SYNERGIES: How does DKIST augment the science of state-of-the-art missions

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COLLAGE; 28 Apr 2020

Two state-of-the-art “missions”:

IRIS

NUV/FUV rastering spectrograph

Spectral Range: 278.5 – 283.5 nm (NUV)
133.2 – 135.8 nm & 139.0 – 140.6 nm (FUV)
FOV = 120” x 0.16” (slit); 170”x170” (SJI)
Cadence: 1- 20 s (single exposure)
Spatial resol: 0.33” – 0.4”

ALMA

Radio interferometer

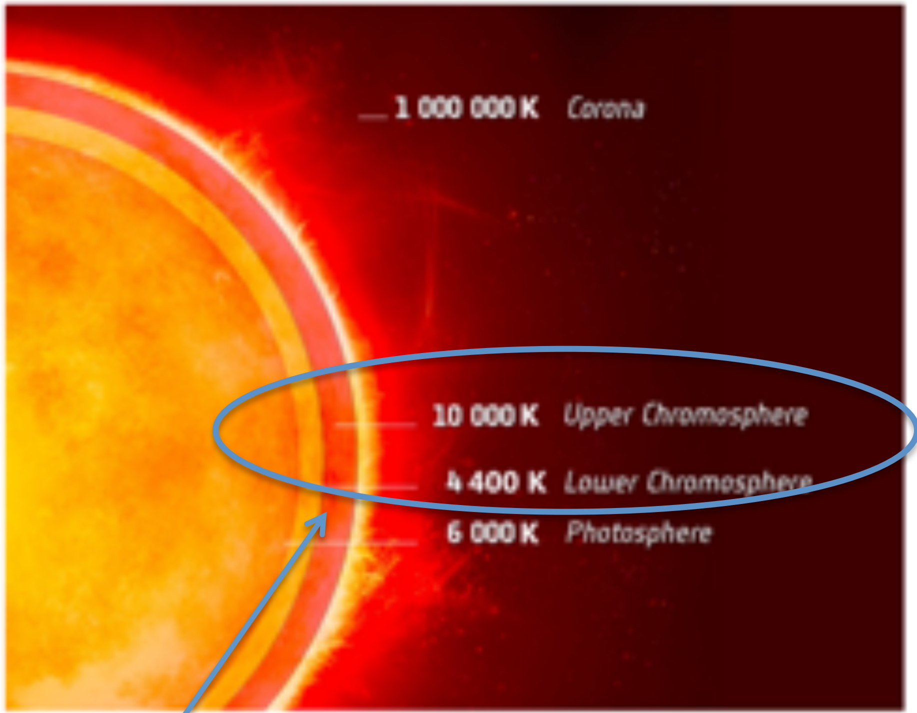
Range: 0.3 – 10 mm
FOV = λ-dependent; e.g. 60” @ 3 mm
Cadence: 1- 2 s
Spatial resol: baseline dependent; up to 0.015” x λ (mm)

BOTH REMOTE SENSING

From your first lesson…..

When we observe, we see the solar **atmosphere.**

- Stars are gaseous, there is no sharp distinction.
- *„Why in the world would anyone want to study stellar atmospheres? They contain only 10^{-10} of the mass of a typical star. Surely such a negligible fraction of a star's mass cannot affect the overall structure and evolution!" (Edward Salpeter to Dmitri Mihalas)*
- A quick answer: We can't see deeper!
- But also, the atmosphere responds to the 'inner' processes

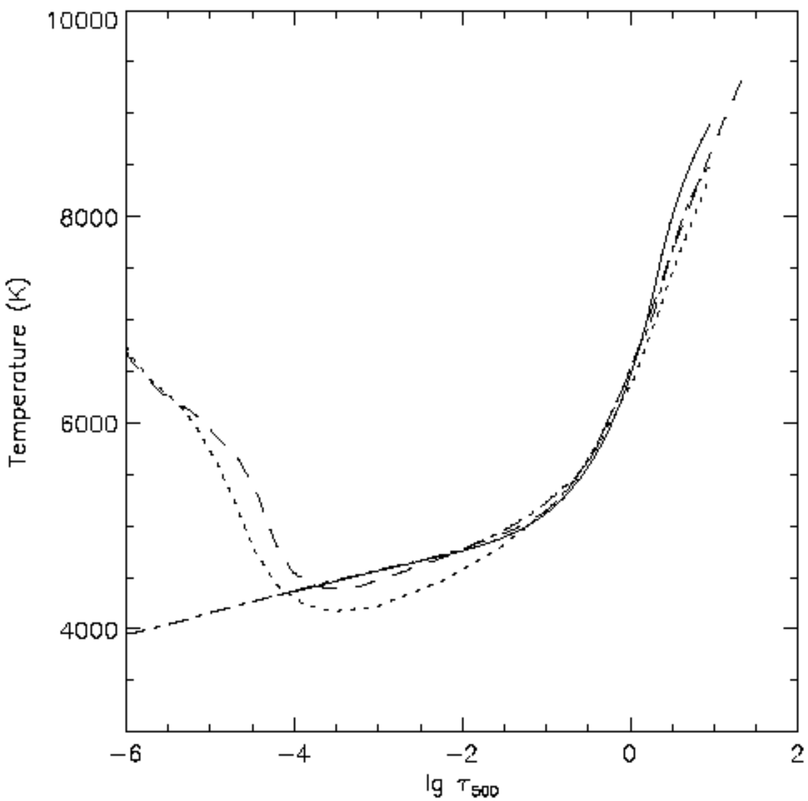


Credits: ESA

Both IRIS and ALMA are well suited to study the chromosphere

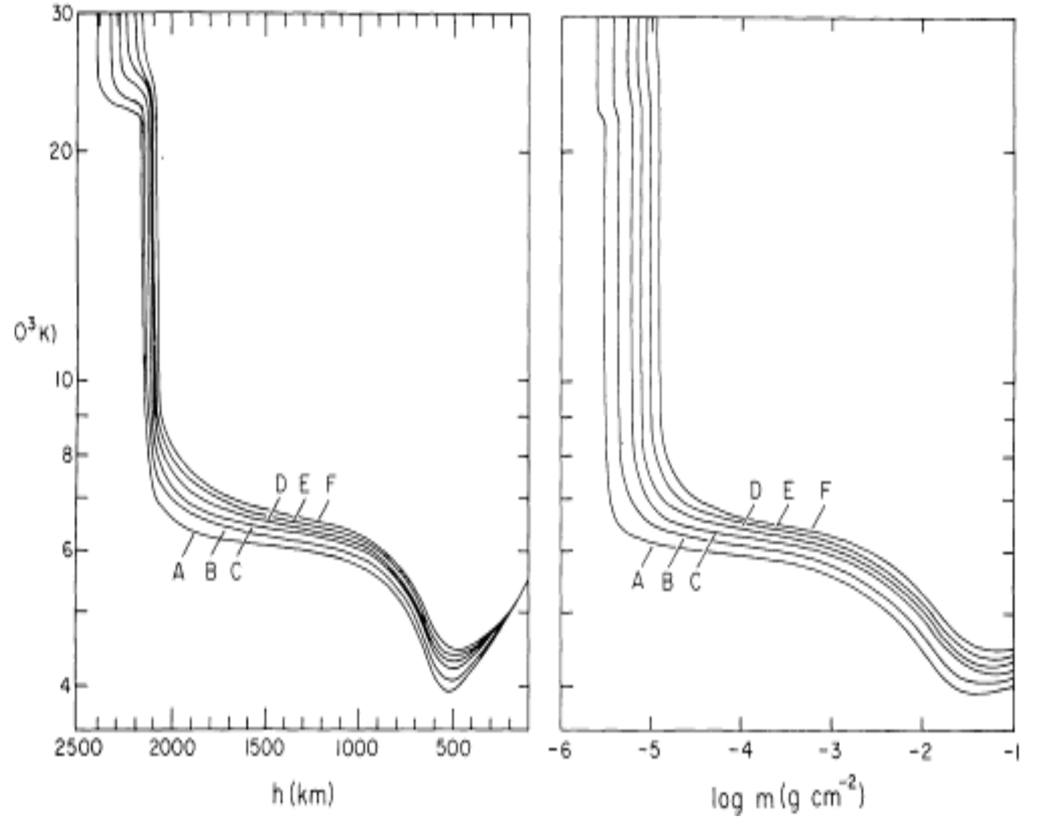
Some quick reminder about the chromosphere (1)

Radiative/convective equilibrium



Carlsson et al 1992

Input of "mechanical energy"

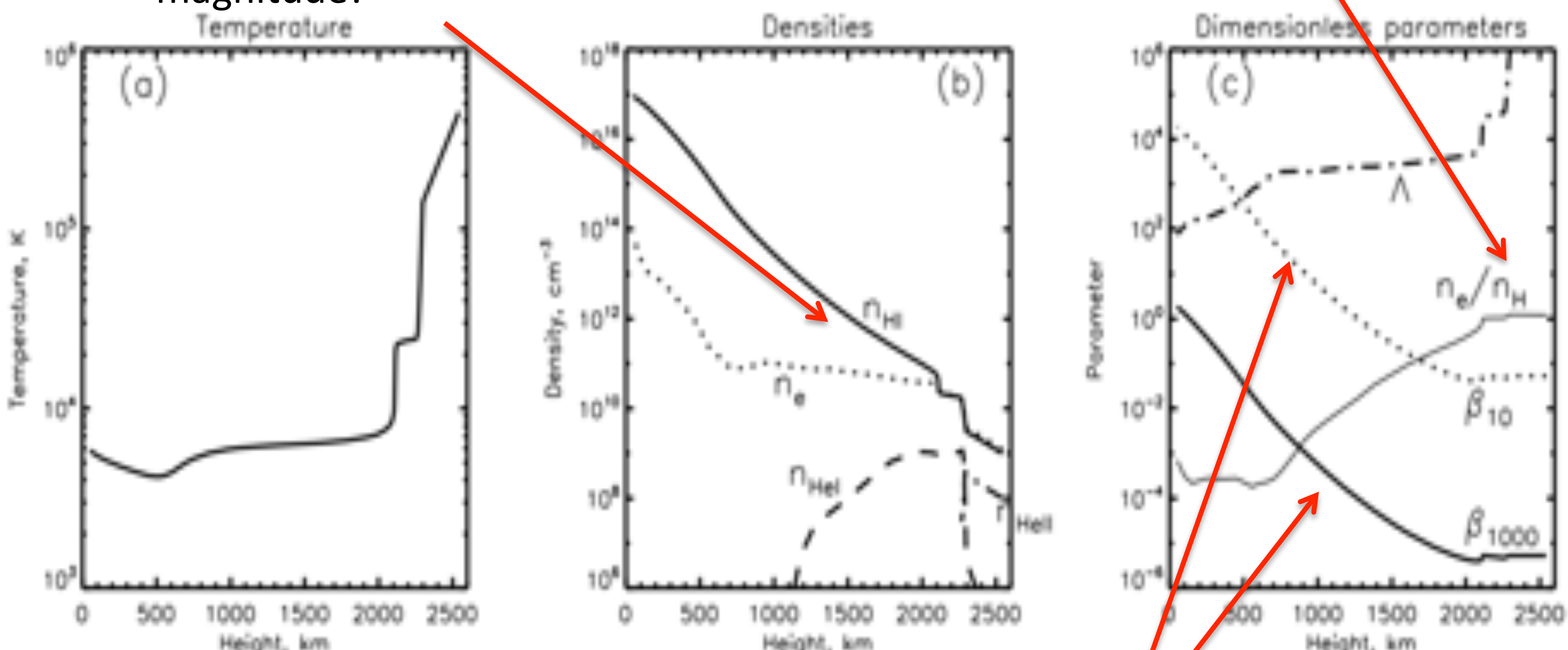


Vernazza et al 1981

Some quick reminder about the chromosphere (2)

Density decreases 6-7 orders of magnitude!

From neutral to fully ionized



Height now goes the other way….

