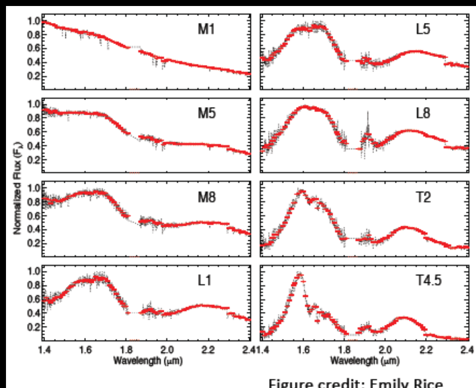
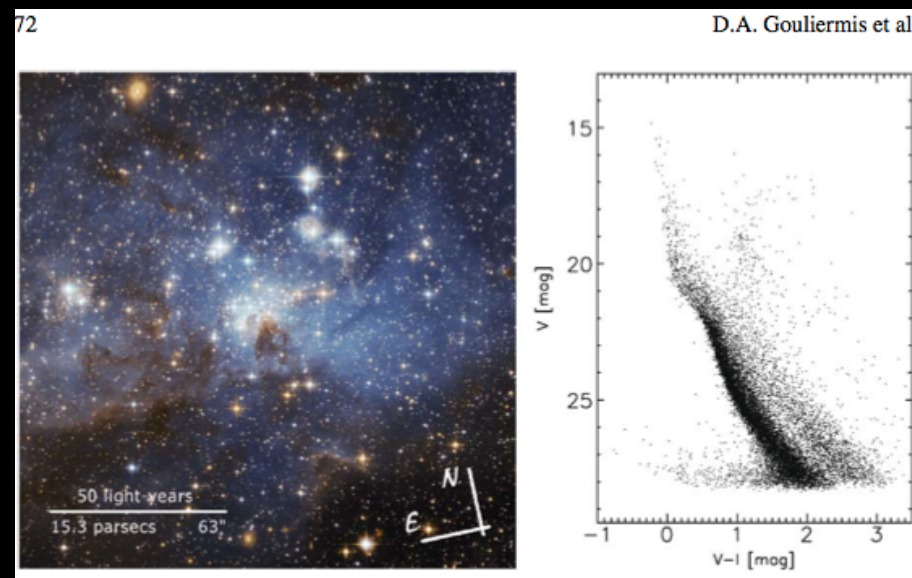
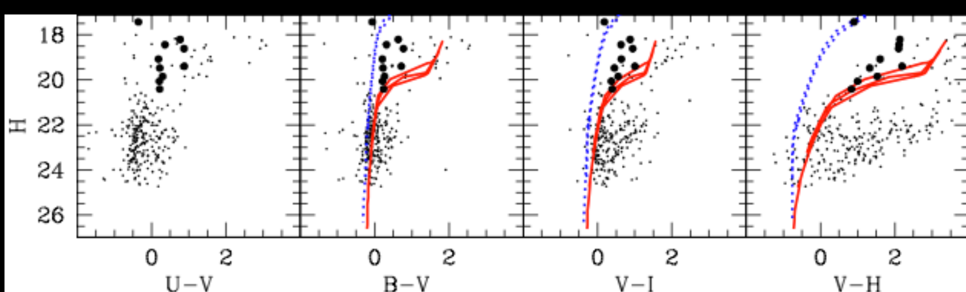
Not my assigned topic: Star Formation



Nearby regions: from Hillenbrand 1p WFIRST concept: spectroscopic ID of low-mass protsotars > low-mass IMF and brown dwarfs



Distant MW, Magellanic Clouds: solar-mass IMF in massive star-forming regions

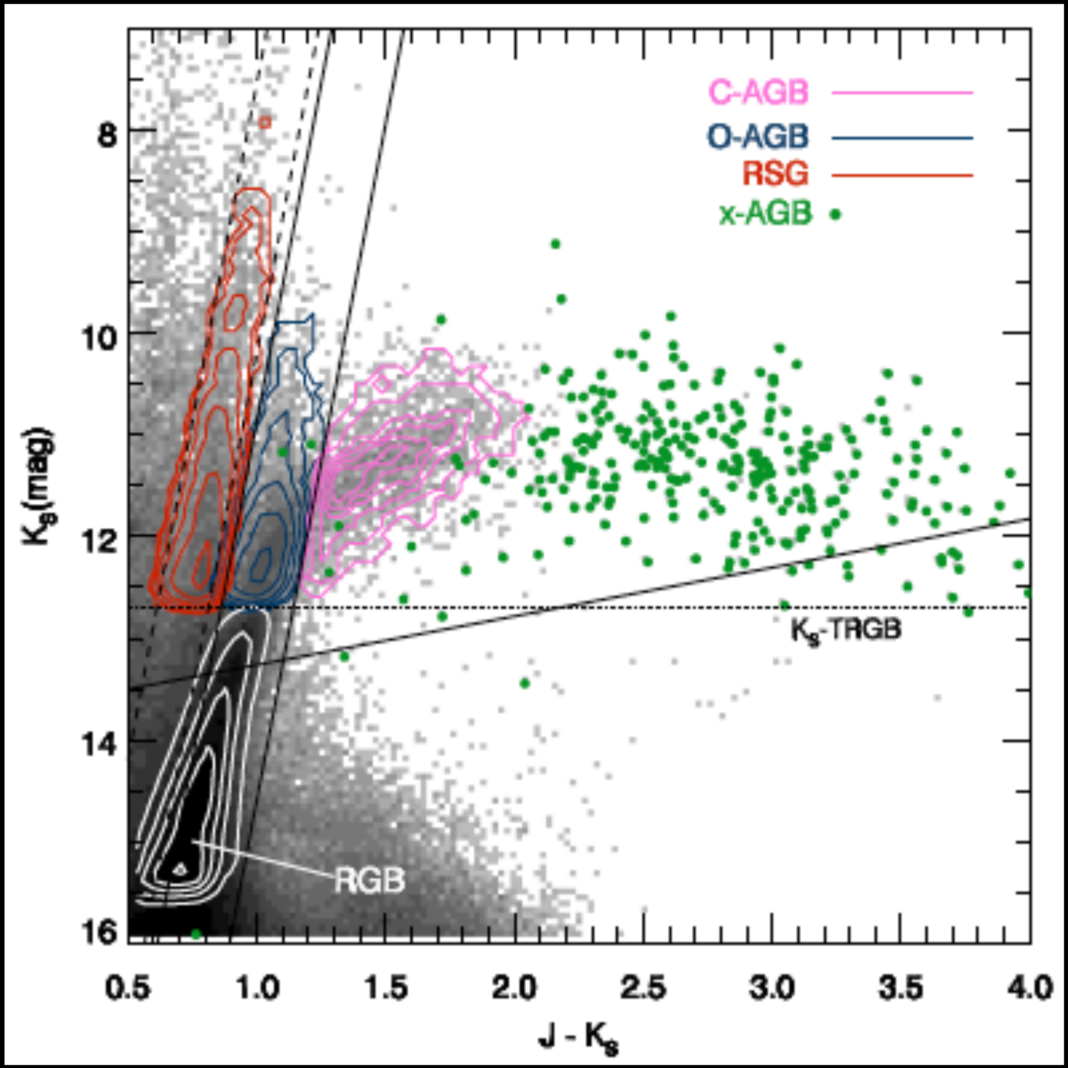


Super-star clusters in nearby galaxies – formation of globulars, IMF in extreme environments

Dust in galaxies, extinction, and you

- Dust is an important part of galaxy evolution
- The extinction curve is less well understood than you probably thought
- We can measure dust properties simultaneously with stellar populations and dust content
- WFIRST can help > Zasowski tomorrow

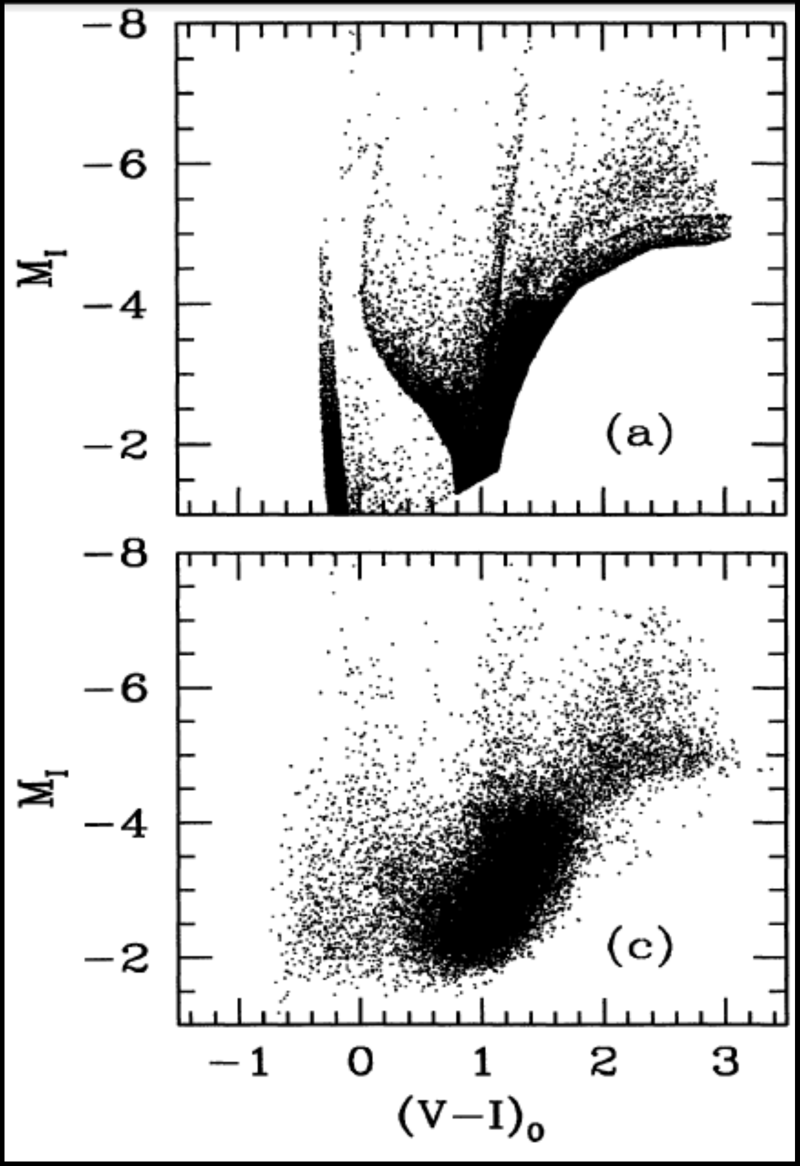
Dust matters: to stellar population studies



e.g. Boyer ++ 2011 SMC:

A few 0.1mag of color (e.g. uncertainty in the extinction curve) matters.

Dust matters: to stellar population studies



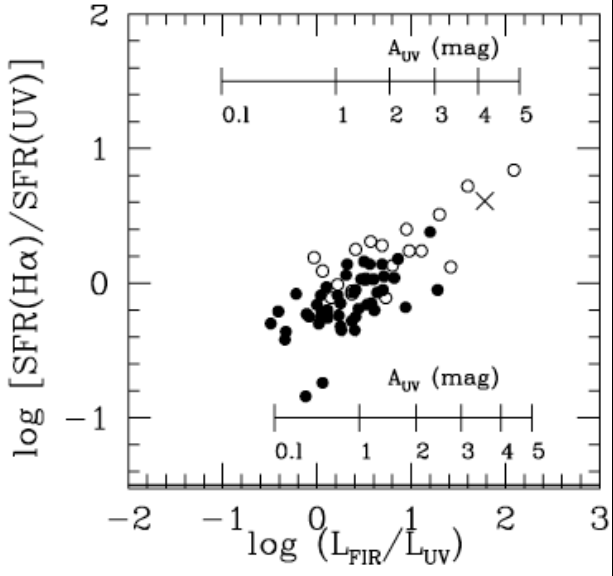
Synthetic CMD

Reddening and crowding

e.g. Gallart ++ 1996

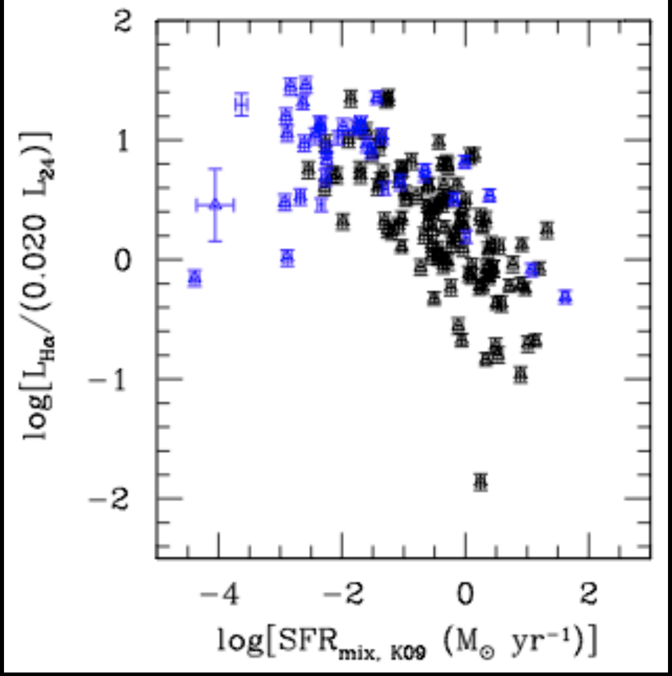
A few 0.1mag of color (e.g. uncertainty in the extinction curve) matters.

Dust matters: to SFRs



e.g. Buat++ 2002,
Calzetti++ 20**

UV, optical, IR SFR vary wildly, and any monchromatic indicator is subject to uncertainty factors of many if you don't know the extinction.



Dust matters: to Gas/Dust & X_{CO}

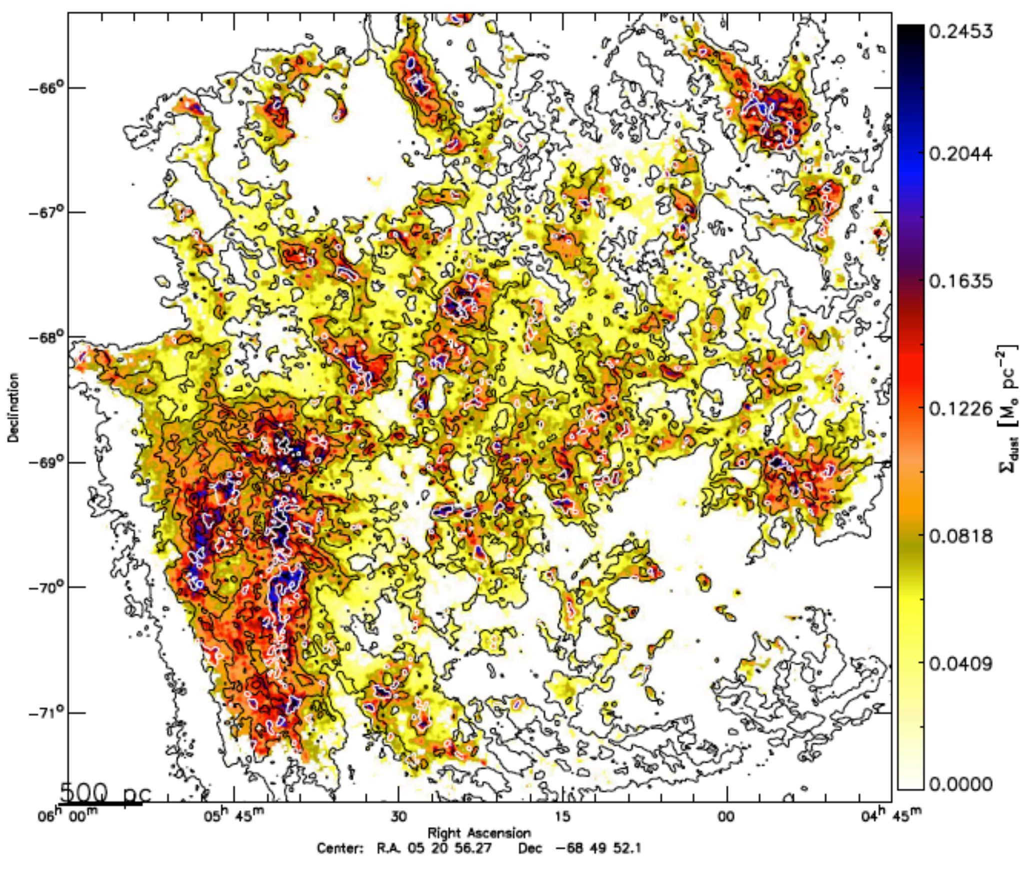
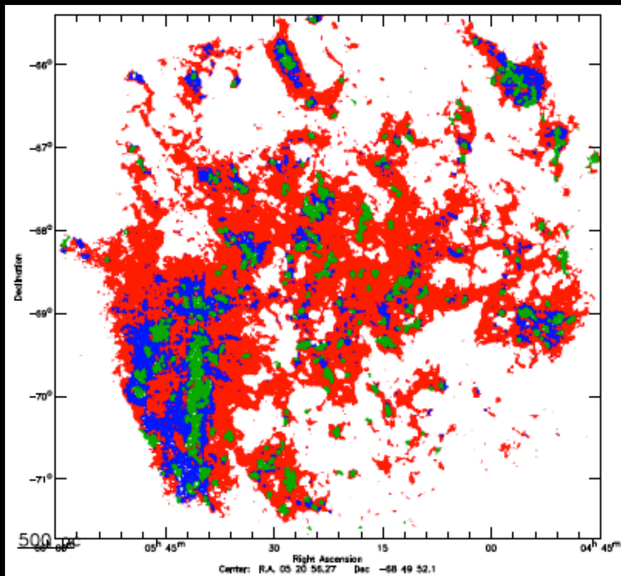


