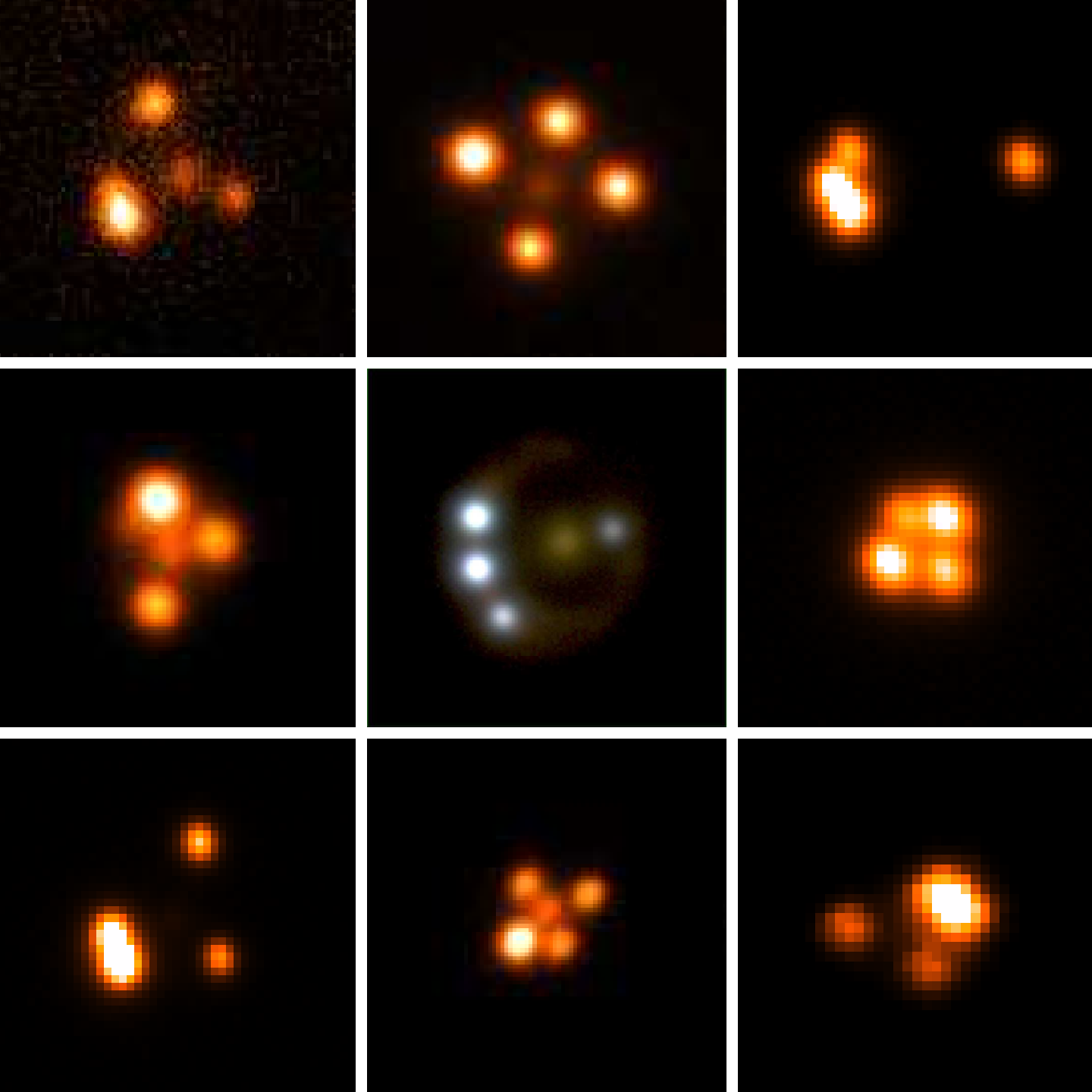
The stellar mass-to-light ratio in elliptical galaxies measured from the static gravitational micro-lensing of multiply imaged quasars



effective 2-D potential:

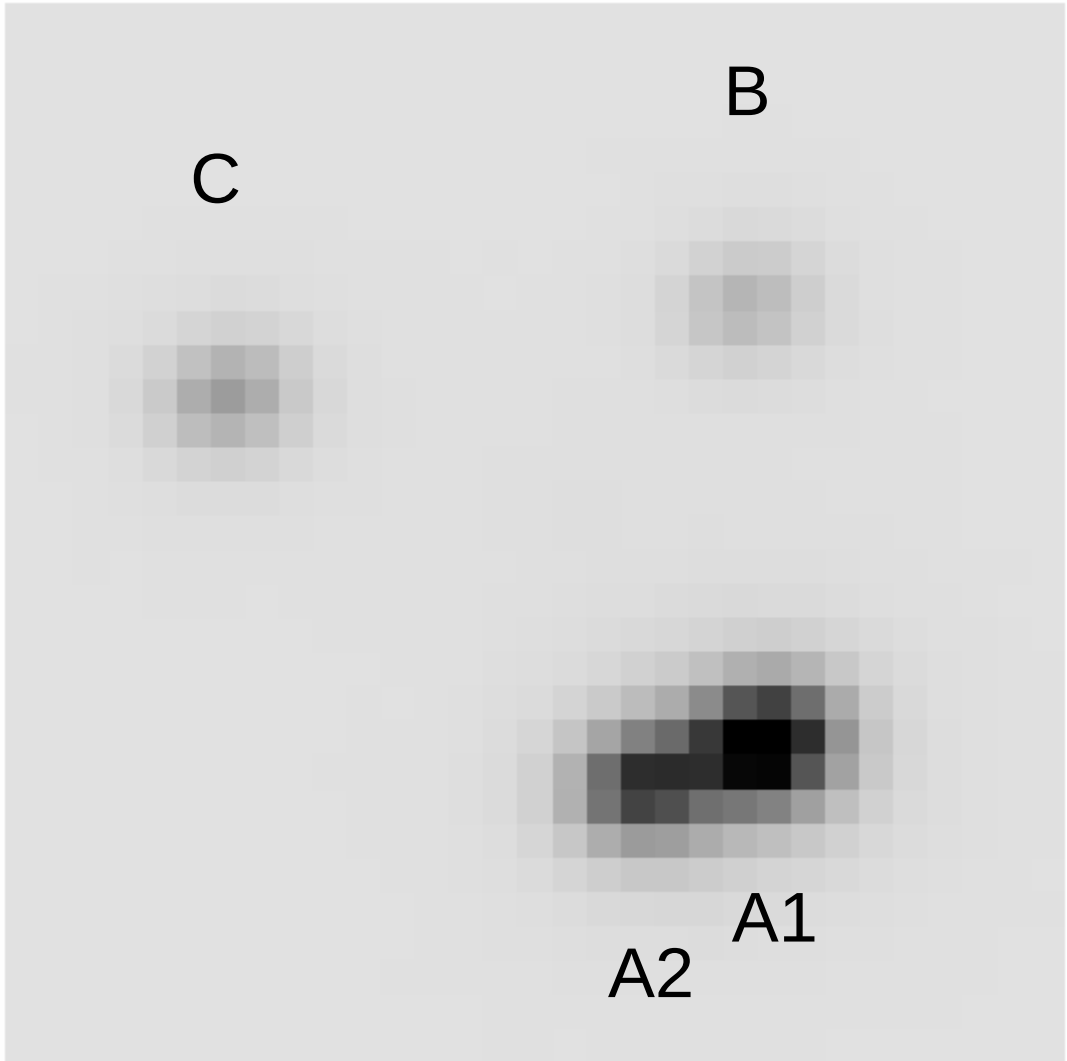
$$\psi_{2D} = \frac{D_{LS}}{D_S} \int_{observer}^{source} \frac{2\Phi_{3D}}{c^2} \frac{d\ell}{D_L}$$

