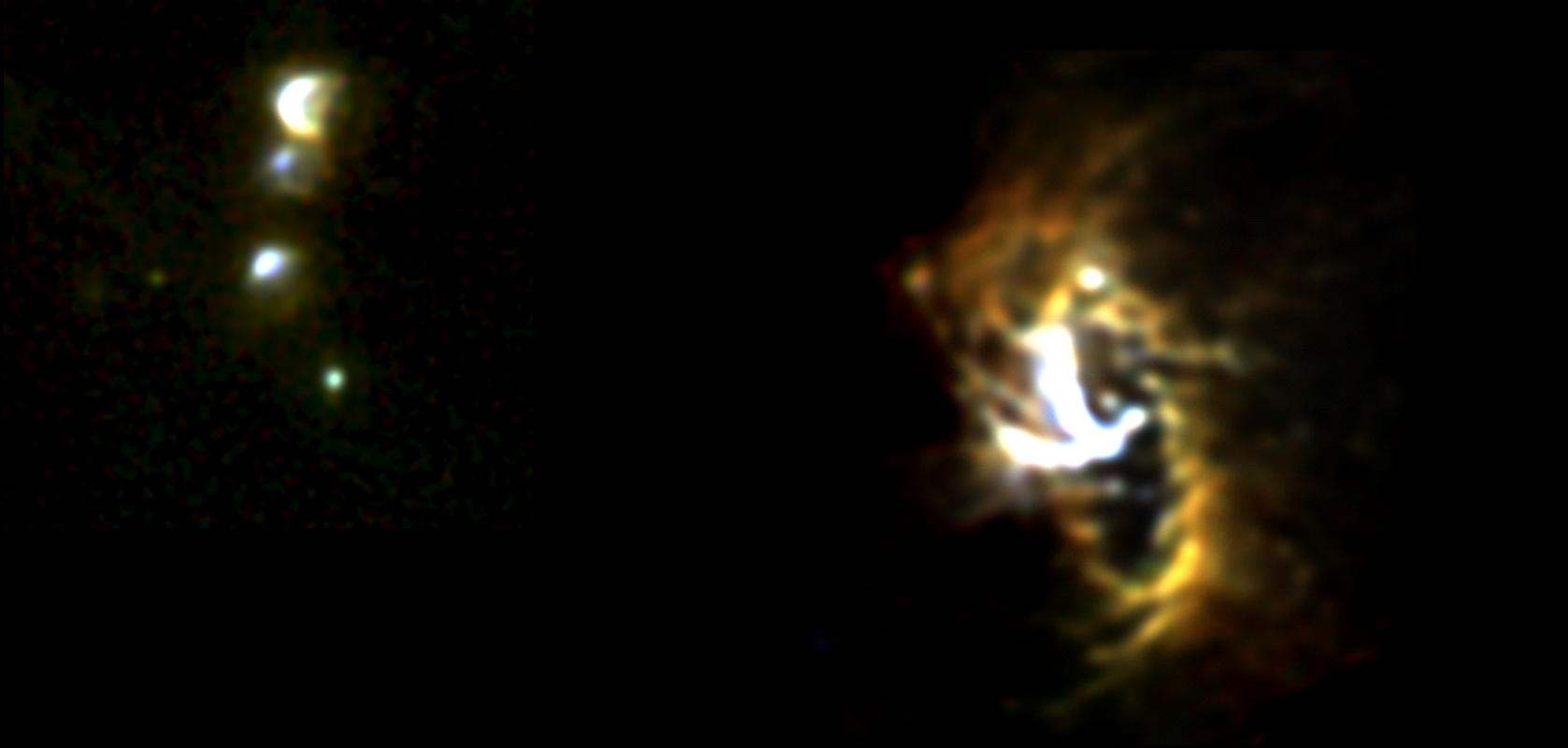


# Dusty Cradles in a Turbulent Nursery: Sgr A East HII Regions at the Galactic Center

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Lau et al. (2014b, submitted to ApJ)

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***Ryan M. Lau***

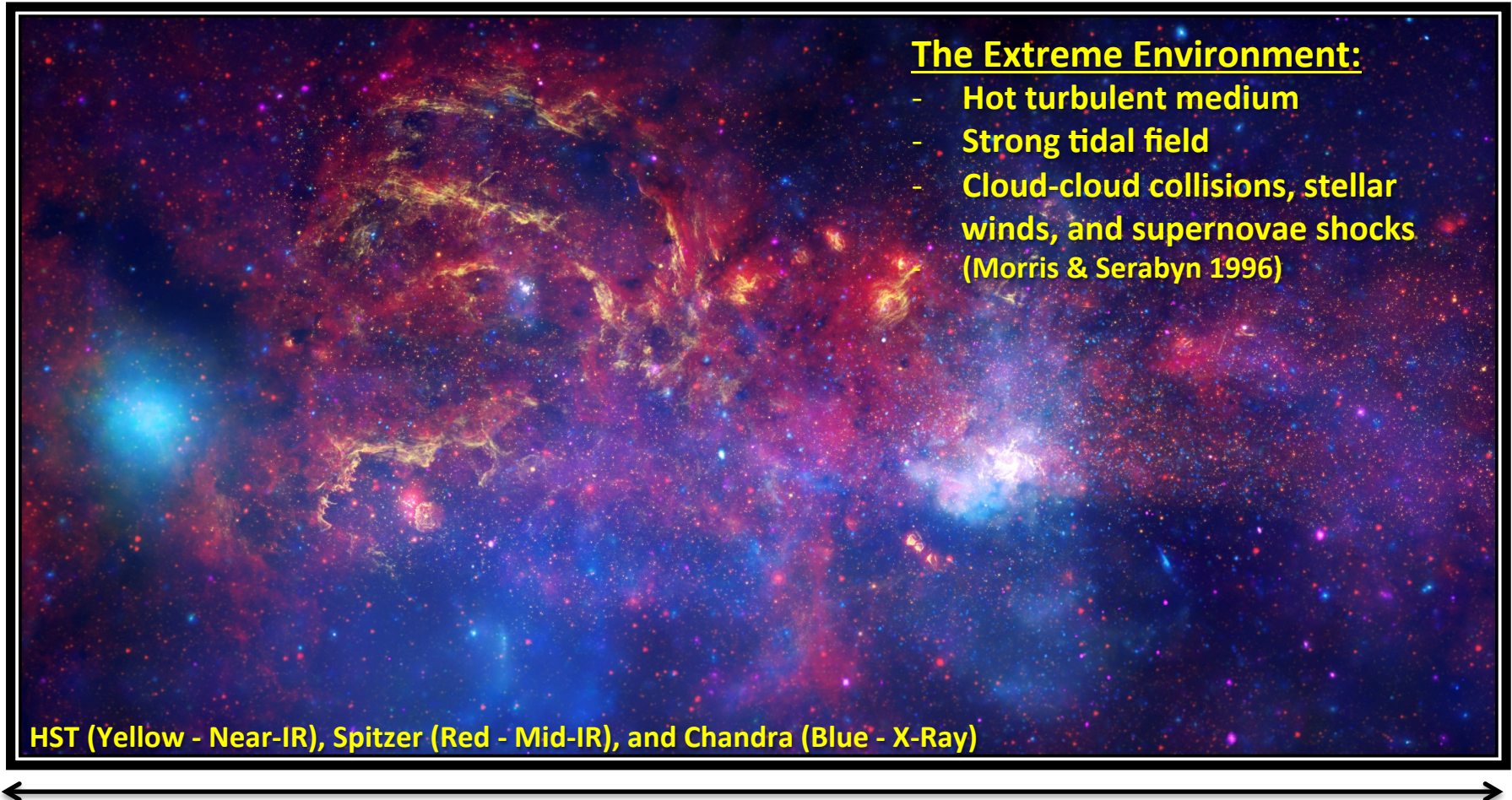
Collaborators: T. L. Herter , M. R. Morris, J. D. Adams

SOFIA Community Tele-talk  
June 25<sup>th</sup>, 2014



# Star Formation in the Galactic Center

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## The Extreme Environment:

- Hot turbulent medium
- Strong tidal field
- Cloud-cloud collisions, stellar winds, and supernovae shocks (Morris & Serabyn 1996)

HST (Yellow - Near-IR), Spitzer (Red - Mid-IR), and Chandra (Blue - X-Ray)

60 pc



# Star Formation in the Galactic Center

---



## The Extreme Environment:

- Hot turbulent medium
- Strong tidal field
- Cloud-cloud collisions, stellar winds, and supernovae shocks (Morris & Serabyn 1996)

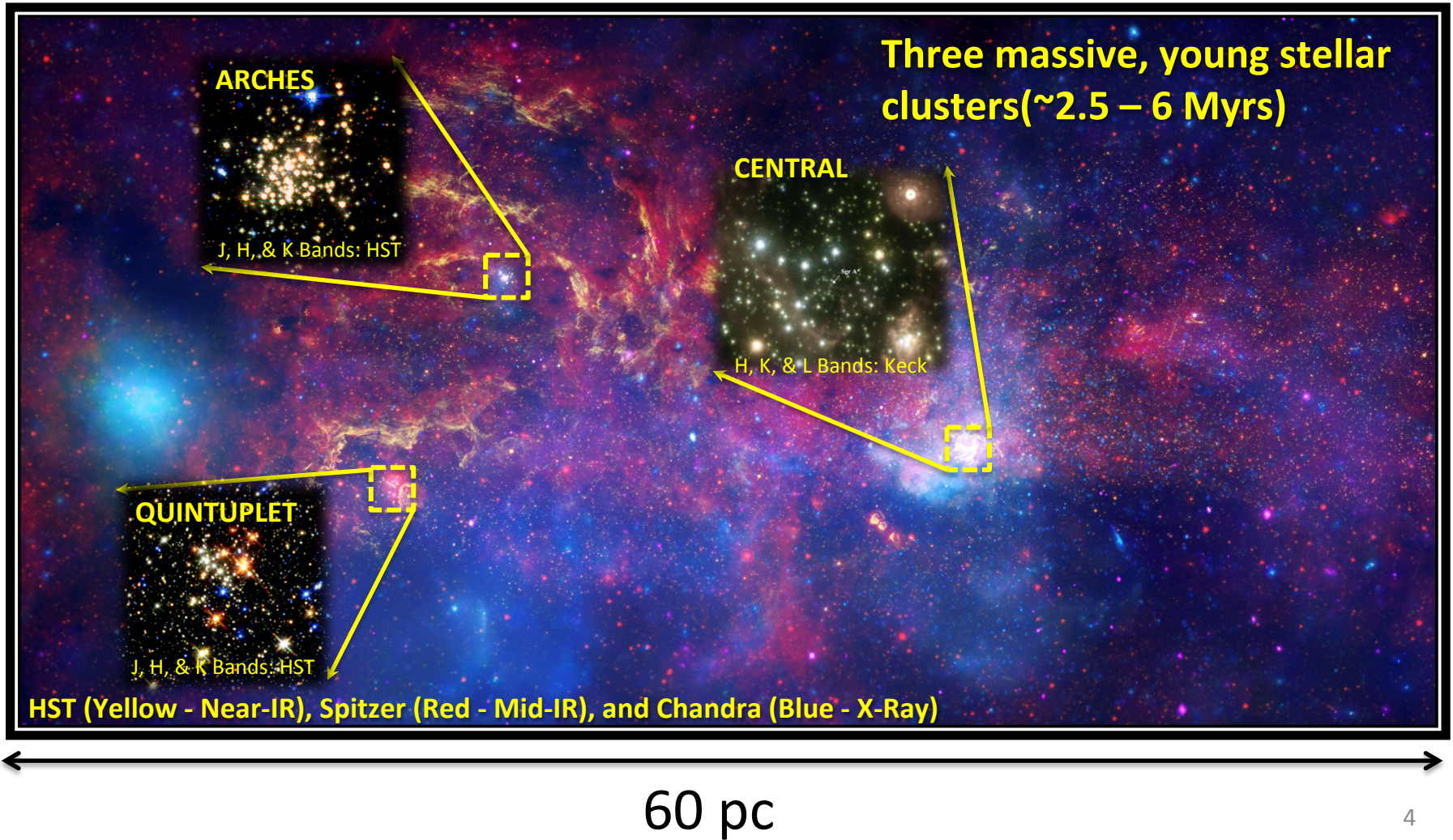
*...Result is sudden events of massive star formation*

HST (Yellow - Near-IR), Spitzer (Red - Mid-IR), and Chandra (Blue - X-Ray)