FIG. 1.— Map of the dust surface density in the LMC from Paper I at 1′ (15 pc)resolution. The black contours show the H I surface density, with levels 10-60 $M_{\odot}$ pc^{-2} in steps of 10 $M_{\odot}$ pc^{-2}. The white contours show the CO integrated intensity, with level 1.2 K km s^{-1}

Roman-Duval++ 2014
MegaSAGE LMC

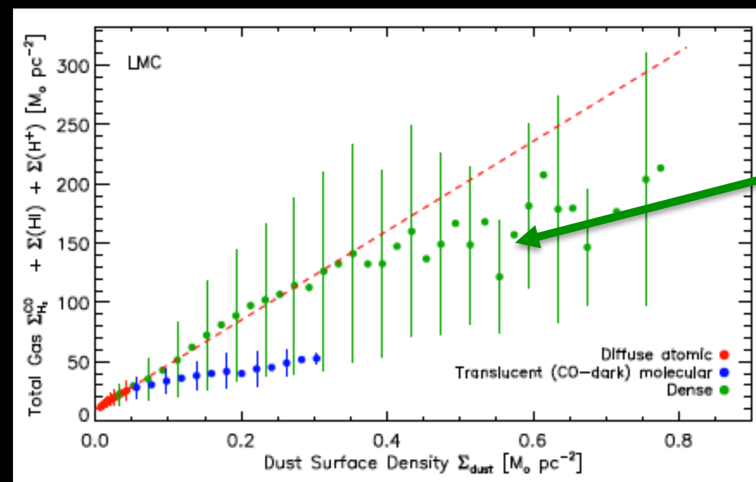
Dust surface density and HI contours

Dust matters: to Gas/Dust & X_{CO}

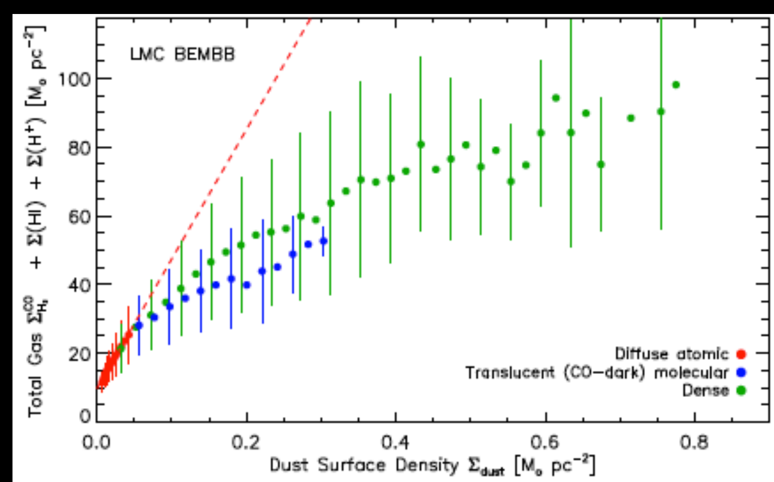


Diffuse atomic
Translucent molecular
Dense molecular

Roman-Duval++ 2014
MegaSAGE LMC



Gas/dust ratio (slope) decreases in the dense ISM

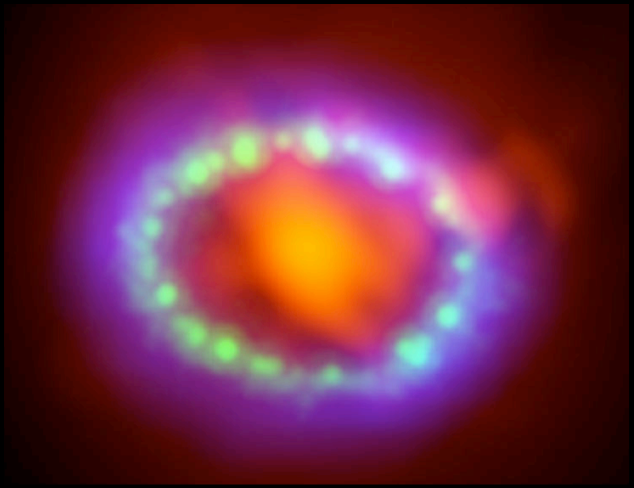


But a change in X_{CO} changes the calculated GDR

Dust: composition, size, and evolution

1) Silicate and carbonaceous grains form in evolved stars and SNe

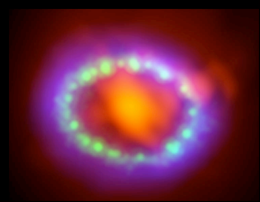
R Sculptoris
Maercker++ 2012 ALMA



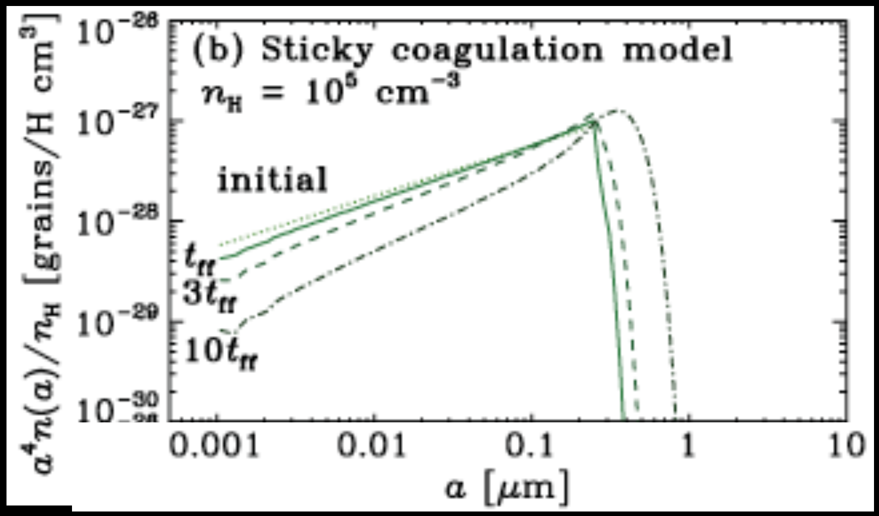
SN1987A
RI++ 2014 ALMA

Dust: composition, size, and evolution

1) Silicate and carbonaceous grains form in evolved stars and SNe

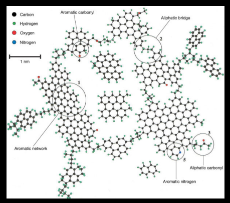


2a) shock shattering
coagulation, accretion, and ice mantle formation



Hirashita & Li 2013 (and many others)

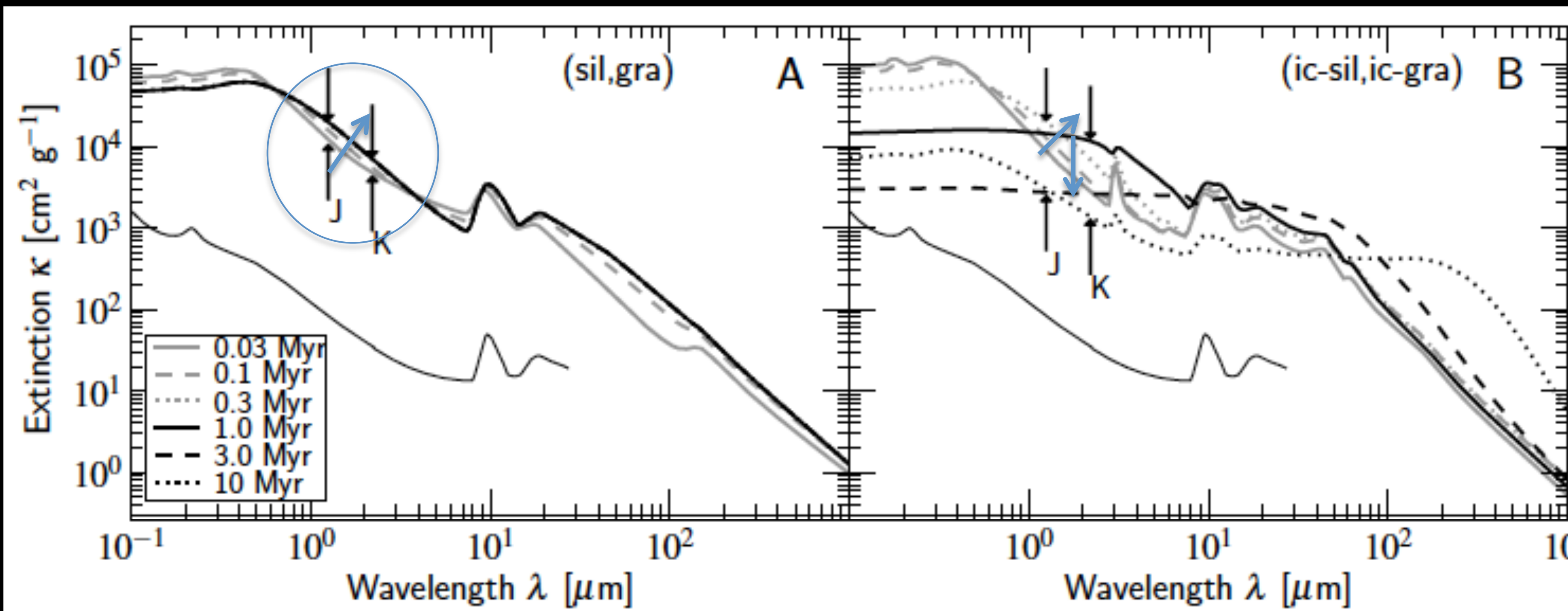
2a) UV: more aromatic
H: more aliphatic, hydrogenated



Models: Grain Growth

Ormel et al 2011

Growth without ices increases A_J/A_K



Growth with ices increases A_J/A_K but then it decreases again after ~1Myr (in a dense cloud)

Models: Grain Growth

Voshchinnikov++ 2006

Porosity – conglomerated grains – flattens the NIR extinction law

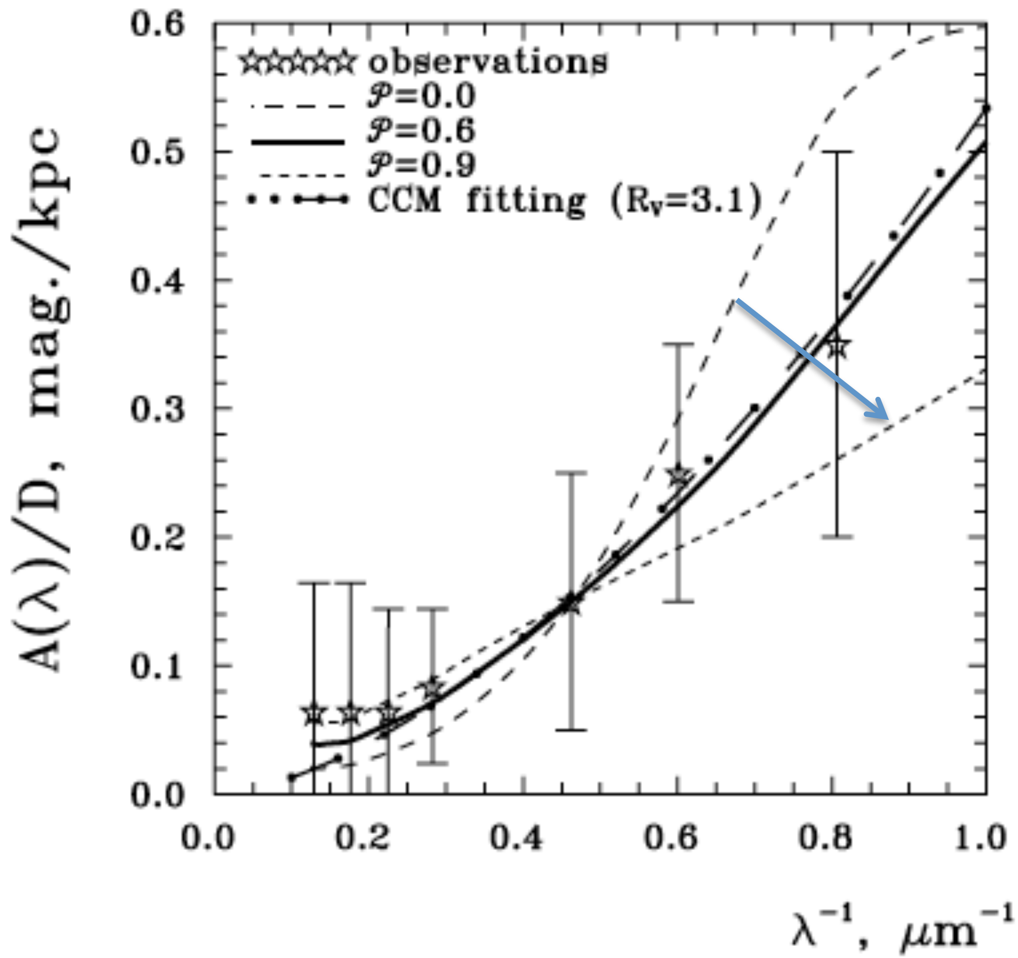


Fig. 6. Observed and calculated extinction in the near-IR part of spectrum. The observations correspond to the average extinction for two lines of sight along the Galactic plane (Indebetouw et al. 2005) transformed into magnitudes of extinction per kpc. The theoretical extinction was calculated for component (I) of the model used for ζ Oph

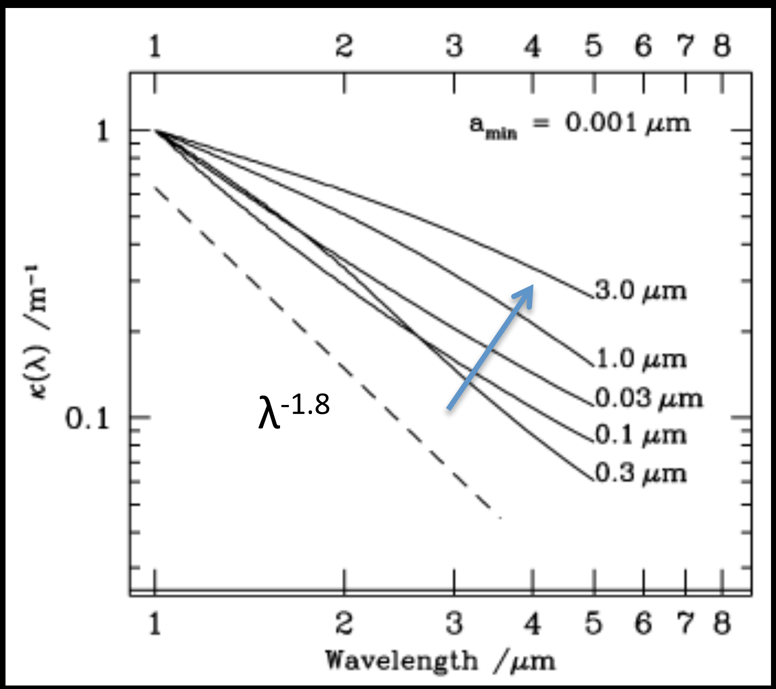
Dust: composition, size, and evolution

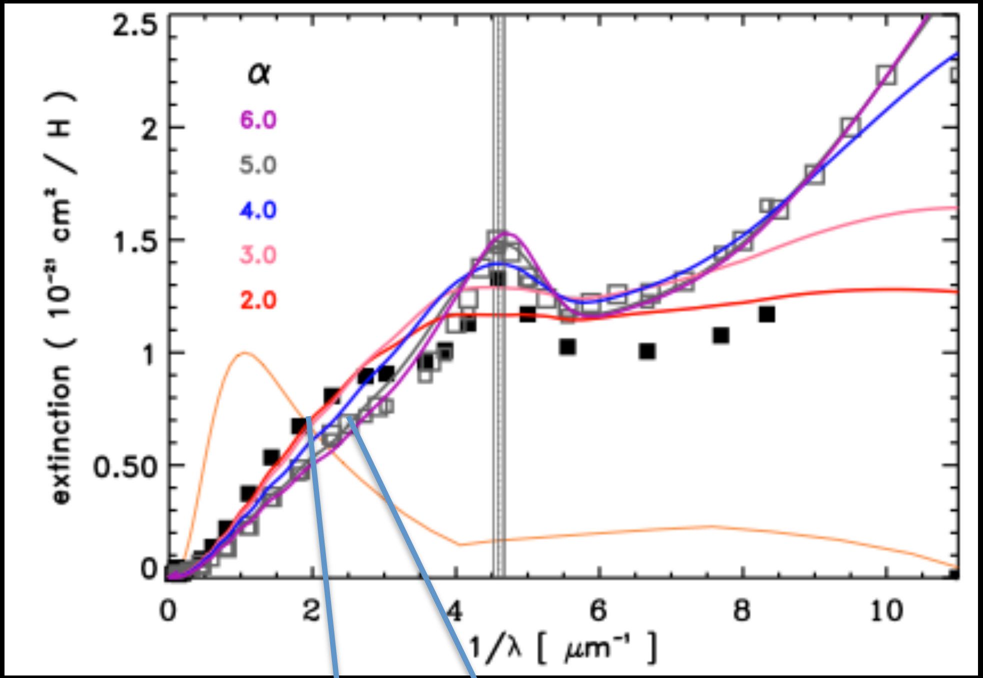
Coagulation (shattering)

