# High Angular Resolution Near-Infrared Studies of Nearby Galaxies with the TMT

T. J. Davidge

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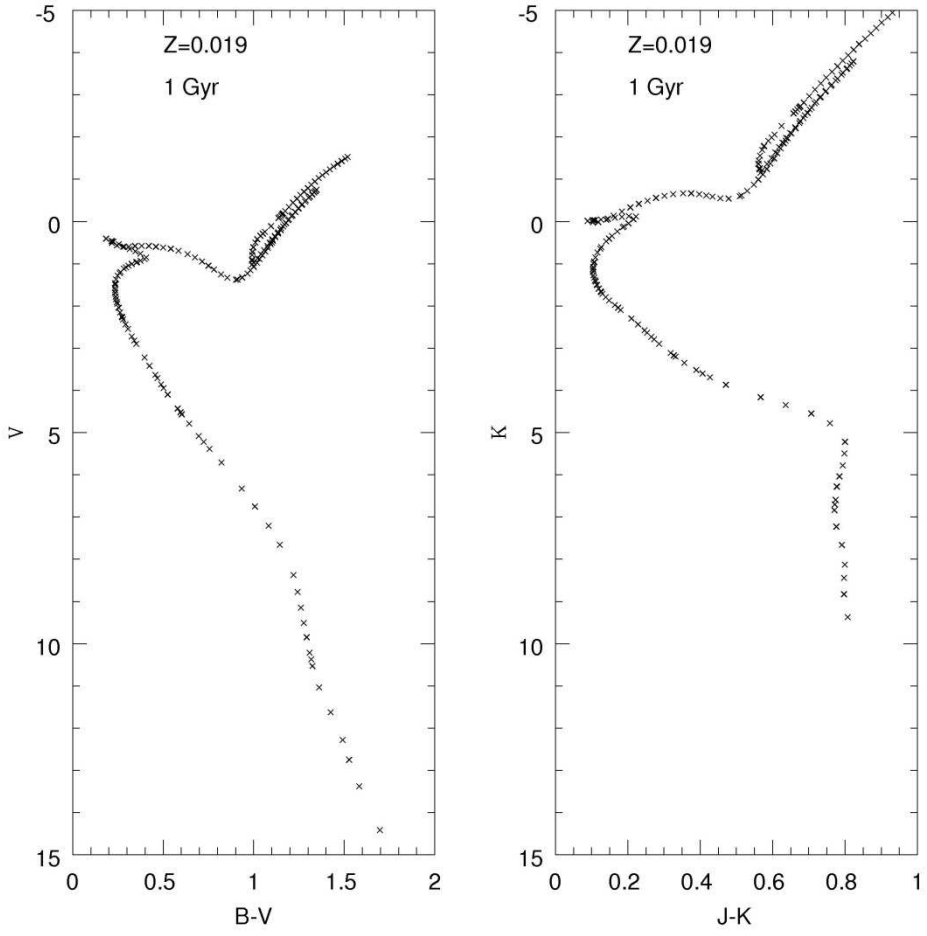
# Why Observe in the NIR?

