

# NEAR-INFRARED INTEGRATED-LIGHT PHOTOMETRY OF MAGELLANIC CLOUDS CLUSTERS



P. PESSEV<sup>(1)</sup>, S. MEYER<sup>(2)</sup>, P. GOUDFROOIJ<sup>(3)</sup>, T. PUZIA<sup>(4)</sup> AND R. CHANDAR<sup>(5)</sup>

(1) GEMINI OBSERVATORY, (2) HARVARD UNIVERSITY, (3) STSCI, (4) PUC, (5) UNIVERSITY OF TOLEDO



**ABSTRACT:** WE PRESENT RESULTS OF SEVERAL CONSECUTIVE STUDIES OF THE NEAR-INFRARED INTEGRATED-LIGHT PROPERTIES OF STAR CLUSTERS IN THE LARGE AND SMALL MAGELLANIC CLOUDS BASED ON 2MASS ARCHIVAL IMAGING. THE SAMPLE IS COVERING A WIDE RANGE IN THE AGE/METALLICITY PARAMETER SPACE AND THE AGES AND METALLICITIES FOR THE MAJORITY OF THE CLUSTERS ARE DERIVED BASED ON DEEP CMDs AND SPECTROSCOPY OF INDIVIDUAL CLUSTER MEMBERS. IT IS A VALUABLE NEW RESOURCE TO STUDY THE EVOLUTION OF THE NEAR-INFRARED INTEGRATED-LIGHT PROPERTIES AS A FUNCTION OF THE PROPERTIES OF THE UNDERLYING STELLAR POPULATIONS. SOME FUTURE PROJECTS ARE BRIEFLY OUTLINED IN TERMS OF FURTHER DEVELOPMENT OF THE INTEGRATED-LIGHT DATABASE AND ITS APPLICATIONS.

## INTRODUCTION

### ★ AT THE VERY BEGINNING

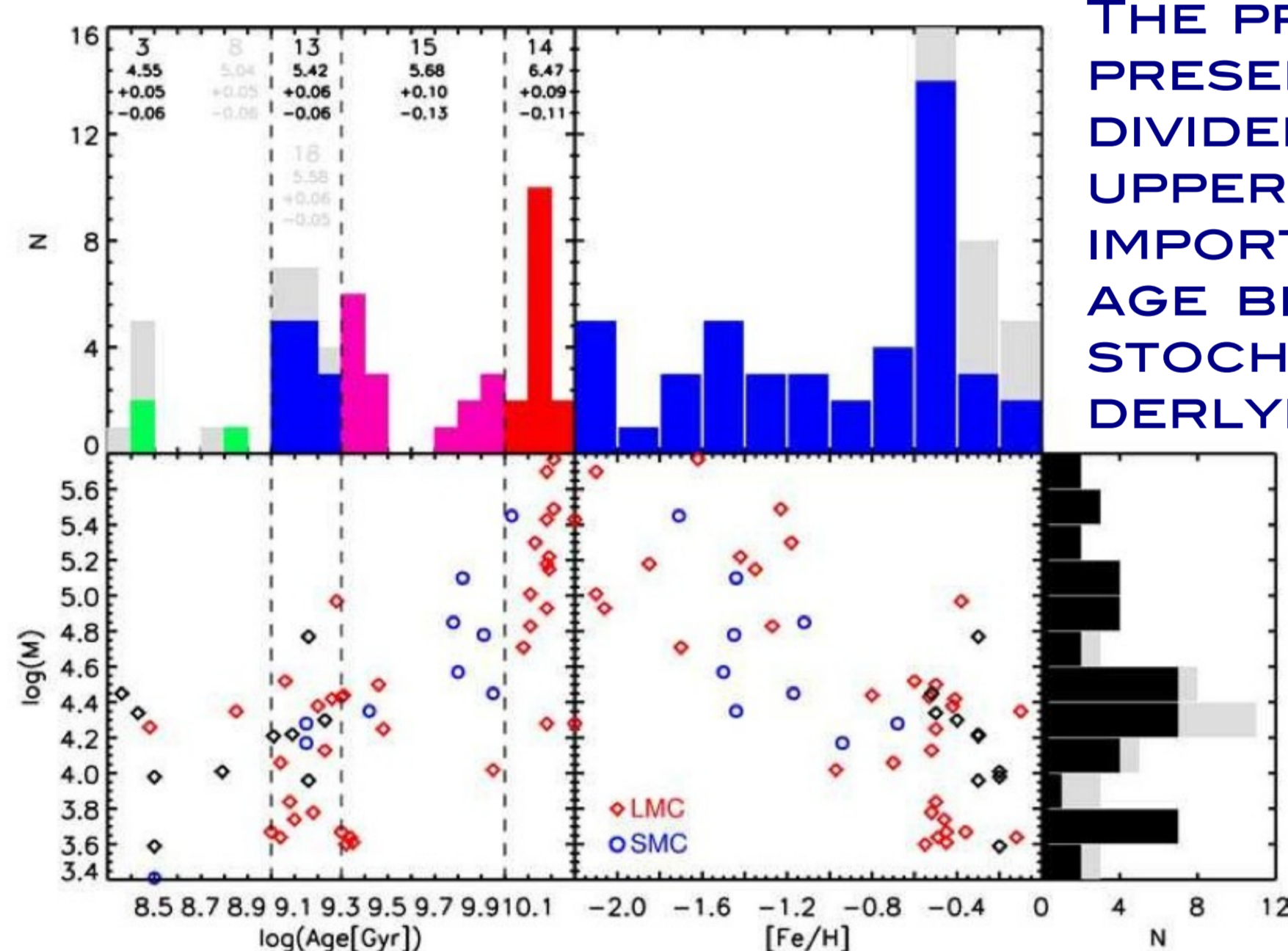
PERSSON ET AL. 1983 PUBLISHED THE FIRST INTEGRATED-LIGHT NEAR-INFRARED PHOTOMETRY DATABASE CONSISTING OF 84 LMC AND SMC STAR CLUSTERS. THEY WERE USING A SINGLE-CHANNEL DETECTOR AND PERFORMED THE PHOTOMETRY WITH A SET OF FIXED APERTURES. THIS WORK REMAINED THE "GOLDEN STANDARD" IN THE FIELD FOR MORE THAN 25 YEARS.

