Magnetic Topology of the Sun - Heliosphere Connection

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- Topology is strong differentiator between competing models
  - Interchange model: Expect (discontinuous?) complex of open and closed field
  - Quasi-Steady solar model (PFSS and MHD): Expect smooth topologies
    - Models generally do not calculate dynamics, but continuous opening/closing implicit
    - Supported by solar observations (CH geometry, downflows, streamer openings, etc)
  - In this talk derive strong constraints on possible Q-S topologies – 3 theorems/conjectures

Assumptions for Quasi-Steady Model

1. Neglect small-scale rapidly-varying structure in photospheric field (magnetic carpet)
   - Expect effects to be limited to low heights
   - Key structure is large-scale polarity-inversion lines (PIL)
     - Determines number of topologically-distinct polarity regions

2. No large-scale, long-lived current sheets in closed field corona
   - Can neglect small-scale transient CSs
   - Allow smooth volumetric currents
   - Allow CSs in open field region
   - True for PFSS and expect to be true for MHD models
   - Basically assuming low-beta, quasi-steady equilibrium

Uniqueness Theorem

Every photospheric polarity region can contain at most one coronal hole

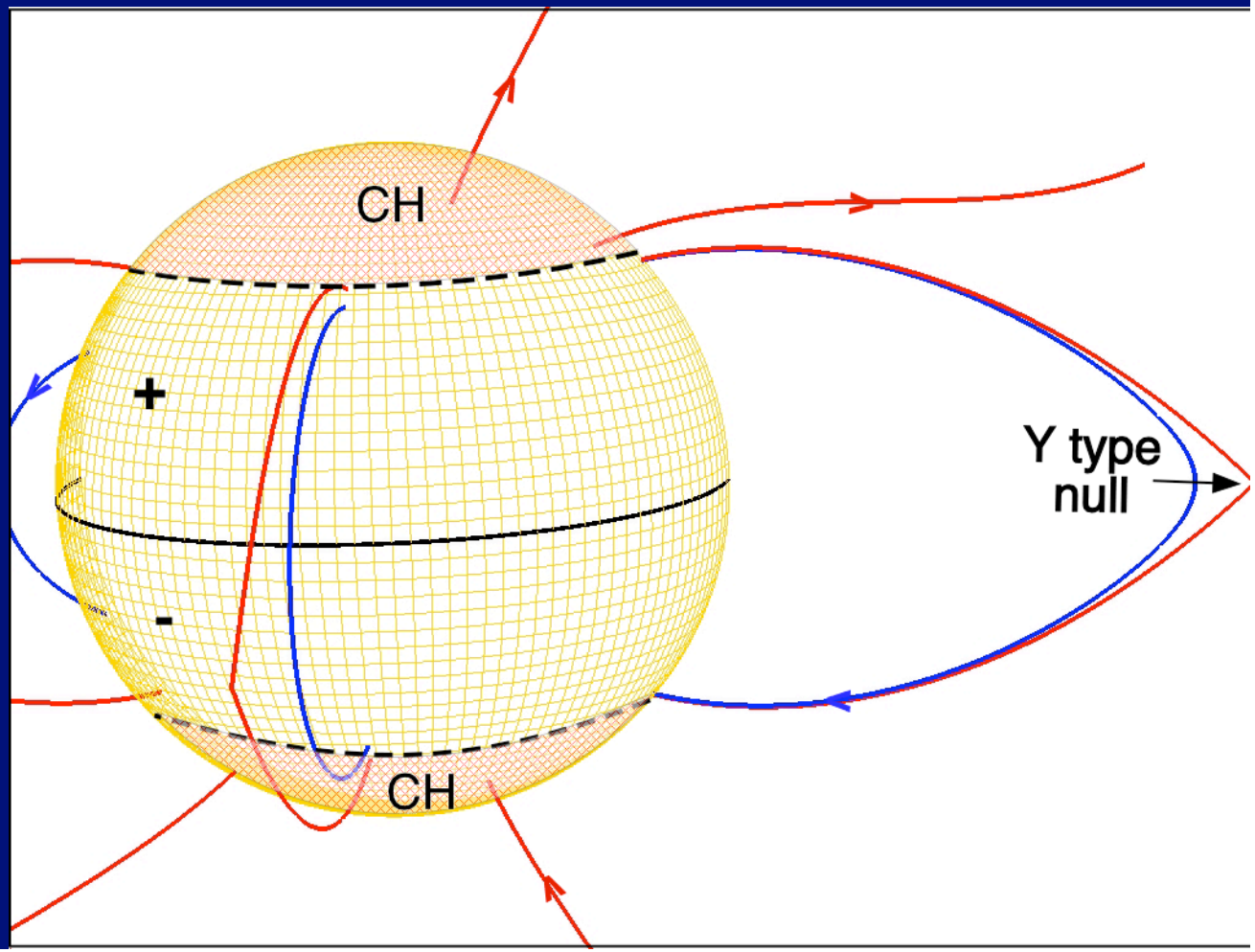
- Calculate PFSS solutions using method of images
  - PFSS adequate for determining topology
- Calculate dynamic solutions using ARMS

