# We use seismology to image large-scale stellar magnetism
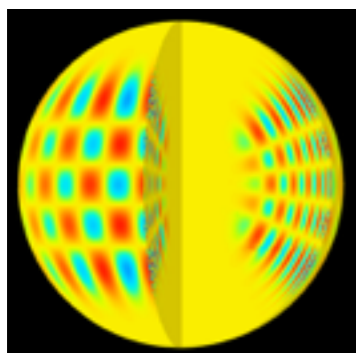
- Measurements of acoustic wavefield at the surface: $O(10^{12})$ for the Sun and $O(10^4)$ for stars

- Parameters: $O(10^6)$ magnetic field, flows, sound speed

- Forward model: hyperbolic linear wave equation

- We have a good starting model

- Adjoint method with conjugate gradient / L-BFGS

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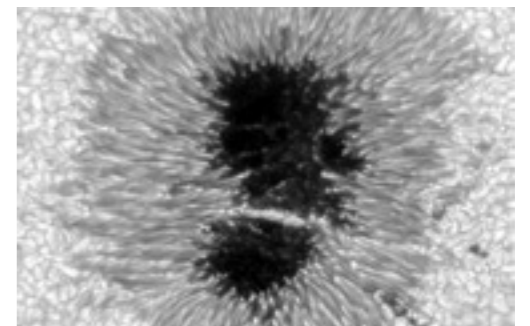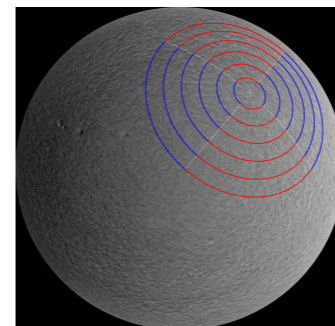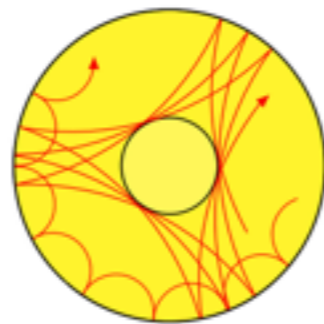
We want PETSc-based wave solvers!

- Frequency-domain (implicit) solution of wave equation

$$\mathcal{L}\xi = -\omega^2\rho\xi - 2i\omega\rho\mathbf{v_0}\cdot\nabla\xi - i\omega\rho\Gamma\xi - \nabla(c^2\rho\nabla\cdot\xi) - \nabla(\xi\cdot\nabla p) + \mathbf{g}\nabla\cdot(\rho\xi)$$
$$-(\nabla\times\mathbf{B})\times[\nabla\times(\xi\times\mathbf{B})] - \{\nabla\times[\nabla\times(\xi\times\mathbf{B})]\}\times\mathbf{B}$$

- Fast parallel solutions required to solve inverse problems

- Typical grid sizes for appropriately-resolved domains ~ 256^3

- Cartesian and Spherical geometry

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Preliminary work suggests forward solvers are expensive

- Convergence is slow, how to speed up?

- Bigger stencils

```
anlextwls026-248:PETSC shravan$ mpiexec -np 4 ./ex5f90 -options_file ops
 0 KSP unpreconditioned resid norm 1.697056274849e+02 true resid norm 1.697056274849e+02 ||r(i)||/||b|| 1.0
 1 KSP unpreconditioned resid norm 1.304952821798e+02 true resid norm 1.304952821798e+02 ||r(i)||/||b|| 7.6
 2 KSP unpreconditioned resid norm 1.302194518260e+02 true resid norm 1.302194518260e+02 ||r(i)||/||b|| 7.6
 3 KSP unpreconditioned resid norm 1.292907265780e+02 true resid norm 1.292907265780e+02 ||r(i)||/||b|| 7.6
 4 KSP unpreconditioned resid norm 1.292475972608e+02 true resid norm 1.292475972608e+02 ||r(i)||/||b|| 7.6
 5 KSP unpreconditioned resid norm 1.267708357934e+02 true resid norm 1.267708357934e+02 ||r(i)||/||b|| 7.4
 6 KSP unpreconditioned resid norm 1.266366102640e+02 true resid norm 1.266366102640e+02 ||r(i)||/||b|| 7.4
 7 KSP unpreconditioned resid norm 1.253782266562e+02 true resid norm 1.253782266562e+02 ||r(i)||/||b|| 7.3
 8 KSP unpreconditioned resid norm 1.243221881858e+02 true resid norm 1.243221881858e+02 ||r(i)||/||b|| 7.3
 9 KSP unpreconditioned resid norm 1.225396142169e+02 true resid norm 1.225396142169e+02 ||r(i)||/||b|| 7.2
10 KSP unpreconditioned resid norm 1.225362381818e+02 true resid norm 1.225362381818e+02 ||r(i)||/||b|| 7.2
11 KSP unpreconditioned resid norm 1.211559062522e+02 true resid norm 1.211559062522e+02 ||r(i)||/||b|| 7.
12 KSP unpreconditioned resid norm 1.208311012541e+02 true resid norm 1.208311012541e+02 ||r(i)||/||b|| 7.
13 KSP unpreconditioned resid norm 1.207383545266e+02 true resid norm 1.207383545266e+02 ||r(i)||/||b|| 7.
14 KSP unpreconditioned resid norm 1.202364335225e+02 true resid norm 1.202364335225e+02 ||r(i)||/||b|| 7.0
15 KSP unpreconditioned resid norm 1.198456258006e+02 true resid norm 1.198456258006e+02 ||r(i)||/||b|| 7.0
^Cmpiexec: killing job...

anlextwls026-248:PETSC shravan$ more ops
-da_grid_x 96
-da_grid_y 300
-ksp_monitor_true_residual
-ksp_type fgmres
-options_left 1
-pc_type gamg
-ksp_view
-mg_levels_ksp_max_it 20
-mg_levels_ksp_type fgmres
-mg_levels_pc_type jacobi
-ksp_rtol 1e-10
-log_summary
```

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