Lens models with two offset mass components and implications for H_0

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Time-Domain Cosmology with Strong Gravitational Lensing

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Observations of iPTF16geu

The 1st resolved multiply imaged SNIa

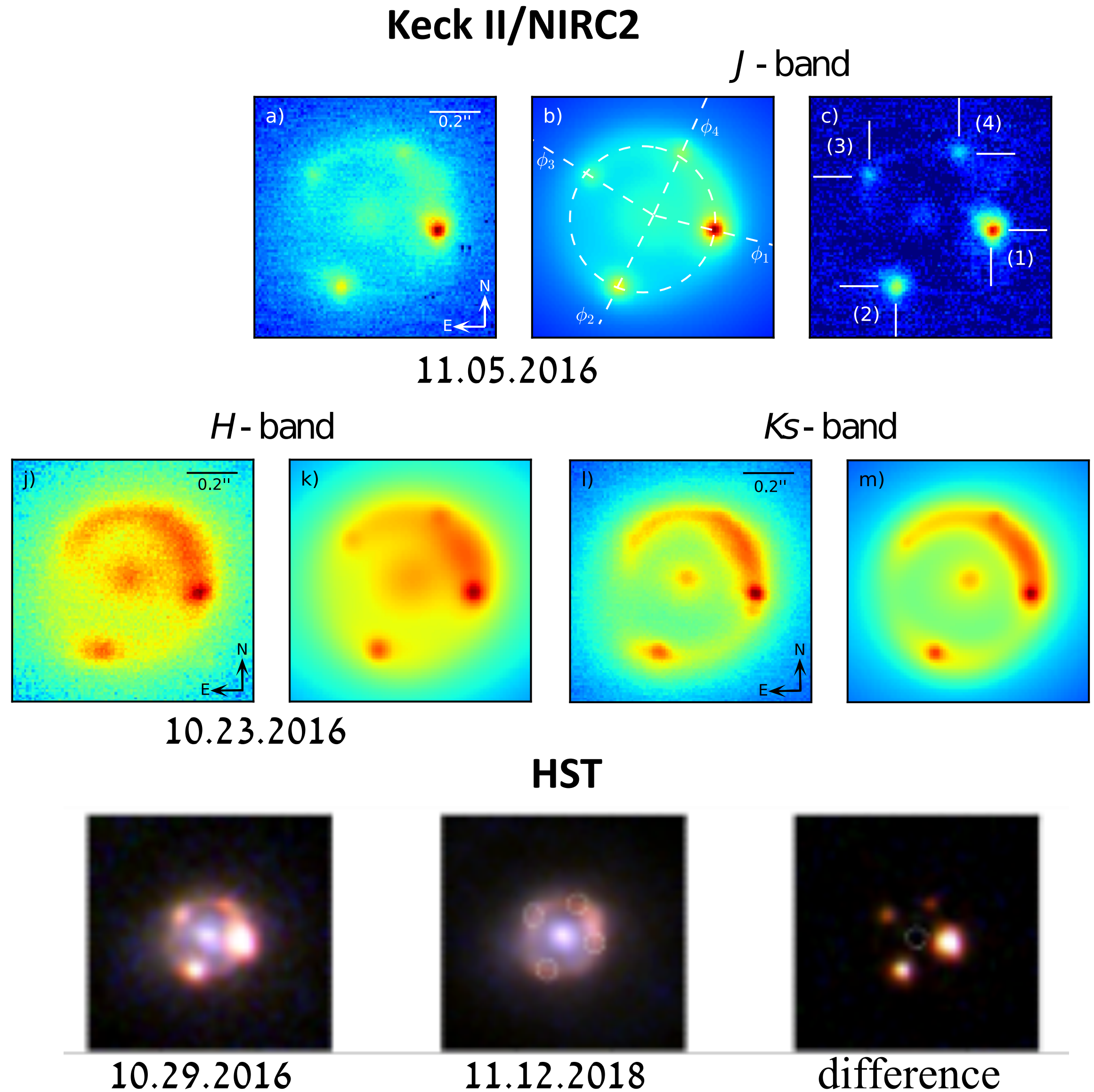
Discovered in intermediate Palomar Transient Factory Sept 5, 2016 (Goobar+2017)

z_{lens}=0.2163

z_{source}=0.409

0.3'' ~ 1 kpc

$$\mu = 67.8^{+2.6}_{-2.9}$$



Dhawan+2019 arXiv:1907.06756
Mortsell+2019 arXiv:1907.06609

Macro- & micro-lensing magnification

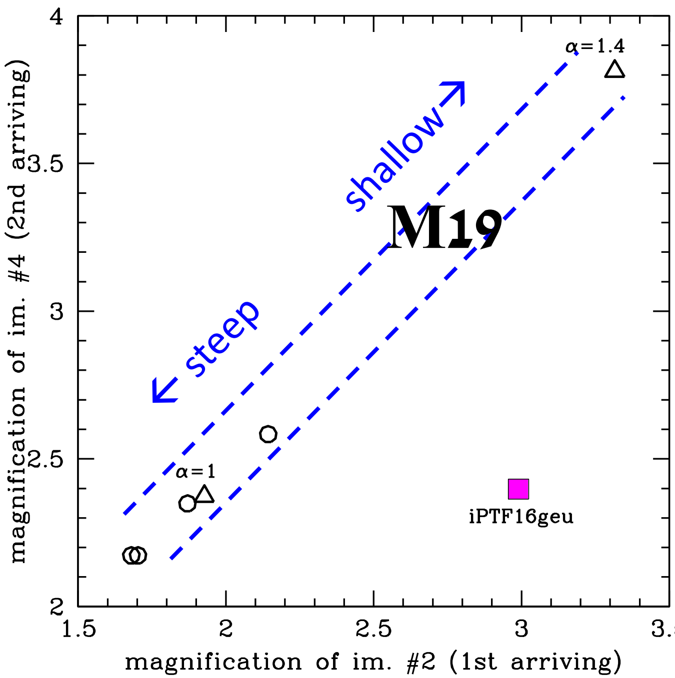
For a SNIa source, we know total (macro + micro) magnification of each image

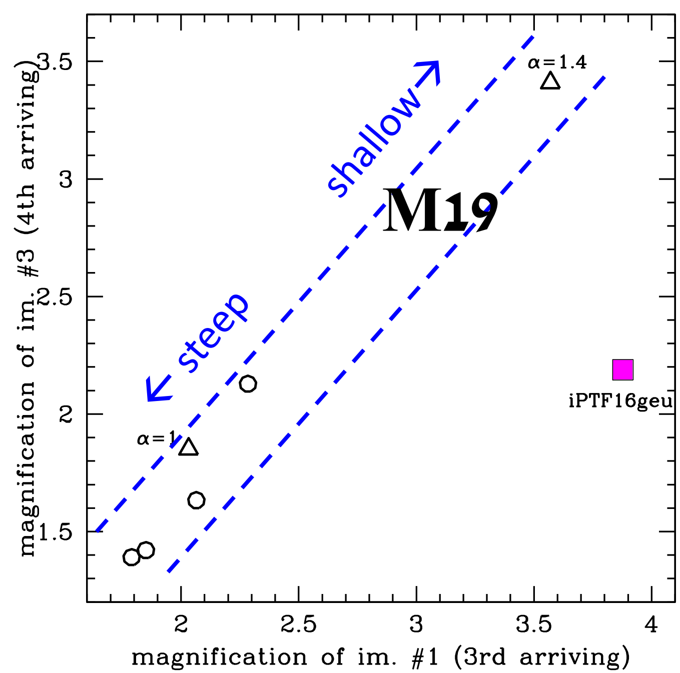
Predictions of elliptical power law galaxy mass models:

projected density profile: $\Sigma \propto r^{\alpha-2}$ $\alpha = 1$ is ``isothermal"

Mismatch between model predictions and iPTF16geu obs. means that microlensing (de)magnifications are important.

