# Circular polarization of AGN on the VLBI scale. New application of the gain transfer method

(if it is at all possible).

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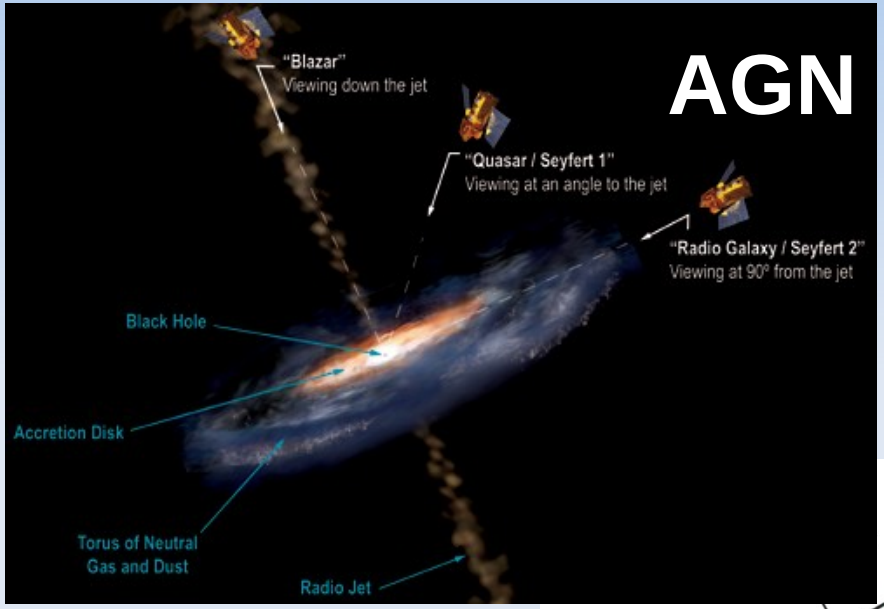
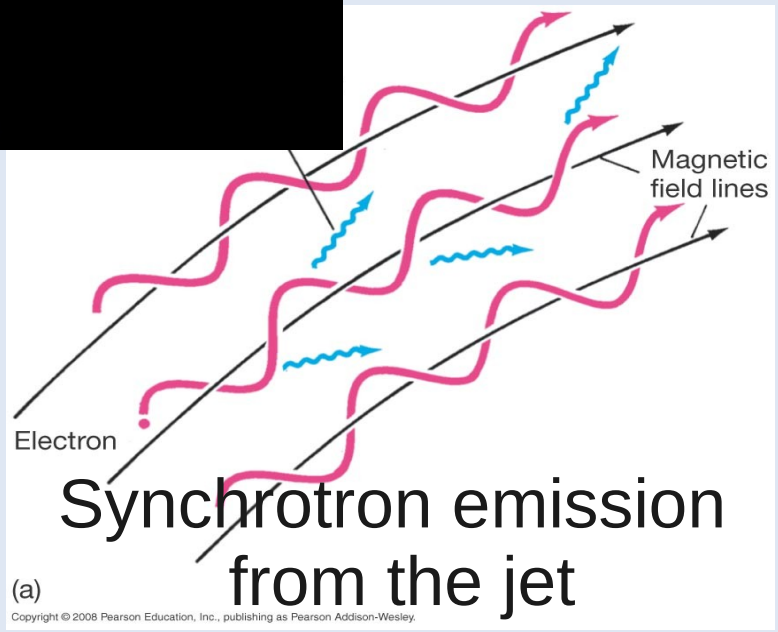
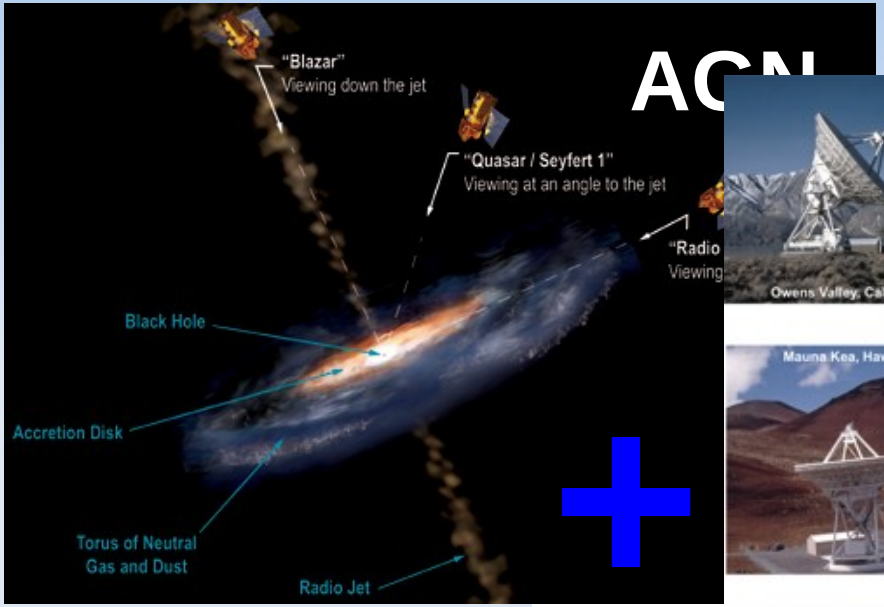
# Synchrotron emission in AGN

