AGN polarimetry at the highest radio frequencies

... and resolutions

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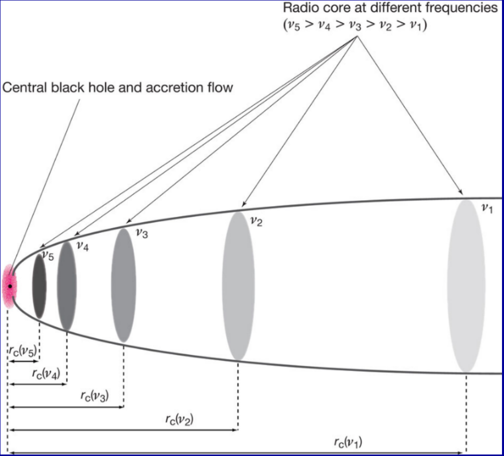
Chalmers University of Technology (Sweden)

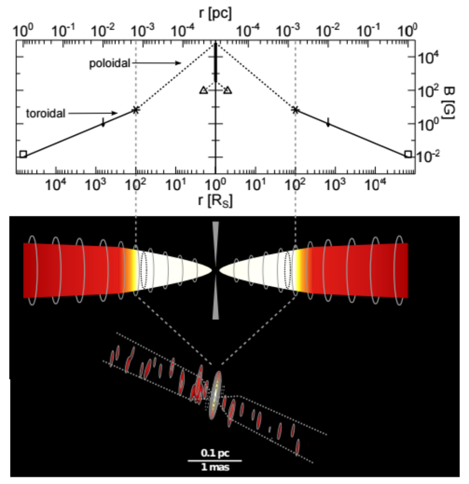
Polarized Emission from Astrophysical Jets
Ιεράπετρα 2017

The SSA Opacity "Problem"



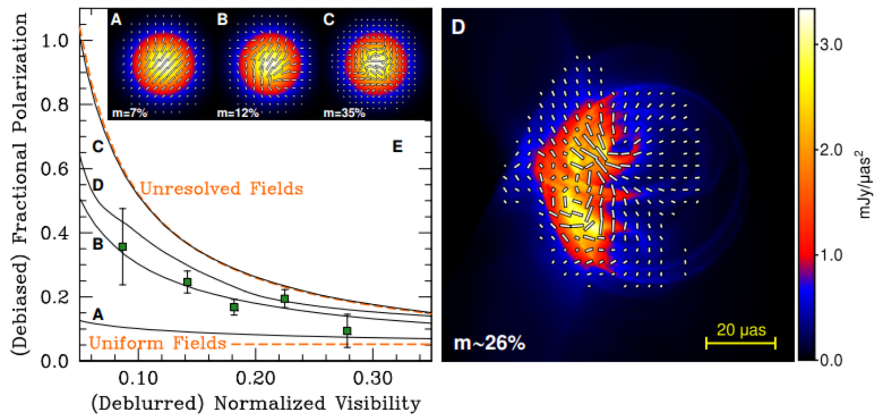
Taken from Hada et al. (2011)

Jet Base at the Highest Resolutions



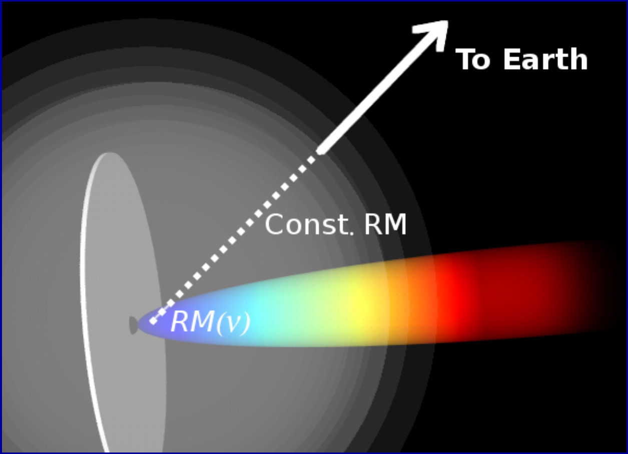
NGC 1052; Baczko et al. (2016)

Jet Base at the Highest Resolutions



Sgr A*; Johnson et al. (2015)

