

# Lessons learned from large surveys of galaxies

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# The S<sup>4</sup>G Team



- **Kartik Sheth, Caltech, Original PI \***
- **Joannah Hinz, University of Arizona \***
- **Armando Gil de Paz, UCM, Madrid \***
- **Michael Regan, STScI \***
- Karin Menendez–Delmestre, OCIW \*
- Mark Seibert, Carnegie Observatories \*
- Juan Carlos Munoz–Mateos, UCM, Madrid
- Trisha Mizusawa (AMNH/SSC/Caltech)
- Tom Jarrett, Caltech
- Eija Laurikainen, University of Oulu, Finland
- Heikki Salo, University of Oulu, Finland
- Dimitri Gadotti, MPIA, Garching
- **Johan Knapen, IAC, Spain**
- **Debra Elmegreen, Vassar College**
- Eva Schinnerer, MPIA, Heidelberg
- Ron Buta, University of Alabama
- Patrick Ogle, Caltech
- Luis Ho, OCIW
- Bruce Elmegreen, IBM
- Lia Athanassoula, OAMP, France
- Albert Bosma, OAMP, France
- Lee Armus, Caltech
- Barry Madore, OCIW
- Dennis Zaritsky, University of Arizona
- George Helou, Caltech
- Chien Peng, NRC, Canada
- Jason Surace, Caltech
- Karen Masters, University of Portsmouth
- Bahram Mobasher, UC- Riverside
- Jin Koda, Caltech
- Peter Capak, Caltech
- **Taehyun Kim (NRAO)**
- Bonita de Swardt (SAAO)
- Sebastien Comeron (IAC, SPAIN)
- Sharon Meidt (UNM / MPIA)
- Mansi Kasliwal (Caltech)
- Manuel Aravena (NRAO)
- Jarkko Laine, University of Oulu, Finland
- Benne Holwerda (SAAO)
- Sabrina Stierwalt (SSC/Caltech)
- Aaron Kingery (UVa)
- Loreto Barcos (UVa)
- Alexa Ross (Reed College)
- Raquel Chicharro (UCM)
- Asha Tailor (U. Witswatersrand)
- Robert Groess (U. Witswatersrand)
- &..we hope more will join the team..

# Motivation



- Nearby galaxies are the “fossil” records of galaxy evolution
- Provide a wealth of detail to test current models of galaxy formation and evolution
- **Create the ultimate survey of the distribution of stellar structures, their masses and properties in the nearby Universe.**
- **Spitzer Warm Mission - an ideal instrument for such a survey!**
- **S<sup>4</sup>G is a volume-, magnitude- and size- limited survey of 2,331 galaxies with IRAC at 3.6 and 4.5mm (240s, 637.2 hrs)**

# The Spitzer Space Telescope



- Launched 25 August 2003
- 85 cm mirror, Earth-trailing orbit, currently  $1.1 \times 10^8$  km from us
- 3 instruments: IRAC, IRS, MIPS, coverage  $\sim$  3-180  $\mu$ m
- Ran out cryogen on May 15, 2009
- Exploratory Science ( $>$  500 hrs) call - October 2008.
- Warm Mission - IRAC Channels 1 & 2 available - 3.6 & 4.5  $\mu$ m
- **10** programs awarded time - only one on nearby galaxies

# Tracing the Stellar mass



- **3.6 and 4.5 mm - ideal tracers of the stellar mass distribution**
  - Rayleigh-Jean limit of blackbody emission at  $T > 2000$  K
  - [3.6]-[4.5] independent of age / mass function of stellar population
  - Effect of dust extinction is negligible
  - Spitzer can image to extremely low stellar mass surface densities **not** (easily) achievable from the ground

# Tracing the Stellar mass



- **Caveats for the 3.6 and 4.6mm bands for tracing the stellar mass**
  - Very weak 3.3mm PAH feature ( $< 2\%$  of EW, Tokunaga et al. )
  - Hot dust ( $T_d > 500$  K) can contribute at 4.5mm - conditions expected only near AGN or extreme starbursts
  - Low level of contamination ( $< 10\%$ ) from young red supergiants.
    - Same as ground-based near-IR but they also suffer from higher dust extinction than the IRAC bands
- 3.6 + 4.5mm critical for removing effects of PAH emission, for better modeling of stellar light and removal of systematics
  - See Meidt et al. (2011a,b) - contamination can be high in star forming regions - these are easily isolated so **BOTTOM LINE:**
  - **S<sup>4</sup>G data ARE the best data for tracing the stellar mass in galaxies**

# Space vs. Ground based

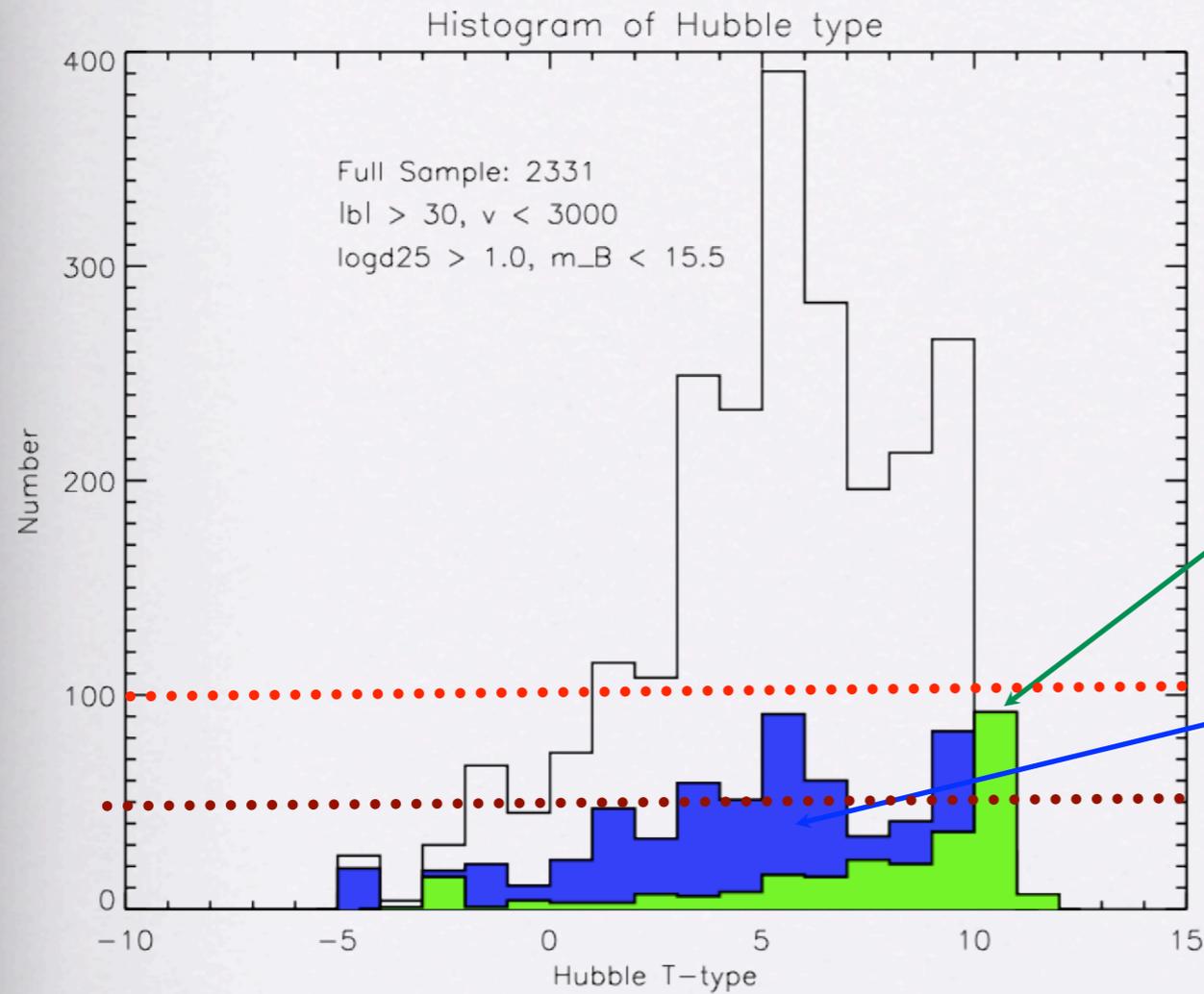


- Ground based NIR offers higher angular resolution than Spitzer but:
  - $m_k(\text{sky}) = 13.4 \text{ mag arcsec}^{-2}$
  - We want to reach  $\sim 13$  magnitudes below sky brightness level, which requires us to characterize variations to  $< 0.0003\%$ 
    - S<sup>4</sup>G reaches  $m_{3.6\text{mm}}(\text{AB}) = 27 \text{ mag arcsec}^{-2} (1\text{s})$
  - UKIDSS LSA, VISTA VHS  $\sim 18.4 (21.2 \text{ AB}) \text{ mag arcsec}^{-2}$ 
    - **Even with brighter stellar emission at Ks band, 2--4  $L_{\odot} \text{ pc}^{-2}$  whereas S<sup>4</sup>G  $\ll 1 M_{\odot} \text{ pc}^{-2}$**
- New Spitzer programs in Cycle 7 and 8 are doing tens of galaxies very deep (1 hr as opposed to 4 minutes, 4x deeper, 1.5 magnitudes deeper)

