Finding gravitational lenses with LOFAR

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JIVE — JOINT INSTITUTE FOR VLBI IN EUROPE

ANGLES — Astrophysics Network for Galaxy LEnsing Studies

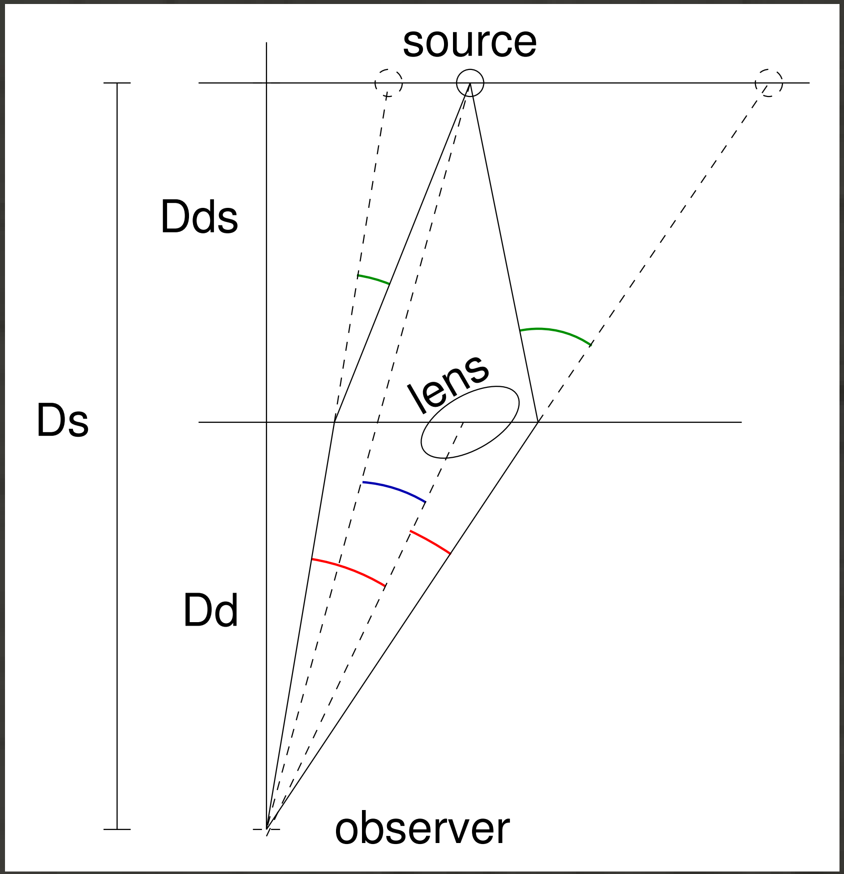
Finding gravitational lenses with LOFAR

- Why lensing?
- Why LOFAR?
- LOFAR (lens) surveys
  - ⋆ source-targeted
  - ⋆ lens-targeted
- What's needed?

Relevant aspects of (strong macro-) lensing

- cosmology, Hubble constant
  - ⋆ time-delays
  - ⋆ good lens models
- mass distributions, models
  - ⋆ global profile
  - ⋆ substructure
  - ⋆ central concentration
- propagation effects
- lens as natural telescope $\leadsto$ Mike Garrett

Measuring distances with time-delays



- distance ratios known
- angles measurable
- geometry can be determined
- need *one* length for scale

⇝ use *time-delay* !

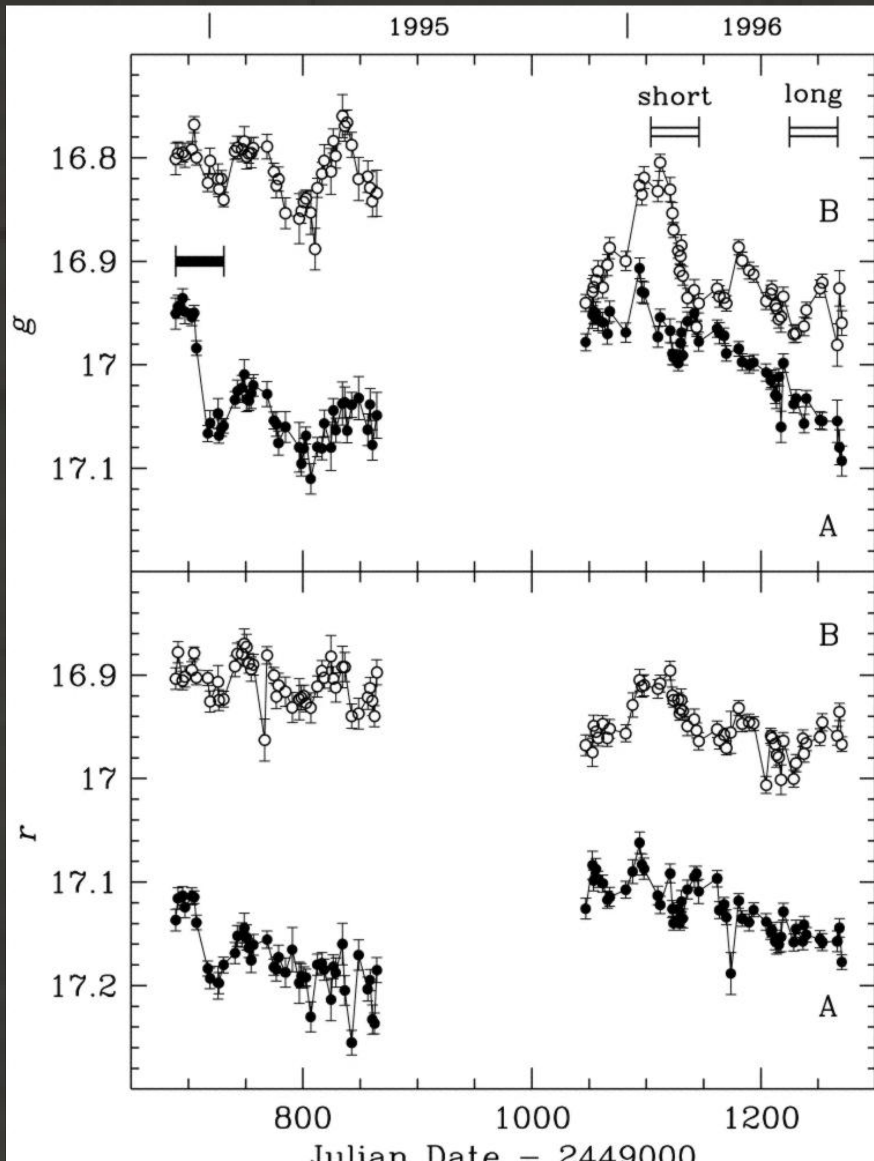
Refsdal (1964), MNRAS 128, 307 :