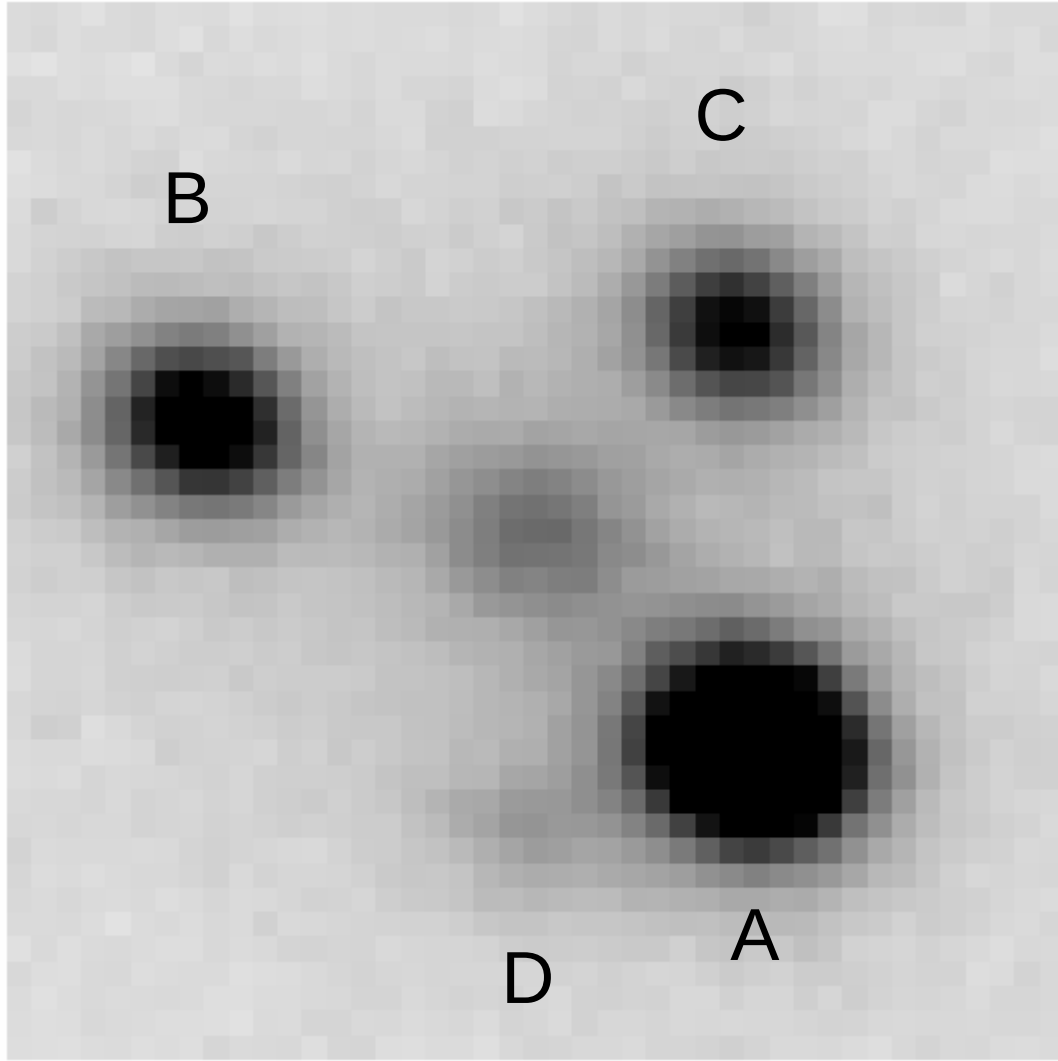
3D's of gravitational lensing

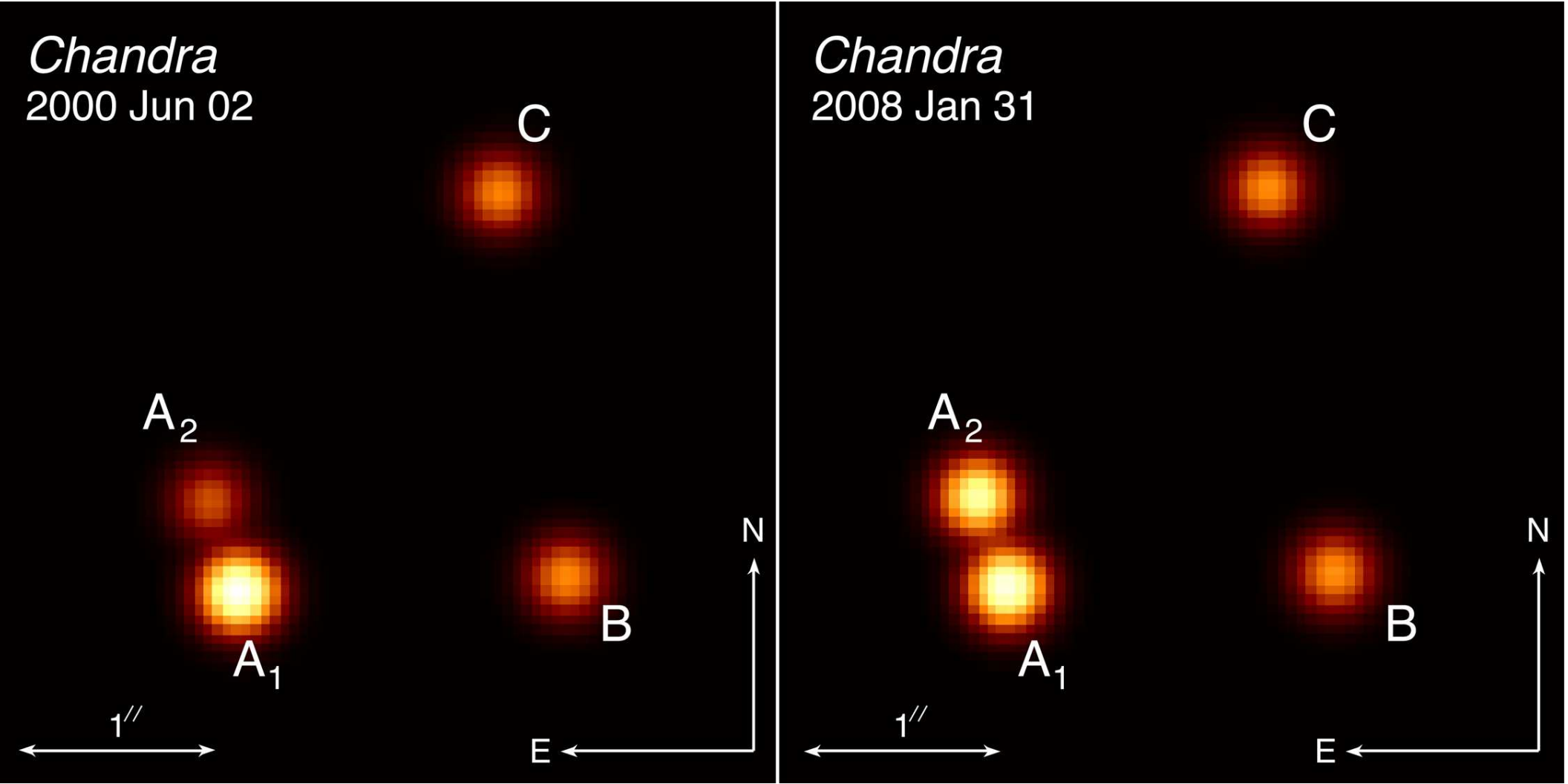
- **Delay** (0^{th} **derivative of** ψ)
- **Deflection** (1^{st} **derivative of** ψ)
- **Distortion** (2^{nd} **derivative of** ψ)
  – includes overall stretching

typical quadrupole potential:

$$\psi_{2D} = b\theta[1 + \gamma \cos 2(\phi - \phi_\gamma)]$$


B
C
A1
A2


C
B
A
D


Chandra
2000 Jun 02