Foxley-Marrable+2018
Yahalomi+2017





(in magnitudes)

Dhawan+2019
Mortsell+2019
More+2017

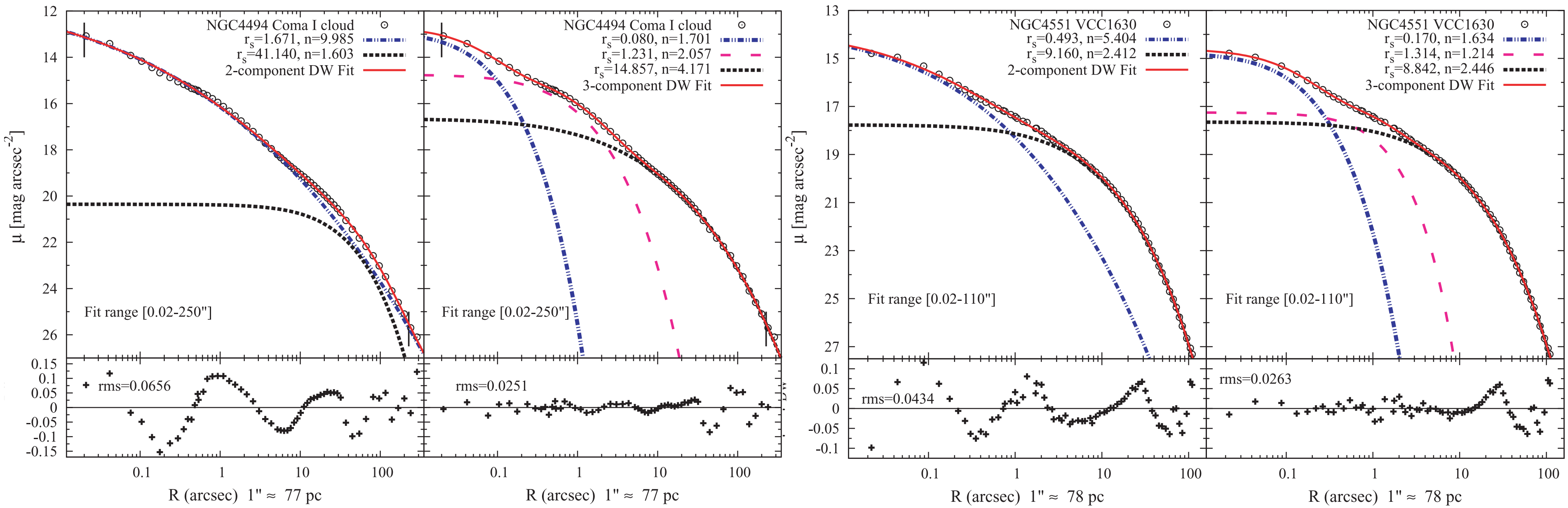
Elliptical power law profile model does not adequately describe the lens galaxy:

- Density profile too shallow, cannot apply to all radii
- The center of observed light and center of fitted mass are offset by 0.03" +/- 0.002"
- Position angle of the observed light and fitted mass are misaligned by 40^{o}

Motivation for our mass models

Images form at ~1/2 effective radius of galaxy light → mass dominated by stars

Similar ellipticals in Virgo:



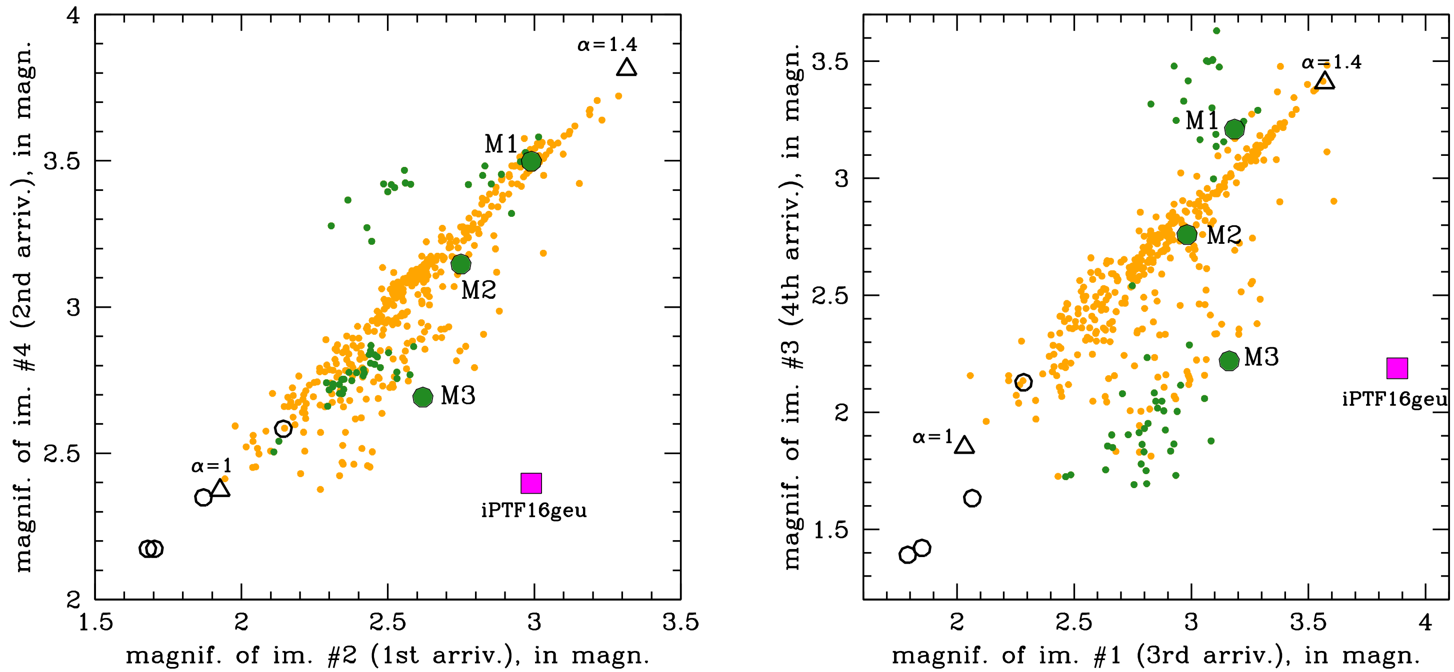
Dhar & Williams (2012)
data: Kormendy+2009

Two mass components: baryons1 + baryons2, ***or*** DM + baryons
with offset centers (Gomer & Williams 2018, Nightingale+2019) → 12 model parameters;
recovery of lens mass distribution from observables is under-constrained → many solutions

Mass models with two offset components

Generate many lens mass models, all fitting image positions.

Magnifications predicted by these galaxy models (without microlensing):