60 pc

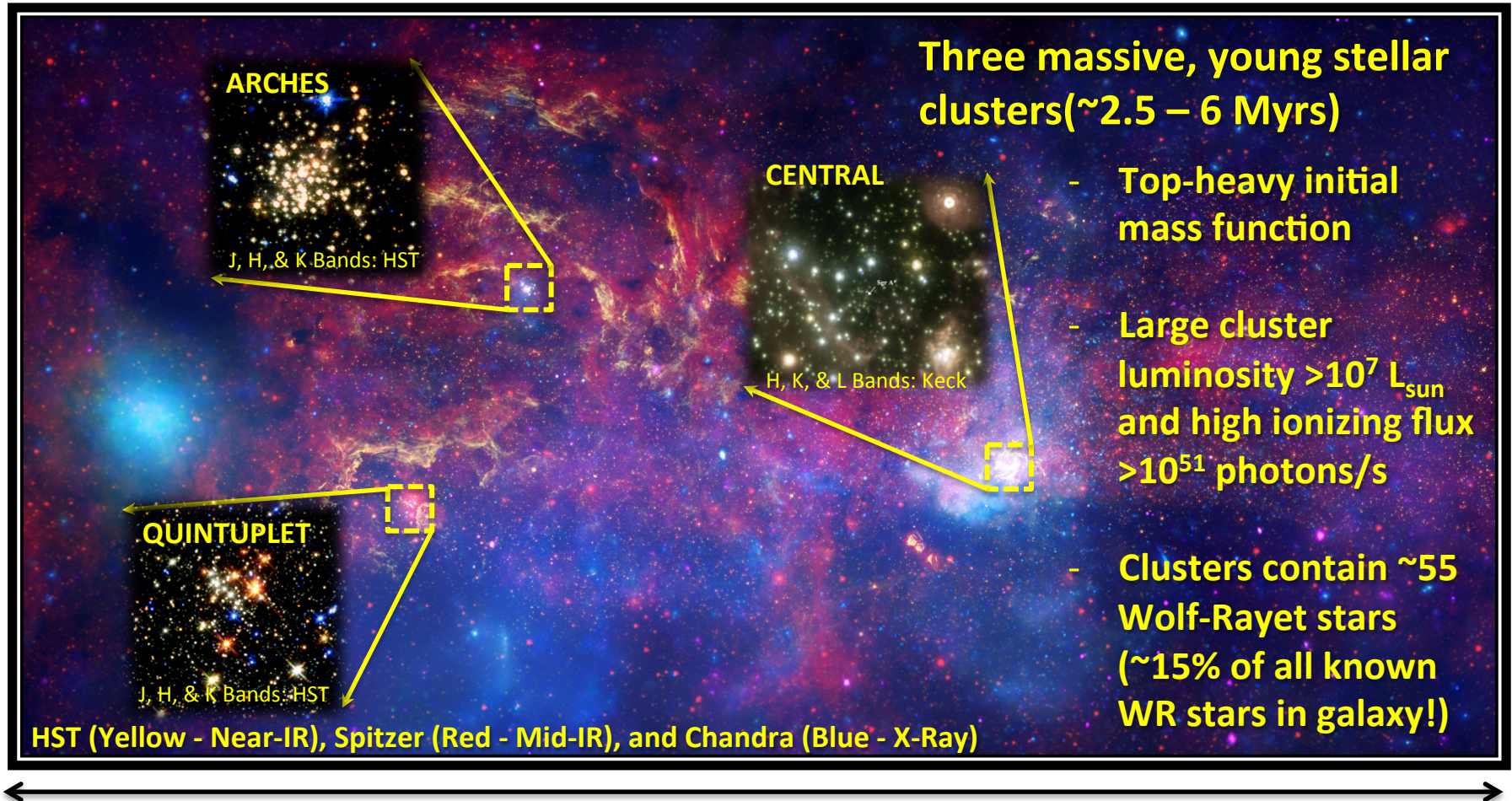


# Star Formation in the Galactic Center



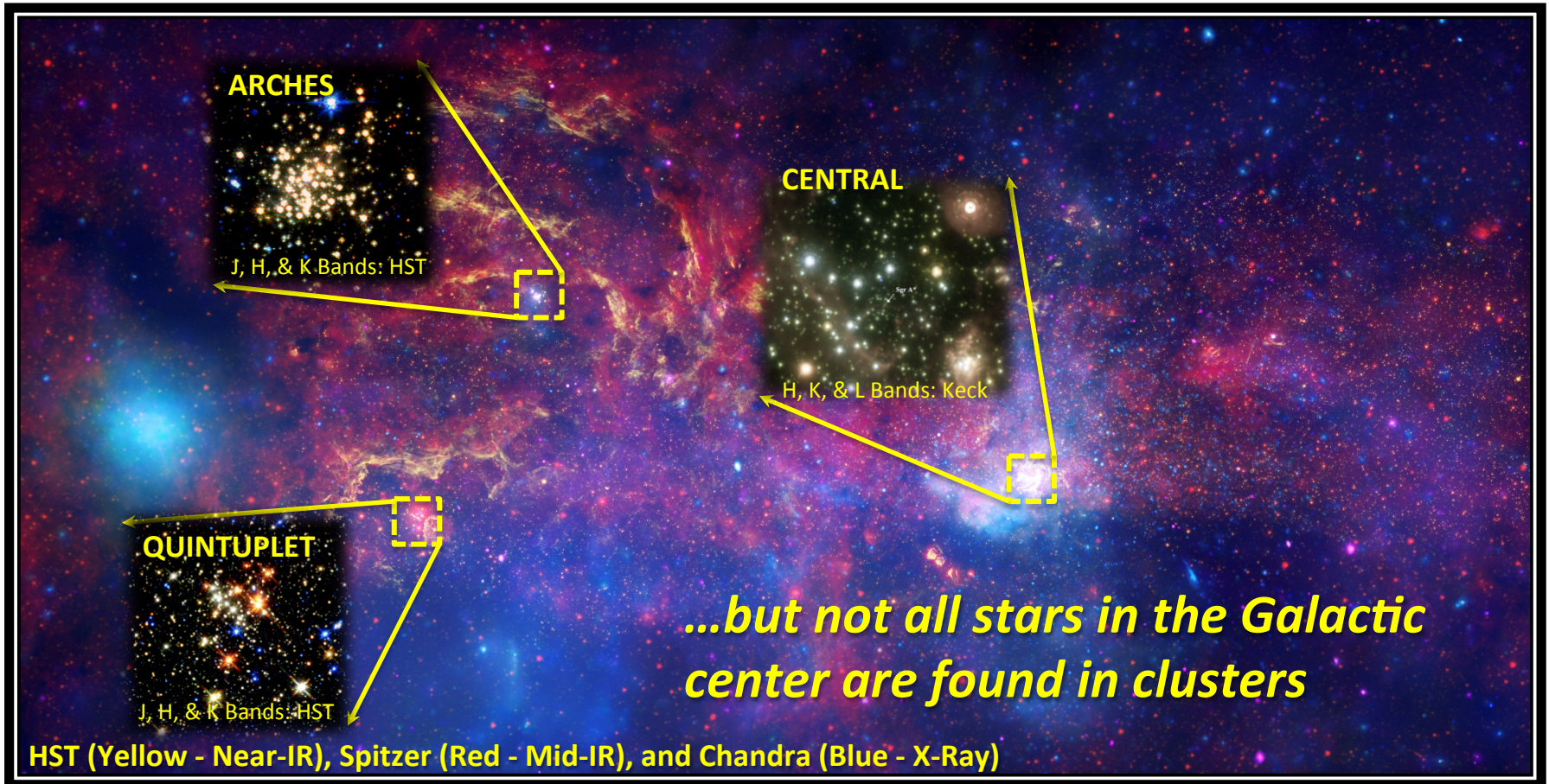


# Star Formation in the Galactic Center





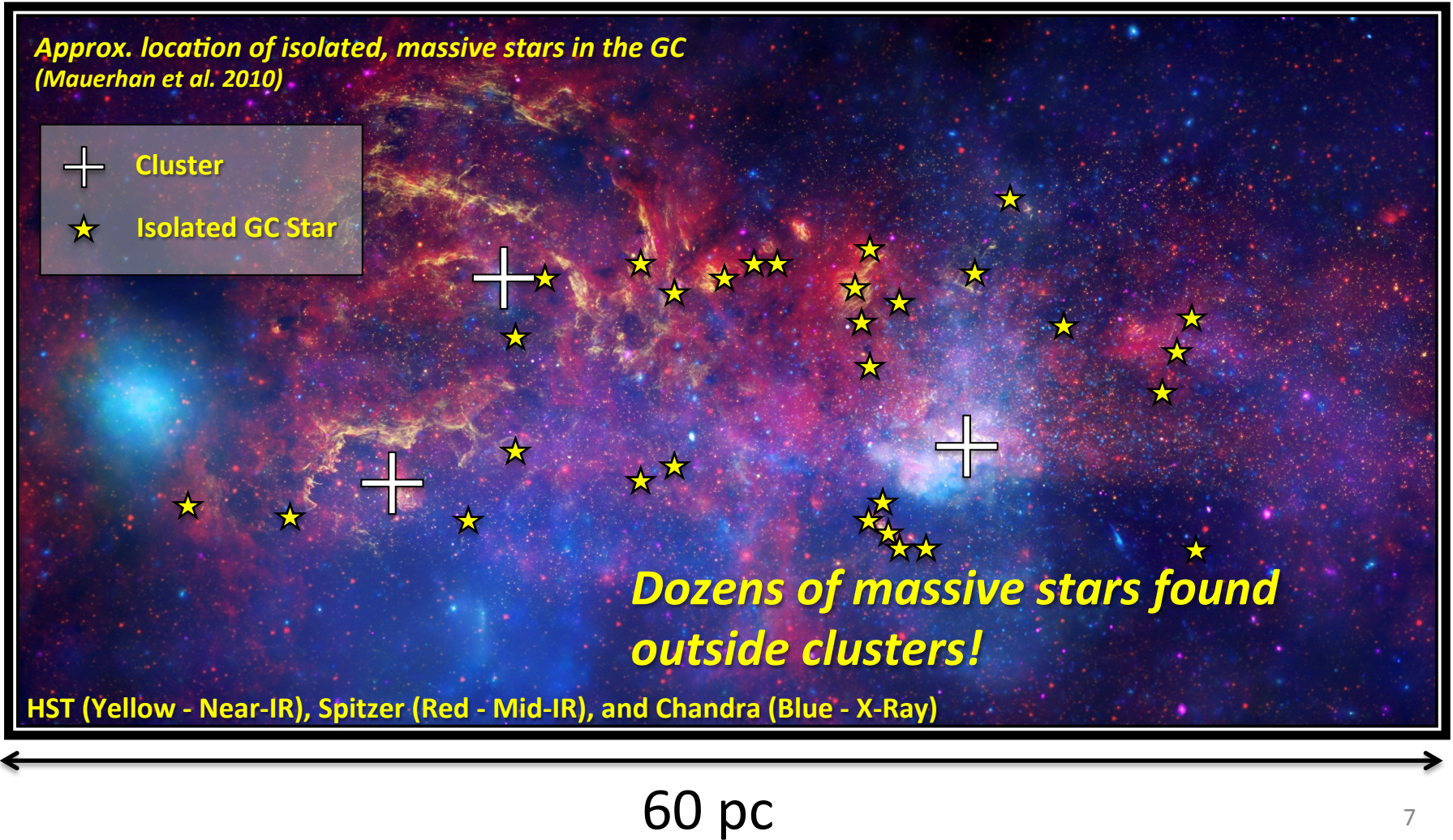
# Star Formation in the Galactic Center



60 pc

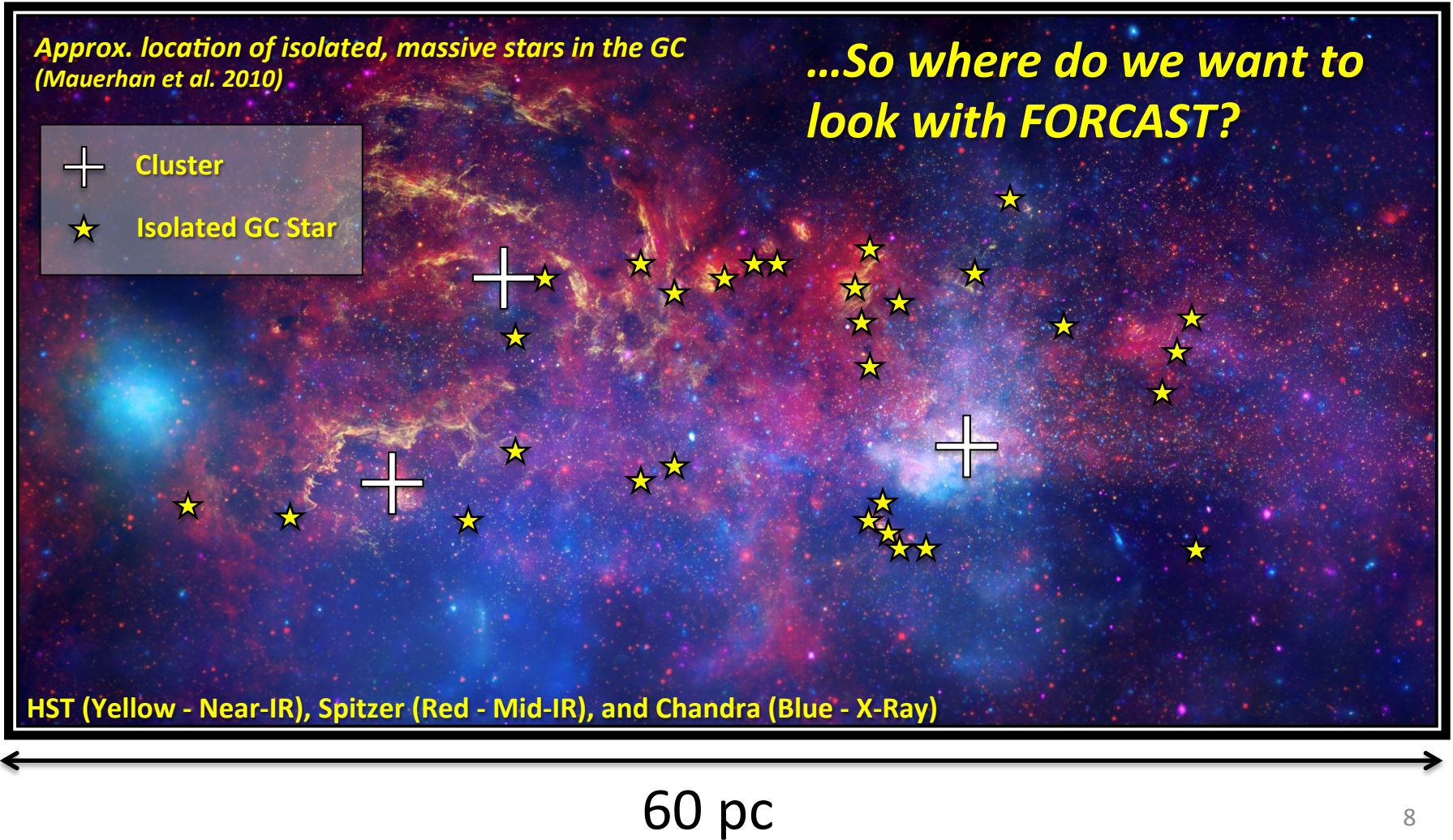


# Star Formation in the Galactic Center



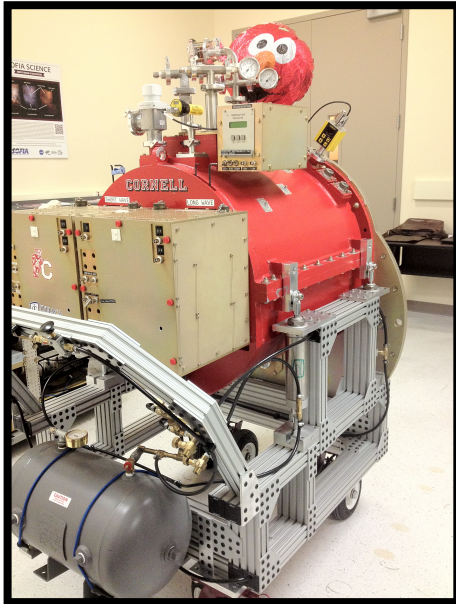
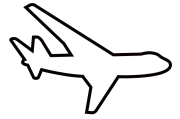


# Star Formation in the Galactic Center





# FORCAST, the Faint Object Infrared Camera for the SOFIA Telescope



- Facility instrument capable of Imaging and spectroscopy from 5 – 40  $\mu\text{m}$ 
  - LHe cooled (4.2 K), 700 lbs
- Dual-Channel 256 x 256 camera w/ Si BIB arrays
  - BIB: Blocked-Impurity-Band
  - 5 – 25  $\mu\text{m}$  with Si:As array
  - 25 – 38  $\mu\text{m}$  with Si:Sb array
- Plate scale: of 0.75 arcsec/pixel: 3.2 x 3.2 arcmin FOV



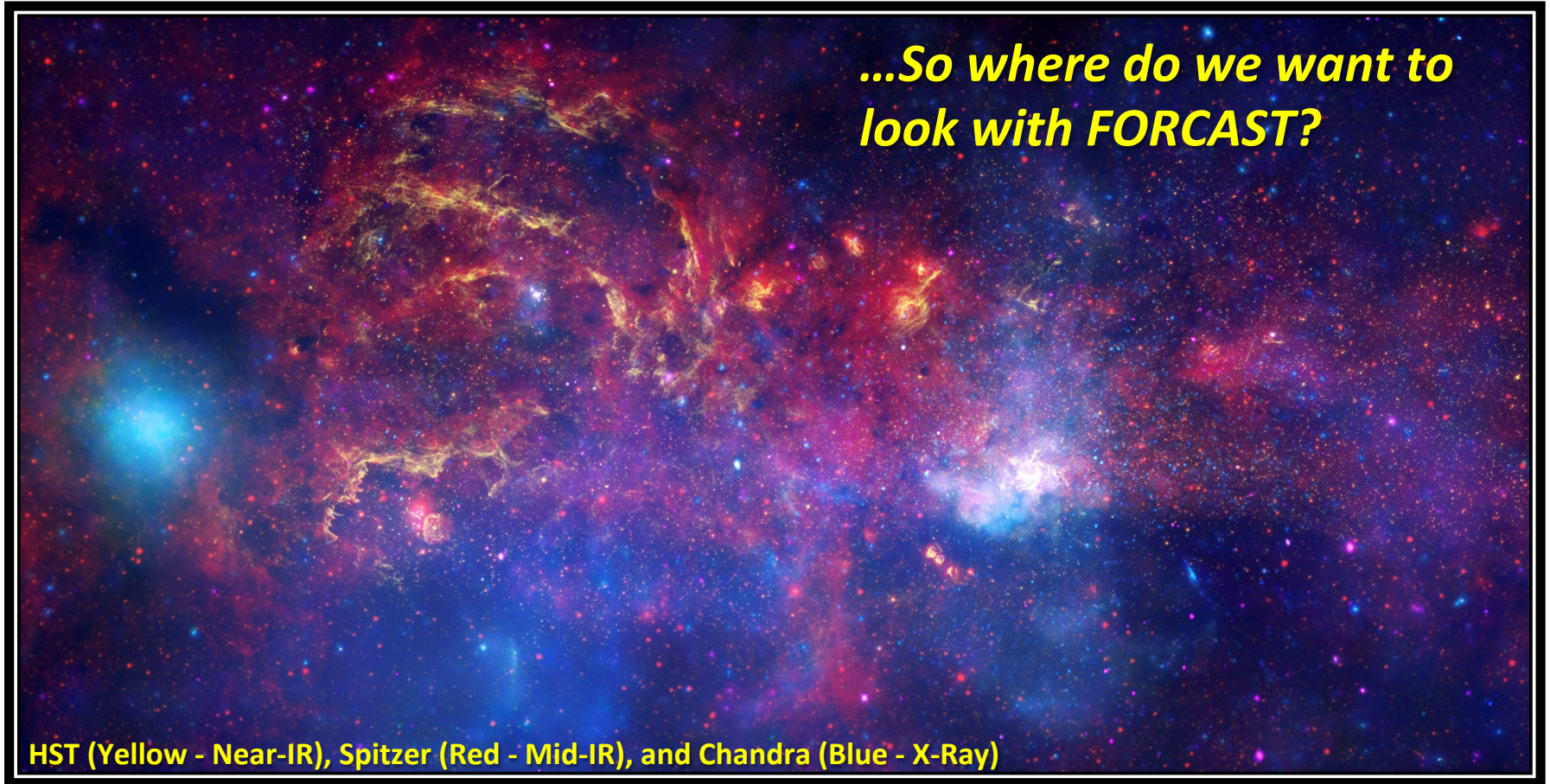
FORCAST just finished up its final flight of the series!

