Blending Workshop Breakout Session #2

Overview of Blending Challenges for LSST Science

Tuesday, August 14, 1:30 to 3:00pm

Presenters:

1. Galaxies - Brant Robertson
2. AGN - Niel Brandt
3. Strong Lensing - Phil Marshall
4. Dark Energy SC - Pat Burchat / David Kirkby
5. Transients & Variable Stars - Federica Bianco
6. Solar System - Henry Hsieh
7. Stars - John Gizis

Galaxies Science Collaboration - **Blending impacts & metrics**

- Describe types of impact(s) of blending on your science.
  - Fragmentation of bright, resolved galaxies.
  - Distant galaxies (fuzzy blobs):
    - incorrect photometric redshifts for blends
    - Cases of lower-z objects contaminating high-z samples are harder to predict
    - Blend of a low-z blue object with a high-z dropout will make you miss the dropout.

Galaxies Science Collaboration - **Blending impacts & metrics**

- Describe types of impact(s) of blending on your science (cont.)
  - LSB structures (e.g. tidal features) to be shredded by deblenders. The deblenders being planned by the Project will preserve flux but we will need to find a way to identify different parts of the same galaxy in the object catalog so that galaxies can be ‘put back together’.
  - Large, LSB galaxies, also shredded by deblenders.

Galaxies Science Collaboration - **Blending impacts & metrics**

- Describe types of impact(s) of blending on your science (cont.).
  - Nearby dwarf galaxies (bigger fuzzy blobs):
    - Getting the space-density of low-L gas-poor dwarfs in the field was in the Science Book
    - LSB galaxies are best detected with matched filters that are larger than likely to be the LSST default
    - Portions of them may well be subtracted as sky background
    - Interested in having clues to "semi-resolved" objects in the LSST database to find the nearest examples.

Galaxies Science Collaboration - **Blending impacts & metrics**

- Types of objects that are most relevant:
  - bright, resolved galaxies
  - highest luminosity candidates; most massive candidates; dustiest, highest SFR
  - high-z galaxies are typically unresolved or barely resolved at LSST resolution (half-light radii < 0.3 arcsec)
  - low-z dwarfs will have half-light radii of 5-30 arcsec, total mag < 23 (i.e. fairly bright, but very low SB)
  - Merging galaxies

Galaxies Science Collaboration - **Blending impacts & metrics**

- Density of these objects (#/sq arcmin) and/or fraction of objects impacted by blending:
  - Based on HSC data, basically every z<0.1, r<20 galaxy is blended. There are ~500/sq deg. Galaxies with z<0.2, r<20 in GAMA.
  - High-z (z>3) objects of interest are several per sq arcmin. Probably ~10% affected by blends. Don't have exact numbers.
  - Low-z dwarfs are that might be semi-resolved at LSST resolution are probably ~ 50 per sq. degree. Most will have an overlapping galaxy or two.
  - At Stripe 82 depth around 15% of galaxies (regardless of morphological type) show LSB tidal features. At full LSST depth 70%+ of galaxies are likely to show LSB features.
  - Serious issues for very extended galaxies (<15th mag). These have a number density on sky of 10s per square degree (pretty near to 40 in the r-band).

Galaxies Science Collaboration - **Blending impacts & metrics**

- Have any metrics for evaluating the impact of blending on your science already been identified and/or tested? If so, what are they?
  - Untested:
    - Fraction of interlopers for different high-z samples based on images simulations
    - Derived mass function for photo-z selected samples from LSST image simulations compared to truth
    - Fraction of low-z LSB dwarfs found in the LSST object catalog (vs input catalog)
    - Fraction of semi-resolved LSB dwarfs found in LSST object catalog (currently unaware of simulations to test this)
  - Truncation in LSB galaxy number counts at bright magnitudes.

Galaxies Science Collaboration - **Blending impacts & metrics**

- Have any metrics for evaluating the impact of blending on your science already been identified and/or tested? If so, what are they?
  - While motivated originally by cosmology systematic errors, a Galaxies team is (Tyson's group) is using mock catalogs based on the Buzzard simulation using the angle between galaxy centroids (independent of the galaxy size or shape) as a surrogate for identifying "ambiguously blended" objects— i.e., overlapping objects that are identified as a single object. The covariance of the (weighted) mixture of sheared intrinsic (Gaussian) shapes of the overlapping objects are used to estimate the impact on shear. The fluxes of these objects are used to estimate the impact on measured magnitudes and then uses TPZ to estimate photo-z's and errors. This can be applied to statistical studies of galaxy parameters at low surface brightness.

Galaxies Science Collaboration - **Simulations & tools**

- Simulations & data sets:
  - HSC/COSMOS Weak Lensing Catalog
    - https://hsc-release.mtk.nao.ac.jp/doc/index.php/weak-lensing-simulation-catalog-pdr1/
  - GREAT3
    - https://github.com/GalSim-developers/GalSim/wiki/RealGalaxy%20Data
  - LSST standard image simulations ought to be okay for ballpark estimates of blending on high-z science mentioned here (not for science of looking for mergers or tidal tails though)
  - A old set of LSST image simulations with injected LSB dwarfs was created, but this was before the DM could process it. Could recreate and run through DM.
  - Is your SC using any data sets that combine space (“truth”) and ground?
    - HST + HSC in COSMOS

