

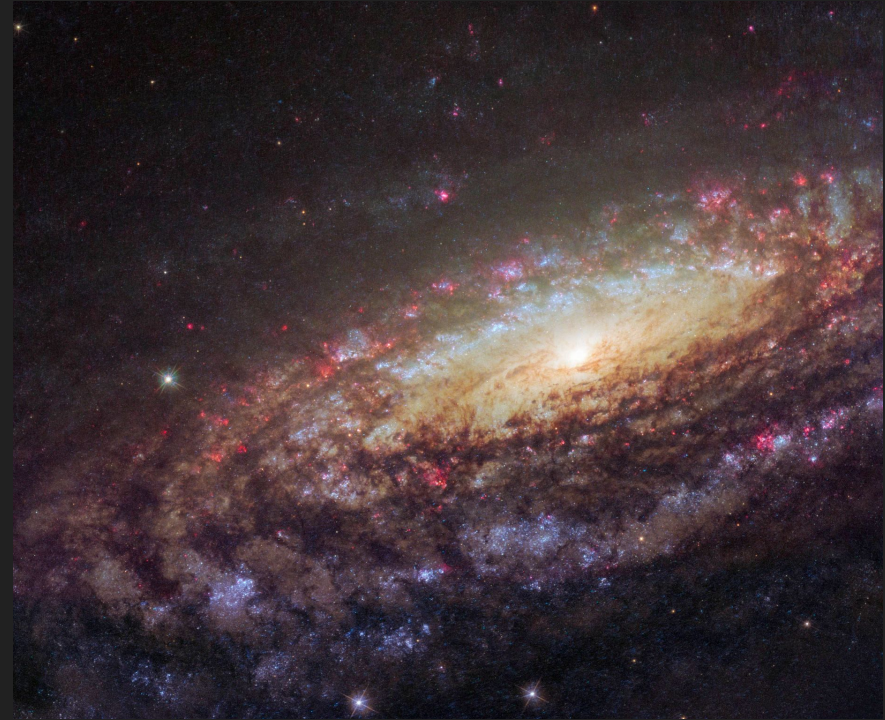
# Environmental Dependence of [CII] Emission in Ringed Galaxy NGC 7331

Sutter & Fadda, ApJ, 926:82 2022



# Outline

- Introduction
  - [CII] emission
  - NGC 7331
- SOFIA FIFI-LS [CII] map
- Environmental dependence of [CII] to other ISM indicators
  - FIR
  - PAH
  - CO
- [CII] from neutral and ionized gas
- Conclusions and future work



# Why study [CII]?

- Often the brightest observed emission line
- Detectable at high-z by ALMA
- Important PDR cooling line
- Potential SFR tracer, ISM Diagnostic

