

Spiral morphology in an intensely star-forming disk galaxy more than 12 billion years ago

Tsukui. Takafumi , Iguchi. Satoru et al. 2021

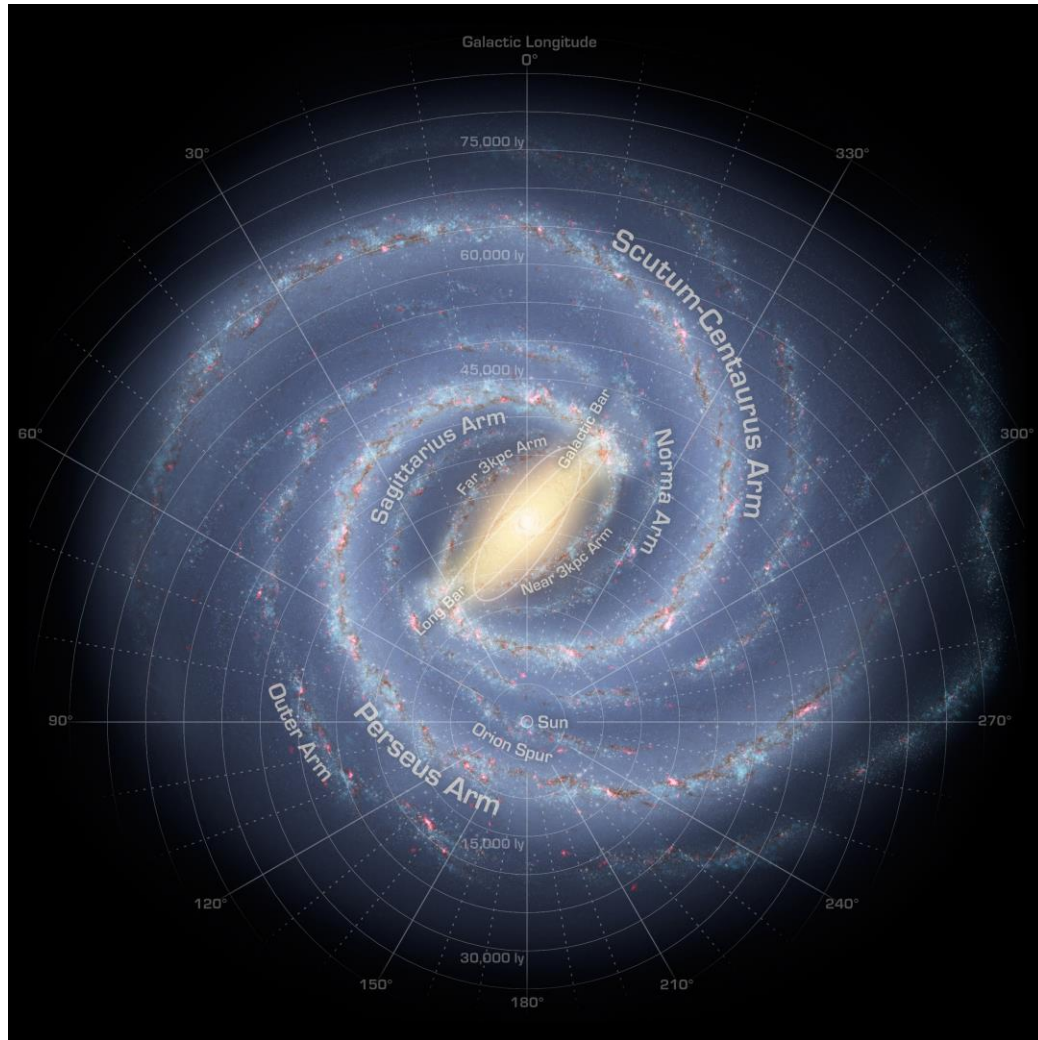
Shengyu Yan

2020.12.24

Outline

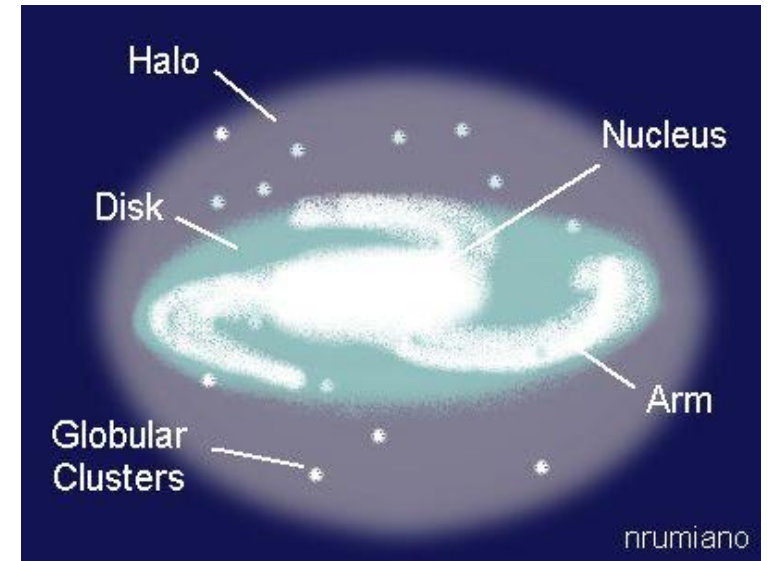
- Background of this Work
 - Structure of Spiral Galaxy
 - [CII] 158 μm : A Powerful Technique in ISM Detection
 - Previous Observations
- Observation of BRI 1335–0417
 - Basic information of BRI 1335–0417
 - ALMA Observation with higher Spatial Resolution
- Summary & Question

The Structure of Spiral Galaxy



The Milky Way Galaxy

NASA/JPL-Caltech/R. Hurt (SSC/Caltech)



Components of Spiral Galaxy

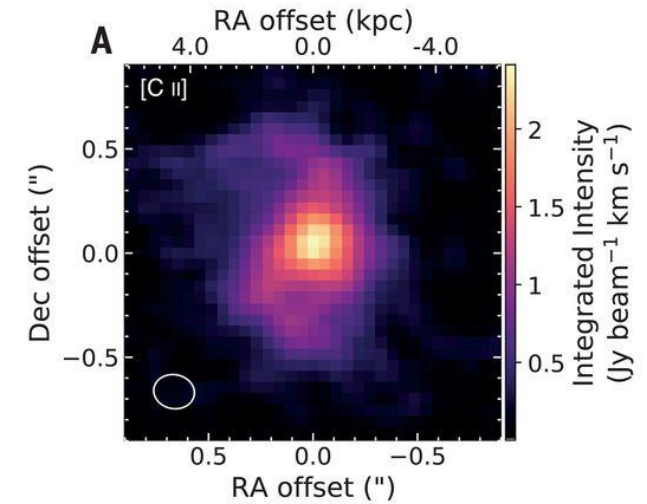


NGC 1300 in infrared light.

