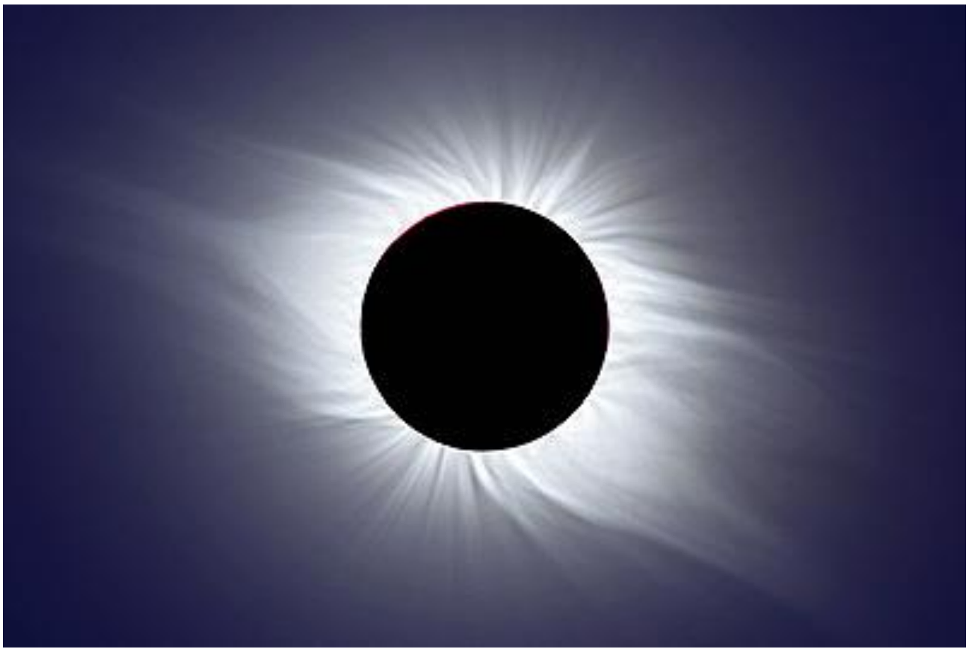


On https://en.wikipedia.org/wiki/Stellar_corona#Physics_of_the_corona we find: The matter in the external part of the solar atmosphere is (...) at very high temperature (a few million kelvin) and at very low density (of the order of 10^{15} particles/m^3).

On https://en.wikipedia.org/wiki/Coronal_mass_ejection#Physical_properties (as of 2021-06-15) we read: Coronal mass ejections reach velocities from 20 to 3200 km/s with an average speed of 489 km/s.

Now consider a body that is orbiting the sun at a very low *altitude* so its *orbital radius* practically equals the *solar radius*. Newtonian mechanics & gravitation then yield:

orbital velocity: $v = \sqrt{\frac{GM_\odot}{R_\odot}} \approx 437$ km/s.

Hmm, isn't that practically the same as the average *CME velocity* given by WikipediA?

In case of a proton its *kinetic energy* were: $E_{\mathrm{k,p}} = ½m_\mathrm{p}v^2 = ½m_\mathrm{p}\frac{GM_\odot}{R_\odot} \approx 1.6 \times 10^{-16}$ J ≈ 1 keV,

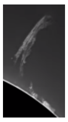
corresponding to a *temperature* of: $T = \frac{2E_{\mathrm{k,p}}}{3k_\mathrm{B}} \approx 7.7 \times 10^6$ K.

Hmm, isn't that practically the same as the few million kelvin given by WikipediA?

A frequent mistake in logic is the flawed inversion of the so called **modus ponens**: *if* ***A*** *then* ***B***, which *does* ***not*** imply: *if* ***B*** *then* ***A***, but it *does* imply the **modus tollens**: *if* ***not B*** *then* ***not A***.

Temperature is an emerging quantity that arises from the **stochastic** motion of particles relative to one another, due to particle collisions. The *mean kinetic energy* of molecules can be derived from the *temperature*: $\overline{E_k} = 3k_\mathrm{B}T/2$. A sample must be large enough in order to have a meaningful mean, I mean by all means a mean mean with no meaningless meaning, meaning that a sufficiently large amount of particles in a relatively small *volume* is required with enough collisions for frequent *energy* exchange. The concept of *temperature* becomes senseless if random collisions are rare. Considering **ballistic** *kinetic energy* a *temperature* via $T = 2E_k/3k_\mathrm{B}$ is a flawed modus ponens inversion!
But particle physicists and cosmologists are doing just that. At CERN, the LHC smashes very fast (but small clusters of) protons frontally together. In this case, the *kinetic energy* of the protons can be seen as a measure of the *temperature* at which comparable collisions would occur in a stationary plasma. But it is not to be seen as a true *temperature* within the LHC. Their motion is not **stochastic**, but **ballistic**.

