Title
A Multisensor system for the detection and characterization of UXO MM-0437

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DEMONSTRATION REPORT

A MULTISENSOR SYSTEM FOR THE DETECTION AND CHARACTERIZATION OF UXO

MM-0437

SITE LOCATION:
U.S. ARMY YUMA PROVING GROUND

DEMONSTRATOR:
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TECHNOLOGY TYPE/PLATFORM:
BUD/CART

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1. BUD DESCRIPTION

The Berkeley UXO discriminator (BUD) (Figure 1) is a portable Active Electromagnetic (AEM) system for UXO detection and characterization that quickly determines the location, size, and symmetry properties of a suspected UXO. The *BUD* comprises of three orthogonal transmitters that "illuminate" a target with fields in three independent directions in order to stimulate the three polarization modes that, in general, characterize the target EM response. In addition, the *BUD* uses eight pairs of differenced receivers for response recording. Eight receiver coils are placed horizontally along the two diagonals of the upper and lower planes of the two horizontal transmitter loops. These receiver coil pairs are located on symmetry lines through the center of the system and each pair sees identical fields during the on-time of the pulse in all of the transmitter coils. They are wired in opposition to produce zero output during the on–time of the pulses in three orthogonal transmitters. Moreover, this configuration dramatically reduces noise in the measurements by canceling the background electromagnetic fields (these fields are uniform over the scale of the receiver array and are consequently nulled by the differencing operation), and by canceling the noise contributed by the tilt of the receivers in the Earth's magnetic field, and greatly enhances receivers sensitivity to the gradients of the target response. The *BUD* performs target characterization from a single position of the sensor platform above a target.

Figure 1. Berkeley UXO Discriminator (BUD)

BUD was designed to detect and characterize UXO in the 20 mm to 155 mm size range for depths between 0 and 1 m. The relationship between the object size and the depth at which it can be detected is illustrated in Figure 2. This curve was calculated for *BUD* assuming that the receiver plane is 20 cm above the ground. Figure 2 shows that, for example, *BUD* can detect and characterize an object with 10 cm diameter down to the depth of 90 cm with depth uncertainty of 10%. Any objects buried at the depth more than 1 m have a low probability of detection. With existing algorithms in the system computer it is not possible to recover the principal polarizabilities of large objects close to the system. Detection of large shallow objects is assured, but at present real time discrimination for shallow objects is not. Post processing of the field data is required for shape discrimination of large shallow targets. Next generation of *BUD* software will not have this limitation. Successful application of the inversion algorithm that solves for the target parameters is contingent upon resolution of this limitation. At the moment, interpretation software is developed for a single object only. In case of multiple objects the software indicates the presence of a cluster of objects but is unable to provide characteristics of each individual object.

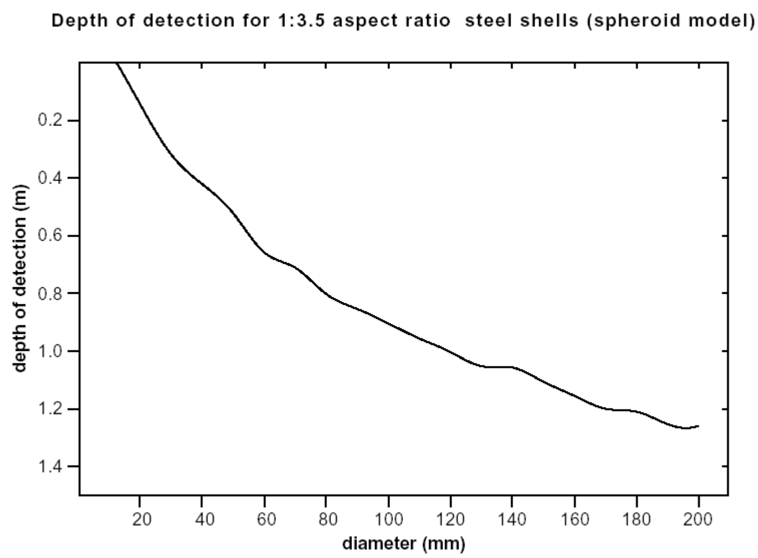


Figure 2. 10% uncertainty in location as a function of object diameter and depth of the detection for BUD with receivers 20 cm above the ground

2. FIELD SURVEY - YUMA PROVING GROUND

The objective of the Yuma Proving Ground (YPG) Demonstration was to acquire multi-component data with *BUD* over the Calibration Grid and the Blind Test Grid. The Calibration Grid is 30 m by 40 m area and consists of seventeen lanes and contains 132 UXO objects. The Blind Test Grid is a 1600 square meter area and contains 400 cells, each of which can be occupied by UXO, clutter, or both, or it can be empty. The field test was conducted from May 1, 2006 to May 6, 2006. The Calibration Grid was surveyed with 1 m spacing along the lanes A through K, and with 0.5 m spacing along the lanes L and M. The Blind Test Grid was surveyed with 0.5 m spacing along the lanes, and 1 m spacing between lanes (~3200 measurements). Figure 3 shows the measurement coverage for both grids.

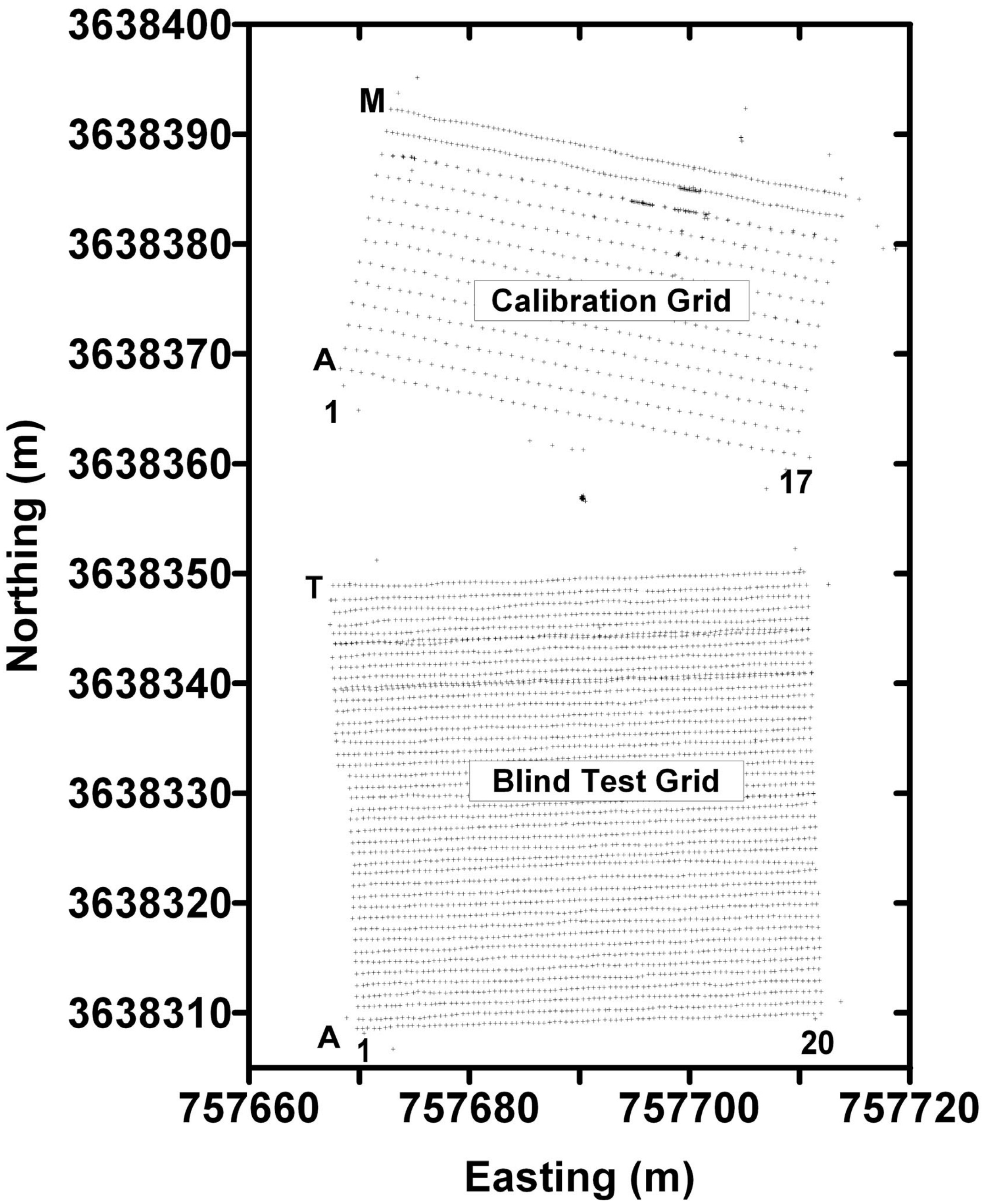


Figure 3: Measurement coverage over the Calibration and Blind Test Grids at Yuma Proving Ground.

3. DATA PROCESSING AND INTERPRETATION

Raw field data are stored in the binary format. One file is created for one measurement point (station), which includes 8 channels of data for each of three transmitters, GPS and orientation information. Data are then stacked, normalized by a peak transmitter current, differenced with a reference trace (background transient) to remove system response transients, and averaged in logarithmically spaced bins with a half-sine weighting function. The resulting 24 channels of normalized responses are then inverted for candidate object position and principal polarizabilities as a function of time after transmitter shut-off. Data before 140 μs are ignored. For the data from the Blind Test Grid an object identification program matches measured equivalent dipole polarizabilities to a database of previous measurements of equivalent dipole polarizabilities of known objects and identifies a candidate object as the object(s) corresponding to the closest matching curves from the Calibration Grid. This is done by minimizing a robust loss function of the normalized absolute differences (residuals) between the measured values and those in the database weighted inversely by estimated uncertainty in polarizabilities. The database consists of all objects in the Calibration Grid and in the test pit.

Table 1 contains principal polarizabilities as a function of time of all objects from the Calibration Grid (132 entries). When the size-depth requirement (Figure 2) is satisfied, the polarizabilities are independent of the depth and orientation of the object. For large objects close to the system the principal polarizabilities curves vary depending on the orientation of the object. All objects, except A17 - a 12 pound shotput at the depth of 2.0 m were detected. ROC curve for the Calibration Grid is shown in Figure 4.

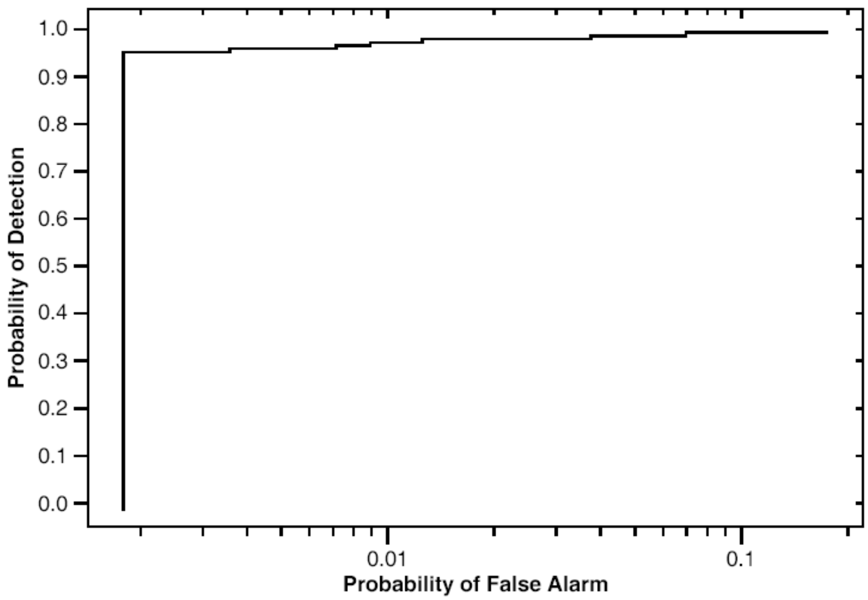


Figure 4: ROC curve for the Calibration Grid

Table 2 contains results from the Blind Test Grid. The table contains all the cells for which BUD indicates there is an object present, and a time weighted average signal strength is above $9x10^{-12}$ Vs/A in response to the Bz transmitter or $4.5x10^{-12}$ Vs/A in response to the either Bx or By transmitters, and the response level is not at a minimum compared to 1 meter forward or backwards along the survey line. For each cell that is not empty (228 occupied cells) the table contains a probability of the cell being occupied in column 1, and cell identification in column 2. These probabilities are based on one minus the probability that the given response level would arise from random fluctuations of the background field in the absence of an object. From a total of 400 cells 228 cells or 57% are occupied. Figure 5 shows the probability of the cell being occupied in a graphical form. Cells with black plus symbols are empty. 85.1% from 228 cells have a probability higher than 90% that the cell is occupied (blue circles), 4.4% have probability between 75% and 90% (green squares), and 10.5% have probability between 30% and 75% (red diamonds). The results given in Table 2 and Figure 5 include objects listed for cells f_02n and f_18n, which are actually 1m off the grid cell centers halfway between f_02 and f_03, and between f_18 and f_19 respectively.

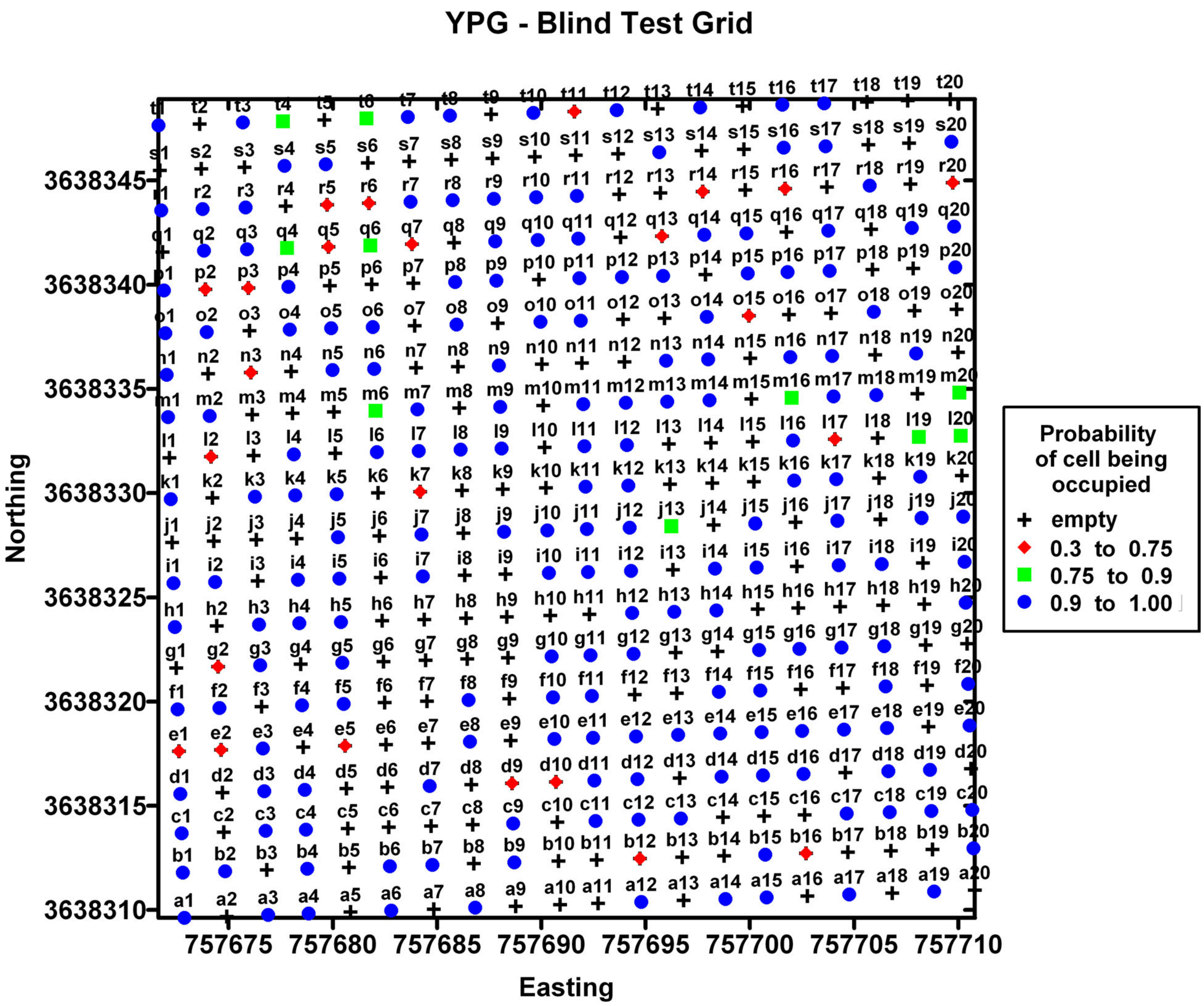
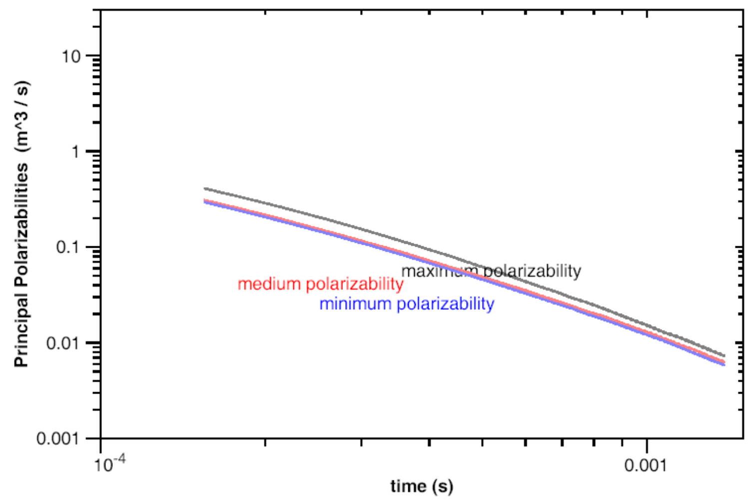
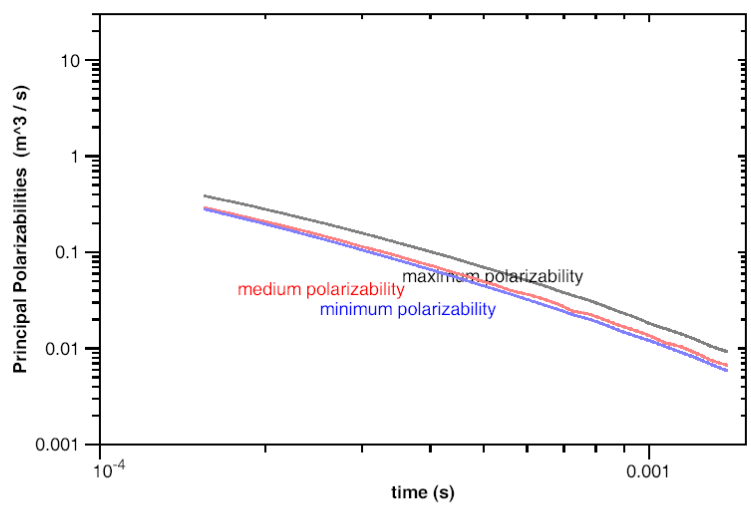
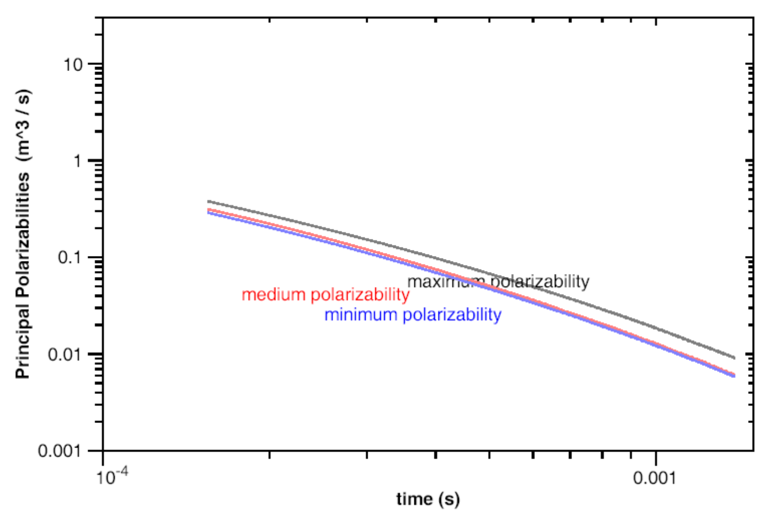


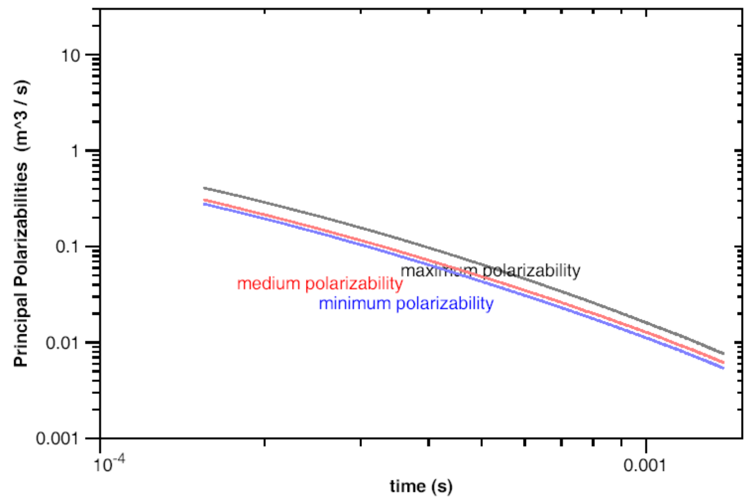
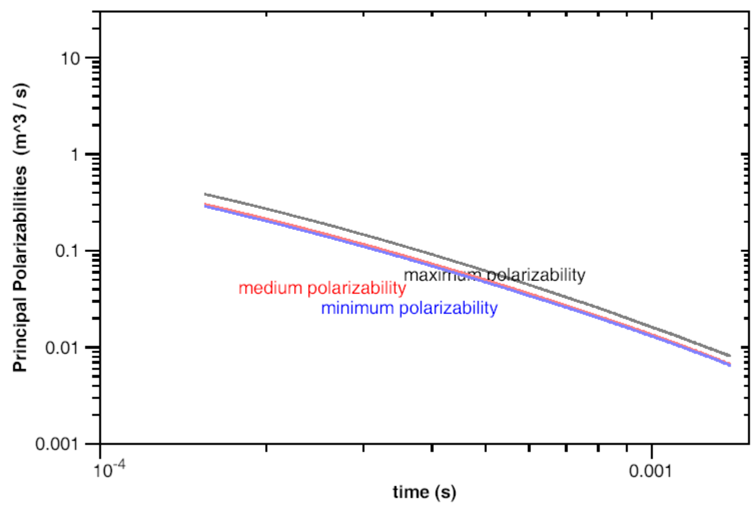
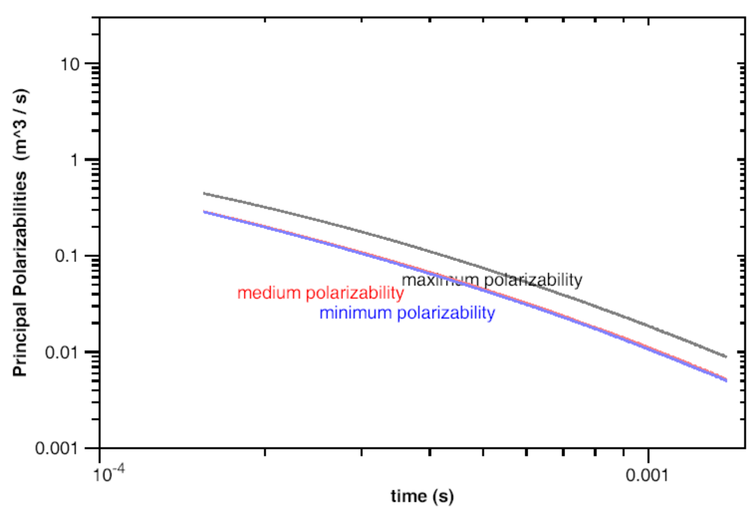
Figure 5: Blind Test Grid detection map

