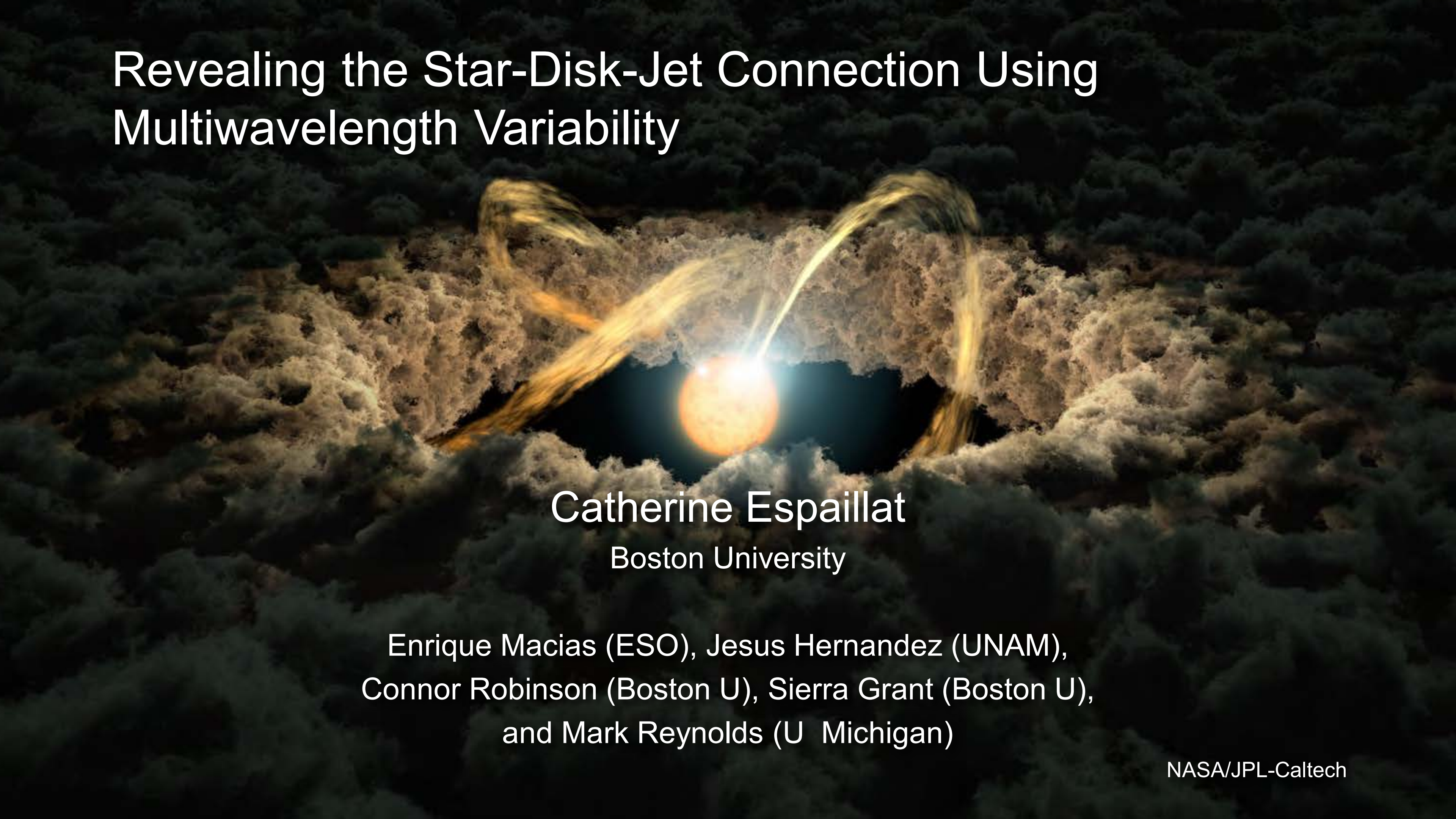
Revealing the Star-Disk-Jet Connection Using Multiwavelength Variability



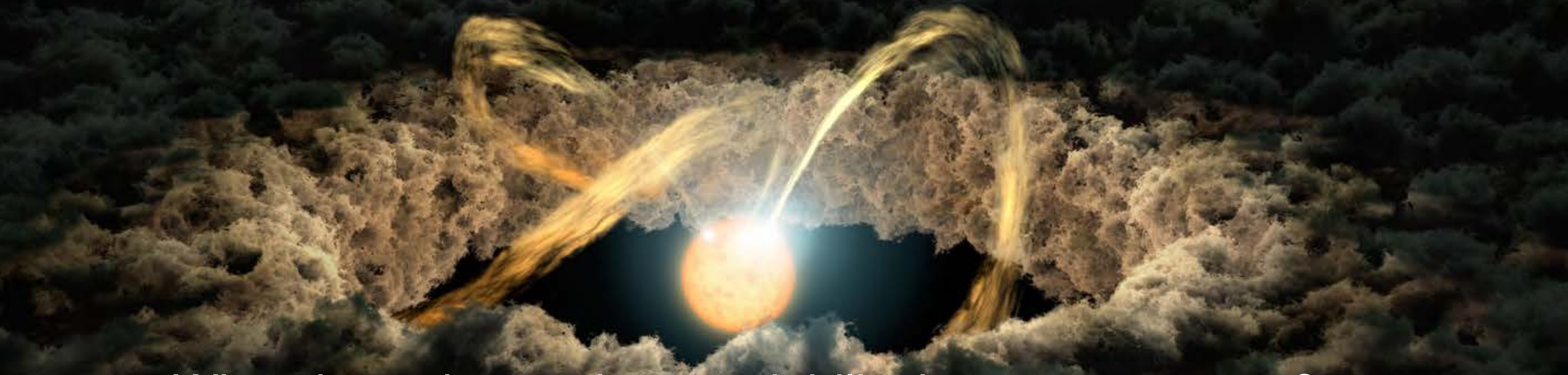
Catherine Espaillat

Boston University

Enrique Macias (ESO), Jesus Hernandez (UNAM),
Connor Robinson (Boston U), Sierra Grant (Boston U),
and Mark Reynolds (U Michigan)

NASA/JPL-Caltech

Revealing the Star-Disk-Jet Connection Using Multiwavelength Variability



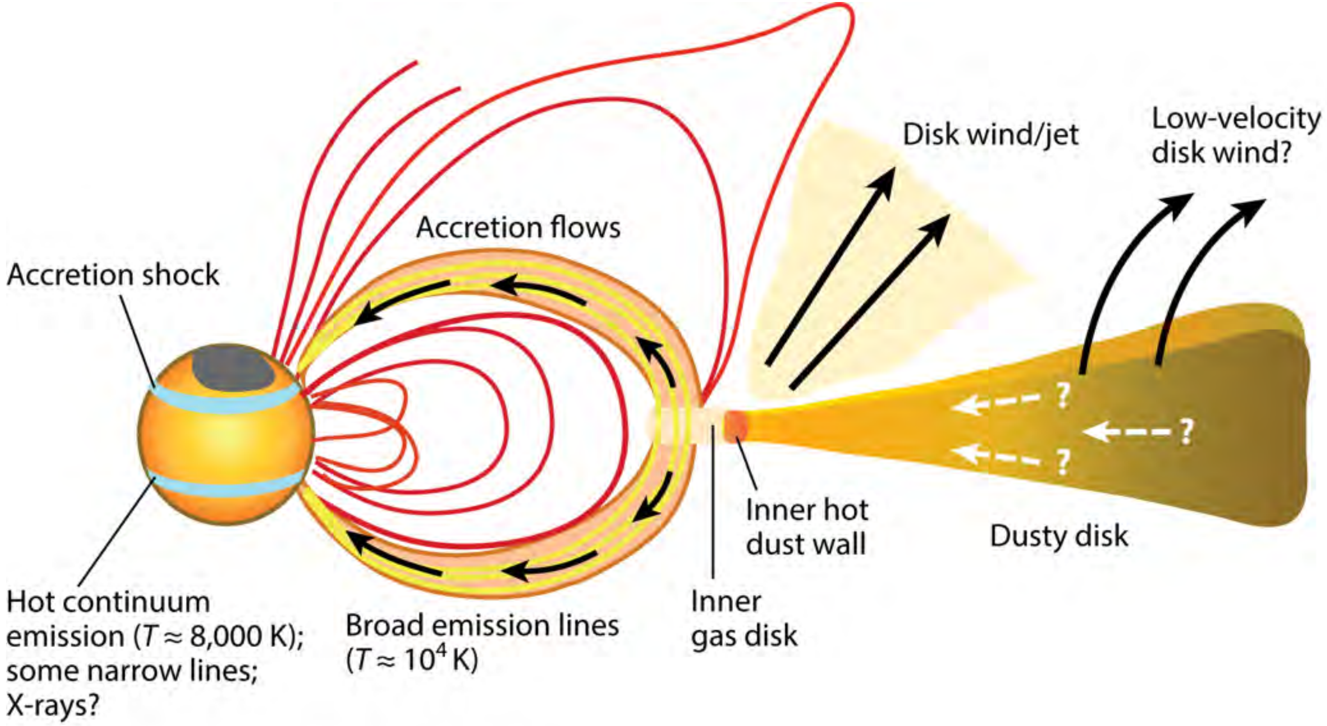
What do we know about variability in young systems?