Magnetic field becomes more important (β -> very small)

Hudson 2007

Some quick reminder about the chromosphere (3)

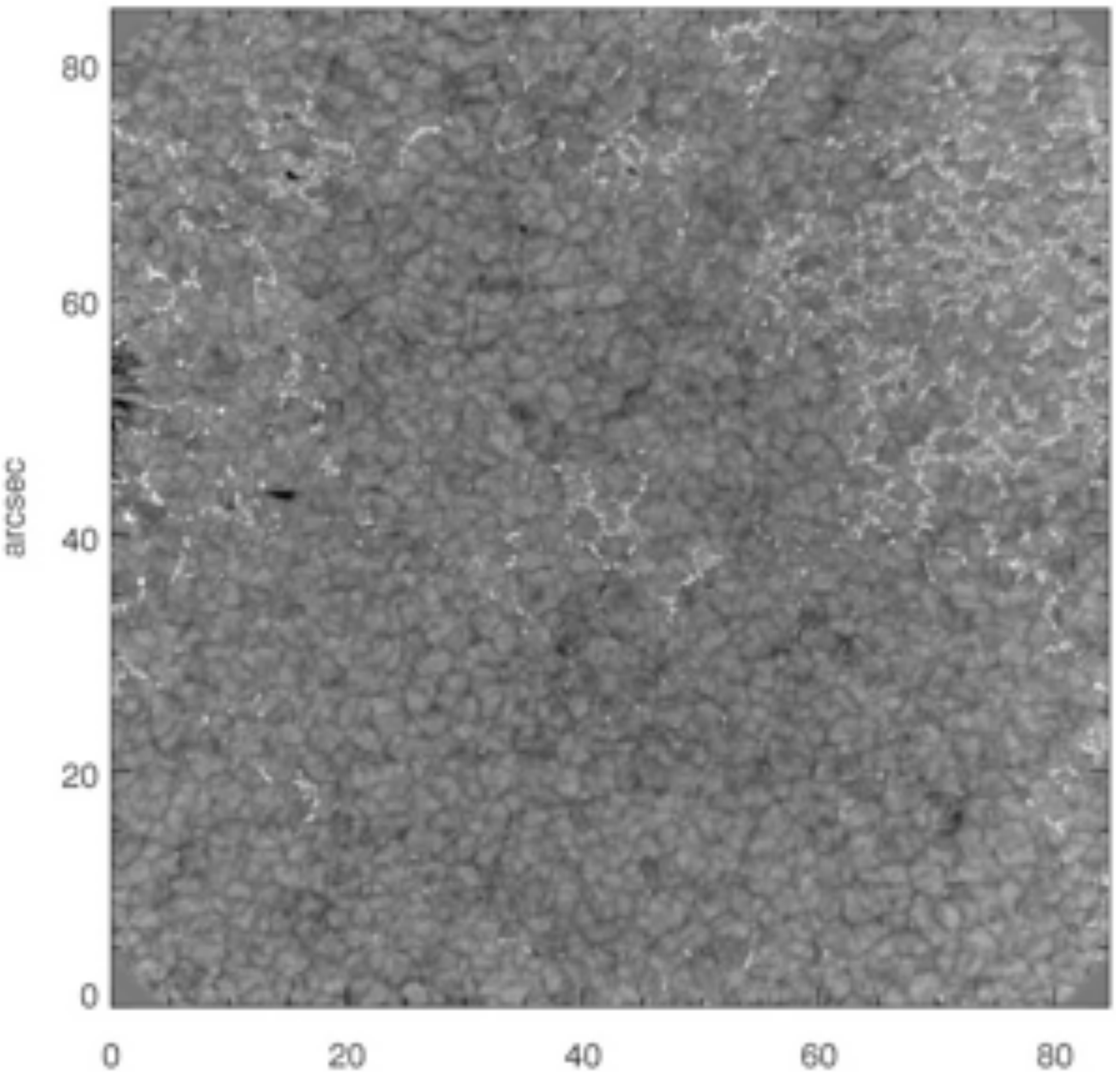
Tenuous gas: we get further and further away from the LTE conditions of the photosphere, that require strong collisions*. Your ε becomes smaller and smaller! Your S_ν becomes less and less like B_ν !*

Tenuous gas: dynamics deviates (strongly) from HS equilibrium, as perturbations (think, waves) can amplify strongly

Tenuous gas: the magnetic field falls off much slower than gas density, so it starts dominating the dynamics ($\beta < 1$)

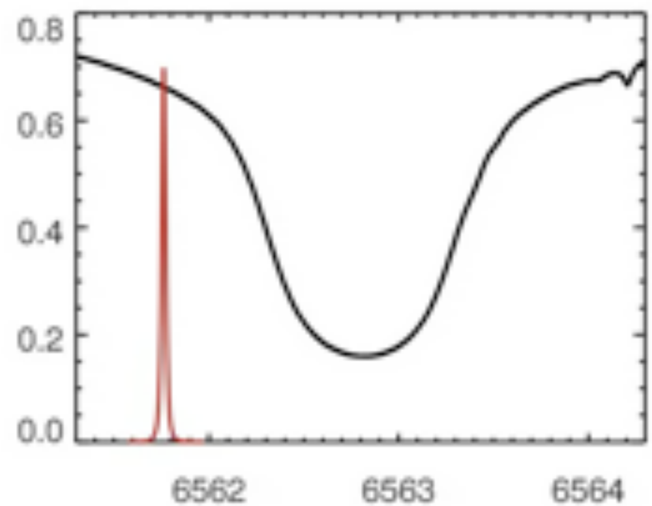
VERY different than the photosphere !!! Inversions feasible but more difficult

Example: Magnetic structuring



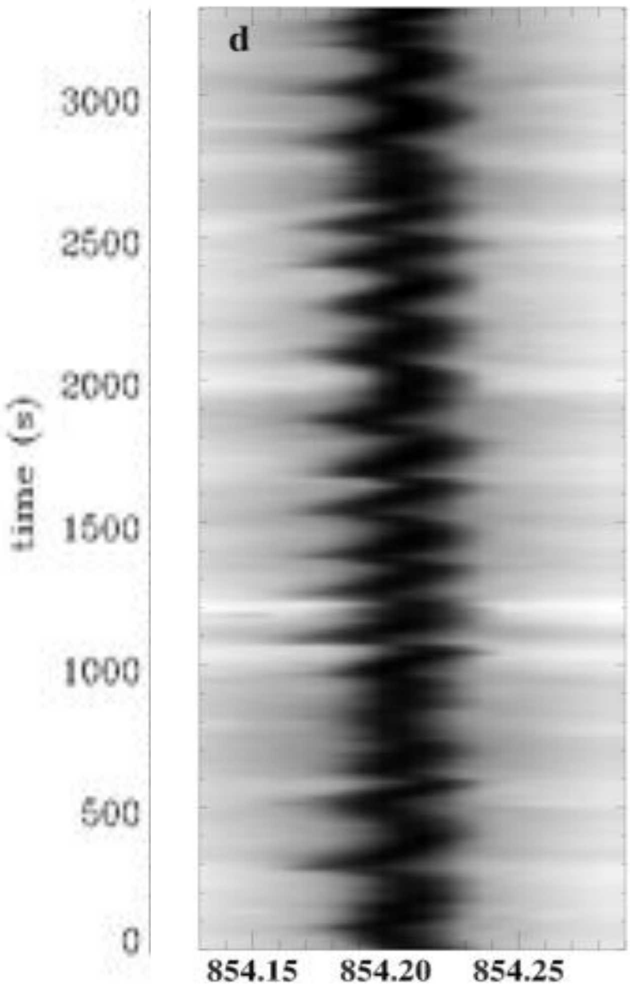
IBIS

23 April 2017

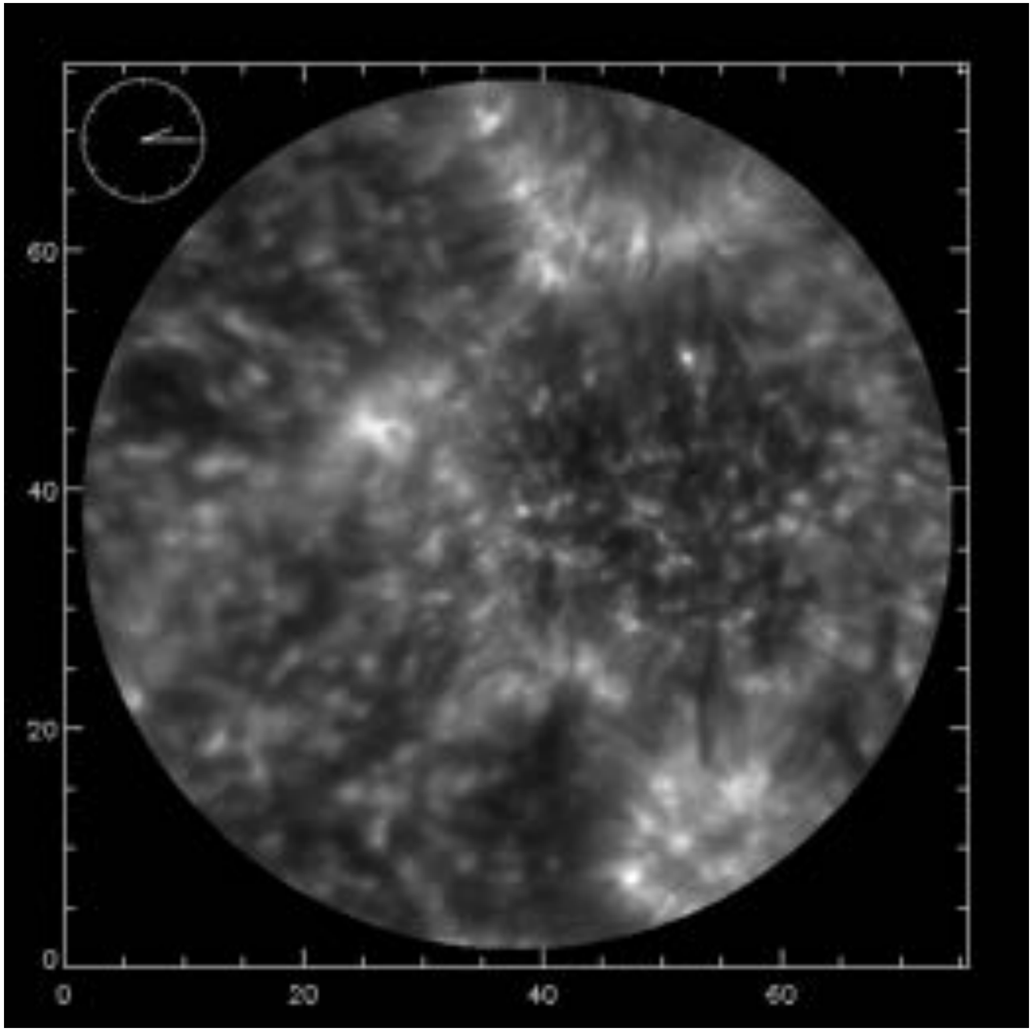


Hα – 653 nm

Example: HD shocks



Vecchio et al 2009; see also Carlsson & Stein 1995



Cauzzi et al. 2008

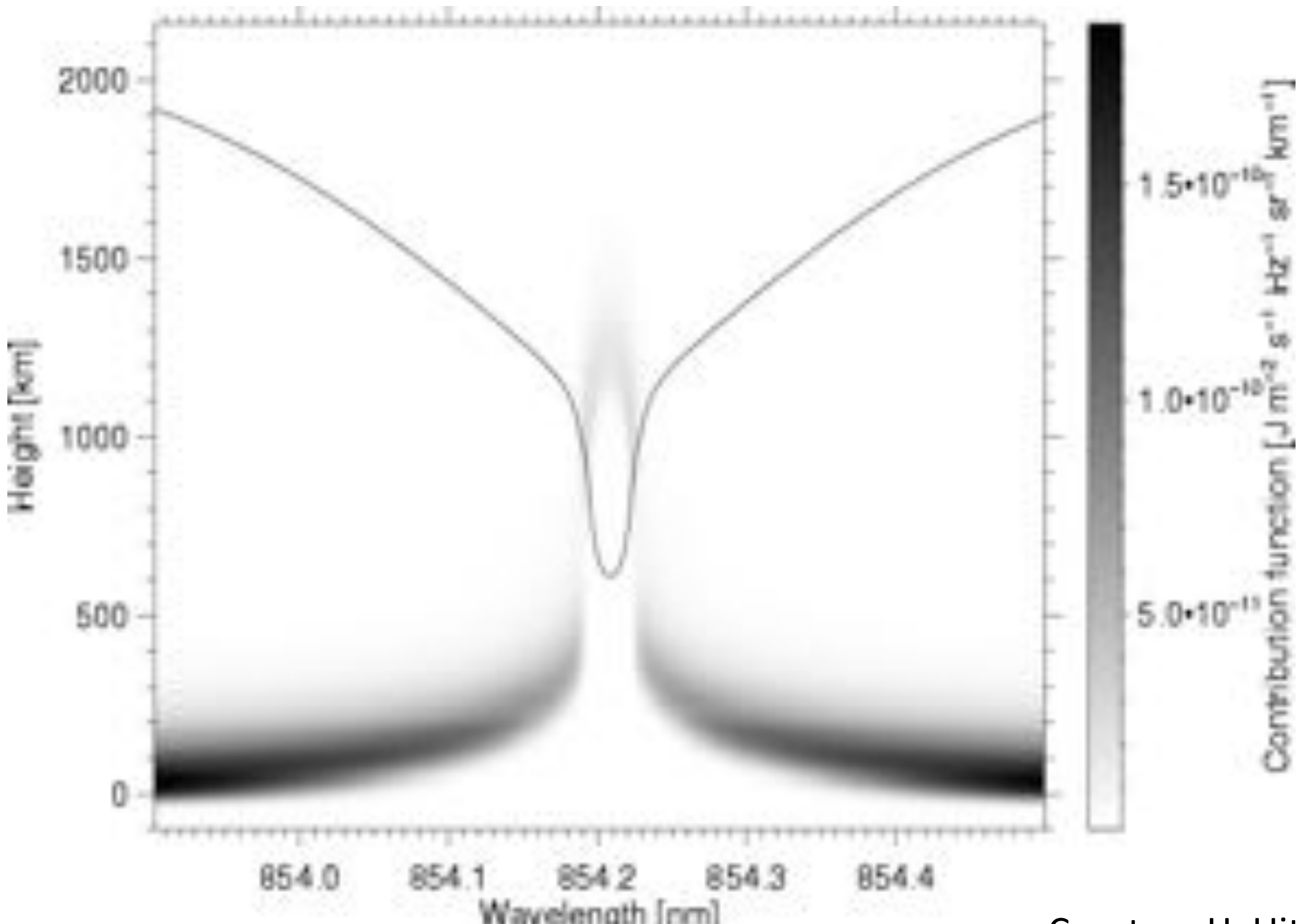
Some quick reminder about the chromosphere (4)