- relatively more (fewer) larger grains
- shallower (steeper) extinction curve

Jones++ 2013:

Changing the power law of the distribution (smaller alpha = fewer small grains)





Moore++ 2005:

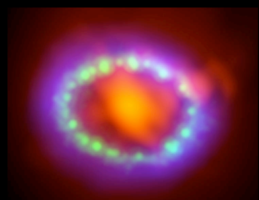
increasing the max grain size in the distribution

R_V=5.5 R_V=3.1

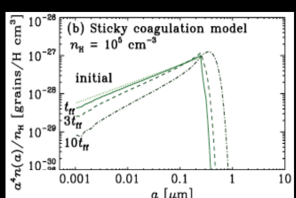
Usually, larger grains and flatter extinction overall means larger $R_V = A_V/(A_B-A_V)$

Dust: composition, size, and evolution

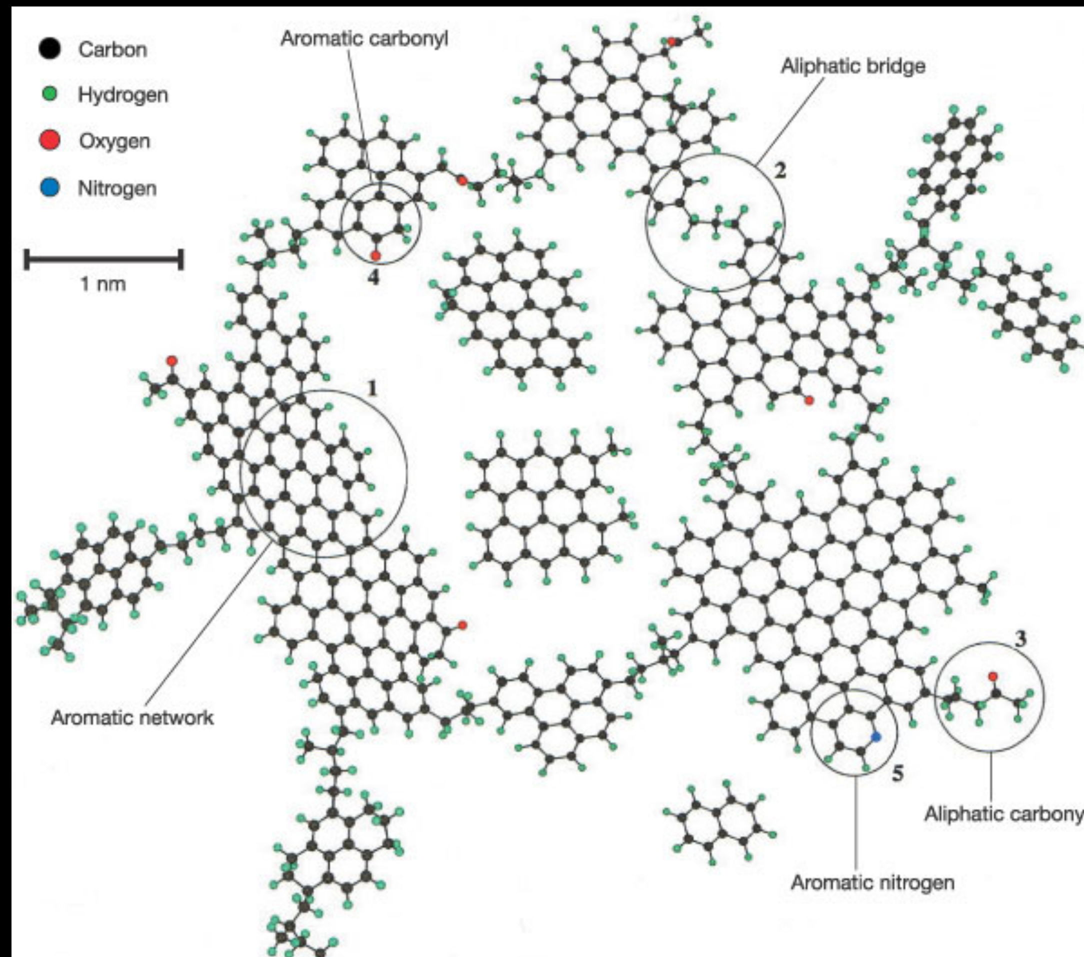
1) Silicate and carbonaceous grains form in evolved stars and SNe



2a) shattering, coagulation, accretion, and ice mantle formation



2b) UV: more aromatic
H: more aliphatic, hydrogenated



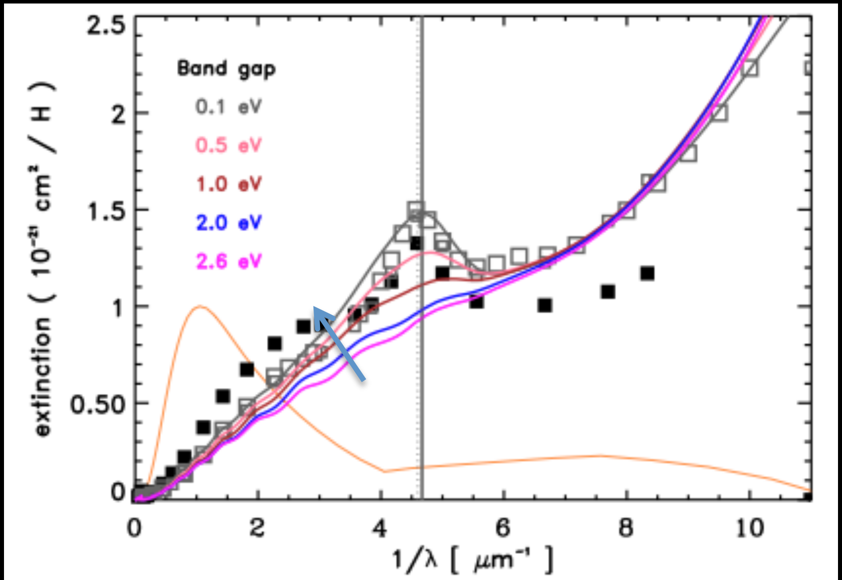
Kwok 2004

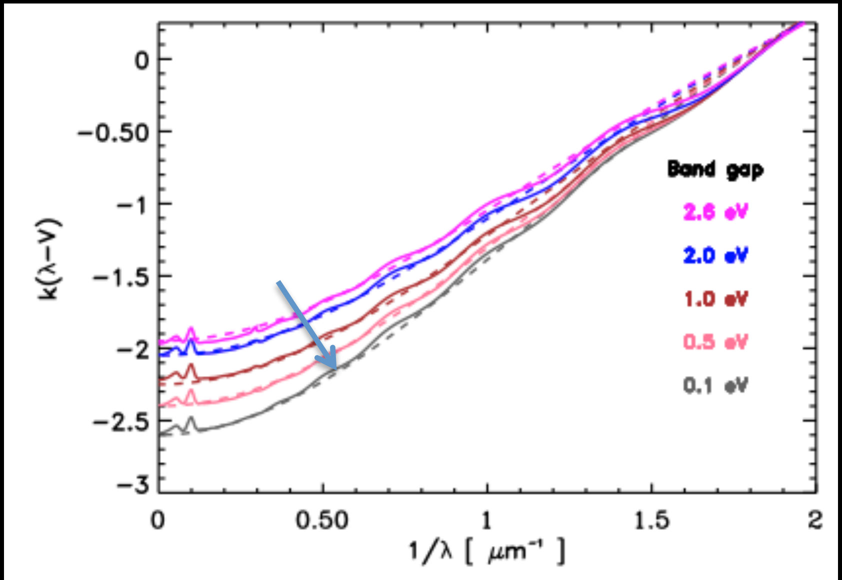
Dust: composition, size, and evolution

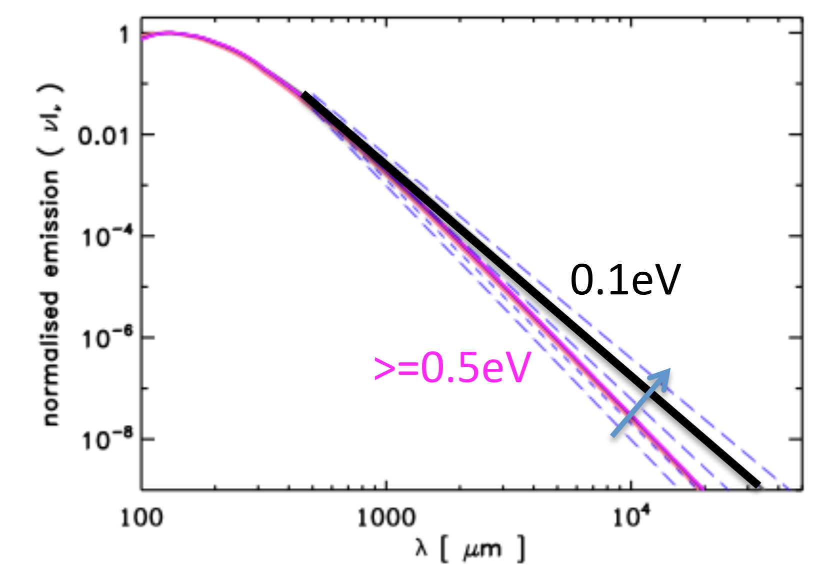
Photoprocessing

Jones++ 2013

- Smaller band gap
- Steeper UV,OIR extinction
- Shallower FIR opacity & emission



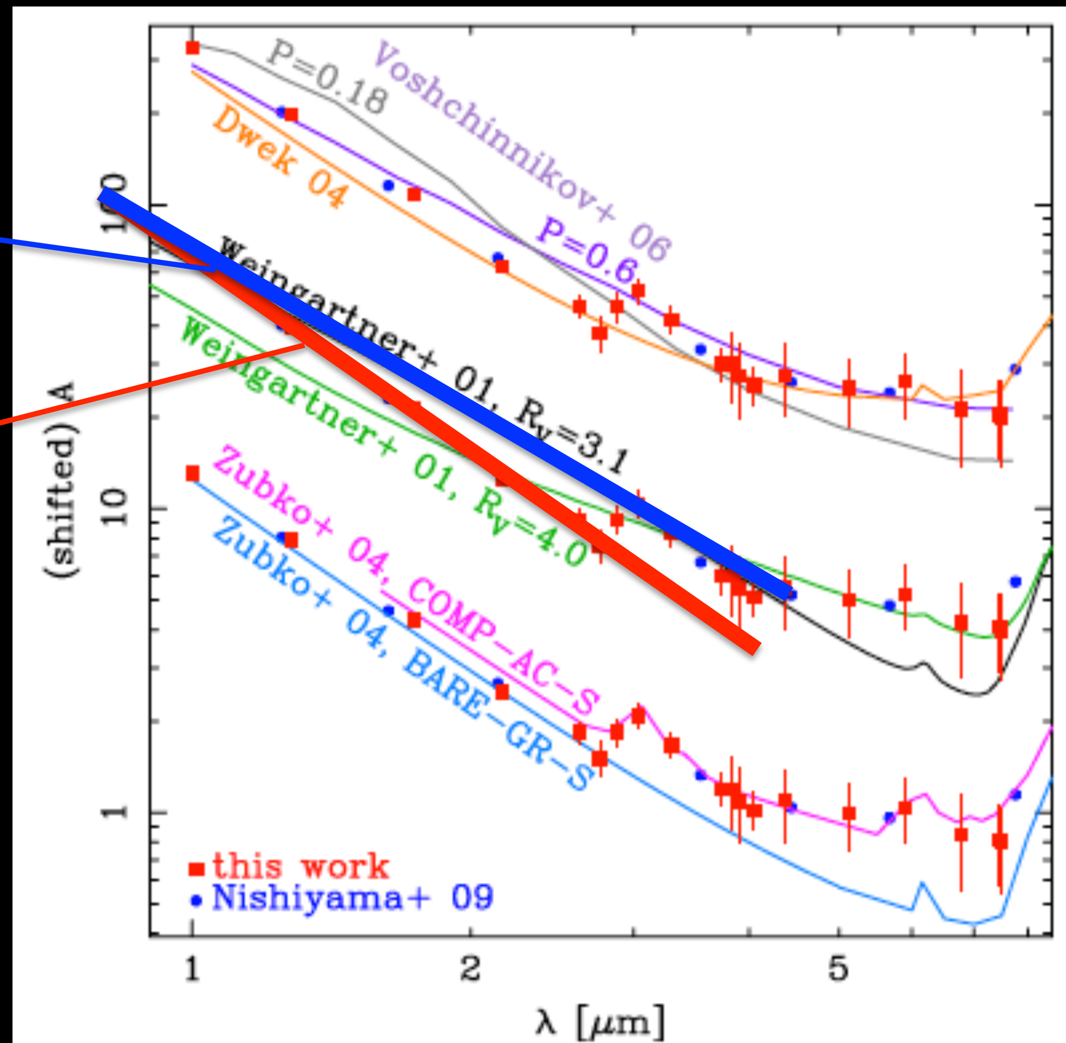




However, models are not very good in NIR

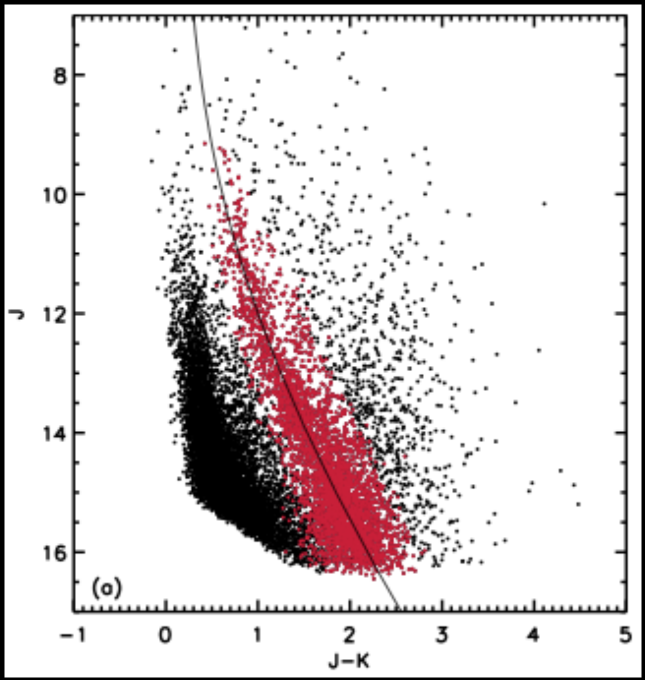
Models:
$A \propto \lambda^{-1.7}$

Most data:
$A \propto \lambda^{-2.1}$



Broad-band techniques: the red clump

RI++ 2005
RC selection



Nataf++ 2013: statistical separation of RC and RGB

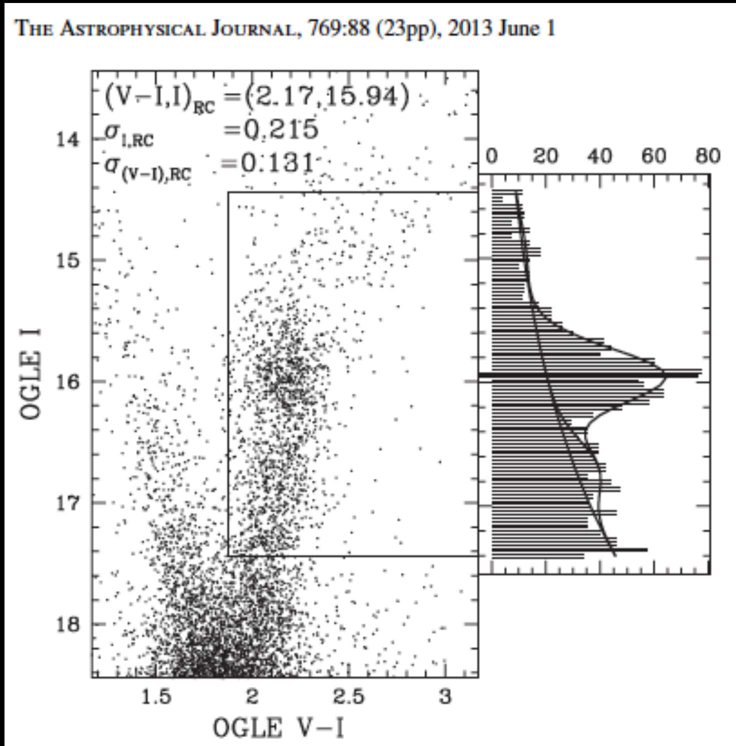
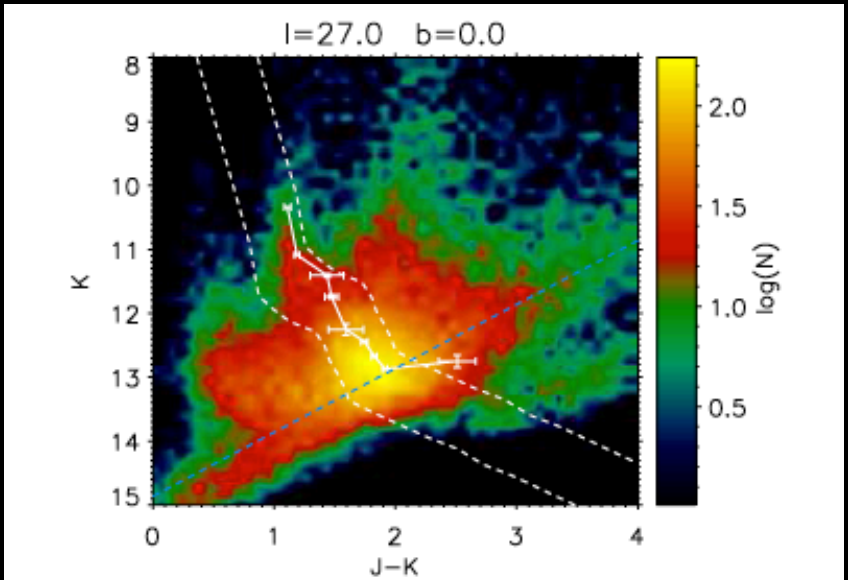