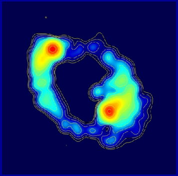
RM at the Highest Frequencies



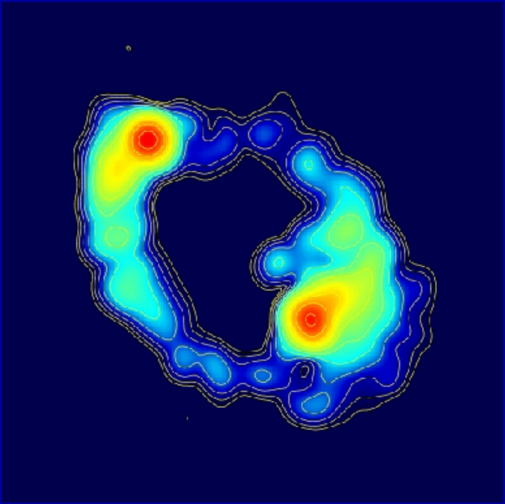
Beating the Error Bars

Intra-field Relative Intensity

- The relative brightness within the same observed field is a very precise and accurate quantity (only limited by *dynamic range*).
- Using the relative brightness, we can improve variability analyses by several orders of magnitude.
- We need:
  - A source with a resolved structure.
  - Spatially correlated variability (e.g., a gravitational lens).



One Ring to Rule Them All



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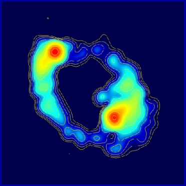


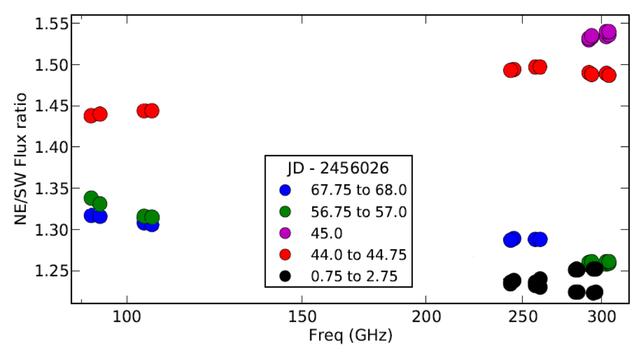
Of the *five* distant radio molecular absorbers known to date, PKS 1830−211 has

- The highest redshift, $z = 0.89$.
- The Brightest mm/submm continuum, ~ 1 Jy.
- The largest amount of absorbing material (many saturated lines!).

In addition, PKS 1830−211

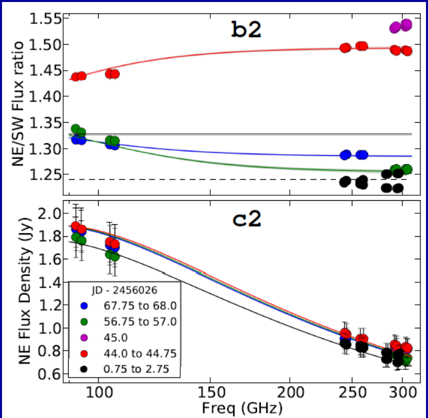
- Is a *gravitational lens* (time delay of ~ 27 days).
- Shows molecular absorption in *both* images.
- Shows *time variations* in continuum and line profiles.