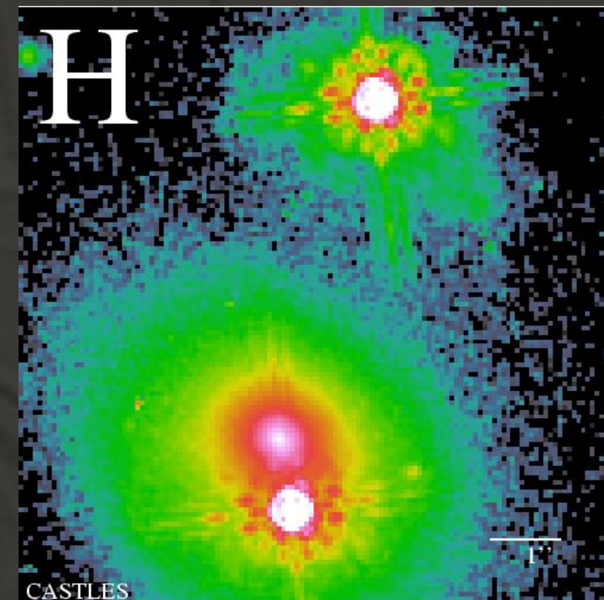
$$\Delta t \propto \frac{D_\mathrm{d}\, D_\mathrm{s}}{D_\mathrm{ds}} \propto \frac{1}{H_0} \quad \rightsquigarrow$$

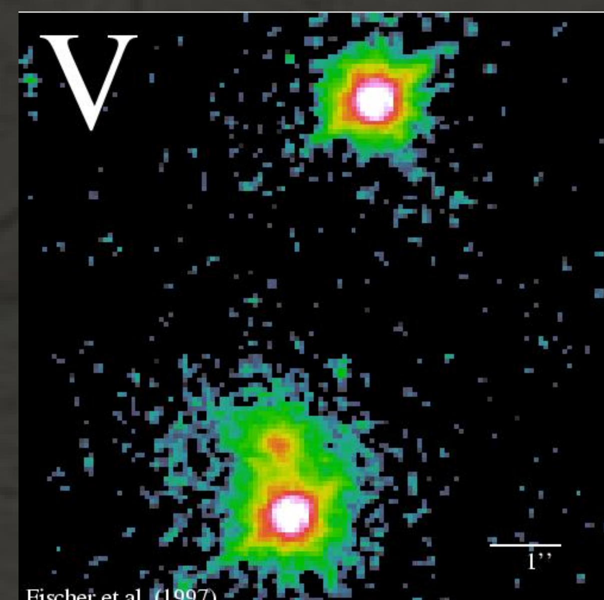
can determine Hubble constant!

The double QSO 0957+561

light curve [*Kundic et al. (1997)*]







[HST, *CASTLES survey*]

Direct motivation for modelling

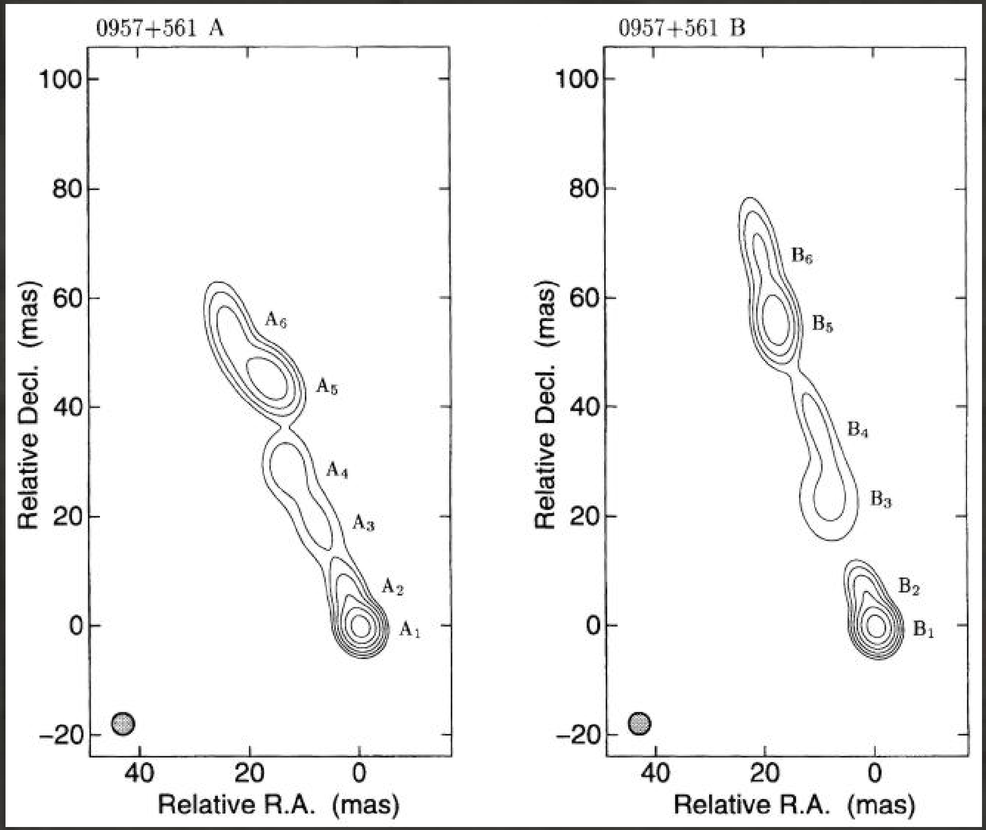
- direct information about mass distribution
- luminous and dark
- even high redshift
- un-biased by light
  in the radio: unbiased by dust! (also no ML)

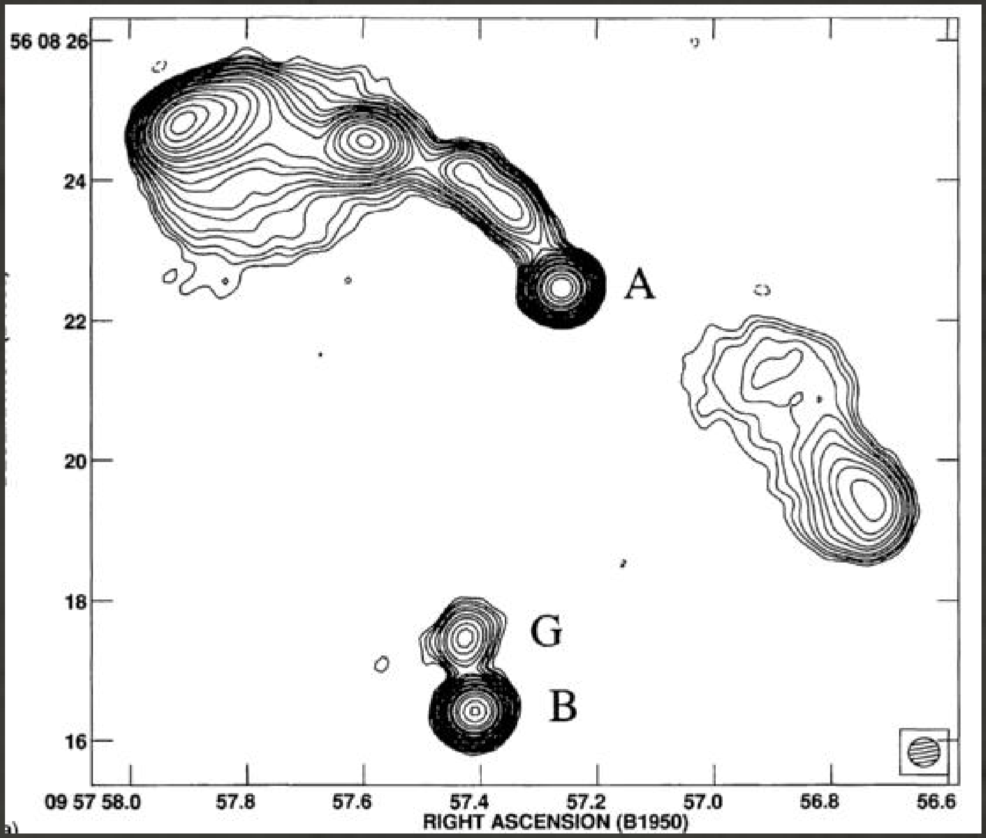
$\rightsquigarrow$ unique tool for structure and evolution of galaxies