Now the solar corona is a very thin plasma with very few collisions, see the calculations further below, so the whole concept of coronal *temperature* merely is an illusion. Yes, it does consist of fast particles with a *kinetic energy* for which $T = 2E/3k$ yields several million kelvin, but this is not **stochastic** motion, hence not to be considered its *temperature*. The particles are essentially orbiting the sun in **ballistic** motion, but very largely influenced by the complicated electromagnetic field, causing them to spiral along magnetic field lines. They obtained their *velocity* during the CME from which they originate.



A nice video of a coronal mass ejection can be watched at apod.nasa.gov/apod/ap211108.html

The **intergalactic medium** would also have a *temperature* of several million kelvin. Same story. The particles hardly ever collide with one another, so it is not to be considered a *temperature*. A black body roaming the IGM will reach an equilibrium at $T_{\mathrm{CMB}} \approx 2.73$ K. **Very cold!**

The *mean free path* of a particle is given by: $\ell = \frac{1}{\rho\,\sigma\,\sqrt{2}}$ (ρ = particle density).

For the solar corona, we have (see above): $\rho_p = \frac{1}{2} \times 10^{15}$ particles/m^3 (proton density).

The proton-proton *cross section* is: $\sigma_\mathrm{p} \approx 50 - 100$ millibarn $\approx 7 \times 10^{-30}$ m^2,

yielding a *mean free path* of: $\boldsymbol{\ell_\mathrm{p}} = \frac{2}{10^{15} \cdot 7 \times 10^{-30} \cdot \sqrt{2}} \approx \mathbf{2 \times 10^{14}\ m} \approx 288\,000 \cdot R_\odot$

which is roughly 1337 au, 44 times Neptune's *distance* from the sun, or 7.7 light days. The average *collision frequency* of individual particles would be: (437 km/s)/(2×10^{14} m) $\approx$ 2 nanohertz $\approx$ 2 collisions every 1 billion[(a)] seconds = P31Y9M9D[(b)]. Compare this to the molecules in air under standard conditions, which have an *individual collision frequency* of roughly 7 gigahertz = 7 billion[(a)] collisions every 1 second.

The *distance* of closest approach of two elementary charges that are colliding head on, with an initial *kinetic energy* $E_{\mathrm{k,p}}$ each, equals: $r_\mathrm{C} = \frac{e^2}{4\pi\varepsilon_0 \cdot 2E_{\mathrm{k,p}}} \approx 7.24 \times 10^{-13}$ m,

giving rise to a very roughly estimated sort of *Coulomb cross section* of about: $\sigma_\mathrm{C} = \pi(2r_\mathrm{C})^2 \approx 6.59 \times 10^{-24}$ m^2,

which would yield: $\boldsymbol{\ell_\mathrm{C}} = \frac{2}{10^{15} \cdot 6.59 \times 10^{-24} \cdot \sqrt{2}} \approx$ **215 000 km** $\approx 0.31 \cdot R_\odot$.

Would we very <u>un</u>realistically calculate with the *cross section* of a hydrogen atom, which roughly equals: $\sigma_\mathrm{H} \approx \pi \cdot (2r_{\mathrm{Bohr}})^2 \approx 3.52 \times 10^{-20}$ m^2,

we would obtain: $\boldsymbol{\ell_\mathrm{H}} = \frac{2}{10^{15} \cdot 3.52 \times 10^{-20} \cdot \sqrt{2}} \approx$ **40 km** $\lll R_\odot$.

We'll ignore this silly idea of atomic hydrogen.

The geometric mean of the other two equals: $\sqrt{\ell_\mathrm{p} \cdot \ell_\mathrm{C}} \approx 207 \times 10^9$ m $\approx 298 \cdot R_\odot \approx 1.4$ au

yielding an *individual collision frequency* of: (437 km/s)/(207×10^9 m) $\approx$ 2.1 microhertz $\approx$ once every 5.5 days.

One orbit around the sun at zero *altitude* lasts: $2\pi\sqrt{R_\odot^3 / GM_\odot} \approx$ 02:46:42.