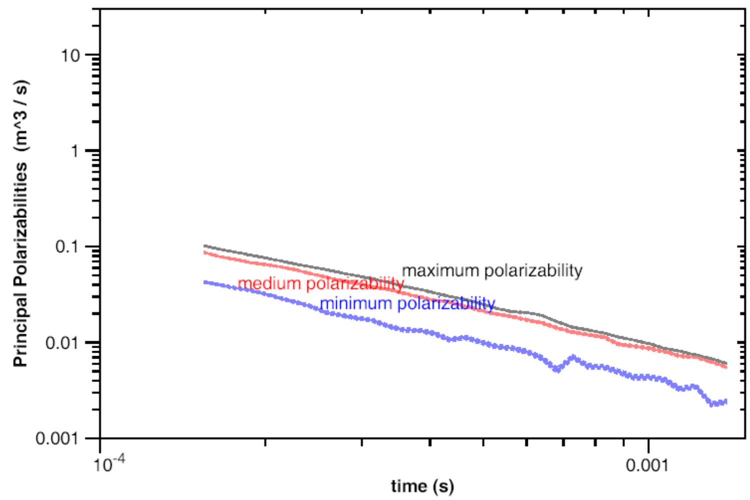
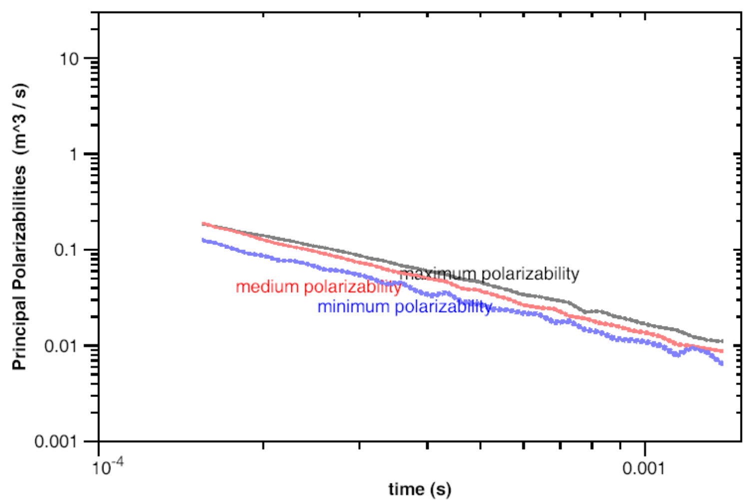
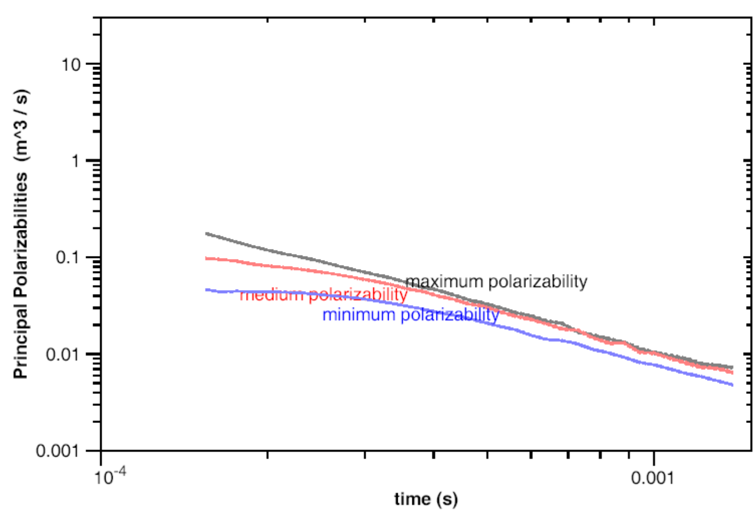
4. CONCLUSIONS

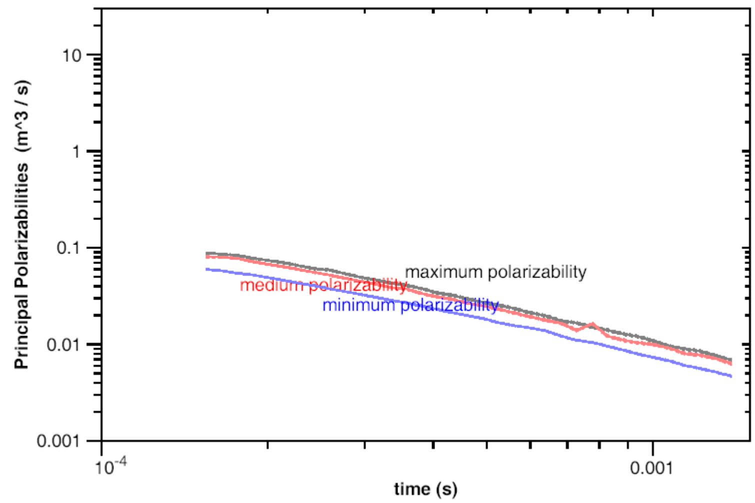
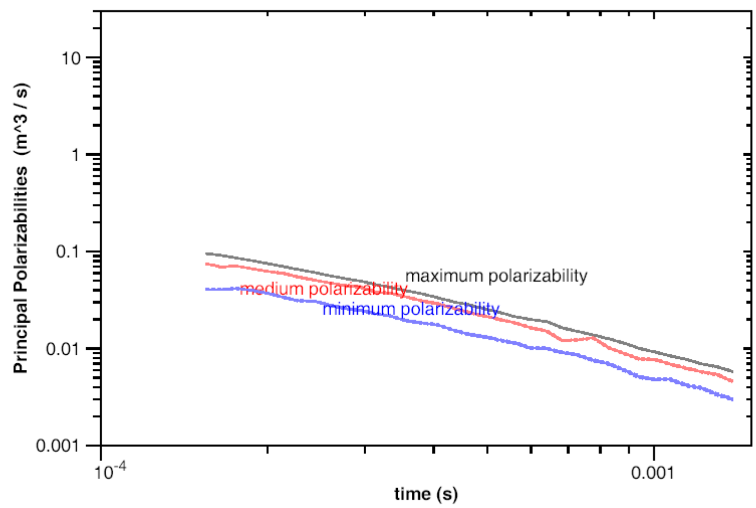
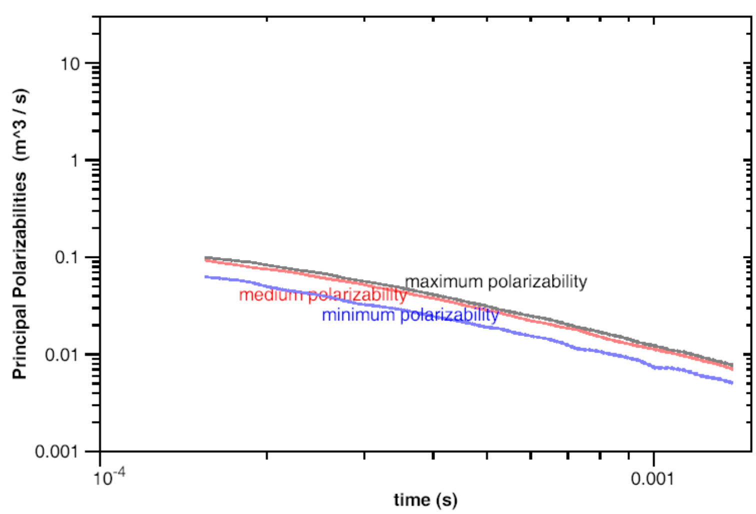
The field survey with BUD at the Yuma Proving Ground was successful. BUD performed extremely well. BUD is easy to use and requires low maintenance - transmitter batteries last for three hours, while acquisition system batteries last for six hours. The system location was recorded with standard GPS with position accuracy about 9 cm. We collected a large amount of multiple-transmitter multiple-receiver data over the Calibration Grid and Blind Test Grid. All data will be available to other researchers upon request. This report contains a table of polarizabilities curves for each object in the Calibration Grid, and detection results from the Blind Test Grid. We will submit another report with discrimination results from the Blind Test Grid after we address current limitations of our software described in Section 1.

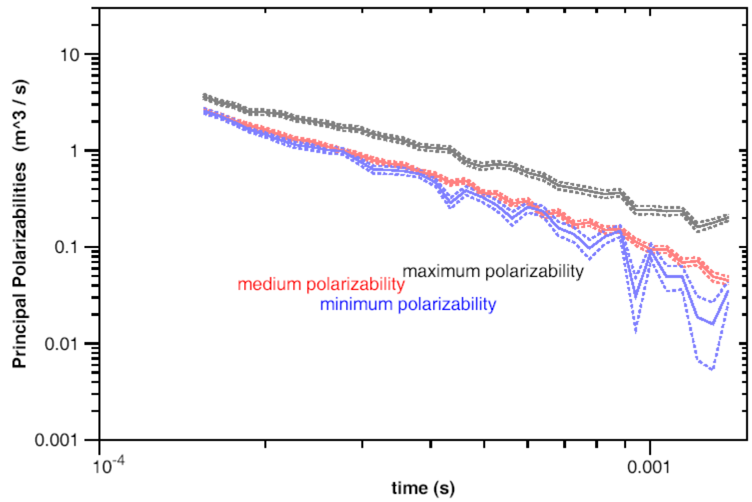
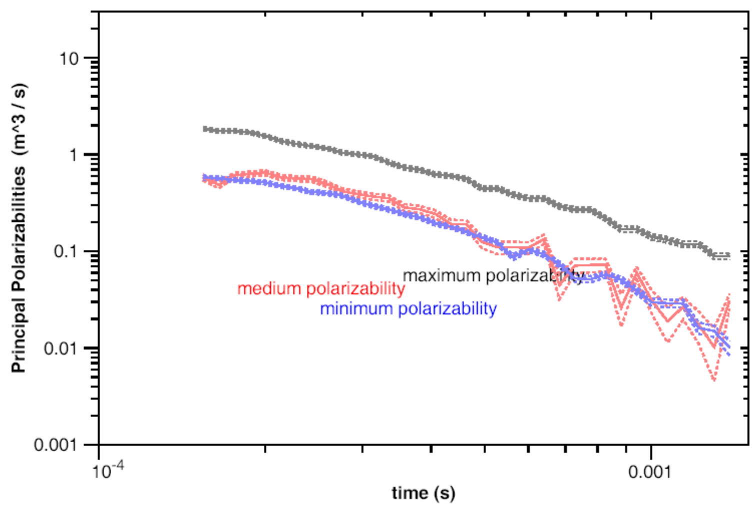
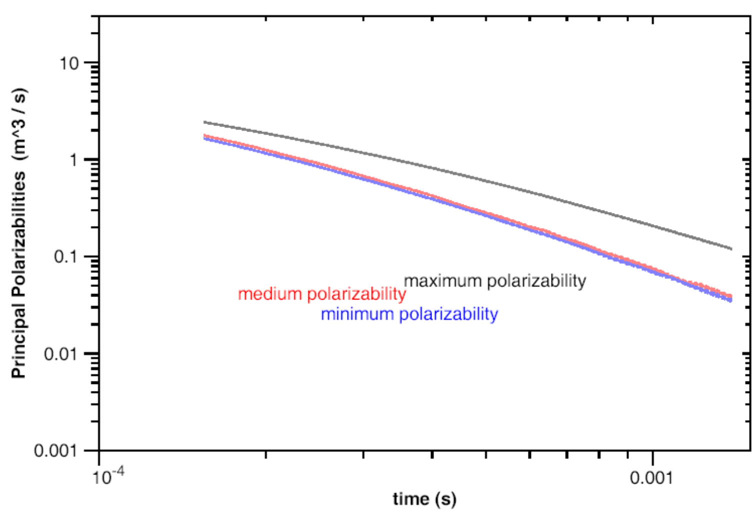
Table 1: Yuma Proving Ground - Calibration Grid

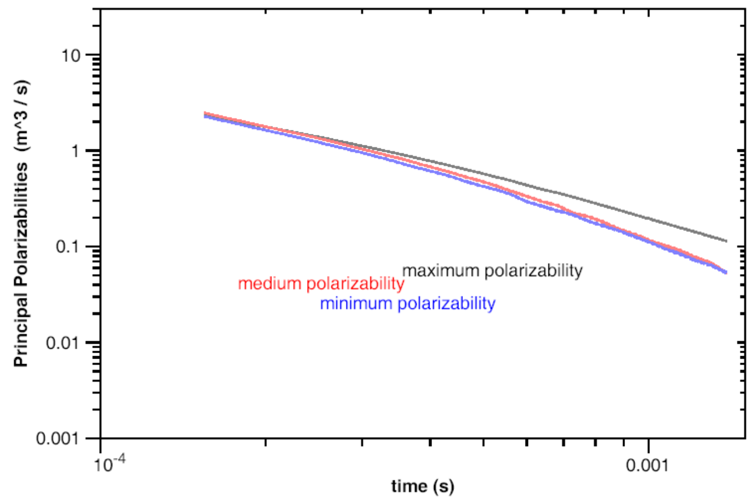
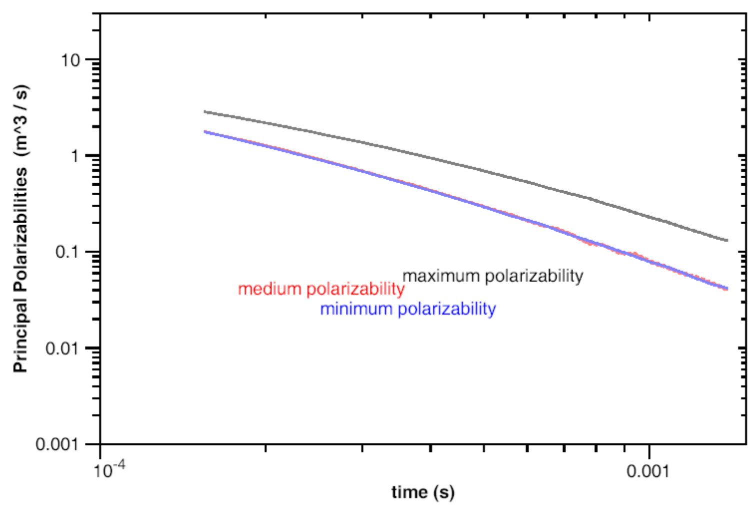
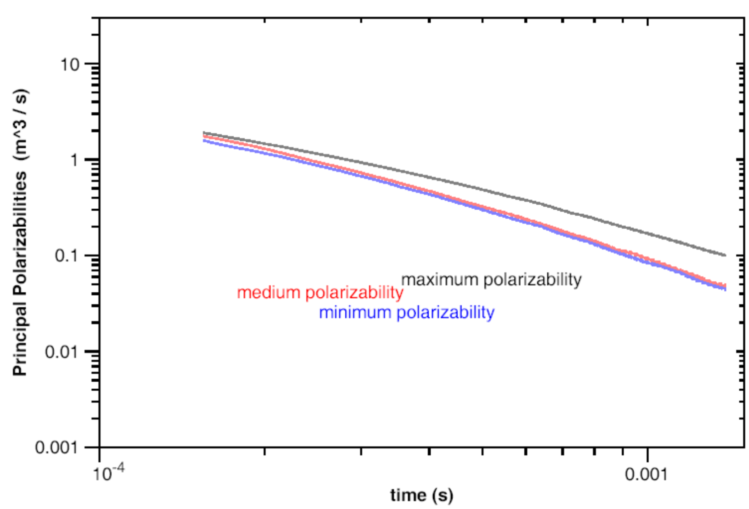
Grid Location	ID	Depth	Dip Angle	Principal Polarizabilities
A1	M75	0.30	0	
B1	M75	0.30	0	
C1	M75	0.15	-90	

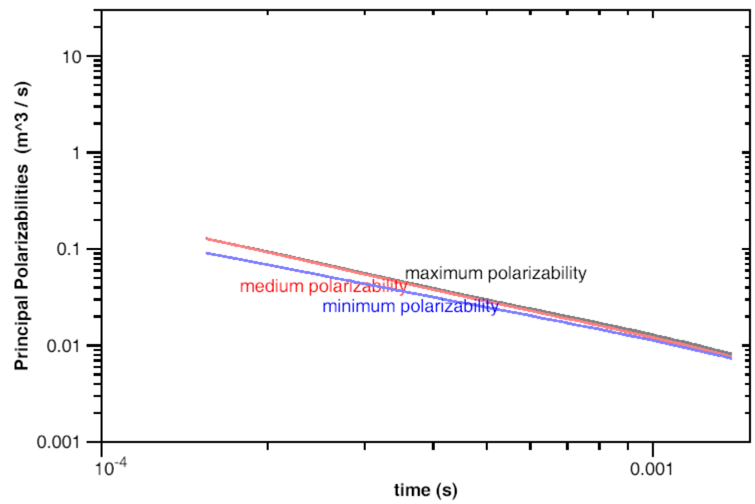
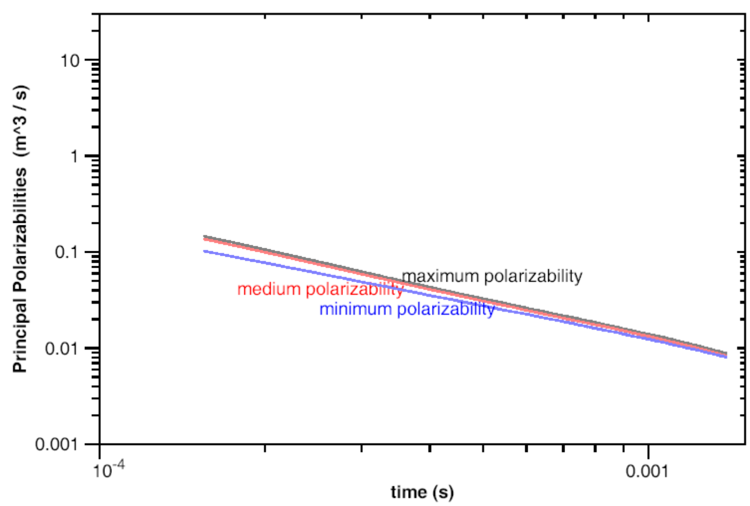
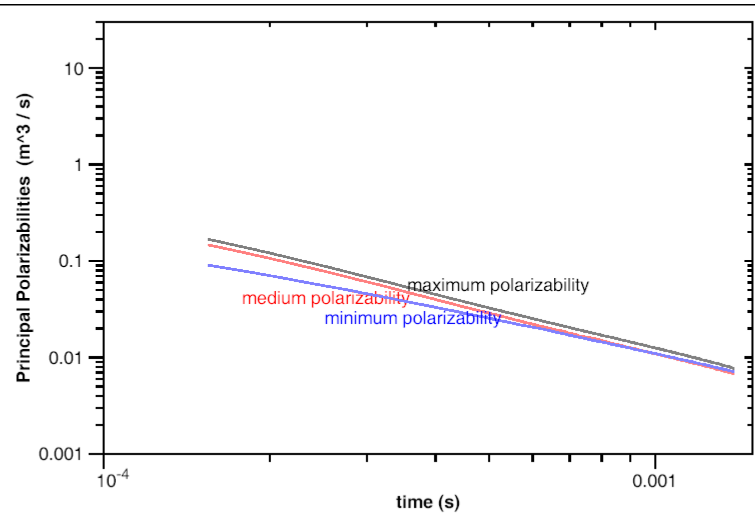
D1	M75	0.15	90	
E1	M75	0.15	-45	
F1	M75	0.15	45	

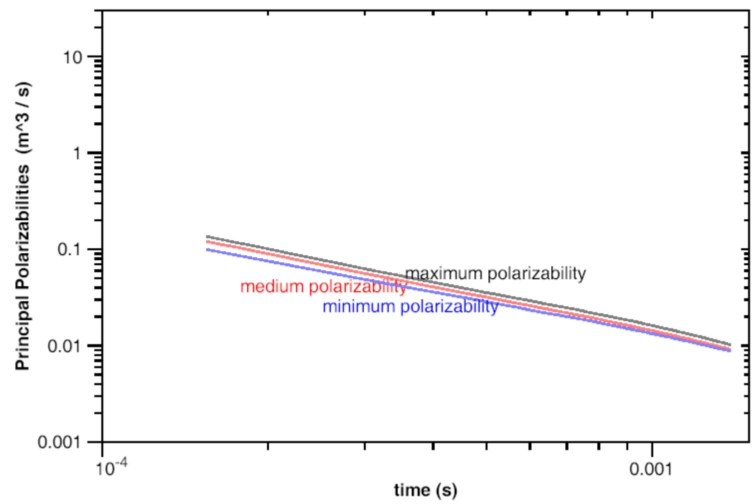
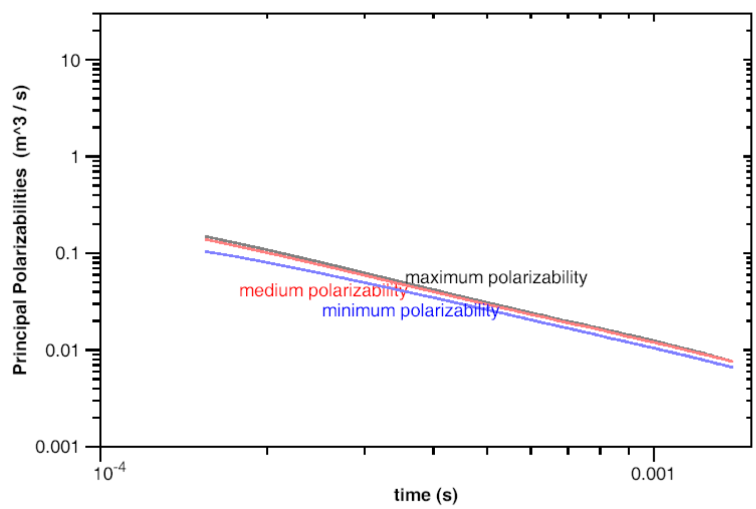
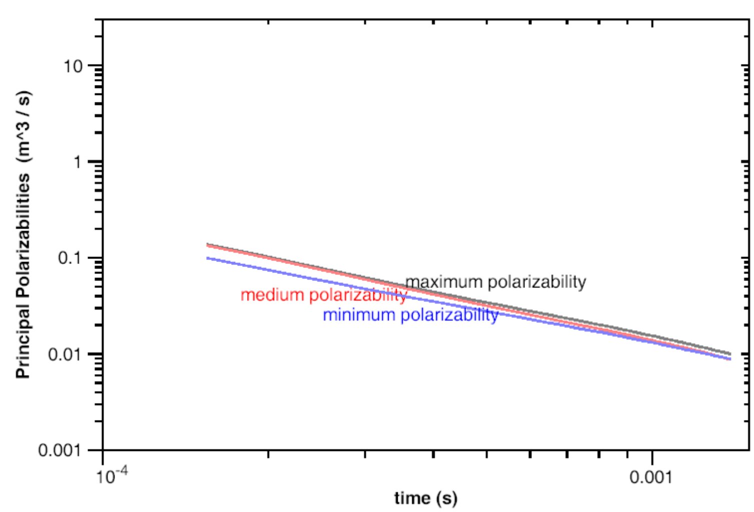
H1	MK118	0.60	0	
I1	MK118	0.60	0	
J1	MK118	0.47	-90	

