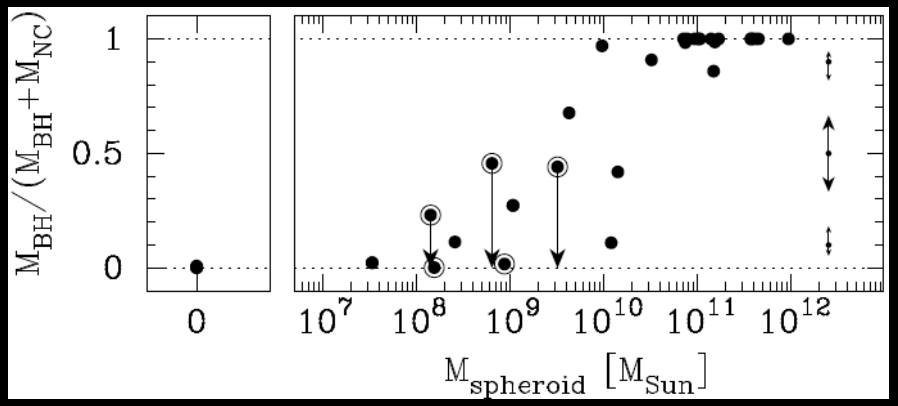
Widefield high-resolution multiwavelength imaging of our Galactic center

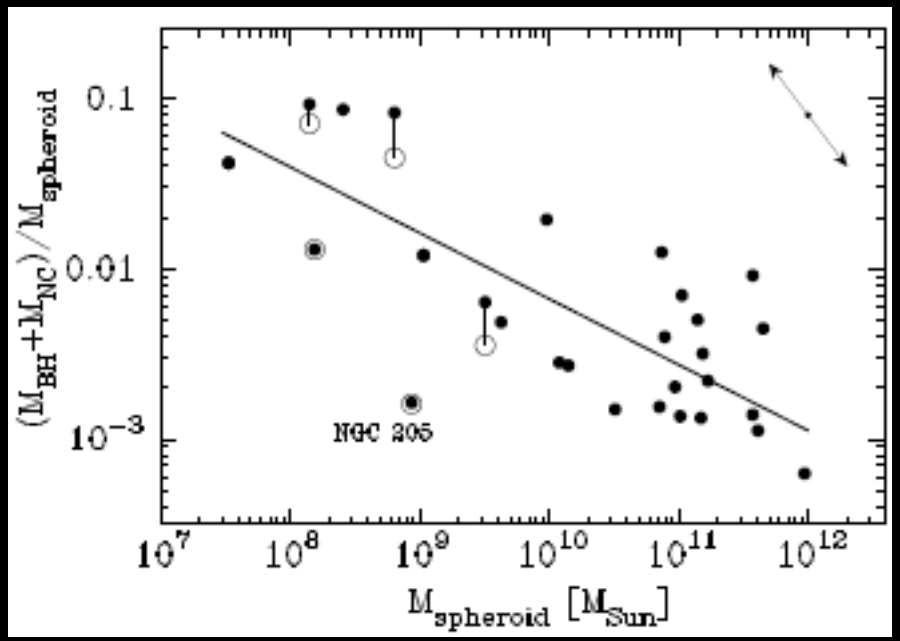
- Chandra surveys
- HST/NICMOS Pa Survey
- LMT/AzTEC 1.1-mm continuuum survey

Q. Daniel Wang

University of Massachusetts

Galactic nuclear regions play a key role in galaxy formation and evolution!





Graham & Spitler 2009

- Every major galaxy probably contains a SMBH and/or a nuclear stellar cluster.
- Their masses are correlated with the spheroid mass.
- How these correlations are achieved is not clear.
- SMBHs accrete gas in two modes :
  - Quasars: radiating ~10% of the rest-mass energy
  - Local SMBHs: radiatively inefficient
- But SMBHs can also grow by mergers

Little is known about the interplay among the ISM, stars, and SMBHs

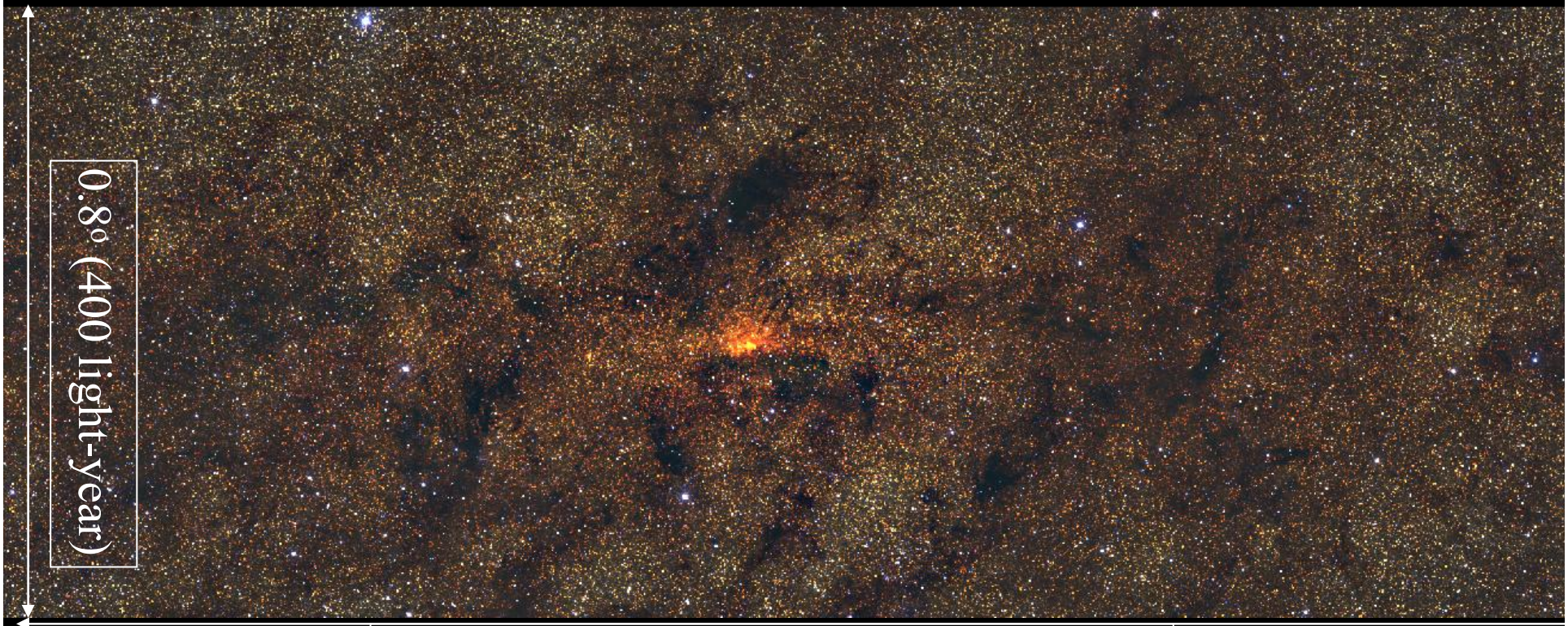
What do we hope to learn from our Galactic Center (GC)?

Understand the interplay among the SMBH, SF and the extreme nuclear environment:

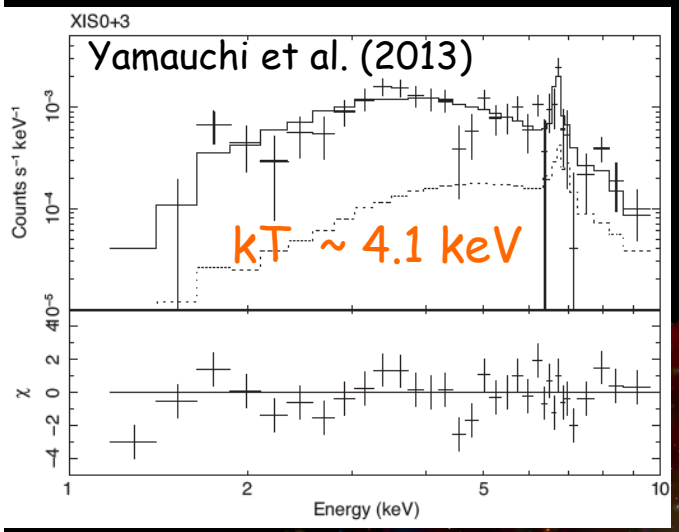
- Massive SF mode and history
- Map out the stellar distribution
- Map out foreground extinction
- Detect and understand various high-energy phenomena and processes (e.g., X-ray sources and hot plasma)

