STELLAR TIDAL STREAMS IN THE LOCAL UNIVERSE

PhD Thesis Juan Miró Carretero

Directors
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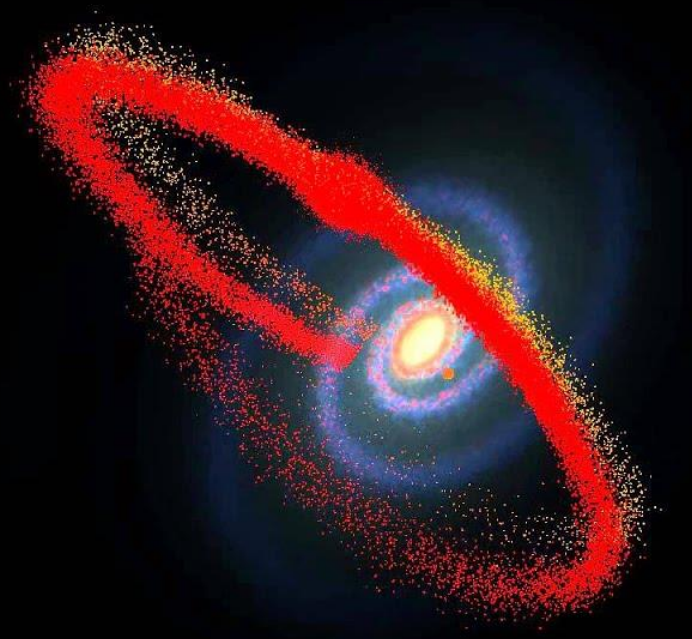
Jornadas de Doctorandos, UCM

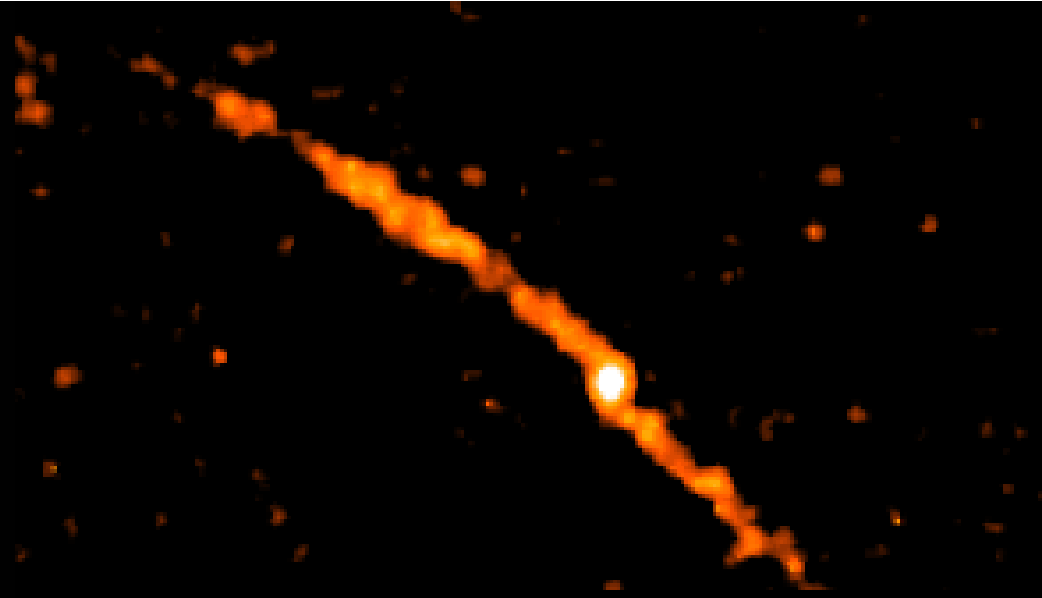
24th March 2022

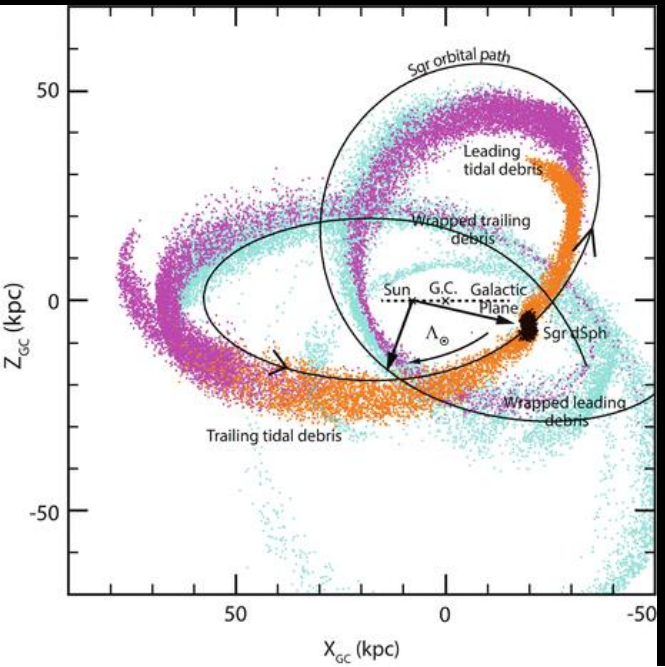
Outline

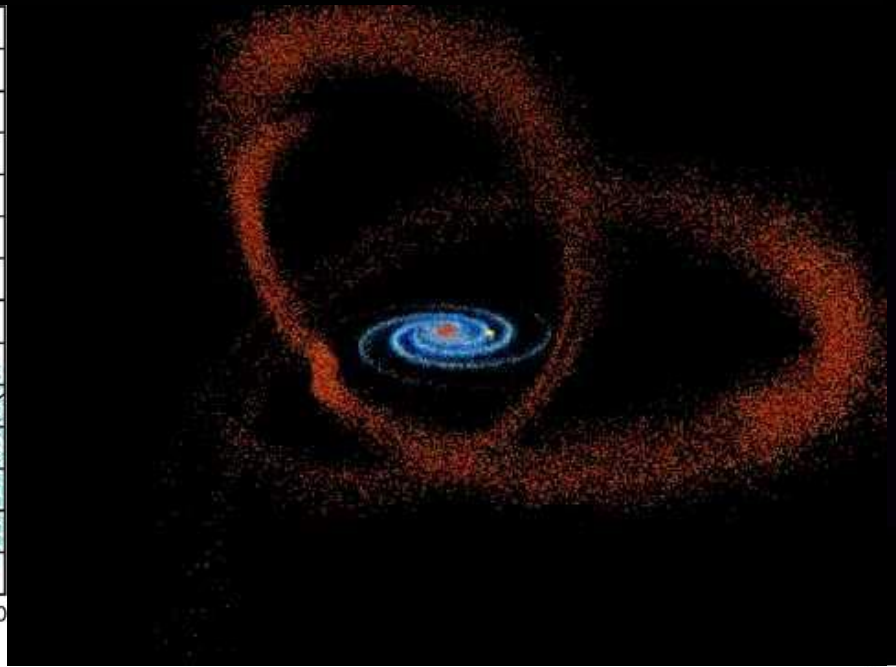
- What are tidal streams?
- Motivation
- Objectives
- Data
- Method
- Examples
- Publications
- Next steps

