EBERHARD KARLS
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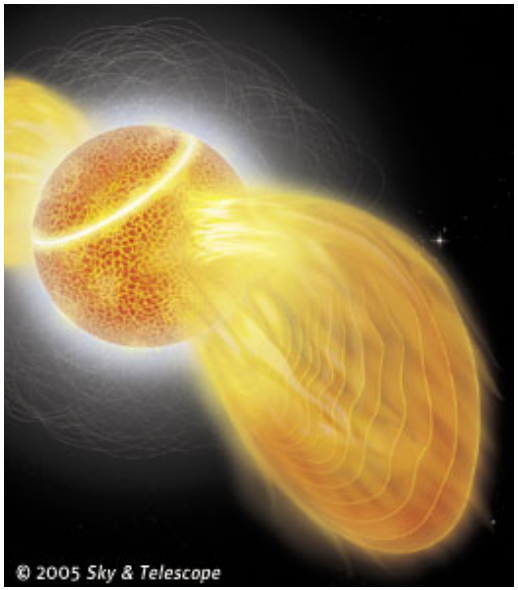
TÜBINGEN

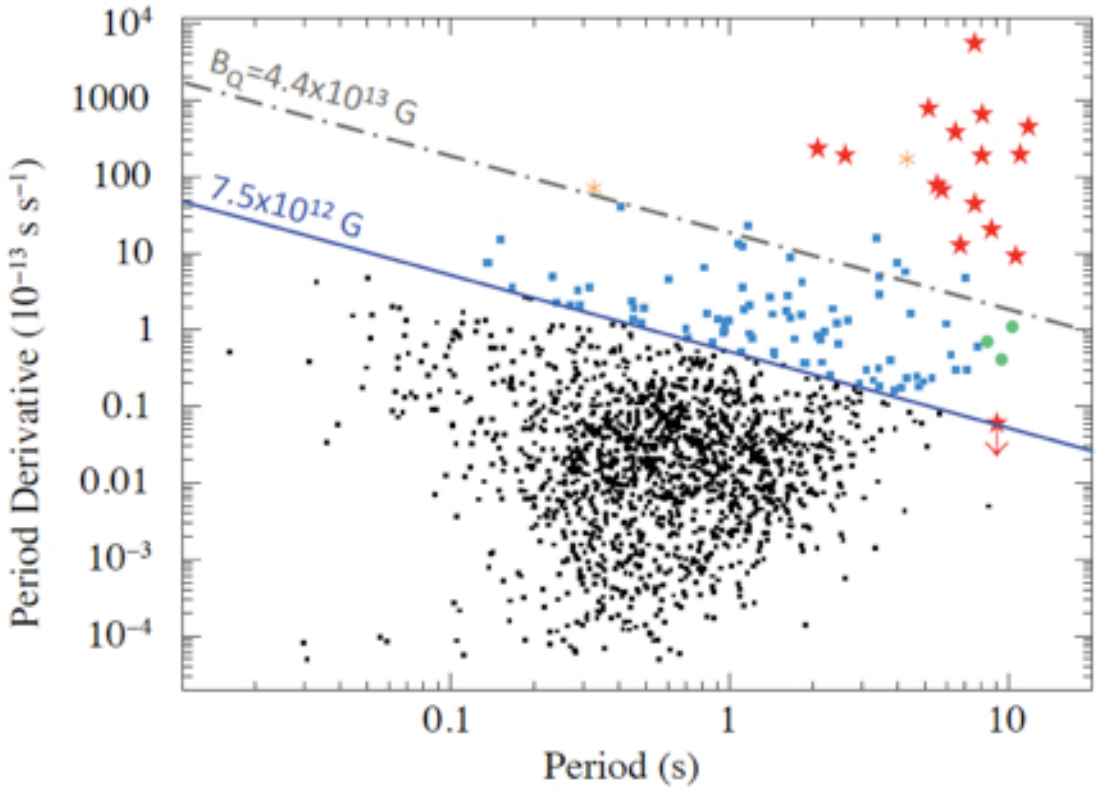
Magnetar Dynamics & Gravitational Waves



KOSTAS KOKKOTAS

- ✓ *Are gravitational waves from giant magnetar flares observable?* ***B. Zink, P.D. Lasky, K.D. Kokkotas (2011)*** ***arXiv:1107.1689v1 [gr-qc]***
- ✓ *Hydromagnetic Instabilities in Neutron Stars.* ***P.D Lasky, B. Zink, K.D. Kokkotas, K. Glampedakis, ApJ, 735, L20 (2011)***
- ✓ *HORIZON: Accelerated General Relativistic Magnetohydrodynamics* ***B. Zink (2011)*** ***arXiv:1102.5202v1 [gr-qc]***
- ✓ *Magnetars oscillations in the presence of a crust* ***A. Colaiuda & K.D.Kokkotas MNRAS 414, 3014 (2011)***

Strong Magnetic Fields in Neutron Stars



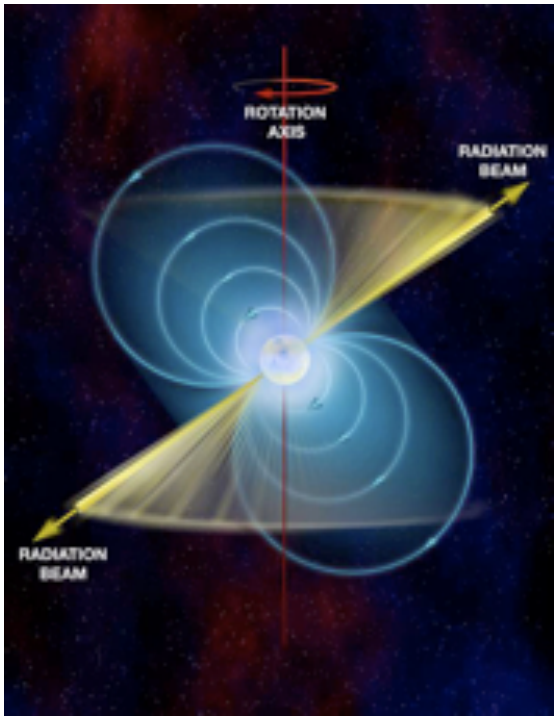
- **Rotation varies due to magnetic breaking**
- **Only infer exterior dipole component**

$$B_d \sim 3.2 \times 10^{19} \left(P\dot{P}\right)^{1/2} G$$

- **Magnetars**

$$B_d \geq 10^{14} - 10^{15} G$$

Magnetars



- **Young, slowly spinning (P~10s) systems (about 21)**
- **Exhibit regular γ-ray flares**
  - Believed to be powered by magnetic field
  - Either trigger or are preceded by starquakes
  - Some linked to glitches
- **Three giant flares observed with peak luminosities ~10^{47} erg/s**
  - March 5, 1979 : SGR 0526-66
  - August 27, 1998 : SGR 1900+14
  - December 27, 2008: SGR 1806-20
- **Giant flares**
  - QPOs – 10's -100's of Hz
  - Magnetic field reconstruction
  - Possible f-mode excitation