C
A2
A1
B
N
E
1″
Chandra
2008 Jan 31
C
A2
A1
B
N
E
1″

radius of Einstein circle:

$$\theta_E = \sqrt{\left(\frac{4GM}{c^2}\right)\left(\frac{D_{LS}}{D_L D_S}\right)}$$

NAIVE CALCULATION

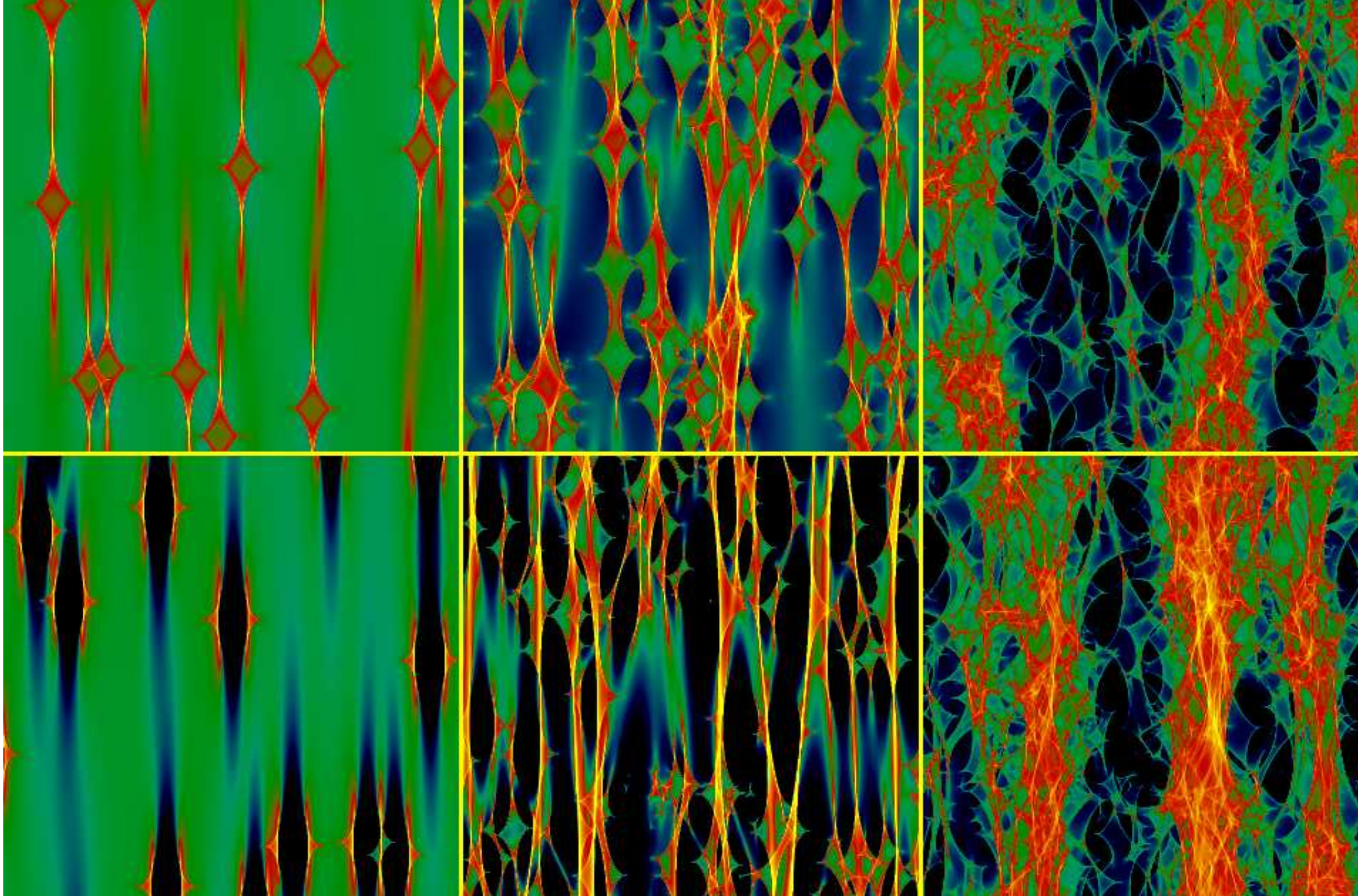
1. **Count fraction of images that are too bright by more than a factor of 1.34;**
2. **calculate covering factor of Einstein circles;**
3. **calculate equivalent mass surface density!**

