WISE Extended Sources
Tutorial for Refined Processing

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WISEfuzzyPhot.py

Python program used to view results and interactively refine parameters to rerun

- Controls "ds9" through pysao (or pyds9)
- View processed images (stamps) & SB profiles
- Refine source subtraction, masking and shape/ size constraints
- Re-process source using refinements

The Basics

about WISE Photometry and Ancillary Files

- Pipeline designed for special-constructed mosaics (aka drizzle images); these mosaics maintain the original (native) angular resolution of WISE imaging (enhanced resolution detailed in Jarrett et al. 2012)
- Pixel scale: 1 arcsec (remember that native is 2.75 arcsec); FWHM = 6 arcsec (W1,W2,W3)
- Most important aspect (task) of measuring resolved galaxies is to identify and remove the foreground stars; the pipeline does this automatically, but typically needs further help to remove additional stars and/or masking and/or initial source shape constraints. This is a big part of the interactive python program.
- Source characterization consists of:
  - Source position (centroid)
  - Shape (elliptical fit to the 3-sigma isophote: axis ratio and position angle; this shape is carried throughout the analysis)
  - Size (elliptical fit to the 1-sigma isophote; other size metrics: convergence, half-light, total)
  - Surface Brightness (means and radial-axi-symmetry)
  - Double Sersic Fits to the 1-D SB: (1) bulge, (2) disk
  - Photometry: isophotal, convergence and curve of growth
  - Colors (optimal, based on matched apertures with: W1 matched to W2; W4 matched to W3)
- Outputs:
  - Photometry (table)
  - Curve of Growth (table)
  - Axi-symmetric Surface Brightness
  - Foreground WISE sources removed
  - Identified additional (not-catalogue) sources removed
  - FITS images – stamps centered on the measured resolved source : original, cleaned, model and uncertainty images

The Basics – 2

Output WISE Photometry and Ancillary Files

Example: ZOA151548.734-600409.37

Photometry file: ZOA151548.734-600409.37.phot.tbl

Curve of Growth Tables: ZOA151548.734-600409.37.W?.growth.tbl

Surface brightness profiles (including Sersic fits): ZOA151548.734-600409.37.profile.w?.txt

Stars: ZOA151548.734-600409.37.stars.txt and ZOA151548.734-600409.37.LOKIstars.tbl

Fits stamp-images:

- ZOA151548.734-600409.37.W?.fits (original images)
- ZOA151548.734-600409.37.W?.clean.fits (stars removed, objects masked)
- ZOA151548.734-600409.37.W?.unc.fits (uncertainty image, used for modeling photometric errors)
- ZOA151548.734-600409.37.W?.model.fits (axi-symmetric model of the galaxy; used for deblending purposes)

The Basics – 3a

Output Photometry Table

```
# WISE Enhanced-Resolution Galaxy Atlas  (jarrett et al. 2013)
# README detailing the catalogue measurements and column key names
#
# All measurements carried out on WISE mosaics created using ICORE and the complete single-frame archive of WISE,
#  where foreground stars have been identified and removed through PSF subtraction or masking (with flux recoever), see below.
# Mosaics are created using the enhanced resampling:  drizzle (native resolution) and HIRES  (deconvolution, super-resolution)
#
# Photometry pipeline created by T. Jarrett with details in Jarrett et al. 2013, AJ, 145, 6.
#     http://adsabs.harvard.edu/abs/2013AJ....145....6J
#
#

#######  Images      ####################################
# Postage-stamp images (and uncertainty) of target galaxy :   name.W<band>.fits  ;  name.W<band>.unc.fits
#    with stars removed  (primary science images)         :  name.W<band>.clean.fits
#    ellipsoid models (used for deblending purposes)       :  name.W<band>.model.fits

#######  Ancillary files/tables
# Photometry               :  name.phot.tbl    (see below for column description)
# Curve of Growth          :  name.W<band>.growth.tbl   (int. flux vs radius; axi-symmetric surface brightness)
# radius surface brightness :  name.profile.w<band>.txt   (axi-symmetric surface brightness;  Sersic fit)
# misc files               :  name.stars.txt   (foreground stars, etc)


########  Photometry  ####################################
_____________________________________________________________________________________
column    name     units       description
_____________________________________________________________________________________
    1    desig     --        name of object/galaxy
    2    ra       deg       galaxy nucleus Right Ascension, degress J2000
    3    dec       deg       galaxy nucleus Declination, degress J2000
    4    Riso      arcsec    W1 1-sigma isophotal radius (semi-major axis)
    5    R2iso      arcsec    W2 1-sigma isophotal radius or photometry aperture (semi-major axis)
    6    R3iso      arcsec  W3 1-sigma isophotal radius or photometry aperture (semi-major axis)
    7    R4iso      arcsec    W4 1-sigma isophotal radius or photometry aperture (semi-major axis)
    8    ba       --        axis ratio based on the W1 3-sigma isophote
    9    pa       --        position angle based on the W1 3-sigma isophote
```

The Basics – 3b

Output Photometry Table

10	flux_1	mJy	W1 integrated flux density
11	err_1	mJy	W1 integrated flux density uncertainty
12	mag_1	mag	W1 integrated magnitude
13	merr_1	mag	W1 integrated magnitude uncertainy
14	flg1	--	W1 photometry confusion flag
15	flux_2	mJy	W2 integrated flux density
16	err_2	mJy	W2 integrated flux density uncertainty
17	mag_2	mag	W2 integrated magnitude
18	merr_2	mag	W2 integrated magnitude uncertainy
19	flg2	--	W2 photometry confusion flag
20	flux_3	mJy	W3 integrated flux density
21	err_3	mJy	W3 integrated flux density uncertainty
22	mag_3	mag	W3 integrated magnitude
23	merr_3	mag	W3 integrated magnitude uncertainy
24	flg3	--	W3 photometry confusion flag
25	flux_4	mJy	W4 integrated flux density
26	err_4	mJy	W4 integrated flux density uncertainty
27	mag_4	mag	W4 integrated magnitude
28	merr_4	mag	W4 integrated magnitude uncertainty
29	flg4	--	W4 photometry confusion flag
30	W1W2	mag	W1-W2 color, where the W1 aperture is matched to the W2 1-sigma isophotal aperture
31	W1W2er	mag	W1-W2 color uncertainty
32	W2W3	mag	W2-W3 color, using the W2 1-sigma isophotal aperture and the W3 1-sigma isophotal aperture
33	W2W3er	mag	W2-W3 color uncertainty
34	W1W3	mag	W1-W3 color, using the W1 1-sigma isophotal aperture and the W3 1-sigma isophotal aperture
35	W1W3er	mag	W1-W3 color uncertainty
36	W3W4	mag	W3-W4 color, where the W4 aperture is matched to the W3 1-sigma isophotal aperture
37	W3W4er	mag	W3-W4 color uncertainty
38	meanSB_1	mag/as^2	W1 mean surface brightness (mag per sq. arcsec)
39	meanSB_2	mag/as^2	W2 mean surface brightness (mag per sq. arcsec)
40	meanSB_3	mag/as^2	W3 mean surface brightness (mag per sq. arcsec)
41	meanSB_4	mag/as^2	W4 mean surface brightness (mag per sq. arcsec)

The Basics – 3c

Output Photometry Table

42	sky_1	dn	W1 local background sky level (dn)
43	sig_1	dn	W1 local background sky RMS (dn)
44	sky_2	dn	W2 local background sky level (dn)
45	sig_2	dn	W2 local background sky RMS (dn)
46	sky_3	dn	W3 local background sky level (dn)
47	sig_3	dn	W3 local background sky RMS (dn)
48	sky_4	dn	W4 local background sky level (dn)
49	sig_4	dn	W4 local background sky RMS (dn)
50	R1iso	arcsec	W1 1-sigma 1-sigma isophotal radius (semi-major axis)
51	R2iso	arcsec	W2 1-sigma 1-sigma isophotal radius (semi-major axis)
52	R3iso	arcsec	W3 1-sigma 1-sigma isophotal radius (semi-major axis)
53	R4iso	arcsec	W4 1-sigma 1-sigma isophotal radius (semi-major axis)
54	SB_1	mag/as^2	W1 1-sigma local background sky brightness (mag per sq. arcsec)
55	SB_2	mag/as^2	W2 1-sigma local background sky brightness (mag per sq. arcsec)
56	SB_3	mag/as^2	W3 1-sigma local background sky brightness (mag per sq. arcsec)
57	SB_4	mag/as^2	W4 1-sigma local background sky brightness (mag per sq. arcsec)
58	scale_1a	arcsec	W1 scale length corresponding to the 1st Sersic fit (bulge)
59	scale_1b	arcsec	W1 scale length corresponding to the 2nd Sersic fit (disk)
60	beta_1a	--	W1 beta-parameter corresponding to the 1st Sersic fit (bulge)
61	beta_1b	--	W1 beta-parameter corresponding to the 2nd Sersic fit (disk)
62	scale_2a	arcsec	W2 scale length corresponding to the 1st Sersic fit (bulge)
63	scale_2b	arcsec	W2 scale length corresponding to the 2nd Sersic fit (disk)
64	beta_2a	--	W2 beta-parameter corresponding to the 1st Sersic fit (bulge)
65	beta_2b	--	W2 beta-parameter corresponding to the 2nd Sersic fit (disk)
66	scale_3a	arcsec	W3 scale length corresponding to the 1st Sersic fit (bulge)
67	scale_3b	arcsec	W3 scale length corresponding to the 2nd Sersic fit (disk)
68	beta_3a	--	W3 beta-parameter corresponding to the 1st Sersic fit (bulge)
69	beta_3b	--	W3 beta-parameter corresponding to the 2nd Sersic fit (disk)
70	scale_4a	arcsec	W4 scale length corresponding to the 1st Sersic fit (bulge)
71	scale_4b	arcsec	W4 scale length corresponding to the 2nd Sersic fit (disk)
72	beta_4a	--	W4 beta-parameter corresponding to the 1st Sersic fit (bulge)
73	beta_4b	--	W4 beta-parameter corresponding to the 2nd Sersic fit (disk)

The Basics – 3d

Output Photometry Table

74	Rtot_1	arcsec	W1 total radius (3 disk scale lengths from the isophotal radius)
75	ftot_1	mJy	W1 total flux density
76	mtot_1	mag	W1 total magnitude
77	Rtot_2	arcsec	W2 total radius (3 disk scale lengths from the isophotal radius)
78	ftot_2	mJy	W2 total flux density
79	mtot_2	mag	W2 total magnitude
80	Rtot_3	arcsec	W3 total radius (3 disk scale lengths from the isophotal radius)
81	ftot_3	mJy	W3 total flux density
82	mtot_3	mag	W3 total magnitude
83	Rtot_4	arcsec	W4 total radius (3 disk scale lengths from the isophotal radius)
84	ftot_4	mJy	W4 total flux density
85	mtot_4	mag	W4 total magnitude
86	Reff_1	arcsec	W1 half-light (effective) radius
87	SBeff_1	mag/as^2	W1 half-light (effective) surface brightness
88	con_1	--	W1 concentration index (75% vs 25% light)
89	Reff_2	arcsec	W2 half-light (effective) radius
90	SBeff_2	mag/as^2	W2 half-light (effective) surface brightness
91	con_2	--	W2 concentration index (75% vs 25% light)
92	Reff_3	arcsec	W3 half-light (effective) radius
93	SBeff_3	mag/as^2	W3 half-light (effective) surface brightness
94	con_3	--	W3 concentration index (75% vs 25% light)
95	Reff_4	arcsec	W4 half-light (effective) radius
96	SBeff_4	mag/as^2	W4 half-light (effective) surface brightness
97	con_4	--	W4 concentration index (75% vs 25% light)
98	R1conv	arcsec	W1 inflection radius (optimal convergence radius)
99	W1conv	mag	W1 inflection magnitude
100	uW1conv	mag	W1 inflection magnitude uncertainty
101	R2conv	arcsec	W2 inflection radius (optimal convergence radius)
102	W2conv	mag	W2 inflection magnitude
103	uW2conv	mag	W2 inflection magnitude uncertainty
104	R3conv	arcsec	W3 inflection radius (optimal convergence radius)
105	W3conv	mag	W3 inflection magnitude
106	uW3conv	mag	W3 inflection magnitude uncertainty
107	R4conv	arcsec	W4 inflection radius (optimal convergence radius)
108	W4conv	mag	W4 inflection magnitude
109	uW4conv	mag	W4 inflection magnitude uncertainty

The Basics – 3e

Output Photometry Table

110	Rinner	arcsec	Local background annulus, inner radius
111	Router	arcsec	Local background annulus, outer radius
112	w1zero	mag	W1 zero point (calibration) magnitude; mag = zero - 2.5 Log (flux(dn))
113	w2zero	mag	W2 zero point (calibration) magnitude
114	w3zero	mag	W3 zero point (calibration) magnitude
115	w4zero	mag	W4 zero point (calibration) magnitude
116	w1mpro	mag	W1 mpro (profile-fit) photometry from the WISE AllSky Release
117	dw1mpro	mag	W1 mpro uncertainty
118	w1rchi2	mag	W1 reduce chi^2 for profile-fit photometry
119	w2mpro	mag	W2 mpro (profile-fit) photometry from the WISE AllSky Release
120	dw2mpro	mag	W2 mpro uncertainty
121	w2rchi2	mag	W2 reduce chi^2 for profile-fit photometry
122	w3mpro	mag	W3 mpro (profile-fit) photometry from the WISE AllSky Release
123	dw3mpro	mag	W3 mpro uncertainty
124	w3rchi2	mag	W3 reduce chi^2 for profile-fit photometry
125	w4mpro	mag	W4 mpro (profile-fit) photometry from the WISE AllSky Release
126	dw4mpro	mag	W4 mpro uncertainty
127	w4rchi2	mag	W4 reduce chi^2 for profile-fit photometry
128	xscprox	arcsec	promimity (radius) from the nearest 2MASS galaxy
129	Rmoment	arcsec	W1 1st moment radius
130	Rminor	arcsec	W1 1st moment radius along the minor axis
131	Rfuzzy	arcsec	W1 fuzzy radius, the primary indicator for resolved emission

execute WISEfuzzyPhot.py

python /Users/jarrett/python/WISEfuzzyPhot.py *galaxyname* WERGA
e.g.
python /Users/jarrett/python/WISEfuzzyPhot.py *ZOA141933.720-580850.19* WERGA

For the MAC desktop, some setup logistics for the .cshrc file in order for python to run correctly:

```
setenv MAGICK_HOME /Users/jarrett/wise/bin/ImageMagick-6.4.0
setenv DYLD_LIBRARY_PATH /Users/jarrett/wise/bin/ImageMagick-6.4.0/lib

set path = (/users/jarrett/wise/bin /Users/jarrett/wise/bin/ImageMagick-6.4.0/bin $path /usr/local/bin /usr/local/scisoft/bin )

set path=(/Library/Frameworks/EPD64.framework/Versions/7.3/bin  $path)
setenv PYTHONPATH /Library/Frameworks/EPD64.framework/Versions/7.3
```

Examples

- Processing of Coma Cluster galaxies
- Processing of nearby large galaxies
- Processing of galaxies in the ZoA

