Star Formation, Young Clusters and Dust in Mergers

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For Higher and Further Education
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Low redshift mergers

- Low redshift merger remnants subject to detailed study
  - HST Imaging
  - Integral field spectroscopy
  - Spitzer, Galex etc.
- Can we use simulations to interpret the observations?

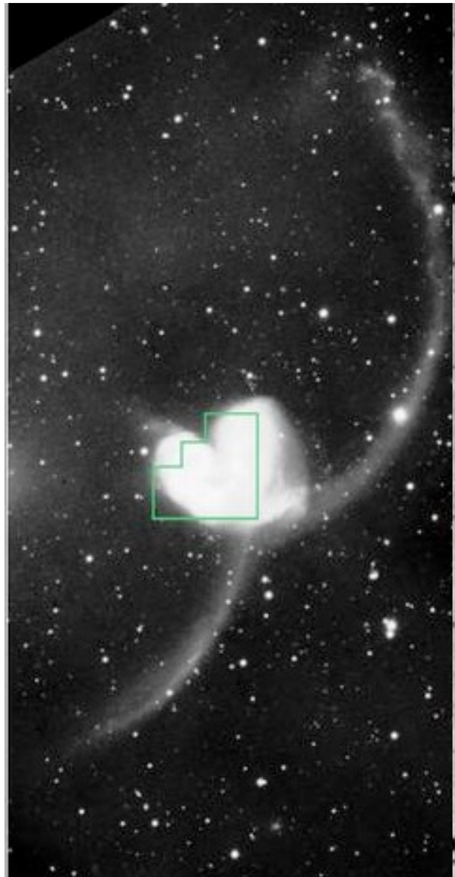
Interesting issues

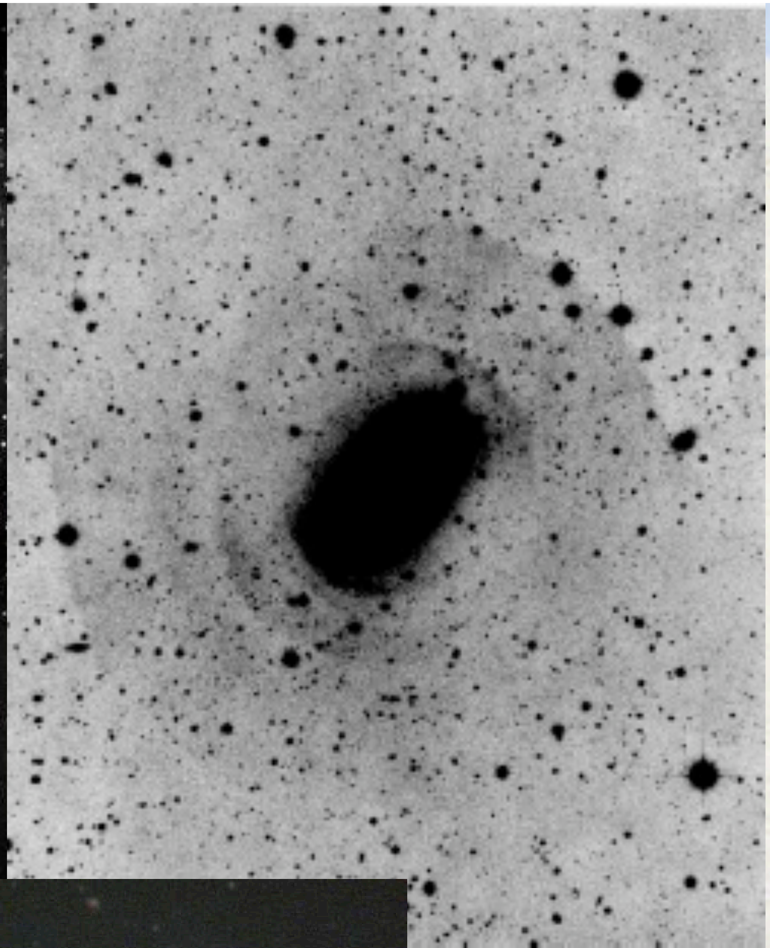
- Stellar remnants - how will they end up?
- What happens to gas and dust ?
- Effect on final remnant morphology and kinematics.
- Where is the star formation:
  - Central star formation
  - Young star clusters
- Build up of nuclear black holes
- Do these remnants tell us about early time mergers.

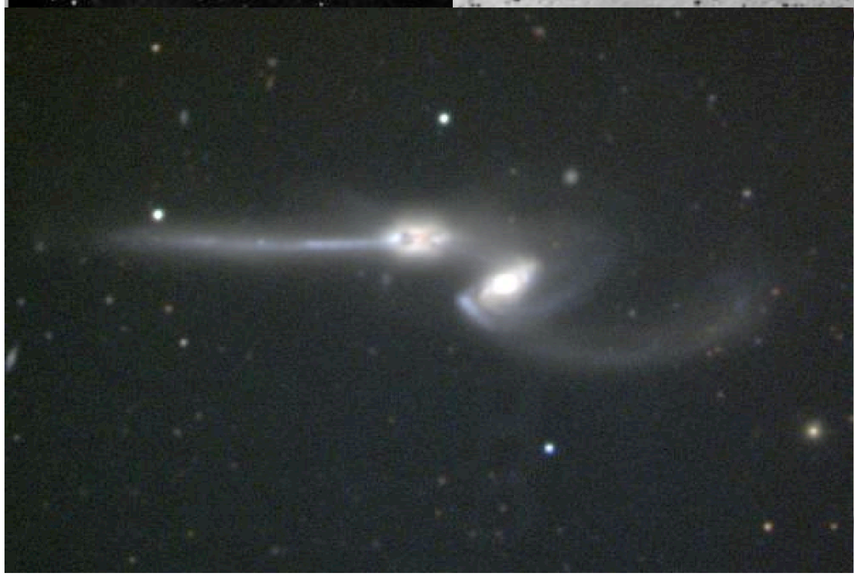
Collisionless mergers

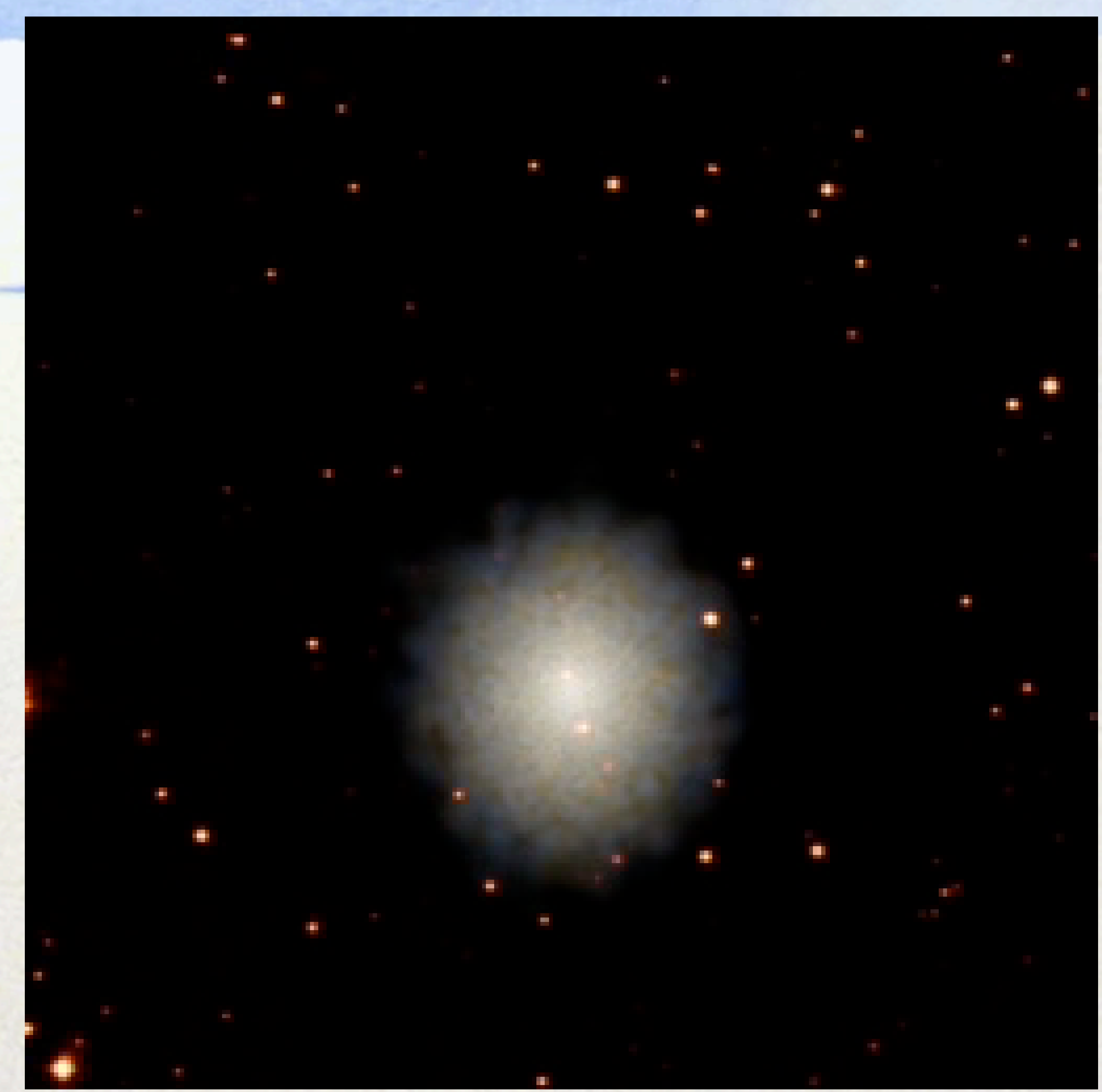
- Observed signatures are shells, ripples and tails.
- Modelling fairly straightforward.
  - Early work of Toomres, Wright and others,
  - Developed by Quinn, Hernquist, Barnes, Springel and many others.