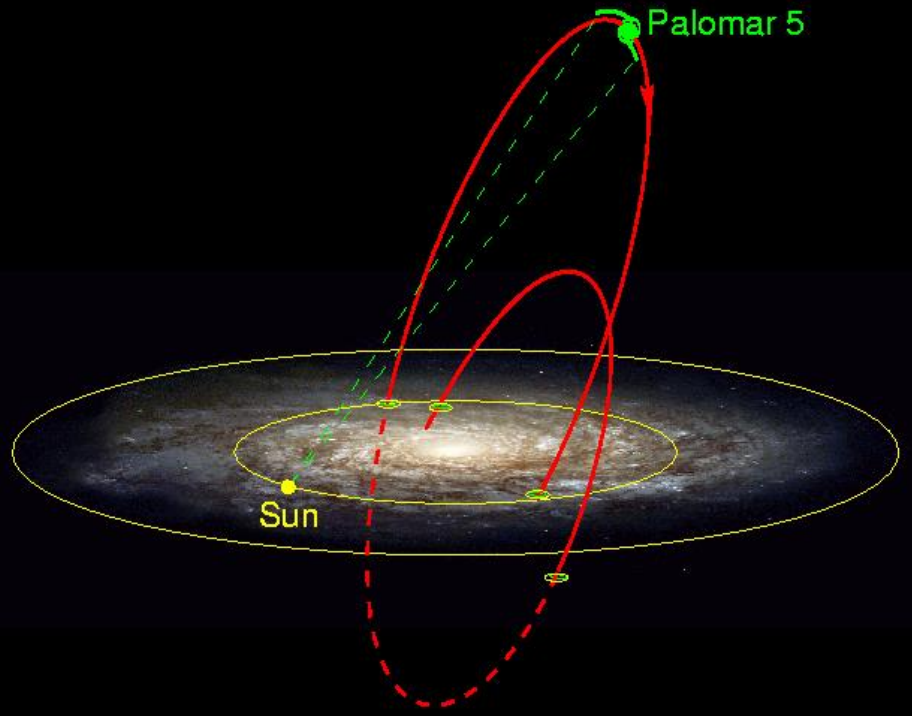
Sagittarius



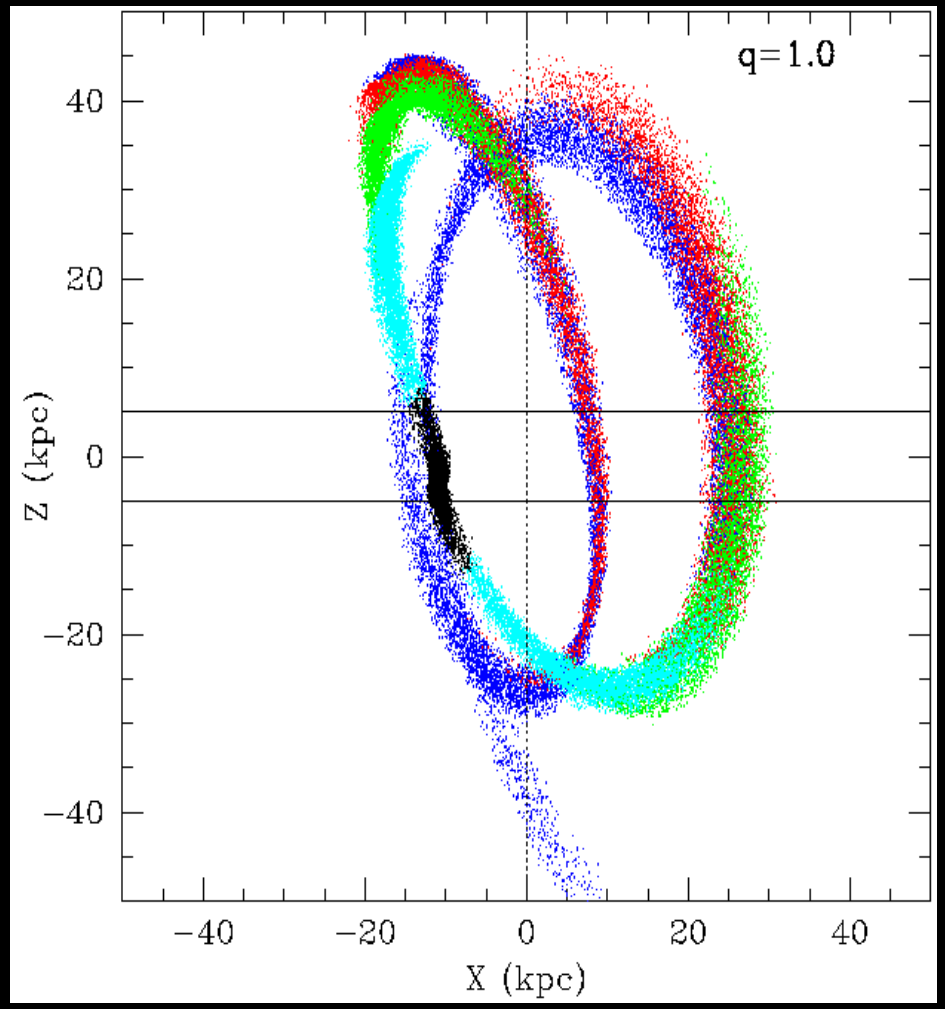








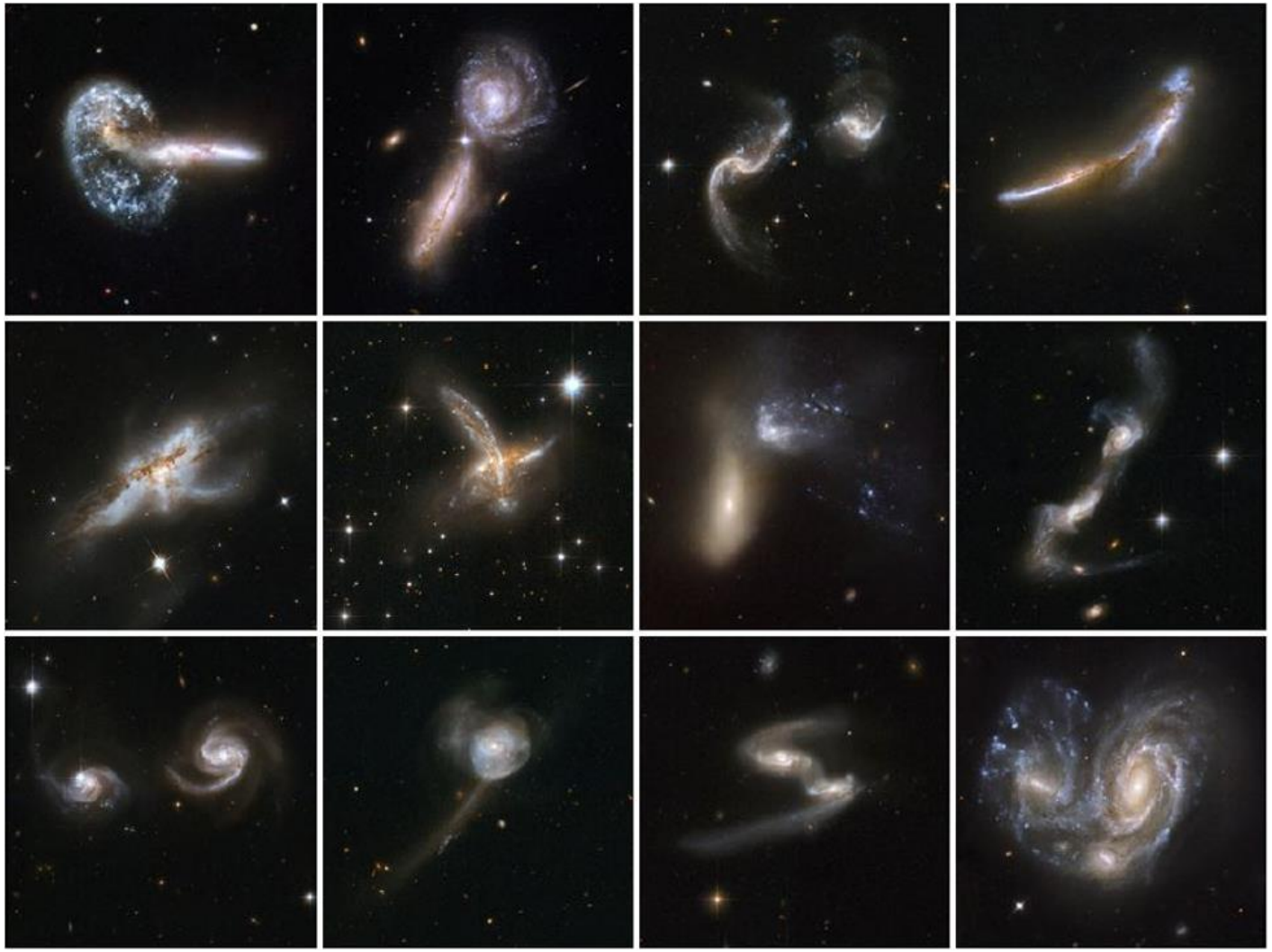
Tidal Streams outside the Milky Way



Tidal stream created by the destruction of a single satellite galaxy accreted 3.5 Gyr ago.
Left: **luminance-filter image,** right**: N-body simulation (Martinez Delgado et al. 2008)**

Hierarchical Galaxy Formation

- Galaxy interactions
- Galaxy mergers
  - Major mergers
  - Minor mergers
- Host Morphology
- Stream Morphology
- Satellite orbit
  - Circular -> streams
  - Eccentric -> shells



(Schneider, Fig 10.1)

Objectives

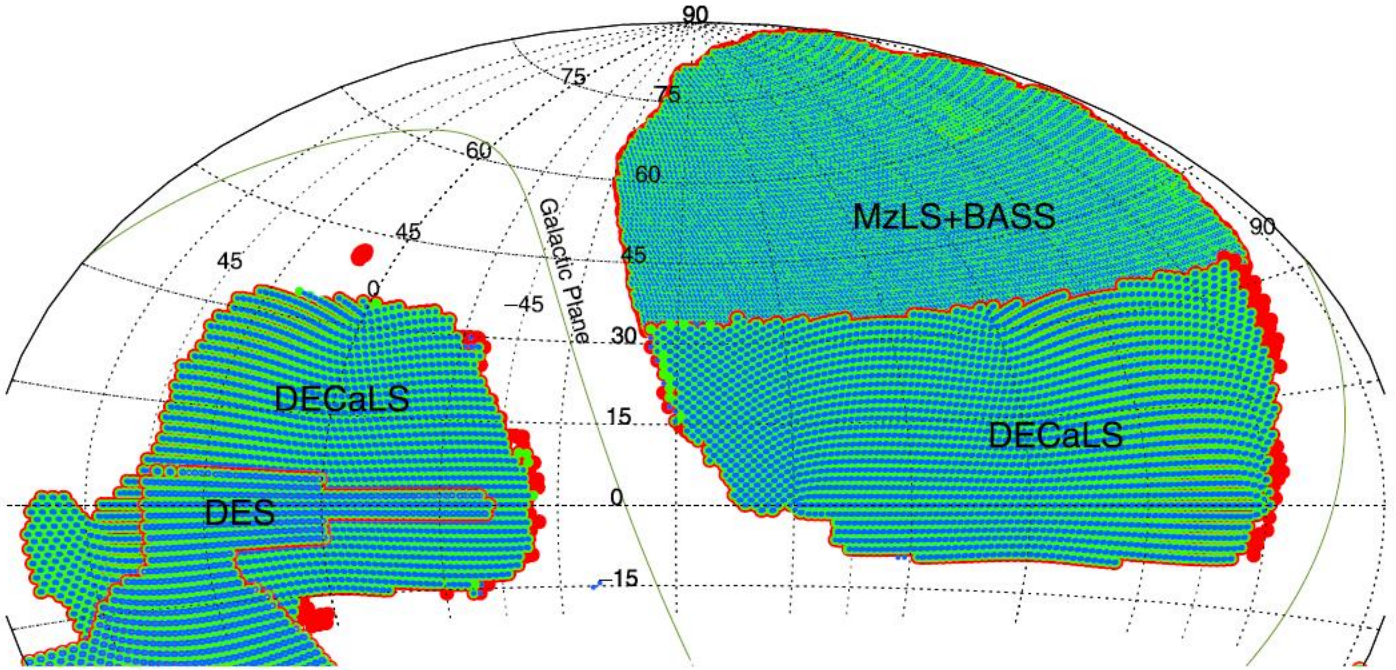
- First systematic detection of stellar tidal streams in around galaxies in the local Universe.
    - deep images: surface brightness limit ~29 mag/arcsec^2
- Catalogue of tidal streams in the local Universe: morphology, surface brightness, colour…
- Comparison with the predictions of cosmological simulations in the ΛCDM paradigm
- Analysis and conclusions on potential constraints on cosmological models

Legacy Surveys

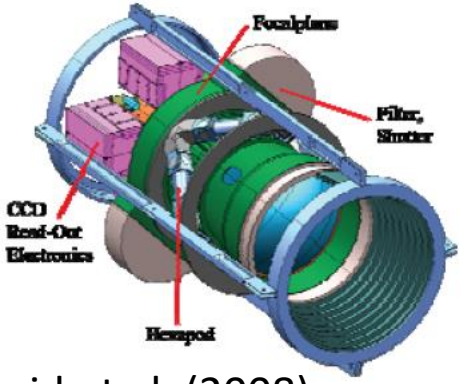
- DESI Legacy Imaging Surveys
  www.legacysurvey.org
- Dark Energy Survey (DES)
  www.darkenergysurvey.org

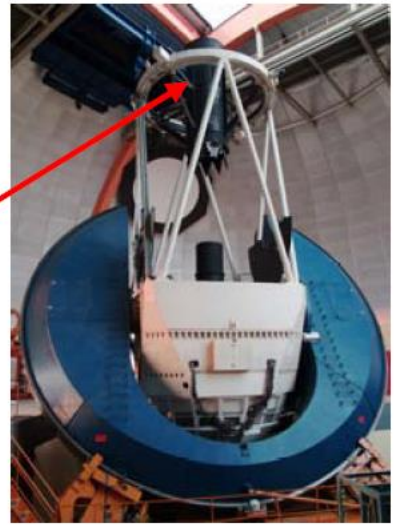
- Dark Energy Camera (DeCAM)
  - 3 deg^2

- Host selection criteria:
  - 30 =< D =< 100 Mpc
  - K-band absolute magnitude M_K < -19.6



Dey et al. (2019)

