Star formation in the extreme outer Galaxy

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ABSTRACT

- **We are planning JWST MIRI/NIRCam (λ = 1.15−21 μm) imaging of young (<1Myr) star-forming regions in the extreme outer Galaxy (EOG) with Rg≧ 18kpc as a part of a Guaranteed Time Observation (GTO1237; PI: Michael Ressler (JPL)).**
- **The EOG has a very different environment from that in the solar neighborhood since it has a much lower gas density, lower metallicity, and small or no perturbation from the spiral arms. The environment is similar to that of nearby dwarf galaxies, damped Lyman-α systems, and the early stage of the formation of the Galactic disk.**
- **The sensitivity and spatial resolution of JWST will enable us to study star- and planet-forming processes in the EOG to the same depth that previous missions (e.g., *WISE* and *Spitzer*) have studied the solar neighborhood. We expect to detect sources down to 8 M_J and to determine whether stars down to 0.5 M⊙ still have disks.**
- **We will investigate main triggers of star formation in such environments, derive IMF down to the very low-mass end (< 0.1 M⊙), and investigate the circumstellar disk evolution.**

What is the EOG?

EOG (Extreme outer Galaxy)

The region with Rg ≳ 18kpc (*Fig. 1*⬇)

EOG has significantly different environments from the solar neighborhood

- Low metallicity (*Fig. 2*⬇)
- Very low gas density
- No or very small perturbation from the spiral arms

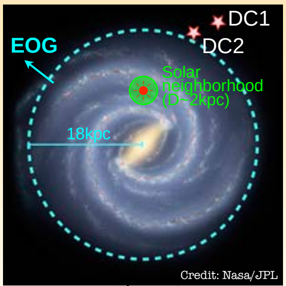

Fig. 1. Top view of our Galaxy

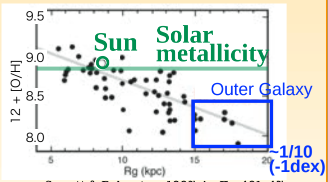

Fig. 2. Metallicity gradient

Good alternative targets to nearby dwarf galaxies

Laboratories for studying the epoch of Galaxy formation

(e.g., Ferguson, A. M. N., Gallagher, J. S., & Wyse, R. F. G. 1998, AJ, 116, 673; Kobayashi+2008, ApJ, 683, 178)

Planned JWST observation

Target star-forming regions

✦Digel Cloud 1 (DC1) and Cloud 2 (DC2)

Most distant known star-forming regions

(DC1: Izumi+2014, ApJ, 795, 66; DC2: Kobayashi & Tokunaga 2000 ApJ, 532, 423)

- Located at Rg≳20 pc (D≳12kpc) (⬅ *Fig. 1*)
- Low abundance: [O/H] = −0.7dex for DC2 (Lubowich+2004)
- Each cluster has two stellar clusters (N*~100) (Yasui et al. 2008 ApJ, 675, 443; Izumi+2014, ibid)

Stellar clusters and dense gas cores can be covered simultaneously (*Fig. 3* ➠)

Very Appropriate targets for parallel observation with MIRI/NIRCAM

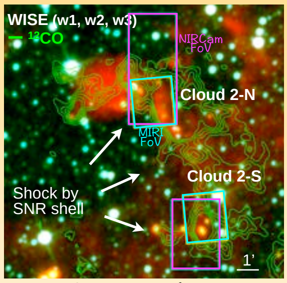

Fig. 3. Wide area image of DC2

MIRI/NIRCam imaging

✦Filters & sensitivities

✓MIRI *F770W, F1280W, F2100W*

[F1280W]$_{AB}$=22.5 mag (17.3mag in Vega)

→Mass detection limit of down to **0.5M⊙**

Corresponding to the lower limit of WISE sources at D=500pc

✓NIRCam *F115W, F150W, F200W (Short)*
F356W, F444W, F405N(Brα) (Long)

[F444W]$_{AB}$=25 mag (23mag in Vega)

→Mass detection limit of down to **8M_J**

✦Spatial resolution

✓MIRI
~0.4”@10μm

✓NIRCam
Short: ~0.06”@2μm
Long: ~0.13”@4μm

Each source can be sufficiently resolved
Cf. Δθ=0.1” corresponds to 1000AU@10kpc

Quite high sensitivities and high spatial resolution will enable us to study star- and planet-forming processes in the EOG on the same basis as solar neighborhood for the first time.

