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FÜR PLASMAPHYSIK

Unusually chaotic W7-X configurations at high iota

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- Configurations selected for study
- Understanding the chaos:
  - **(1) Magnetic field line trajectories (“videos”)**
  - **(2) A Target-Independent Heat Metric**
- Conclusions, Speculations and Future Work

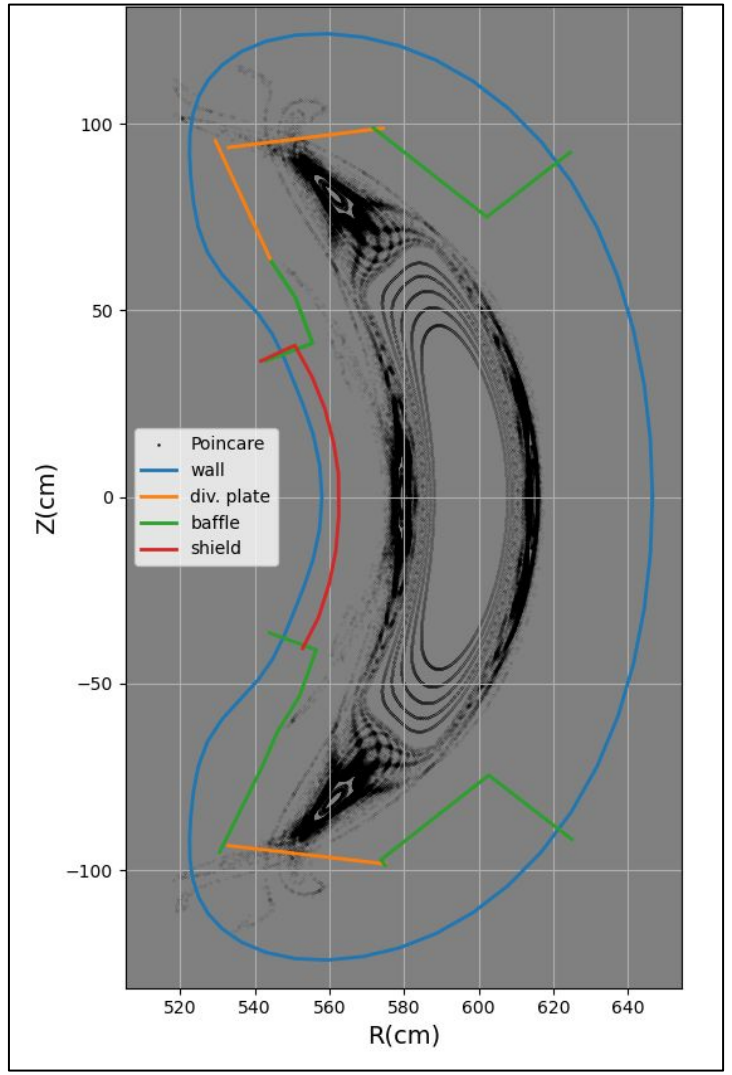
Motivation & Background

- Magnetic field chaos* can occur in W7-X configurations
  - **Vacuum fields at high iota**
  - **Finite beta and/or toroidal current**

- What are the consequences of this chaos?
  - **How does transport (heat, ionised particles) change?**
  - **Consequences for neutral particles/neutral exhaust?**
  - **What about ExB flows, recycling, resilience, ….**

Is chaos good or bad in W7-X?

**chaos indicated by regions where good flux surfaces do not exist*

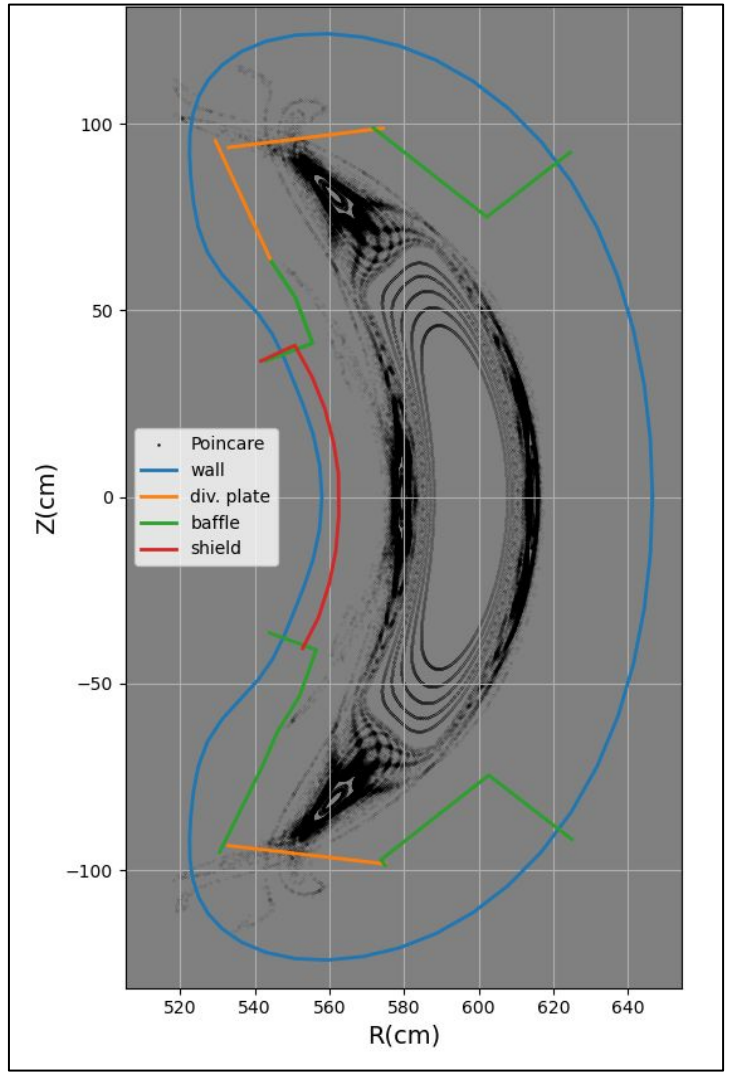


(W7-X new configuration GYM000+1750)

Configurations selected for study

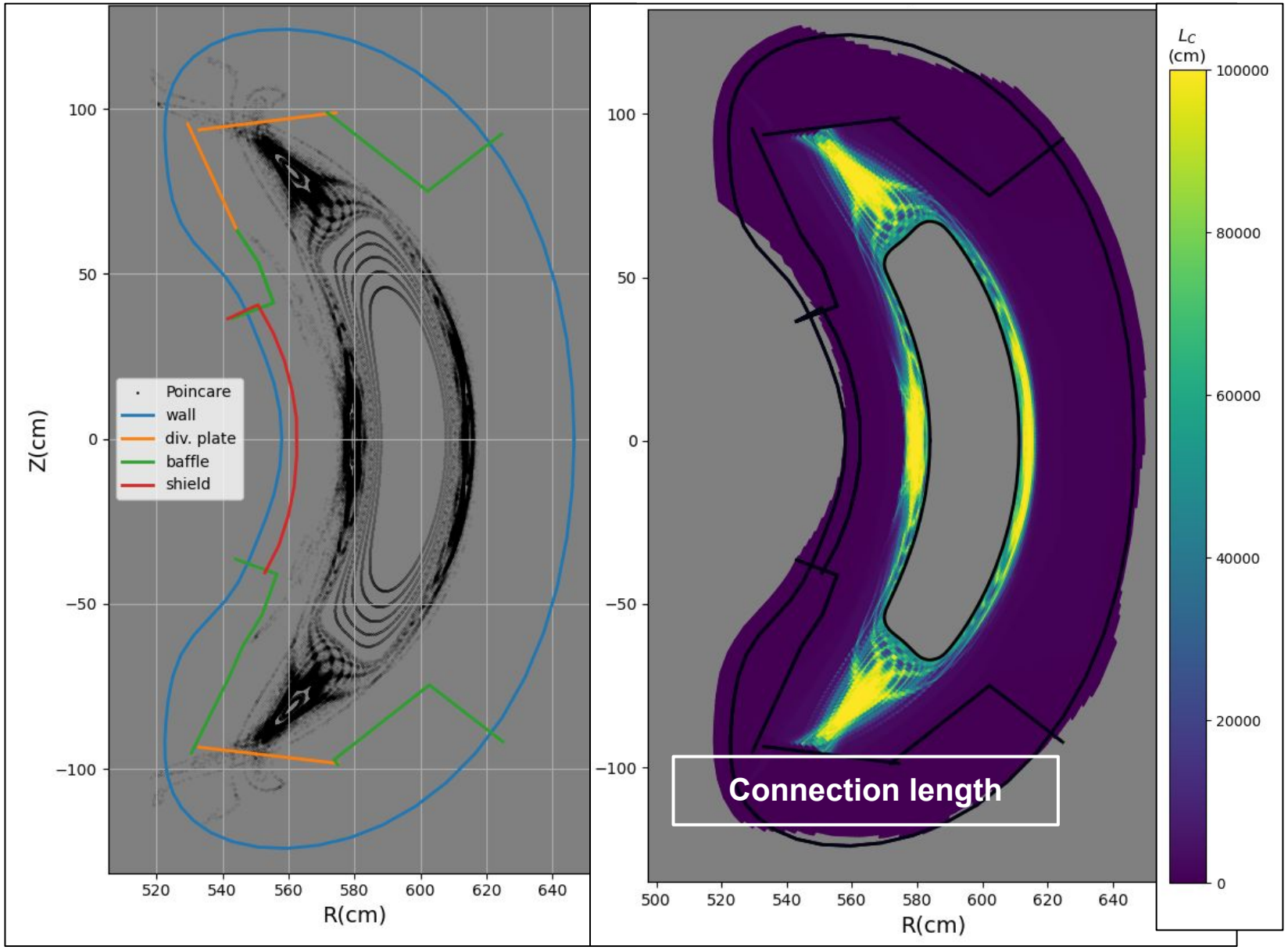
- “Unusually chaotic” vacuum configurations found at very high iota
  - **Increase ratio of planar coil current/ non-planar coil current beyond the normal limit**
  - **Possible when operating at low field strength**

