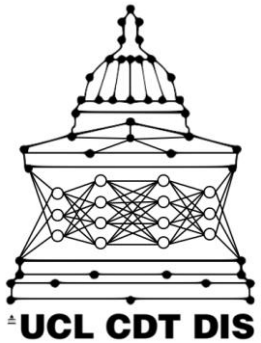
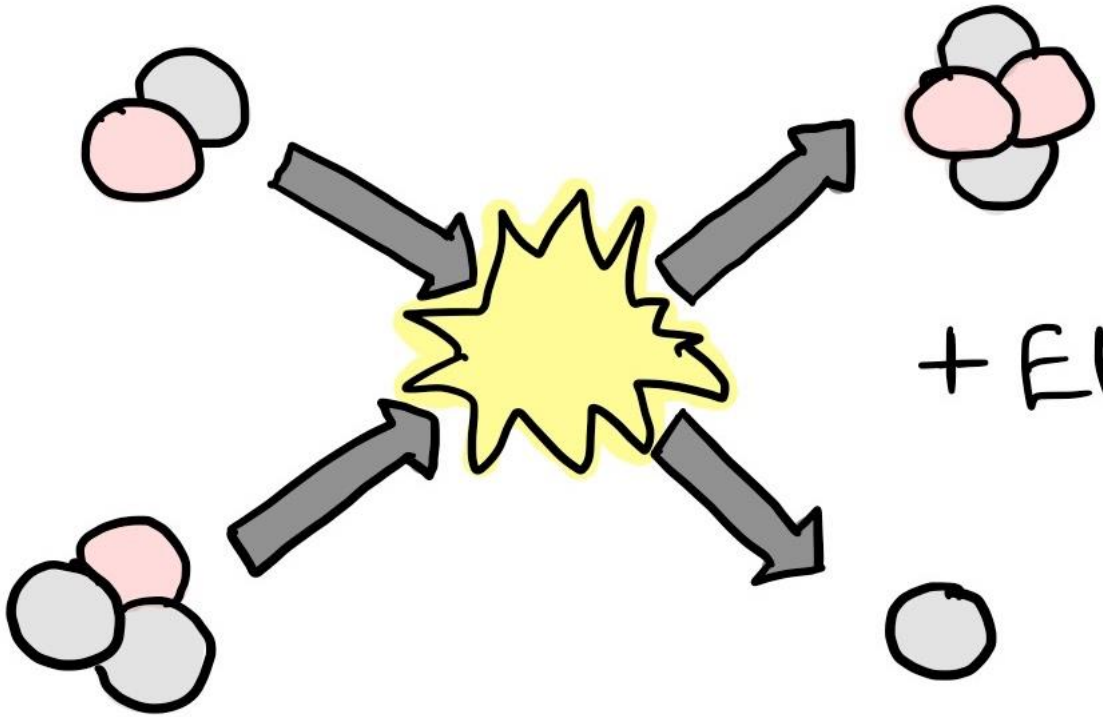
Data-Driven Physics Aware Learning for Disruption Prediction in Nuclear Fusion

Katya Richards

UK Atomic Energy Authority





$$ {}^{2}_{1}D + {}^{3}_{1}T \longrightarrow {}^{4}_{2}He + {}^{1}_{0}n $$

+ 17.6 MeV

Tokamak

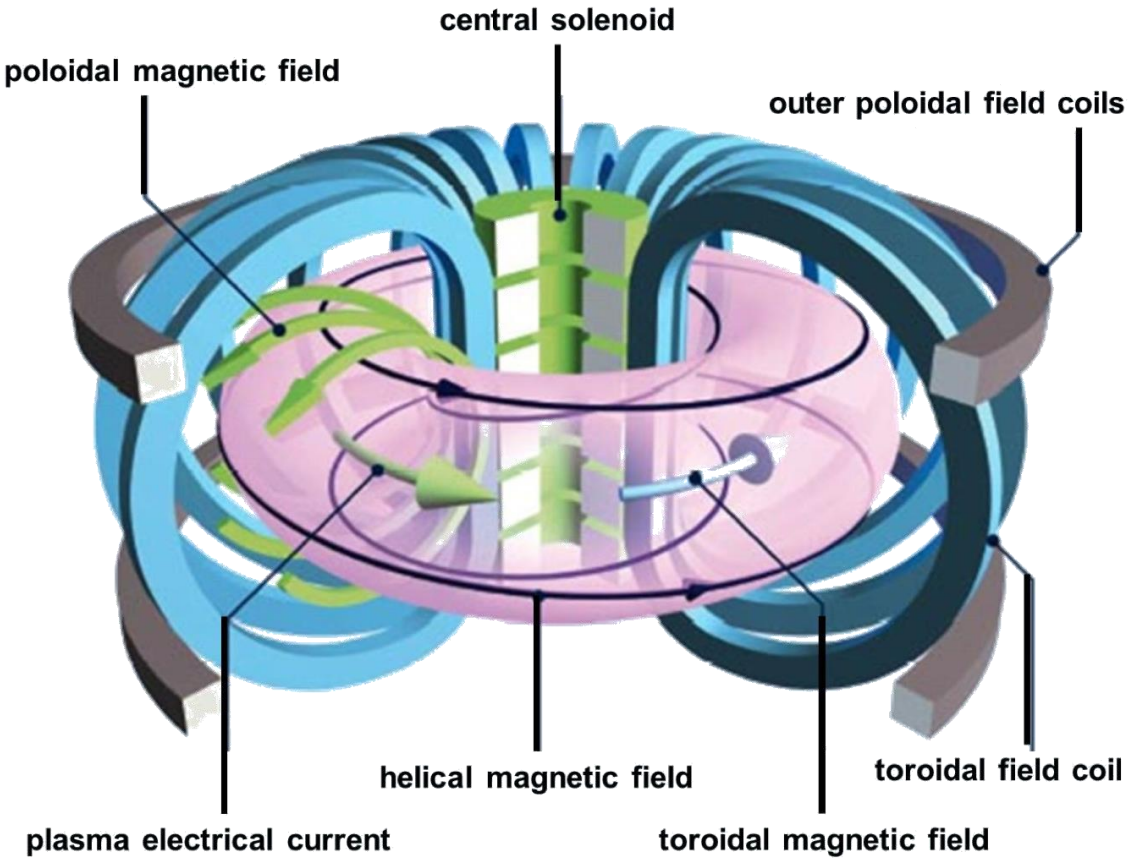
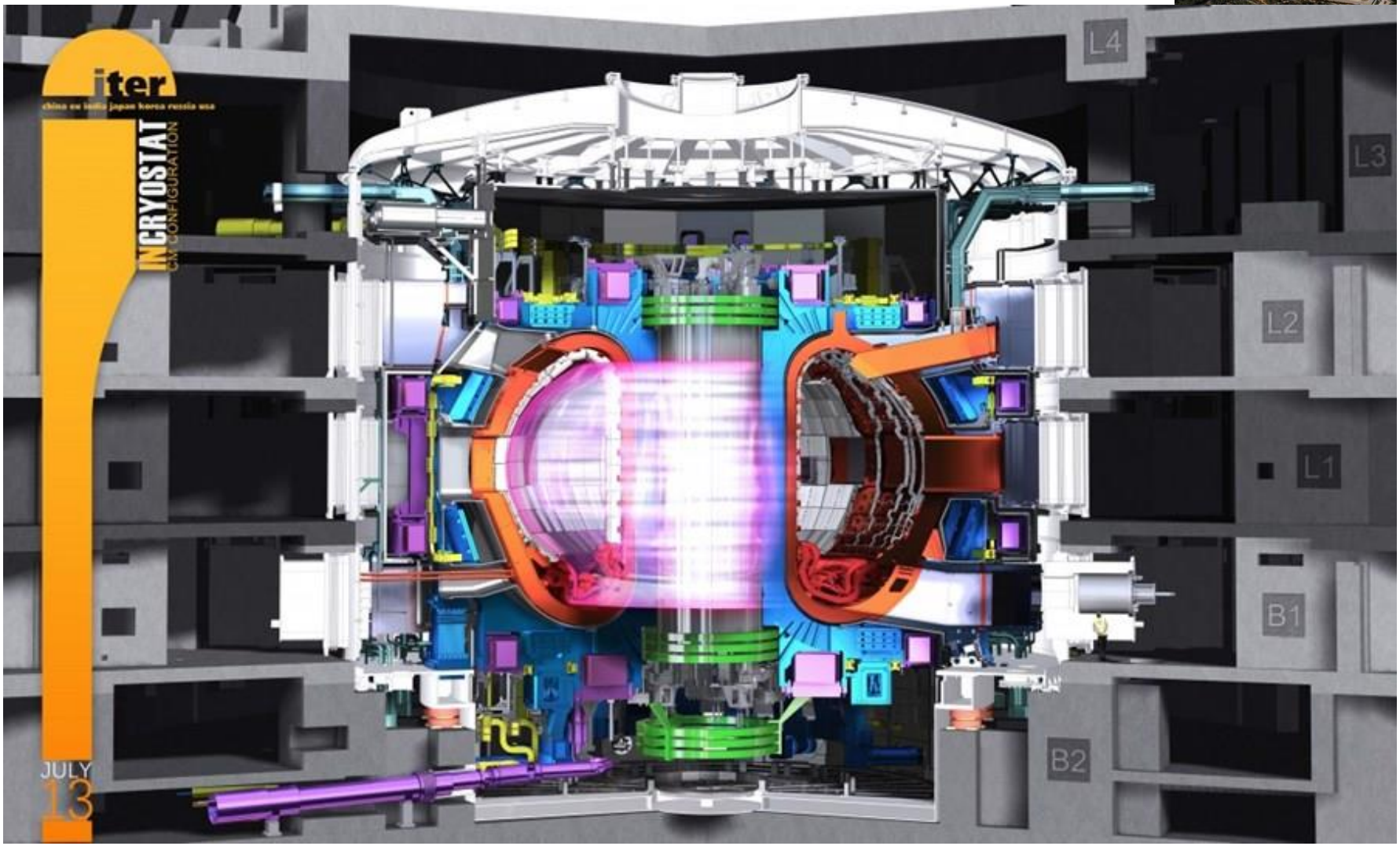