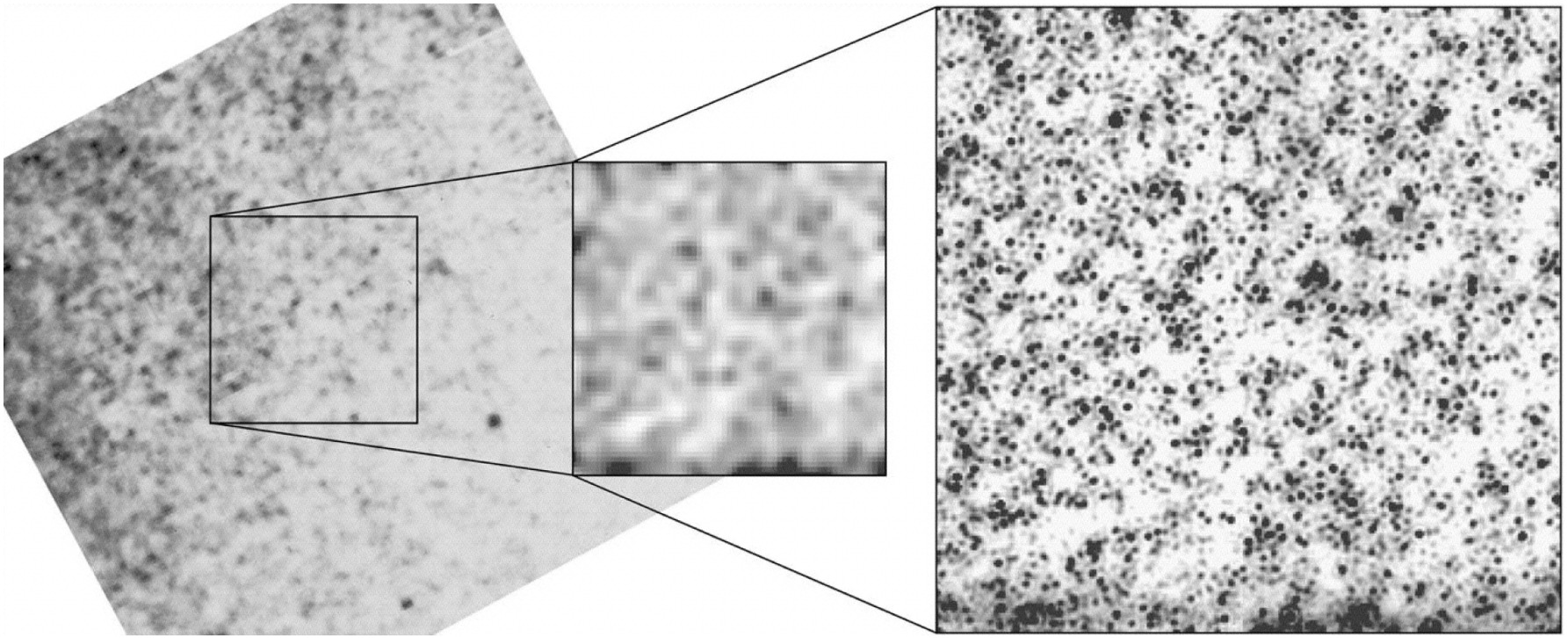



- The giant branch extends over a larger range of brightnesses in the IR than at visible wavelengths, making it easier to resolve these objects.
- Low mass dwarfs contribute a greater fraction of the integrated light in the NIR, making spectroscopic signatures of dwarfs easier to detect – important for IMF studies using integrated light.
- The location of the opacity-induced break on the lower main sequence can be used as an age indicator when measured with respect to the main sequence turn-off.

# Challenges and Limitations to Studies of Resolved Stars in Nearby Galaxies

- Crowding
  - Difficulty resolving individual stars
  - Difficulty identifying isolated AO guide stars in crowded environments.
- High backgrounds with irregular structure produced by unresolved stars.
  - Complicates the extraction of stellar spectra.
- Deep high angular resolution imaging studies from the ground are restricted to the near-infrared
  - Not ideal for main sequence stars.
    - Could target fields with HST data to obtain MSTO information.
  - Uncertainties in physics of stars in the advanced stages of evolution, especially at low metallicities because of a lack of nearby calibrators.
  - Evolved stars provide leverage for probing recent episodes of star formation.
    - The impact of line blanketing on cool, evolved stars is greatly reduced. This will help in obtaining a comprehensive census of RGB and AGB stars over the full range of metallicities.
    - Diminished sensitivity to binaries when compared with MS stars.

