Synergy with ALMA

Joten Okamoto
(NAOJ, Japan)

Capability of ALMA

- high spatial resolution

  0.1” in Band 10 (expected, but no better than 0.5”, finally ?)

  0.6” in Band 6 in Cycle 4, 5, 6

  (restricted by compact antenna configuration for solar observations)

- high temporal resolution

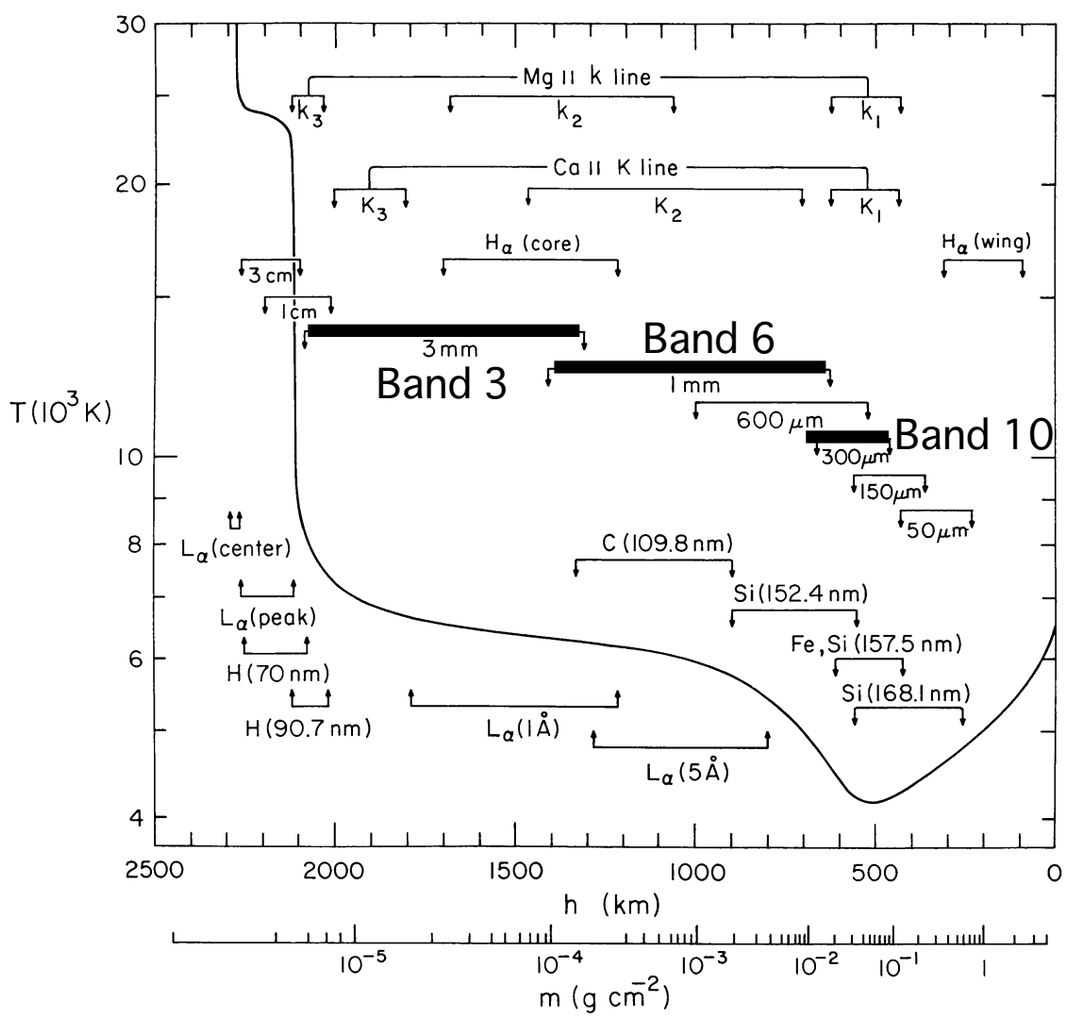
  2 sec (0.5 sec in future ?)

- easy interpretation for radiative transfer

  temperature minimum

  ~ chromosphere on disk

  optically thin in off-limb



Current status

▶ observing time

13—19 UT
early 2019 for Cycle 6 ?

(Dec-April 2017 for Cycle 4, April-July 2018 for Cycle 5)

▶ observing instrument

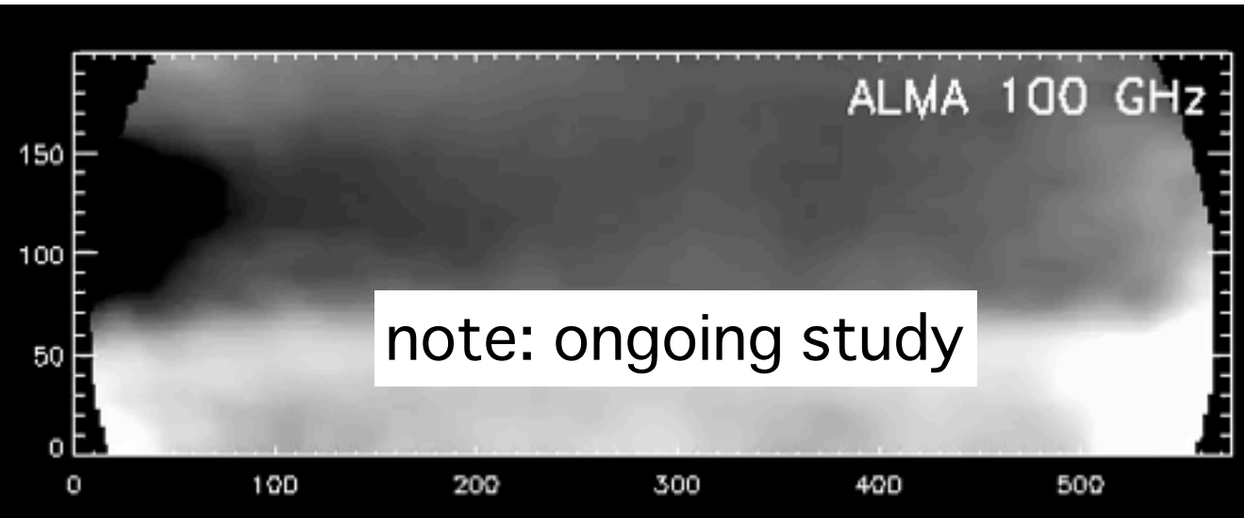
Band 3 (100 GHz, 3 mm) : 1.5” — FOV 60”
Band 6 (230 GHz, 1 mm) : 0.6” — FOV 25” (for single dish)

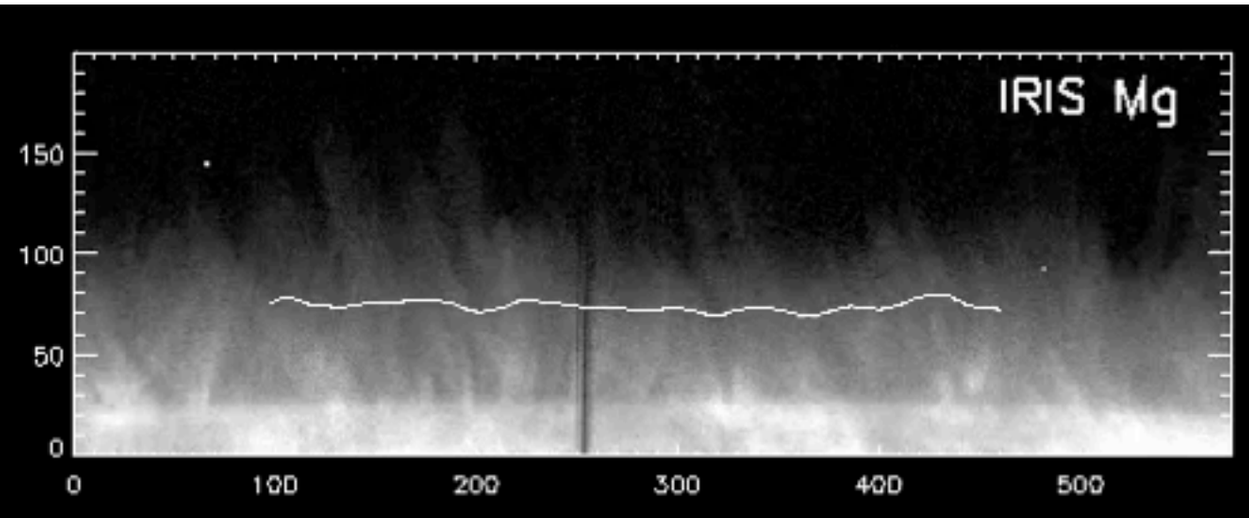
▶ accepted proposals for solar observations

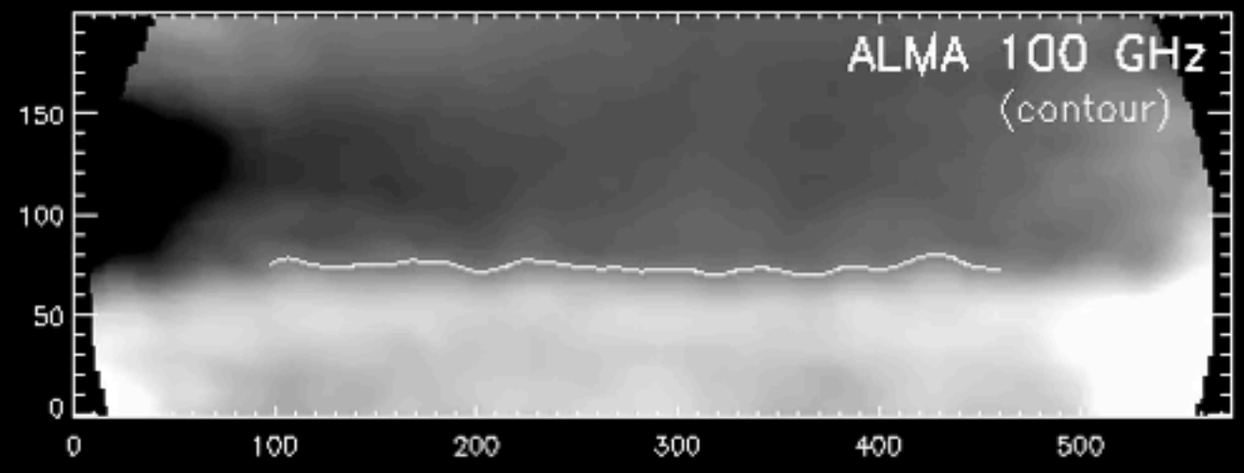
16 in Cycle 4 (← my observation finally failed because of no prominence)
15 in Cycle 5 (← retry this year)

