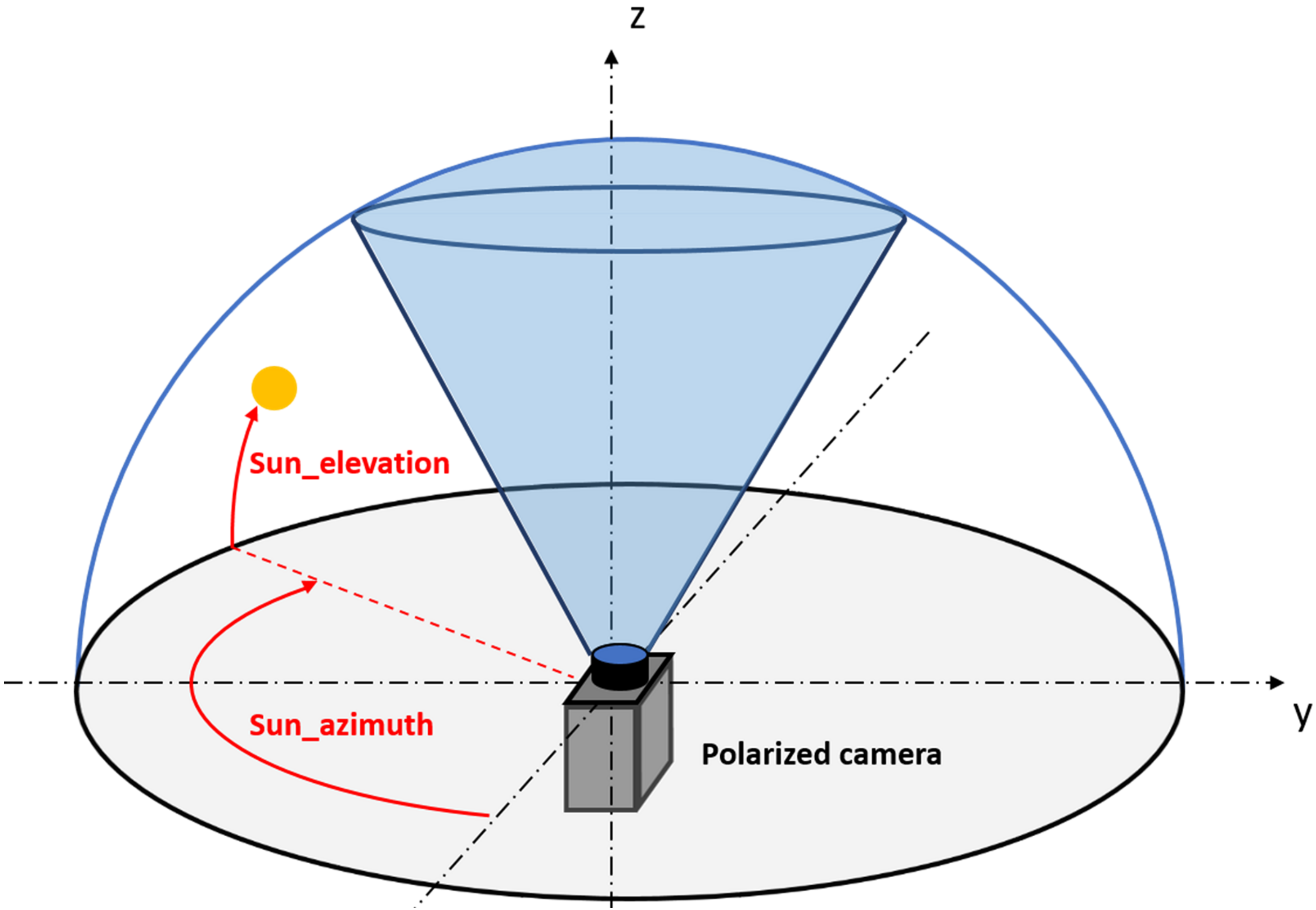
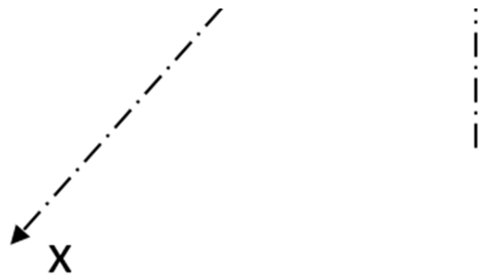
SETUP





In [1]:
```
import matplotlib.pyplot as plt
import numpy as np
```

OPTICS SIMULATION INPUTS

here we compute the visual field of our sensor, for a camera pointing toward true vertical axis (up, zenith axis)

"particules_azimuth_matrix_deg" and "particules_elevation_matrix_deg" are the coordinate in degree, of the atmosphere particles conjugated with the sensor's pixels. azimuth is expressed in x,y camera image plane, seen from above. xyz is direct frame, z is up true vertical axis. seen from outputed camera image, y axis goes up on the image, x axis goes left on the image

In [2]:
```
from Simu_Optical_Conjugation import *
from Zenital_tilt import *
from Simu_Rayleigh import *
from Simu_Berry import *
from Simu_Sky_Intensity_CIE import *
from Simu_Micro_Polarizers import *
from Simu_Sensor import *
from Simu_Data_Processing import *
import matplotlib.pyplot as plt
```

In [3]:
```
#pixel size in micrometers
pixel_size = 3.45
#focal length in millimeters
f = 8
#sensor high in pixels
sensor_rows = 2048
#sensor length in pixels
sensor_cols = 2448
#conjugation type
r_conj = 'r0'
```

OPTICS SIMULATION

In [4]:
```
#np.transpose(np.ones(3)[:,np.newaxis])

(np.ones(3)[np.newaxis,:]) #ligne
(np.ones(3)[:,np.newaxis]) #col
```

Out[4]:
```
array([[1.],
       [1.],
       [1.]])
```

In [5]:
```
particules_azimuth_matrix_rad,particules_elevation_matrix_rad,X_coordinate_pixels,Y_coordinate_pixels = Simu_Optica
```

PARAMETERS FOR FUTURE RESULTS' PRINTS

In [6]:
```
x_pixel_mesh = (np.ones((Y_coordinate_pixels.size))[:,np.newaxis]) * X_coordinate_pixels[np.newaxis,:]
y_pixel_mesh = np.ones(X_coordinate_pixels.size)[np.newaxis,:]*((Y_coordinate_pixels))[:,np.newaxis]
```

TILTED FIELD INPUTS

In [7]:
```
# here we compute

rotation_axis_aziluth_deg = 0
rotation_angle_deg = 0
rotation_axis_aziluth_rad = (np.pi / 180) * rotation_axis_aziluth_deg
rotation_angle_rad = (np.pi / 182) * rotation_angle_deg
```

TILTED FIELD COMPUTATION

In [8]:
```
particules_azimuth_matrix_rad,particules_elevation_matrix_rad = Zenital_tilt(particules_azimuth_matrix_rad,particul
```

RAYLEIGHT'S MODEL INPUTS

sun azimuth is expressed in x,y camera image plane, seen from above. xyz is direct frame, z is up true vertical axis. seen from outputed camera image, y axis goes up on the image, x axis goes left on the image

