GDT ECH with linear Slab Profiles cold electrons, 50ev ions

Open Additional files:

Get dispersion routines by evaluating Disper.nb
Get plotting and printing routines by evaluating PlotPack.nb
Set Parameters by opening a Parameter Window

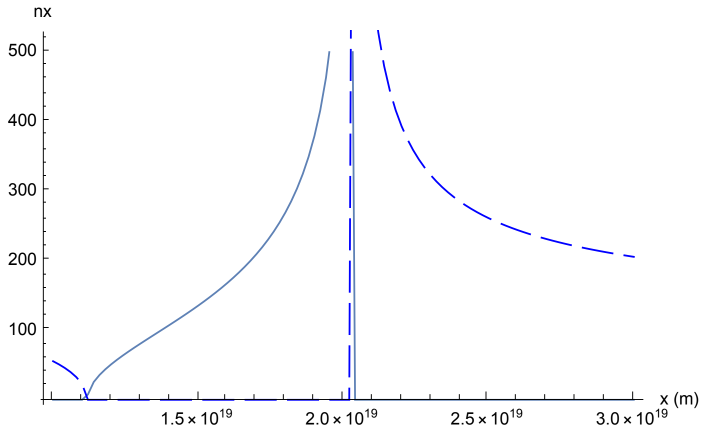
Note: Slab profile models defined in initialization cells at the bottom of this notebook.

First Do Cold Plasma

Plot Real and Imaginary parts of nx from 2nd order warm plasma dispersion relation (i.e. $E_{||}\equiv 0$)

```
In[1729]:= nPerpCold[x_] := Module[{ne, b, x0}, x0 = x;
    ne = nprof[x0];
    b = bprof[x0];
    ColdDis0[freq, ne, b, nz, etaList]]
nt = Table[{x, nPerpCold[x]}, {x, xmin, xmax, (xmax - xmin)/(nPoints - 1)}];
ComplexListPlot[nt, "x (m)", "nx"]
paramPrint[{dataSet, xProfileMin, xProfileMax,
   nXmin, nXmax, BXmin, BXmax, freq, nz, etaList, xmin, xmax}];
```

Out[1731]=



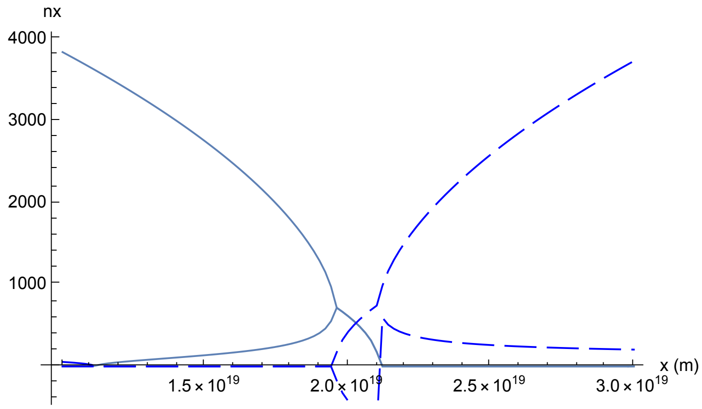

```
dataSet=GDT Kinetic Alfven 50 ev
xProfileMin=1. × 10^19
xProfileMax=3. × 10^19
nXmin=1. × 10^19
nXmax=3. × 10^19
BXmin=1.2
BXmax=1.2
freq=7.5
nz=127.324
etaList={0., 1., 0., 0., 0.}
xmin=1. × 10^19
xmax=3. × 10^19
```

Plot Real and Imaginary parts of nx from 4nd order cold plasma dispersion relation (i.e. fast and slow)

