The University of Manchester
Jodrell Bank Observatory

After CLASS: LOFAR and future lens surveys

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Astrophysics in the LOFAR era
26.04.07

Outline

The science of lenses

- Mass profiles and dark matter
- CDM substructures
- Structure of galaxy centres
- The Hubble constant

CLASS and after

- The CLASS system and other systems
- Using LOFAR with more efficient surveys
- Direct discovery of lenses with LOFAR

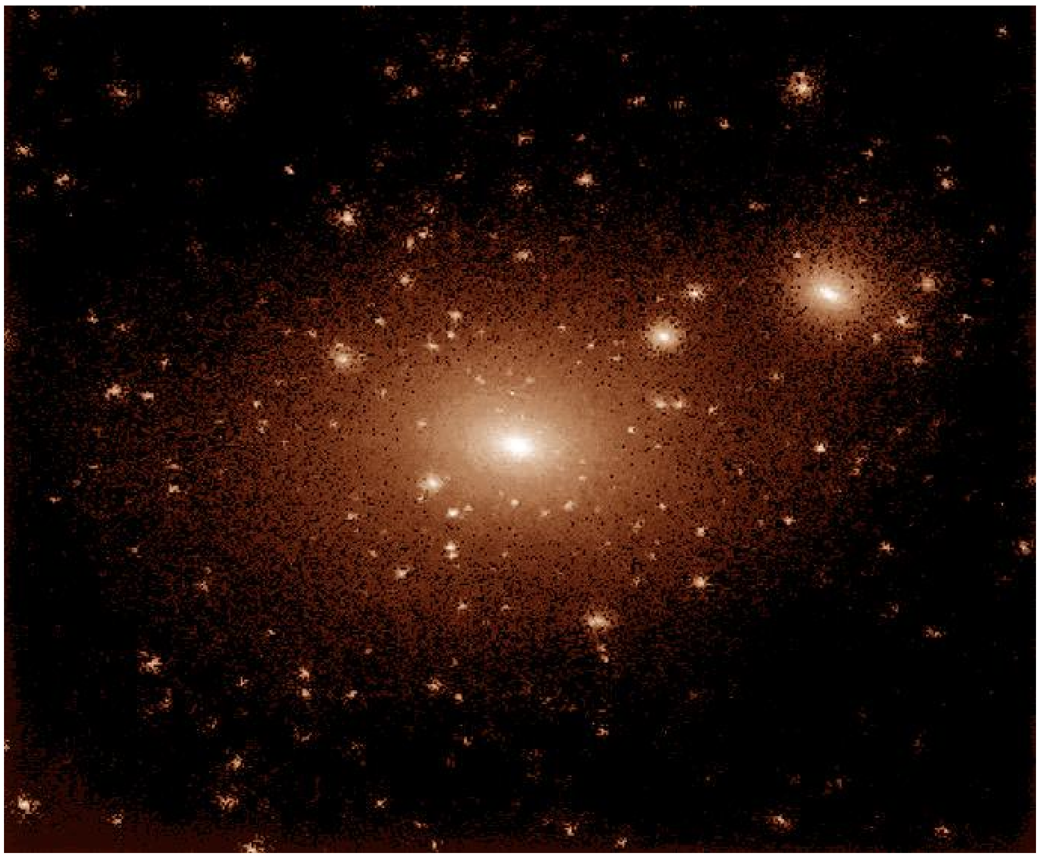
*already described by Olaf Wucknitz

Lensing and CDM substructure

* Strong prediction of CDM
* Occurs on scales to subgalactic
* May be required by quad lenses
* Radio useful – no microlensing

CDM galaxy halo (Moore et al. 1999)

Lensing and CDM substructure



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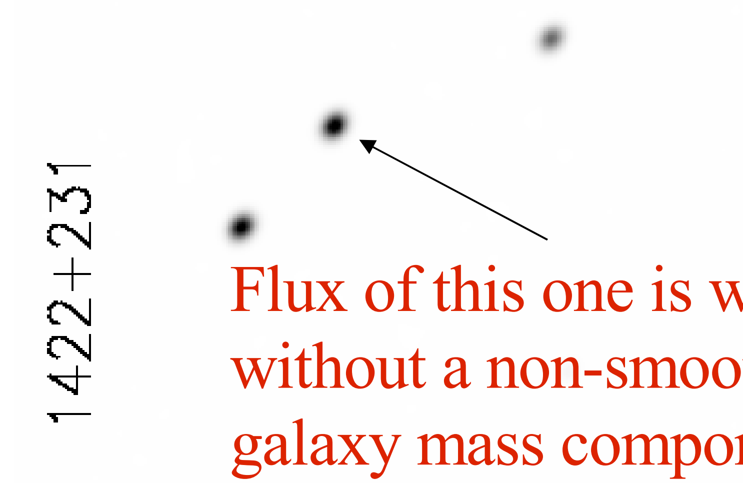
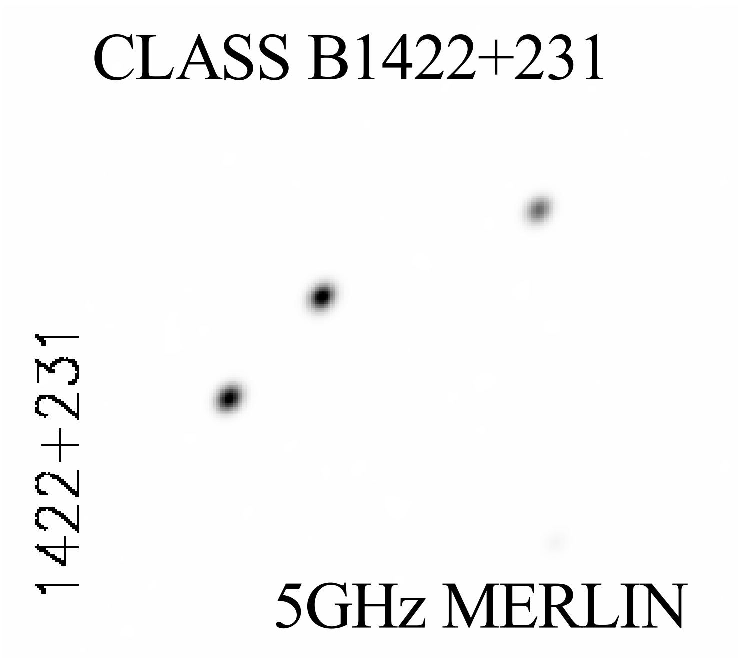
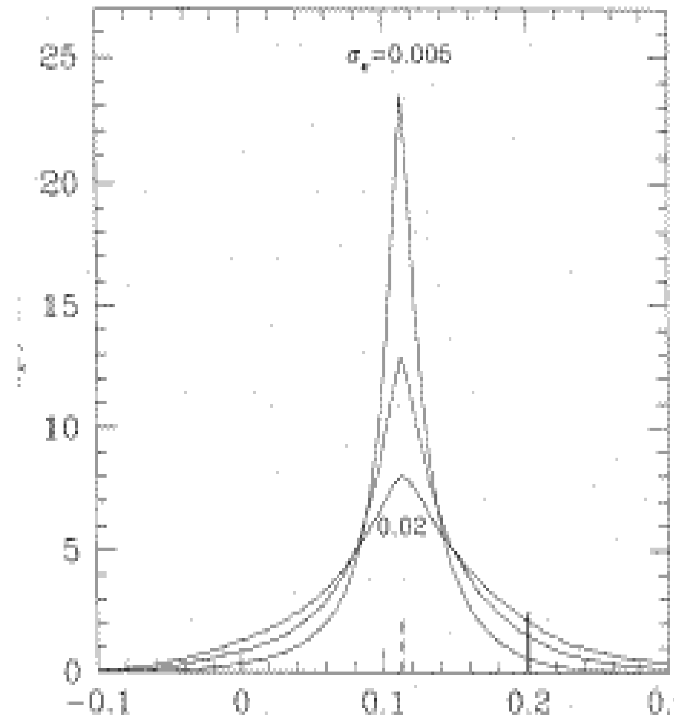
EVIDENCE in CLASS 1422+231
(Mao & Schneider 1998)



