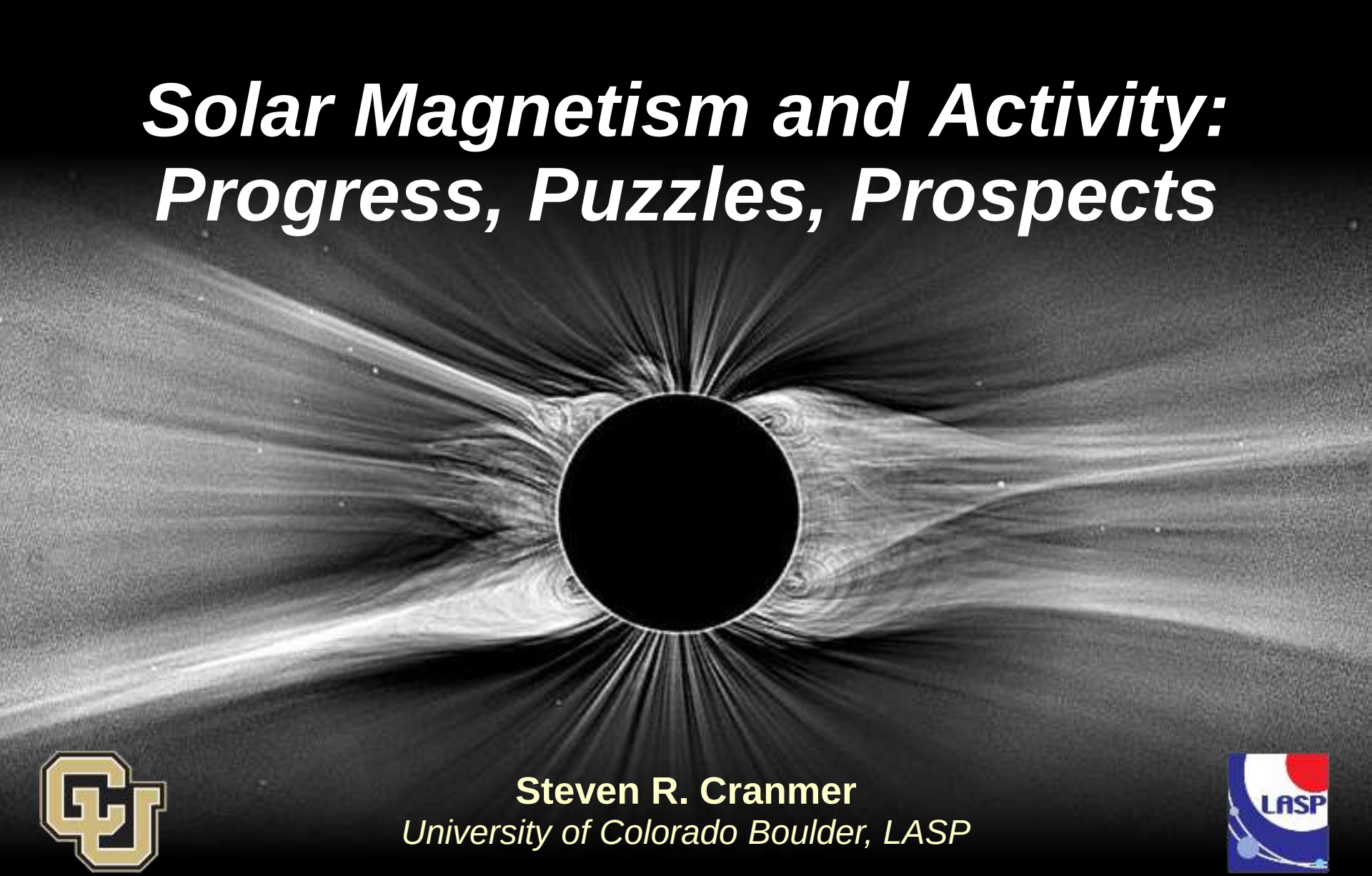
Solar Magnetism and Activity: Progress, Puzzles, Prospects



Steven R. Cranmer
University of Colorado Boulder, LASP

With colleagues from National Solar Observatory, Harvard-Smithsonian CfA, High Altitude Observatory, Naval Research Laboratory, U. New Hampshire

Solar Magnetism and Activity: Progress, Puzzles, Prospects

Magnetic fields are:

1. Jostled by convection on Sun's surface
2. Twisted & braided in the hot corona
3. Stretched out by the solar wind
4. **Doing all this in other stars, too!**

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The Sun's active atmosphere

- Over the last 75 years, we've gotten a much better view of how the dense, hot gas that makes up the Sun interacts with magnetic fields…

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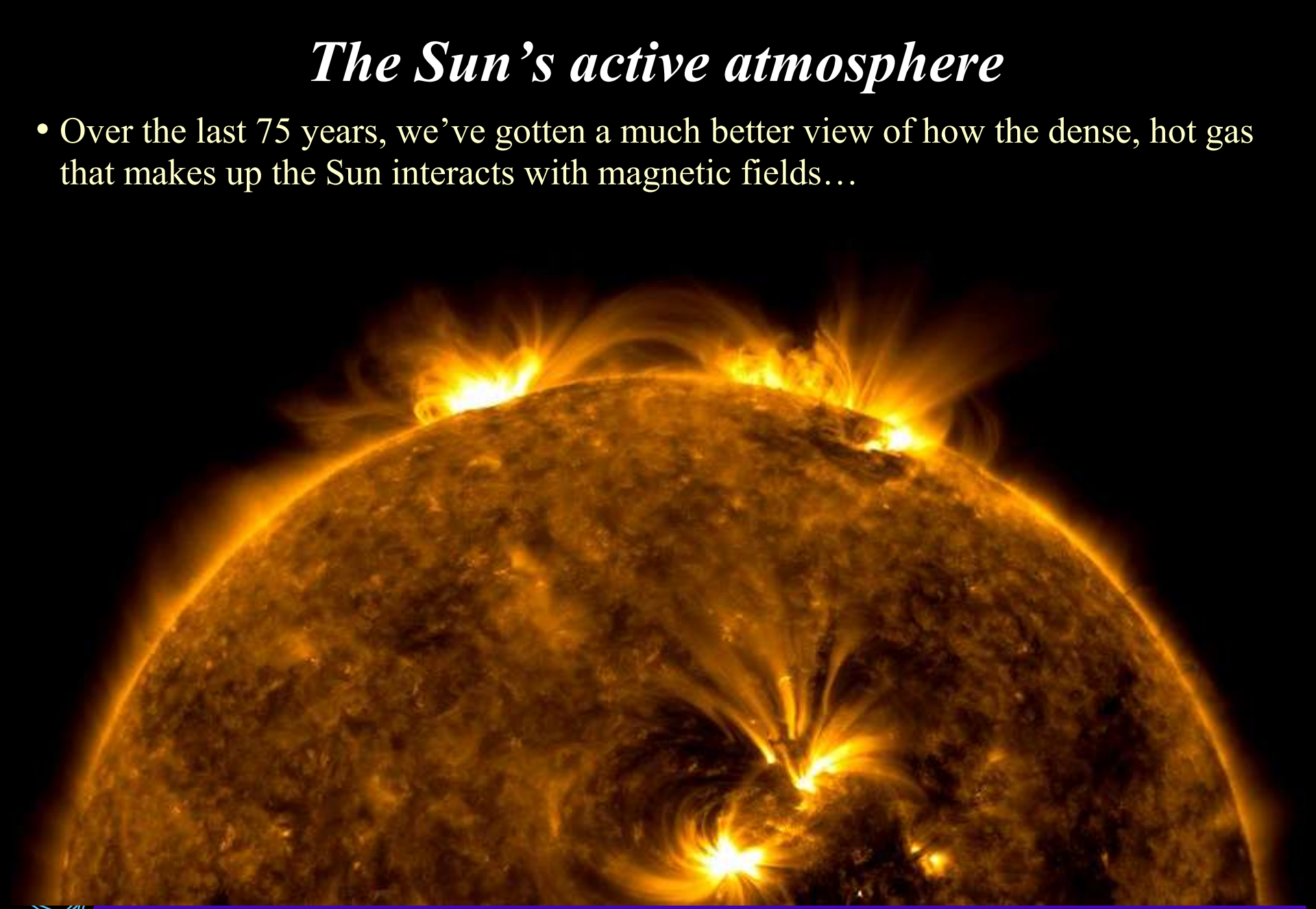