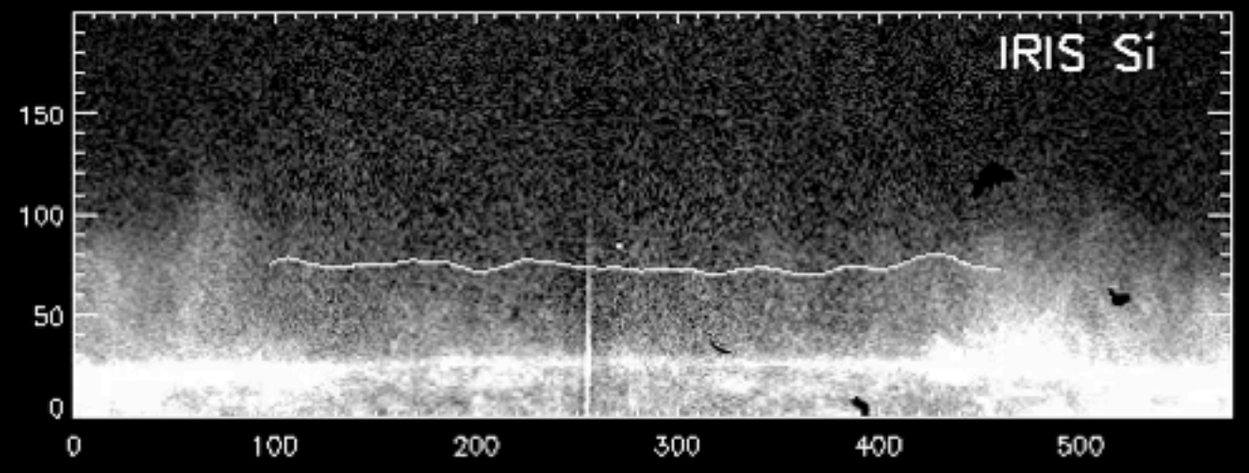
Current status

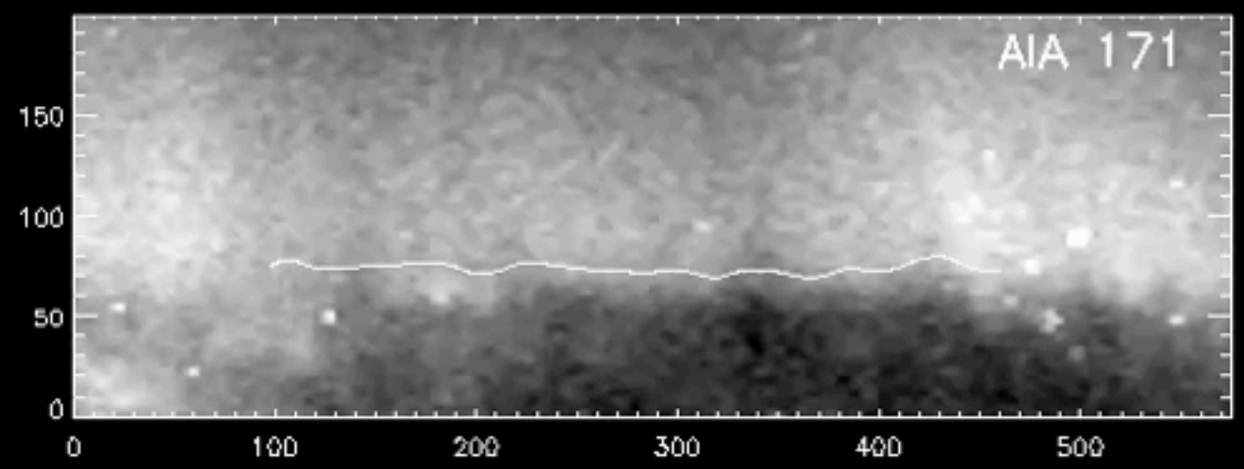
example of off-limb spicule observation (2”, Band 3) Yokoyama+ in prep.

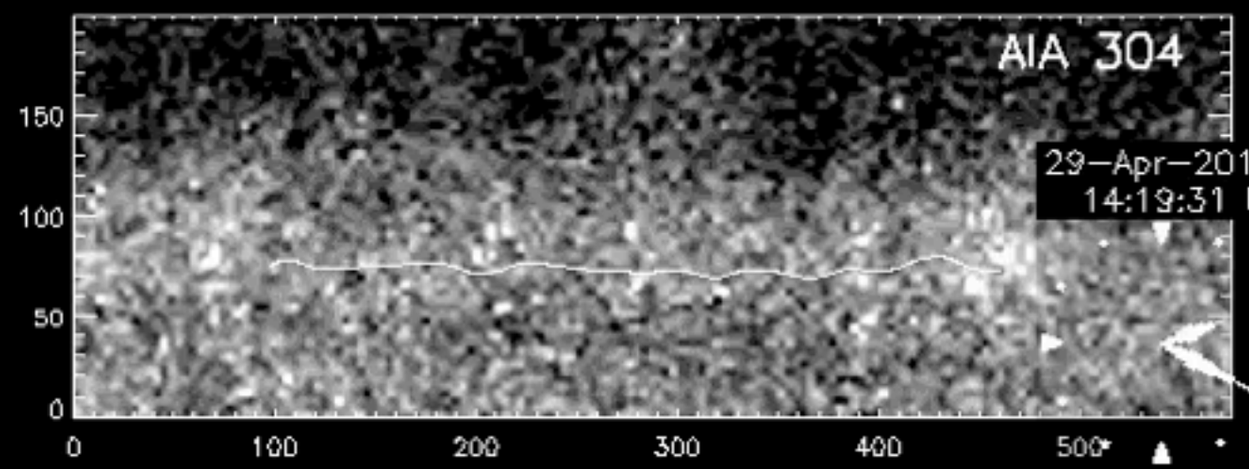












Recent publications 1

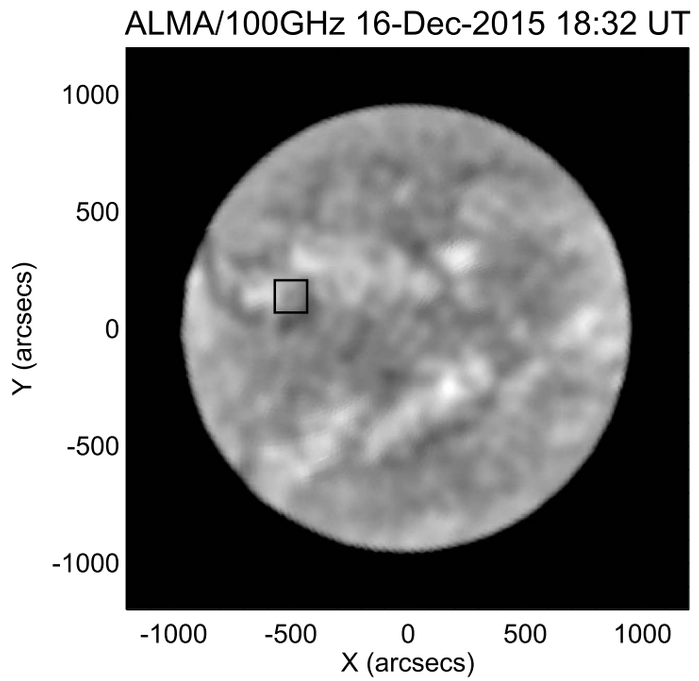
umbral brightness enhancement

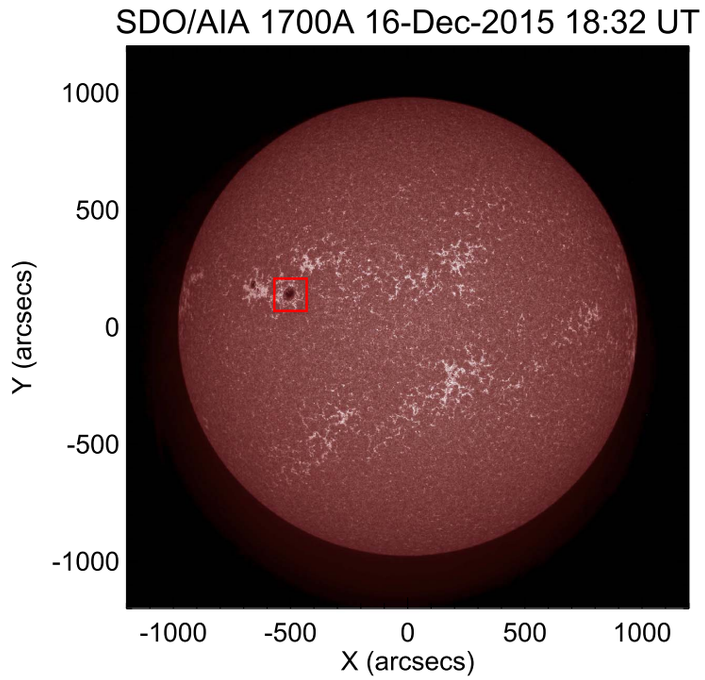
Iwai+2017

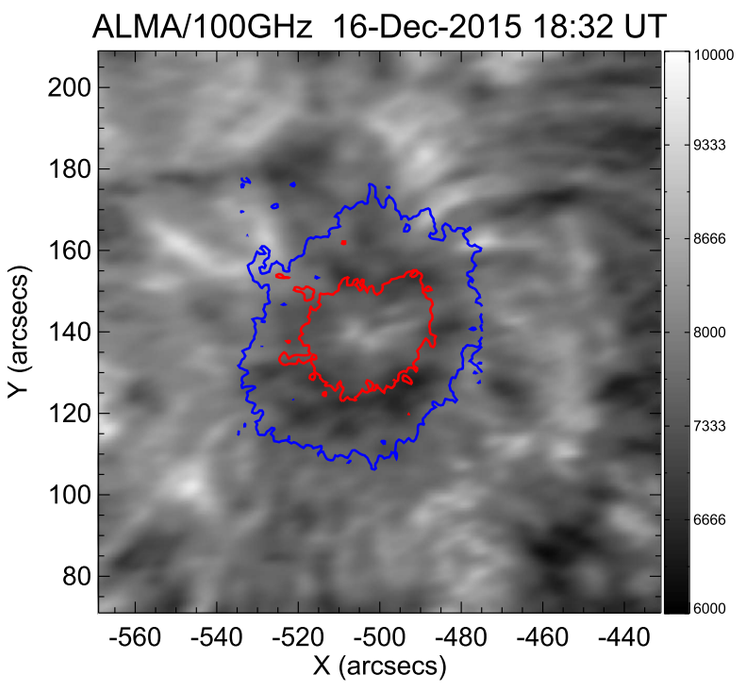
- Science Verification (SV) Data
- 300” x 300” (res. 5” x 2”)
- AR 12470
- Band 3 (3 mm, 100 GHz)

