COUPLING OF LARGE AND SMALL SOLAR EVENTS: PROPAGATING CASCADES FROM WHICH TO LEARN ABOUT THE CORONA, WITH NASA'S *SOLAR DYNAMICS OBSERVATORY*

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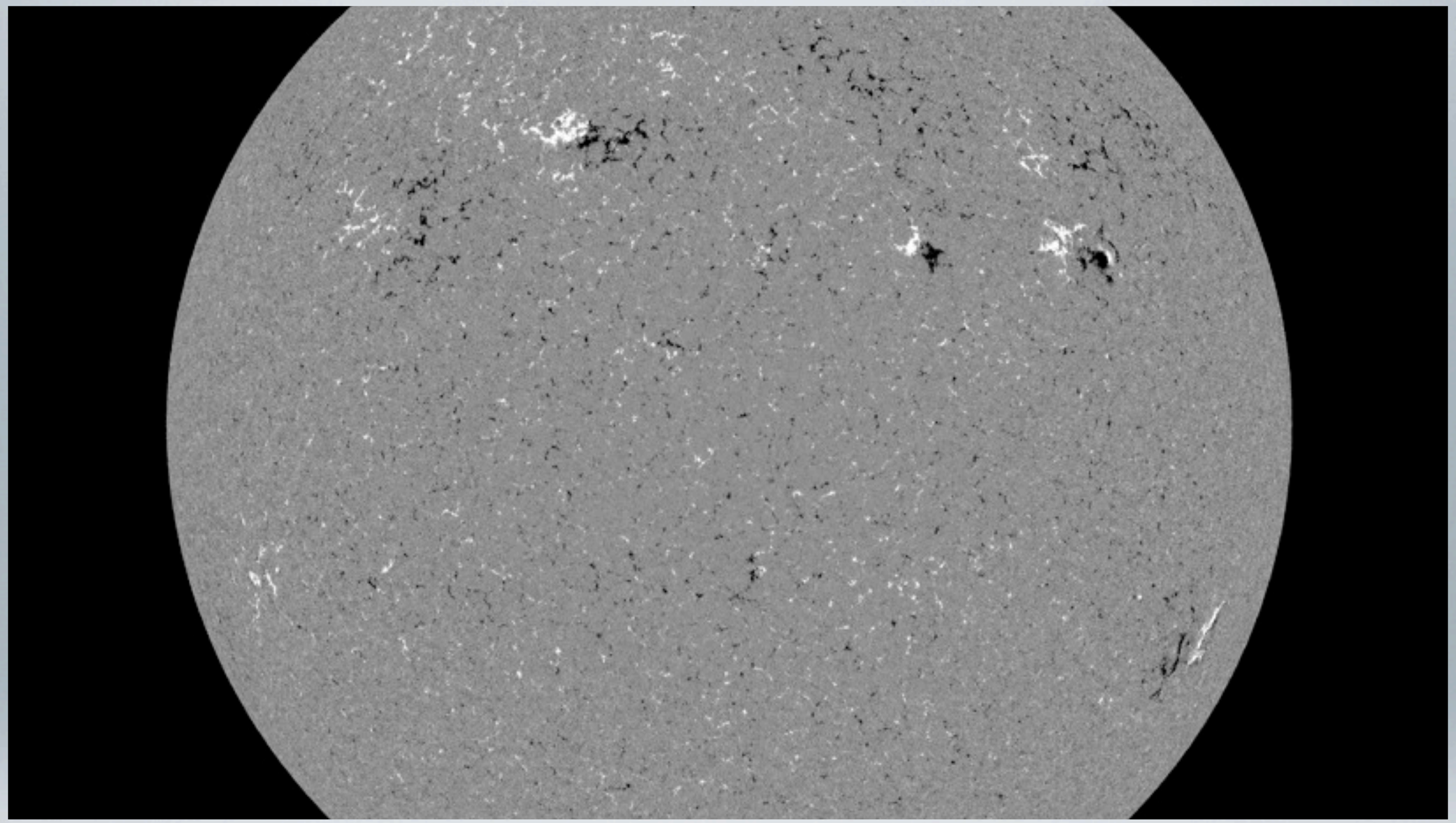
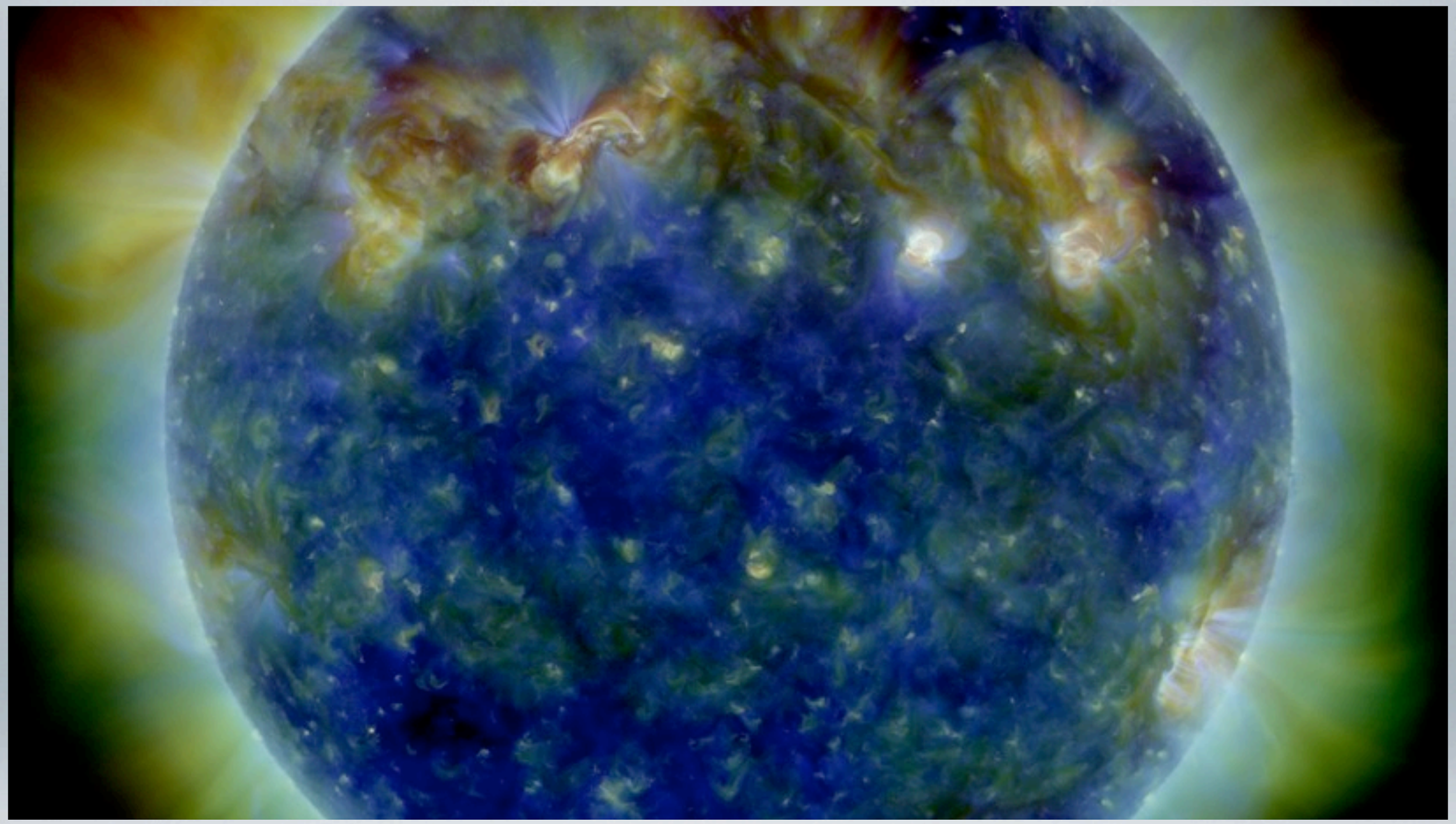


