Parametric morphological modeling

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This talk is mainly based upon the following two references:
https://users.obs.carnegiescience.edu/peng/work/galfit/galfit.html
https://www.nottingham.ac.uk/astronomy/megamorph/

GALFIT

2-D galaxy profile fitting routine

Parametric fitting

Functions allowed include:
sersic, nuker, expdisk, edgedisk, devauc, king, moffat, gaussian, ferrer, psf, sky

```
================================================================================
# IMAGE and GALFIT CONTROL PARAMETERS
A) gal.fits                # Input data image (FITS file)
B) imgblock.fits           # Output data image block
C) none                    # Sigma image name (made from data if blank or "none")
D) psf.fits   #            # Input PSF image and (optional) diffusion kernel
E) 1                       # PSF fine sampling factor relative to data
F) none                    # Bad pixel mask (FITS image or ASCII coord list)
G) none                    # File with parameter constraints (ASCII file)
H) 1    93   1    93       # Image region to fit (xmin xmax ymin ymax)
I) 100    100              # Size of the convolution box (x y)
J) 26.563                  # Magnitude photometric zeropoint
K) 0.038  0.038            # Plate scale (dx dy)   [arcsec per pixel]
O) regular                 # Display type (regular, curses, both)
P) 0                       # Options: 0=normal run; 1,2=make model/imgblock & quit
```

Sigma image: usually you can directly get it from data reduction pipelines, e.g. HST: ***_wht.fits (1/sigma^2); JWST: the 'ERR' extension

In case you don't have a sigma map, GALFIT can help you calculate one by
1. converting ADU to electrons; 2. calculating sigma(in electrons) = sqrt(pixel value + rms of the sky) and 3. convert sigma(in electrons) to sigma(in ADU)
!! Make sure (1) the input image is in counts, NOT counts rate and (2) the sky dominates the image region being fitted

In general, the steeper the inner galaxy profile and the broader the PSF, the larger the convolution box size should be. As a rule of thumb, use a convolution box diameter at least 40-80 times the FWHM of the PSF.

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$$m_{AB} = -2.5\log_{10}(ADU) + zpt$$

For DJA data, the pixel unit is 10nJy (~28.9 AB), so zpt ~ 28.9.

For JADES, the pixel unit is MJy/Sr, and the pixel size of JADES/NIRCam images is ~0.03 arcsec, so … zpt ~ 28.085
(Note that 1 steradian = 1 rad^2 = 3282.8 deg^2 = **4.25 x 10^10 arcsec^2)**

$$1ADU = 1MJy/Sr = (10^6 Jy)/(4.25 \times 10^{10} arcsec^2) \times (0.03 arcsec)^2 \sim 2.117 \times 10^{-8} Jy \sim 28.085\,AB$$

```
# INITIAL FITTING PARAMETERS
#
# column 1:  Parameter number
# column 2:
#          -- Parameter 0: the allowed functions are: sersic, nuker, expdisk
#             edgedisk, devauc, king, moffat, gaussian, ferrer, psf, sky
#          -- Parameter 1-10: value of the initial parameters
#          -- Parameter C0: For diskiness/boxiness
#             <0 = disky
#             >0 = boxy
#          -- Parameter Z: Outputting image options, the options are:
#             0 = normal, i.e. subtract final model from the data to create
#                 the residual image
#             1 = Leave in the model -- do not subtract from the data
#
# column 3: allow parameter to vary (yes = 1, no = 0)
# column 4: comment

# Sersic function

 0) sersic                 # Object type
 1) 300.   350.   1 1      # position x, y        [pixel]
 3) 20.00       1          # total magnitude
 4) 4.30        1          #     R_e              [Pixels]
 5) 5.20        1          # Sersic exponent (deVauc=4, expdisk=1)
 9) 0.30        1          # axis ratio (b/a)
10) 10.0        1          # position angle (PA)  [Degrees: Up=0, Left=90]
 Z) 0                      #  Skip this model in output image?  (yes=1, no=0)
```

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```
# Component/    parameter   constraint  Comment
# operation     (see below)   range

  3_2_1_9          x         offset     # Hard constraint: Constrains the
                                        # x parameter for components 3, 2,
                                        # 1, and 9 to have RELATIVE positions
                                        # defined by the initial parameter file.

  1_5_3_2          re        ratio      # Hard constraint: similar to above
                                        # except constrain the Re parameters
                                        # by their ratio, as defined by the
                                        # initial parameter file.

    3              n        0.7 to 5    # Soft constraint: Constrains the
                                        # sersic index n to within values
                                        # from 0.7 to 5.