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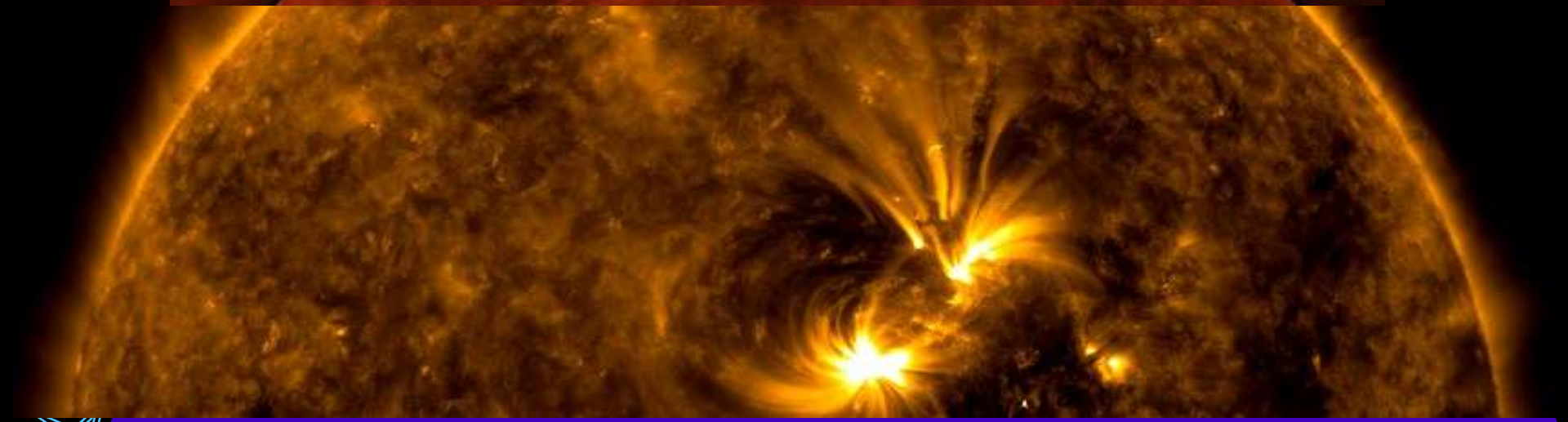
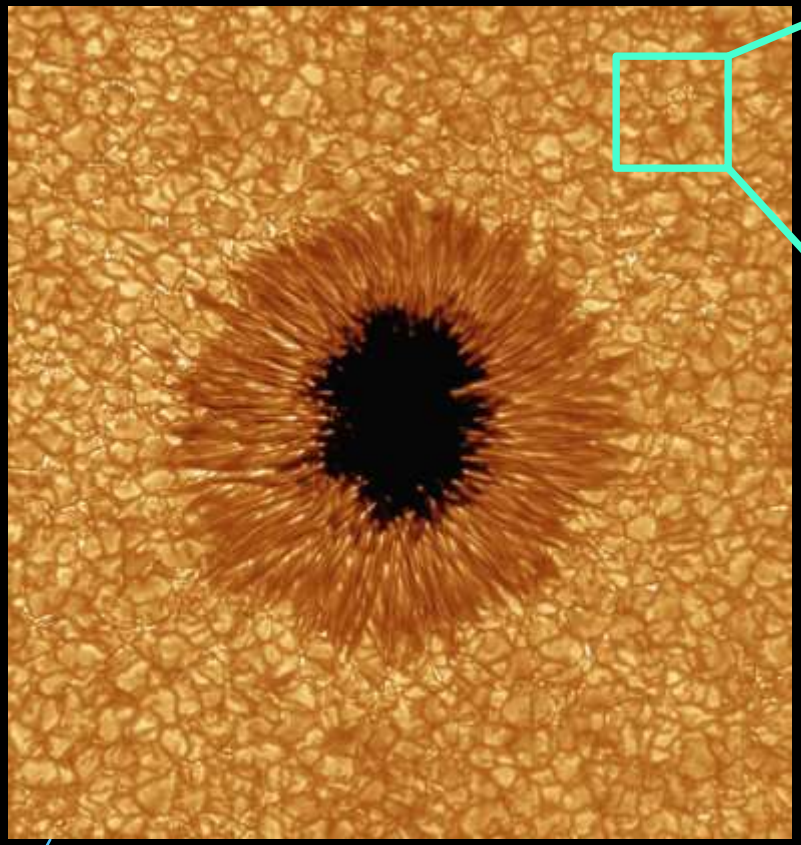
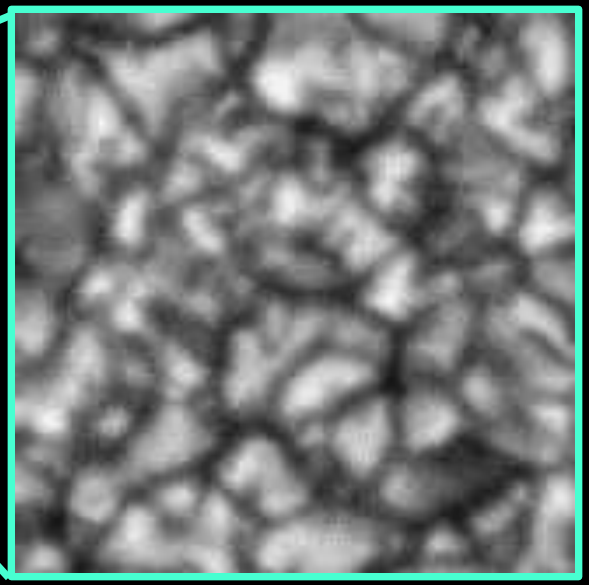
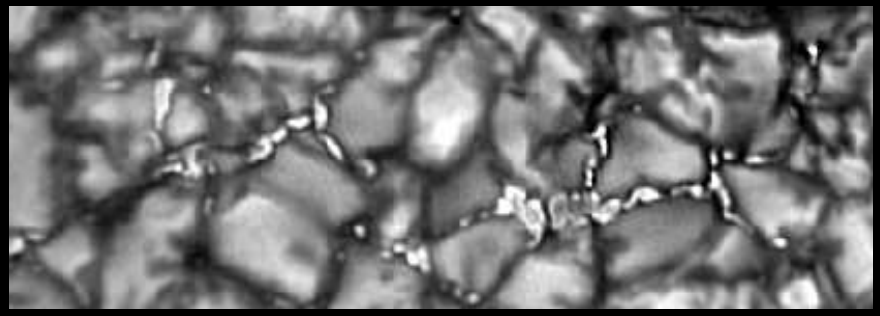


Out of the interior

- Below the solar surface, convection cells ("granules") rise & fall stochastically.
- Magnetic fields poke through the surface, follow the flow, and get dragged into the dark downflow lanes between granules.

