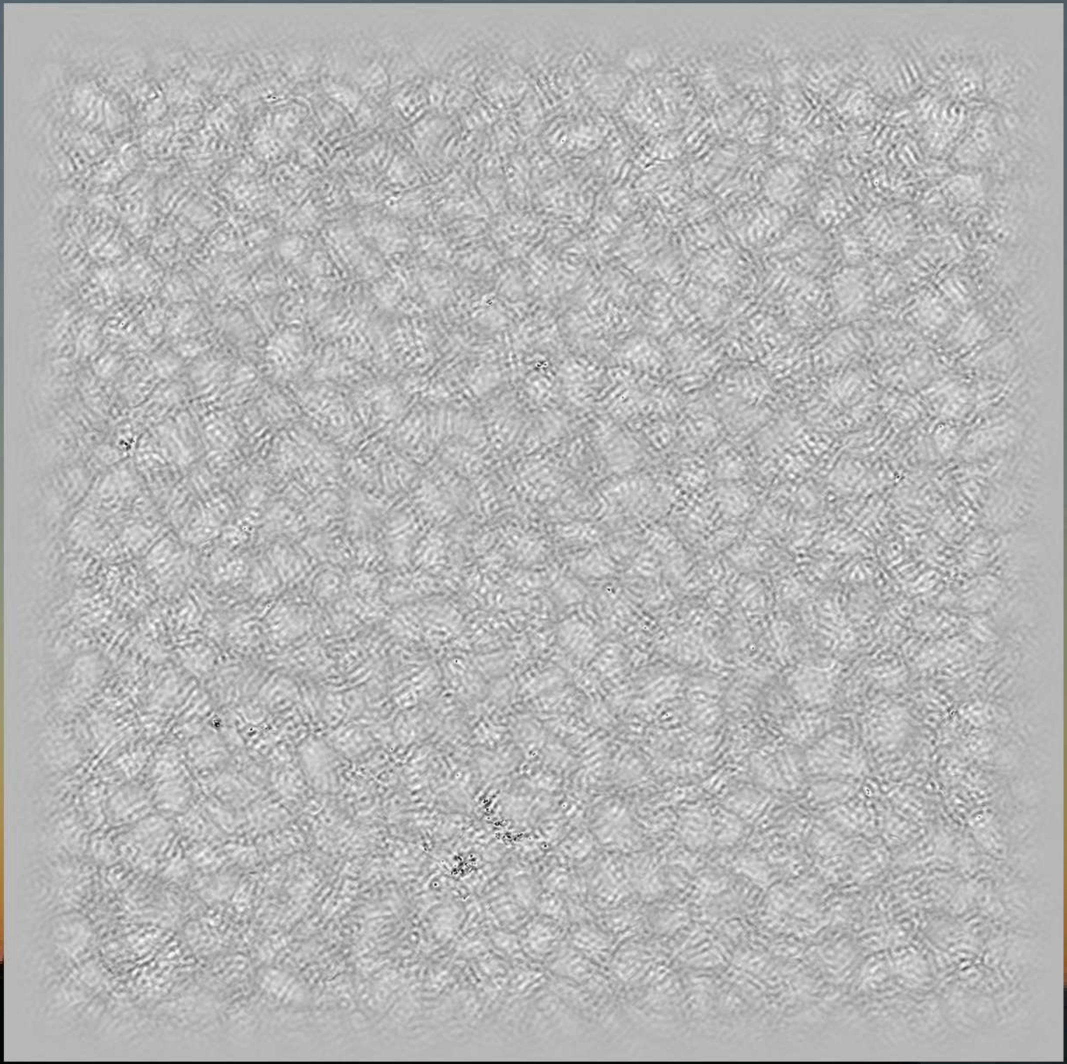
- LOS velocity shows combination of
  - granules,
  - p-modes
  - higher frequency waves



Acoustic wave power and small-scale events

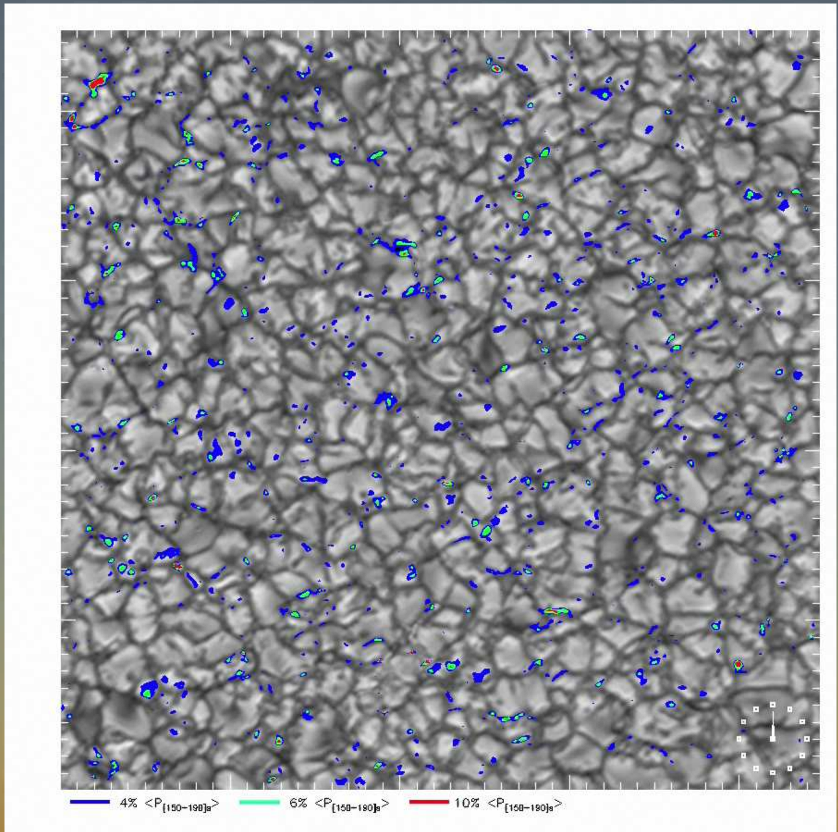
Sunrise provided first evidence that acoustic wave power ($l > 1000$) is enhanced prior to granule splitting (exploding granules) and displays vortices