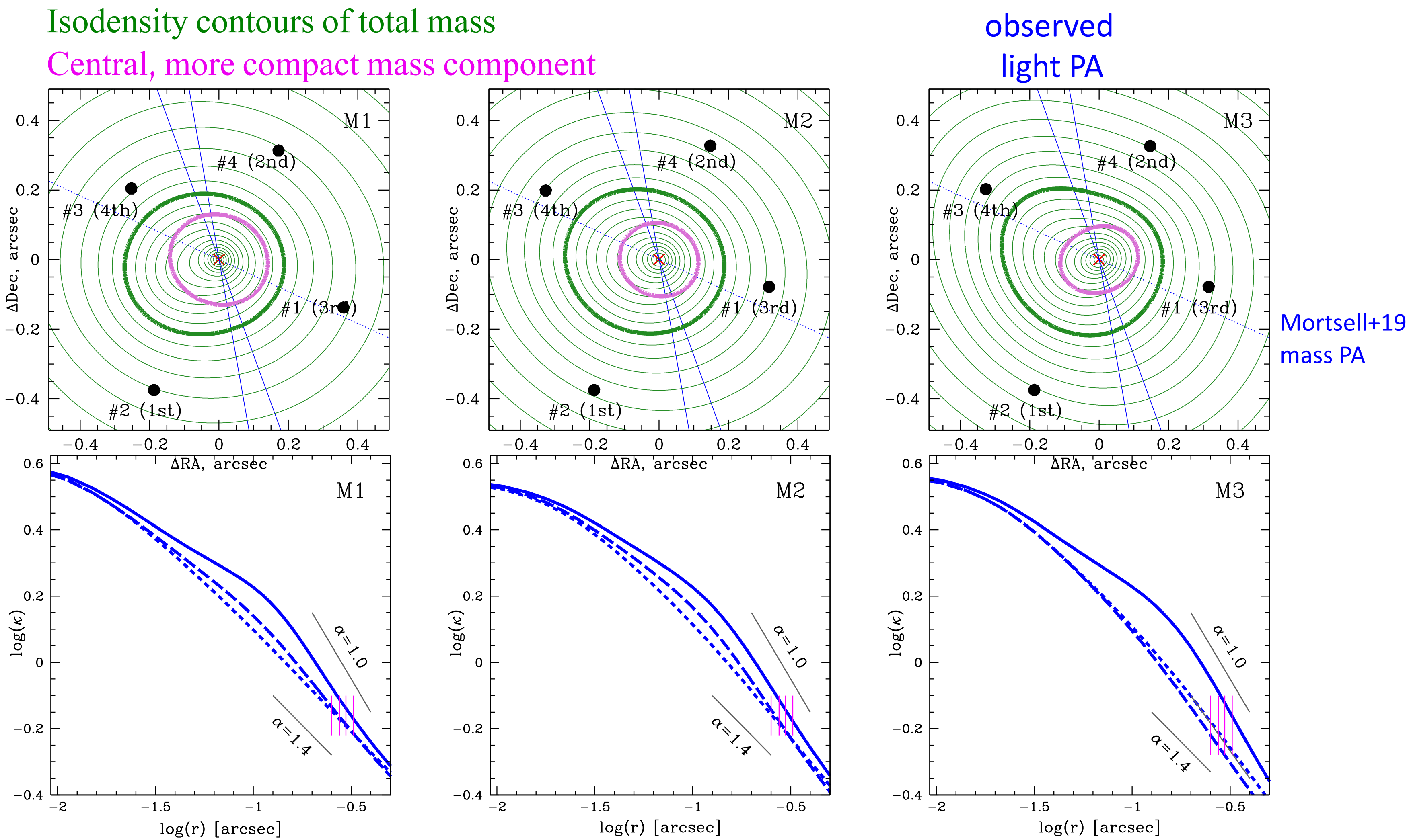


Observed magnification of SNIa

Green models (incl. M1, M2, M3): primary mass component has >50% of total mass within image radius, single mass & light centroid

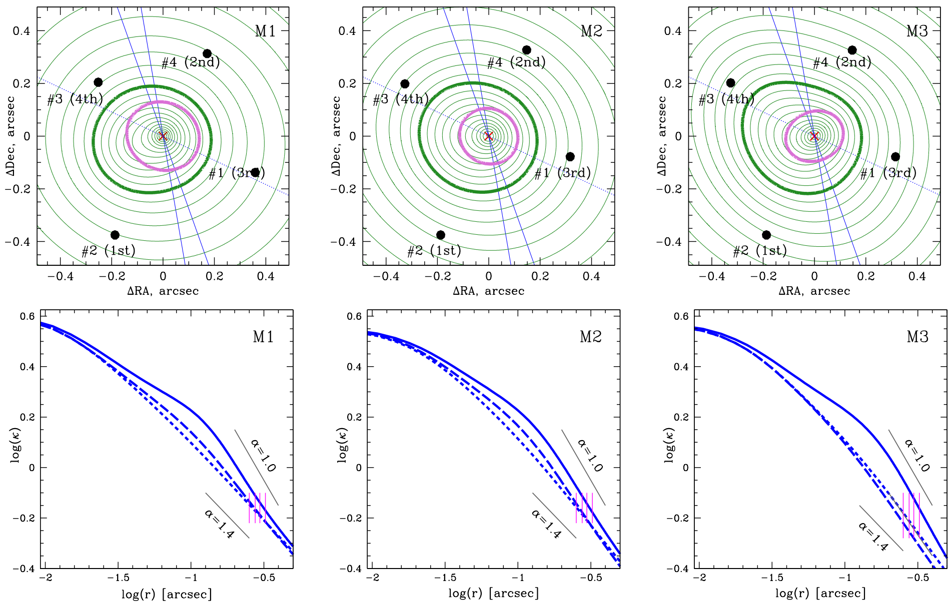
Williams & Zegeye (2020)

Mass models with two offset components



- Center of mass is coincident with center of light; mass maps are lopsided
- Density profiles steepen at large radii; slopes depend on azimuthal position
- Microlensing is not in conflict with magnification probabilities
- Position angle of mass elongation not same as that of light

Two general features of iPTF16geu lensing galaxy can help explain properties of other galaxy quads



1

lopsidedness (dipole)

azimuthal lens structure

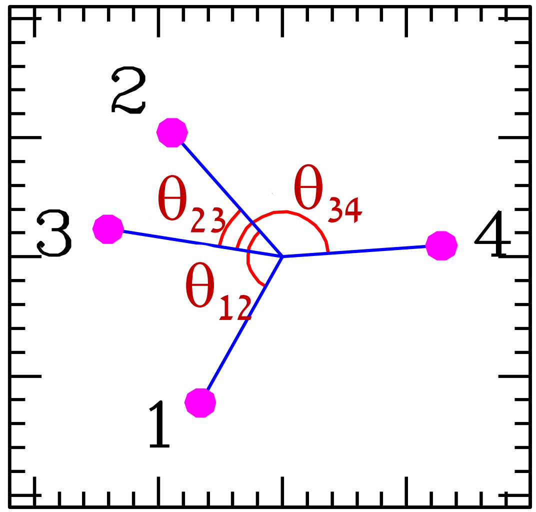
2

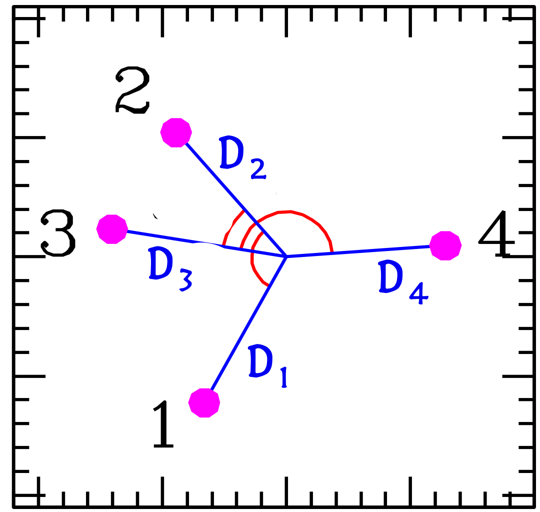
a range of density profile slopes, including shallower than isothermal

radial lens structure

Radial-azimuthal decomposition: Quad population → common features of lens galaxies

Azimuthal structure of quad population





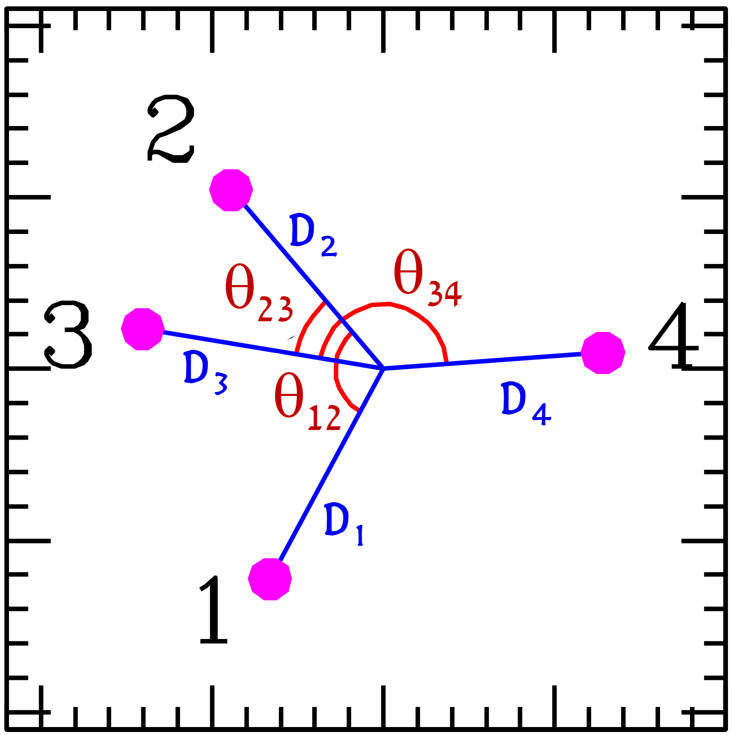
Radial structure of quad population

Azimuthal structure of lens galaxy population

Radial structure of lens galaxy population

Azimuthal and radial properties of lens galaxies are <u>approximately</u> reflected in azimuthal and radial properties of their quads

Model-free analysis of quads



Absolute scale of quads not important for structure → $d_2 = D_2/D_1$, etc.