Example 1: Small Galaxy in the Coma Cluster

python /home/jarrett/wise/resolved/python/WISEfuzzyPhot.py master.phot.tbl

```
total number of sources in table:
    964  129221 1064258 master.phot.tbl
Last ID =  J125227.57+285831.1   at line  558

Enter desig ID or Line number: 1558

source found:  558 J125227.57+285831.1

ra,dec =  193.11494 28.97526
axis ratio, pa =  0.772 74.9
    band            R     flux  eflux  mag  dmag flag w?rchi2 Rmoment Rminor Rfuzzy
W1 iso photometry:  16.41 1.028 0.021  13.687 0.022 1 3.317     19.80 11.20 17.50
W2 iso photometry:  13.43 0.648 0.021  13.551 0.035 1  1.359
W3 iso photometry:  11.65 1.386 0.101  10.803 0.079 0  0.910
W4 iso photometry:  12.00 1.474 0.551  9.375 0.406 0   0.958

    band             R      mag    dmag
W1 conv photometry: 16.41  13.687 0.022
W2 conv photometry: 15.50  13.512 0.040
W3 conv photometry: 11.65  10.803 0.079
W4 conv photometry: 12.00  9.375 0.406

W1-W2 (mag , err) : 0.20  0.039
W2-W3 (mag , err) : 2.75  0.087
W3-W4 (mag , err) : 1.41  0.405

Given the w1 brightness, the Rfuzzy limit = 11.50  ; source is resolved?  True
Given the w1 SNR, the Rfuzzy limit = 11.50  ; source is resolved?             True
181 181 2.20994475138
zoom factor =  2.20994475138
J125227.57+285831.1/stamp_1.fits
J125227.57+285831.1/stamp_2.fits
J125227.57+285831.1/stamp_3.fits
J125227.57+285831.1/stamp_4.fits
16.41 0.772
**************************************************************
 r : redisplay
 m : to mark stars
 ma :  to mark stars for clobber masking
 sp :  diffraction spike masking
 u : undo a star subtraction
 u2 :  undo star masking (but subtraction ok)
 s : set a fixed aperture as a first guess fit to the isophote
 sm :  set the Self-Model flag
 x : run again
 z : run again *later*
 y : make a png image
 w : radial plot
 c : comment/classify
 <return> to move on to the next source
```

here i request source #558 in my list

the source ID (name) was returned

coordinates and the shape

primary photometry

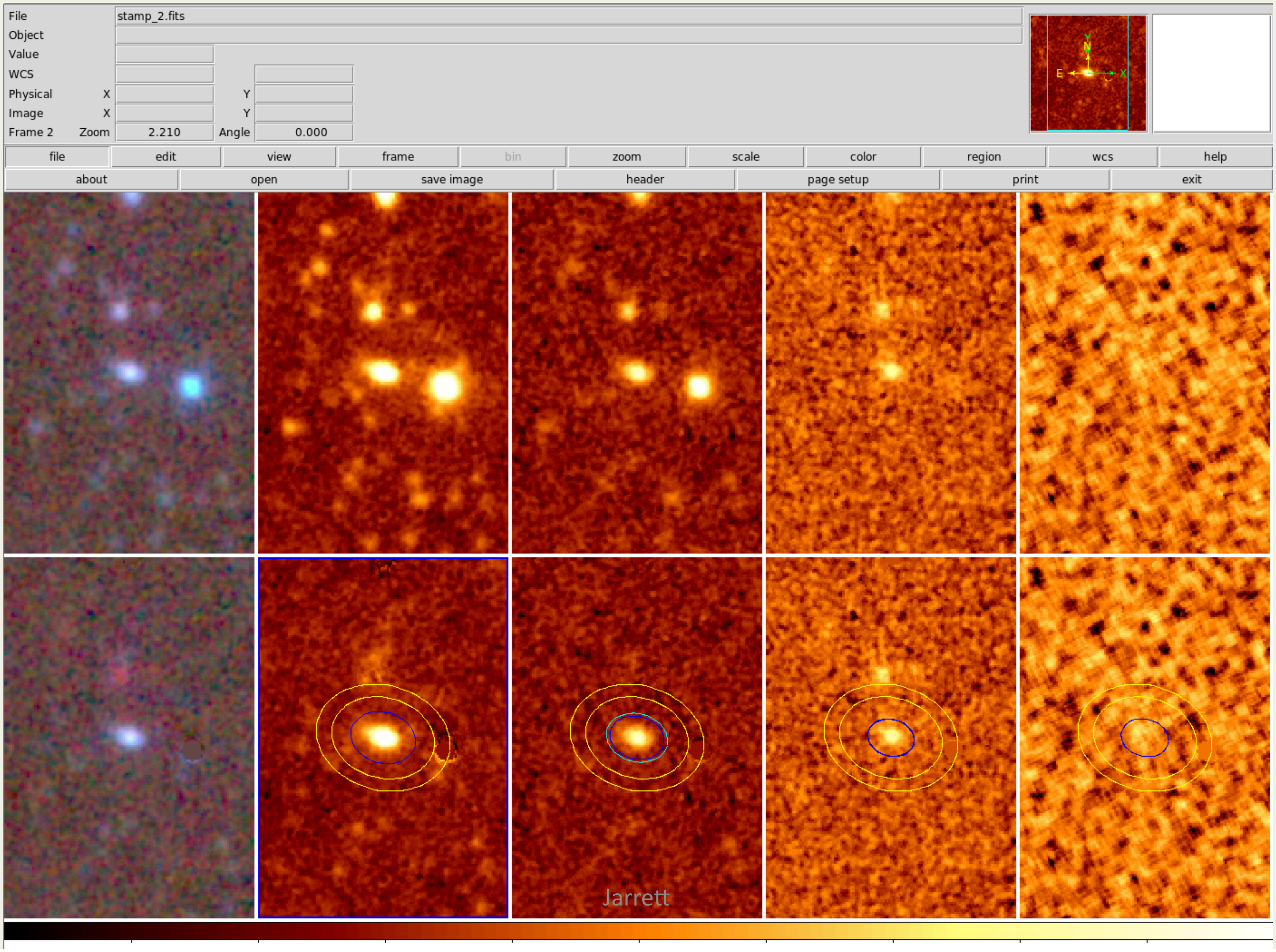
inflection or
convergence photometry

colors (optimum-matched)

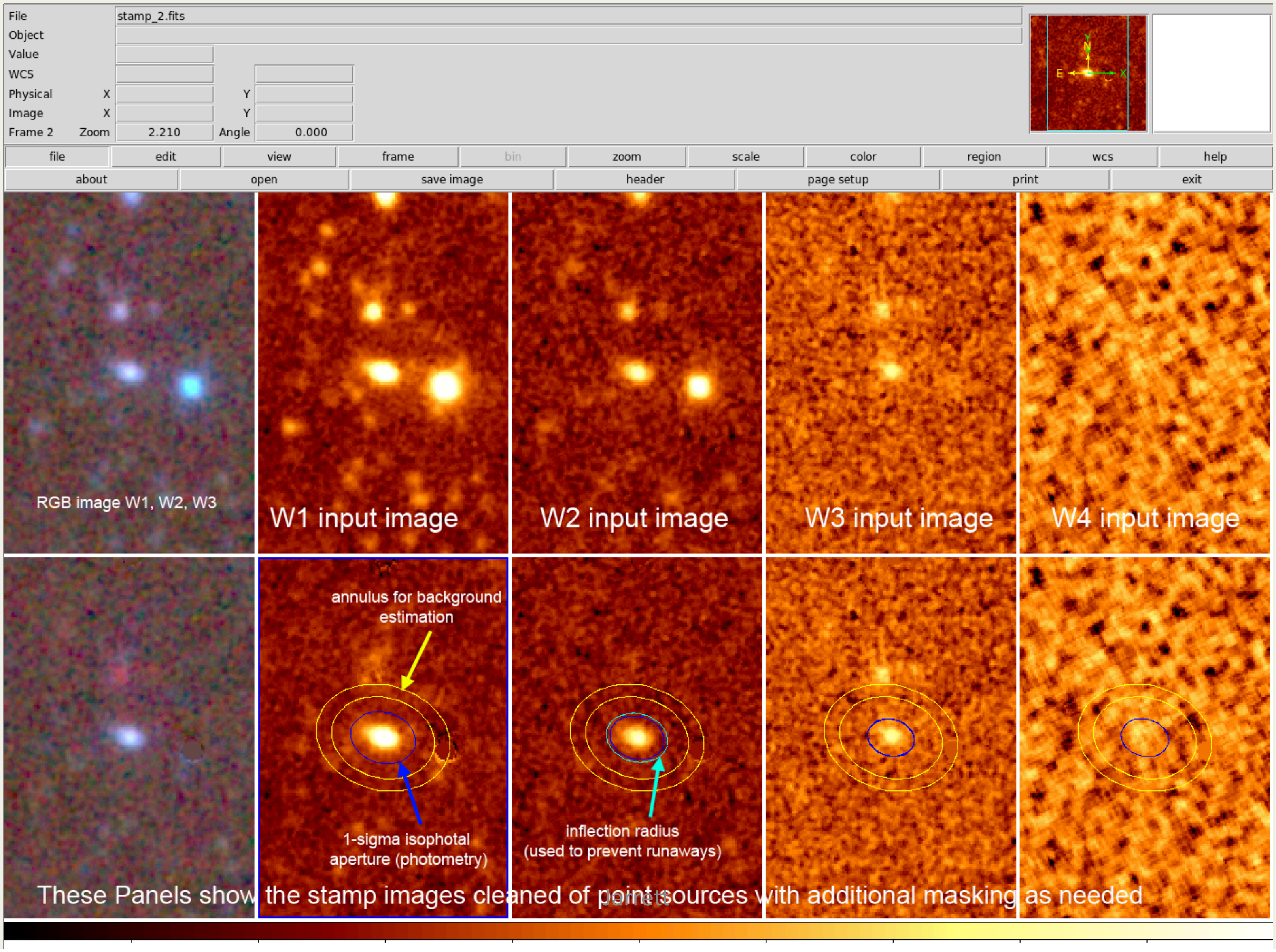
this is the metric for deciding
whether "fuzzy" or not

these are the various options you
have; the program is waiting as this
point for some input from you
(see next page for the images that pop up)

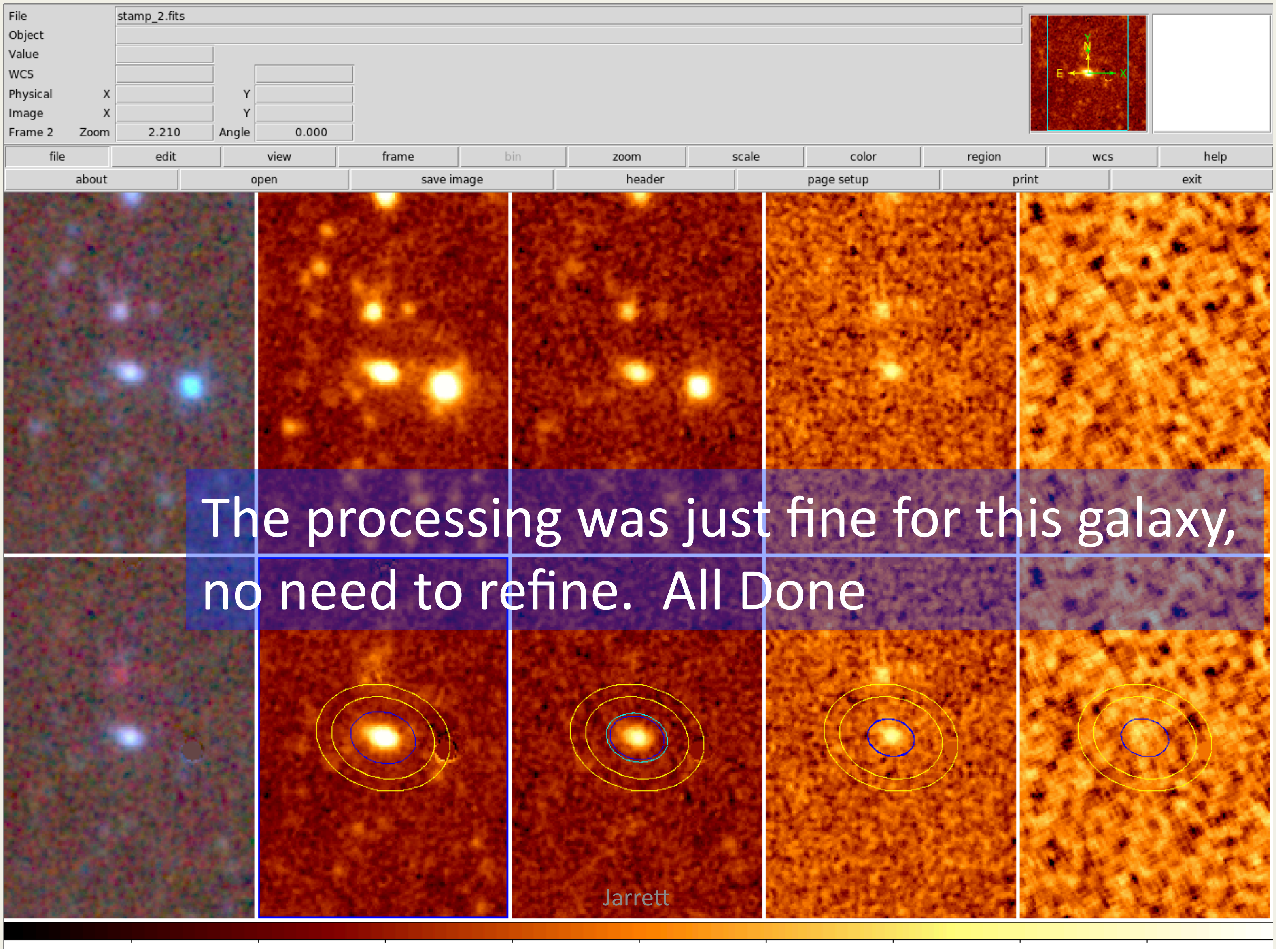
Example 1: Small Galaxy in the Coma Cluster



