measuring polarization with CARMA

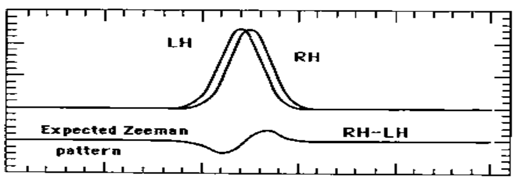
(currently possible only in the 1mm band)

210-270 GHz: dual circular polarization receivers			
mode	**measure**	**benefits**	**correlator**
LL	<LL*>	most flexible correlator setup	8 independent windows
RR	<RR*>	NONE! (Tsys is slightly higher for RCP rcvrs)	8 independent windows
DUALPOL	<LL*>, <RR*>	√2 improvement in spectral line sensitivity	4 independent pairs of windows
FULLPOL	<LL*>, <RR*>, <LR*>, <RL*>	measure all 4 Stokes parameters	4 independent pairs of windows, fewer channels

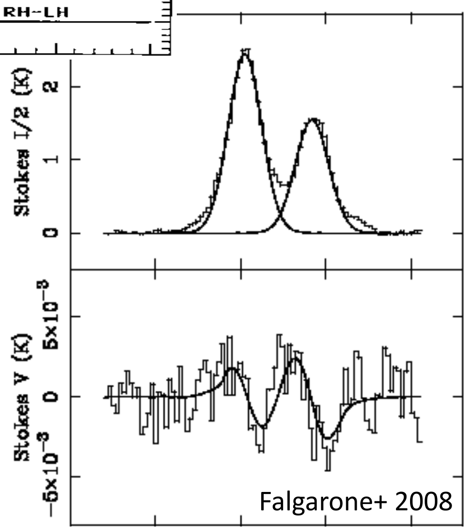
80-115 GHz: single pol rcvrs; only “LL” = <YY*> allowed

primary scientific motivation: study magnetic fields

- Zeeman effect splits circular polarization of spectral lines
- measures $B_{parallel}$

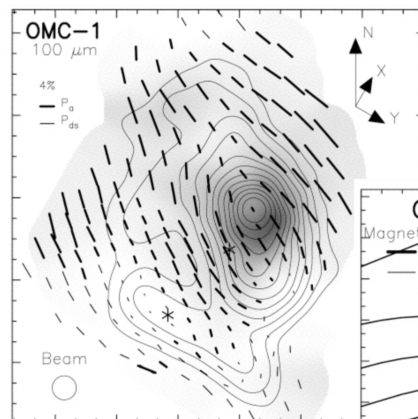


CN, other molecules with magnetic moments; splitting is << linewidth; a very difficult experiment

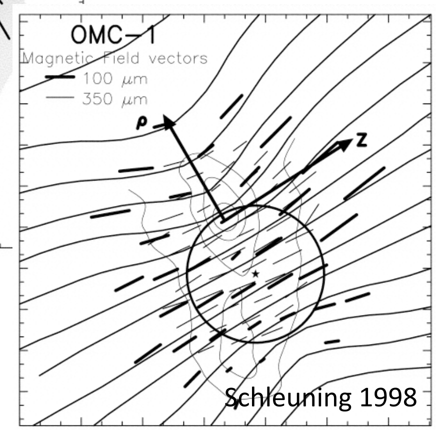


Falgarone+ 2008

- linearly polarized thermal emission from magnetically aligned dust grains
- measures orientation of B_{perp}

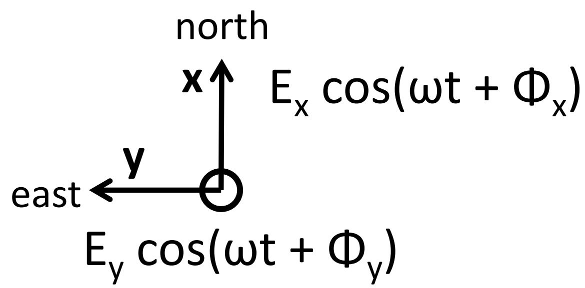


B ⊥ to polarization direction



Schleuning 1998

the goal of polarization observations is to map Stokes parameters



$I = \langle E_x^2 \rangle + \langle E_y^2 \rangle$

$Q = \langle E_x^2 \rangle - \langle E_y^2 \rangle$

$U = 2 \langle E_x E_y \cos(\Phi_x - \Phi_y) \rangle$

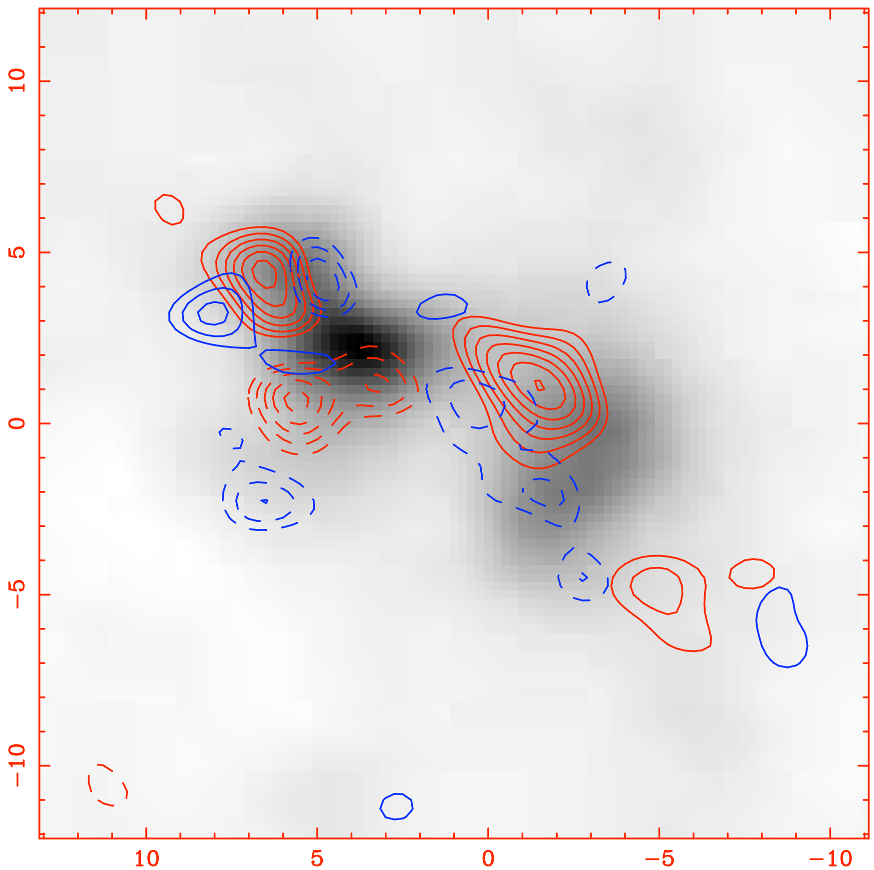
$V = 2 \langle E_x E_y \sin(\Phi_x - \Phi_y) \rangle$