SDO/HMI

A magnetic map of the Sun as observed by the Helioseismic Magnetic Imager on the Solar Dynamics Observatory. The dark and bright regions show areas of magnetic field on the solar surface of southern and northern polarity, respectively. Image courtesy of the SDO/HMI team.

INSTANCE OF THE SUN'S MAGNETIC FIELD

(SOLAR DYNAMICS OBSERVATORY/HELIOSEISMIC MAGNETIC IMAGER).

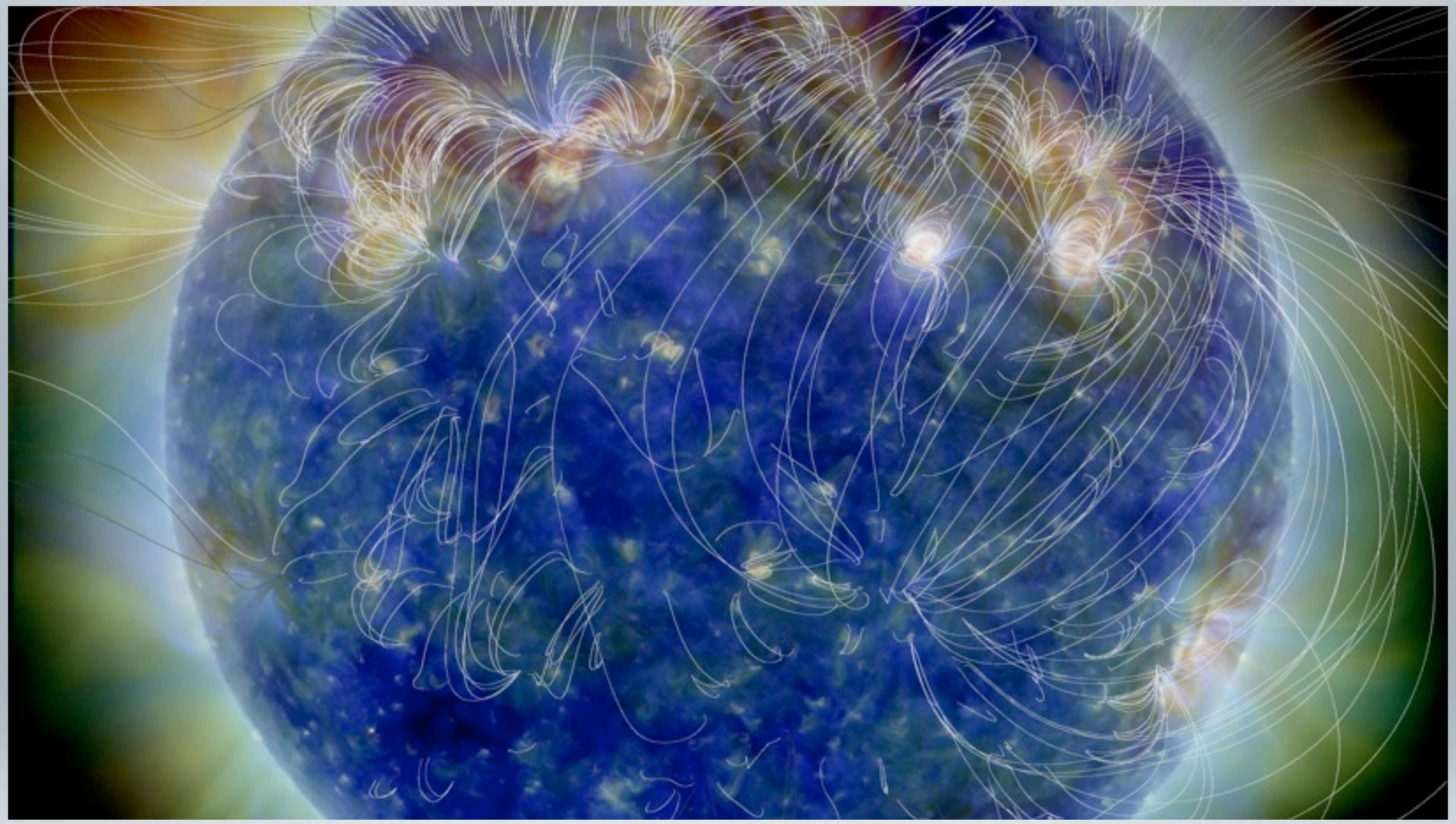


SDO/AIA

A false-color image of the solar corona taken by the Atmospheric Imaging Assembly onboard the Solar Dynamics Observatory. The image combines data from three AIA channels sensitive to light emitted by gas at different temperatures: red at 2 million degrees, green at 1.5 million degrees, and blue at 1 million degrees. Image courtesy of the SDO/AIA team.

THE MAGNETIZED HOT CORONA

(SOLAR DYNAMICS OBSERVATORY/ATMOSPHERIC IMAGING ASSEMBLY)



SDO/AIA

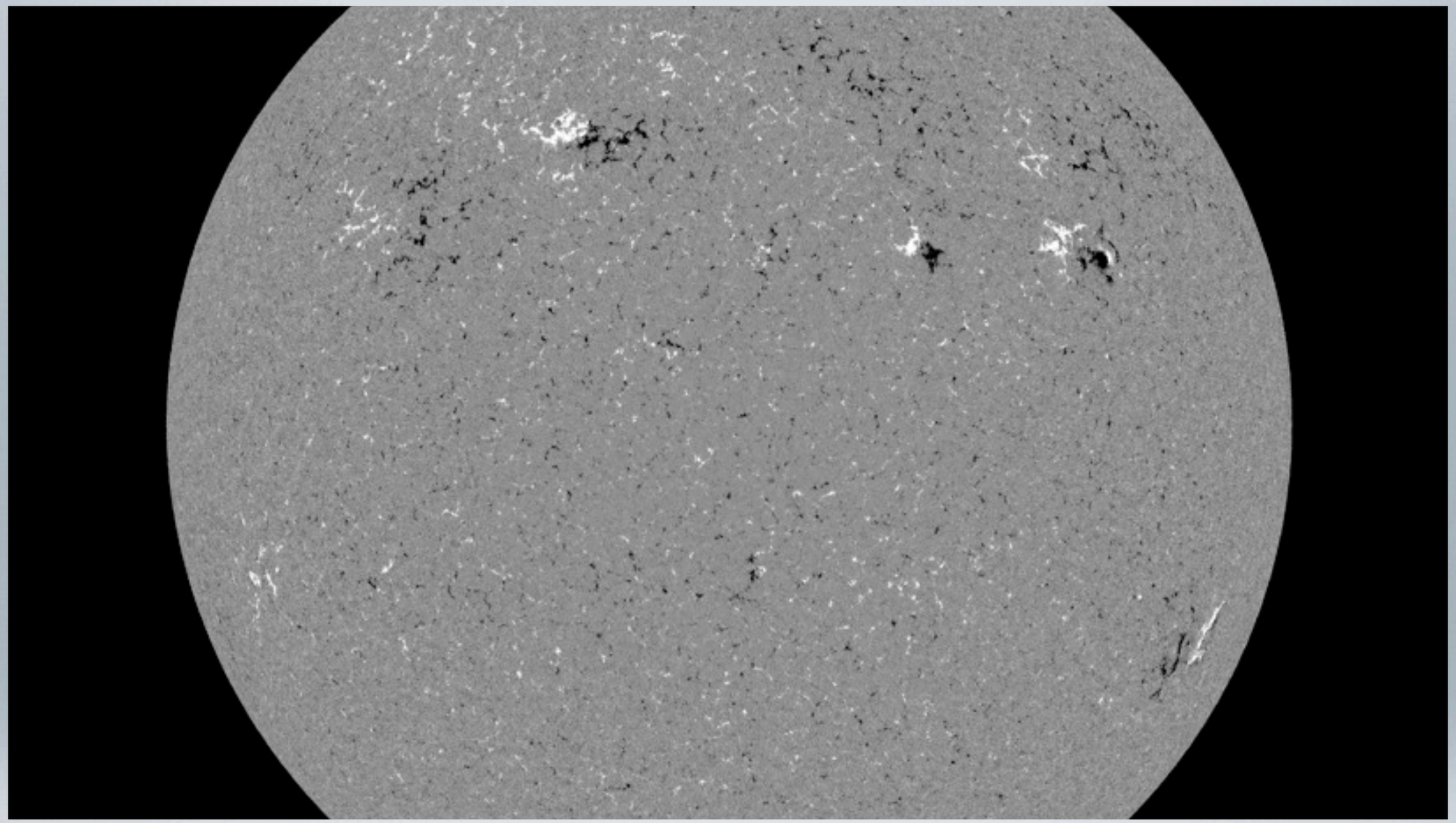
A false-color image of the solar corona taken by SDO's AIA. The image combines data from three AIA channels sensitive to light emitted by gas at different temperatures: red, green, and blue at 2, 1.5, and 1 million degrees, respectively. Also shown is a rendering of the Sun's magnetic field, based on a computer model that assumes there are no electrical currents. Image courtesy of the SDO/AIA team.