Example 1: Small Galaxy in the Coma Cluster

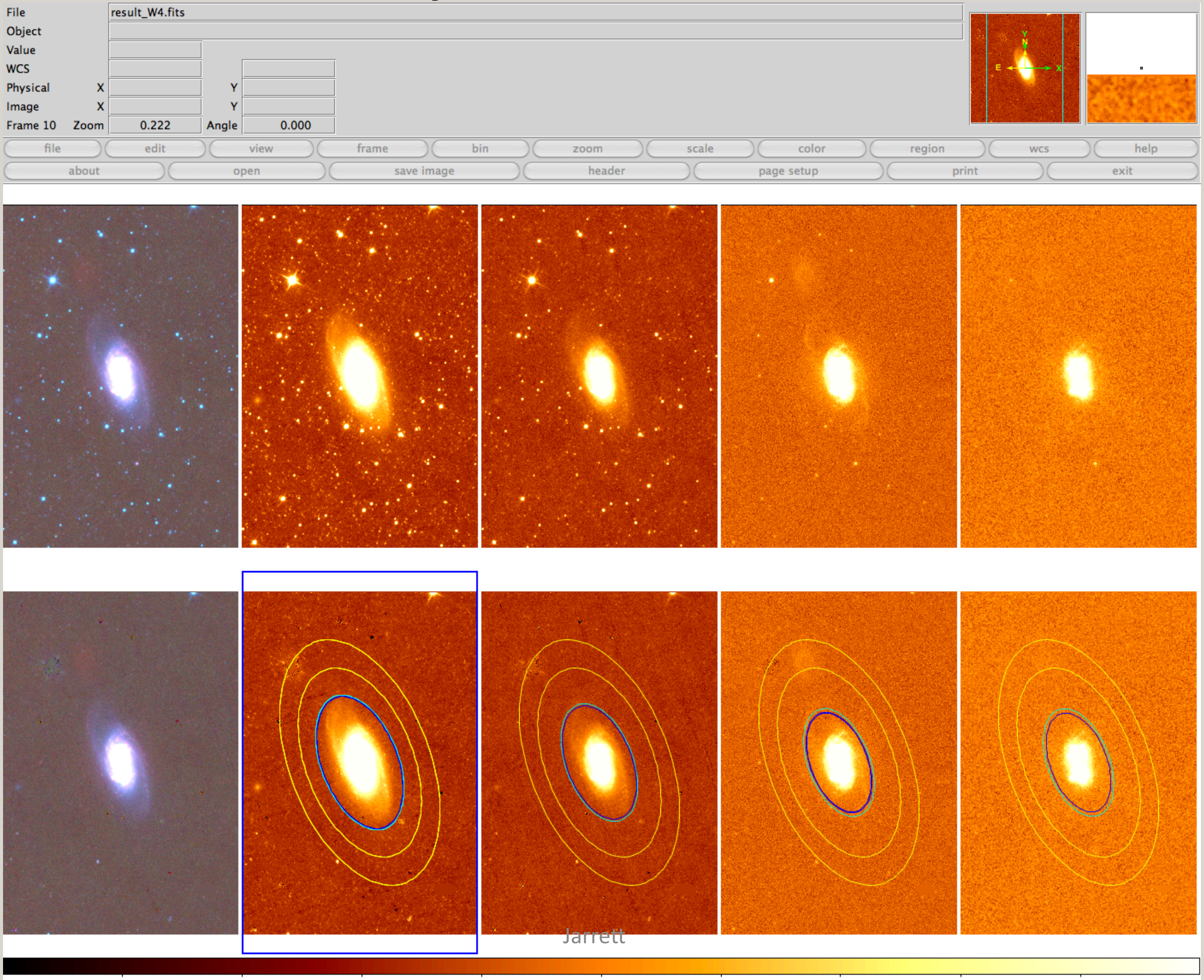


Example 1: Small Galaxy in the Coma Cluster

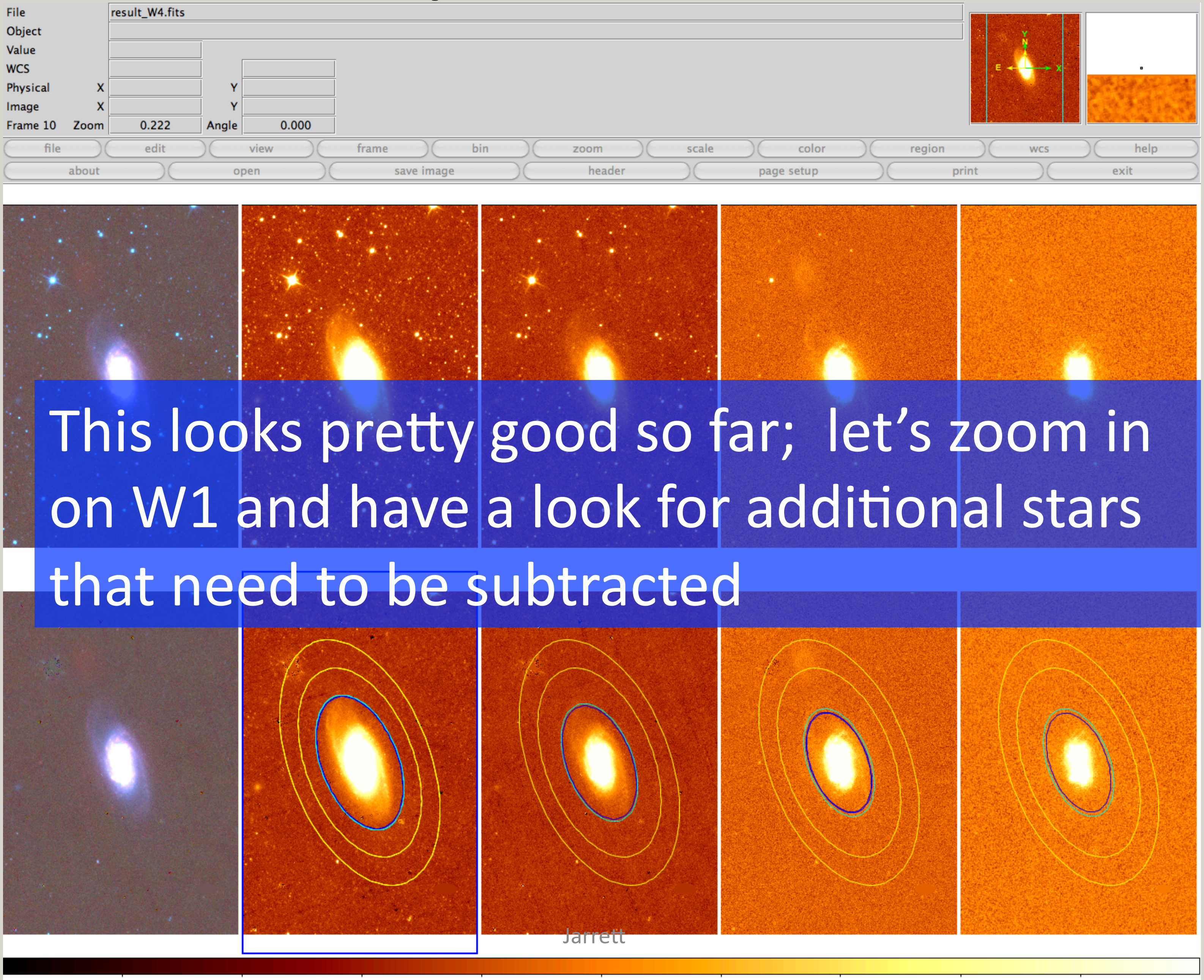


The processing was just fine for this galaxy, no need to refine. All Done

Example 2: NGC2903

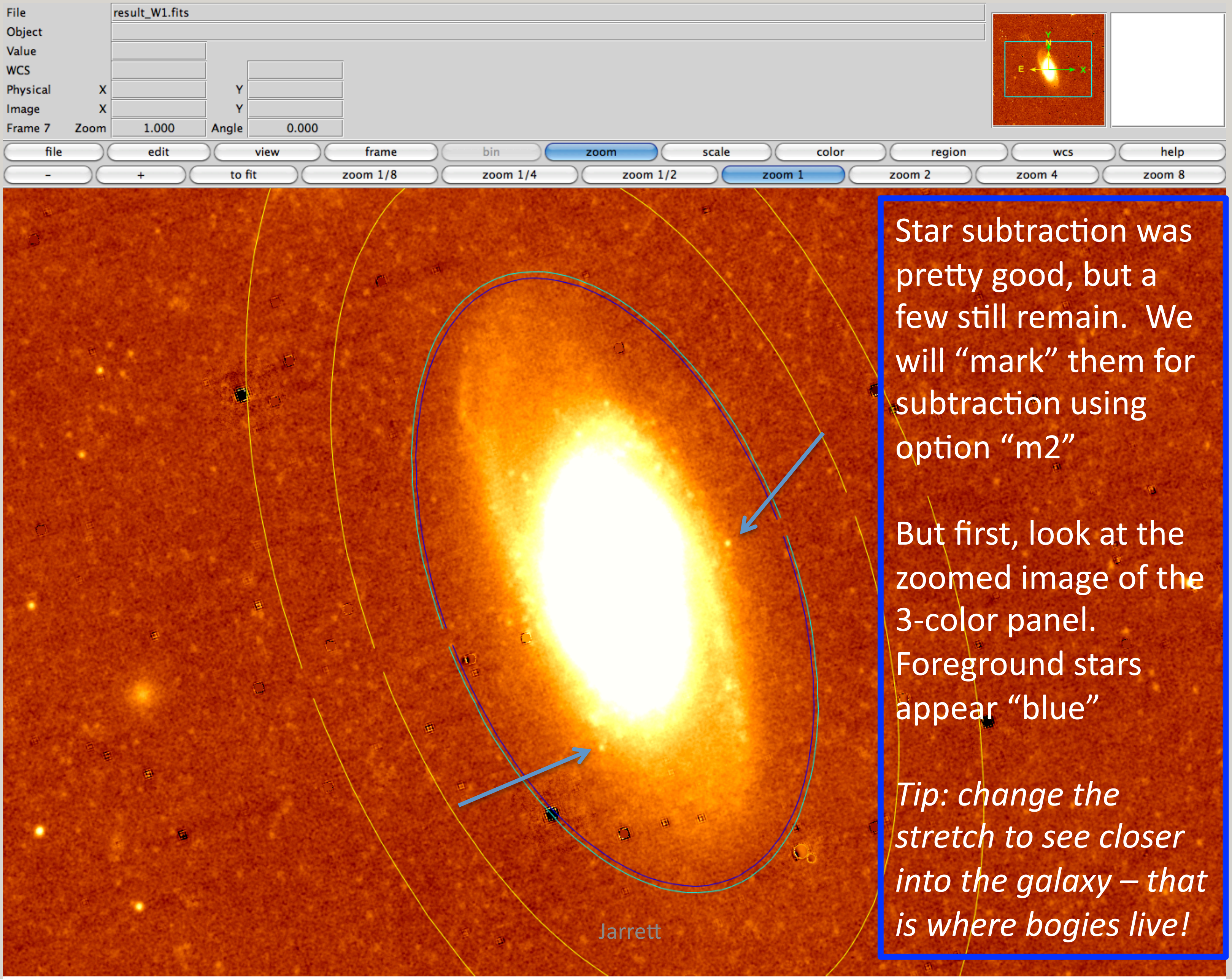


Example 2: NGC2903



This looks pretty good so far; let's zoom in on W1 and have a look for additional stars that need to be subtracted

Example 2:   NGC2903

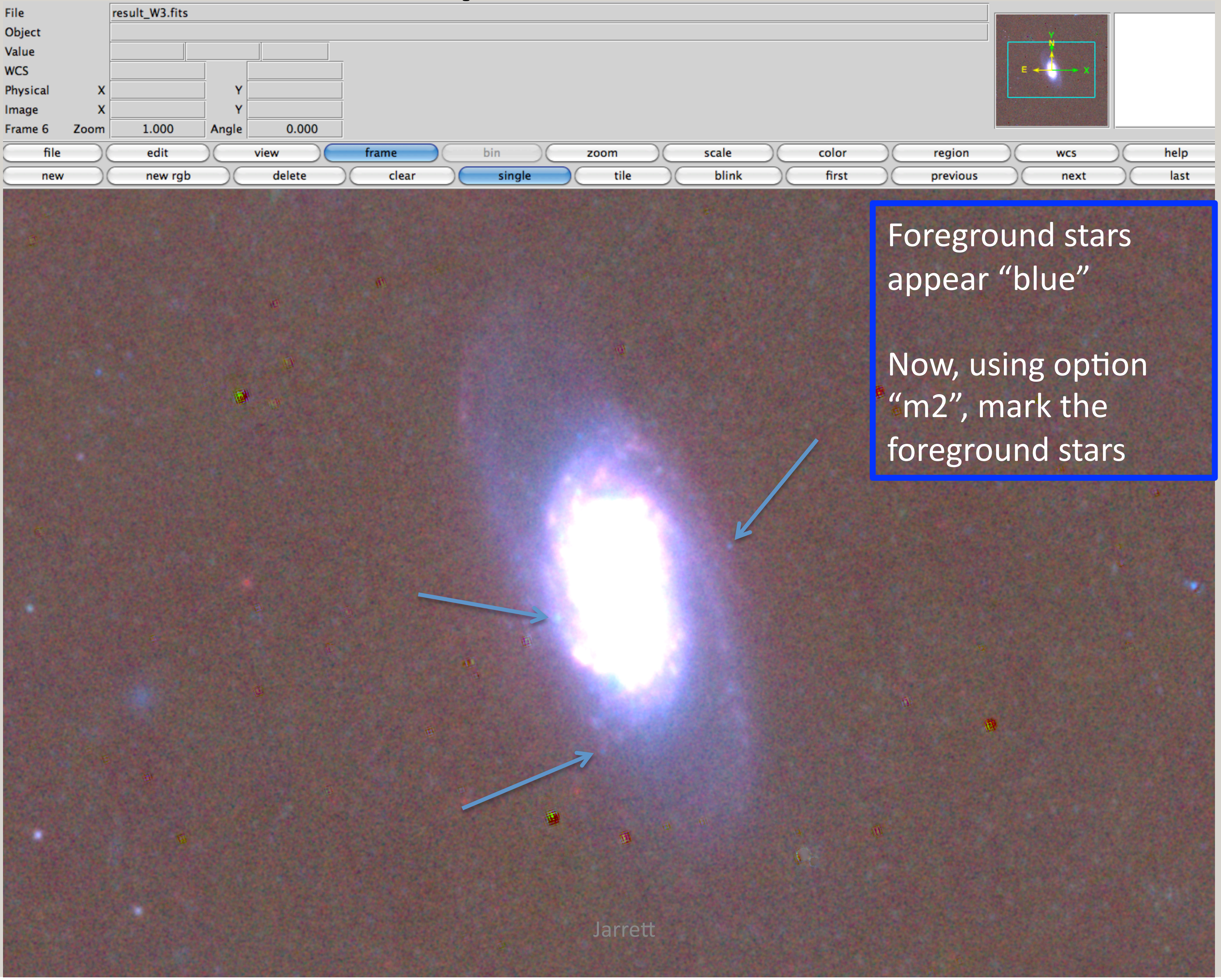


Star subtraction was pretty good, but a few still remain. We will “mark” them for subtraction using option “m2”

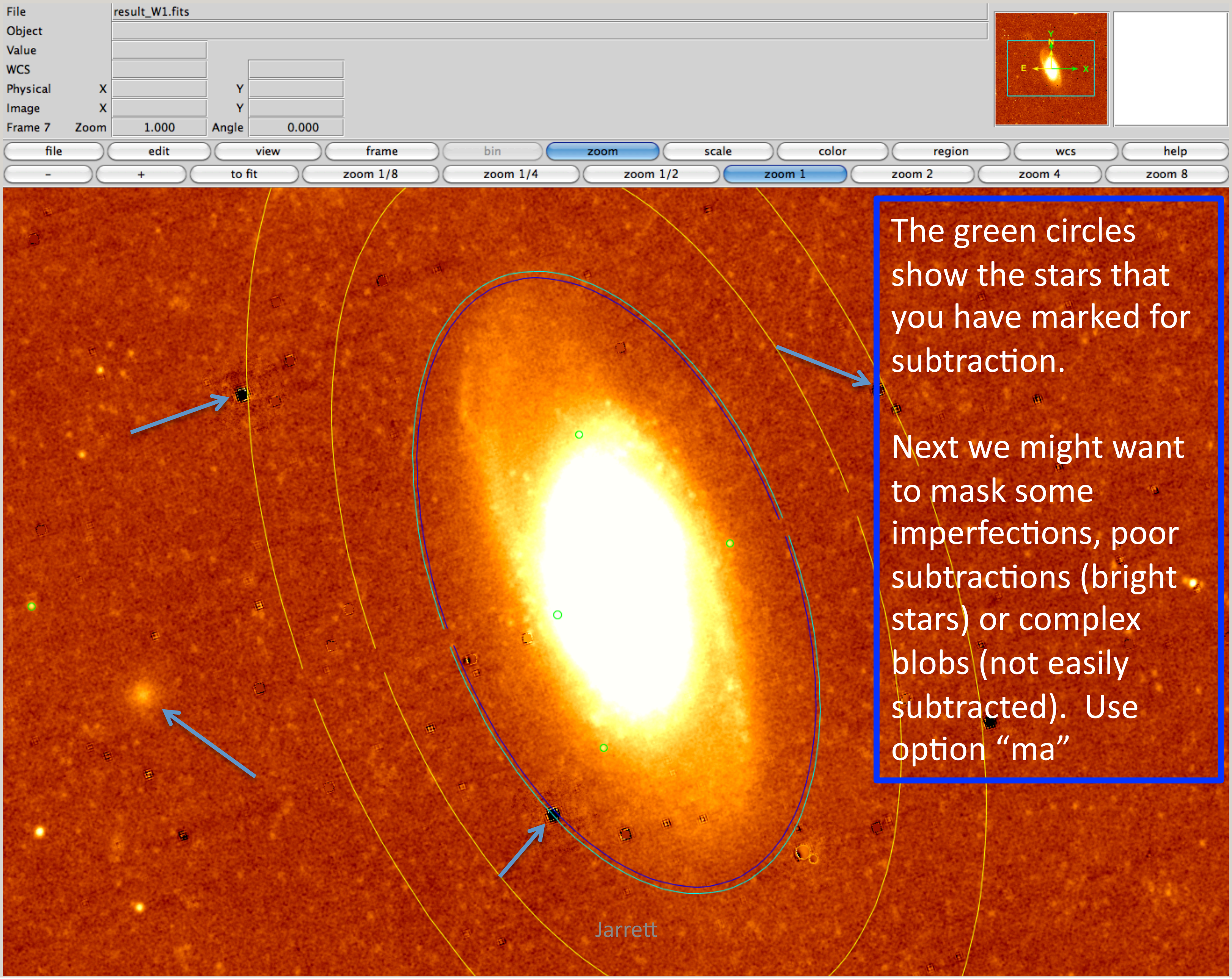
But first, look at the zoomed image of the 3-color panel. Foreground stars appear “blue”

Tip: change the stretch to see closer into the galaxy – that is where bogies live!