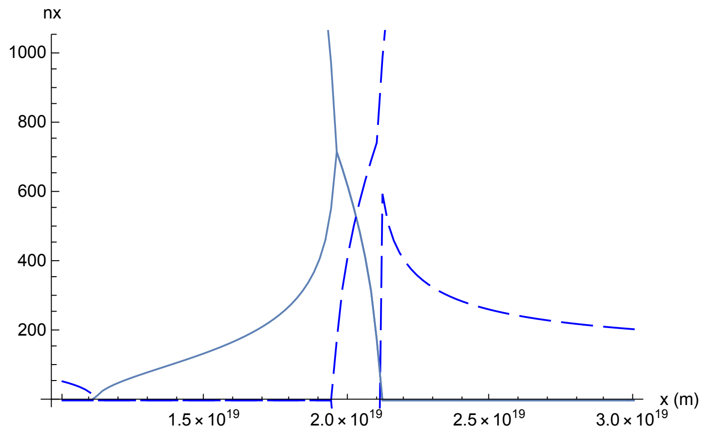
In[1733]:=

```
nPerp2FS[x_] := Module[{ne, b, x0}, x0 = x;
  ne = nprof[x0];
  b = bprof[x0];
       ColdDis2FS[freq, ne, b, nz, etaList]]
nt2FS = Table[Flatten[{x, nPerp2FS[x]}], {x, xmin, xmax, (xmax - xmin)/(nPoints - 1)}];
nF = Transpose[{Transpose[nt2FS][[1]], Transpose[nt2FS][[2]]}];
nS = Transpose[{Transpose[nt2FS][[1]], Transpose[nt2FS][[3]]}];
g1 = ComplexListPlot[nF, "x  (m)", "nx"];
g2 = ComplexListPlot[nS, "x  (m)", "nx"];
Show[{g1, g2}, PlotRange → All]
Show[{g1, g2}, PlotRange → {0., 1000.}]
paramPrint[{dataSet, xProfileMin, xProfileMax,
   nXmin, nXmax, BXmin, BXmax, freq, nz, etaList, xmin, xmin}];
```

Out[1739]=



Out[1740]=



dataSet=GDT Kinetic Alfven 50 ev

xProfileMin=$1. \times 10^{19}$

xProfileMax=$3. \times 10^{19}$

nXmin=$1. \times 10^{19}$

nXmax=$3. \times 10^{19}$

BXmin=1.2

BXmax=1.2

freq=7.5

nz=127.324

etaList={0., 1., 0., 0., 0.}

xmin=$1. \times 10^{19}$

xmin=$1. \times 10^{19}$

Now Warm Plasma Stuff

Plot Real and Imaginary parts of nx from 6th order warm plasma dispersion relation (expanded to 2nd order in $k_\perp \rho$)

In[1742]:=
```
nPerpWarm6[x_] := Module[{ne, te, b, x0, TL},
        x0 = x;
  ne = nprof[x0];
  b = bprof[x0];
     TL = tprof[x0] * TList;
     WarmDis6[freq, ne, b, nz, etaList, TL]]
```

Compare to cold plasma roots

In[1743]:=
```
nPerp2FS[xmin]
nPerpWarm6[xmin]
```

Out[1743]= {0. + 54.7543 i, 3838.1}

Out[1744]= $\{1.52288\times10^{-9} + 50.1853\,i,\ 3825.44 - 2529.23\,i,\ 3825.44 + 2529.23\,i,\ -1.52288\times10^{-9} - 50.1853\,i,\ -3825.44 + 2529.23\,i,\ -3825.44 - 2529.23\,i\}$

Gets a root near the cutoff fast wave branch, but slow wave is way off. Check if small Γ expansion is valid.

In[1745]:=
```
xpoint = 1.0 * 10^19;
TL = tprof[xpoint] * TList;
roots6 = nPerpWarm6[xpoint];
Warmgamma[freq, BXmin, roots6[[1]], TL]
Warmgamma[freq, BXmin, roots6[[2]], TL]
Warmgamma[freq, BXmin, roots6[[3]], TL]
```

Out[1748]= $\{0. + 0.\,i,\ 0. + 0.\,i,\ -0.0000899484 + 5.45898\times10^{-15}\,i,\ 0. + 0.\,i,\ 0. + 0.\,i,\ 0. + 0.\,i\}$

Out[1749]= {0. + 0. i, 0. + 0. i, 0.294178 - 0.691097 i, 0. + 0. i, 0. + 0. i, 0. + 0. i}

Out[1750]= {0. + 0. i, 0. + 0. i, 0.294178 + 0.691097 i, 0. + 0. i, 0. + 0. i, 0. + 0. i}

Small $k_x \rho$ expansion not valid for 2 large roots.

In[1751]:=
```
nPerp2FS[1.8 * 10^19]
nPerpWarm6[1.8 * 10^19]
```

Out[1751]= {276.548, 1784.18}

Out[1752]= $\{300.421 + 1.02095\times10^{-8}\,i,\ 2424.99 - 1850.53\,i,\ 2424.99 + 1850.53\,i,\ -300.421 - 1.02095\times10^{-8}\,i,\ -2424.99 + 1850.53\,i,\ -2424.99 - 1850.53\,i\}$

Here we get 3 propagating roots. Check if small Γ expansion is valid.