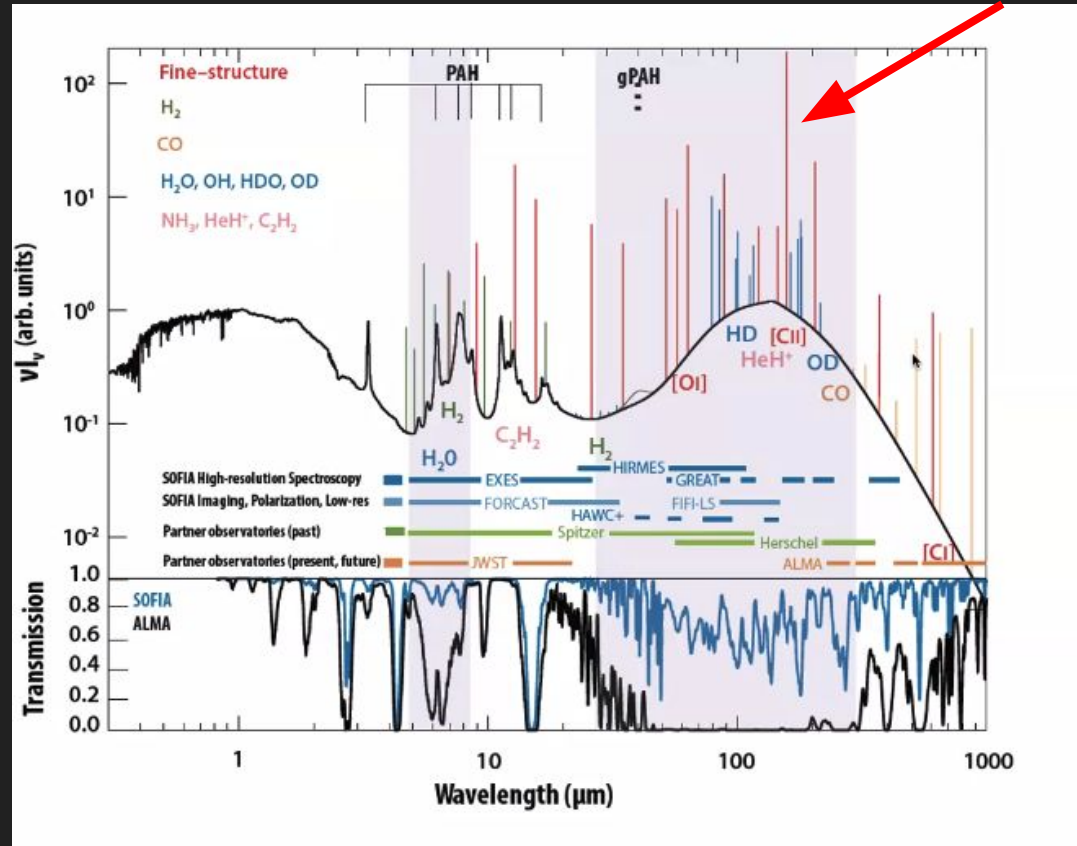


Image Credit: Science with SOFIA, Schulz 2020

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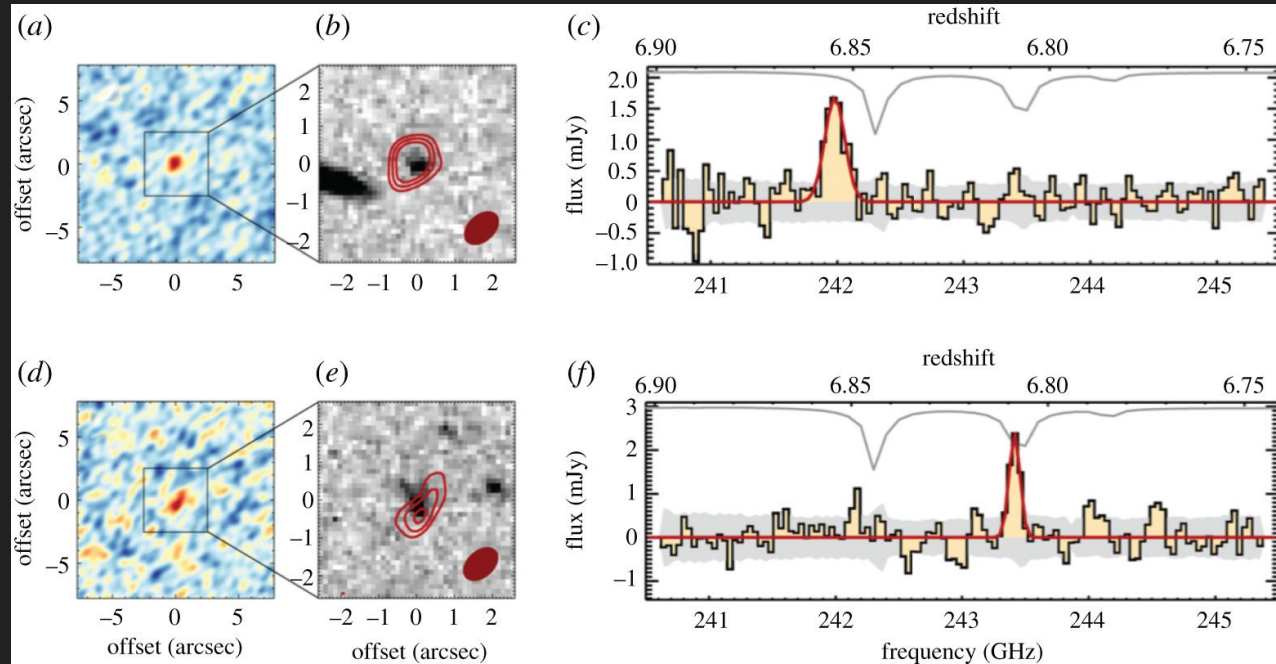


Image Credit: Hodge & da Cunha, 2020

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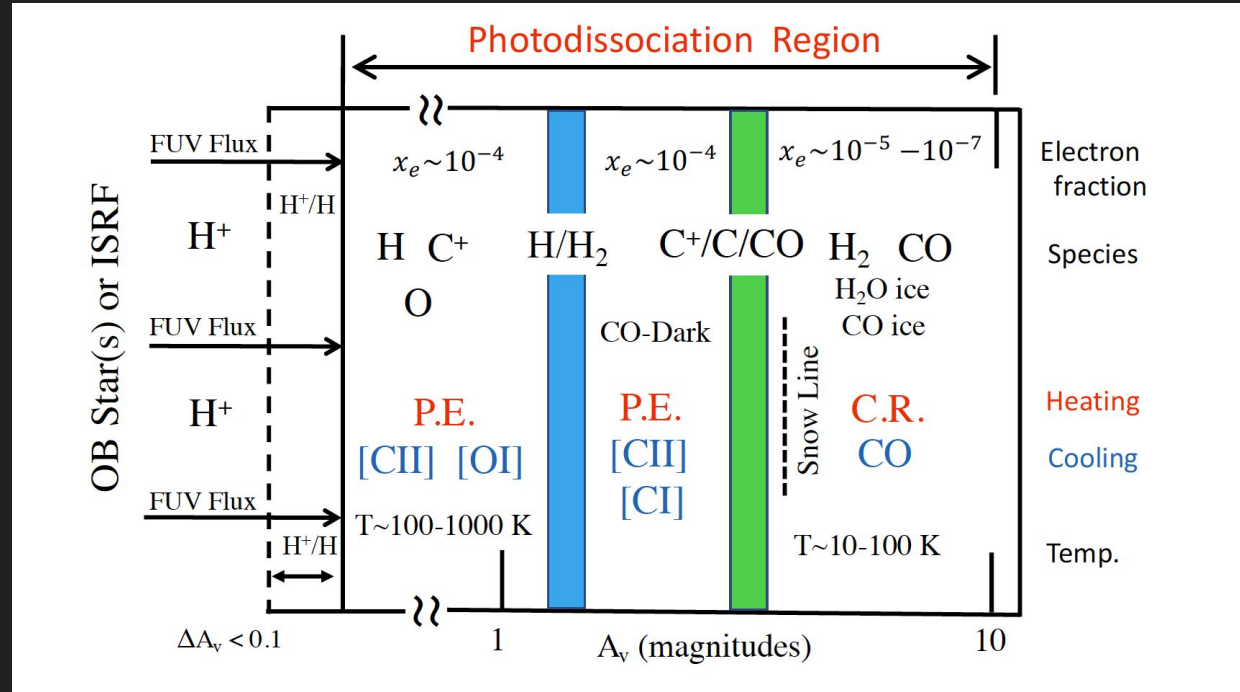


Image Credit: Wolfire, Vallini, & Chevance 2022

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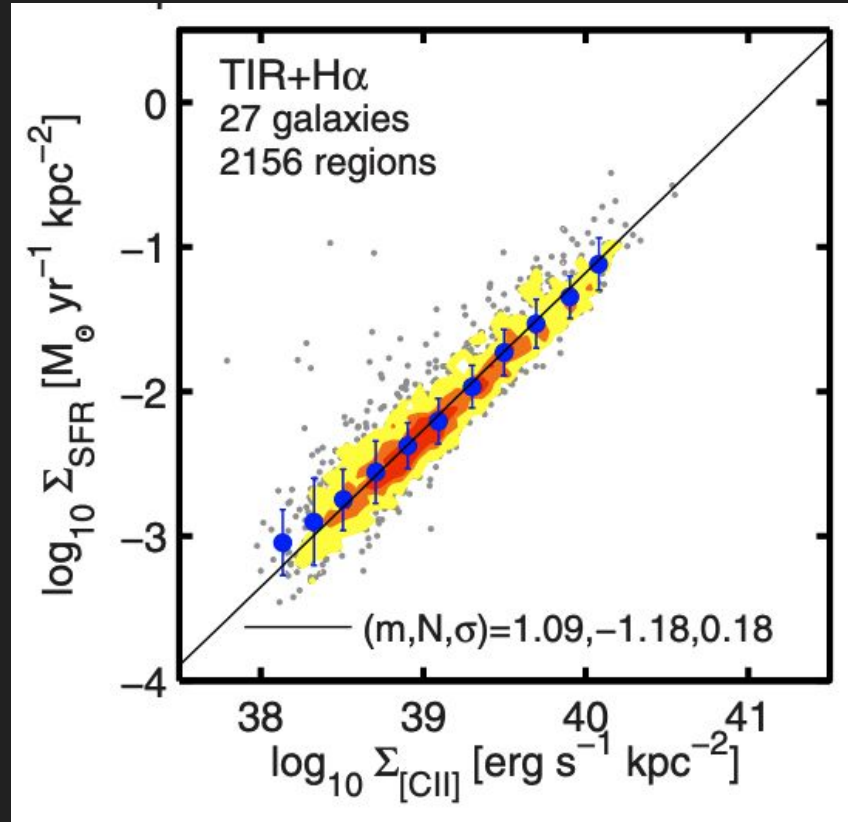