6D "phase-space" of galaxy lensing

For now, use only 2+1 D space

azimuthal structure:

a 2D projection of 3D angle space

radial structure:

D_{min}/D_{max}

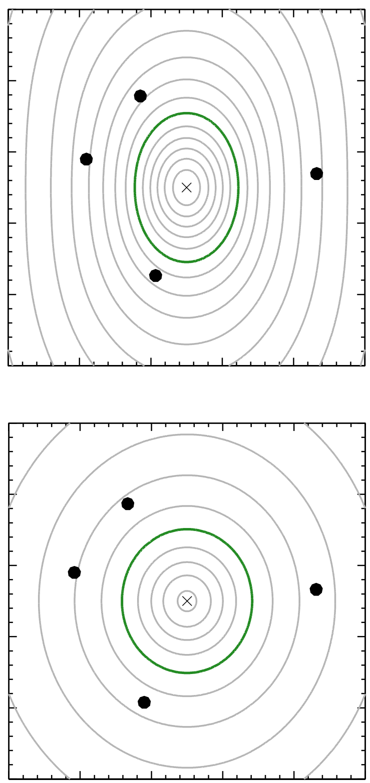
*The goal is not to model individual quads, but to compare properties of observed vs. synthetic quad **populations.***

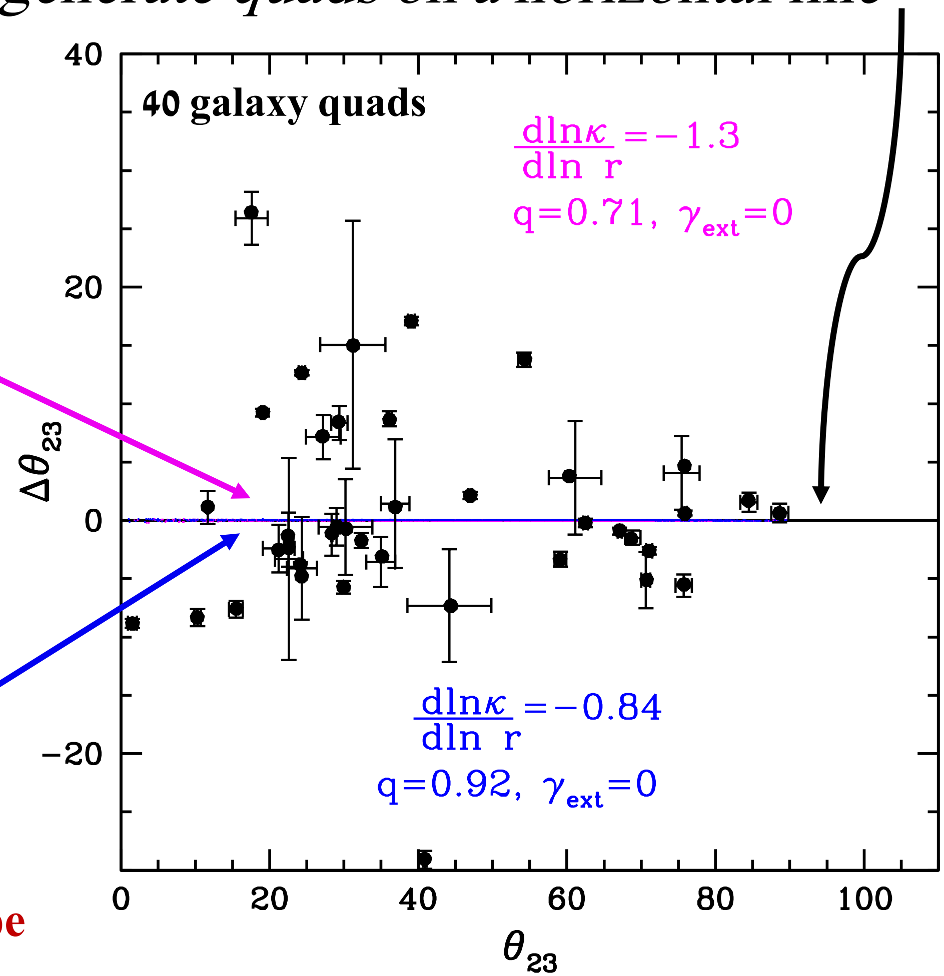
For a different take on model-independent analysis of lenses, see Jenny Wagner's talk.

Woldesenbet & Williams (2012, 2015)
Gomer & Williams (2018)

Azimuthal properties

Elliptical lenses of any ellipticity and density slope, but without shear generate quads on a horizontal line