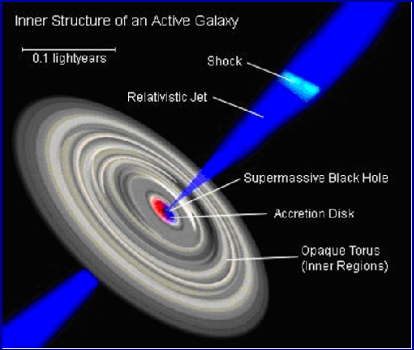
Relative Brightness NE/SW



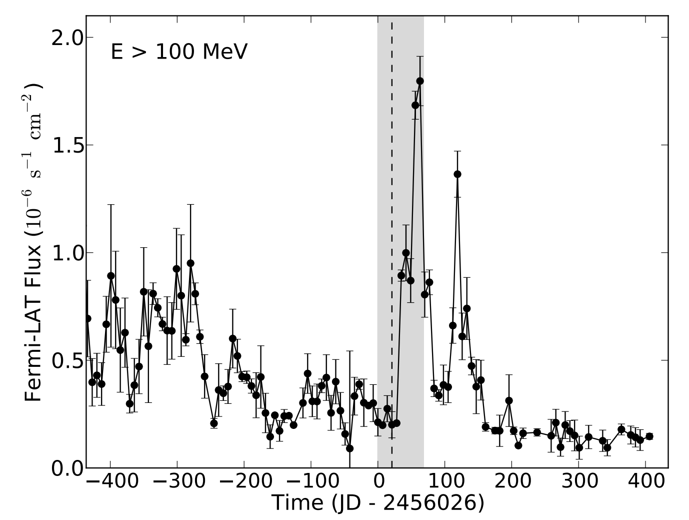
Martí-Vidal et al. (2013)

A Feature Moving Downstream from the Base

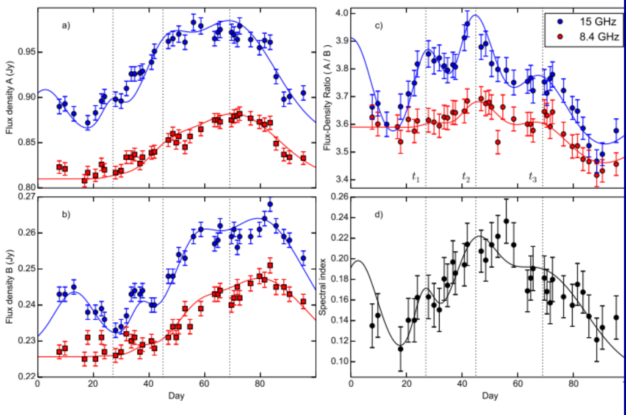




... and a Strong γ-ray Counterpart!



Parenthesis: B 0218+357 (VLA)

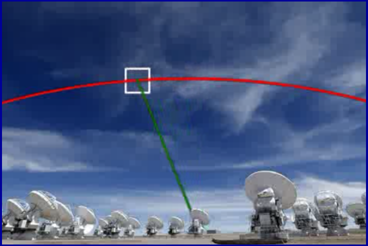


Martí-Vidal et al. (2016)

We model the 15 GHz data only.

The 8.4 GHz model is got from one extra parameter (besides α).

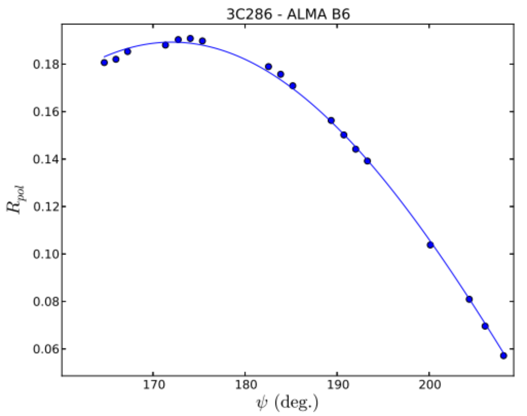
Intra-field Relative Polarization (from Dual-pol Data)



Parallactic angle: the source rotates w.r.t. the antenna mount

- XX observes $I + Q_{ant}$
- YY observes $I - Q_{ant}$
- Q_{ant} rotates with parallactic angle.
- If the source is unresolved $\rightarrow$ Earth-Rotation Polarization Synthesis.

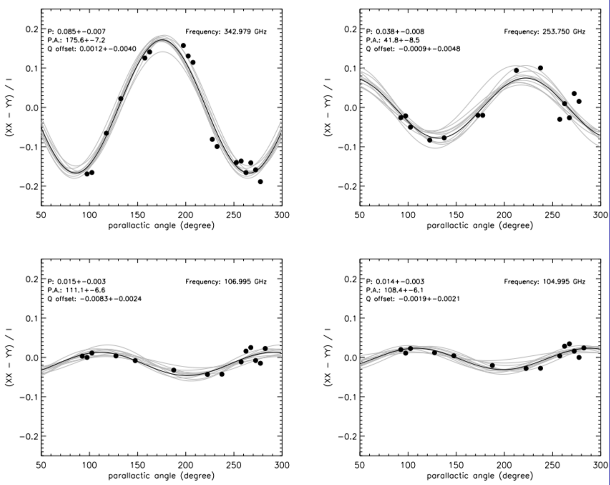
Real Data (ALMA): 3C 286 (SV @ B6)