Image Credit: Herrera-Camus+2015

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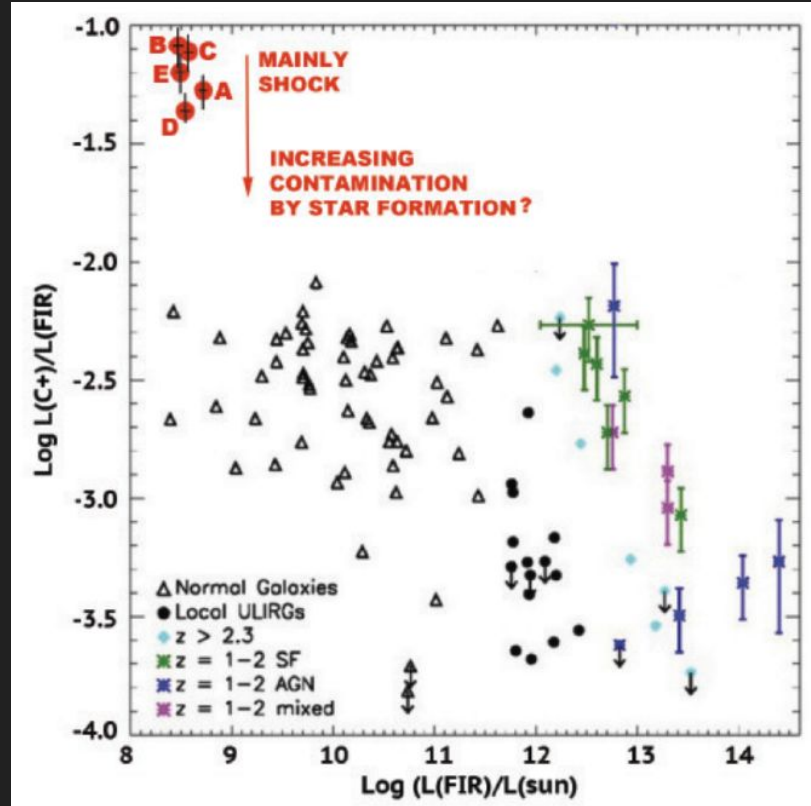


Image Credit: Appleton+2013

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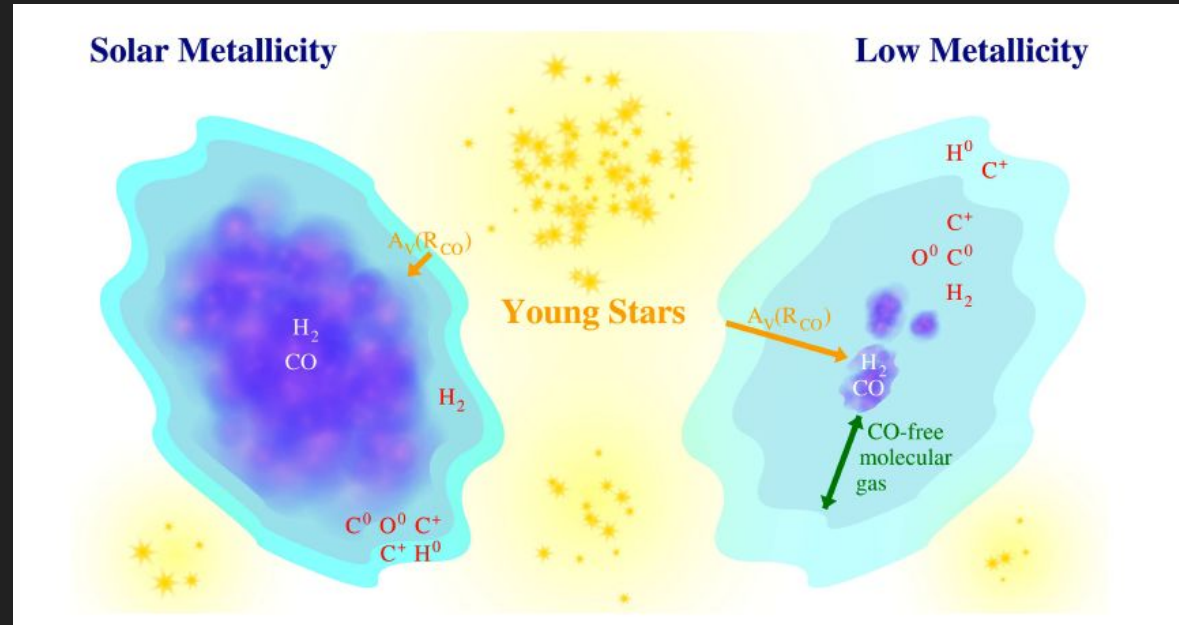
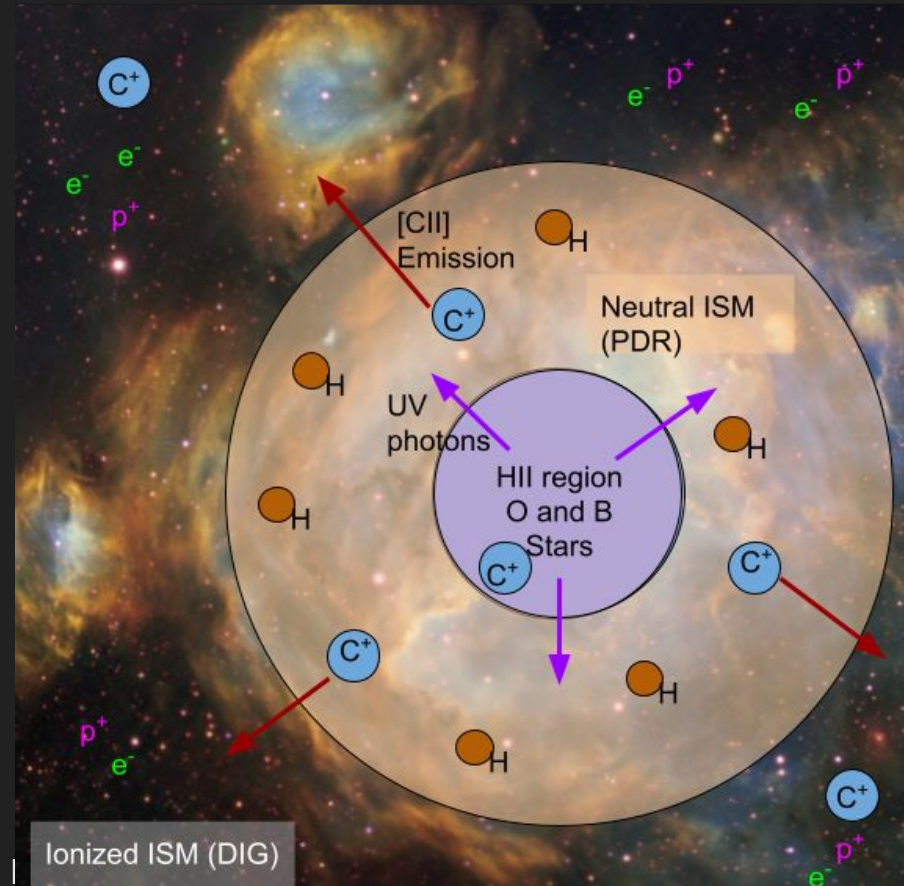


Image Credit: Madden+2020



# Issues with [CII] as a diagnostic tool

- Despite benefits of [CII], there are some unknowns
- Multiphase origins complicates [CII] observations
  - Can be excited by collisions with electrons, H atoms, or H<sub>2</sub> molecules
- [CII] deficit is observed in a variety of sources
  - Proposed causes include grain charging, [CII] self attenuation, [CII] thermalization, and many more!



