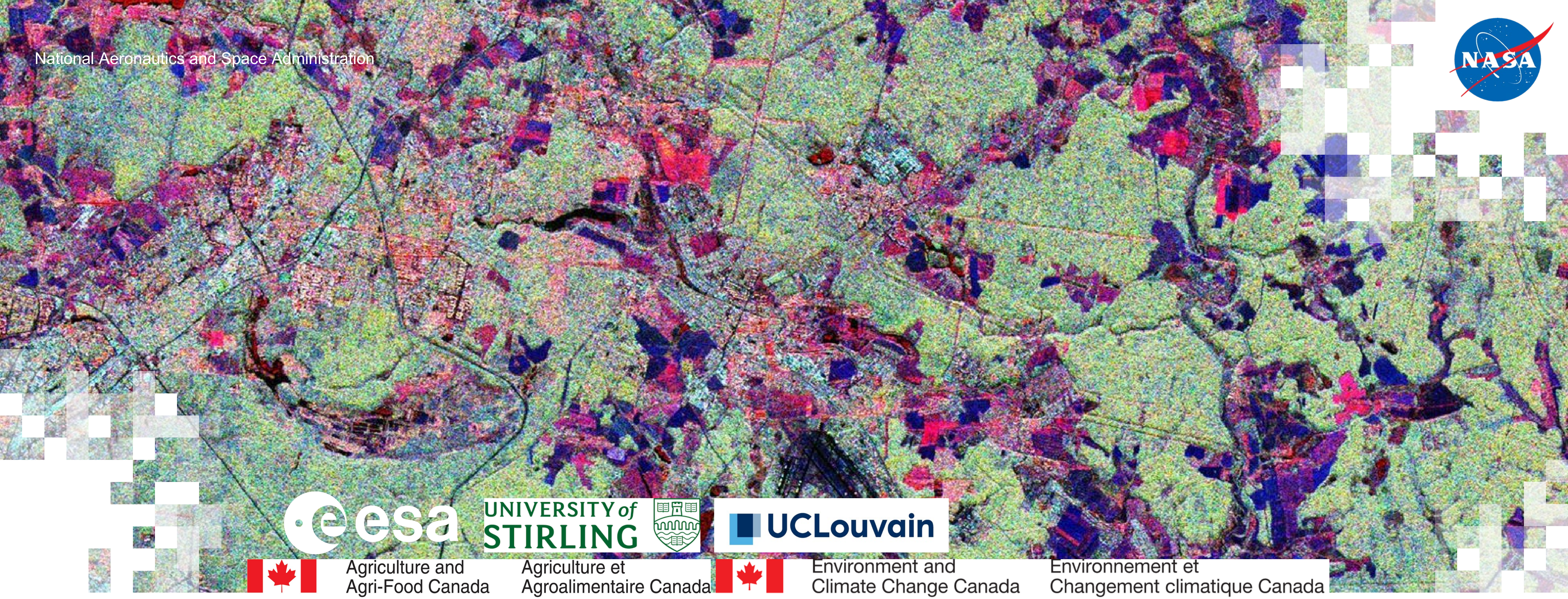


Mapping Crops and their Biophysical Characteristics with Polarimetric Synthetic Aperture Radar and Optical Remote Sensing

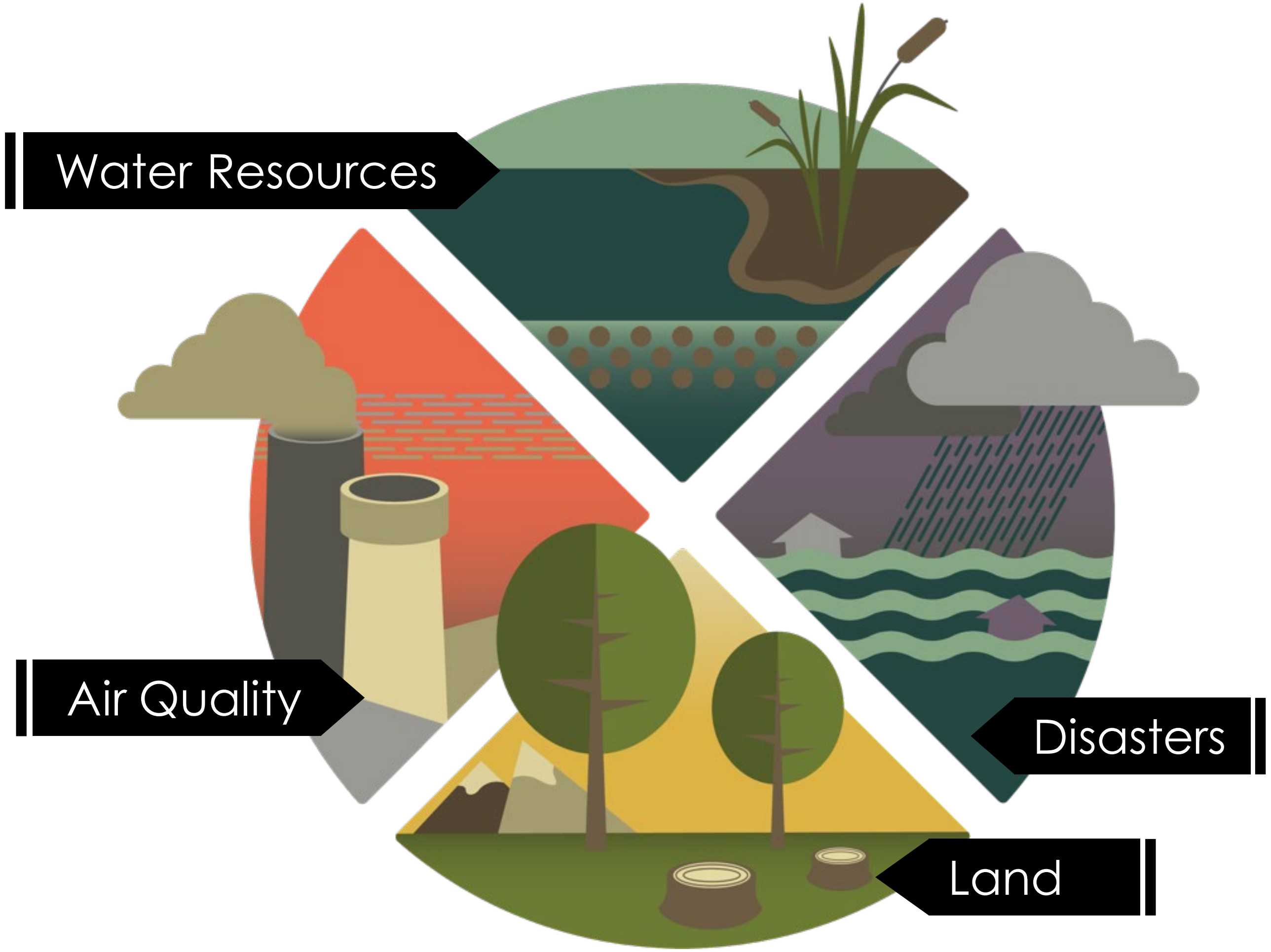
Part 1: SAR Polarimetry for Agriculture (Theory and Practice)

12 April 2022

NASA's Applied Remote Sensing Training Program (ARSET)

https://appliedsciences.nasa.gov/what-we-do/capacity-building/arset

- Part of NASA's Applied Sciences Capacity Building Program
- Empowering the global community through online and in-person remote sensing training
- Topics for trainings include:
  – Water Resources
  – Air Quality
  – Disasters
  – Land
  – Climate & Energy (recently added)



NASA’s Applied Remote Sensing Training Program (ARSET)

https://appliedsciences.nasa.gov/what-we-do/capacity-building/arset

- ARSET’s goal is to increase the use of Earth science remote sensing and model data in decision-making through training for:
  - Professionals in the public and private sector
  - Environmental managers
  - Policy makers

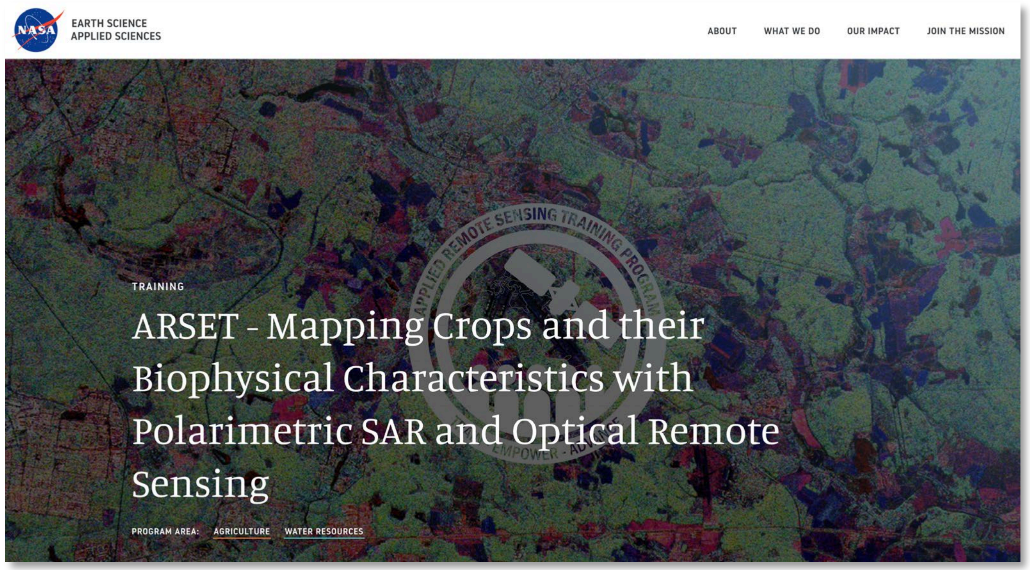
All ARSET materials are freely available to use and adapt for your curriculum. If you use the methods and data presented in ARSET trainings, please acknowledge the NASA Applied Remote Sensing Training (ARSET) program.

Training Format

- Four 2.5-hour sessions including presentations and question and answer sessions
- The same content will be presented at two different times each day.
- Session A will be presented in **English.**
- Session B will be presented in **Spanish.**
  - Session A: 10:00-12:30 EST (UTC-4)
  - Session B: 13:00-15:30 EST (UTC-4)

- Training materials and recordings will be available from:

  https://appliedsciences.nasa.gov/join-mission/training/english/arset-mapping-crops-and-their-biophysical-characteristics



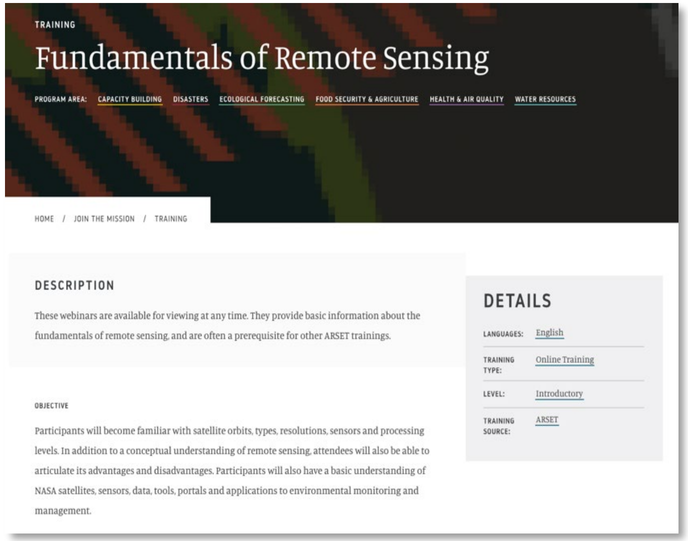
Homework and Certificate

- Homework Assignment:
  - Answers must be submitted via Google Form
  - Due Date: May 17, 2022
- A certificate of completion will be awarded to those who:
  - Attend all live webinars
  - Complete the homework assignment by the deadline (access from website)
  - You will receive a certificate approximately two months after the completion of the course from: marines.martins@ssaihq.com

Prerequisites

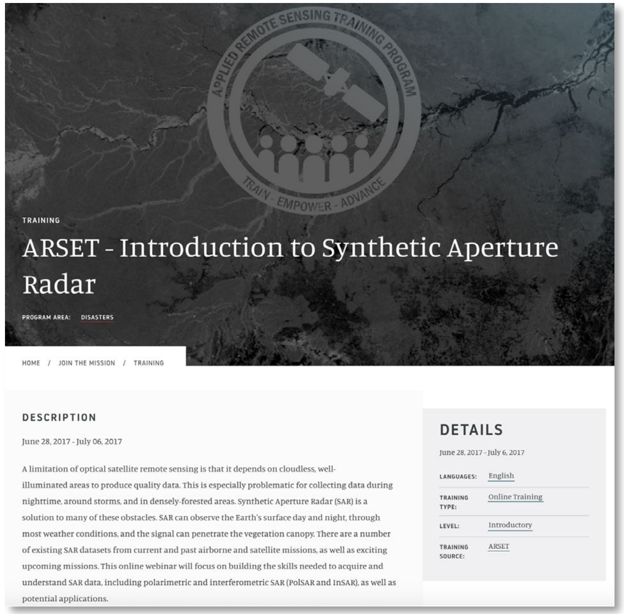
Fundamentals of Remote Sensing:

https://appliedsciences.nasa.gov/join-mission/training/english/fundamentals-remote-sensing



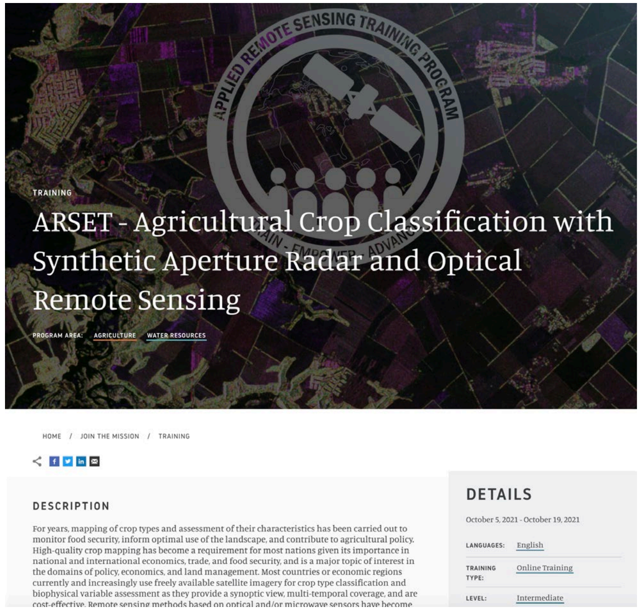
Introduction to Synthetic Aperture Radar:

https://appliedsciences.nasa.gov/join-mission/training/english/arset-introduction-synthetic-aperture-radar



Agricultural Crop Classification with Synthetic Aperture Radar and Optical Remote Sensing

https://appliedsciences.nasa.gov/join-mission/training/english/arset-agricultural-crop-classification-synthetic-aperture-radar-and



Training Outline

April 12, 2022

SAR Polarimetry for Agriculture (Theory and Practice)

April 19, 2022

Polarimetry Practical Part 2: SAR Polarimetry with Sentinel-1, RCM, & SAOCOM Imagery for Agriculture

April 26, 2022

Sen4Stat Open-Source Toolbox (Theory and Practical)

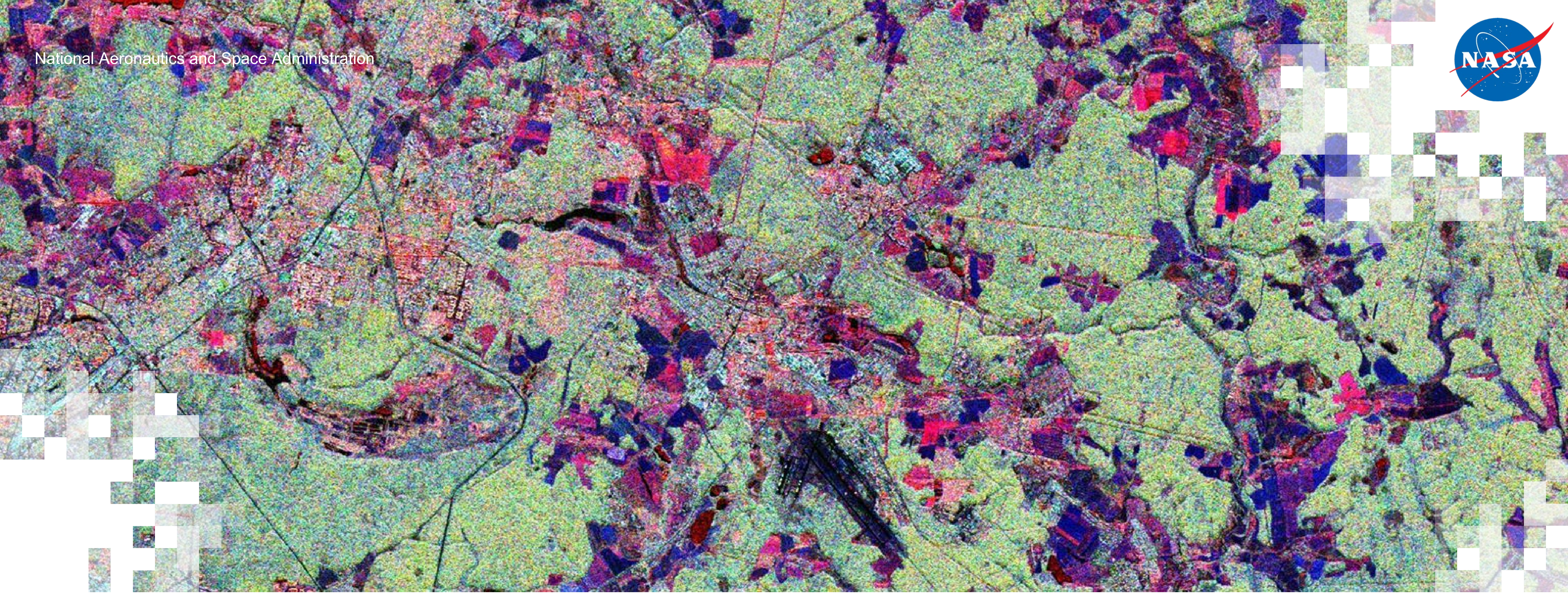
May 3, 2022

Crop-Specific Time Series Analysis for Growth Monitoring

Training Objectives

By the end of this training attendees will be able to:

- Explain the theory behind SAR Polarimetry, especially as related to crop characteristics
- Generate polarimetric parameters using open-source imagery/software and perform a time series analysis of crop growth
- Identify how Sen4Stat can support National Statistical Offices in the uptake of satellite Earth observations for agricultural statistics
- Perform a time series analysis of crop types using Sentinel-2 derived LAI index



SAR Polarimetry Theory

Learning Objectives

By the end of this training, participants will be familiar with the following:

- Electromagnetic radiation
- SAR system characteristics
- Interference and speckle
- Common SAR imaging modes
- Polarimetry

Pre-requisite material
https://youtu.be/Xemo2ZpduHA?t=54
(0:54 – 51:04)
https://youtu.be/2SGP30TGHXM?t=365
(6:05 – 1:43:43)

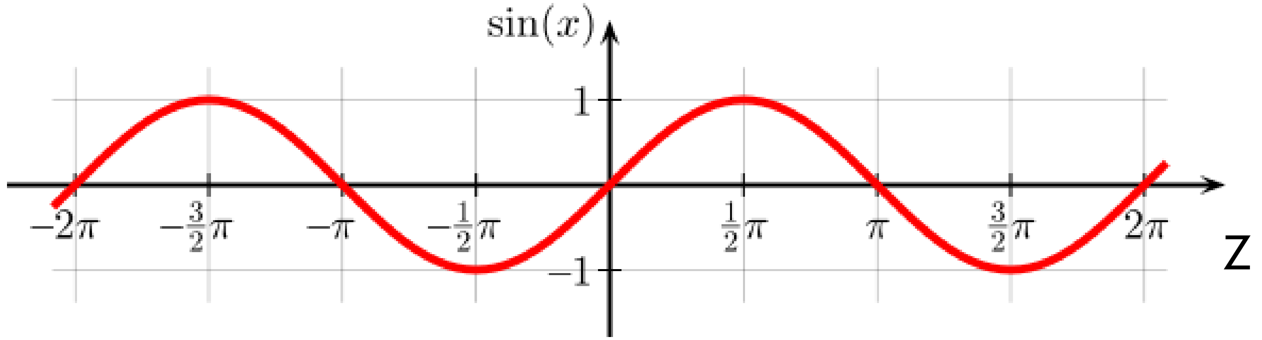
Electromagnetic Radiation

- Different ways to describe waves mathematically

- For simplicity, the wave's profile can be based on a sine (or cosine) curve
  – Mathematical function, mathematical curve
  – Useful to model periodic phenomena

- Convenient to represent this on an x, y, z (Right-handed Cartesian) coordinate system

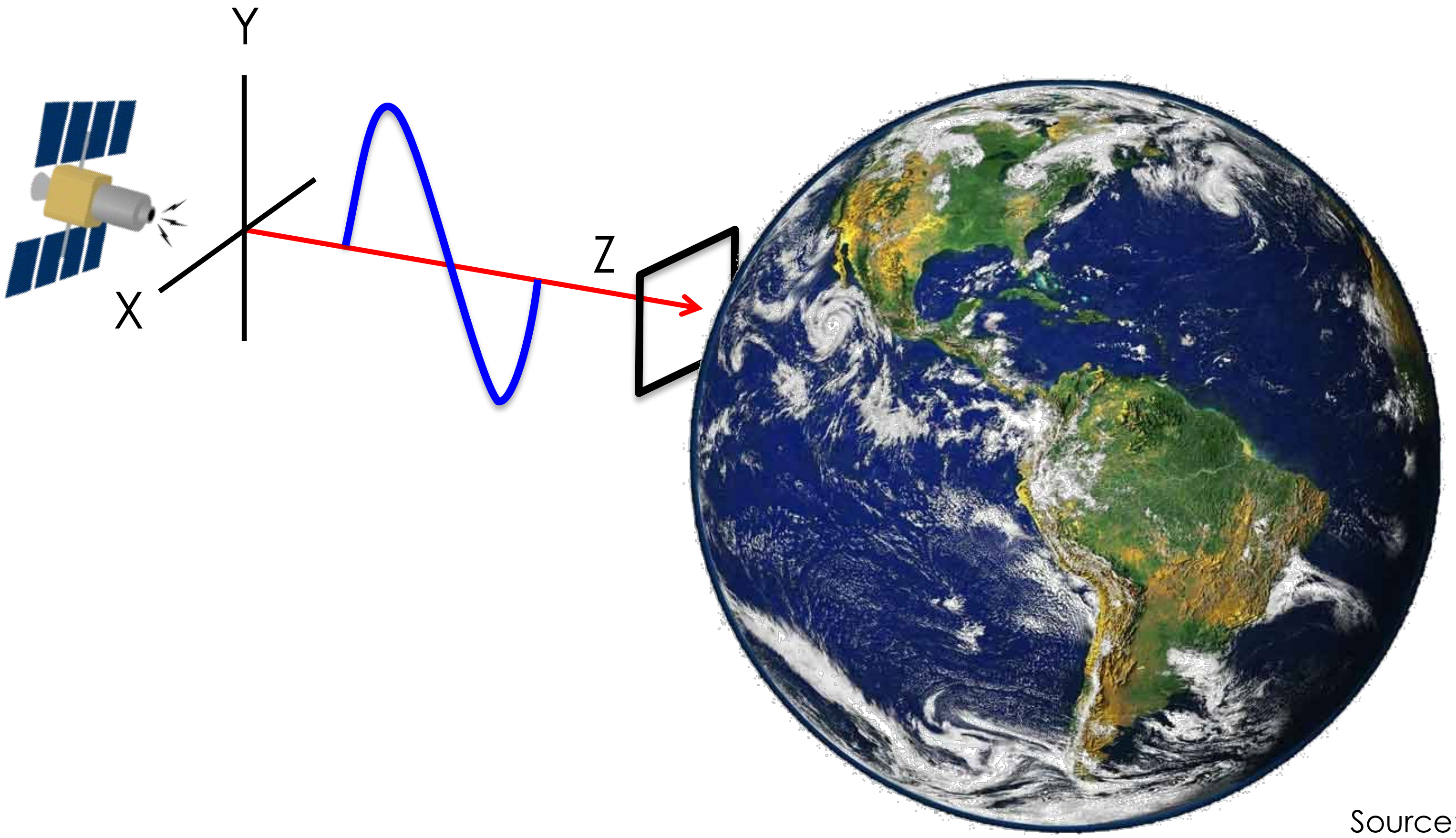
  – Z-axis = direction of travel



Source: [Geek3; Wikimedia Commons]

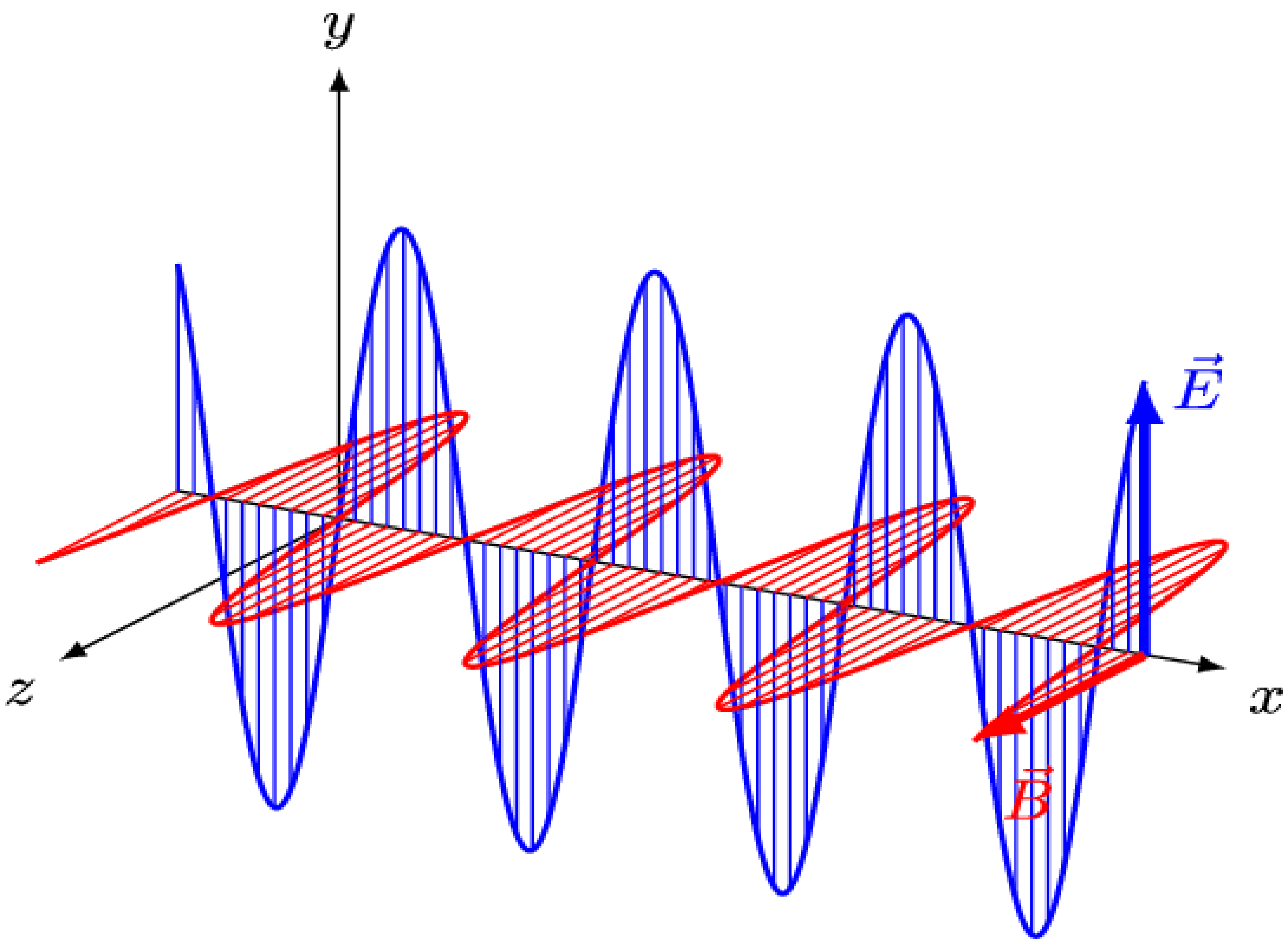
Electromagnetic Radiation

- X-Y plane defined at sensor
- Convention: X is parallel to Earth's surface



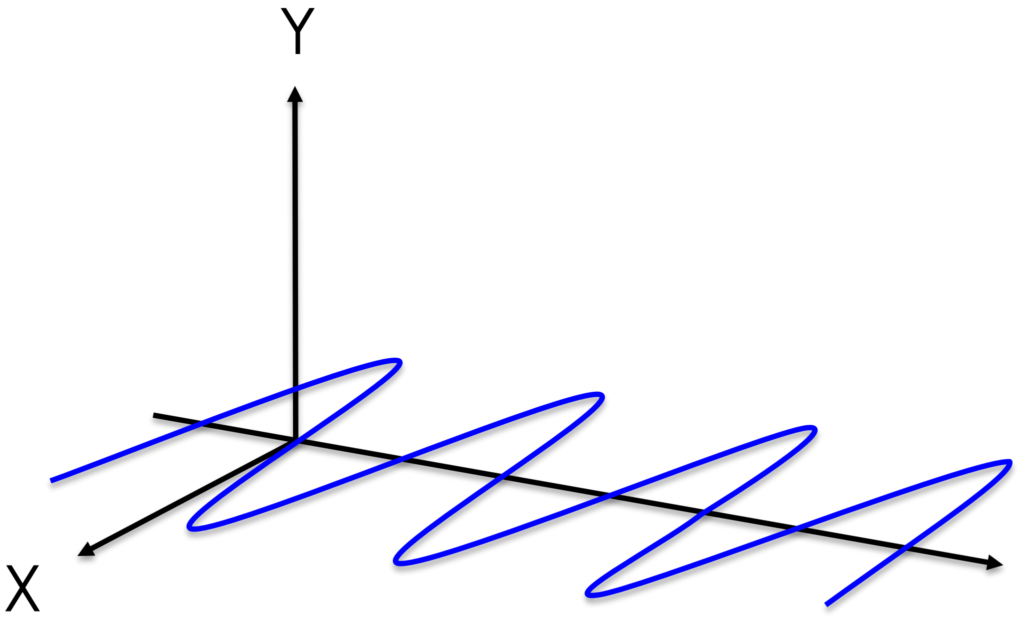
Source: Science4Fun

System Characteristics – Polarization



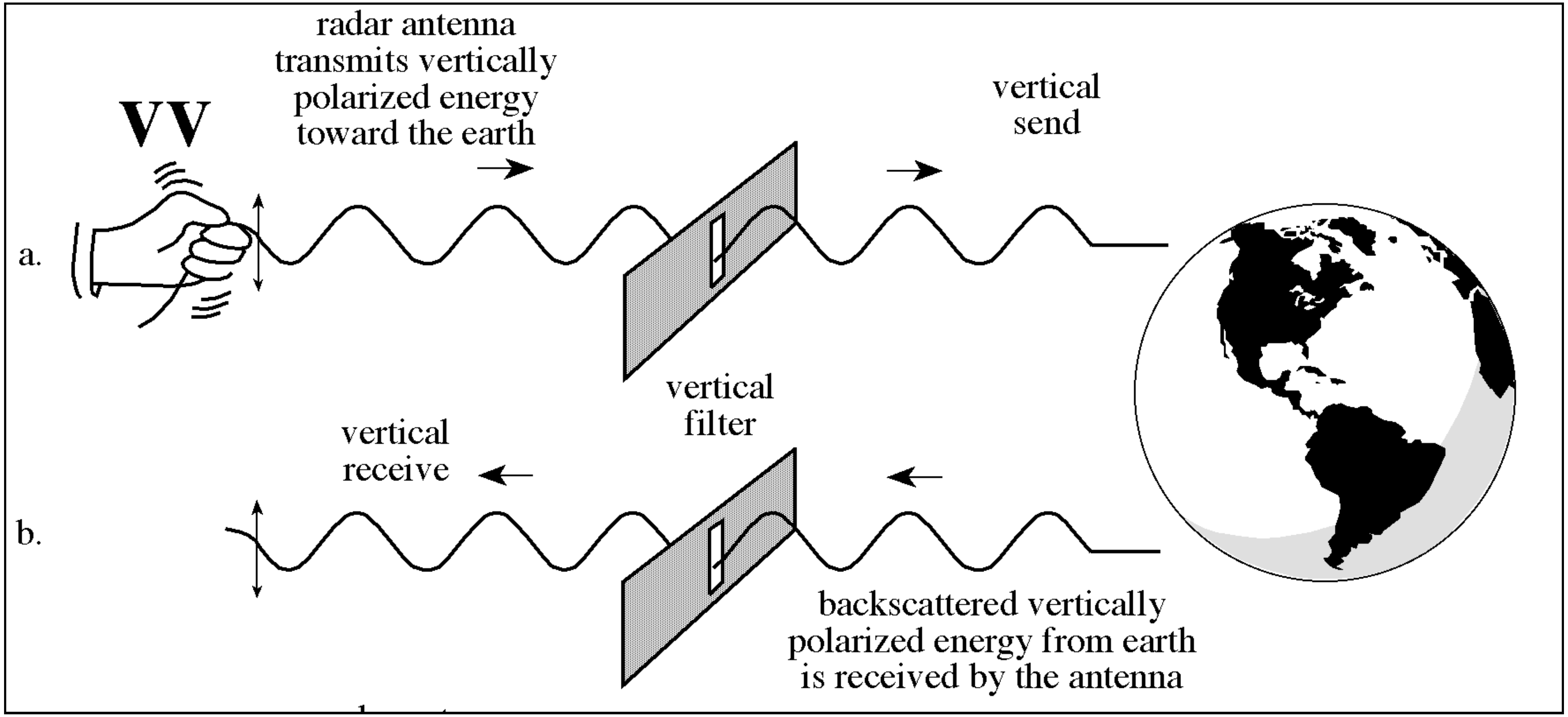
Plane linearly polarized wave – Source: And1mu – Wikimedia Commons

System Characteristics – Polarization



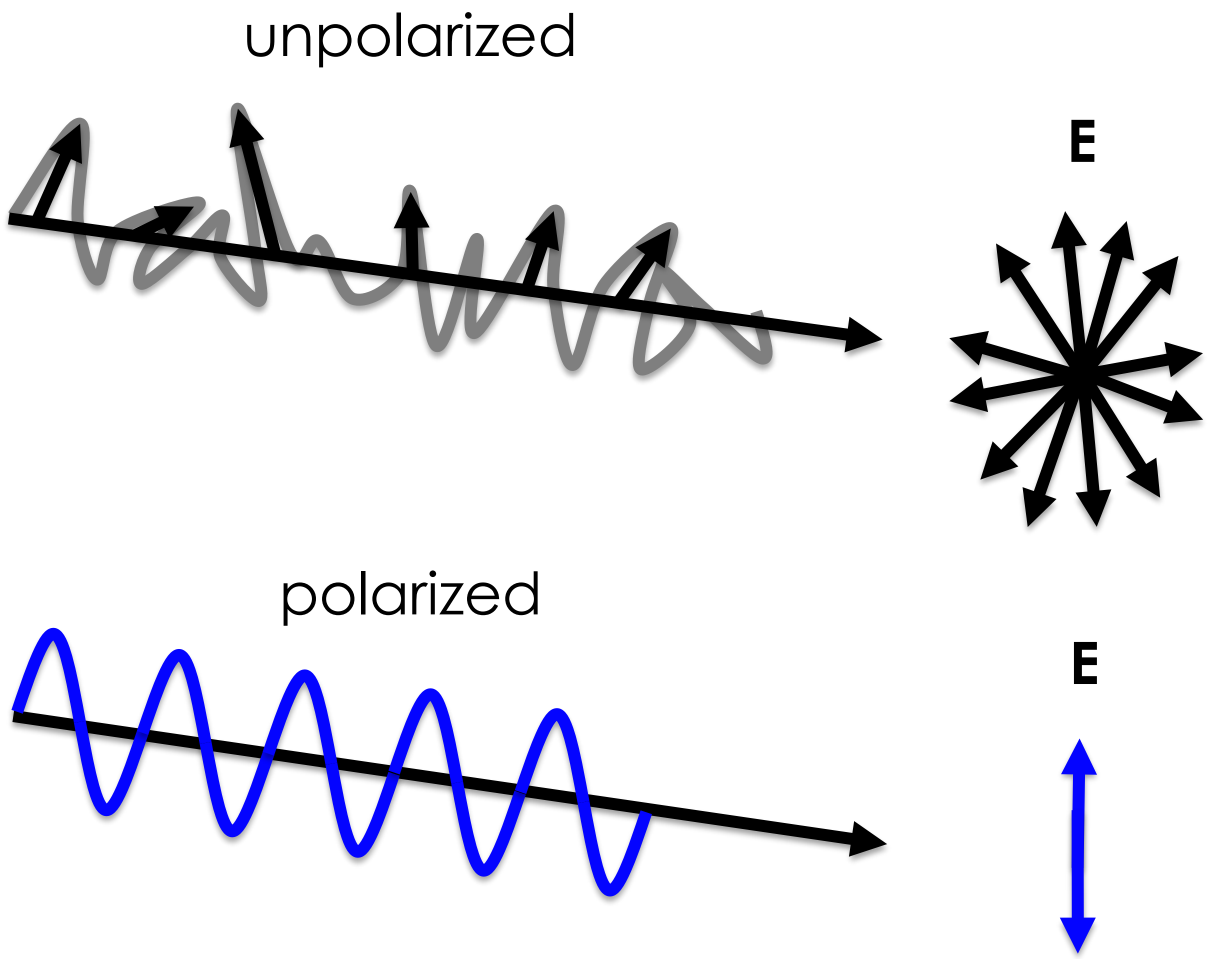
Plane linearly polarized wave – Source: And1mu – Wikimedia Commons

System Characteristics – Polarization



Source: https://courses.eas.ualberta.ca/eas451/radar%20section.pdf, https://www.physicsclassroom.com/class/light/Lesson-1/Polarization

System Characteristics – Polarization



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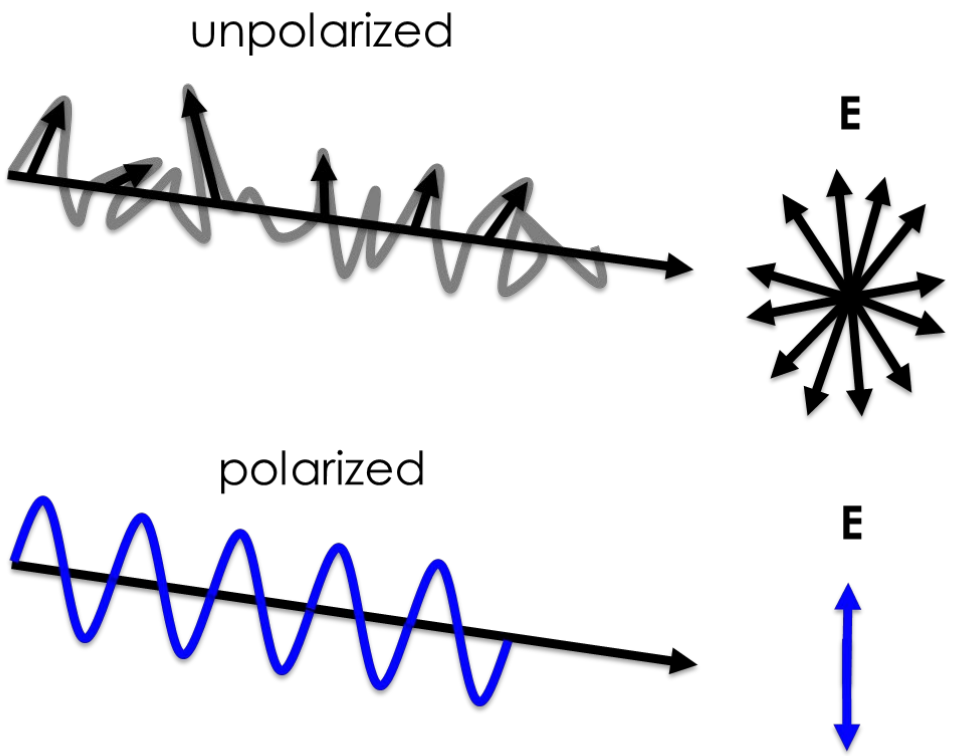
System Characteristics – Polarization