A change of diagnostics: from neutral to ionized elements

Tenuous gas: requires “strong” lines (probable transitions). E.g. from very abundant species (H, He) or resonance lines of other, relatively abundant elements

In the visible / near IR: not much! H Balmer lines (strongly scattering!), some HeI lines (e.g. 1083 nm); CaII H&K (resonance) and IR triplet.

CaII 854.2 nm contribution function



Courtesy H. Uitenbroek

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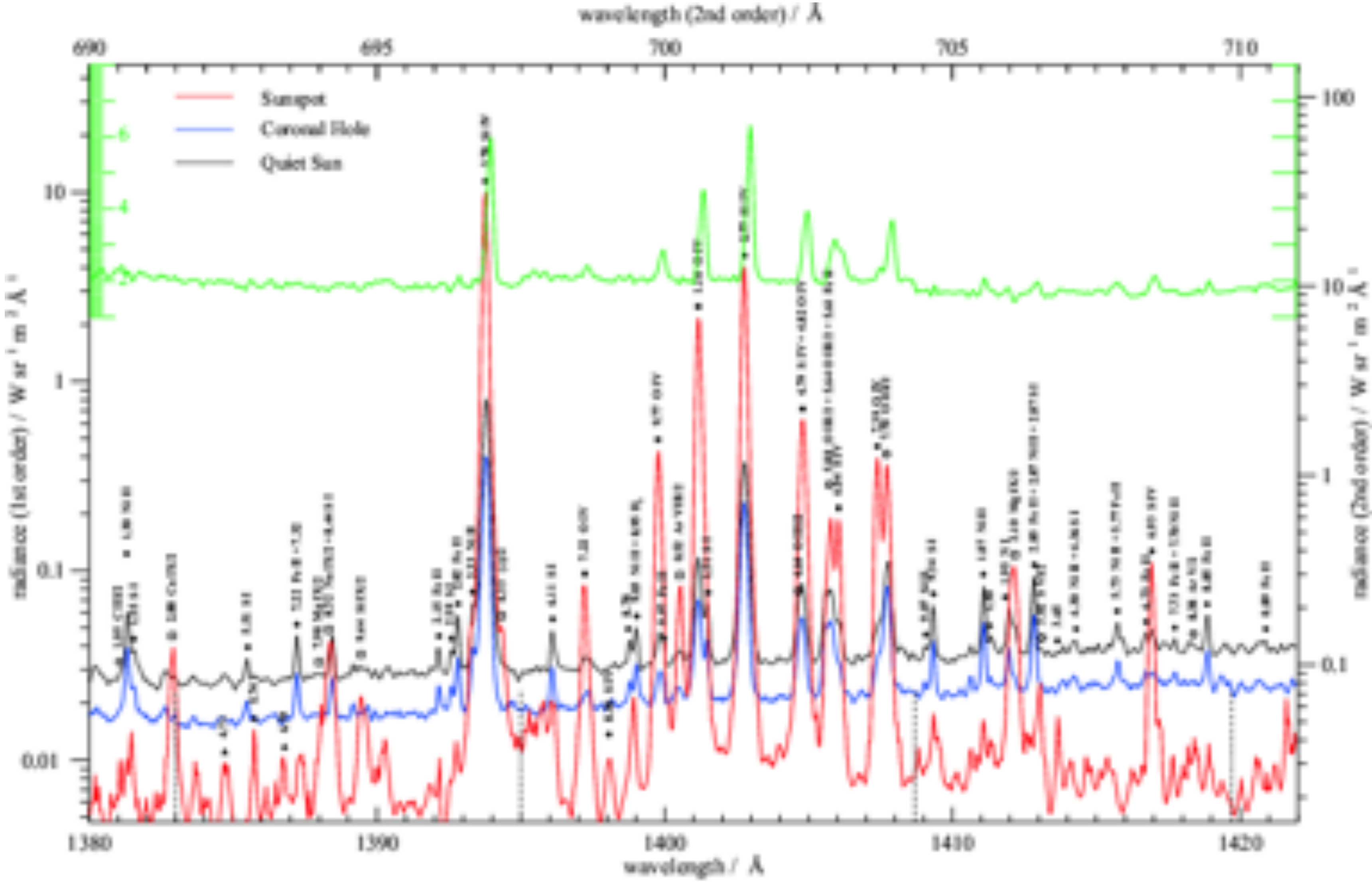
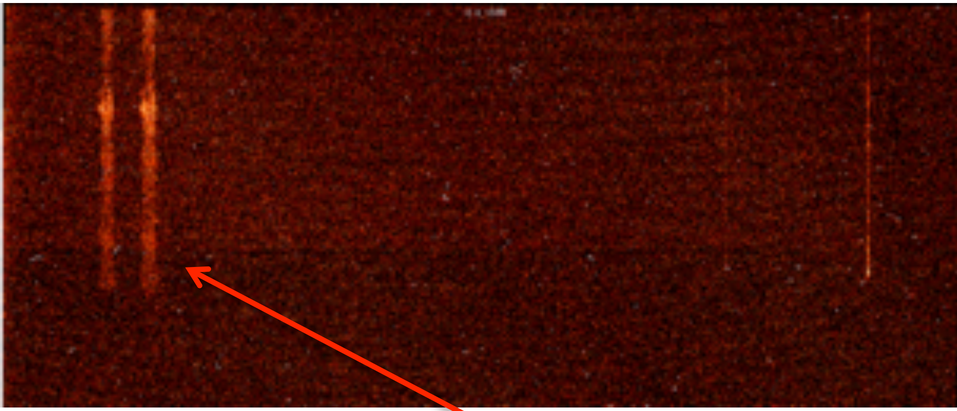
Most resonance lines are at UV wavelengths (or shorter). E.g. H I, C I-IV, N I-V, O I, Mg I-II, Si I-II, S I-II, Fe II. So the UV is a PRIME hunting ground for chromospheric diagnostics.

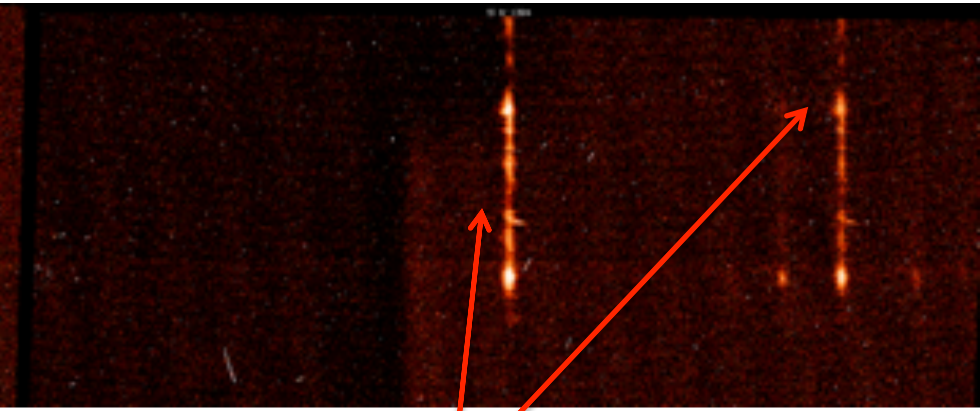
SUMER full disk atlas



Curdt et al 2001

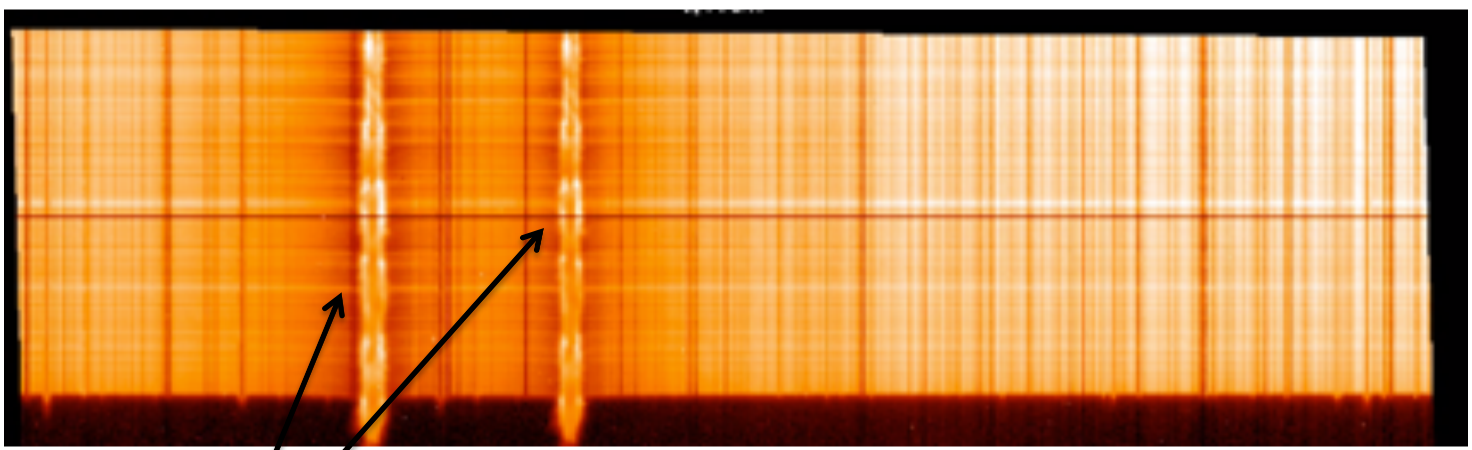
IRIS example data





FUV 1
(C II resonance lines @ 133.5 nm)

FUV 2
(Si IV resonance lines @ 140 nm)