Flux of this one is wrong without a non-smooth galaxy mass component

Early evidence for substructure

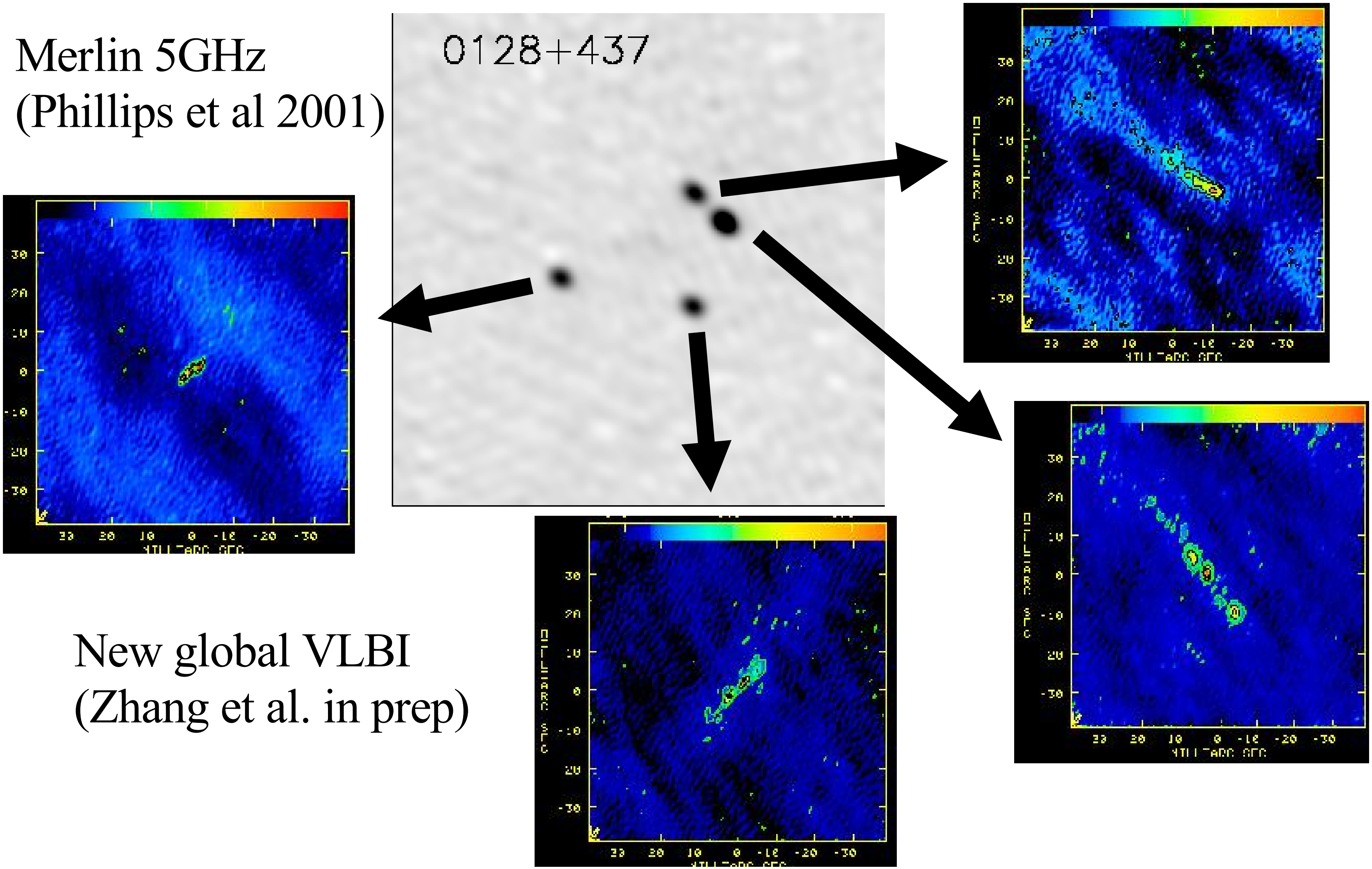




Mao & Schneider 1998

Low probability of obtaining observed flux ratios unless sub-galactic-mass substructure is added.

