Multi-band & temporal analysis of lensed blazar PKS 1830-211

MIT Haystack REU Seminar
10 August 2023

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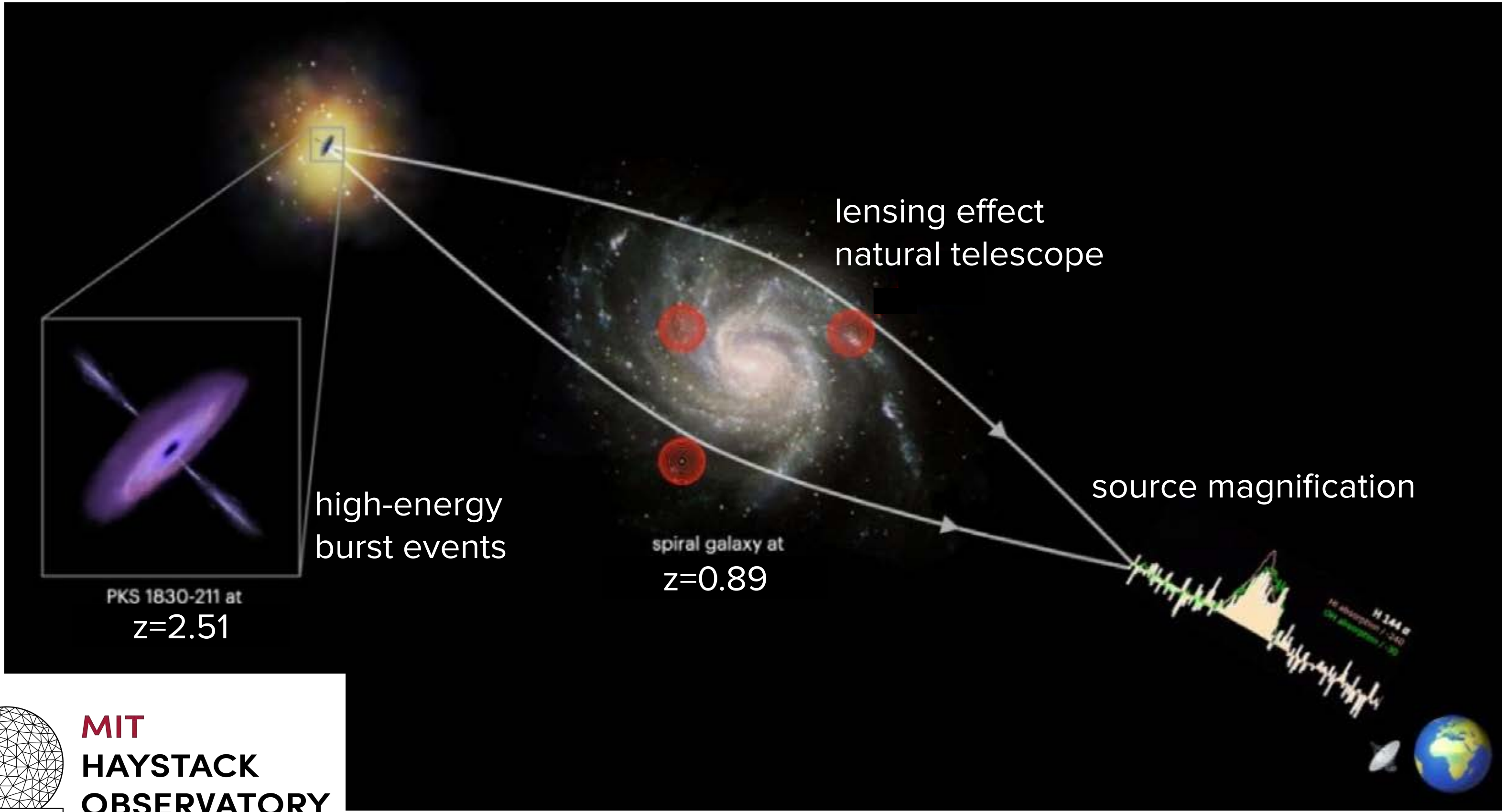
introduction: blazars as active galactic nuclei (AGN)



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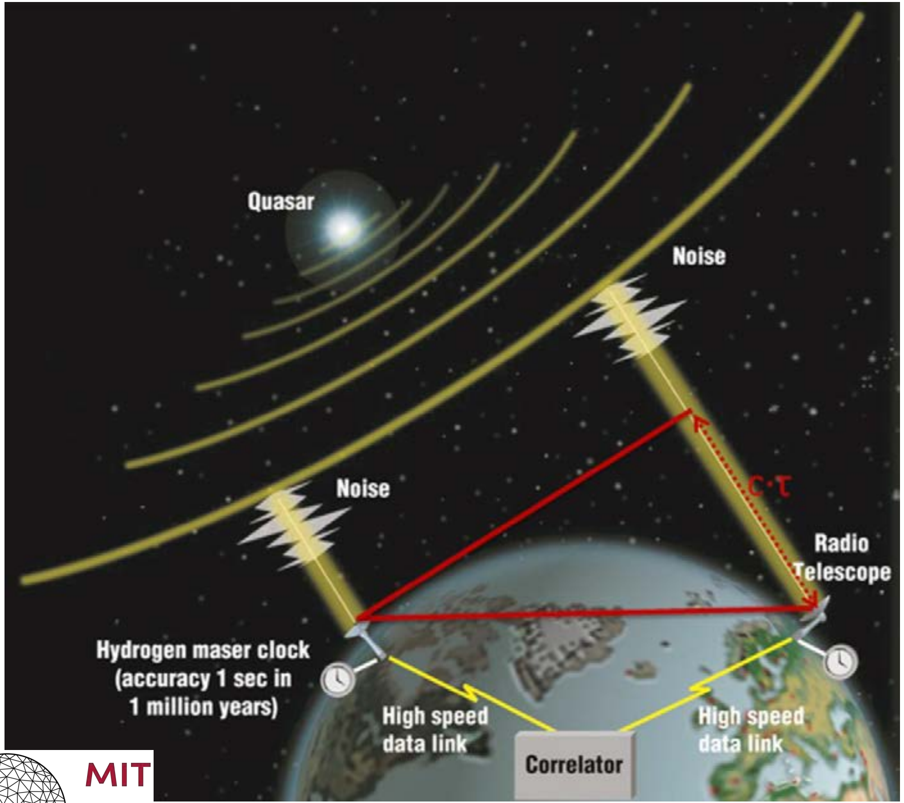
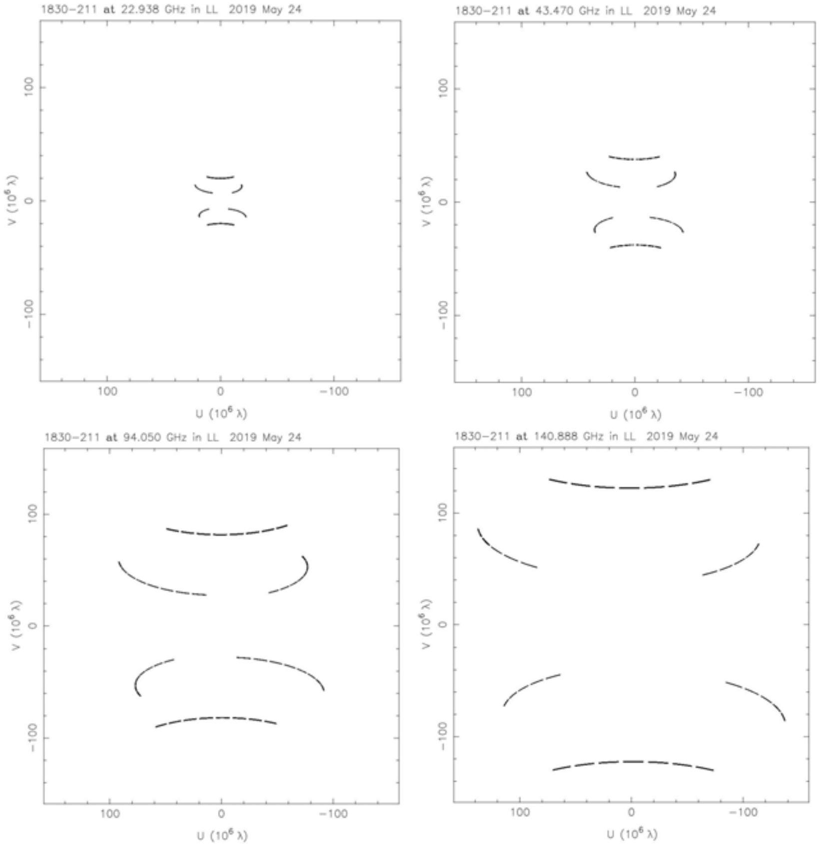
introduction: very-long baseline interferometry (VLBI)