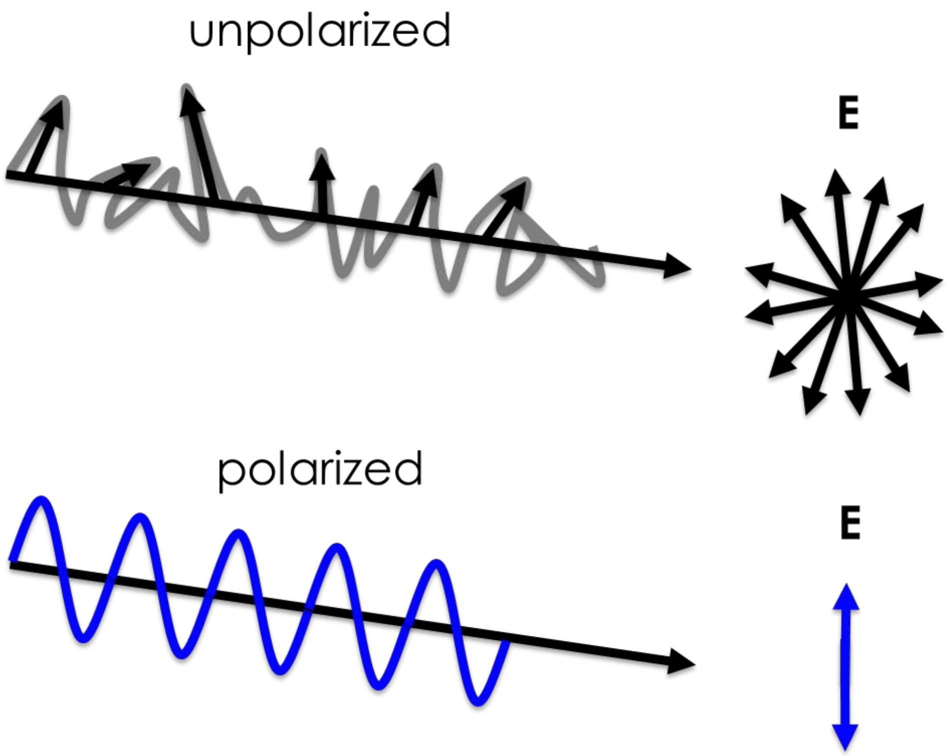
Completely unpolarized – oscillates randomly

Completely polarized – oscillates in plane of polarization

Partially polarized – combination

Source: https://courses.eas.ualberta.ca/eas451/radar%20section.pdf, https://www.physicsclassroom.com/class/light/Lesson-1/Polarization

System Characteristics – Polarization



Transmitted: always polarized

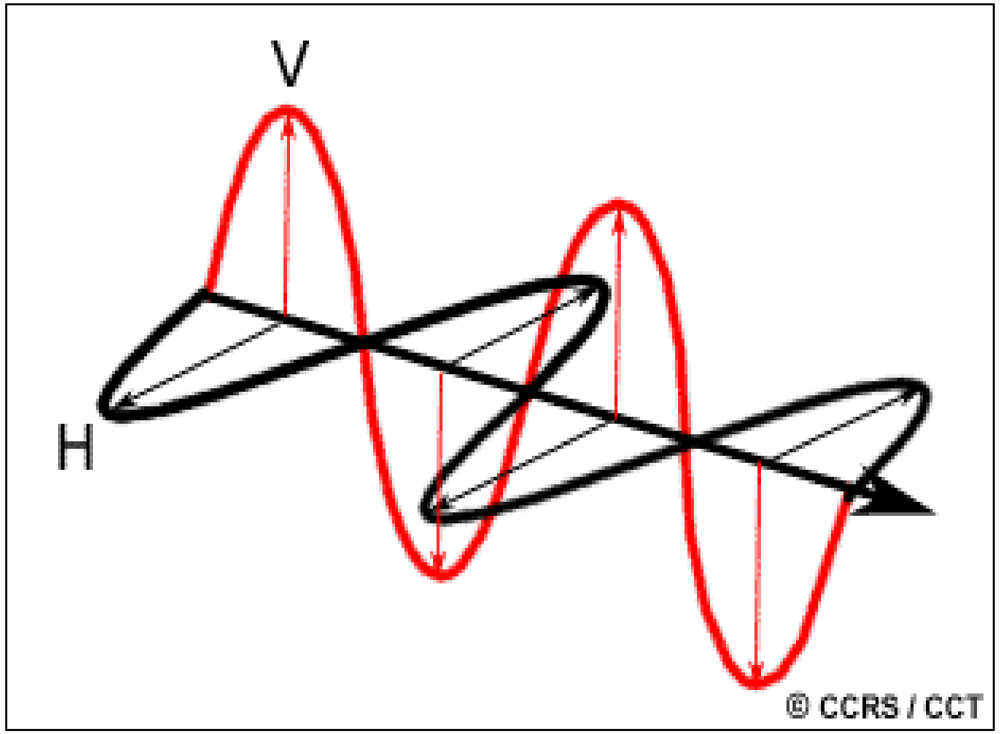
Received: partially or completely unpolarized

Degree of polarization = polarized power/total power

Source: https://courses.eas.ualberta.ca/eas451/radar%20section.pdf, https://www.physicsclassroom.com/class/light/Lesson-1/Polarization

System Characteristics – Polarization

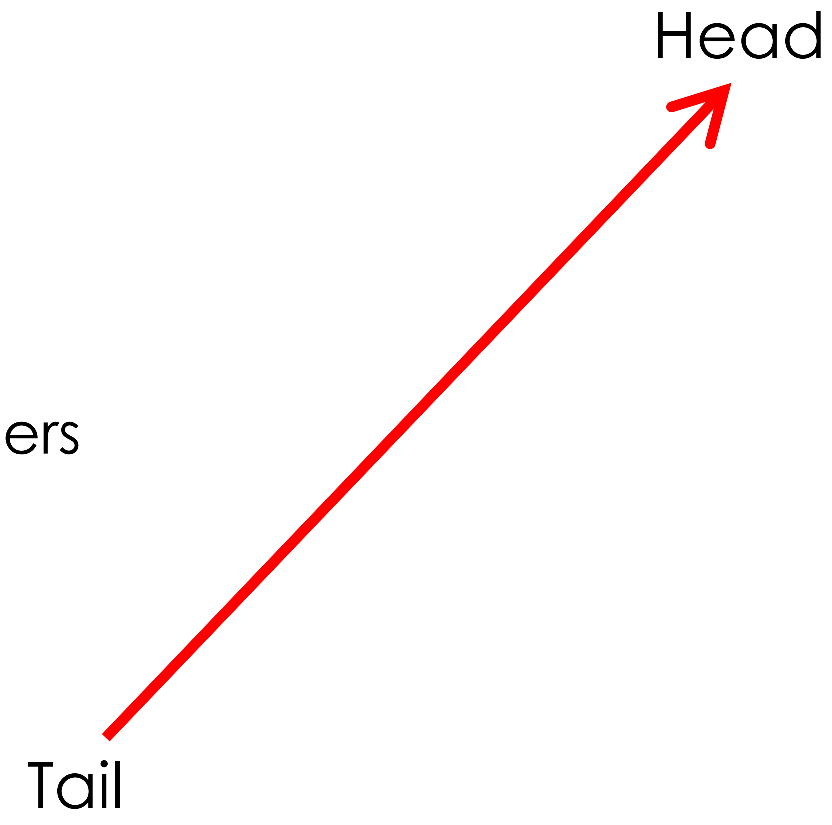
Most radars transmit and/or receive: horizontally polarized (H) or vertically polarized (V)



Source: Government of Canada

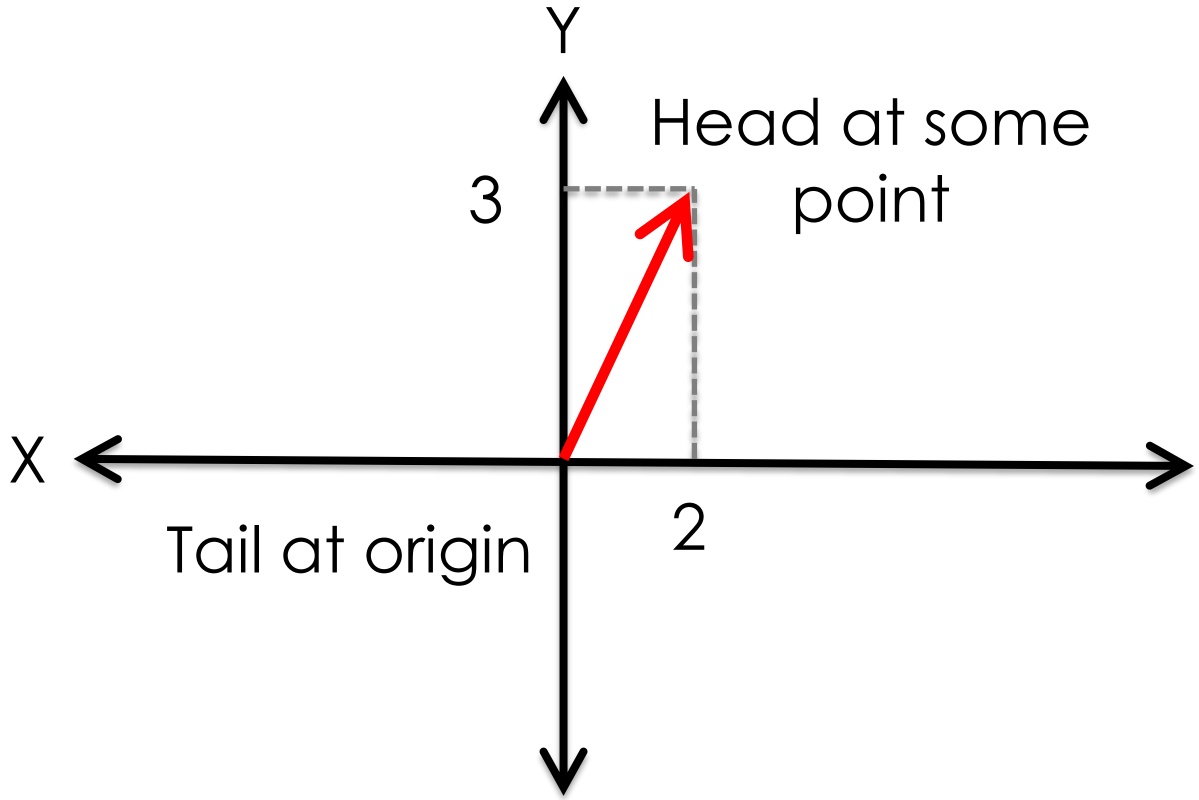
System Characteristics – Phase and Polarization

- Vectors:
  - Quantity with:
    1) Direction
    2) Magnitude (length)
  - Represented as an arrow, ordered list of numbers
  - Denote using **boldface** or $\vec{\boldsymbol{a}}$
  - Magnitude only using $||\boldsymbol{a}||$
  - E.g. velocity (speed in a given direction)



System Characteristics – Phase and Polarization

- Vectors:
  - Can represent vectors on a Cartesian (x, y) coordinate system
  - Note: same notation for a vector & point (point is a vector with its tail at the origin)
  - In linear algebra the tail is usually at the origin

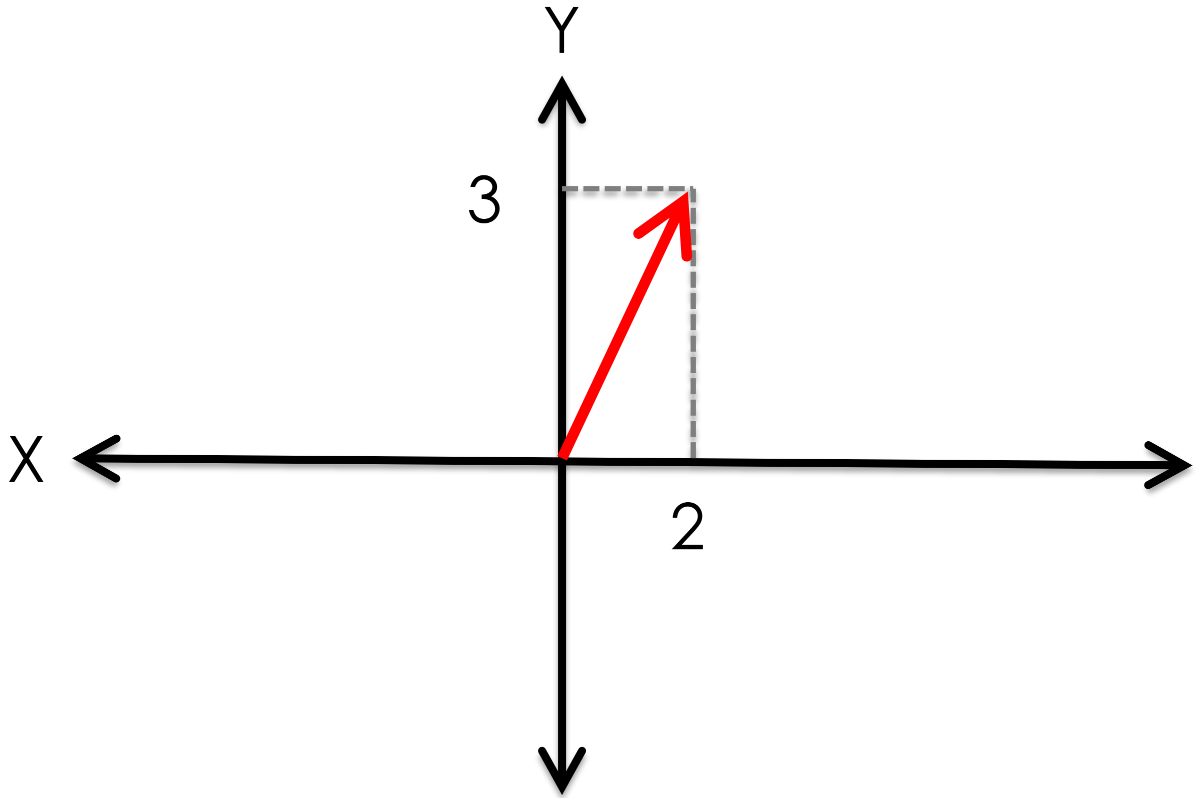


System Characteristics – Phase and Polarization

- Vectors:
  - Coordinates of a vector is a **list of ordered numbers:**

$$\begin{bmatrix} 2 \\ 3 \end{bmatrix}$$

  - Tells you how to get from tail to head
  - Convention: write vertically with square brackets

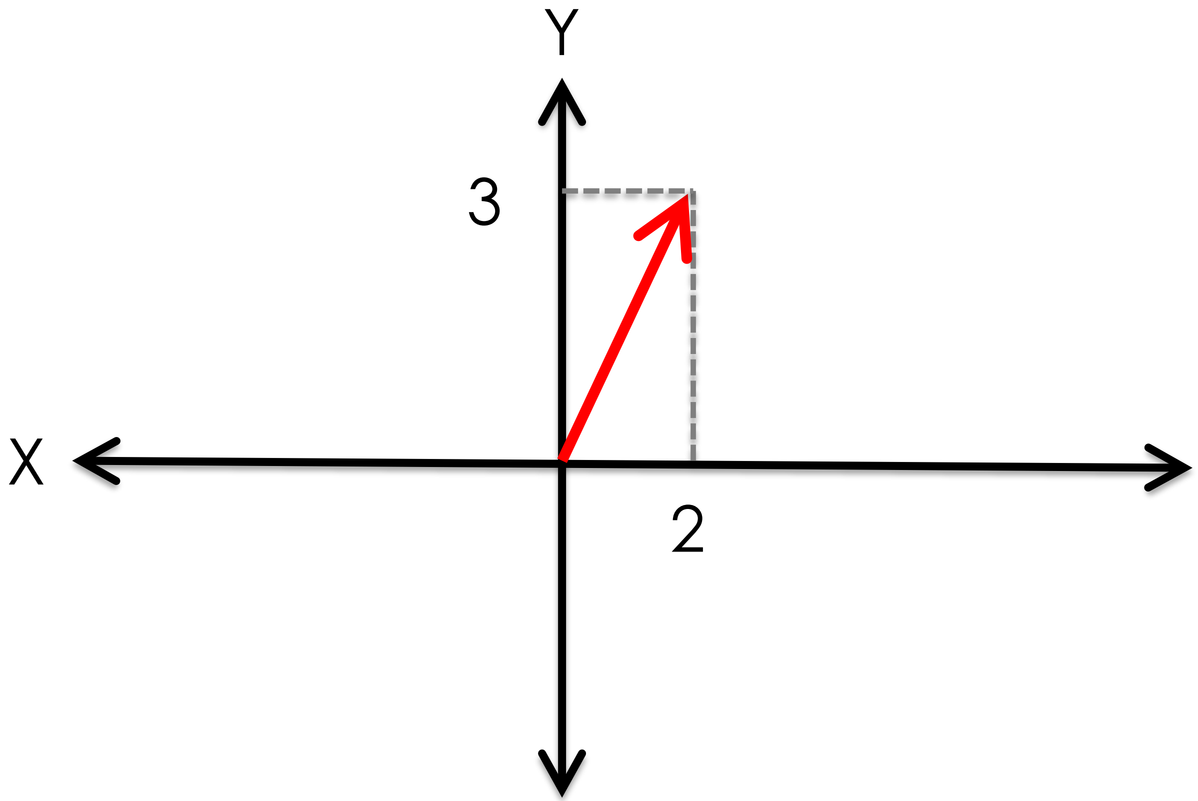


System Characteristics – Phase and Polarization

- Vectors:
  - Easier to manipulate coordinates than direction & magnitude

Magnitude = length of vector

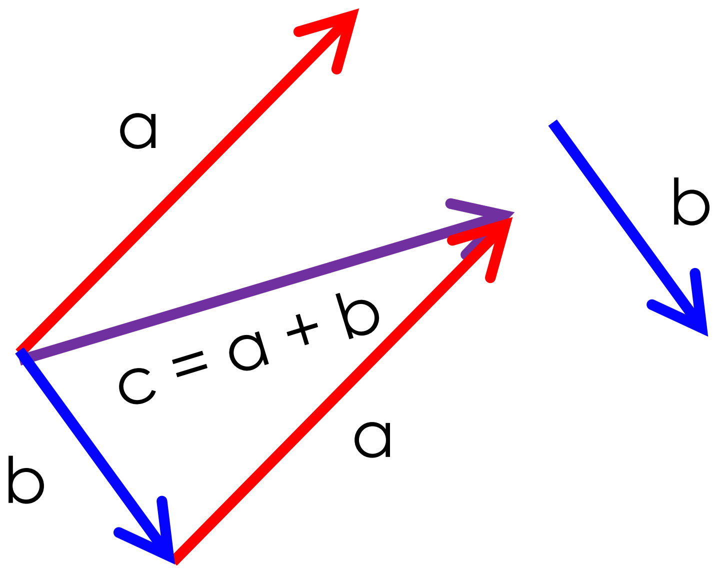
$$\|\boldsymbol{a}\| = \sqrt{2^2 + 3^2}$$



System Characteristics – Phase and Polarization

- Adding Vectors:
  - E.g. a + b
  - Translate b's tail to head of a
  - New vector (c = a + b) is the direct line segment of tail (a) to head (b)
  - Order of addition doesn't matter

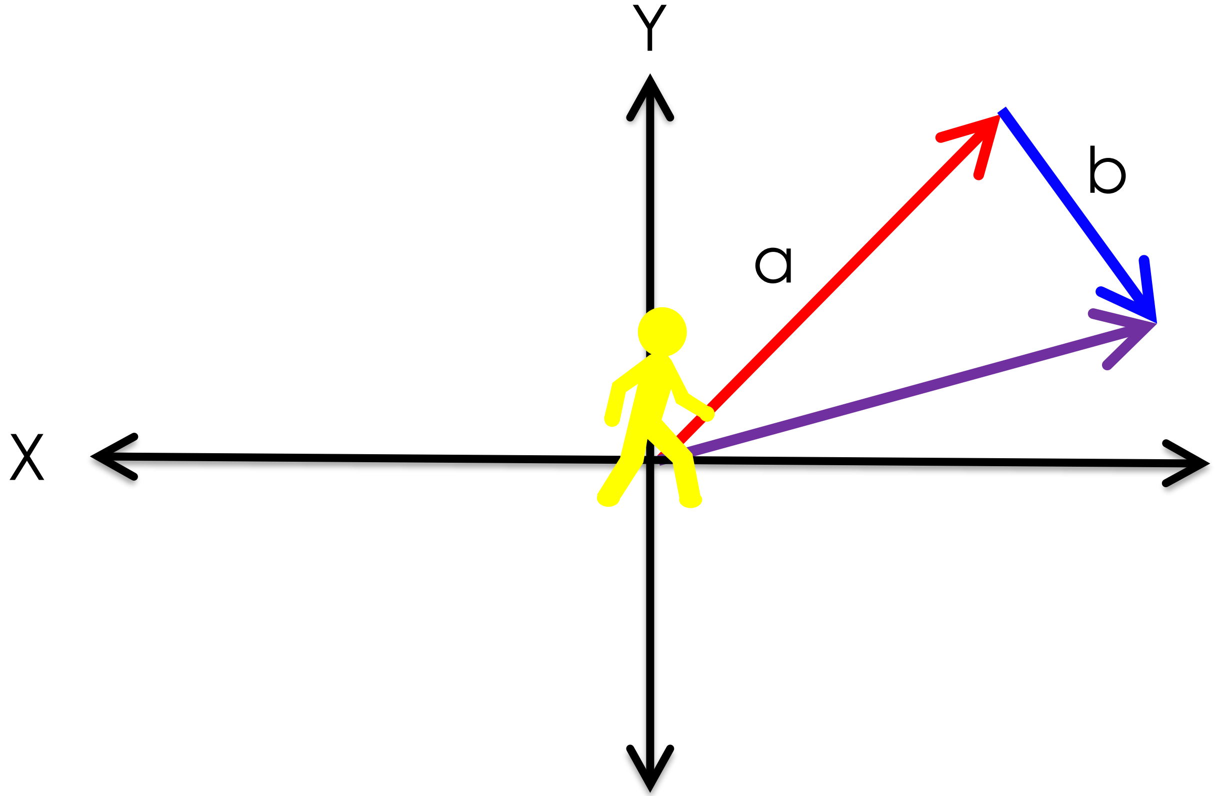
a + b = b + a



System Characteristics – Phase and Polarization

- Adding Vectors:
  - List of directions

$$\begin{bmatrix} 5 \\ 5 \end{bmatrix} + \begin{bmatrix} 2 \\ -2 \end{bmatrix}$$



System Characteristics – Phase and Polarization

- Adding Vectors:
  - Useful for visualizing something called interference

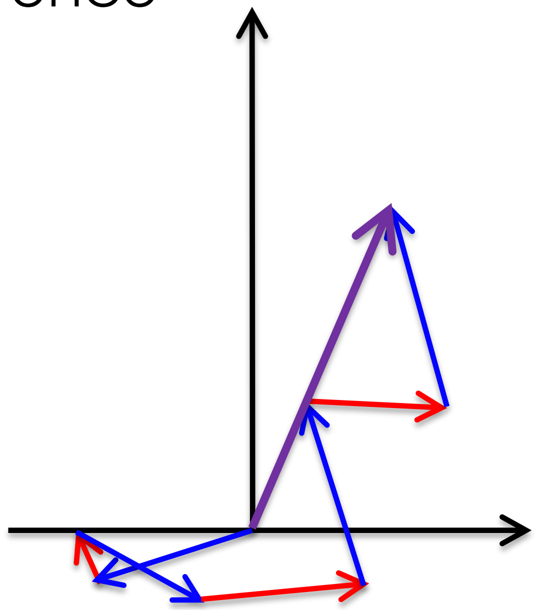


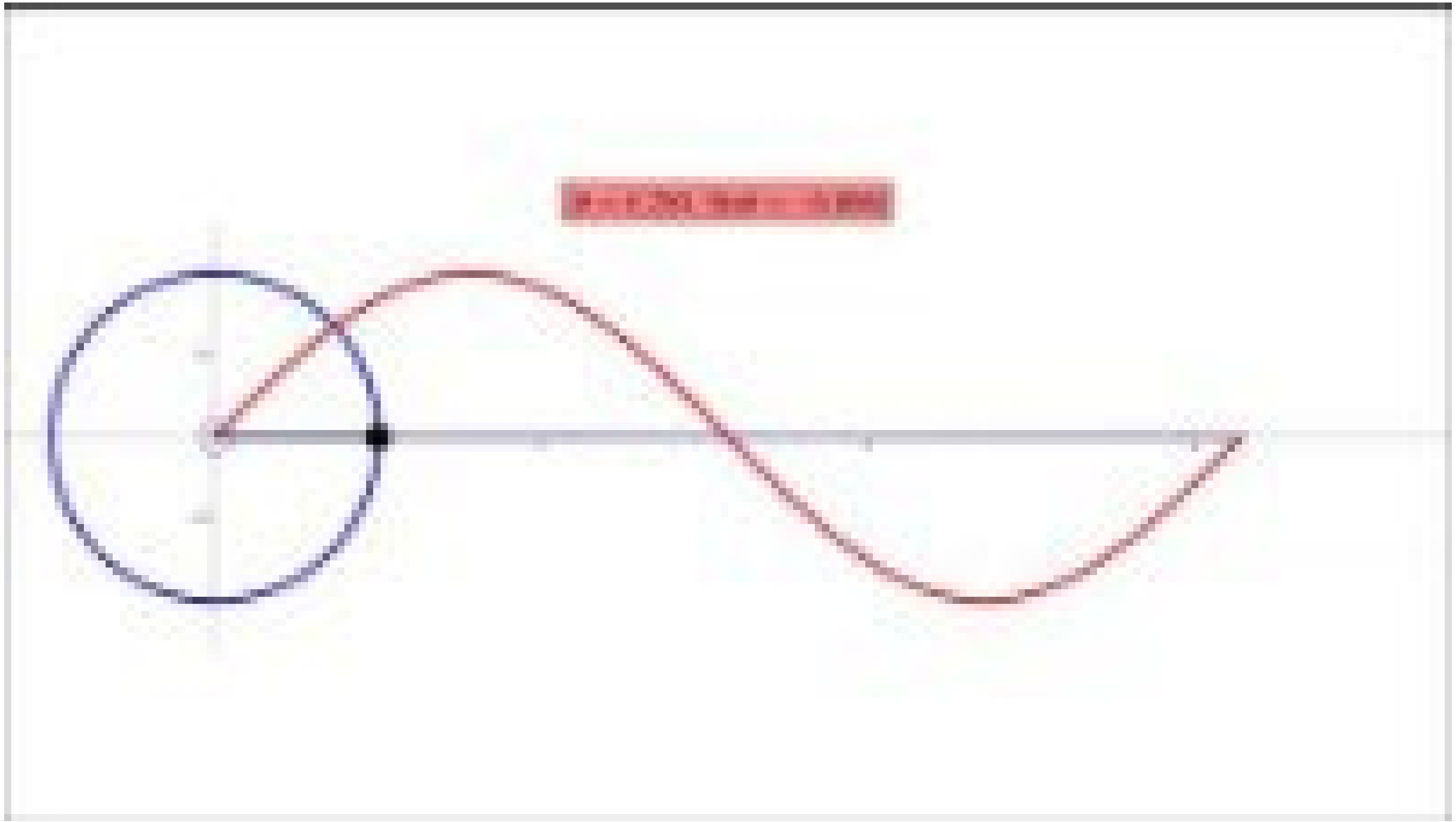
Image recreated after Woodhouse, 2006.

Arrows represent different waves; the product is the sum of all amplitudes & phases!

More on this coming up…

System Characteristics – Phase and Polarization

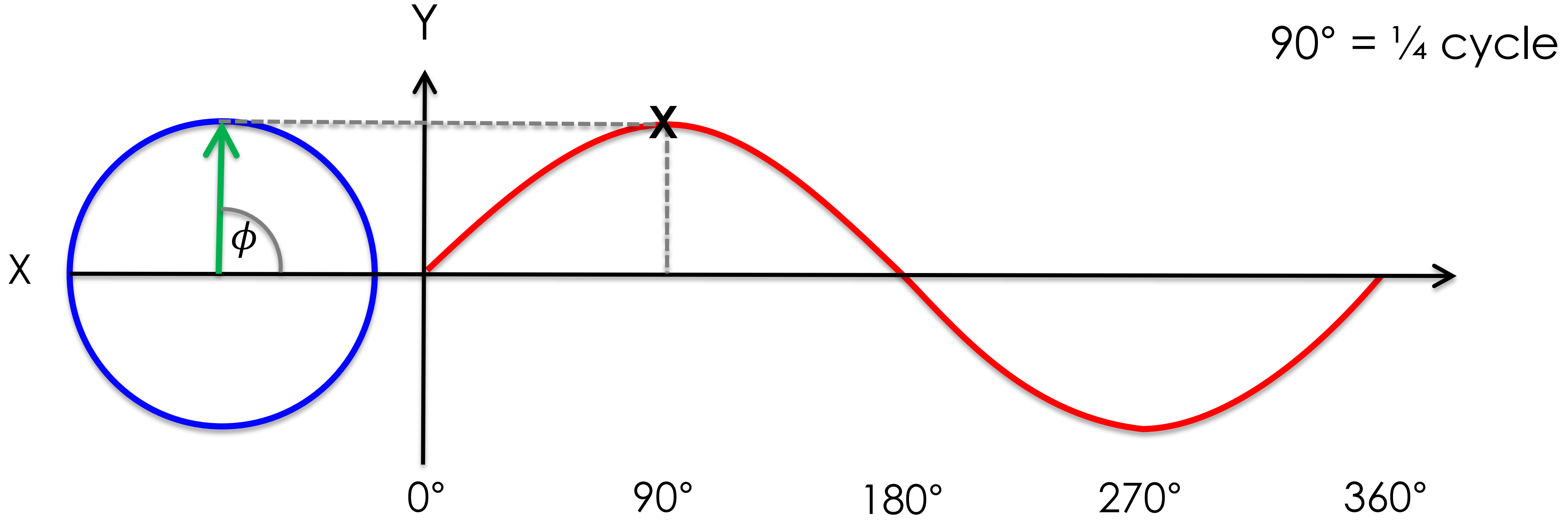
- Interesting relationship between sine waves & circles



Source: https://www.youtube.com/watch?v=miUchhW257Y

System Characteristics – **Phase** and Polarization

- **Phase**: stage of the wave cycle; measured in degrees or radians.



Source: Lucas Vieira

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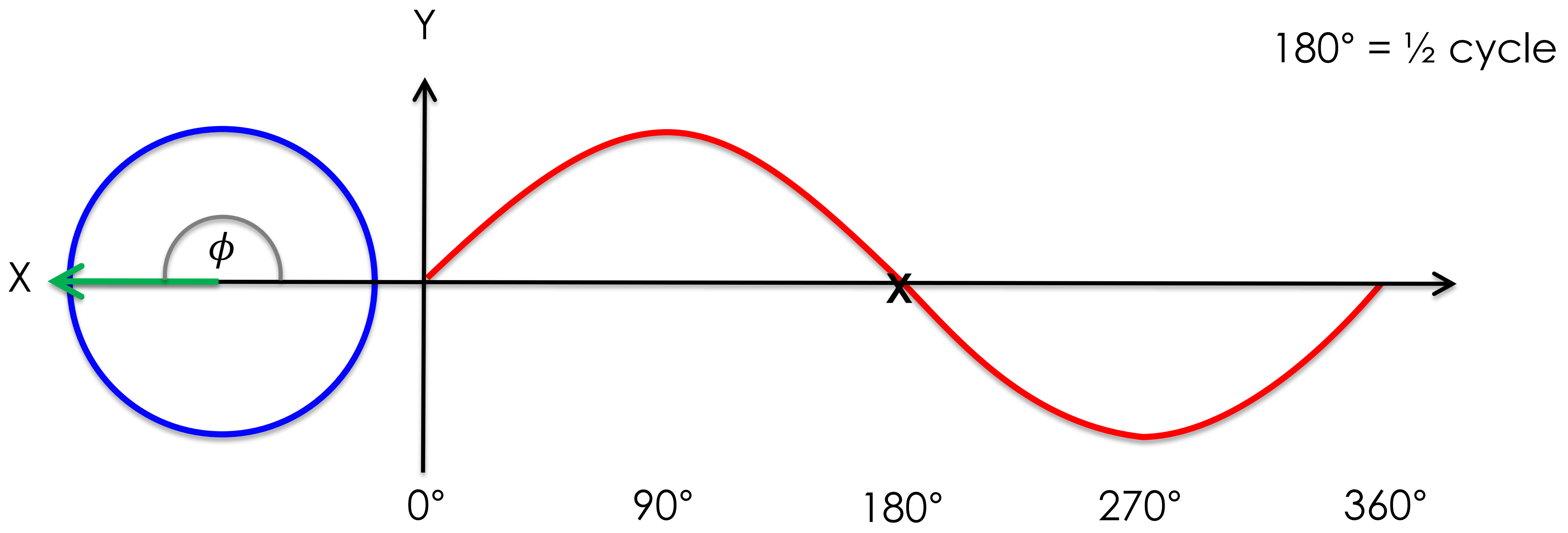

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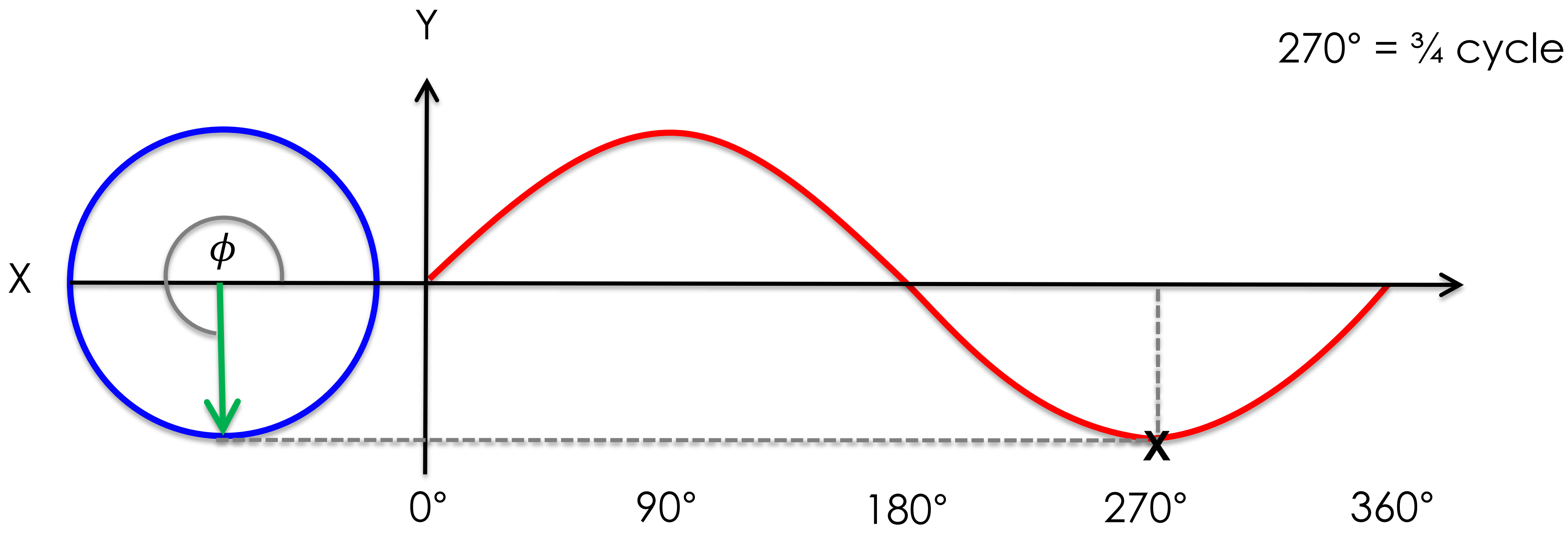

Source: Lucas Vieira

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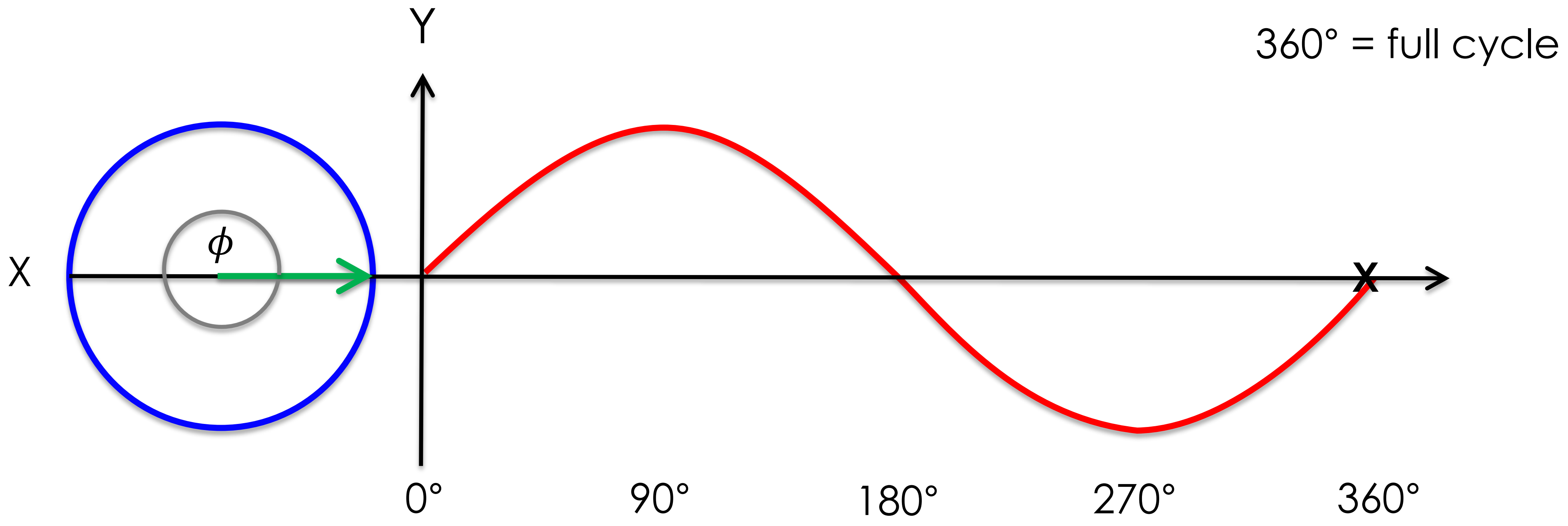
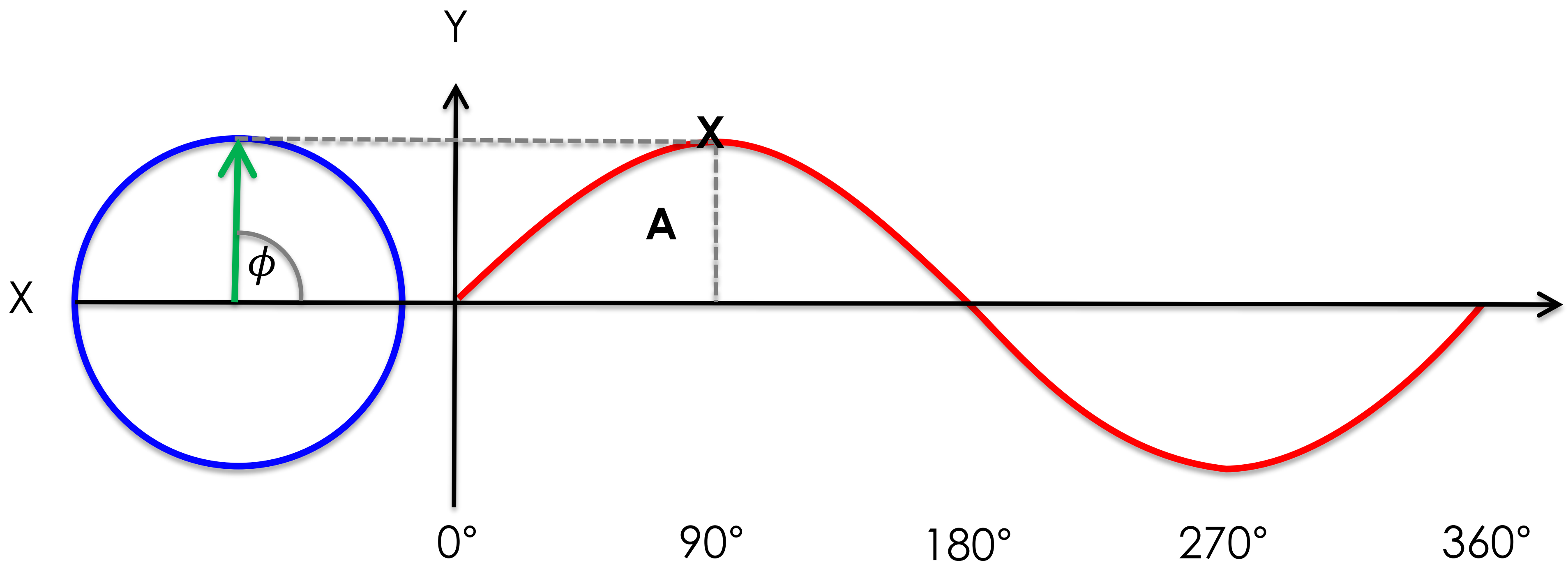


Source: Lucas Vieira

System Characteristics – **Phase** and Polarization

- Projection of the vector onto the y-axis is amplitude (A); at a given point in the wave cycle



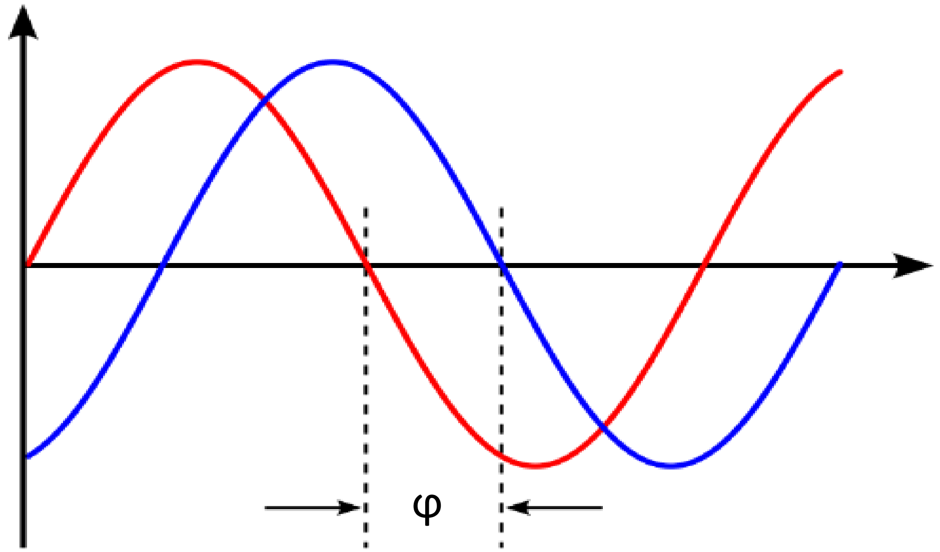
Recreated aftter: https://commons.wikimedia.org/wiki/File:Sine_curve_drawing_animation.gif

Source: Lucas Vieira

System Characteristics – **Phase** and Polarization

- **Initial phase:** the stage in which a wave starts
- **Phase difference (φ):** the offset, in time or space, of one wave with respect to another; waves are in phase if their origins of phase 0 degrees are perfectly aligned. When this is not met, waves are said to be out-of-phase.