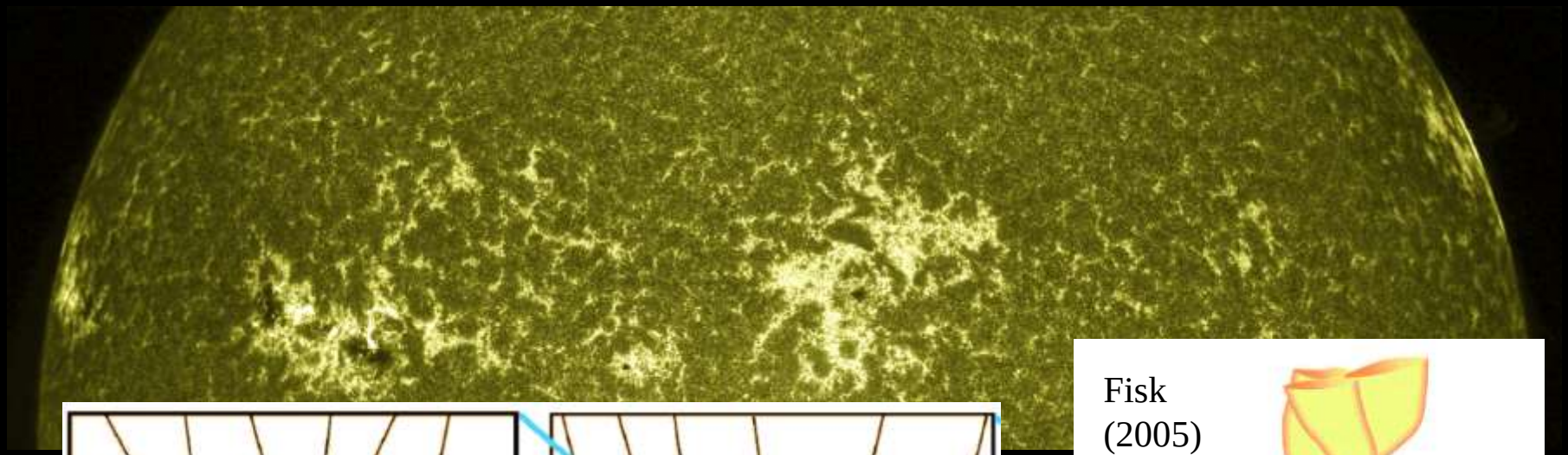


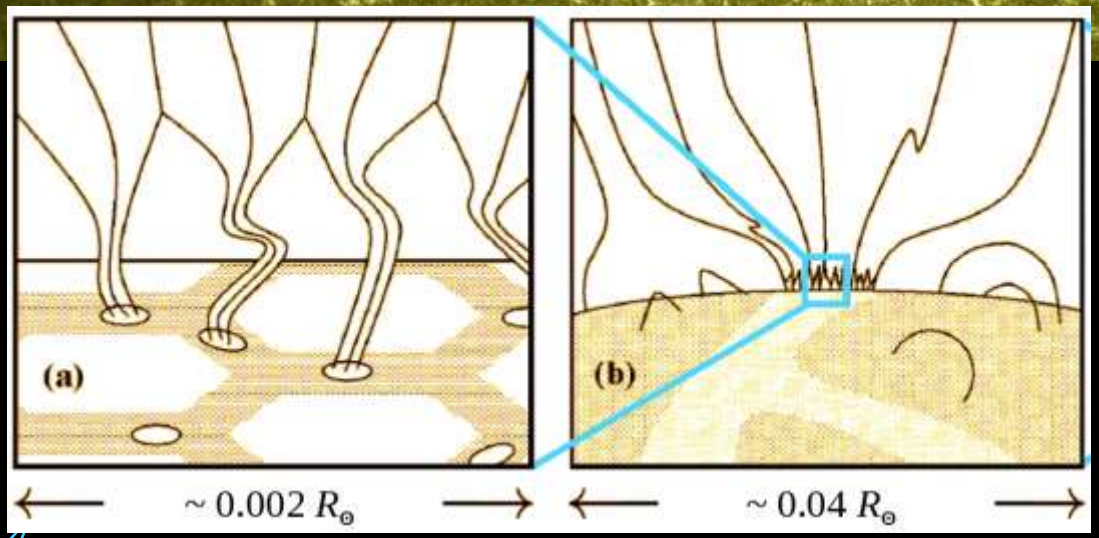


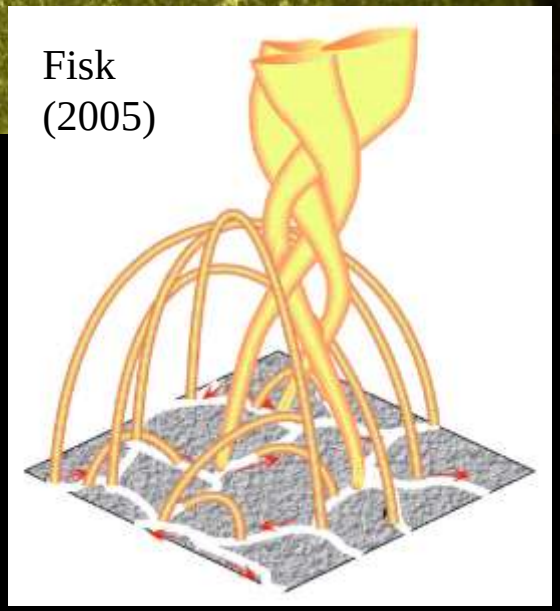


Supergranulation

- On larger scales (30 times granule size), magnetic fields *slowly* collect together into bright supergranular network… the Sun's **"magnetic carpet."**



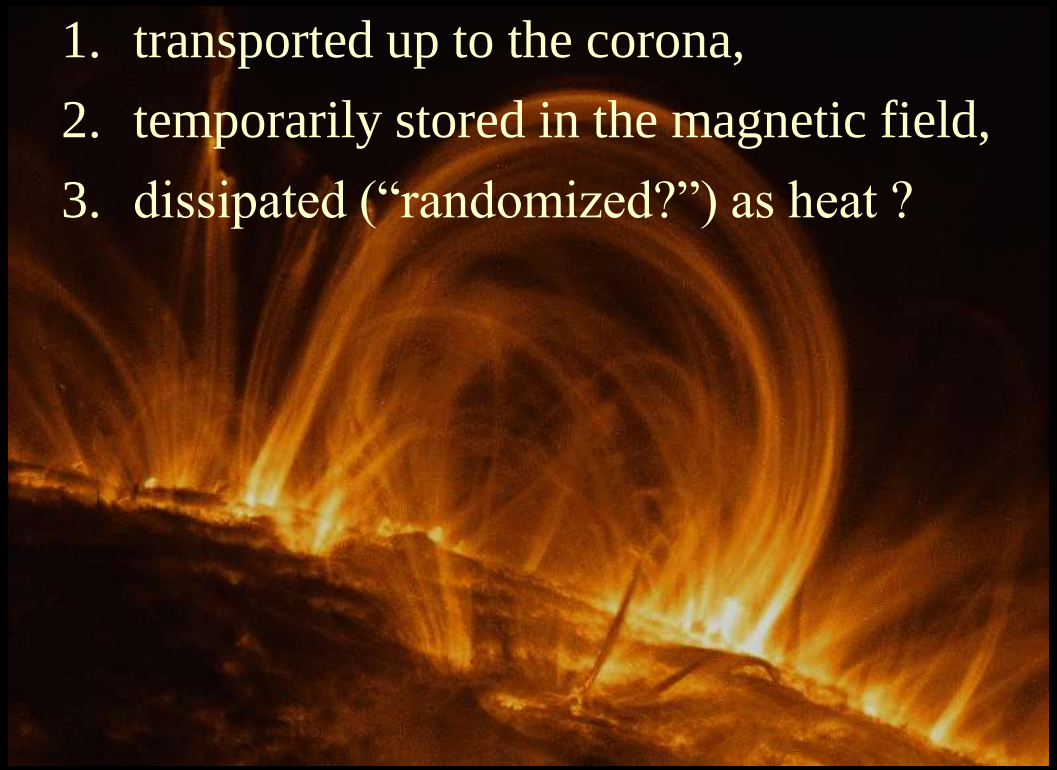


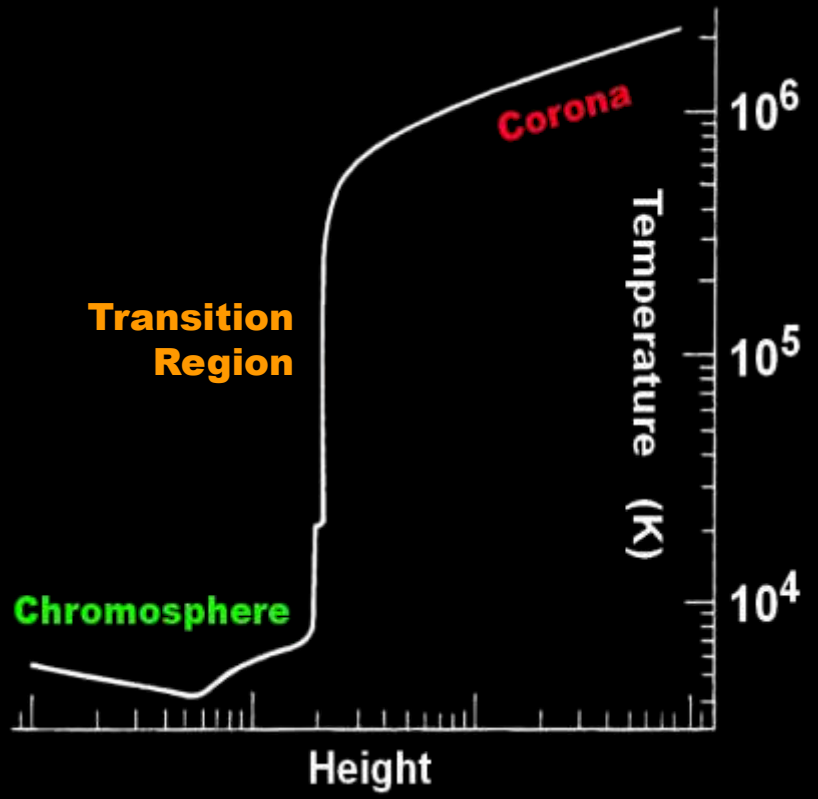


The coronal heating problem

- One practical reason that we care about all this magnetic chaos: it seems to be related to why the temperature starts to **increase** above the surface.
- (Nearly!) everyone agrees that there is more than enough kinetic energy in the convection to heat the corona. But how does a fraction (~1%) of that energy get:

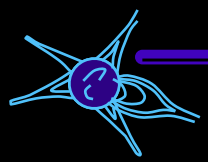
1. transported up to the corona,
2. temporarily stored in the magnetic field,
3. dissipated ("randomized?") as heat ?





The coronal heating problem

- Identifying the processes that get the job done is difficult; no shortage of theories.
- Is the energy coming up in the form of **waves?** Do the fields get slowly **tangled & braided** to the point where they ultimately "snap" in the form of tiny flares?