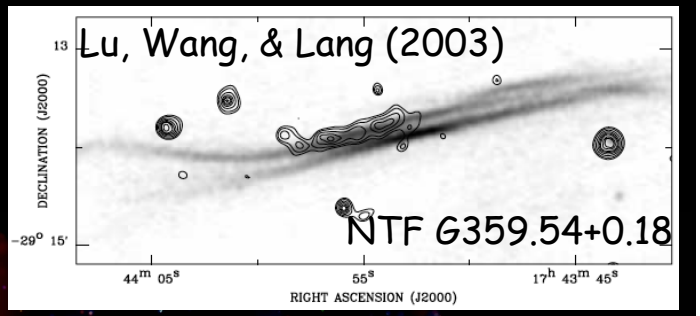
2MASS Image of the GC region

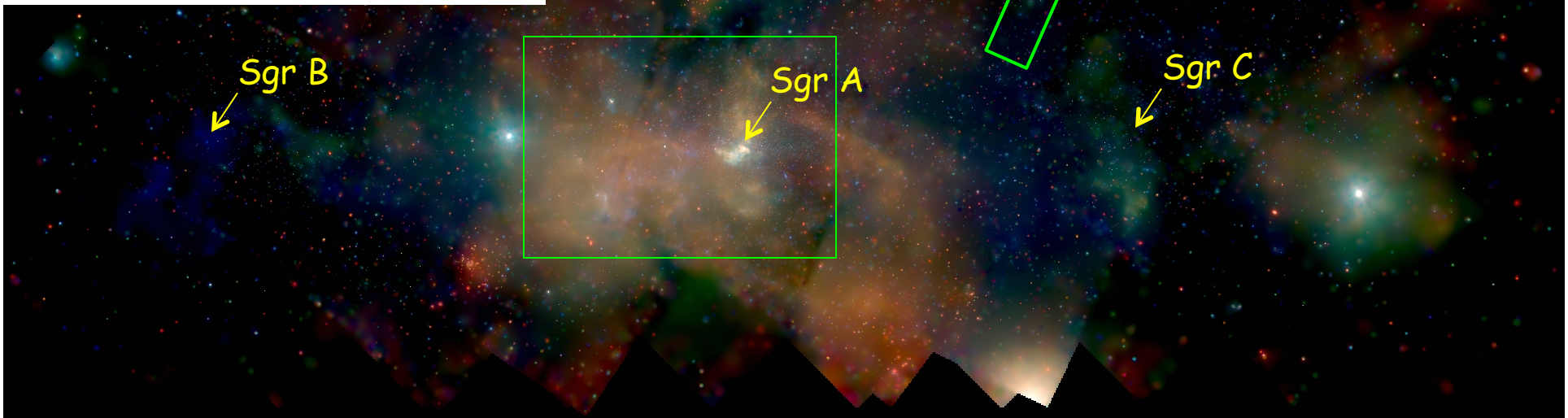
Red: K band Green: H band Blue: J band



Chandra survey of the GC

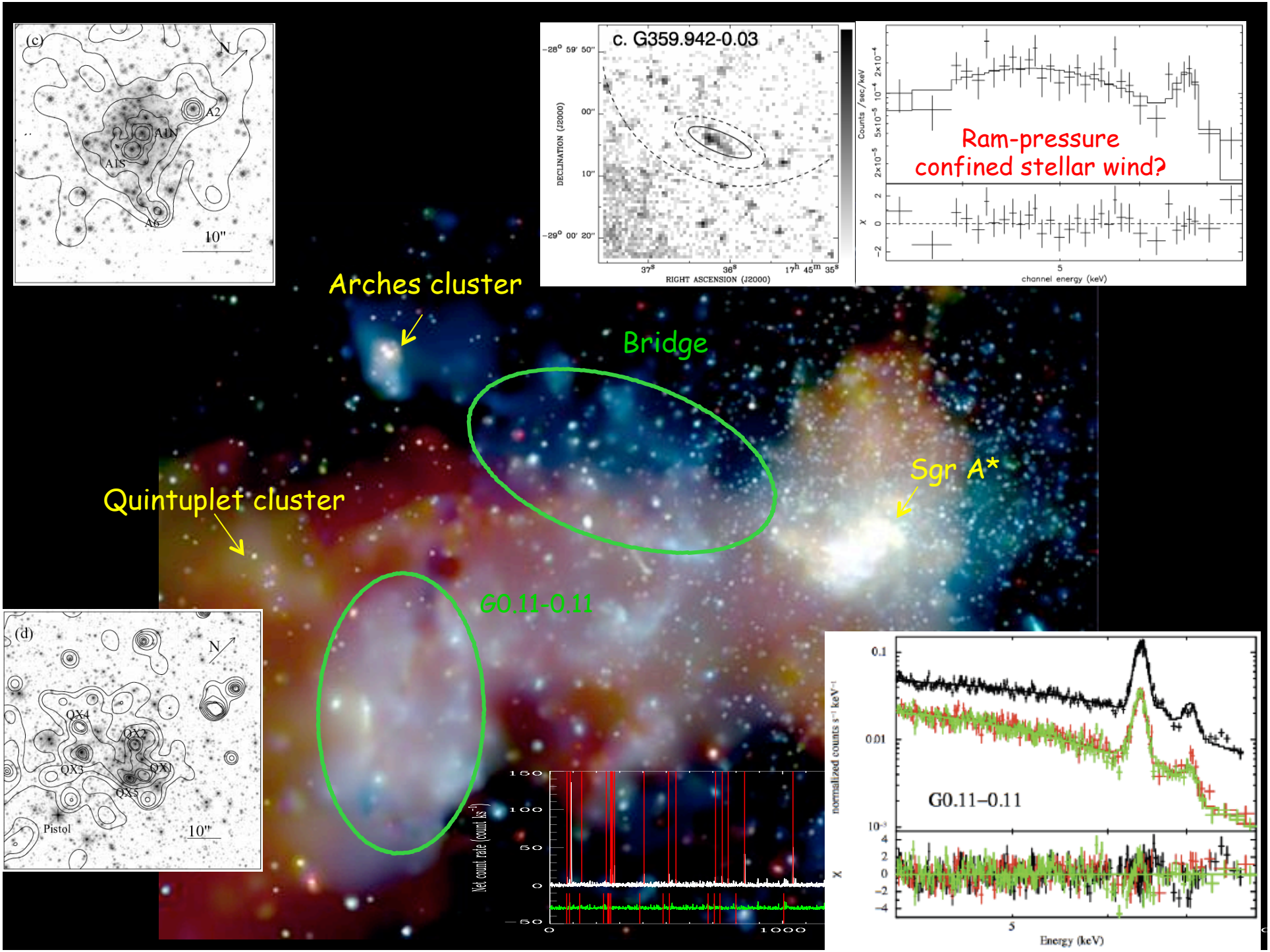




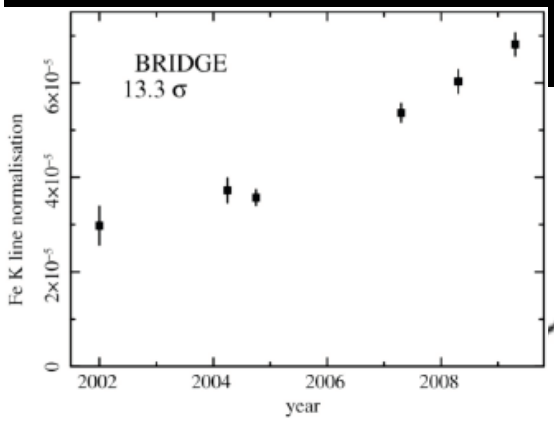


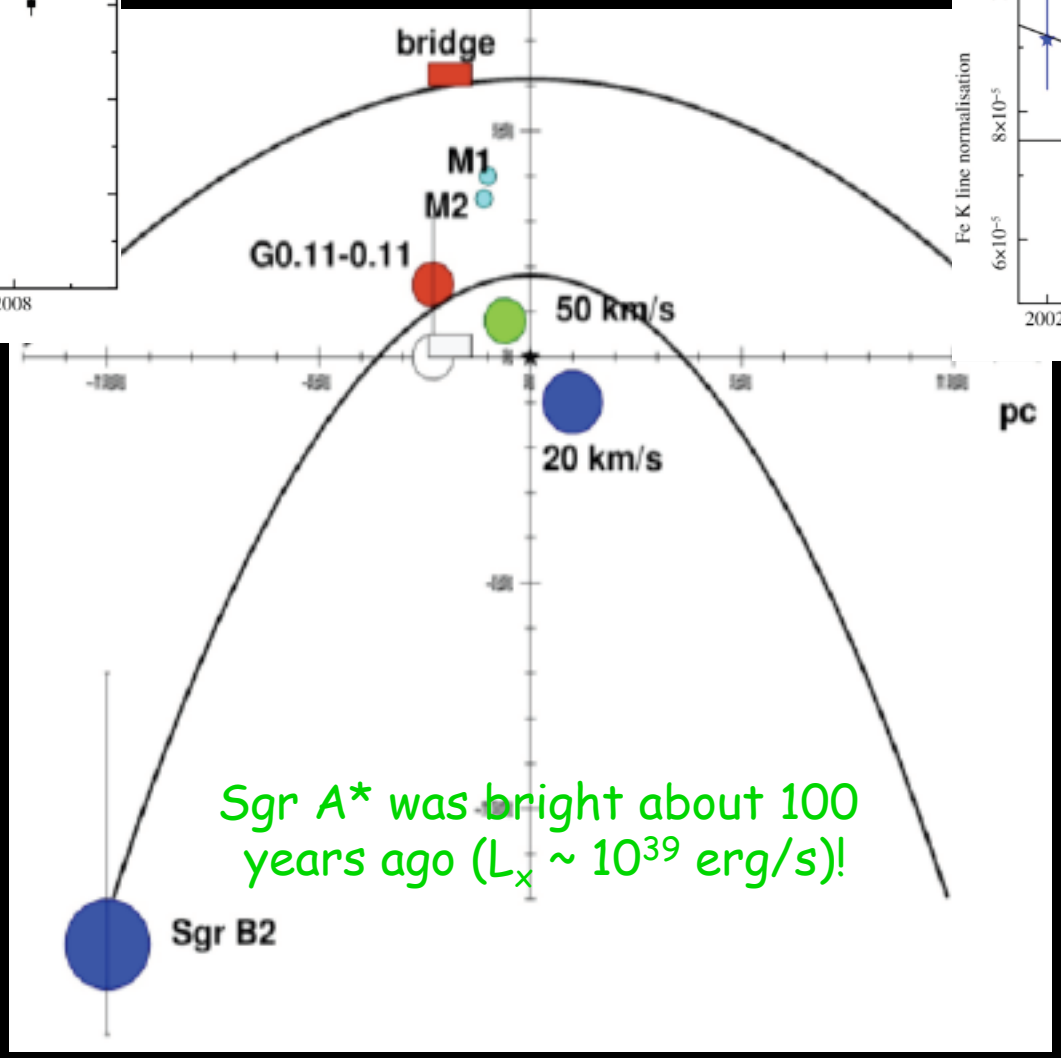
Red: 1-3 keV Green: 3-5 keV Blue: 5-8 keV

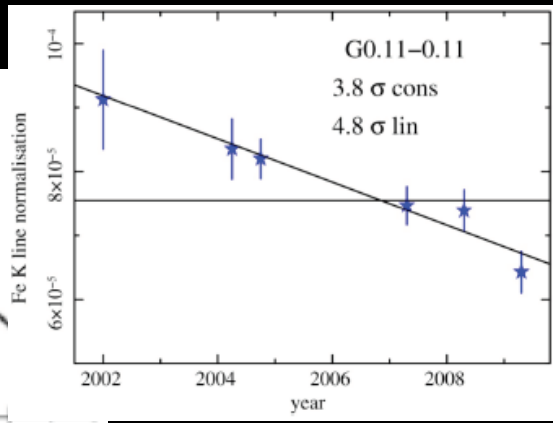
Wang, Gotthelf, & Lang (2002), Muno et al. (2006)


(c)
N
A2
A1N
A1S
A6
10"
c. G359.942-0.03
DECLINATION (J2000)
RIGHT ASCENSION (J2000)
Counts /sec/keV
channel energy (keV)
Ram-pressure
confined stellar wind?
Arches cluster
Bridge
Sgr A*
Quintuplet cluster
G0.11-0.11
(d)
N
QX4
QX2
QX3
QX1
QX5
Pistol
10"
Net count rate (count ks^{-1})
normalized counts s^{-1} keV^{-1}
G0.11–0.11
Energy (keV)

X-ray reverberation of a Sgr A* burst ~ 100 years ago



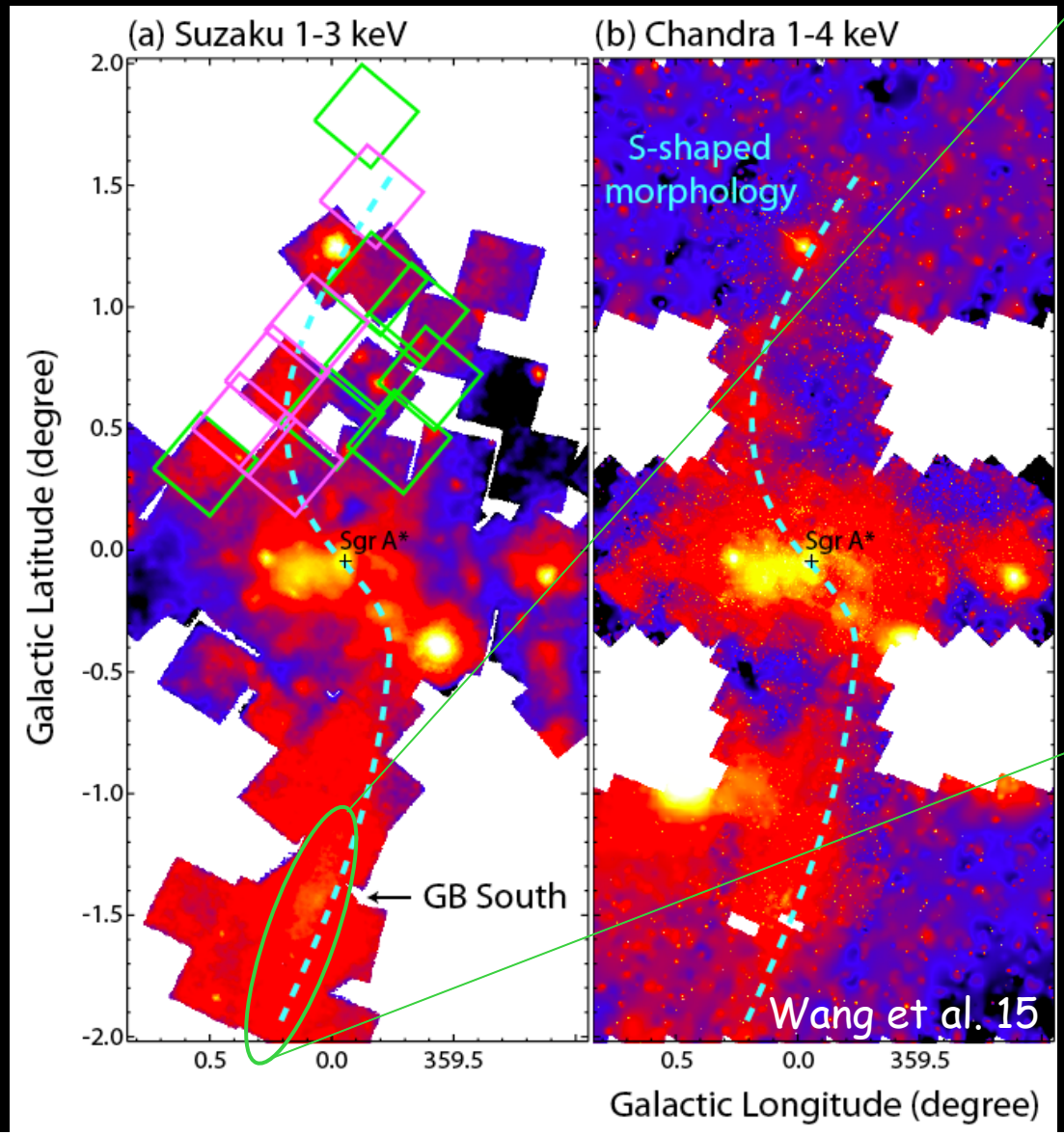


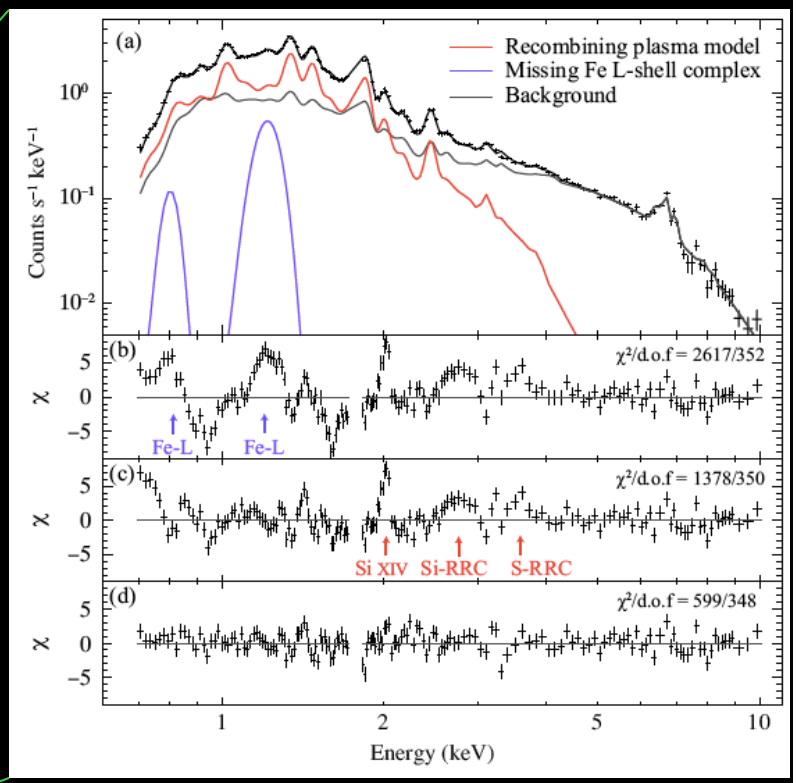


Sgr A* was bright about 100 years ago (L_x ~ 10^{39} erg/s)!

