3D Models of Astrophysical Masers with Polarization

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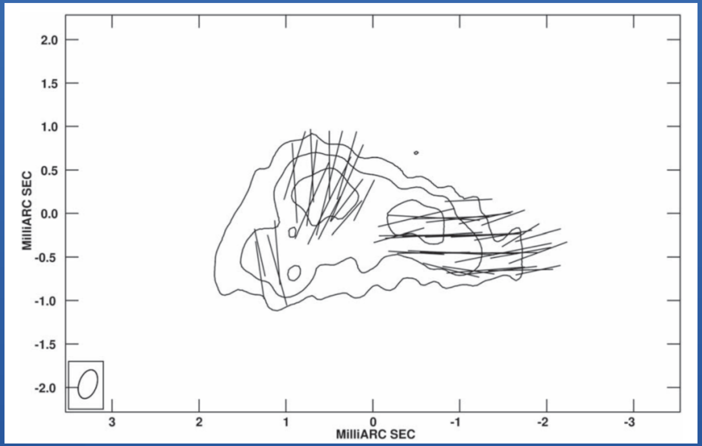
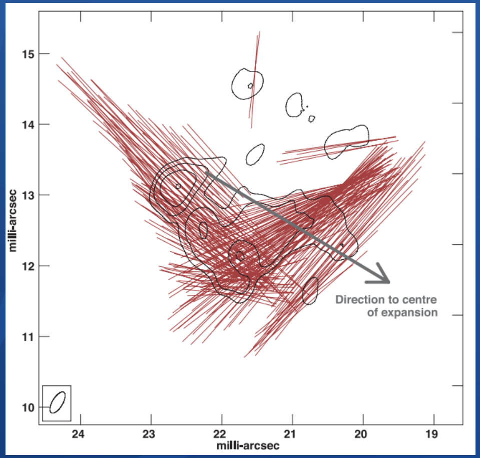
EVPA Reversals



TX Cam



R Cas

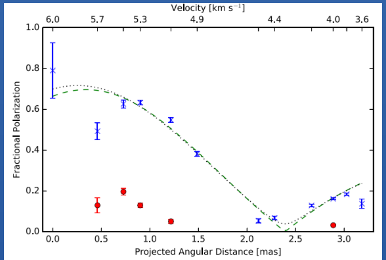
- Examples of EVPA flips ~90 degrees in single VLBI features
- TX Cam in ring SW (Tobin+, 2019)
- R Cas in ring NE (Assaf+, 2013)
- EVPA = 0.5atan(U/Q)
- Higher polarized intensity in RCas (800 vs 10)mJy/beam

Interpretations

- Zeeman

Regime $g\Omega >> R >> \Gamma$

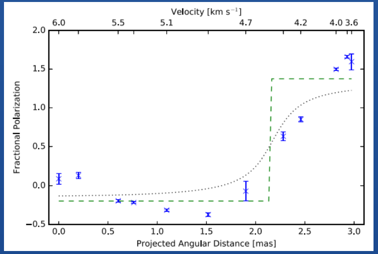
m_l as function of distance as predicted



Rotation too smooth

- Local Curvature of B

Could explain smooth transition of EVPA



Would not fit Zeeman m_l curve

- Anisotropic Radiative Pump

$g\Omega$ mixes substates too much?

Could have a null position in m_l as observed

Expected fall in m_l with r

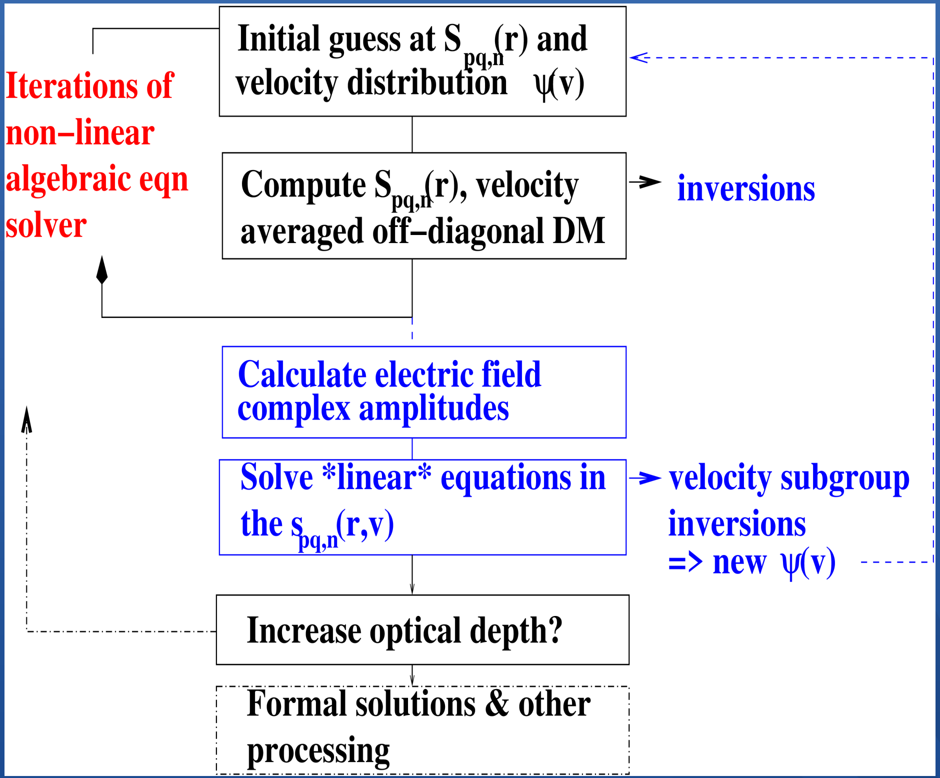
(not in TX Cam)

