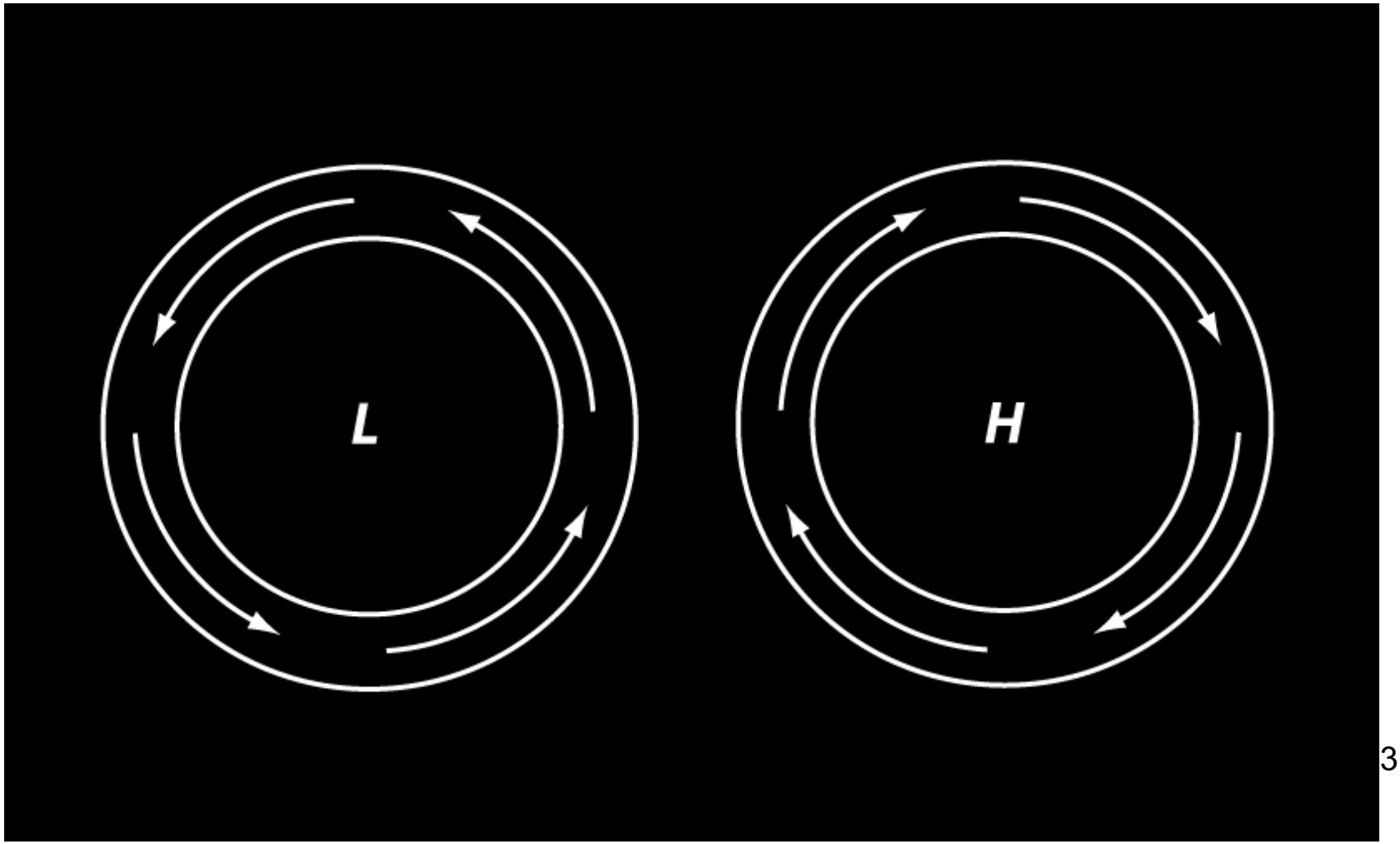
Hurricane Katrina (2005), gradient wind, the centripetal force, and spin

ATM 210 -- Fall 2023 -- Fovell

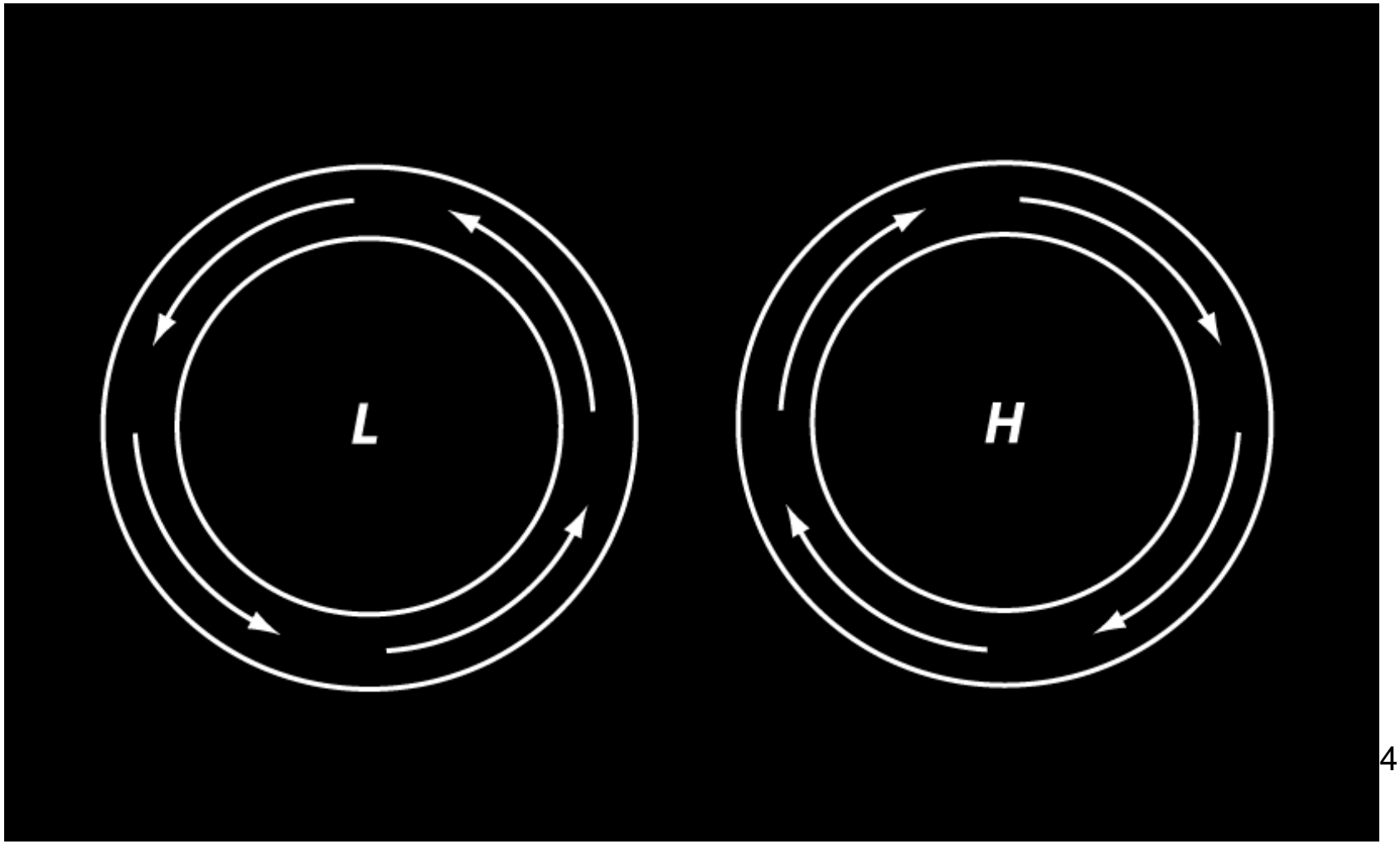
Review

- Four fundamental forces influence the horizontal wind
  - Pressure gradient force (PGF)
  - Coriolis force
  - Centripetal or centrifugal force
  - Friction force
- Coriolis is a self-serving apparent force that explains real, important phenomena
- Centrifugal is a self-serving apparent force that is often centripetal force and/or inertia in disguise

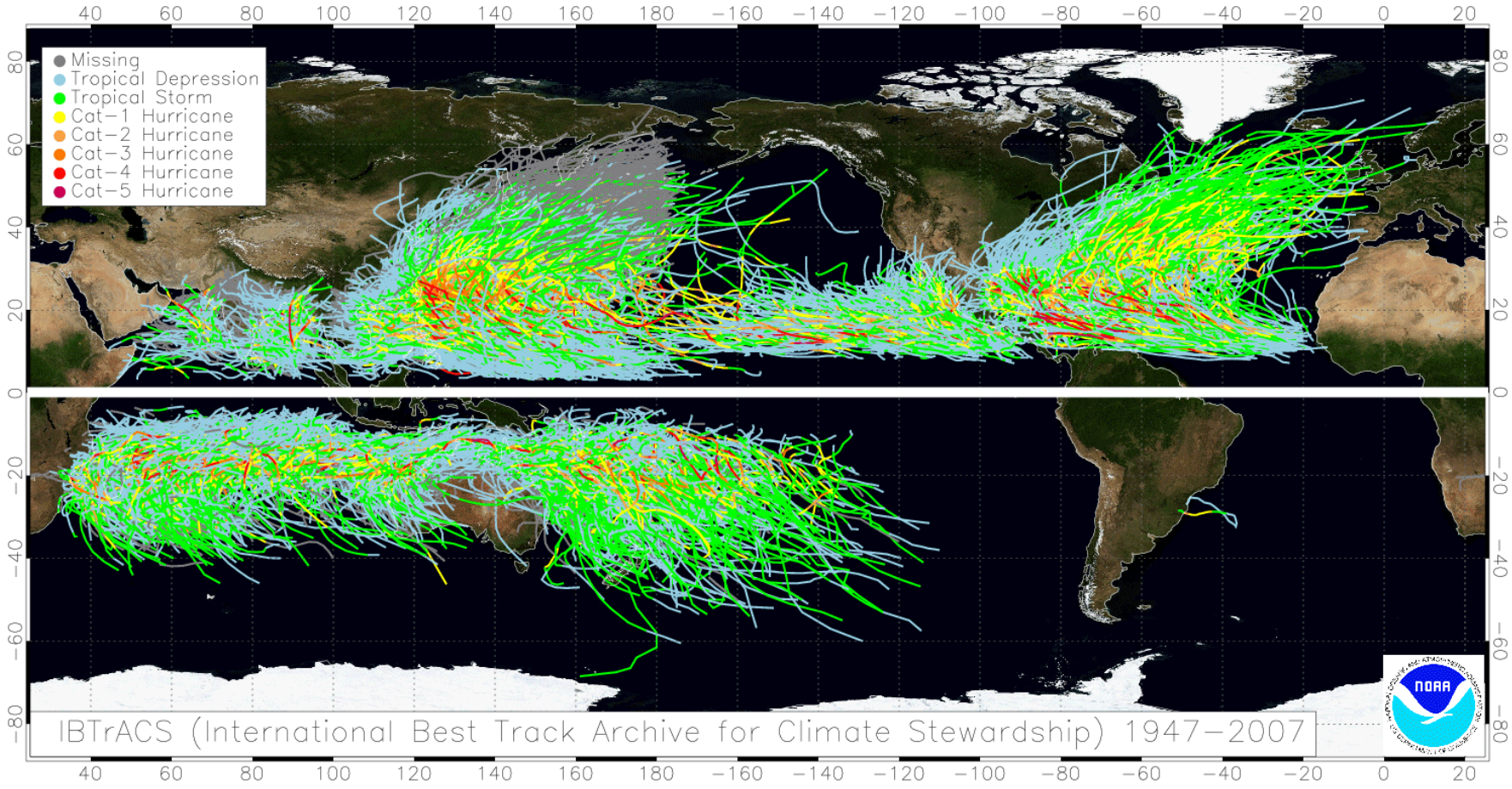
Gradient wind balance: Recipe: PGF + Coriolis + Centripetal