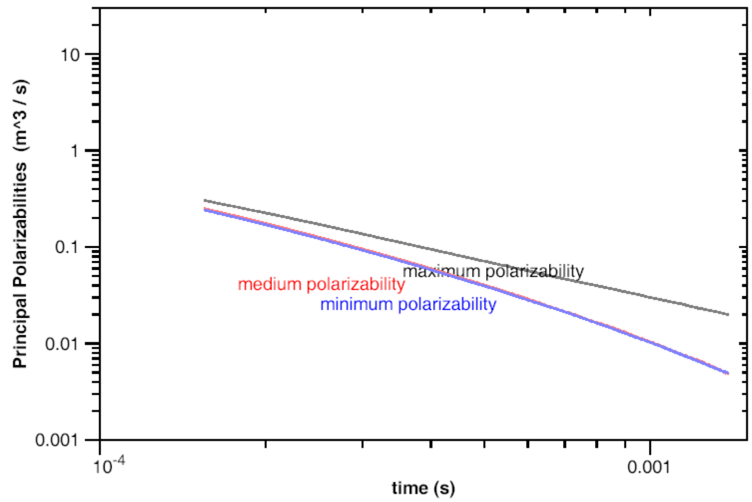
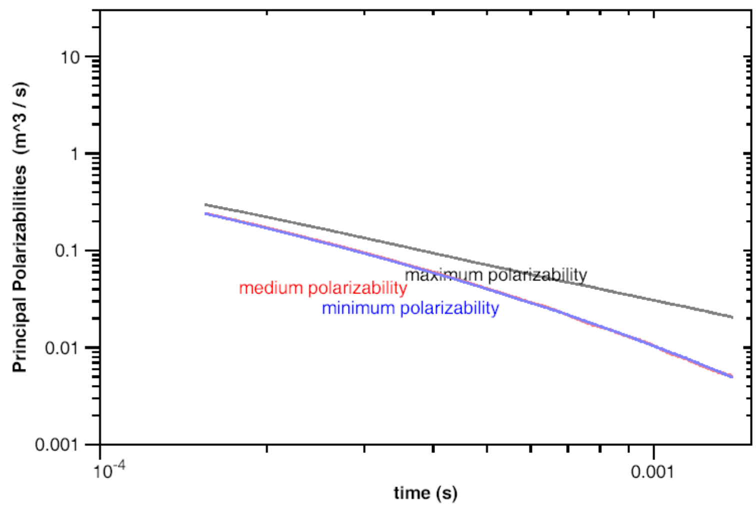
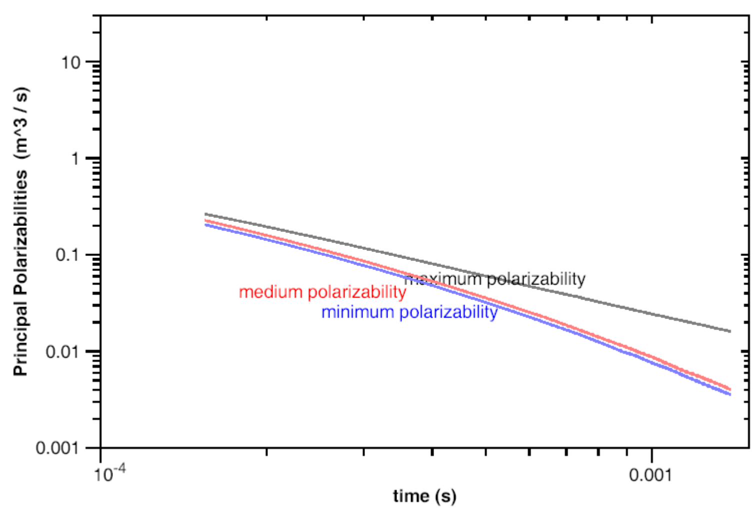
K1	MK118	0.47	90	
L1	MK118	0.42	-45	
M1	MK118	0.42	45	

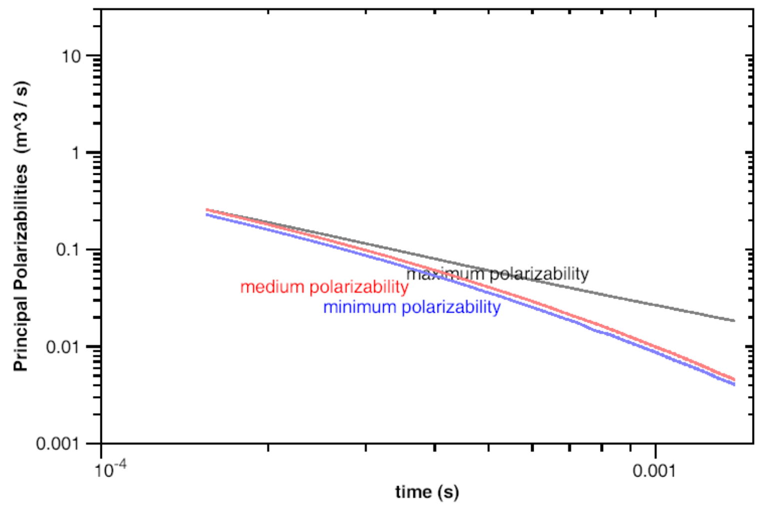
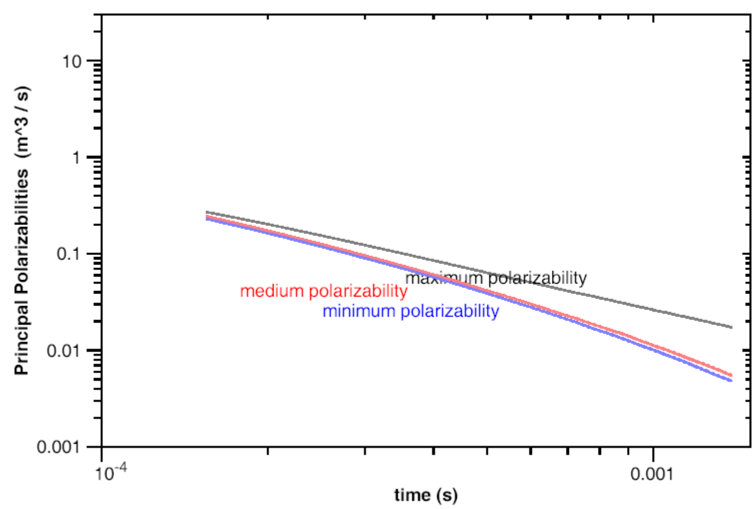
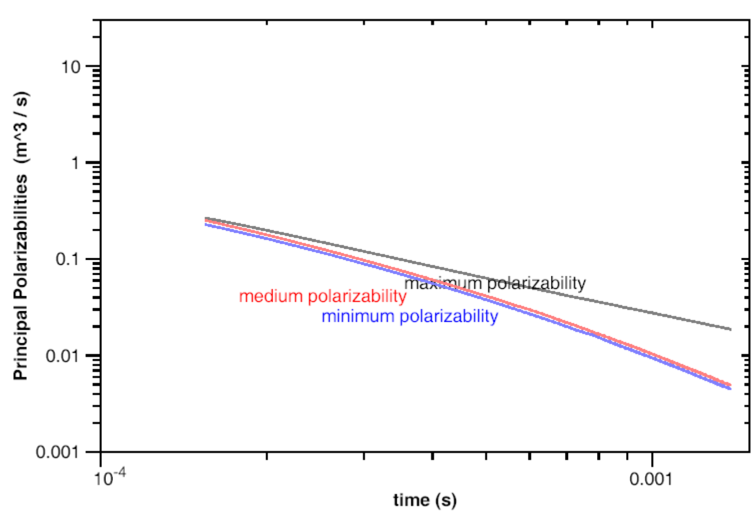
A2	81mm M374	1.50	0	
B2	81mm M374	1.50	0	
C2	81mm M374	0.75	-90	

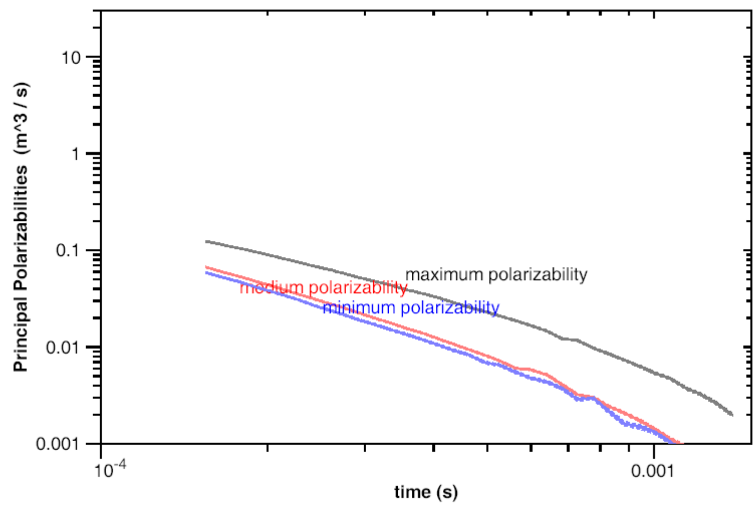
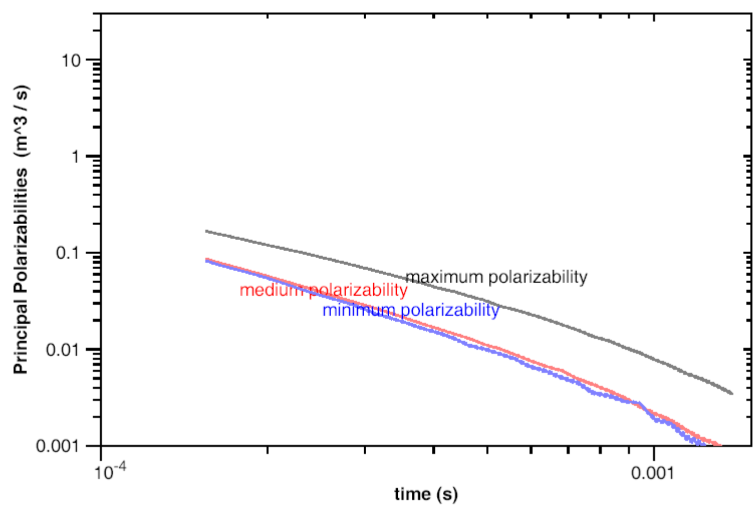
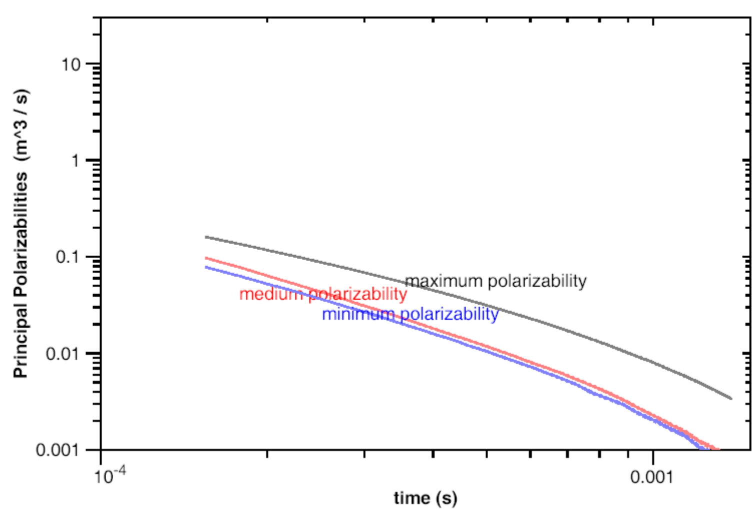
D2	81mm M374	0.75	90	
E2	81mm M374	0.67	-45	
F2	81mm M374	0.67	45	

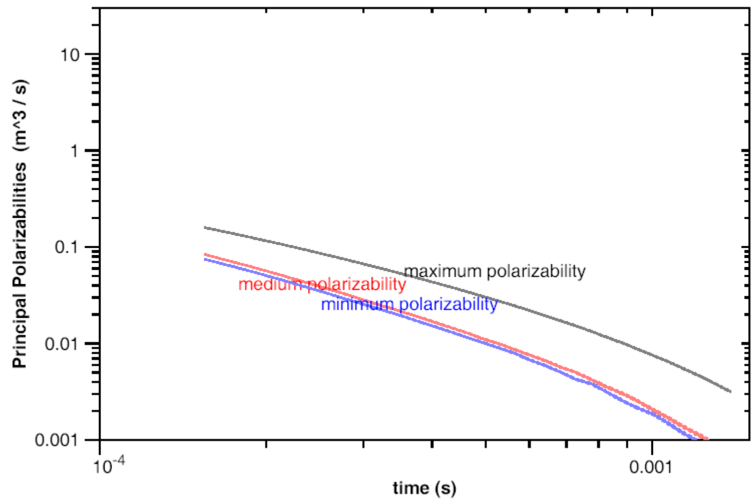
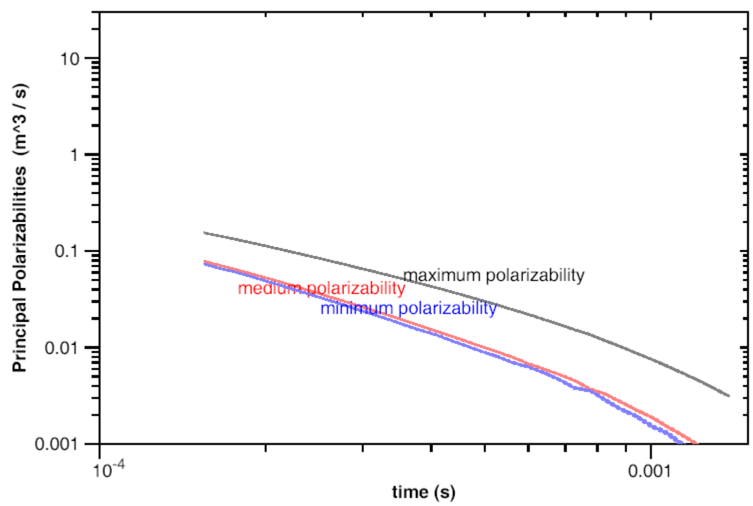
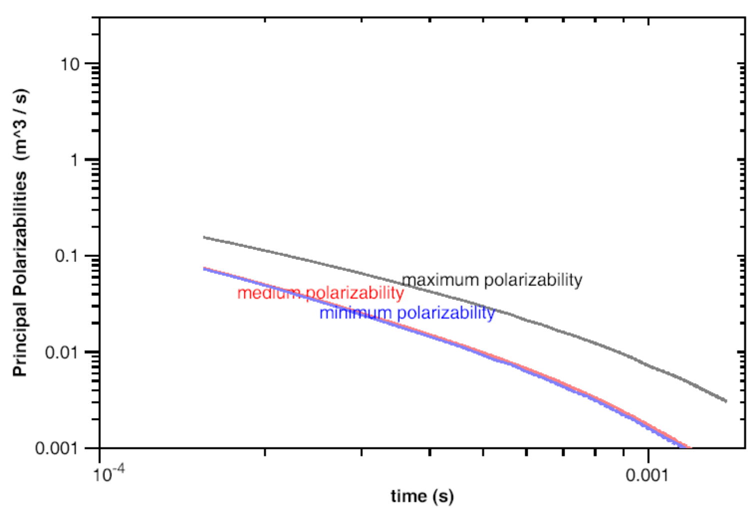
H2	BDU-28	0.20	0	
I2	BDU-28	0.20	0	
J2	BDU-28	0.15	-90	

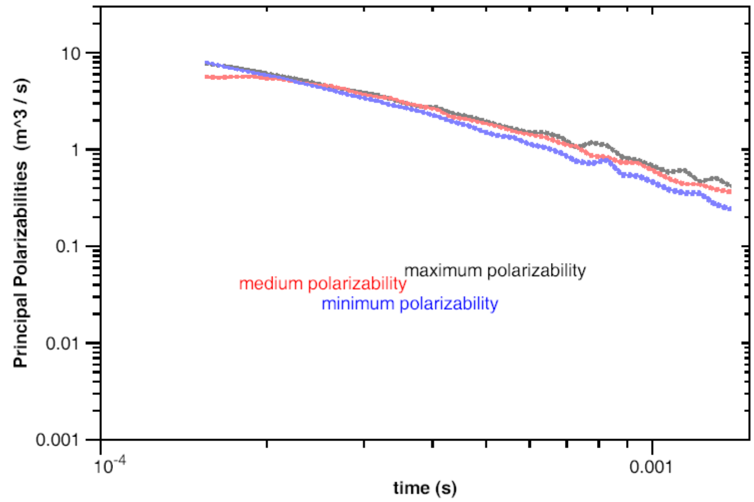
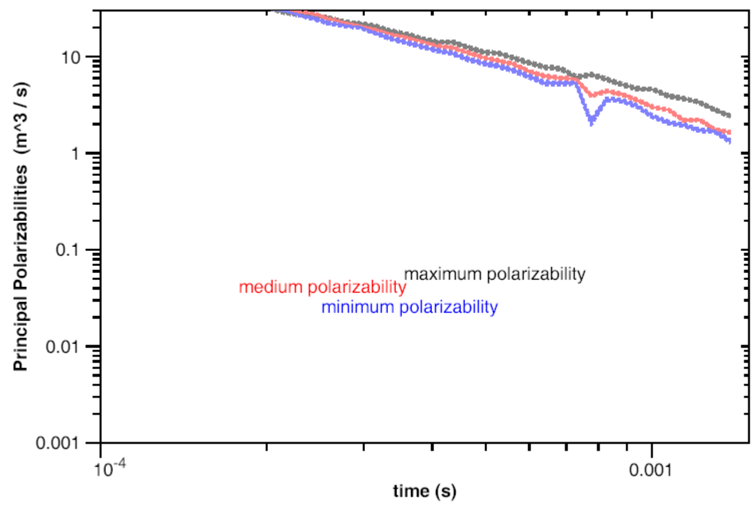
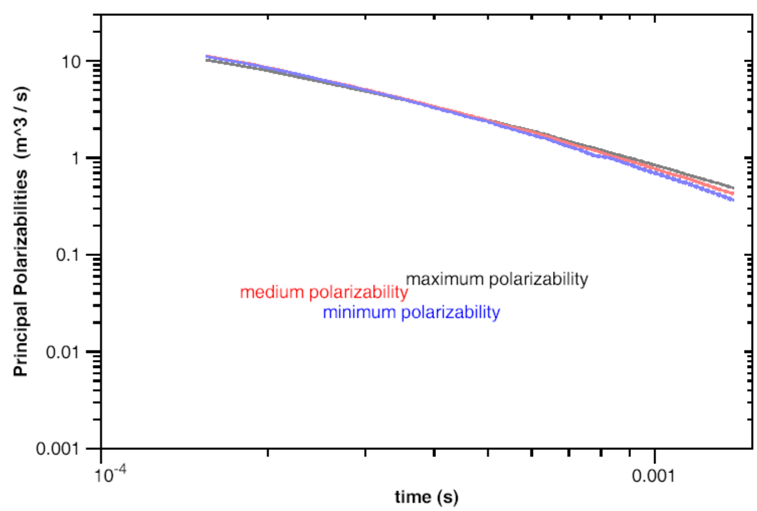
K2	BDU-28	0.15	90	
L2	BDU-28	0.14	-45	
M2	BDU-28	0.14	45	

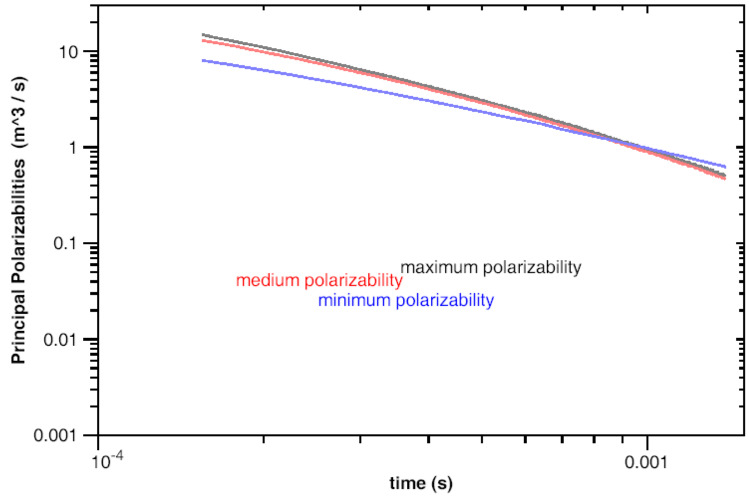
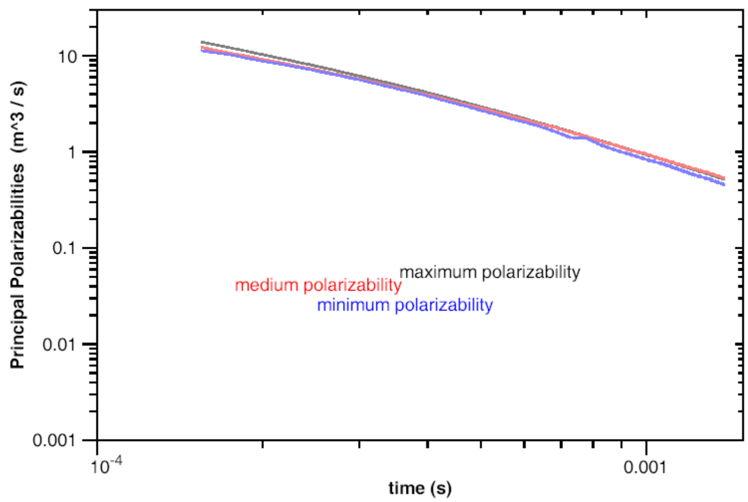
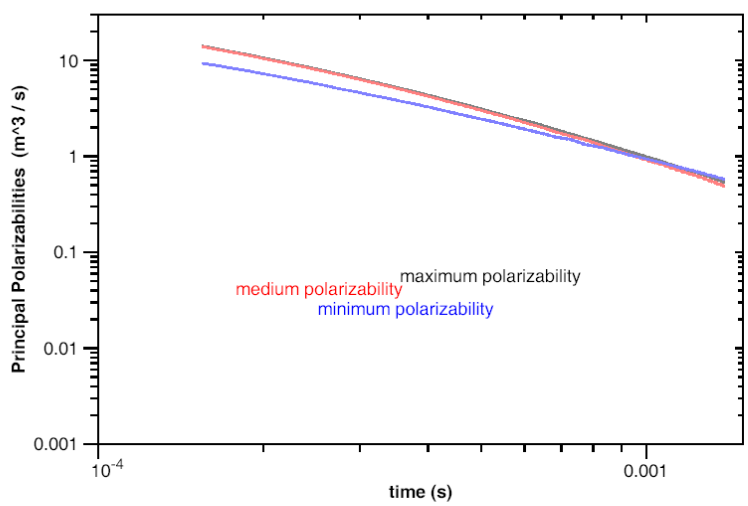
A3	40mm MKII	0.30	0	
B3	40mm MKII	0.30	0	
C3	40mm MKII	0.22	-90	