What do we learn from simultaneous multiwavelength data?

What are possibilities for future variability work?

NASA/JPL-Caltech

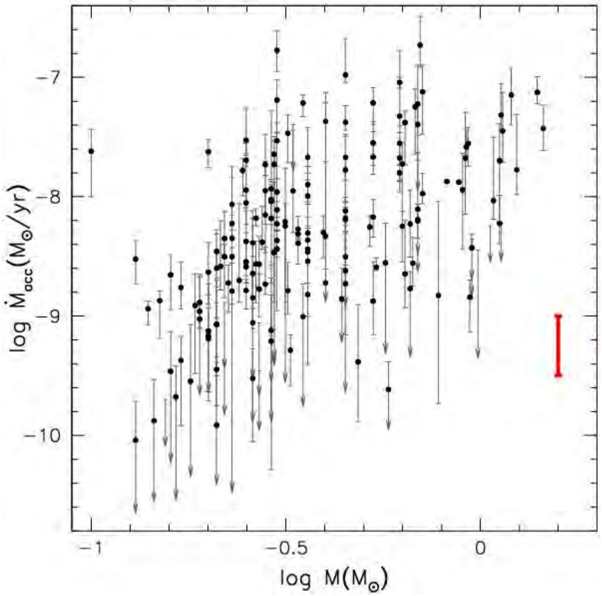
Mass accretes from the disk onto the star via the magnetic field lines and is launched via jets/winds



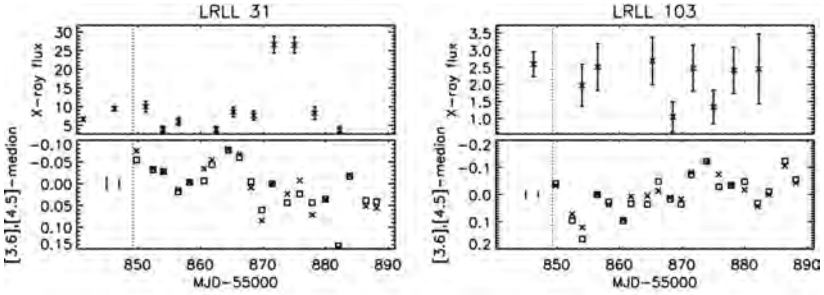
Hartmann, Herczeg, & Calvet 2016

Young stars appear to be variable at many wavelengths

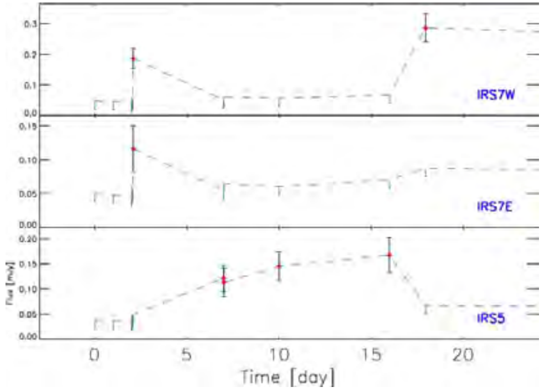
UV Emission



X-ray and MIR Emission

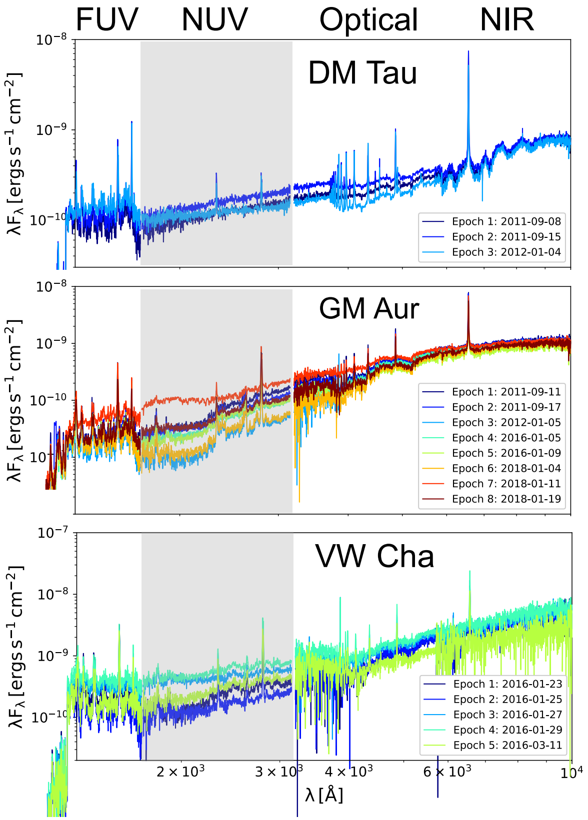


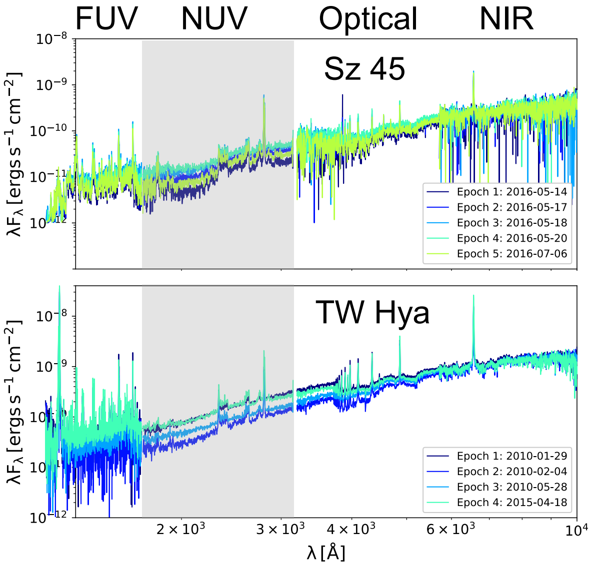
Radio Emission



Venuti et al. 2014; Flaherty et al. 2014; Liu et al. 2014

Young stars display NUV variability due to accretion





Robinson & Espaillat 2019

Revealing the Star-Disk-Jet Connection Using Multiwavelength Variability

What do we know about their variability?

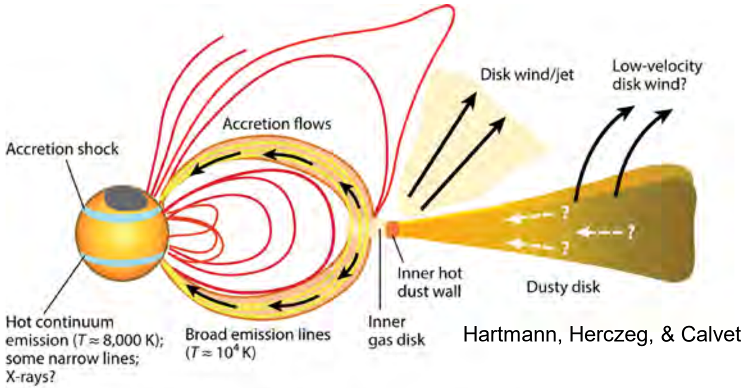
What do we learn from simultaneous multiwavelength data?

- Viewing the star-disk-jet connection

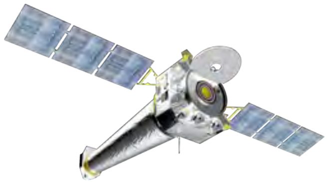
What are possibilities for future variability work?