Martí-Vidal et al. 2016

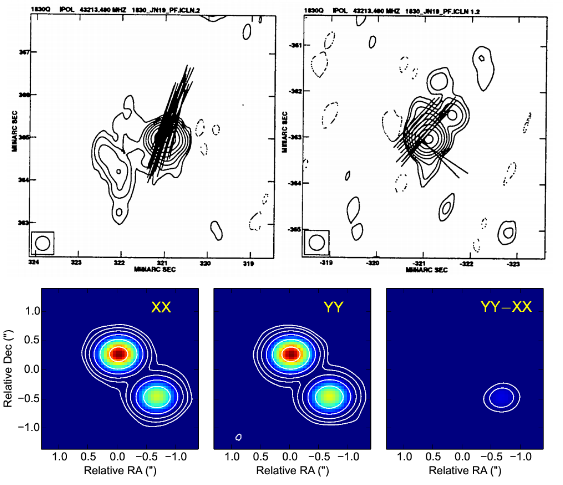
(Result compatible with full-pol calibration: Nagai et al. 2016)

Real Data (ALMA): Sgr A* (B3,6,7)



Baobab et al. (2016)

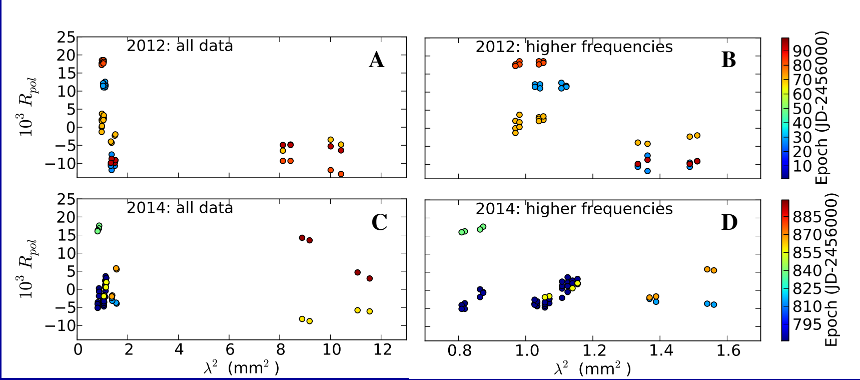
Real Data (ALMA): PKS 1830−211



Top: VLBA @ 7mm (Garrett et al. 1998)

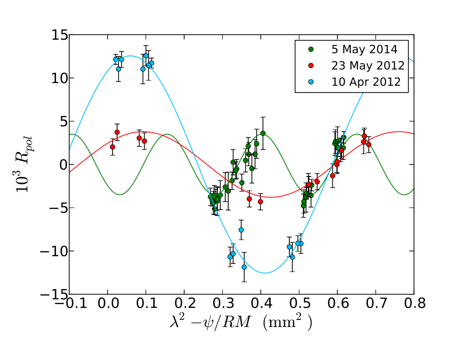
Bottom: ALMA @ 3mm (Martí-Vidal et al. 2015)

Differential Polarimetry NE/SW



Martí-Vidal et al. (2015)

Differential Polarimetry NE/SW



Martí-Vidal et al. (2015)

- The highest Faraday rotation so far ($10^7 - 10^8$ rad m^{-1}).
- The highest rest frequencies so far (1 THz, corrected for z).
- Typical RM measured in other AGN (at lower frequencies): $\sim 10^6$ rad m^{-1} at 250 GHz (e.g., Plambeck et al. 2014).

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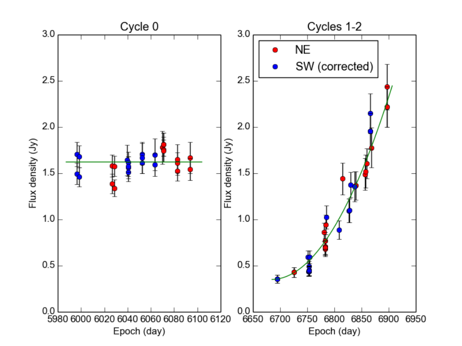

Muller, Martí-Vidal et al. (in prep.)

