

# Polarization with ALMA

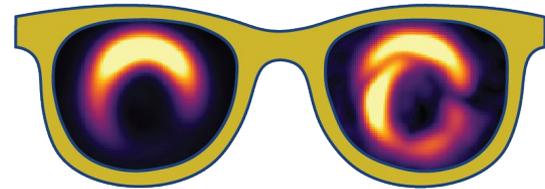
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*Rosita Paladino*

*ESO ARC astronomer*



- **Fundamentals of polarization**
- **Physical mechanisms generating polarization @ mm**
- **ALMA observations**
  - **Capabilities and available data**
  - **Polarization calibration principles (with some formulas)**
  - **Limitations**
  - **weblog and archive**
- **Tutorial**



designed by Katarina

# Credits

Rick Perley, Steven Meyers, George Moellenbrock, Ivan Marti-Vidal,  
Michiel Brentjens, Rainer Beck, Richard Crutcher,  
Shane O'Sullivan, Francesca Bacciotti, Cameron Van Eck

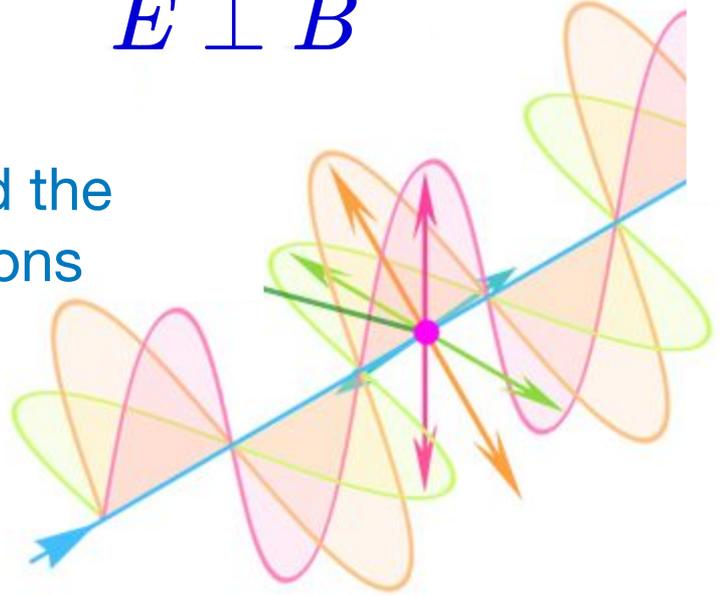
# Electromagnetic radiation

Propagating sets of oscillating **vectors:**  
**Electric & Magnetic fields**

$$\vec{E} \perp \vec{B}$$

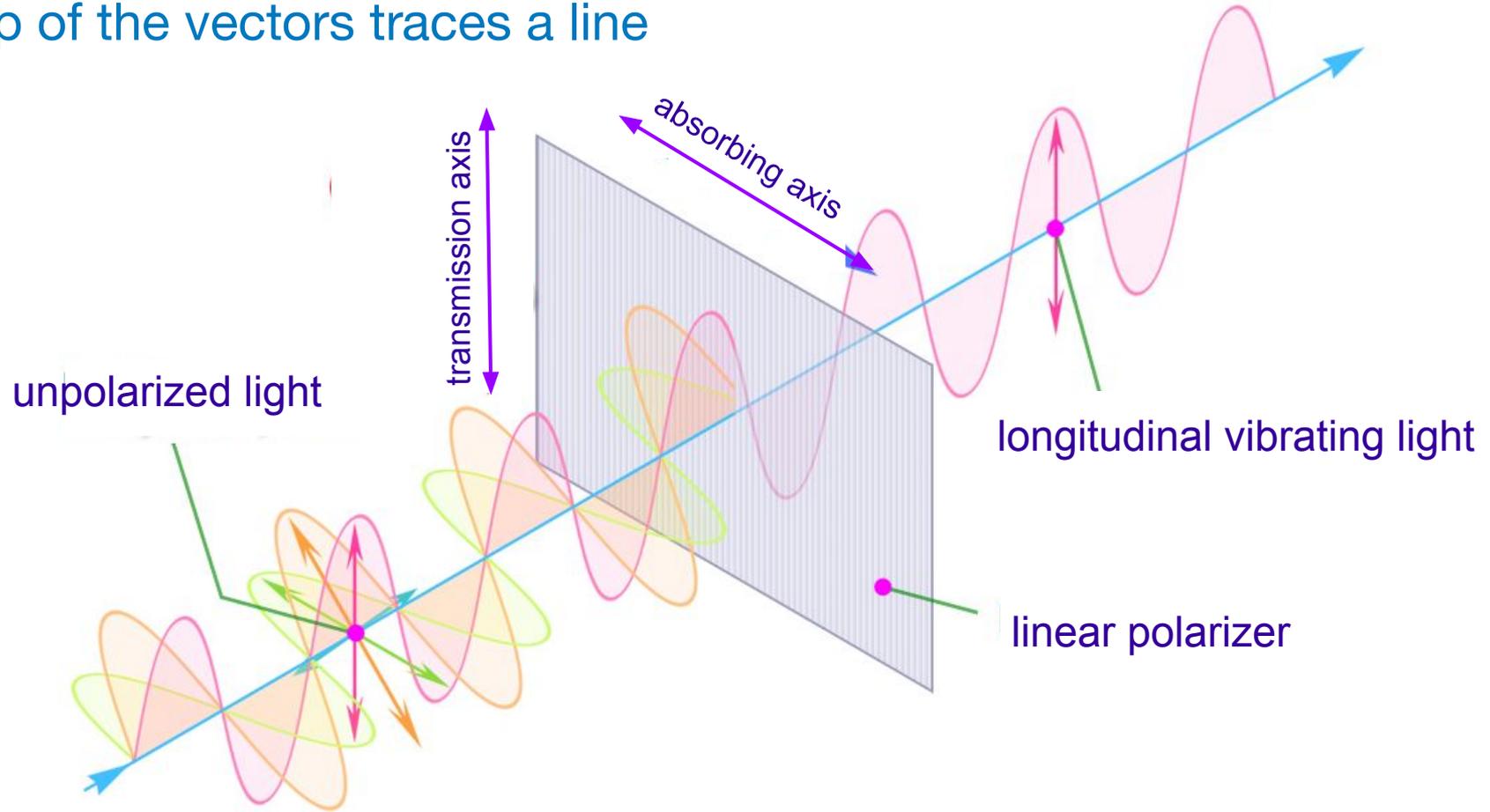
To properly describe it we need to add the  
geometrical orientation of the oscillations  
(=**polarization**)

**Normal (unpolarized) light:**  
vectors vibrate in every direction  
NO preferred polarization



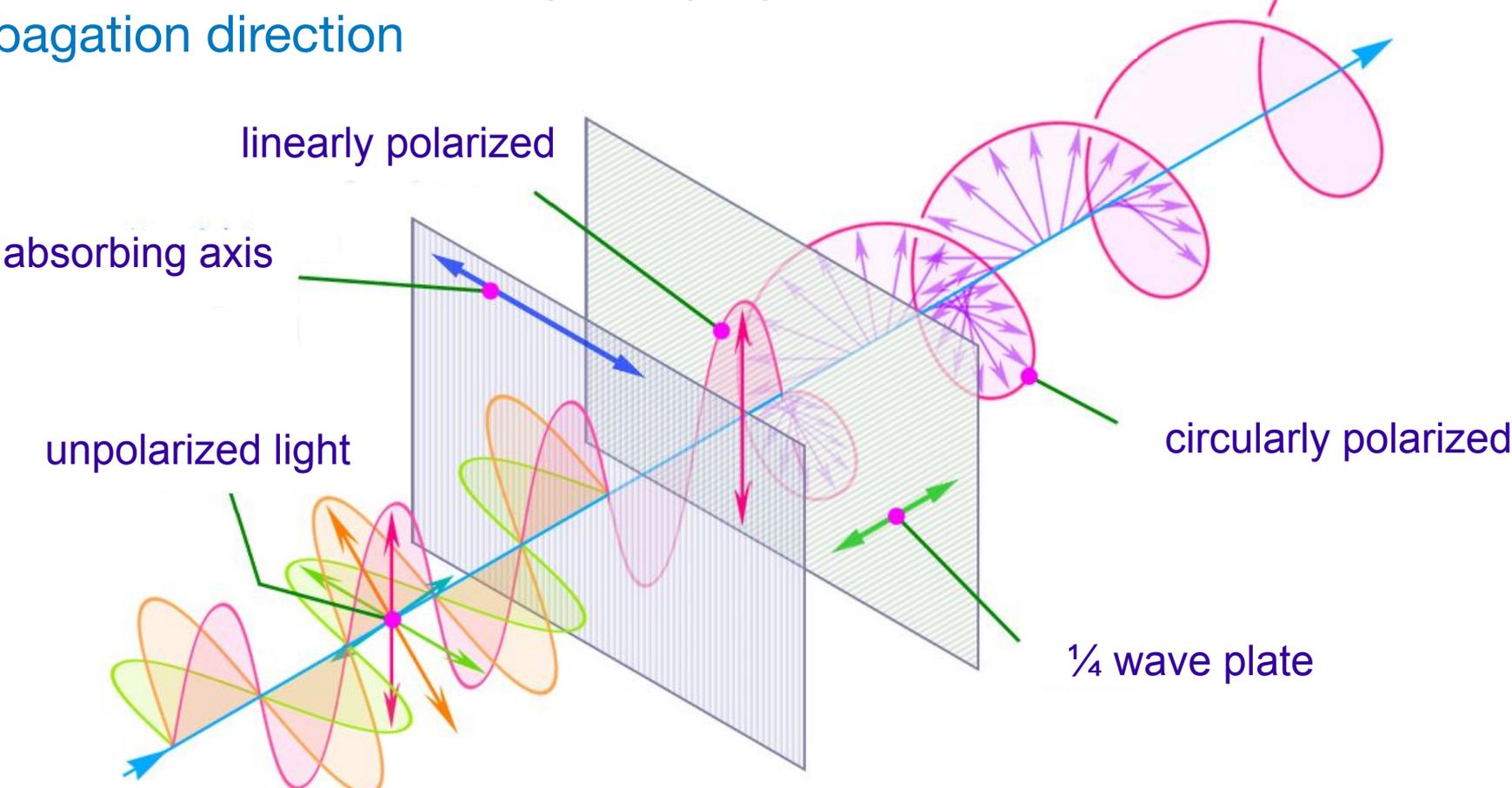
**electric field only**

# Linearly polarized light: the tip of the vectors traces a line



# Circularly polarized light:

vectors trace a circle in the plane perpendicular to the propagation direction

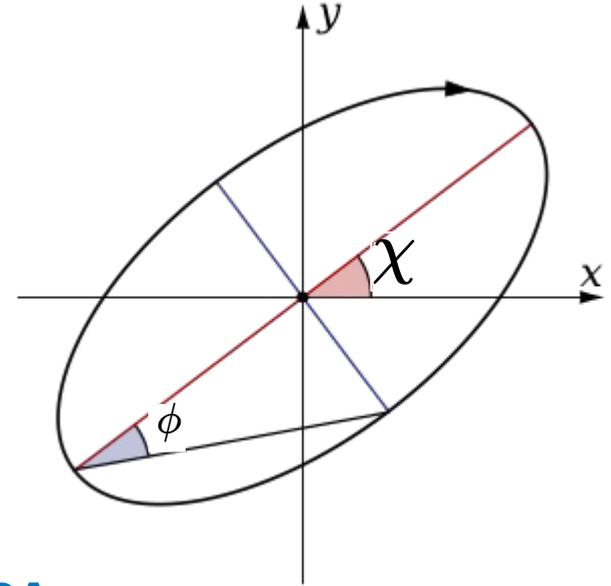


## Most general polarized light:

a mixture of linear and circular polarization = elliptical polarization

Need to know:

- ellipticity  $e = a/b \rightarrow \phi = \arctan(1/e)$
- dimension  $a$
- azimuth  $\chi$
- clockwise or counterclockwise



$\chi$  is the electric vector Position Angle **EVPA**

it has the symmetry

$$\chi + \pi \rightarrow \chi$$



**A** in the archive

# Stokes parameters

$$I^2 = Q^2 + U^2 + V^2$$

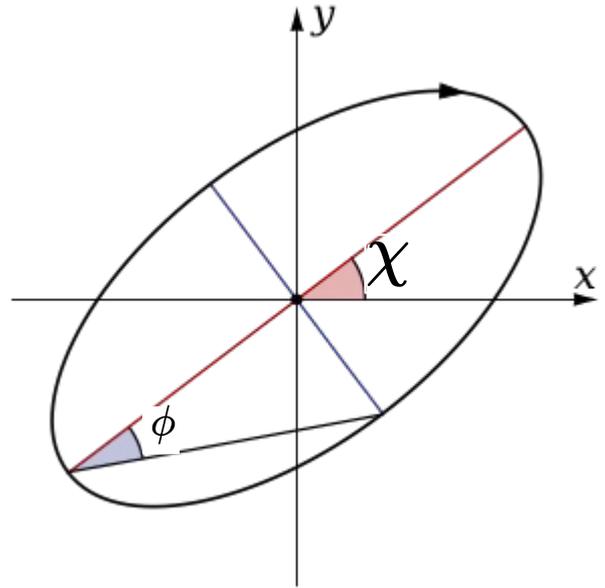
$$Q = \cos 2\phi \cos 2\chi$$

$$U = \cos 2\phi \sin 2\chi$$

$$V = \sin 2\phi$$

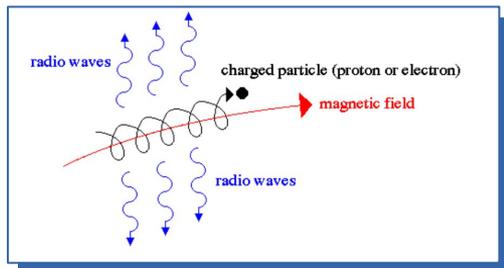
(ideal full polarized case)

- I is the total intensity (polarized + unpolarized)
- Q and U describe linear polarization
- V gives the circular polarization

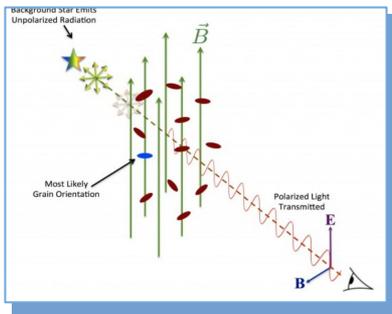


# Physical mechanisms generating polarization @ mm

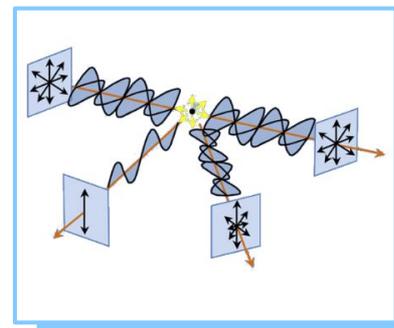
## continuum



Synchrotron

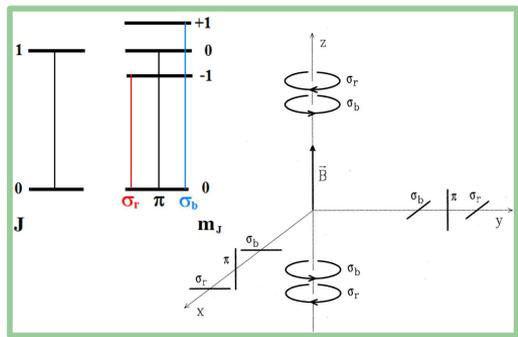


Dust

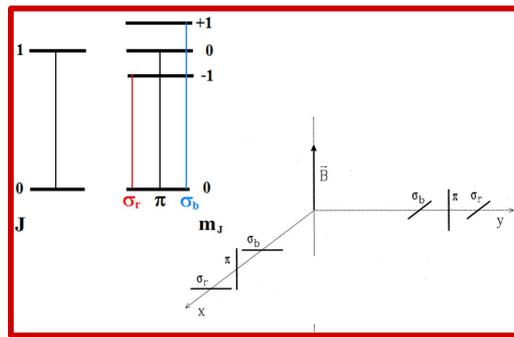


Scattering

## spectral lines

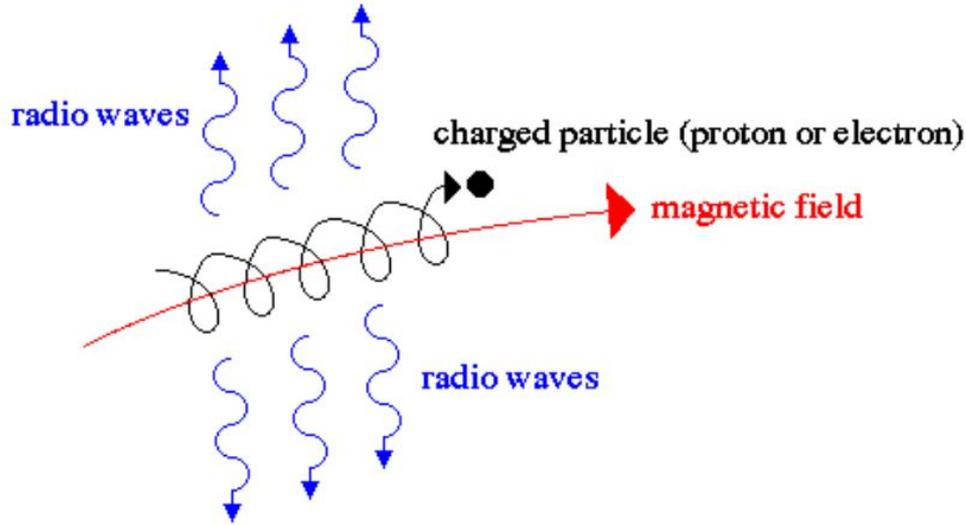


Zeeman



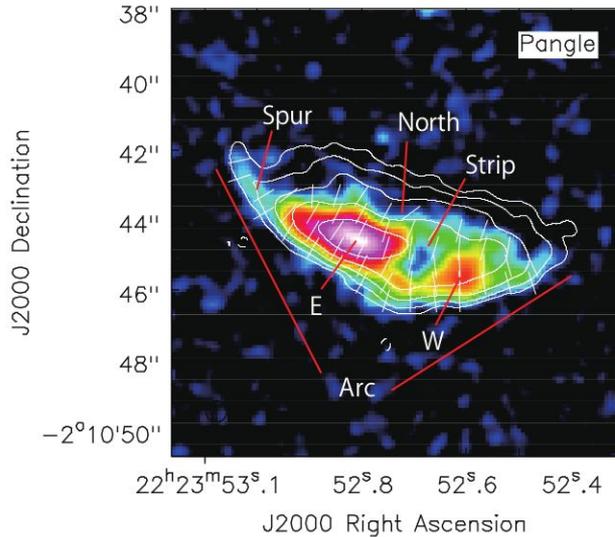
Goldreich-Kylafis

# Synchrotron emission - continuum

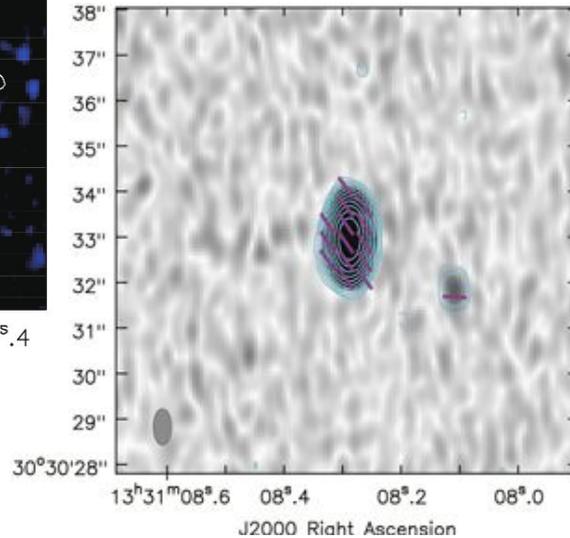


- Intrinsically polarized  $\perp \vec{B}$
- From total intensity
$$I_\nu \propto N_0 B^{(\delta+1)/2} \nu^{-\alpha}$$
**B strength** with assumptions (e.g. equipartition)
- From polarization angle  $\rightarrow$   
**orientation of B in the plane of the sky**  
fraction  $\rightarrow$   
**uniformity of B**