*SOFIA to undergo heavy maintenance soon*



# Back to the Galactic Center...

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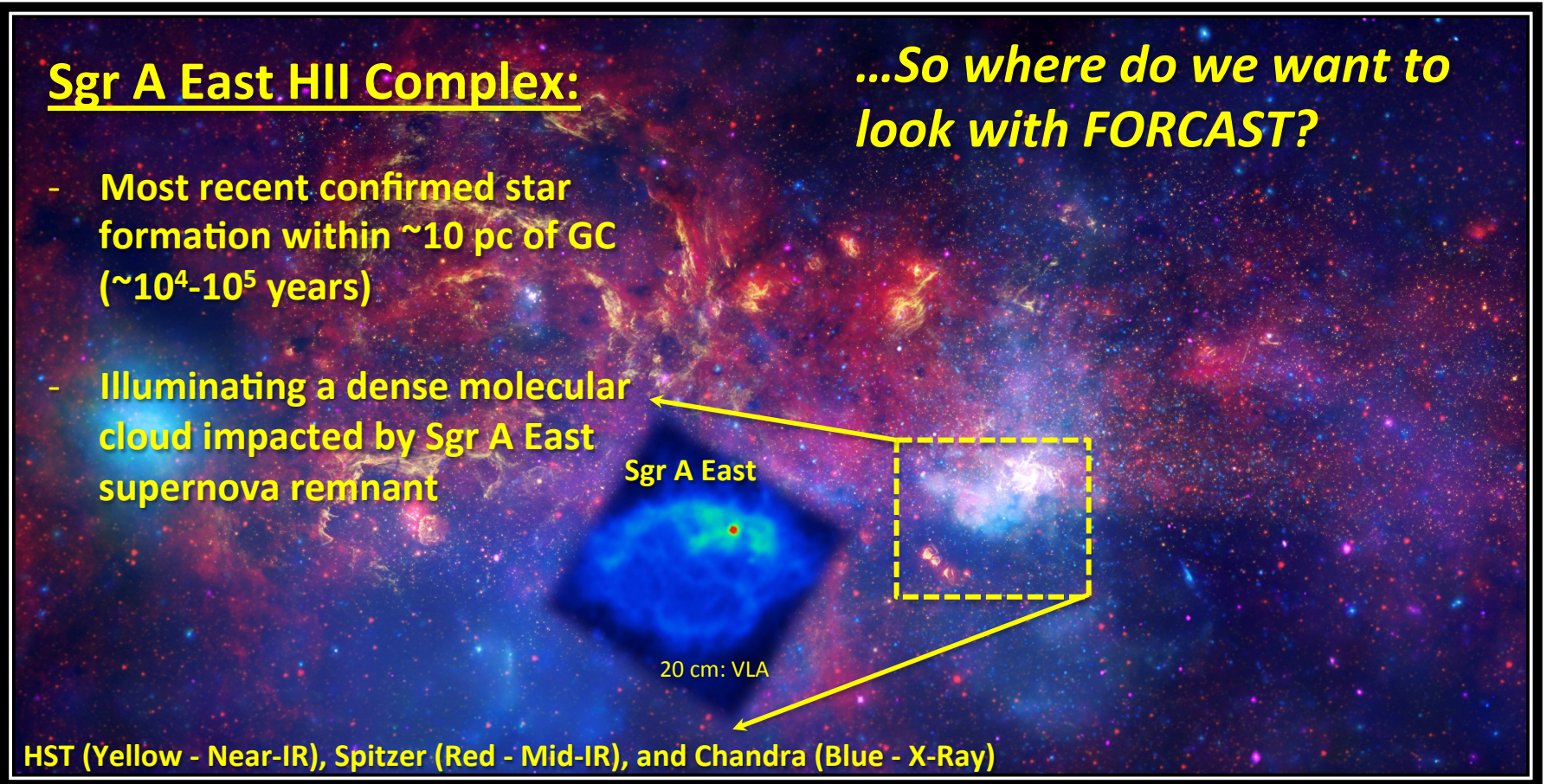
60 pc

# Back to the Galactic Center...

## Sgr A East HII Complex:

- Most recent confirmed star formation within  $\sim 10$  pc of GC ( $\sim 10^4$ - $10^5$  years)
- Illuminating a dense molecular cloud impacted by Sgr A East supernova remnant

*...So where do we want to look with FORCAST?*



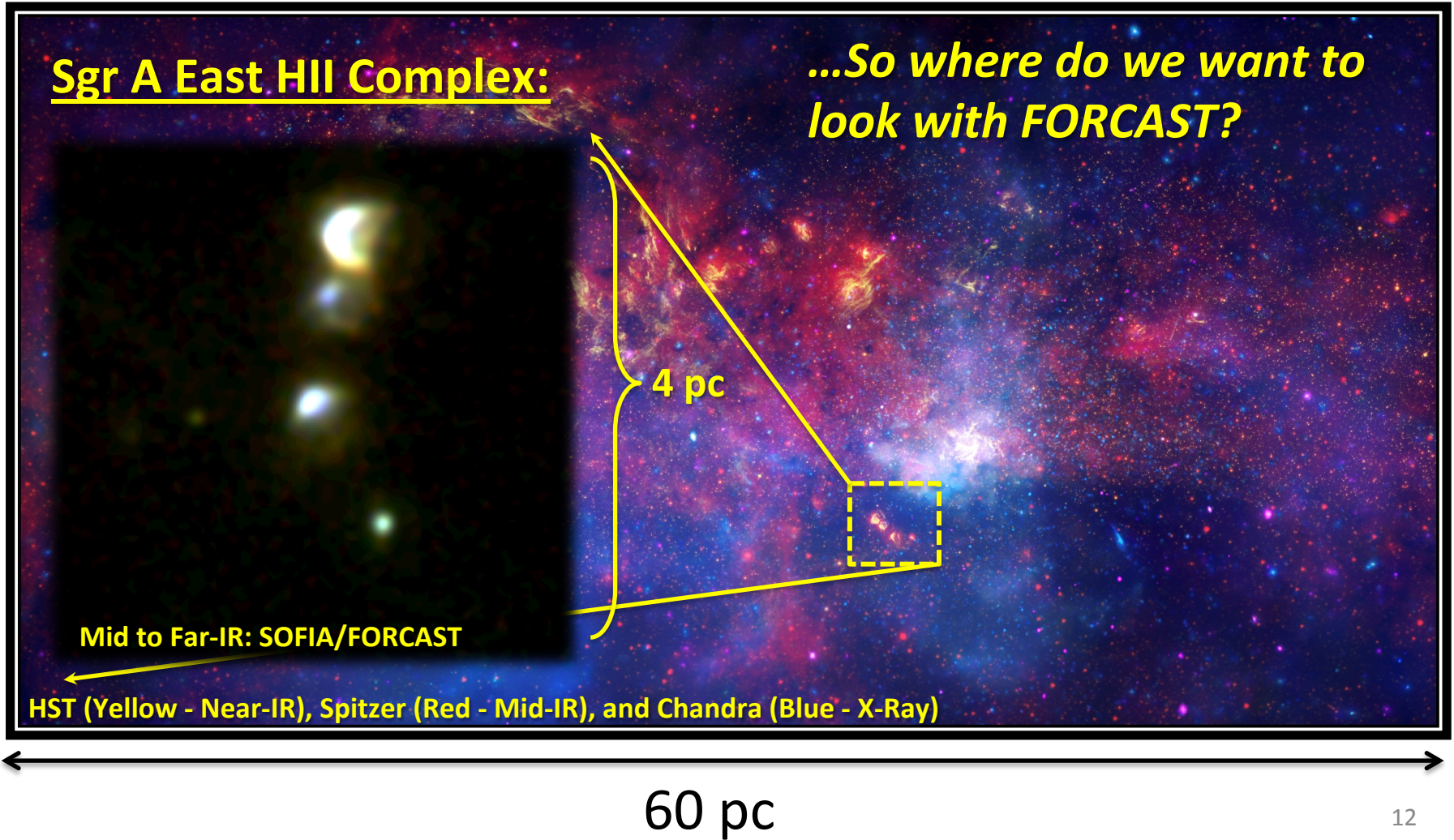
HST (Yellow - Near-IR), Spitzer (Red - Mid-IR), and Chandra (Blue - X-Ray)

60 pc

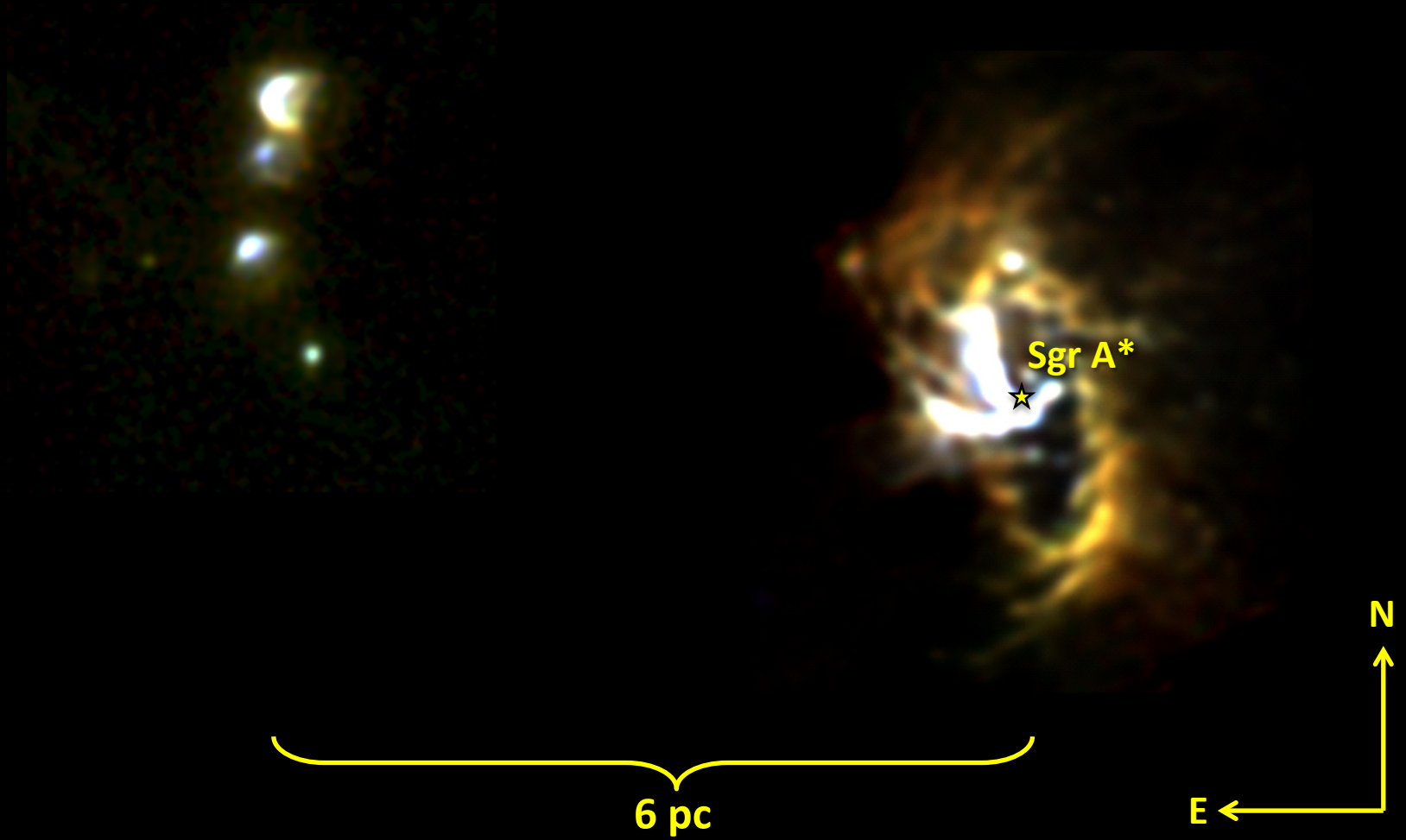


# Back to the Galactic Center...

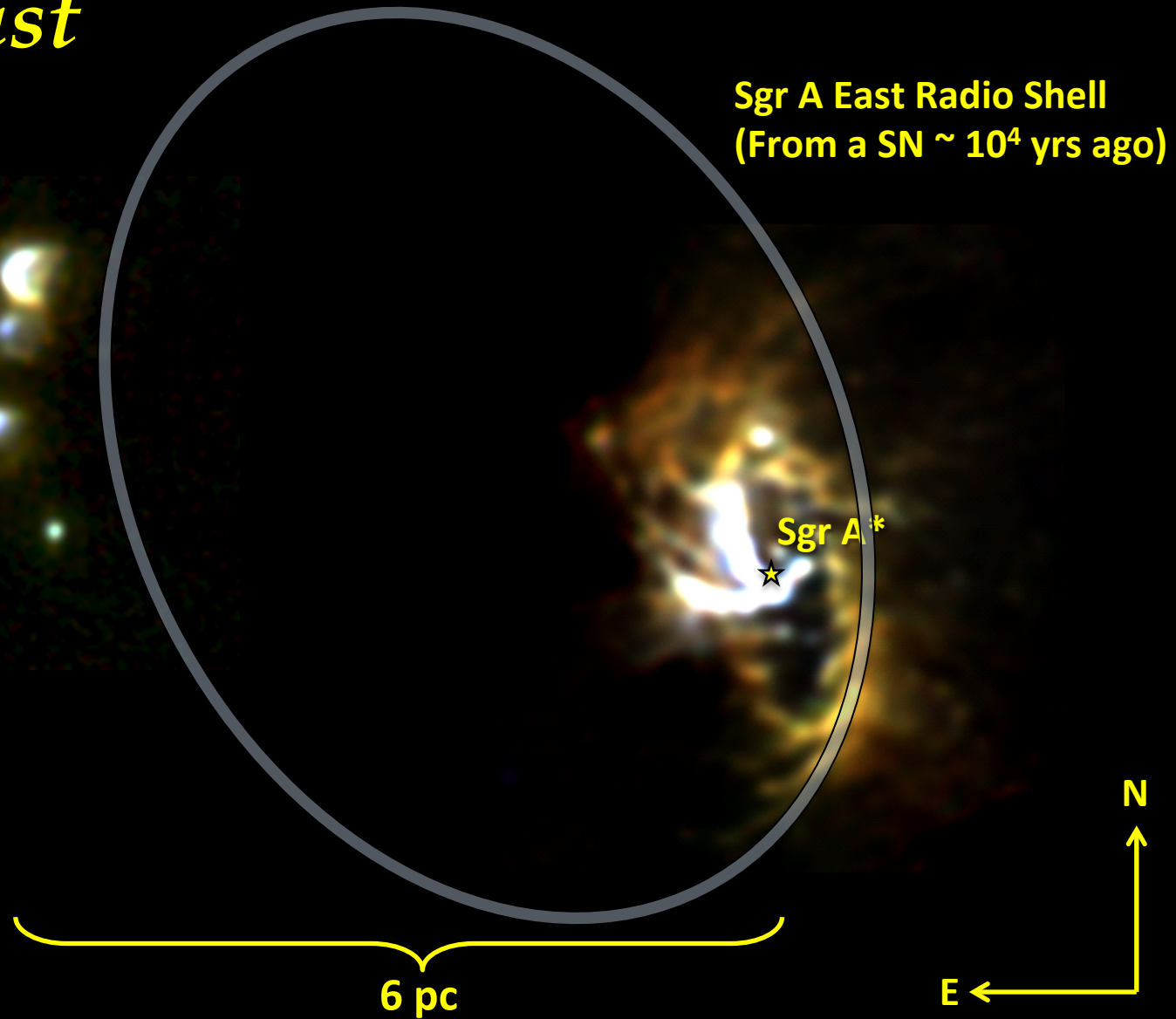
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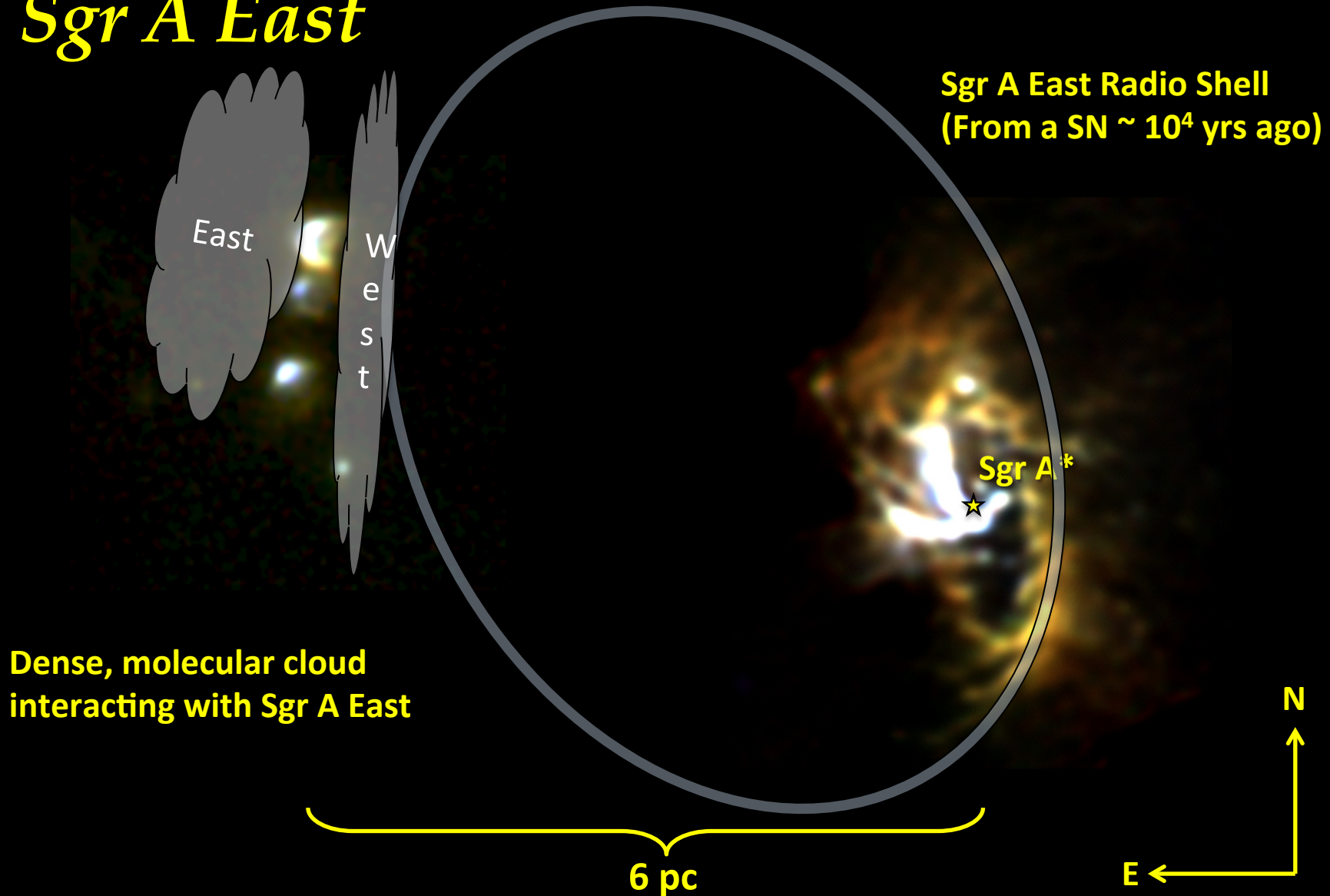
# *A detailed look at what's going on in Sgr A East*