In[1753]:=
```
xpoint = 1.8 * 10^19;
TL = tprof[xpoint] * TList;
roots6 = nPerpWarm6[xpoint];
Warmgamma[freq, BXmin, roots6[[1]], TL]
Warmgamma[freq, BXmin, roots6[[2]], TL]
Warmgamma[freq, BXmin, roots6[[3]], TL]
```

Out[1756]= $\{0. + 0.\,i, 0. + 0.\,i, 0.00322329 + 2.1908 \times 10^{-13}\,i, 0. + 0.\,i, 0. + 0.\,i, 0. + 0.\,i\}$

Out[1757]= $\{0. + 0.\,i, 0. + 0.\,i, 0.0877185 - 0.320536\,i, 0. + 0.\,i, 0. + 0.\,i, 0. + 0.\,i\}$

Out[1758]= $\{0. + 0.\,i, 0. + 0.\,i, 0.0877185 + 0.320536\,i, 0. + 0.\,i, 0. + 0.\,i, 0. + 0.\,i\}$

Not valid for the large root, and I worry about the slow wave root too.

In[1759]:=
```
nPerp2FS[1.9 * 10^19]
nPerpWarm6[1.9 * 10^19]
```

Out[1759]= {407.791, 1288.35}

Out[1760]= $\{459.141 + 2.97858 \times 10^{-8}\,i, 2018.57 - 1547.85\,i, 2018.57 + 1547.85\,i, -459.141 - 2.97858 \times 10^{-8}\,i, -2018.57 + 1547.85\,i, -2018.57 - 1547.85\,i\}$

In[1761]:=
```
nPerp2FS[2.0 * 10^19]
nPerpWarm6[2.0 * 10^19]
```

Out[1761]= $\{612.814 - 423.427\,i, 612.814 + 423.427\,i\}$

Out[1762]= $\{708.224 - 1084.76\,i, 708.224 + 1084.76\,i, 1866.67 + 2.24612 \times 10^{-7}\,i, -708.224 + 1084.76\,i, -708.224 - 1084.76\,i, -1866.67 - 2.24612 \times 10^{-7}\,i\}$

In[1838]:=
```
nPerp2FS[2.1 * 10^19]
nPerpWarm6[2.1 * 10^19]
```

Out[1838]= $\{175.467 - 742.538\,i, 175.467 + 742.538\,i\}$

Out[1839]= $\{8.28196 \times 10^{-8} - 2518.38\,i, 2.46314 \times 10^{-8} + 483.329\,i, 2697.35 + 5.79755 \times 10^{-8}\,i, -8.28196 \times 10^{-8} + 2518.38\,i, -2.46314 \times 10^{-8} - 483.329\,i, -2697.35 - 5.79755 \times 10^{-8}\,i\}$

Here we get 1 propagating root. Check if small Γ expansion is valid.

In[1842]:=
```
xpoint = 2.1 * 10^19;
TL = tprof[xpoint] * TList;
roots6 = nPerpWarm6[xpoint];
Warmgamma[freq, BXmin, roots6[[1]], TL]
Warmgamma[freq, BXmin, roots6[[2]], TL]
Warmgamma[freq, BXmin, roots6[[3]], TL]
```

Out[1845]= $\{0. + 0.\,i, 0. + 0.\,i, -0.226507 - 1.48979 \times 10^{-11}\,i, 0. + 0.\,i, 0. + 0.\,i, 0. + 0.\,i\}$

Out[1846]= $\{0. + 0.\,i, 0. + 0.\,i, -0.00834307 + 8.5036 \times 10^{-13}\,i, 0. + 0.\,i, 0. + 0.\,i, 0. + 0.\,i\}$

Out[1847]= $\{0. + 0.\,i, 0. + 0.\,i, 0.259845 + 1.117 \times 10^{-11}\,i, 0. + 0.\,i, 0. + 0.\,i, 0. + 0.\,i\}$