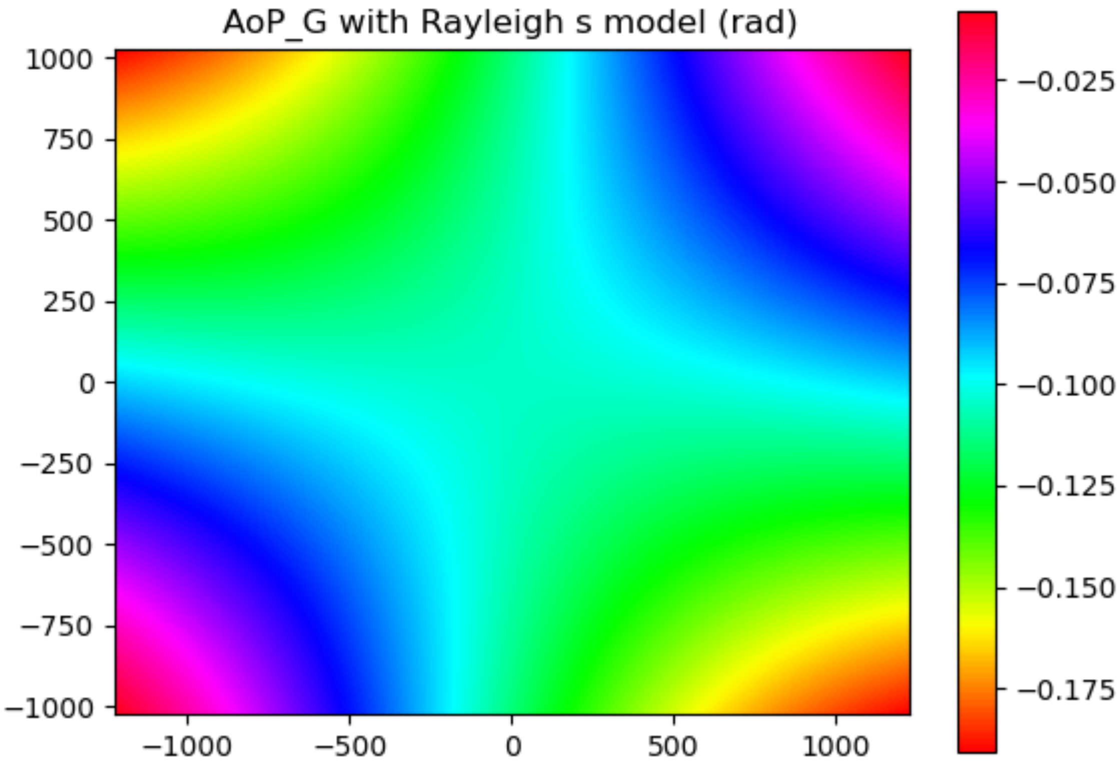
In [9]:
```
sun_azimuth_deg = 84
# sun elevation, in degree, from the ground (0) to the vertical z axis (or
# zenith (90)

sun_elevation_deg = 0

# maximum DoLP observable in sky, 0.75 for usual clear sky
DoLP_Max = 0.4
## RAYLEIGHT'S MODEL SIMULATION

sun_elevation_rad = sun_elevation_deg * np.pi / 180
sun_azimuth_rad = sun_azimuth_deg * np.pi / 180
AoP_Matrix_Global_rad_Rayleigh,DoLP_Matrix_Rayleigh = Simu_Rayleigh(sun_elevation_rad,sun_azimuth_rad,particules_el
```

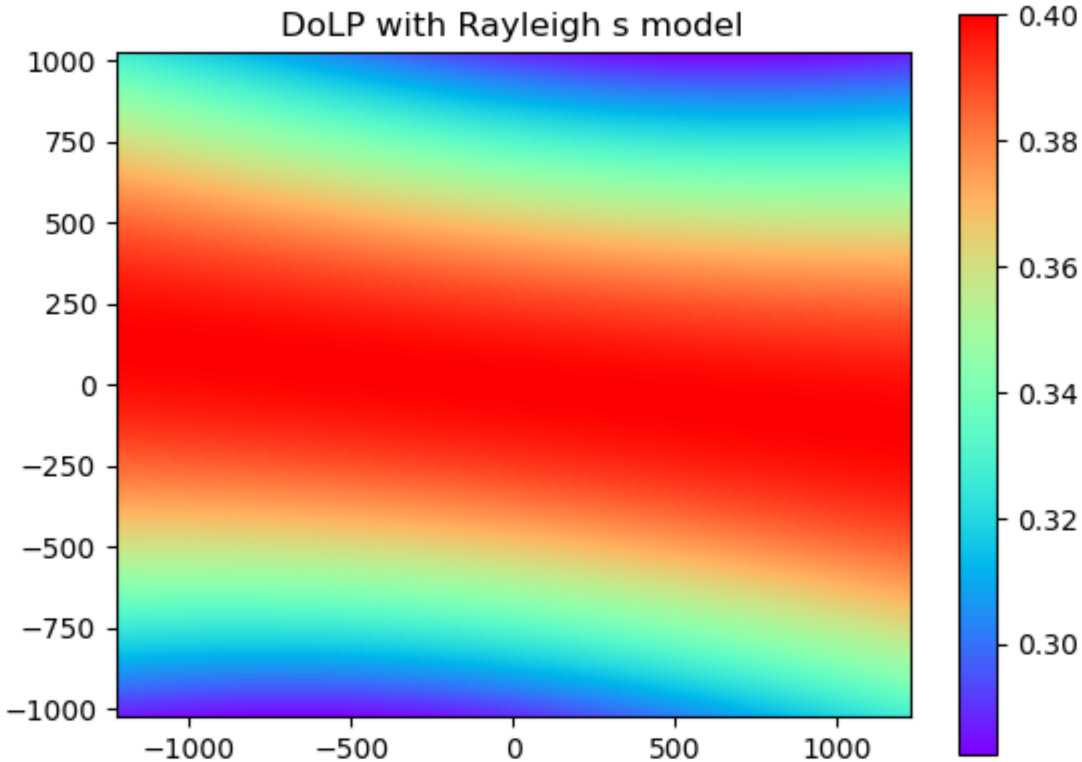
```
(2048, 2448)
```

PRINT RAYLEIGH'S MODEL SIMULATION RESULTS

In [10]:
```
#Prepare colors for figures
#map = cmap('C1')
plt.figure()
h0 = plt.pcolormesh(x_pixel_mesh,y_pixel_mesh,AoP_Matrix_Global_rad_Rayleigh,cmap='hsv')
#colormap(map)
#set(h,'EdgeColor','none')
#colorbar
plt.colorbar()
plt.axis('image')
plt.title('AoP_G with Rayleigh s model (rad)')

plt.figure()
h00 = plt.pcolormesh(x_pixel_mesh,y_pixel_mesh,DoLP_Matrix_Rayleigh,cmap='rainbow')
#set(h,'EdgeColor','none')
#colorbar
plt.colorbar()
plt.axis('image')
plt.title('DoLP with Rayleigh s model')
```

Out[10]:
```
Text(0.5, 1.0, 'DoLP with Rayleigh s model')
```


AoP_G with Rayleigh s model (rad)
1000
750
500
250
0
−250
−500
−750
−1000
−1000
−500
0
500
1000
−0.025
−0.050
−0.075
−0.100
−0.125
−0.150
−0.175



BERRY'S MODEL INPUTS

sun azimuth is expressed in x,y camera image plane, seen from above. xyz is direct frame, z is up true vertical axis. seen from outputed camera image, y axis goes up on the image, x axis goes left on the image

In [11]:
```
sun_azimuth_deg

# sun elevation, in degree, from the ground (0) to the vertical z axis (or
# zenith (90)

sun_elevation_deg

# maximum DoP observable in sky, 0.75 for usual clear sky
DoLP_Max

# angle between Babinet and Brewster points in degrees:
delta_deg = 140
```