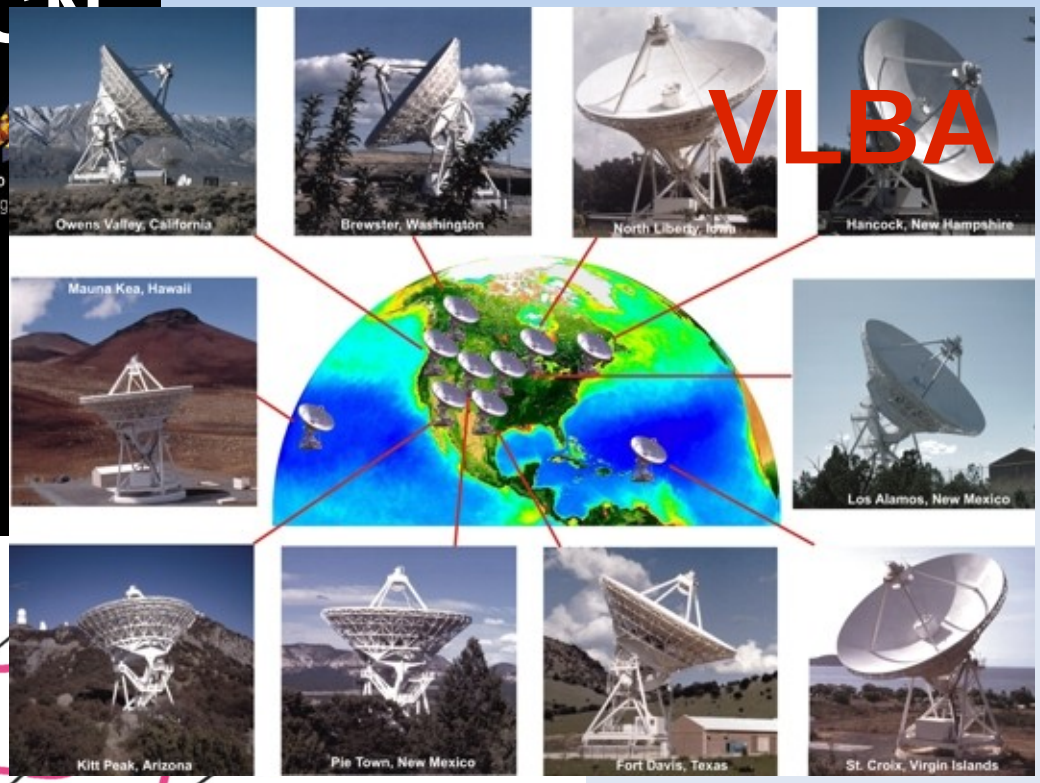


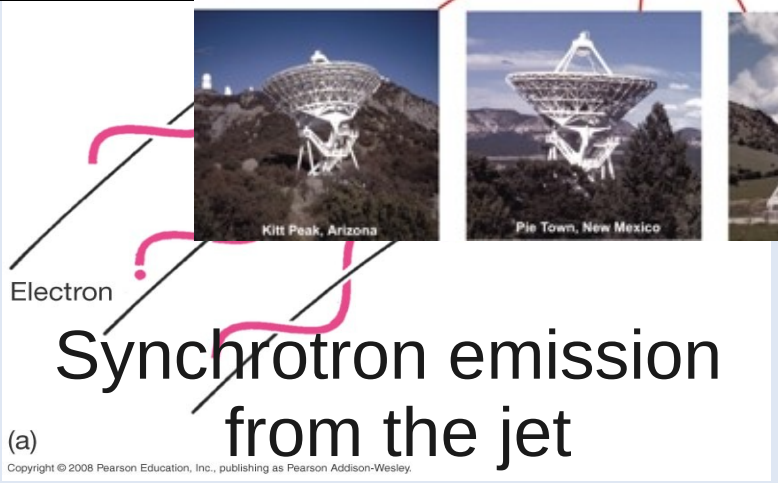




Synchrotron emission from the jet

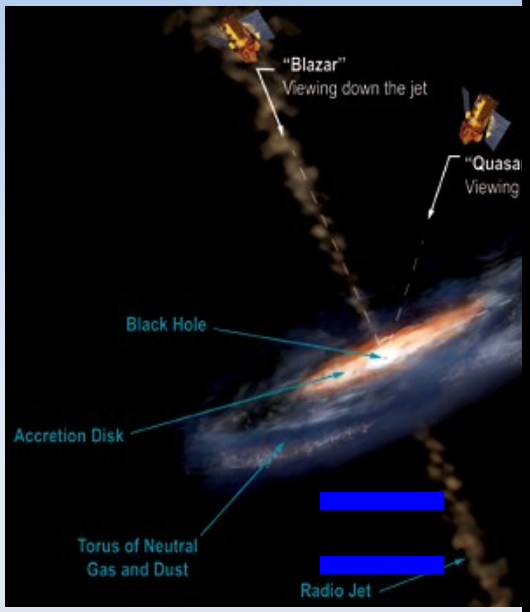
# VLBI observations Aof AGN

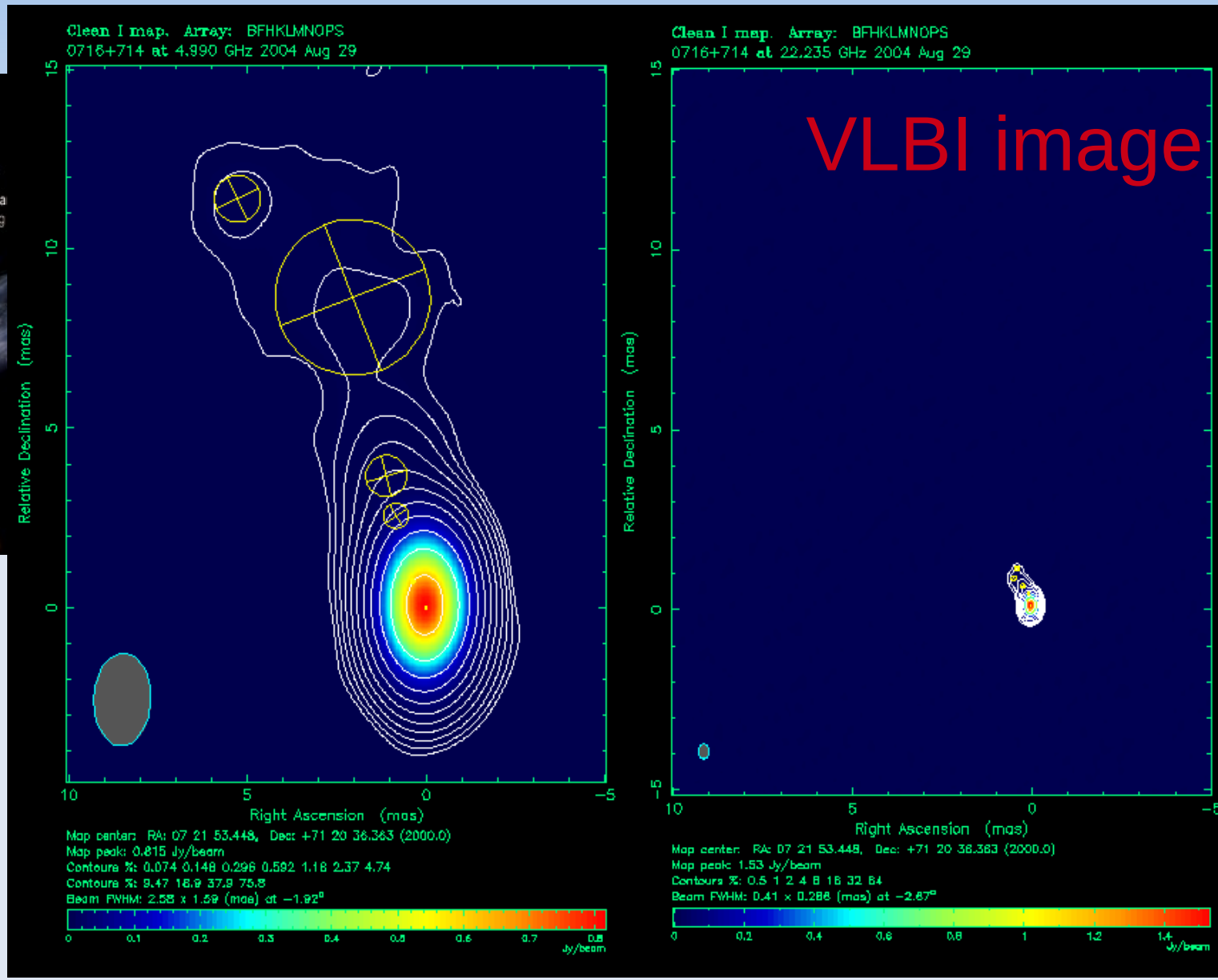


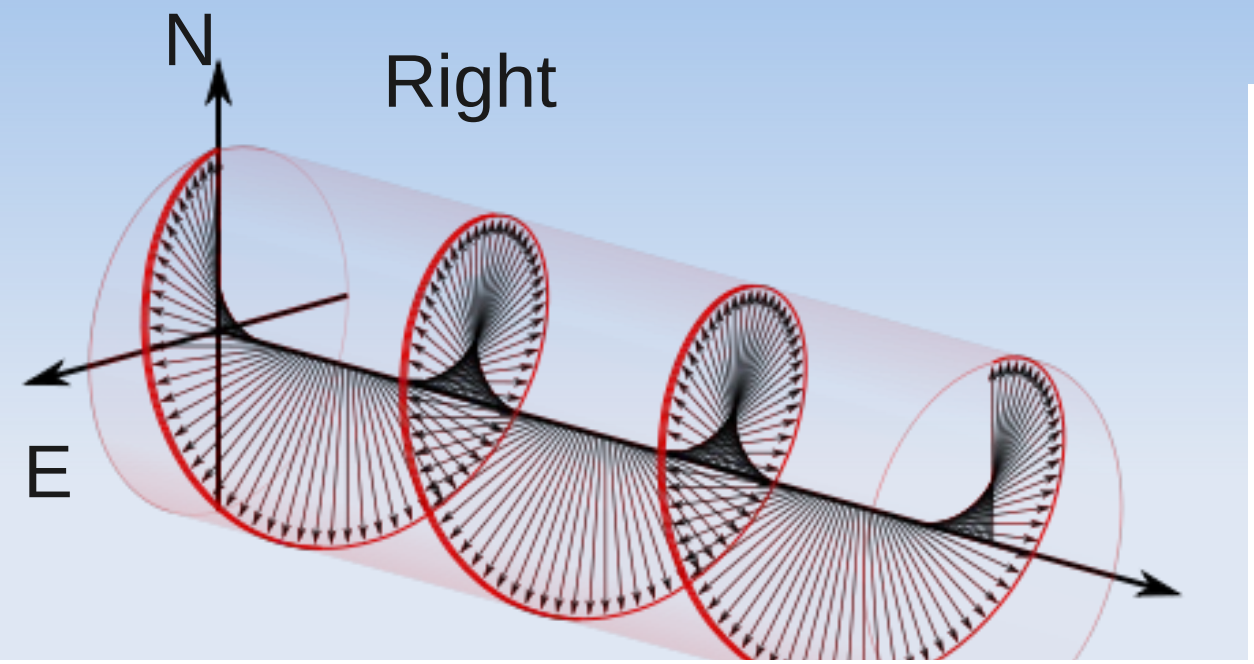



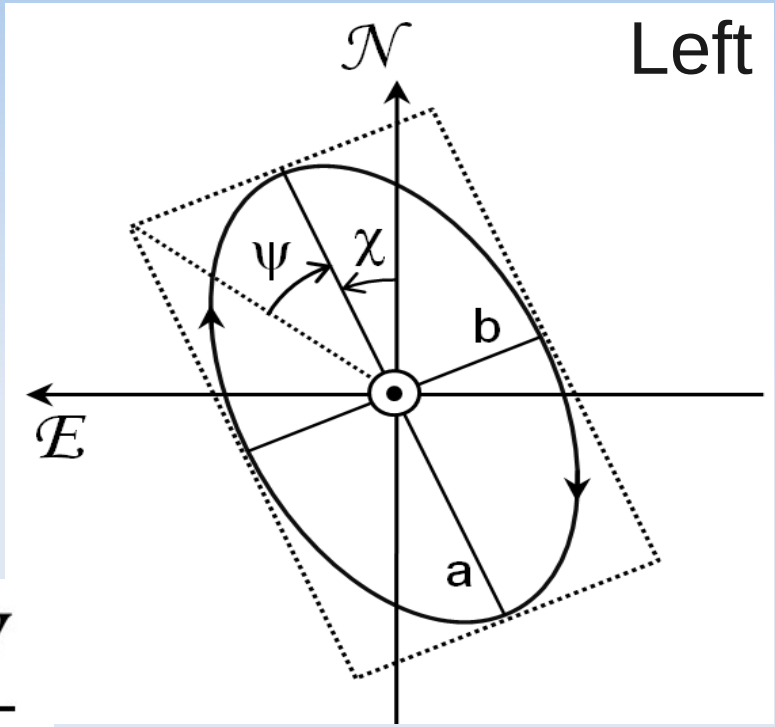
# VLBI observations Aof AGN



# Polarization of radiation: definition




$$\tilde{I}_{ij} = \frac{1}{2}\left(\langle R_i R_j^* \rangle + \langle L_i L_j^* \rangle\right)$$

$$\tilde{Q}_{ij} = \frac{1}{2}\left(\langle L_i R_j^* \rangle + \langle R_i L_j^* \rangle\right)$$