Propagating root has Γ~0.26, expansion questionable

In[1818]:=
```
nPerp2FS[3.0 * 10^19]
nPerpWarm6[3.0 * 10^19]
```

Out[1818]= $\{0. + 205.063\,i, 0. + 3728.56\,i\}$

Out[1819]= $\{1.56244 \times 10^{-8} - 5301.1\,i, 7.17984 \times 10^{-10} + 202.855\,i, 3991.03 + 9.86508 \times 10^{-9}\,i, -1.56244 \times 10^{-8} + 5301.1\,i, -7.17984 \times 10^{-10} - 202.855\,i, -3991.03 - 9.86508 \times 10^{-9}\,i\}$

Plot kx profile for 6 th order system

In[1765]:=
```
nxwarm = Table[Flatten[{x, nPerpWarm6[x]}], {x, xmin, xmax, (xmax - xmin)/(nPoints - 1)}];
roots = rootSort[nxwarm];
rootsRe = Table[Flatten[{roots[[i]][[1]],
     Table[Re[roots[[i]][[j]]], {j, 2, Length[roots[[i]]]}]}], {i, Length[roots]}];

rootsIm = Table[Flatten[{roots[[i]][[1]],
     Table[Im[roots[[i]][[j]]], {j, 2, Length[roots[[i]]]}]}], {i, Length[roots]}];

g6 = ComplexVectorListPlot[roots, "x (m)", "nx"];
paramPrint[{dataSet, xProfileMin, xProfileMax, nXmin, nXmax, BXmin,
   BXmax, freq, nz, etaList, TeXmin, TeXmax, TList, modelList, xmin, xmax}];
Show[g6, PlotRange → All]
Show[g6, PlotRange → {-2000., 2000.}]
ComplexVectorListPlot[rootsRe, "x", "Re[kx]", PlotRange → {-2000., 2000.}]
ComplexVectorListPlot[rootsIm, "x", "Im[kx]", PlotRange → {-2000., 2000.}]
```

