MAVIS: VISIBLE MCAO ON THE VLT, AN AUSTRALIAN-LED INSTRUMENT

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(B) LAM - LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE, MARSEILLE, FRANCE
(C) AAO - AUSTRALIAN ASTRONOMICAL OBSERVATORY, SYDNEY, AUSTRALIA
(D) SWINBURNE UNIVERSITY
(E) MELBOURNE UNIVERSITY

MAVIS IN A FEW BULLETS

- On **VLT UT4** (Adaptive Optics facility)
- Benefits from **AOF** infrastructure (4 LGS Facility, deformable M2)
- **30” field of view** @ close to the diffraction limit (**15-20mas FWHM**)
- **450-980nm** Science
- 4k x 4k **imager**
- IFU/MOS, **Spectroscopy TBD**
- **> 15% Strehl at 500nm** (> 50% @ 850nm)
- **> 30% Sky coverage**
- Phase A to start in 10/2018, 7 years development timeline
- **Australian + European** consortium led by Australia. **This is our opportunity to provide a major, ambitious and innovative instrument to ESO, something that could be a major argument in Australia joining as a full partner in 10 years.**

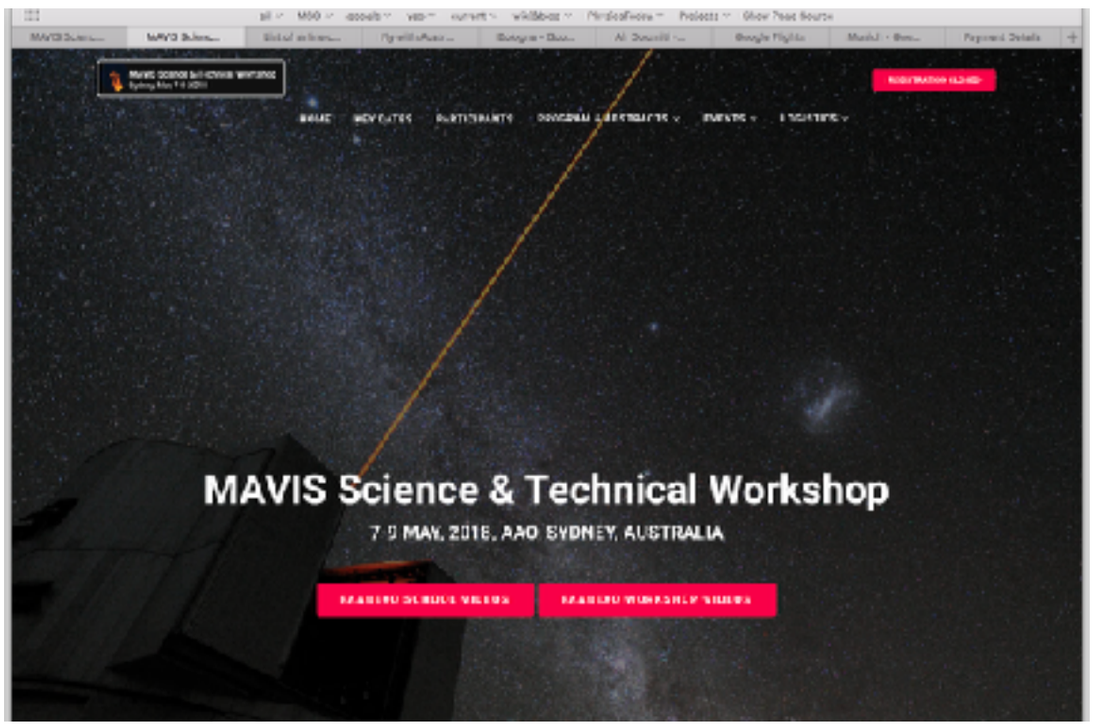
ESTABLISHING A SCIENCE CASE FOR MAVIS

November 2017 MAVIS science workshop participants:

- **Geraint Lewis**, “Halos, Streams & Shells”
- **Karl Klazebrook**, “High resolution galaxy morphology and kinematics”
- **Sarah Martell**, “Spectroscopy in resolved stellar population”
- **Chris Lidman**, “Galaxy Tranformation in Galaxy Clusters"
- **Michele Trenti**, “A sharpened view of star formation at the edge of reionization “
- **Richard McDermid**, “Resolved and semi-resolved stellar populations beyond the local group”
- **Stuart Ryder**, “Transients + Circumstellar disks”
- **Michael Ireland**, “Exoplanets”
- **Michael Dopita**, “Resolving the coronal emission line and dust sublimation regions of Seyfert Galaxies”

MAVIS workshop, 7-9 May 2018, AAO.

- 3 day workshop to discuss instrumentation design, AO performance and science case
- **Now is the time to get involved if you want to shape this instrument for your science. Everybody’s welcome, attend this workshop, your contribution is important!**
- **SOC** being formed/confirmed (50/50 men/women, 50/50 Instrument&AO/Astro, 50/50 Australia/Europe emphasis on the science).



STEPPING INTO ESO INSTRUMENTATION

- Australia joined ESO as a **strategic partner**
- Restricted to La Silla & Paranal access and instrument building
- **VLT** instrumentation already very crowded. **AOF** being commissioned
- **"ESO community days"** workshop is a yearly platform to discuss instrument upgrade or new instrumentation
  - In community days 2015 and 2016, a **visible MCAO plus focal plane instrumentation** gathered interest
    - Concept initially presented by Simone Esposito (INAF Arcetri)
- ANU was approached to participate to the consortium being formed to answer the anticipated ESO call for phase A. Meeting @ LAM on 12-13 October. "Kick-off" + assembled consortium made of INAF (Arcetri & Padova), Laboratoire d'Astrophysique de Marseille (LAM), AAO and ANU
- Consensus within consortium for Australia to take a lead role on MAVIS, given heavy involvement of European institutes into E-ELT instrumentation. **Strong Interest from Aussie community** (as demonstrated by attendance to MAVIS November 27 workshop)
- ANU & AAO experience and credentials in 8-m instrumentation & AO

CONSORTIUM

AO system engineering
Opto-mechanics
NGS WFS

Software
Opto-mechanics

Simulations
Post-processing
AO Control

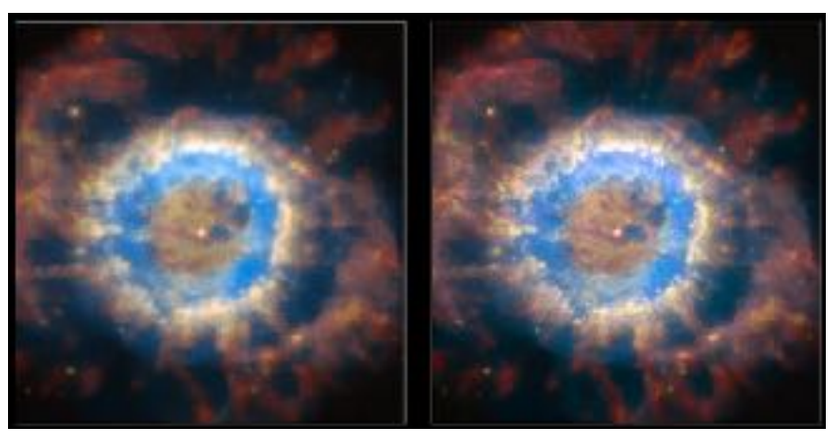
Management
LGS WFS
RTC, AO expertise

Post-focal instrumentation
+ Macquarie (Project Scientist)

AOF FACTS

- AOF is the upgrade of VLT UT4 to a full AO facility, being commissioned right now
- A deformable secondary mirror (DSM or ASM) with 1170 actuators, conjugated to the ground (≈20cm actuator spacing projected on M1)
- Four laser guide stars 20W each, driving a 40x40 Shack-Hartmann WFS for GLAO (4 WFSs in total). High photon return
- **Appropriate to push the correction to shorter wavelengths**
- **Adding post-focal DMs would enable MCAO in the visible**

  ➜ Increase the corrected field of view beyond limitations of natural angular anisoplanatism

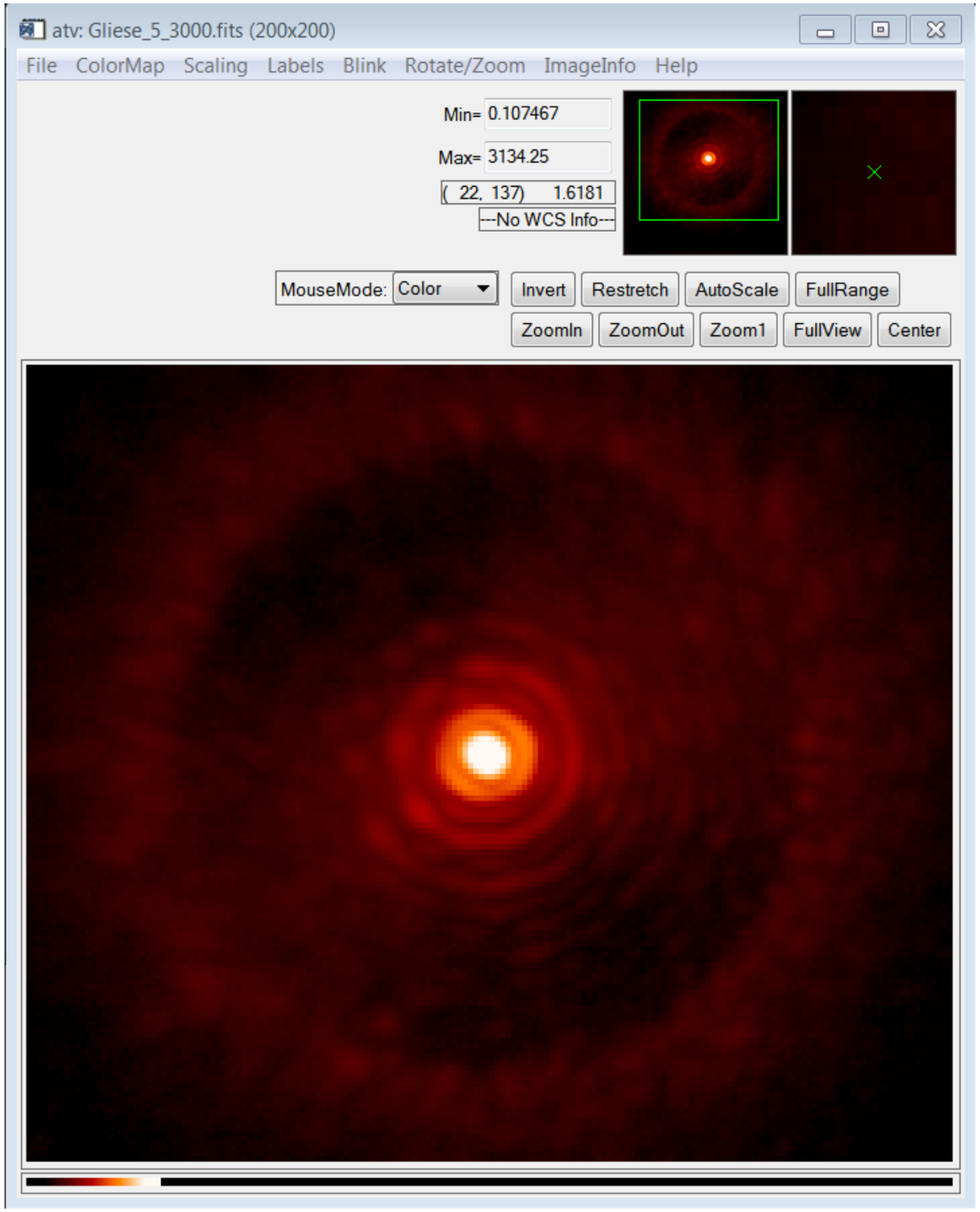


WHY GO TO THE VISIBLE?

- **Science and physical arguments** compared to NIR
  - Sky background is much smaller (1000 to 10000 darker than K)
  - Difference with space is smaller too
  - Most of the action is in the visible (atomic lines)!
  - Colour differences significantly more marked than in the NIR
  - **500nm on an 8-m ➜ same angular resolution as 2µm on an ELT**
  - Provides largest gain in crowded environments (clusters)
  - Astrometry challenging but lots of studies for ELT MCAO systems (NFIRAOS & MAORY)
  - Photometry currently at 0.02 to 0.01 magnitudes, better with MCAO
- **Technological arguments** compared to NIR
  - Large visible detectors are cheap and detector quality is much better
  - Low noise (<1e- RON), large (4kx4k) and fast (10 frames/s) detectors exist

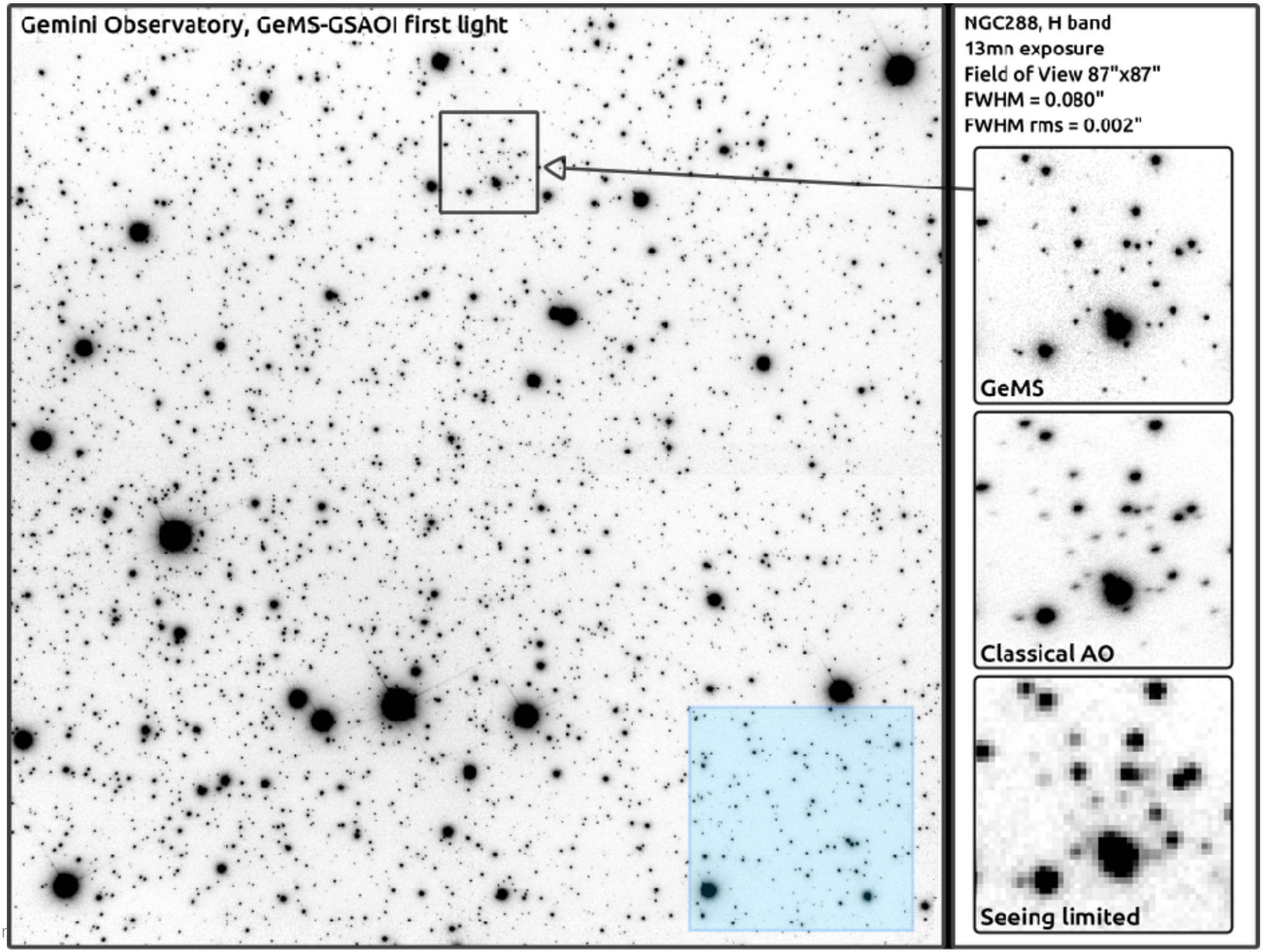
SINGLE CONJUGATE AO CORRECTION IN THE VISIBLE

- 650nm images from Forerunner @ LBT
  - Adaptive secondary mirror similar to the one on AOF
  - 0.8” seeing
  - 50% Strehl ratio!
  - 18 milliarcsec FWHM
- There are similar images from SPHERE @ VLT (95% Strehl @ K band ➜ 37% @ V band) and MAG-AO on Magellan
- **Visible is do-able!**

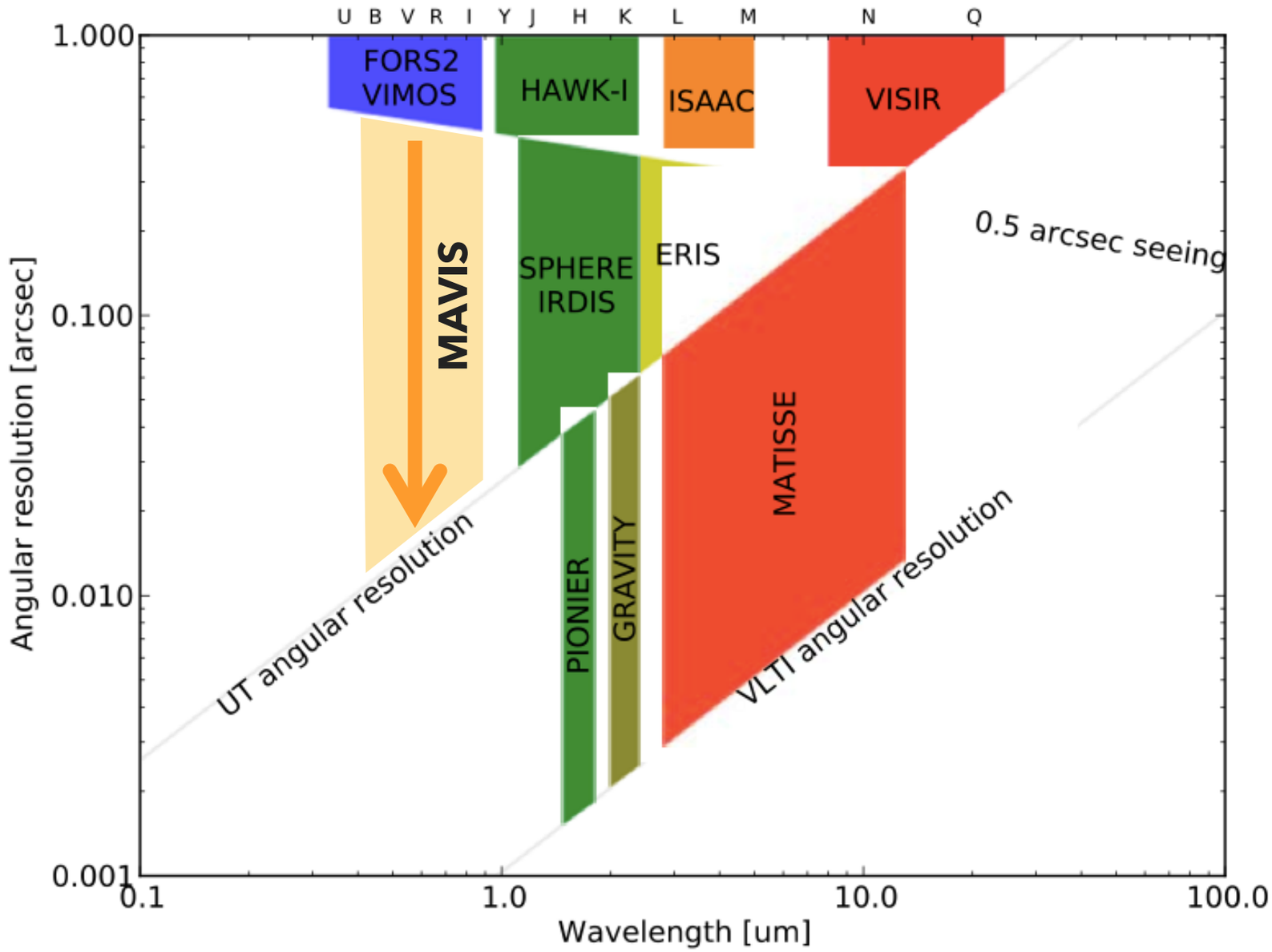


MCAO IN THE VISIBLE: IS IT DOABLE?