Science cases

i) Triggered star formation

What are the major processes by which stars formed in the early epoch of galaxy formation?

Previous works: From large scale unresolved multiwavelength data, triggered star forming activities are suggested:

- High-velocity cloud impact for DC1 (Izumi+2014, ibid)
- A supernova event for DC2 (*Fig. 3*➚) (Kobayashi+2008, ibid)

JWST study: Comprehensive data set from NIR to MIR with high spatial resolution can classify the evolutionary stages of each YSOs and reveal spatial distribution of the classified YSOs.

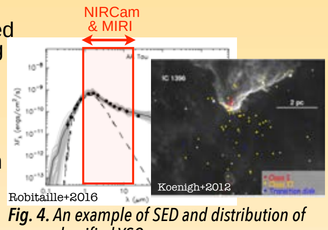

Fig. 4. An example of SED and distribution of classified YSOs

→ **The many additional YSOs will help to clarify the relationship of DC1 and DC2 with their surrounding environment and to suggest possible formation mechanisms.**

ii) Initial Mass Function (IMF)

IMF is one of the most fundamental parameters which determines physical and chemical evolution of stellar systems.

Previous works: . Based on the fitting of K-band luminosity functions (KLFs), IMF down to substellar mass regime (~0.1M⊙) does not show significant differences from that in the solar neighborhood. (Yasui+2017)

JWST study: IMF in this low metallicity environment down to the very low-mass end (< 0.1 M⊙) can be derived.

The IMF in the very low mass end may be a sensitive function of formation environment. (Lada & Lada 2003, ARAA, 41, 57)

→**Will be the first study of brown dwarfs (BD) and planetary mass objects (PMO) in low-metallicity environments and will enable us to investigate whether they are common in such environments.**

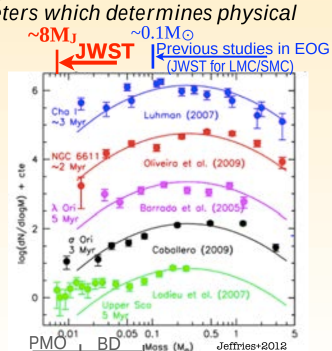

Fig. 5. Variations of IMF in very low mass range

iii) Lifetime of protoplanetary disks

Disk lifetime is one of the most fundamental parameters directly connected to planet formation probability

Previous works: The fraction of stars with a K-band excess (r ≲ 0.1 AU) is significantly lower (~1Myr) than those in the solar neighborhood (~5Myr).

→ A metallicity dependence of the disk lifetime is suggested (Yasui+2009, ApJ, 705, 54; Yasui+2010, 723, L113)

JWST study: We will gain new insights into outer (~0.1–5 AU) circumstellar disk evolution. Whether stars down to 0.5 M⊙ still have disks can be distinguished. (*Fig. 6*➡)

→ **Quantitative comparison of the disk lifetimes in low-metallicity regions with those in the solar neighborhood that have been extensively characterized by *Spitzer* will be possible.**

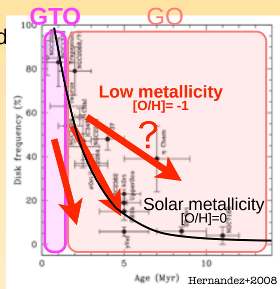

Fig. 6. Evolution of MIR disk fraction using Spitzer for nearby clusters

Future prospects

In future Guest Observations (GO), we will aim for the following science cases:

- By observing ***more evolved star forming regions*** with ages of >3Myr, **disk lifetime** in low-metallicity environments can be estimated (in *Fig. 6*⬆)
- By observing ***star forming regions having a large number of members***, e.g., N*>1000, the **IMF** in low-metallicity environments can be conclusively established with high S/N (*Fig. 7* ➠)

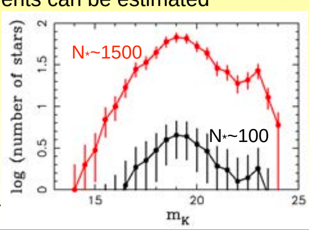

Fig. 7. KLFs that are used for deriving IMF by model fitting.