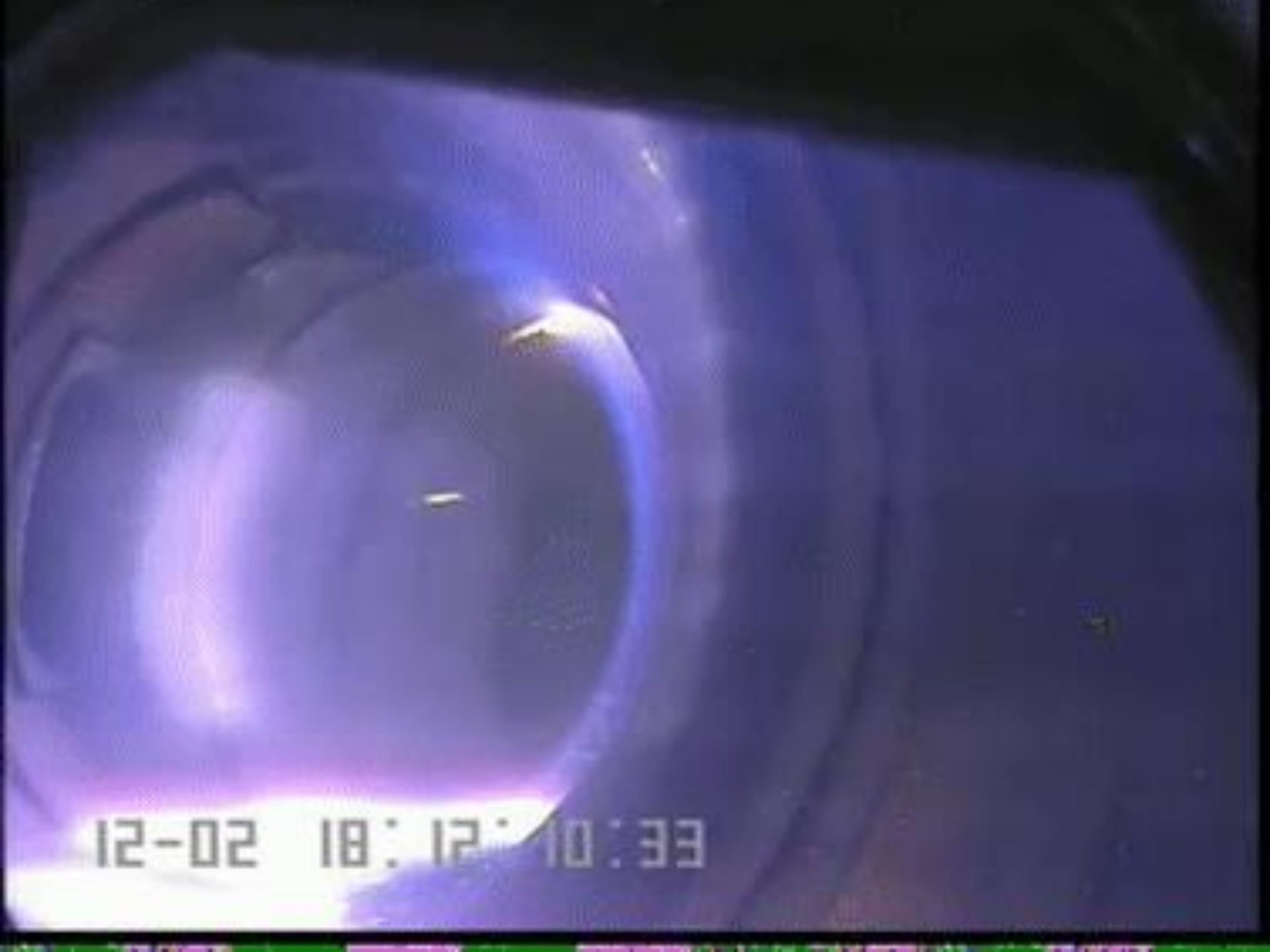
Image: EUROfusion

ITER


iter
china eu india japan korea russia usa
IN CRYOSTAT
CM CONFIGURATION
JULY
13
L4
L3
L2
L1
B1
B2