Equal amplitude; out of phase



Source: Peppergrower; Dr. Heather McNairn, Carleton University SAR summer course

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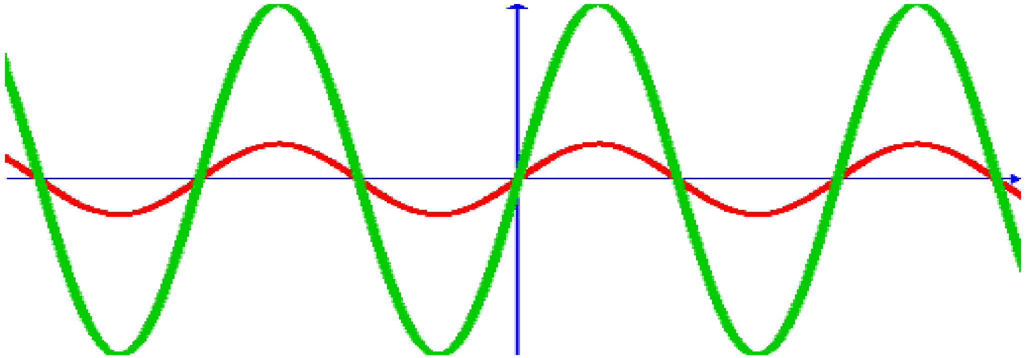
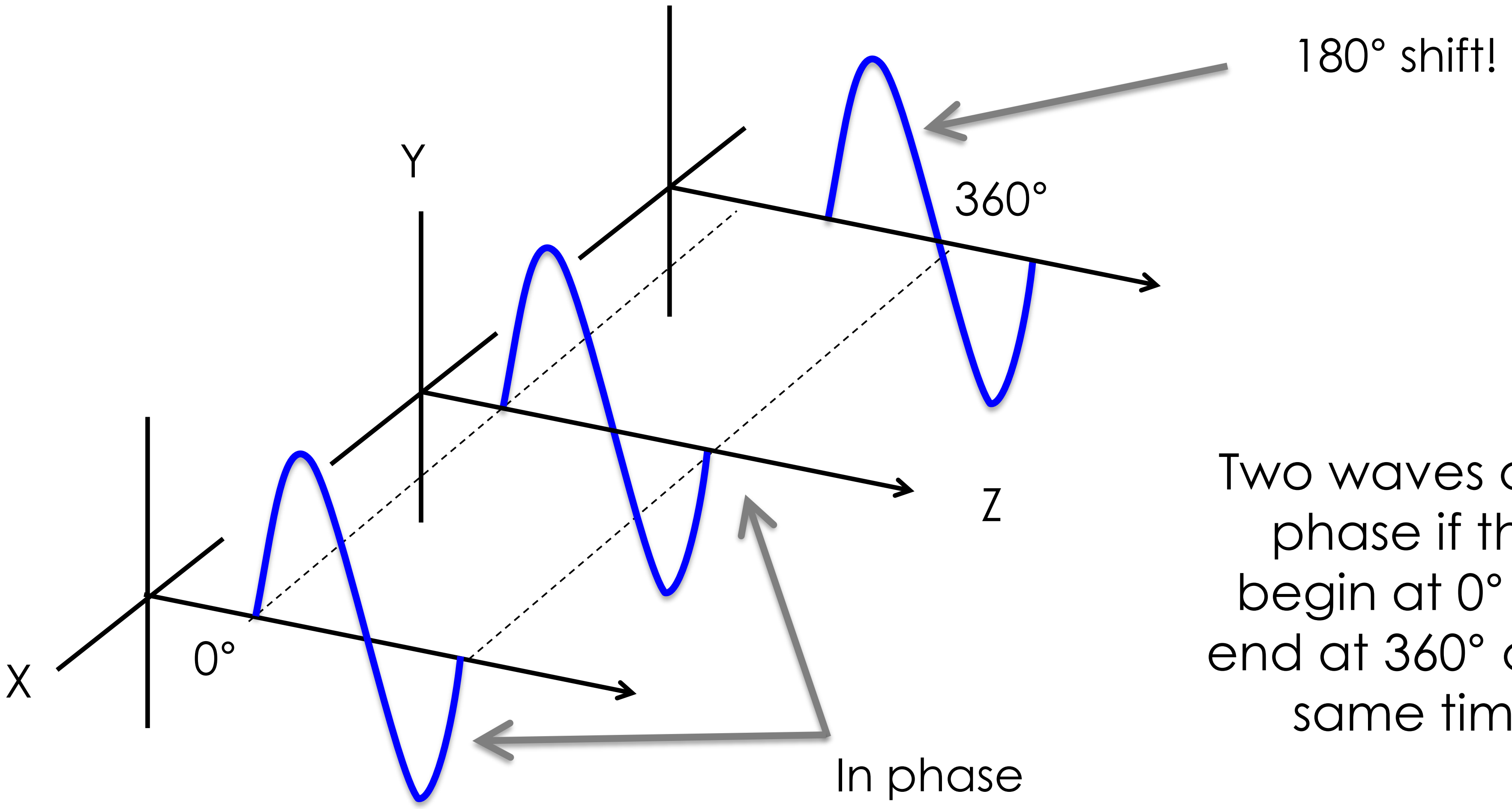
Different amplitudes; in phase



Source: Wikipedia; Dr. Heather McNairn, Carleton University SAR summer course

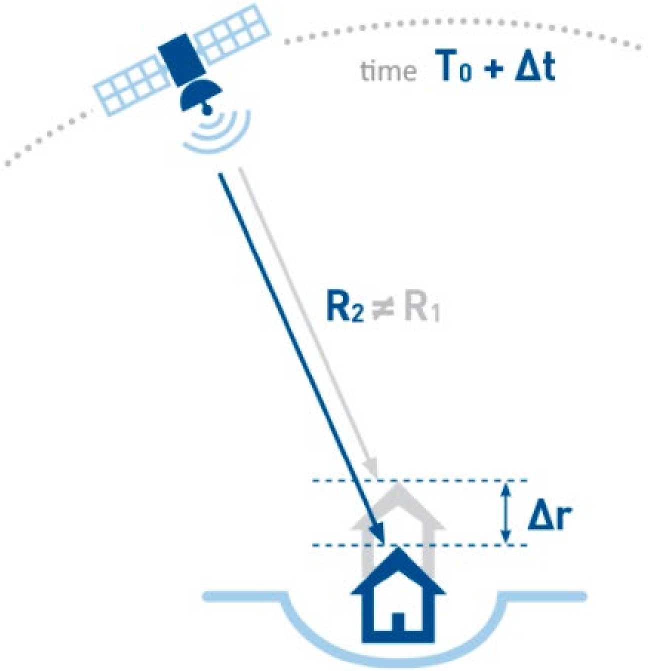
System Characteristics – Phase and Polarization

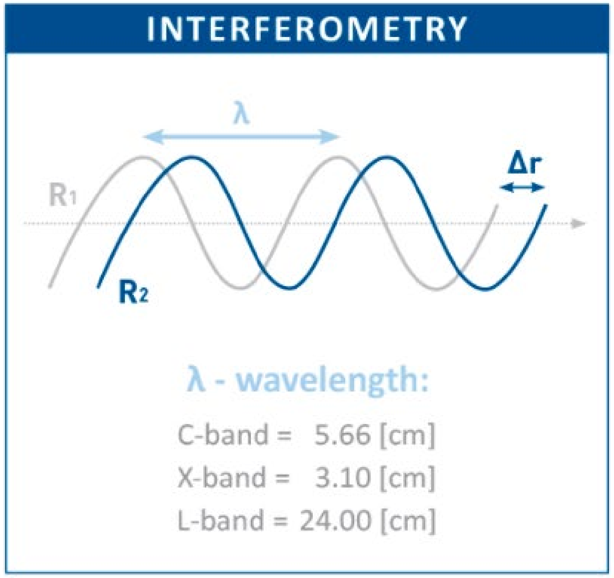


Two waves are in phase if they begin at 0° and end at 360° at the same time!

System Characteristics – Phase and Polarization

- Key in interferometric as well as in polarimetric SAR





- Phase difference is impacted by the structure of the target

Source: TRE ALTAMIRA; Dr. Heather McNairn, Carleton Summer SAR Course

System Characteristics – Phase and Polarization

- Phase information can be really useful; not always available/calibrated

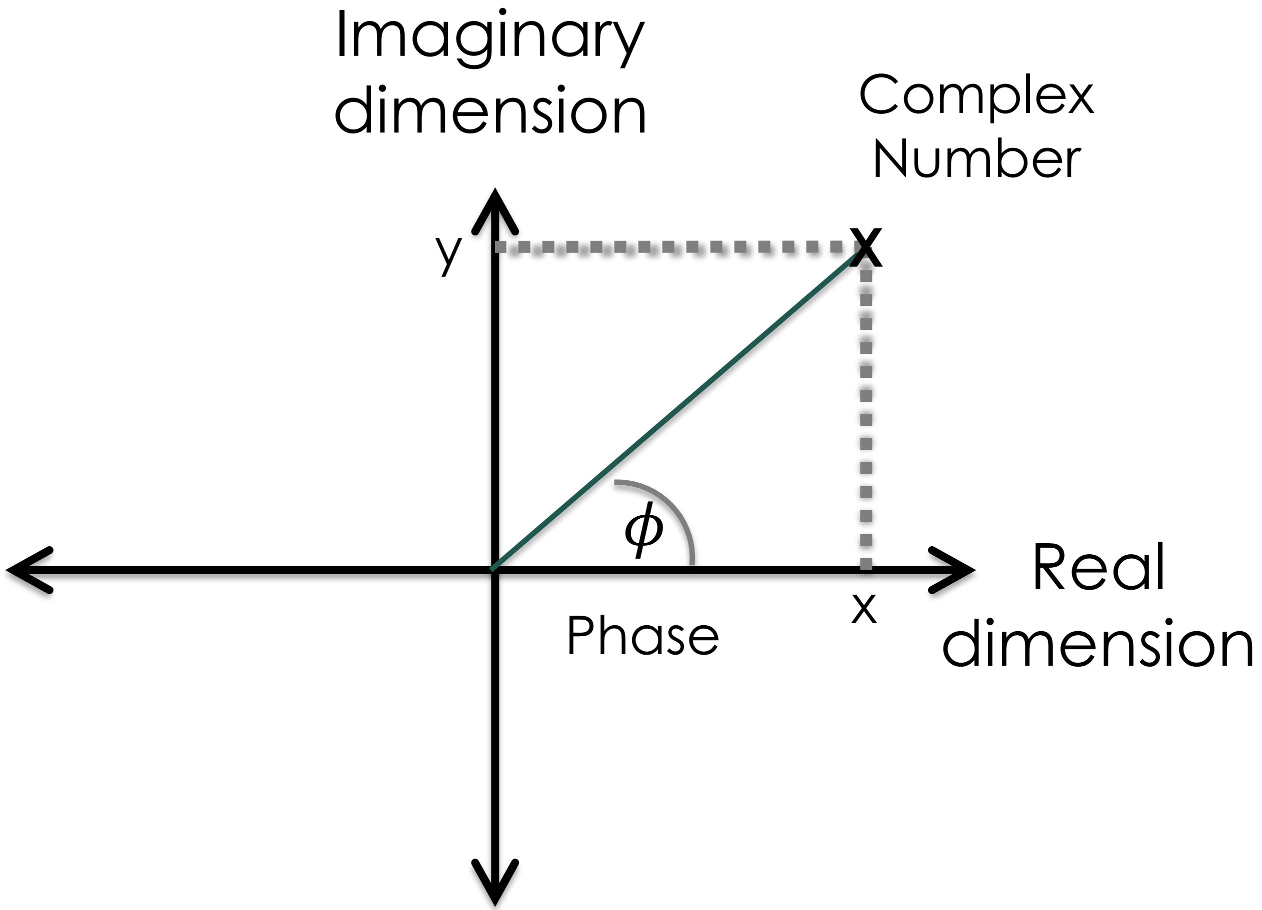
- Two common types of data you will encounter:

  – Phase information is available for **Single Look Complex (SLC)** products
    - E.g. Radarsat-2 fine wide quad pol mode, raw SLC Sentinel-1 data

  – Phase information is lost with **Ground Range Detected (GRD)** products
    - E.g. Sentinel-1 GRD products (GEE)

System Characteristics – Phase and Polarization

- How do we store intensity and phase information?
  - Complex Wave Description



Source: Better Explained

System Characteristics – Phase and Polarization

- Complex Wave Description
  - Have both "real" & "imaginary" parts, expressed as:

$$x + iy$$

  - x & y are real numbers, i is the number whose square = -1 … (i^2 = -1)

Source: Better Explained

System Characteristics – Phase and Polarization

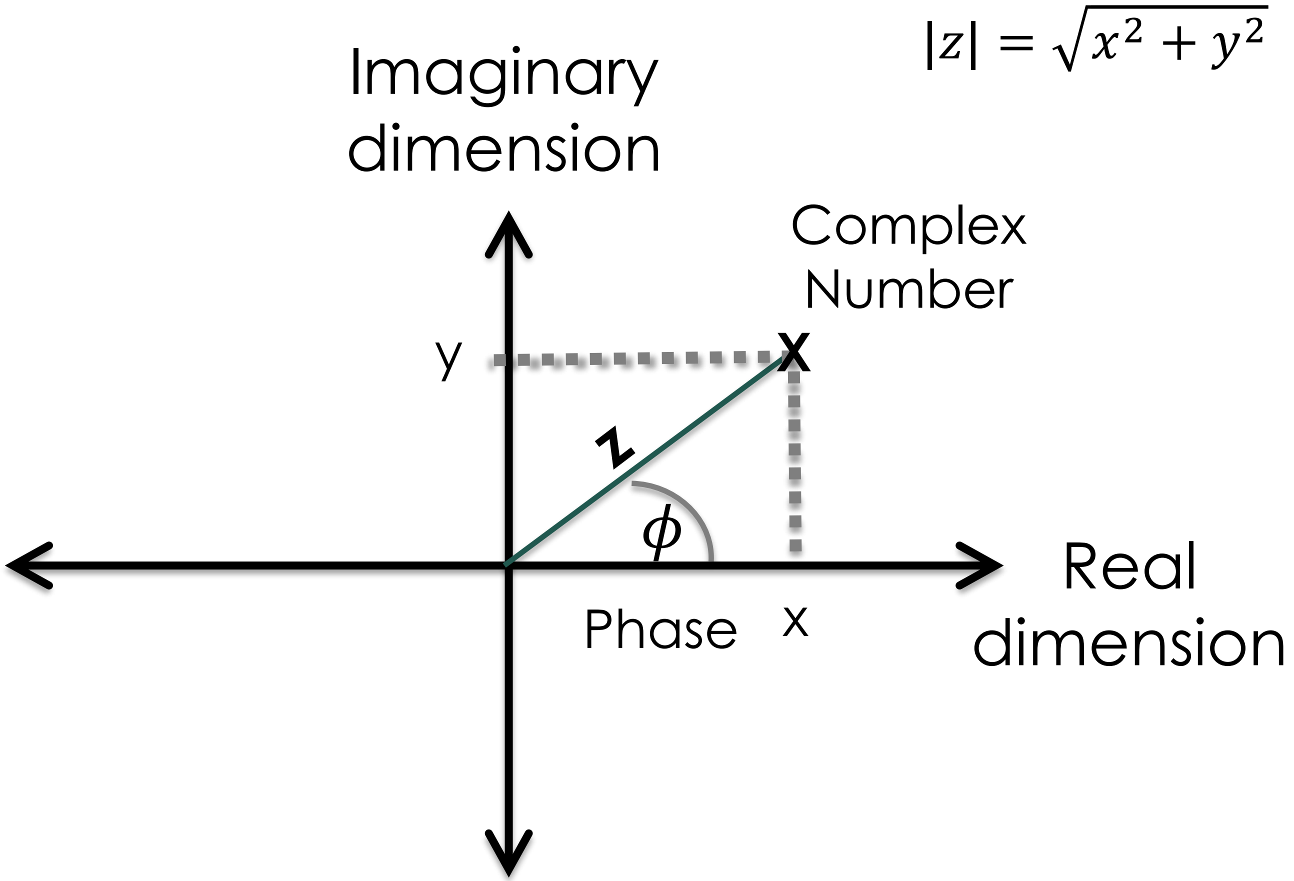
- Complex Wave Description

Fact	Negative Numbers (-x)	Complex Numbers (a+bi)
Strange because…	How can you have less than nothing?	How can you take the square root of less then nothing?
Intuitive meaning	“Opposite”	“Rotation”
Use in coordinates	Go backwards from origin	Rotate around origin

Source: Better Explained

System Characteristics – Phase and Polarization

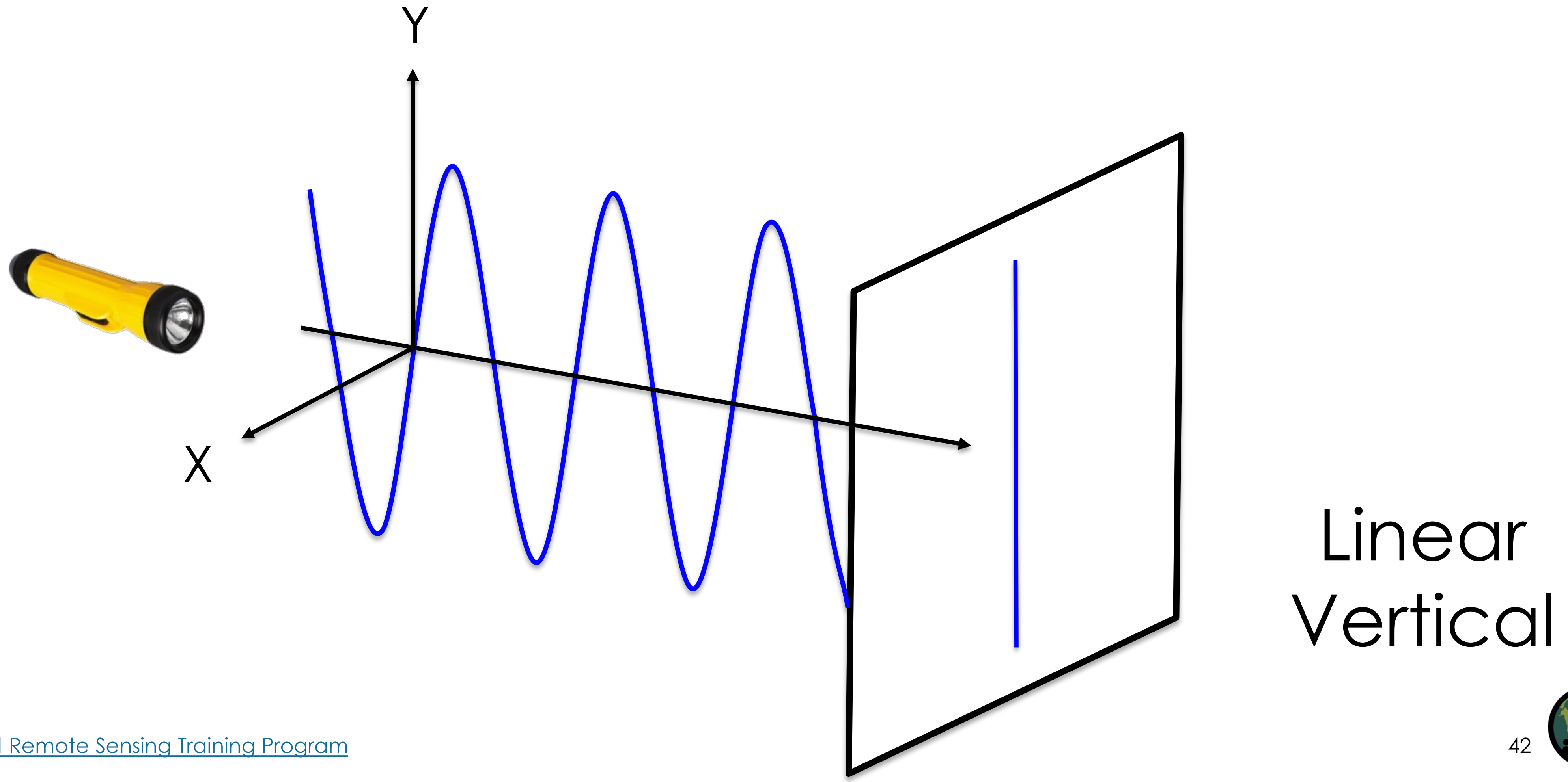
- Complex Wave Description



Source: Better Explained

System Characteristics – Phase and Polarization

- Describes the orientation & shape traced by the wave's electric field
- Consider a shape traced by the tip of a rotating vector, projected onto a plane



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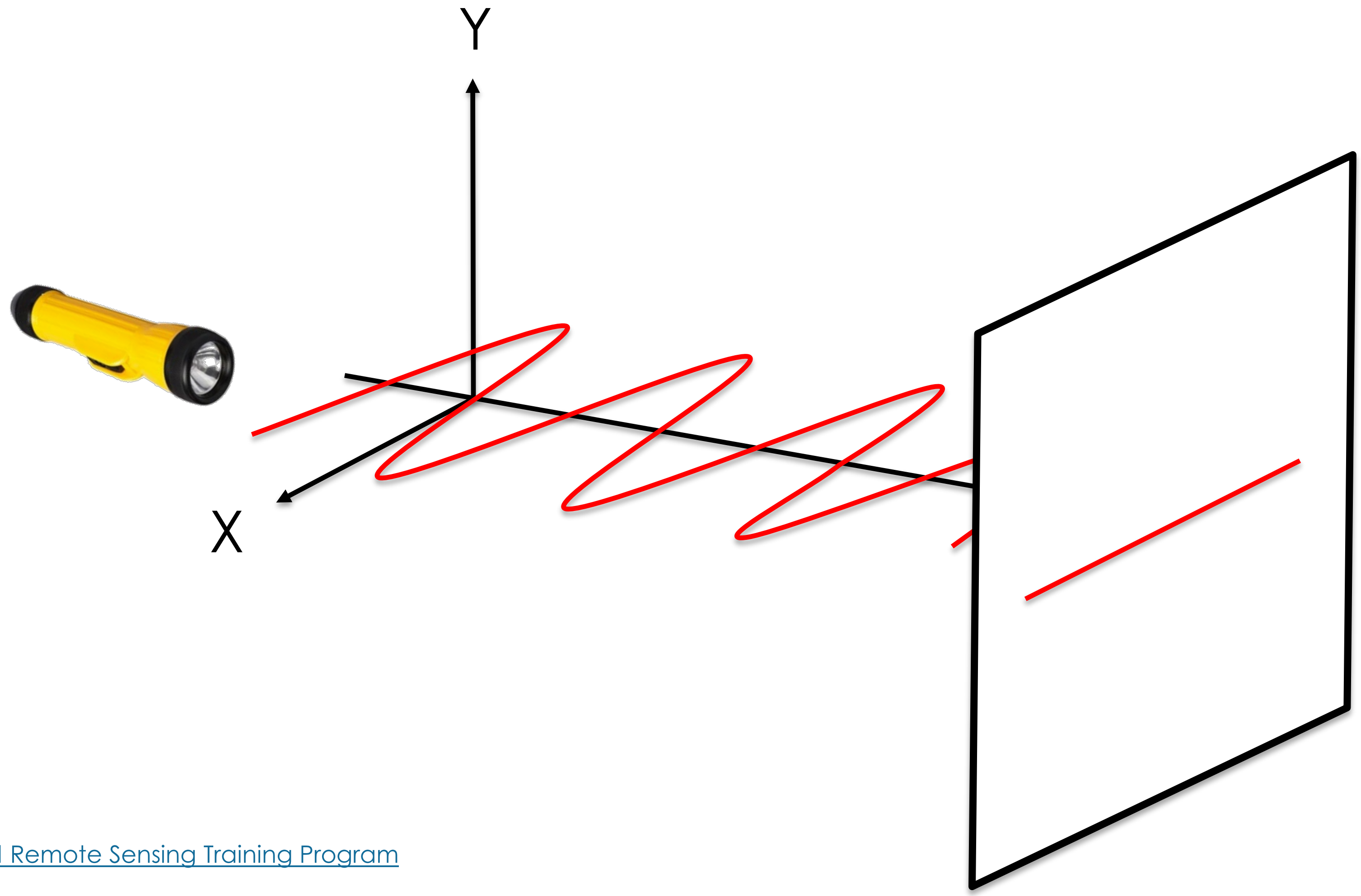
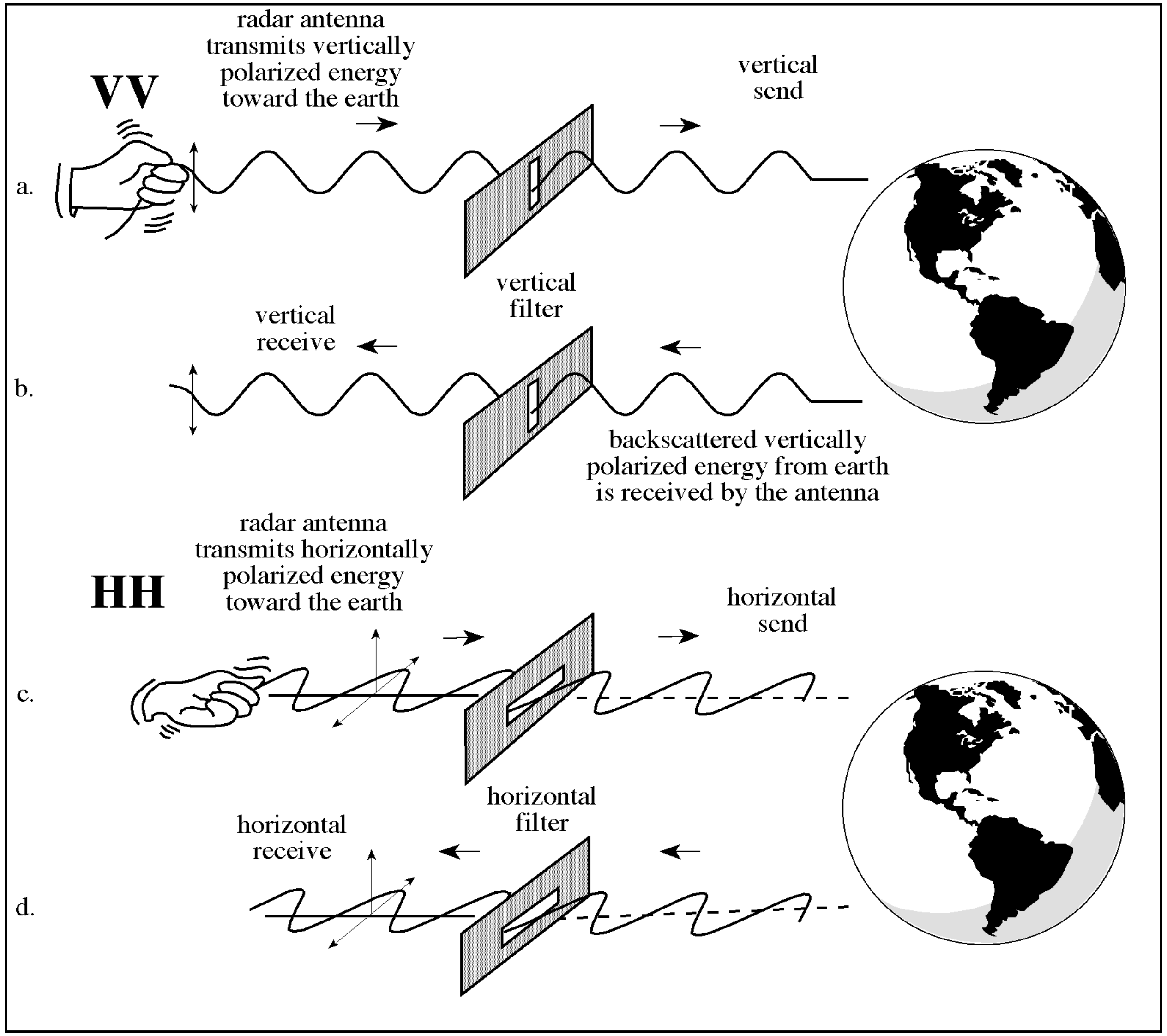


Linear
Vertical

System Characteristics – Phase and Polarization

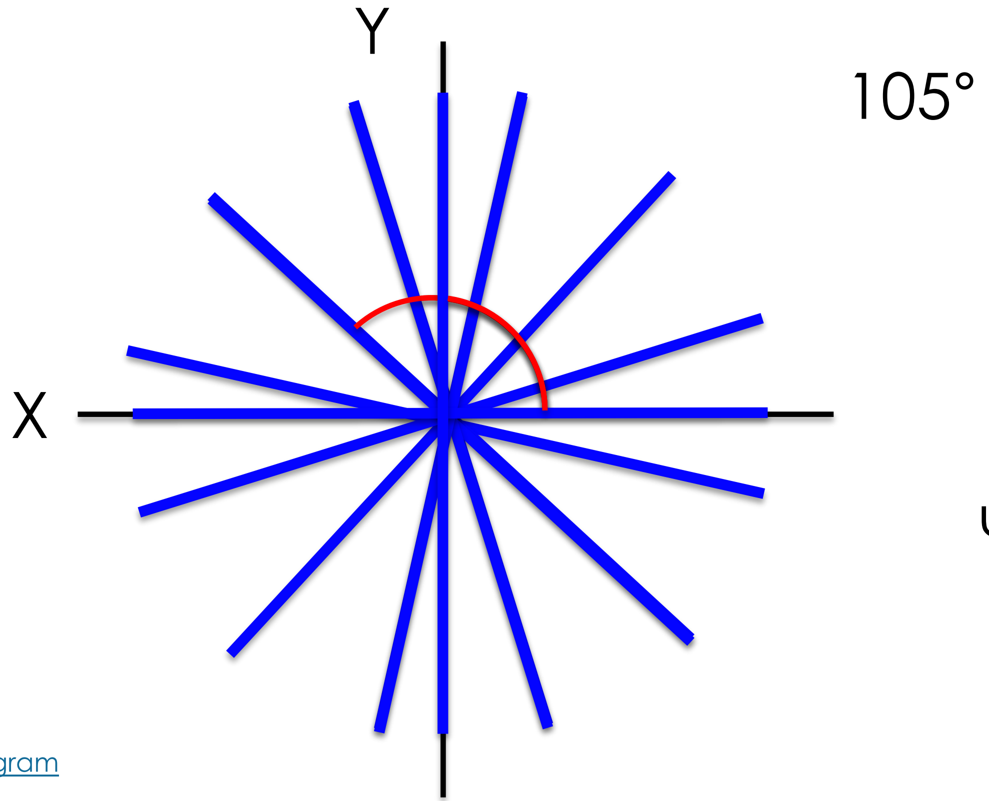


Source: https://courses.eas.ualberta.ca/eas451/radar%20section.pdf, https://www.physicsclassroom.com/class/light/Lesson-1/Polarization

System Characteristics – Phase and Polarization

- Orientation Angle
  - Convention: measure from positive horizontal x-axis in anti-clockwise direction
  - Range from 0–180°, represented using ψ (Psi /ˈsaɪ/)

Two very important orientation angles to remember!

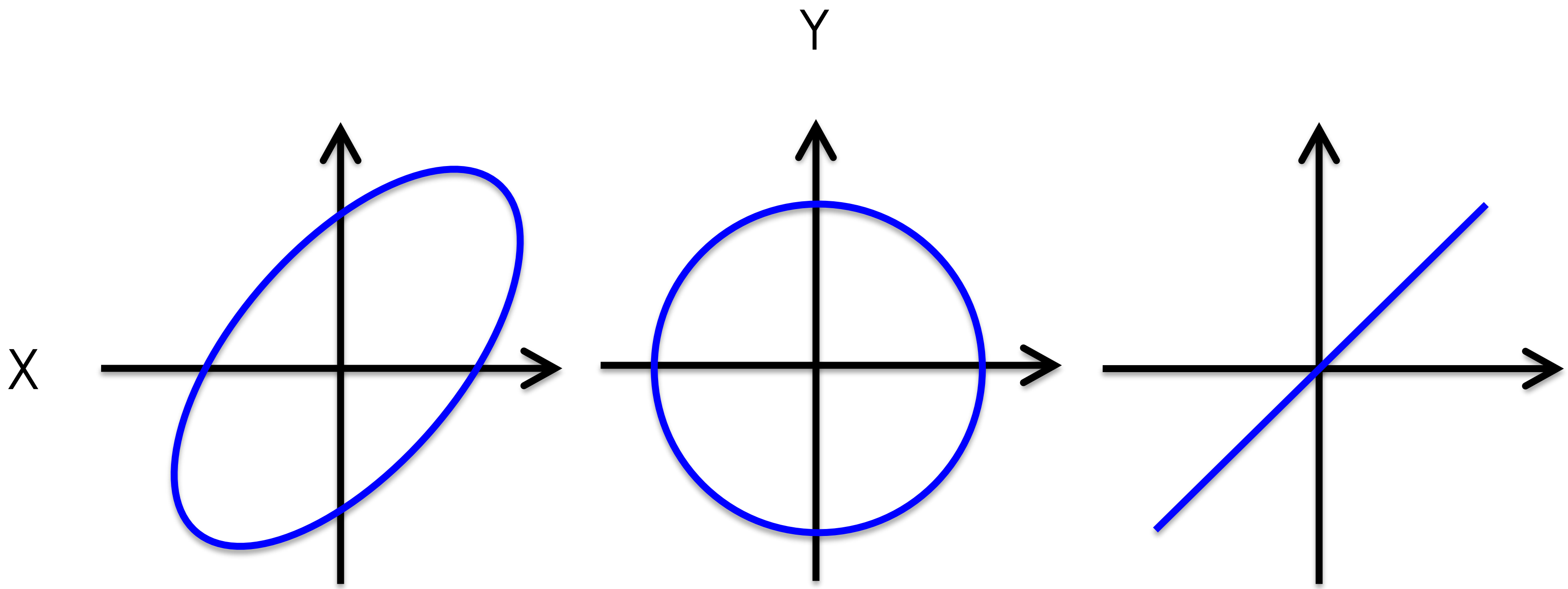


Ψ for linear horizontal = 0°

Ψ for linear vertical = 90°

System Characteristics – Phase and Polarization

- Three canonical states of polarization

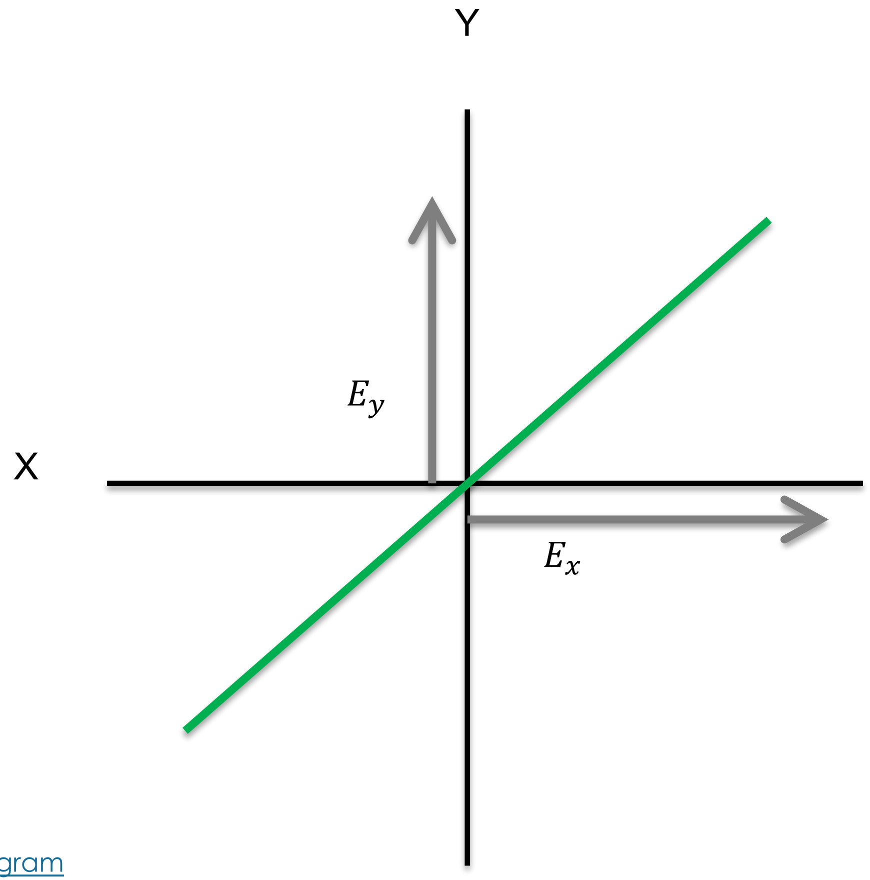


Elliptical Circular Linear

Source: recreated after https://eo-college.org/

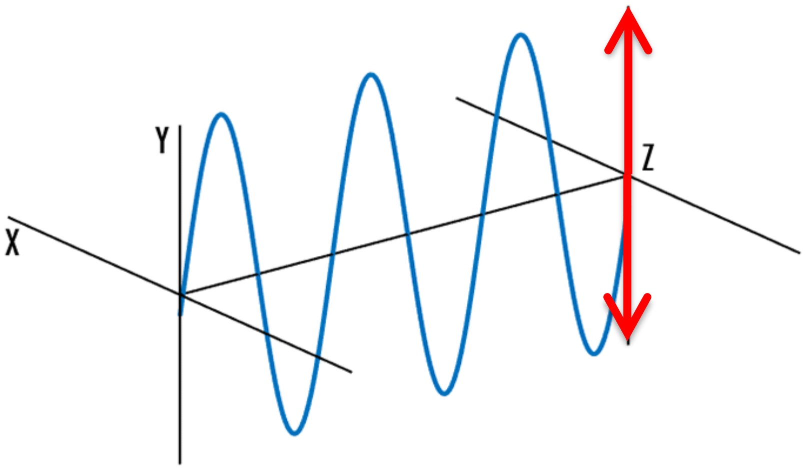
System Characteristics – Phase and Polarization