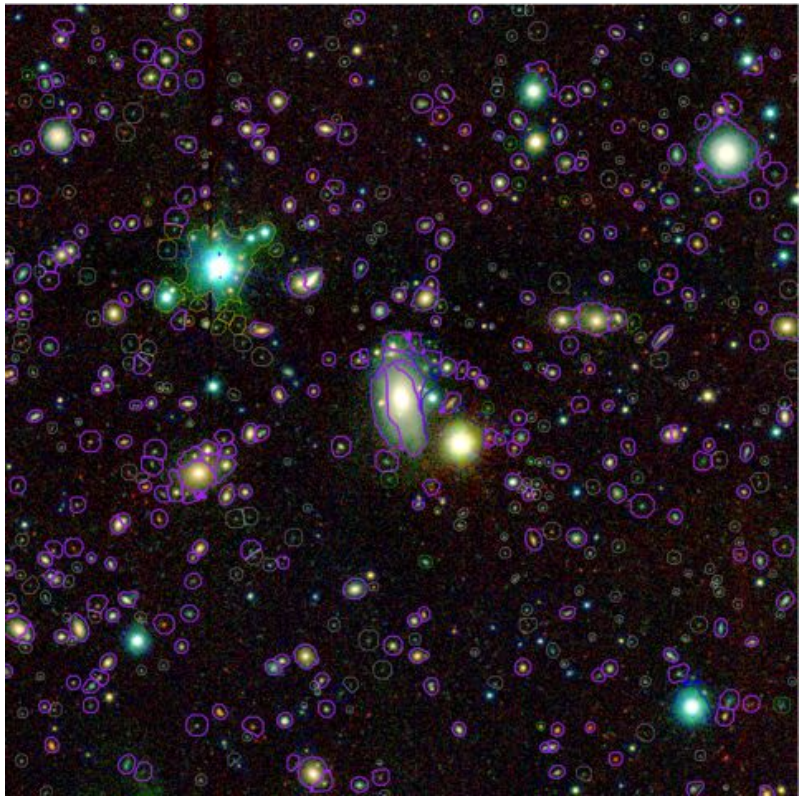
Galaxies Science Collaboration - **Simulations & tools**

- Tools:
  - ProFound
    - http://adsabs.harvard.edu/abs/2018MNRAS.476.3137R
  - PyProfit
    - https://github.com/lsst-dm/pyprofit
  - A team within Galaxies (Kaviraj's group) is developing an unsupervised machine learning algorithm to do morphological classifications of galaxies using LSST. This algorithm works at the pixel level (i.e. it doesn't blend anything in the first place) so might be useful for reconstructing galaxies.

Galaxies Science Collaboration - **Simulations & tools**

ProFit Results

Courtesy Driver and Robotham.



Galaxies Science Collaboration - **Existing algorithms**

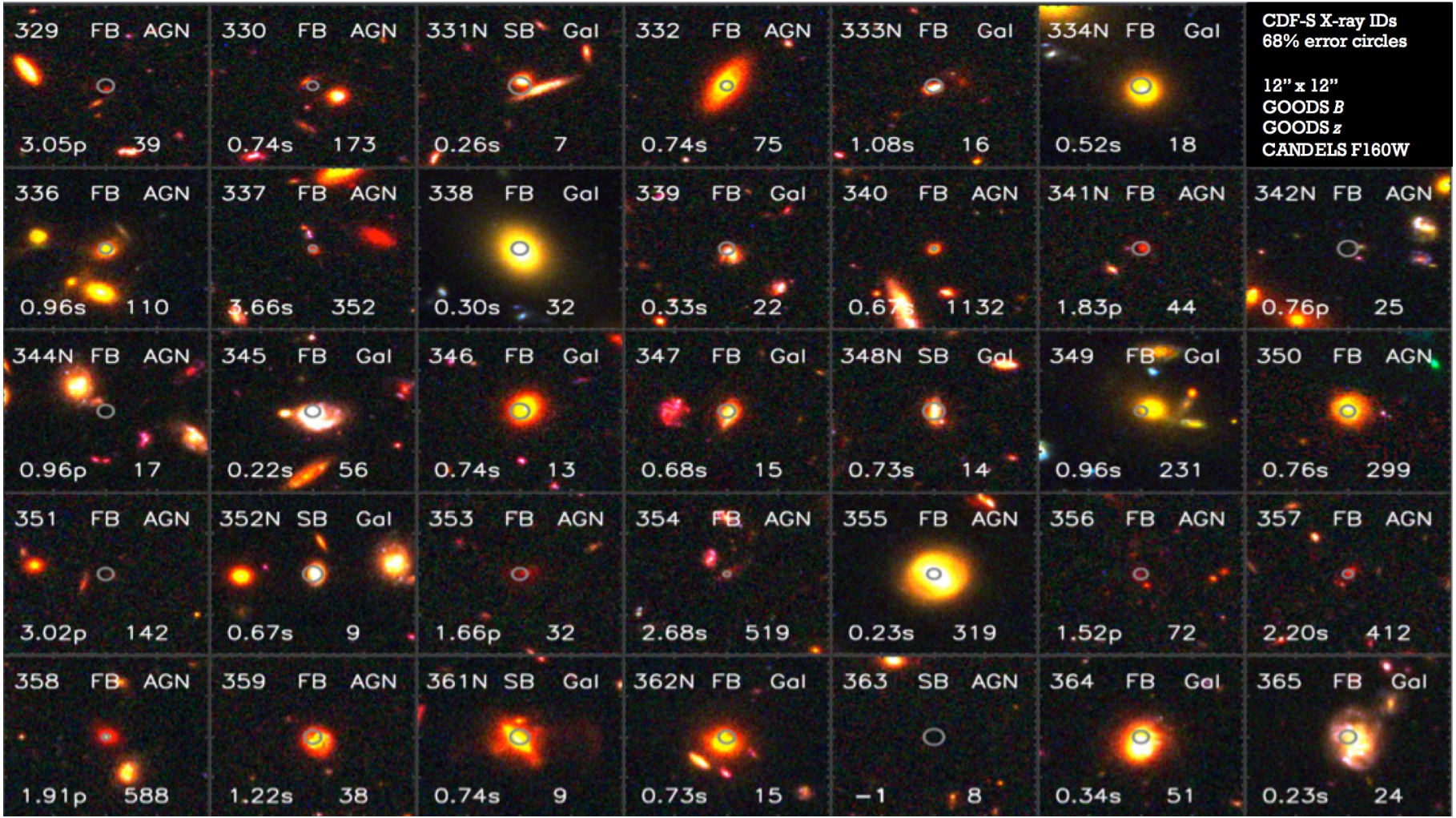
- Are existing or planned (e.g., LSST DM/Scarlet) algorithms and pipelines expected to meet your science requirements for handling blending objects?
  - TBD, lots of hope expressed for Scarlet
- Anything else we should all know about blending challenges for your science collaboration, relevant resources, etc.?
  - Concerns over using co-adds exclusively for static science.
  - Good PSF models and sky subtraction methods.
  - Bright stars can cause serious issues for blending/de-blending since they create complex backgrounds, often creating artificial bridges between sources, etc.