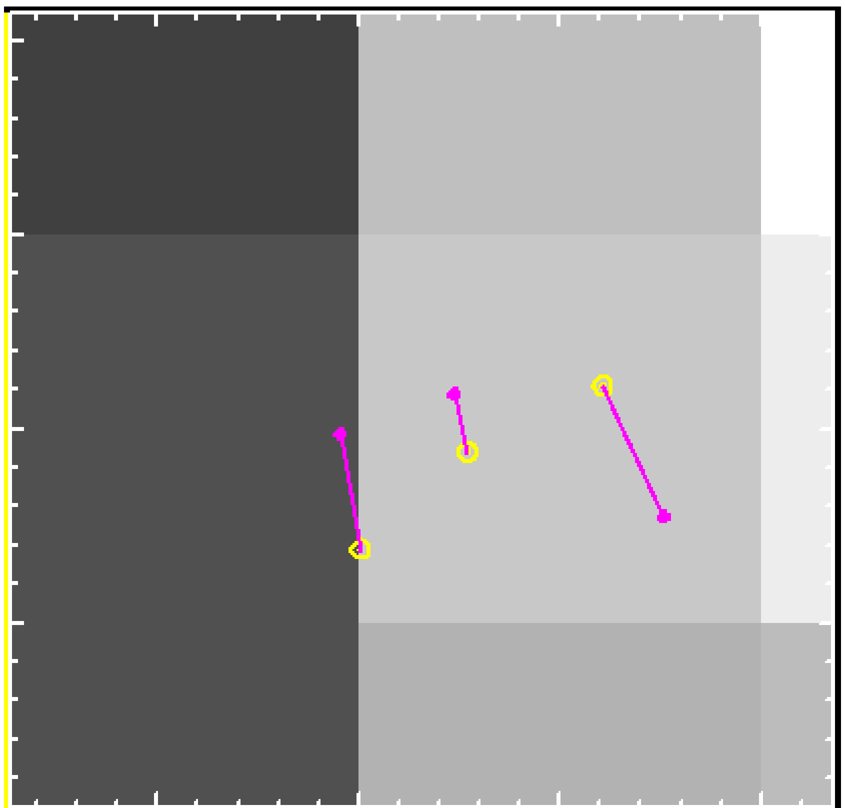
The case of CLASS0128+437



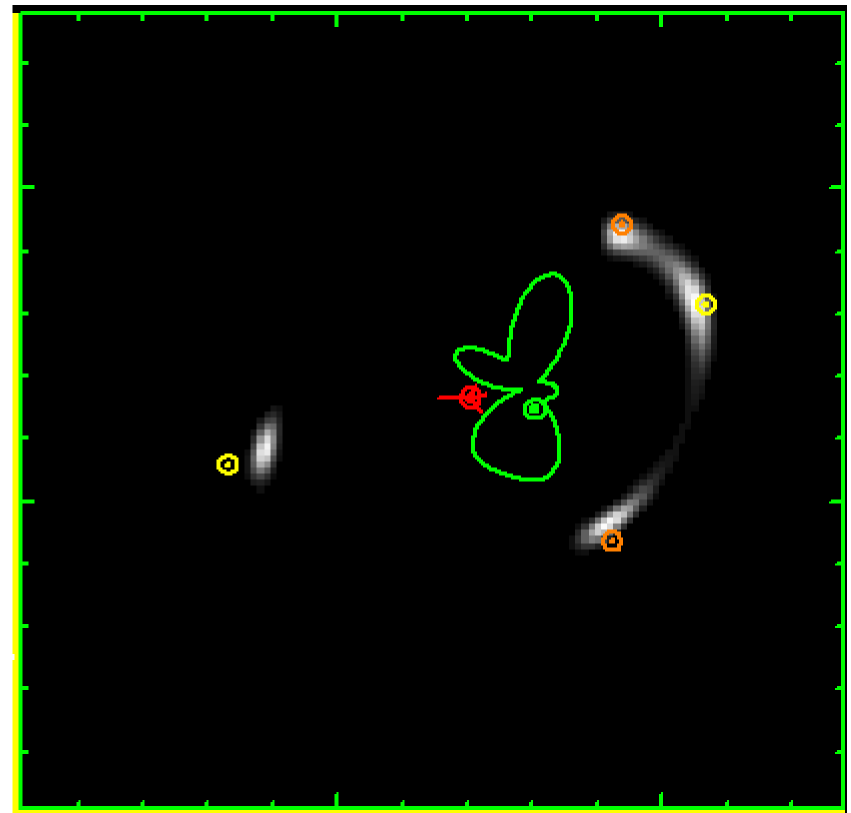
Merlin 5GHz
(Phillips et al 2001)

New global VLBI
(Zhang et al. in prep)

Why 0128+437 is interesting



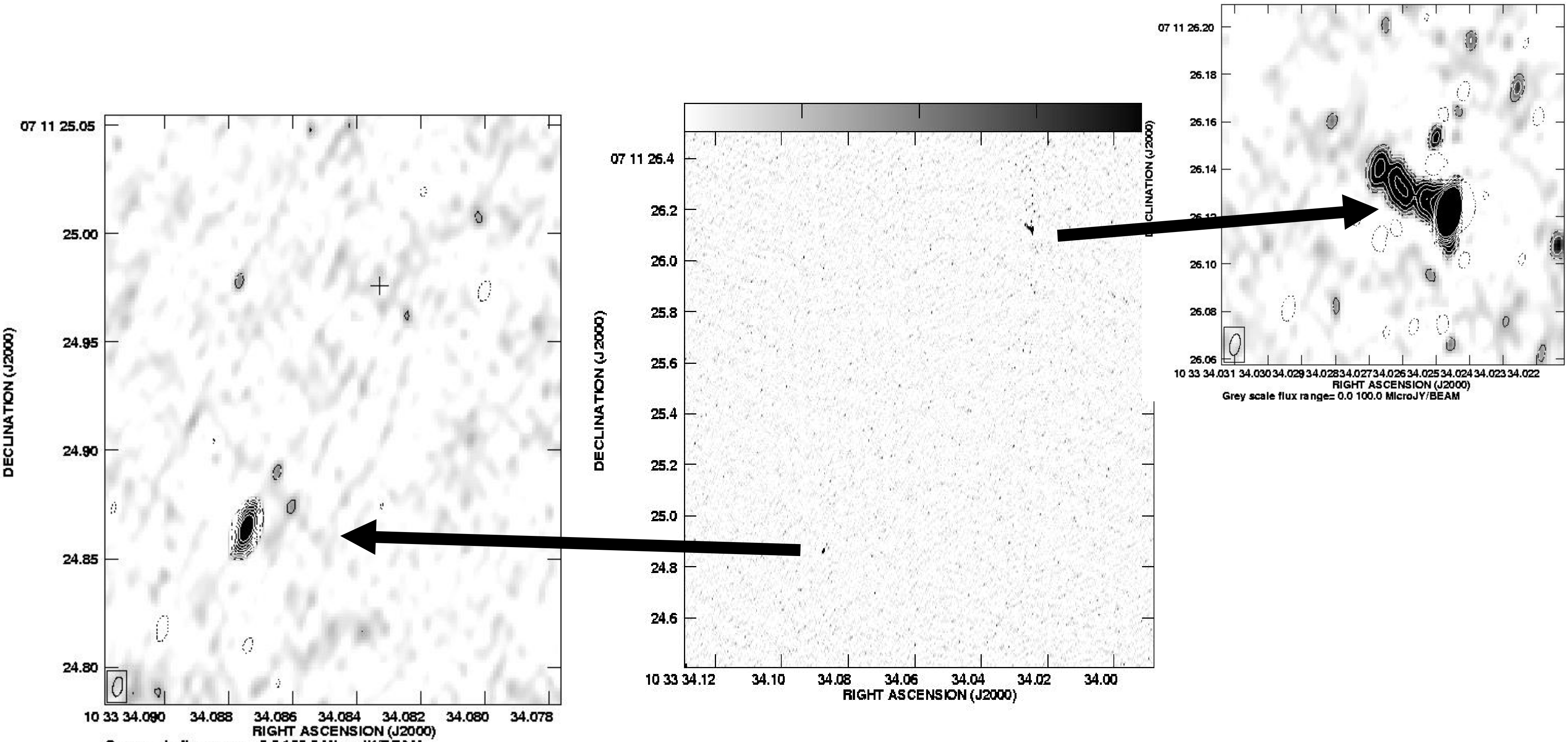
Smooth model: component C does not fit (Biggs et al. 2004). New data: B difficult too.



Fit data exactly (method of Evans & Witt 2001): galaxy is not smooth!