VISUALIZATION: THE SUN'S MAGNETIC FIELD

(BASED ON A SIMPLIFIED DESCRIPTION: NO ELECTRICAL CURRENTS)

CONTEXT: THE SOLAR MAGNETIC FIELD

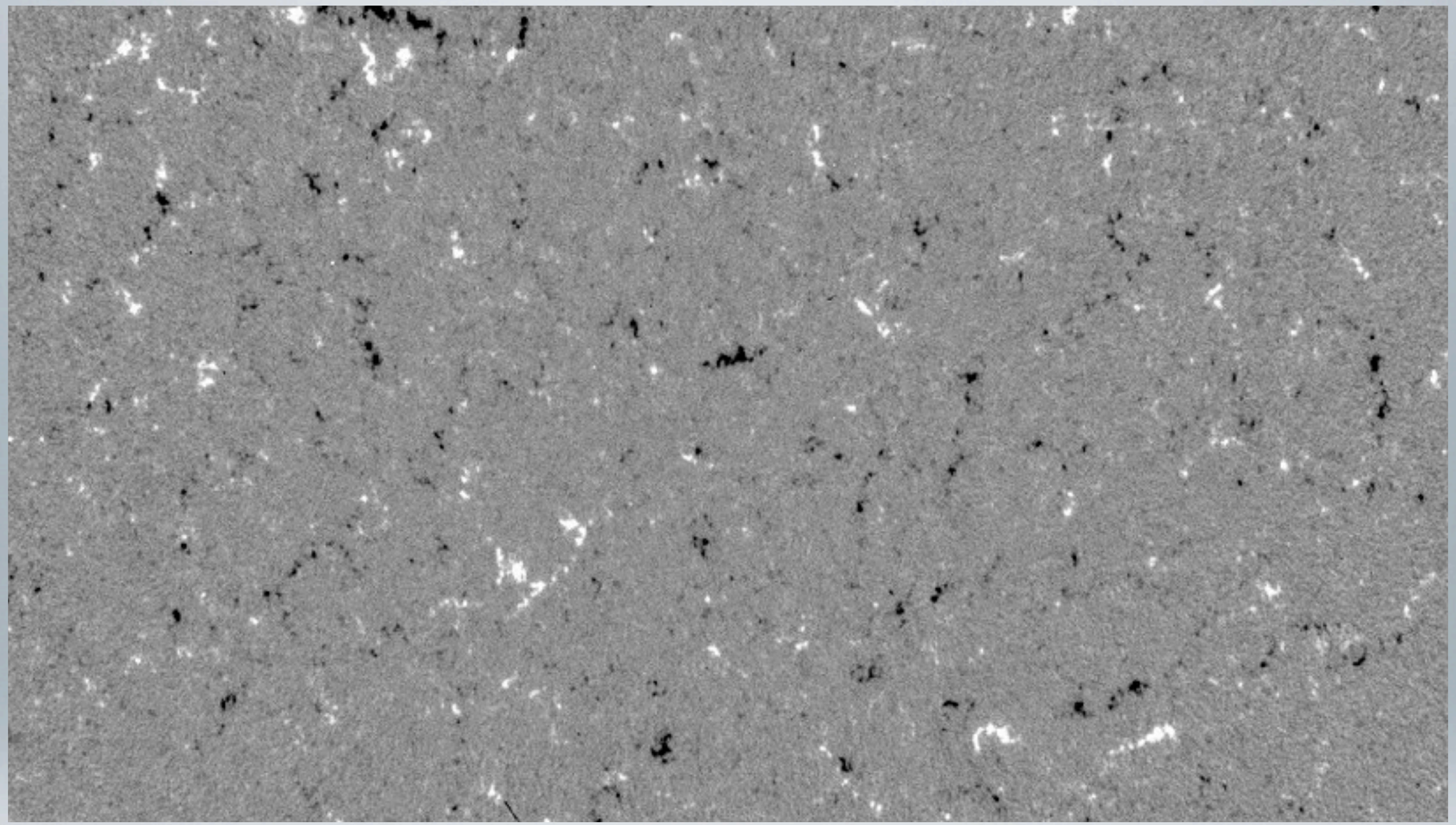
- The Sun's magnetic field is the sum of fields of very many bar magnets, from as large as the entire Sun to as small as we can observe.
- The smallest observed 'magnets' on the solar surface evolve on a time scale of minutes, the largest take ~22 years to alternate (through the solar magnetic cycle).
- As new field emerges from below the solar surface, or as existing field erupts, the surrounding corona responds within seconds to hours. These responses tell us about coronal properties that are otherwise unobservable.