- First consider simplest possible coronal magnetic topology
  - Field due to single dipole

- One large-scale PIL on photosphere
  - Two polarity regions
  - Two separatix curves defining coronal hole boundaries
- Field defines smooth mapping, except at separatrix lines/points, even if $J \neq 0$.

Field line equations:
$dx/ds = B_x/B$
$dy/ds = B_y/B$
$dz/ds = B_z/B$

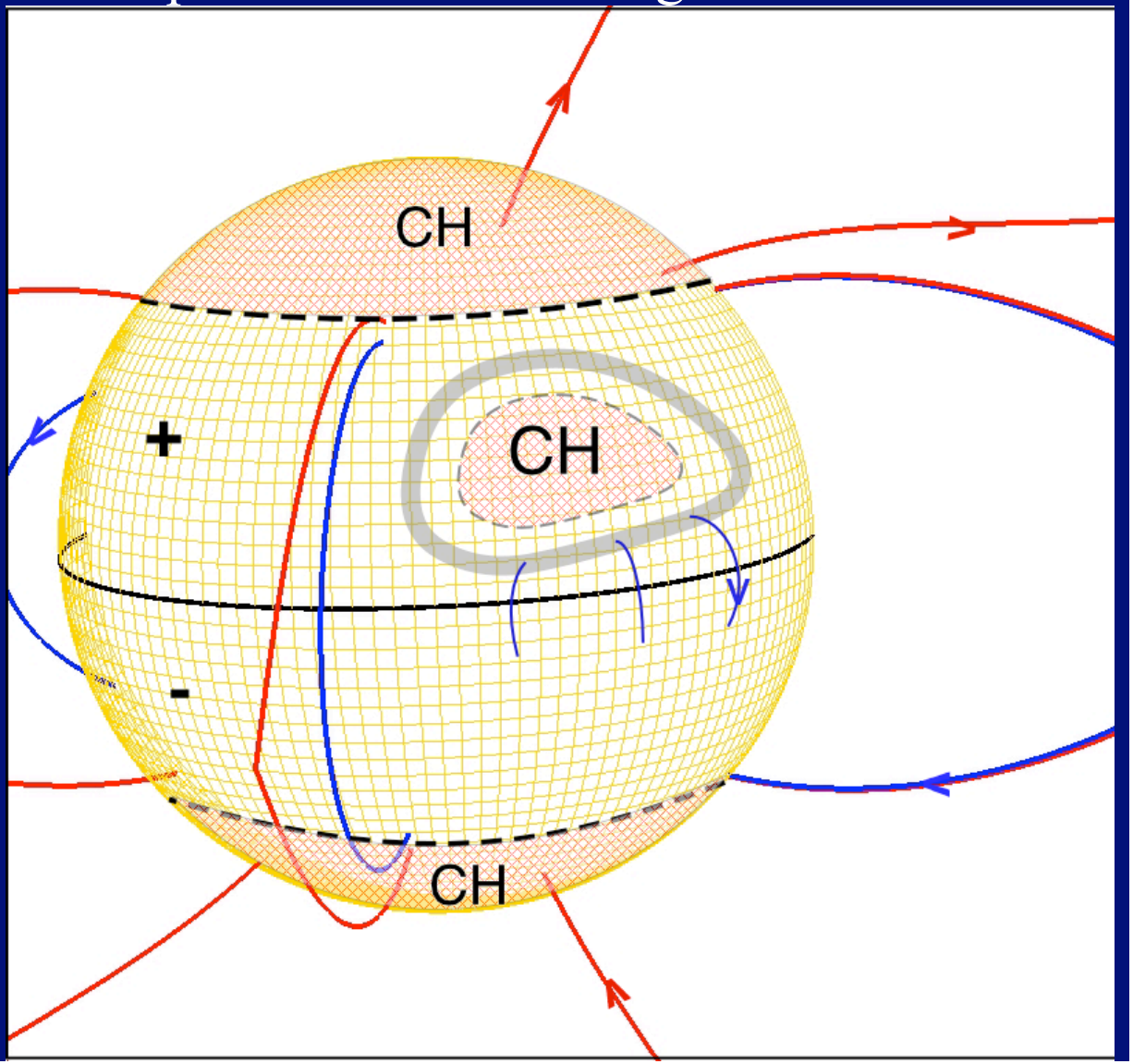
Singularity e.g., splitting, only if, B_x, B_y, or B_z discontinuous or B vanishes