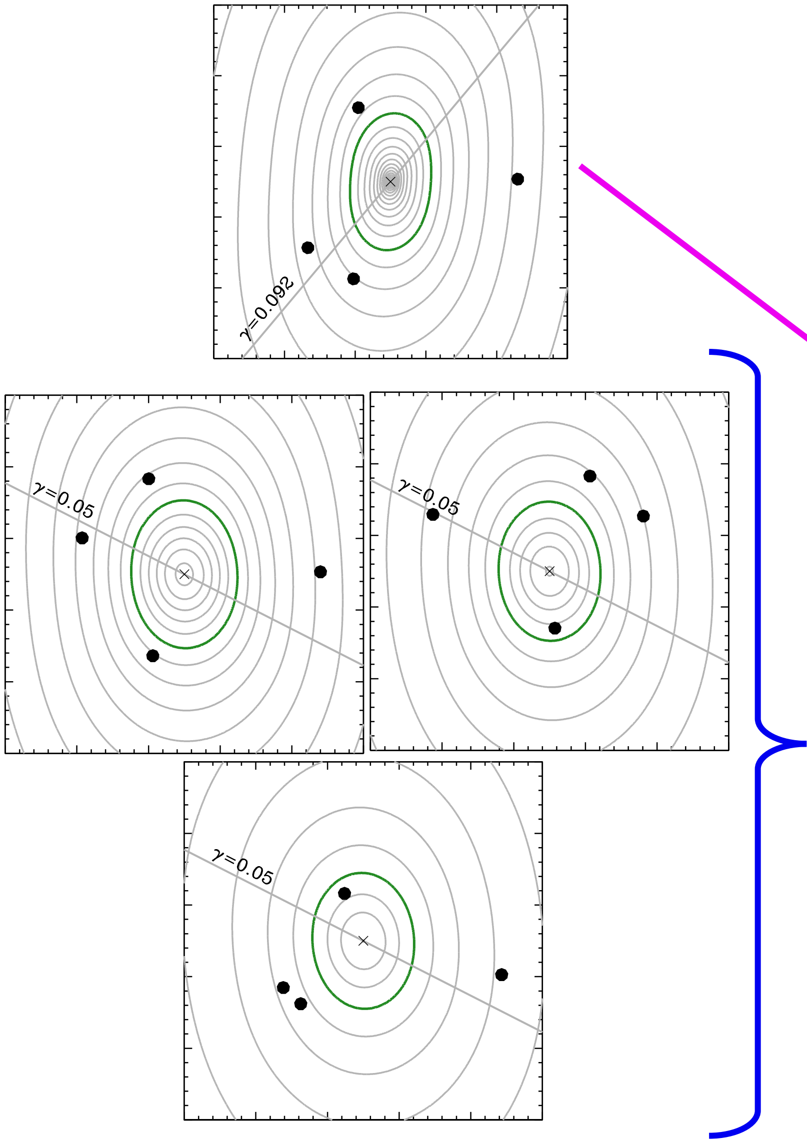


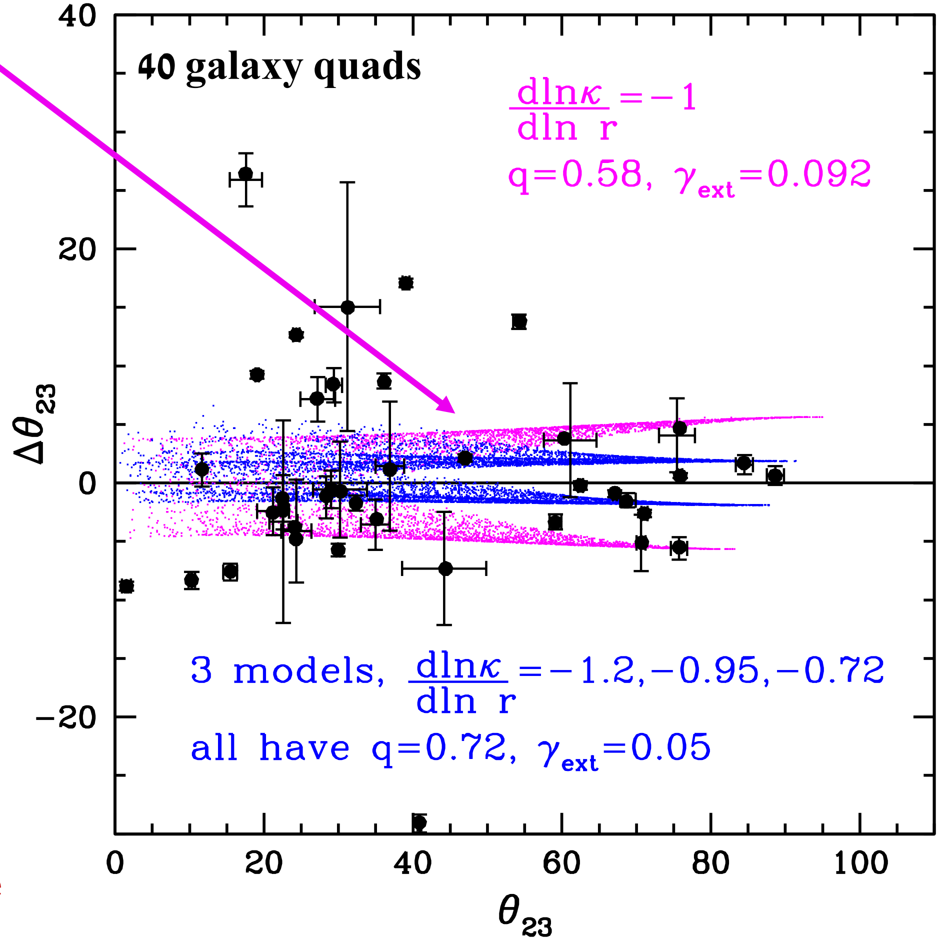


Not sensitive to mass profile slope

Azimuthal properties

Elliptical lenses with shear produce two 'spiky' distributions



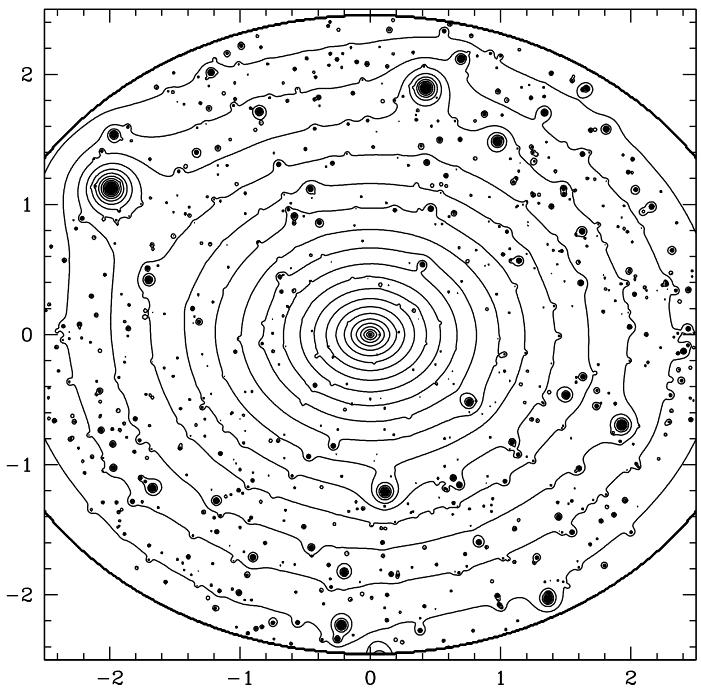


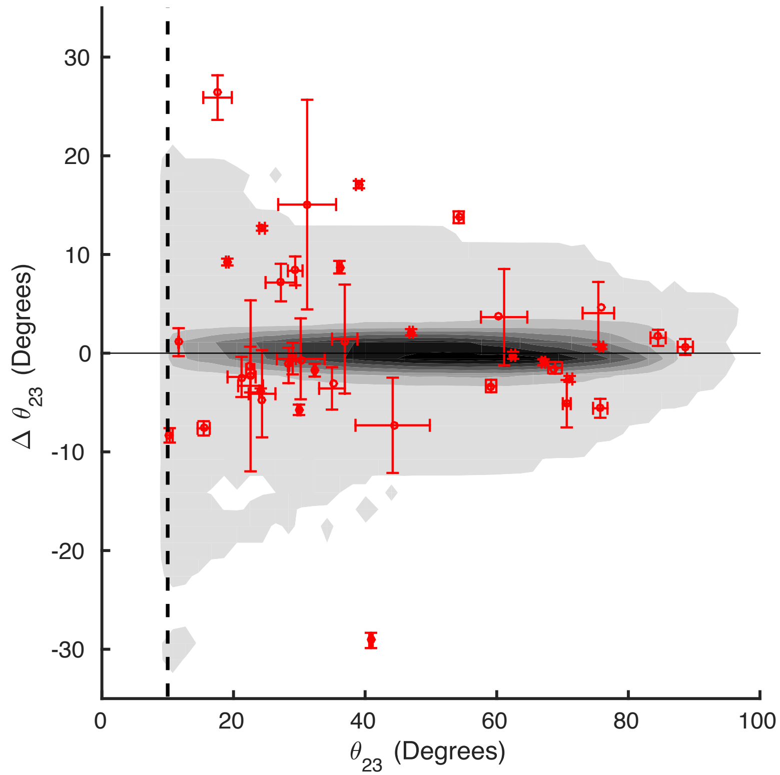
Not sensitive to mass profile slope

Azimuthal properties

Elliptical lenses with ΛCDM substructure produce a quad population resembling that of purely elliptical lenses