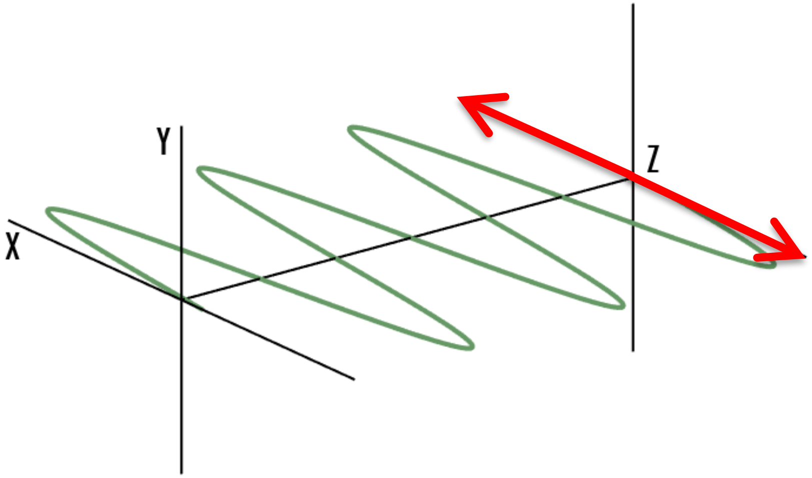
- Any polarization state can be described by two linear, orthogonal waves! (as long as the phase between them is also measured!)
- Vertical (E_y) & horizontal (E_x)



System Characteristics – Phase and Polarization

- Circular polarization
  - Superposition of two linear, orthogonal waves
  - 90°out of phase
  - Equal amplitude





Source: Edmund Optics

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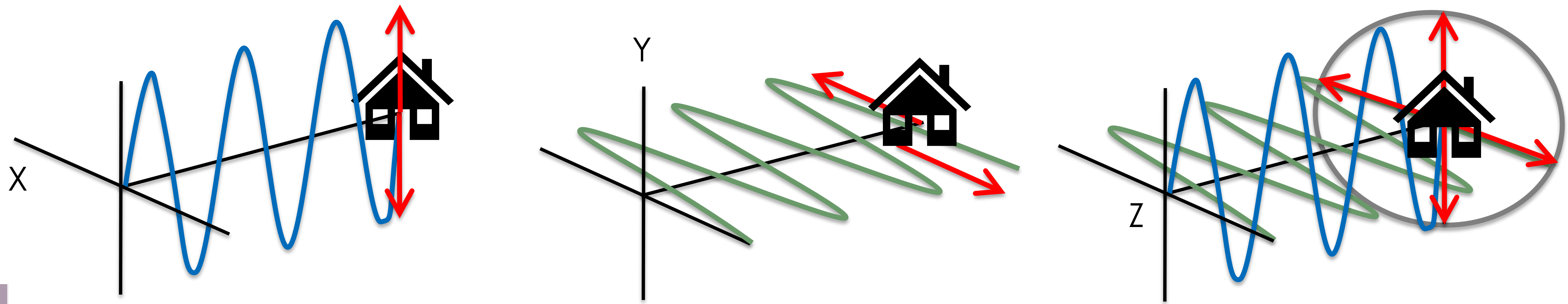

Source: Edmund Optics

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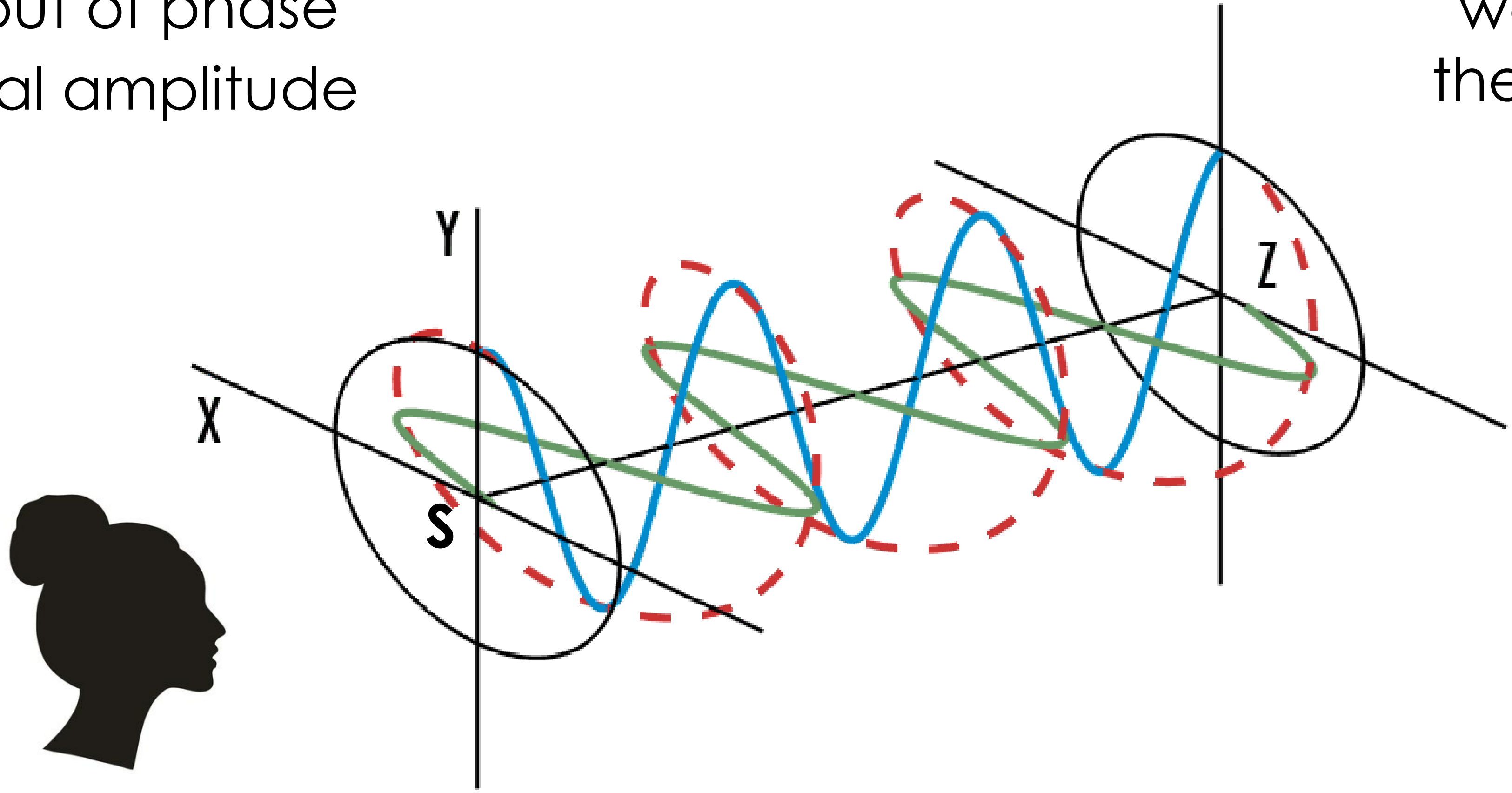
  - Superposition of two linear, orthogonal waves
  - 90°out of phase
  - Equal amplitude

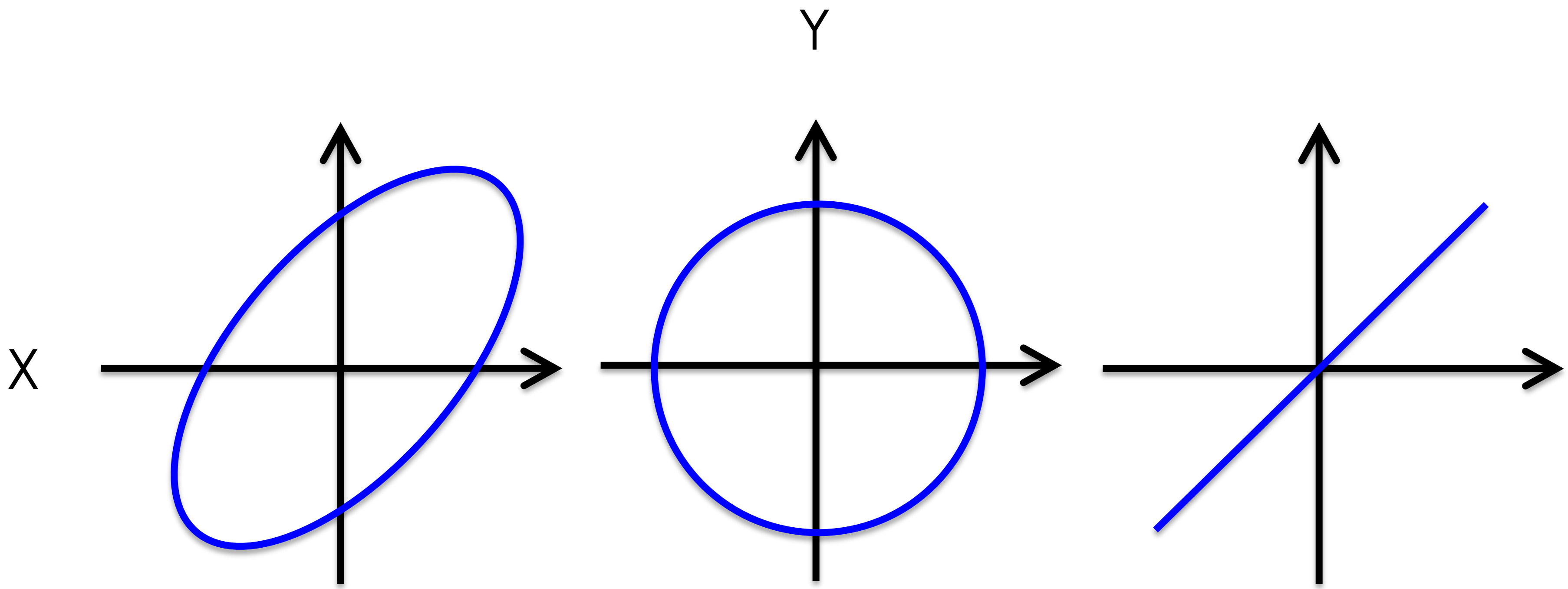


Viewed from the wave source (S): the electric vector is spinning clockwise

Source: Edmund Optics; /ca/search?k=%22face+silhouette%22

System Characteristics – Phase and Polarization

- Three canonical states of polarization



Elliptical Circular Linear

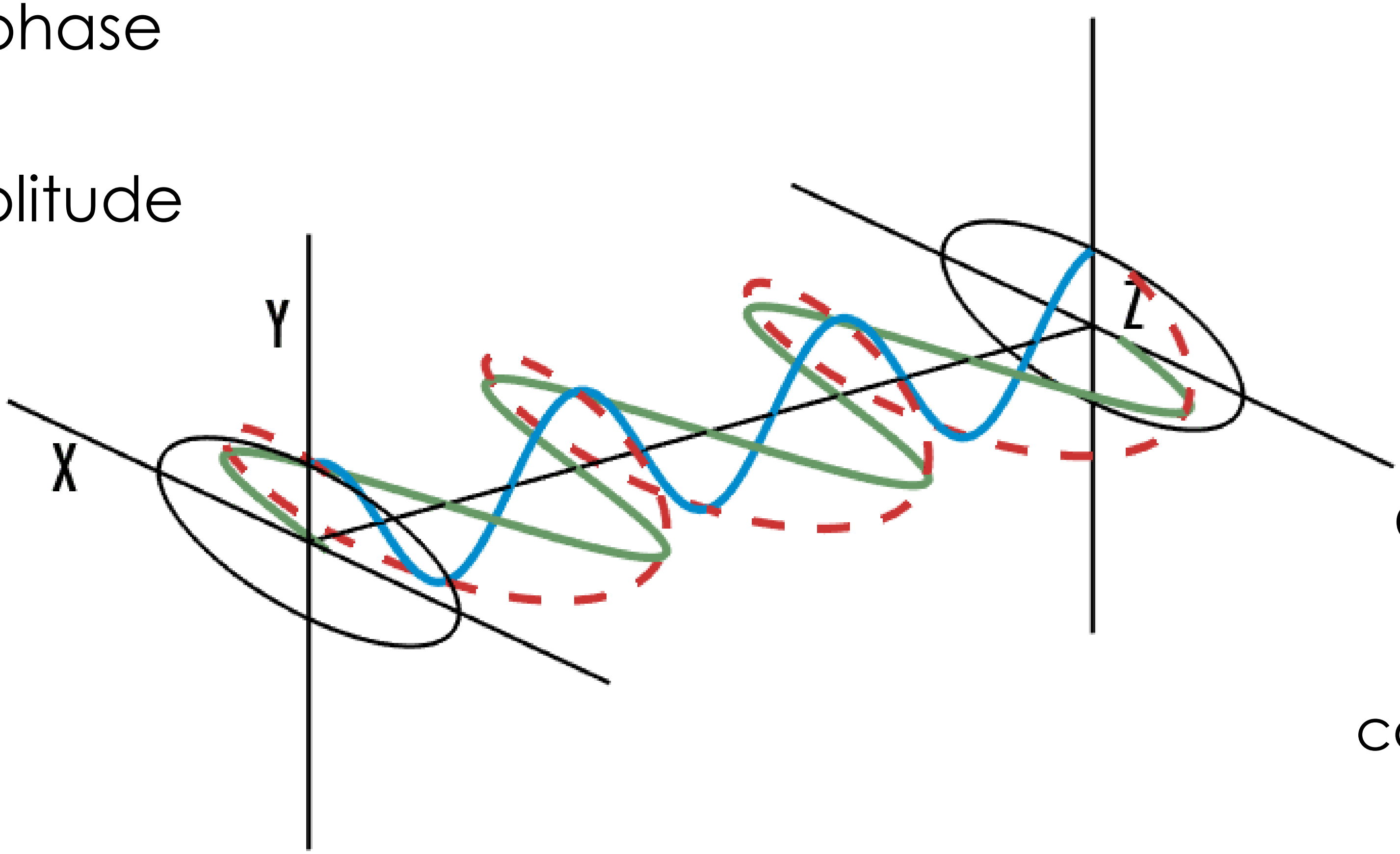
Source: recreated after https://eo-college.org/

System Characteristics – Phase and Polarization

- Elliptical polarization
  - Superposition of two linear, orthogonal waves
  - ~~90° out of~~ phase

and or…

  - ~~Equal am~~plitude

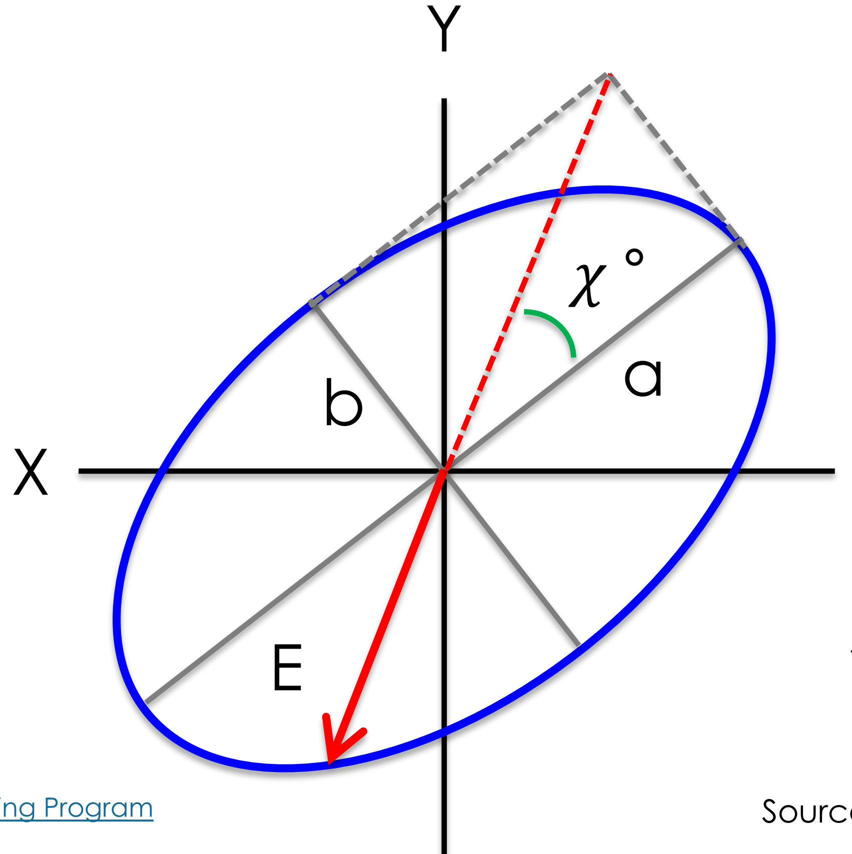


Can describe any wave using just 2 orthogonal components (usually H and V)

Source: Edmund Optics

System Characteristics – Phase and Polarization

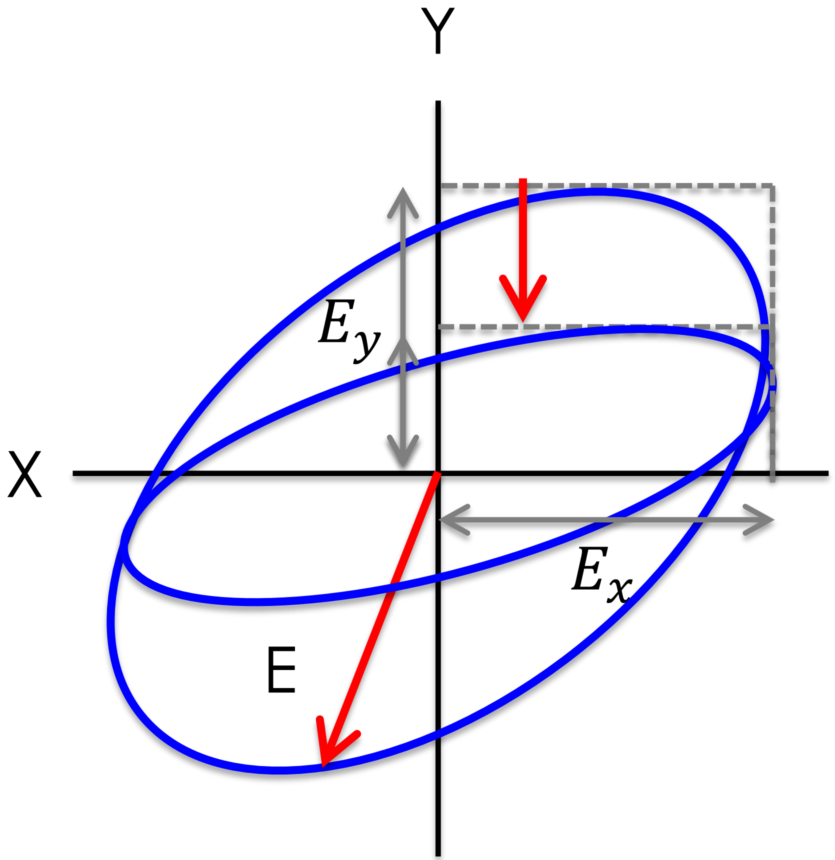
- Ellipticity/eccentricity
  - Degree of non-circularity
  - A function of the semi-major and semi-minor axes, a and b
  - Range from -45° and +45°, represented using χ Chi /ˈkaɪ/



χ = 34°

System Characteristics – Phase and Polarization

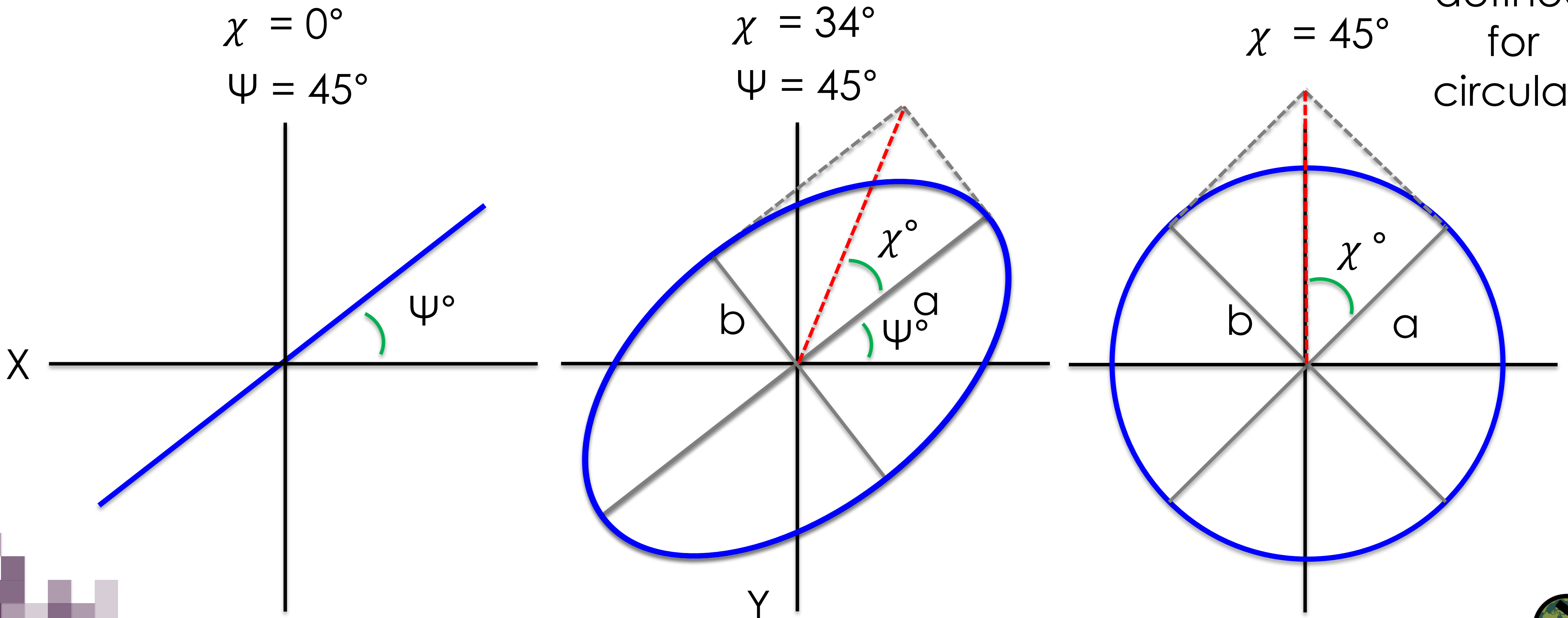
- Don't forget there is a vertical (E_y) and horizontal (E_x) component
- Wave tends toward horizontal as E_y component tends to zero & vice versa



Same system can measure circular, linear, and or elliptical!

System Characteristics – Phase and Polarization

- χ – ellipticity (extent to which the shape is oval)
- Ψ – orientation angle (measured counter clockwise from positive X)

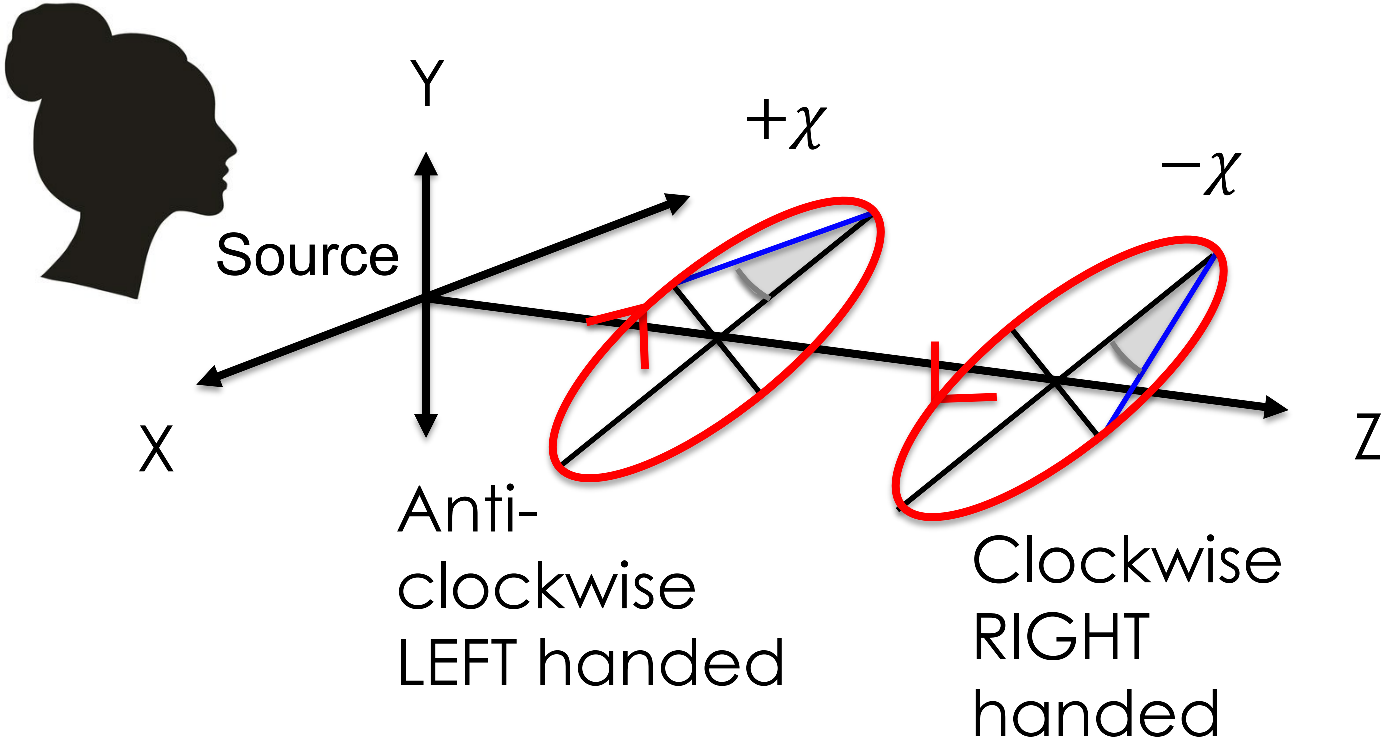


Ψ not defined for circular!

Source recreated after: Government of Canada

System Characteristics – Phase and Polarization

- Elliptically & circularly polarized waves have a direction of rotation
- “Handedness” tells us if the vector tip is rotating clockwise or anti-clockwise
- But imagine viewing it from the other direction?

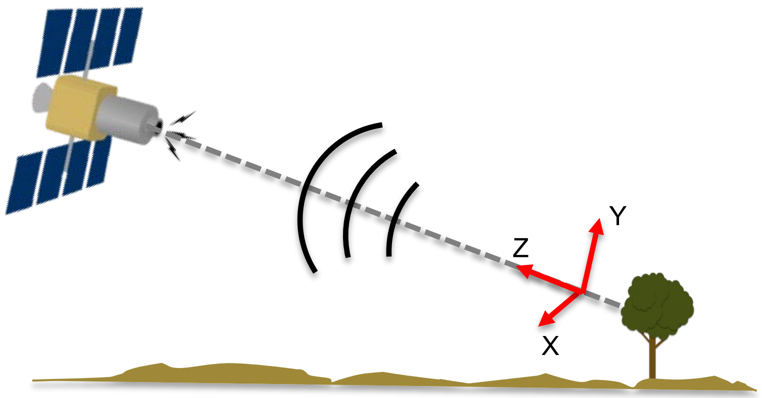


Source: Eric POTTIER; https://stock.adobe.com/ca/search?k=%22face+silhouette%22

System Characteristics – Phase and Polarization

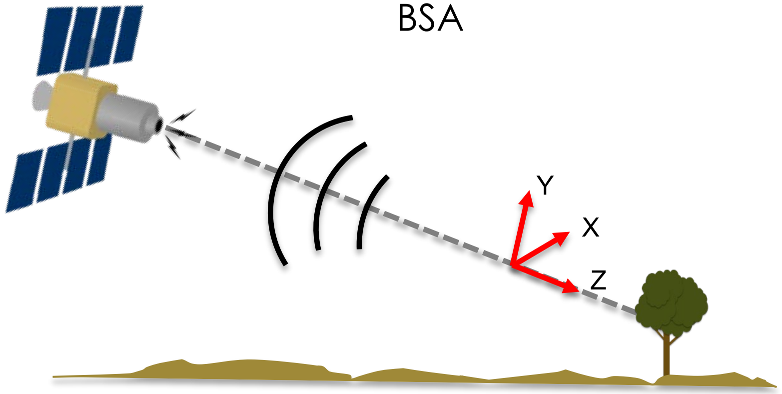
- Coordinate system defined by 3 axes (X, Y and Z)
- Two conventions

FSA



1) Forward Scatter Alignment (FSA)
   - Positive z always points in the direction of travel

BSA

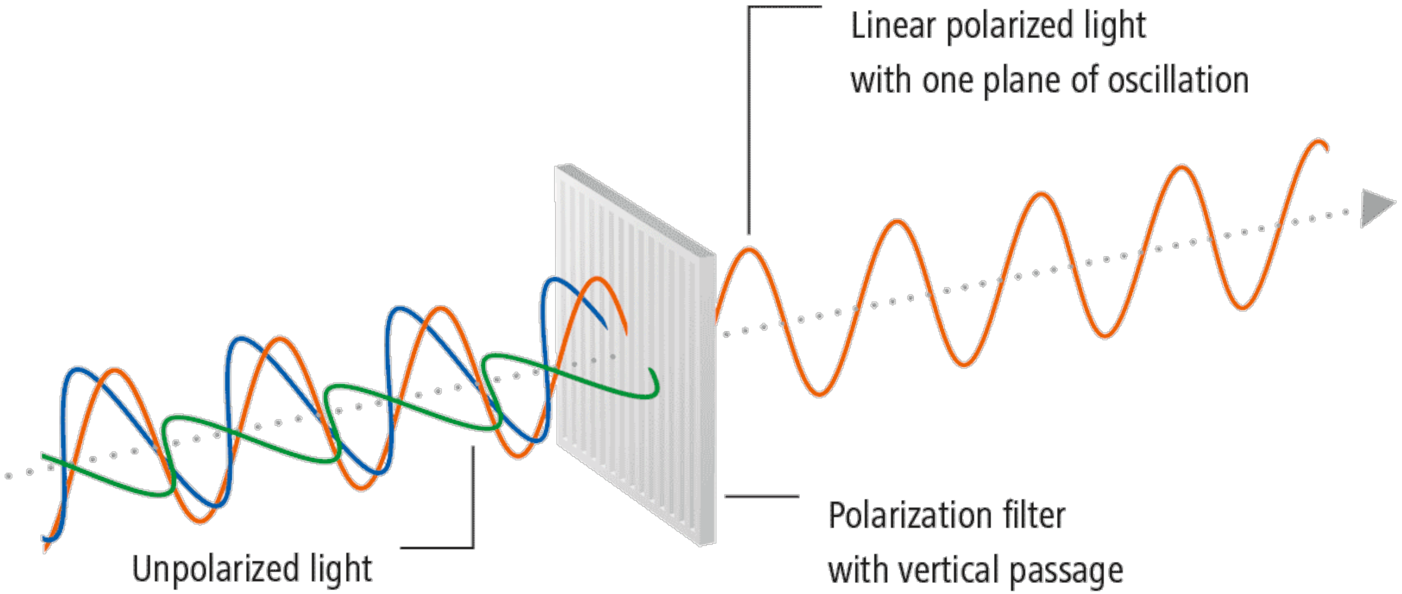


2) Back Scatter Alignment (BSA)
   - Positive z always points toward the target
   - *More common

Image recreated after: Gabriel Vasile, Nikola Besic. Fundamental of Remote Sensing: SAR polarimetry. GIPSA-lab.

System Characteristics – Phase and Polarization

– Completely unpolarized – oscillates randomly; no clearly defined polarization
– Completely polarized –oscillates in plane of polarization at all times
– Partially polarized – combination; superposition of many different polarizations; one or more dominate



Source: Baumer

System Characteristics – Phase and Polarization

- Transmitted wave completely polarized
- Scattered wave depends on:

  1) Coherent targets
     – Backscatter completely polarized (e.g., buildings)

  2) Incoherent targets
     – Backscatter partially or completely unpolarized (e.g., trees)
     –Depolarization from multiple bounces within the medium of randomly oriented structures

- Degree of polarization = polarized power/total power

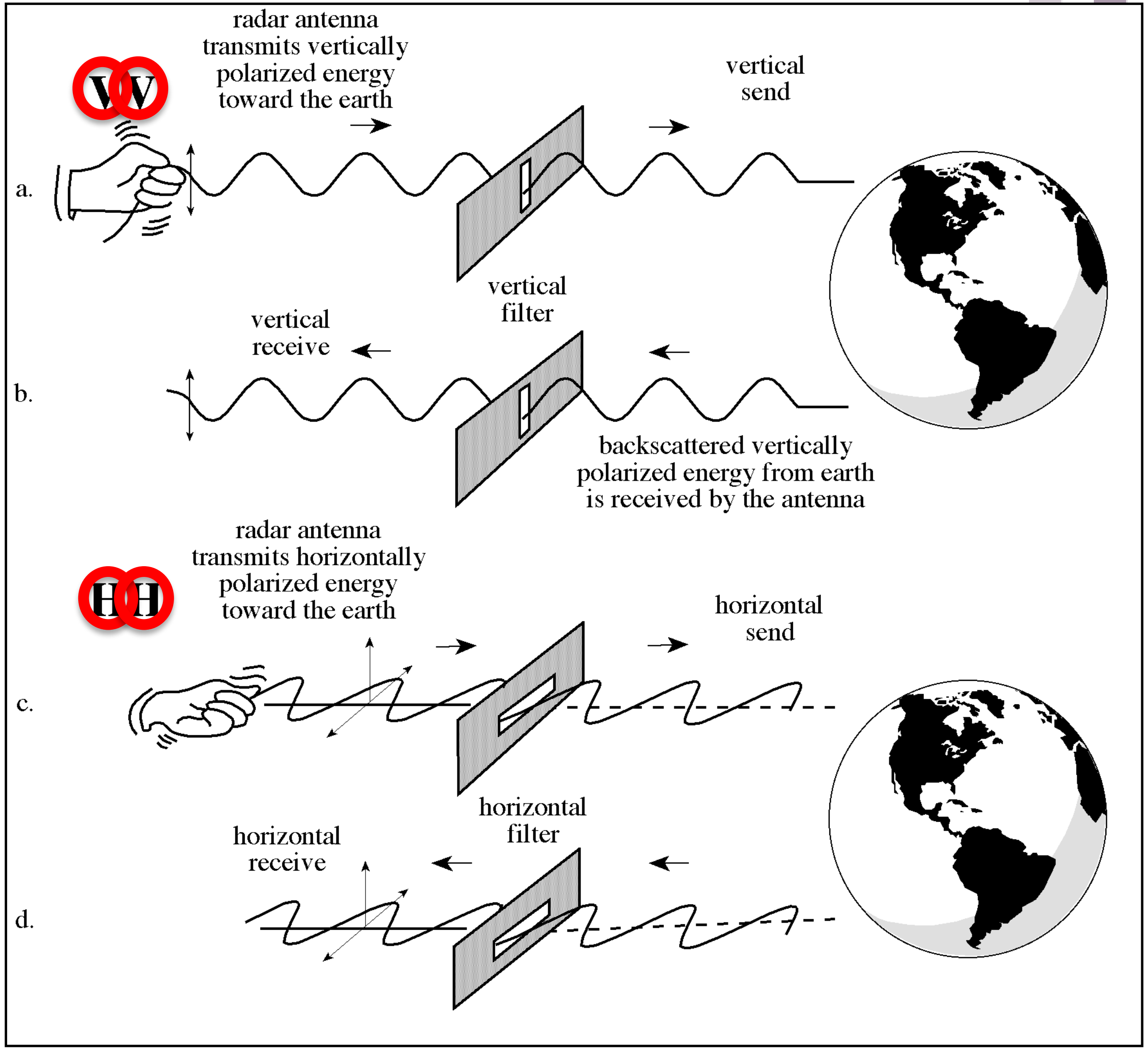
Source: Baumer

Common SAR Imaging Modes

- Different polarization configurations; rep. by two letters

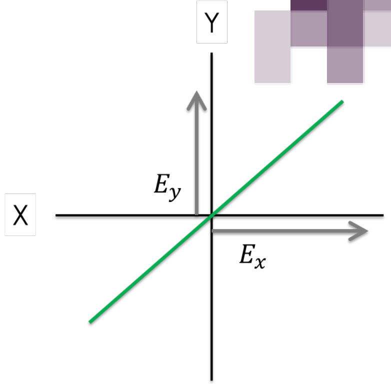
- First: transmit polarization
- Second: receive polarization

- Typically H: linear horizontal & V: linear vertical

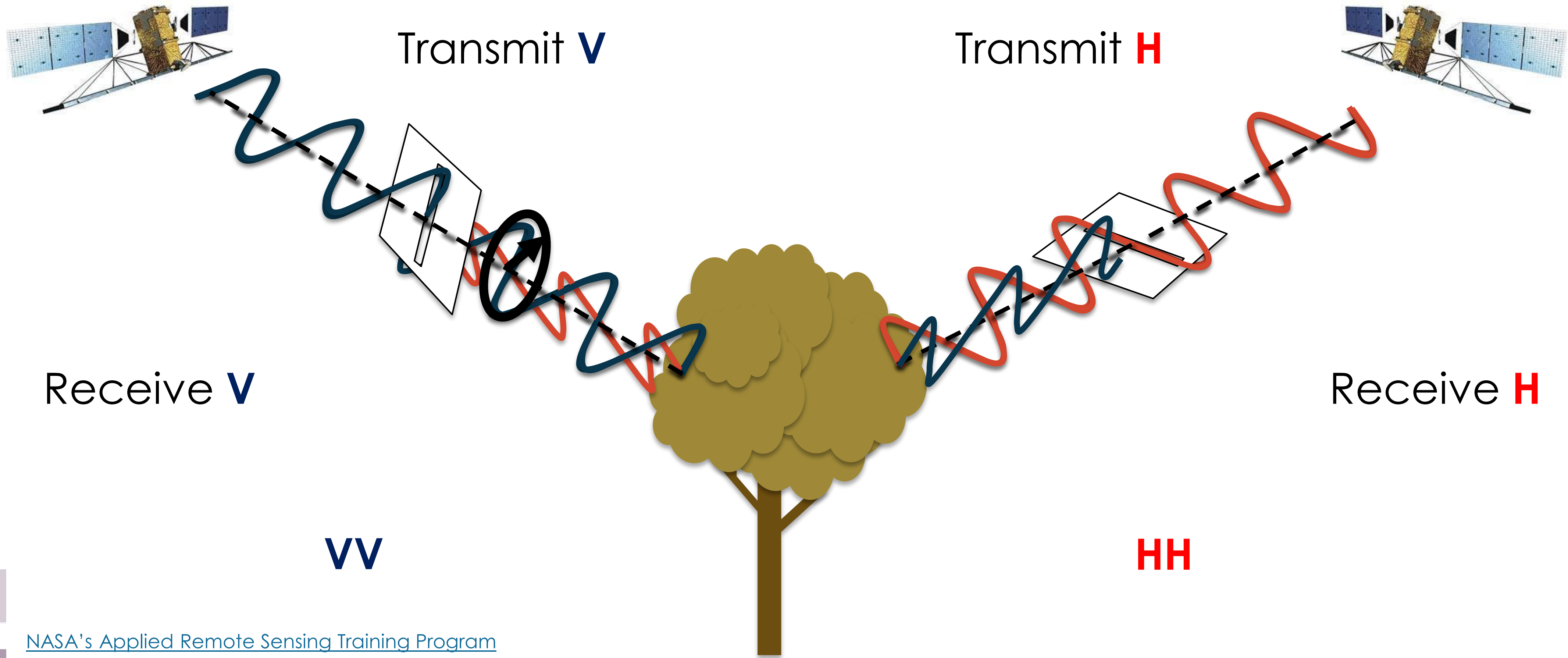


Source: https://courses.eas.ualberta.ca/eas451/radar%20section.pdf, https://www.physicsclassroom.com/class/light/Lesson-1/Polarization