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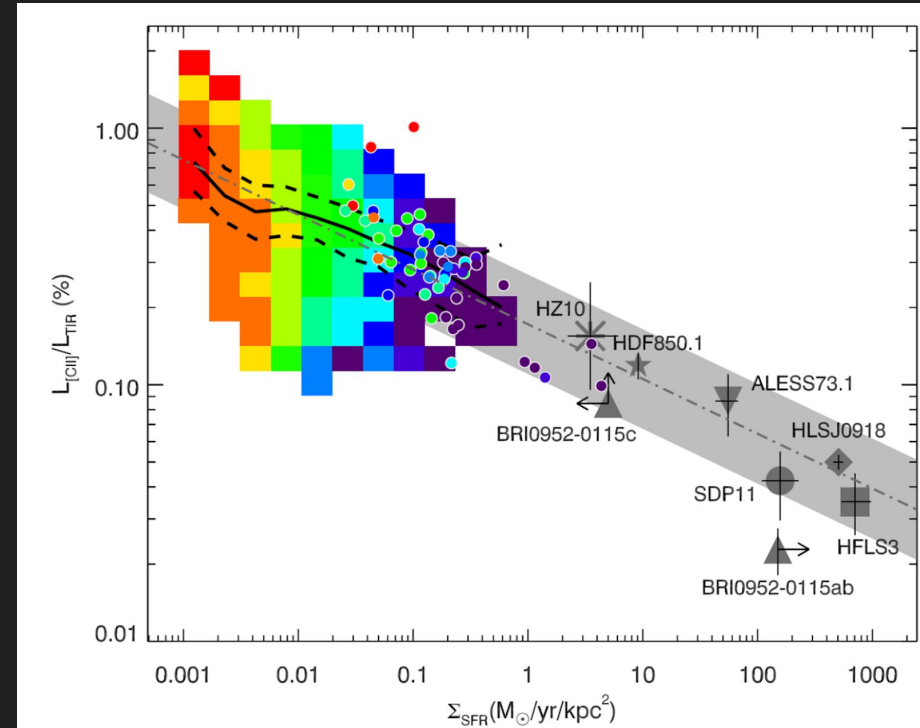


Image Credit: Smith+2017

# Why NGC 7331?

- Nearby (14 Mpc), highly-inclined ( $72^\circ$ ) galaxy
- Milky Way analog
- Molecular ring
- Wide range of archival data



# New FIFI-LS [CII] Map

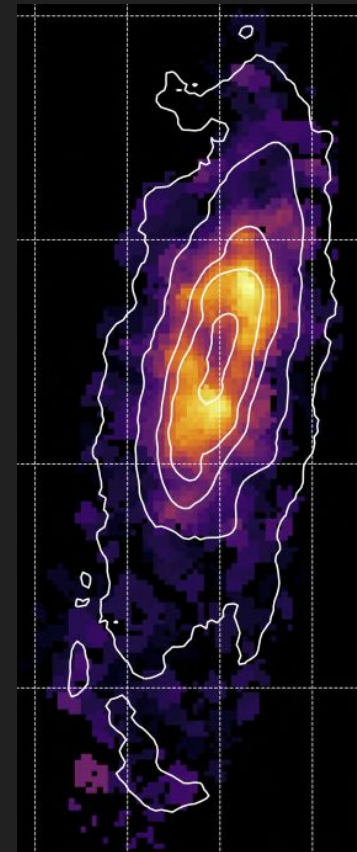
- Obtained during Cycle 7
- 13 AORs, covering much of the disk
- Molecular ring is clearly visible



Optical  
(SDSS)



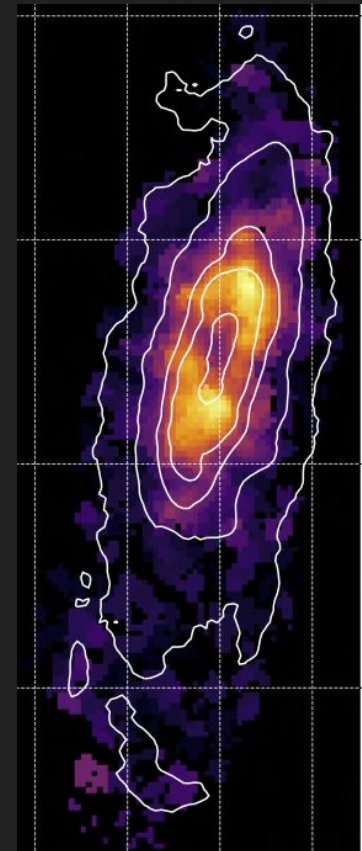
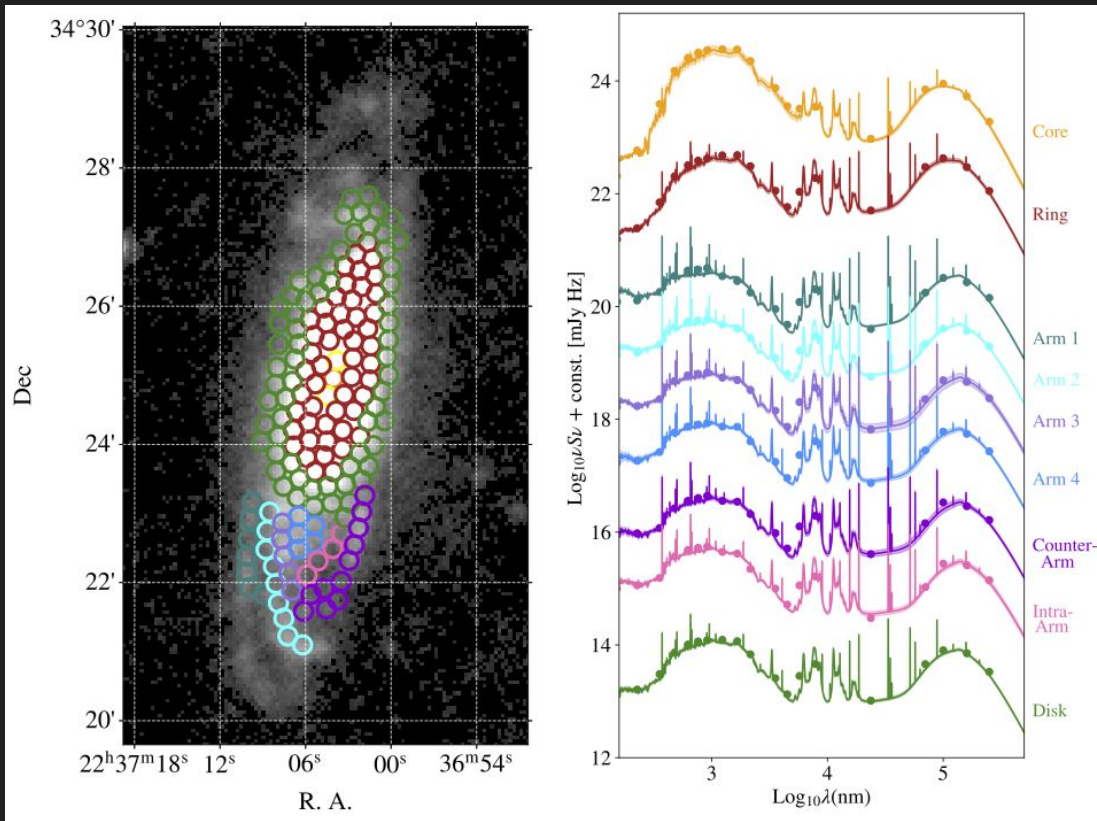
Infrared  
*Spitzer*  
3.6  $\mu\text{m}$