COMPLICATING FACTORS

1. highly sheared macro-images

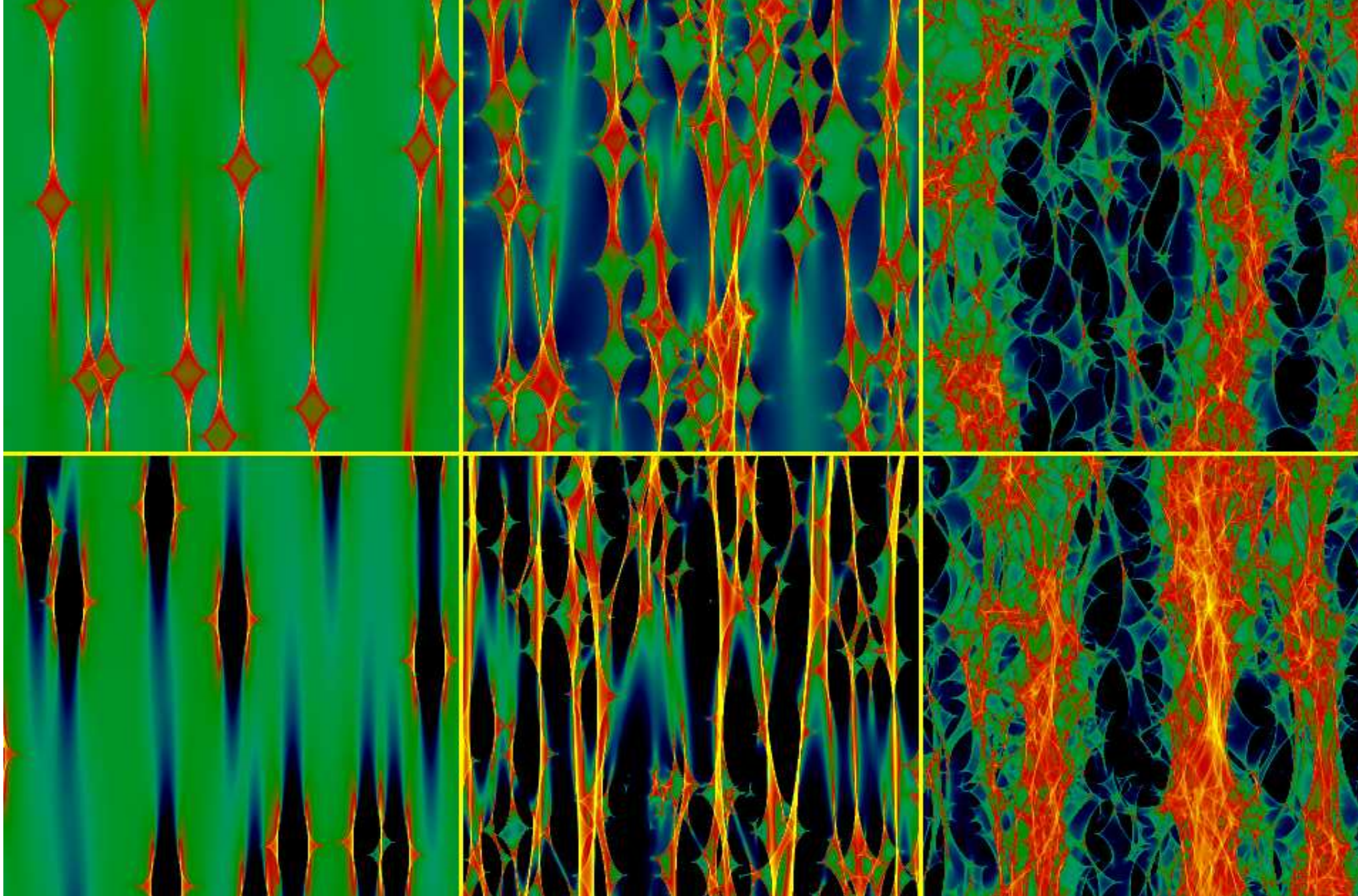
COMPLICATING FACTORS

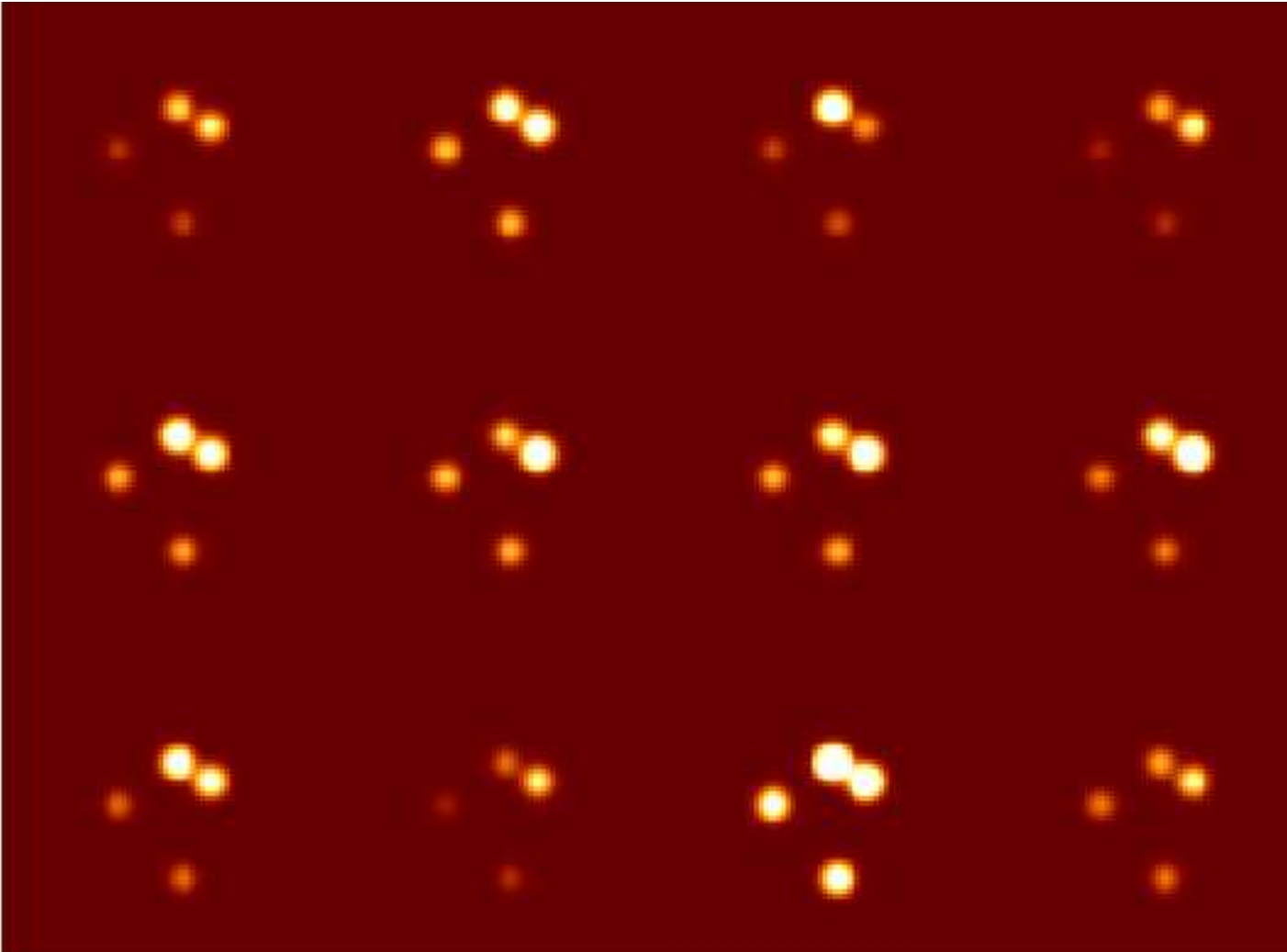
1. **highly sheared macro-images**