AGN Science Collaboration - **Blending impacts & metrics**

- *All* AGNs will be blended with their host galaxies -- want best measurements possible of both AGN and host properties. Also TDEs.
- AGN blending issues for LSST will be much more severe than for past wide-field AGN surveys, since aim to push much further down the AGN luminosity function where $L_{AGN} \sim L_{Host}$.
- In total, we expect to detect some light from ~ 300 million active galaxies, corresponding to ~ 5 per arcmin^2. However, only some fraction of these (~20-40%) will be identifiable as AGNs.
- The AGN SC has not yet developed formal LSST metrics for evaluating blending impacts. However, some assessments of LSST blending issues have been made in, e.g., the Chandra Deep Fields.

AGN Science Collaboration - **Simulations & tools**

- Simulations & data sets:
  - There are LSST image simulations with AGNs placed in host galaxies, but the AGN SC has not done extensive analysis work on these (no funding) - better communication to the AGN SC needed on these.
  - These likely can be improved with the latest results on the AGN luminosity function, AGN host galaxies, optical AGN variability, etc.
  - Some members of the AGN SC have been using HST vs. ground-based imaging in deep fields to assess blending issues - mainly in the GOODS and CANDELS regions.
- Tools:
  - The AGN SC has not yet developed LSST-specific tools for testing of algorithms or evaluation of metrics. Again, however, we are working on complementary data sets.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0.74s 173
331N SB Gal
0.26s 7
332 FB AGN
0.74s 75
333N FB Gal
1.08s 16
334N FB Gal
0.52s 18
CDF-S X-ray IDs
68% error circles
12" x 12"
GOODS B
GOODS z
CANDELS F160W
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0.96s 110
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3.66s 352
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0.30s 32
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0.33s 22
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0.67s 1132
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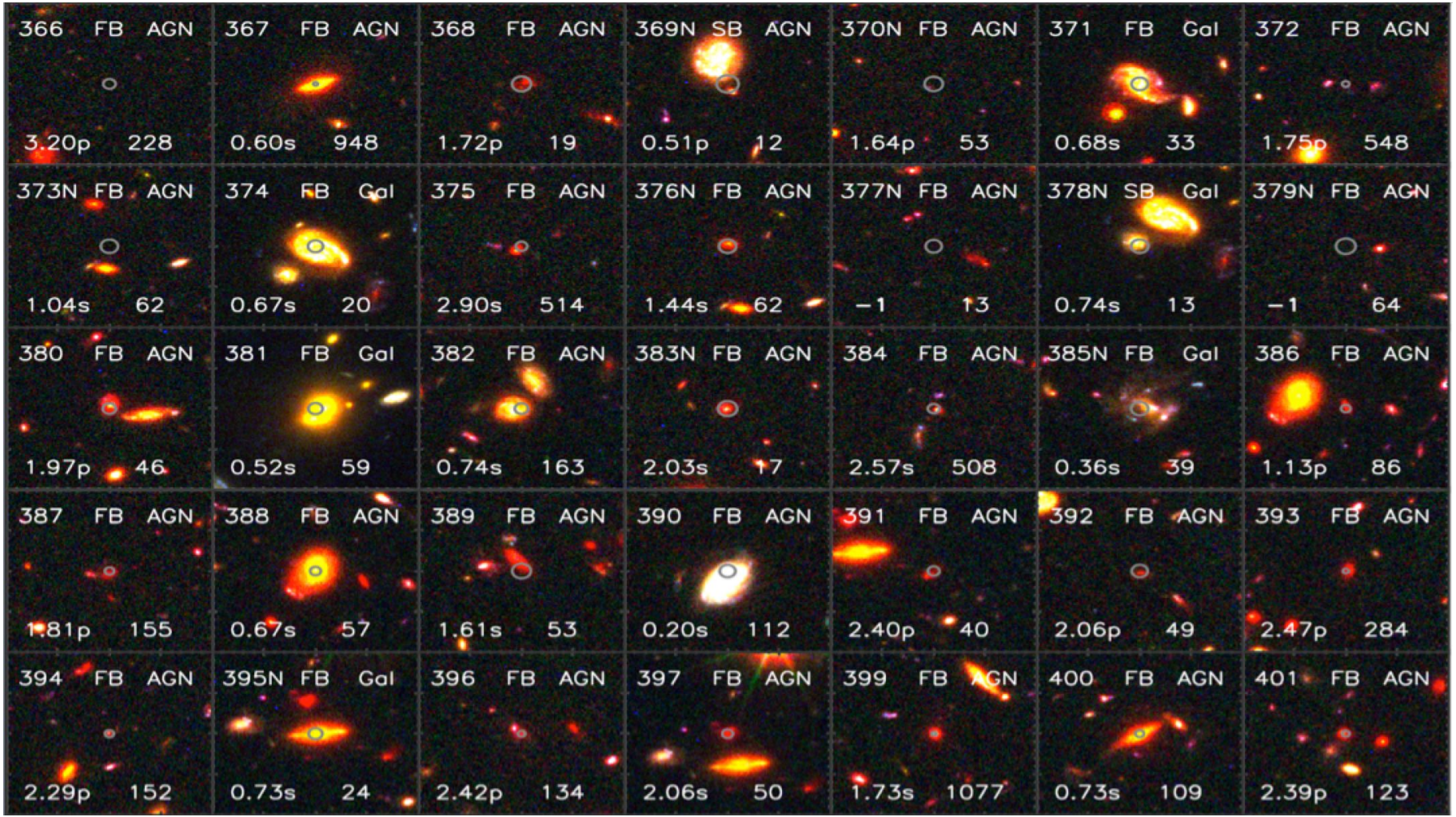
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−1 64
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397 FB AGN
2.06s 50
399 FB AGN
1.73s 1077
400 FB AGN
0.73s 109
401 FB AGN
2.39p 123