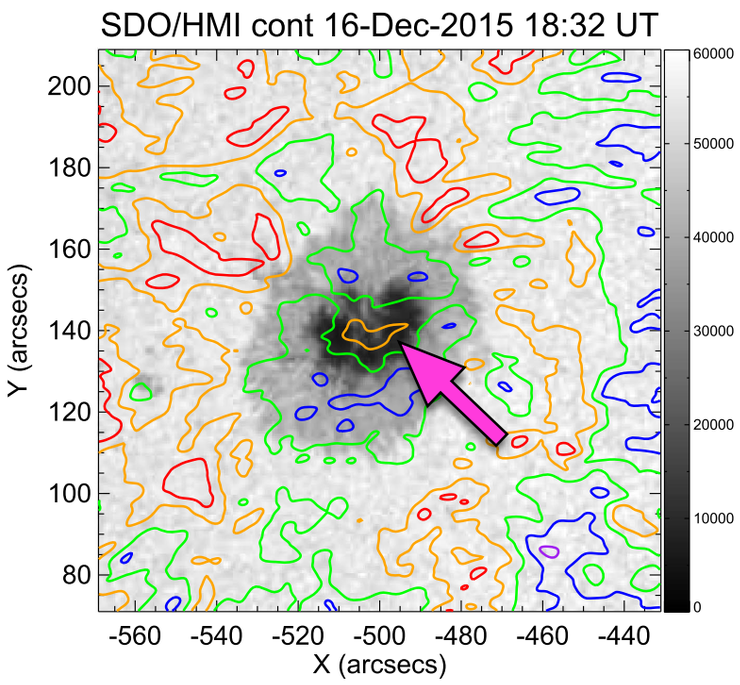
higher brightness temperature
in the center of the umbra
than in the surrounding penumbra
and plage (also in the QS)

8,000 K at central umbra
7,200 K at penumbra
7,600 K at plage
7,100 K at QS









Recent publications 1

umbral brightness enhancement

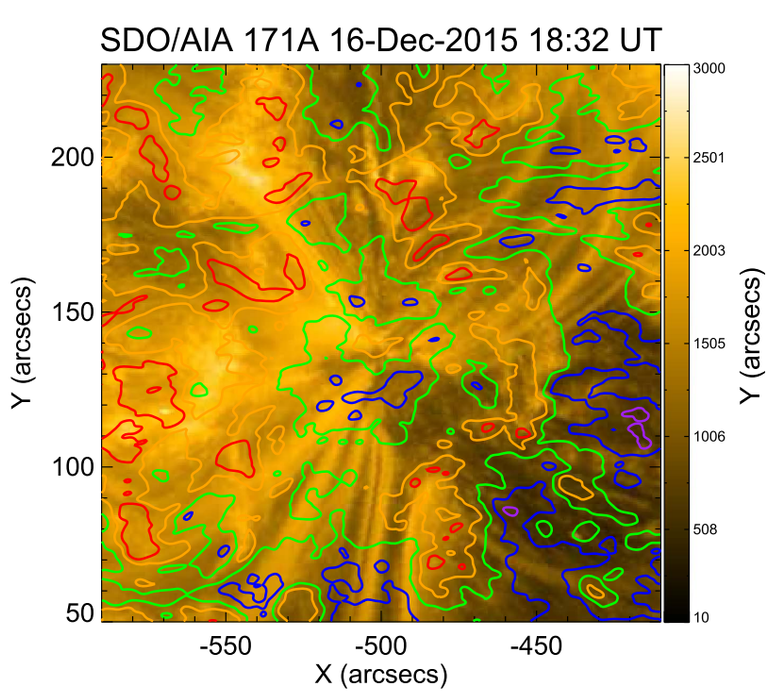
Iwai+2017

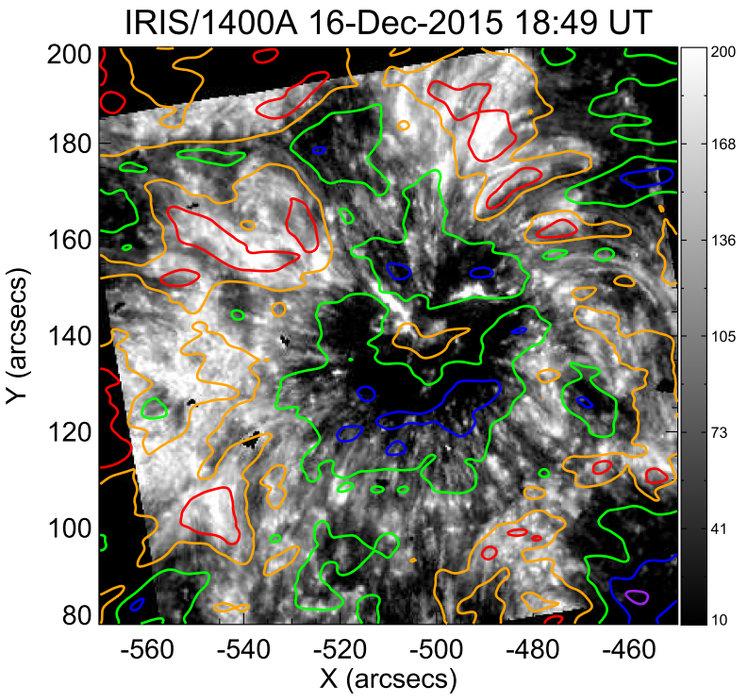
the umbral core harbors the footpoints of bright loops in AIA/171

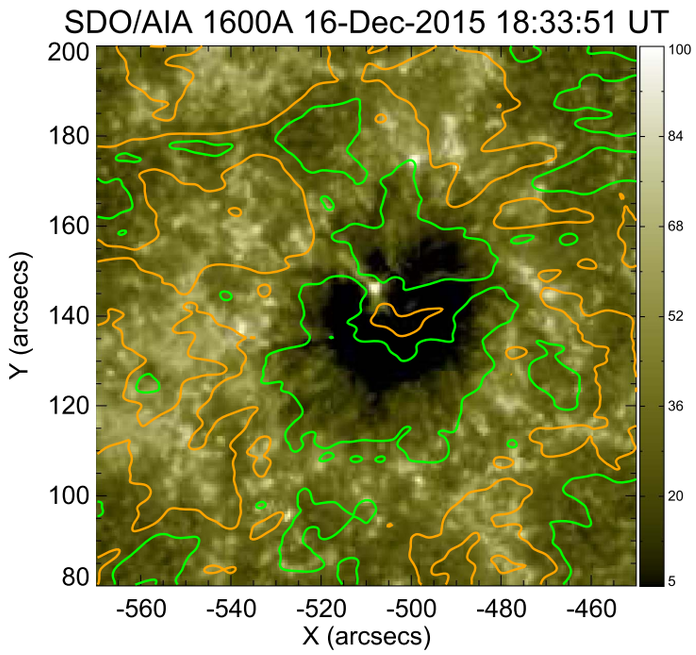
umbral brightness enhancement is located at the end of a light bridge in IRIS/1400 (and also in 1330)

brightening appears in AIA/1600 on the light bridge, but out of the umbral brightness enhancement

the light bridge is less apparent in ALMA/100 GHz



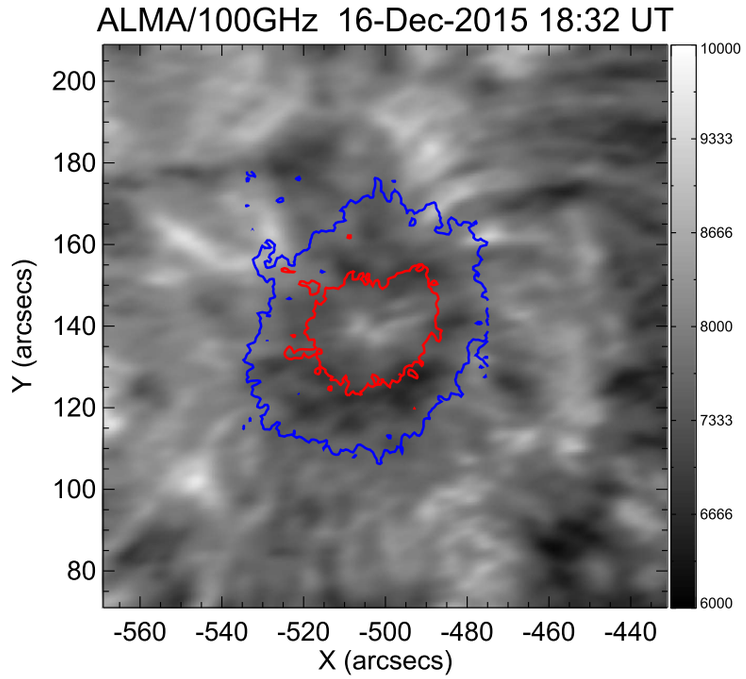




Recent publications 1

umbral brightness enhancement

Iwai+2017



the origin of the brightness enhancement is not solved

- penumbral darkening (not umbral brightening)
- coronal plume
- umbral flash (shock formation)

further high-res ALMA observations are important, of course

- not unlikely to perform simultaneous observations at multiple radio frequency bands