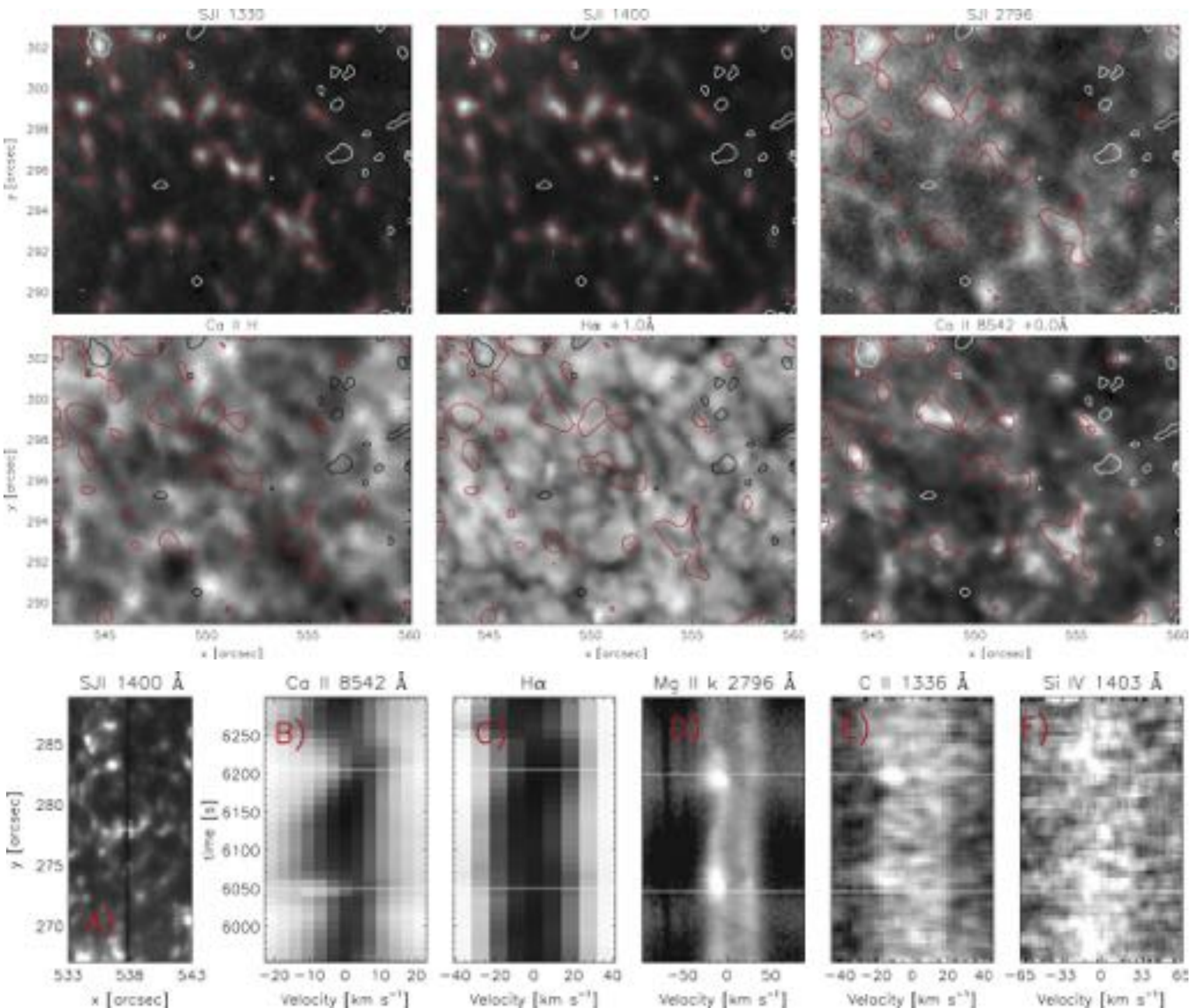


NUV (Mg II resonance lines @ 280 nm) + many other, also photospheric

IRIS data webpage:

https://iris.lmsal.com/data.html

Some IRIS results: acoustic shocks



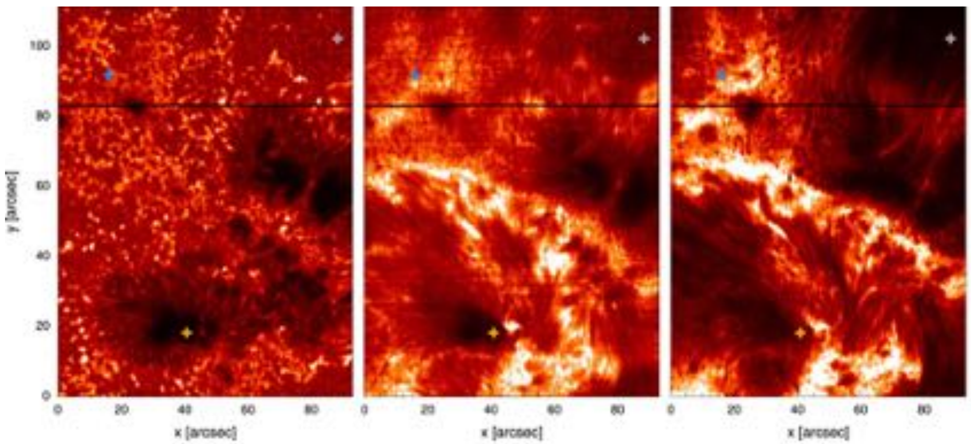
Investigate whether acoustic shocks in quiet Sun are heated at TR temperatures?

Answer: NO

Higher resolution (spatio/temporal) investigation with VTF + ViSP might offer further insight on spatial structuring

Martinez Sykora et al 2015

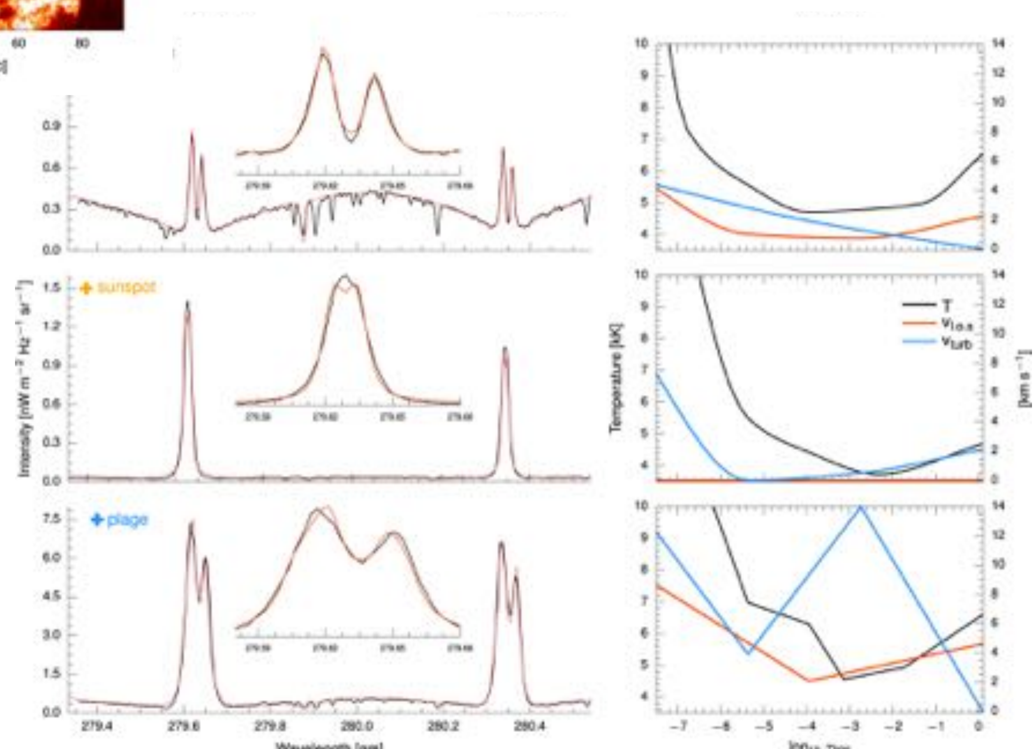
Some IRIS results: spectral inversions to derive the chromospheric temperature structure



MgII k wing; MgII (subordinate) core; Mg II k core

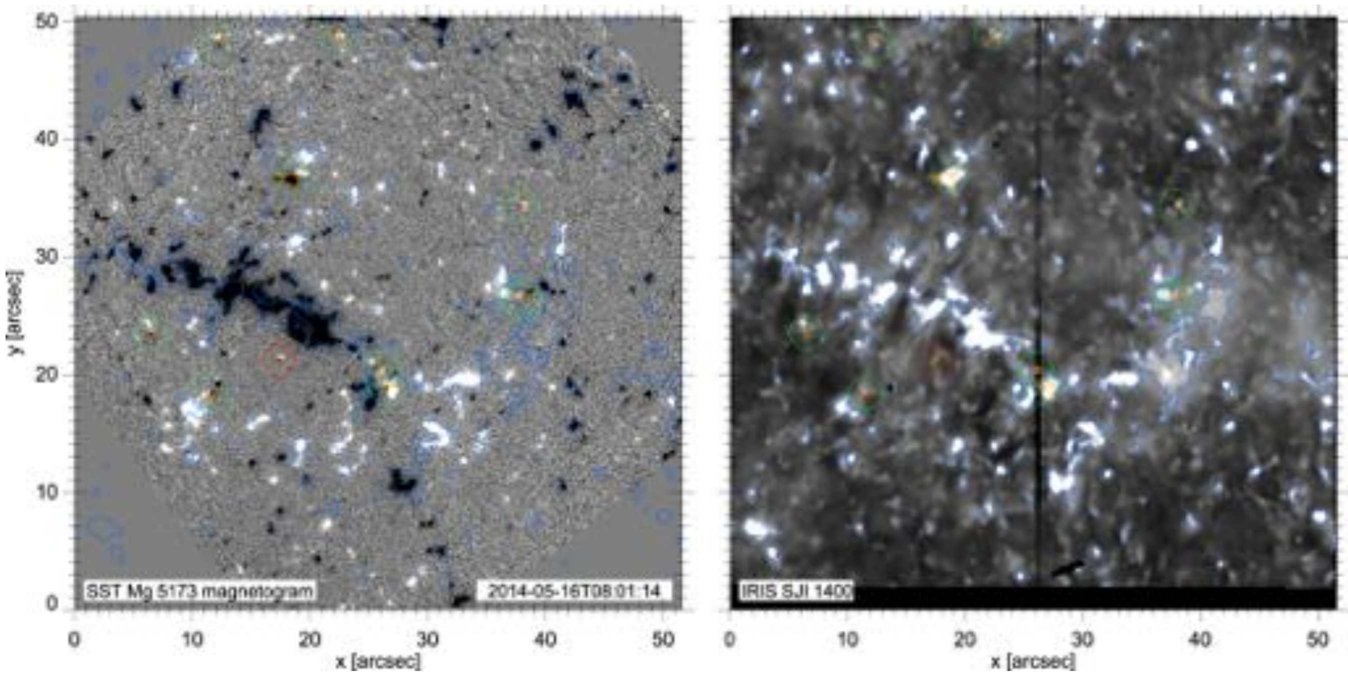
De la Cruz Rodriguez et al 2016

Spectral inversions:
Non LTE, PRD



Complementary chromospheric signatures (CaII 854.2, Halpha…..) with ViSP/DL-NIRPS, as well as polarimetric data will improve our understading of chromospheric heating

Some IRIS results: effects of small-scale magnetic cancellation



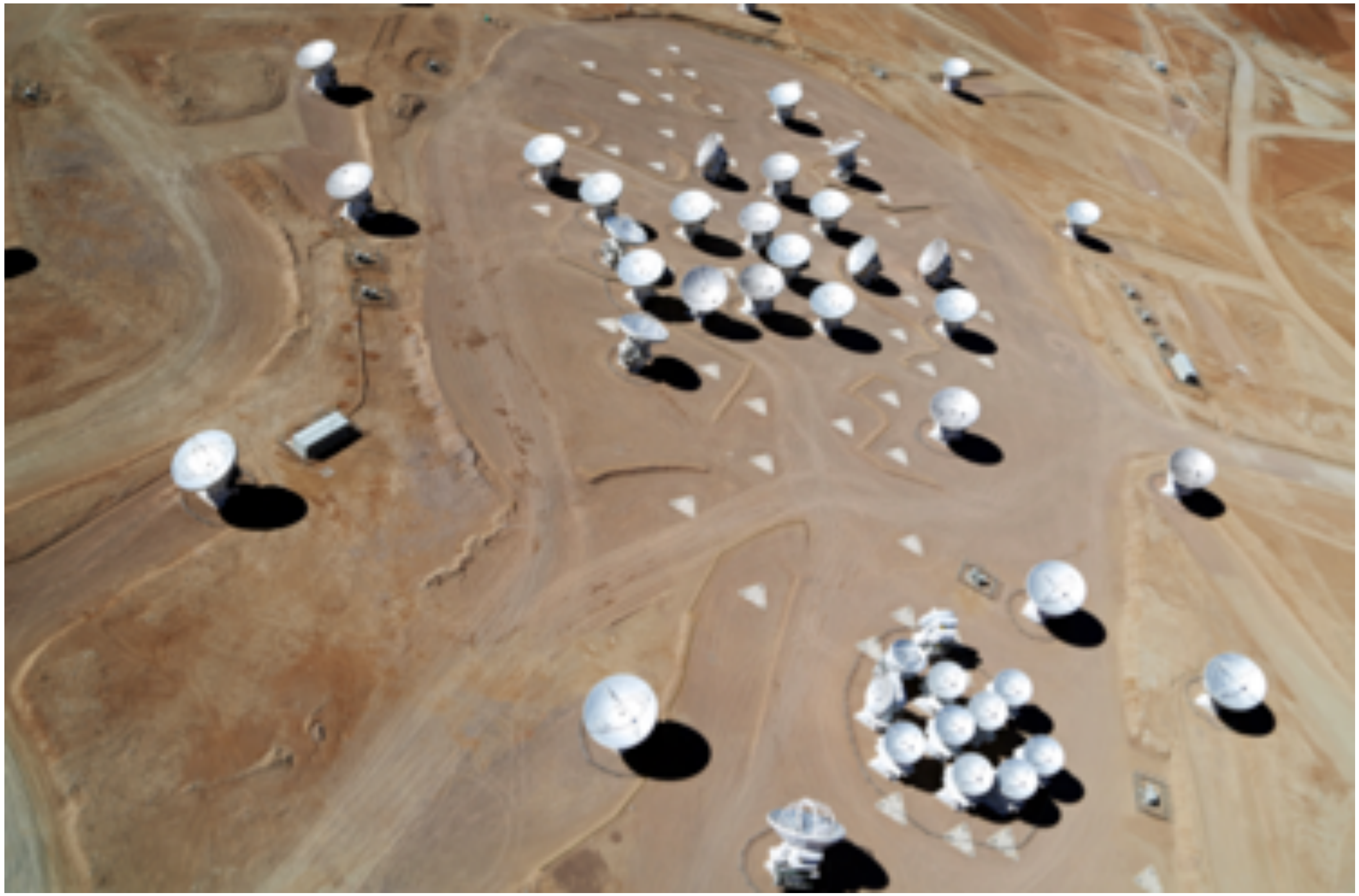
Gosic et al 2018

Photospheric magnetograms from visible (FeI 6302.5 nm; SST) reveal small scale cancellation of flux in the quiet Sun. IRIS shows related heating events in chromosphere. Using inversions of MgII, they determine heating is still low to justify global chromospheric heating

