The University of Manchester
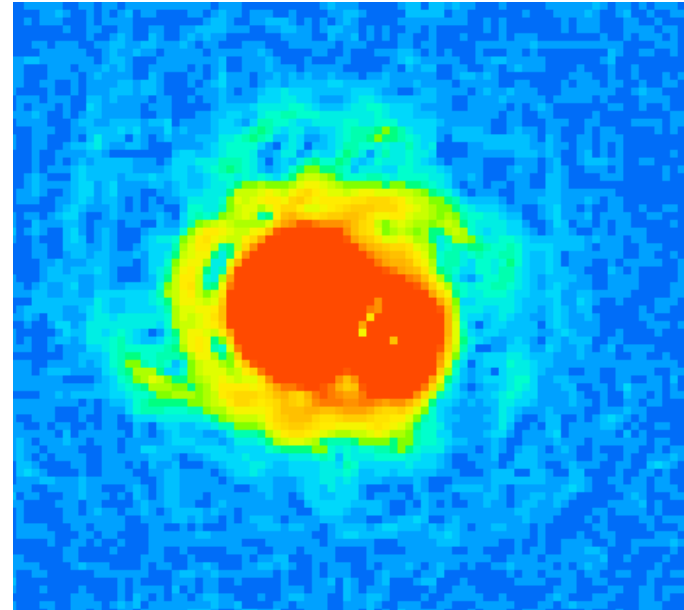Jodrell Bank
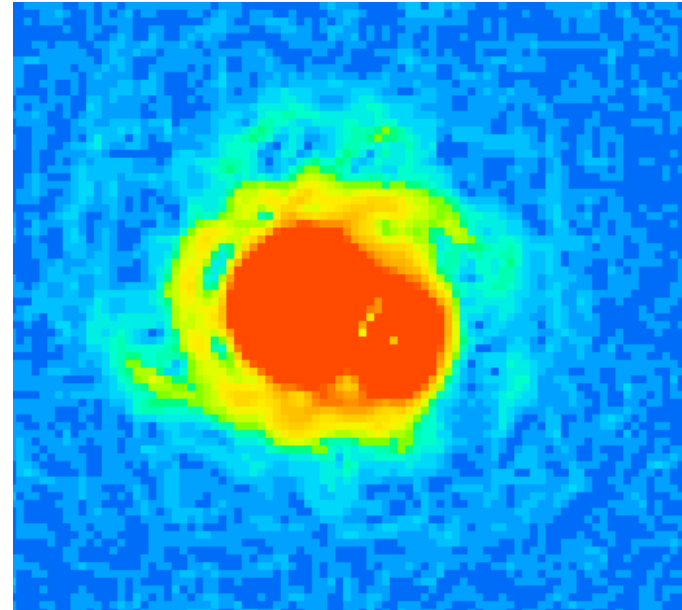Observatory

MANCHESTER
1824

Introduction to gravitational lensing
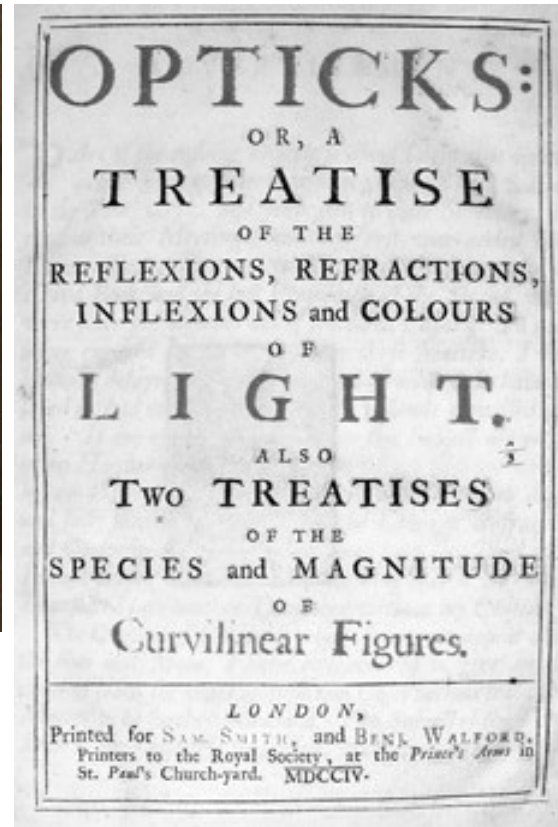
Neal Jackson
BALTICS workshop
5.12.2018

Introduction to gravitational lensing

1. What it is
2. Finding lenses
3. Science from lenses:
   a) Cosmology
   b) Magnification: the sources
   c) Mass and other properties
      of the lenses

The story starts with Newton...

OPTICKS:
OR, A
TREATISE
OF THE
REFLEXIONS, REFRACTIONS,
INFLEXIONS and COLOURS
OF
LIGHT.
ALSO
Two TREATISES
OF THE
SPECIES and MAGNITUDE
OF
Curvilinear Figures.

LONDON,
Printed for Sam. Smith, and Benj. Walford,
Printers to the Royal Society, at the Prince's Arms in
St. Paul's Church-yard. MDCCIV.

...or Jean-Paul Marat
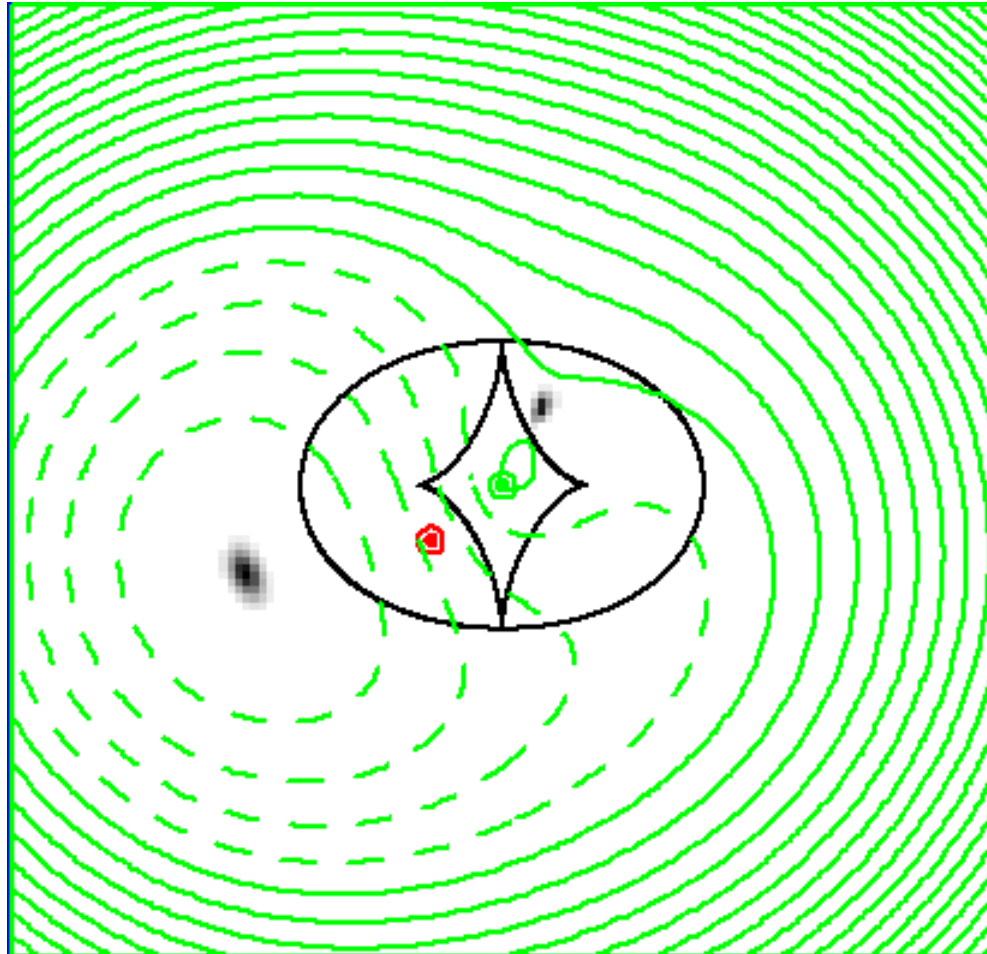
..but Einstein worked out the equation correctly