MCAO IN THE NIR: GEMS @ GEMINI

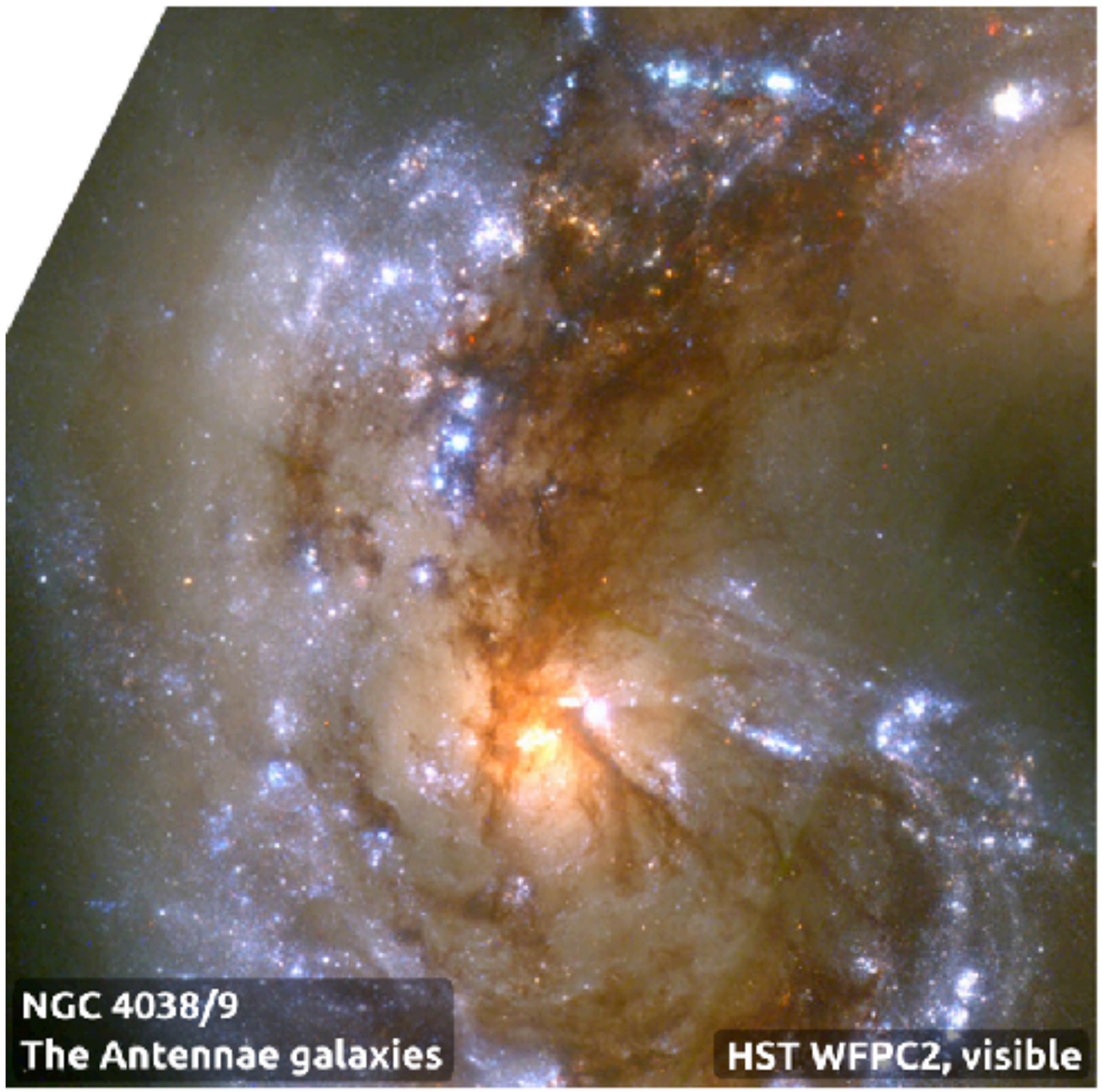


FILLING A RESOLUTION GAP



- There is large potential for an optical instrument to fill the gap in spatial resolution of current VLT/I instrumentation

AO COMPLEMENTING SPACE BASED OBSERVATIONS, OR MAVIS (VIS) COMPLEMENTING MAORY ON THE E-ELT (NIR)



CREDIT GEMS COMMISSIONING TEAM

VISIBLE MCAO SCIENCE CASE

- ESO Working Group produced a pre-Phase A science case for a Visible MCAO Instrument
- Published earlier this year

Programme: PIP

Project/WP: PIP New III Instrument

Science Cases for a VLT Visible MCAO Instrument

Document Number: ESO-299554

Document Version: 1

Document Type: Science Report (SRP)

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Document Classification: Public

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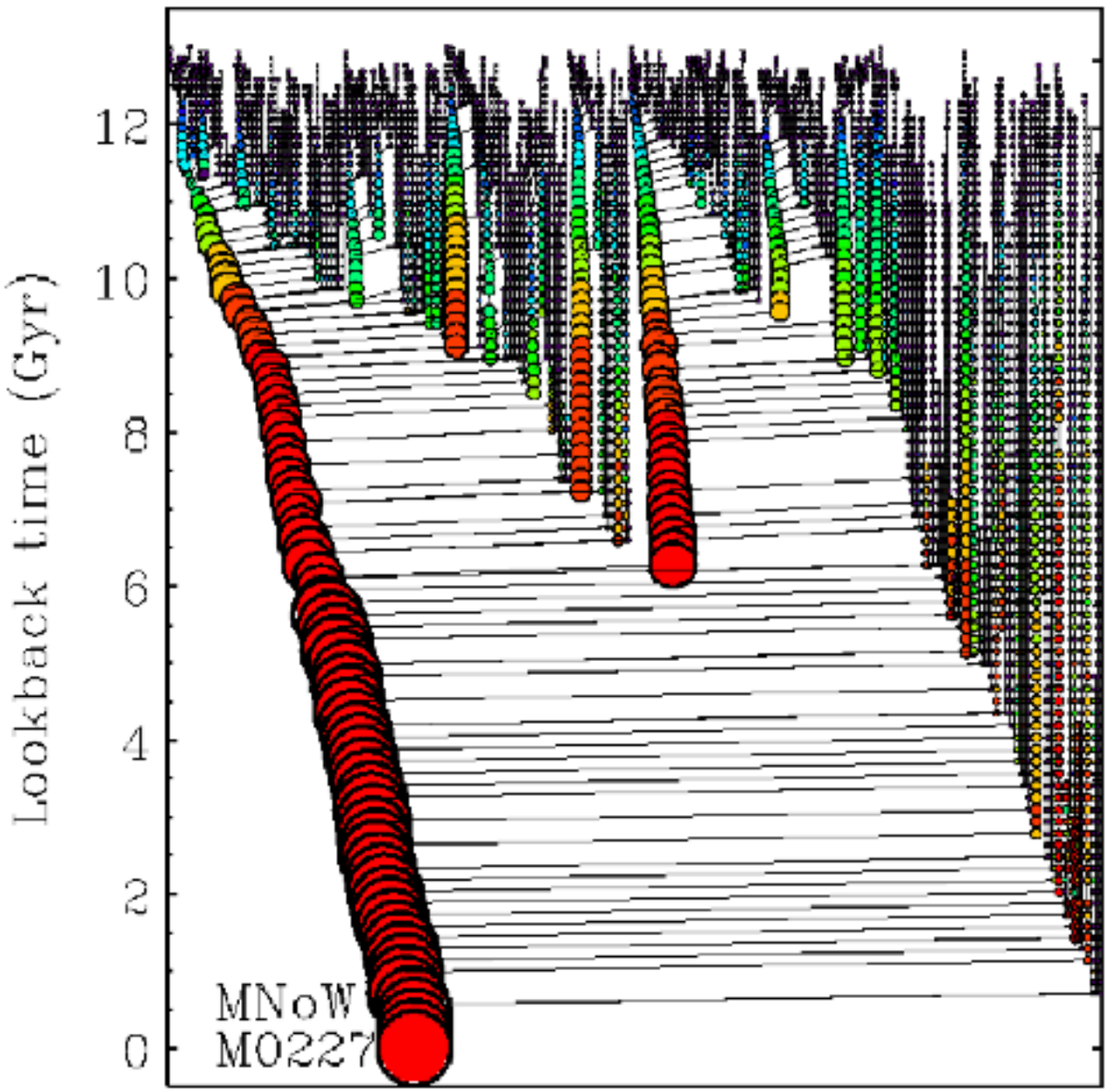
VISIBLE MCAO SCIENCE CASE

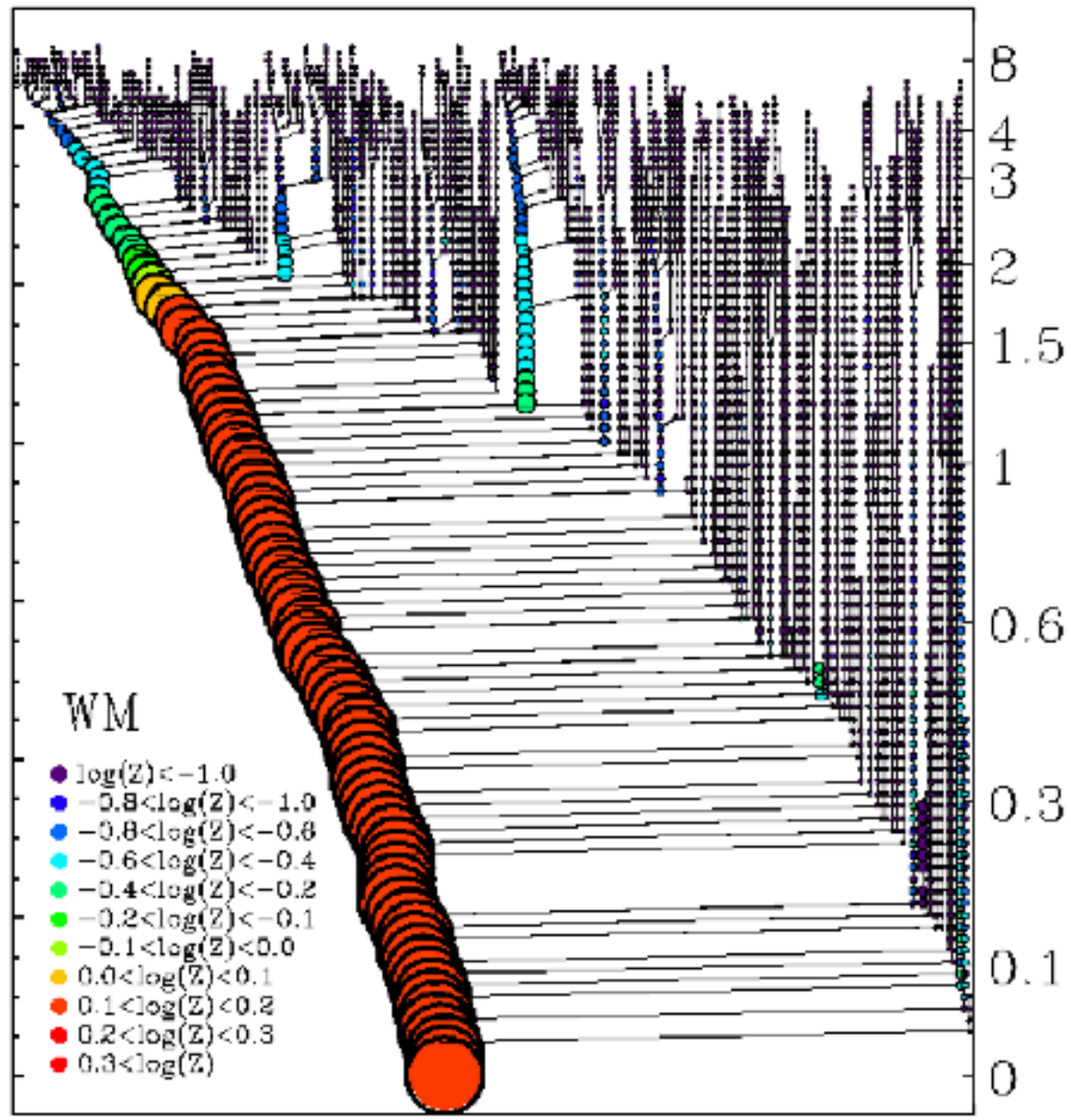
- **ESO Working Group** produced a **pre-Phase A science case** for a Visible MCAO Instrument
- Published earlier this year
- Main topics:
  - Resolved Stellar Populations
  - Solar System Science and Outreach
  - Star Formation Processes
  - Intermediate Mass Black Holes in Globular Clusters
  - Quasar Absorption Lines
  - Star Forming Clumps at High Redshift
  - Gravitational Lensing
- Good overlap with proposed Australian science cases presented at November ANU Workshop