### ★ BRINGING THE FIELD UP TO SPEED

BY THE BEGINNING OF THE NEW CENTURY THE INTEGRATED-LIGHT NEAR-INFRARED DATA OF MAGELLANIC CLOUDS CLUSTERS WAS SIGNIFICANTLY LAGGING BEHIND COMPARED TO OTHER FIELDS OF THE NIR ASTRONOMY. IN PESSEV ET AL. 2006 A NEW DATA SET BASED ON 2MASS ATLAS IMAGES WAS PUBLISHED. WE PRESENTED CURVE OF GROWTH PHOTOMETRY FOR 75 CLUSTERS, COVERING A WIDE RANGE OF AGES AND METALLICITIES. THE CURVES OF GROWTH ALLOW AN EASY COMBINATION WITH PRE-EXISTING OPTICAL INTEGRATED-LIGHT PHOTOMETRY (USUALLY PERFORMED WITH A SET OF FIXED APERTURES).

### ★ UTILIZING THE NEW DATABASE

THE PHOTOMETRY FROM PESSEV ET AL. 2006 WAS COMBINED WITH OPTICAL INTEGRATED-LIGHT DATA AND A TEST SAMPLE WAS DEFINED UTILIZING ONLY THE CLUSTERS WITH THE BEST AGE AND METALLICITY DATA AVAILABLE. THE PERFORMANCE OF THE MOST WIDELY USED SETS OF SIMPLE STELLAR POPULATIONS (SSP) MODELS WAS TESTED (SEE PESSEV ET AL. 2008). SEE THE FIGURE BELOW FOR MORE INFORMATION ABOUT THE TEST SAMPLE. WE ALSO ADDED 9 MORE CLUSTERS TO OUR PHOTOMETRY DATABASE.



THE PROPERTIES OF THE TEST SAMPLE ARE PRESENTED ON THIS ILLUSTRATION. IT WAS DIVIDED INTO FOUR AGE BINS (SEE THE UPPER LEFT PANEL). IT WAS EXTREMELY IMPORTANT TO ADD ENOUGH MASS IN EACH AGE BIN TO MINIMIZE THE EFFECTS OF THE STOCHASTIC FLUCTUATIONS IN THE UNDERLYING STELLAR POPULATIONS. (SEE THE PAPER FOR MORE DETAILS.) THIS FORCED US TO ADD A FEW CLUSTERS WITH STELLAR POPULATION PROPERTIES NOT KNOWN IN SUCH EXQUISITE DETAIL. IT IS EASY TO SEE THAT THESE ARE MOSTLY IN THE YOUNGEST AGE BINS. AND THIS NATURALLY LED TO THE NEXT PROJECT.