Common SAR Imaging Modes

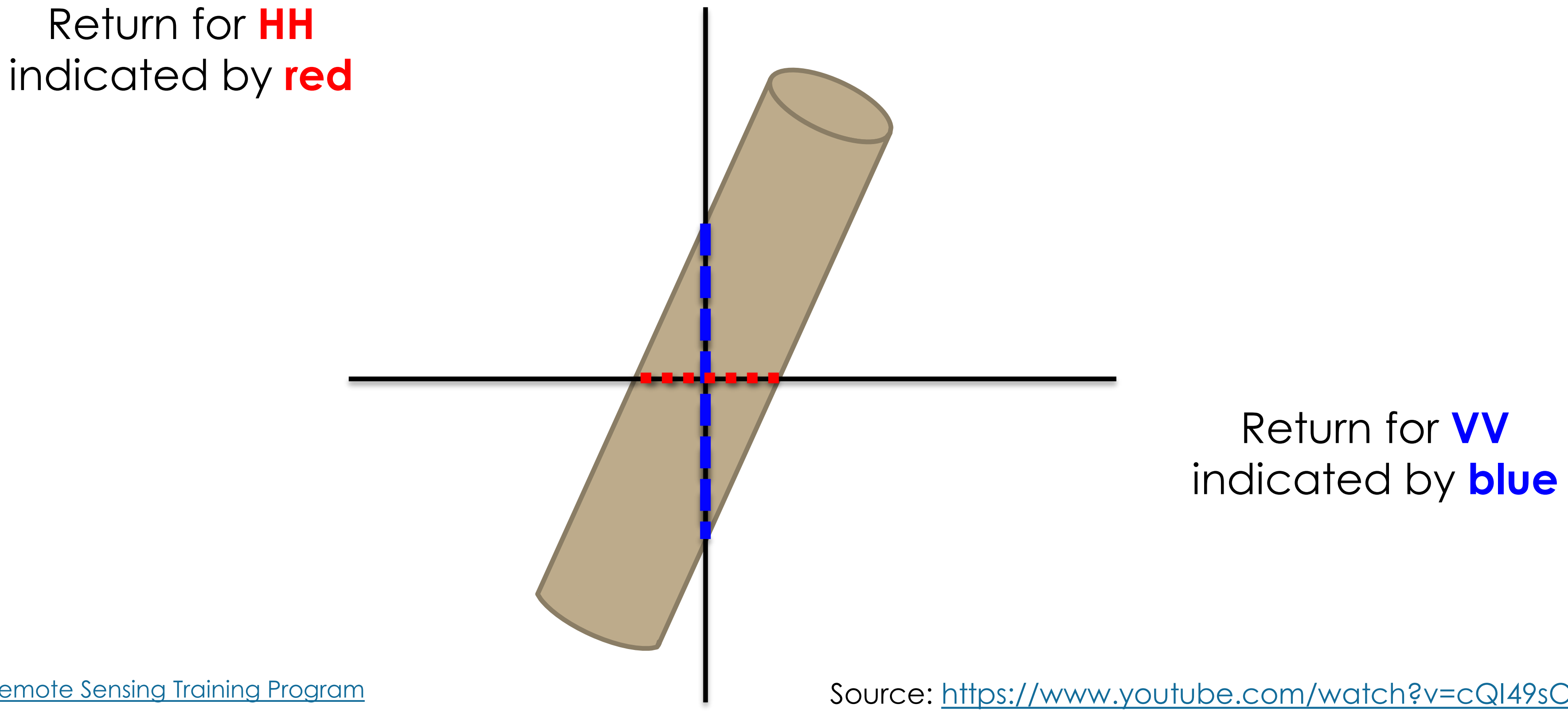


- Wave arrives polarized (e.g., **H** or **V**)
- Only record a portion of what is scattered back toward the sensor



Common SAR Imaging Modes

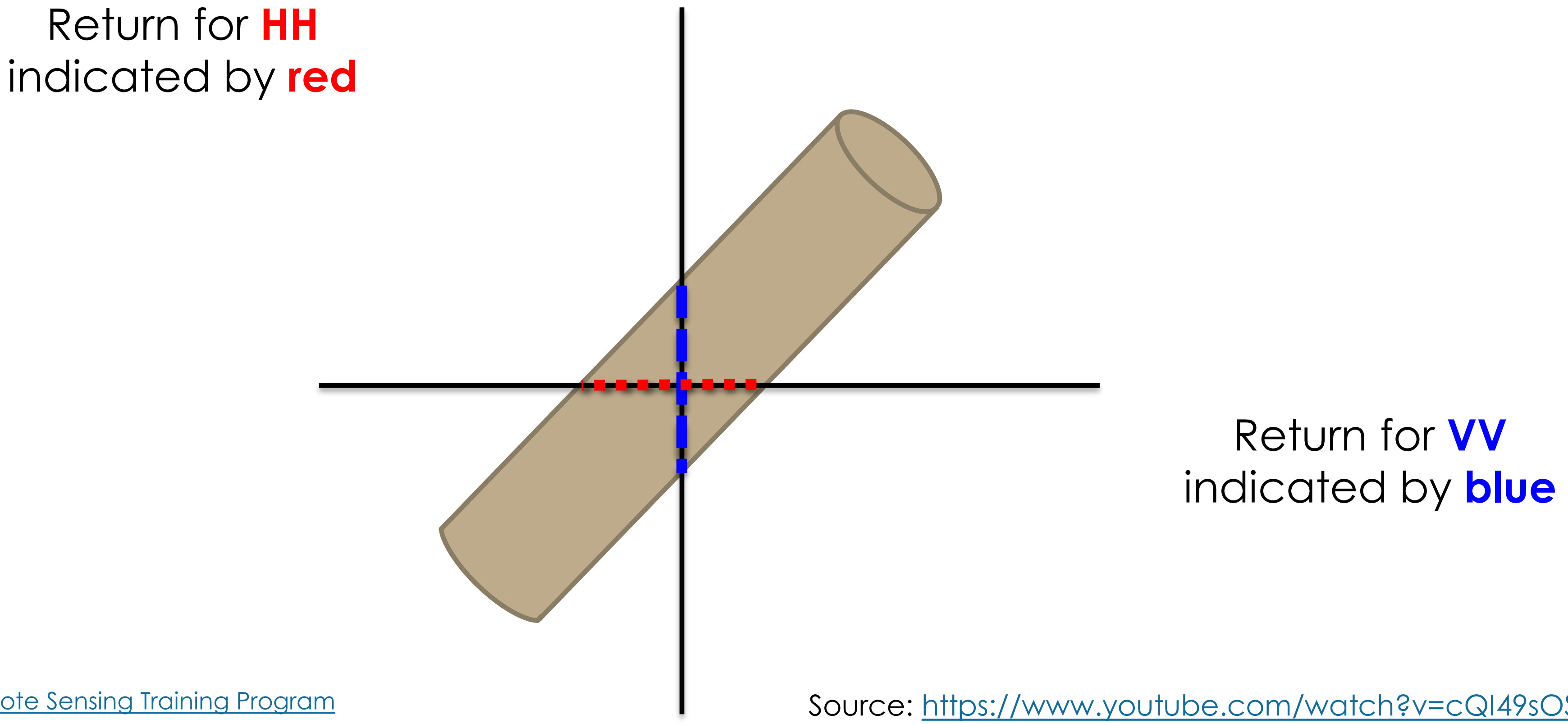
- Returns
  - Proportional to target cross section; amount of energy hitting the target
  - **Orientation** and **polarization** we transmit determines amount of return



Source: https://www.youtube.com/watch?v=cQI49sOSc2g

Common SAR Imaging Modes

- Returns
  - Proportional to target cross section; amount of energy hitting the target
  - **Orientation** and **polarization** we transmit determines amount of return

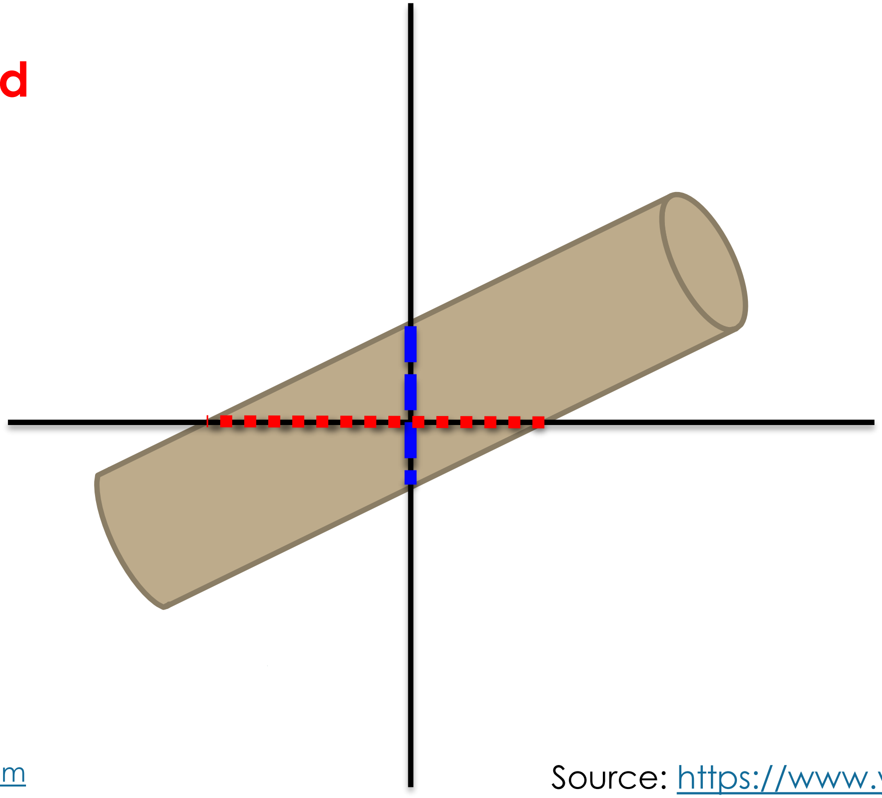


Source: https://www.youtube.com/watch?v=cQI49sOSc2g

Common SAR Imaging Modes

- Returns
  - Proportional to target cross section; amount of energy hitting the target
  - **Orientation** and **polarization** we transmit determines amount of return

Return for **HH**
indicated by **red**



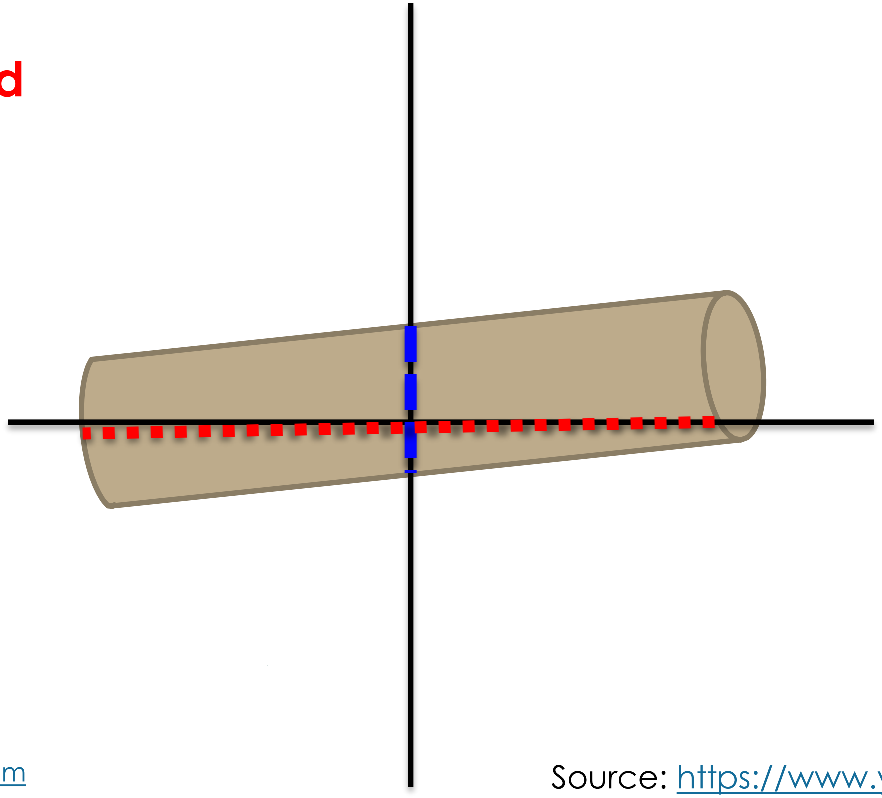
Return for **VV**
indicated by **blue**

Source: https://www.youtube.com/watch?v=cQI49sOSc2g

Common SAR Imaging Modes

- Returns
  - Proportional to target cross section; amount of energy hitting the target
  - **Orientation** and **polarization** we transmit determines amount of return

Return for **HH** indicated by **red**

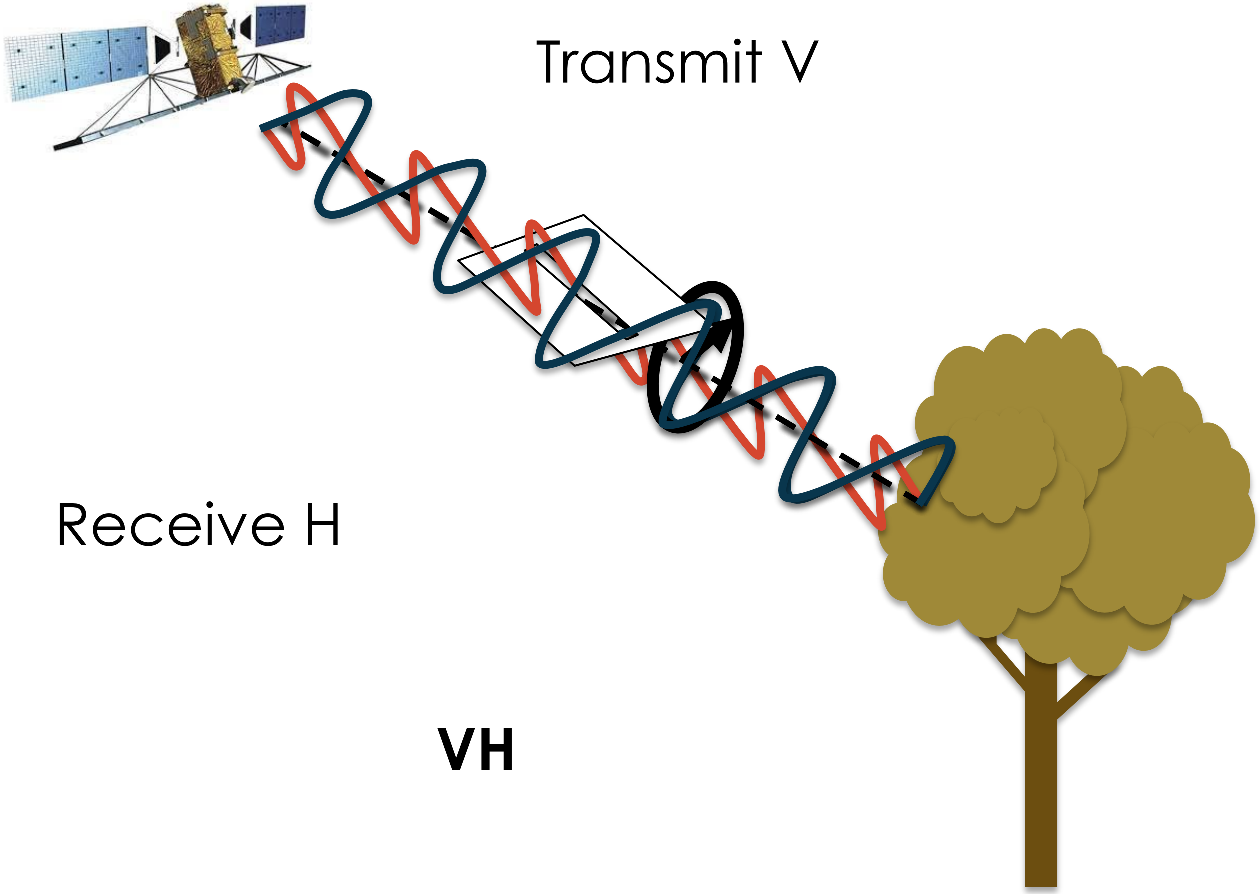


Return for **VV** indicated by **blue**

Source: https://www.youtube.com/watch?v=cQI49sOSc2g

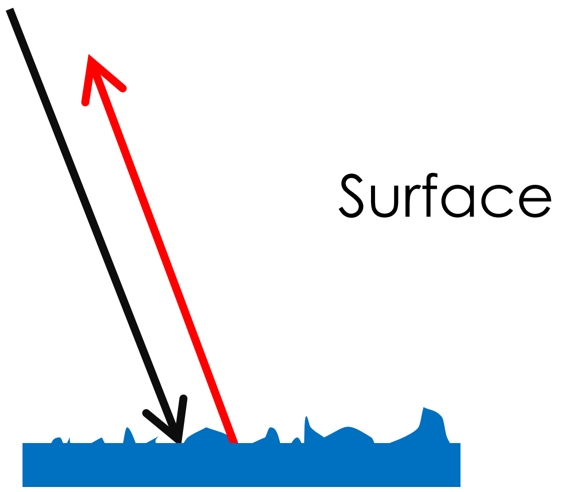
Common SAR Imaging Modes

- Co-pol: HH or VV
- Cross-pol: HV or **VH**

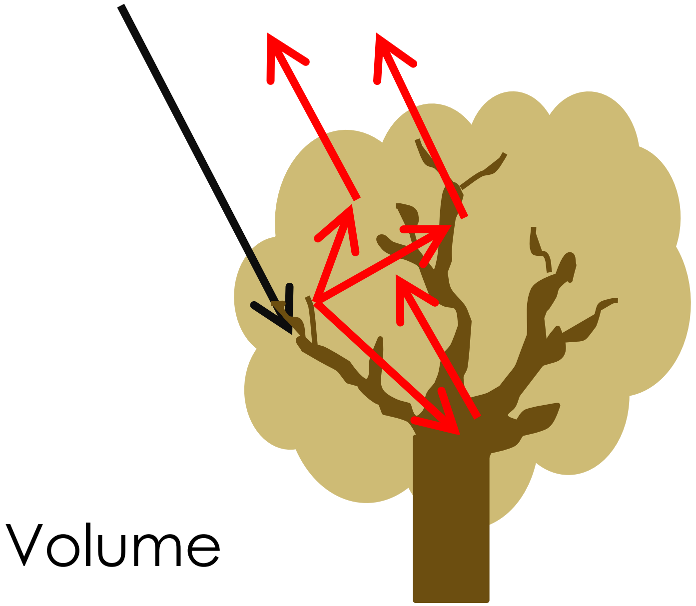


Common SAR Imaging Modes

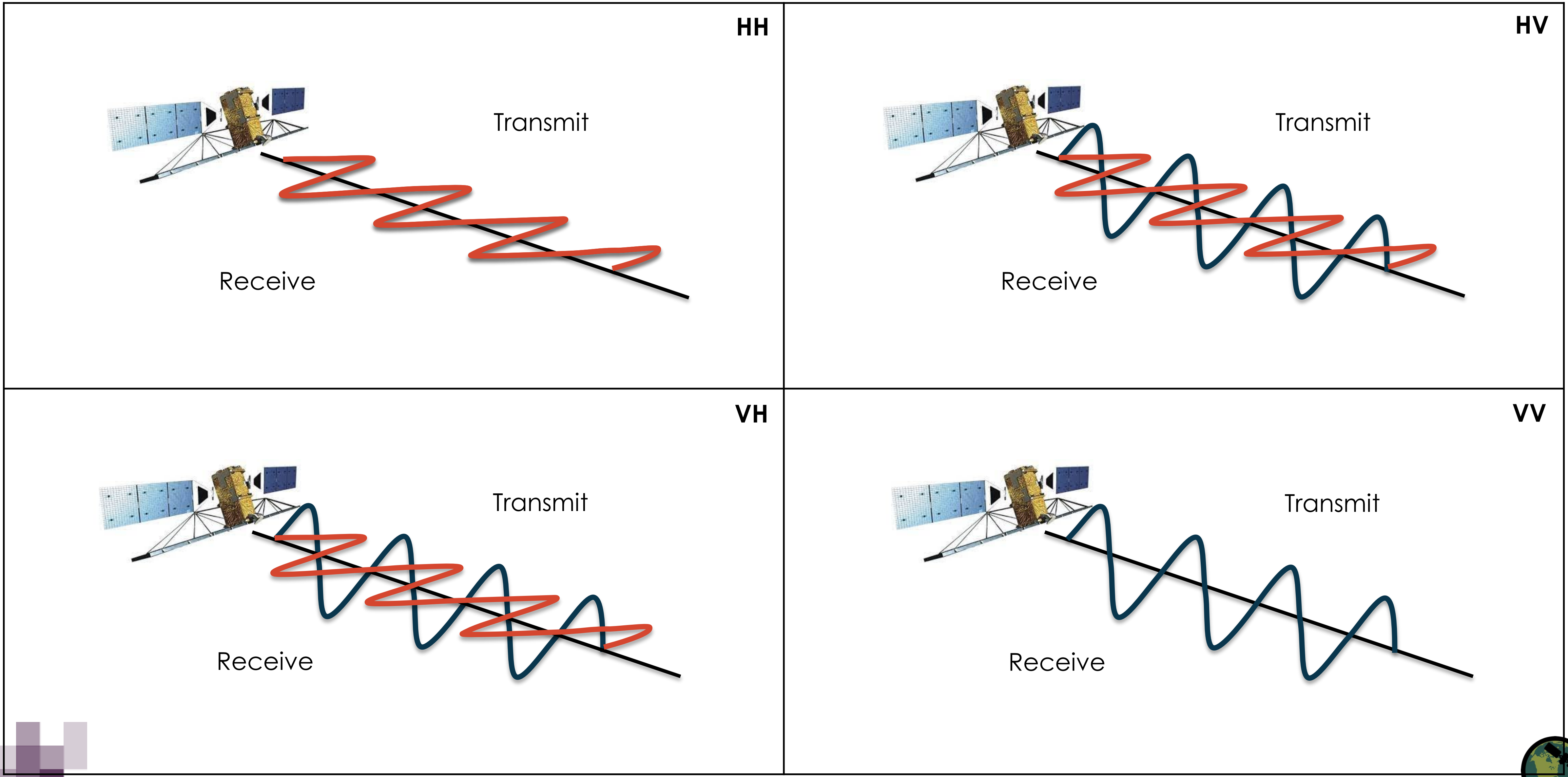
- Surface scattering: returns are mostly in the same polarization as the transmitted pulse



- Volume scattering: multiple bounces within the medium of randomly oriented structures depolarizes the signal

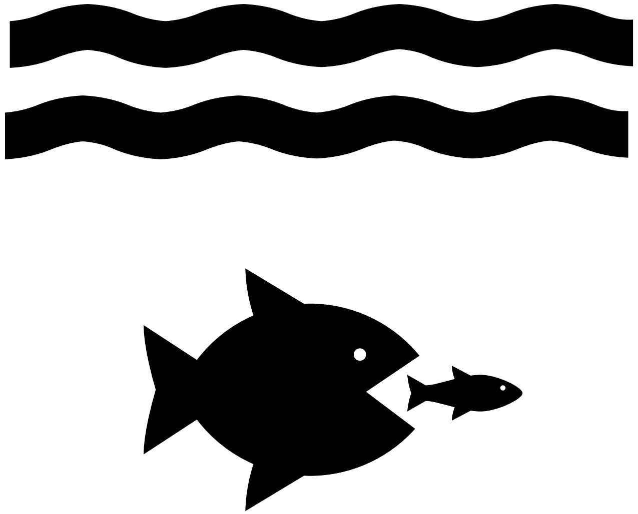


Common SAR Imaging Modes

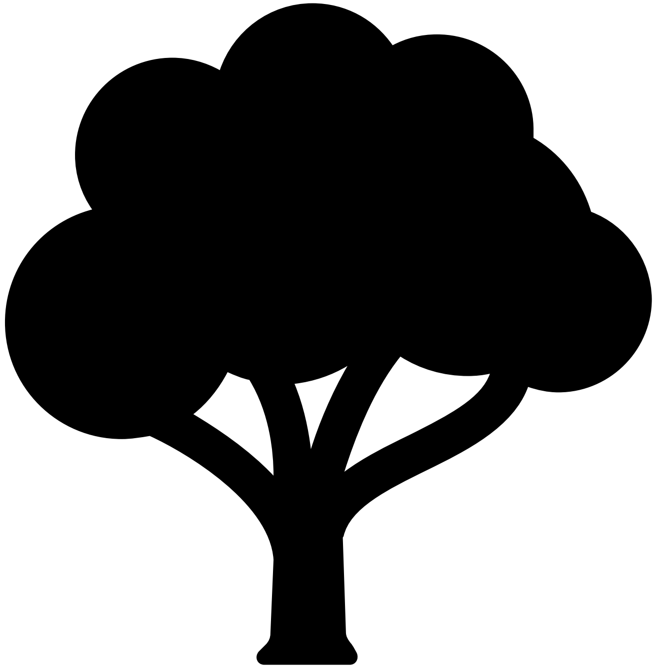


Common SAR Imaging Modes

Low



Medium



Bright

Source: https://www.youtube.com/watch?v=cQI49sOSc2g

Common SAR Imaging Modes

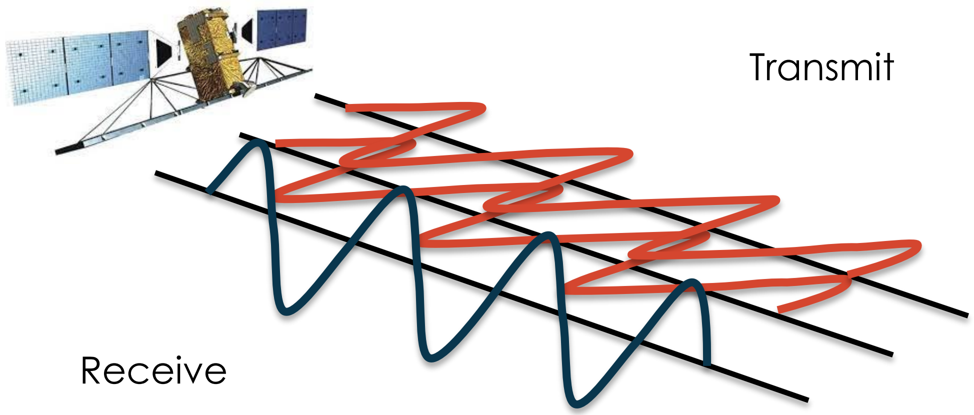
Processing/Storage
Power Requirements
Information Content

Low → High

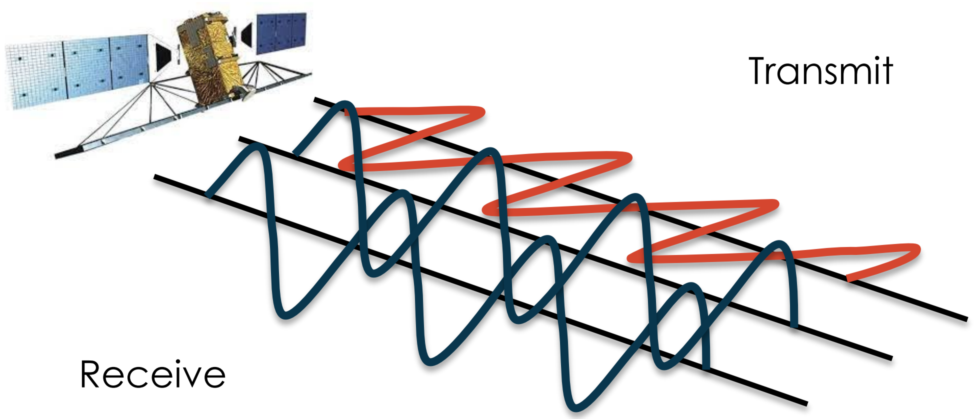
single	- HH - VV - HV - VH
dual (with and without phase)	- HH and HV - VV and VH - HH and VV

Common SAR Imaging Modes

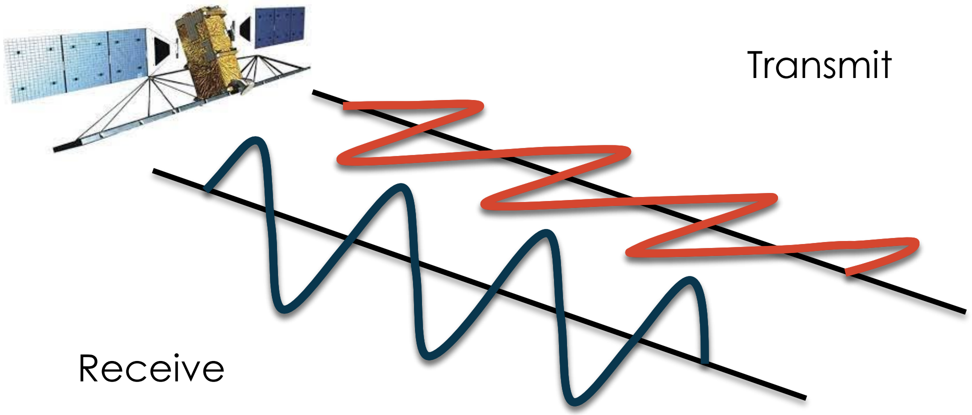
HH & HV



VV & VH



HH & VV

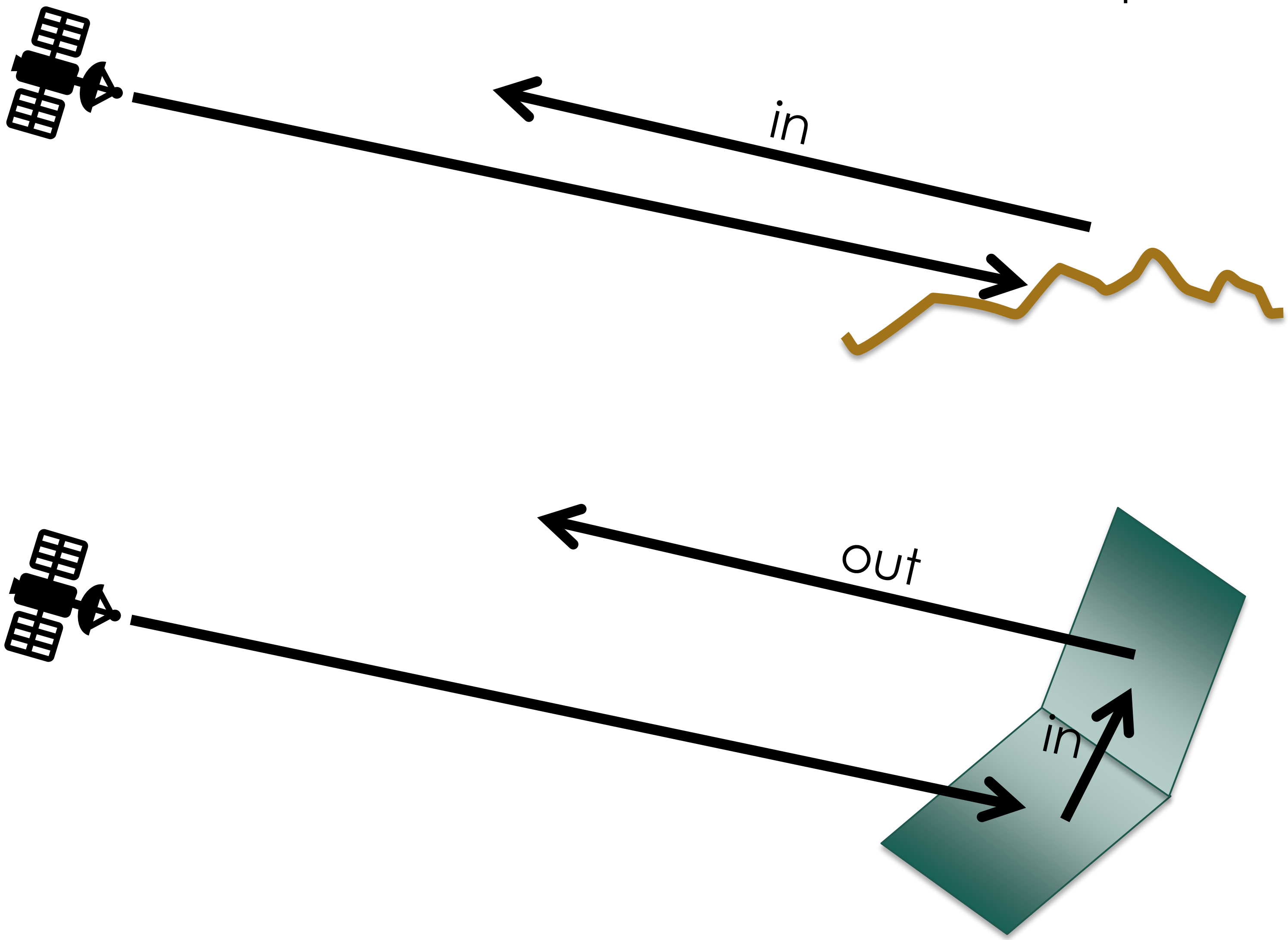


"Standard": intensity only
"Coherent": relative phase

Common SAR Imaging Modes

H and V in phase: “in”

H and V out of phase: “out”



Co-pol phase difference: HH-VV

Source: L3Harris Geospatial Solutions, Inc.

Common SAR Imaging Modes

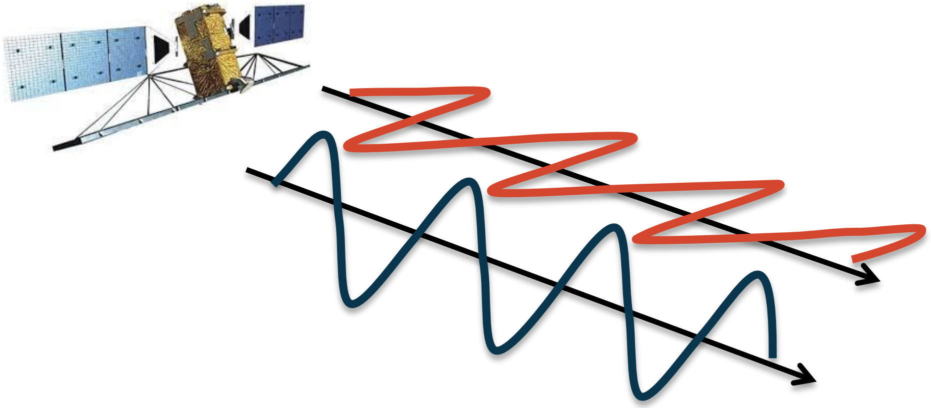
Processing/Storage
Power Requirements
Information Content

Low → High

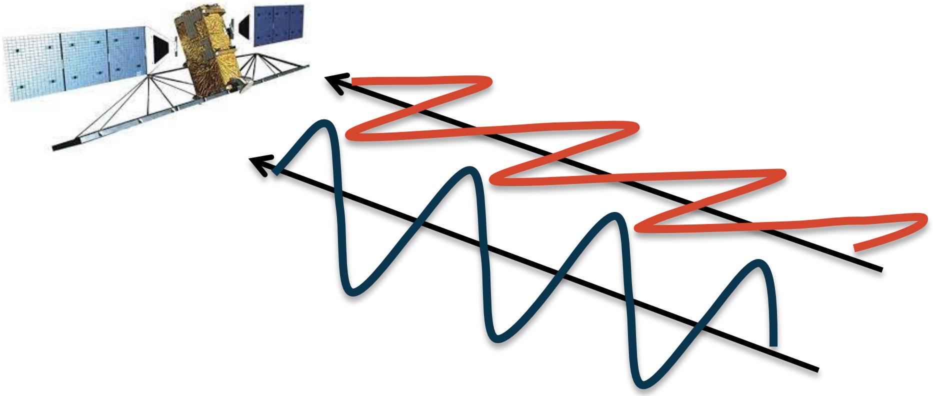
single	- HH - VV - HV - VH
dual (with and without phase)	- HH and HV - VV and VH - HH and VV
polarimetric	- HH, VV, HV, and VH

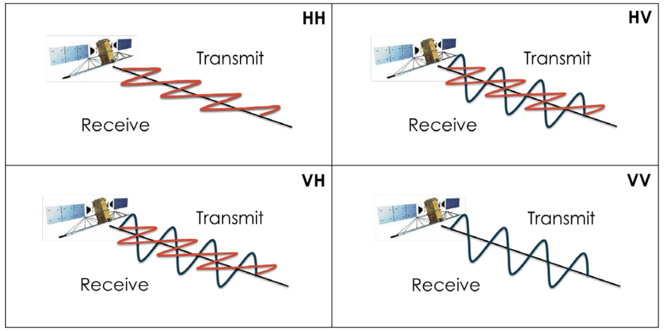
Common SAR Imaging Modes

- Two orthogonal polarizations on transmit & receive (typically H & V)
- Switch directs energy to the H & V parts of the antenna in sequence

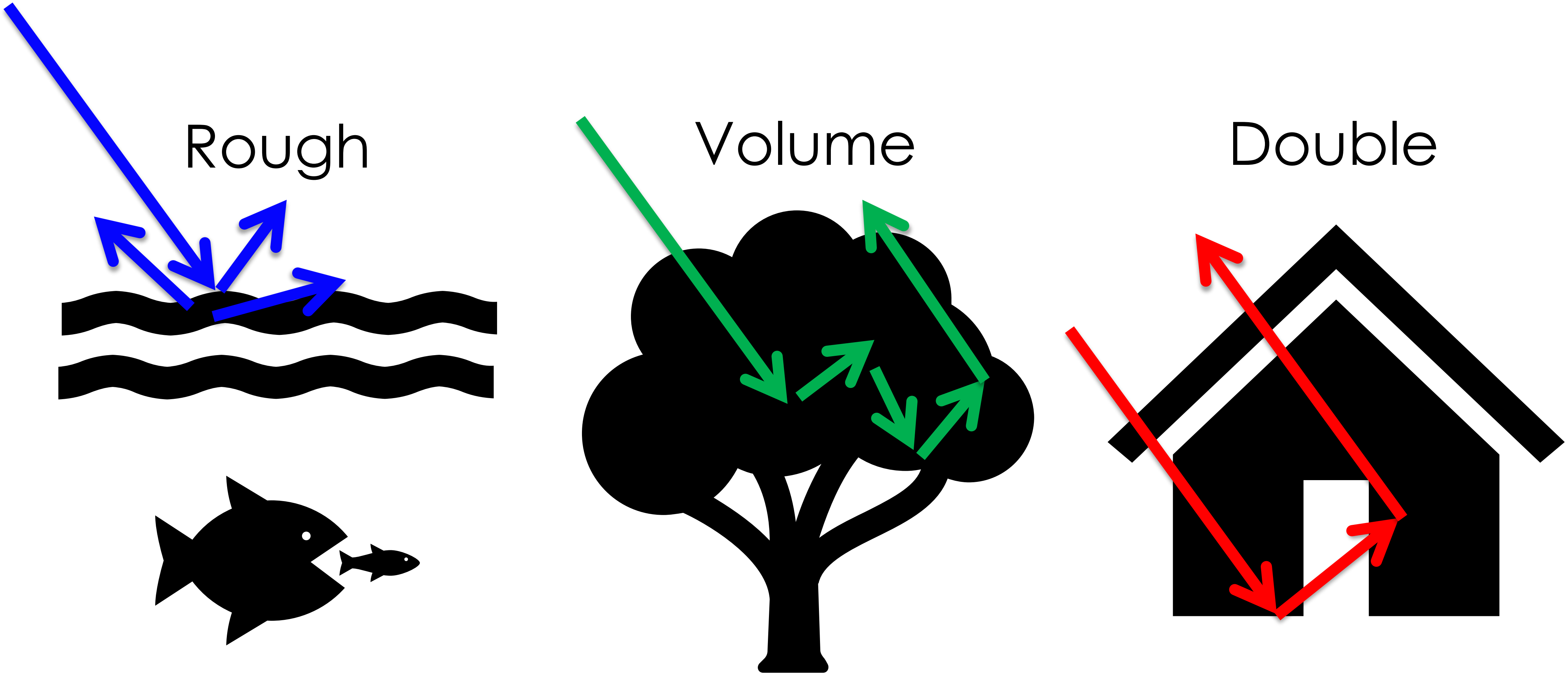


- Receive: H & V intensity **AND** their relative phase recorded simultaneously





Common SAR Imaging Modes



Source: https://www.youtube.com/watch?v=cQI49sOSc2g

Common SAR Imaging Modes

- Pros of fully polarimetric SAR:
  - Complete scattering characteristics
  - Can perform polarization synthesis