FIFI-LS  
[CII] 158



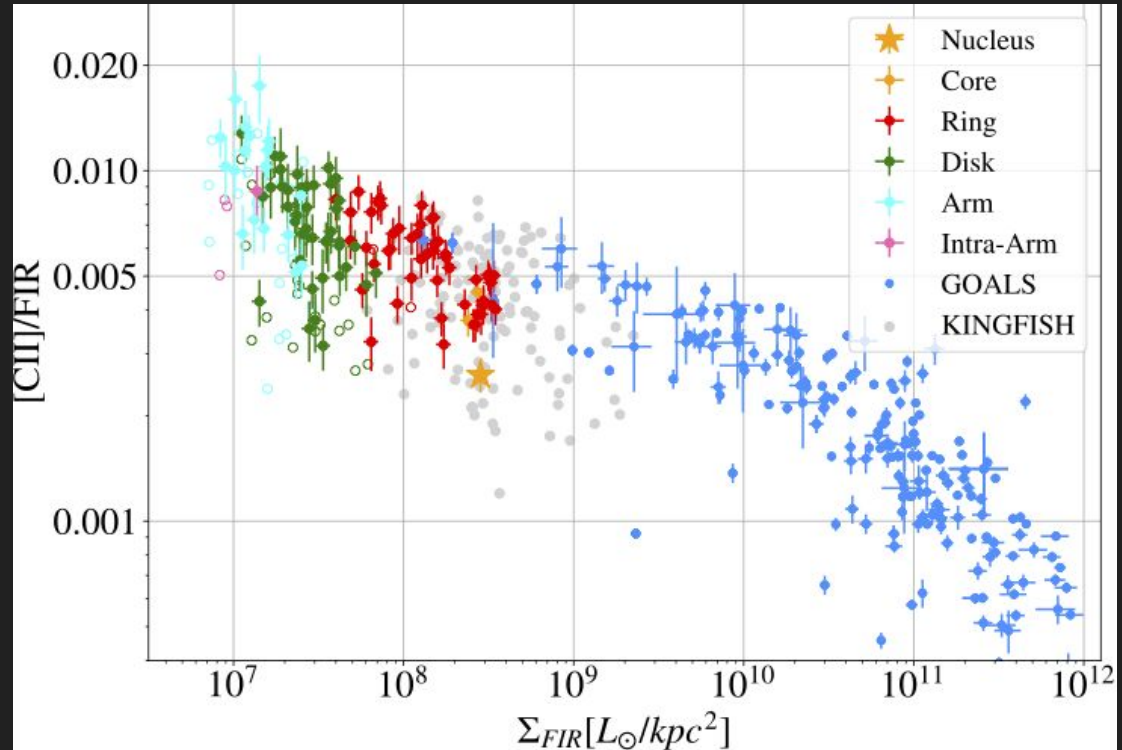
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FIFI-LS  
[CII] 158

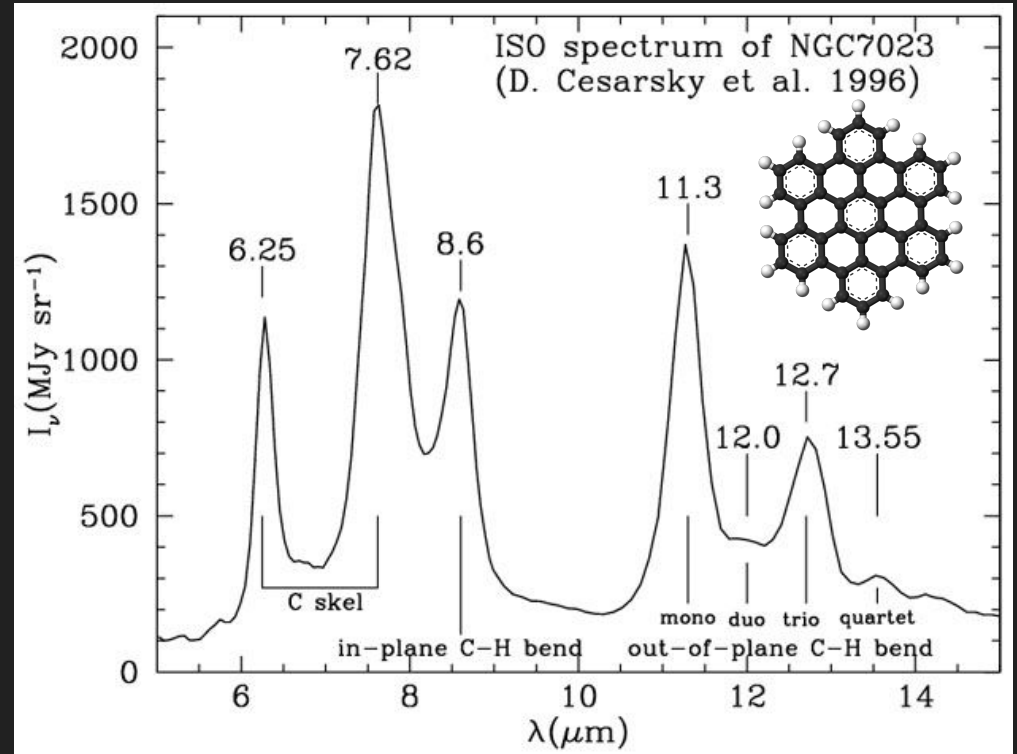
# Local extension of the [CII] deficit

- [CII] deficit is a frequently cited issue with using [CII] as SFR indicator
- Adding data from NGC 7331 to plots of [CII]/FIR shows clear extension from ULIRGS to NGC 7331's quiescent disk