ΛCDM clump mass x 10

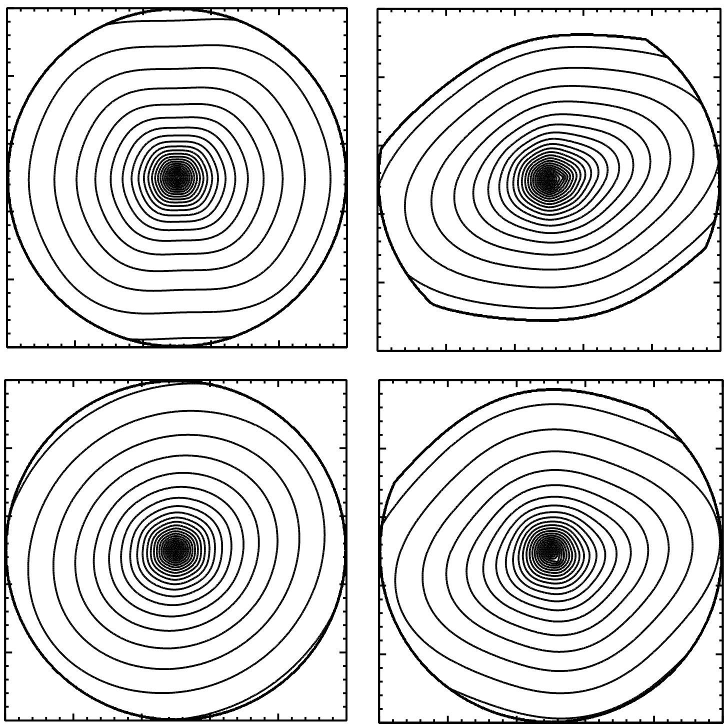


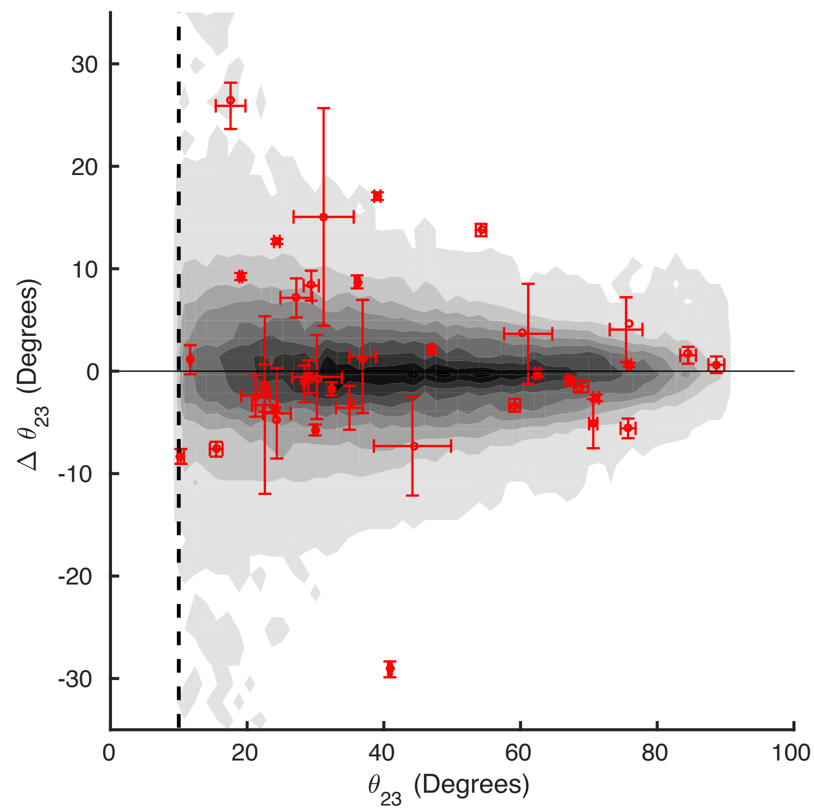


Gomer & Williams (2018)

Azimuthal properties

Lopsided, approximately elliptical lenses produce a quad population similar to the observed quad pop.

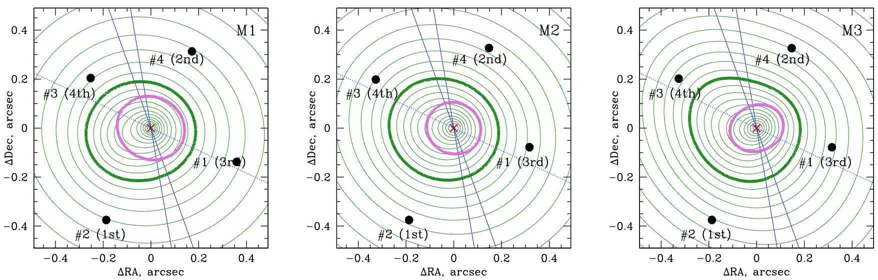


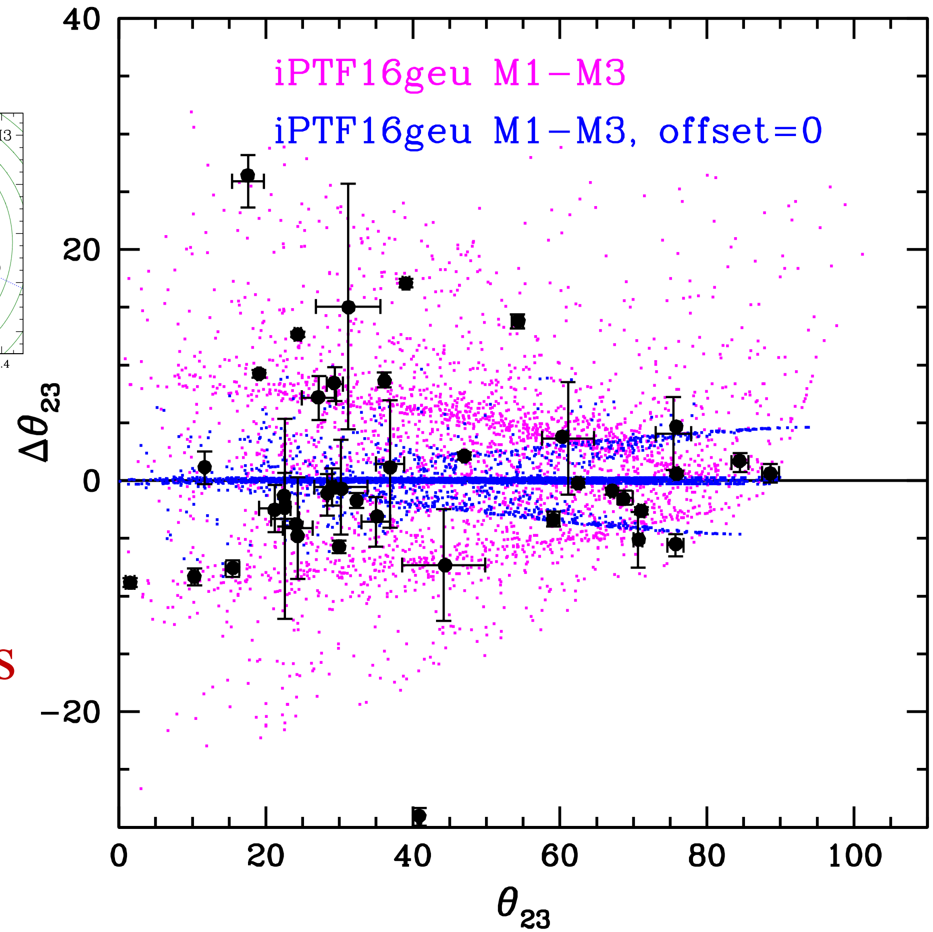


Gomer & Williams (2018)

Azimuthal properties

Lopsided, approximately elliptical lenses produce a quad population resembling the observed quad pop.

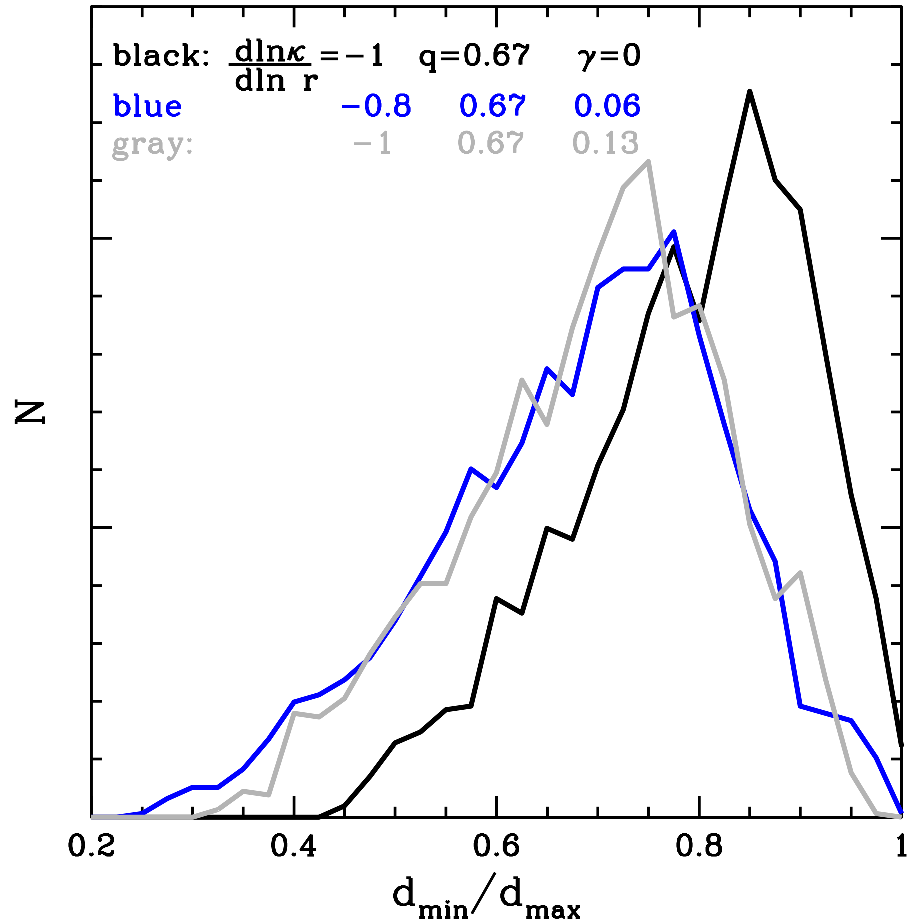




Azimuthal structure of quads is very sensitive to lopsidedness vs. shear of lensing galaxies; not sensitive to profile slope