Movie shows wave pattern overplotted on intensity structure (granules)



Roth et al. 2010, ApJ 723, L 175

High acoustic wave flux above cutoff



method / data	uncorr. (W m^{-2})	corrected (W m^{-2})
wavelet: binned (2×2)	3975	4600–4900
wavelet: binned (1×1)	5495	6470–6945
Fourier: binned (1×1)	6340	10280–14050
other work		
Bello González et al. (2010)		
$h = 500 - 600\,km$, 0.″4	–	1700–2000
Bello González et al. (2009)		
$h = 250\,km$, 0.″4	2500	3000–3650
Straus et al. (2008)		
$h = 250\,km$, ∼0.″4	–	1400
$h = 500\,km$, ∼0.″5	–	1000
Carlsson et al (2007)		
$h = 200\,km$, ∼0.″22	–	800
Fossum & Carlsson (2006)		
$h = 430\,km$, ∼1″	–	510

Bello González et al. 2010, ApJ 723, L134

4500–14000 W m^{-2} needed to explain quiet chromosphere emission

Difference to earlier work may partly be due to different methods. However, the difference to work of Bello González et al. (2009) by factor of 2.2-2.5 is due to the higher quality of Sunrise data

High acoustic wave flux above cutoff

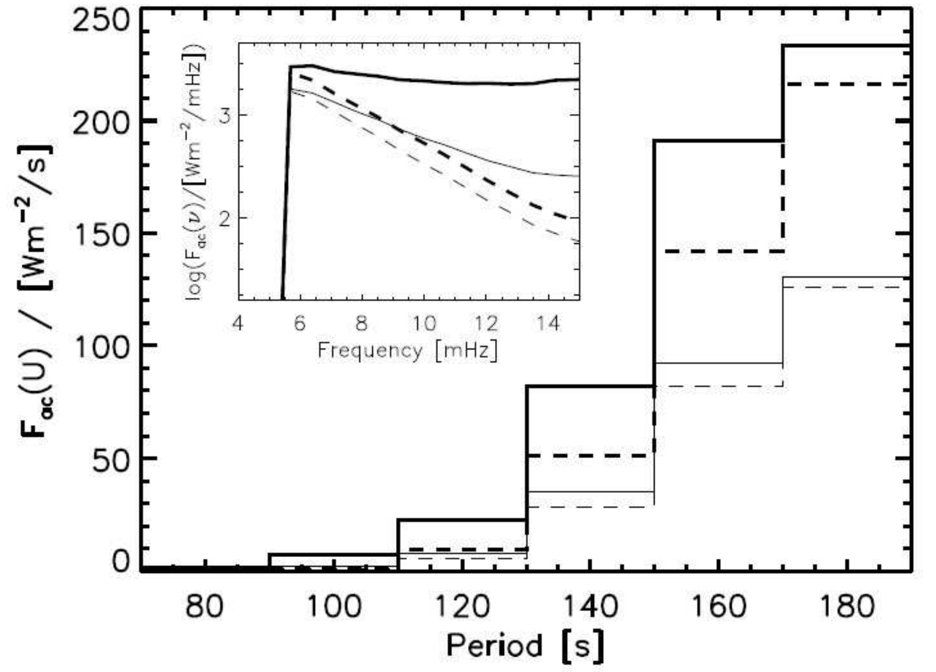


Fig. 2.— Velocity flux spectra from wavelet (vs. period) and Fourier (vs. frequency) analysis. *Thin* and *thick* represent GR and IGR spectra, before (*dashed*) and after (*solid*) correction for atmospheric transmission, respectively.