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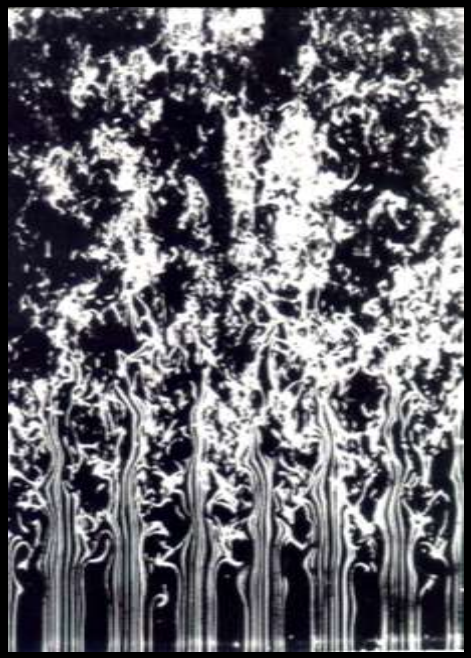
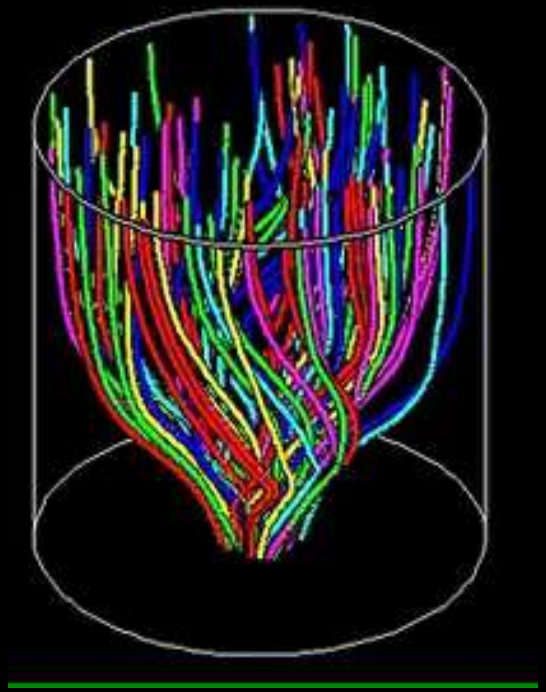
- Identifying the processes that get the job done is difficult; no shortage of theories.
- Is the energy coming up in the form of **waves?** Do the fields get slowly **tangled & braided** to the point where they ultimately "snap" in the form of tiny flares?
- **Turbulence** (cascade from large to small eddies) seems to explain much of it.

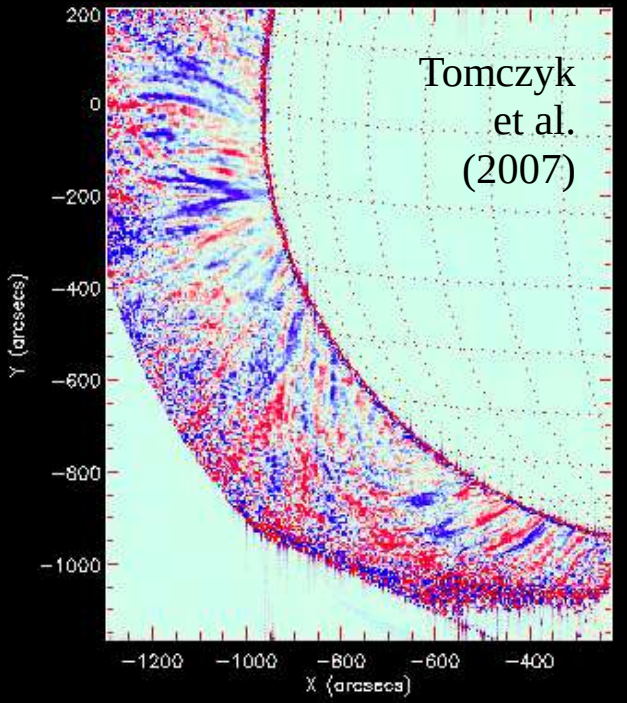
Laboratory



Computer



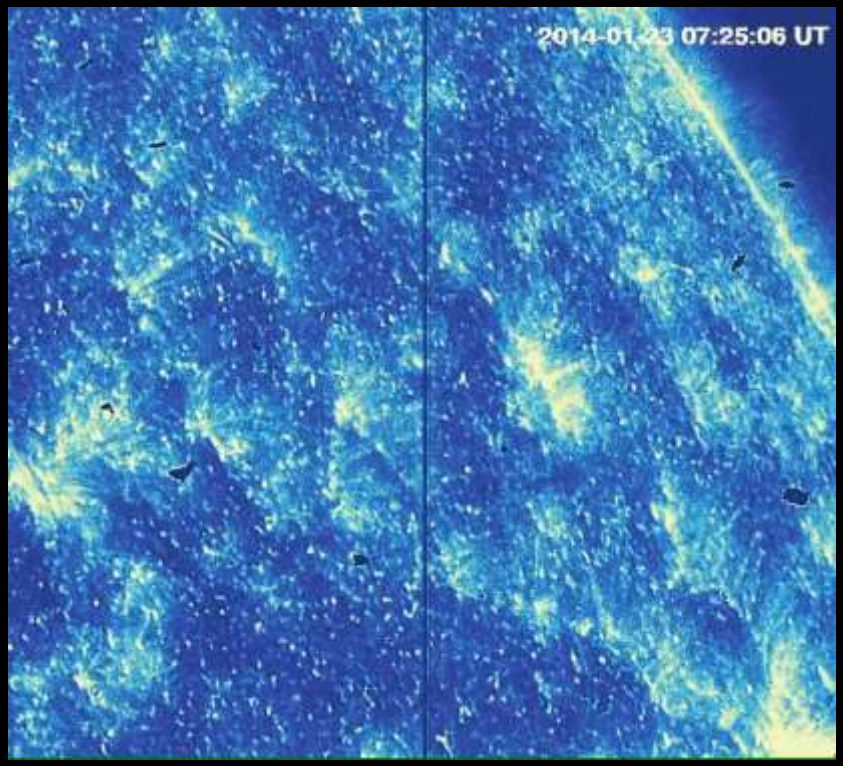
Telescope



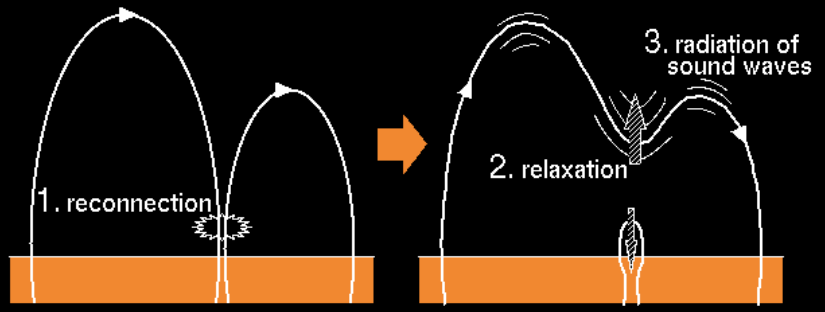
Other controversies

- Hinode & IRIS discovered thin **spicules & jets** rooted in the network.
- Jets have rapid upward motions. Do they contribute hot gas to corona?
- Or are they just cool, chromospheric gas that falls back down?

- Is "footpoint jostling" the only source of turbulence?
- Granular flux tubes shake with periods of **2–5 min**. (similar to **jet** lifetimes)
- However, in interplanetary space, magnetic fields fluctuate with periods of **hours to days!**

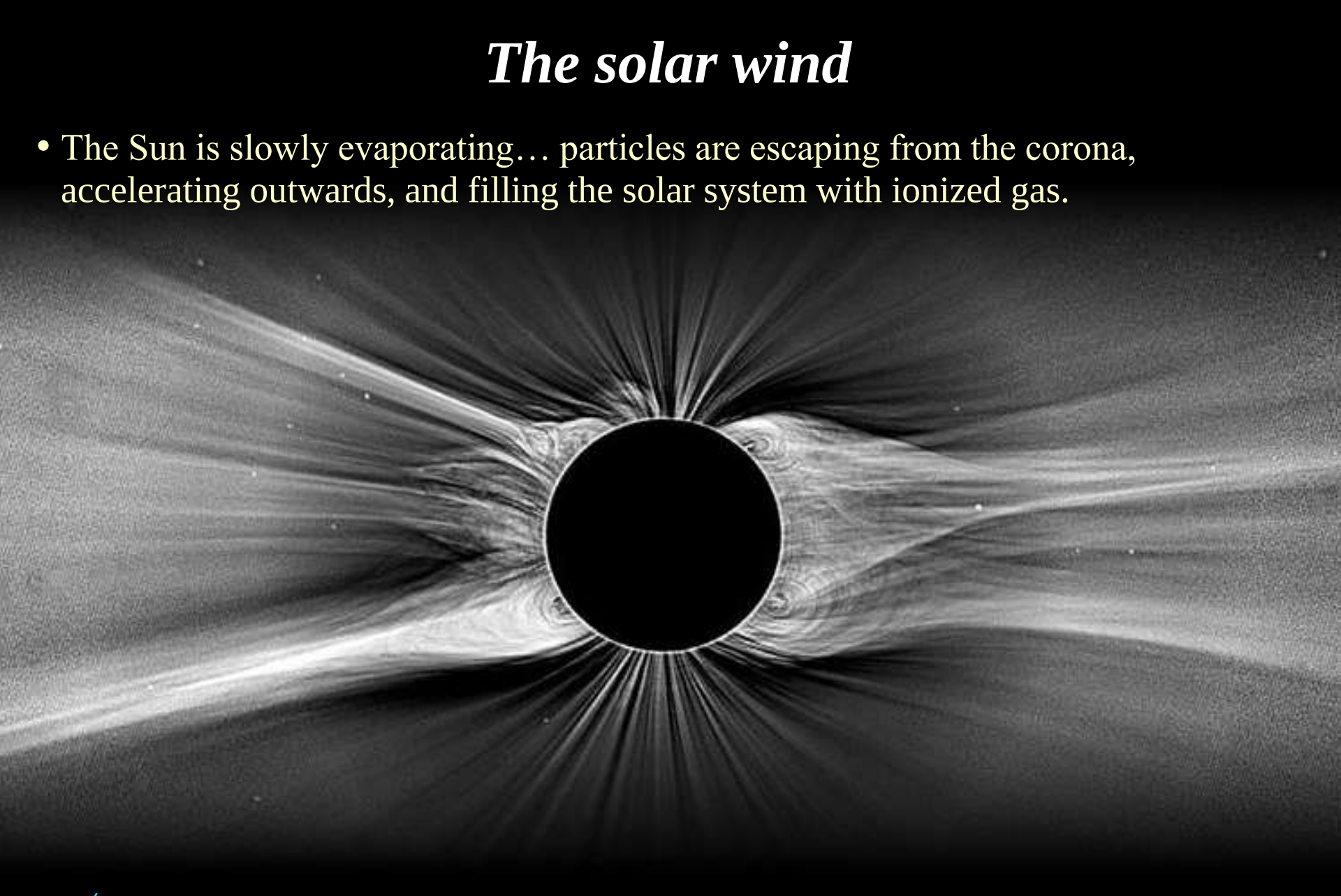


Tian et al. (2014)



The solar wind

- The Sun is slowly evaporating… particles are escaping from the corona, accelerating outwards, and filling the solar system with ionized gas.