Ponti et al. 2010

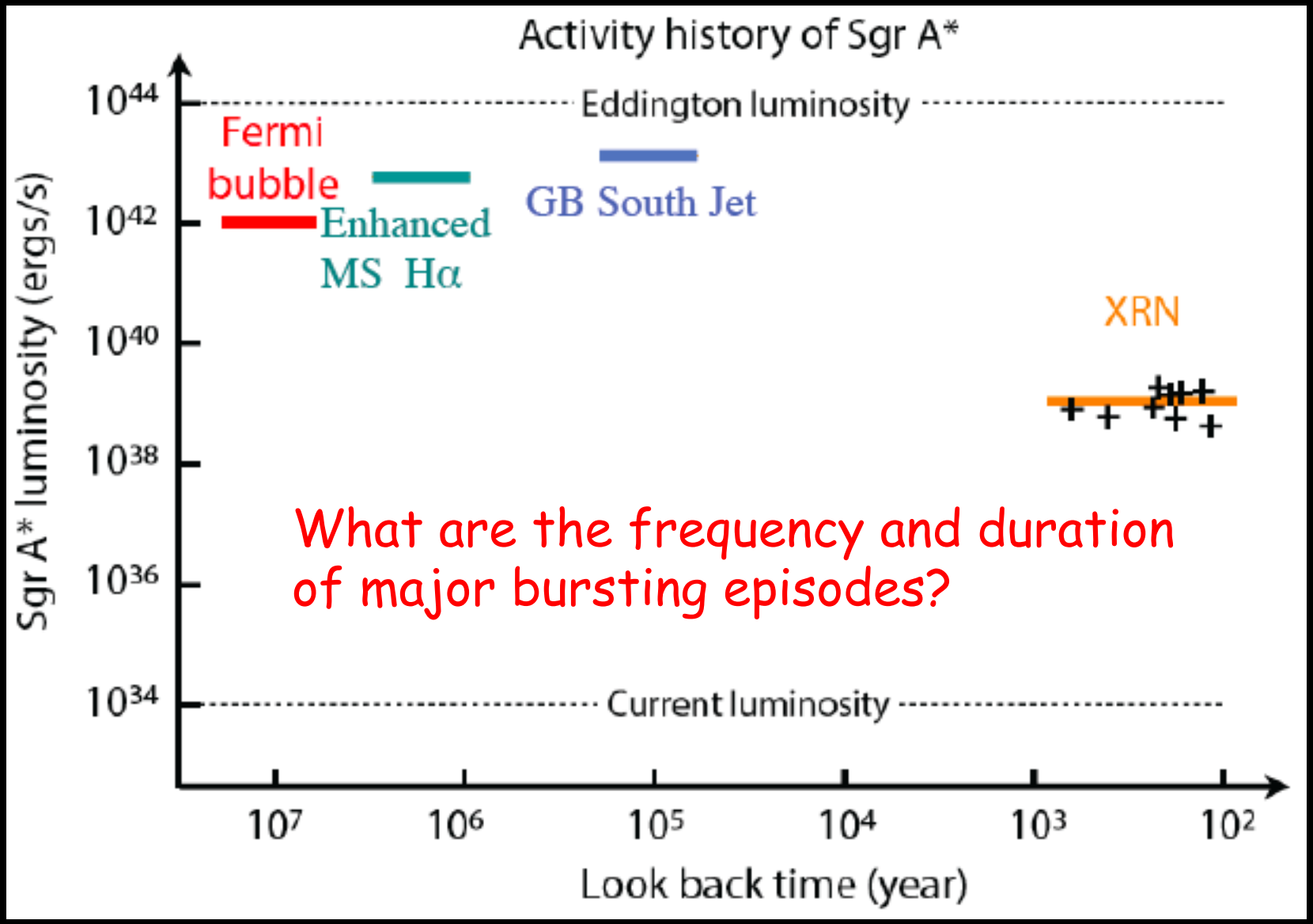
Earlier GC activity: Detection of recombining plasma.





S. Nakashima et al. 2013

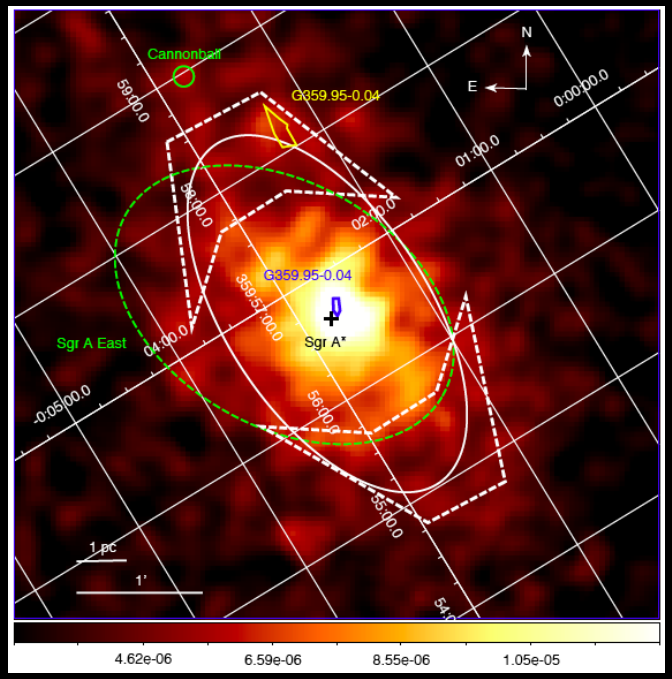
We have an ongoing Suzaku key program of 500 ks to map out the Galactic northern counterpart of the plasma.

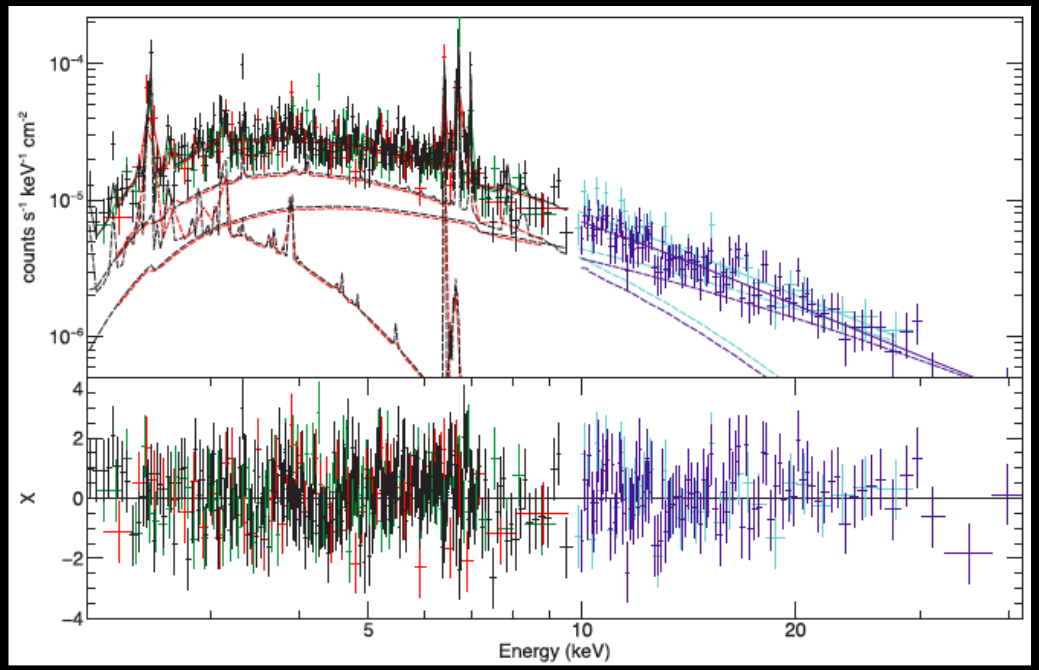


Enhanced ionization of the Magellanic Stream

Bland-Hawthorn et al. (2013)

Extended Hard X-ray Emission in the Inner Parsecs of the GC

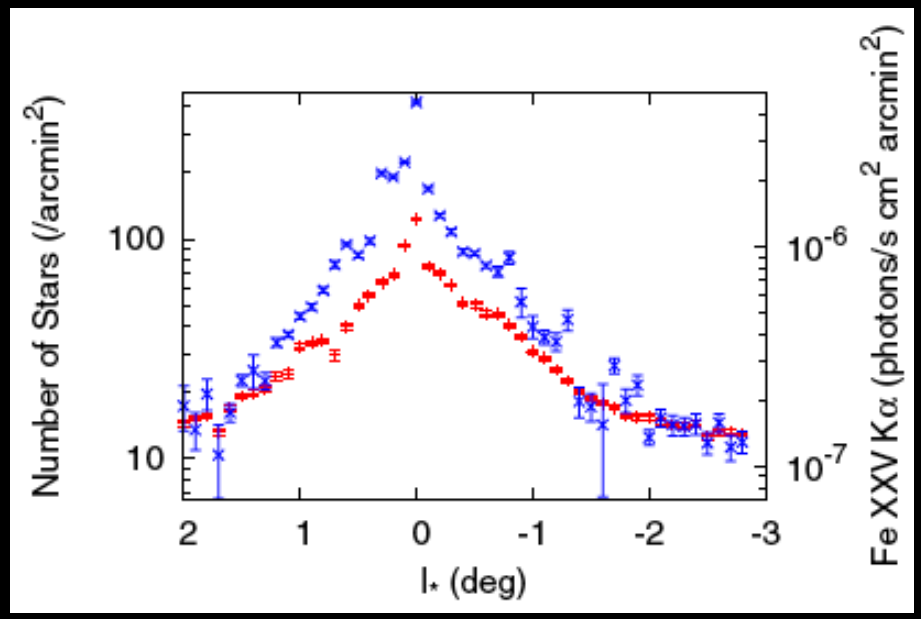


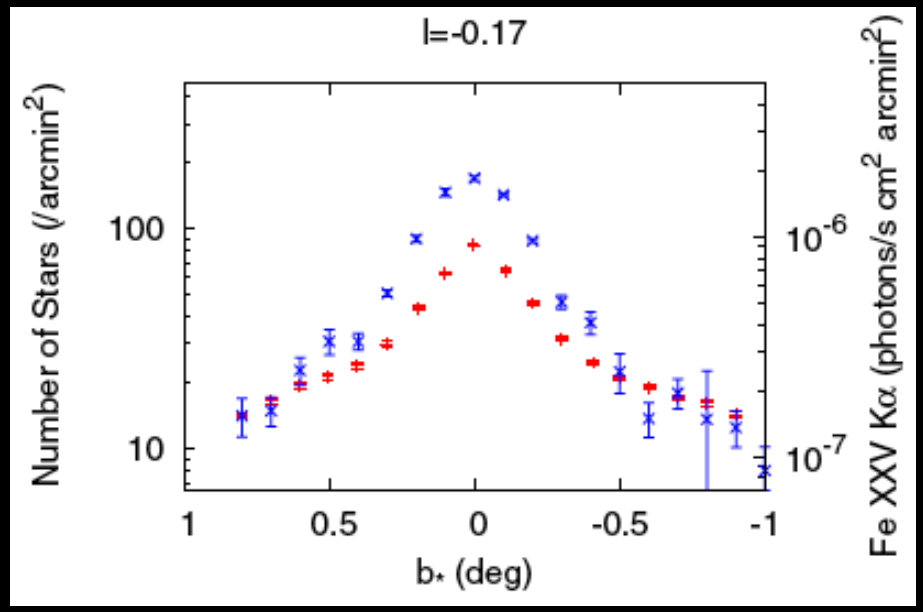


- Detected mostly in 20-40 keV.
- More sharply peaked than the soft X-ray population.
- Massive population (10^3 - 10^4) of intermediate polars with the accreting white dwarfs > 0.9 $M_\odot$, compared to ~0.5 $M_\odot$?

