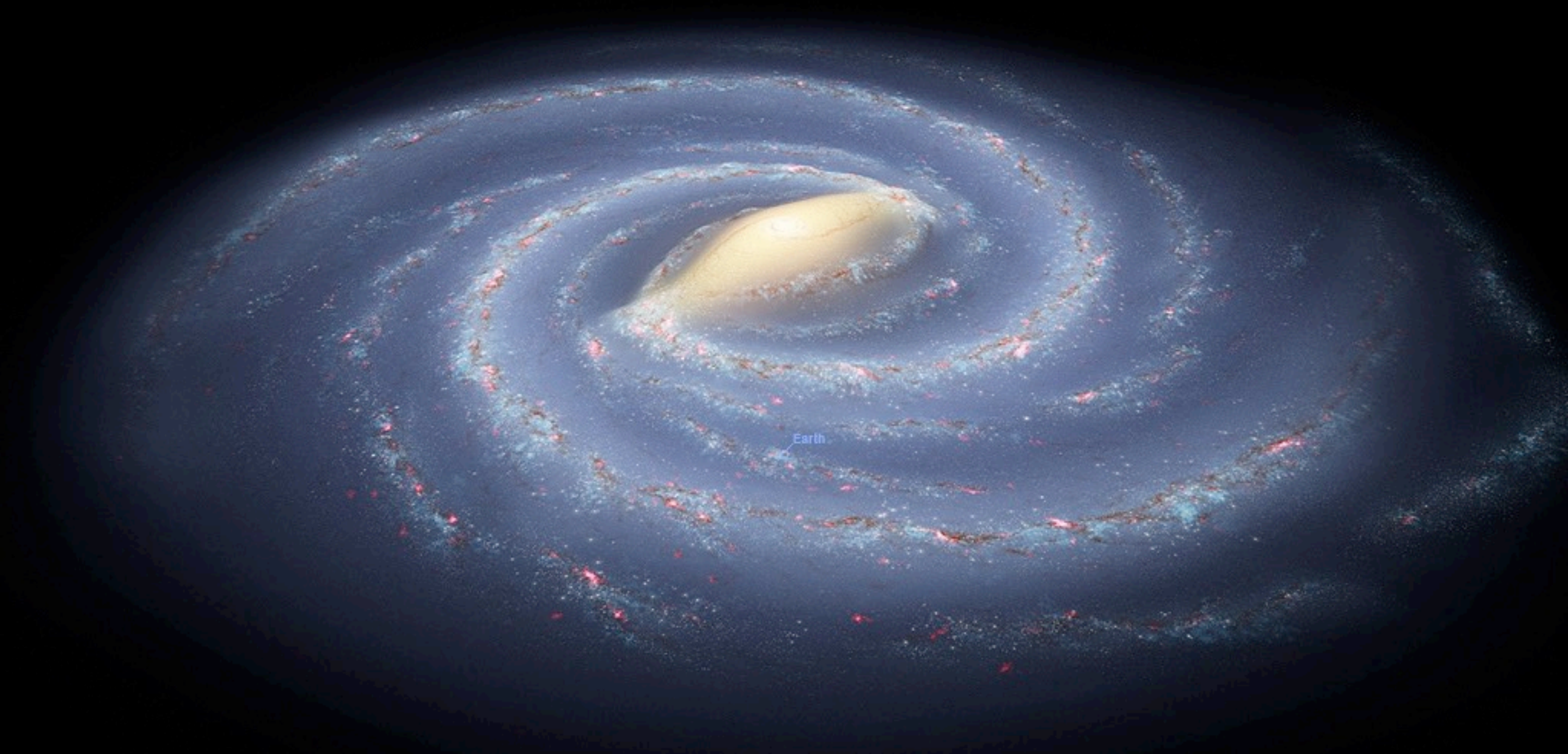
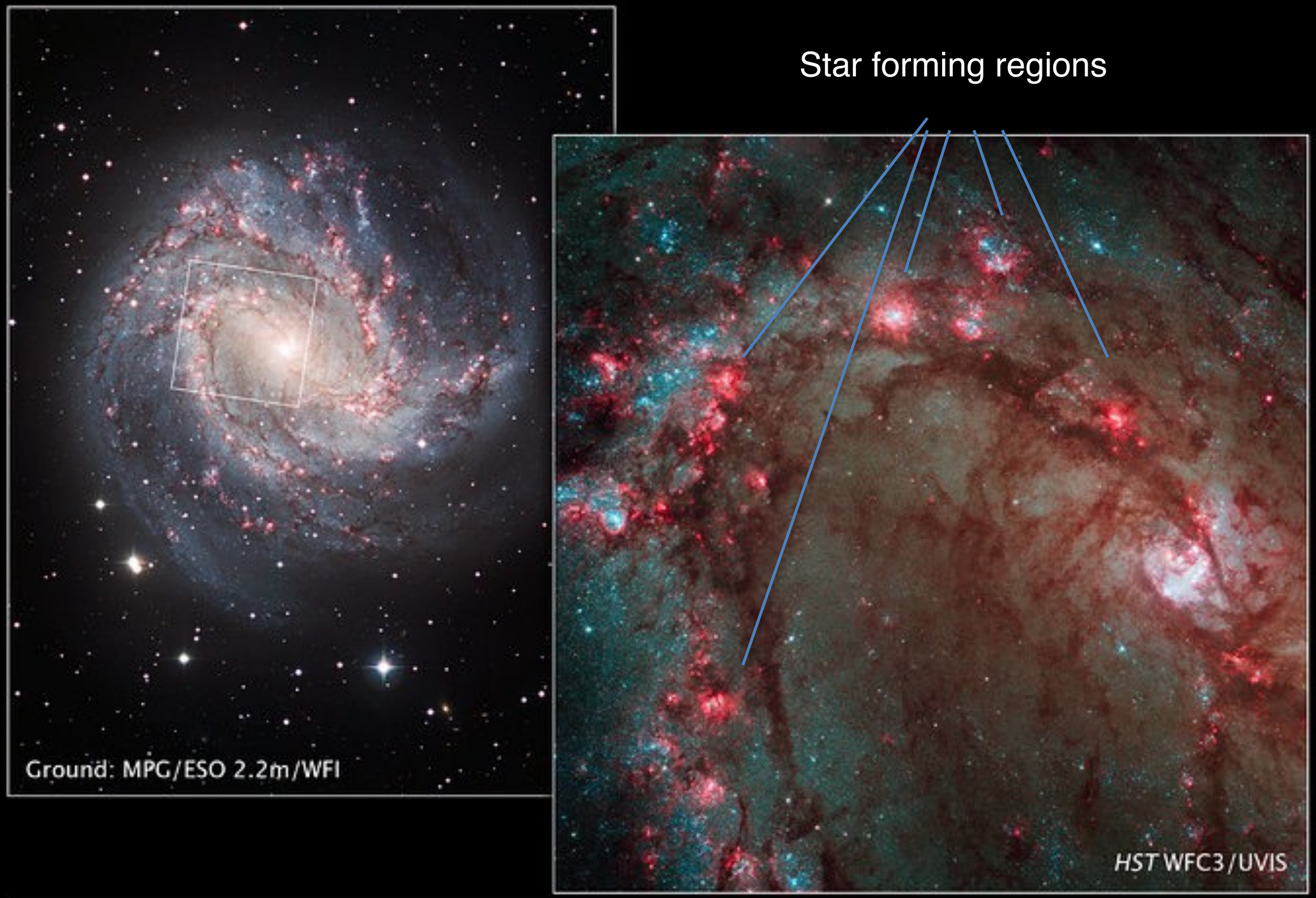
Star formation, case uses

Ross A. Burns, RIKEN



https://www.spacetelescope.org/images/opo0929a/

Star forming regions



Spiral Galaxy M83
Hubble Space Telescope ▪ WFC3/UVIS

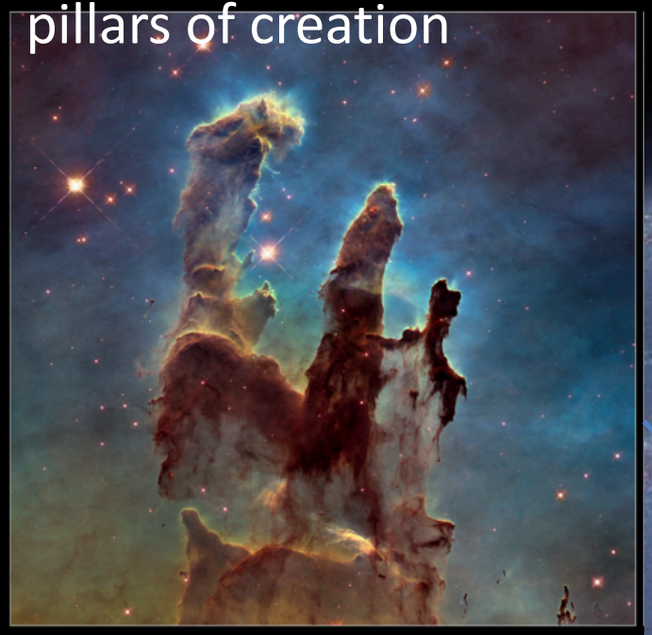
NASA, ESA, R. O'Connell (University of Virginia), the WFC3 Science Oversight Committee, and ESO