## EXPANDING THE SAMPLE TO YOUNGER AGES

### ★ RATIONALE

CURRENTLY OBSERVATIONAL ASTRONOMY IS ACQUIRING NEW TOOLS TO PROBE THE UNIVERSE AT HIGHER AND HIGHER REDSHIFT. MEANWHILE THE AVAILABLE WAVELENGTH PARAMETER SPACE IS GETTING BROADER AS WELL. FOR EXAMPLE WITH ALMA WE'LL BE ABLE TO OBSERVE REST-FRAME NEAR-IR OF YOUNG STELLAR POPULATIONS. HENCE WE NEED TO TEST THE PERFORMANCE OF THE SSP MODELS FOR THESE AGES OF THE UNDERLYING STELLAR COMPONENT. ONCE AGAIN THE MAGELLANIC CLOUDS ARE THE PERFECT LABORATORIES TO COMPLETE THIS TEST. RECENTLY GLATT ET AL. 2010 PUBLISHED A NEW EXTENSIVE DATABASE OF AGES OF LMC AND SMC CLUSTERS. ALTHOUGH BASED ON GROUND-BASED DATA (MAGELLANIC CLOUD PHOTOMETRIC SURVEY /MCPS/ BY ZARITSKY ET AL. 1997) THE LARGE NUMBER OF POTENTIAL TARGETS IS GOING TO COMPENSATE FOR THE UNCERTAINTY OF THE AGES. ALSO THE MCPS DATA IS EXTREMELY SUITABLE TO WORK WITH RELATIVELY YOUNG STELLAR POPULATIONS AND TO DERIVE THE AGES OF THE CLUSTERS.

### ★ DATA REDUCTION AND ANALYSIS

FOR THE **SAMPLE SELECTION** WE FOCUSED ON THE MOST UNDER-REPRESENTED AGE BIN OF THE TEST SAMPLE AVAILABLE SO FAR (AGES BETWEEN  $10^{8.5}$  AND  $10^{8.9}$  YEARS). ALL CLUSTERS FROM GLATT ET AL. IN THE AGE INTERVAL WERE CHECKED ON THE 2MASS (SKRUTSKIE ET AL. 2006) ATLAS IMAGES. OUR MAIN SELECTION CRITERION WAS THAT A GIVEN OBJECT IS DETECTED IN ALL THREE BANDS OF THE SURVEY. OVERALL 22 CLUSTERS WERE RELIABLY DETECTED. A REPRESENTATIVE ILLUSTRATION OF THE CLUSTER SAMPLE IS PRESENTED.

FOR THE **ANALYSIS OF THE DATA** WE APPLIED THE METHODOLOGY INTRODUCED BY PESSEV ET AL. 2006 TO PERFORM THE PHOTOMETRY OF THE 22 CLUSTERS IN OUR SAMPLE. THE MAIN STEPS IN THE PROCESS ARE:

- 1) PERFORMING PSF PHOTOMETRY ON THE ATLAS IMAGES
- 2) DERIVING THE CLUSTER CENTERS
- 3) BACKGROUND/FOREGROUND CONTAMINATION SUBTRACTION USING THE LUMINOSITY FUNCTIONS OF THE CLUSTER AND BACKGROUND REGIONS ON THE IMAGES
- 4) APERTURE PHOTOMETRY CURVES OF GROWTH OF THE CLUSTERS

A PROBABILISTIC METHOD WAS USED FOR THE BACKGROUND/FOREGROUND CONTAMINATION SUBTRACTION AND 100 REALIZATION OF THE LAST TWO STEPS WERE PERFORMED TO PROVIDE A RELIABLE STATISTICAL ESTIMATE OF THE UNCERTAINTIES OF THE ENTIRE PROCESS. TO MINIMIZE THE EFFECT OF THE STOCHASTIC FLUCTUATIONS WE DEFINED AN "OPTIMAL APERTURE".