- Is it possible to have another CH in northern hemisphere?
  - NO! Consider closed field annulus around second CH
  - Field lines would have to split in closed field region

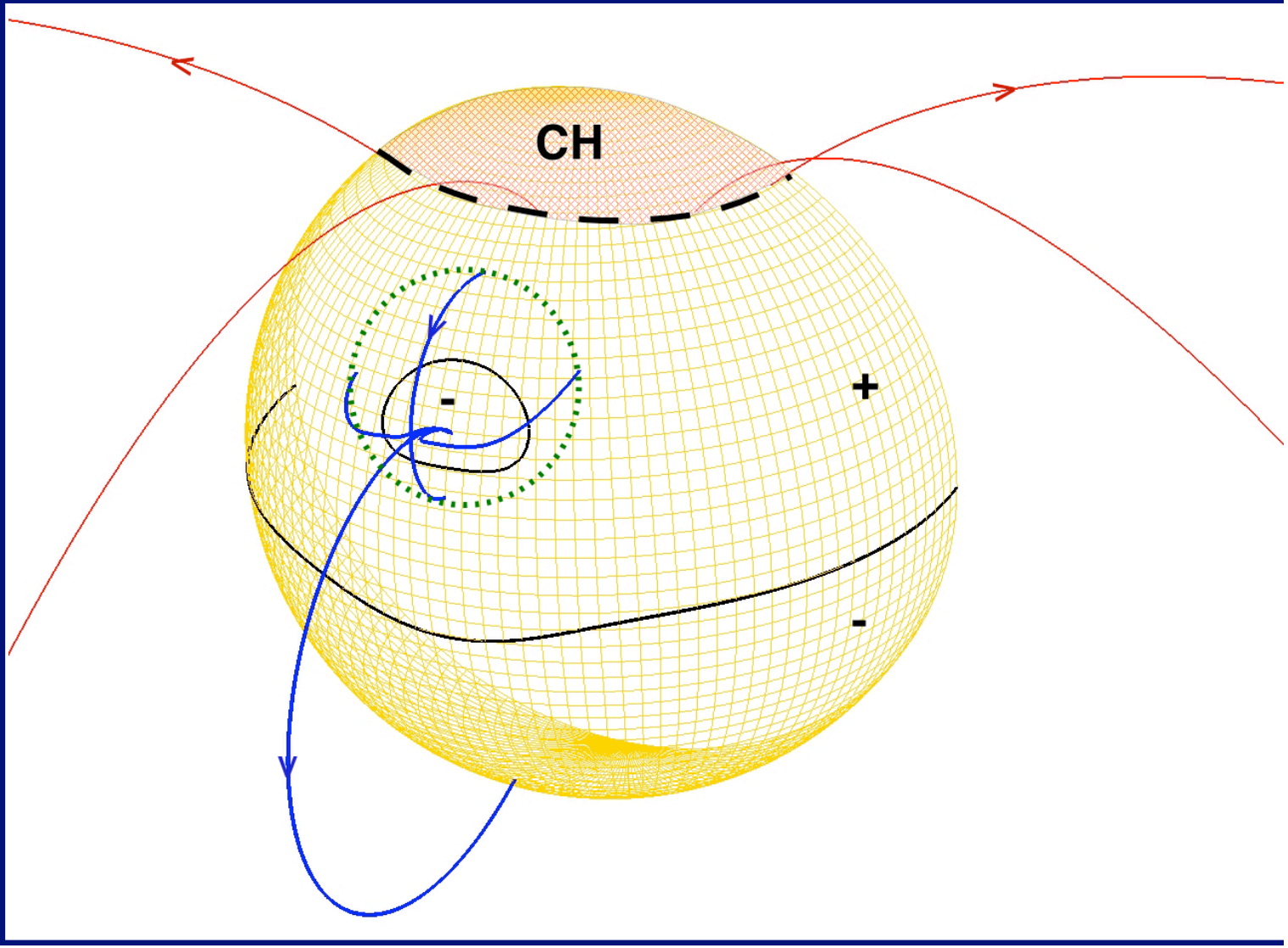
- Must have lots of CSs in interchange models