Key Science Case 1: Resolved Stellar Populations

MASSIVE GALAXIES GROW IN DIFFERENT WAYS



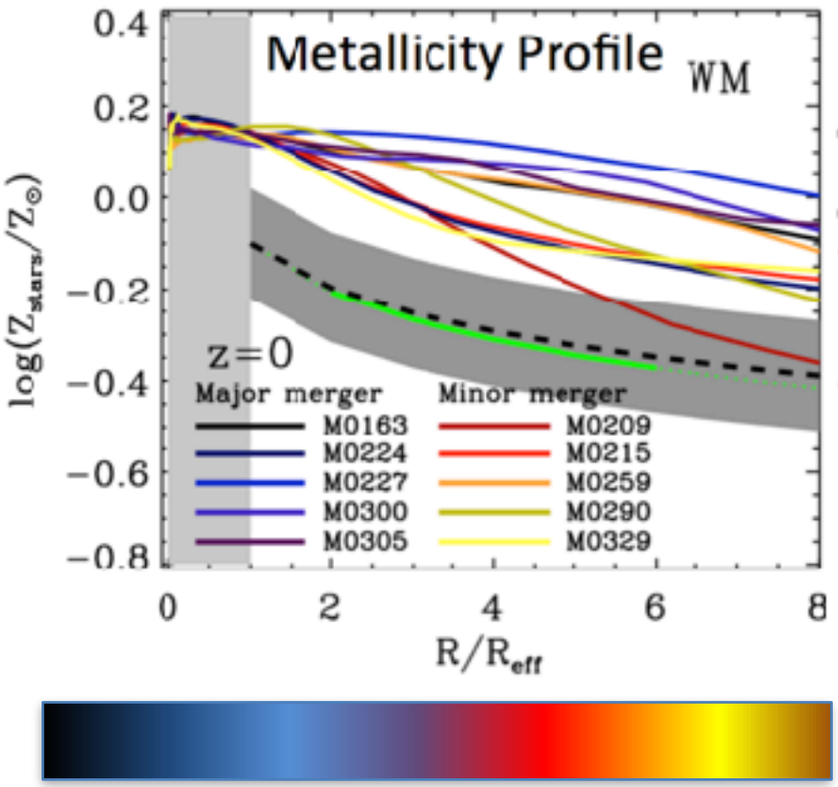
Growth through **major** mergers

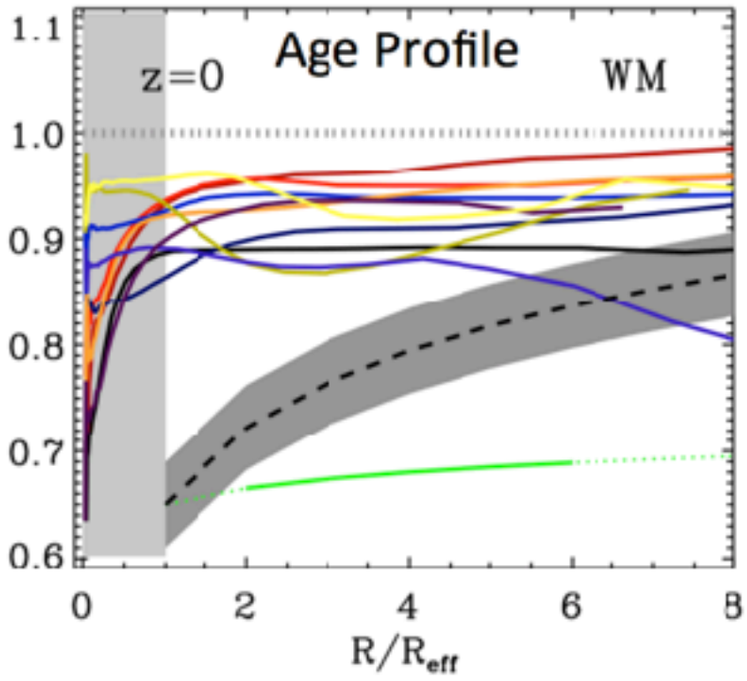


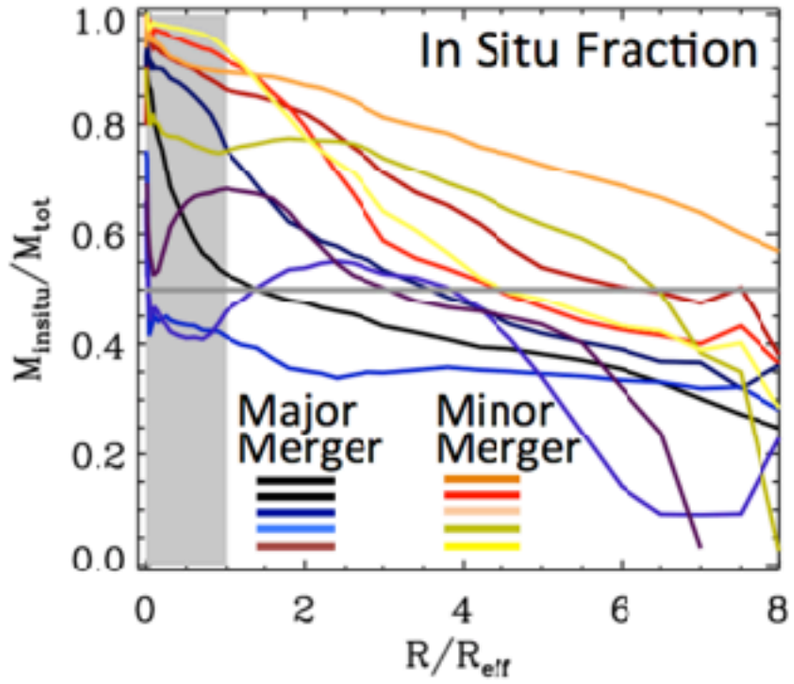
Growth through **minor** mergers

Hirschmann+15

HALO STELLAR POPULATIONS HOLD CLUES TO THIS ASSEMBLY







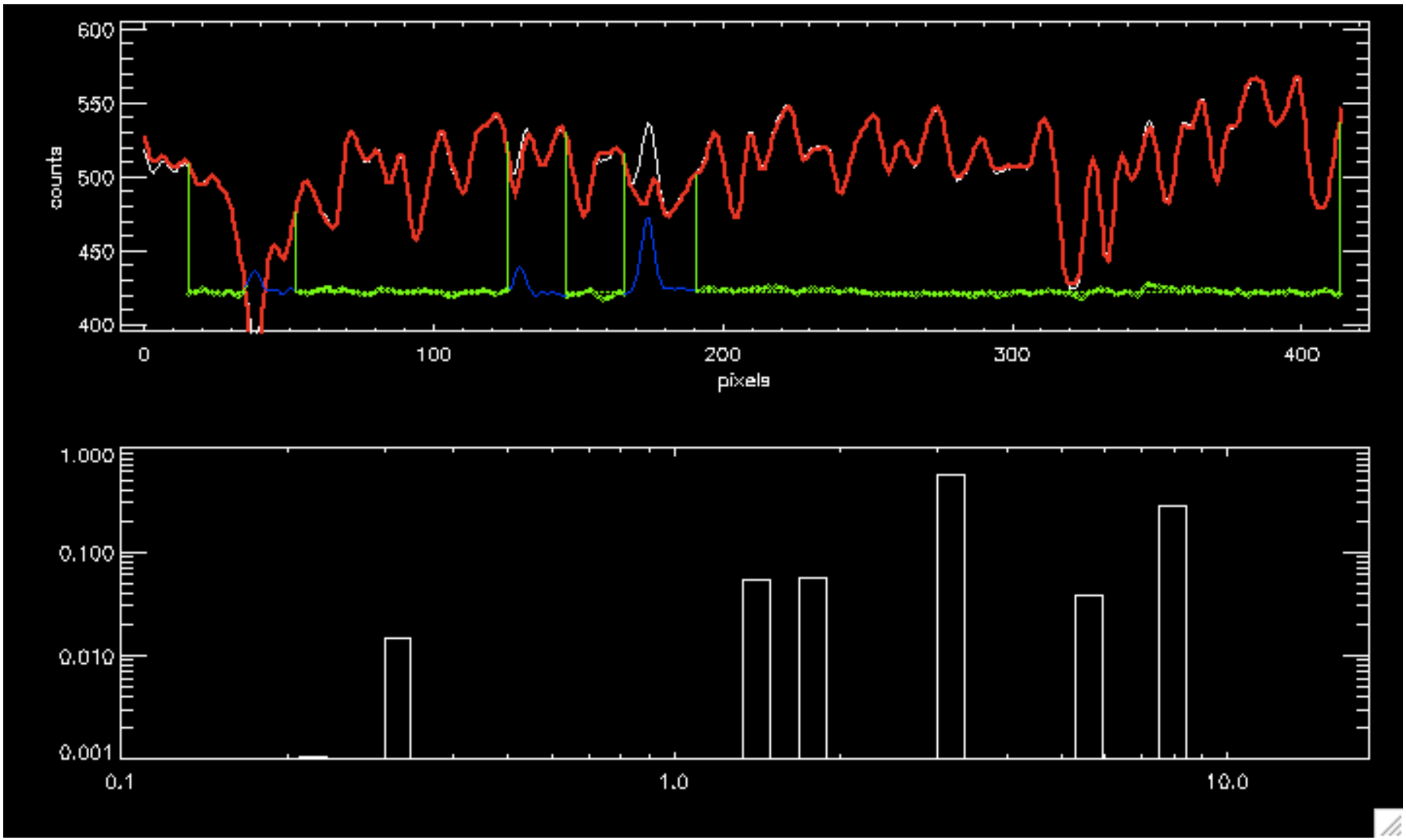
Major Mergers -- Minor Mergers

Different assembly history shows in spatial distribution of age and metallicity, especially at large radius

R_e>4 is difficult with integrated light – surface brightness is too low

Hirschmann+15

INTEGRATED LIGHT STAR FORMATION HISTORIES ARE DEGENERATE



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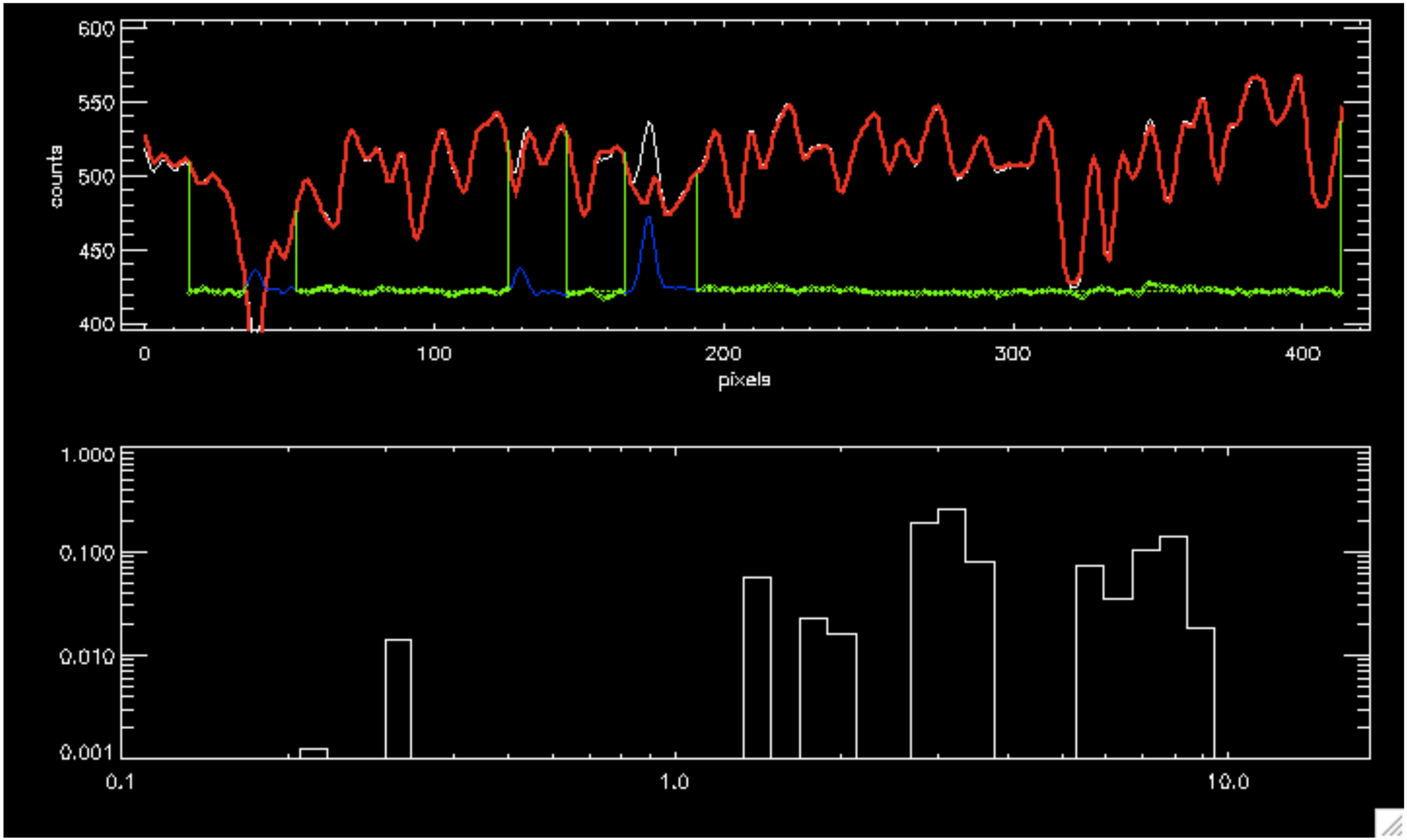

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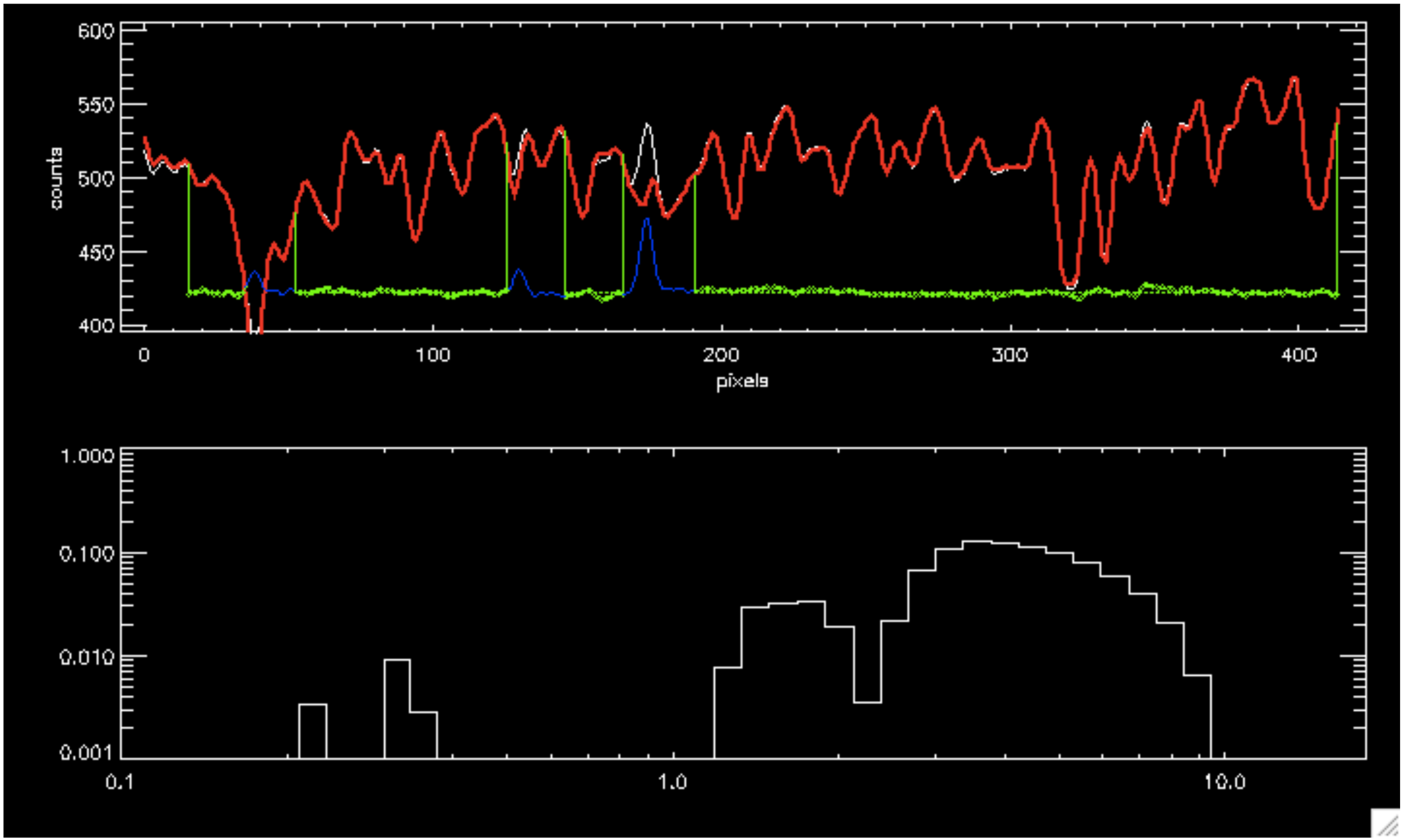

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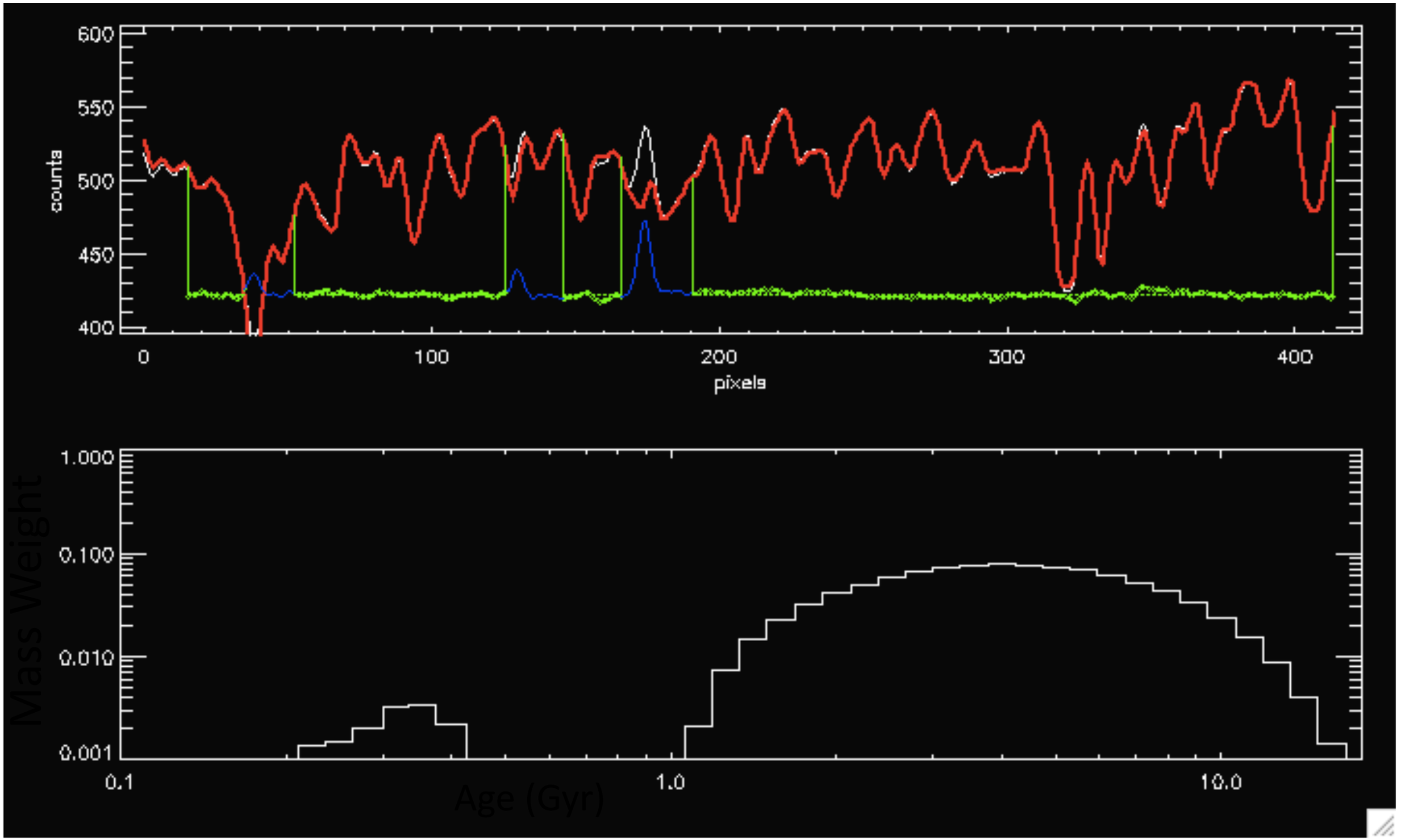

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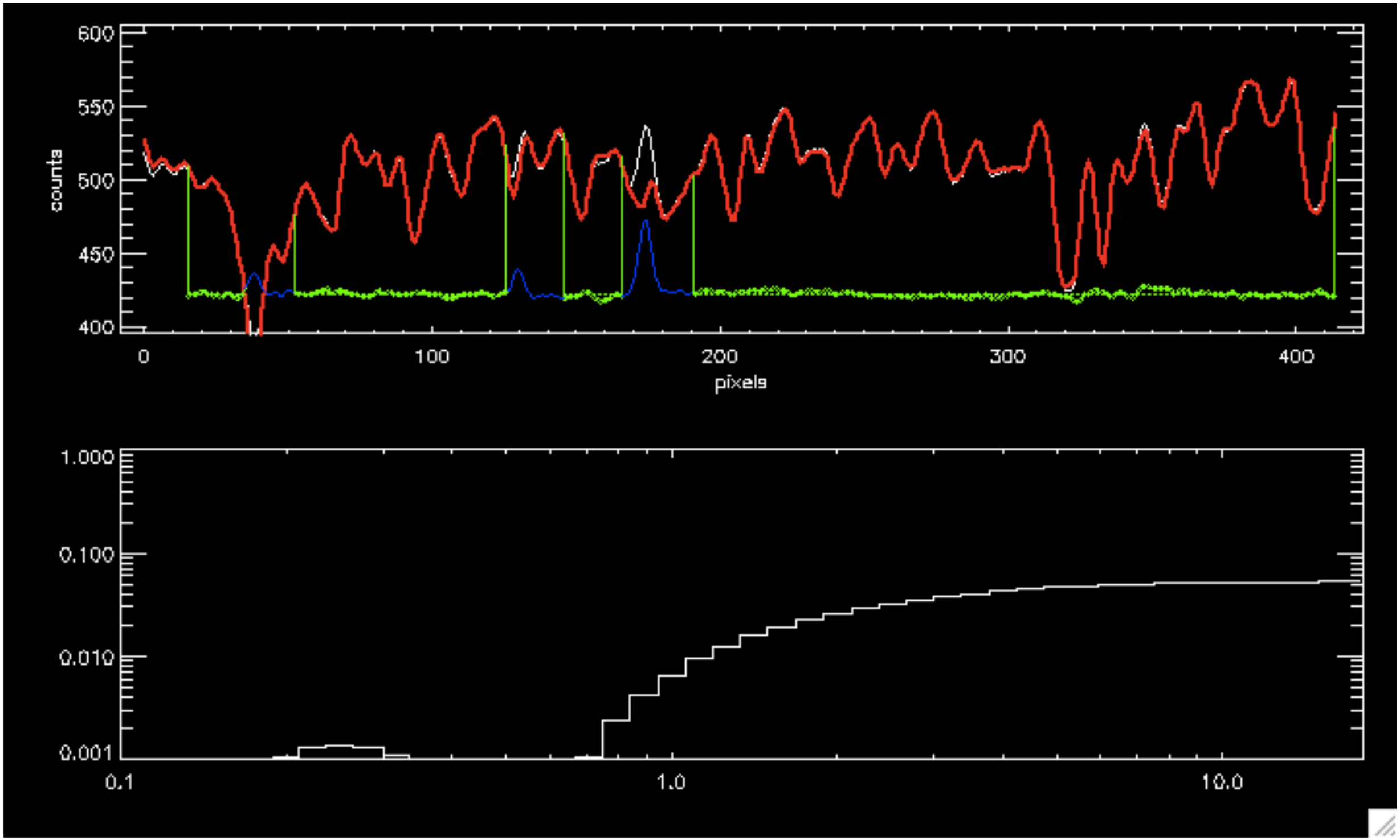