AGN Science Collaboration - **Existing algorithms**

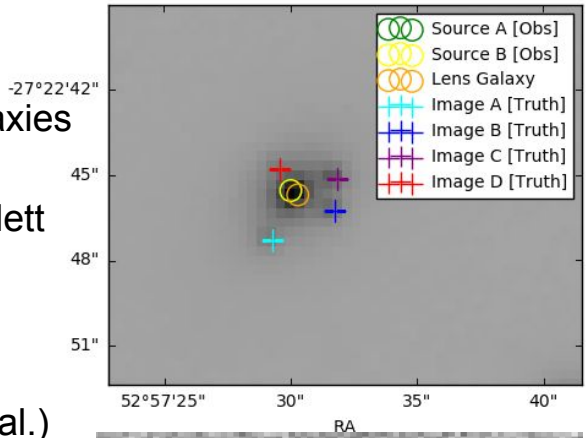
- Based on discussions with Lupton and Bosch in Princeton, LSST DM will give a good start on some key issues - e.g., via image differencing and forced PSF photometry on variable sources in the centers of galaxies.
- However, additional work is likely needed; e.g., in optimal removal of host-galaxy light, utilization of stacked images, and host-galaxy measurements after accounting for the AGN.

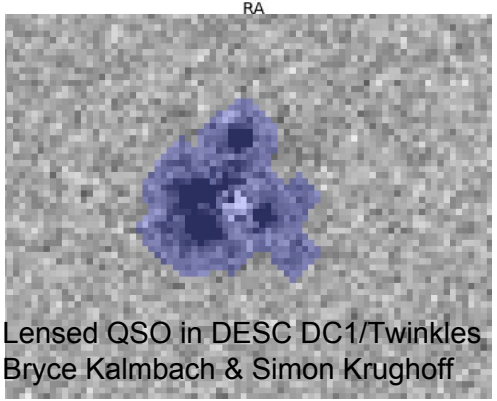
Strong Lensing SC - **Blending impacts & metrics**

- Strong lensing by individual galaxies, groups or clusters, creates valuable images of the background galaxies in **complex environments**
- Blending challenging due to diversity in SL systems
- Accurate photometry/morphometry can be challenging for:
  - Foreground lensing galaxies/groups/clusters
  - Lensed background sources (extended and point sources) that overlap foreground galaxies
  - Extended arcs
  - Faint images
  - Range of magnitudes, sizes and shapes
- Lenses are rare (~1/sq.deg), but issues on individual lens basis
  - <1” galaxy-galaxy lenses, ~few” galaxy groups, several arcsec (cluster-scale)
  - Deblender would have some impact on ~100% of lenses
- Metrics are still to be developed

Strong Lensing Science Collaboration - **Simulations & tools**

- DESC / SLSC Simulations & data sets:
  - DESC DC1 and DC2 contain SL quasars and SL SN host galaxies (focussed on DE applications)
  - DESC/SLSC discussion on a wider set of SL sims (e.g. T. Collett LensPop, A. More SimCT) to be ingested into DC2/3
  - Includes realistic blending by definition
  - Large samples of lenses and “imposters” (incl HSC)
  - Catalogue level searches (SLRealizer, J. Park, P. Marshall et al.)
- Tools & Metrics (to be developed):
  - Determine photometric accuracy & impact on derived parameters
    - Time-variable cases - lensed QSO time delays, lensed SNe on host galaxy backgrounds (DESC DC2)
    - Explore range of properties with R_{Ein}, lens+source brightness, lens+source morphologies, diversity of image configurations etc.