Perez et al. (2015, Nature)

Nature of the enhanced specific He-like Fe Ka line emission toward the center



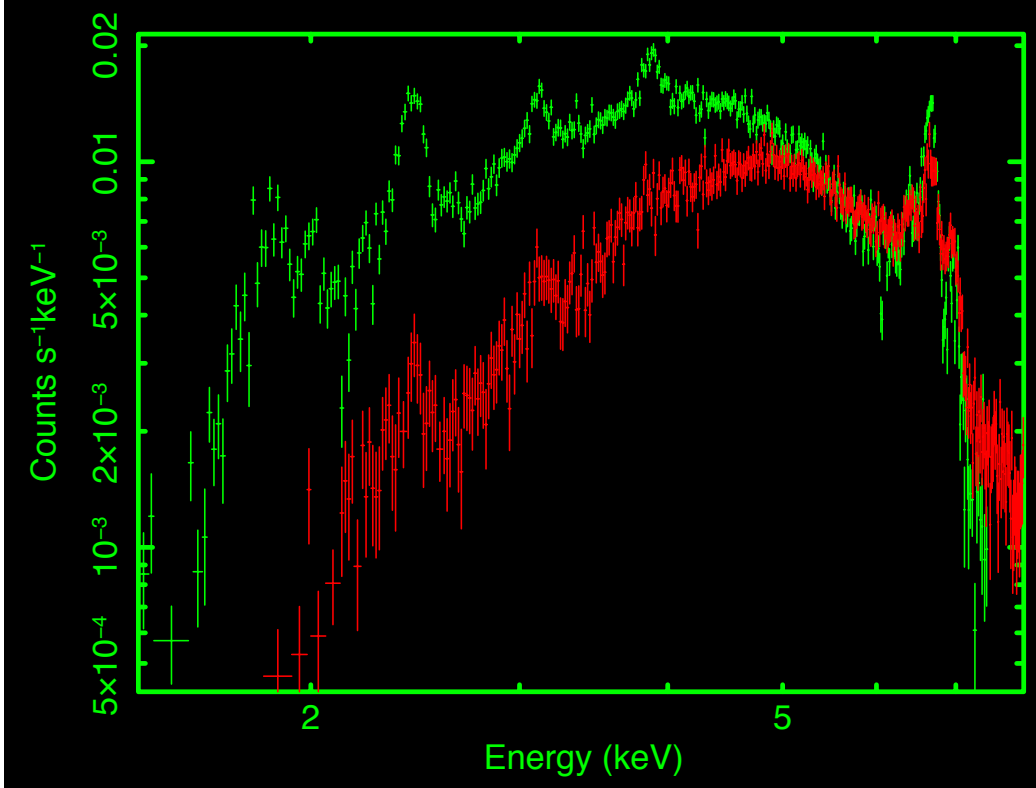


Nishiyama et al. 2013

Possibilities:

1. Presence of T ~ 10^8 K plasma
2. Enhanced number density of CVs
3. Problematic stellar mass distribution model

Chandra spectra of resolved and unresolved emissions

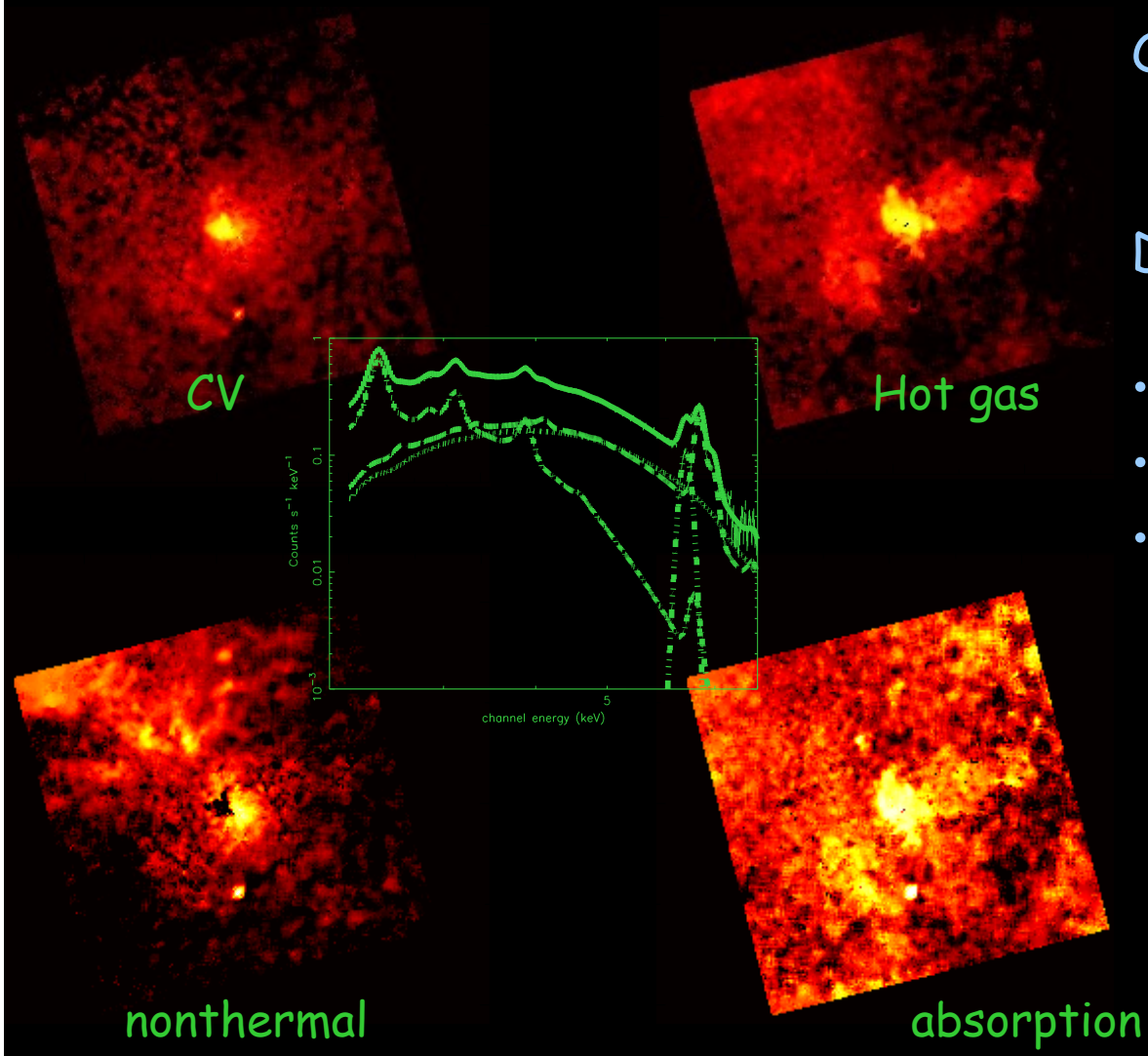


Chandra detected sources are on average substantially harder than that of the diffuse emission.

Is this an intrinsic absorption effect of CVs?

Wang et al. (2015)

Spatially resolved decomposition of the "diffuse" X-ray Spectrum



Only about 15% of the observed X-ray emission is resolved.

Decomposed into three components:

- CVs with T ~ 10^8 K
- Hot gas with T ~ 10^7K
- Nonthermal: inverse Compton scattering, bremstrahlung, and reflection

This decomposition is, however, sensitive to the assumed spectral models.

Wang et al. (2015)

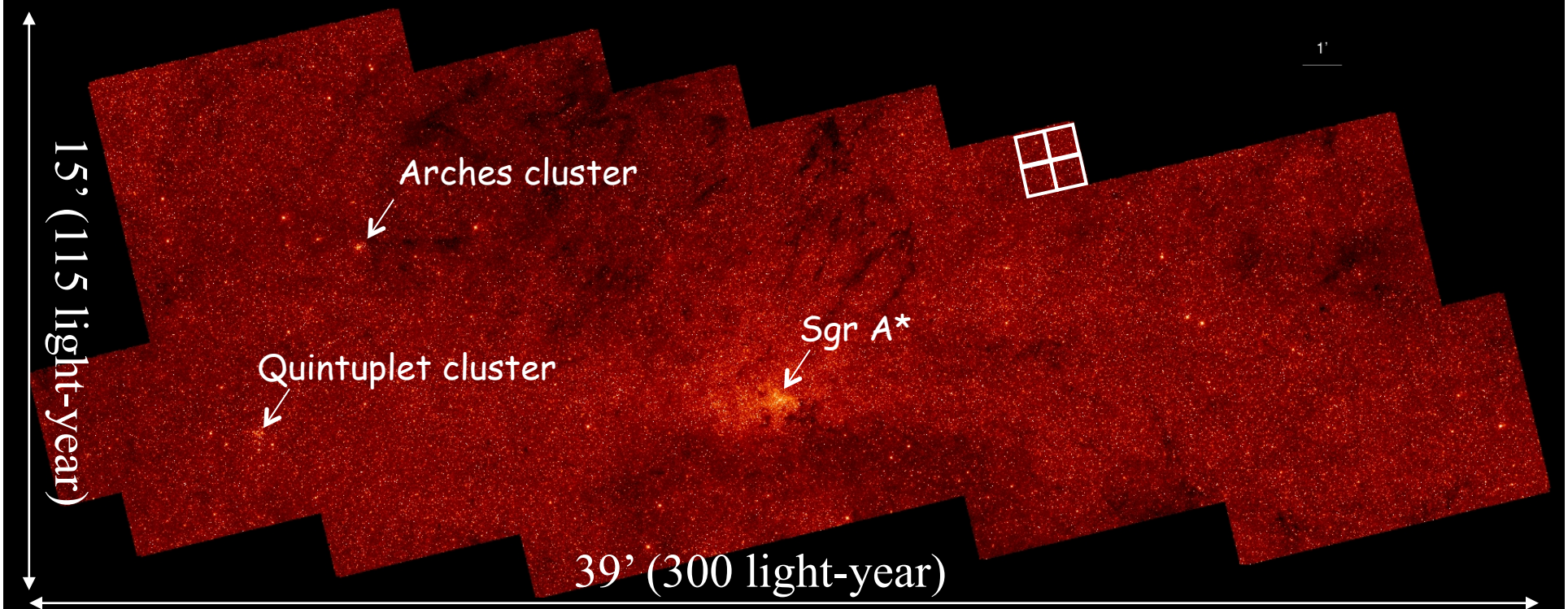
HST/NICMOS Mapping of the GC

Q. D. Wang (PI), H. Dong, D. Calzetti (Umass)

M. R. Morris, E. A. Mills (UCLA), S. Stolovy, M. Muno, J. Mauerhan, (Caltech/IPAC/JPL), Cotera (SETI), C. C. Lang (U. of Iowa),

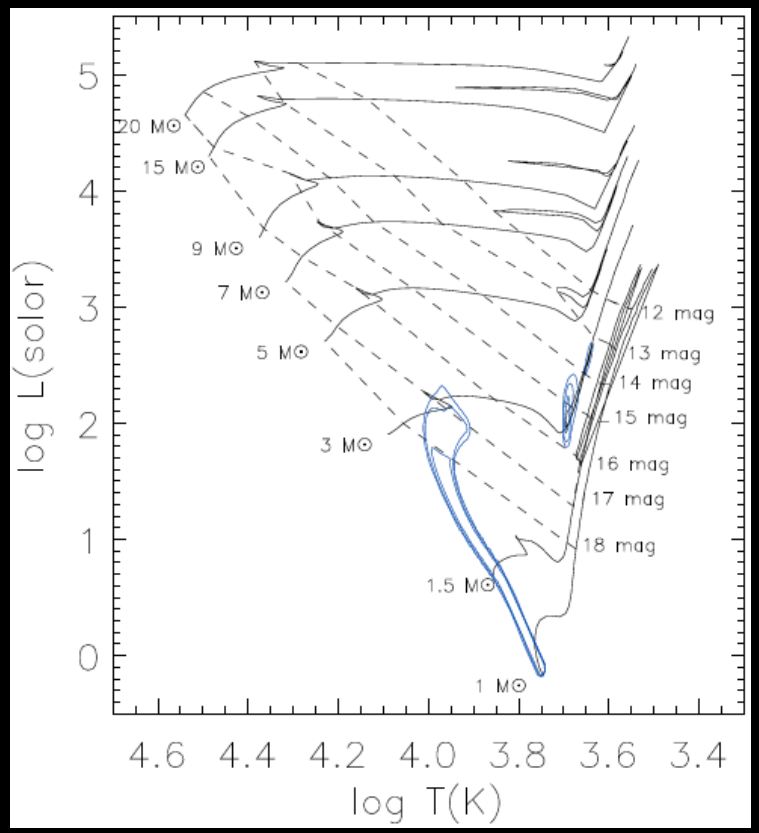
G. Schneider (U. Arizona)

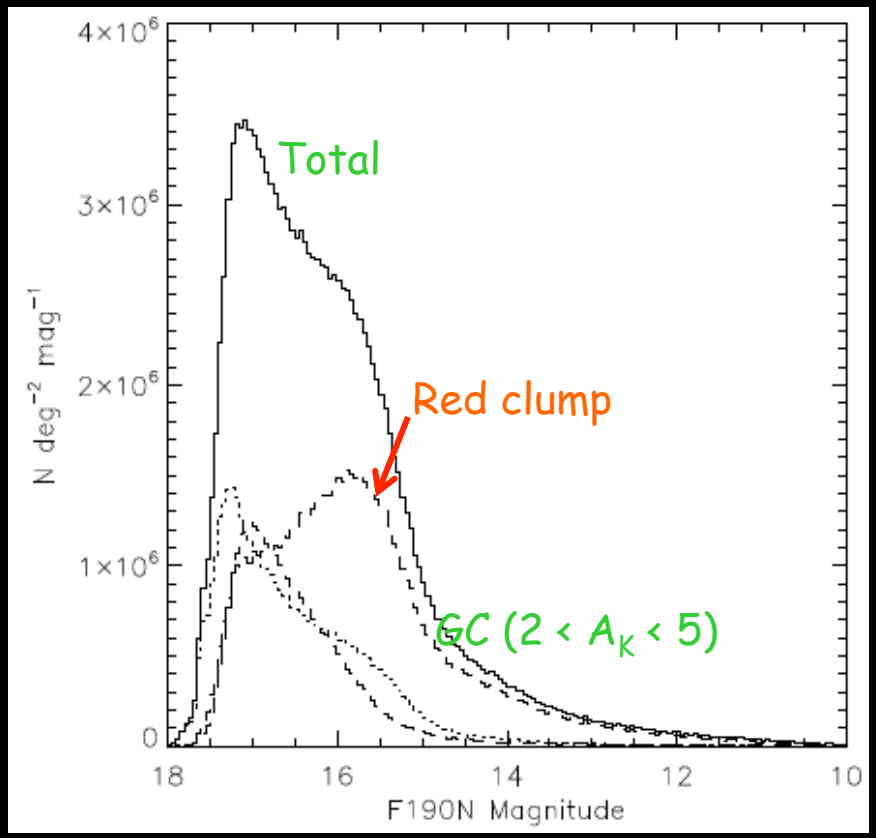
HST/NICMOS 1.9μm Map of the GC



- 144 HST orbits → 144X4X4=2304 images for each of the 1.9μm and 1.87μm narrow-band filters (Wang et al. 10; Dong et al. 10)
- Resolution: 0.025 light-year (0.2")
- Instrumental background removal and astrometry correction (to better than 0.04") are based mainly on overlapping regions.
- The 1.9μm filter is sensitive to the stellar continuum emission.