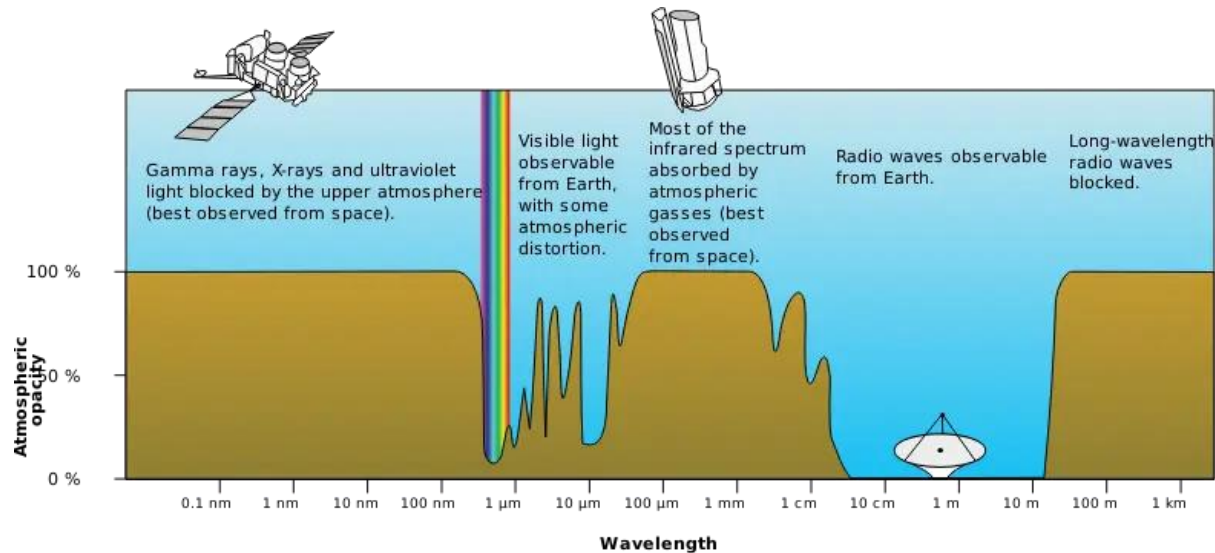
High Spatial Resolution Image



Atacama Large Millimeter and Submillimeter Array (ALMA)