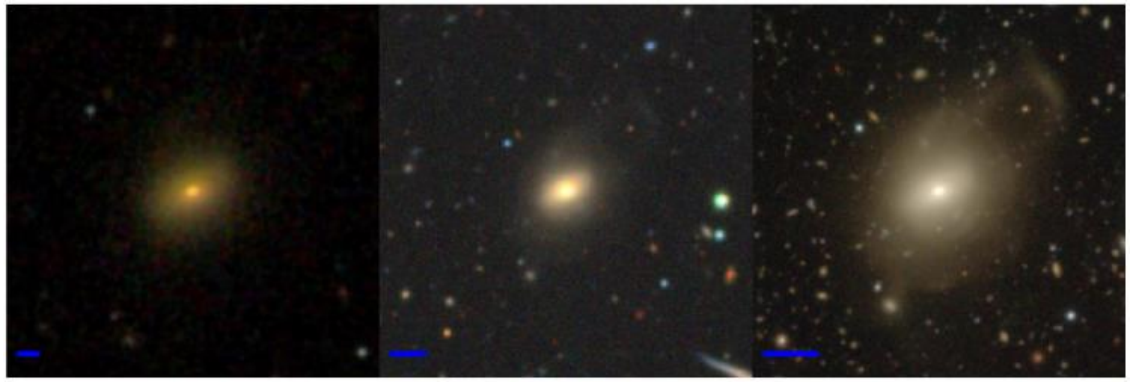


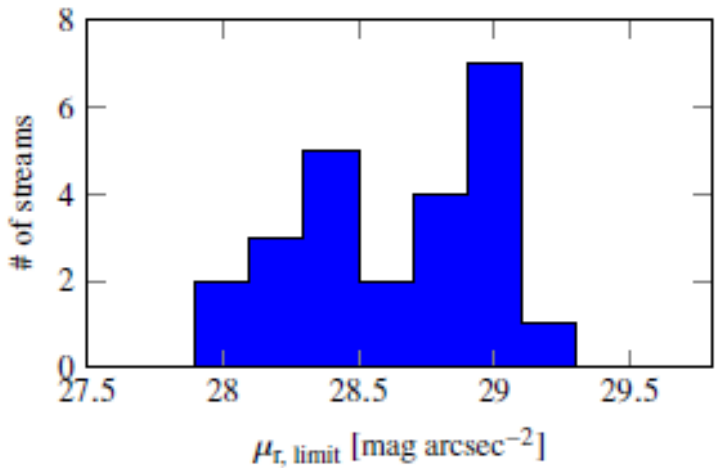


Honscheid et al. (2008)

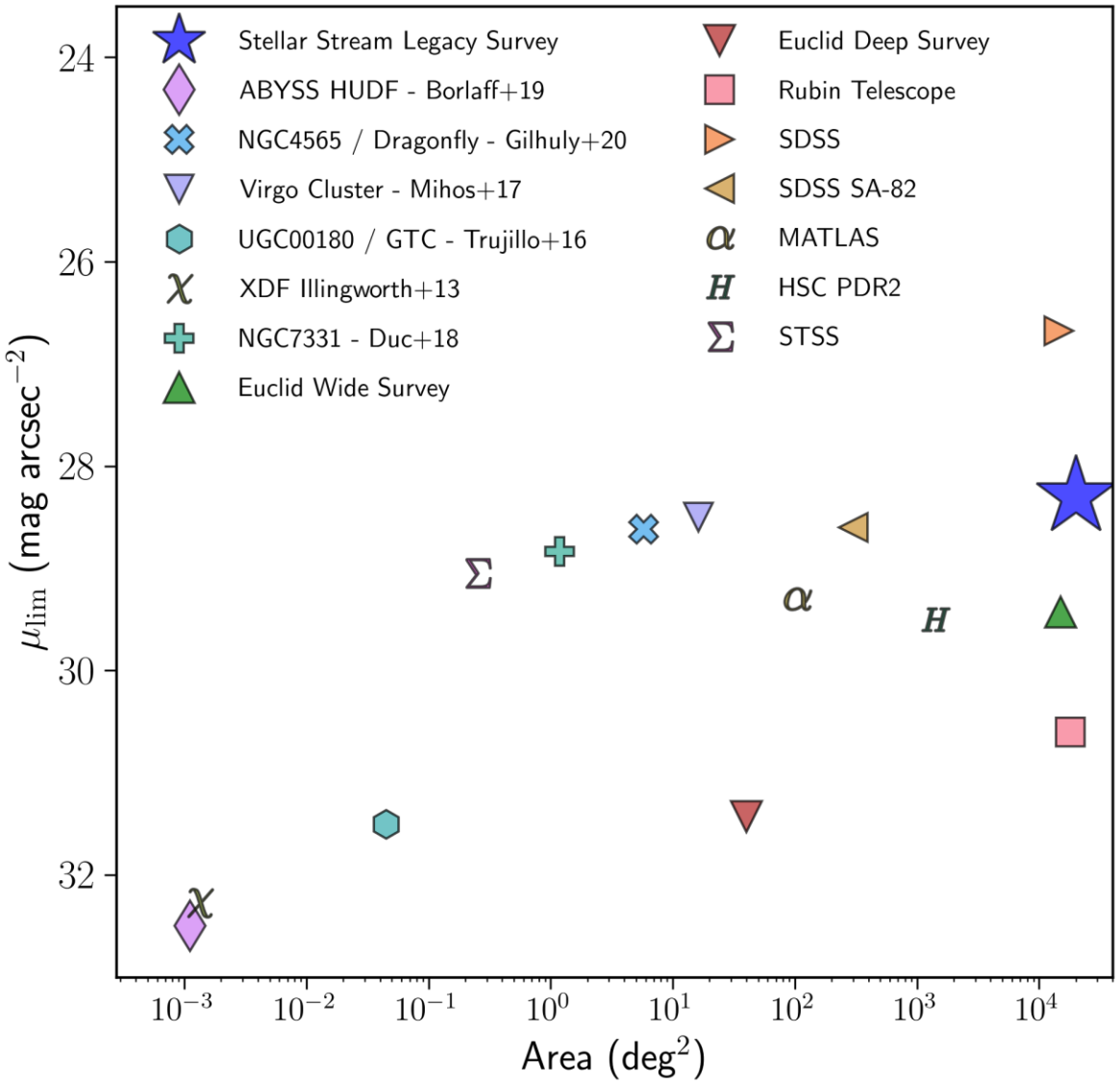
Deep Images: Surface Brightness Limit

Jacskon et al. (2022)





Miró-Carretero et al. (in preparation)

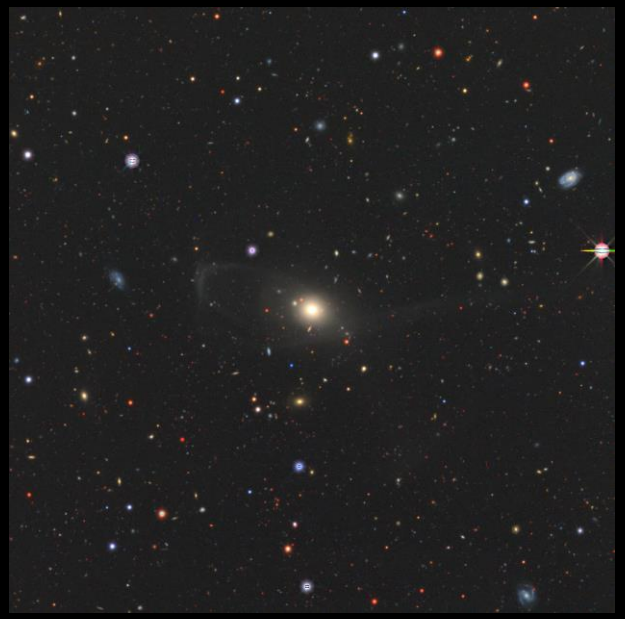


Martinez-Delgado et al. (2021)

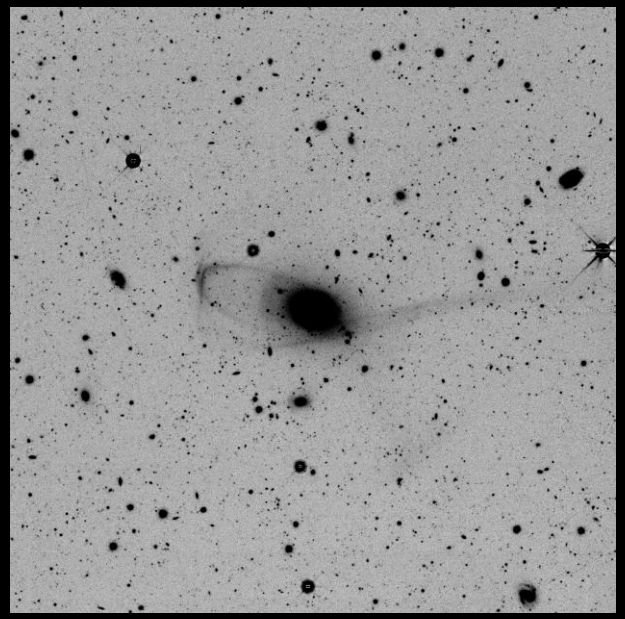
Example of Photometry Processing

- GNU Astronomy Utilities (Gnuastro)
  http://www.gnu.org/software/gnuastro
  - Open source software
  - Detection of faint structures