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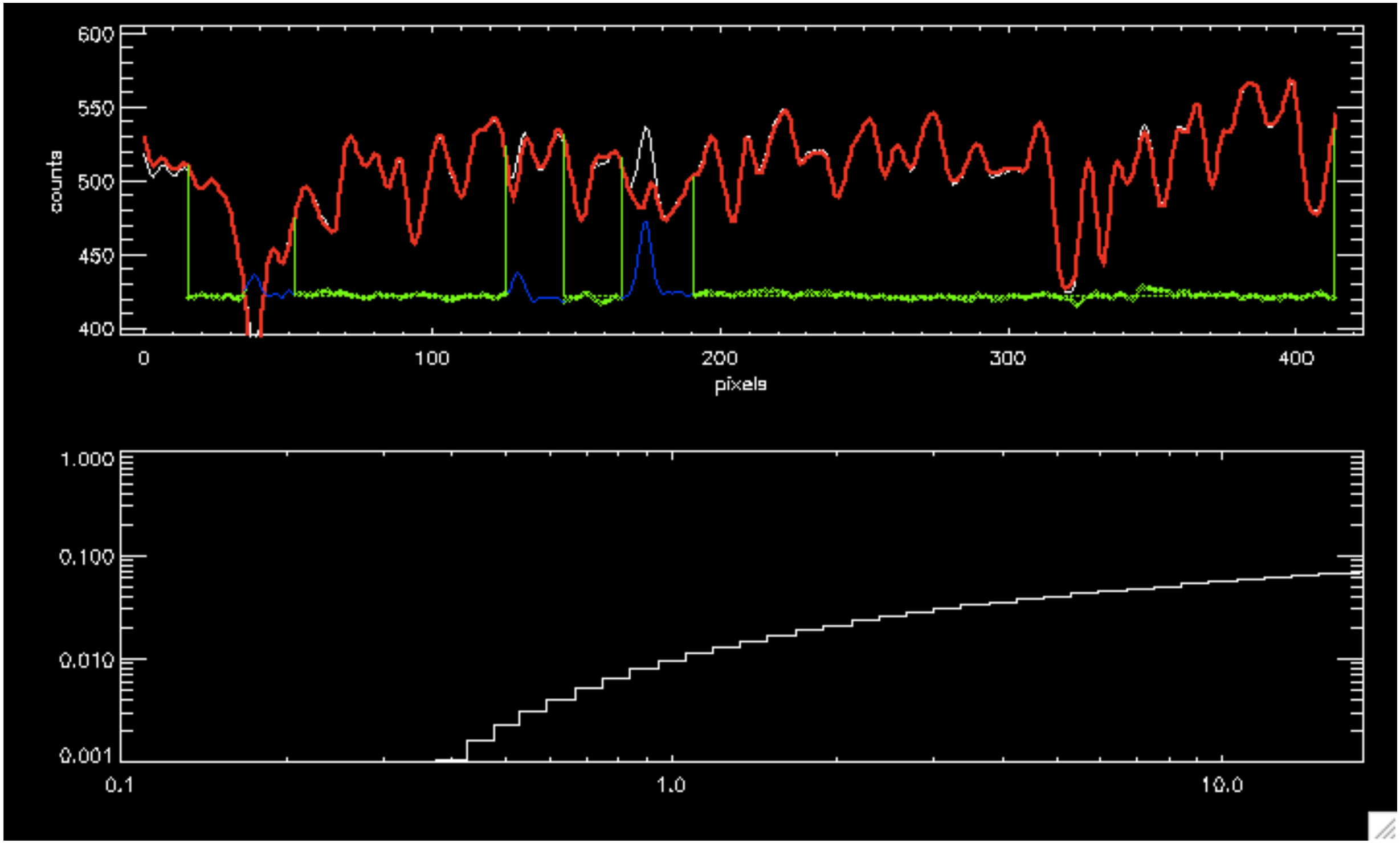
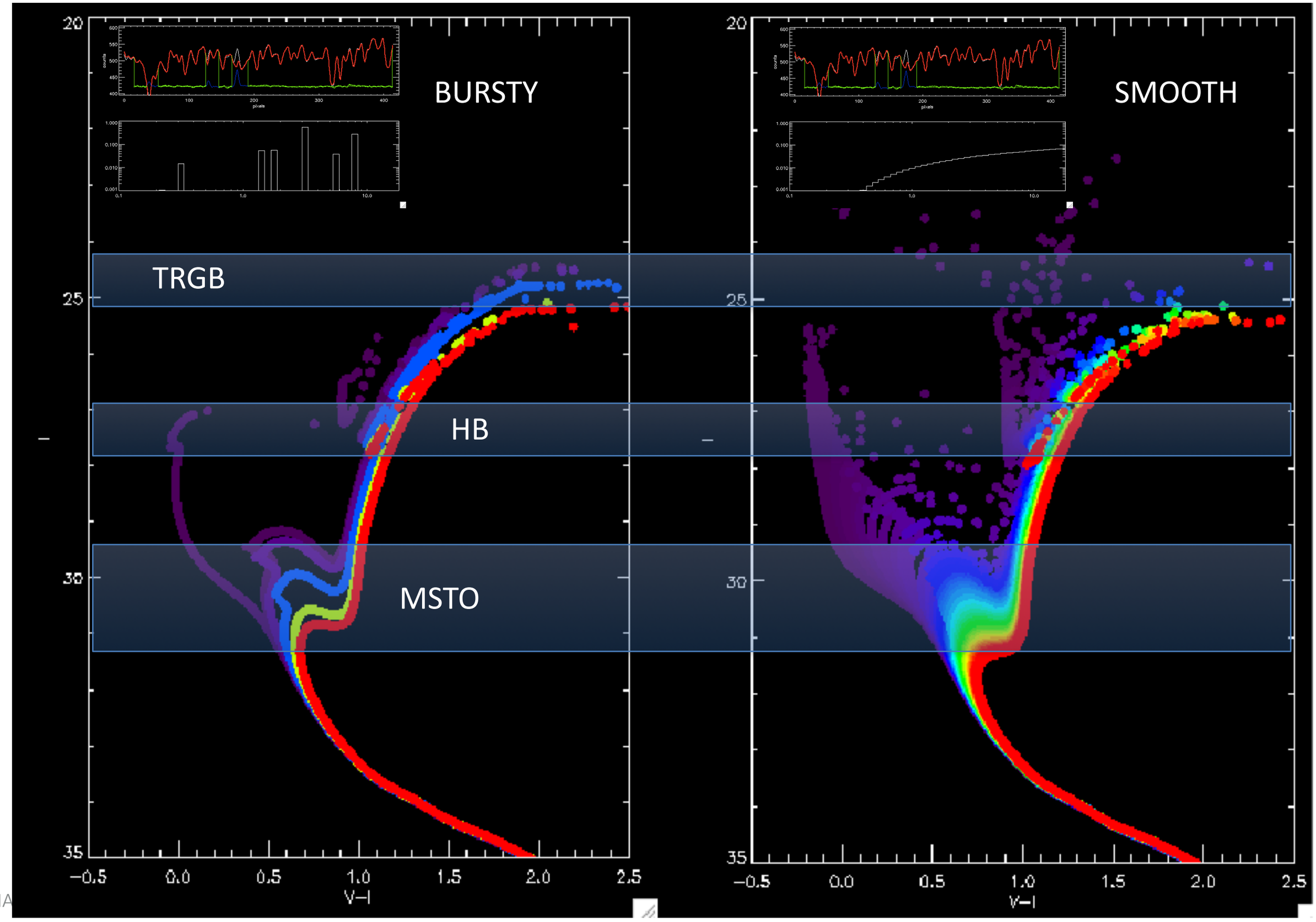
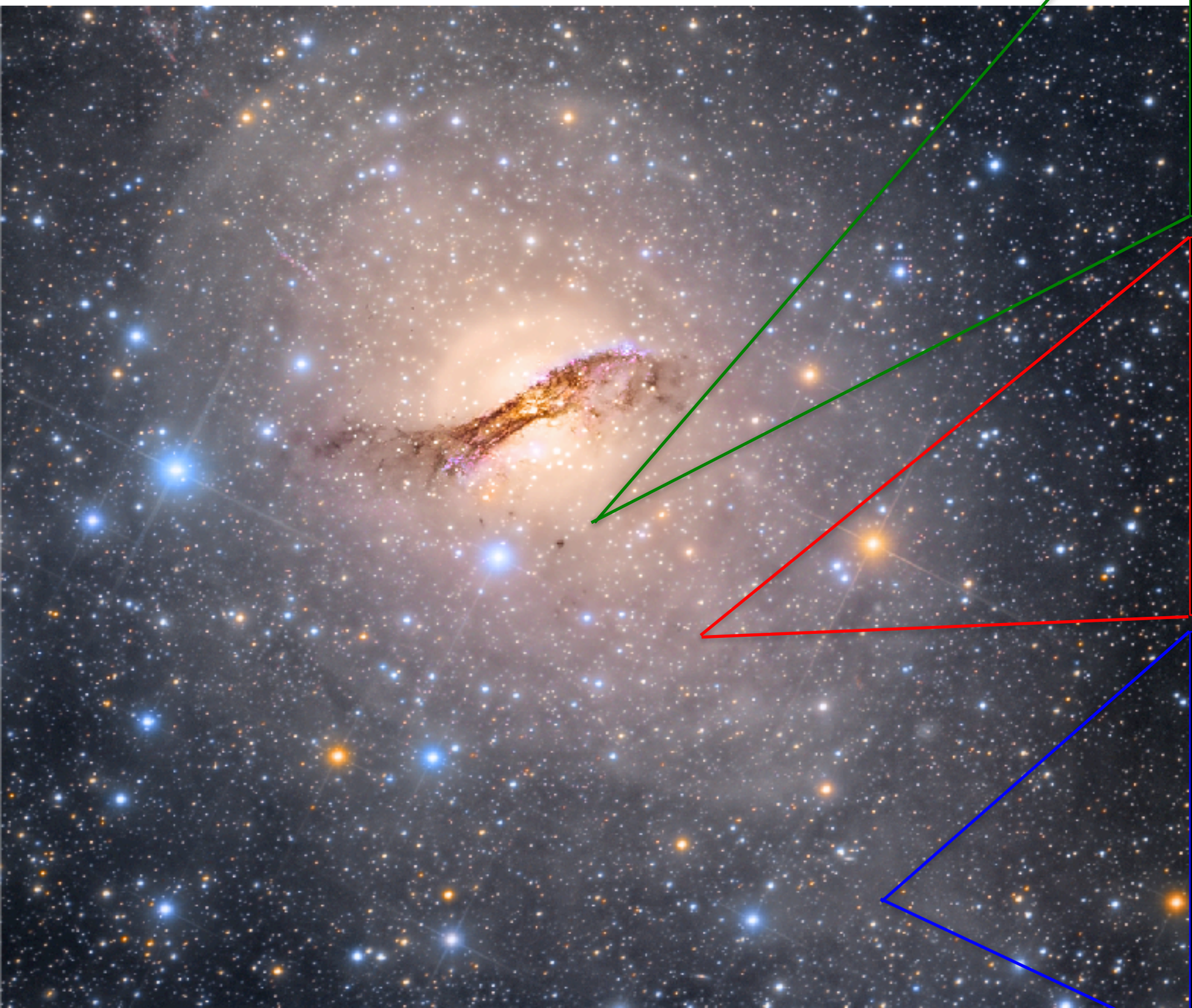


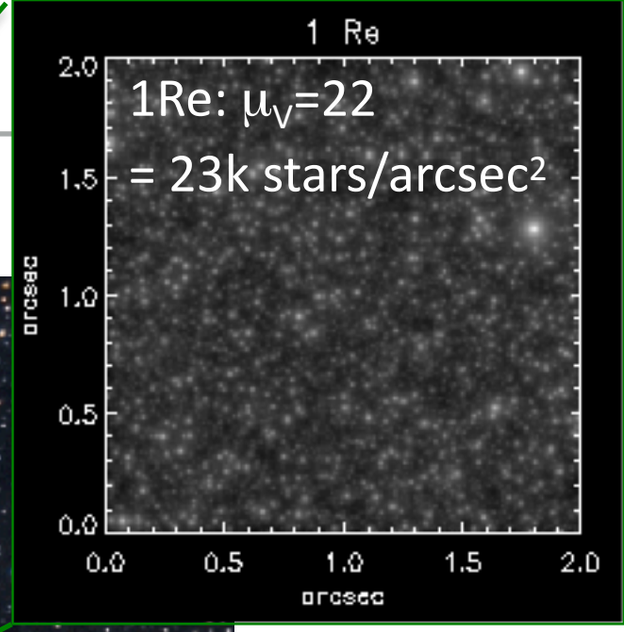
RESOLVED COLORS BREAK THE DEGENERACY

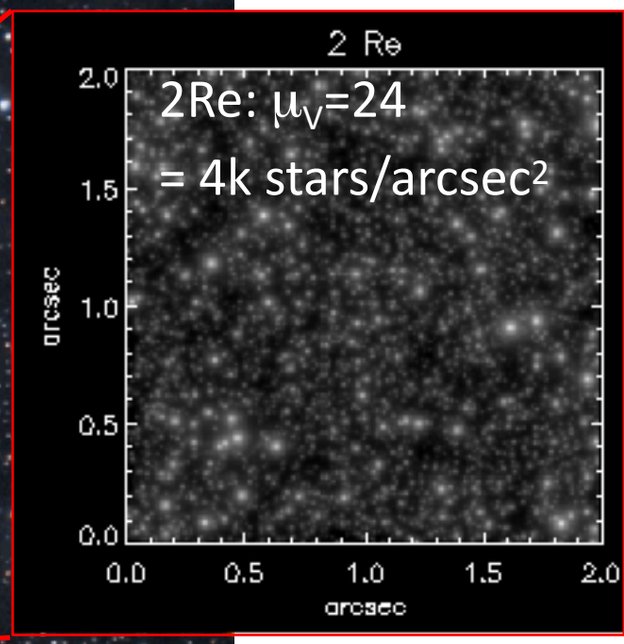


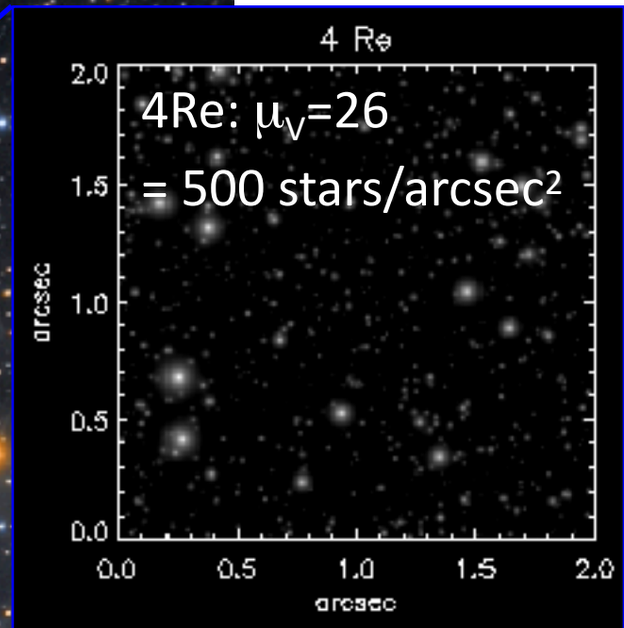
SCIENCE: RESOLVED STELLAR POPULATIONS

SIMULATION OF CEN A (3.5MPC) @ FWHM=0.015”