STScI-PRC09-29

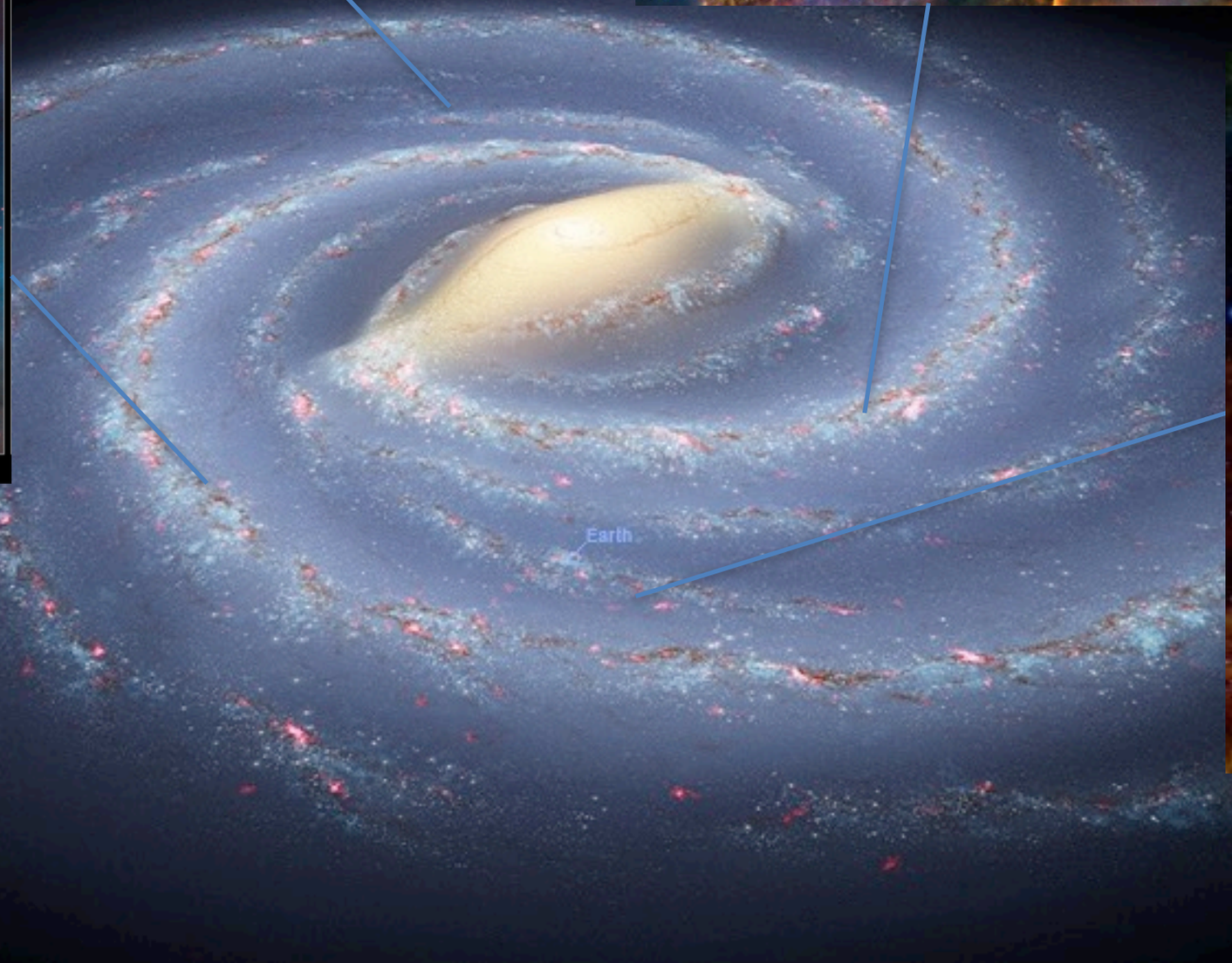
N90

Carina nebula

pillars of creation



Visible · WFC3 · 2015



https://www.nasa.gov/sites/default/files/thumbnails/image/heic1501c.jpg

Star forming regions

Optical

Dust is opaque

可視光 · WFC3 · 2015

Multi-wavelength observations

http://coolcosmos.ipac.caltech.edu/image_galleries/ir_zoo/lessons/background.html

Optical

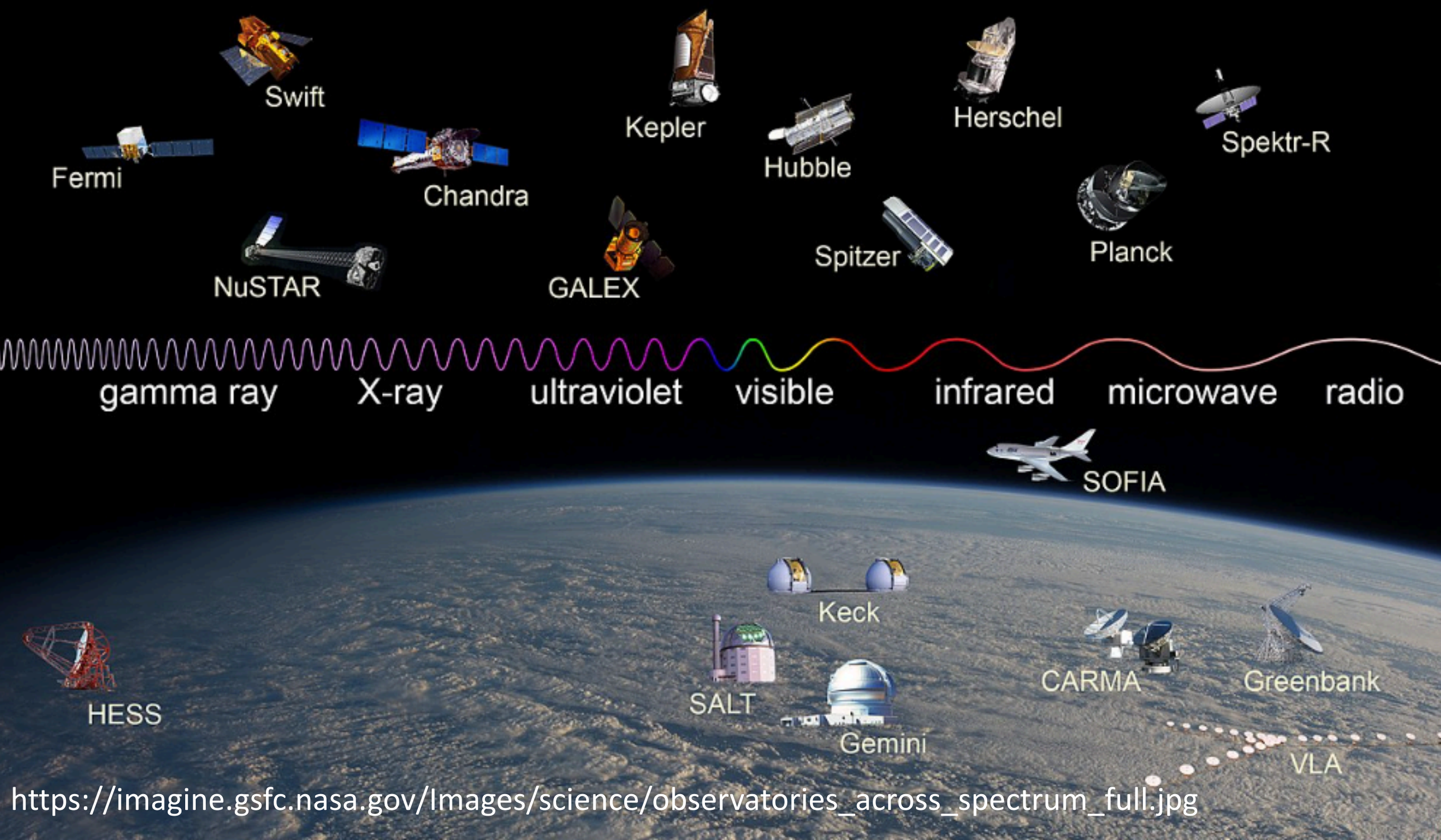
Infrared

Optical

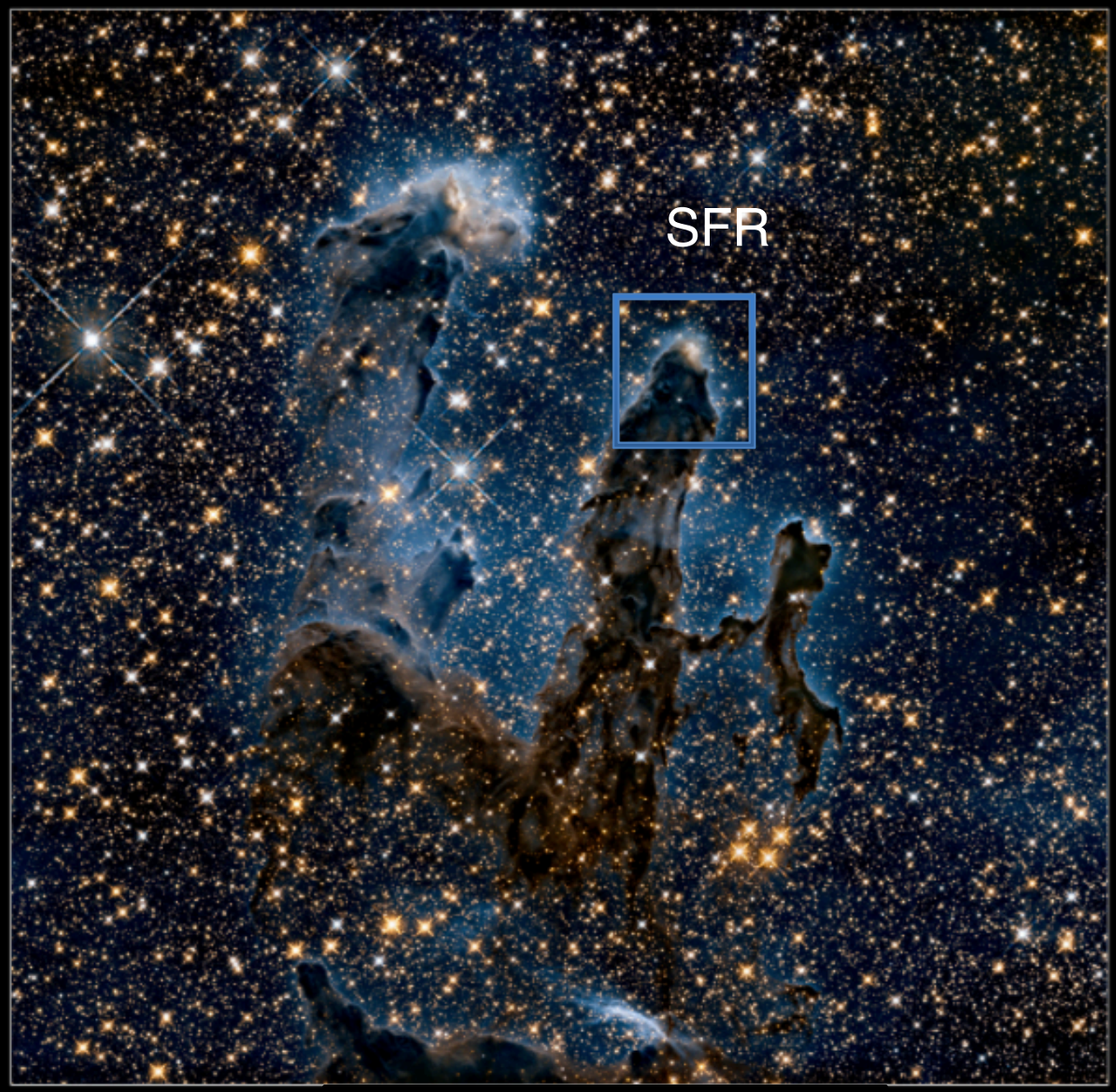
Infrared

https://www.nasa.gov/sites/default/files/thumbnails/image/heic1501c.jpg

Astronomical observations



https://imagine.gsfc.nasa.gov/Images/science/observatories_across_spectrum_full.jpg