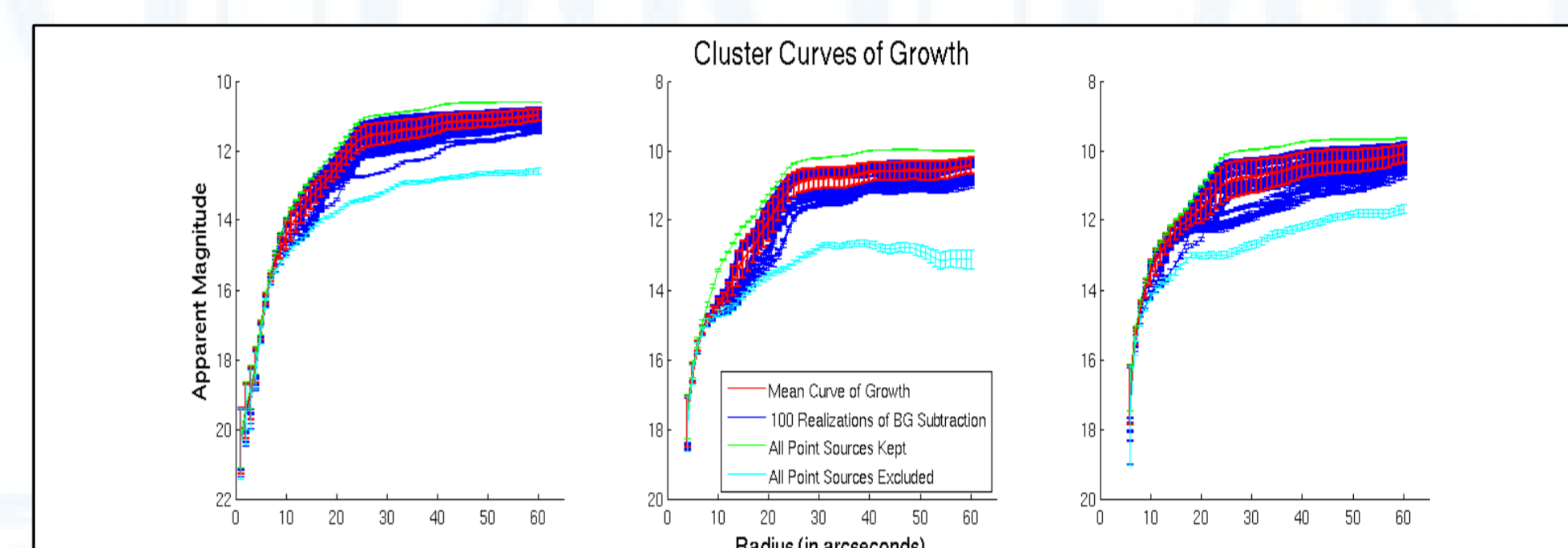
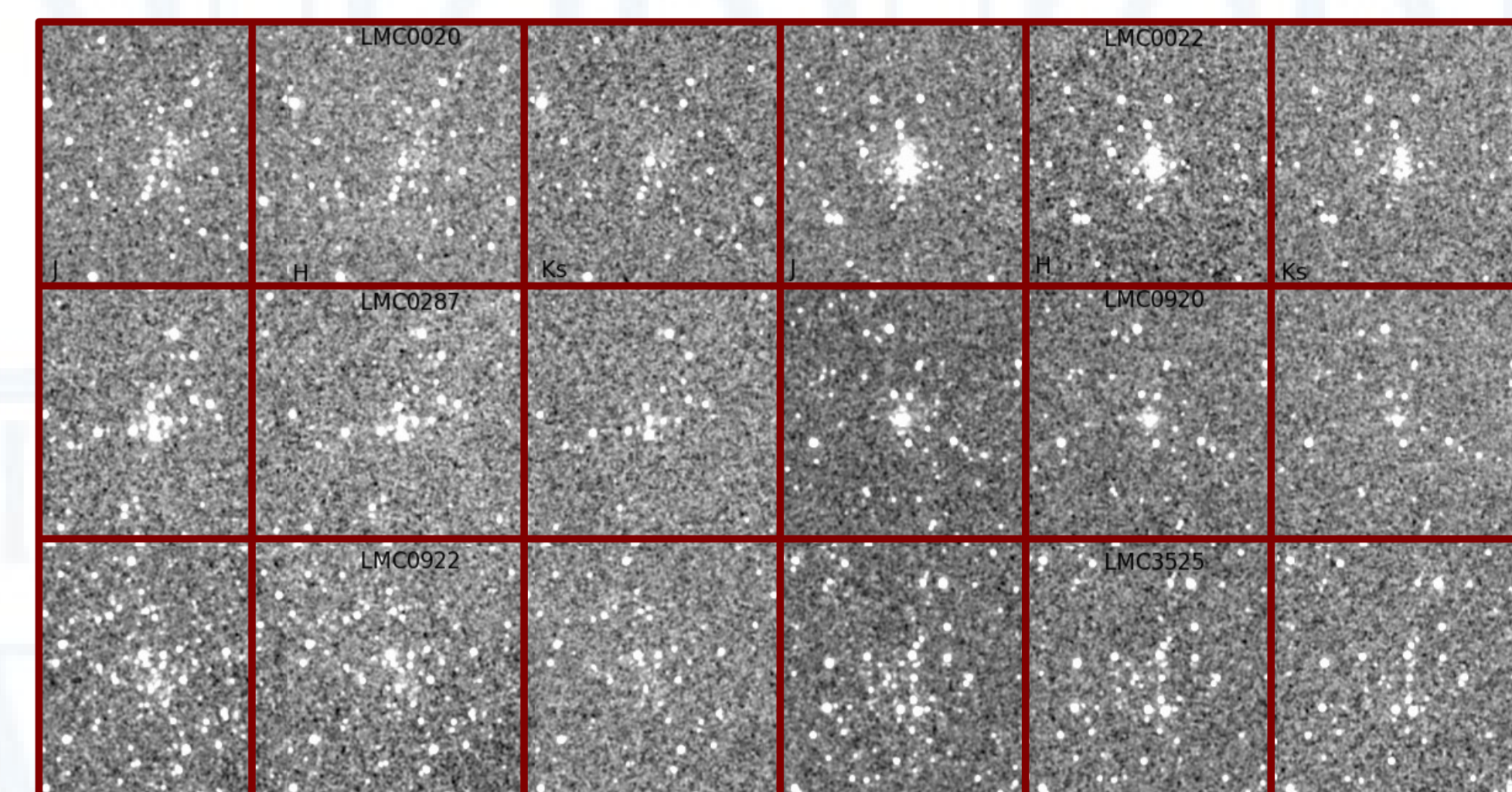