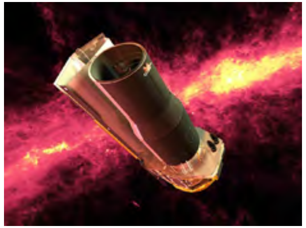
NASA/JPL-Caltech

Multiwavelength simultaneous data can provide snapshots of the star-disk-jet connection



Hartmann, Herczeg, & Calvet 2016

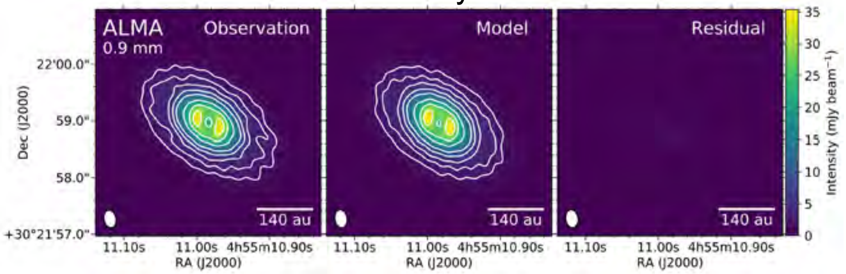




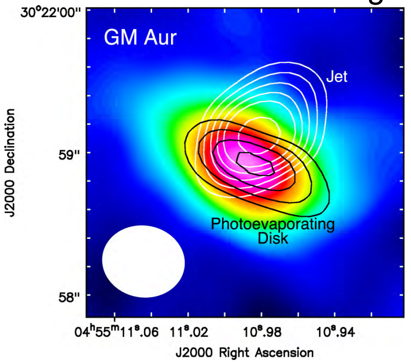
X-ray	UV	Optical	IR	Radio (cm)
Stellar corona	Accretion & gas in inner disk		Dust in inner disk	Jet

GM Aur is an accreting low-mass star with a jet

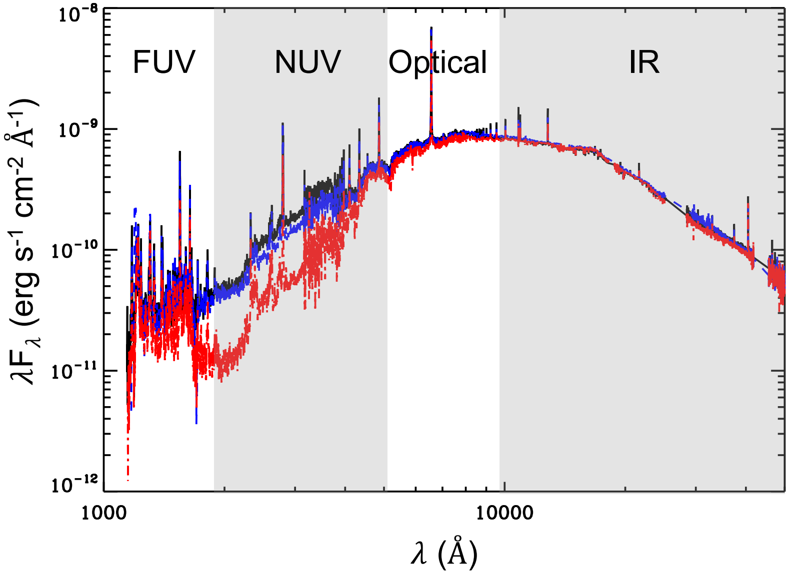
~20 AU radius cavity in dust distribution



Jet detected in cm images



NUV emission indicates accretion & there is IR emission from small dust grains close to star



Macias, Espaillat, et al. 2018; Macias et al. 2016; Ingleby, Espaillat, et al. 2015

Revealing the Star-Disk-Jet Connection Using Multiwavelength Variability

What do we know about their variability?

What do we learn from simultaneous multiwavelength data?

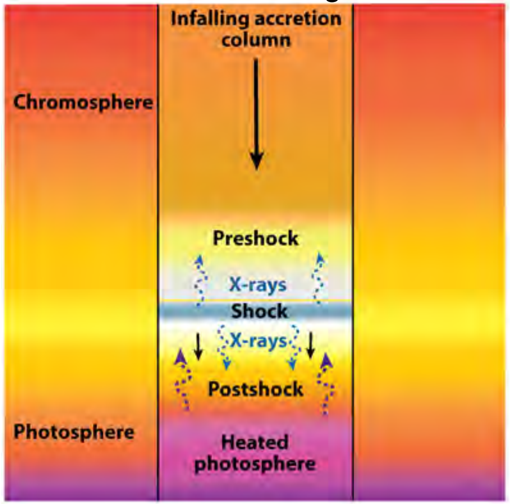
- Viewing the star-disk-jet connection
  - ➡ Mass accretion rate
  - Dust and gas in the innermost disk
  - Mass loss via the jet

What are possibilities for future variability work?