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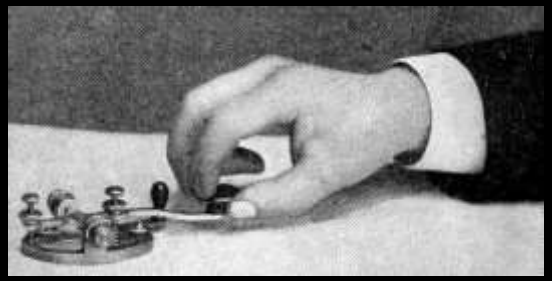
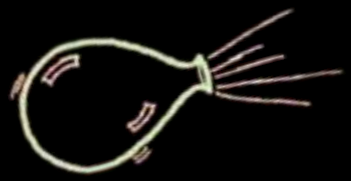
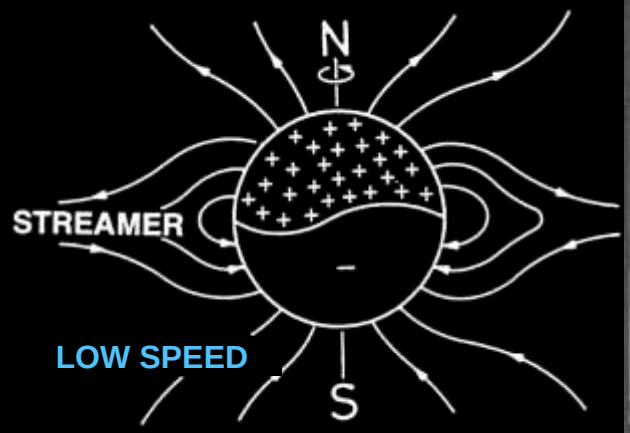
History:

- 1850–1950: Evidence builds for outflowing magnetized plasma from the Sun:
  - solar flares → aurora, telegraph snafus, geomagnetic "storms"
  - comet ion tails point anti-sunward (no matter comet's motion)



- 1958: Eugene Parker put the pieces together: the million-degree corona has such a high **gas pressure** that it naturally expands.

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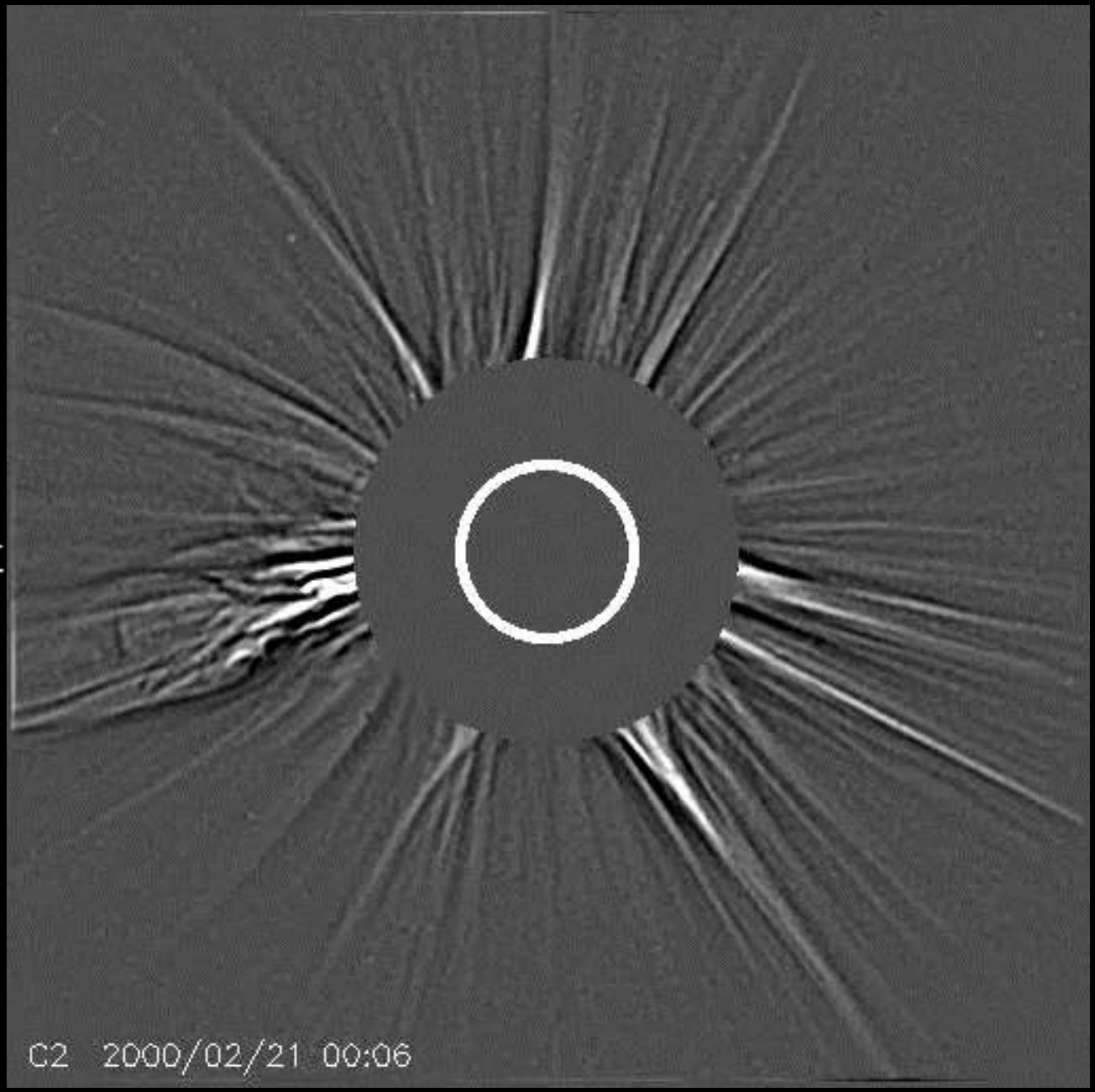
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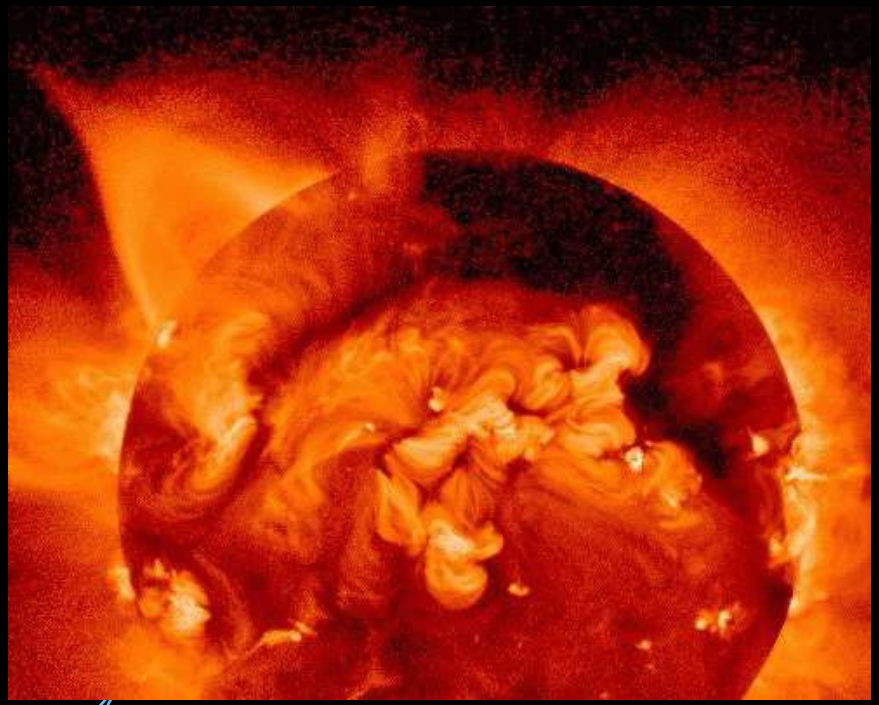
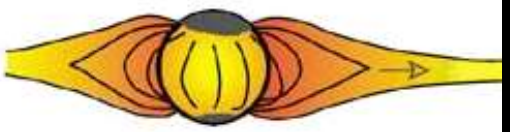
The solar wind: fast vs. slow

- 1962 (Mariner 2): Wind speeds go from 250 km/s (slow) to >800 km/s (fast).
- **High-speed wind:** strong connections to the largest **coronal holes**
- **Low-speed wind:** still no agreement on the full range of coronal sources:
  - hole/streamer boundary region
  - small coronal holes
  - active regions (some with streamer cusps)
  - pseudo-streamers!