If M is the mass of the deflector and b the distance of approach of the light ray, then the deflection angle is given by…
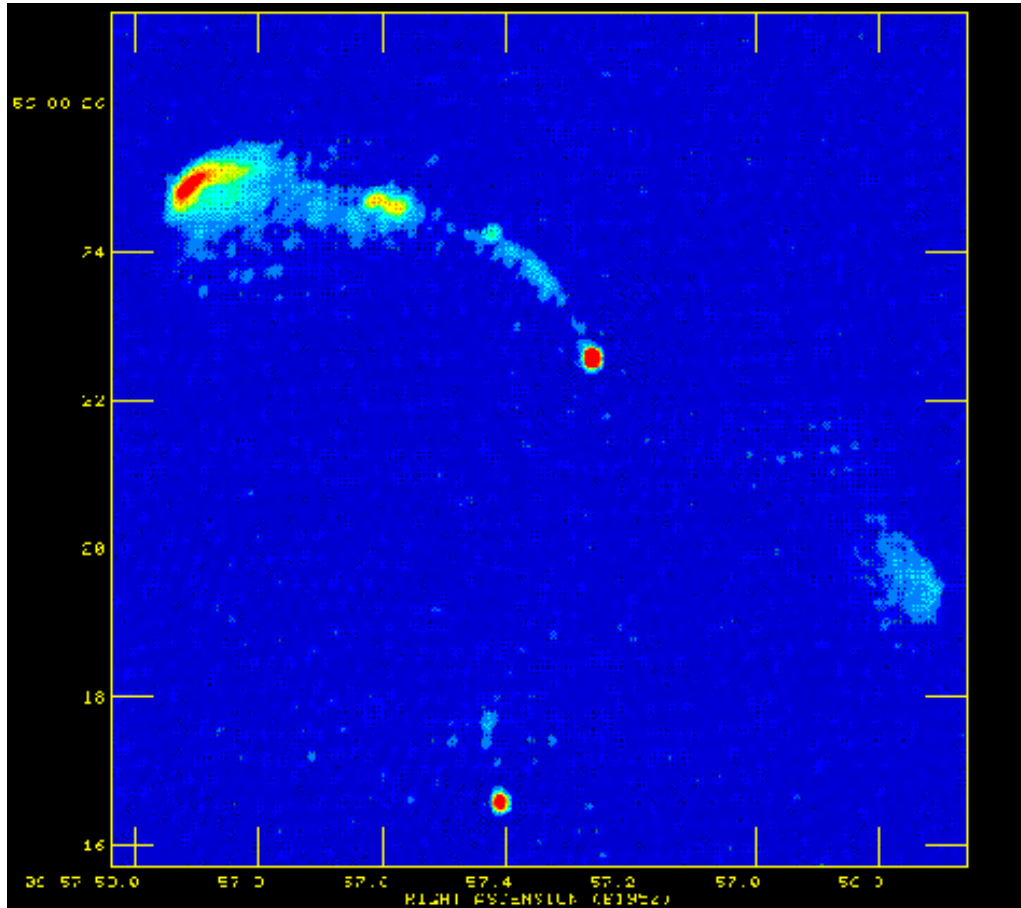
$$\alpha = \frac{4GM}{bc^2}$$

Observer's point of view
Light from source (red) deflected by galaxy (green)