Example 2: NGC2903



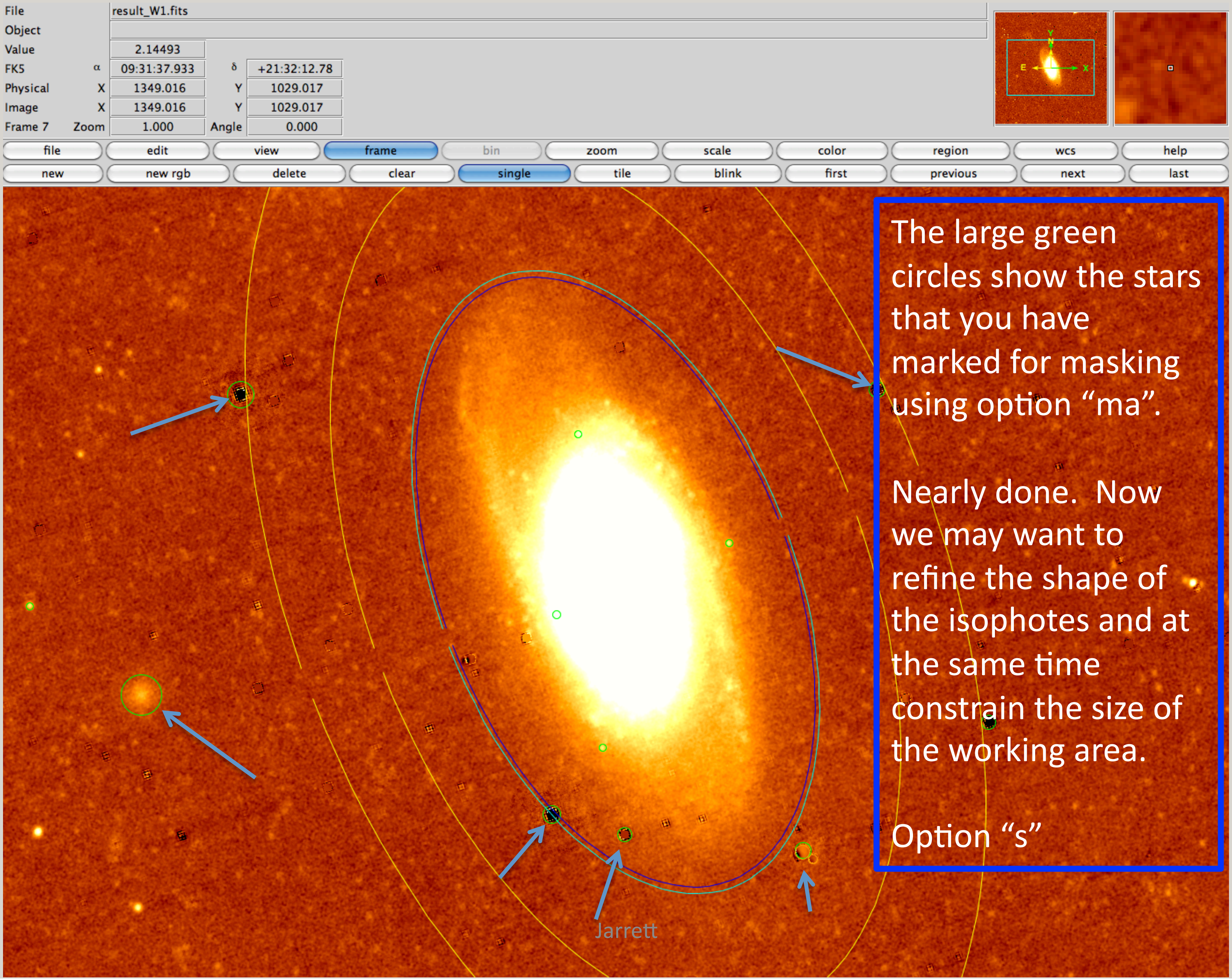
Example 2: NGC2903



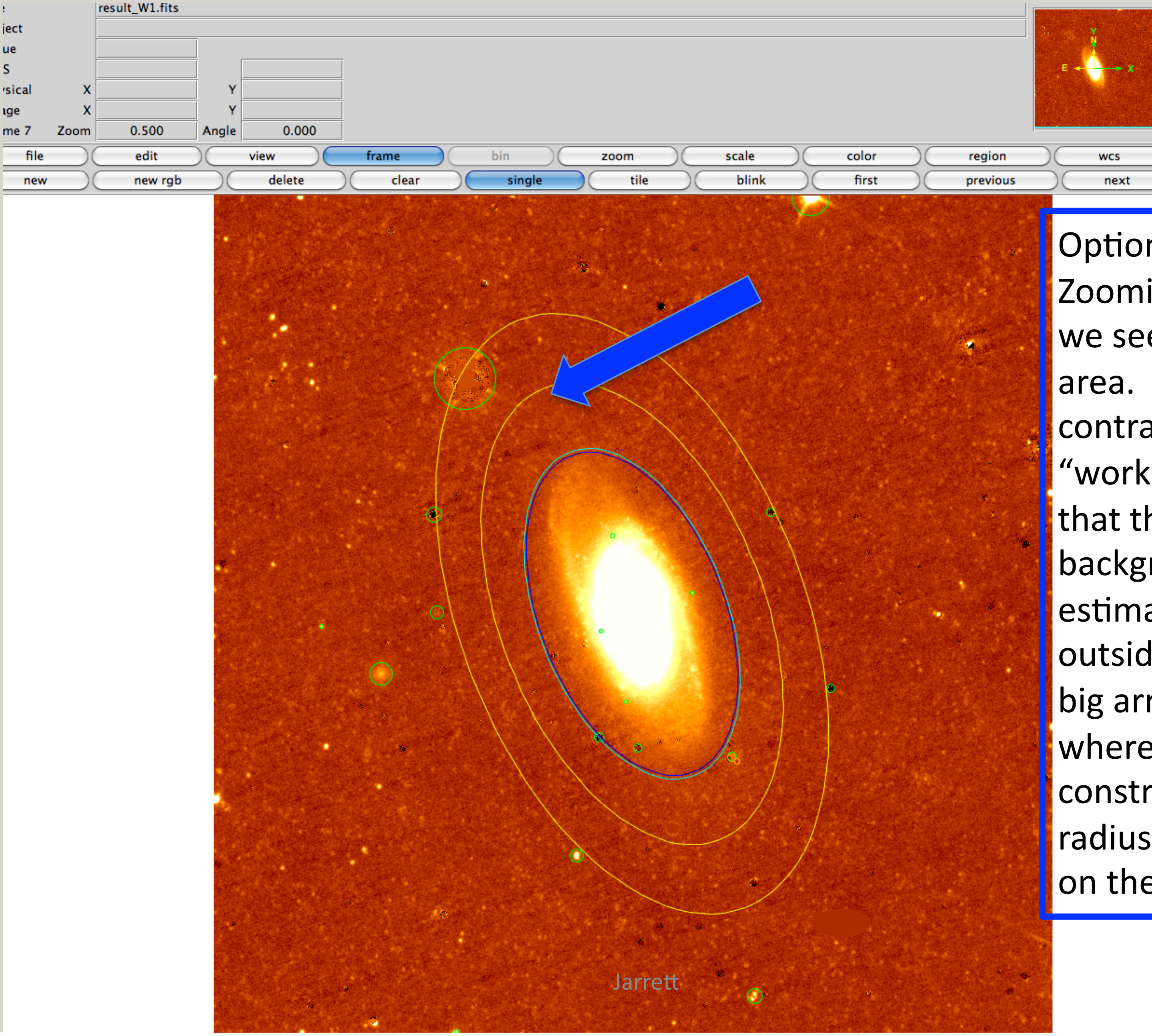
The green circles show the stars that you have marked for subtraction.

Next we might want to mask some imperfections, poor subtractions (bright stars) or complex blobs (not easily subtracted). Use option "ma"

Example 2: NGC2903

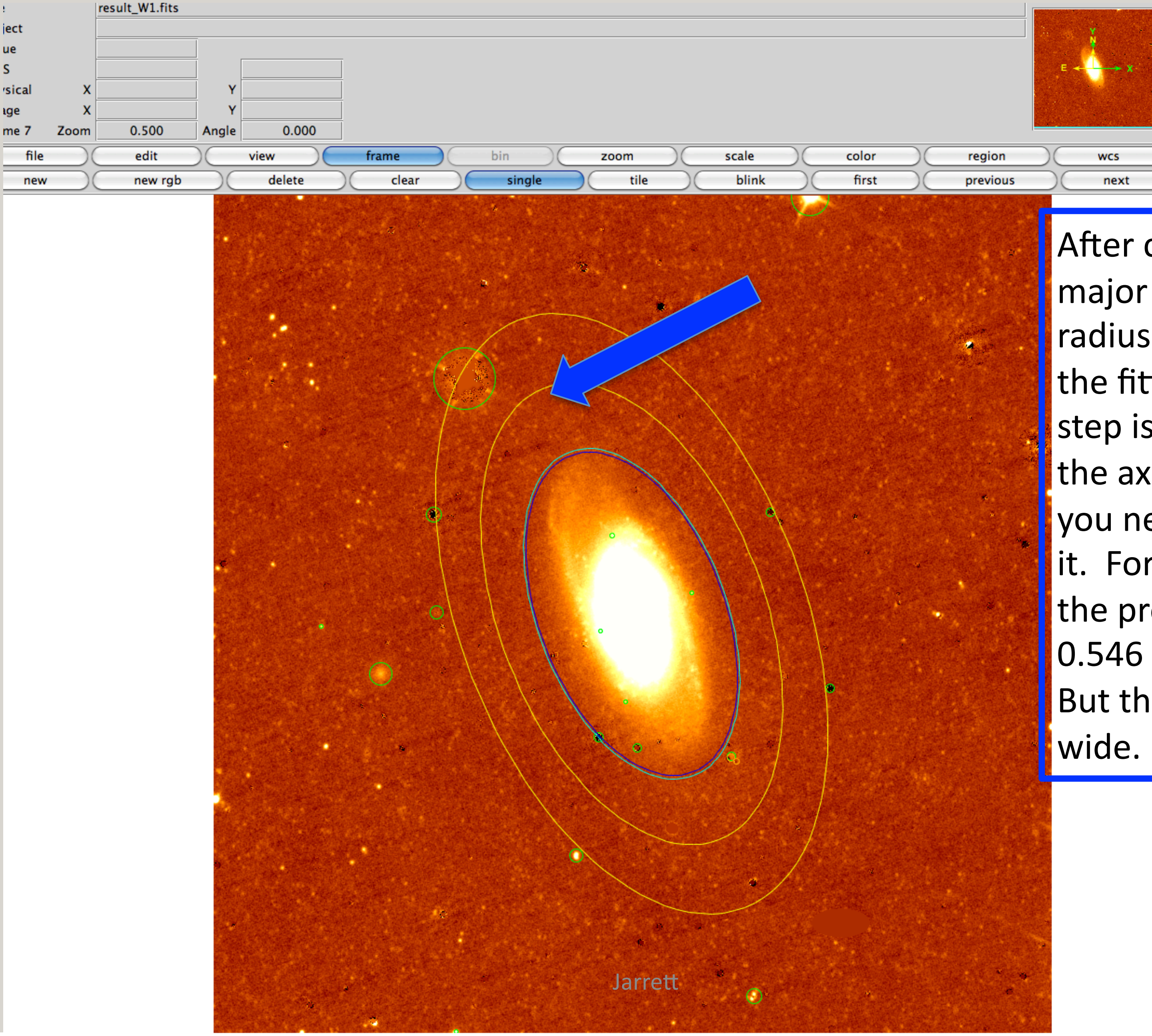


Example 2:   NGC2903



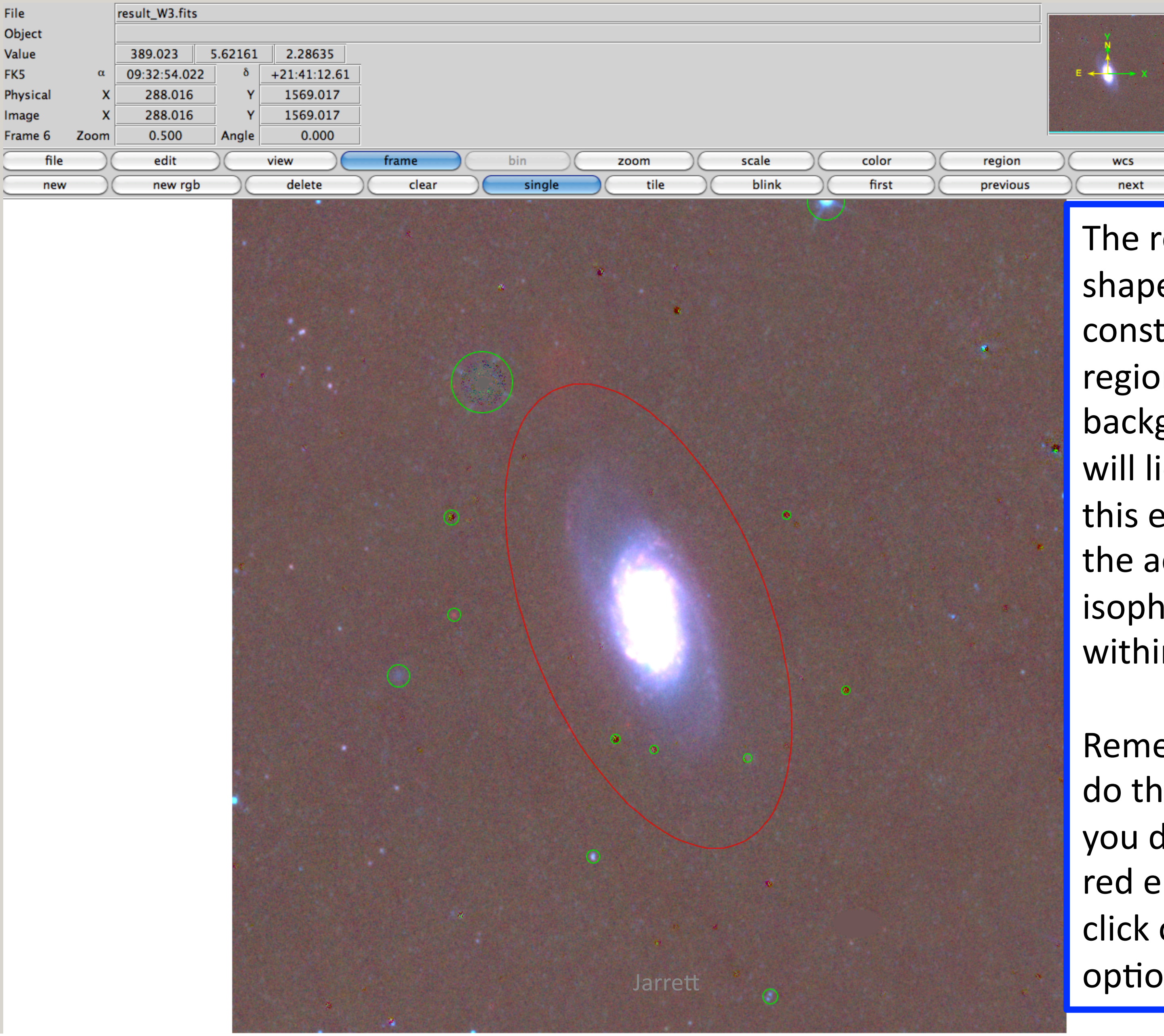
Option "s"
Zooming out a bit, we see the larger area. We want to contrain the "working area" so that the annulus for background estimation is just outside of this. The big arrow marks where we want to constraint the max radius. It is placed on the major axis (!)

Example 2: NGC2903



After clicking on the major axis, maximum radius (contraining the fitting area), next step is to *specify* the axis ratio. Here you need to estimate it. For this example, the processing found 0.546 for the ratio. But that looks a bit wide. Let's try 0.489.

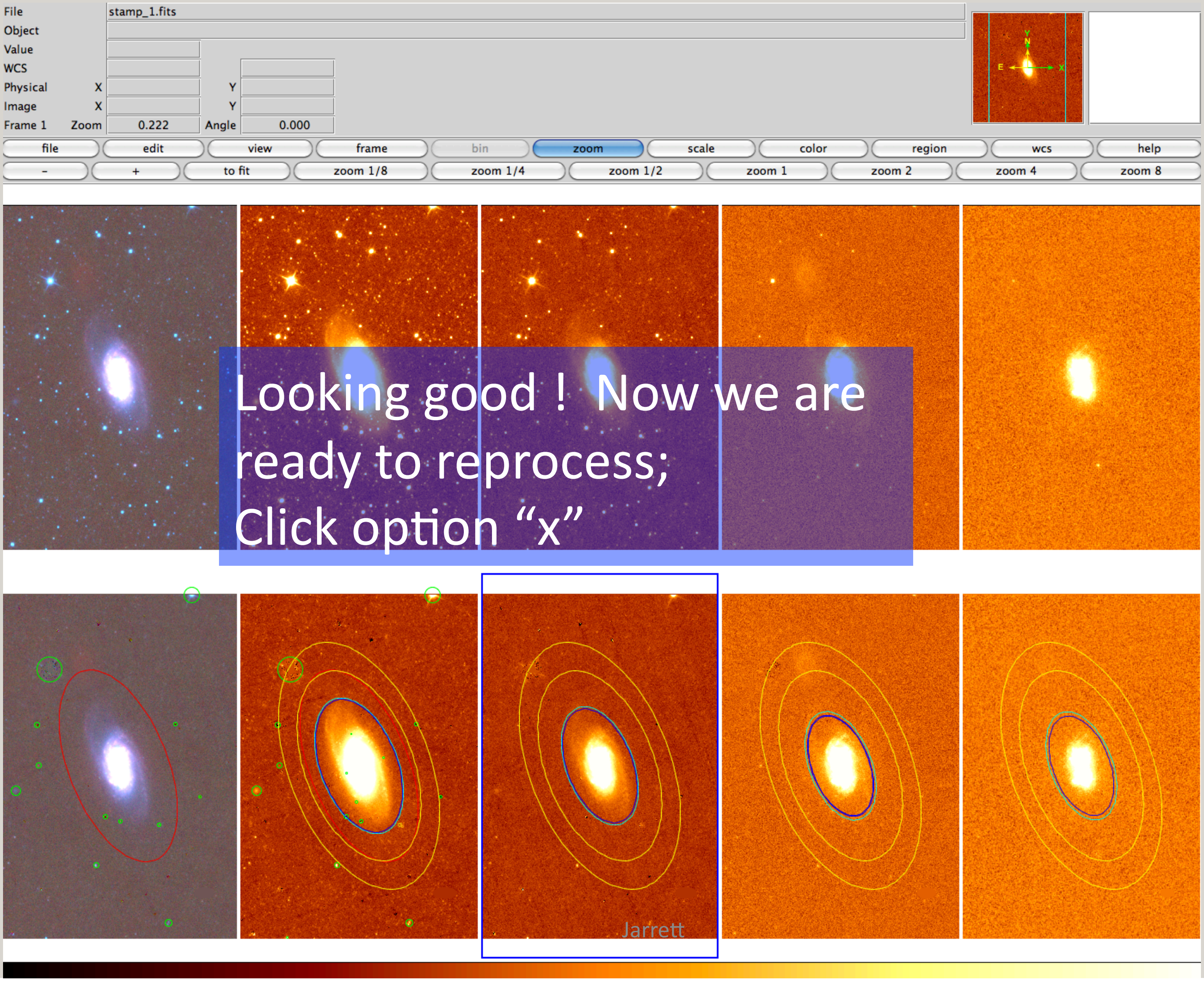
Example 2: NGC2903



The resulting ellipse shape that will constrain the fitting region. The background annulus will lie just outside this ellipse; while the actual 1-sigma isophote will lie within.