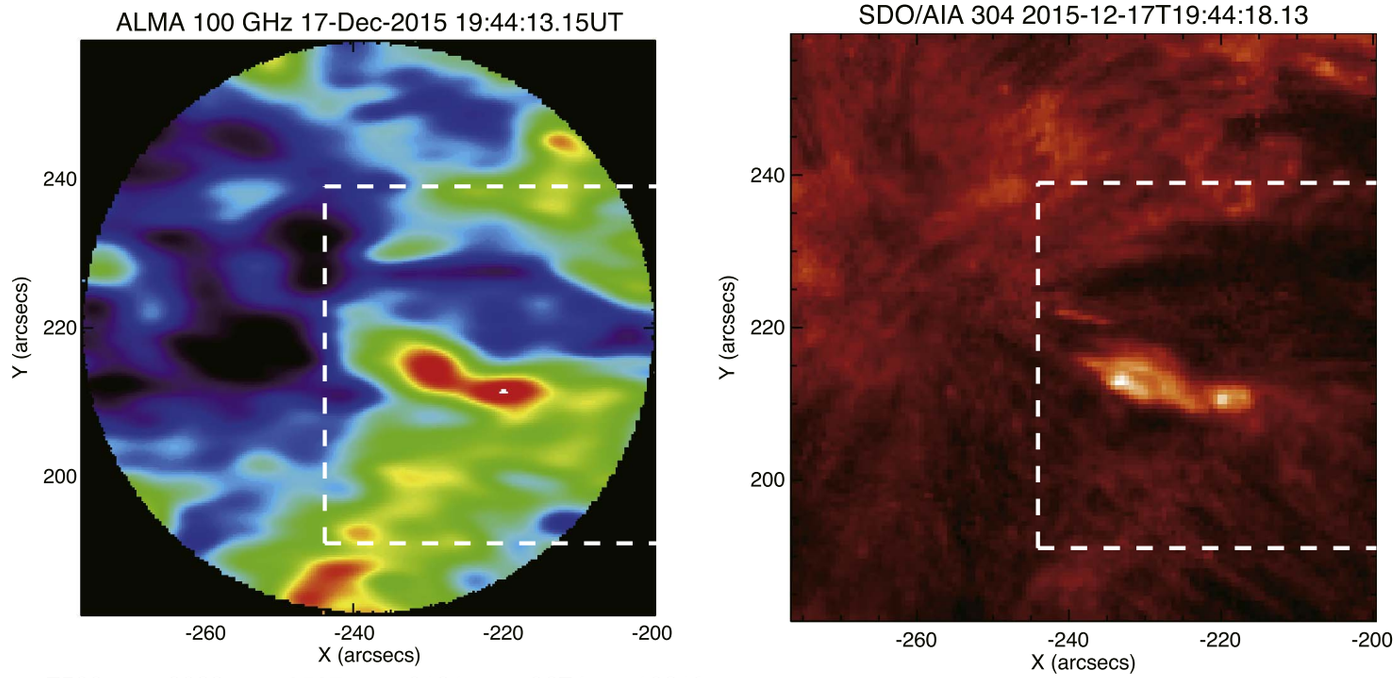
→ simultaneous observations are also essential in other chromospheric lines from ground such as DKIST as well as IRIS and SDO

Recent publications 2

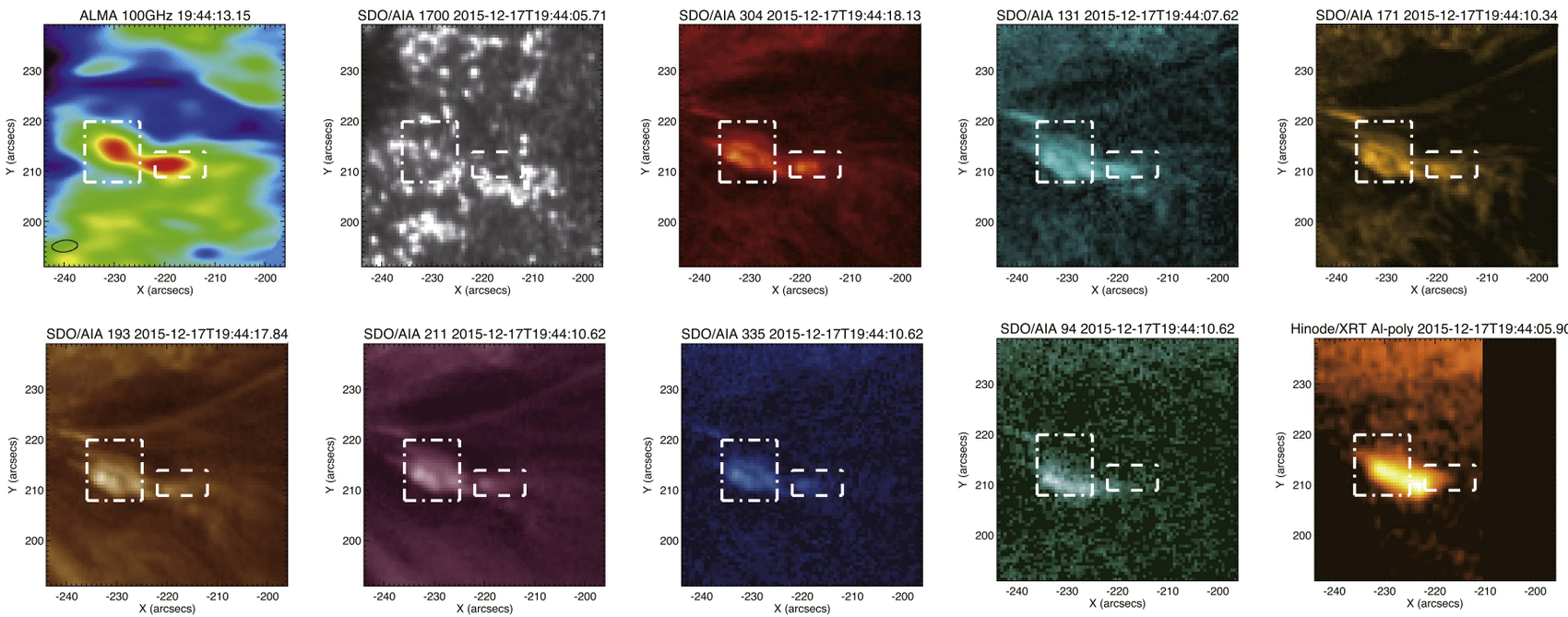
plasmoid ejection

Shimojo+2017

- Science Verification (SV) Data
- res. 6” x 2”
- AR 12470
- Band 3 (3 mm, 100 GHz)



plasmoid ejection
can be seen in almost
all the AIA images
(except 94 and 1700)