method / data	uncorr. (W m^{-2})	corrected (W m^{-2})
wavelet: binned (2×2)	3975	4600–4900
wavelet: binned (1×1)	5495	6470–6945
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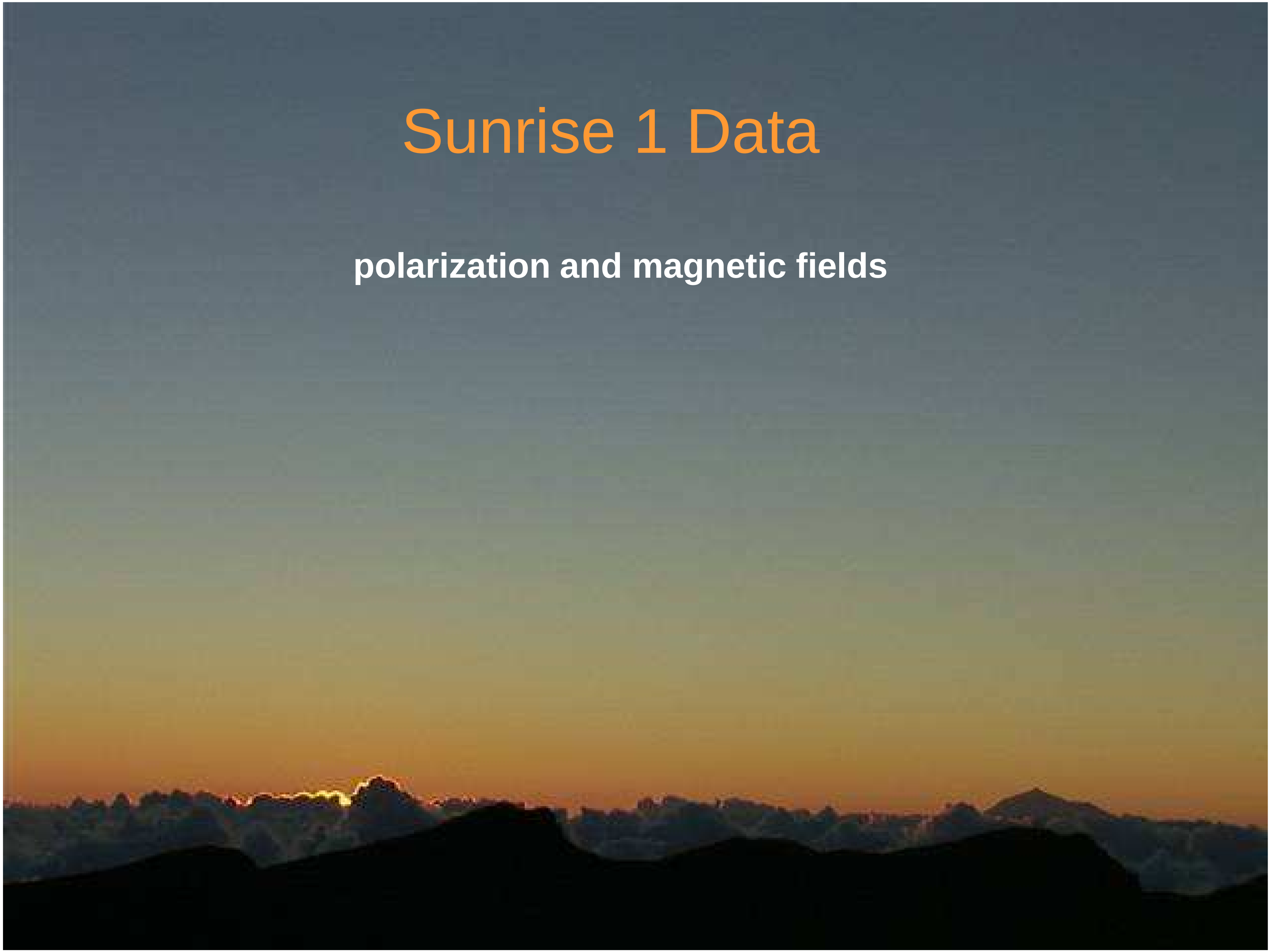
Carlsson et al (2007)		
$h = 200\, km$, ~0″.22	–	800
Fossum & Carlsson (2006)		
$h = 430\, km$, ~1″	–	510
Wunnenberg et al. (2002)		
$h = 600\, km$, ~0″.5	–	900

Required to explain quiet chromosphere: 4500 – 14000 W m^{-2}

The “missing acoustic wave flux” seems to be hidden not at high frequencies, but at small spatial scales (inter granules)