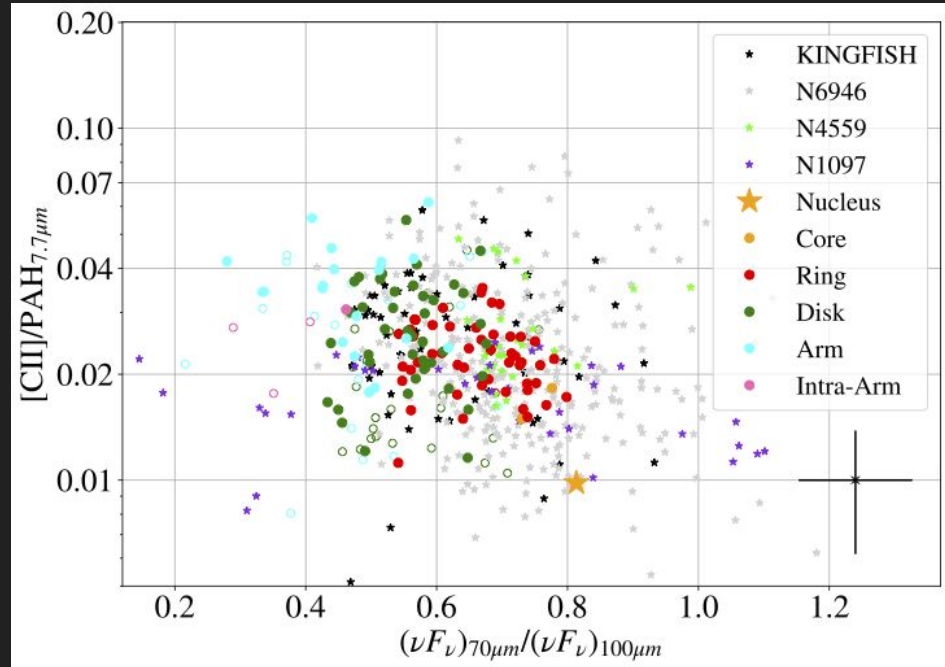
# [CII] and PAHs

- Polycyclic Aromatic Hydrocarbons (PAHs) provide the majority of free electrons in PDRs
- PAH bending modes produce emission features in the NIR
- [CII] / PAH can therefore trace the photoelectric heating efficiency ( $\epsilon_{\text{Phot}}$ )



# [CII] and PAHs

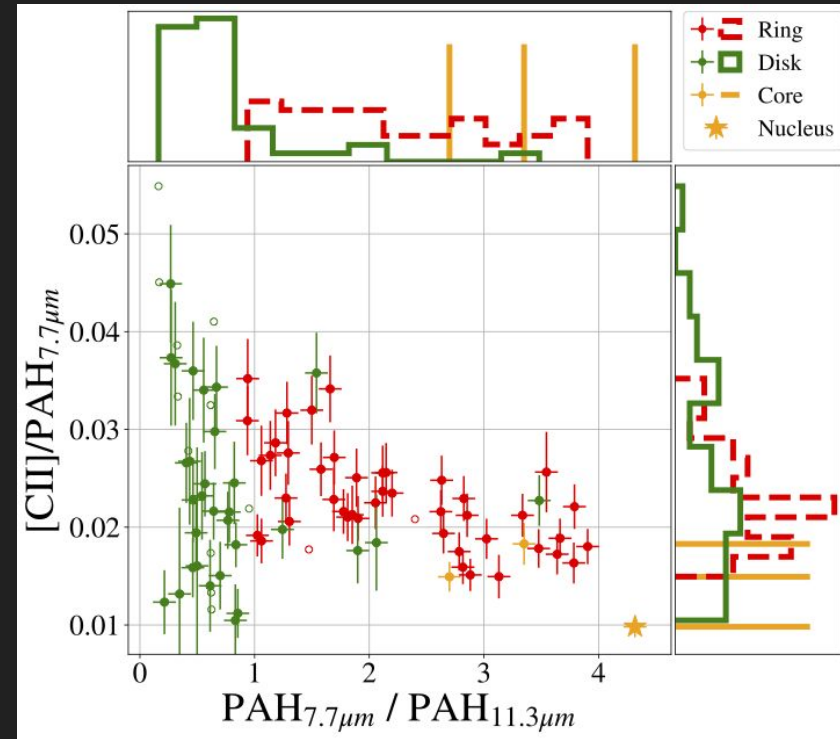
- PAH measured by subtracting SED modelled stellar continuum from IRAC 8.0 micron photometry
- See slight deficit, but less than observed in [CII]/FIR
- Slight differences observed between the different environments





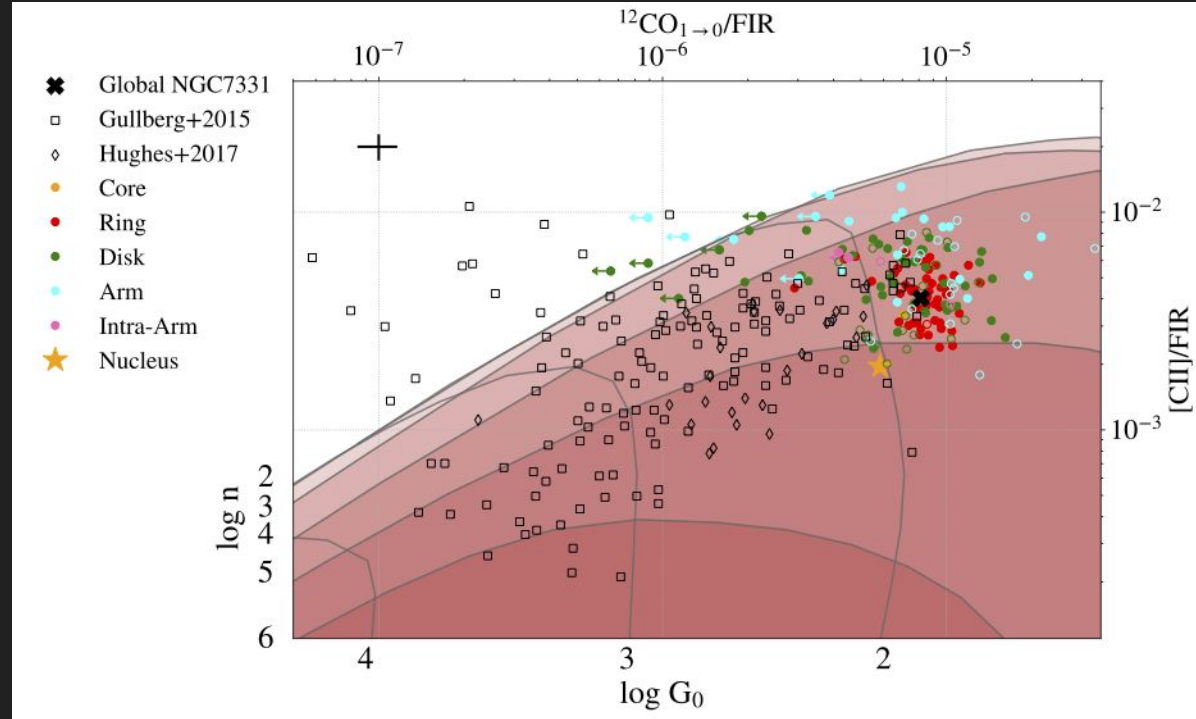
# [CII] and PAHs

- Also compare to PAH charge
- 7.7/11.3 micron feature ratio is considered an indicator of grain charge
- Increased grain charge shows slight decrease trend in [CII]/PAH
- Clear differences in environments



# Comparisons to CO

- Use HERACLES CO map to compare [CII] and CO
- See areas with [CII] emission but no CO emission
  - Potentially CO-dark molecular gas?