Green contours: lines of equal travel time given geometry and influence of lens
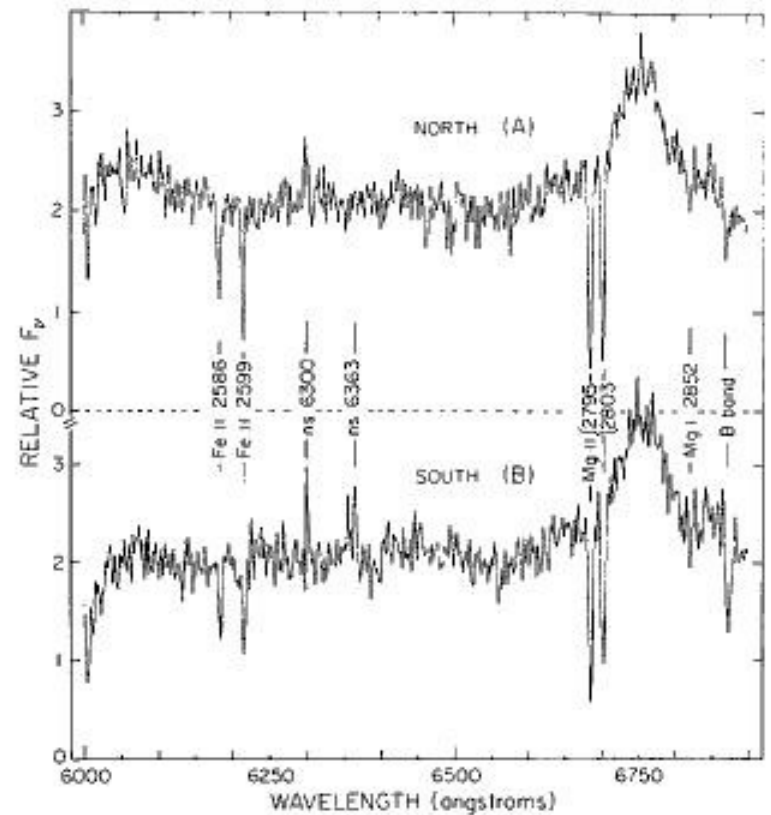Images form at stationary points of this surface
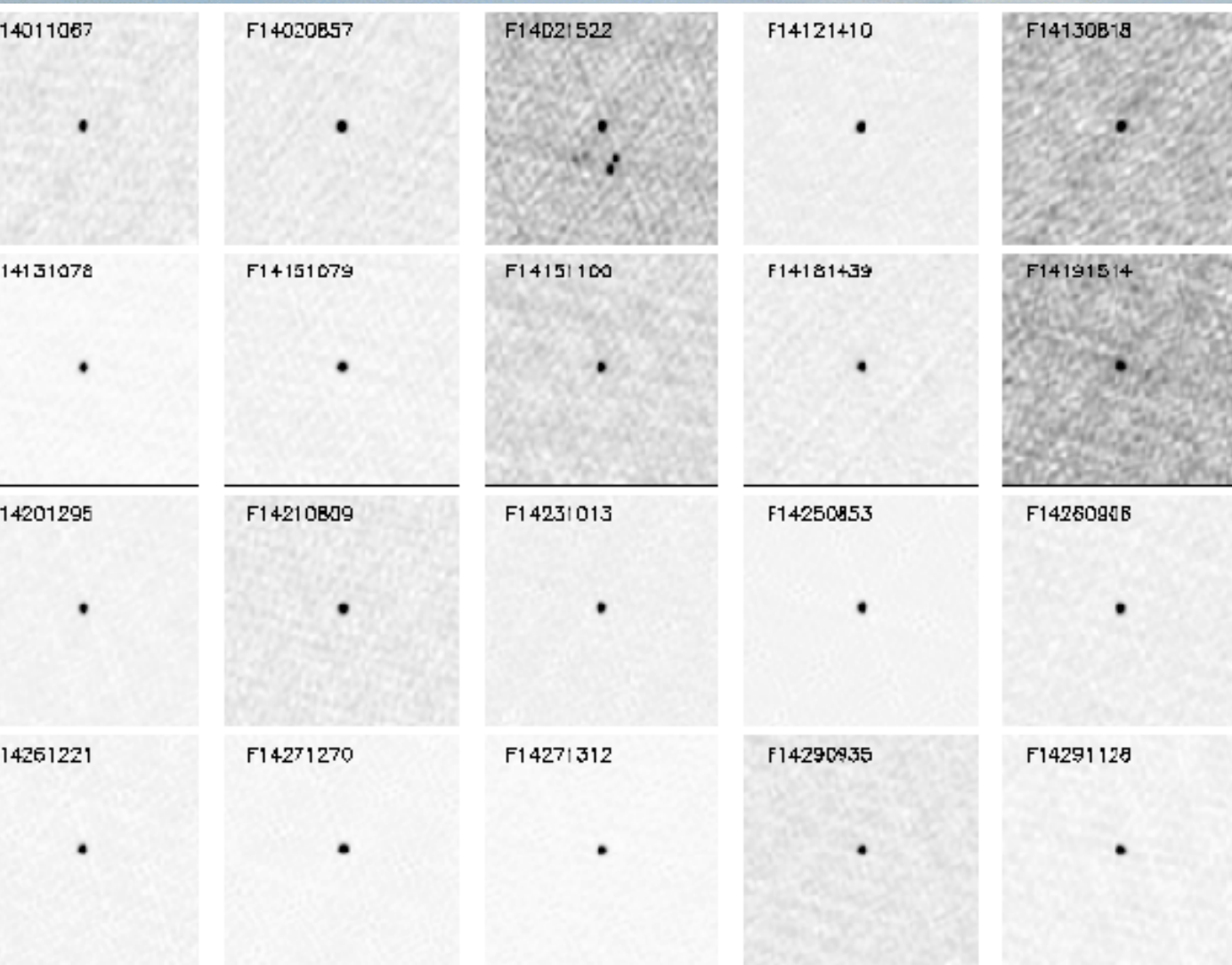
0957+561: the first lens system

Merlin 5 GHz

Walsh, Carswell & Weymann 1979
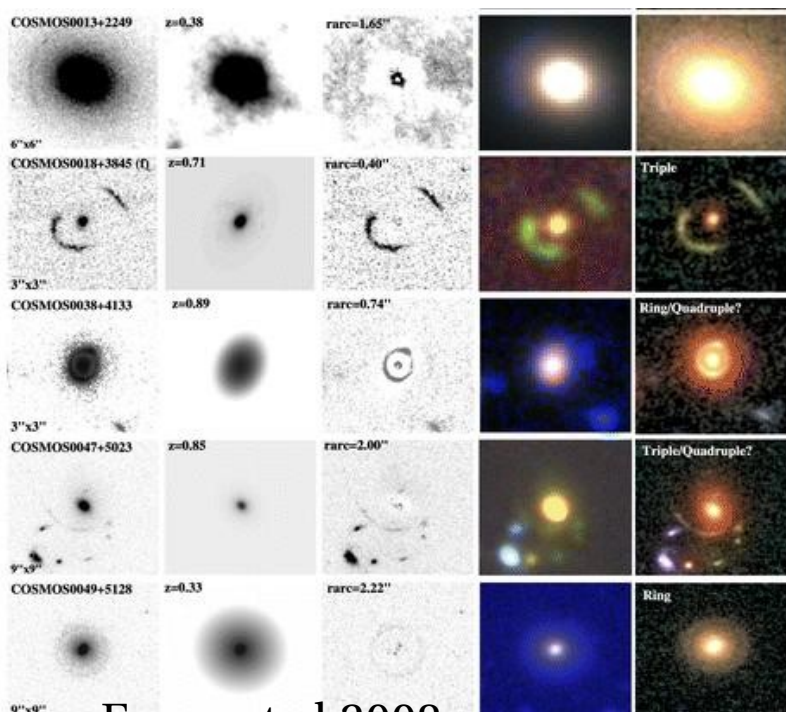

Optical (Weymann et al.)