    2              x         -1  0.5    # Soft constraint: Constrains
                                        # x-position of component
                                        # 2 to within +0.5 and -1 of the
                                        # >>INPUT<< value.

    3-7            mag       -0.5 3     # Soft constraint:  The magnitude
                                        # of component 7 is constrained to
                                        # be WITHIN a range -0.5 mag brighter
                                        # than component 3, 3 magnitudes
                                        # fainter.

    3/5            re          1  3     # Soft constraint:  Couples components
                                        # 3 and 5 Re or Rs ratio to be greater
                                        # than 1, but less than 3.
```

E.g., If we want to perform a single Sersic fit with Sersic index n varying only between 0.5-6, we should do

0   n   0.5 to 6

Known issues

GALFIT underestimates parameter uncertainties.

- A Monte Carlo way: resample the image pixel values using the sigma map by N times, and repeat the same GALFIT fitting, get the parameter covariances, and their uncertainties.
- Codes that allow MCMC: PySersic etc.
- Or, more advanced codes: Forcepho

Because GALFIT is using Levenberg-Marquardt algorithms, sometimes it returns a local-minimum solution, not a global best-fit.

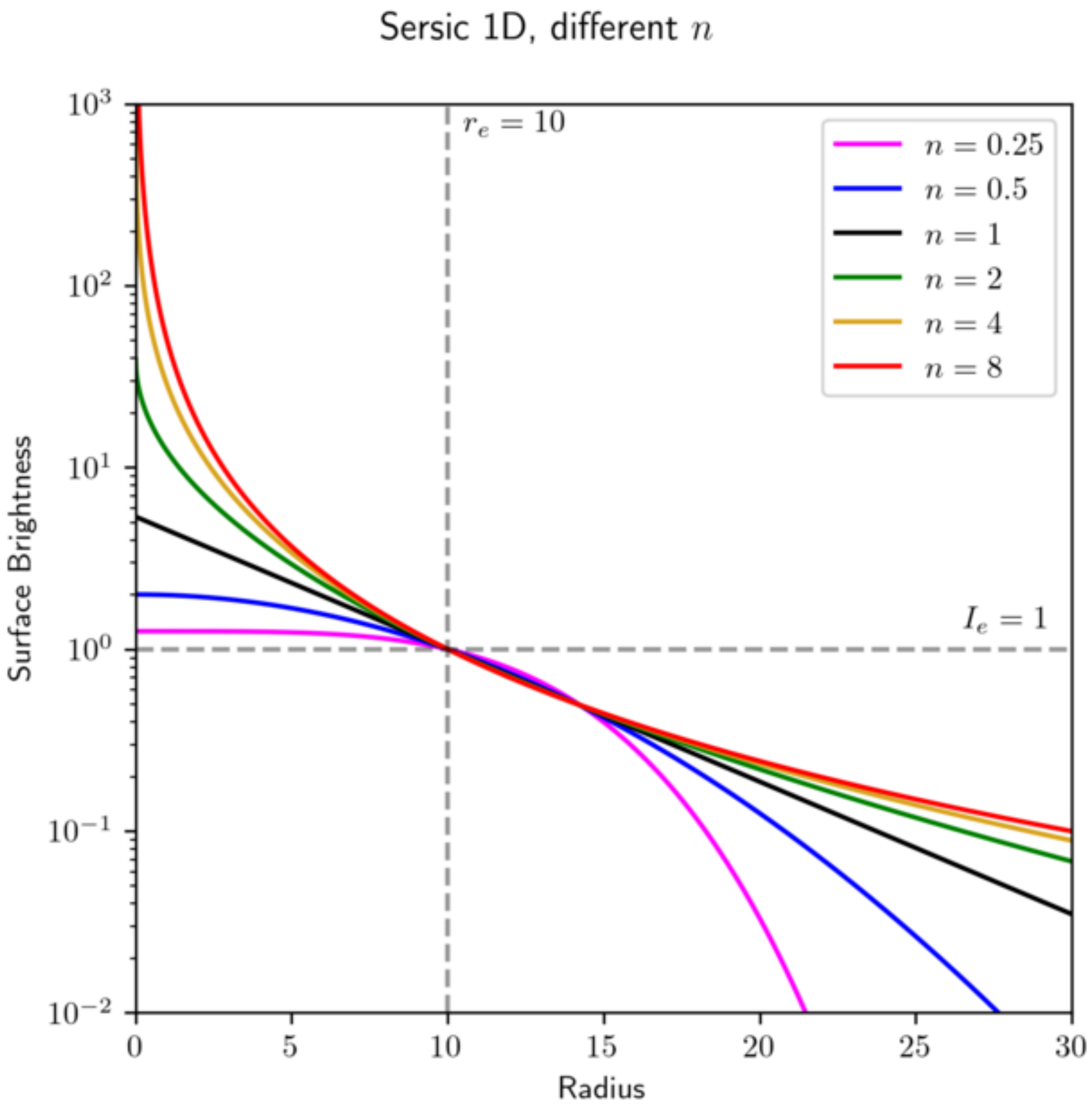
Instead of using a single initial guess, start with a grid of parameters (especially when the number of free parameters is large, e.g., bulge-to-disk decomposition).

About sky background

The common practices in literature to determine the background sky value is to use SExtractor, or similar softwares. (i.e. thresholding-based sky estimates —> always over-predict the sky.)