# The Importance of Angular Resolution

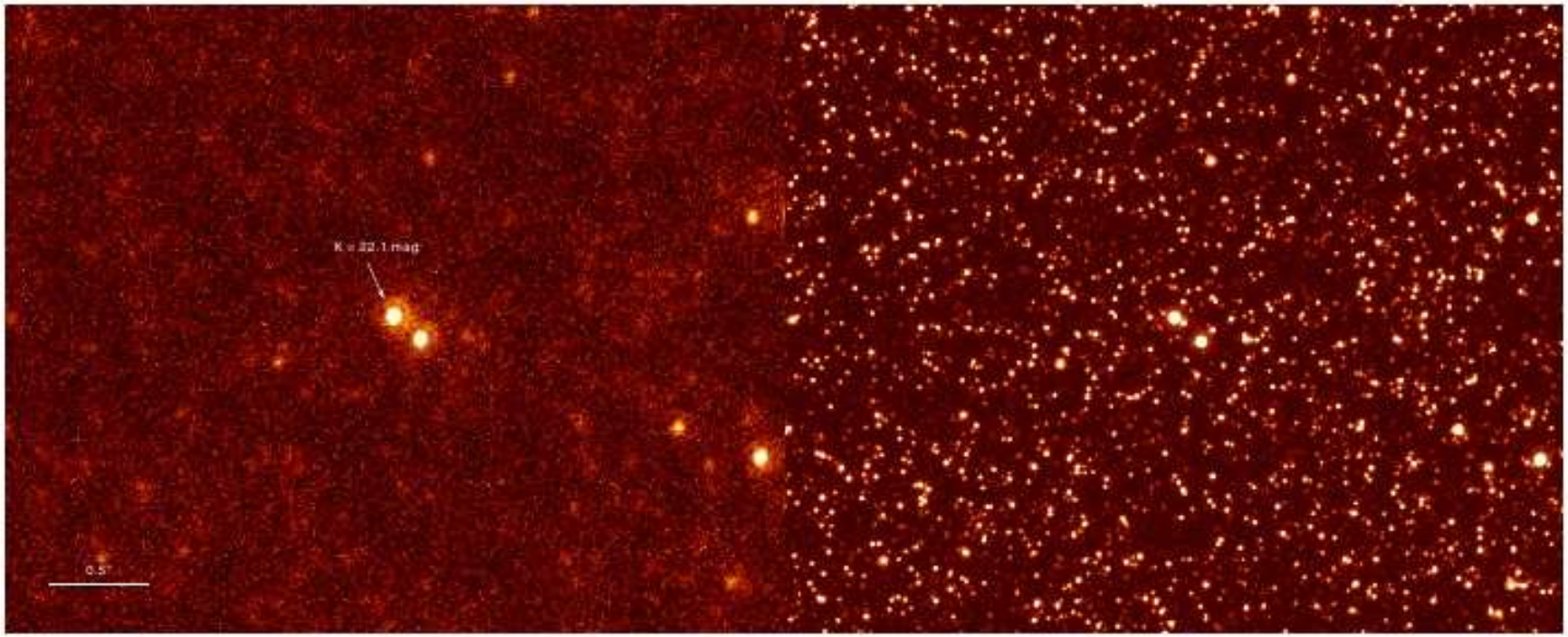


K-band ground-based K-band NIC2

Figure 15 of Stephens et al. (2003, AJ, 125, 2473)

*Note lessons to be learned from early studies of the M31 bulge*

# The Virgo Cluster: The $D^4$ Advantage in Action



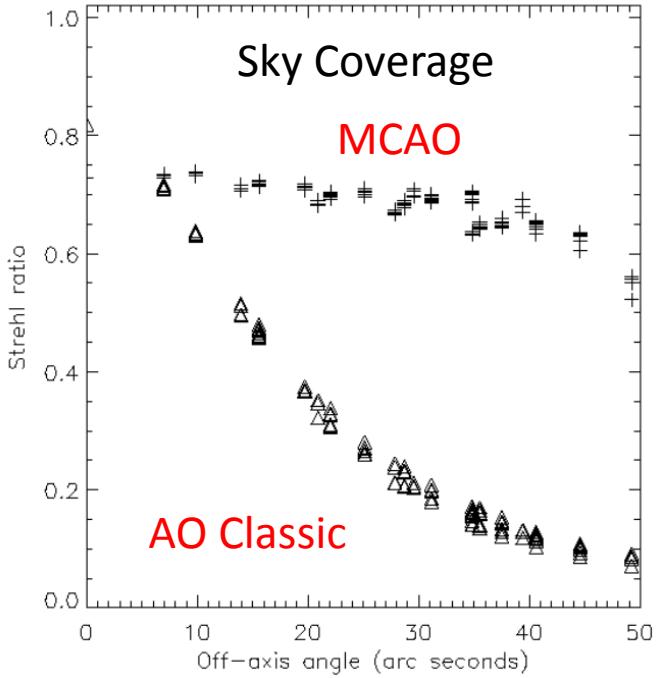

Keck TMT

Virgo spheroid, with 22.5 mag arcsec$^2$ surface brightness and three hour exposure time.

*Coma cluster galaxies observed with the TMT will look like Virgo observed with 8 – 10 metre facilities.*

# GeMS: Gemini MCAO System

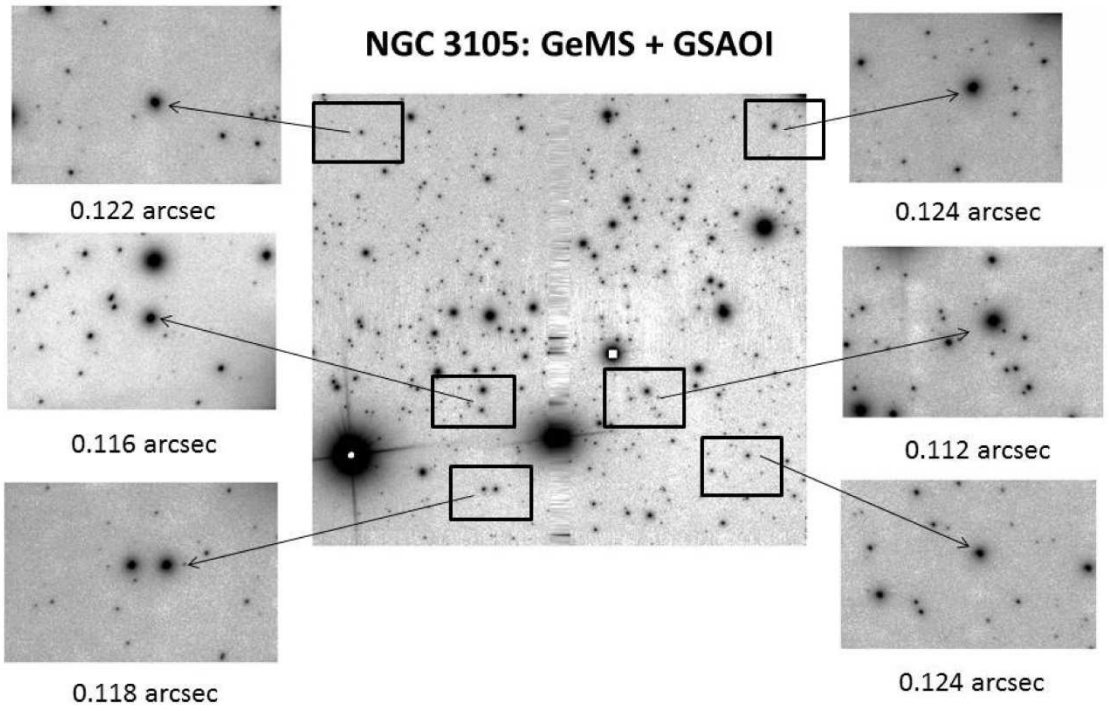
- Experience with GeMS can provide lessons that can be applied to NFIRAOS (e.g. operations – see next slide).
- Three main sub-systems:
  - Laser + Laser Launch Telescope (LTT)
  - Beam Transfer Optic (BTO)
  - Canopus (AO bench)
- Goal → deliver (diffraction limited + uniform) image quality (Near IR) in a FoV > 1 arcmin$^2$
- Two dedicated instruments:
  - GSAOI (NIR imager)
  - Flamingos-2 (NIR Imager and spectrograph).



