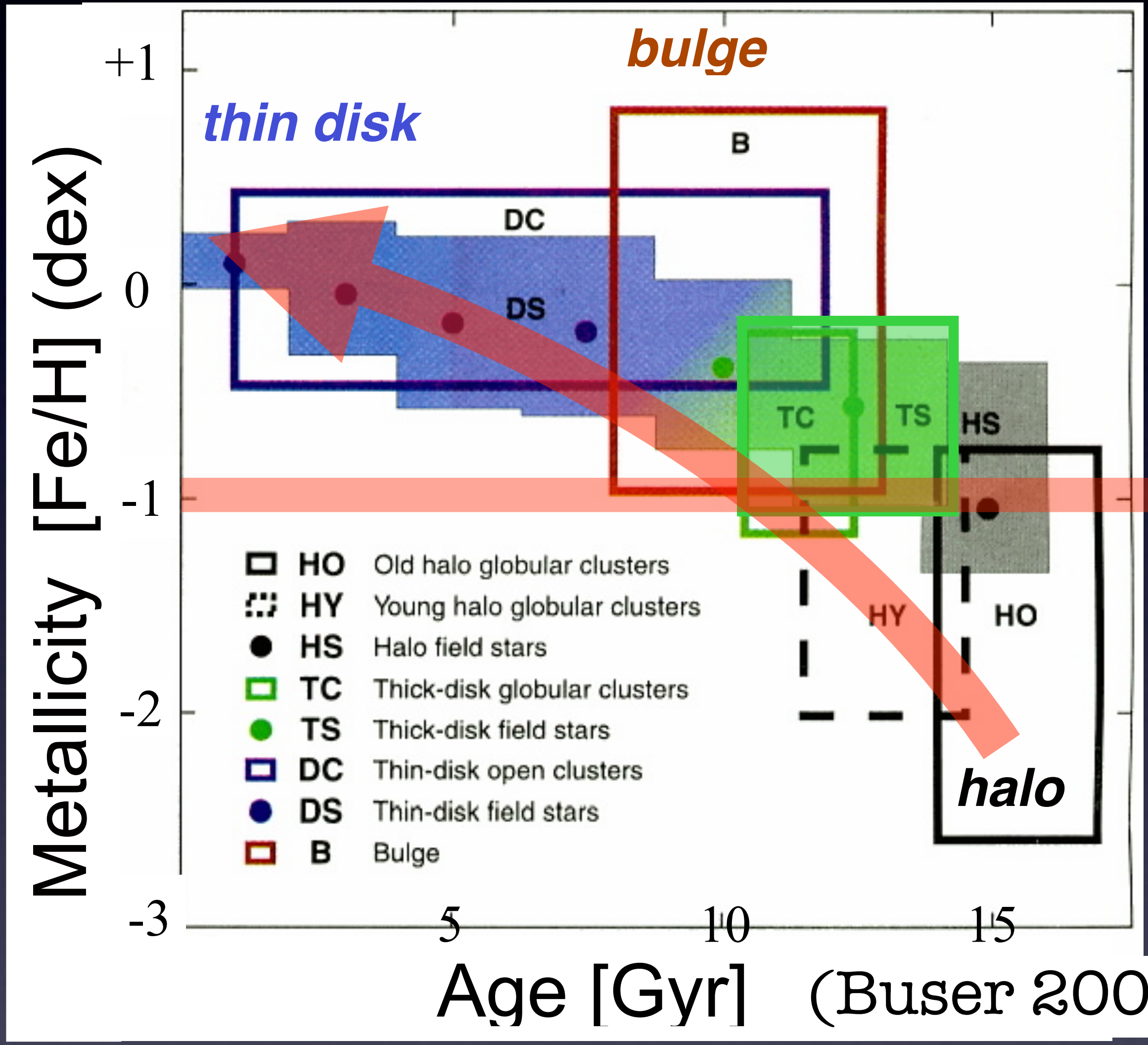
Mass Function of Young Clusters in Galactic Low-metallicity Environments

Chikako Yasui
(National Astronomical Observatory of Japan)

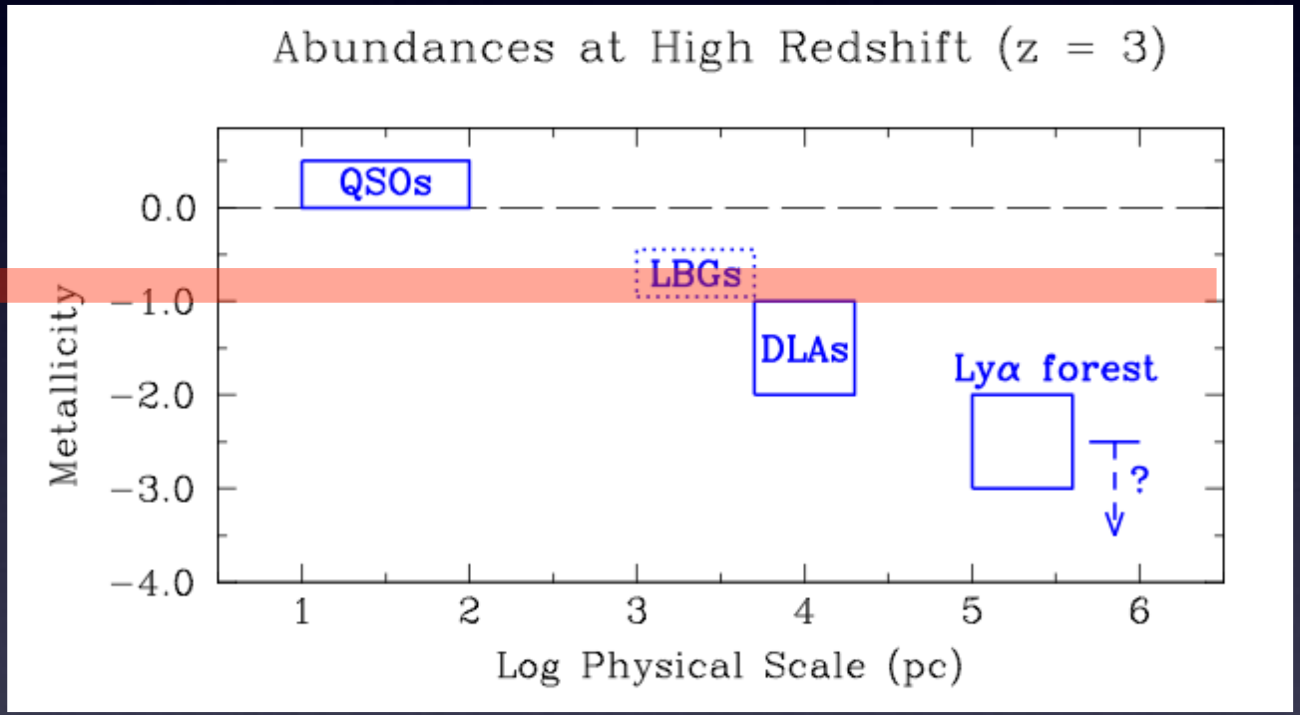
Collaborators:
Natsuko Izumi (ASIAA)
Masao Saito (NAOJ)
Naoto Kobayashi (Univ. of Tokyo)
Yuji Ikeda (Photocodng)
Ryan Lau (NOIRLab)
Michael E. Ressler (JPL/Caltech)