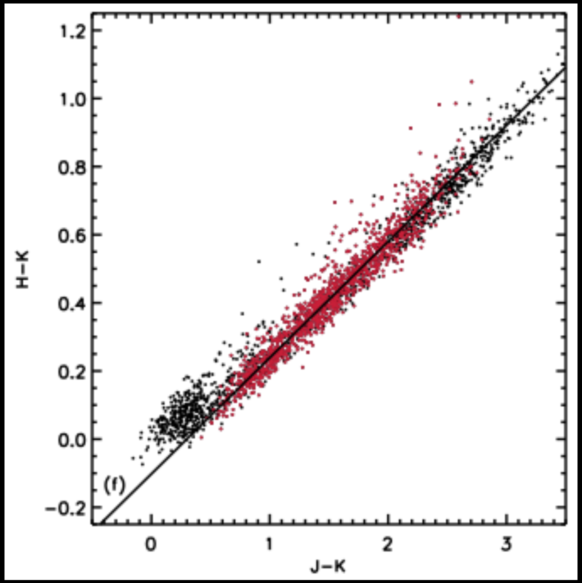
Figure 3. OGLE-III CMD toward $(l, b) = (-2.^{\circ}29, -3.^{\circ}12)$ shown in the left panel. The best-fit values of the color and magnitude of the RC, the magnitude dispersion, and the color dispersion are shown on the top left of the left panel. The color–magnitude selection is denoted by the thick black lines. The magnitude histogram of stars in the color–magnitude selection box is shown to the right of the CMD, on the same scale as the vertical axis, along with a model fit for the RG, RC+RG, and total RG+RGBB+RC+AGBB. The parameter values for the RGBB and AGBB is measured in Nataf et al. (2013).

Gonzalez ++ 2014: RC selection

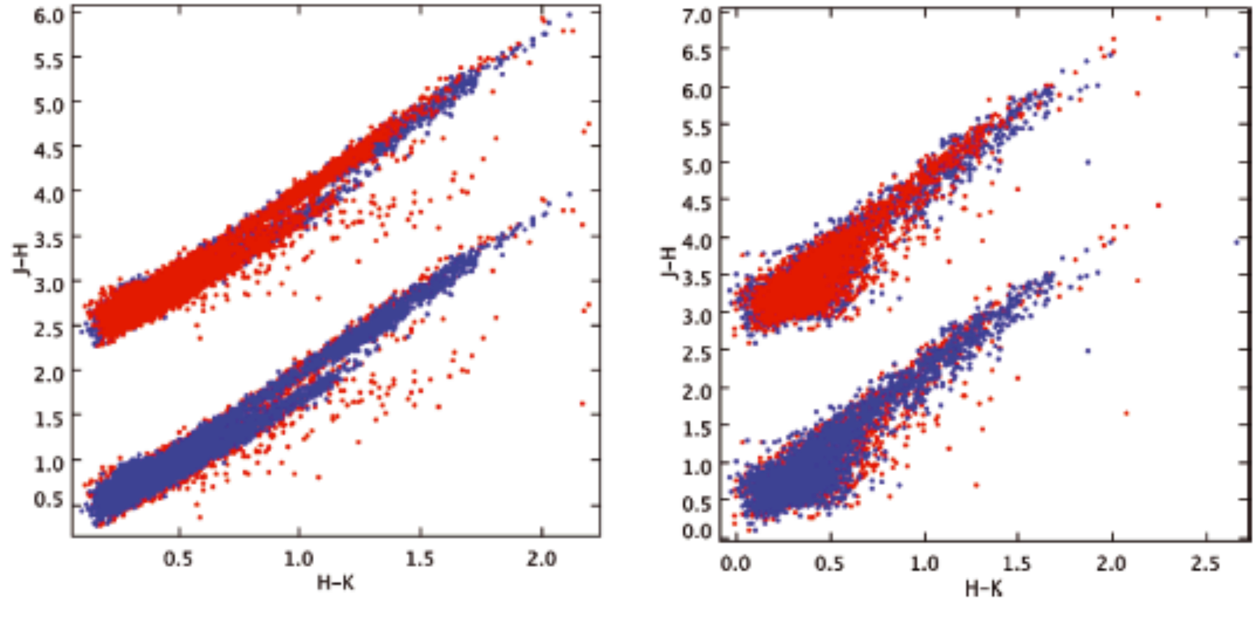


Broad-band techniques: fit the excesses – details matter

RI++ 2005:
Red are RC



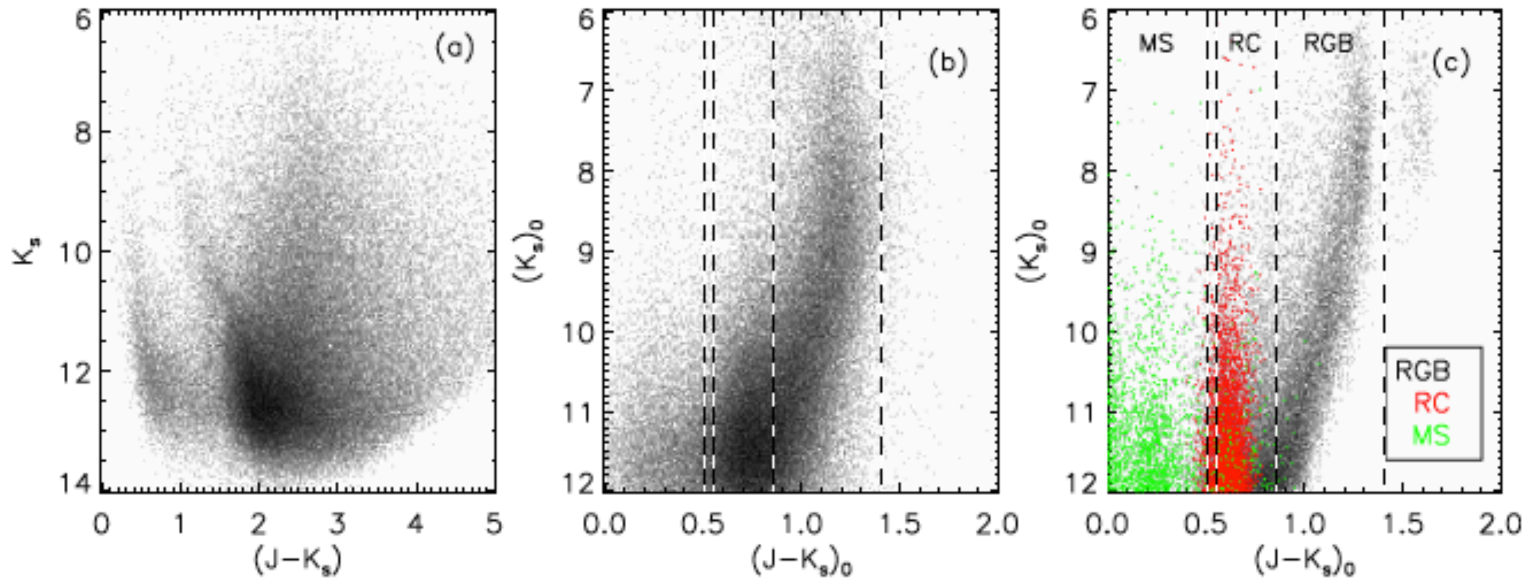
Stead & Hoare 2005:
(L) UKIDDS filters have curved tracks because of changing effective filter wavelength
(R) 2MASS isn't as pronounced



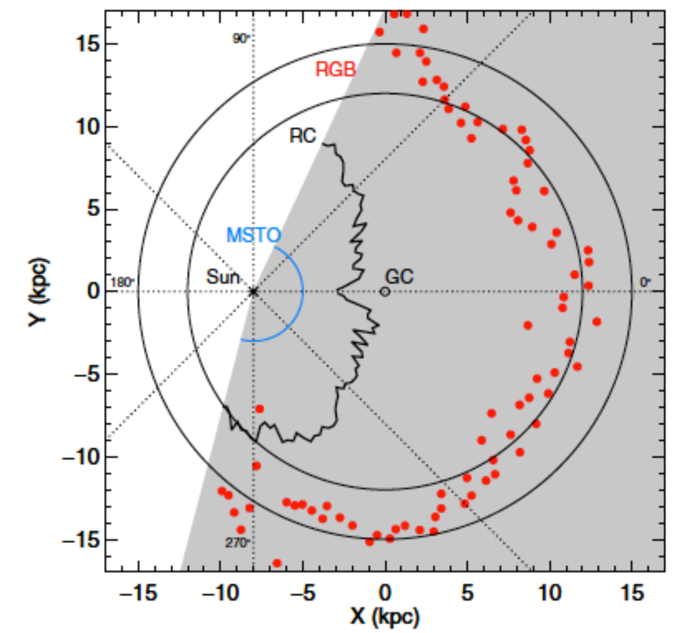
And many others including:
López-Corredoira++ 2002
Cabrera-Lavers++ 2005
Straižys++ 2009
Ascenso++ 2012
González-Fernández++ 2014
Maíz Appelániz ++ 2014

Broad-band techniques: MSTO, RC, RGB

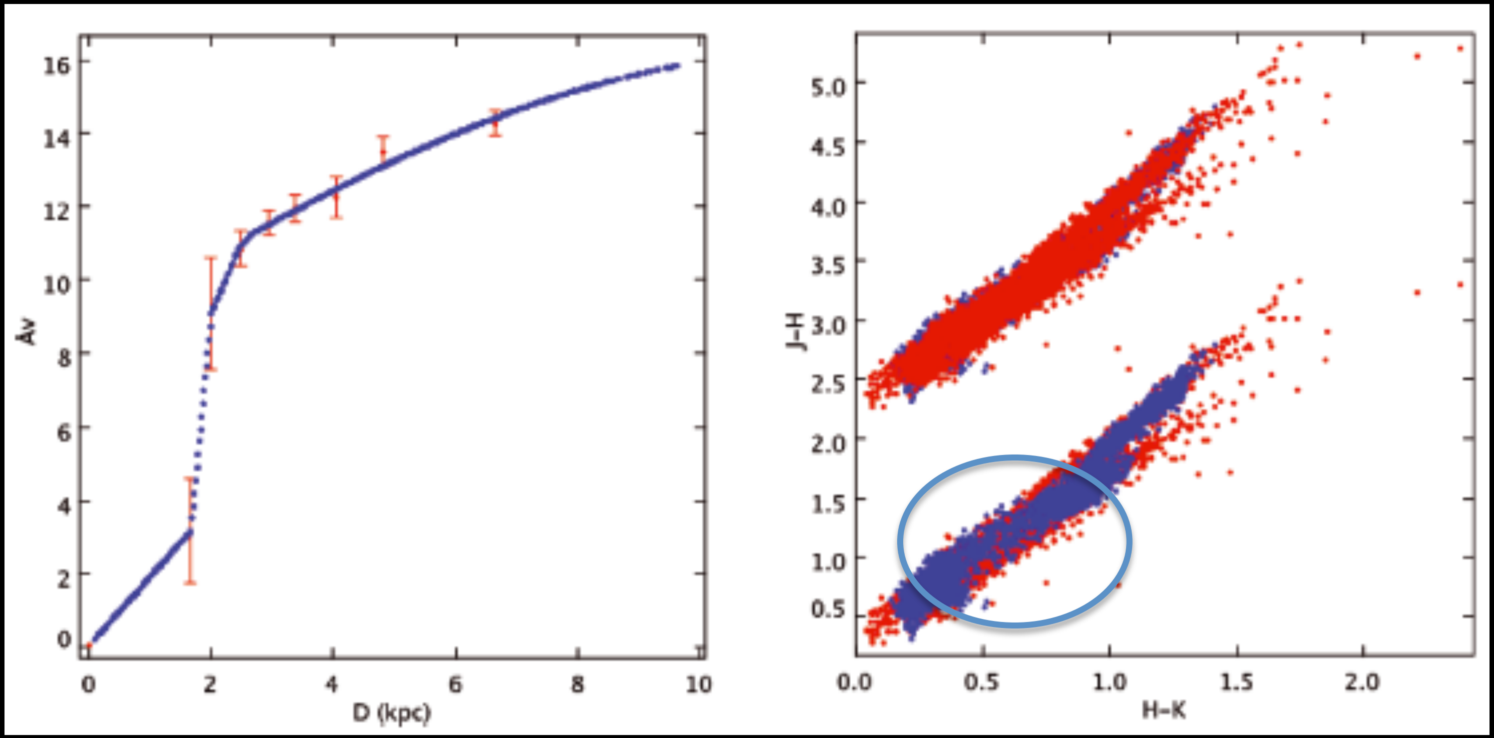
The Astrophysical Journal Supplement Series, 201:35 (21pp), 2012 August Nidever, Zasowski, & Majewski



More tomorrow
Zasowski talk



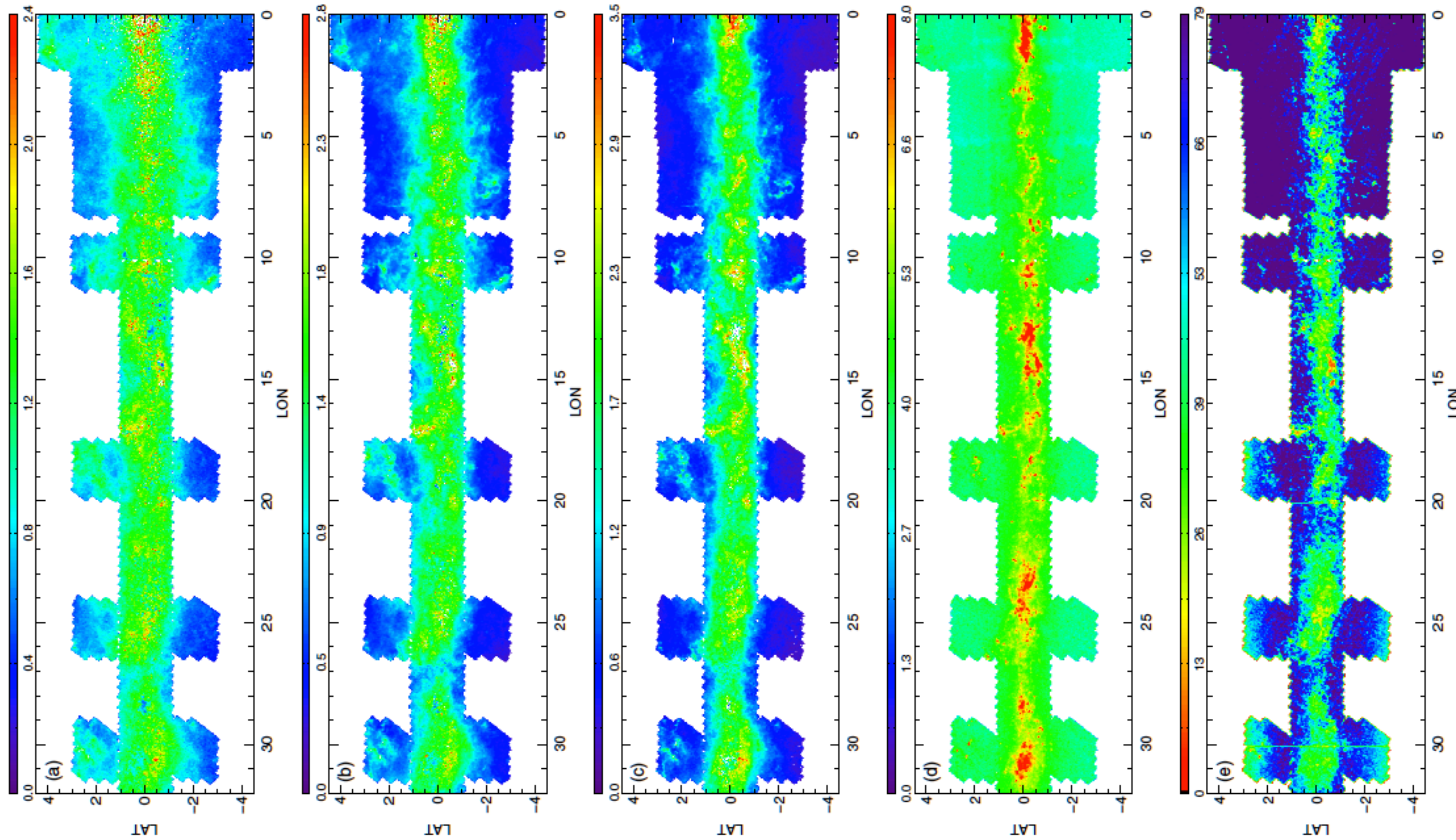
Broad-band techniques: can model along the LOS: 3D maps



Results: Milky Way 3D

Zasowski, Nidever, Majewski, et al.