1.9 μm magnitude distribution

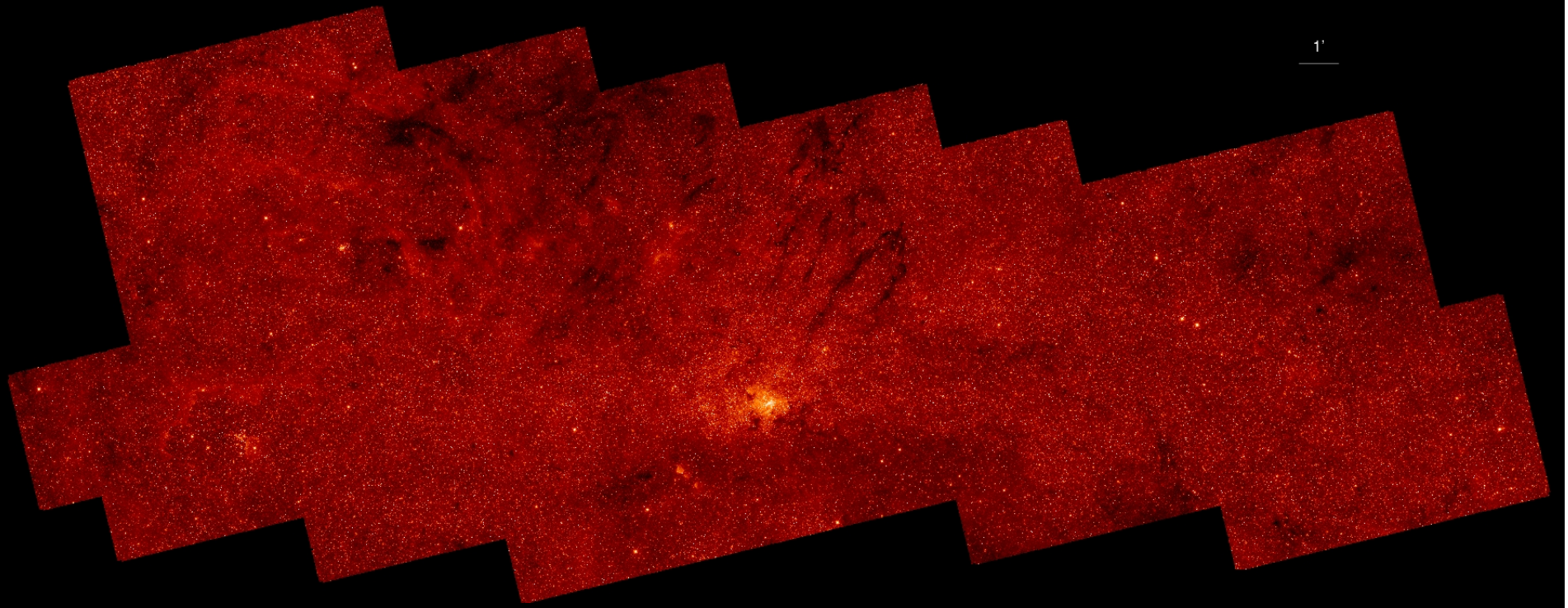




0.6 million stars are detected:

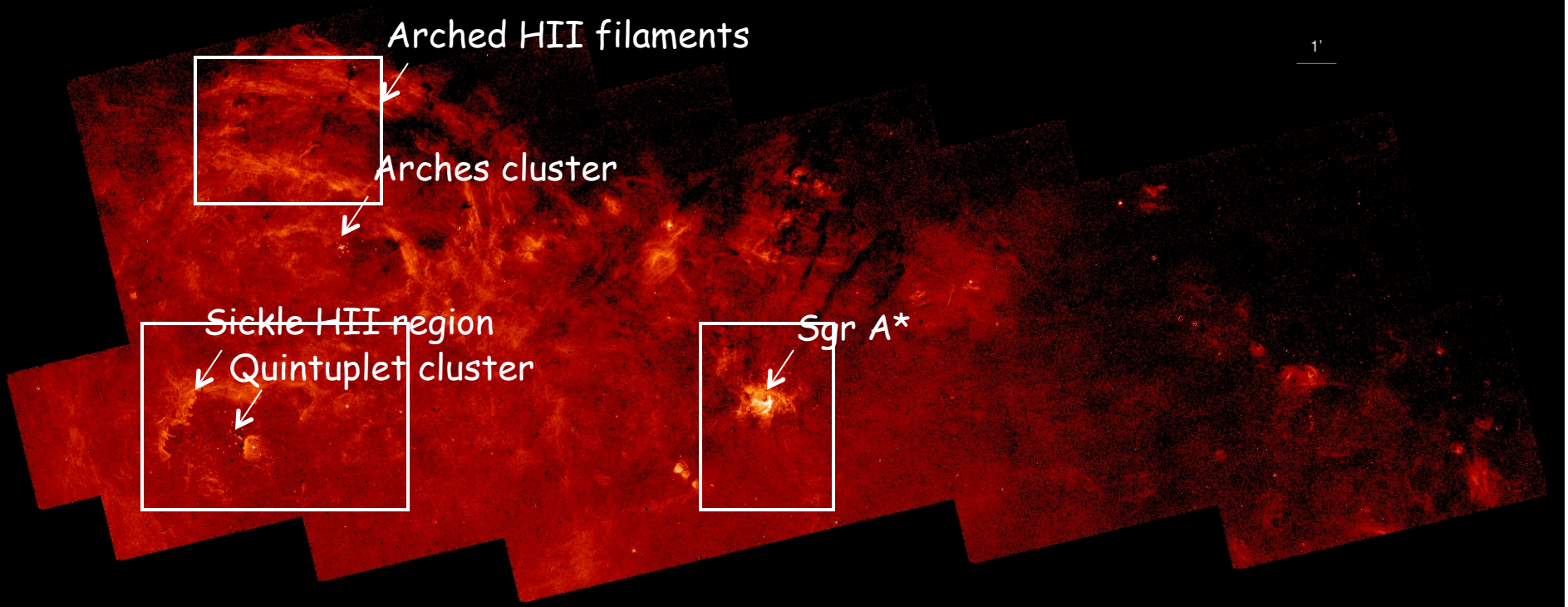
- accounting for > 80% light, essential all stars with M > 8 $M_\odot$ and evolved lower mass ones.
- strong red clump indicates a major starburst ~300 Myr ago.

HST/NICMOS 1.87μm Map of the GC



- The 1.87μm filter covers the Pα line.
- Subtracting the 1.9μm map from the 1.87μm map adaptively → A net Pα line emission map.

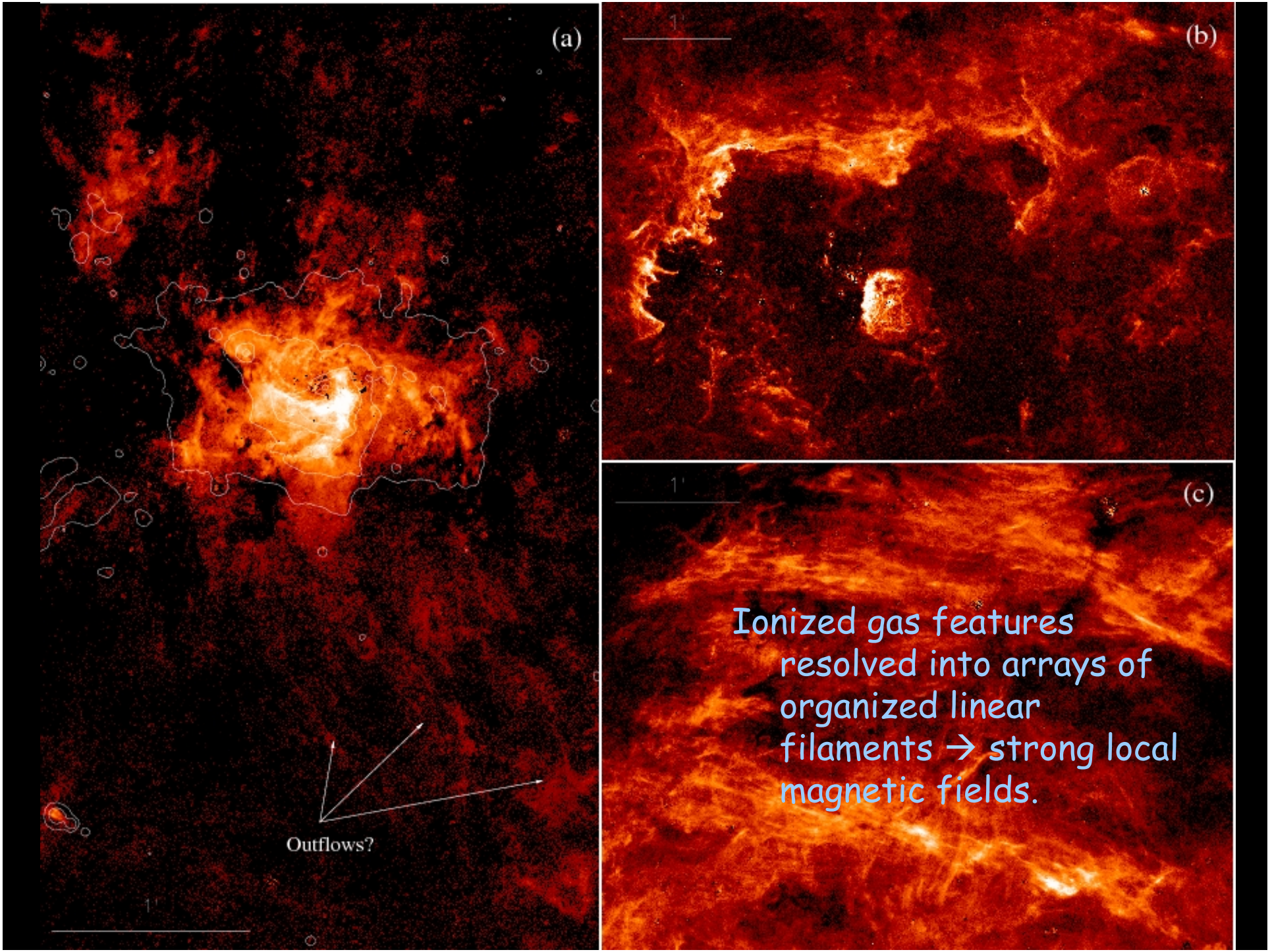
Net Pa Map of the Galactic Center



Why do we need the HST?

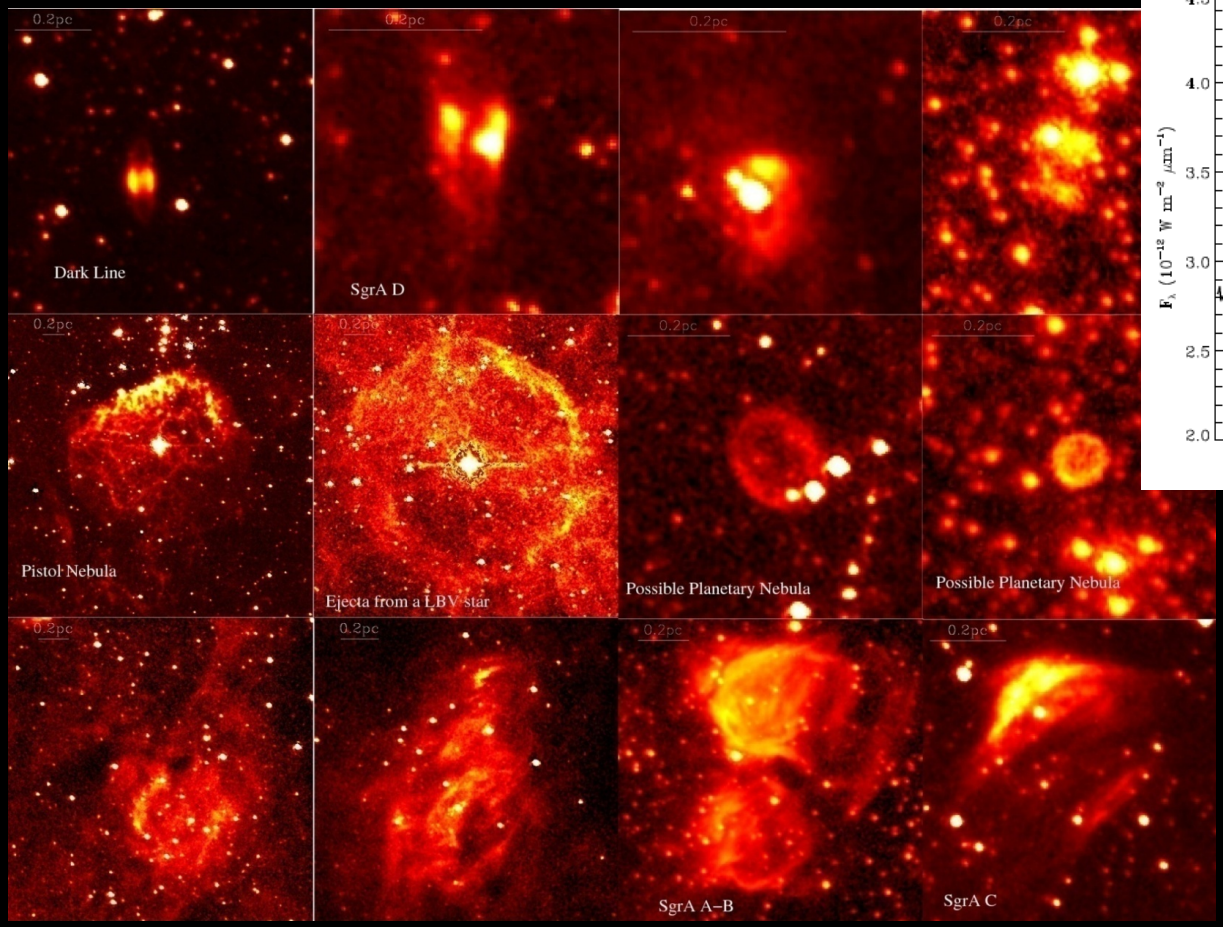
- Only observable from the space
- Excellent imaging stability
- Little background due to the Earth's warm atmosphere