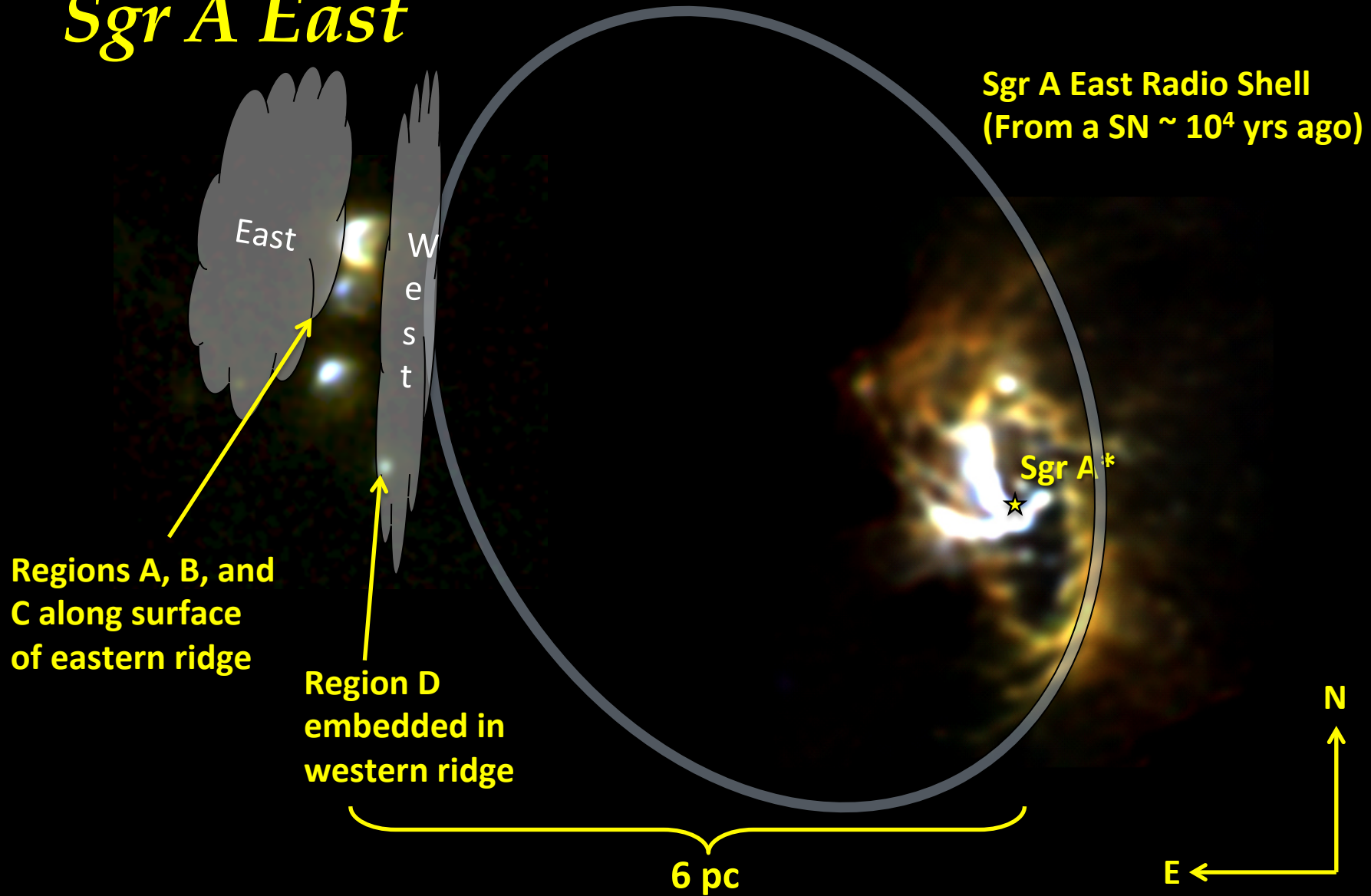
# *A detailed look at what's going on in Sgr A East*



# *A detailed look at what's going on in Sgr A East*



# *A detailed look at what's going on in Sgr A East*







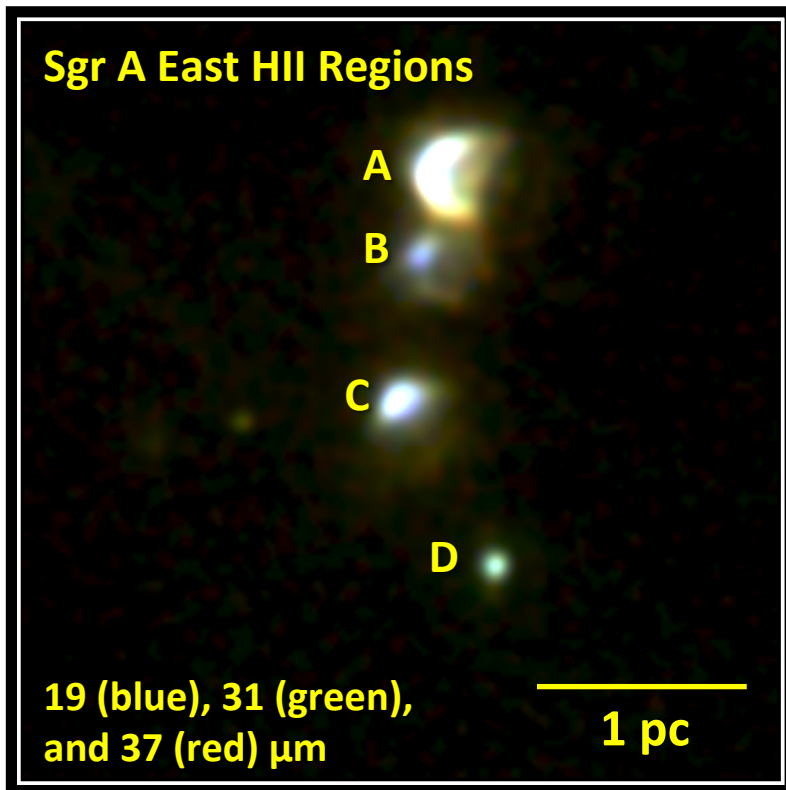
**Molecular cloud**  
(450  $\mu\text{m}$ ; Pierce-Price et al. 2000)

**Sgr A East Radio Shell**  
(1.4 GHz; Lang et al. 2010)

**HII Regions**  
(Paschen- $\alpha$ ; Wang et al. 2010)

**Figure from Mills et al. 2011**

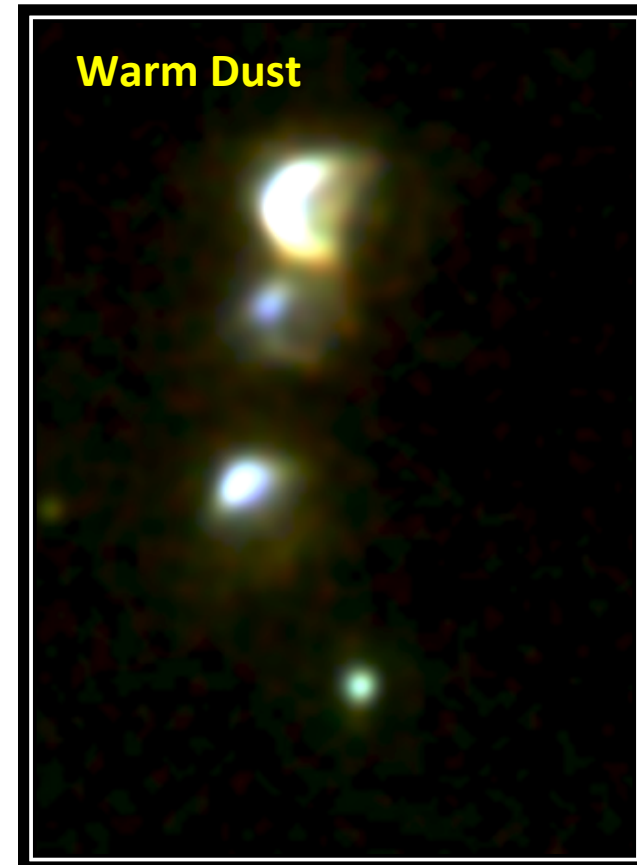
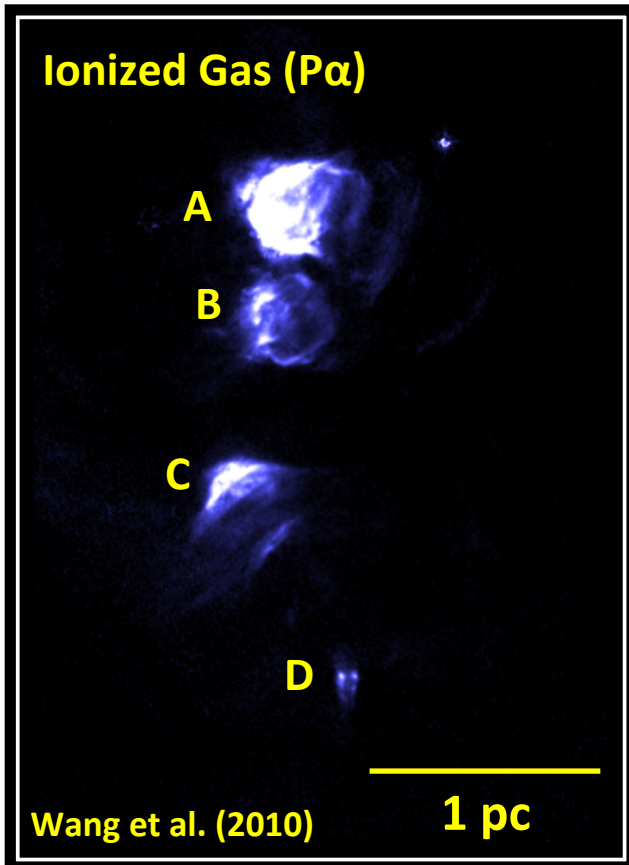
# Investigating the Dusty Cradles



- ⊛ *Can we learn more about the young stellar objects heating the dust?*
- ⊛ *What can we learn about the dust in the HII regions?*
- ⊛ *Are there any other young stars in the region?*

Warm dust emission from the  
Sgr A East HII Region Complex

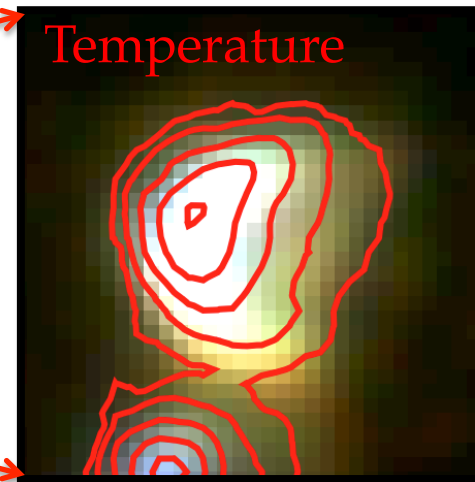
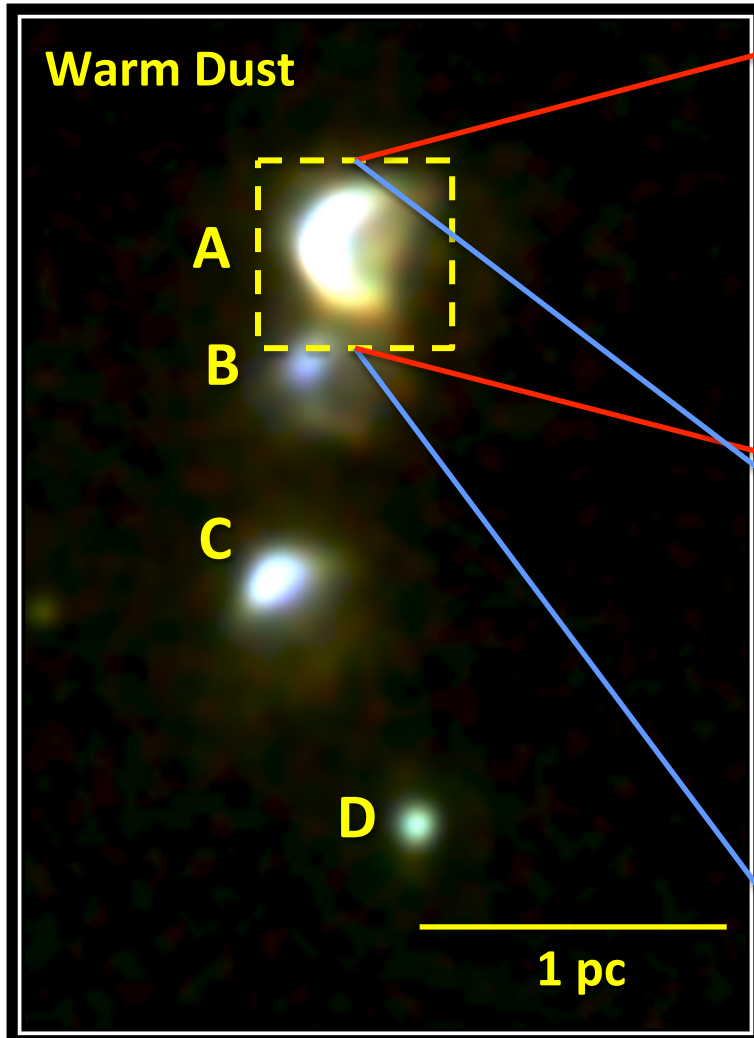
# Ionized Gas and Warm Dust