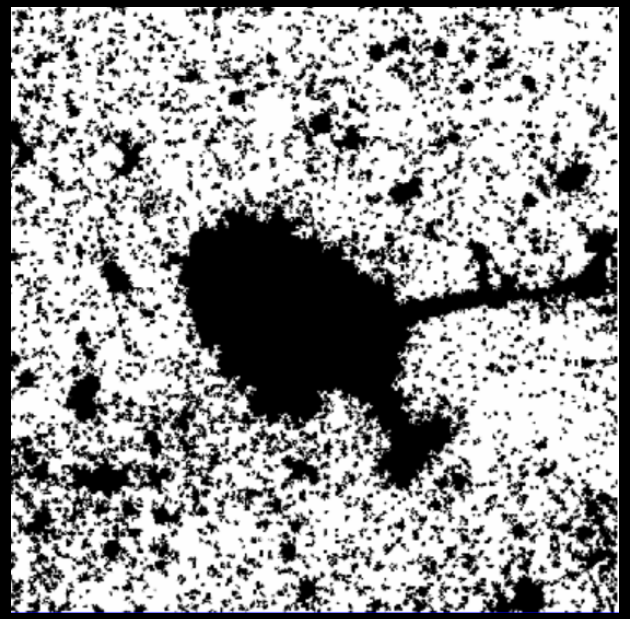
INPUT IMAGE



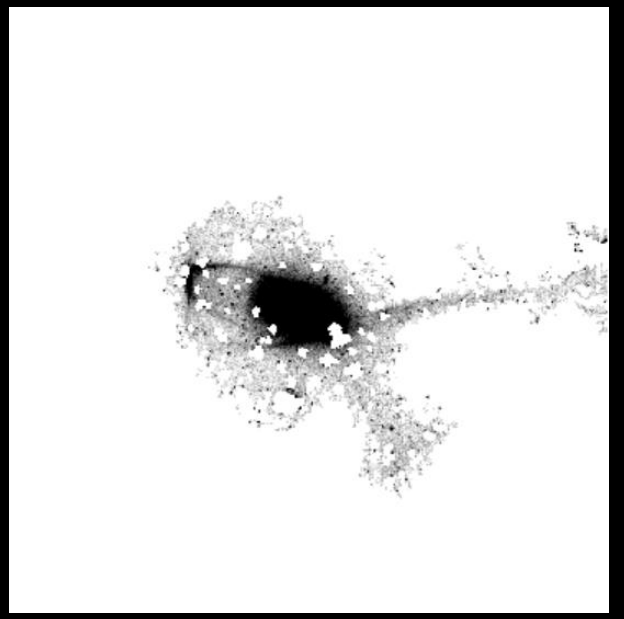
INPUT NO-SKY



DETECTIONS

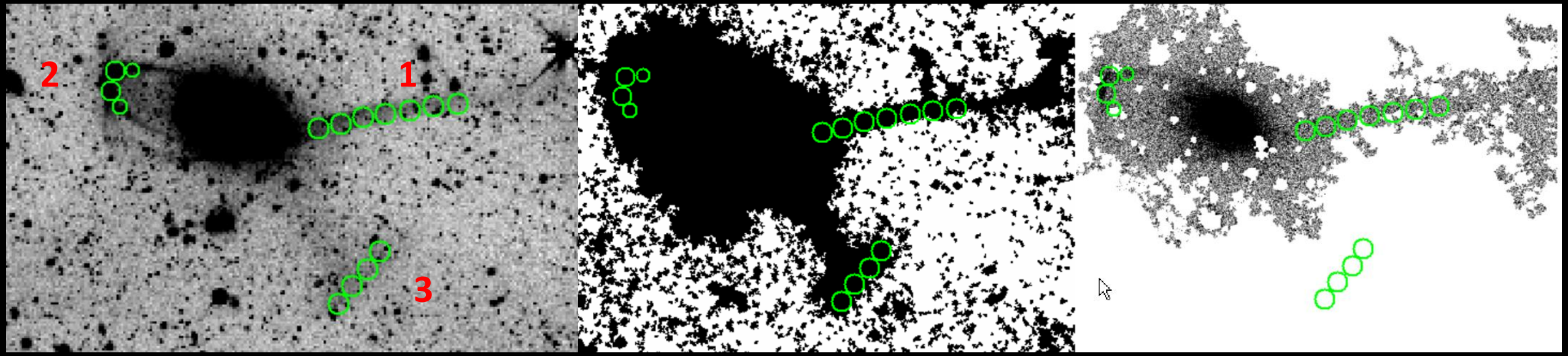


GALAXY
+
DIFFUSE STRUCTURE



Example of Photometry Processing

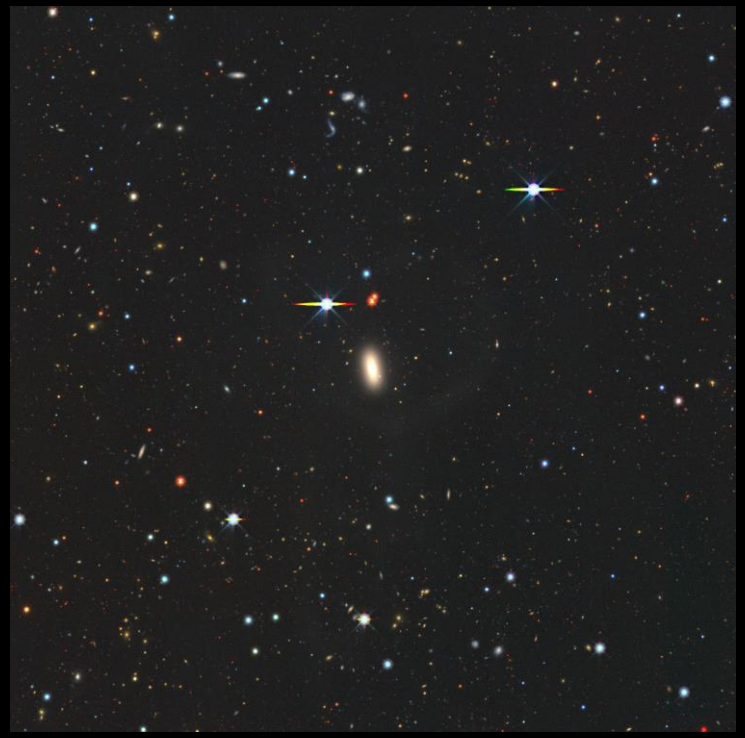
INPUT NO-SKY (block x 8) DETECTIONS GALAXY + DIFFUSE STRUCTURE



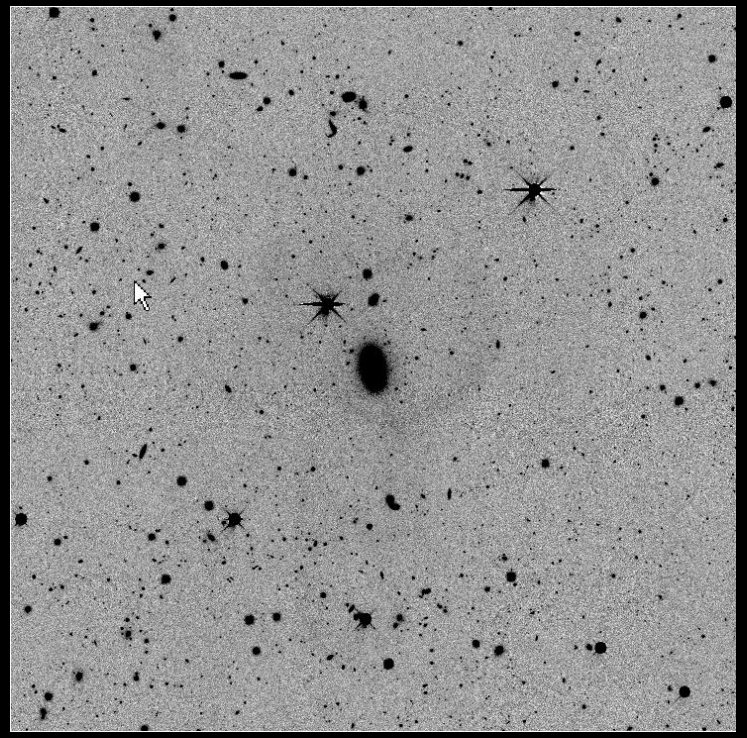
Stream zone	Surface Brightness	Colour g-r
1	**26.78**	**0.42**
2	**25.57**	**0.66**
3	**27.07**	**0.87**
Average	**26.53**	**0.61**

Example of gradient measurement along the stream

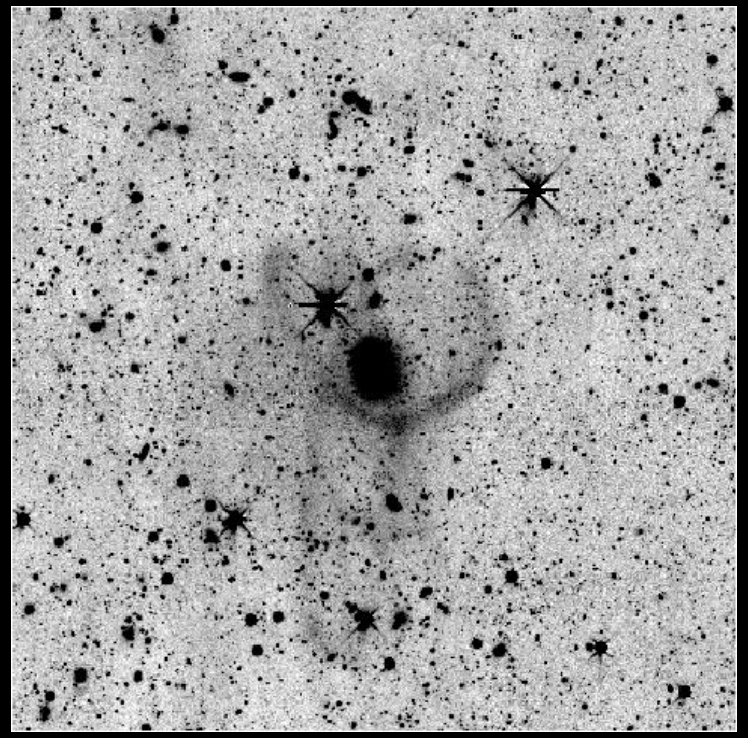
INPUT IMAGE (JPG)



INPUT IMAGE (FITS)