dataSet=GDT Kinetic Alfven 50 ev

xProfileMin=$1. \times 10^{19}$

xProfileMax=$3. \times 10^{19}$

nXmin=$1. \times 10^{19}$

nXmax=3. × 10^19

BXmin=1.2

BXmax=1.2

freq=7.5

nz=127.324

etaList={0., 1., 0., 0., 0.}

TeXmin=0.1

TeXmax=0.1

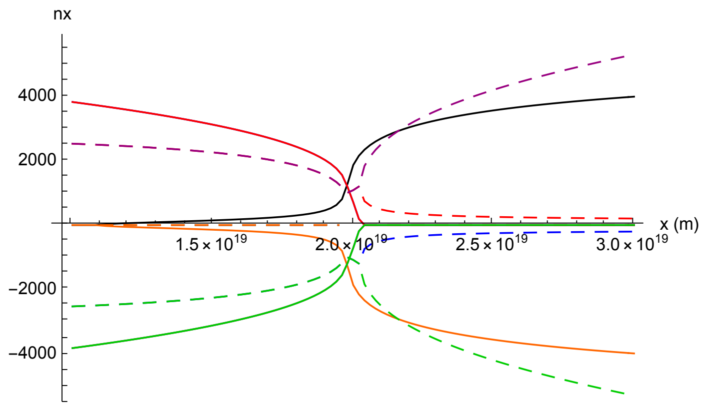
TList={0., 0., 1., 0., 0., 0.}

modelList={2, 2, 2, 2, 2, 2}

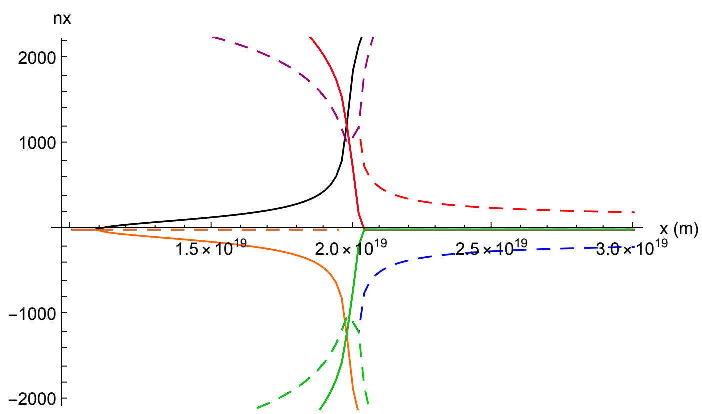
xmin=1. × 10^19

xmax=3. × 10^19

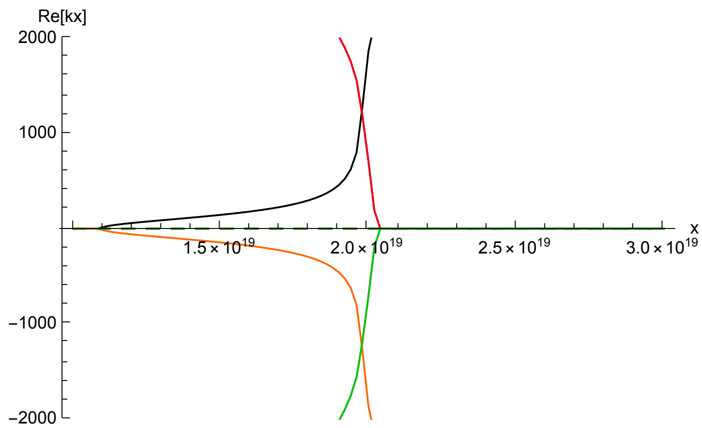
Out[1771]=



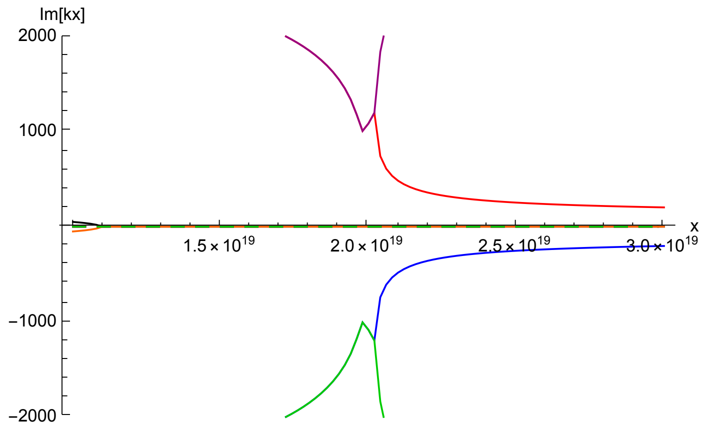
Out[1772]=



Out[1773]=



Out[1774]=



There finally is something that looks like Stix's KAW picture. BUT electrons are cold and $k_x\,\rho$ expansion is questionable.

Now Try with Hot Plasma Dispersion using root finder

In[1775]:=
```
nPerpHot[x_, nxGuess_] := Module[{ne, b, x0, TL, nx0},
        x0 = x;
  nx0 = nxGuess;
  ne = nprof[x0];
  b = bprof[x0];
  TL = tprof[x0] * TList;
rootRule = FindRoot[DisFuncGeneral[freq, ne, b, nz, nx, etaList, TL,
     nminList, nmaxList, modelList], {nx, nx0}, MaxIterations -> 30];
  nx /. rootRule]
```

First try root finding on warm plasma dispersion rel (model = 1)

In[1776]:=
```
modelList = Table[1, {i, 1, 6}];
```

Compare to cold plasma and 6th order system roots

In[1777]:=
```
xpoint = 1.0 * 10^19;
TL = tprof[xpoint] * TList;
roots6 = nPerpWarm6[xpoint]
nPerpHot[xpoint, roots6[[1]]]
nPerpHot[xpoint, roots6[[2]]]
nPerpHot[xpoint, roots6[[1]]]
nPerpHot[xpoint, roots6[[2]]]
nPerpHot[xpoint, roots6[[3]]]
```

Out[1779]= $\{1.52288 \times 10^{-9} + 50.1853\, i,\ 3825.44 - 2529.23\, i,\ 3825.44 + 2529.23\, i,\ -1.52288 \times 10^{-9} - 50.1853\, i,\ -3825.44 + 2529.23\, i,\ -3825.44 - 2529.23\, i\}$

Out[1780]= $1.52288 \times 10^{-9} + 50.1853\, i$

Out[1781]= $3825.44 - 2529.23\, i$

Out[1782]= $1.52288 \times 10^{-9} + 50.1853\, i$

Out[1783]= $3825.44 - 2529.23\, i$

Out[1784]= $3825.44 + 2529.23\, i$

Solutions from FindRoot (nPerpHot) agree with solutions from NSolve (nPerpWarm). But still not valid.