- ⋆ large-scale mass profile
- ⋆ CDM substructure
- ⋆ central mass concentrations (central images)

Mass model constraints for 0957+561

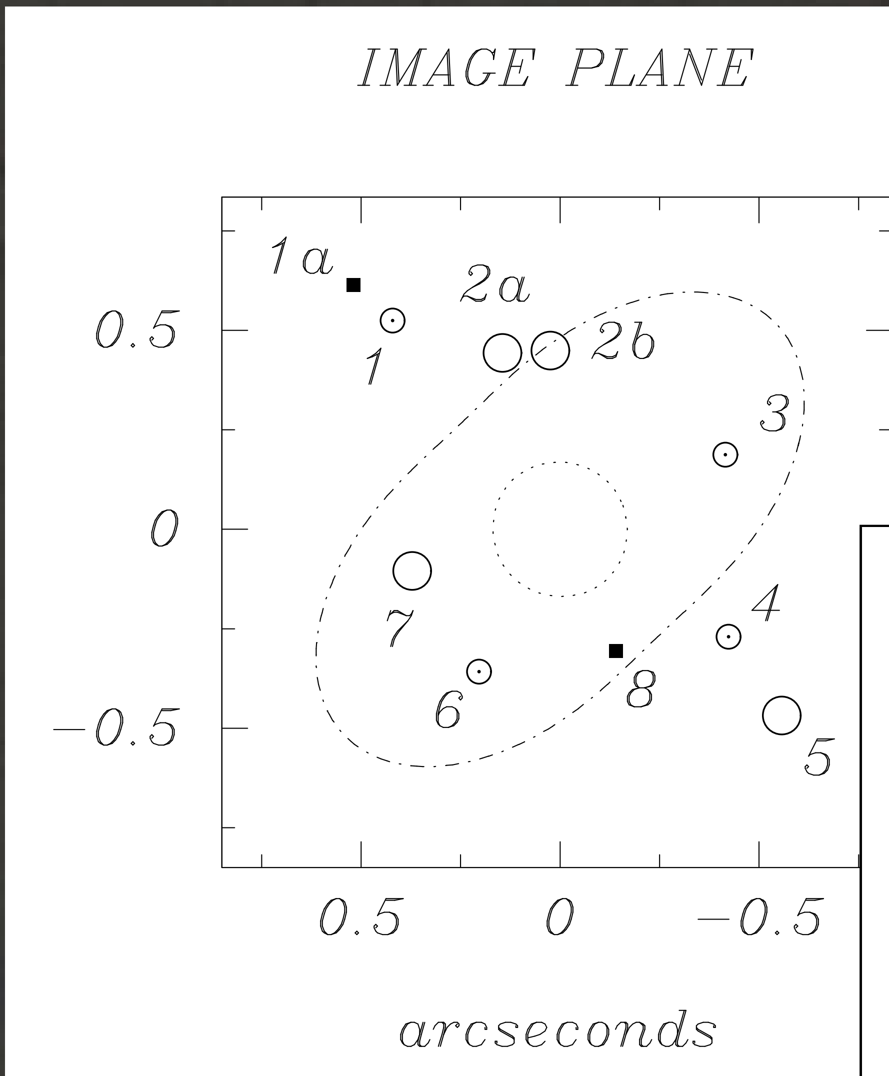
VLBI [*Garrett et al. (1994)*]

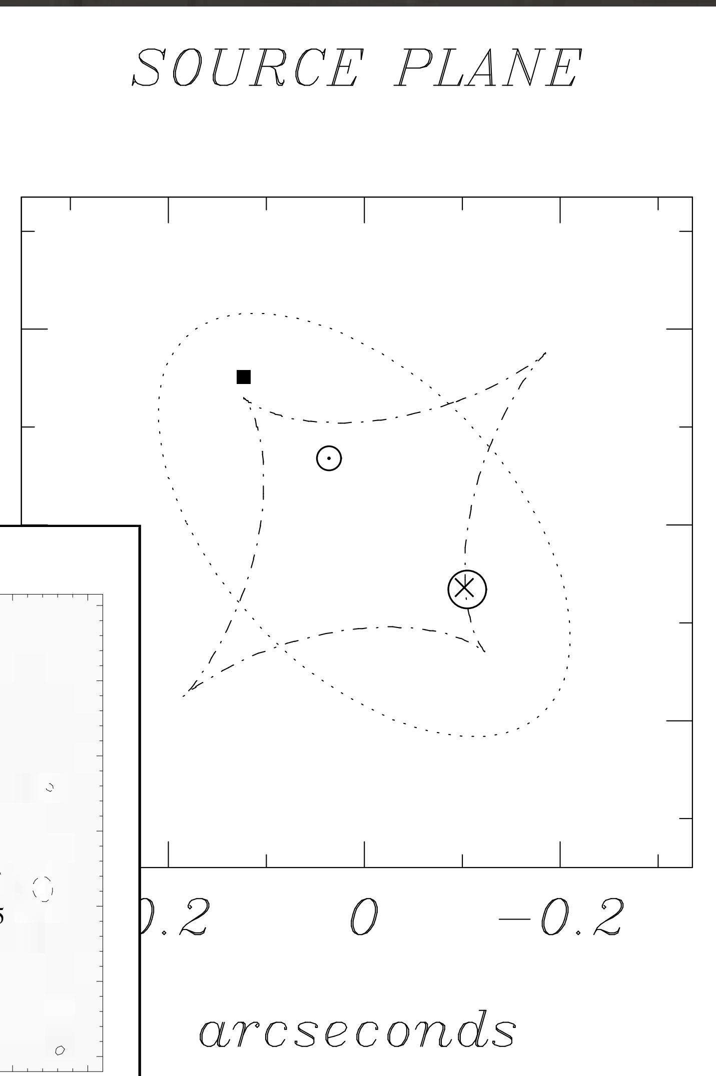




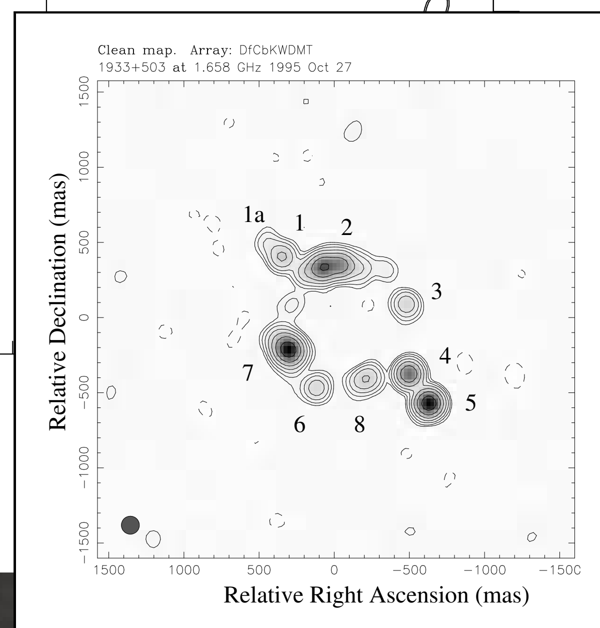
VLA [*Harvanek et al. (1997)*]