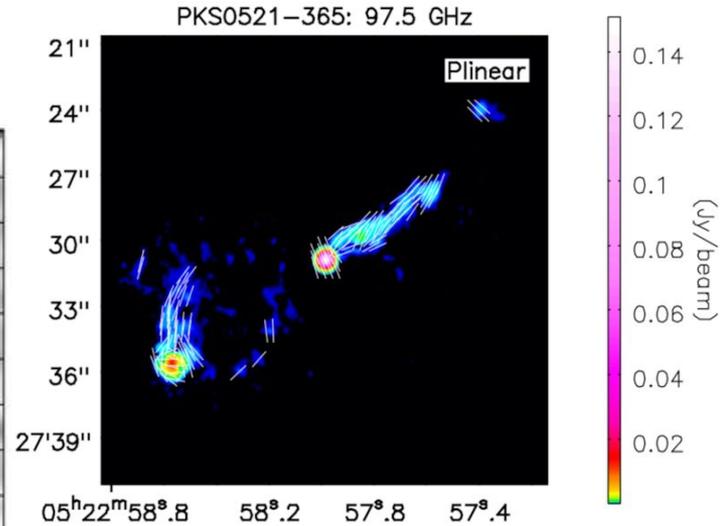
# Synchrotron emission - continuum



**Orienti et al. 2017**

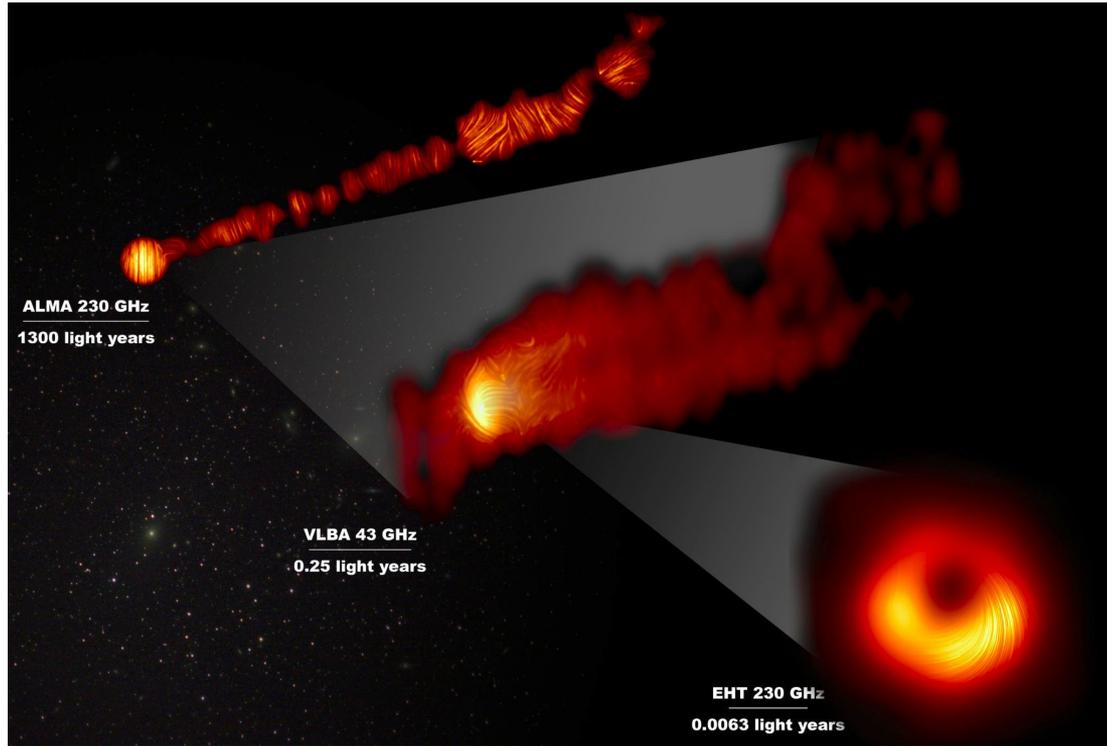


**Nagai et al. 2016**



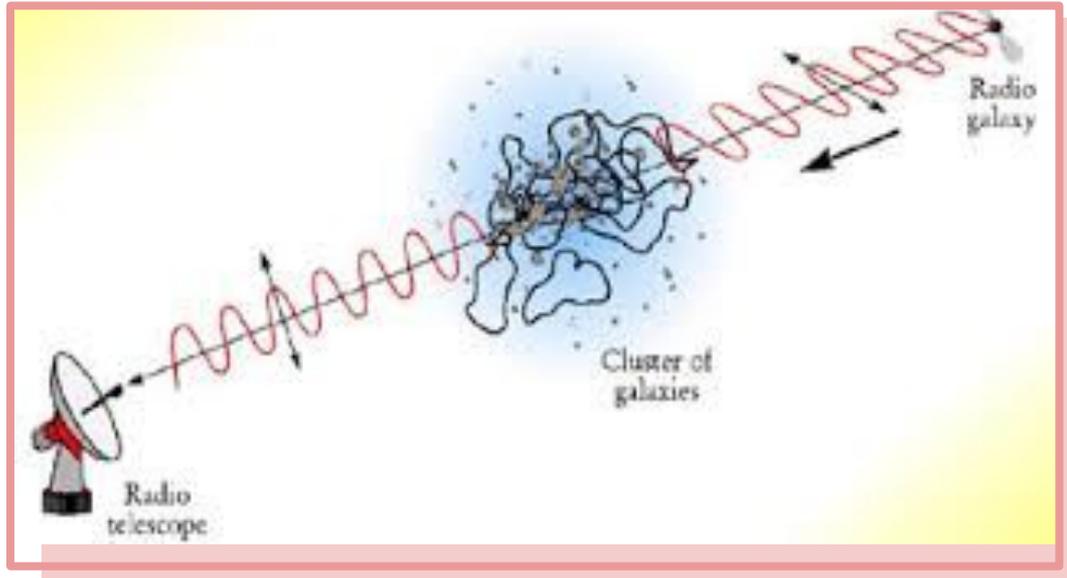
**Galluzzi et al. 2019**

# Synchrotron emission - continuum



EHT collaboration. 2021

# Faraday rotation - continuum



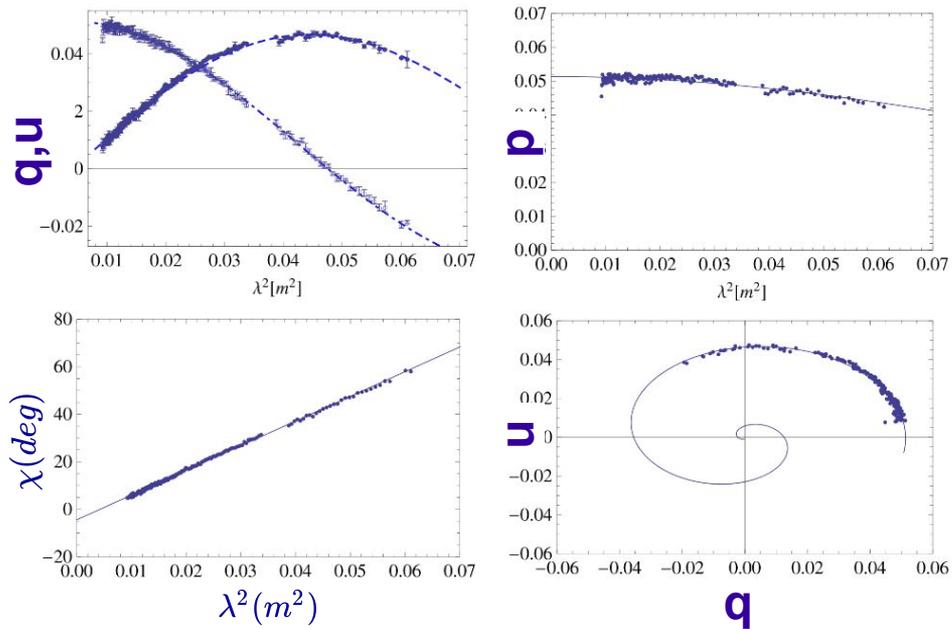
- Linearly polarized EM waves through magnetized plasma change the EVPA

$$\chi_{obs} = \chi_0 + RM\lambda^2$$

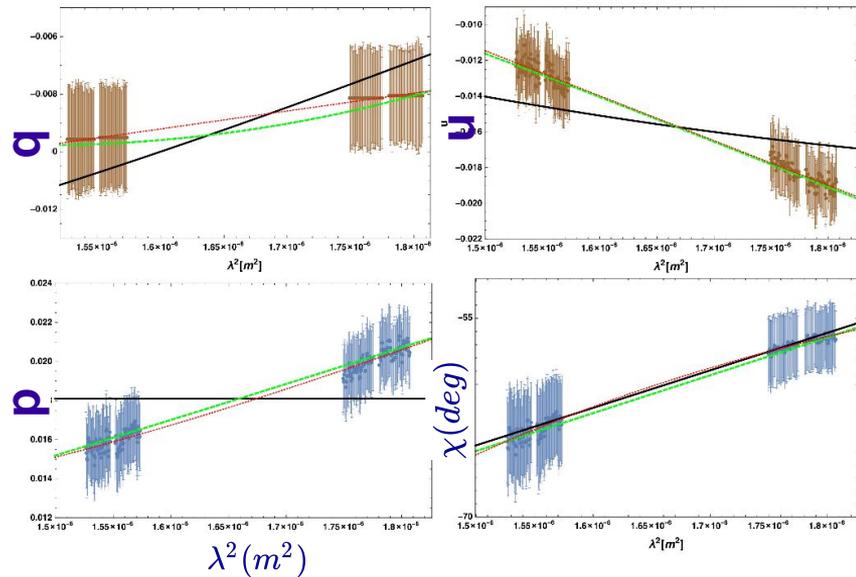
$$RM \propto \int n_e \vec{B} dl$$

- magnetic field along the line of sight

# Faraday rotation - continuum

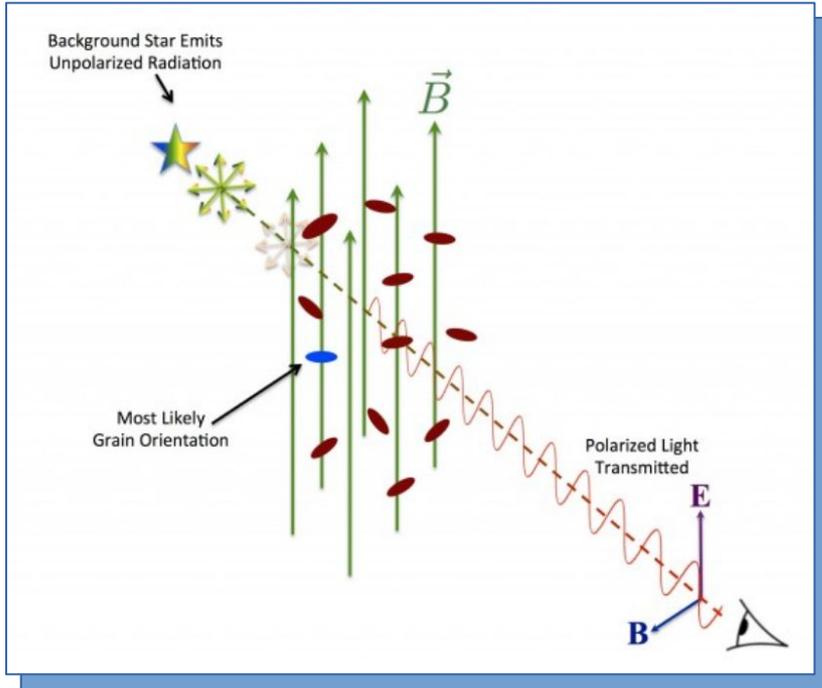


ATCA data  
O'Sullivan et al. 2012



Hovatta et al. 2019

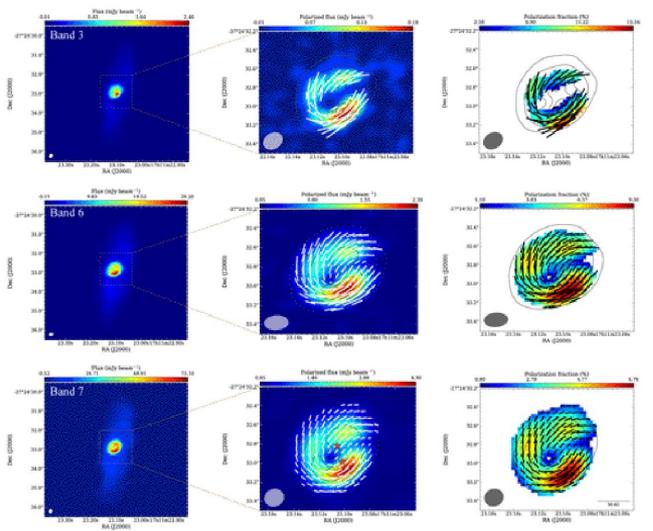
# Dust polarization - continuum



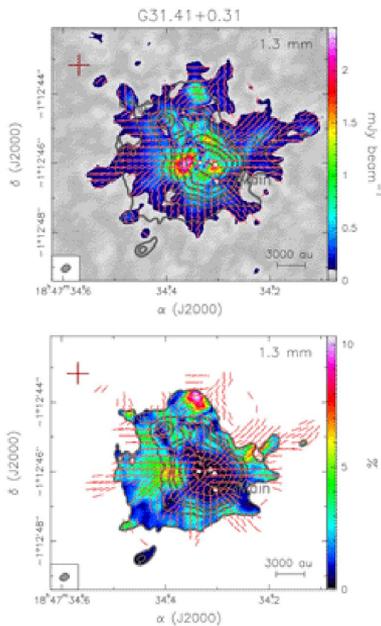
- Dust grains align minor axis with the magnetic field
- Different  $\lambda$  sample different grain size
- Polarization determines the **orientation of the field in the sky plane**
- Davis, 1951, Chandrasekar - Fermi 1953  
A statistical method  
**B strength**