Recent publications 2

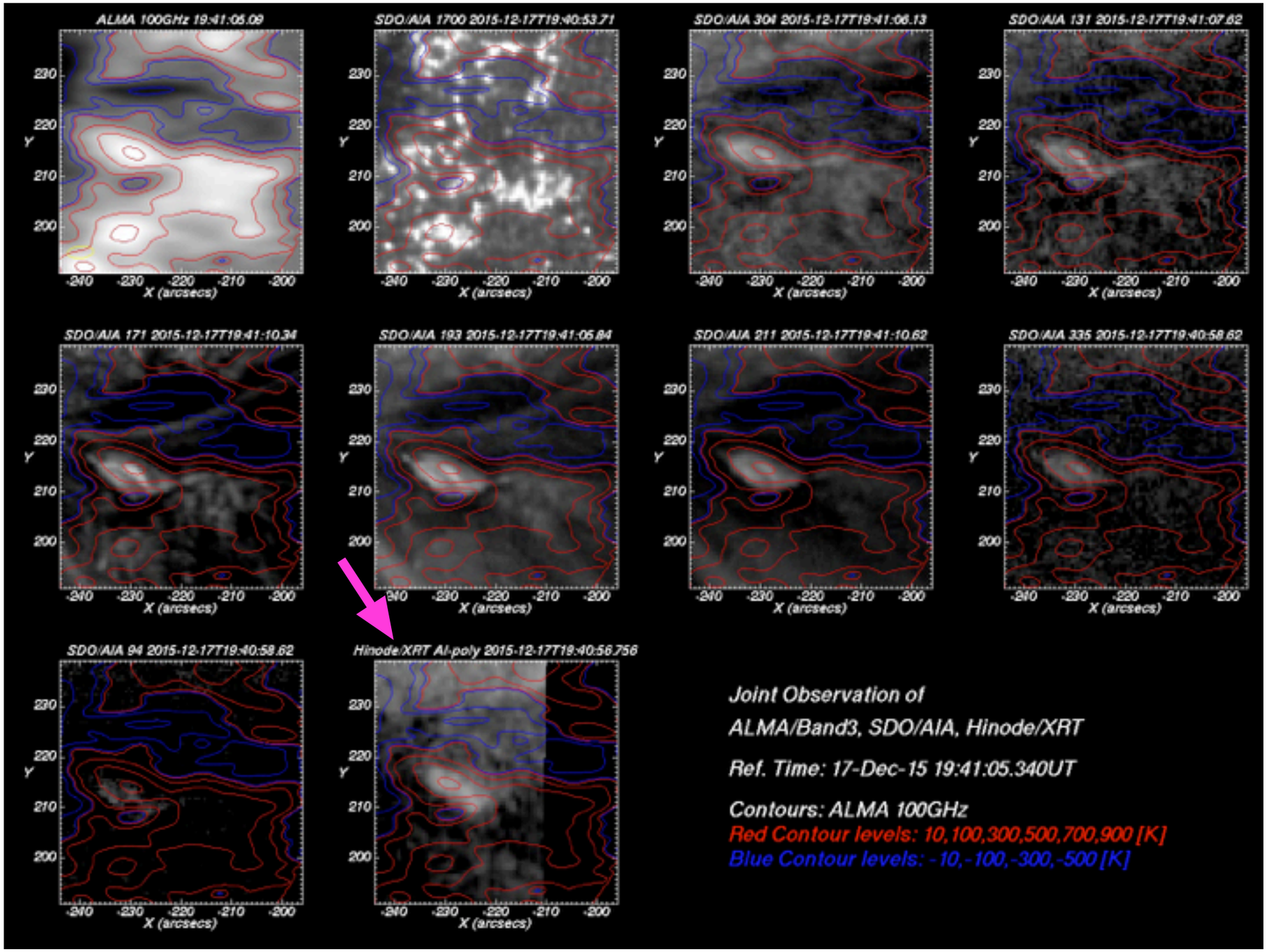
plasmoid ejection

Shimojo+2017

XRT does not show the plasmoid

the plasmoid does not include significant coronal plasma > 1 MK

also no enhancement in AIA/1700, so this is not predominantly chromospheric



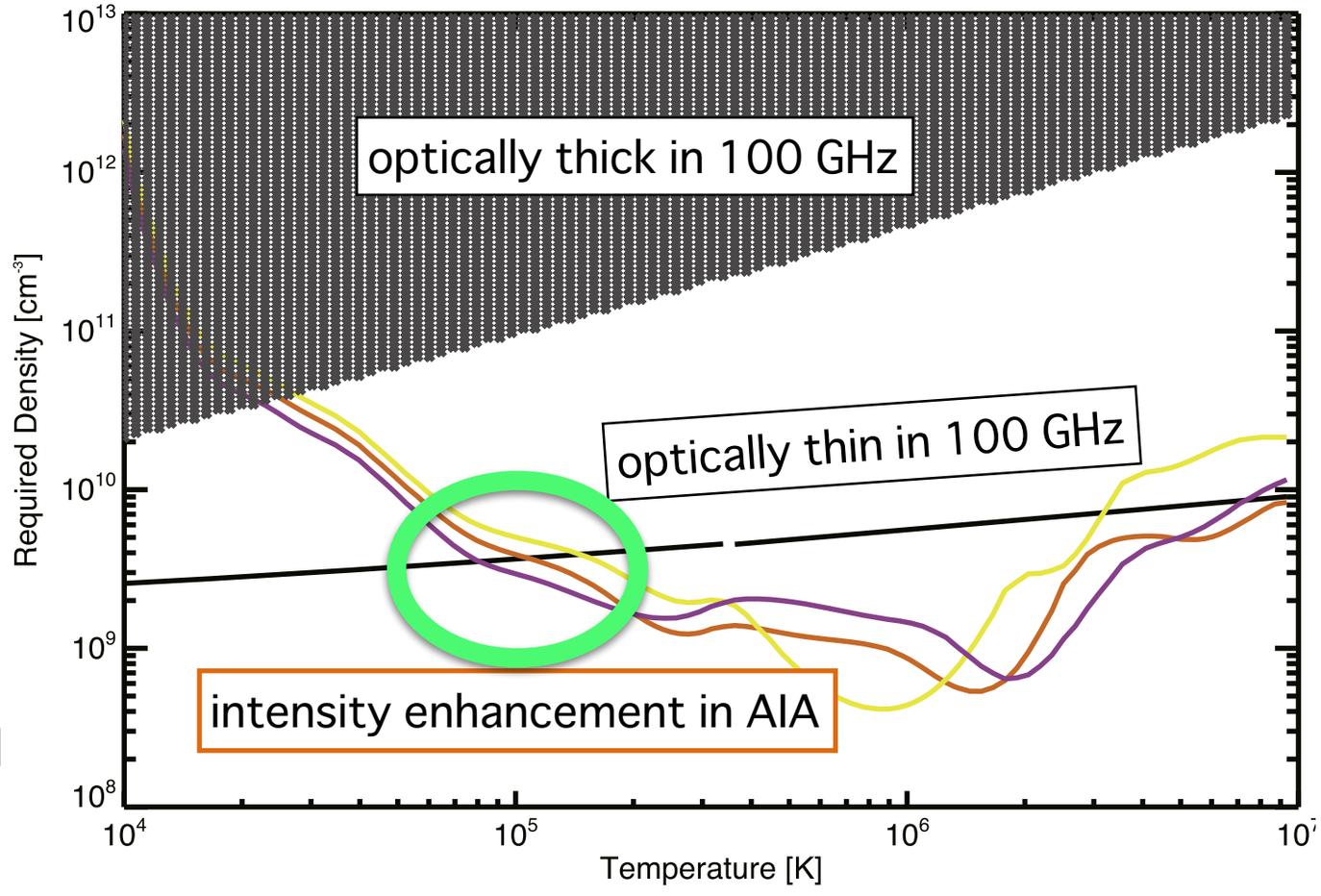
Recent publications 2

plasmoid ejection

Shimojo+2017

- isothermal and optically thick in 100 GHz

  10^4 K, 10^{12} cm^{-3} required
  → EUV images should have shown absorption, so not likely



- isothermal and optically thin in 100 GHz

  $8.0\times10^4 \sim 1.4\times10^5$ K, 4×10^9 cm^{-3} required
  → reasonable

- multi-thermal

  100 GHz emission from a cool dense core
  EUV emission from a hot sheath surrounding the core ($5\times10^5 \sim 10^6$ K)
  → reasonable

Recent publications 3

3D modeling of prominence

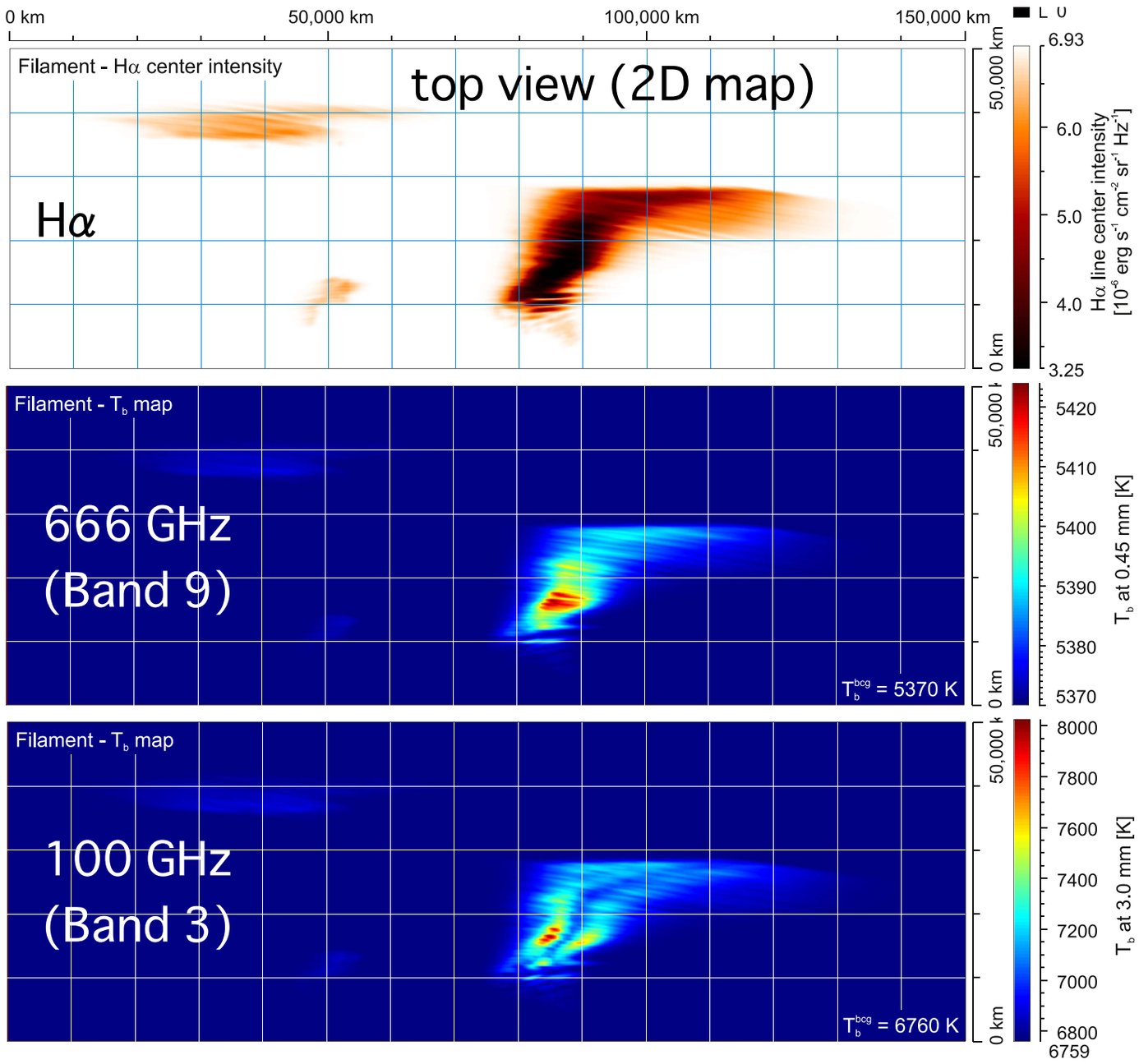
Gunar+2016

prominence can be observed
both in the off-limb and on disk

on-disk prominence shows similarities
between in Hα and ALMA bands

a bright region of Tb is divided by an
area of lower Tb only in ALMA/100 GHz
→ partial absorption

useful to understand the nature of
prominence fine structures, but quite
important to have simultaneous
observations in the optical range



Prominence observation

chromospheric plasma ～ 10,000 K　　・・・ how accurate ?