SDO/HMI

A magnetic map of the Sun as observed by SDO's HMI. The dark and bright regions show areas of magnetic field on the solar surface of southern and northern polarity, respectively. As we zoom in, we see more of the small-scale mixed-polarity field: the smaller the scale, the more frequent such structures occur. Image courtesy of the SDO/HMI team.

LENGTH SCALES IN THE MAGNETIC FIELD RANGE FROM LARGE TO SMALL



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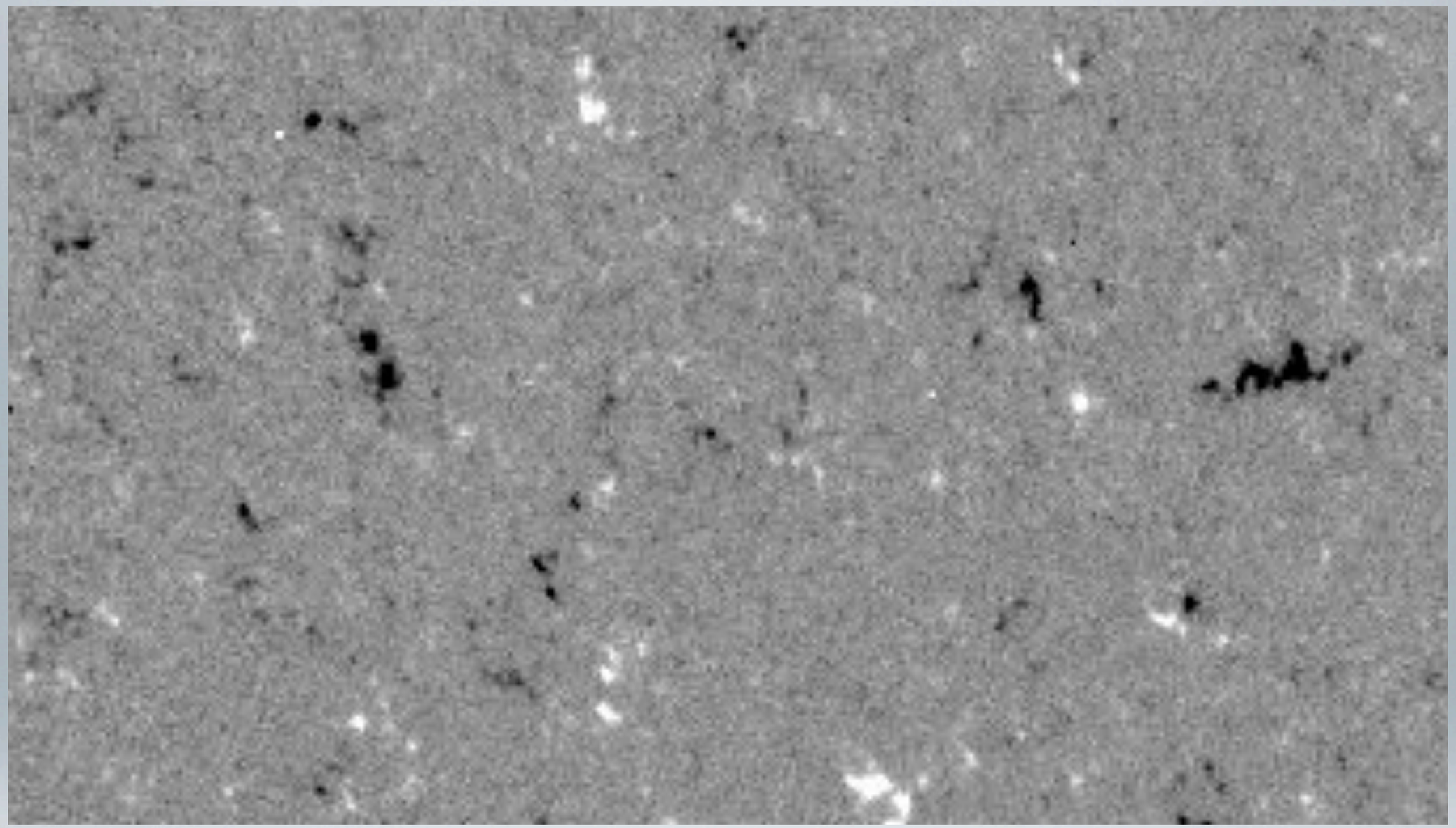