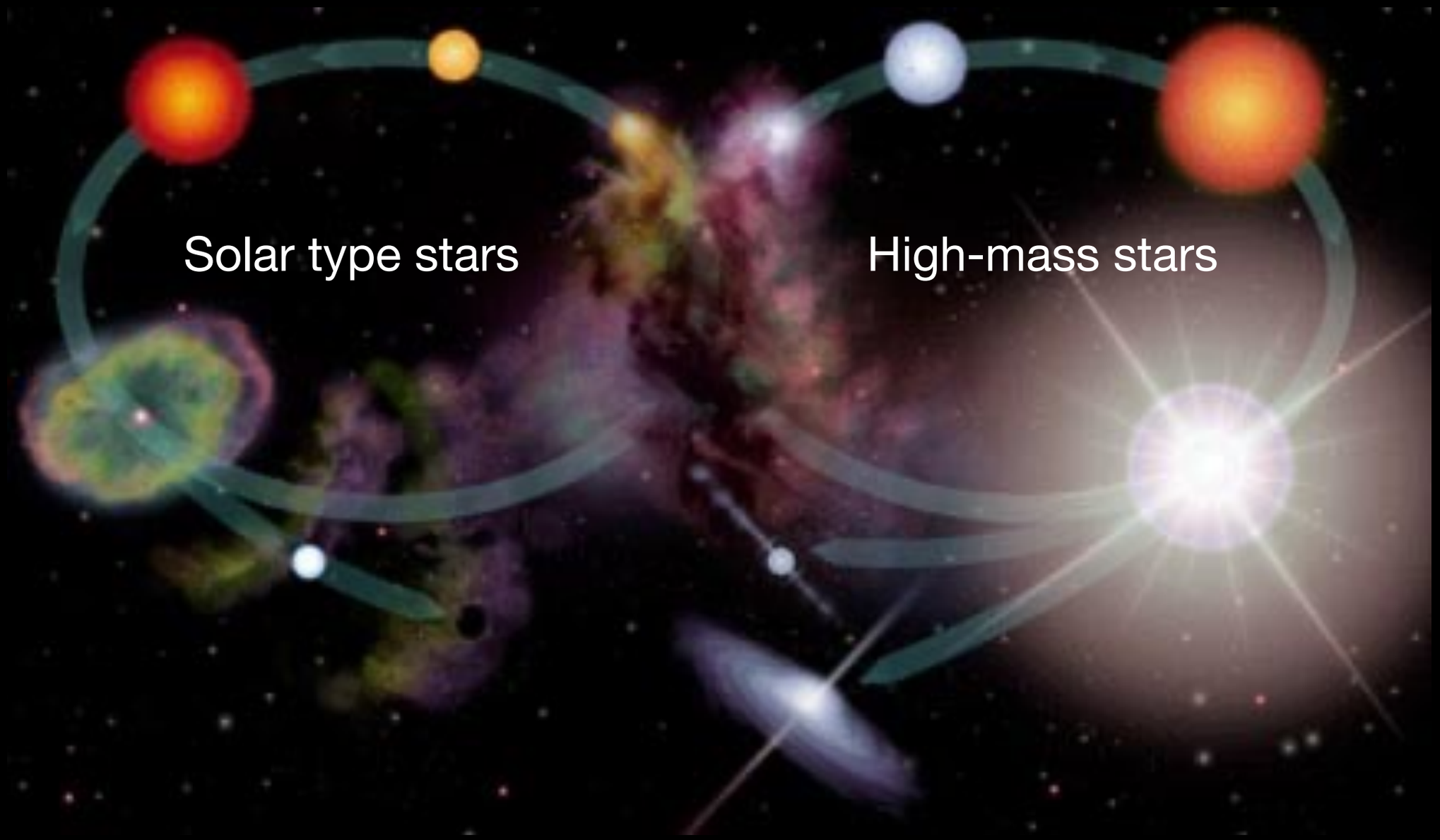


Optical

Infrared

https://www.nasa.gov/sites/default/files/thumbnails/image/heic1501c.jpg

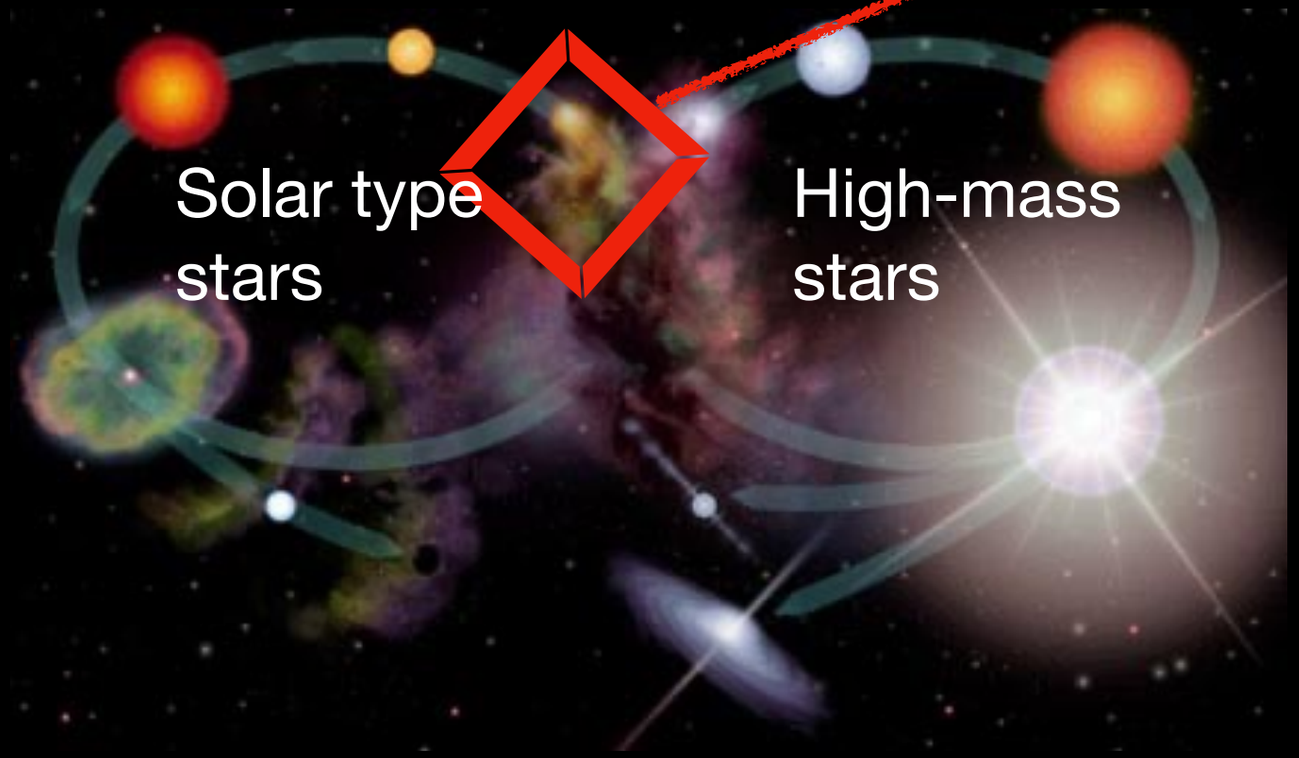
LifeCycle of a star

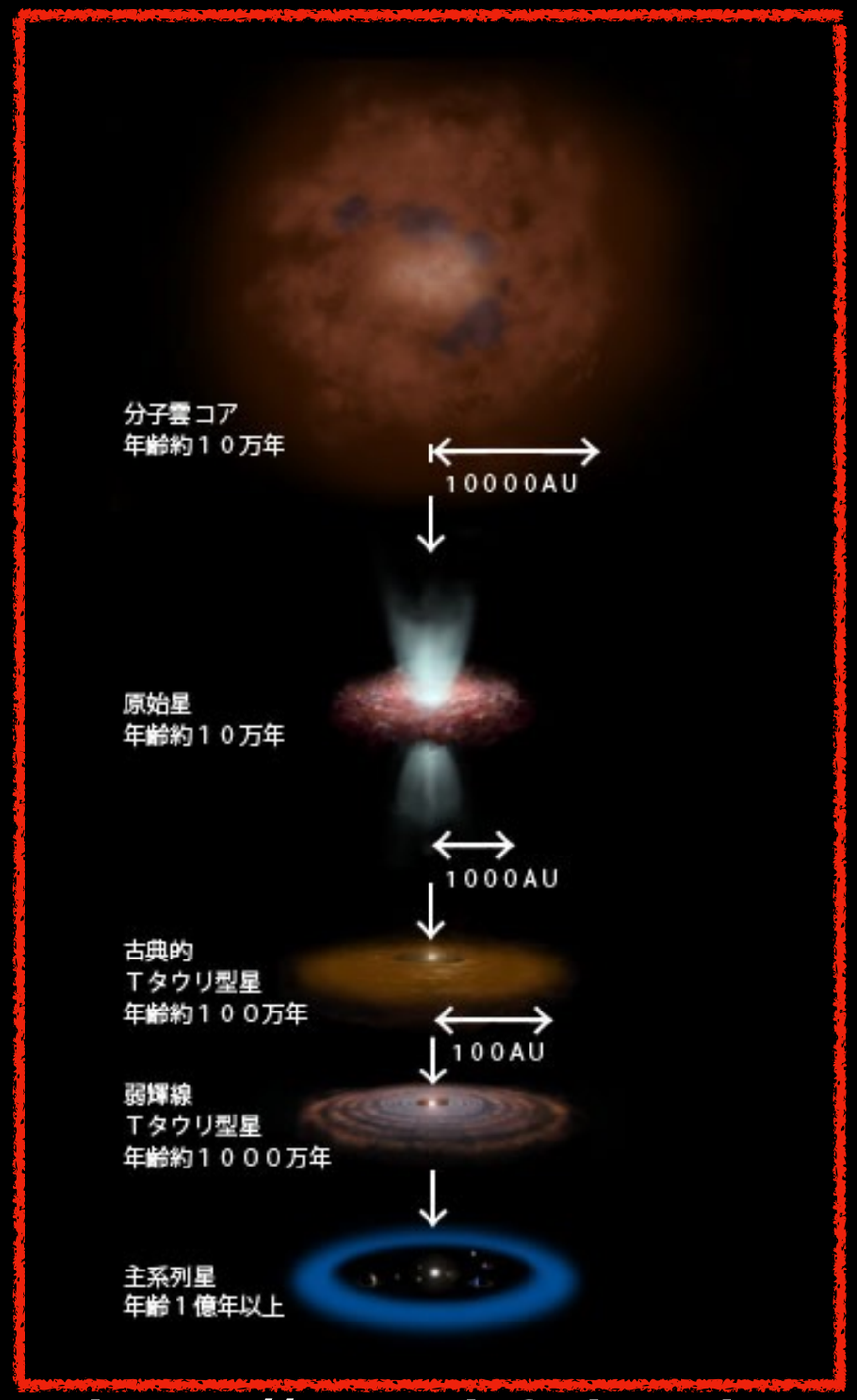


https://imagine.gsfc.nasa.gov/educators/lessons/xray_spectra/background-lifecycles.html

