# Statistical Investigation of Supersonic Downflows in the Transition Region above Sunspots


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**with**

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Contributed Talk

3. Magnetic coupling and mass flux through the atmosphere

# Statistical Investigation of Supersonic Downflows in the Transition Region above Sunspots

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Downflows at supersonic speeds have been observed in the transition region (TR) above sunspots for more than three decades. These downflows are often seen in different TR spectral lines above sunspots. We have performed a statistical analysis of these downflows using a large sample which was missing earlier. The Interface Region Imaging Spectrograph (IRIS) has provided a wealth of observational data of sunspots at high spatial and spectral resolution in the past few years. We have identified sixty datasets obtained with IRIS raster scans. Using an automated code, we identified the locations of strong downflows within these sunspots. We found that around eighty percent of our sample show supersonic downflows in the Si IV 1403 Å line. These downflows mostly appear in the penumbral regions, though some of them are found in the umbrae. We also found that almost half of these downflows show signatures in chromospheric lines. Furthermore, a detailed spectral analysis was performed by selecting a small spectral window containing the O IV 1400/1401 Å and Si IV 1403 Å transition region lines. Six Gaussian functions were simultaneously fitted to these three spectral lines and their satellite lines associated with the supersonic downflows. We calculated the intensity, Doppler velocity and line width for these lines. Using the O IV 1400/1401 Å line ratio, we find that the downflow components are one order of magnitude less denser than the regular components. Results from our statistical analysis suggest that these downflows may originate from the corona and that they are independent from the background TR plasma.

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# Outline of the Talk

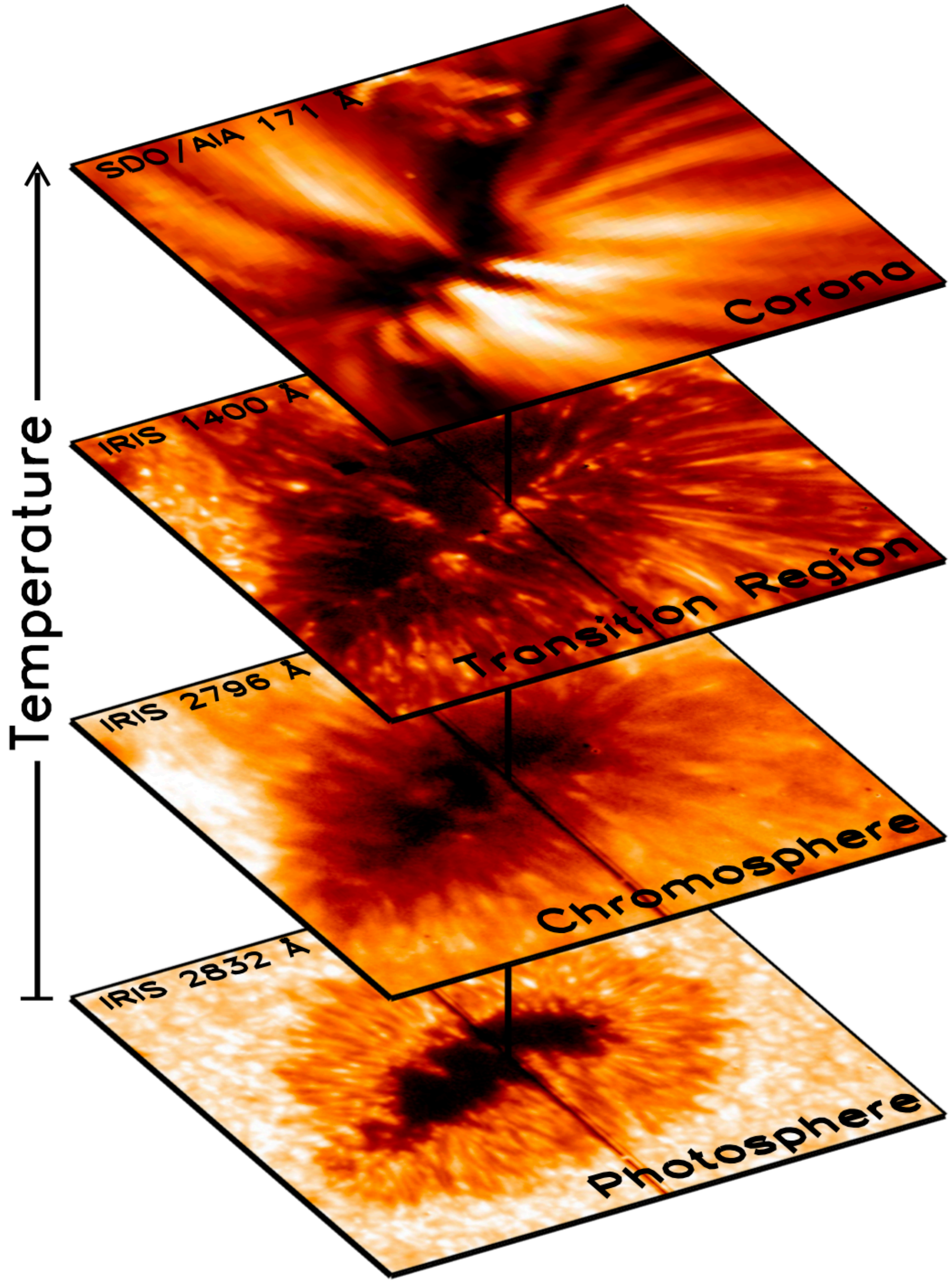
## Supersonic Downflow:

- Introduction
- Some earlier results

## IRIS Spectral Analysis:

- Detection of downflows
- Statistical properties

## Conclusion




The transition region above sunspots:
Tian, Samanta, & Zhang, Geosci. Lett., 2018

# Observations of Supersonic Downflows

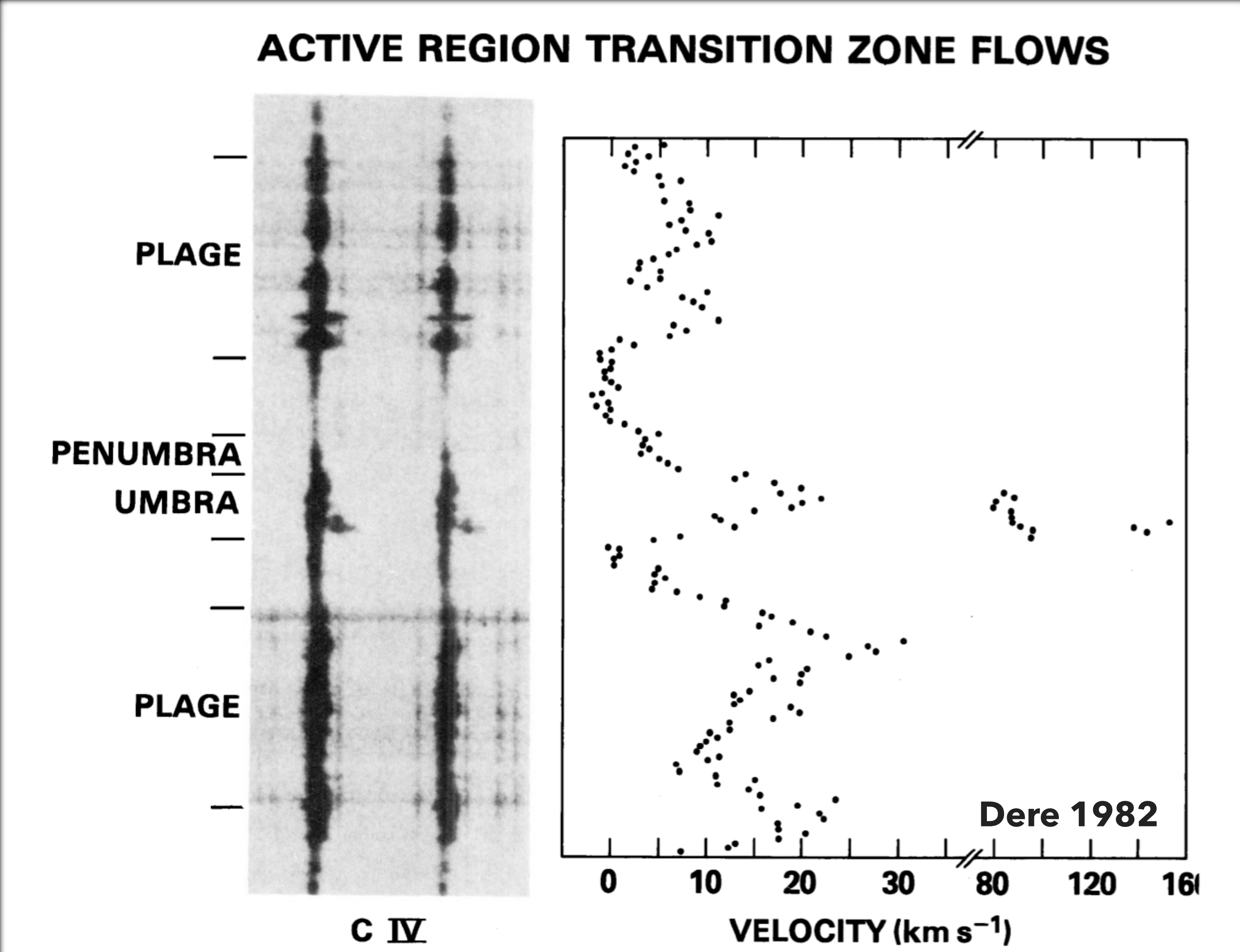



Fig. 3. Doppler velocities at $10^5$ K in an active region plage and sunspot derived from EUV HRTS