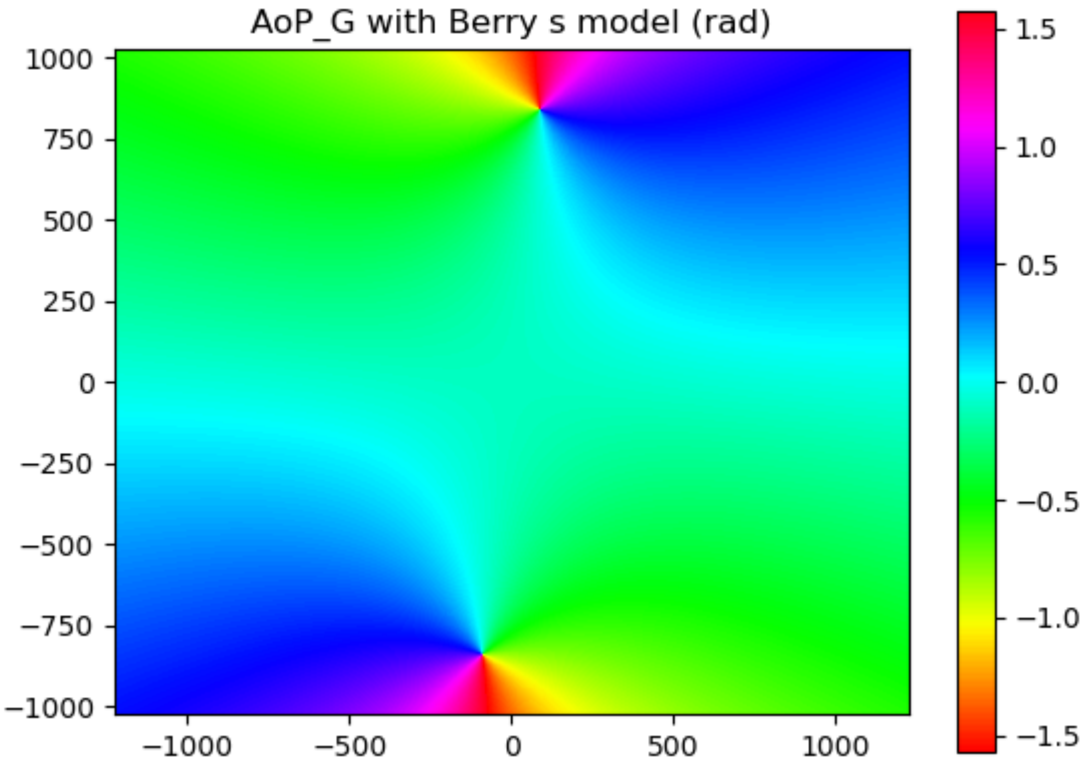
BERRY'S MODEL SIMULATION

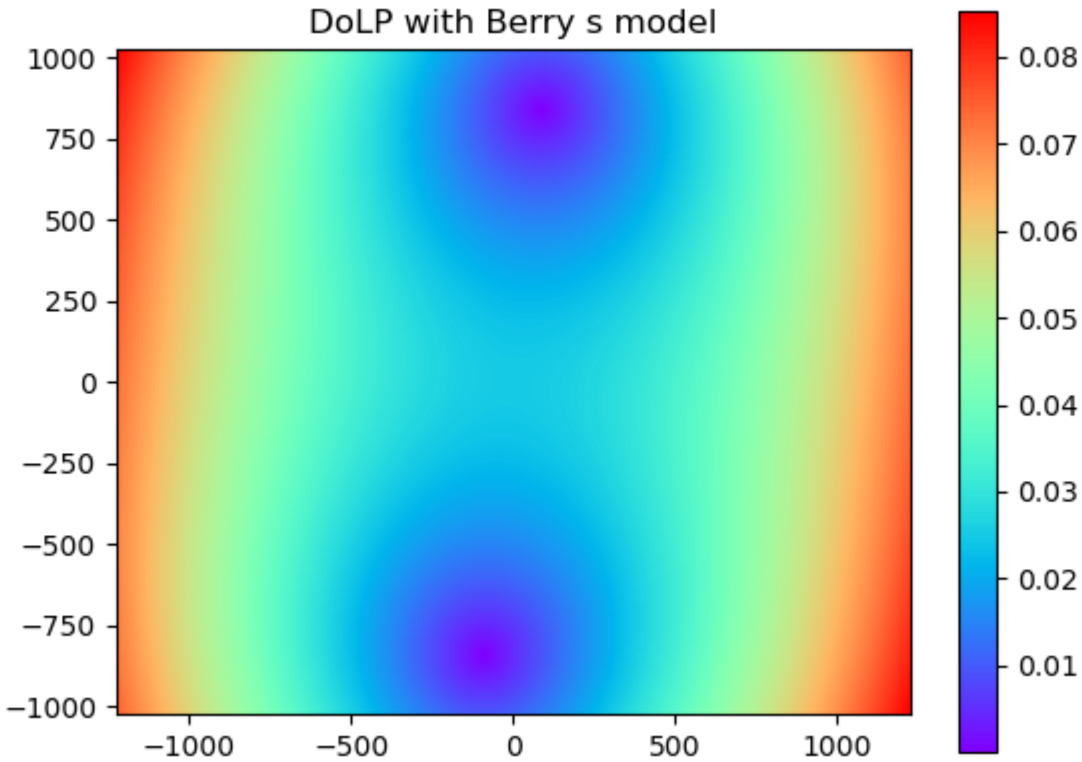
In [12]:
```
sun_elevation_rad = sun_elevation_deg * np.pi / 180
sun_azimuth_rad = sun_azimuth_deg * np.pi / 180
delta_rad = delta_deg * np.pi / 180
AoP_Matrix_Global_rad_Berry,DoLP_Matrix_Berry = Simu_Berry(sun_elevation_rad,sun_azimuth_rad,particules_elevation_m
```

PRINT BERRY'S MODEL SIMULATION RESULTS

In [13]:
```python
#print on pixel map
#x_pixel_mesh = np.transpose(np.ones((Y_coordinate_pixels.shape,Y_coordinate_pixels.shape))) * X_coordinate_pixels
#y_pixel_mesh = (np.transpose(Y_coordinate_pixels)) * np.ones((X_coordinate_pixels.shape,X_coordinate_pixels.shape)
#Prepare color for figures
plt.figure()
h1 = plt.pcolormesh(x_pixel_mesh,y_pixel_mesh,AoP_Matrix_Global_rad_Berry,cmap='hsv')
#colormap(map)
#set(h,'EdgeColor','none')
plt.colorbar()
plt.axis('image')
plt.title('AoP_G with Berry s model (rad)')
plt.figure()
h2 = plt.pcolormesh(x_pixel_mesh,y_pixel_mesh,DoLP_Matrix_Berry,cmap='rainbow')
#set(h,'EdgeColor','none')
plt.colorbar()
plt.axis('image')
plt.title('DoLP with Berry s model')
```

Out[13]:
```
Text(0.5, 1.0, 'DoLP with Berry s model')
```


AoP_G with Berry s model (rad)
1000
750
500
250
0
−250
−500
−750
−1000
−1000
−500
0
500
1000
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5



SKY RADIANCE SIMULATION INPUTS

In [14]:
```
# sun azimuth is expressed in x,y camera image plane, seen from above.
# xyz is direct frame, z is up true vertical axis.
# seen from outputed camera image, y axis goes up on the image, x axis goes
# left on the image
sun_azimuth_deg

# sun elevation, in degree, from the ground (0) to the vertical z axis (or
# zenith (90)

sun_elevation_deg

# CIE table sky model number, refere to the Article
#"Analysis of vertical sky components under various CIE standard
# general skies" from D.H.W. Li, C. Li, S.W. Lou, E.K.W. Tsang and J.C. Lam
# wrote in 2015
CIE_Sky_number = 9
```