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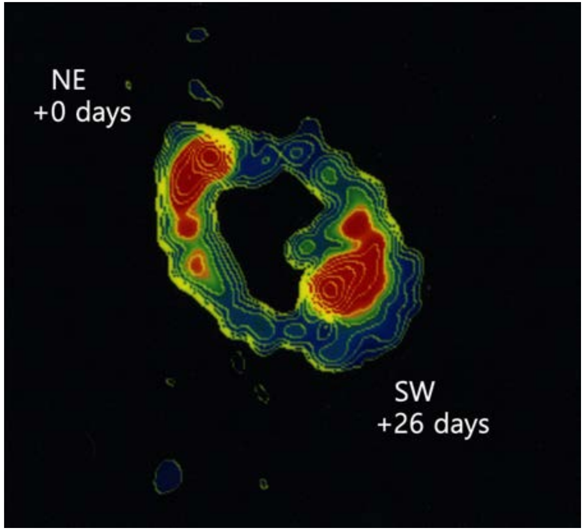
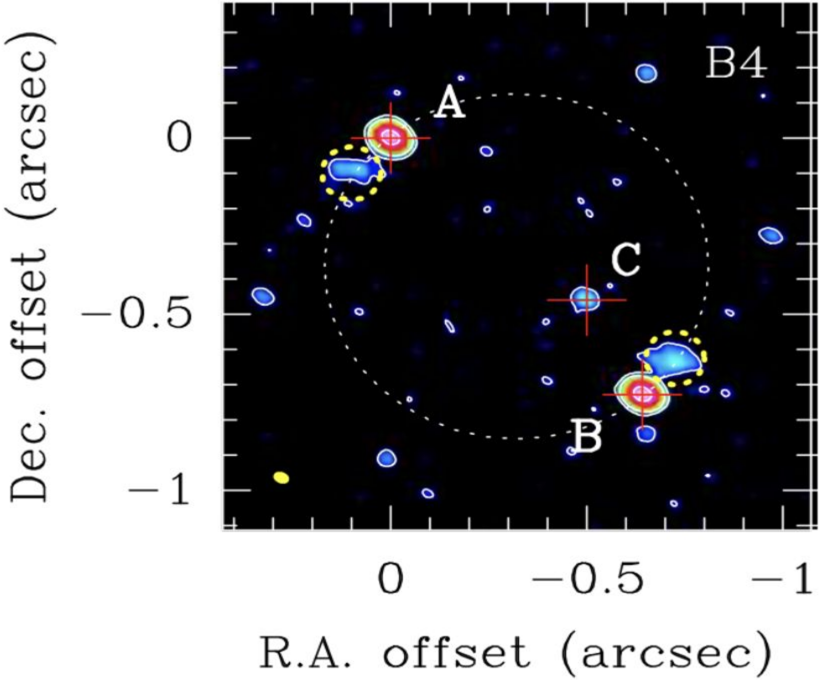
introduction: PKS 1830-211

- parameters have been modeled
- can observe flares
- expect frequency-independent structure
- goal: check structure, understand mechanism
    - more frequencies
    - connect to time-monitoring (delay)