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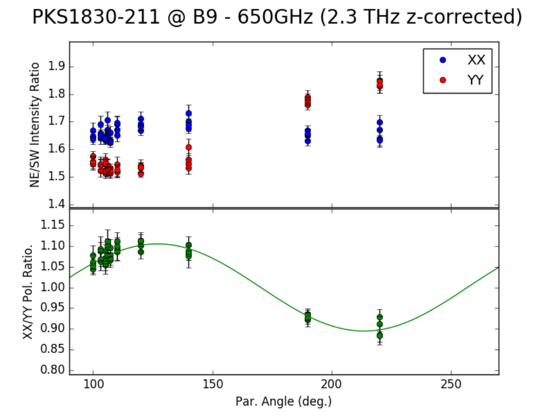
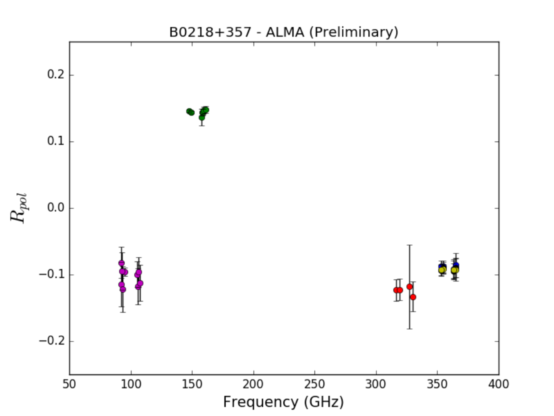
The Sky is the Limit: ALMA Band 9



The highest frequency used so far: 2.3 THz (z-corrected)

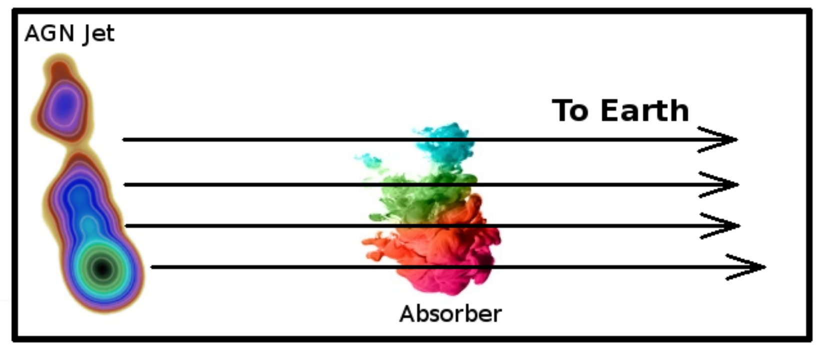
Martí-Vidal et al. (in prep.)

The Other "Diamond" Source: B 0218+357 @ 3−1 mm



Stronger R_{pol} signal than in PKS 1830−211, but too sparse observations (Martí-Vidal et al., in prep.).

Jet Substructure ⇔ Absorption



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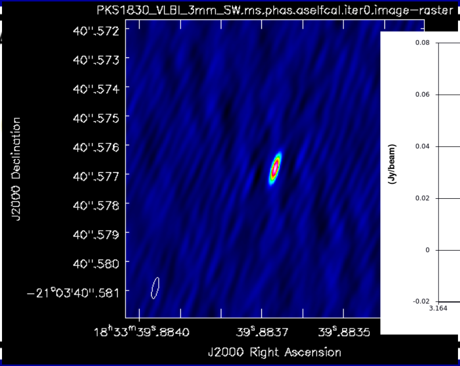
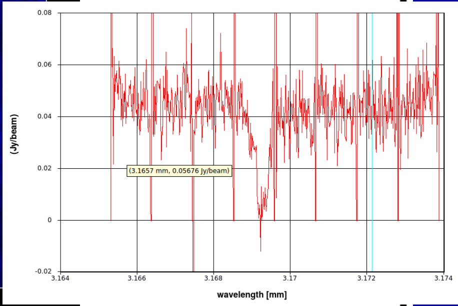




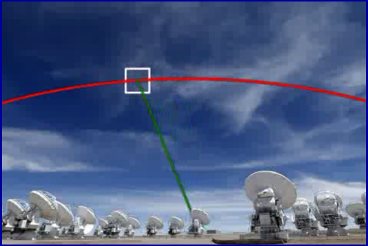
Muller, Martí-Vidal, et al. (in prep.)