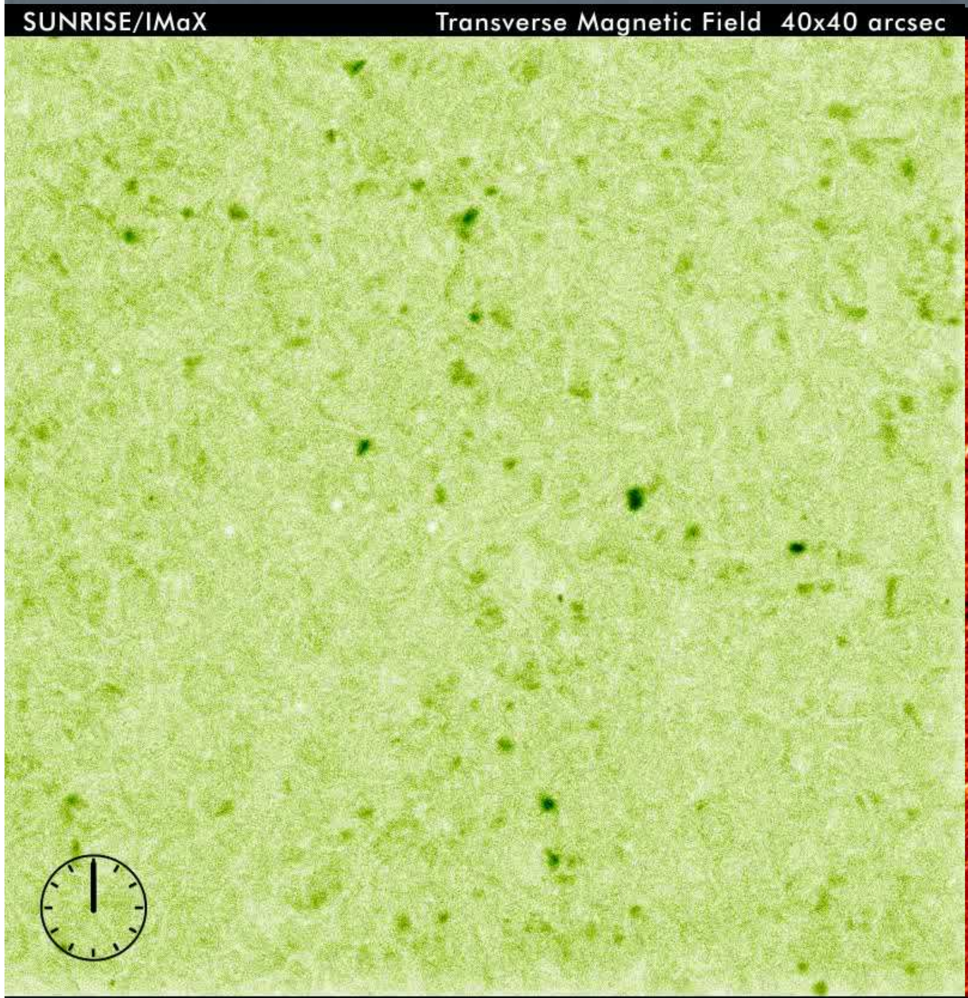
Sunrise 1 Data

polarization and magnetic fields

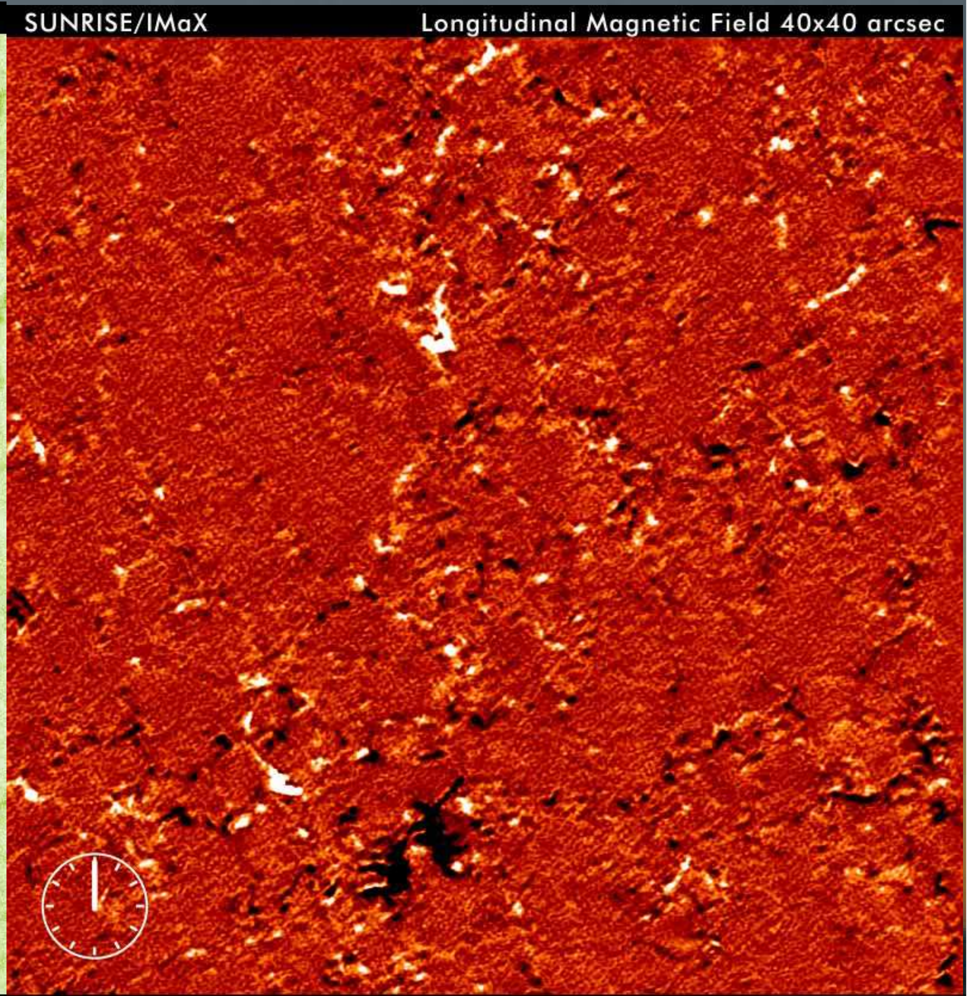


Sunrise 1 IMaX data:

Total linear polarization

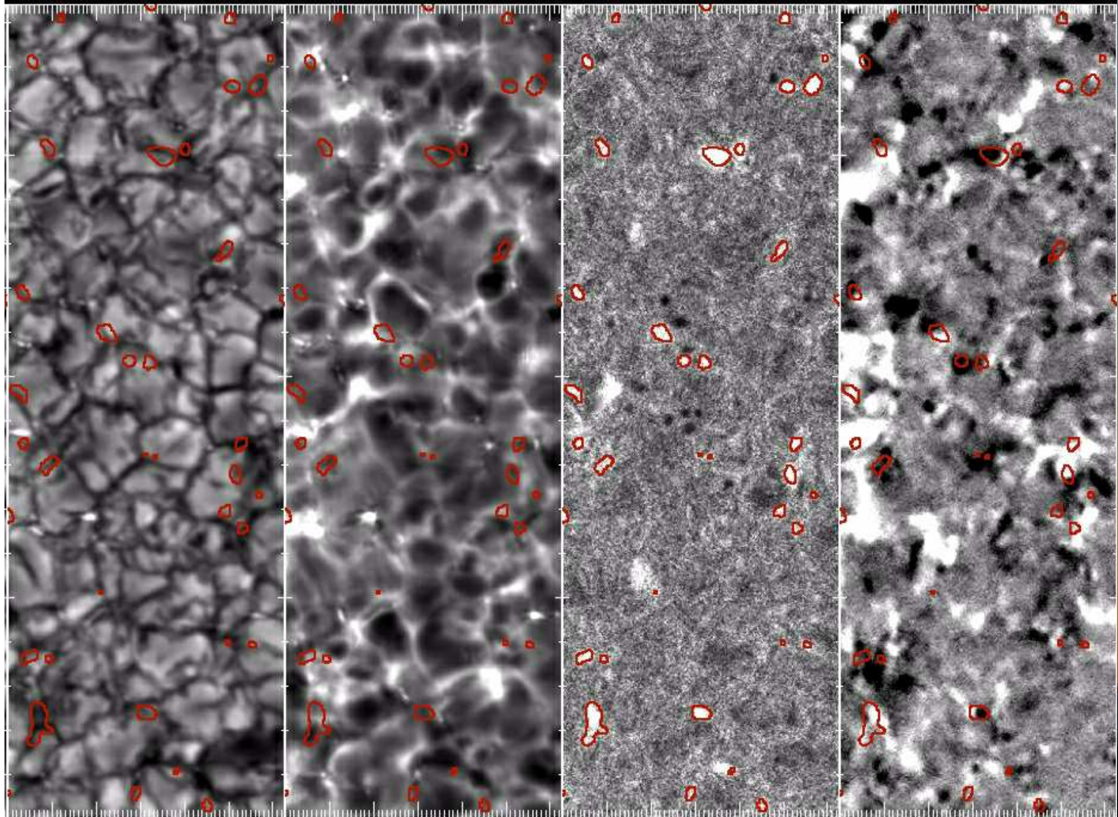


Stokes V



Ubiquitous linear polarization features in quiet sun

A number of features show downflows only.
They cannot be emerging loops!