- Anisotropic Resonant Scattering

Difficult to get observed $m_c << m_l$: needs special field orientation

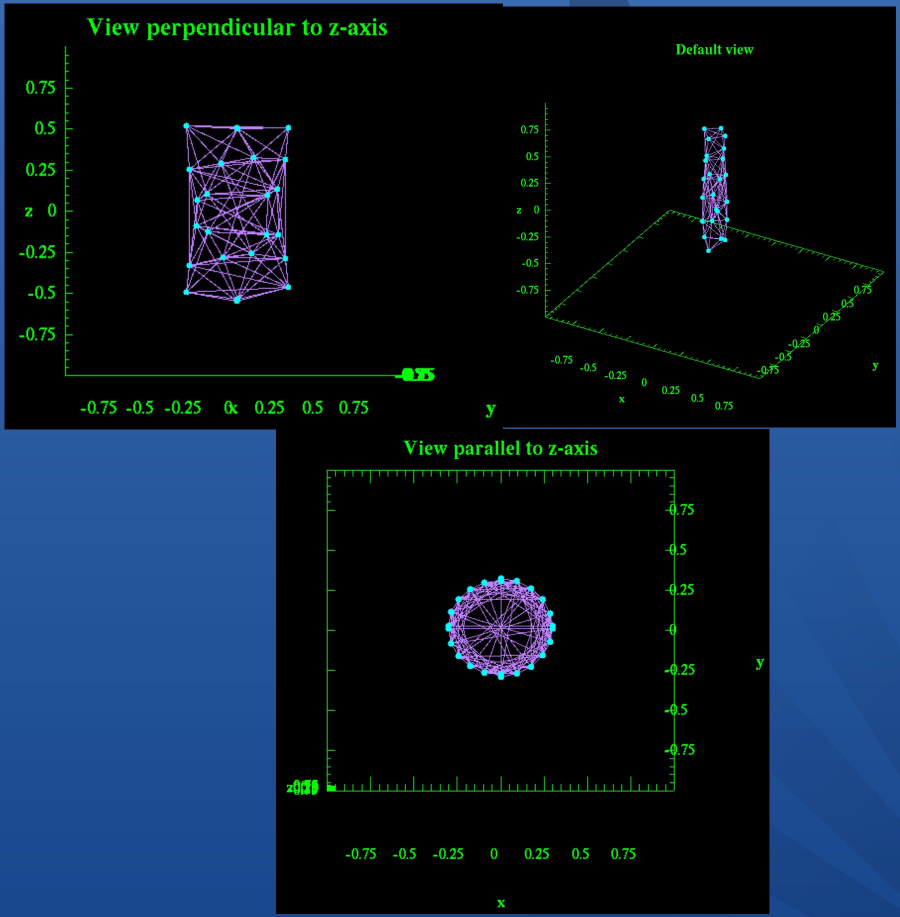
New Model

- Need to analyse irregular objects at VLBI scale
- Stokes parameters problematic in 3D
- Use electric field components; naturally leads to polarization
- Solve for off-diagonal DM elements

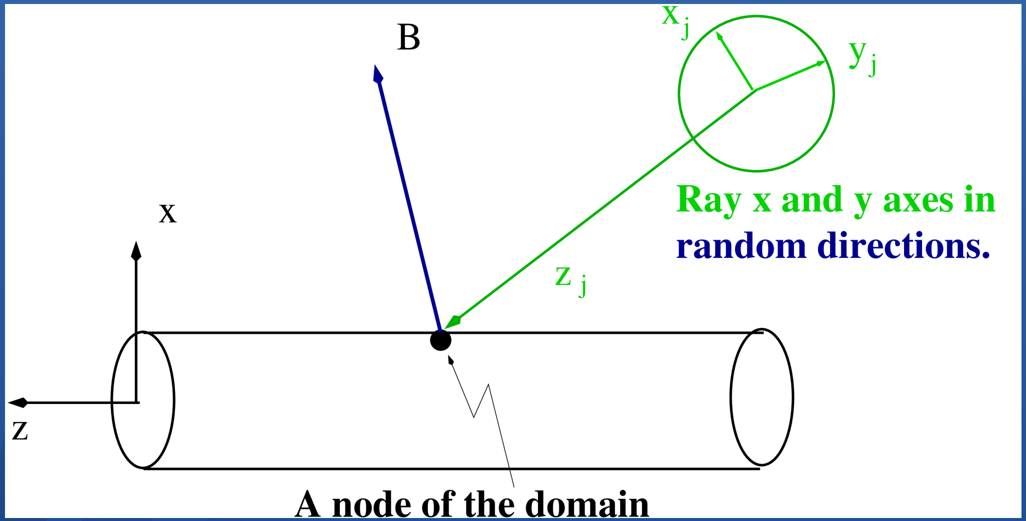


Testing: domains

- Only have 1D models for comparison
- Construct tube domains in the hope that a long, thin cylinder will do
- Various aspect ratios
- Usual model has L/r = 10
- Long axis defines global z