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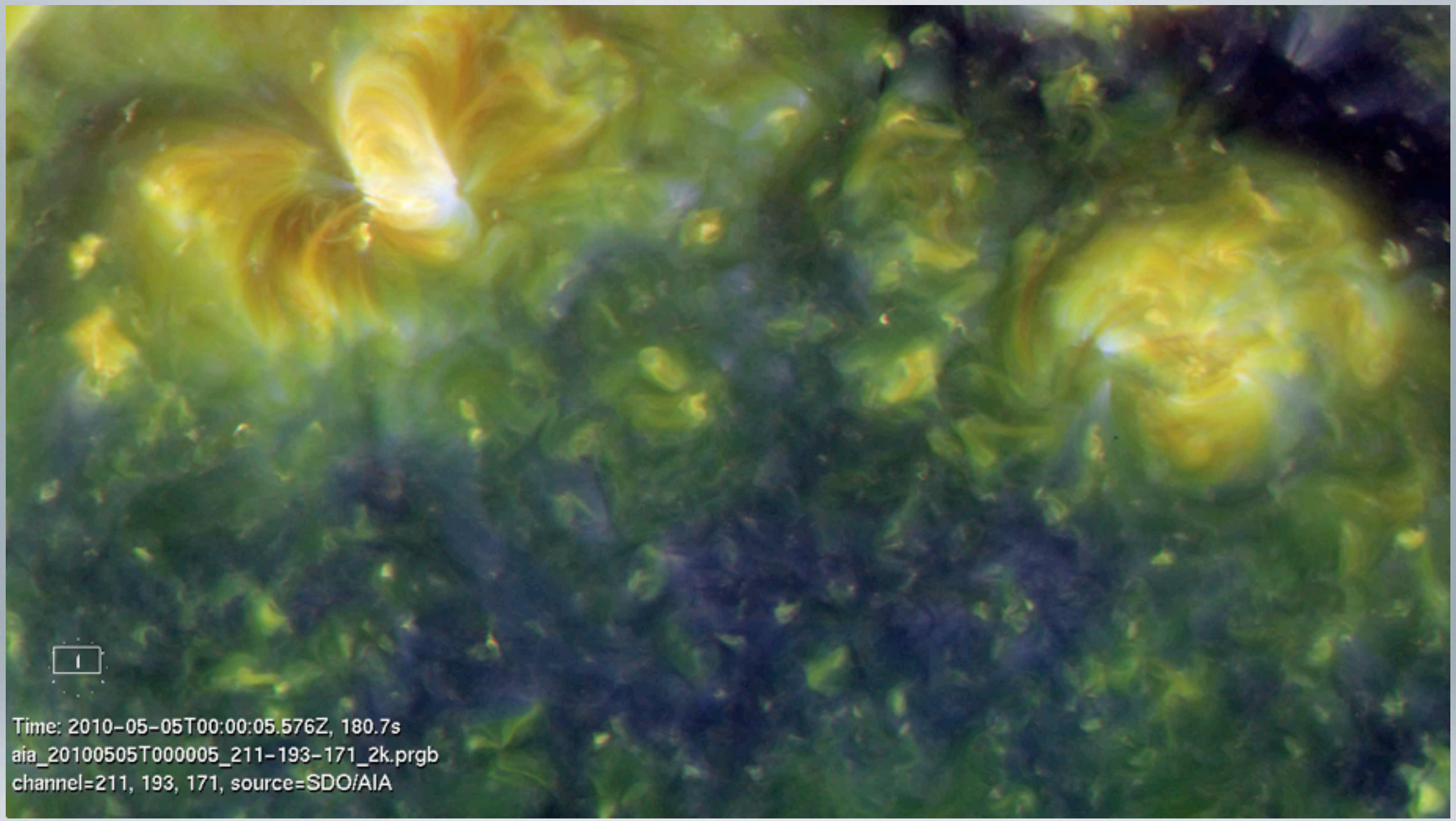
LENGTH SCALES IN THE MAGNETIC FIELD RANGE FROM LARGE TO SMALL

- The Sun's magnetic field generally changes gradually when new field emerges from below the surface (example movie is next).
- The surrounding corona resists change through induced "shielding" electrical currents which build up as the perturbation signal reaches new locations.
- When these electrical currents change (redirect or decay), the local magnetic field can reconfigure, either gradually or explosively (in "flares" or "coronal mass ejections").
- Field and current reconfigurations can induce changes both nearby and far away
- The behavior of invisible electrical currents in the corona is what makes the corona difficult to understand. With SDO's AIA we can now study how small and large events cause cascades of changes in the wide surroundings.