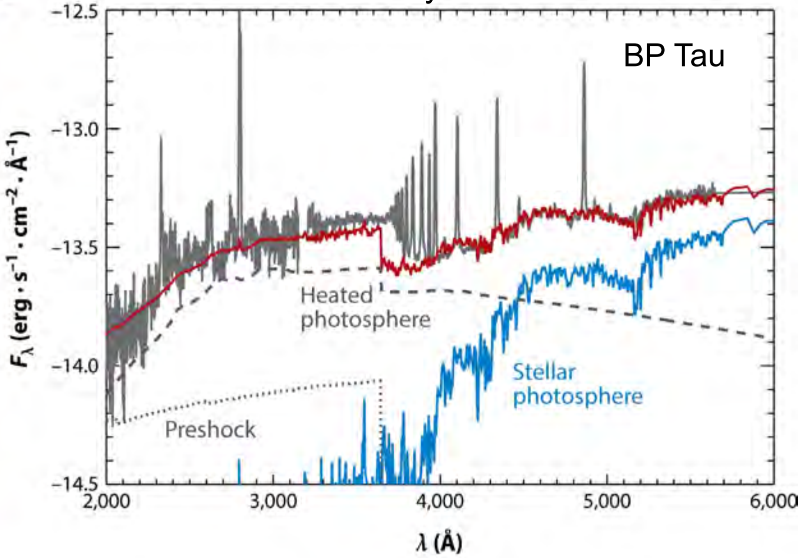
NASA/JPL-Caltech

The accretion process produces significant NUV excess emission

Accretion shock model of Calvet & Gullbring 1998

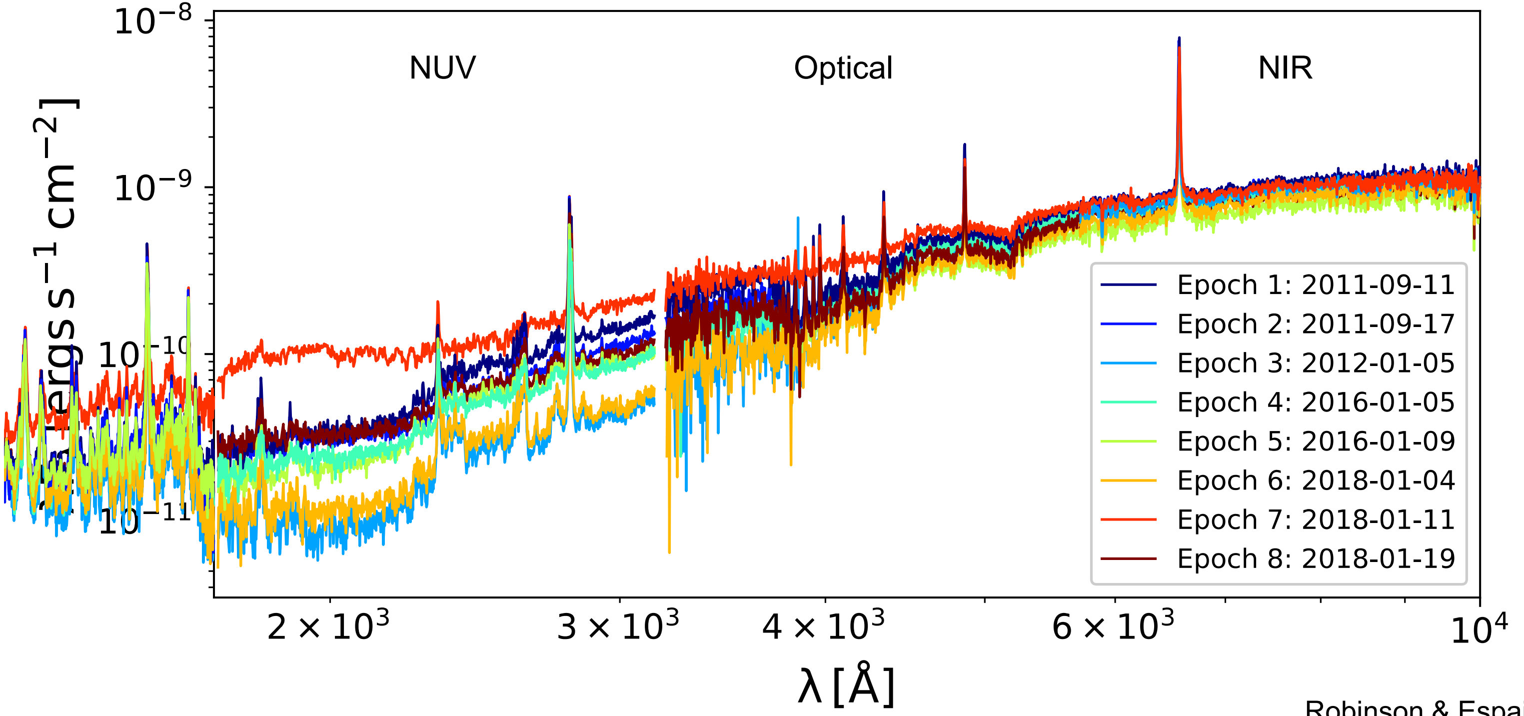


Modeling the NUV excess emission to extract the accretion luminosity



Hartmann, Herczeg, & Calvet 2016

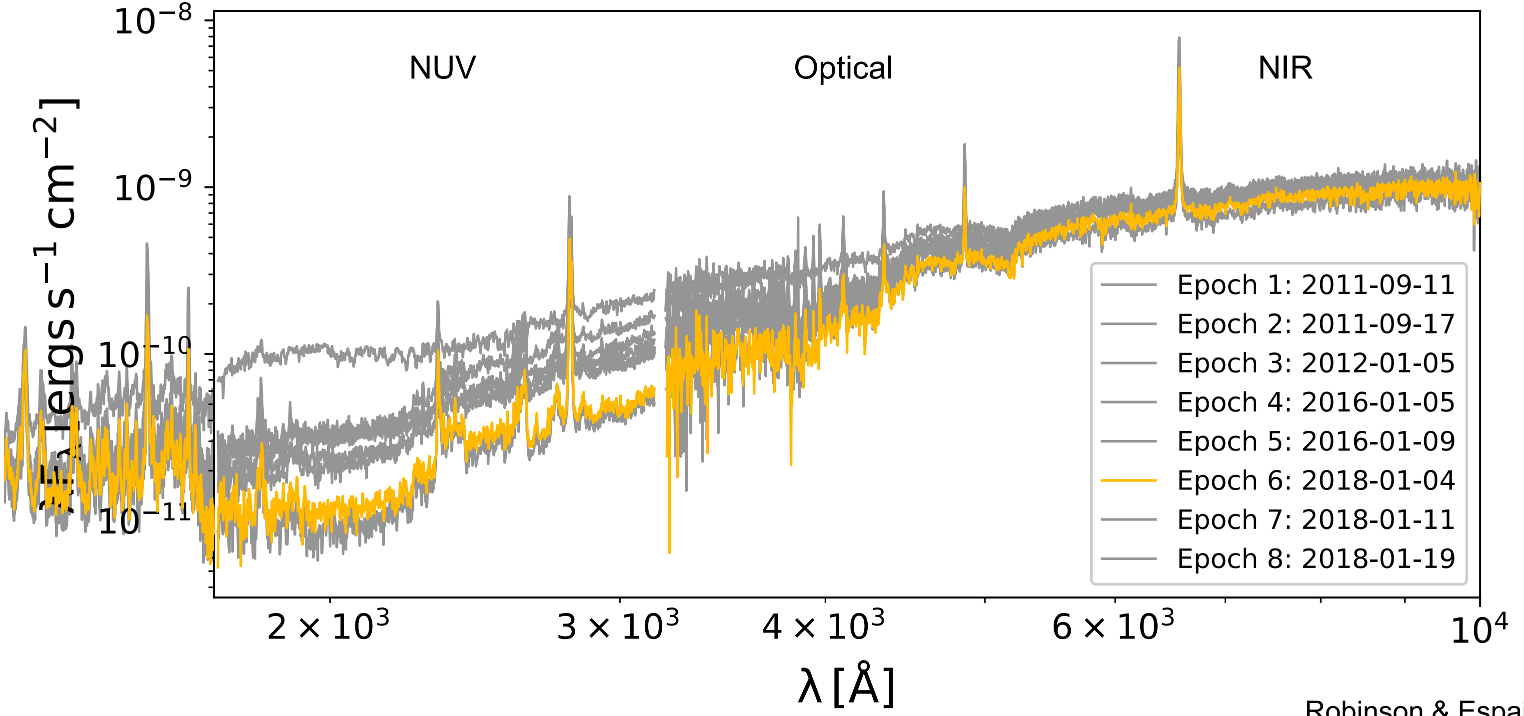
GM Aur was caught during an accretion burst



Robinson & Espaillat 2019

GM Aur was caught during an accretion burst

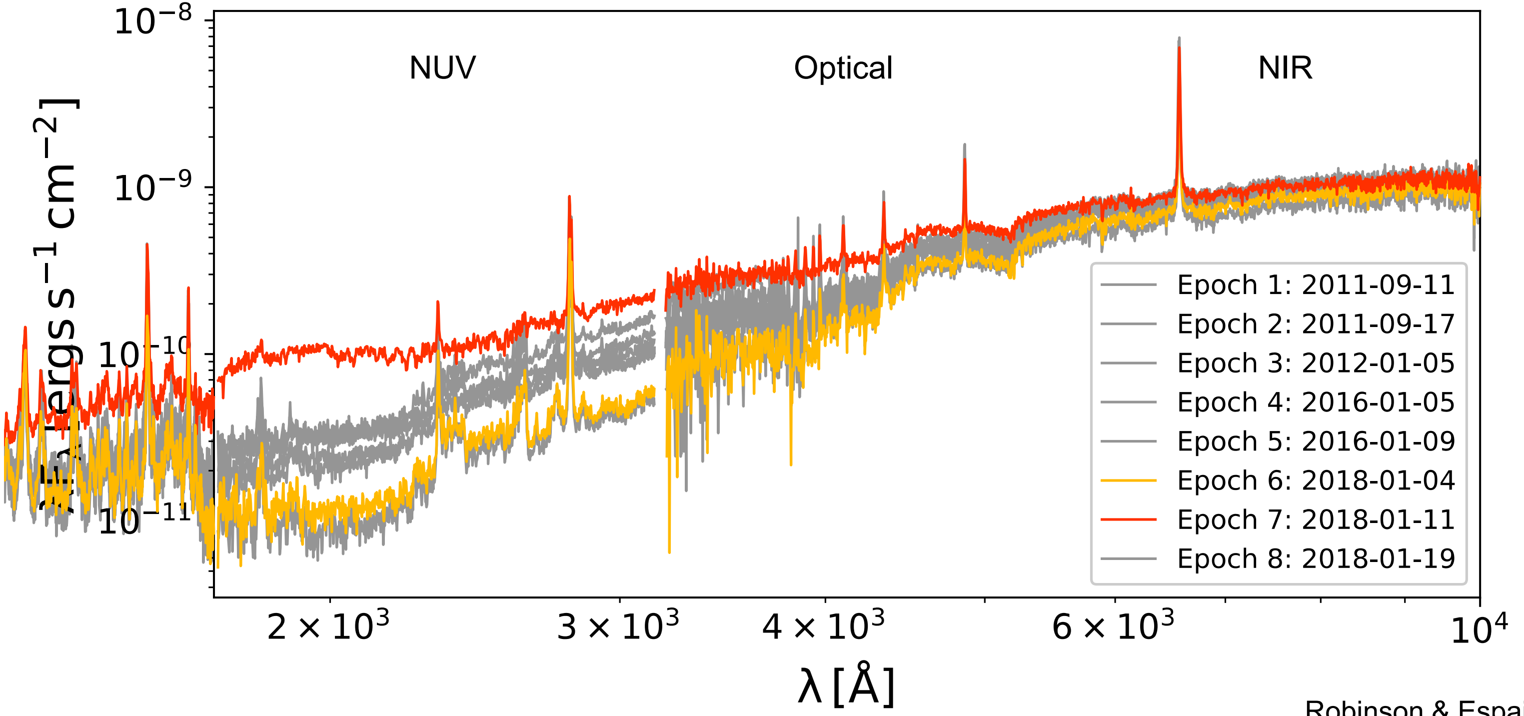
$$\dot{M} = 0.6 \times 10^{-8} M_{\odot}\, yr^{-1}$$