- Can remove problem by adding thin (irresolvable) open field corridor connecting CHs

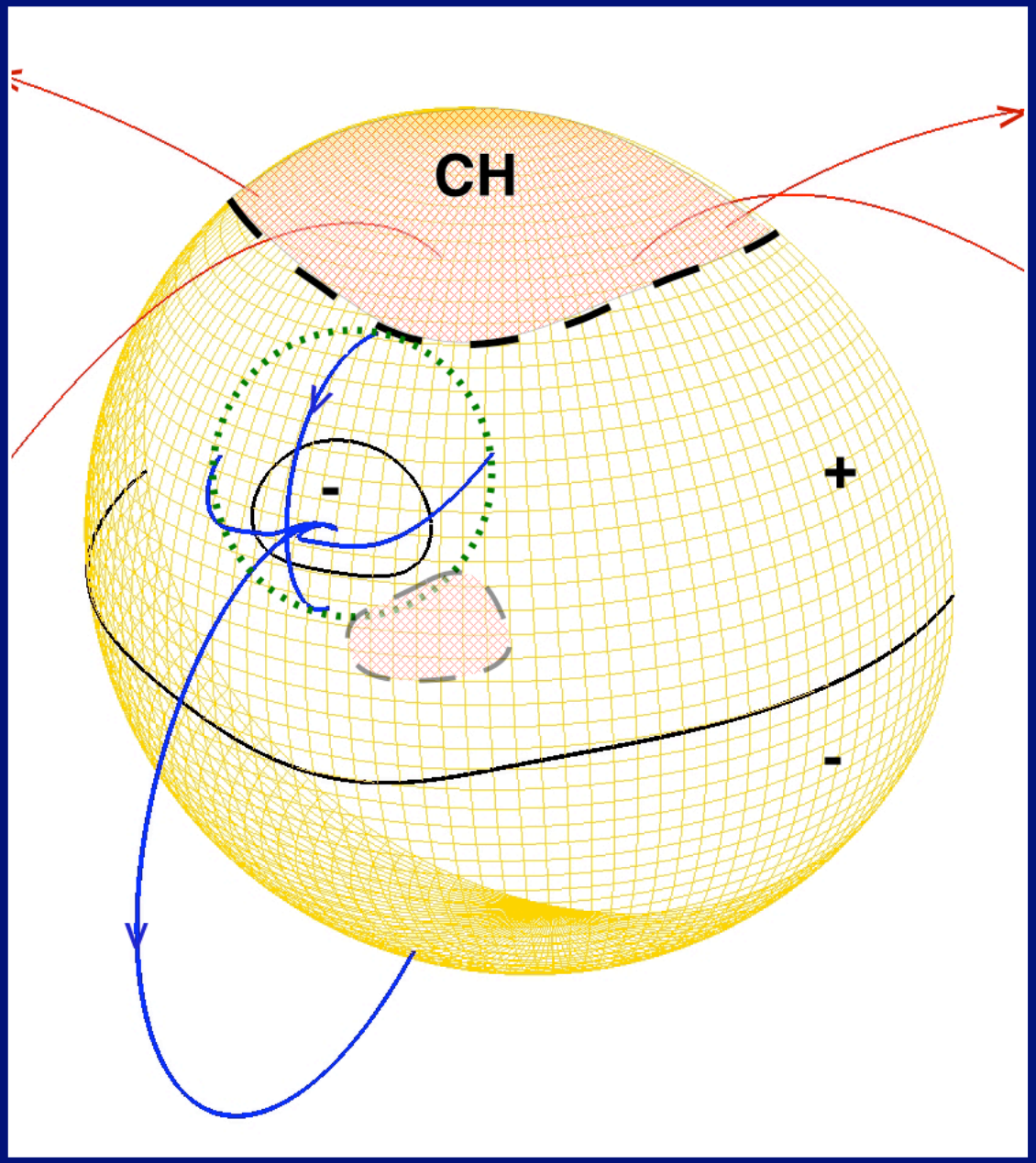


- Now consider more complex magnetic topologies
  - Add AR dipole in closed-field northern hemisphere
  - Second PIL due to embedded polarity region – generic topology

- Null point and new separatrix curve
- Fan-spines topology
- Field lines do split at null
  - effect on theorem?