Merger remnants



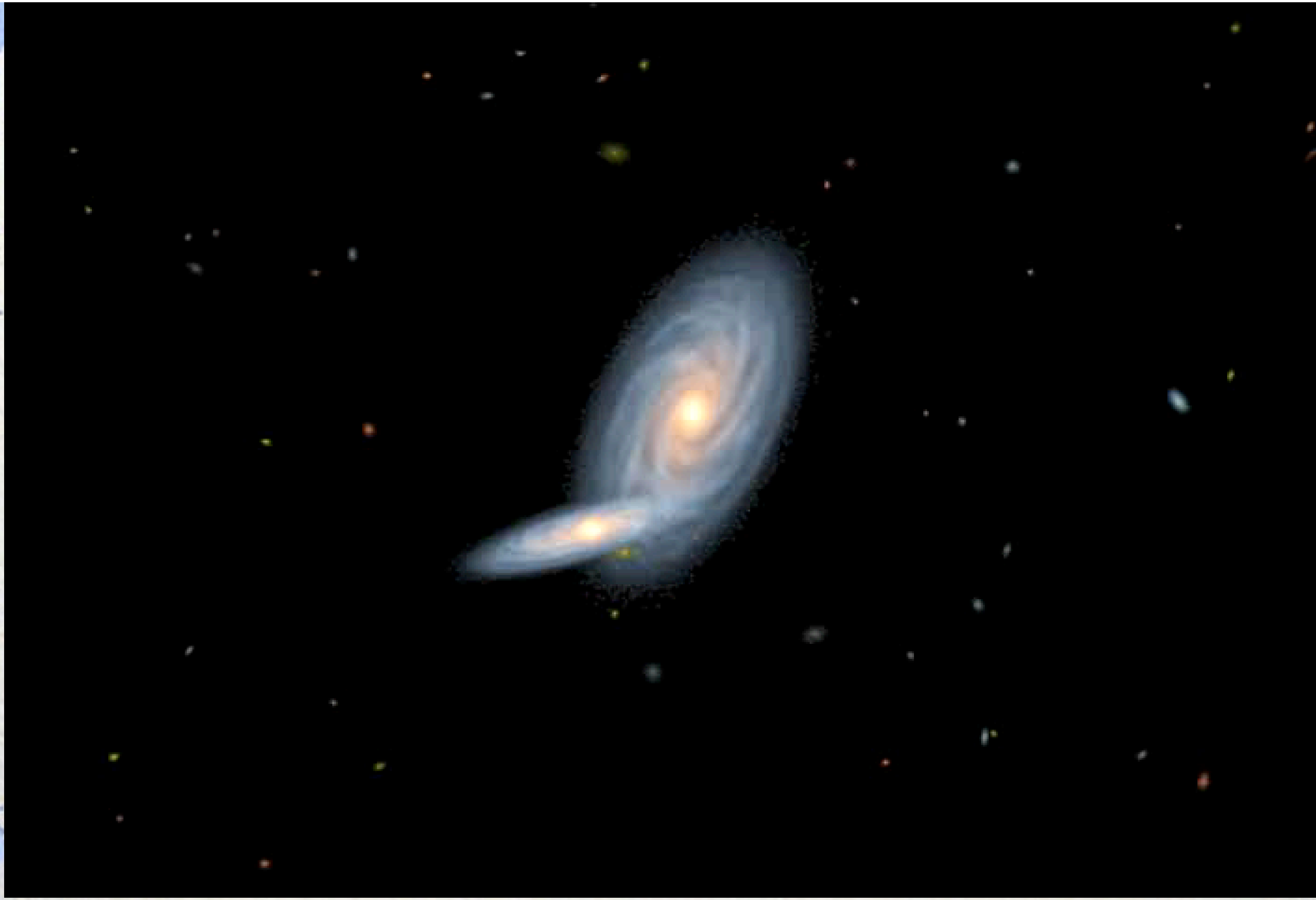






Collisionless major merger simulation (Volker Springel)

Cluster formation movie by John Dubinski



Simulation of the Mice (Dubinski)

Simulation of Mice (Barnes)

Gas and dust in mergers

- You cannot make galaxies like present day ellipticals from mergers of disks because of the high phase-space density in ellipticals (Carlberg 1986; Naab & Trujillo 2006)

Gas and Dust in mergers

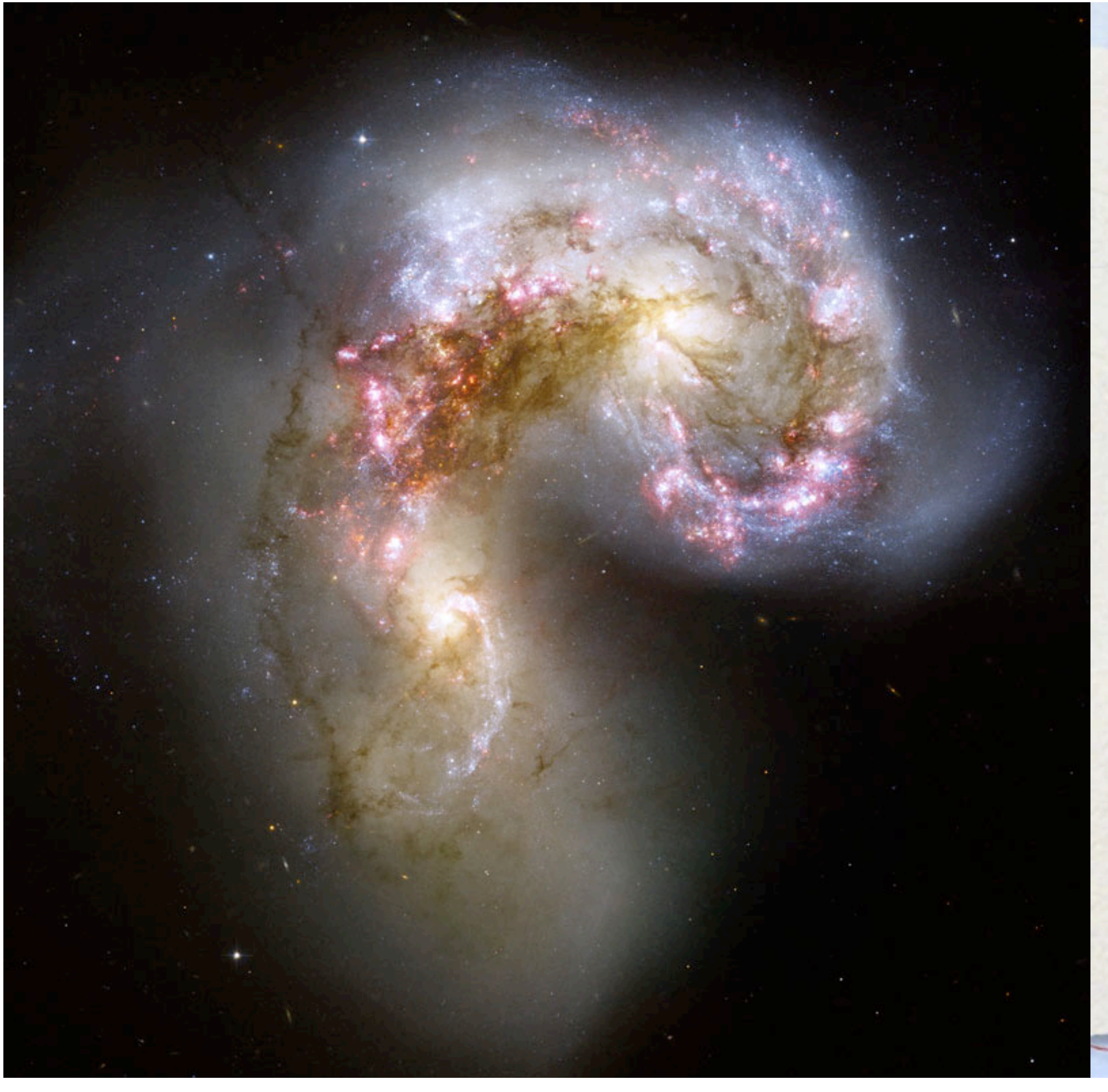
- Real galaxies contain gas and dust
- We observe of gas and dust in known merger remnants.
- Enhanced star formation in nuclear regions and clusters.

Gas and Dust in mergers

- Gas in mergers alters density gradients, final orbital structure and the form of the potential (Barnes 1998; Barnes and Hernquist 1996).

Morphology from HST Images

- A few observations of individual systems or small samples (Schweizer, Whitmore, Goudfrooij, Carter).
- Much of this is targetted at looking for young or forming star clusters.
- Some work (Sikkema et al.) on shell properties (profiles, colours, morphology)