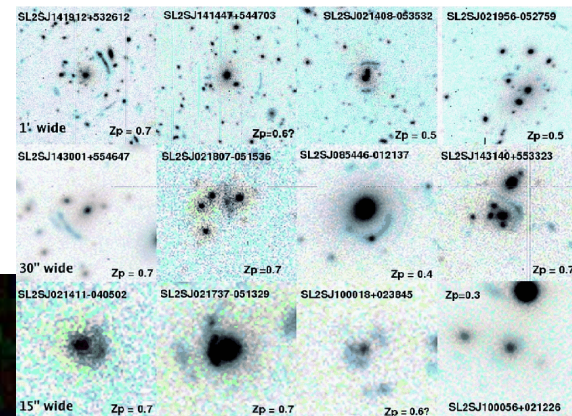# CLASS radio survey (1990-2000s)

Discovery of new lenses:

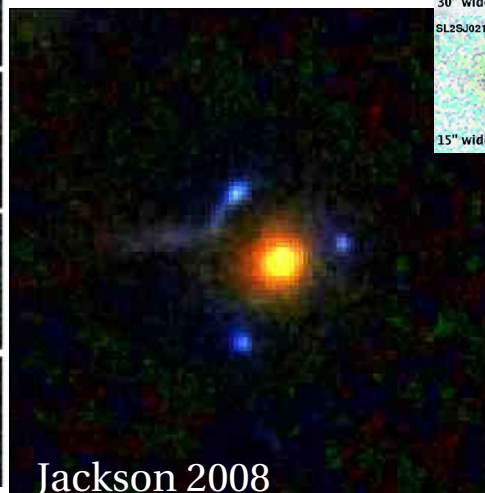short-term: efficient use of existing surveys (SL2S, hundreds of lenses)

long-term: Euclid space mission, LSST (100000s!)
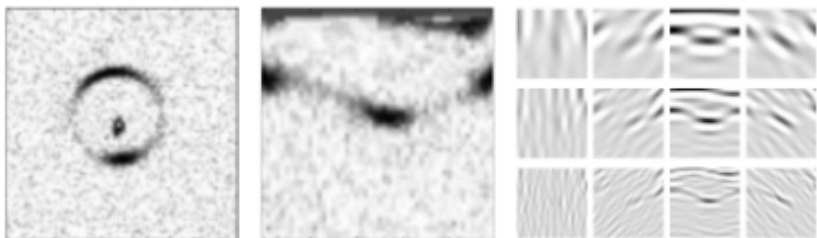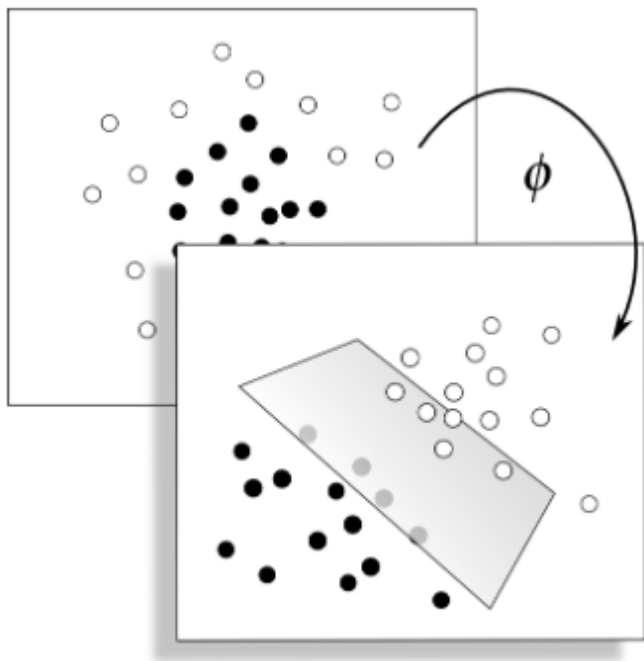

Faure et al. 2008

Jackson 2008

Cabanac et al. 2008
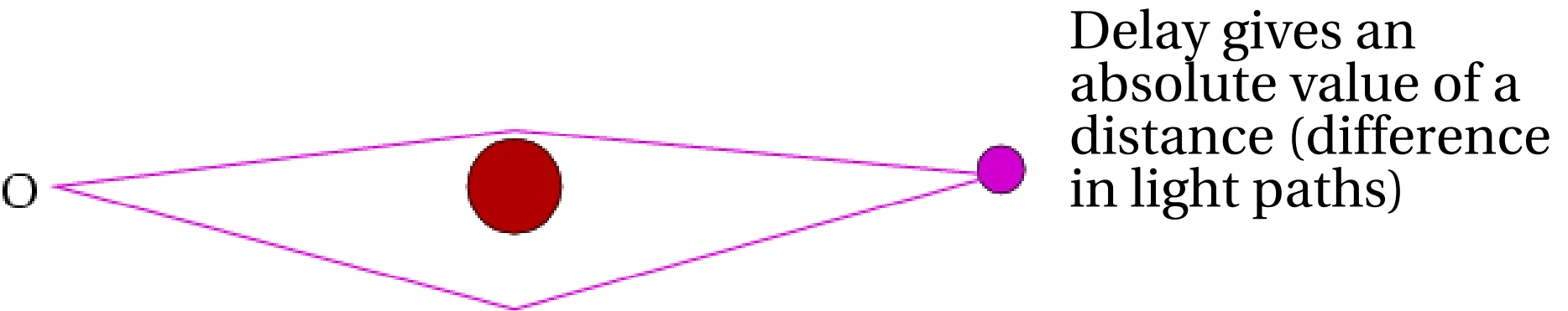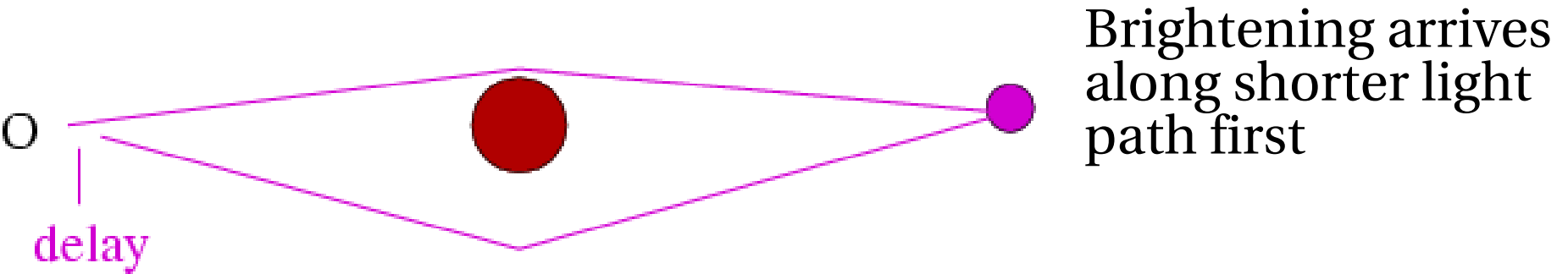
The future is machine learning (with billions of images)