Metallicity and galactic evolution

★The metallicity increases as galaxies evolve



(Buser 2000, Sci)



(Pettini 2003)

✓IMF affects metallicity of next generation, and in tern metallicity can change IMF
Dependence of IMF on metallicity is necessary to understand galaxy evolution

✓Metallicity of interest here: ~−1 dex
Corresponds to $z \approx 2$, or late stage of halo formation and early stage of disk formation in the Galaxy

IMF in low-metallicity environments

★Globular clusters

Globular clusters are very old (~10^{10} yr)

✓Mass segregation
Present-day mass function may not reflect the IMF

✓Small mass range (≲1M⊙)
In contrast, massive stars (≲20 M⊙) have not yet ended their lived in young clusters (10^6 yr)

★Young clusters in LMC/SMC

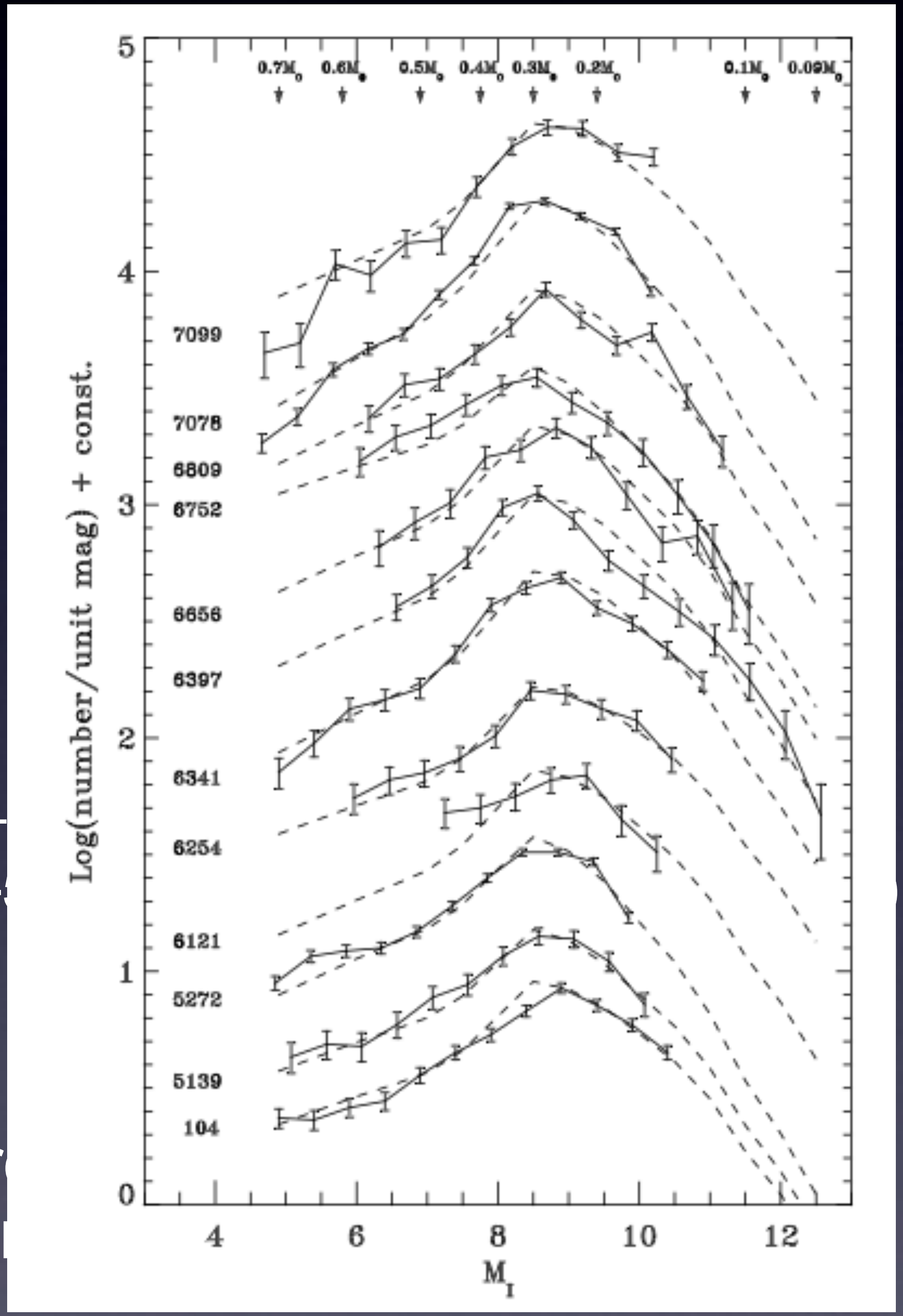
Large distances (~50 kpc)

✓Different scales (Andersen 2009)
Cf. typical cluster scale in the solar neighborhood: r~1 pc (Adams+
The existence of multiple generations are pointed out (e.g., ~0.1–

✓Lack of spatial resolution
~10^2–10^5 stars arcsec^{-2} (Leschinski & Alves 2020)