$$B \propto \sqrt{4\pi\rho} \frac{\delta V_{los}}{\delta\theta}$$

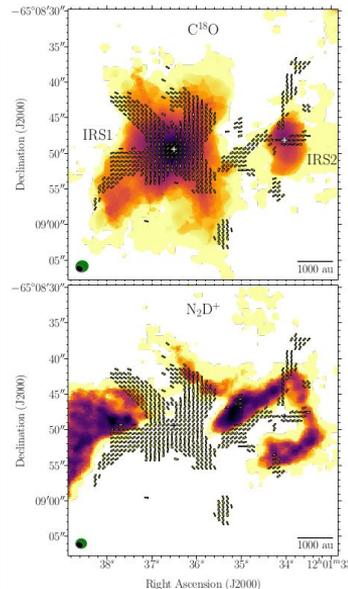
# Dust polarization - continuum



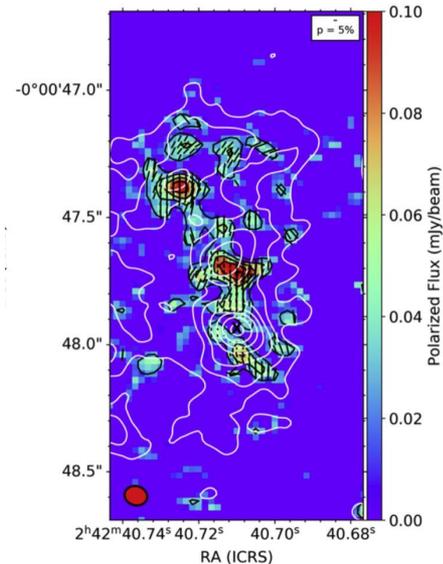
Alves et al. 2018



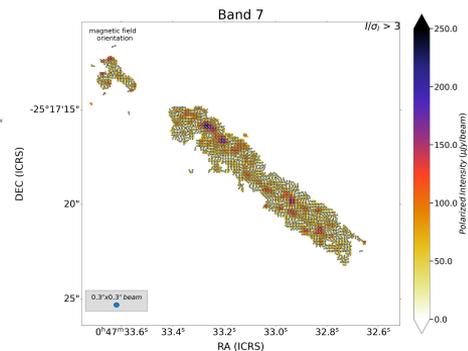
Beltran et al. 2019



Hull et al. 2019

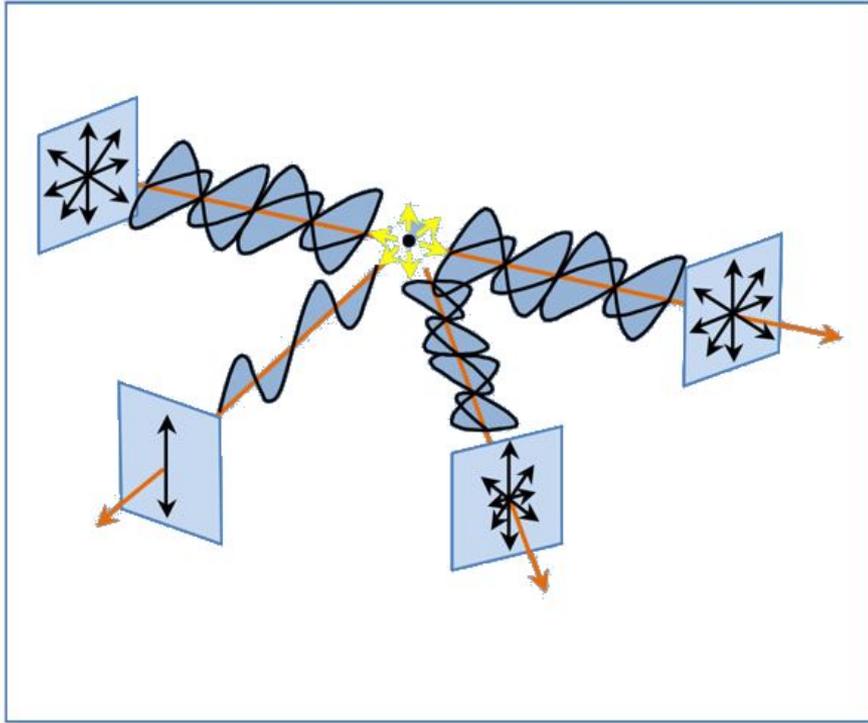


Lopez-Rodriguez et al. 2020



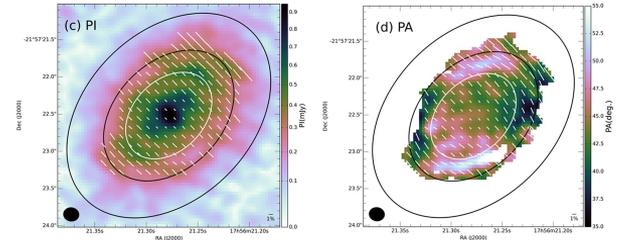
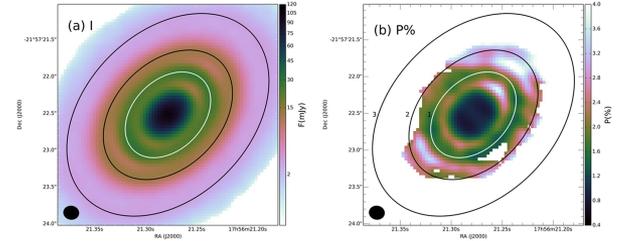
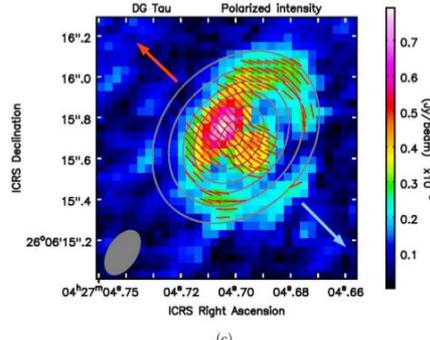
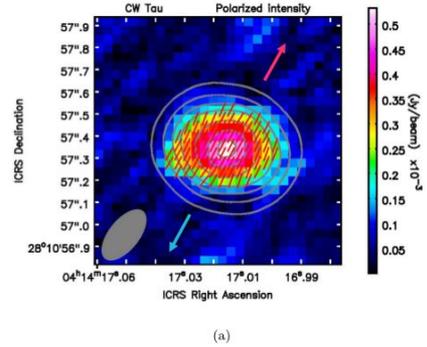
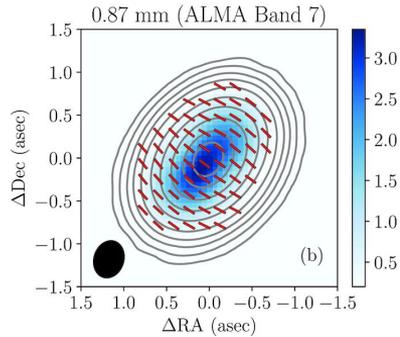
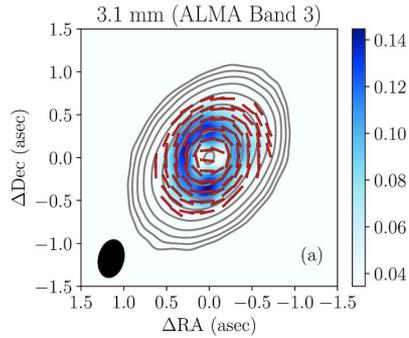
Belfiori et al. 2025

# Scattering - continuum



- Polarized (sub) mm wave emission can be produced partially or completely by the **self-scattering** of dust emission from (sub) mm-sized grains

# Scattering - continuum

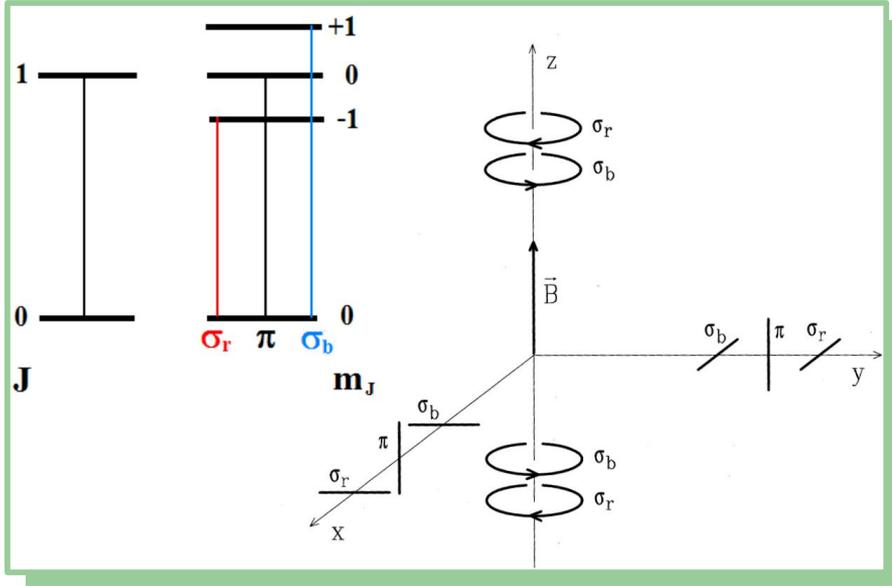


**Kataoka et al. 2017**  
**Stephens et al. 2017**

**Bacciotti et al. 2018**

**Dent et al. 2018**

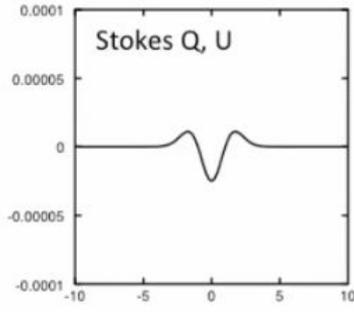
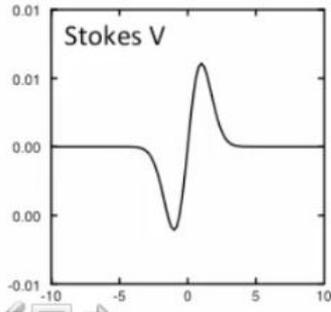
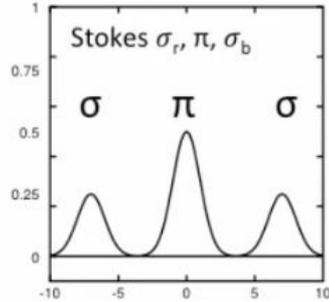
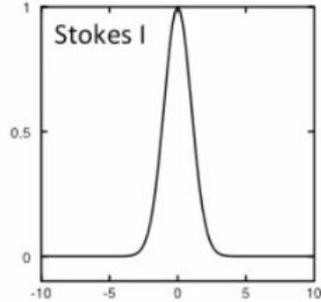
# Zeeman effect – spectral lines



- Magnetic fields split the levels of a molecular line, and the distance between sublevels:

$$\delta\nu_z \propto ZB$$

# Zeeman effect – spectral lines

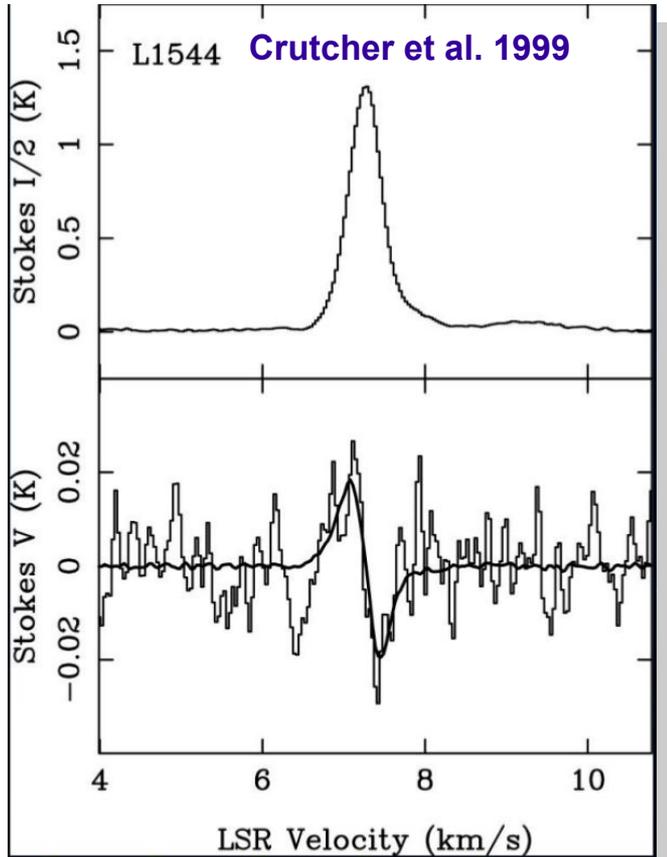


- Magnetic fields split the levels of a molecular line, and the distance between sublevels:

$$\delta\nu_z \propto ZB$$

- Parallel to the field --->  
only 2  $\sigma$  components circularly polarized  
Perpendicular to B --->  
3 components linearly polarized

# Zeeman effect – spectral lines



Typically only circular polarization is visible: due to the blending of the three components the linear polarization is very faint.

**CN Zeeman effect in a molecular cloud**

# Zeeman effect – spectral lines

## Possible Zeeman lines

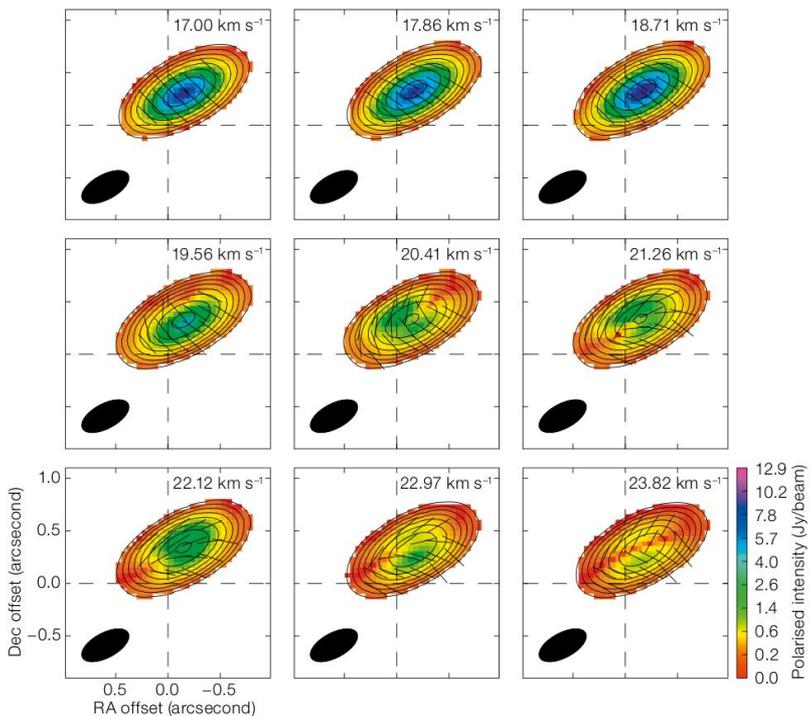
Species	Frequency GHz	ALMA Band
CN	113.5	3
	226.3	6
CCH	87.4	3
SO	99.3	3
	138.2	4
	159.0	4
	220.0	6
	236.5	6

Perez-Sanchez &  
Vlemmings 2013

## and Maser lines

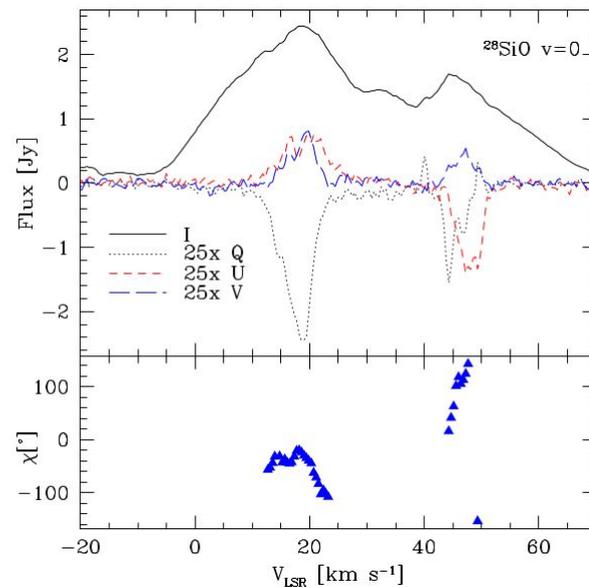
Species	Frequency GHz	ALMA band
SiO	86.24	3
	129.363	4
	172.481	5
	215.596	6
	258.707	6
H <sub>2</sub> O	83.310	3
	325.153	7
	439.151	8
HCN	89.0877	3
	177.238	4
	267.199	6
	354.461	7

# Zeeman effect – spectral lines

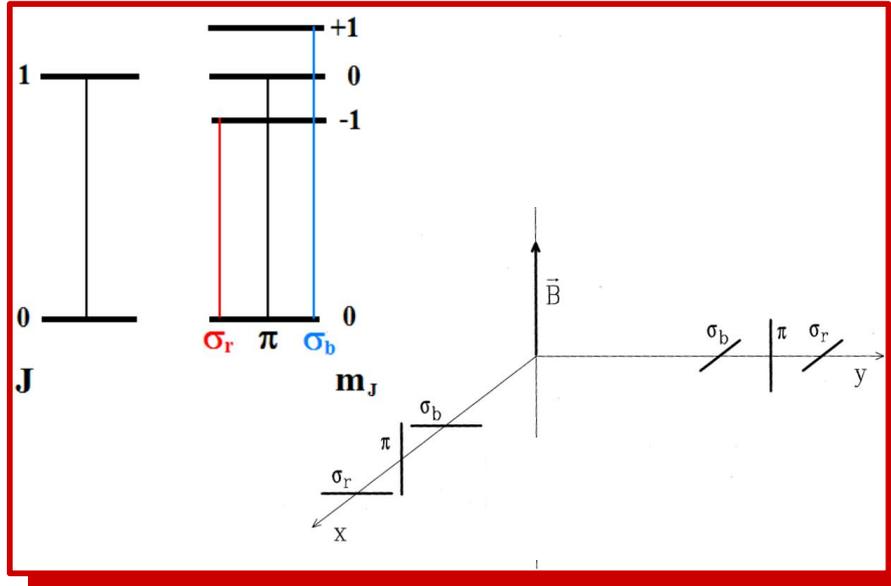


Vlemmings et al. 2017

## SiO maser polarization



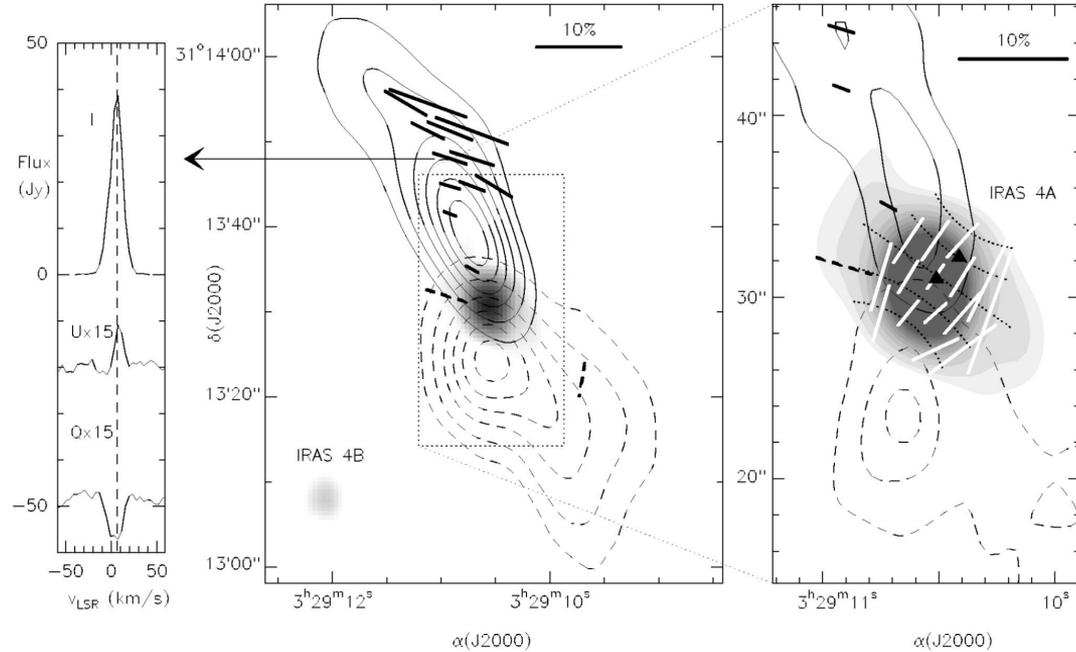
# Goldreich-Kylafis (G-K) effect – spectral lines



- Local anisotropy in line optical depths or in radiation fields
- Population imbalance of the  $\pi$  and  $\sigma$  transitions
- **Linear polarization of spectral lines, parallel or orthogonal to magnetic fields**
- **Direction of  $B$  in the plane of the sky**