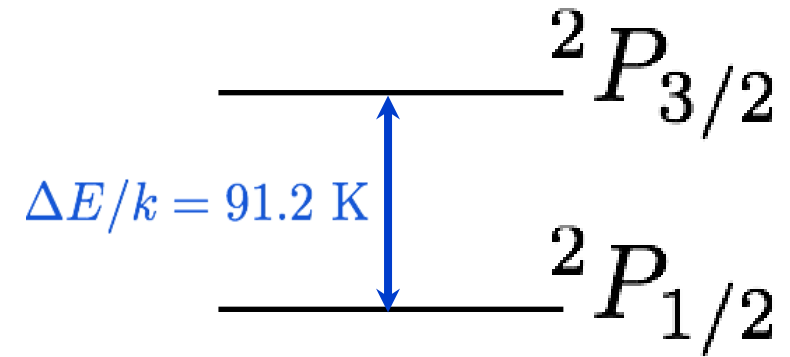
BRI 1335-0417 taken by ALMA



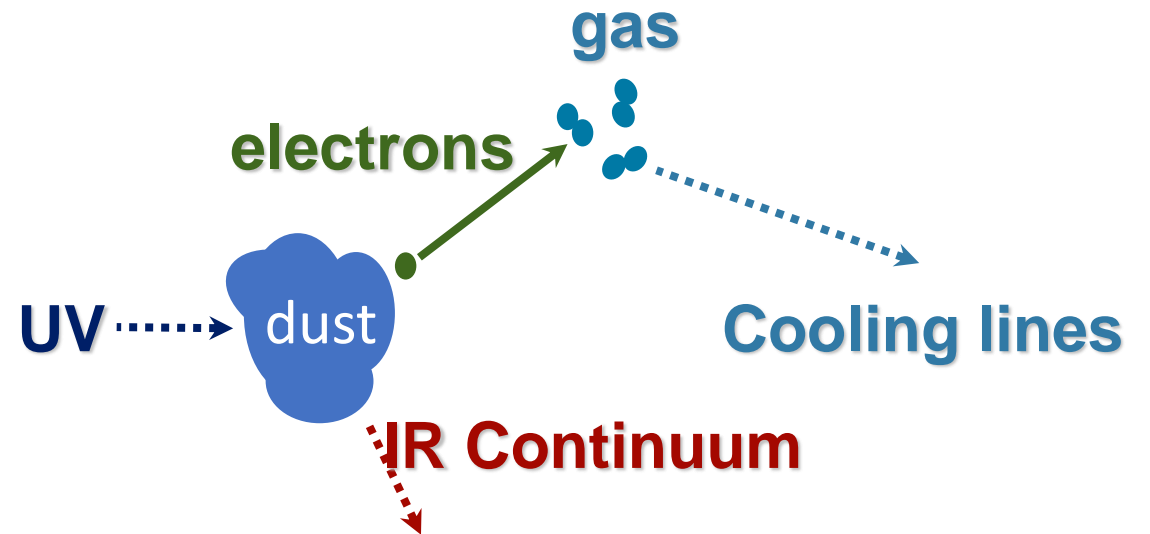
Spiral galaxy NGC 6384 taken by HST

High-redshift ISM Tracer

- Carbon monoxide
 - Polar molecule
 -
- [CII] 157.74 μm line

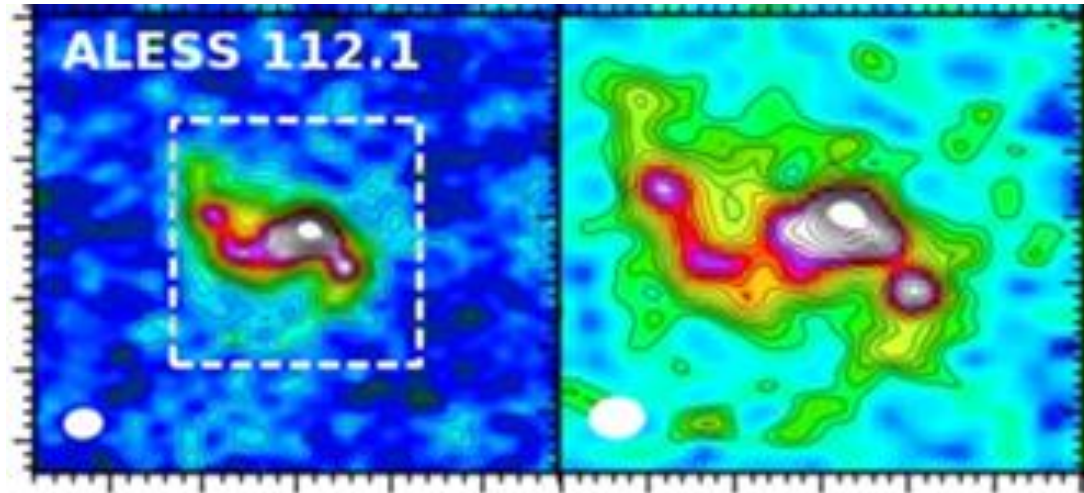


Fine structure of the ground state of C+

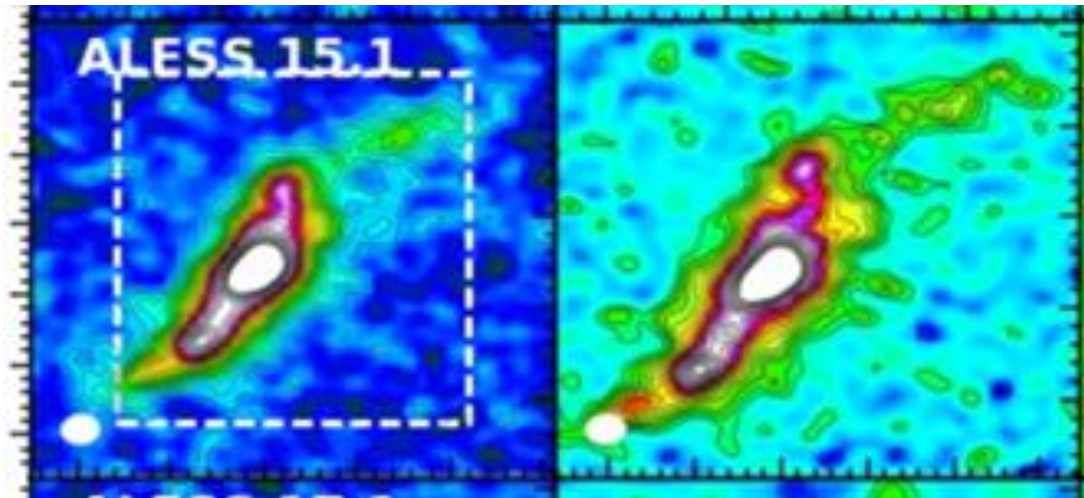


UV to IR energy transfer via photoelectric effect