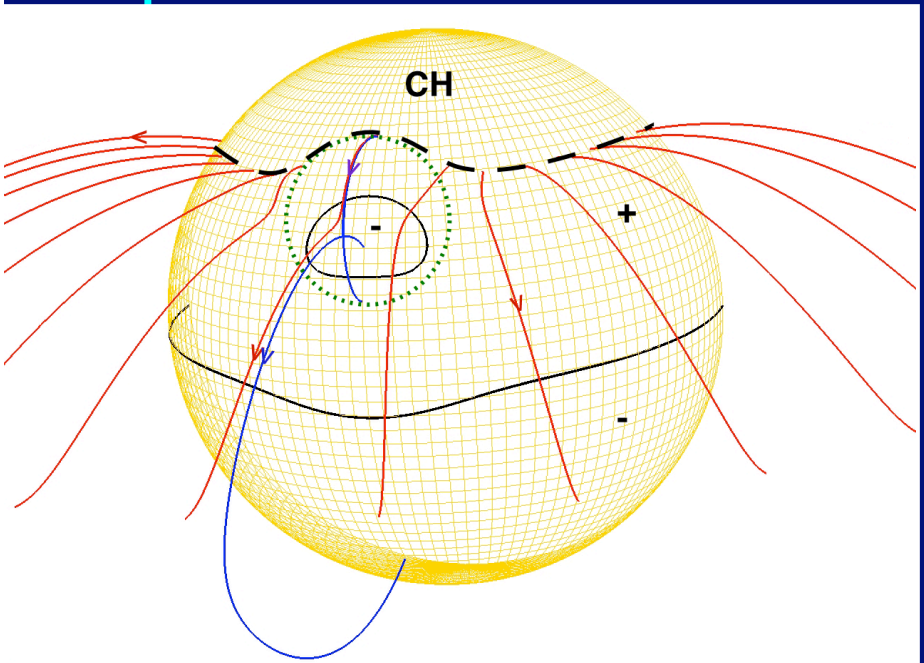


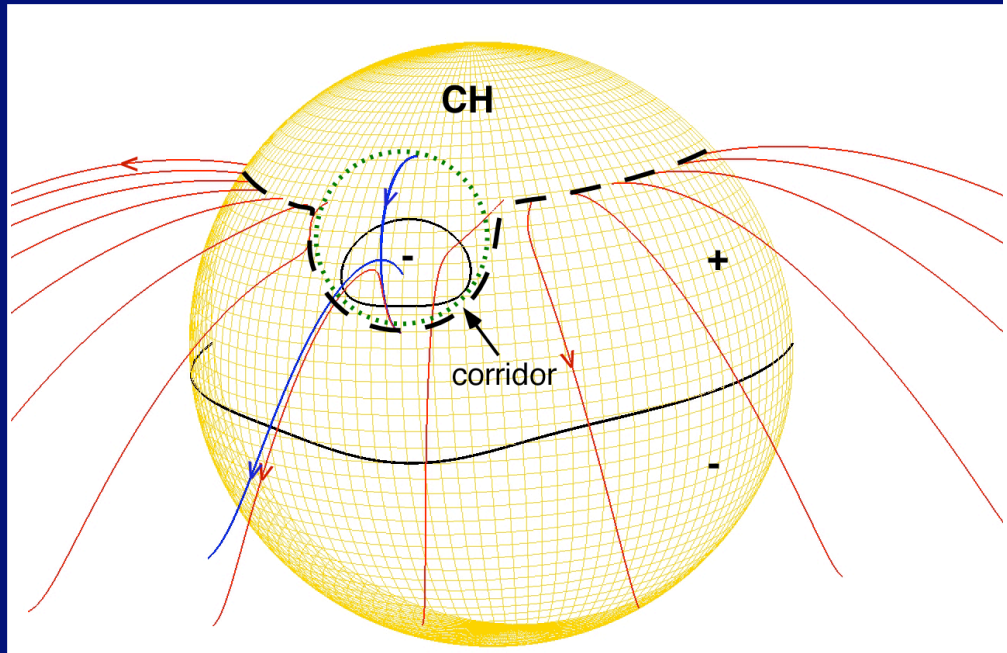
- Counter-example to Uniqueness??
- NO! forbidden by Embeddedness