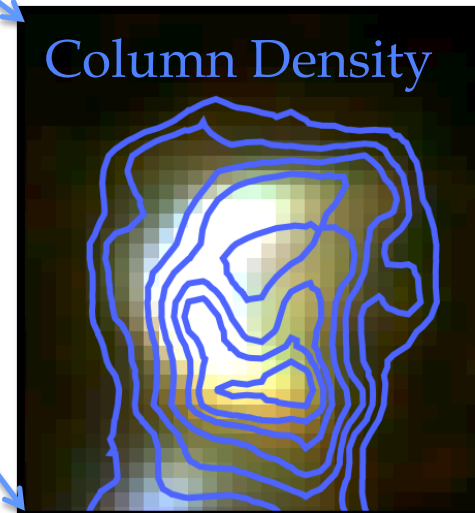
⊙ Warm dust traces the ionized gas emission (as expected for HII regions)

⊙ Heated and ionized by single O7 - O9 type star

# What's Going on at Region A?



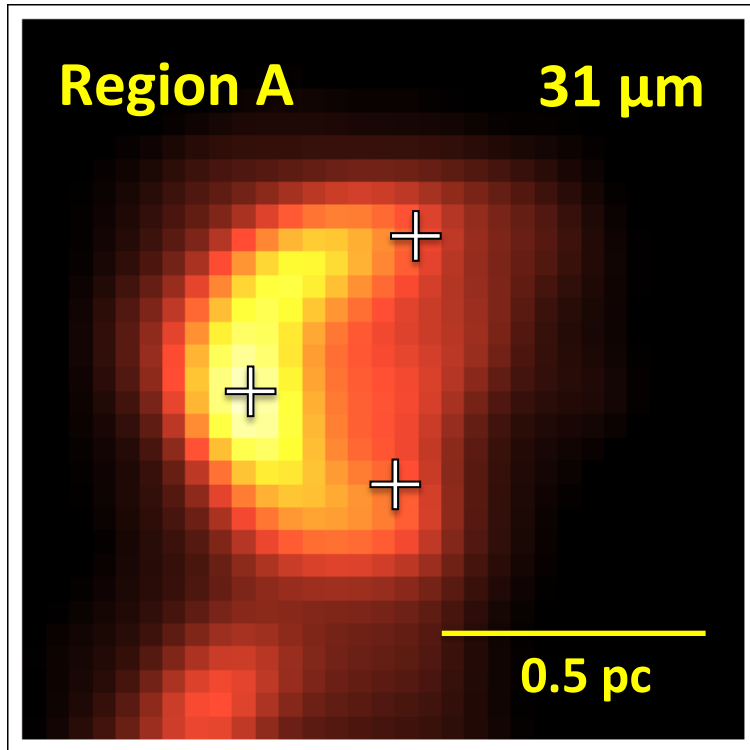
- ⊛ Temperature range: 90 - 130 K
- ⊛ Temperature peak offset from center



- ⊛ Column density enhancement at south

*Where is the heating source?*

# Locating the Heating Source

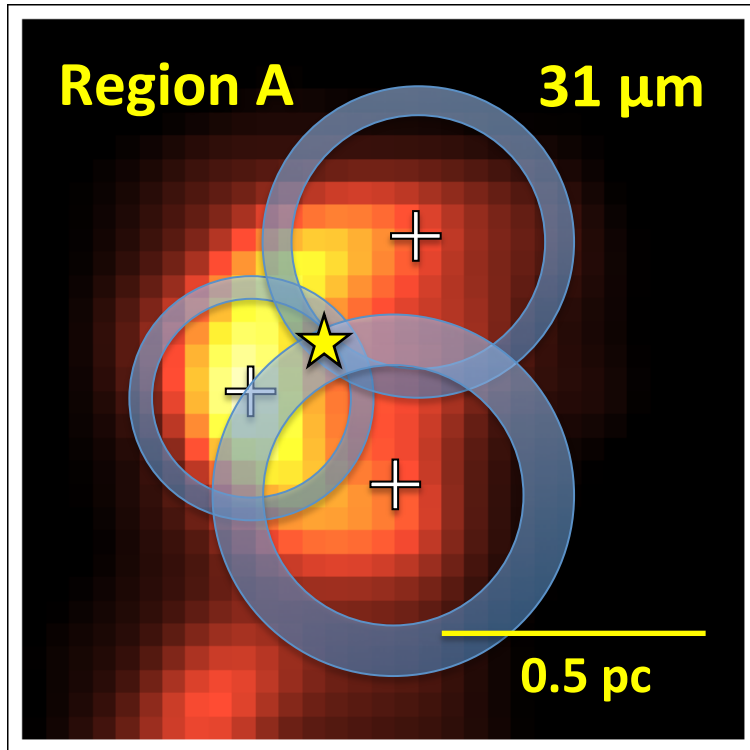


Zoom-in of Region A dust emission

- ① Stellar luminosity from models fit to the spectral energy distribution:  
 $L_* \sim 2 * 10^5 L_{Sun}$
- ① Use temperatures to triangulate location of heating source

$$r \propto T_{dust}^{-3/2} L_*^{1/2}$$

# Locating the Heating Source

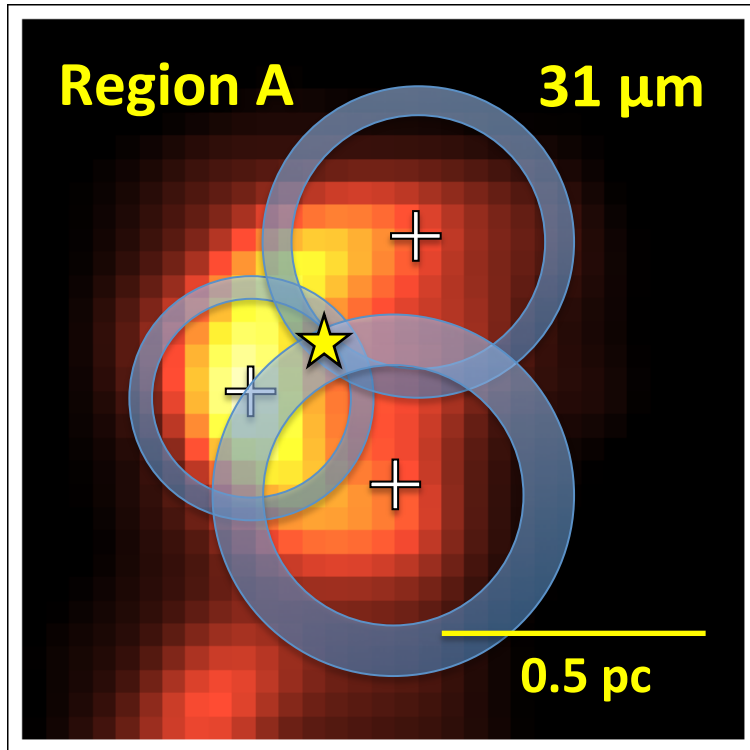


Zoom-in of Region A dust emission with heating source locations overlaid

- ⊛ Stellar luminosity from models fit to the spectral energy distribution:  
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# Locating the Heating Source



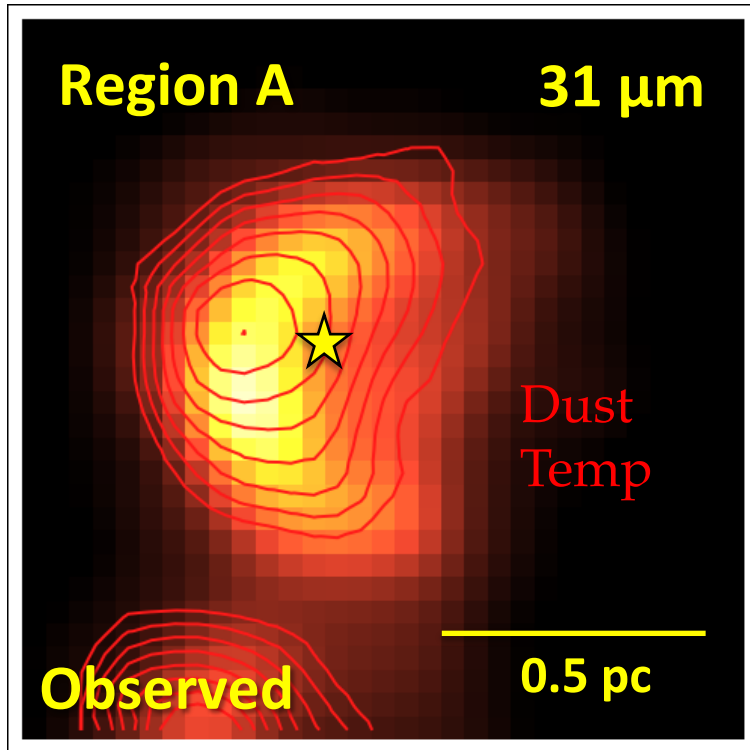
Zoom-in of Region A dust emission with heating source locations overlaid

*This is interesting... but can we reproduce this in a model?*

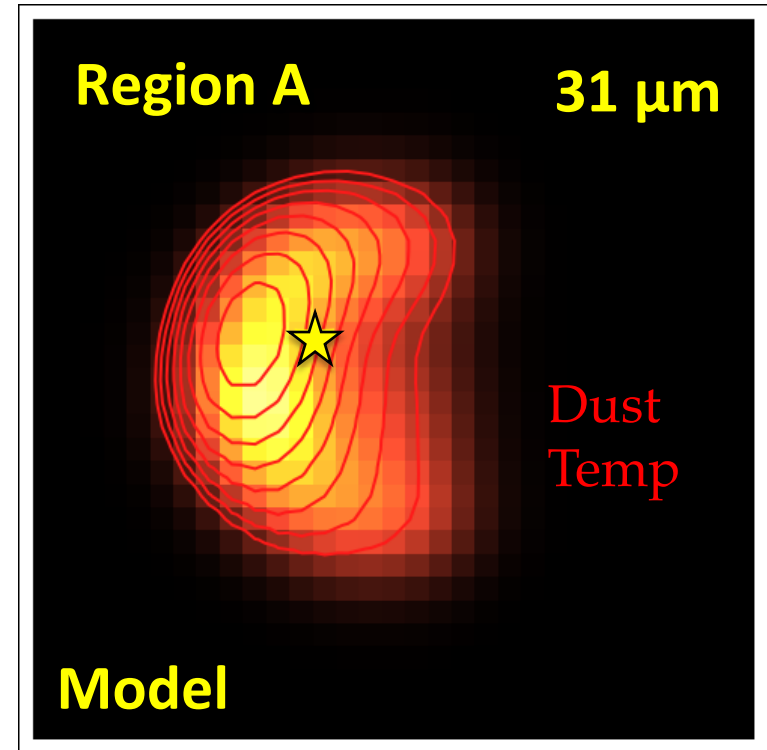
Model must...

- Be a hemispherical shell
- Exhibit dust temperature asymmetry
- Reproduce column density enhancement at south