Previous Observation

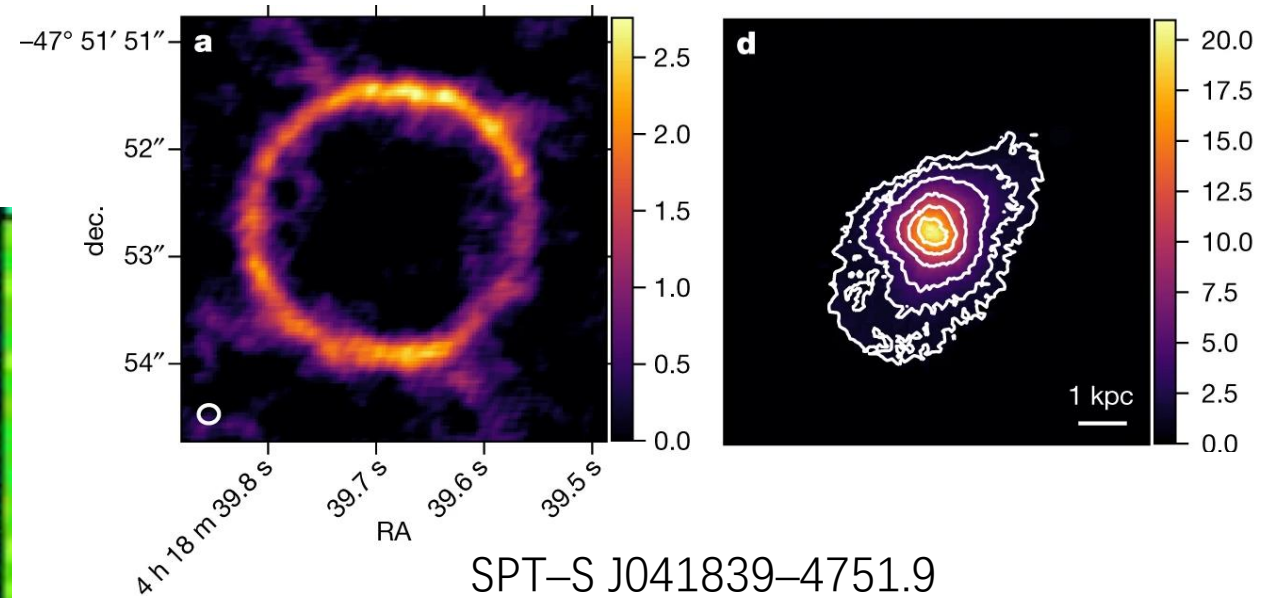


ALESS 112.1 $z=2.315$

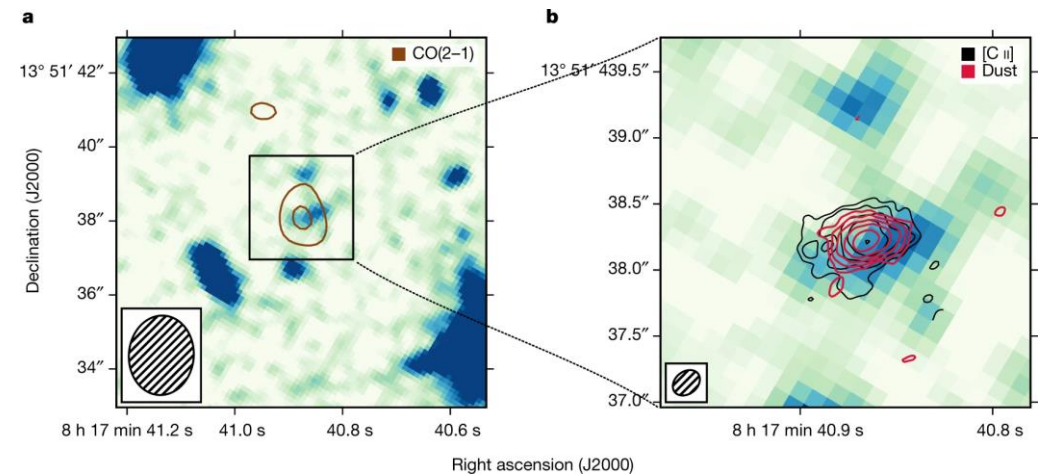


ALESS 15.1 $z=2.67$

J. A. Hodge et al. 2019

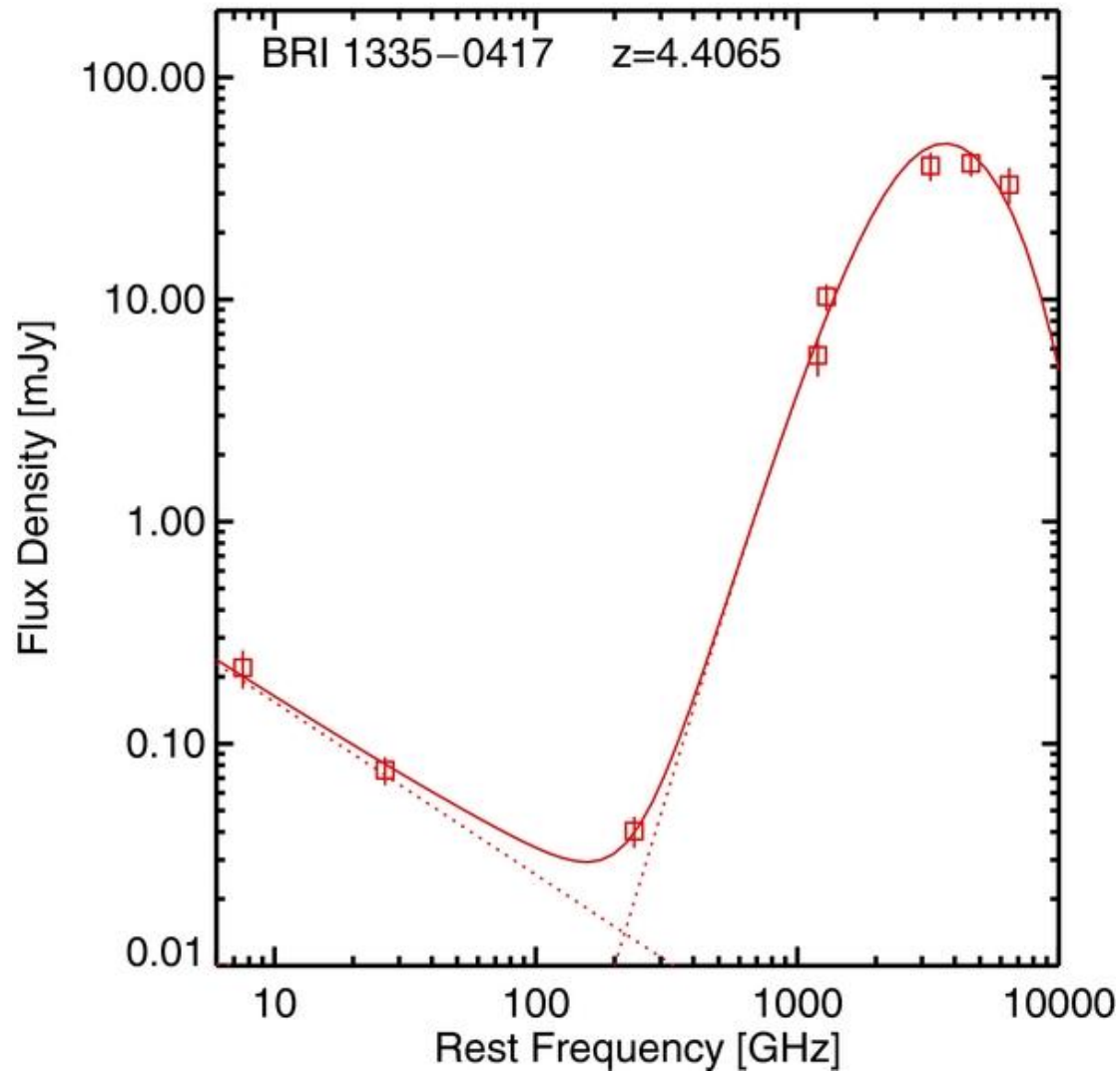


SPT-S J041839-4751.9
cold disk $z=4.2248$ F. Rizzo et al. 2020



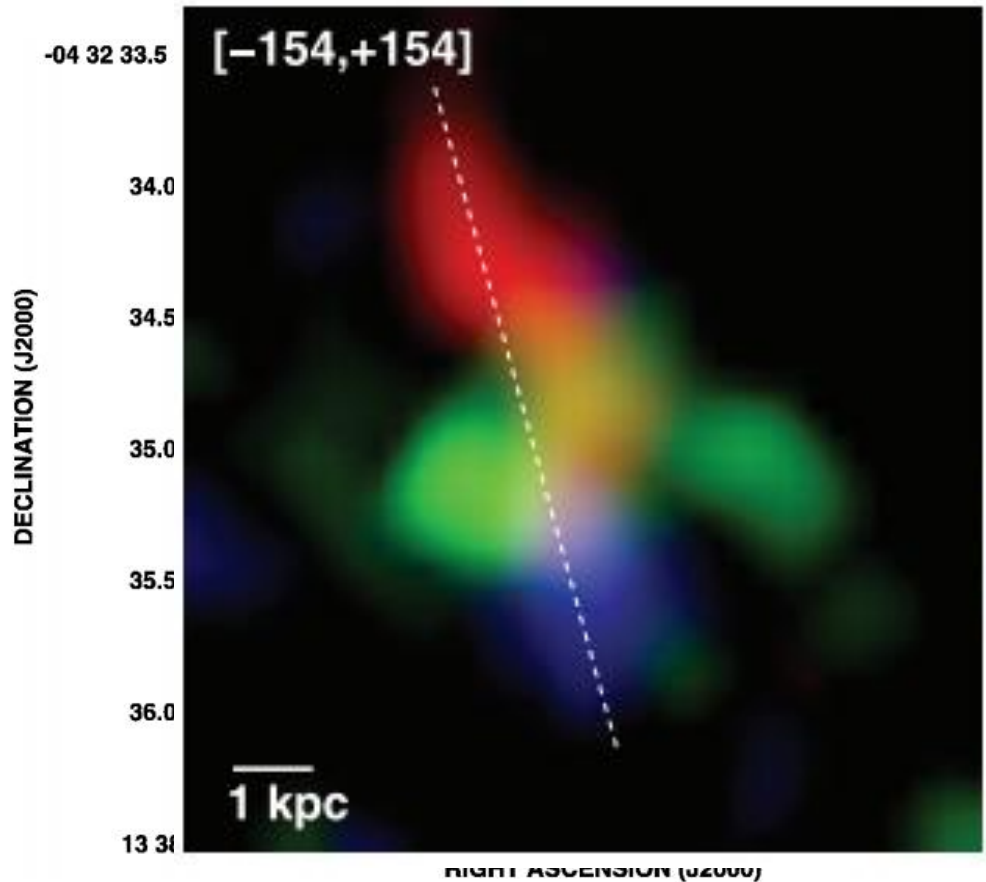
DLA0817g
 $z\sim 4.26$ M. Neeleman et al. 2021