Robinson & Espaillat 2019

GM Aur was caught during an accretion burst

$\dot{M} = 0.6 \times 10^{-8} M_{\odot}\, yr^{-1}$ $\dot{M} = 2.0 \times 10^{-8} M_{\odot}\, yr^{-1}$

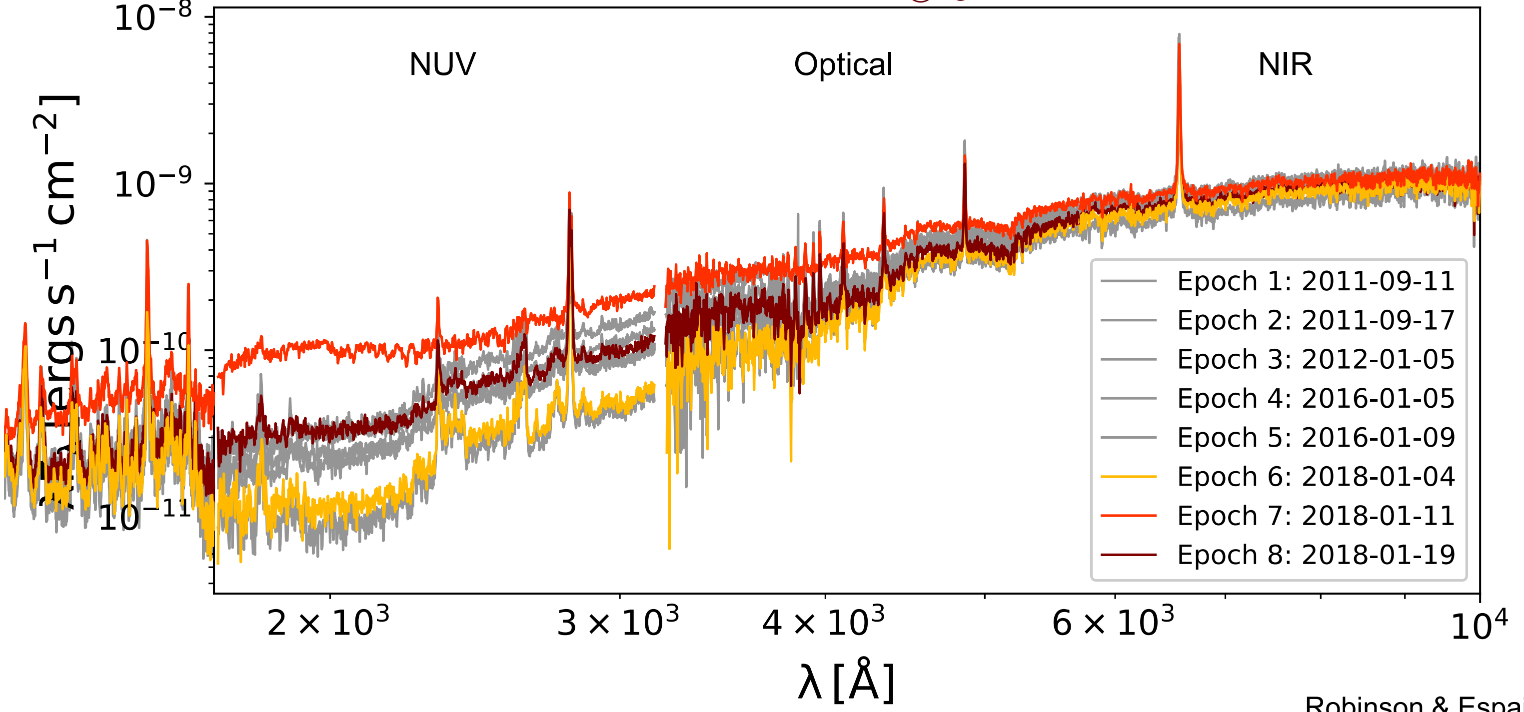


Robinson & Espaillat 2019

GM Aur was caught during an accretion burst

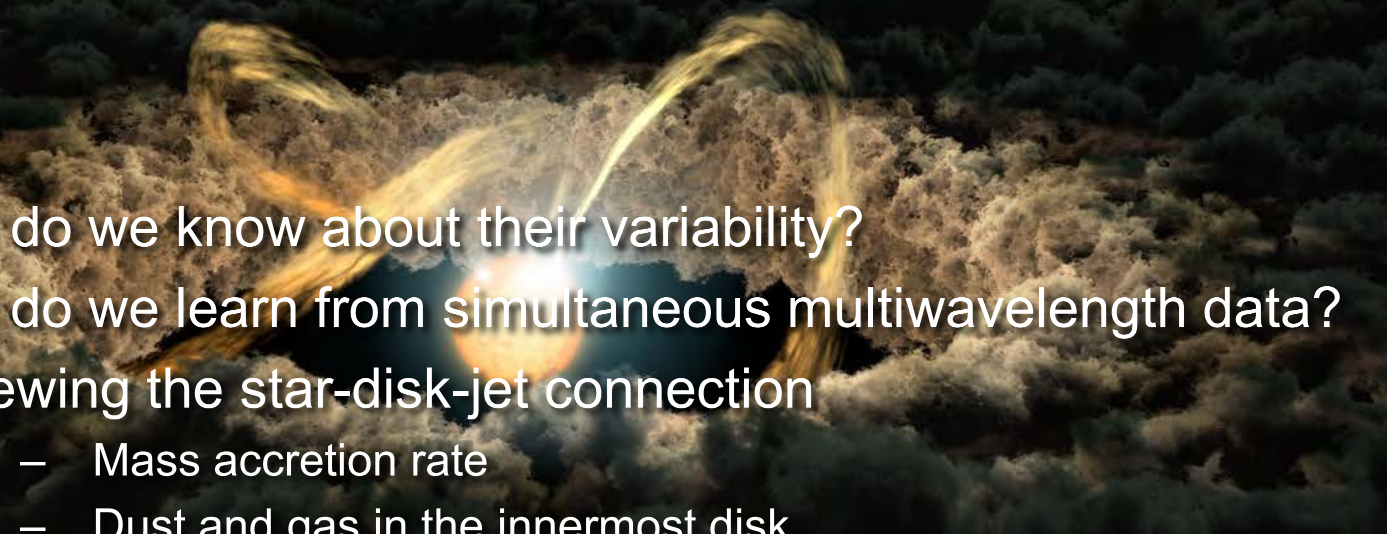
$\dot{M} = 0.6 \times 10^{-8} M_{\odot}\, yr^{-1}$ $\dot{M} = 2.0 \times 10^{-8} M_{\odot}\, yr^{-1}$

$\dot{M} = 1.0 \times 10^{-8} M_{\odot}\, yr^{-1}$



Robinson & Espaillat 2019

Revealing the Star-Disk-Jet Connection Using Multiwavelength Variability



What do we know about their variability?

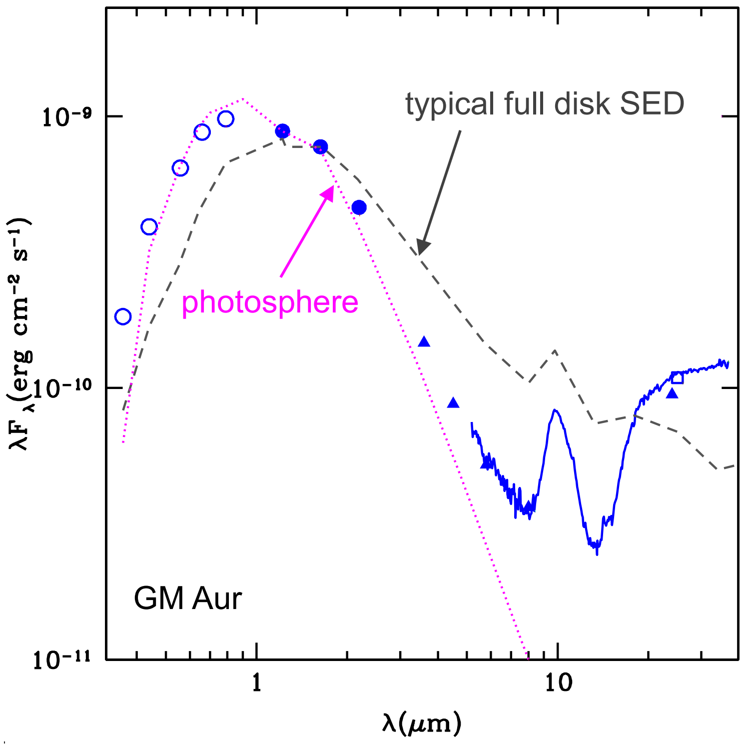
What do we learn from simultaneous multiwavelength data?