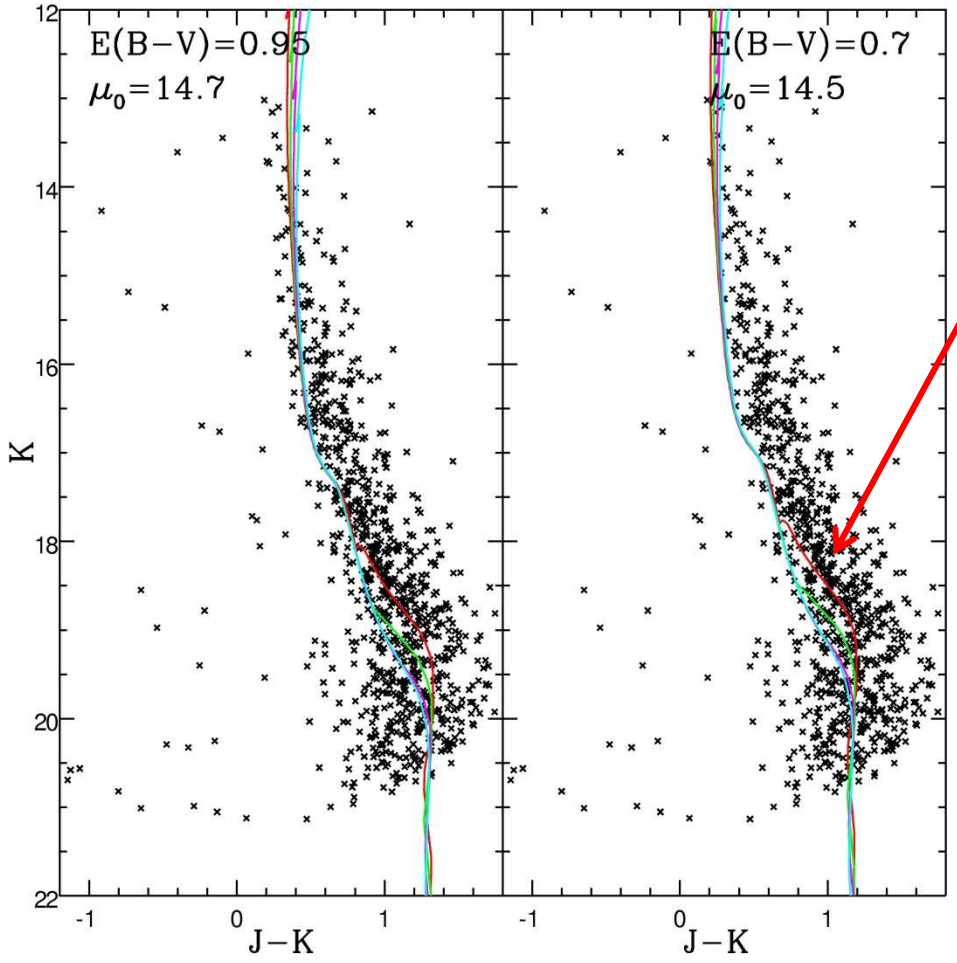

- Strehl ratio under median seeing: ~15% (J), ~35% (H), ~55% (K)
- Strehl uniformity: 5% (J), 2% (K)
- Requires 3 TTP WFS (R<17.5mag)

# ***Gauging the Performance of an MCAO system during mediocre seeing conditions.***

- MCAO systems will be used extensively on VLOTs, and there will be demand to use these systems over a range of conditions. ***How well will these systems perform during `soft' seeing conditions?***
- The GeMS SV program was designed to investigate MCAO performance during 85%ile IQ conditions.
- FWHM in K is stable to within +/- 10%.