The ten image system B1933+503



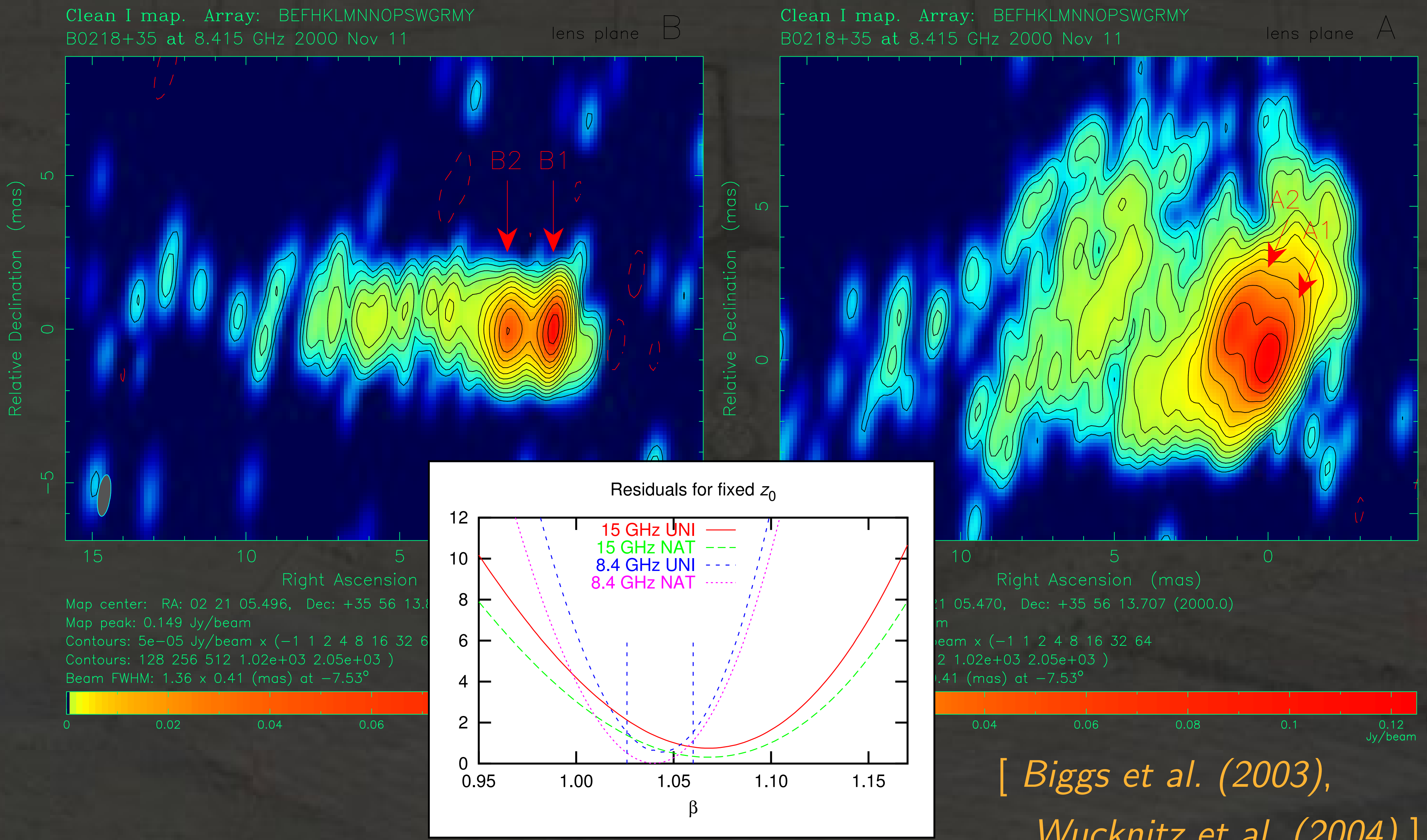


[*Nair (1998)*]



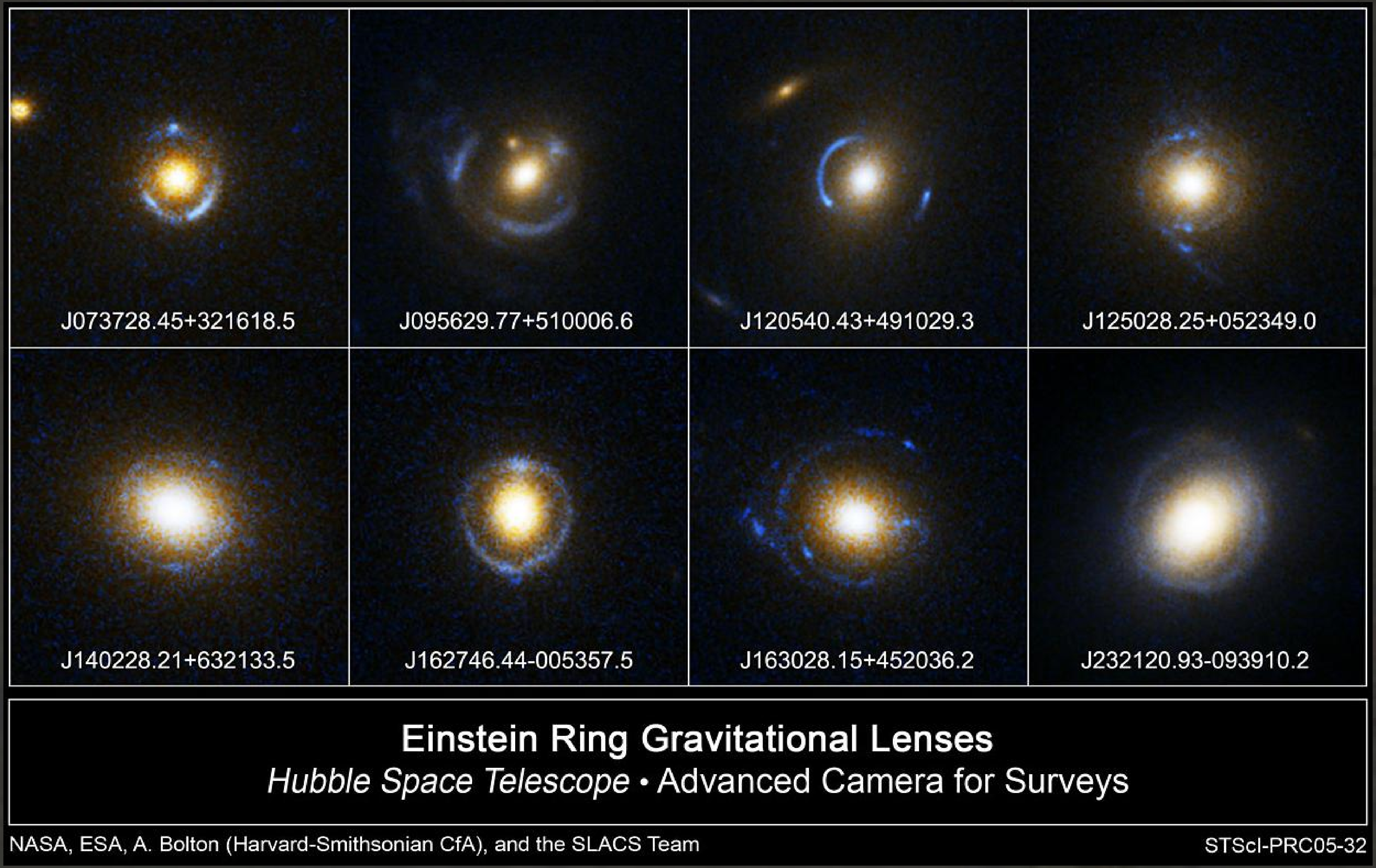
[*Sykes et al. (1998)*]