# Origin of the [CII] Emission

- The [NII] 205 can be used to isolate [CII] emission from ionized and neutral ISM phases
- Nitrogen IP: 14.5 eV
  - Predominantly found in ionized ISM
- Carbon IP: 11.3 eV
  - Found in both neutral and ionized ISM
- Similar critical densities for collisions with electrons

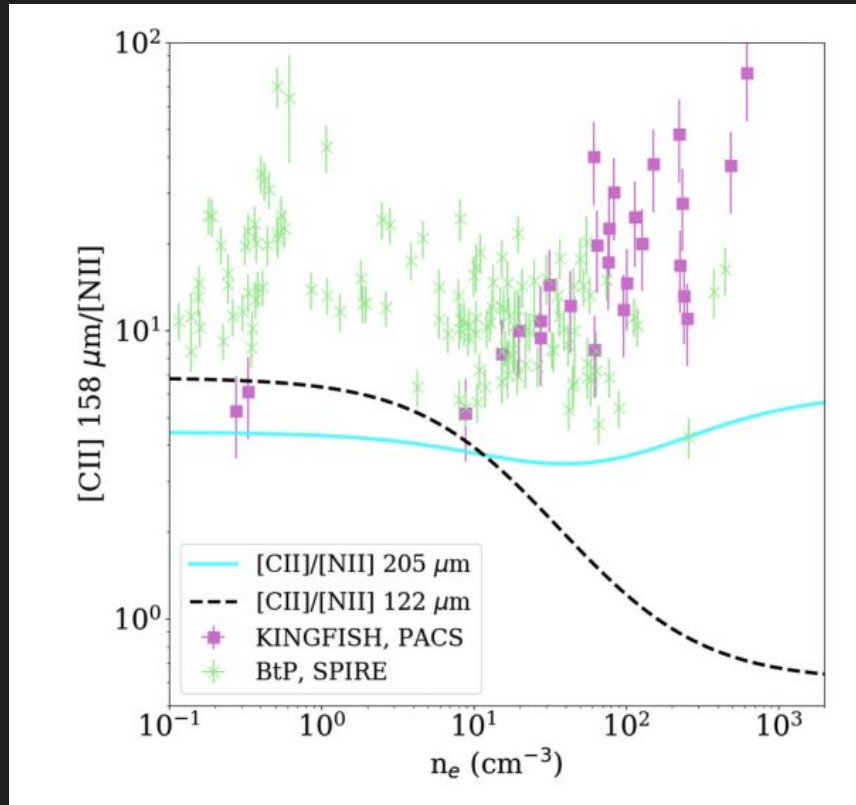
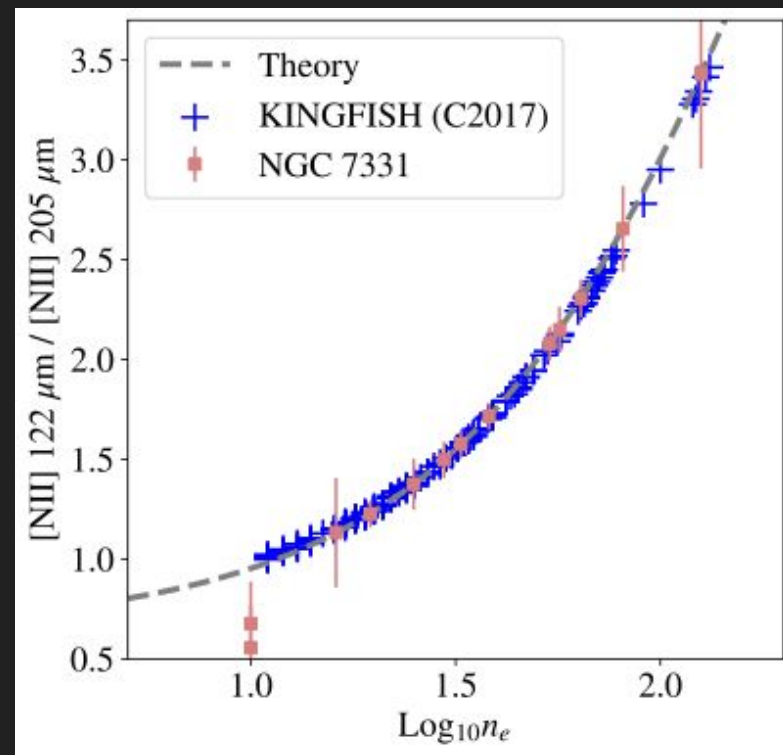
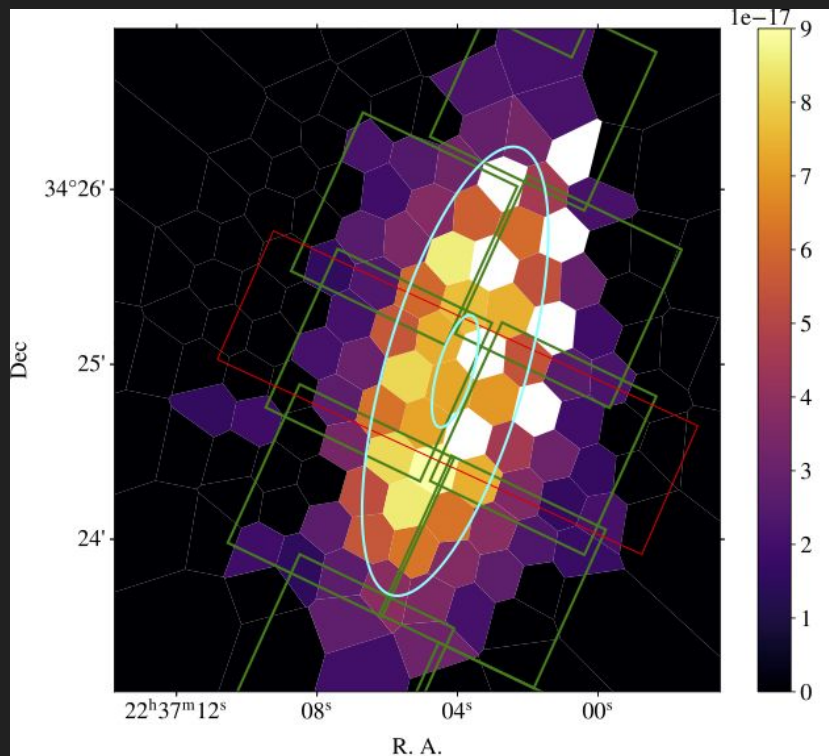