Global VLBI on two other lenses being analysed

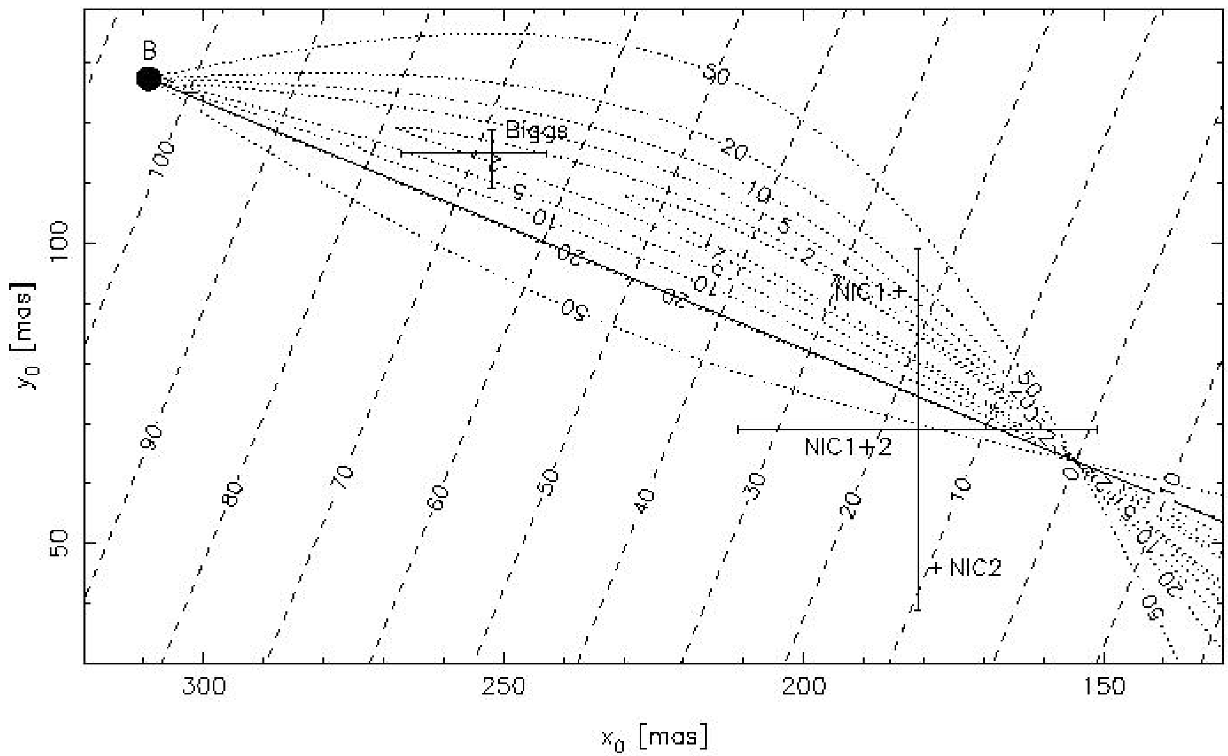
The science of lenses: central regions of galaxies



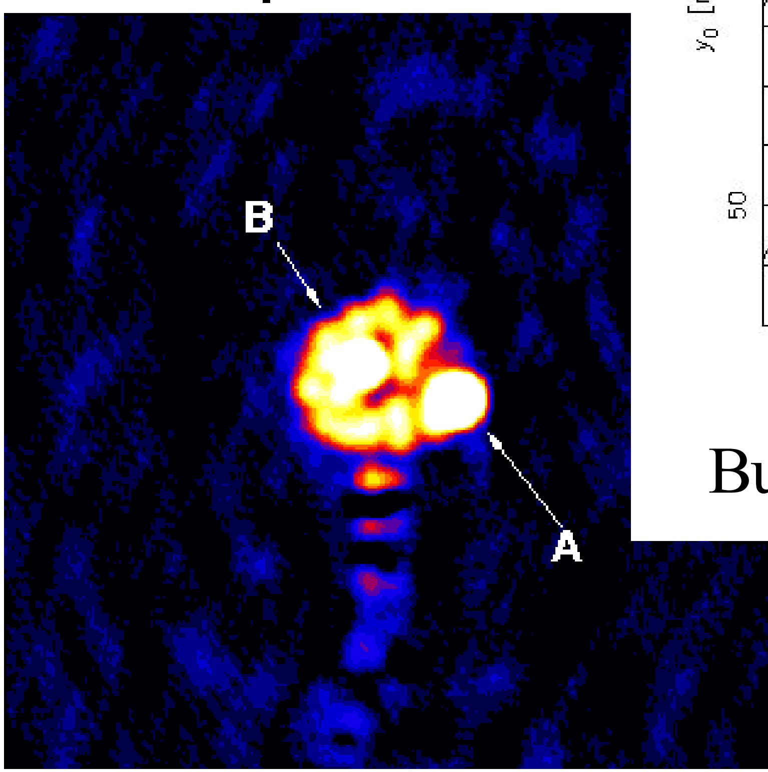
Recent HSA (VLA+GB+VLBA+Arecibo) observations of CLASS B1030+074 (Zhang et al. in prep)