2. **saddlepoints are different**

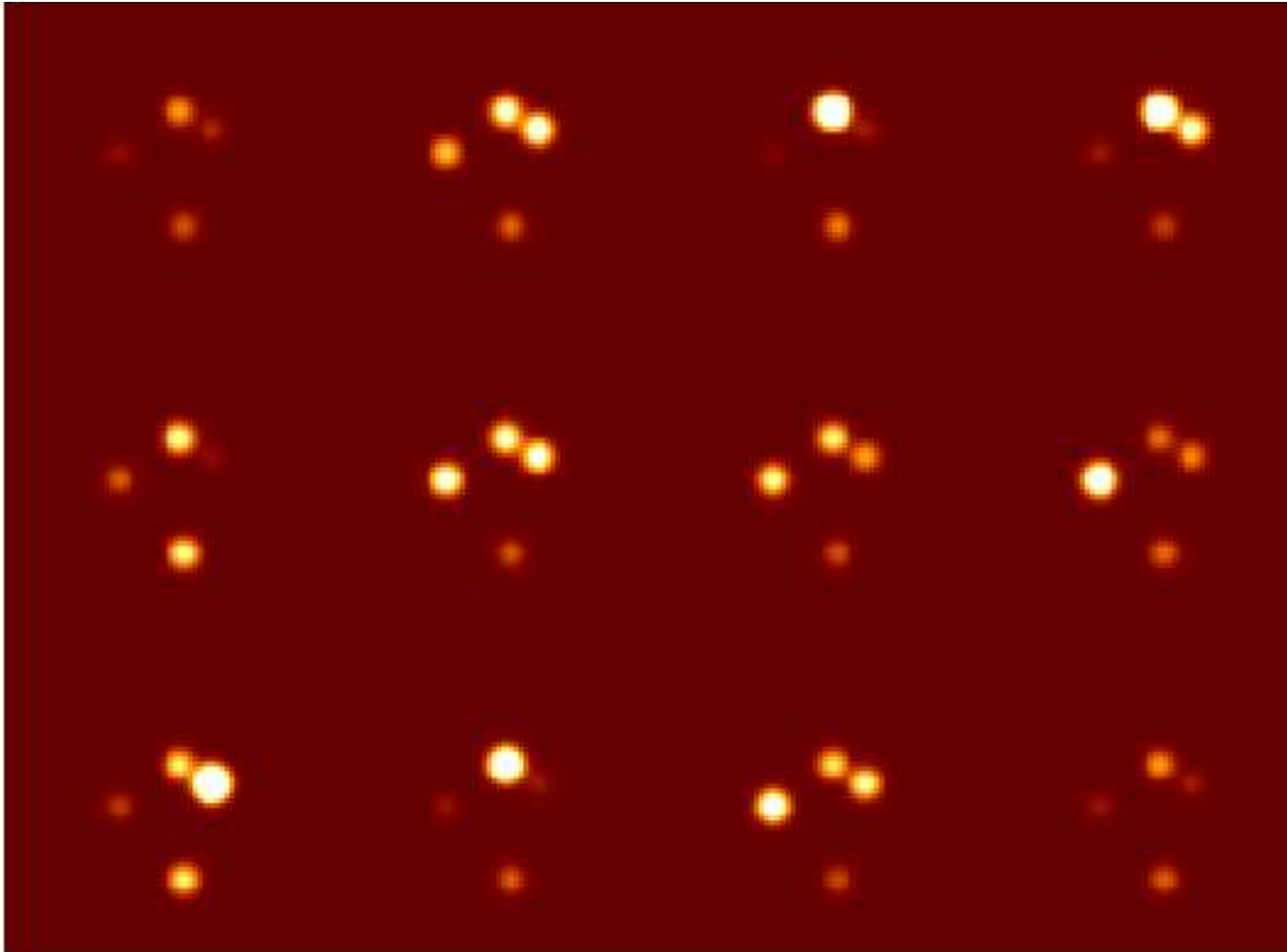


COMPLICATING FACTORS

1. **highly sheared macro-images**
2. **saddlepoints are different**
3. **optical depth $\kappa \sim 1$**