(a) My dear fellow Dutchmen: billion = *miljard* = 10^9 (and: trillion = *biljoen* = 10^{12}, quadrillion = *biljard* = 10^{15}, quintillion = *triljoen* = 10^{18}).

(b) I.e. a **P**eriod of **31 Y**ears, **9 M**onths, and **9 D**ays in ISO 8601 format, yielding one collision every ~16 years.

Presuming this *collision frequency* is a reasonable estimate, there would on average be 47 orbits between two collisions, from which we can conclude that particle collisions within the corona are rather scarce.

The sun practically continuously blows new particles into the corona at or around the average CME *velocity*. They'll roughly have equal *velocities*, so the electrons have ~1836 times less *kinetic energy* than the protons. In case of thermal equilibrium, the protons would have lost most of their *kinetic energy* to the electrons and then they would – were there no electromagnetic forces by the remaining plasma – fall back to the solar surface. The observed ~~tempera~~ *kinetic energy* of coronal particles agrees with that of **ballistic** motion around the sun and, as just calculated/estimated, **stochastic** collisions are rare, so **the whole concept of *temperature* does not apply at all to the corona**.

If we apply the Stefan-Boltzmann law: $j^* = \sigma_{\mathrm{SB}} T^4$ ($\sigma_{\mathrm{SB}} \approx 5.67 \times 10^{-8}$ W/m²/K⁴),
it yields a *luminosity* of: $L = A_r \sigma_{\mathrm{SB}} T^4$
where A_r is the radiating *surface area*. In a very thin medium this may be far less than that of its circumscribed sphere. This has to do with *escape depth* (opposite of *penetration depth*) of the photons.

Would the corona's radiating *area* be: $A_r = A_\odot$
and its *temperature* indeed: $T_{cor} = 1$ million kelvin,
then its *luminosity* were: $L'_{\mathrm{cor}} = A_\odot \sigma_{\mathrm{SB}} T_{cor}^4 = 3.447 \times 10^{35}$ W,
whilst that of the sun equals: $L_\odot = 3.828 \times 10^{26}$ W.
The corona would radiate 900 million times more than the sun itself! **Ridiculous. Instantly lethal.** The actual radiation by the corona is far less than that of the sun. Given the particle density (or better: thinness) this makes sense.

On https://en.wikipedia.org/wiki/Coronal_radiative_losses we find that in active regions the coronal *energy flux* is about 10^7 erg cm^{-2}sec^{-1}. **WHY DO PEOPLE STILL USE THE OBSOLETE CGS SYSTEM?**

In S.I. units this equals: $j^*_{\mathrm{cor}} = 10^{-4}$ W/m²,
which renders a ***coronal temperature*** of: $T_{\mathrm{cor}} = \sqrt[4]{j^*_{\mathrm{cor}}/\sigma_{\mathrm{SB}}} \approx$ **6.5 kelvin. Very cold!** (But 2.4 × warmer than the IGM...)

Effective irradiated *coronal surface area*: $A_{\mathrm{cor}} = A_\odot \left(\frac{T_{\mathrm{cor}}}{T_\odot}\right)^4 \approx 9.7$ km² (estimated),
which more or less equals its radiating area,
yielding the true *coronal luminosity* as: $L_{\mathrm{cor}} = j^*_{\mathrm{cor}} \cdot A_{\mathrm{cor}} \approx 974$ W (yes, a mere kW; *during an eclipse, we see Thomson scattered sunlight, not thermal radiation by the corona itself*).