# Sample Selection



- Representative sample of spiral, elliptical and dwarf galaxies
- All galaxies with
  - $v_{\text{radio}} < 3000 \text{ km/s}$  ( $d < 40 \text{ Mpc}$ )
    - Led to a bias of only a few lenticular and elliptical galaxies
  - $m_B < 15.5$ ,
  - $D_{25} > 1.0'$
  - $|b| > 30^\circ$
- 2,331 galaxies (1,733 new targets)
- Mosaicked or mapped to  $1.5 \times D_{25}$
- 240s per pixel -> Image all galaxies to  $S_* < 0.1 M_\odot \text{ pc}^{-2}$ 
  - $m = 0.00722, 0.0093 \text{ MJy /sr} \sim 27 \text{ mag arcsec}^{-2}$
- **637.2 hrs**



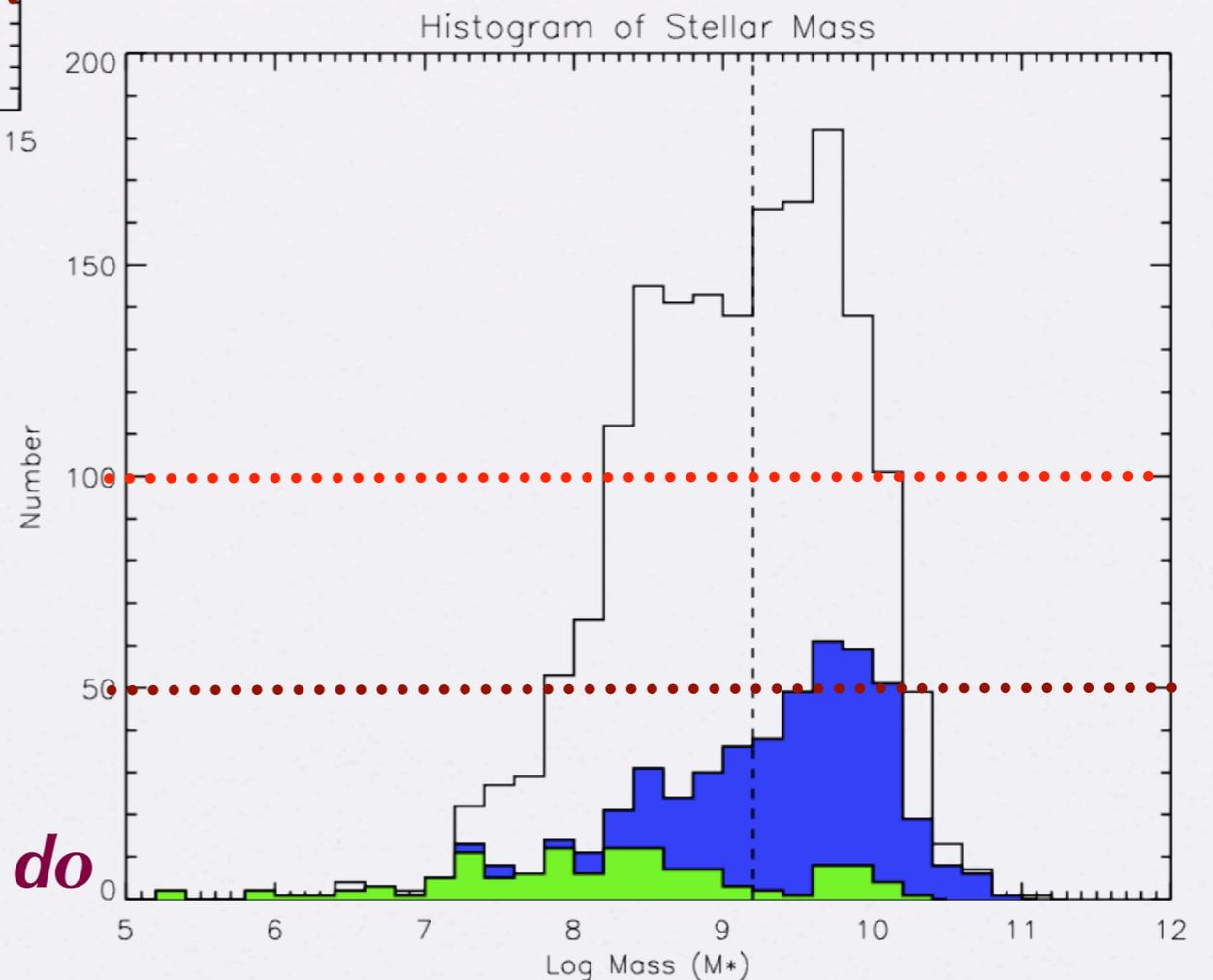
Local Galaxy Volume (3 Mpc)  
 survey (258 galaxies)

SINGS + GO + GTO  
 (339 galaxies)

★  $S^4G$  is needed to explore the full mass and T-type space.



*More and more convinced we should do things as mass selected samples*

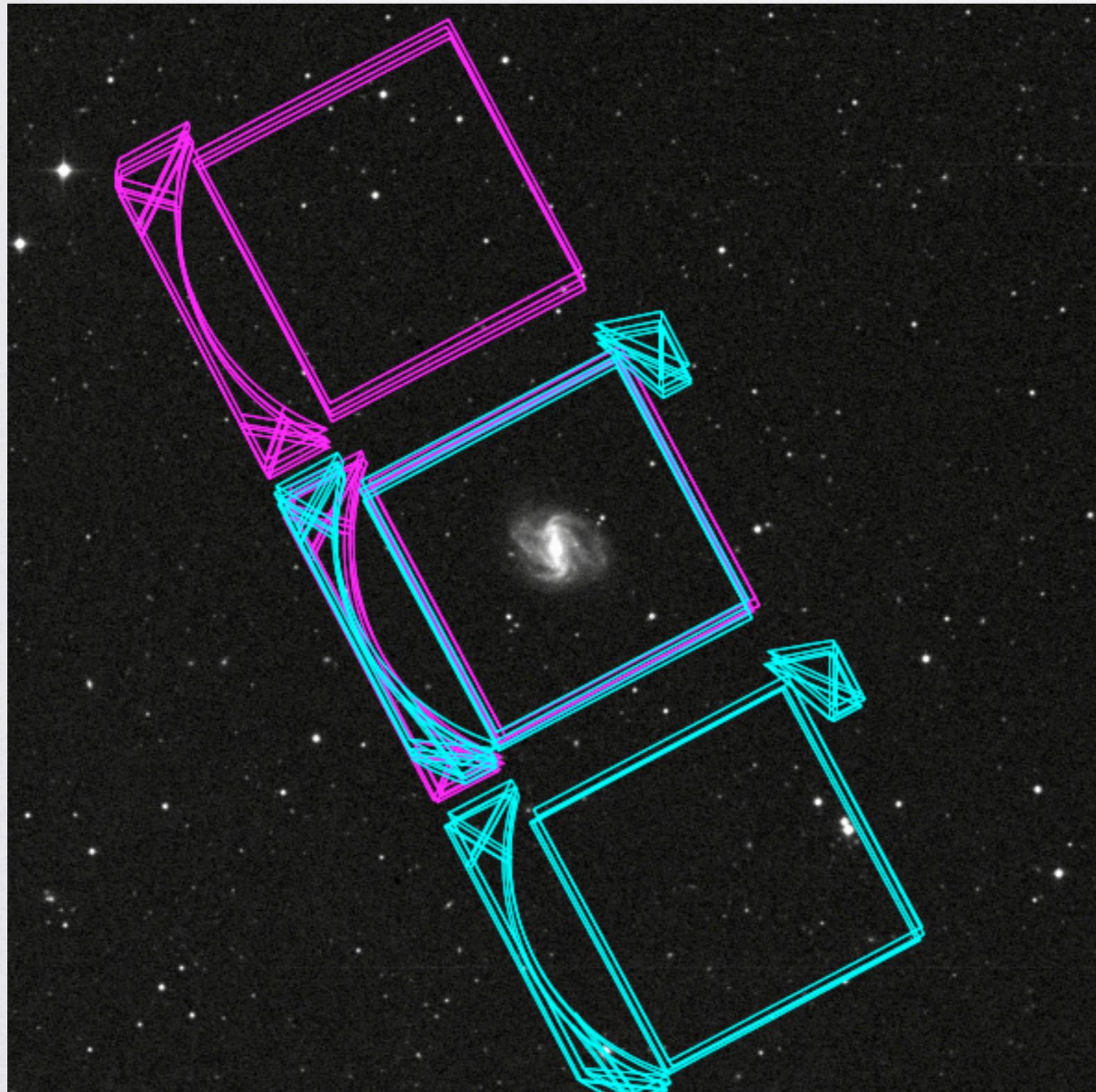


- 
- ★  $S^4G$  explores a range of large scale structure!
  - ★ *We need a LSS catalog (either as suggested by Barry using NED or using Tom's 2MASS catalog)*

*Like mass, consider the role of LSS in our studies (see Peng et al. 2010, 2011)*