Remember you can do this step again if you do not like the red ellipse result. Just click option “s” or option “rc”

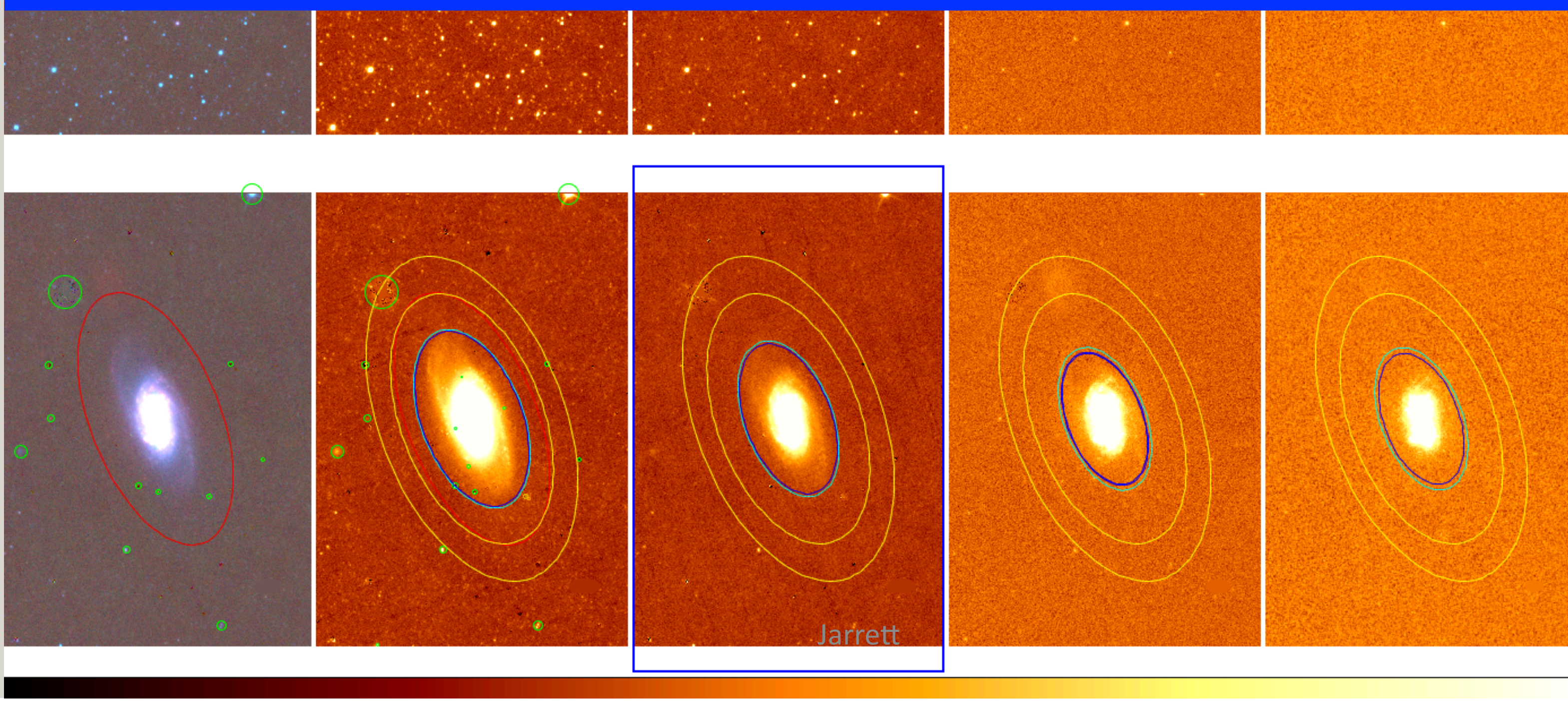
Example 2: NGC2903



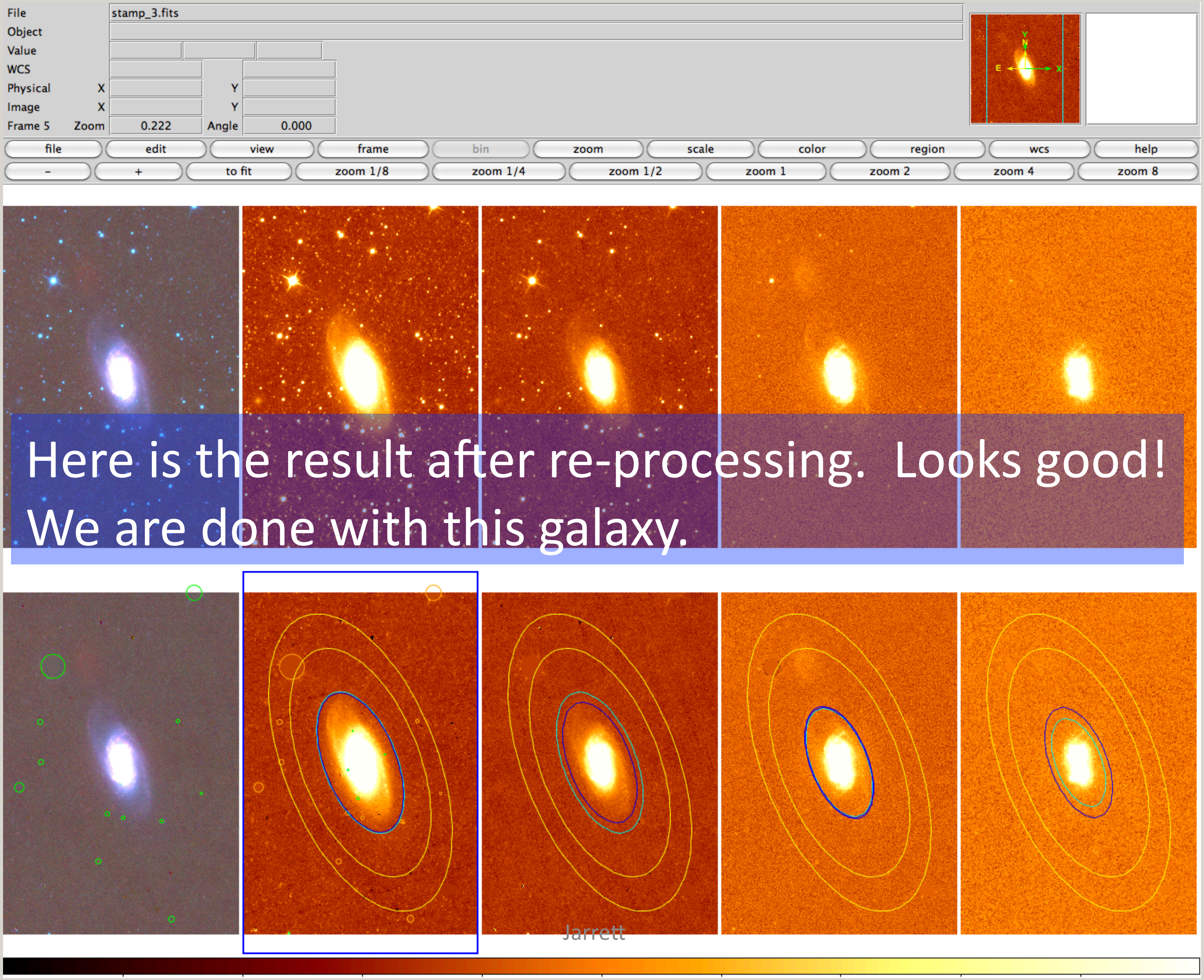
Looking good ! Now we are ready to reprocess;
Click option “x”

Example 2: NGC2903

For large galaxies, we do have to decide whether to lock W2 to W1, W3 to W2, W4 to W3, etc. You must look at the W3 and W4 signal for the answer. Usually W3 is faint and not well matched to W2 (or W1). I generally prefer to lock W4 to W3. For this example, I will lock W3 to W2 and W4 to W3.



Example 2: NGC2903



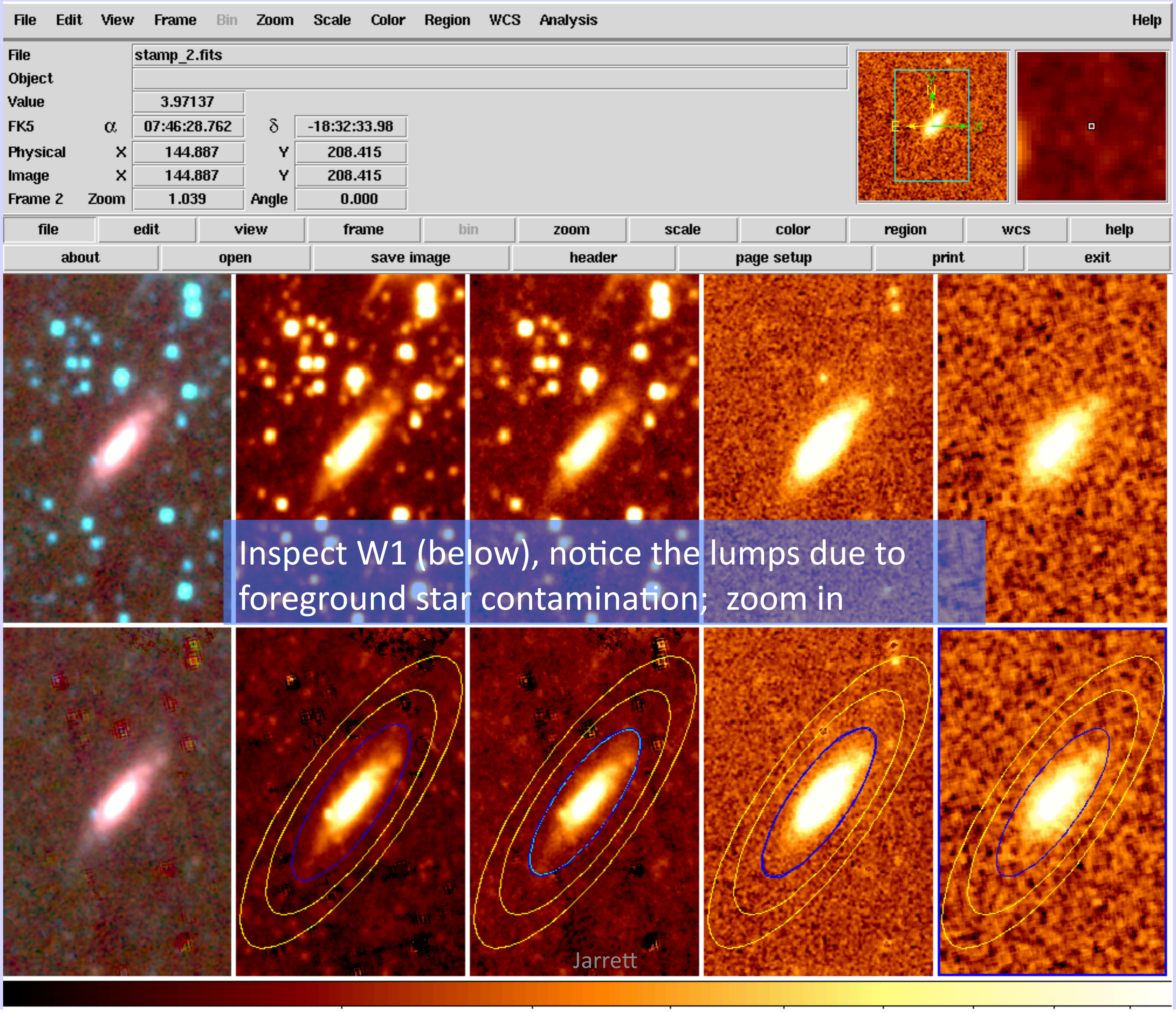
Here is the result after re-processing. Looks good!
We are done with this galaxy.

Example 3: Galaxy in the ZoA

Galaxies in the ZoA are especially tricky because of the stellar confusion.

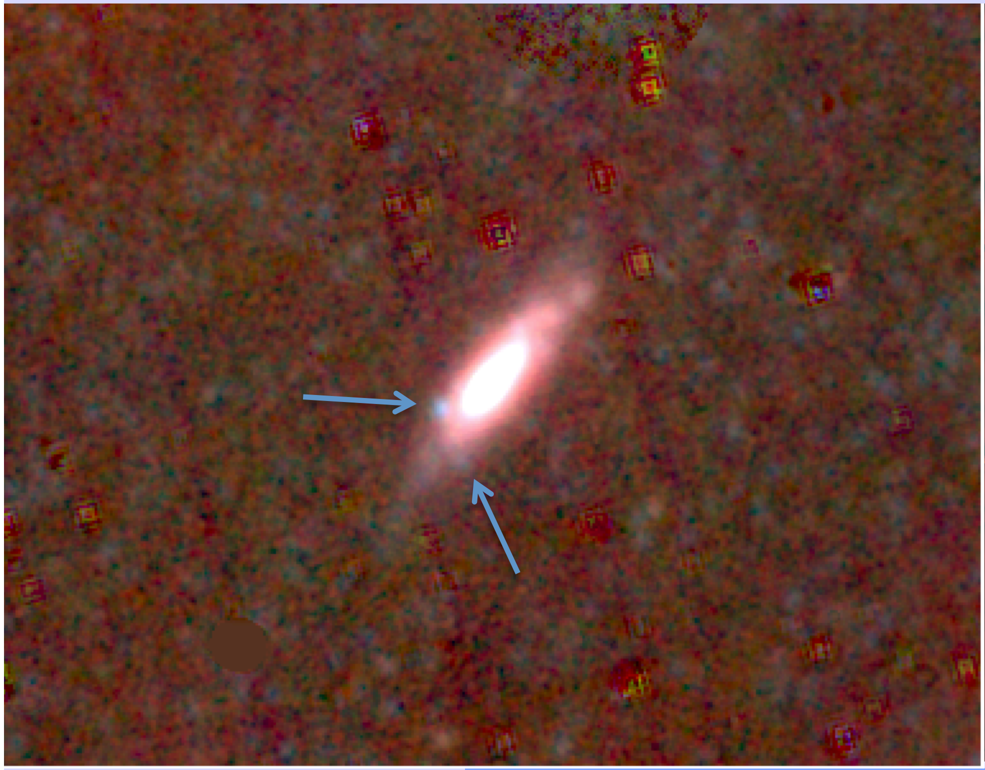
This means the initial processing is likely to miss stars and blends that are close to the galaxy. Who are you gonna call?

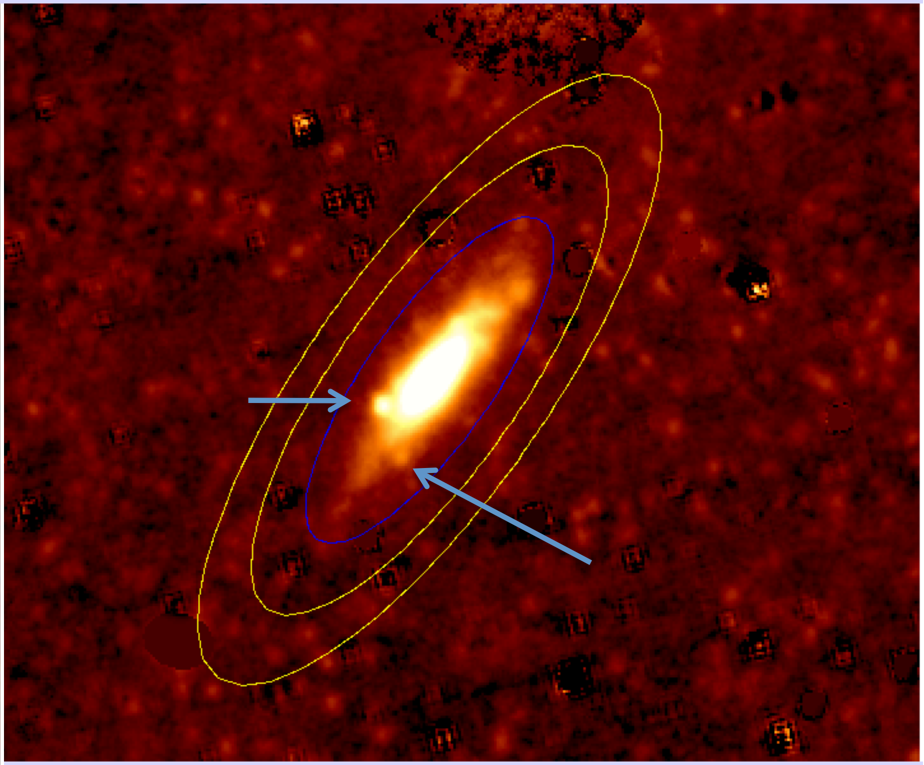
Example 3: Galaxy in the ZoA



Inspect W1 (below), notice the lumps due to foreground star contamination; zoom in