Average Doppler Velocity from

C IV,
O IV,
N IV
Lines

10^5 K Plasma

# Observations of Supersonic Downflows

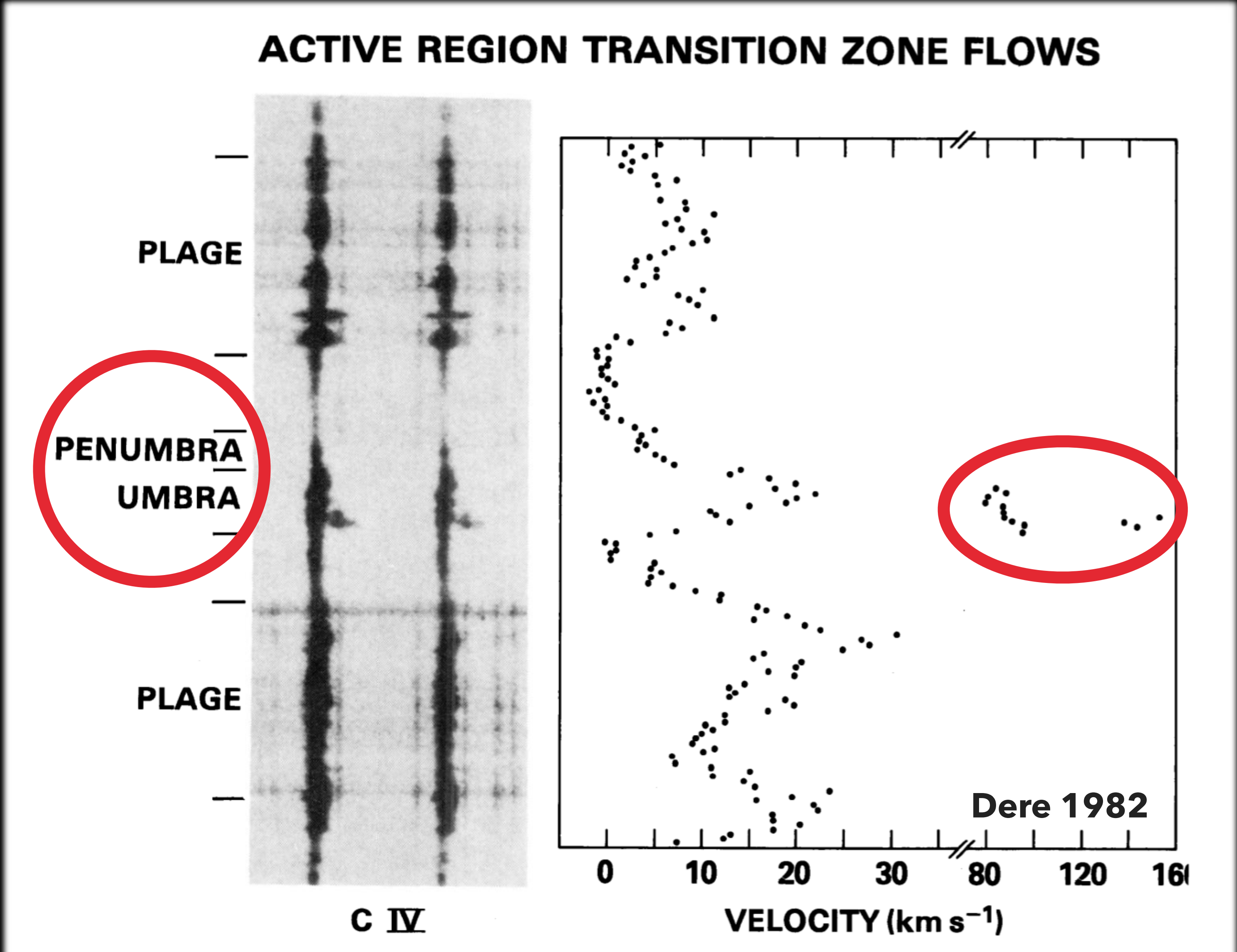



Fig. 3. Doppler velocities at $10^5$ K in an active region plage and sunspot derived from EUV HRTS

Average Doppler Velocity from

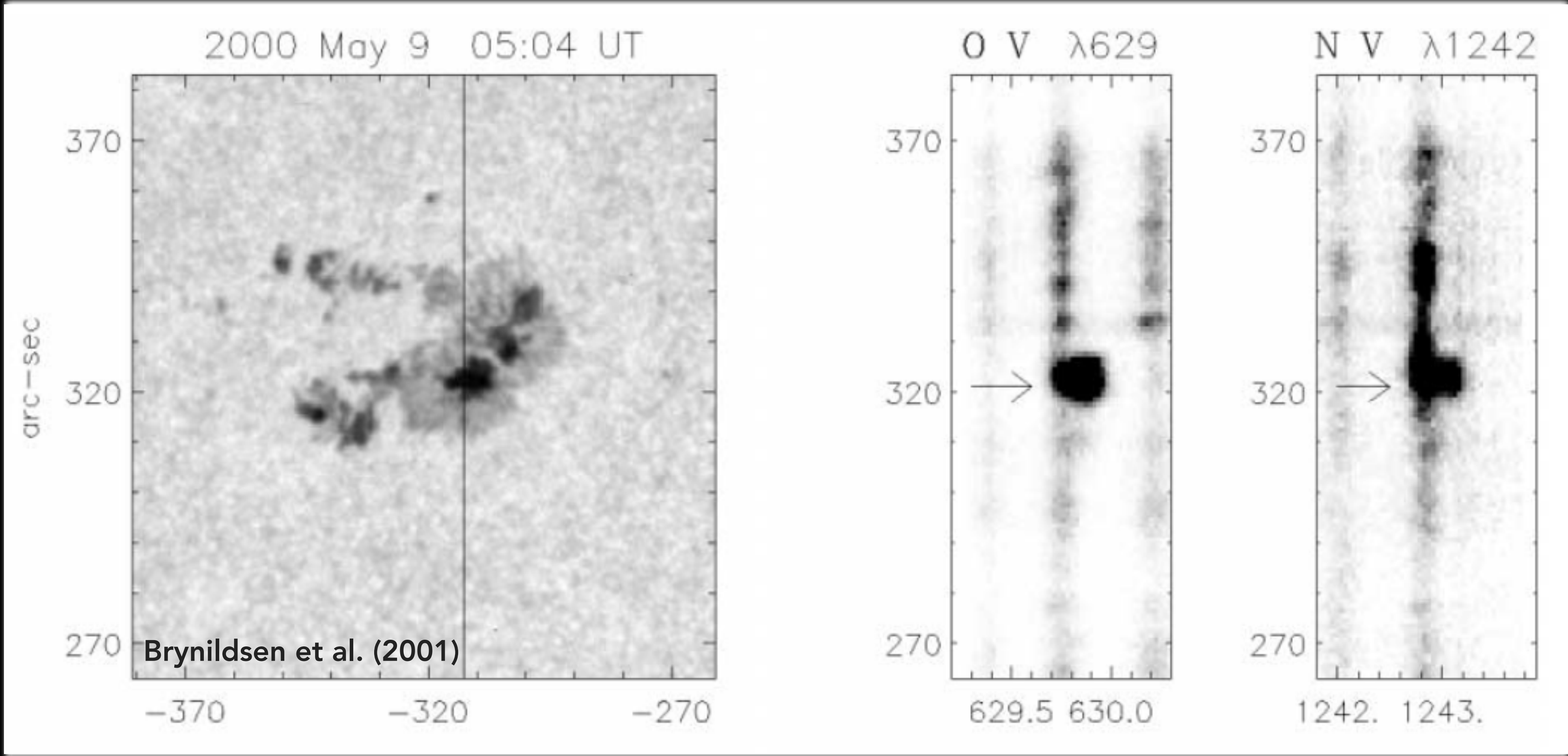
C IV,
O IV,
N IV
Lines

10^5 K Plasma

**Some places in sunspot show velocity ~ 100 km/s.**

Sound speeds around TR temp. ~50 km/s; Observed flows are supersonic.

# Observations of Supersonic Downflows




SUMER Observation of O V and N V lines

The TR lines have two component.

# Open Questions about Supersonic Downflows

With IRIS: few case studies of supersonic downflows

Several open questions about these supersonic downflows

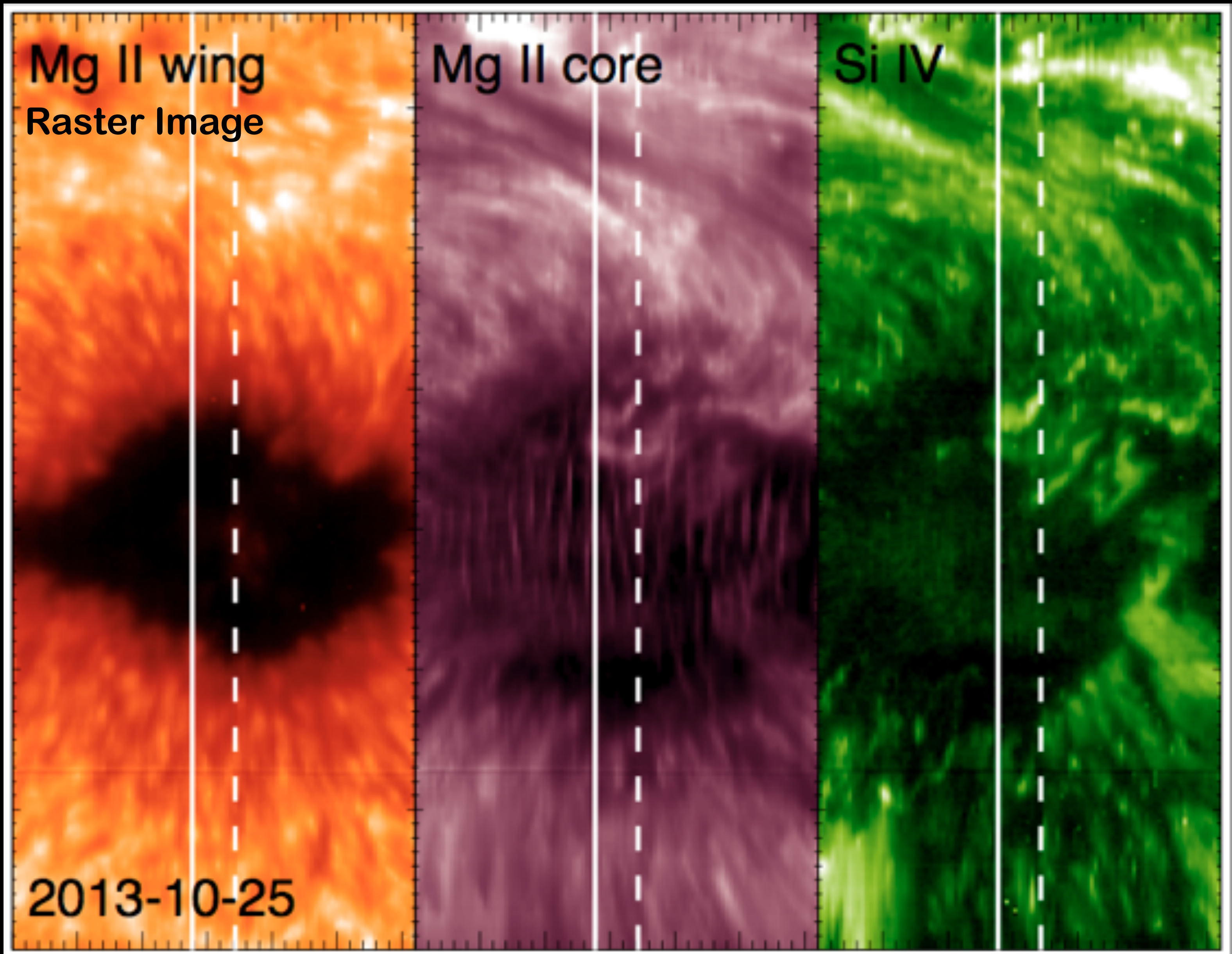
a) How common are they?
b) Do they show signatures in chromosphere lines?
c) Are they mostly common in penumbral regions?
d) What are the density & mass flux of these downflows?
e) Originated in the TR or coming from a higher height?