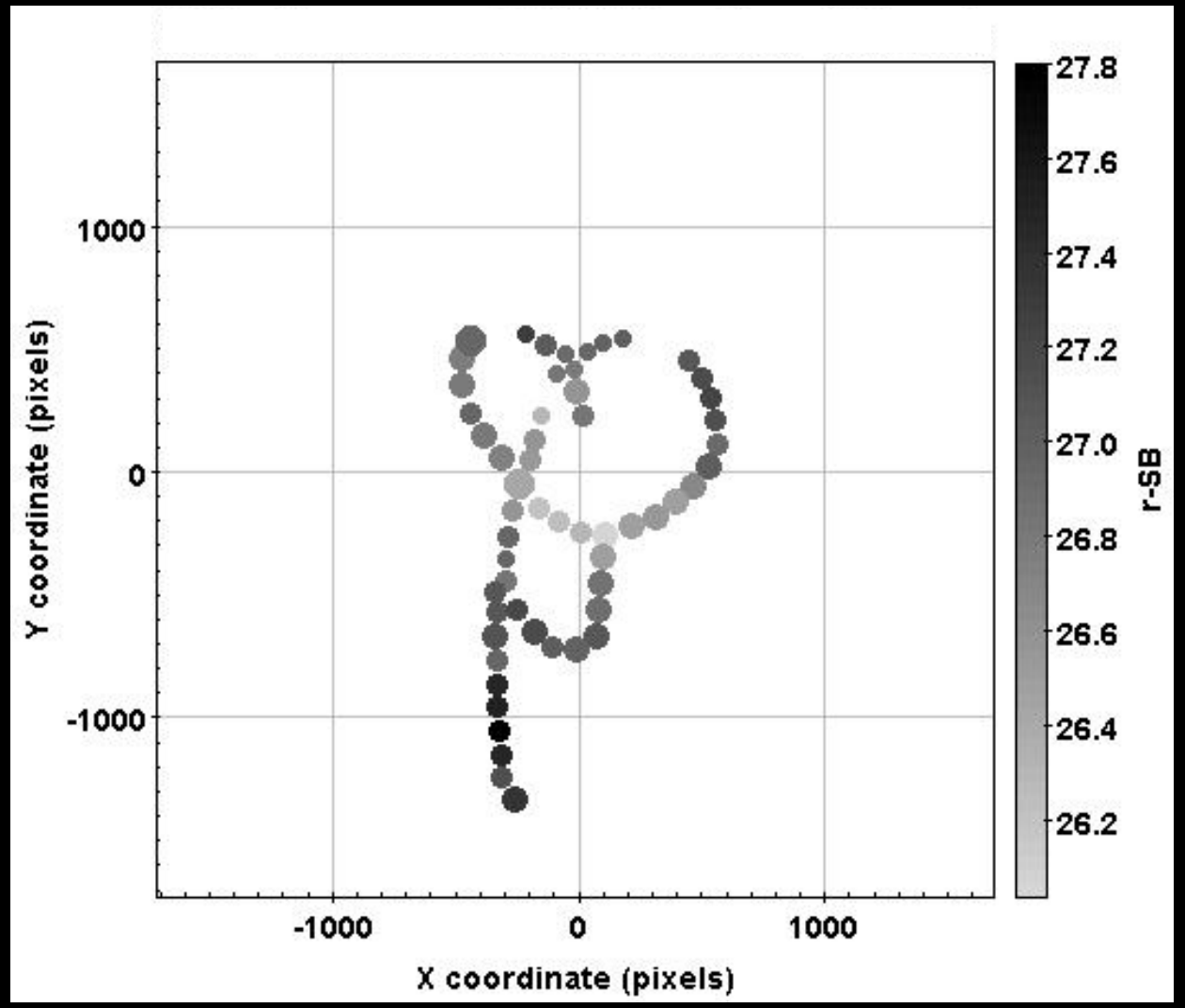


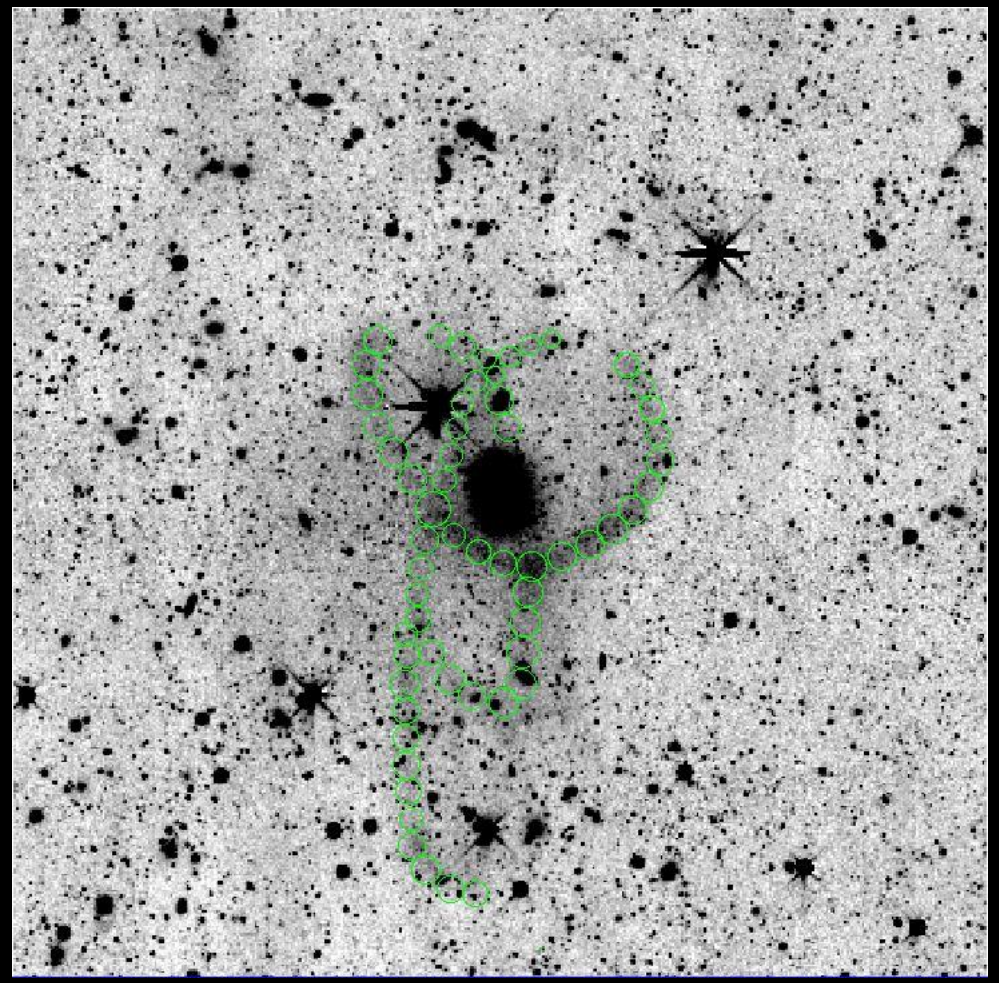
INPUT NO-SKY



Surface brightness gradient measurement

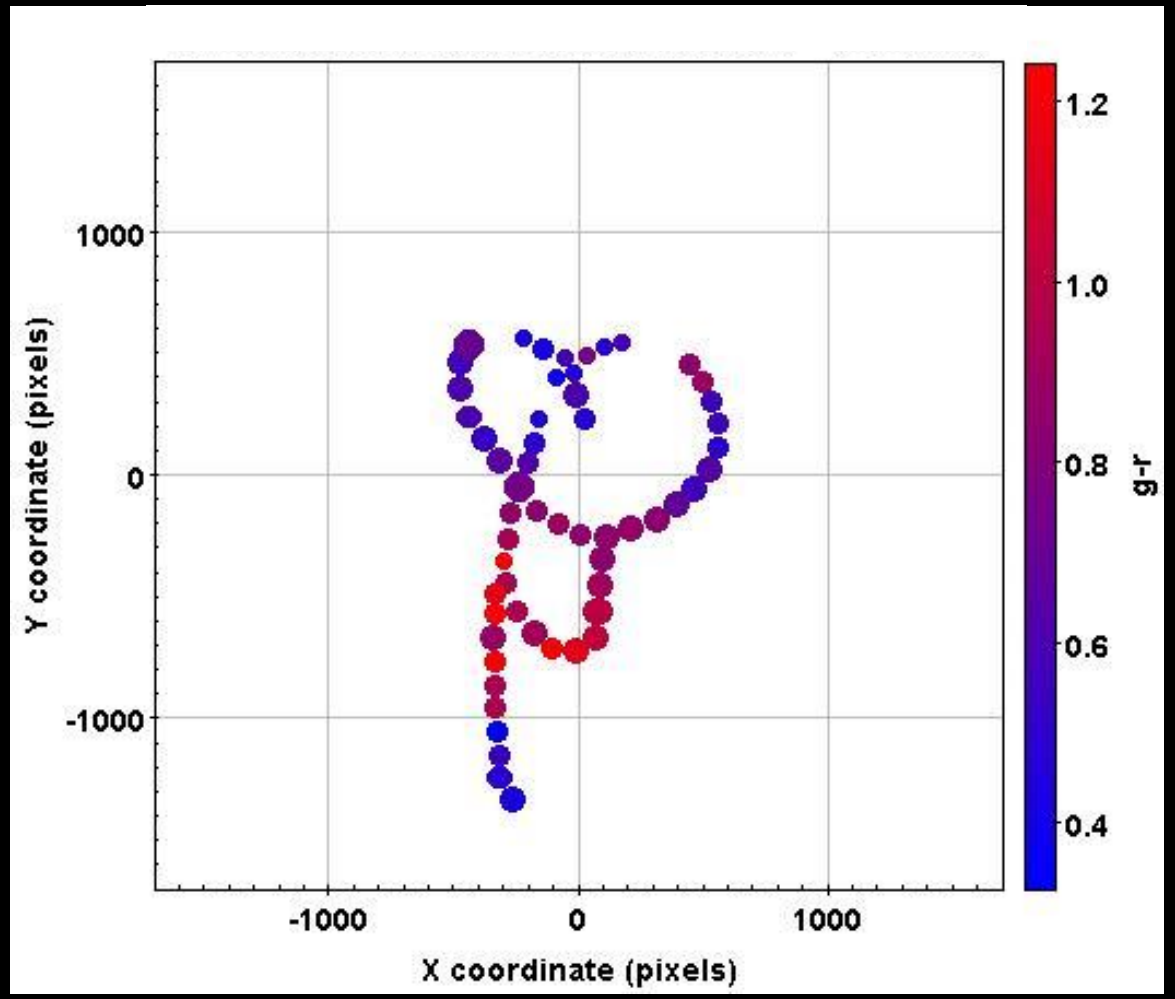
r – surface brightness



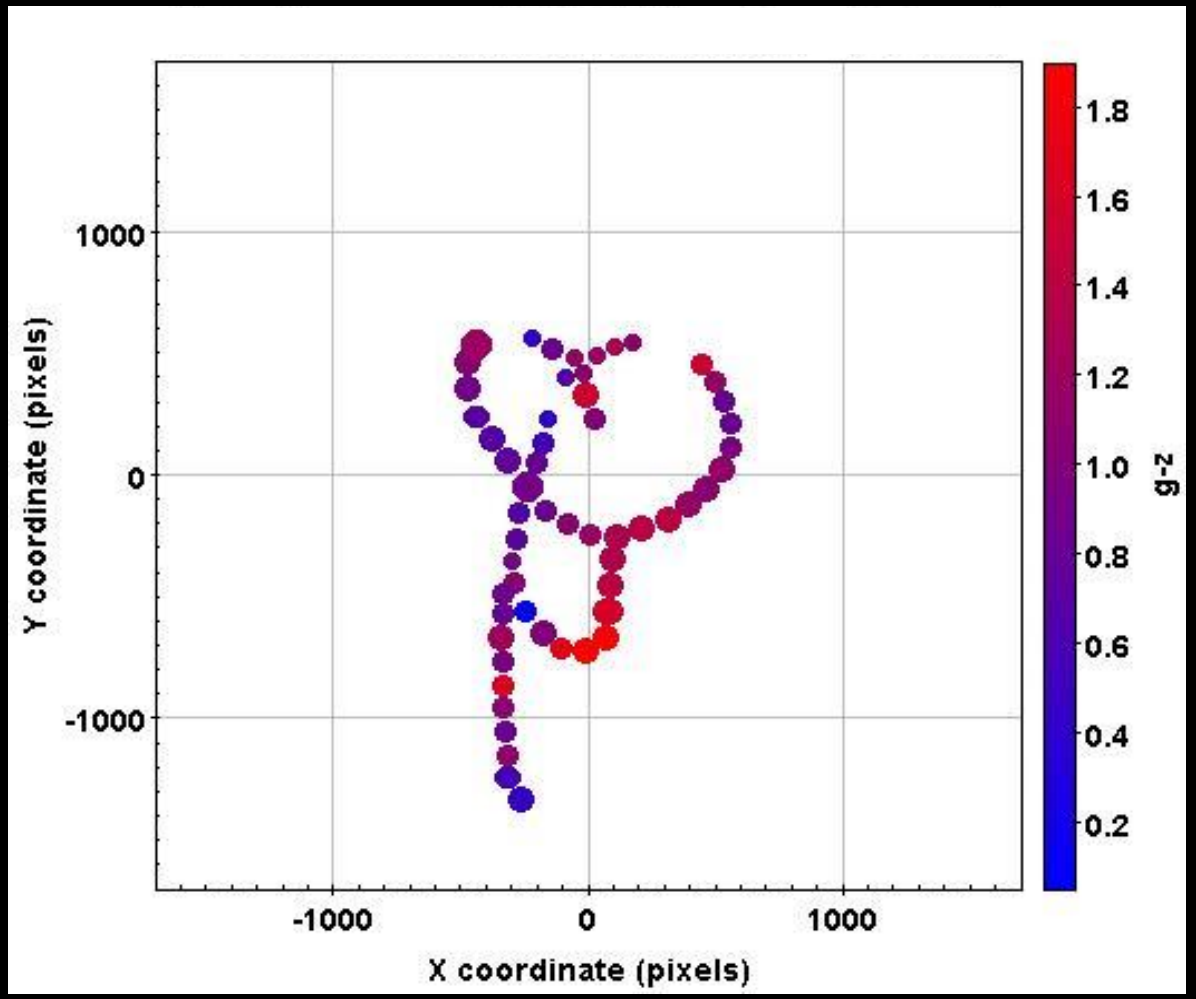


Colours measurement results with 59 apertures

g - r



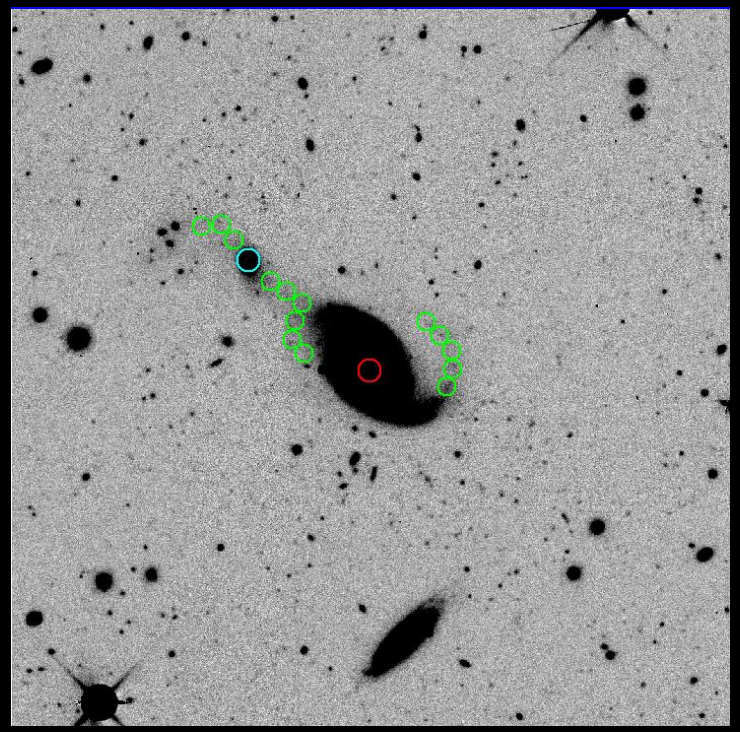
g - z



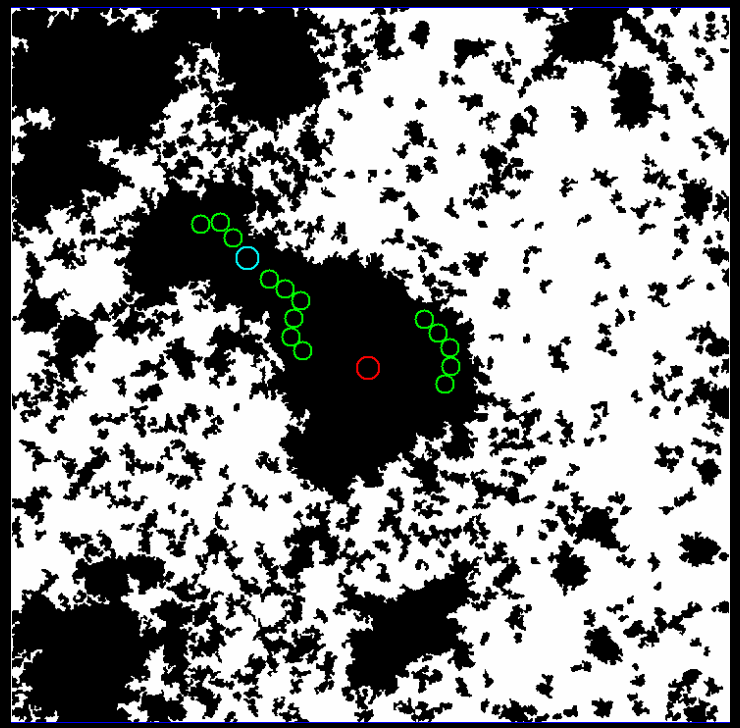
Example of Stream with progenitor