Embeddedness Theorem

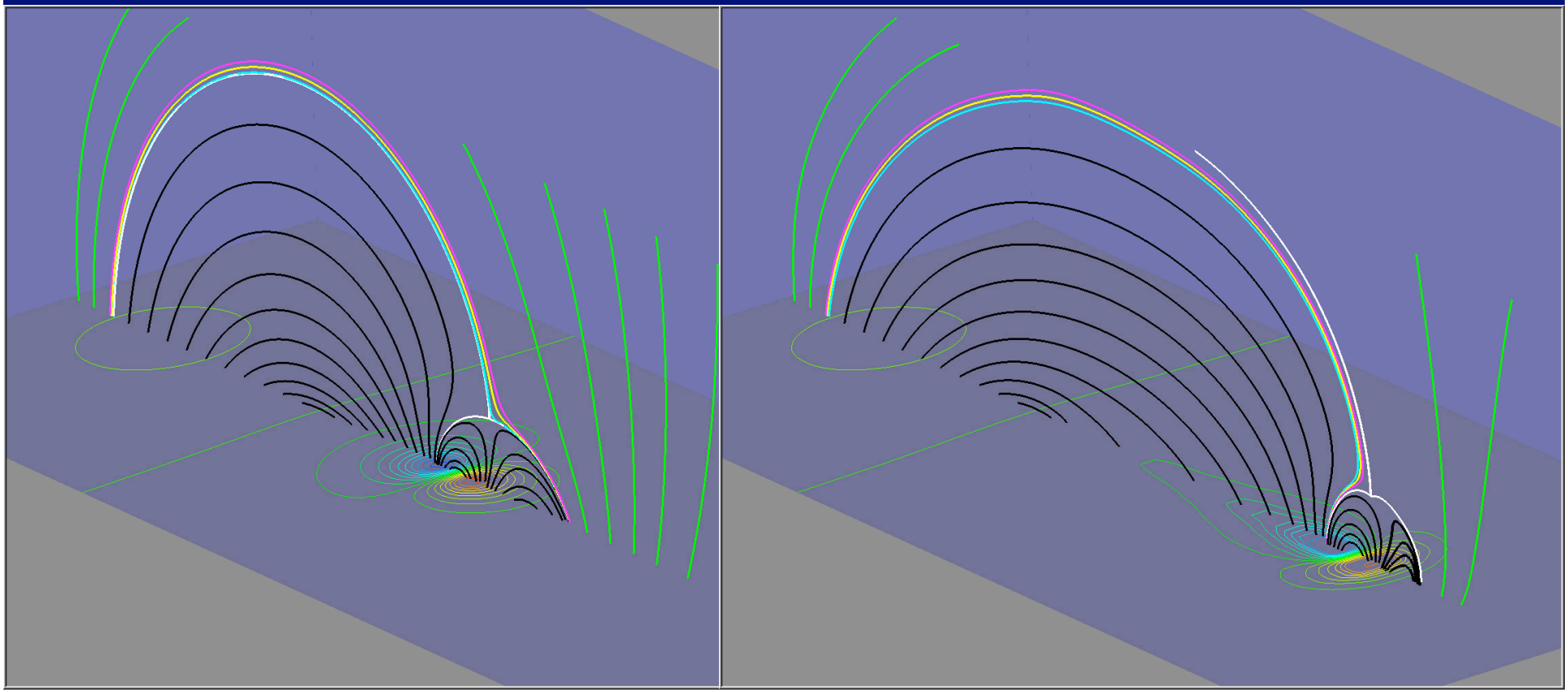
Every embedded polarity region is surrounded by all open or all closed field