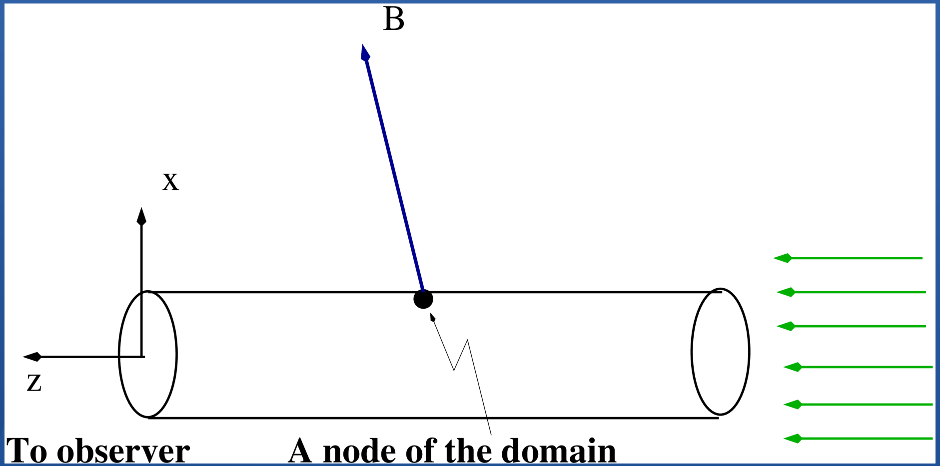


Population Solutions



- Long axis of tube always z
- Many rays, j, with own axes and come from distant sphere
- B is aligned on its own z axis
- Molecule dipoles pure in system based on B
- Solve for off-diagonal DM elements at each node
- Compute inversions

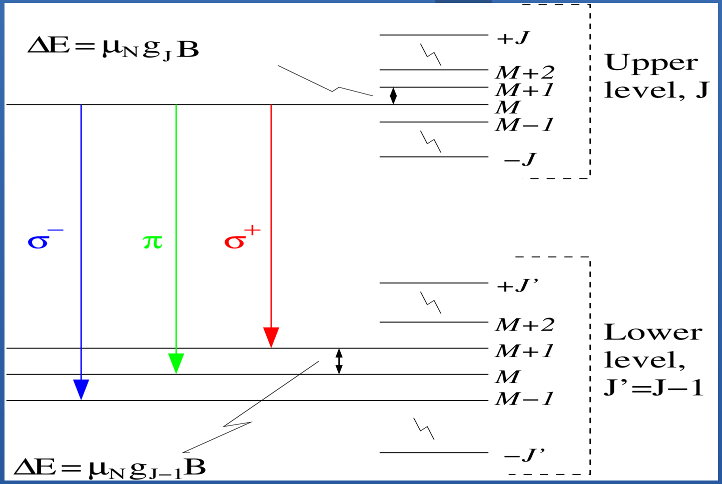
Formal Solutions

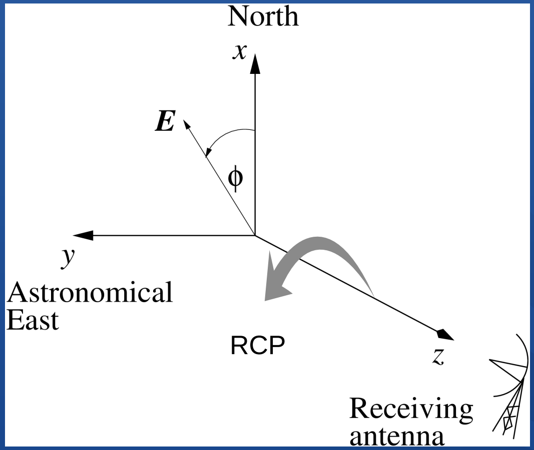


- (Almost) parallel rays from small patch of sky propagate to observer
- Current models have observer at z or -z, 1000 units away
- Inversions and DM elements now **known** at all nodes
- Calculate images, spectra