# Goldreich-Kylafis (G-K) effect – spectral lines

## CO line linear polarization on NGC1333



Girart et al., 1999

**Questions?**

# Polarization capabilities offered over the cycles

From Cycle 2 to Cycle 12

## 12 m array

Band 3, 6, 7, 4, 5, 1

**On-axis** continuum and spectral line  
**linear** with 0.1% accuracy  
**circular** with limited accuracy

**Mosaics** continuum linear

**Solar** observations

## 7 m array

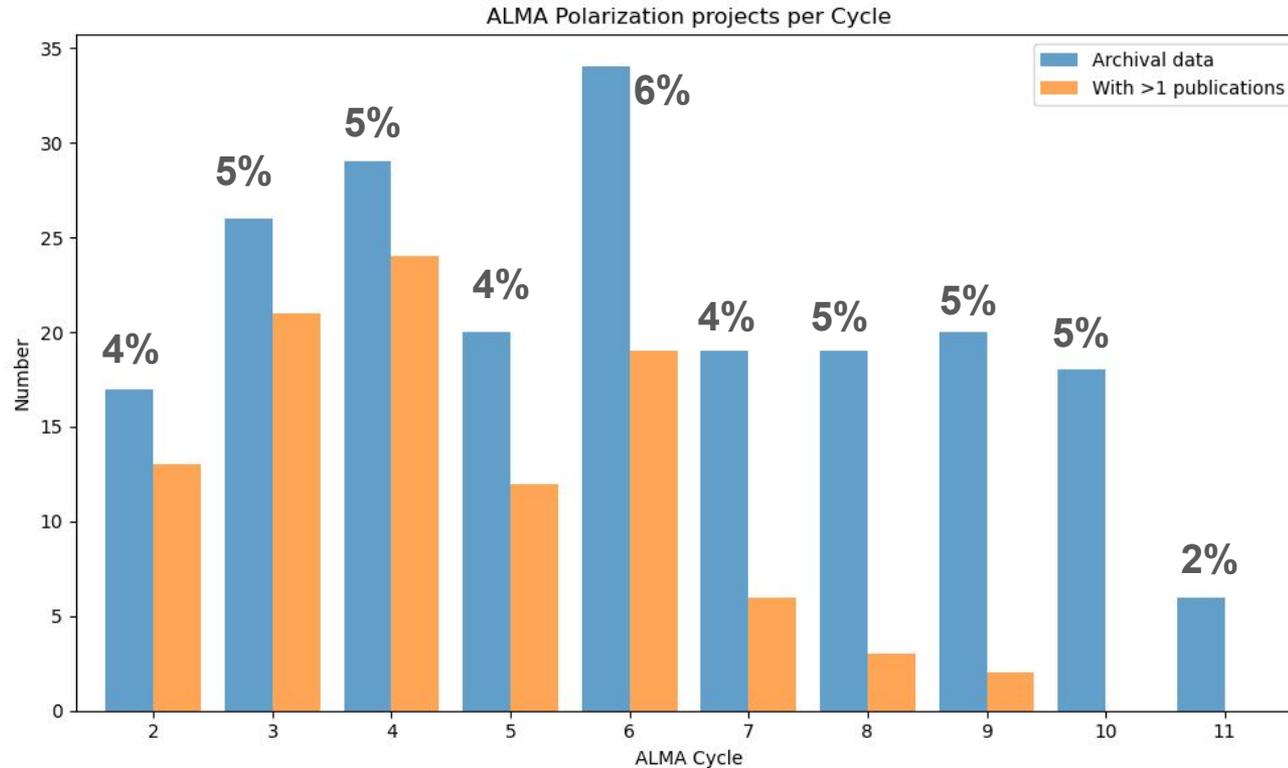
Band 3, 6, 7, 4, 5, 1

**On-axis** continuum and spectral line  
**linear** with 0.1% accuracy

**Mosaics** continuum linear

Observations taken in sessions  
OT assigns at least 3 hrs for a session  
Data combination not supported  
Pipeline calibration (since Cycle 10)

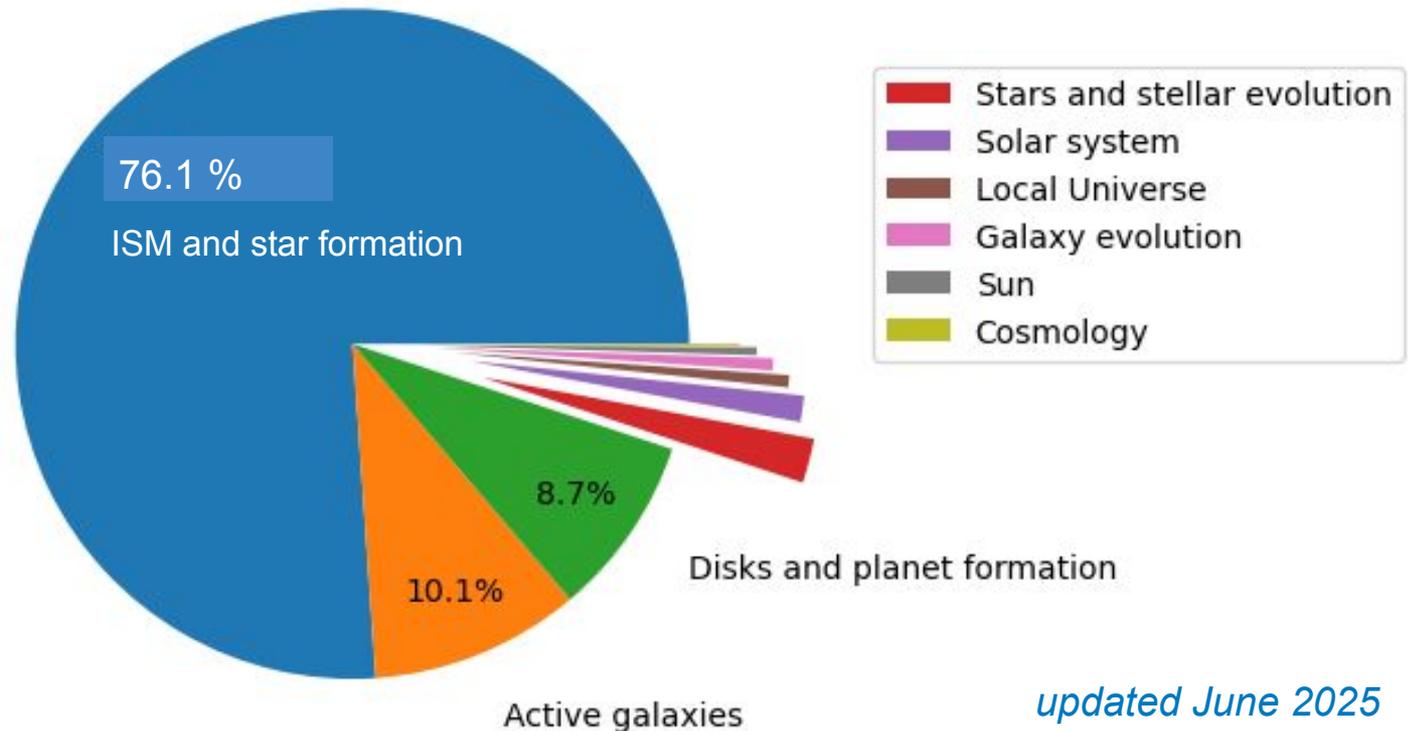
# Polarization data available in ALMA archive (excluding VLBI projects)



*updated June 2025*

# Polarization data available in ALMA archive

(excluding VLBI projects)  
per scientific category

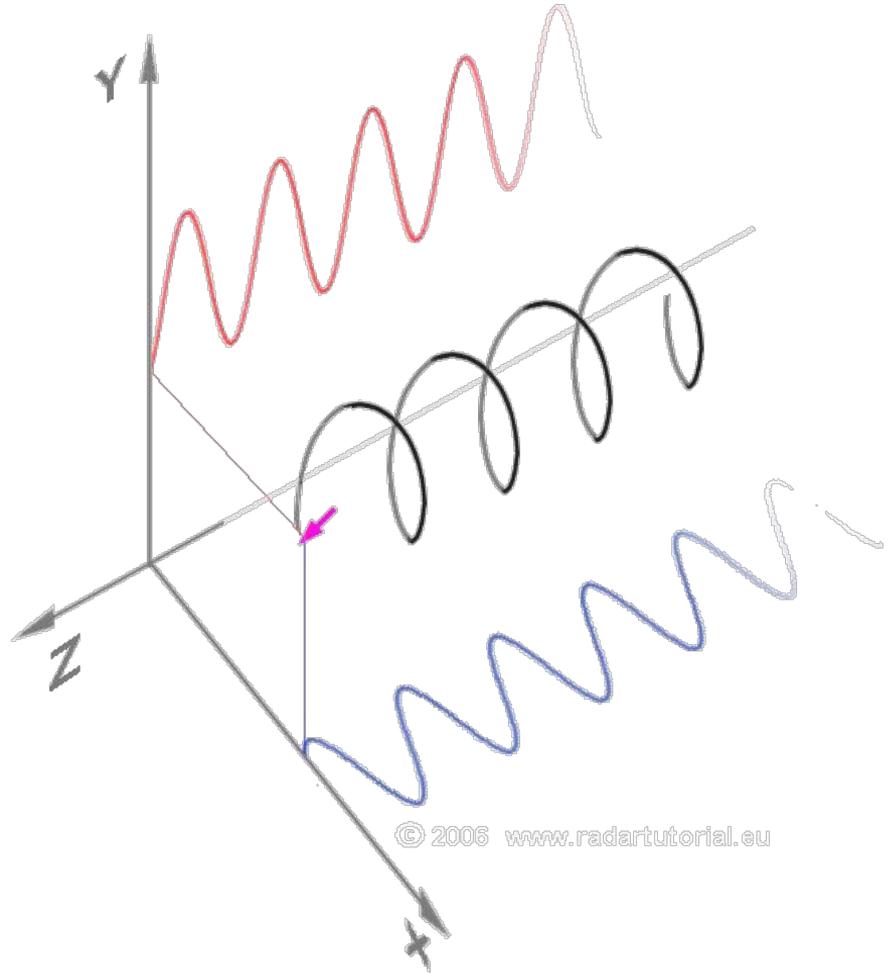


*updated June 2025*

# What does ALMA measure?

every polarized wave can be decomposed using two orthogonal polarizers registering linear or circular polarization.

**ALMA has linear feeds:**  
two orthogonal dipoles registering coherently two orthogonal polarization states



# What does ALMA measure?

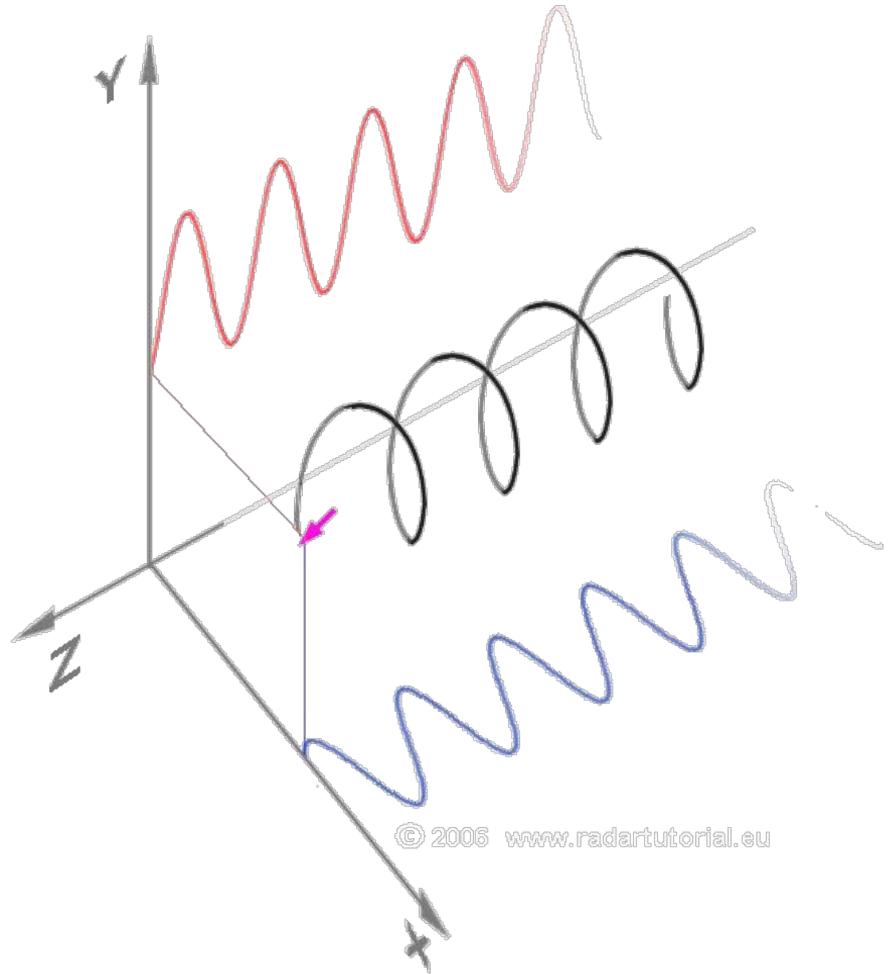
## ALMA has linear feeds

### Advantages:

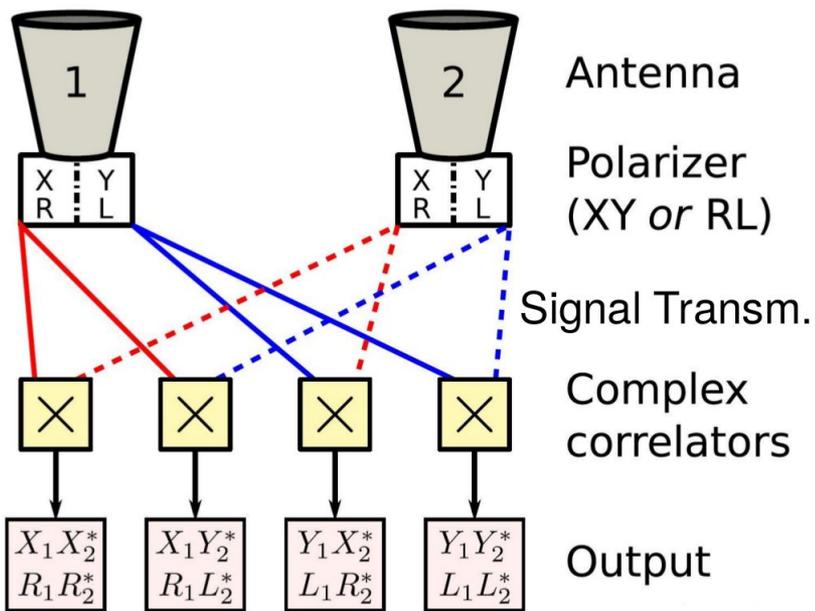
- antennas polarizers are natively linear
- extra component needed to make it circular hurts performances and are of narrower bandwidth
- phase shifter not available at mm

### Disadvantages:

- calibration is much simpler with circular feeds :-)

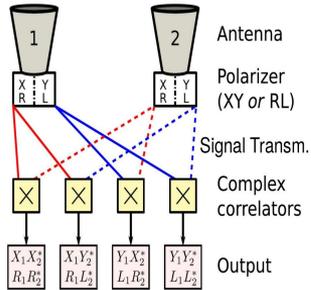


# Interferometric polarization observations



- **dual mode: only XX and YY** are registered → Stokes I only
- **full polarization mode** the four correlations **XX YY YX XY** are saved

# Interferometric polarization observations



In an ideal world we would get

- total intensity ----> Stokes I
- circular polarization ----> Stokes V

$$I = \frac{1}{2} (XX + YY)$$

$$Q = \frac{1}{2} (XX - YY)$$

$$U = \frac{1}{2} (XY + YX)$$

$$V = \frac{1}{2i} (XY - YX)$$

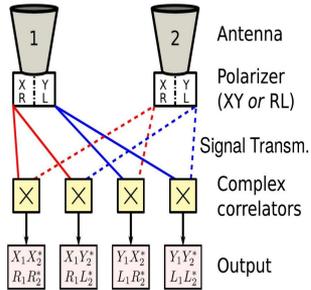
- linear polarization

$$PI = \sqrt{Q^2 + U^2}$$

- EVPA

$$\tan 2\chi = \frac{U}{Q}$$

# Interferometric polarization observations



$$I = \frac{1}{2} (XX + YY)$$

$$Q = \frac{1}{2} (XX - YY)$$

$$U = \frac{1}{2} (XY + YX)$$

$$V = \frac{1}{2i} (XY - YX)$$

## In the real world

- total intensity ---> Stokes I

**Instrumental effects corrupt cross-hands visibilities XY and YX:**

- linear polarization  $I = \sqrt{Q^2 + U^2}$
- beam polarization  $\tan 2\chi = \frac{U}{Q}$
- EVPA

# Polarization data reduction concepts

Ideal Visibilities:  $V^{true}$

$$V_{XX} = I + Q$$

$$V_{XY} = U + iV$$

$$V_{YX} = U - iV$$

$$V_{YY} = I - Q$$

Stokes visibilities

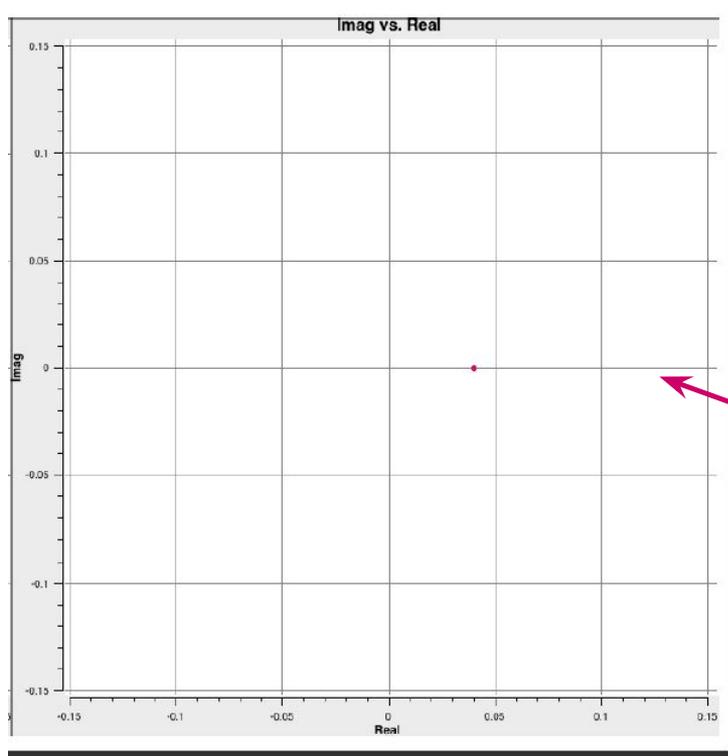
$$I = (V_{XX} + V_{YY}) / 2$$

$$Q = (V_{XX} - V_{YY}) / 2$$

$$U = (V_{XY} + V_{YX}) / 2$$

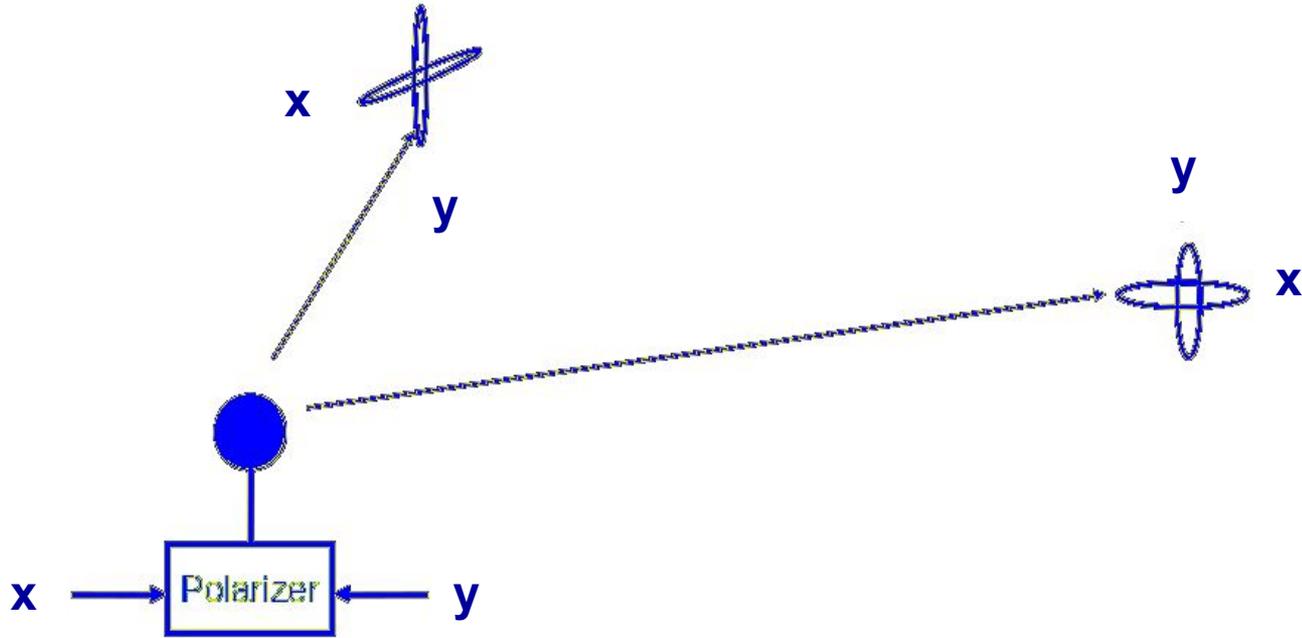
$$V = (V_{XY} - V_{YX}) / 2i$$

# Cross-hands visibilities



$V_{\text{true}}$

a single point



## For alt-az telescopes

the axis of the feeds rotates in the sky while tracking the source.