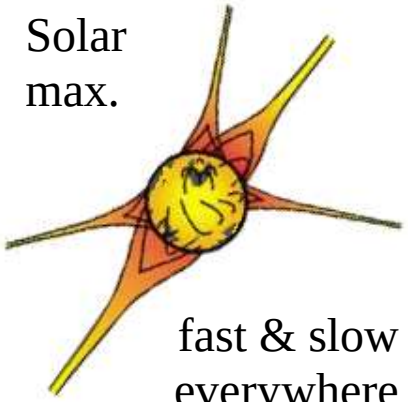


Solar minimum



Polar regions fast;
Equatorial belt slow

Solar max.



fast & slow everywhere

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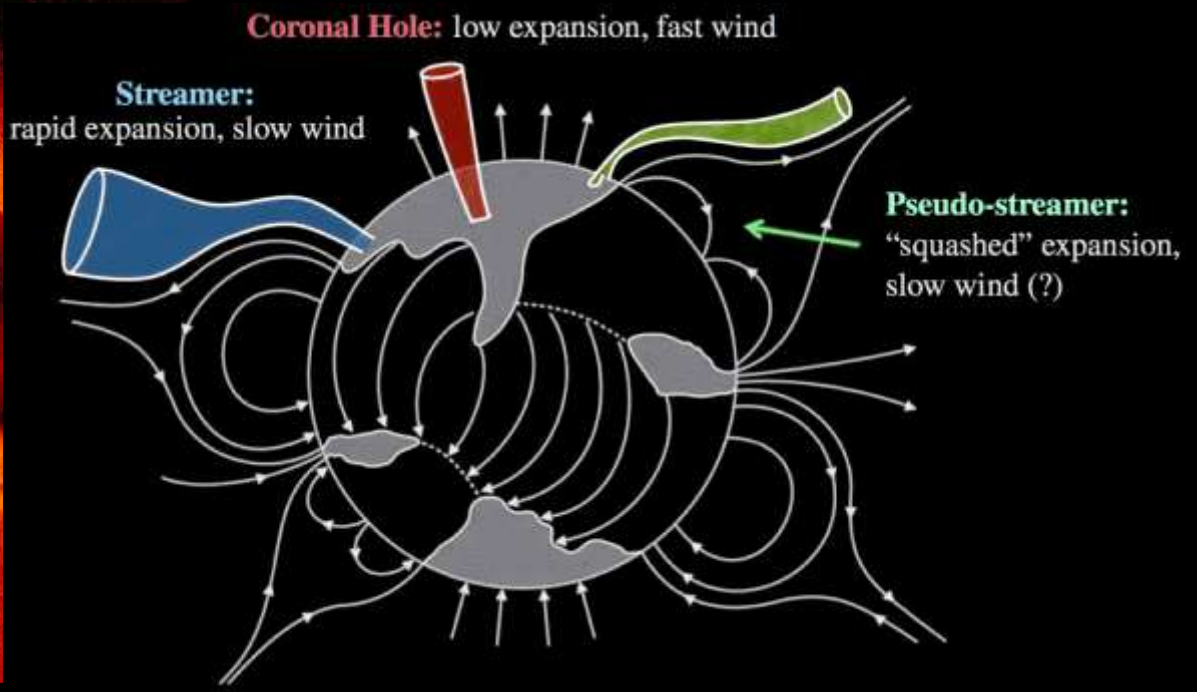
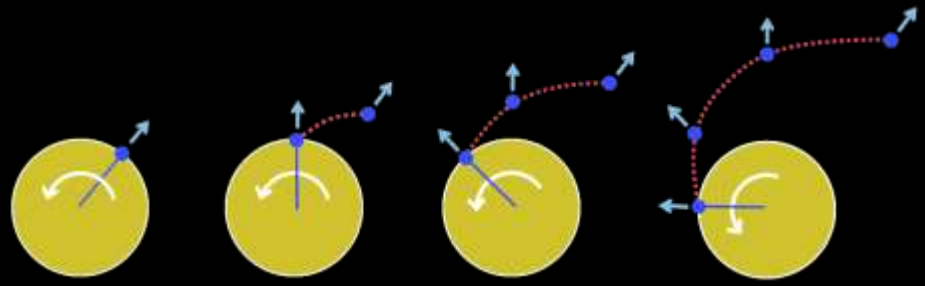
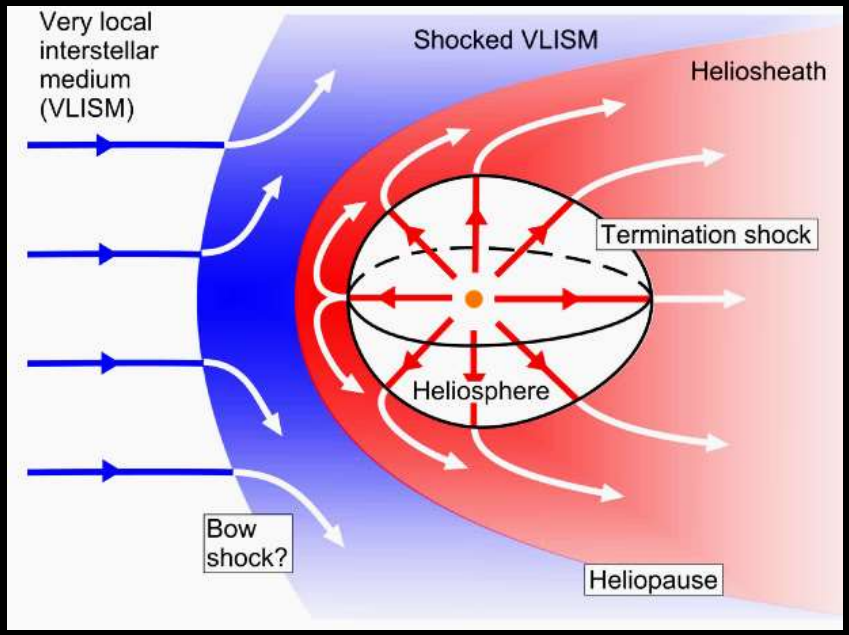
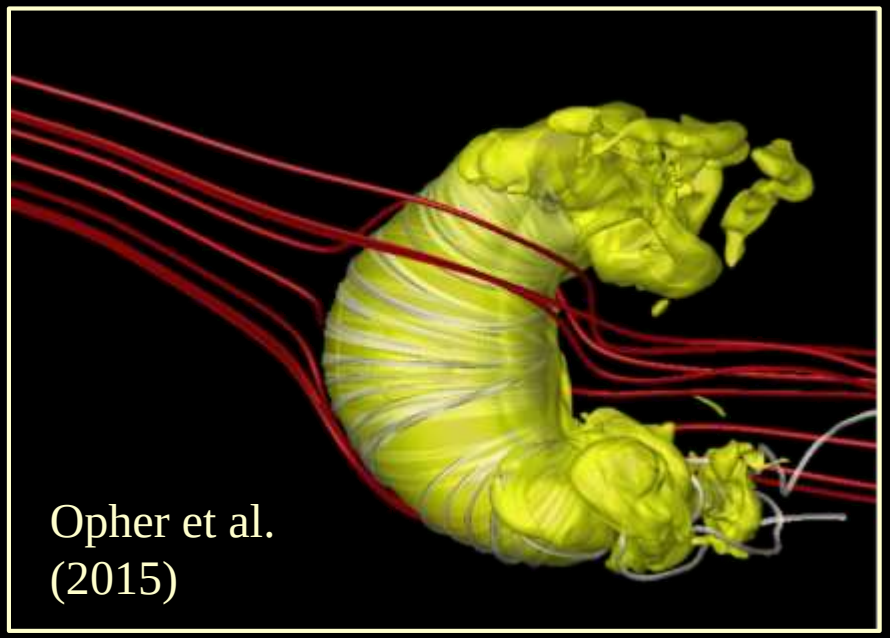