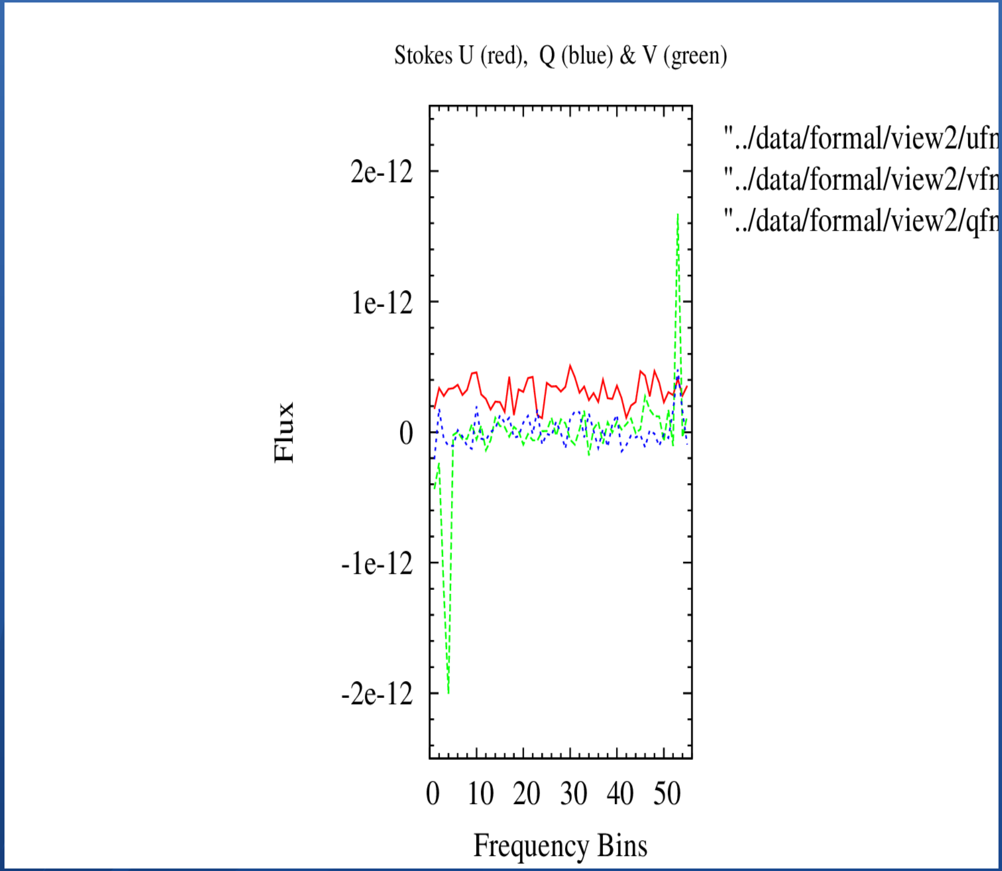
Tests: Wide Splitting

- Definitions:
- IEEE axis system for formal solution (see figure)
- For molecule like OH, s+ has the lower frequency (Garcia Barreto et al. 1988 (see figure)
- IAU Stokes V = RCP – LCP
- To agree with observations, +ve V at lower frequency → B away from observer





Results



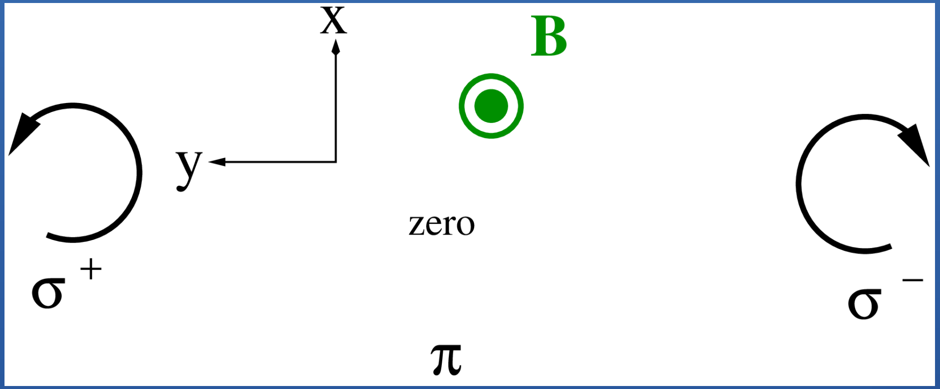
- No pi transition present: ok
- Field towards observer, -ve Stokes V at lower frequency
- Consistent with expectations