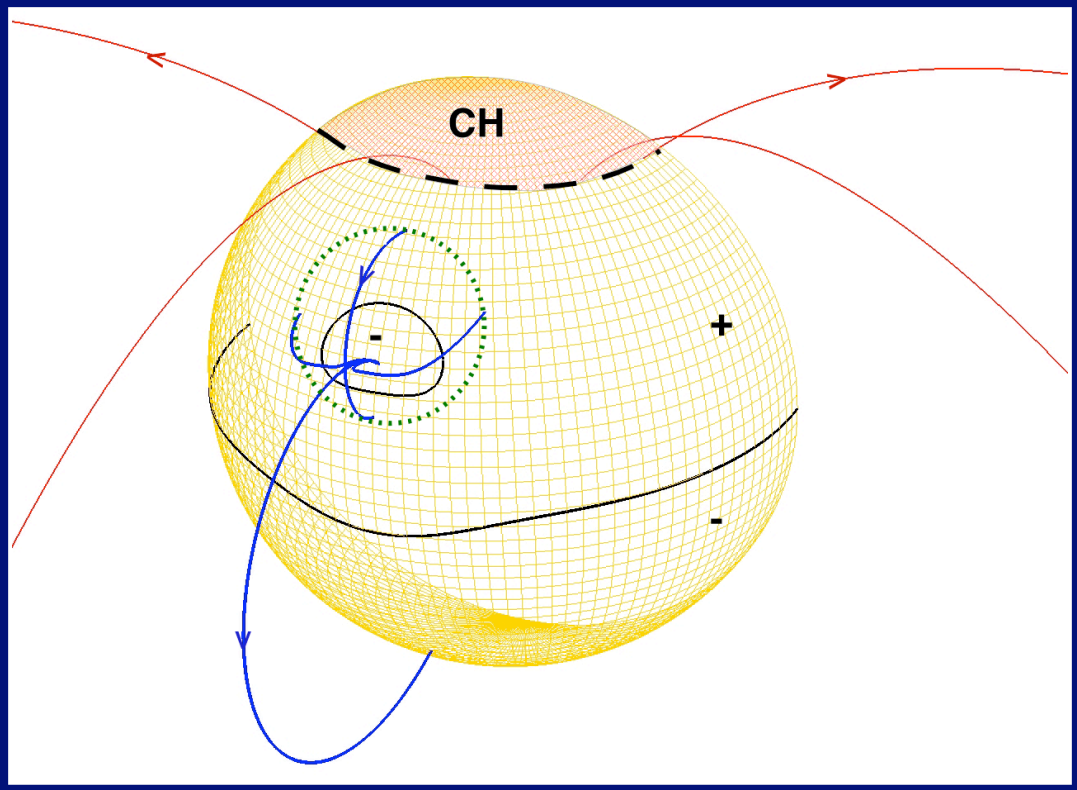


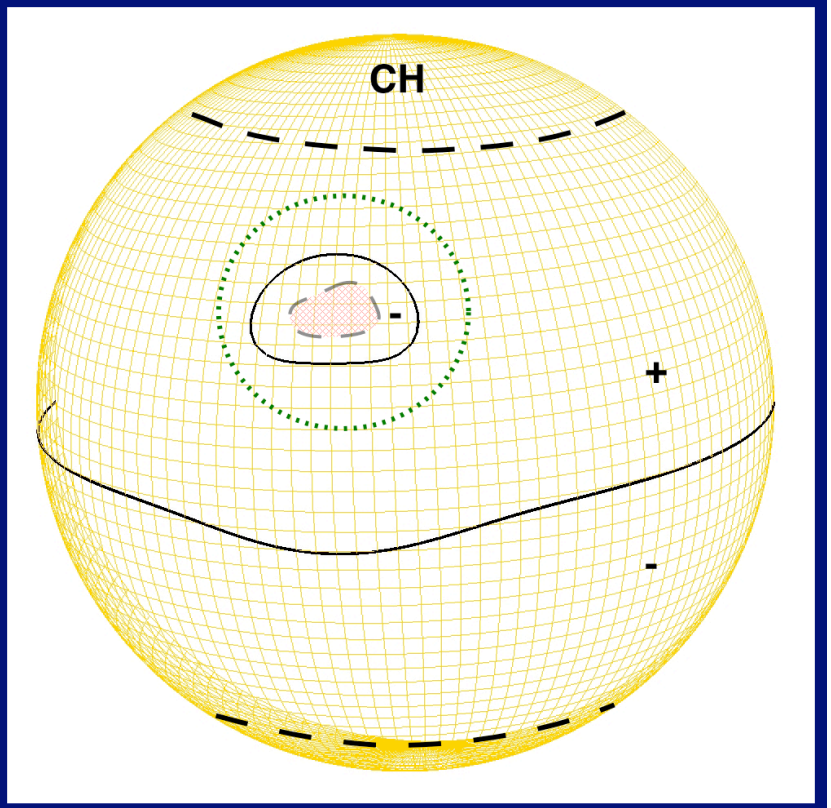
- Dipole moved by only 1 degree
- Outer spine determines whether inside/outside CH
- Note, CH corridor – no imaging signatures, but possibly in situ