Gradient wind balance: CCW around L, CW around H in NH

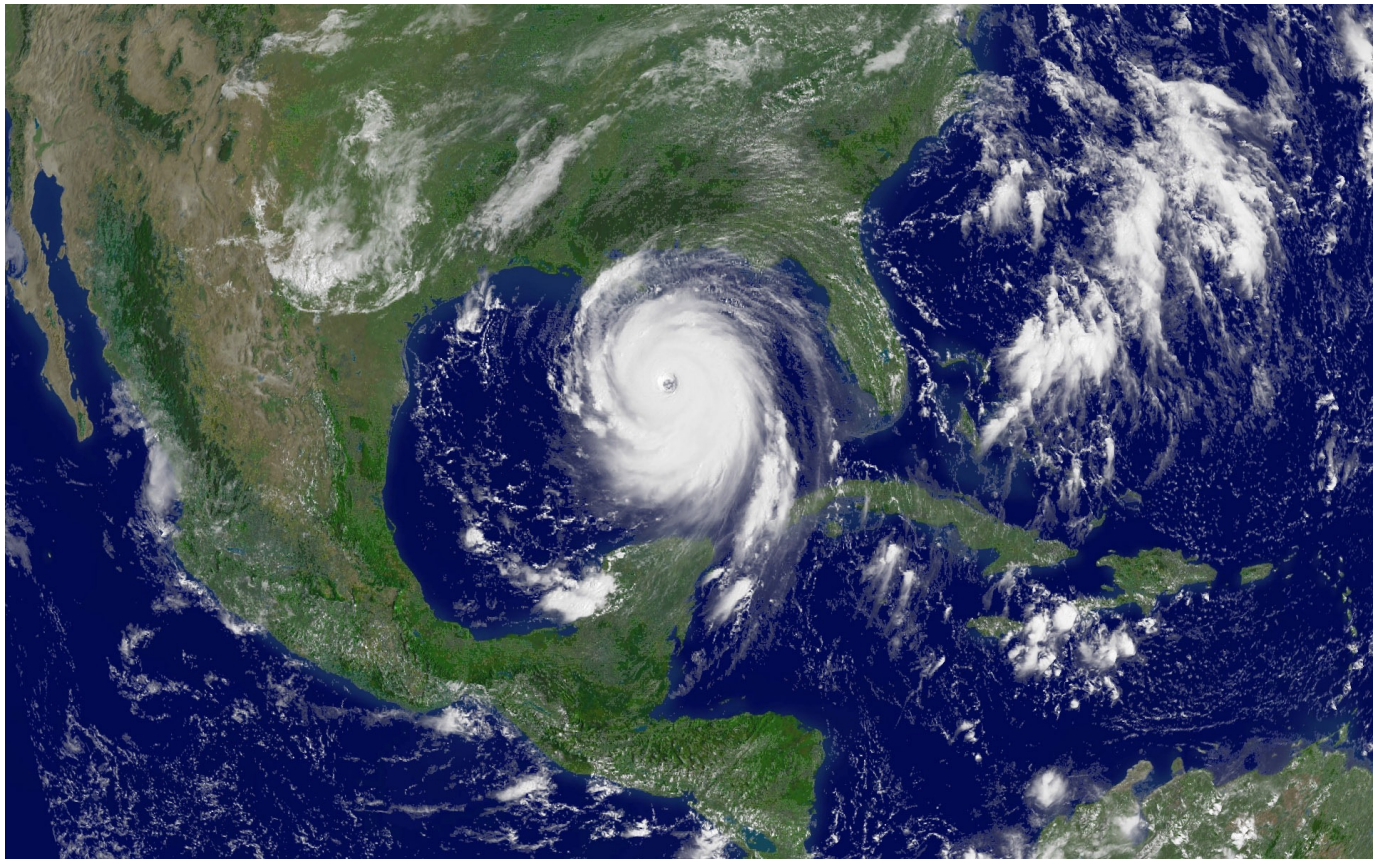


Reminder: tropical cyclones do not form on, or cross, the equator

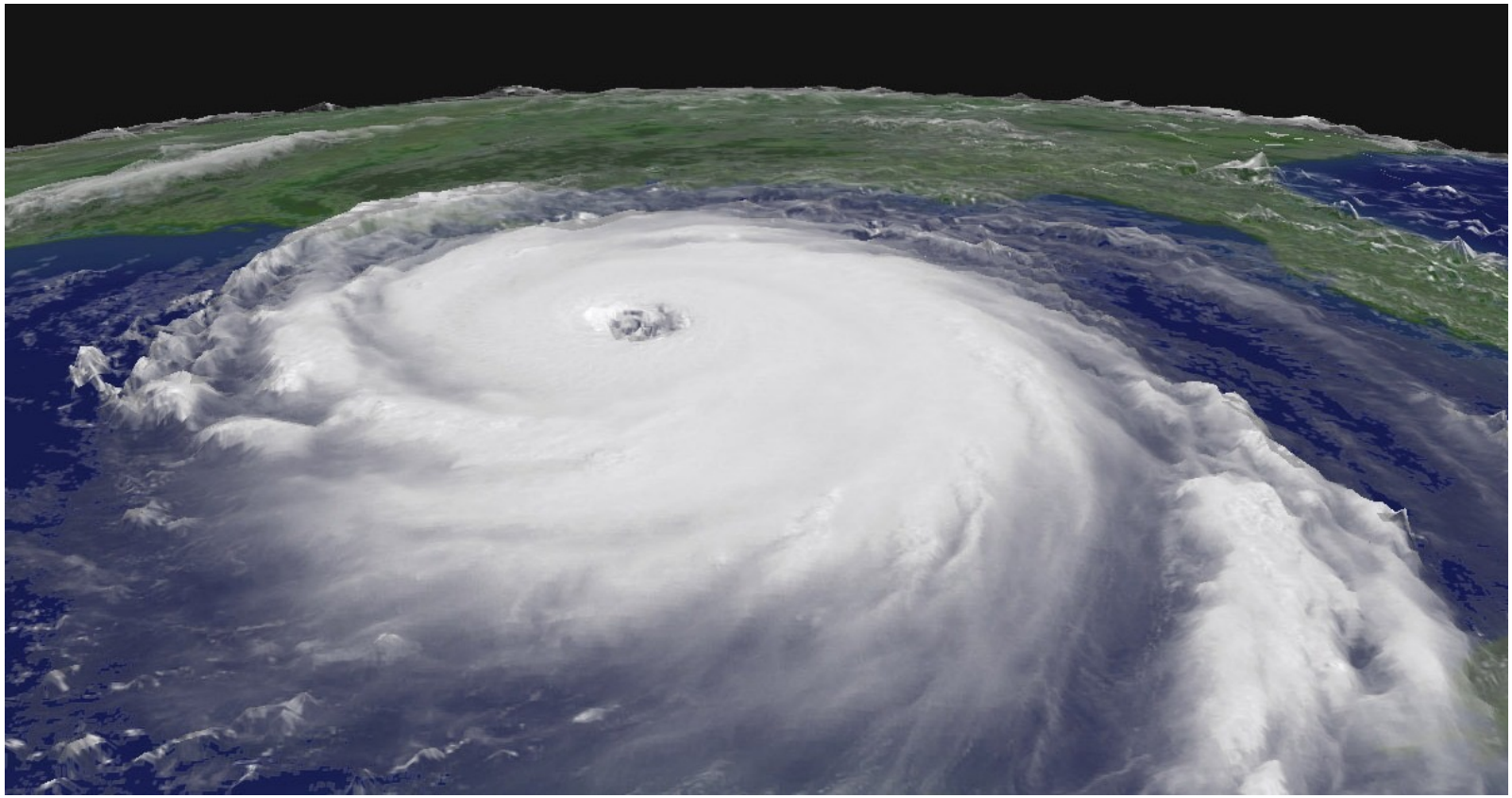


61 years of tropical cyclone tracks

Hurricane Katrina (2005)

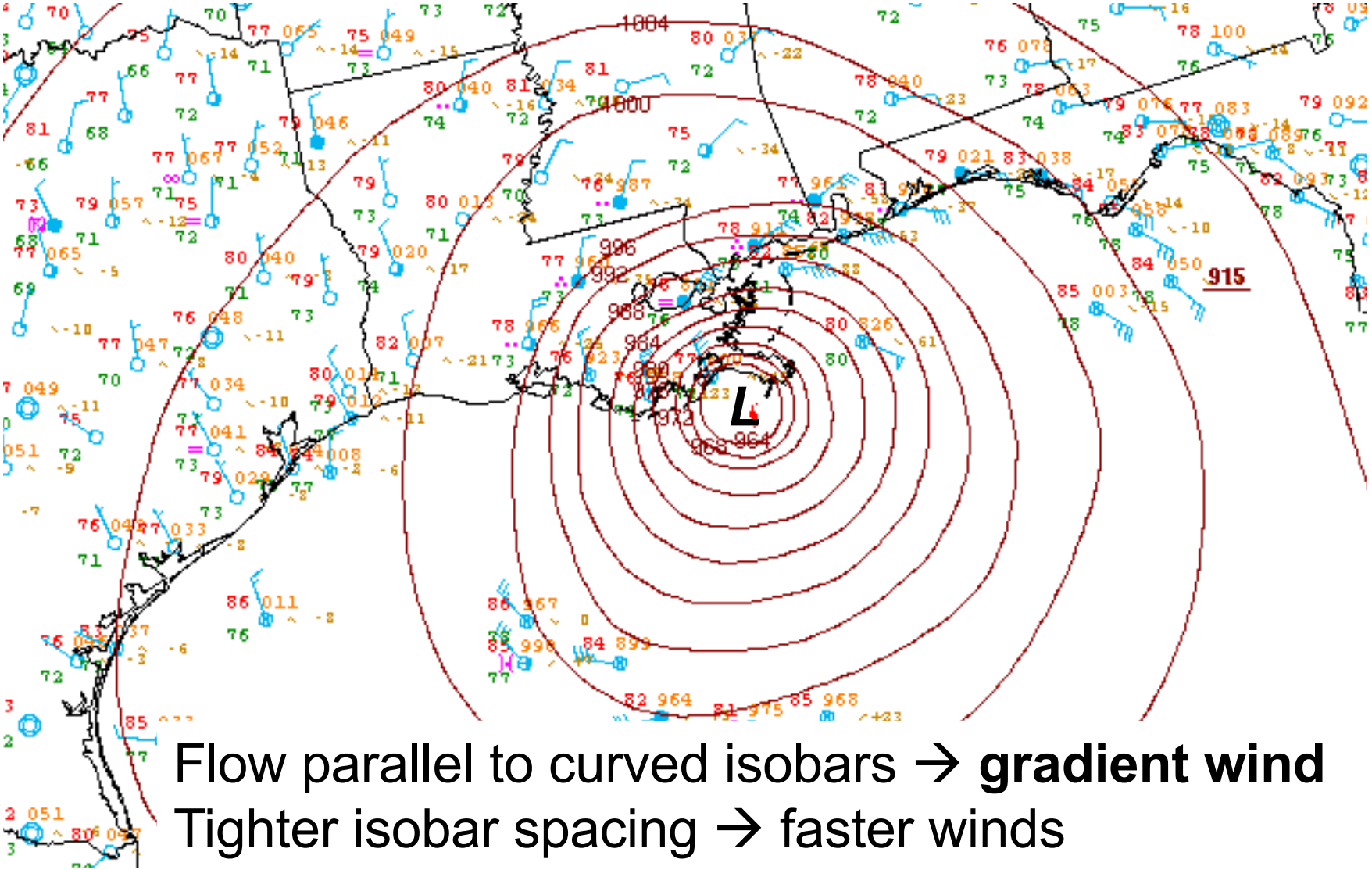


Oblique view



Surface chart showing sea-level pressure (SLP)