We performed a statistical analysis of these downflows using 1.5-years of IRIS raster data of sunspots

Samanta et al., 2018, ApJ

# IRIS Spectra:
# Detection of Supersonic Downflows

# Observations with IRIS




**Mg II wing: 5 – 8,000 K**

**Mg II core: 10,000 K**

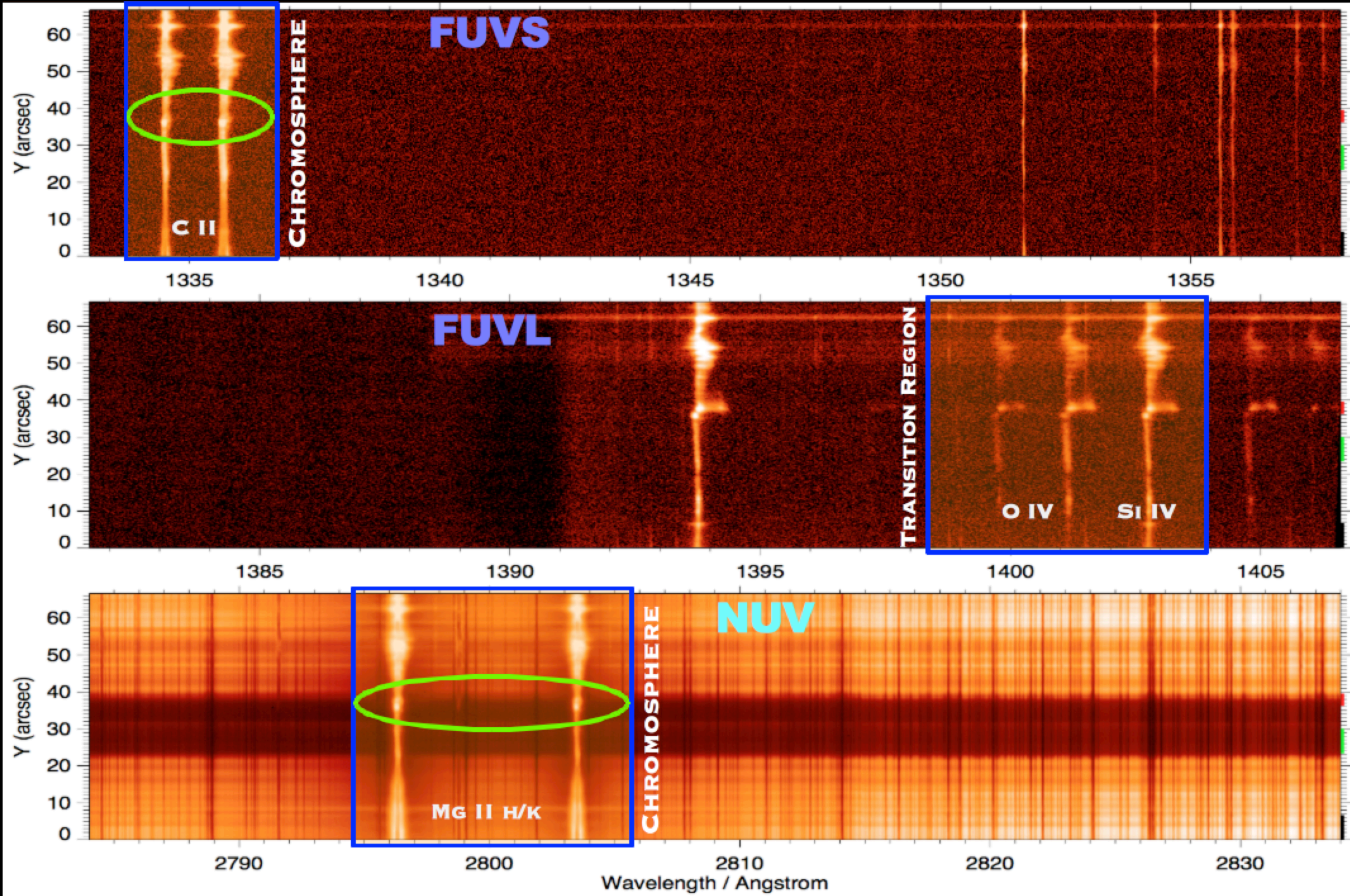