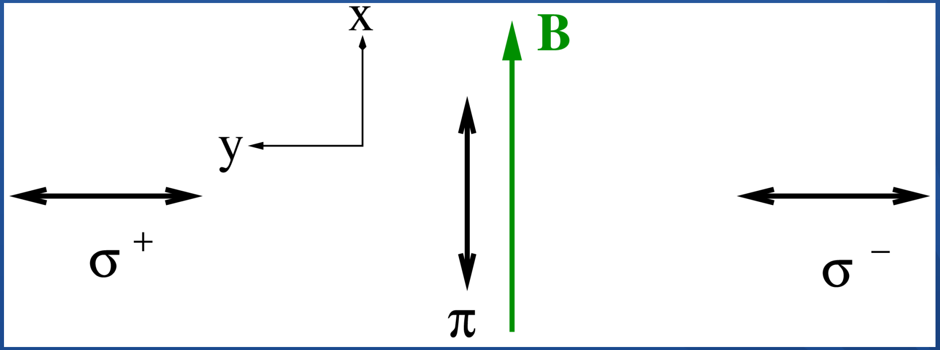
- Problems

  (1) Stokes U appears to have a constant offset from zero

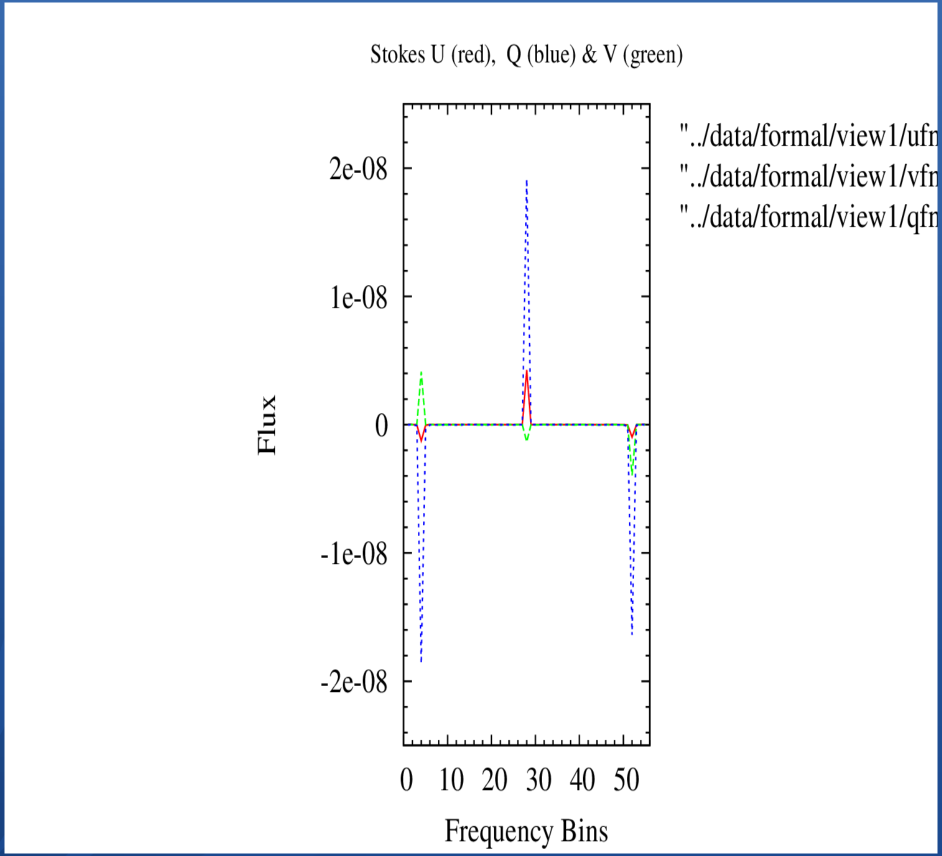
Cross field

- Field now along x axis
- Z-axis still points at observer
- Pi dipole aligned with field (x)
- Sigma dipoles helical about x-axis; we see them edge on along y-axis
- Expect pi to have opposite Q from sigmas; pi should be +ve (x-dominated), sigmas negative





Results

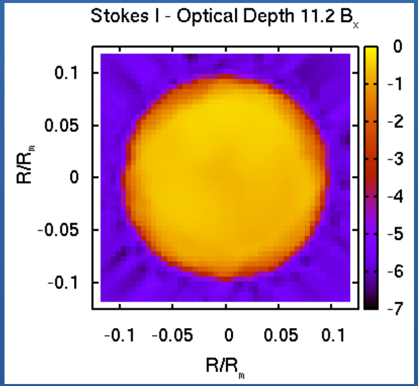


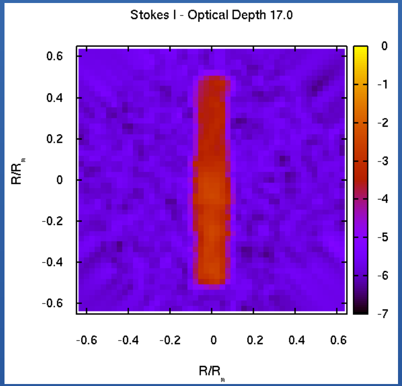
- Pi has positive Q; sigmas both have -ve Q
- U and V much weaker
- Conforms to expectations

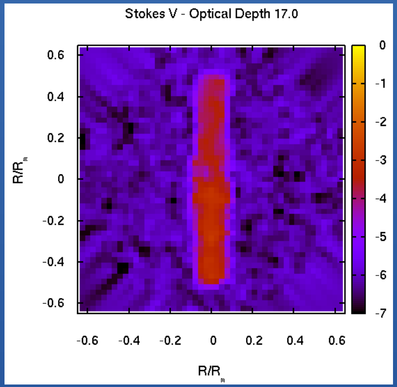
- Problems

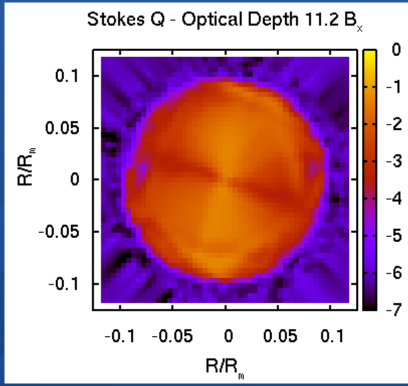
  Are surviving amounts of U & V acceptable (model is not completely 1D)?