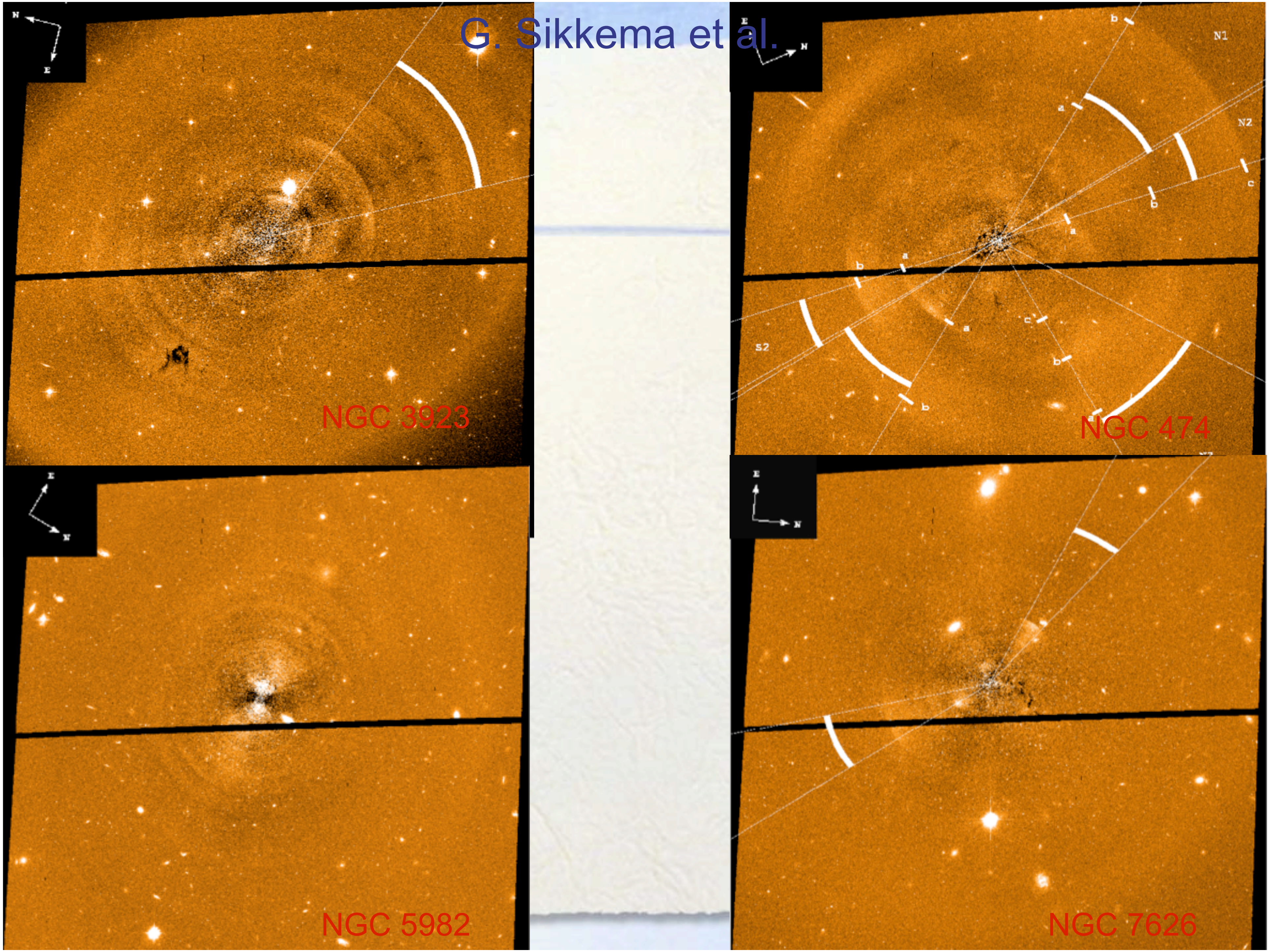


NGC4038/9

HST Image

PI: B/ Whitmore

G. Sikkema et al.

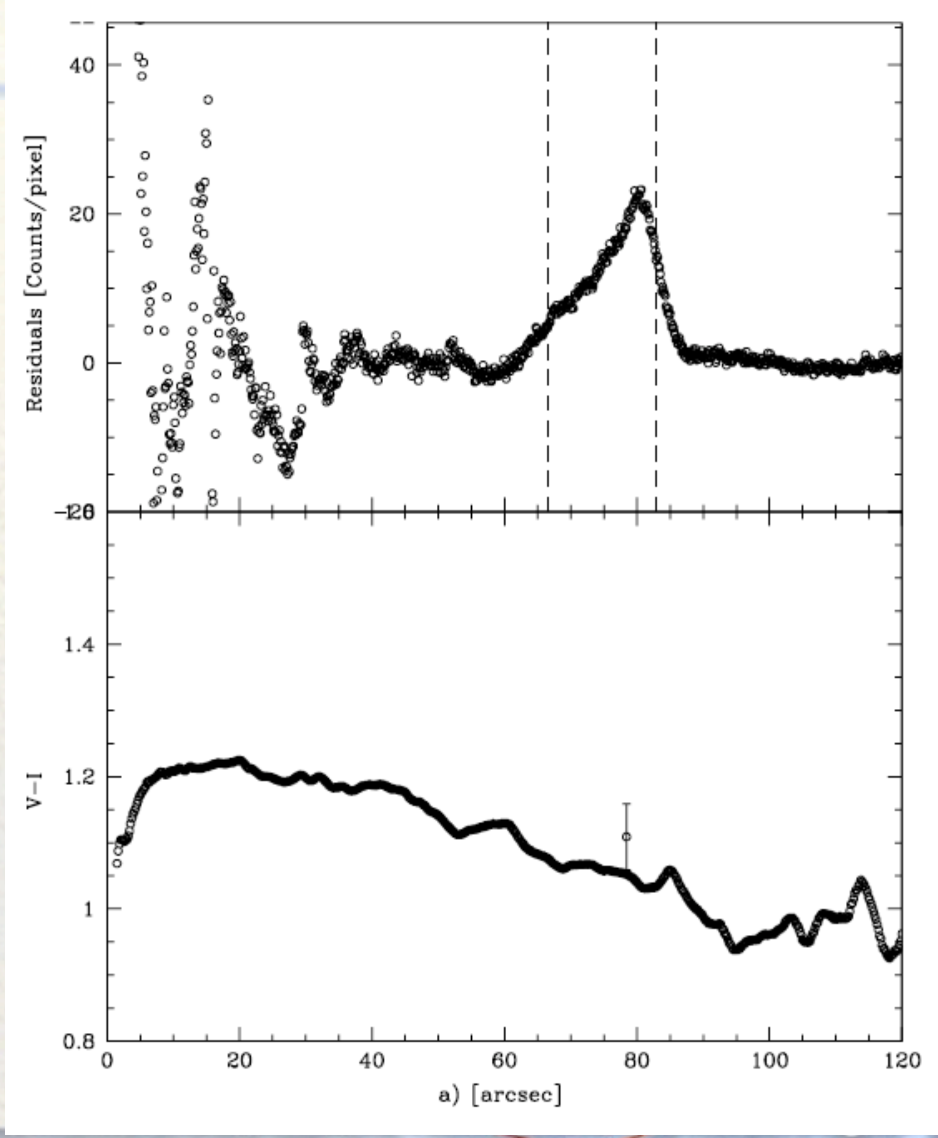


Shell properties (Sikkema et al.)

- HST does not find shells closer in towards the centre than the ground-based work.
- Some shells are red, suggesting the presence of dust in the shells.
- Spitzer observations of NGC 5982 (Carlos del Burgo) point to extended and nuclear dust.

Shell properties (Sikkema et al.)

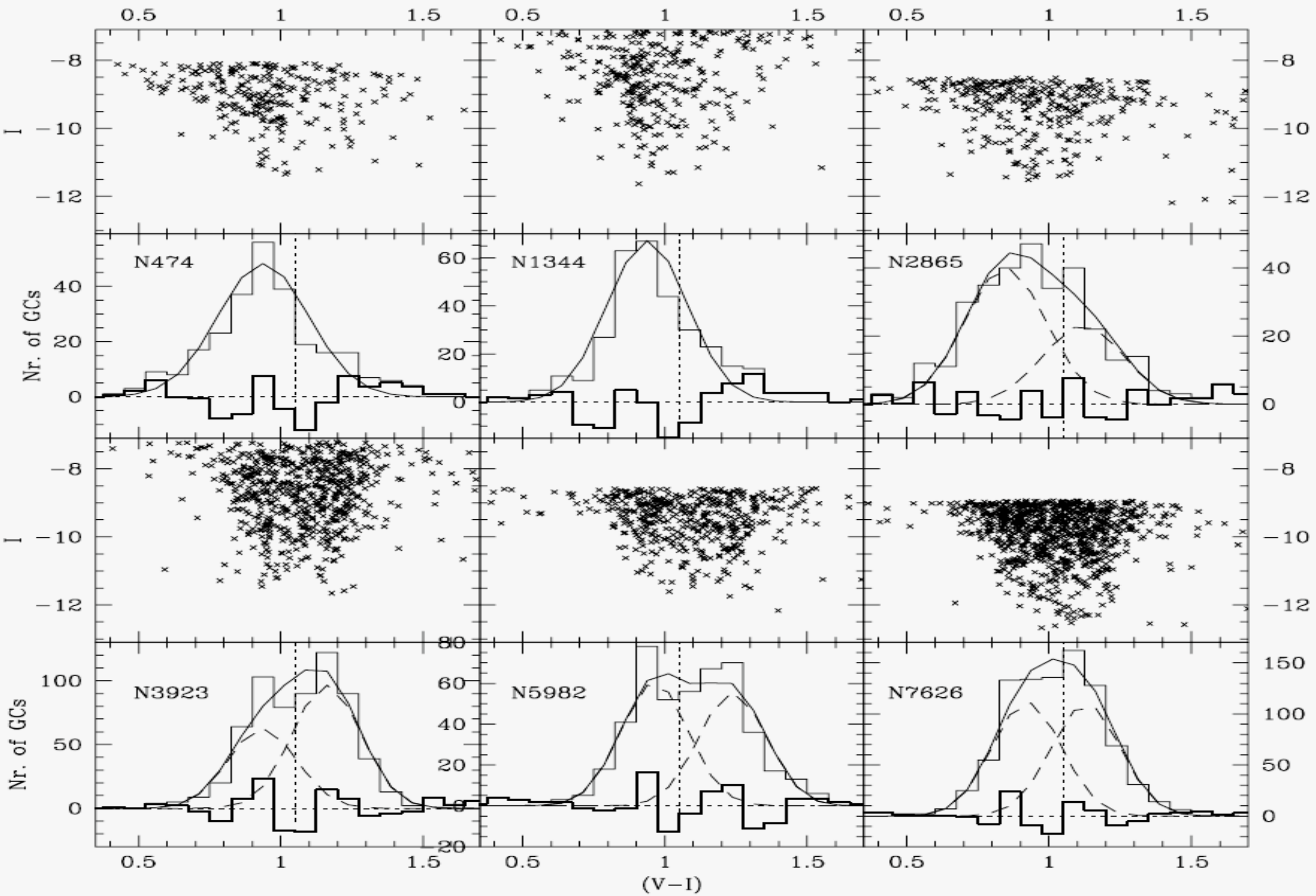
- Shell profiles are as expected from simple merger models (e.g. Quinn-Hernquist test particle models).



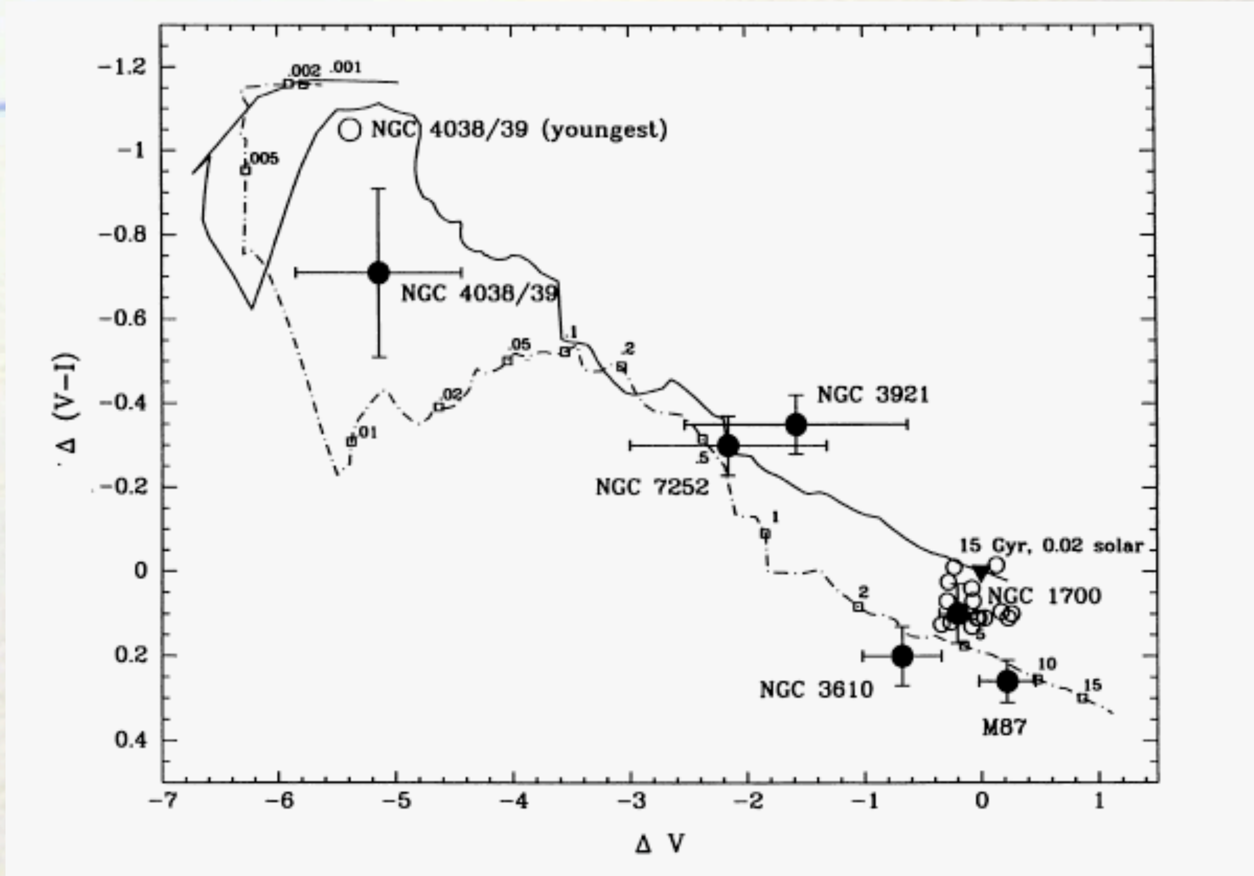
Young clusters

- There appear to be young clusters in some merger remnants (Holtzman, Zepf etc.)
- This is NOT the same issue as that of bimodal GC colour distributions in ellipticals, those clusters are all old and the difference is a metallicity difference.
- Bimodal colour distributions can indeed make intermediate age clusters hard to detect.