Disruptions

- It’s not all sunshine
- Symptoms include:
  - Sudden loss of confinement
  - Melting of walls
  - Lifting of entire tokamak off ground


12-02 18:12:10:33

Big Disruptions

"On a small tokamak, it doesn't matter so much if you let the plasma go bang…"

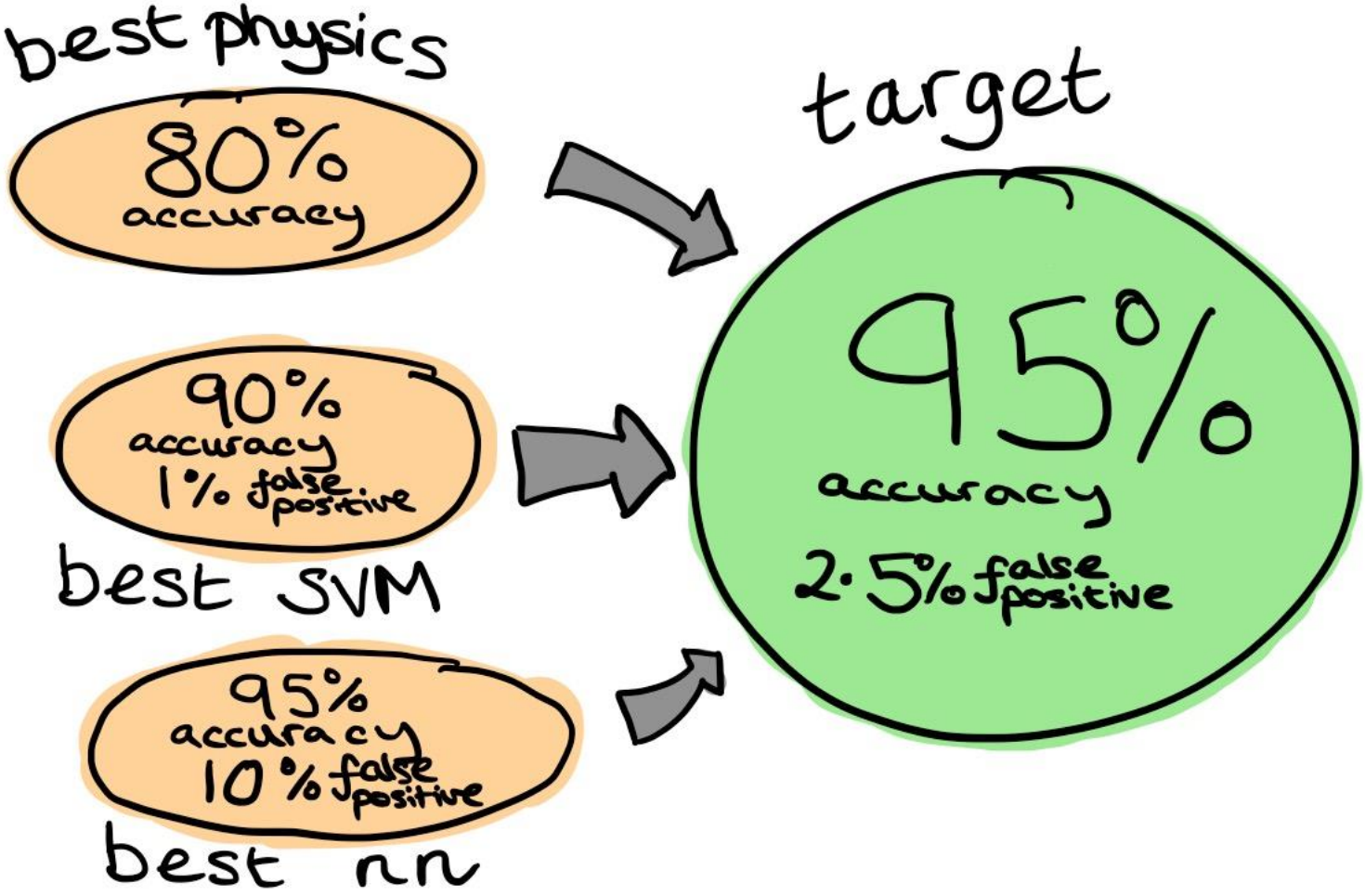
- It gets worse