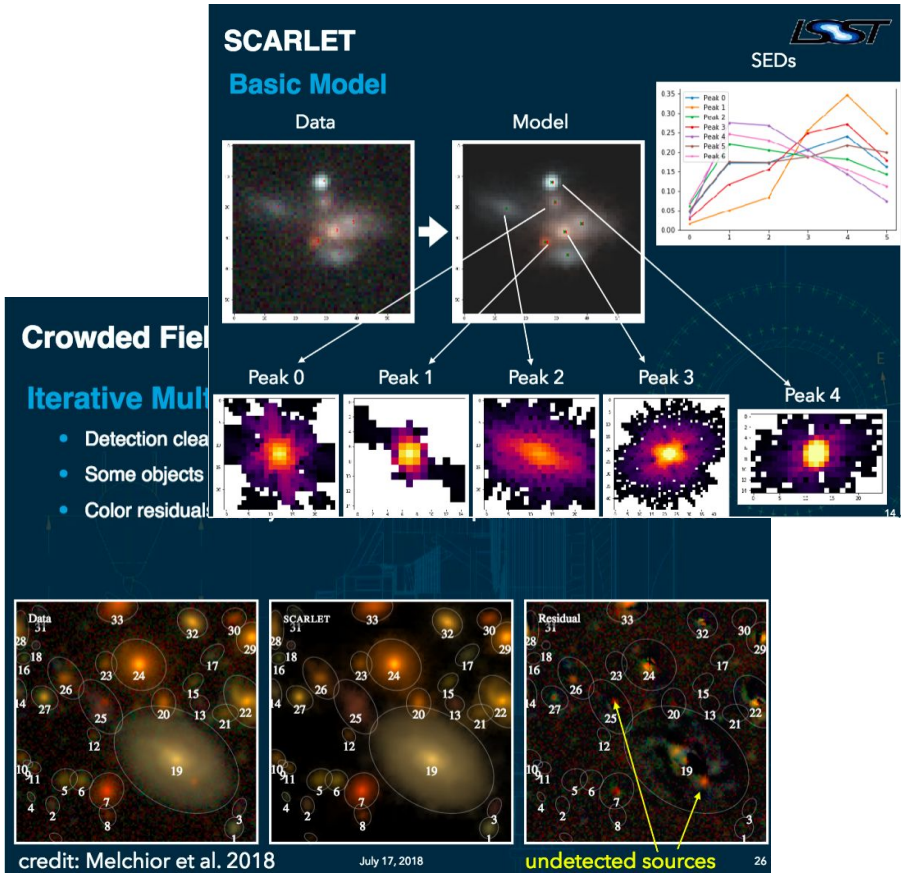




Lensed QSO in DESC DC1/Twinkles
Bryce Kalmbach & Simon Krughoff

Strong Lensing Science Collaboration - Existing algorithms

- Lens subtraction & photometry codes exist
- Explore SCARLET with range of SL cases
  - Galaxy-scale, group-scale, cluster scale...
    - Catalogue vs. image based searches
    - Optimise parameters prompt & release products
  - Hidden lenses (low R_{Ein})
    - “Survey” mode - some SLs SCARLET undetected sources (post-deblend extraction)
    - “Targeted” mode - e.g. Blue Rings (T. Collett et al.)
- Evaluate & compare performance
  - Finding lenses (e.g. presence in deblended catalogues)
  - Measuring lenses (e.g. accuracy of resultant deblended photometry & derived properties)



Dark Energy Science Collaboration - **Blending impacts**

Blending impacts all dark energy probes.

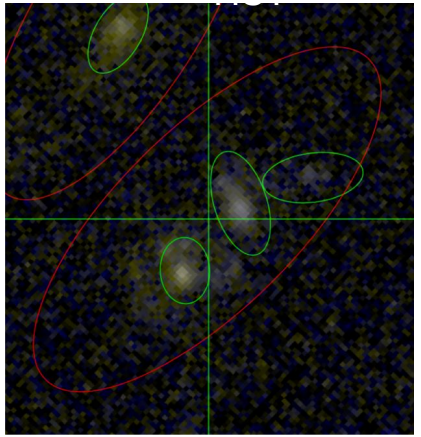
Probe:	Weak lensing	Large scale structure	Galaxy clusters	Strong lensing	SNIa
Shape bias	Yes		Yes		
Selection bias	Yes	Yes	Yes		
Photo-z bias	Yes	Yes	Yes	Yes	Yes
Inaccurate detections	Yes	Yes	Yes	Yes	Yes

Recognized as a major issue for DESC => Blending Task Force (BTF).

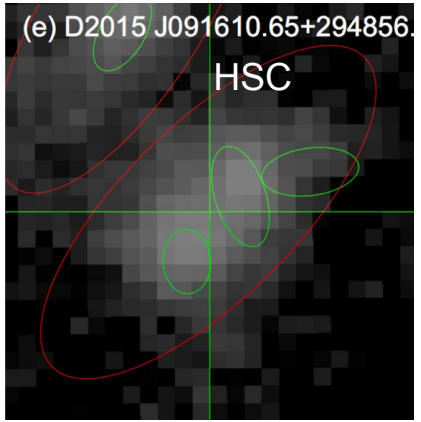
See >20 50-minute presentations (slides+videos) on LSST2018 page.

Dark Energy SC - **Types of blends; metrics**

- For WL, LSS, Clusters: small, faint galaxies (and stars).
- Density of these objects: >40 objects / sq arcmin; close to half are blended (i.e., cannot be treated as isolated) at full depth.
- Examples of studies of metrics & impact of blending already in progress [see Blending Task Force presentations for details]:
  - Decrease in “effective” galaxy density (n_{eff}) and increase in pixel-noise bias for ***shear*** measurements, assuming blends are recognized [pixel level simulations].
  - Shear bias for different deblending algorithms (Scarlet, MOF) using Metacal [pixel level simulations].
  - Increase in shape measurement bias for ***galaxy clusters*** [HST images with LSST PSF + ten-year noise].
  - Bias in galaxy/shear ***2-pt correlations*** due to “neighbor exclusion” and unrecognized blends [catalog level].



Dawson, Schneider, Tyson, Jee



Dark Energy Science Collaboration - **Simulations & data sets**

- Hubble Space Telescope & Hyper Suprime-Cam images of same fields are being used to study the impact of unrecognized blends on the ellipticity distribution of detected galaxies.
- Catalogs combined with simple *parameterized* blending effects are being used to study specific effects on measurements of 2-pt correlation functions.
- The open-source GalSim package is widely used in the DESC for *pixel-level blending studies.*
    - Can simulate galaxies with parameterized profiles & colors, or ingest multi-band HST images and produce Real Chromatic Galaxies.
- GalSim and PhoSim are both used for DESC-wide simulation production.