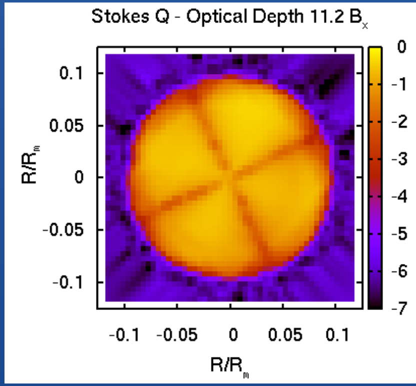
Images

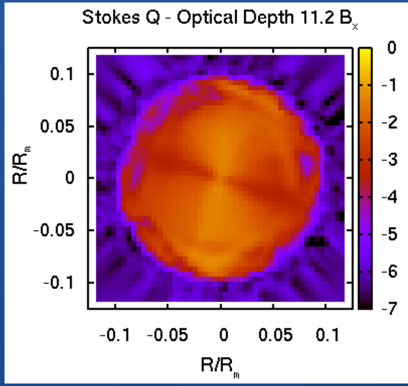

Stokes I - Optical Depth 11.2 Bx
R/R
R/R


Stokes I - Optical Depth 17.0
R/R
R/R


Stokes V - Optical Depth 17.0
R/R
R/R

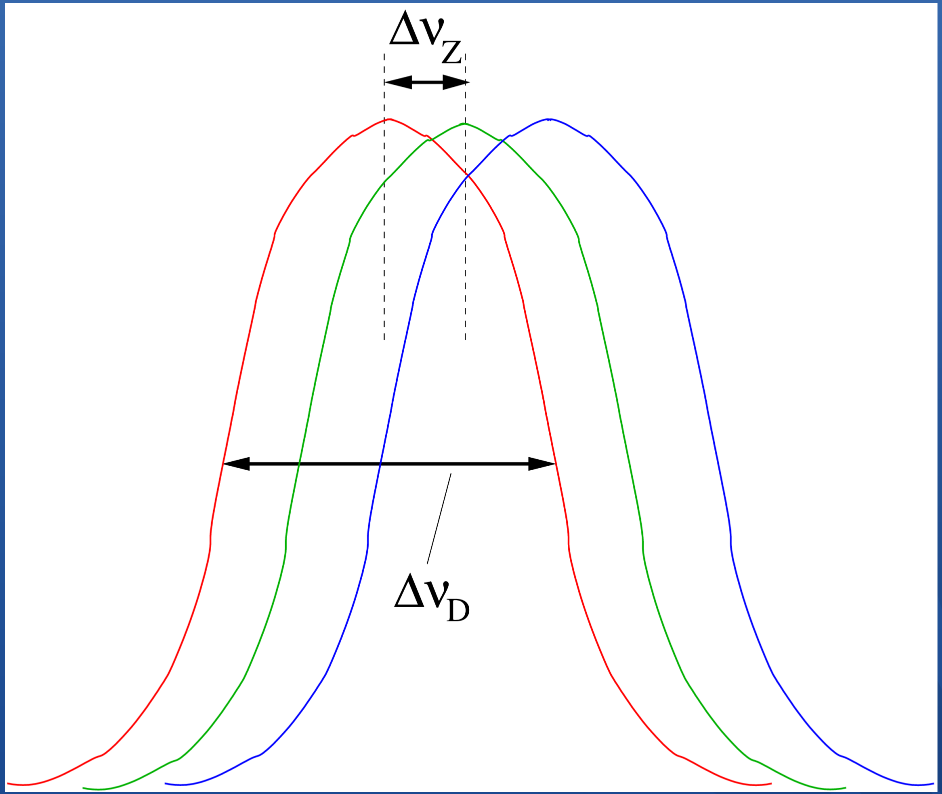

Stokes Q - Optical Depth 11.2 Bx
R/R
R/R


Stokes Q - Optical Depth 11.2 Bx
R/R
R/R


Stokes Q - Optical Depth 11.2 Bx
R/R
R/R

Narrow Splitting Tests

- ν_0 = 43.122 GHz (SiO)
- Coverage 3 Doppler widths
- Loss rate Γ = 5 Hz
- B = 10 G
- $\Delta\nu_Z$ = 740.5 B(G) = 7.405kHz
- $\Delta\nu_D = 156\sqrt{T_3}$ kHz; $T_3 = 1$
- $\Delta\nu_D/\Delta\nu_Z \sim 21$; use 63 bins