Look closer to resonance

In[1785]:=
```
xpoint = 1.8 * 10^19;
TL = tprof[xpoint] * TList;
roots6 = nPerpWarm6[xpoint]
nPerpHot[xpoint, roots6[[1]]]
nPerpHot[xpoint, roots6[[2]]]
nPerpHot[xpoint, roots6[[1]]]
nPerpHot[xpoint, roots6[[2]]]
nPerpHot[xpoint, roots6[[3]]]
```

Out[1787]= $\{300.421 + 1.02095 \times 10^{-8}\, i,\ 2424.99 - 1850.53\, i,\ 2424.99 + 1850.53\, i,\ -300.421 - 1.02095 \times 10^{-8}\, i,\ -2424.99 + 1850.53\, i,\ -2424.99 - 1850.53\, i\}$

Out[1788]= $300.421 + 1.02095 \times 10^{-8}\, i$

Out[1789]= $2424.99 - 1850.53\, i$

Out[1790]= $300.421 + 1.02095 \times 10^{-8}\, i$

Out[1791]= $2424.99 - 1850.53\, i$

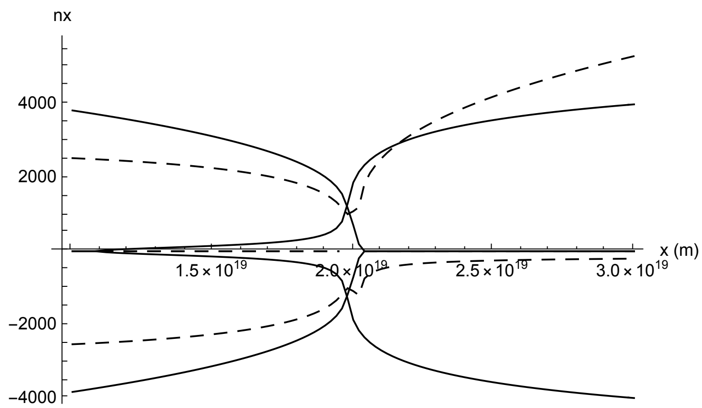
Out[1792]= $2424.99 + 1850.53\, i$

Plot nx profile from root finder but still with 6th order system (model = 1)

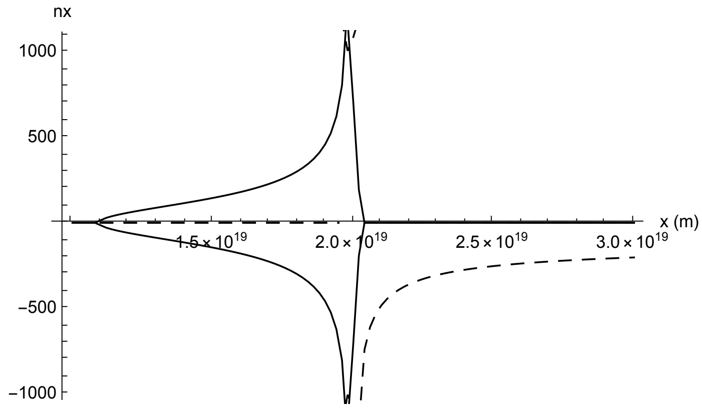
In[1793]:=
```
modelList = Table[1, {i, 1, 6}];(* Set model *)
```

In[1794]:=
```
nxhot[iRoot_] := Module[{iRoot0, nxWarm, rootsWarm, nxH, x0, ne, b, t, TL},
   nxWarm = Table[Flatten[{x, nPerpWarm6[x]}], {x, xmin, xmax, (xmax - xmin)/(nPoints - 1)}];
   iRoot0 = iRoot;
   rootsWarm = rootSort[nxWarm];
   nxH = Table[0., {i, 1, nPoints}];
   Do[
    (x0 = xmin + (i - 1) (xmax - xmin)/(nPoints - 1);
     nxGuess = rootsWarm[[i]][[iRoot0 + 1]];
     (*Print["x0 = ", x0,"  nxGuess= ",nxGuess];*)
     nxH[[i]] = {x0, nPerpHot[x0, nxGuess]};), {i, 1, nPoints}];
   nxH];
g7 = ComplexVectorListPlot[nxhot[1], "x (m)", "nx"];
g8 = ComplexVectorListPlot[nxhot[2], "x (m)", "nx"];
g9 = ComplexVectorListPlot[nxhot[3], "x (m)", "nx"];
g10 = ComplexVectorListPlot[nxhot[4], "x (m)", "nx"];
g11 = ComplexVectorListPlot[nxhot[5], "x (m)", "nx"];
g12 = ComplexVectorListPlot[nxhot[6], "x (m)", "nx"];
Show[{g7, g8, g10, g11}, PlotRange → All]
Show[{g7, g8, g10, g11}, PlotRange → {-1000., 1000.}]
paramPrint[{dataSet, xProfileMin, xProfileMax, nXmin, nXmax, BXmin,
   BXmax, freq, nz, etaList, TeXmin, TeXmax, TList, modelList, xmin, xmax}];
```