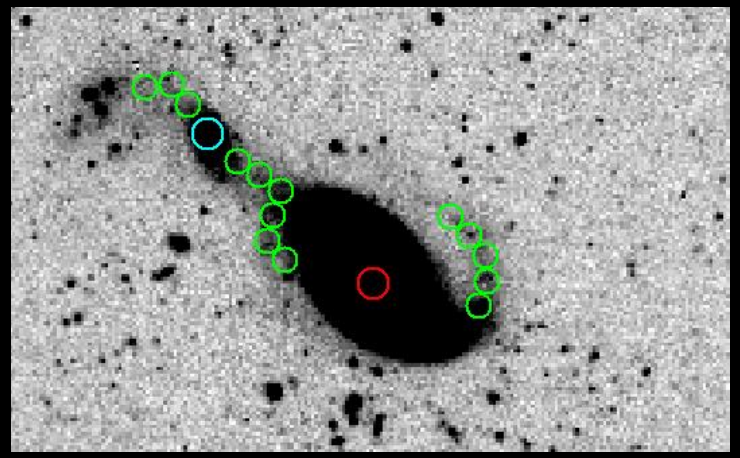
DES LEGACY SURVEY (JPG)

INPUT NO-SKY

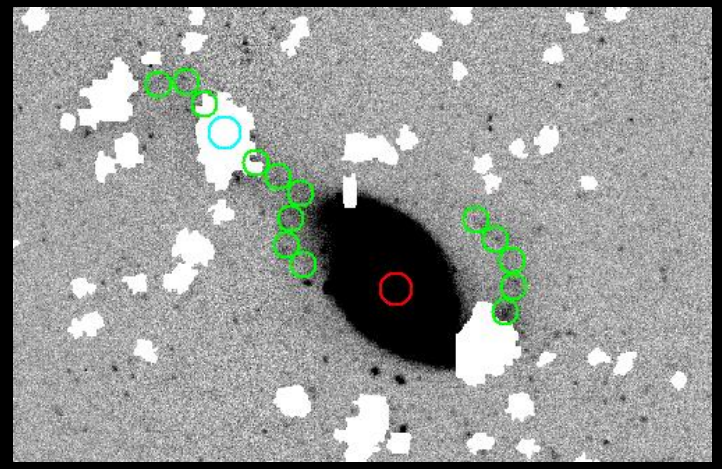


DETECTIONS





INPUT NO-SKY Block x 4



MASKED CLUMPS

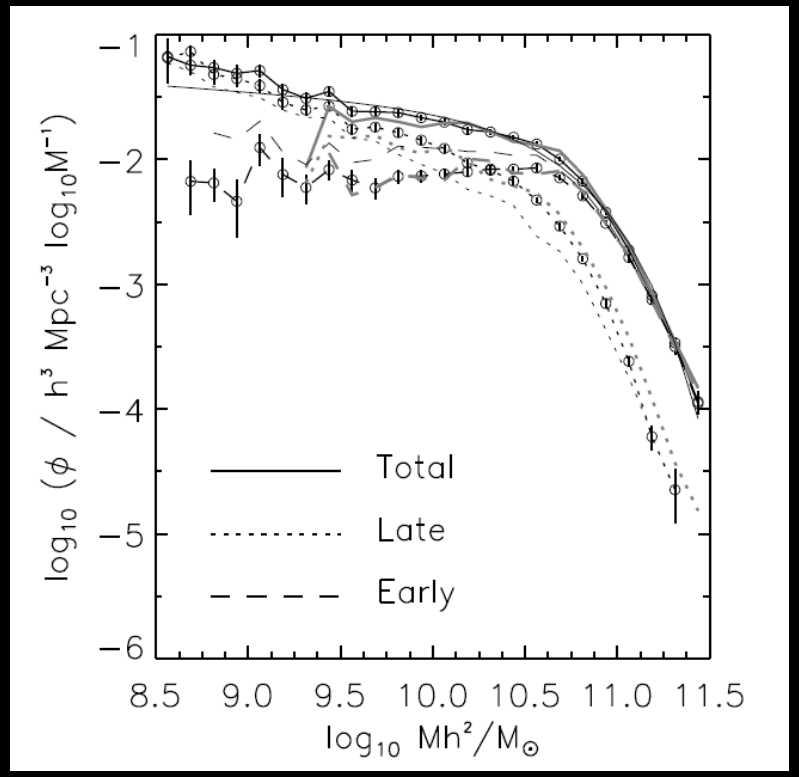
Example of satellite mass estimation

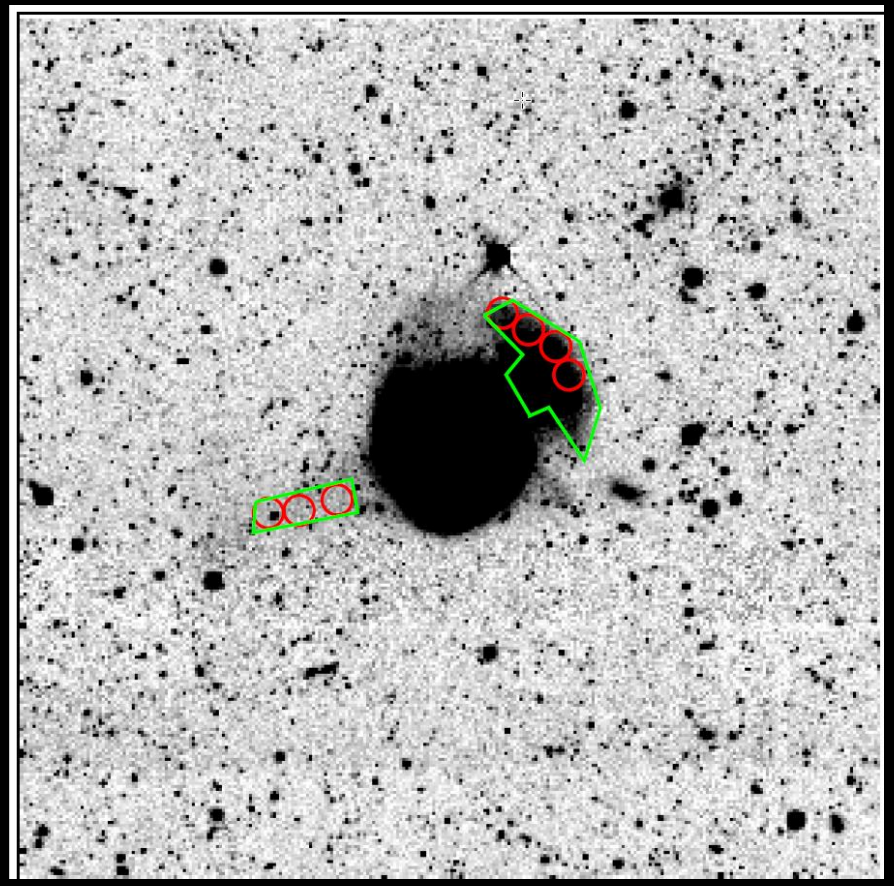
- Absolute Magnitude
- Luminosity

$$\frac{L_g}{L_{\odot,g}} = 10^{0.4(M_{\odot,g} - M_g)} = 4.45 \times 10^9$$

- M/L correlation

  Bell et al. (2003)