The outer heliosphere

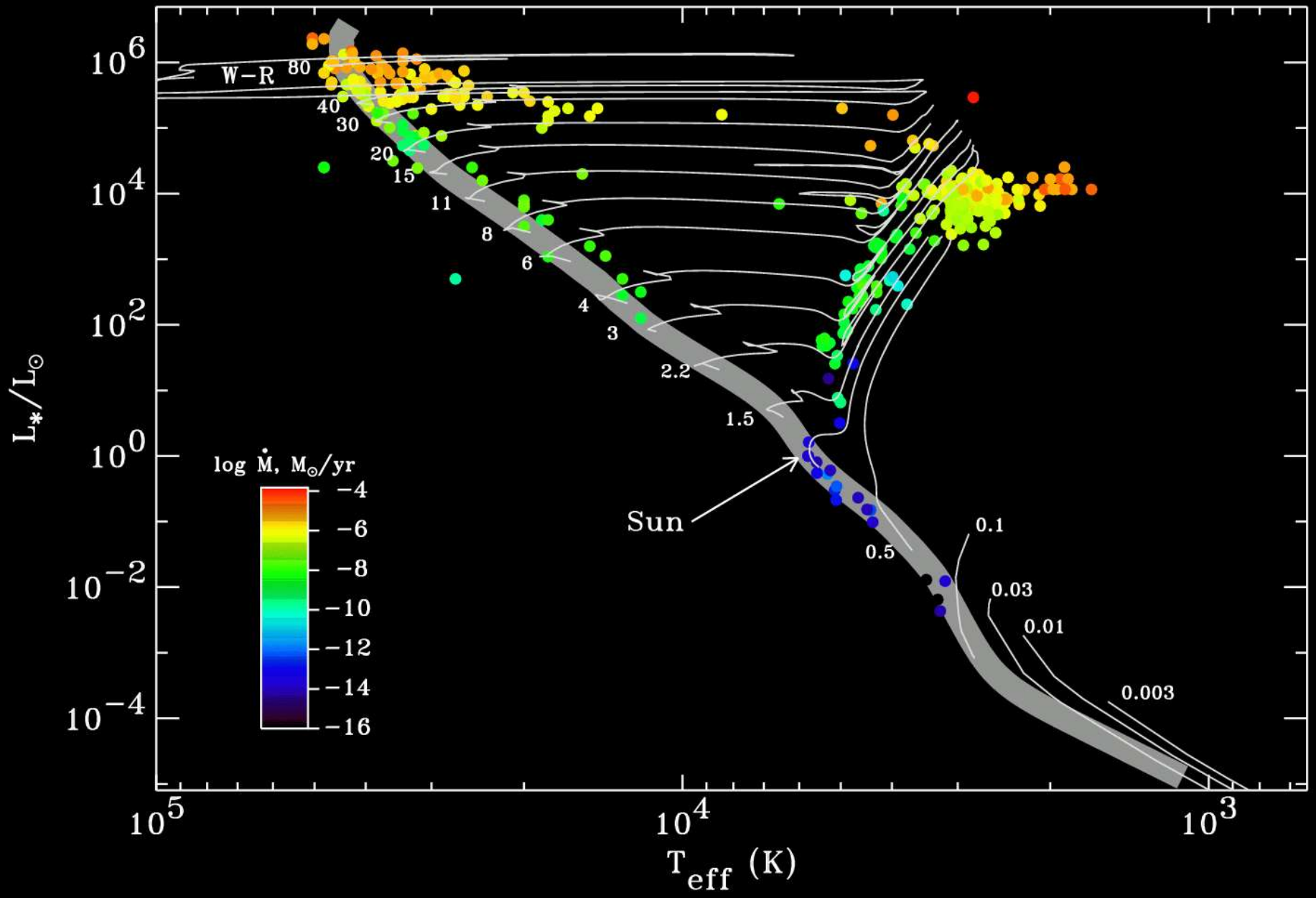
- The solar magnetic field is stretched out by the solar wind & curled into a **"Parker spiral"** by Sun's rotation.
- Eventually, the solar wind weakens and is pushed back by the interstellar (galactic!) magnetic field.





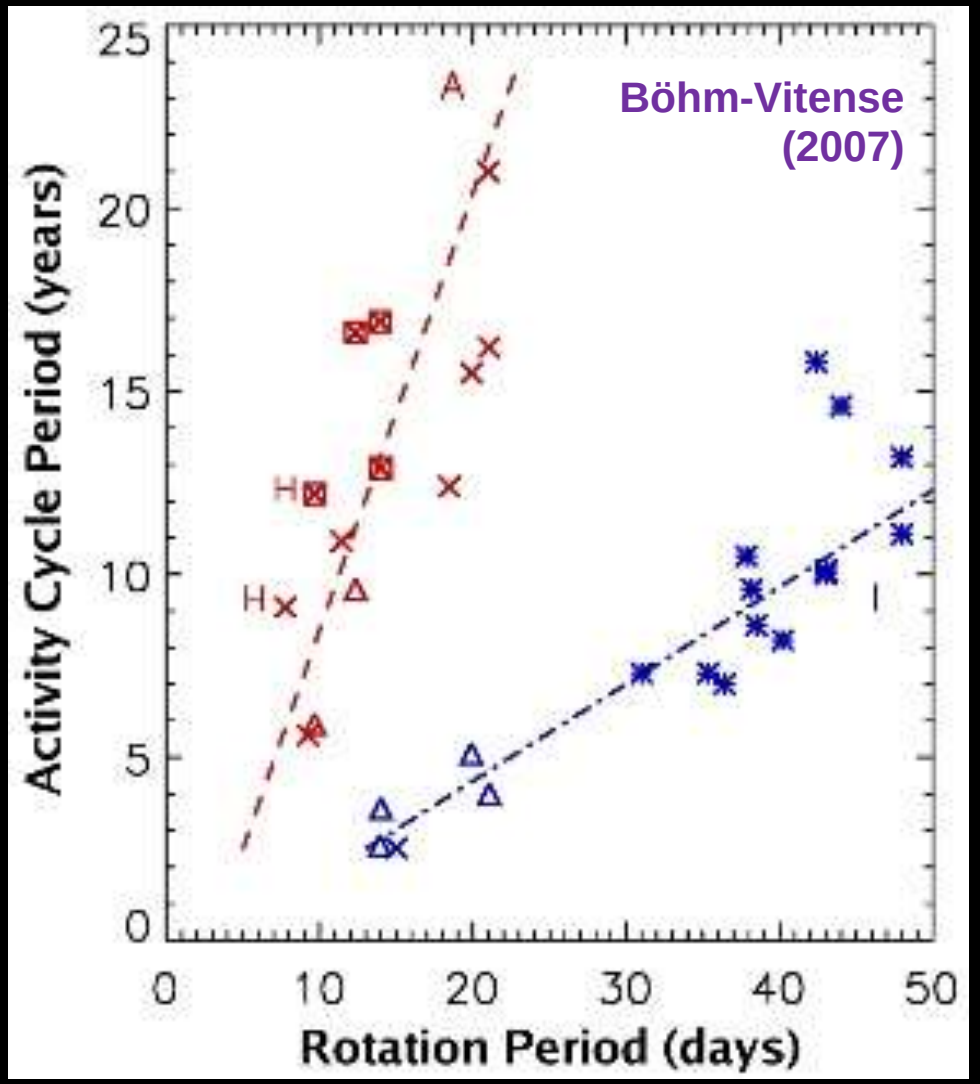


Other suns . . . other fields . . . other winds



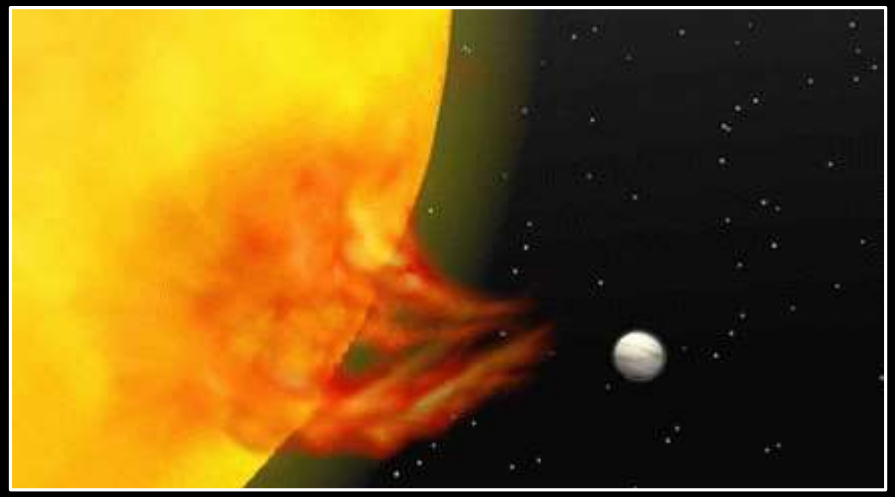
Do sun-like stars have similar activity cycles?