<time average> because E_x, E_y, Φ_x, Φ_y vary randomly with time

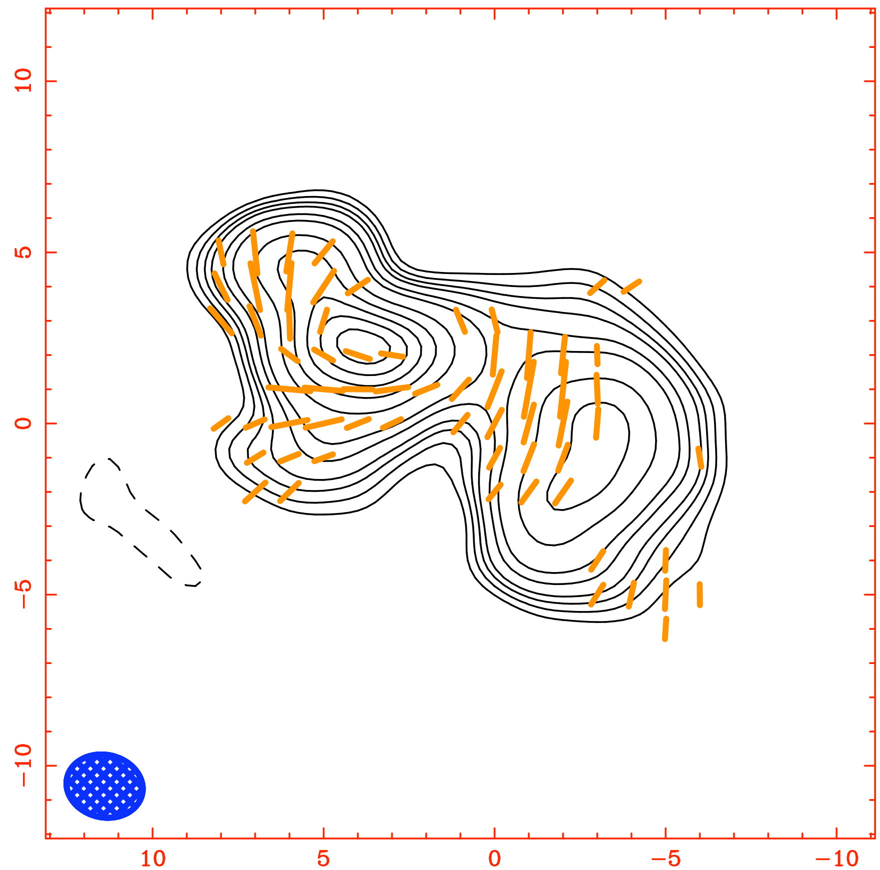
- units: Jy/beam
- map Q, U, V just like total intensity I
- I is always positive, but Q,U,V can be negative
- if unpolarized Q,U,V = 0
- derived quantities:
  - fractional linear pol $= (Q^2 + U^2)^{½}/I$
  - position angle $= ½ \operatorname{atan2}(U,Q)$

example: DR21OH

maps of Stokes parameters and pol vectors



I = halftone, Q = red, U = blue
contour interval 1σ beginning at ±3σ



I = contours
orange = polarization ‘vectors’

interferometer measures Stokes *visibilities*
(cross correlation of ant *i* with ant *j*)

linearly polarized feeds

$$I_v = \left\langle X_i X_j^* \right\rangle + \left\langle Y_i Y_j^* \right\rangle$$

$$Q_v = \left\langle X_i X_j^* \right\rangle - \left\langle Y_i Y_j^* \right\rangle$$

$$U_v = \left\langle X_i Y_j^* \right\rangle + \left\langle Y_i X_j^* \right\rangle$$

$$V_v = -j\left\langle X_i Y_j^* \right\rangle + j\left\langle Y_i X_j^* \right\rangle$$

circularly polarized feeds

$$I_v = \left\langle R_i R_j^* \right\rangle + \left\langle L_i L_j^* \right\rangle$$

$$Q_v = j\left\langle R_i L_j^* \right\rangle - j\left\langle L_i R_j^* \right\rangle$$

$$U_v = \left\langle R_i L_j^* \right\rangle + \left\langle L_i R_j^* \right\rangle$$

$$V_v = \left\langle R_i R_j^* \right\rangle - \left\langle L_i L_j^* \right\rangle$$

- X, Y, R, L are the (complex) voltages at the correlator
- I_v, Q_v, U_v, V_v are complex, but Hermetian (-> maps are real)

why use circularly polarized feeds to measure linear polarization?