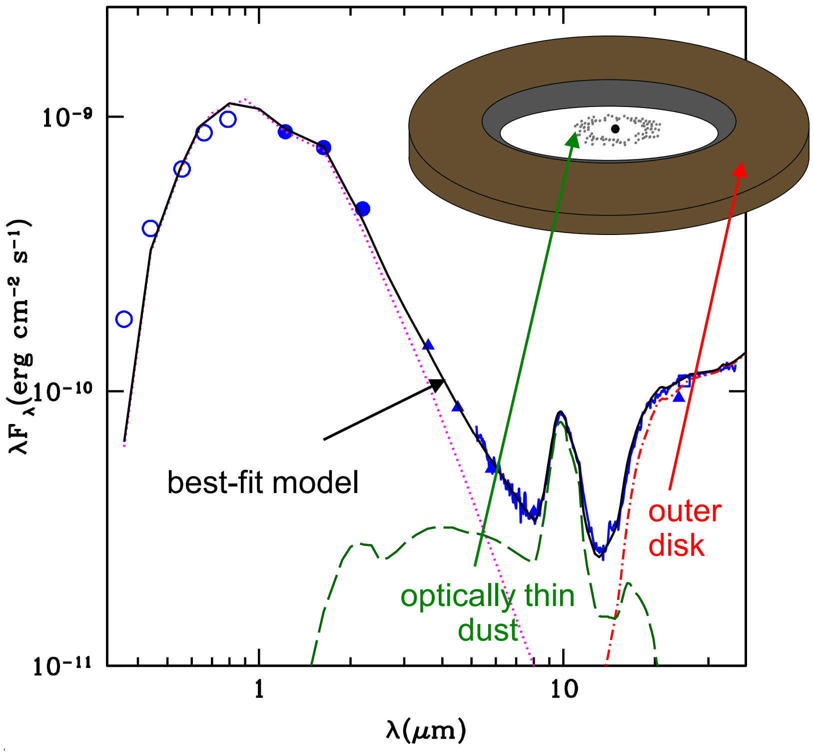
- Viewing the star-disk-jet connection
  - Mass accretion rate
  - ➡ Dust and gas in the innermost disk
  - Mass loss via the jet

What are possibilities for future variability work?

NASA/JPL-Caltech

MIR emission traces dust in the innermost disk

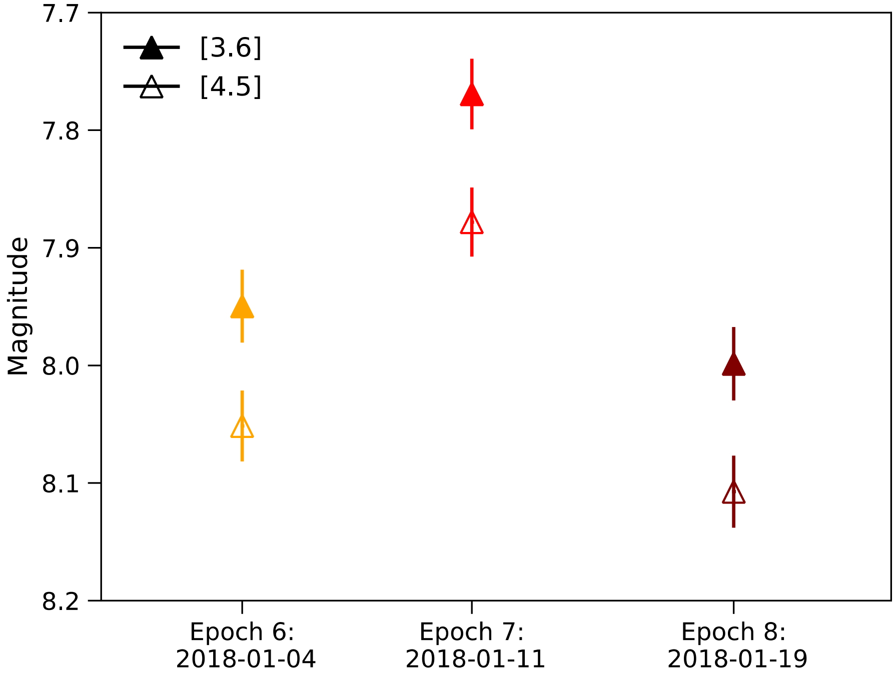




Espaillat et al. 2011

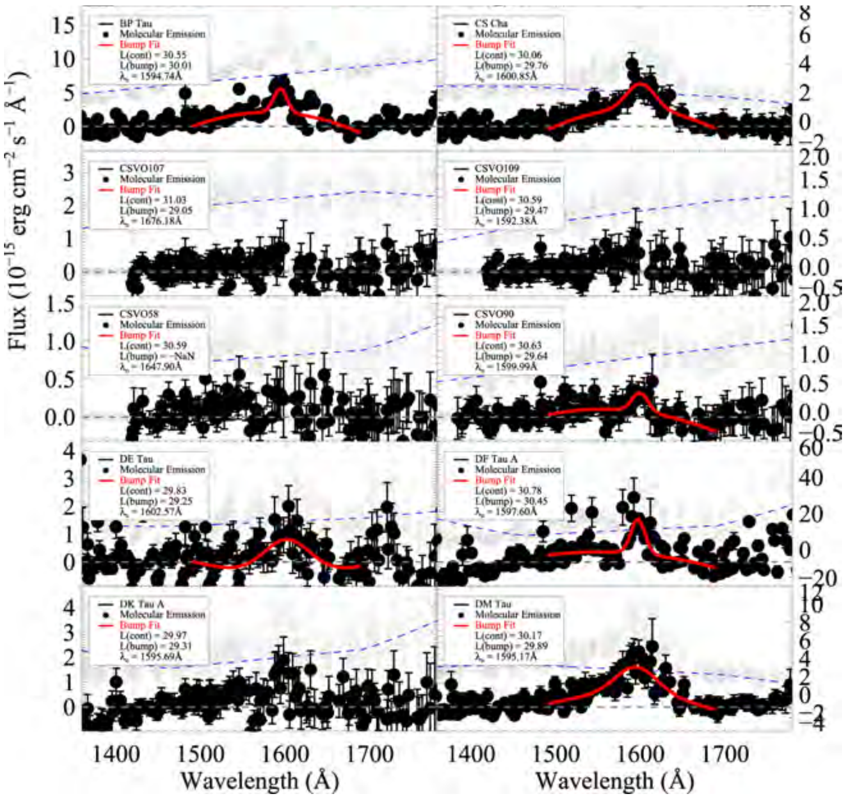
MIR emission was highest during the accretion burst

The change in the MIR emission between Epoch 6 and Epoch 7 is consistent with a dust mass increase of a factor of ~2.5, roughly consistent with the accretion rate change factor of ~3.