## Parallactic angle variation

# Parallactic Angle, $P$

- Sky orientation rotates in the field of view of an alt-az telescope:

$$\psi(t) = \frac{\cos b \sin H(t)}{\sin b \cos \delta - \cos b \sin \delta \cos H(t)}$$

$b = \text{latitude}; H(t) = \text{Hour Angle}; \delta = \text{declination}$

$$\mathbf{P}^{lin} = \begin{pmatrix} \cos \psi & \sin \psi \\ -\sin \psi & \cos \psi \end{pmatrix}$$

- At  $\psi = 0$  (meridian:  $H = 0$ ), mechanical feed position angle may be offset (linear basis)

# Parallactic Angle: $\mathbf{P} \mathbf{V}^{true}$

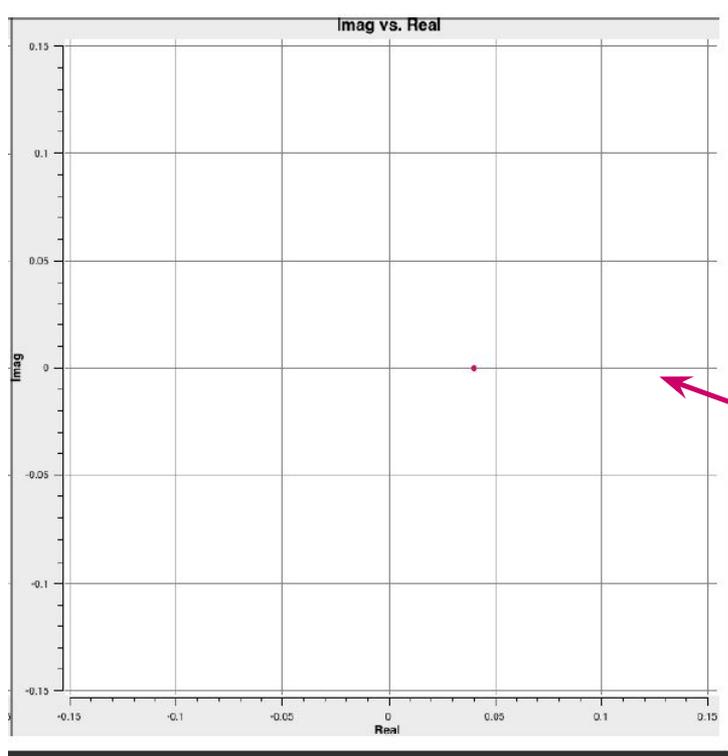
$$V_{XX} = \mathcal{I} + (Q \cos 2\psi + \mathcal{U} \sin 2\psi) = \mathcal{I} + Q_\psi$$

$$V_{XY} = (-Q \sin 2\psi + \mathcal{U} \cos 2\psi) + i\mathcal{V} = \mathcal{U}_\psi + i\mathcal{V}$$

$$V_{YX} = (-Q \sin 2\psi + \mathcal{U} \cos 2\psi) - i\mathcal{V} = \mathcal{U}_\psi - i\mathcal{V}$$

$$V_{YY} = \mathcal{I} - (Q \cos 2\psi + \mathcal{U} \sin 2\psi) = \mathcal{I} - Q_\psi$$

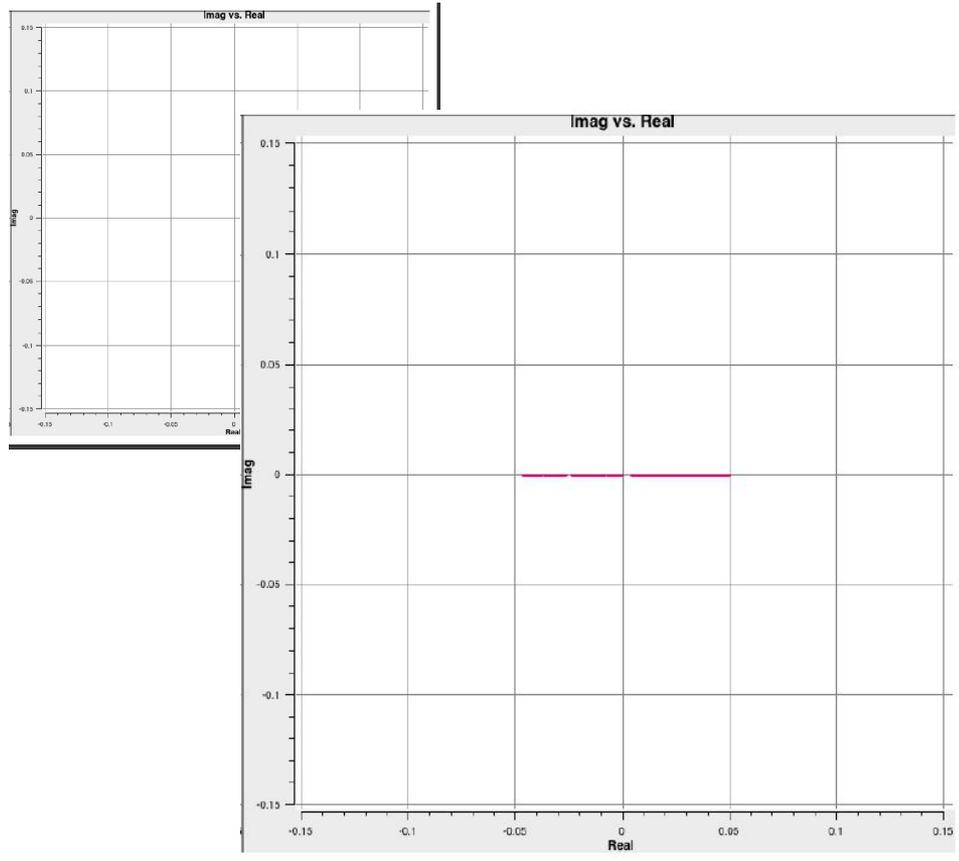
# Cross-hands visibilities



$V_{\text{true}}$

a single point

# Cross-hands visibilities



**PV**<sub>true</sub>

# Instrumental Polarization, $D$

- Each polarized receptor sees some of the other polarization:

$$D = \begin{pmatrix} 1 & d_p(v) \\ d_q(v) & 1 \end{pmatrix}$$

- General matrix
- Notation: “ $d_p$ ” is “the fraction of  $q$  polarization sensed by  $p$ ”
- |
- Origins:
  - Finite impurities in polarizers
  - Reflections that return in opposite polarization: standing waves
  - Asymmetry in optics

# $D$ in the Linear Basis

$$\mathbf{V} = \mathbf{D} \mathbf{P} \mathbf{V}^{true}:$$

$$V_{XX} = (\mathbb{1} + Q_\psi) + (\mathcal{U}_\psi + i\mathcal{V})d_{Xj}^* + d_{Xi}(\mathcal{U}_\psi - i\mathcal{V}) + d_{Xi}(\mathbb{1} - Q_\psi)d_{Xj}^*$$

$$V_{XY} = (\mathbb{1} + Q_\psi)d_{Yj}^* + (\mathcal{U}_\psi + i\mathcal{V}) + d_{Xi}(\mathcal{U}_\psi - i\mathcal{V})d_{Yj}^* + d_{Xi}(\mathbb{1} - Q_\psi)$$

$$V_{YX} = d_{Yi}(\mathbb{1} + Q_\psi) + d_{Yi}(\mathcal{U}_\psi + i\mathcal{V})d_{Xj}^* + (\mathcal{U}_\psi - i\mathcal{V}) + (\mathbb{1} - Q_\psi)d_{Xj}^*$$

$$V_{YY} = d_{Yi}(\mathbb{1} + Q_\psi)d_{Yj}^* + d_{Yi}(\mathcal{U}_\psi + i\mathcal{V}) + (\mathcal{U}_\psi - i\mathcal{V})d_{Yj}^* + (\mathbb{1} - Q_\psi)$$

**We assume second order terms are negligible**

**D** in the Linear Basis  $\mathbf{V} = \mathbf{D}\mathbf{P}\mathbf{V}^{\text{true}}$ .

- Linearized, sorted:

$$V_{XX} = (\mathcal{I} + Q_{\psi}) + (\mathcal{U}_{\psi} + i\mathcal{V})d_{Xj}^* + d_{Xi}(\mathcal{U}_{\psi} - i\mathcal{V})$$

$$V_{XY} = (\mathcal{U}_{\psi} + i\mathcal{V}) + (\mathcal{I} + Q_{\psi})d_{Yj}^* + d_{Xi}(\mathcal{I} - Q_{\psi})$$

$$V_{YX} = (\mathcal{U}_{\psi} - i\mathcal{V}) + d_{Yi}(\mathcal{I} + Q_{\psi}) + (\mathcal{I} - Q_{\psi})d_{Xj}^*$$

$$V_{YY} = (\mathcal{I} - Q_{\psi}) + d_{Yi}(\mathcal{U}_{\psi} + i\mathcal{V}) + (\mathcal{U}_{\psi} - i\mathcal{V})d_{Yj}^*$$

**We assume Stokes  $\mathbf{V} = 0$**

**D** in the Linear Basis  $\mathbf{V} = \mathbf{D}\mathbf{P}\mathbf{V}^{\text{true}}$ .

- Linearized, sorted,  $d\mathcal{V} \sim 0$ , regrouped Stokes

$$V_{XX} = (\mathcal{I} + Q_\psi) + \mathcal{U}_\psi(d_{Xj}^* + d_{Xi})$$

$$V_{XY} = (\mathcal{U}_\psi + i\mathcal{V}) + \mathcal{I}(d_{Yj}^* + d_{Xi}) + Q_\psi(d_{Yj}^* - d_{Xi})$$

$$V_{YX} = (\mathcal{U}_\psi - i\mathcal{V}) + \mathcal{I}(d_{Yi} + d_{Xj}^*) + Q_\psi(d_{Yi} - d_{Xj}^*)$$

$$V_{YY} = (\mathcal{I} - Q_\psi) + \mathcal{U}_\psi(d_{Yi} + d_{Yj}^*)$$

**D** in the Linear Basis  $\mathbf{V} = \mathbf{D}\mathbf{P}\mathbf{V}^{\text{true}}$ .

- Linearized, sorted,  $d\mathcal{V} \sim 0$ , regrouped Stokes

$$V_{XX} = (\mathcal{I} + Q_\psi) + \mathcal{U}_\psi (d_{Xj}^* + d_{Xi})$$

$$V_{XY} = (\mathcal{U}_\psi + i\mathcal{V}) + \mathcal{I} (d_{Yi}^* + d_{Xi}) + Q_\psi (d_{Yj}^* - d_{Xj})$$

$$V_{YX} = (\mathcal{U}_\psi - i\mathcal{V}) + \mathcal{I} (d_{Yi} + d_{Xj}^*) + Q_\psi (d_{Yi} - d_{Xj}^*)$$

$$V_{YY} = (\mathcal{I} - Q_\psi) + \mathcal{U}_\psi (d_{Yi} + d_{Yj}^*)$$

In the cross-hands complex offset proportional to I constant in time

## D in the Linear Basis $\mathbf{V} = \mathbf{D}\mathbf{P}\mathbf{V}^{\text{true}}$ :

- Linearized, sorted,  $d\mathcal{V} \sim 0$ , regrouped Stokes

$$V_{XX} = (\mathcal{I} + Q_\psi) + \mathcal{U}_\psi(d_{Xj}^* + d_{Xi})$$

$$V_{XY} = (\mathcal{U}_\psi + i\mathcal{V}) + \mathcal{I}(d_{Yj}^* + d_{Xi}) + Q_\psi(d_{Yj}^* - d_{Xi})$$

$$V_{YX} = (\mathcal{U}_\psi - i\mathcal{V}) + \mathcal{I}(d_{Yi} + d_{Xj}^*) + Q_\psi(d_{Yi} - d_{Xj}^*)$$

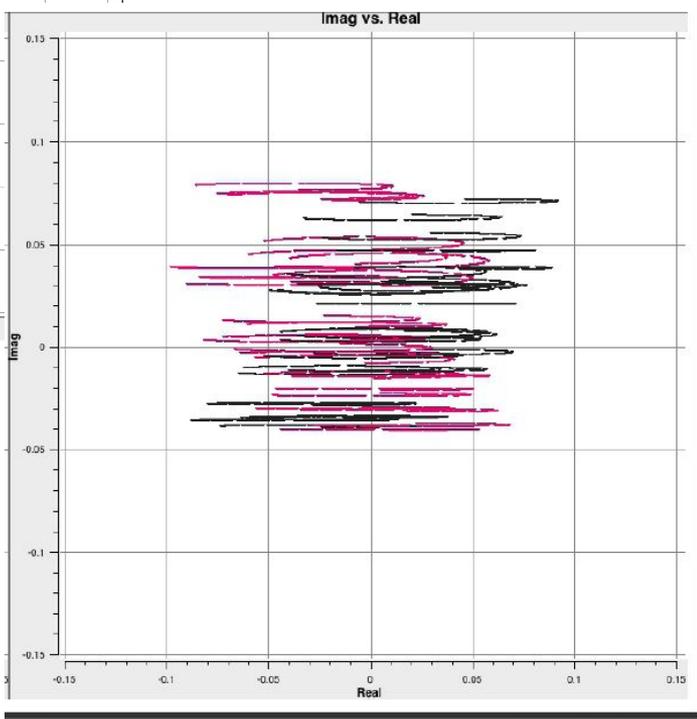
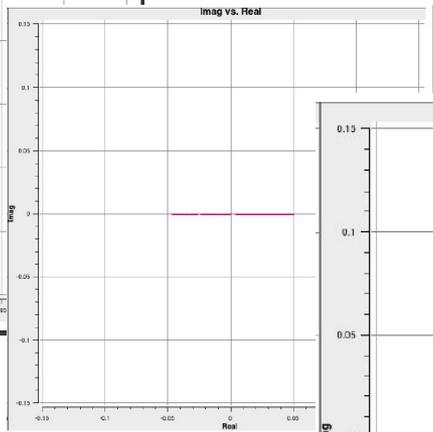
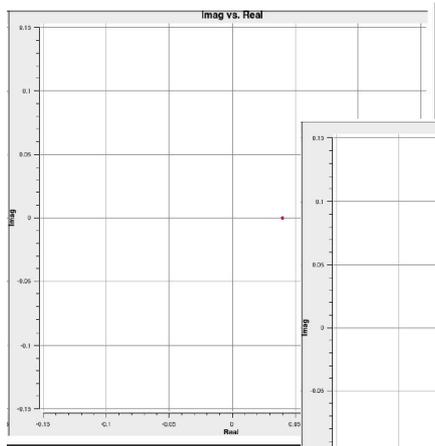
$$V_{YY} = (\mathcal{I} - Q_\psi) + \mathcal{U}_\psi(d_{Yi} + d_{Yj}^*)$$

In the cross-hands complex offset proportional to I constant in time

In all correlations a d-scaled time-dependent source linear polarization

# Cross-hands visibilities

**DPV**<sub>true</sub>



## XY-phase

### An artifact of gain calibration refant

We don't measure absolute G and B

We fix to zero in both polarizations the phases of a reference antenna.