GCs in shell ellipticals - G. Sikkema et al.

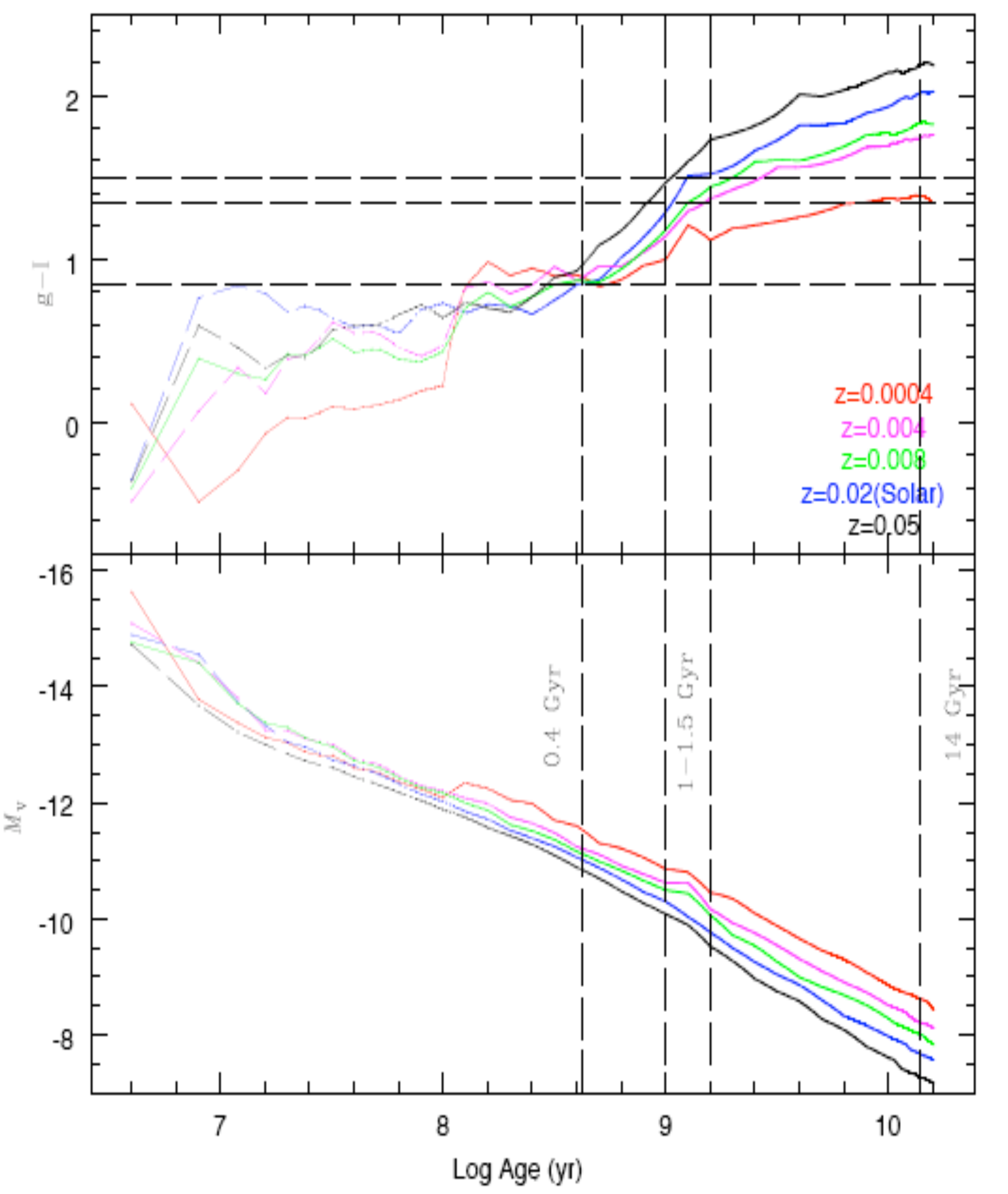


Evolution of young GC populations



From Whitmore et al. 1997. Δ(V-I) is the the colour difference between young and old metal poor histogram peak. ΔV is the magnitude difference between the 10th brightest clusters in each. Note Δ(V-I)=0 for a 1-2 Gyr metal rich population

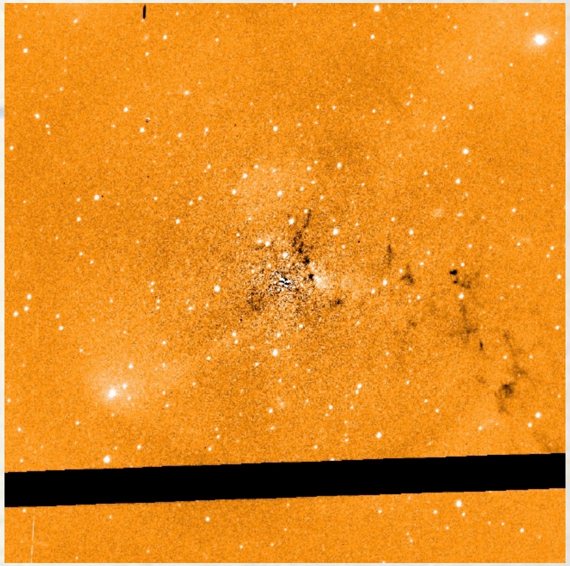
Evolution of young GC populations



- From Maybhate et al. 2007
- Single burst, Salpeter IMF models using GALEV
- Top panel shows colour evolution of the histogram peak
- Lower panel evolution of a characteristic absolute magnitude
- Note degeneracy in upper panel

Young GC populations

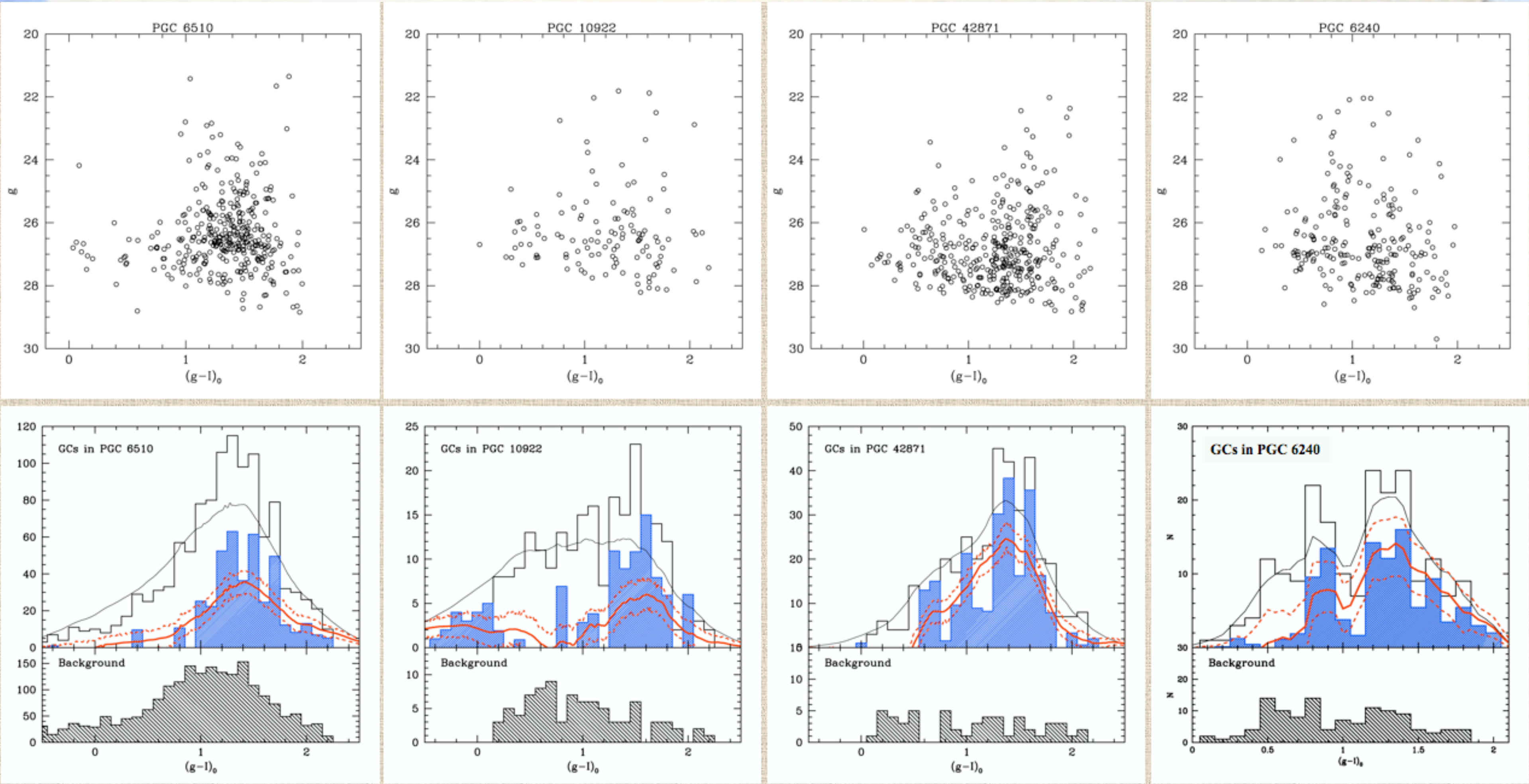
- NGC7626 - population of anomalously bright clusters - 2-5 Gyr old



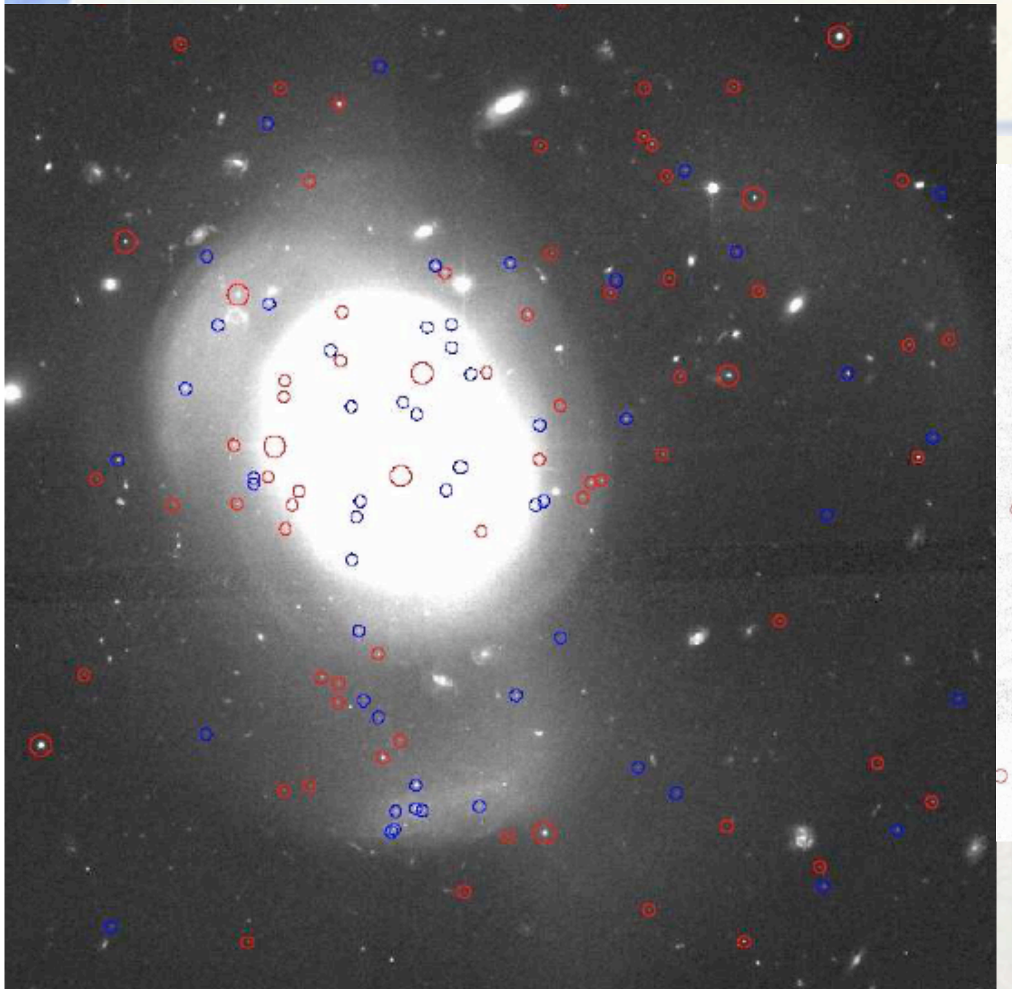
- NGC2865 - very blue population, not very luminous or numerous. Possible 0.5 - 1Gyr blue population (consistent with nuclear starburst age from Hau)