Off-topic Bonus:

Wide-band VLBI and Polarimetry

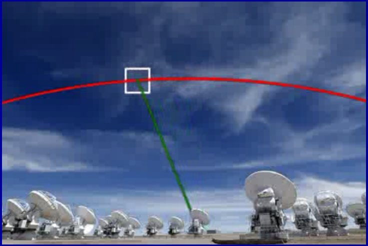
Linear Polarizers in VLBI

- The parallactic angle, ϕ, can only be corrected after the calibration.
- BUT, we need to apply it before the calibration (especially in phase referencing).
- MOREOVER, ionosphere effects appear as time-dependent bandpass artifacts.



Linear Polarizers in VLBI

- The parallactic angle, ϕ, can only be corrected after the calibration.
- BUT, we need to apply it before the calibration (especially in phase referencing).
- MOREOVER, ionosphere effects appear as time-dependent bandpass artifacts.
- How to convert to circular polarization in VLBI? $\rightarrow$ POLCONVERT



Calibration Approach (non-ALMA)

Global *Cross-Polarization* Fringe Fitting (Martí-Vidal et al. 2016):

$$\min\left[\chi^2(\vec{\rho})\right] \text{ with } \chi^2(\vec{\rho}) = \sum_k \left(RR_k/LL_k - 1\right)^2 + \lambda \left[\sum_k \left(RL_k^2 + LR_k^2\right)\right]$$

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$$\chi^2 = \chi^2_{+\odot} + \chi^2_{\odot\odot} \text{ with } \chi^2_{+\odot} = \sum_k \omega_k \left[\frac{V^k_{xr}\rho_+^{-1} - jV^k_{yr}}{V^k_{xl}\rho_+^{-1} + jV^k_{yl}}(e^{\psi_+})(e^{\psi^*_\odot})(\rho_\odot^{-1})^* - 1\right]^2$$

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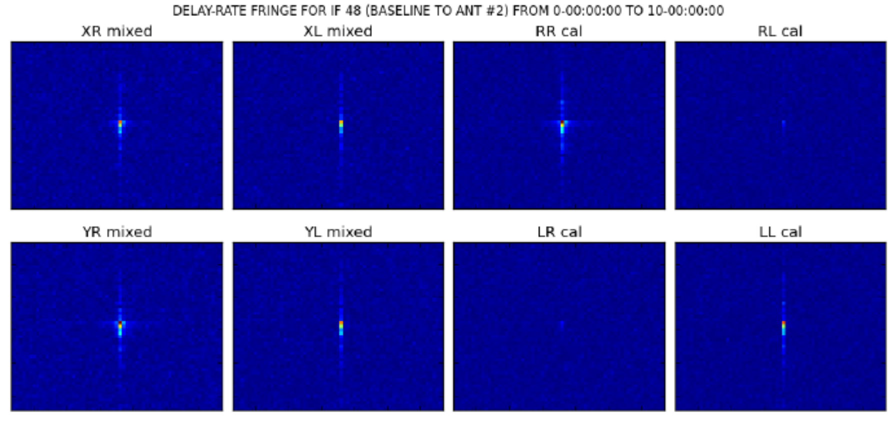
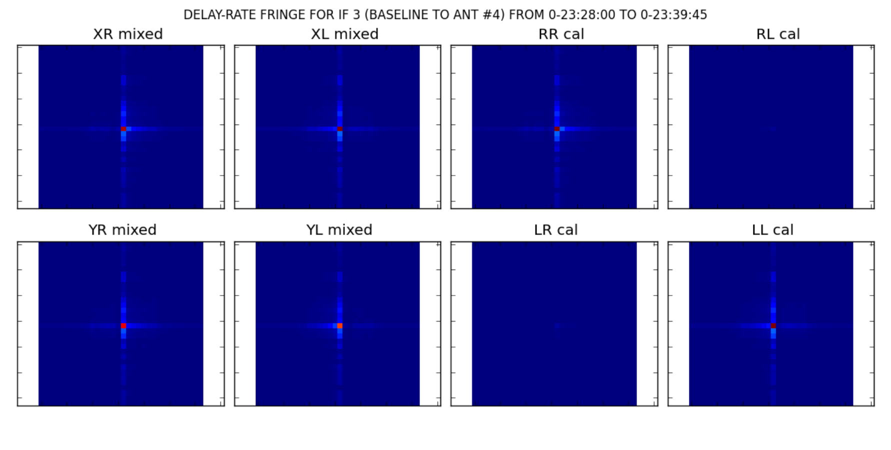
- The idea is to derive all the cross-polarization gain ratios in one shot (for both linear and circular polarizers).
- This approach is independent of the source structure! (and you don't even need to fringe-fit nor amplitude-correct first!)
- And you can get the absolute EVPA calibration for free!!!