# Region A Dust Emission Model



Observed Region A dust emission



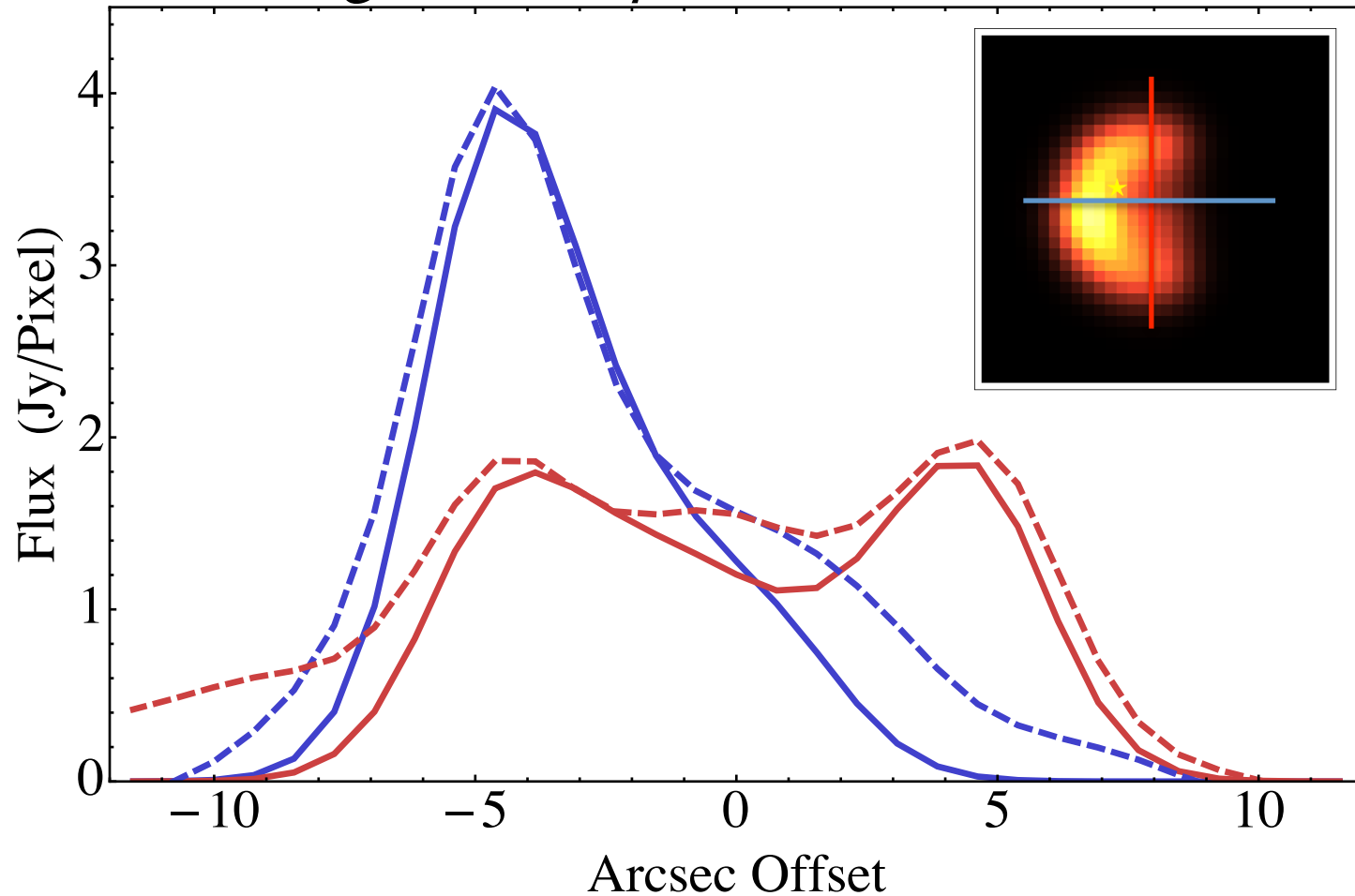
Region A Dust emission model



# Model and Observed Fluxes



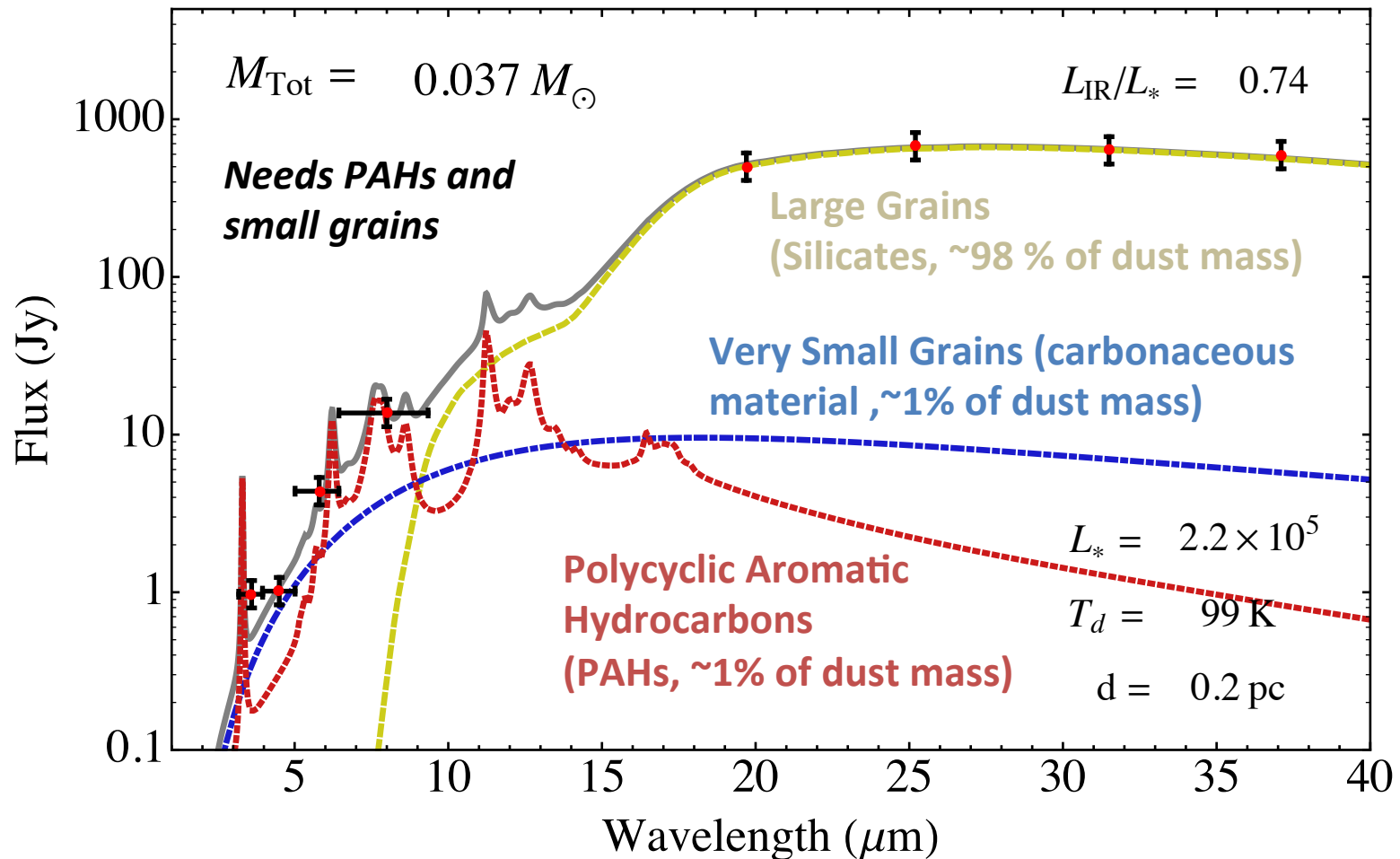
## Region A 31 $\mu\text{m}$ Line Flux Profile



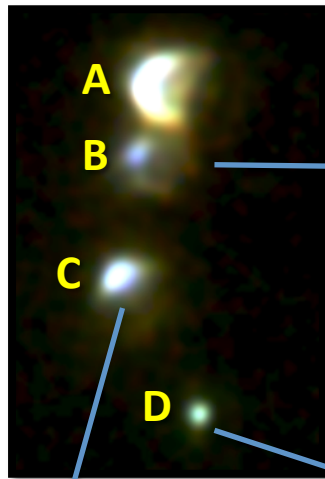
# A Detailed Inspection of the Dust



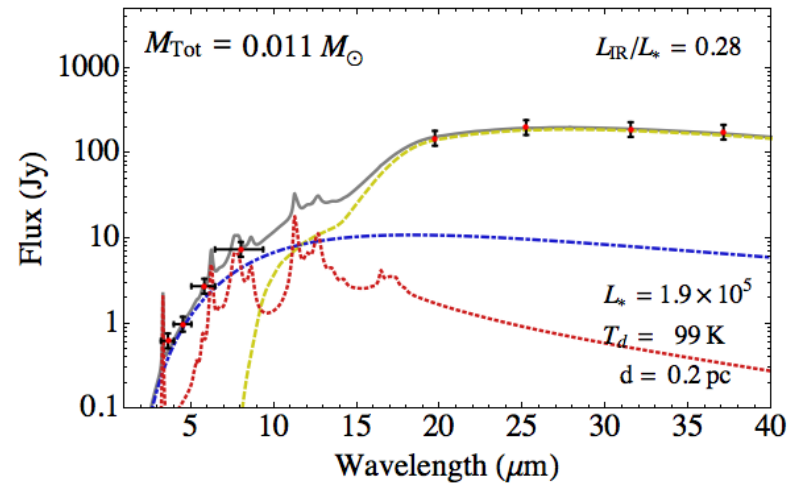
## GC HII Region A SED



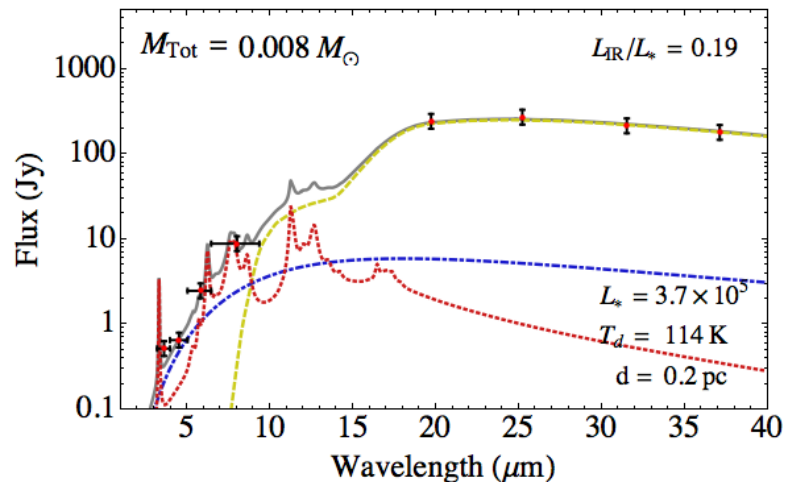
# A Detailed Inspection of the Dust



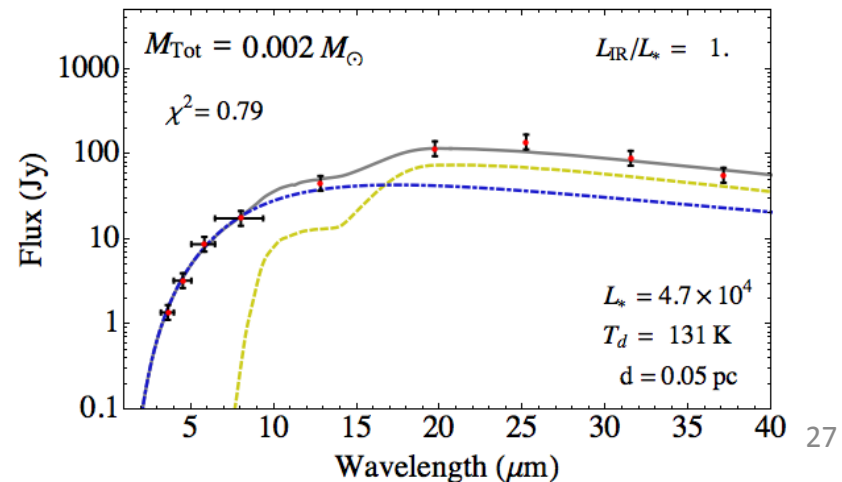
### GC HII Region B SED



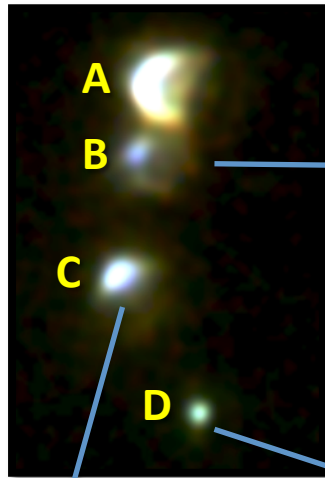
### GC HII Region C SED



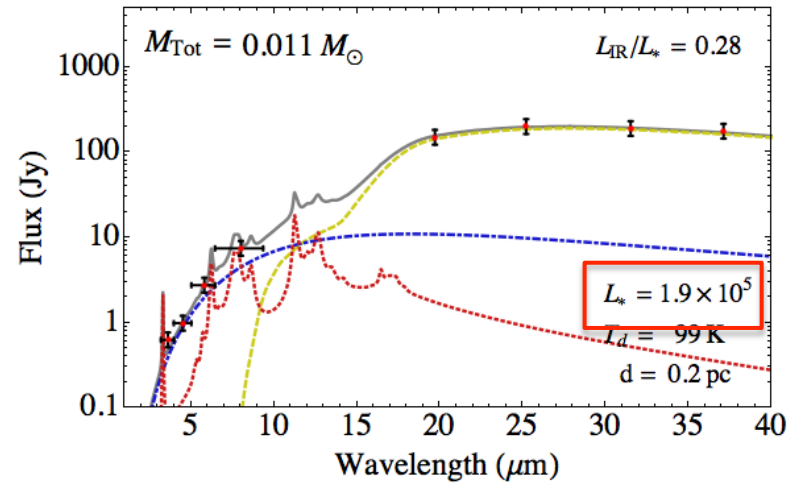
### GC HII Region D SED



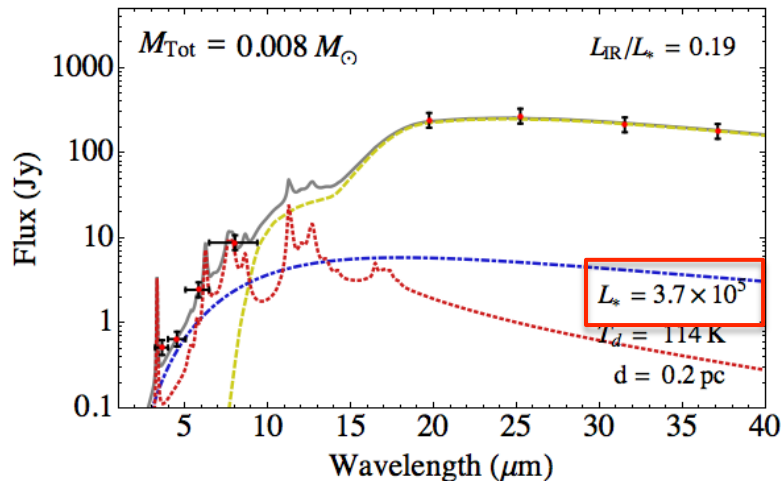
# Heating Source Luminosities



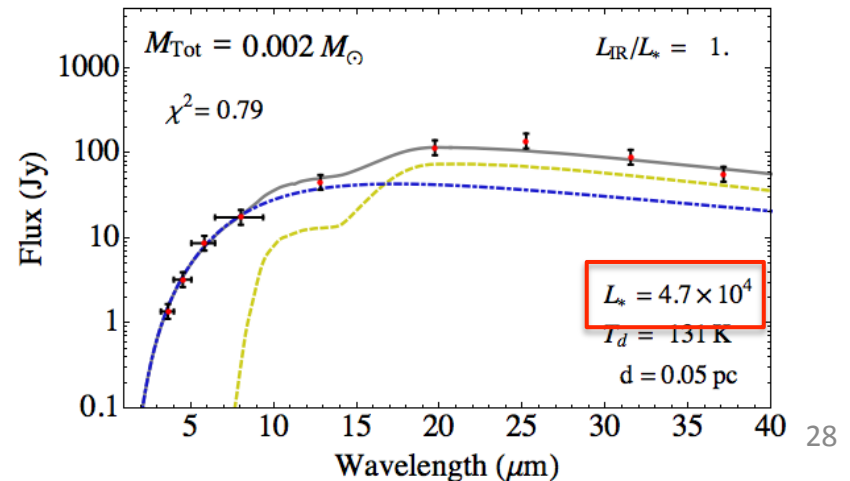
GC HII Region B SED



GC HII Region C SED



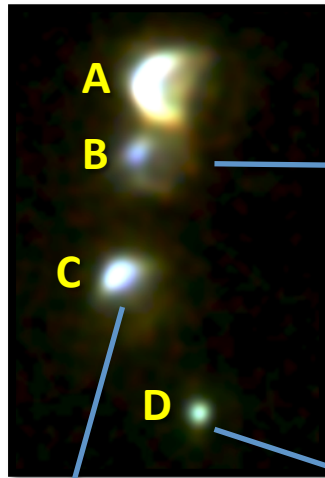
GC HII Region D SED



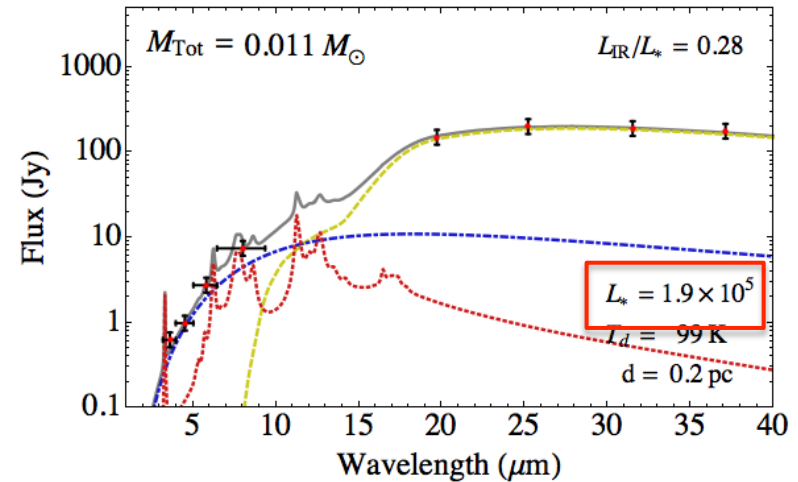
# Heating Source Luminosities



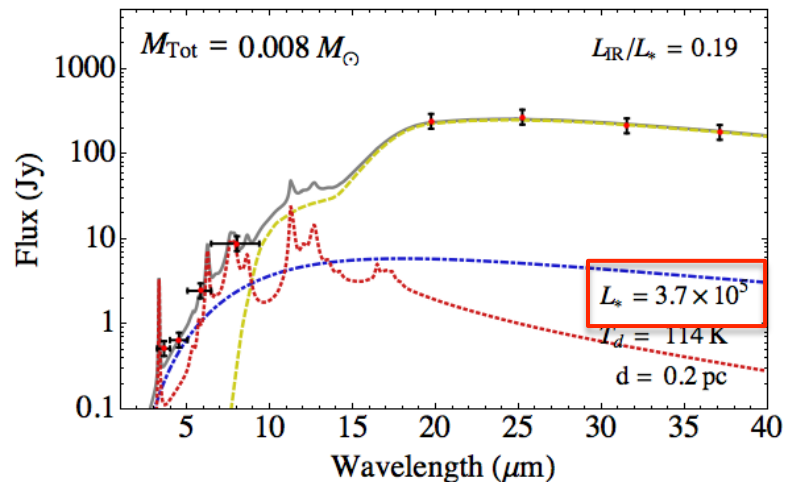
Can we find stars with the expected luminosity/flux?