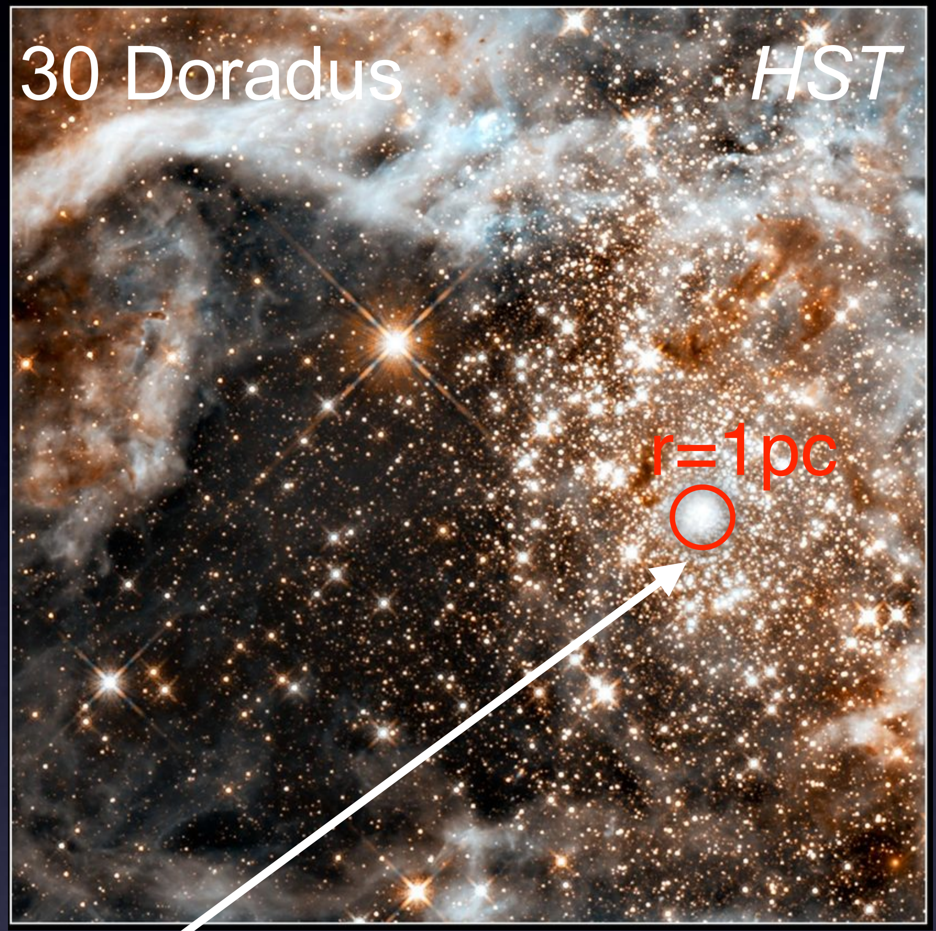
Although it is not clear whether this is the direct reason, in some r
derived the standard IMF (Kerber & Santiago 2006), while in othe
R136; Sirianni et al. 2000).

Globular clusters



Paresce & De Marchi 2000

IMF in low-metallicity environments



★Globular clusters

Globular clusters are very old (~10^{10} yr)

✓Mass segregation

Present-day mass function may not reflect the IMF

✓Small mass range ($\lesssim 1 M_\odot$)

In contrast, massive stars ($\lesssim 20\ M_\odot$) have not yet ended their lived in young clusters (10^6 yr)

★Young clusters in LMC/SMC

Large distances (~50 kpc)

✓Different scales (Andersen 2009)

Cf. typical cluster scale in the solar neighborhood: r~1 pc (Adams+2006)

The existence of multiple generations are pointed out (e.g., ~0.1–50 Myr; De Marchi et al. 2017)

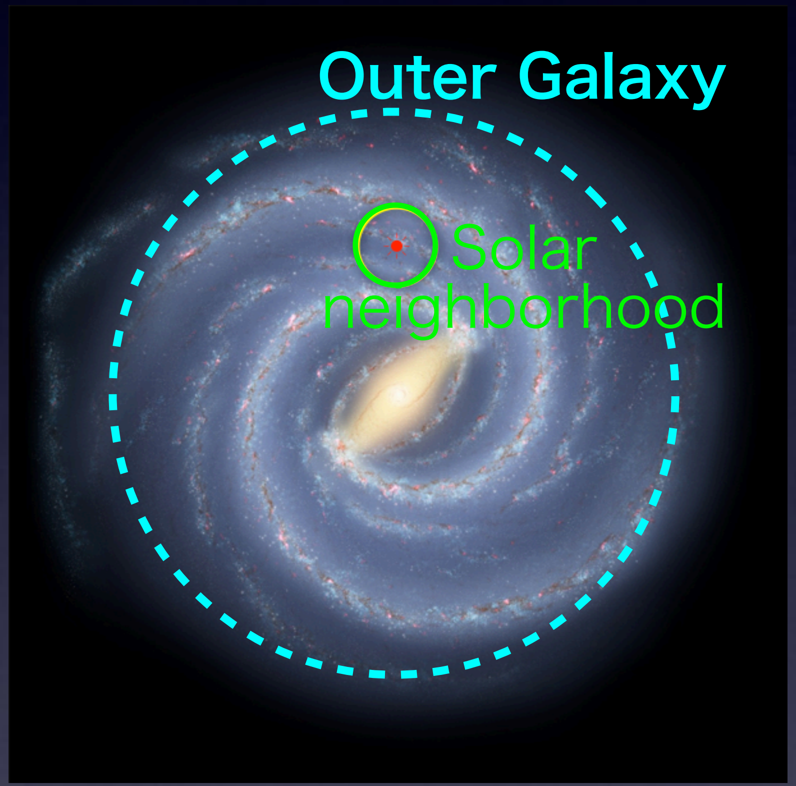
✓Lack of spatial resolution

~10^2–10^5 stars arcsec^{-2} (Leschinski & Alves 2020)