MSTO | RC | RGB | 90% A_K | Stellar density



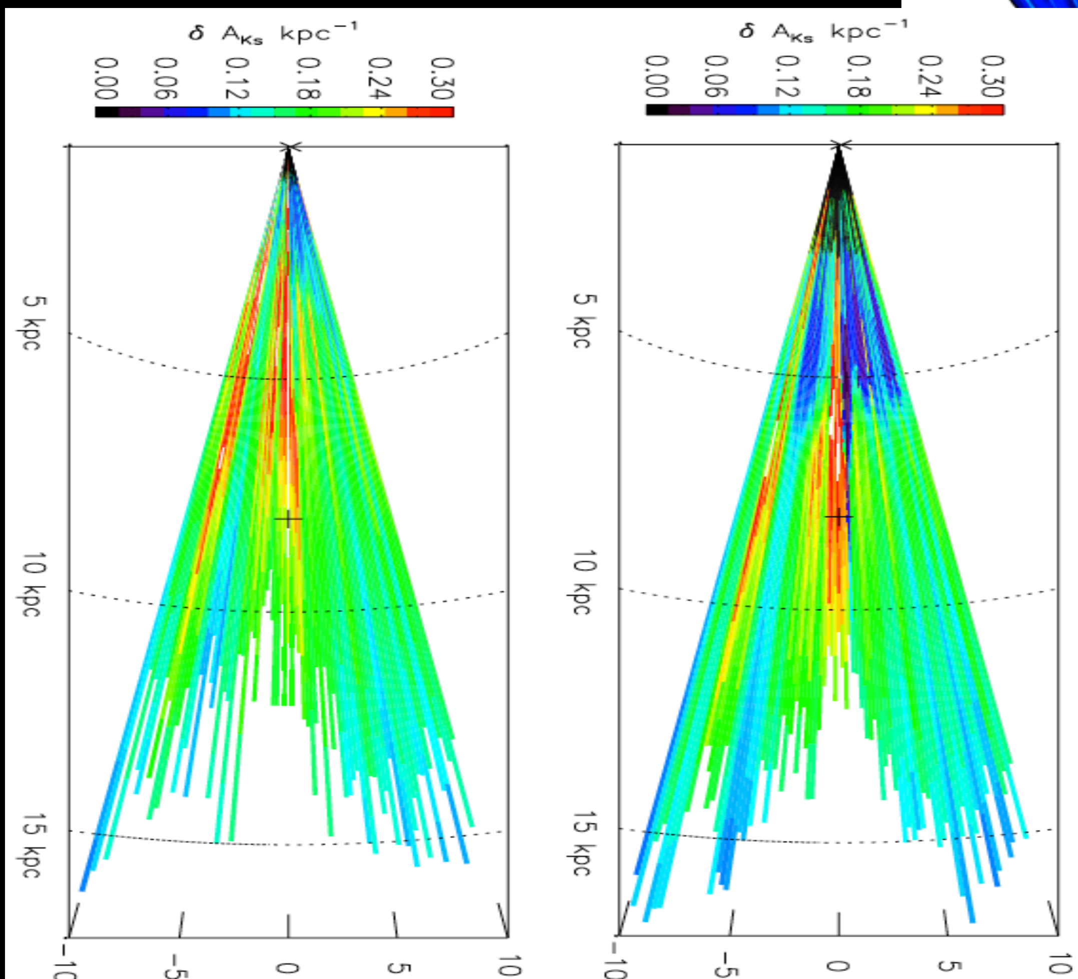
Results: Milky Way 3D

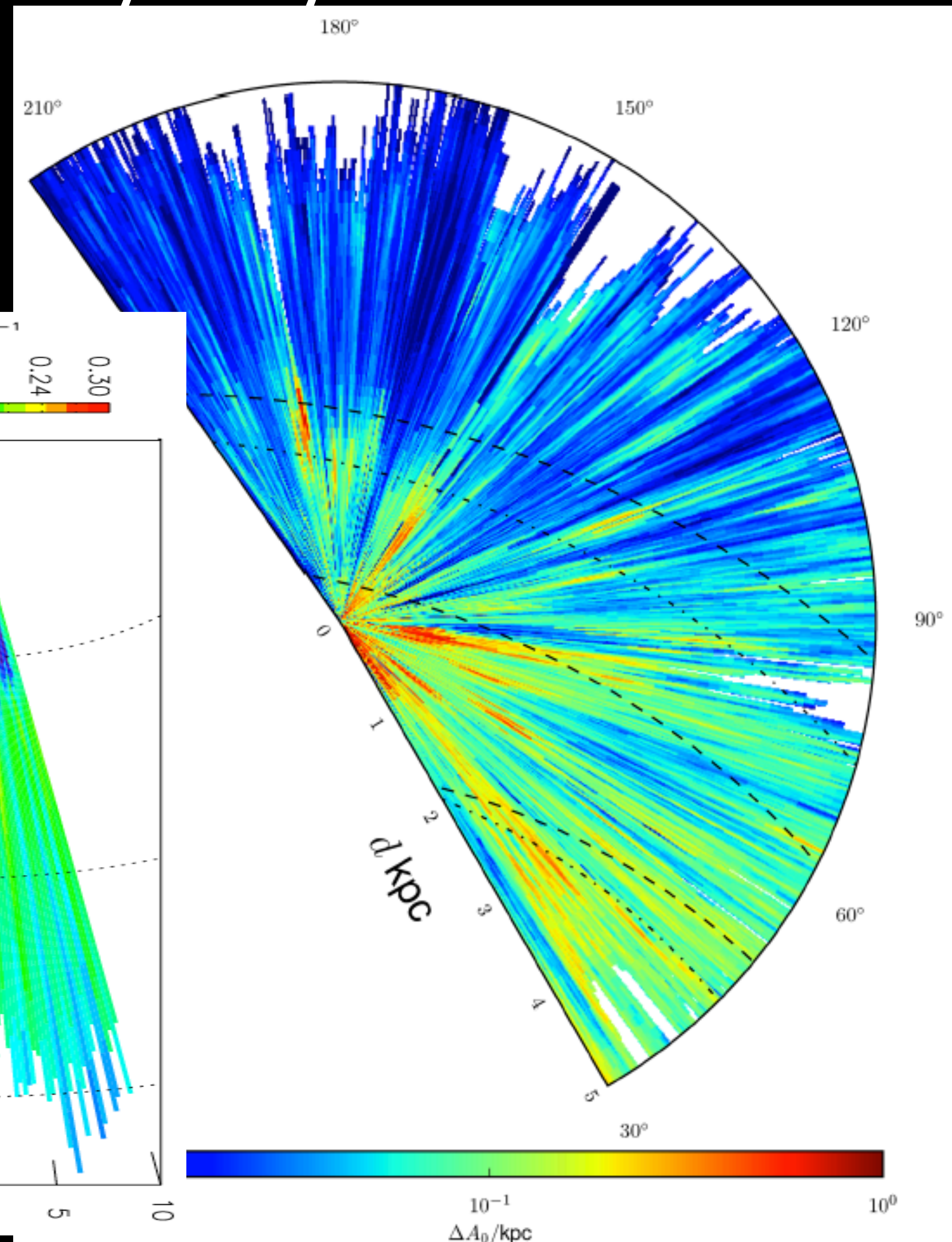
More tomorrow
Zasowski talk

Sale++ 2013

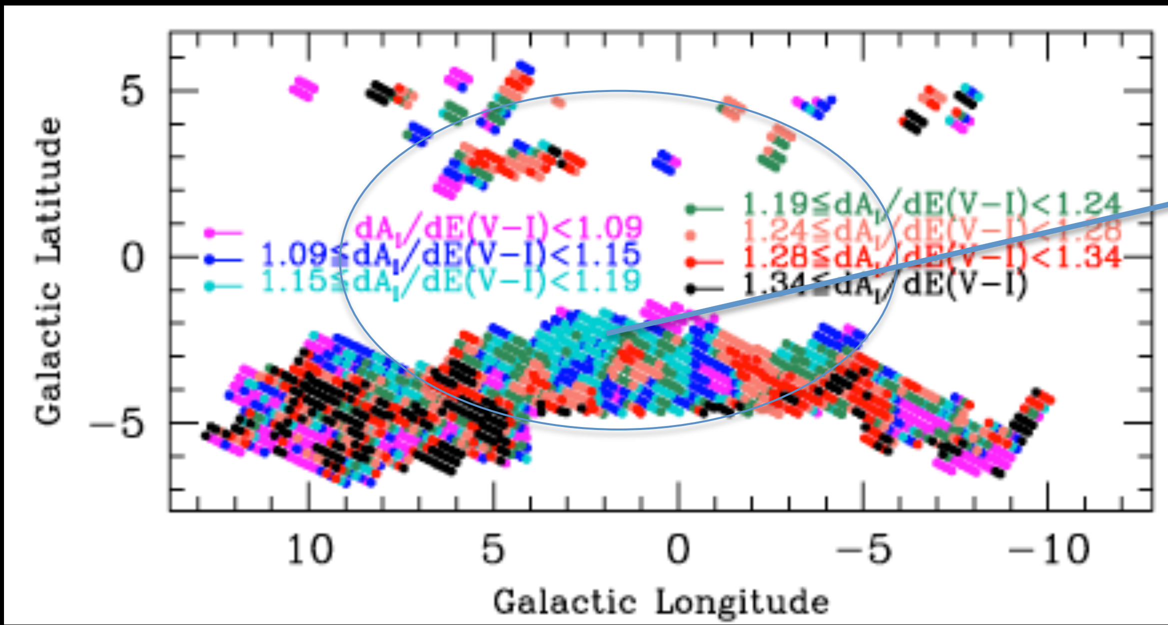
Marshall++ 2006

Chen++ 2013

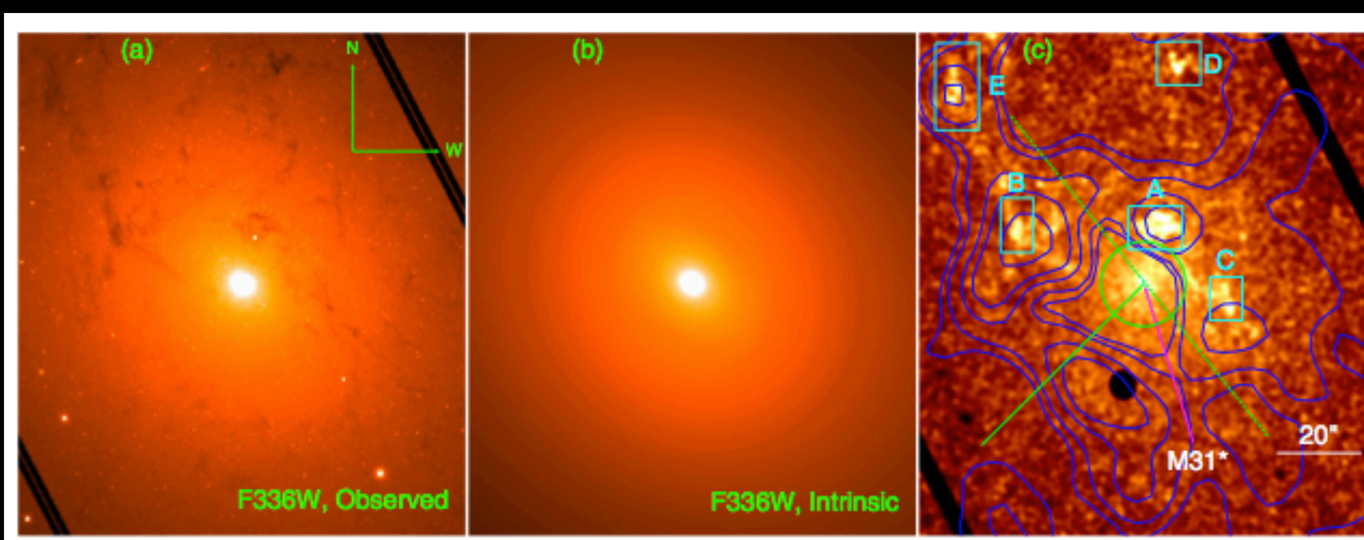




Results: steeper extinction in bulges



Nataf++ 2013: Milky Way bulge values cluster around R_V ~2.5: more shattering, less growth?



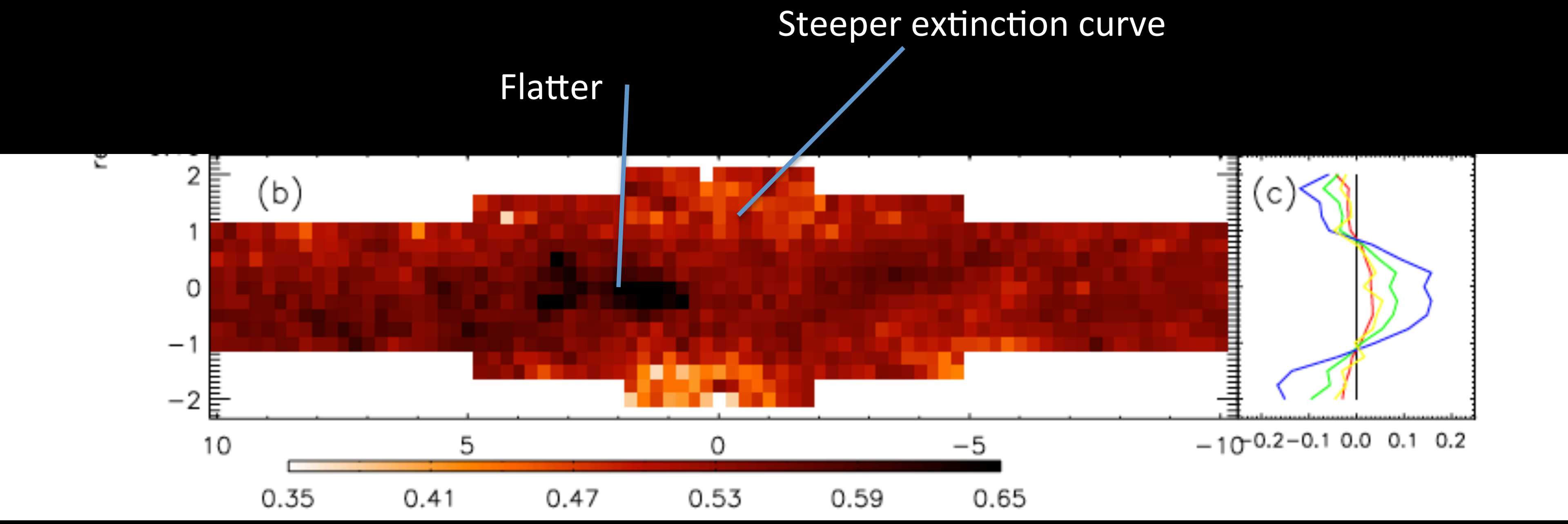
Dong++ (PHAT) 2014

< F160W/F336W shows dusty clumps

Their R_V is 2.3-2.5

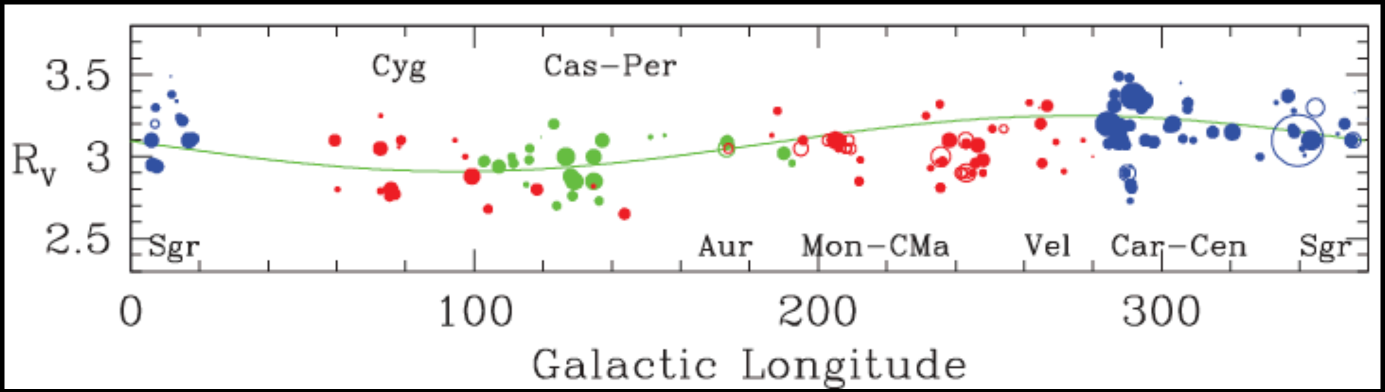
Results: steeper extinction in bulges, shallower in midplane

Chen++ 2013



$A_{3.6} / A_K$

Results: trends with MW longitude?