Common SAR Imaging Modes

- Cons of fully polarimetric SAR:
  - 2X pulse repetition frequency (data rate) & power usage of dual pol SAR
  - Available power & data rate extremely limited for spaceborne platforms
  - To keep power use constant, swath often ½ of dual-pol

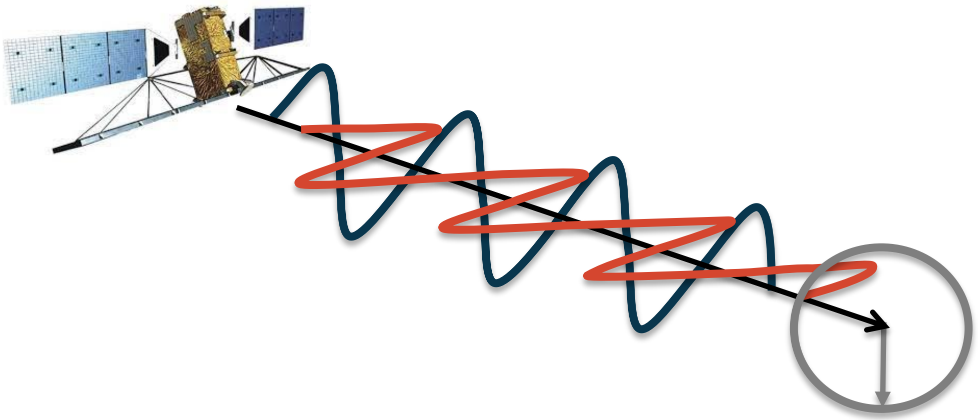
Common SAR Imaging Modes

- Compact Pol (CP)
  - Transmit one polarization; receive two orthogonal polarizations & relative phase
  - Circular-Linear or CL is preferred
    - H & V transmitted simultaneously & 90° out of phase (R or L)
    - Dual receive linearly-polarized (H or V)
  - Satellites with CP option: ALOS-2, RISAT-1, SAOCOM, RCM, NISAR

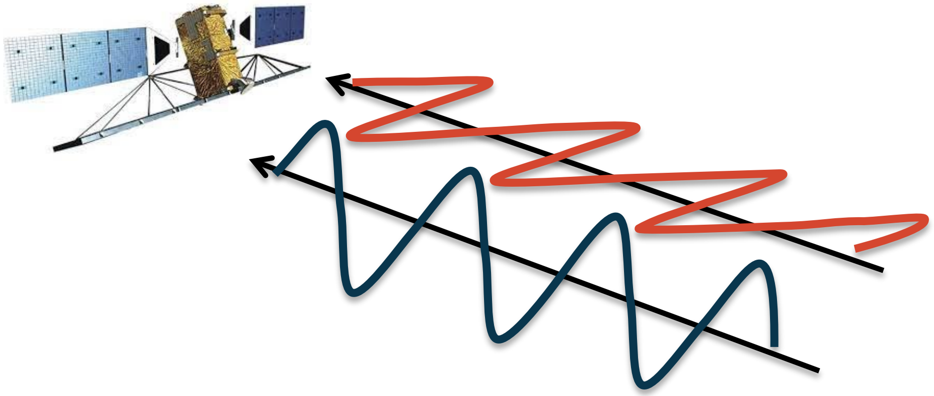
Information Source: Dr. Keith Raney, Johns Hopkins University

Common SAR Imaging Modes

- Right hand circular transmit



- Receive: H & V intensity **AND** their relative phase recorded simultaneously



Polarimetry

- "… science of acquiring, processing & analyzing the polarization state of an electromagnetic field" – Eric Pottier

DLR-HR

1) Transmit: fully polarized

2) Receive: multiple waves, variety amplitudes, phases, partially or completely unpolarized

Source: Wolfgang-Martin Boerner

Learning Objectives

- Polarimetry
  - Review of vectors and matrices
  - Commonly used vectors and matrices
  - Decomposition

Polarimetry

- Matrix:
  - Array of numbers
  - Arranged in m rows & n columns
  - Vector: matrix with 1 row or 1 column -> by default column vectors

$$\begin{bmatrix} 1 & 2 & 1 \\ 2 & 2 & 2 \end{bmatrix} \qquad \begin{bmatrix} 1 \\ 2 \end{bmatrix} \qquad \begin{bmatrix} 2 & 3 & 1 \\ 9 & 7 & 7 \\ 6 & 4 & 2 \end{bmatrix}$$

2 x 3 **2 x 1** **3 x 3**

Dimensions (rows and columns) tell us the size

Say “two (**rows**) by three (**columns**)”

Polarimetry

- Matrix:
  - For matrix **A**…
  - Element $a_{1,2}$ is first row, second column **= 3**
  - Element $a_{1,3}$ is first row, third column **= 1**
  - $a_{2,3}$ is second row, third column **= 7**

$$\begin{bmatrix} 2 & 3 & 1 \\ 9 & 7 & 7 \\ 6 & 4 & 2 \end{bmatrix}$$

Polarimetry

- Vectors vs Matrices:

$$\begin{bmatrix}1\\2\end{bmatrix} \quad \begin{bmatrix}18 & 3\end{bmatrix}$$

Vector

Ordered list of numbers; one row or column

$$\begin{bmatrix}2 & 3 & 1\\9 & 7 & 7\\6 & 4 & 2\end{bmatrix}$$

Matrix

Array of numbers, one or more rows/columns

Polarimetry

- Transposing a matrix $\boldsymbol{A}$:
  - Mirroring a matrix at the main diagonal
  - Superscript T reminds us it has been transposed ($\boldsymbol{A}^T$)

$$A = \begin{bmatrix} 1 \\ 2 \end{bmatrix} \quad A^T = \begin{bmatrix} 1 & 2 \end{bmatrix}$$

Polarimetry

- Adding and Subtracting Matrices:
  - For two matrices **A** and **B**; add/subtract elements at same position
  - Dimensions have to be the same (if not the same = undefined!)

$$C = A \pm B$$

$$= \begin{bmatrix} 2 & 5 \\ 6 & 7 \end{bmatrix} + \begin{bmatrix} 1 & 5 \\ 6 & 3 \end{bmatrix}$$

$$= \begin{bmatrix} 3 & 10 \\ 12 & 10 \end{bmatrix}$$

Polarimetry

- Adding and Subtracting Matrices:

$$C = A - B$$

$$= \begin{bmatrix} 1 & 4 \\ 6 & 7 \end{bmatrix} - \begin{bmatrix} 6 & 5 \\ 6 & 3 \end{bmatrix}$$

$$= \begin{bmatrix} 1-6 & 4-5 \\ 6-6 & 7-3 \end{bmatrix}$$

$$= \begin{bmatrix} -5 & -1 \\ 0 & 4 \end{bmatrix}$$

Polarimetry

- Multiplying matrices:

$$= \begin{bmatrix} 1 & 4 \\ 6 & 7 \end{bmatrix} \text{x} \begin{bmatrix} 2 & -1 \\ 3 & 2 \end{bmatrix}$$

  - More complicated!
  - As shown, is a construct (could have done it many different ways!)
  - Only works when the number of columns of **A** = the number of rows of **B**
  - Order matters! **A**x**B** is not always = **B**x**A**

2x2 2x2

Polarimetry

- Multiplying matrices:
  - Top left entry: product of first row with first column

$$= \begin{bmatrix} 1 & 4 \\ 6 & 7 \end{bmatrix} x \begin{bmatrix} 2 & -1 \\ 3 & 2 \end{bmatrix}$$

$$= \begin{bmatrix} (1)(2) + (4)(3) & \\ & \end{bmatrix}$$

Polarimetry

- Multiplying matrices:
  - Top right entry: product of first row with second column

$$= \begin{bmatrix} 1 & 4 \\ 6 & 7 \end{bmatrix} \text{x} \begin{bmatrix} 2 & -1 \\ 3 & 2 \end{bmatrix}$$

$$= \begin{bmatrix} (1)(2) + (4)(3) & (1)(-1) + (4)(2) \\ & \end{bmatrix}$$

Polarimetry

- Multiplying matrices:
  - Bottom left entry: product of second row with first column

$$= \begin{bmatrix} 1 & 4 \\ 6 & 7 \end{bmatrix} \text{x} \begin{bmatrix} 2 & -1 \\ 3 & 2 \end{bmatrix}$$

$$= \begin{bmatrix} (1)(2) + (4)(3) & (1)(-1) + (4)(2) \\ (6)(2) + (7)(3) & \end{bmatrix}$$

Polarimetry

- Multiplying matrices:
  - Bottom right entry: product of second row with second column

$$= \begin{bmatrix} 1 & 4 \\ 6 & 7 \end{bmatrix} \text{x} \begin{bmatrix} 2 & -1 \\ 3 & 2 \end{bmatrix}$$

$$= \begin{bmatrix} (1)(2) + (4)(3) & (1)(-1) + (4)(2) \\ (6)(2) + (7)(3) & (6)(-1) + (7)(2) \end{bmatrix}$$

Polarimetry

- Multiplying matrices:

$$= \begin{bmatrix} 1 & 4 \\ 6 & 7 \end{bmatrix} x \begin{bmatrix} 2 & -1 \\ 3 & 2 \end{bmatrix}$$

$$= \begin{bmatrix} (1)(2) + (4)(3) & (1)(-1) + (4)(2) \\ (6)(2) + (7)(3) & (6)(-1) + (7)(2) \end{bmatrix}$$

$$= \begin{bmatrix} 14 & 7 \\ 33 & 8 \end{bmatrix}$$

Learning Objectives

- Polarimetry
  - Review of vectors and matrices
  - **Commonly used vectors and matrices**
  - Decomposition

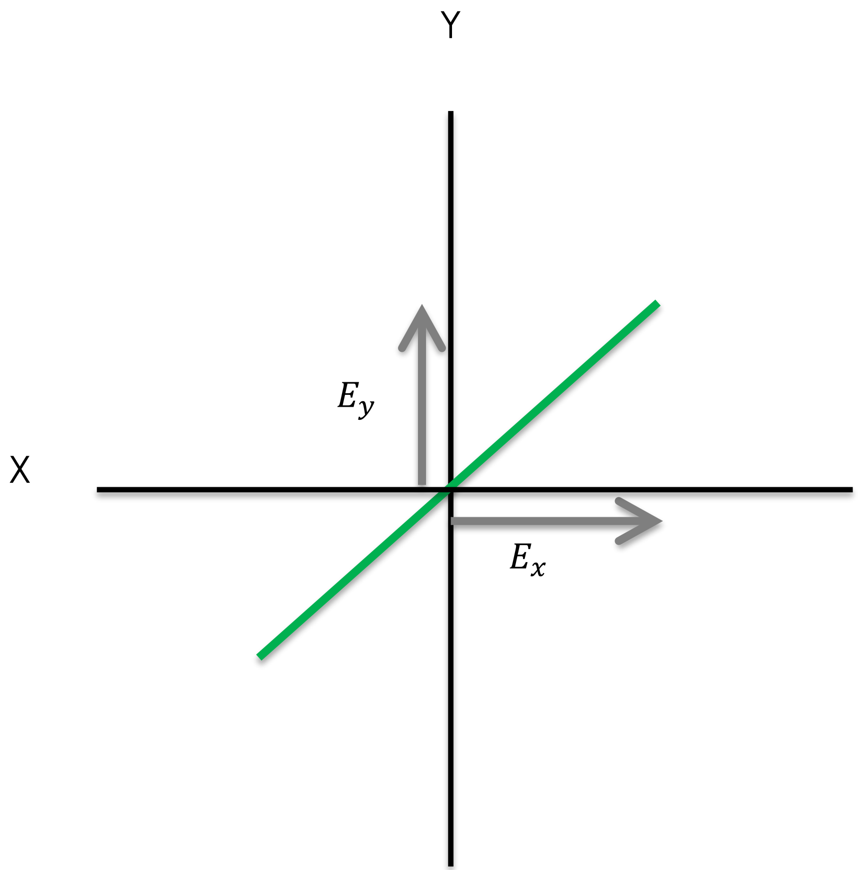
Polarimetry

- "Wave vector" is the simplest way to describe wave polarization mathematically

$$E = \begin{pmatrix} E_x \\ E_y \end{pmatrix}$$

- However, it's not always practical!

Linear polarized at 45°



Polarimetry

- Stokes parameters were introduced
  - Can fully describe completely & partially polarized waves
  - I, Q, U, V

Or …

  - S_0, S_1, S_2, S_3

Or …

  - S_1, S_2, S_3, S_4

Polarimetry

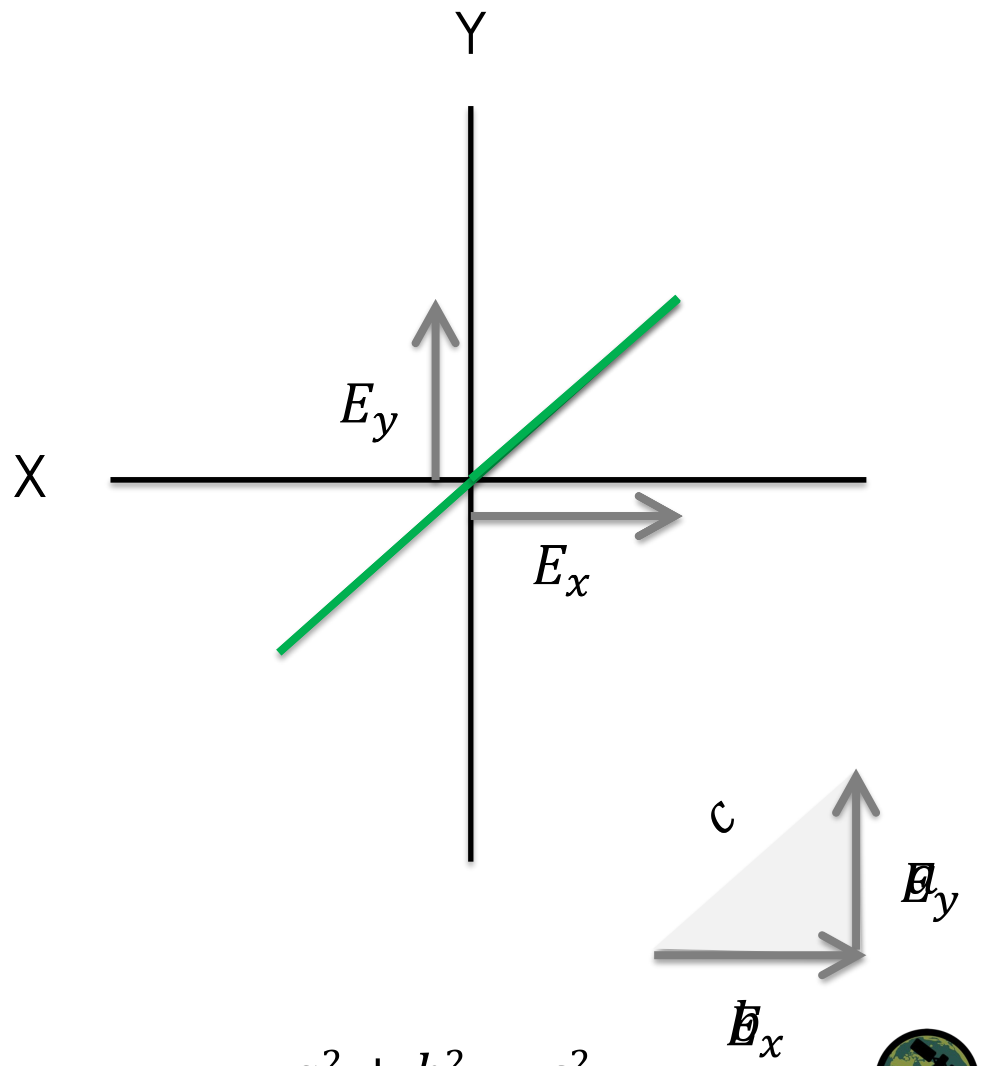
- Stokes Parameters ($\boldsymbol{I}, Q, U, V$)

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

  - Total power/intensity
  - Why square amplitudes?

    Total amount of energy in the wave!
  - ⟨ ⟩ means average over time (necessary for waves are partially polarized)
  - No polarization information!
  - Amplitude = $\sqrt{\langle E_y^2 \rangle + \langle E_x^2 \rangle}$

Linear polarized at 45°



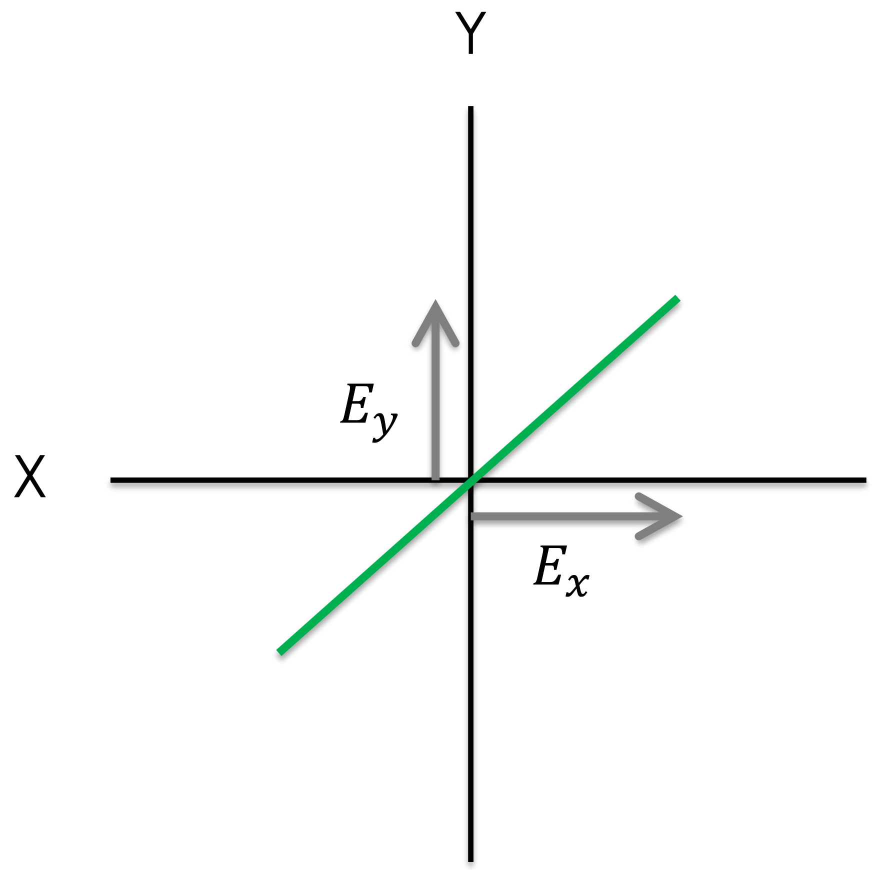
$a^2 + b^2 = c^2$

Polarimetry

- Stokes Parameters (I, $\boldsymbol{Q}$, U, V)

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

  - If we want to know how linearly polarized a wave is, take the difference between H & V components!
  - Tells us the extent to which a wave is Vertically or Horizontally oriented
  - Q > 0 more vertically oriented
  - Q < 0 more horizontally oriented

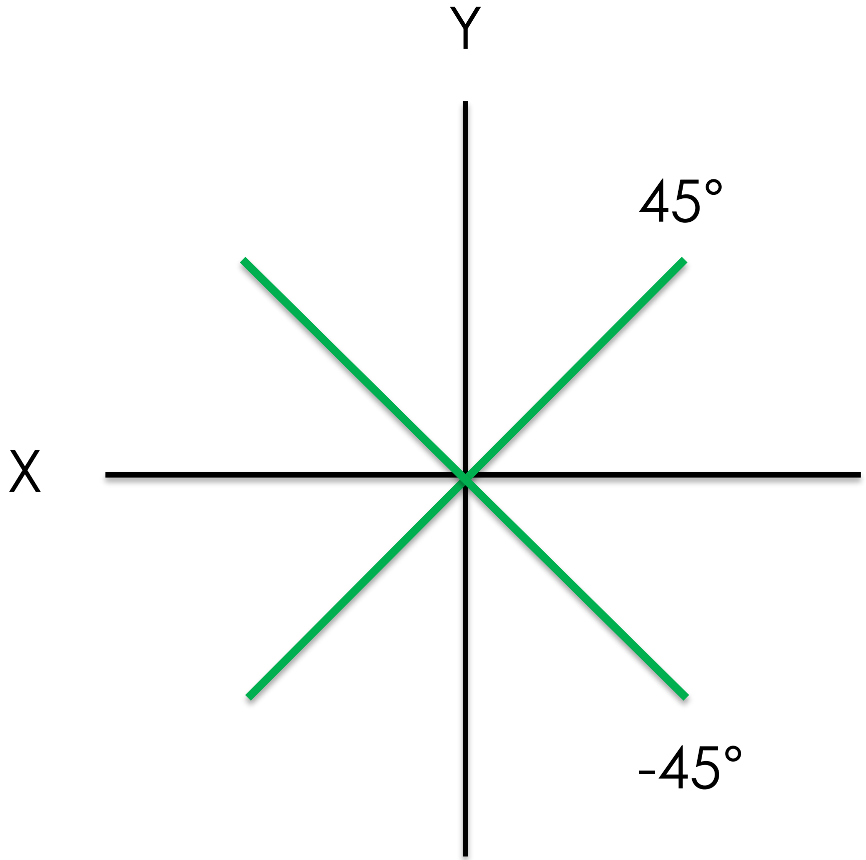


Polarimetry

- Stokes Parameters (I, Q, $\boldsymbol{U}$, V)

U

  - We need another term because if oriented at 45° or -45°, the wave would still be linearly polarized but Q would be 0, but the wave would still be polarized
  - U tells us the extent to which a wave is polarized at 45° or -45°
  - $U > 0$ more 45°
  - $U < 0$ more -45°

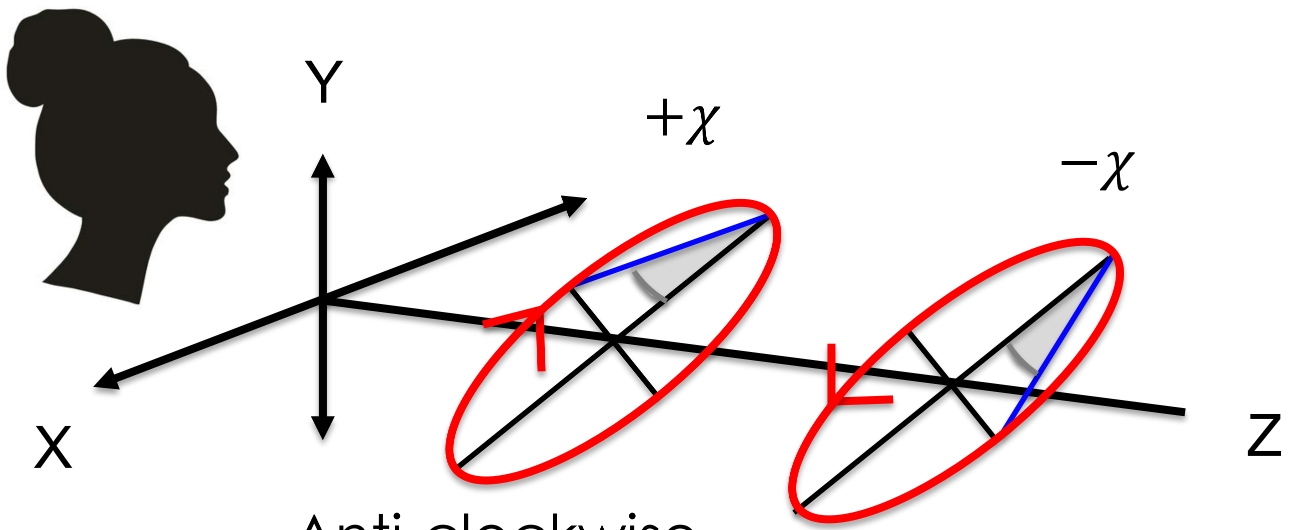


Polarimetry

- Stokes Parameters $(I, Q, U, \boldsymbol{V})$

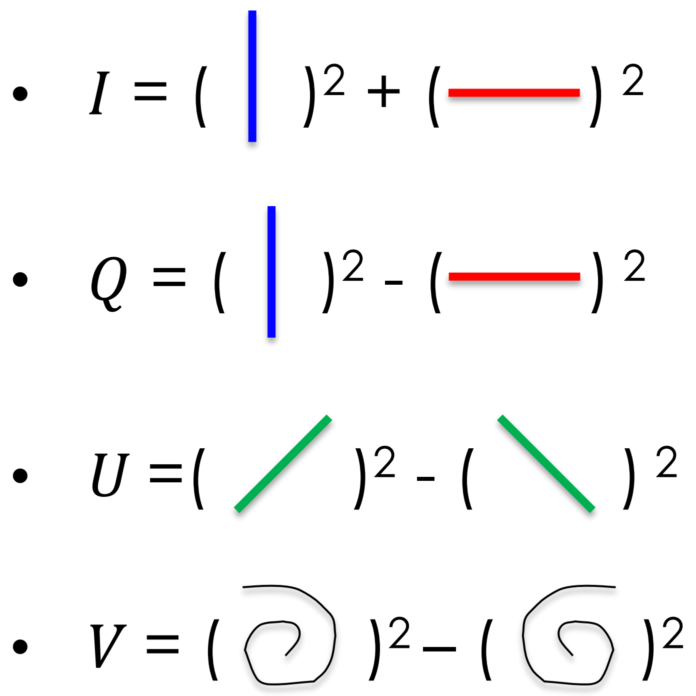
$$V$$

  - Tells us about handedness
  - $V > 0$ left handed
  - $V < 0$ right handed



Source: Eric POTTIER; https://stock.adobe.com/ca/search?k=%22face+silhouette%22

Polarimetry

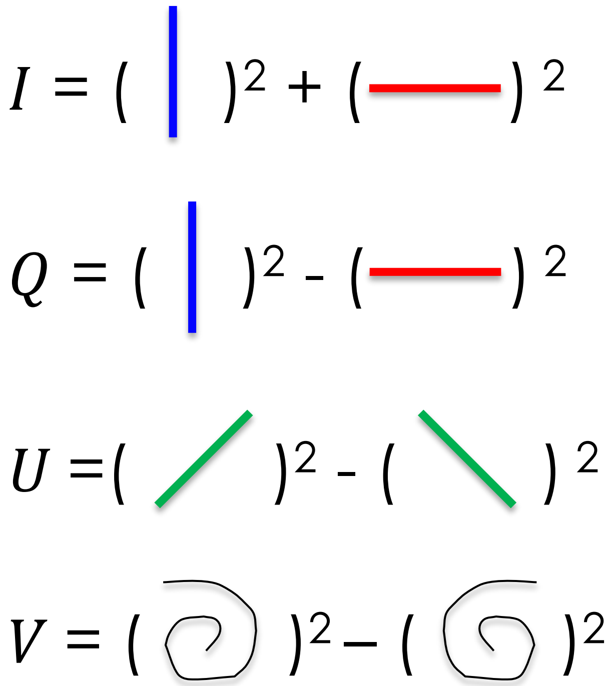


$E_x = E_y$

Unpolarized			
+			
0			
0			
0			

Define polarization state & there is none!

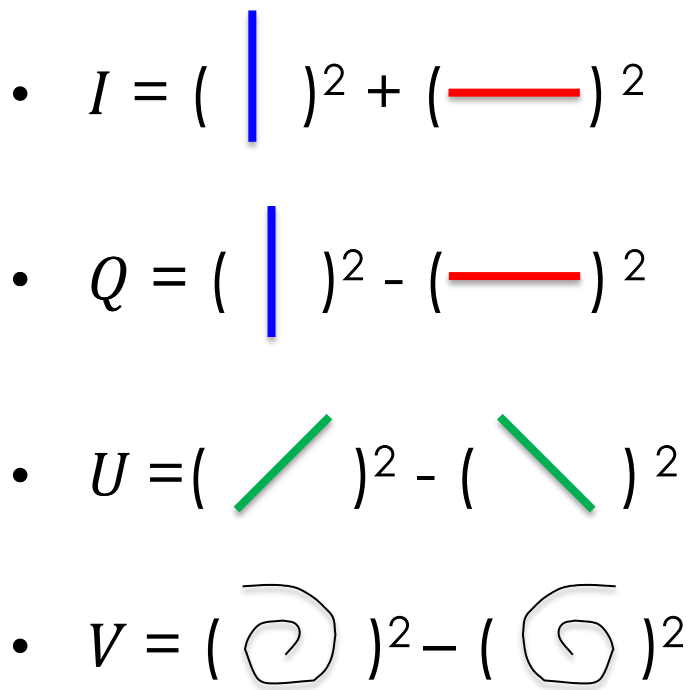
Polarimetry



Unpolarized	Vertical		
+	+		
0	+		
0	0		
0	0		

Source: https://www.youtube.com/watch?v=_bX1YrqB8uI

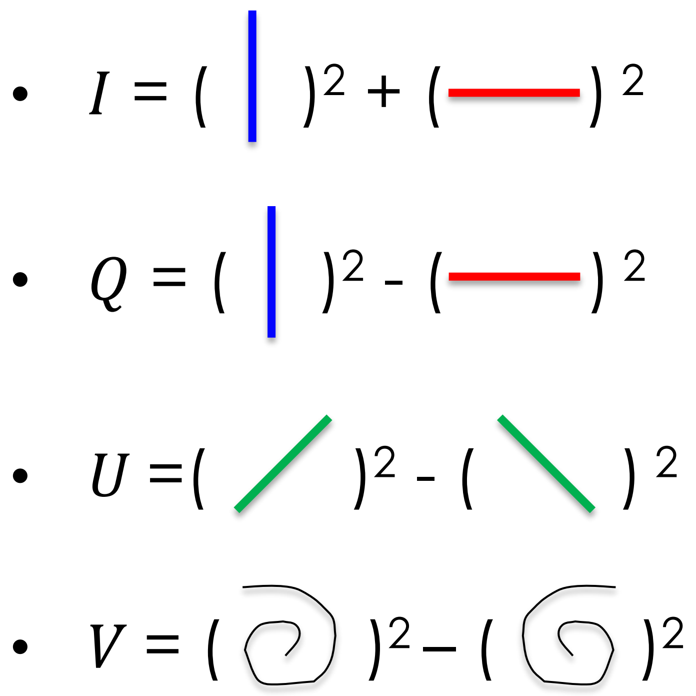
Polarimetry



Unpolarized	Vertical	-45	
+	+	+	
0	+	0	
0	0	-	
0	0	0	

Source: https://www.youtube.com/watch?v=_bX1YrqB8uI

Polarimetry



Unpolarized	Vertical	-45	RHC
+	+	+	+
0	+	0	0
0	0	-	0
0	0	0	+

Source: https://www.youtube.com/watch?v=_bX1YrqB8uI

Polarimetry

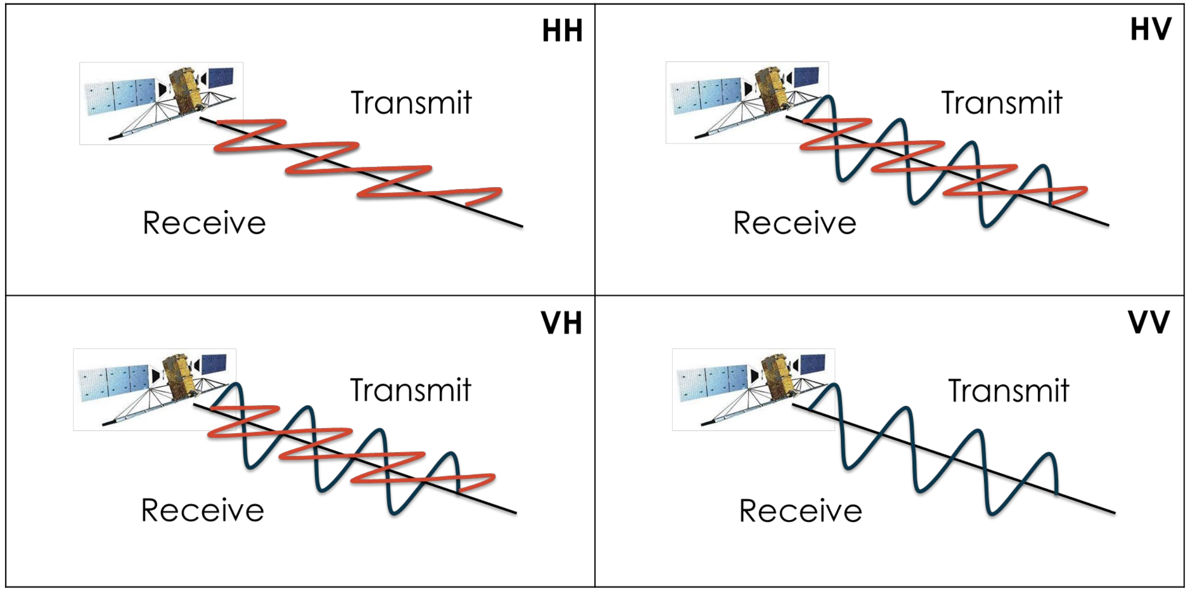
- Stokes parameters can also measure degree of polarization (m)

$$m = \frac{polarized\ power}{total\ power} = \frac{\sqrt{Q^2+U^2+V^2}}{I}$$

  - m = 1 completely polarized
  - m = 0 completely unpolarized

Polarimetry

- But what about quad pol data?



- Need at least two sets of Stokes vectors!

Polarimetry

- For fully polarimetric SAR data the Stokes vector is not the most efficient
- **Scattering Matrix** $[S]$

$$\begin{bmatrix} E_h^s \\ E_v^s \end{bmatrix} = \begin{bmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{bmatrix} \begin{bmatrix} E_h^i \\ E_v^i \end{bmatrix}$$

S= scattered wave

i = incident wave

- First subscript of S_{pq} is transmit; second is receive polarization

Polarimetry

- For fully polarimetric SAR data the Stokes vector is not the most efficient
- **Scattering Matrix** $[S]$

$$\begin{bmatrix} E_h^s \\ E_v^s \end{bmatrix} = \begin{bmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{bmatrix} \begin{bmatrix} E_h^i \\ E_v^i \end{bmatrix}$$

S= scattered wave

i = incident wave

- First subscript of S_{pq} is transmit; second is receive polarization

p and q can be any pair of polarizations as long as they are orthogonal!

Polarimetry

- **Scattering Matrix** $[S]$

$$\begin{bmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{bmatrix}$$

- 4 complex numbers
- Co-pol: HH & VV
- Cross-pol: HV & VH

Polarimetry

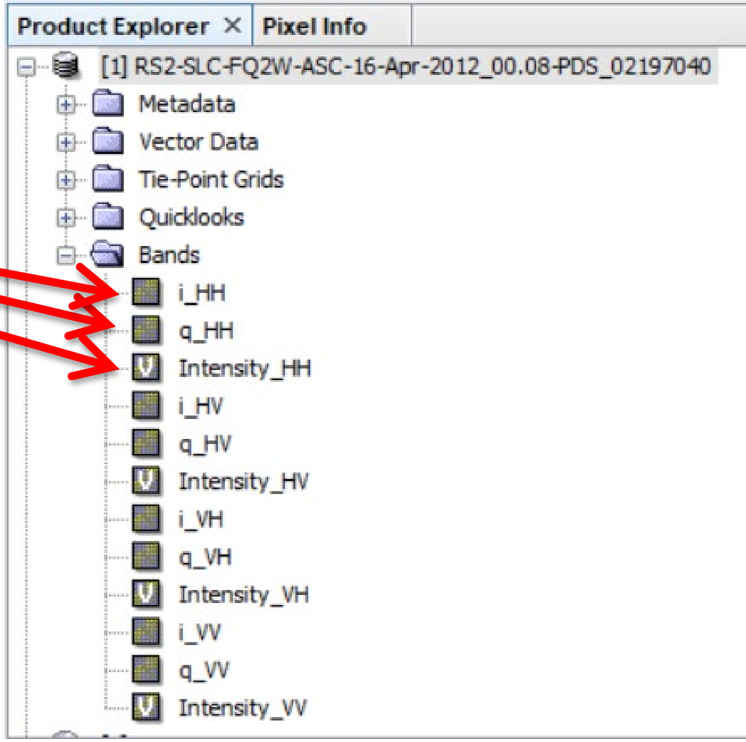
- **Scattering Matrix** $[S]$

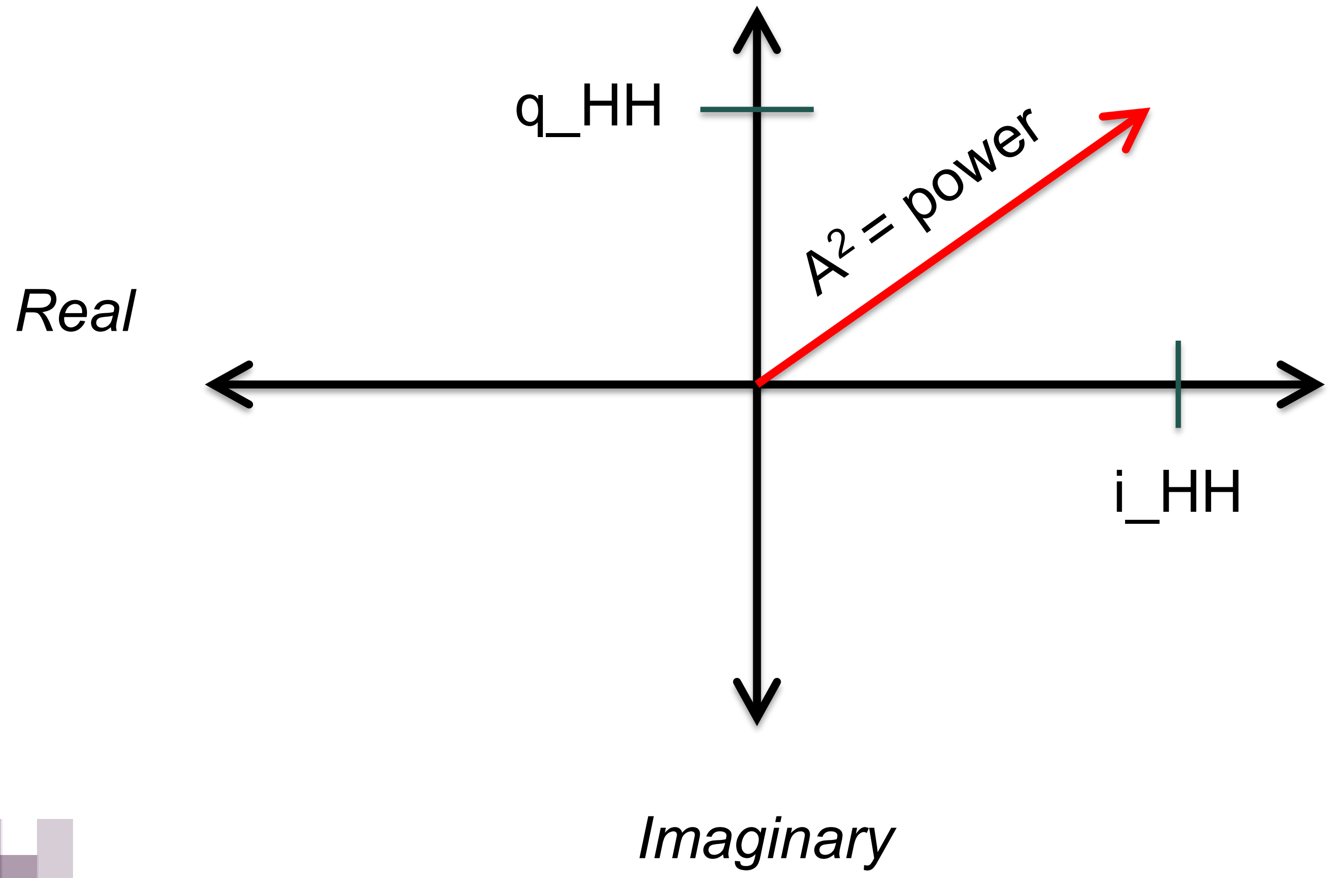
$$\begin{bmatrix} E_h^s \\ E_v^s \end{bmatrix} = \begin{bmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{bmatrix} \begin{bmatrix} E_h^i \\ E_v^i \end{bmatrix}$$

  – Describes the transformation of the incident wave to backscattered wave

Polarimetry

$$\begin{bmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{bmatrix}$$





Polarimetry

$$[S] = \begin{bmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{bmatrix}$$

- For most natural features there are only 3 independent parameters
- $S_{hv} = S_{vh}$ are reciprocal (process is the same forward & backward)
- Usually HV represents $= \frac{1}{2}(S_{hv} + S_{vh})$ – great because it averages noise!