Espaillat et al. 2019b

The FUV H_2 "bump" emission feature traces gas close to the star

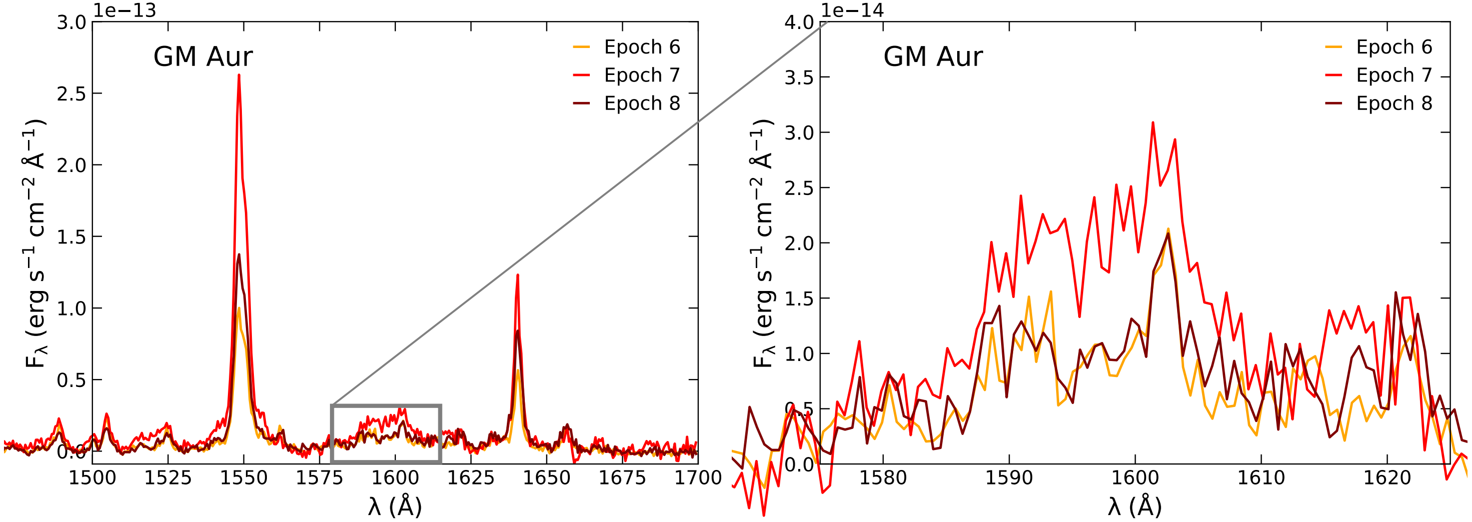


Identified in FUV by Herczeg et al. (2002) and Bergin et al. (2004) and observed from several T Tauri stars (Ingleby et al. 2011, France et al. 2017, Espaillat et al. 2019a)

France et al. 2017

FUV H_2 feature was highest during the accretion burst

The H_2 feature luminosity between Epoch 6 and Epoch 7 increased by of a factor of ~2, roughly consistent with the accretion rate change factor of ~3.



Espaillat et al. 2019a

Revealing the Star-Disk-Jet Connection Using Multiwavelength Variability

What do we know about their variability?

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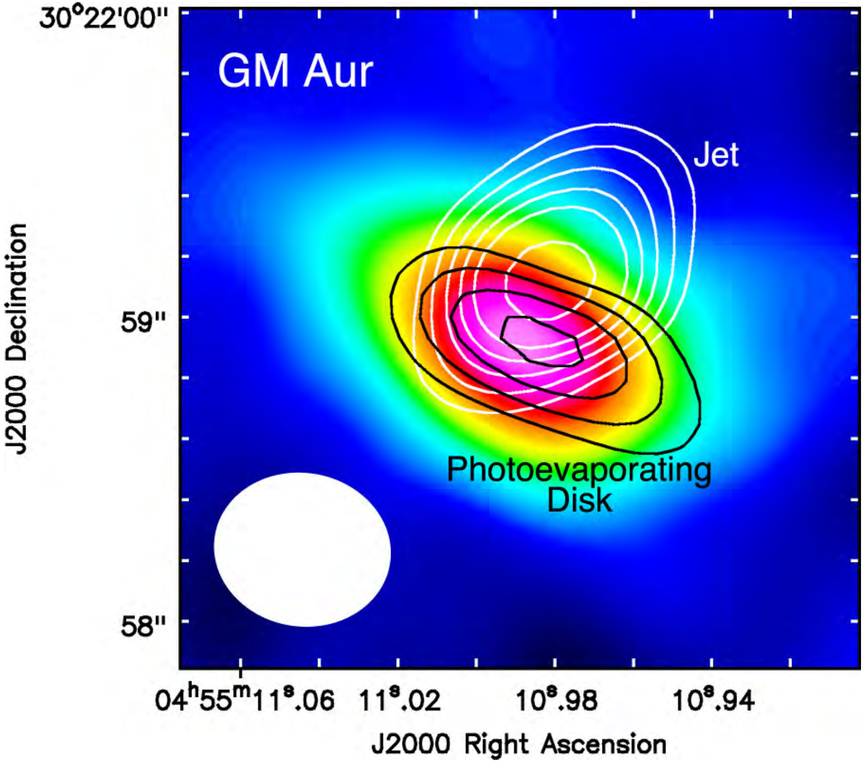
What are possibilities for future variability work?