ϕ
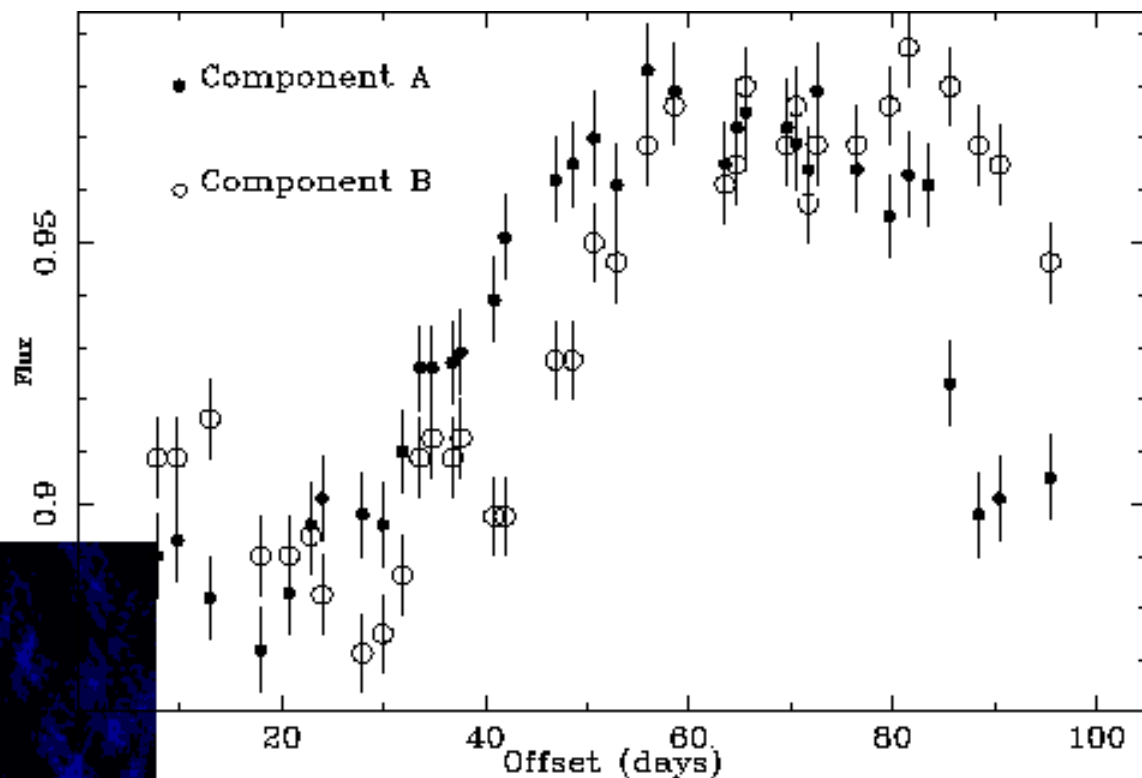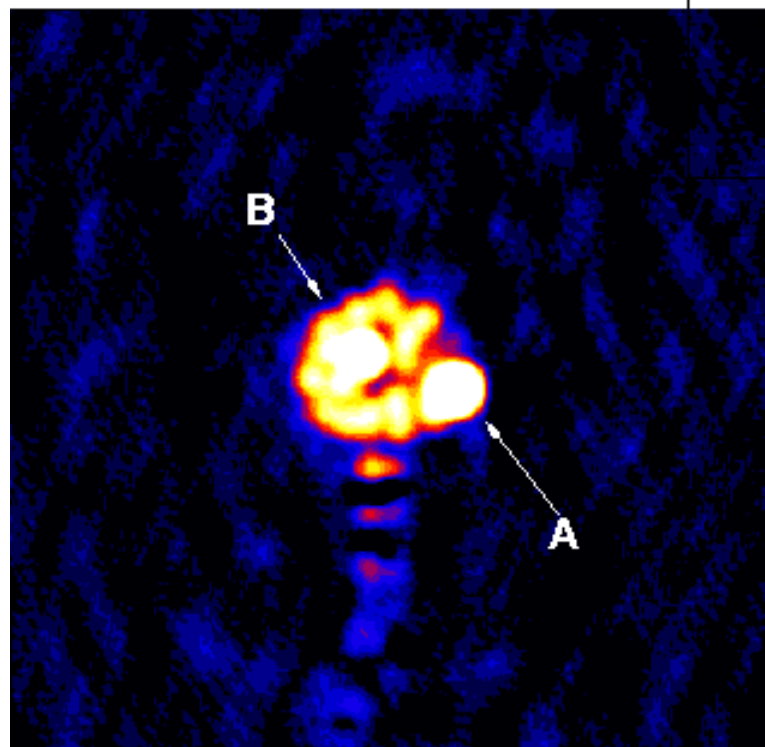
Hartley et al. 2017