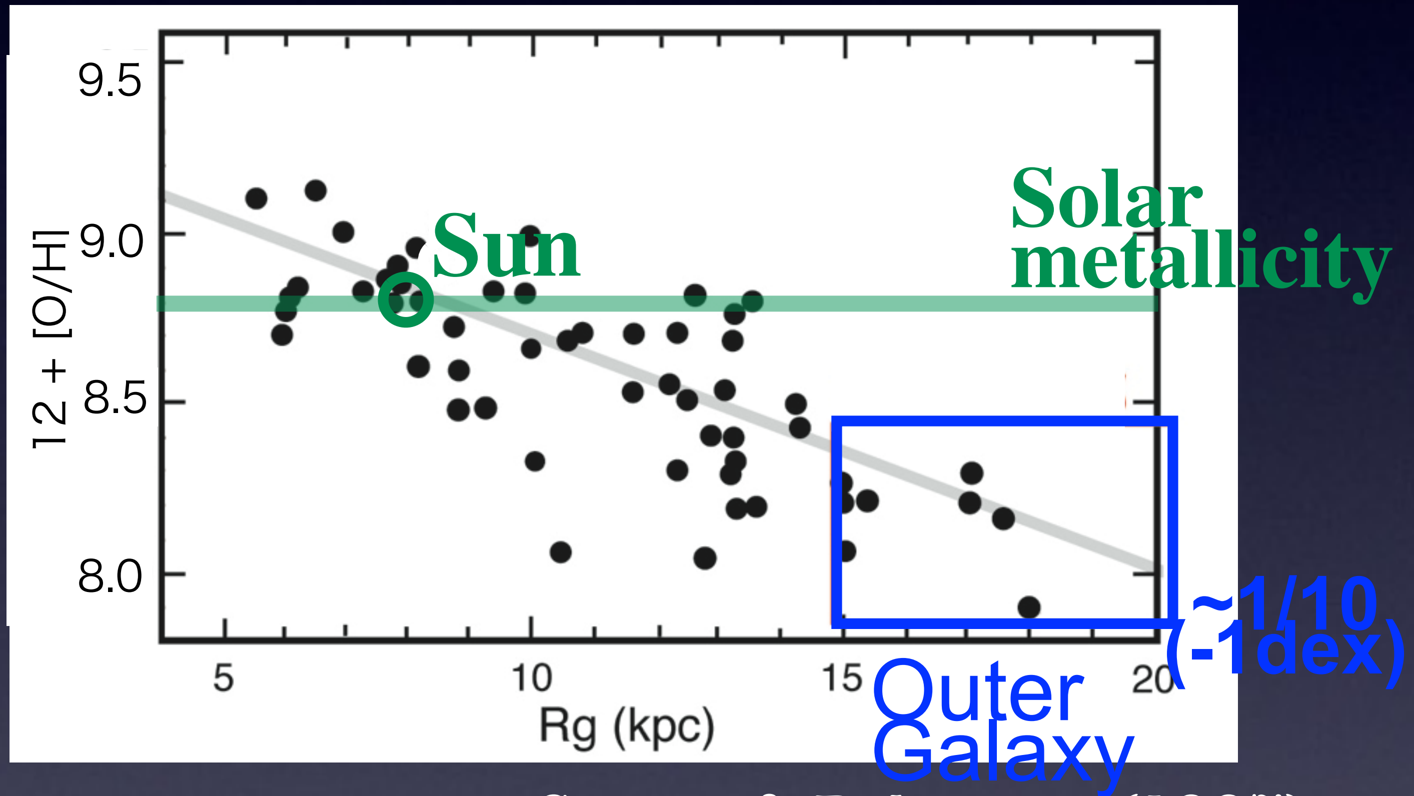
Although it is not clear whether this is the direct reason, in some regions investigators have derived the standard IMF (Kerber & Santiago 2006), while in others the IMF is flatter (e.g., R136; Sirianni et al. 2000).

The outer Galaxy

★Galactic radius of ≳15 kpc: ~1/10 metallicity in the solar neighborhood



Credit: Nasa/JPL



Smartt & Rolenston (1997)

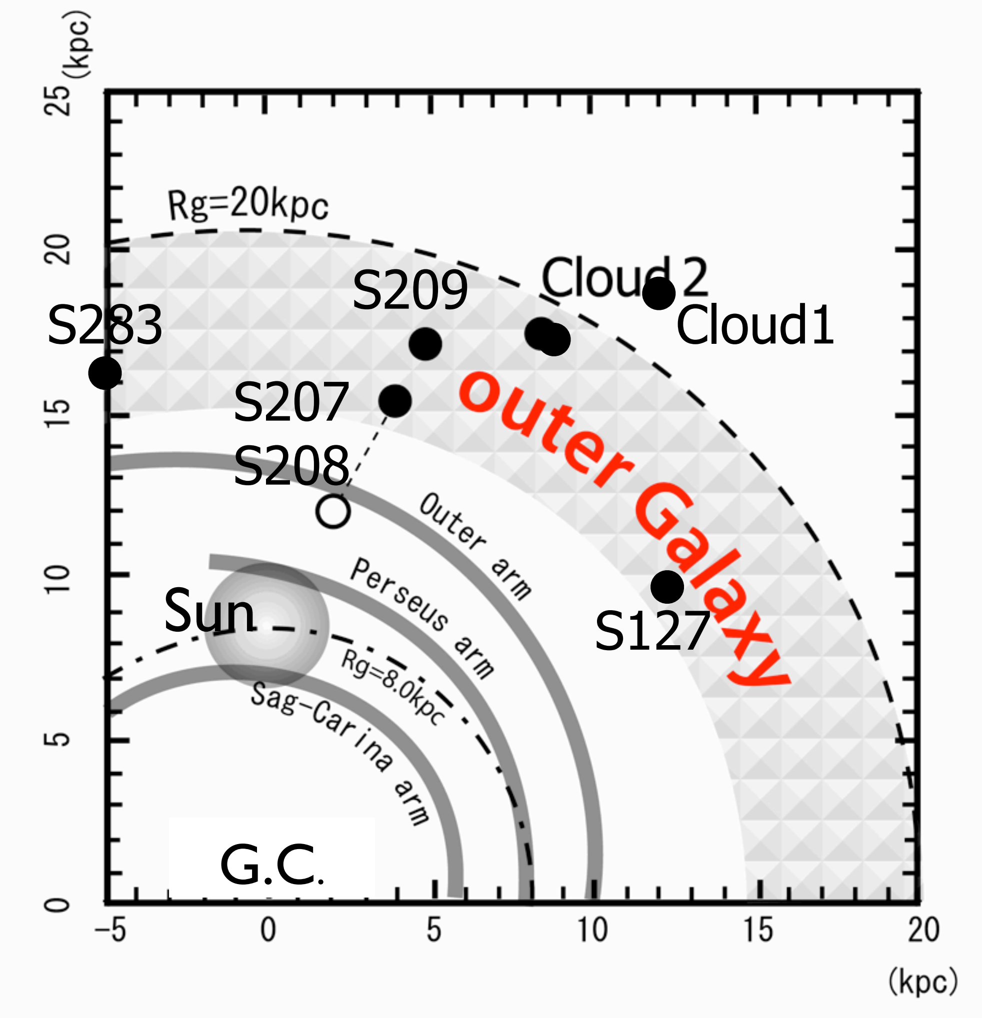
✓Relatively small distances D~5-10 kpc (Cf. ~50 kpc for LMC/SMC)