- linearly polarized feeds:

$$\boxed{Q = g_{xi} g_{xj} \left\langle X_i X_j^* \right\rangle - g_{yi} g_{yj} \left\langle Y_i Y_j^* \right\rangle}$$

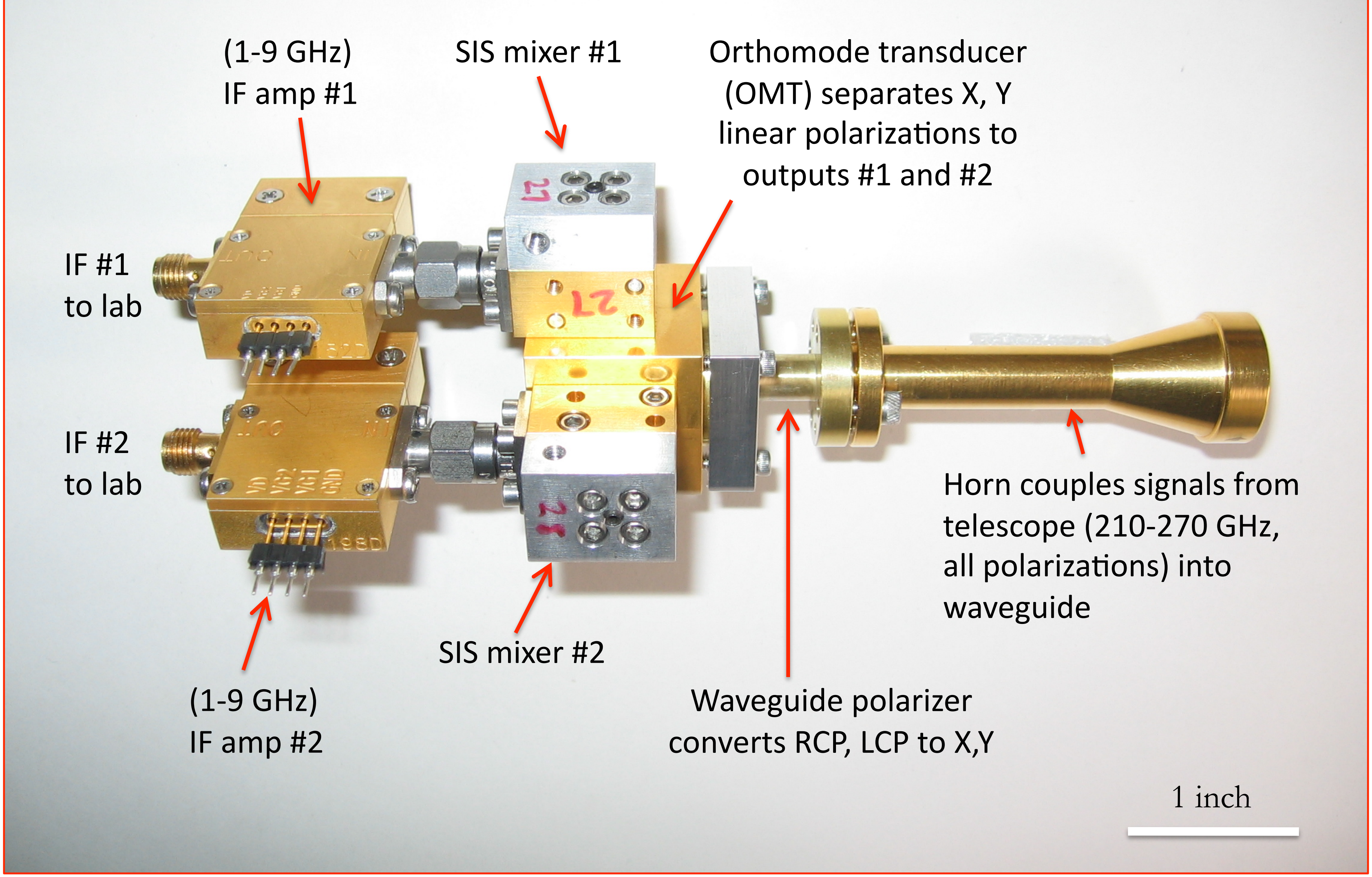
  – difference of 2 large numbers, sensitive to tiny errors in the receiver gains g_x, g_y

- circularly polarized feeds:

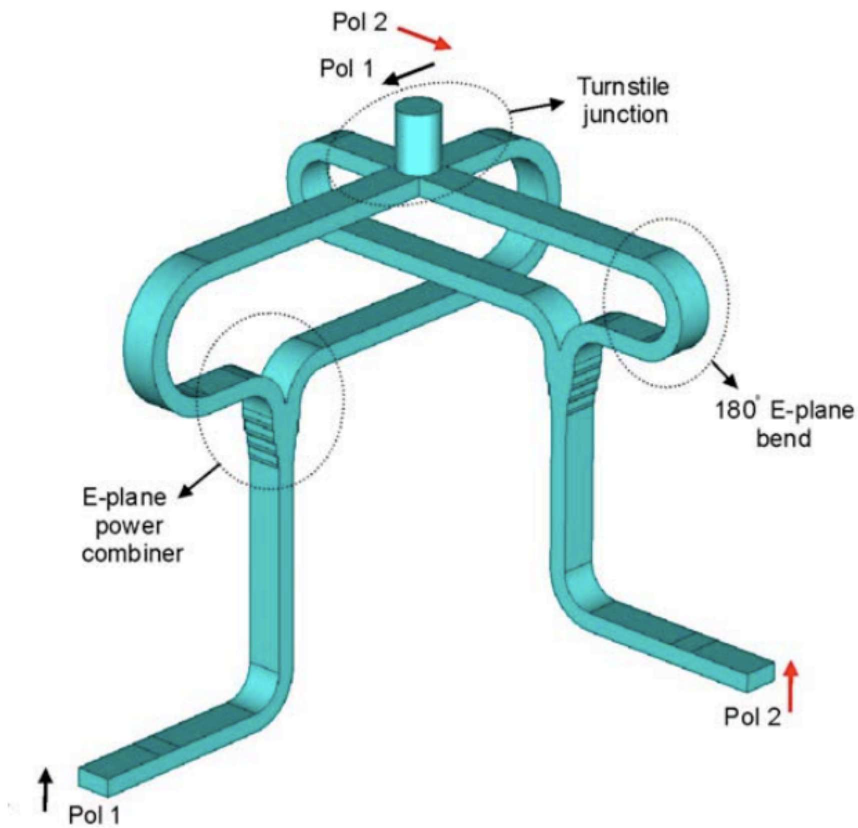
$$\boxed{Q = \tfrac{1}{2} j \, g_{Ri} g_{Lj} \left\langle R_i L_j^* \right\rangle + \tfrac{1}{2} j \, g_{Li} g_{Rj} \left\langle L_i R_j^* \right\rangle}$$