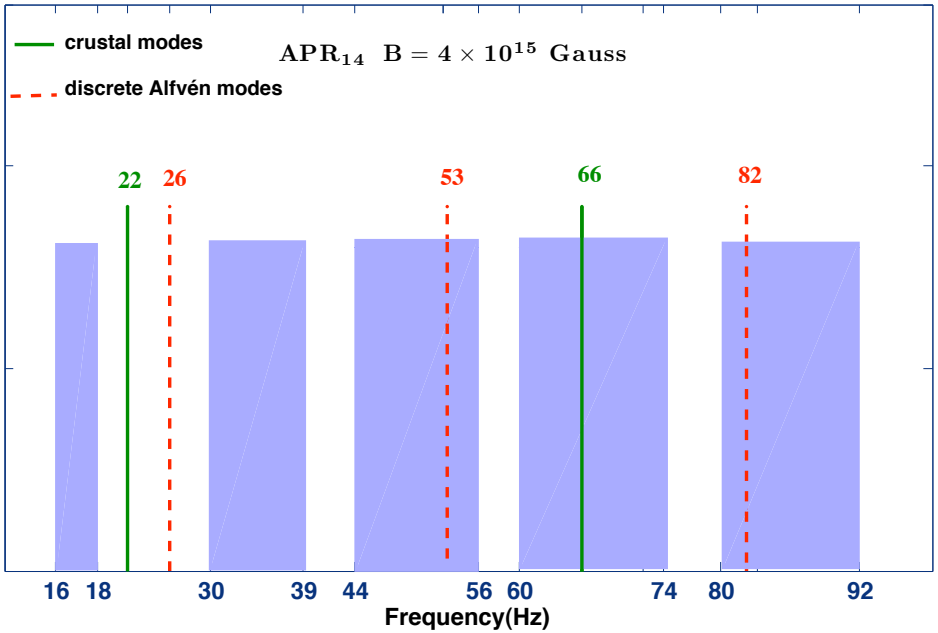
Magnetars

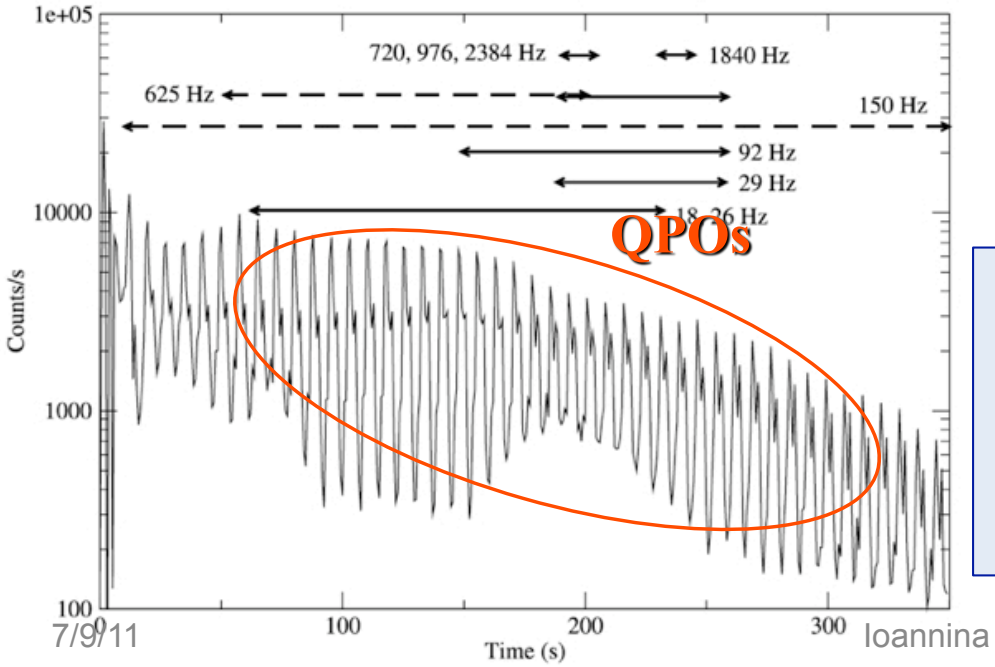
QPOs in decaying tail (Israel *et al.* 2005; Watts & Strohmayer 2005, 2006)

SGR 1900+14 : 28, 54, 84, & 155 Hz

SGR 1806-20 : **18**, **26**, 29, 92.5, 150, 626.5, 720, 1837 & 2384 Hz

- A few more : 17, 21, 36, 59, 116 Hz (Habaryan, Neuhauser, KK 2011)





Sotani, KK, Stergioulas '07,`08,'09
Levin `07,`08,`10, Glampedakis etal '07
Cerda-Duran etal '09,'10, Samuelsson etal '07
Colaiuda+KK '08,`09,`11

For **SGR 1806-20** (Colaiuda+KK '09,'11)

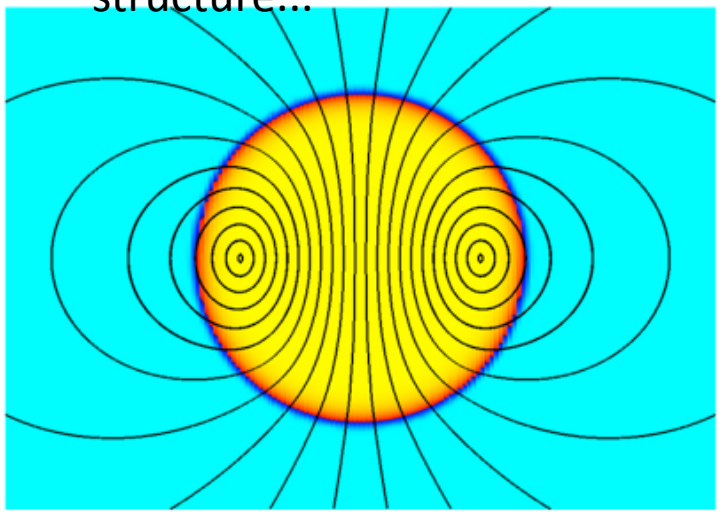
- We show that crust and Alfvén modes can explain all observed QPOs.
- The magnetar has EoS **APR**, mass **1.4M$_\odot$** and **11.6km** radius.

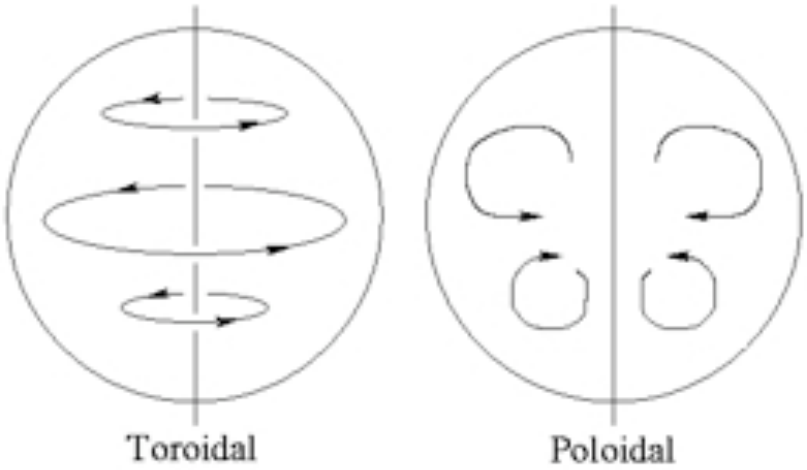
Our aim…

- **3D - GRMHD simulations of known and arbitrary initial magnetic field configurations**