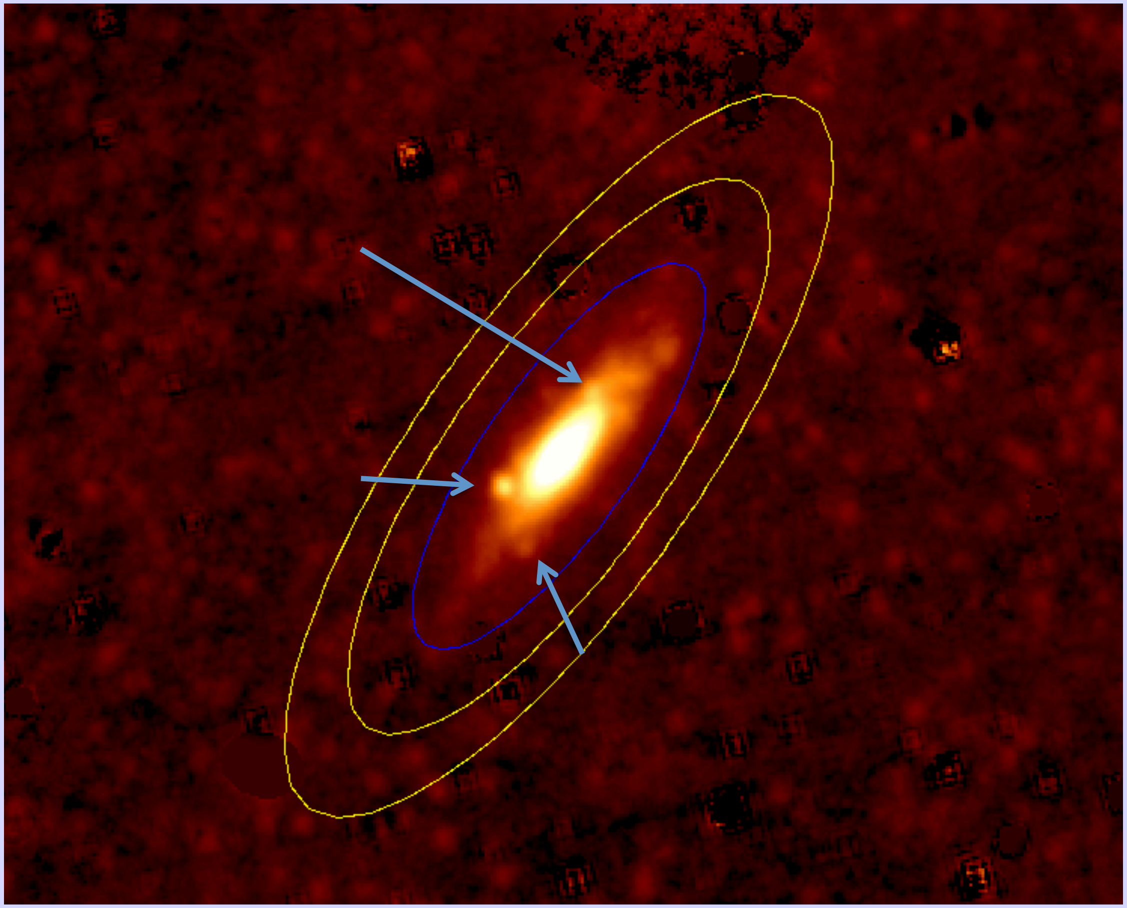
Example 3: Galaxy in the ZoA





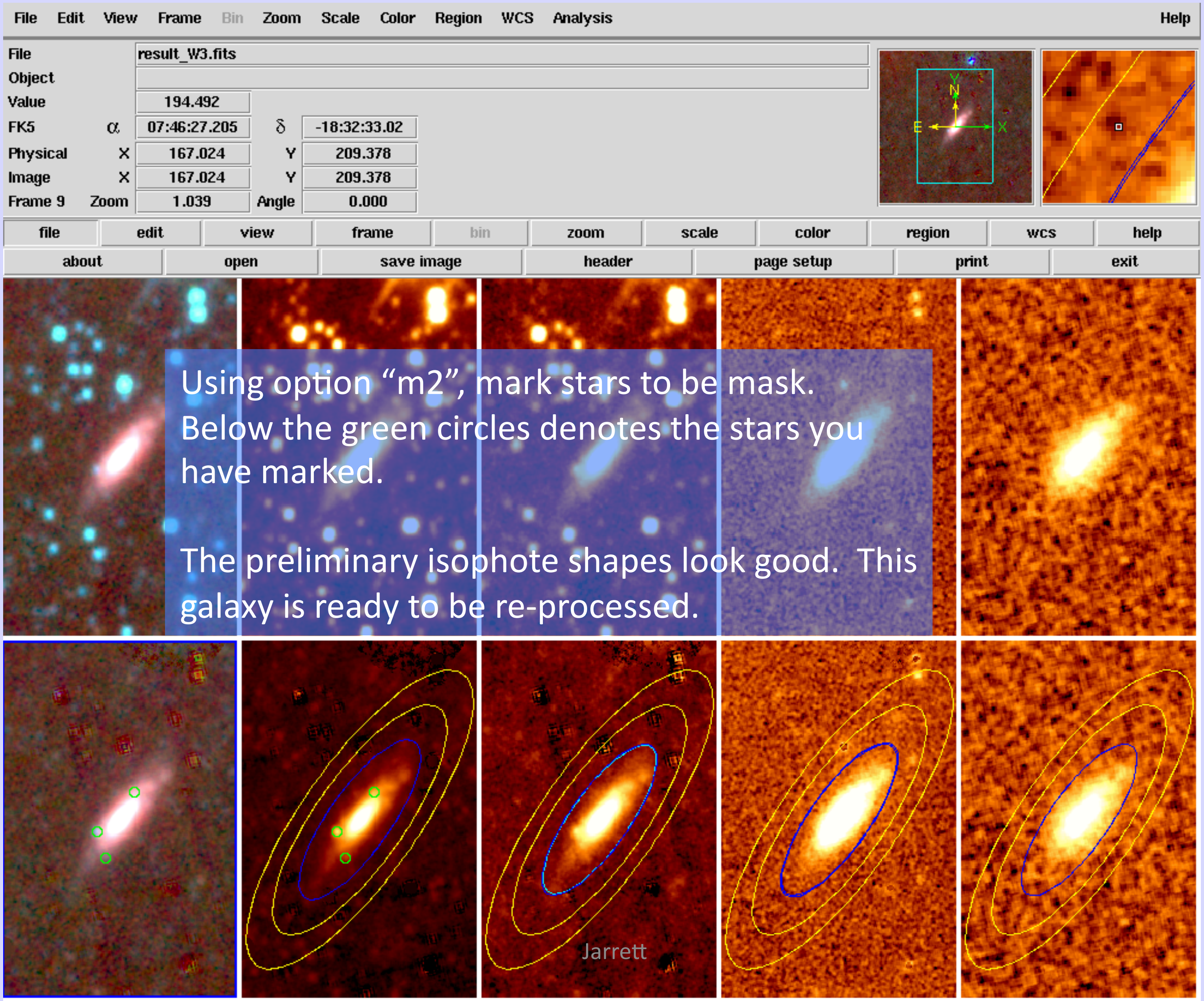
Remember, foreground stars are “blue” compared to the galaxy or the bits of the galaxy that are lumpy (HII regions)

Example 3: Galaxy in the ZoA



Always a good idea to change the stretch of the W1 image so that you improve the contrast, peer deep to find hidden stars. This one has a star hiding near the top of the disk.

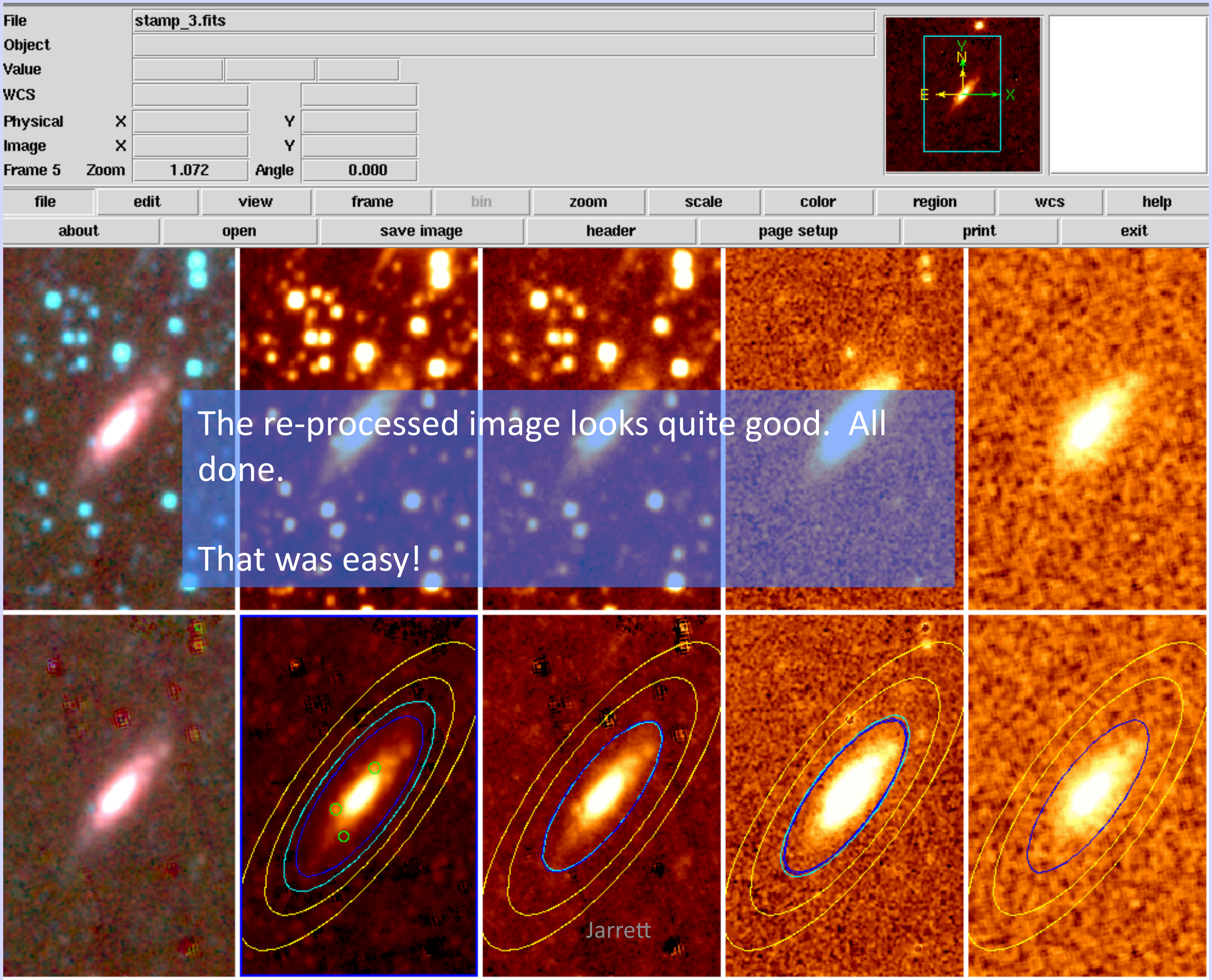
Example 3: Galaxy in the ZoA



Using option "m2", mark stars to be mask.
Below the green circles denotes the stars you have marked.

The preliminary isophote shapes look good. This galaxy is ready to be re-processed.

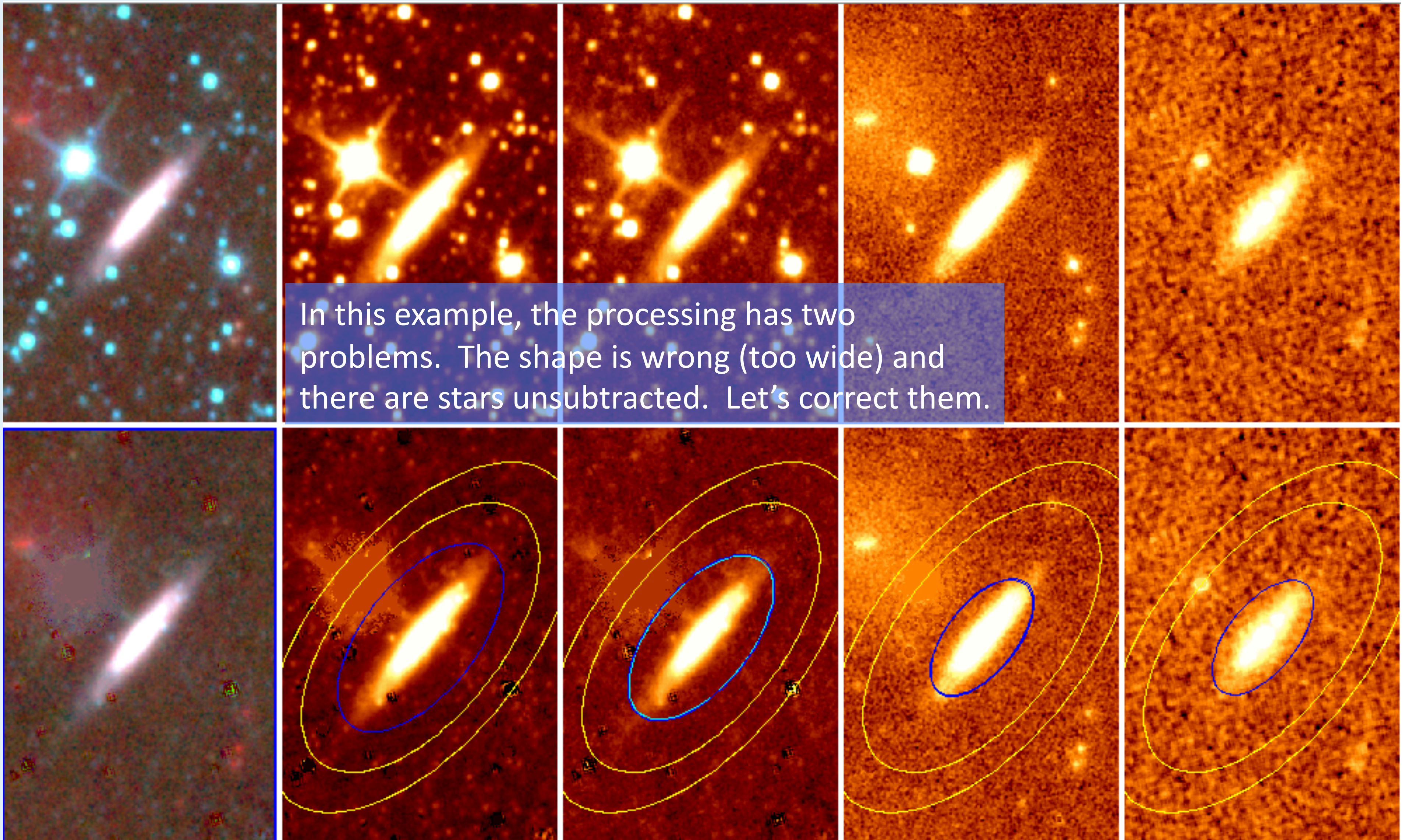
Example 3: Galaxy in the ZoA



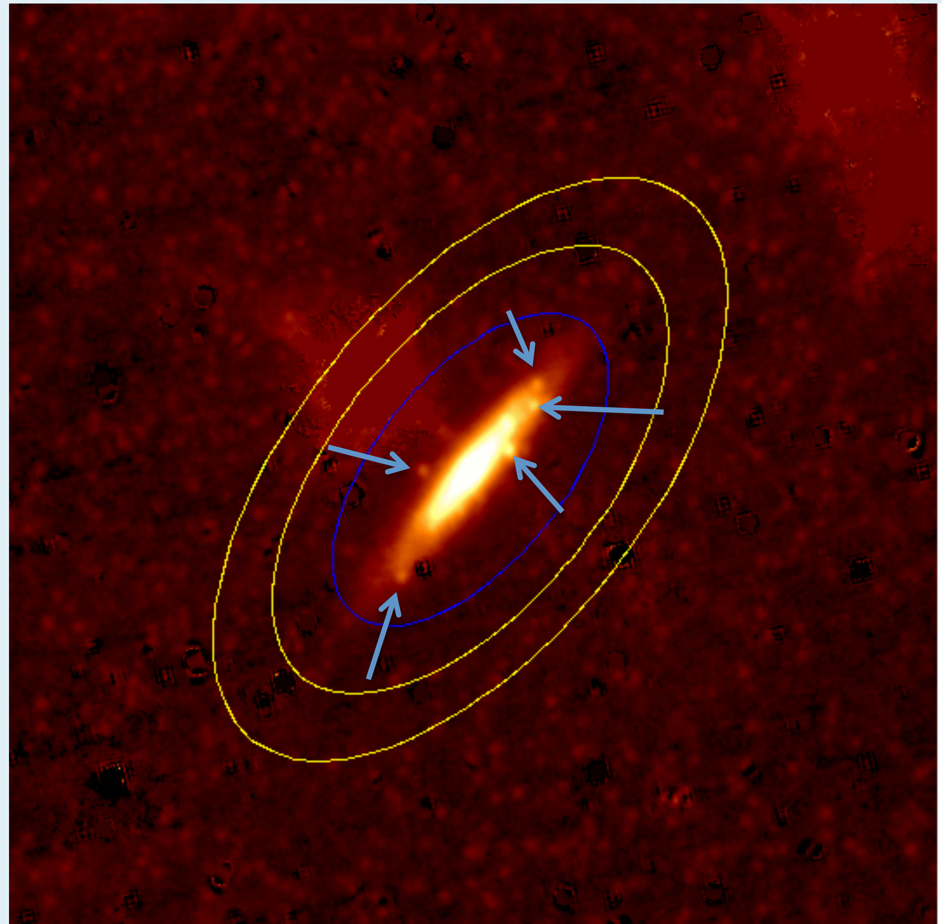
The re-processed image looks quite good. All done.

That was easy!