Out[1798]=



Out[1799]=




```
dataSet=GDT Kinetic Alfven 50 ev
xProfileMin=1. × 10^19
xProfileMax=3. × 10^19
nXmin=1. × 10^19
nXmax=3. × 10^19
BXmin=1.2
BXmax=1.2
freq=7.5
nz=127.324
etaList={0., 1., 0., 0., 0.}
TeXmin=0.1
TeXmax=0.1
TList={0., 0., 1., 0., 0., 0.}
modelList={1, 1, 1, 1, 1, 1}
xmin=1. × 10^19
xmax=3. × 10^19
```

Now try with hot plasma (model = 2) for all species. Can I find the warm plasma roots with the full dispersion relation?

- Change model to 2

In[1801]:=
```
modelList = Table[2, {i, 1, 6}];
```

In[1802]:=
```
xPoint = xmin;
nPerp2FS[xPoint]
guesses = nPerpWarm6[xPoint] (* Warm plasma roots at x=0  *)
```

Out[1803]= {0. + 54.7543 i, 3838.1}

Out[1804]= {1.52288 × 10^-9 + 50.1853 i, 3825.44 - 2529.23 i, 3825.44 + 2529.23 i, -1.52288 × 10^-9 - 50.1853 i, -3825.44 + 2529.23 i, -3825.44 - 2529.23 i}

In[1805]:=
```
{nPerpHot[xPoint, guesses[[1]]],
 nPerpHot[xPoint, guesses[[2]]],
 nPerpHot[xPoint, guesses[[3]]],
 nPerpHot[xPoint, guesses[[4]]],
 nPerpHot[xPoint, guesses[[5]]],
 nPerpHot[xPoint, guesses[[6]]]}
paramPrint[{dataSet, xProfileMin, xProfileMax, nXmin, nXmax, BXmin, BXmax, freq,
   nz, etaList, TeXmin, TeXmax, TList, modelList, nminList, nmaxList, xmin, xmax}];
```

Out[1805]= $\{1.52288\times10^{-9}+50.1853\,i,\ 4476.34-3958.2\,i,\ 4476.34+3958.2\,i,\ -1.52288\times10^{-9}-50.1853\,i,\ -4476.34+3958.2\,i,\ -4476.34-3958.2\,i\}$

dataSet=GDT Kinetic Alfven 50 ev

xProfileMin=$1.\times10^{19}$

xProfileMax=$3.\times10^{19}$

nXmin=$1.\times10^{19}$

nXmax=$3.\times10^{19}$

BXmin=1.2

BXmax=1.2

freq=7.5

nz=127.324

etaList={0., 1., 0., 0., 0.}

TeXmin=0.1

TeXmax=0.1

TList={0., 0., 1., 0., 0., 0.}

modelList={2, 2, 2, 2, 2, 2}

nminList={-1, -2, -2, -2, -2, -2}

nmaxList={1, 2, 2, 2, 2, 2}

xmin=$1.\times10^{19}$

xmax=$3.\times10^{19}$

Hot plasma root finder gets fast root but slow root is way different from 6th order, i.e. not damped. Not surprising since $k_x\,\rho$ expansion not valid Try initializing with cold plasma roots

In[1807]:=
```
nPerp2FS[xPoint]
{nPerpHot[xPoint, nPerp2FS[xPoint][[1]]], nPerpHot[xPoint, nPerp2FS[xPoint][[2]]]}
```