Global mass profile: B0218+357



[*Biggs et al. (2003),*
Wucknitz et al. (2004)]

SLACS

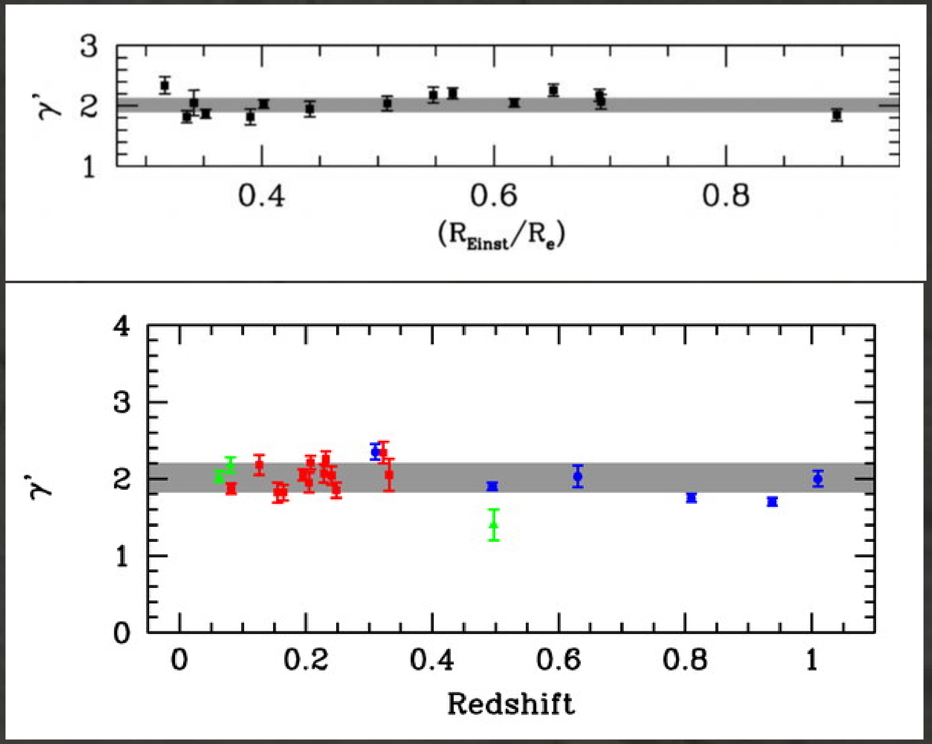


J073728.45+321618.5
J095629.77+510006.6
J120540.43+491029.3
J125028.25+052349.0
J140228.21+632133.5
J162746.44-005357.5
J163028.15+452036.2
J232120.93-093910.2
Einstein Ring Gravitational Lenses
Hubble Space Telescope • Advanced Camera for Surveys
NASA, ESA, A. Bolton (Harvard-Smithsonian CfA), and the SLACS Team
STScI-PRC05-32

SLACS (+ LSD) and radial mass profiles

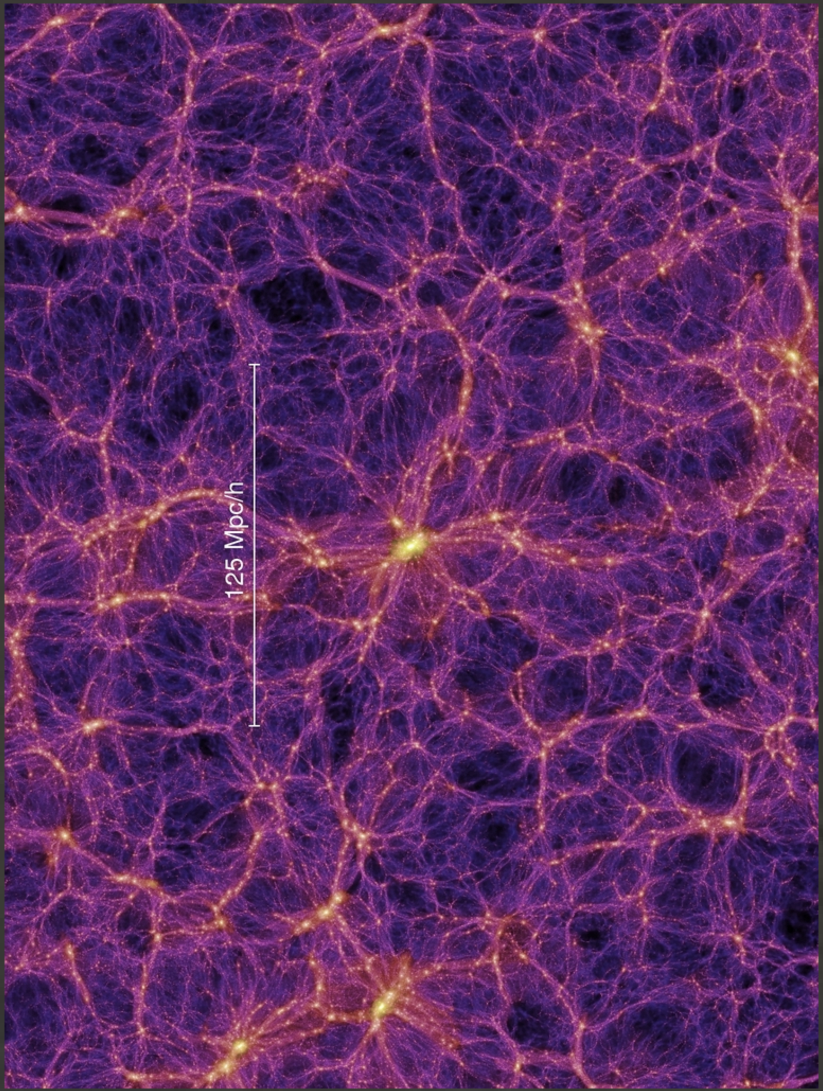
- lensing: mass within R_E
- velocity dispersion: $\sim$ mass within R_e
- combine the two for mean slope $\rho \propto r^{-\gamma}$
- all isothermal!
- like spiral 0218+357
- extension with weak lensing [*Gavazzi et al. (2007)*]