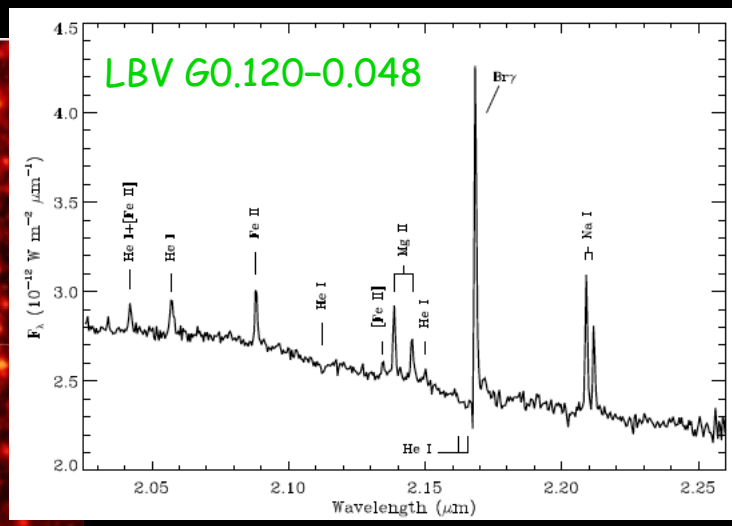
Wang et al. 2009



Ionized gas features resolved into arrays of organized linear filaments → strong local magnetic fields.

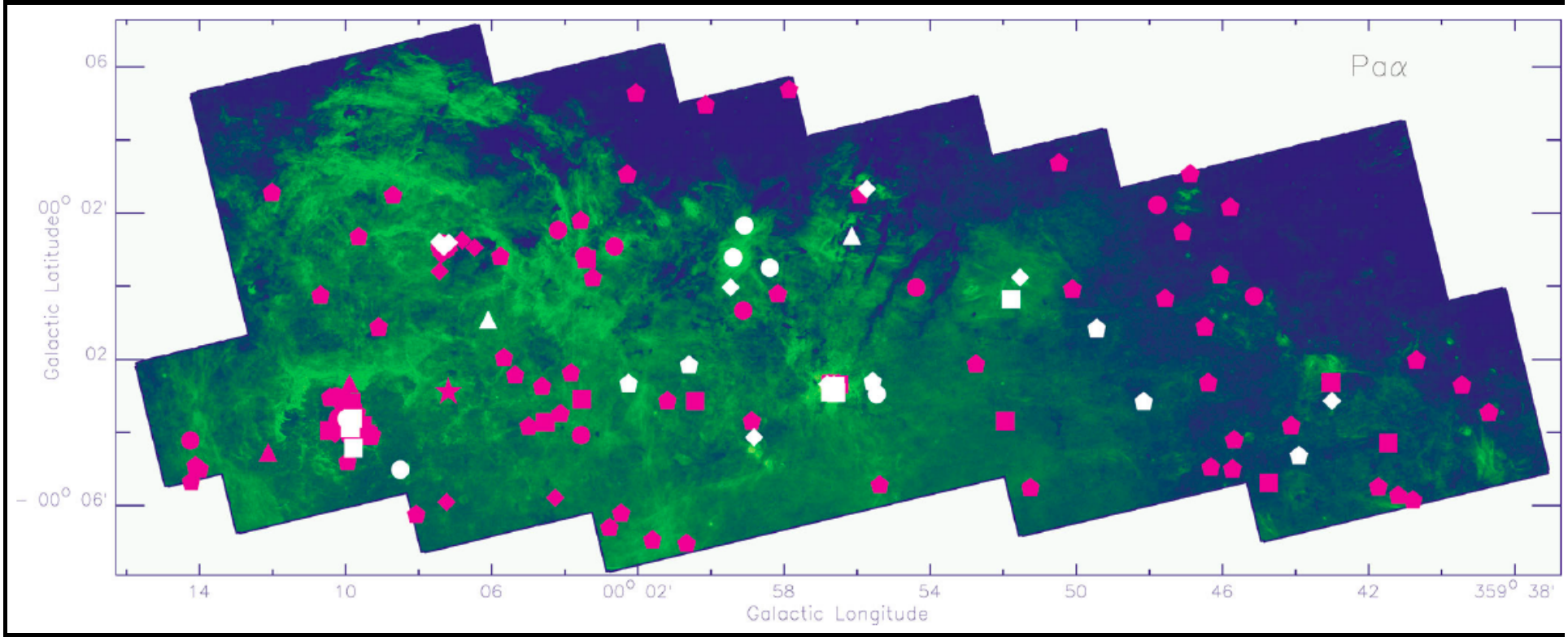
Detailed views of individual compact HII regions





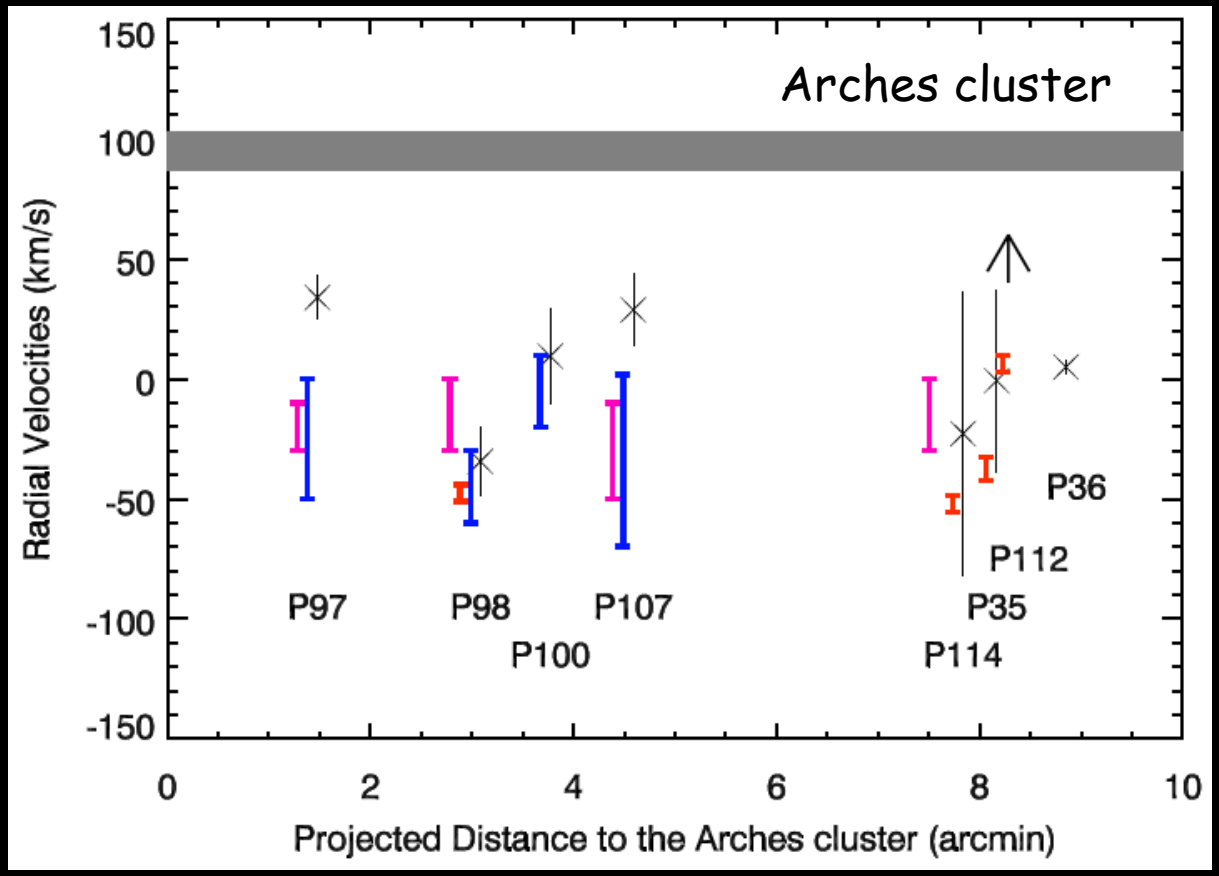
Discovery of a Luminous Blue Variable (Mauerhan et al. 10)

New Population of young massive stars



- ~180 stars show enhanced Pa emission.
- ~2/3 of them are located outside the three known clusters.
- 20 have been followed up spectroscopically, confirming that they are indeed massive stars (Mauerhan et al. 09; 10).

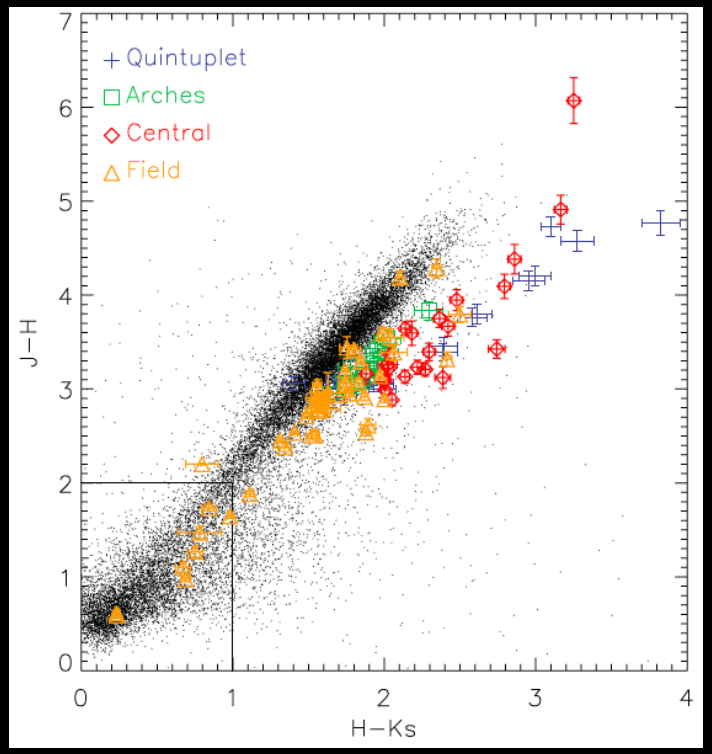
A new population of massive stars?

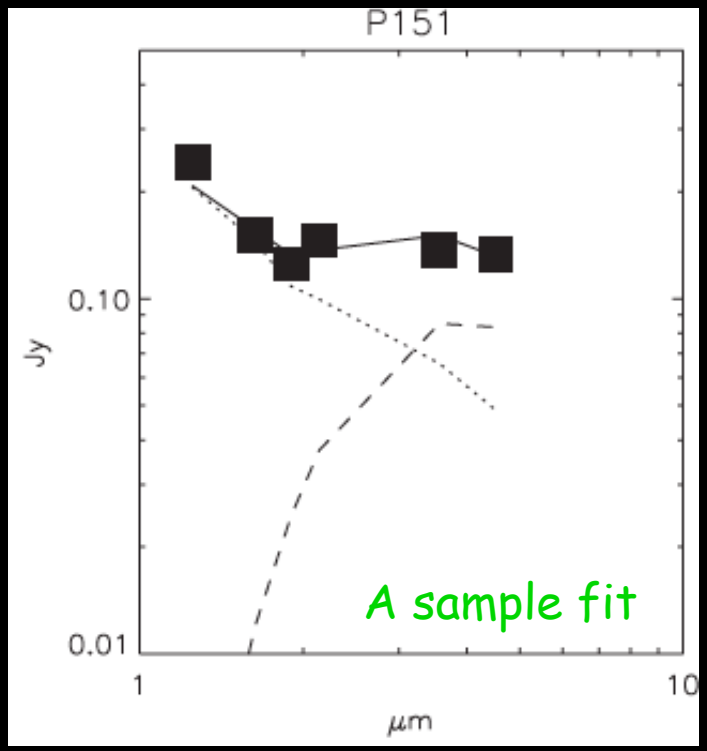


Dong et al. 15

- Radial velocities of stars
- (crosses), compared with those of adjacent ionized (red and blue) and molecular (Cyan) gases.