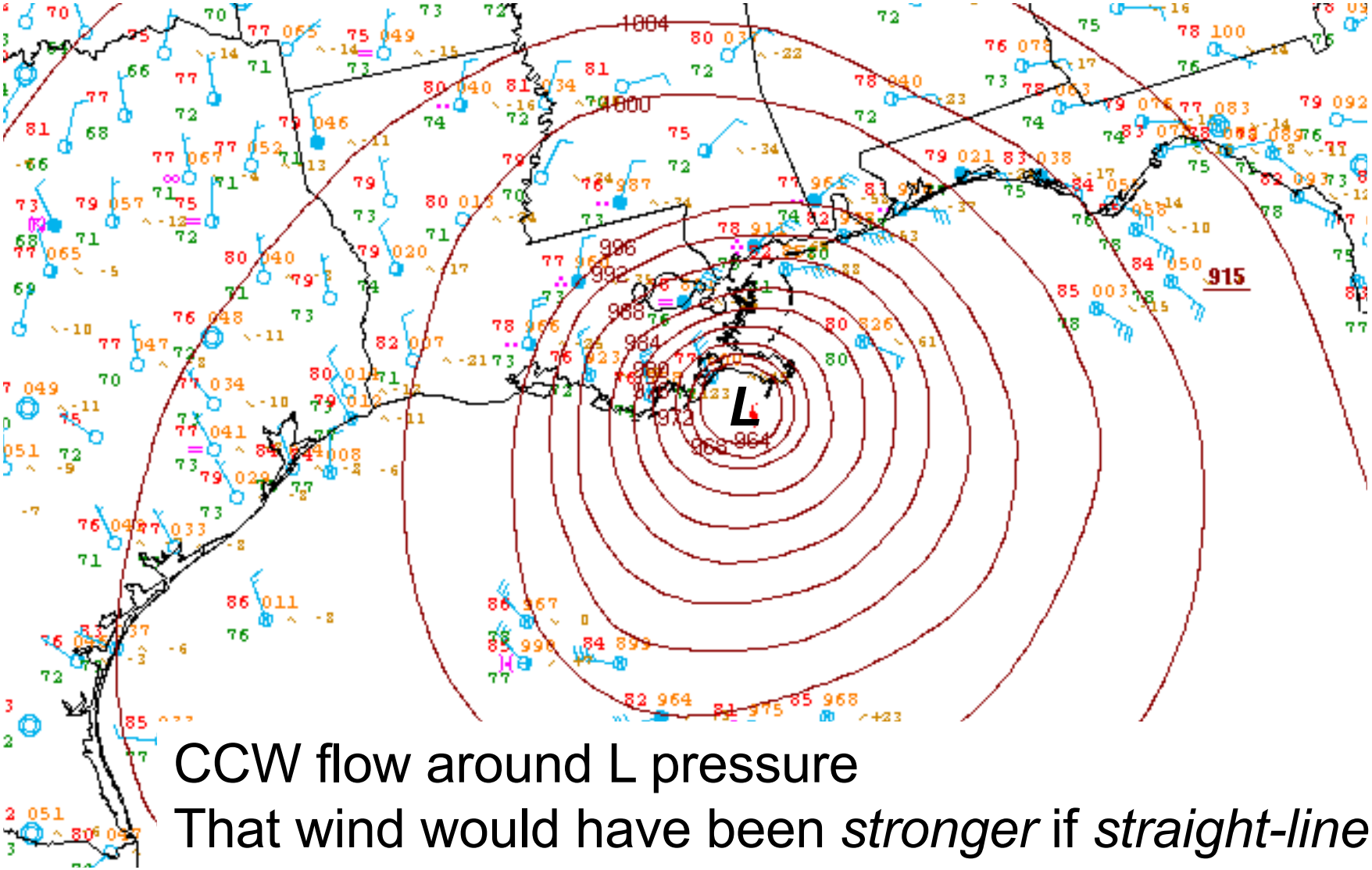
09 UTC 8/29/2005



Flow parallel to curved isobars → **gradient wind**

Tighter isobar spacing → faster winds

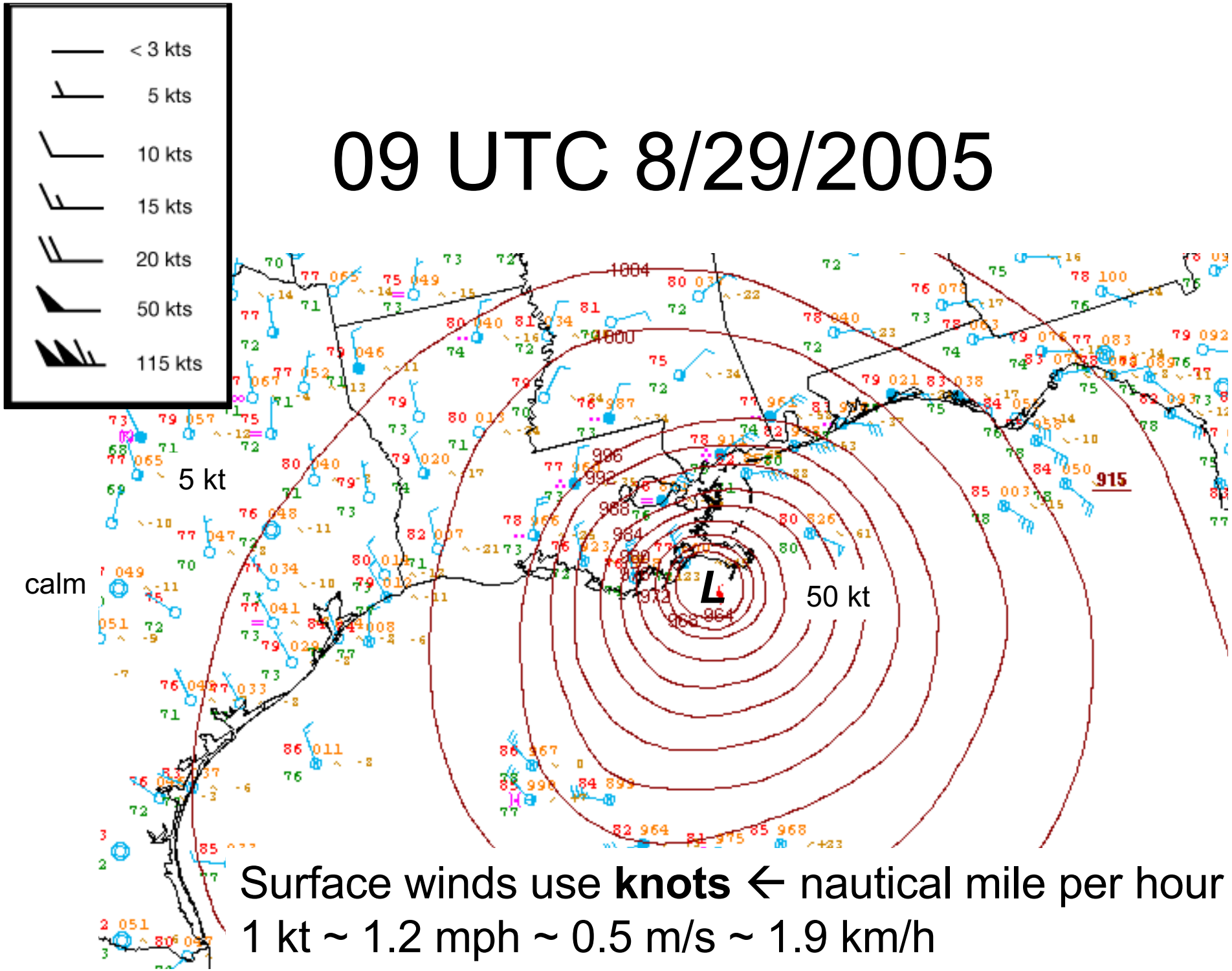
09 UTC 8/29/2005



CCW flow around L pressure

That wind would have been *stronger* if *straight-line*

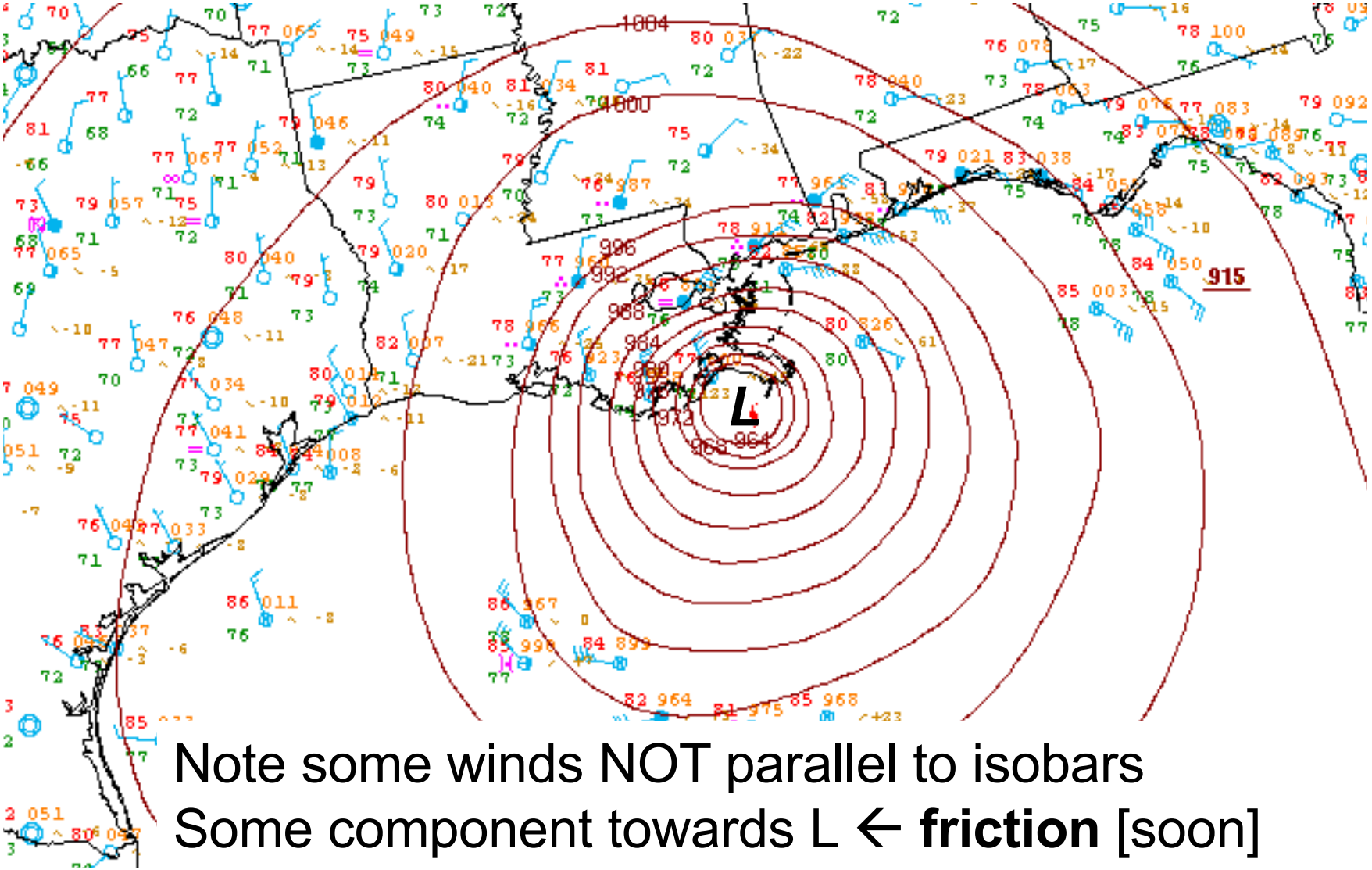
09 UTC 8/29/2005



Surface winds use **knots** ← nautical mile per hour

1 kt ~ 1.2 mph ~ 0.5 m/s ~ 1.9 km/h

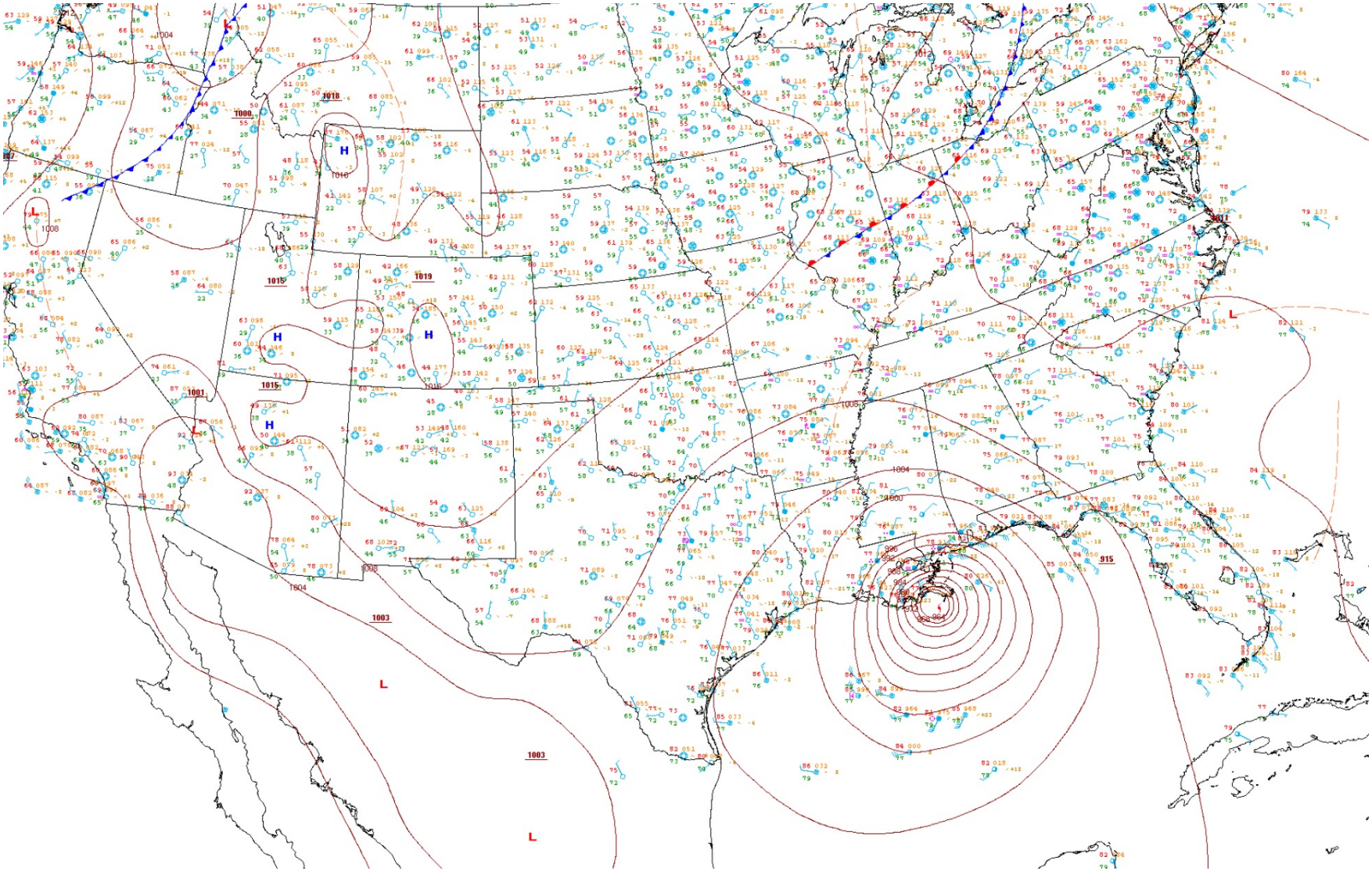
09 UTC 8/29/2005



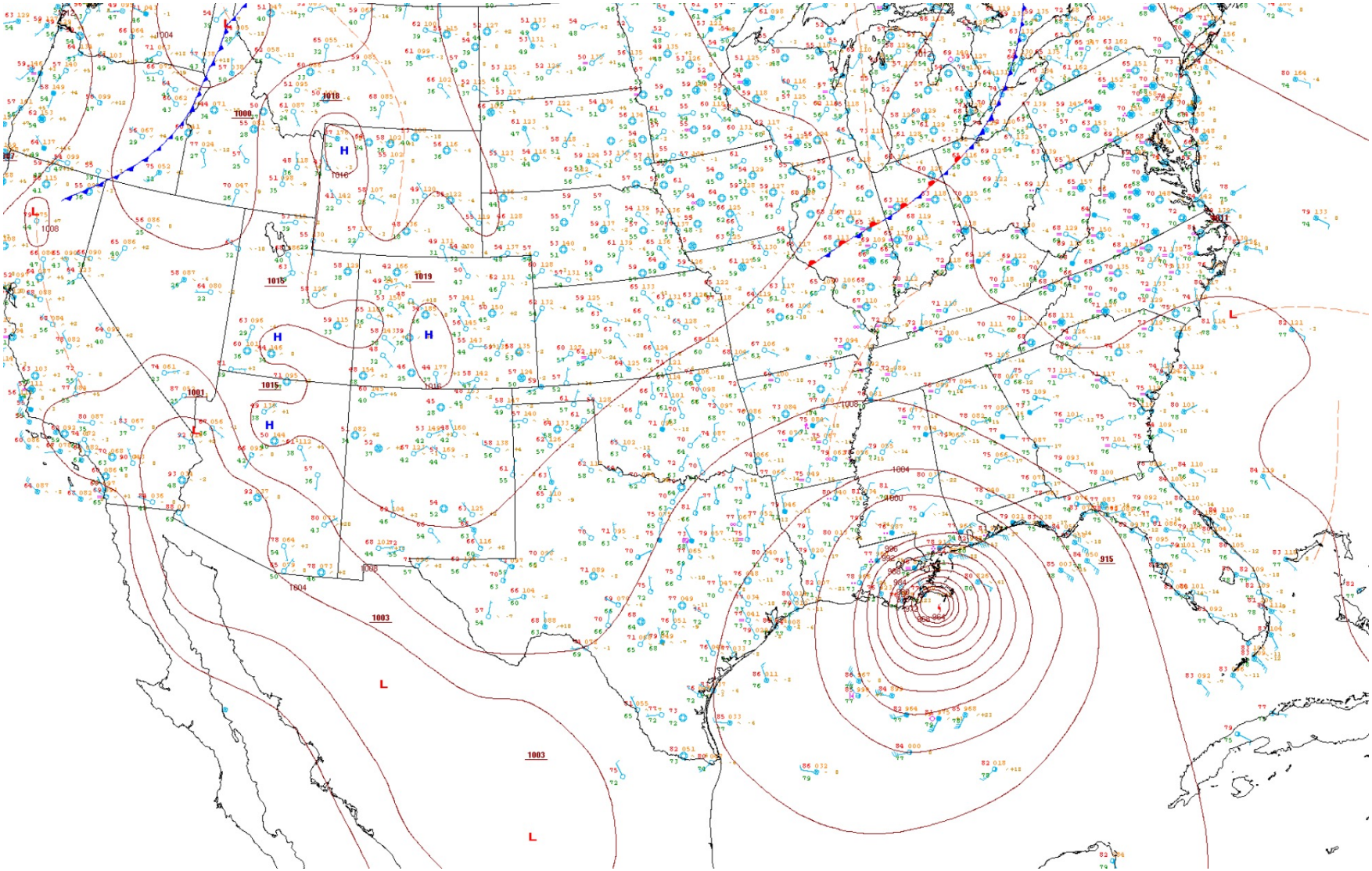
Note some winds NOT parallel to isobars

Some component towards L ← **friction** [soon]

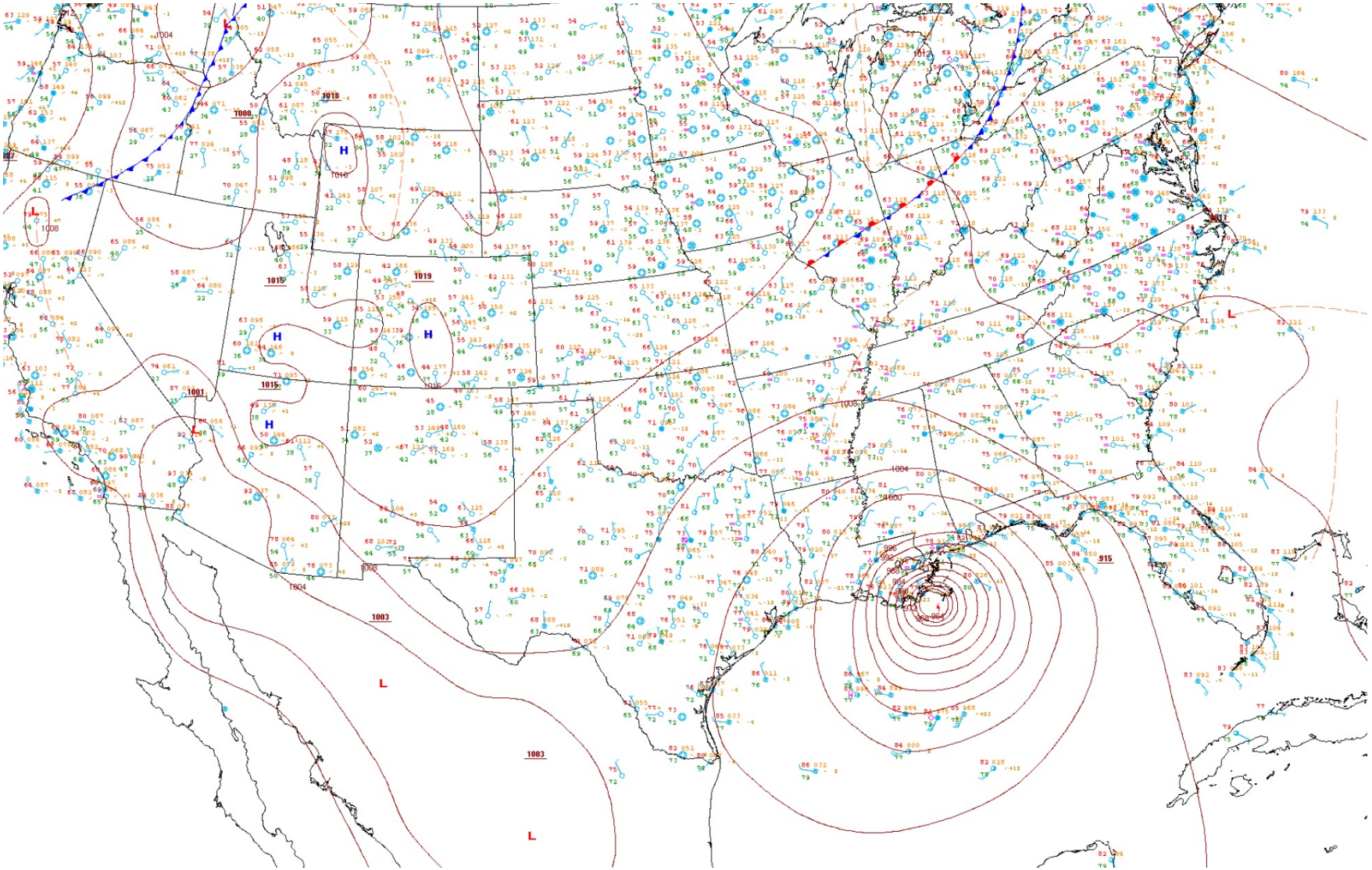
Question #1: We often see strong flow around L, but almost never around H. Why?



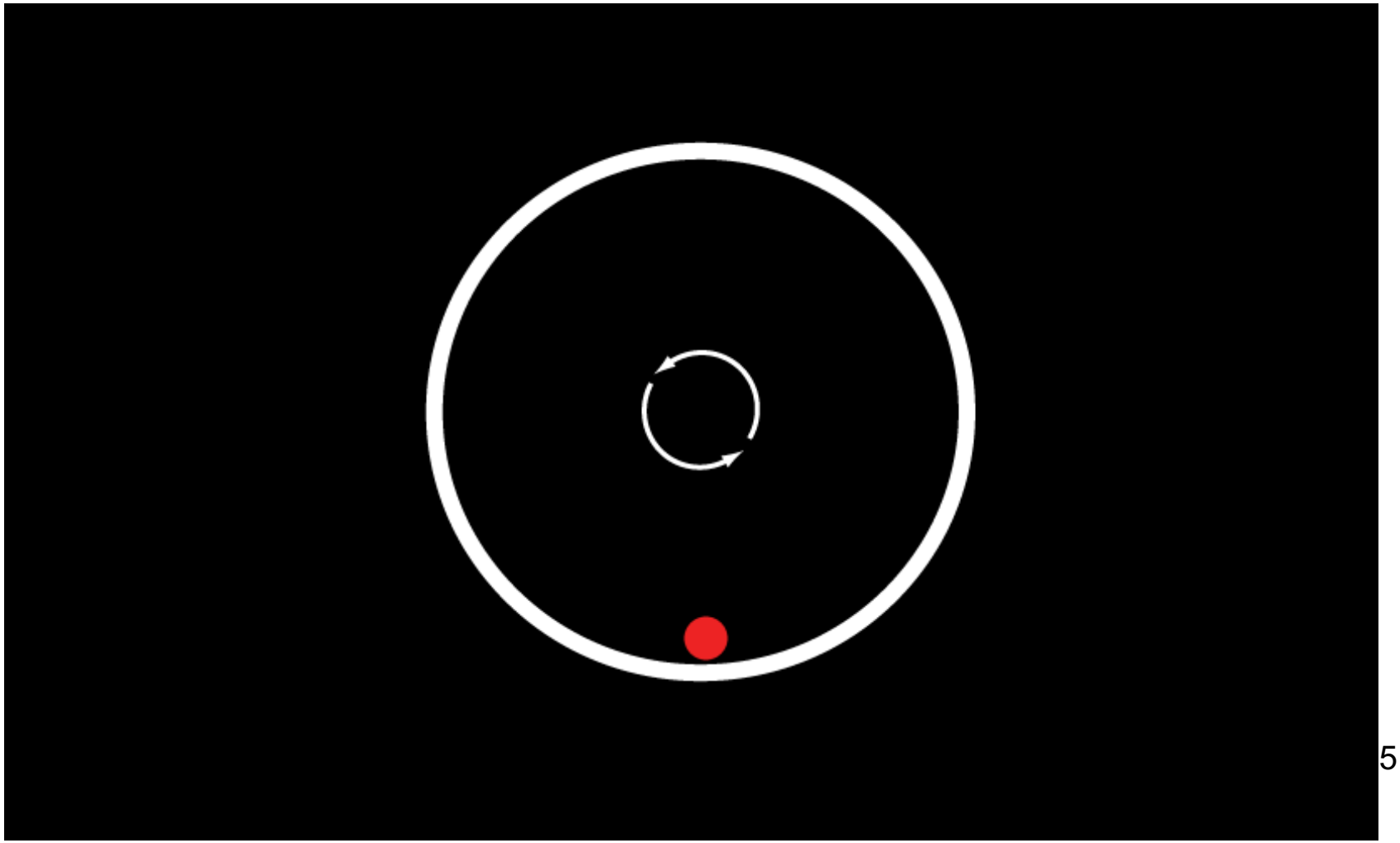
Question #2: Curving flow involves centripetal force. But where did the force come from?