Example 4: Galaxy in the ZoA

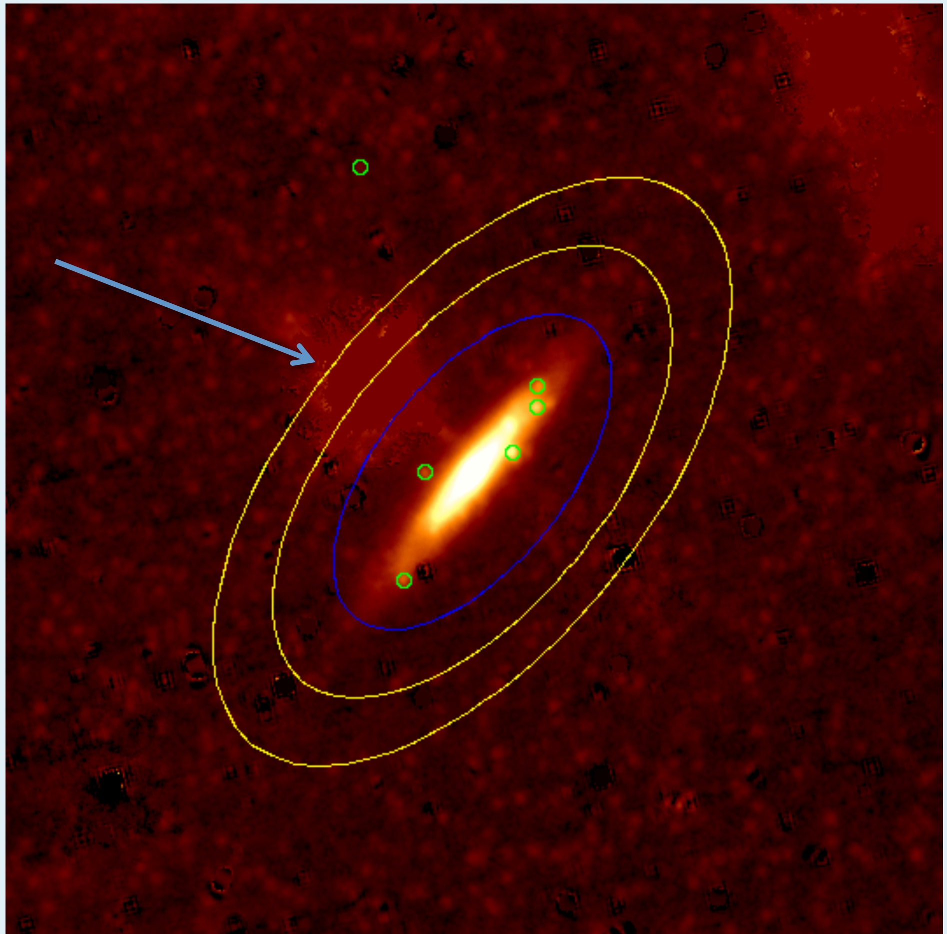


Example 4: Galaxy in the ZoA



Change the W1 stretch to see better, note the lumpy stars popping. Be careful, do not subtract real galaxy !

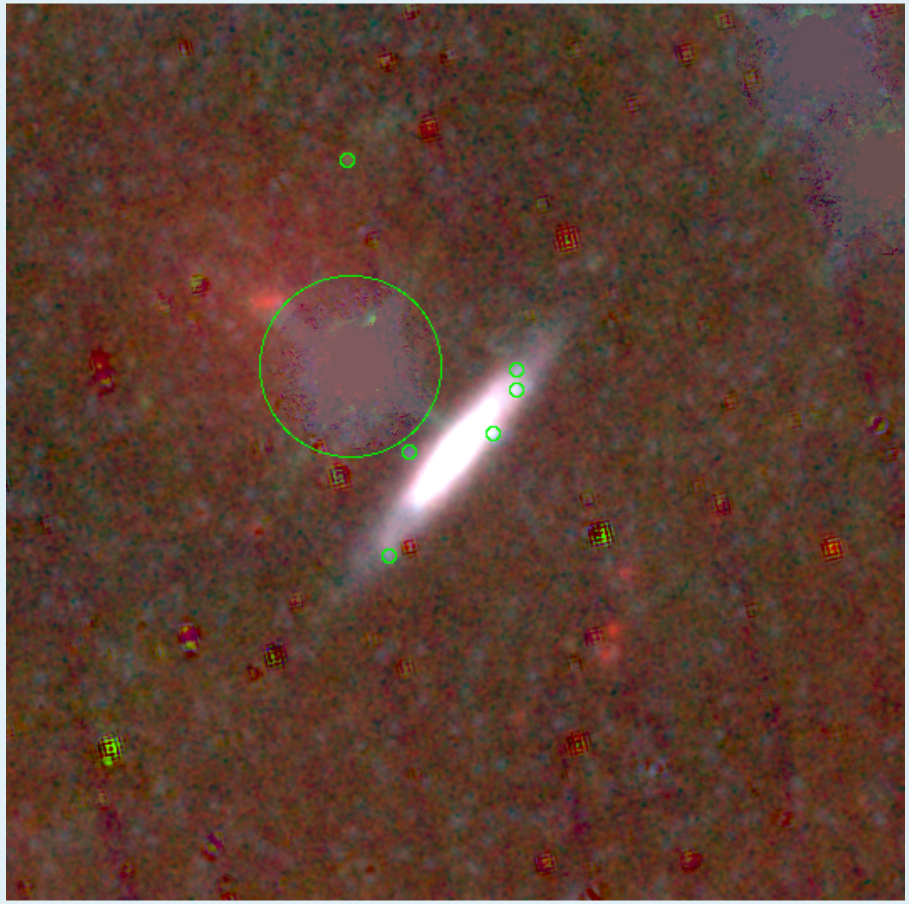
Example 4: Galaxy in the ZoA



Here we used option "m2" to mark stars for subtraction.

What about that bright star masking, it's a bit sloppy.
Let's make a bigger mask to clean it up. Option "ma"

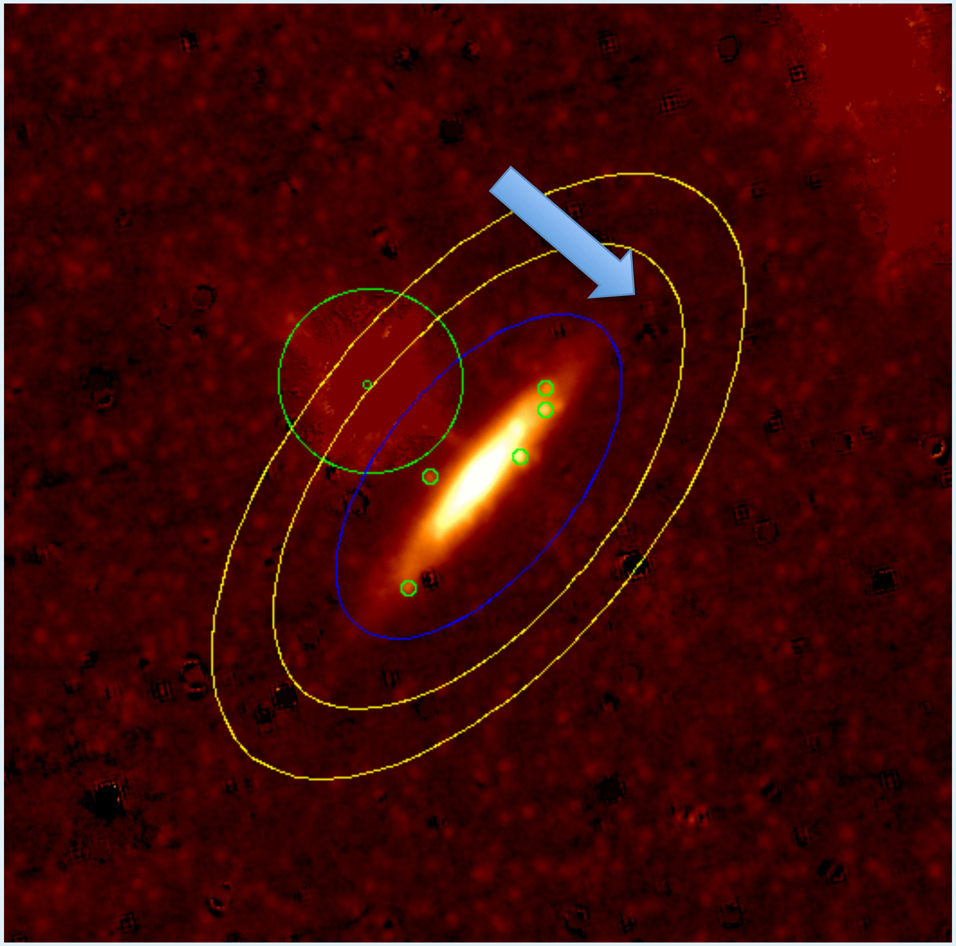
Example 4: Galaxy in the ZoA



Here we used option "ma" to mask the bright star (already masked). It's ok to remask a source or region.

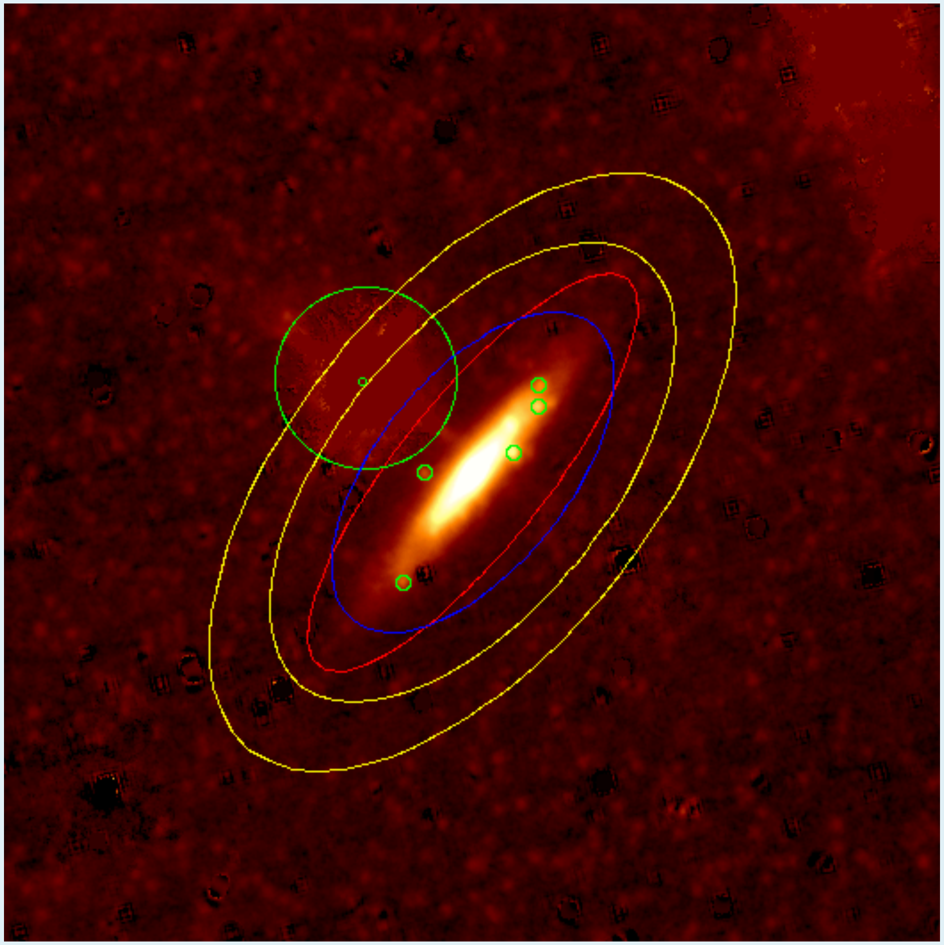
Next, let's constrain the shape and working region; option "s"

Example 4: Galaxy in the ZoA



The preliminary processing finds an axis ratio of 0.503, which is clearly too wide (this source is edge-on). Looks more like 0.3. Let's use option "s", click on the major axis where you want the maximum working area. Note the arrow above, that is where I want it to go.

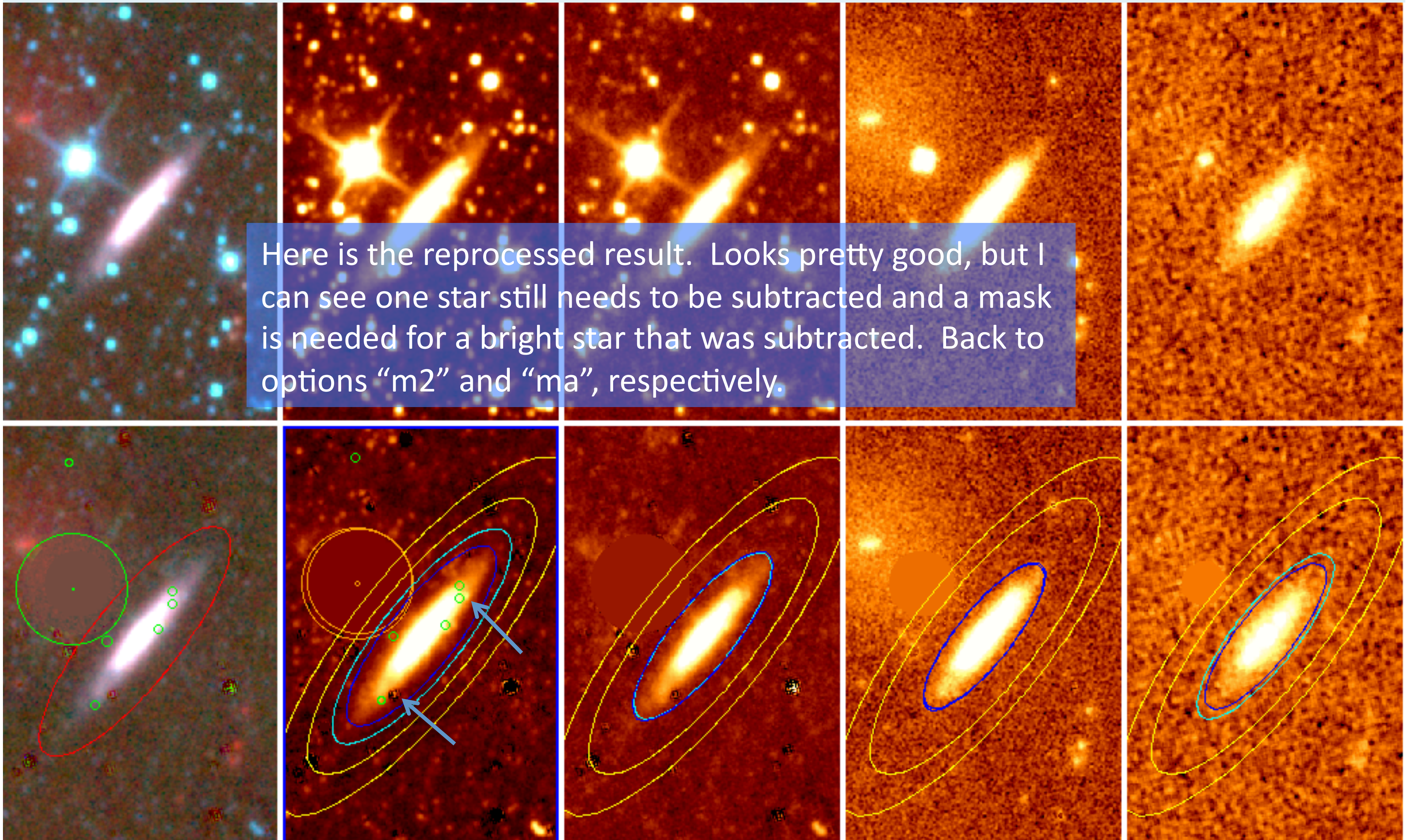
Example 4: Galaxy in the ZoA



This is the result of using option “s”. The processing will not use this shape to constrain the measurements and the active region (the background annulus will be just outside the ellipse).

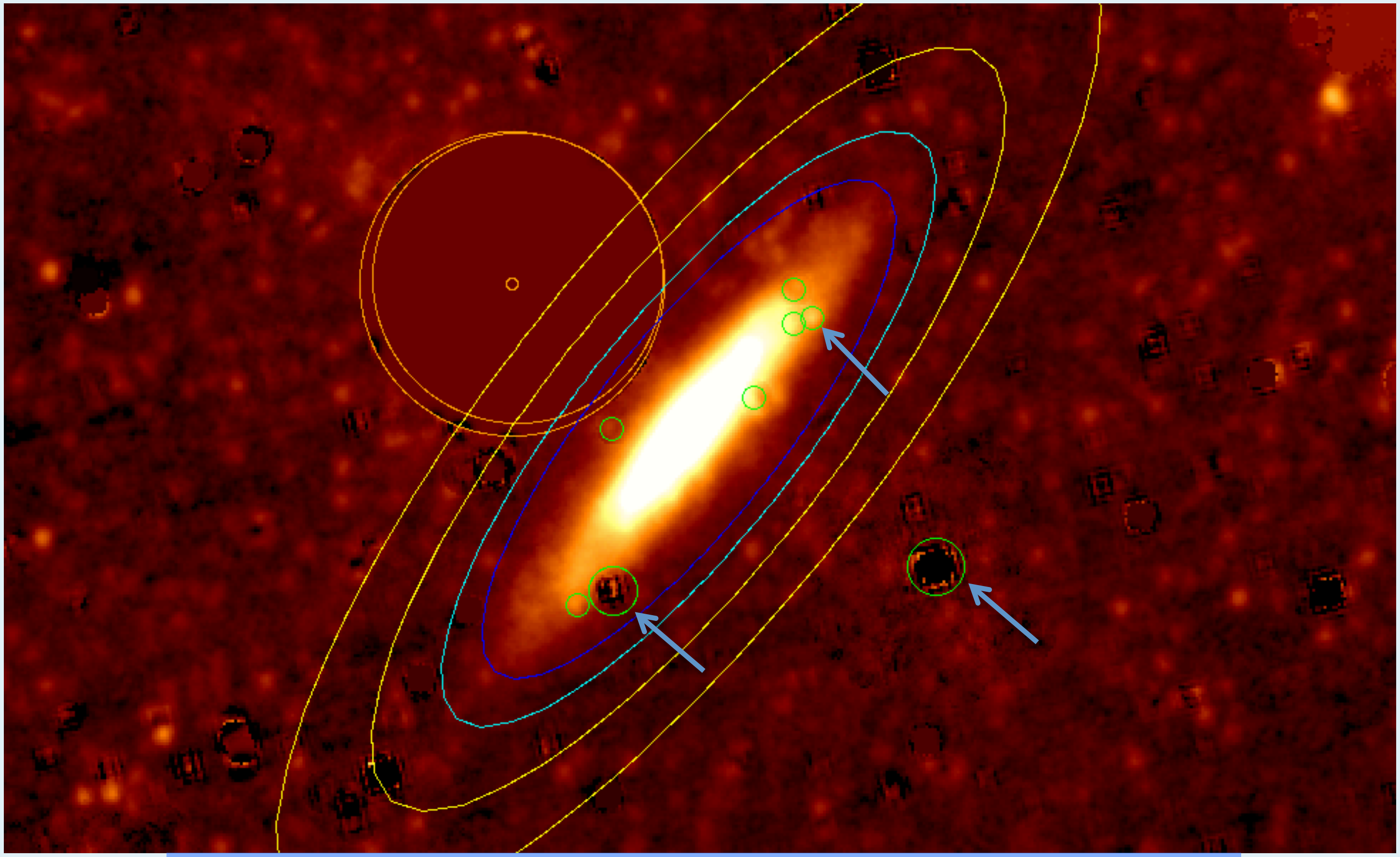
Ready to reprocess: option “x”

Example 4:   Galaxy in the ZoA



Here is the reprocessed result. Looks pretty good, but I can see one star still needs to be subtracted and a mask is needed for a bright star that was subtracted. Back to options "m2" and "ma", respectively.