# Observing Strategy



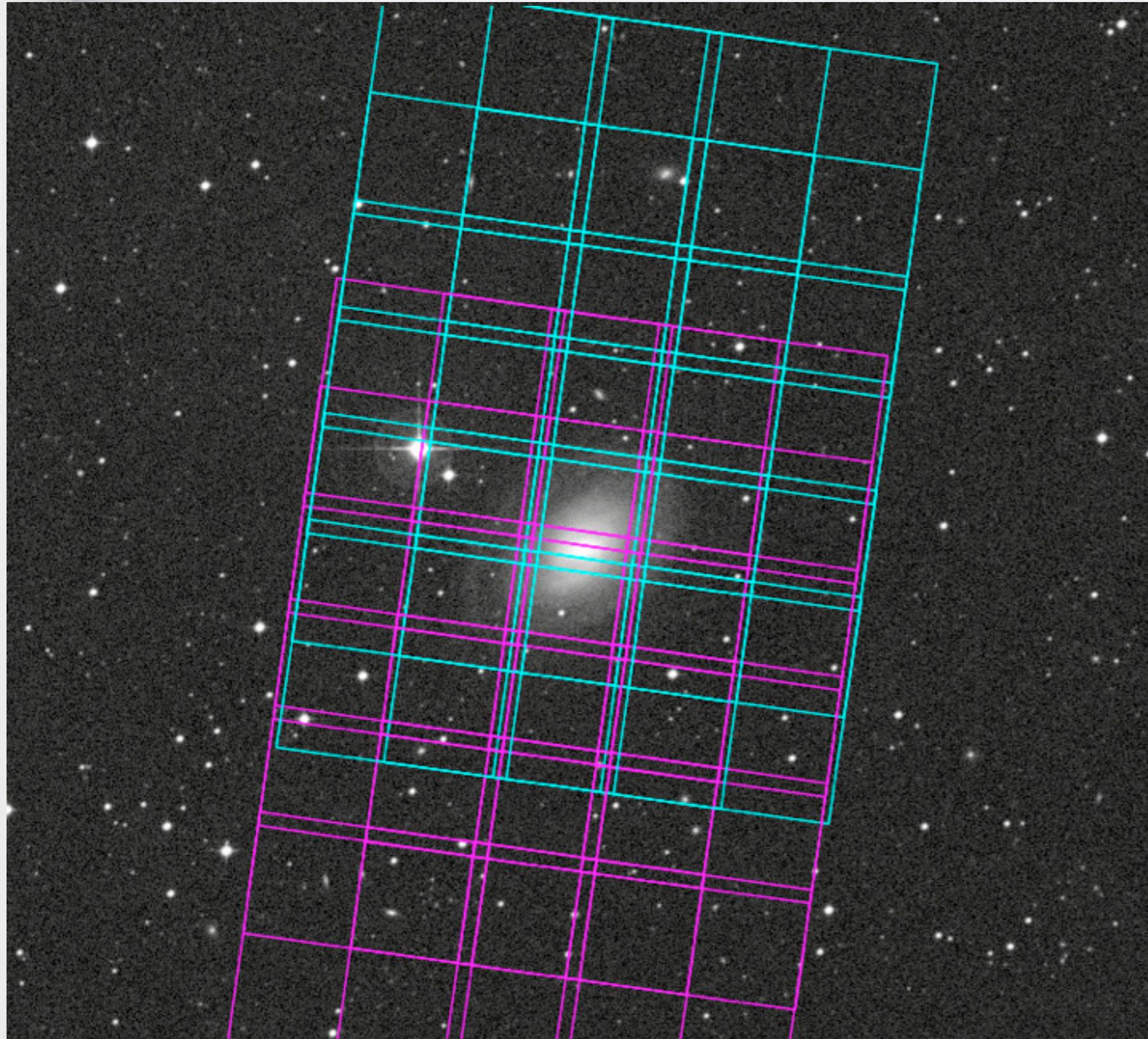
Small galaxies are observed with a dither map