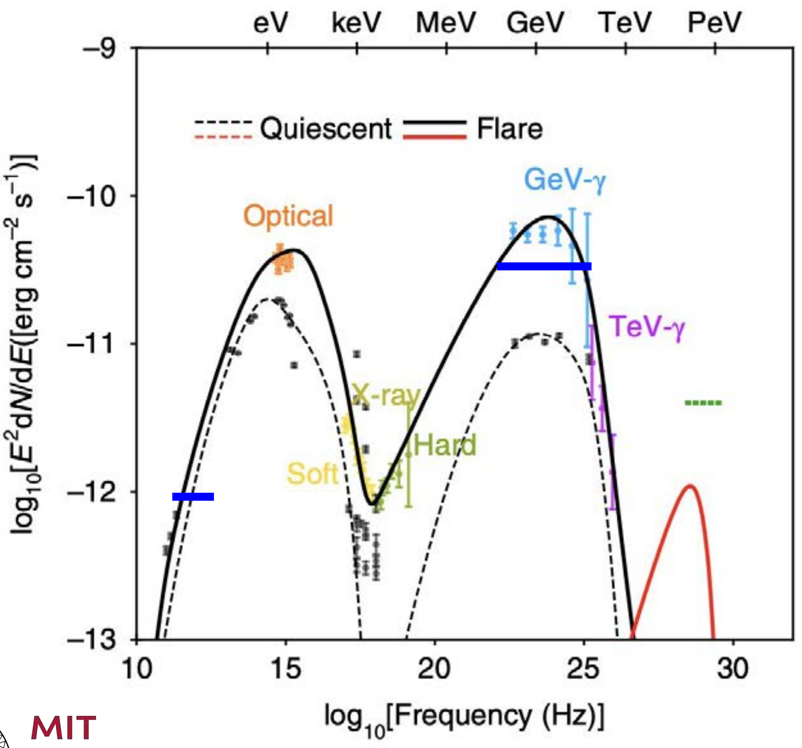


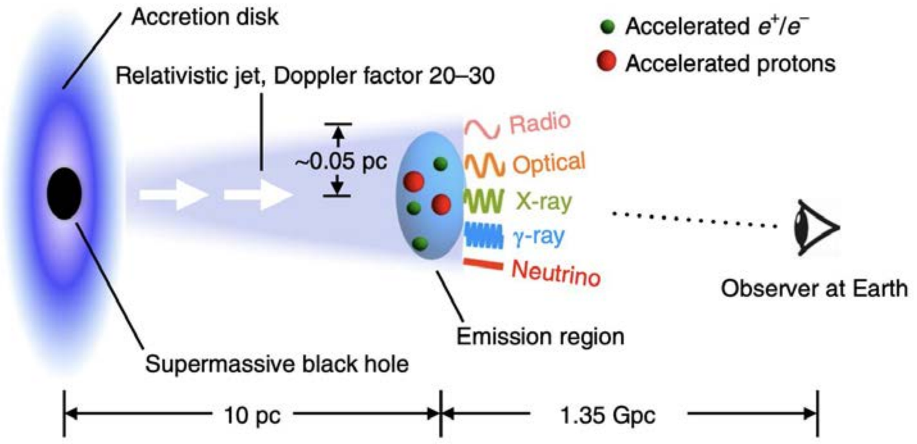
5 GHz MERLIN image;
https://www.atnf.csiro.au/news/results/95Highlights_Gravit.Lens.html



ALMA image; Mueller et al., 2020

motivation: connected radio and high-energy emission



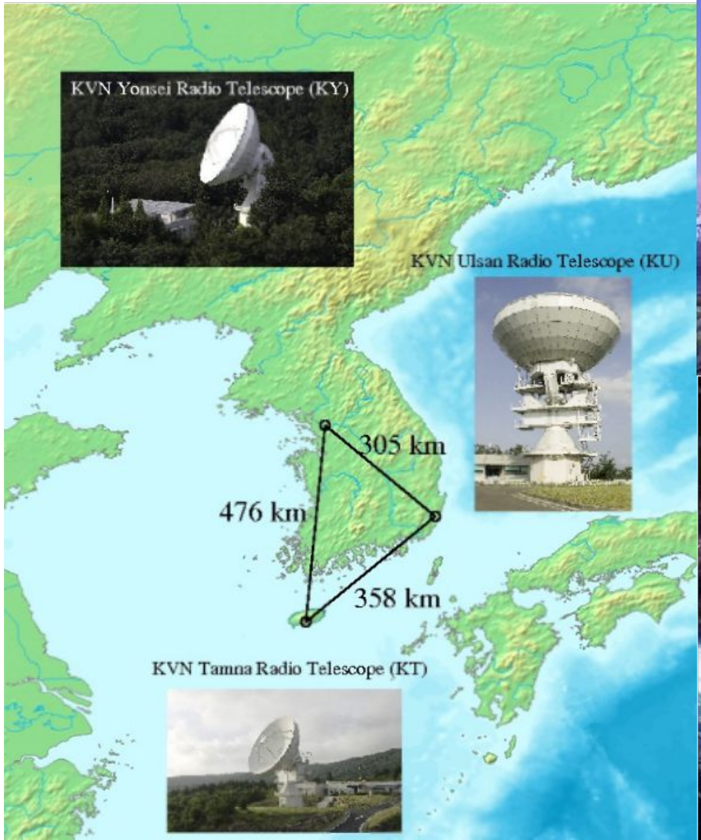


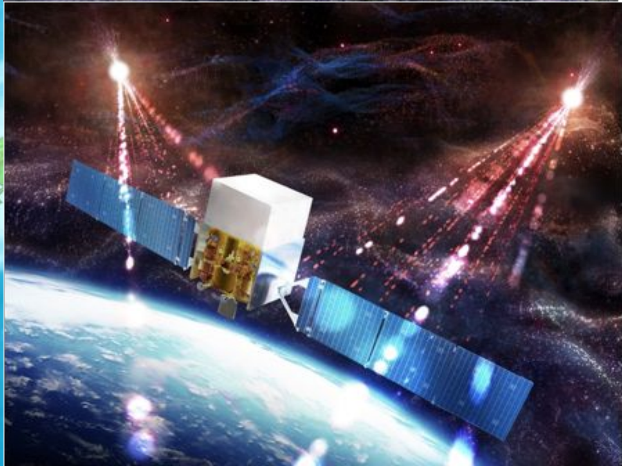
- example: TXS0506 + 056
- causality between emission at different frequencies
- understand PKS 1830-211 flaring events