Dust generated by WR stars



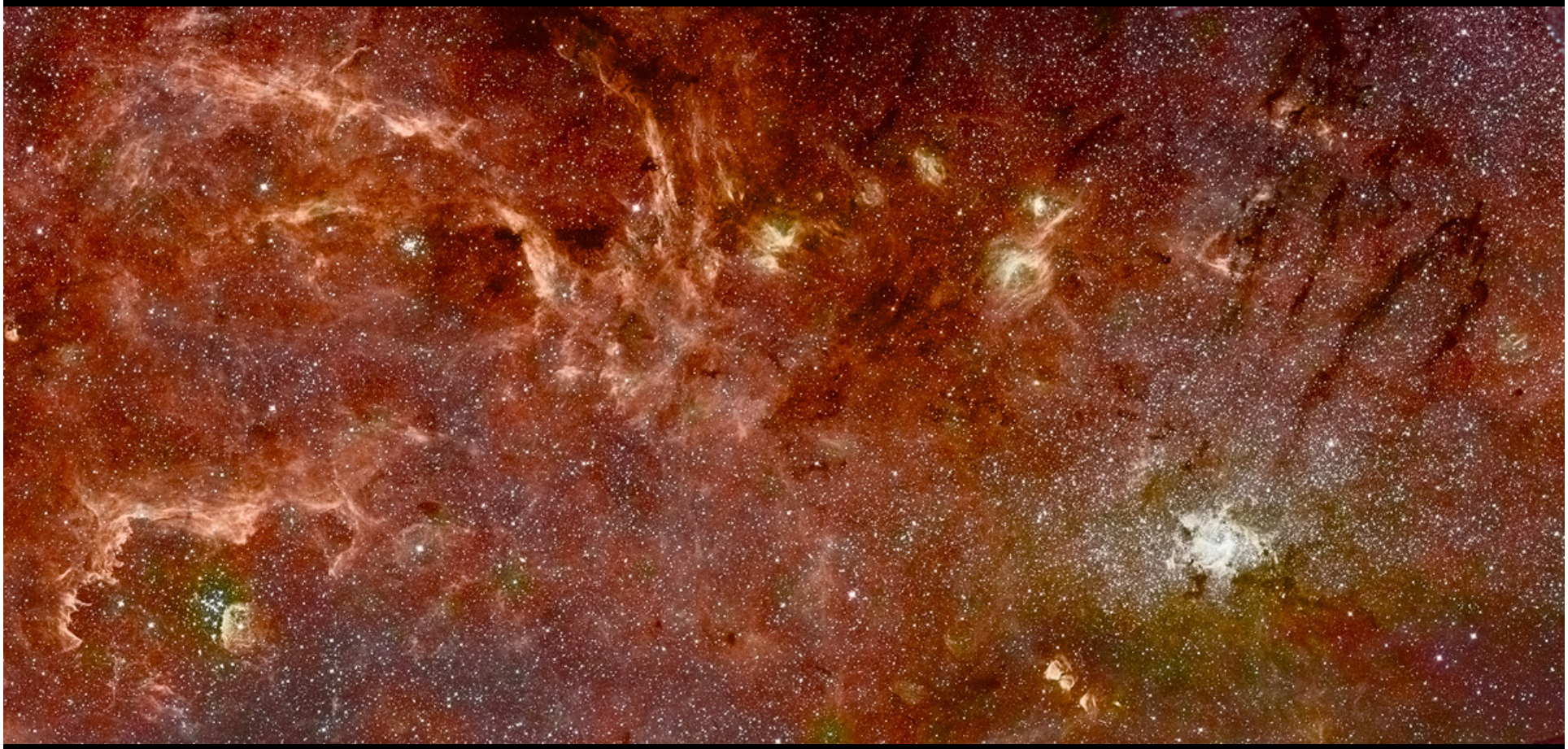


Detected dust mass associated with individual WC stars in the quintuplet cluster can reach 10^{-5} $M_{\odot}$.

→ Could WC be responsible for dust in high-z galaxies?

Dong et al. (2012)

A Panoramic HST Infrared View of the GC



1.87 and 1.90 μm narrow bands: on and off Pα line (Wang et al. 2010)

Results from the HST/NICMOS survey

- Construction of a high-res extinction map toward the GC.
- Fine filamentary structures of ionized diffuse gas indicating strong influence of local strong magnetic field.
- Compact nebulae, tracing various stages of massive star evolution
- A new pop of very massive stars in relative isolation and with strong winds.
- Large amounts of hot dust associated any WC stars.

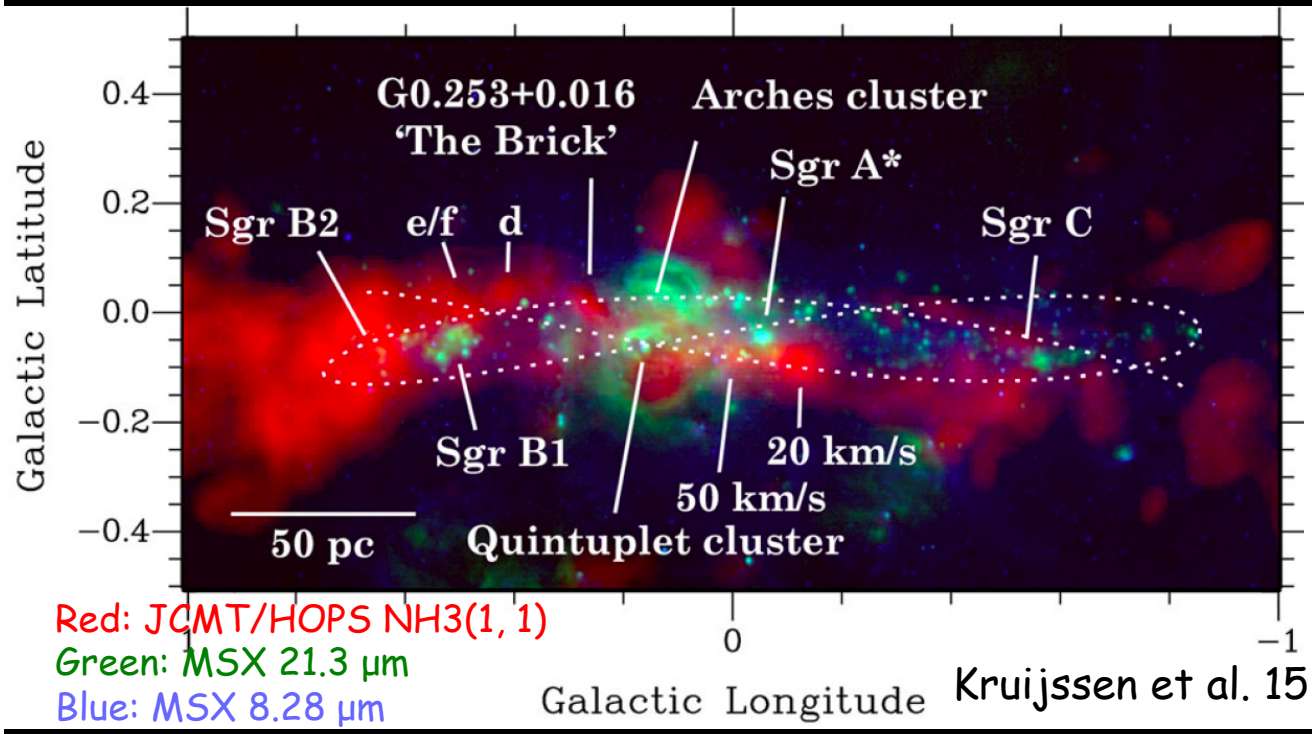
Millimeter survey of the CMZ

Q. Daniel Wang (PI)

Grant Wilson, Min Yun, Mark Heyer, Robert Gutermuth, Yuping Tang, Daniela Calzetti (Umass)

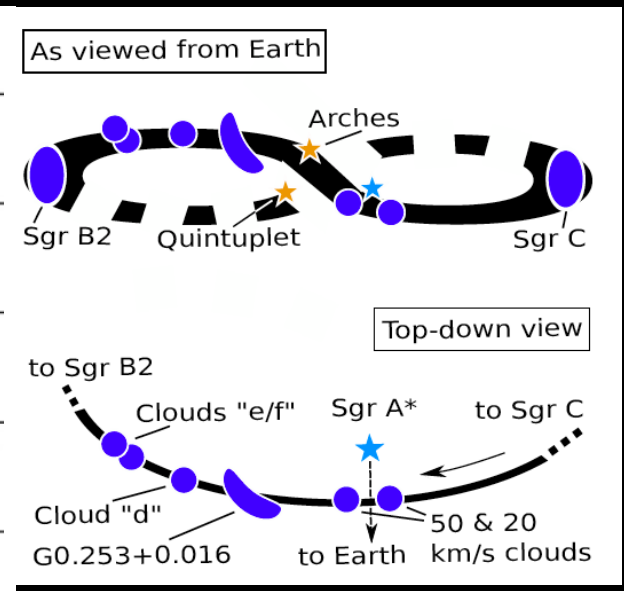
Laurent Loinard (UNAM), Miguel Chavez, Sergiy Silich, David Hughes (INAOE) & John Bally (U. of Colorado)

The Central Molecular Zone (CMZ)



Red: JCMT/HOPS NH3(1, 1)
Green: MSX 21.3 μm
Blue: MSX 8.28 μm

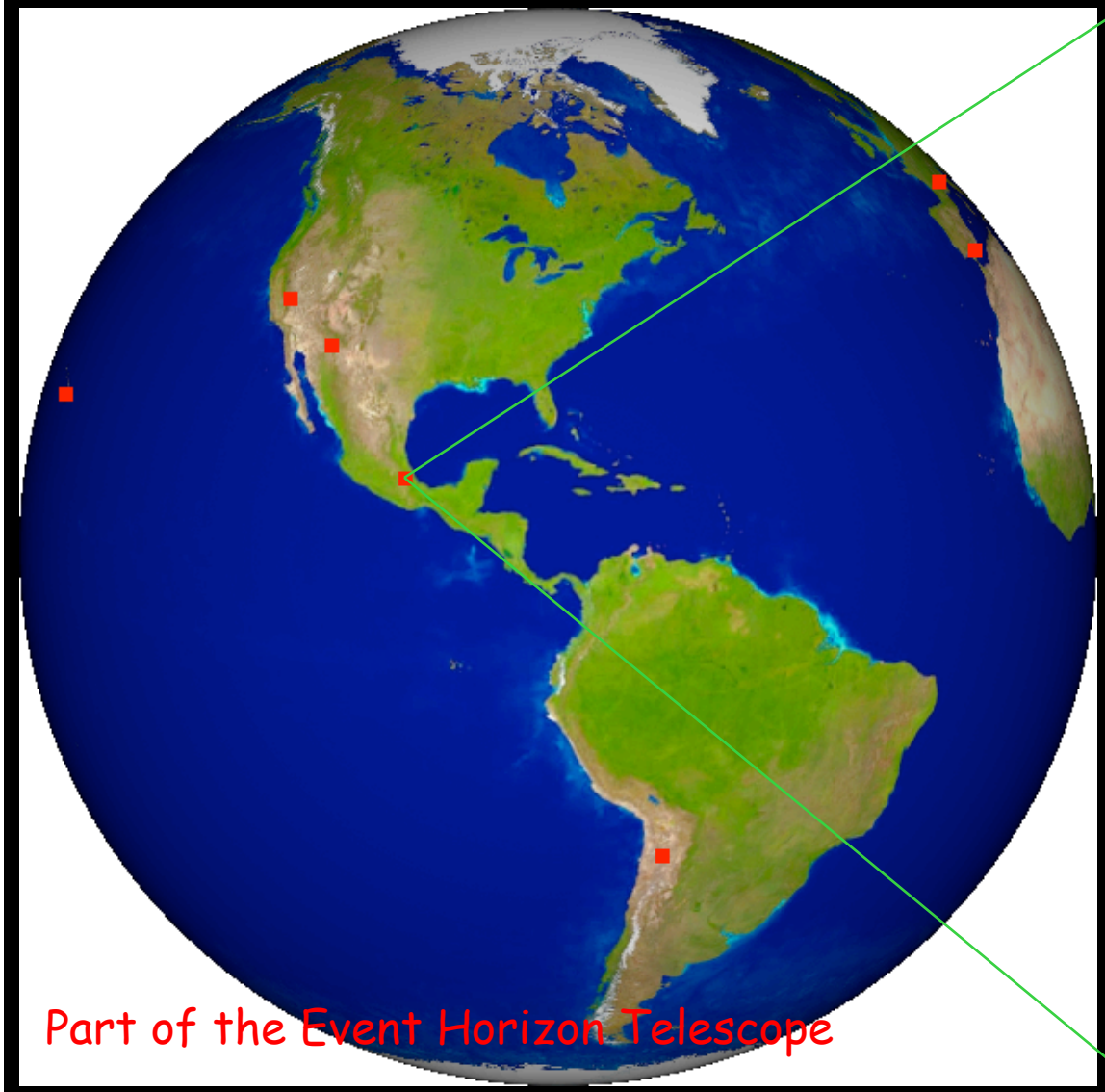
Kruijssen et al. 15



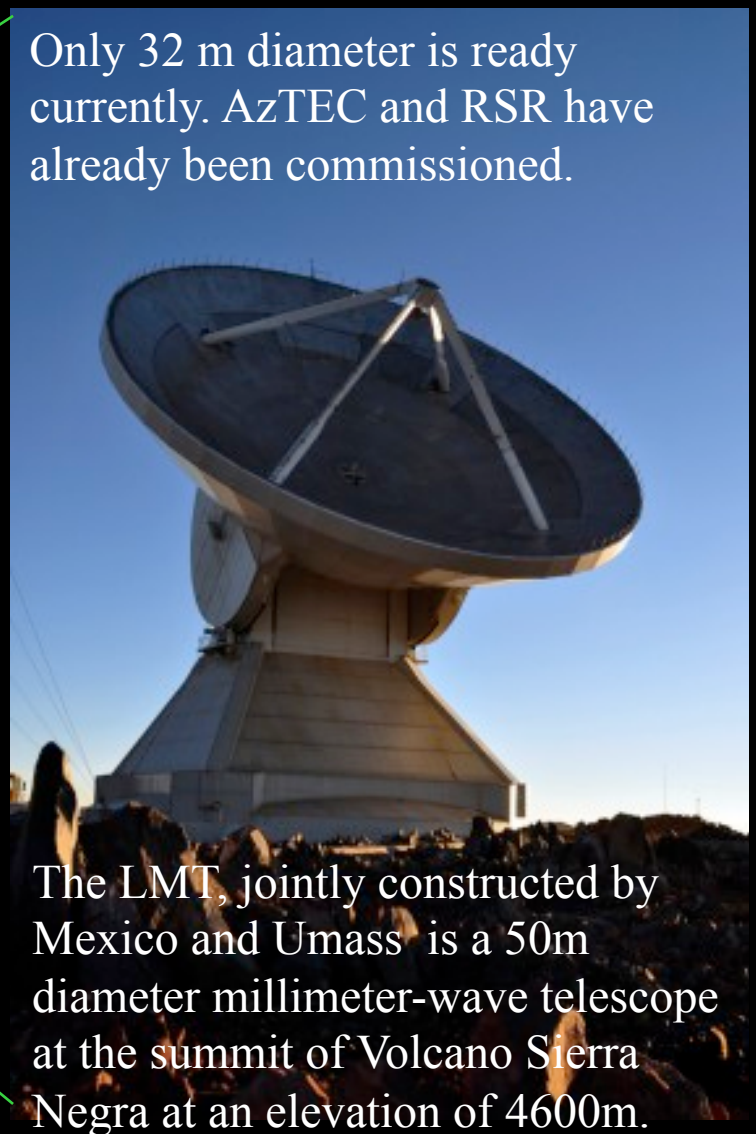
Longmore et al. 13

- The highest concentration of (sub)mm-emitting dense clouds in the Galaxy.
- An unusual low SF rate per gas mass and may thus be at the dawn of a major starburst.