- **Resolved detection of individual sources** is possible (e.g., Yasui+ 2006)
- High sensitivity observations allow **low mass detection limit** to be achieved

★Targets in the outer Galaxy for Subaru observations

✓Large Galactrocentric distance: (R_g) ≳ 15 kpc
✓Very low metallicity: [O/H]~**−0.5**–**−1** dex

Targets	R_g / Distance (kpc)	[O/H] (dex)	
Sh 2-127	13.5/10	-0.6	Yasui+2021a
Digel Cloud 1	22/16		Izumi+2014, 2022
Digel Cloud2	19/12	-0.7	Yasui+2006, 2008, 2009
Sh 2-207	12/4	-0.8	Yasui+2016a
Sh 2-208	12/4	-0.8	Yasui+2016b
Sh 2-209	18/10 → 10/2.5	-0.5	Yasui+2023
Sh 2-283	15/8	-0.6	
Sh 2-98	15/8	-0.5	



~10 star-forming regions are selected

★Previous results on derivation of IMF in the outer Galaxy

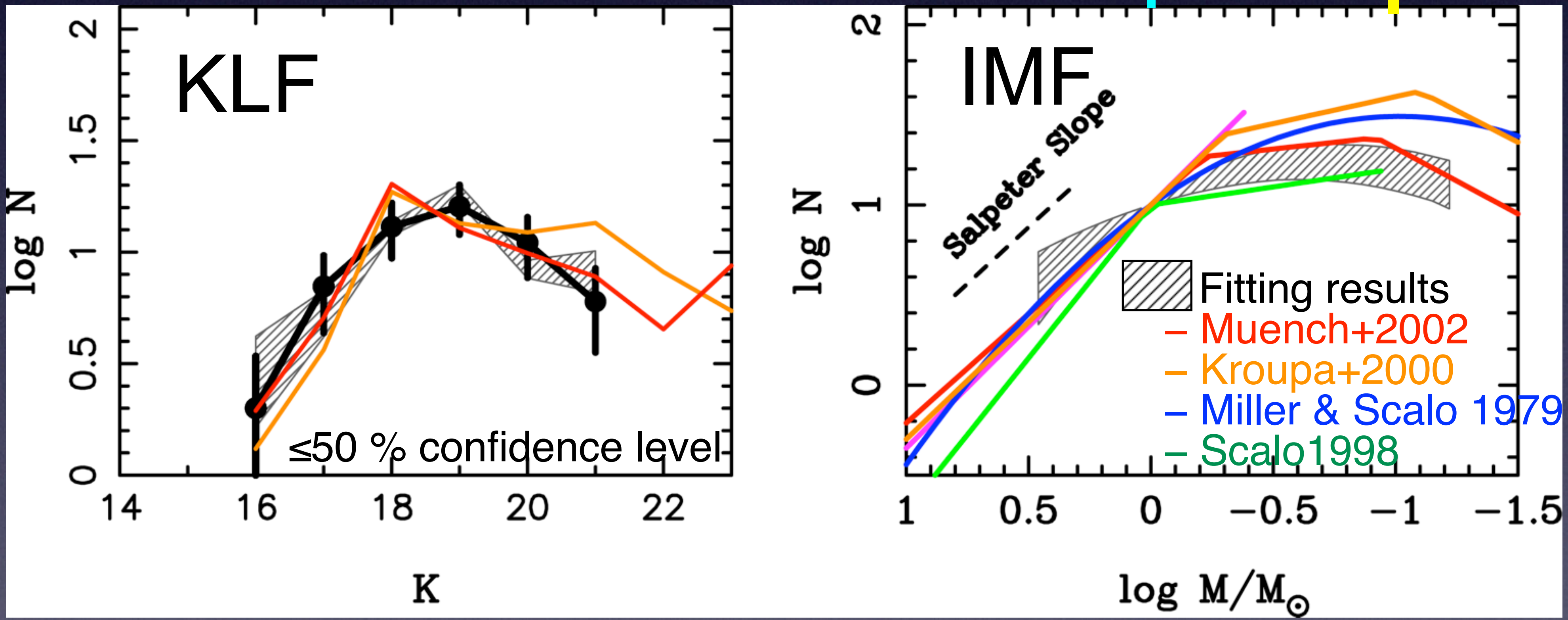
✓Mass detection limit of ~0.1 $M_\odot$ (Cf. ~1 $M_\odot$ for LMC/SMC w/HST; e.g., Sirianni+2000)

✓Fitting of K-band luminosity function (KLF)

- Assuming the Gaussian IMF (Miller & Scalo 1979)
- Assuming single cluster ages (w/o age spread) and single reddening values

◆Cloud 2-N (N* ~ 100)

M_{lim}(LMC/SMC)~1$M_\odot$ M_{lim}~0.1$M_\odot$



(Yasui+2008, 2016)

Consistent with IMF in the solar neighborhood (high-mass slope (Γ) & IMF peak (Mc))

However, the derived IMF have a large scatter

→ Targets with more members are essential

Subaru observation

★Sh 2-209 (S209)

✓Metallicity

12+log(O/H) ≃ 8.3 (≃−0.5 dex)

Very low metallicity comparable to SMC

✓Distance

Photometric/kinematic distance: D ≃10 kpc (Rg ≃18 kpc) (Chini&Wink 1984, Foster & Brunt 2015)