$$\tilde{U}_{ij} = \frac{1}{2} i \left(\langle L_i R_j^* \rangle - \langle R_i L_j^* \rangle\right)$$

$$\tilde{V}_{ij} = \frac{1}{2}\left(\langle R_i R_j^* \rangle - \langle L_i L_j^* \rangle\right),$$

$$m_c = \frac{V}{I}$$

VLBA antennas **i** and **j** measure Right and Left circular polarization **R** and **L**. Stokes parameters as measured for a i-j baseline.

# Circular polarization: calibration

- Standard self-calibration procedure: RR and LL separately

$$\left\| \langle R_i R_j^* \rangle - G_{R,i} G_{R,j}^* \tilde{I}_{i,j}^{mod} \right\| = min$$
$$\left\| \langle L_i L_j^* \rangle - G_{L,i} G_{L,j}^* \tilde{I}_{i,j}^{mod} \right\| = min$$

⇒ circular polarization signal is suppressed

- RR and LL together (CALIB aparm(3)=1)

$$\left\| \frac{\langle R_i R_j^* \rangle + \langle L_i L_j^* \rangle}{2} - Q_i Q_j^* \tilde{I}_{i,j}^{mod} \right\| = min$$

⇒ circular polarization signar remains untouched and uncalibrated

# Circular polarization: calibration

$$\langle R_i R_j^* \rangle^{\mathrm{I}} = Q_i Q_j^* \langle R_i R_j^* \rangle = Q_i Q_j^* G_{R,i} G_{R,j}^* \langle R_i R_j^* \rangle^{\mathrm{true}}$$
$$\langle L_i L_j^* \rangle^{\mathrm{I}} = Q_i Q_j^* \langle L_i L_j^* \rangle = Q_i Q_j^* G_{L,i} G_{L,j}^* \langle L_i L_j^* \rangle^{\mathrm{true}},$$