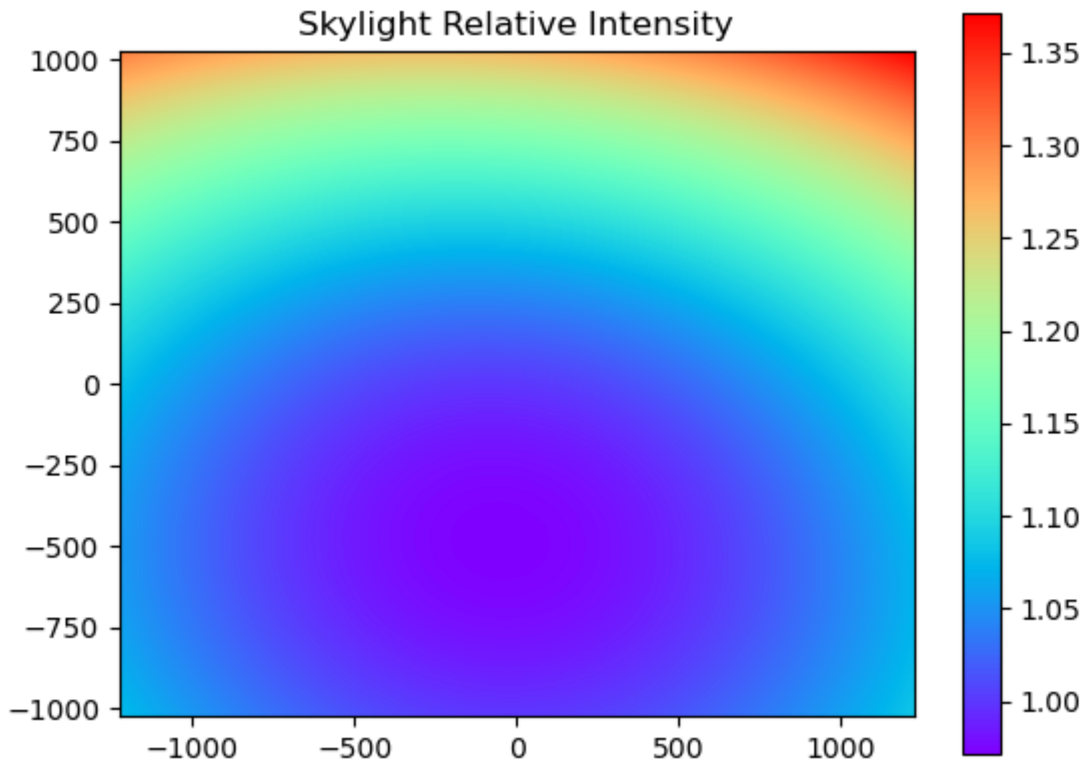
SKY RADIANCE SIMULATION

In [15]:
```
Skylight_Relative_Intensity = Simu_Sky_Intensity_CIE(sun_azimuth_rad,sun_elevation_rad,particules_azimuth_matrix_ra
```

PRINT SKY RADIANCE SIMULATION RESULTS

In [16]:
```
plt.figure()
h3 = plt.pcolormesh(x_pixel_mesh,y_pixel_mesh,Skylight_Relative_Intensity,cmap='rainbow')
#set(h,'EdgeColor','none')
plt.colorbar()
plt.axis('image')
plt.title('Skylight Relative Intensity')
```

Out[16]:
```
Text(0.5, 1.0, 'Skylight Relative Intensity')
```



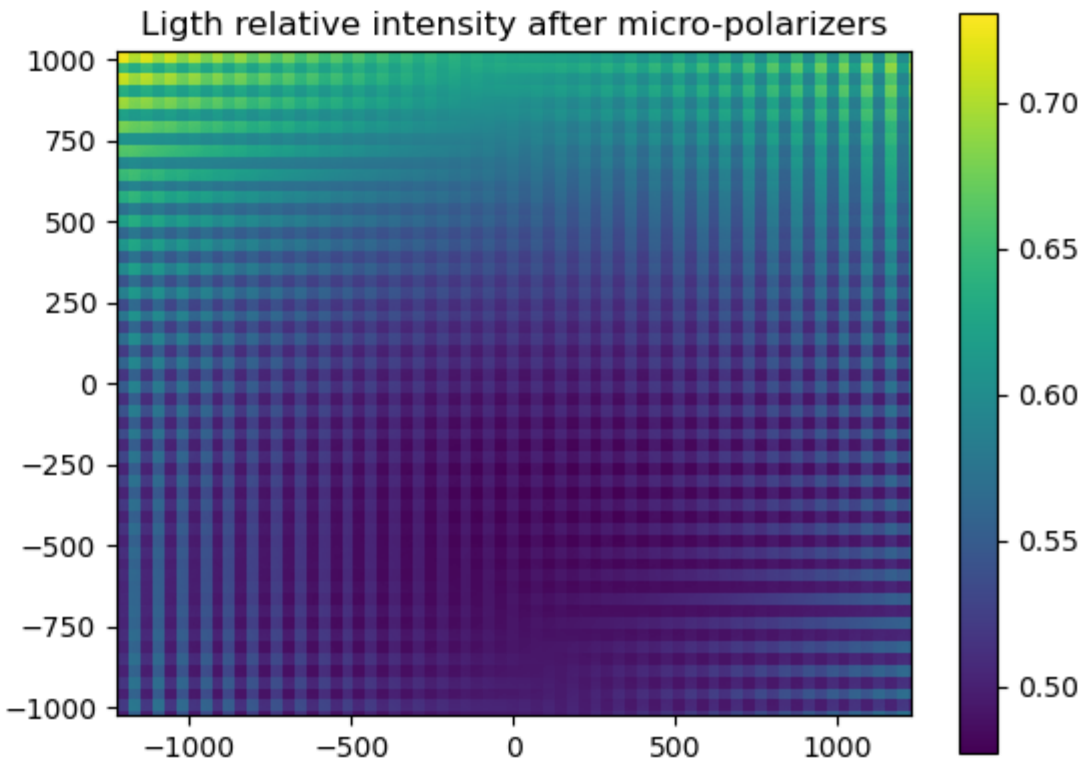
MICRO POLARIZER SIMULATION INPUTS

In [17]:
```
# The sensor called in this simulation  is based on sony IMX250MZR sensor
# used in FLIR BFS-U3-51S5P-C camera.
# It is a sensor with a micro-polarizer array, each block of 2 by 2 pixels
# possess 4 type of linear micro-polarizer oriented at 0,45,90 and 135
# degrees.

# Here we compute micro-polarizer array effects

# we already set size in OPITCS SIMULATION INPUTS :
sensor_rows
sensor_cols
# each polarizer is not realy at its supposed orientation, here we put the
# mechanical tolerance in polarizer orientation in degrees
tolerance_deg = 1
# If T1 is the intensity transmitance for an incident ray totaly linearly
# polarized along transmission axis and T2 is the intensity transmittance
# for an incident ray totally linearly polarized at 90 degrees from
# transmission axis, then the extinction rassio is (T1-T2)/(T1+T2).
# Because we work with relative intensity their is no need to take into
# account absorbance, so we suppose null absorbance, which means T1+T2=1.

extinction_ratio = 0.99
## MICRO POLARIZER SIMULATION

tolerance_rad = tolerance_deg * np.pi / 180
# We chose to use results from Berry's model for this example:
Intensity_on_pixels = Simu_Micro_Polarizers(Skylight_Relative_Intensity,AoP_Matrix_Global_rad_Berry,DoLP_Matrix_Ber
```

PRINT MICRO POLARIZER SIMULATION RESULTS

In [18]:
```
#here the figure is set as returned image
plt.figure()
h4 = plt.pcolormesh(- x_pixel_mesh,y_pixel_mesh,Intensity_on_pixels)
#set(h,'EdgeColor','none')
plt.colorbar()
plt.axis('image')
plt.title('Ligth relative intensity after micro-polarizers')
```