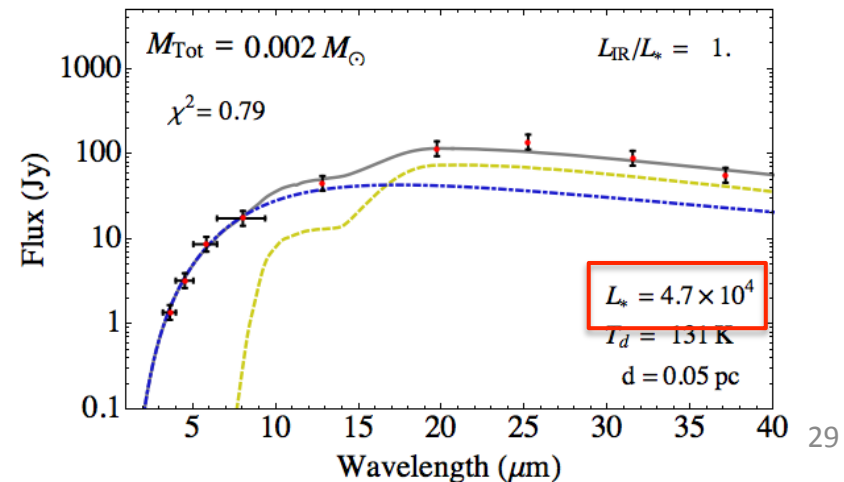
GC HII Region B SED



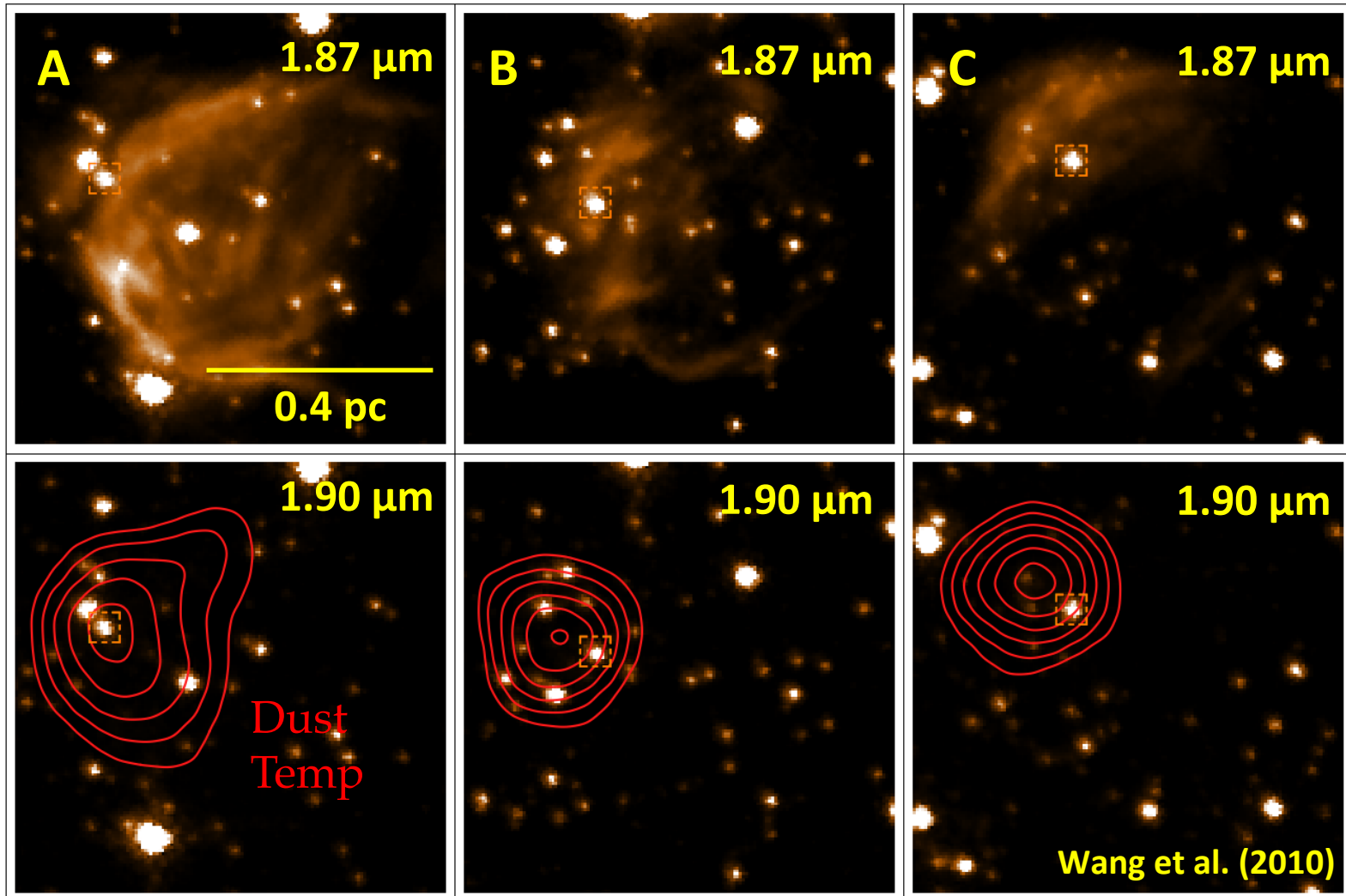
GC HII Region C SED



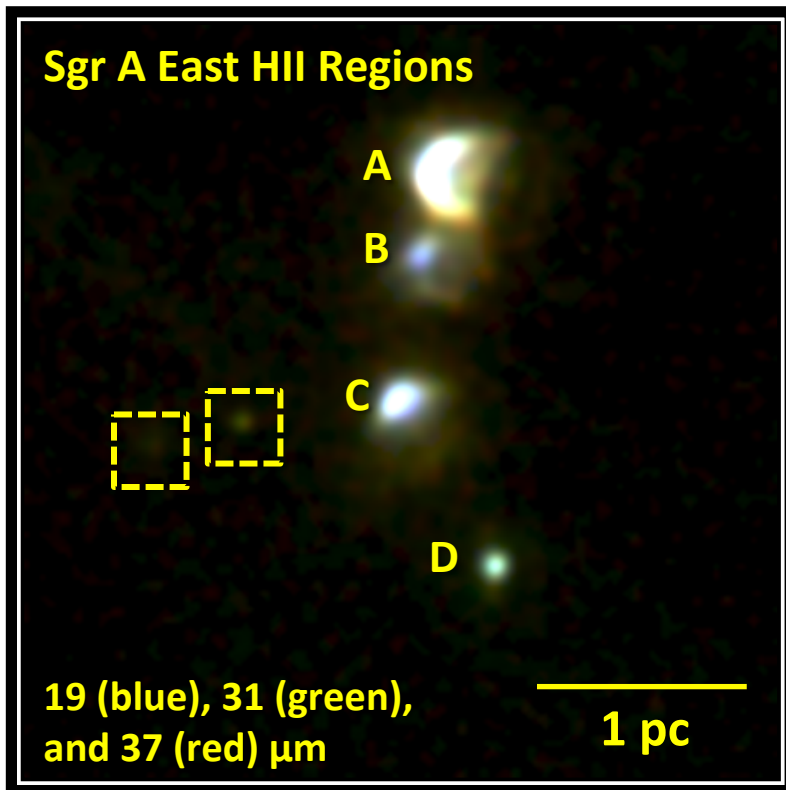
GC HII Region D SED



# Locating the Heating Sources



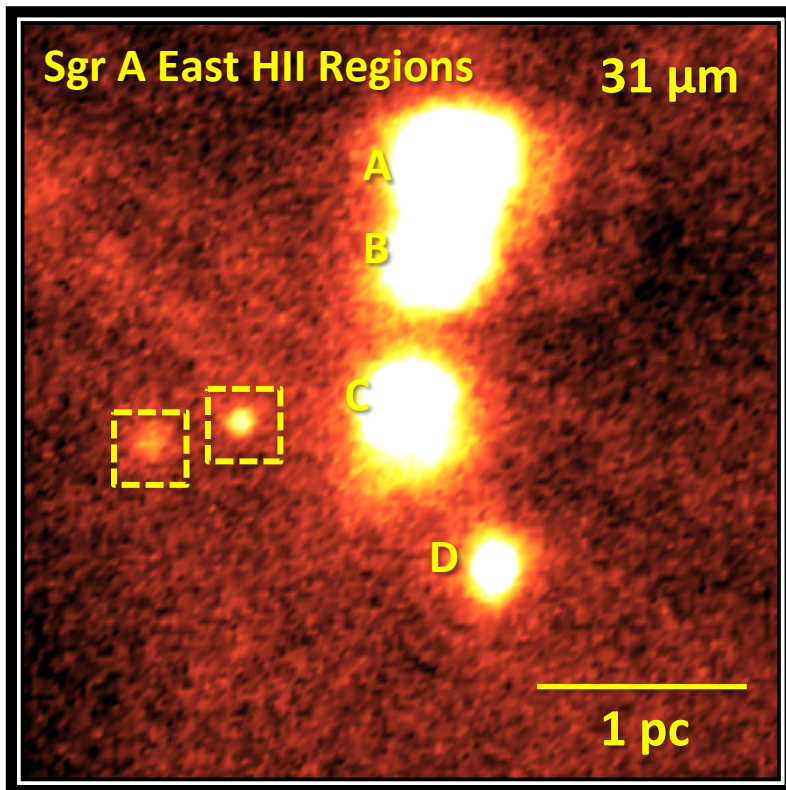
# Searching for More Young Stars



- ⊛ We detect two faint sources east of Region C
- ⊛ They are also seen by Spitzer/IRAC (4.5 – 8.0  $\mu\text{m}$ )

Warm dust emission from the Sgr A East HII Region Complex

# Searching for More Young Stars



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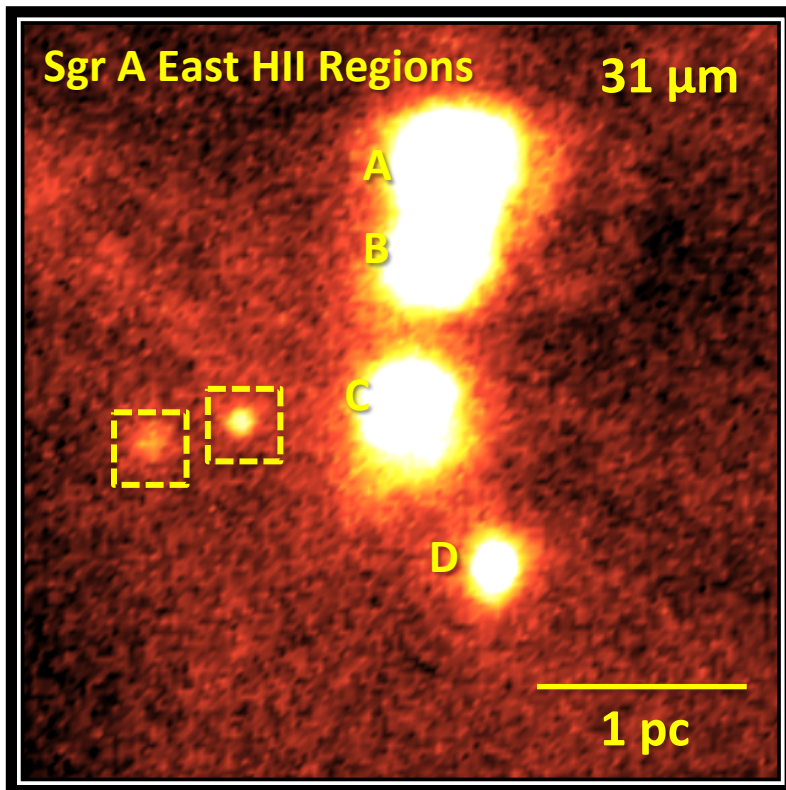
⊛ *What do we label them?*

*“Faint Infrared Source 1 and 2”?*

Warm dust emission from the Sgr A East HII Region Complex



# Searching for More Young Stars



Warm dust emission from the Sgr A East HII Region Complex

⊛ We detect two faint sources east of Region C

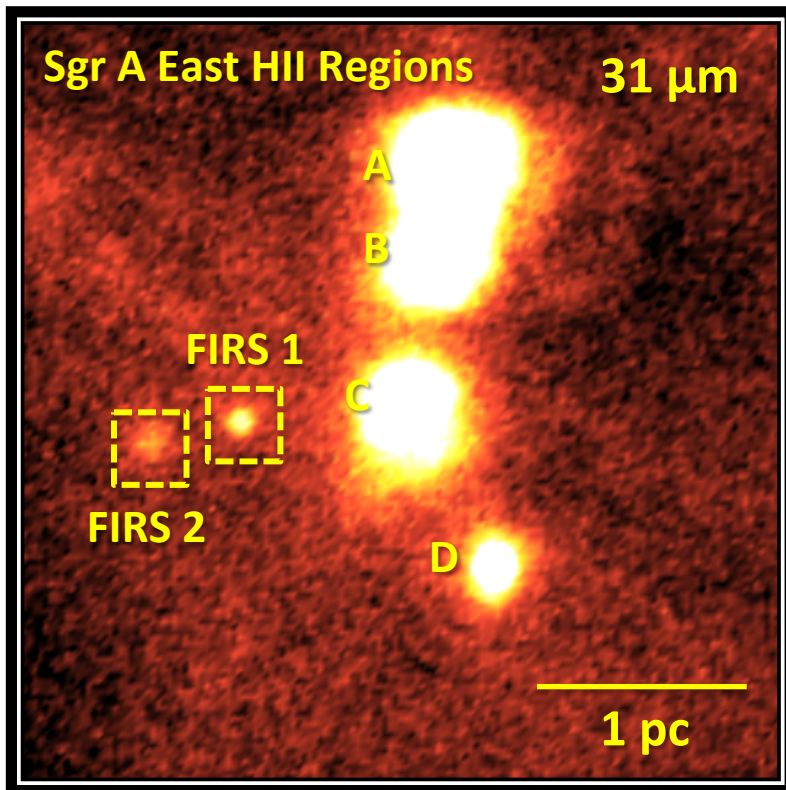
⊛ They are also seen by Spitzer/IRAC (4.5 – 8.0  $\mu\text{m}$ )

⊛ *What do we label them?*

~~*“Faint Infrared Source 1 and 2”?*~~

*“Infrared Source (IRS) E and D”?*

# Searching for More Young Stars



Warm dust emission from the Sgr A East HII Region Complex

⊛ We detect two faint sources east of Region C

⊛ They are also seen by Spitzer/IRAC (4.5 – 8.0  $\mu\text{m}$ )