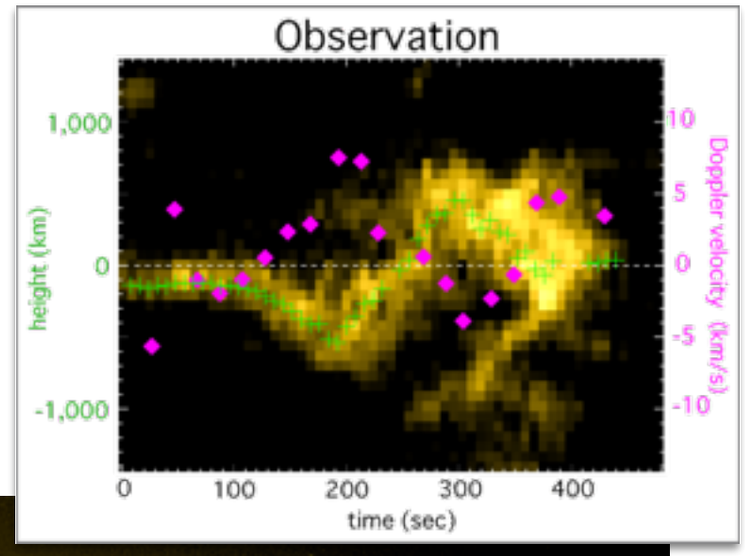
ALMA provides brightness temperature of prominences,
but other observations are also essential

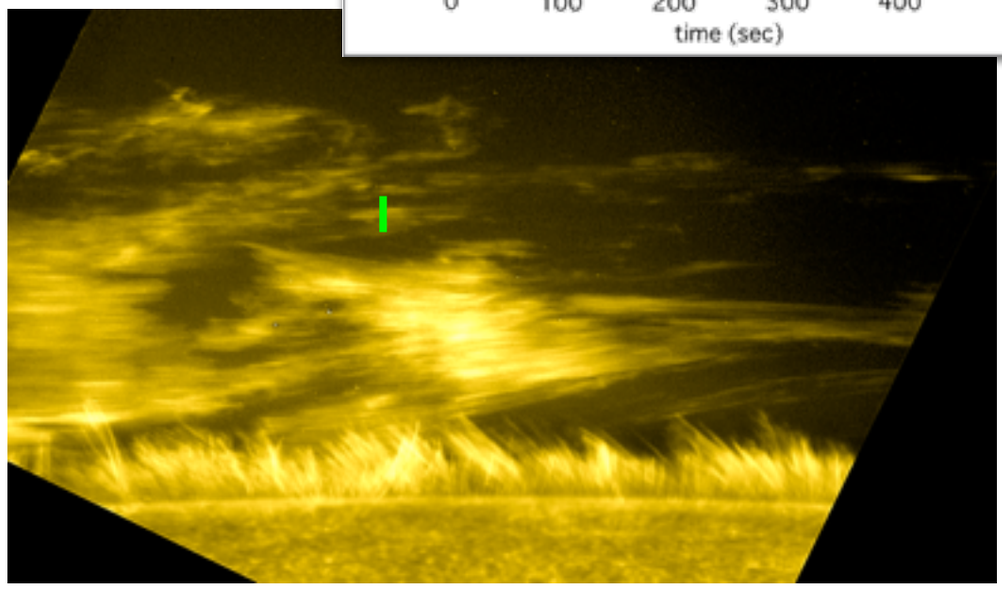
(I do not think it is enough to observe only by ALMA)

wave heating in prominences

correlation between oscillations
and temperature change

obtaining the change of ρ, B
in fine structures by DKIST
is very attractive for this study





Okamoto+2015

Synergy with ALMA

ALMA is not designed for solar observations

We cannot have enough information only with ALMA,
but simultaneous observations from ground and/or space
are essential.

additional suggestion (not associated with ALMA) → next page

Proposal (request) for DKIST

Okamoto+2018

The Astrophysical Journal Letters, 852:L16 (6pp), 2018 January 1 https://doi.org/10.3847/2041-821

Super-strong Magnetic Field in Sunspots

Takenori J. Okamoto[1] and Takashi Sakurai
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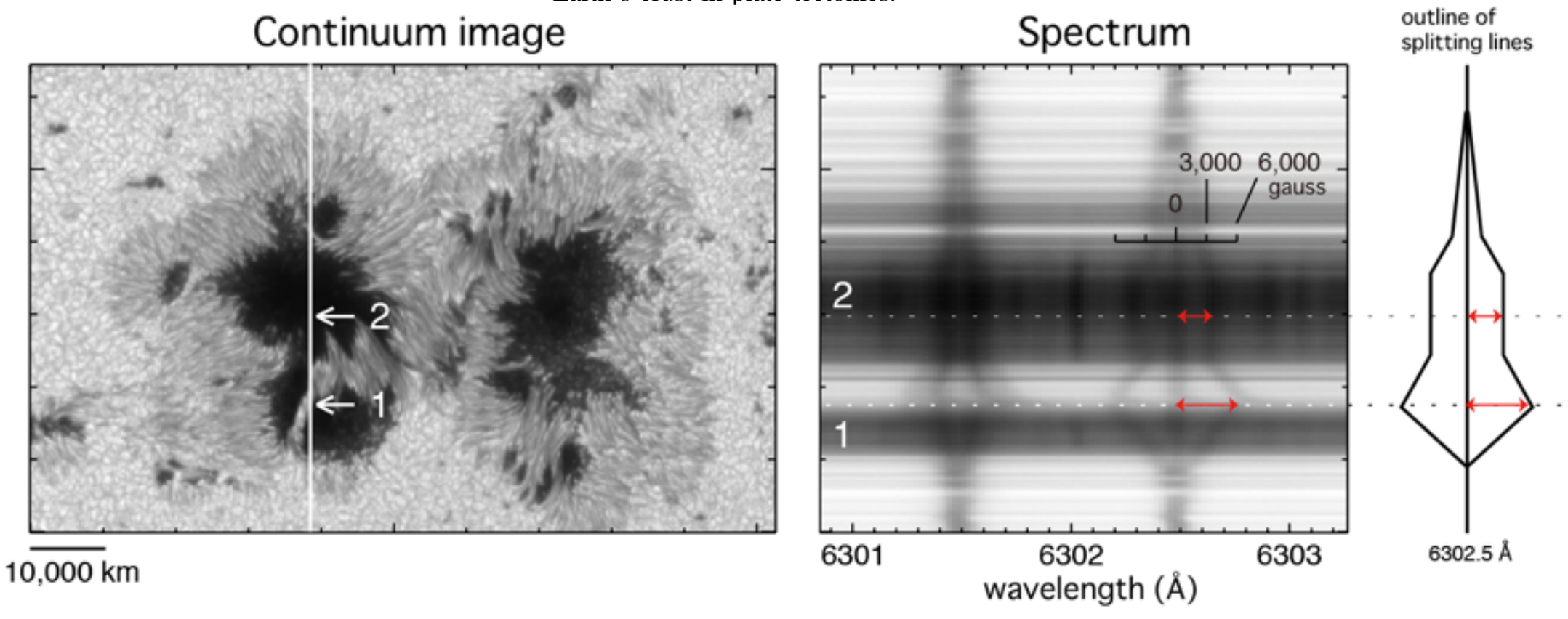
Received 2017 August 1; revised 2017 December 12; accepted 2017 December 22; published 2018 January 4

Abstract

Sunspots are the most notable structure on the solar surface with strong magnetic fields. The field is generally strongest in a dark area (umbra), but sometimes stronger fields are found in non-dark regions, such as a penumbra and a light bridge. The formation mechanism of such strong fields outside umbrae is still puzzling. Here we report clear evidence of the magnetic field of 6250 G, which is the strongest field among Stokes *I* profiles with clear Zeeman splitting ever observed on the Sun. The field was almost parallel to the solar surface and located in a bright region sandwiched by two opposite-polarity umbrae. Using a time series of spectral data sets, we discuss the formation process of the super-strong field and suggest that this strong field region was generated as a result of compression of one umbra pushed by the horizontal flow from the other umbra, such as the subduction of the Earth's crust in plate tectonics.

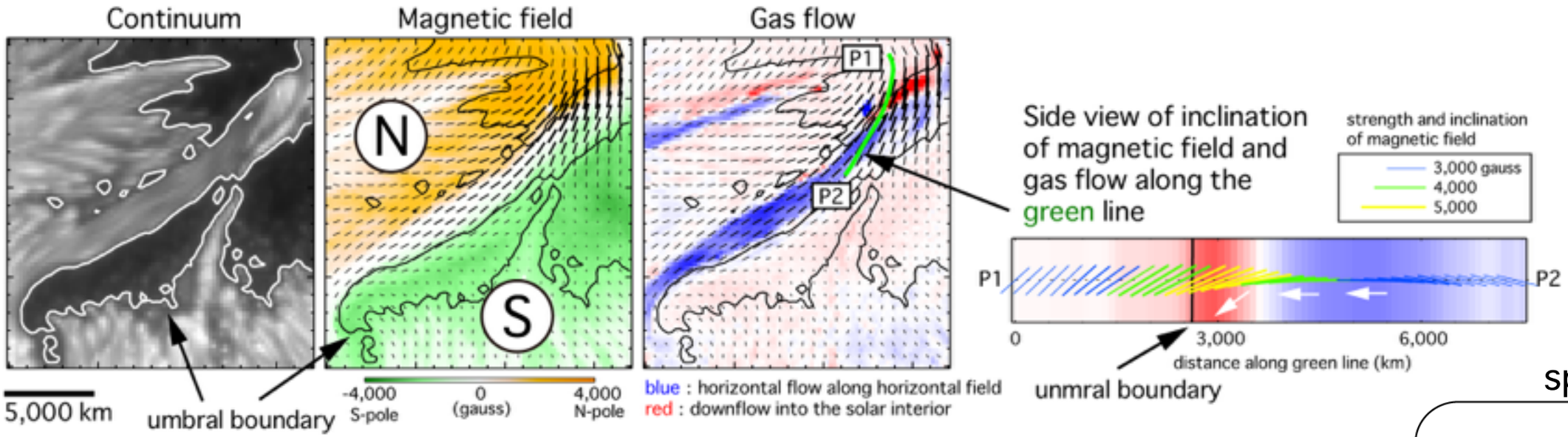
6,250 G



Proposal (request) for DKIST

The strongest magnetic field in many sunspots is NOT located at the central umbra, but on the penumbra/light bridge.