Out[18]:
```
Text(0.5, 1.0, 'Ligth relative intensity after micro-polarizers')
```



SENSOR'S SIMULATION INPUTS

In [19]:
```
# This part deals with pixels simulation

# Here we enter the saturation ratio
# It is the ratio between the sensor irradiance saturation value and the
# maximum relative irradiance comming on sensor's pixels.
pixel_saturation = 1.6

# Here we enter the number of output bits for grayscale
number_of_bits = 12
# Here we enter the per pixel gaussian noise Signal to Noise Ratio
SNR = 50
```

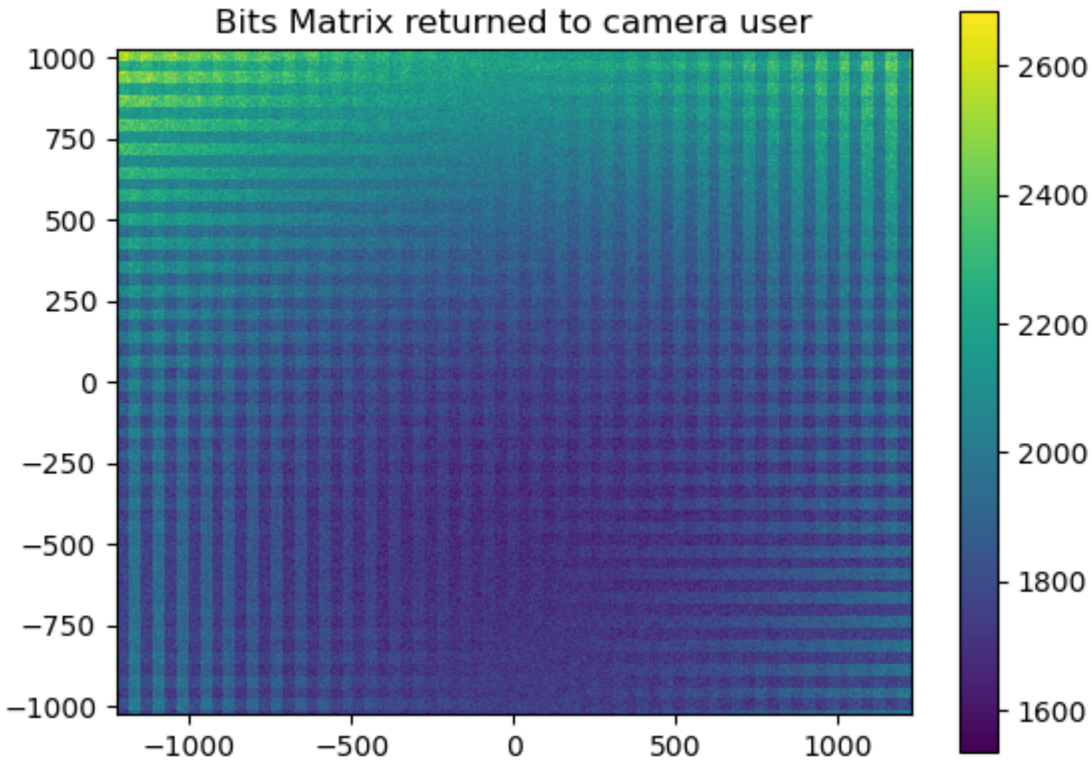
SENSOR'S SIMULATION

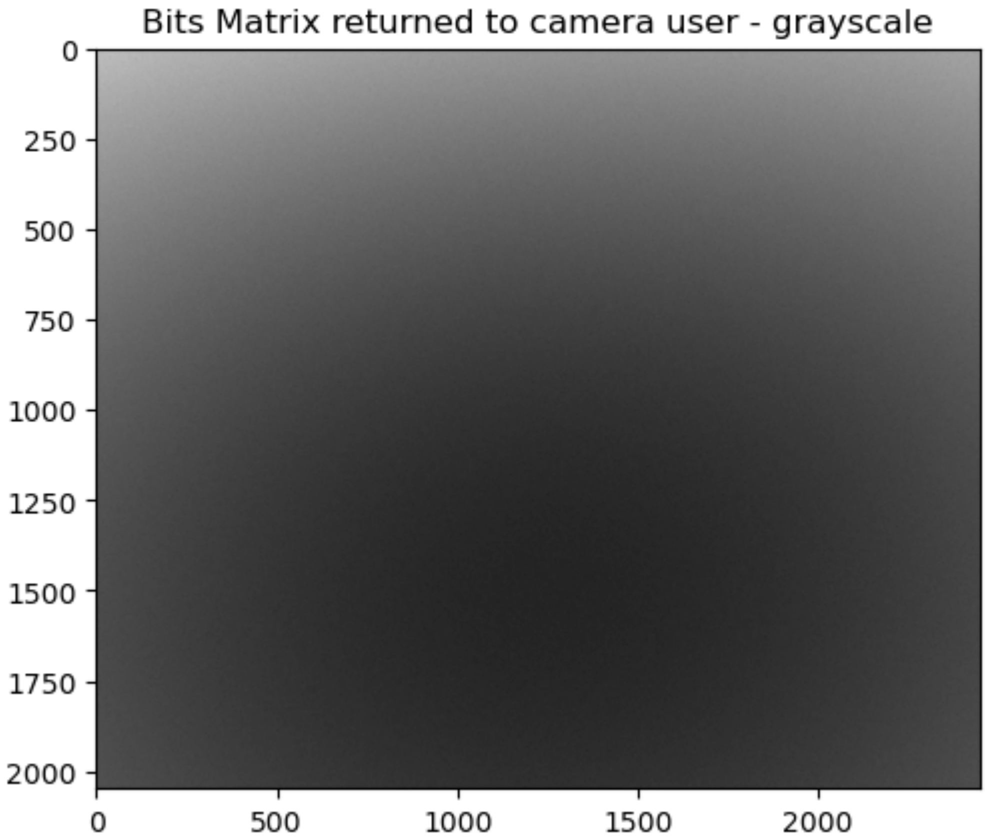
In [20]:
```
Bits_Matrix = Simu_Sensor(Intensity_on_pixels,pixel_saturation,number_of_bits,SNR)
```

PRINT SENSOR SIMULATION RESULTS

In [21]:
```
#here the figure is set as returned image
plt.figure()
h5 = plt.pcolormesh(- x_pixel_mesh,y_pixel_mesh,Bits_Matrix)
#set(h,'EdgeColor','none')
plt.colorbar()
plt.axis('image')
plt.title('Bits Matrix returned to camera user')
#transform grayscale image in 8 bits grayscale image
Bits_Matrix_8B = ((np.floor(255 * (1 / (2 ** number_of_bits - 1)) * (Bits_Matrix).astype('double'))).astype('uint8'
#here the figure is set as returned image
plt.figure()
plt.imshow(Bits_Matrix_8B,cmap='gray')
plt.title('Bits Matrix returned to camera user - grayscale')
```

Out[21]:
```
Text(0.5, 1.0, 'Bits Matrix returned to camera user - grayscale')
```