LifeCycle of a star

Star-formation

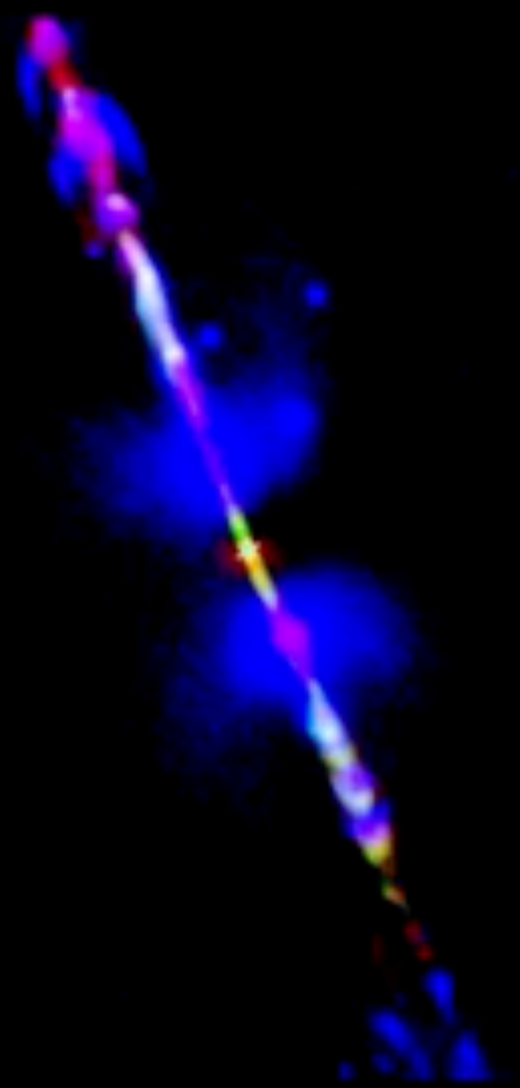




https://spaceinfo.jaxa.jp

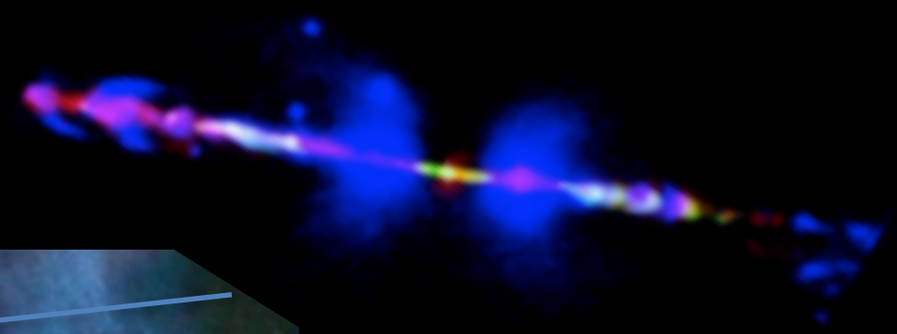
https://imagine.gsfc.nasa.gov/educators/lessons/xray_spectra/background-lifecycles.html

How stars are born

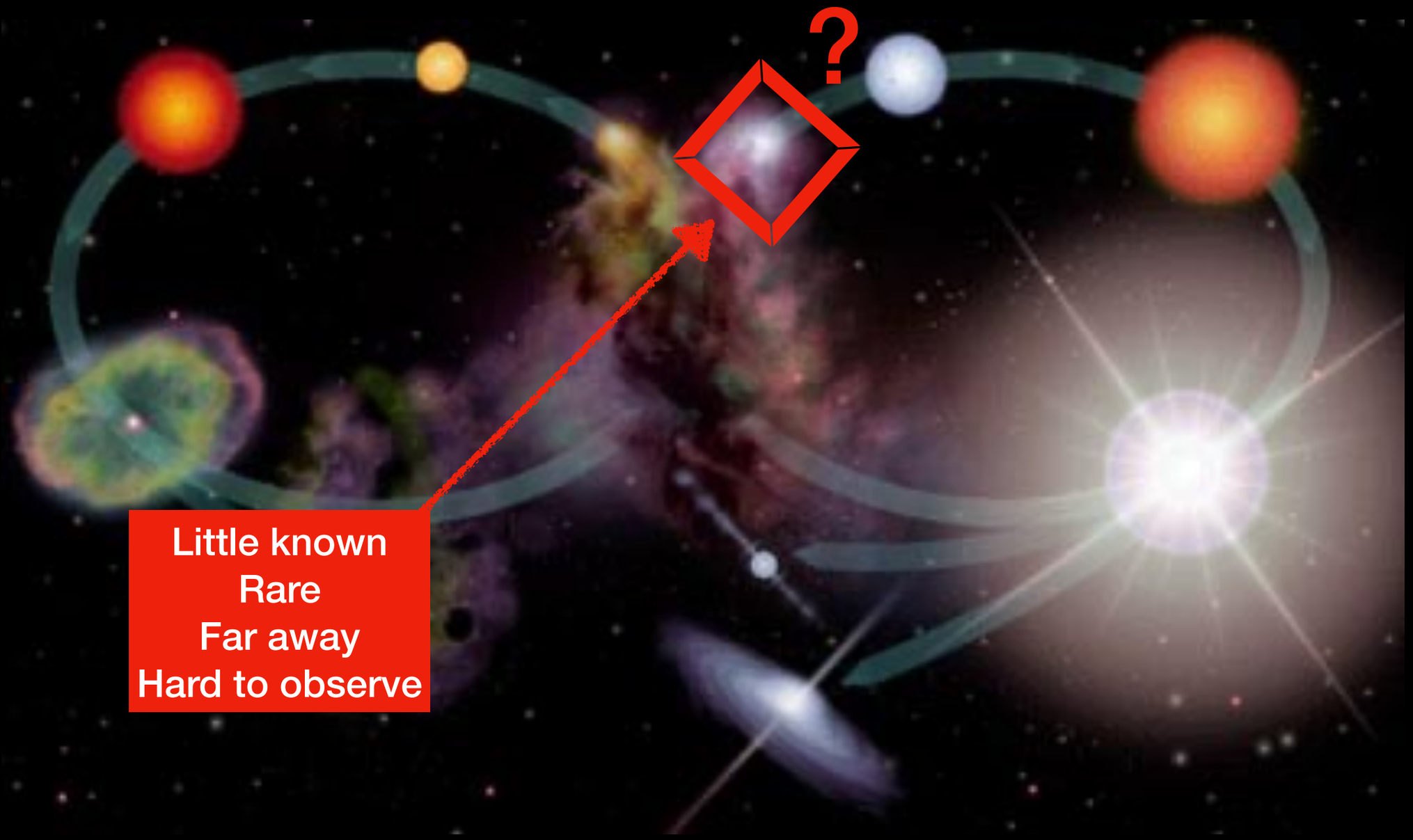


HH212 Jet

Embedded in the SFR

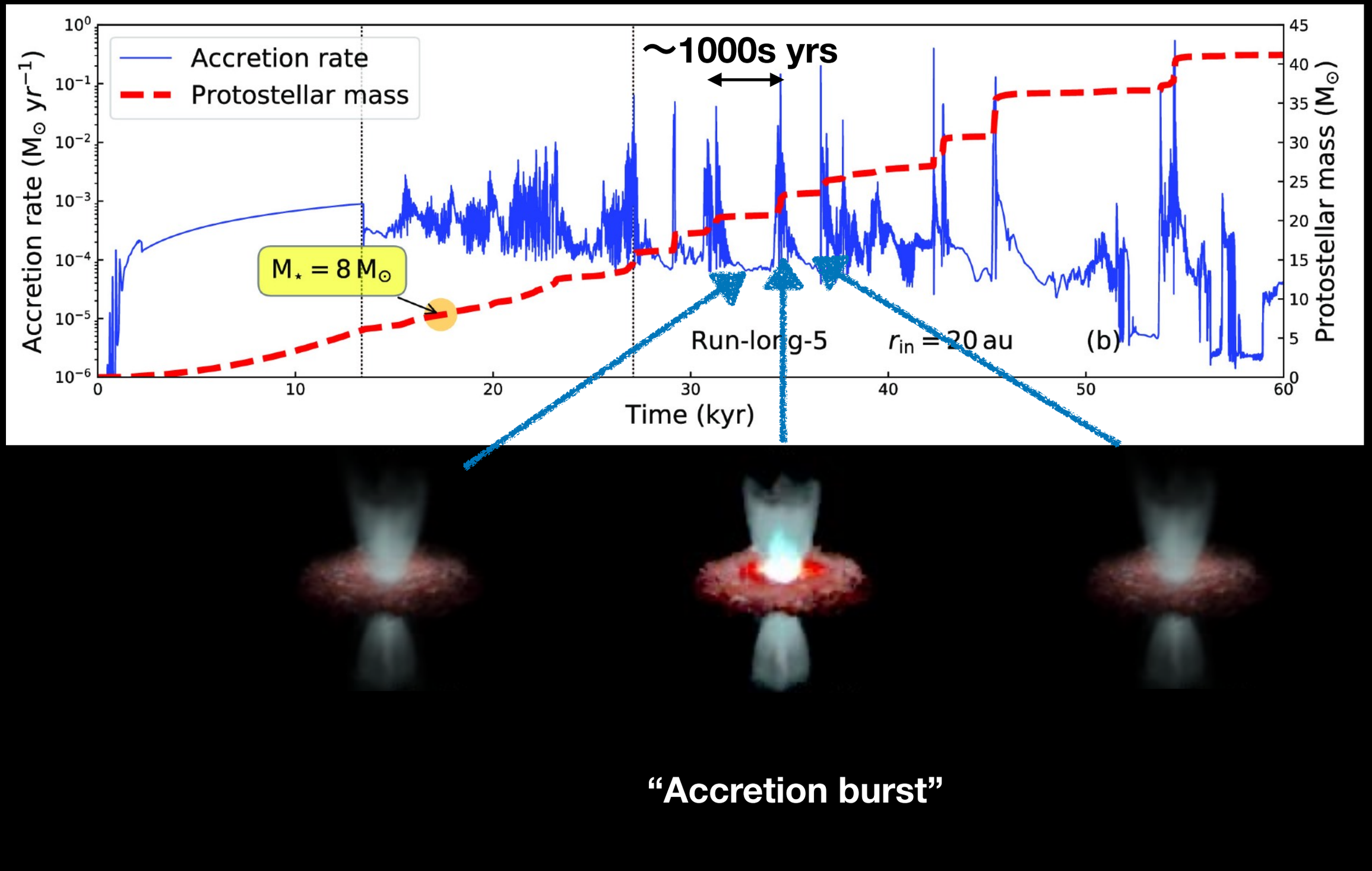


Solar-type vs high-mass



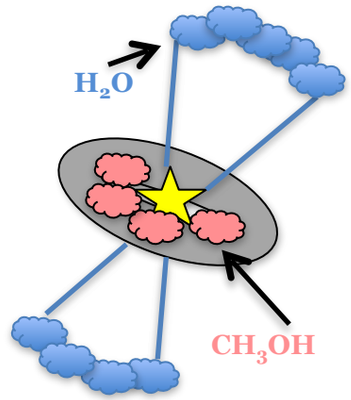
https://imagine.gsfc.nasa.gov/educators/lessons/xray_spectra/background-lifecycles.html