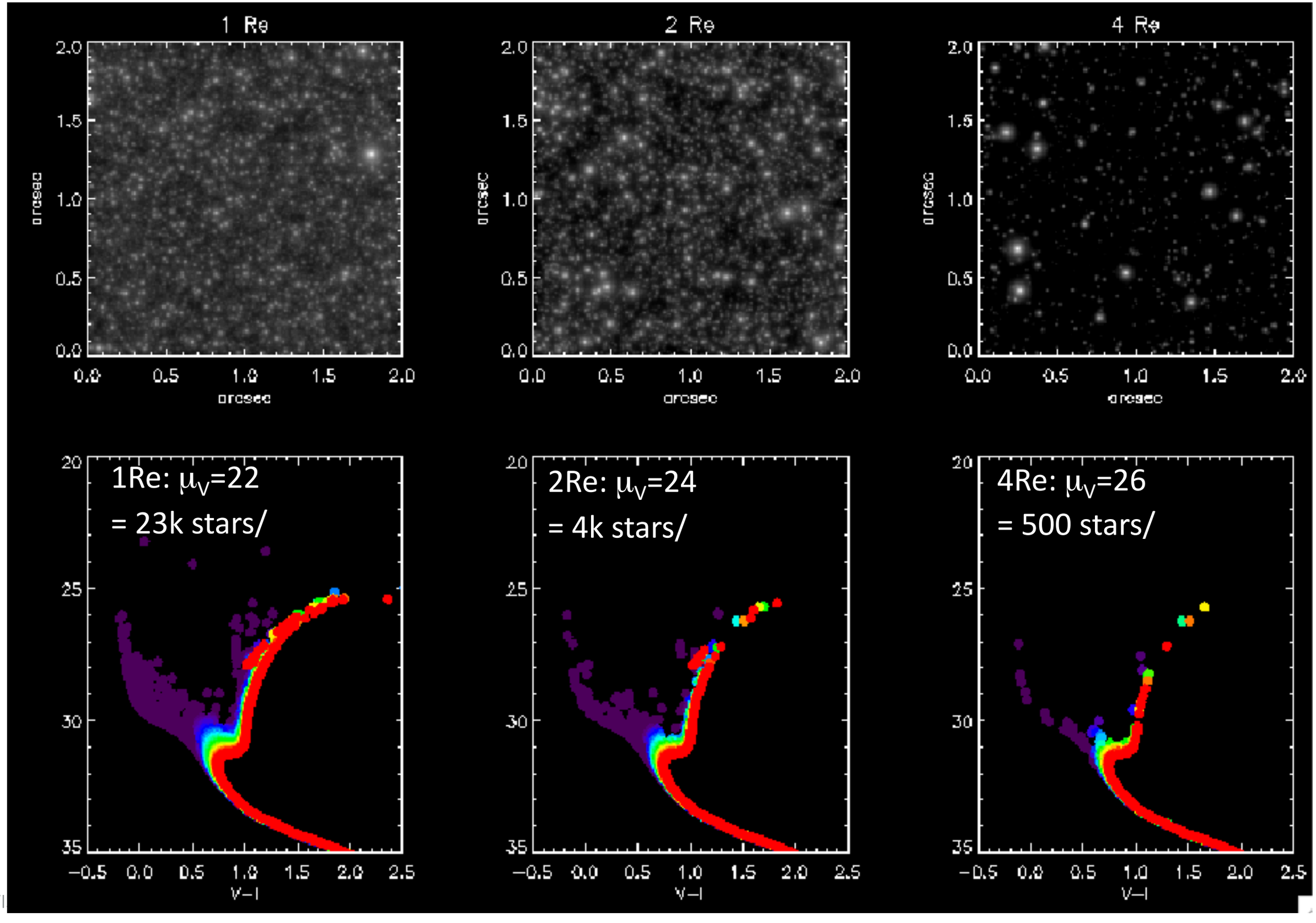






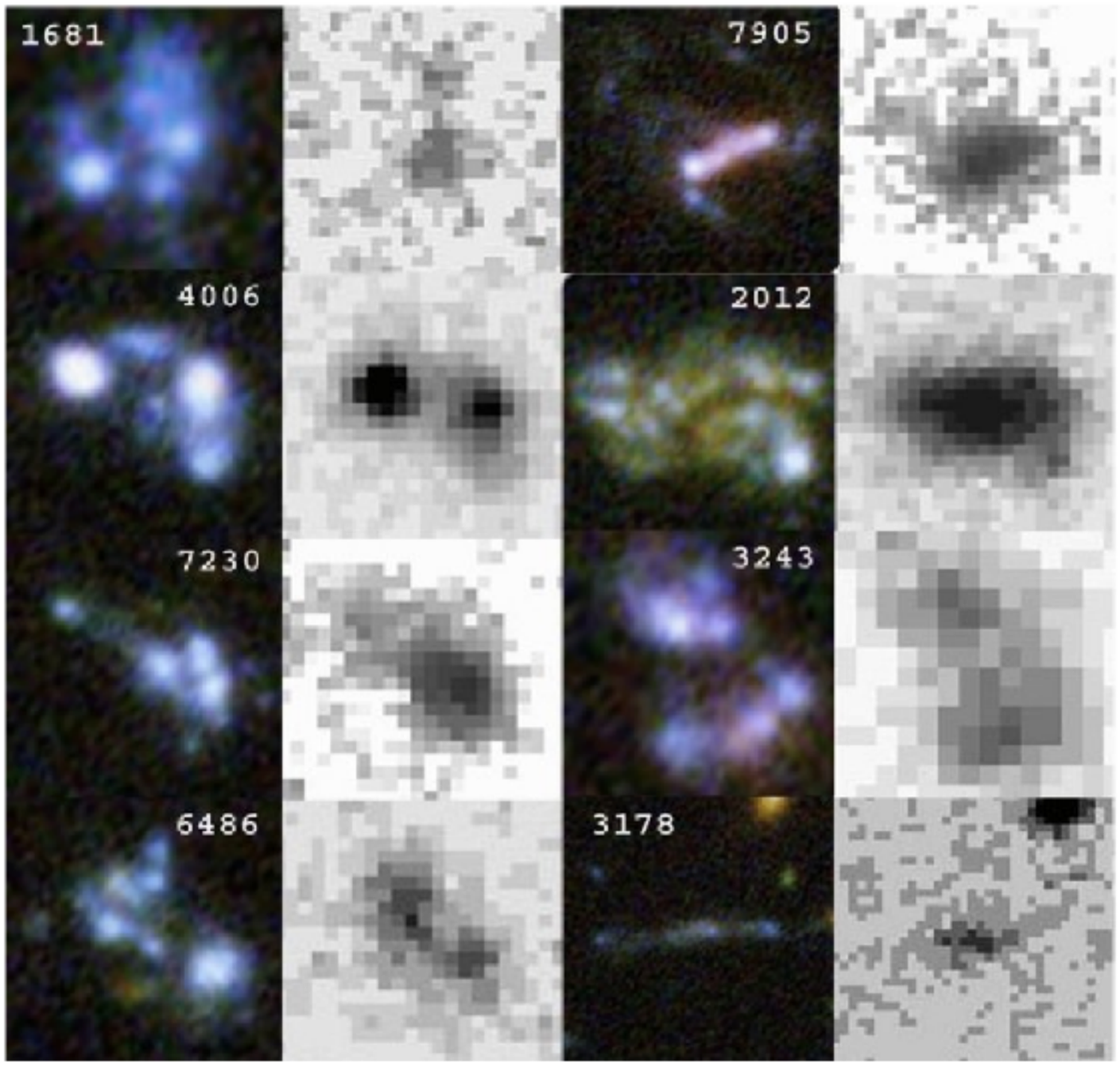


SIMULATION OF CEN A (3.5MPC) @ FWHM=0.015"



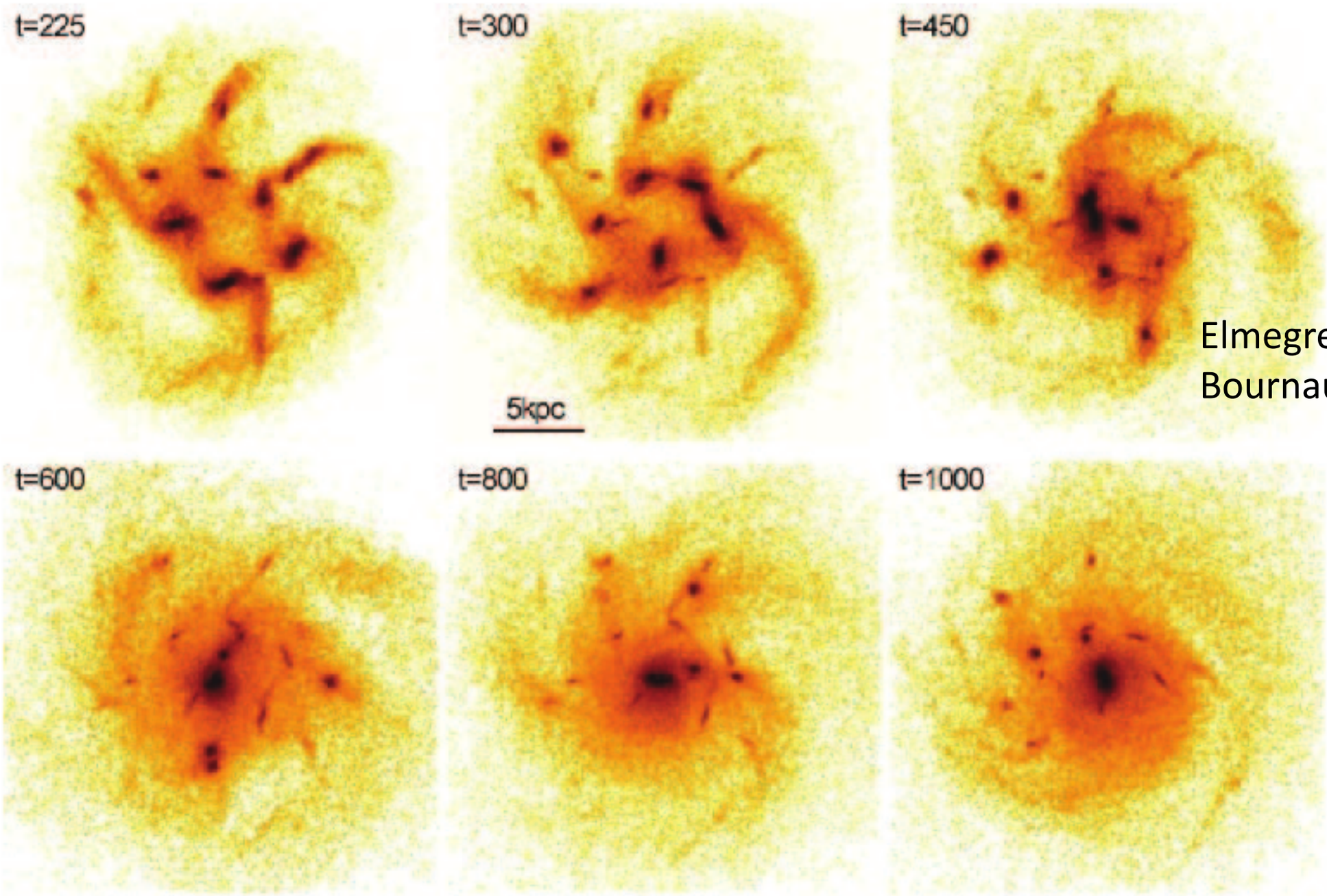
Key Science Case 2: Young Galaxy Morphology

GIANT STAR-FORMING CLUMPS AT HIGH REDSHIFT



- >=L* galaxies at z~1-4 are typically observed to be ‘clumpy’
- Rare (but not absent) at lower redshift
- Characterized by high SFR and gas fraction
- Large clumps can be 10^9 $M_\odot$ and 1-2kpc

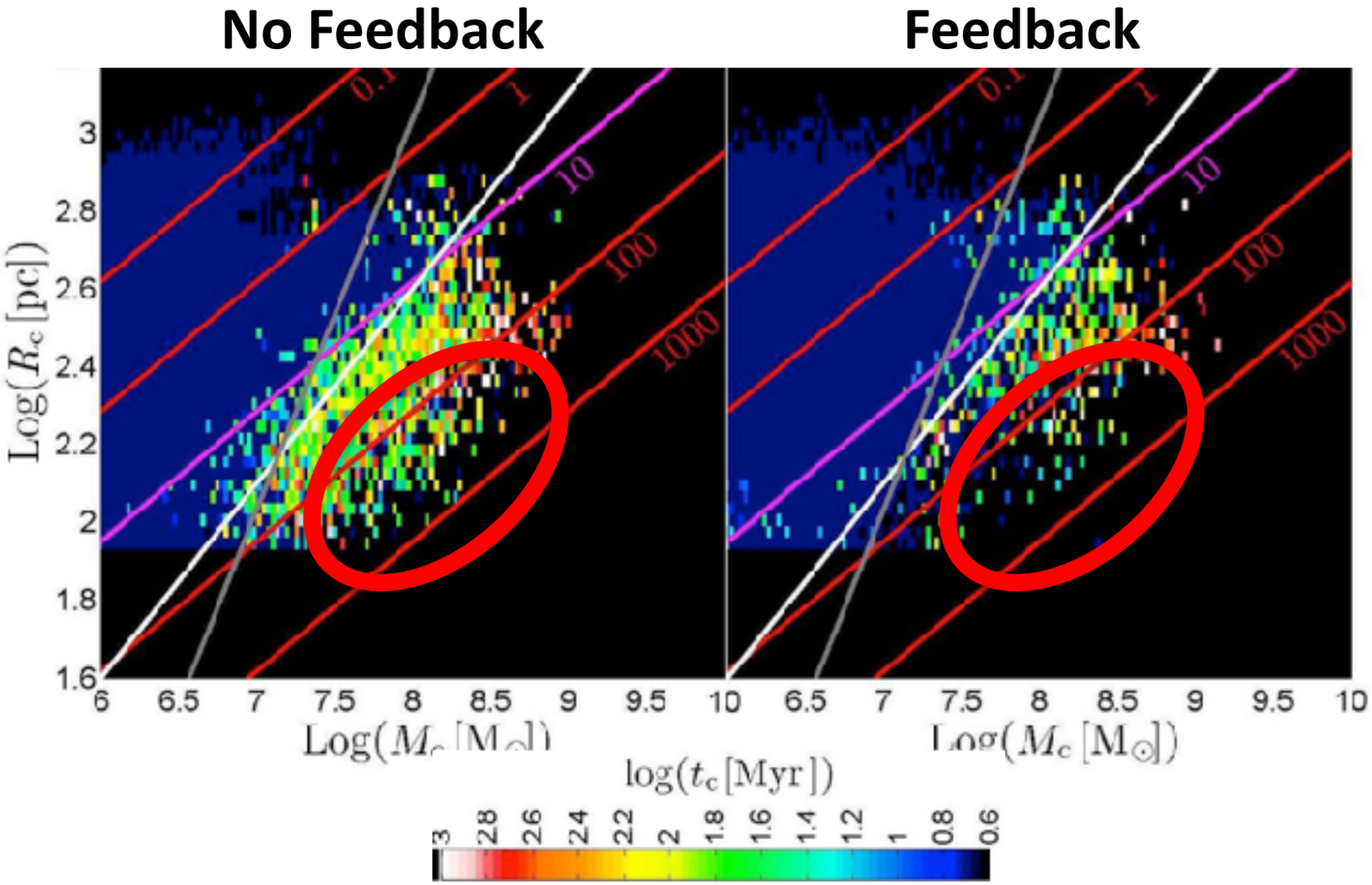
DO CLUMPS BUILD BULGES?

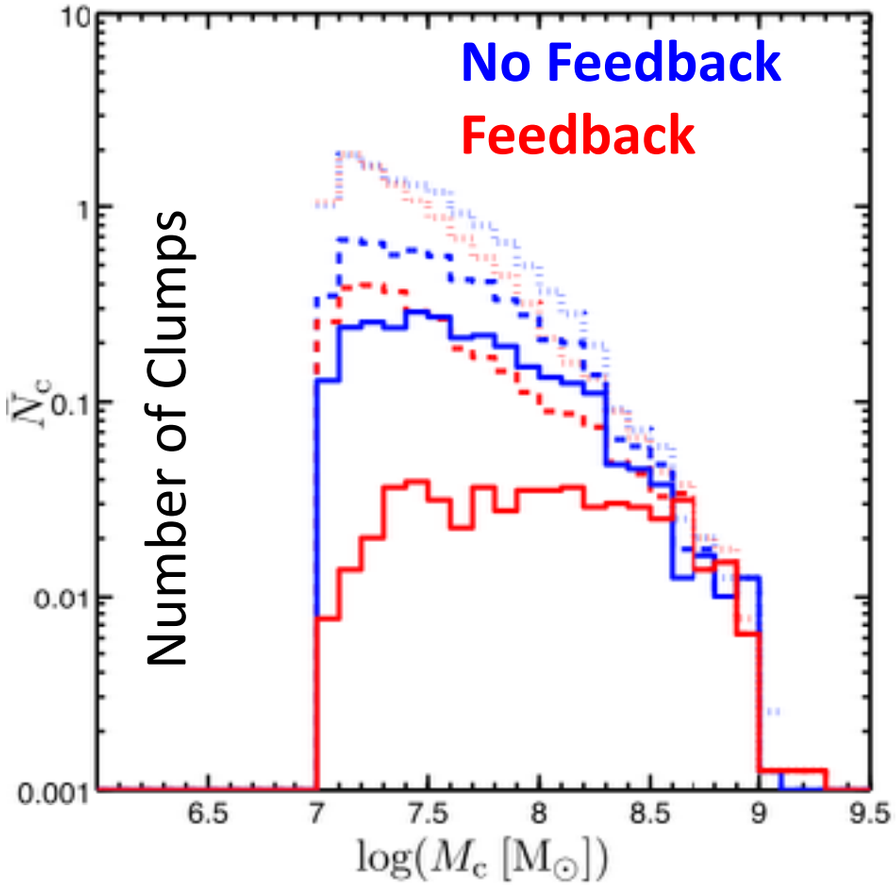


Elmegreen & Bournaud 2008

- Depends critically on clump mass, size and lifetimes

DO CLUMPS BUILD BULGES?





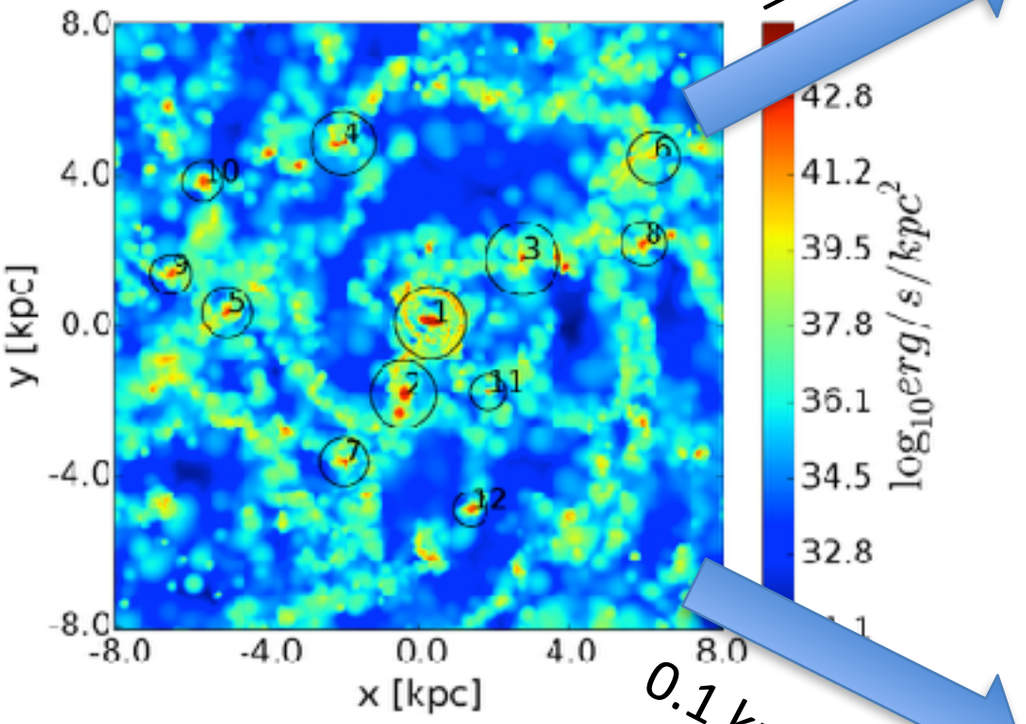
Mandelker et al. 2017

- Depends critically on clump mass, size and lifetimes
  ….and feedback

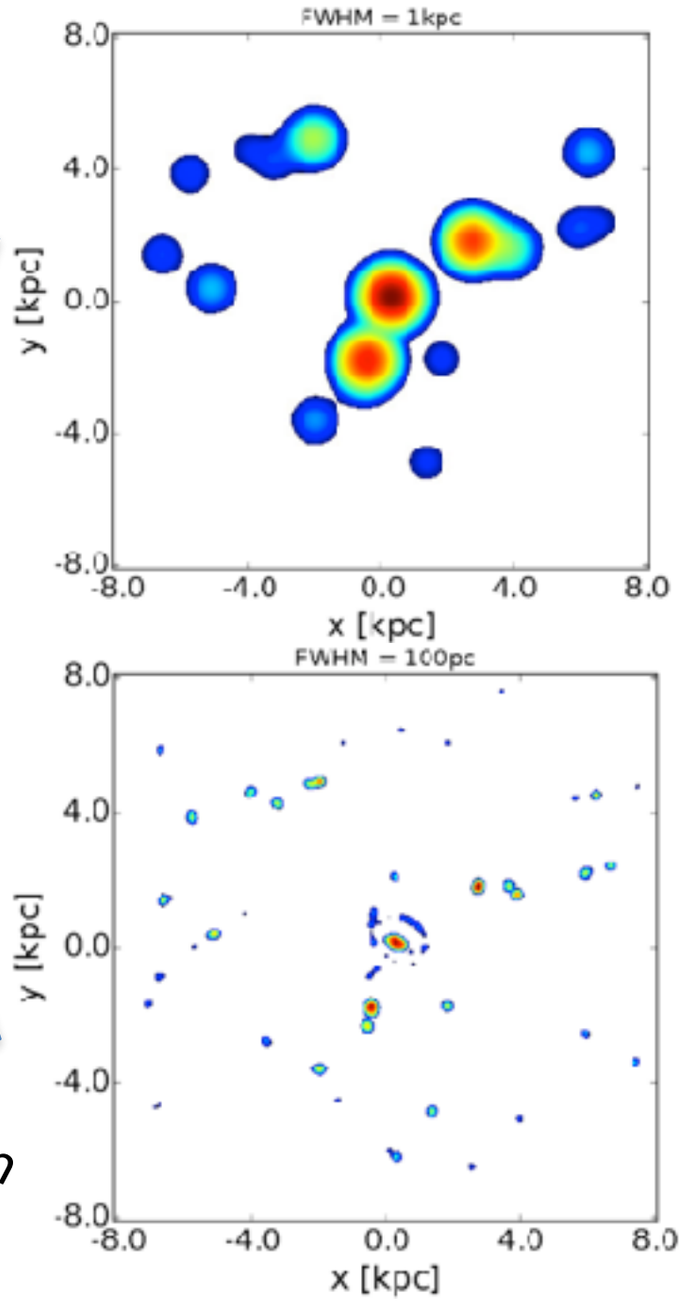
DO CLUMPS BUILD BULGES?