- Planned experiment in next W7-X campaign
  - **Proposal: rsd_001 (“*Exploration of non-resonant/chaotic divertor configurations at W7-X*”)**
  - **Configurations: GYM000+1750 , JYM+1730, TYM+1701**



(W7-X new configuration GYM000+1750)

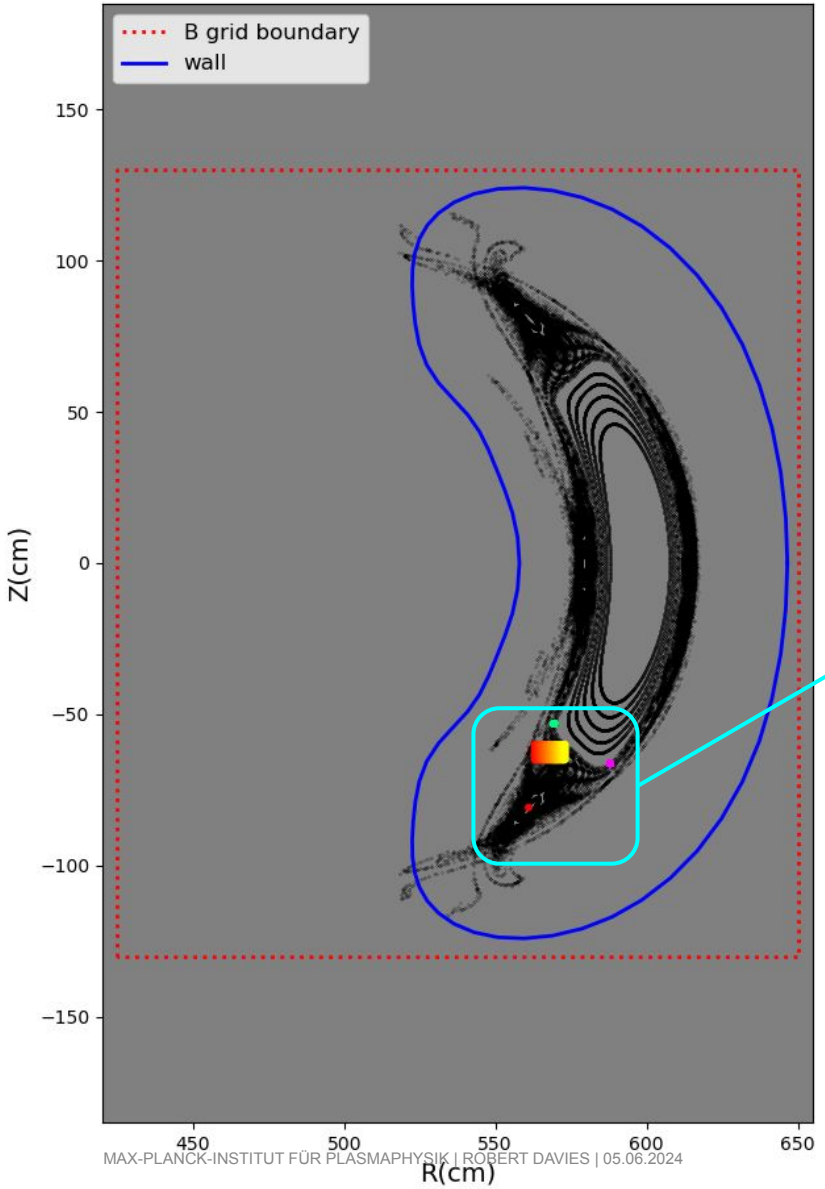
Configurations selected for study - a look at GYM

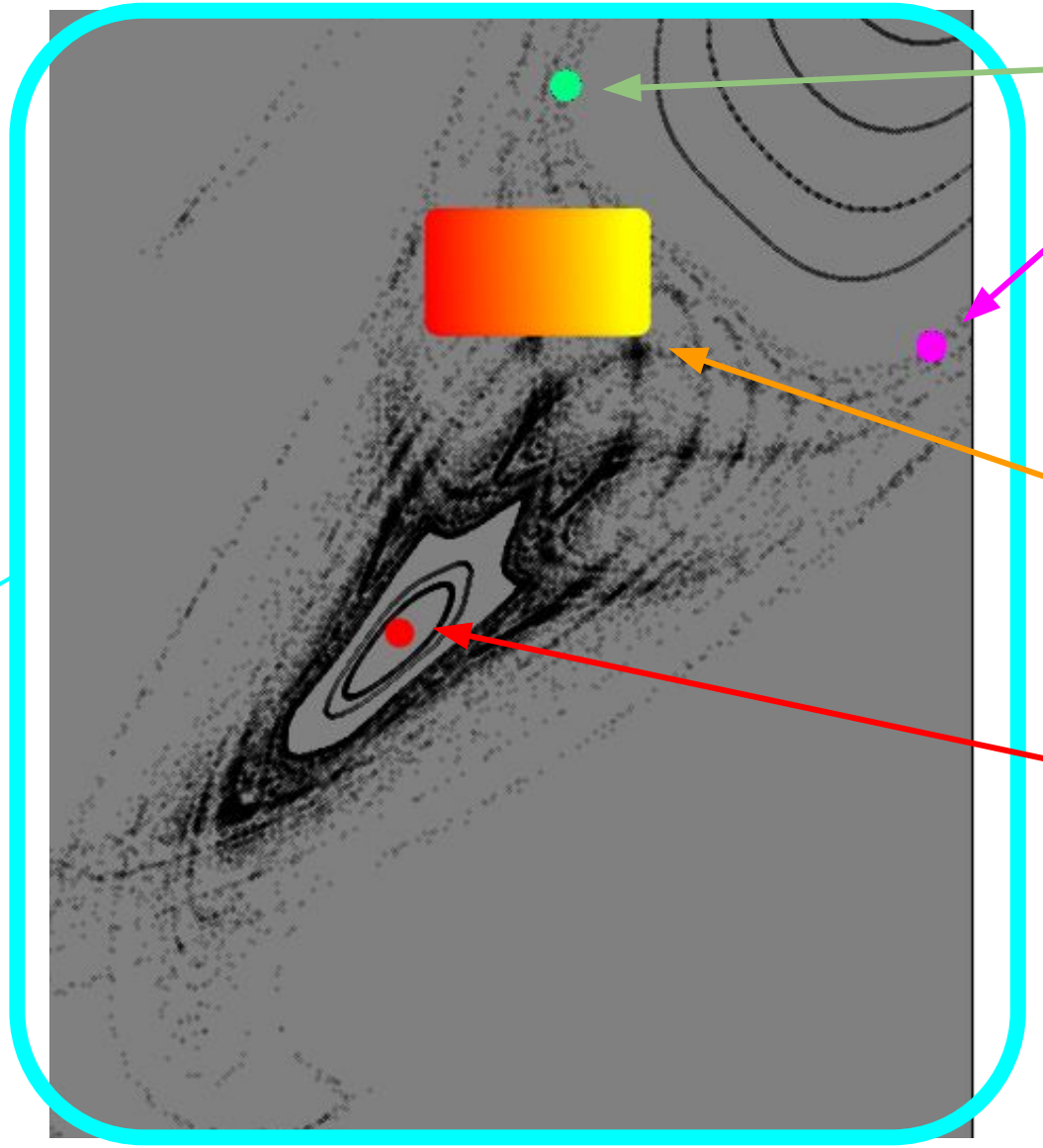


- GYM: what we learn from Poincare + connection length
  - PFCs no longer intersected by good flux surfaces
  - Web-like structures in Poincare and connection length
  - Fine structure in connection length
- **Can we understand these features?**