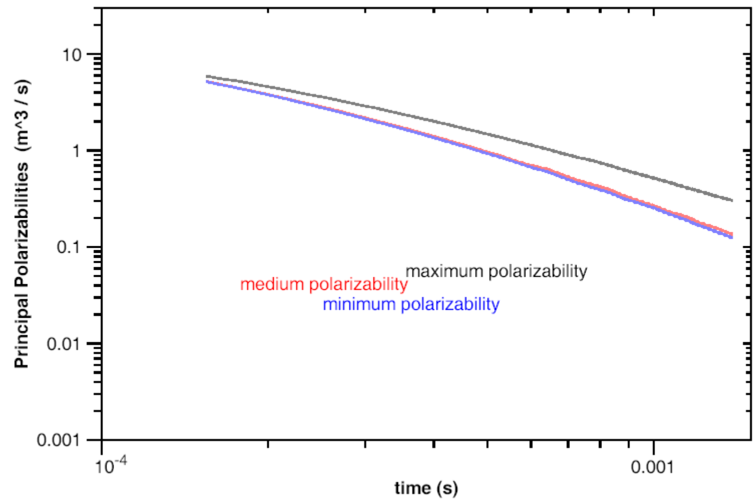
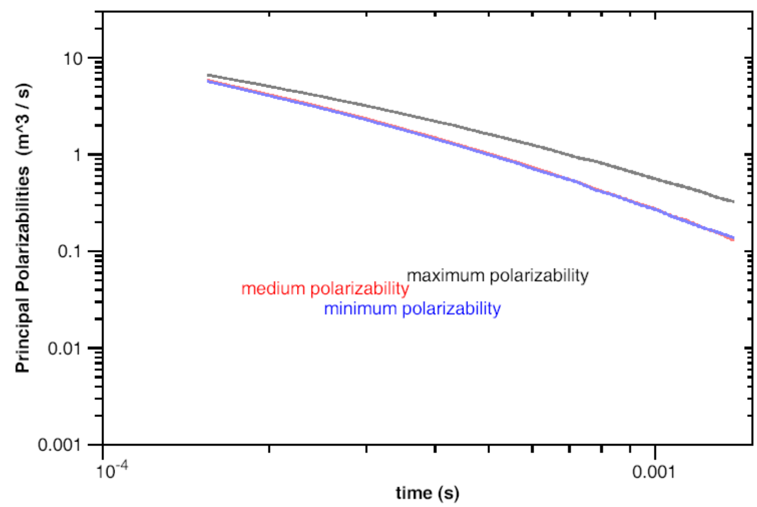
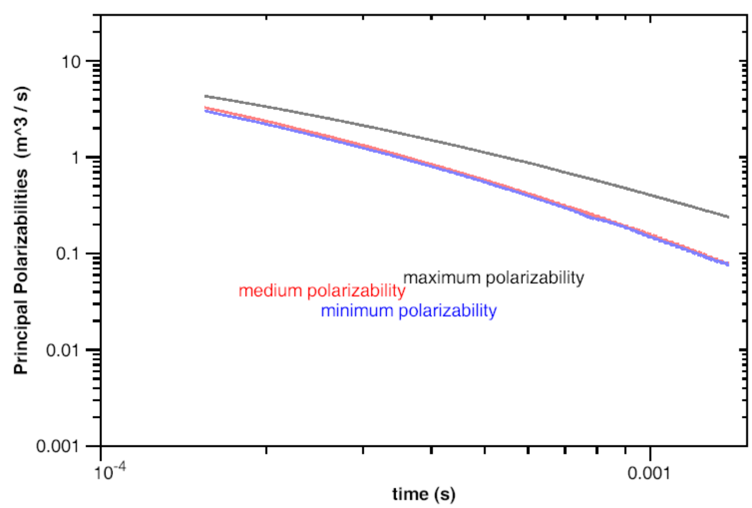
D3	40mm MKII	0.22	90	
E3	40mm MKII	0.20	-45	
F3	40mm MKII	0.20	45	

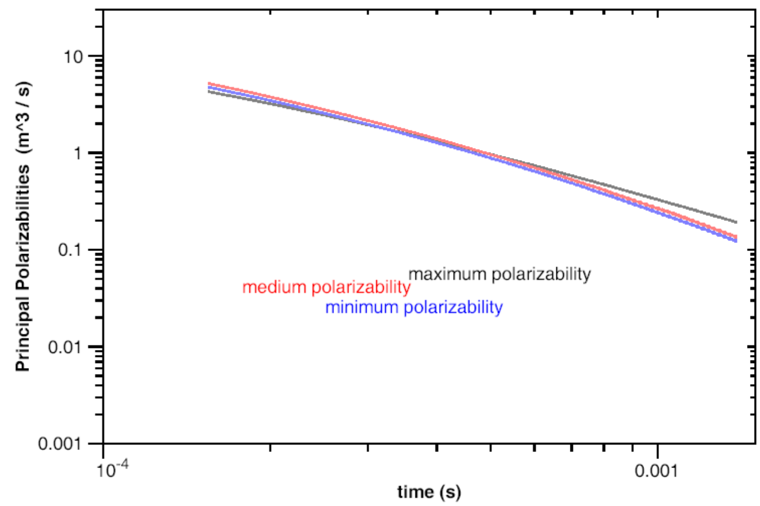
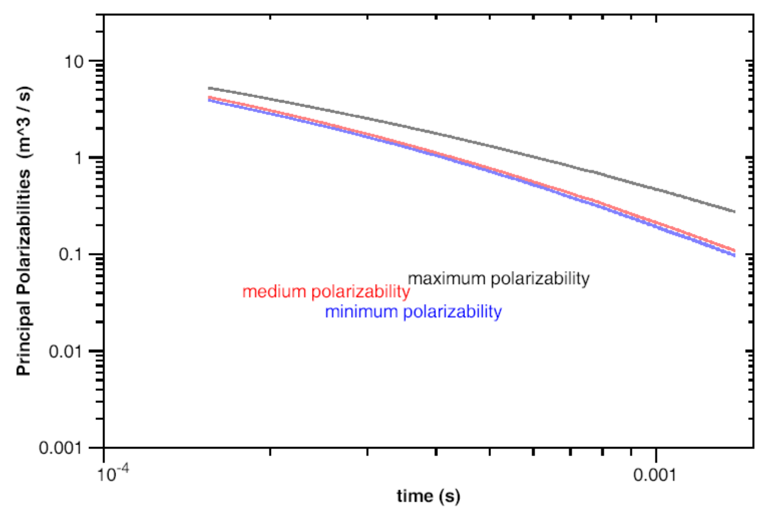
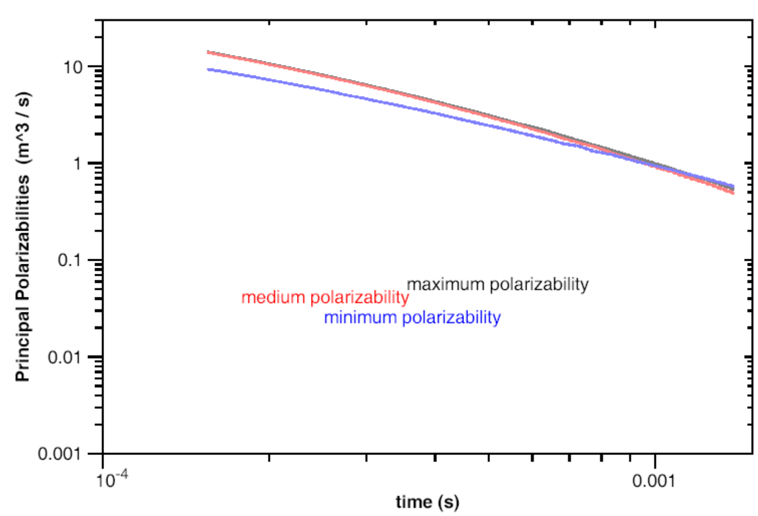
H3	M42	0.35	0	
I3	M42	0.35	0	
J3	M42	0.18	-90	

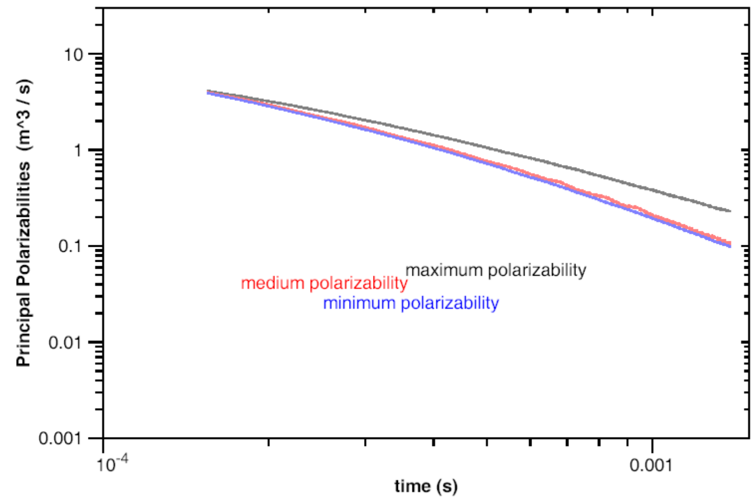
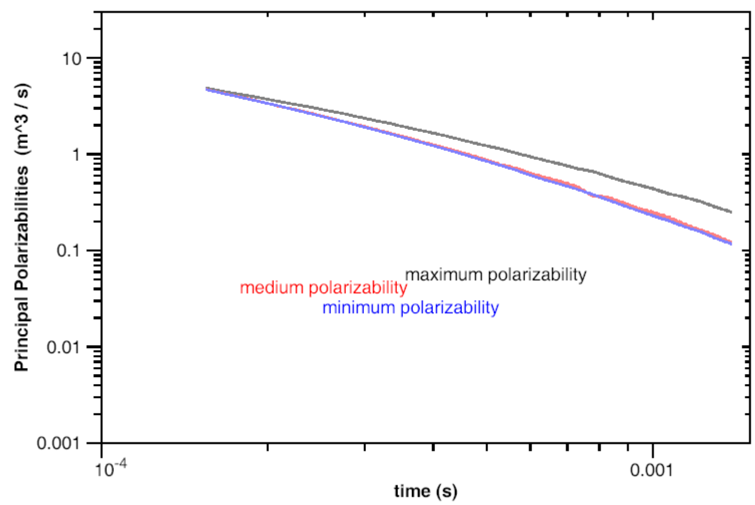
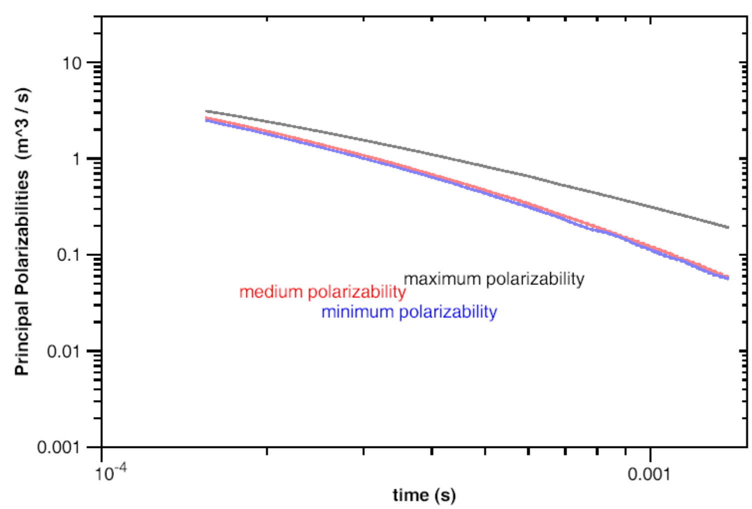
K3	M42	0.18	90	
L3	M42	0.17	-45	
M3	M42	0.17	45	

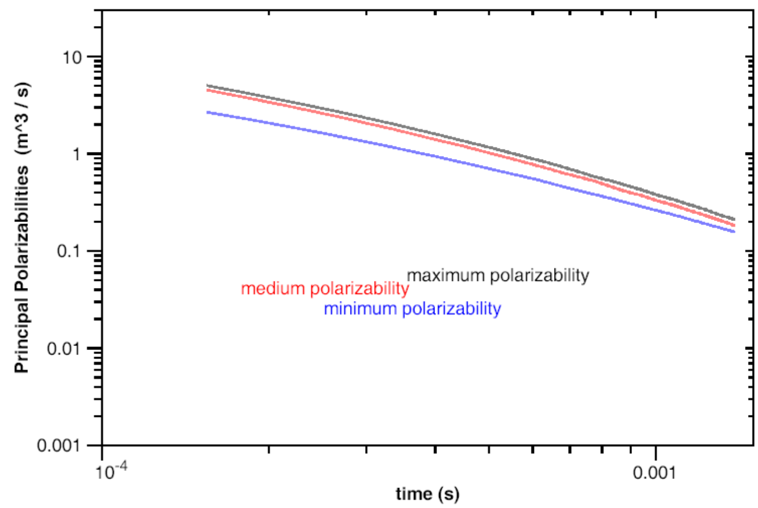
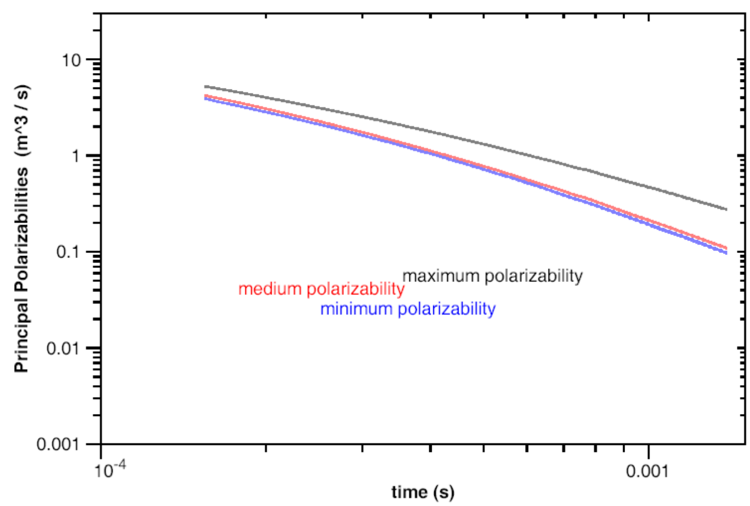
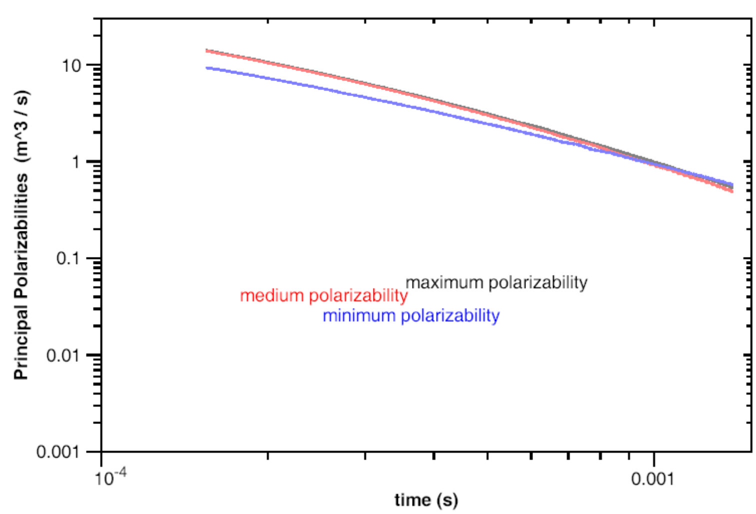
B4	155mm M483A1	1.50	0	
D4	155mm M483A1	1.50	0	
F4	155mm M483A1	1.19	-90	

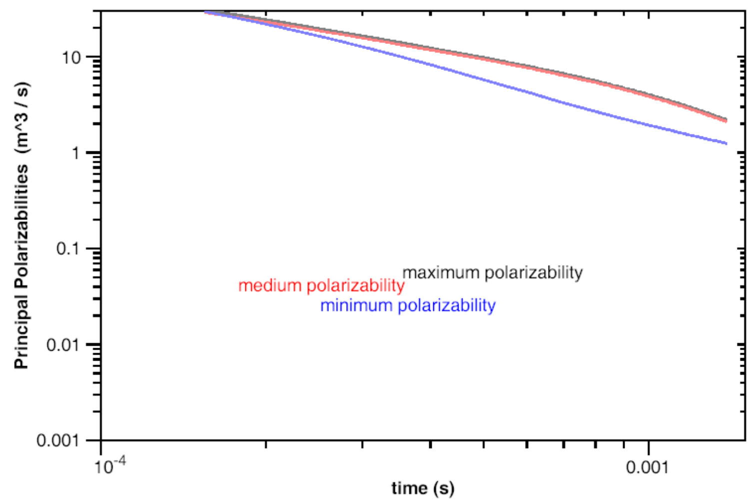
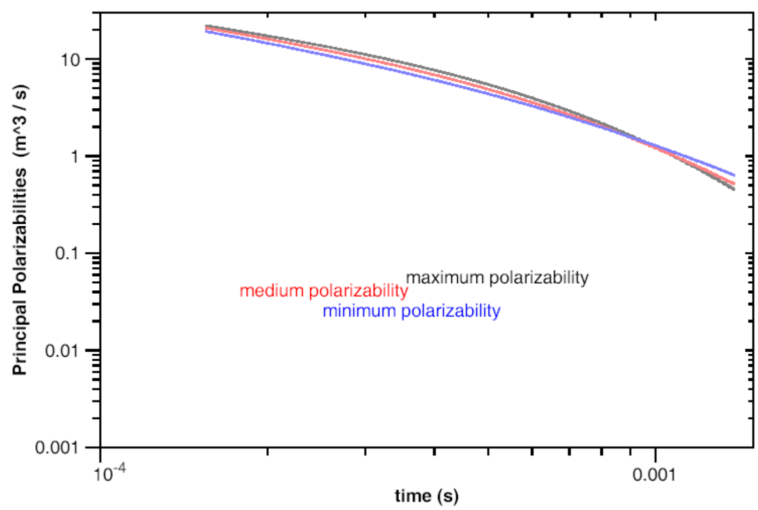
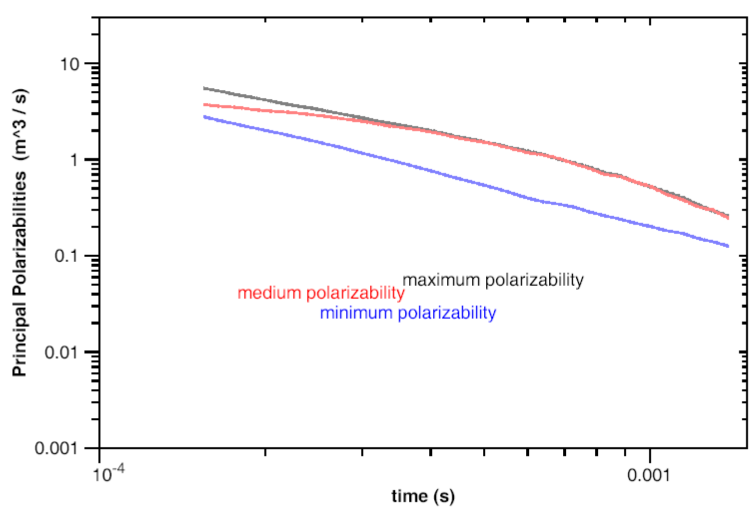
H4	155mm M483A1	1.19	90	
J4	155mm M483A1	1.06	-45	
L4	155mm M483A1	1.06	45	

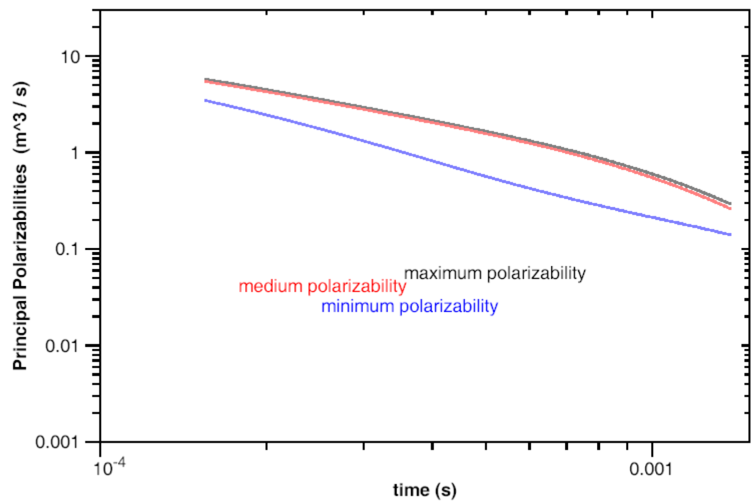
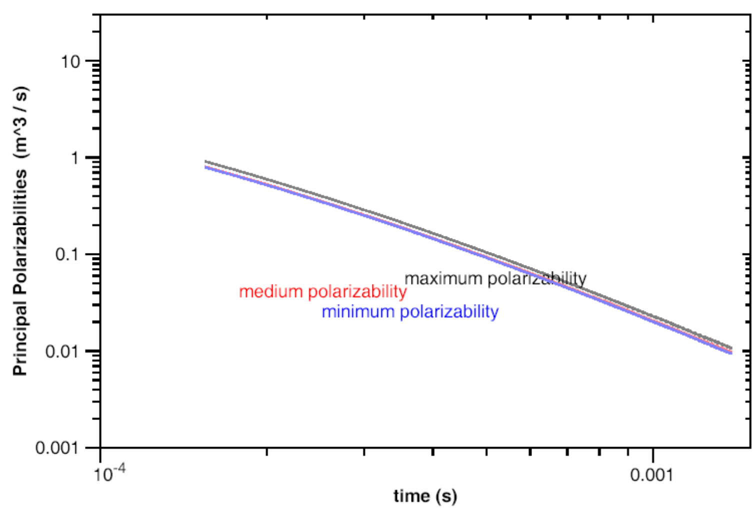
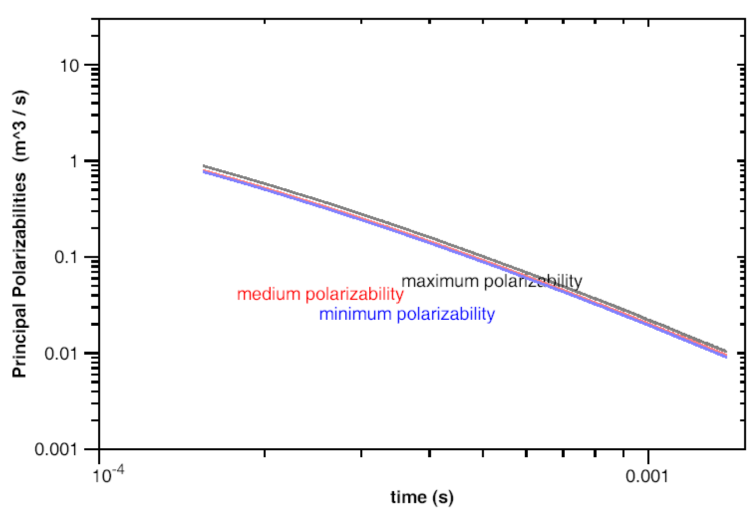
B5	105mm M60	0.80	0	
D5	105mm M60	0.80	0	
F5	105mm M60	0.62	-90	

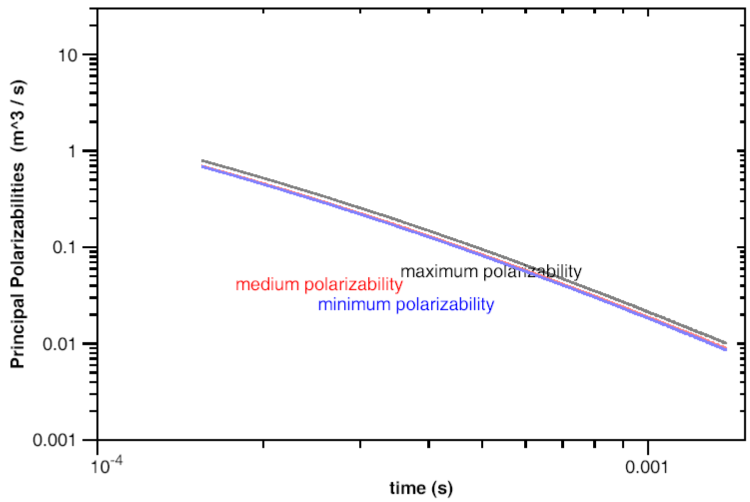
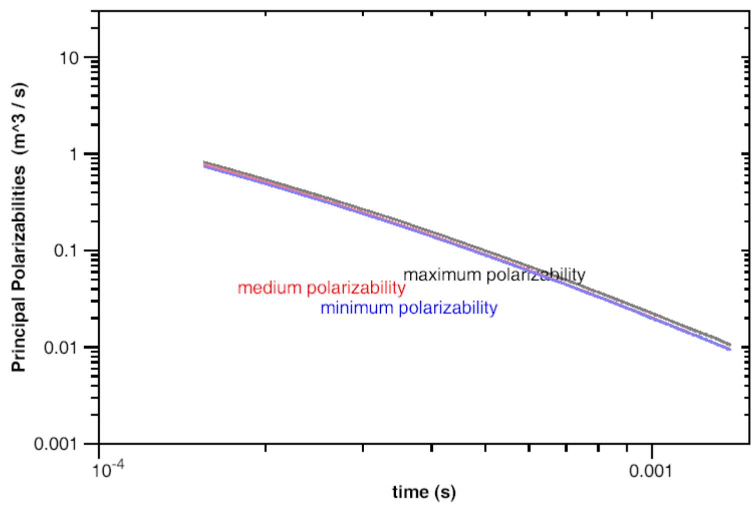
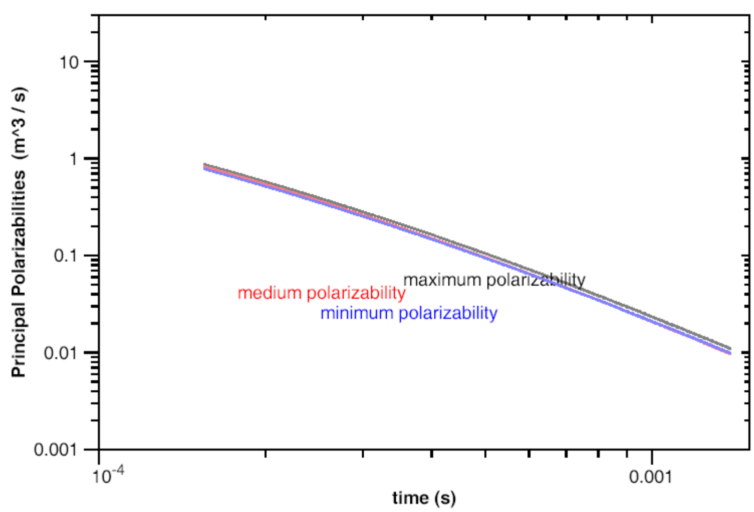
H5	105mm M60	0.62	90	
J5	105mm M60	0.55	-45	
L5	105mm M60	0.55	45	