Scattered light from stars a problem

Medium dither the other possibility

21 day interval between 2 AORs  
- we have not looked for moving objects

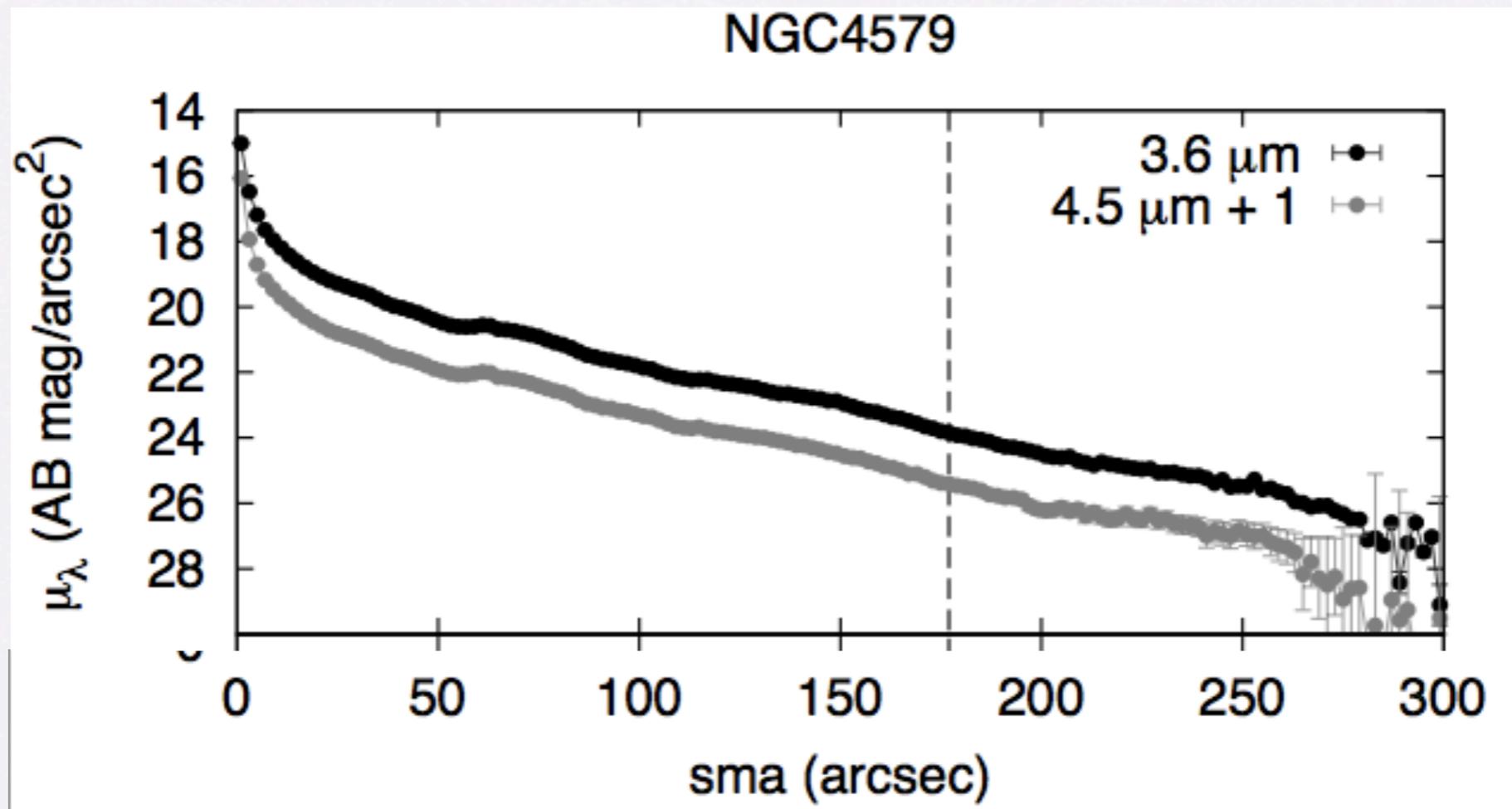
# Observing Strategy



Big galaxies are  
mosaicked with  
146.6" steps,

And with a slight  
offset from galaxy  
center

Also in 2 epochs



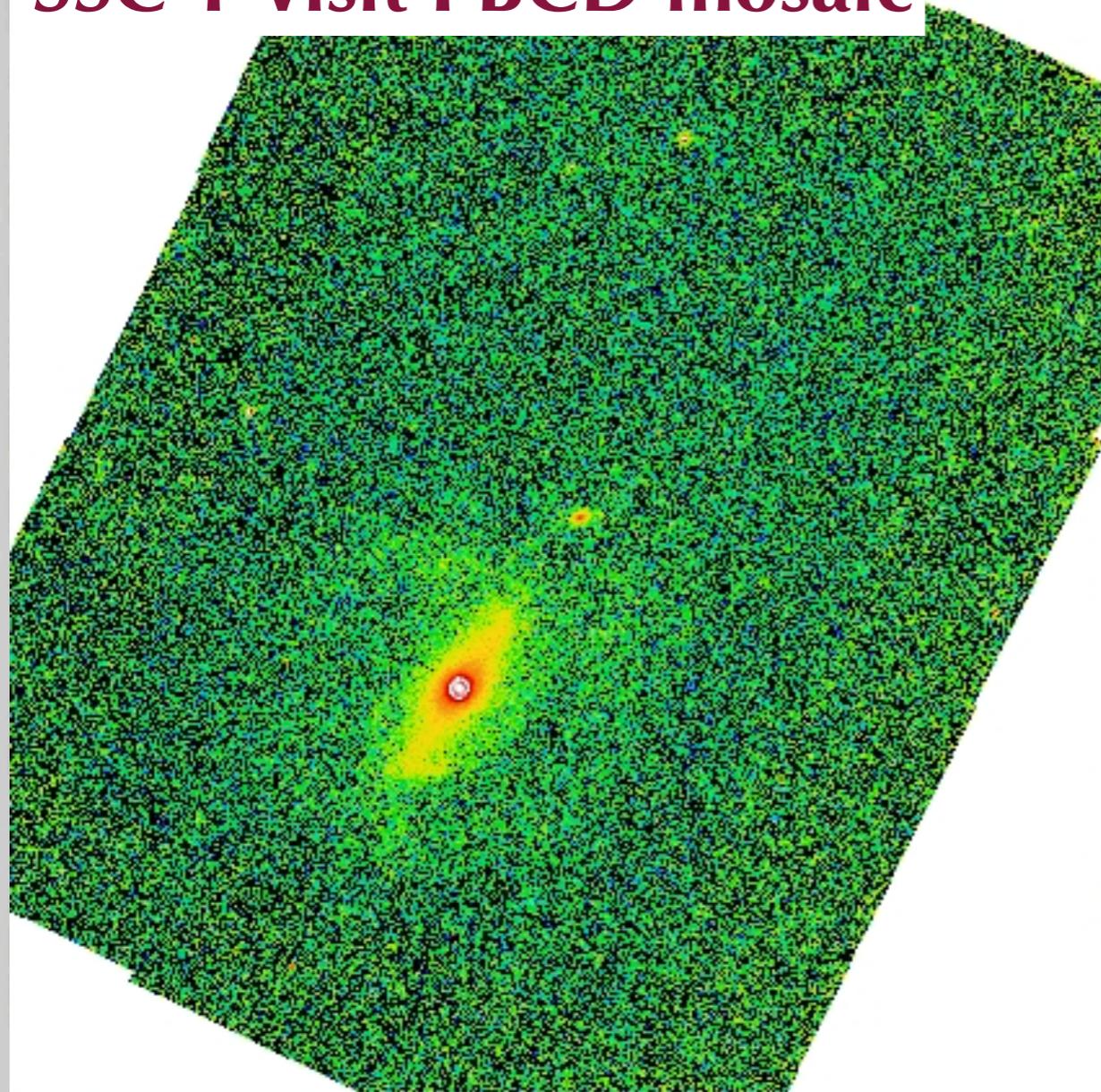
- ★ S<sup>4</sup>G images the extreme outer regions of galaxies
- ★ **Comparison to XUV disks critical (Chicharro et al.)**

# S<sup>4</sup>G Data Analysis & Pipelines

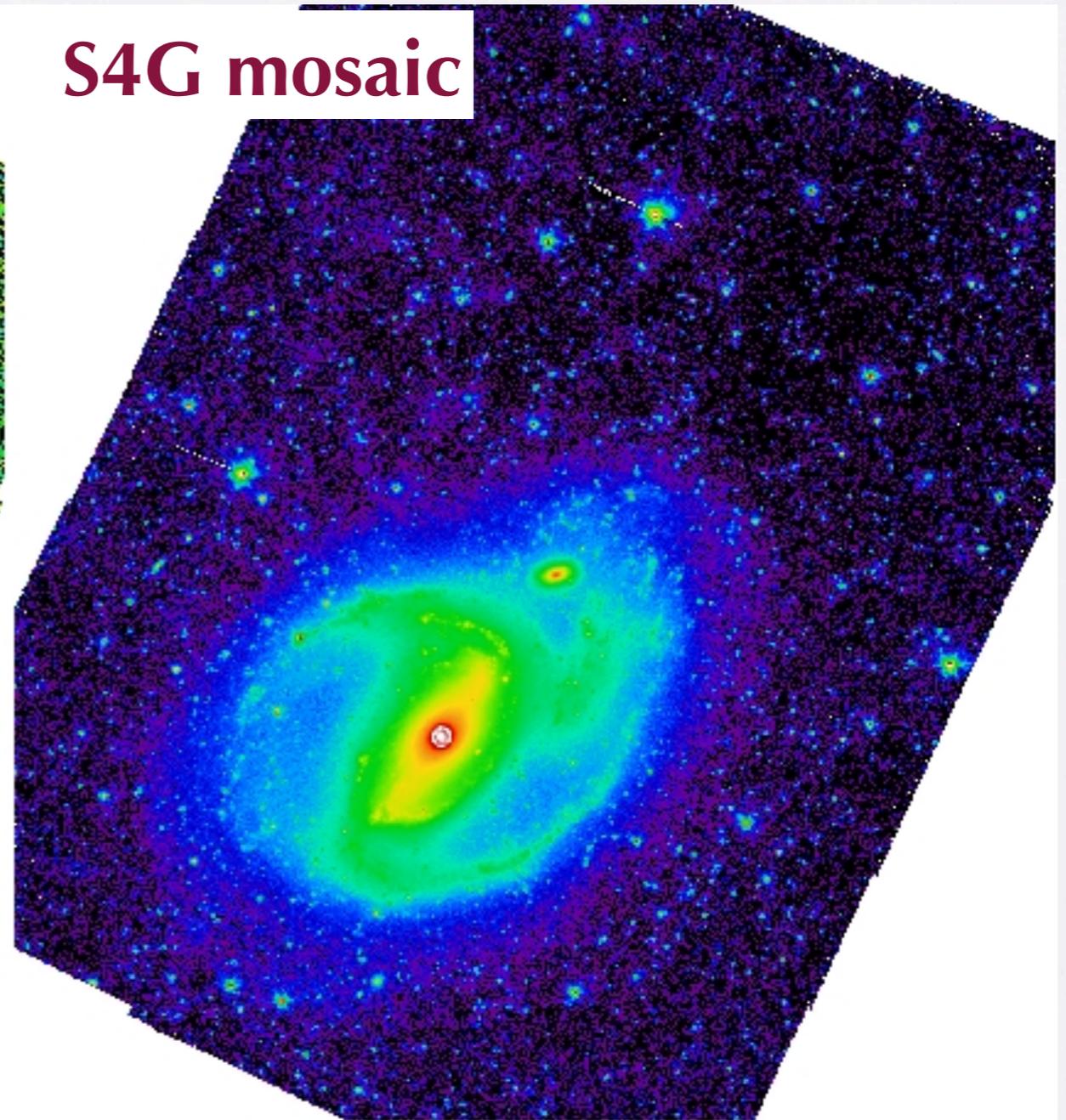
Enhanced from SINGS - [Regan et al.](#)



**SSC 1-visit PBCD mosaic**



**S<sup>4</sup>G mosaic**



We hope everyone uses S<sup>4</sup>G processed data

# Pipeline 1 & Remaining Time

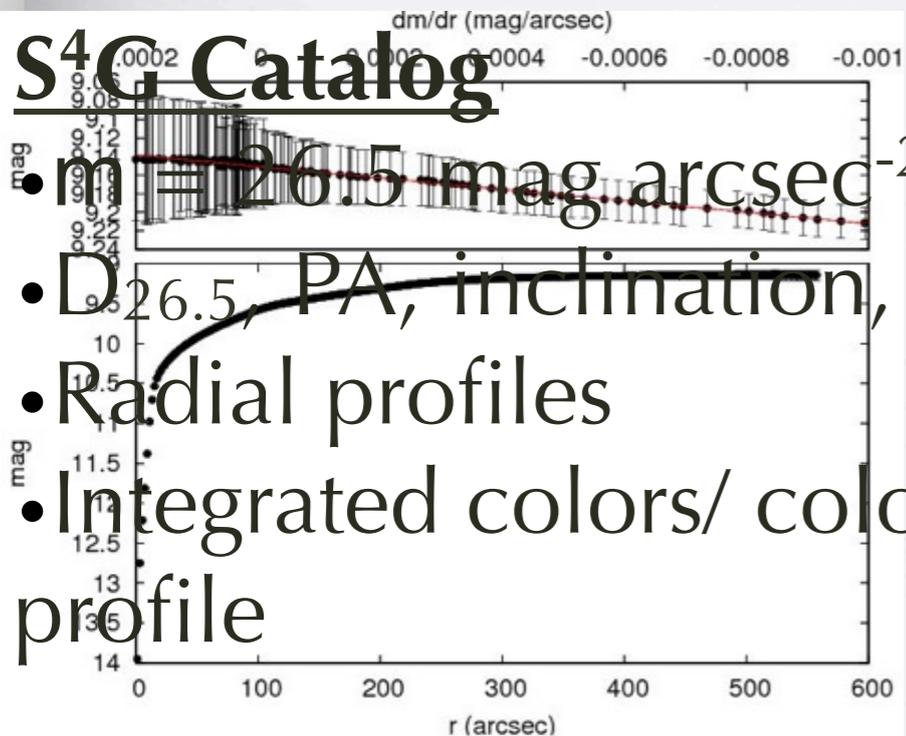
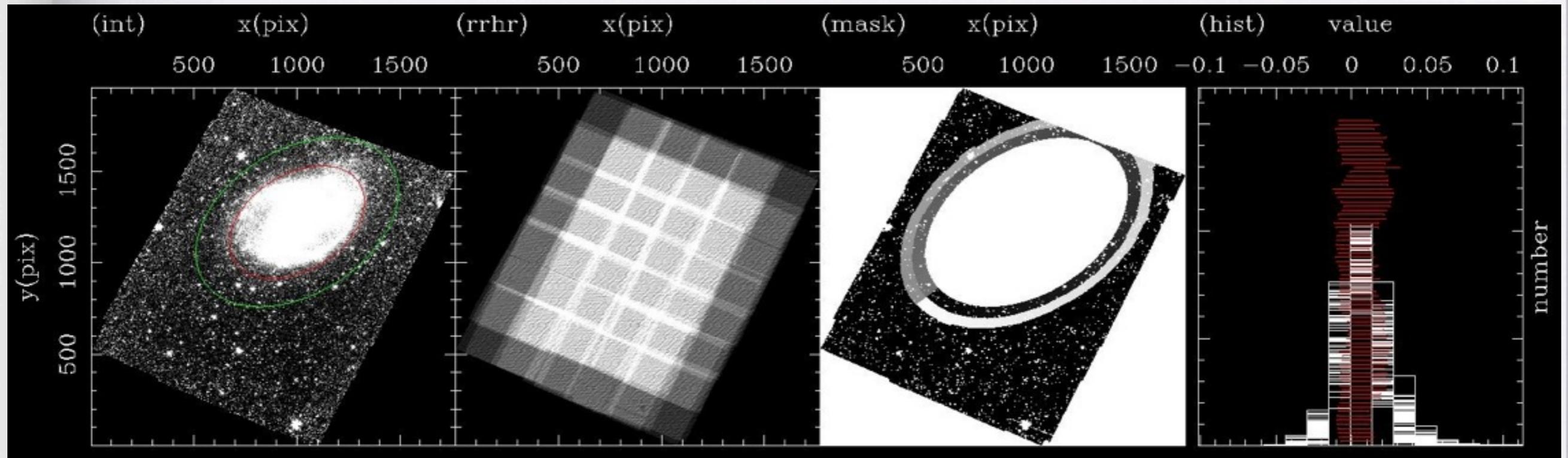
- **2129 Galaxies done and available to the team**
- 202 to be done (all but 7 scheduled / AORs submitted)
- NGC3166, NGC4491, NGC7314, PGC029653, UGC01862, UGC06903, UGC09837
  