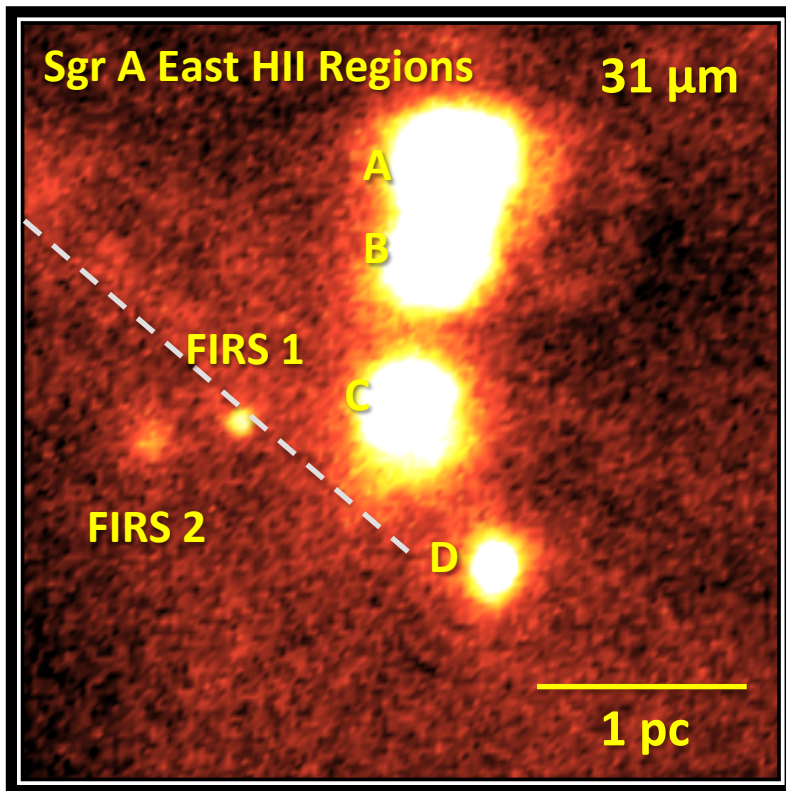
⊛ *What do we label them?*

~~*“Faint Infrared Source 1 and 2”?*~~

~~*“Infrared Source (IRS) E and D”?*~~

*“Faint Infrared Source (FIRS) 1 and 2”*

# Faint Infrared Sources 1 and 2



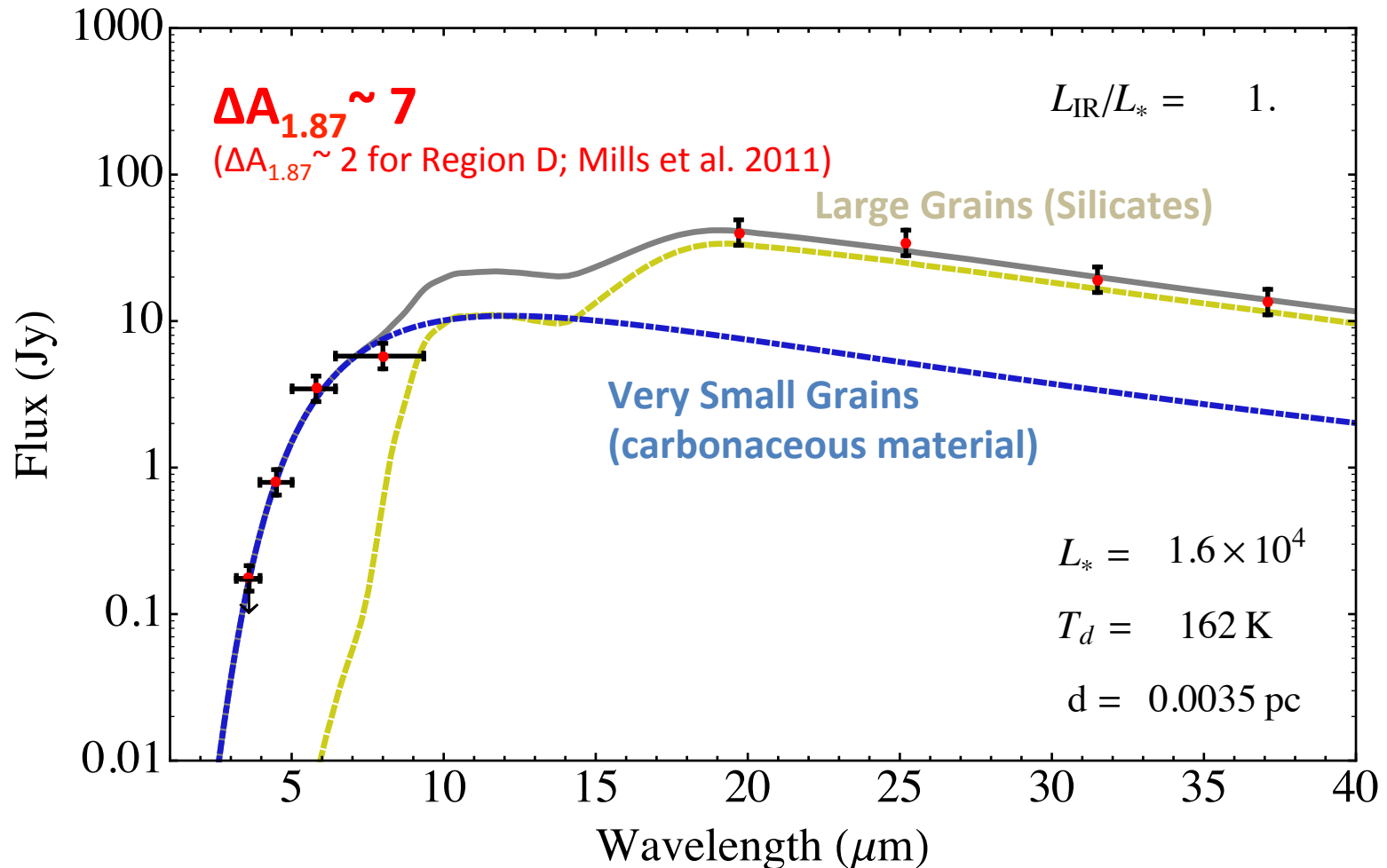
Warm dust emission from the Sgr A East HII Region Complex

- ⊛ FIRS 1 is a point source.  
FIRS 2 is partially resolved (FWHM  $\sim 5''$  at  $31 \mu\text{m}$ )
- ⊛ FIRS 1 has no ionized gas counterpart.  
FIRS 2 has a faint 6 cm emission counterpart
- ⊛ FIRS 1 appears coincident with a faint dust ridge tracing the surface of the molecular cloud (Mills et al. 2011)  
*We find it is deeply embedded*

# Dust Emission from FIRS 1



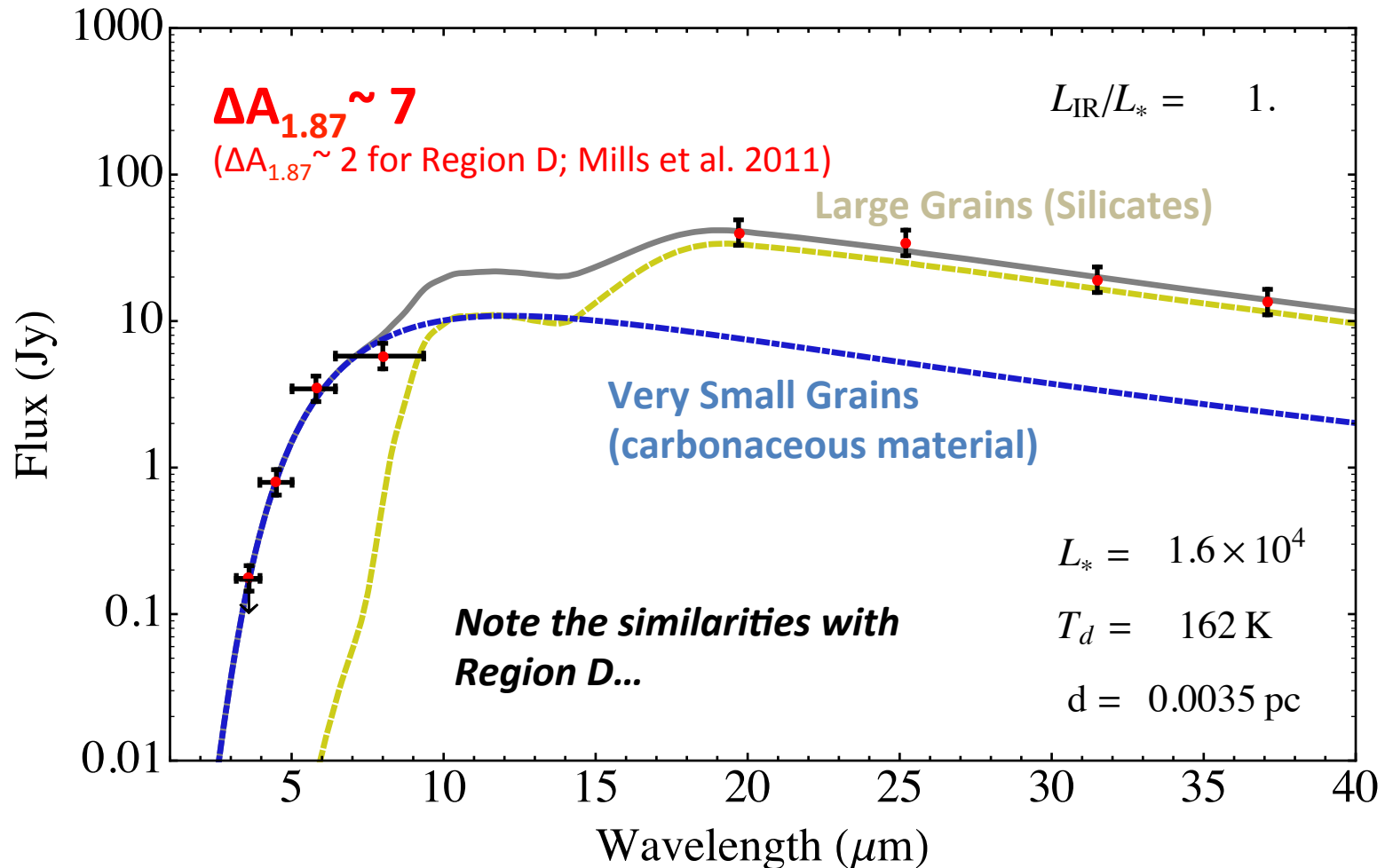
## Faint IR Source 1 SED



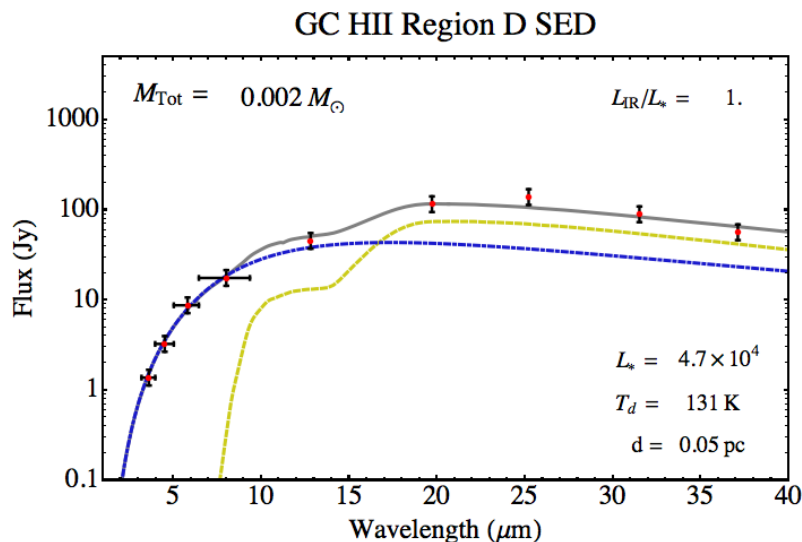
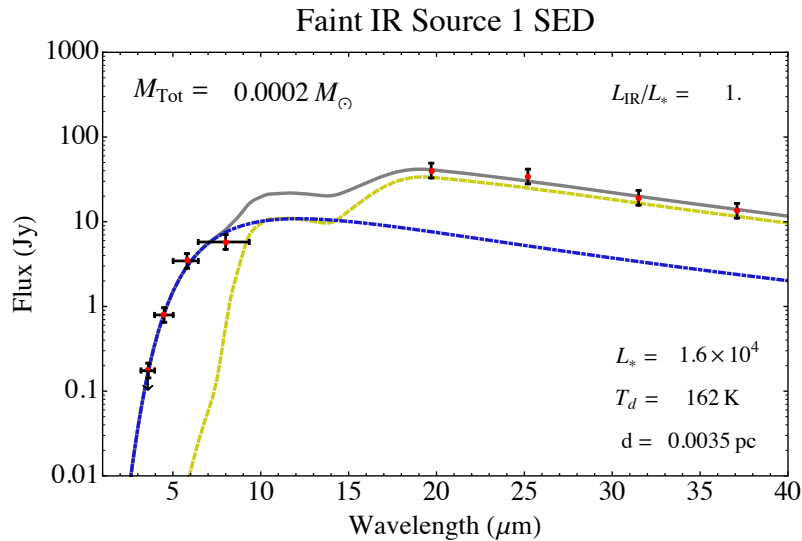
# Dust Emission from FIRS 1



## Faint IR Source 1 SED



# FIRS 1 and Region D



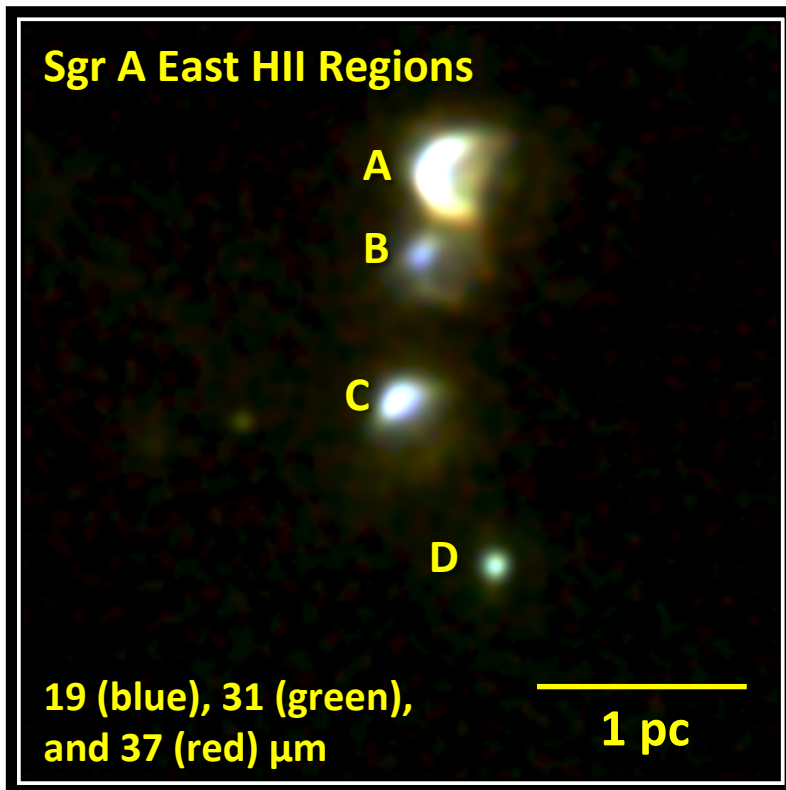
⊛ Both SEDs do not require the presence of PAHs (unlike the Regions A, B, and C)

⊛ Both sources are embedded and exhibit similar luminosities

⊛ FIRS 1 a precursor to a Region D-like source?

*Spectroscopic follow-up could help trace reveal dust evolution/PAH production in HII regions*

# Recap and Summary

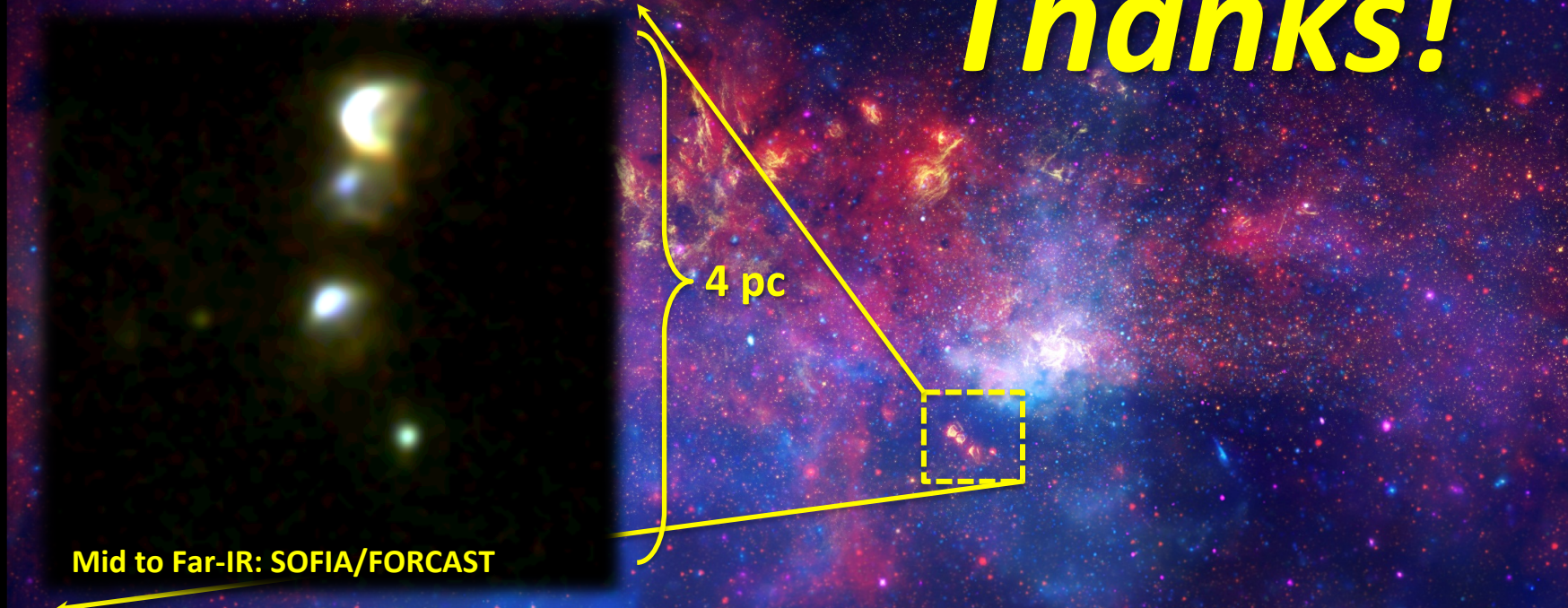


Warm dust emission from the  
Sgr A East HII Region Complex

- ⊛ We identify and characterize the heating sources from dust temperature analysis and SED-fitting
- $L_* \sim 5 - 40 \times 10^4 L_{\text{Sun}}$
- ⊛ We find that all the regions contain large and very small grains, but only A, B, and C, require PAHs
  - ⊛ We detect two faint infrared sources, one of which may be an embedded young stellar object (FIRS 1)

Sgr A East HII Complex:

*Thanks!*



Mid to Far-IR: SOFIA/FORCAST

HST (Yellow - Near-IR), Spitzer (Red - Mid-IR), and Chandra (Blue - X-Ray)