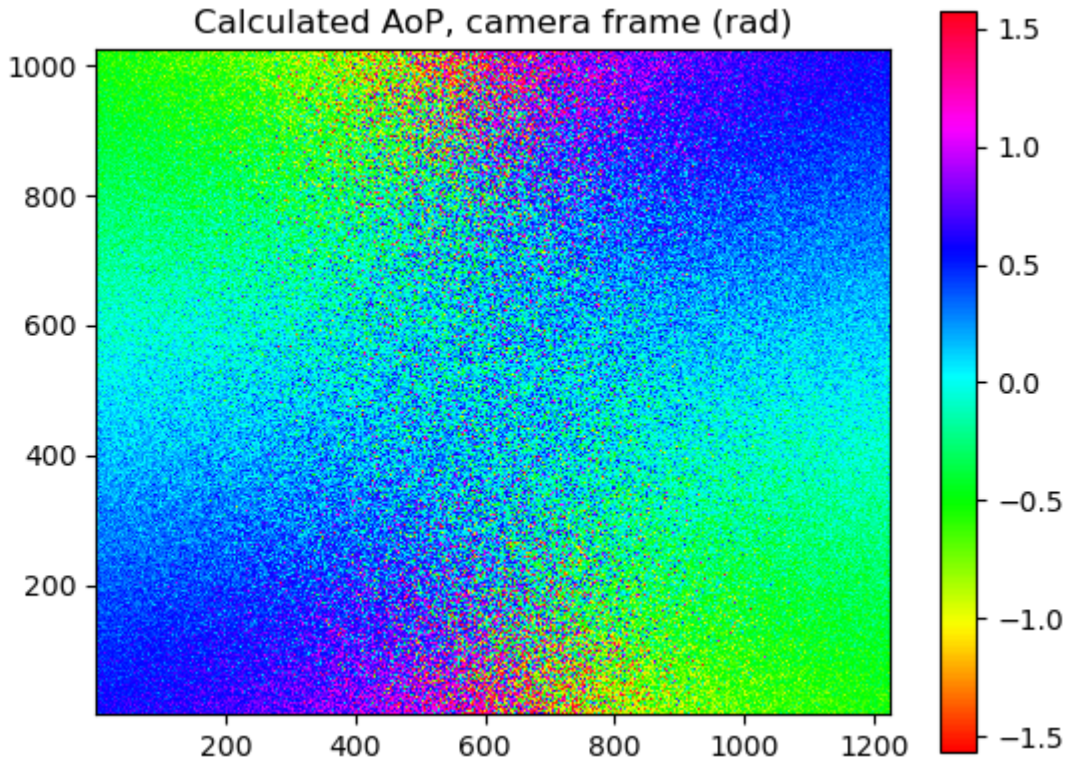

Bits Matrix returned to camera user
1000
750
500
250
0
−250
−500
−750
−1000
−1000
−500
0
500
1000
2600
2400
2200
2000
1800
1600