	$<\mu_g>$ [mag arcsec^{-2}]	$<\mu_r>$ [mag arcsec^{-2}]	$<\mu_z>$ [mag arcsec^{-2}]	$<g-r>_{stream}$ [mag]	$<g-z>_{stream}$ [mag]	m_g [mag]	m_r [mag]	m_z [mag]
LS Custom Image								
Shell	25.85 ± 0.02	25.34 ± 0.01	24.96 ± 0.03	0.53 ± 0.01	0.87 ± 0.005	16.80 ± 0.004	16.27 ± 0.004	15.93 ± 0.003
Tail	27.92 ± 0.08	27.27 ± 0.07	27.04 ± 0.16	0.61 ± 0.05	0.84 ± 0.04	19.95 ± 0.04	19.35 ± 0.03	19.11 ± 0.03
Subtracted Image								
Shell	25.88 ± 0.02	25.41 ± 0.02	25.03 ± 0.03	0.47 ± 0.01	0.82 ± 0.01	16.91 ± 0.004	16.43 ± 0.004	16.09 ± 0.003
Tail	27.95 ± 0.09	27.41 ± 0.08	27.27 ± 0.21	0.49 ± 0.05	0.67 ± 0.05	20.00 ± 0.04	19.51 ± 0.04	19.33 ± 0.03
Host Galaxy	22.59 ± 0.003	22.23 ± 0.003	22.21 ± 0.004	0.36 ± 0.003	0.58 ± 0.004			

Related Publications

Hidden Depths in the Local Universe: the Stellar Stream Legacy Survey

David Martínez-Delgado[1,2]*, Andrew P. Cooper[3,4]†, Javier Román[1,11,12], Annalisa Pillepich[5], Denis Erkal[6], Sarah Pearson[7]‡, John Moustakas[8], Chervin F. P. Laporte[9], Seppo Laine[10], Mohammad Akhlaghi[11,12], Dustin Lang[13], Dmitry Makarov[14], Alejandro S. Borlaff[15], Giuseppe Donatiello[16], William J. Pearson[17], Juan Miró-Carretero[18], Jean-Charles Cuillandre[19], Helena Domínguez[20], Santi Roca-Fàbrega[18], Carlos S. Frenk[21], Judy Schmidt[22], María A. Gómez-Flechoso[18], Rafael Guzman[18], Noam I. Libeskind[23], Arjun Dey[24], Benjamin A. Weaver[24], David Schlegel[25], Adam D. Myers[26], Frank G. Valdes[24]

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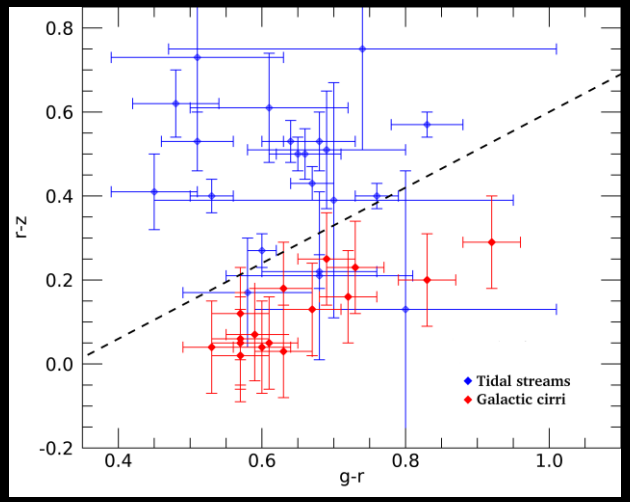
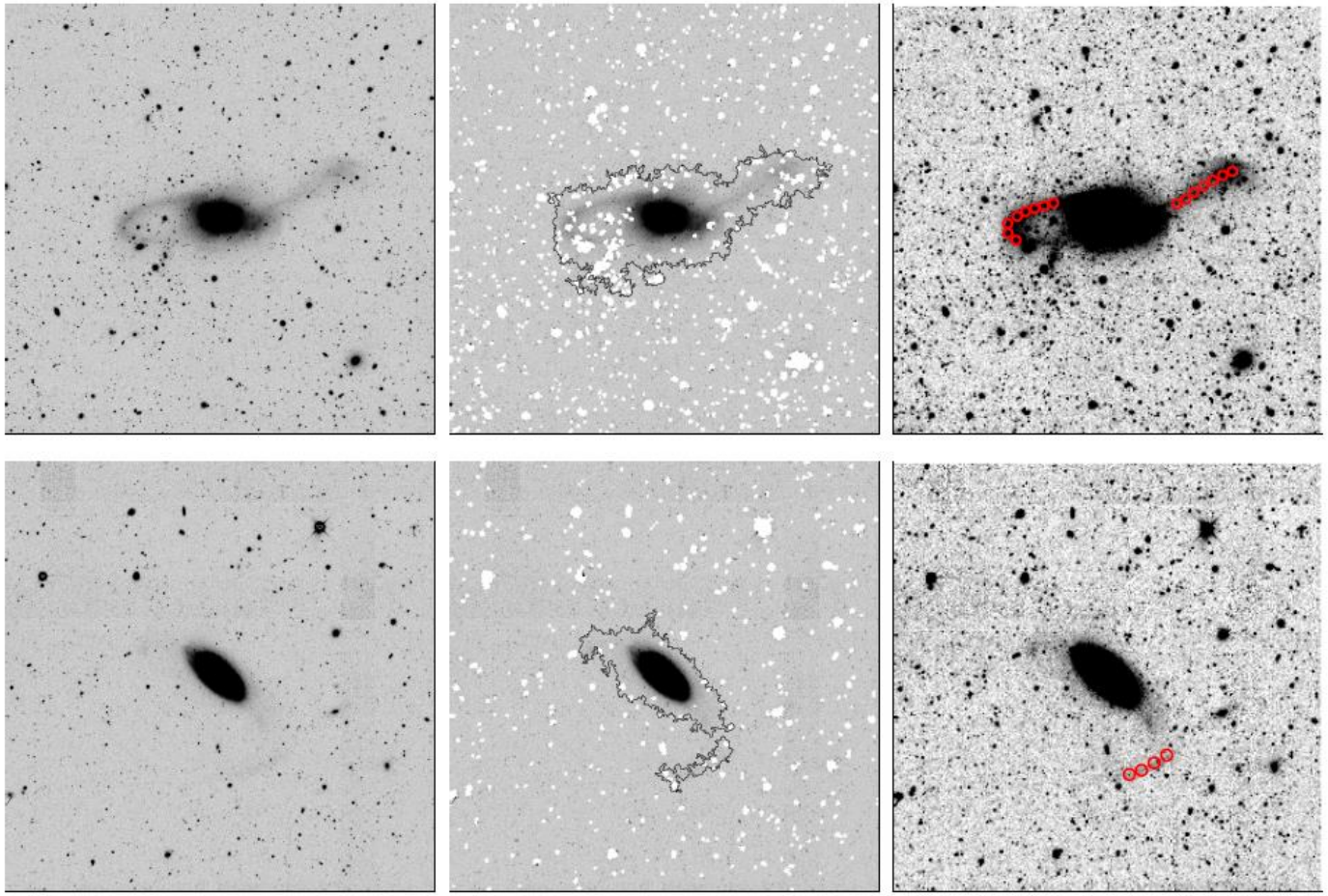
[2]*Astronomisches Rechen-Institut, Zentrum für Astronomie der Universität Heidelberg, Mönchhofstr. 12–14, 69120 Heidelberg, Germany*
[3]*Institute of Astronomy and Department of Physics, National Tsing Hua University, Kuang Fu Rd. Sec. 2, Hsinchu 30013, Taiwan*
[4]*Center for Informatics and Computation in Astronomy, National Tsing Hua University, Kuang Fu Rd. Sec. 2, Hsinchu 30013, Taiwan*
[5]*Max Planck Institut für Astronomie, Heidelberg, Germany*
[6]*Department of Physics, University of Surrey, Guildford GU2, 7XH, UK*
[7]*Center for Cosmology and Particle Physics, Department of Physics, New York University, 726 Broadway, New York, NY 10003, USA*
[8]*Siena College, Department of Physics & Astronomy, 515 Loudon Road, Loudonville, NY, 12211, USA*
[9]*Kavli Institute for the Physics and Mathematics of the Universe (WPI), The University of Tokyo, Chiba 277-8583, Japan*
[10]*IPAC, Mail Code 314-6, Caltech, 1200 E. California BLVd., Pasadena, CA 91125 USA*
[11]*Instituto de Astrofísica de Canarias (IAC), Calle Vía Láctea s/n, E-38205 La Laguna, Tenerife; Spain*
[12]*Facultad de Física, Universidad de La Laguna, Avda. Astrofísico Fco. Sánchez s/n, 38200La Laguna, Tenerife, Spain.*
[13]*Perimeter Institute for Theoretical Physics, 31 Caroline St N, Waterloo, Canada*
[14]*Special Astrophysical Observatory of the Russian Academy of Sciences, Nizhnij Arkhyz, 369167, Russia*
[15]*NASA Ames Research Center, Moffett Field, CA 94035, USA*
[16]*UAI - Unione Astrofili Italiani /P.I. Sezione Nazionale di Ricerca Profondo Cielo, 72024 Oria, Italy*
[17]*National Centre for Nuclear Research, ul. Pasteura 7, 02-093 Warszawa, Poland*
[18]*Departamento de Física de la Tierra y Astrofísica, Universidad Complutense de Madrid, E-28040 Madrid, Spain*
[19]*AIM, CEA, CNRS, Université Paris-Saclay, Université de Paris, F-91191 Gif-sur-Yvette, France*
[20]*Institute of Space Sciences (ICE,CSIC), Campus UAB, Carrer de Magrans, E-08193 Barcelona, Spain*
[21]*Institute for Computational Cosmology, University of Durham, UK*
[22]*Astrophysics Source Code Library, University of Maryland, 4254 Stadium Drive College Park, MD 20742, USA*
[23]*Leibniz-Institut für Astrophysik Postdam (AIP), An der Sternwarte 16, D-14482 Postdam, Germany*
[24]*NSF's National Optical-Infrared Astronomy Research Laboratory, 950 N. Cherry Ave., Tucson, AZ, 85719*
[25]*Lawrence Berkeley National Laboratory, 1 Cyclotron Rd., Berkeley, CA 94720*
[26]*Department of Physics & Astronomy, University of Wyoming, 1000 E. University, Dept. 3905, Laramie, WY 82071, USA*