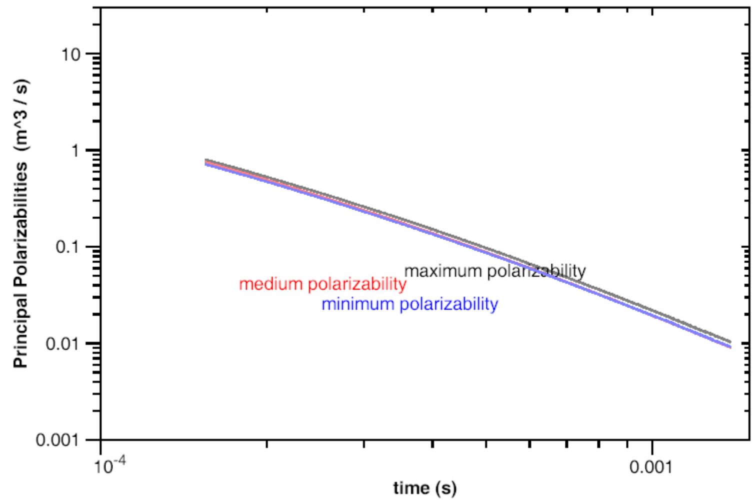
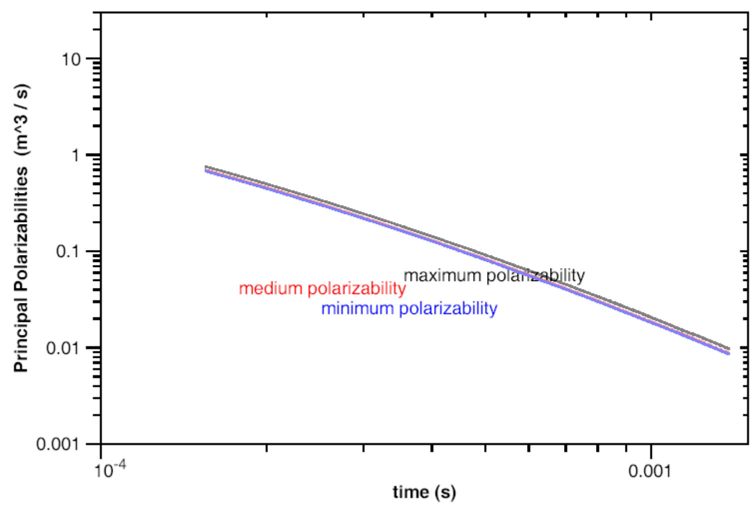
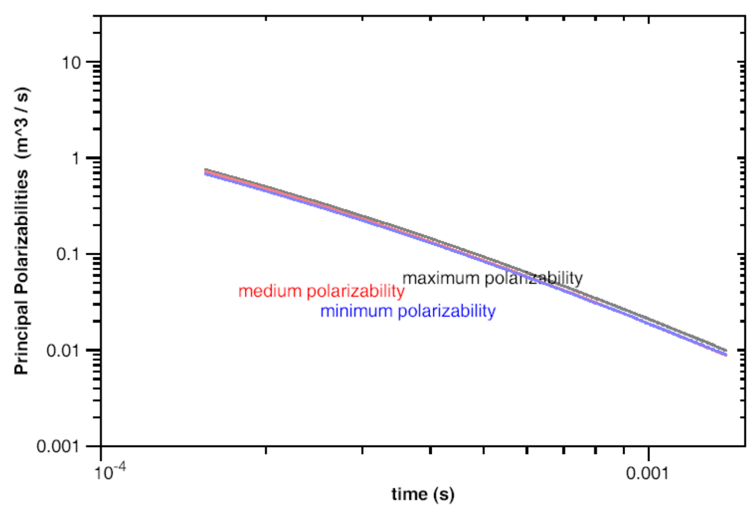
B6	105mm M456 HEAT	0.80	0	
D6	105mm M456 HEAT	0.80	0	
F6	105mm M456 HEAT	0.72	-90	

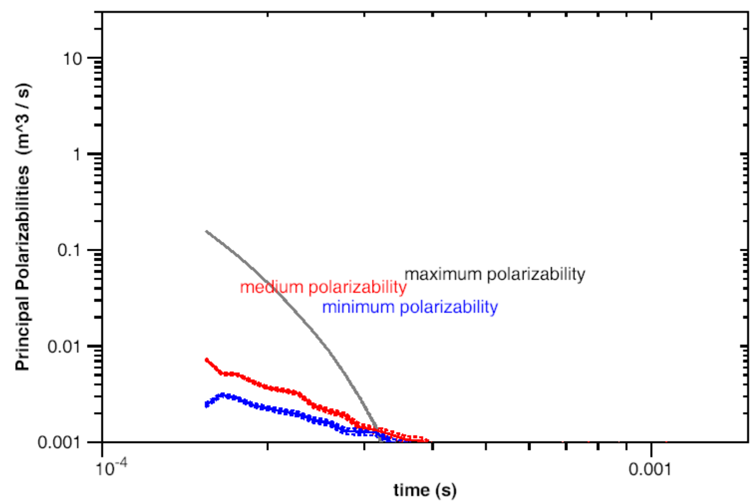
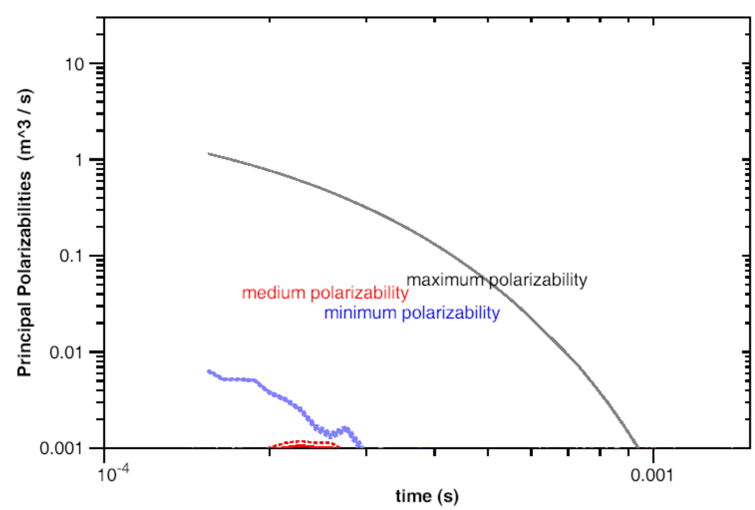
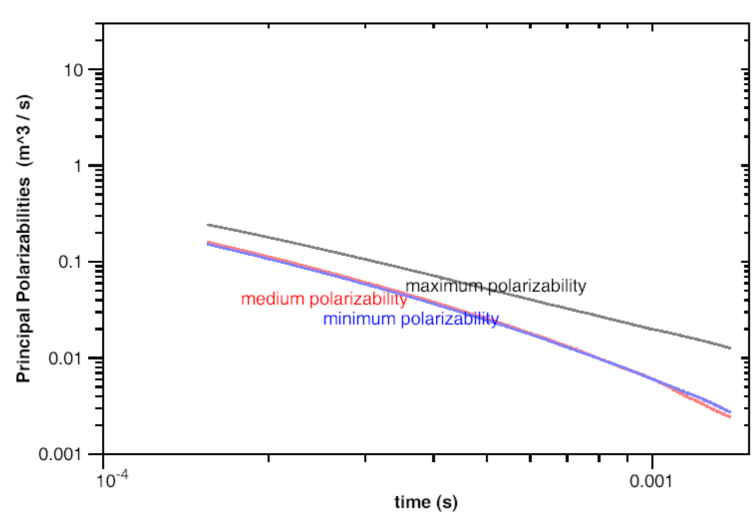
H6	105mm M456 HEAT	0.72	90	
J6	105mm M456 HEAT	0.63	-45	
L6	105mm M456 HEAT	0.63	45	

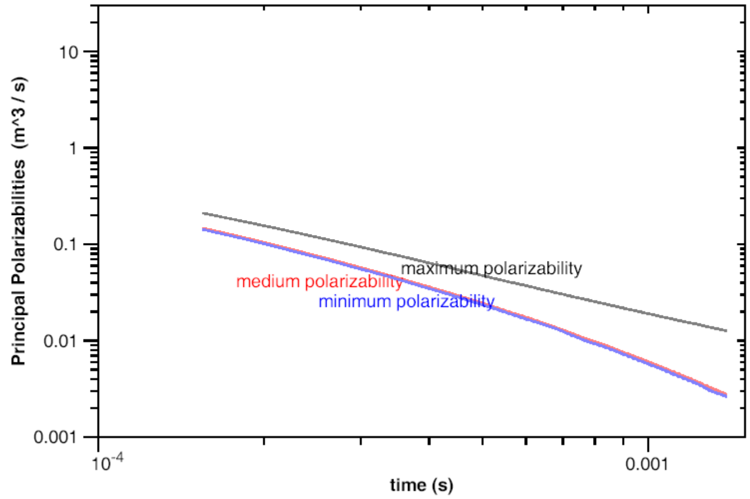
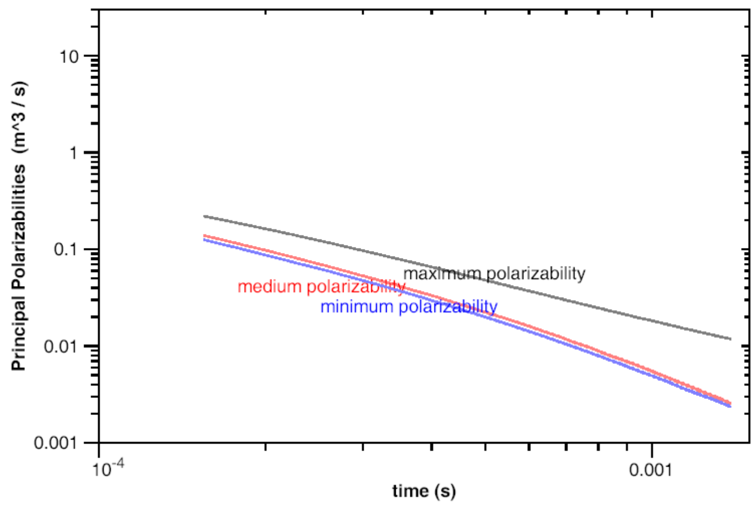
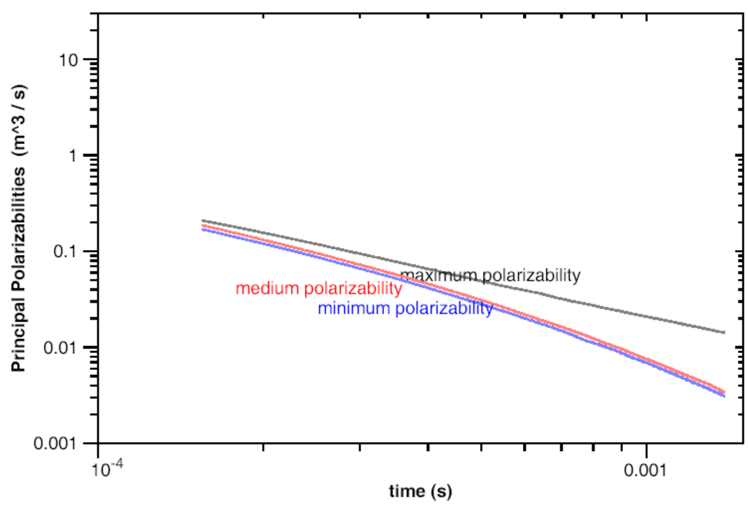
F7	60 cm steel plate	1.00	0	
H7	60 cm steel plate	0.50	0	
J7	30 cm steel plate	1.0	0	

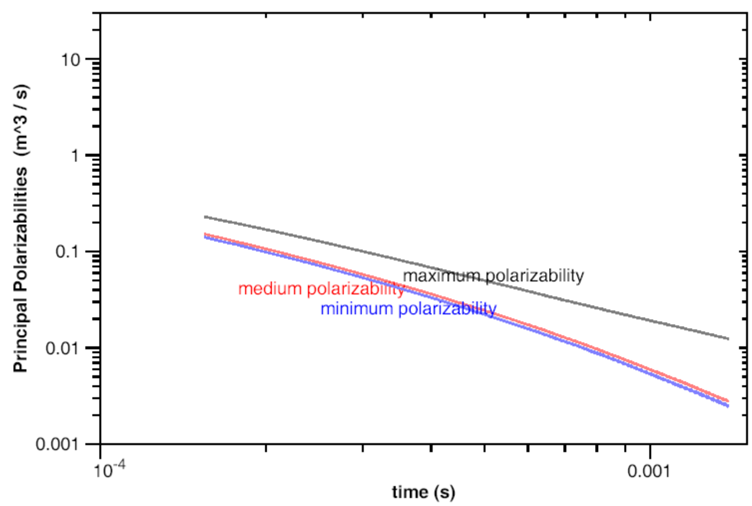
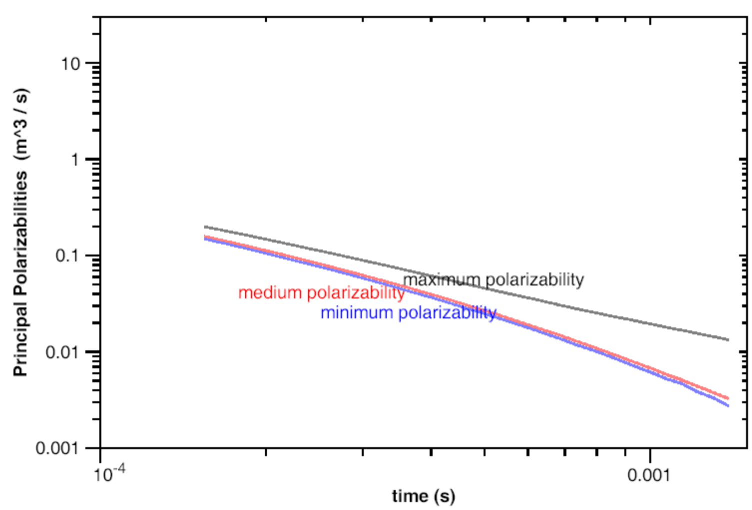
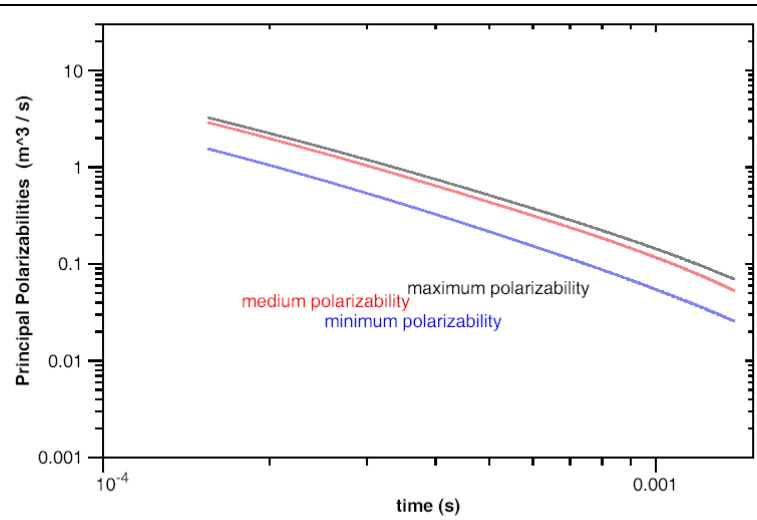
L7	30 cm steel plate	0.5	0	
G8	8# shot	0.20		
G9	8# shot	0.20		

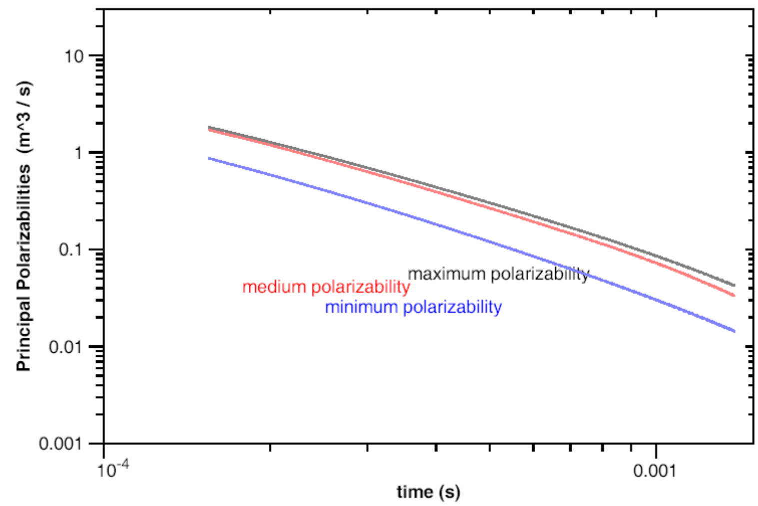
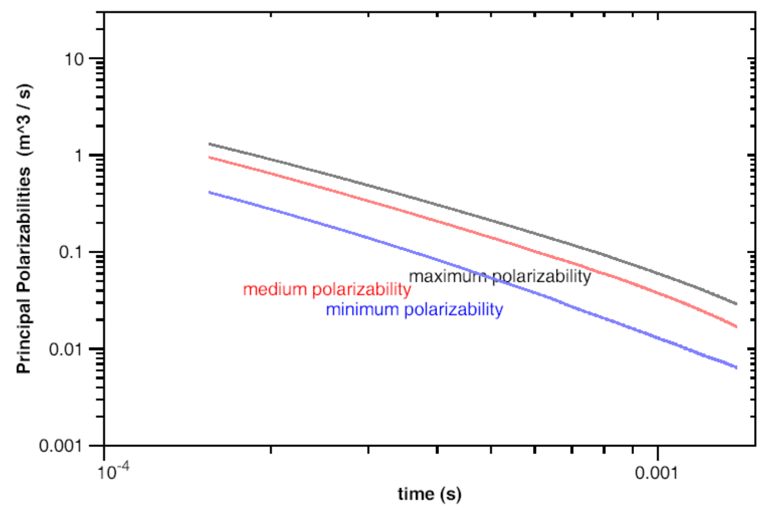
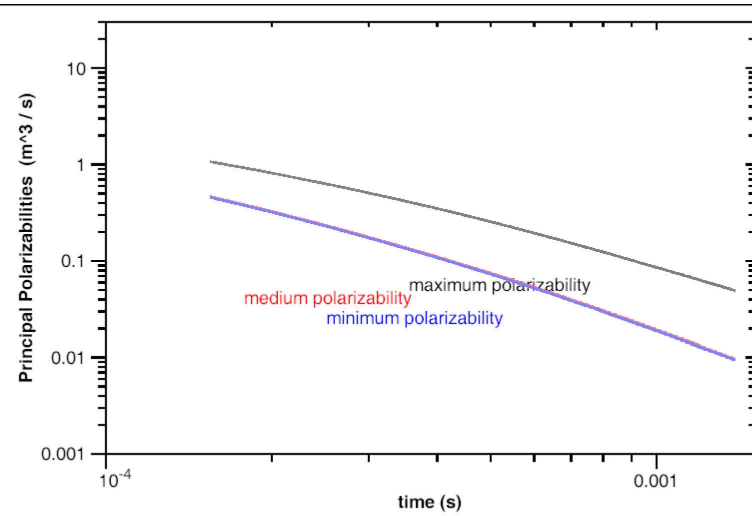
G10	8# shot	0.20		
G11	8# shot	0.20		
G12	8# shot	0.20		

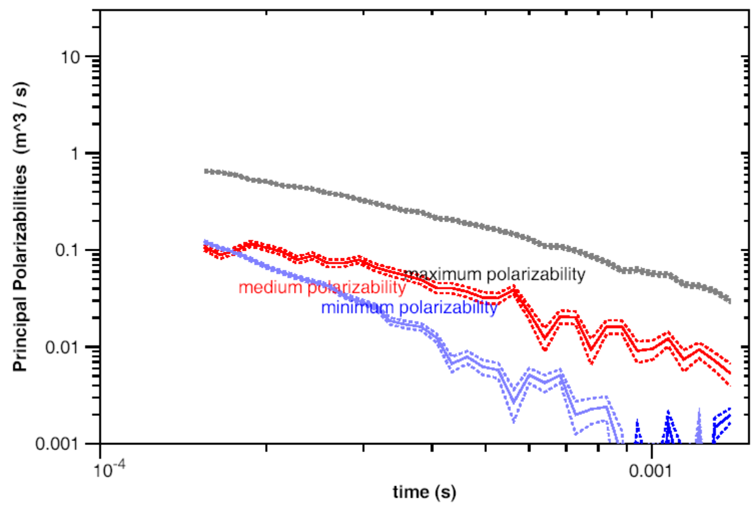
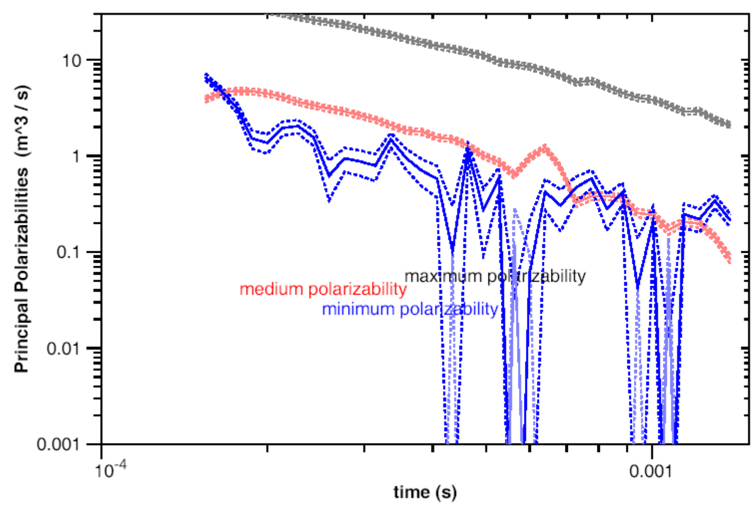
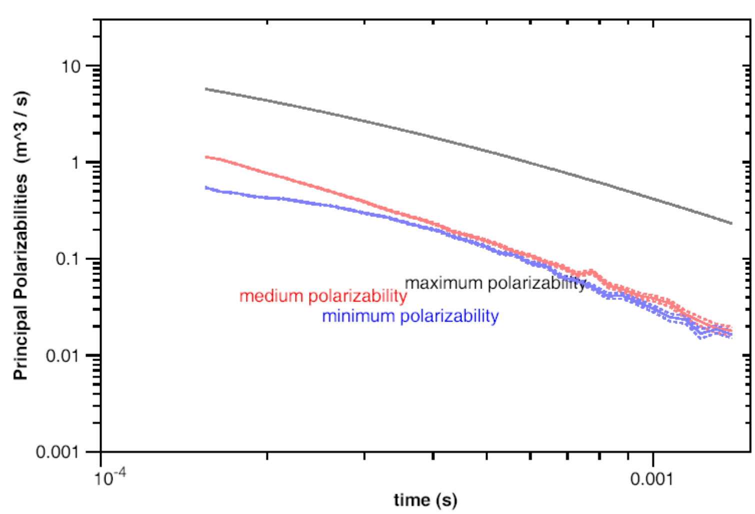
G13	8# shot	0.20		
G14	8# shot	0.20		
G15	8# shot	0.50		