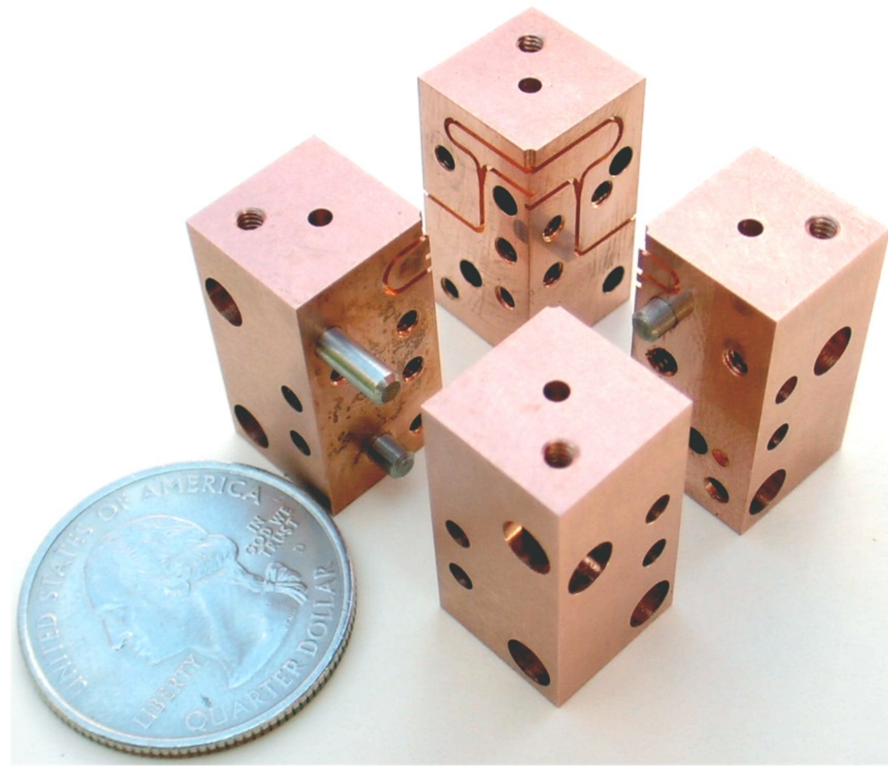
  – <RL> = <LR> = 0 in the absence of linearly polarized emission
  – a null experiment, insensitive to fluctuations in gains g_R, g_L

hardware


(1-9 GHz)
IF amp #1
SIS mixer #1
Orthomode transducer (OMT) separates X, Y linear polarizations to outputs #1 and #2
IF #1 to lab
IF #2 to lab
Horn couples signals from telescope (210-270 GHz, all polarizations) into waveguide
(1-9 GHz)
IF amp #2
SIS mixer #2
Waveguide polarizer converts RCP, LCP to X,Y
1 inch

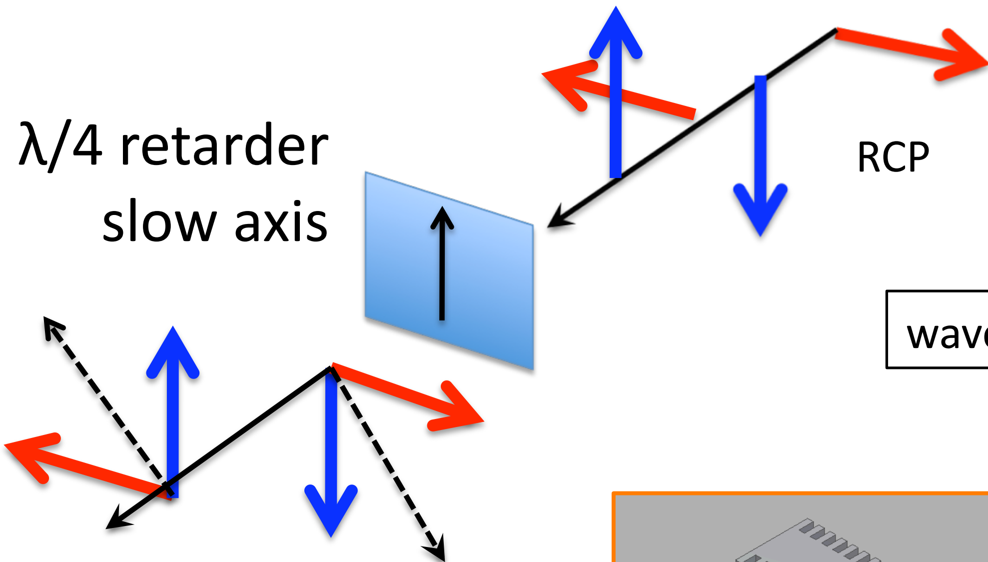
orthomode transducer
separates orthogonal *linear* polarizations