The Large Millimeter Telescope



Only 32 m diameter is ready currently. AzTEC and RSR have already been commissioned.

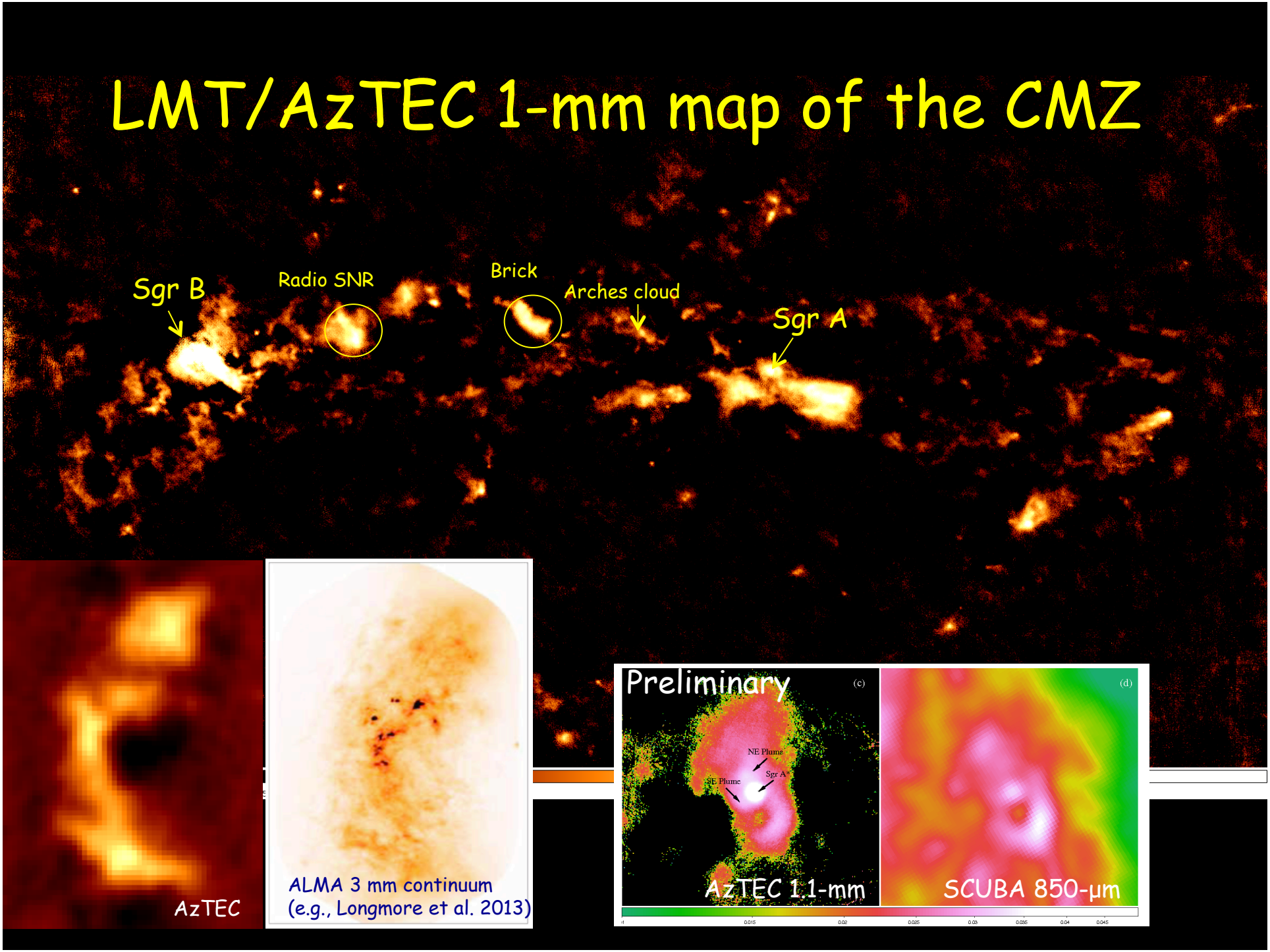


The LMT, jointly constructed by Mexico and Umass is a 50m diameter millimeter-wave telescope at the summit of Volcano Sierra Negra at an elevation of 4600m.

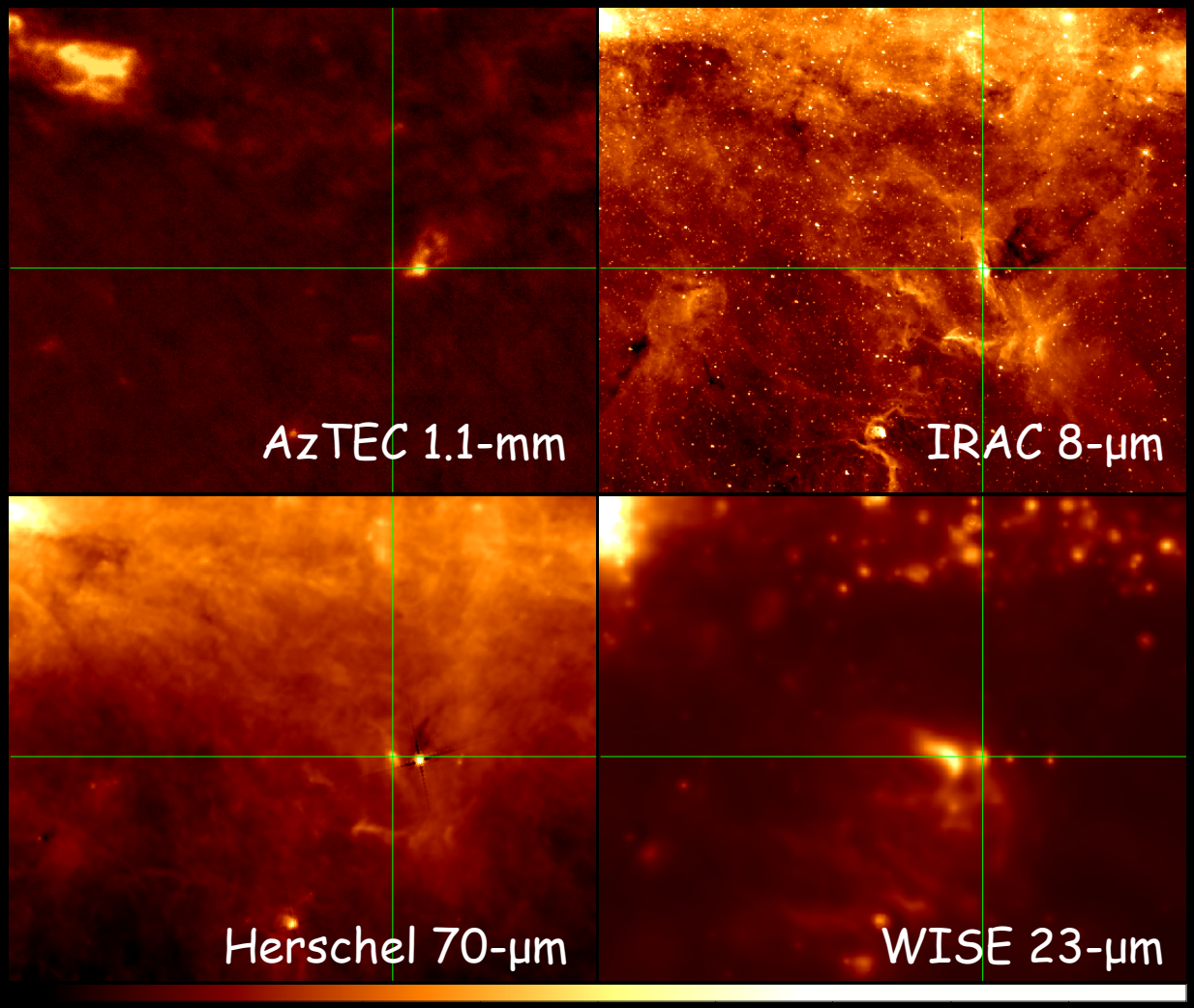
Scientific Goals of the LMT mapping

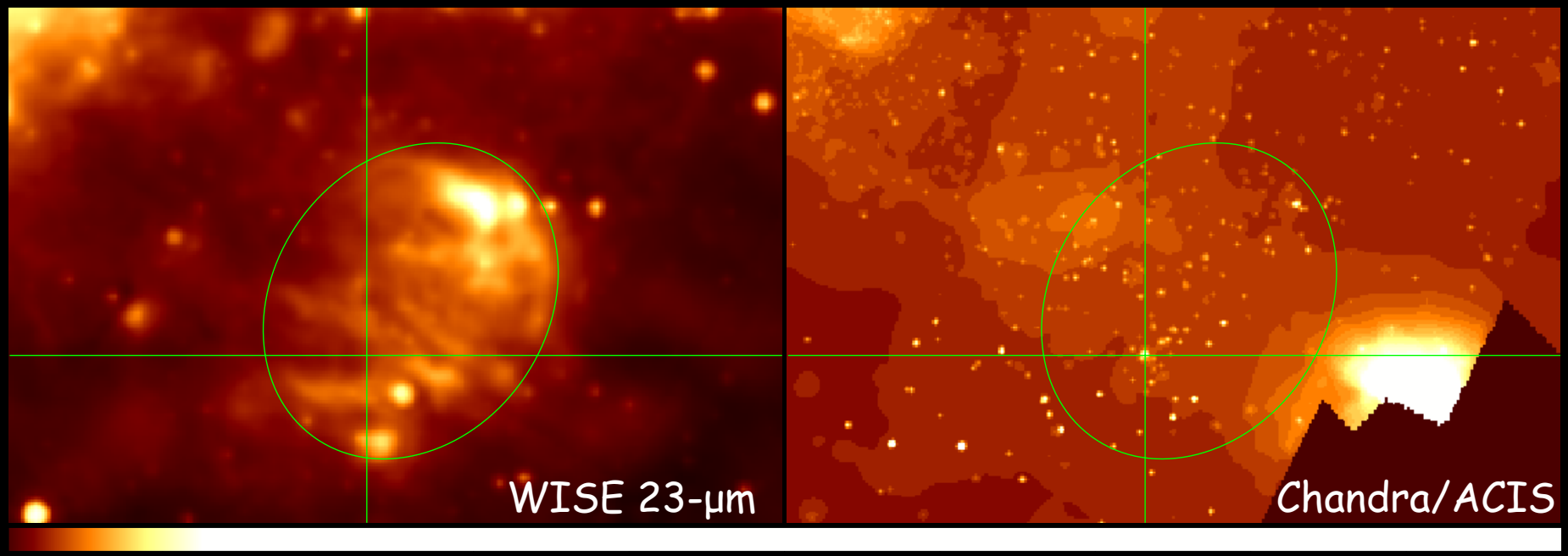
- To produce a large-scale, moderate resolution, systematic map of massive pre- and proto-cluster clumps in the CMZ and study how they are assembled on various scales.
  - The LMT/AzTEC provides a 9" resolution, compared to such existing surveys as the CSO/Bolocam map (33") at 1.1 mm.
- To characterize the dust opacity/emissivity, temperature, dust/gas mass, density, etc., as well as the spatial structure.
  - At 1.1 mm, dust emission is optically-thin and is only linearly dependent of temperature.
- To understand why dust is substantially colder than molecular gas, how and under what conditions SF occurs in isolation/small group or in clusters.

LMT/AzTEC 1-mm map of the CMZ



SF properation in an imploding cloud?




WISE 23-μm
Chandra/ACIS

Summary

- We have made widefield, arcsec resolution surveys of the GC in X-ray, near-IR, and 1.1-mm.
- These surveys, in combination with complementary maps (e.g., from Spitzer and Herschel in mid- and far-IR), enable detailed studies of the GC: SF mode, massive star pop, stellar winds, spatial distribution of stars, dust and gas properties, as well as various high-energy phenomena and processes.
- Follow-up CO surveys with JCMT and LMT are planned for studying kinematics and dust to CO ratio, etc.