See Blending Workshop Breakout #5 for more details on all of the above.

Dark Energy Science Collaboration - **Tools**

- WeakLensingDeblending - an existing package that takes GalSim input and facilitates studies of impacts of a set of objects being isolated versus blended.
    - Used to study reduction in statistical sensitivity & increase in pixel-noise bias for cosmic shear measurements.
- Blending Tool Kit - new effort; builds on WeakLensingDeblending; facilitate data augmentation for training and testing detection/deblending/measurement.

See Blending Workshop Breakout #5 for more details on both of the above.

DESC Blending Task Force Presentations [link]

DATE	PRESENTER	TItle	Slides	VIDEO
10/02/2017	Jim Bosch	LSST Data Release Pipelines; Big Questions for Blending	animated google presentation, pdf	Zoom
10/16/2017	Peter Melchior, Fred Moolekamp	Multi-band deblending for LSST (also see 05/07/2018 presentation on Scarlet) [arXiv:1708.09066)]	Peter (pdf), Fred (pdf)	Zoom
10/23/2017	Gary Bernstein	Shear estimation with Bayesian Fourier Domain (BFD) method; thoughts on blending at LSST depths	pdf	Zoom
10/30/2017	Simon Samuroff	Im3shape and blending in DES	pdf	Zoom
11/06/2017	Erin Sheldon	The MOF deblender used in DES + discussion of interplay with metacalibration	pdf	Zoom
11/20/2017	Robert Lupton	Failure modes due to blended objects, at LSST depth (e.g., HSC), in detection, photometry, shape measurements, etc.	pdf	Zoom
11/27/2017	Rachel Mandelbaum	Shear estimation and blending in HSC	pdf	N/A
12/04/2017	Ian Dell'Antonio, Shenming Fu, Binyang Liu	Effects of blending on cluster shear profiles	google presentation (updated Aug 2018)	N/A
12/18/2017	Laurence Perreault Levasseur	Convolutional neural networks and independent component analysis of multi-filter imaging data (continued on Jan 29) [arXiv:1708.08842]	pdf	N/A
01/22/2018	David Kirkby	Image simulations for blended objects	pdf	Zoom
01/29/2018	Laurence Perreault Levasseur	Convolutional neural networks and independent component analysis of multi-filter imaging data (continued	pdf	N/A

Season 1

02/26/2018	Benne Holwerda	What do we know about occulting galaxy pairs? [arXiv:1605.02420]	pdf	Zoom
03/05/2018	Joachim Harnois-Deraps	Testing the blend-exclusion bias on cosmic shear with mocks lensing data [arxiv:1805.04511]	pdf	Zoom
03/19/2018	Erin Sheldon	Single object co-adds: implementations and testing	pdf	Zoom
04/16/2018	Alexie Leauthaud	Study of photometric performance of HSC pipeline by superimposing GalSim images on HSC images (SynPipe)	arXiv:1705.01599, SynPipe github	
04/30/2018	Raphael Shirley	Using the Bayesian Evidence for Source Extraction, Model Comparison and Deblending	pdf	N/A
05/07/2018	Peter Melchior, Fred Moolekamp	Improvements to SCARLET deblender, update on integration into the LSST stack, and future directions in deblending (including multi-survey) [arXiv:1802.10157]	Fred (pdf), Peter (pdf)	Zoom
05/21/2018	Sowmya Kamath	Quantifying effects of blending using simulated galaxy pairs + Hybrid use of the LSST science pipelines & Scarlet	pdf	Zoom
06/18/2018	Jim Bosch	Co-addition algorithms and impacts of blending	animated google presentation	Zoom
07/02/2018	Cyrille Doux	Deblending galaxies with deep, convolutional, probabilistic neural networks	pdf	1st half of Zoom
07/02/2018	Sowmya Kamath	Addressing blending challenges with neural networks – A case study: Mask R-CNN	animated google presentation, pdf	2nd half of Zoom
07/24/2018	Francois Lanusse	CMU DeepLens: Deep Learning For Automatic Image-based Galaxy-Galaxy Strong Lens Finding		N/A

Season 2

Transients & Variable Stars SC - **Blending impacts & metrics**

Blending will be more severe than in previous time-domain surveys.
Higher resolution helps partially alleviate the issue.

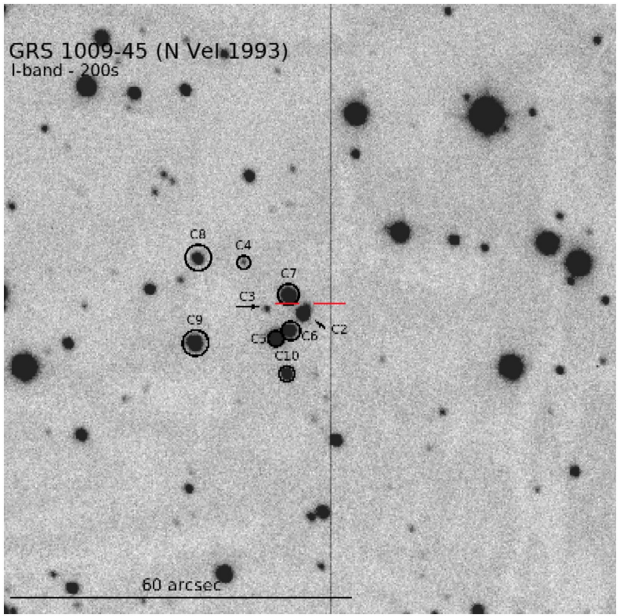
TVS interest in galactic plane science - blending will affect galactic transients (e.g. microlensing, quasi periodic X-ray binaries) & variable stars.