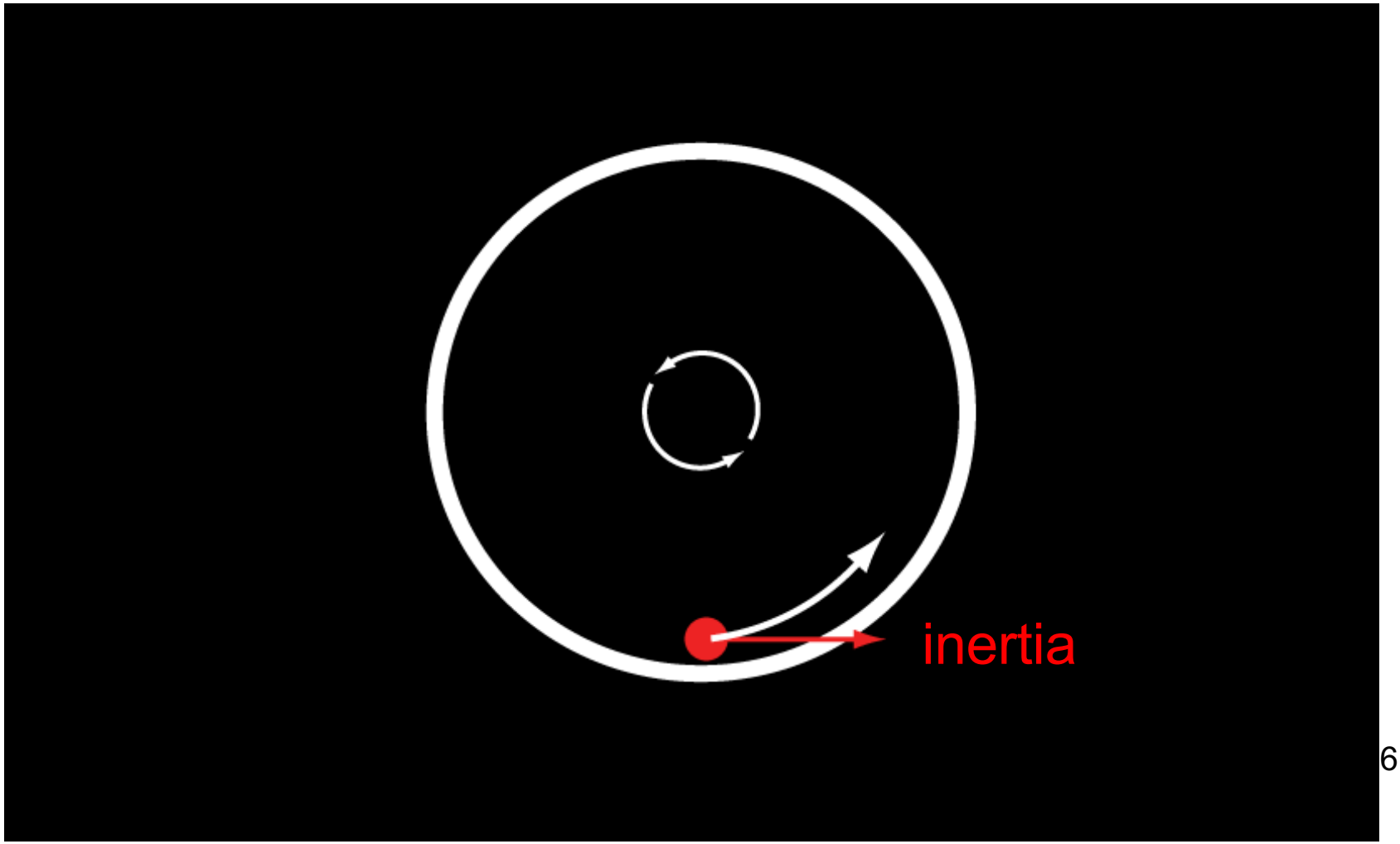
Question #3: Why use centripetal force and not centrifugal force?



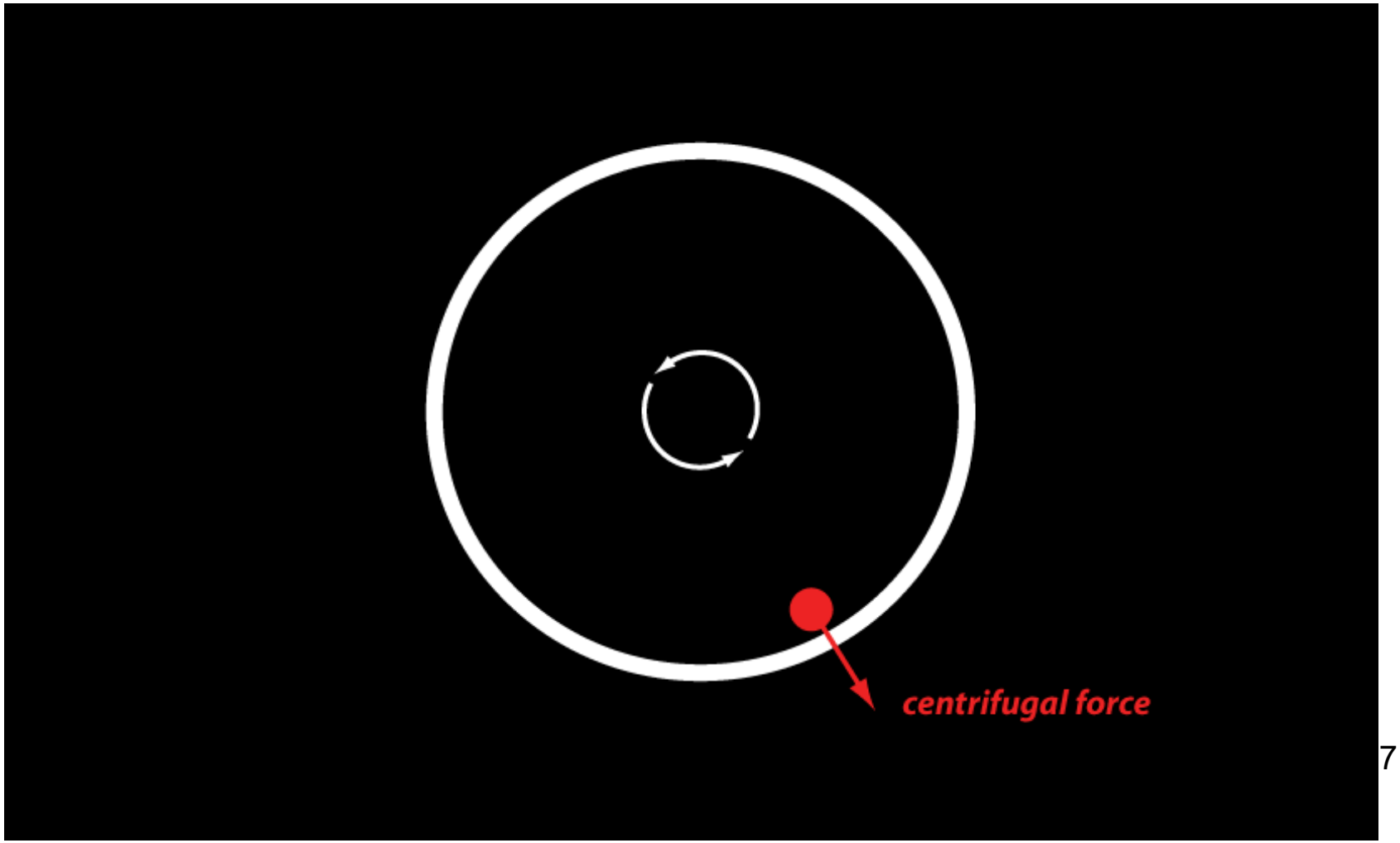
You in the cylinder ride. CCW or CW, it's all the same pain.



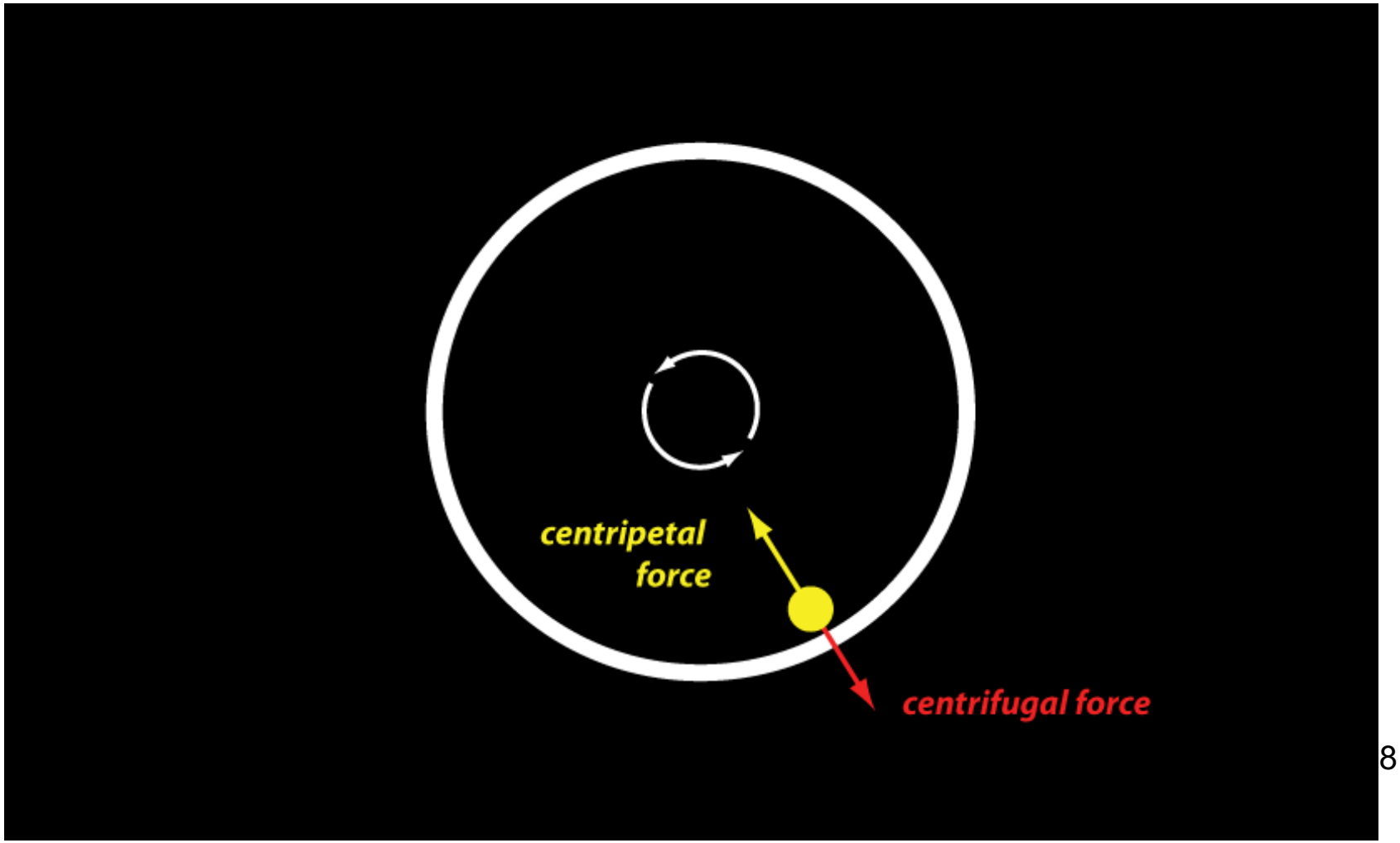
At any instant, **inertia** wants you moving **straight**



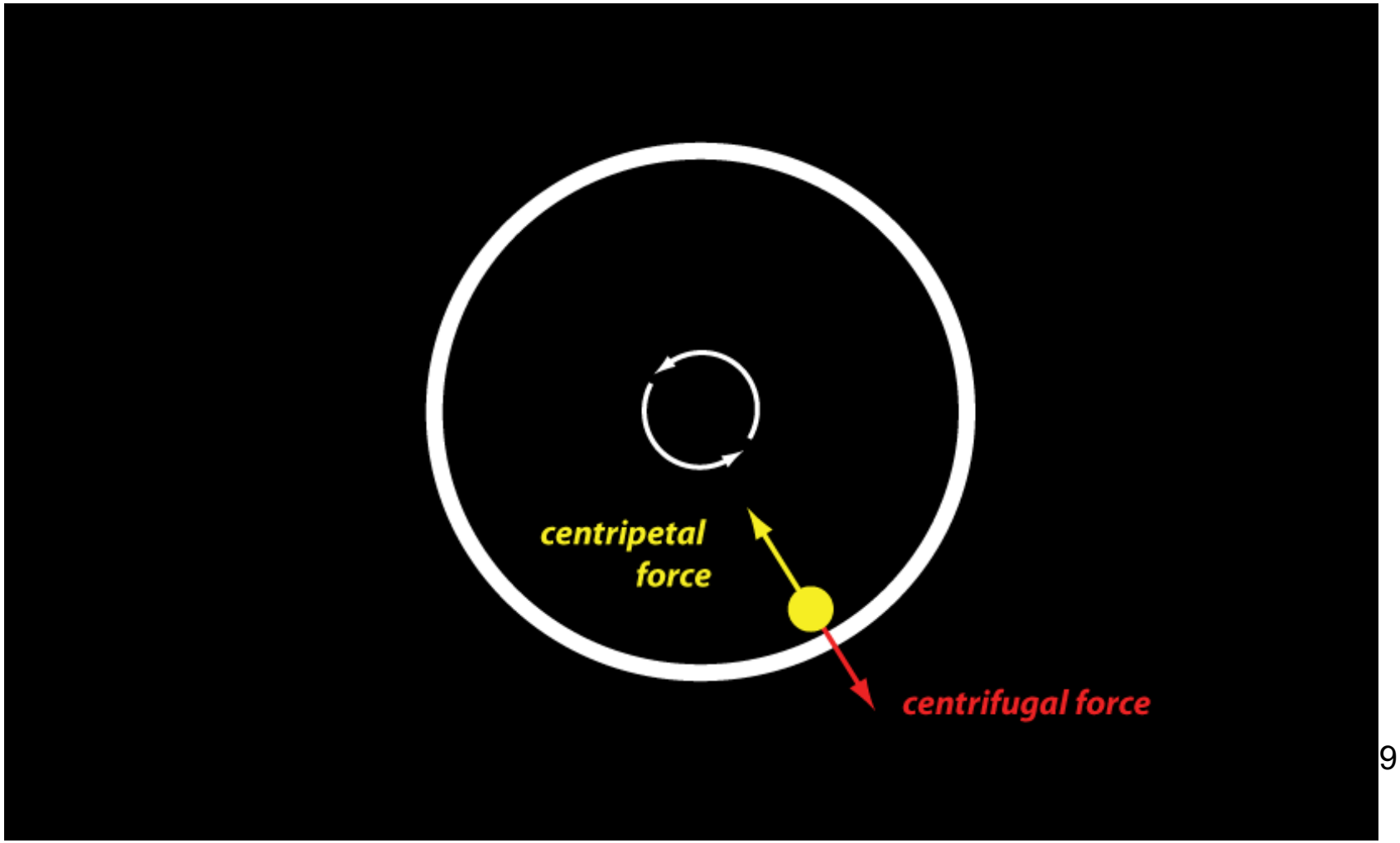
You may interpret this as a **centrifugal force**, pushing you against the wall