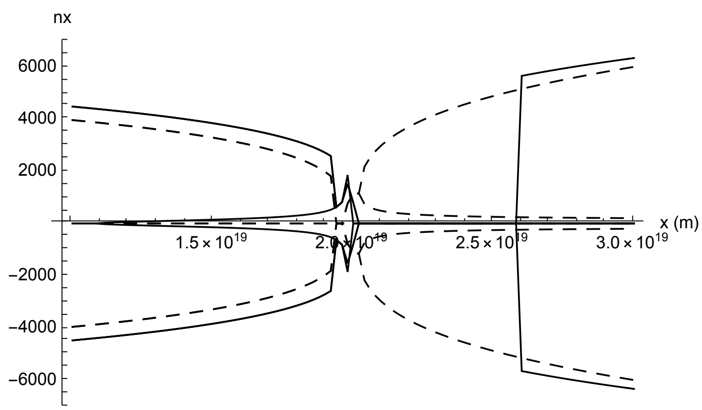
Out[1807]= $\{0.+54.7543\,i,\ 3838.1\}$

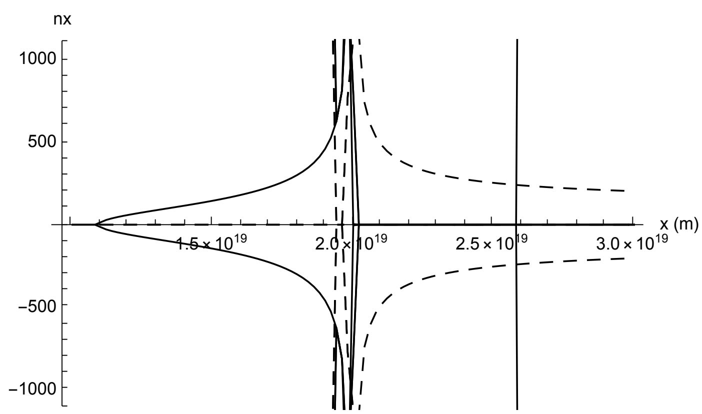
Out[1808]= $\{1.52288\times10^{-9}+50.1853\,i,\ 0.0114009+3.46098\times10^{-8}\,i\}$

Same as before.

Plot hot plasma vs x

In[1809]:=
```
g7 = ComplexVectorListPlot[nxhot[1], "x (m)", "nx"];
g8 = ComplexVectorListPlot[nxhot[2], "x (m)", "nx"];
g9 = ComplexVectorListPlot[nxhot[3], "x (m)", "nx"];
g10 = ComplexVectorListPlot[nxhot[4], "x (m)", "nx"];
g11 = ComplexVectorListPlot[nxhot[5], "x (m)", "nx"];
g12 = ComplexVectorListPlot[nxhot[6], "x (m)", "nx"];
Show[{g7, g8, g9, g10, g11, g12}, PlotRange → All]
Show[{g7, g8, g9, g10, g11, g12}, PlotRange → {-1000., 1000.}]
paramPrint[{dataSet, xProfileMin, xProfileMax, nXmin, nXmax, BXmin, BXmax, freq, nz,
   etaList, TeXmin, TeXmax, TList, modelList, nminList, nmaxList, xmin, xmax}];
```

Out[1812]=


Out[1813]=


dataSet=GDT Kinetic Alfven 50 ev

xProfileMin=$1.\times10^{19}$

xProfileMax=$3.\times10^{19}$

nXmin=$1.\times10^{19}$

nXmax=$3.\times10^{19}$

BXmin=1.2

BXmax=1.2

freq=7.5

nz=127.324

etaList={0., 1., 0., 0., 0.}

TeXmin=0.1

TeXmax=0.1

TList={0., 0., 1., 0., 0., 0.}

modelList={2, 2, 2, 2, 2, 2}

nminList={-1, -2, -2, -2, -2, -2}

nmaxList={1, 2, 2, 2, 2, 2}

xmin=$1. \times 10^{19}$

xmax=$3. \times 10^{19}$

No sign of any kinetic Alfven wave. Really looks about the same as with warm electrons

Initialization

Magnetic field,Density and Temperature Profiles

In[1815]:=
```
bprof[x_] := If[Abs[(BXmax - BXmin) / BXmax] > 10^-6,
   BXmin + (x - xProfileMin) / (xProfileMax - xProfileMin) (BXmax - BXmin), BXmin];
```

In[1816]:=
```
nprof[x_] := If[Abs[(nXmax - nXmin) / nXmax] > 10^-6,
   nXmin + (x - xProfileMin) / (xProfileMax - xProfileMin) (nXmax - nXmin), nXmin];
```

In[1817]:=
```
tprof[x_] := If[Abs[(TeXmax - TeXmin) / TeXmax] > 10^-6,
   TeXmin + (x - xProfileMin) / (xProfileMax - xProfileMin) (TeXmax - TeXmin), TeXmin];
```