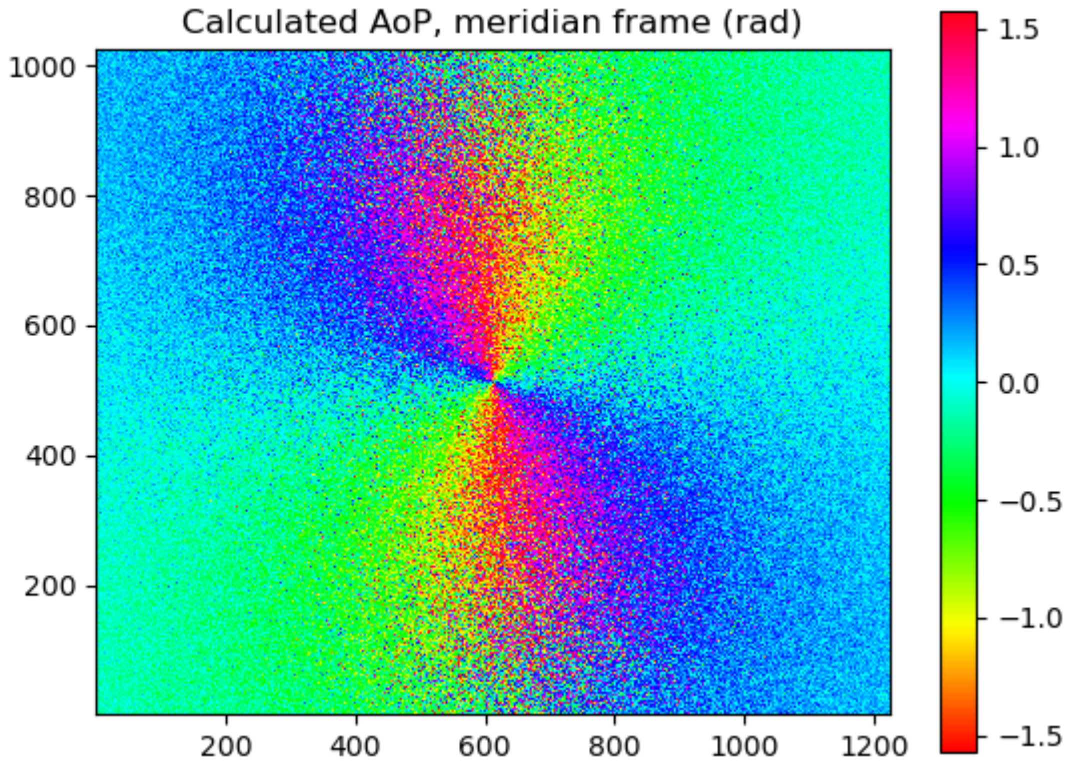


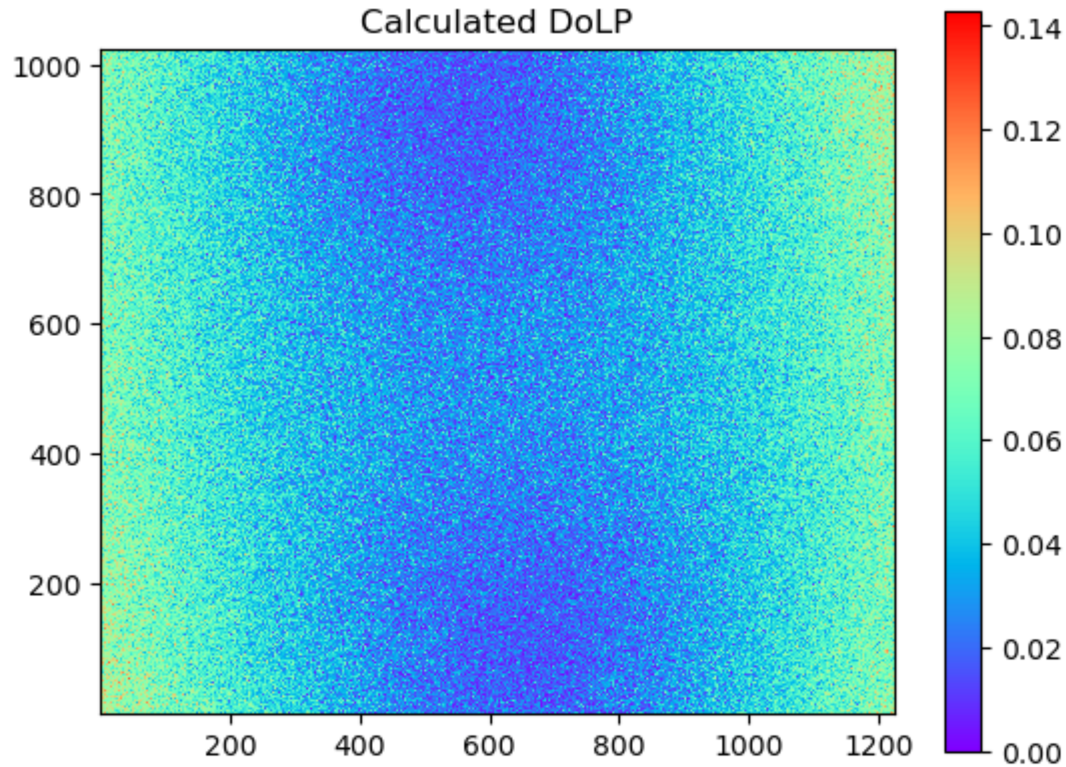
DATA PROCESSING

In [22]:
```python
# This part is not a real part of the simulator.
# It is just about to deal with camera output and compute polarization
# measurment, just like we would do with a real camera.

AoP_data_processing_imframe,AoP_data_processing_meridianframe,DoLP_data_processing = Simu_Data_Processing(Bits_Matr
rows_print,cols_print = DoLP_data_processing.shape
X_mesh_print = np.ones((rows_print,1)) * (np.arange(1,cols_print+1,1))
Y_mesh_print = ((np.arange(rows_print,1+- 1,- 1)))[:,np.newaxis] * np.ones((1,cols_print))
#map = cmap('C1')
#map=plt.colormap('hsv')
plt.figure()
h6 = plt.pcolormesh(X_mesh_print,Y_mesh_print,AoP_data_processing_imframe,cmap='hsv')
#colormap(map)
#set(h,'EdgeColor','none')
plt.colorbar()
plt.axis('image')
plt.title('Calculated AoP, camera frame (rad)')
plt.figure()
h7 = plt.pcolormesh(X_mesh_print,Y_mesh_print,AoP_data_processing_meridianframe,cmap='hsv')
#colormap(map)
#set(h,'EdgeColor','none')
plt.colorbar()
plt.axis('image')
plt.title('Calculated AoP, meridian frame (rad)')
plt.figure()
h8 = plt.pcolormesh(X_mesh_print,Y_mesh_print,DoLP_data_processing,cmap='rainbow')
#set(h,'EdgeColor','none')
plt.colorbar()
plt.axis('image')
plt.title('Calculated DoLP')
```

Out[22]:
```
Text(0.5, 1.0, 'Calculated DoLP')
```


Calculated AoP, camera frame (rad)
1000
800
600
400
200
200
400
600
800
1000
1200
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5


Calculated AoP, meridian frame (rad)
1000
800
600
400
200
200
400
600
800
1000
1200
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5

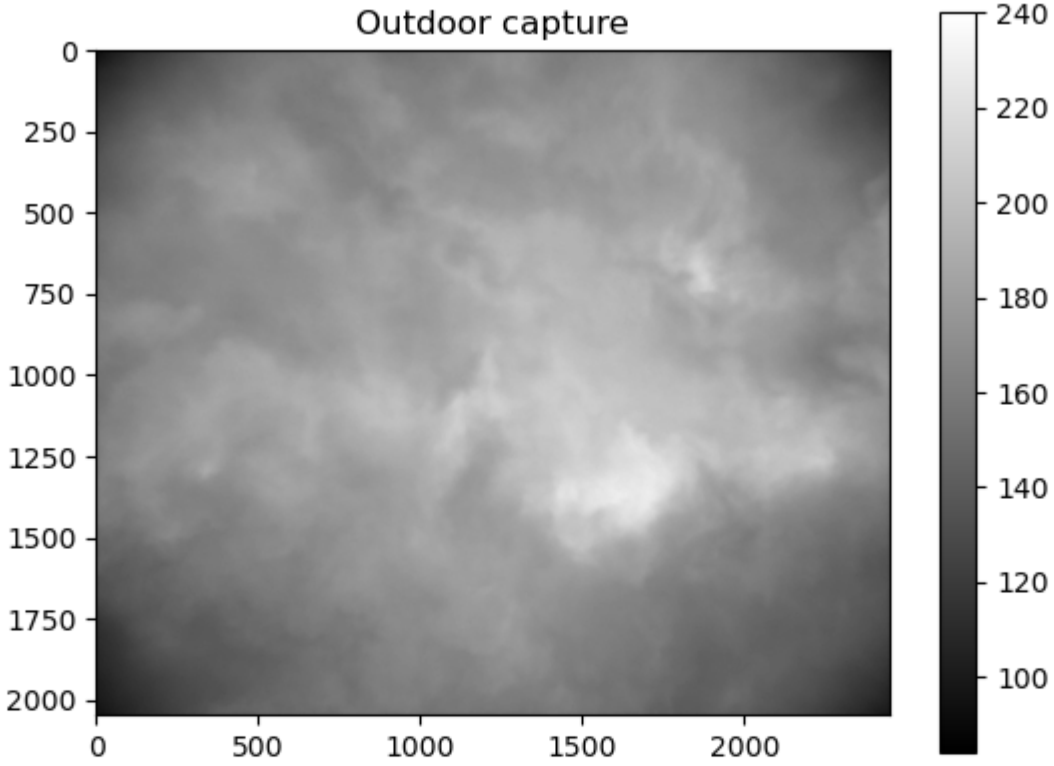


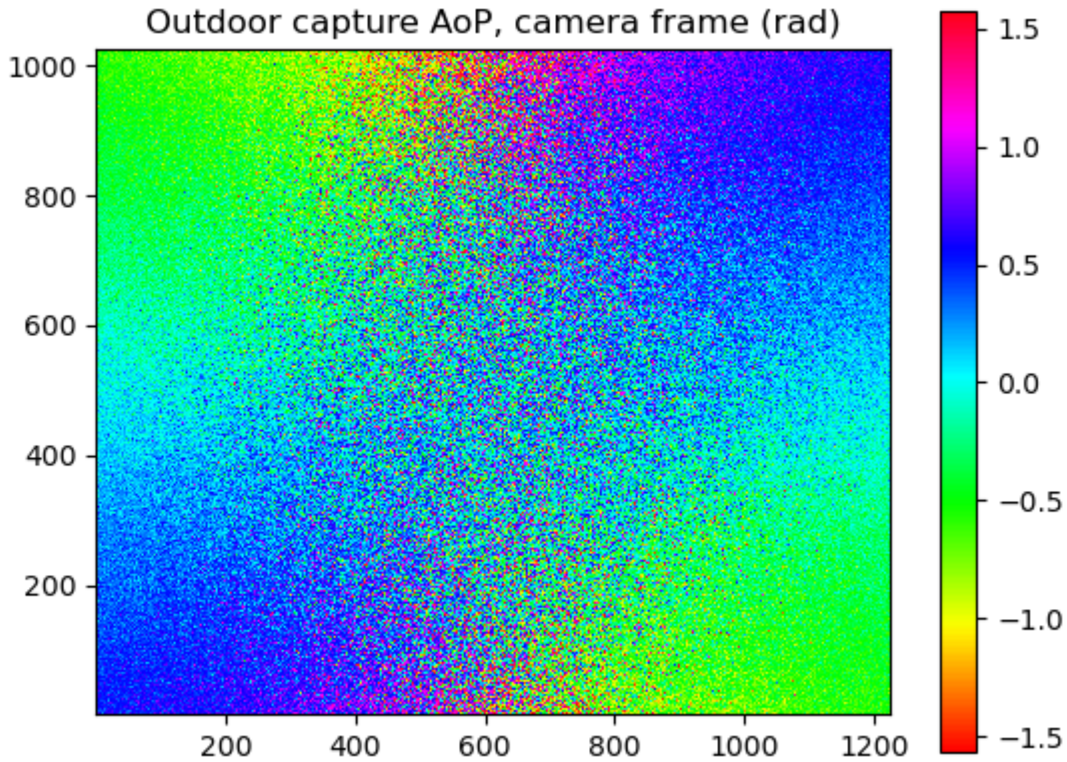
COMPARISON WITH OUTDOOR REAL CAMERA CAPTURE