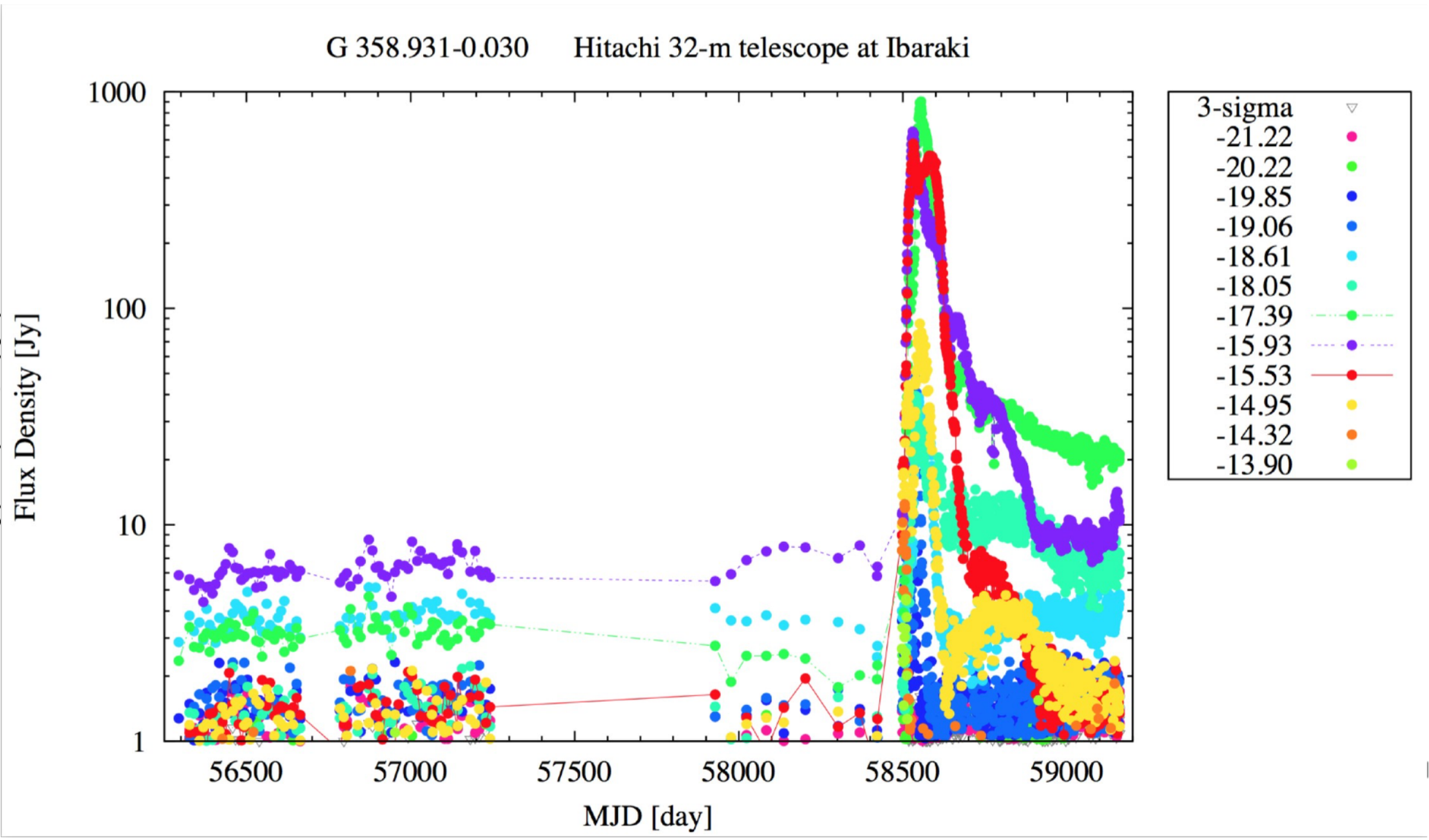
High-mass star formation theory



Maser flare: G358.93-0.03

First flare of the 6.7 GHz methanol maser reported to the M2O





Hitachi 32m

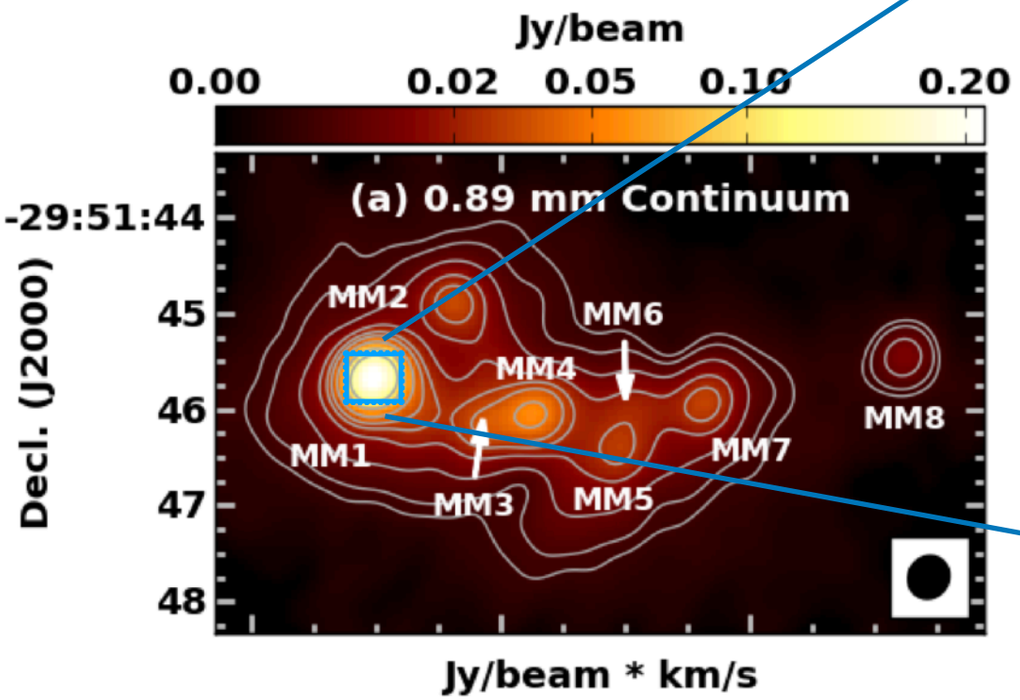
Operated by Ibaraki-U

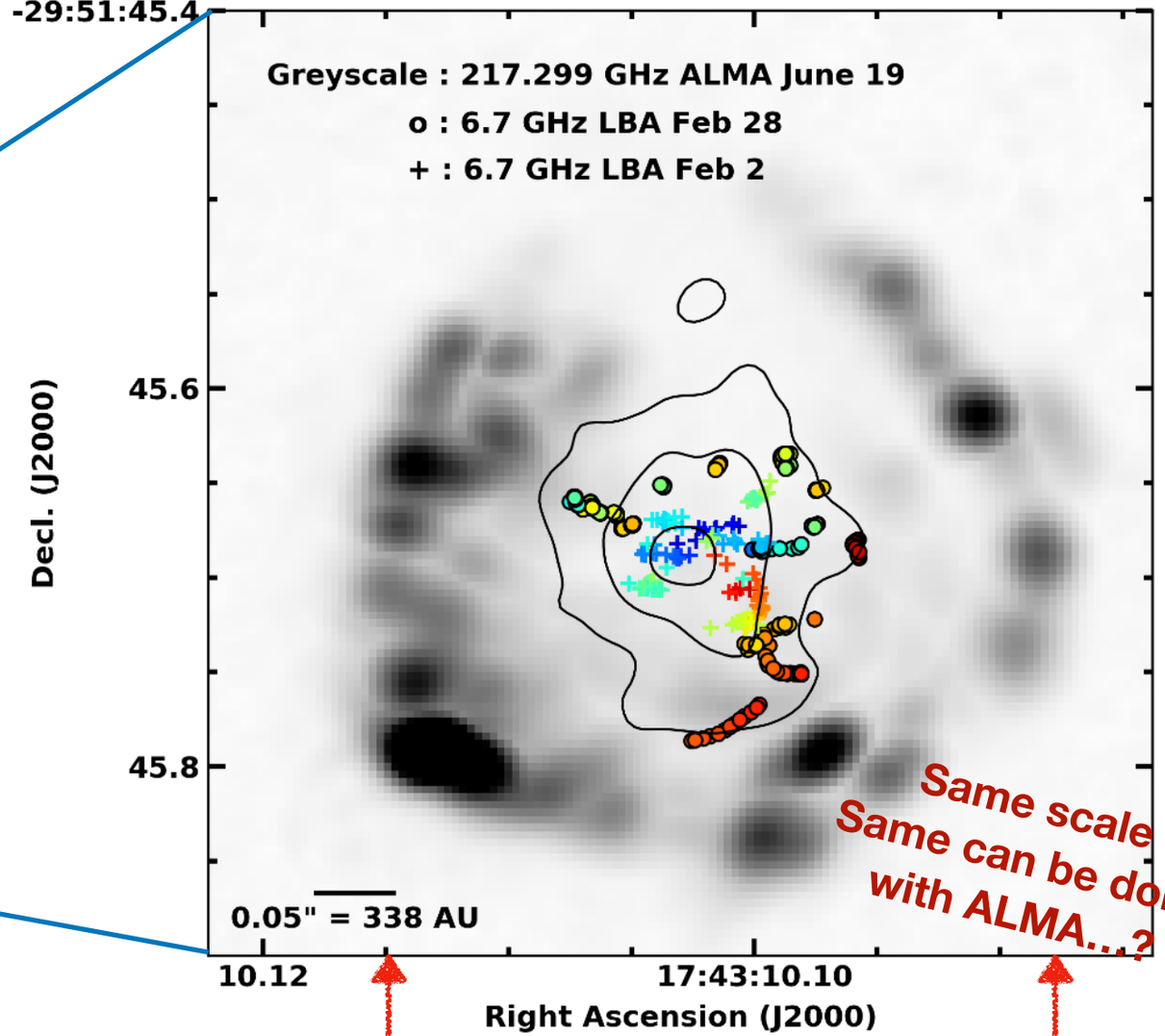
K. Sugiyama alerted the M2O in mid January 2019

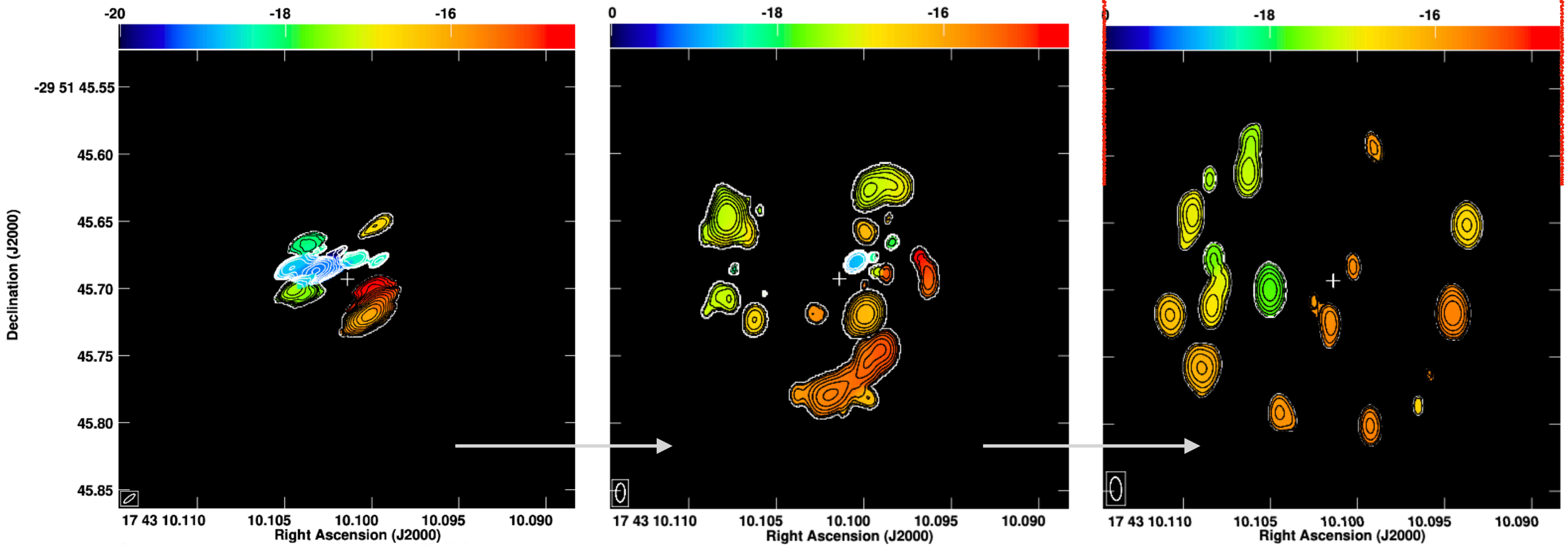
Daily monitoring

http://vlbi.sci.ibaraki.ac.jp/iMet/G358.9-00-190114/ **KS, Y. Yonekura, et al. (2019), ATel**