Higher resolution and polarimetric sensitivity with DKIST might provide further insights

Atacama Large Millimeter Array
ALMA

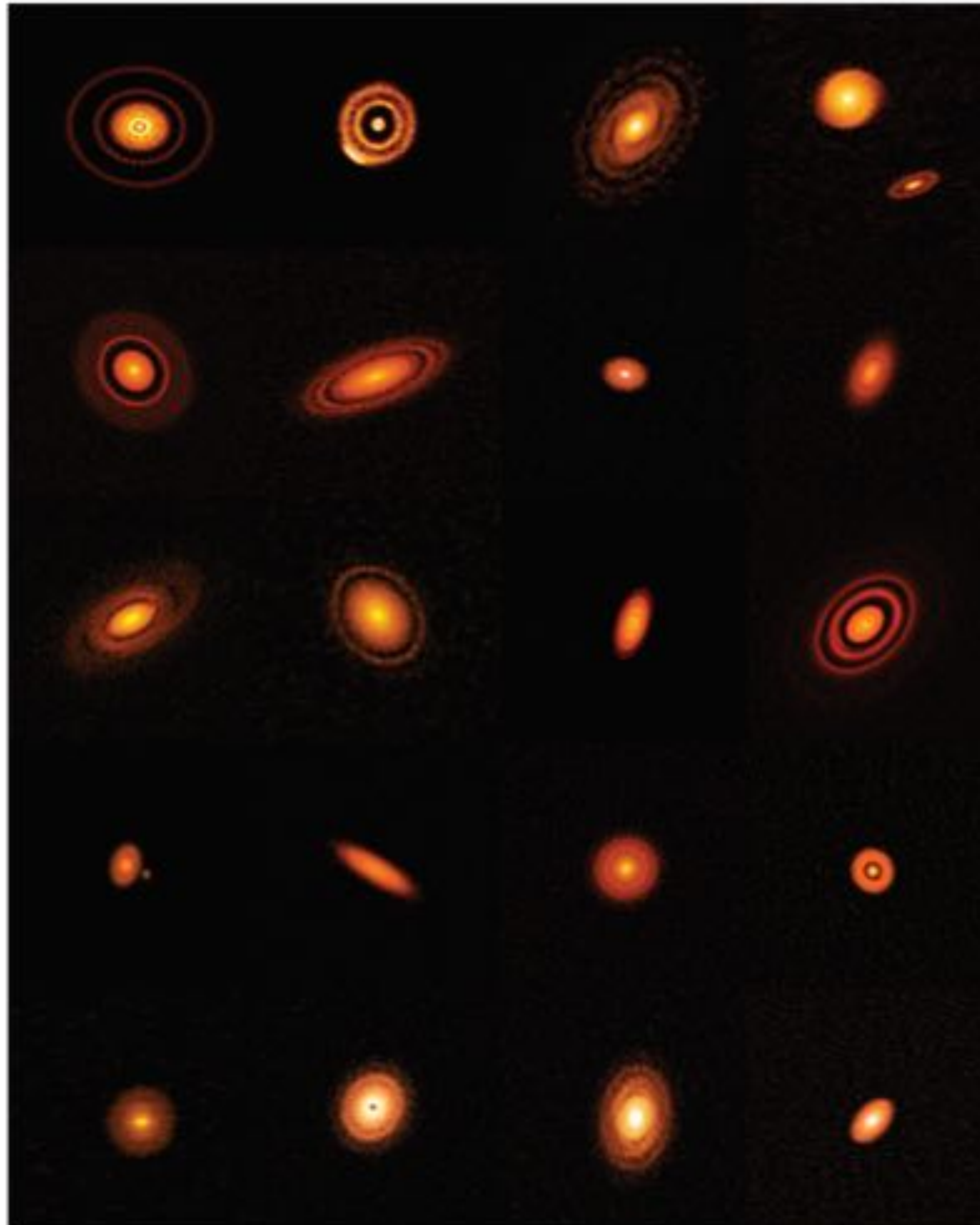
0.3 − 9 mm range
30-950 GHz



- Atacama desert, northern Chile (5000+ m)
- One array of 50 (goal: 64), 12-m diameter antennas, baseline 150 m to 15 km (the 12 m array)
- One array with 4, 12-m antennas, and 12, 7-m antennas in a compact configuration (ACA).

Broad range of science (molecular clouds, GRB, protoplanetary disks, black holes…

Long baselines allow very high spatial resolution, up to 4 mas (0.015” x λ (mm))



ALMA for solar observations

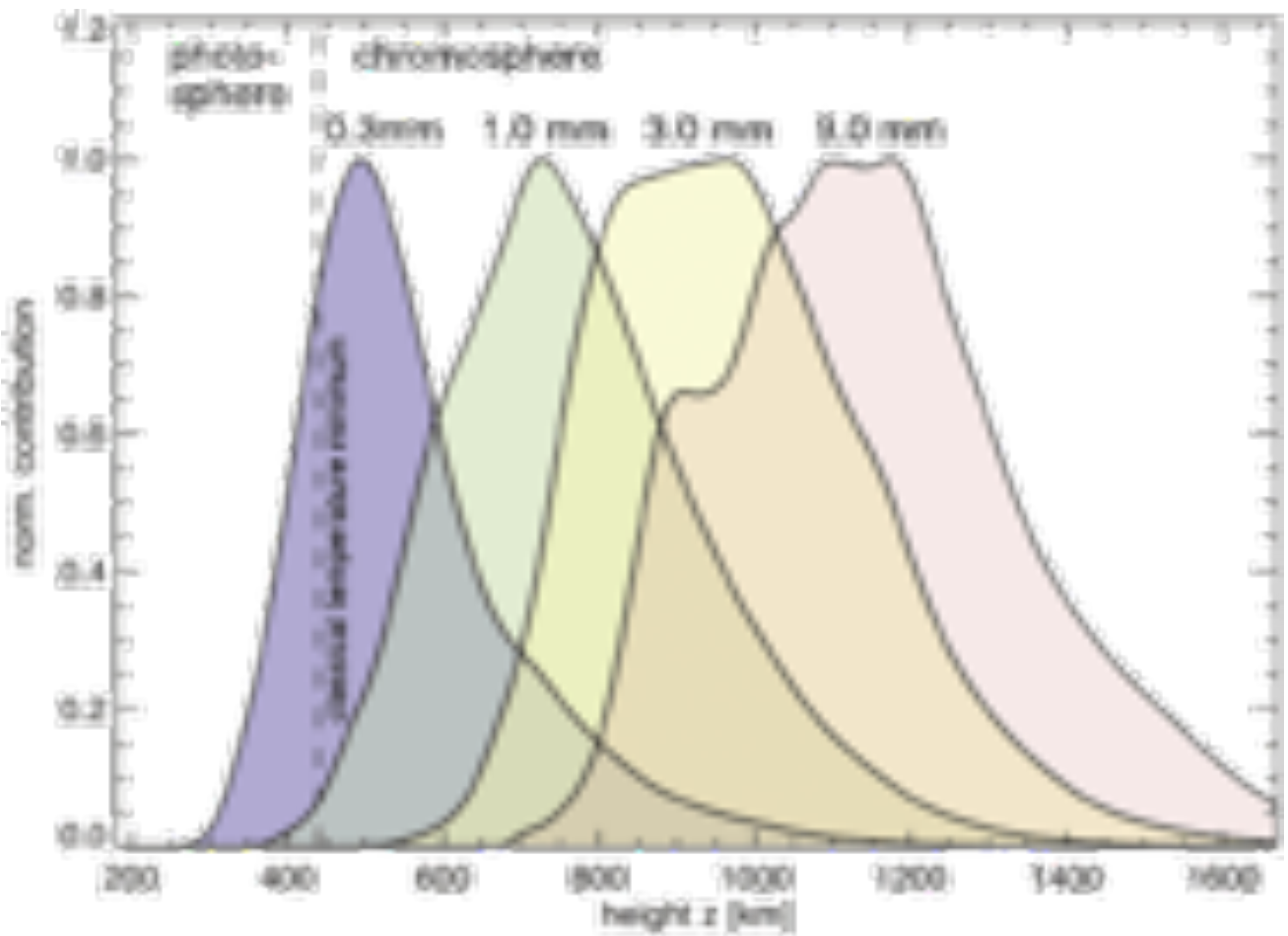
- ALMA bands 6 (1.25 mm) and 3 (3 mm) available since late 2016 for solar obs.
- Max. baseline ~ 500 m -> max. spatial res. ~ 0.6” (band 6) and 1.6” (band 3)
- Limited FOV: 25” (band 6) 50” (band 3)
- High temporal cadence: 1-2 s

ALMA as a linear chromospheric thermometer

- In the Sun, the continuum at mm wavelength is formed at chromospheric heights
- The 1-3 mm continuum is due to f-f emission, mostly electron – ion interaction ($H^+ + e^- + \gamma$)
- Processes are coupled solely to local plasma conditions (no scattering): LTE is valid; $S_\nu = B_\nu$
- At long wavelength, the Rayleigh-Jeans limit holds: $B(T) \propto T$ => intensity scales linearly with temperature ($T_B = T_e$)

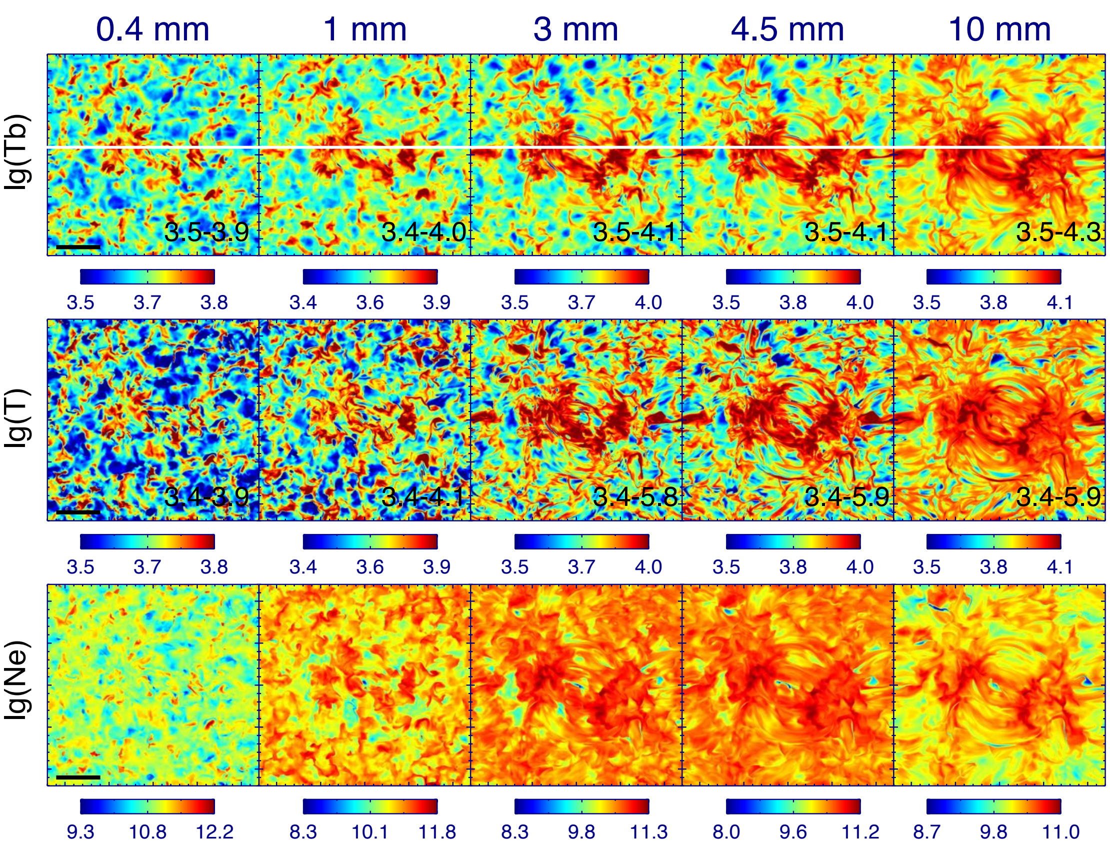
cf. Loukitcheva et al. 2015; Wedemeyer et al. 2016, SSRv