Danilovic et al. 2010, ApJ 723, L149

≈ 5000 features analyzed

Most associated with bipoles

Occurrate: $7*10^{-4}$ s^{-1} $arcsec^{-2}$

➔ Order of magnitude more than earlier estimates. E.g.

Ishikawa & Tsuneta (2009): $6.3*10^{-5}$ s^{-1} $arcsec^{-2}$

Martinez Gonzalez & Bellot Rubio (2009): $5.6*10^{-6}$ s^{-1} $arcsec^{-2}$

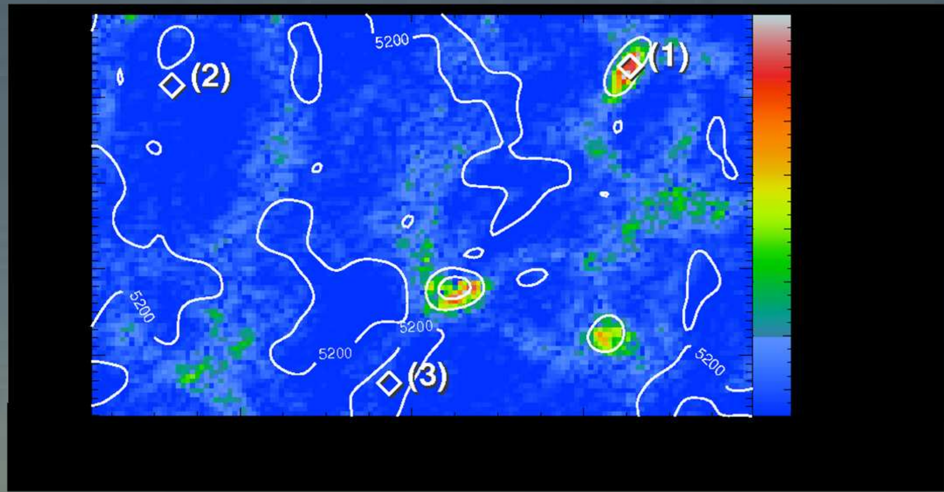
Lites et al. (1997): $2.8*10^{-5}$ s^{-1} $arsec^{-2}$

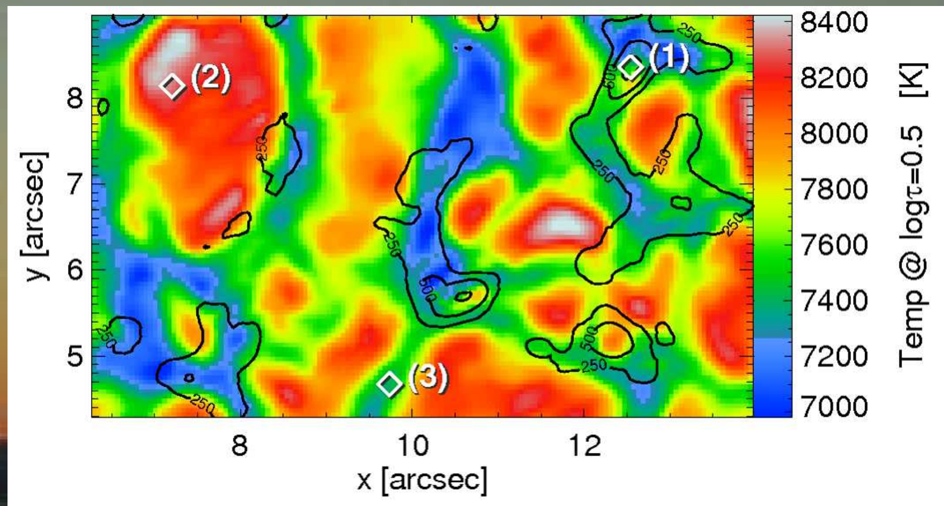
Kilo Gauss fields resolved

- Inversions with different codes & techniques give:
  - kilo Gauss fields without the need to introduce magnetic filling factor
  - temperature enhancement that agrees with empirical flux-tube models

➔ Sunrise finally resolved magnetic elements even in the quiet Sun

➔ Many magnetic elements are ≈100 km in size (even in QS internetwork)