VLBI, HWM, ALMA comment…

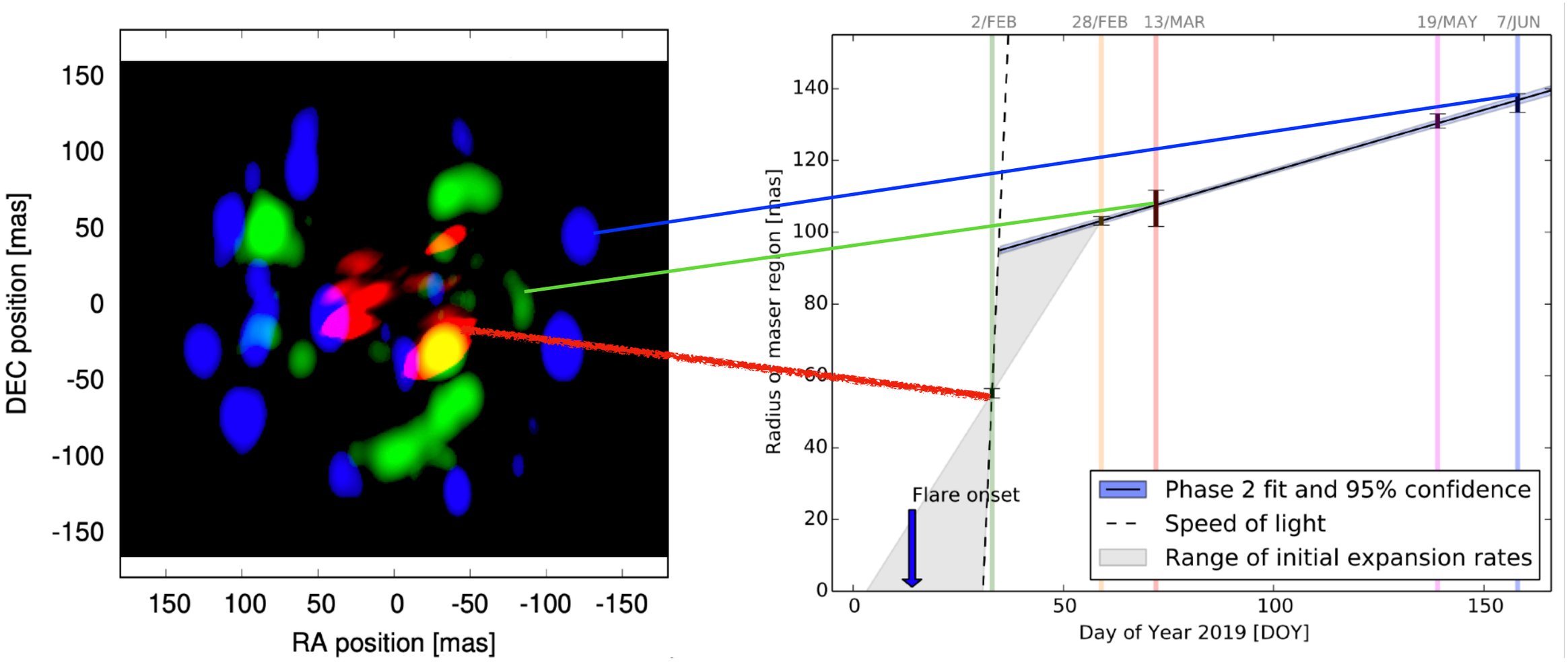






Brogan et al., 2019, ApJ, 881L, 39B

Two phase ‘heat-wave’



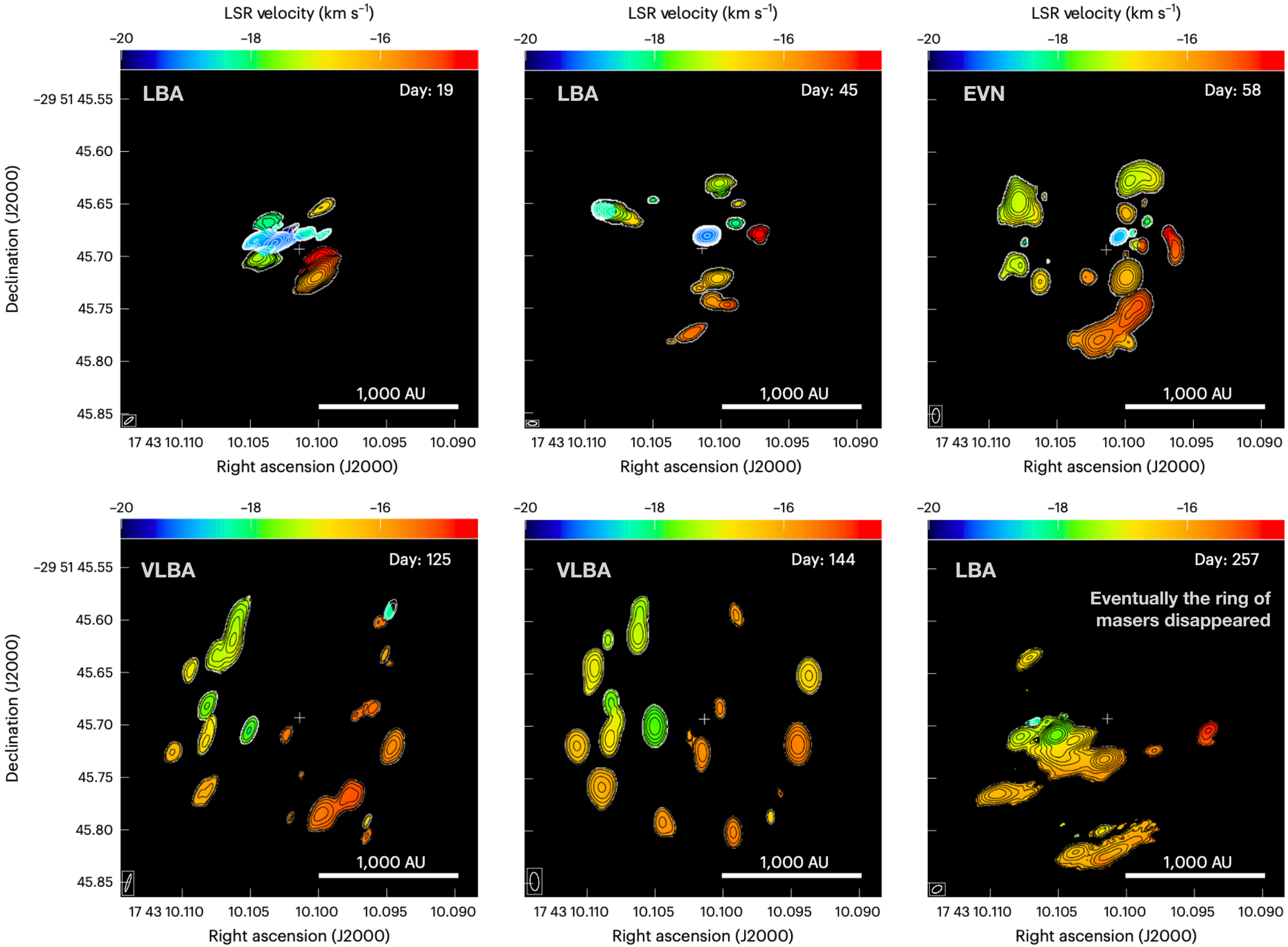
Expansion of the maser emitting radius phase expansion about 665.25 ± 28.7 AU:

R < 665 AU, ≥1.847 mas/day, ≥7.2% of c

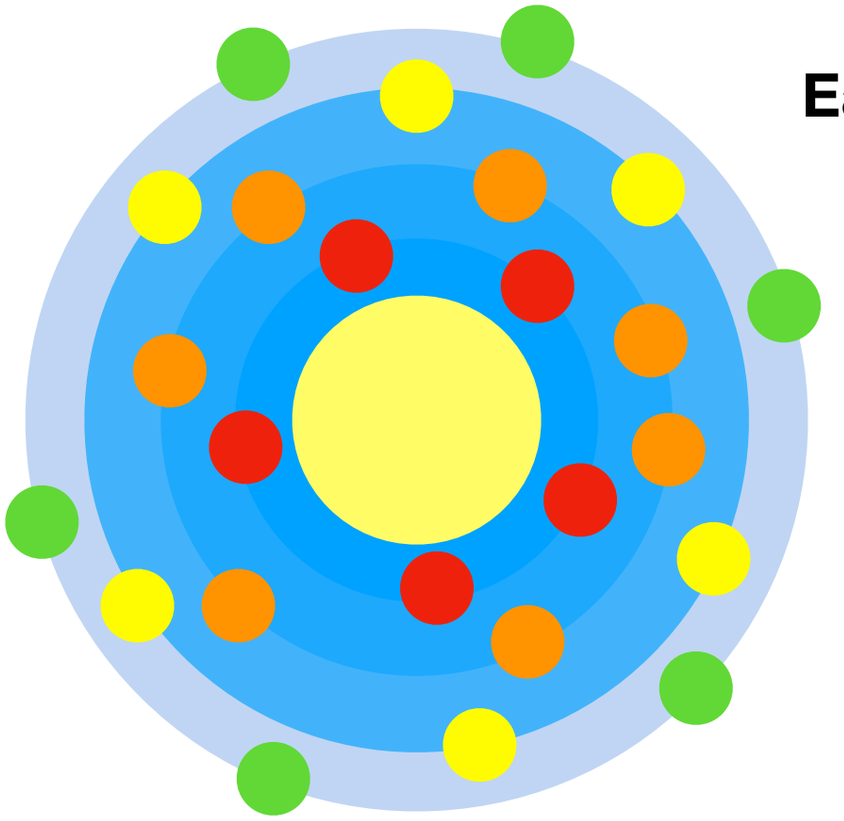
R > 665 AU, 0.340 ±0.008 mas/day, =1.3% of c

Transition could be due to a phase change such as the methanol snow line.