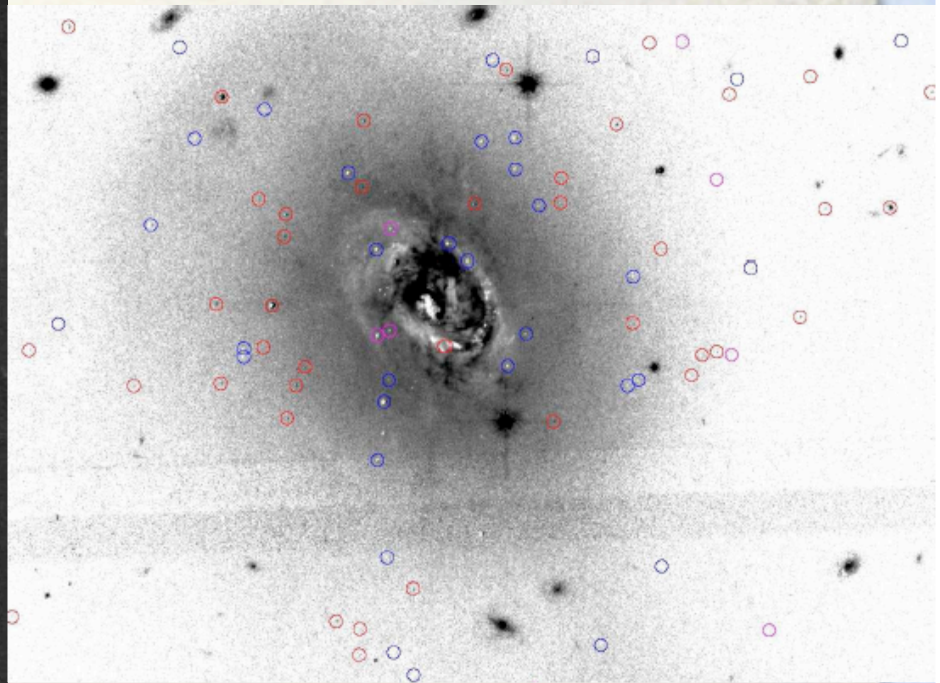
Young clusters in star forming Shell galaxies

Maybhate, Goudfrooij, Schweizer, Puzia, Carter



PGC 6240 clusters (Maybhate et al.)





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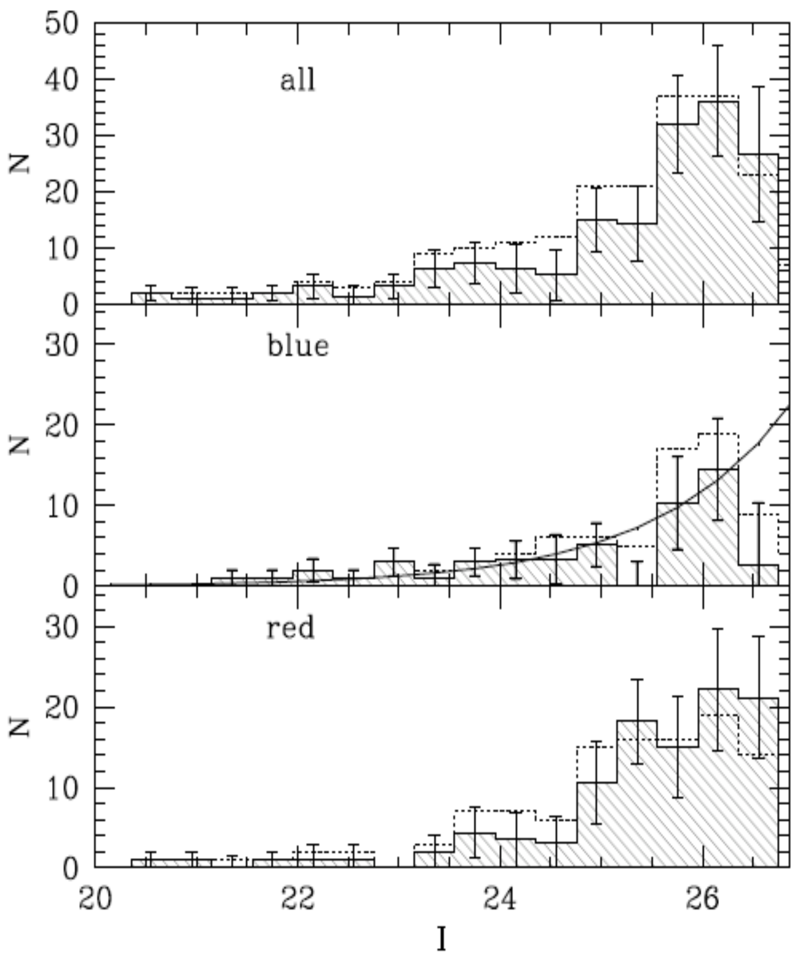


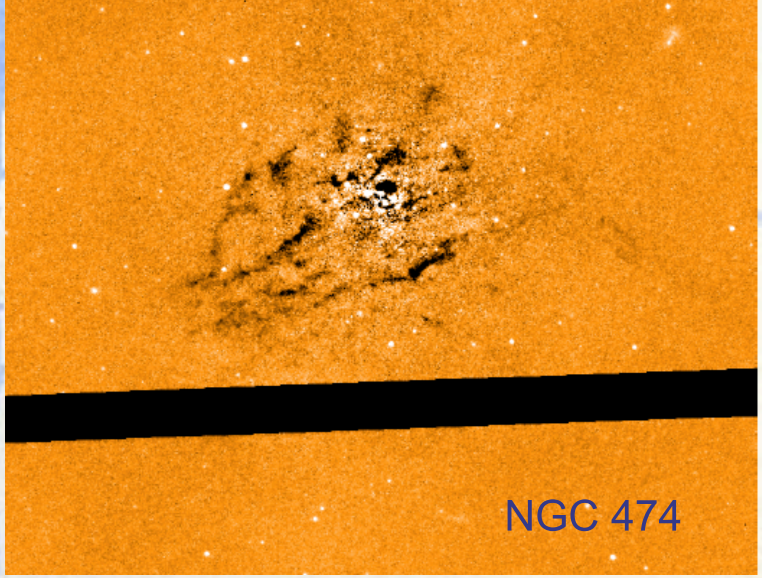
- Blue population has age about .4 Gyr with power-law LF.
- Red population appears to be a mixture of a Gaussian LF and a bright power-law tail.
- Possible intermediate age (1-1.5 Gyr) metal-rich population.

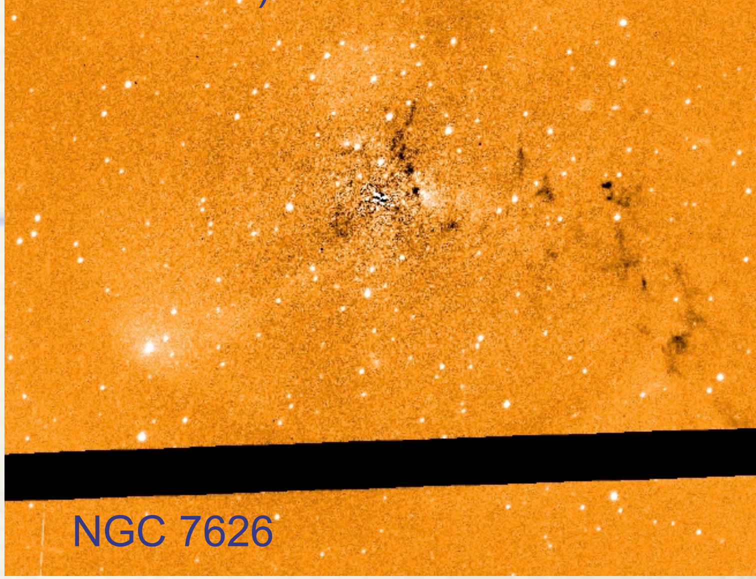
Gas, dust and central star formation

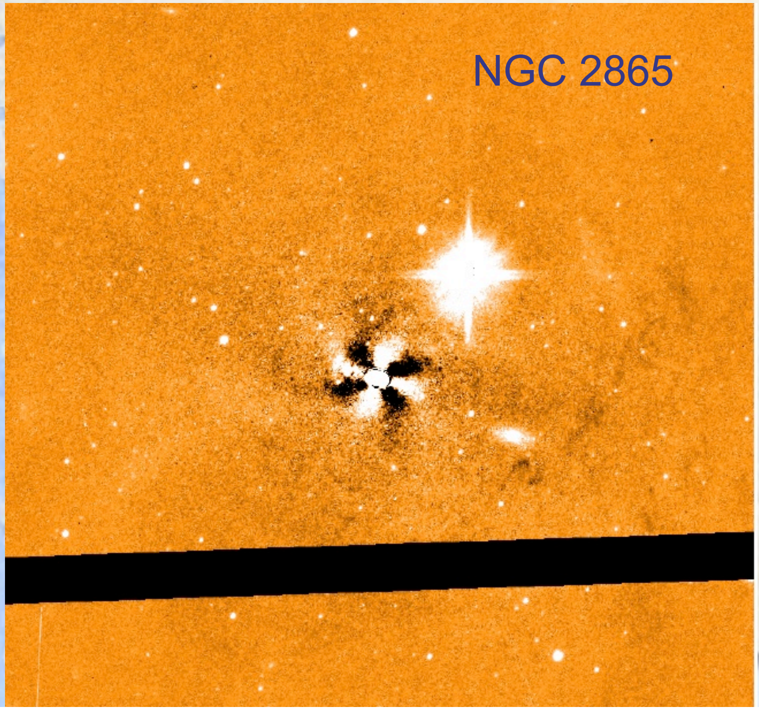
- What can we do with gas and dust morphology. ?
- What other information do we need?
- Can we model the mergers?