R-L ratio of gain factors should be determined using a **0 CP calibrator** (real or ”constructed”) throughout the whole observation

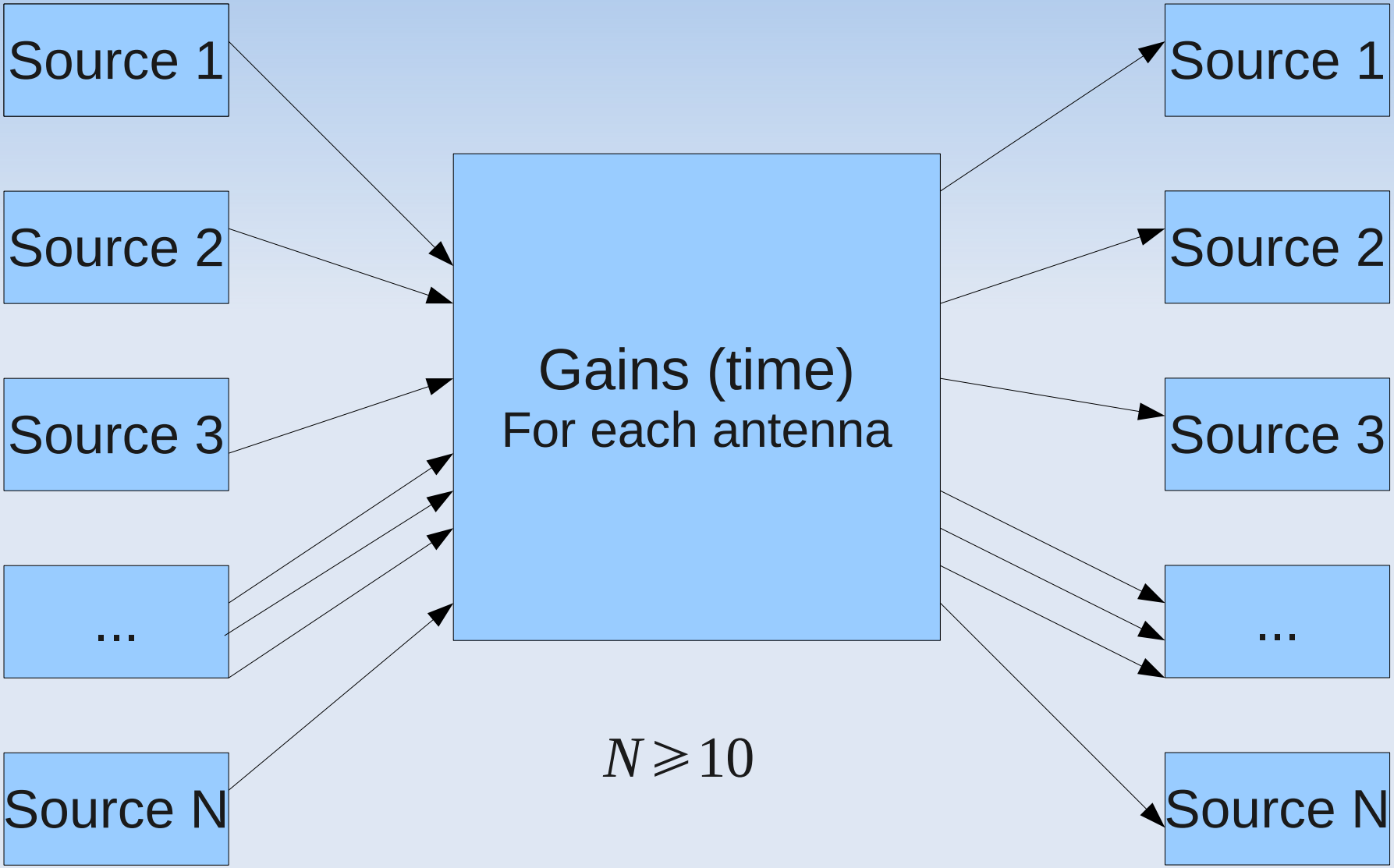
**Gain transfer technique**

(Homan&Wardle, 1999, AJ, 118, 1942; Homan&Attridge& Wardle, 2001, ApJ, 556, 113)

# Gain transfer method: practice

- Calibrator has to be close to the target on the sky.
- On practice, **all sources** (except those with known high circular polarization) are used to calibrate each of them (**gain curves are merged**)
- The experiment for the circular polarization should be specially planned. It should include suitable calibrators, which should be observed every now and then between scans on the target. Preferred are the multi-source observations (>10, ~24 hours).
- CP is distributed randomely, it tends to cancel each other so that the resulting curve corresponds to 0 CP

# Gain transfer method: combined curve




$N \geqslant 10$

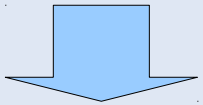
# Gain transfer method: experiment

Is it possible to extend this method to the one-source experiments? (~5 sources, ~9 hours)