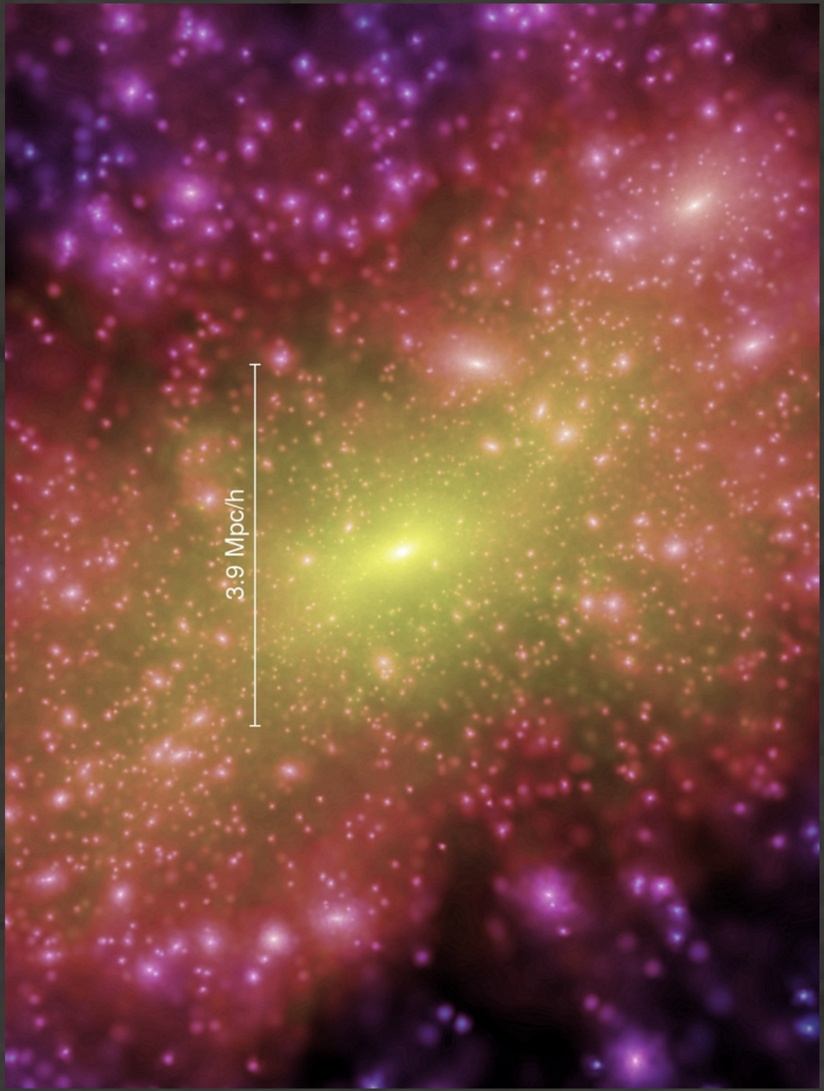
$\rightsquigarrow$ 3–300 h^{-1} kpc = 1–100 R_eff



[*Koopmans et al. (2006)*]