PolConvert on ALMA B6 Data



PolConvert on eEVN Data (C Band; EB in linear)



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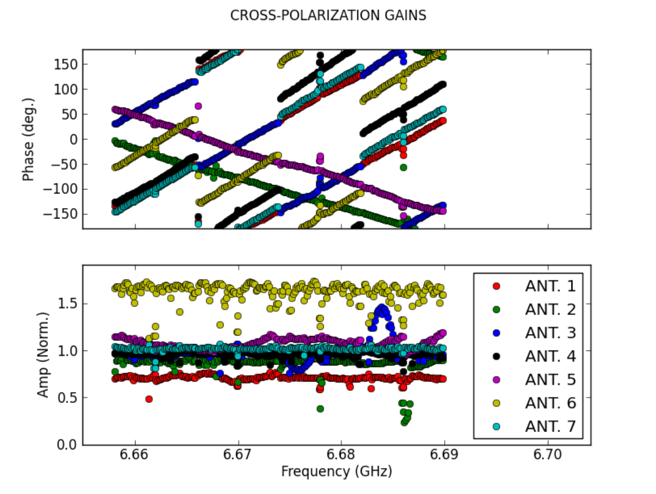
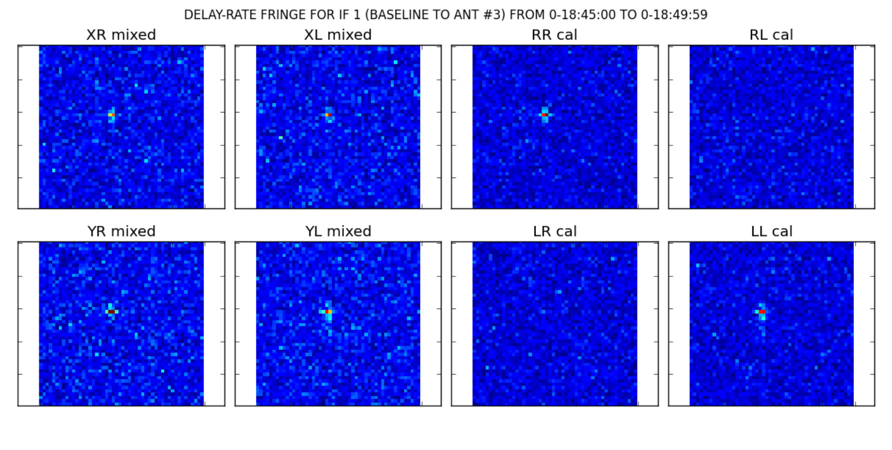


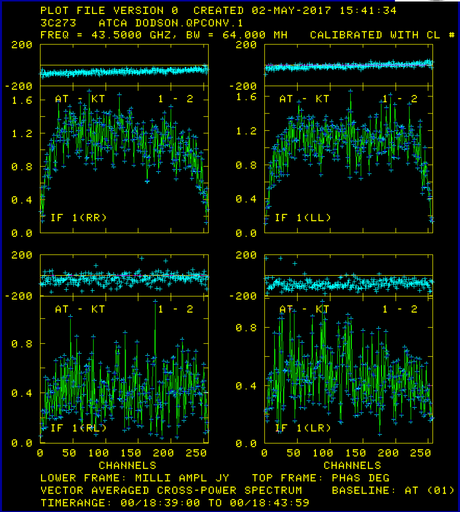
Effelsberg (linear) in green (Ant. 2)