# NGC 3105: A Well-Populated Young Cluster in the Outer Galaxy




Note agreement with 20 Myr PMS sequence.

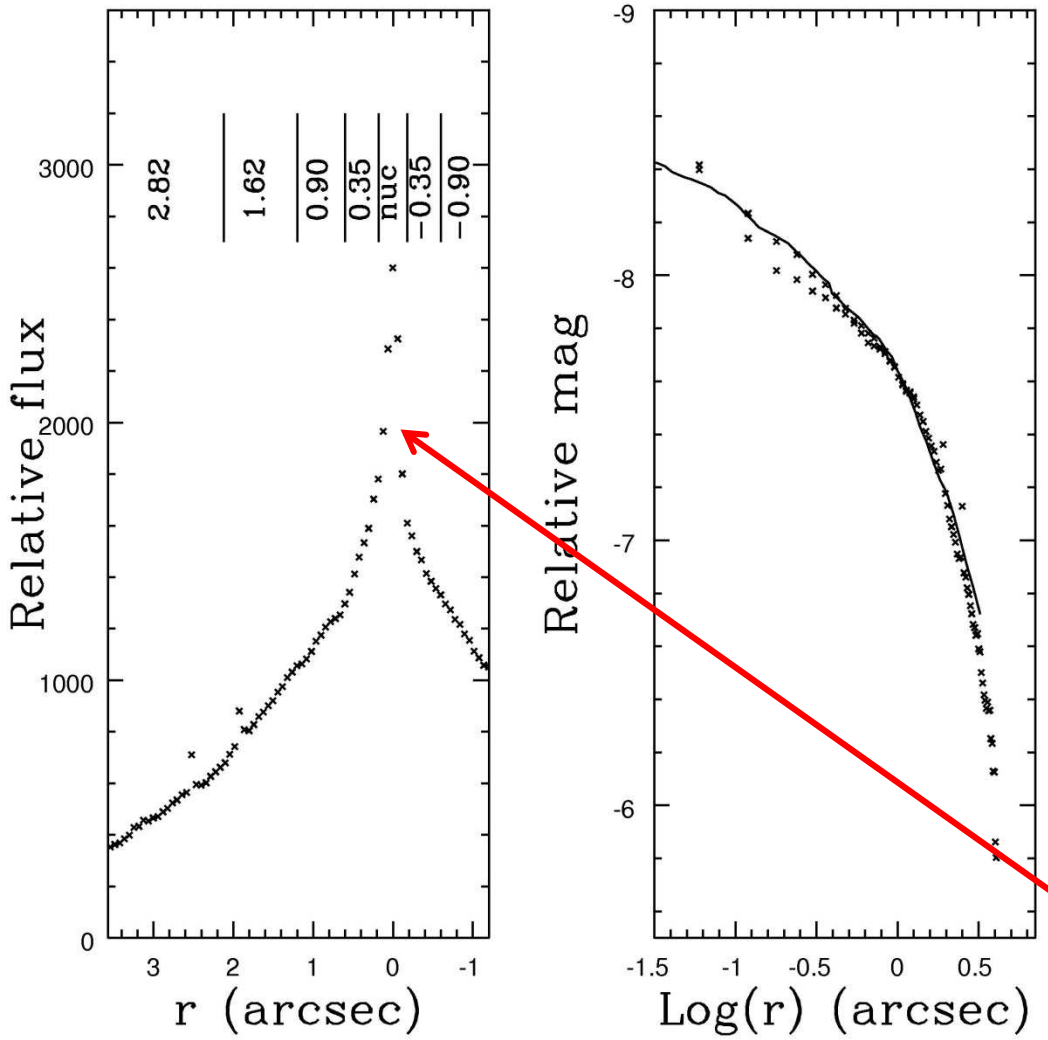
Take away points:

- MCAO is not exclusively a good IQ capability. This may prove important during the early stages of operations.
- With TMT could extend observations of PMS stars in young, modest-sized clusters to other Local Group galaxies.
  - There is better agreement with model PMS sequences in the IR than in the visible.

# RAVEN: An MOAO System

- Multi-Object Adaptive Optics (MOAO) demonstrator used on the Subaru telescope. Collaboration between UVic, HIA, NAOJ, and Tohoku University.
- Turbulence properties over a 3.5 arcmin FOV are monitored with three NGSs.
- Two pick-offs with 4 arcsec FOVs patrol the science field
  - An 11 x 11 DM in each pick-off runs in open loop mode to correct for turbulence at the probe location
- Signal is fed to IRCS where either images or spectra can be generated.
- While not available for first light on the TMT, may appear in future instrumentation suites.
- Demonstration observations of Maffei 1:
  - Obtained spectra with the H+K grism, which delivers R ~ 500
  - One pick-off sampled the galaxy center, the other a background field 1 arcmin distant along the minor axis.
  - The slit was oriented along the minor axis of Maffei 1