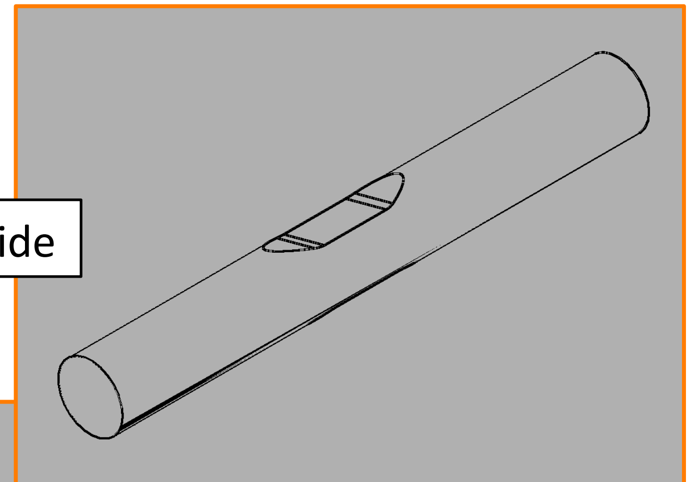


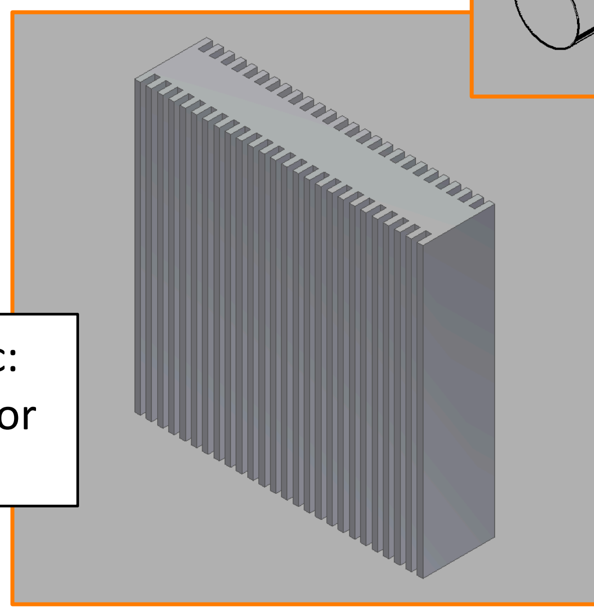


Navarrini & Plambeck 2006, IEEE-MTT, 54, 272-277

polarizer converts R,L circular to X,Y linear



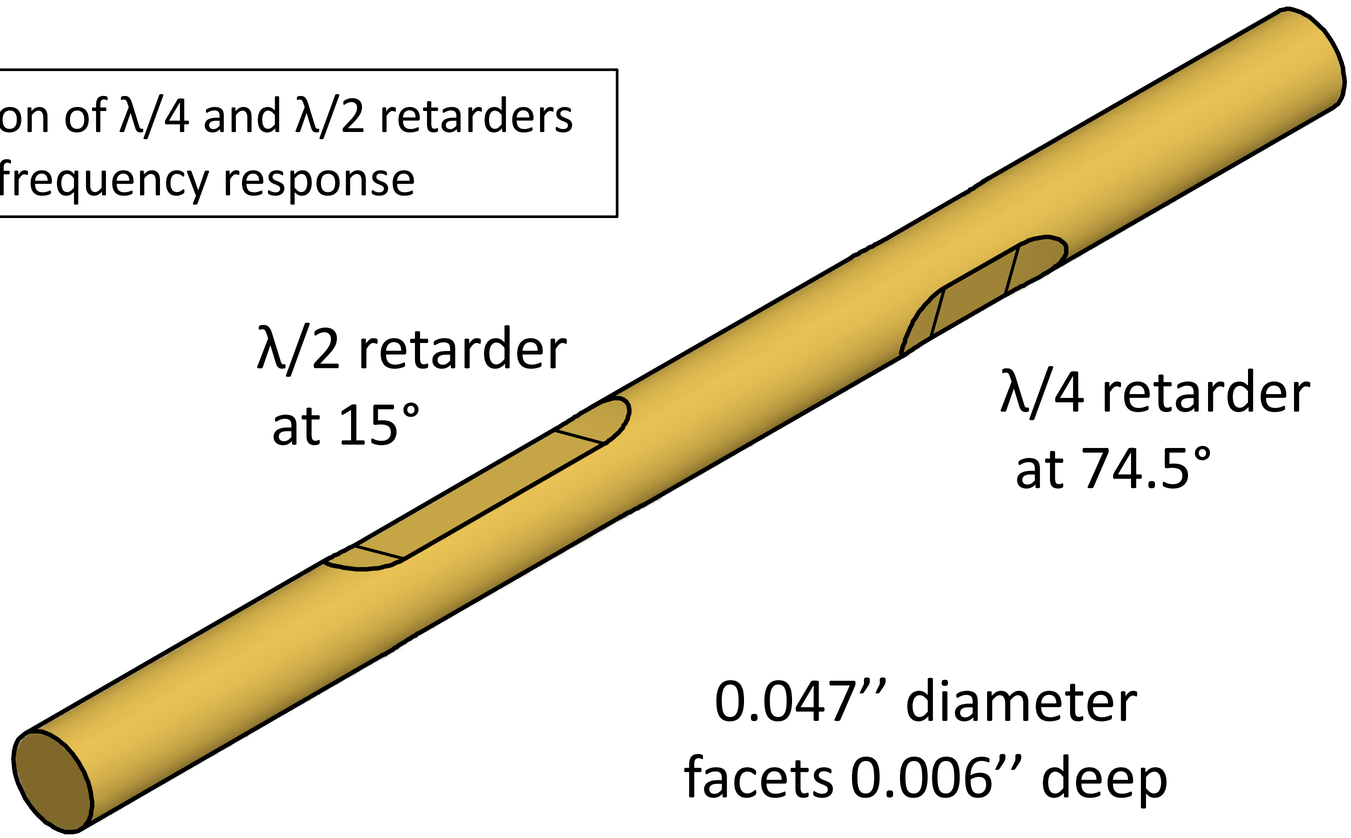




examples of
retarders