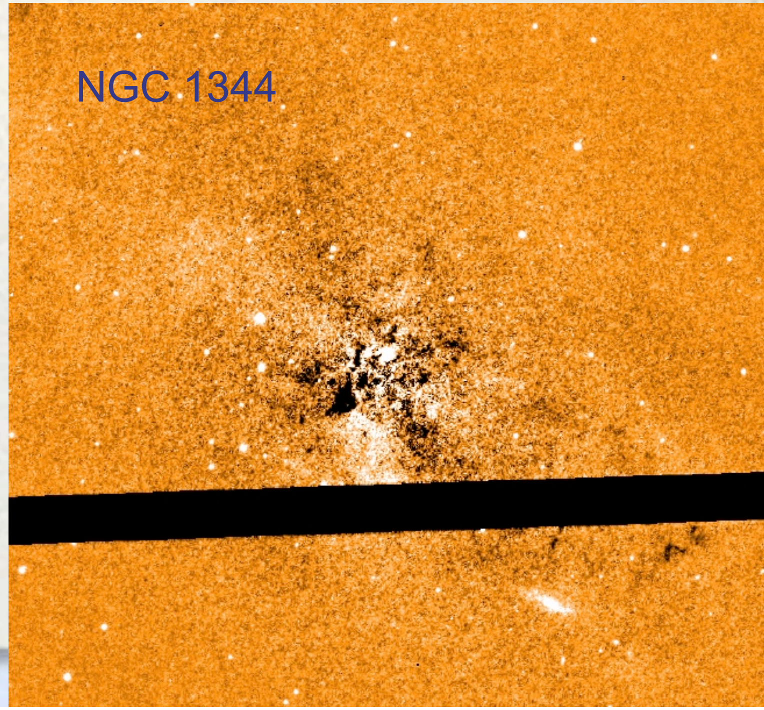
Nuclear gas and dust

Model subtracted images (Sikkema et al.)





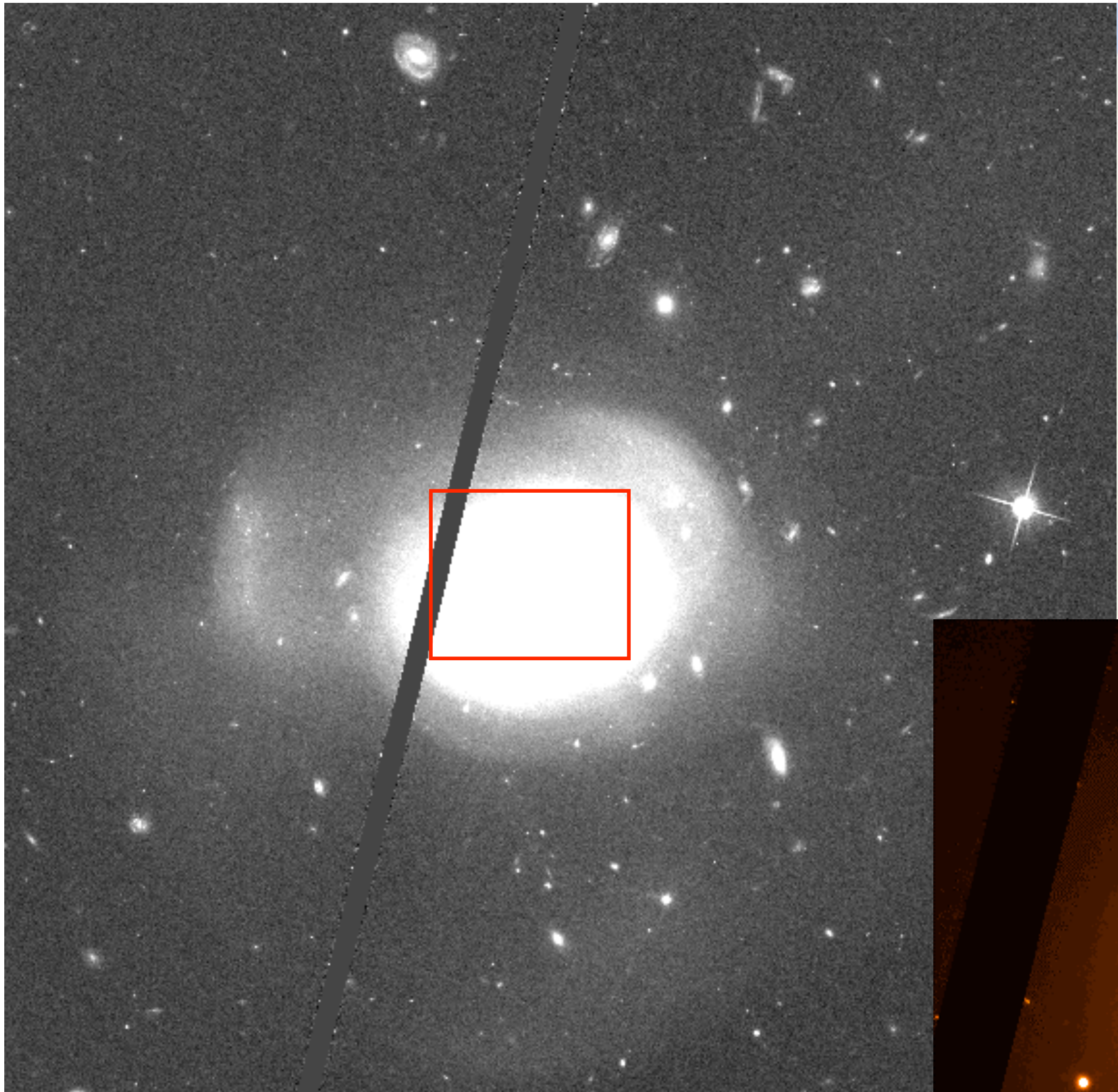




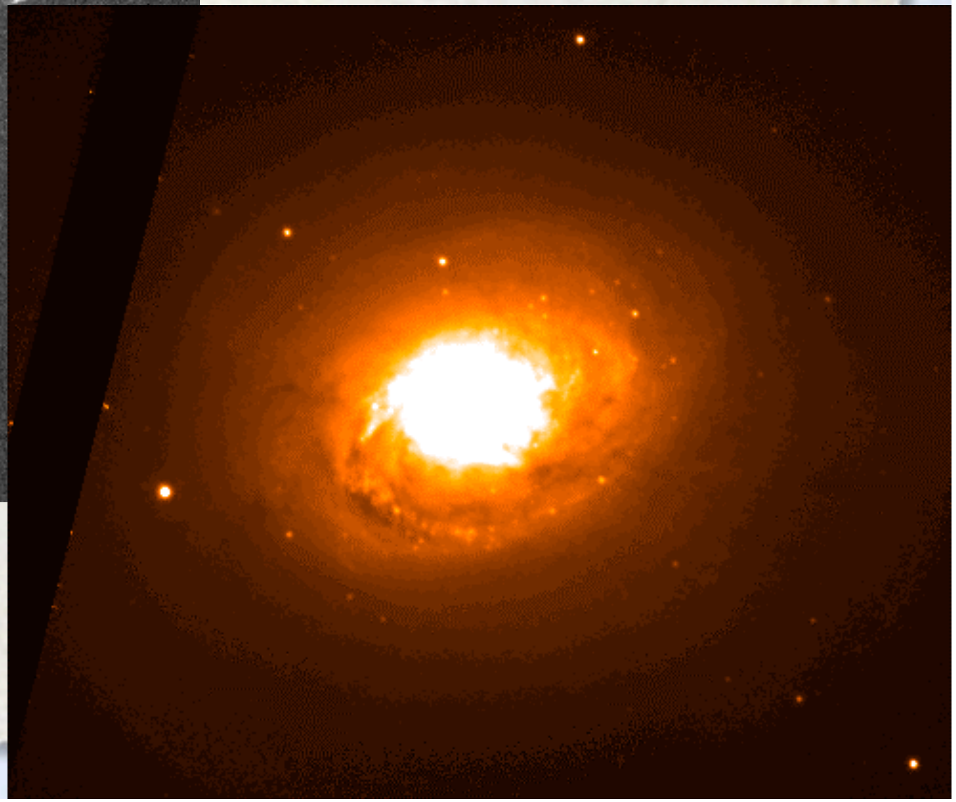
Star forming shell galaxies

- Subset of Malin/Carter catalogue
- Selected for nuclear starburst or poststarburst spectra
- HST images aimed at young clusters (PI: P. Goudfrooij)