ALMA intensity – formation heights

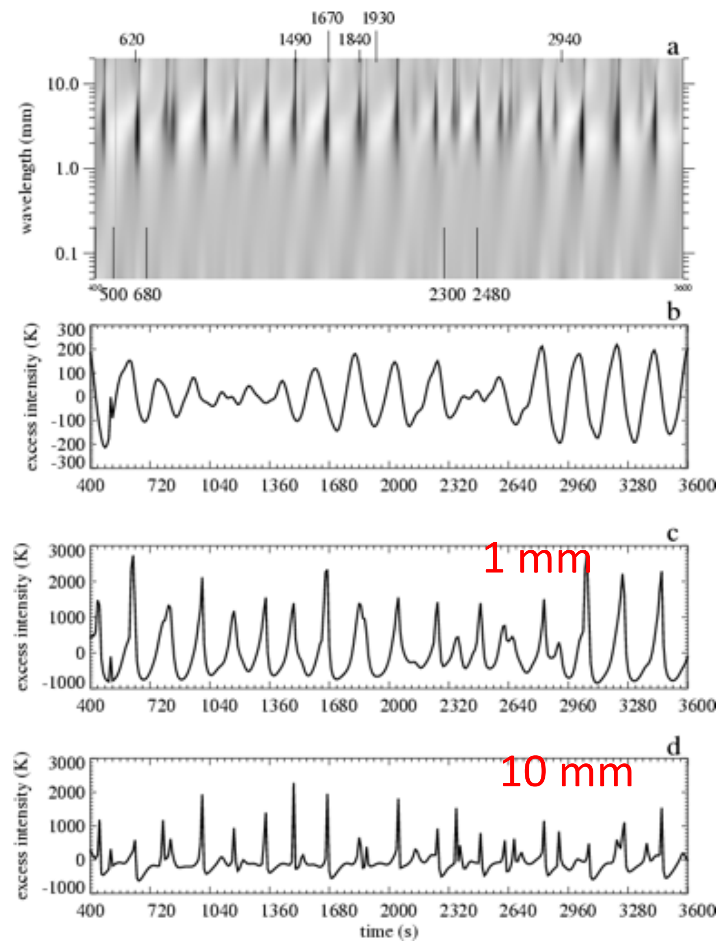


Wedemeyer Bohm et al 2015

ALMA as a linear chromospheric thermometer: model predictions



(FOV + 24 Mm x 24 Mm) Loukitcheva et al. 2015

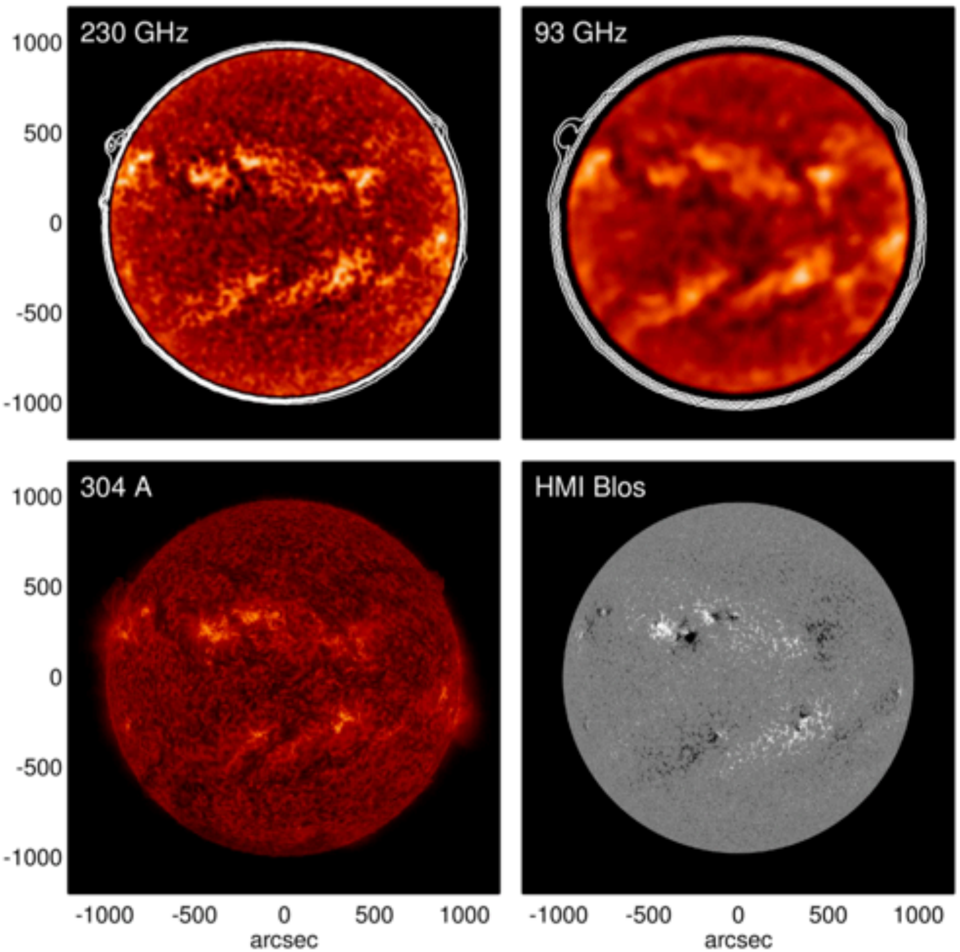


Loukitcheva et al. 2004

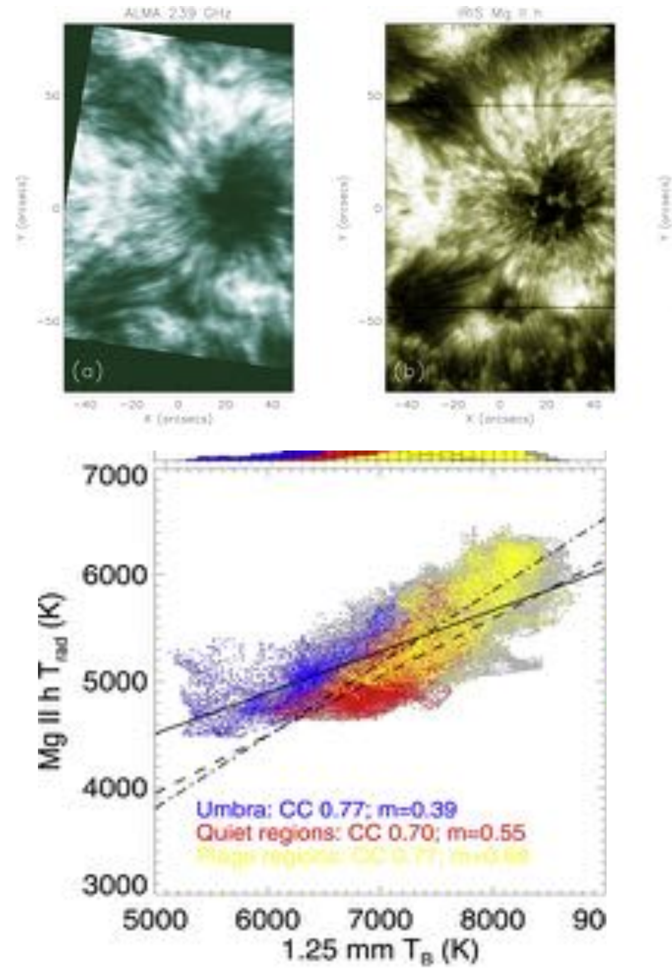
Some first ALMA results

1.3 mm; 5300-7400 K

3 mm; 6700-8800 K



White et al 2017



Bastian et al 2017

ALMA – DST – IRIS coordinated observations 23-Apr-2017

DST:

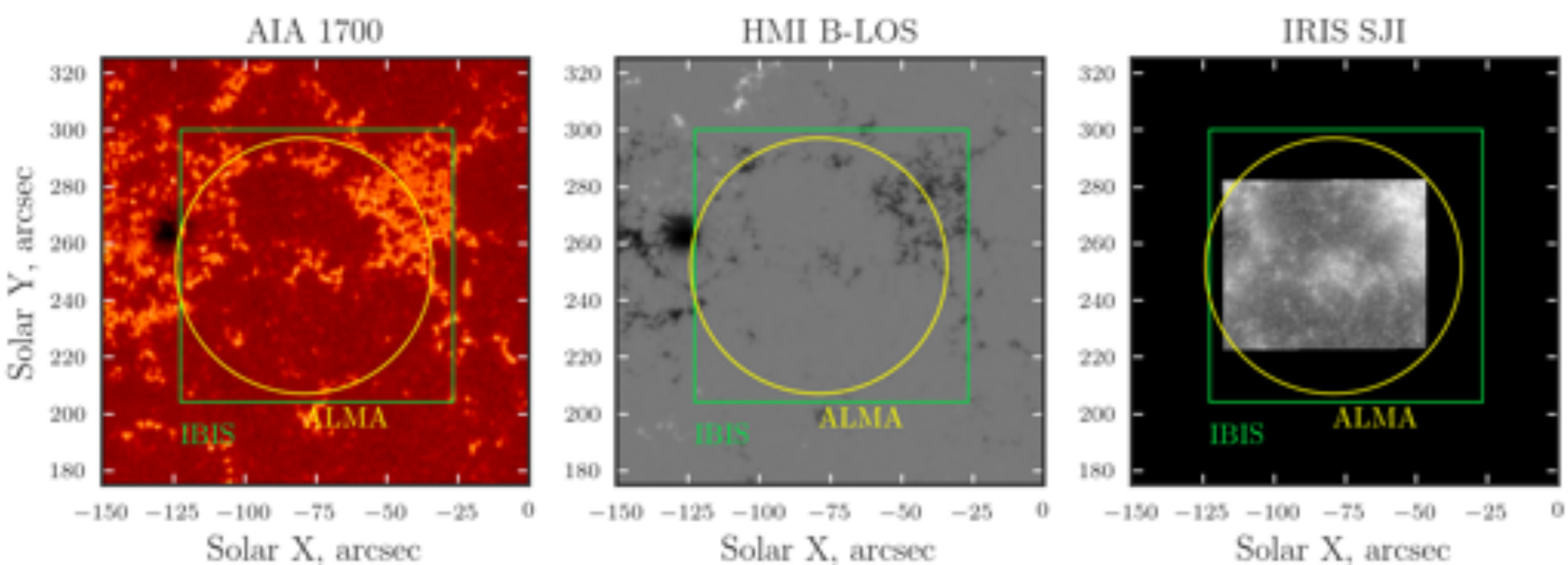
IBIS : Hα, CaII 854.2 nm, Na D1
FOV: 96” x 96”
Cadence: 16 s, ~ 40 min

IRIS:

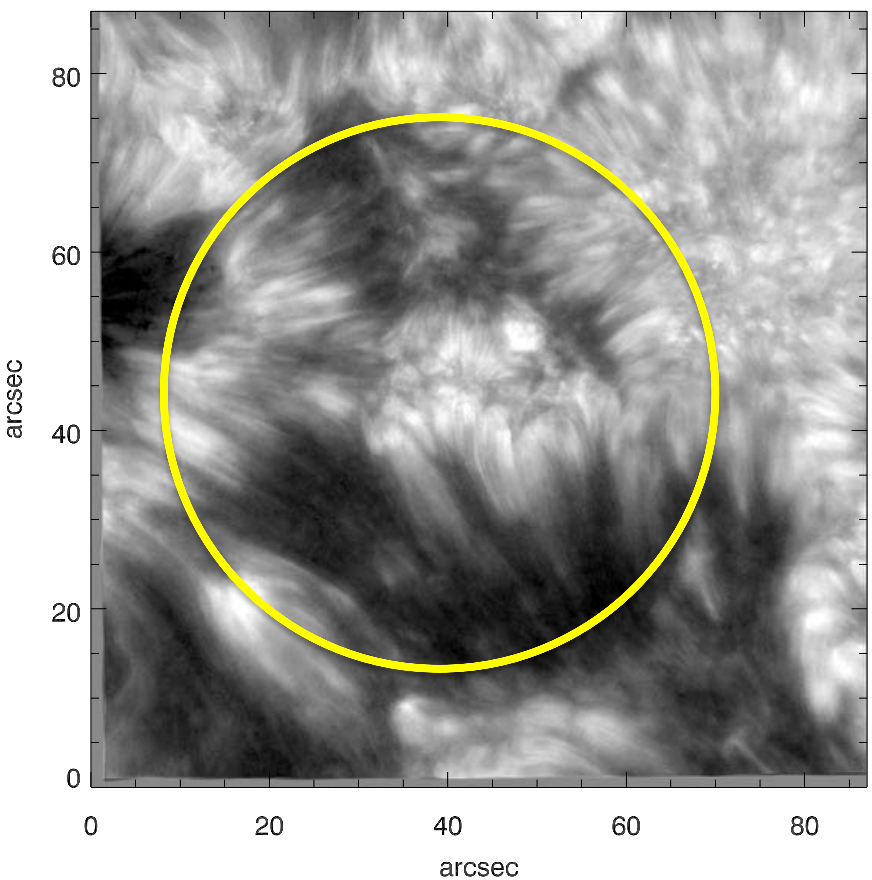
Medium coarse 8-step raster, Mg II

ALMA:

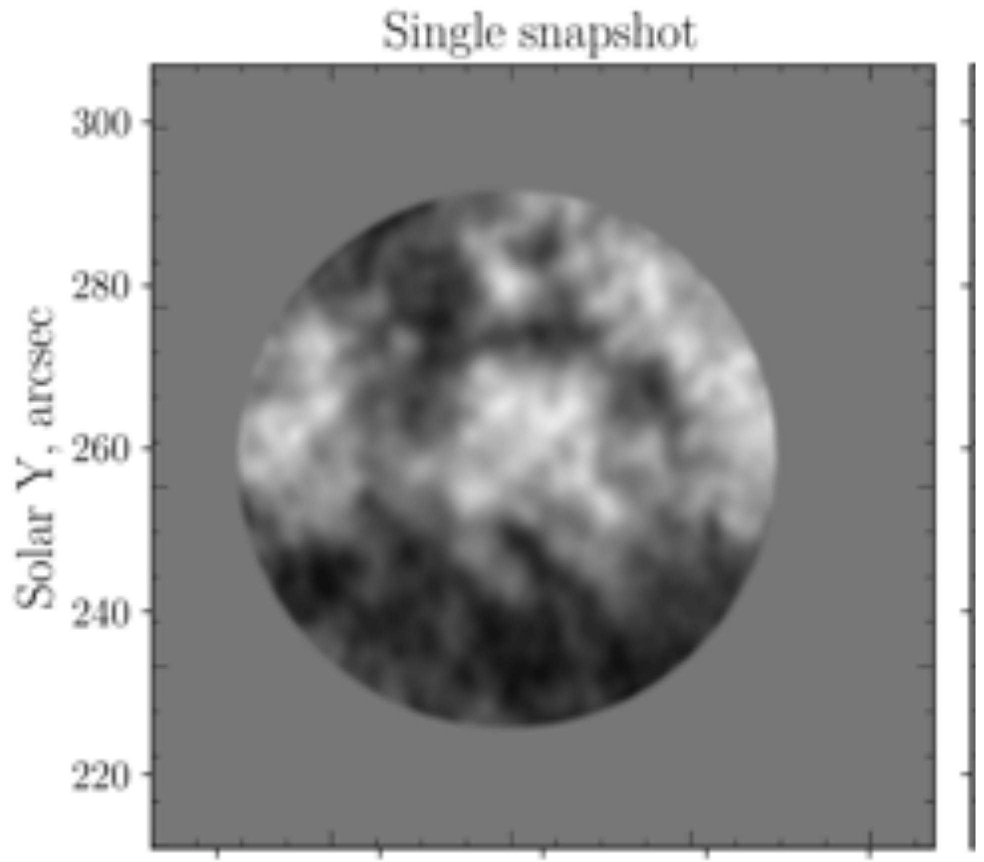
Band 3 (3 mm) and band 6 (1.25 mm)
FOV: ~ 90” diameter (-> 60”)
10 min obs. block, followed by 2 min calibrations
Cadence: ~ 2 s



IBIS Hα –ALMA 3 mm comparison



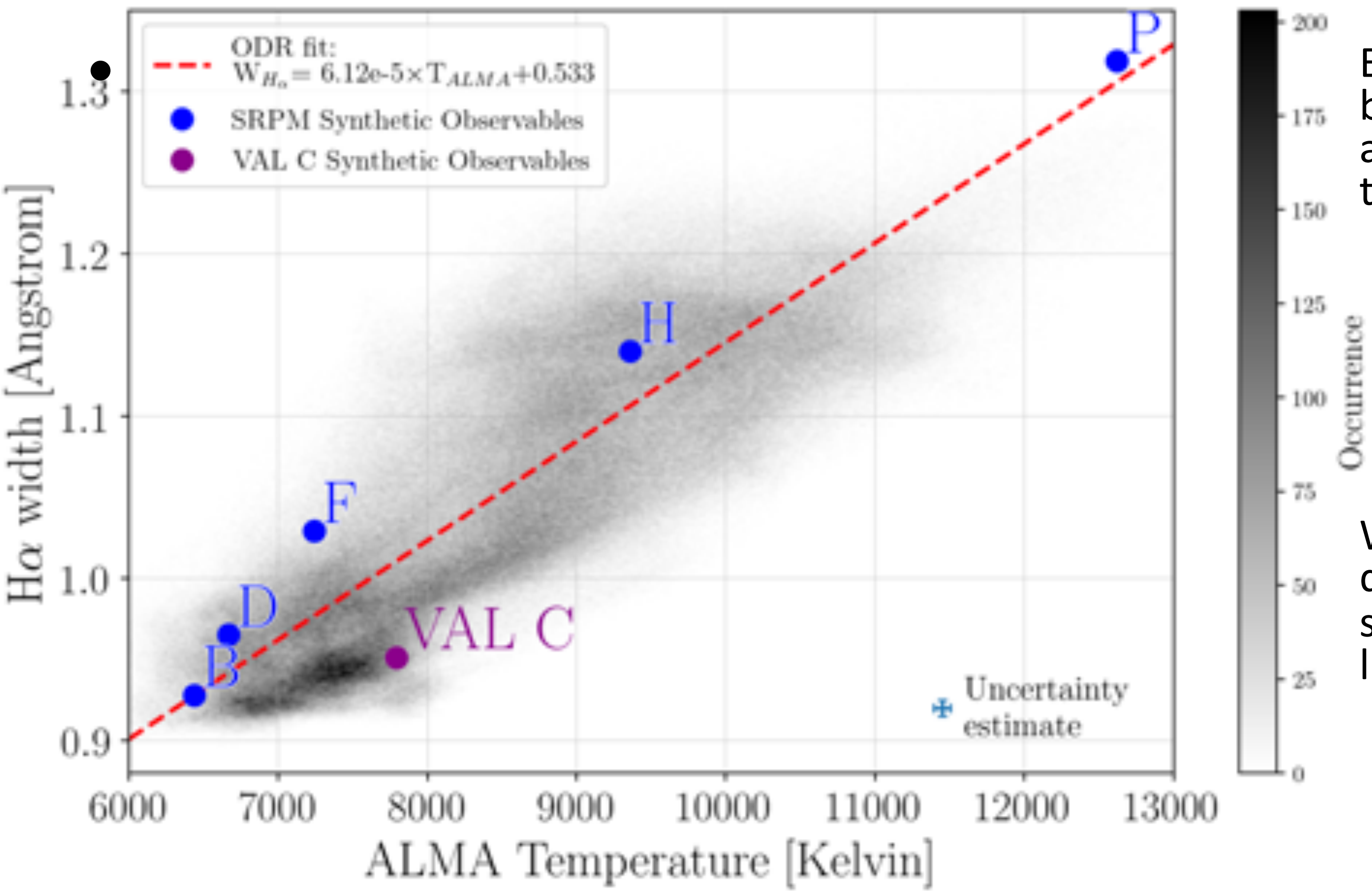
Hα width – single snapshot



ALMA band 3 – single snapshot

Molnar et al 2019

IBIS Hα –ALMA 3 mm comparison



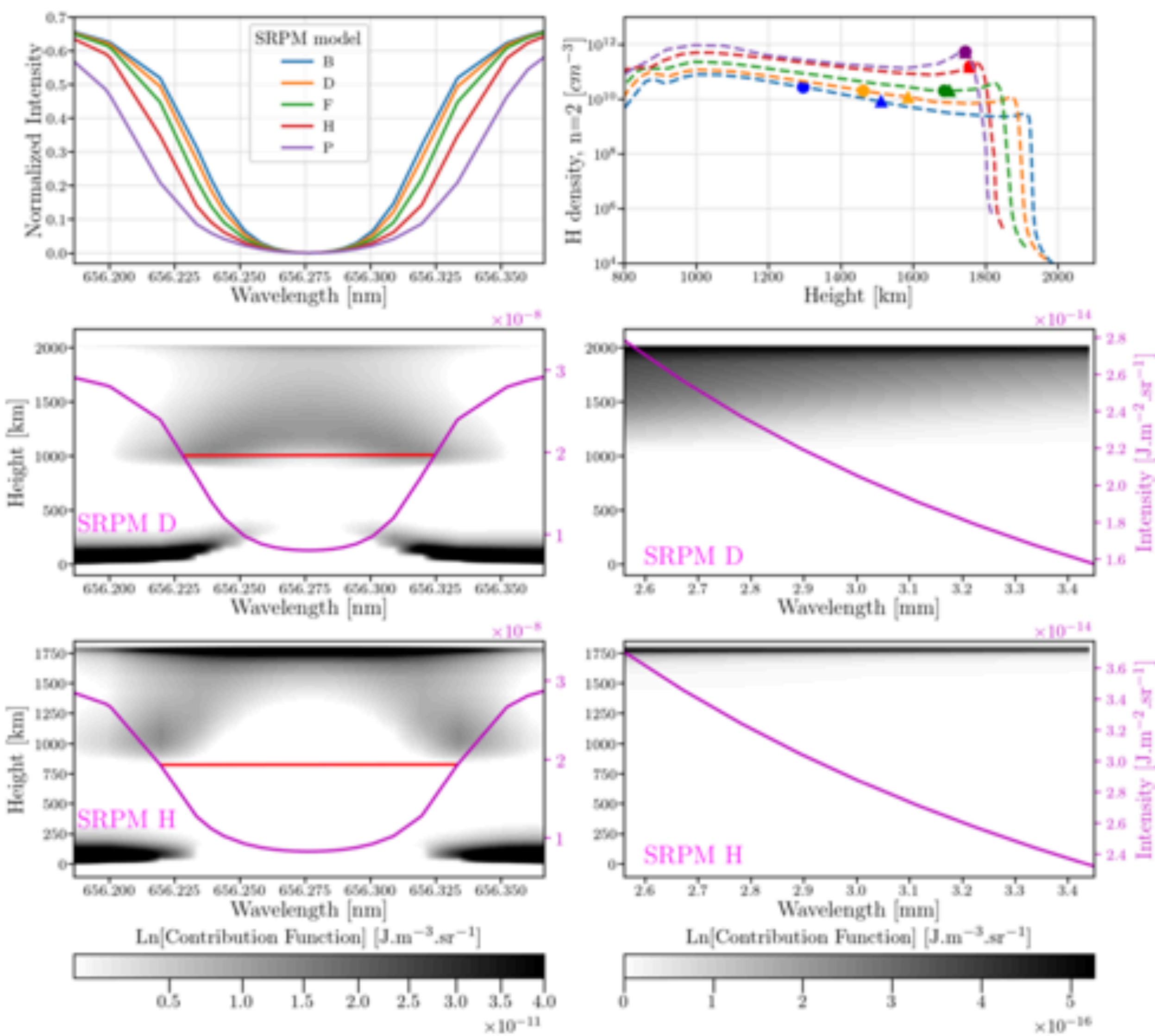
Excellent correlation between Halpha width and brightness temperature

BUT

Why does a LTE-diagnostics correlate so well with a non-LTE line?