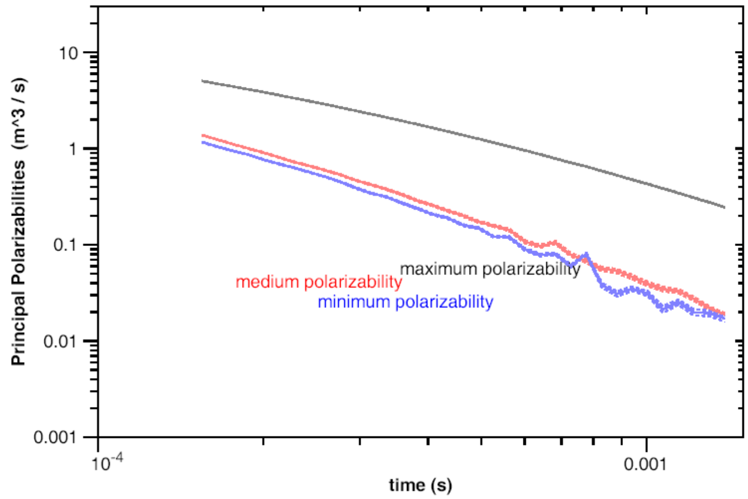
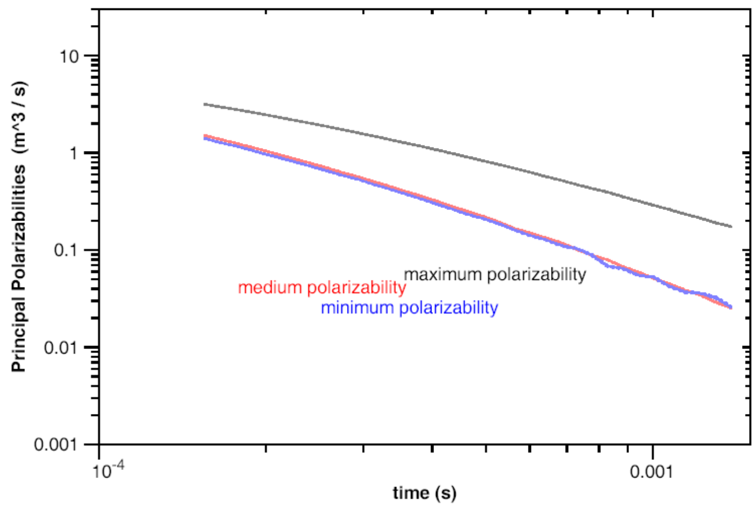
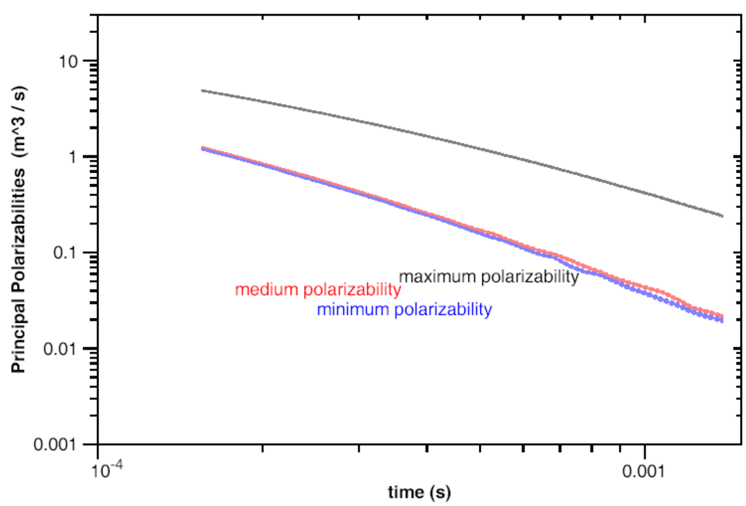
G16	20 GAGE 15cm LOOP	0.25	0	
G17	16 GAGE 15cm LOOP	0.25	0	
H9	37 mm	0.20	0	

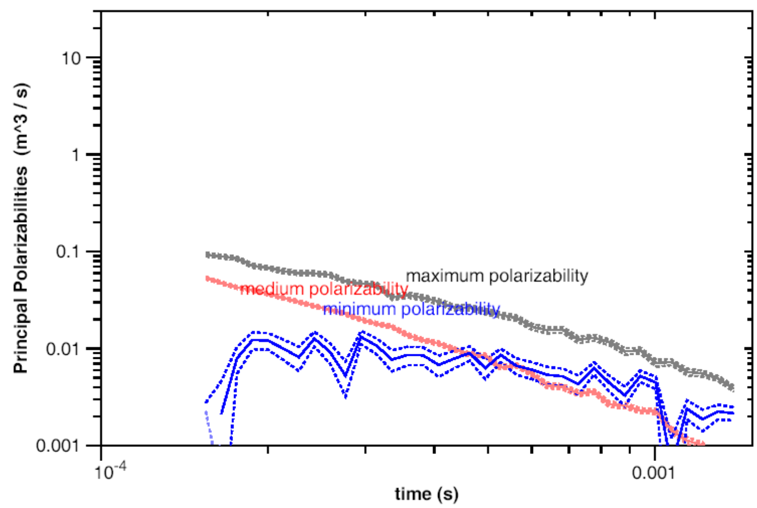
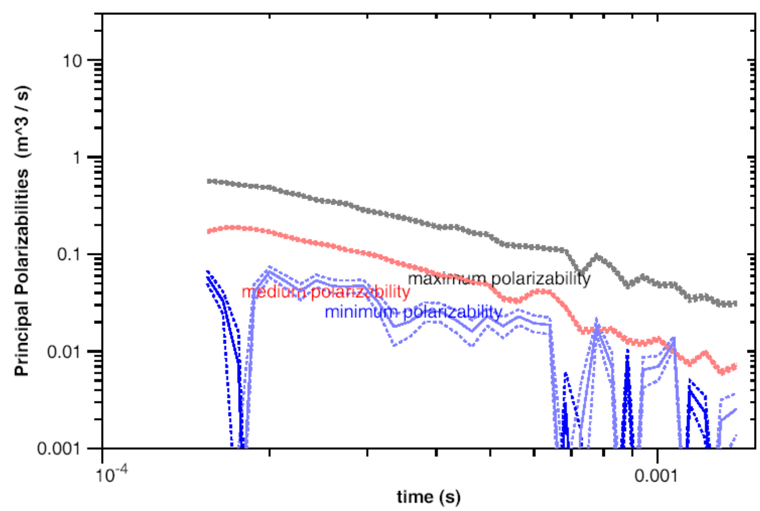
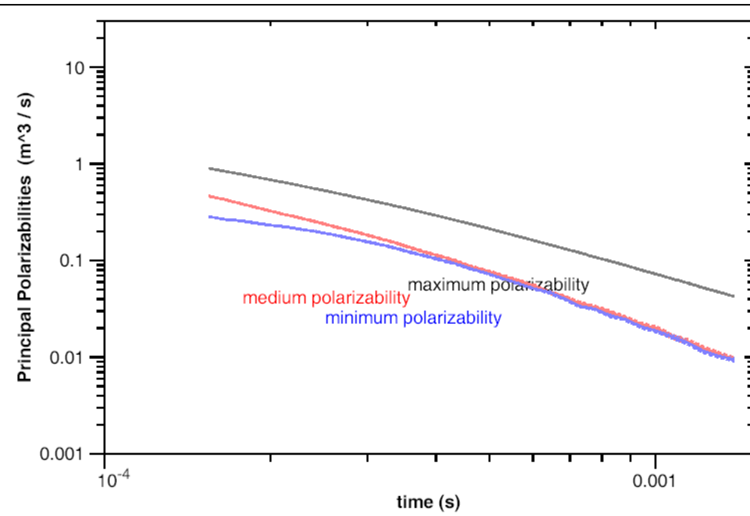
I9	37 mm	0.20	0	
J9	37 mm	0.14	-90	
K9	37 mm	0.14	90	

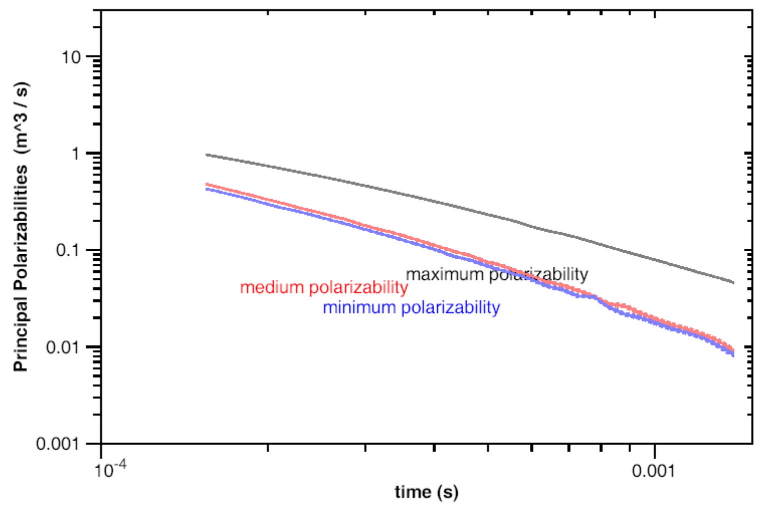
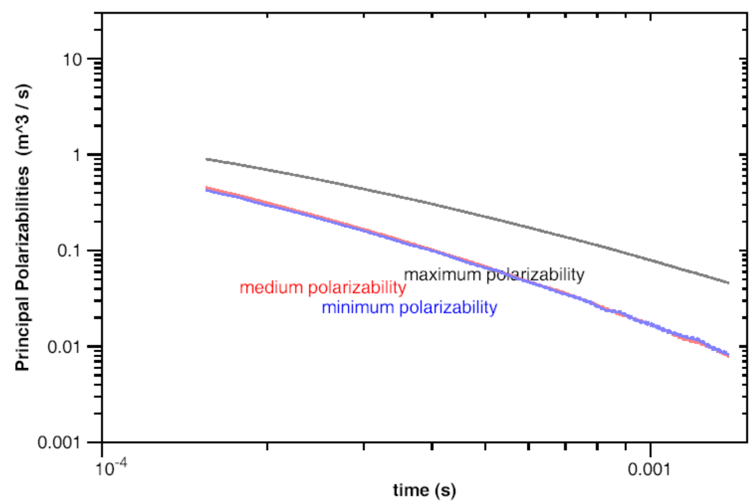
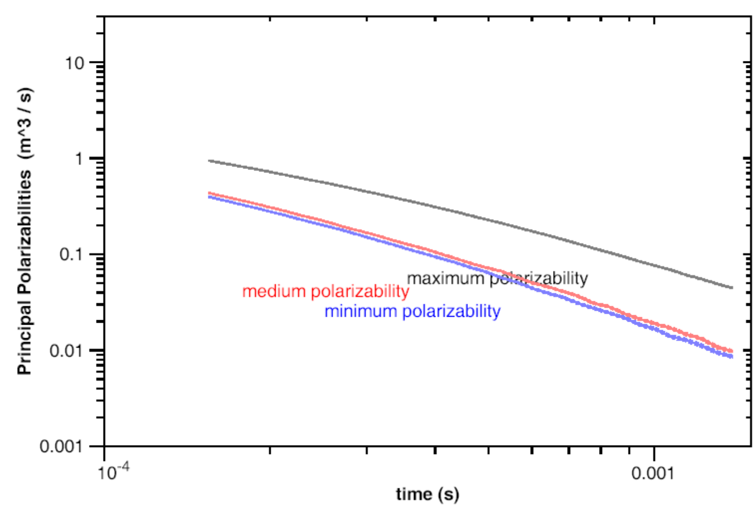
L9	37 mm	0.13	-45	
M9	37 mm	0.13	45	
C10	60mm M49A3/High Clutter	0.25	0	

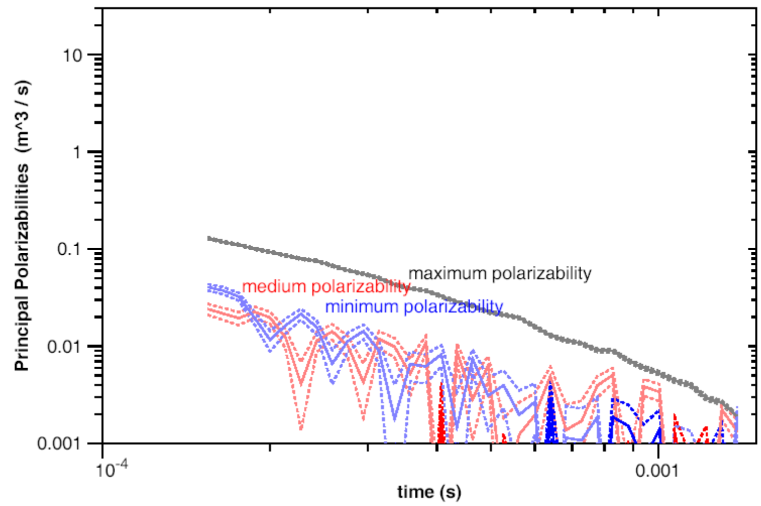
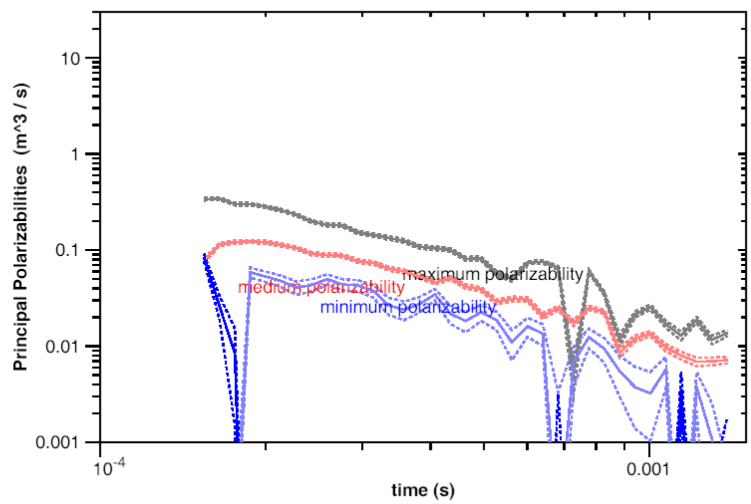
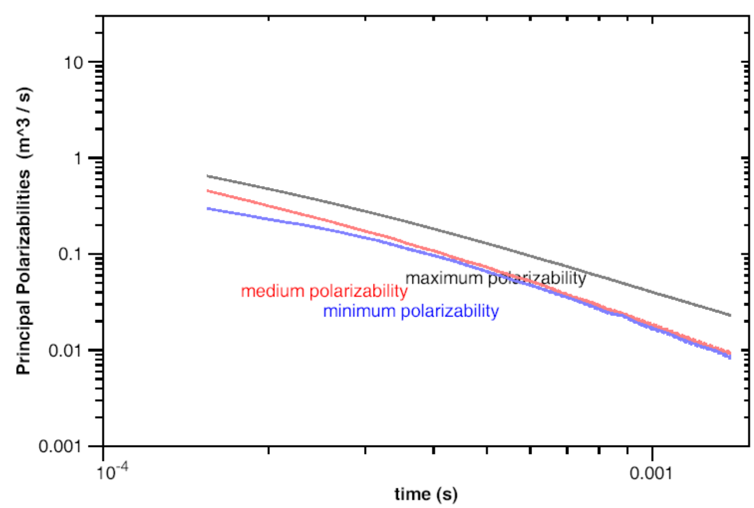
D10	60mm M49A3/Medium Clutter	0.25	0	
E10	60mm M49A3/Low Clutter	0.25	0	
F10	60mm M49A3/No Clutter	0.25	0	

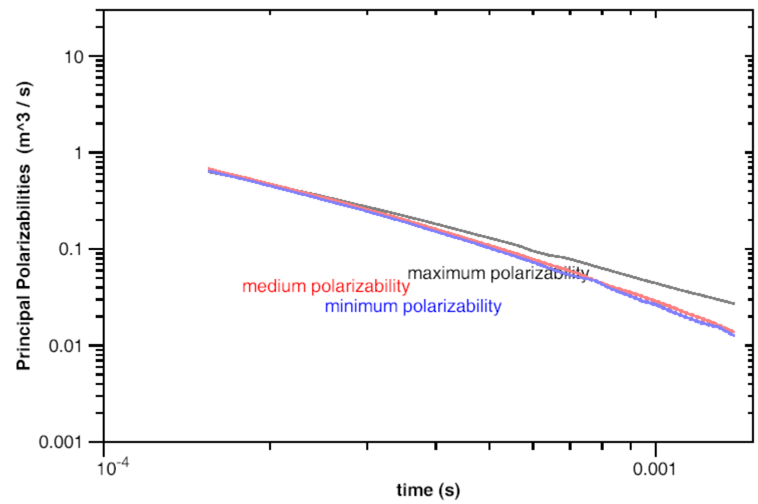
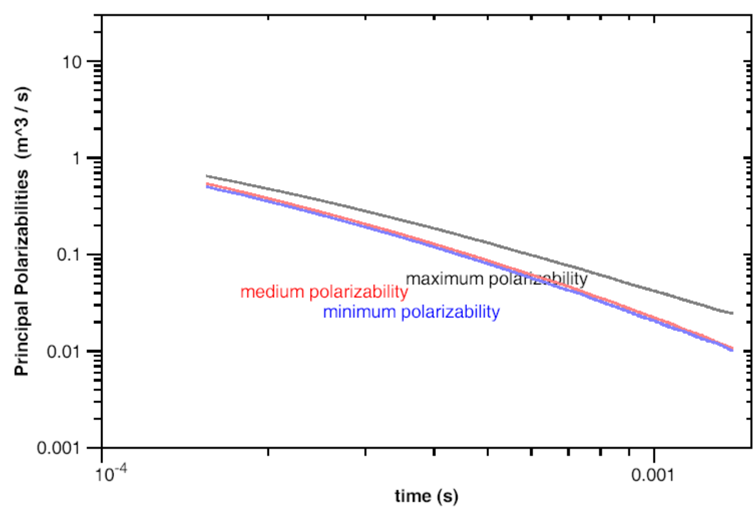
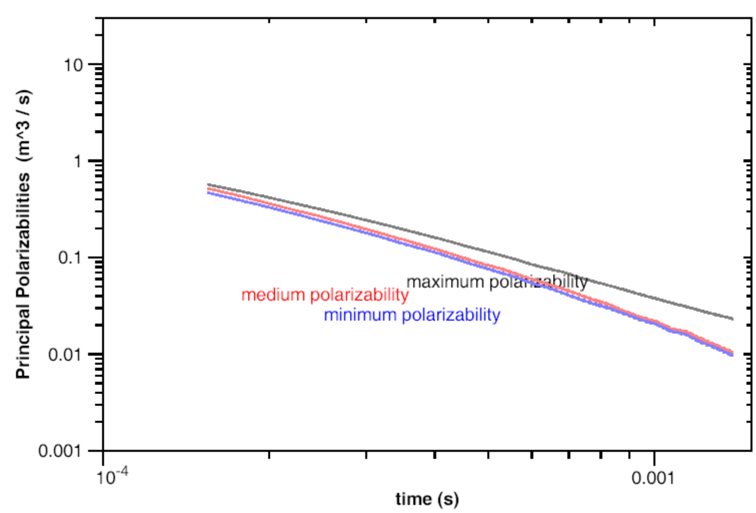
H10	2.75" M230	1.20	0	
I10	2.75" M230	1.20	0	
J10	2.75" M230	0.70	-90	

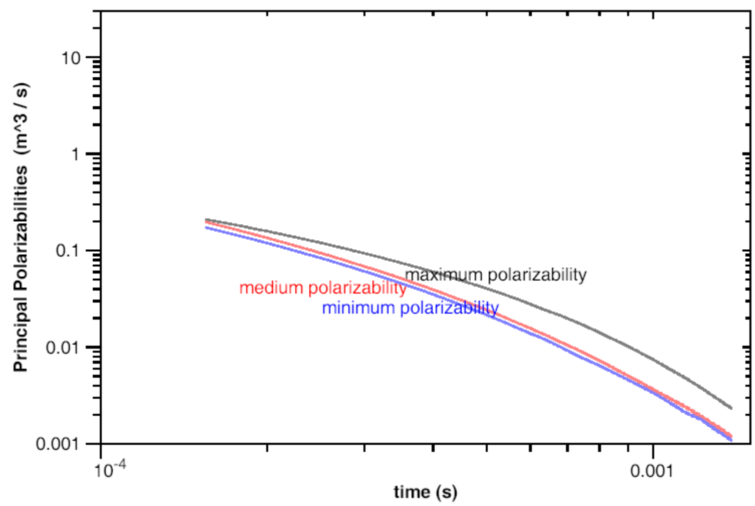
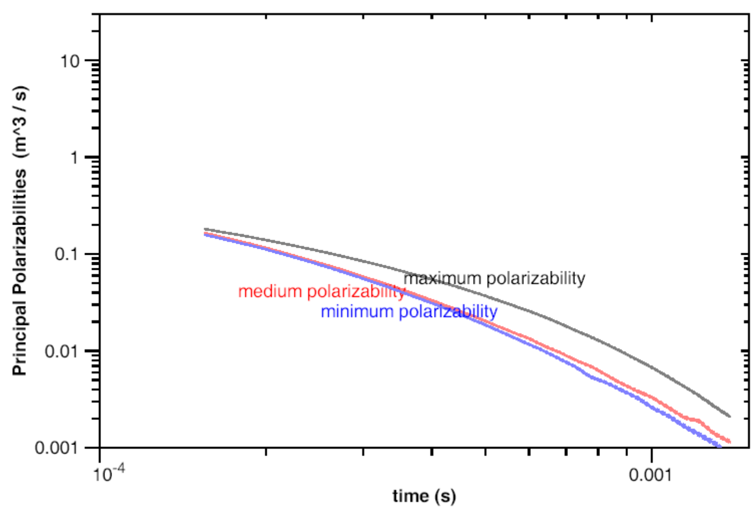
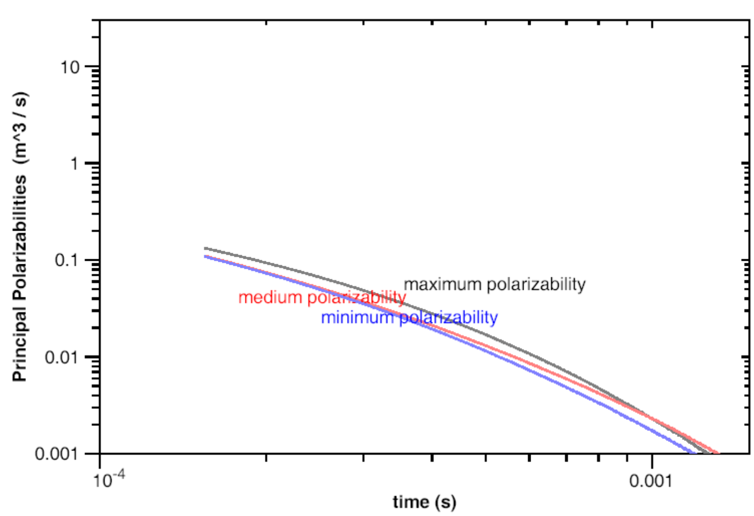
K10	2.75" M230	0.70	90	
L10	2.75" M230	0.64	-45	
M10	2.75" M230	0.64	45	