**Si IV : 80,000K**

**O IV : 150,000 K**

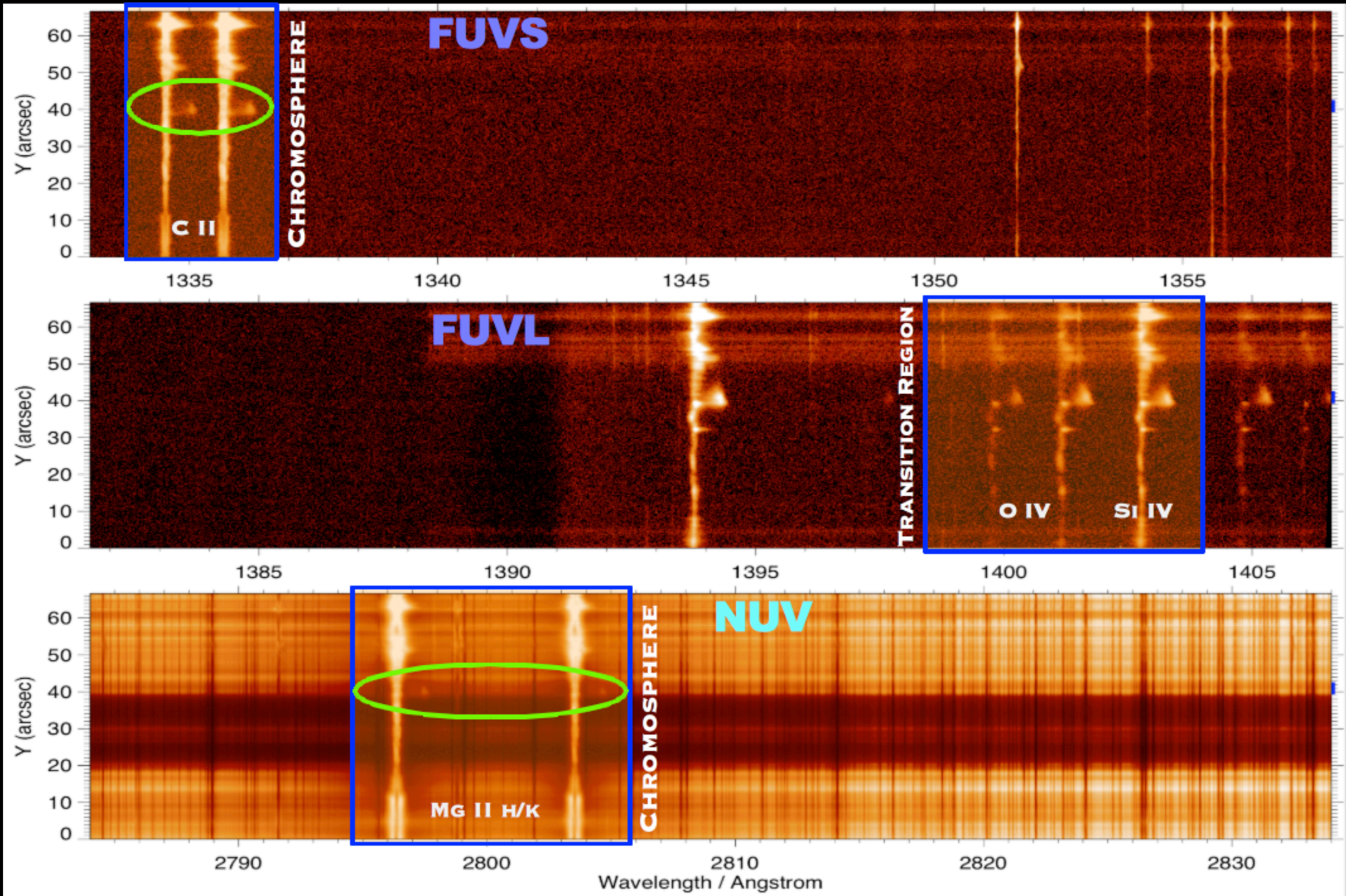
**IRIS Raster scan of a sunspot**

**Spectra along solid & dashed line in the next slide**

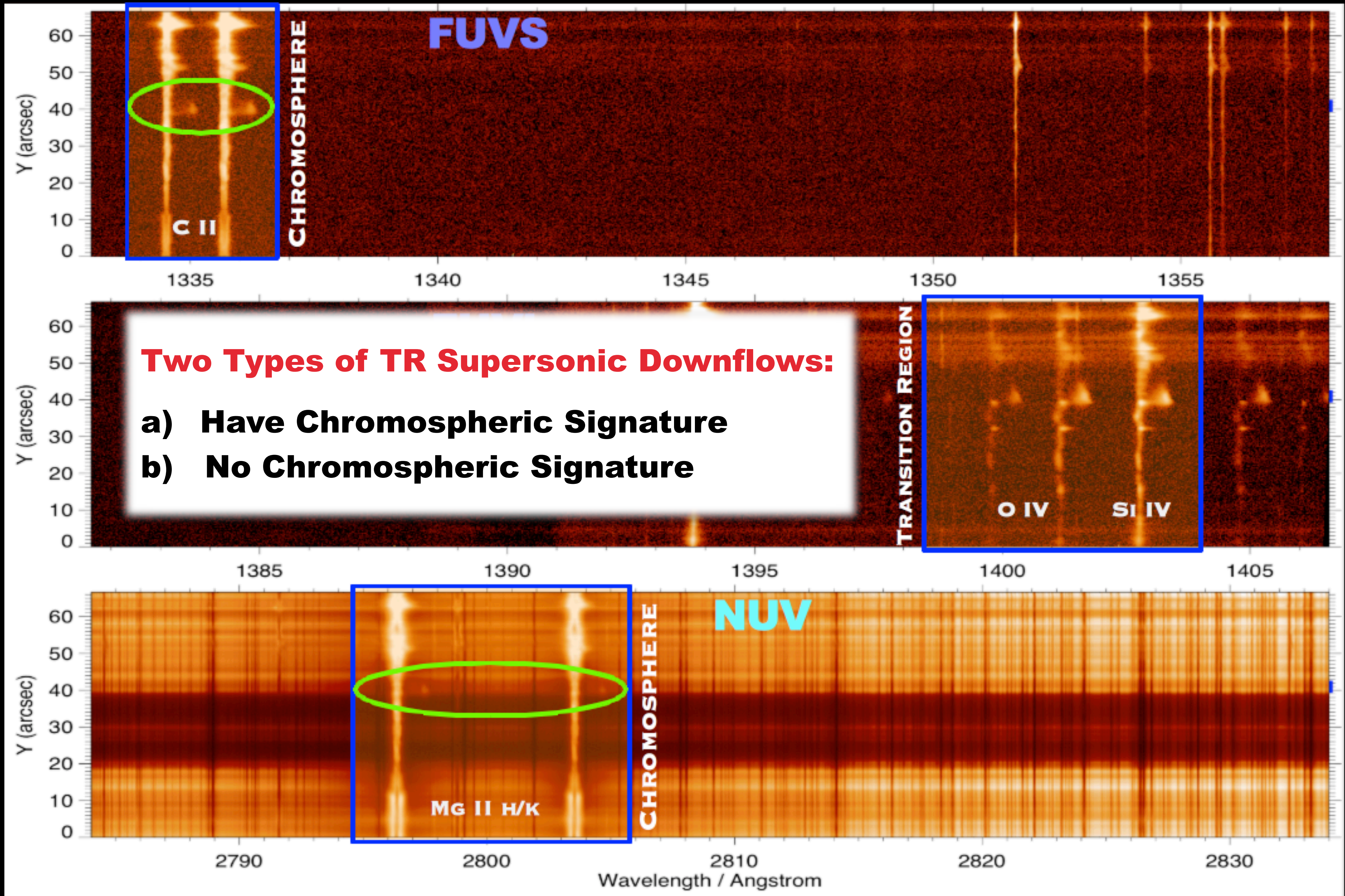
# Spectra along the solid line



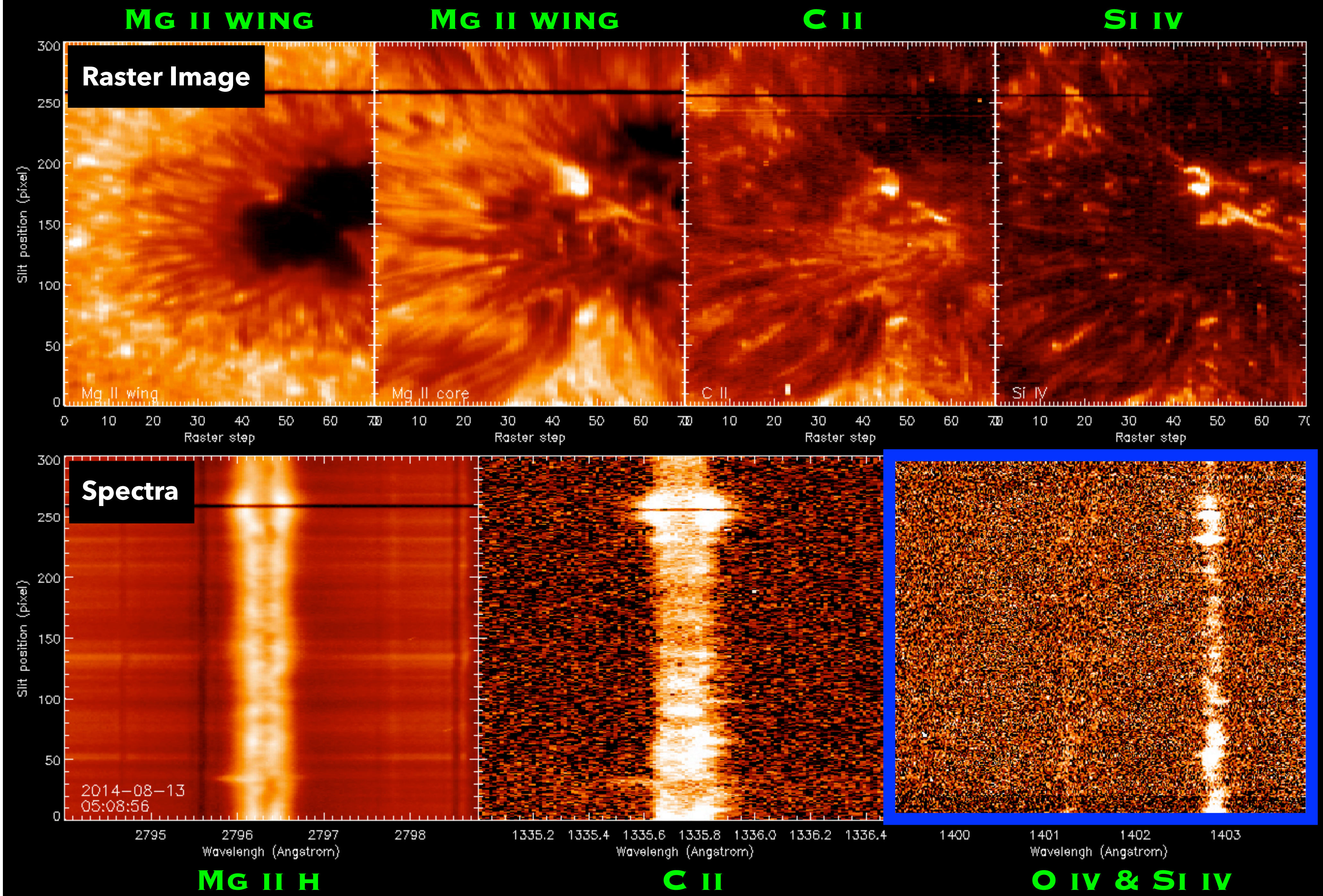
# Spectra along the dashed line



# Spectra along the dashed line

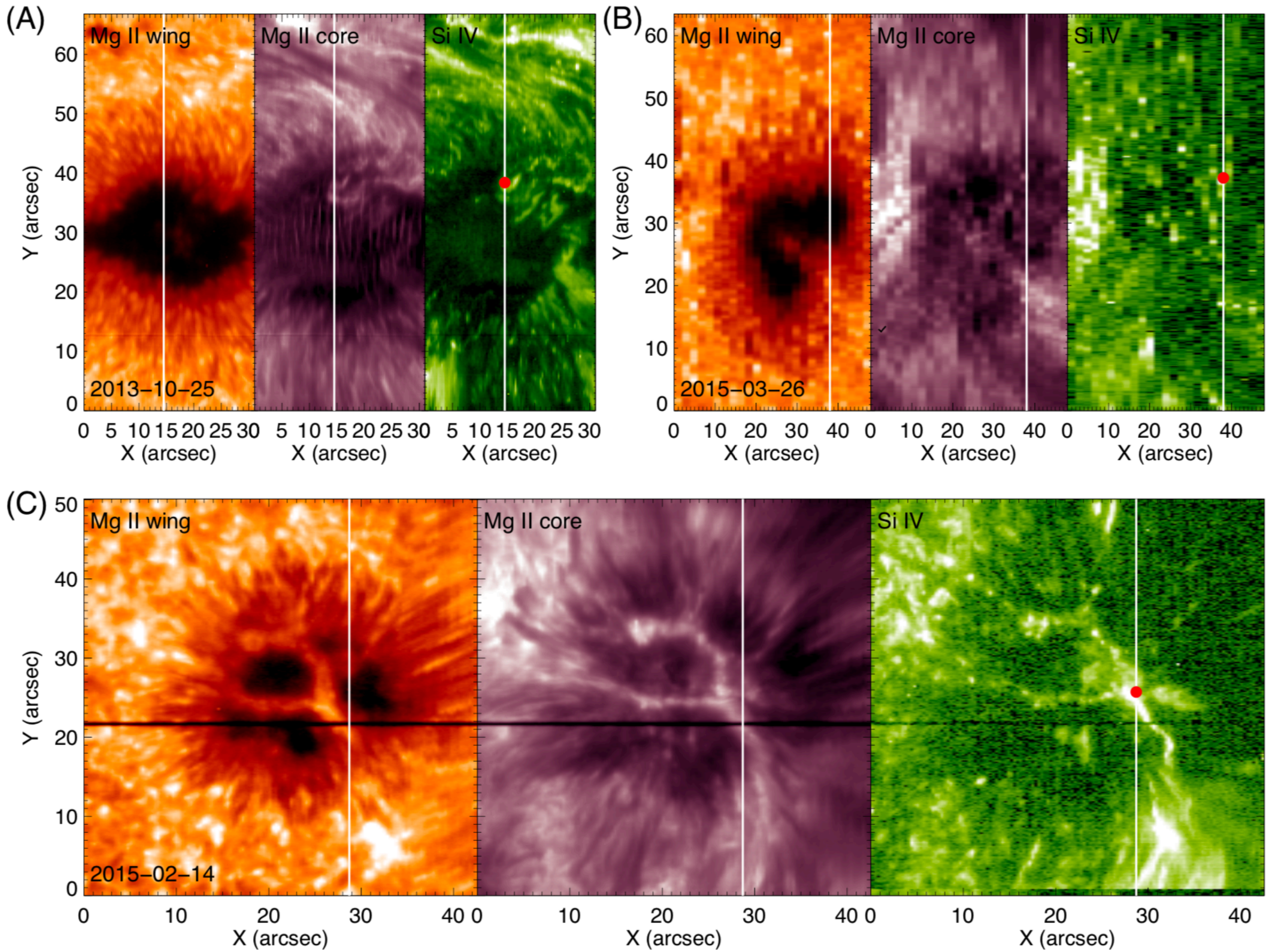