PolConvert on ATCA-KVN (Q/W)



Chanapote (PI of data) & Dodson

PolConvert on ATCA-KVN (Q/W)



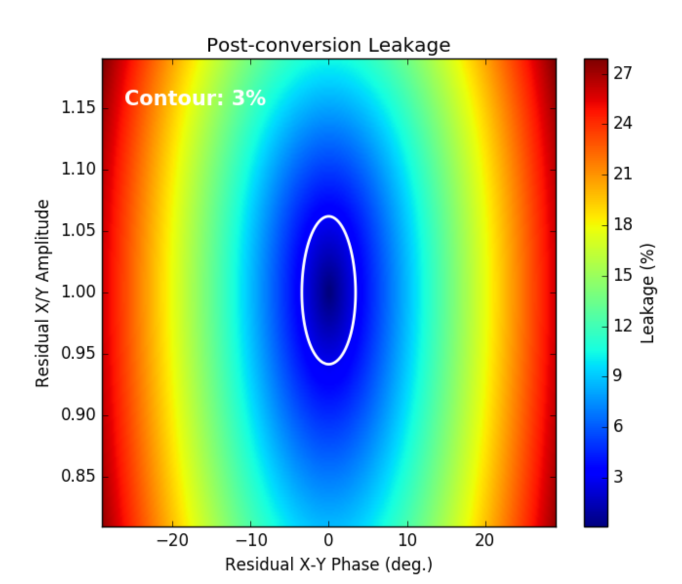
Chanapote (PI of data) & Dodson

Main Take-aways

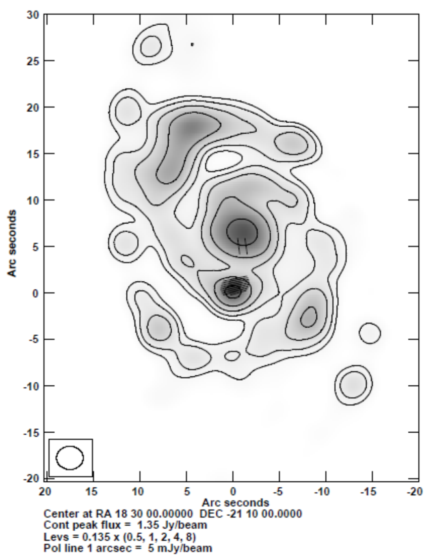
- mm/submm polarimetry probes the immediate SMBH magneto-ionic neighborhood.
- The mm/submm observations are strongly limited by sensitivity and resolution.
  - Resolution $\rightarrow$ VLBI (EHT).
  - Sensitivity $\rightarrow$ ALMA (and use of dynamic-range-limited observables).
- Frequency-dependent mm/submm variability in a gravitationally-lensed AGN (coupled to a γ-ray flare).
- "Differential polarimetry" allowed us to estimate the *RM* in an AGN jet at the highest radio frequencies (1 THz, z-corrected).
- Detected polarization ($\sim$ 10%, at least) at 2.3 THz (z-corrected).

THANKS!

Post-conversion leakage



Simulations I.



- Simulated source: M51ha.fits.
- Peak brightness of 1.35 Jy. Size of 20×30 arcsec.
- Polarized component: 1 Jy with $p = 0.08$.
- There are only 2 fitting parameters!

Martí-Vidal et al. *A&A* (2016)

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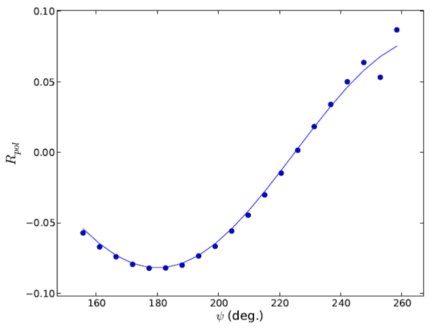

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Simulations II.

R_{pol} vs. ψ

Simulations II.