Gaia astrometric distance: D ≃2.5 kpc (Rg ≃10.5 kpc)

★NIR imaging

✓Instrument

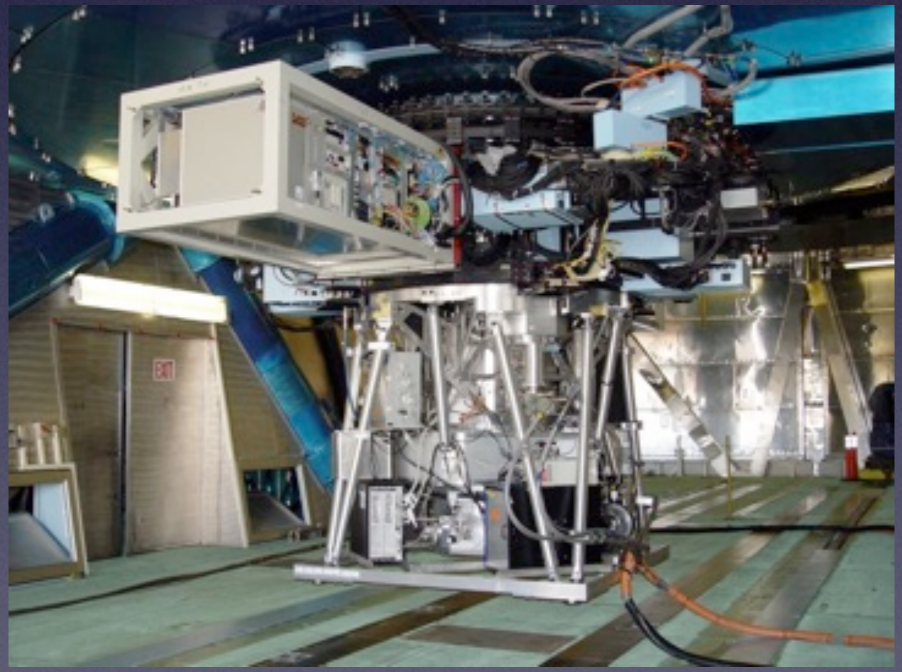
Subaru MOIRCS

✓Filters

J (1.25 μm), H (1.65 μm), Ks (2.12 μm)

Integration time: ~500–1000 sec

Limiting magnitudes Ks=20.5 mag (10σ)



(Ichikawa+2006, Suzuki+2008)

Web release on July 5, 2023
Introduced in AAS Nova
Used as a picture of Subaru calendar 2024

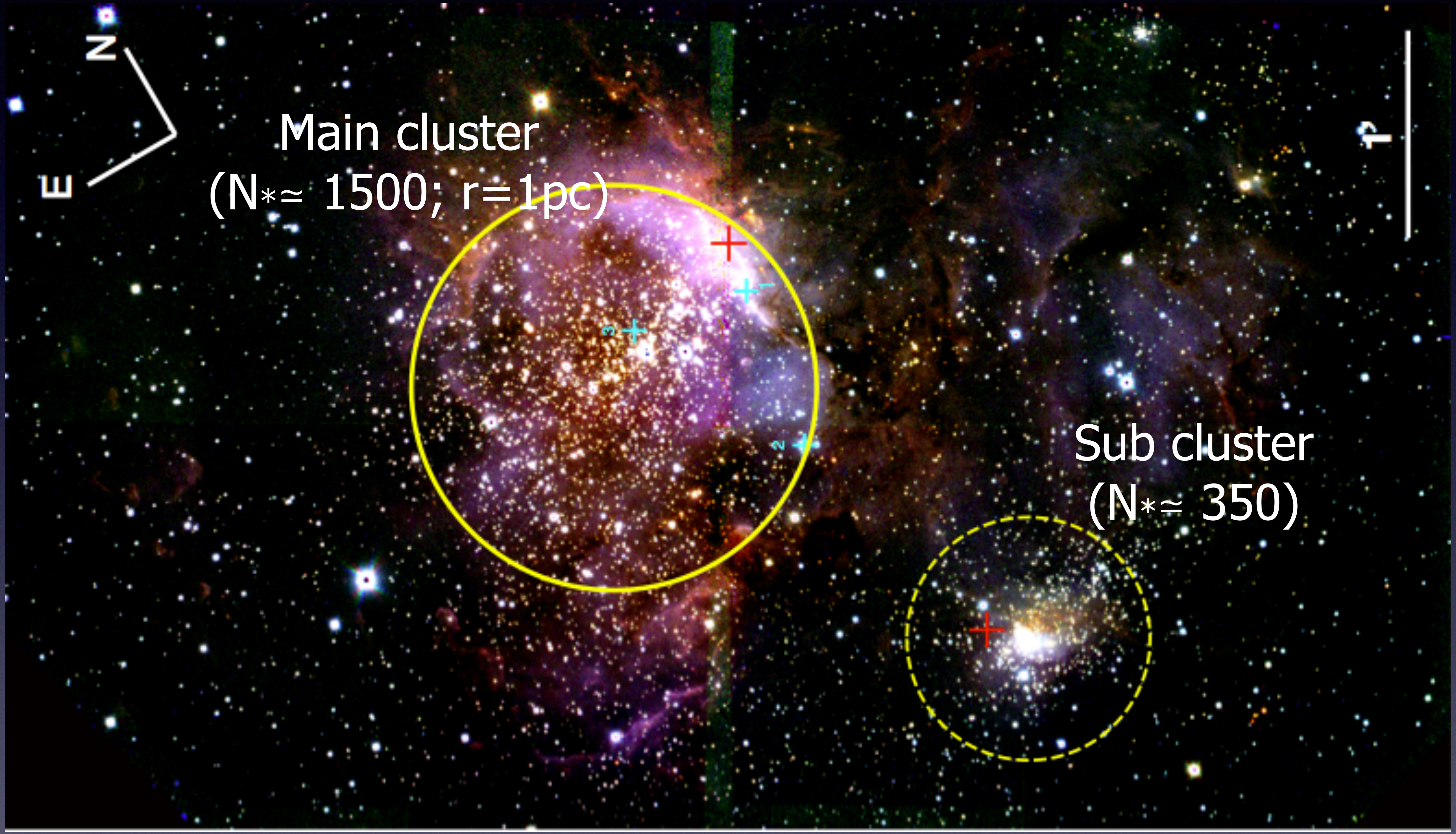
Obtained NIR images

The largest star-forming regions in the outer Galaxy

Two clusters with a large number of cluster members are identified

Web release on July 5, 2023
Introduced in AAS Nova
Used as a picture of Subaru calendar 2024