Stellar density up to

~30/sq arcmin/mag @ I=16,

~1000/sq arcmin/mag @ I=20

Poshak Ghandi: The correct source is less than an arcsec north of a much brighter star marked C2. We really need deblending for such objects.



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But at LSST depths even high-latitude fields are crowded with galaxies!

Stellar Variability in Crowded Fields TVS task force (leads: Hambelton, DallOra)
https://lsst-tvssc.github.io/cfp_task_force_work_plan.html

Stellar blending can affect:

- *magnitudes*
- *variability (indices such as Stetson's)*
- *periods (period finding metrics)*
- *precision on astrometric solutions - followup (astrometry metrics)*
  - *distance scale determinations*
  - *microlensing models (fit must lightcurve include blending parameters)*

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SN light echoes are severely affected by blending and deblender does not perform as per J. Bosch (SN physics, progenitors, mass ejection)

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Light echoes of historical transients - variable extended sources

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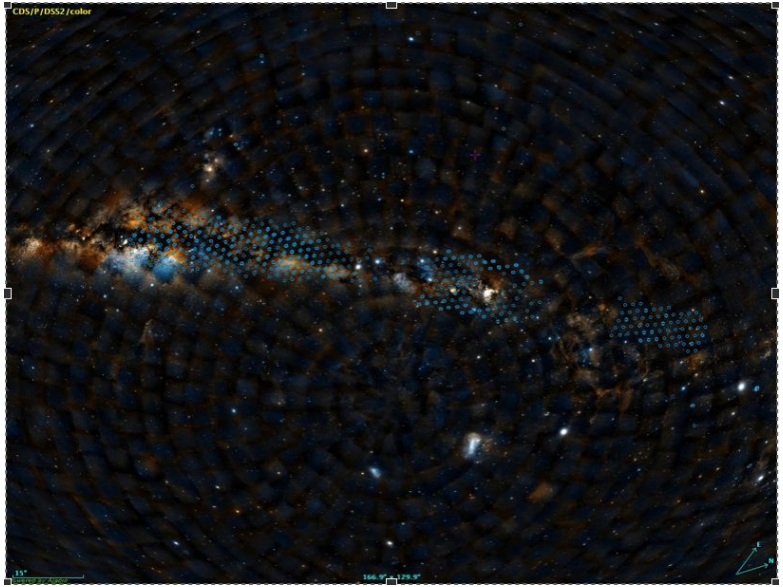
Light echoes of historical transients - variable extended sources

ExtraGalactic transient host characterization

Transients & Variable Stars SC - **Simulations & images**

- Simulations:
  - Image-level simulations by Matthew Penny for microlensing (not suited to variable seeing)
  - *Have the DM team already simulated a crowded field of **point** sources (not galaxies)?*
- Datasets adequate to test crowded field photometry:
  - DECam bulge images in the OGLE IV footprint
  - Time series from OGLE IV (need permission for publication) / KMTNet



2013A-0719, bands ugriz, 4156 images (PI: Saha)
2014A-0429: bands griz, 1328 images (PI: Finkbeiner)
2016A-0327: bands grizY, 2319 images (PI: Finkbeiner)
2016B-0279: bands grizY, 6150 images (PI: Finkbeiner)
2016A-0951: bands griz, 90 images of 3 fields w overlap (PI: Penny)
2017A-0936: bands grizY, 190 images (PI: A. Calamida)

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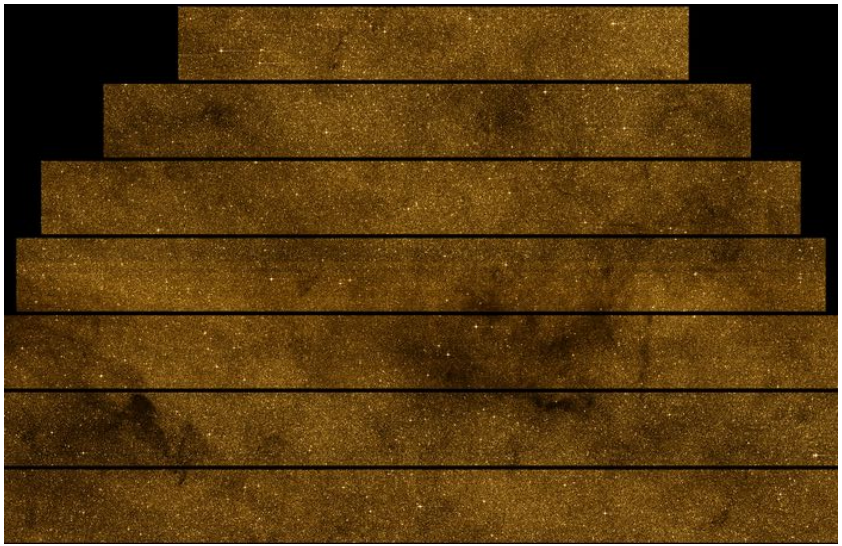
  - *Gaia, but magnitude gap*

Gaia Sagittarius I Window (Sgr-I) 2deg below the Galactic Centre.
https://www.esa.int/spaceinimages/Images/2017/08/Gaia_sky_mapper_image_near_the_Galactic_centre

"The stellar density here is an incredible 4.6 million stars per square degree. The image covers about 0.6 square degrees, making it conceivable that there are some 2.8 million stars captured in this image sequence alone."



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  - DECam bulge images in the OGLE IV footprint
  - Time series from OGLE IV (not public) / KMTNet
  - *Gaia, but magnitude gap*
  - *In the future WFIRST, Euclid*
- Tools:

  Stellar Variability in Crowded Fields Task Force tested DECAM with DOPHOT + is gearing up to test with LSST stack (#stack-club!)