3a. Uses of lenses: cosmology

Source brightens

delay

Brightening arrives along shorter light path first

Delay gives an absolute value of a distance (difference in light paths)
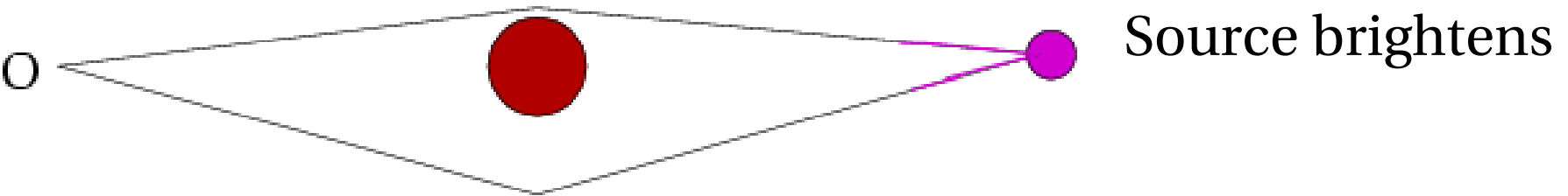
Determines Hubble constant (scale of universe)
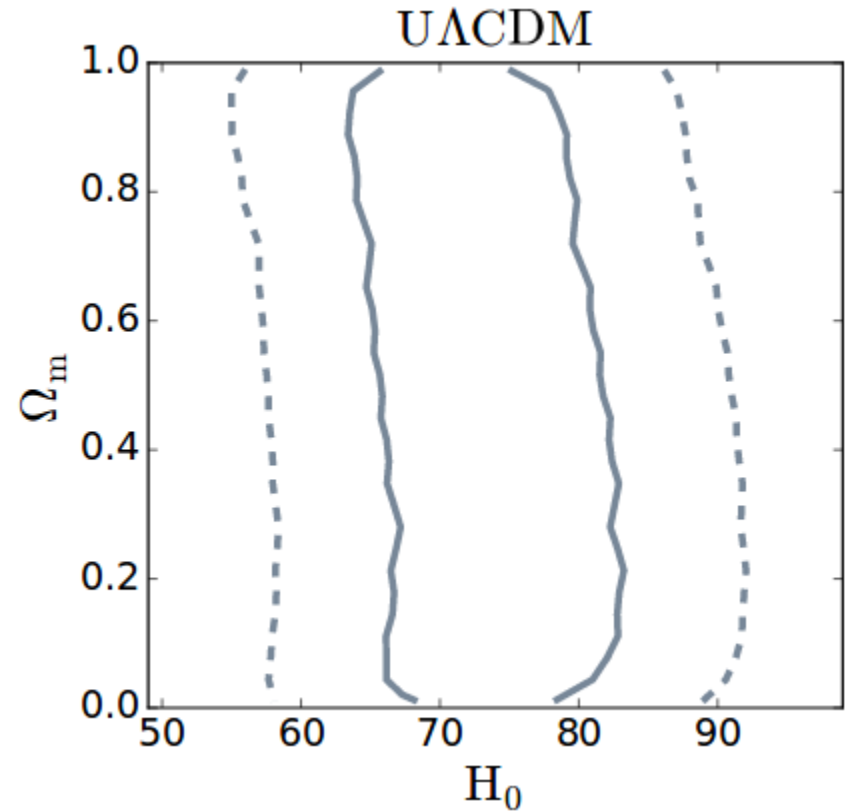
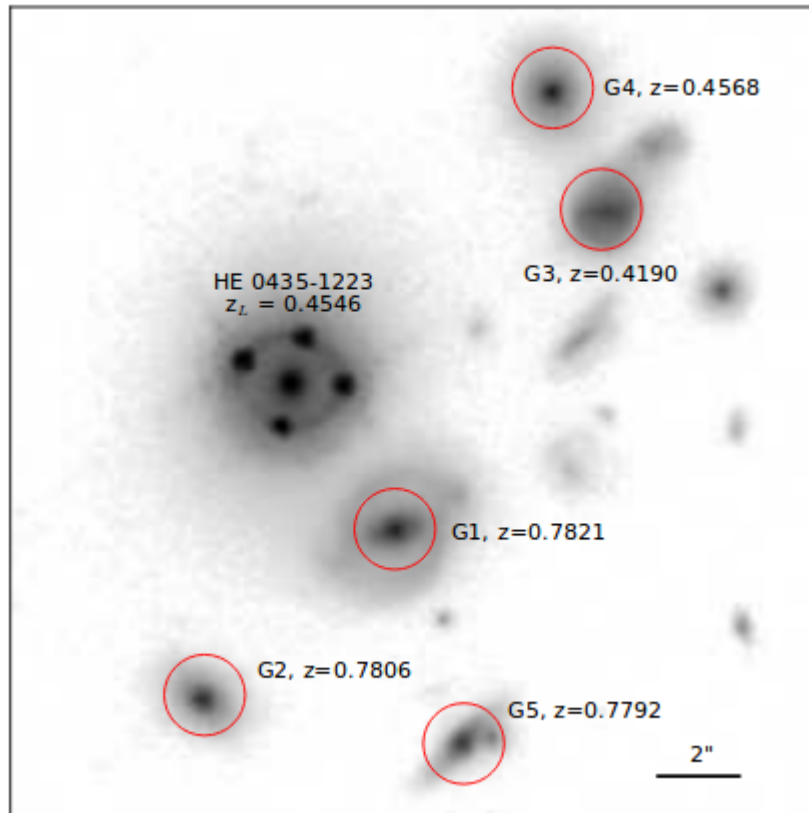# The gravitational lens JVAS0218+357
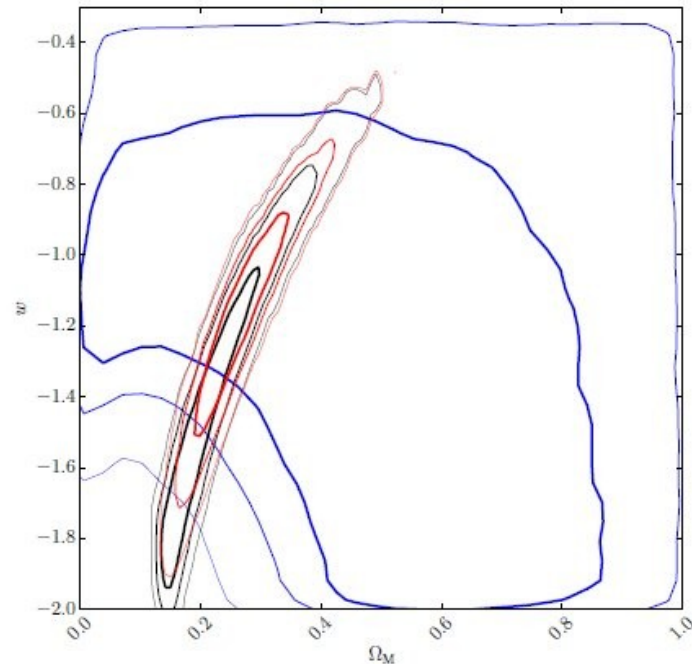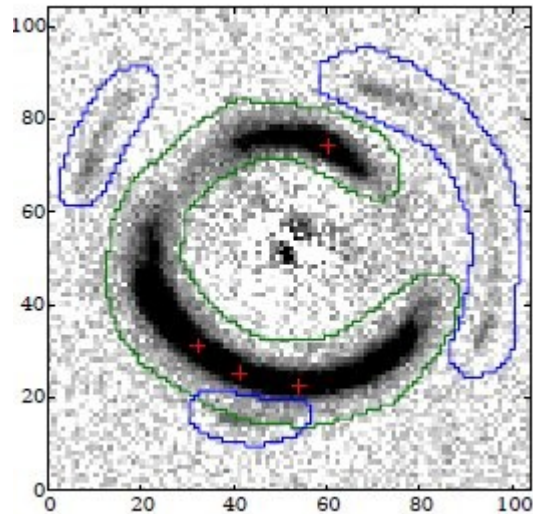
Radio map