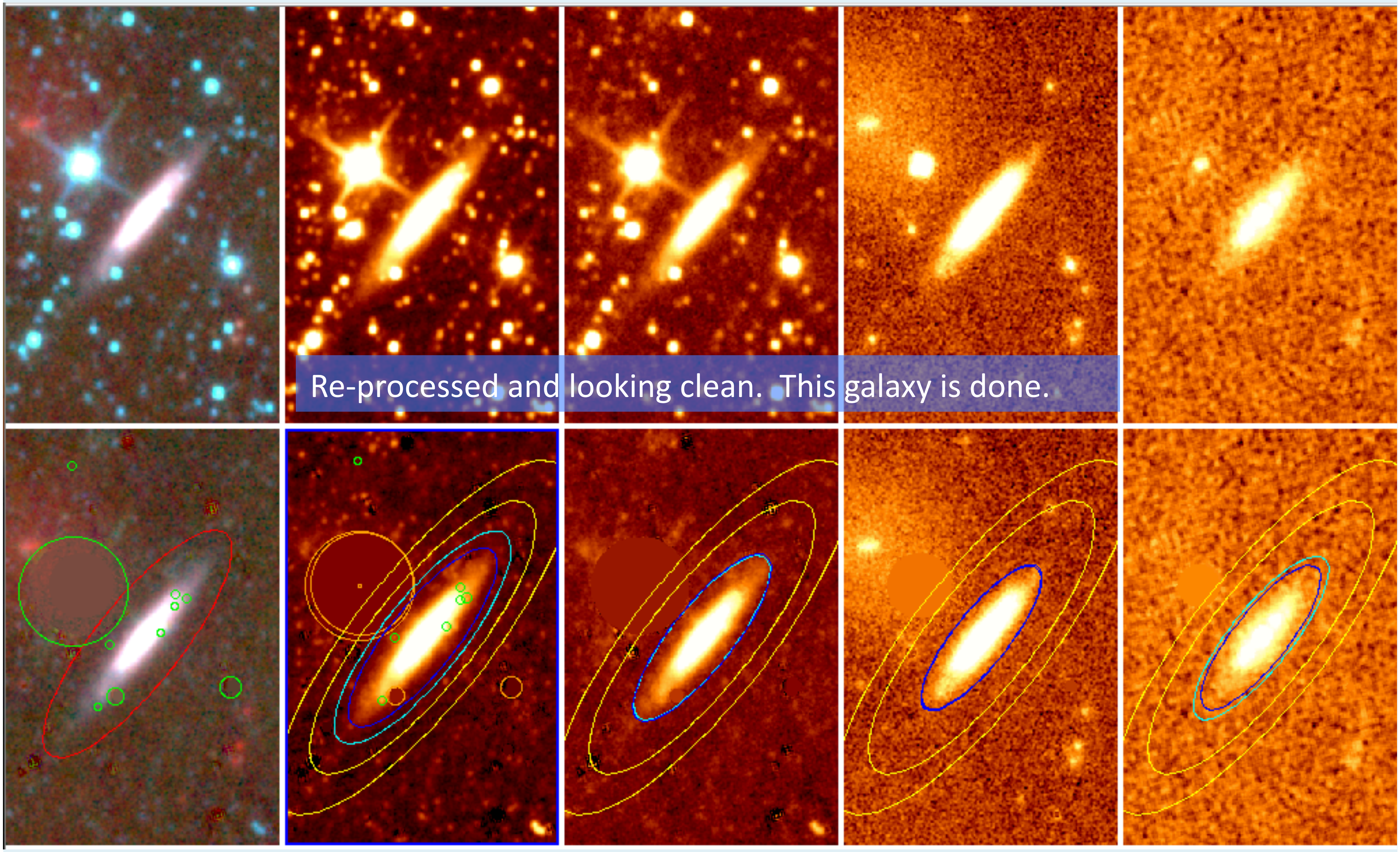
Example 4: Galaxy in the ZoA



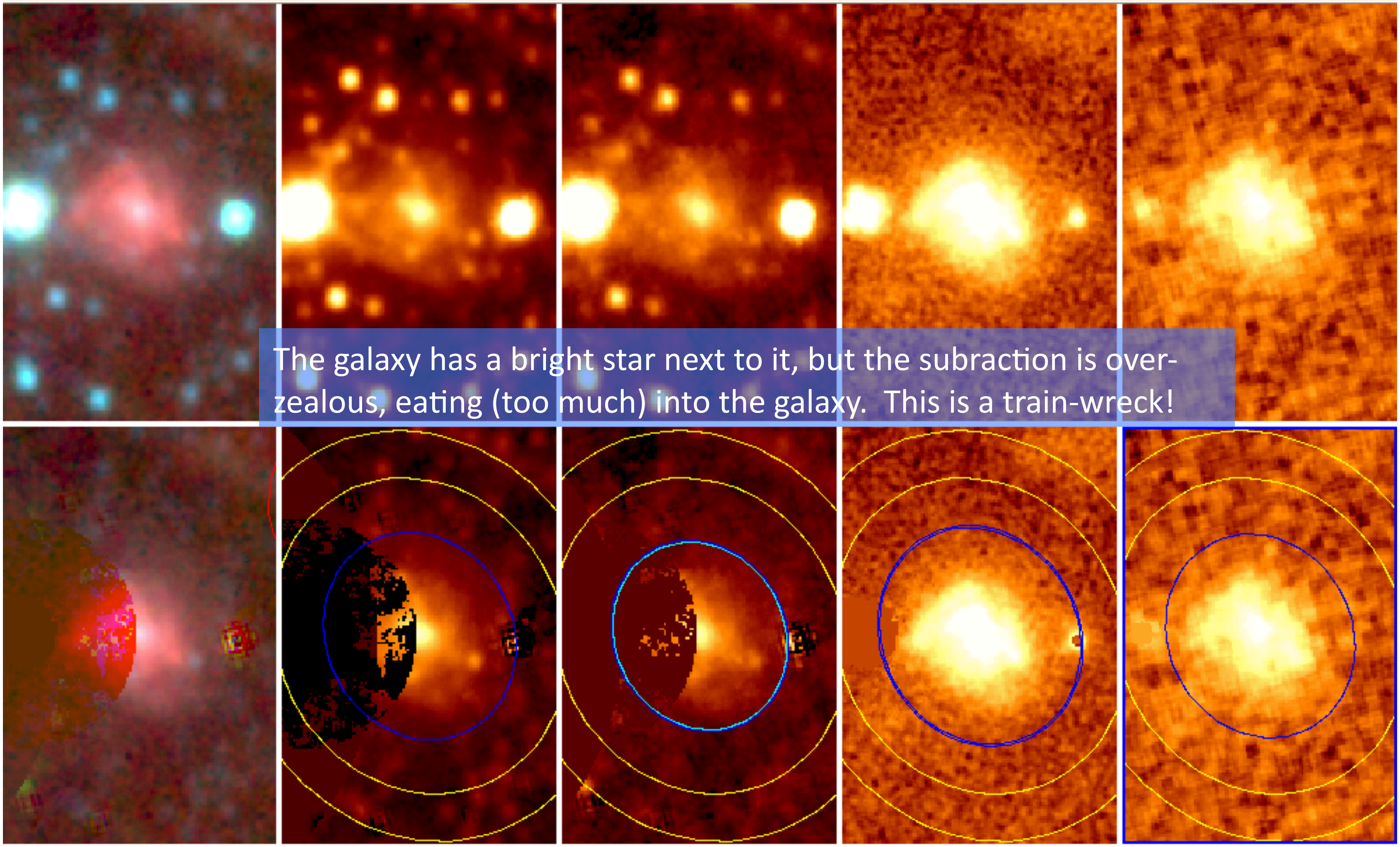
So we are going to subtract the little star at the top of the disk, and mask the previously-subtracted bright stars; options “m2” and “ma”

Ready to reprocess, option “x”

Example 4: Galaxy in the ZoA

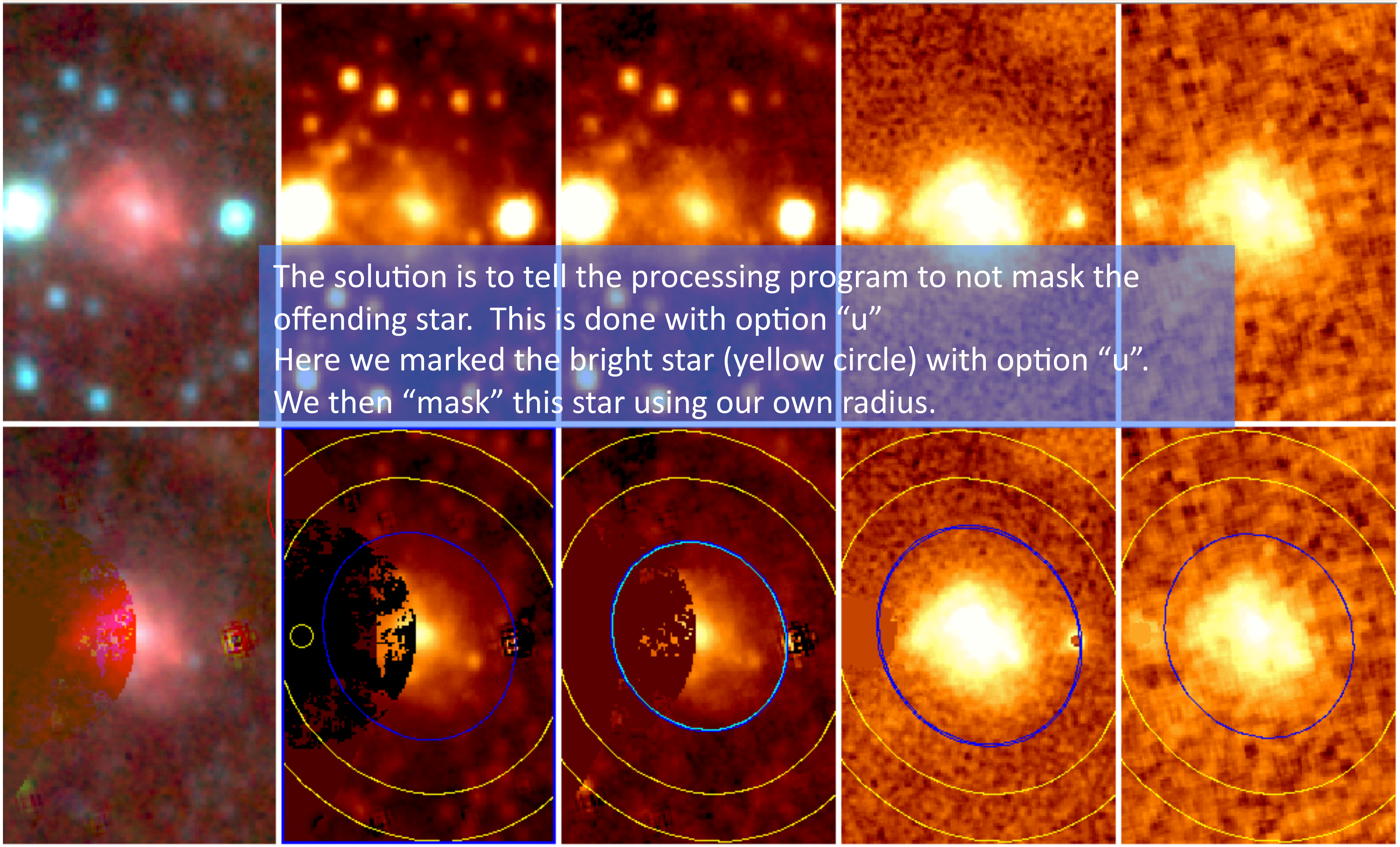


Example 5: Galaxy in the ZoA



The galaxy has a bright star next to it, but the subraction is over-zealous, eating (too much) into the galaxy. This is a train-wreck!

Example 5: Galaxy in the ZoA

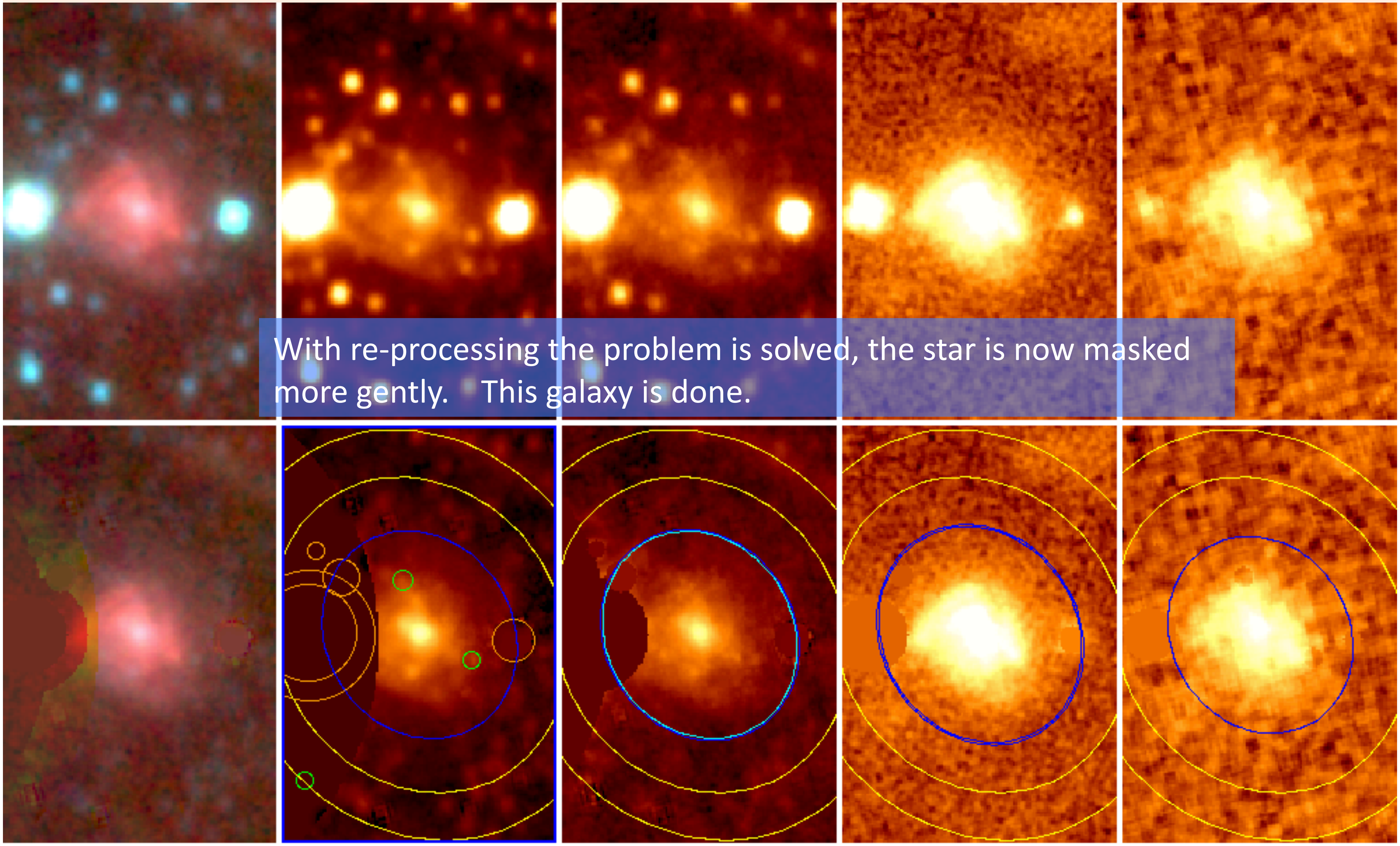


The solution is to tell the processing program to not mask the offending star. This is done with option "u"

Here we marked the bright star (yellow circle) with option "u".

We then "mask" this star using our own radius.

Example 5: Galaxy in the ZoA



With re-processing the problem is solved, the star is now masked more gently. This galaxy is done.