Gao et al. 2019

methodology: data sources

1. Korean VLBI Network (KVN)
2. Caltech Owens Valley Radio Observatory (OVRO)
3. Fermi Satellite





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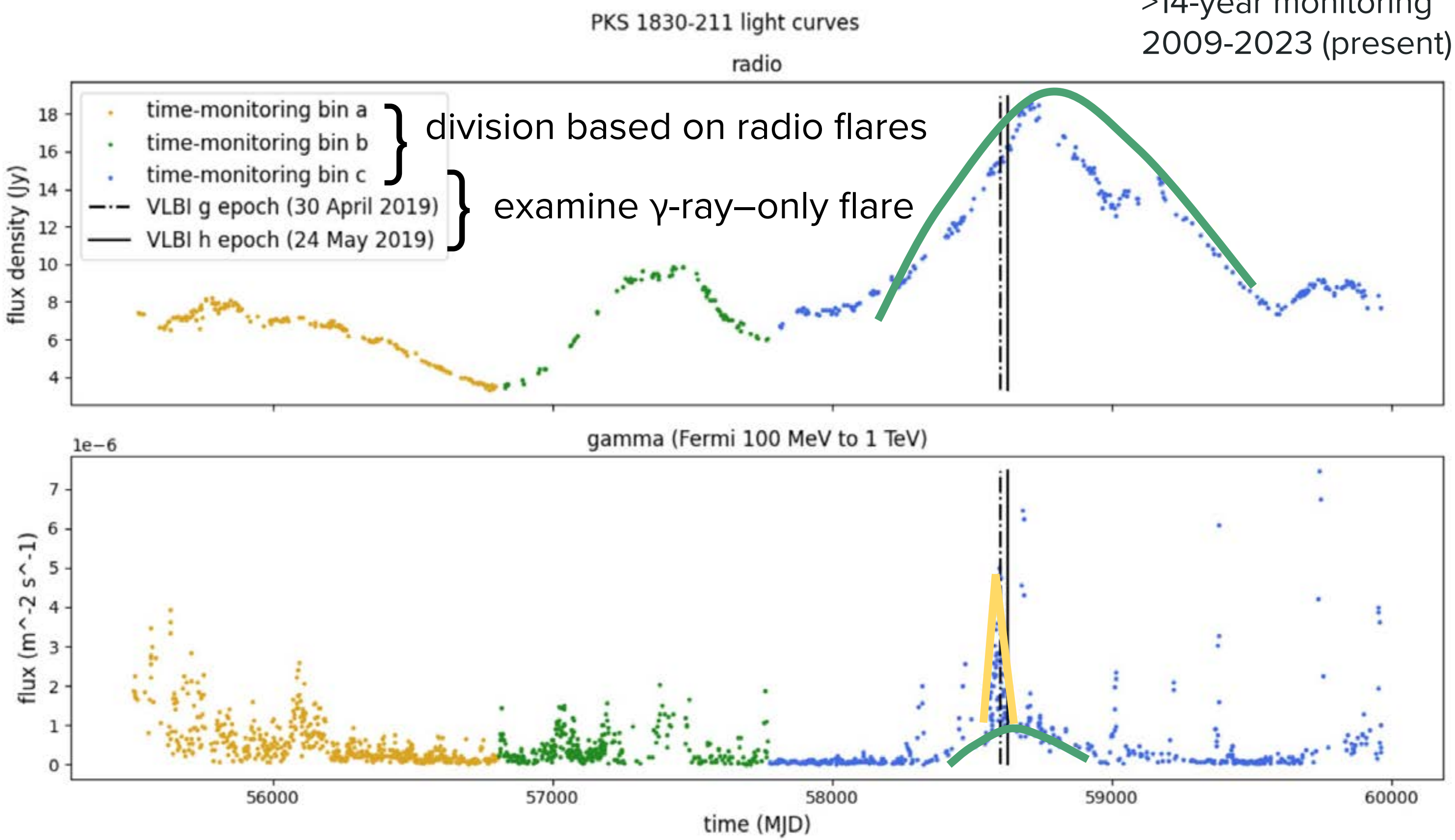
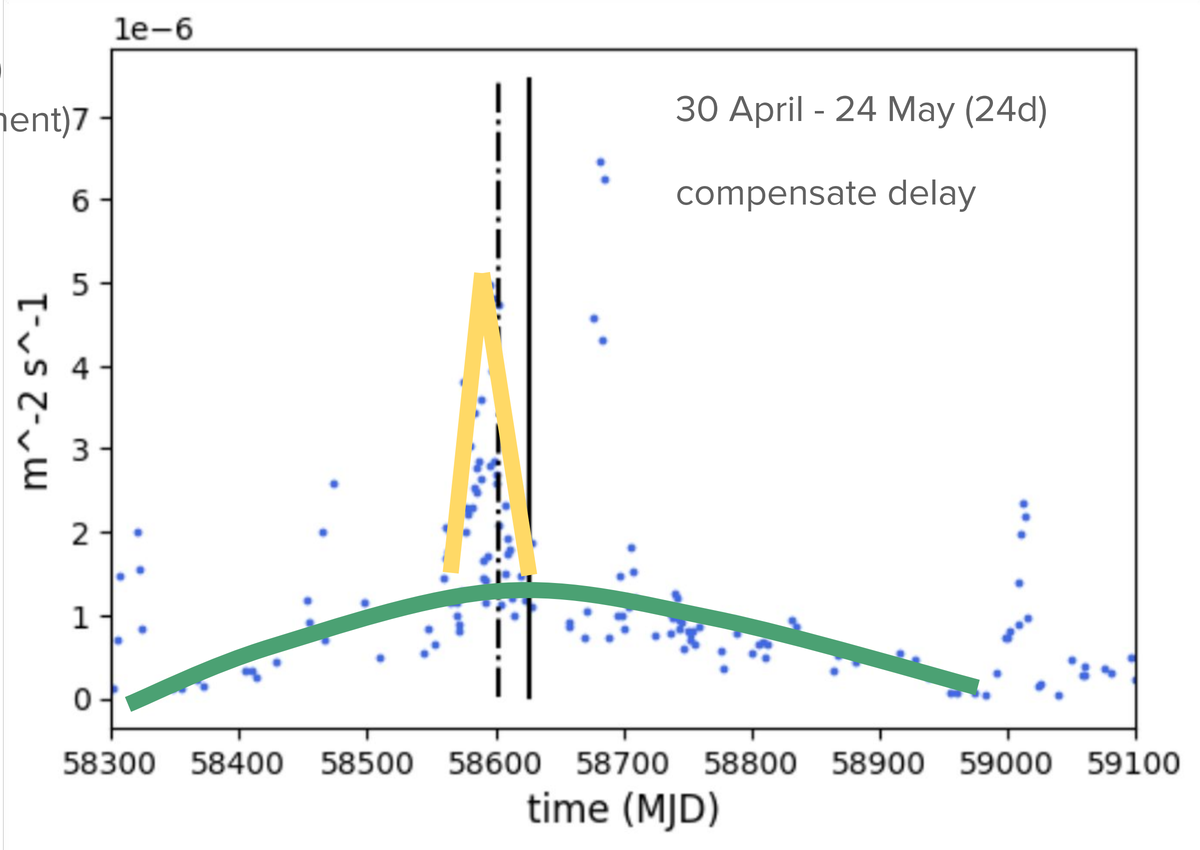
methodology: spatial and temporal analysis

>14-year monitoring
2009-2023 (present)



methodology: spatial and temporal analysis

- multi-wavelength flares (radio, γ)
- independent flares (one component)
- orphan flares (γ-ray only)