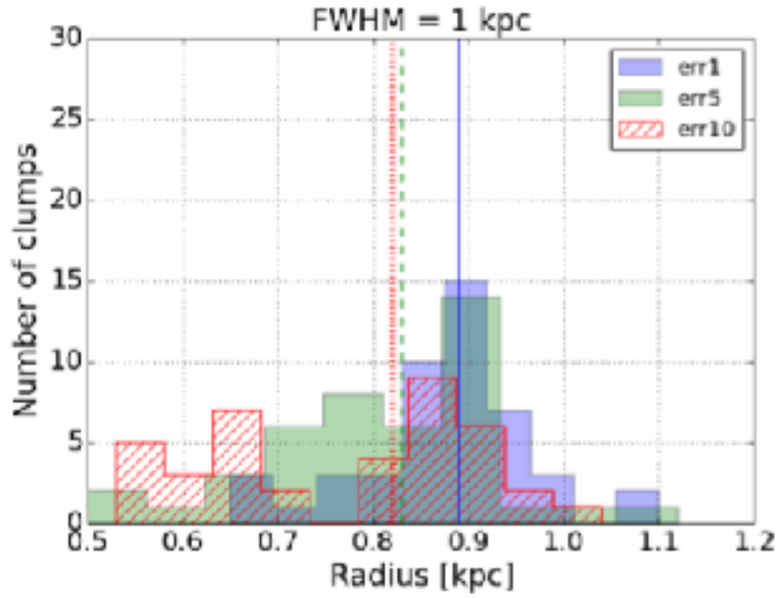
Tamburello et al. 2017

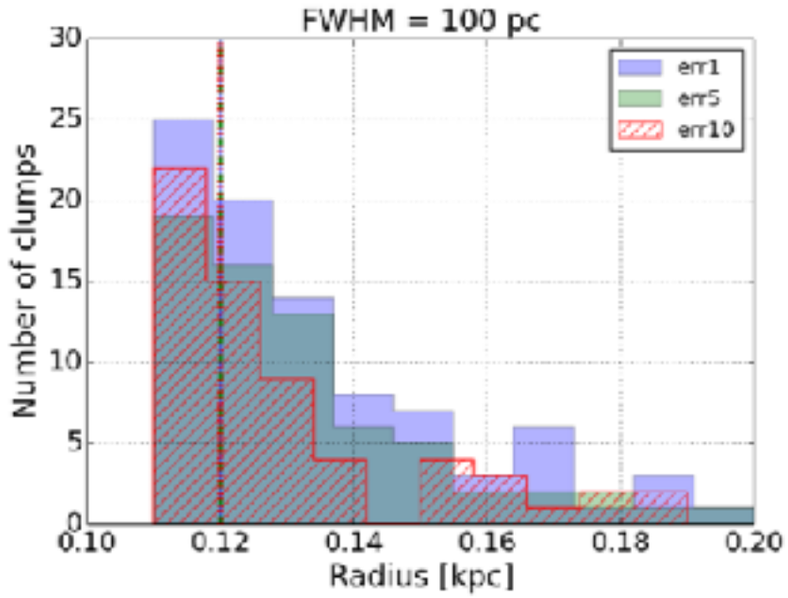
1 kpc resolution = 0.12" @ z>1 = **NACO**



0.1 kpc resolution = 0.012" @ z>1 = **MAVIS**





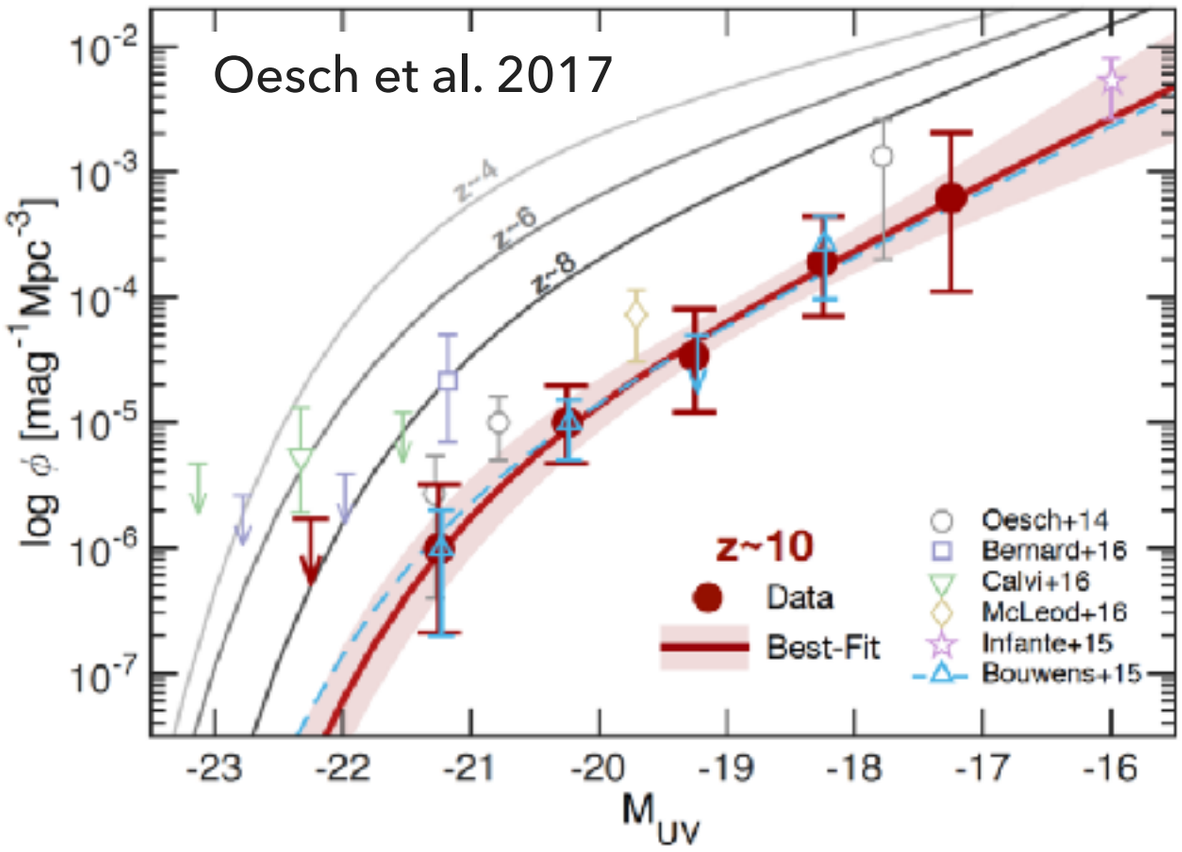


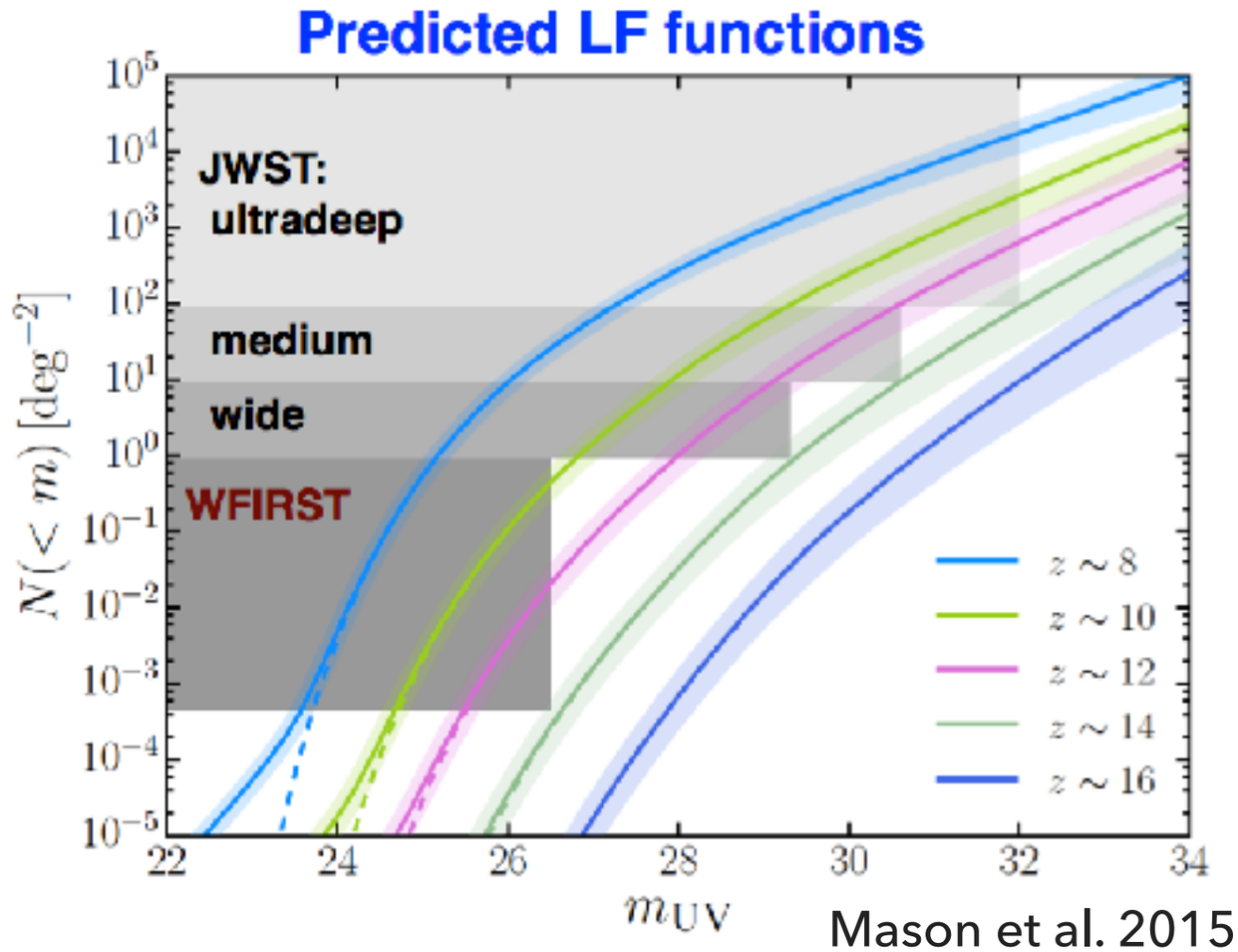
- Depends critically on clump mass, size and lifetimes

  ….and feedback…..and resolution!

Key Science Case 3: Probing the Edge of Reionisation

CONFIRMING z>10 GALAXY CANDIDATES

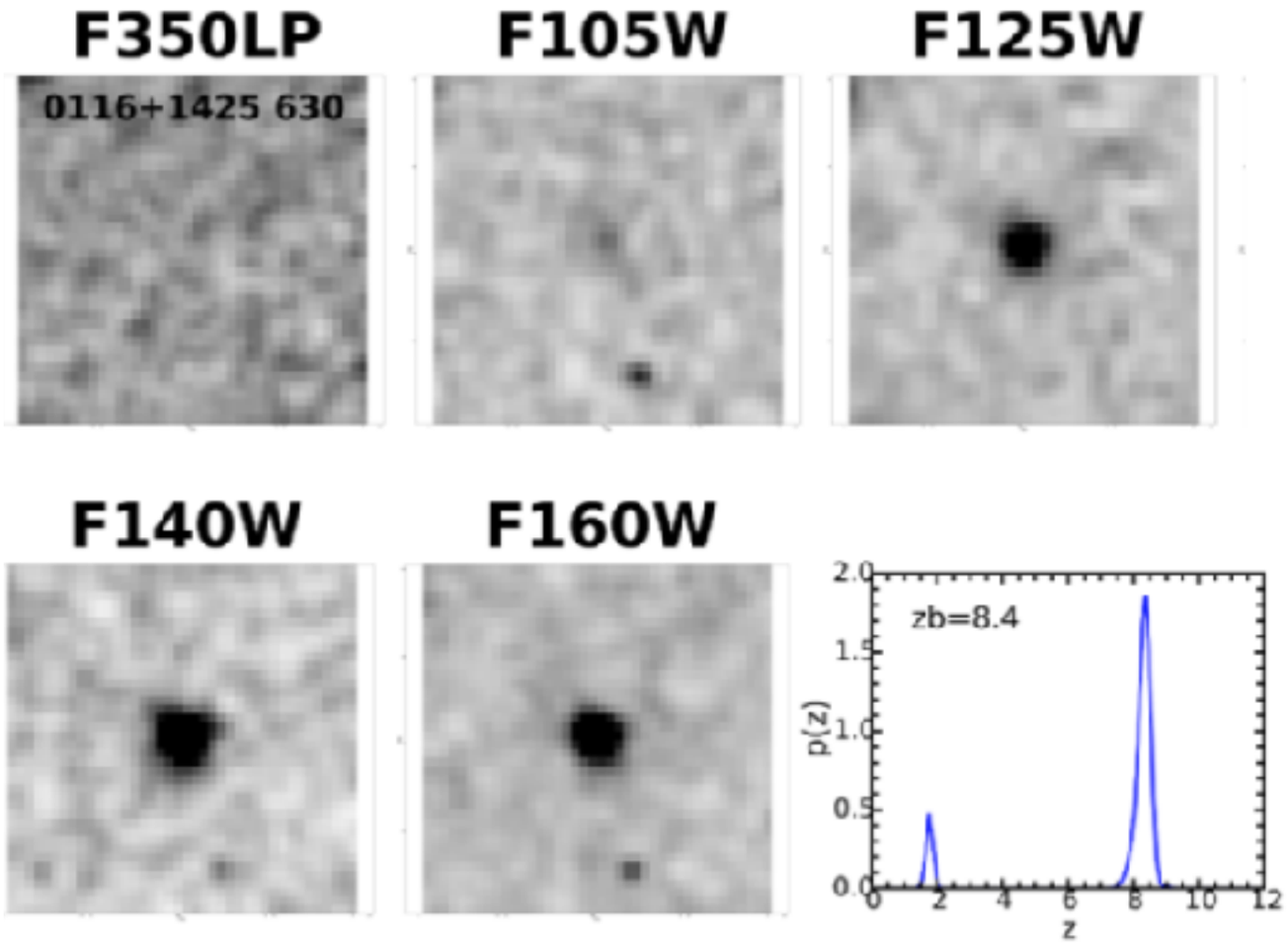


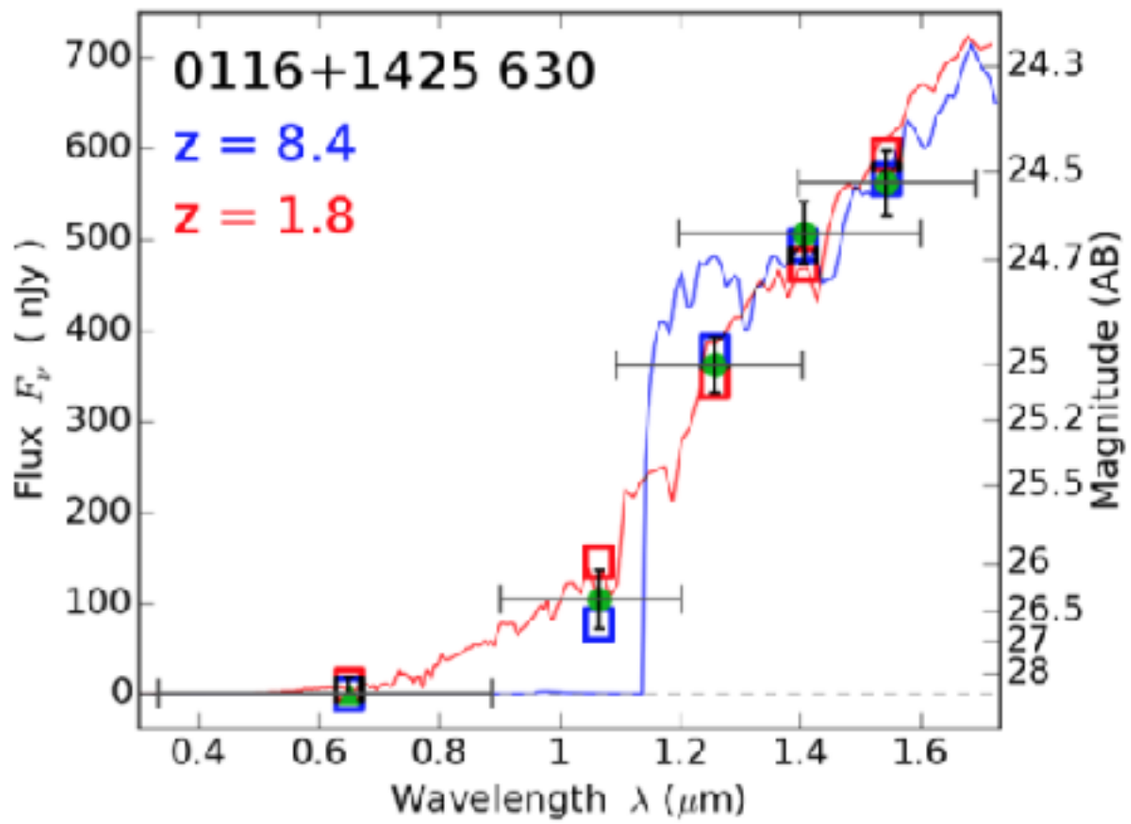


Mason et al. 2015

- Luminosity functions at z>10 put strong constraints on galaxy formation models
- New facilities will open up the candidate discovery space

CONFIRMING z>10 GALAXY CANDIDATES



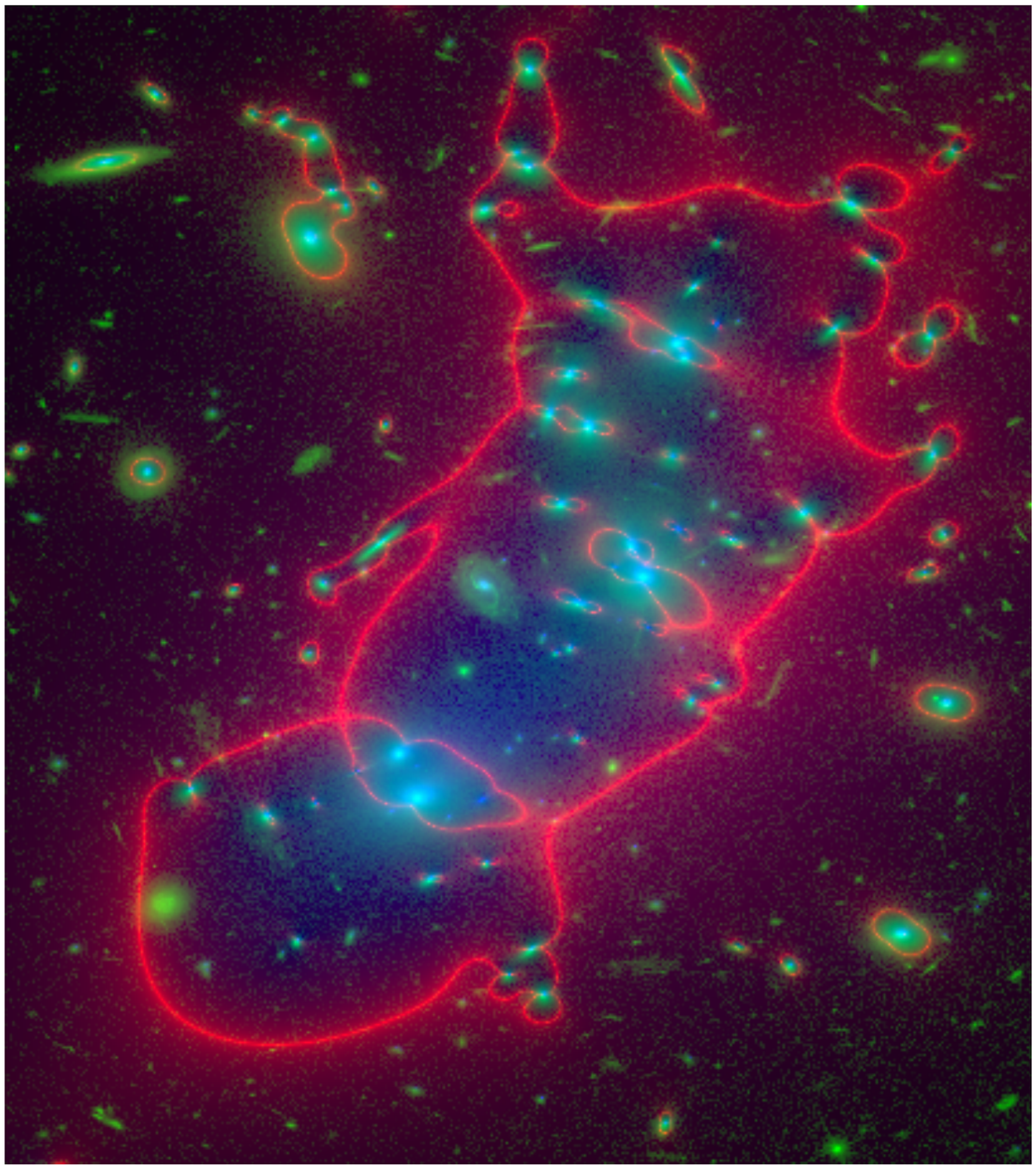


Calvi et al. 2016

- Luminosity functions at z>10 put strong constraints on galaxy formation models
- New facilities will open up the candidate discovery space
- JWST lacks blue coverage, but optical at comparable resolution is critical to avoid contamination