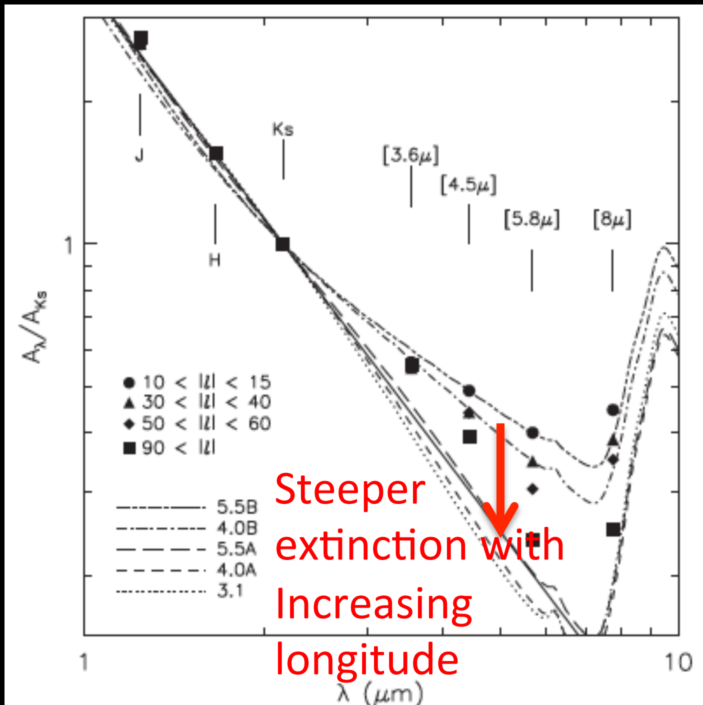


Sung+Bessell 2014 (curve from Whittet 1977)

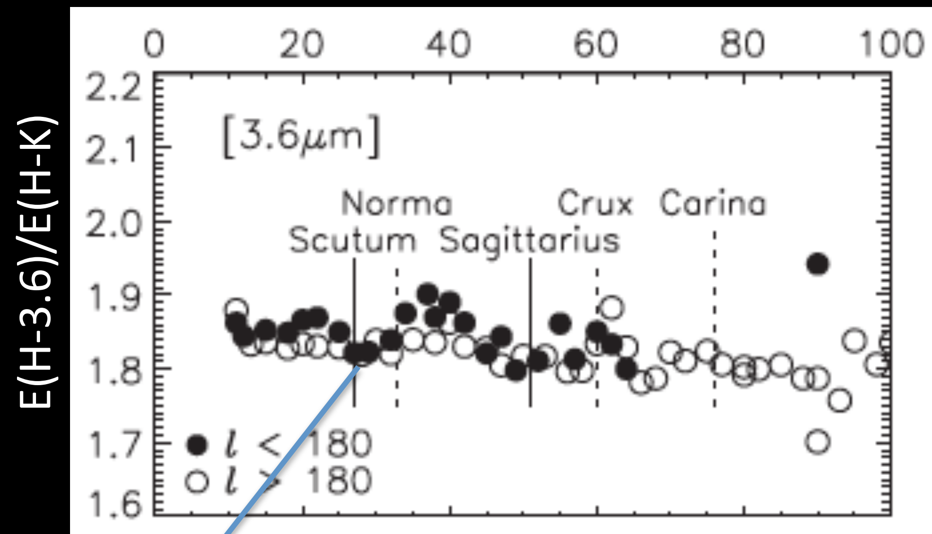
- Optical measurements, Probably local material

Results: trends with MW longitude?

Zasowski++ 2009

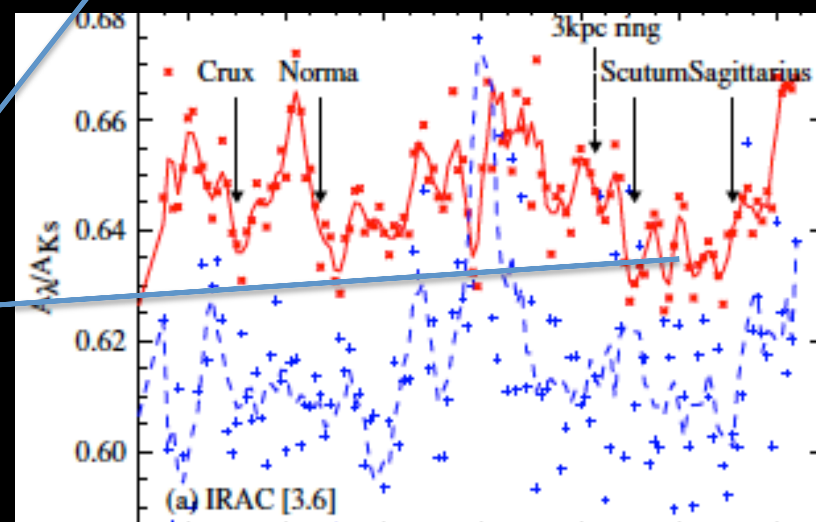


angle from Gal. center



Flatter extinction in spiral arms, maybe

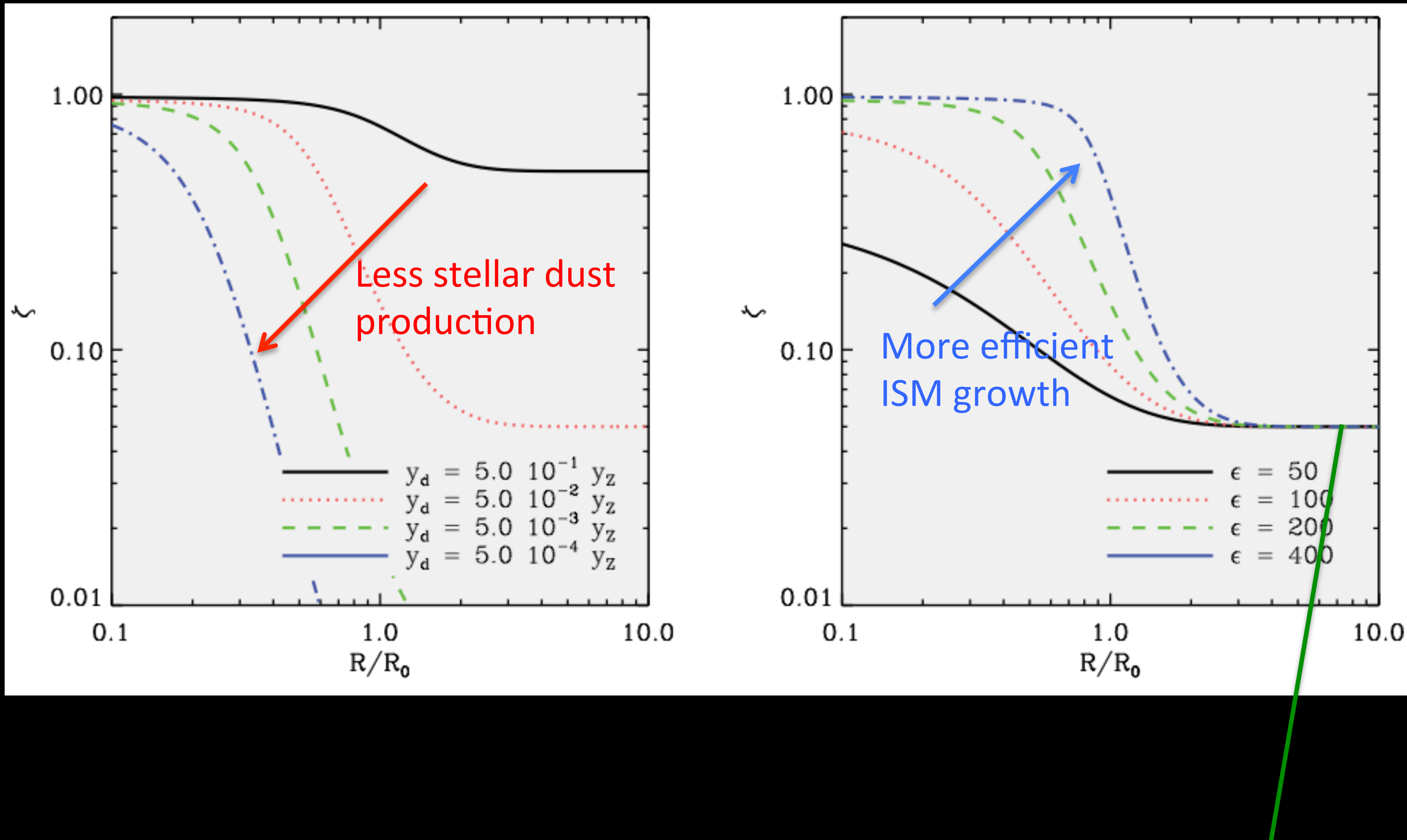
Gao++ 2009



l= -60 -40 -20 0 20 40 60

Theory: trends with R_gal

Dust / metals

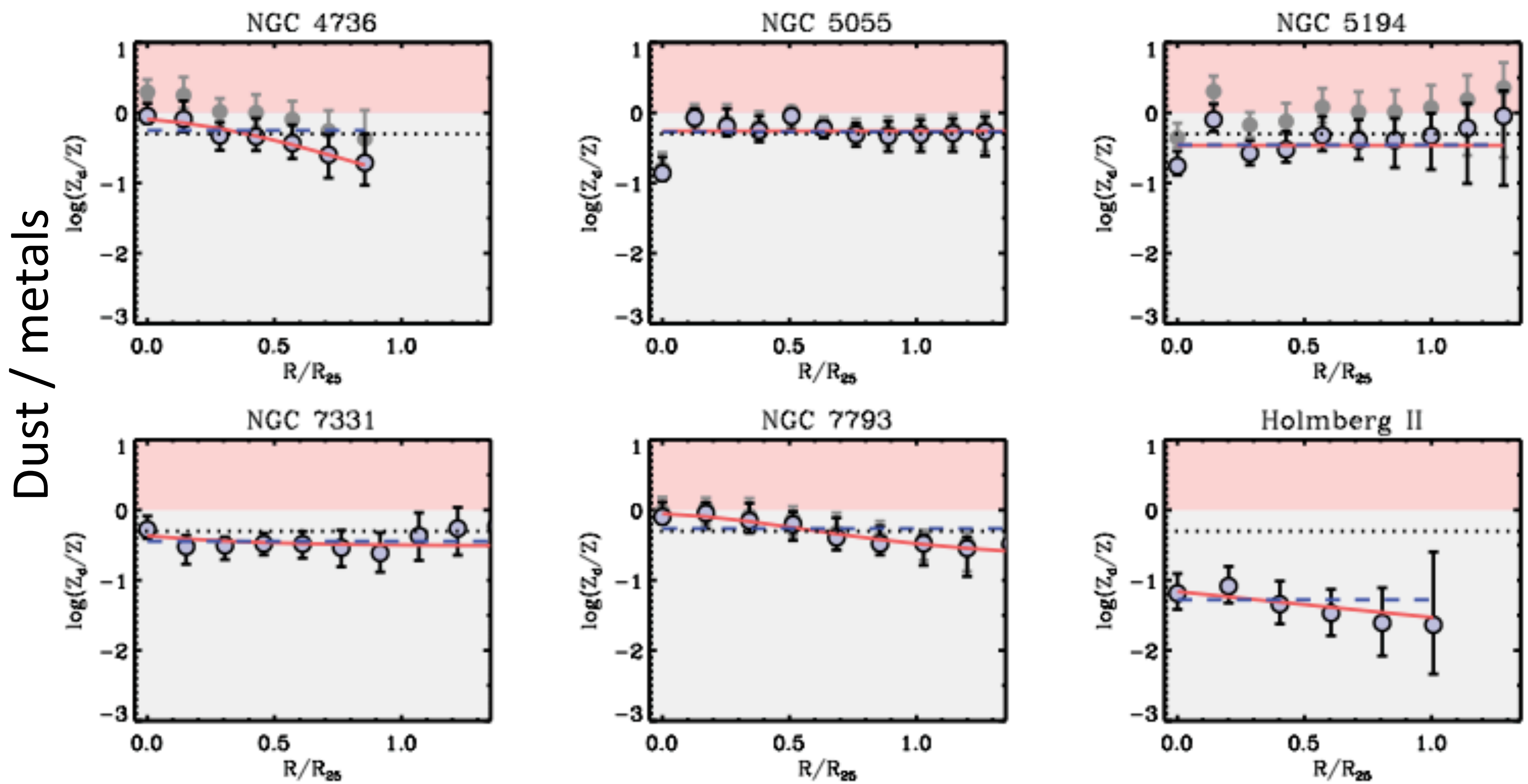


Mattsson, Andersen, & Munkhammar 2012

Outer disk: below a threshold Z for effective growth, essentially see stellar production.

Results: trends with R_gal

Mattsson & Andersen 2012b

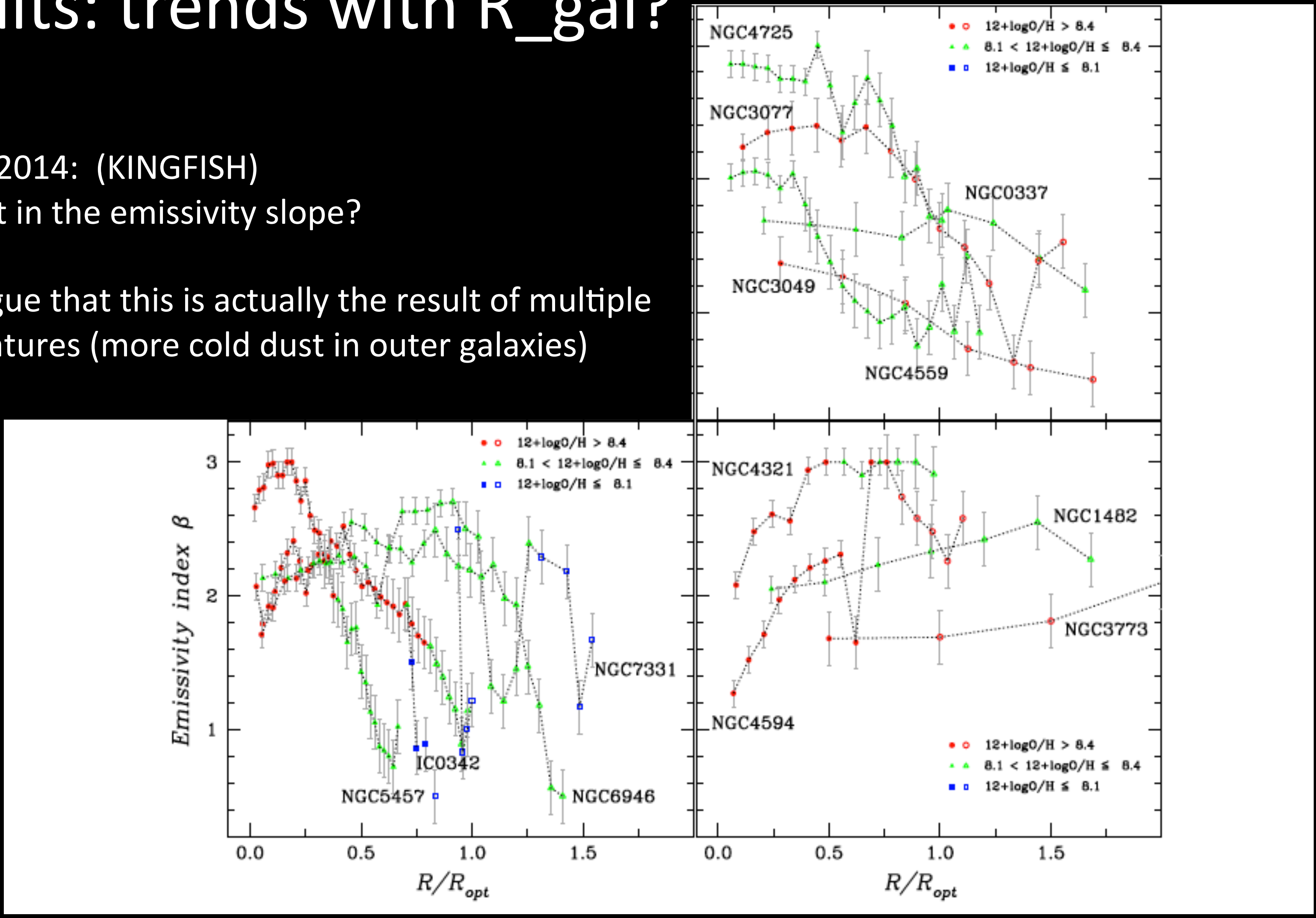


Flat and near 1: lots of growth, not much destruction?