SDO/AIA

A false-color image sequence of the solar corona taken by SDO's AIA. The images combine data from three AIA channels sensitive to light emitted by gas at different temperatures: red, green, and blue at 2, 1.5, and 1 million degrees, respectively. The images span one day on the Sun, and follow a region against the Sun's slow rotation. Each image spans 1.2 million kilometers - or 90 Earth diameters - horizontally. Movie courtesy of the SDO/AIA

EXAMPLE OF CORONAL EVOLUTION: A DAY IN THE CORONA



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EXAMPLE OF CORONAL EVOLUTION: A DAY IN THE CORONA

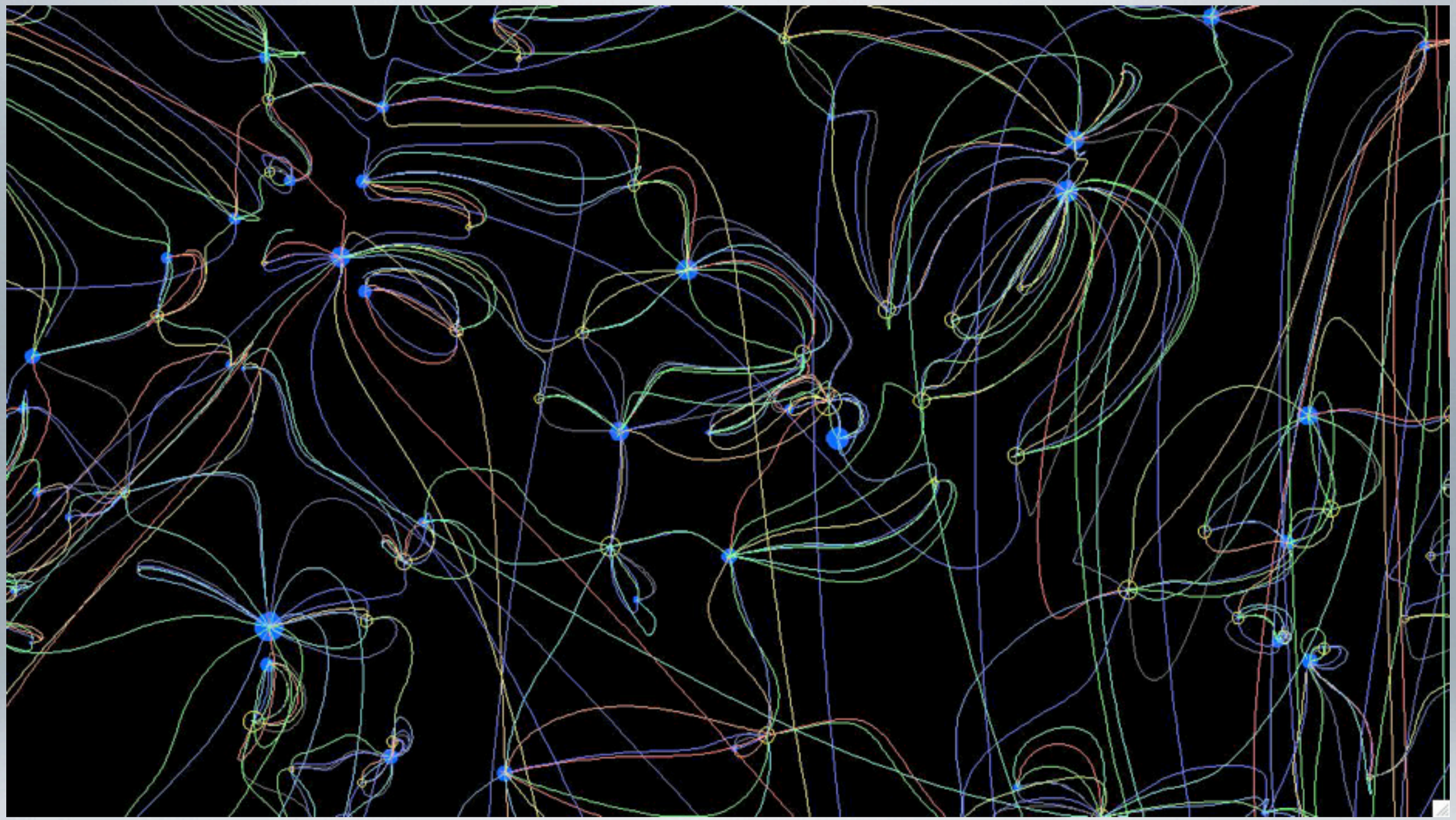
PERTURBATIONS & CASCADES

- If something changes in an atmosphere, the signature of its change propagates at a characteristic velocity from its source:
  - in a gas: at the sound speed - in the Earth's atmosphere at 0.3 km/s, in the solar corona at 50-150 km/s.
  - in a magnetic field in vacuum (or a cold atmosphere): at (nearly) the speed of light - 300,000 km/s.
  - in a very hot gas with a magnetic field, as in the Sun's corona, at the "Alfvén speed", between sound and light speeds: hundreds to thousands of km/s.