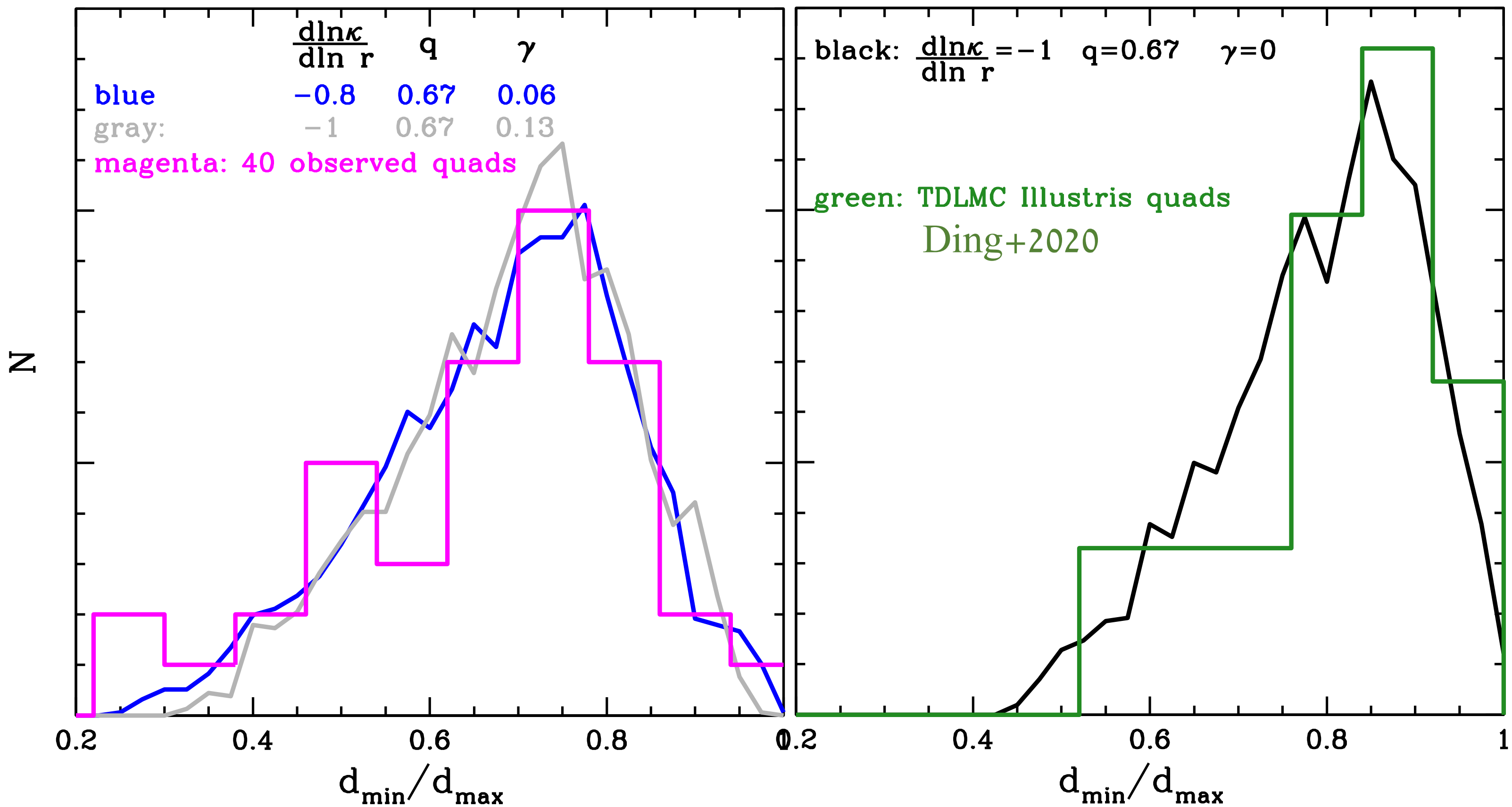
Radial properties

To obtain large radial range of image pos. need lens models with:
large ellipticity or shear
or
shallower density profiles



Radial structure of quads
is sensitive to profile slope,
ellipticity and shear
of lensing galaxies;
not sensitive to lopsidedness

Radial properties



also see Gomer & Williams (2021 [under review])

To reproduce the population of observed quads, need isothermal density slopes with large-ish shear / ellipticity

or

shallower density profiles with small-ish shear / ellipticity

(in some systems, modeled shear is larger than the lens environment may justify)

Conclusions & implications for the determination of H_0

Model-free analysis of quad populations (6D "phase-space") complements the information obtained from modeling of individual lenses. Unlike modeling, it tells us about common (frequently occurring) properties of lens galaxies.

Azimuthal structure of quads is very sensitive to lopsidedness vs. shear of galaxies; not sensitive to profile slope.

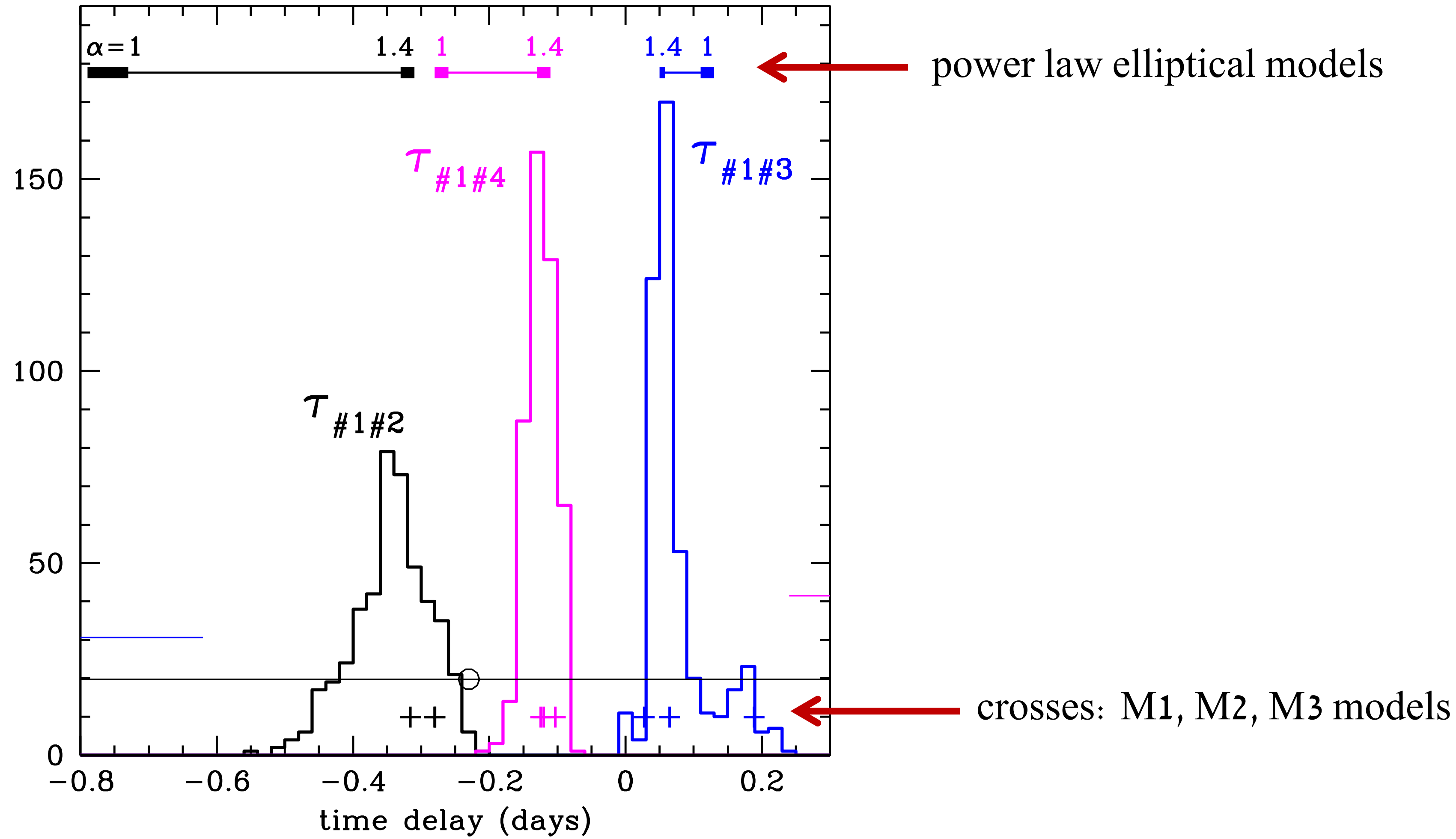
Radial structure of quads is sensitive to profile slope, ellipticity and shear of lensing galaxies; not sensitive to lopsidedness or deviations from ellipticity.