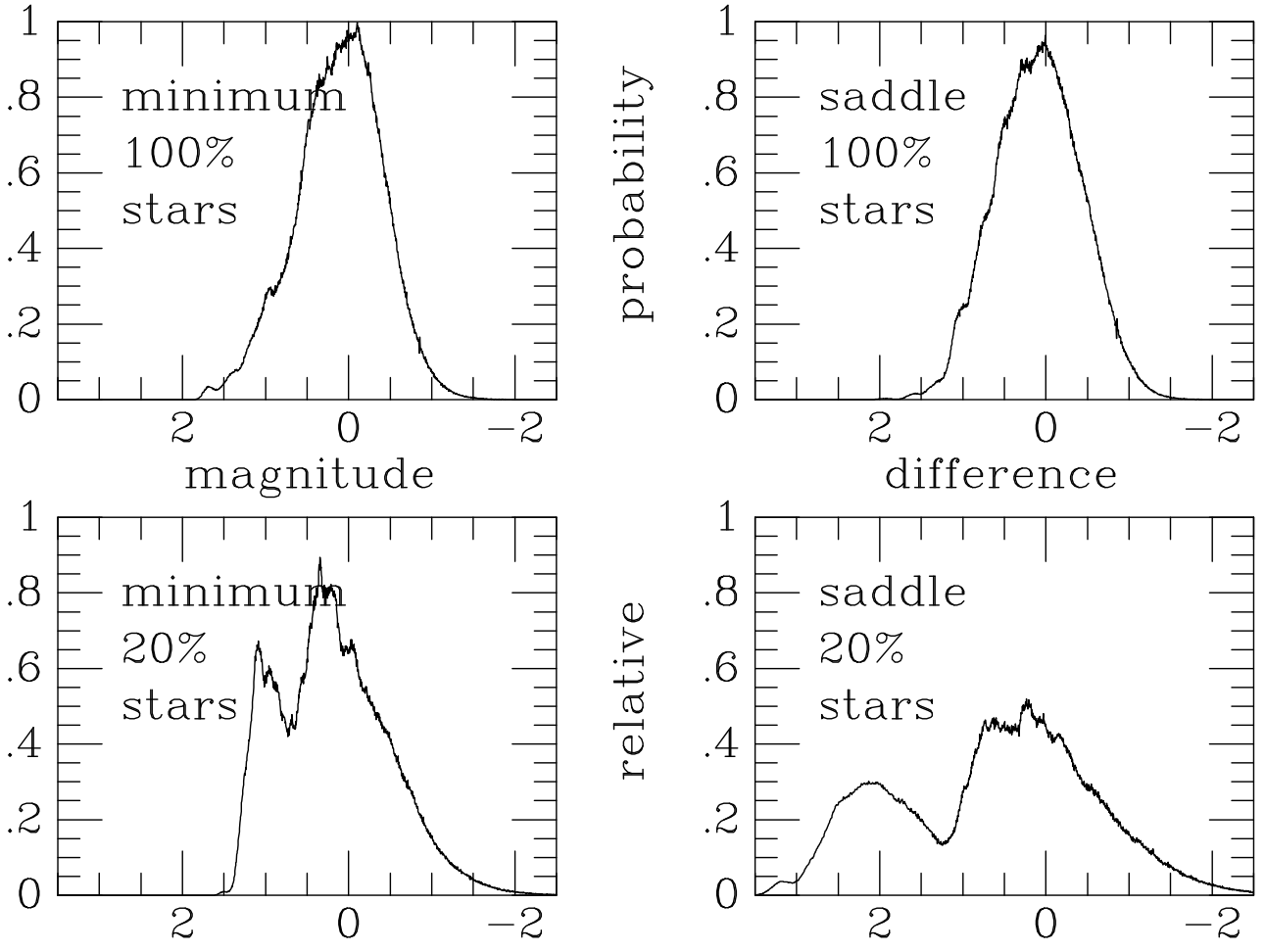


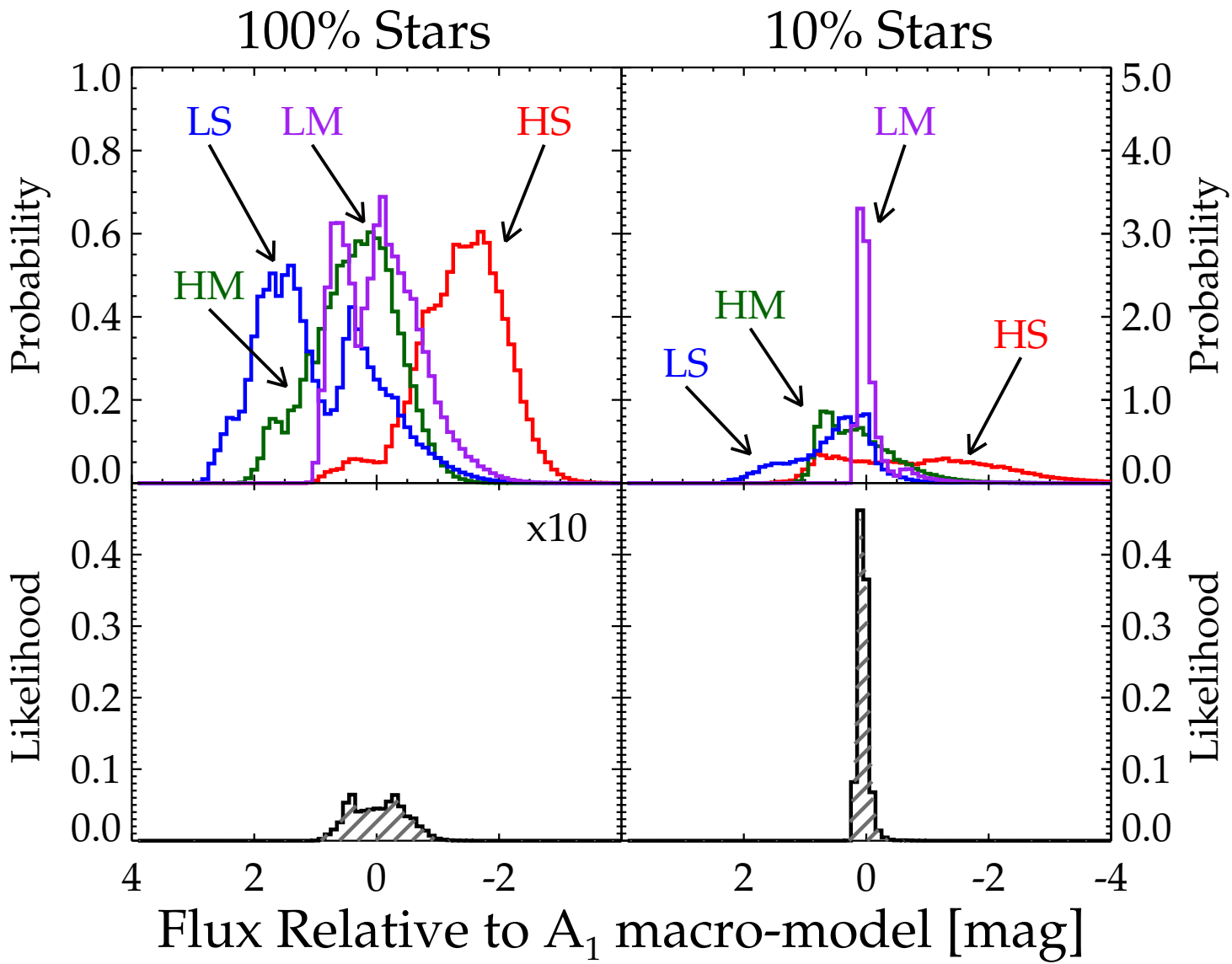




COMPLICATING FACTORS

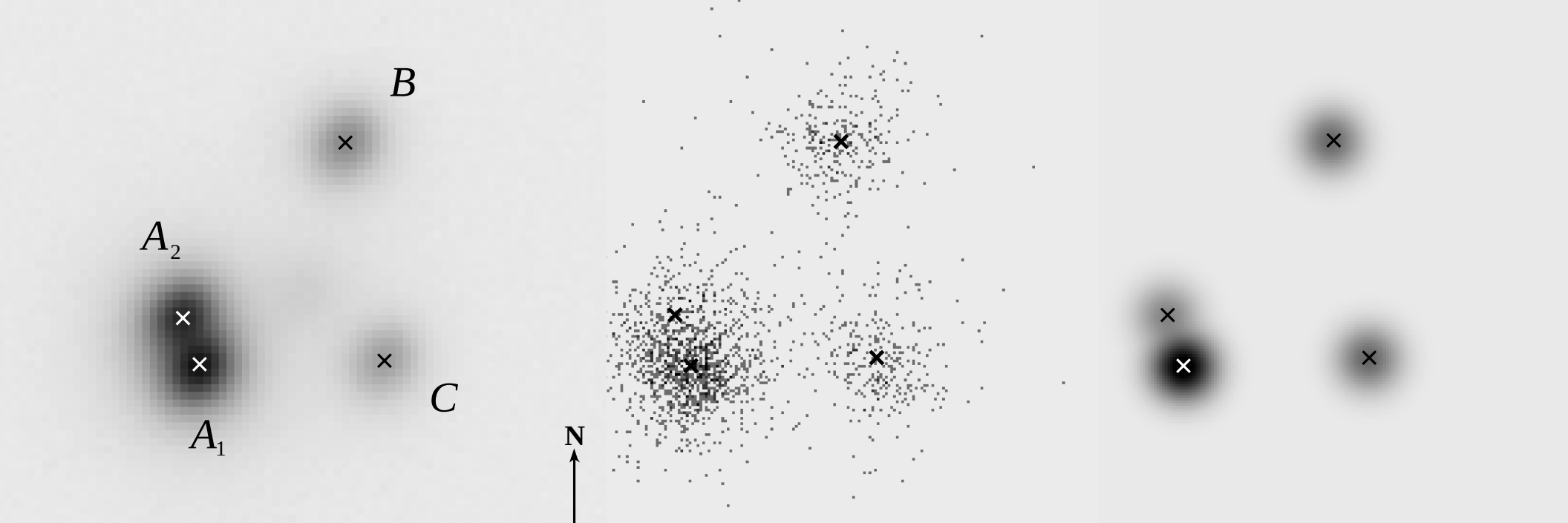
1. **highly sheared macro-images**
2. **saddlepoints are different**
3. **optical depth $\kappa \sim 1$**
4. **magnification histograms are broad**