A model magnetic field. For randomly positioned field concentrations as in the quiet Sun, the magnetic field was computed, and traced by select field lines (that would light up as 'loops' in coronal images as taken by SDO's AIA). In this computer model, only two sources near the center grow in strength; the model shows how even distant field can respond to such a localized change in the surface magnetic field. Visualization by Karel

FAST SIGNAL PROPAGATION

In vacuum, signals propagate at light speed. This would appear to be instantaneous on the Sun (within ~4.3 seconds).



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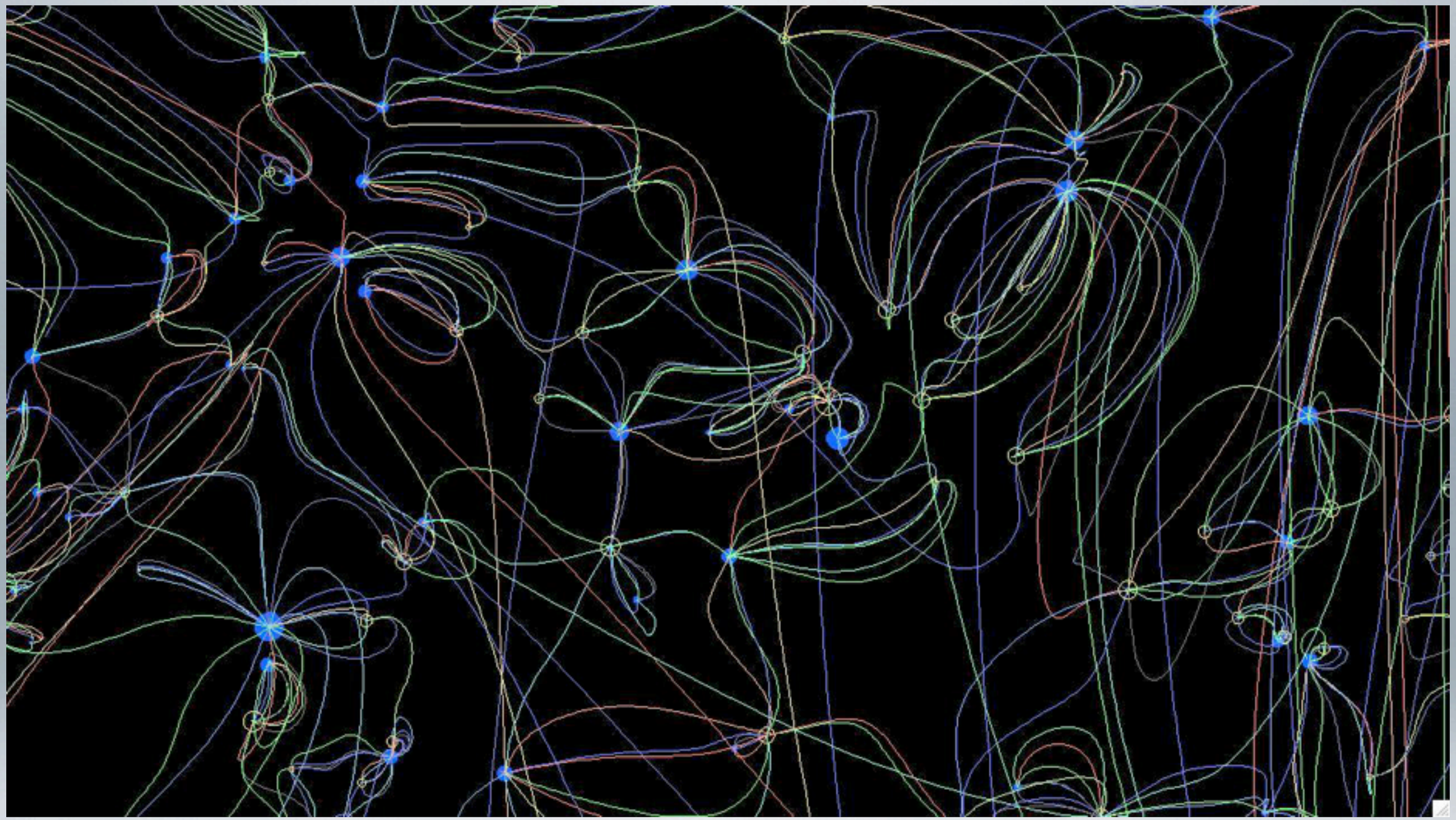
A model magnetic field as on the preceding slide, but now the signal of the field change propagates relatively slowly outward from the center. In the real solar coronal magnetic field, all sources would be evolving at their own pace, and the signal propagation speed would depend on both the magnetic field and on the density of the coronal gases. Visualization by Karel Schrijver.

SLOW SIGNAL PROPAGATION

In the real corona, travel-time effects occur that can be used to measure the properties of the magnetic field and of the hot gas.



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THE "PHYSICS" OF THE CORONA

- With the SDO AIA observations of propagating perturbations, we can constrain properties of the Sun's magnetic field, electrical currents, and of the coronal gases.

- A new "tool": like seismology (in Earth and Sun), the study of propagation of changes enables measurements of electrical currents, magnetic field, and gas properties that we cannot directly observe.