PROBING FAINT SOURCES WITH LENSING

- Search for hi-z sources along high magnification critical lines
- Can get 100x magnification
- Combined with near-diffraction limit, could bring proto-globular clusters at z~6 within reach (M_{AB} ~ -12)

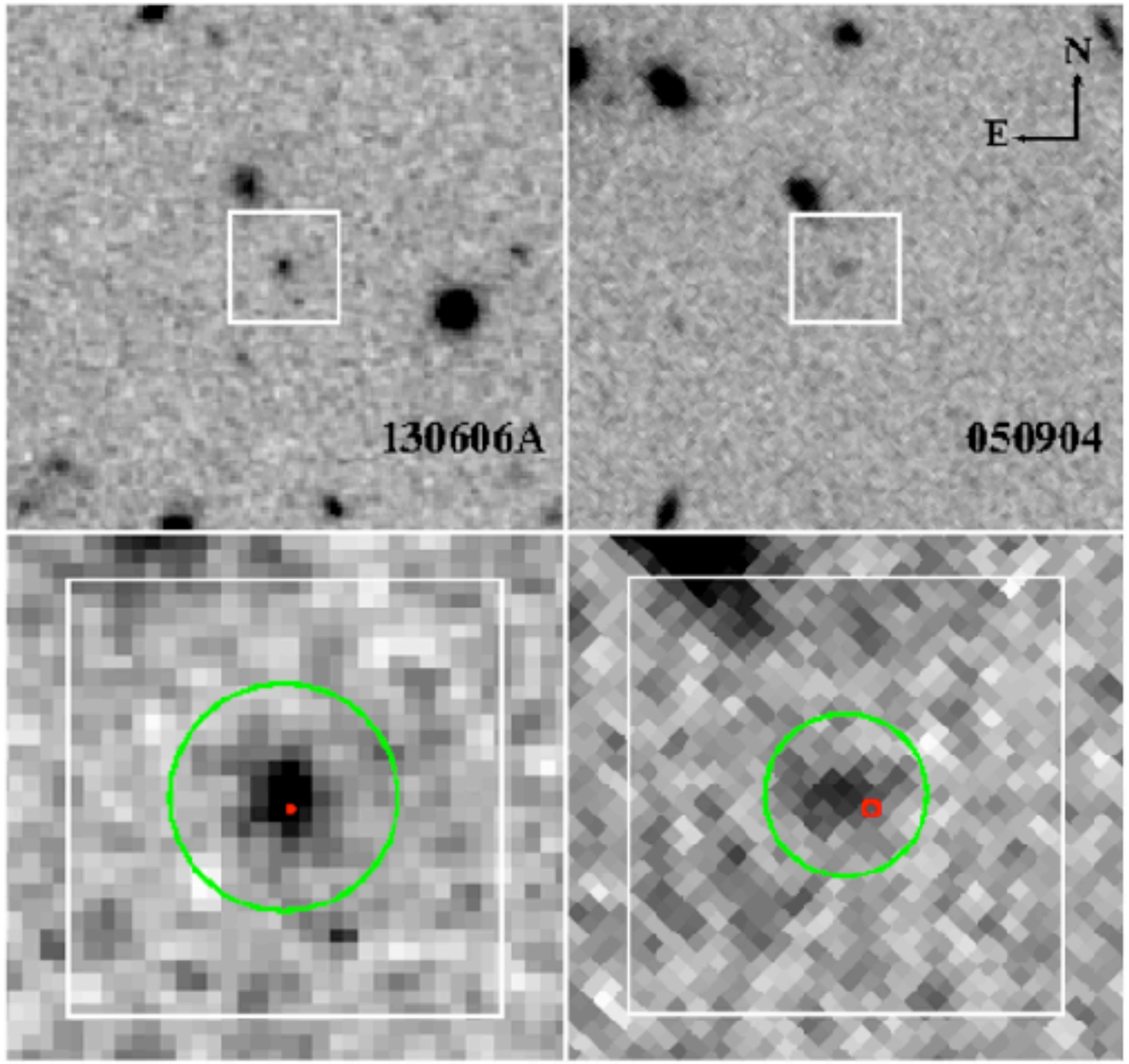


Abel 2744 - HST Frontier Fields project

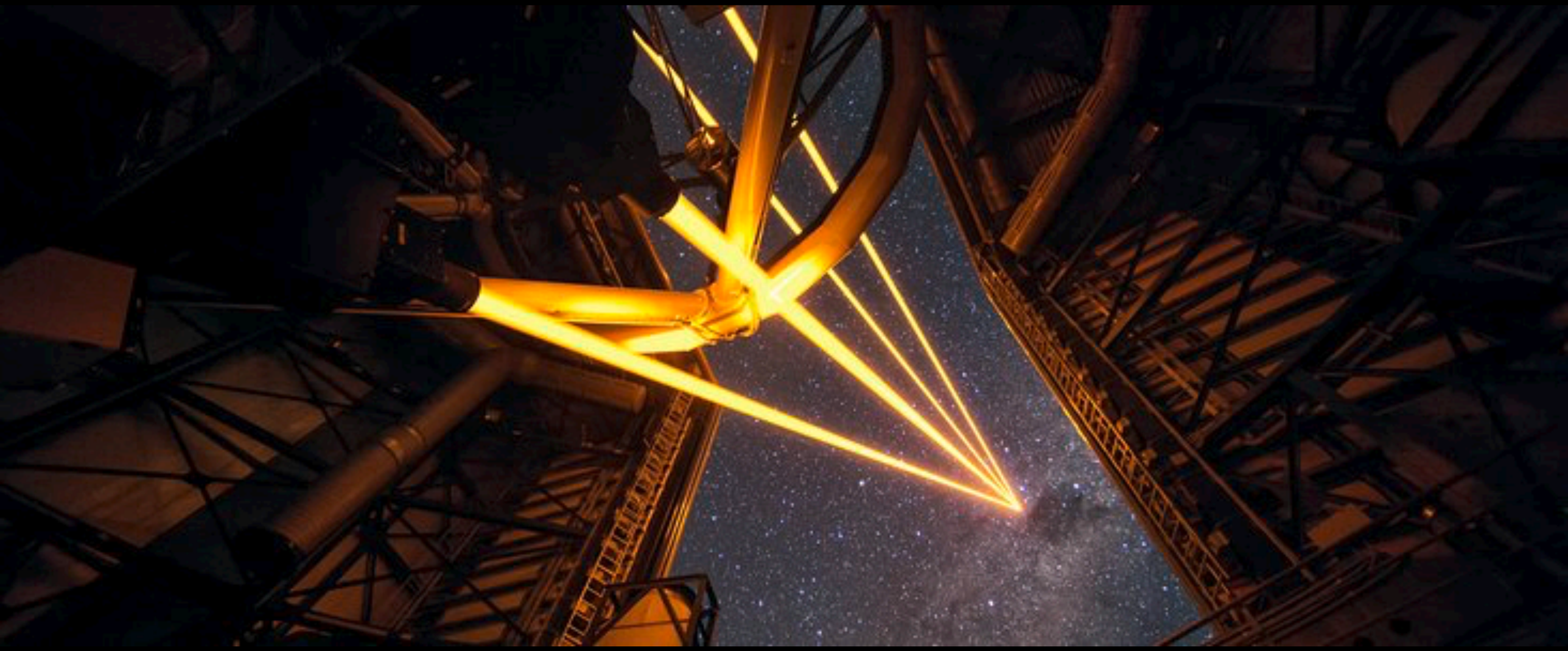
DETECTING GRB HOSTS AT z=5-6

- HST only detects <20% of GRB hosts at z~5-6
- MAVIS could increase this fraction via better sensitivity

z~6 GRB hosts, HST WFC3, F140W



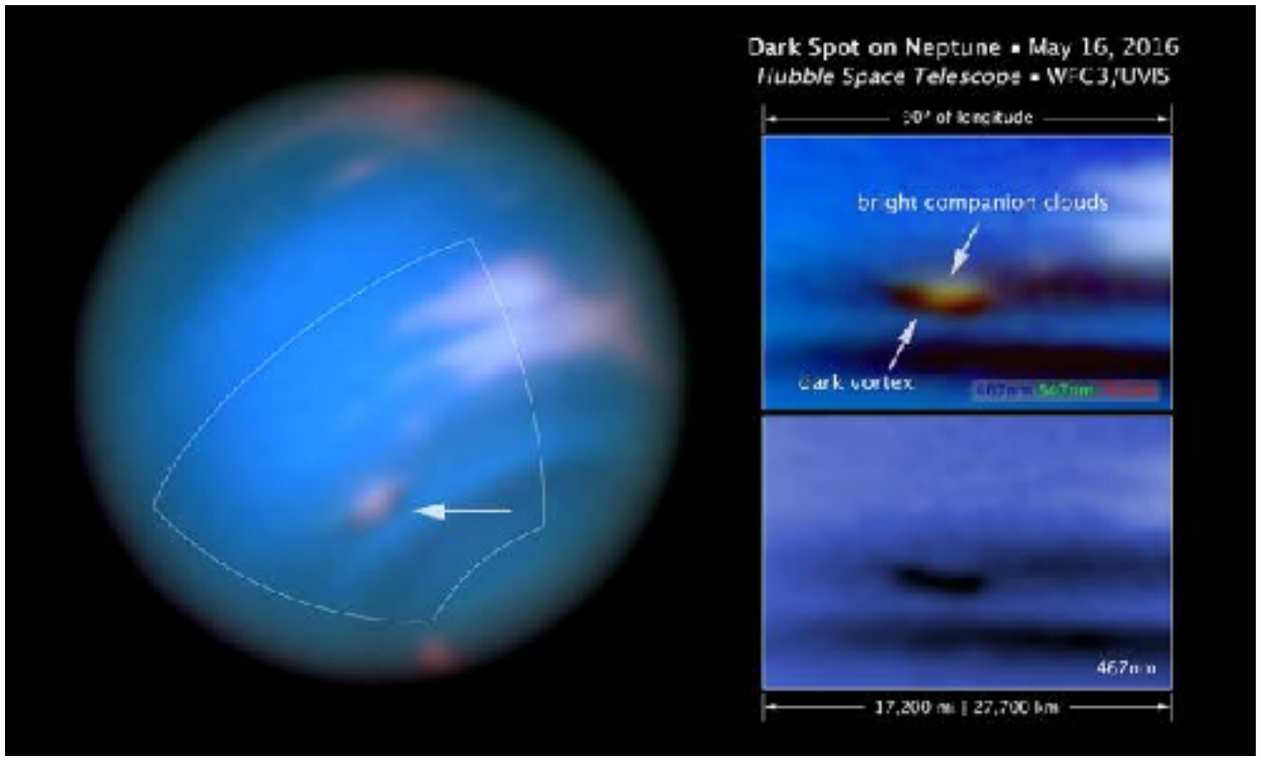
McGuire et al. 2016

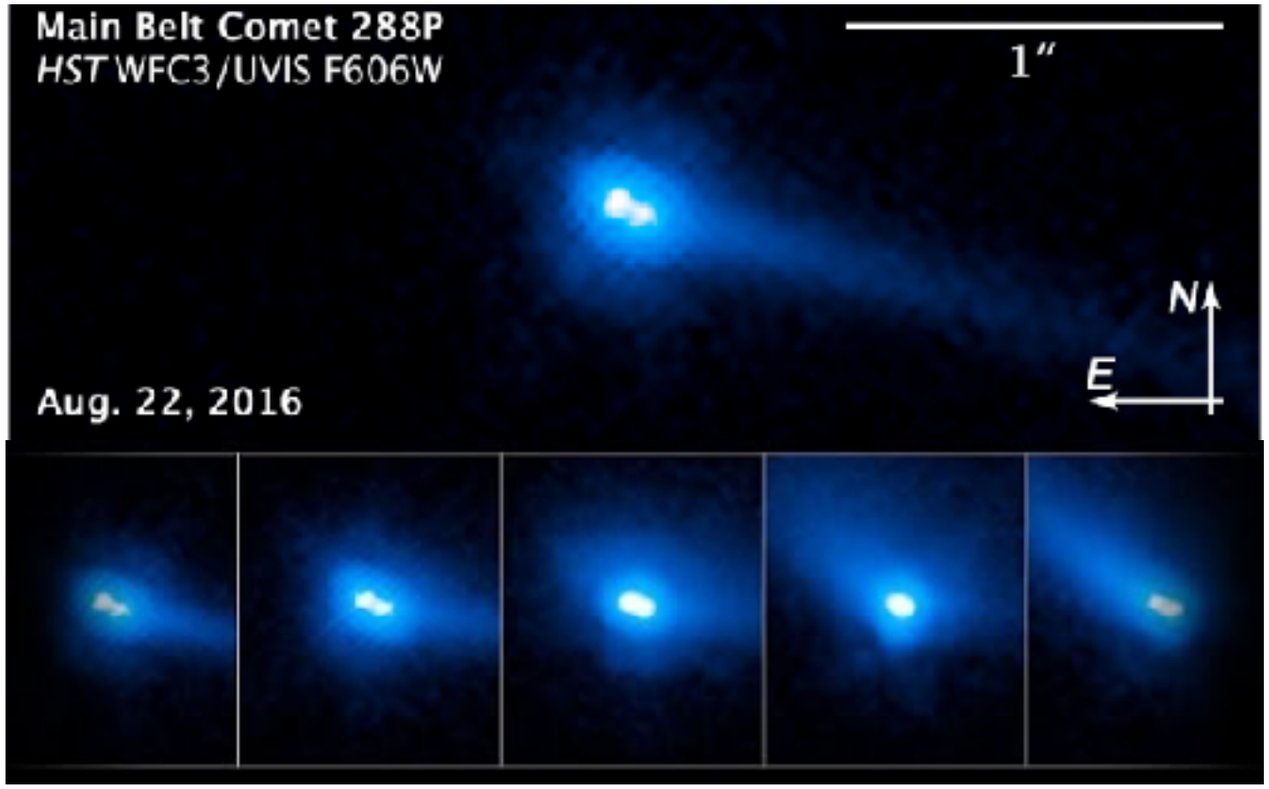


Other Key Science

SOLAR SYSTEM AND OUTREACH

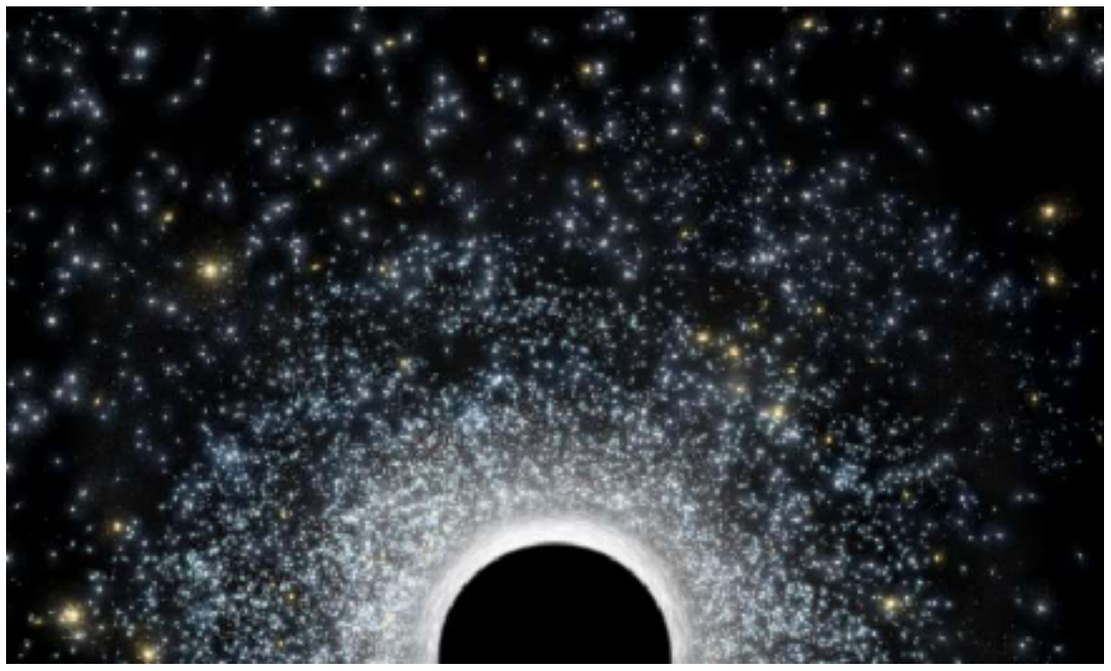
- Monitoring planetary/ satellite weather
- Asteroid morphology
- Supporting space missions
- Outreach images