- 8 will NOT be done because of a very bright star within 3' of the galaxy
- ESO400-026, ESO508-066, ESO603-006, IC0630, NGC3107, NGC7232B, NGC7233, PGC037625
  
- Preparing final AOR submission for remaining time:
- 1 or 2 deep observations (1 hr per galaxy?)
  - Should we try and just go deep in one band instead?
  
- Try to beef up SOs and Ellipticals following a list from Eija and Heikki
  - Should be able to do many tens of these (I hope!)

# Pipeline 2 & Progress (and lack thereof!)

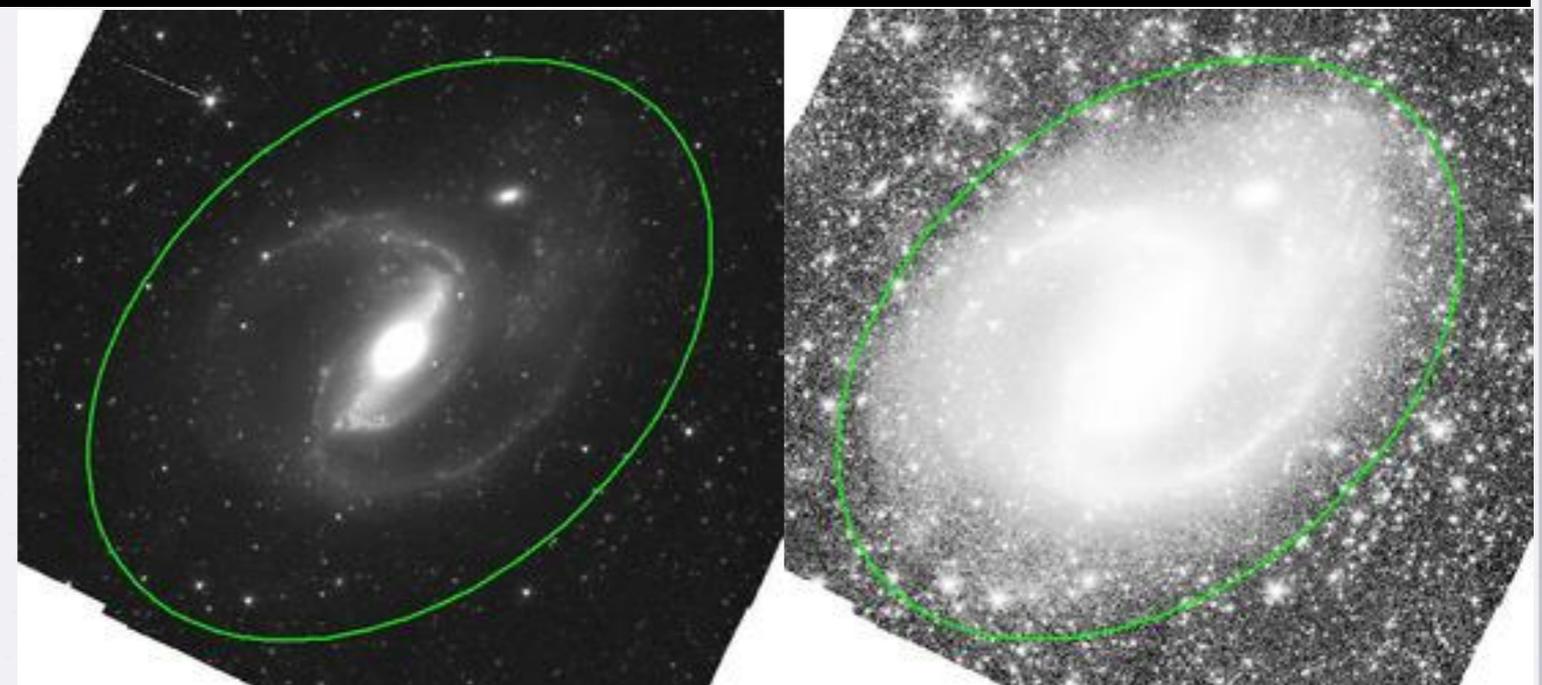
- **2129 SExtractor masks with low, medium and high thresholds done and available to the team (Kim, Mizusawa, Hinz, Sheth)**
- These then have to be checked by hand and an edited mask is created.
- **H. Salo** developed a script and process for doing so & their group did ~800 galaxies about a year ago.
- **Kim, Munoz-Mateos and Sheth** developed scripts for applying it to Ch2
- Technique taught to Kim, Regan, Erroz and Munoz-Mateos at October 2010 retreat and then to Rachel (STScI DA Analyst)
- Slow progress. Santi and Taehyun have delivered ~400 edited masks.
- Current total is **1274**, **855 more could be done - lack of progress?**