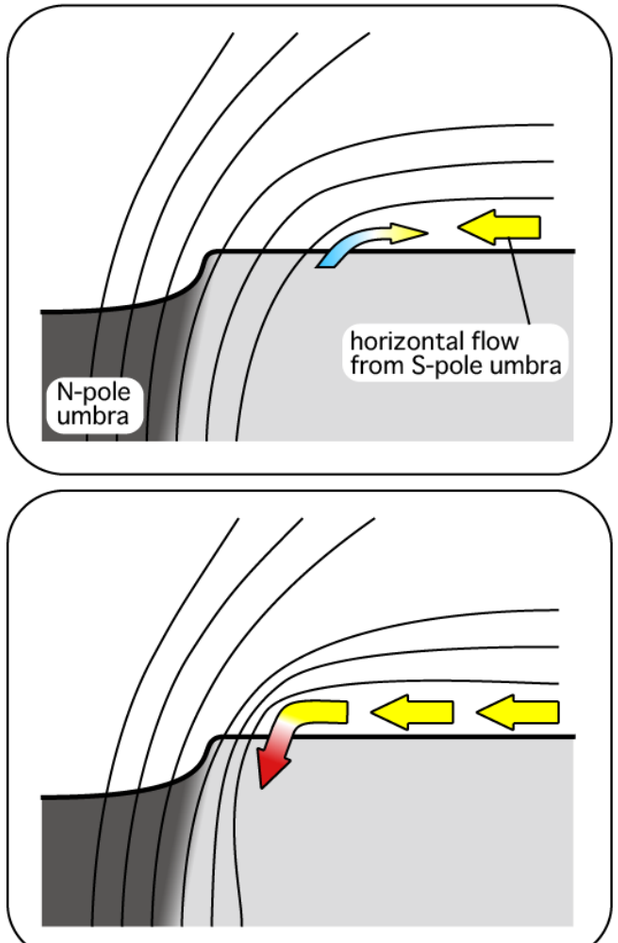
Okamoto+2018



(third quadrant)

This can be interpreted:
the strong field was generated as a result of compression of one umbra pushed by the outward flow from the other umbra.

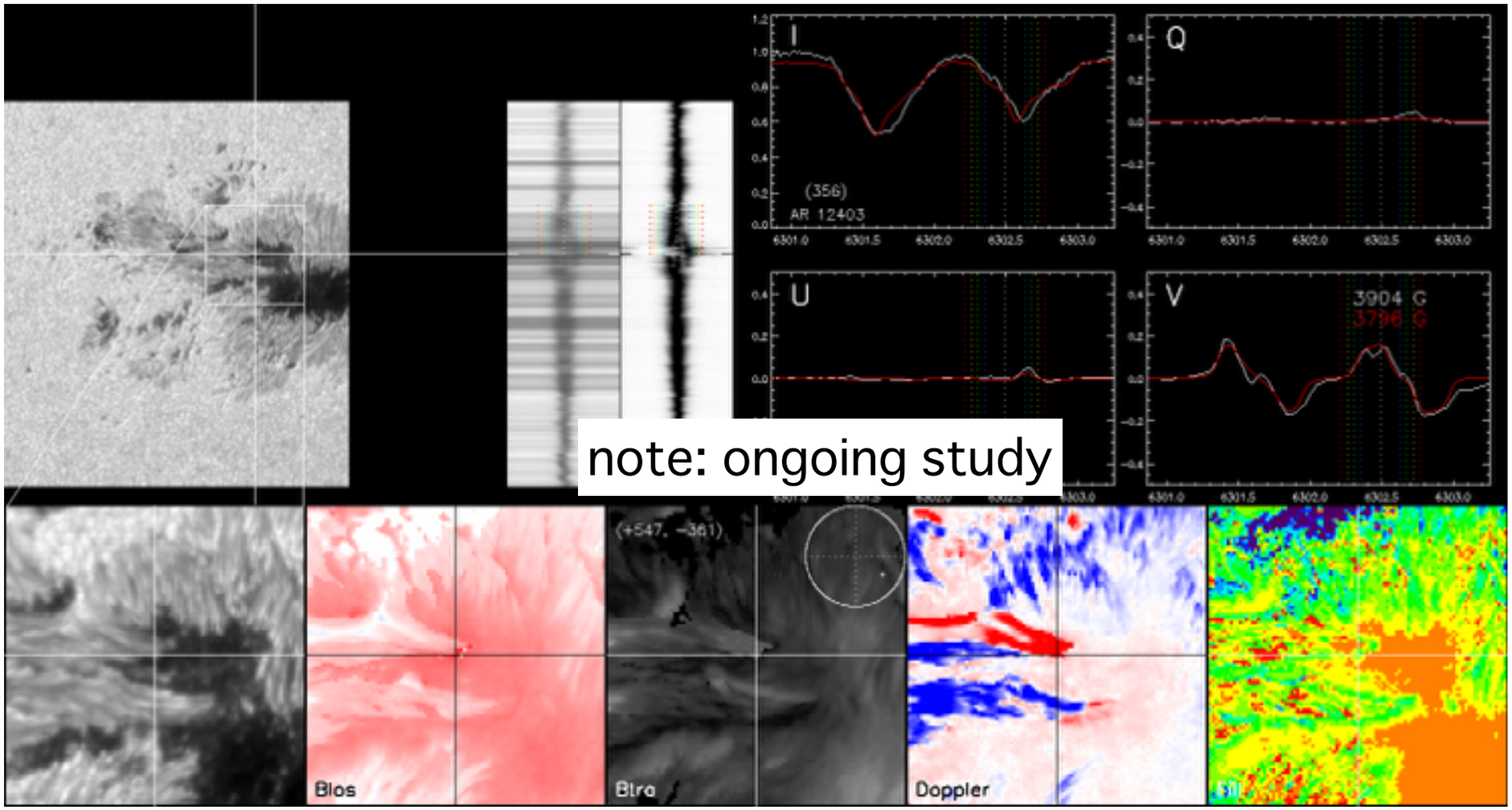
speculation



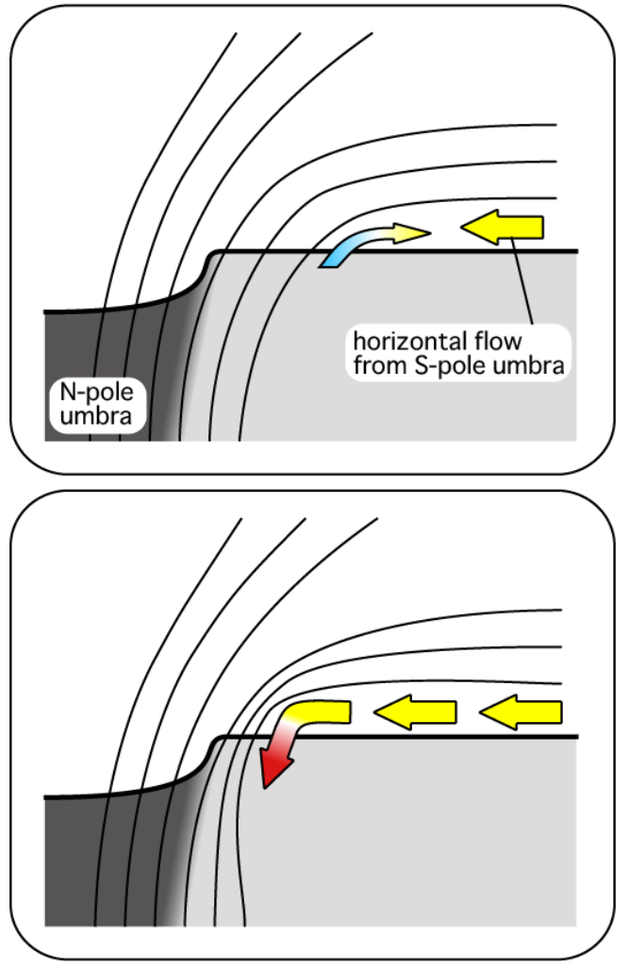
Proposal (request) for DKIST

Okamoto+ in prep.

According to my statistical analysis, a similar tendency can be seen
in many sunspots (82/419 ARs observed in 2006~2016):
at the cross point where a possible horizontal flow reaches an umbra.
(confirmed by Dopplershifts at different locations on the disk)



speculation



(I will show the details in near future conferences after the completion of my analysis)