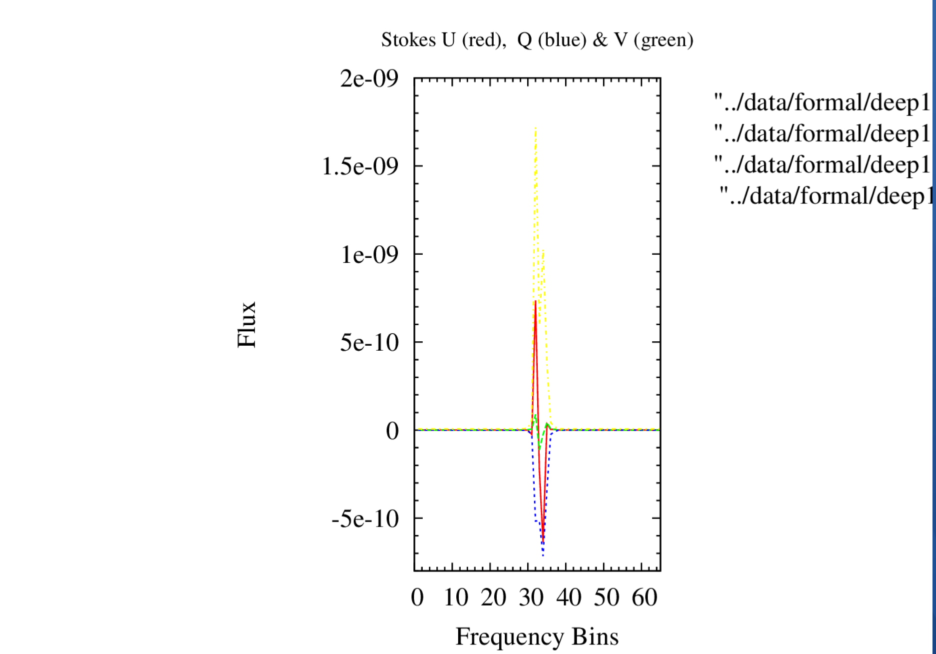


Comments

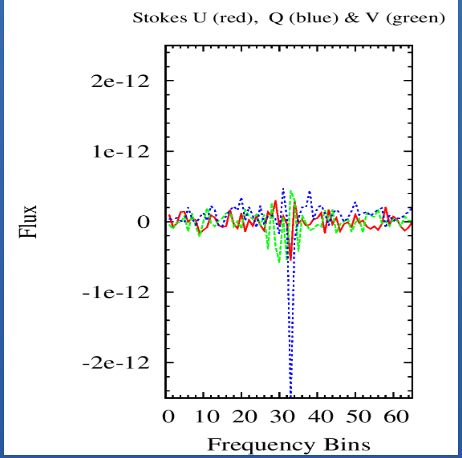
- Situation $\Delta\nu_D >> \Delta\nu_Z >> \Gamma$
- Stimulated emission rate R from ~ 0 to level << $\Delta\nu_Z$
- Essentially case 2a in GKK (1973)
- $\Delta\nu_Z$ often written as (½) g Ω
- High B of 10G means case good for large R
- Quantization based on direction of B-field
- If R >> $\Delta\nu_Z$ should change to ray axis quantization

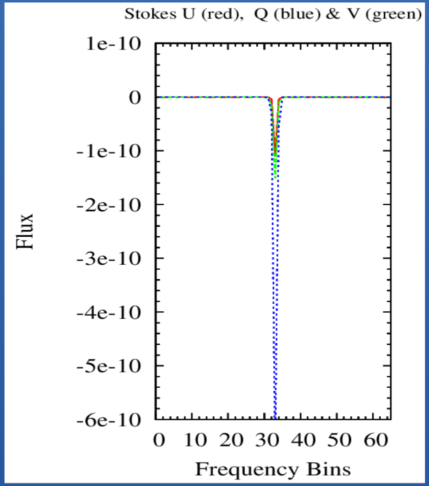
General Results:Full Stokes

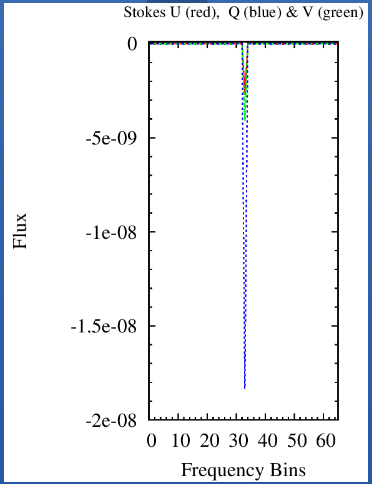
- Polarized flux density limited to ~40% (good)
- U,V often close to zero at line centre (good)
- Polarized flux density varies with angle of magnetic field to z-axis of domain
- Typical polarization fraction of a few per cent

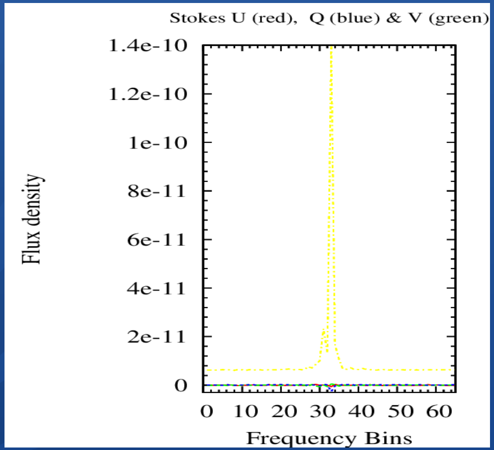


Some results





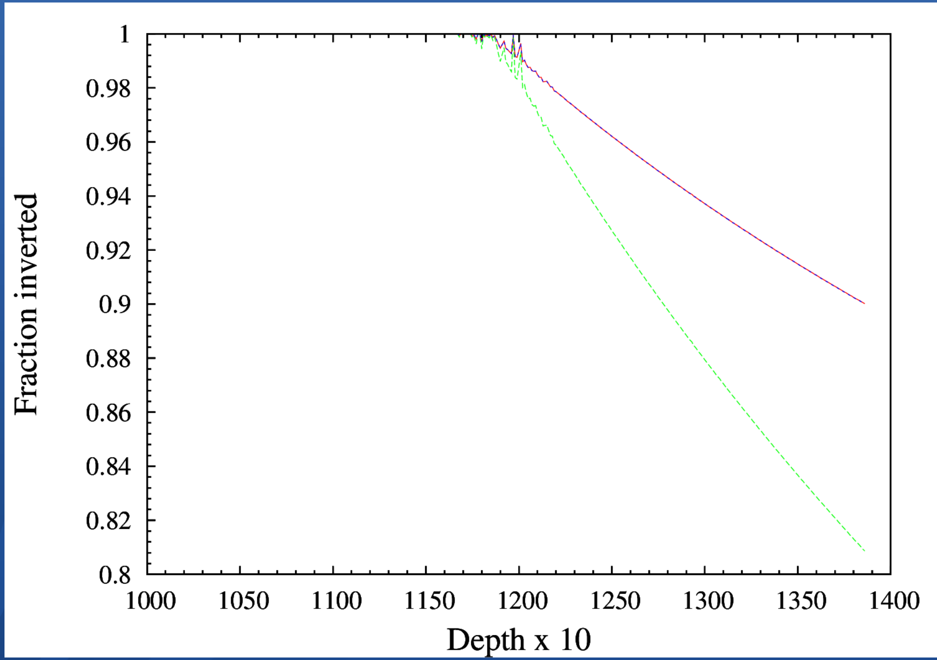




- Spectral narrowing
- Saturation

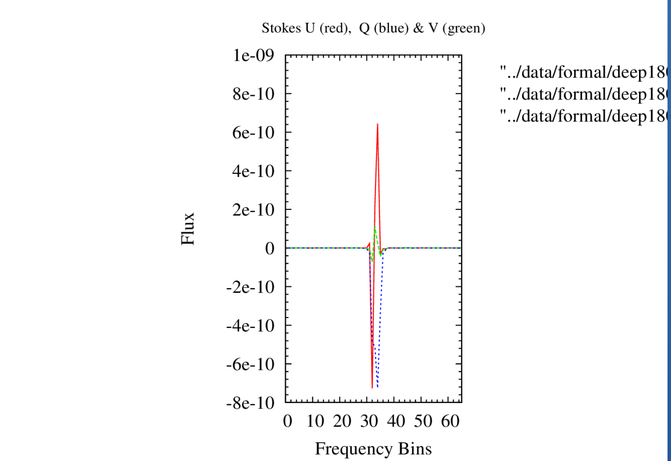
- Development of polarization
- Correct behaviour with angle to B?

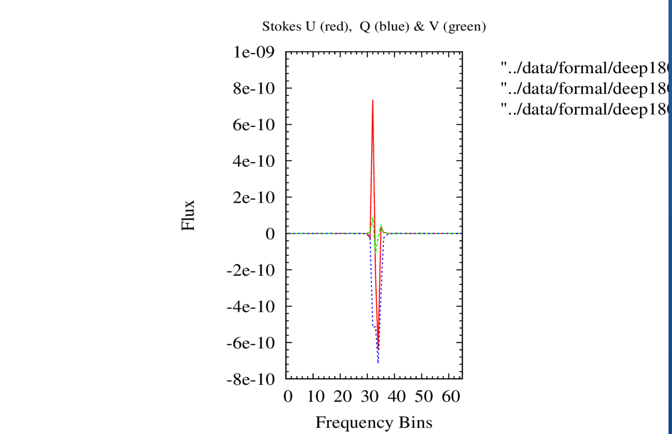
Development of Saturation



- Inversion in pi-transition drops fastest (expected for B at 90 degrees)
- Sigmas symmetric
- Most unstable part of model where saturation sets in strongly (~depth 115-120)
- Earlier version run to frational inversion <0.4 in some nodes

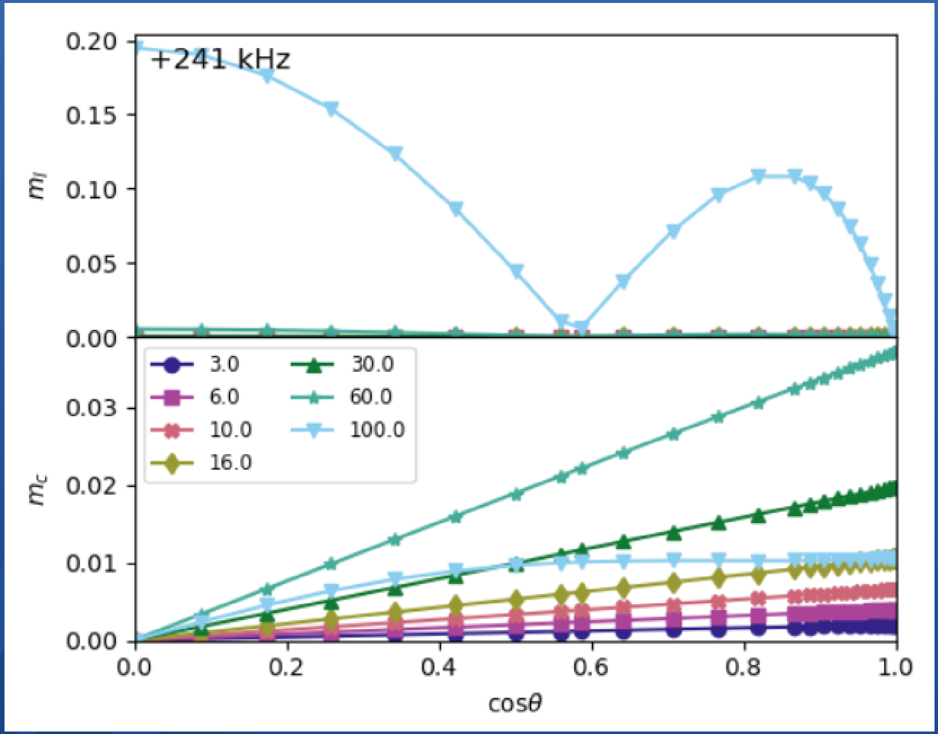
S-curve





- Upper: observer at 0 degrees (distant z)
- Lower: observer at 180 degrees (distant -z)
- Flip in sign of U & V with viewpoint
- Expected behaviour; Q has constant -ve sign
- Is this consistent with angle?

Variation with Field Angle



- Compare to 1D predictions (on left)
- Not same field, but expect only a weak dependence over wide saturation range
- Circular off-centre by smaller frequency than current model
- Need to run new version with >10 angles