- 15000 tons worse

- Remind audience that disruptions are not meltdowns

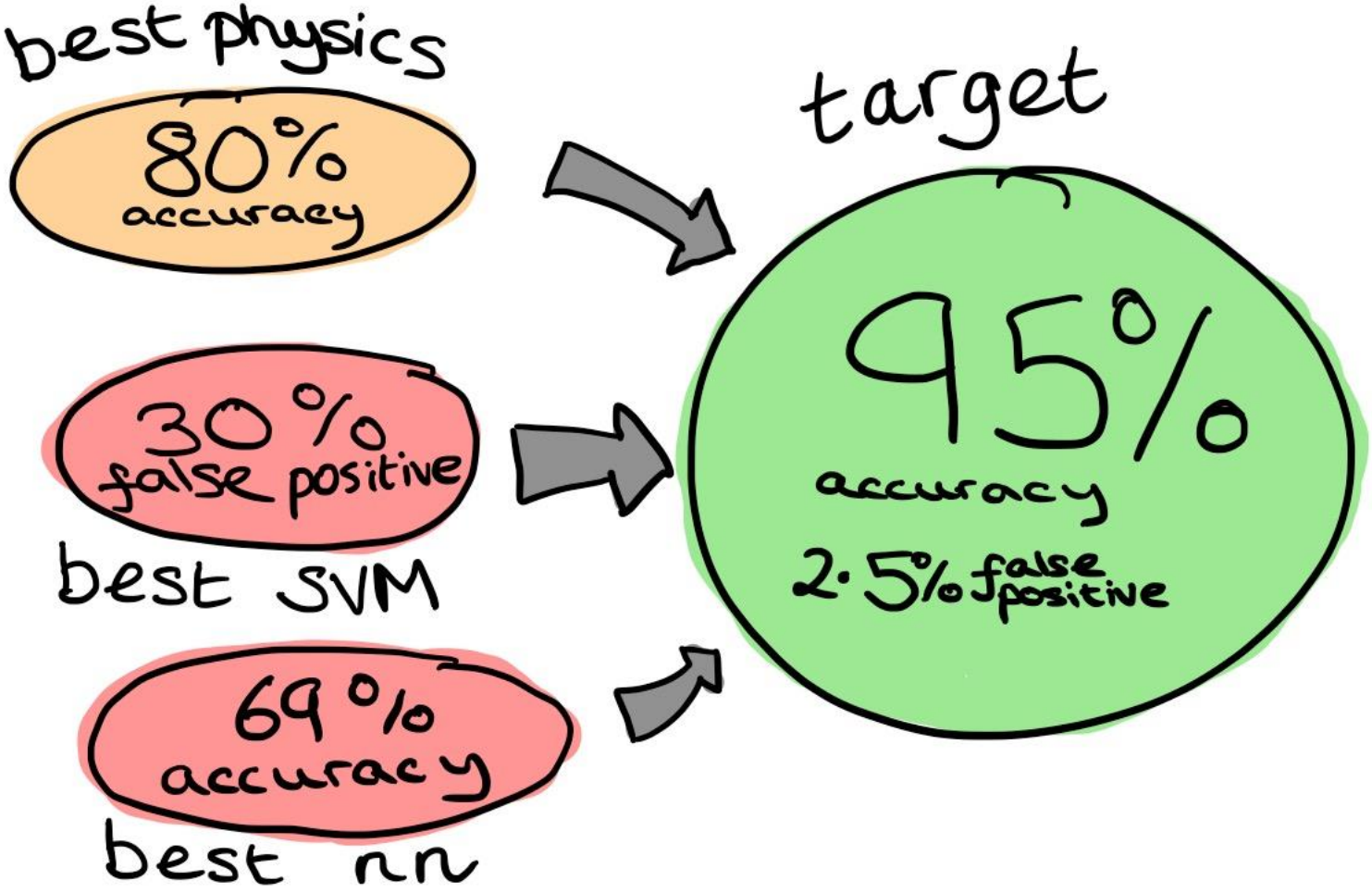
Disruption prediction

- All is not lost!
  - 30ms warning needed

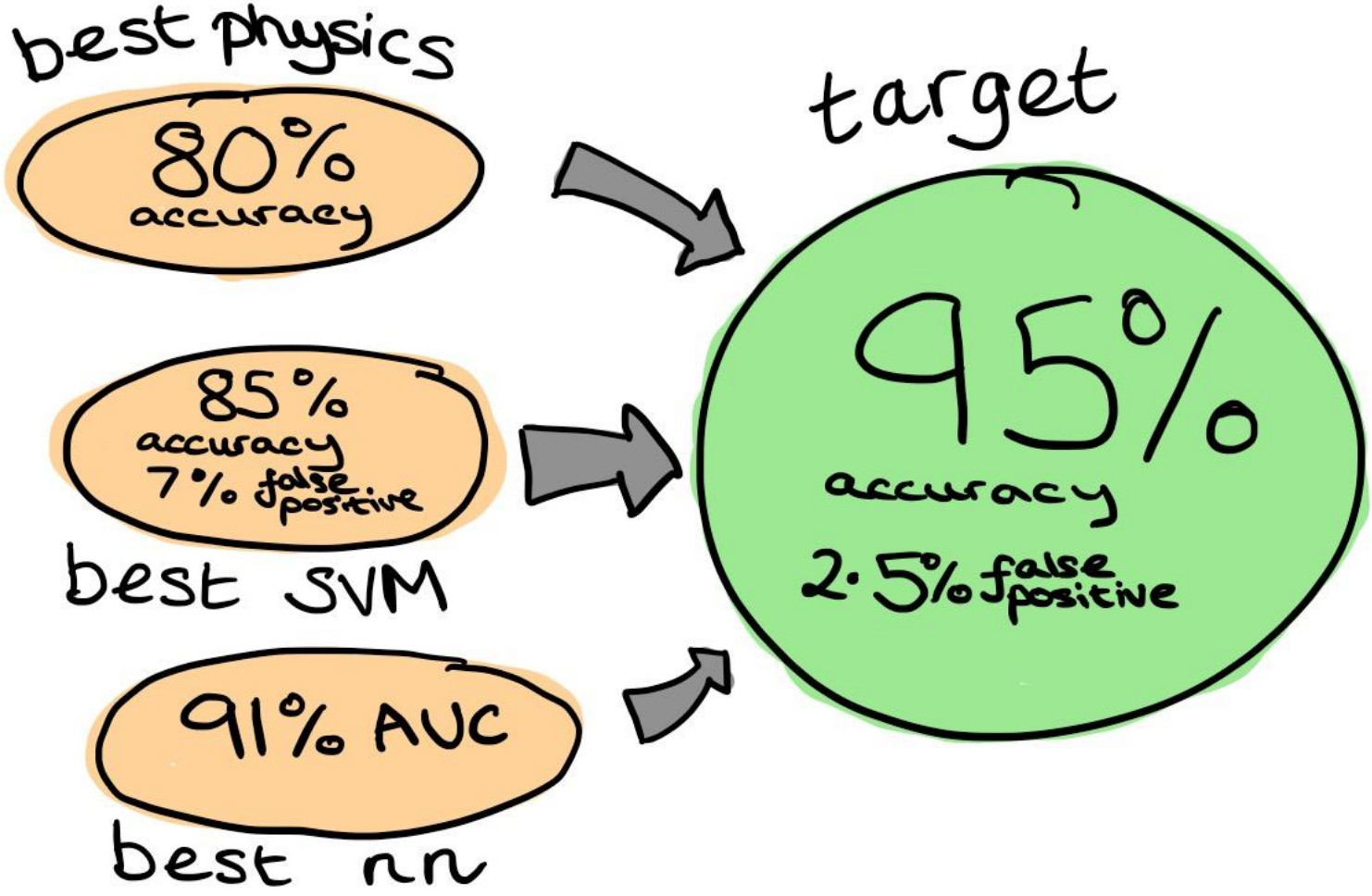
Same-tokamak



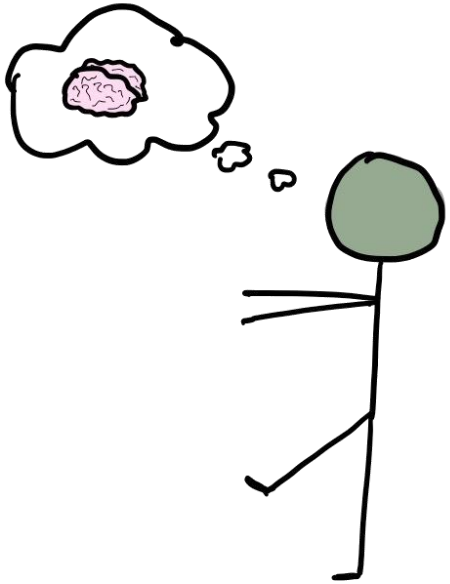
Cross-tokamak

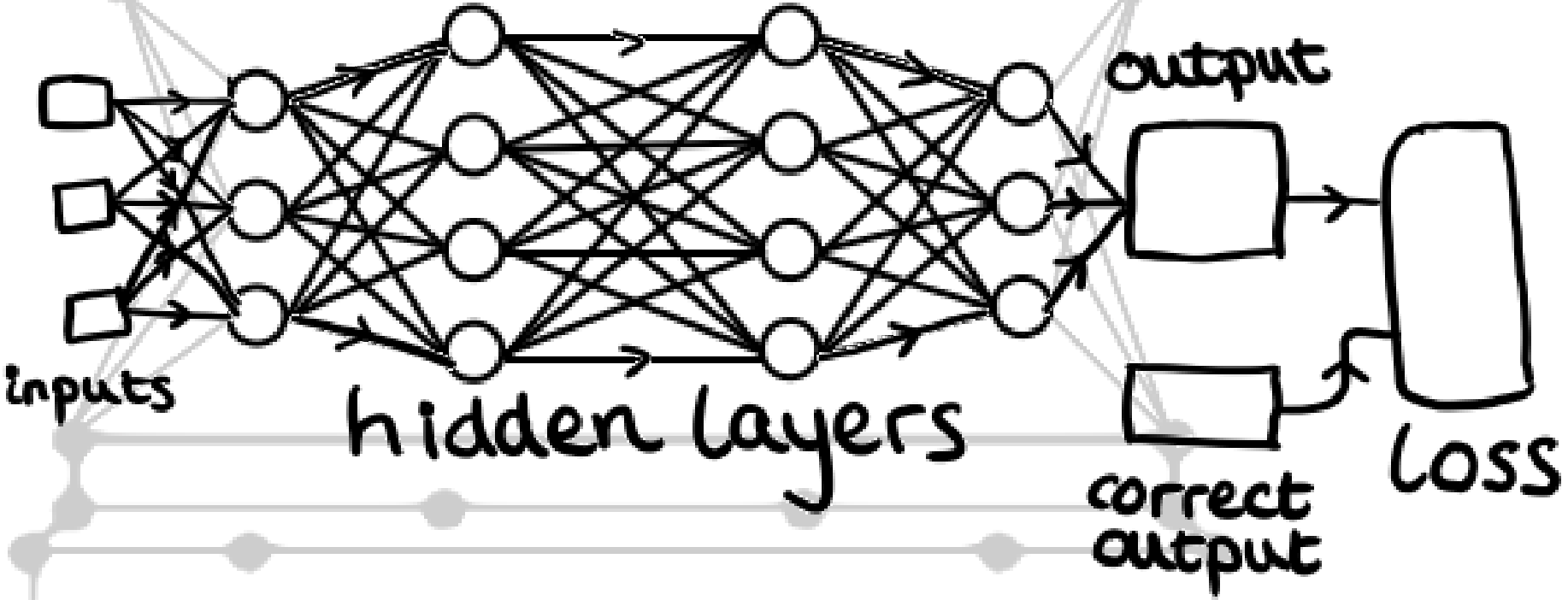


Cross-tokamak with glimpse



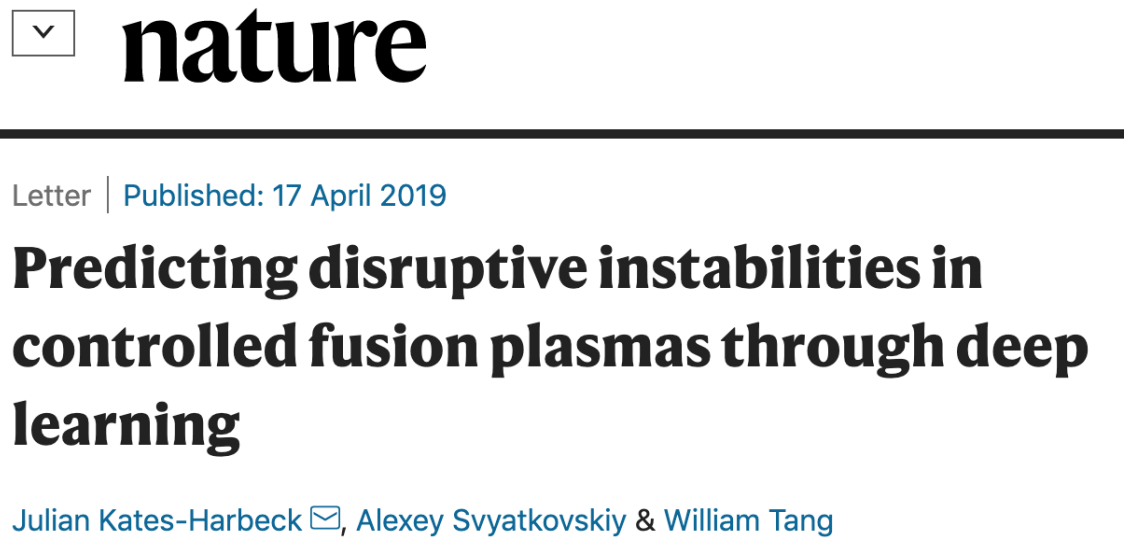
Neural networks

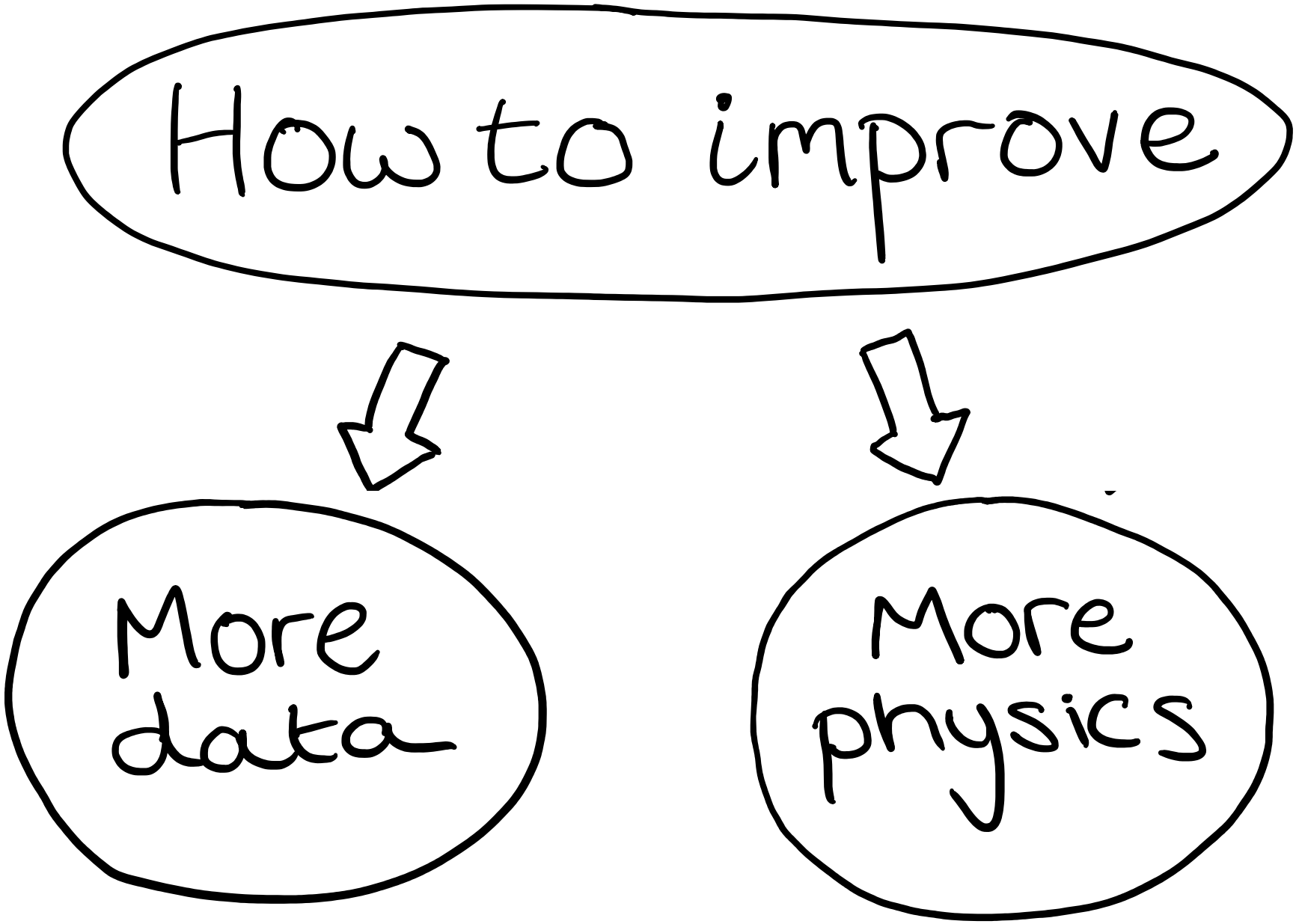




FRNN

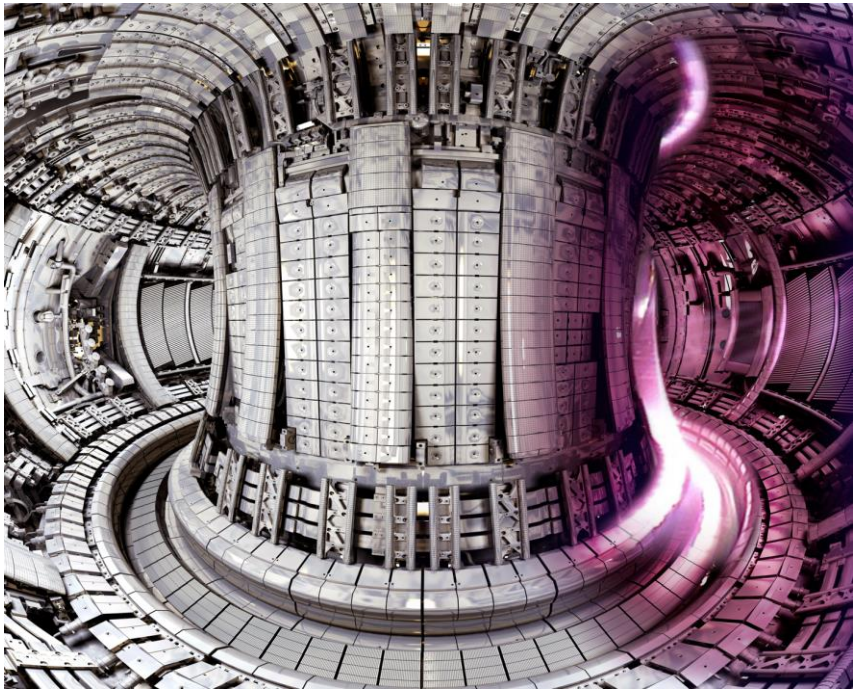
- Fusion Recurrent Neural Network
  - Inputs: various tokamak diagnostics, every 1ms
  - Outputs: time to disruption/chance will disrupt



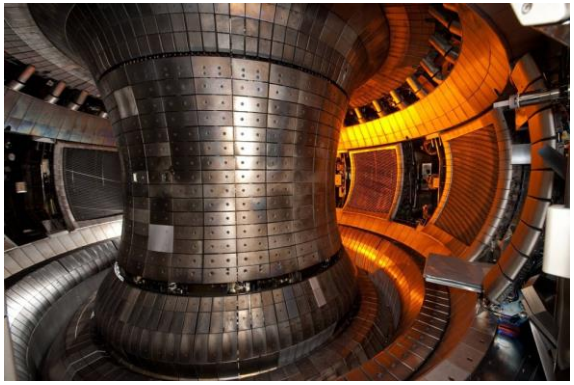

How to improve
More data
More physics

More Data

JET



ASDEX-U



COMPASS

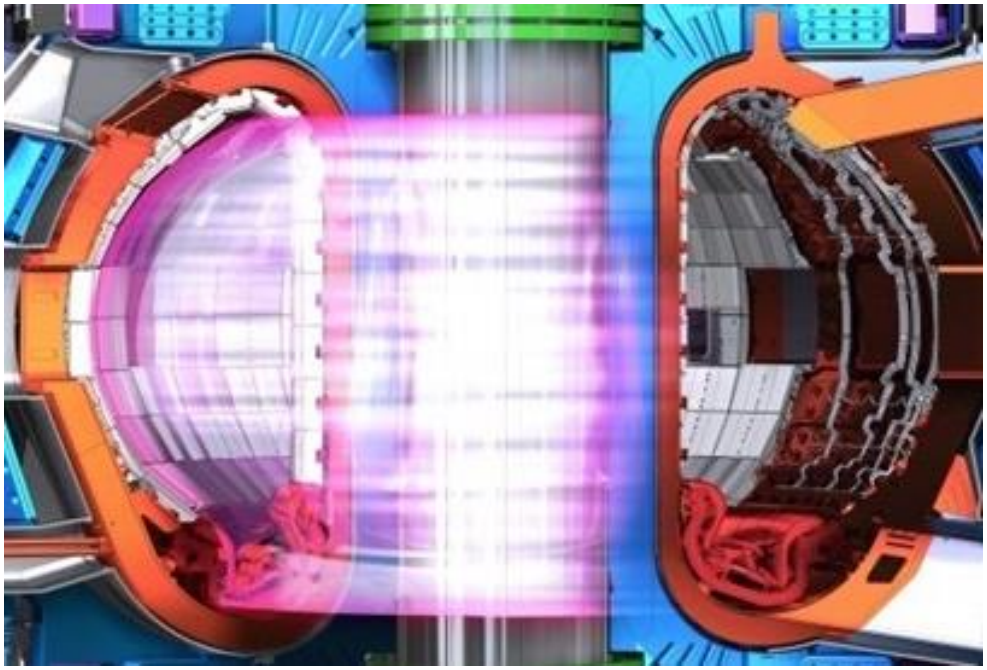
2.96m

1.65m

0.56m

More Data

ITER



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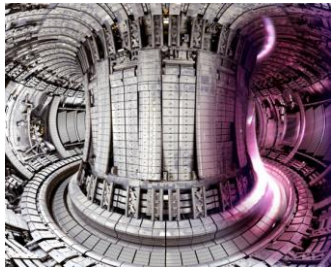

ASDEX-U

COMPASS

0.56m

1.65m

2.96m

6.2m

More Physics

- Physics Guided Neural Networks (PGNNs)
  - Include physics laws in loss function

cs.LG] 20 Feb 2018

Physics-guided Neural Networks (PGNN): An Application in Lake Temperature Modeling

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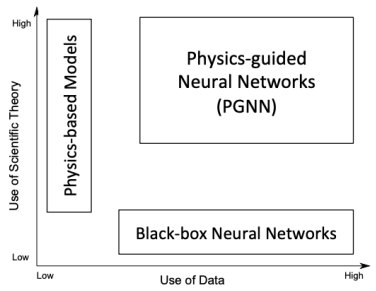
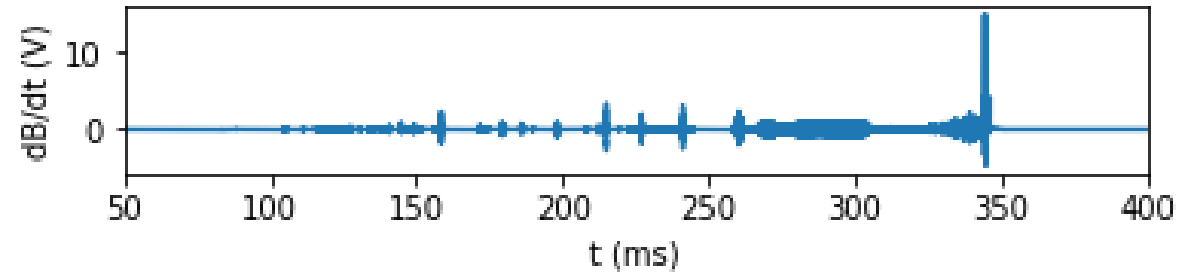
Abstract

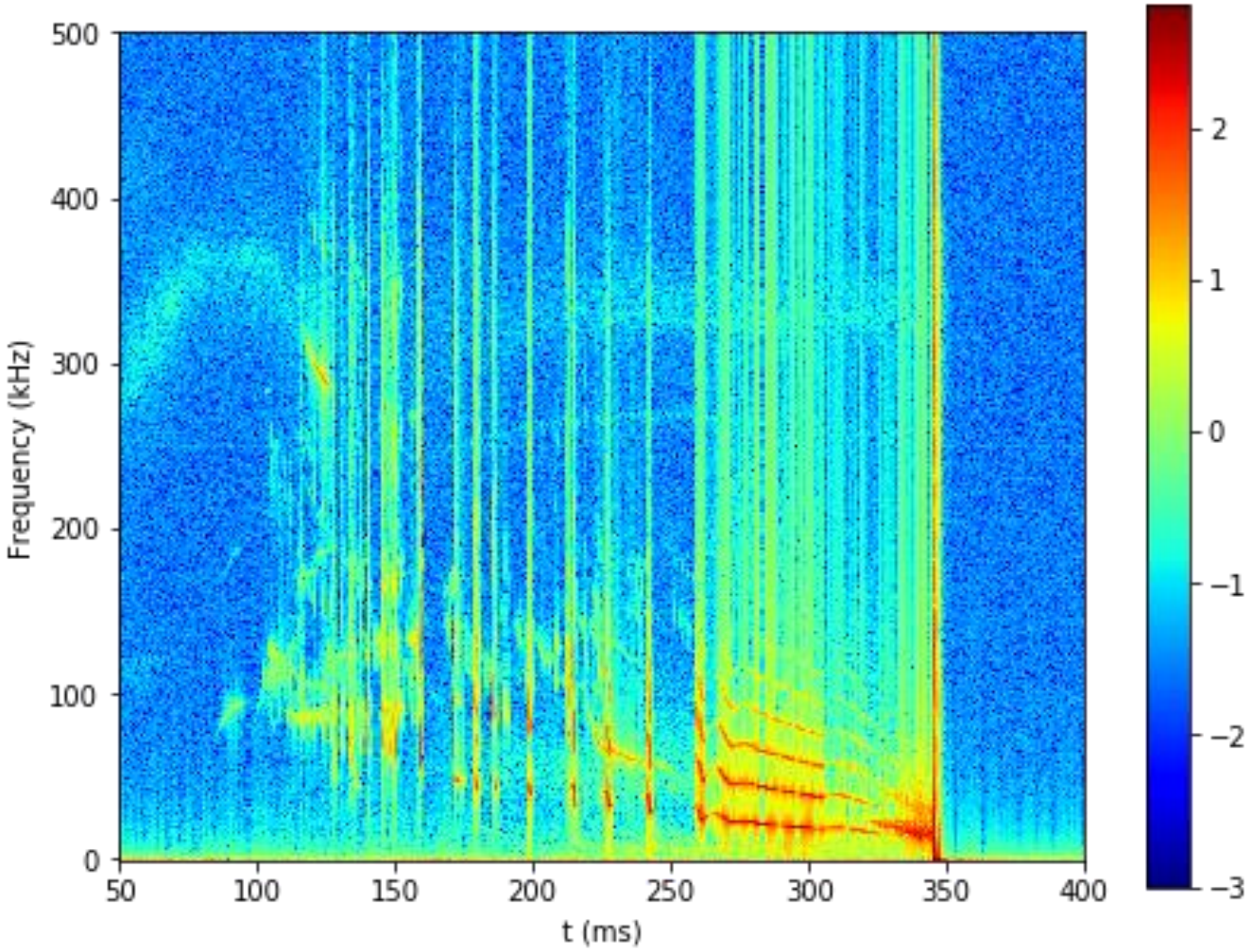
This paper introduces a novel framework for combining scientific knowledge of physics-based models with neural networks to advance scientific discovery. This framework, termed as physics-guided neural network (PGNN), leverages the output of physics-based model simulations along with observational features to generate predictions using a neural network architecture. Further, this paper presents a novel framework for using physics-based loss functions in the learning objective of neural networks, to ensure that the model predictions not only show lower errors on the training set but are also scientifically consistent with the known physics

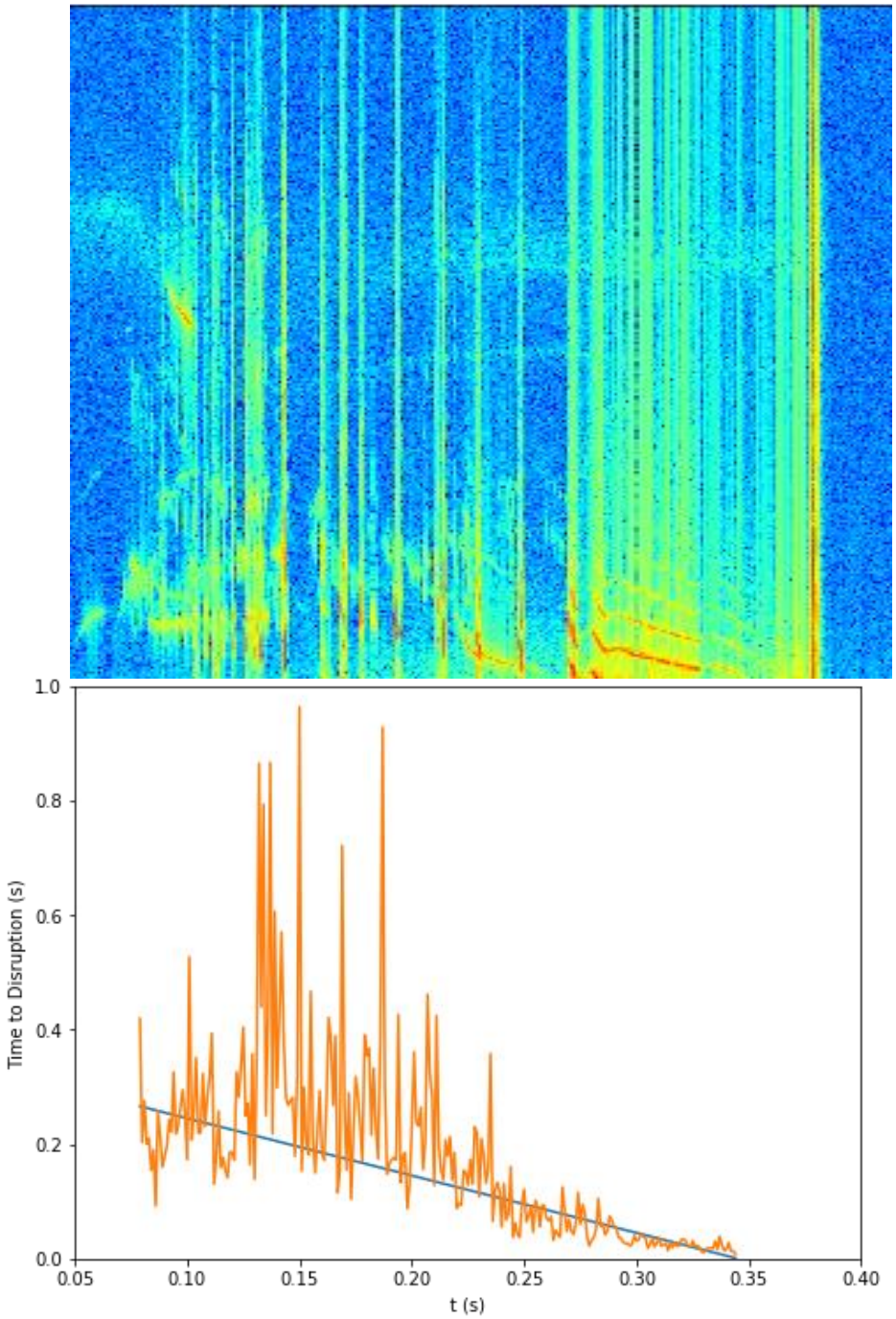


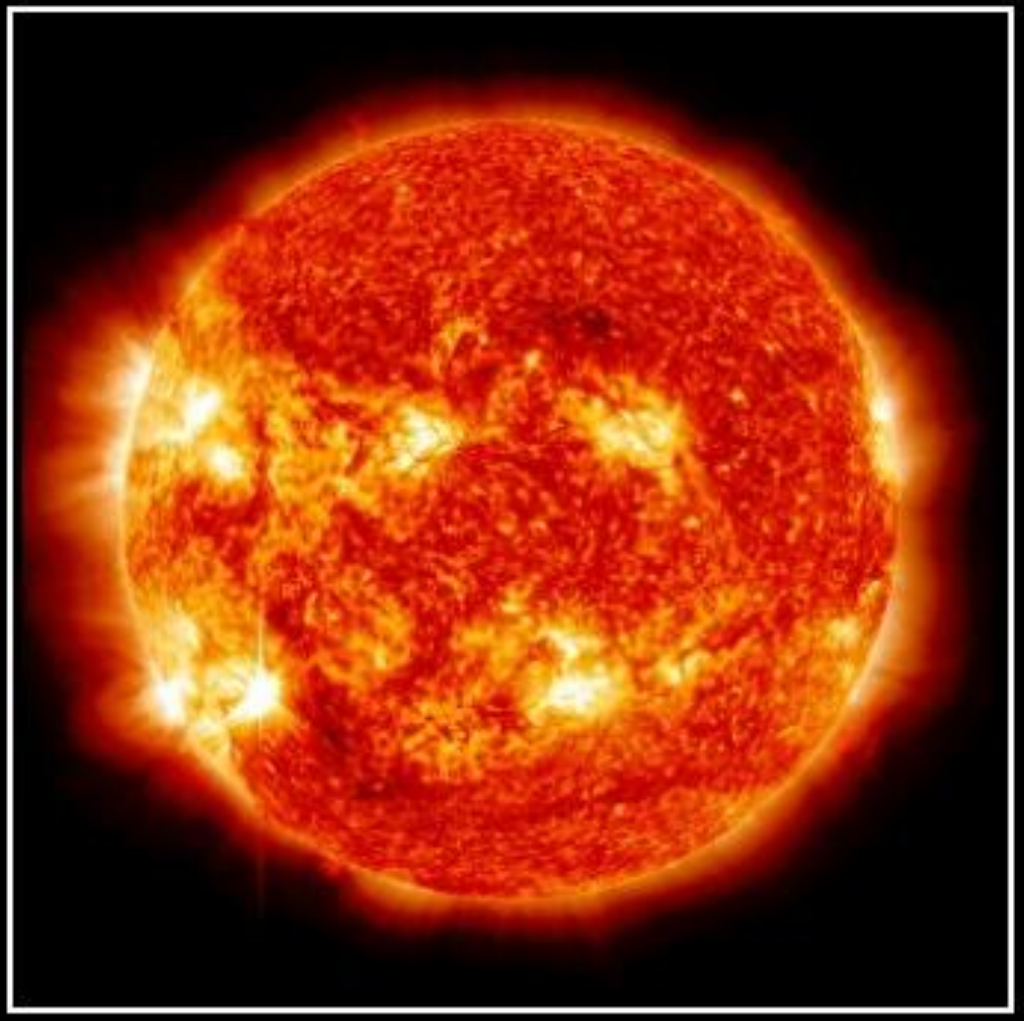
What I’ve actually been doing

- Fourier transforms


dB/dt (V)
10
0
50
100
150
200
250
300
350
400
t (ms)


Frequency (kHz)
500
400
300
200
100
0
50
100
150
200
250
300
350
400
t (ms)
2
1
0
−1
−2
−3


1.0
0.8
0.6
0.4
0.2
0.0
Time to Disruption (s)
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
t (s)



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