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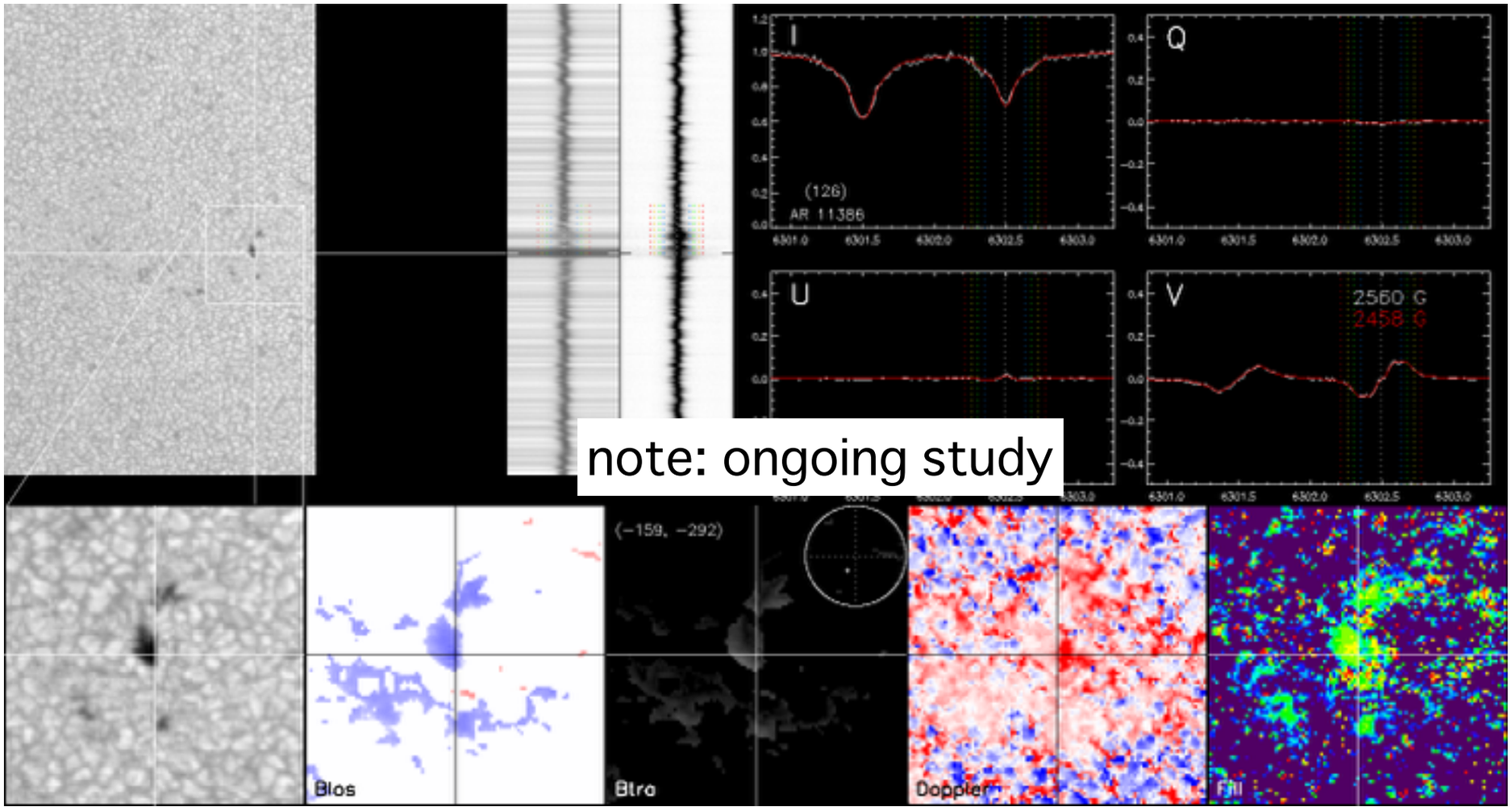
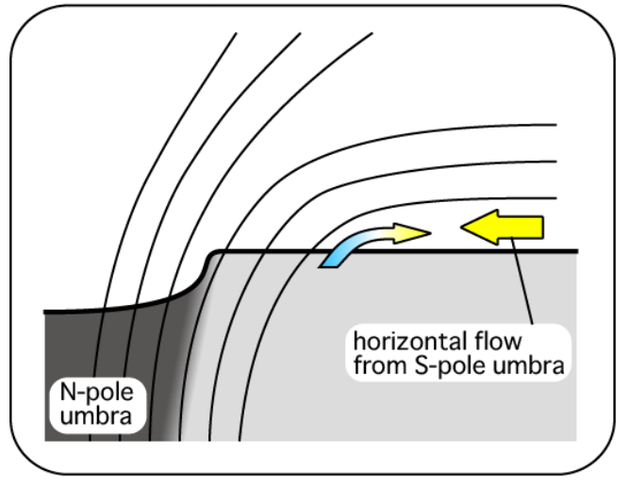
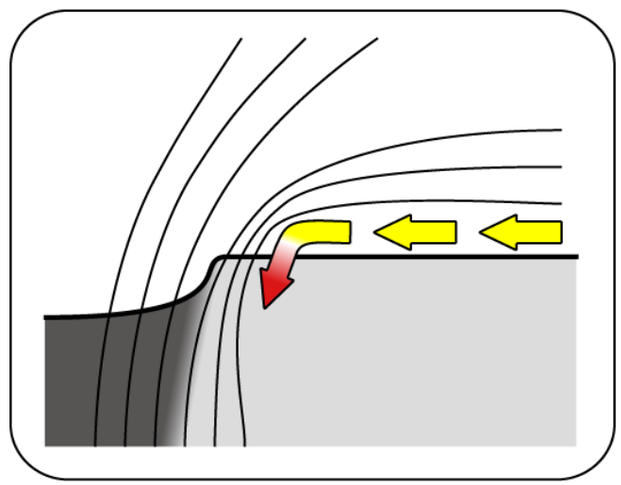


speculation





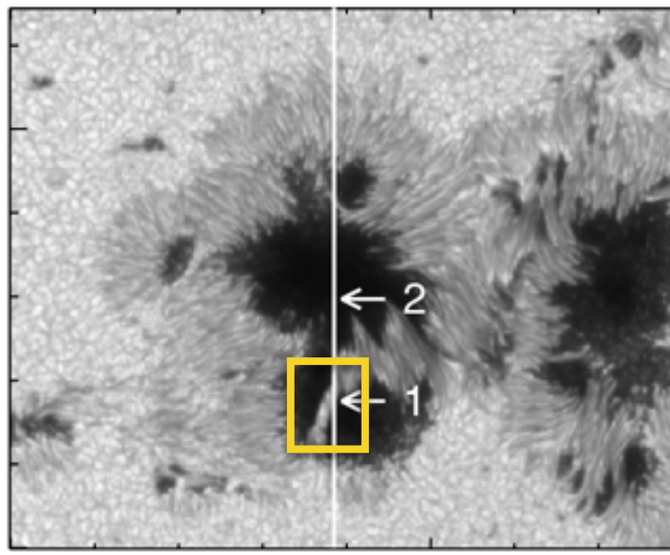
(I will show the details in near future conferences after the completion of my analysis)

Proposal (request) for DKIST

I would like to get more info about the physical properties
and the dynamics to enhance field strengths.

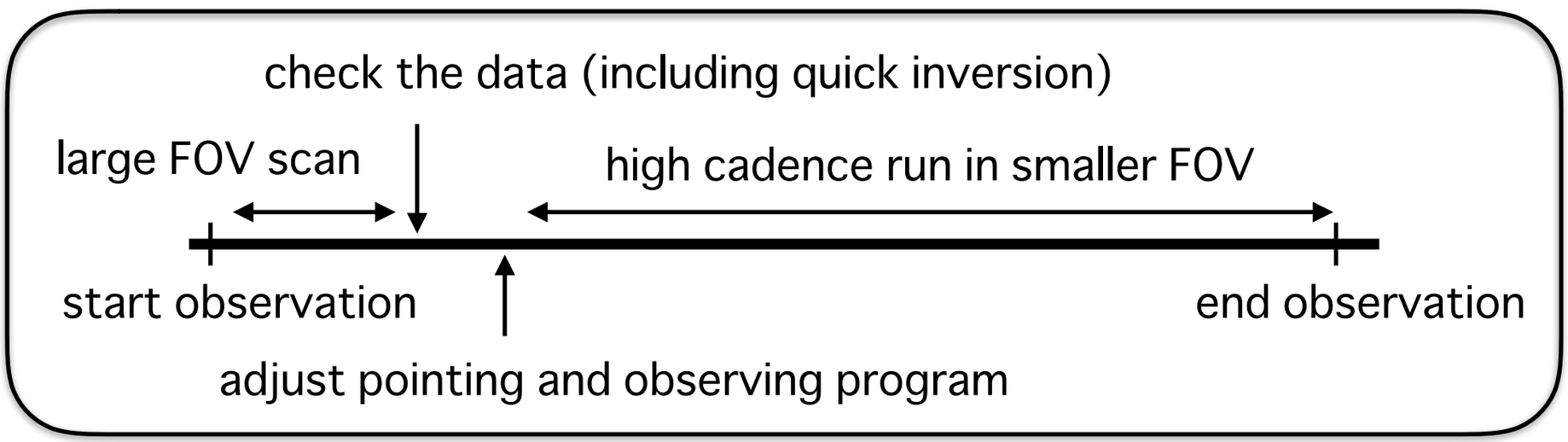
For this purpose (high cadence), we must know the exact location
to focus on when the observation is performed.

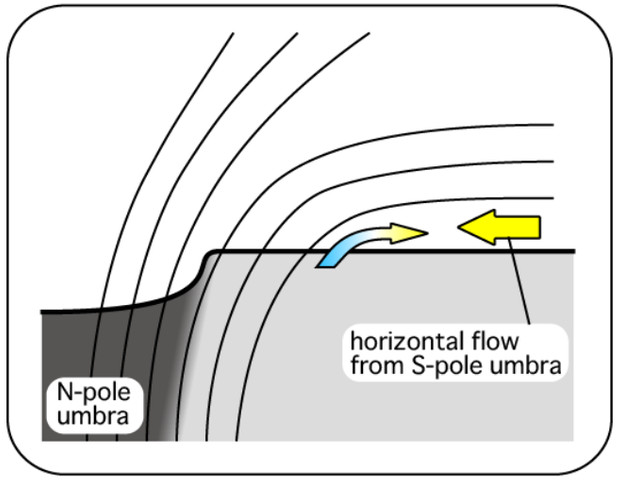
most important : to find a counter-flowing penumbra

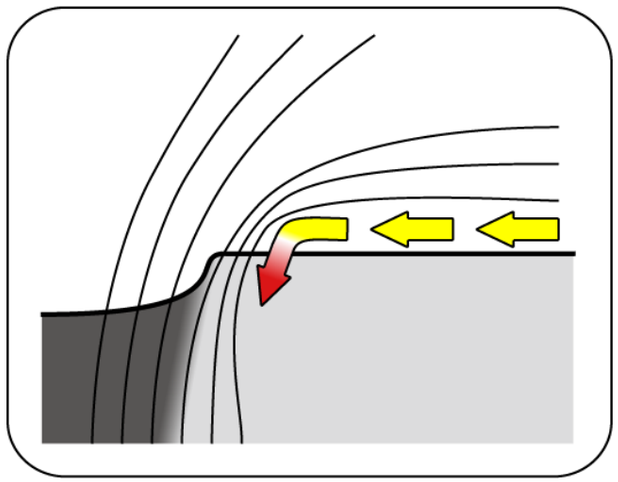


speculation

Hence, can I ask the feasibility that we will check the earliest data
(Doppler velocity and magnetic field strength) and that the quick result
will be reflected to the remaining operation on a single day ?







of course, if we can check the configuration 1 day before, it may be enough