Understanding the chaos (1): Magnetic field line trajectories

- Method: follow trajectories of selected magnetic field lines





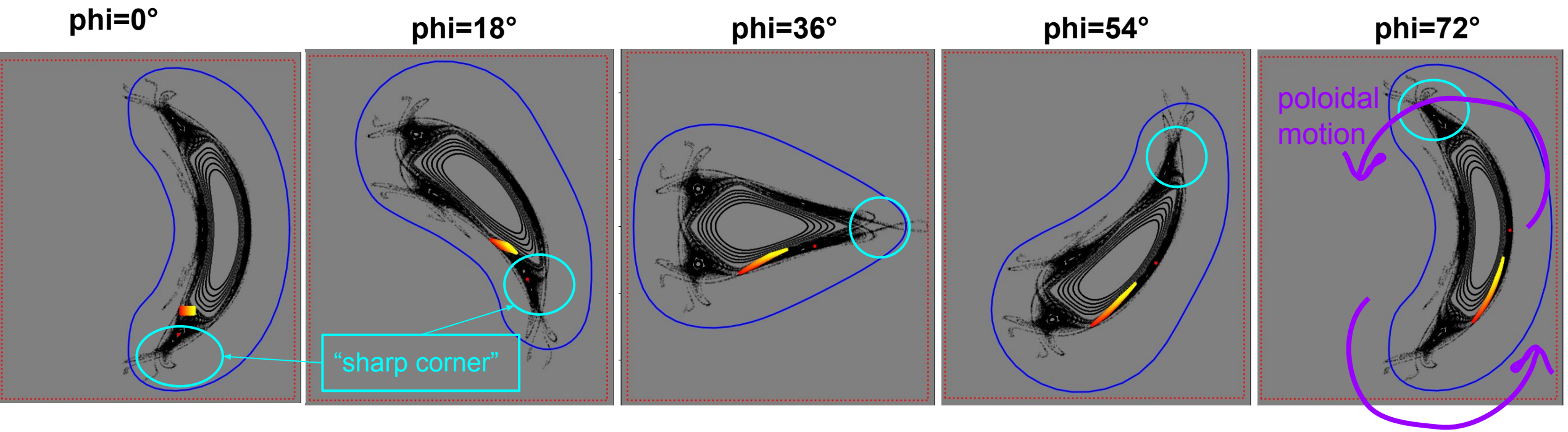
X-points

Blob of points

O-point

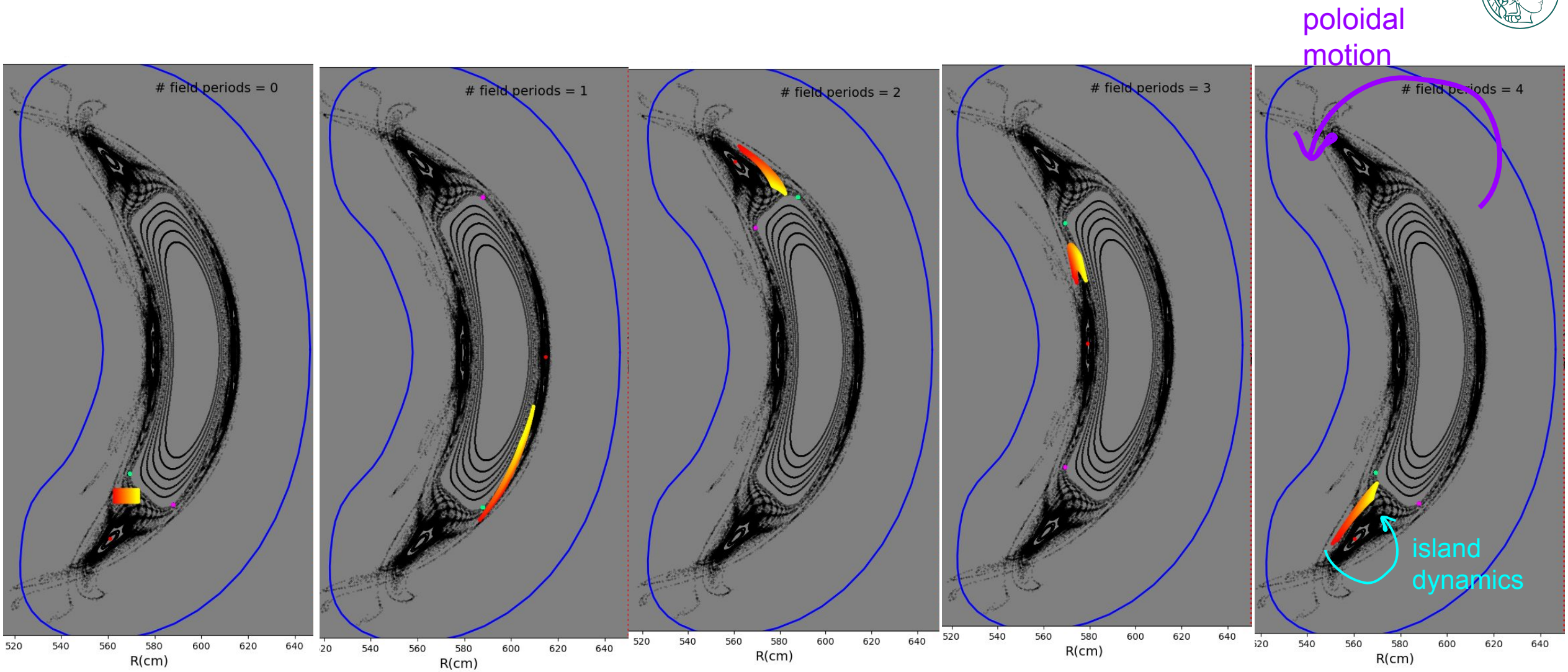
Understanding the chaos (1): Magnetic field line trajectories

- Method: follow trajectories of selected magnetic field lines



- Leading order motion: poloidal (anticlockwise)
- Same direction as the motion of “sharp corner”, but slower

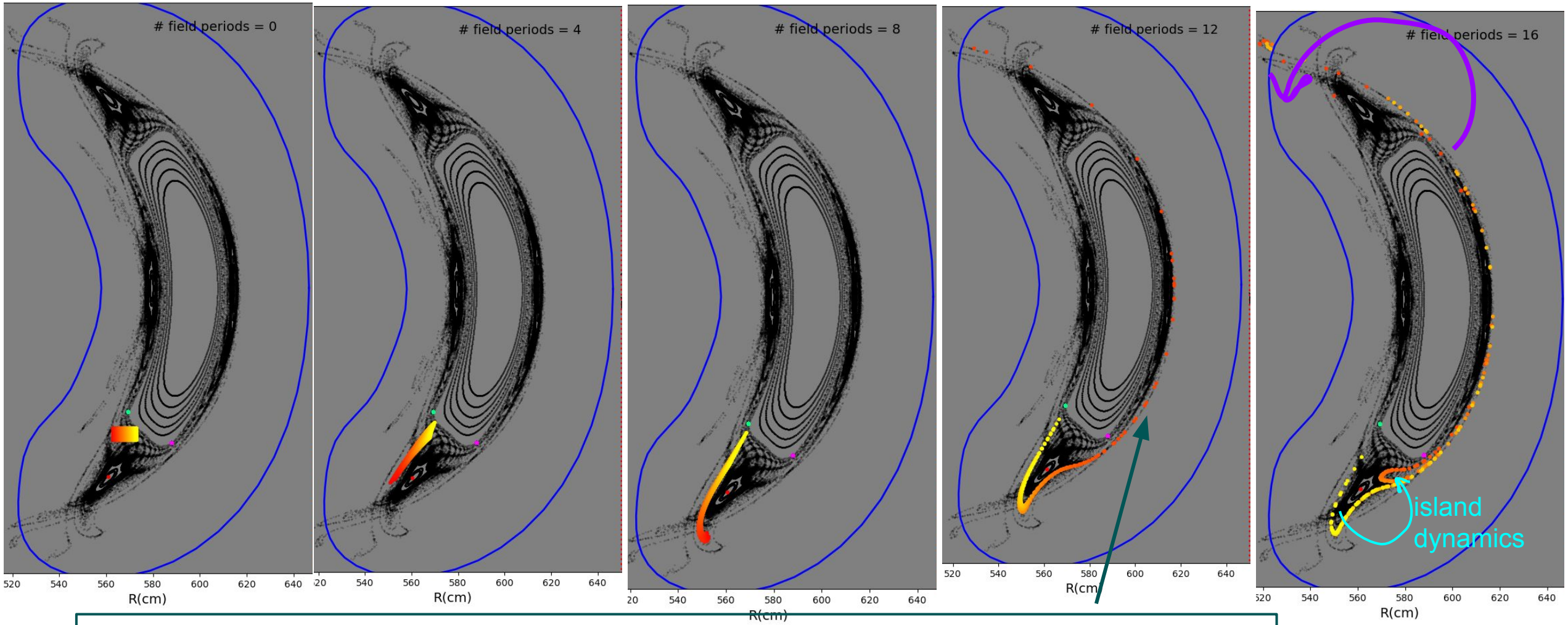
Understanding the chaos (1): Magnetic field line trajectories



- Leading order motion: poloidal (anticlockwise)
- Next order motion: island dynamics (5/4 island chain dominant) (anticlockwise)