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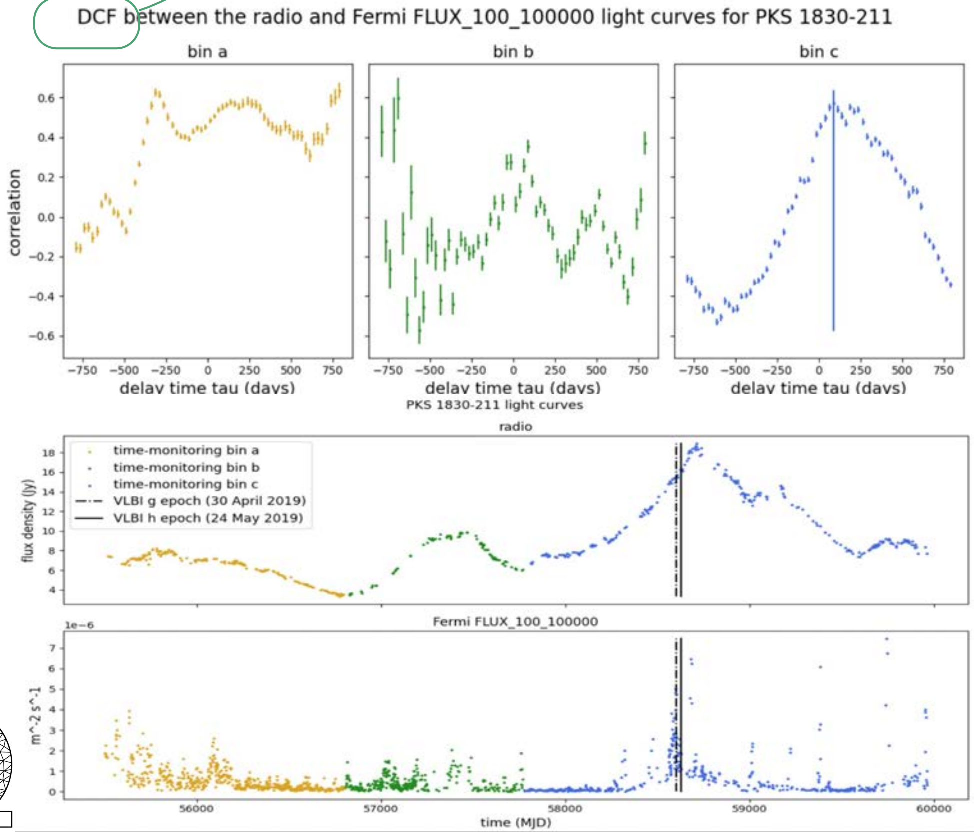
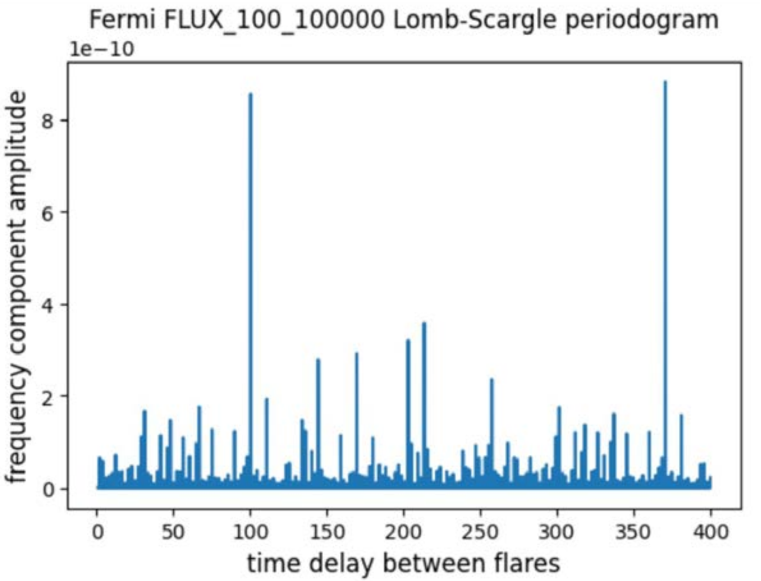
results: time-monitoring data analysis