# Pipeline 3

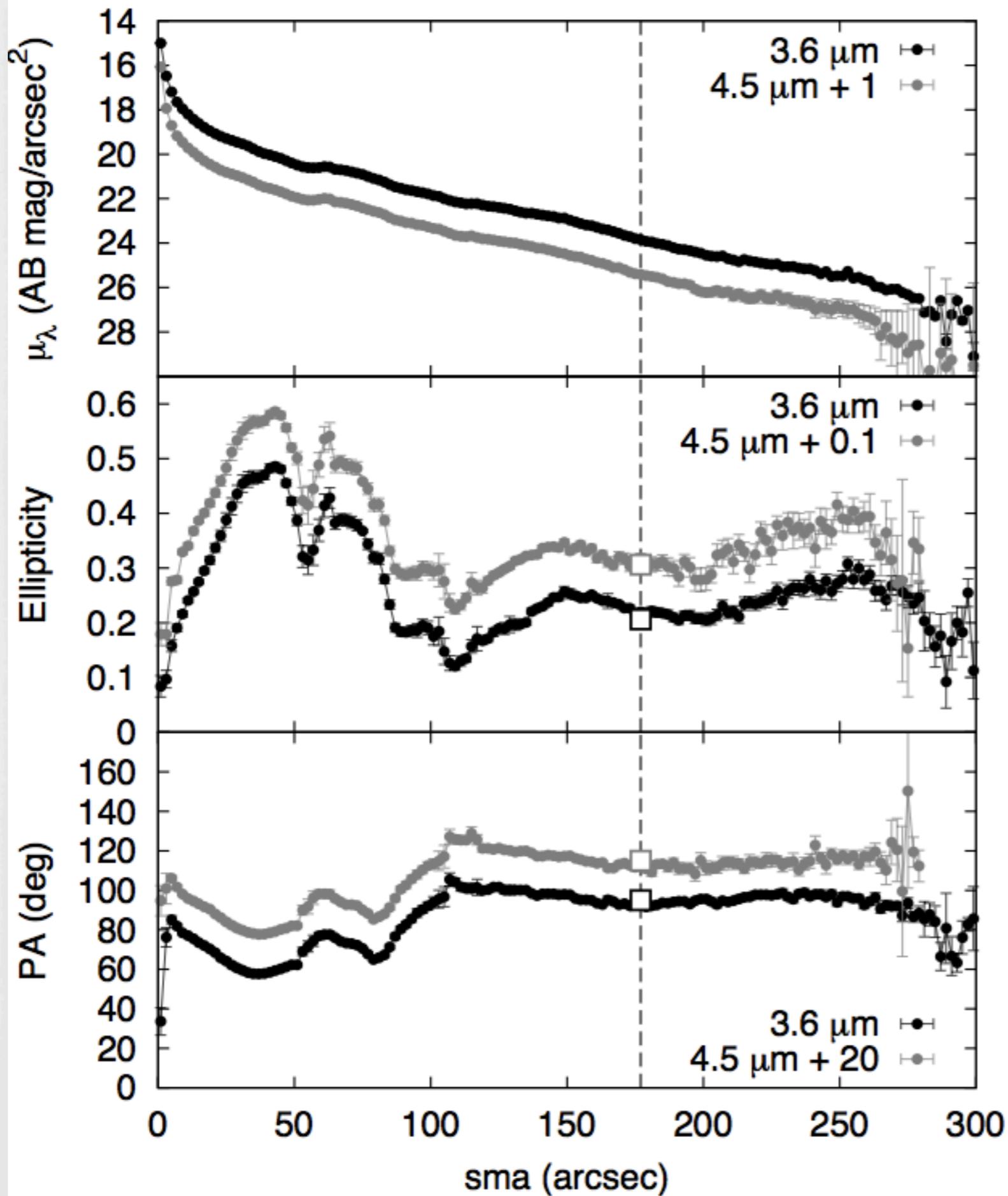
Munoz-Mateos, Gil de Paz, Laine



- $m = 26.5 \text{ mag arcsec}^{-2}$
- $D_{26.5}$ , PA, inclination,  $m$
- Radial profiles
- Integrated colors/ color profile



# NGC4579



## P3 & S<sup>4</sup>G Catalog

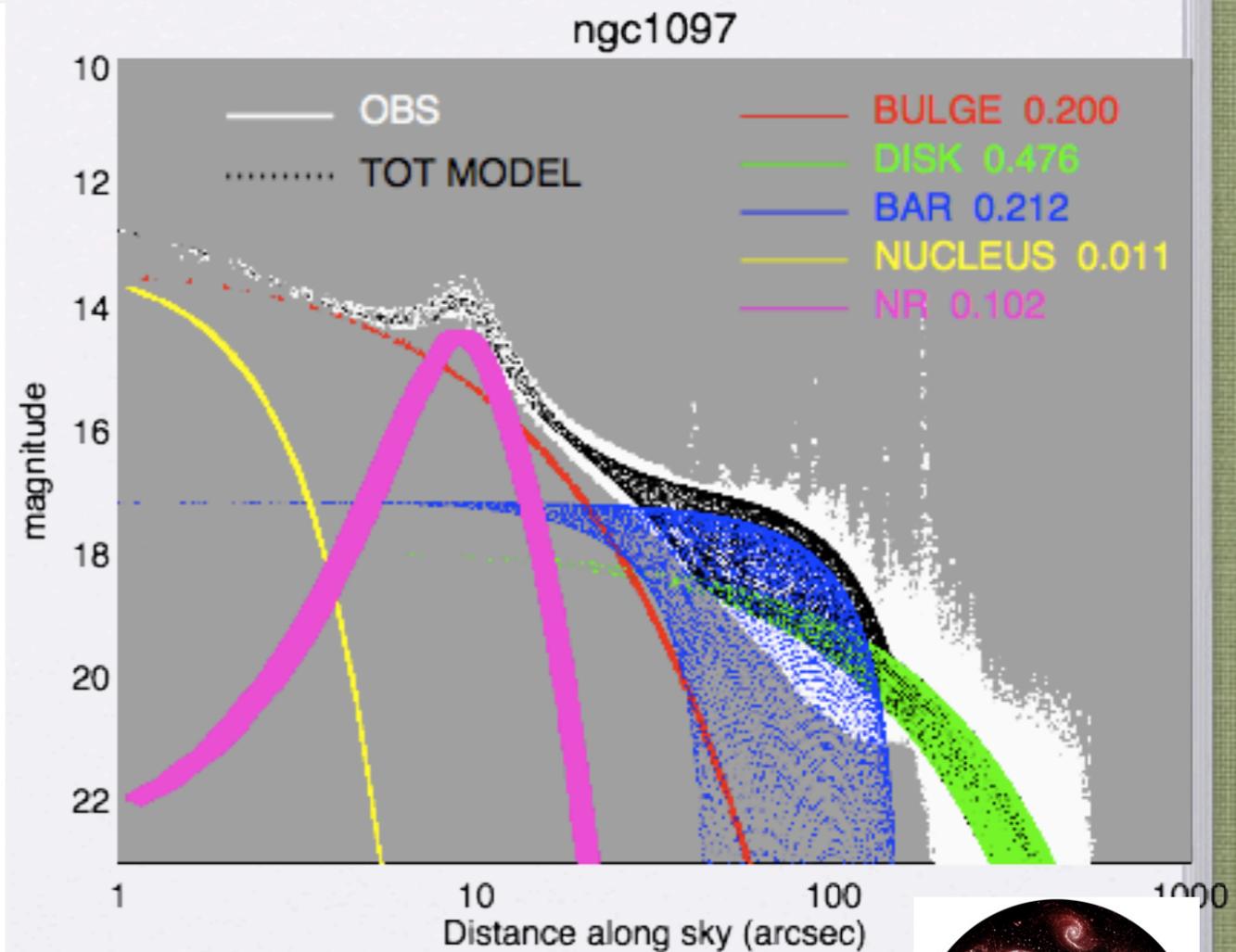
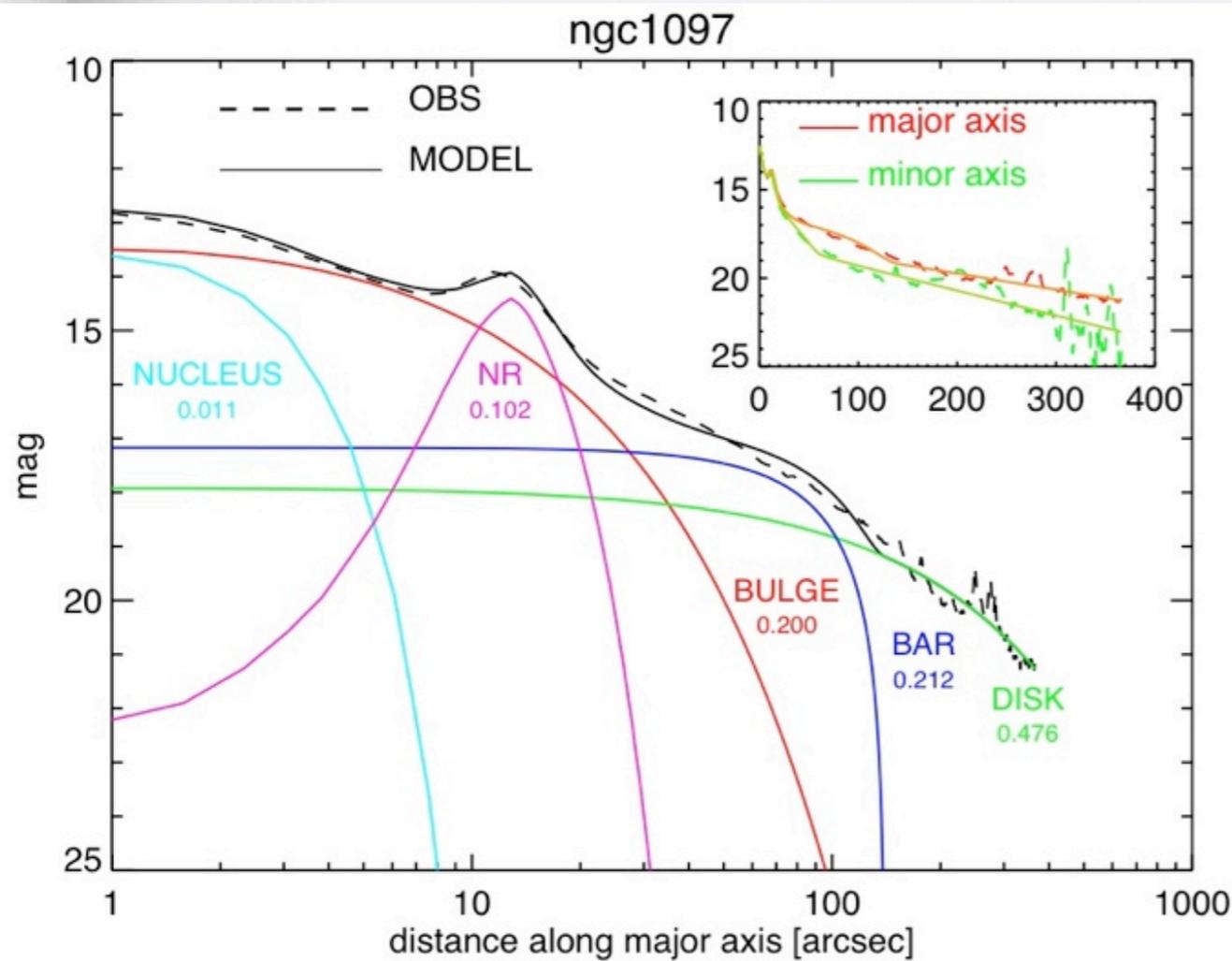
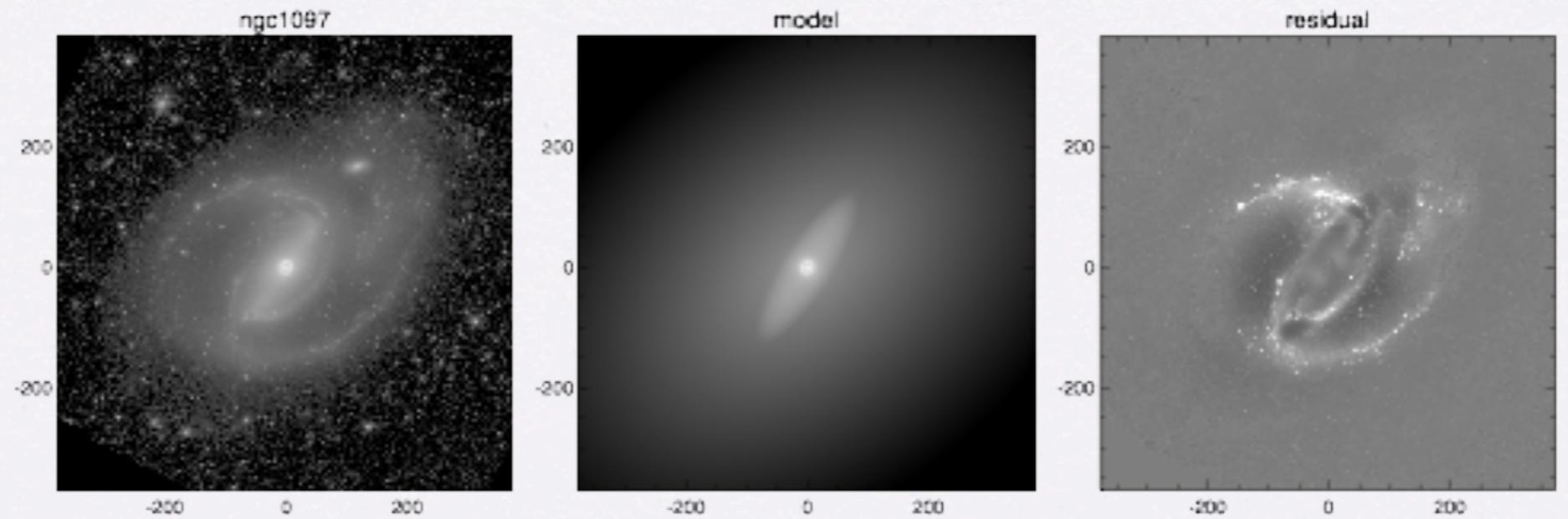
- Pipeline 3 has tremendous value.
- Not just global properties - it also provides azimuthally-averaged ellipticity, PA and surface brightness profiles!
- What can we learn from these?
- Truncations, Bars, Arms, Twists..what else?