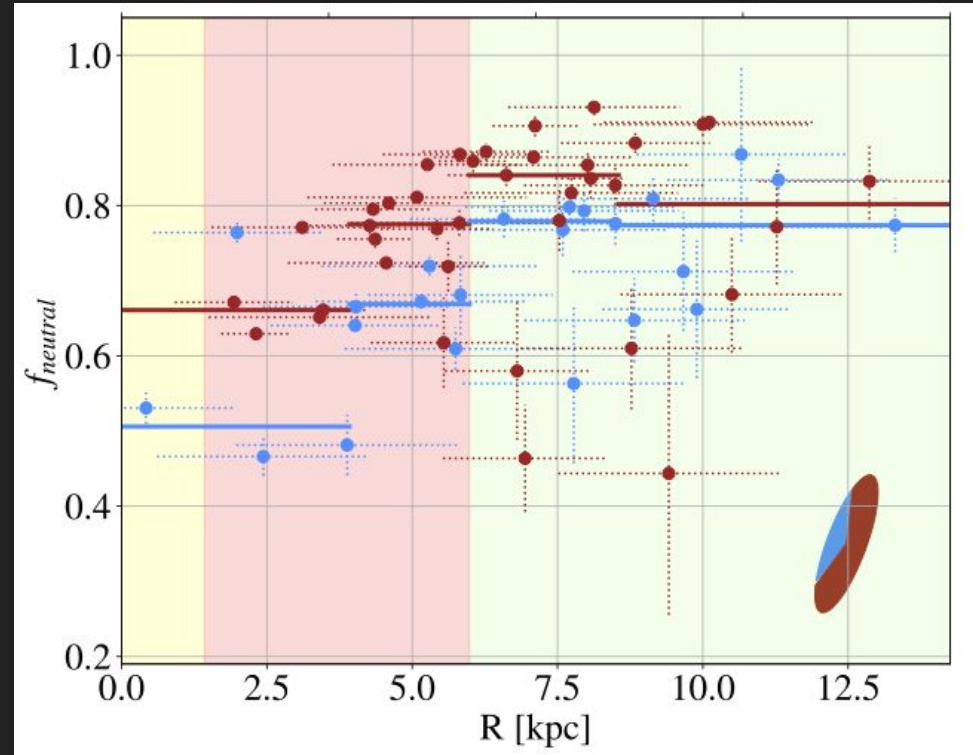
Image Credit: Sutter+2021

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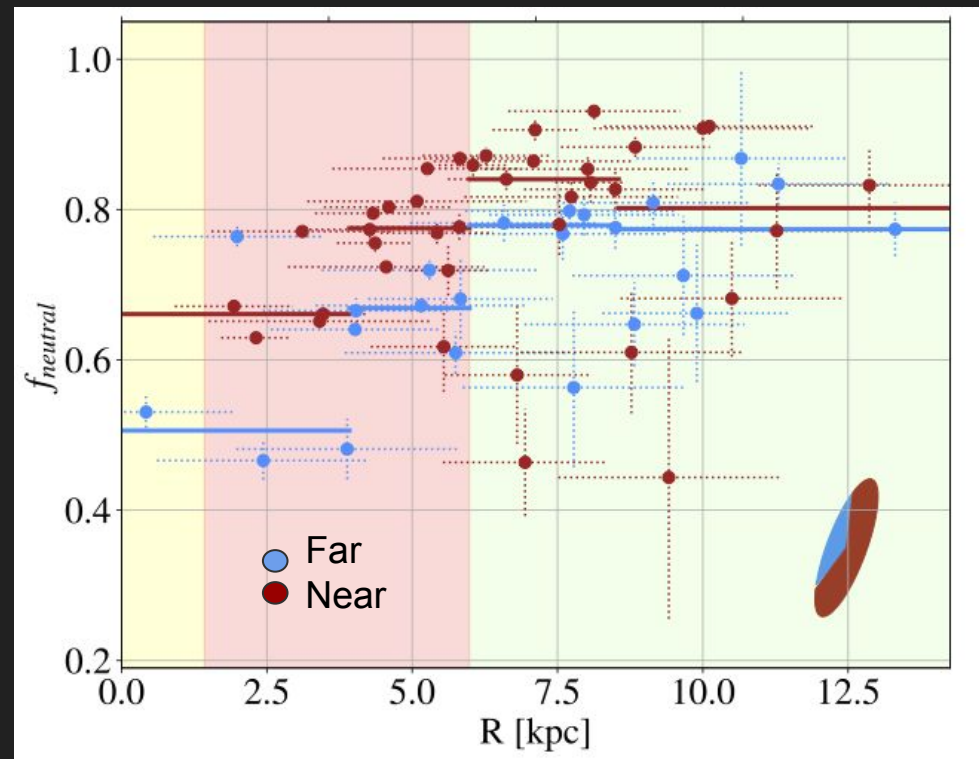
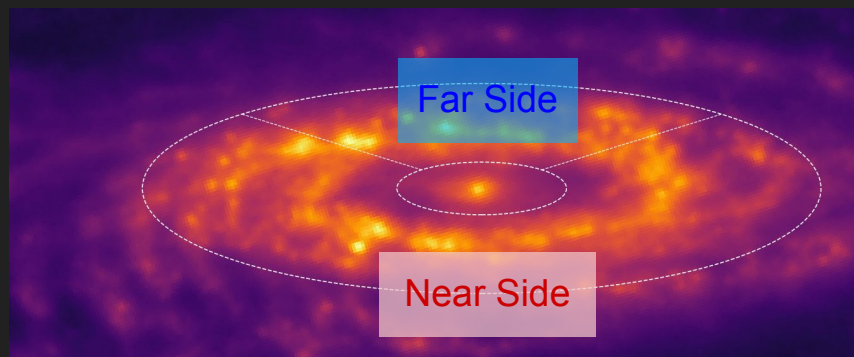
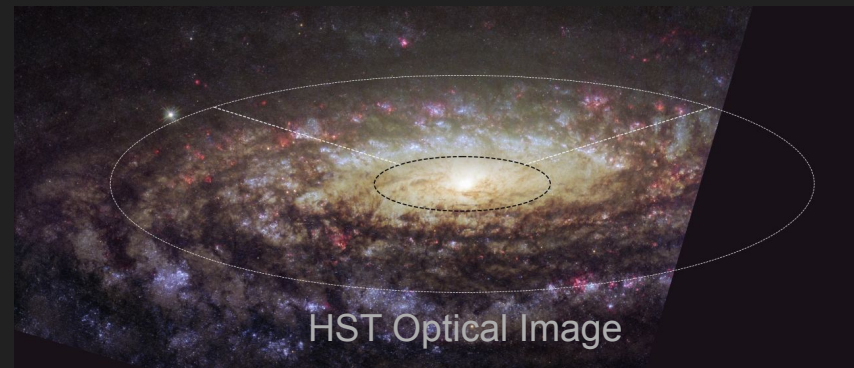


# Origin of the [CII] Emission

- Use archival [NII] 205 data to determine the fraction of [CII] emission from neutral ISM
- Azimuthal and radial dependencies suggest environmental differences in [CII] origin location



# Origin of the [CII] Emission



# Conclusions and future work

- The origin of the [CII] emission in NGC 7331 varies both radially and azimuthally
- The [CII] deficit trend extends from the global measurements from the GOALS U/LIRGS to local measurements
- We plan to extend this work through comparisons to archival [CII] maps from PACS and FIFI-LS



NGC 4736, Image Credit: R. Jay GaBany

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