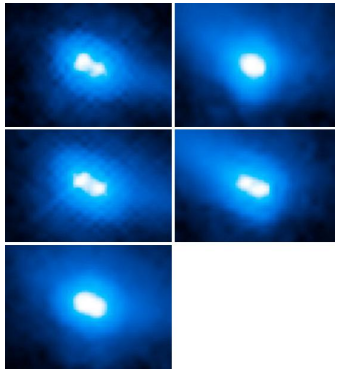
  Metrics:
  - Variability: spread of the photometry (Stetson's index) $I = \sqrt{\frac{1}{n(n-1)}} \sum_{i=1}^{n} \left(\frac{b_i - \bar{b}}{\sigma_{b,i}} \right) \left(\frac{v_i - \bar{v}}{\sigma_{v,i}} \right),$
  - Periodicity: FFT (but unevenly sampled lcvs), Phase Dispersion Minimization
  - Cross-match lightcurves with the OGLE IV catalogue
  - Microlensing models parameter recovery (Somayeh Khakpash will write it, #stack-club!)

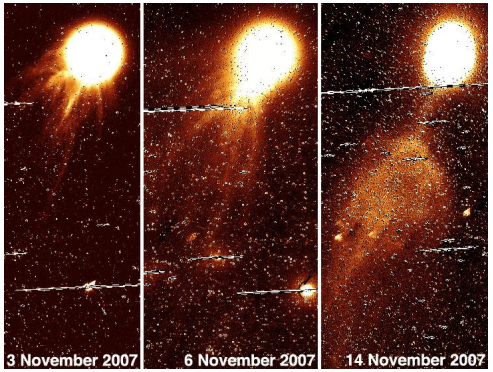
Transients & Variable Stars SC - **Outstanding Issues**

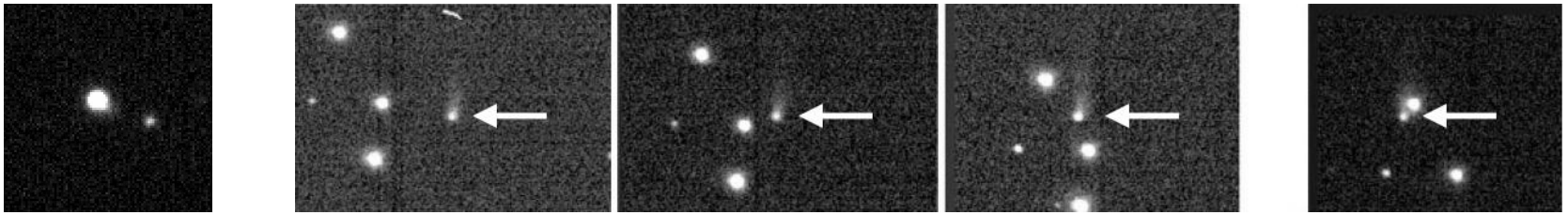
- LSST DM Stack DIA should work just fine if blending is with static non-saturated sources
- Exceptions:
  - Distinguishing transient events (e.g. microlensing) blended with background variables (or saturated stars) is an outstanding issue.
  - DIA false positives will increase or *change* w blending - will existing real/bogus ML to evaluate the artifacts be adequate?
  - Blending with extended sources? dust features, background galaxies… see discussion on community “, “it’s up to how well we can deblend that pair, and that will depend a lot on the relative fluxes of the components and how extended the host galaxy is” (JBosch Feb 21 https://community.lsst.org/t/data-model-for-variable-sources-at-time-of-data-releases/2695)
- the computing resources needed by PhoSIM scale strongly with N stars, so *are there computing resources available for this that TVS could access to simulate variables and transients in crowded fields?*

Solar System Science Collaboration - **Blending impacts**

- Examples of solar system science areas impacted by blending
  - Comet detection and characterization
  - Detection/characterization of multi-object systems
  - Characterization of extended features







Solar System Science Collaboration - **Blending impacts/metrics**

- Generally assumed that difference imaging will resolve most cases, so not much thought specifically put into dealing with blending to date
  - Might be true, but will depend on quality of difference imaging analysis, especially in challenging situations (e.g., early in the survey, in crowded fields, near saturated sources, for extended sources/features, etc.)
  - Expected density/fraction of impacted objects currently undetermined
  - No metrics for evaluating impact on solar system science identified yet

Solar System Science Collaboration - **Simulations & tools**

- Simulations & data sets
  - No simulations studying the impact of blending on solar system science or tools for testing algorithms for dealing with blending currently exist
  - Various data of blended solar system objects are available for potential testing if needed
  - Evaluation of the effectiveness of difference imaging will be key (Do any artifacts remain? How good will difference images be early in the survey? What if saturated sources, extended sources, or non-uniform background is present?)
- Not known if existing or planned algorithms and pipelines will meet solar system science requirements for handling blending objects
  - Looking forward to discussions during this workshop

Stars Science Collaboration - **Blending impacts & metrics**

- Stars will be blended (crowded) towards Galactic Plane.
- Both photometry and astrometry are important.
- This is an “easier” problem (stellar PSF).
- There will be a transition between galaxy-dominated and star-dominated blending. Can this be handled by a single software set and appropriate priors?

Stars Science Collaboration - **Simulations & tools**

- Simulations & data sets:
  - There are a number of community-accepted crowded field photometry tools.
  - Bulge, Milky Way data, LMC observations from 4-meter and 8-meter class telescopes provide real datasets now.
  - Efforts are underway to compare DM products to other software.
  - Potential of Gaia comparison in crowded fields.

Stars Science Collaboration - **Existing algorithms**

- Key Question: Will DM deliver state-of-the art crowded field photometry for dense Milky Way stellar fields [“best effort”] or is this a community product?
- How well does the DM pipeline perform?