Basic information of BRI 1335–0417

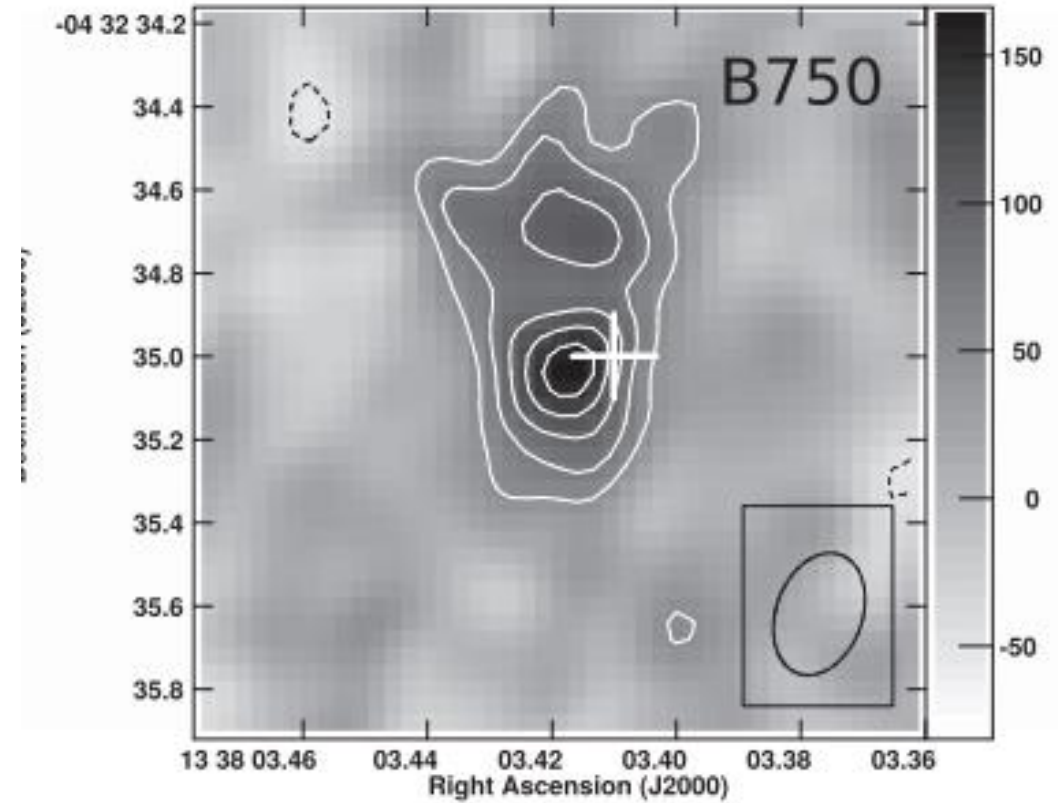


- Redshift $z=4.4074 \pm 0.0015$
 - S. Guilloteau et al. 1998
- Hyper-luminous infrared galaxy
 - $L_{\text{FIR}} = 3.1 \times 10^{13} L_{\odot}$
 - Jansky Very Large Array observation
 - C. L. Carilli et al 2002
- High star-formation
 - $5040 \pm 1304 M_{\odot} / \text{year}$
 - J. Wagg 2014

Previous Observation of BRI 1335–0417



VLA map of the CO($J = 2-1$)
D. A. Riechers et al. 2008



VLA map of the CO($J = 2-1$)
G. C. Jones et al. 2016

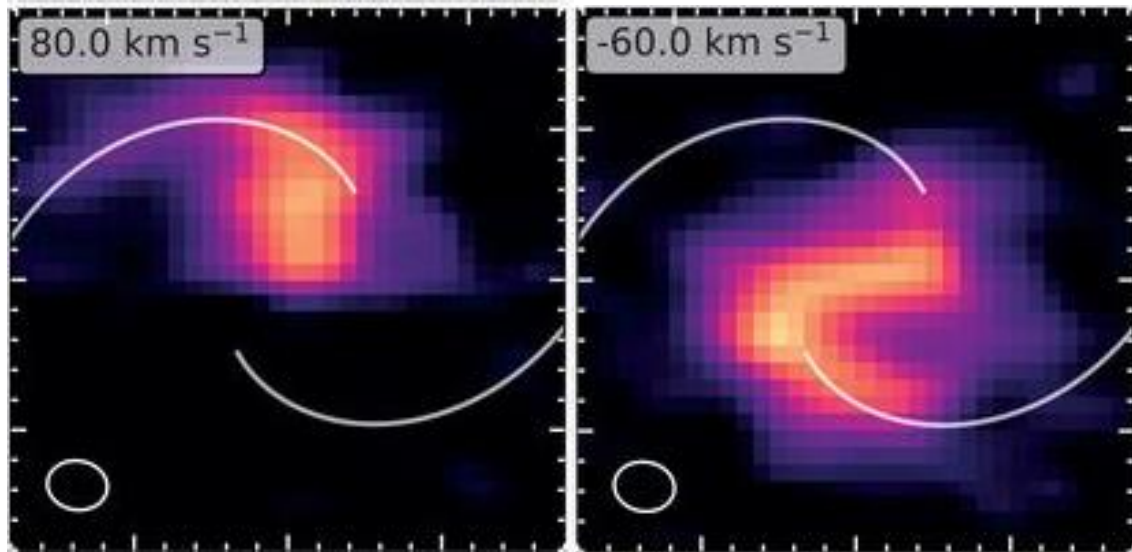
ALMA Observation with higher Spatial Resolution