- Total Power (total power scattered back in the direction of the antenna)

$$Total\ Power\ or\ SPAN = |S_{hh}|^2 + |S_{hv}|^2 + |S_{vh}|^2 + |S_{vv}|^2$$

$$= |S_{hh}|^2 + 2|S_{hv}|^2 + |S_{vv}|^2$$

Polarimetry

1) Forward Scatter Alignment (FSA)
   – Positive z always points in the direction of travel

2) Back Scatter Alignment (BSA)
   – Positive z always points toward the target

Take home: BSA is more commonly used. The scattering matrix takes on different forms depending on convention.

Polarimetry

- Target vector (Linear Basis)
  - $[\boldsymbol{S}]$ has three independent parameters
  - Can also define a vector instead of a matrix
  - For linear coordinates we use:

Just reminds us it has been transposed

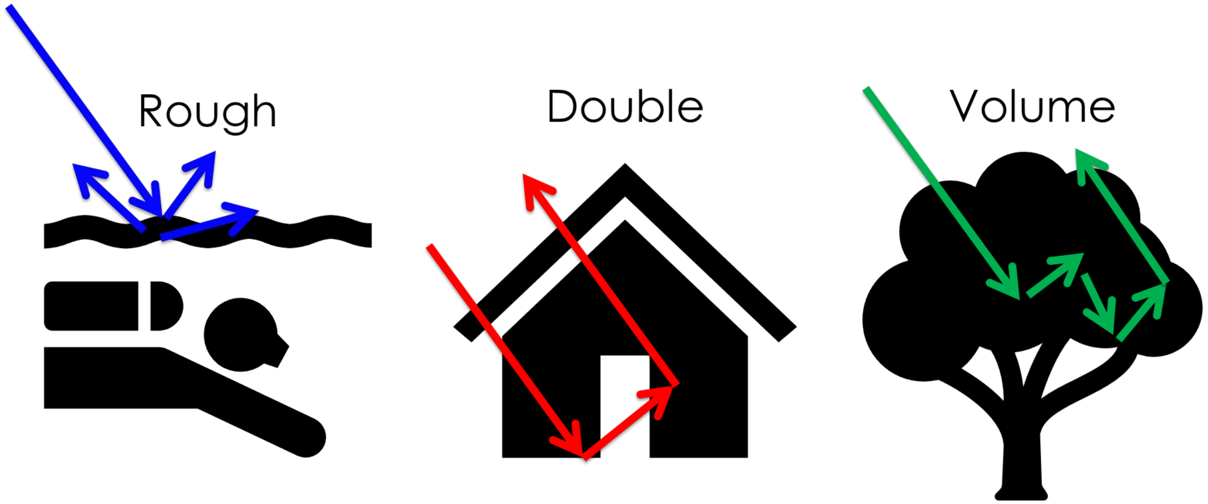
These are complex numbers

$$k = [S_{HH} + S_{HV} + S_{VV}]^T$$

Polarimetry

- Target vector (Pauli basis)
  - Sum and difference of co-pol, twice cross-pol
  - $\frac{1}{\sqrt{2}}$ to normalize result

$$k_P = \frac{1}{\sqrt{2}} [S_{hh} + S_{vv} \quad S_{hh} - S_{vv} \quad 2S_{hv}]^T$$



Polarimetry

- Other matrices defined from target vectors
- Second order descriptors of $[\boldsymbol{S}]$
- Statistical inter-relationship
- Averaging
  - Linear basis (k) for covariance matrix $[\boldsymbol{C}]$
  - Pauli basis (k_P) for coherency matrix $[\boldsymbol{T}]$

Polarimetry

- Covariance Matrix $[\boldsymbol{C}]$
  - Multiply k by its conjugate transpose
  - For polarimetric channels, characterizes their degree of similarity

$$C = k.k^{*T} = \begin{bmatrix} S_{HH} \\ \sqrt{2}S_{HV} \\ S_{VV} \end{bmatrix} \begin{bmatrix} S_{HH}^* & \sqrt{2}S_{HV}^* & S_{VV}^* \end{bmatrix}$$

$$= \left\langle \begin{bmatrix} |S_{HH}|^2 & \sqrt{2}S_{HH}S_{HV}^* & S_{HH}S_{VV}^* \\ \sqrt{2}S_{HV}S_{HH}^* & 2|S_{HV}|^2 & \sqrt{2}S_{HV}S_{VV}^* \\ S_{VV}S_{HH}^* & \sqrt{2}S_{VV}S_{HV}^* & |S_{VV}|^2 \end{bmatrix} \right\rangle$$

⟨ ⟩ brackets indicate averaging

Polarimetry

- Covariance Matrix $[\boldsymbol{C}]$
  - 9 elements
  - 3 real: intensities (diagonal)
  - 6 complex: degree of similarity between polarimetric channels

$$C = k.k^{*T} = \begin{bmatrix} S_{HH} \\ \sqrt{2}S_{HV} \\ S_{VV} \end{bmatrix} \begin{bmatrix} S_{HH}^{*} & \sqrt{2}S_{HV}^{*} & S_{VV}^{*} \end{bmatrix}$$

$$= \left\langle \begin{bmatrix} |S_{HH}|^2 & \sqrt{2}S_{HH}S_{HV}^{*} & S_{HH}S_{VV}^{*} \\ \sqrt{2}S_{HV}S_{HH}^{*} & 2|S_{HV}|^2 & \sqrt{2}S_{HV}S_{VV}^{*} \\ S_{VV}S_{HH}^{*} & \sqrt{2}S_{VV}S_{HV}^{*} & |S_{VV}|^2 \end{bmatrix} \right\rangle$$

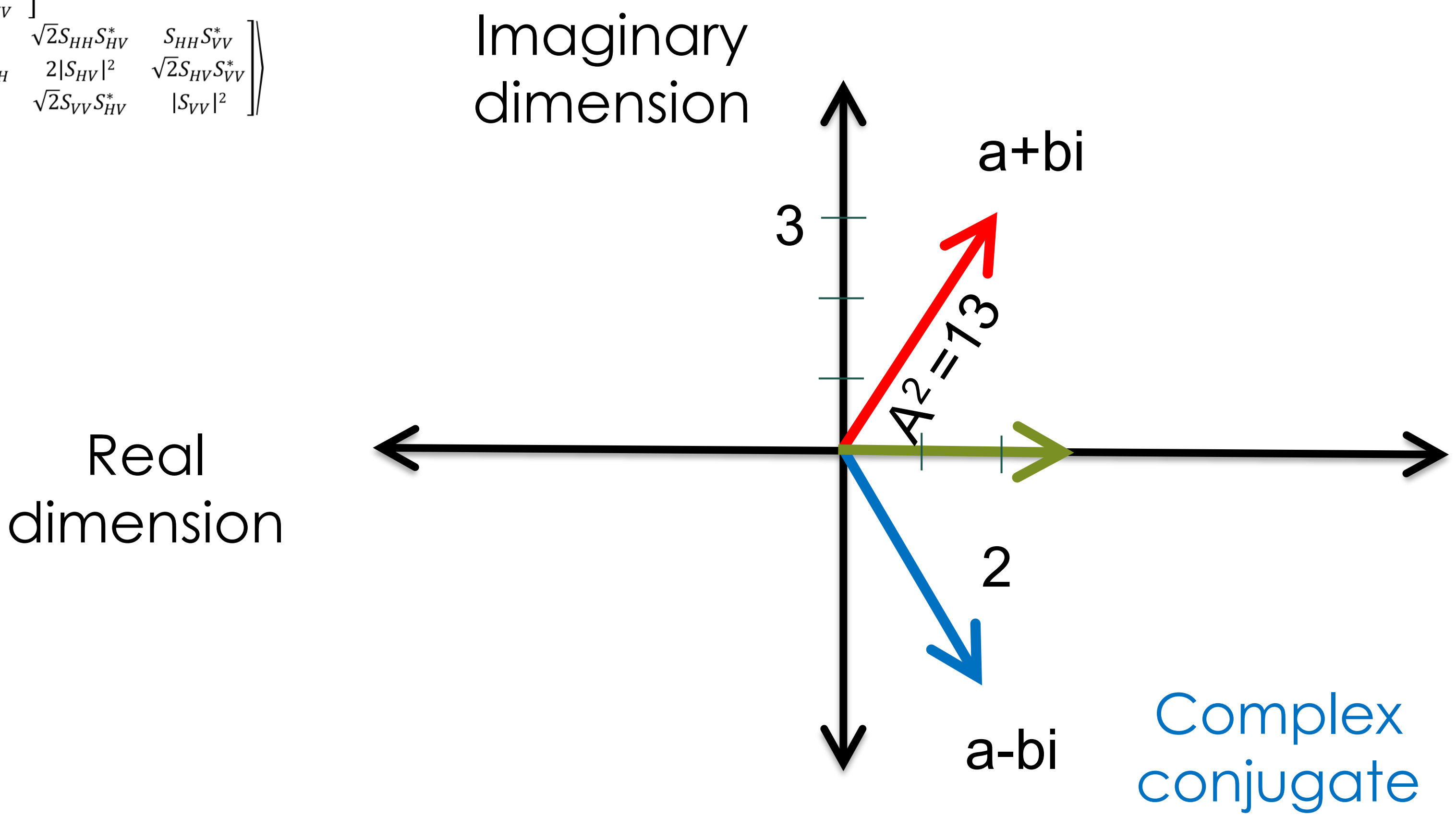
… Total power is sum of 3 diagonal elements

Polarimetry

- How we get power values along the diagonal:

$$C = k.k^{*T} = \begin{bmatrix} S_{HH} \\ \sqrt{2}S_{HV} \\ S_{VV}\end{bmatrix}\begin{bmatrix} S_{HH}^* & \sqrt{2}S_{HV}^* & S_{VV}^*\end{bmatrix}$$

$$= \left\langle \begin{bmatrix} |S_{HH}|^2 & \sqrt{2}S_{HH}S_{HV}^* & S_{HH}S_{VV}^* \\ \sqrt{2}S_{HV}S_{HH}^* & 2|S_{HV}|^2 & \sqrt{2}S_{HV}S_{VV}^* \\ S_{VV}S_{HH}^* & \sqrt{2}S_{VV}S_{HV}^* & |S_{VV}|^2 \end{bmatrix}\right\rangle$$



$(a+bi)\ (a-bi)$

$(2+3i)(2-3i)$

$=4-6i+6i-9i^2$

$(i^2=-1)$

$=4-6i+6i-9(-1)$

$=4+9$

$=13$

$=A^2$

$= |S_{hh}|^2$

Polarimetry

- Covariance Matrix $[\boldsymbol{C}]$
  - C_{12} & C_{21}: close to zero for natural targets (e.g. wetlands)
  - C_{12} & C_{21}: have some useful info in urban area/anthropogenic targets
  - C_{13}: phase difference between HH and VV (used to distinguish odd (0°) from even bounce (180°))

$$= \left\langle \begin{bmatrix} |S_{HH}|^2 & \sqrt{2}S_{HH}S_{HV}^* & S_{HH}S_{VV}^* \\ \sqrt{2}S_{HV}S_{HH}^* & 2|S_{HV}|^2 & \sqrt{2}S_{HV}S_{VV}^* \\ S_{VV}S_{HH}^* & \sqrt{2}S_{VV}S_{HV}^* & |S_{VV}|^2 \end{bmatrix} \right\rangle$$

Polarimetry

- Coherency Matrix $[\boldsymbol{T}]$
  - Multiply k_P by its conjugate transpose
  - For polarimetric channels, characterizes their degree of similarity

Polarimetry

- Are $|\boldsymbol{C}|$ and $|\boldsymbol{T}|$ equivalent?
  - Can transform one into the other
  - Same information about: correlations, phase angles, amplitudes
  - $|\boldsymbol{T}|$ provides better physical interpretation, elements more related to geometric & physical scattering process

Source: Eric POTTIER

Polarimetry

Matrices for Complex Data	Number of Channels
s4c: non-symmetrized scattering matrix (single-look only)	4
S3c: symmetrized scattering matrix	3
s2c: incomplete scattering matrix (dual-pol single-look only)	2
s1c:incomplete scattering matrix (single-pol single-look only)	1
c4r6c: non-symmetrized covariance matrix (best for multi-look)	10
C3r3c: symmetrized covariance matrix	6
c2r1c: incomplete covariance matrix (best for dual-pol multi-look)	3
t4r6c: non-symmetrized coherence matrix (best for multi-look)	10
T3r3c: symmetrized coherence matrix	6
k16r: non-symmetrized Kennaugh matrix (best for multi-look)	16
K9r: symmetrized Kennaugh matrix	9

Source: PCI Geomatics Enterprises, Inc.

Polarimetry

- What about coherent dual pol data?
- Can construct 2x2 covariance matrix
- Co or cross-pol

$$C = k.k^{*T} = \begin{bmatrix} S_{HH} \\ S_{VV} \end{bmatrix} \begin{bmatrix} S_{HH}^{*} & S_{VV}^{*} \end{bmatrix}$$

$$= \left\langle \begin{bmatrix} |S_{HH}|^2 & S_{HH}S_{VV}^{*} \\ S_{VV}S_{HH}^{*} & |S_{VV}|^2 \end{bmatrix} \right\rangle$$

Learning Objectives

- Polarimetry
  - Review of vectors and matrices
  - Commonly used vectors and matrices
  - **Decomposition**

Polarimetry

- Polarimetric decomposition
  - Describes scattering properties
  - Partitions total power into relative contributions of different, idealised scatterers
  - Makes interpretation easier!

- Methods
  - Coherent (unnatural targets)
  - Incoherent (natural targets)

Polarimetry

- Coherent Decomposition
  - Direct interpretation of the scattering matrix ***[S]*** is difficult
  - Express ***[S]*** as the combination of responses from simpler (canonical) objects
  - Coherent targets/point/pure targets: phase is known & predictable
  - E.g., urban areas

Polarimetry

- Incoherent Decomposition
  - Speckle → must characterize some targets statistically → **[C]** and **[T]**
  - Direct interpretation of the scattering matrix **[C]** and **[T]** difficult
  - Incoherent targets
  - E.g., forested areas

Polarimetry

[S]

Coherent Decomposition

- W. Pauli (1900-1959)
- E. Krogager (1990)
- W. L. Cameron (1990)

[T]

Eigen-based Decomposition

- S. R. Cloude (1985)
- W. A. Holm (1988)

Eigenvectors/Eigenvalues Analysis

- S. R. Cloude & E. Pottier (1996-1997)

[C]

Model Based Decomposition

- A. Freeman (1992)

Eigen-based/model Based Decomposition

- J. J. Van Zyl (1992)

Polarimetry

- Cloude-Pottier Decomposition
  - Eigenvector Eigenvalue based decomposition of **[T]**
  - From this we get three secondary parameters

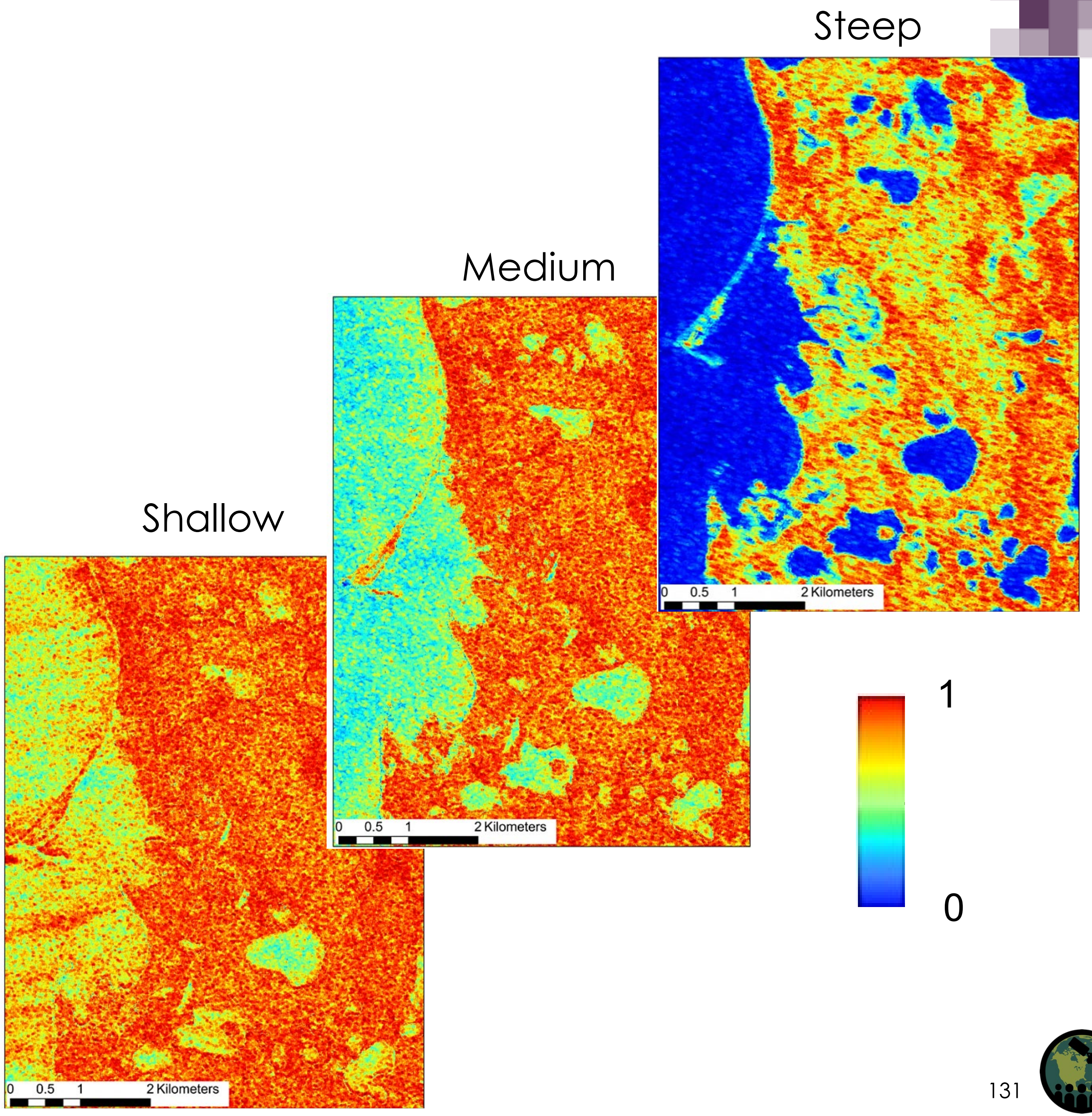
1) Entropy (H)

2) Anisotropy (A)

3) Mean Alpha angle (α)

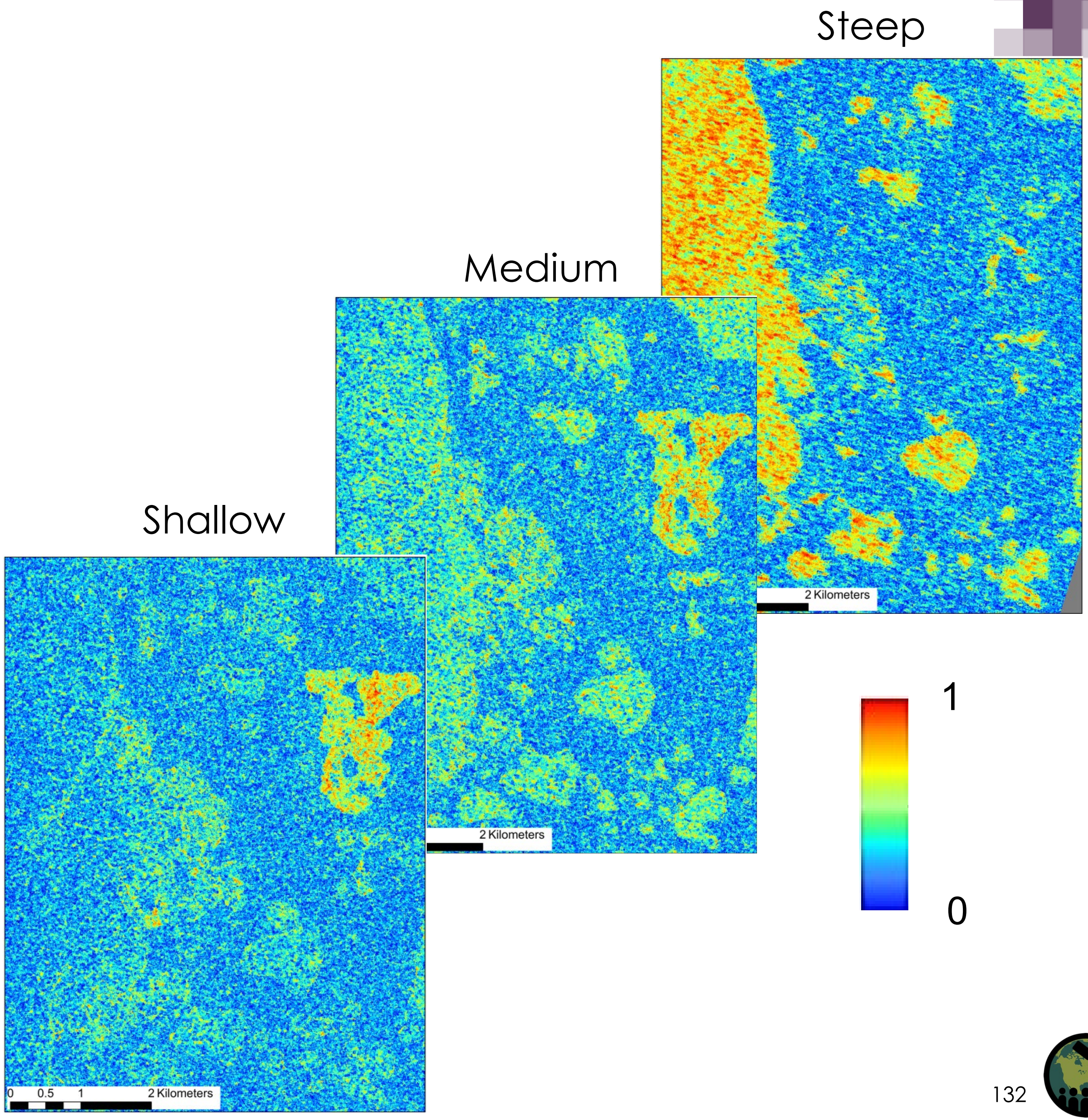
Polarimetry

- Entropy (H)
  - Degree of randomness
  - H = 1 → distributed target
  - H = 0 → pure target, one scattering mechanism
  - When H > 0.7 hard to discriminate; Anisotropy complements value



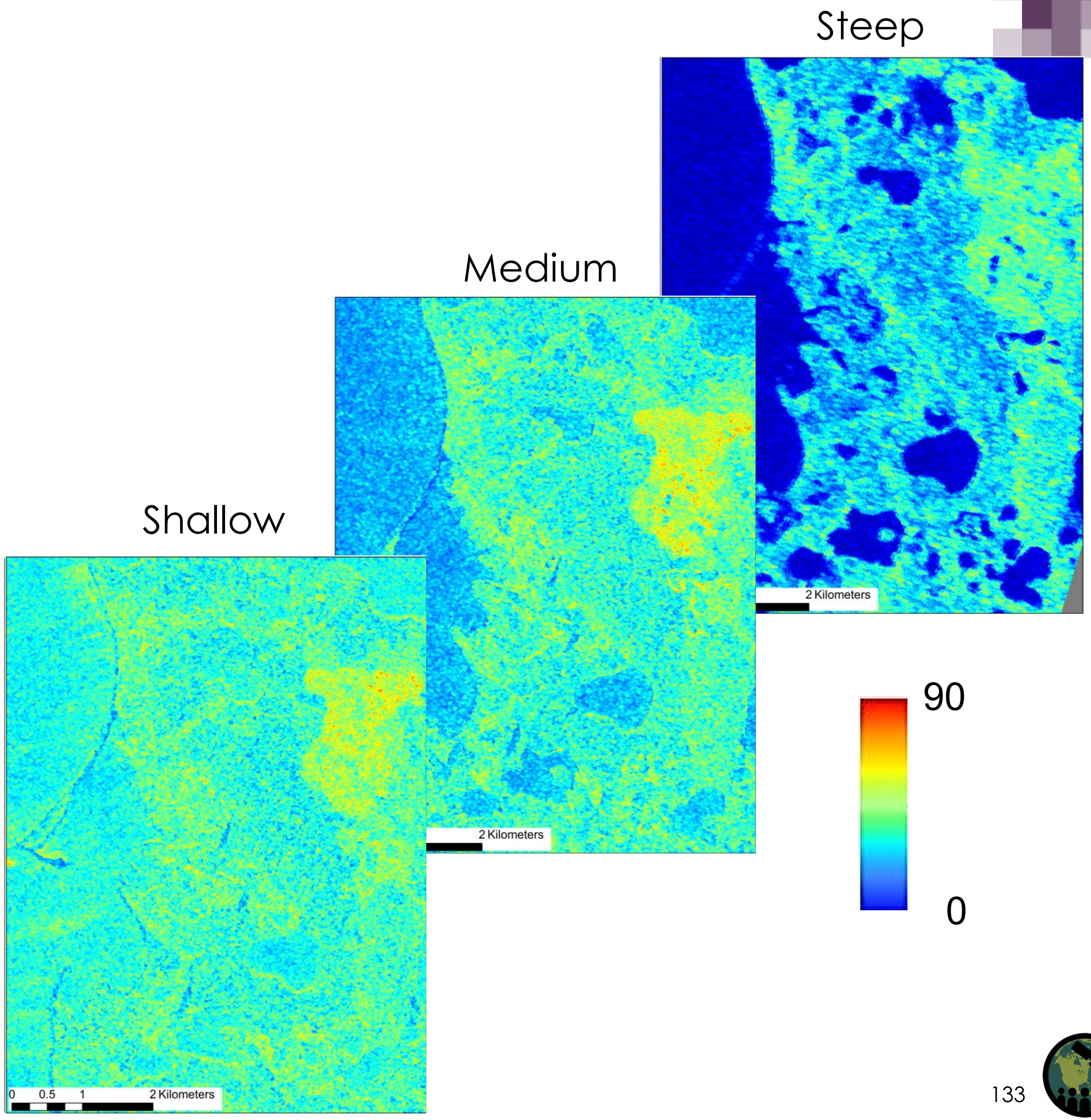
Polarimetry

- Anisotropy (A)
  - Relative importance between second & third mechanisms
  - A > 0
    - Low: third mechanism contributes significantly to total power
    - High: only second mechanism contributes significantly to total power
  - A = 0 contributions from second & third mechanism are equal



Polarimetry

- Mean alpha angle(α)
  - Can be used to determine dominant scattering mechanism
  - 0-90°
  - Low (0-45°): surface
  - Intermediate (~45°): volume
  - High (>45°): double



Additional Resources

- Polarisation: Applications in Remote Sensing Shane R. CLOUDE Oxford University Press, October 2009, pp 352 ISBN: 978-0199569731

- Polarimetric Radar Imaging: From basics to applications Jong-Sen LEE – Eric POTTIER CRC Press; 1st ed., February 2009, pp 422 ISBN: 978-1420054972

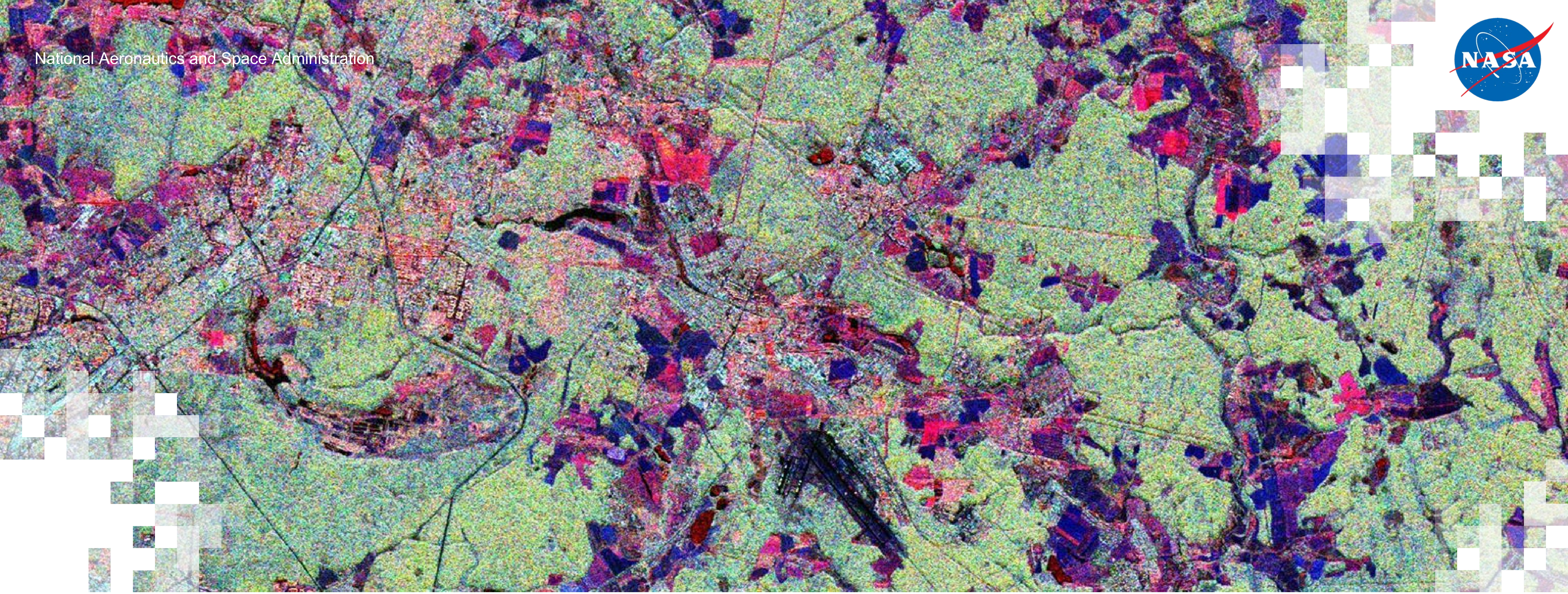
- Polarisation: Applications in Remote Sensing Shane R. CLOUDE Oxford University Press, October 2009, pp 352 ISBN: 978-0199569731

- Polarimetric Radar Imaging: From basics to applications Jong-Sen LEE – Eric POTTIER CRC Press; 1st ed., February 2009, pp 422 ISBN: 978-1420054972

References

- Introduction to Microwave Remote Sensing. I. WOODHOUSE CRC Press, 2006, ISBN: 0-415-27123-1
- Dr. Mehdi Hosseini
- https://earth.esa.int/documents/653194/656796/Polarimetric_Decompositions.pdf
- http://seom.esa.int/polarimetrycourse2017/files/materials/PolSAR_theory_EPottier.pdf
- http://step.esa.int/docs/tutorials/S1TBX%20Polarimetry%20with%20Radarsat-2%20Tutorial_v2.pdf

National Aeronautics and Space Administration



Polarimetry Practical Part 1: Intensity-Derived Parameters

Intensity-Derived Parameters

- Total Power (Span)
- Radar Vegetation Index
  - Radar Forest Degradation Index
  - Biomass Index
  - Canopy Structure Index
- Co-Pol and Cross-Pol Ratios (HH/VV, HH/HV, VV/VH)
  - Integrates backscatter from different polarizations to one value.
  - Like optical indices, mitigates system error and noise
  - Assuming calibration error the same for all polarizations, a Ratio or Index may mitigate some error AND may mitigate some of the impacts with changes in incidence angles (between imagery)
  - Generally requires fully polarimetric data (like RCM, SAOCOM, etc.) but newer indices and ratios are being generated with Sentinel-1 SLC data

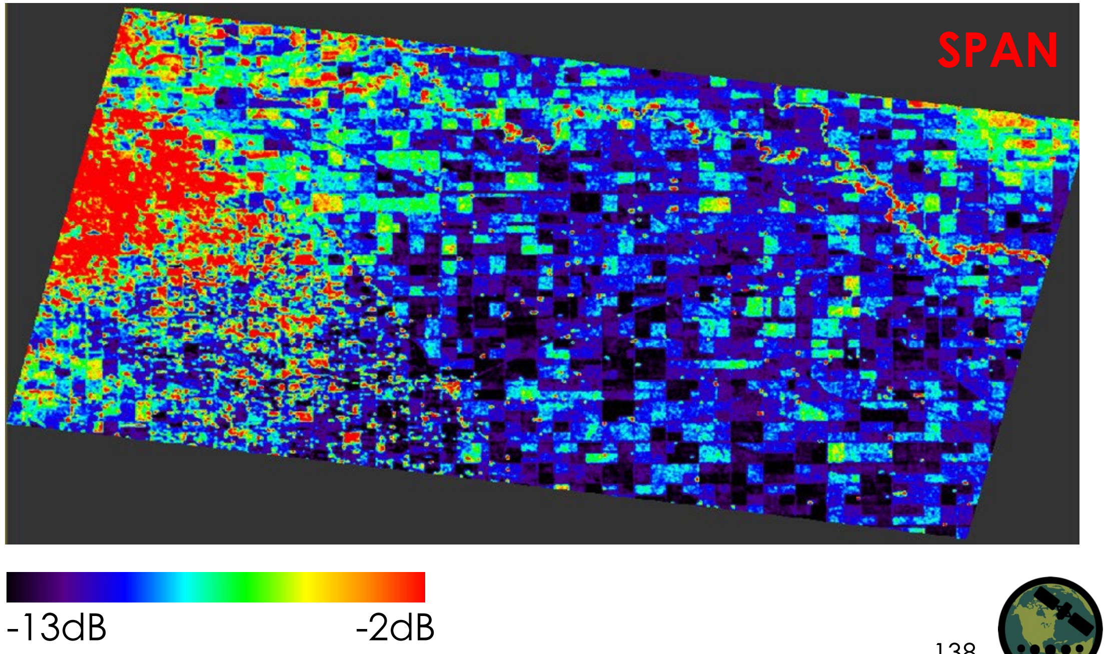
Span

Total Intensity (Span)

- A quantity giving the total power (intensity) received by the four channels of a fully polarimetric radar system.
- In terms of the scattering matrix, the total power is equal to the sum of all the matrix elements.

$$Span = HH + 2HV + VV$$

- Low Span in bare agricultural fields due to the quasi-specular reflection of the SAR waves
- High Span in mixed forest and shrub areas due to the high radar return linked to volume scattering



Radar Vegetation Index & Other Indices

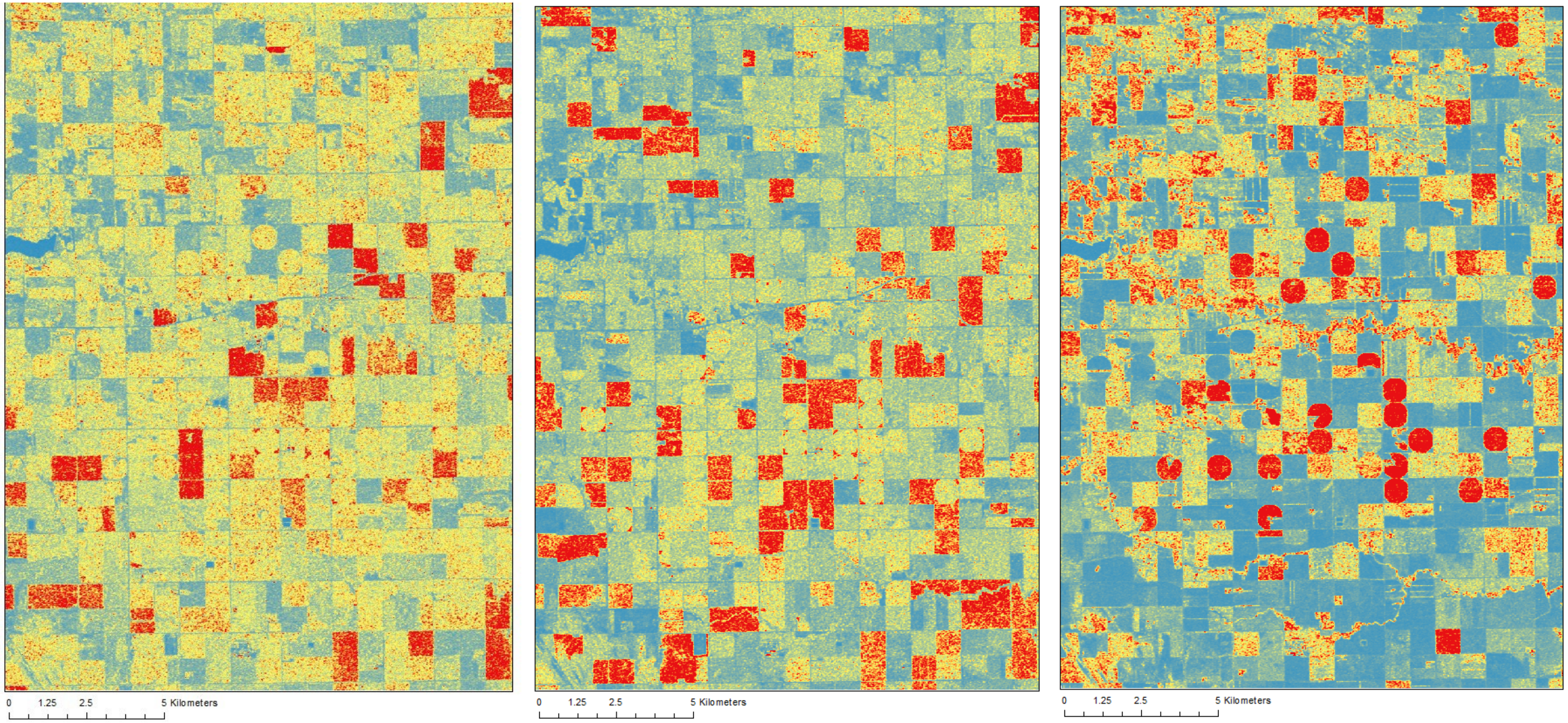
- The Radar Vegetation Index (RVI) is used to estimate vegetation conditions, similar to NDVI
- HV backscatter is highly impacted by vegetation
- 8 is a scaling factor (as HV values are lower compared to HH & VV)

$$\mathrm{RVI} = \frac{8\sigma_{hv}}{\sigma_{hh} + \sigma_{vv} + 2\sigma_{hv}}.$$

- Other indices available in SNAP:
  - Radar Forest Degradation Index
  - Biomass Index
  - Canopy Structure Index
  - Biomass Index
- When using these, try to understand the physics behind them and whether or not they will be useful for your application.

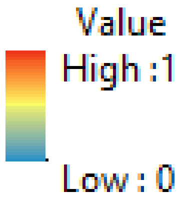
Temporal RVI

Carman, Manitoba, Canada



July 19, 2020 | August 16, 2020 | September 17, 2020

Declining RVI values as the growing season winds down.