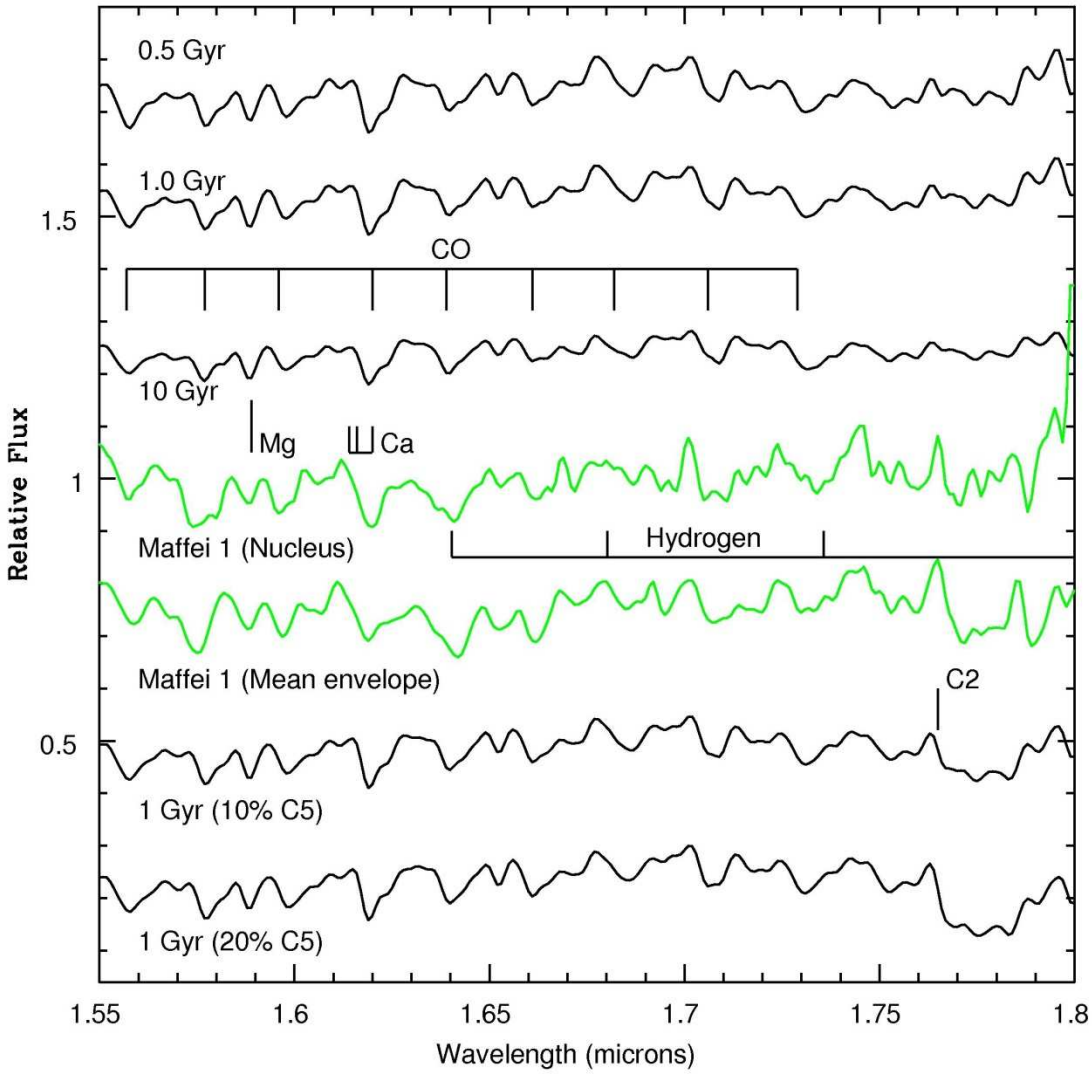
# 1.6μm Light Profile Constructed from the IRCS Spectrum




- The solid line is the F814W light profile from Buta & McCall (2003), adjusted to sample the minor axis, and shifted vertically to match the RAVEN light profile at log(r) = 0.0.
- The RAVEN light profile agrees well with the HST profile.