But it's really a **centripetal force**, supplied by the **wall**

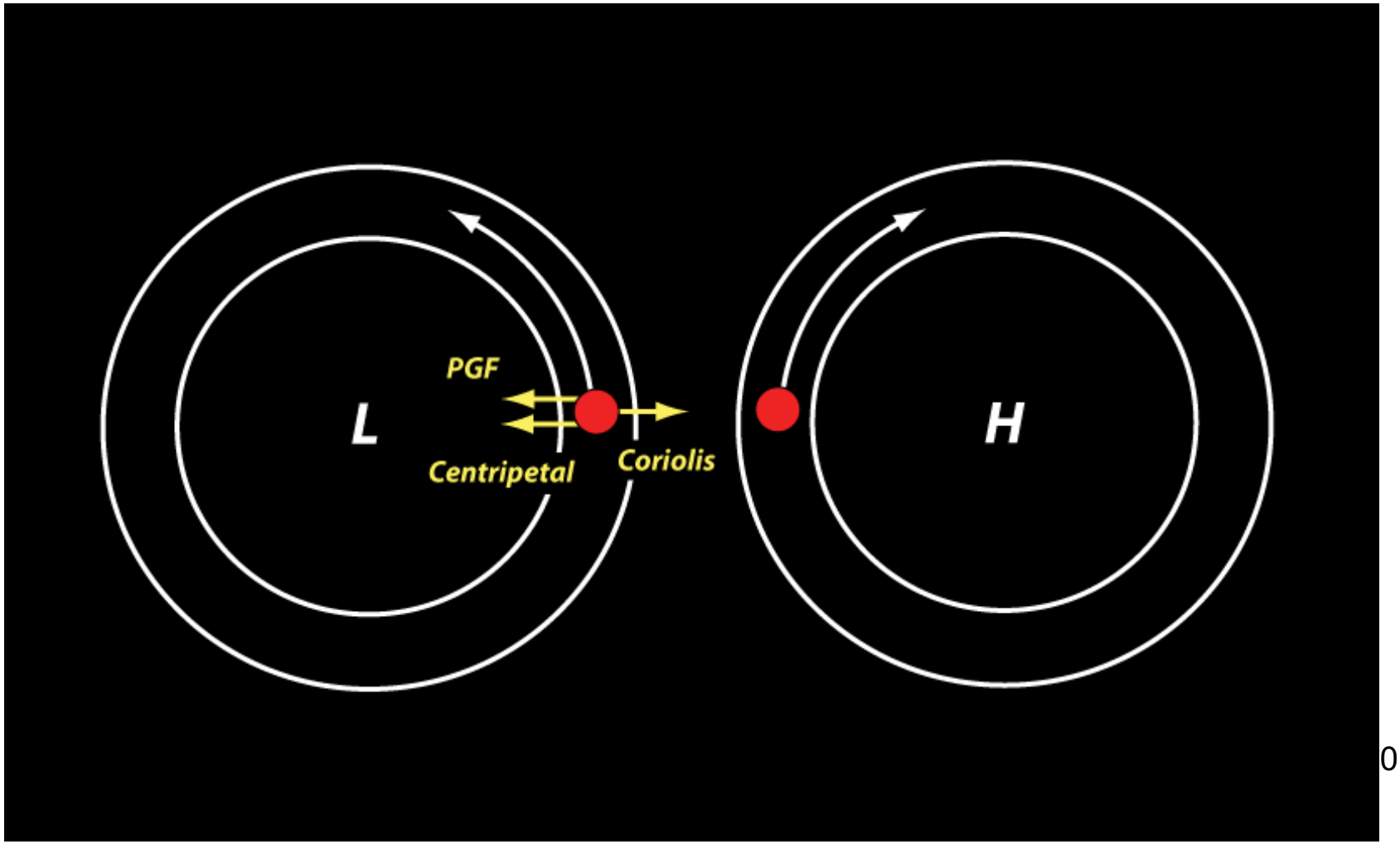


Centripetal force points **in** towards the center of **spin**



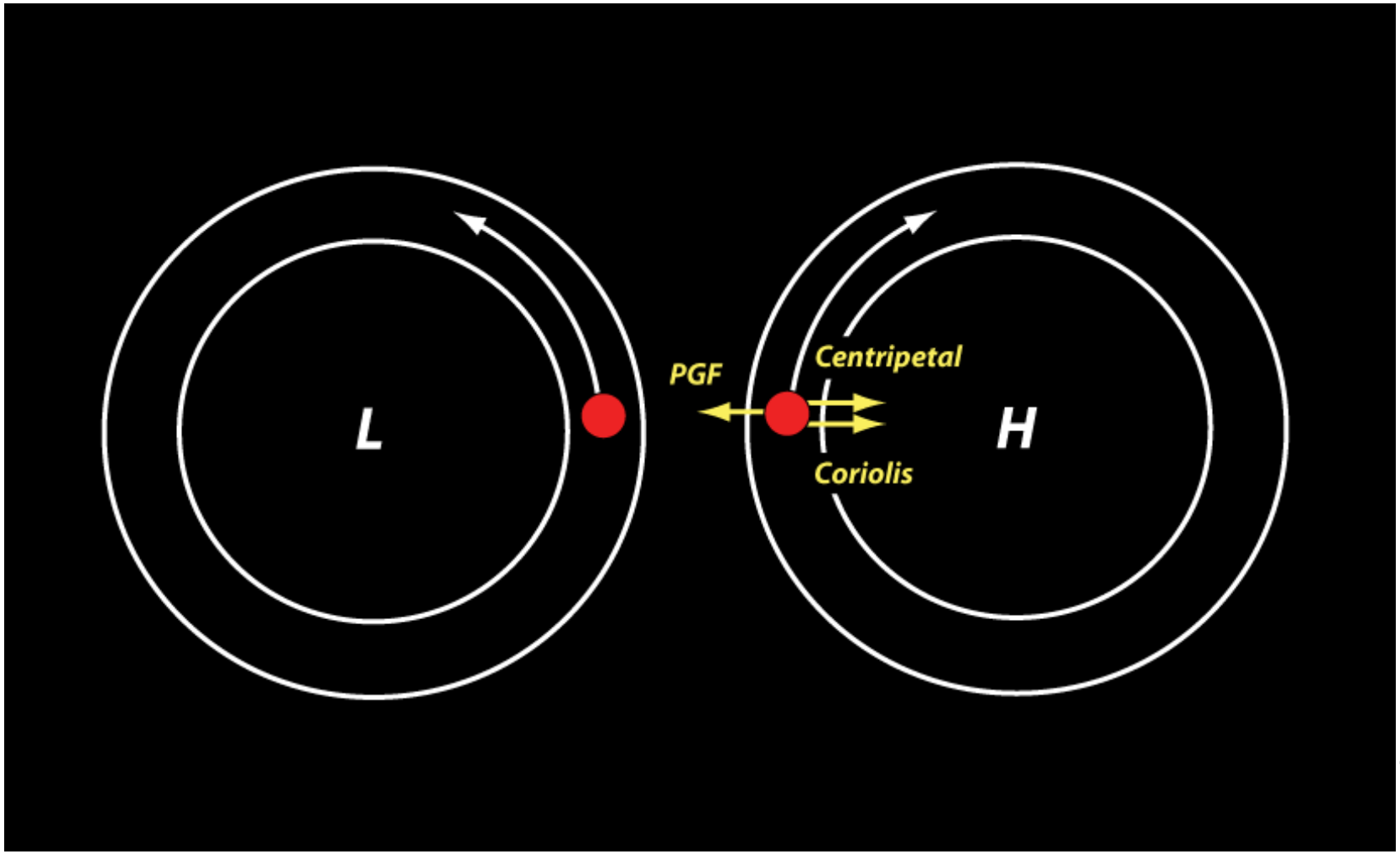
(in NH)

Adding centripetal to the L means flow curves CCW



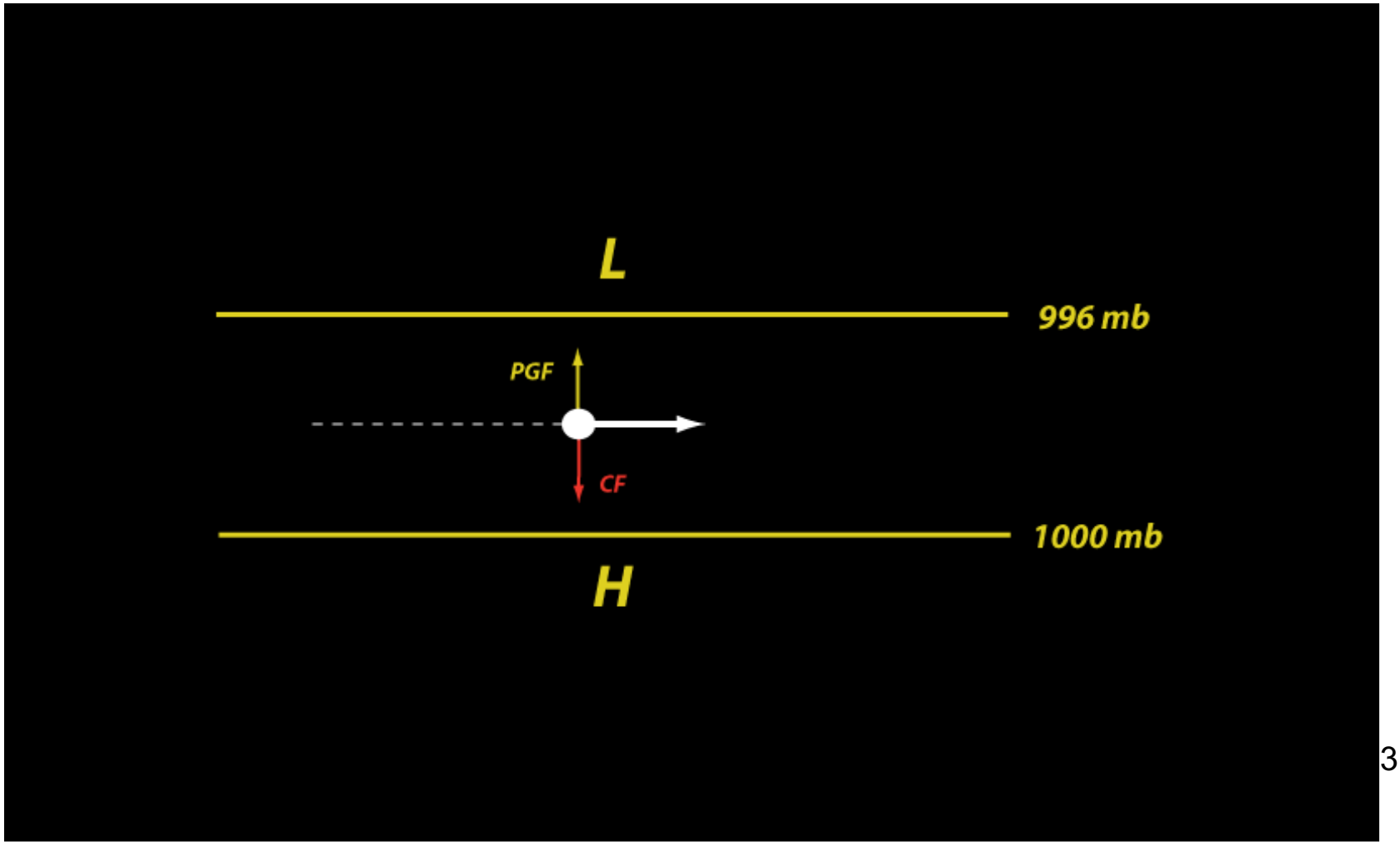
(in NH)

Adding centripetal to the H means flow curves CW

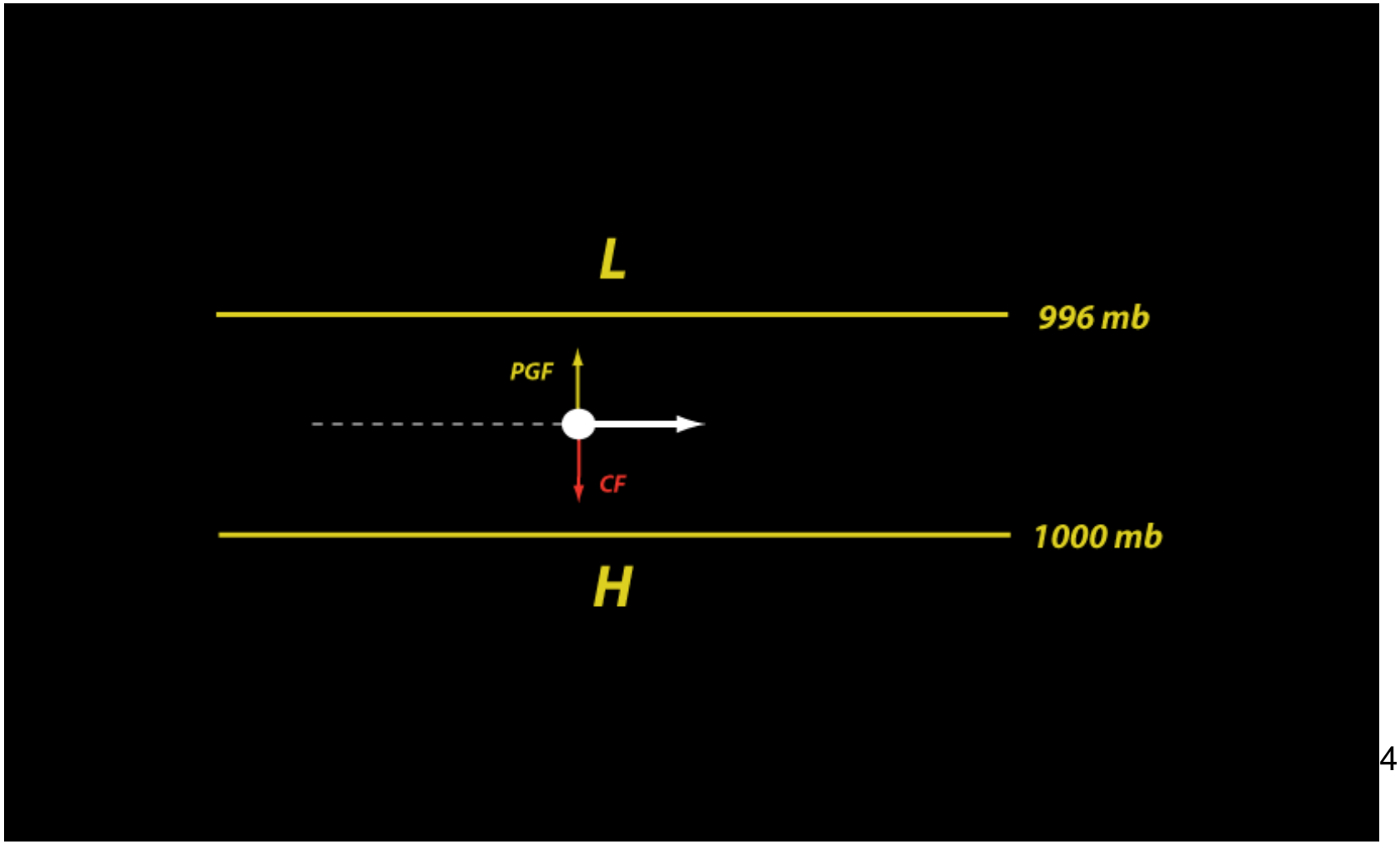


But this does not explain where the centripetal force came from, why the speed changes, and why CCW flow is subgeostrophic and CW flow is supergeostrophic

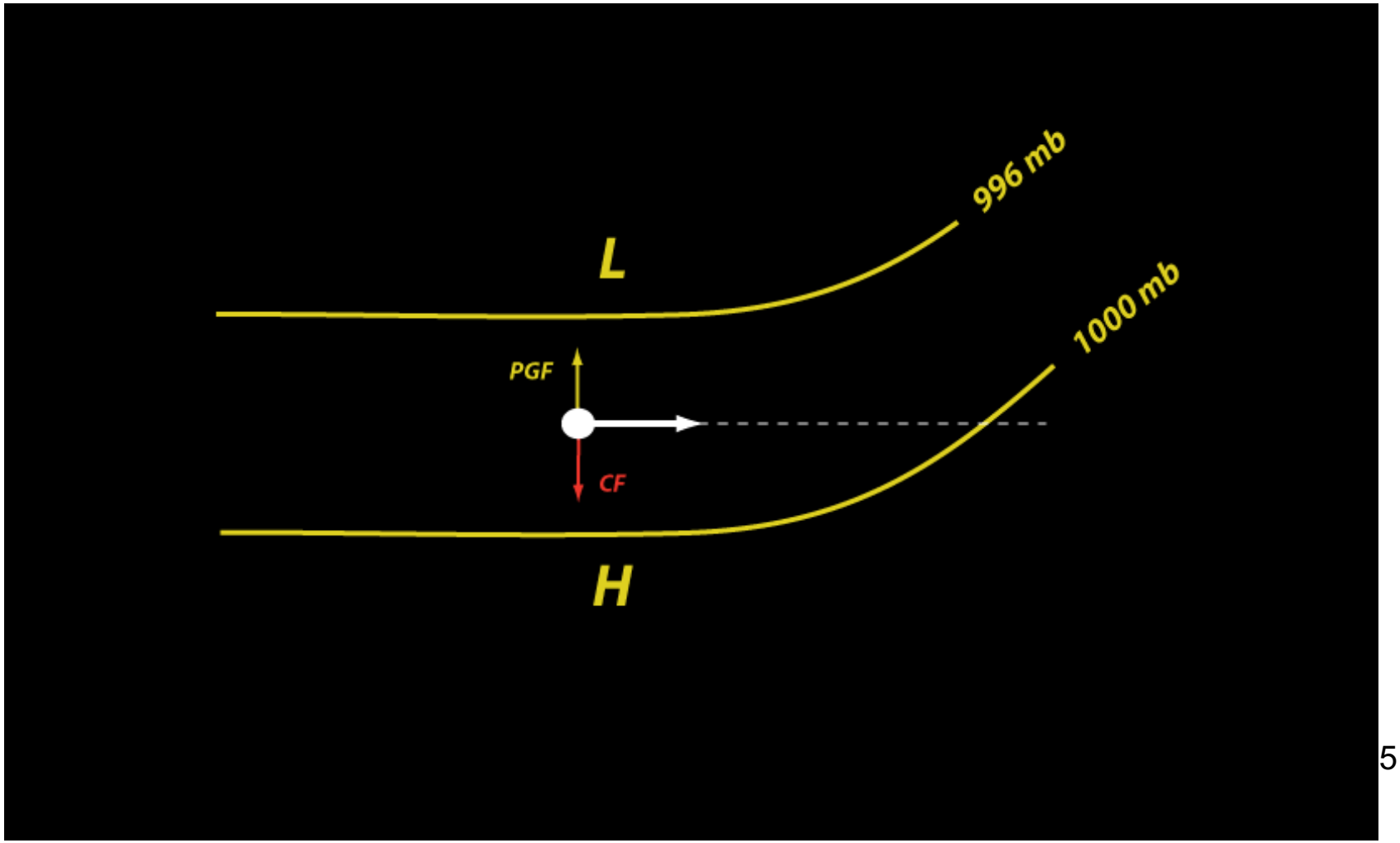
Start with geostrophic balance: PGF + Coriolis