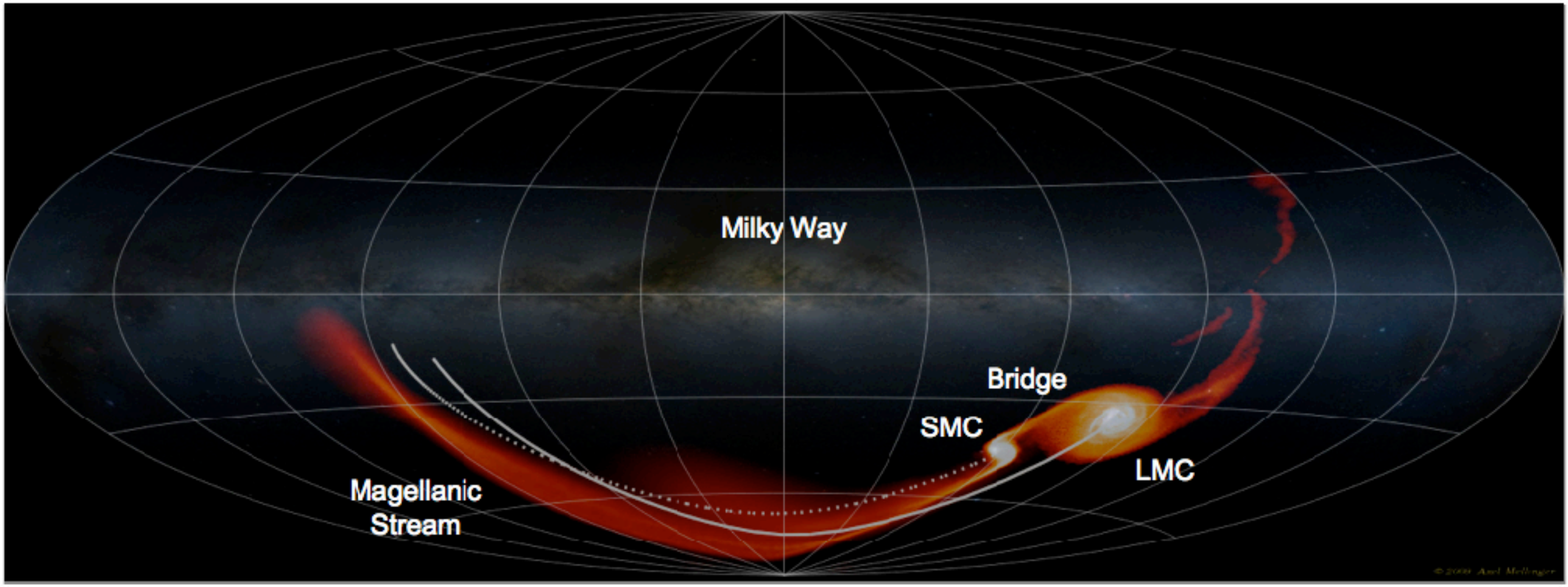




ASTROMETRY AND PROPER MOTIONS

- Search for intermediate mass black holes and neutron stars in star clusters
- Long-term monitoring of LMC/SMC proper motion

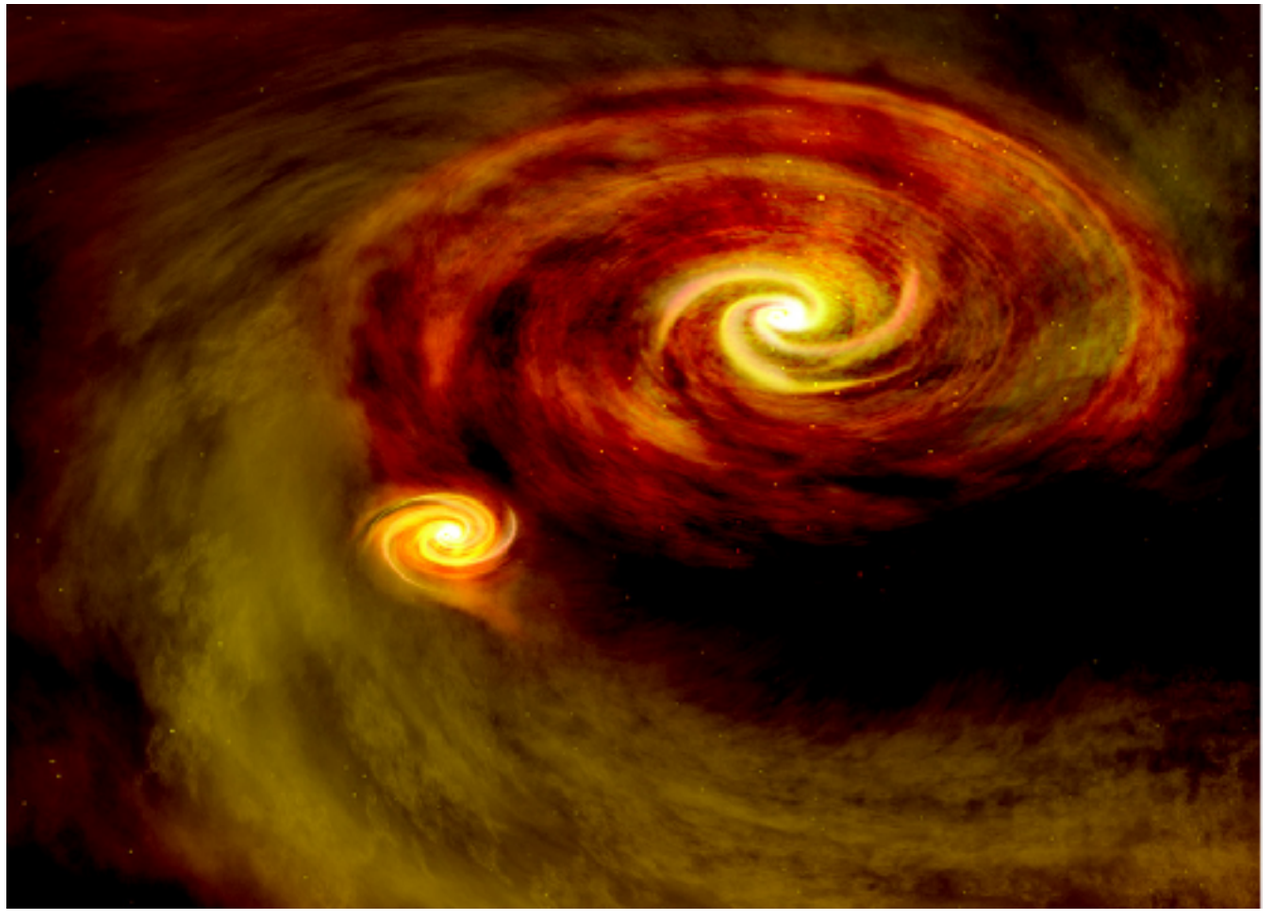




MAVIS Overview, Feb 2018. © 2018 Rigaut, McDermid, Esposito, Lawrence, Glazebrook, Trenti.

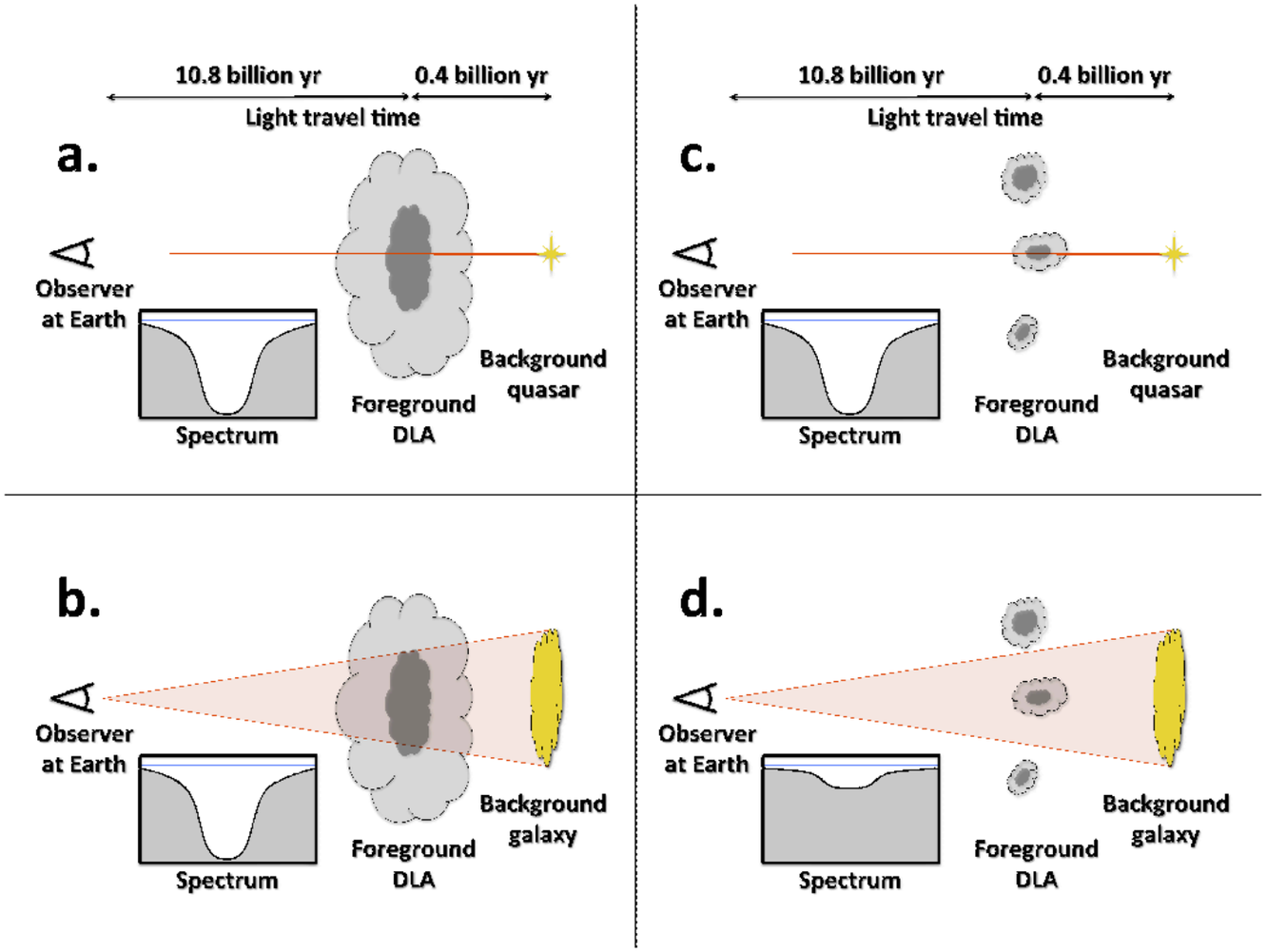
STAR FORMATION PROCESSES

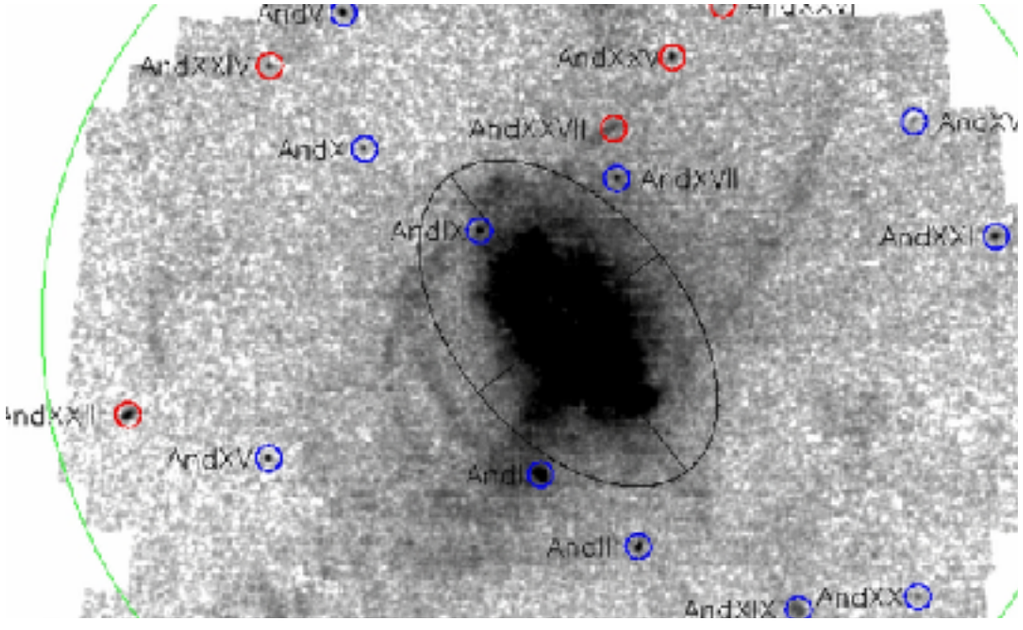
- Forming multiple stars
- Star formation in the Magellanic Clouds

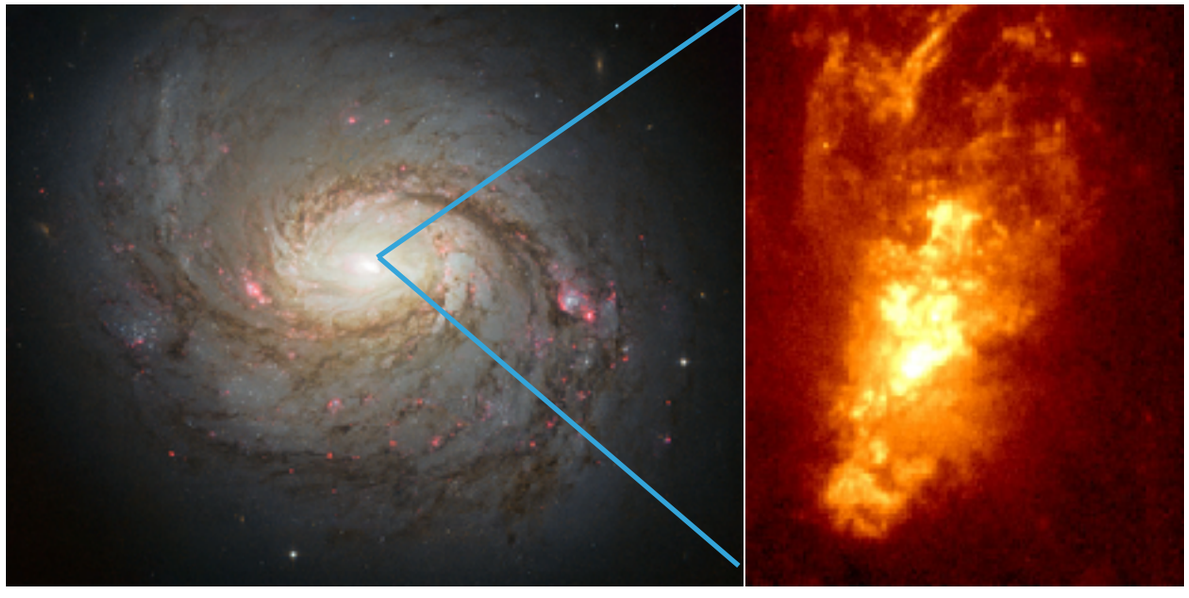


SPECTROSCOPIC SCIENCE

- Quasar sight lines
- Local Active Galactic Nuclei
- Stellar abundances and radial velocities in faint and/or crowded fields







PLUS MANY OTHERS…

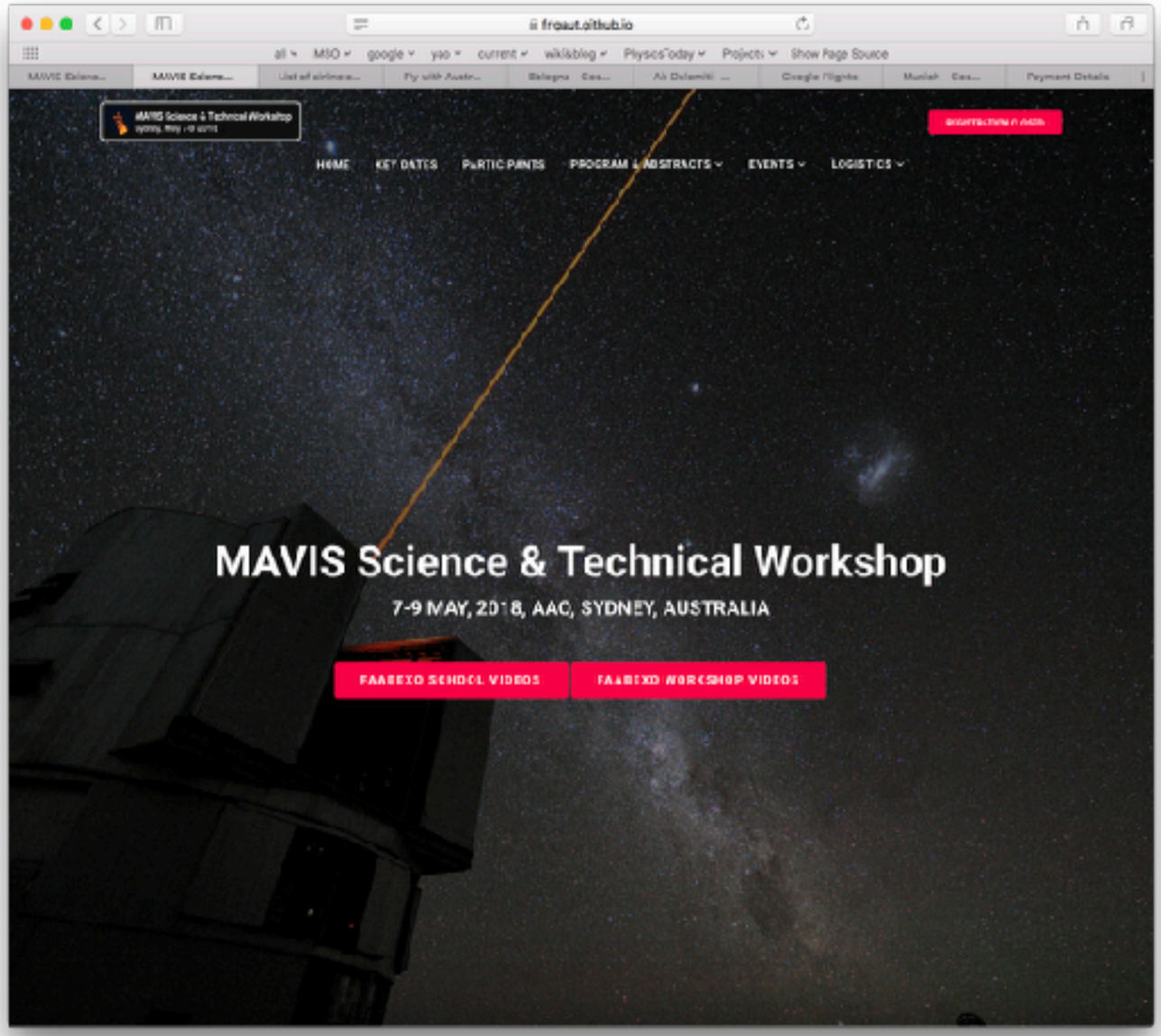
- Transient follow-ups
- ExoPlanets
- Galaxy structure and morphology
- Galaxy transitions
- Initial Mass Function via microlensing
- Partially-resolved stellar populations
- Calibrating emission line and stellar population models
- Dark matter substructure
- Proto-planetary disks
- Binary stars
- Synergy with future facilities like LSST, SKA, E-ELT, JWST, 4MOST, etc.
- Serendipitous discovery potential

CHALLENGES

- Performance at **short wavelength**: How short?
  - A few science cases require going < 500nm
- **Generalised fitting**: Field of view vs number of deformable mirrors
  - Increase number of DM (generalised fitting)?
  - Increase number of guide stars (GS) (tomographic error)?
  - Reduce/variable field of view?
  - **30" field of view seems possible with a total of 3DMs**
- **Sky coverage**. 20%? More?
  - Natural GS needed for image motion and field distortion correction
  - Sensing could be done in the NIR (0 noise Saphira)
- **Astrometry**: Proper motions important for science - feasible?
- **Spectroscopy**: Adds significant cost - needed for your science?
- **Error budget**: need to establish novel method for live control of each term

THIS IS JUST THE BEGINNING…

- MAVIS Science and Technical workshop in **May (7-9th)**
- Drafting MAVIS Science Case starts now
- Final documents expected in June/July
- Baseline will be imager
- Spectroscopic options will be fully considered
- We need you: what do you need?



STAY TUNED!