Characteristic width of ~0.15 arcsec

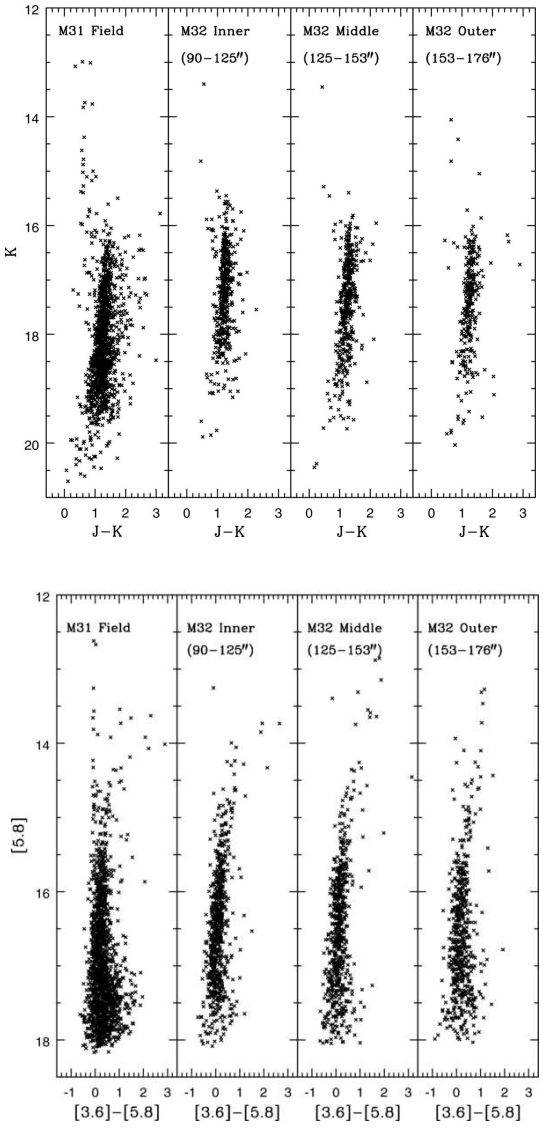
# The Maffei 1 Spectrum: Comparison with Models




- Model spectra were constructed by combining stars from Rayner et al. (2009) based on solar metallicity Padova isochrones that include evolution on the TP-AGB.
- Models that are restricted to oxygen-dominated photospheres do not provide a good match to the Maffei 1 observations.
- Adding a C star component improves the agreement with the observations between 1.75 and 1.80 μm.

Davidge et al. 2015, submitted.

# Adding Value: Combining IR and MIR Datasets

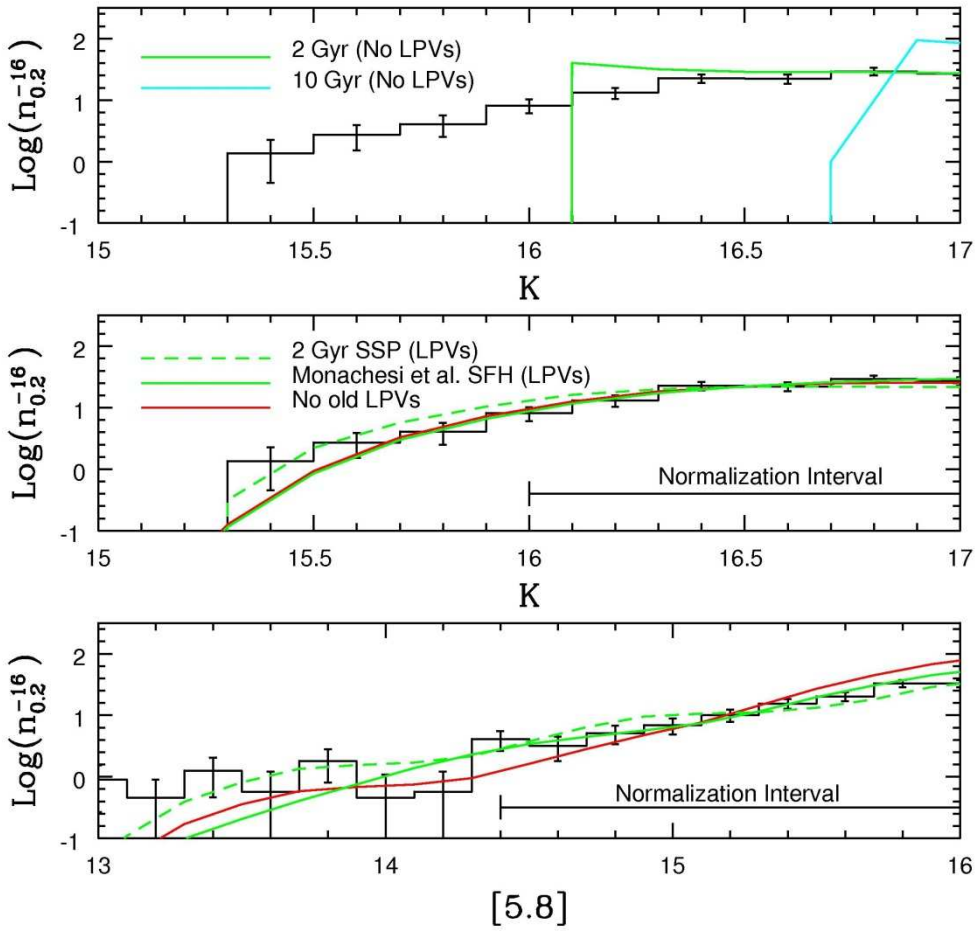



- NIR light is emitted by the photosphere; much of the MIR light can be thermal emission from dust in circumstellar envelopes .
  - The properties of the circumstellar envelope are related to the mass and metallicity of the central star, and so MIR emission can be used to probe the star-forming history.