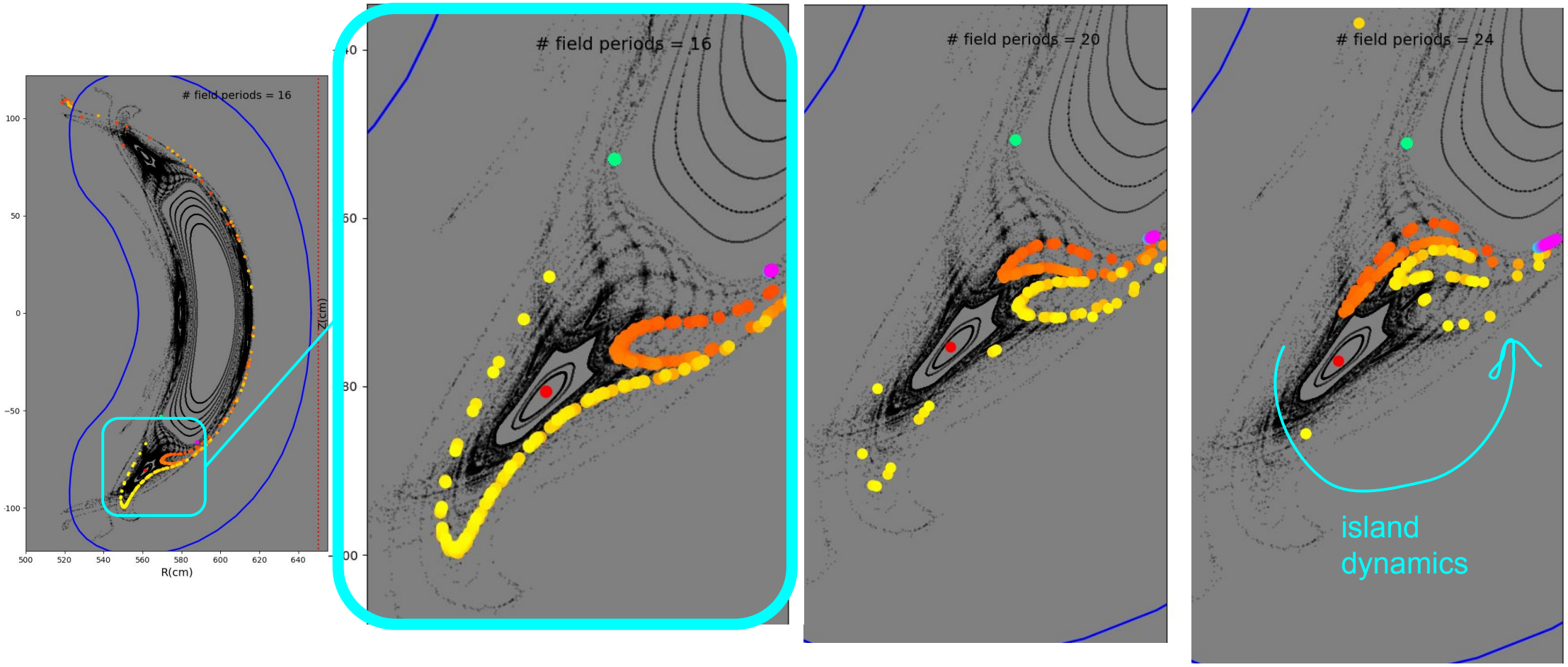
Understanding the chaos (1): Magnetic field line trajectories

poloidal motion



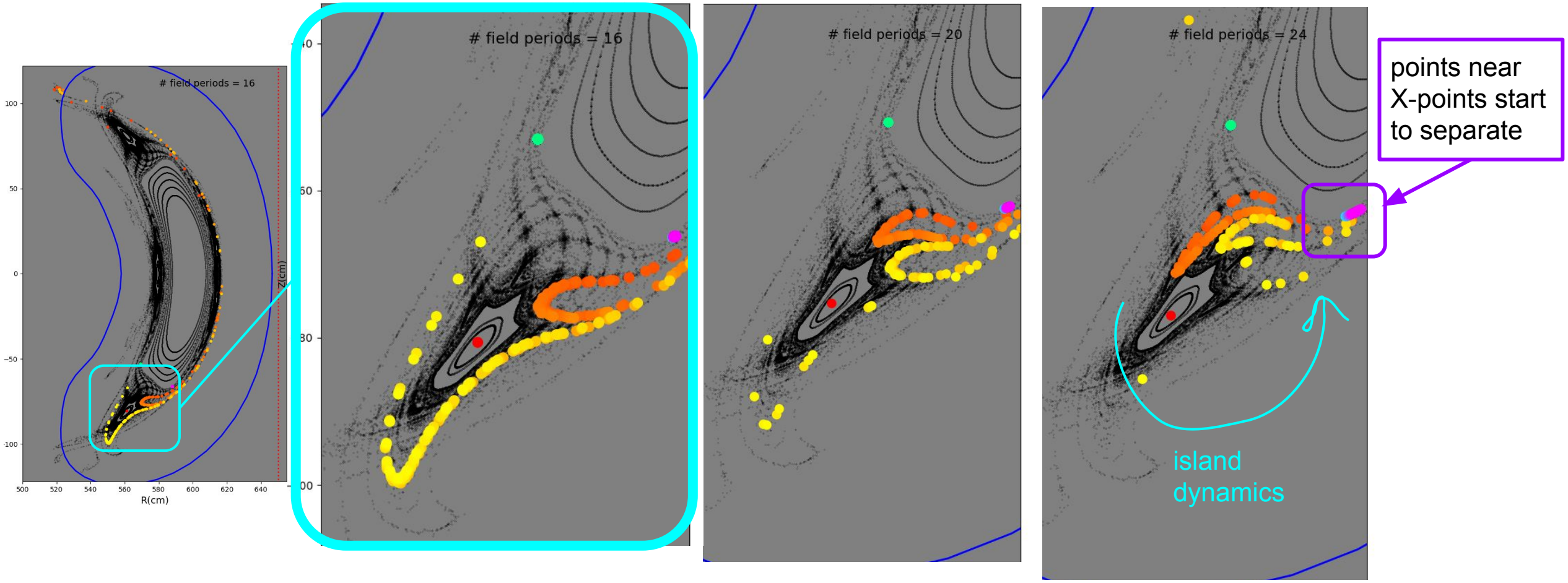
- Additional “irregular” motion (responsible for flux surface breaking)
- Caused by trajectories making large radial excursions (flux expansion) and rotational transform increasing (“surfing the sharp corner”)

Understanding the chaos (1): Magnetic field line trajectories



- Irregular motion creates void regions/field lines “bunch up”

Understanding the chaos (1): Magnetic field line trajectories



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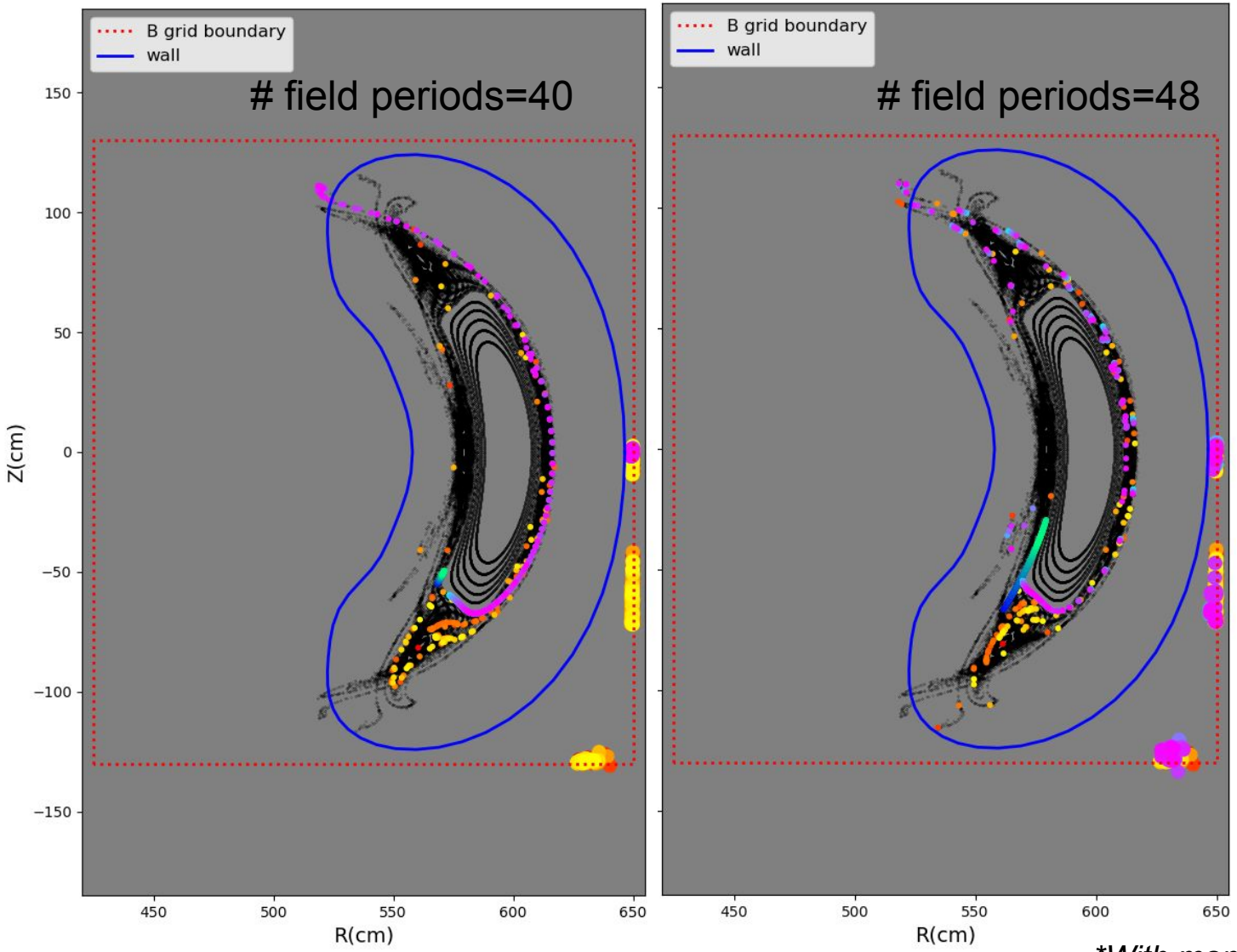
Understanding the chaos (1): Magnetic field line trajectories