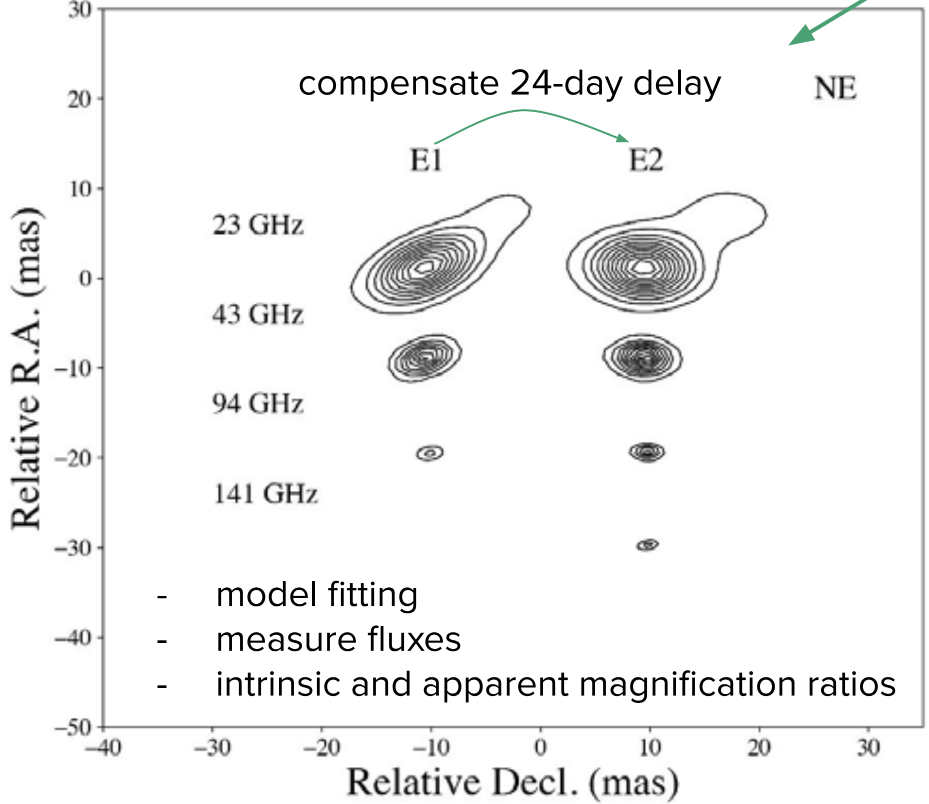
discrete correlation function



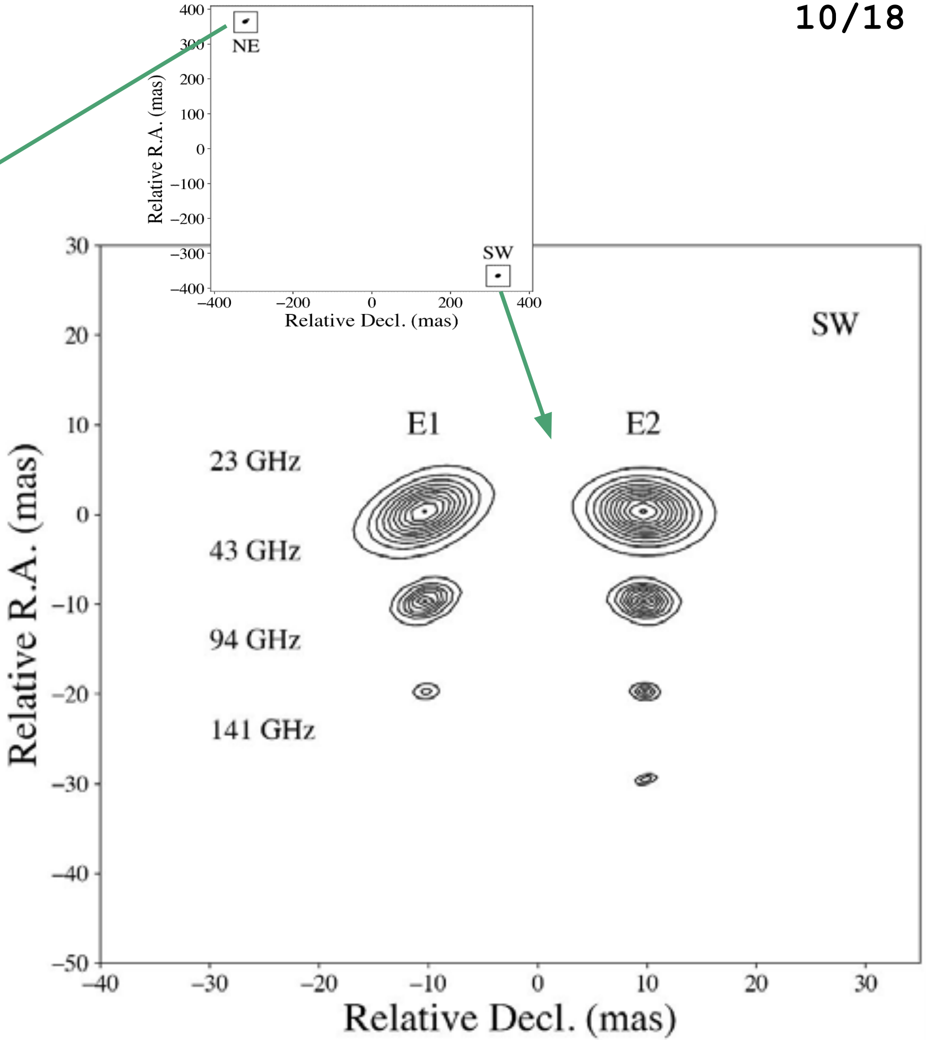


results: VLBI imaging

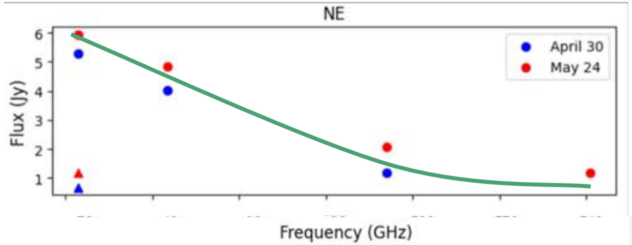
compensate 24-day delay

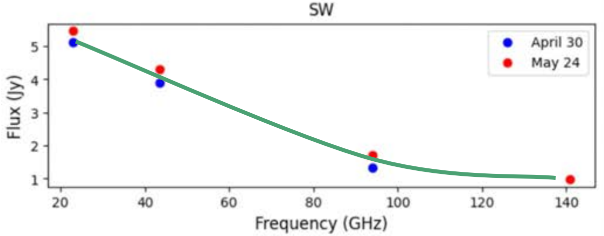


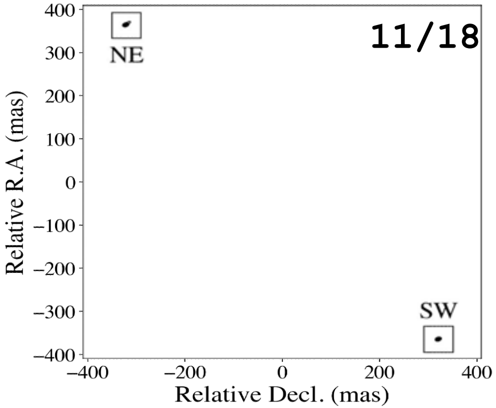
- model fitting
- measure fluxes
- intrinsic and apparent magnification ratios



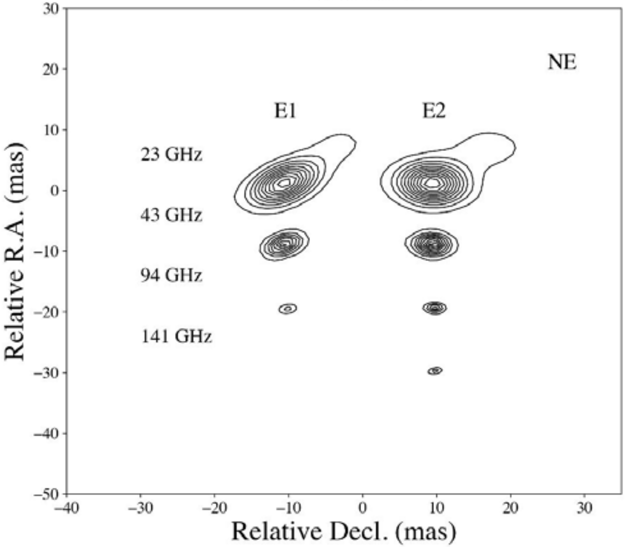
analysis: a chromatic, time-variable jet