# An example of Supersonic Downflows

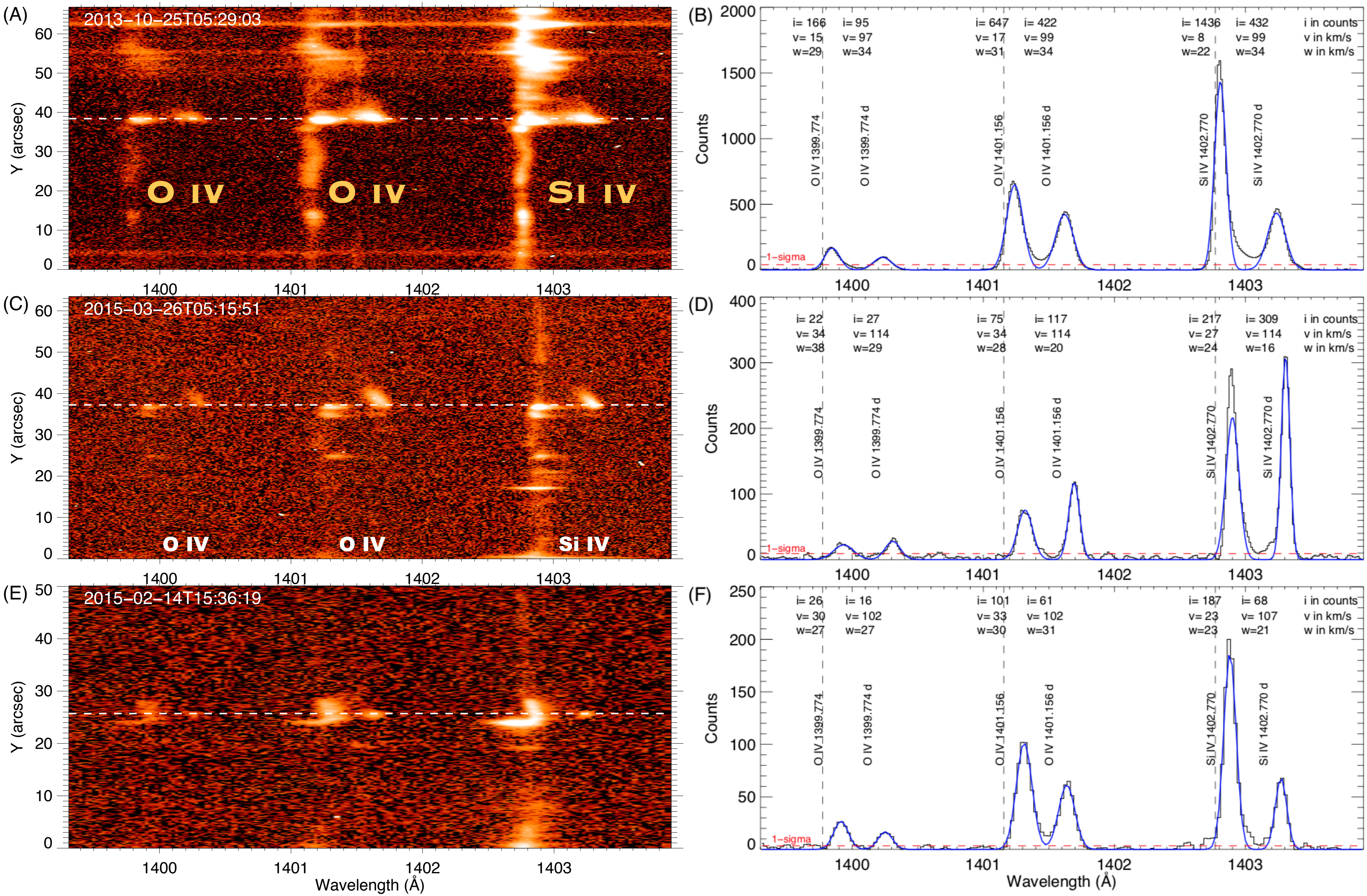


# Spectral analysis:
# Multi-Gaussian fitting to the spectra

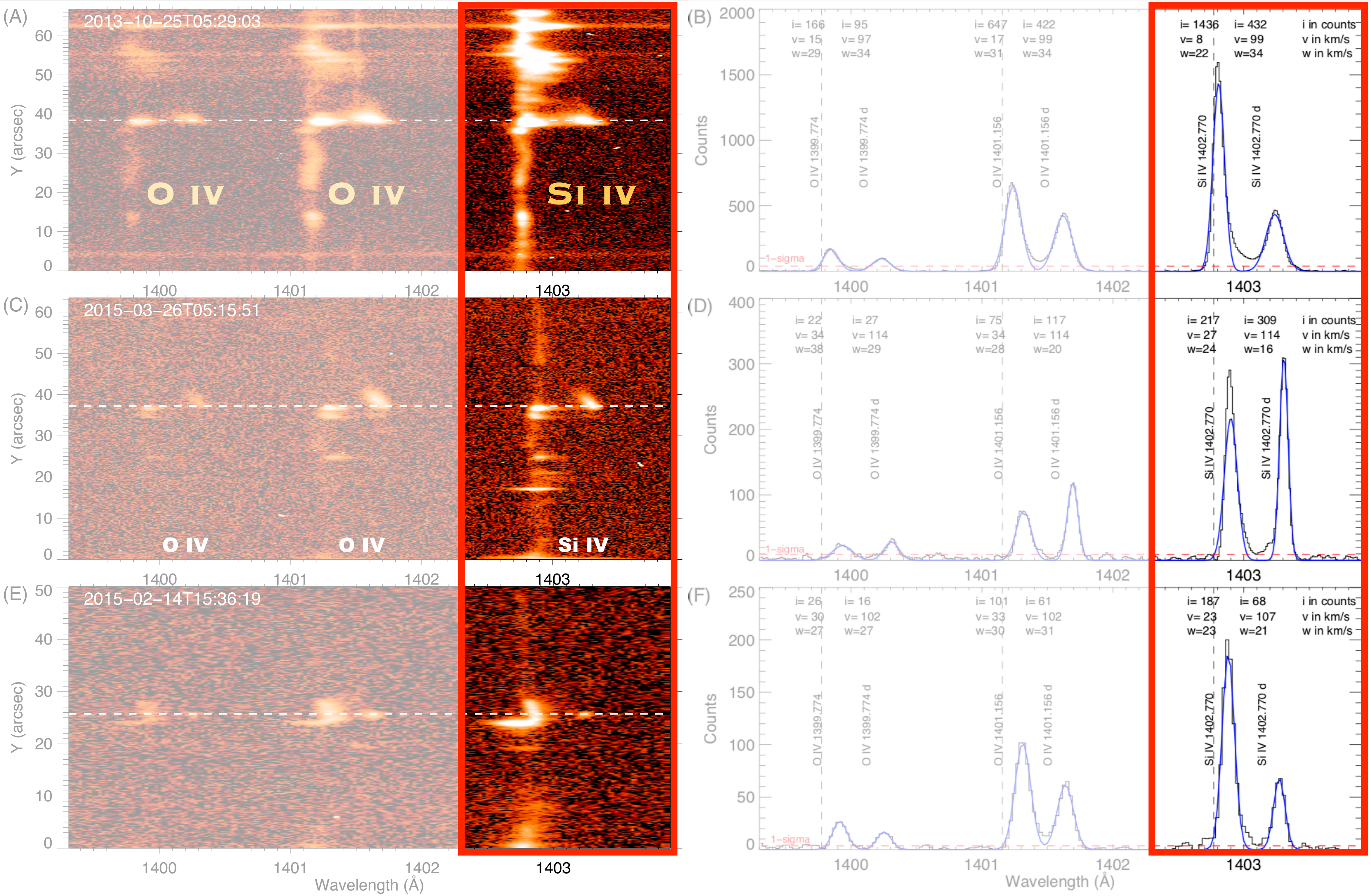
# IRIS Raster Observations of Sunspots



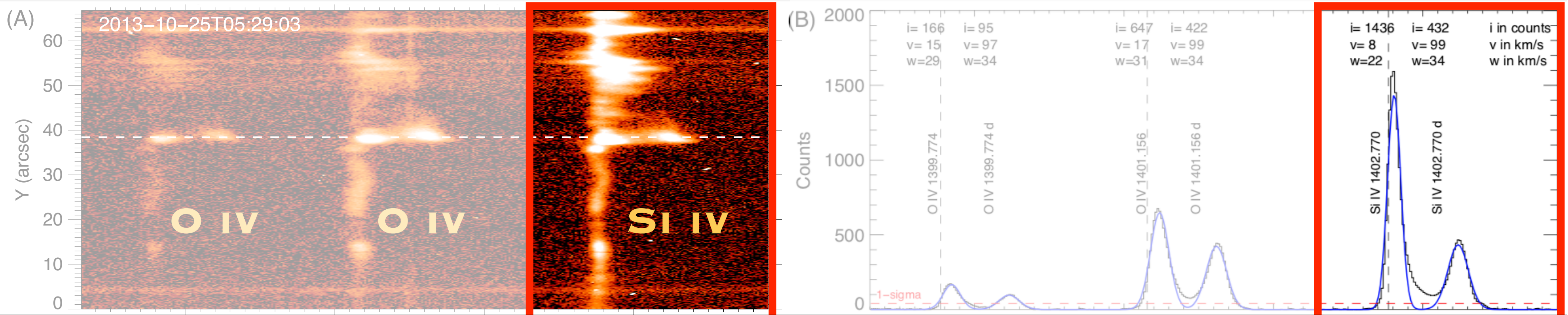