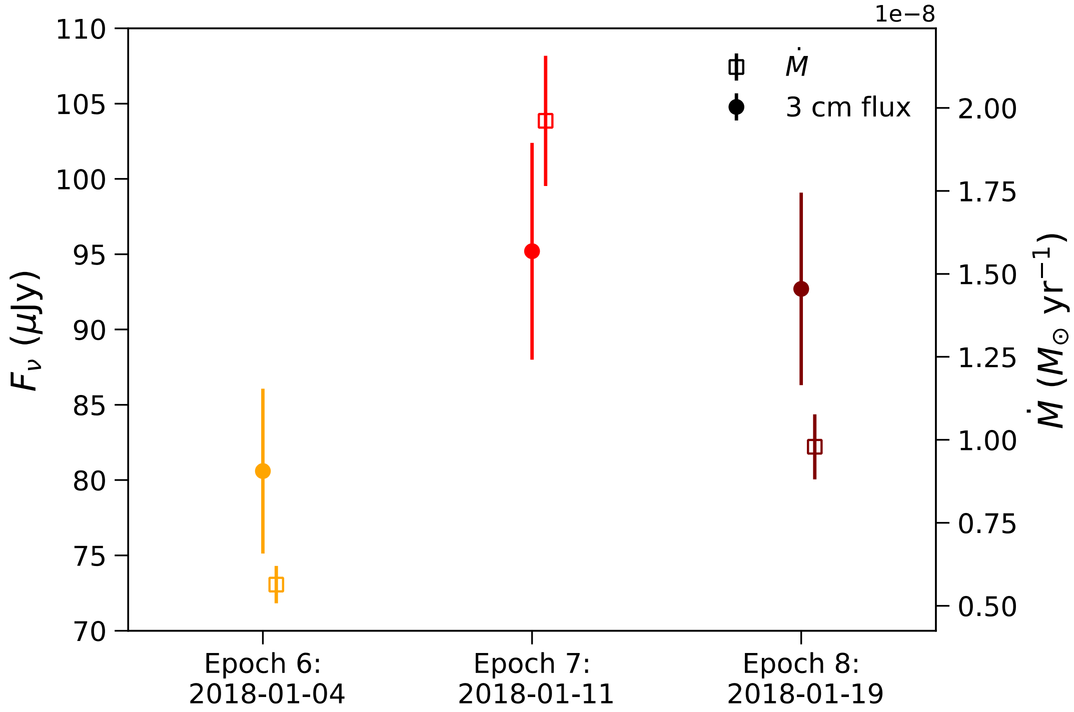
NASA/JPL-Caltech

GM Aur displays a jet in 3cm images



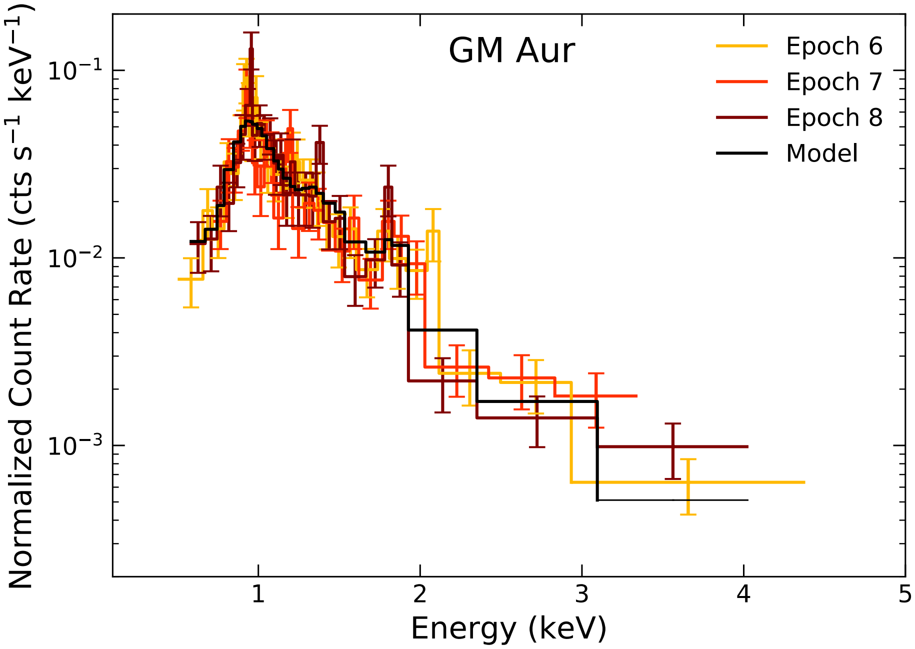
Macias et al. 2016

The radio emission was highest during the accretion burst



Espaillat et al. 2019b

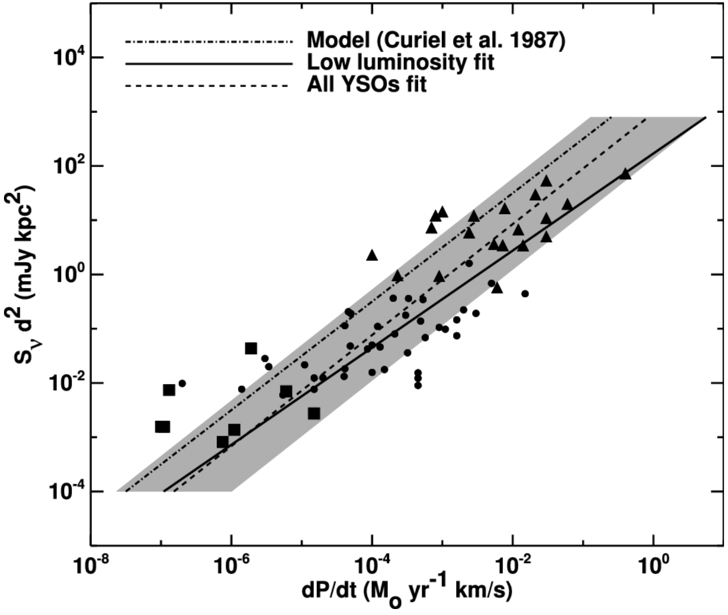
The X-ray emission remained constant, ruling out X-ray radiation as the cause of the variability



Espaillat et al. 2019b

The change in the cm emission is consistent with $\dot{M}_{\text{loss}} \sim 10\%\ \dot{M}_{\text{acc}}$

We can use the empirical correlation between the radio continuum luminosity and outflow momentum rate to estimate the cm variability expected from a variable mass-loss rate.



$$\left(\frac{S_\nu d^2}{\text{mJy kpc}^2}\right) = 10^{2.22\pm0.46}\left(\frac{\dot{P}}{M_\odot\ \text{year}^{-1}\ \text{km s}^{-1}}\right)^{0.89\pm0.16}$$

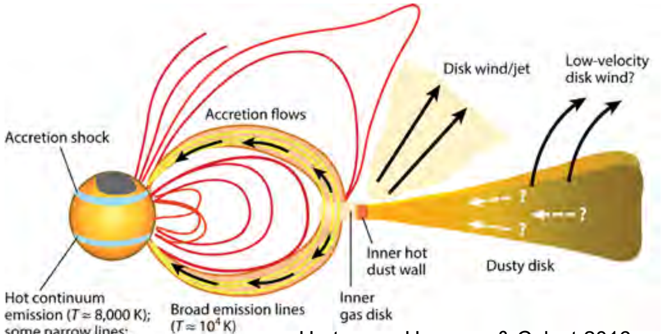
Assuming v_{jet}=300 km/s and $\dot{M}_{\text{loss}} \sim 10\%\ \dot{M}_{\text{acc}}$

the expected $\Delta S\upsilon$ (Epoch 6 → Epoch 7) ~ 13 μJy

& the observed $\Delta S\upsilon$ is ~15 μJy.

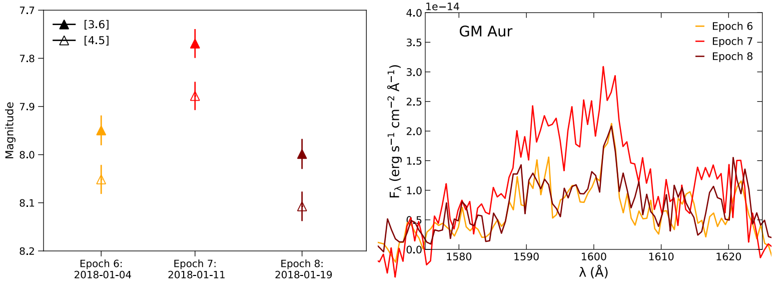
Anglada, Rodriguez, Carrasco-Gonzalez 2018

Viewing the star-disk-jet connection

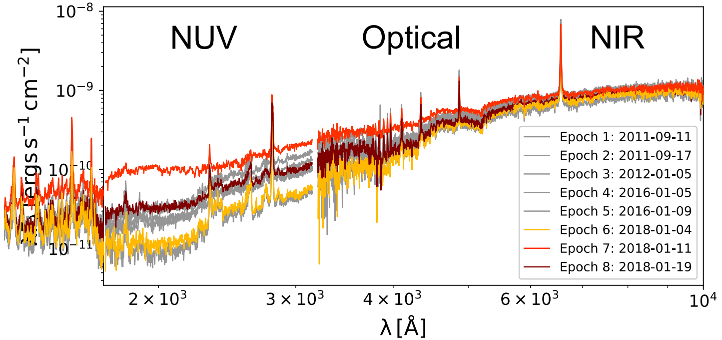


Hartmann, Herczeg, & Calvet 2016

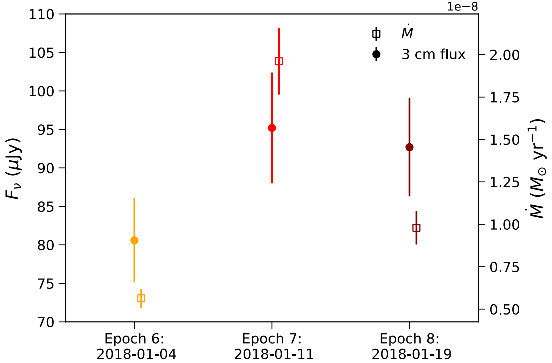
Surface density in the inner disk increases…



causing an increase in the mass accretion rate….



which leads to an increase in the mass loss rate.



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What do we know about their variability?

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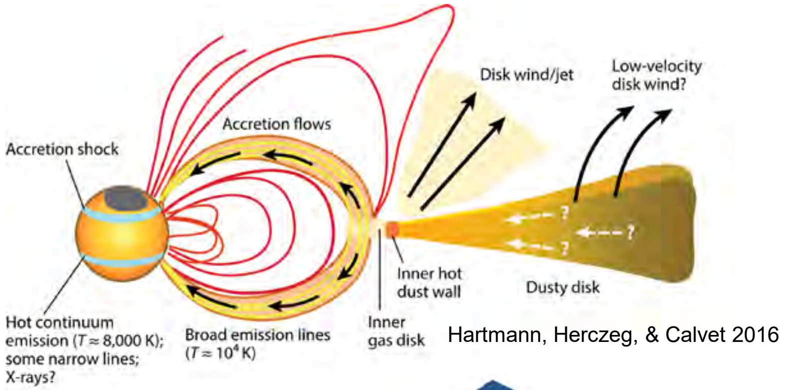
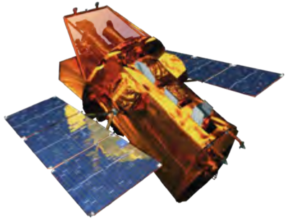
➡ What are possibilities for future variability work?

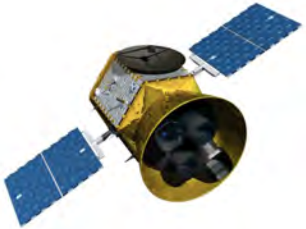
NASA/JPL-Caltech

Follow up campaign of the star-disk-jet connection



Hartmann, Herczeg, & Calvet 2016





X-ray	UV	Optical	IR	Radio (cm)

Stellar corona

Accretion

Jet

ULYSSES: Hubble UV Legacy of Young Stars as Essential Standards

The STScI Director has decided to devote 600-1000 orbits of Director's Discretionary time in observing Cycles 27-29 to a new Hubble Ultraviolet Legacy program focused on **star formation and associated stellar physics**. The Ultraviolet Legacy program will be modeled after the Frontier Fields program: all data obtained will be non-proprietary.

Young, low-mass star science areas:
accretion and ejection physics,
jet launching and angular momentum evolution,
disk evolution and dispersal,
chemistry of planet formation,
unveiling the chromosphere,
irradation of young planetary atmospheres

Revealing the Star-Disk-Jet Connection Using Multiwavelength Variability

What do we learn from simultaneous multiwavelength data?

- We see evidence for the star-disk-jet connection
  - There is an increase in UV, MIR, and radio emission while the X-ray emission is constant in GM Aur.
  - This supports an increase in the surface density of the inner disk leading to more mass loading onto the star and therefore a higher mass accretion rate and a higher mass-loss rate via the jet.

NASA/JPL-Caltech