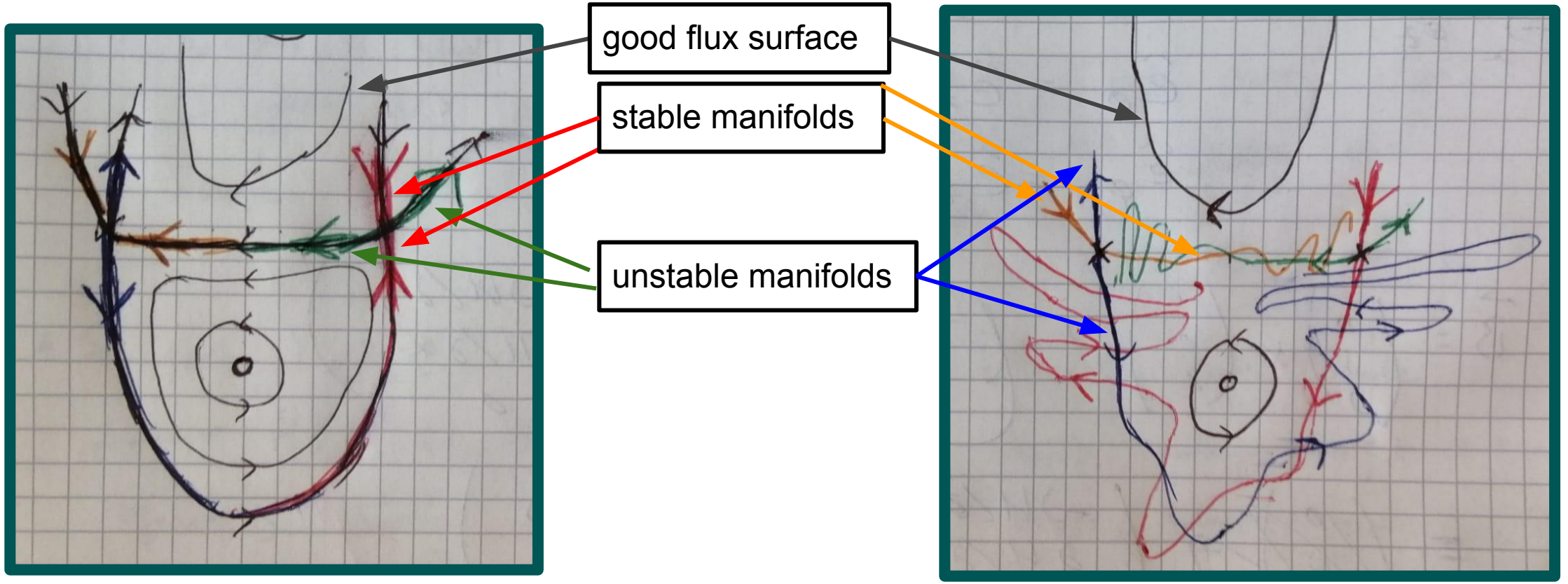


- After many field periods:
  - **Initial blob spread out / decorrelated (chaos: extreme sensitivity to initial (R,Z))**
  - **Points created near X-points start to separate.**
- Theory*: Near the X-point, we have 2 **stable** and 2 **unstable** manifolds
  - **Magnetic field lines on the stable manifold asymptotically approach the X-point**
  - **Field lines on the unstable manifold exponentially move away from the X-point.**
- So by tracing field lines near the X-point we can trace out the unstable manifolds of the X-points
- **Tracing** the field lines **backwards** (negative phi) we can also see the **stable** manifolds

**With many thanks to C. Smiet for useful discussions*

Understanding the chaos (1): Magnetic field line trajectories

A little aside: manifolds in chaotic & non-chaotic fields (homo/heteroclinic “tangle”)

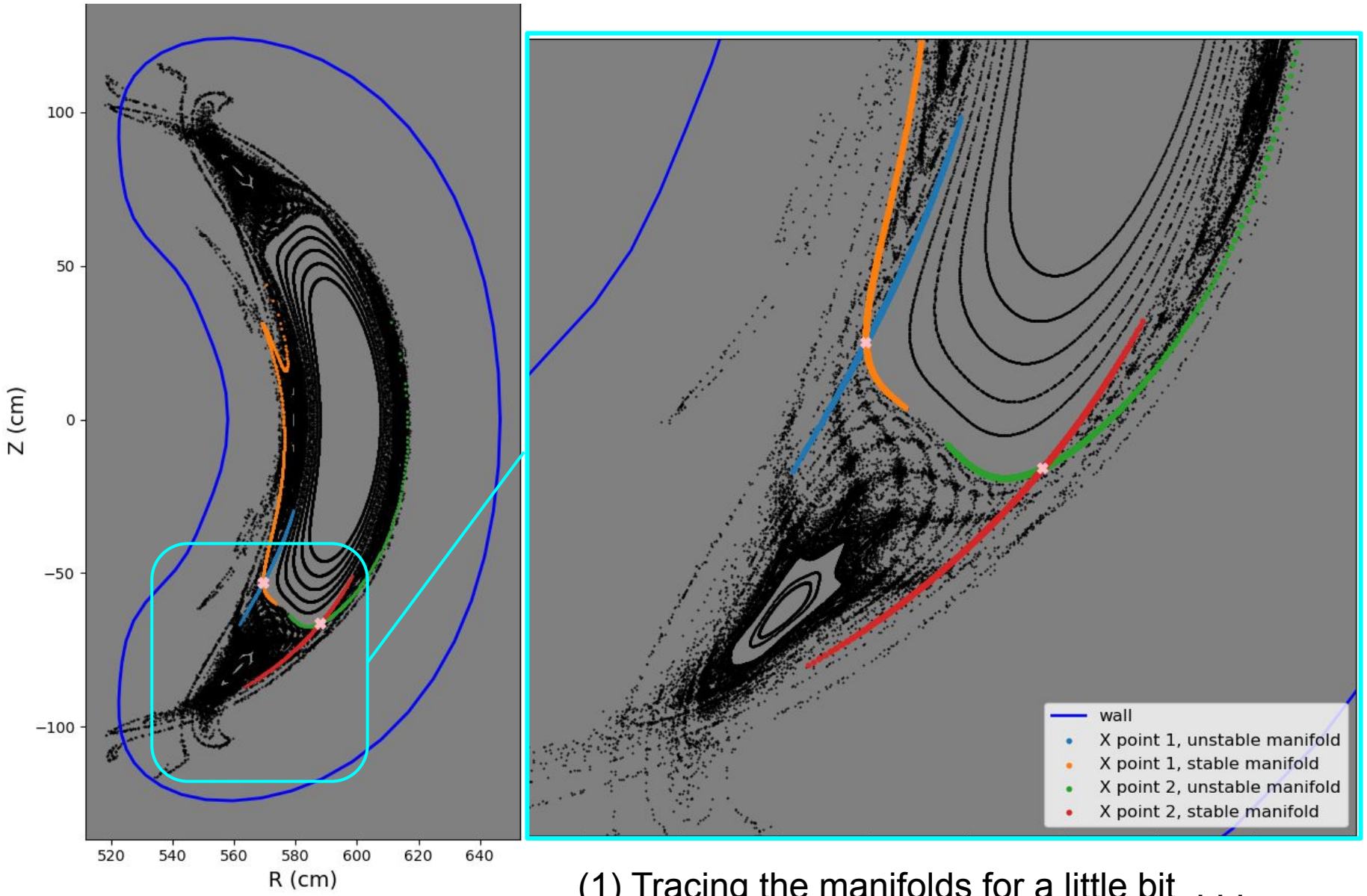


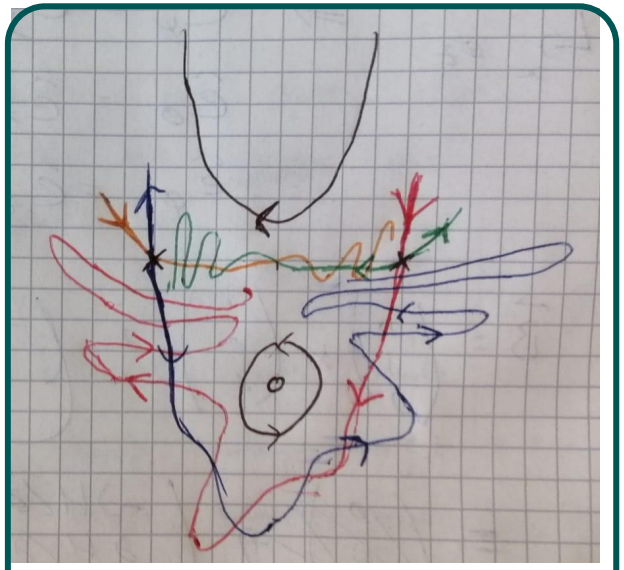
Non-chaotic case: The unstable manifolds of one X-point lies on top of the stable manifold of the other, making a flux surface.