# Spectra with Supersonic downflows



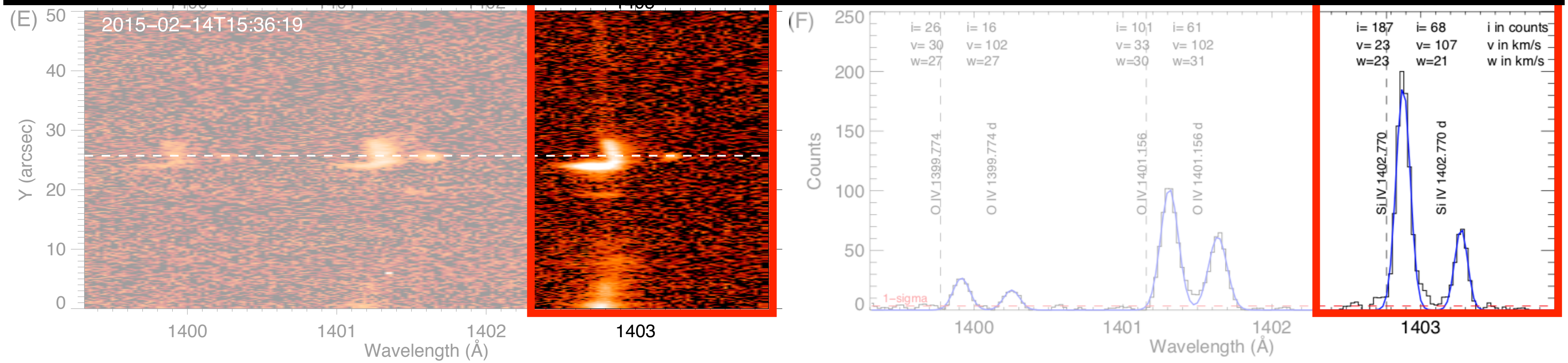
# Spectral fitting



# Spectral fitting

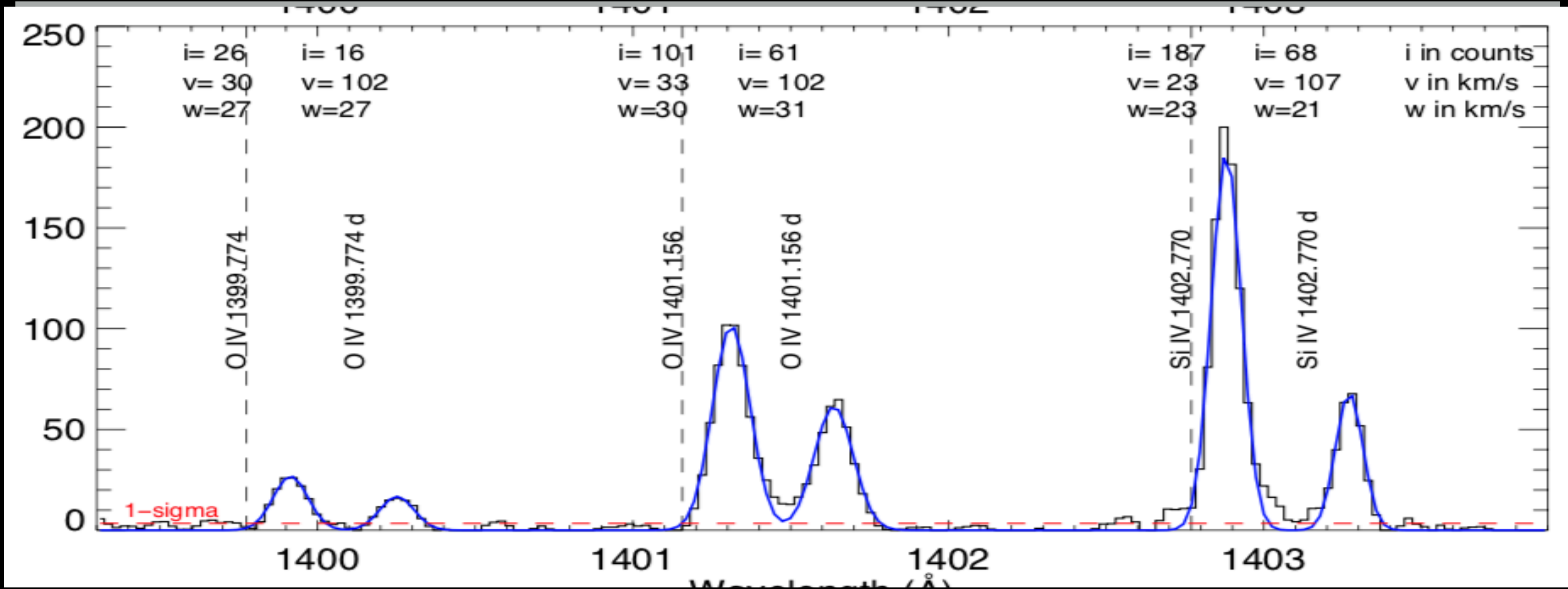



**Out of 60, 48 (80%) show supersonic downflows: 28 in penumbrae, 4 in umbrae and 16 in both.**



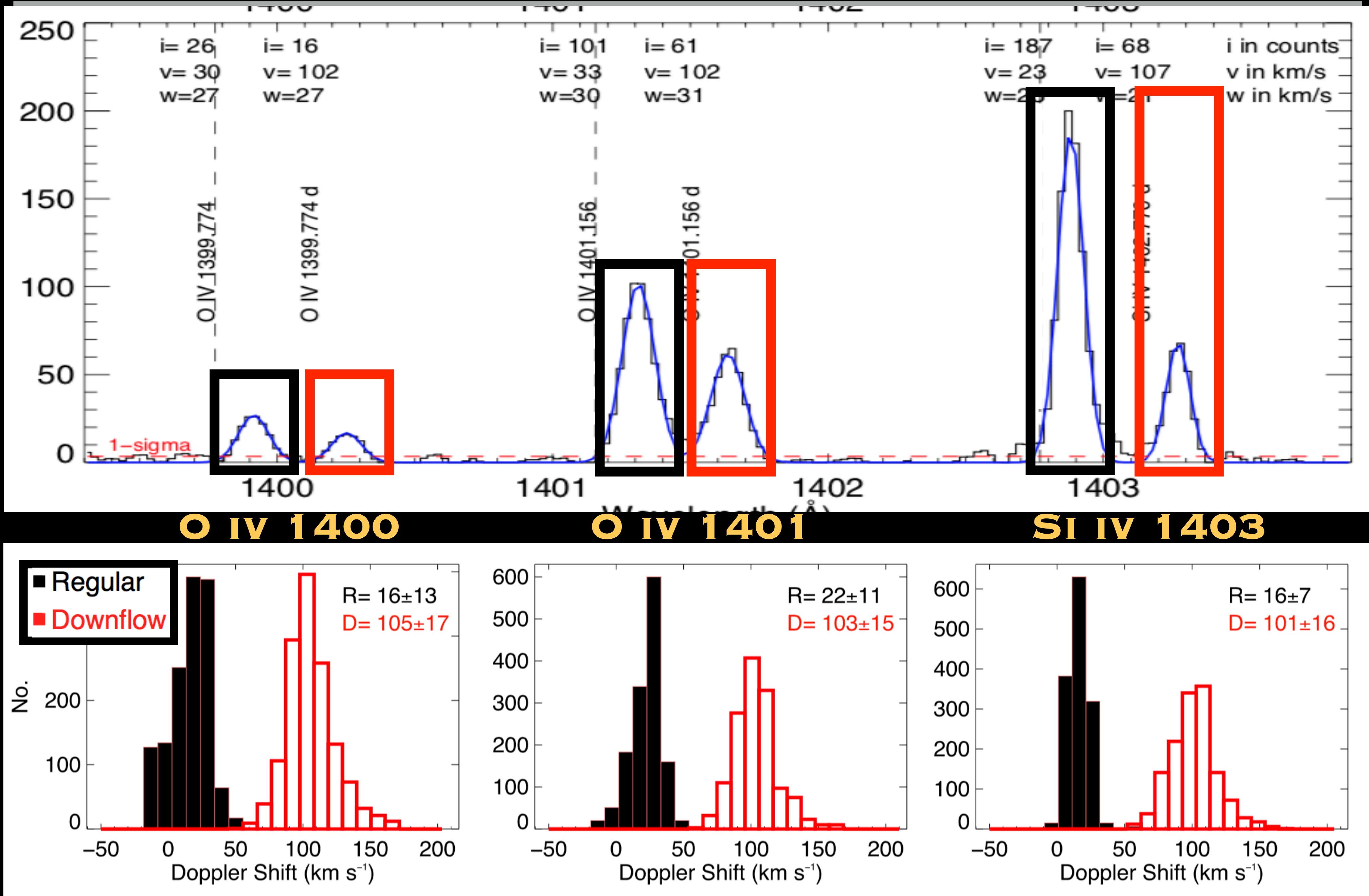
# Statistical properties of Supersonic Downflows