- Number of CP observations is growing

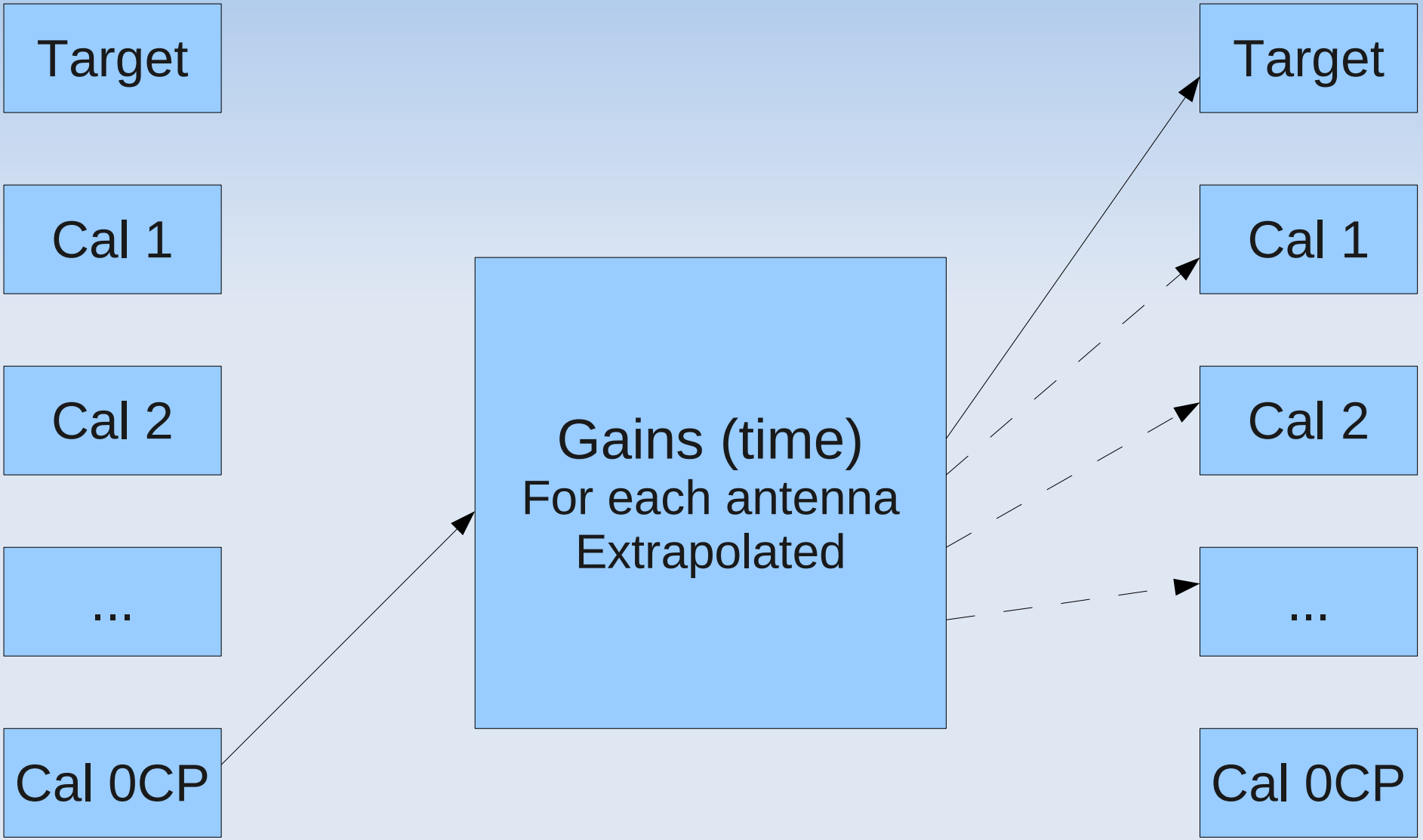
(Homan, D. C. & Wardle, J. F. C. 1999, AJ, 118, 1942; Homan, D. C., Attridge, J. M., & Wardle, J. F. C. 2001, ApJ, 556, 113;

Homan, D. C. & Lister, M. L. 2006, AJ, 131, 1262;
Vitrishchak, V. M., Gabuzda, D. C., Algaba, J. C., et al. 2008, MNRAS, 391, 124; + more in preparation )



chance to find suitable 0-CP calibrators (genuine)

# Gain transfer method: experiment



# Gain transfer method: experiment

Why we believe it is possible to apply this method to a one-source experiment?

- Antenna gains vary on a timescales of *several hours*.
- Single-source experiments are short (~9 hours), and antenna gains do not change significantly on the time scale of the observation.