- Does embeddedness hold dynamically?
  - Use ARMS to simulate dynamics
  - Apply photo motion that moves AR into CH
  - Interchange reconnection at null current sheet opens spine (*movie)*



Nested Coronal Holes



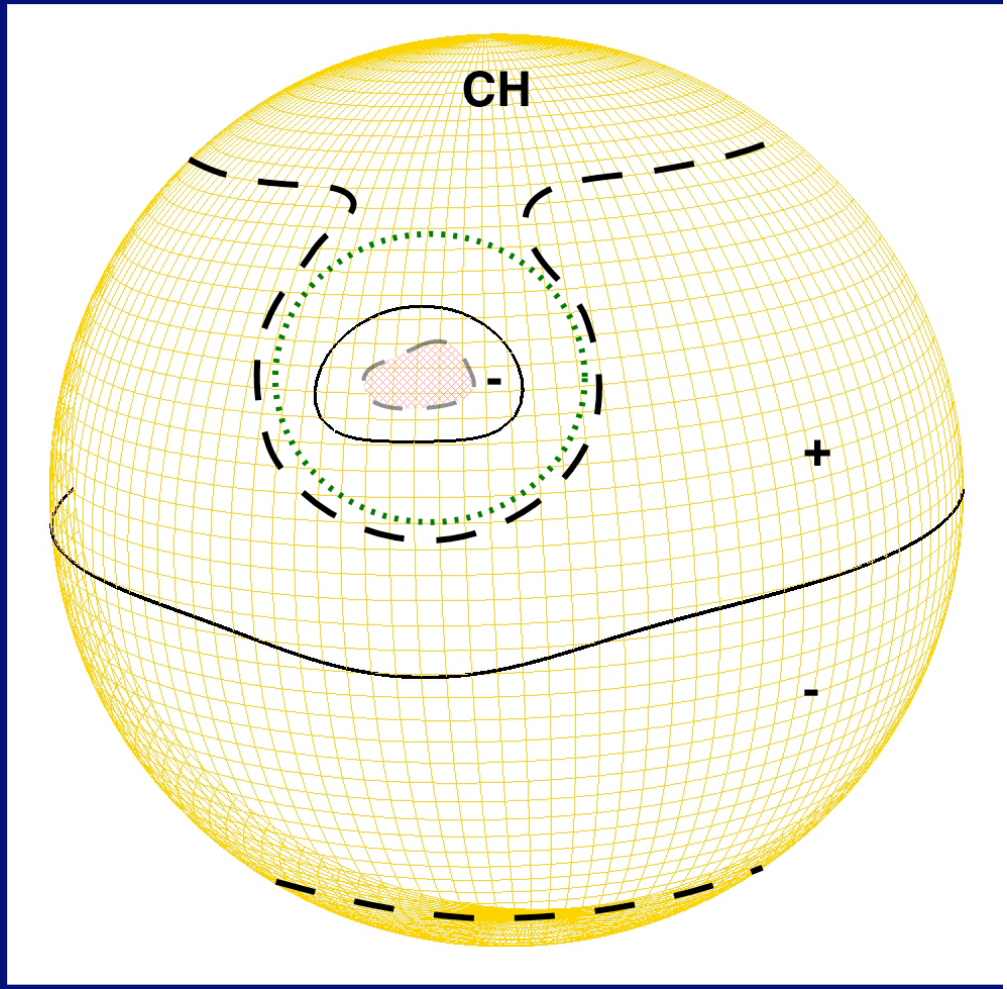


- Can an embedded polarity region contain a CH?
- Annulus argument forbids topology on right

Nestedness Theorem

Coronal holes of nested polarity regions must themselves be nested

- Topology compatible with annulus argument
- Opening field in embedded polarity must open field in external region
- Also opening must extend to spine/fan



Conclusions

- Quasi-steady model implies strong constraints on topology of Sun-Heliosphere connection
  - Uniqueness, 1 CH per PIL
  - Coronal hole corridors may explain open field in seemingly closed regions
  - Embeddedness, embedded polarity bounded by all open or all closed field
  - Nestedness, nested polarities imply nested CHs
- Interchange models violate all three theorems
  - Possible test of models