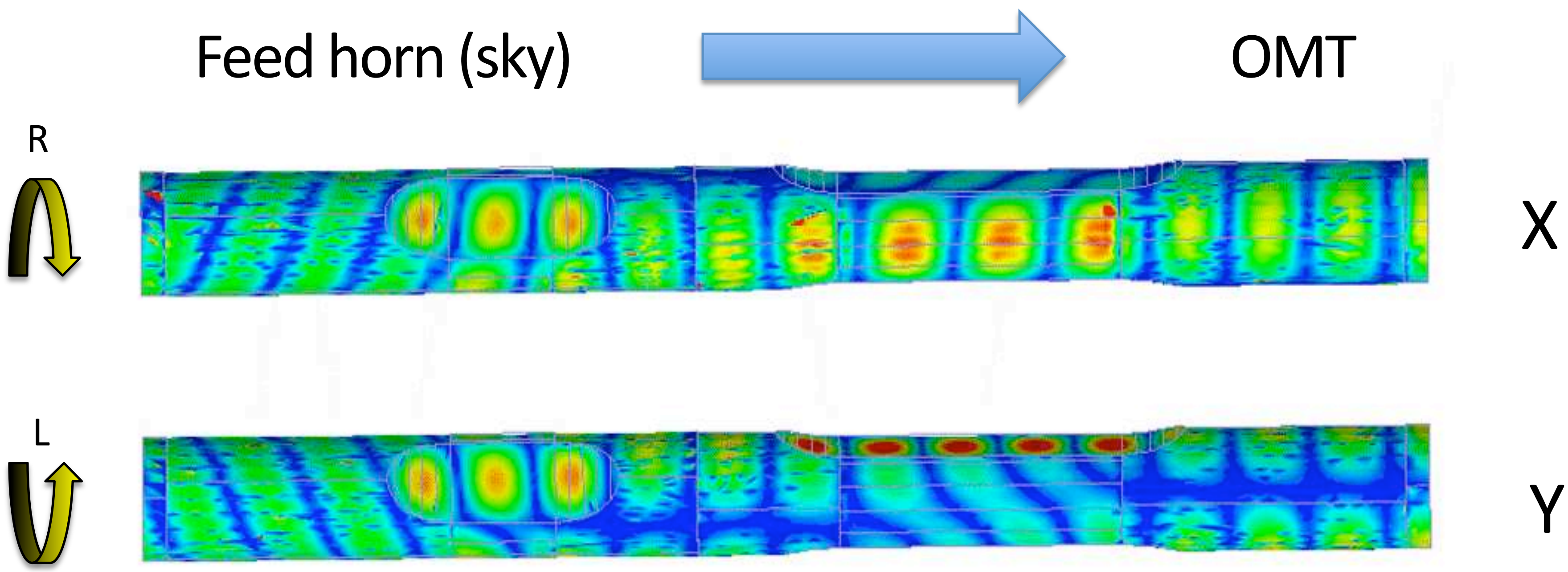
2-section
waveguide circular polarizer

combination of λ/4 and λ/2 retarders
broadens frequency response

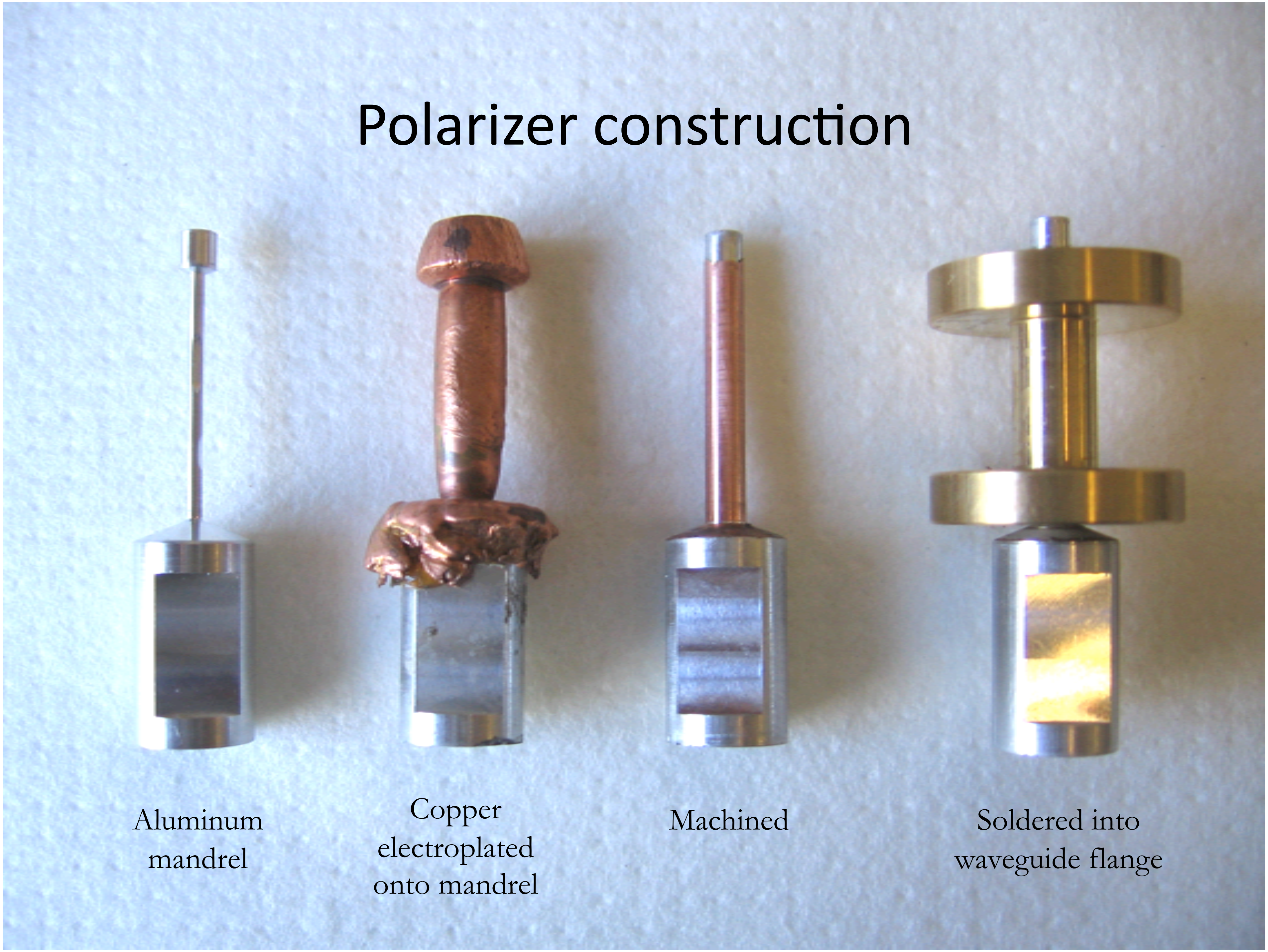


Plambeck & Engargiola, CARMA Memo #54

electromagnetic simulation