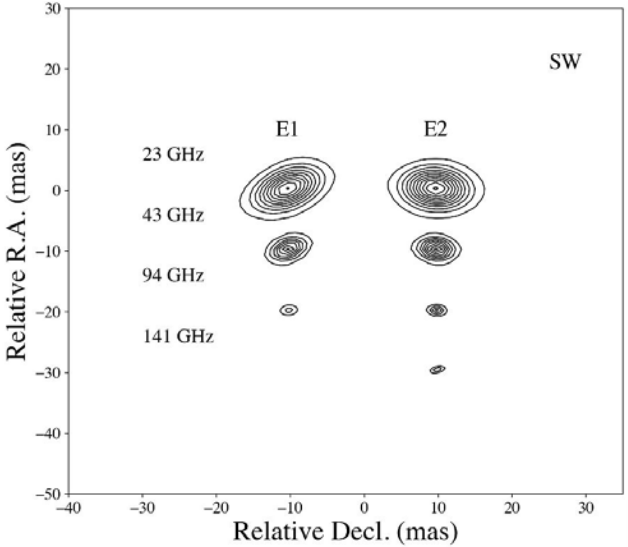


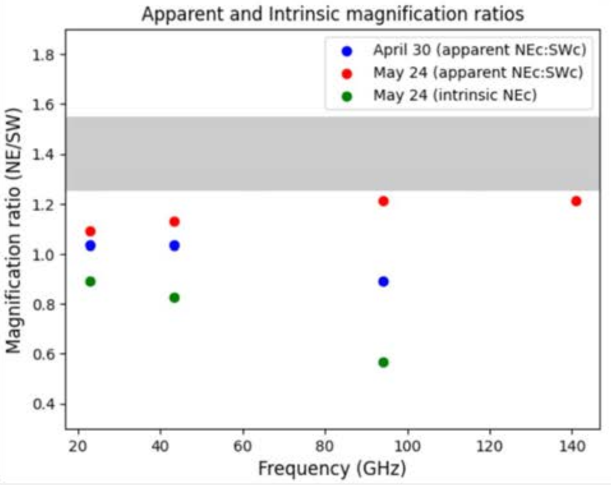




compare to “plain” strong lensing, which is achromatic



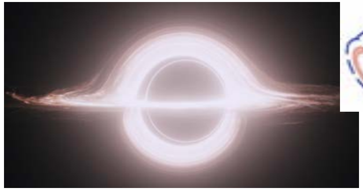




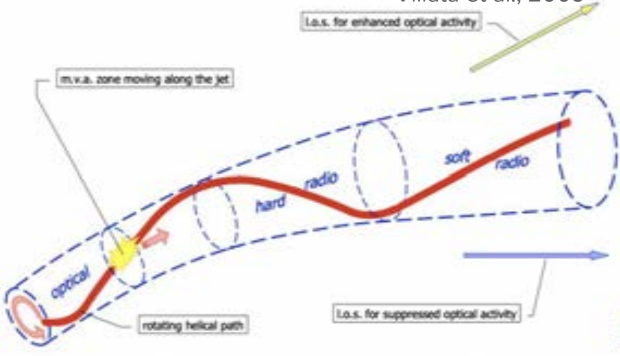
conclusion: interpreting the chromatic, time-variable jet

time-monitoring data

- radio peak delayed by **87 d**
  - moving shock in the jet
  - opacity effect
  - inverse Compton scattering—photon source:
    - internal
    - external
- orphan (no radio), independent (no 2^{nd} γ-ray component) γ-ray flare
  - microlensing
- **371 d** γ-ray flare periodicity
  - jet kinematics (precession)



Villata et al., 2009



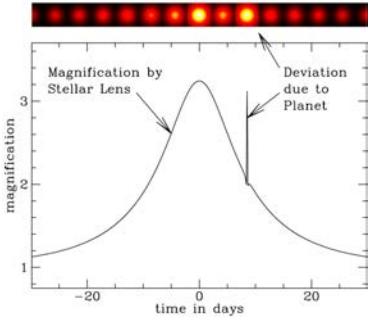
VLBI data

- frequency-dependent magnification ratios (**0.9-1.2 +/- 5% intrinsic**, **0.5-0.9 +/- 5% apparent**)
  - chromatic jet structure
  - opacity and size varies with frequency
- low magnification ratios during flaring event
  - further study is necessary

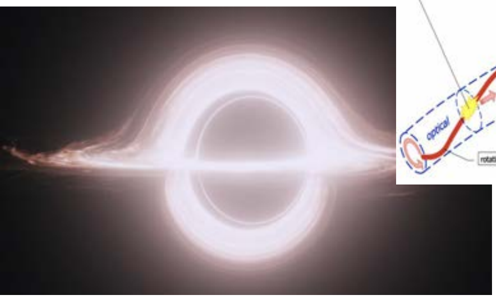
not to scale!

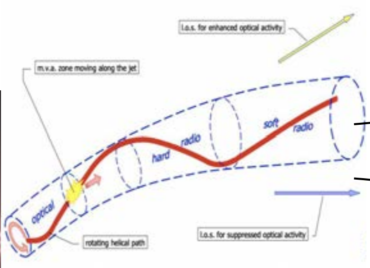
conclusion: interpreting the chromatic, time-variable jet

microlensing (cartoon overview)

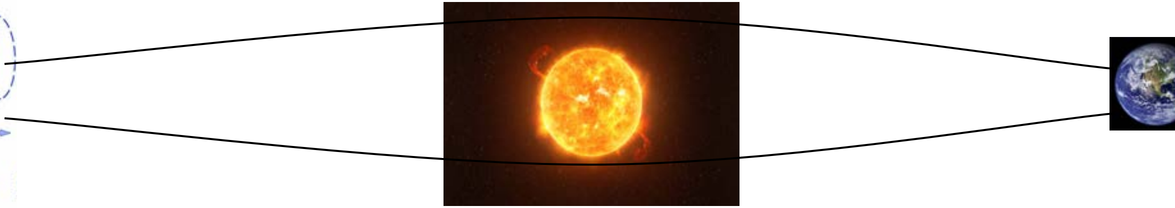


star-planet analogy
source: NASA





Villata et al., 2009



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not to scale!

summary

- investigate correlation between radio and γ-ray emission from PKS 1830-211
- gravitational lensing serves as a "natural cosmic telescope"
- known 26-day delay of SW component
- time-monitoring light curves & high–angular resolution VLBI flare observations
- understand jet mechanisms
- independent flares ➔ microlensing
- associated flares ➔ jet ICS
- frequency-dependent flux ratios ➔ chromatic, evolving jet structure (opacity effect)

acknowledgements

Thank you to Dongjin, Kazu, and Vincent, for their helpful explanations of everything from interferometry to AIPS; to the entire Haystack community, for their illuminating seminars; to the NSF, for funding this REU; and to the other members of the Haystack REU, for Carl quotes and everything else.