Chaotic case: The unstable manifolds of one X-point does not lie on top of the stable manifold of the other. Instead of forming a flux surface, we have a chaotic region.

With many thanks to C. Smiet for useful discussions

Understanding the chaos (1): Magnetic field line trajectories



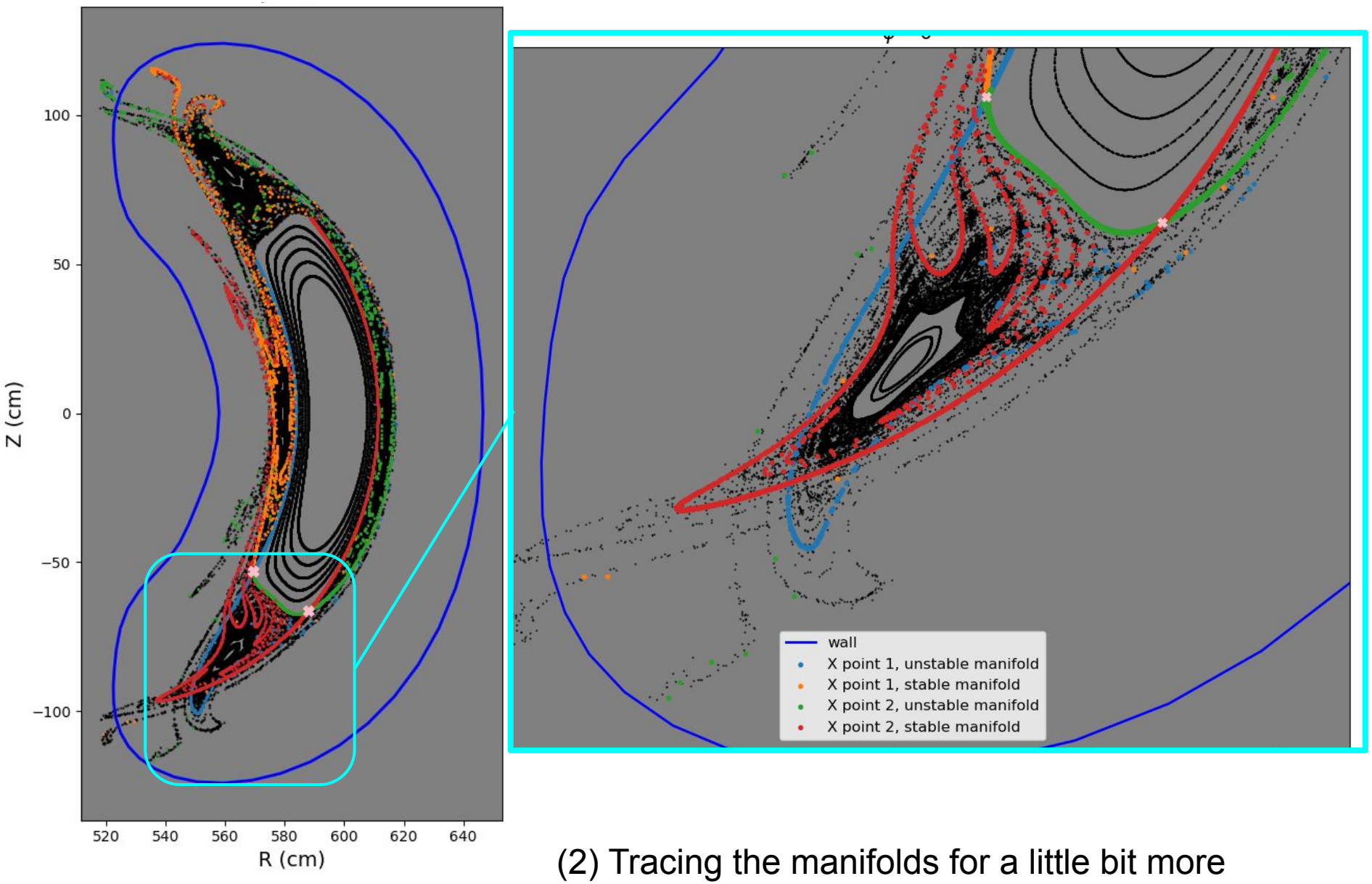


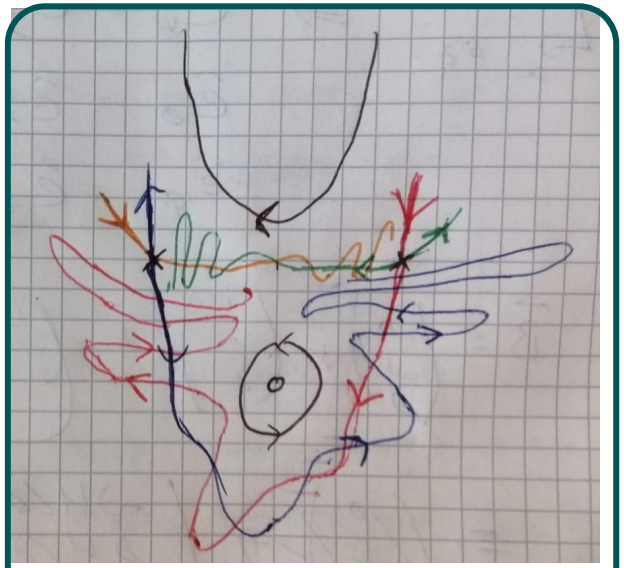
cartoon of manifolds

(1) Tracing the manifolds for a little bit . . .