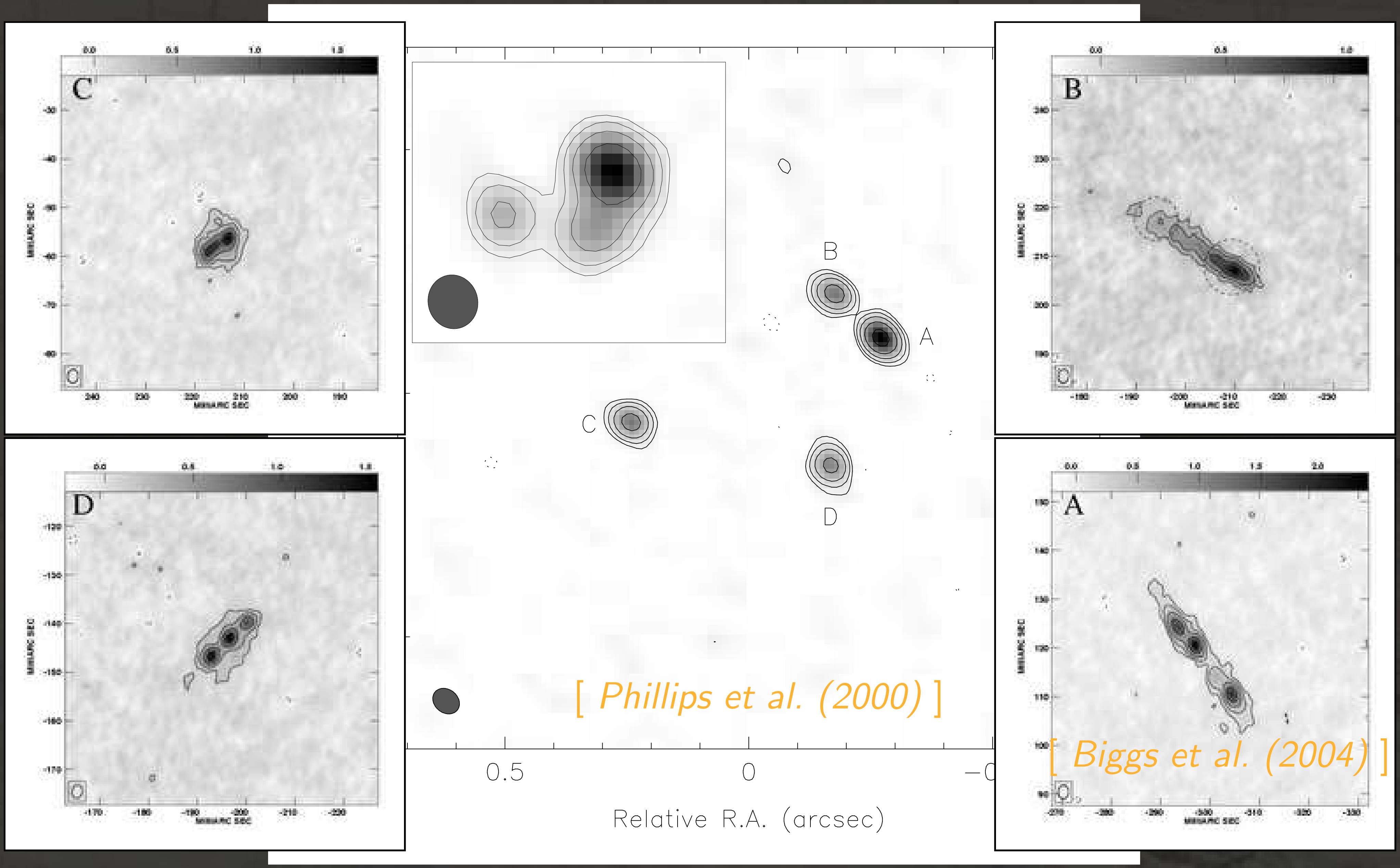
Mass substructure: simulations



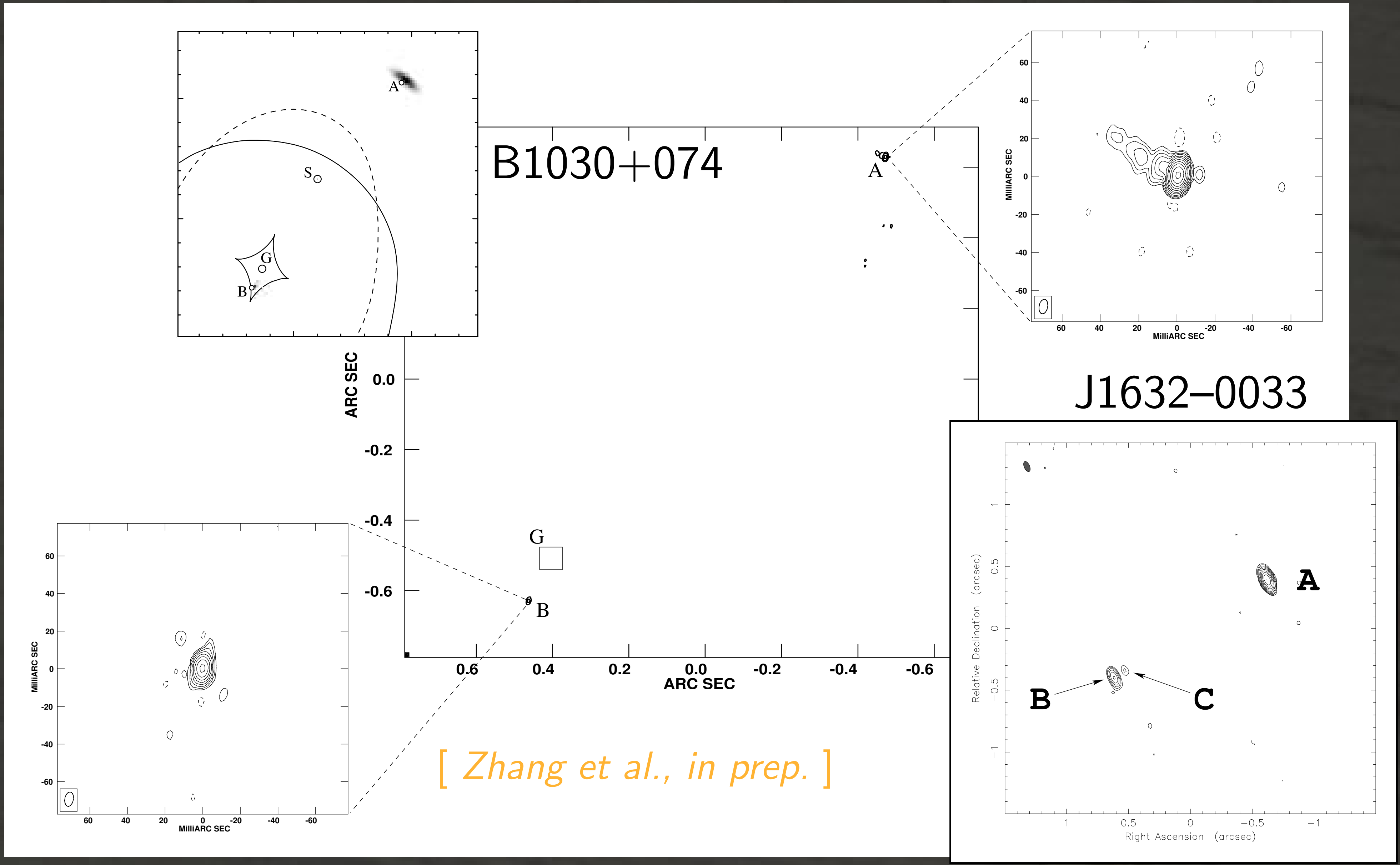


[Springel et al. (2005), Virgo Consortium & MPA]

Mass substructure: B0128+437



Central images?

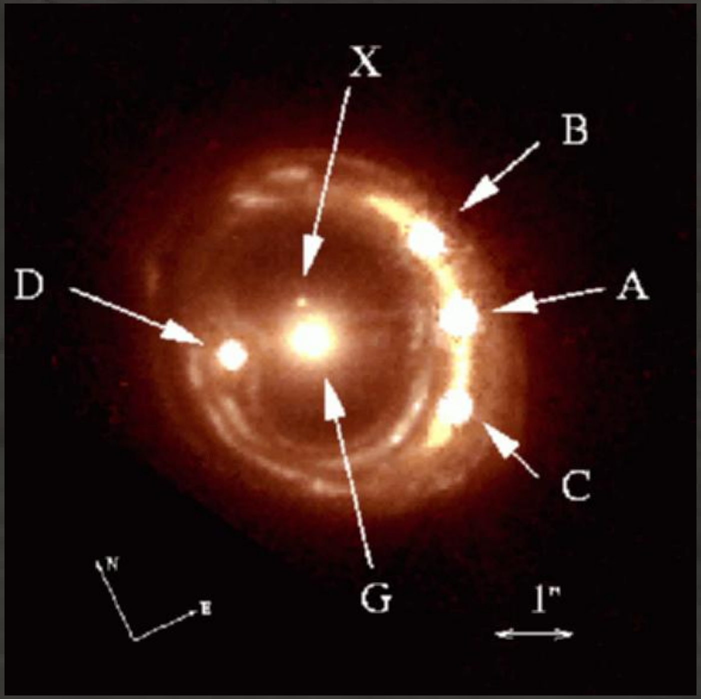


[*Zhang et al., in prep.*]

[*Winn et al. (2003)*]

Extended sources

- good: compact sources provide some information
  - ⋆ CLASS survey, completeness for compact sources
- better: many components
  - ⋆ some systems
- best: lensed extended sources
  - ⋆ find them!
- go to low frequencies
  - ⋆ low surface brightness
  - ⋆ steep spectrum
  - ⋆ star-bursts
- caveat: modelling difficult



[*Claeskens et al.* (2006)]

LOFAR surveys

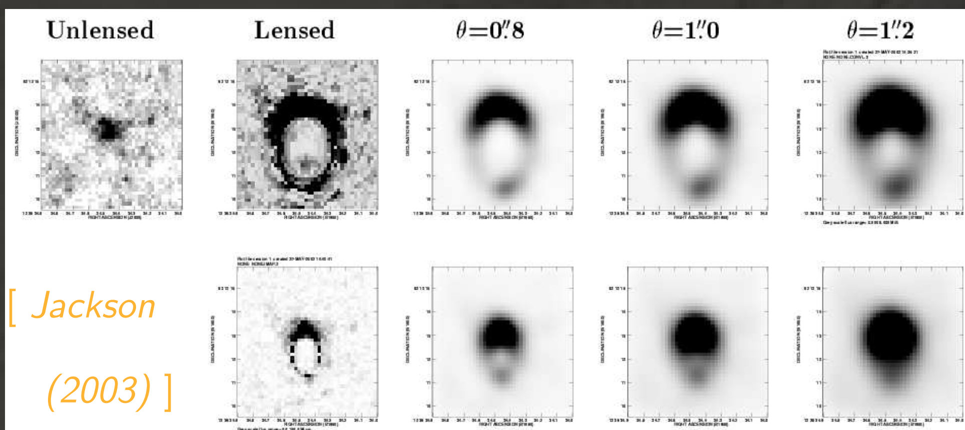
survey array	frequency rms/flux limit	area definition	number of sources density	resolution (400 km)
LOFAR-120	120 MHz 14/43 μJy	half-sky	860×10^6 42 000/ deg^2	1.″3
LOFAR-200	200 MHz 4.7/14 μJy	250 deg^2	30×10^6 120 000/ deg^2	0.″8
FIRST, VLA B	1.4 GHz 0.15/1 mJy	galactic caps 9 033 deg^2	811 000 90/ deg^2	5″
NVSS VLA D/DnC	1.4 GHz 0.45/2.5 mJy	$\delta > -40°$	1.8×10^6 53/ deg^2	45″
WENSS+WISH WSRT	330 MHz 4/18 mJy	$\delta > +30°$ $-26° < \delta < -9°$	230 000 22/ deg^2	$\geq$ 60″
VLSS VLA BnA/B	74 MHz 0.1/0.5 Jy	$\delta > -30°$	~90 000 3/ deg^2	80″