Differences among antennas in each polarization are preserved

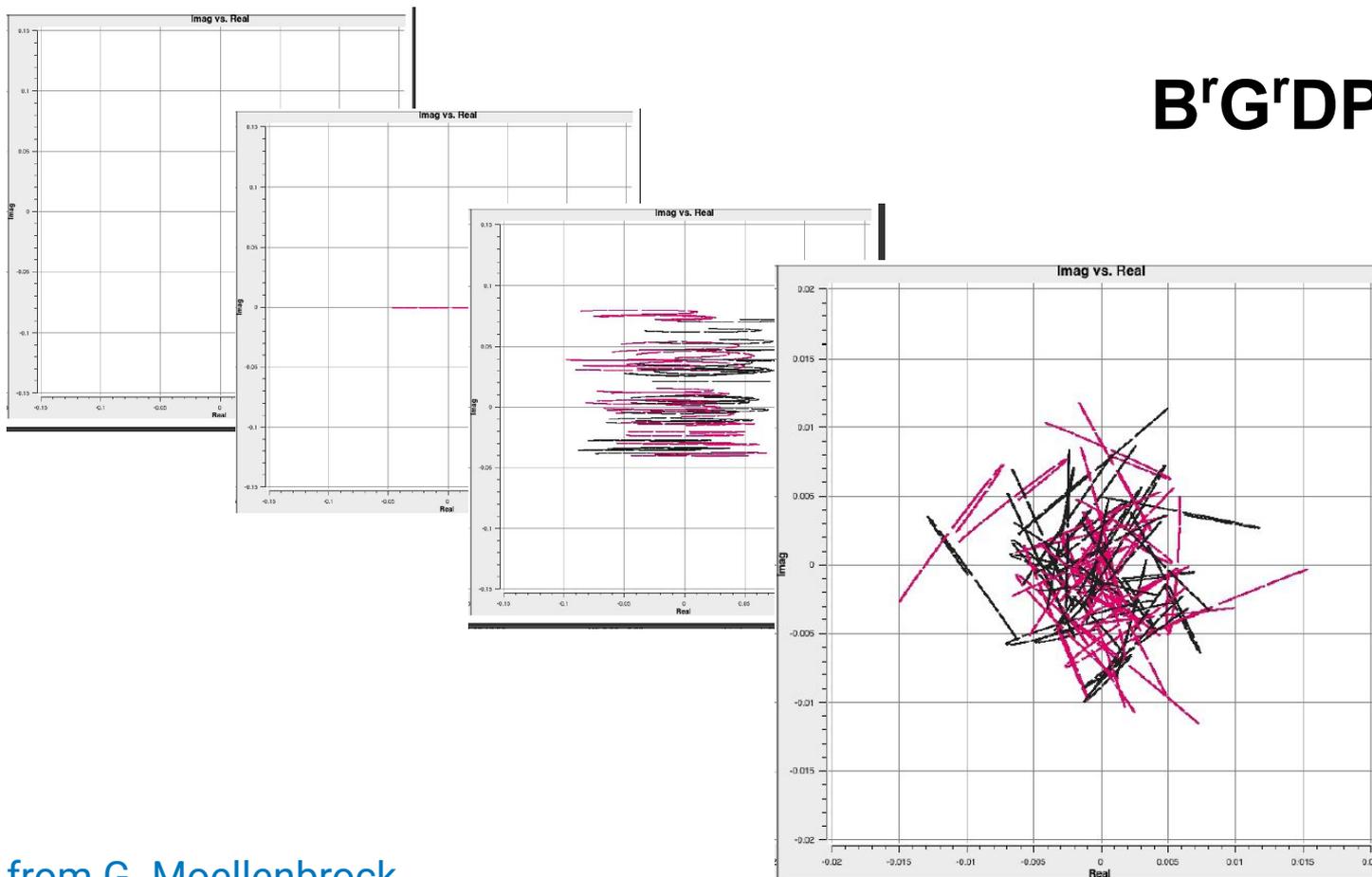
---> **no effect on parallel-hand calibration**

**But the refant's cross-hand bandpass phase remains undetected and uncorrected.**

**We need to correct for it in order to be able to combine the cross and parallel hands to extract the correct Stokes.**

# Cross-hands visibilities

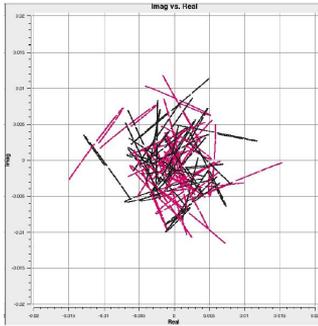
**B<sup>r</sup>G<sup>r</sup>DPV<sub>true</sub>**



# Polarization calibration

The calibration of the polarization dependent terms is defined as a module to be added to the parallel-hand calibration.

$$V^{\text{obs}} = \mathbf{B}^r \mathbf{G}^r \mathbf{D}^r \mathbf{X}^r \mathbf{P} V^{\text{true}}$$



## 4 Standard Calibrations

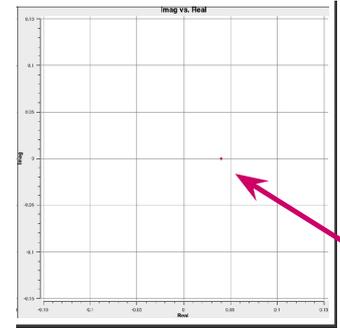
4.1 Bandpass

4.2 Flux Scaling

4.3 Gain Calibration

4.4 Apply Calibrations for Inspection

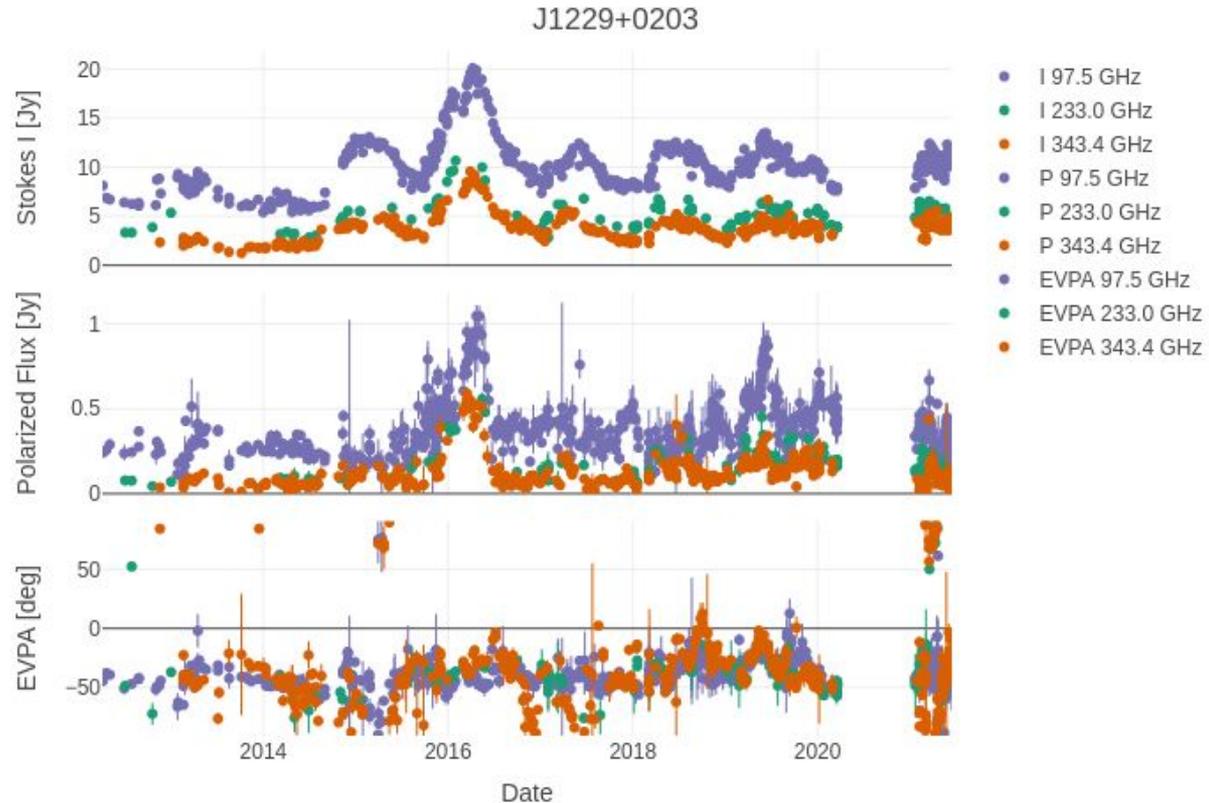
## 5 Polarization Calibration



# Calibration of instrumental likeages

calibrators properties  
are highly variable  
especially @ mm  
wavelengths.

**We cannot assume  
their properties**



<https://www.alma.cl/~skameno/AMAPOLA/>

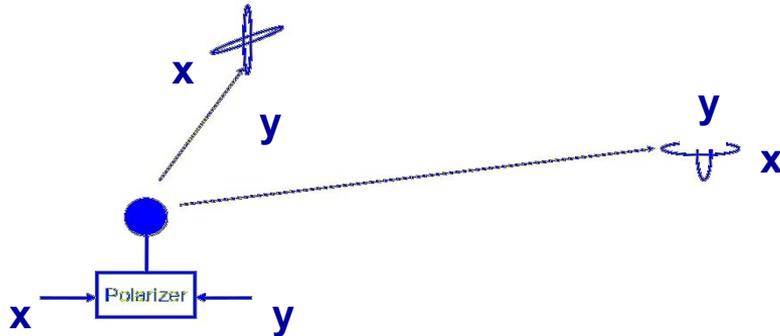
# Calibration of instrumental likeages

## Parallactic angle

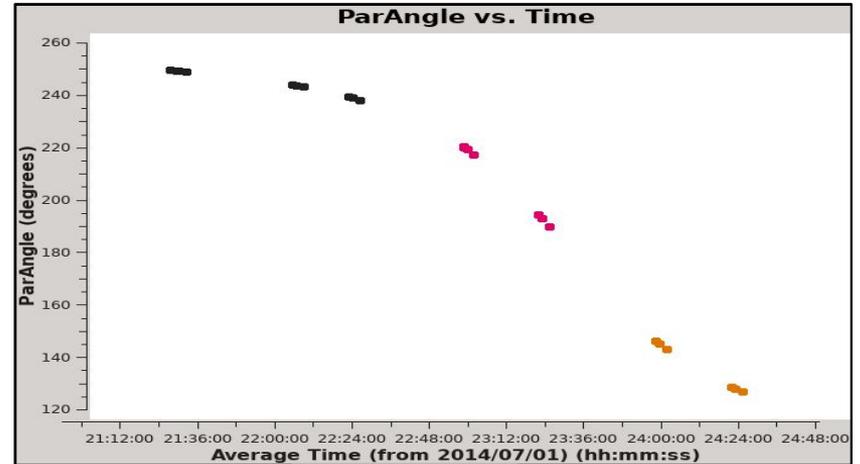
angle between the axis of the antenna mount and the source

While tracking the source the axis of the feeds is tied to the Earth, but it rotates on the sky --->

**Parallactic angle variation**



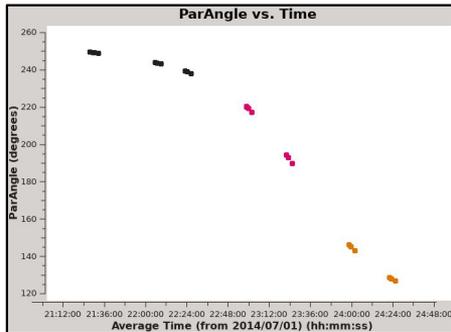
**Parallactic angle**



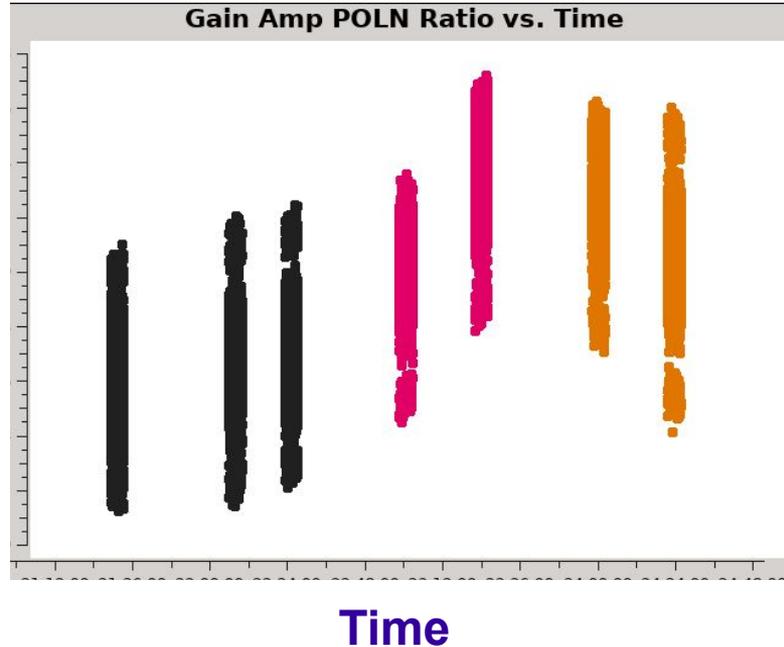
**Time**

# Calibration of instrumental likeages

the parallactic angle variation of the polarized signal allows us to disentangle instrumental from the intrinsic polarization of the calibrator



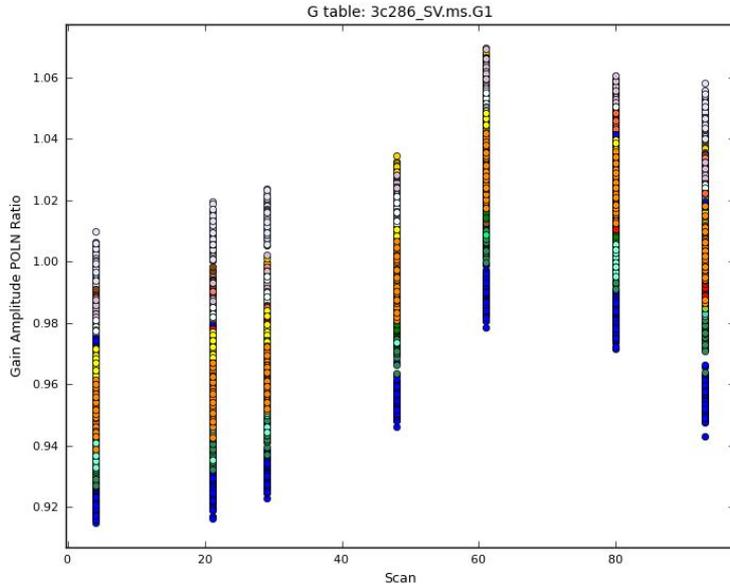
X/Y gain ratio



# Calibration of instrumental likeages

From this variation in the data

we solve for  $Q_\psi$ ,  $U_\psi$   
and D-terms



$$V_{XX} = (\mathcal{I} + Q_\psi) + \mathcal{U}_\psi(d_{Xj}^* + d_{Xi})$$

$$V_{XY} = (\mathcal{U}_\psi + i\mathcal{V}) + \mathcal{I}(d_{Yj}^* + d_{Xi}) + Q_\psi(d_{Yj}^* - d_{Xi})$$

$$V_{YX} = (\mathcal{U}_\psi - i\mathcal{V}) + \mathcal{I}(d_{Yi} + d_{Xj}^*) + Q_\psi(d_{Yi} - d_{Xj}^*)$$

$$V_{YY} = (\mathcal{I} - Q_\psi) + \mathcal{U}_\psi(d_{Yi} + d_{Yj}^*)$$

# Calibration of instrumental likeages

Current calibration scheme (Nagai et al. 2016) and

[https://casaguides.nrao.edu/index.php?title=3C286\\_Polarization](https://casaguides.nrao.edu/index.php?title=3C286_Polarization)

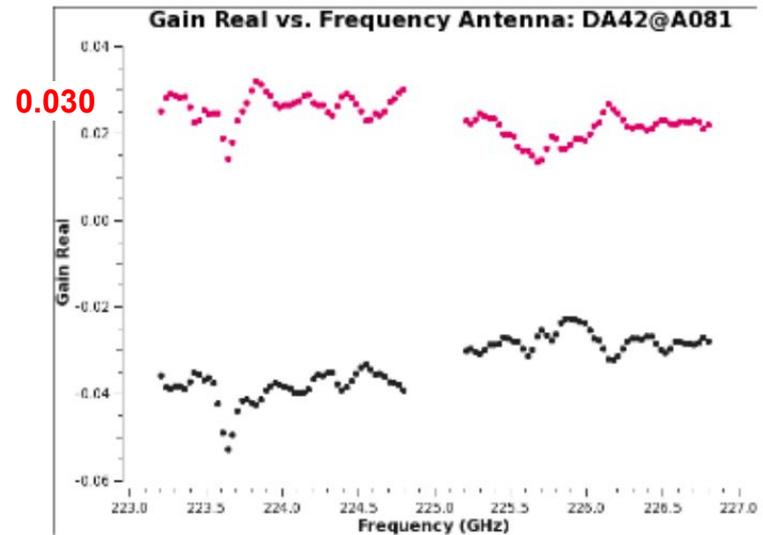
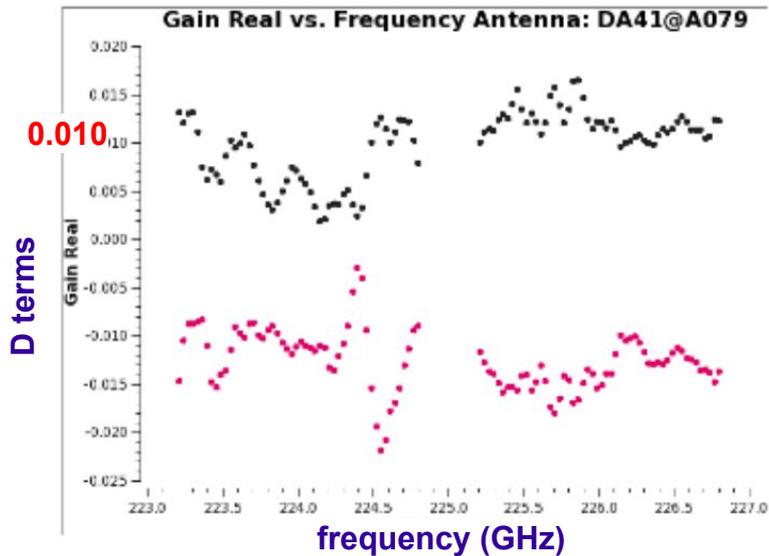
- **No assumptions** on the linear polarization of the calibrator
- **Stokes  $V = 0$**
- **Need a long observation (the OT assumes 3 hours)**  
to cover > 60 deg in parallactic angle

# Calibration of instrumental likeages

Current calibration scheme (Nagai et al. 2016) and

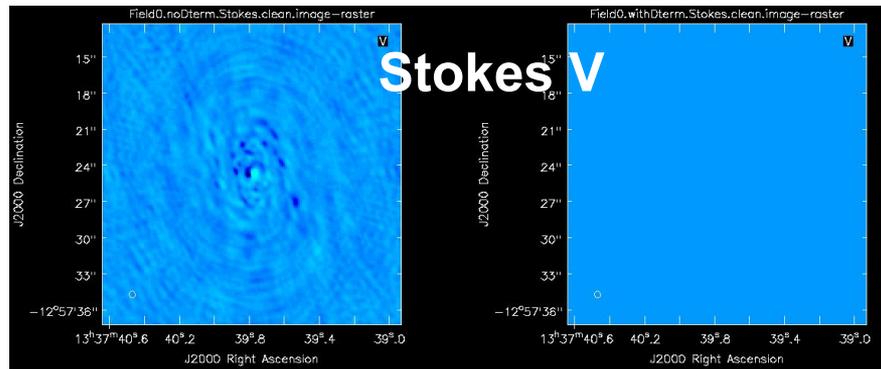
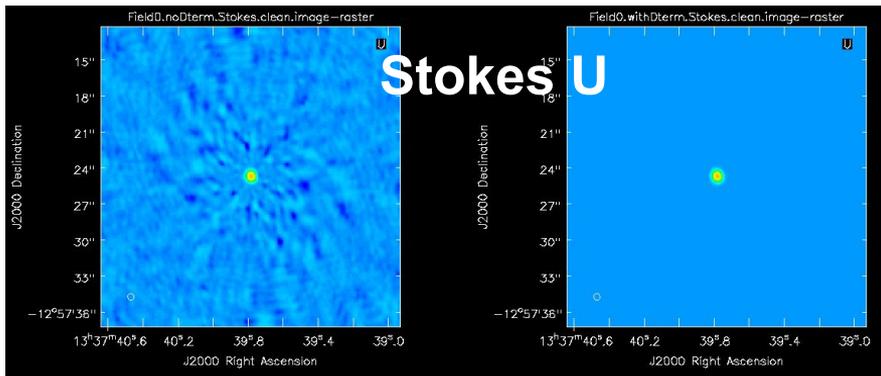
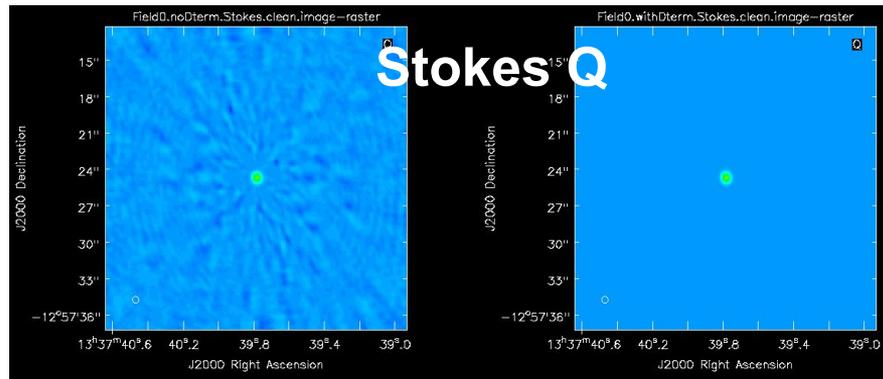
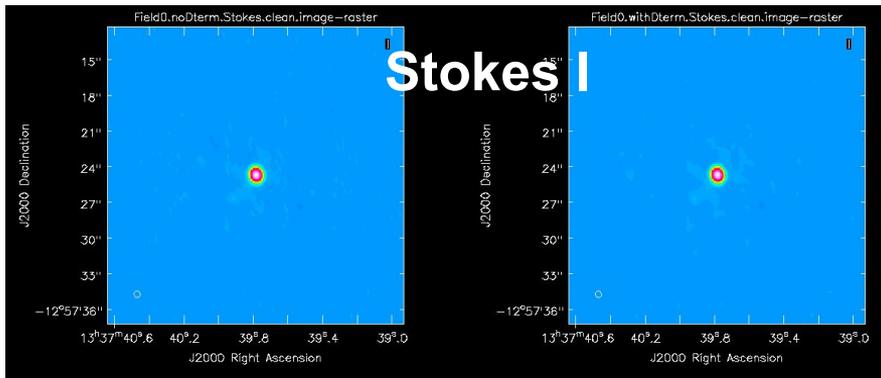
[https://casaguides.nrao.edu/index.php?title=3C286\\_Polarization](https://casaguides.nrao.edu/index.php?title=3C286_Polarization)

