Revealing the Star-Disk-Jet Connection Using Multiwavelength Variability

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What do we know about variability in young systems?
What do we learn from simultaneous multiwavelength data?
What are possibilities for future variability work?
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

Young stars display NUV variability due to accretion

- DM Tau
- GM Aur
- VW Cha
- Sz 45
- TW Hya

Robinson & Espaillat 2019
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?
Multiwavelength simultaneous data can provide snapshots of the star-disk-jet connection.

Hartmann, Herczeg, & Calvet 2016

<table>
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<td>Accretion &amp; gas in inner disk</td>
<td>Dust in inner disk</td>
<td>Jet</td>
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GM Aur is an accreting low-mass star with a jet

- ~20 AU radius cavity in dust distribution
- NUV emission indicates accretion & there is IR emission from small dust grains close to star
- Jet detected in cm images

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?
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

BP Tau

Hartmann, Herczeg, & Calvet 2016
GM Aur was caught during an accretion burst

Robinson & Espaillat 2019
GM Aur was caught during an accretion burst

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What are possibilities for future variability work?
MIR emission traces dust in the innermost disk

\[ \lambda F_\lambda (\text{erg cm}^{-2} \text{s}^{-1}) \]

\( \lambda (\mu m) \)

GM Aur

typical full disk SED

photosphere

best-fit model

outer disk

optically thin dust

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.
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)
FUV H$_2$ feature was highest during the accretion burst

The H$_2$ feature luminosity between Epoch 6 and Epoch 7 increased by a factor of ~2, roughly consistent with the accretion rate change factor of ~3.

Espaillat et al. 2019a
What do we know about their variability?

What do we learn from simultaneous multiwavelength data?

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What are possibilities for future variability work?
GM Aur displays a jet in 3cm images

Macias et al. 2016
The radio emission was highest during the accretion burst.
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.

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

the expected $\Delta S_v$ (Epoch 6 $\rightarrow$ Epoch 7) $\sim 13$ $\mu$Jy

& the observed $\Delta S_v$ is $\sim 15$ $\mu$Jy.

Anglada, Rodriguez, Carrasco-Gonzalez 2018
Viewing the star-disk-jet connection

causing an increase in the mass accretion rate....

which leads to an increase in the mass loss rate.

Hartmann, Herczeg, & Calvet 2016
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What are possibilities for future variability work?
Follow up campaign of the star-disk-jet connection

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ULKOSSES: 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,  
irradiation of young planetary atmospheres
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.