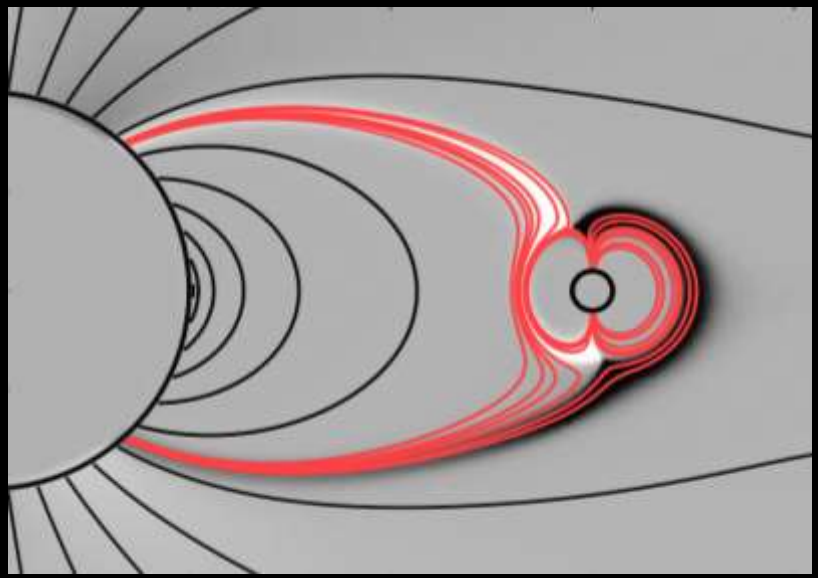
- Several stars have now been observed for multiple decades, with techniques that allow us to track their magnetic activity cycles.
- Faster rotation means more rapid cycles, as expected from dynamo theory.
- But there are 2 tracks.
- Which one does the Sun fall on?



Do "close-in" exoplanets affect their stars?

- A huge fraction of the ~2000 extrasolar planets discovered so far orbit **closer to their stars** than Mercury orbits the Sun.
- "Hot Jupiters" may have strong enough planetary magnetic fields to send waves/turbulence/particles back down to the stellar surface.
- **Bright chromospheric spots,** phased with planet orbits, have been observed, but sporadically.
- Is it an "on/off" phenomenon (i.e., when the orientations are just right)?
- Or might it ***not*** be really happening?





No convection? No problem!

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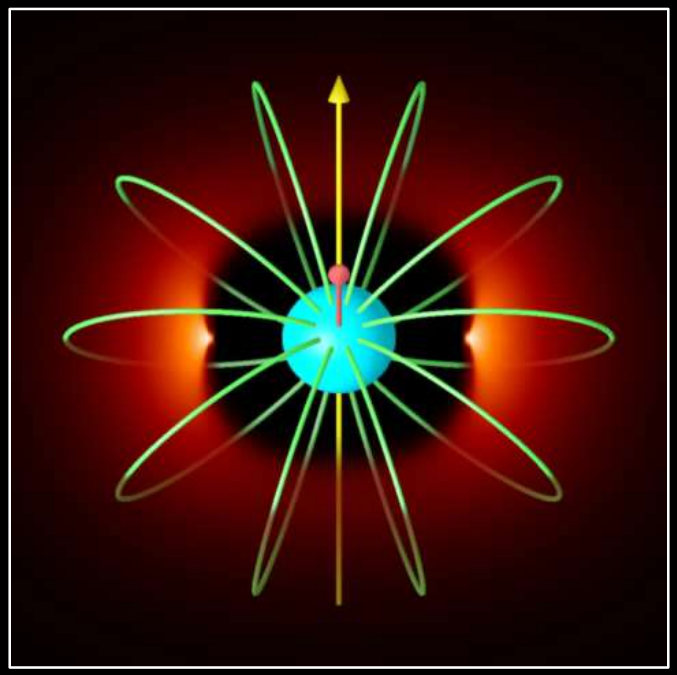
- Some stars have strong magnetic fields that may be "fossils" from birth.



Centrifugal forces keep stellar wind gas "pinned" to field (Townsend et al. 2007)

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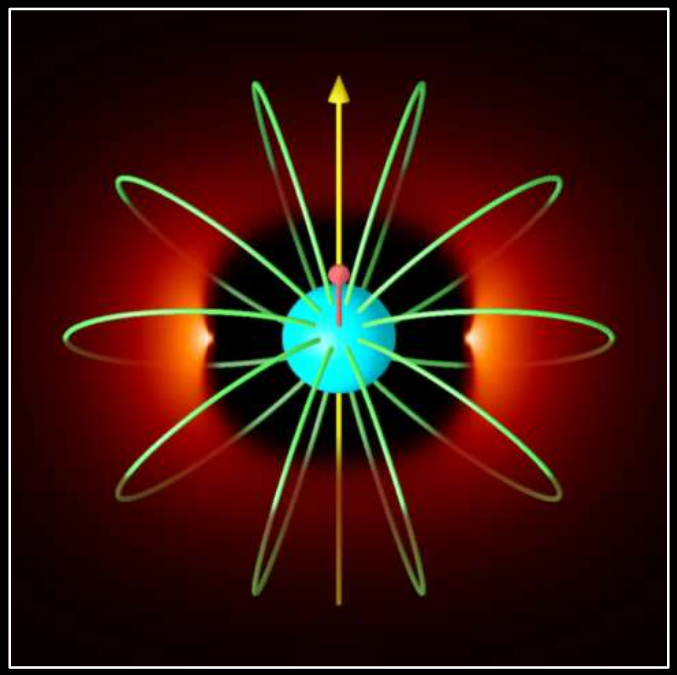
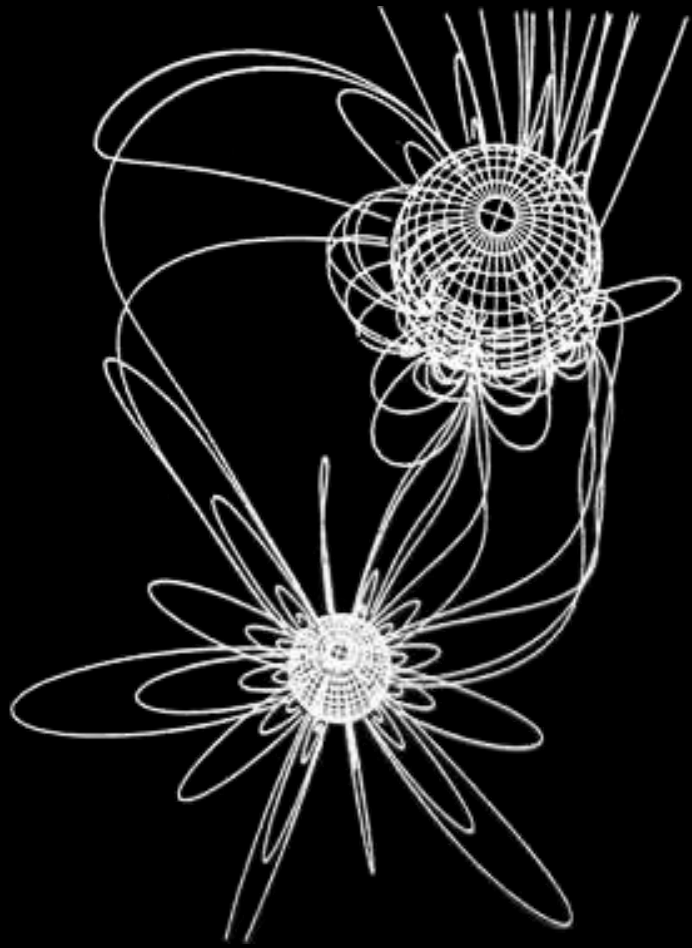


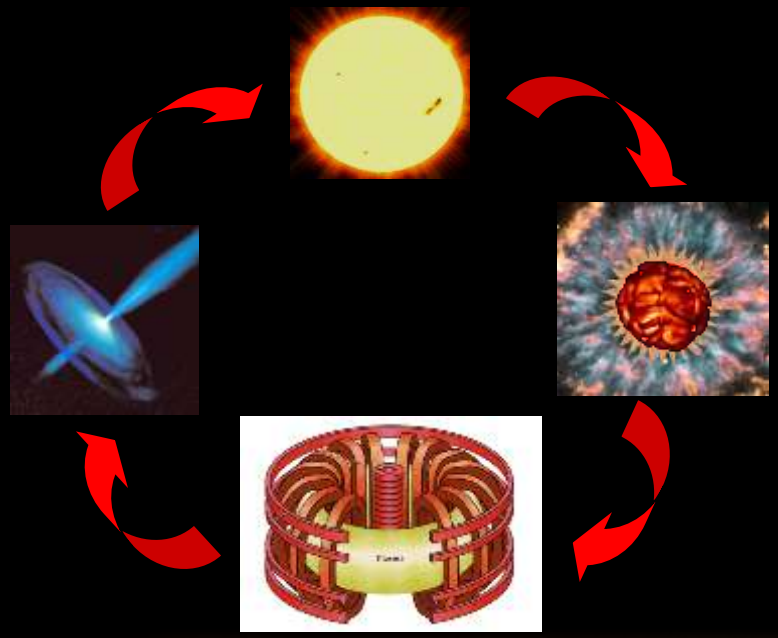
Centrifugal forces keep stellar wind gas “pinned” to field (Townsend et al. 2007)

- Some have fields that could be churned up by tidal forces from close neighbors.



Conclusions

- Within an order of magnitude, theories aren't doing *too* badly in predicting observed properties of solar & stellar activity.
- However, truly comprehensive understanding is limited by not being able to identify the dominant physical processes. Need to define the "right" observations.
- Understanding is greatly aided by ongoing collaboration between the solar physics, plasma physics, and astrophysics communities.



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