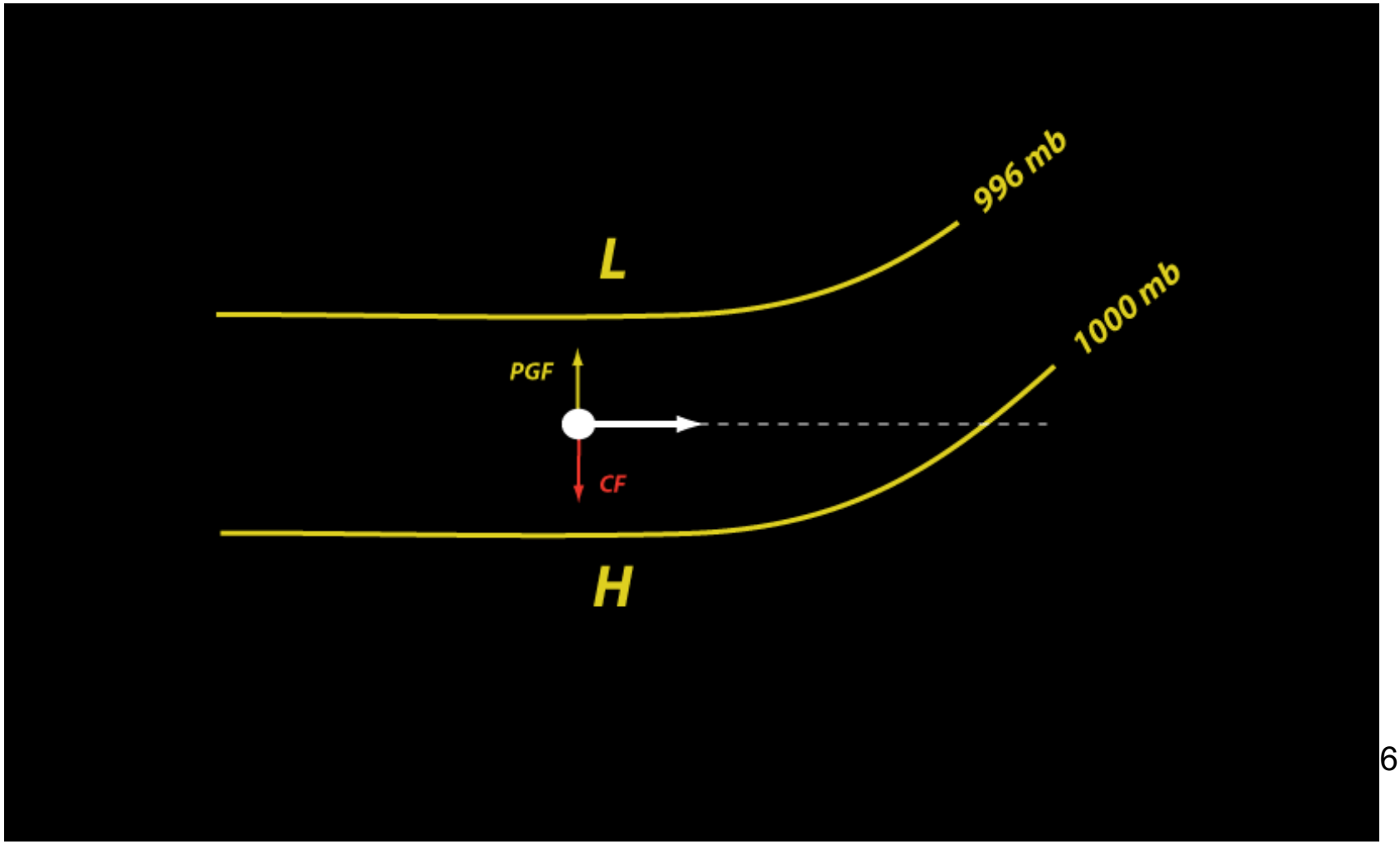
There is a force balance. No acceleration. Yet.



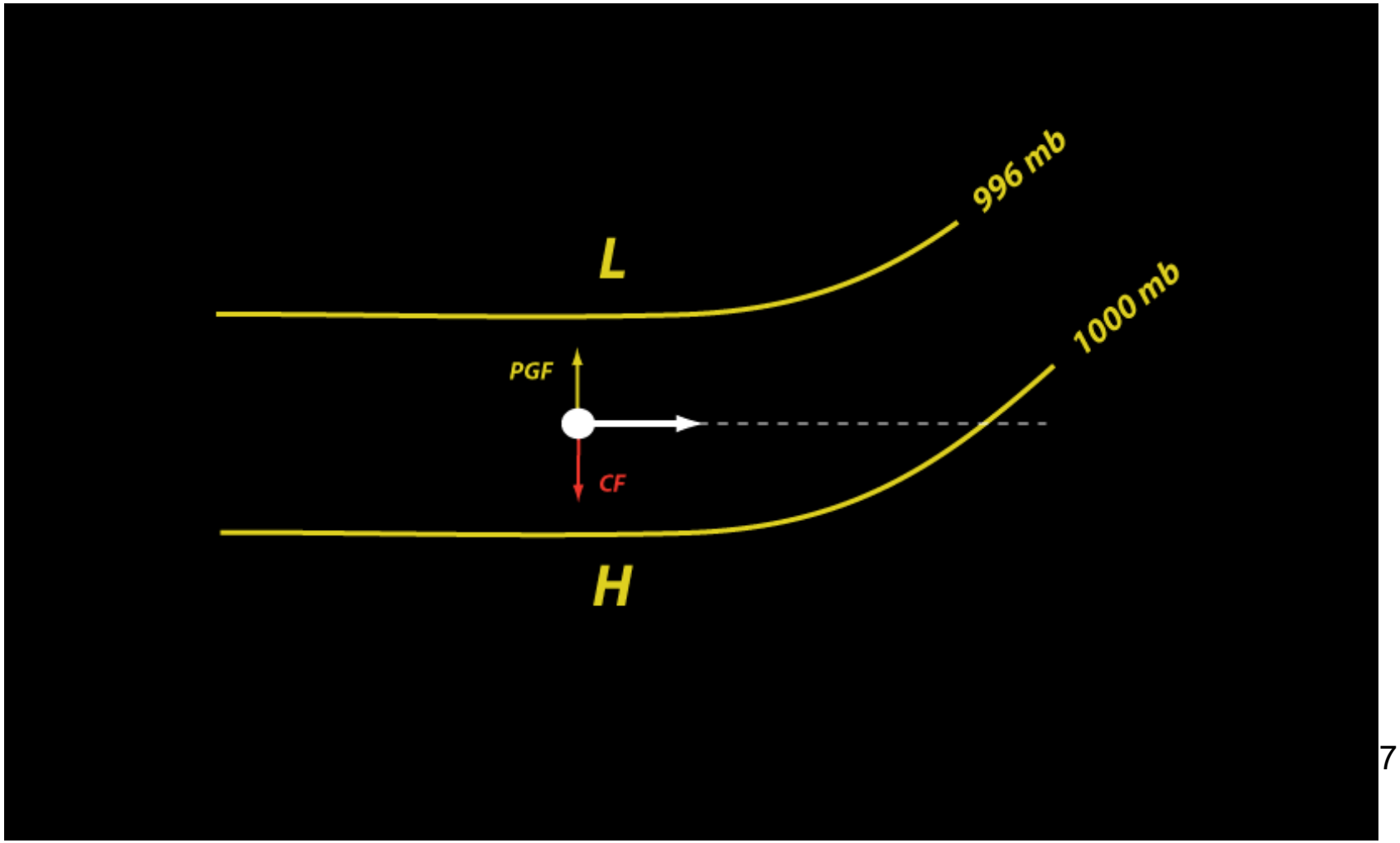
Suppose the air path is towards curving isobars…



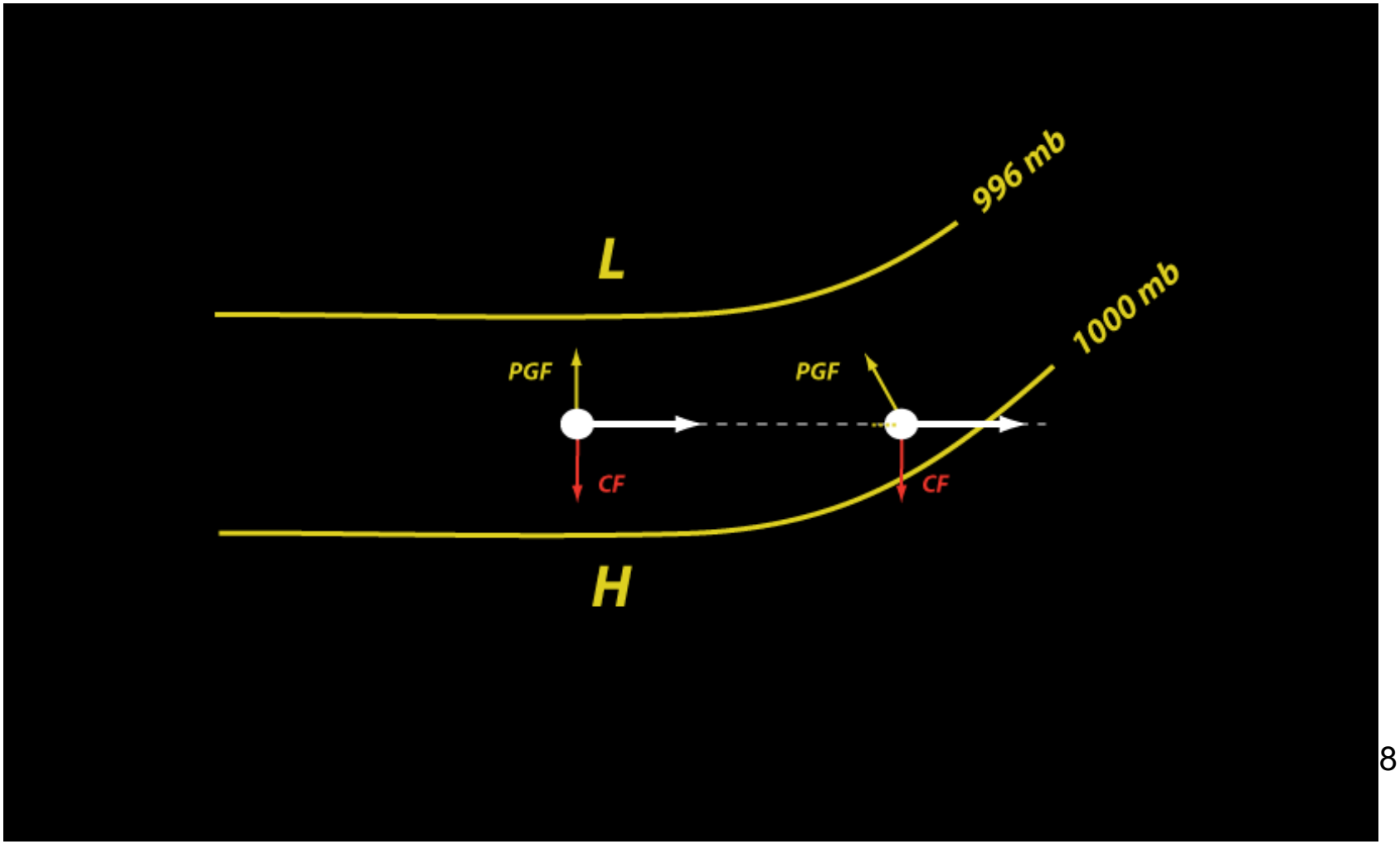
Air **can** cross isobars. But the forces will become unbalanced.



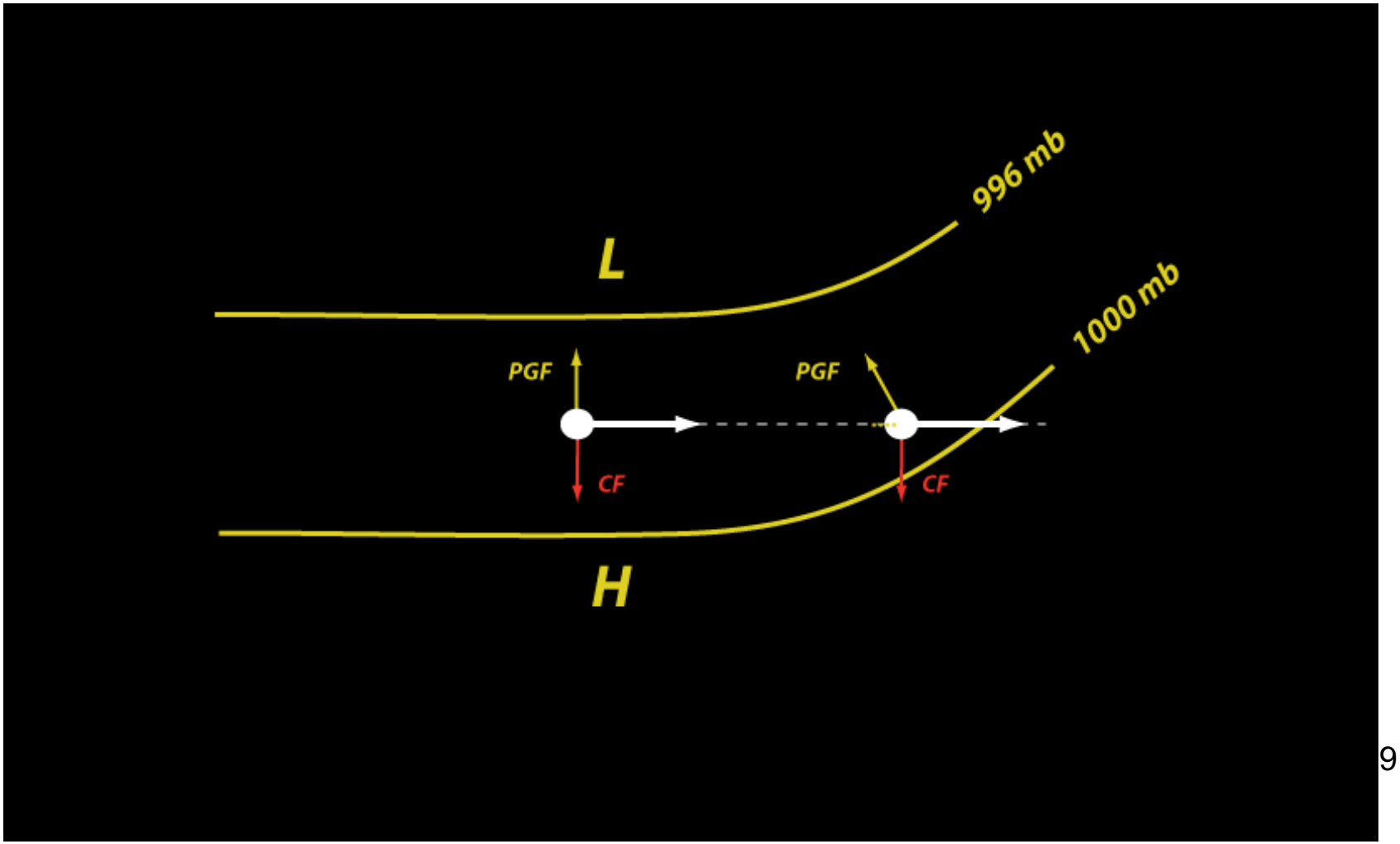
Notice also that this path is carrying the air towards higher pressure!