Intensity Ratios: Cross Pol, Co-Pol Ratios

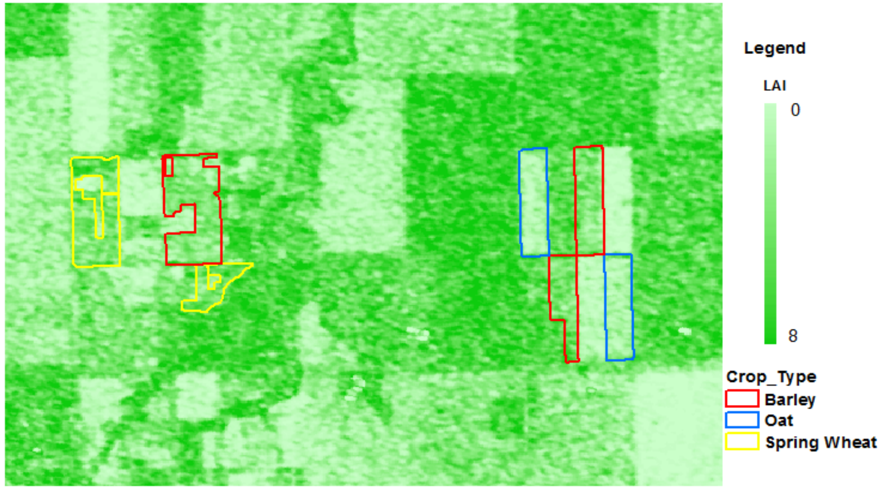
- Integrates backscatter from different polarizations to one value
- Correlations have been found with simple ratios and LAI, Biomass, etc.

$$Cross\ pol\ ratio = {}^{HH}/_{HV}$$

$$Cross\ pol\ ratio = {}^{VV}/_{VH}$$

$$Co\ pol\ ratio = {}^{HH}/_{VV}$$

RS2 derived LAI map on June 24th



Correlations Between SAR Parameters and LAI

SAR Parameter	Wheat	Oats	Barley
HV/HH ratio	-0.78	-0.73	-0.75
HV/VV ratio	0.84	0.71	0.80
HH/VV ratio	0.69	0.75	0.80

Correlation Coefficients (R)

Generating Polarimetric Parameters in SNAP

Radiometric Conversion

↓

POLARIMETRIC PARAMETERS

↓

Speckle Filtering

↓

Geometric Correction

↓

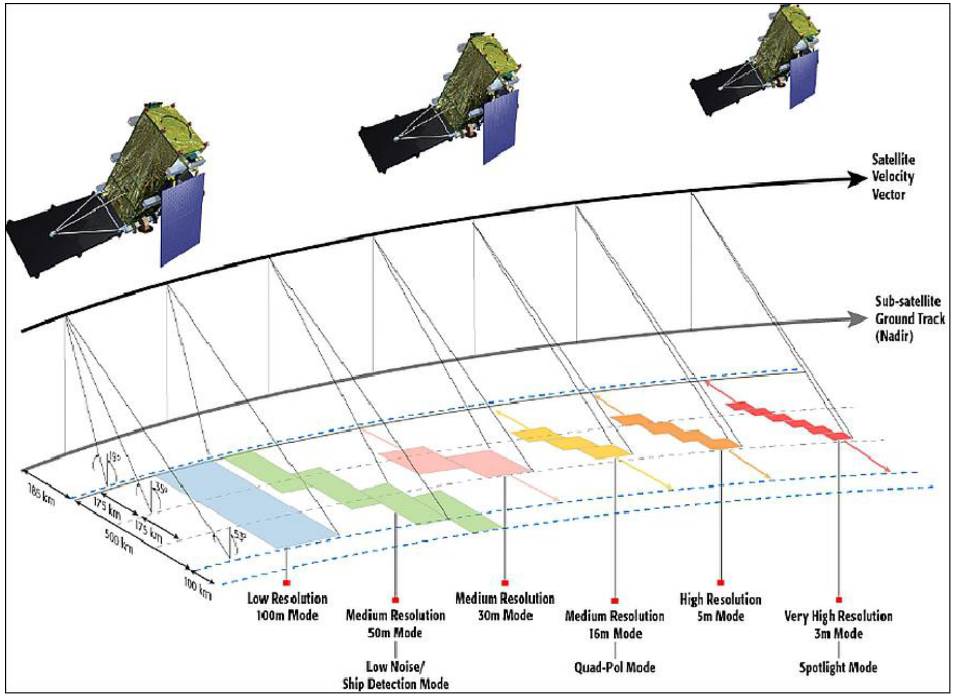
Final Polarimetric Parameters

RCM Fully Polarimetric Imagery

Slant Range SLC Product (Single Look Complex)

- Each image pixel is represented by a complex (real I and imaginary Q) magnitude value.
- No interpolation into ground range coordinates is performed during processing for SLC image products, and the range coordinate is given in radar slant range rather than ground range (i.e., the range resolution is measured along a slant path perpendicular to the track of the sensor).
- The processing for all SLC products covers a single look in range and azimuth directions.

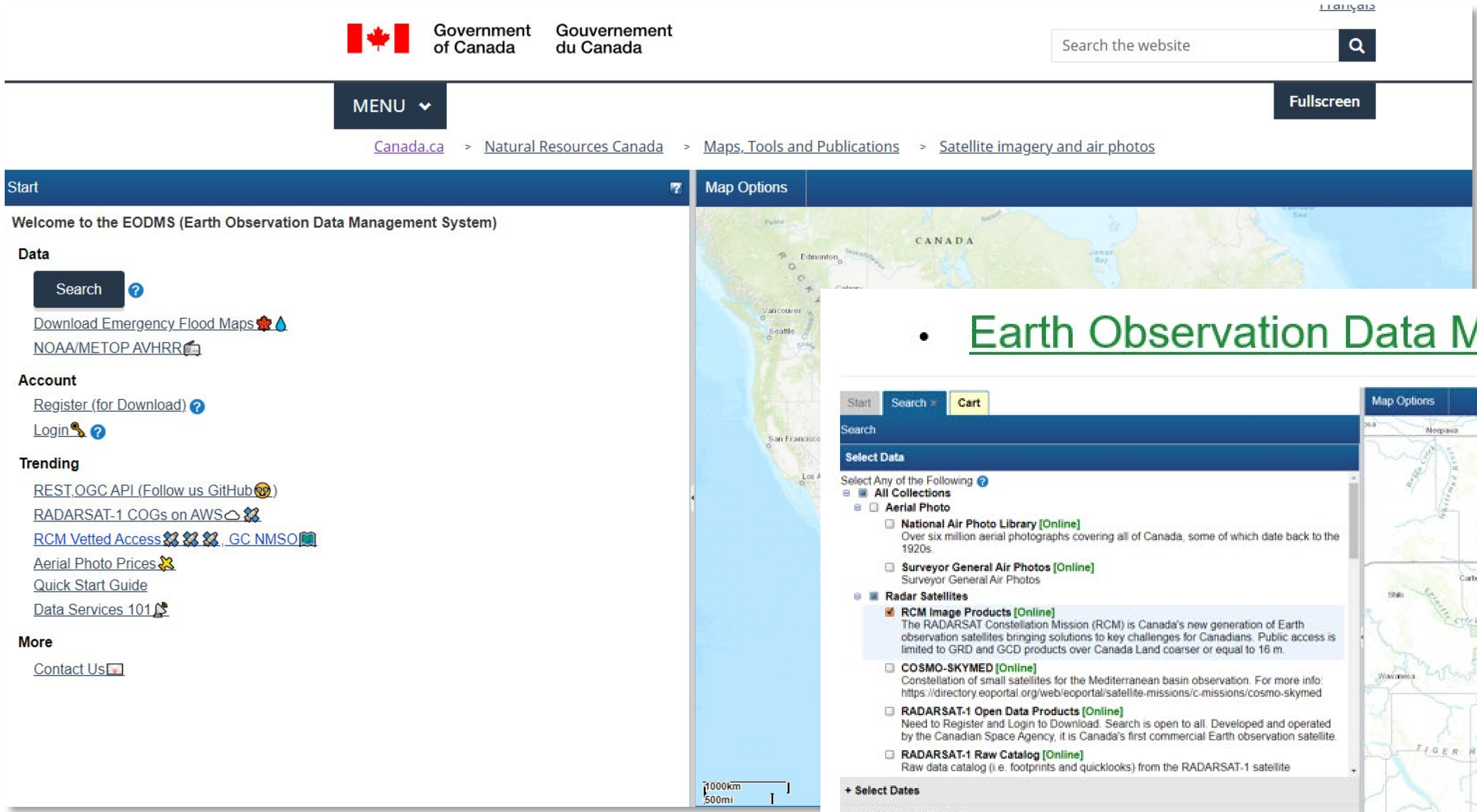
Mode	Res. m	Looks rng × az	Swath Width (accessible) km	Nominal NESZ (dB)	Polarization Options
					HH+VV+ HV+VH
Quad-Polarization	9	1	20 (250)	-24	Yes



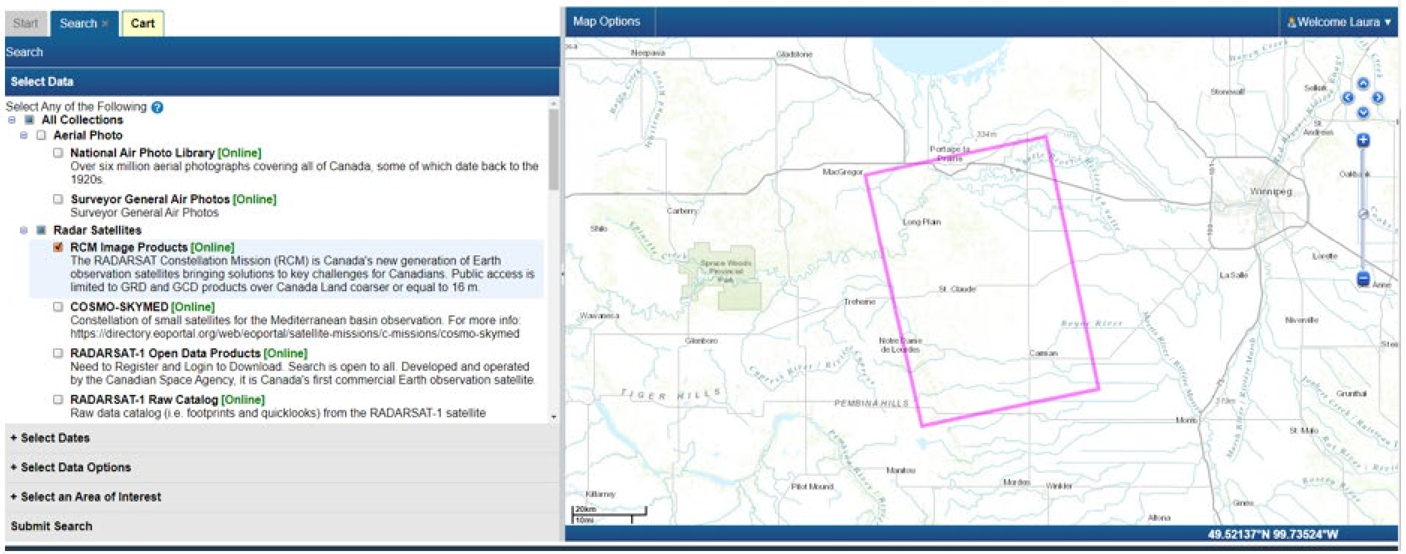
RCM SAR Beam Modes – Revisit Time: 4 days

RCM Fully Polarimetric Imagery

Slant Range SLC Product (Single Look Complex)



- [Earth Observation Data Management System]()

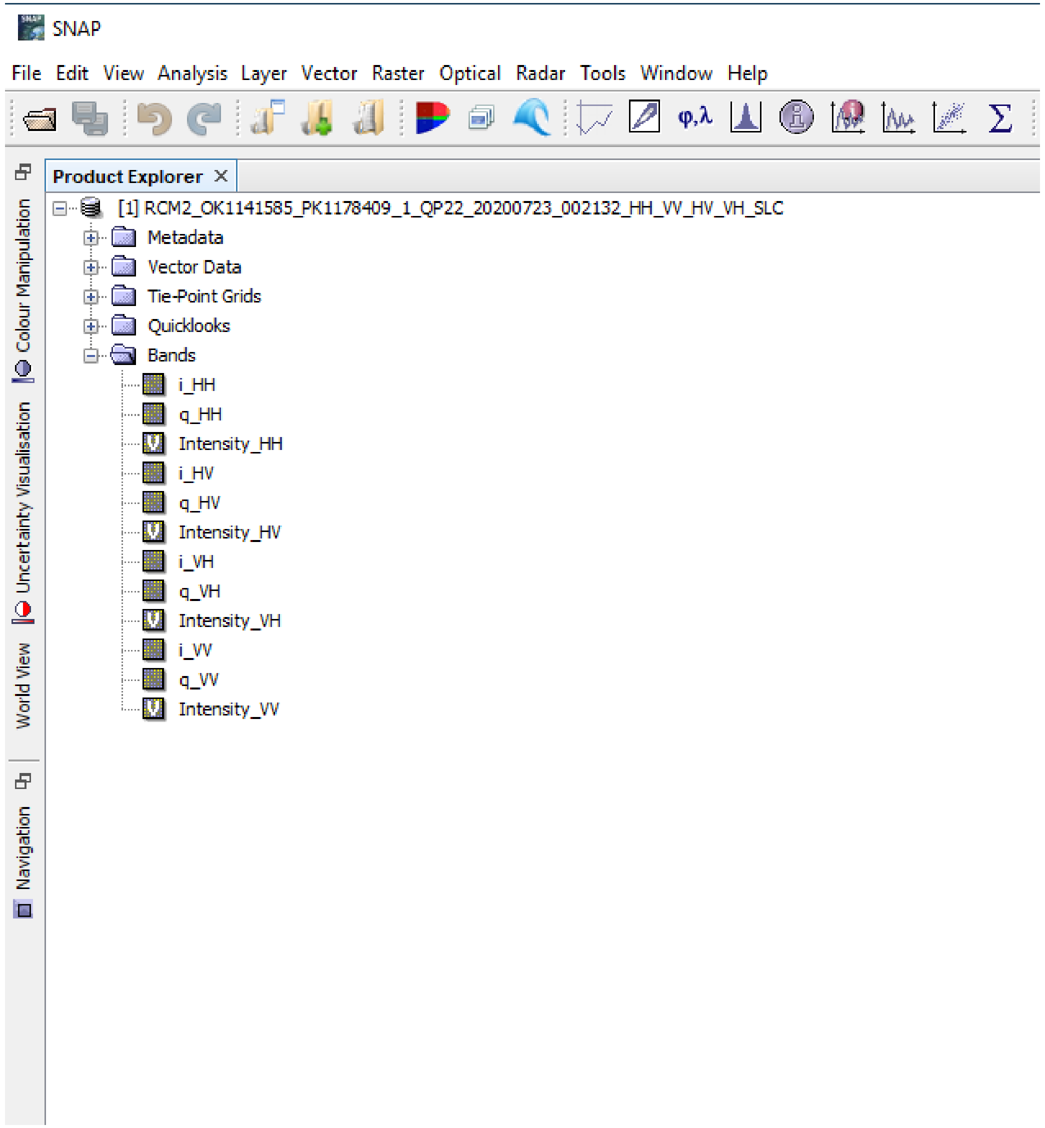


Radiometric Conversion

- SAR SLC products are complex and must be converted to intensity and phase channels.
- The conversion is mission-specific, and for polarimetric processing the data must be complex.
- Look Up Tables (LUTs) provided with the RCM SLC products are used to convert DN to complex real and imaginary bands.
- SNAP will automatically determine what kind of input product you have and what conversion needs to be applied based on the product's metadata.

Open RCM Image in SNAP

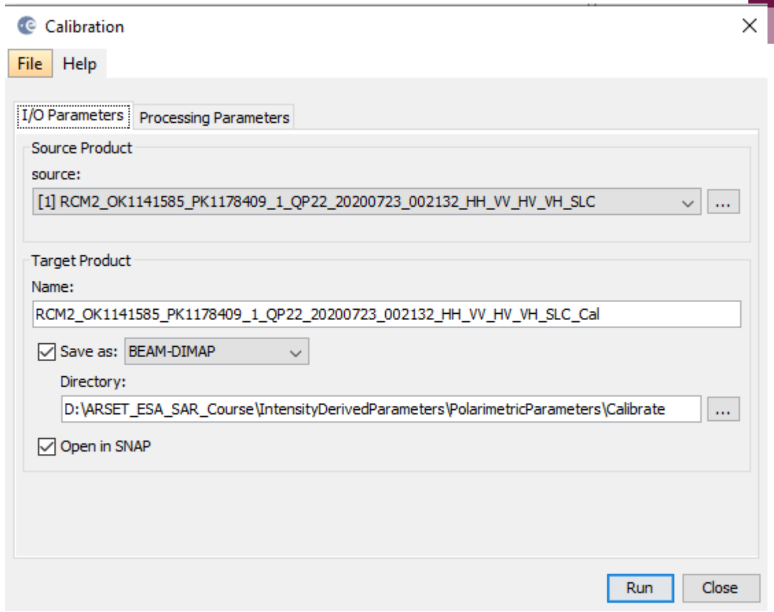
- Start the SNAP tool. Be sure to unzip the RCM image.
- In the SNAP interface, go to File menu >> open product.
- Click through the RCM folders until you find the manifest.safe file, select ‘Advanced’ & ‘Yes’.
- You can also “Drag and Drop” the folder into the SNAP Product Explorer Window.
- The Product Explorer window of SNAP contains like-pol and cross-pol bands in intensity and complex formats.

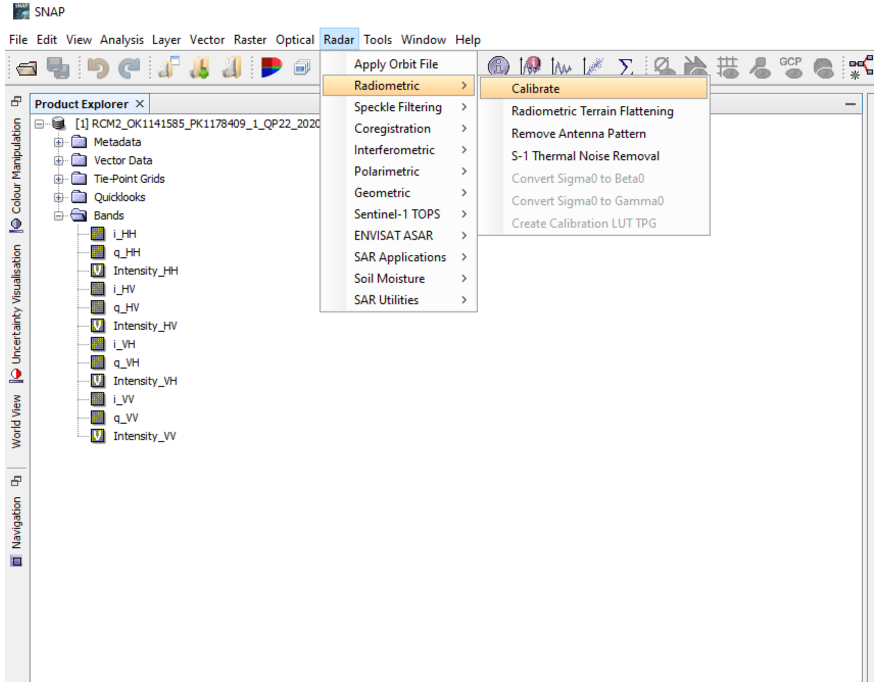


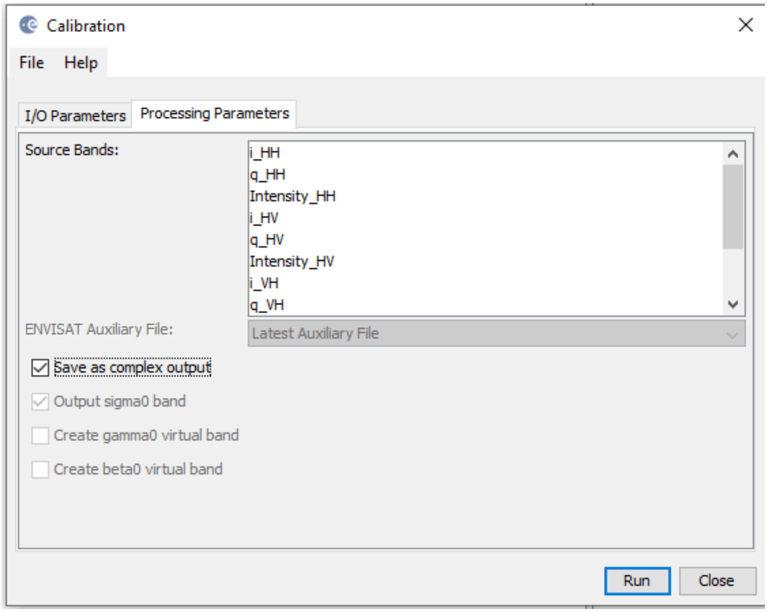
Radiometric Conversion in SNAP

Go to Radar Menu >> Radiometric >> Calibrate – Calibration:

- I/O Parameters tab: source → Raw RCM image + Target product
- Processing Parameters tab: Source Bands → all bands; Save as complex output
- Click Run and Close window when completed



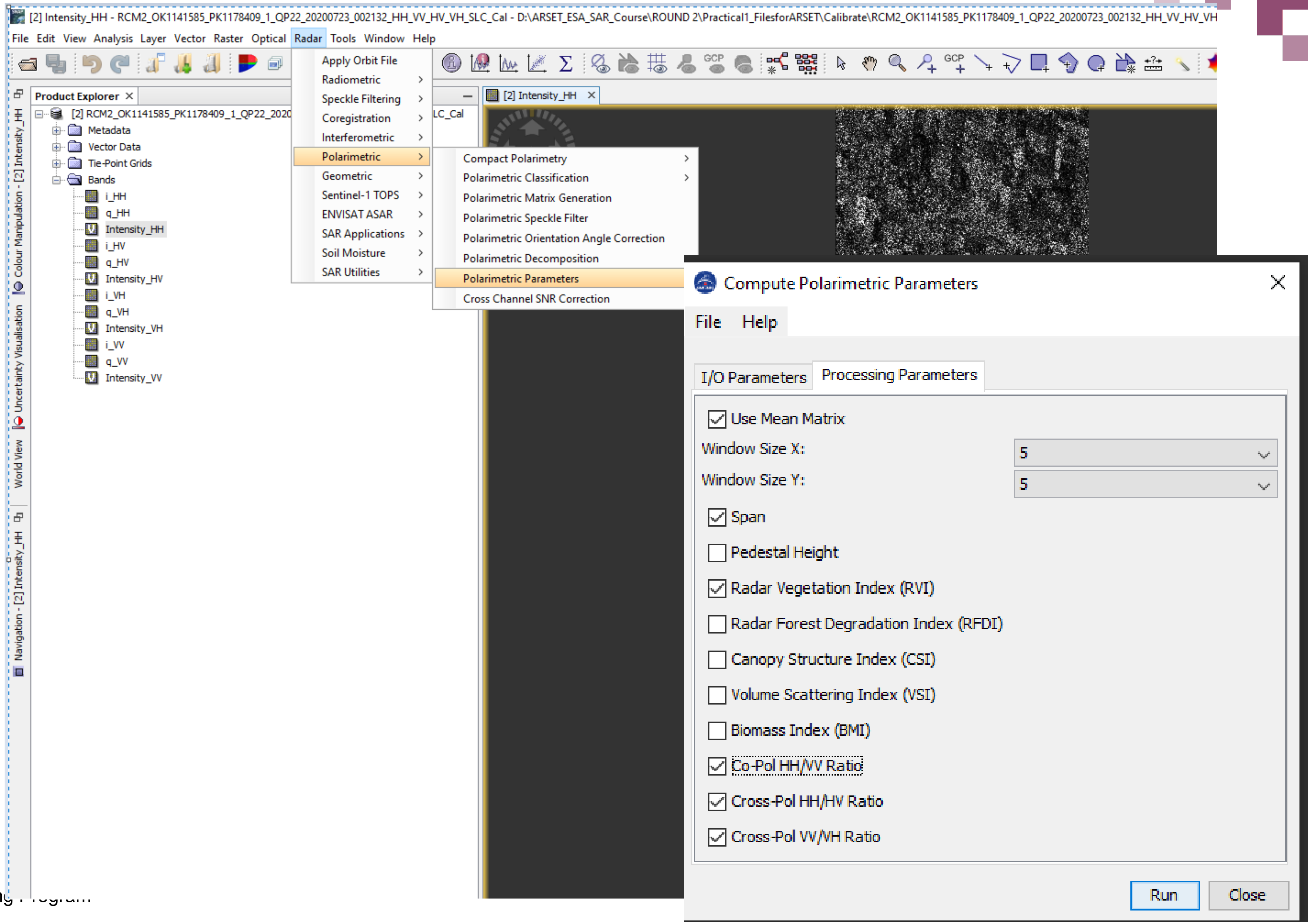




Polarimetric Parameters in SNAP

Go to Radar Menu >> Polarmetric>> Polarimetric Parameters :

- I/O Parameters tab: source → Calibrated images + Target product
- Processing Parameters tab:
  - Use Mean Matrix: Choose a window size to generate parameters
  - Choose the parameters to run
  - Click Run and Close window when completed

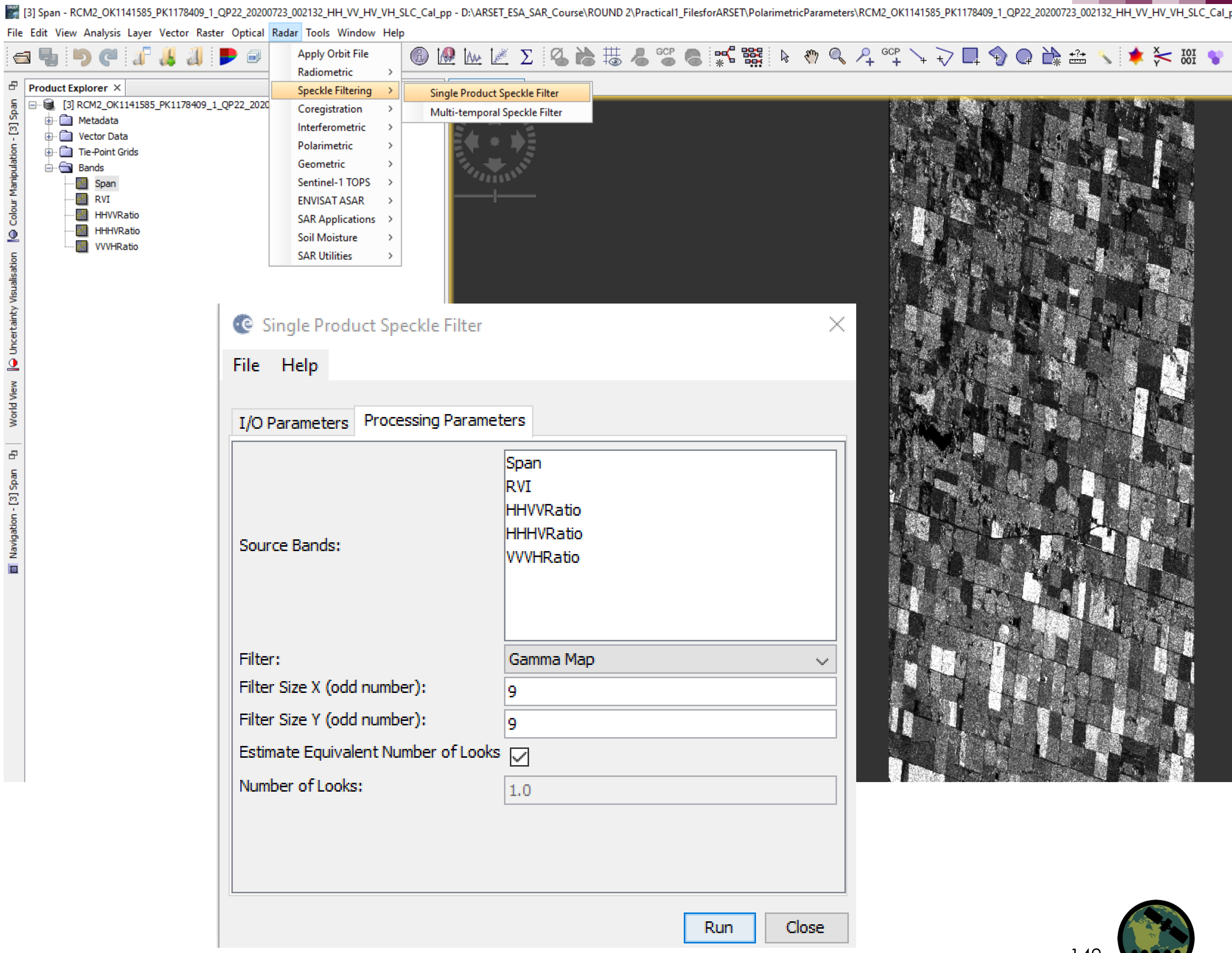


RADAR Speckle Filter

These are intensity-derived parameters and therefore regular radar speckle filtering can be used. The choice of filter type and size should be related to the AOI and what the final data will be used for.

Go to Radar Menu >> Speckle Filtering >> Single Product Speckle Filter :

- I/O Parameters tab: source → Calibrated Parameters images + Target product
- Processing Parameters tab:
  - Speckle Filter: Choose one of speckle filter types
  - Filter Size: Select filter size
  - Click Run and Close window when completed

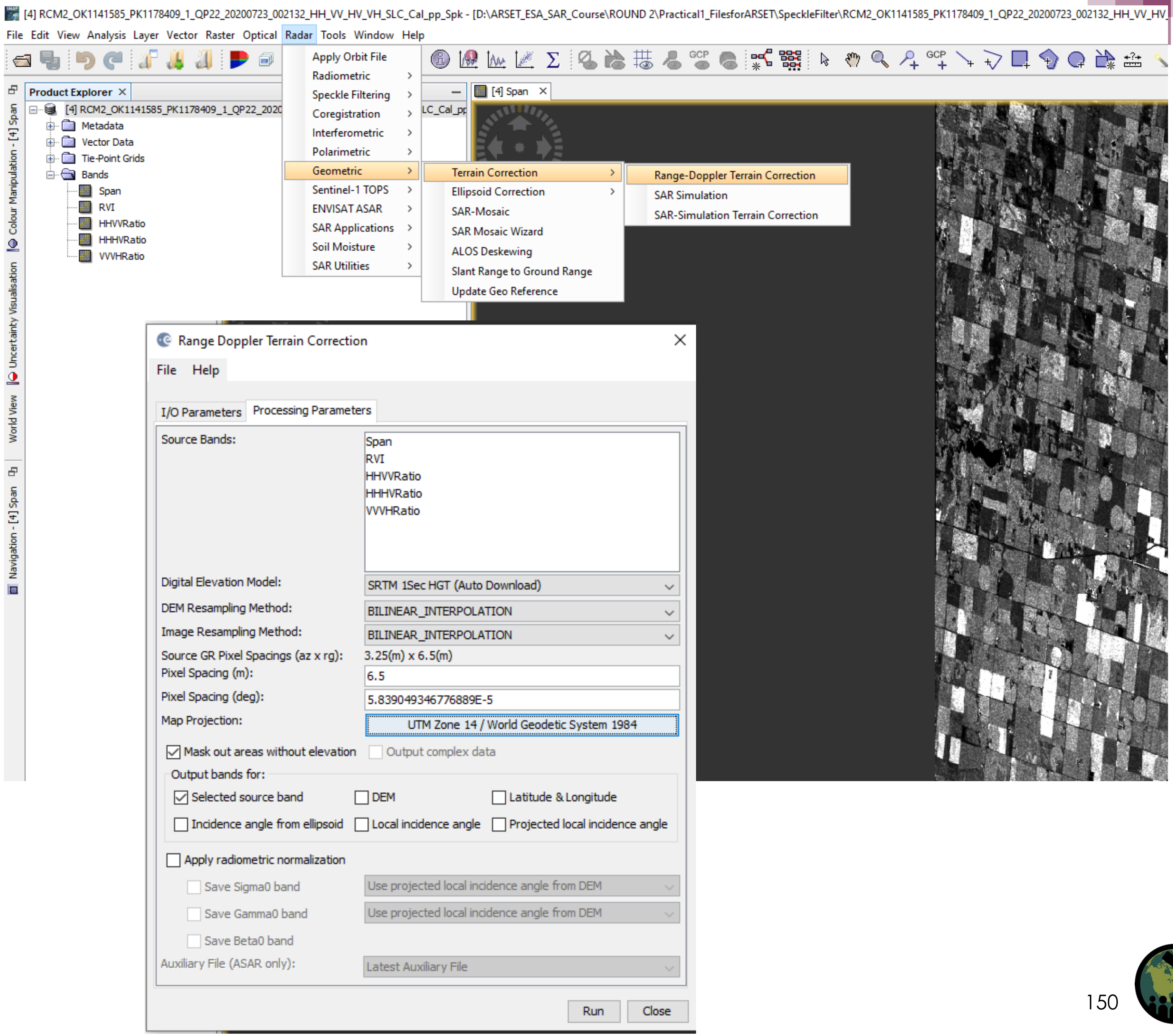


Terrain Correction

- Terrain correction, with the use of Digital Elevation Model (DEM) data, corrects topographical distortions like foreshortening, layover, or shadowing.
- The Range-Doppler approach is one way to perform geometric correction. The method needs information about the topography (normally provided by a DEM) as well as orbit satellite information to correct the topographic distortions and derive a precise geolocation for each pixel of the image.

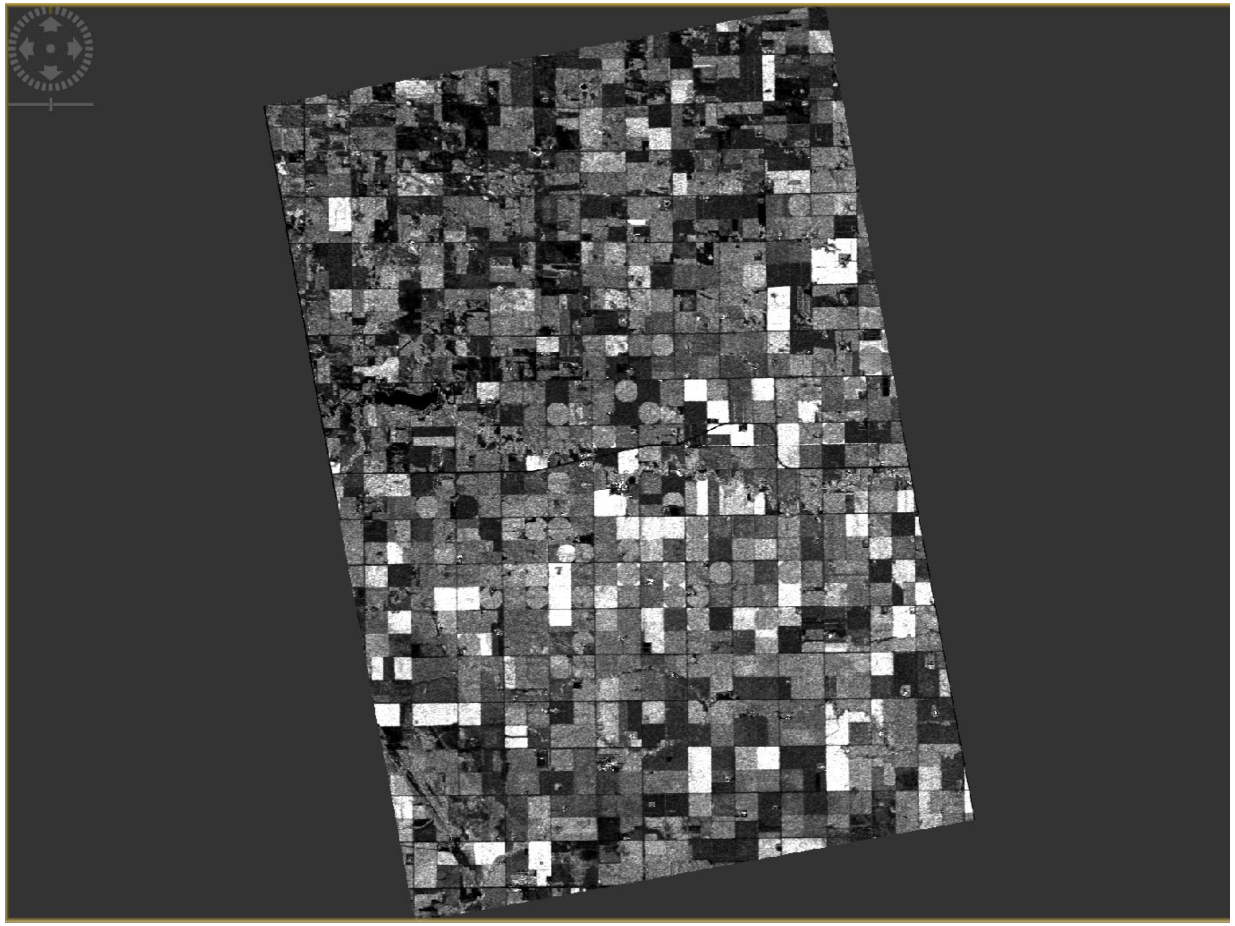
Go to Radar Menu >> Radar>> Geometric >> Terrain Correction >> Range Doppler Terrain Correction:

- I/O Parameters tab: source → Speckled Filtered Parameters + Target product
- Processing Parameters tab:
  - Digital Elevation Model: SRTM 1SEC HGT (or appropriate for your area)
  - Most parameters will be set as per your AOI
  - Click Run and Close window when completed



Once generated…

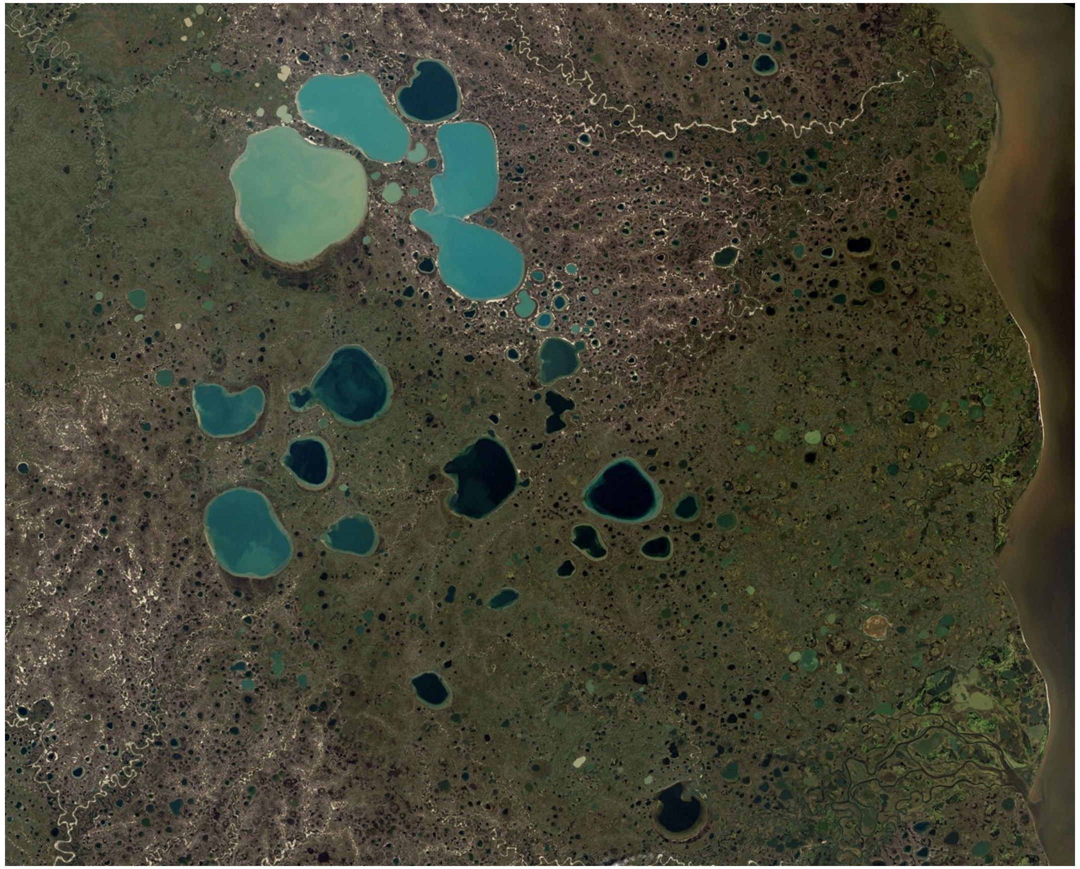
- As noted, there are many things you can do with these parameters for monitoring agriculture.
- Use them:
  - In classifications
  - In correlations with biomass, LAI, etc.
  - In assessments of change



Span Image – RCM July 23, 2020, Carman, Manitoba, Canada

Questions?

- Please enter your questions in the Q&A box. We will answer them in the order they were received.
- We will post the Q&A to the training website following the conclusion of the webinar.



https://earthobservatory.nasa.gov/images/6034/pothole-lakes-in-siberia

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  - https://appliedsciences.nasa.gov/join-mission/training/english/arset-mapping-crops-and-their-biophysical-characteristics
- ARSET Website:
  - https://appliedsciences.nasa.gov/arset
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Thank You!