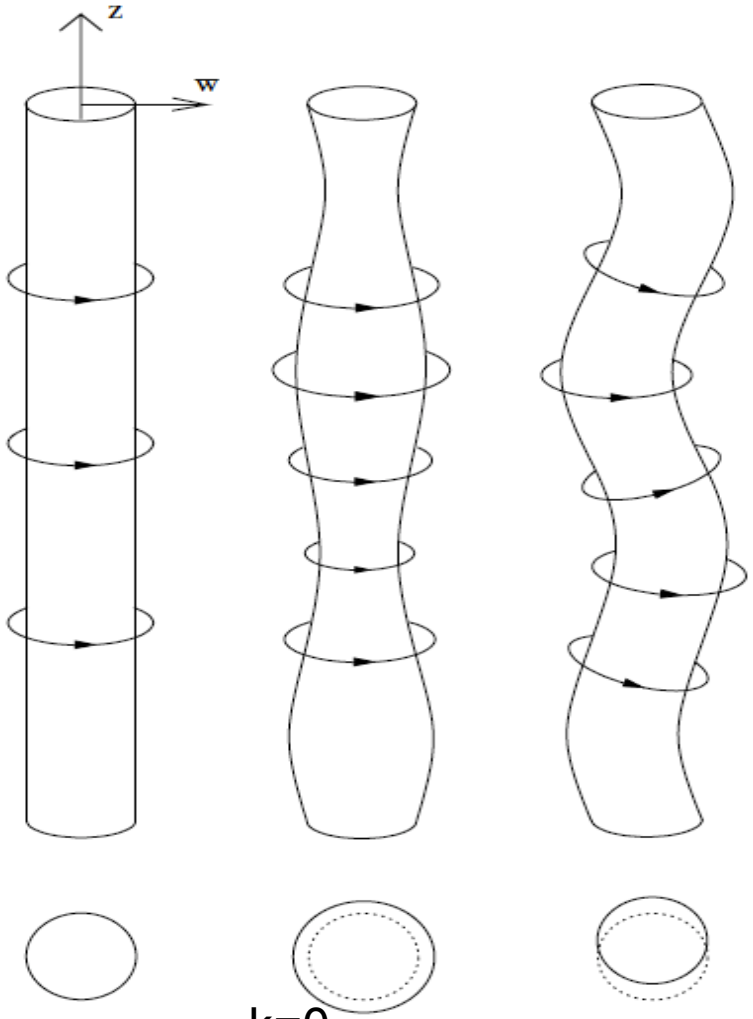
- **Magnetic field instabilities relevant for flare generation** instability mechanisms, relevant timescales, phenomenology (GR)

- **Understanding stable magnetic field configurations** mixed poloidal - toroidal configurations, relevant strengths of components, multipolar structure...



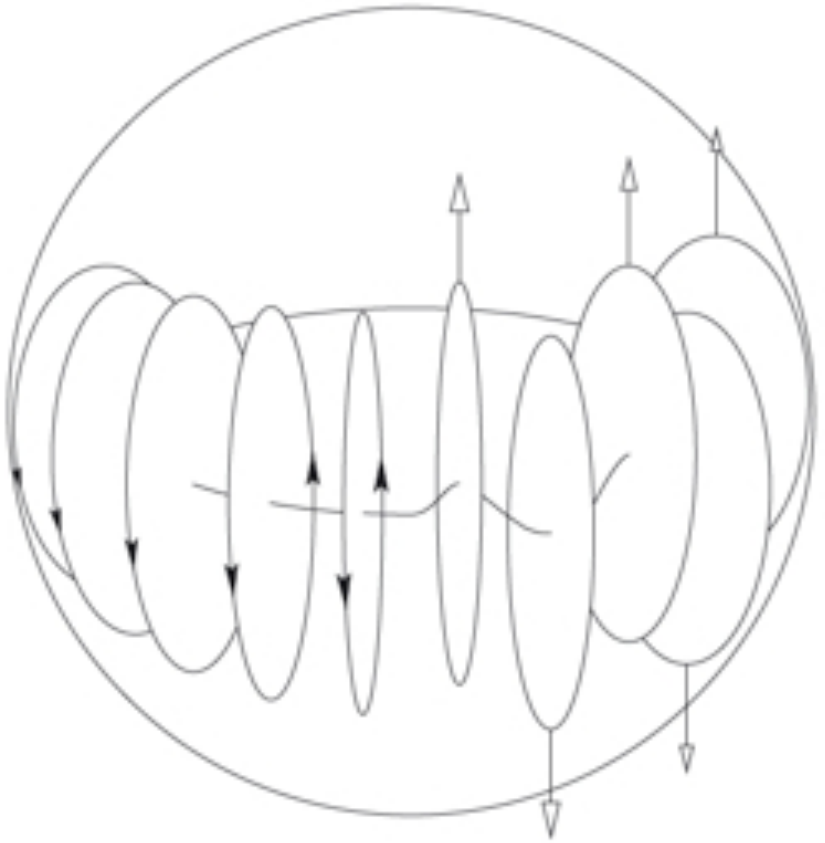


Poloidal Field Instabilities



k=0
"Varicose/
Sausage"

k=1
kink

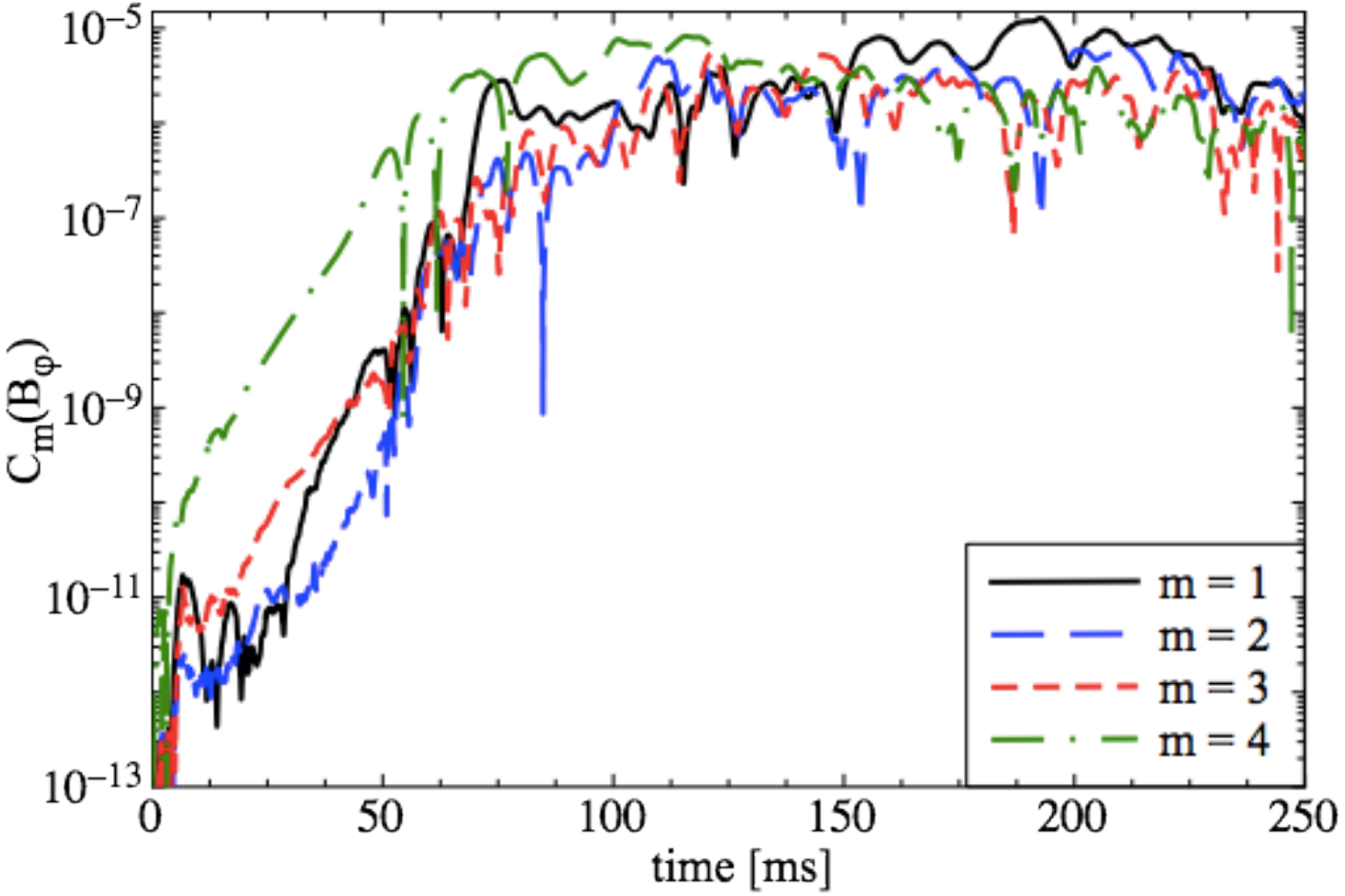


Markey & Tayler 1973
Braithwaite& Spruit 2006


✓ 3 Dimensional
✓ Fully Non-Linear
✓ General Relativistic
✓ GR-MHD
✓ Cactus
THOR
Horizon
GPU version of THOR
(the fastest code in the market!)
www.elantifaz.cjb.net

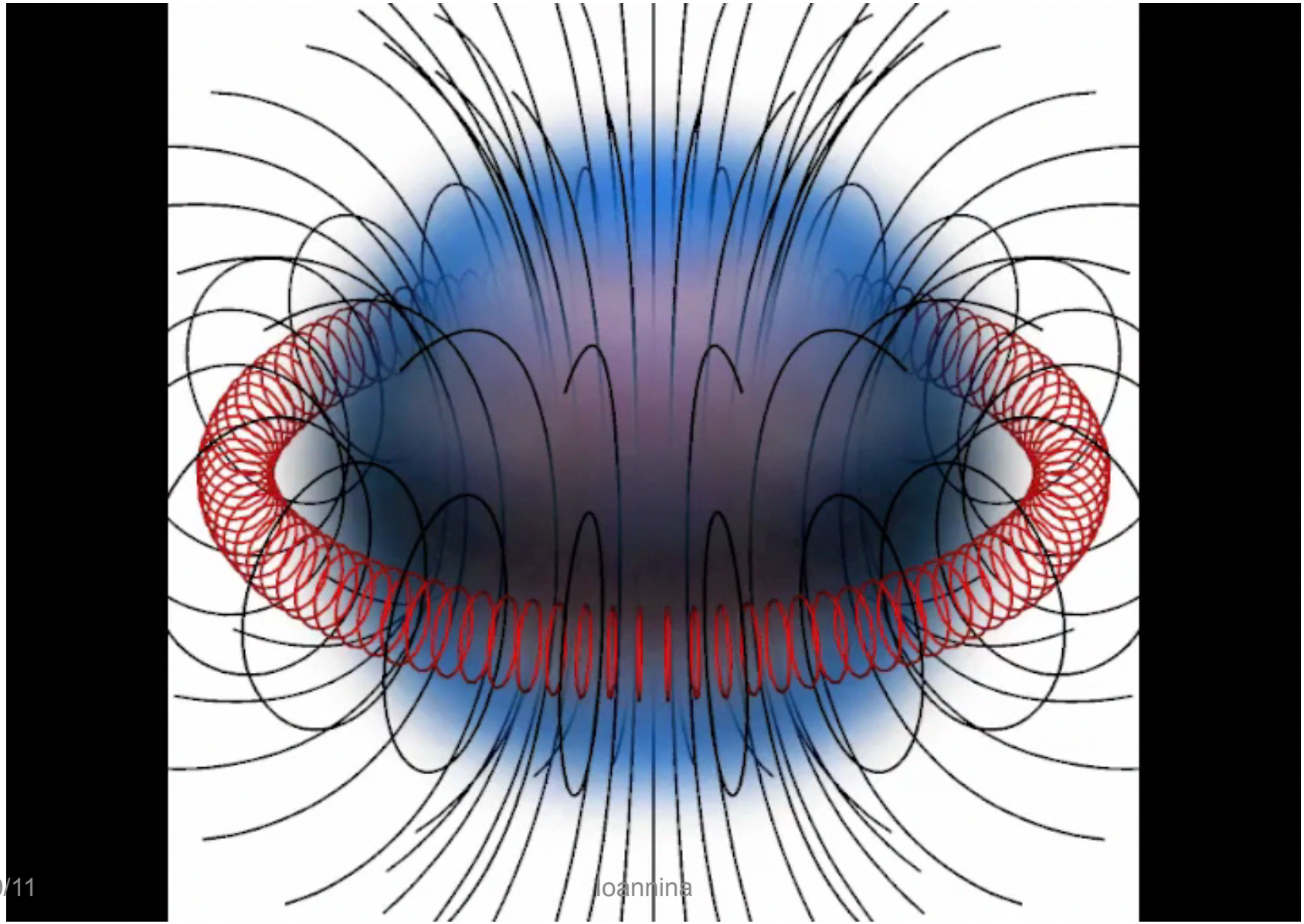
Poloidal Field Instabilities

Lasky, Zink, KK, Glampedakis ApJL (2011)



Simulation of Magnetic Field Instability

Lasky, Zink, KK, Glampedakis ApJL (2011)



GW from Magnetars

- **EM energies**: SGR 1806-20, 2004 …… ~5×10^{46} erg
- GW energy upper limits (Abadie etal 2011)
  - White noise: 3×10^{44} erg
  - F-mode: 2×10^{47} erg

Theoretical Work

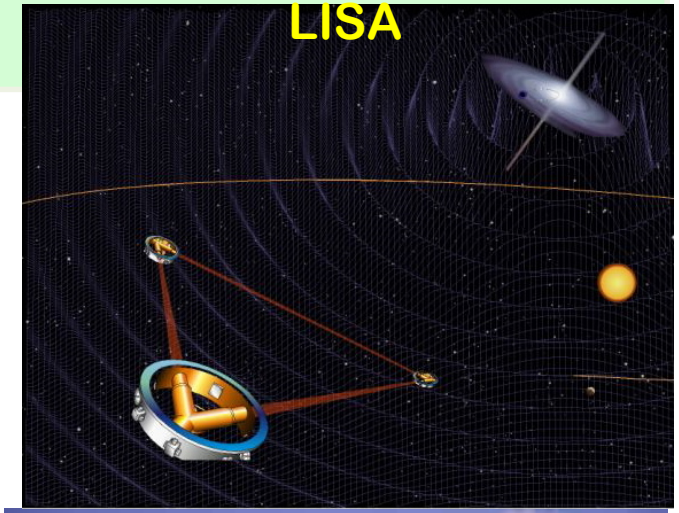
- **Ioka (2001)** – change in moment of inertia from optimal B-field reconfigure …….. 10^{49} erg
- **Corsi & Owen (2011**) – as above …….. 10^{49} erg
- **Levin & van Hoven (2011)** – excitation of f-mode from external field excitation …… $\leq 10^{41}$ erg
- **Ciolfi etal (2011)** - NR excitation of the f-mode fro inertial field rearrangements (B~10^{17}) **(S/N ~2-5)**

Interferometer Projects

- ✓ Current detectors can measure strains $\Delta L/L \sim 10^{-21}$ on timescales of 0.01 s.
- ✓ Over 4 km this corresponds to $\Delta L \sim 10^{-16}$ cm, smaller than a proton.

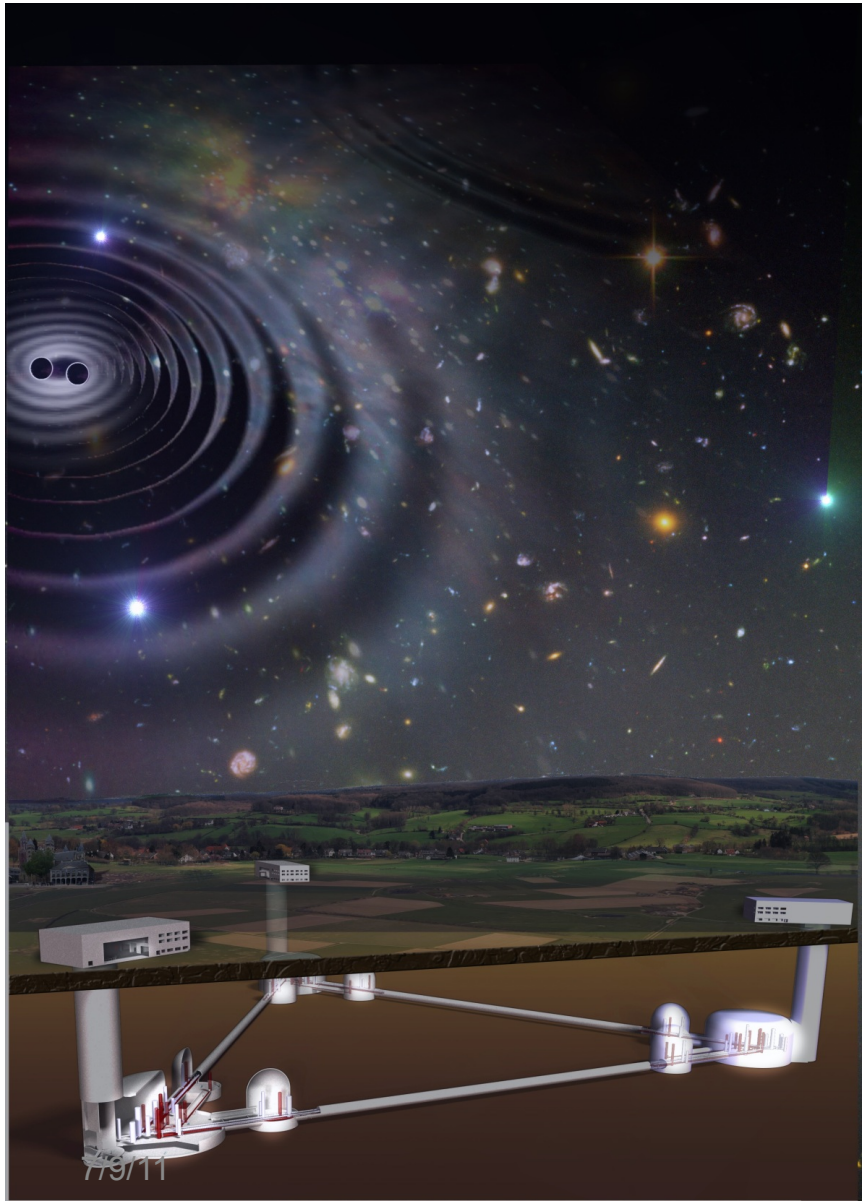
GEO

LIGO



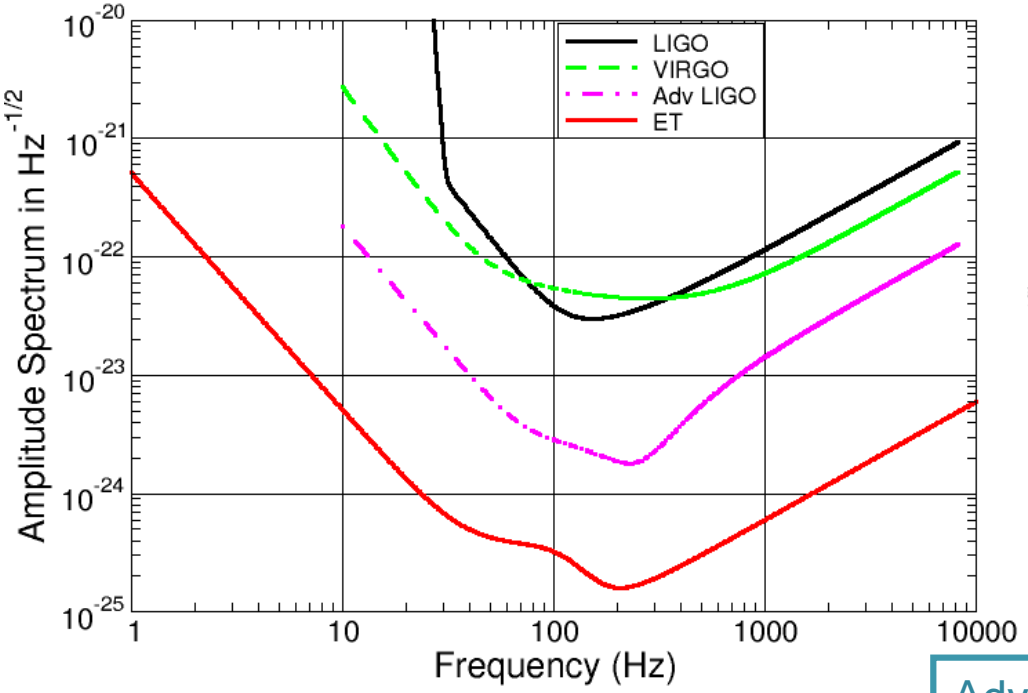
VIRGO

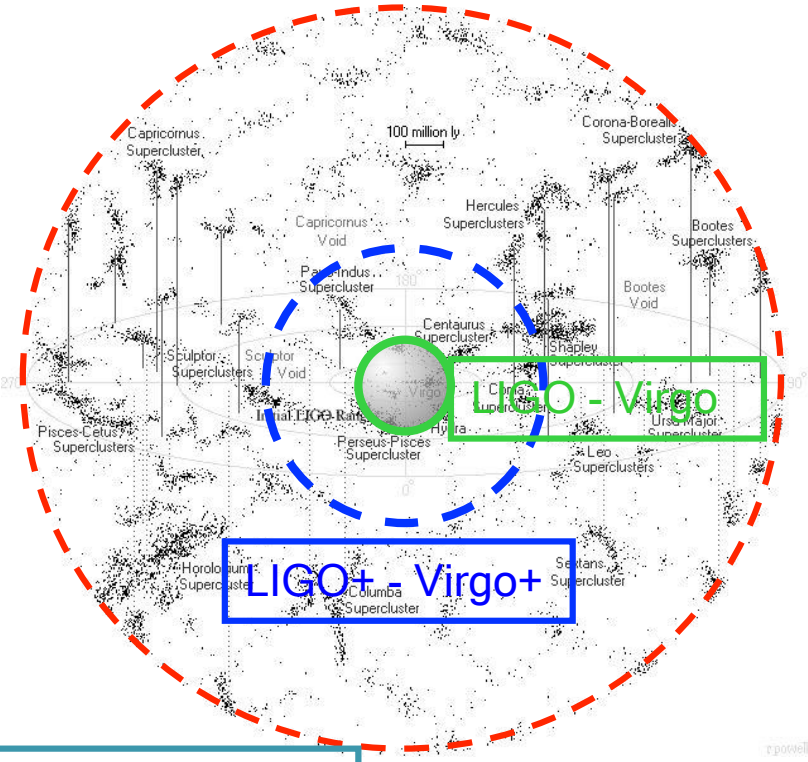
Einstein Telescope (ET)



- ✓ Entering the era of routine GW astronomy
- ✓ A pan-European project
- ✓ Built underground
- ✓ 10 km triangle
- ✓ Timescale: start 2018 lasting for many decades

Towards GW Astronomy
2014...

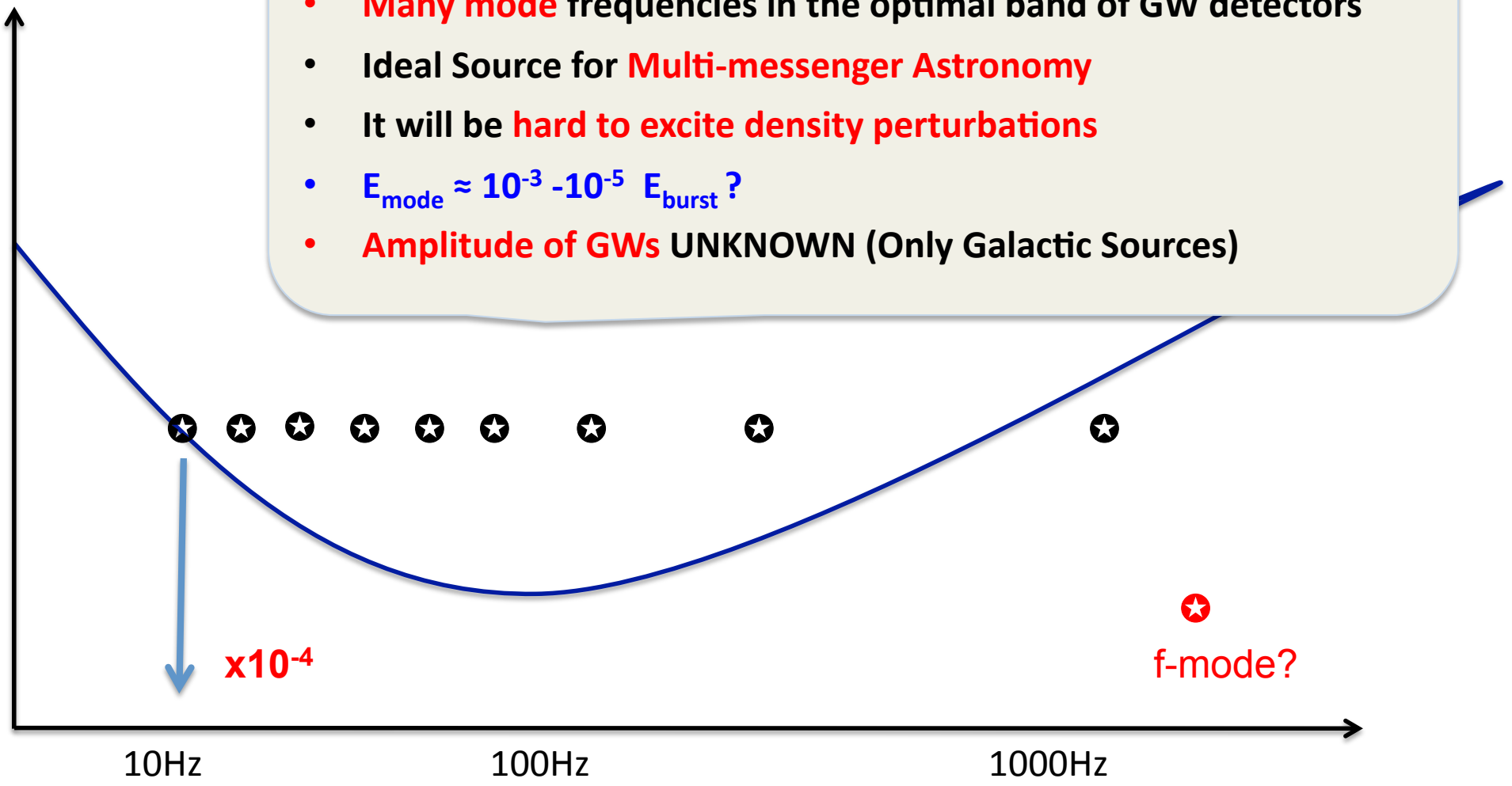




Credit: R.Powell

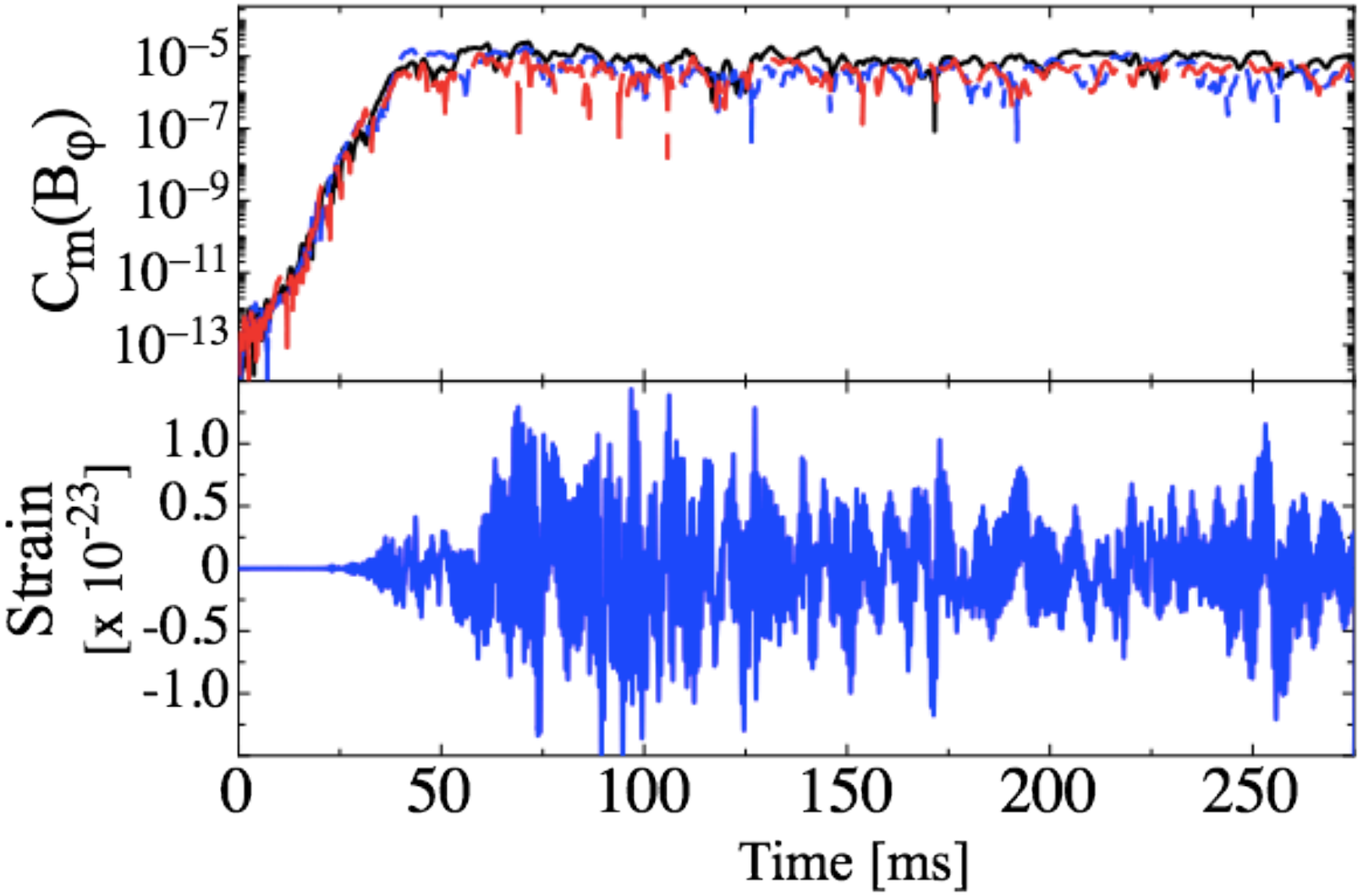
Magnetars & GWs

- Many mode frequencies in the optimal band of GW detectors
- Ideal Source for Multi-messenger Astronomy
- It will be hard to excite density perturbations
- $E_{mode} \approx 10^{-3} - 10^{-5}\ E_{burst}$?
- Amplitude of GWs UNKNOWN (Only Galactic Sources)

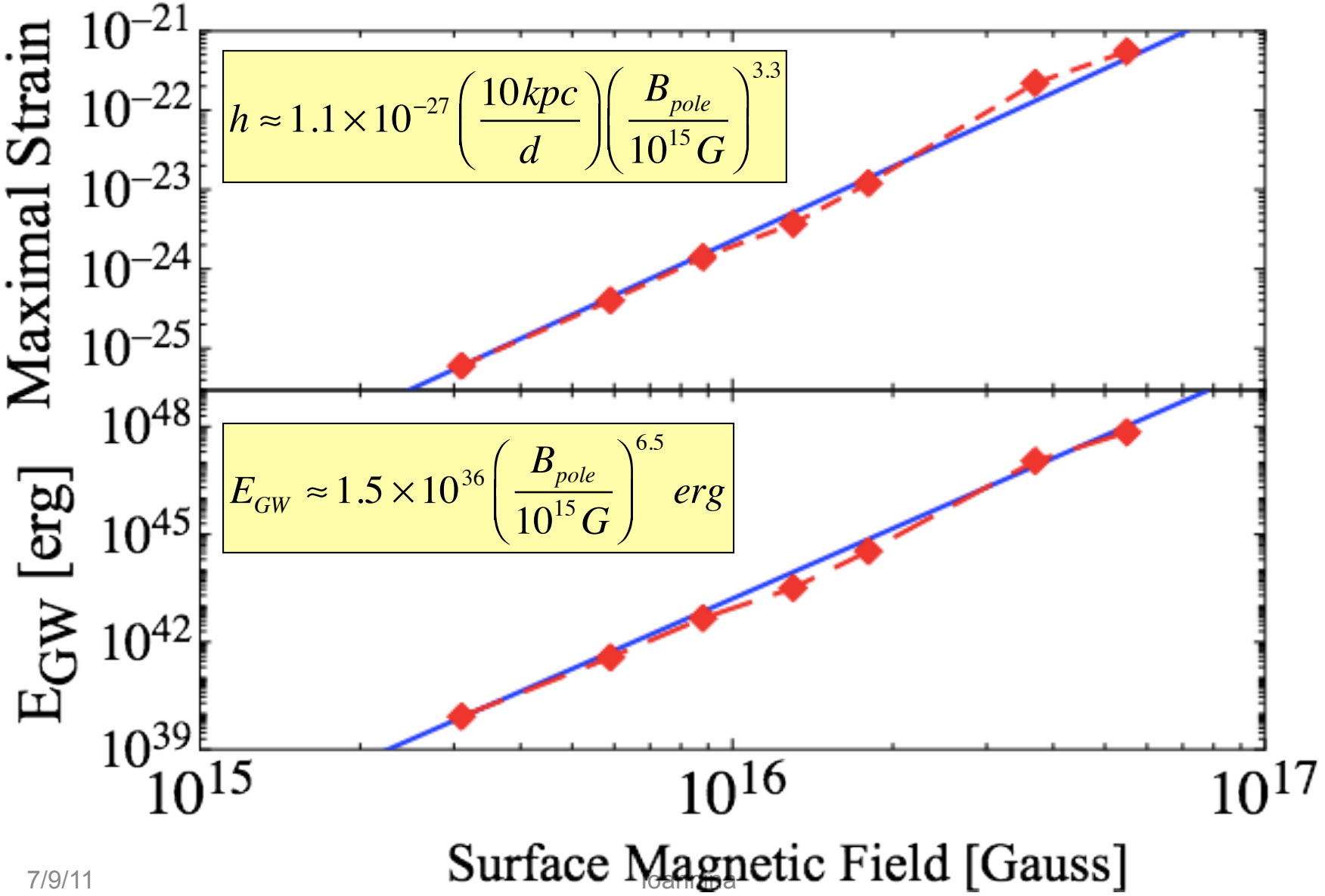


Gravitational Waves

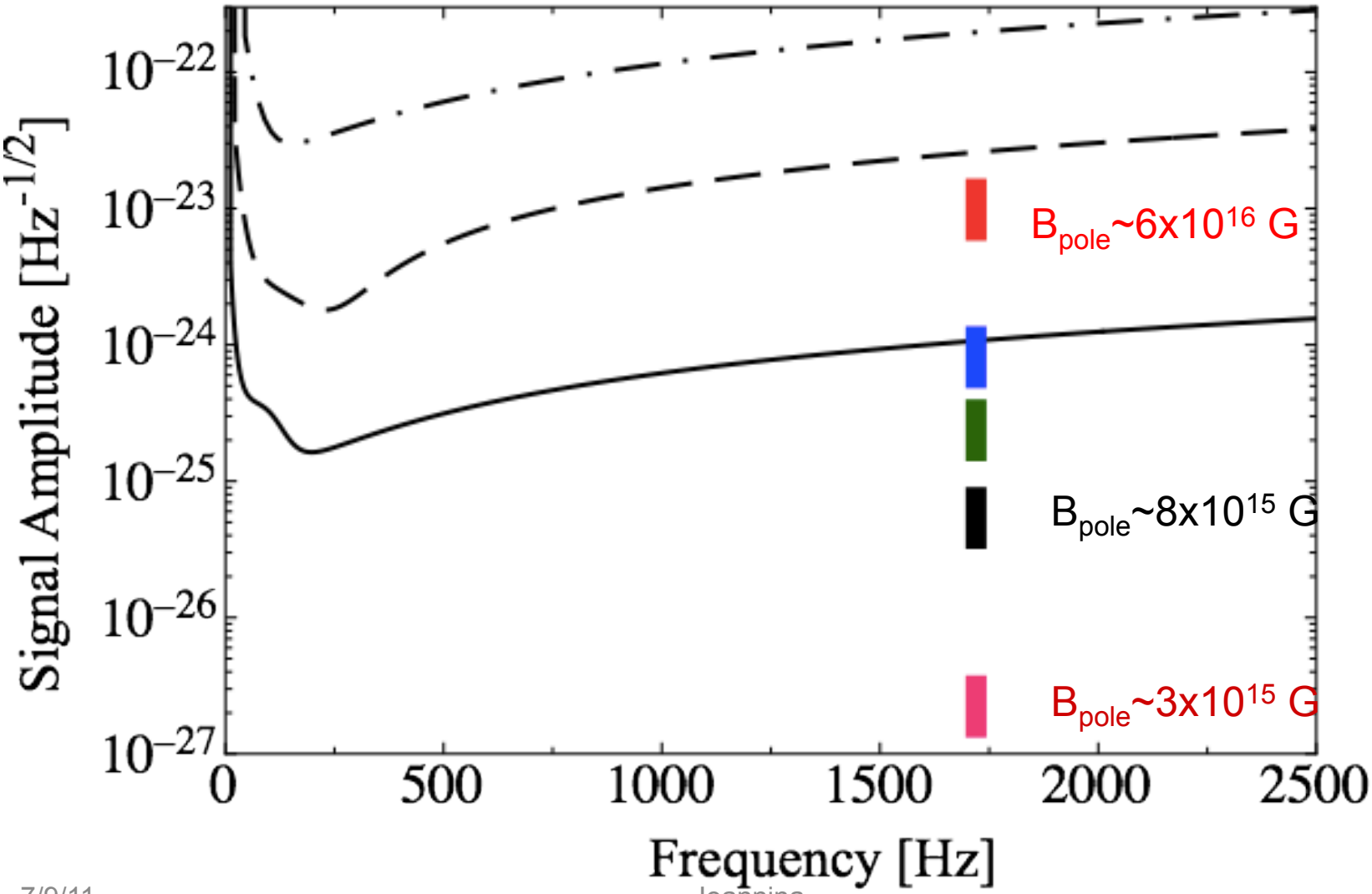
Zink, Lasky, KK (2011)



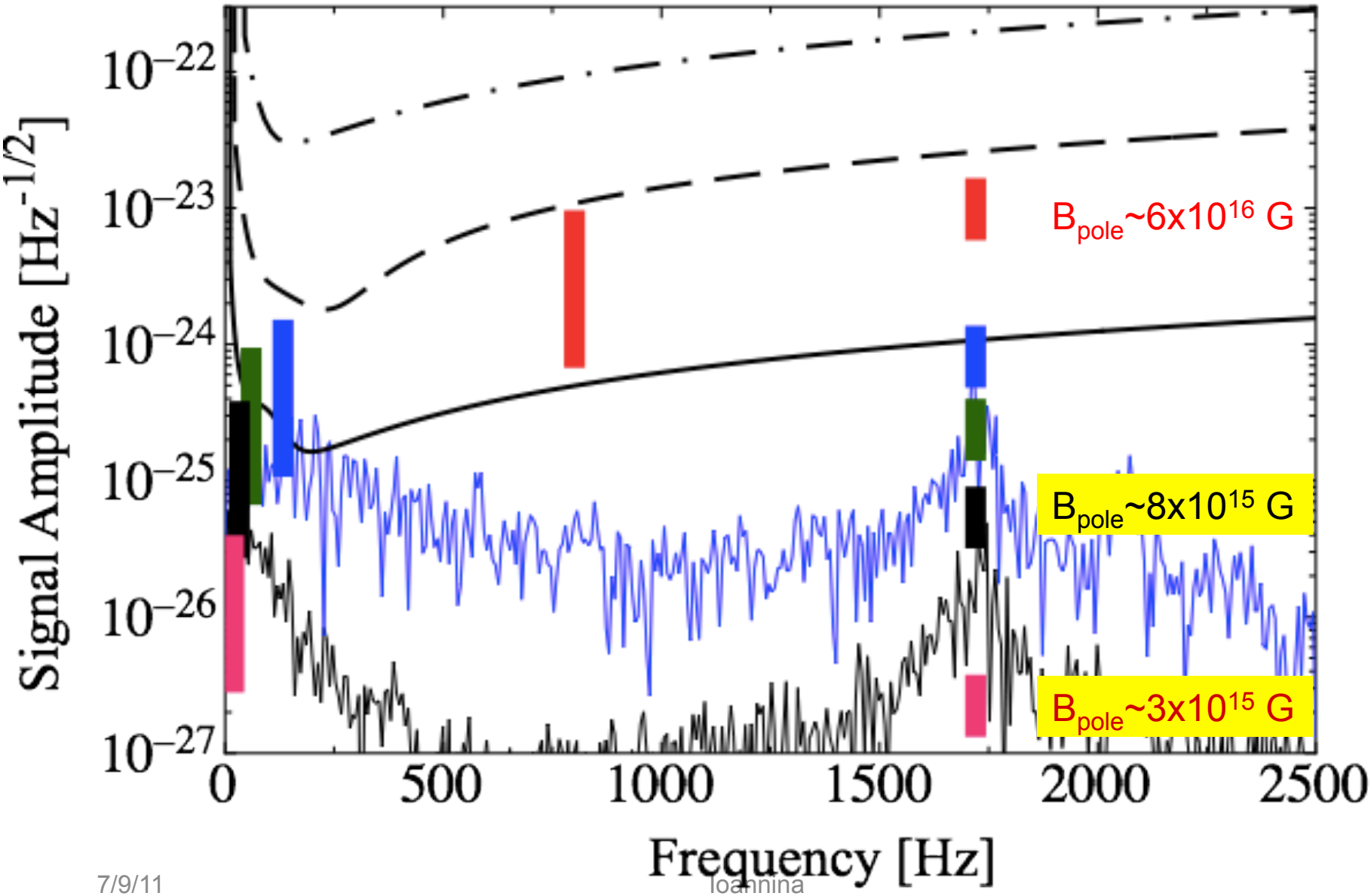
Gravitational Waves



Detectability I



Detectability II



Conclusion

- Study of the global, catastrophic magnetic field reconfiguration with 3D-GRMHD simulations
  - Attempted upper limit for internal mechanisms

- **f-modes**
  - $E_{GW} \sim 10^{41 - 43}$ for "observed" B-field strengths
  - **Unlikely detection!**
  - Scales like B^6 ➔ need much stronger internal field
  - Realistic fields Alfven speed << sound speed

- Alfvén & g-modes (10 - 500 Hz)
  - Very dynamic background in simulations
  - More work required - watch this space...

Outlook

What could change this picture?

- **More coherent motion in Alfvén waves**
- **Alternative magnetic field topologies**
  - Hard to imagine changing emission by orders of magnitude
  - Should be tested
- **Strong internal toroidal field?**
  - Recent work on equilibria shows this is not likely
  - Ciolfi et al. 2009, Glampedakis et al. 2011, Lander et al. 2011
- **Superconductivity in core**
  - Boosts Alfvén speed by 20 - 80%
  - Promotes better coupling with f-mode