Results: trends with R_gal?

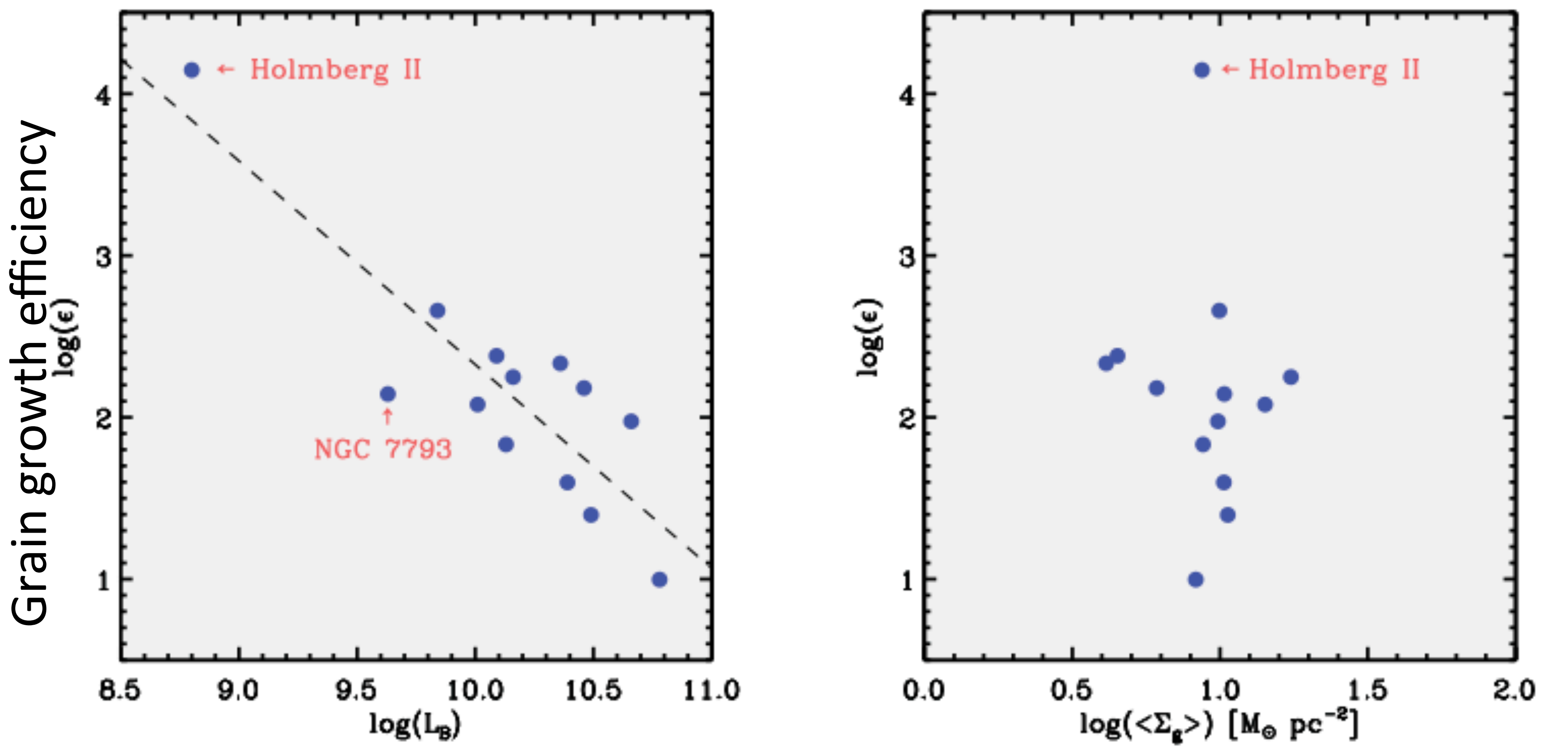
Hunt++ 2014: (KINGFISH)
Gradient in the emissivity slope?

They argue that this is actually the result of multiple temperatures (more cold dust in outer galaxies)



Results: trends with R_gal

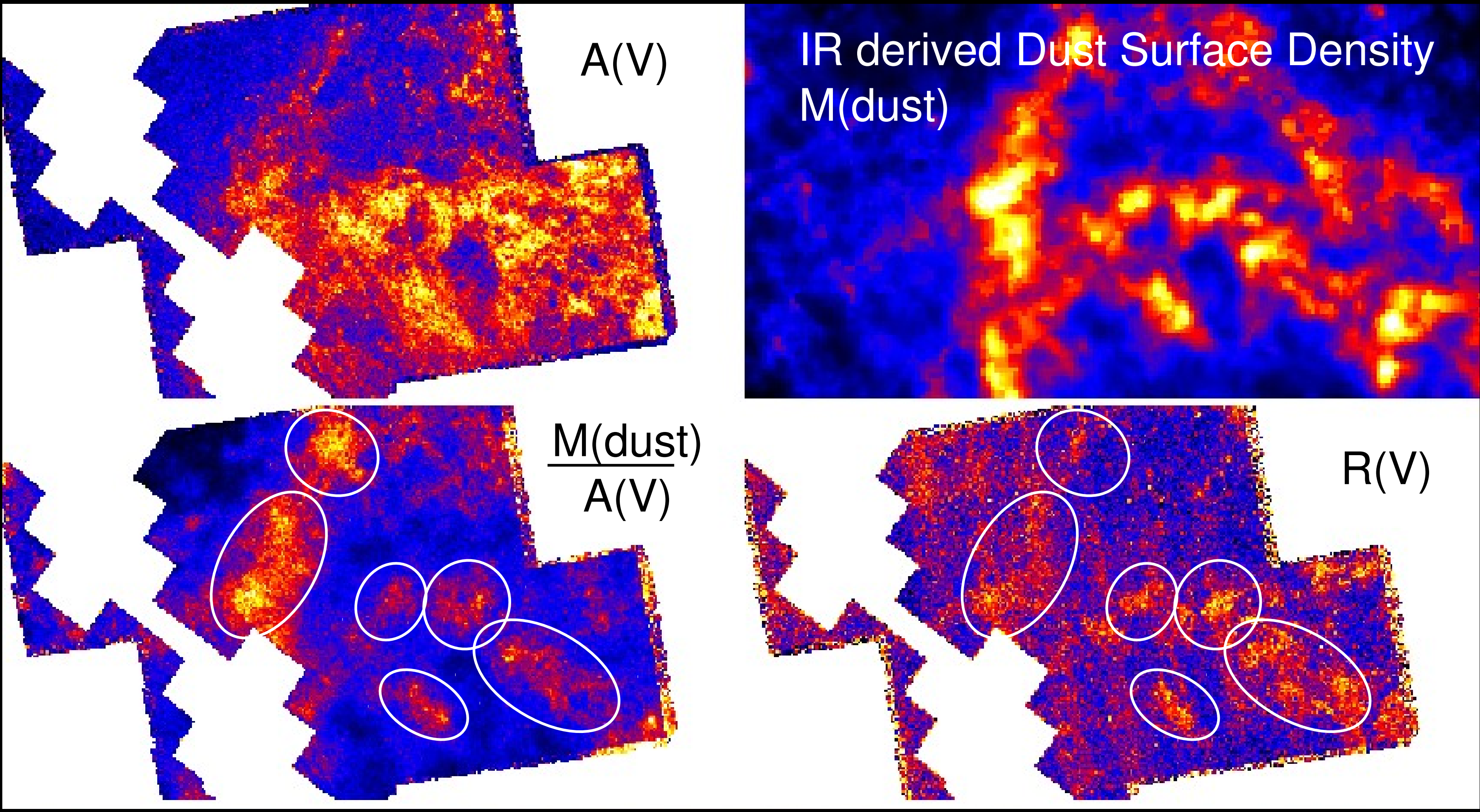
Mattsson & Andersen 2012b



? Larger galaxies less net grain growth, but
no dependency on disk surface density ?

Results: detailed maps in galaxies

Courtesy of Karl Gordon and the PHAT team:

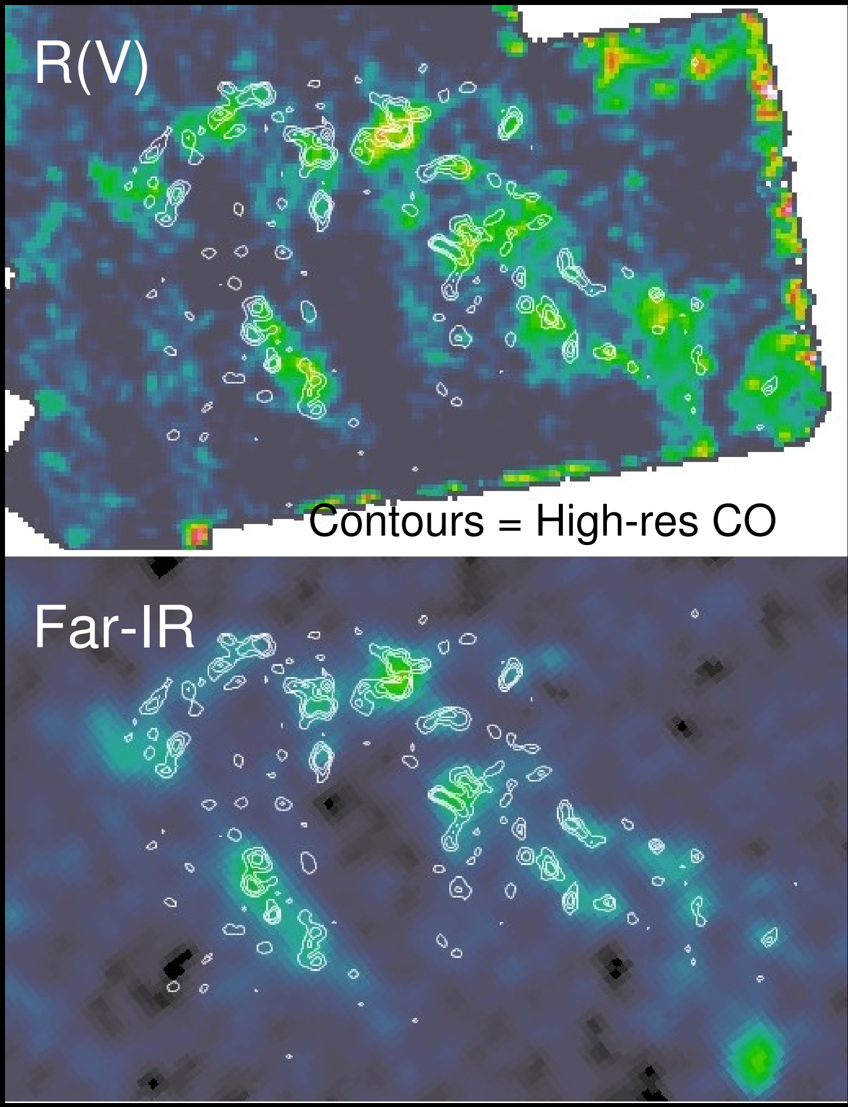


◯ = high IR/A(V) & high R(V) = larger than average grain sizes

Results: detailed maps in galaxies

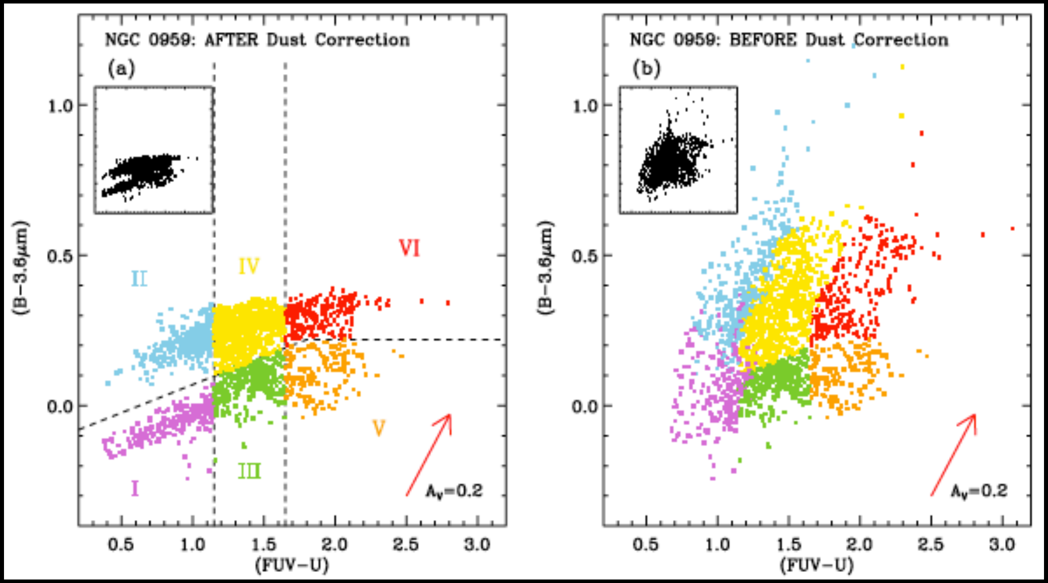
Courtesy of Karl Gordon and the PHAT team:

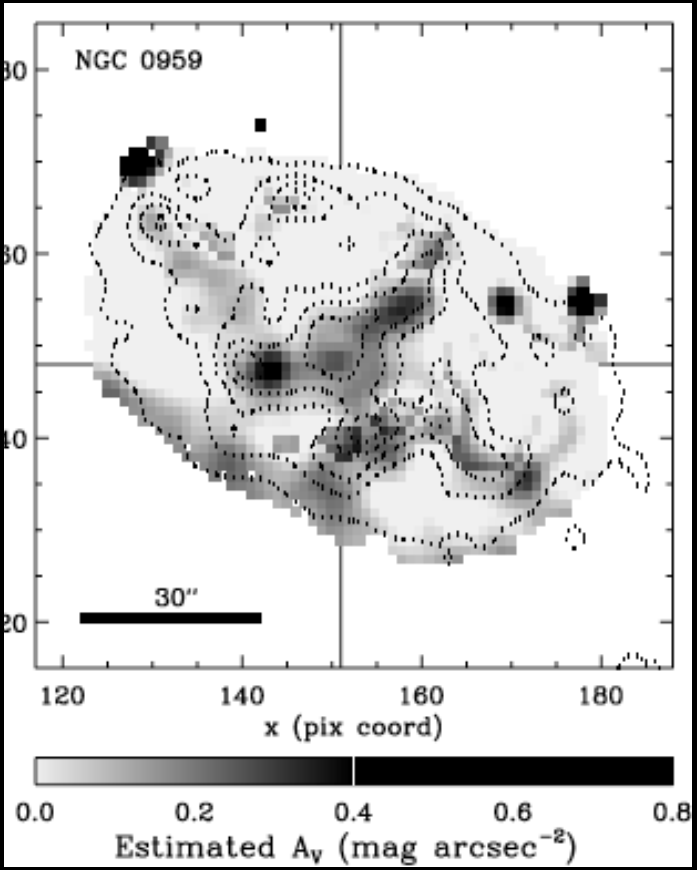
- M31 CARMA CO Survey
  - Andreas Schruba (lead)
  - high resolution interferometric CO observations of PHAT regions
  - Resolves out low spatial frequency CO emission (existing single dish CO obs)
  - CO cloud properties
  - Compare to nearby SF (Lori Beerman)
- R(V) peaks match CO peaks!
  - Find molecular clouds using UV/NIR data
- CO peaks match IR peaks