Results from VLBI: 6.7 GHz

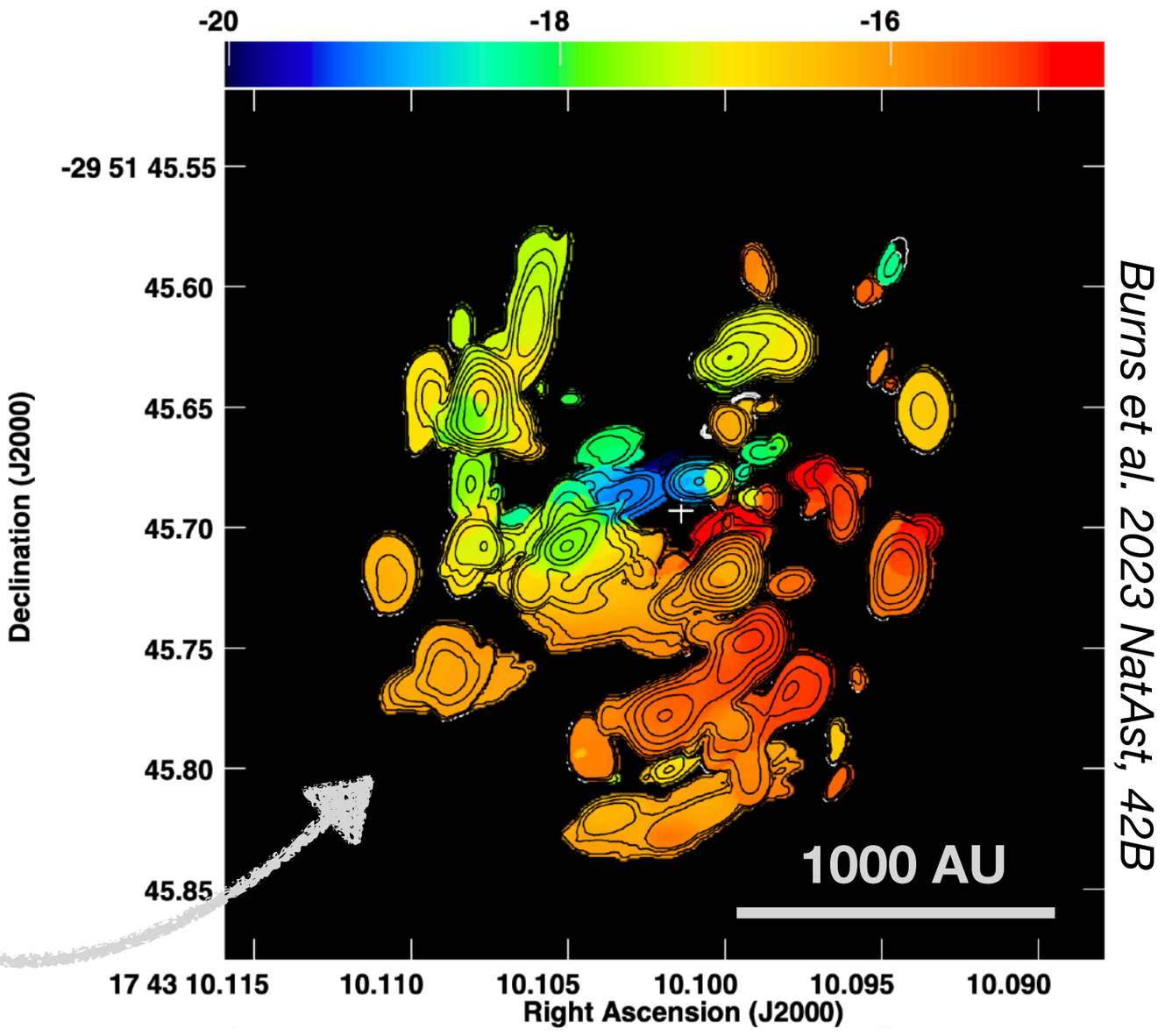


‘Heat-wave mapping’ of the disk



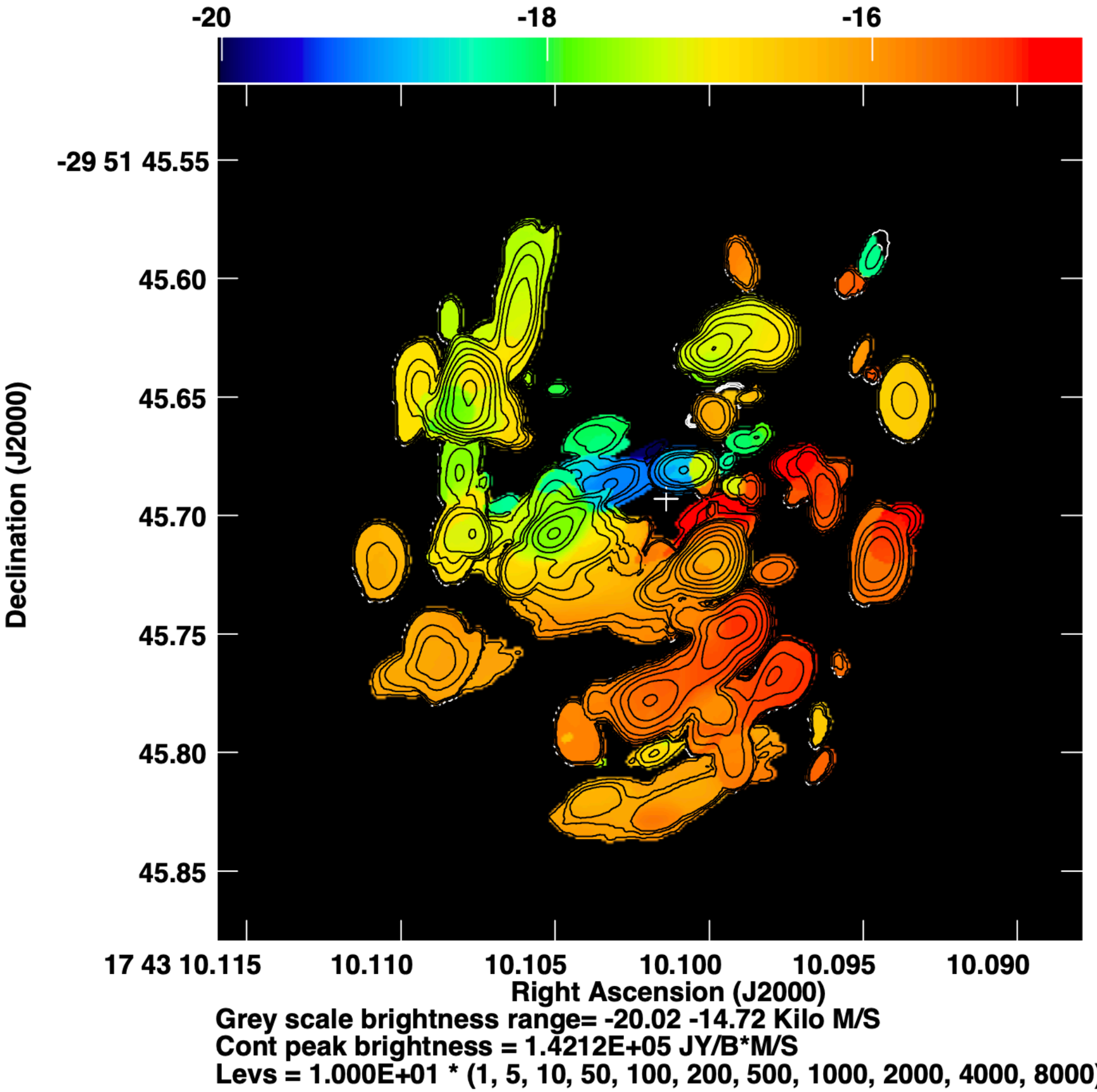
Each VLBI epoch traces one radius of the disk

By compiling all VLBI epochs we can fully trace the disk



Burns et al. 2023 NatAst, 42B

Discovery: Sub-structures in the disk



Combined FITS images revealed:

Disk radius:
920 AU

Velocity dispersion:
within +- 5 km/s

PA:
45 degrees

Inclination:
Near face-on

Artist's impression

Comparing models and data

$$Q = \frac{c_s \kappa}{\pi G \Sigma} = f \frac{M_\star}{M_d} \frac{H}{r}$$

The number of arms correlates with the disk-to-star mass ratio via:

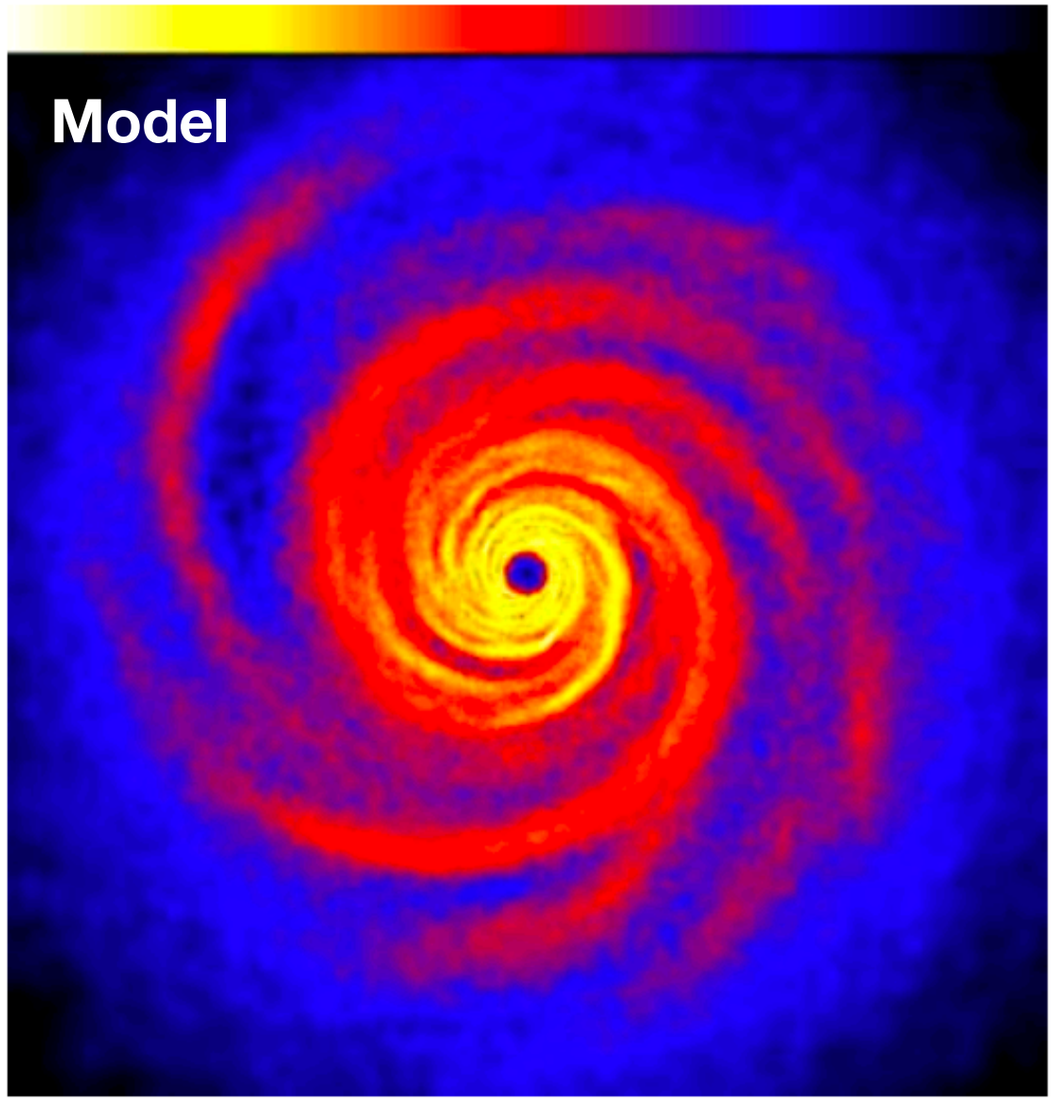
$M_d/M_\star \sim 1/m$

For G358-MM1:

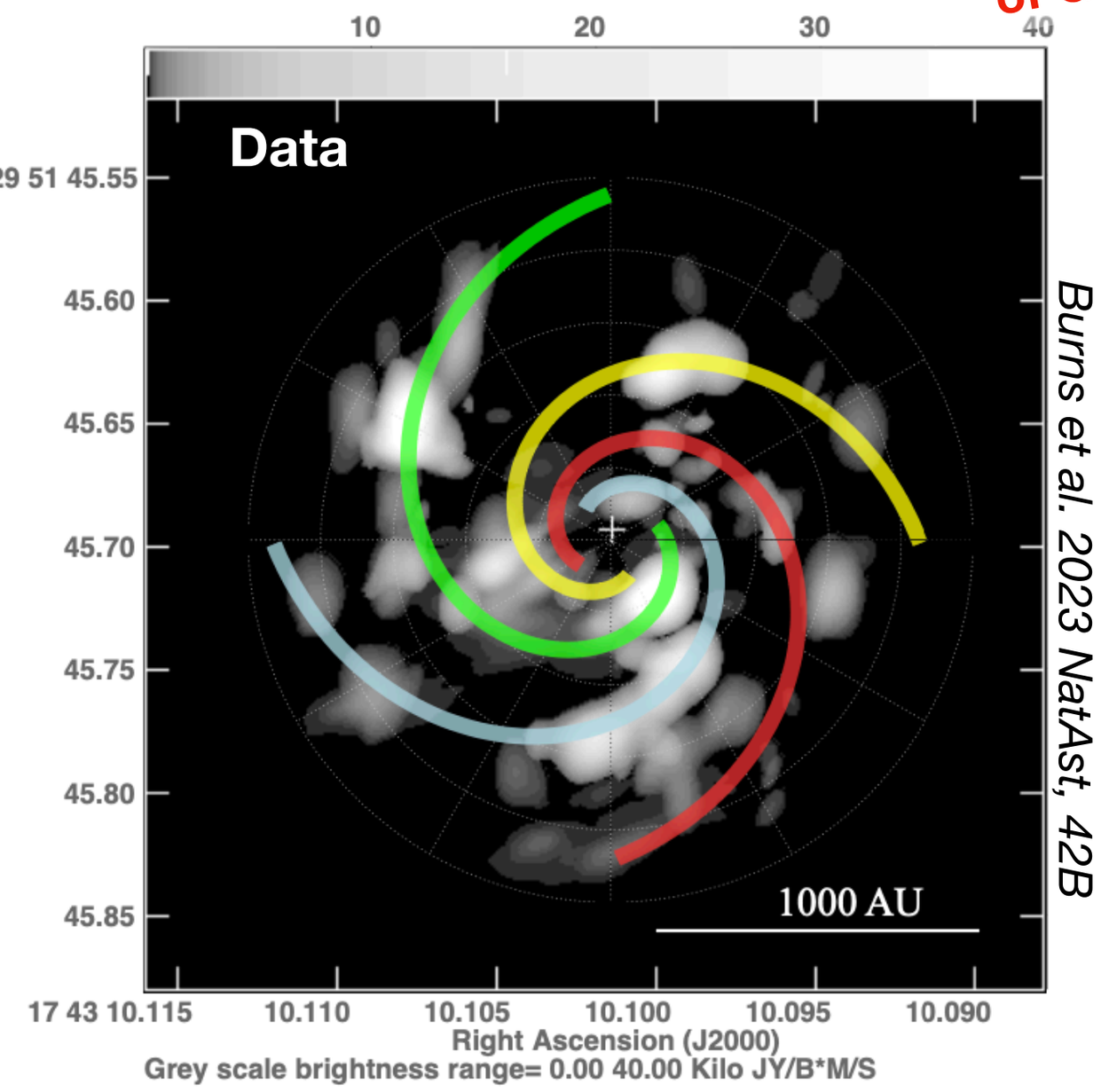
1/m = 1/4

Therefore $M_d/M_\star$ = Q ~ 0.25

Evidence of GI



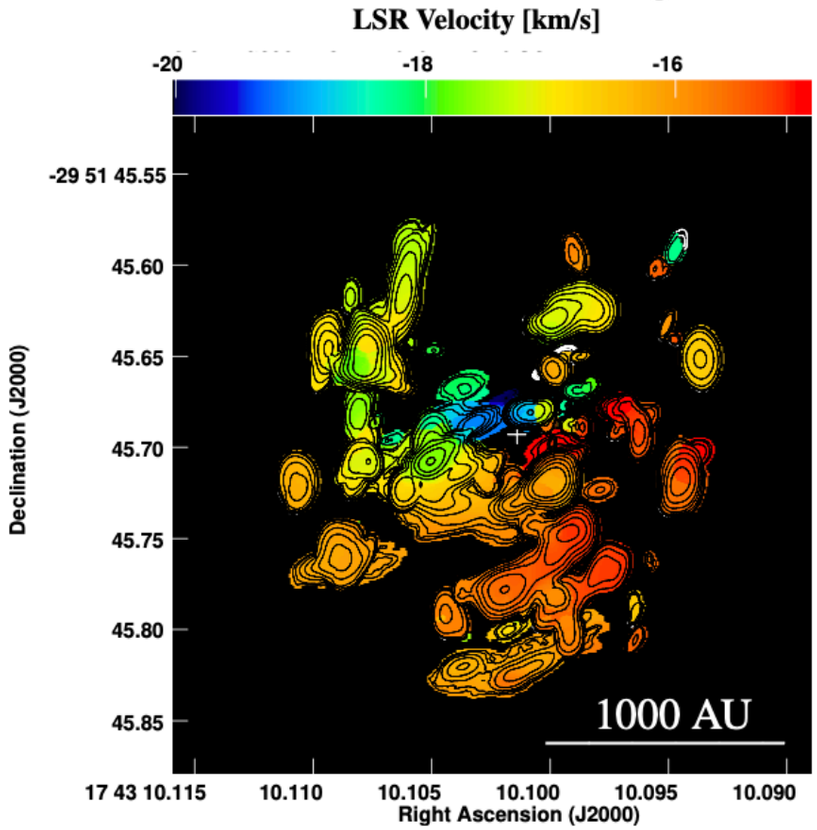
Lodato & Rice 2005 MNRAS 358 1489



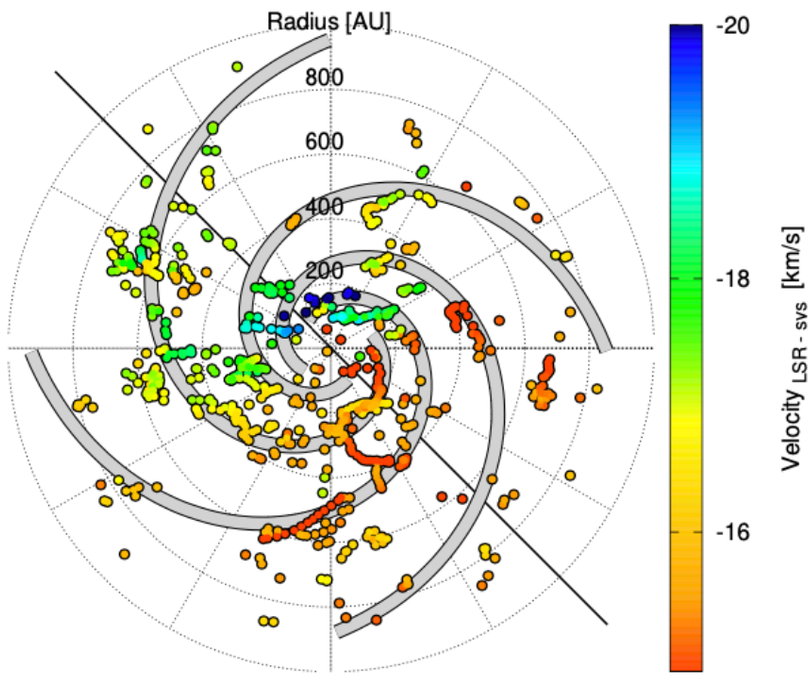
Burns et al. 2023 NatAst, 42B

Heat-wave mapping of G358-MM1
Conclusion page

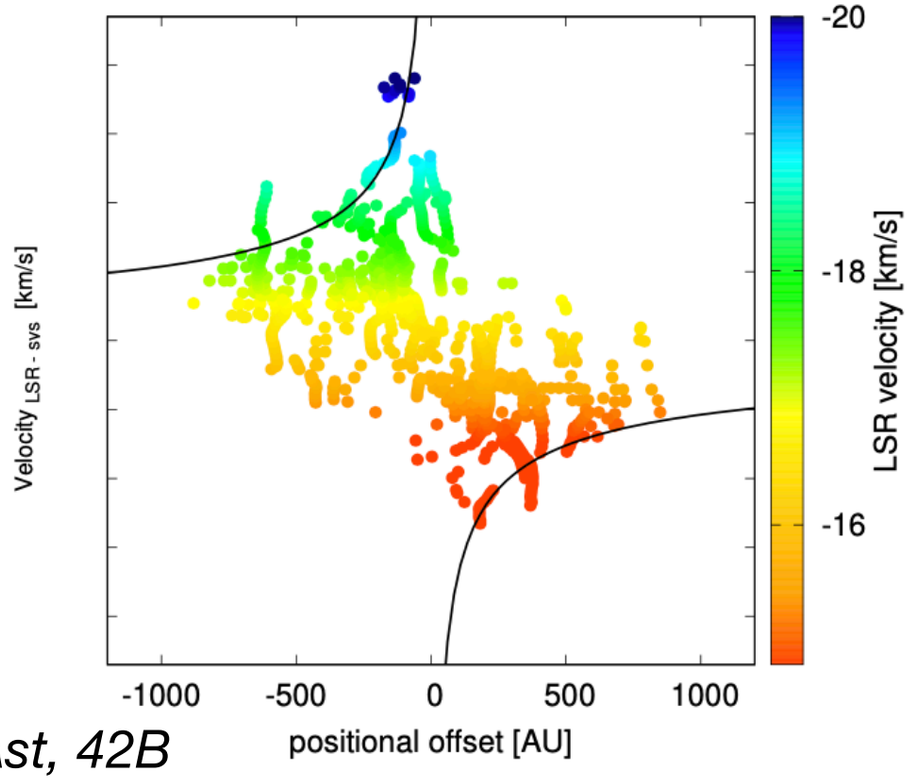
Combined FITS images



Spot map + model



Position-Velocity



Burns et al. 2023 NatAst, 42B

Disk size:
920 AU

Inclination:
21 ± 5 degrees

Enclosed mass:
11 ± 7 Mo

We found association between gravitationally unstable disks and accretion bursts in a high-mass protostar

Confirmed predictions of eppi. acc. HMSF theory

EVN and other VLBI arrays