Time delay+mass model = H_0

The gravitational lens JVAS0218+357



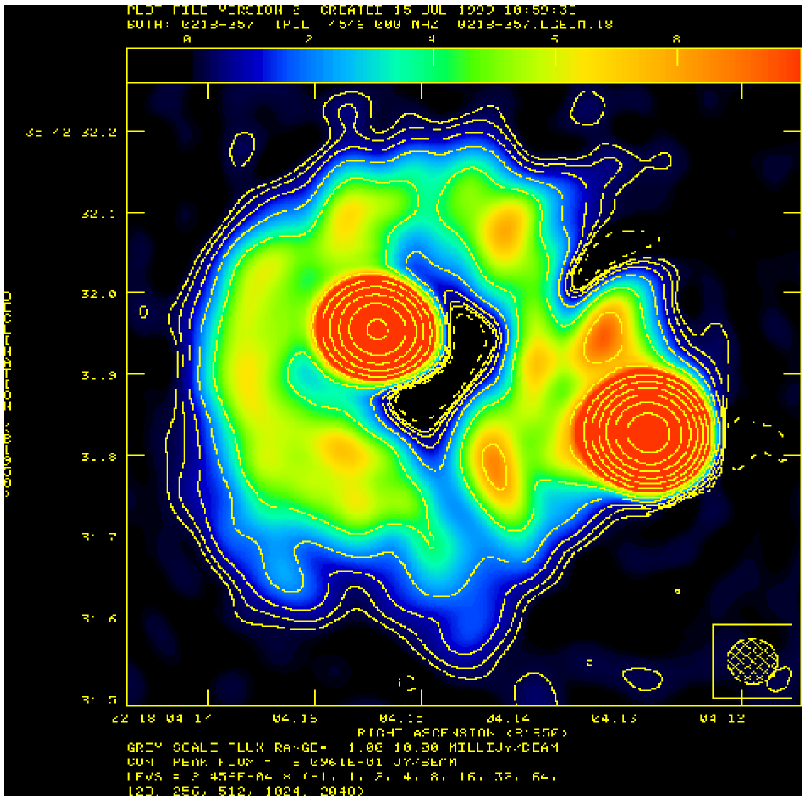
Radio map

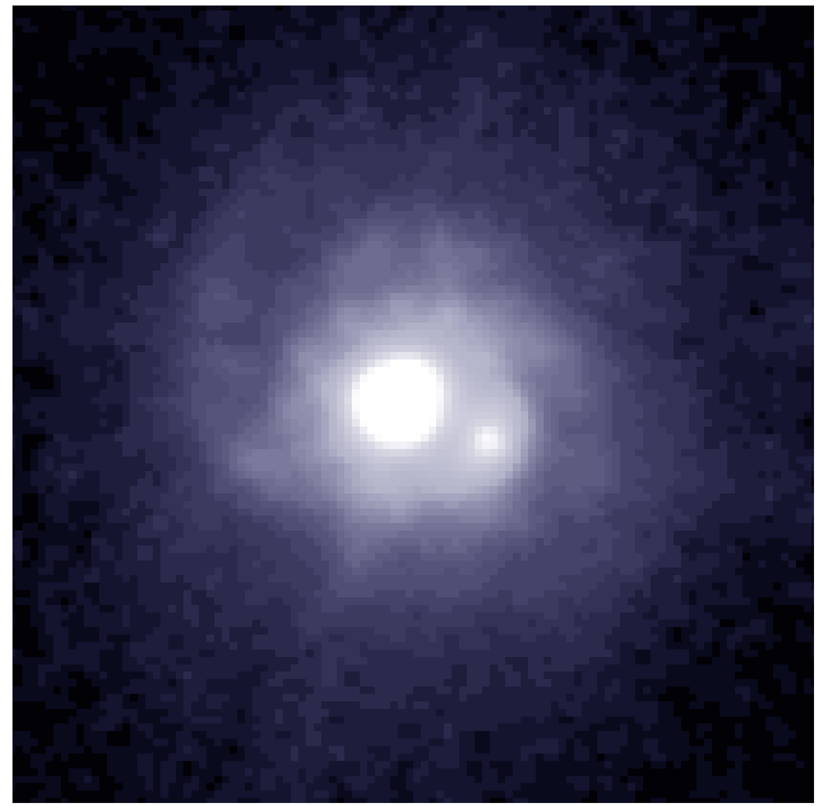


But critically dependent on galaxy position…

Time delay = 10.5+/-0.4 days
Hubble constant estimate:
69 km/s/Mpc (+13/-19, 95%)

0218+357 continued...





ACS image and determination of mass slope and Hubble constant in the lens system CLASS B0218+357 (York et al. 2005b)

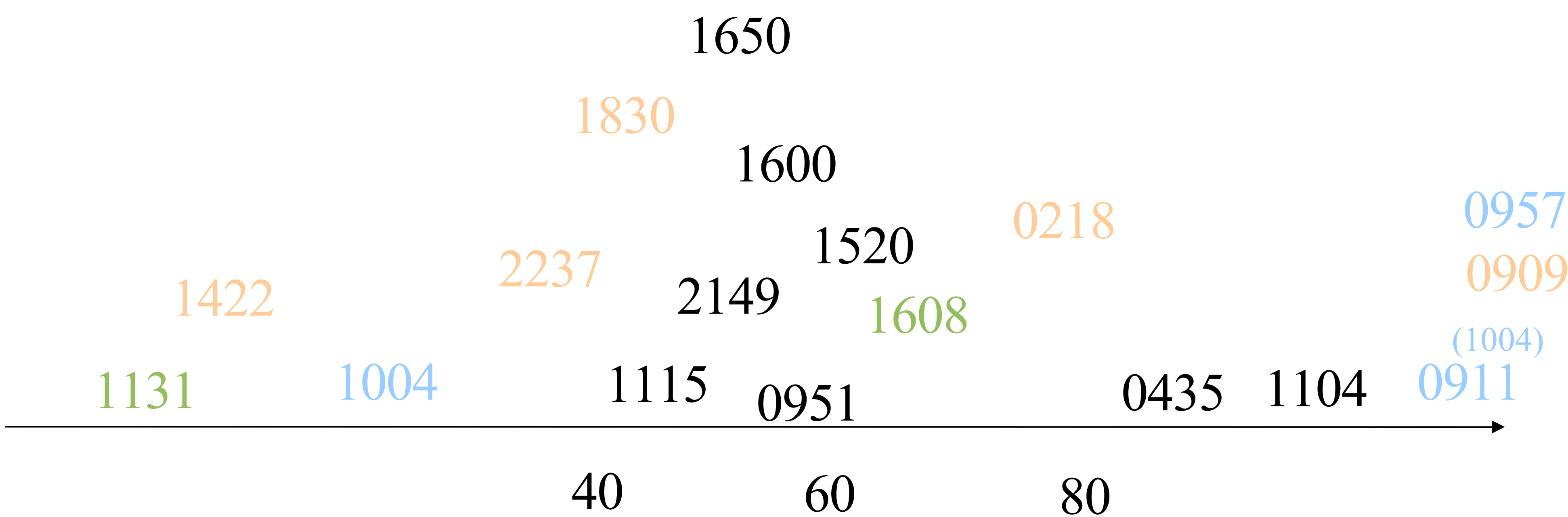
Current status

CLASS 0218+357	10.5 ± 0.2	Biggs et al. 1999
HE 0435−1223	$14.4^{+0.8}_{-0.9}$ (AD)	Kochanek et al. 2006
SBS 0909+532	45^{+1}_{-11} (2σ)	Ullan et al. 2006
RX 0911+0551	146 ± 4	Hjorth et al. 2002
FBQ 0951+2635	16 ± 2	Jakobssen et al. 2005
Q 0957+561	417 ± 3	Kundic et al. 1997
SDSS 1004+4112	38.4 ± 2.0 (AB)	Fohlmeister et al. 2006
HE 1104−185	161 ± 7	Ofek & Maoz 2003
PG 1115+080	23.7 ± 3.4 (AC)	Schechter et al. 1997
RX 1131−1231	$12.0^{+1.5}_{-1.3}$ (AB)	Morgan et al. 2006
CLASS 1422+231	8.2 ± 2.0 (BC)	Patnaik & Narasimha 2001
SBS 1520+530	130 ± 3	Burud et al. 2002
CLASS 1600+434	51 ± 4	Burud et al. 2000
	47^{+5}_{-6}	Koopmans et al. 2000
CLASS 1608+656	31 ± 7 (AB)	Fassnacht et al. 2002
	36 ± 7 (BC)	
	76 ± 9 (BD)	
SDSS 1650+4251	49.5 ± 1.9	Vuissoz et al. 2006
PKS 1830−211	26^{+4}_{-5}	Lovell et al. 1998
HE 2149−2745	103 ± 12	Burud et al. 2002
Q 2237+0305	$2.7\mathrm{h}^{+0.5\mathrm{h}}_{-0.9\mathrm{h}}$	Dai et al. 2003

Now 18 with time delays (cf. 11 in 2004)

Remove anything with uncertain time delay
Remove anything with large cluster contribution
Remove anything with dodgy astrometry
Remove anything with two merging lens galaxies
Remove anything with a big substructure blob along a line of sight

NB: words like "uncertain", "dodgy" and "large" are subjective



With few exceptions, convergence around 50-60 (problem pointed out by Kochanek 2002) – systematically non-isothermal OR H_0=50 OR CDM is wrong