- JWST will be able to resolve individual bright AGB stars out to ~4 Mpc with the same intrinsic resolution as SPITZER in the Local Group.

CMDs of M32 obtained with WIRCAM and IRAC

# Star-Forming Histories from NIR and MIR Observations




Models that do not include variability of AGB stars can not match the upper ends of the LF.

Achieve much better agreement if include LPV-like nature of AGB stars. However, age-sensitive features are also blurred.

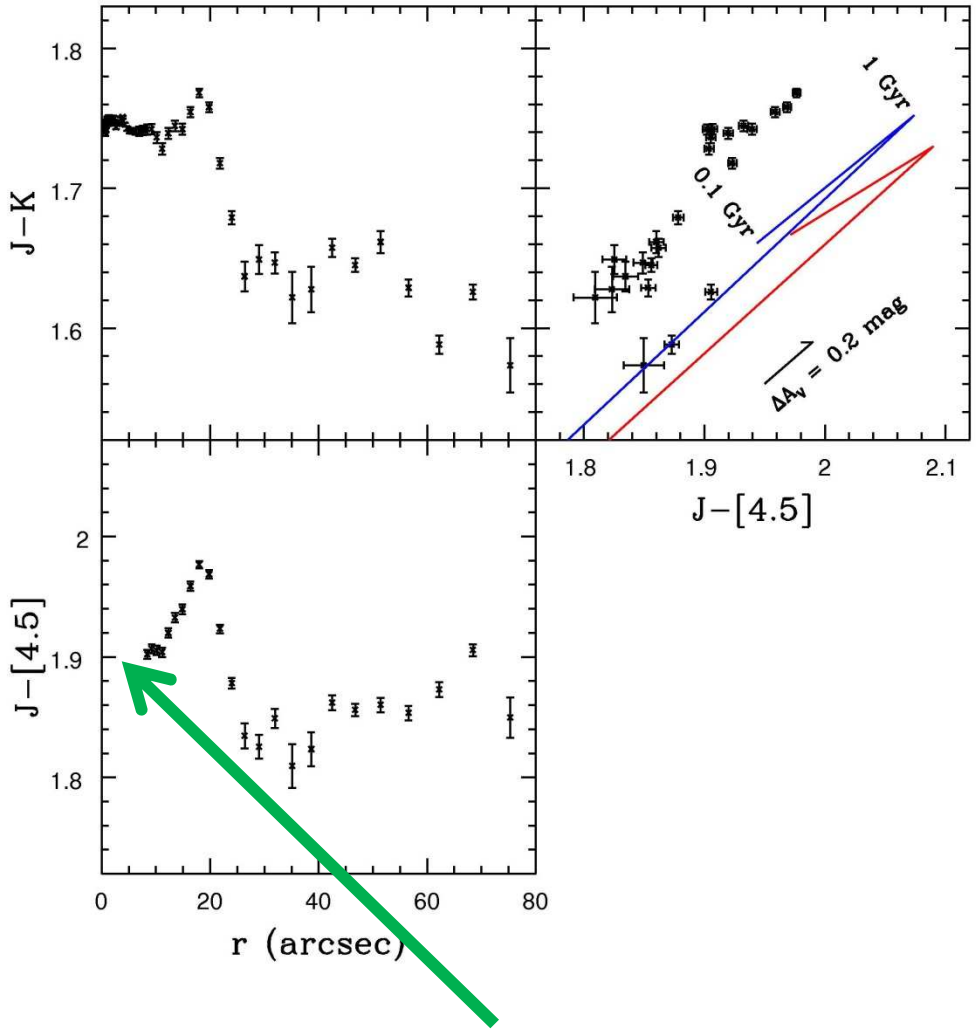
In the MIR have the potential to place constraints on star-forming activity during early epochs.

Take away points:

- Variability is an essential consideration for SFH models.
- NIR and MIR datasets can be used to probe the SFH of nearby galaxies.


The End
A WARNER BROS.
FIRST NATIONAL PICTURE

# Consistency Check: The Combined Near and Mid-IR Photometric Properties of Maffei 1




Spitzer data are saturated near the galaxy center

- J and K data are from the 2MASS Large Galaxy Atlas.
- [4.5] data from Spitzer science archive, smoothed to match the resolution of the 2MASS images
- Note flat J-K profile at radii < 10 arcsec, indicating that the red stellar content near the center is well-mixed.
- There is a ring of very red stars at r ~ 20 arcsec.
- Solar and super-solar metallicity models from the Padova isochrones that include TP-AGB evolution indicate that the J-K colors are consistent with an intermediate age population.
  - Recall strong central Hβ index