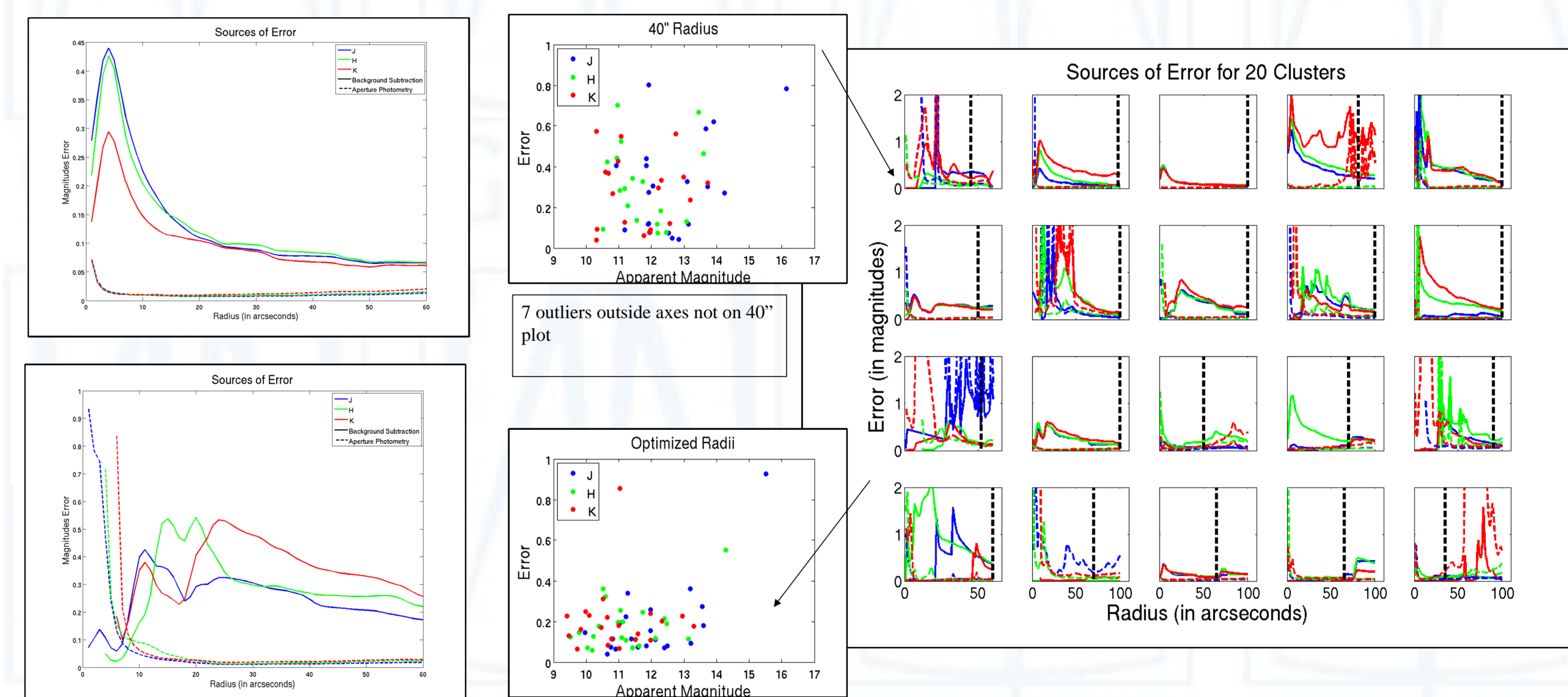