next steps

- statistical significance
  - Lomb-Scargle periodogram
  - DCF
- more confidence in mechanism
  - VLBI observations
  - light curve reduction
- spectral lines
- experimental cosmology

questions

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selected references

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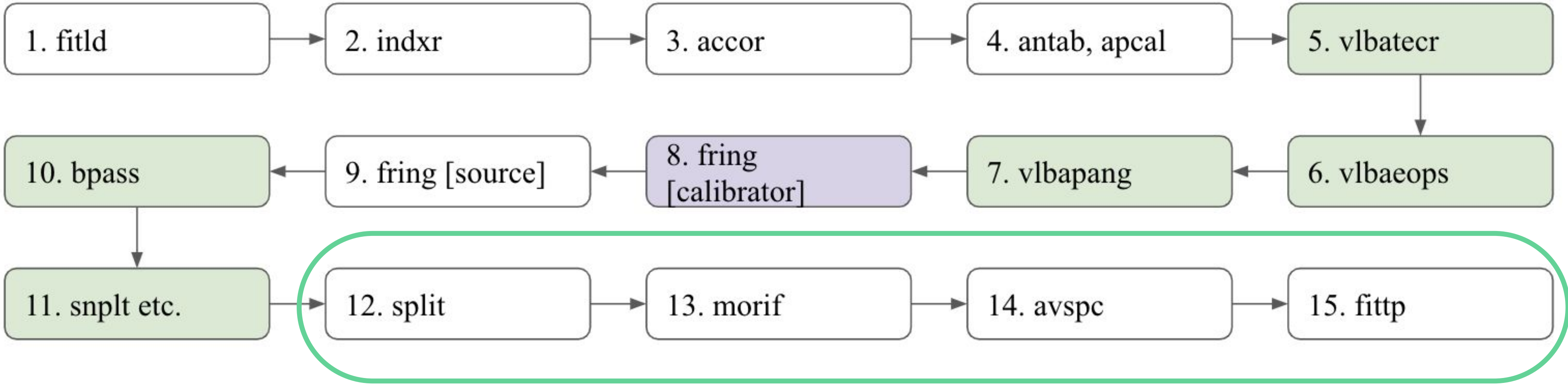
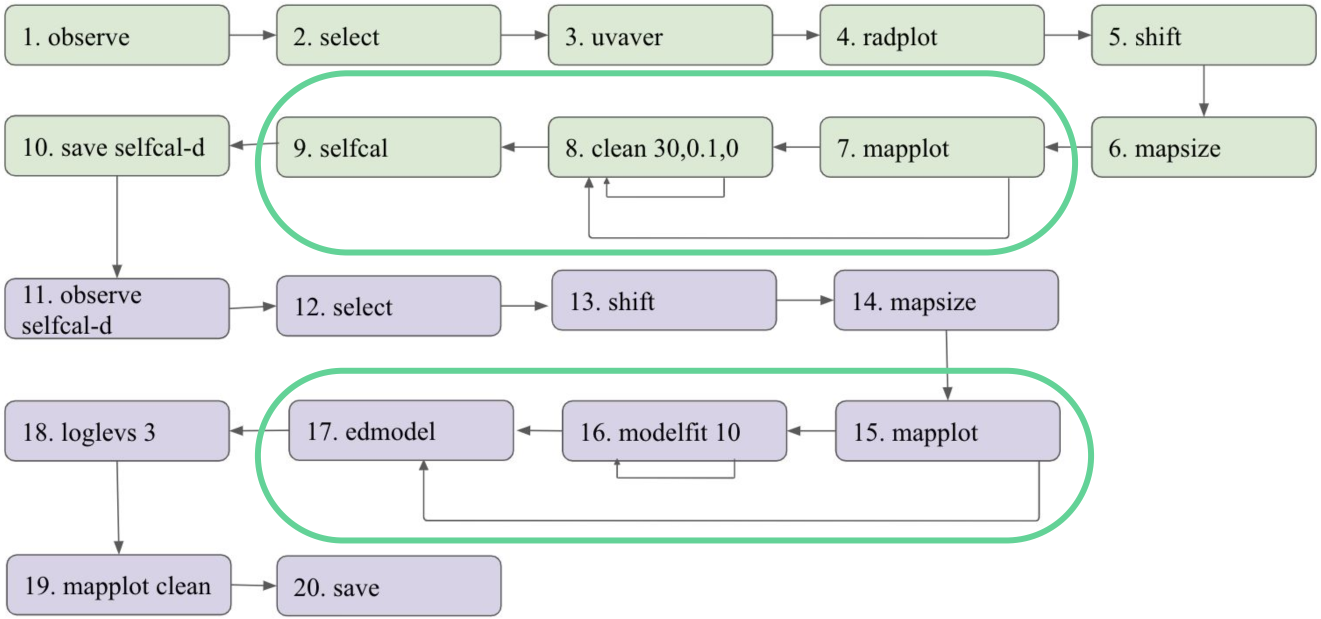
export reduced data from AIPS

- bandpass is flat for middle channels
- exclude first 50 and last 50 channels → 19 sub-IFs with 100 channels each
- K, Q, W, D bands during the epochs starting 30 April 2019 and 24 May 2019
- non-detection in epoch g, IF 4 → to image: g1, g2, g3, h1, h2, h3, h4

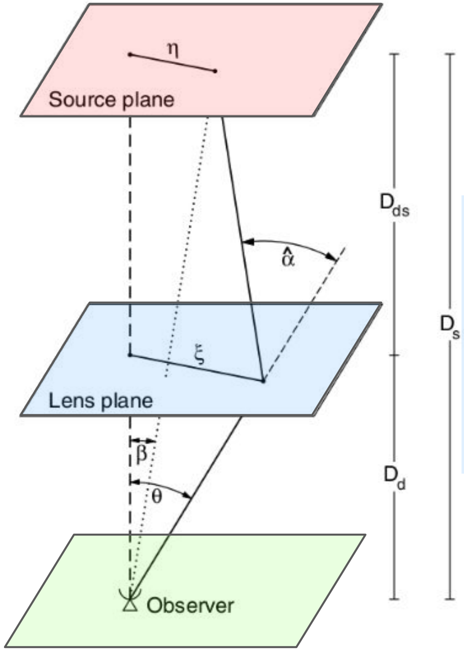


difmap imaging procedure

- correct non-uniformities in the residual map
- fit a model
    - δ-function components (clean components)
    - circular or elliptical gaussian components
- recover the observed flux—phase, amplitude
- low u-v coverage



gravitational lensing



Schneider et al., 2006