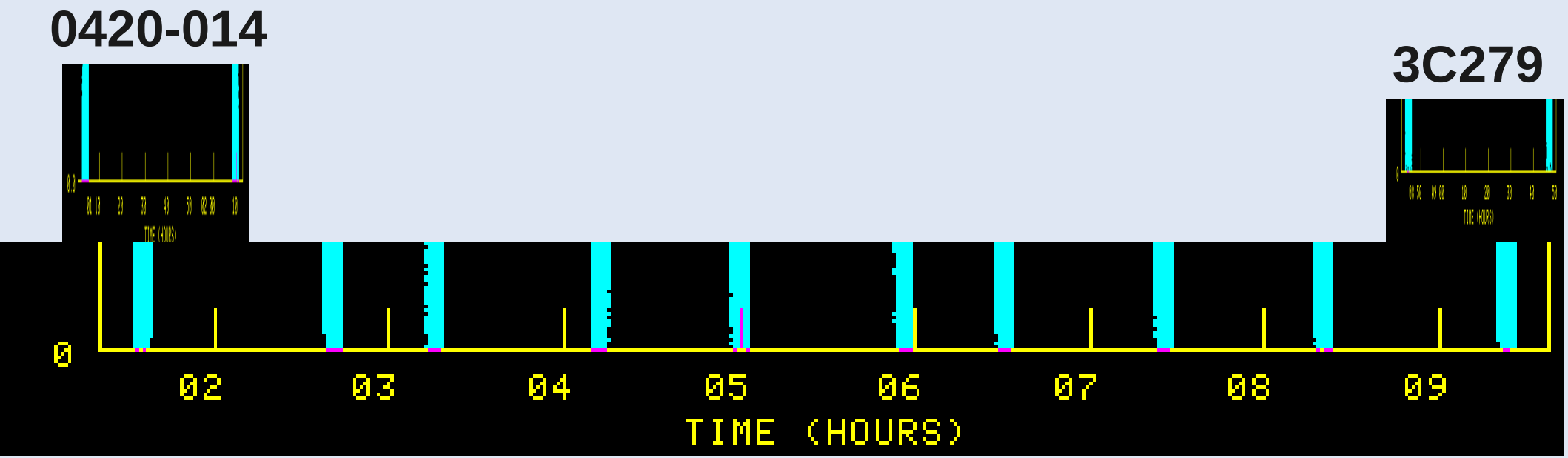
- We can transfer gains from a calibrator to the target, extrapolating them in time

# Gain transfer method: experiment

- Dual-pol VLBA observations of 0716+714 in 2004, gain amplitude, phase and polarization angle calibrators were observed.
- 0420-014 is one of them, the best ”0-CP” calibrator candidate.
- 3 epochs (Feb+May+Aug 2004) at 5+22 GHz

# Gain transfer method: experiment

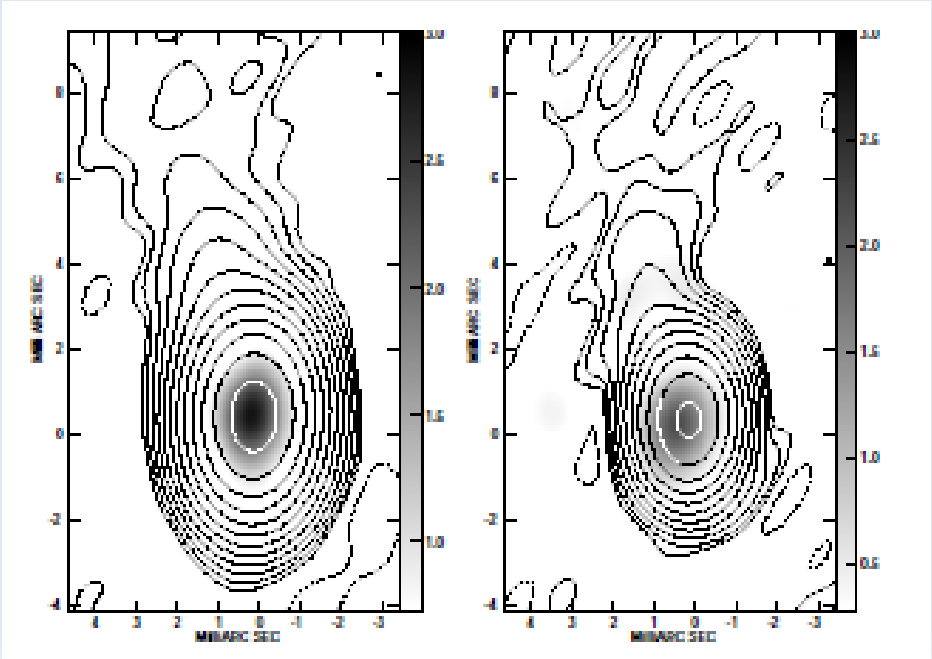
| Source | Epoch | 5 GHz | 15 GHz | 22 GHz | 43 GHz | Reference |
|---|---|---|---|---|---|---|
| | | $m_c$, % | $m_c$, % | $m_c$, % | $m_c$, % | |
| 0420-014 | 1996 Dec | < 0.11 | – | – | – | Homan et al. (2001) |
| 0420-014 | 2003 Mar | – | < 0.16 | – | – | Homan & Lister (2006) |
| 0420-014 | 2005 Mar | – | < 0.16 | < 0.30 | < 0.50 | Vitrishchak et al. (2008) |
| 0420-014 | 2008 Nov | – | < 0.13 | < 0.20 | < 0.54 | Algaba (2011)[1] |