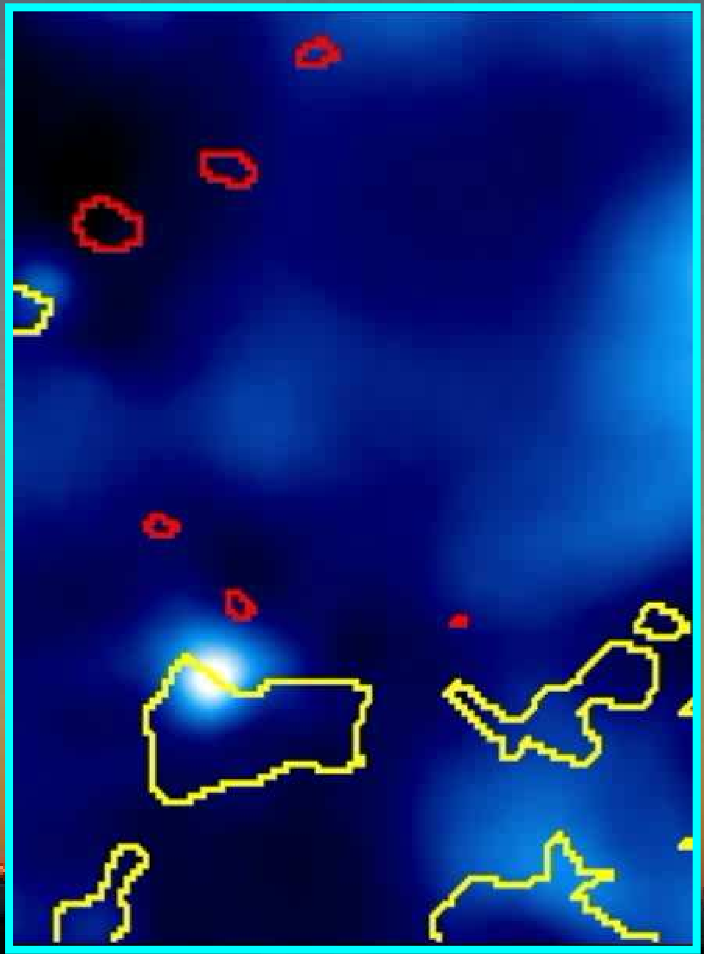


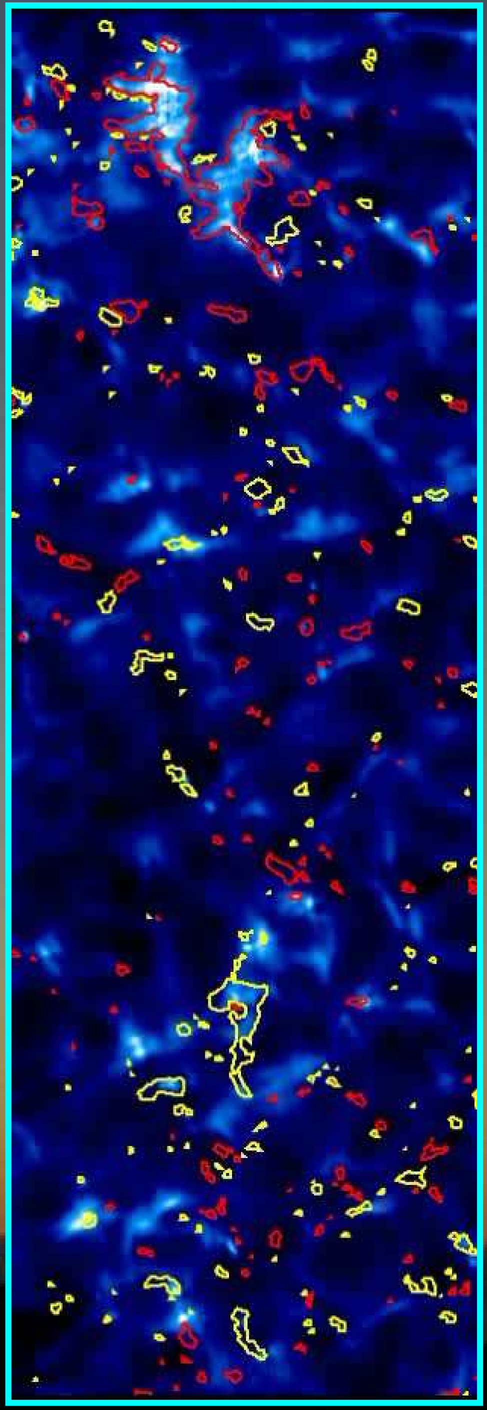


Lagg et al. 2010, ApJL

Ca II dynamics and magnetic field

- Clearly distinguish between magnetic and non-magnetic (waves) Ca bright features
- Magnetic Ca bright pts tend to have a ballistic, rather than a random-walk trajectory