Radio light curves

Time delay = 10.5+/-0.4 days
Hubble constant estimate:
69 km/s/Mpc (+13/-19, 95%)
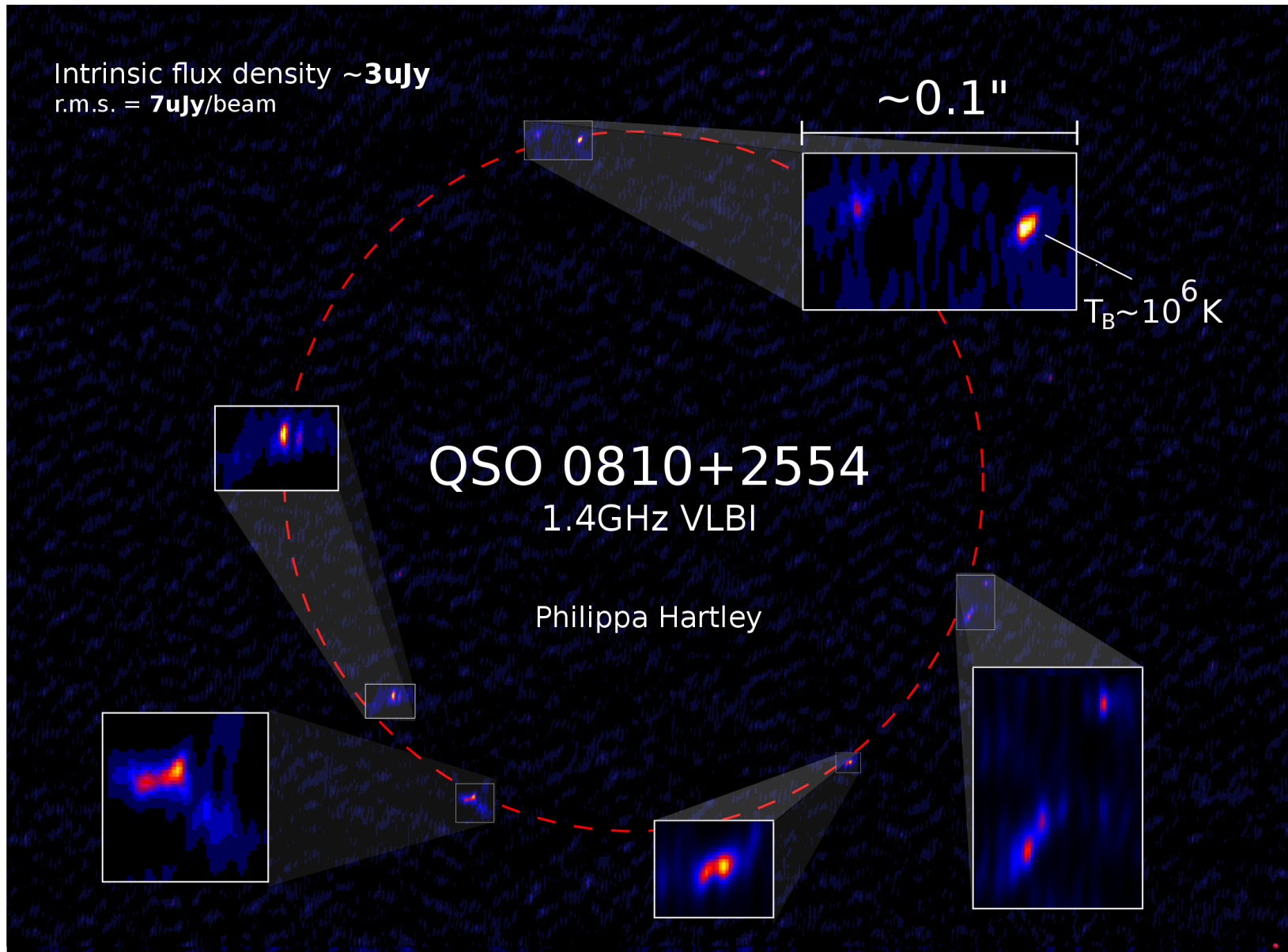
Most careful job so far: Suyu et al. 2013 H0LiCoW

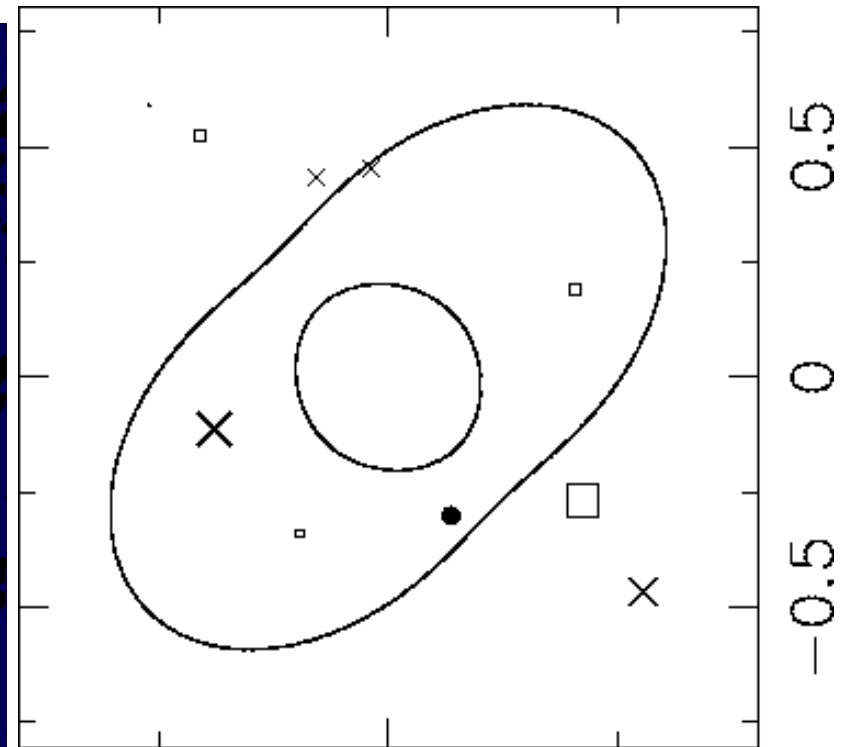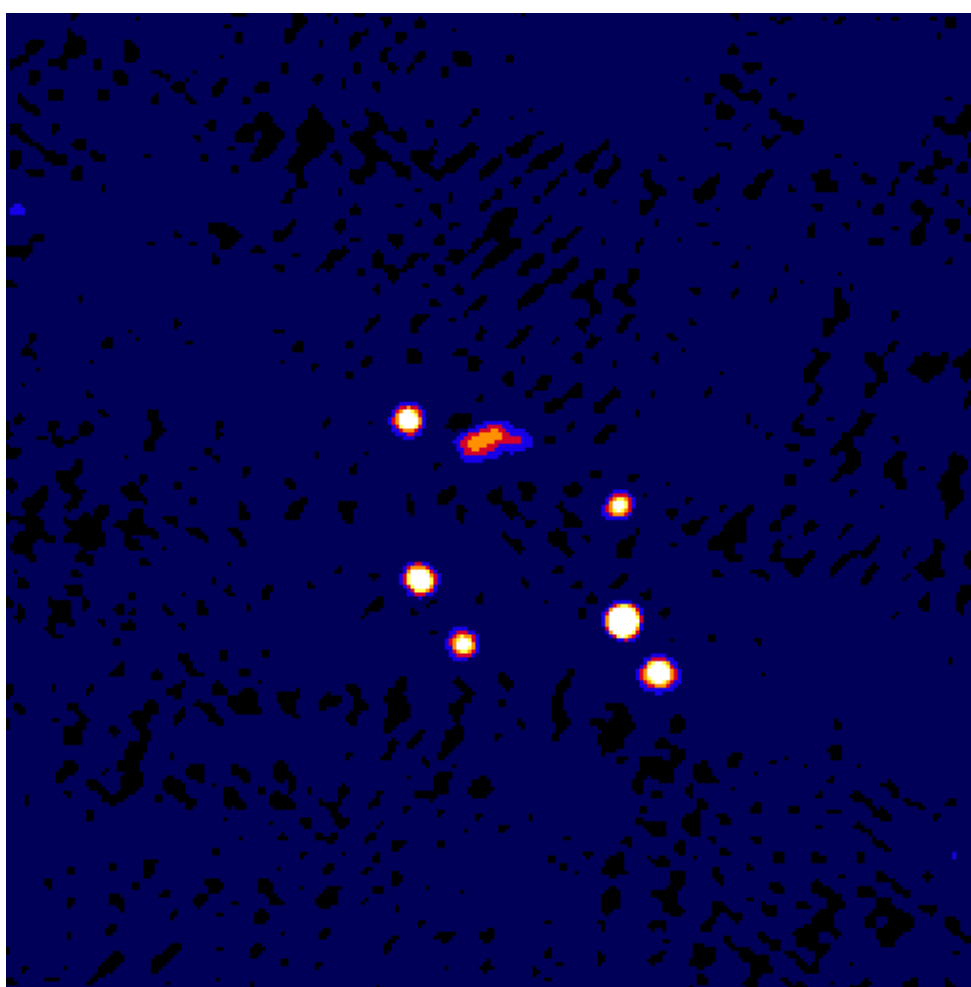# Double-source plane lenses (Collett & Auger 2012) – 2 known