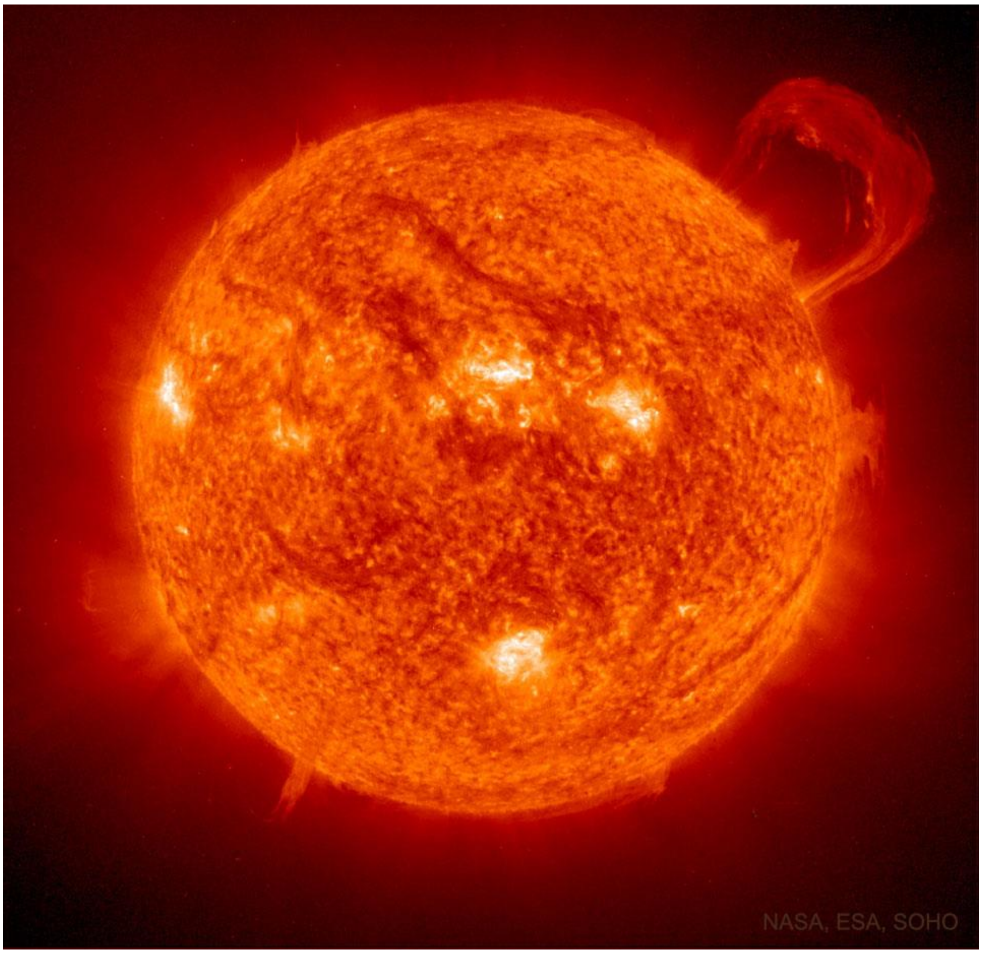
At **1 million kelvin**, the corresponding radiating coronal *surface area* were: $\boldsymbol{A_{\mathrm{cor,1MK}} = \frac{L_{\mathrm{cor}}}{\sigma_{\mathrm{SB}} \cdot (1\ \mathrm{MK})^4} \approx 0.0172\ \mu\mathrm{m}^2 \approx (131\ \mathrm{nm})^2}$.

The presumed coronal temperature of a few million kelvin is *flapdoodle*
and that of the intergalactic medium is *malarkey, applesauce*.
But maybe they are phlogisticated?

https://www.redbubble.com/people/thedrawingpanda/works/32455253-so-hot-sun

https://www.kissclipart.com/pixel-art-5yqxrv/

THIS is where the coronal particles get their *velocity* from:



https://apod.nasa.gov/apod/ap220130.html

A Solar Prominence from SOHO

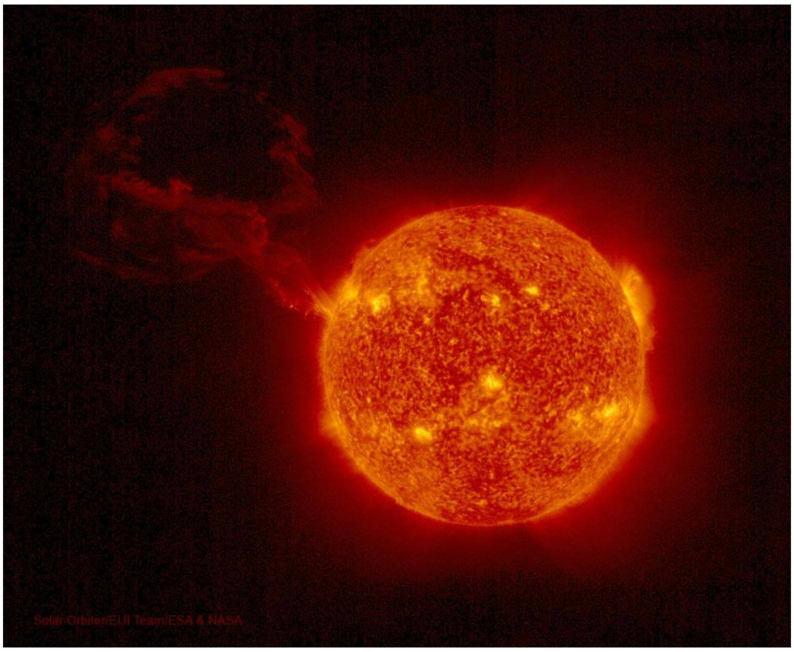
Image Credit: NASA, ESA, SOHO-EIT Consortium