Plambeck & Engargiola, CARMA Memo #54


Polarizer construction
Aluminum mandrel
Copper electroplated onto mandrel
Machined
Soldered into waveguide flange

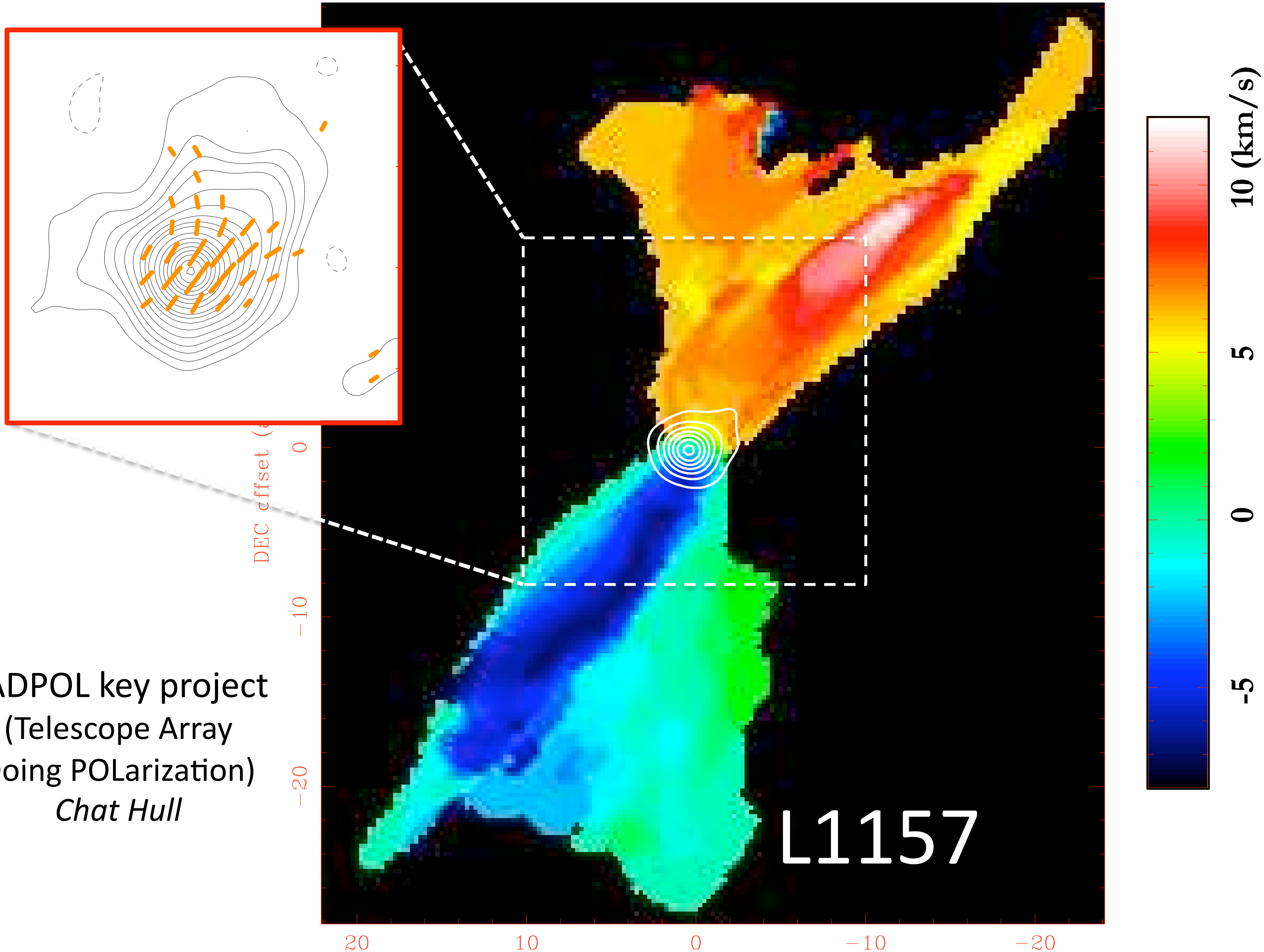
polarization observations require 2 additional calibrations