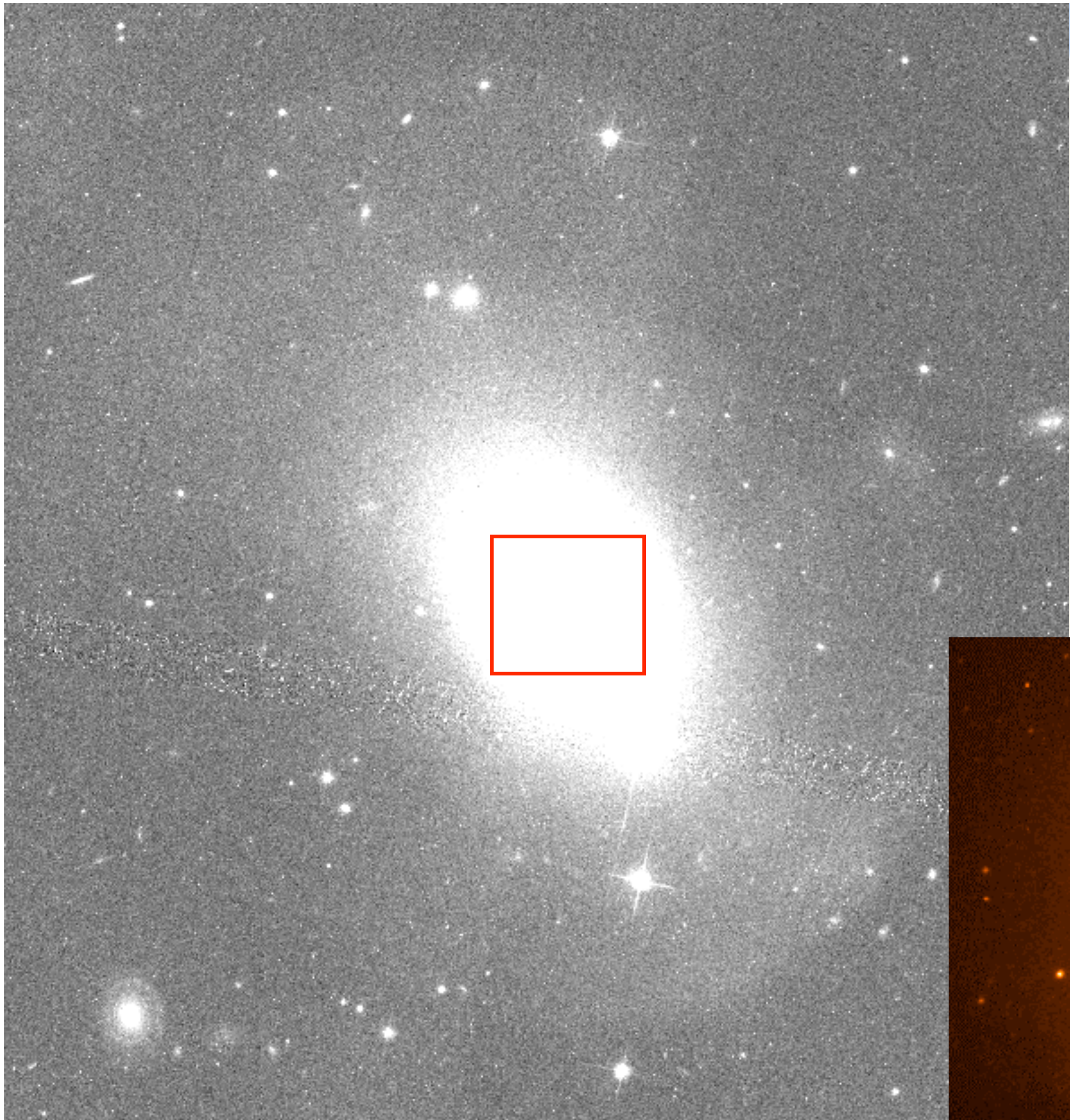
PGC6240



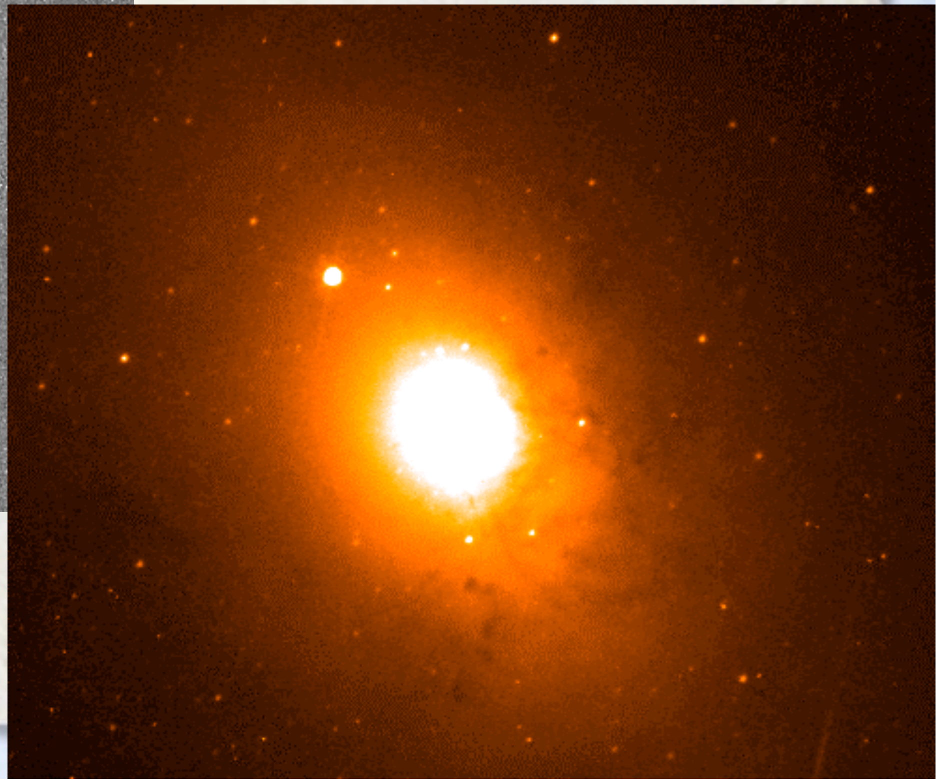
HST Image, PI: P. Goudfrooij



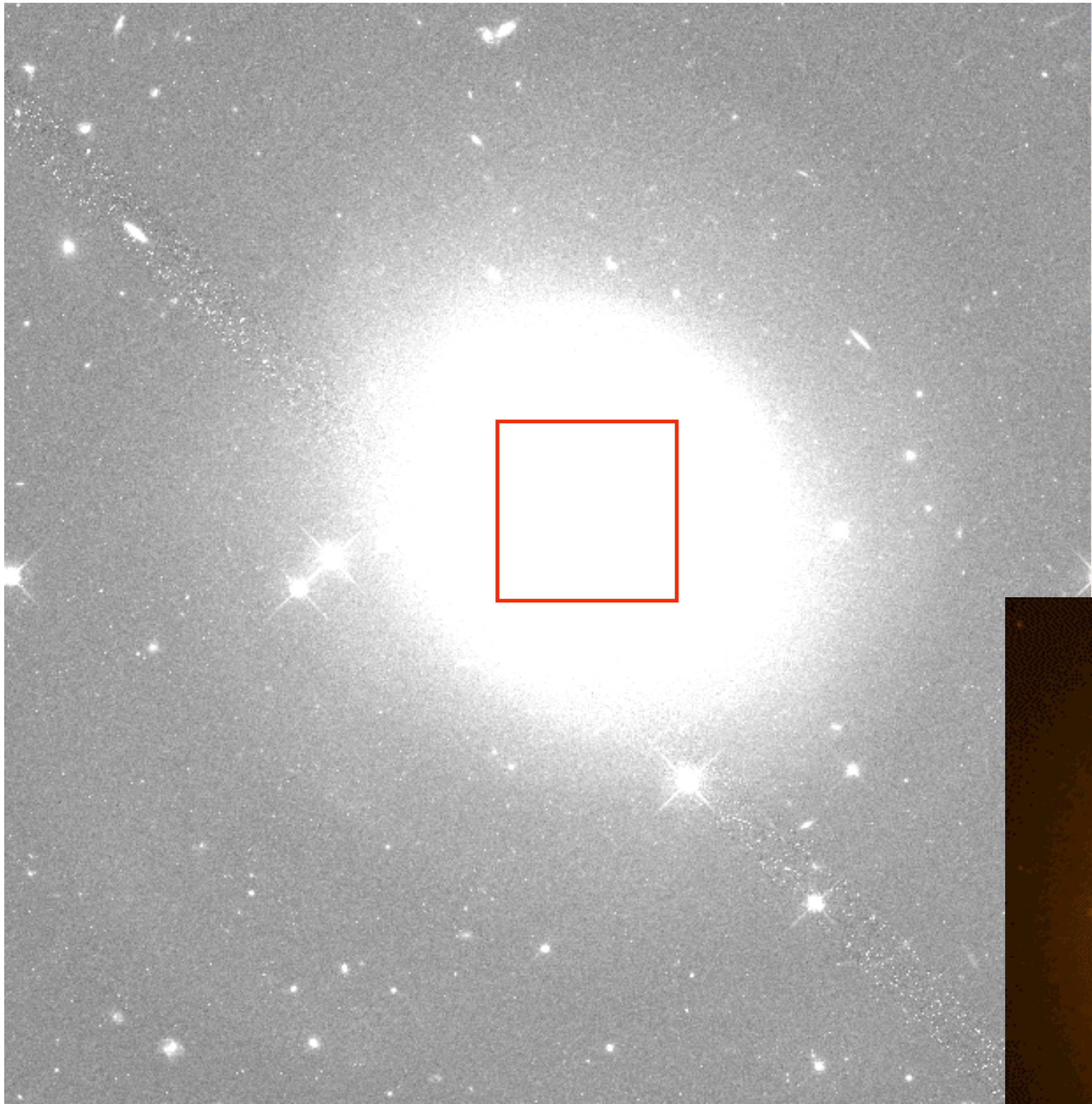
PGC6510

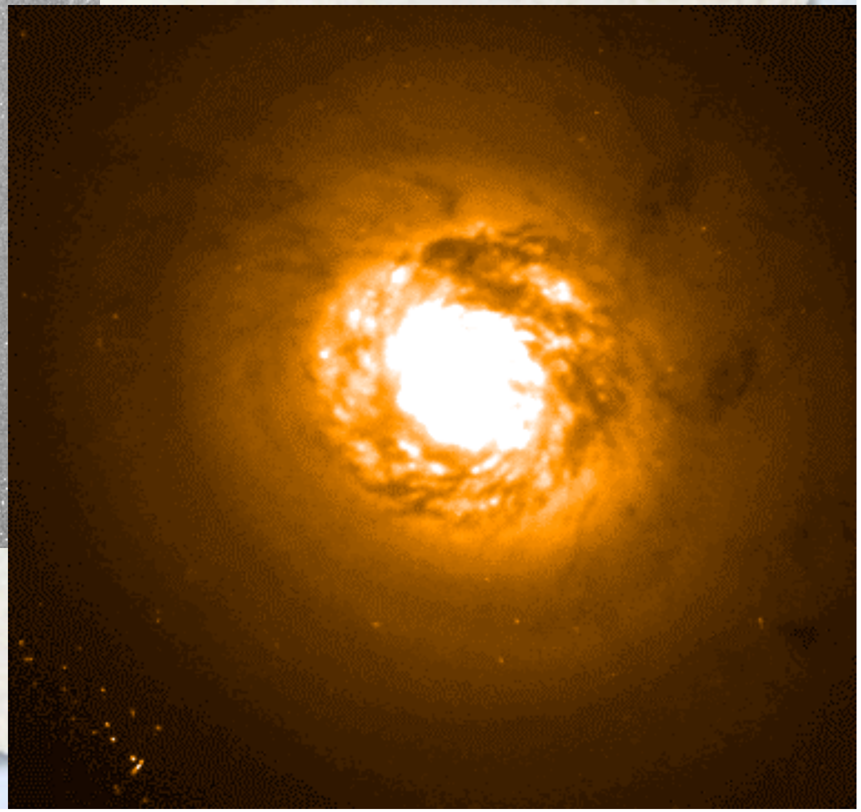


HST Image, PI: P. Goudfrooij



PGC10922

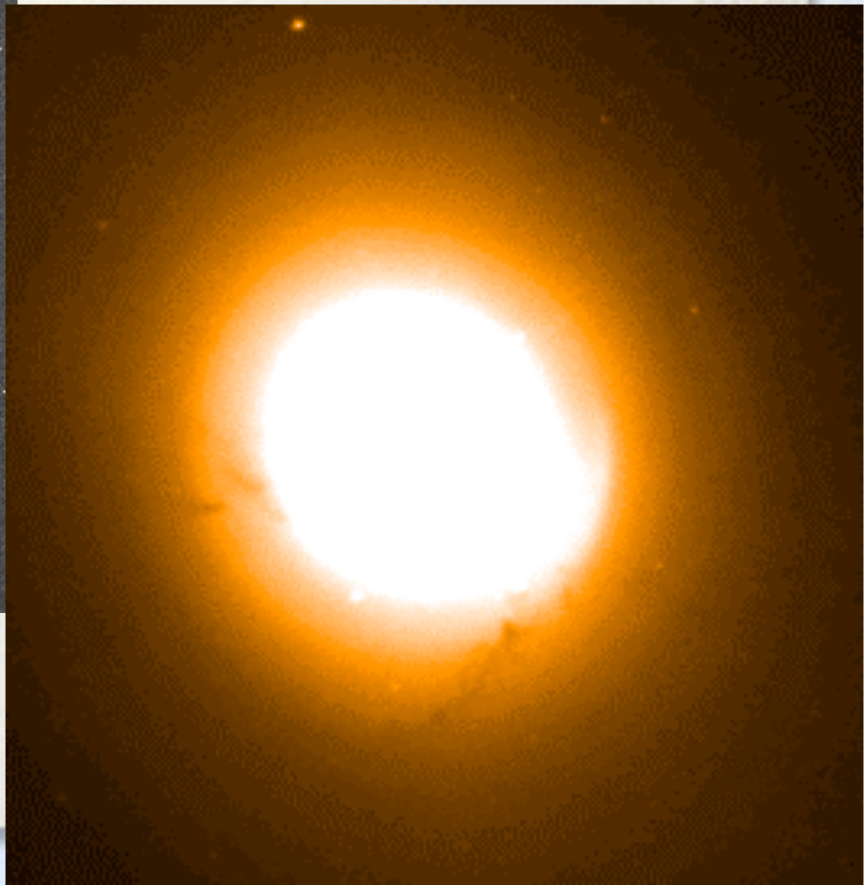




HST Image, PI: P. Goudfrooij

PGC42871

HST Image, PI: P. Goudfrooij



IFU spectroscopy

- Needed for stellar and gas kinematics, which are often different.
- Also stellar populations if calibrated,
- However SAURON survey does not specifically target merger remnants.
- Gemini and VLT bizarrely do not regard such observations as interesting (not high enough redshift?)