They got their **ballistic** *velocity* from the CME that launched them into a complicated solar orbit through the labyrinthine combination of the gravitational and electromagnetic fields.

This **ballistic** *kinetic energy* should not be translated to a *temperature* of several million kelvin; the *flux*-based *SB-temperature* originating from **stochastic** movement is not more than a few kelvin.

The very thin corona has a negligible absorbing *surface area*, so it is hardly warmed up by the thermal radiation that originates from the solar surface.

And what about this:



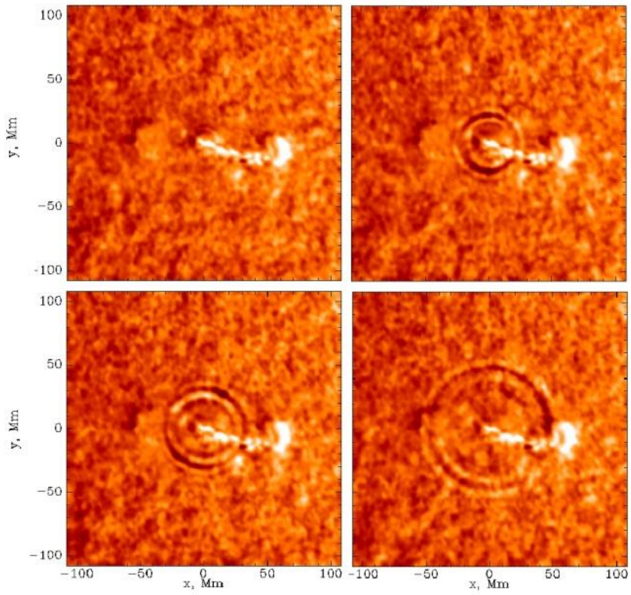
https://apod.nasa.gov/apod/ap220302.html

Record Prominence Imaged by Solar Orbiter

Image Credit: Solar Orbiter, EUI Team, ESA & NASA; *h/t:* Bum-Suk Yeom

Isn't this ***ballistic*** (Greek: $\beta\alpha\lambda\lambda\varepsilon\iota\nu = ballein =$ *to throw*) *kinetic energy* that will turn into *orbital energy* for many of the particles?

It has nothing to do with *temperature*.



https://soho.nascom.nasa.gov/gallery/images/quakes.html

Ever thrown a stone into a pond or so?

The outer shell and its surface seem to behave like a liquid, definitely not a gas.

Do YOU believe the sun is gaseous?

The sun is of course super critical at high pressure, so in that sense it's both gaseous and liquid, i.e. a fluid. It's fully ionised, but not a plasma, which is gaseous. To me, *gas* means freely moving particles with no other interactions than collisions, but have a look at the solar density:

Mean density: $M_\odot / \frac{4}{3}\pi R_\odot^3 \approx 1\,410\ \mathrm{kg/m^3}$,

core density: $\rho \approx 150\,000\ \mathrm{kg/m^3}$.

Stuff at this ***mean*** density can't float on water, it is 20 times as dense as LH2, 2⅓ × metallic hydrogen, 70% of close-packed atomic H.

Proton-proton distance in core: $\sim\mathbf{0.4}\boldsymbol{r}_\mathbf{B}$ **.**

GASEOUS? Come on...

In the deeper interior, atoms have no room to exist, hence they are all crushed, forming a "soup" of protons and electrons, way too dense for a gas or liquid, but it most probably cannot form a crystalline lattice. This means it would be **gLass**-like and not liquid or solid, let alone gas or plasma.

Internal energy transfer from core to surface probably is mostly thermal conduction & very slow convection. The solar interior must be practically opaque to radiation. Photons do not travel from core to surface (not even in a few million years), they are produced at the surface. We observe a thermal spectrum corresponding to the surface temperature according to Planck's radiation law, don't we?