Instrumental polarization  $\rightarrow$  D terms for each antenna  $\sim$  few % ( $\ll 10\%$ )



# Calibration of instrumental likeages

Comparison with and without leakage calibration applied



# Calibration's accuracy

Linear polarization 0.1% of Stokes I

Circular polarization 1.8% of Stokes I

**Limited** due to

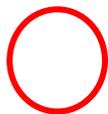
- the assumption of Stokes  $V=0$  for the calibrator
- errors on X-Y phase calibration

# Instrumental beam polarization

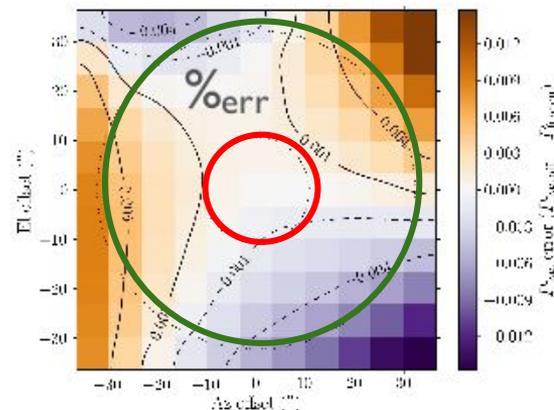
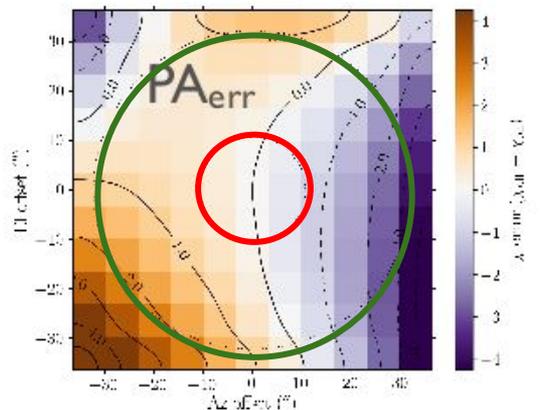
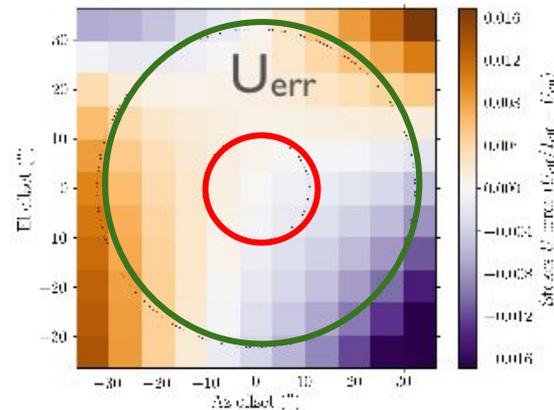
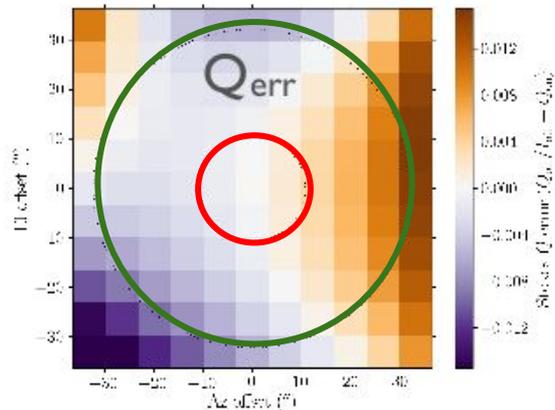
## Stokes Q and U

due to the offset between receiver feeds and the reflector off-axis errors appear in linear polarization

within the  $\frac{1}{3}$  FOV  
Pfrac error < 0.1%  
PA error < 1 deg



Band 3 (3 mm)



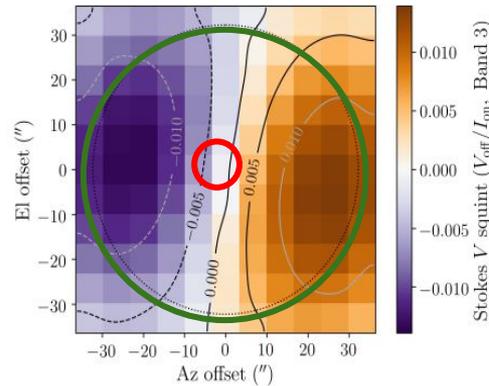
# Instrumental beam polarization

## Stokes V beam shape (beam squint)

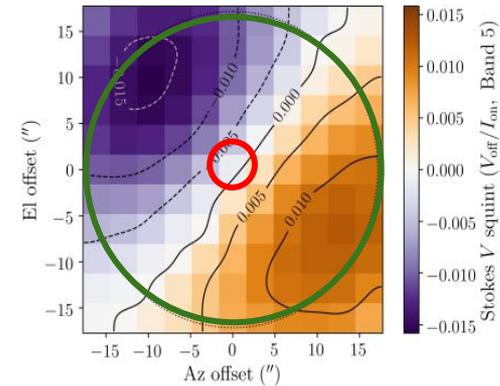
when dual polarization receivers are offset, the response to left and right circular polarization are displaced from one another → double lobed beam pattern

Squint profile at all bands is very compact!

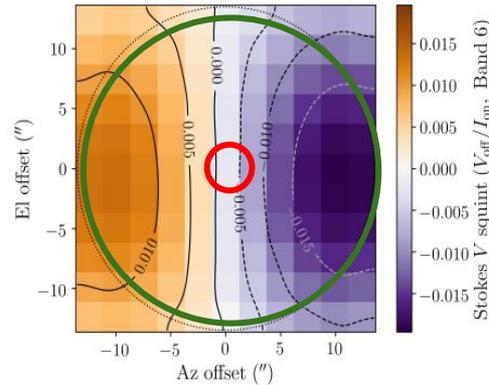
### band 3



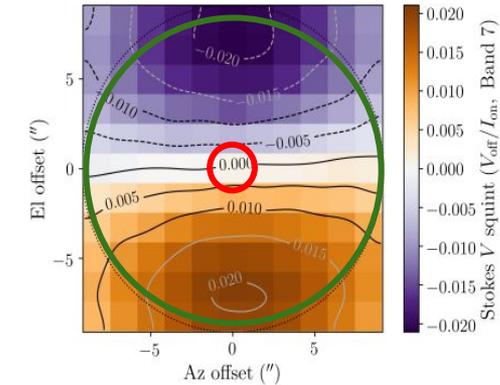
### band 5



### band 6



### band 7



# Beam polarization → Consequences on actual observations

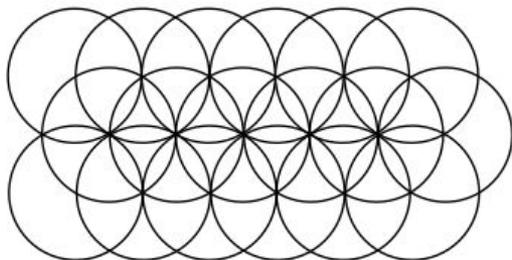
To correct for beam polarization

We would need to know the antenna pattern for each Stokes.  
We don't have these Stokes PB corrections at the moment.

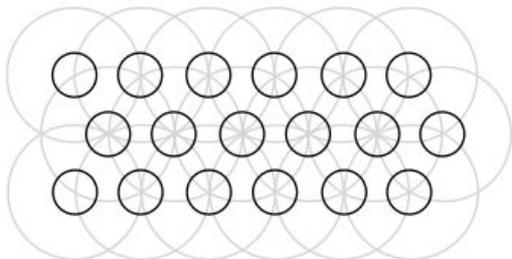
Single pointing polarization observations are limited to

$$\frac{FOV}{3} \text{ for linear and } \frac{FOV}{10} \text{ for circular}$$

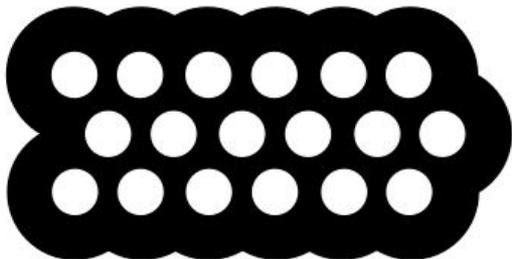
# Mosaicking mitigates off-axis errors



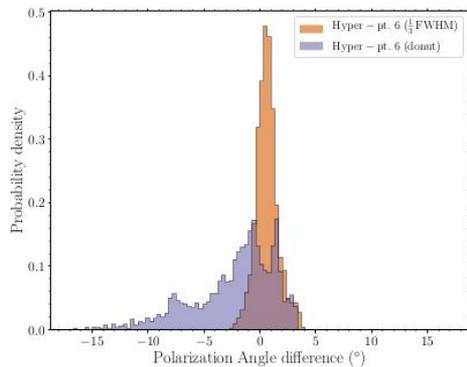
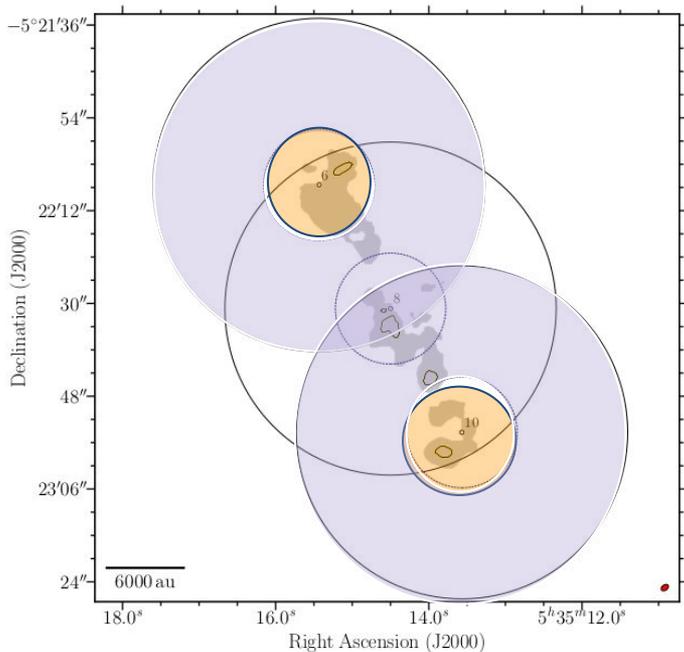
Nyquist mosaic



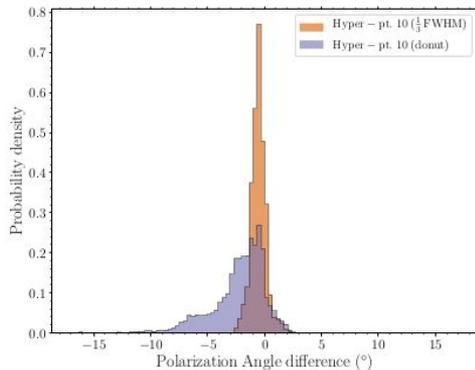
Inner 1/3 FWHM  
highlighted in black



Overlapping regions  
outside the inner  
1/3 FWHM

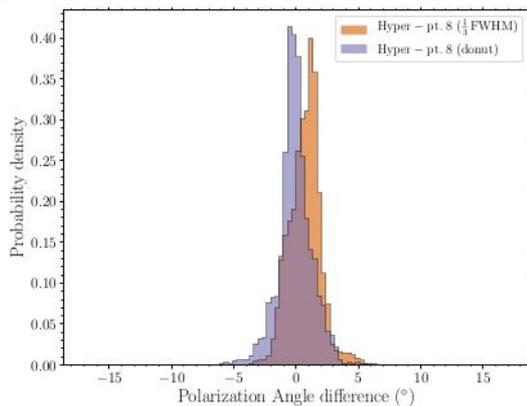
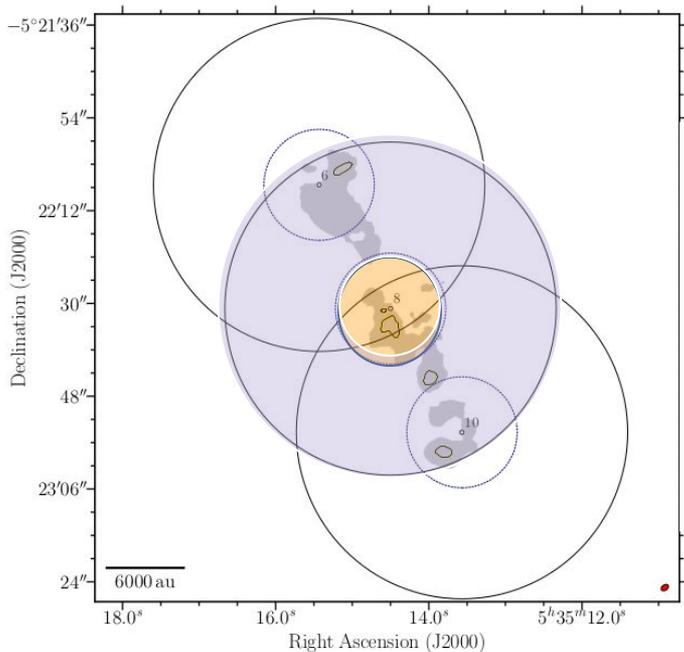


Differences between  $\mathcal{N}$  measured in mosaics vs single point in the **inner 1/3** and in the **outer ring**



residual of off-axis errors are visible in the two outer pointings

# Mosaicing mitigates the off-axis errors due to overlapping pointings



Differences between  $\mathcal{N}$  measured in mosaics vs single point in the **inner 1/3** and in the **outer ring**

In the central pointing off-axis error are mitigated

# ALMA nominal accuracies

- Linear polarization:  
Single pointing (1/3 of PB)  
accuracy on polarization ratio: 0.1% of Stokes I  
on polarization angle: 1 deg

Mosaicking: upper limits on the error outside the 1/3 PB  
polarization ratio 0.5% of Stokes I  
polarization angle 4 deg

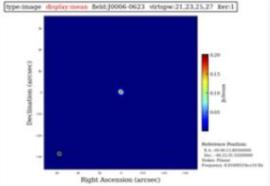
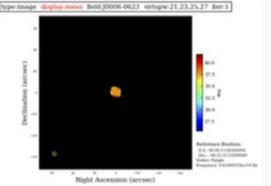
- Circular polarization:  
Single pointing (1/10 of PB)  
accuracy on polarization ratio: 1.8% of Stokes I

NO mosaic

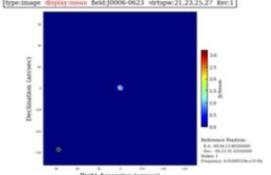
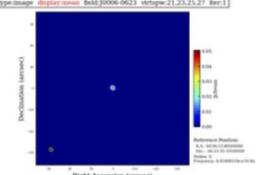
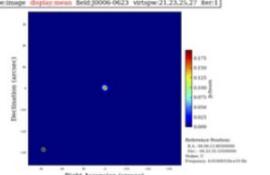
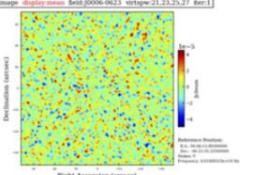
# Pipeline polarization calibration and imaging additional tasks in the weblog

- 11. hif\_setmodels
- 12. hifa\_bandpassflag
- 13. hifa\_bandpass
- 14. hifa\_spwphaseup
- 15. hifa\_gfluxscaleflag
- 16. hifa\_polcalflag
- 17. hifa\_session\_refant
- 18. hifa\_lock\_refant
- 19. hifa\_bandpass
- 20. hifa\_spwphaseup
- 21. hifa\_gfluxscale
- 22. hifa\_timegaincal
- 23. hifa\_renorm
- 24. hifa\_makeimlist (cals/pol)
- 25. hifa\_polcal
- 26. hifa\_makeimlist (cals/pol)
- 27. hif\_makeimlist (cals/pol)
- 28. hif\_makeimages (cals/pol)
- 29. hif\_makeimlist (checksrc)
- 30. hif\_makeimages (pol)
- 31. hif\_makeimlist (checksrc)
- 32. hif\_makeimages (checksrc)
- 33. hifa\_imageprecheck
- 34. hif\_checkproductsize
- 35. hifa\_exportdata
- 36. hif\_mstransform
- 37. hifa\_flagtargets
- 38. hif\_makeimlist (mfs)

## Polarization Calibrator Fit Results

Session	EBs	Field	Virtual SPW	Polarization Fraction	Polarization Angle	Polarization Intensity Plot	Polarization Angle Plot
session_1	uid___A002_X133789a_X4b24,uid___A002_X133789a_X4e97,uid___A002_X133789a_X550d	J0006-0623	21,23,25,27	6.27 +/- 0.00%	37.73 +/- 0.01 deg		