Observing time: 1.0 h

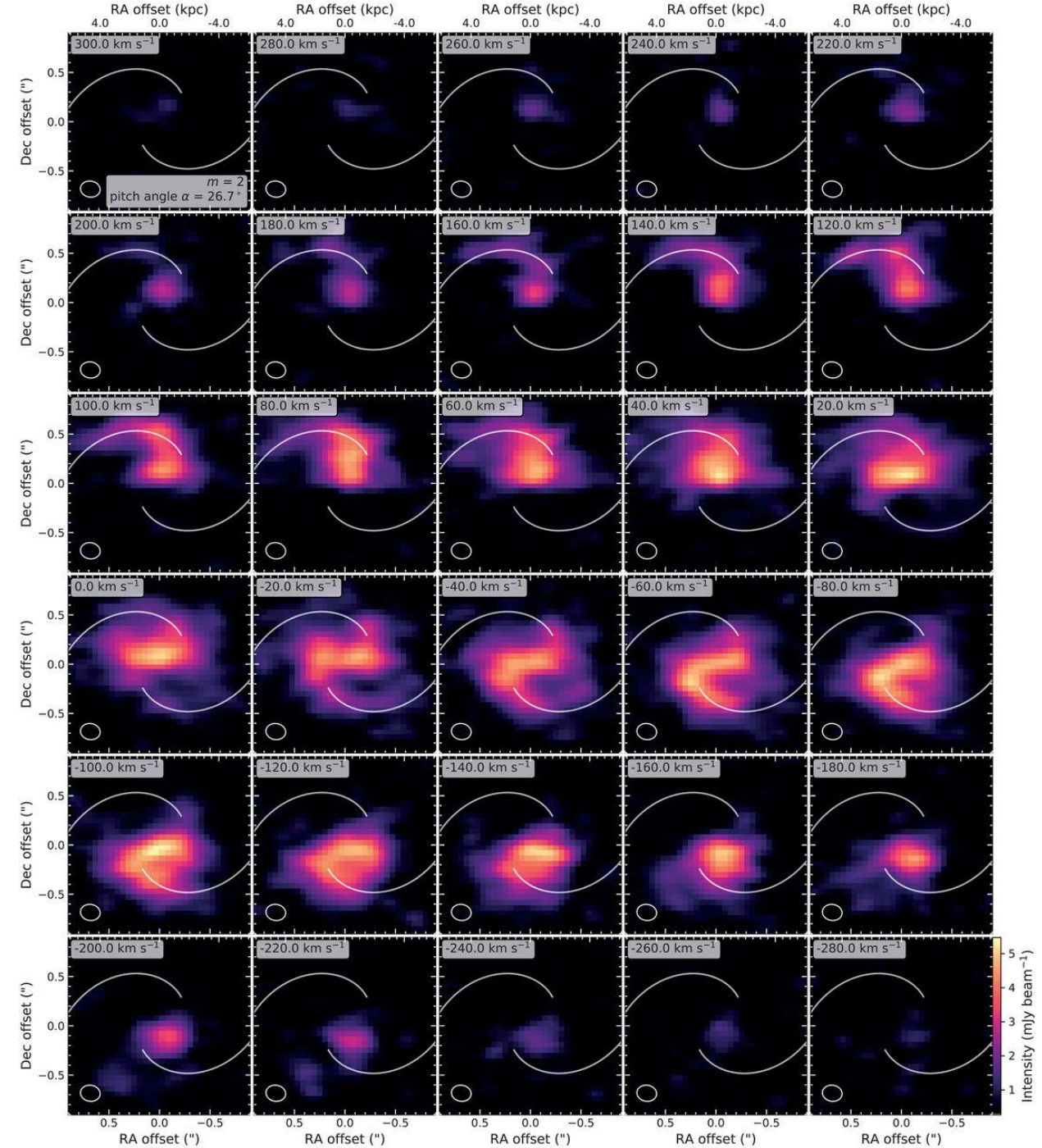
Observing band: ALMA Band 7

LSB: 337.434 GHz - 341.433 GHz

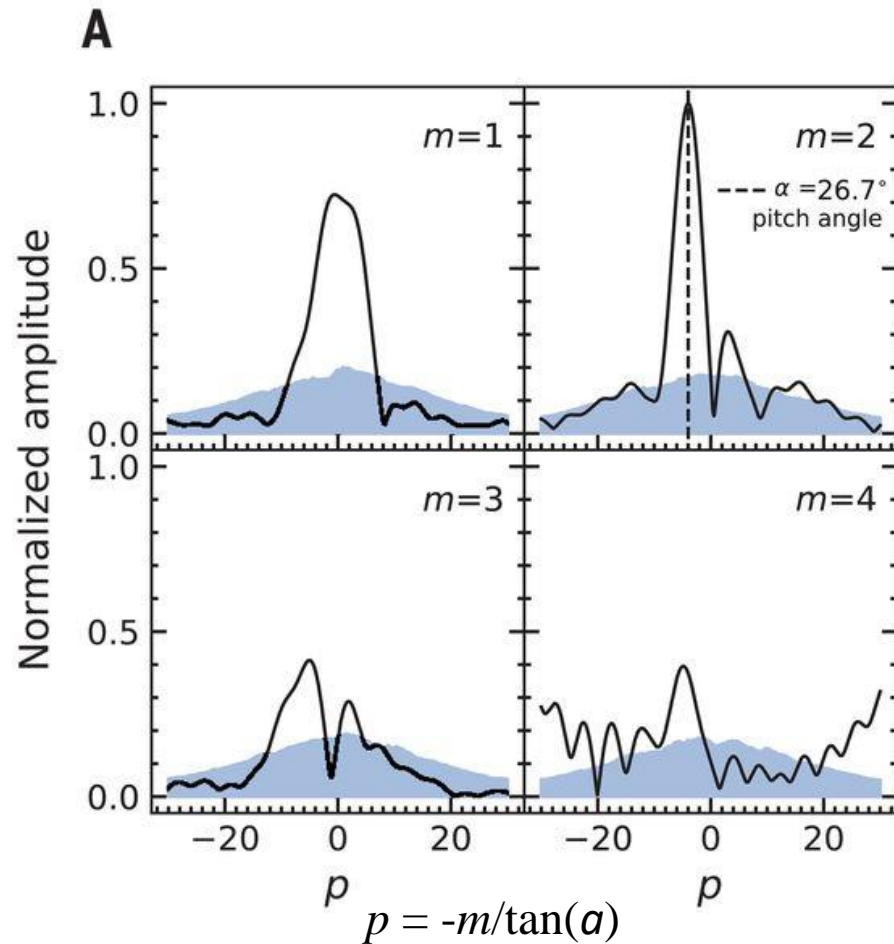
USB: 349.705 GHz - 353.271 GHz



Most prominent arm structure
Takafumi Tsukui et al. 2021

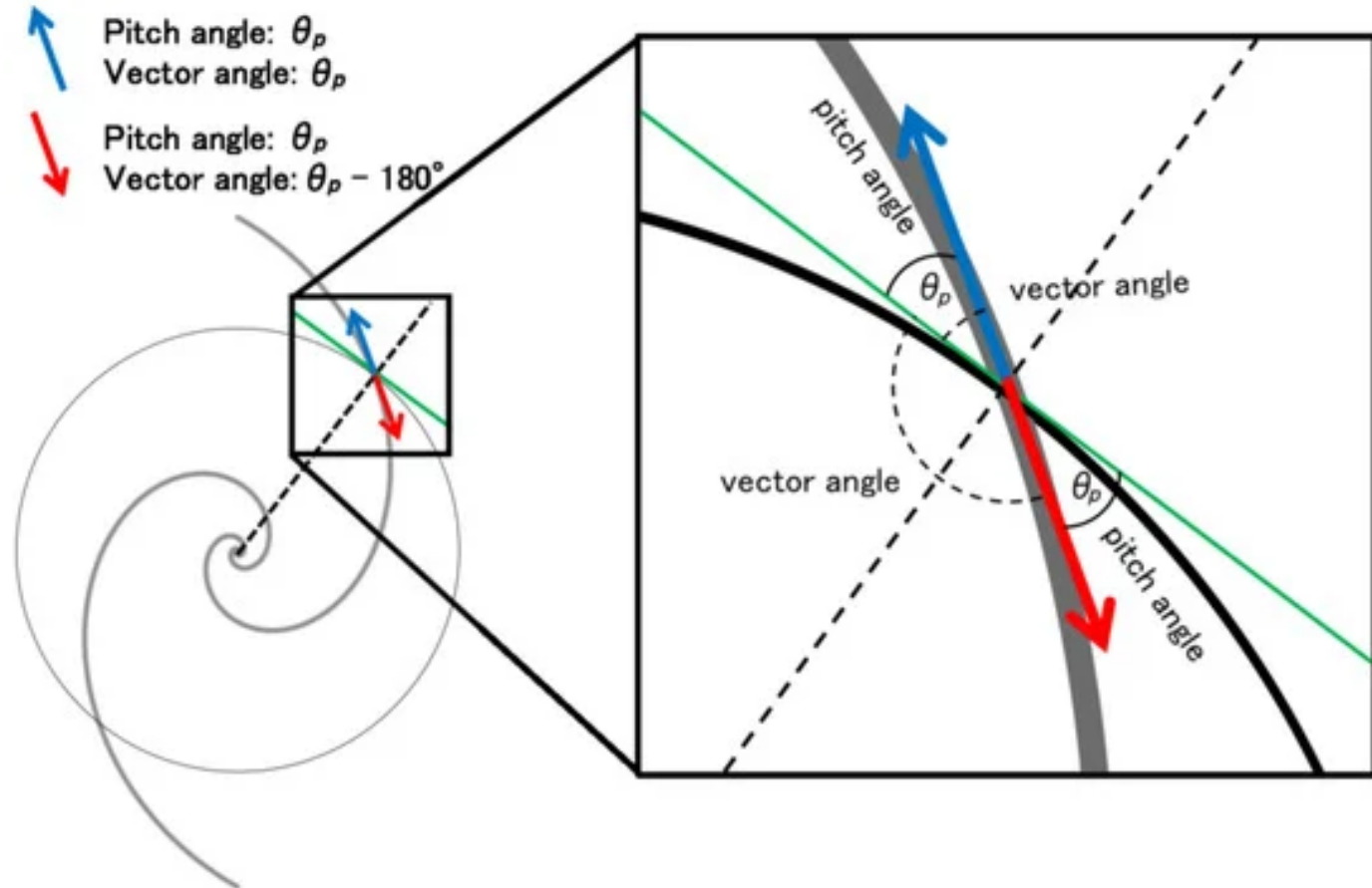


Degree of Spiral Arms

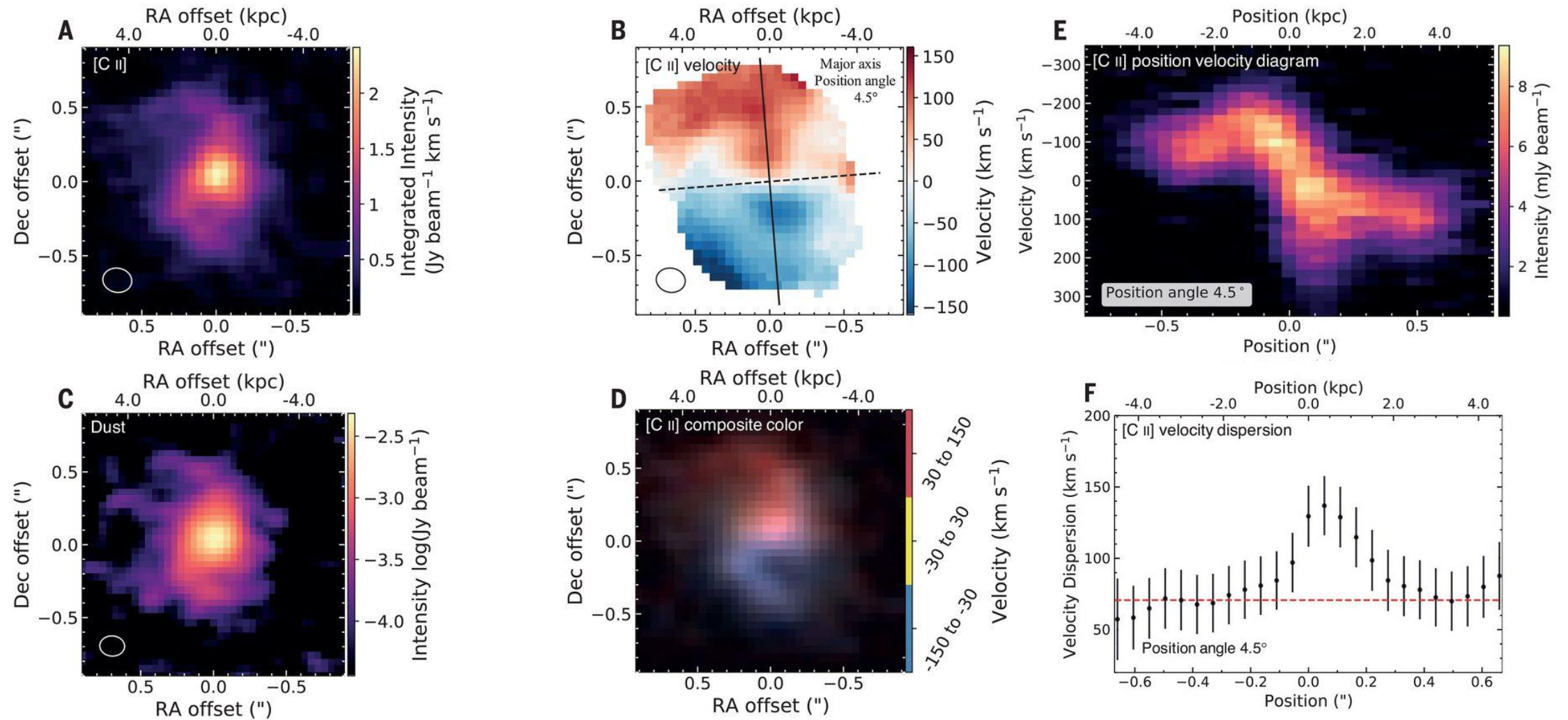


$$\rho = \rho_0 \exp\left(-\frac{m}{p}(\varphi + \varphi_0)\right)$$

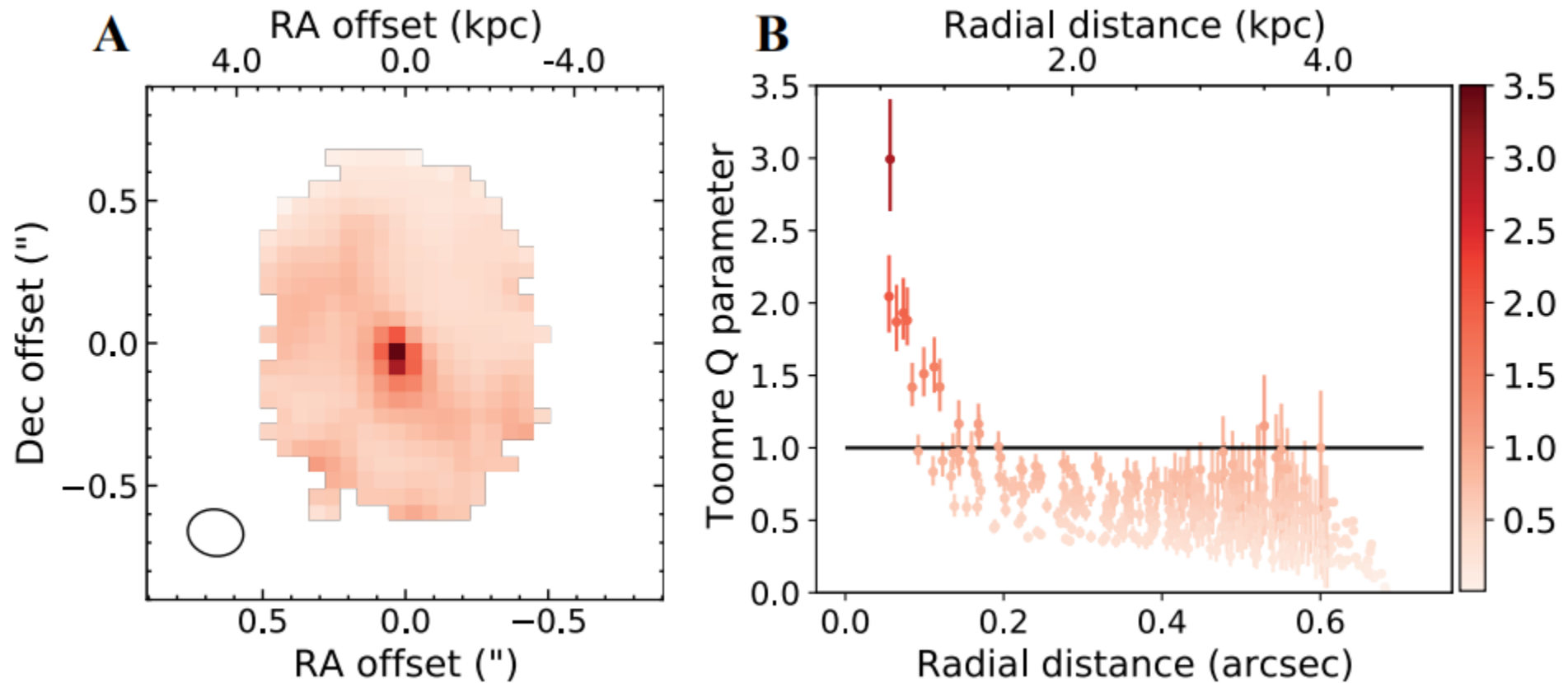
$$A(p, m) = \frac{1}{D} \sum_{j=1}^N f_j \exp\left(-i(pu_j + m\varphi_j)\right)$$



Position-Velocity Diagram



Toomre Parameter of Gas Disk



$$Q_{\text{star}} \equiv \frac{\sigma_R \kappa}{3.36 G \Sigma}, \quad \kappa = \sqrt{2 \left(\frac{v_{\text{rot}}^2}{r^2} + \frac{v_{\text{rot}}}{r} \frac{dv_{\text{rot}}}{dr} \right)}$$

Summary

- BRI 1335–0417 is a Spiral galaxy 1.4 billion years after the Big Bang.
- Star formation rate of BRI 1335–0417 is high, and it's long before the peak of cosmic star formation.
- The compact object in central bulge structure is very massive.

Possible Question

- How was this distinct spiral structure formed in only 1.4 billion years after the Big Bang
- Dose the BRI 1335–0417 have bar structure?
- The ratio of the black hole mass to the compact structure mass is 1 to 0.2. Why the ratio is much larger than the SMBH in local universe?
- Why the star-formation rate so high?