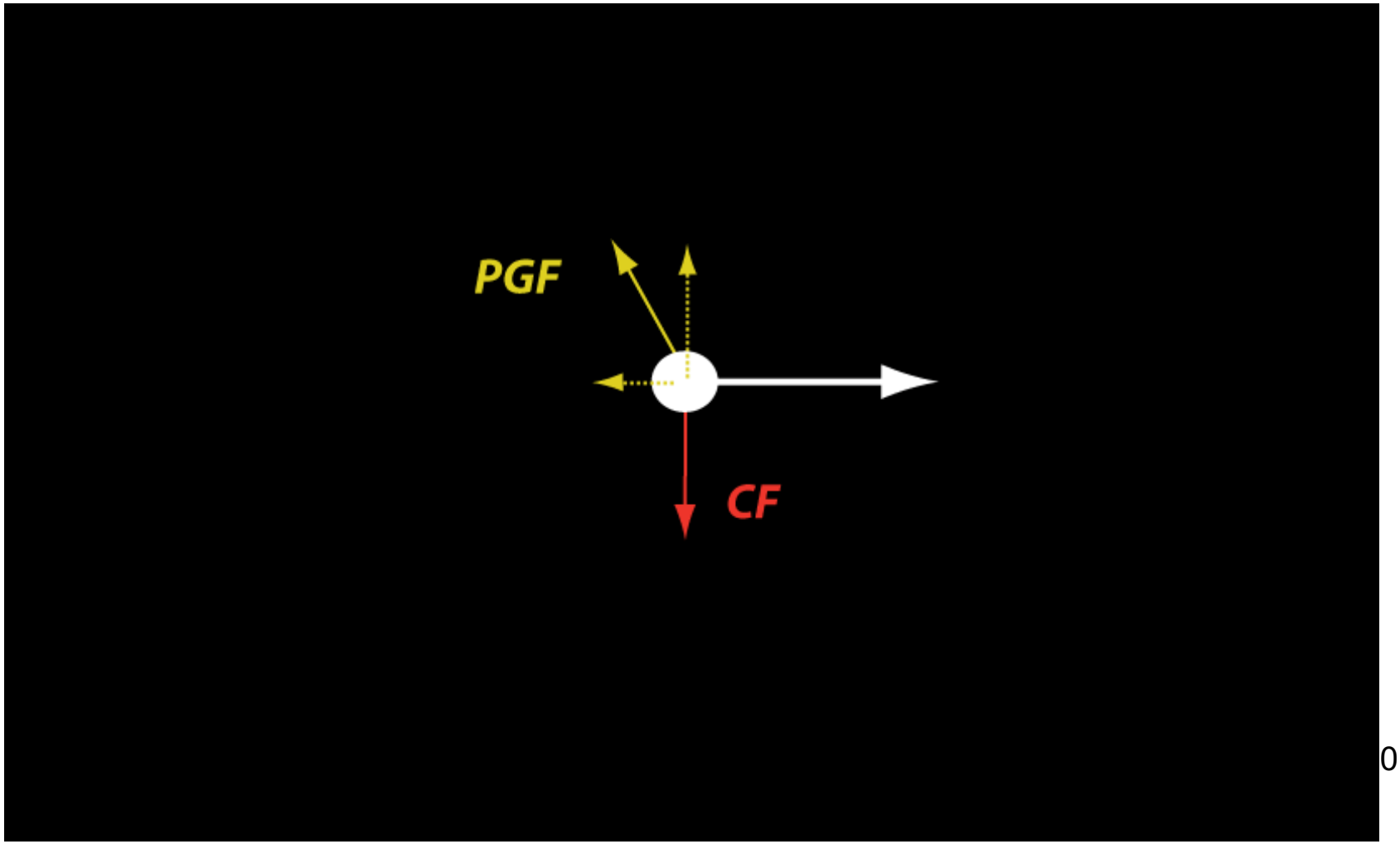
PGF always points H → L
Coriolis always to right…



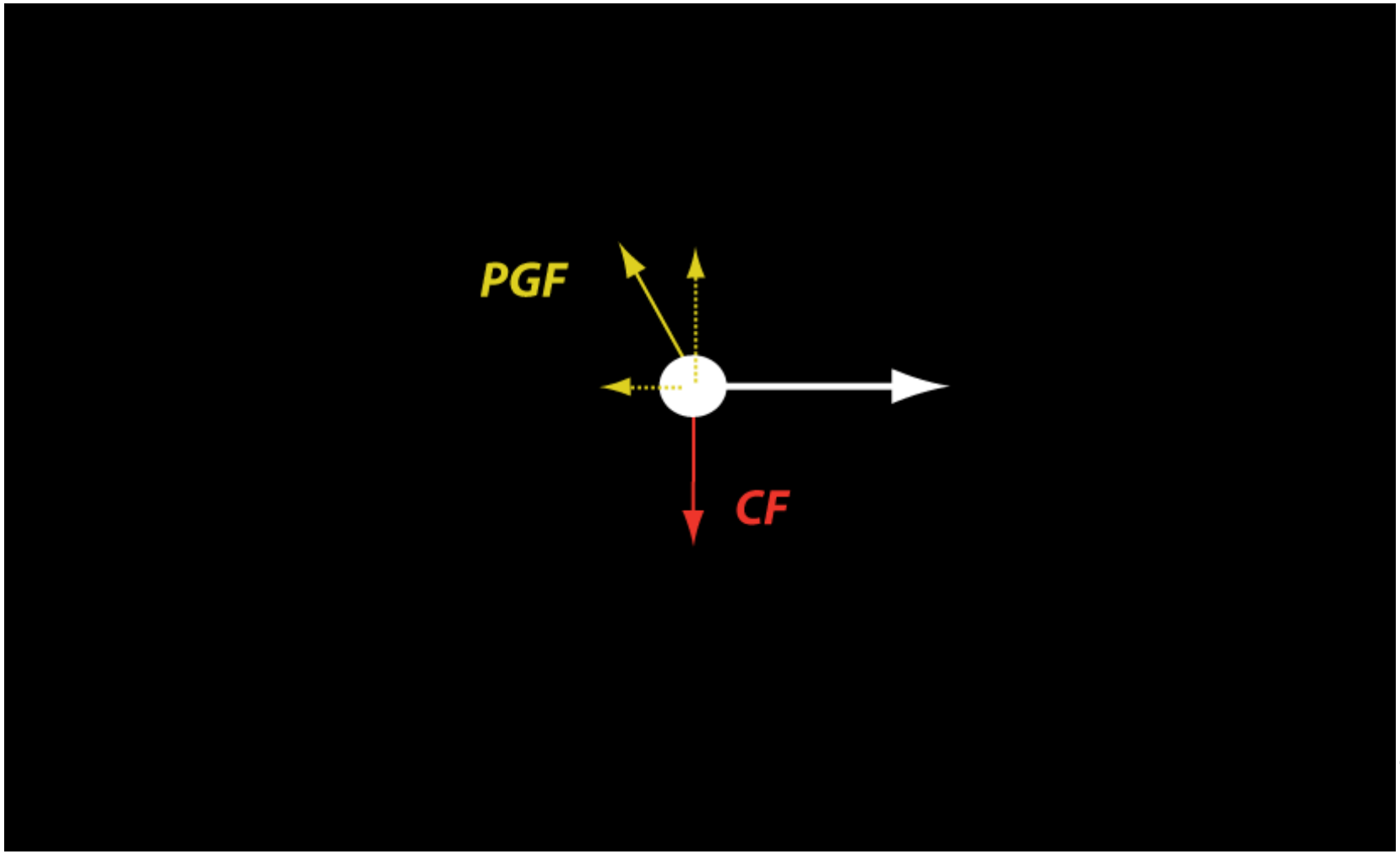
…but note the forces are no longer opposing. They are **unbalanced**.



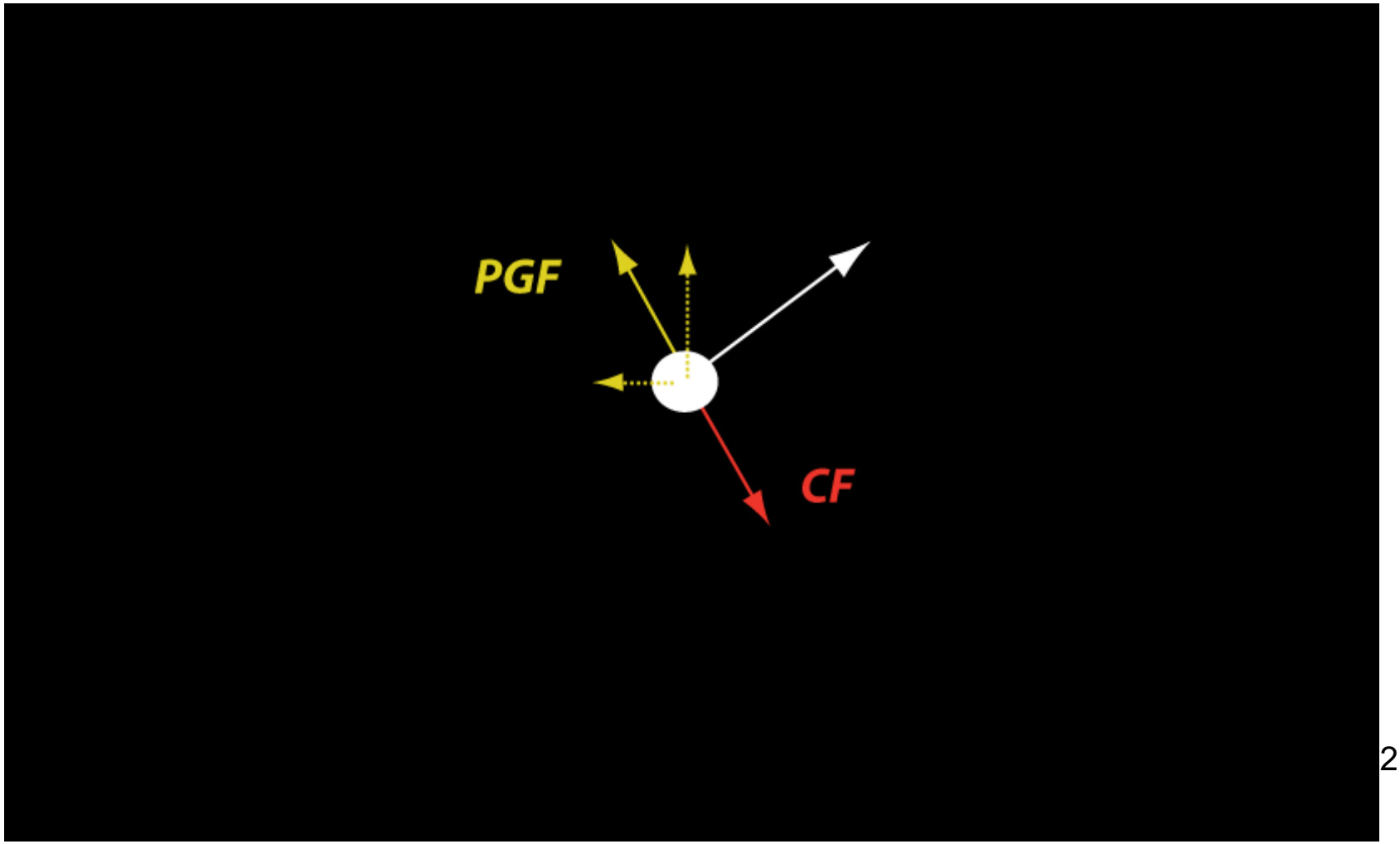
A component of the PGF is now **opposing** the motion. The air **slows down**.



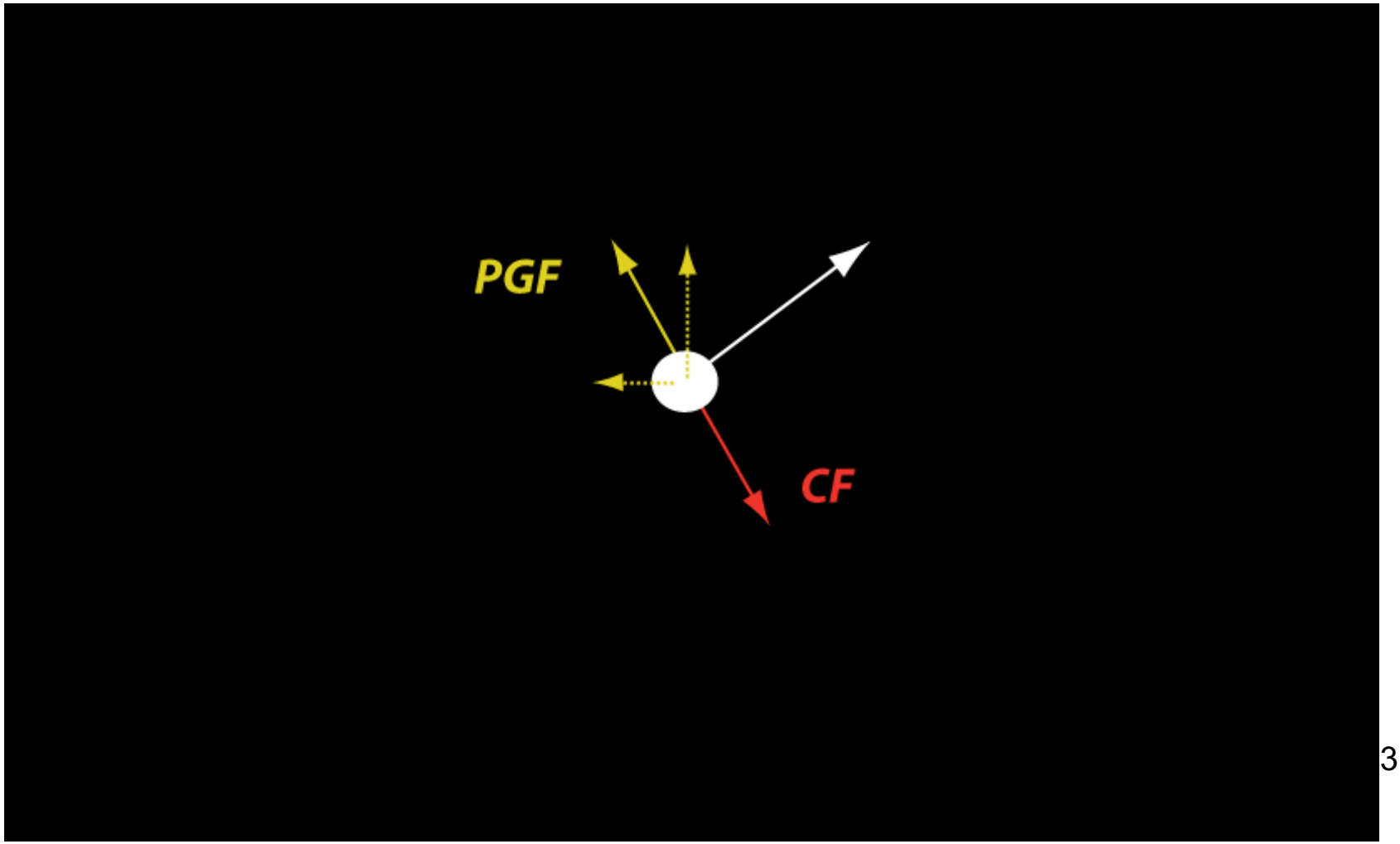
Coriolis is proportional to speed. As the air **slows**, Coriolis gets **weaker**.