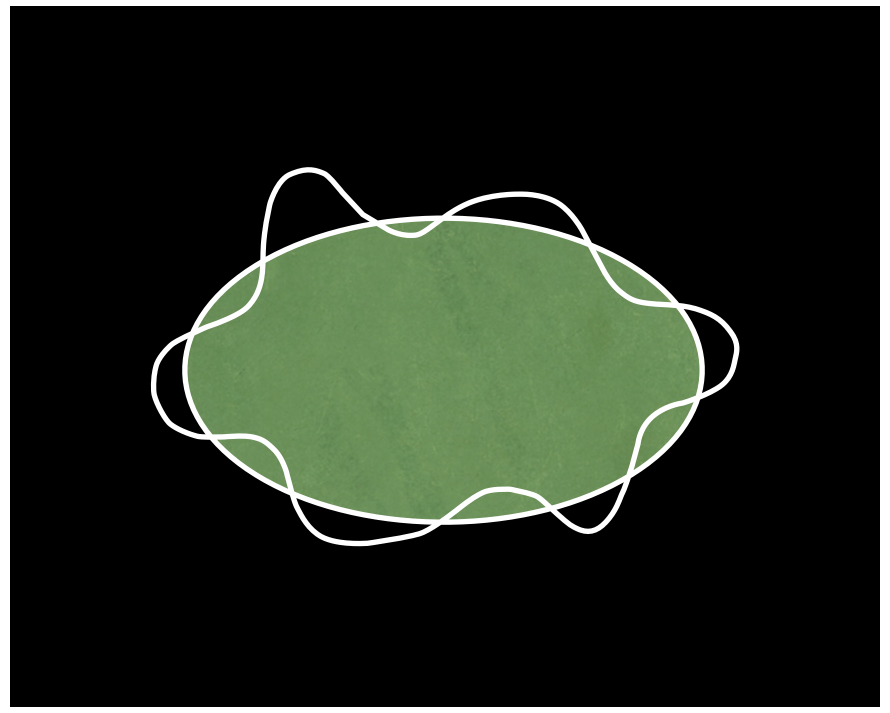
What GALFIT really needs is the sky value based on extrapolating out to infinite radius … (We can leave the sky as a free parameter in GALFIT. But when the field is crowded, and/or the cutout to fit is small, this way may be problematic …)

Independent ways to estimate the sky, e.g. GALAPAGOS (based on curve of growth of a large number of galaxies in a much larger mosaic)

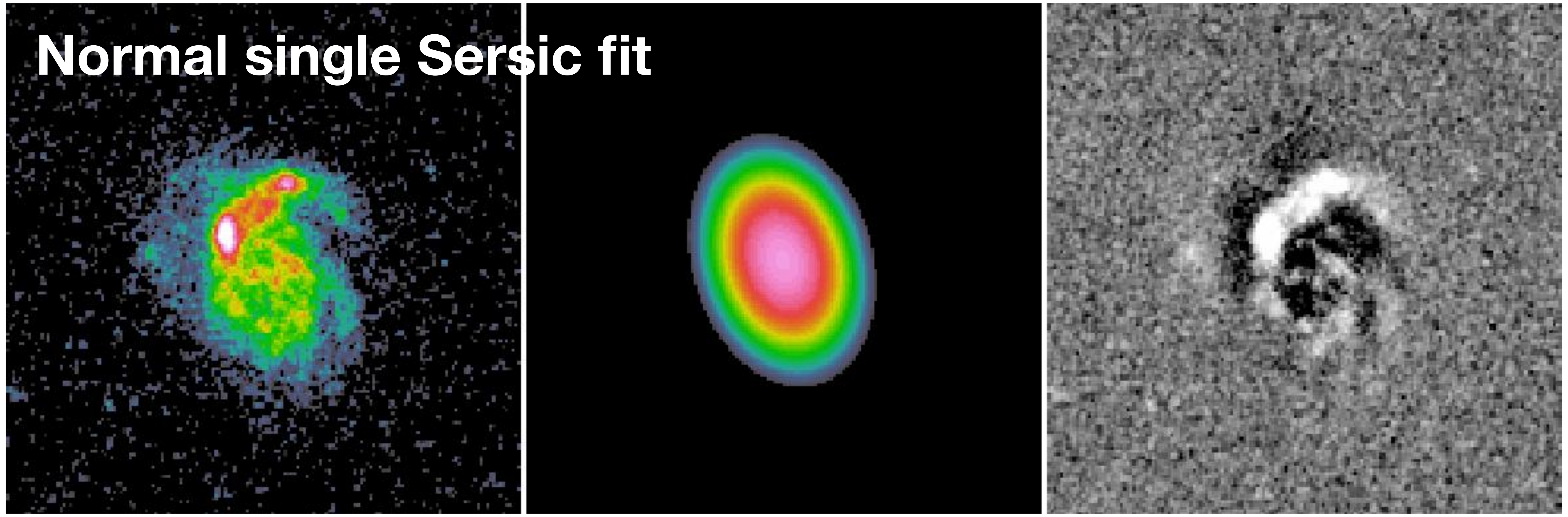


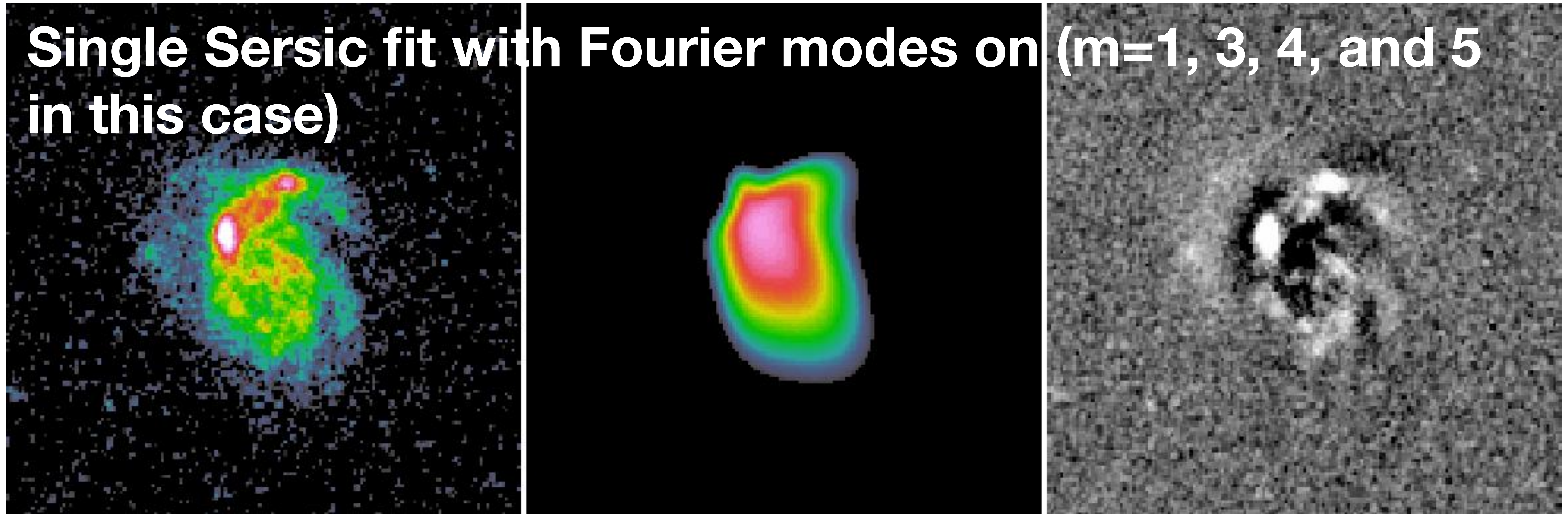
More advanced morphological modeling

Fourier Modes in GALFIT



$$r(x,y) = r_0(x,y) \times \{ 1 + \sum_{m\neq 2} a_m \cos(m[\theta_{PA} + \varphi_m]) \}$$





More advanced morphological modeling

Simultaneously model multiple images

- GALFIT-M (allows morphological parameters, e.g. size, to vary with wavelength following a user-defined Nth-order Chebyshev polynomial)