With many thanks to C. Smiet for useful discussions

Understanding the chaos (1): Magnetic field line trajectories



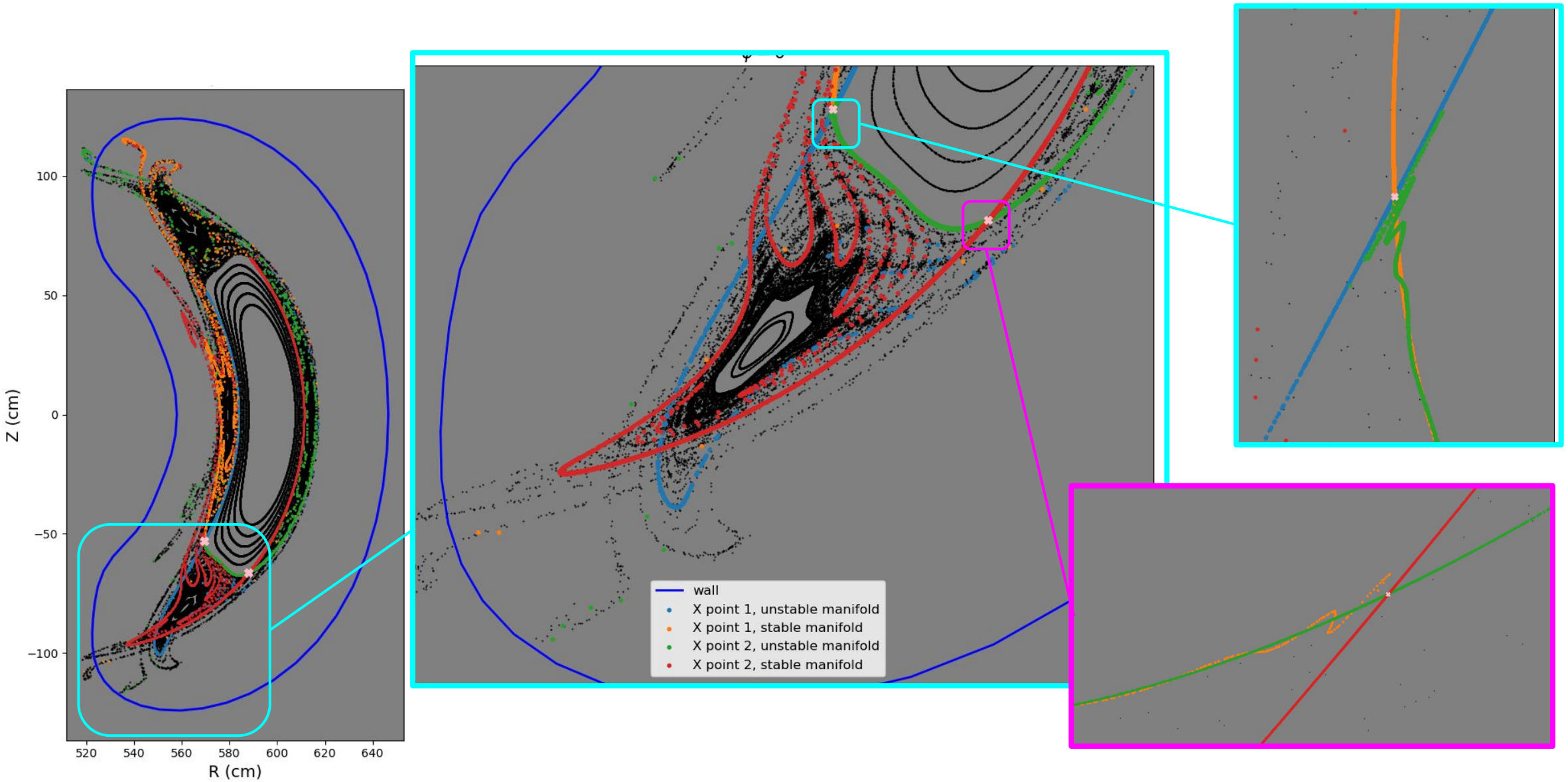


cartoon of manifolds

(2) Tracing the manifolds for a little bit more

With many thanks to C. Smiet for useful discussions

Understanding the chaos (1): Magnetic field line trajectories



With many thanks to C. Smiet for useful discussions

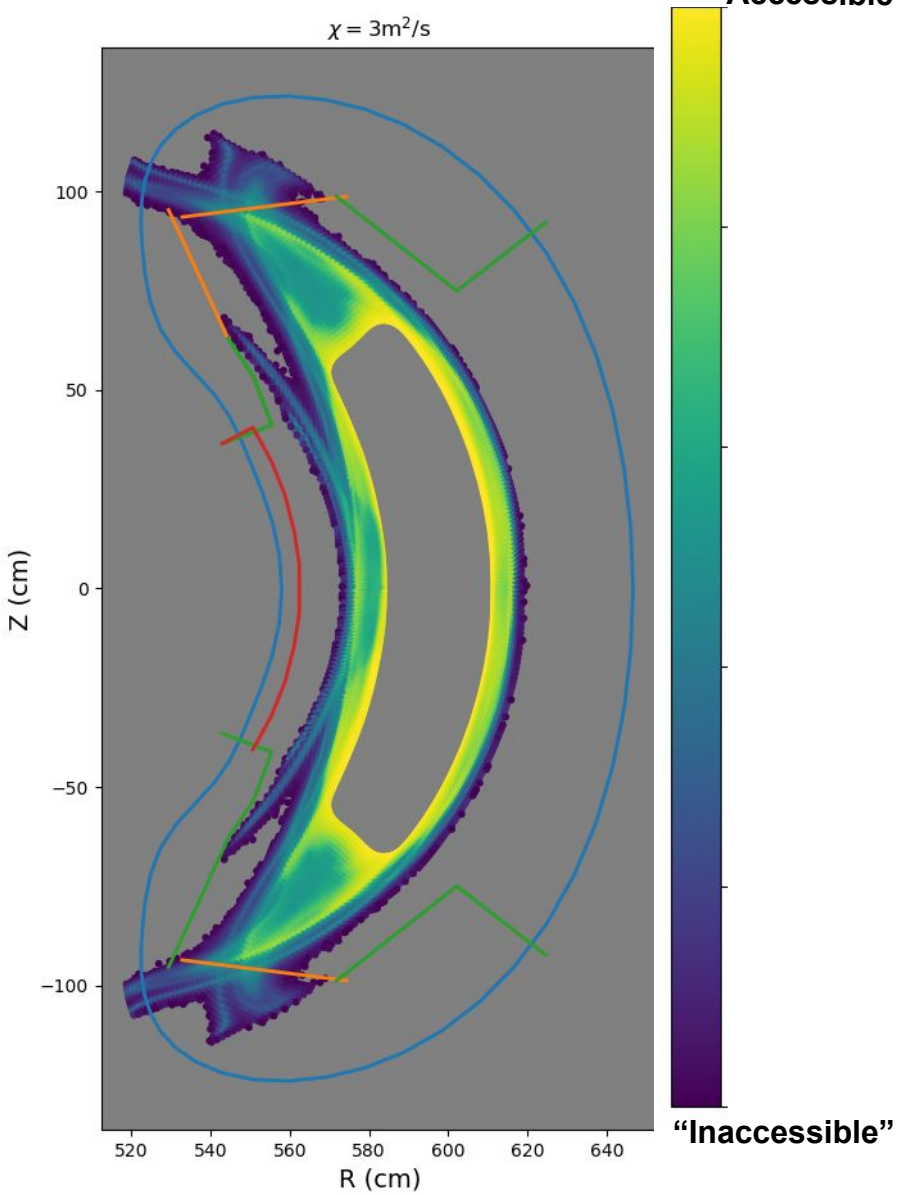
Understanding the chaos (2): a Target-Independent Heat Metric

- **Idea**: PFC-independent metric describing where heat can easily access, assuming diffusive transport
- Method:
  - Discretise volume into flux tubes
  - Create “random walk” Monte Carlo particles on LCFS and track them, **ignoring** PFC interactions
  - Score each flux tube:

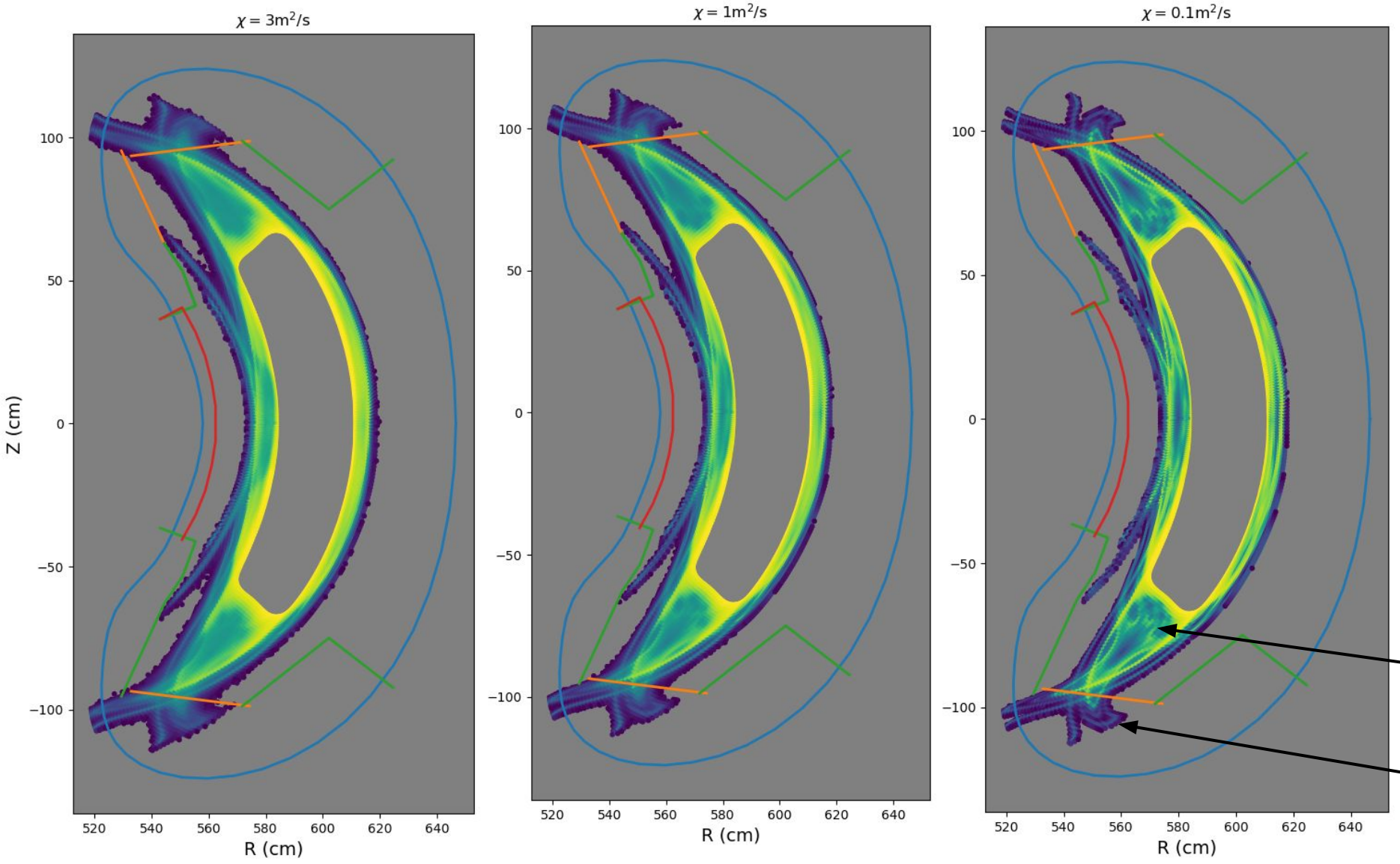
metric ~ (#MC particles per flux tube) * (1 - #flux tubes travelled per particle)