Obtained NIR images



The largest star-forming regions in the outer Galaxy

Two clusters with a large number of cluster members are identified

Derived S209 Clusters' IMF

★Results of KLF fitting

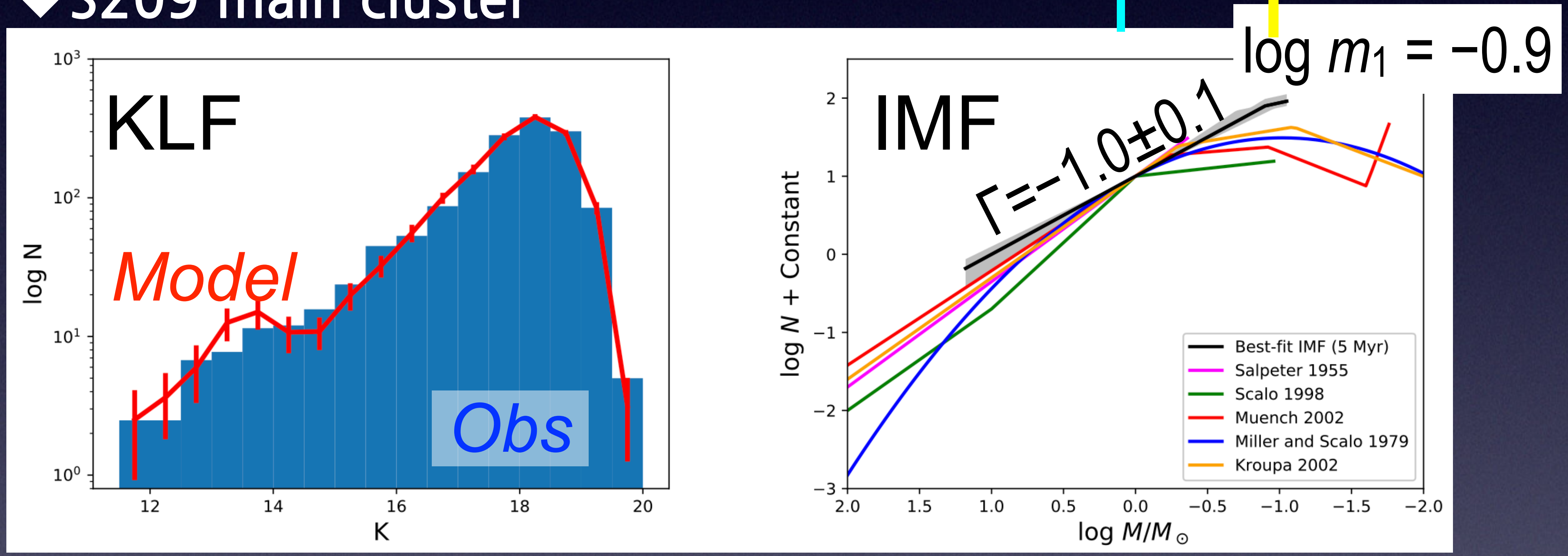
✓The parameters of the best-fit IMF for main/sub clusters

Assuming the Power-law IMF

$dN/d\log m = M^{*\Gamma}$

◆S209 main cluster

M_{lim}(LMC/SMC)~1M⊙ M_{lim}~0.1M⊙



(Yasui+2023)

The obtained IMF suggests

- Slightly top-heavy high-mass slope (Γ=−1.0±0.1 Cf. Salpeter Γ=−1.35)
- Low break mass (≃0.1 M⊙) → Low characteristic mass (Mc <0.1 M⊙)?

Summary

★IMF in a low-metallicity environment in the Galaxy

✓NIR imaging of the largest star-forming region with high spatial resolution
- **Resolved detection of individual source**
- Mass detection limit of ≃0.1 $M_\odot$

✓Derived IMF using IMF + ***age*** as parameters from KLF fit
- Confirmed that the estimates of cluster ages are reasonable
- The obtained IMF suggests
  - The high-mass slope (Γ_1) is **slightly top-heavy**
  - The break mass (m_1) is slightly smaller (~0.1 $M_\odot$)?
- Found that the method used here can obtain IMFs with high accuracy for large clusters, but is difficult for small clusters due to large uncertainties
  → Derive IMF statistically for the already acquired data of ~10 star forming regions for the next step

The IMF for young star-forming regions has been derived on a cluster scale with high spatial resolution in a low-metallicity environment for the first time.