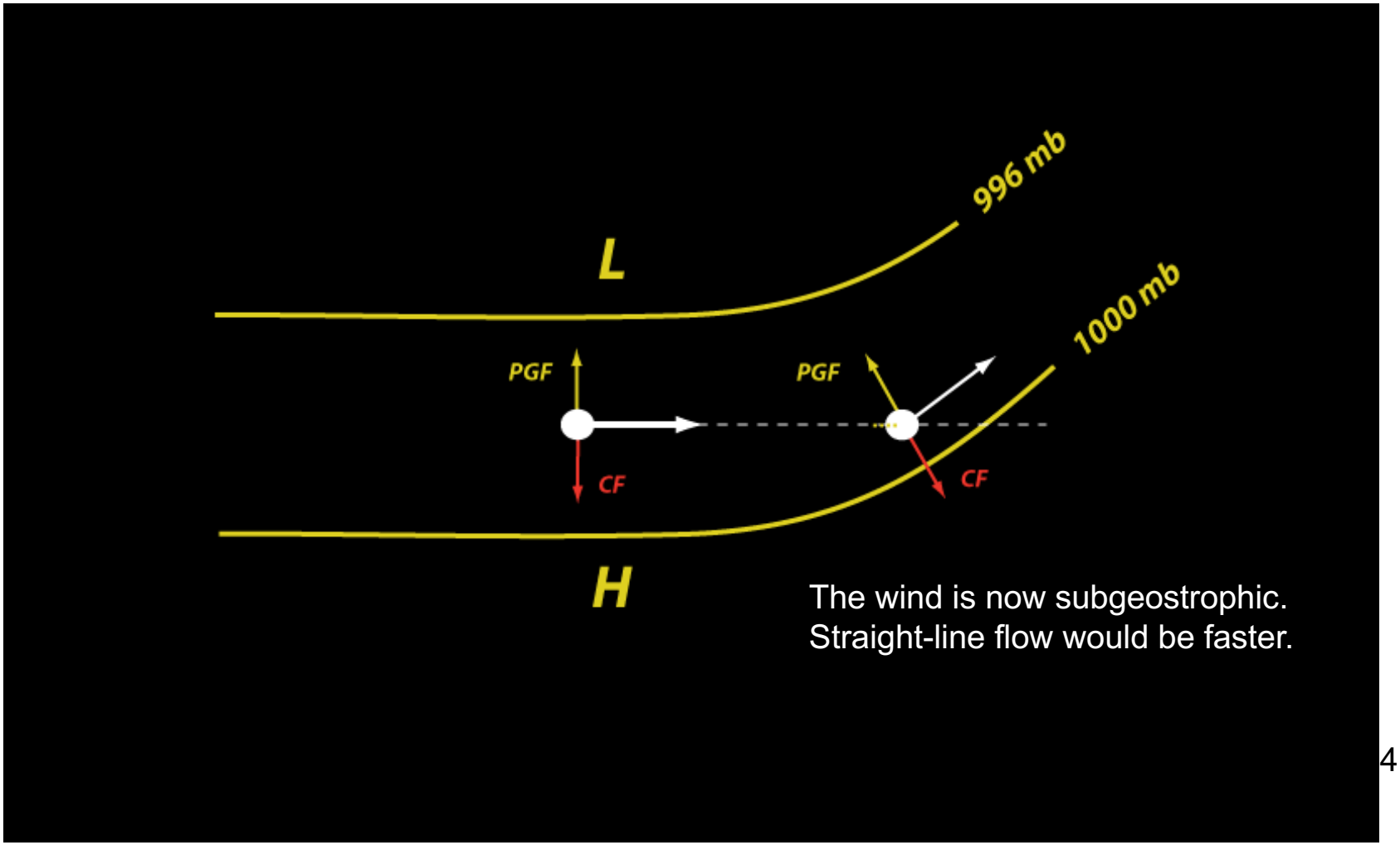
PGF “wins” the tug-of-war, turning the wind.



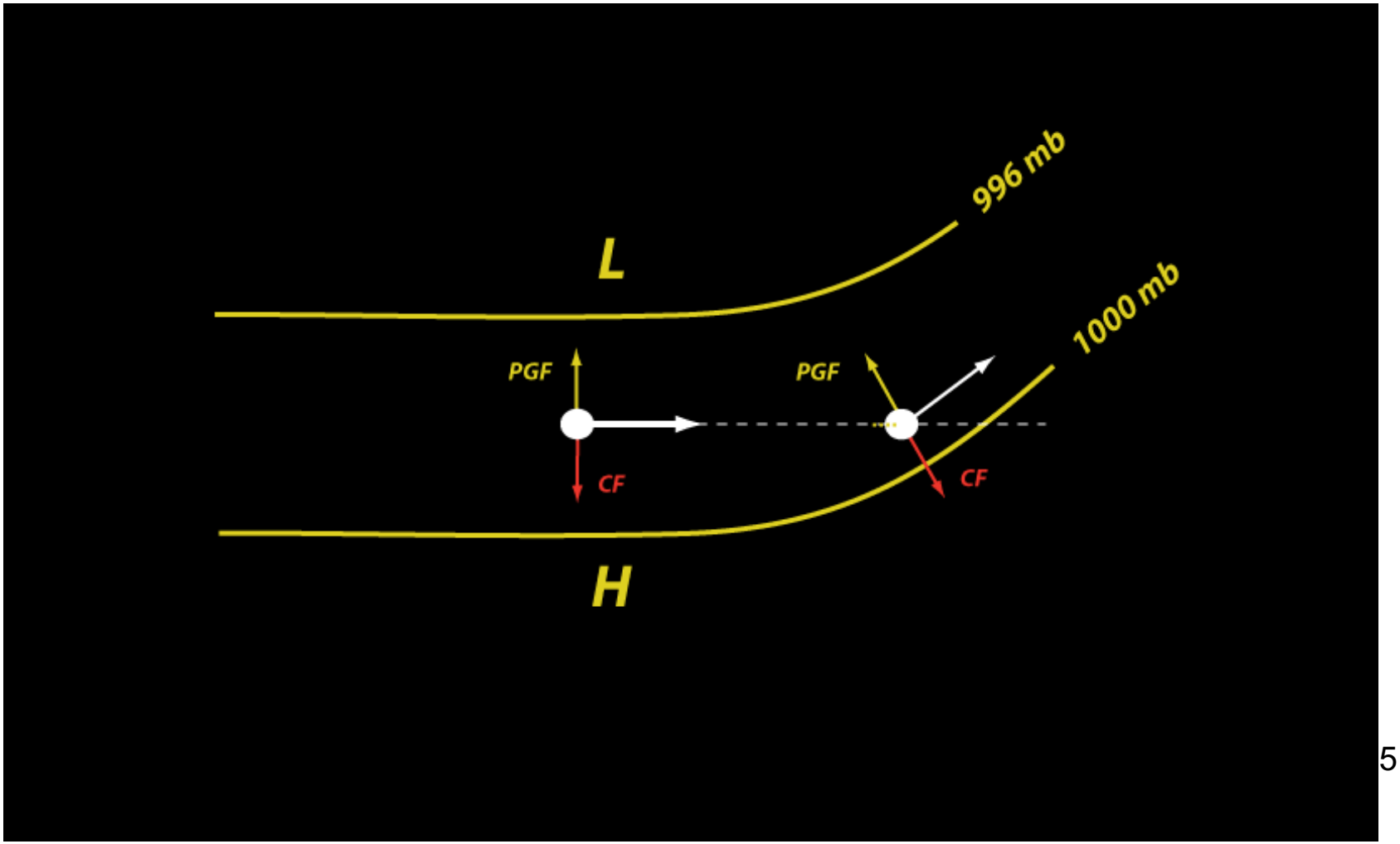
As the wind turns, so does Coriolis, always to the right.



So the air **slows** into the CCW turn as PGF gains the upper hand



Where is the centripetal force? It is the **force imbalance**.



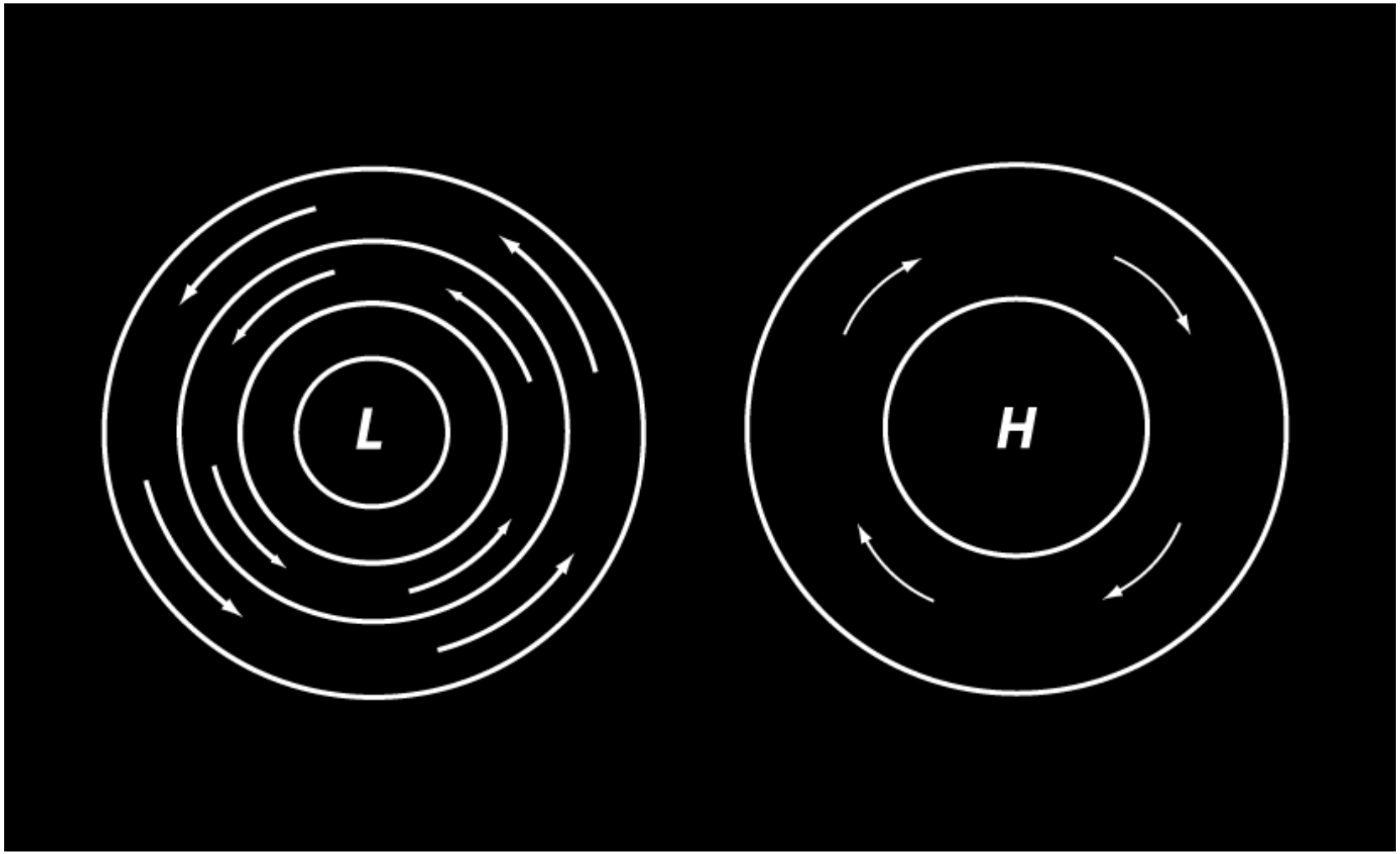
Implications of Newton's 1st and 2nd laws

- Unbalanced forces → acceleration
- Acceleration is a change of speed, direction, or both
- Air circulating CCW around a large-scale L (cyclone) parallel to isobars is **constantly changing direction**
- A portion of the PGF is acting against the motion, slowing the air down
- You don't need a centrifugal force to explain this
- You don't really need a centripetal force either

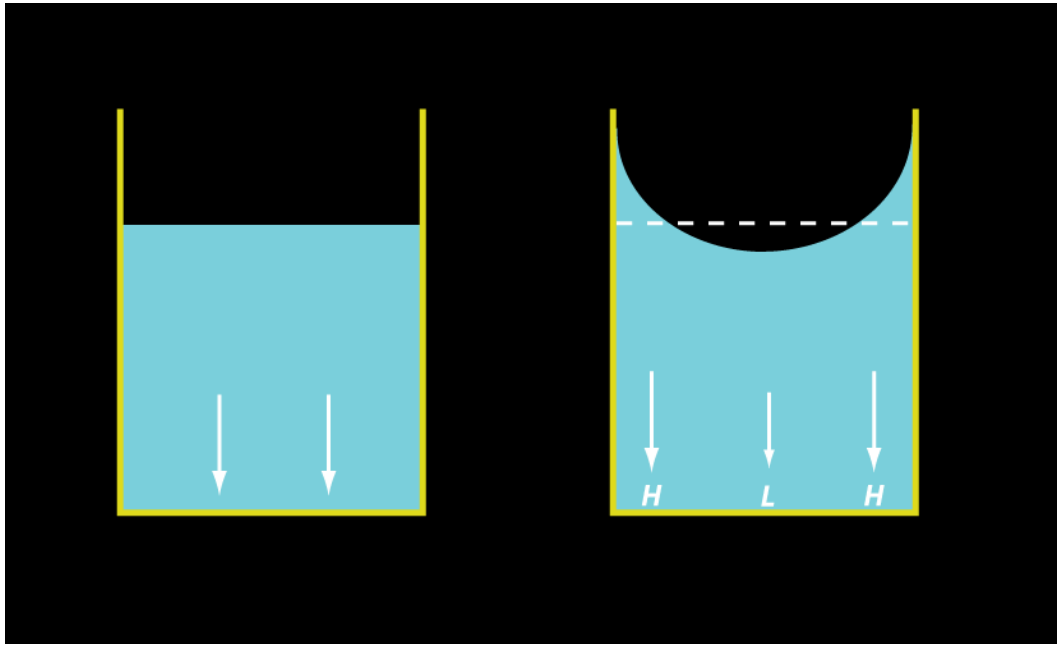
Do the same for CW flow and see the air *speeds up* as it curves CW

So why don't we see stronger winds around anticyclones (H)?

Typical situation. Something is breaking the symmetry.

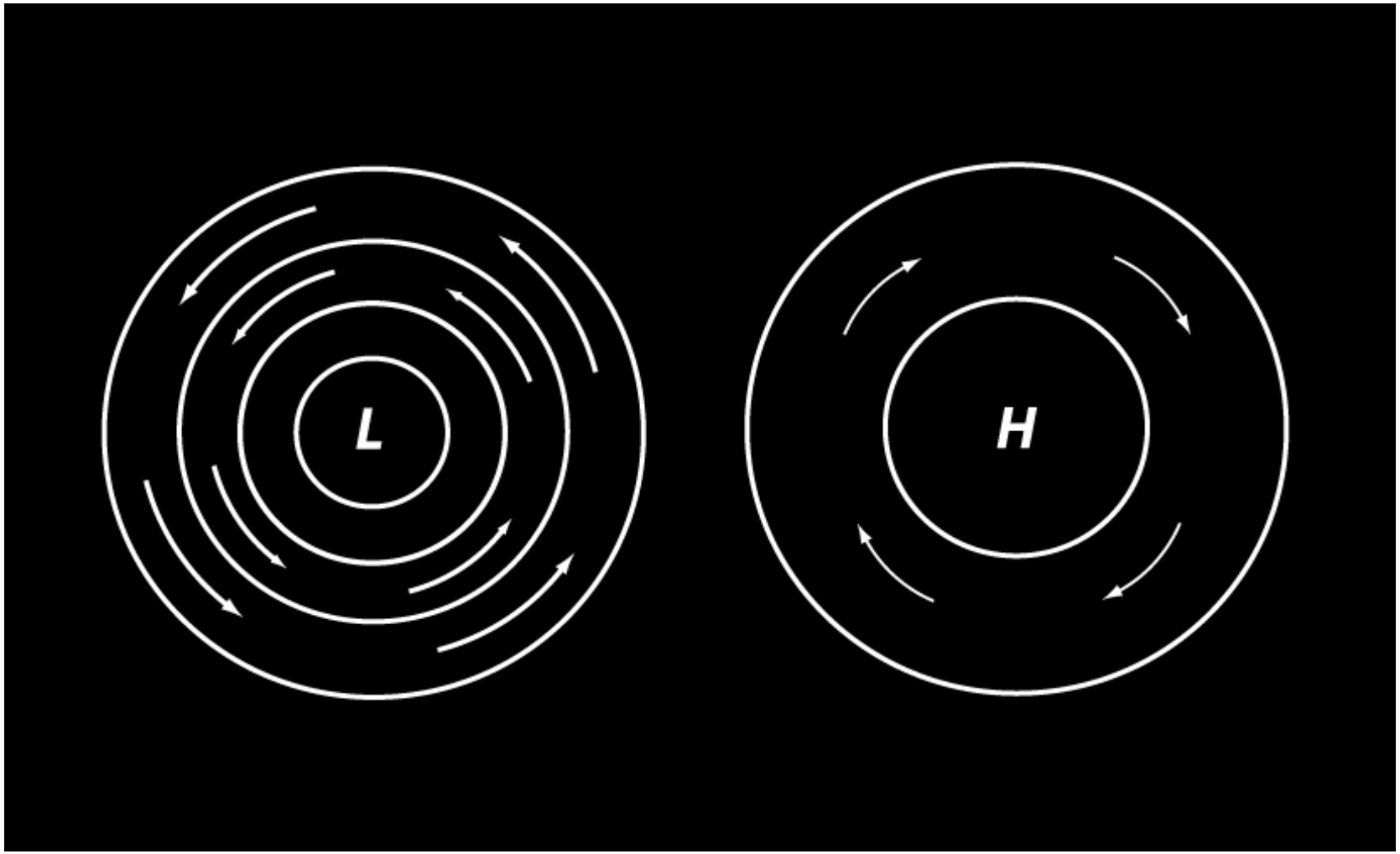


Part of the answer:
spin makes low pressure



And it doesn't matter which way you stir.
Cyclostrophic flow: "to turn in a circle".

Spin supports the low and works against the high.



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