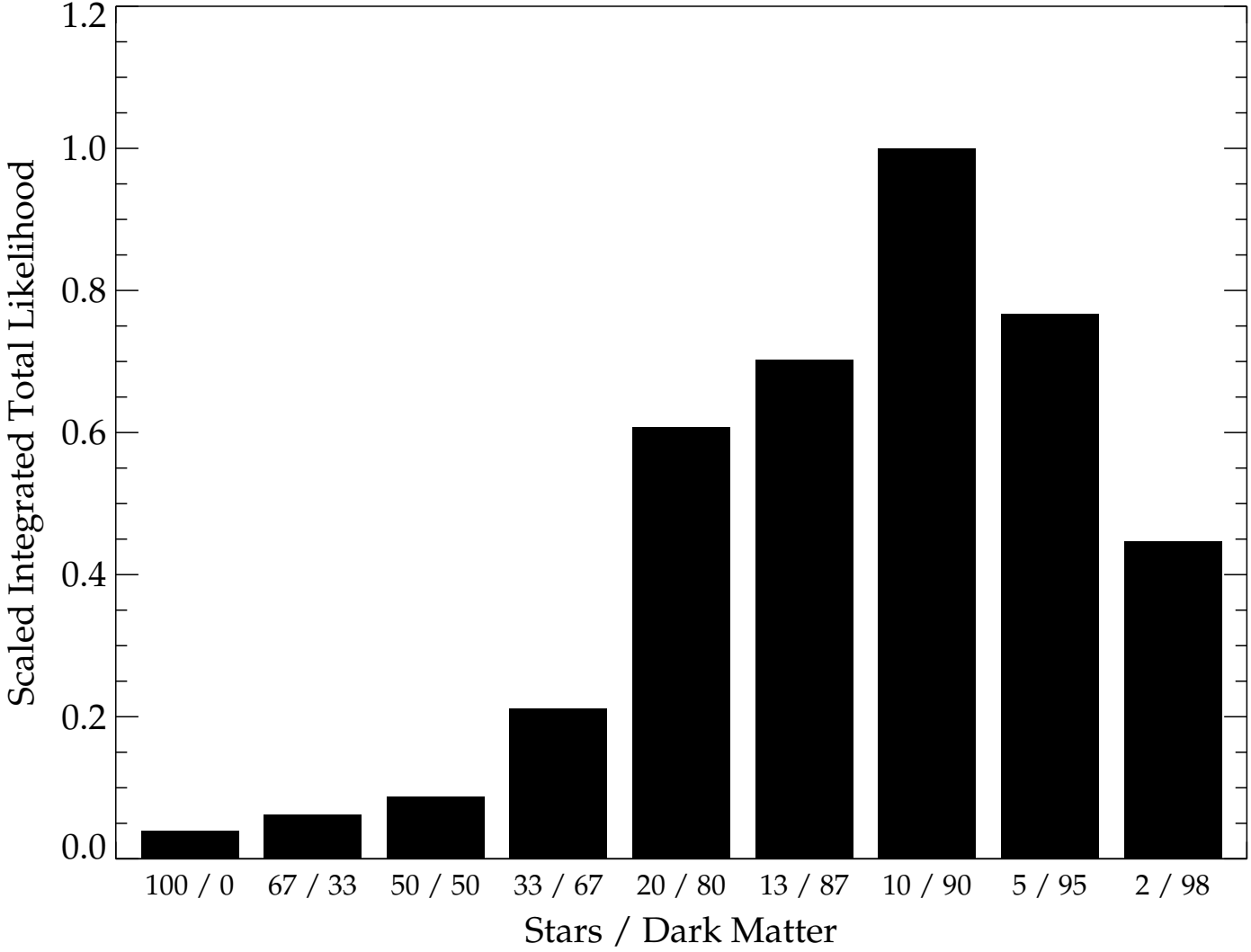

minimum
100%
stars
saddle
100%
stars
minimum
20%
stars
saddle
20%
stars
probability
relative
magnitude
difference
1
.8
.6
.4
.2
0
2
0
−2


100% Stars
10% Stars
LS
LM
HS
HM
Probability
Likelihood
x10
Flux Relative to A1 macro-model [mag]

COMPLICATING FACTORS

1. **highly sheared macro-images**
2. **saddlepoints are different**
3. **optical depth $\kappa \sim 1$**
4. **magnification histograms are broad**
5. **optical emitting region $\sim$ stellar Einstein ring**


B
A_2
A_1
C
N


1.2
1.0
0.8
0.6
0.4
0.2
0.0
Scaled Integrated Total Likelihood
100 / 0
67 / 33
50 / 50
33 / 67
20 / 80
13 / 87
10 / 90
5 / 95
2 / 98
Stars / Dark Matter

THE PARAMETERIZATION PROBLEM

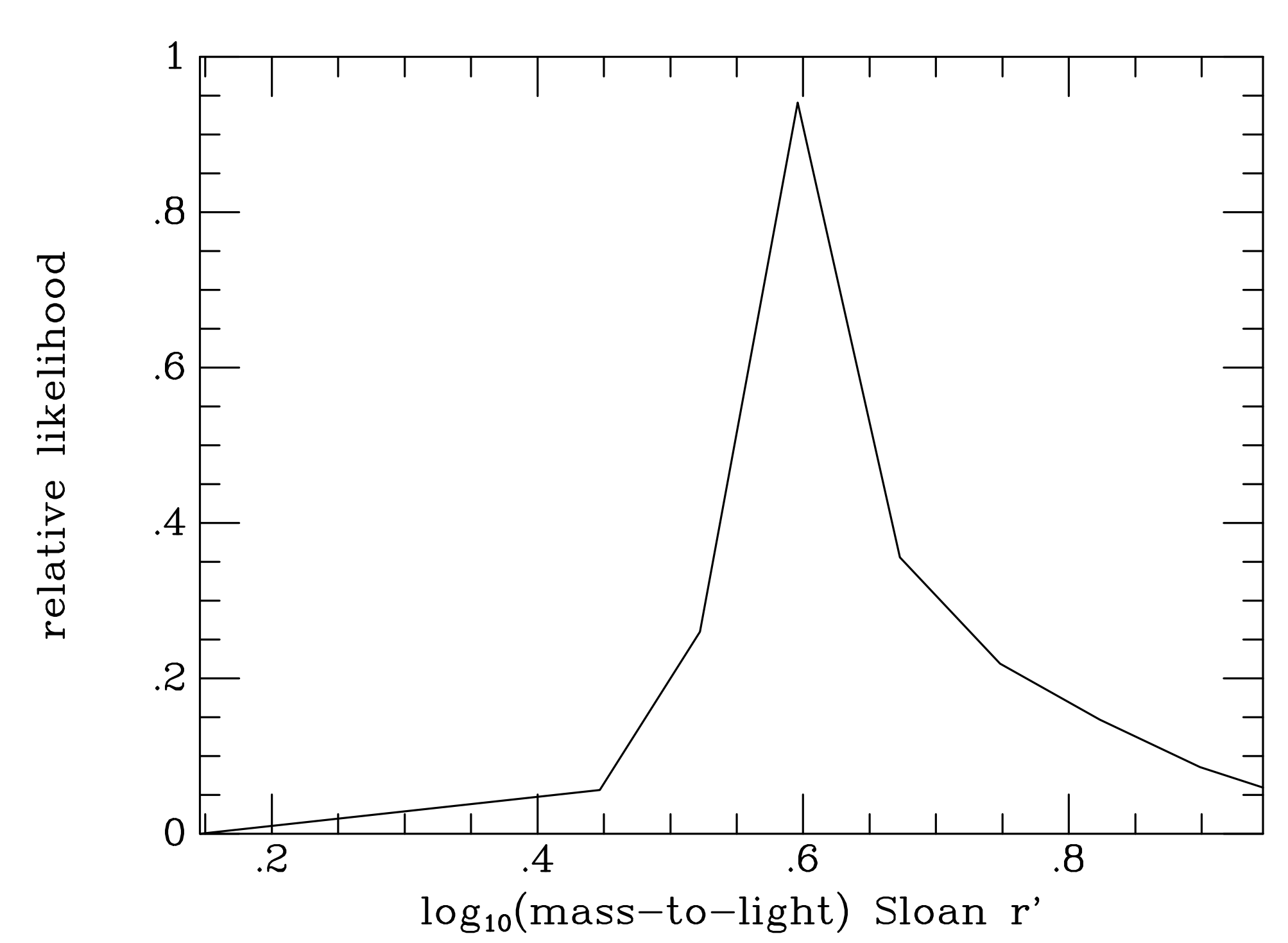
Choose a single parameter that characterizes the stellar surface density and averages over differences in the lensing galaxies that is maximally useful yet does minimal violence to the observations.

ALTERNATIVE PARAMETERS

1. stellar mass fraction?
   (a) at r_e?
   (b) at what redshift?
2. stellar surface mass density?
3. stellar mass-to-light ratio?
   (a) at what wavelength?
   (b) for what color?

AN EXPEDIENT CHOICE

1. **Assume that the mass surface density Kormendy relation does not evolve with time.**
2. **Compute the mass-to-light ratio for Sloan r' at zero redshift.**


1
.8
.6
.4
.2
0
relative likelihood
.2
.4
.6
.8
log10(mass−to−light) Sloan r'

COLLABORATORS

- **Jeffrey Blackburne**
- **David Pooley**
- **Saul Rappaport**
- **Josiah Schwab**
- **Joachim Wambsganss**