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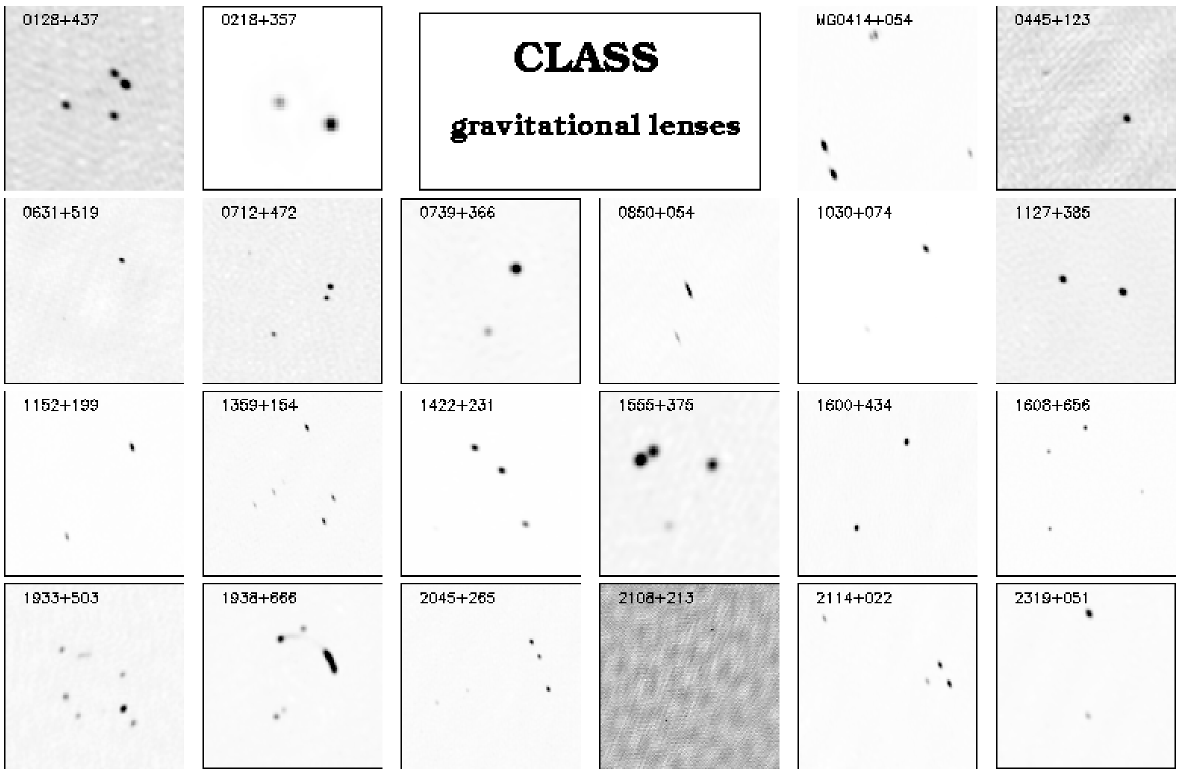
CLASS and after

CLASS system (and others)



Observations of compact radio sources with VLA

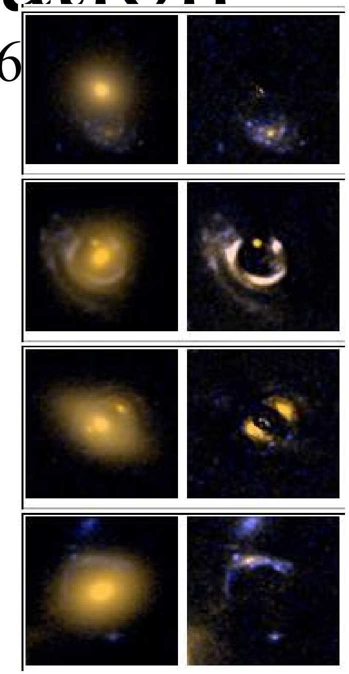
High-resolution followup of candidates

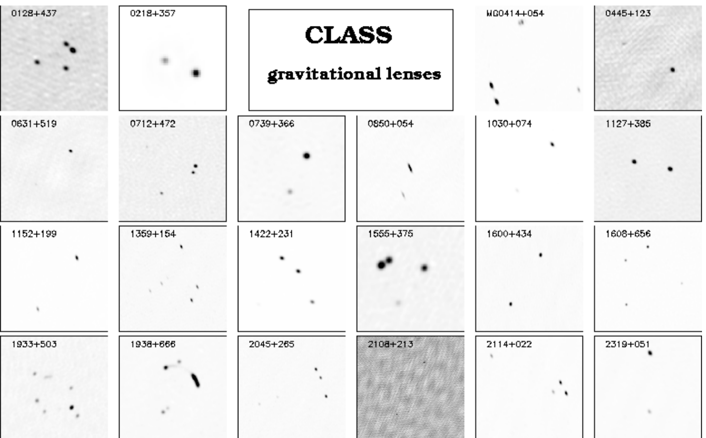
Lensing rate 1:800

Other techniques for radio steep-spectrum sources limited success
Optical: highly successful SDSS quasar searches
highly successful galaxy-lens searches (SLACS,OLS,CFHTLS)
Now ~100 lenses in this way