# Statistical properties of the two components



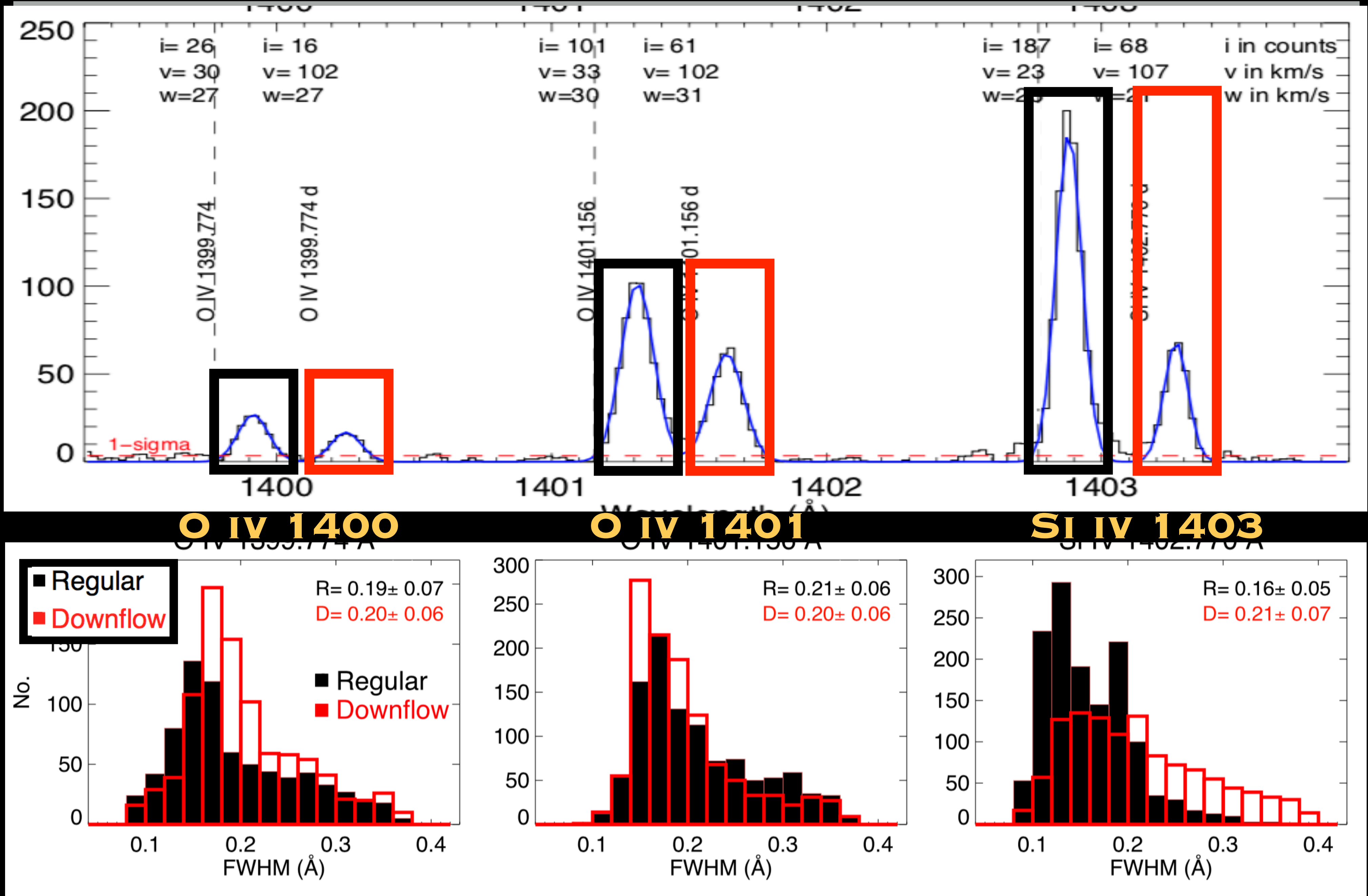

O IV 1400 O IV 1401 Si IV 1403

# Statistical properties of the two components



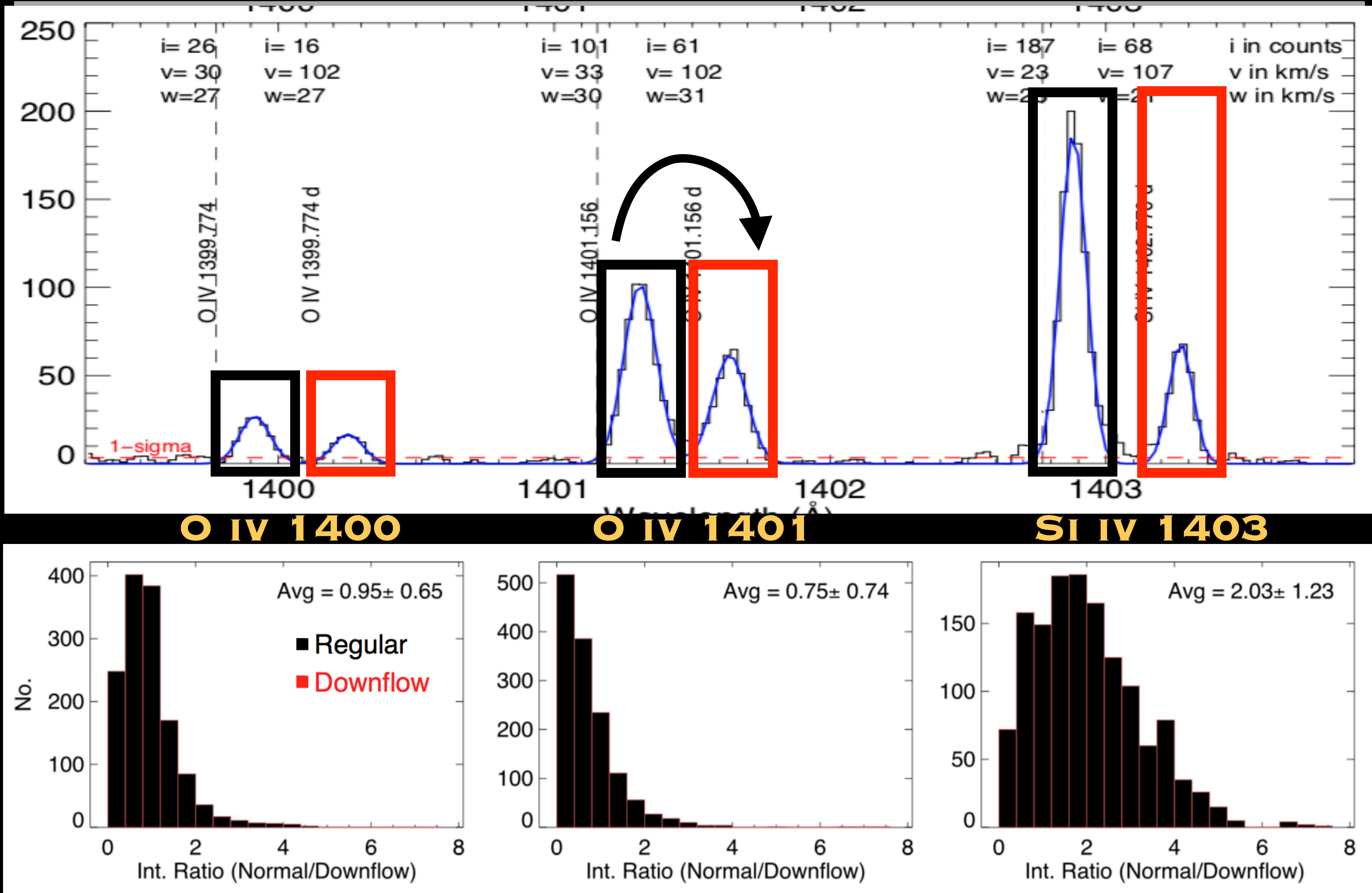

**Supersonic Downflows velocity ~ 100 km/s (O IV, Si IV)**

# Statistical properties of the two components




Line-width: Similar for O IV; Slightly larger for Si IV

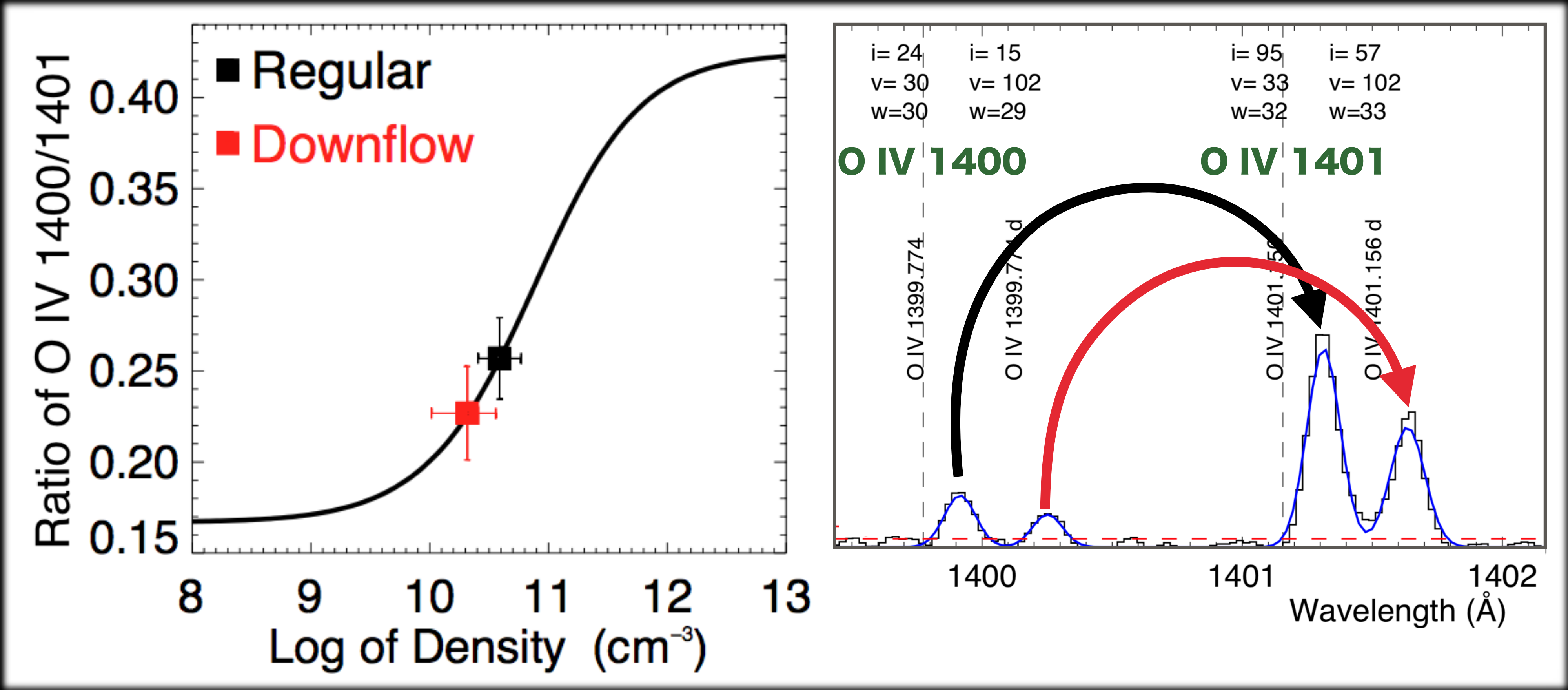
# Statistical properties of  the two components




Intensity ratio: O IV ~1, Si IV~2

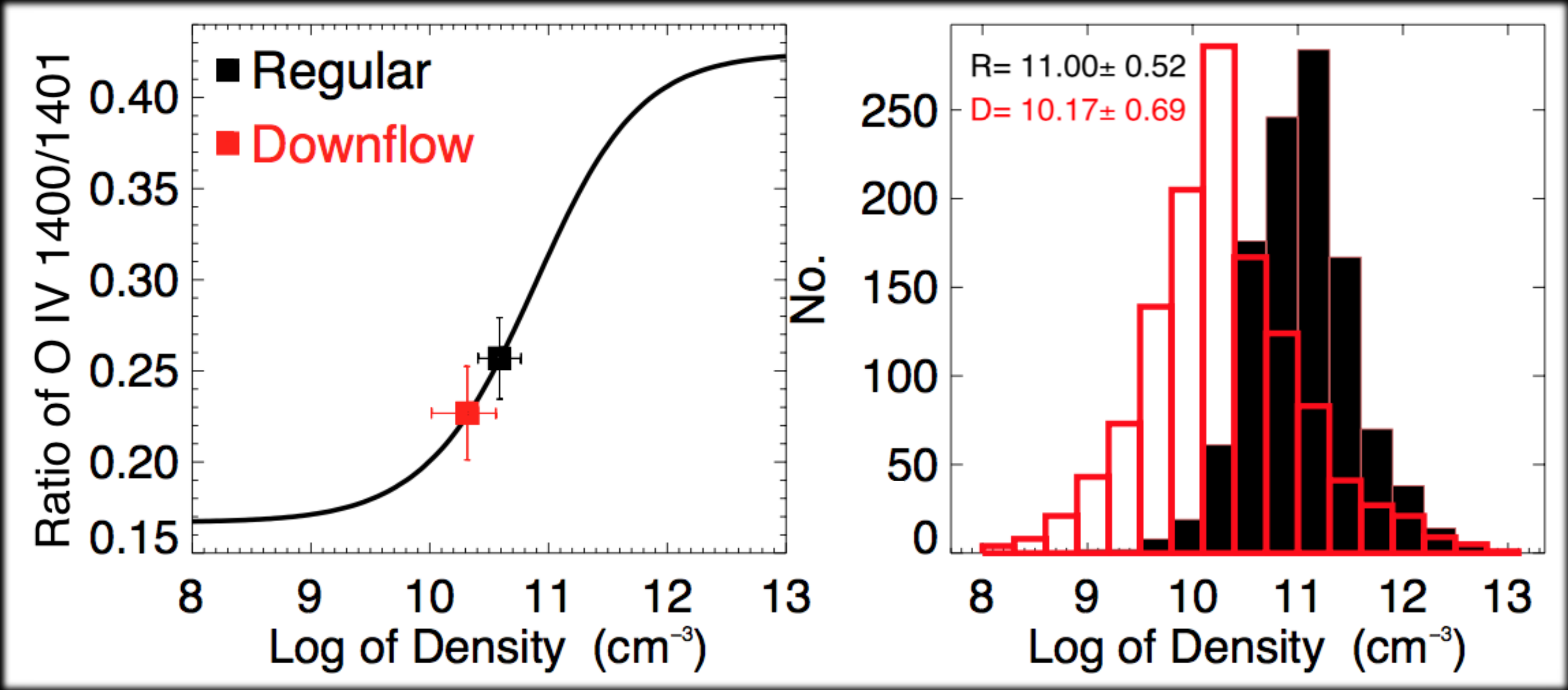
O IV int.  is higher than Si IV int. at many locations for the downflow component.