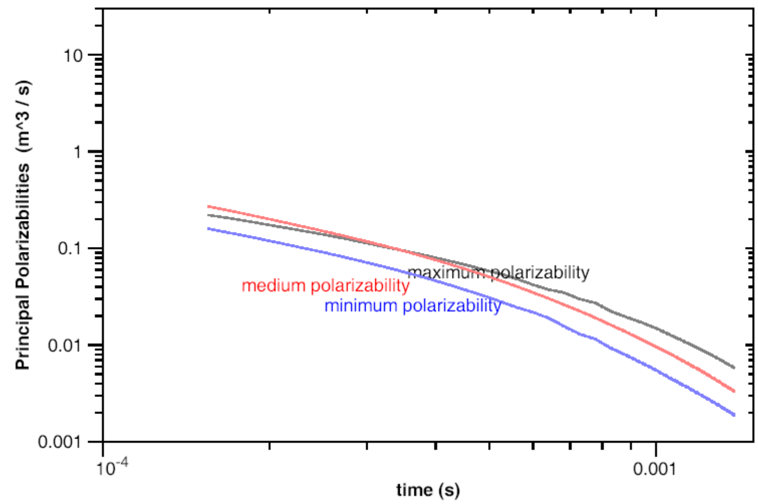
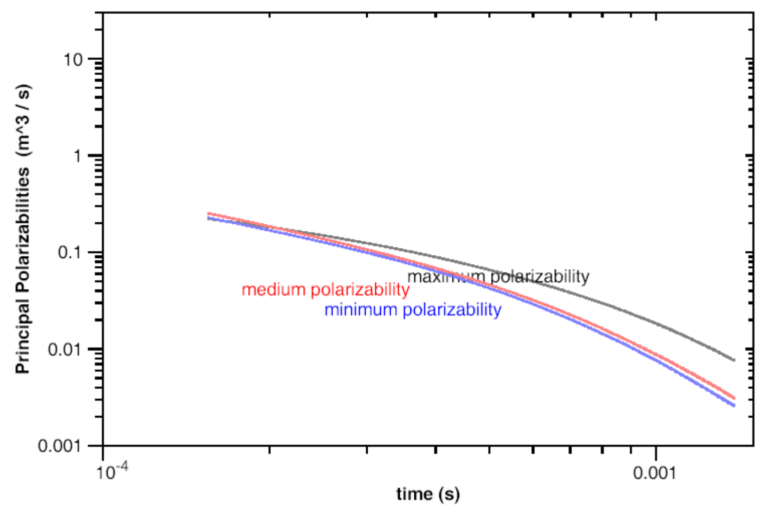
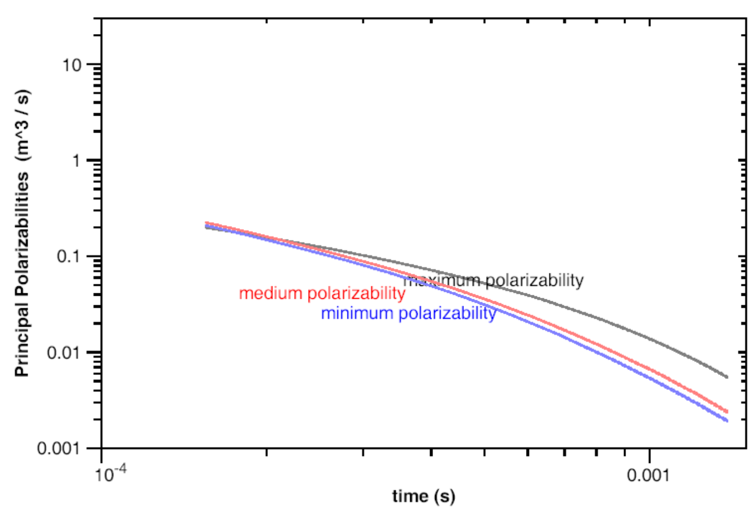
H11	60mm M49A3	0.91	0	
I11	60mm M49A3	0.40	0	
J11	60mm M49A3	0.52	-90	

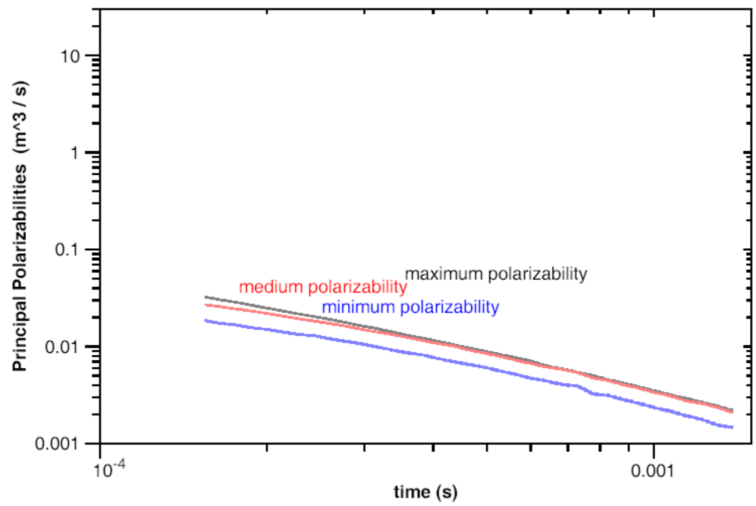
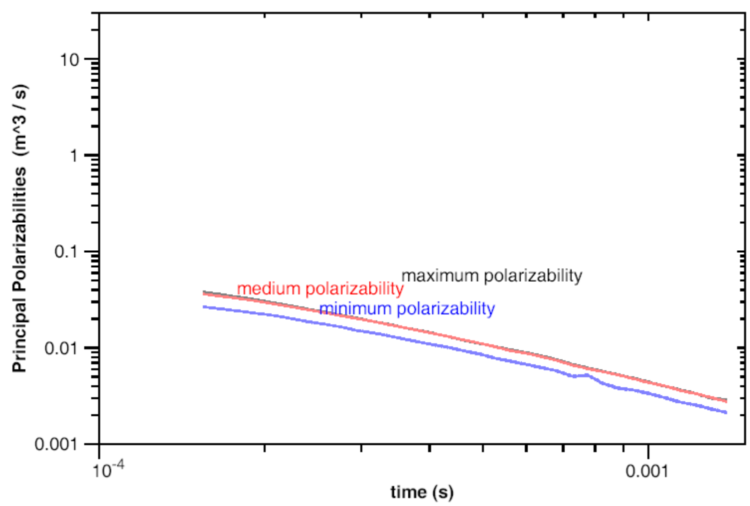
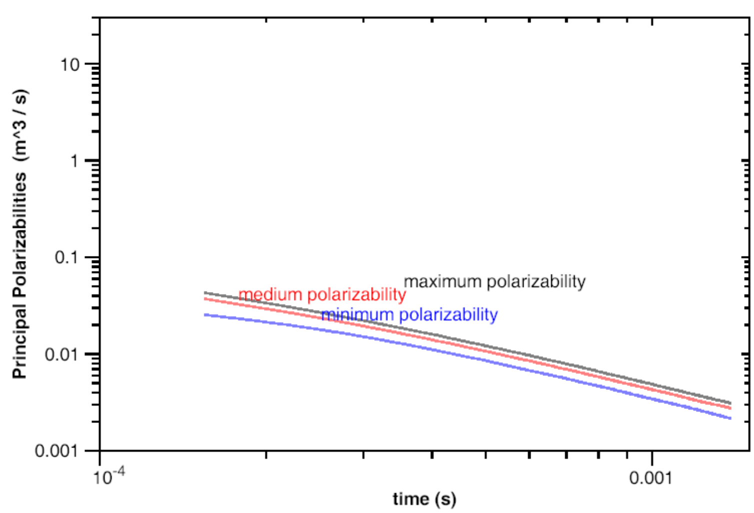
K11	60mm M49A3	0.52	90	
L11	60mm M49A3	0.48	-45	
M11	60mm M49A3	0.48	45	

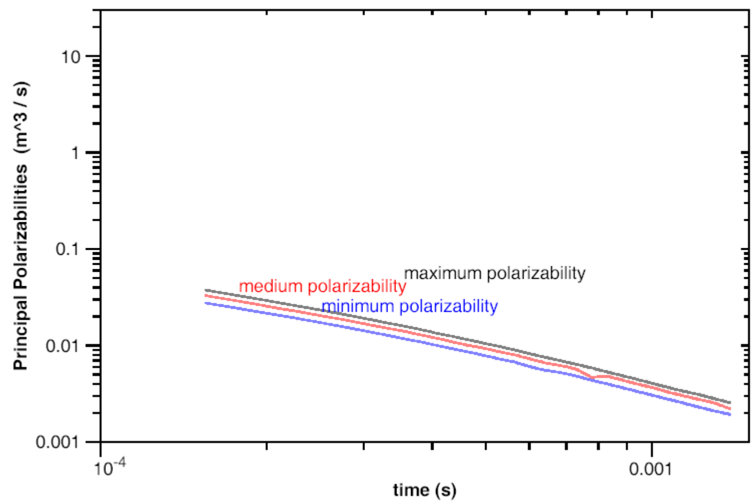
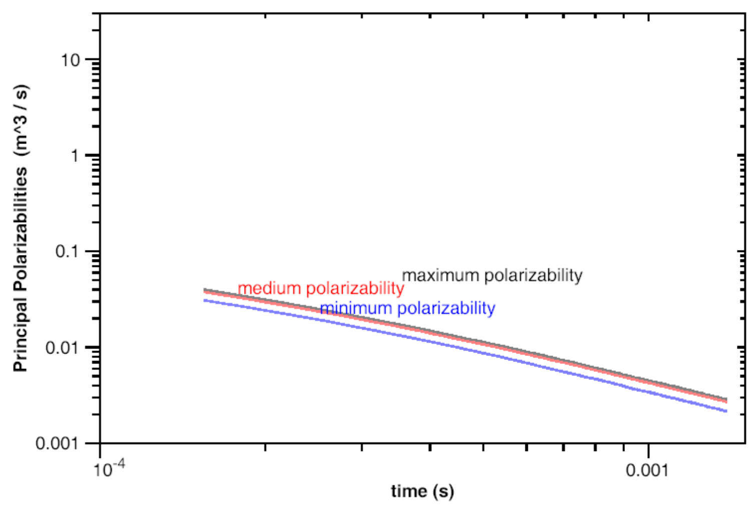
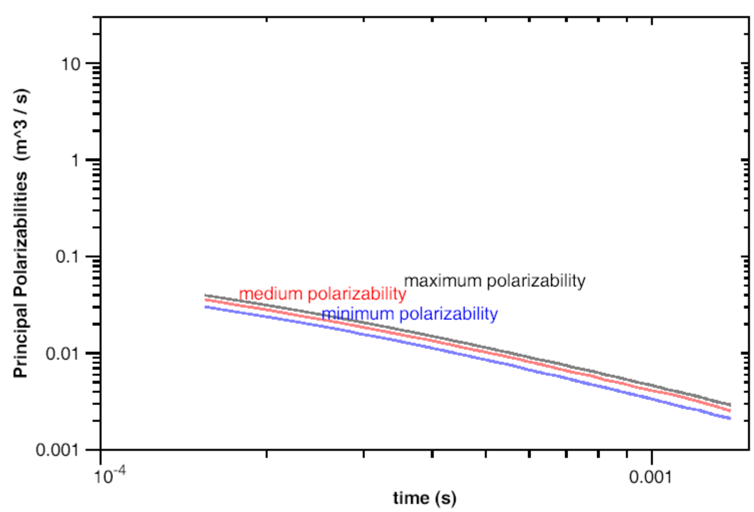
H12	57mm M86	0.91	0	
I12	57mm M86	0.91	0	
J12	57mm M86	0.49	-90	

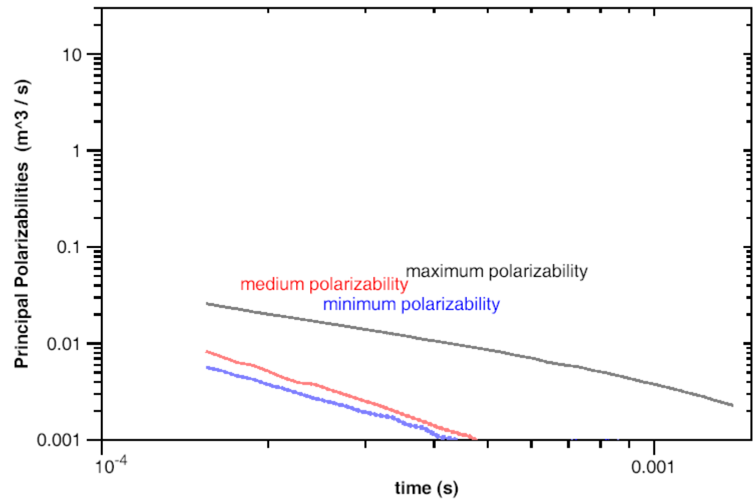
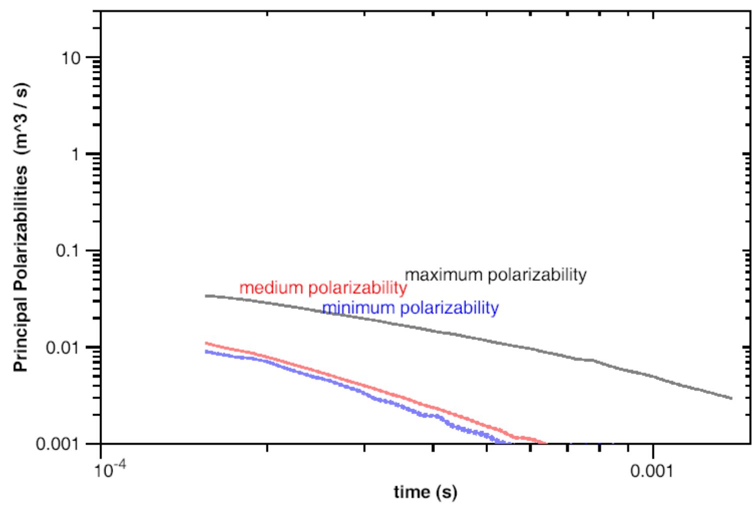
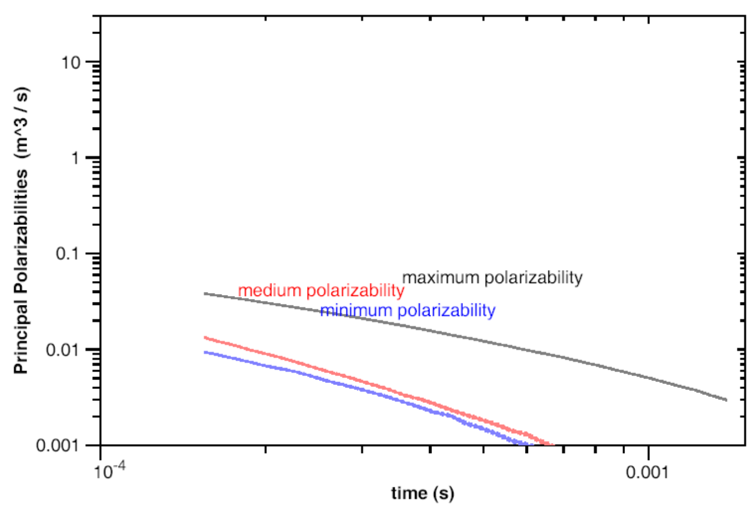
K12	57mm M86	0.49	90	
L12	57mm M86	0.46	-45	
M12	57mm M86	0.46	45	

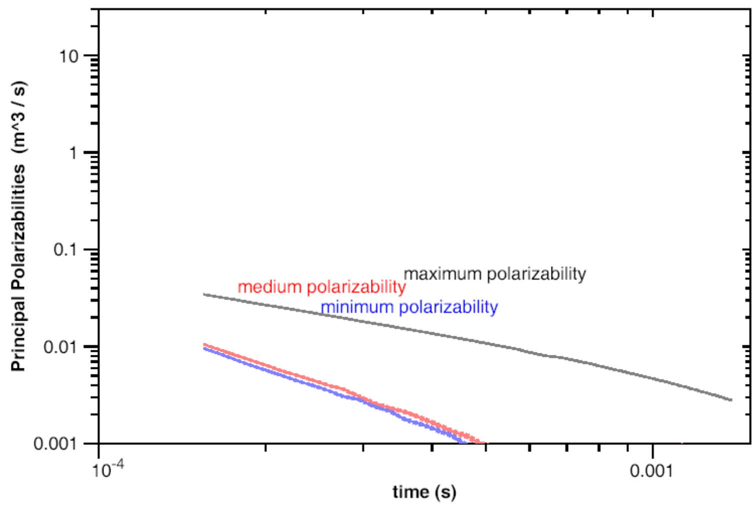
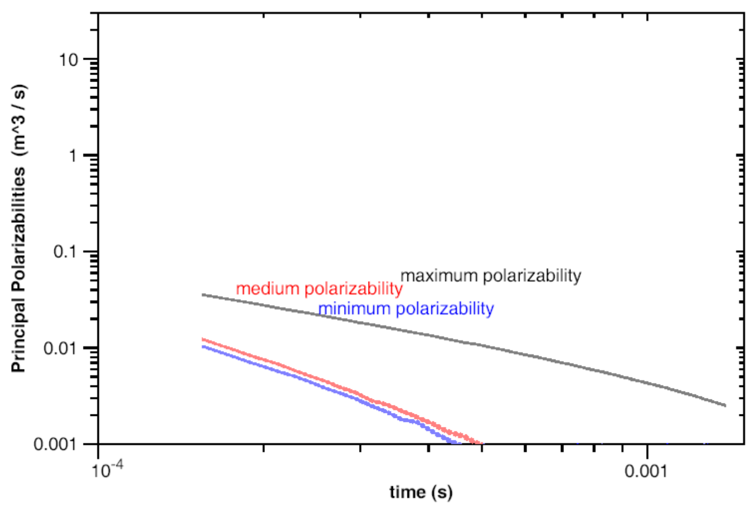
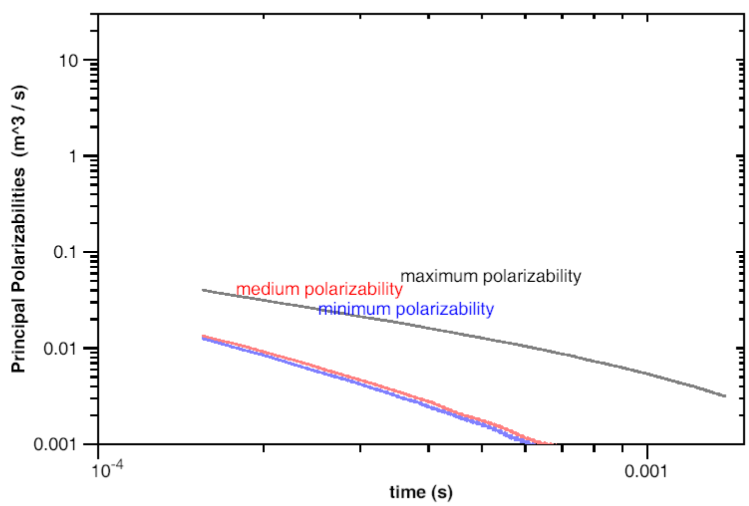
H13	BLU-26	0.20	0	
I13	BLU-26	0.20	0	
J13	BLU-26	0.10	0	

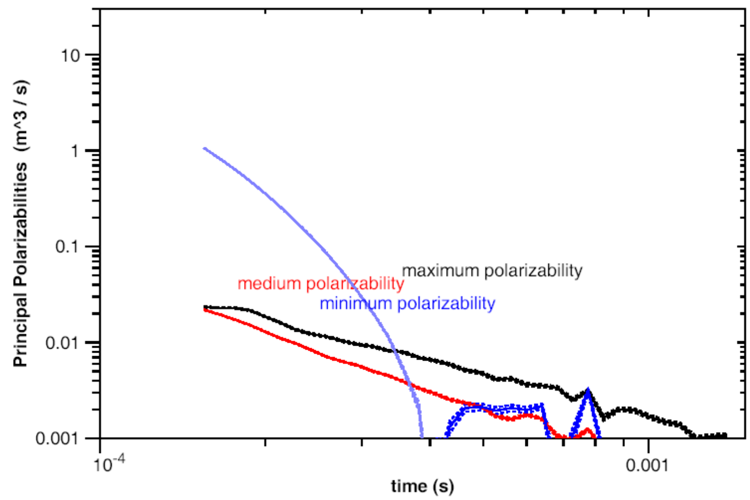
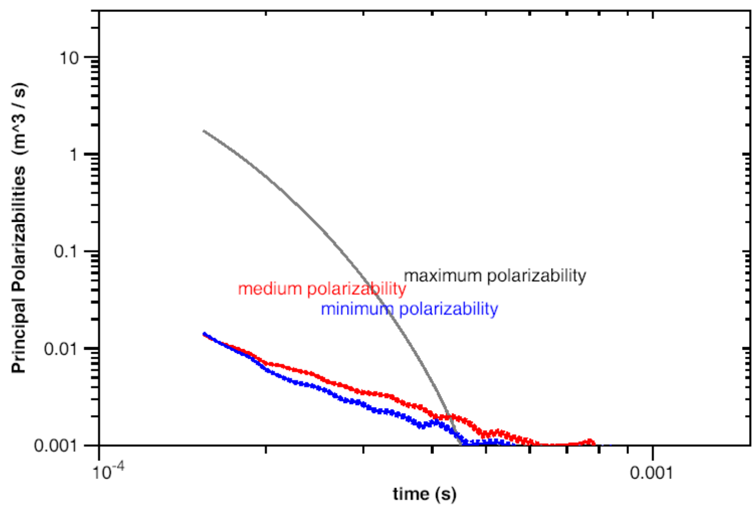
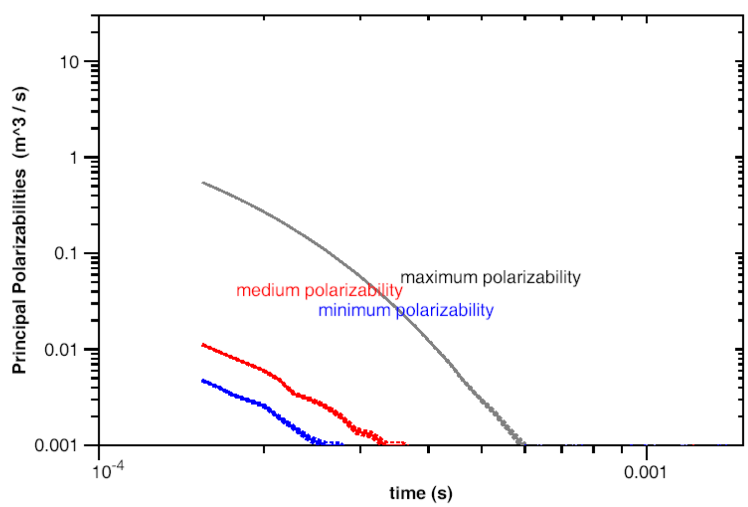
K13	BLU-26	0.10	0	
L13	BLU-26	0.10	0	
M13	BLU-26	0.10	0	