1. "xyphase" = phase difference between R and L receivers on each telescope
   - signals travel through different fibers to control bldg
   - R,L cable lengths differ for each correlator section
   - 2° error in xyphase -> 1° error in pol PA

2. "leakage" = cross-coupling between R and L receivers on each telescope
   - due mostly to imperfections in the polarizers and orthomode transducers
   - introduces errors in pol intensity and PA

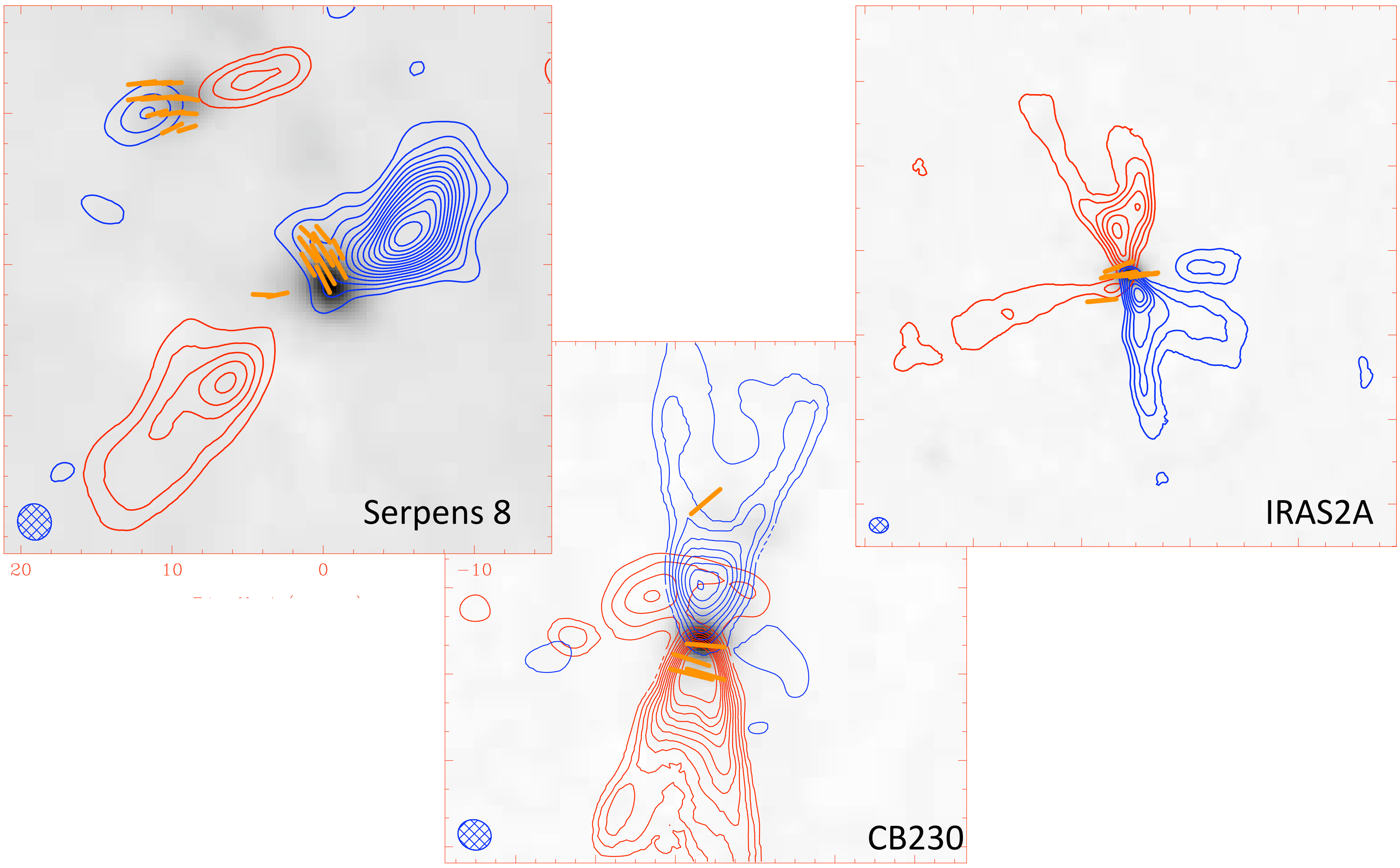
making polarization observations

- observing script: *configastroband* setup is different
  - there are just 4 bands (1,3,5,7 only – 2,4,6,8 are Siamese twins)
  - continuum bandwidth is still 4 GHz in each sideband: 4 x 500 MHz x 2pol
  - fewer channels/band; BW500 allows only 2-bit mode
- data reduction: 2 extra steps
  - *xyauto* computes xyphase correction from grid calibration data
  - solve for leakages with *gpcal*, or copy them from a pre-existing file
- mapping
  - map all 4 Stokes parameters (*invert stokes=I,Q,U,V map=I.mp,Q.mp...*)
  - measure noise in Q,U,V maps, then compute polarized intensity and position angles with *impol*



TADPOL key project
(Telescope Array
Doing POLarization)
Chat Hull

a few other TADPOL results



more information about TADPOL and CARMA polarization observations

http://carma.astro.umd.edu/wiki/index.php/TADPOL