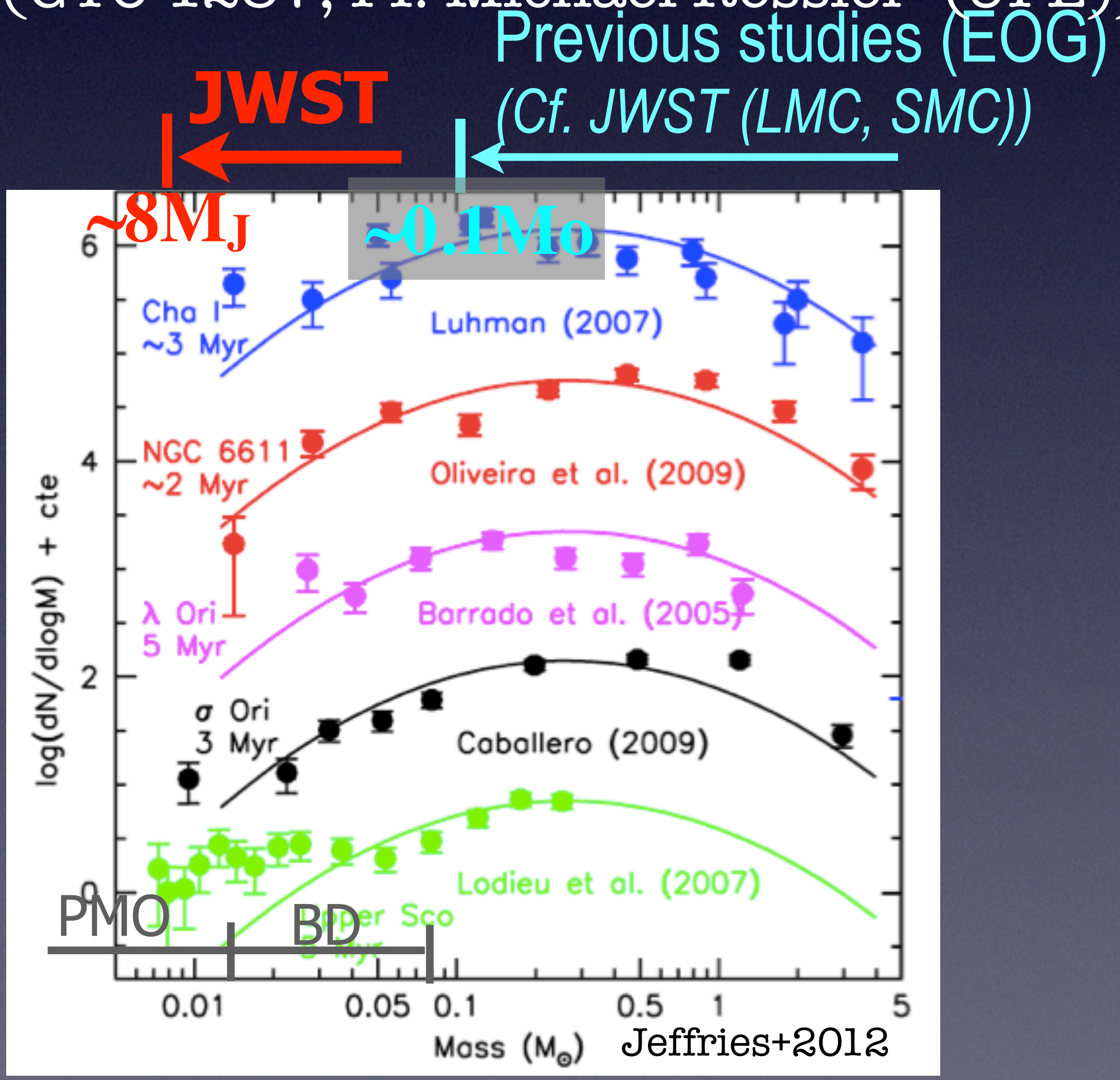
Future prospects

✓JWST

Quite high sensitivities, but the spatial resolution is comparable to existing telescopes.
→ Still focus on the outer Galaxy

Down to the very low-mass end

NIR/MIR imaging planned for GTO
(GTO 1237; PI: Michael Ressler (JPL))

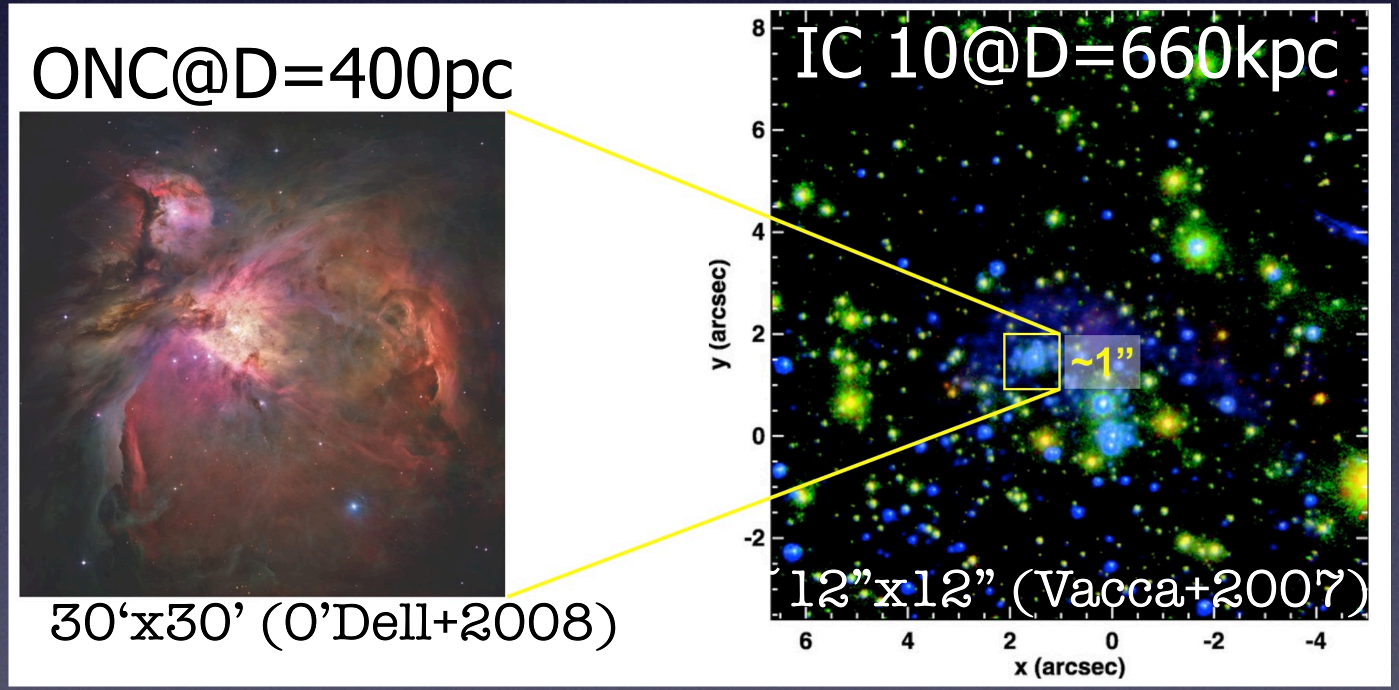


✓TMT

Quite high spatial resolution (Δθ~0".01 w/AO) will enable us to extend spatially resolved studies to **the Local Group** for the first time.

→Mass detection limit of < 1M⊙ (K~27 mag)

For 1 Myr-old targets at D=770kpc,
~0.1 M⊙ (Av=0mag) / ~0.5 M⊙ (Av=10mag)



(Yasui+2020)

Heavily dependent on how effective the AO systems on the ELTs will work.