## Image Details

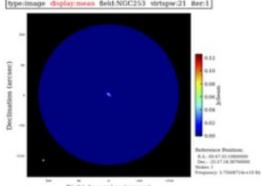
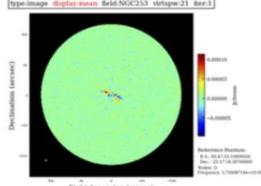
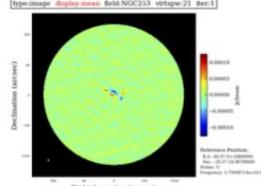
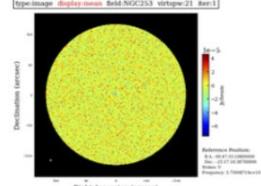
Field	Spw	Stokes	Stokes	Stokes	Stokes
J0006-0623 (POLARIZATION) (REGCAL)	X127/X63462536/X1765#X1898839461#AL MA_RB_01#BB_4#SW-01#FULL_RES	21, 23, 25, 27 / X127/X63462536/X1762#X1898839461#AL	21, 23, 25, 27 / X127/X63462536/X1762#X1898839461#AL	21, 23, 25, 27 / X127/X63462536/X1762#X1898839461#AL	21, 23, 25, 27 / X127/X63462536/X1762#X1898839461#AL
					
<a href="#">View other QA images...</a>	<a href="#">View other QA images...</a>	<a href="#">View other QA images...</a>	<a href="#">View other QA images...</a>		
<b>data type</b>	REGCAL_CONTLINE_ALL	REGCAL_CONTLINE_ALL	REGCAL_CONTLINE_ALL	REGCAL_CONTLINE_ALL	
<b>stokes</b>	I	Q	U	V	

# Pipeline polarization calibration and imaging mfs, continuum and cube full polarization images

- 27. hif\_makeimlist (cals/pol)
- 28. hif\_makeimages (cals/pol)
- 29. hif\_makeimlist (pol)
- 30. hif\_makeimages (pol)
- 31. hif\_makeimlist (checksrc)
- 32. hif\_makeimages (checksrc)
- 33. hifa\_imageprecheck
- 34. hif\_checkproductsize
- 35. hifa\_exportdata
- 36. hif\_mstransform
- 37. hifa\_flagtargets
- 38. hif\_makeimlist (mfs)
- 39. hif\_findcont
- 40. hif\_uvcontsub
- 41. hif\_makeimages (mfs)
- 42. hif\_uvcontsub (mfs)
- 43. hif\_makeimages (mfs\_fullpol)
- 44. hif\_uvcontsub (cont)
- 45. hif\_makeimages (cont)
- 46. hif\_makeimlist (cont\_fullpol)
- 47. hif\_makeimages (cont\_fullpol)
- 48. hif\_makeimlist (cube)
- 49. hif\_makeimages (cube)
- 50. hif\_makeimlist (cube\_fullpol)
- 51. hif\_makeimages (cube\_fullpol)
- 52. hif\_makeimlist (repBW)
- 53. hif\_makeimages (cube\_repBW)
- 54. hif\_makeimlist (repBW\_fullpol)

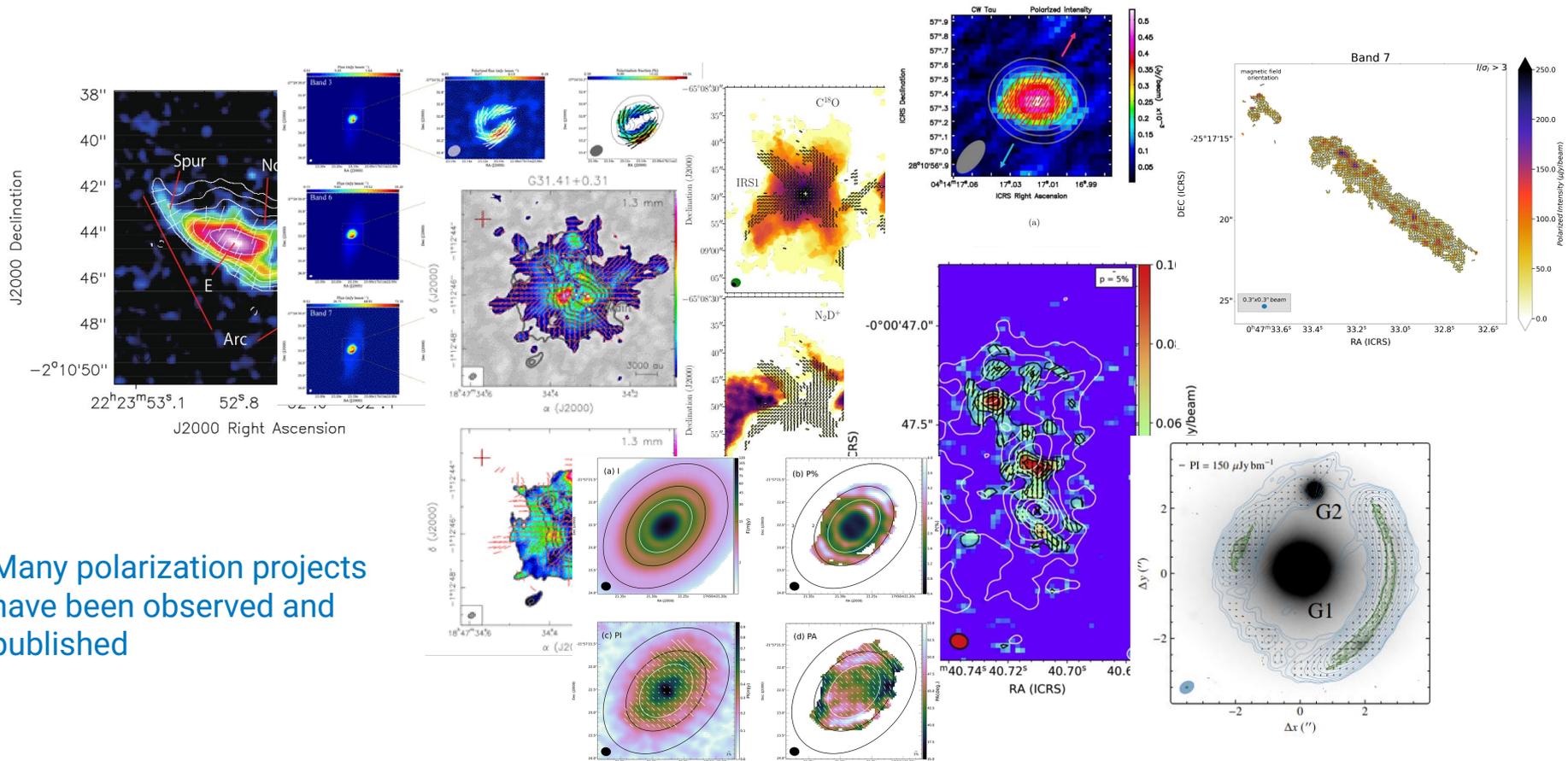
The DR correction adopted is a function of the dirty dynamic range (abbreviated as "Dirty DR"), which is defined as the peak intensity divided by the theoretical rms sensitivity delivered by the visibilities.

## Image Details

Field	Spw		
21 / X127/X63462536/X1762#X1898839461#AL	21 / X127/X63462536/X1762#X1898839461#AL	21 / X127/X63462536/X1762#X1898839461#AL	21 / X127/X63462536/X1762#X1898839461#AL
			
<a href="#">View other QA images...</a>	<a href="#">View other QA images...</a>	<a href="#">View other QA images...</a>	<a href="#">View other QA images...</a>
<b>data type</b>	REGCAL_CONTLINE_SCIENCE	REGCAL_CONTLINE_SCIENCE	REGCAL_CONTLINE_SCIENCE
<b>stokes</b>	I	Q	U
<b>centre frequency of image</b>	37.5609GHz (LSRK)	37.5609GHz (LSRK)	37.5609GHz (LSRK)
<b>beam</b>	1.85 x 1.54 arcsec	1.85 x 1.54 arcsec	1.85 x 1.54 arcsec
<b>beam p.a.</b>	50.6deg	50.6deg	50.6deg
<b>final theoretical sensitivity</b>	9.3 uJy/beam	9.3 uJy/beam	9.3 uJy/beam
<b>cleaning threshold</b>	1.7 mJy/beam Dirty DR: 1.4e+04 DR correction: 2.5	1.7 mJy/beam Dirty DR: 1.4e+04 DR correction: 2.5	1.7 mJy/beam Dirty DR: 1.4e+04 DR correction: 2.5
<b>total number of major cycles</b>	2	2	2

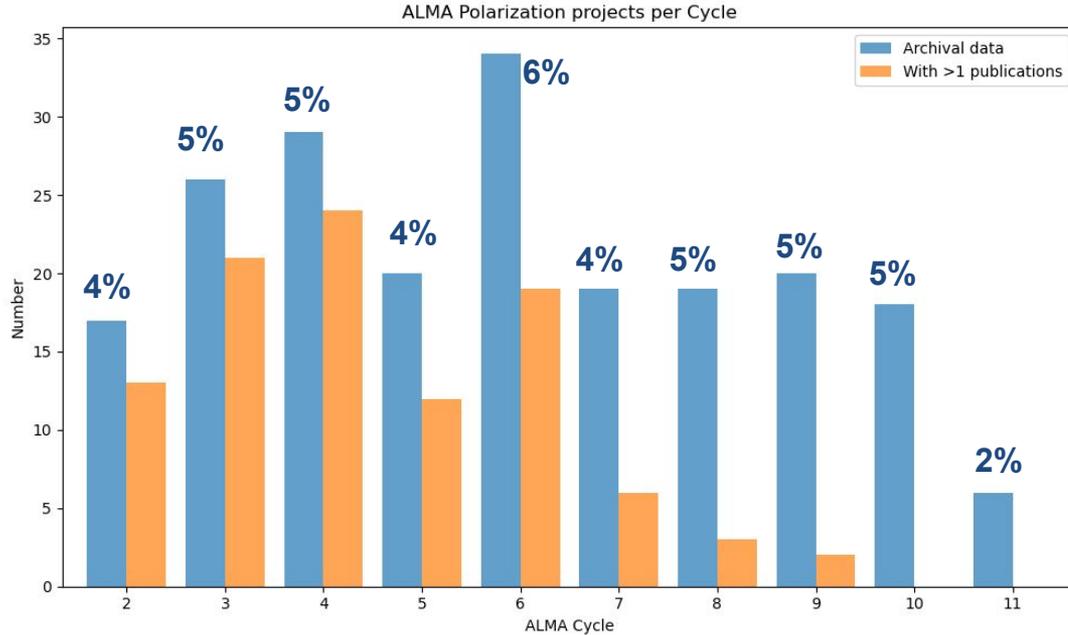
# In the ALMA archive

Member OUS uid://A001/X133d/X2fda	2019-12-17
SB NGC_253_a_04_TM1	
<input checked="" type="checkbox"/> readme	<a href="#">member.uid__A001_X133d_X2fda.README.txt</a>
<input checked="" type="checkbox"/> product	<a href="#">2018.1.01358.S_uid__A001_X133d_X2fda_001_of_001.tar</a>
<input type="checkbox"/> product	<a href="#">member.uid__A001_X133d_X2fda.J0006-0623_polleak.spw0_1_2_3.mfs.IQUV.manual.mask.tgz</a>
<input type="checkbox"/> product <b>Polarization angle A</b>	<a href="#">member.uid__A001_X133d_X2fda.J0006-0623_polleak.spw13_15_17_19.mfs.A.manual.fits</a>
<input type="checkbox"/> product	<a href="#">member.uid__A001_X133d_X2fda.J0006-0623_polleak.spw13_15_17_19.mfs.IQUV.manual.pb.fits.gz</a>
<input type="checkbox"/> product <b>IQUV images</b>	<a href="#">member.uid__A001_X133d_X2fda.J0006-0623_polleak.spw13_15_17_19.mfs.IQUV.manual.pbcor.fits</a>
<input type="checkbox"/> product <b>Polarized intensity</b>	<a href="#">member.uid__A001_X133d_X2fda.J0006-0623_polleak.spw13_15_17_19.mfs.P.manual.fits</a>
<input type="checkbox"/> product	<a href="#">member.uid__A001_X133d_X2fda.NGC_253_sci.spw0_1_2_3.mfs.IQUV.manual.mask.tgz</a>
<input type="checkbox"/> product	<a href="#">member.uid__A001_X133d_X2fda.NGC_253_sci.spw13_15_17_19.mfs.A.manual.fits</a>
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<input type="checkbox"/> product	<a href="#">member.uid__A001_X133d_X2fda.NGC_253_sci.spw13_15_17_19.mfs.IQUV.manualtest.mask.tgz</a>
<input type="checkbox"/> product	<a href="#">member.uid__A001_X133d_X2fda.NGC_253_sci.spw13_15_17_19.mfs.P.manual.fits</a>



Many polarization projects  
 have been observed and  
 published

## Many polarization projects have been observed but not yet published



*updated June 2025*

In the tutorial we are going to have a first look in CARTA to full polarization images

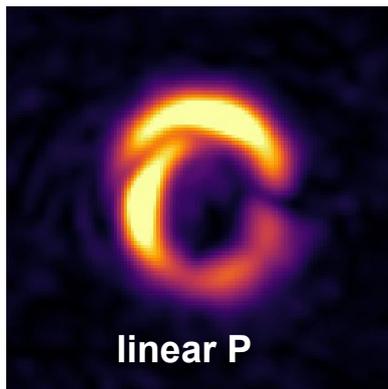
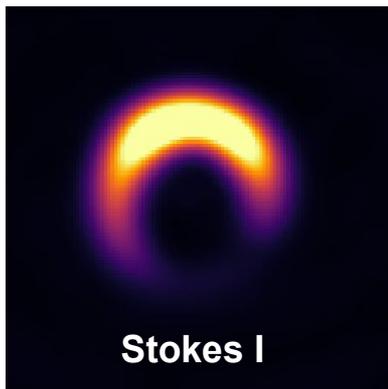
# Archival dataset for the hands-on

Stephens et al. 2020

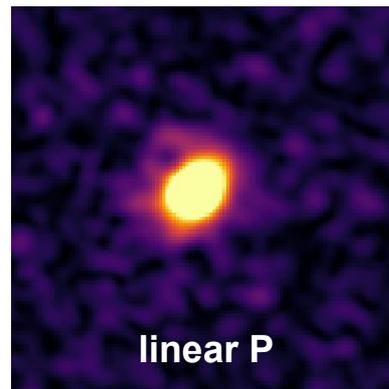
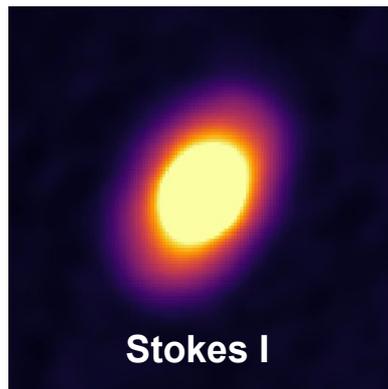
[https://ui.adsabs.harvard.edu/link\\_gateway/2020ApJ...901...71S/doi:10.3847/1538-4357/abaef7](https://ui.adsabs.harvard.edu/link_gateway/2020ApJ...901...71S/doi:10.3847/1538-4357/abaef7)

- ALMA Band 6 observations of two protoplanetary disks
- both continuum and spectral lines (CO(2-1),  $^{13}\text{CO}(2-1)$ ,  $\text{C}^{18}\text{O}(2-1)$ )
- full polarization

HD 142527



IM Lup

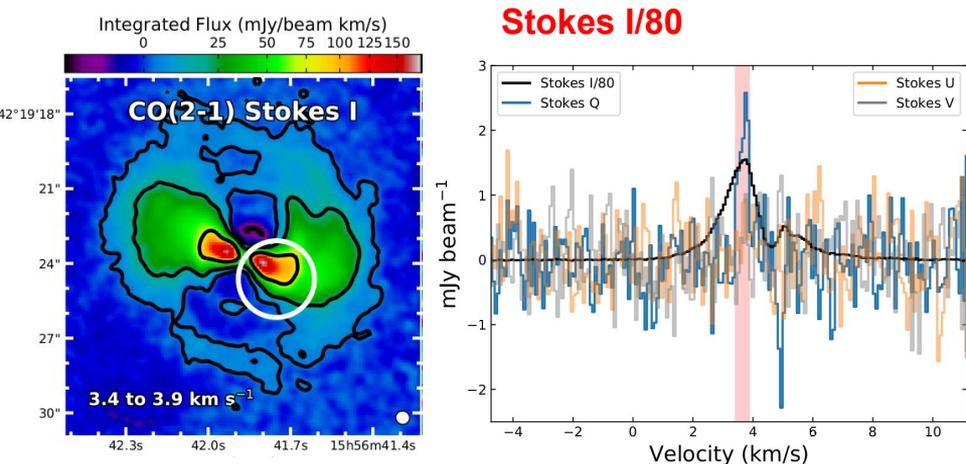


Continuum emission -- Origin still unclear: possibly dust scattering

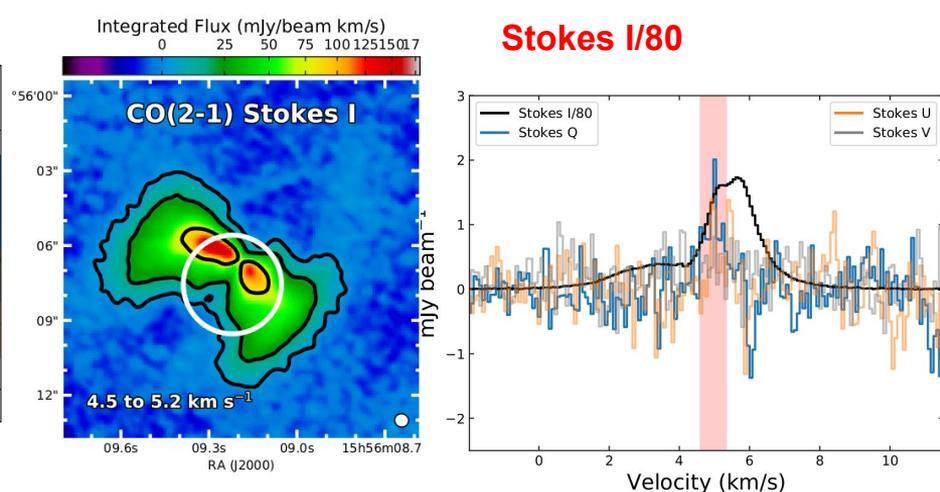
# Stephens et al. 2020

[https://ui.adsabs.harvard.edu/link\\_gateway/2020ApJ...901...71S/doi:10.3847/1538-4357/abaef7](https://ui.adsabs.harvard.edu/link_gateway/2020ApJ...901...71S/doi:10.3847/1538-4357/abaef7)

## HD 142527



## IM Lup



## Line emission

- <sup>13</sup>CO(2-1) and C<sup>18</sup>O(2-1) expected to be optimal to probe G-K effect ---> **NO detections**
- **CO(2-1) polarization marginal signal for Stokes Q** ---> peculiar result

# Thank you!

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