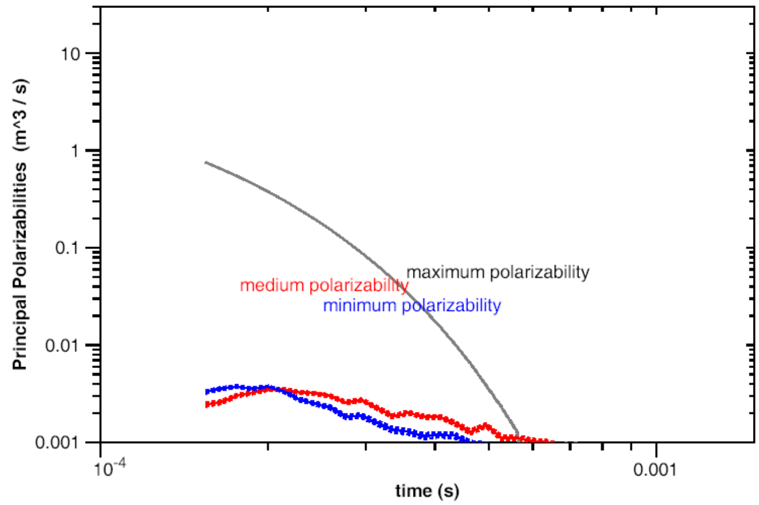
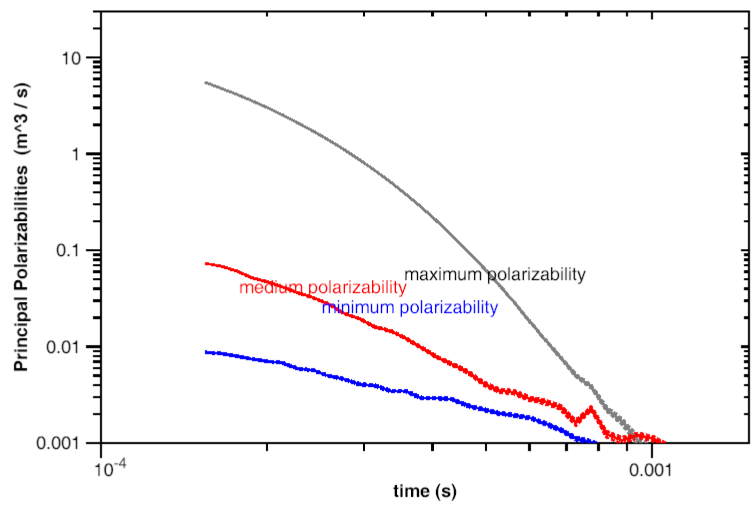
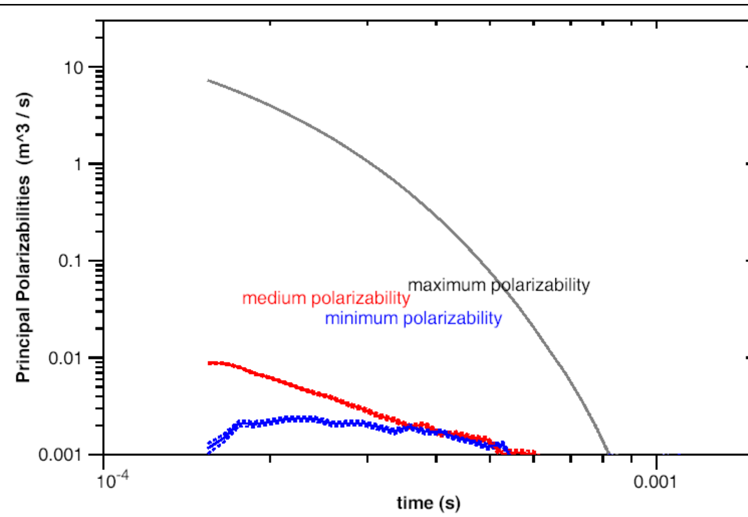
H14	40mm M385	0.20	0	
I14	40mm M385	0.20	0	
J14	40mm M385	0.14	-90	

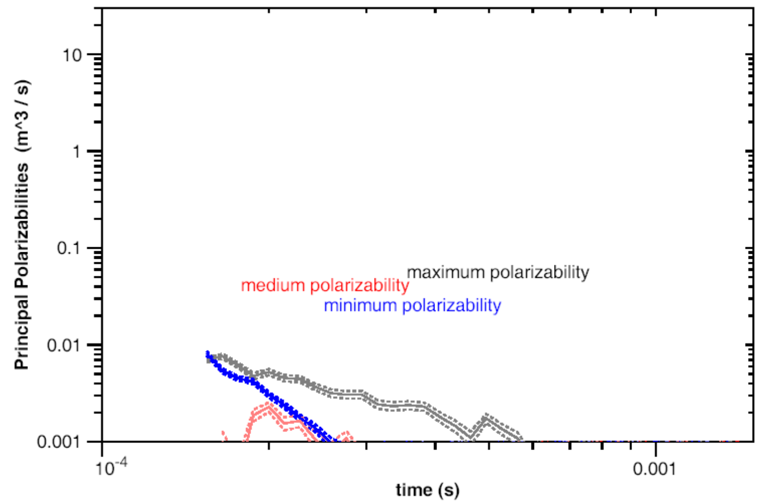
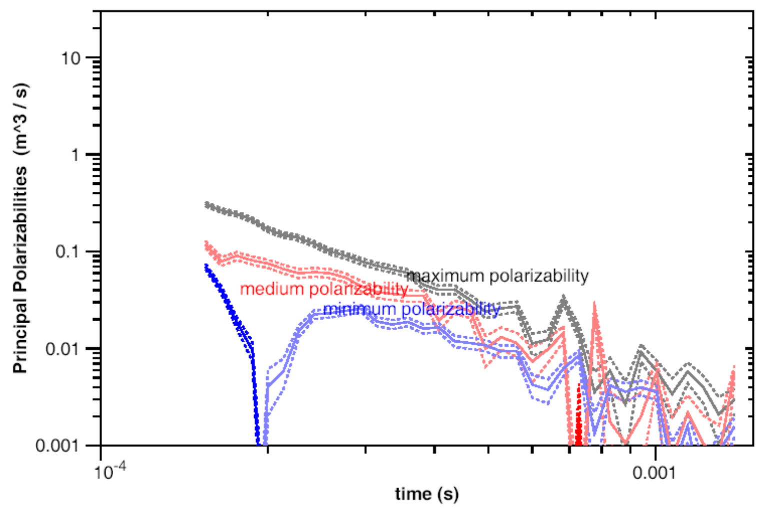
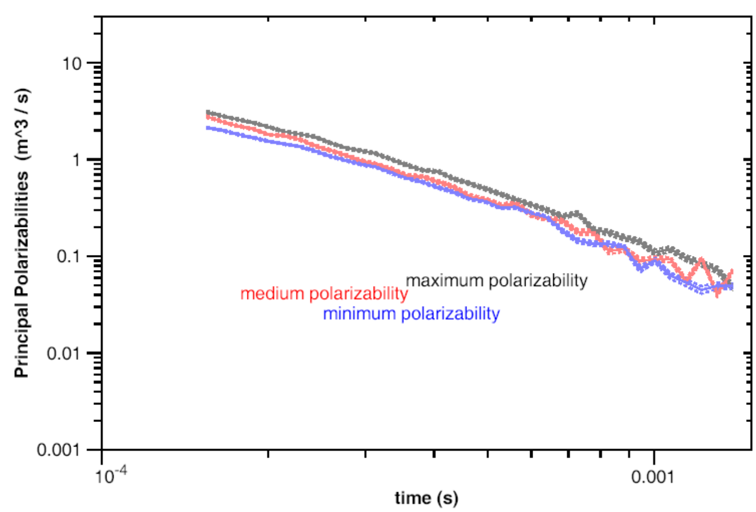
K14	40mm M385	0.14	90	
L14	40mm M385	0.13	-45	
M14	40mm M385	0.13	45	

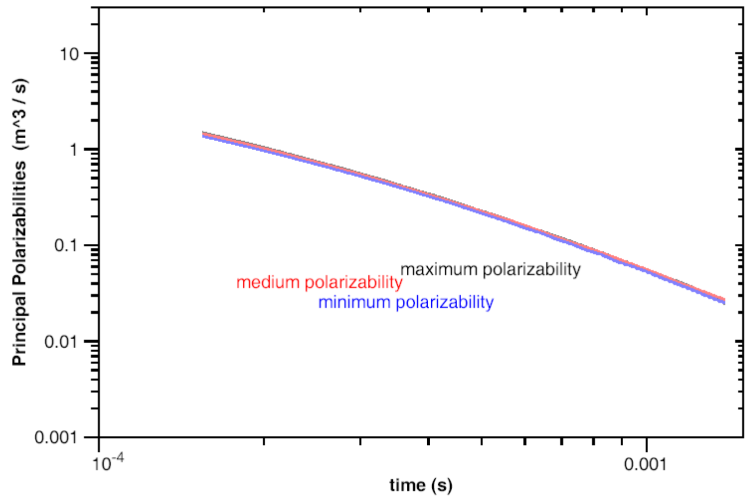
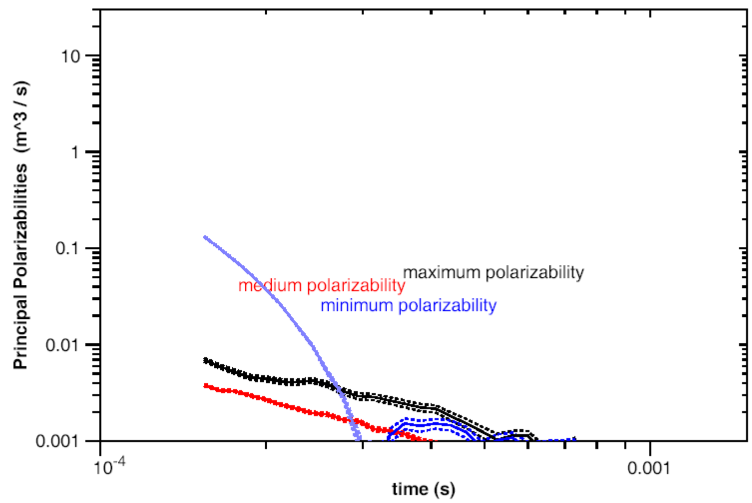
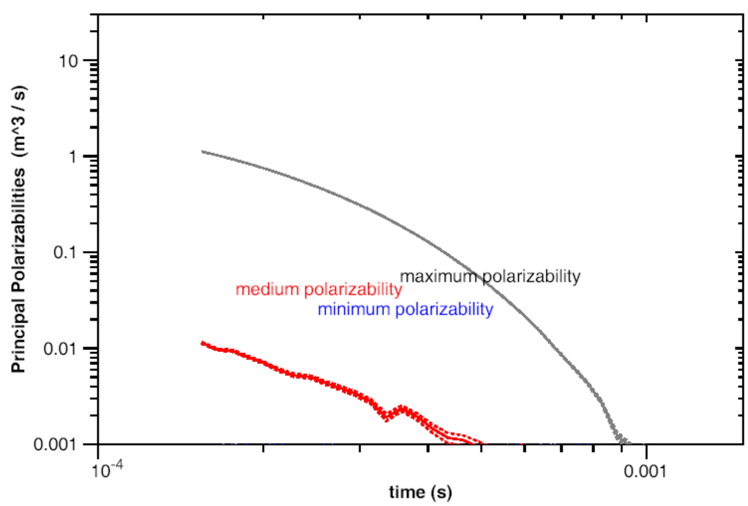
H15	20mm M55	0.20	0	
I15	20mm M55	0.20	0	
J15	20mm M55	0.14	-90	

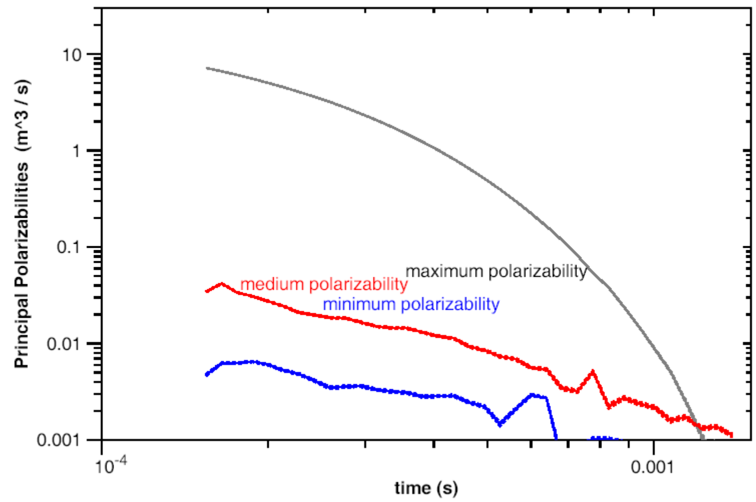
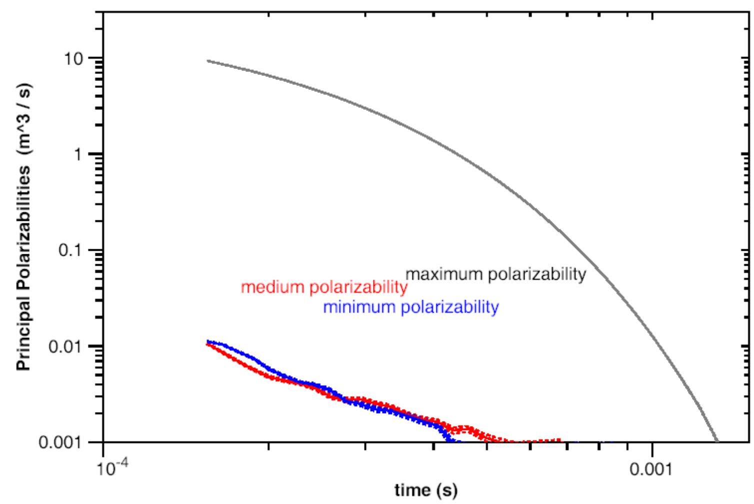
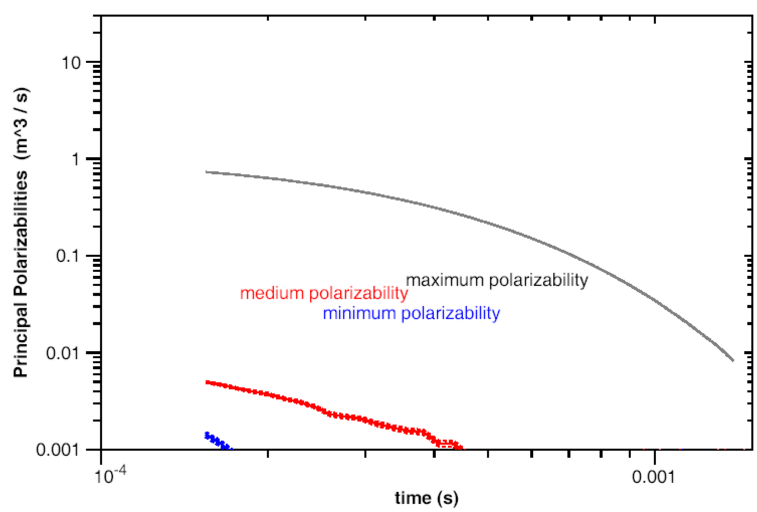
K15	20mm M55	0.14	90	
L15	20mm M55	0.13	-45	
M15	20mm M55	0.13	45	

H16	20 GAGE 30cm LOOP	0.40	90	
I16	20 GAGE 30cm LOOP	0.25	0	
J16	18 GAGE 15cm LOOP	0.33	90	

K16	18 GAGE 15cm LOOP	0.25	0	
L16	18 GAGE 30cm LOOP	0.40	90	
M16	18 GAGE 30cm LOOP	0.25	0	

A17	12# shot	2.00		
B17	12# shot	1.50		
C17	12# shot	1.00		

D17	12# shot	0.50		
F16	20 GAGE 15cm LOOP	0.33	90	
F17	16 GAGE 15cm LOOP	0.33	90	

H17	16 GAGE 30cm LOOP	0.40	90	
I17	16 GAGE 30cm LOOP	0.25	0	
J17	12 GAGE 15cm LOOP	0.33	90	

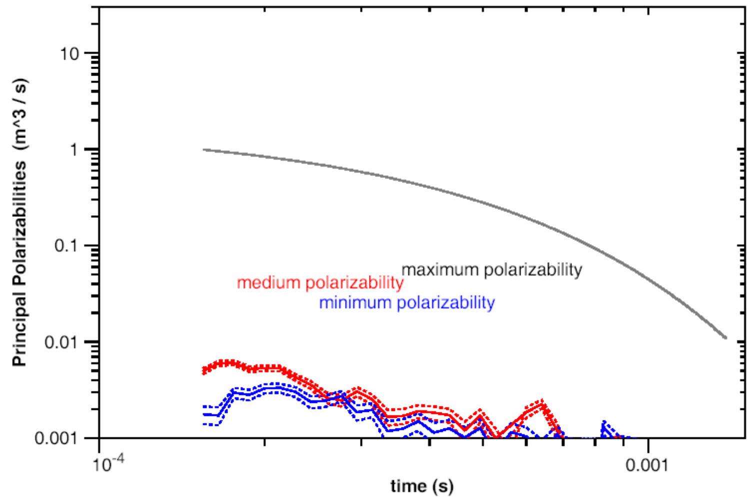
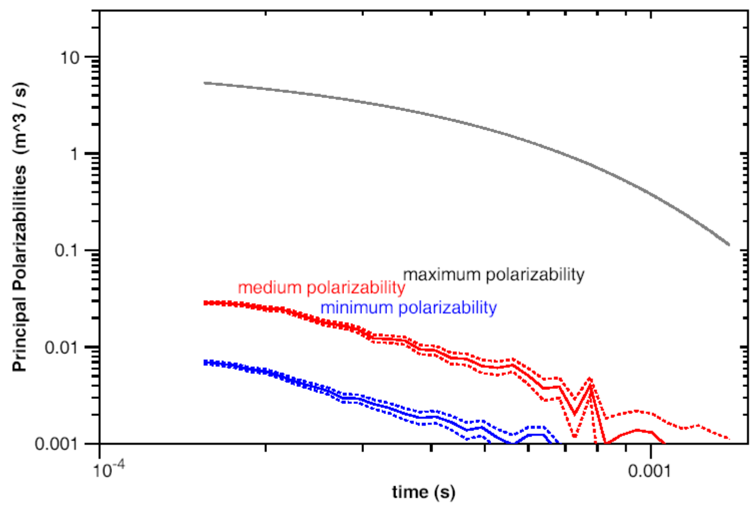
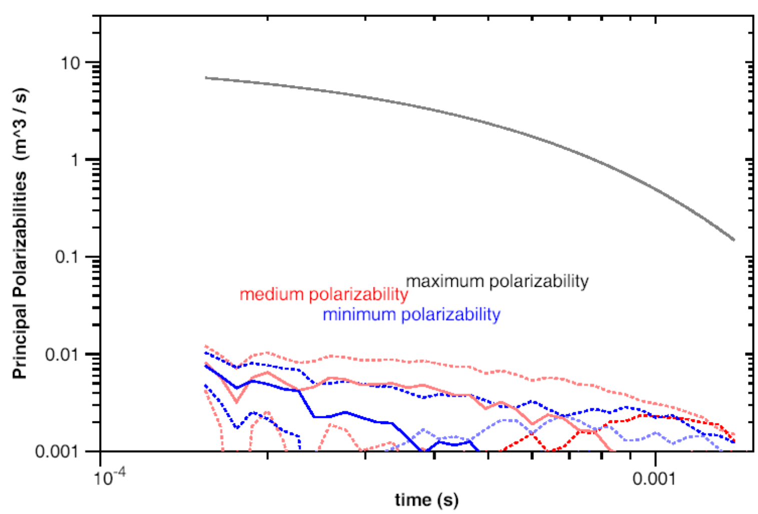
K17	12 GAGE 15cm LOOP	0.25	0	
L17	12 GAGE 30cm LOOP	0.40	90	
M17	12 GAGE 30cm LOOP	0.25	0	

Table 2: Yuma Proving Ground – Blind Test Grid

Probability	Cell Identification
1	btg_a_01
1	btg_a_03
1	btg_a_04p
1	btg_a_06
1	btg_a_08
1	btg_a_12m
1	btg_a_14
1	btg_a_15
1	btg_a_17
1	btg_a_19
1	btg_b_01
1	btg_b_02
1	btg_b_04p
1	btg_b_06
1	btg_b_07p
1	btg_b_09
0.6131	btg_b_12
1	btg_b_15
0.6556	btg_b_16
1	btg_b_20
1	btg_c_01
1	btg_c_03
1	btg_c_04
1	btg_c_09
1	btg_c_11
1	btg_c_12
1	btg_c_13m
1	btg_c_17
1	btg_c_18
1	btg_c_19
1	btg_c_20
1	btg_d_01p
1	btg_d_03
1	btg_d_04
1	btg_d_07
0.4961	btg_d_09p
0.5591	btg_d_10p
0.9879	btg_d_11p
1	btg_d_12
1	btg_d_14p
1	btg_d_15
1	btg_d_16

1	btg_d_18
1	btg_d_19
0.5814	btg_e_01
0.5844	btg_e_02
1	btg_e_03
0.6306	btg_e_05m
1	btg_e_08
1	btg_e_10
1	btg_e_11
1	btg_e_12
1	btg_e_13
0.9761	btg_e_14
1	btg_e_15
1	btg_e_16
1	btg_e_17
1	btg_e_18
1	btg_e_20p
1	btg_f_01
1	btg_f_02h
1	btg_f_04
1	btg_f_05
1	btg_f_08
1	btg_f_10
1	btg_f_11p
0.9052	btg_f_14
1	btg_f_15
0.9999	btg_f_18h
1	btg_f_20
0.531	btg_g_02
1	btg_g_03
1	btg_g_05
1	btg_g_10
1	btg_g_11
1	btg_g_12
1	btg_g_15
1	btg_g_16
1	btg_g_17
1	btg_g_18
1	btg_h_01
0.9999	btg_h_03m
1	btg_h_04
1	btg_h_05
1	btg_h_12
1	btg_h_13
1	btg_h_14
1	btg_h_20

1 1 1 1 1 1 1 1 1 1 1 1 1	btg_i_01 btg_i_02 btg_i_04 btg_i_05 btg_i_07 btg_i_10 btg_i_11m btg_i_12 btg_i_14 btg_i_15 btg_i_17 btg_i_18 btg_i_20
1 1 1 1 0.9364 1 0.7599 1 1 1 1	btg_j_05 btg_j_07 btg_j_09 btg_j_10m btg_j_11m btg_j_12 btg_j_13 btg_j_15 btg_j_17 btg_j_19 btg_j_20
1 1 1 1 0.5425 0.9904 1 1 1 1	btg_k_01 btg_k_03 btg_k_04 btg_k_05 btg_k_07 btg_k_11 btg_k_12 btg_k_16 btg_k_17 btg_k_19
0.505 1 1 1 1 1 1 1 0.9807 0.5871 0.7633 0.8082	btg_l_02p btg_l_04p btg_l_06 btg_l_07 btg_l_08 btg_l_09 btg_l_11 btg_l_12p btg_l_16 btg_l_17 btg_l_19 btg_l_20

1	btg_m_01
1	btg_m_02
0.7622	btg_m_06
1	btg_m_07
1	btg_m_09
1	btg_m_11
1	btg_m_12
1	btg_m_13
1	btg_m_14
0.877	btg_m_16
1	btg_m_17
1	btg_m_18
0.7829	btg_m_20
1	btg_n_01
0.7261	btg_n_03
1	btg_n_05
1	btg_n_06
1	btg_n_09
1	btg_n_13
1	btg_n_14
1	btg_n_16
0.9996	btg_n_17
1	btg_n_19
1	btg_o_01
1	btg_o_02
1	btg_o_04
1	btg_o_05
1	btg_o_06
1	btg_o_08p
1	btg_o_10p
1	btg_o_11p
1	btg_o_14
0.6334	btg_o_15
1	btg_o_18
1	btg_p_01
0.6934	btg_p_02m
0.6001	btg_p_03p
1	btg_p_04
1	btg_p_08
1	btg_p_09
1	btg_p_11
1	btg_p_12
1	btg_p_13
1	btg_p_15
1	btg_p_16
1	btg_p_17

1	btg_p_20
1	btg_q_02
1	btg_q_03
0.8878	btg_q_04
0.5236	btg_q_05
0.7798	btg_q_06p
0.5219	btg_q_07p
1	btg_q_09
1	btg_q_10
1	btg_q_11
0.5923	btg_q_13m
1	btg_q_14
1	btg_q_15
1	btg_q_17
1	btg_q_19
1	btg_q_20
1	btg_r_01
0.9849	btg_r_02
1	btg_r_03
0.4781	btg_r_05m
0.3288	btg_r_06
1	btg_r_07
1	btg_r_08
0.997	btg_r_09
1	btg_r_10
1	btg_r_11
0.3466	btg_r_14
0.4386	btg_r_16
1	btg_r_18
0.3896	btg_r_20
1	btg_s_04
1	btg_s_05
1	btg_s_13
1	btg_s_16
1	btg_s_17
1	btg_s_20
1	btg_t_01
1	btg_t_03
0.7831	btg_t_04
0.8698	btg_t_06
1	btg_t_07
1	btg_t_08
1	btg_t_10
0.5821	btg_t_11
1	btg_t_12
1	btg_t_14

1	btg_t_16
1	btg_t_17