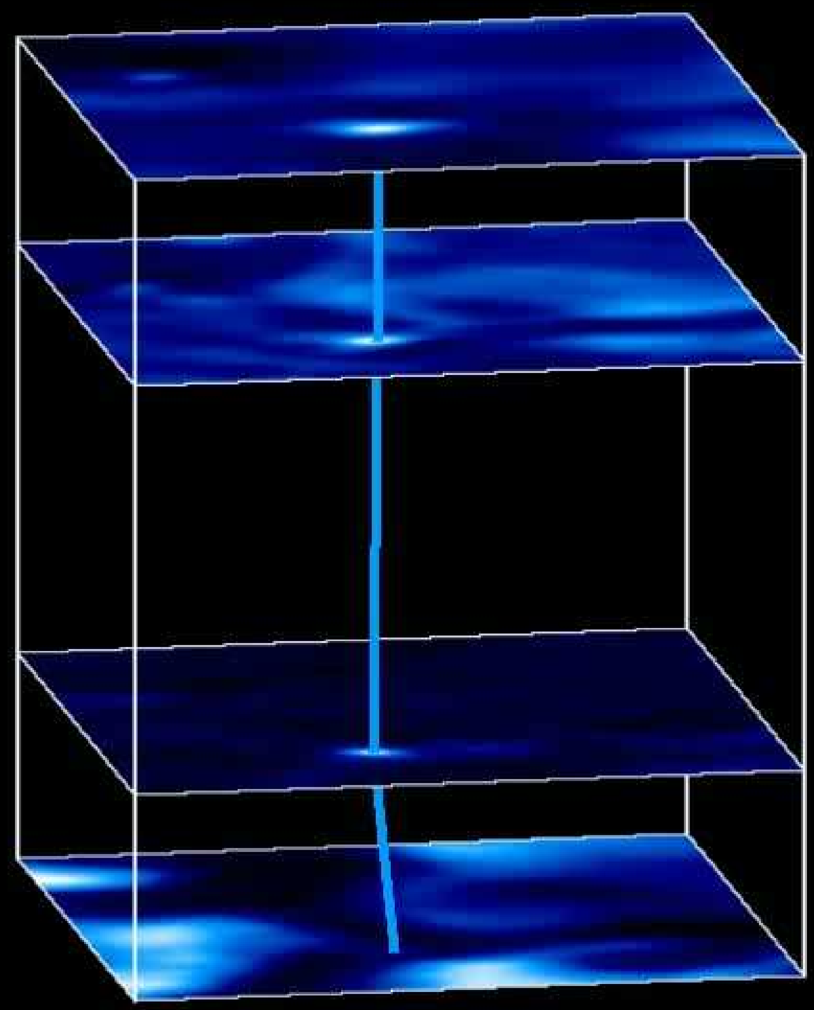
Dissertation of Shahin Jafarzadeh

purely geometrical
determination
of the
inclination of fluxtubes

yields almost vertical fields
in contradiction to
different inversion runs

establishes a
complementary method to
independently analyze
inclination of flux tubes

Dissertation of
Shahin Jafarzadeh



Other interesting studies

"Supersonic Magnetic Upflows in Granular Cells"

first observed in IMaX data (Borrero et al. 2010, ApJ 723, L144)
later also found in Hinode/SP data as

„Ubiquitous quiet-Sun jets" (Martinez Pillet et al., 2011, A&A, in press

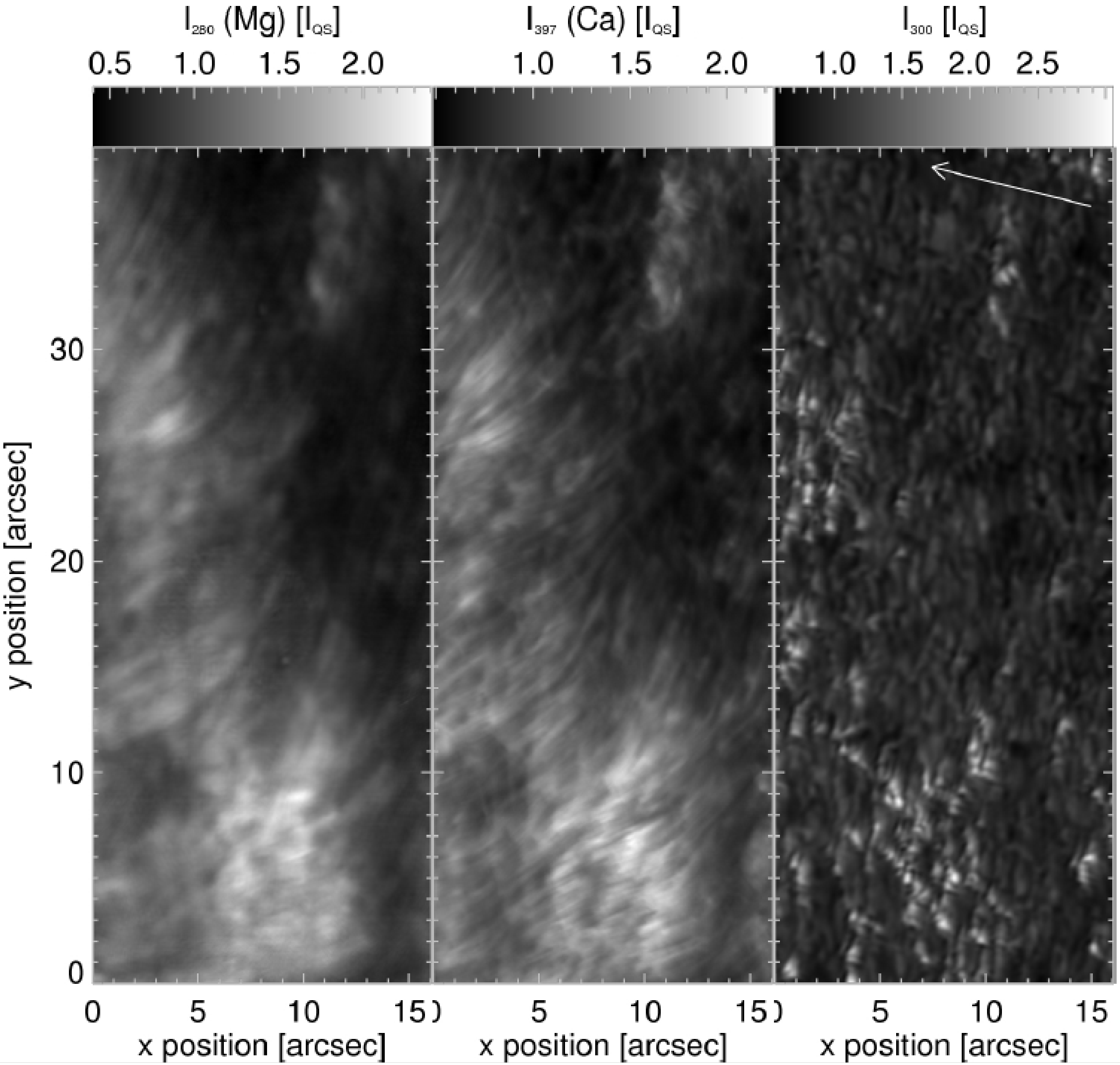
„Emergence of an intermediate-scale bipole" (Guglielmino et al., submitted to ApJ) see talk on Tuesday

"Unnoticed Magnetic Field Oscillations in the Very Quiet Sun" (Martínez González et al., 2011, ApJ 730, L37