Two sightlines at different redshifts → geometry, hence w

These lenses are very, very rare – so need huge samples!

3b) Magnification of background sources

Intrinsic flux density ~**3uJy**
r.m.s. = **7uJy**/beam

~0.1"

$T_B \sim 10^6 K$

QSO 0810+2554
1.4GHz VLBI

Philippa Hartley

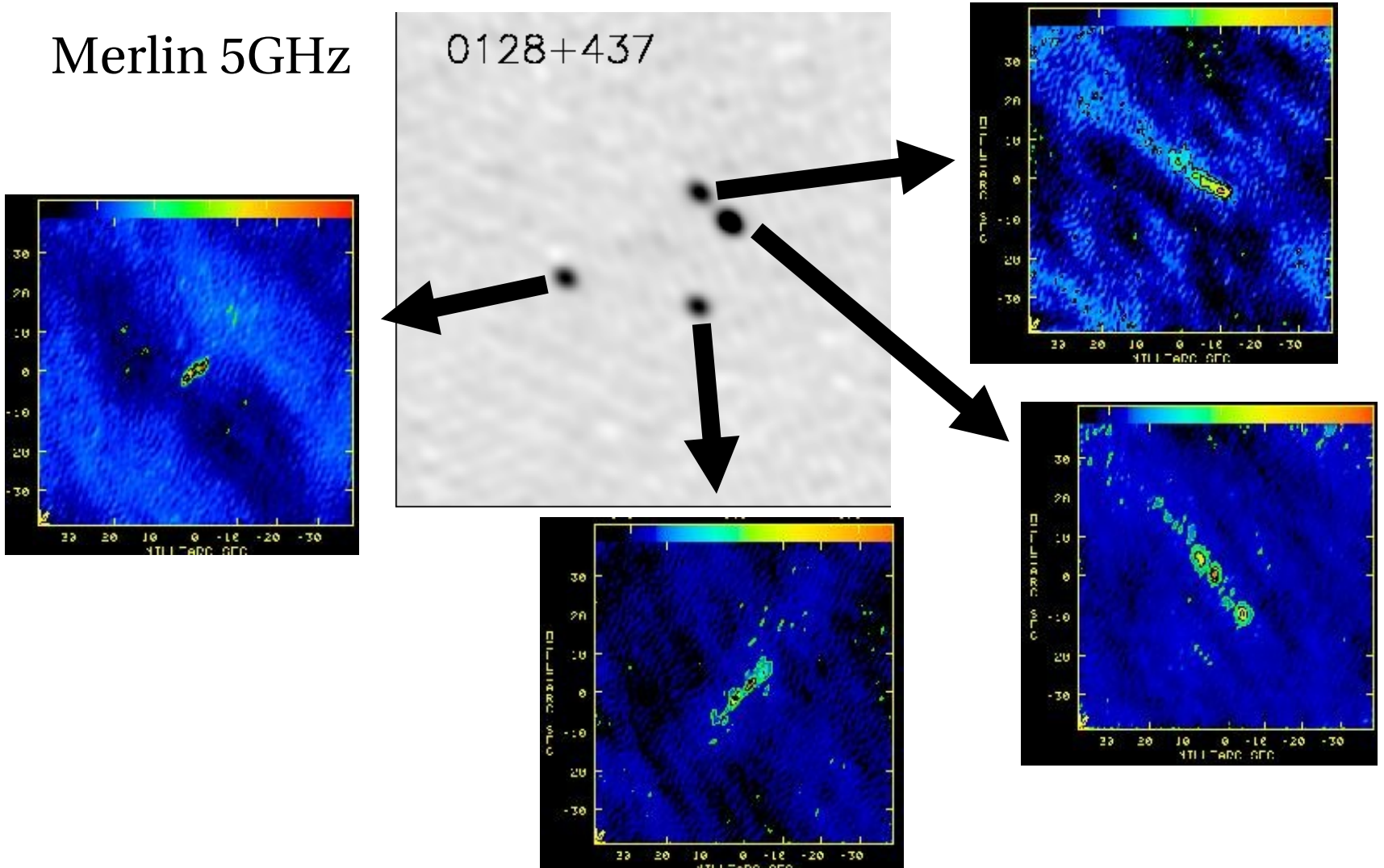# 3c) Properties of the lensing galaxies: Modelling light and dark matter

Galaxy model: mass, radial mass profile, ellipticity, and orientation (lots of constraints)

Cohn et al. 2001

3c) Using radio imaging to model small-scale structures in lenses

Merlin 5GHz

0128+437

3c) Other properties of lens galaxies (magnetic field, scattering)

See talk by K. Prusis later!

Conclusions

- 40 years since first lens system, now know of 500
- Will shortly have 100000!
- Unique probe of masses in universe
- Also powerful as probes of cosmology and natural magnifying glasses