# Pipeline 3 Progress

- **Automatic ellipses are available for all galaxies - ok for getting disk PA and inclination and thus as robust input to P4 if needed.**
- All fits need to be checked for failures in ellipse fitting code (centroid, bright objects, etc.) - slow because fitting has to be repeated!
- **805 done and available to the team** (also new P3 being run on these because images themselves changed in size)
- Juan Carlos + Laine about to add 400+ more?
- **Expect to have all P3 done for edited P2 masks by Aug 30?**

# Pipeline 4

- Decompose into: point source (if needed), bulge, bar and disk.



Decomposing galaxies using GALFIT



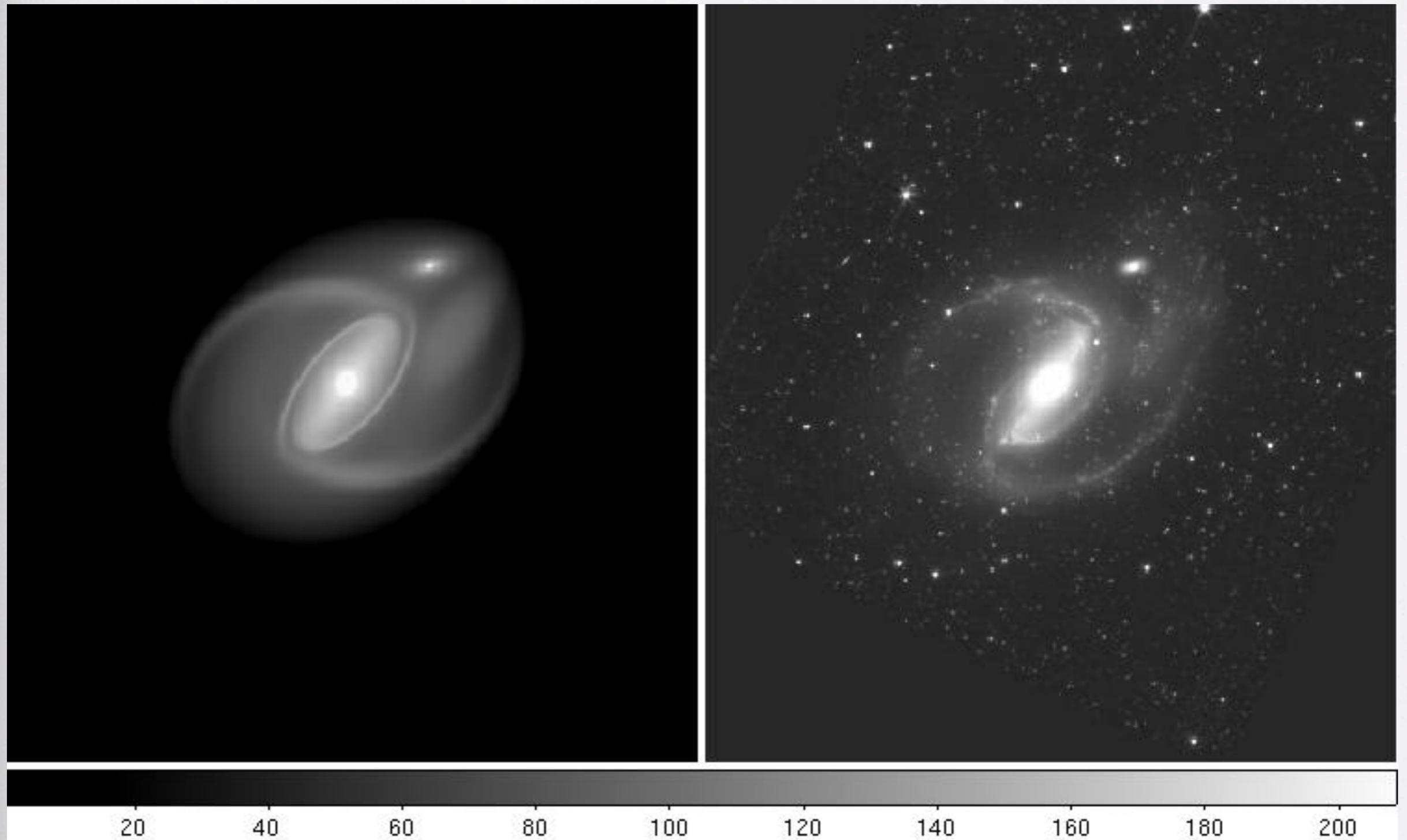
# Pipeline 4

- ~1000 done with 2 components?
- How many with 3 or 4 components?
- **NONE** on the server - will change very soon?
- Lesson learned from comparing fitting by experts (Gadotti vs. Laurikainen vs. Salo vs. Hinz)
  - Should we look at other fitting approaches within GALFIT and/or BUDDA (COSMOS precedent)
  - What about CAS parameters (Holwerda)?





Pathological galaxies = Complex analysis



9 component GALFIT fit by J. Hinz and CY Peng

# Team Policy, Data Products



- **Everyone in the community is welcome** to work with us - a unique? and detailed team policy in place.
  - No one working on more than 1 or 2 papers at a time
  - No proprietary area of science within team
  - At least 3 chances for everyone to be on all papers
  - Core data team only on all papers until publication
- Ultimately full catalogs with RC3-like (P3) and structural measurements (P4+) -> 2013-2014.

# Review of team logistics

- Team is growing - 40+ co-Is
- **SAC: Sheth, Regan, Hinz, Gil de Paz, Elmegreen, Knapen, Zaristky, Schinnerer**
- Server downloads ok - data shared openly & freely
- Abstracts on wiki - not working as well - need to do a reboot & perhaps automatic notifications for them / set deadlines for abstract review?
- Communication - good & bad
  - ~monthly telecons (average attendance ~ 15)
  - ~SAC mostly works through emails - needs to have more regular telecons
  - Team meetings: Pasadena, Marseilles, Lake Arrowhead, Oulu
    - Mini-meetings: IAC, Marseille, Charlottesville
  - Team participation can be improved, getting everyone together remains a problem.
- EU-ITN / DAGAL project successful
- New observational initiatives also underway - radio, optical, etc

# The Y-S<sup>4</sup>G

## ● Postdocs

1. Munoz-Mateos
2. Comeron
3. Meidt
4. de Swardt
5. Skibba
6. Masters
7. Stierwalt?
8. Wong?
9. Nair?
10. Aravena?

## Graduate Students

1. Taehyun Kim
2. Santiago Erroz
3. Jarkko Laine
4. Aaron Kingery
5. Loreto Barcos
6. Raquel Chicharro
7. Zaritsky-student?
8. Asha Taylor
9. 5 more EU-ITN?