Results: more distant galaxies

Even when stars are not resolved, spatially varying extinction calculation and correction is important e.g. Tamura++ 20





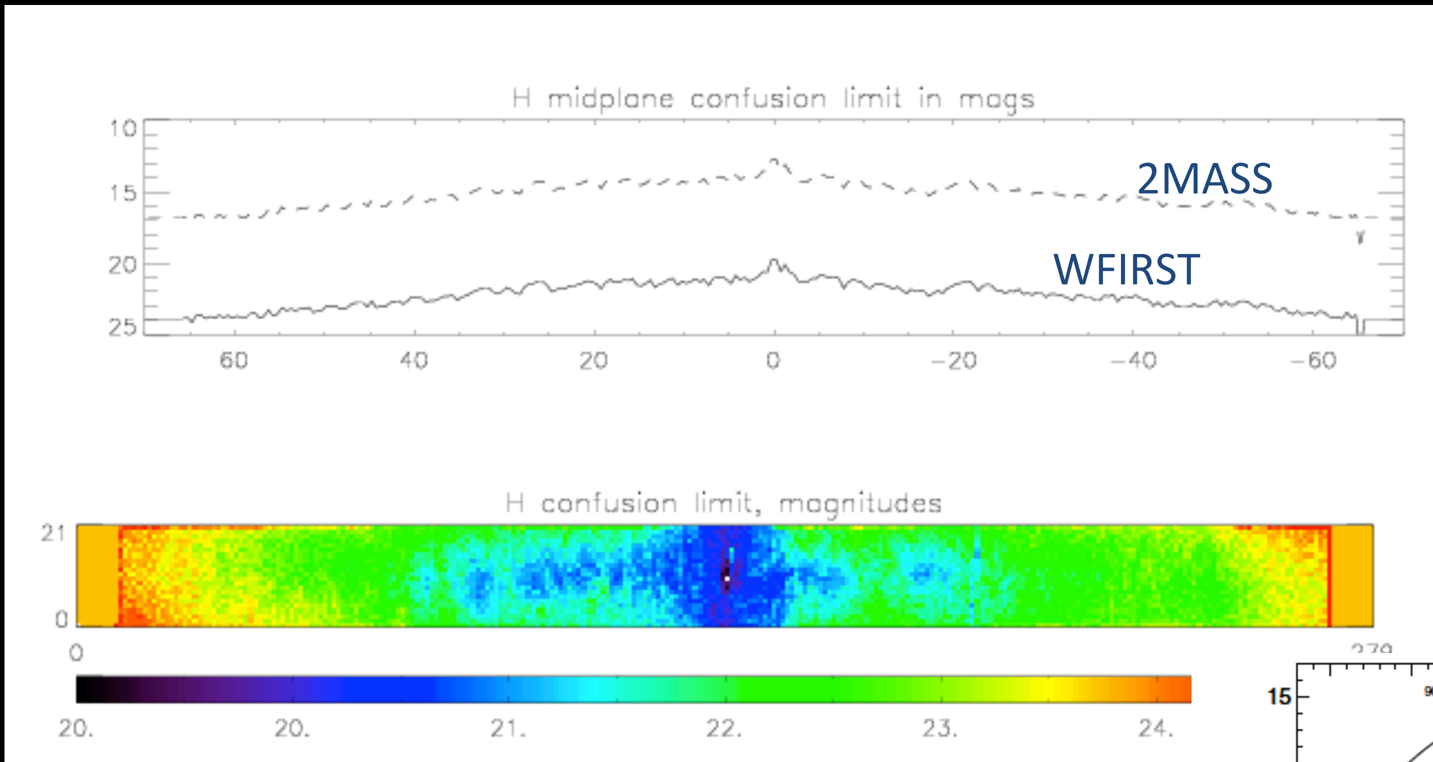
I mostly young/OB

II 2-pop old/young

V intermediate age

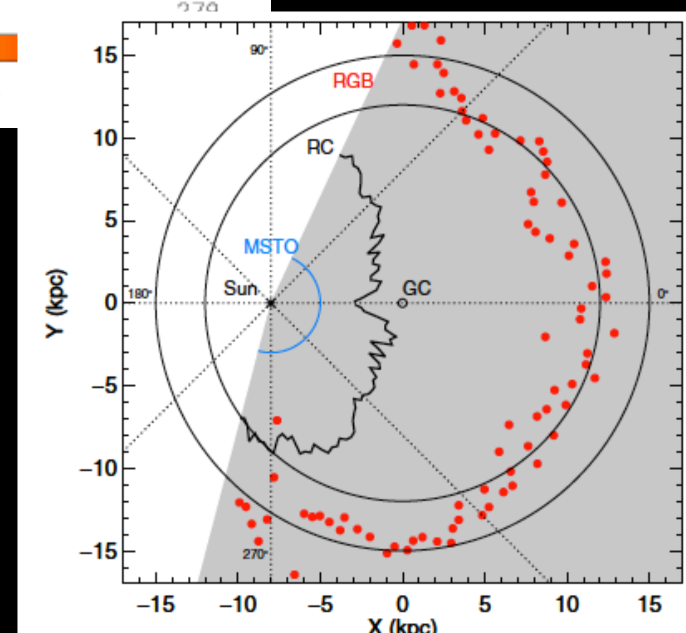
VI old

WFIRST: MW confusion limit

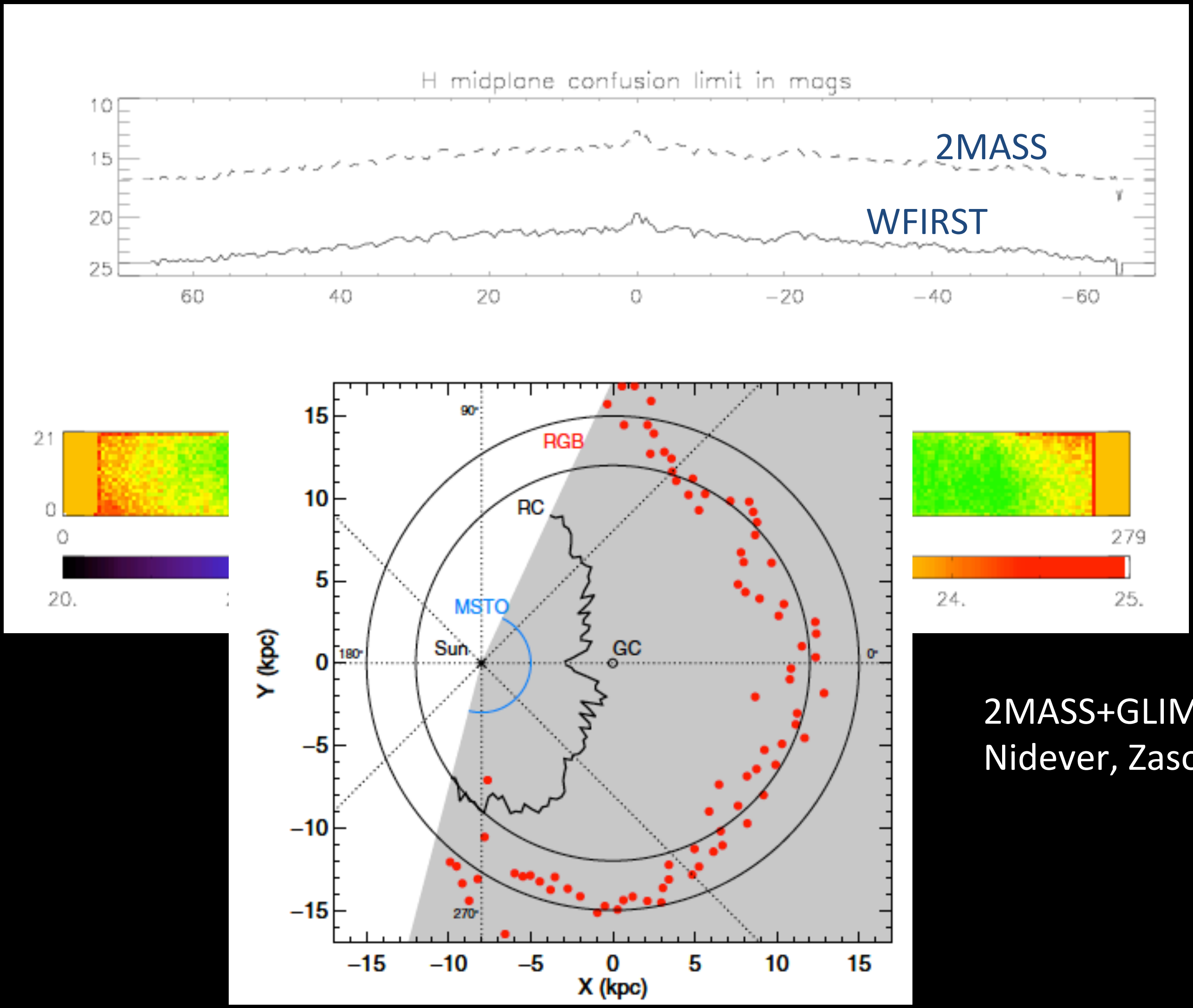


100x fainter – cover entire MW disk even along heavily obscured sightlines

2MASS+GLIMPSE
Nidever, Zasowski, Majewski



WFIRST: MW confusion limit

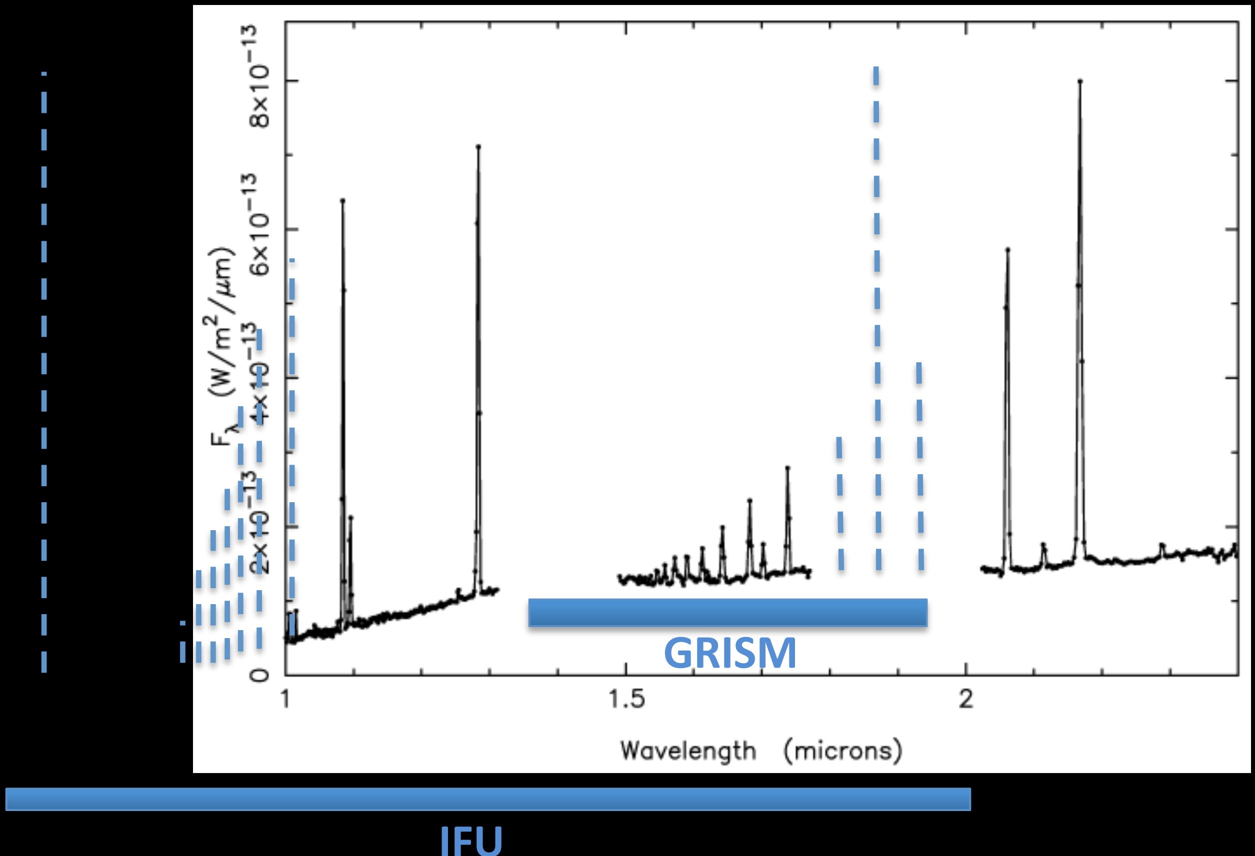


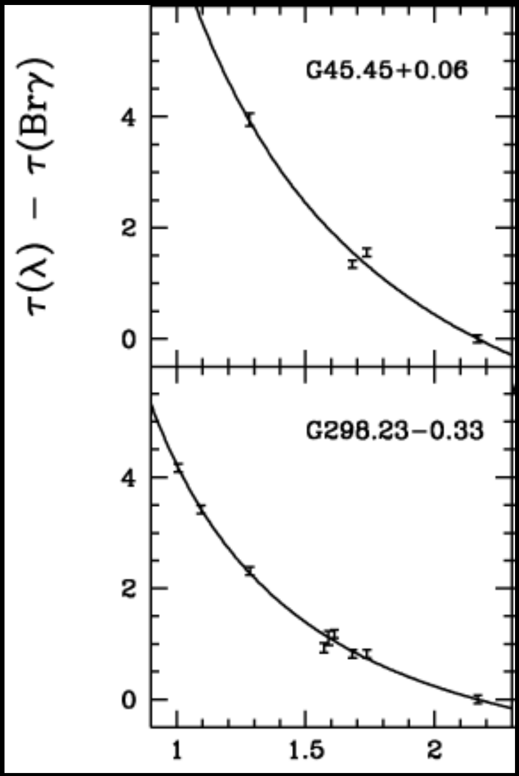
100x fainter – cover entire MW disk even along heavily obscured sightlines

2MASS+GLIMPSE
Nidever, Zasowski, Majewski

WFIRST grism & IFU

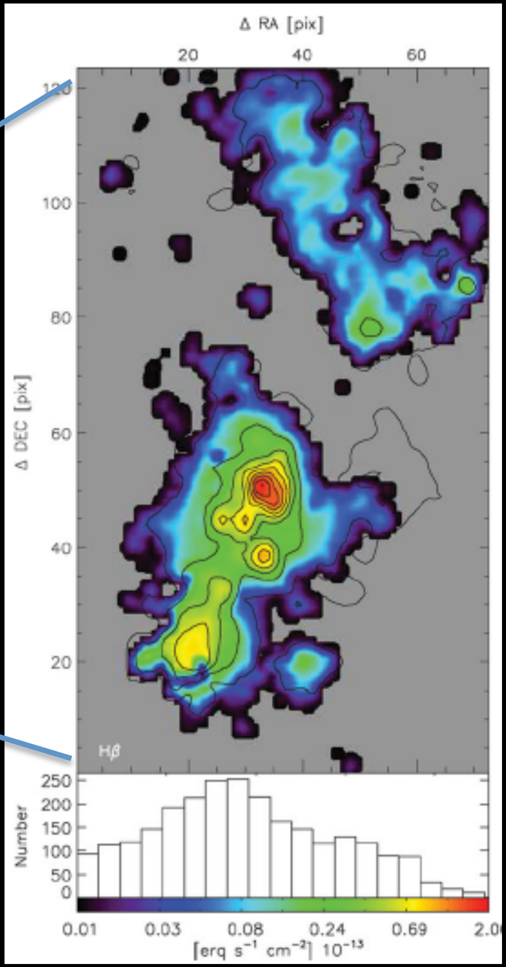
Moore++ 2005:
H recombination lines in an UCHII region





WFIRST grism & IFU

Joseph Brimacombe and google – M33 in Hα



Hβ López-Hernández++ 2013

> Should be resolvable to some 10s of Mpc, and (Br) recombination series ~10^{-16} erg/s/cm^2, measurable in <1h

Summary

- 0.1 mag variations in specific extinction have significant effects on resolved population studies, SF rates and histories

- The extinction curve can be fit, and used
- to understand dust evolution in galaxies, i.e. SF histories, SN rates and energy and metal dispersal, molecular cloud lifetimes, etc

- Broad-band methods with WFIRST will reveal the entire MW disk and detailed studies of many local galaxies

- Grism or IFU will allow more precise extinction curve measurements