# Our results

| Epoch | Frequency, GHz | $m_L$, % | $V_{peak}$, $mJy/beam$ | $m_c$, % | Significance, $\sigma$ | Location |
|---|---|---|---|---|---|---|
| 2004, Feb 10 (A) | 5 | 1 | -1.22 ± 0.54 | < 0.07 | – | Core |
| 2004, May 3 (B) | 5 | 4 | +2.83 ± 0.44 | +0.32 ± 0.06 | 5.0 | Core |
| 2004, Jul 29 (D) | 5 | 11 | +2.18 ± 0.43 | +0.20 ± 0.06 | 3.2 | Core |
| 2004, Feb 10 (A) | 22 | 2 | +10.00 ± 0.26 | +0.25 ± 0.17 | 1.5 | Core |
| 2004, Feb 10 (A) | 22 | – | – | +0.31 ± 0.28 | 1.1 | Jet |
| 2004, May 3 (B) | 22 | 4 | -5.63 ± 0.76 | −0.19 ± 0.17 | 1.1 | Core |
| 2004, Jul 29 (D) | 22 | 4 | -1.02 ± 0.10 | < 0.45 | – | Core |

5 GHz
May and
August 2004



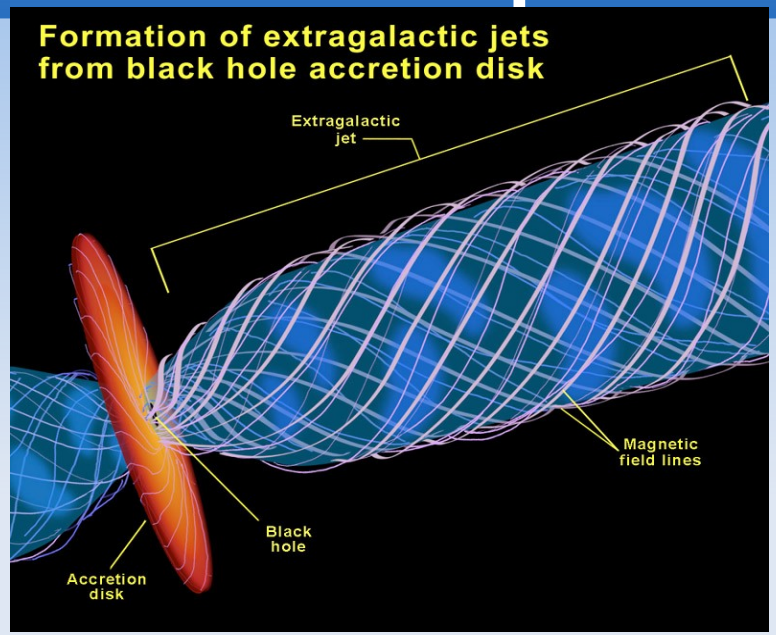
# Account of errors

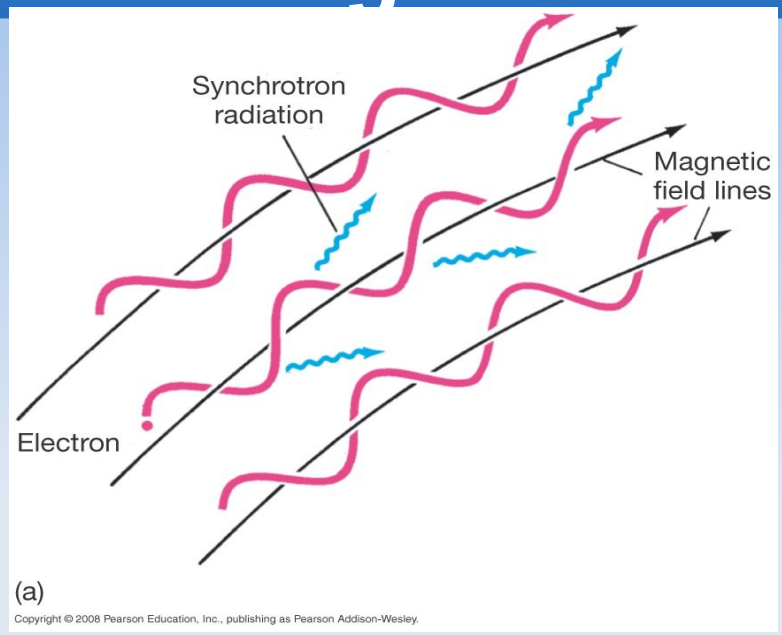
- The relative uncertainty of the CP degree is 20%. It includes ucertainties due to:
  - smoothed antenna gains (estimated from the scatter of gain solutions)
  - the apparent CP of the calibrator (from the rms on the calibrator CP map)
  - imaging uncertainties (from the target source map rms)
- Measured is the **difference** between CP in 0716+714 and 0420-014.
- It reveals geniune CP only if 0-CP calibrator is verified .

# Conclusions

- The gain transfer from the single 0-CP calibrator is possible to use, provided that:
  - Good account of errors is performed
  - 0 CP of the calibrator(s) is verified by
    - a quasi-simultaneous VLBA CP measurements in a large experiment
    - single-dish CP observations

# Synchrotron emission in AGN and CP production: reading




- Rybicky&Lightman, ”Radiative Processes in Astrophysics”, Chap. 6
- Jones&O'Dell, 1977, ApJ, 214, 522
- Ruszkowski&Begelman, 2002, Ap.J., 573, 485
- Wardle&Homan, 2003, AP&SS, 288, 143

# Our results: circular polarization, 3C279

| Calibrator | 3c279 | |
|---|---|---|
| | A | D |
| 0420-014 | 0.08+/-0.06% (1.5σ) | 0.53+/-0.07% (7σ) |