## Undergrads

1. Alexa Ross
2. Trisha Mizusawa

We should do:

- Short (1) & long (6 month) visits?
  - S<sup>4</sup>G has paid for Santi, Jarkko, Munoz-Mateos
  - ESO + S<sup>4</sup>G paid Kim in Chile
- Exchanges for visitors
  - Buta coming to NRAO
  - S<sup>4</sup>G paid for reg fees at Lake Arrowhead
  - Oulu paying for reg fees here

Working groups could help this!

# Team Policy, Data Products



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# The S<sup>4</sup>G Policy

- Science Policy developed input from a lot of folks and previous experience (SINGS, SONG, COSMOS, etc.) - verbally approved by everyone
- Anyone joining the team is asked to read it and agree to it in writing.
  - The S<sup>4</sup>G collaboration is built on these **four** principles:
    - 1) Promote the most prompt and widest possible scientific exploitation of the continuously growing S<sup>4</sup>G database. Every S<sup>4</sup>G team member will have an equal opportunity to lead research and publications with S<sup>4</sup>G data.
    - 2) Respect the legitimate expectation of a team member who has contributed to the project to have an opportunity to exploit the data scientifically, either on their own if no one else is doing the same thing, or in collaboration with others in the S<sup>4</sup>G team
    - 3) Respect, communicate, collaborate, interact and share freely science ideas, comments and suggestions, data, and professional opportunities with fellow S<sup>4</sup>G members
    - 4) Publish and discuss finished S<sup>4</sup>G results with the broader astronomical community.

Policy now being used by LADUMA, N1097-ALMA, others..

# Our Ground Rules

- Salient Points to Remember:
  - Open collaboration (**mostly**) - short term and long term participation encouraged
  - NO carving out of territory is allowed (*so refrain from wanting to address every issue of a topic in one paper if feasible*) -- nor is anyone prevented from leading any science that interests them.
  - Team members may not lead more than one (or at most two papers) at any given time. It is understood that thesis students and postdocs may define a series of papers they want to do as a cohesive whole over a multi-year project yet the above statement still applies.

# Our Ground Rules

- Open communication to encourage collaboration but internal competition is also considered good (*Two papers addressing the same science question in different ways / techniques only help bolster the confidence in the result / robustness of the outcome and the papers mutually strengthen each other.*)
- All projects to be announced via an abstract on the wiki (should be have an automated version for this?) - anyone welcome to join - contact PI
- SAC may take a proactive role and encourage teams to include certain team members as co-Is
- At least **3 chances** for everyone to contribute and be on a paper.
- Once when abstract is posted, then when a draft is posted (at least 3 weeks prior to submission - see policy), and even after referee comments. Essentially one should feel free to contribute to a paper at any time.
- Considering policy wording change for faster turnarounds on press-ready results?

# Our Ground Rules

- Salient Points to Remember:
  - PI responsible for authorship and ordering of authorship - Science Advisory Committee to ensure fairness / resolve conflicts.
    - *Authors must remember that the project has been a long term project and many folks have made it successful from writing the proposal to collecting the data etc. Guests do not automatically pass core team on paper authorship if all they do is make extensive comments on the paper drafts - role has to be of critical importance on other team members papers (policy wording change proposed)*
  - **All papers will contain “S<sup>4</sup>G” in the title and reference the main overview paper and include the acknowledgement to the team, NASA, and NSF.**
  - **All talks should use the S<sup>4</sup>G logo on each page.**
  - **Page charges to first draw on local resources but \$10K set aside for 2011 & 2012**
  - Talks and conference proceedings will also be posted on the wiki, announced to the team and contain S<sup>4</sup>G in the title.

# S<sup>4</sup>G in the next decade

- **Ancillary Data (Products?) Teams:**

- ADT - well-defined group that contributes a significant value-added data set to enhance the IRAC S<sup>4</sup>G data
  - GALEX, Halpha, Fabry-Perot, HI, Optical, Simulations, CO, HCN etc.
- Proposed policy based on experience with COSMOS:
  - ADT team spends significant effort to produce product and so ADT team gets some time / privilege to exploit data set, during which others within team may work with ADTs - SAC to mediate as necessary
  - ADT releases coherent data set to team privately after initial time and whole team can use data + expect to involve ADT team as co-Is on papers using those data.

**Significant new efforts should build on S4G brand name and avoid rebranding the effort (example: C-COSMOS, S-COSMOS, zCOSMOS) - team cohesion, greater visibility and better synergy.**

# Science Achievements

- Overview Paper (Sheth et al. PASP, 2010)
  - Needs erratum for positions / incorrect LEDA properties
  - Update from Spitzer obs / addition of E + SOs. - how do we do it?
- Morphology paper for 200 galaxies (**Buta** et al. 2010)
- New one with 1500 galaxies - Buta visits NRAO for a week in August
- Edge on galaxies papers - NGC 4314, 3 disks letter + 46 galaxy sample (**Comeron** et al.)
- Spiral arms and arm-interarm in MIR (**Elmegreen** et al.)
- Two mass map papers (**Meidt** et al. 2011)
- ETG paper (**Kim** et al. 2011) - draft sent today.
- NGC 3906 paper (**de Swardt** et al.) - almost complete draft
- 5 submitted / in print.. time is ripe for us to now be as strategic!

# Now what?

- *Commonly heard criticisms: “Nearby galaxies are boring” // Morphology / shapes - its very classical and uninteresting. // Butterfly collecting - was done so long ago.*
- **Let us dream bigger!**
- **We must connect to physics, dark matter, star formation, galaxy evolution and assembly and cosmological evolution.**
- **Draw in people otherwise uninterested in nearby galaxies, structure and secular evolution!**
- **Critical for :**
  - Getting significant time on telescopes
  - To secure funding
  - To get the best graduate students and postdocs.

# A Strategic Plan - Bars

- Outstanding questions in the field of bars:
- What is the true distribution of bars? How does it vary at the extremes of the Hubble sequence? as a function of mass?
- Can we place the rectangular vs. oval type of bar in better context of secular evolution - are there two or more kinds of bars? Do they change over time?
- Do bars drive spiral arms? In what types of galaxies? How?
- How do we characterize bar strength? What is the impact on mass inflow / secular evolution? Do they feed AGN? How do they feed central starbursts?
- Why are there unbarred spirals? Any evidence of destroyed bars?
- How do bars evolve over time? What are the observational constraints on bar shapes, properties etc. with time?
- How old are bars?
- What is relationship between rings and bars? lenses and bars? What is the implication of the bar frequency as a function of galaxy host properties?

# A Bars Special Issue?

- Regular group meetings at NRAO
- Bars sub-meeting -- November or Dec in Chile?
- Frequency of bars /  $f(\text{host properties})$  - Sheth et al.
- Structure of bars / later in cosmological context - Kim et al.
- Bars and star formation - Barcos et al.
- Inner rings and Bars - Kingery et al. + Rings in general - Comeron et al.?
- Impact of bars on disks - Munoz-Mateos et al., Gadotti et al.
- Strength of bars - Salo et al.
- $Q_g$  and ellipticity of bars - Tailor et al.
- Bar properties as a function of wavelength - Menendez-Delmestre et al.
- Offset bar frequency - Ross et al.
- NGC 3906 - de Swardt et al.
- Bars in the UV - Chicharro et al.
- Bars driving spiral arms - Salo et al.
- Bar pattern speeds - Salo ?
- Other papers - theoretical underpinnings / simulations?

# What other special issues are there?

**I would like to leave Oulu with a clear plan on what specific and cohesive science issues we are working on. I would like leaders to step up to this and provide an initial plan + time line.**

- Bulges -- Dimitri to lead?
- Spiral arms - Athanassoula / Elmegreen?
- Low mass systems / dwarfs - Buta / Kingery?
- Formation of E / S0s - Laurikainen ?
- Star formation history of disks - Knapen
- Disk truncation / disk growth - Gil de Paz + Munoz-Mateos
- Structure and dynamics of disks -- very broad - perhaps divide into multiple parts?
- TF with S4G - note some of this is already being done within S4G and outside of S4G (e.g., CHP, Tully etc.)
- S4G + COSMOS - ??

# Papers being worked on at this meeting

- 1. Disk growth / truncations by a bar - Juan Carlos, Sheth, Laine, ++
- 2. ETG paper - wrapping it up - T. Kim, Sheth ++. (I have a nearly final draft of this)
- 3. Boxy Bulges paper - Gadotti, Kim, Sheth, Athanassoula, Bosma ++
- 4. Mass I - Meidt ++ (submitted / replied to referee)
- 5. Mass II - Meidt ++ (working on draft)
- 6. Disk profiles in 200 S4G galaxies (Laine, Laurikainen, Salo ++ (draft?))
- 7. CAS analysis of S4G galaxies (Holwerda ++ (draft?))
- 8. Offset bar in NGC 3906 (de Swardt, Sheth, Kim, Knapen, Hinz ++ -
- 9. Bar frequency in S4G galaxies -(Sheth et al., draft started)
- 10. Multifit - techniques (Hinz, Peng et al. status?)
- 11. Bar strengths (Salo et al, - status?)
- 12. ..??