Molnar et al 2019

Hα –ALMA 3 mm formation



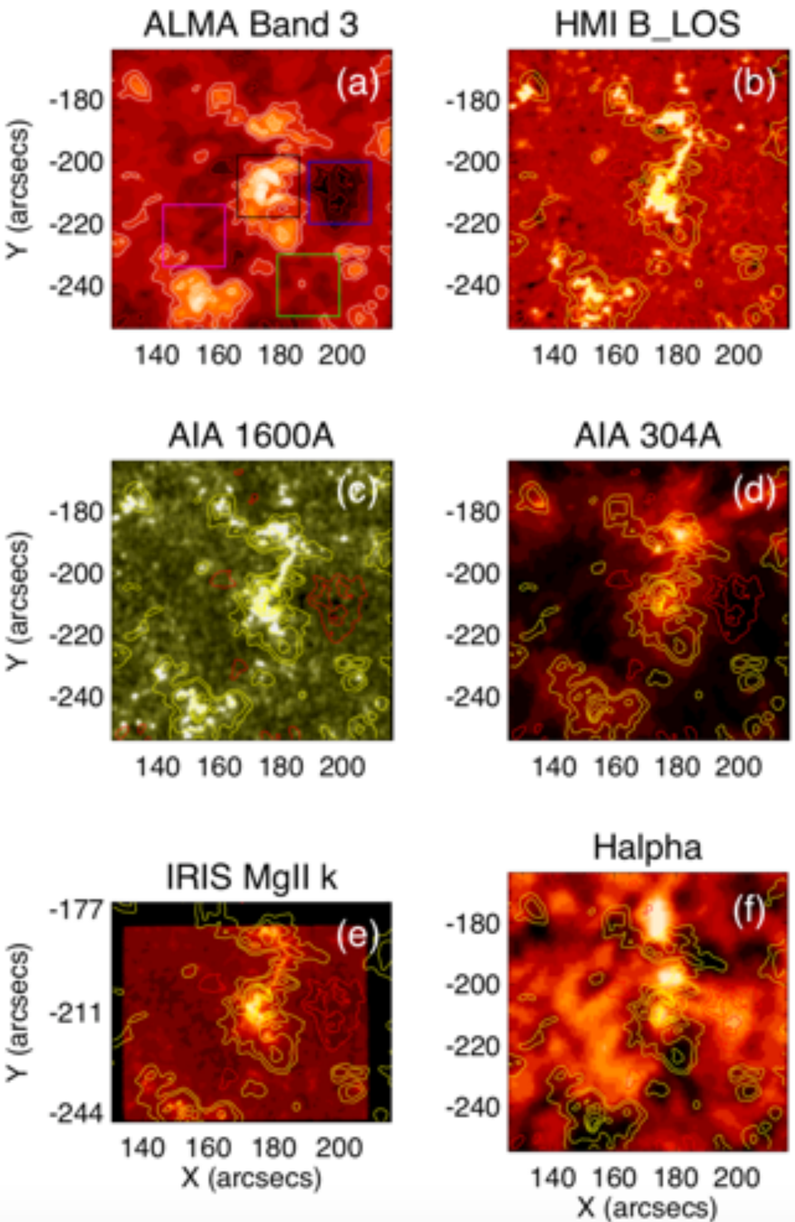
Symbols = where τ=1 in Hα core (circles) and at 3 mm continuum (triangles)

For hotter models (H, P) , the locations coincide -> better correlation

I (ALMA) = Te, BUT at a variety of different heights in the atmosphere depending on the feature

Molnar et al 2019

ALMA 3 mm “dark holes”



Band 3 observations of “cold” chromospheric features (60% of quiet Sun)

“Chromospheric ALMA Holes (ChAH)”

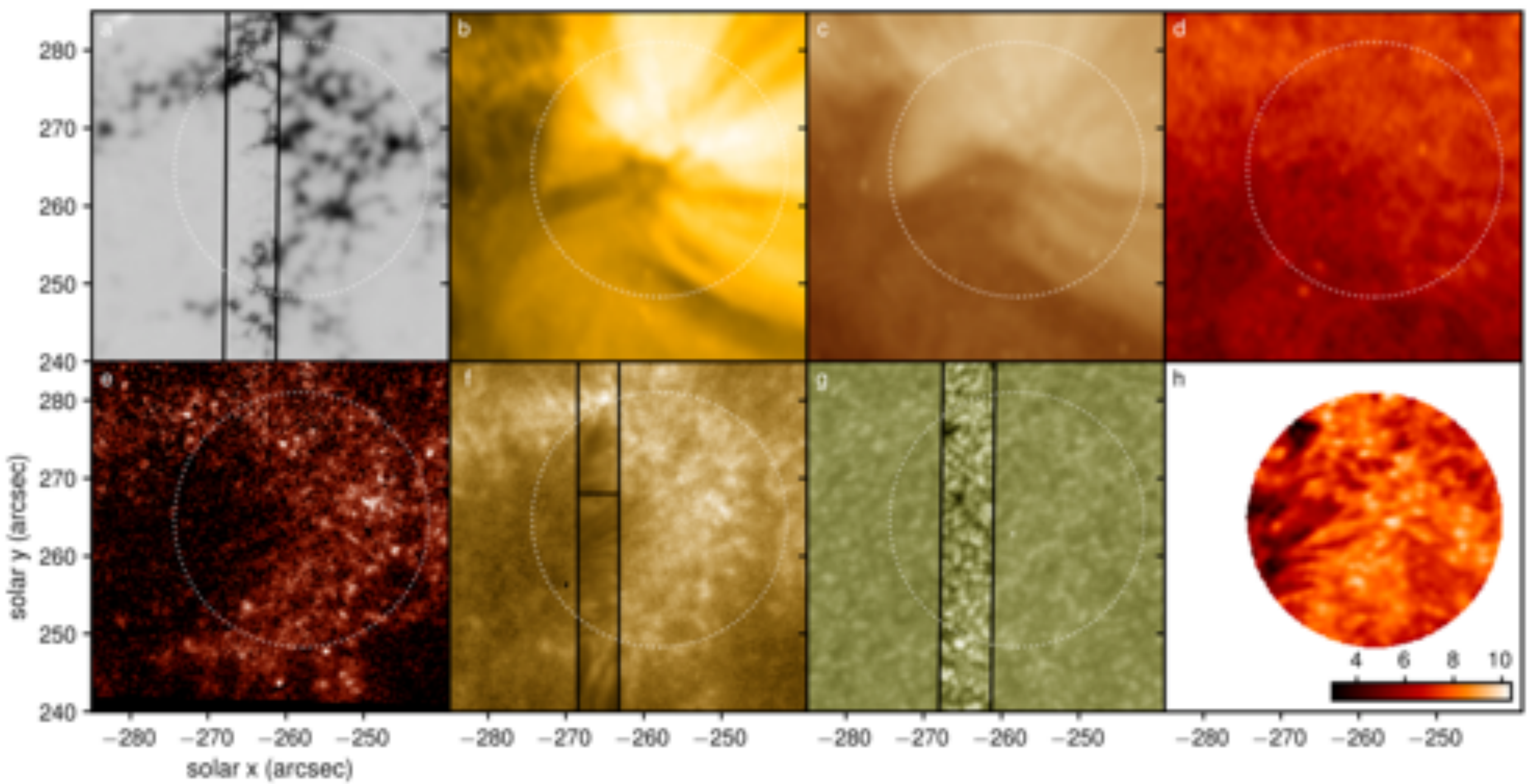
Not visible in other chromospheric signatures (even Ha)

Cold “CO-mosphere”?

Prime Science Use Case: coordinated observations with DKIST Cryo-NIRSP @ 4.7 μm (CO lines, sample cold gas in chromosphere)

Loukitcheva et al. 2019

ALMA data to enhance chromospheric spectral inversions

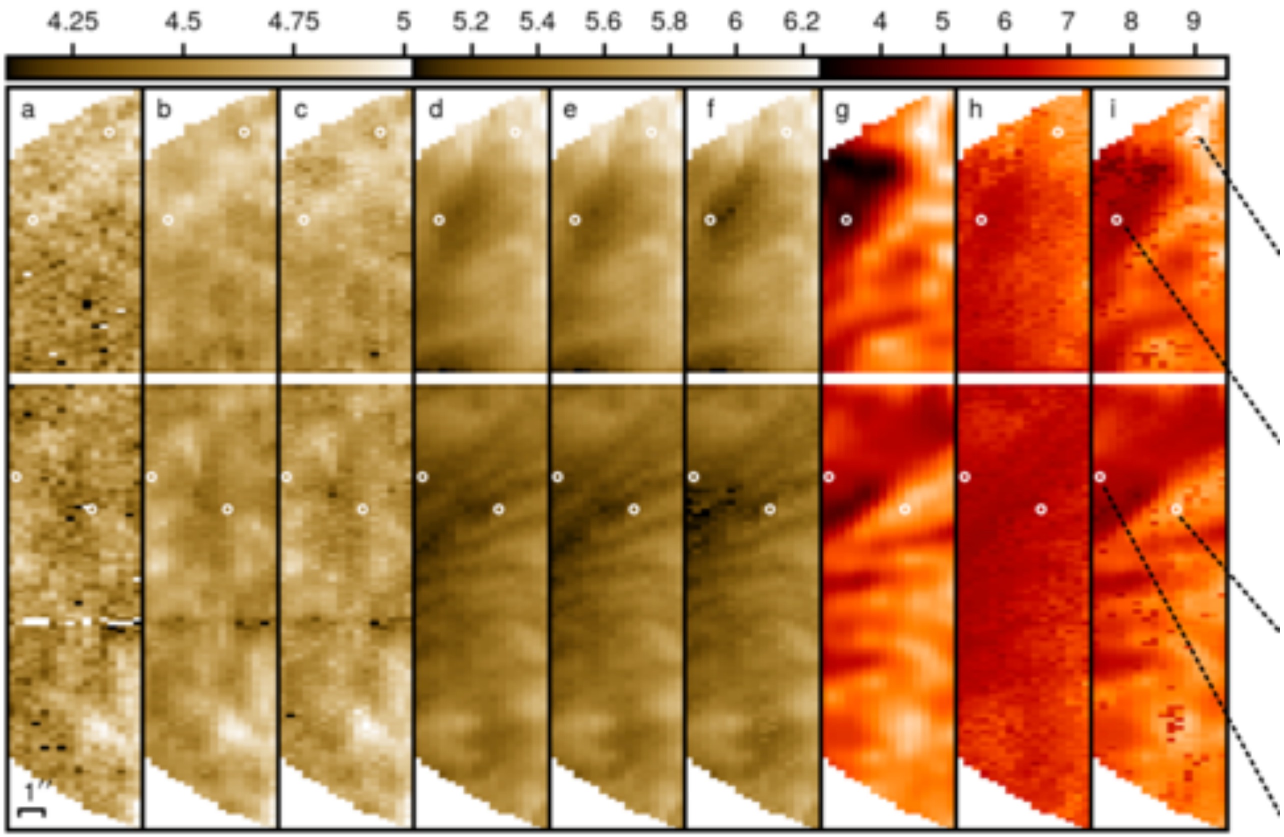


Da Silva Santos et al 2020

Multi-wavelength, multi-instrument dataset

ALMA Band 6 (1.25 mm) and IRIS MgII + Ni I + NUV continuum used for inversions

ALMA data to enhance chromospheric spectral inversions



Including ALMA severely constrains the resulting T structure (a.k.a. IRIS only is not enough to reproduce ALMA!)

Dark, cold feature visible in ALMA, with no photospheric counterpart: a ChAH ??

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Da Silva Santos et al 2020

ALMA & IRIS & DKIST :
GREAT OPPORTUNITY FOR SYNERGIES

ALMA & IRIS & DKIST : GREAT OPPORTUNITY FOR SYNERGIES

How to plan IRIS observations

- Call Bart (de Pontieu) !!
- Observe when you need
- Data is available in few days
- Data is fully calibrated and aligned

How to plan ALMA observations

Wait for ALMA proposal call (1/year)

Have proposal judged by (mostly) non-solar referees

Wait for proper ALMA configuration to occur

Wait for data delivery from ALMA data center

Fight vagaries of data …