# Density diagnostics




**O IV 1400/1401 A lines intensity ratio is sensitive to electron density.**

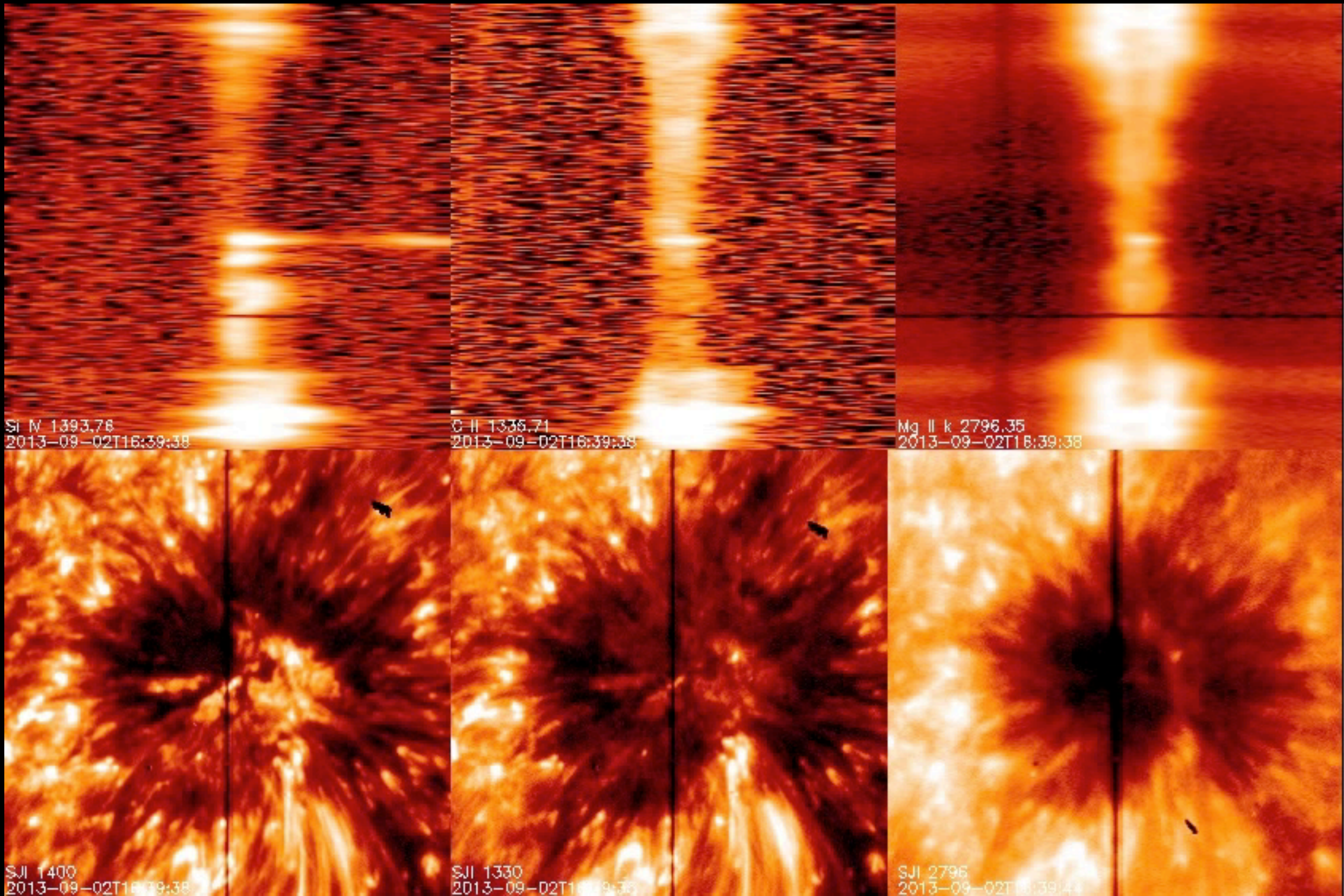
## Density diagnostics




**Downflow components are one order of magnitude less denser than the regular components.**

**Probably coming from the corona.**

# Sit-and-stare observation with IRIS

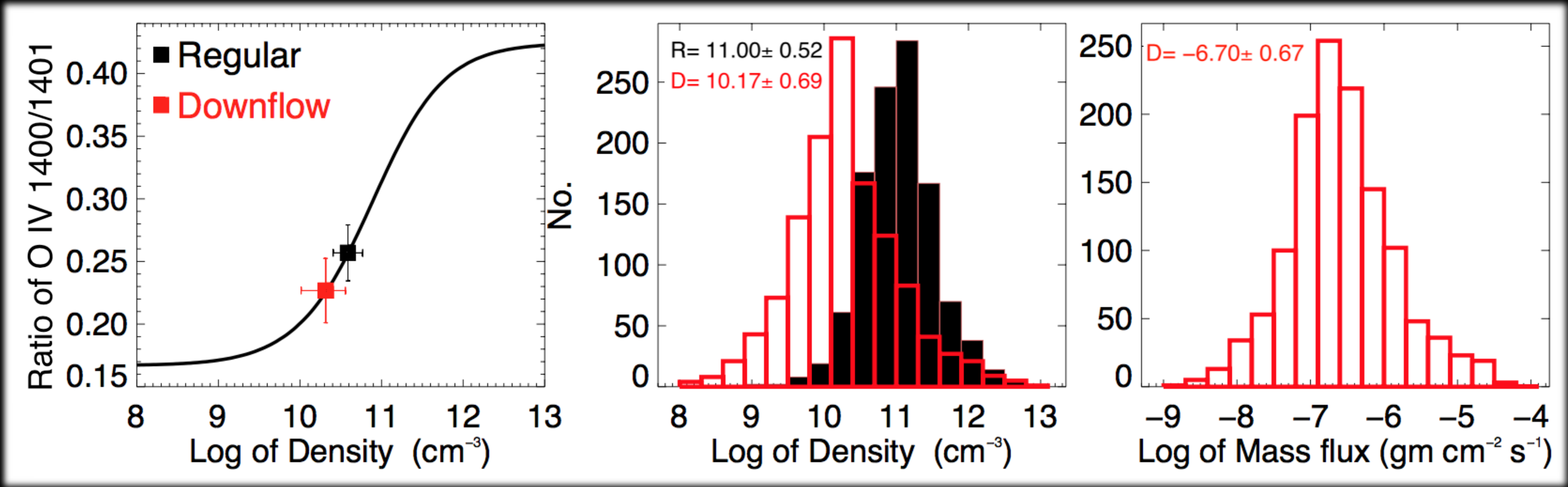



Tian et al. 2014, Straus et al. 2015: 80 minutes continuous observation.

The “satellite” line is remarkably steady over the observing period.

Does not participate in the 3 min shock wave dynamics.

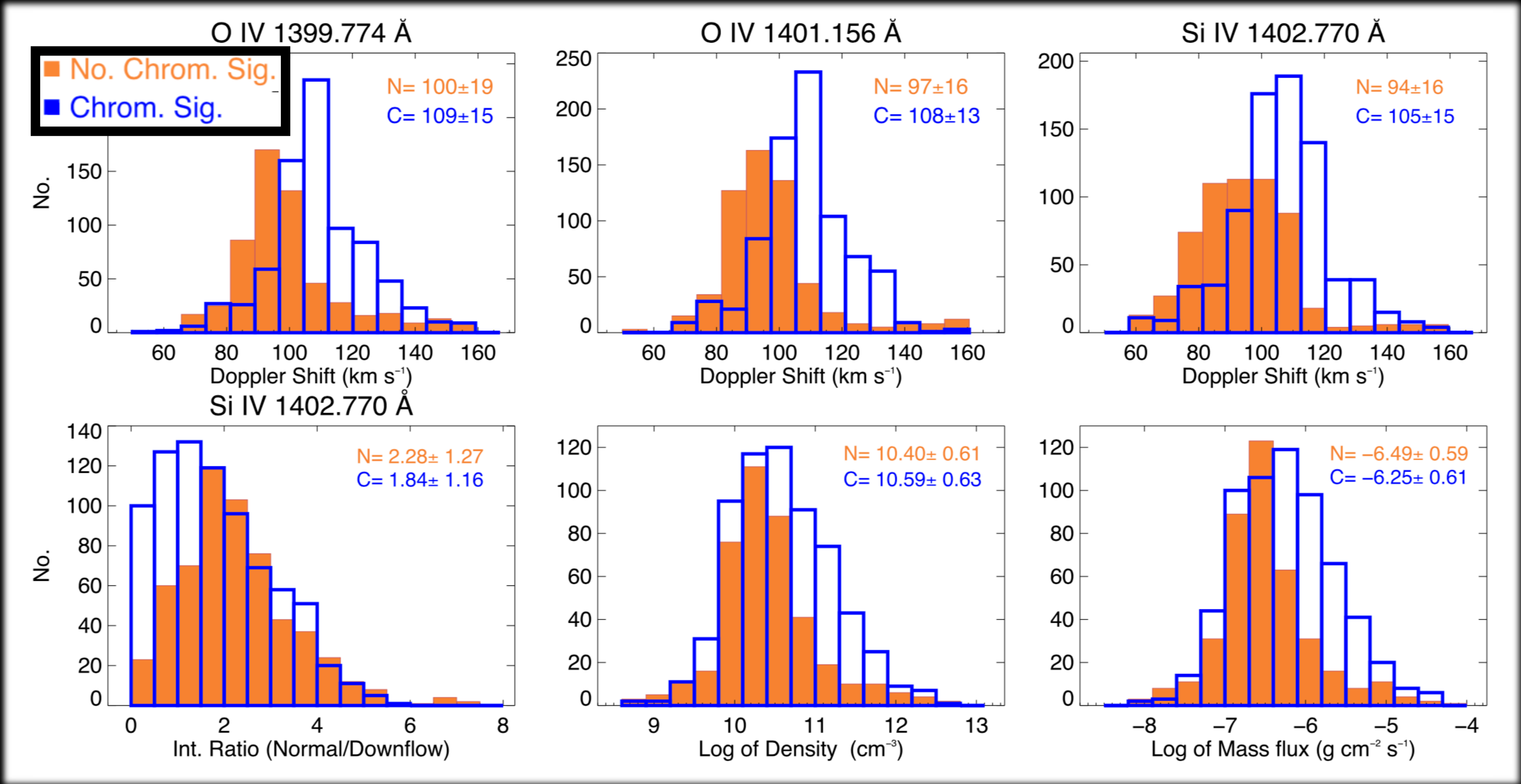
# Density and Mass flux




**Mass flux due to supersonic downflows is very high.**

**It would evacuate a overlying coronal loop on a time scales ~ 100 s.**

# Chromospheric Signature of TR  SSdownflows




**Around half of these downflows leave a trail in chromospheric lines.**

a) Average Doppler shift is about 10 km/s higher.  b) Density and mass flux are slightly higher.

**This indicate that downflows originating from a dense medium and having a higher velocity could reach the chromosphere.**

## Summary

Statistical analysis shows that supersonic downflows in the TR above sunspots are very common (~80 % of sunspots)

- Observed both in umbra and penumbra.
- Half show signatures in chromosphere.

- Downflow component has much lower density compared to the regular component.
- At some locations there is only downflow component and no rest component (Probably due to exposure time).

Downflowing materials are independent of the background plasma in sunspots and may originate from the corona.

Downflow velocity is similar for Si IV and O IV (also Mg II)
> independent of temperature > multi-thermal plasma !!!!

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How these downflows sustain for long time?

Siphon flow (Straus et al. 2015, Chitta et al. 2016) !!

*Thanks*