  - More details: W7-X DCD meeting 13/02/2024

- Important physics parameter: Ratio of parallel to perpendicular diffusivity
  - **χ = perp. diffusivity**



Understanding the chaos (2): a Target-Independent Heat Metric



- Fine structure visible at low perp. diffusivity χ
- “Inside island” structure washed out by χ, likely unimportant
- “Outside island” structure persistent with χ. Likely important for heat transport
- Exhaust performance probably resembles island divertor but with funny-shaped separatrix

Probably-unimportant fine structure

Probably-important fine structure (~separatrix)

Conclusions, Speculations and Future Work

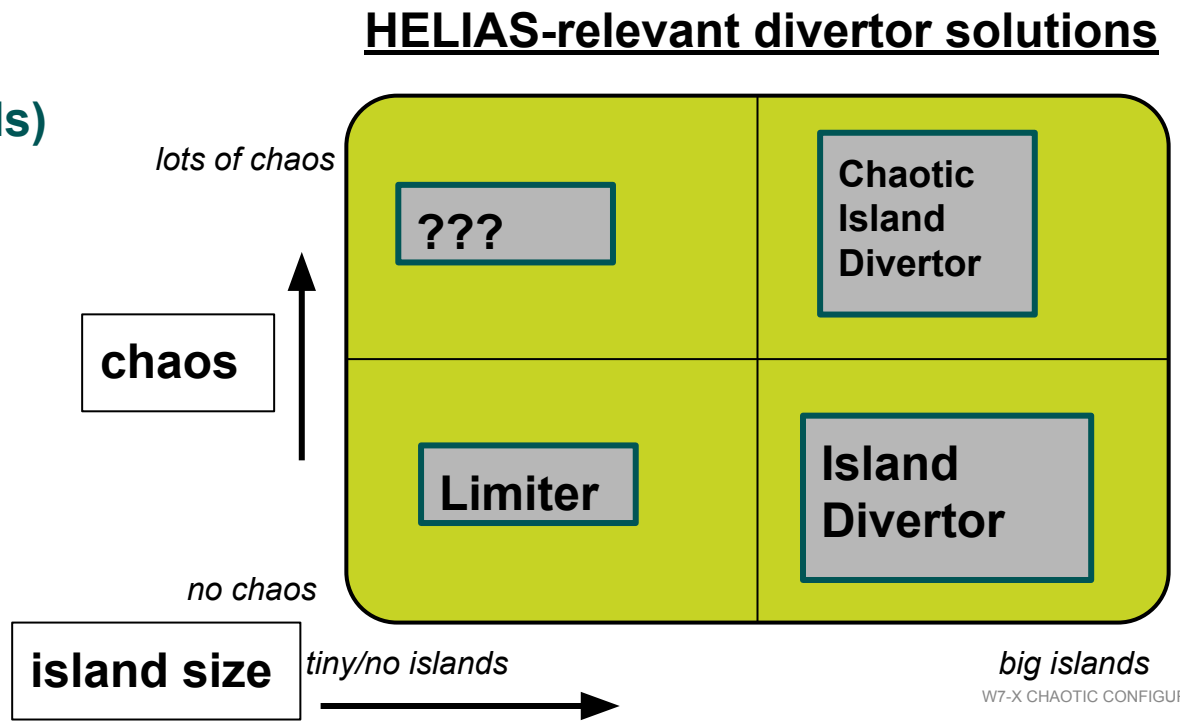
- Conclusions from FL tracing (“videos”):
  - A clear hierarchy of magnetic field motion:
    - **Toroidal**
    - **Poloidal (main rotational transform)**
    - **Island dynamics (island rotational transform)**
    - **“Irregular motion” (field line surfing, bunching up)**
  - Stable/unstable manifolds emerge from X-points
    - **Creates something like an island separatrix, but chaotic**

- Conclusions from Target-Independent Heat Metric:
  - **Island separatrix appears important**
  - **“Inside island” fine structure probably washed out by perp. diffusivity**

Conclusions, Speculations and Future Work

- **Speculation**: Might be helpful to create the label "**Chaotic Island Divertor**": PFC heat deposition not governed by good magnetic surfaces, but there's a dominant island chain
  - **Like an island divertor, but with a funny-looking "separatrix"**

- In "Chaotic Island Divertors", the important properties affecting performance are likely to be:
  - **Island rotational transform**
  - **"Separatrix" shape (X-point manifolds)**



Conclusions, Speculations and Future Work

Future work

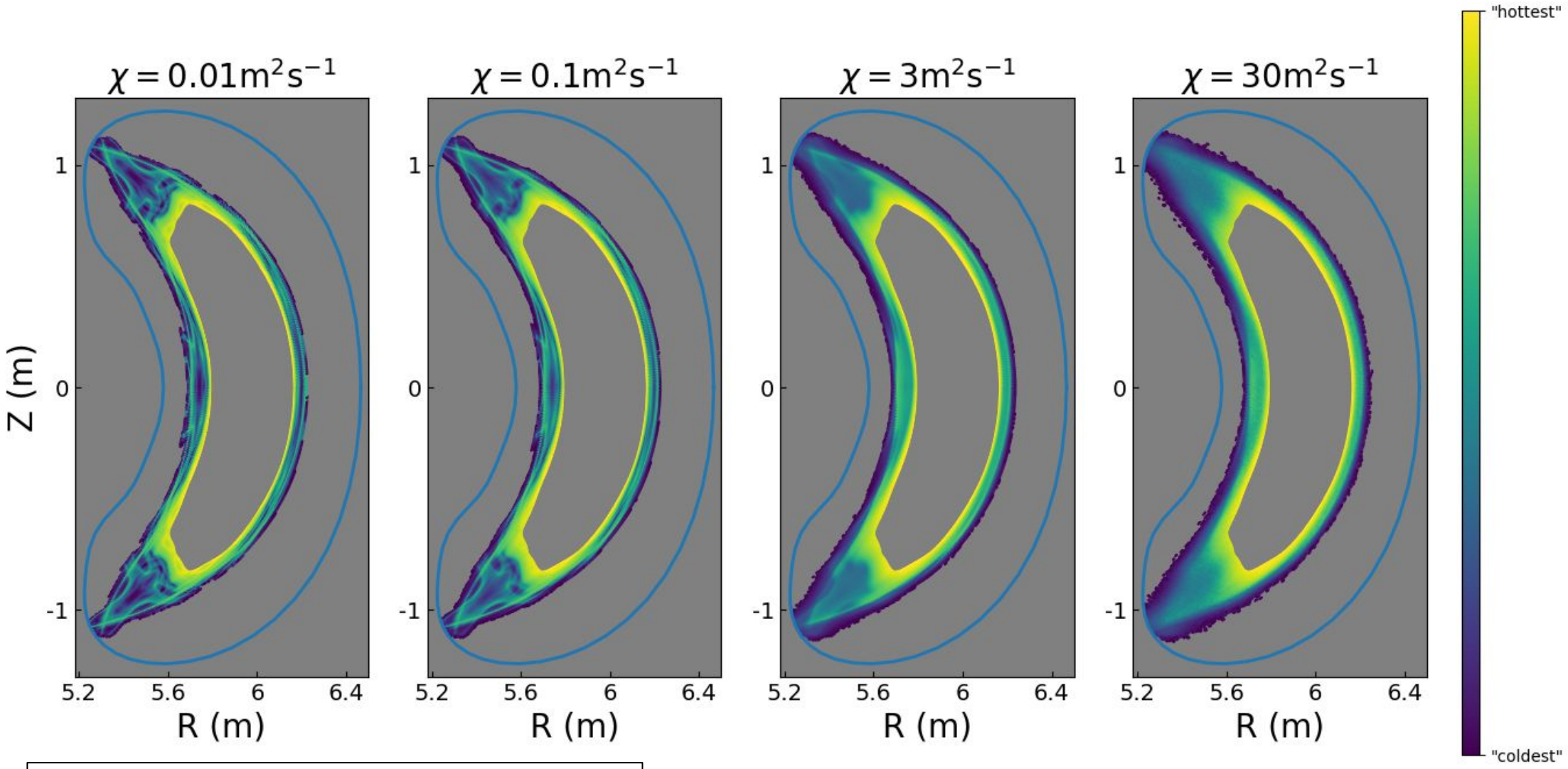
- Similar analysis for other “Chaotic Island Divertor” candidates
- Improved methods of manifold calculation[1]
- EMC3-EIRENE simulations
- Experiment planning / experiment
  - **All collaborations welcome!**

Thanks for listening

[1] *L. Rais & C. Smiet, EPFL. More information at CWGM NRD JA meeting on 13/06 (ask Bob for details).*

APPENDIX

Target-Independent Heat Metric for high iota at finite beta



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