Numerical models

- State of the art models now include stellar, dark matter and gaseous components.
- GADGET2 is an example.
- Merger models tend to be either equal-mass mergers or models in which the larger galaxy is represented by the potential only.
- Few 1:3 or 1:10 merger models

Numerical models

- Star formation
  - Schmidt-Kennicutt law
  - Proportional to energy dissipation in shocks (Barnes)
- Dust attenuation (Jonsson radiative transfer code)
- Feedback from star formation and central AGN

Numerical models

- Some examples from Cox, Jonsson, Springel, Hernquist, di Matteo and others

Equal mass Sbc merger (Patrik Jonsson)

left: Projected gas density

right: Projected stellar density

XY, the orbital plane

G Model Minor Merger
Run: G3G2r-u3
T.J. Cox & Patrik Jonsson, UC Santa Cruz
UC Santa Cruz, 2004

1:3 spiral-spiral merger model (T.J. Cox & P. Jonsson)

Left - Gas; Right - Stars

left: Projected gas density

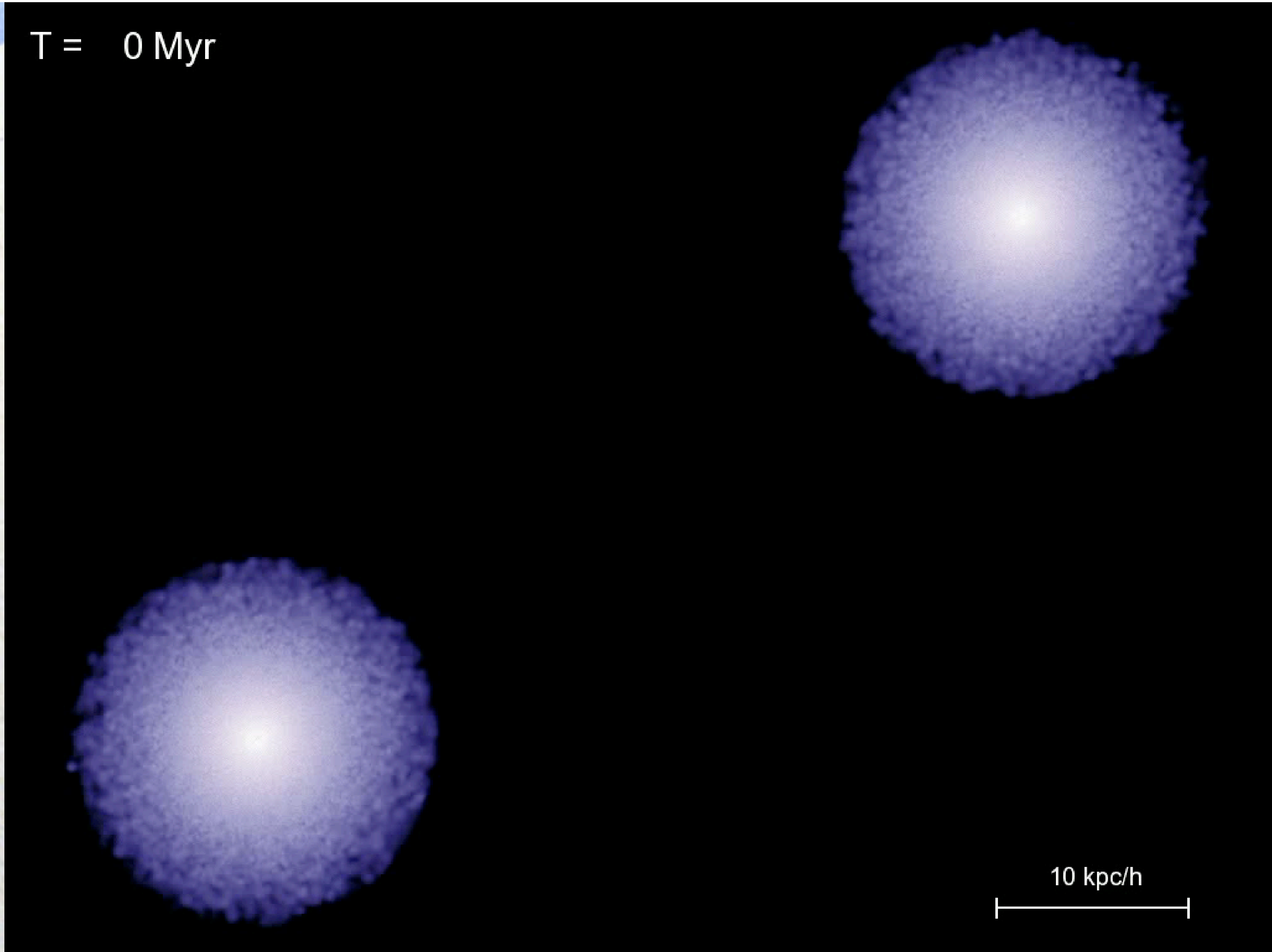
right: Projected NEW stellar density

XY, the orbital plane

Isolated Disk (Sbc) Galaxy
Run: execute/G3G1-u3
T.J. Cox & Patrik Jonsson, UC Santa Cruz
UC Santa Cruz, 2004

1:6 spiral-spiral minor merger (Cox & Jonsson)

Left - Gas; Right - New Stars

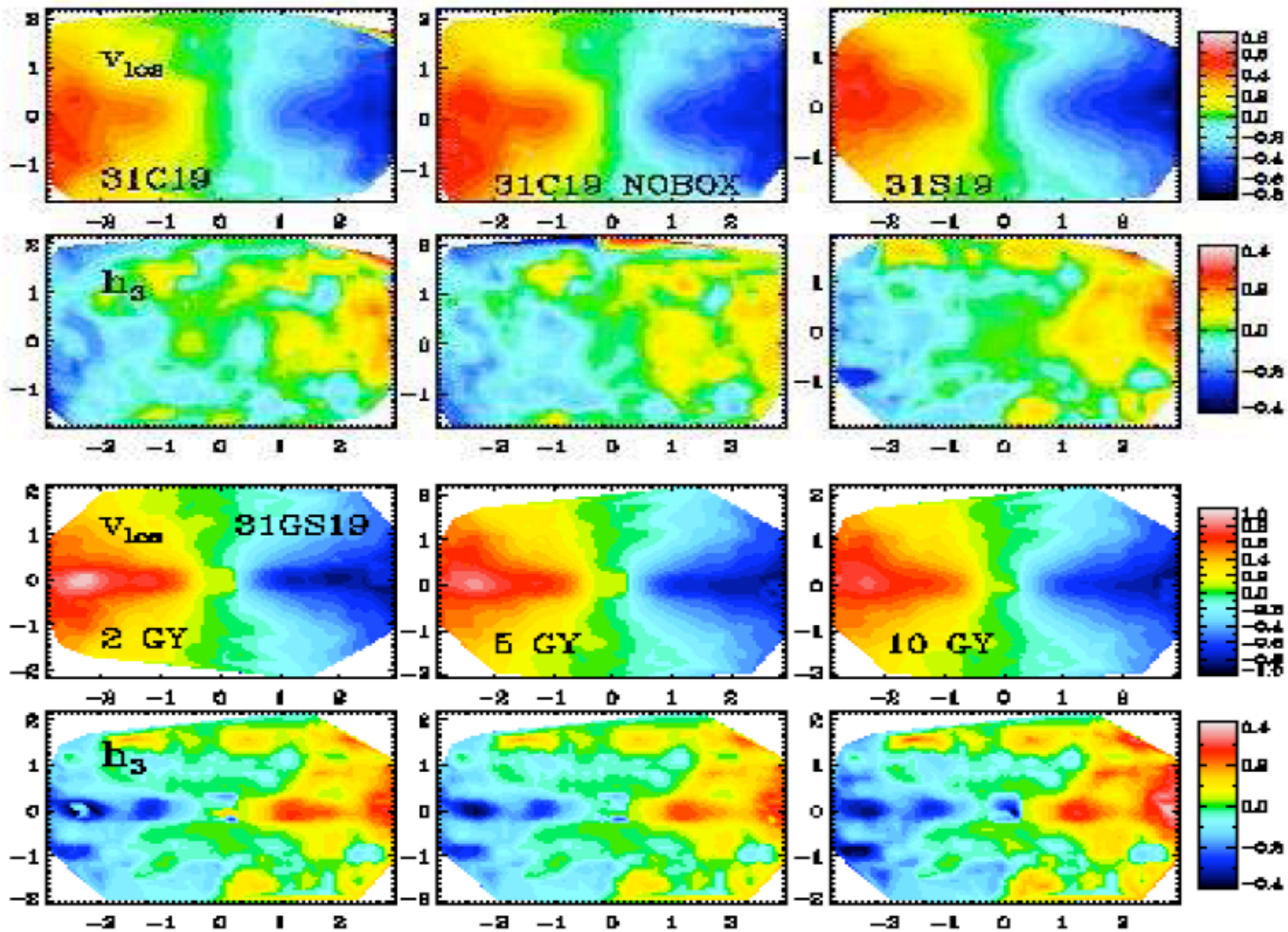


Feeding supermassive black holes (Springel)

Can we use the current generation of models together with observations of morphology and velocity fields, to constrain interesting parameters for local minor mergers, such as the mass ratio, type (B/T), gas fraction, relative velocity, impact parameter, and a number of angles, or is parameter space just too large?

Kinematics of merger models

- Simulations of velocity fields of dissipationless mergers by Balcells, Gonzalez-Garcia and others.
- Naab et al., Jesseit et al.
  - Simulations of velocity fields of 1:1 and 3:1 mergers, dissipationless and with gas. Mergers with gas can produce kinematic peculiarities seen in morphologically normal elliptical galaxies: misaligned rotation; counter-rotating cores etc.



3:1 merger models from Jesseit et al. Top: dissipationless; bottom: 10% gas.

Summary

- HST images show complicated structure in the gas and dust at the centres of merger remnants.
- Star formation is ongoinmg in clusters and in the gas in the cores.
- IFU observations of velocity fields are urgently needed
- Much work still to do to understand the parameters and prescriptions required as input to numerical simulations of mergers.