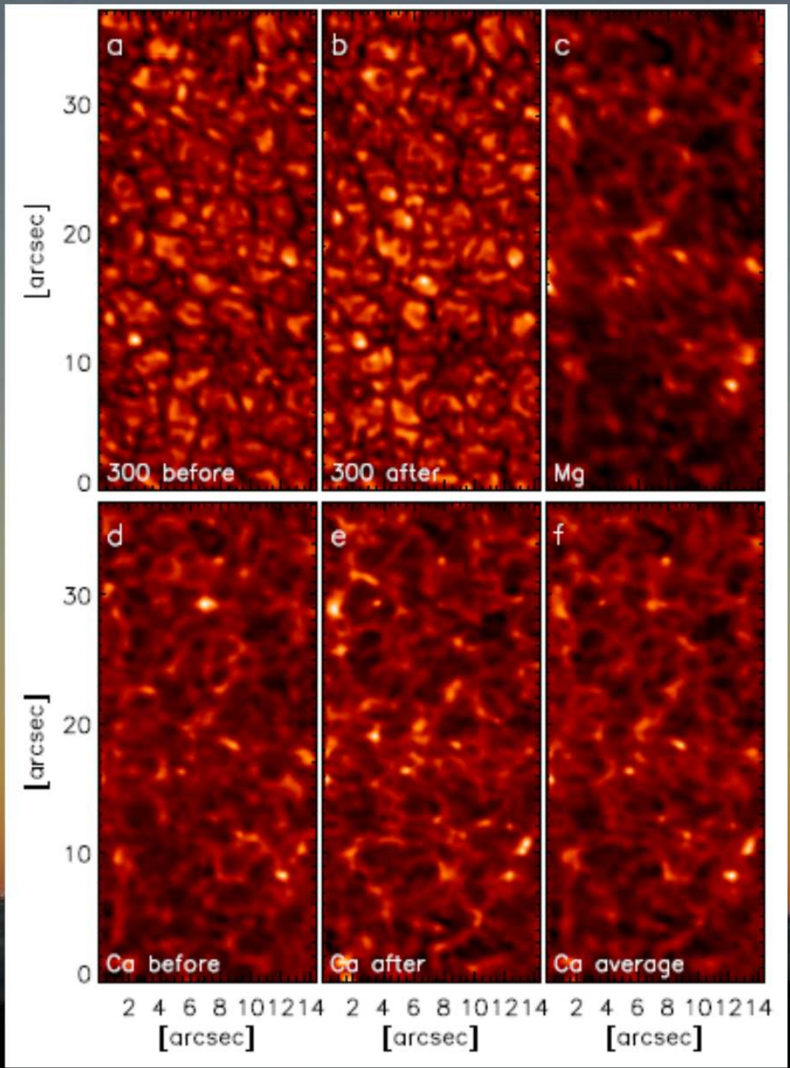
"Mesogranulation and the Solar Surface Magnetic Field Distribution" (Yelles Chaouche et al., 727, L30)

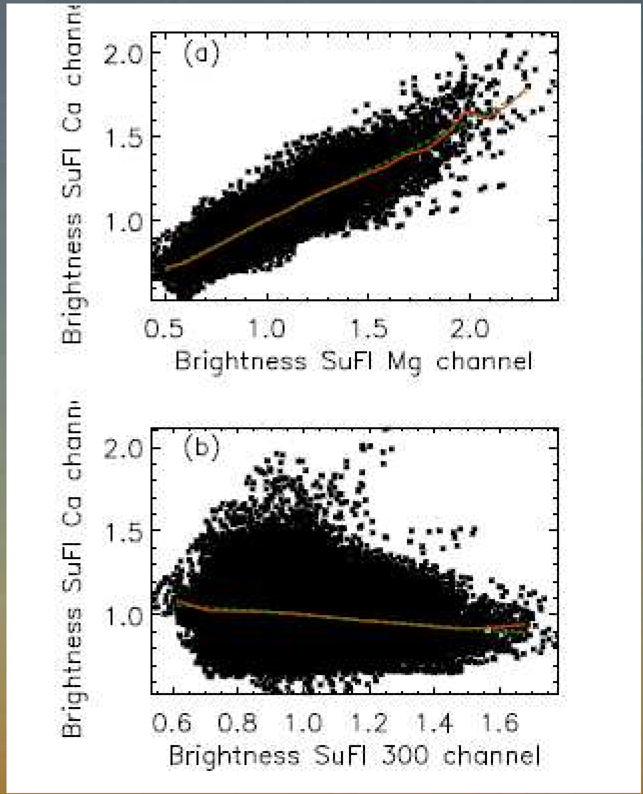
and many, many more to be expected......

Riethmüller et al., 2013, APJL



Remarkable similarity between Mg II k and Ca II h





Danilovic et al., submitted

Summary

- In spite of a number of issues (early loss of telemetry; extremely quiet Sun; only short time series) first Sunrise science flight was highly successful, providing unique data
- A significant number of results have been obtained, almost all of them were unexpected
- A lot more exciting science is still hidden in these data
- Data of second flight 2013 not fully reduced so far, but first data are promising
- first results of SUFI Mg II k data are published

Outlook

- Quality of Sunrise data is resounding, but they are not perfect
  - residual jitter
  - residual aberrations
  - photon noise in blue channels
- Phase diversity can help, but cannot do magic
  - photon noise is dominant driver at larger apertures!
  - becomes more and more severe when going to apertures larger than 1m

On behalf of the SUNRISE team:

Thank you very much for your interest!

Sunrise data access

http://star.mpae.gwdg.de/Sunrise/

The SuFI data are available on the web:

http://www.mps.mpg.de/data/projekte/sunrise/sufidata/level2/

http://www.mps.mpg.de/data/projekte/sunrise/sufidata/level3/

Please see the readme files:

http://www.mps.mpg.de/data/projekte/sunrise/sufidata/level2/readme.pdf

The IMaX data are available on the web:

http://www.mps.mpg.de/data/projekte/sunrise/imaxdata/level1/

http://www.mps.mpg.de/data/projekte/sunrise/imaxdata/level2/