ILLUSTRATION OF THE CURVES OF GROWTH TECHNIQUE. J, H AND Ks DATA IS PRESENTED FROM LEFT TO RIGHT. THE STATISTICAL EVALUATION OF THE ERRORS DUE TO THE BACKGROUND SUBTRACTION IS PARTICULARLY IMPORTANT IN THE CASE OF THESE RELATIVELY FAINT CLUSTERS. WE PERFORMED A TEST THAT SHOWED THAT THE BRIGHTER CLUSTERS FROM THE PREVIOUSLY PUBLISHED DATA SETS WERE NOT AFFECTED BY SUCH EFFECTS.



THE "OPTIMAL APERTURE" METHOD IS PRESENTED ABOVE. ON THE LEFT SIDE – ERROR PLOTS AS A FUNCTION OF THE RADII FOR TWO CLUSTERS. ON THE TOP – "NORMALLY BEHAVING" ERROR PLOT OF A RELATIVELY BRIGHT CLUSTER. ON THE BOTTOM – AN EXAMPLE OF A FAINT OBJECT. THE ERROR PLOTS AS FUNCTION OF RADIUS ARE PRESENTED FOR 20 OBJECTS ON THE RIGHT. OPTIMAL APERTURES ASSURING THE LOWEST UNCERTAINTIES OF THE PHOTOMETRY ARE ALSO MARKED. NOTE THE IMPROVEMENT OF THE ERRORS FOR THE FINAL PHOTOMETRY.

### ★ RESULTS

WE PRESENT NEW APERTURE PHOTOMETRY DATABASE FOR A SAMPLE OF 22 YOUNG LMC CLUSTERS. WITH THE PRE-EXISTING DATA THE NUMBER OF MAGELLANIC CLOUDS OBJECTS WITH INTEGRATED-LIGHT NEAR-INFRARED PHOTOMETRY AVAILABLE INCREASES TO 106 OBJECTS. A NEW APPROACH FOR "OPTIMAL APERTURE" PHOTOMETRY EXTRACTION WAS INTRODUCED. THIS APPROACH HAS A GREAT POTENTIAL WHEN WORKING WITH THE FAINT CLUSTER POPULATION IN A GIVEN DATA SET. AN ANALYSIS WAS PERFORMED THAT THE CURRENT DATA SET EFFECTIVELY PUSHES THE LIMITS OF THE 2MASS 6X LMC ATLAS DATA. FUTURE WORKS WILL PROBABLY UTILIZE DATA FROM NEWER AND DEEPER SURVEYS.

STAY TUNED FOR FUTURE RESULTS FROM THIS AND RELATED PROJECTS!

PART OF THIS PROJECT WAS CONDUCTED IN THE FRAMEWORK OF THE CTIO REU PROGRAM, WHICH IS SUPPORTED BY THE NATIONAL SCIENCE FOUNDATION UNDER GRANT AST-1062976.

THIS PUBLICATION MAKES USE OF DATA PRODUCTS FROM THE TWO MICRON ALL SKY SURVEY, WHICH IS A JOINT PROJECT OF THE UNIVERSITY OF MASSACHUSETTS AND THE INFRARED PROCESSING AND ANALYSIS CENTER/CALIFORNIA INSTITUTE OF TECHNOLOGY, FUNDED BY THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION AND THE NATIONAL SCIENCE FOUNDATION.