Potential for lens searches

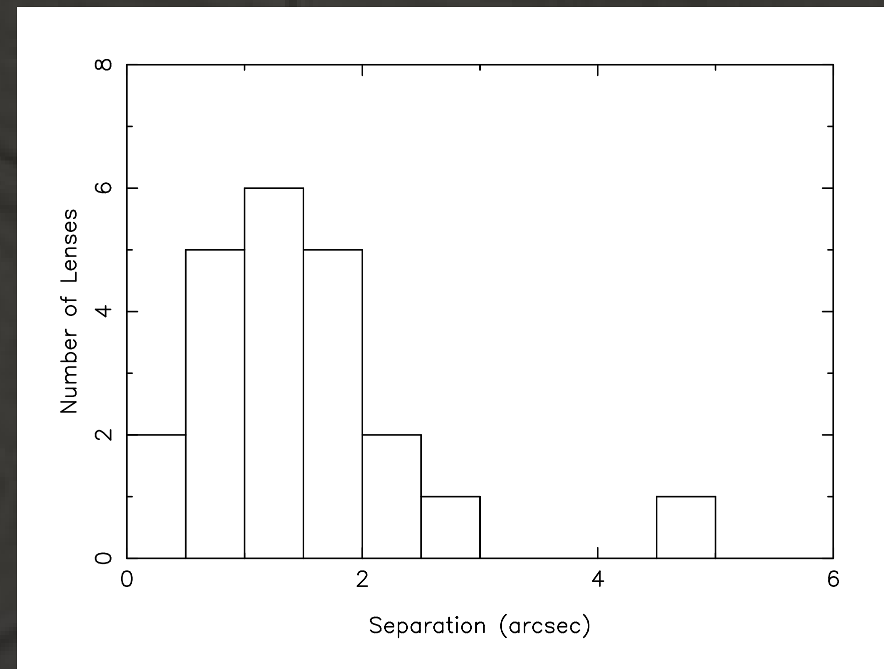
- assumptions
  - ⋆ 400 km baselines with sufficient sensitivity
  - ⋆ long baselines included for surveys
  - ⋆ lensing rate $\sim$ 1:2000 (higher for extended sources)
- direct identification possible for first time
- LOFAR-120 — 430 000 lenses
  - $S/N > 30$ — 43 000 lenses
- LOFAR-200 — 15 000 lenses
  - $S/N > 30$ — 1500 lenses
- problem: avoid false positives!
- aim for rejection rate of $\gtrsim$ 99.5–99.95 %

Realistic source-targeted search

- LOFAR-120
  - ⋆ high rejection rate needed (source numbers!)
  - ⋆ resolution not sufficient
  - ⋆ currently not realistic



[*Jackson (2003)*]



- LOFAR-200
  - ⋆ separations $> 1''$ (60 %)
  - ⋆ rejection rate 99.7 %

$\sim$ 900 lenses

$\sim$ 10 000 candidates

Target the lenses

- We know where the lens galaxies are!
  - ⋆ optical surveys
  - ⋆ well defined samples
- SDSS LRG
  - ⋆ typ. $z = 0.15$–0.5
  - ⋆ typ. lensing separation $1\overset{''}{.}2$
  - ⋆ $\sim 100\,000$ galaxies
- search for LOFAR sources close to optical galaxies
  - ⋆ typ. $z_\mathrm{s} > z_\mathrm{g}$

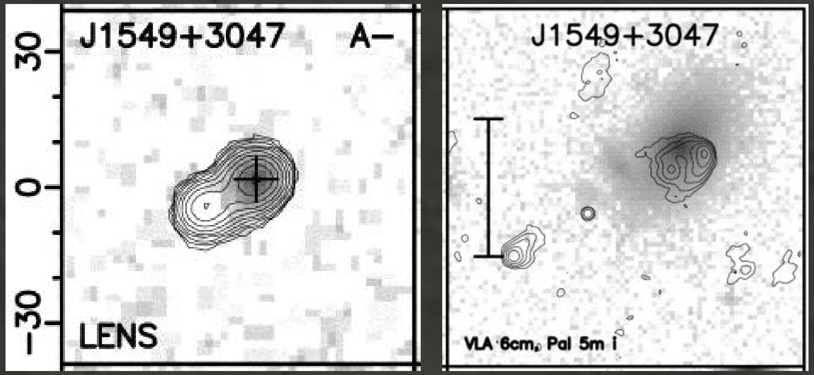
$$\#\ \text{lenses} = A \times n_\mathrm{g} \times \sigma \times n_\mathrm{s} \quad \times \text{corrections}$$

- LOFAR-120 + SDSS LRG   500 lenses   5000 candidates
- offsets for compact sources ⇝ Neal [*Jackson & Browne (2007)*]

FIRST + APM/SDSS

- similar approach tried for lensed radio lobes [*Lehár et al. (1993), Lehár et al. (2001), Haarsma et al. (2005)*]

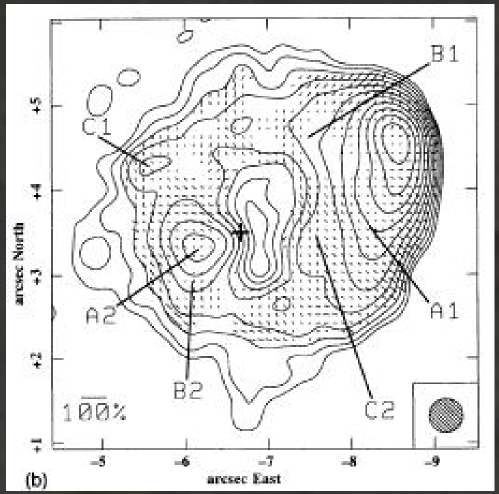
  ⋆ 125 lobe + galaxy combinations
  ⋆ 3 good candidates
  ⋆ 1 certain lens (known before)



[*Lehár et al. (2001)*]

- reasons for 'failure'

  ⋆ size of radio lobes (many arcsecs)
  ⋆ resolution of FIRST (5″)
  ⇝ too many candidates
  ⇝ difficult identification



[*Lehár et al. (1993)*]

Summary LOFAR lens searches

- source-targeted
  - ⋆ LOFAR-200 — **$\sim$ 900 lenses**
    10 000 candidates
  - ⋆ resolution critical
- lens-targeted
  - ⋆ LOFAR-120 + SDSS LRG — **$\sim$ 500 lenses**
    5000 candidates
  - ⋆ radio properties?
  - ⋆ cluster lenses $\rightsquigarrow$ Mike Garrett
- 1000 – 2000 new radio lenses (now: < 40)
- **need long baselines**

Study of new lenses

- many ($> 50\,\%$) extended on scales 1–2″
- many star bursts (structure on small scales!)
- follow-up and detailed observations
  - EVLA
  - *e*-MERLIN
  - VLBI
- lens modelling: combined source and lens reconstruction
  - LensClean
  - semi-linear methods

$\rightsquigarrow$ **structure and evolution of galaxies**

Organisation

- small group based in Bonn (University)
- start August 2007 for 5 years
- me + 2 × 3 years PhD fellowships + ?

job advert!

- funding from DFG (german science foundation)
- work programme
  - ⋆ prepare for the lens search
    - ∗ simulations of realistic E-LOFAR array
    - ∗ lens-selection algorithms
  - ⋆ analysis methods (deconvolution, lens modelling)
  - ⋆ study of individual systems
- part of GLOW, connection to survey KSP
- close collaboration with Neal Jackson and Mike Garrett

Contents