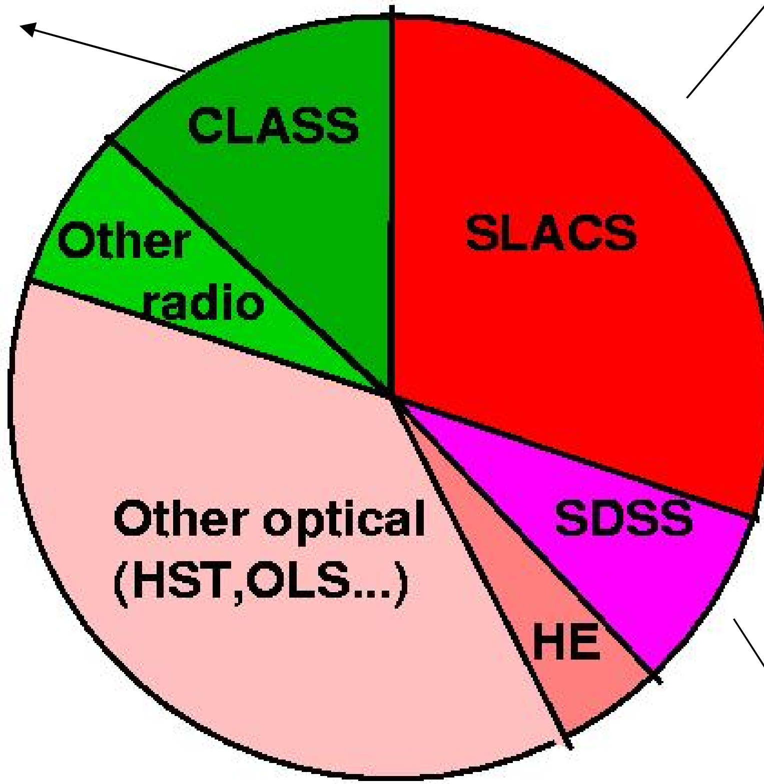
Current observational situation

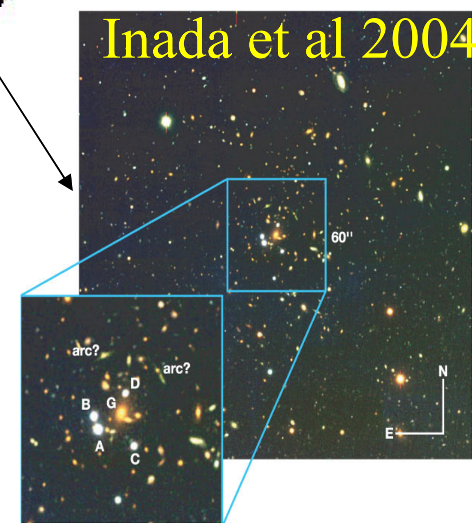
Bolton et al. 2006





Browne et al. 2003





~150 lenses known

SLACS ~50 lenses

CLASS 22 lenses

SDSS 15-20

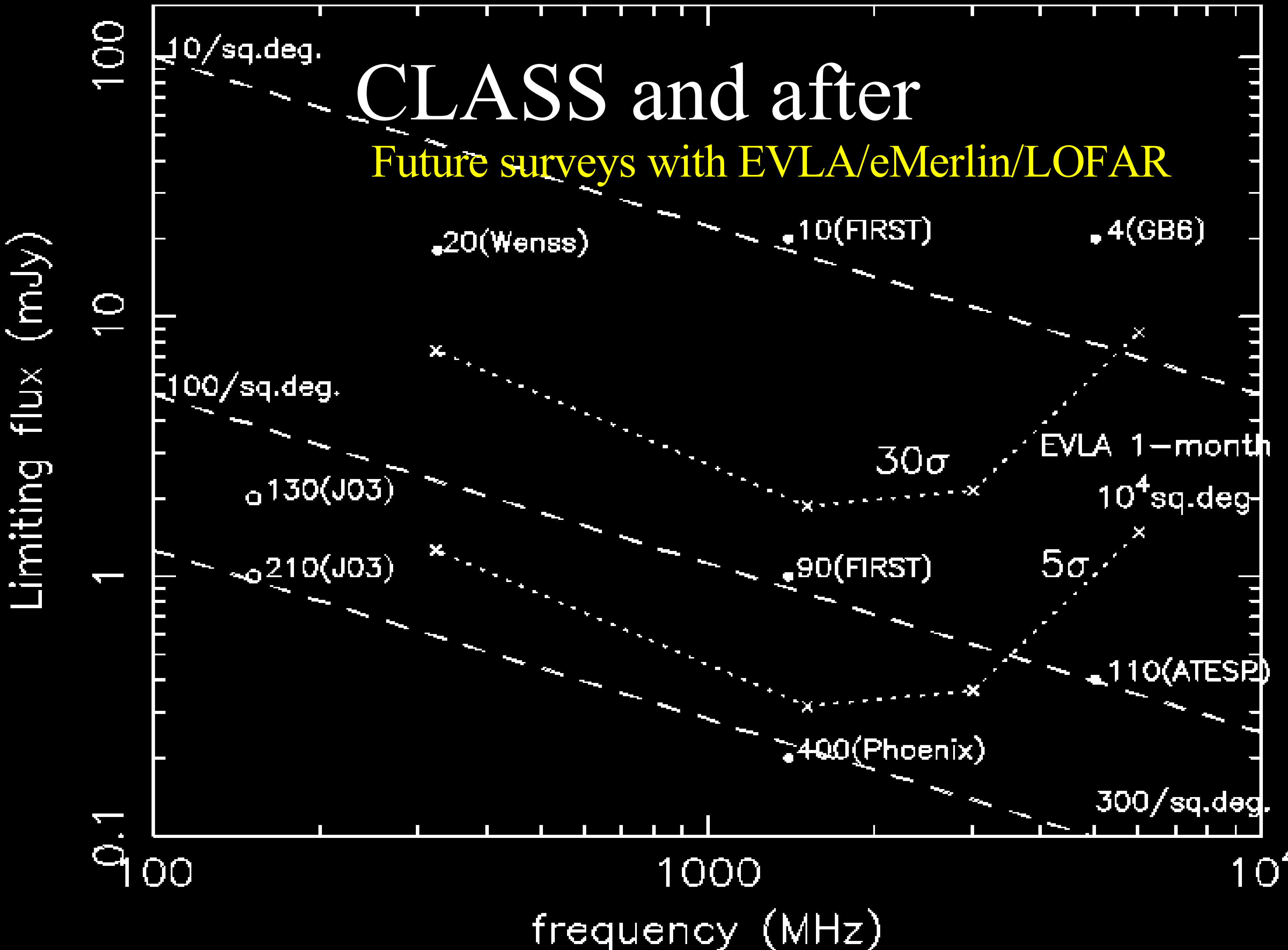
SLACS (extended sources) best for overall mass models

Substructure: SLACS or radio quad lenses

Central images: radio double lenses

CLASS and after

Future surveys with EVLA/eMerlin/LOFAR



The basic problem

To be interesting, surveys should be 10 times as big.

All bright sources have been done, so the survey will have to be 10 times as big AND 10 times as faint.

EVLA/eMerlin sensitivity takes care of 10 times as faint, but for 10 times as big you need 10 times more efficient.

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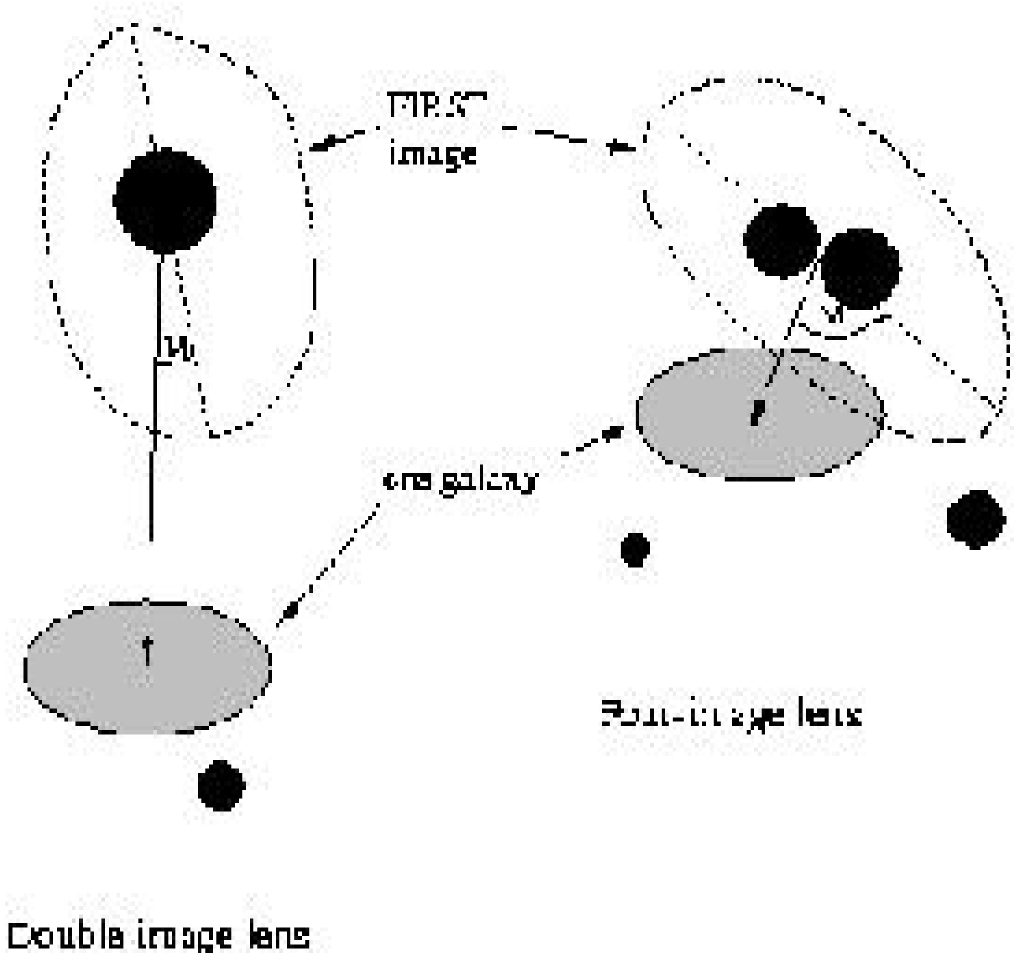
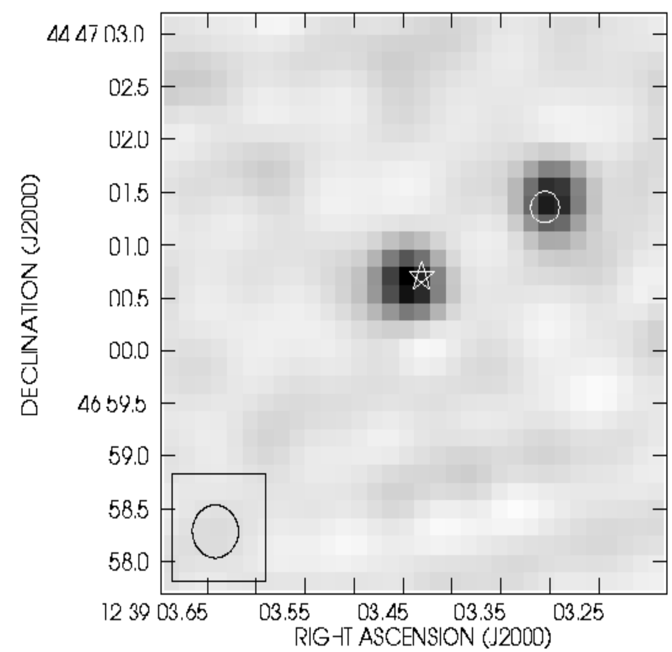
"efficient" -> either 10 times more area coverage at once
or 10 times better selection of existing sources