Related Publications in preparation

Astronomy & Astrophysics manuscript no. output
February 27, 2022

Stellar Streams Around Milky Way Analogs

J. Miró-Carretero[1], S. Farras-Aloy[2], D. Martínez-Delgado[3], M.A. Gomez-Flechoso[1], M. Akhlaghi[4], A. Cooper[5]

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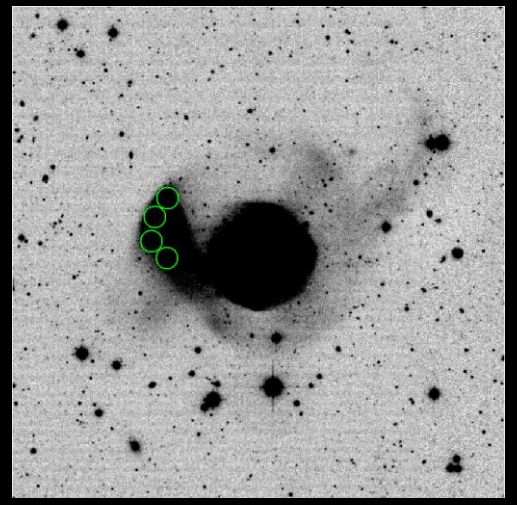
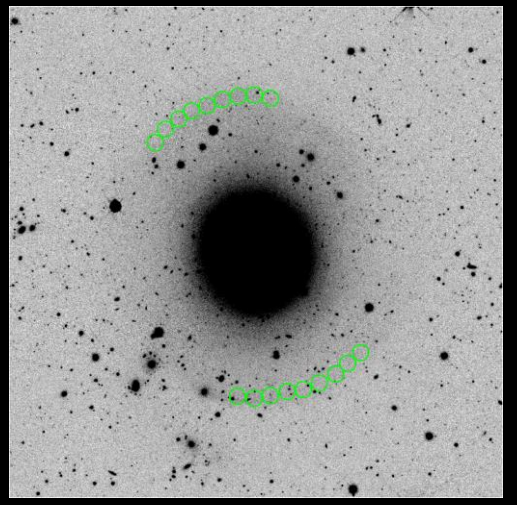
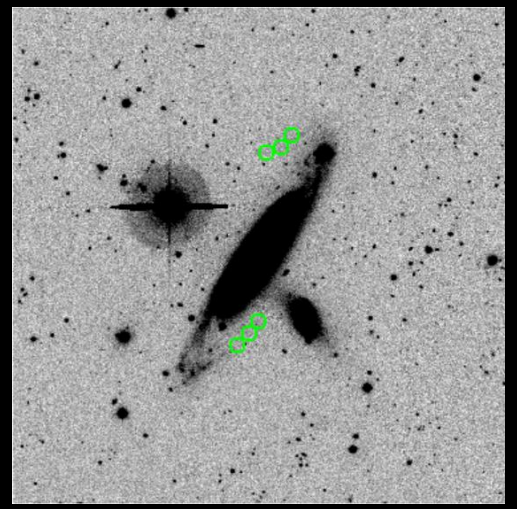
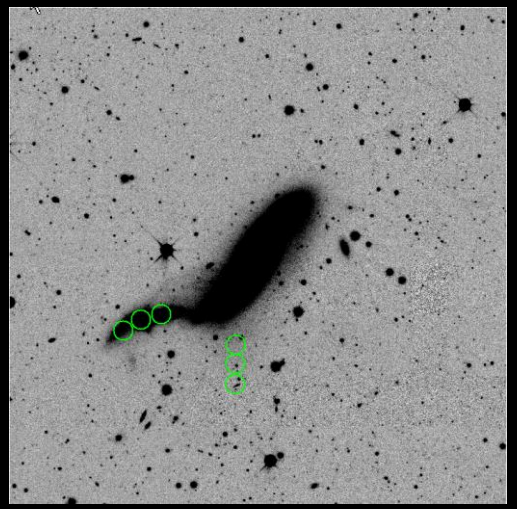
e-mail: juamiro@ucm.es
[2] Valencian International University. Spain
e-mail:
[3] Instituto de Astrofísica de Andalucia, Spain
e-mail: dmartinez@iaa.es
[4] Centro de Estudios de Física del Cosmos de Aragón, Spain
e-mail:
[5] Durham University, UK
e-mail:

Host galaxy	$\mu_{r,\,limit}$ [mag arcsec^{-2}]	$<\mu_g>_{stream}$ [mag arcsec^{-2}]	$<\mu_r>_{stream}$ [mag arcsec^{-2}]	$<\mu_z>_{stream}$ [mag arcsec^{-2}]	$<g\text{-}r>_{stream}$ [mag]	$<g\text{-}z>_{stream}$ [mag]
NGC0636	28.88	26.66	25.86	25.38	0.79	1.27
NGC1079	28.78	27.51	27.00	26.79	0.51	0.72
NGC1084	28.92	26.97	26.44	26.12	0.53	0.85
NGC1209	28.91	28.71	27.98	27.09	0.73	1.62
NGC2460	28.81	26.59	25.49	28.30	1.10	-1.47
NGC2543	28.54	26.50	25.82	28.18	0.68	-1.68
NGC2648	28.19	25.11	24.51	23.88	0.59	1.22
NGC2701	28.58	26.99	26.56	26.85	0.43	0.09
NGC2782	28.50	26.14	25.63	27.83	0.51	-1.75
NGC3583	28.36	27.34	26.95	27.98	0.39	-0.60
NGC3614	28.57	27.91	27.29	28.19	0.62	-0.38
NGC4378	28.21	27.24	26.53	25.99	0.71	1.24
NGC4750	28.57	26.81	26.30	27.89	0.51	-1.11
NGC4793	28.11	26.16	25.60	25.24	0.57	093
NGC4799	27.93	26.88	26.60	26.37	0.29	0.51
NGC5297	28.55	26.53	26.13	27.89	0.40	-1.36
NGC5604	28.18	26.35	25.81	25.24	0.54	1.11
NGC5631	28.54	27.98	27.30	28.28	0.68	-0.20
NGC5750	28.23	27.38	26.69	26.08	0.69	1.30
NGC5812	28.38	26.54	25.67	25.05	0.87	1.48
NGC7721	27.87	26.44	26.08	25.62	0.37	0.82

Stream Catalogue

- Portal-like catalogue
- Open Access
- Available to scientific community
- Standardised interface,
- Interoperable

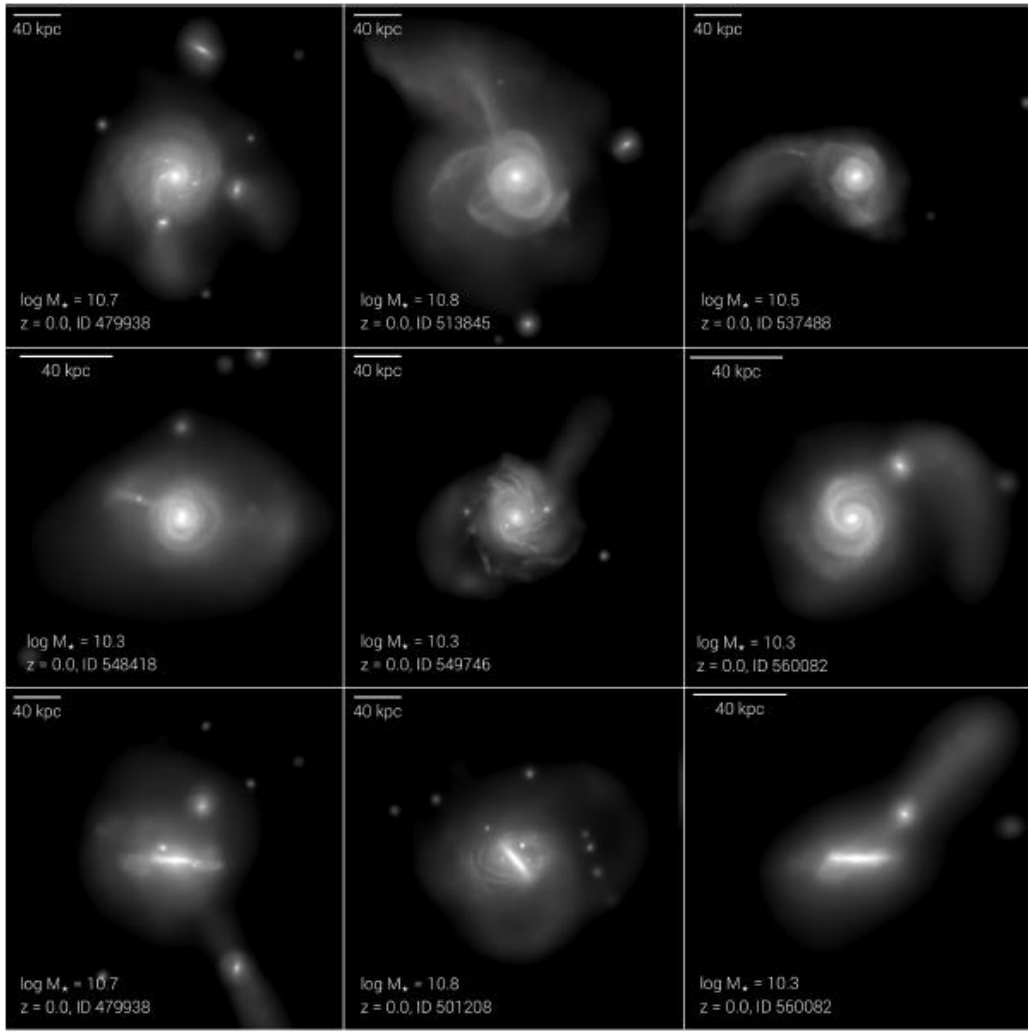
(Virtual Observatory, tbc)

Object	Parameters	Source	Format
Host galaxy			
Photometry	Surface Brightness (r,g,z) ??	DES	table
	Colours (g-r, g-z, r-z) ??	DES	table
	Luminosity	DES	Table
Geometry	Morphology (spiral. Sph,.), coordinates	Visual ds9/SIMBAD?	Table/img
	Coordinates	DES/SIMBAD	Table
	Distance from the Sun	DES/SIMBAD	Table

Object	Parameters	Source	Format
Stream			
Photometry	Surface Brightness (r,g,z)	Gnuastro	table
	Colours (g-r, g-z, r-z)	Gnuastro	table
	Stream flux/counts wrt noise 1σ (max, min, avg?)	Gnuastro	table
	Location, geometry, dimensions of apertures used in measurement	Gnauastro/ds9	Image / map
	statistics?, max, min..?	Excel	file
	Luminosity (not always possible, low priority) only what is needed to calculate it, if available	Gnuastro	Table
Geometry	thickness	Visual ds9	Table/img
	length? (only visible?)	Visual ds9	Table/img
	Morphology (Shell, Circular Orbit, longitudinal..	Visual ds9	Table/img
	Apocentre: max distance to host galaxy centre	Visual/ds9	Table/img
	Location (e.g. distance to host galaxy centre, inclination, radius if circular orbit or shell	Visual ds9	Table/img
Progenitor	Surface Brightness, morphology, colour, Magnitude, distance to host galaxy centre, orbit (if detected)	Visual/ ds9	Table/img

Cosmological Simulations

- Cosmological Model ΛCDM
- Hydrodynamical Simulation
- Particle tracking
- Mock Images
- Stream formation
- Satellite infall



Martinez-Delgado et al. (2021)

Questions ?