Based on iPTF16geu and azimuthal structure of observed quads, commonly used lens mass models, elliptical + shear, or models with co-centered two components may not fully reflect the detailed structure of lens galaxies, which is needed to accurately predict model time delays, and hence H_0.

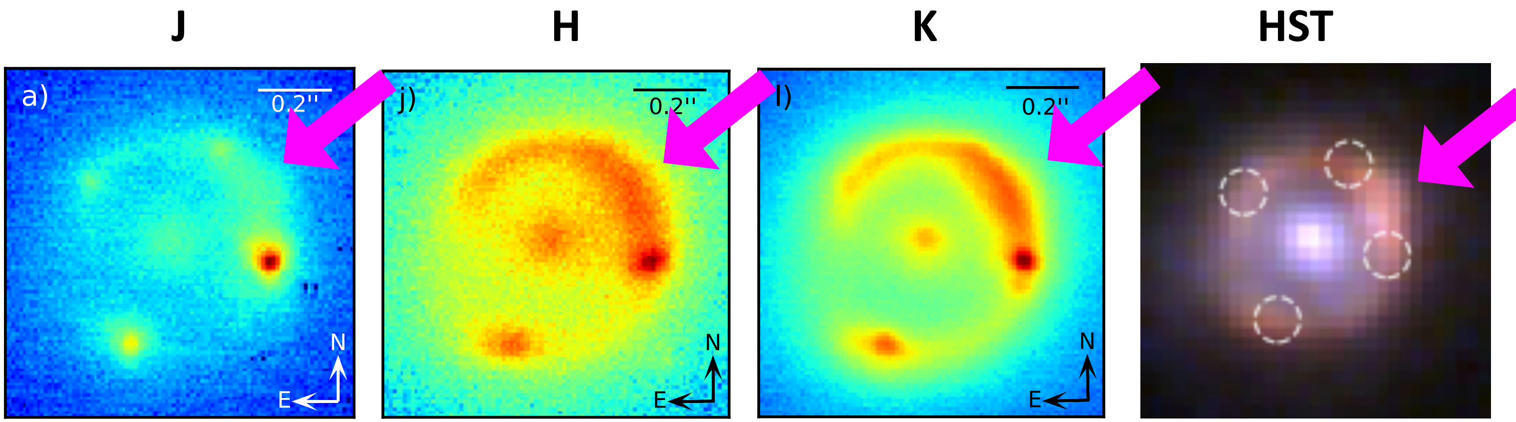
In general, ***accurate, ~few%-level*** determination of H_0 requires that mass models match very closely the real mass distribution of the lens galaxy.
This talk: model-free arguments that mass models may need improvement.
Matt Gomer's talk: model-based conclusions on the accuracy of H_0 determination.

extra slides

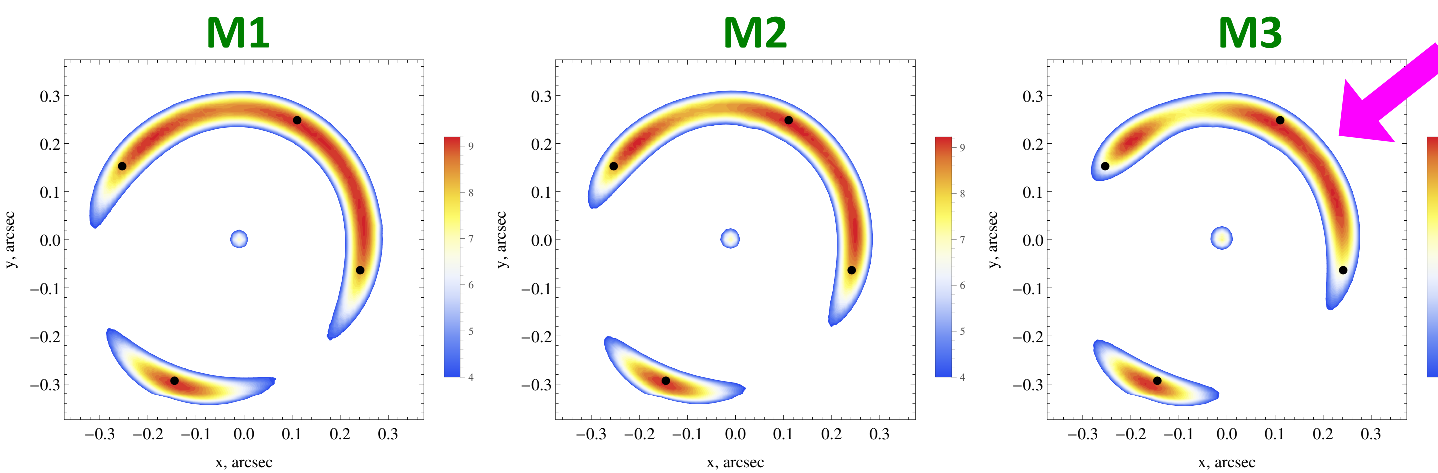
Time delays in SNIa iPTF16geu



Extended ring of SNIa host galaxy



brightest ring segment

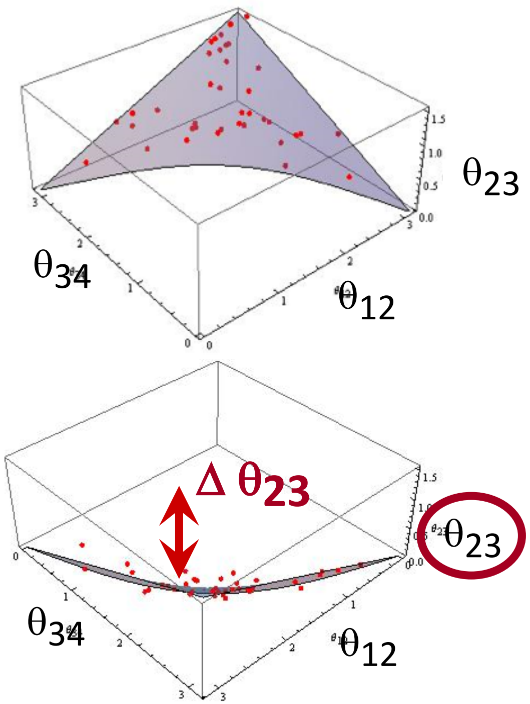


these rings are predictions of mass models; not a fit to observations

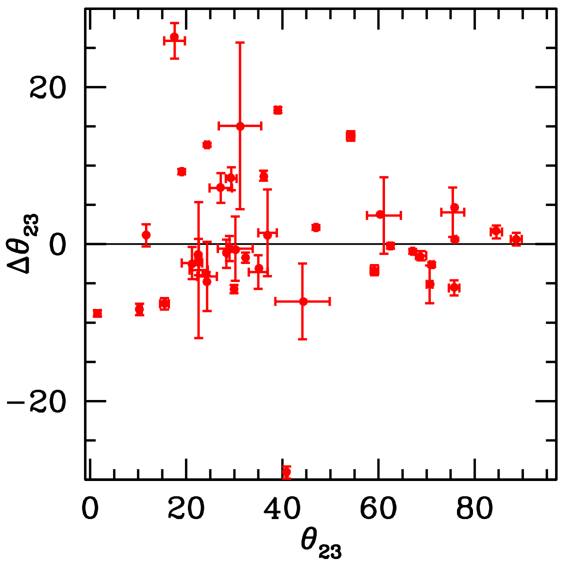
Fundamental Surface of Quads (FSQ)

Lenses that are not double-mirror symmetric do not lie on FSQ.
Instead, produce different distributions of quads around FSQ.

3D angles space



2D projected angles



Each general type of lens has its own characteristic distribution, i.e. deviations from FSQ.