CLASS and after

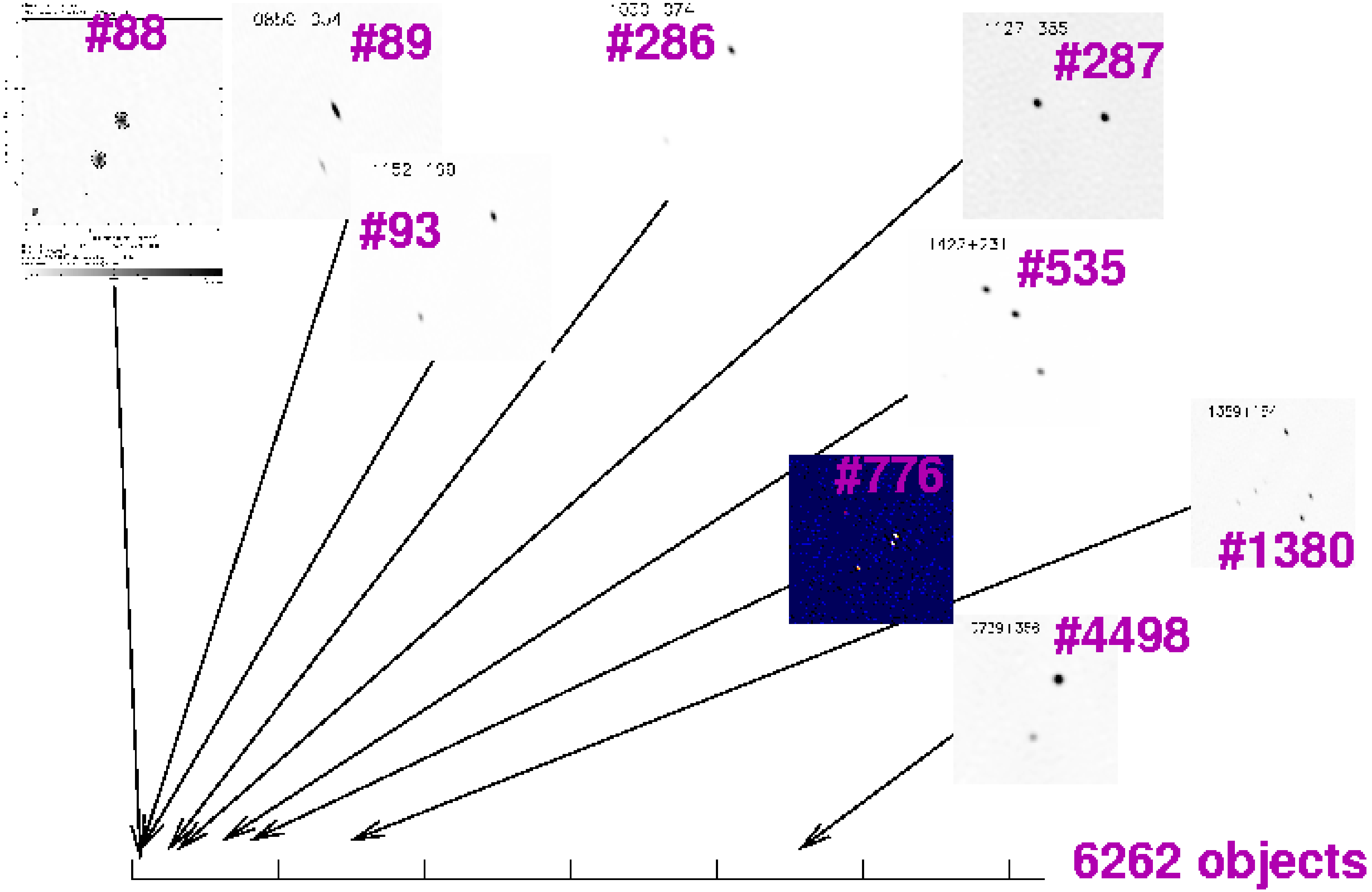
"Efficient" surveys





Jackson & Browne, astro-ph/0609818

CLASS and after



* Using sub-resolution information in FIRST could have discovered 50% of CLASS lenses in 5% of the time
* Using FIRST and SDSS information together could discover 50% of lenses in 1% of the time; further studies planned...

LOFAR and lens discovery

Direct discovery – rings/starburst galaxies
resolution and stable PSF critical

Use of LOFAR as "super-FIRST" for very efficient selection
for EVLA/e-Merlin
(100-1000 times more sources)
resolution critical, stable PSF very critical

Summary

Scientific case based on distribution of dark matter in galaxies (and clusters)

- mass profiles (cf. CDM models)
- substructures (cf. CDM models)
- central density profiles (cusps/cores/massive Bhs)

Observationally

- potential to x10 more lenses (different Hubble types, evolution)
- LOFAR discovers lenses directly and vastly increases efficiency of conventional surveys