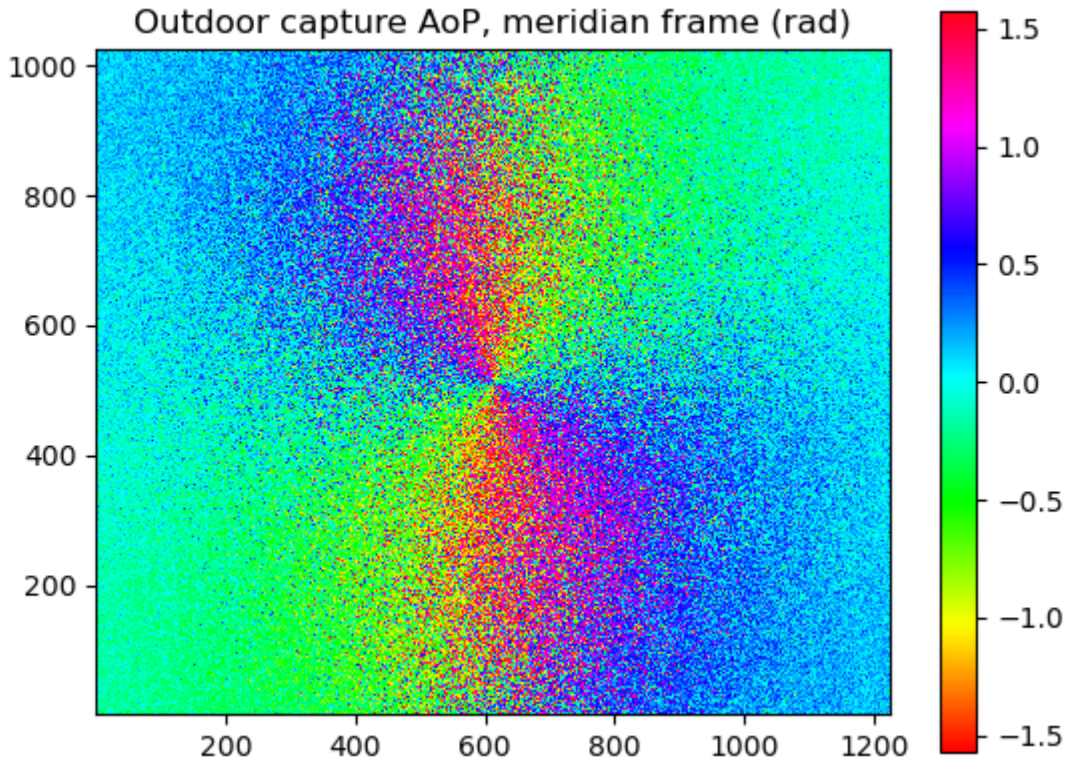
In [23]:
```
#This part is not a real part of the simulator.
#Here we compare our simulation with real outdoor capture
#To do so we use the same data treatment for outdoor output camera data
#than for simulated output camera data

Camera_capture = plt.imread('TEST_overcast_sky.tiff')
Camera_capture_8B = (np.uint8(np.floor((255 / (- 1 + 2 ** 16)) * Camera_capture)))
plt.figure()
plt.imshow(Camera_capture_8B,cmap='gray')
plt.colorbar()
plt.title('Outdoor capture')
MaxCapture = np.amax(np.amax(Camera_capture))
print("outside capture results")
Camera_capture_double = (Camera_capture).astype('double')
AoP_expe_imframe,AoP_expe_meridianframe,DoLP_expe = Simu_Data_Processing(Camera_capture_double)
rows_print_cam,cols_print_cam = DoLP_expe.shape
X_mesh_print_cam = np.ones((rows_print_cam,1)) * (np.arange(1,cols_print_cam+1,1))[np.newaxis,:]
Y_mesh_print_cam = ((np.arange(rows_print_cam,1+- 1,- 1)))[:,np.newaxis] * np.ones((1,cols_print_cam))
#map = cmap('C1')
plt.figure()
h9 = plt.pcolormesh(X_mesh_print_cam,Y_mesh_print_cam,AoP_expe_imframe,cmap='hsv')
#colormap(map)
#set(h,'EdgeColor','none')
plt.colorbar()
plt.axis('image')
plt.title('Outdoor capture AoP, camera frame (rad)')
plt.figure()
h10 = plt.pcolormesh(X_mesh_print_cam,Y_mesh_print_cam,AoP_expe_meridianframe,cmap='hsv')
#colormap(map)
#set(h,'EdgeColor','none')
plt.colorbar()
plt.axis('image')
plt.title('Outdoor capture AoP, meridian frame (rad)')
plt.figure()
h11 = plt.pcolormesh(X_mesh_print_cam,Y_mesh_print_cam,DoLP_expe,cmap='rainbow')
#set(h,'EdgeColor','none')
plt.colorbar()
plt.axis('image')
plt.title('Outdoor capture DoLP, meridian frame (rad)')
```

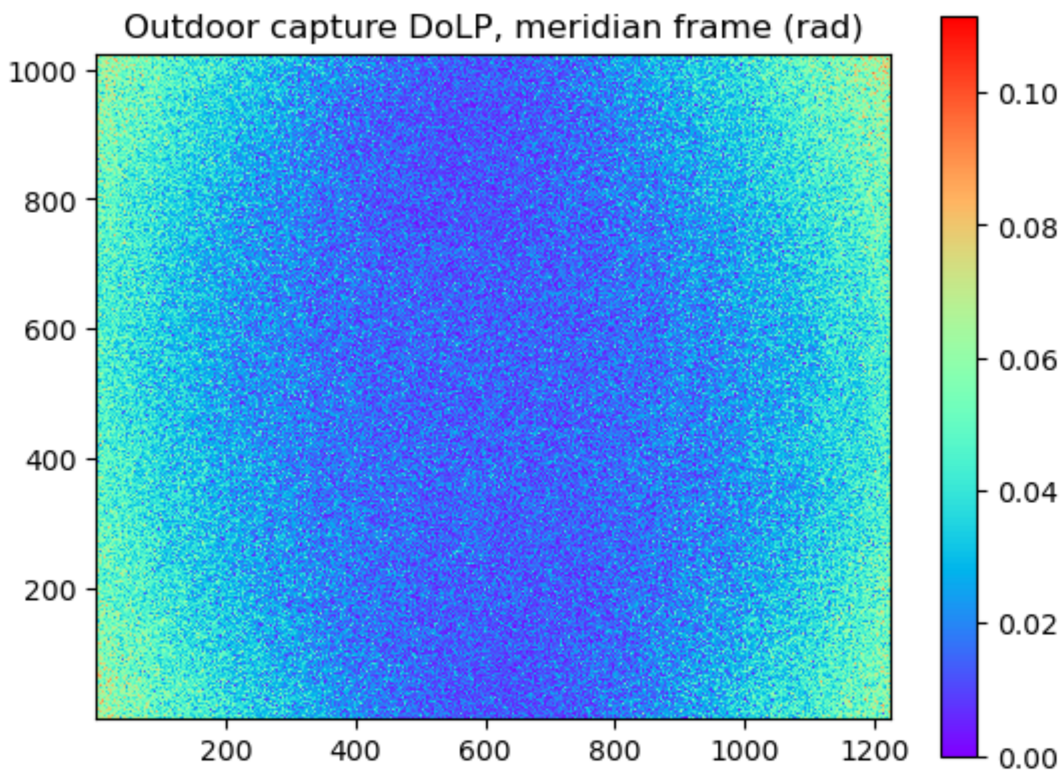
```
outside capture results
```

```
Out[23]: Text(0.5, 1.0, 'Outdoor capture DoLP, meridian frame (rad)')
```




Outdoor capture AoP, camera frame (rad)
1000
800
600
400
200
200
400
600
800
1000
1200
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5


Outdoor capture AoP, meridian frame (rad)
1000
800
600
400
200
200
400
600
800
1000
1200
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5


Outdoor capture DoLP, meridian frame (rad)
1000
800
600
400
200
200
400
600
800
1000
1200
0.10
0.08
0.06
0.04
0.02
0.00

In [ ]:

In [ ]:

In [ ]: