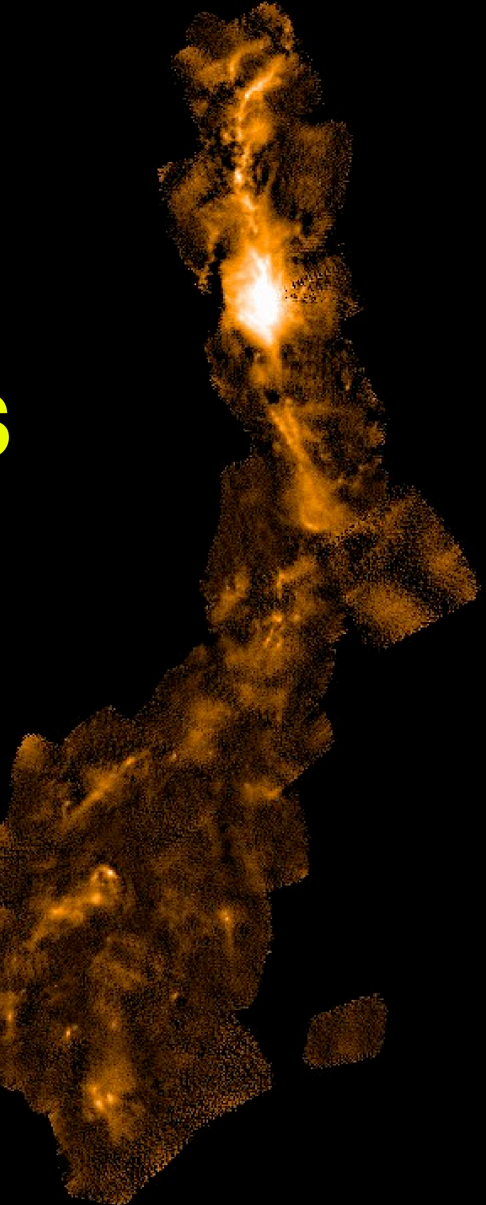
# Jets and protostars

## ... mainly in Orion



Plenty of CoIs:

Hans Zinnecker, Mark J. McCaughrean

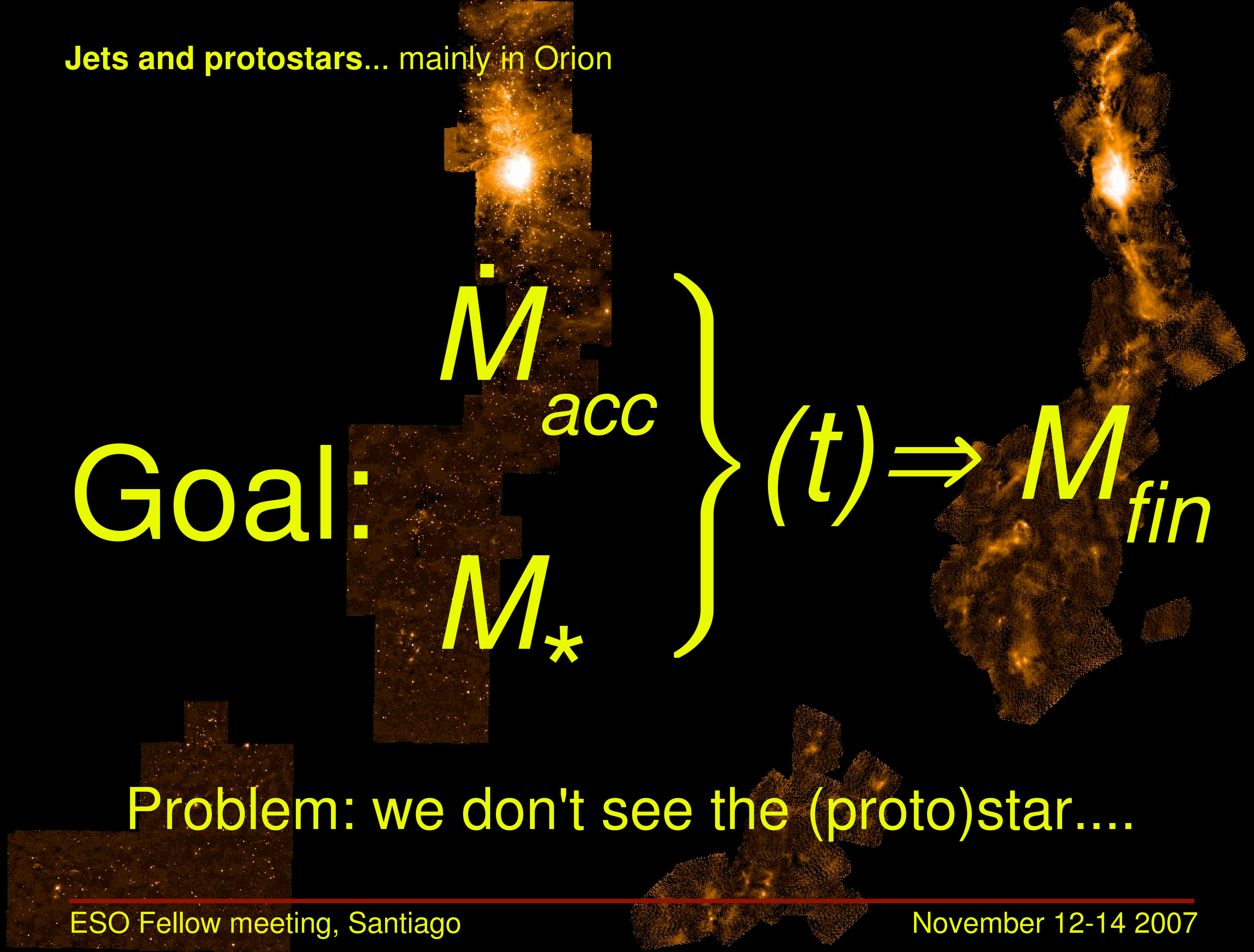
Michael D. Smith

Karl Menten, Peter Schilke

Chris Davis, Tigran Khanzadyan

Jonathan Williams, Sebastian Wolf, Jonathan Tan

Jochen Eislöffel, Diego Mardones, Tom Megeath,...

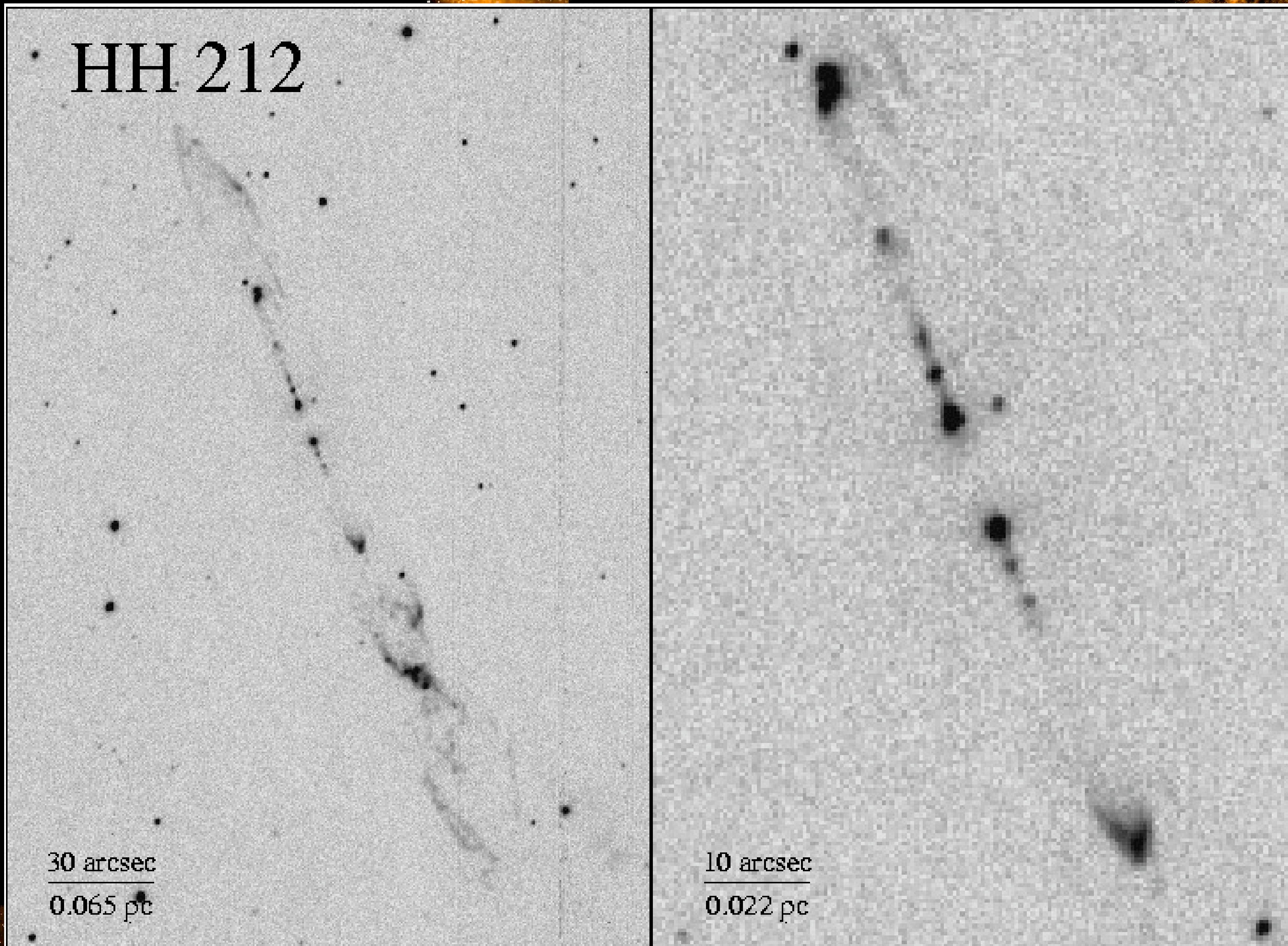


**Jets and protostars...** mainly in Orion

$$\text{Goal: } \left.\begin{matrix} \dot{M}_{acc} \\ M_* \end{matrix}\right\} (t) \Rightarrow M_{fin}$$

Problem: we don't see the (proto)star....

## **Jets and protostars...** mainly in Orion



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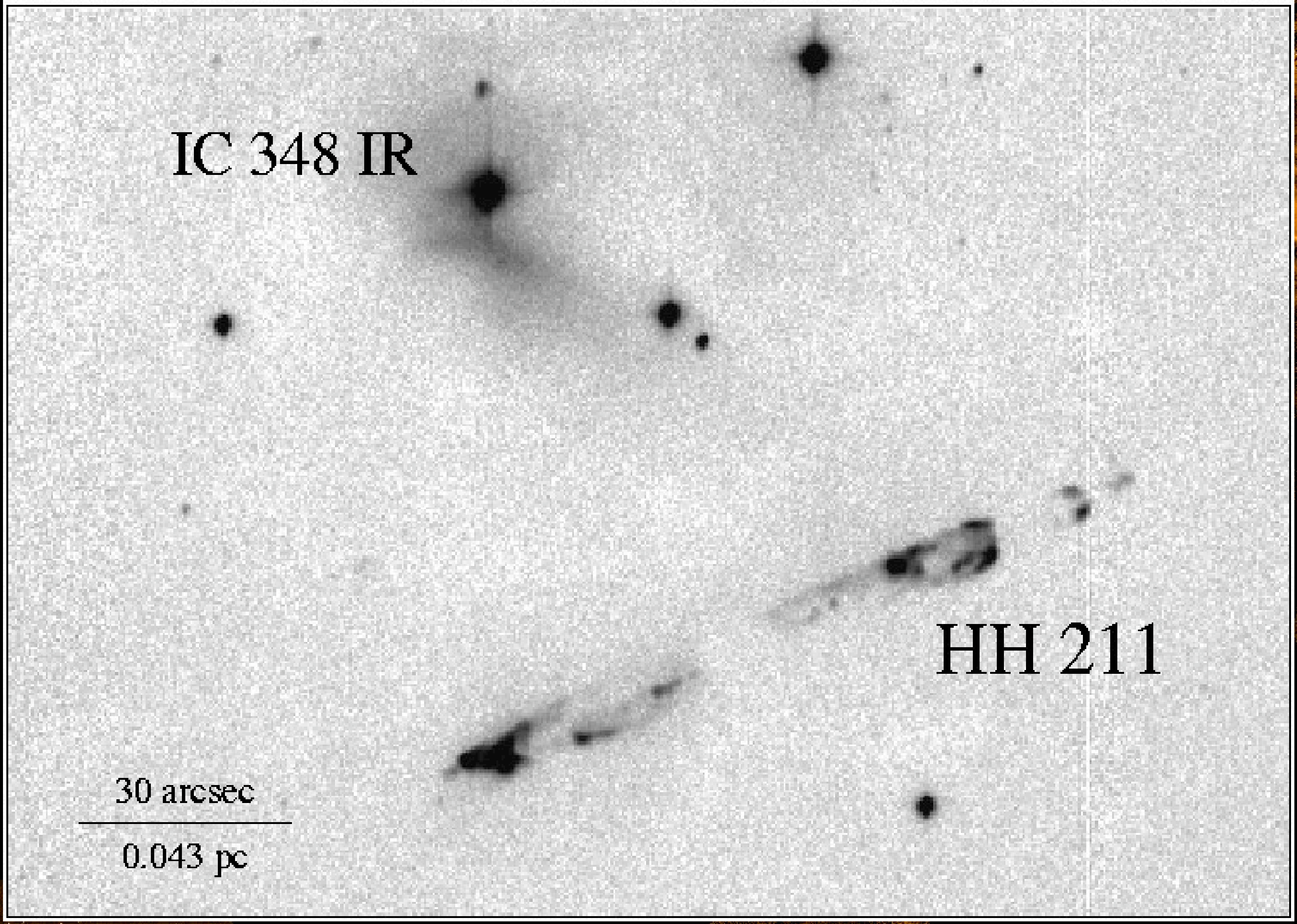

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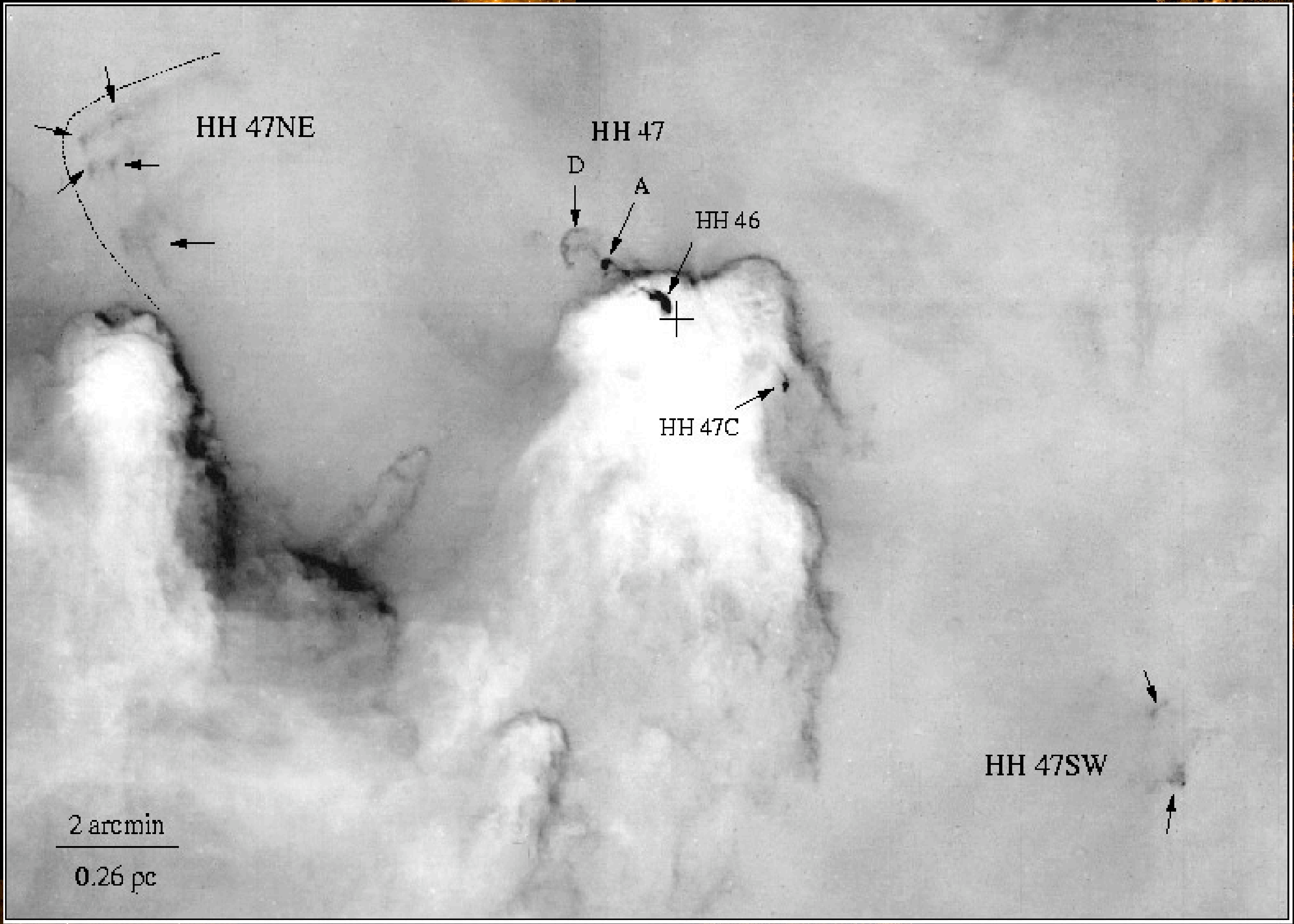
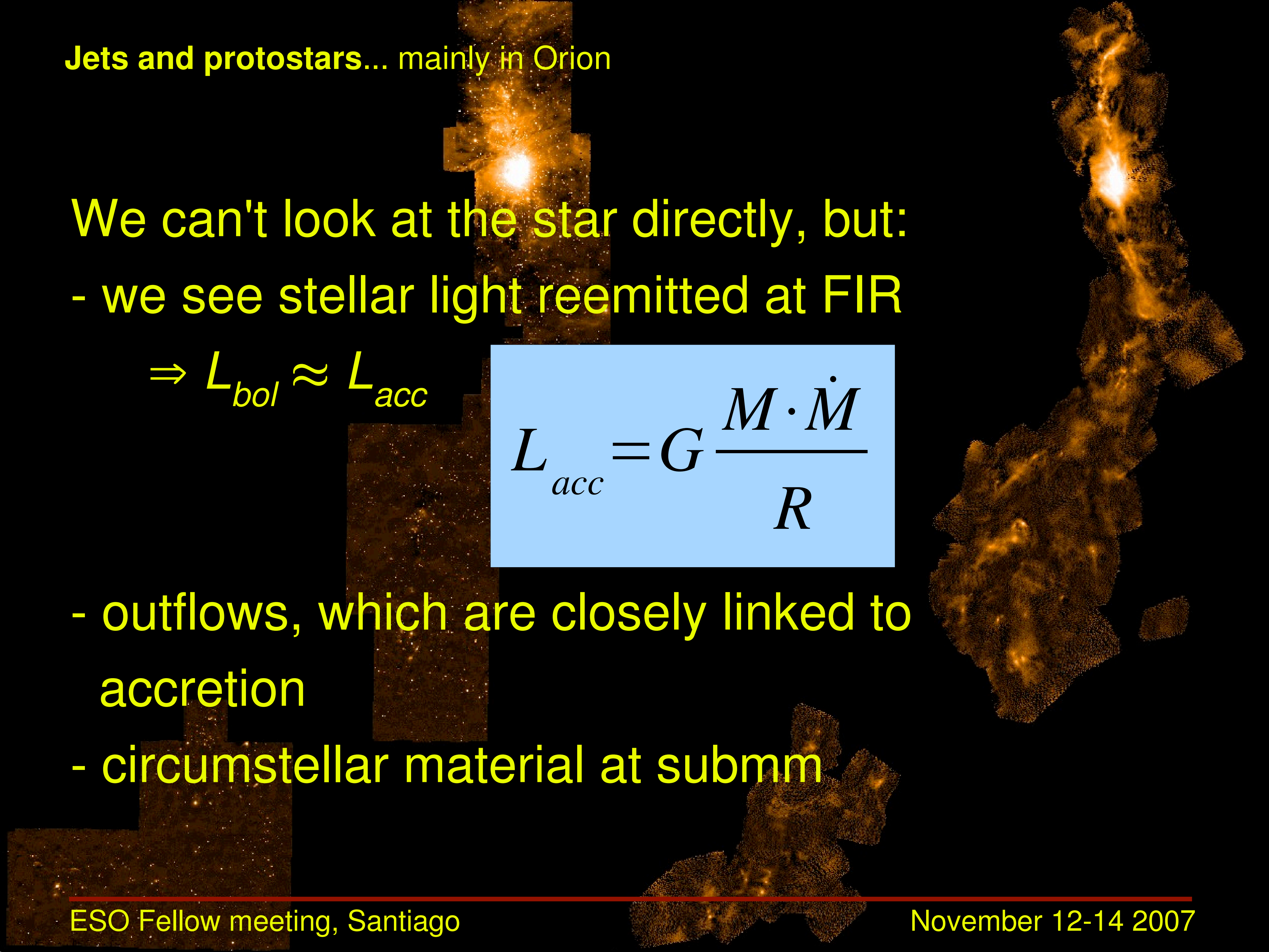




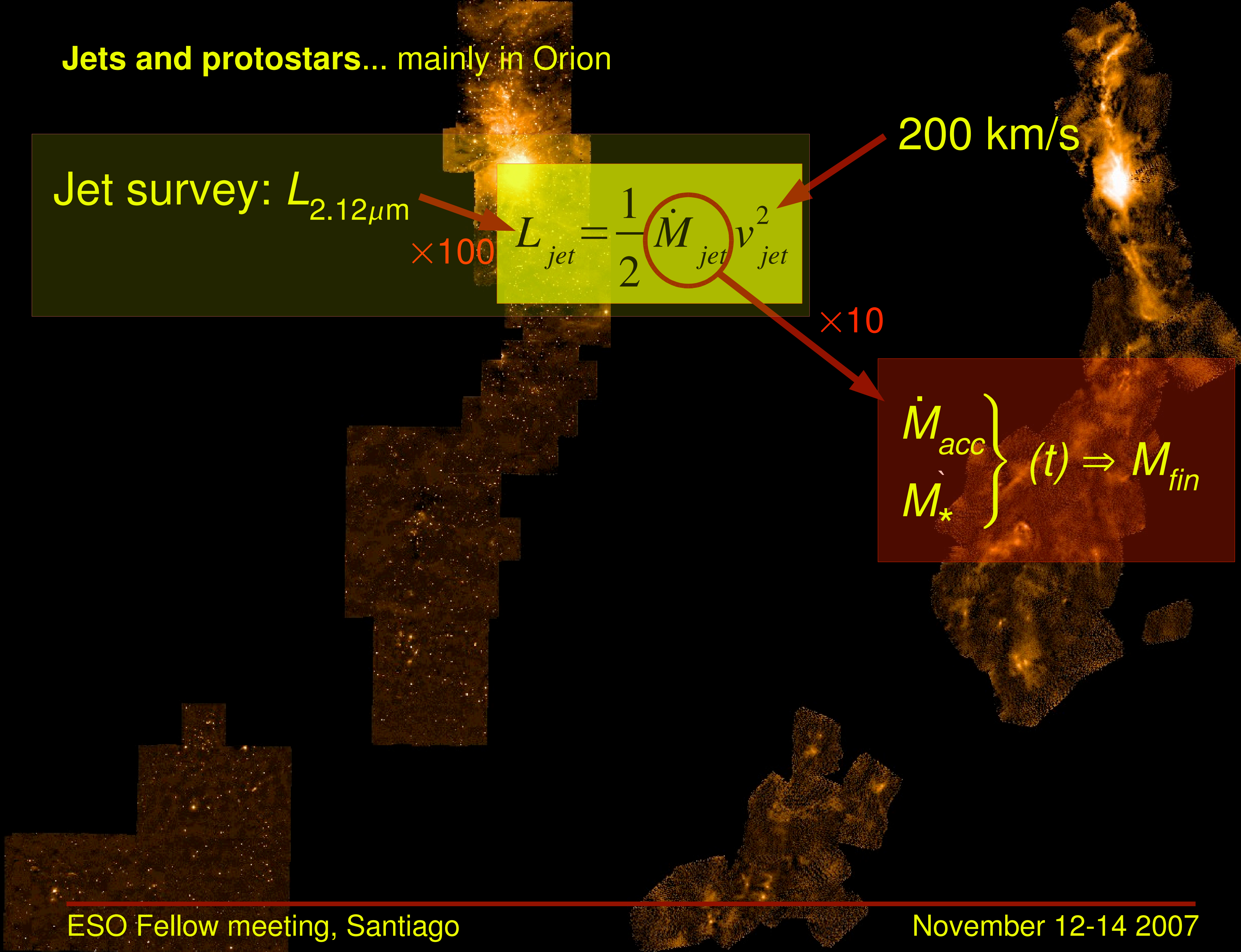
We can't look at the star directly, but:

- we see stellar light reemitted at FIR

  $\Rightarrow L_{bol} \approx L_{acc}$

$$L_{acc} = G \frac{M \cdot \dot{M}}{R}$$

- outflows, which are closely linked to accretion
- circumstellar material at submm


**Jets and protostars...** mainly in Orion
Jet survey: $L_{2.12\mu m}$
$\times 100$
$L_{jet} = \frac{1}{2}\dot{M}_{jet} v^2_{jet}$
200 km/s
$\times 10$
$\left.\begin{array}{l}\dot{M}_{acc}\\ \grave{M}_*\end{array}\right\}(t) \Rightarrow M_{fin}$

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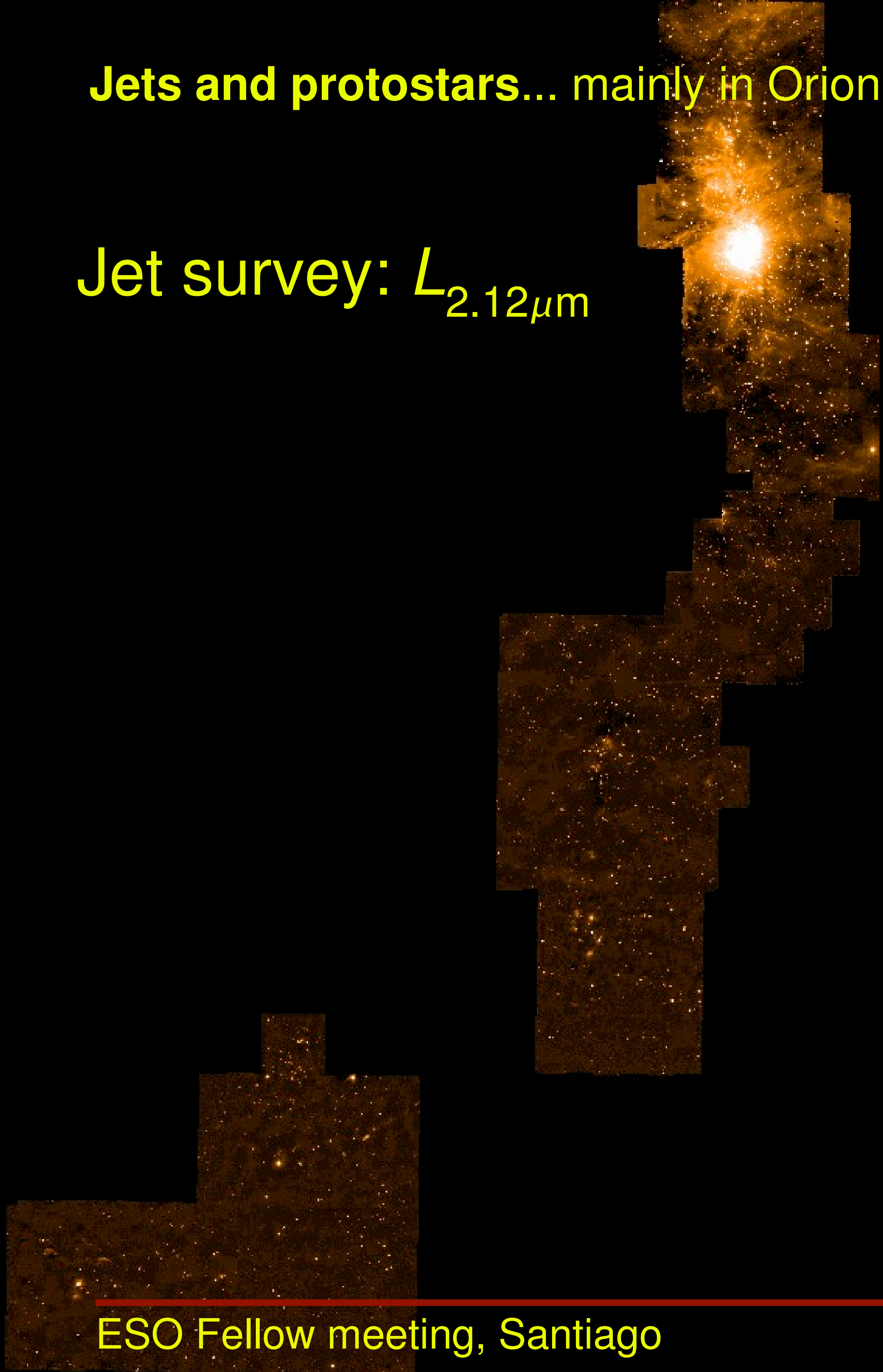


Jet survey: $L_{2.12\mu m}$

1 square degree surveyed
at 2.12$\mu$m (NB) and K'

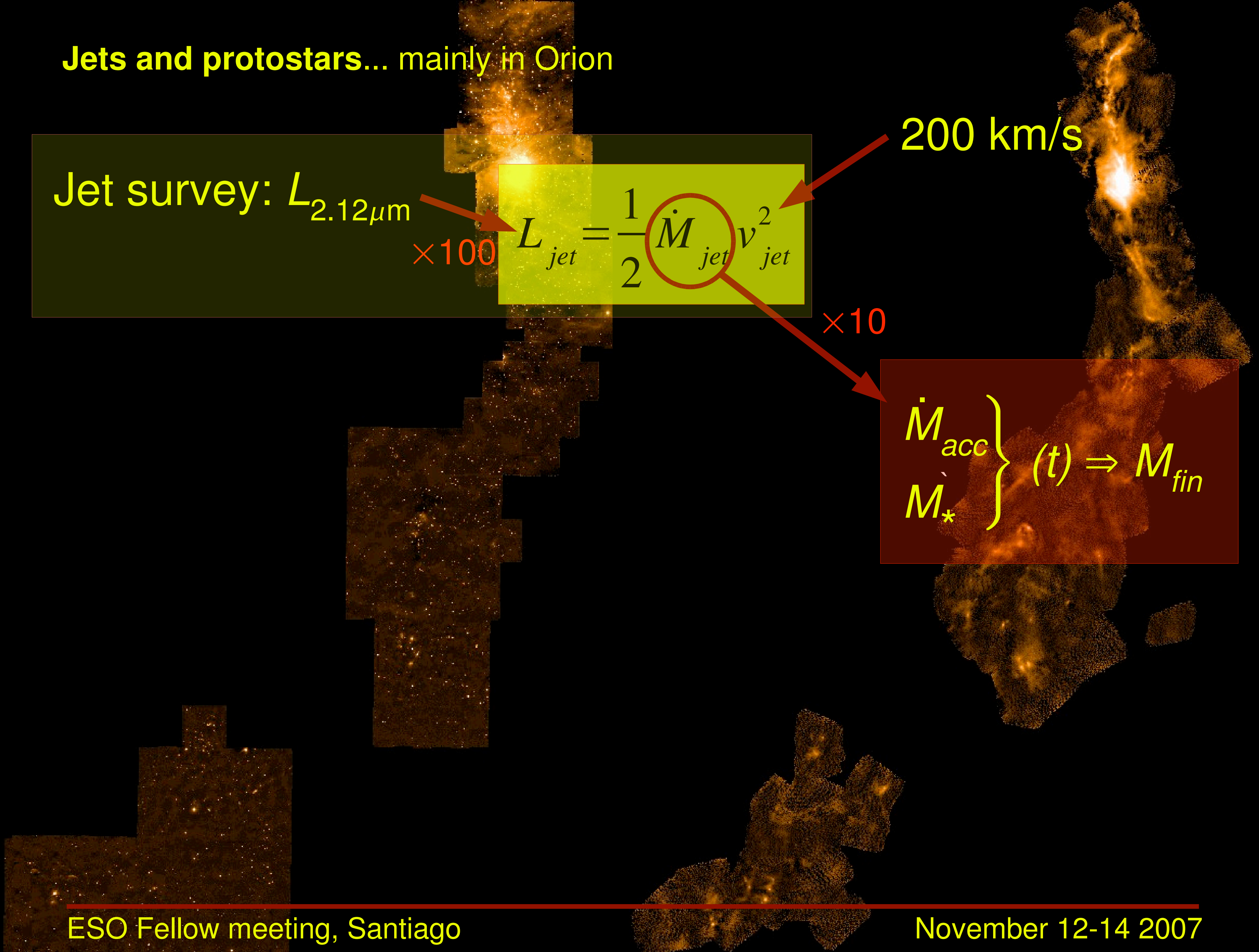
> 70 outflows found

sample:
free from selection effects
all outflows at same distance

*M*dot:
~ $5 \times 10^{-5}$ – $5 \times 10^{-7}$ $M_{\odot}$/yr

(canonical: $10^{-6}$, T Tauris: $<10^{-7}$)

## **Jets and protostars...** mainly in Orion



Jet survey: $L_{2.12\mu m}$ $\times 100$ $\rightarrow$

$$L_{jet} = \frac{1}{2} \dot{M}_{jet} v_{jet}^2$$

200 km/s

$\times 10$

$$\left.\begin{matrix} \dot{M}_{acc} \\ \dot{M}_* \end{matrix}\right\} (t) \Rightarrow M_{fin}$$

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Driving sources' SED: $L_{bol}$

Evolutionary stage: Class 0/I/II

$$L_{acc} = G \frac{\dot{M} M}{R}$$

**Jets and protostars...** mainly in Orion

# Photometry:

optical I-Band: ESO 2.2m WFI

near-IR JHK: Calar Alto 3.5m OmegaPrime

mid-IR: IRAS, ESO 3.6m TIMMI2

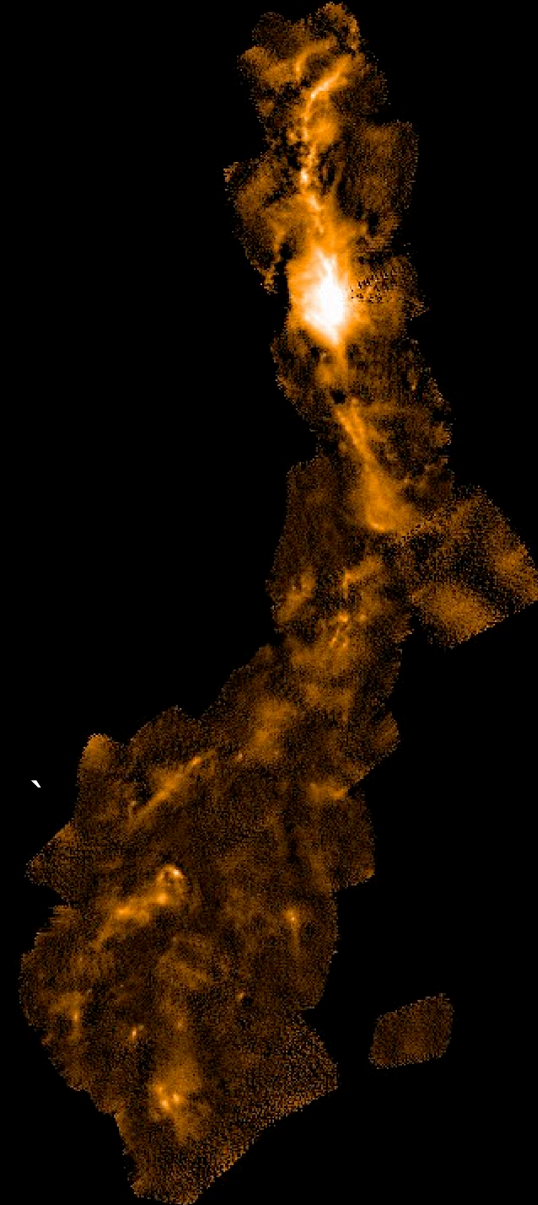
(Spitzer...)

far-IR: IRAS

(Herschel)

(1.3mm: IRAM 30m)

+ literature



## Driving sources' SED: $L_{bol}$

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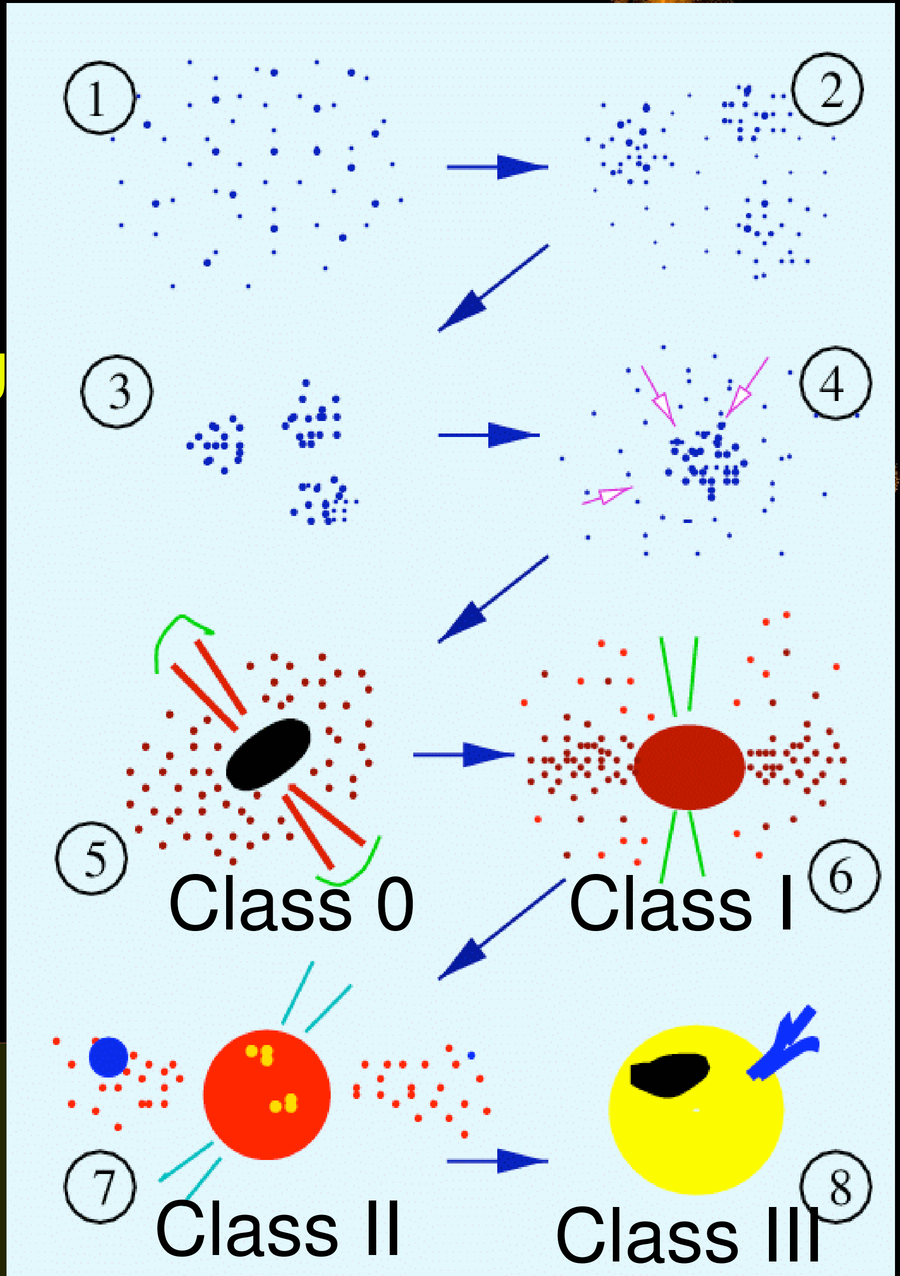
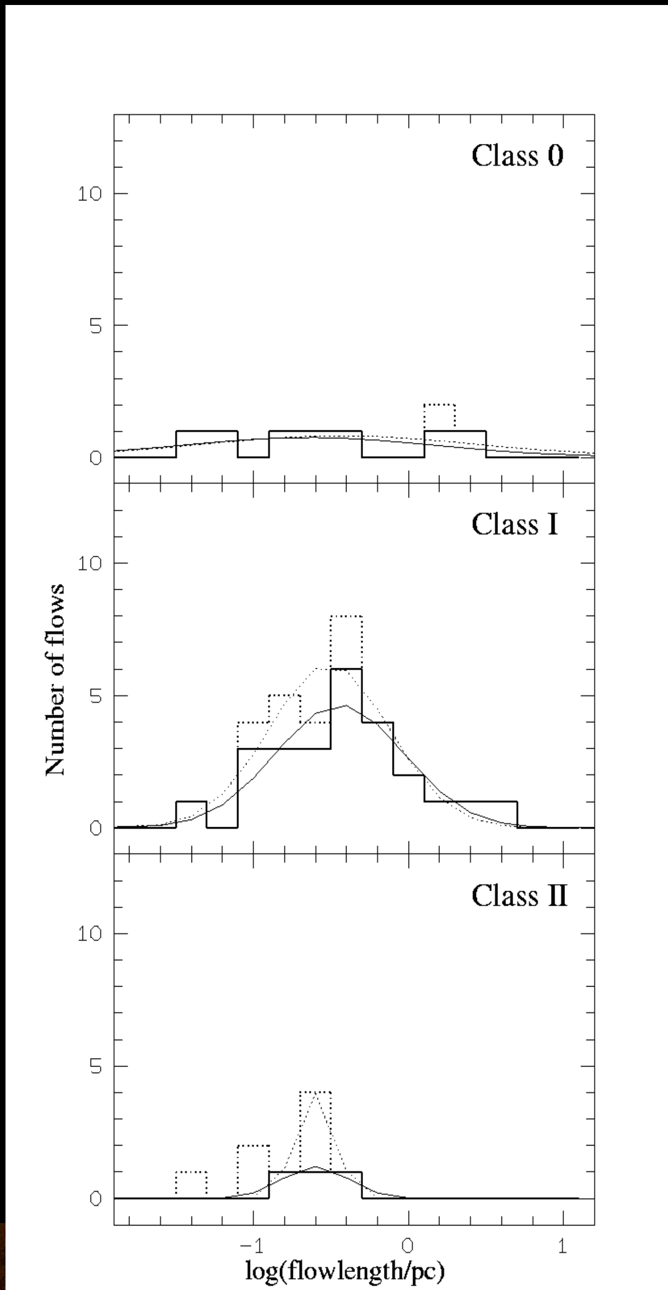
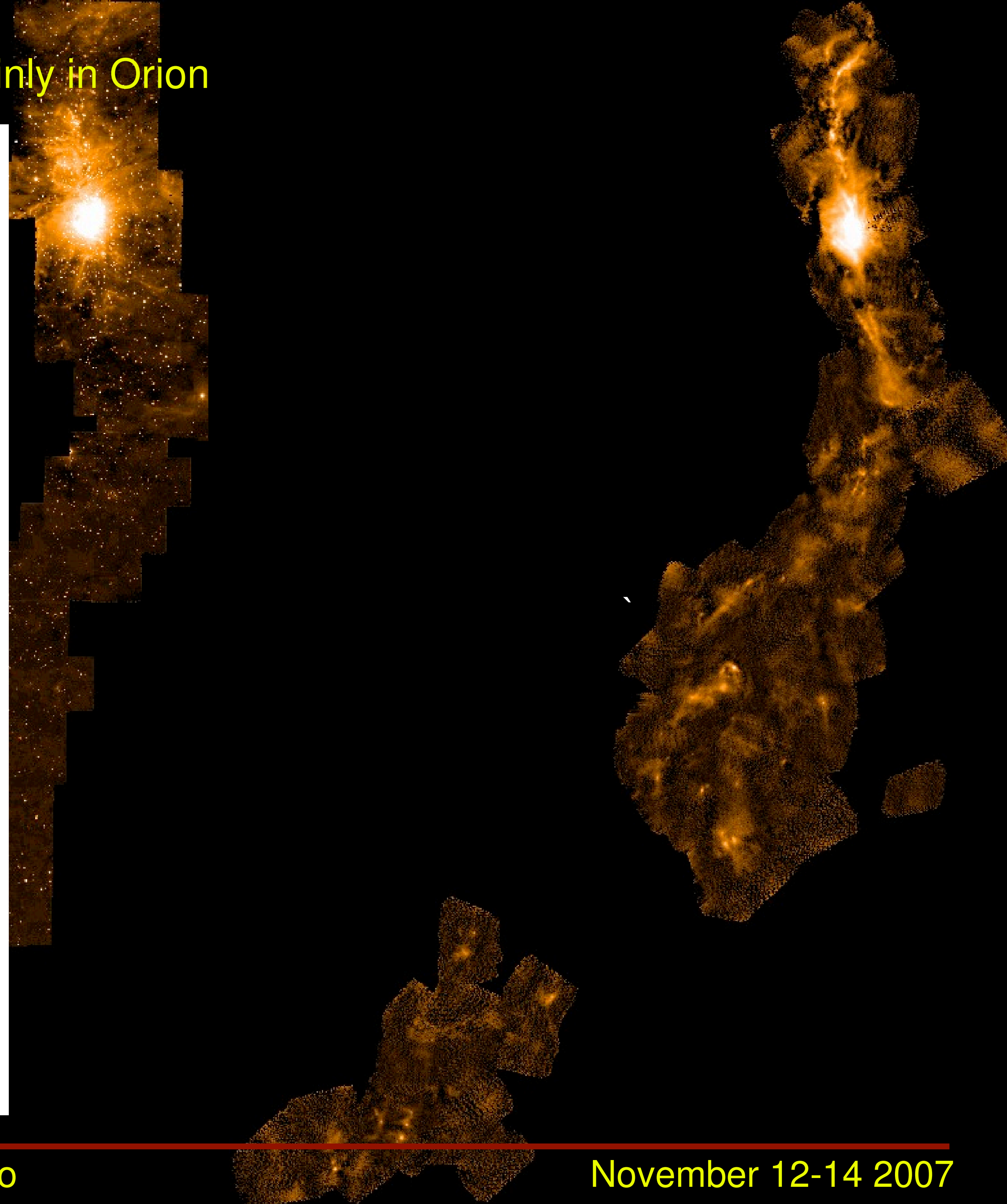


Figure 1: Eight stages in the formation of a low-mass star.

# **Jets and protostars...** mainly in Orion



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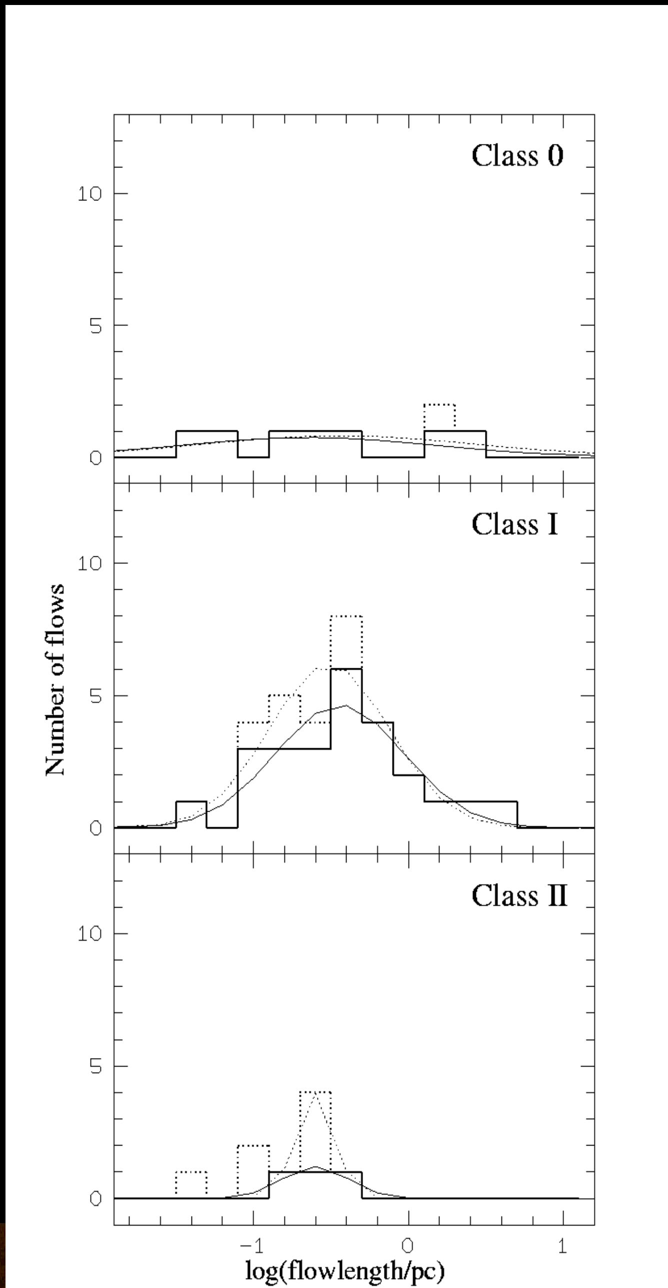
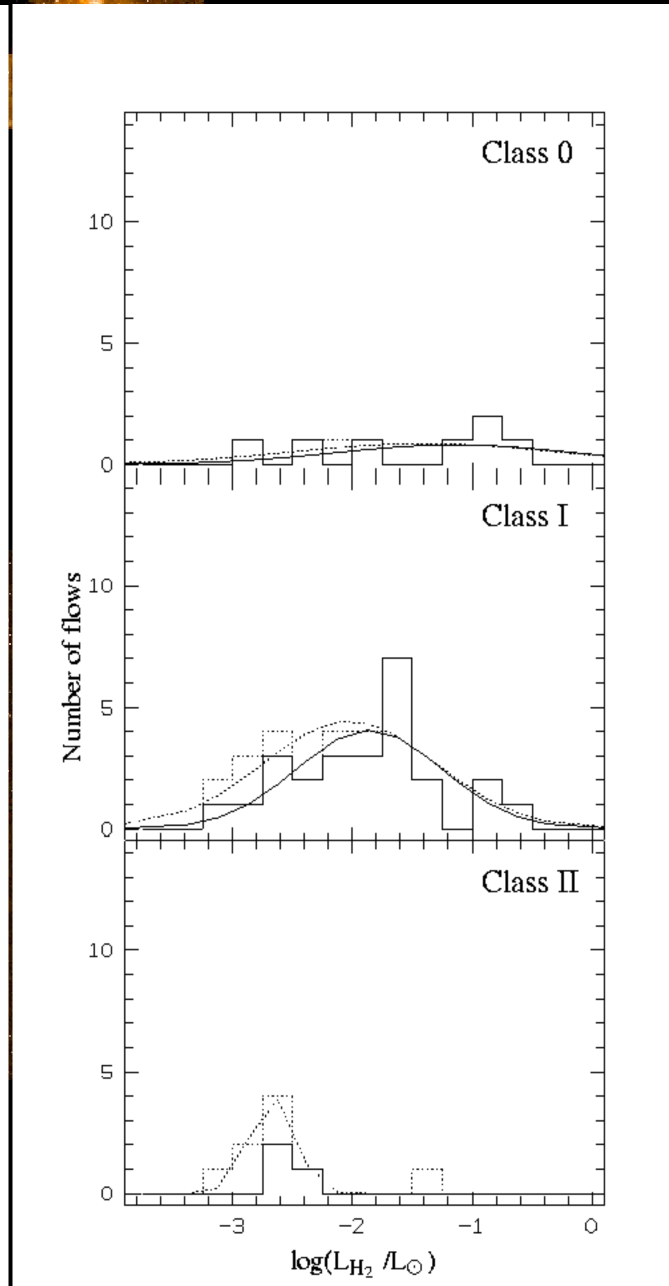
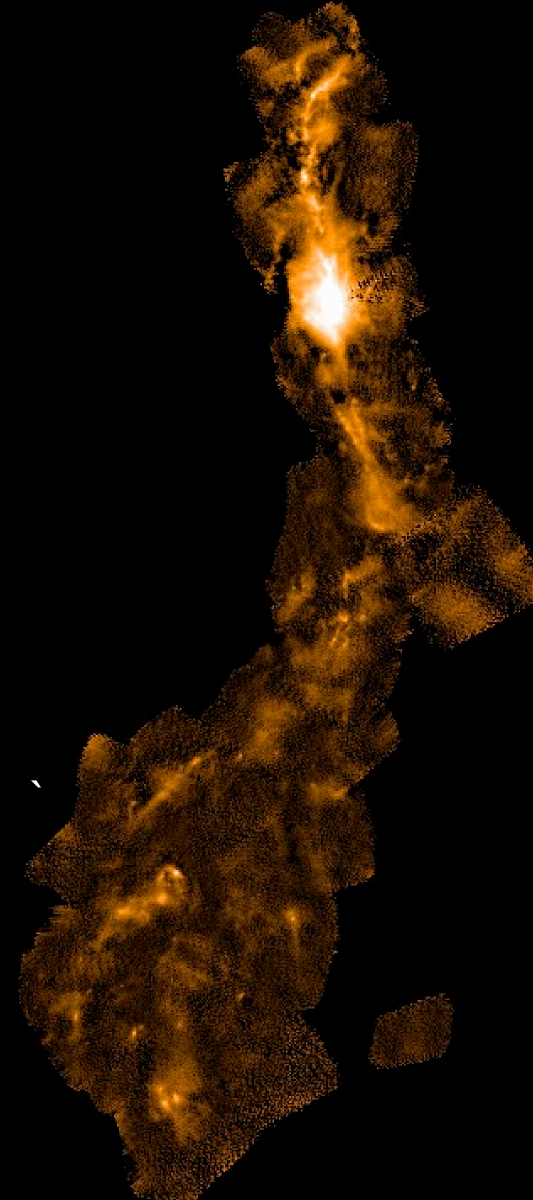
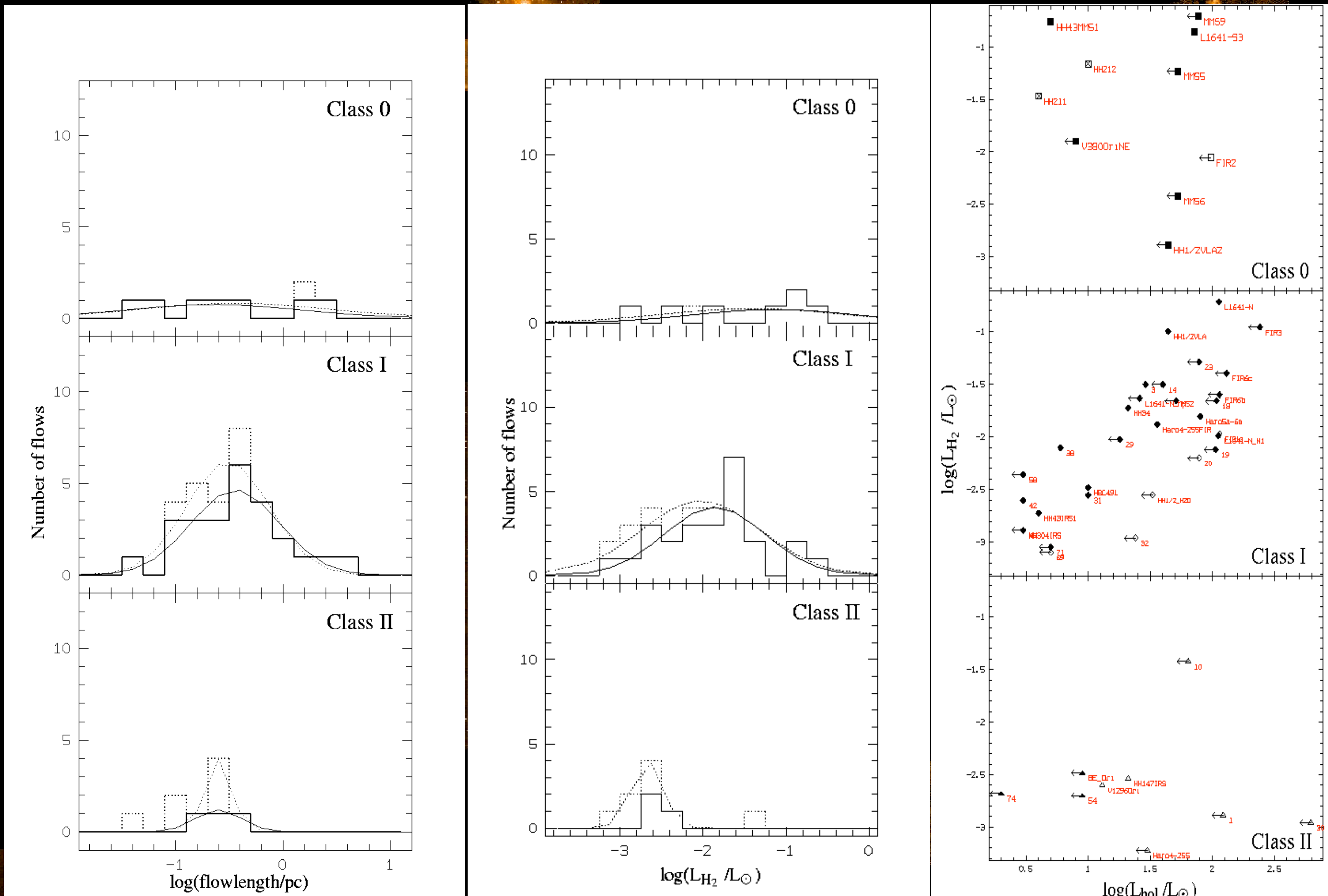


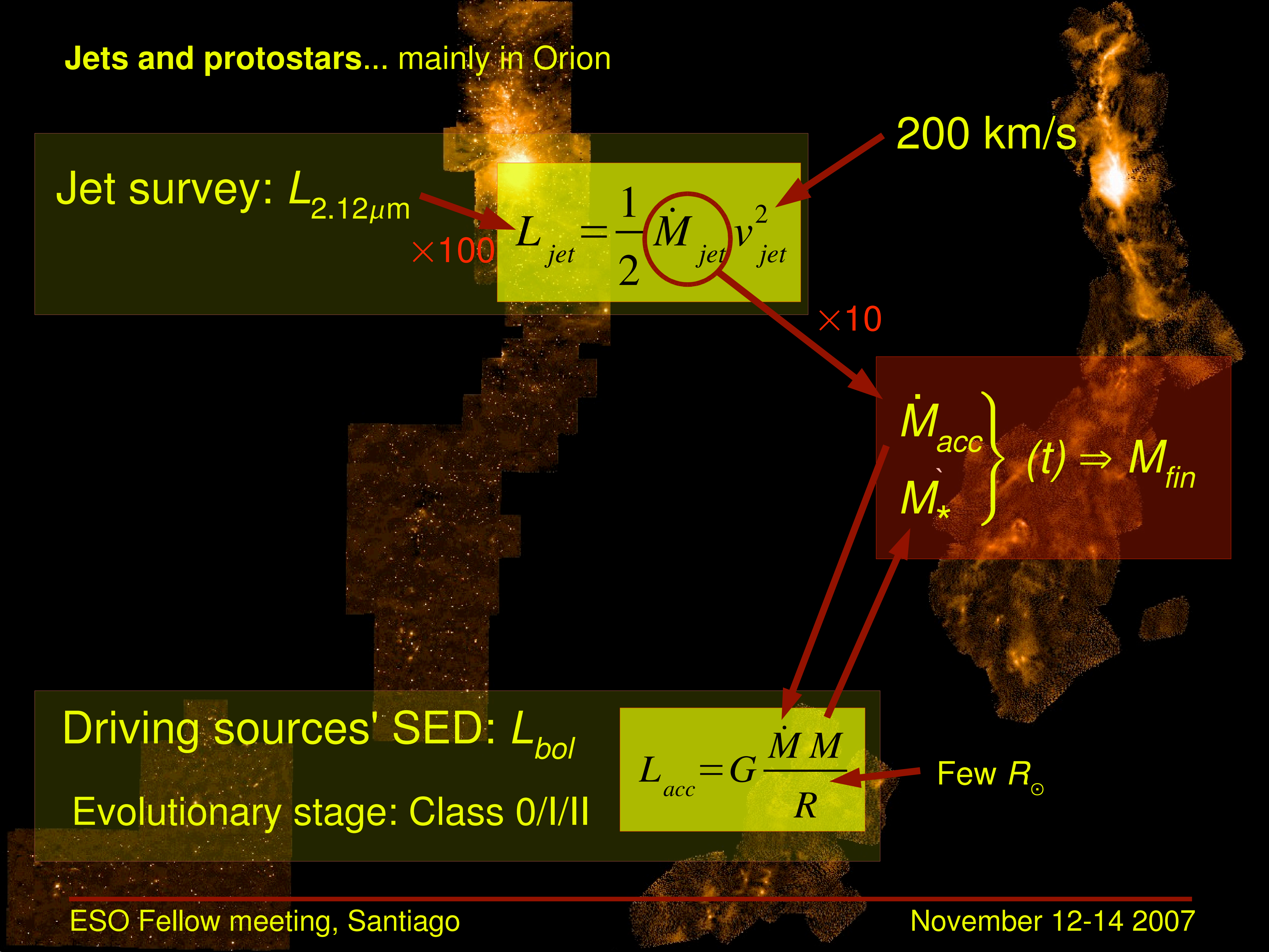



# **Jets and protostars...** mainly in Orion



**Jets and protostars...** mainly in Orion

| Protostar evolution | Jet evolution |
| --- | --- |
| early Class 0 | short, bright (possibly extincted) |
| late Class 0/very early Class I | giant flow (few parsec), bright |
| early Class I | giant flow (few parsec), getting fainter |
| most of Class I | subparsec scale flow, moderately bright to faint |
| late Class I/early Class II | short, faint (residual H2 jet) |
| Class II | optical T Tauri star jets, microjets |



**Jets and protostars...** mainly in Orion

Jet survey: $L_{2.12\mu m}$

$\times 100$

$$L_{jet} = \frac{1}{2}\dot{M}_{jet} v^2_{jet}$$

200 km/s

$\times 10$

$$\left.\begin{array}{l}\dot{M}_{acc} \\ \dot{M}_{*}\end{array}\right\} (t) \Rightarrow M_{fin}$$

Driving sources' SED: $L_{bol}$

Evolutionary stage: Class 0/I/II

$$L_{acc} = G\frac{\dot{M} M}{R}$$

Few $R_{\odot}$

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$v_{jet}(t)$

Smith, M.D. 2000, Irish Astr. J. 27, 25:

Unification Scheme:

protostar – disk – envelope

jet – CO outflow

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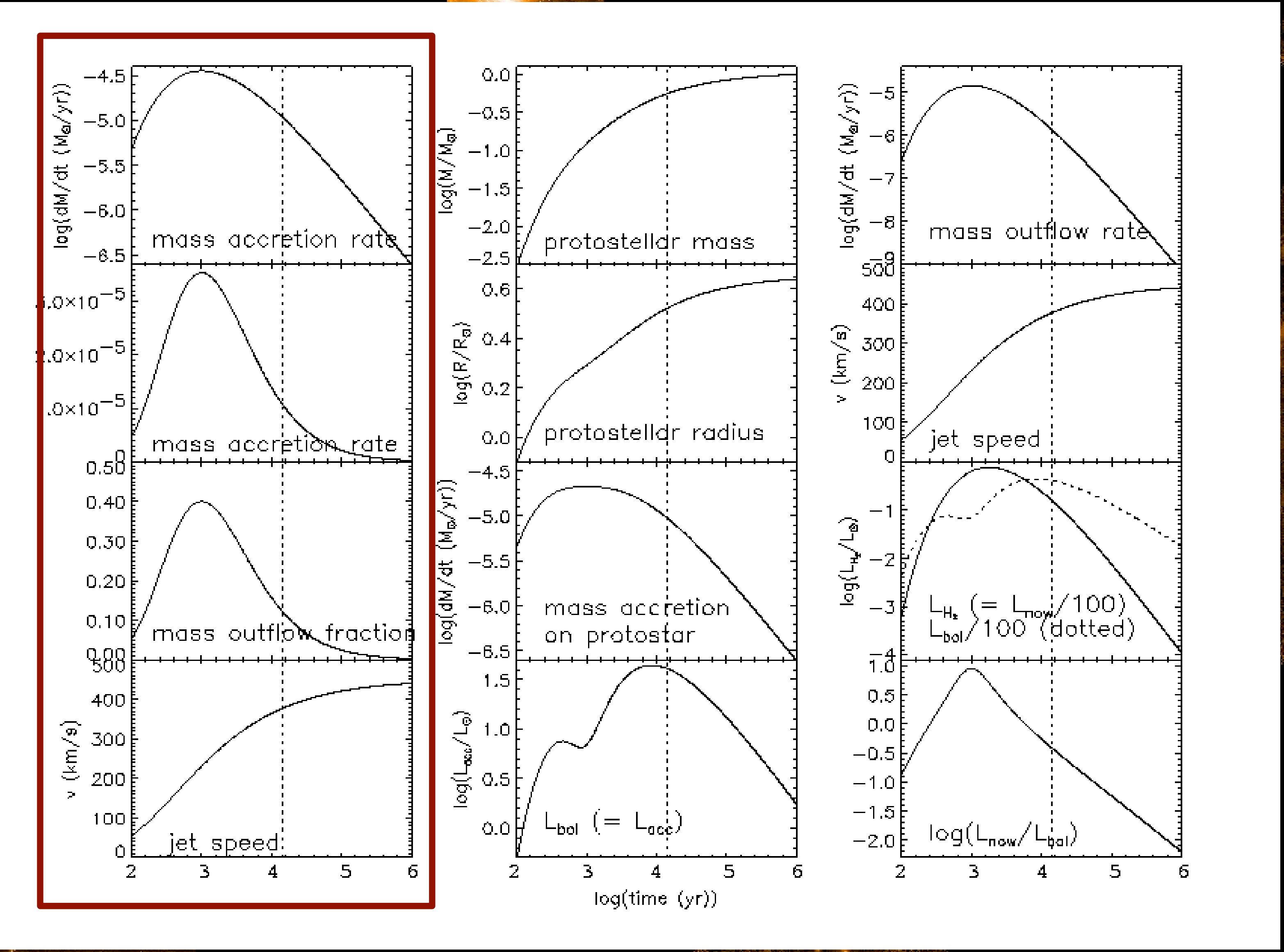
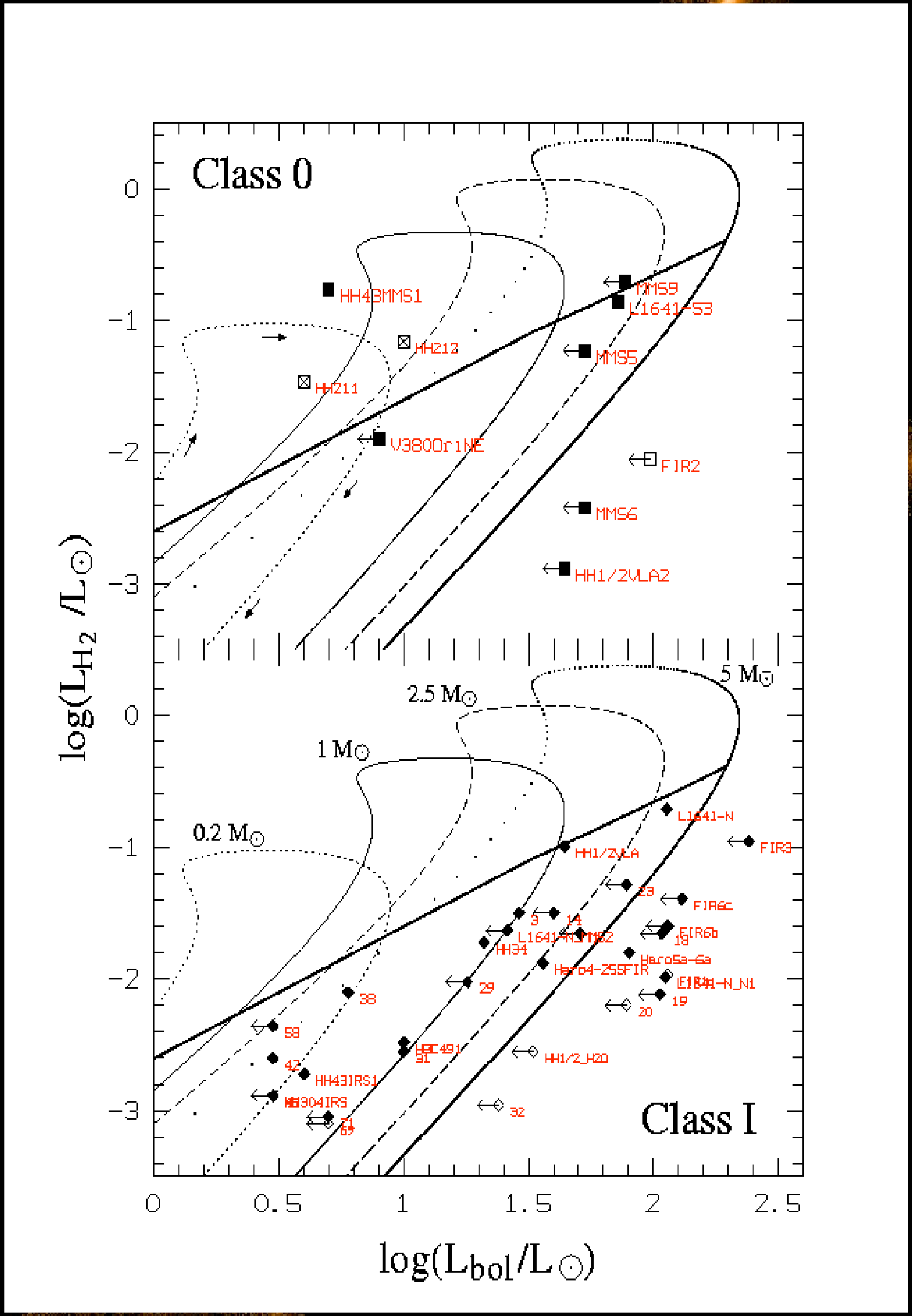


**Jets and protostars...** mainly in Orion

# The unification scheme:

... e.g., evolutionary tracks

for $L_{bol}$ and $L_{H2}$



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1.3mm continuum:

$M_{circ}$

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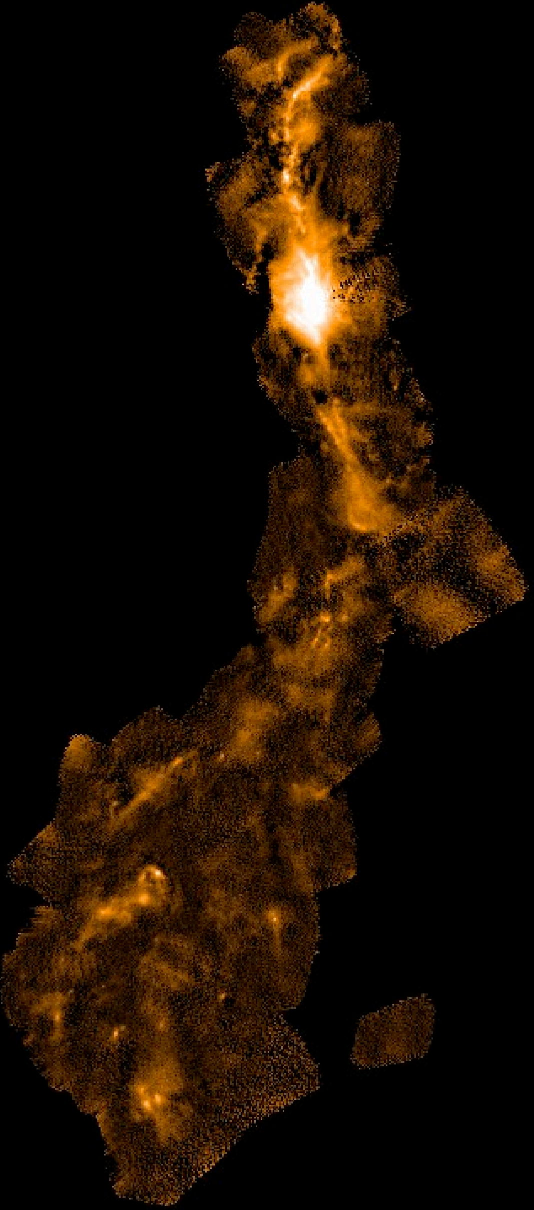
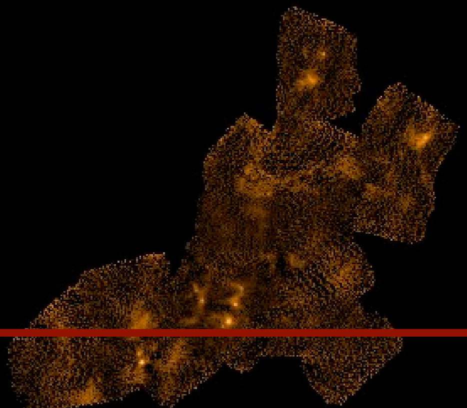
## **Jets and protostars...** mainly in Orion

1 square degree surveyed
at 1.3mm

> 500 sources found
(diffuse clumps, cores,
protostars, circumstellar disks)

1.3mm continuum:
*$M_{circ}$*





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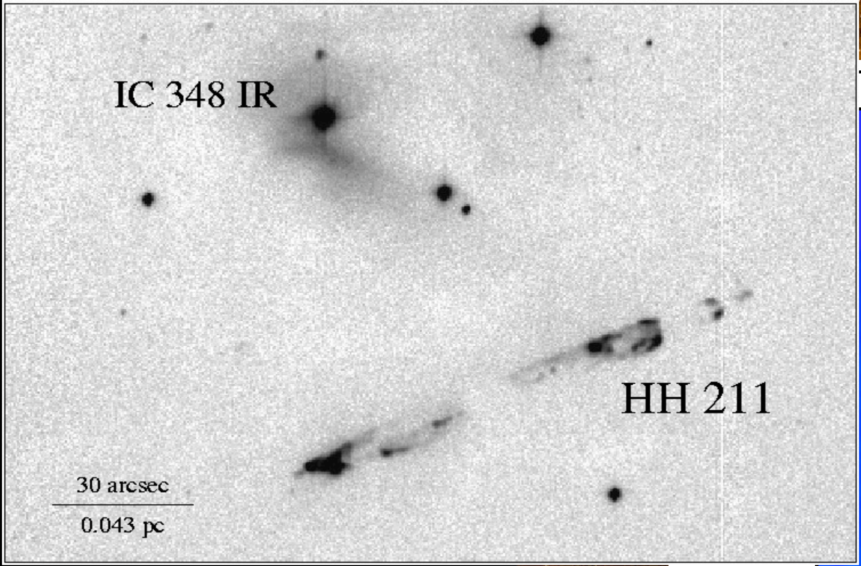
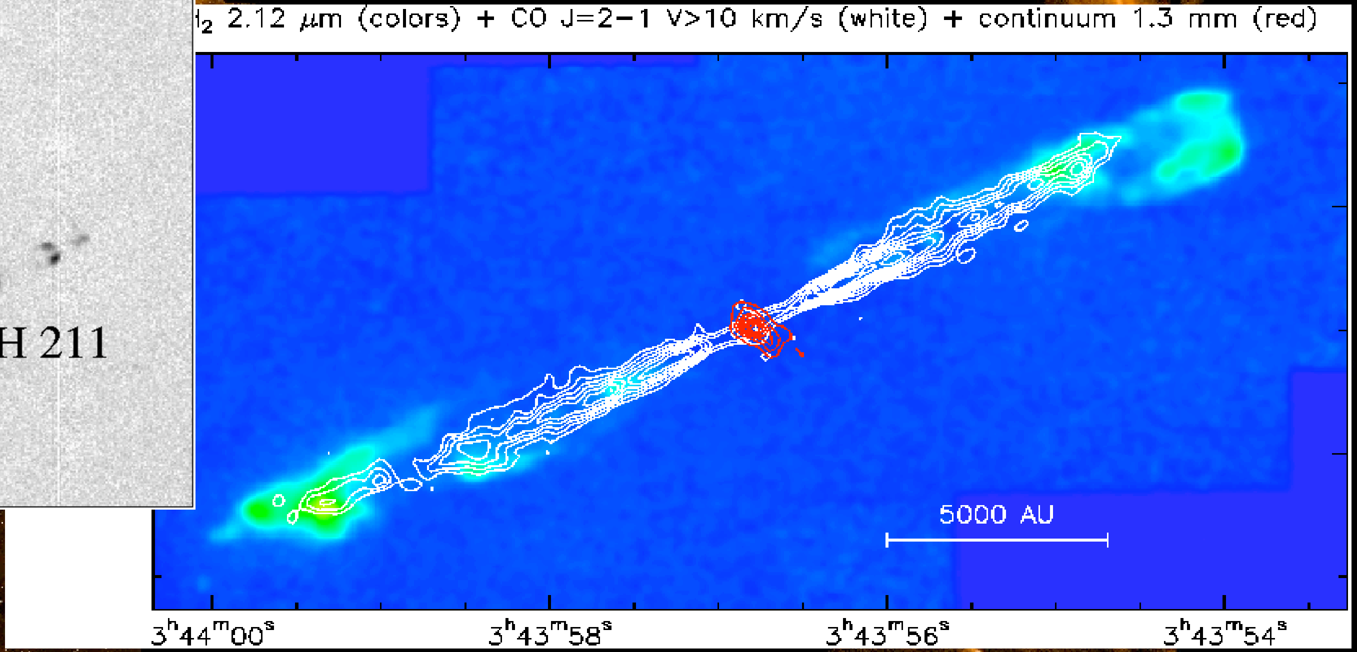
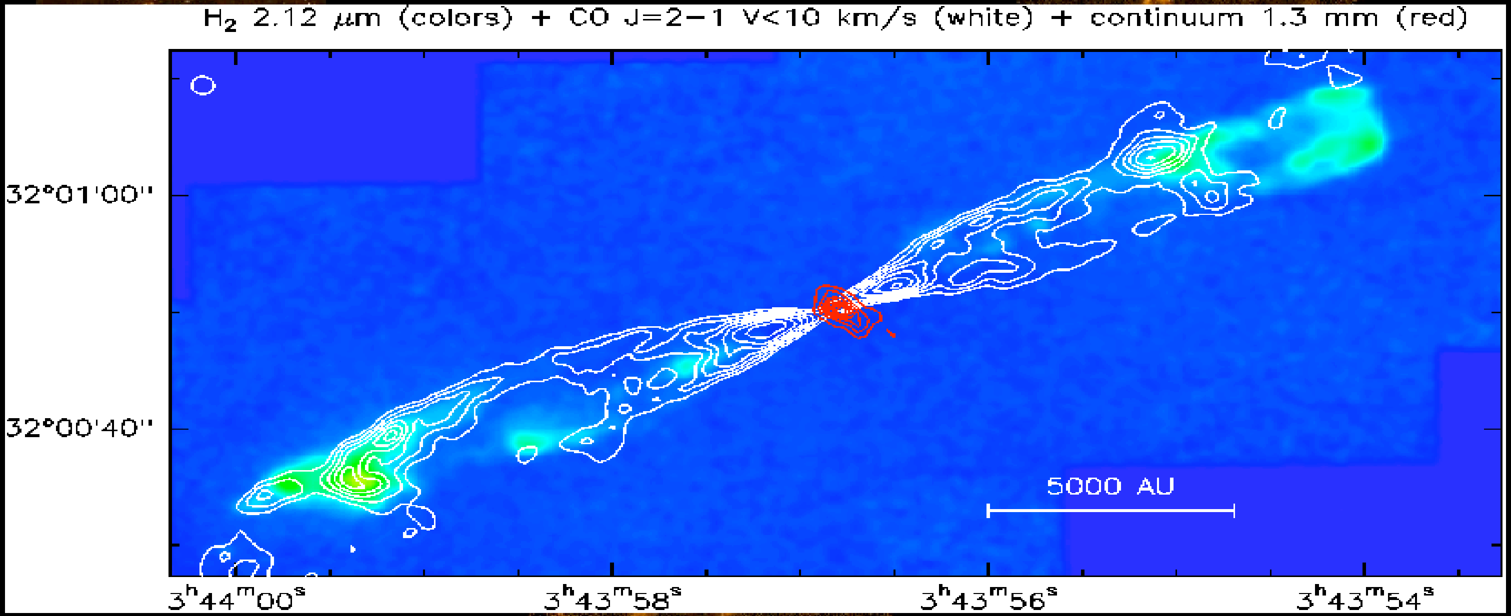



CO outflows



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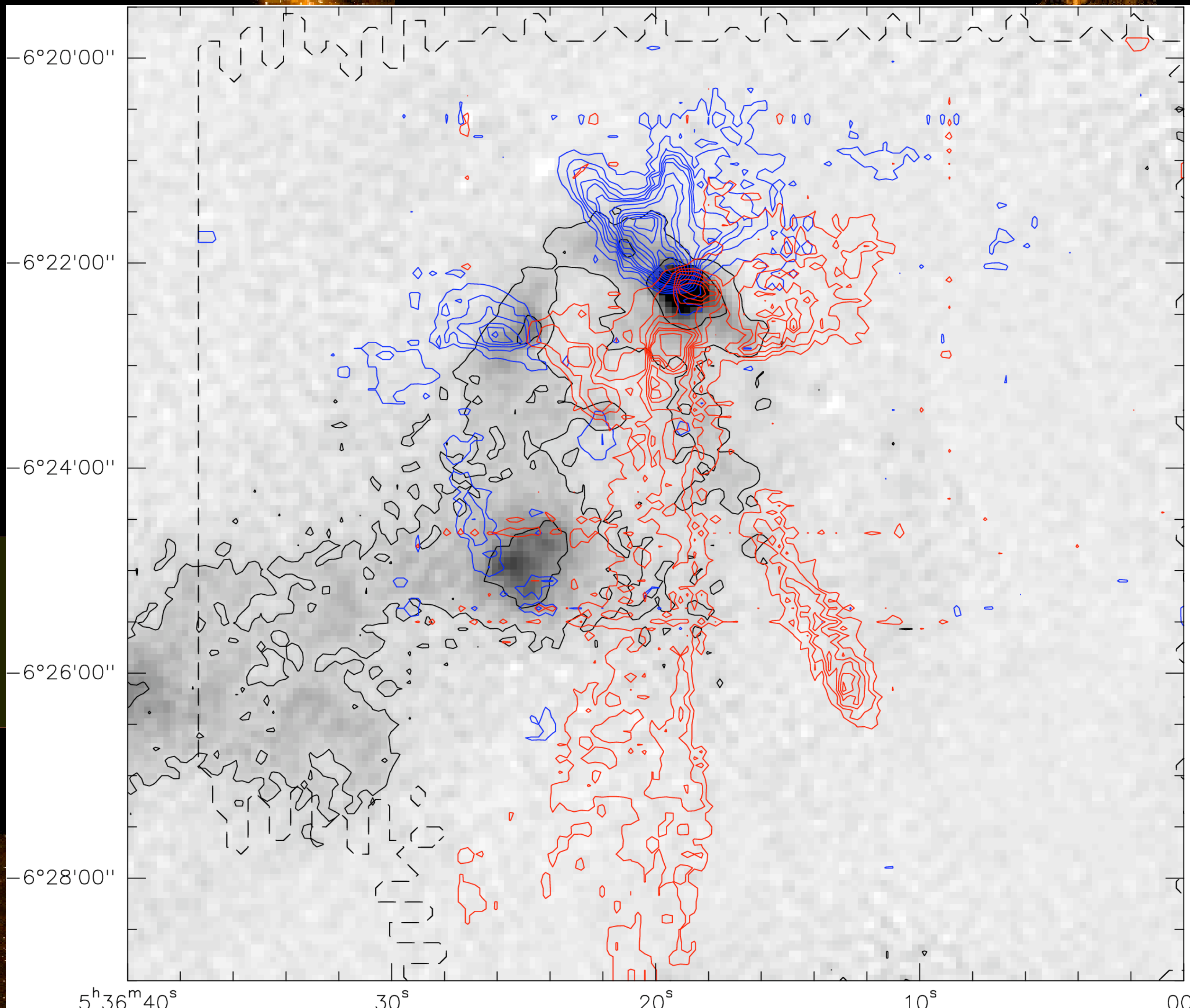

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$v_{jet}(t)$

Proper motions

radial velocities

1.3mm continuum: $M_{circ}$

CO outflows

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1.3mm continuum:

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Unification Scheme:

protostar – disk – envelope

jet – CO outflow

CO outflows

$\dot{M}_{acc}$, $\dot{M}_*$ $(t) \Rightarrow M_{fin}$

ALMA:

disk kinematics

$M_{star}$

Driving sources' SED: $L_{bol}$

Evolutionary stage: Class 0/I/II

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$R(t)$

~~Few $R_\odot$~~

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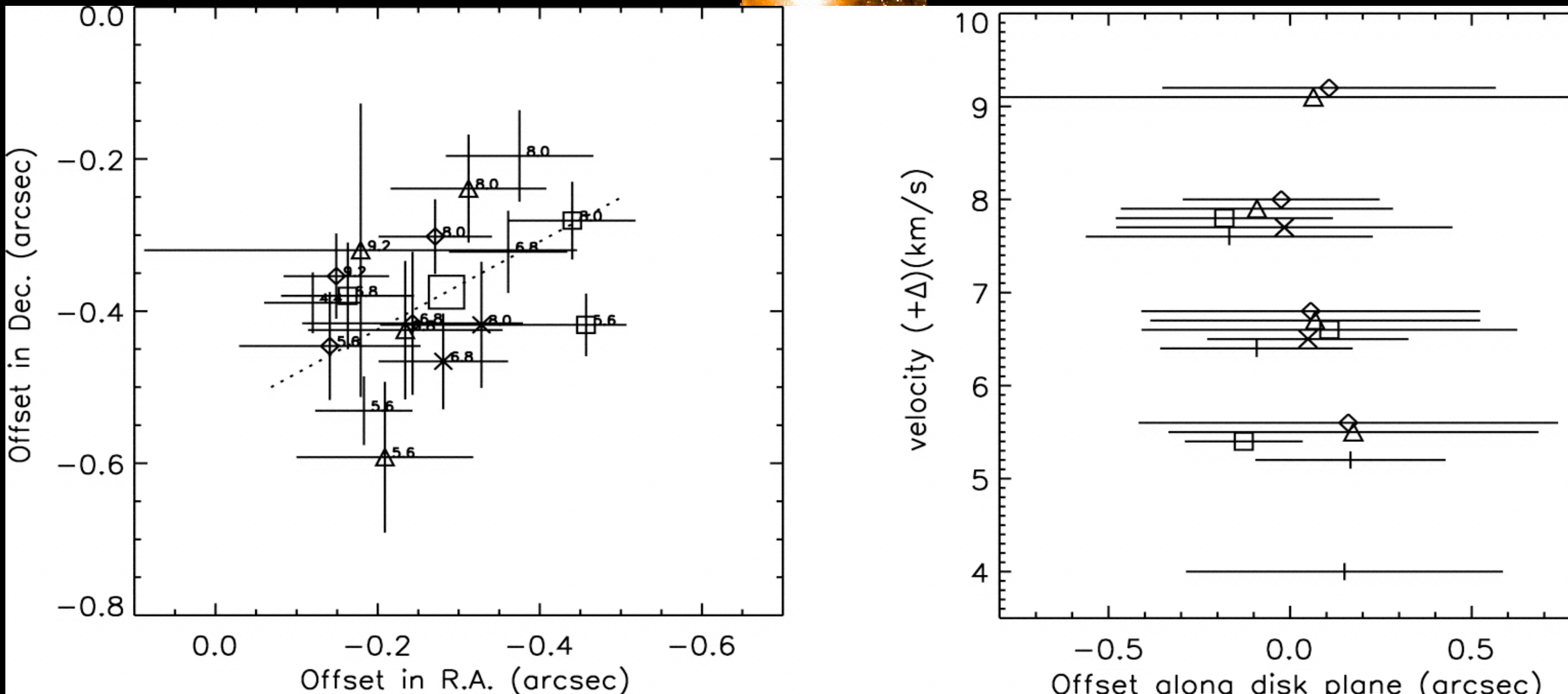
# L1641-N MM1 ... a rotationally supported disk?




SMA: $CH_3CN$, OCS

ALMA:
disk kinematics
$M_{star}$

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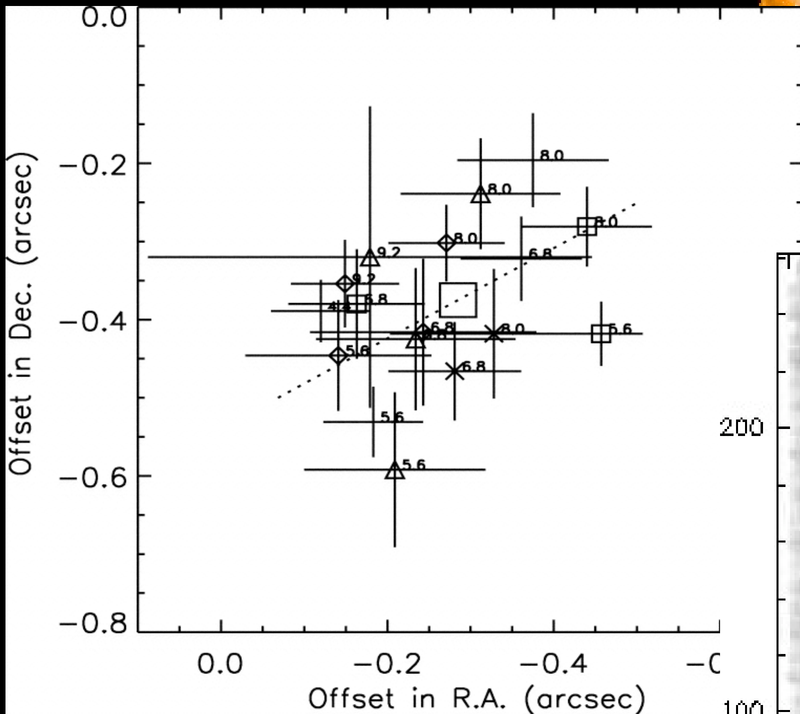


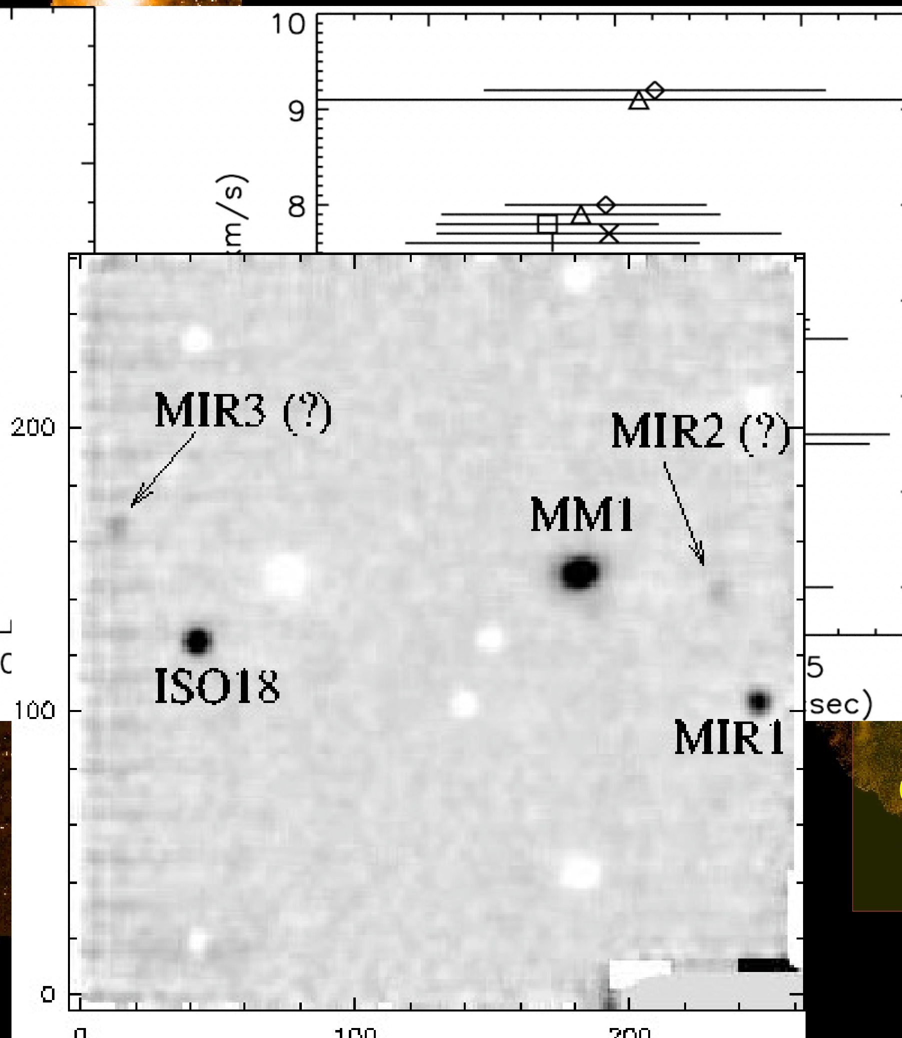


SMA: $CH_3CN$, OCS

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VLT/VISIR 18µm

**Jets and protostars...** mainly in Orion

...and rho-Ophiuchus, and Circinius,...

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$v_{jet}(t)$

Proper motions

radial velocities

1.3mm continuum:

$M_{circ}$

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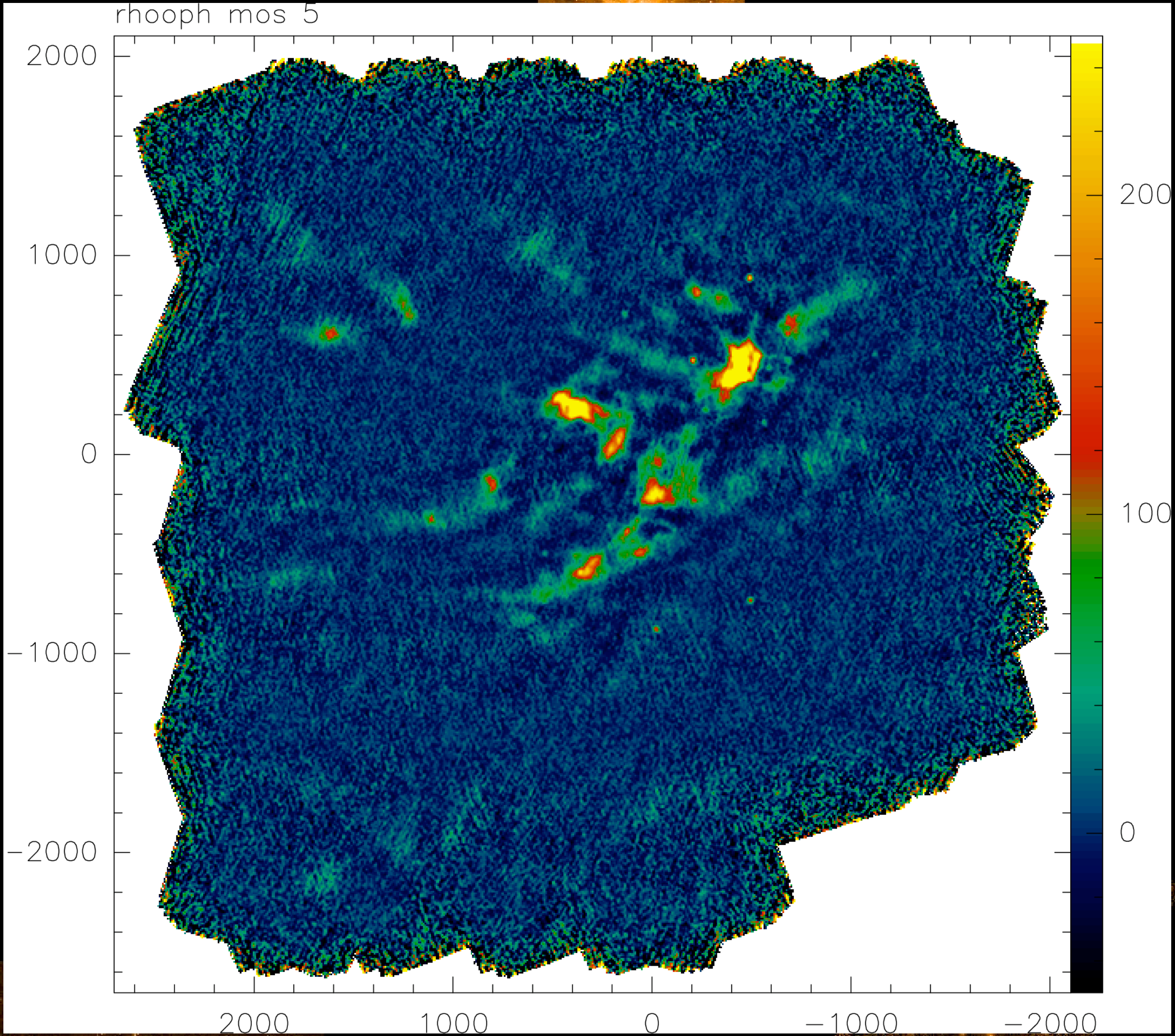


SEST SIMBA:
1.3mm dust continuum

UKIRT WFCAM:
2.12μm, K', J, H

Spitzer...

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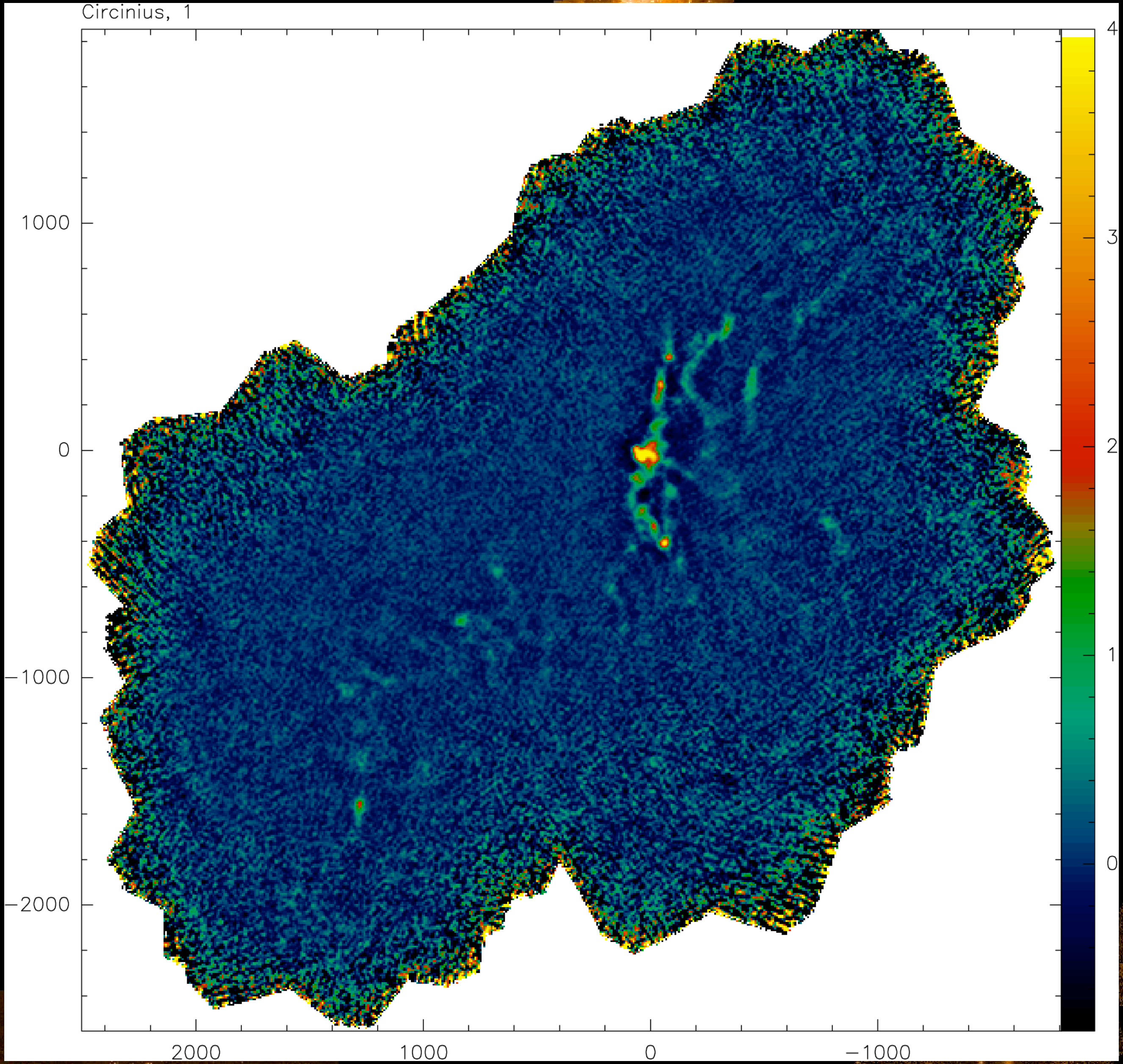
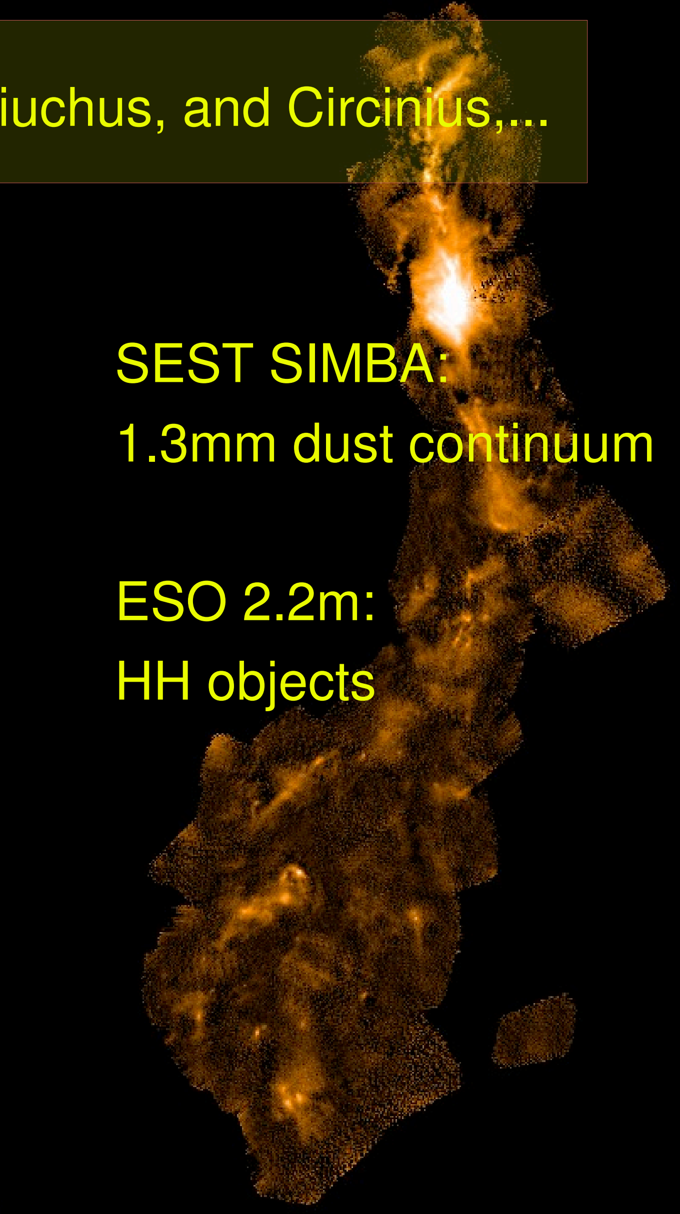


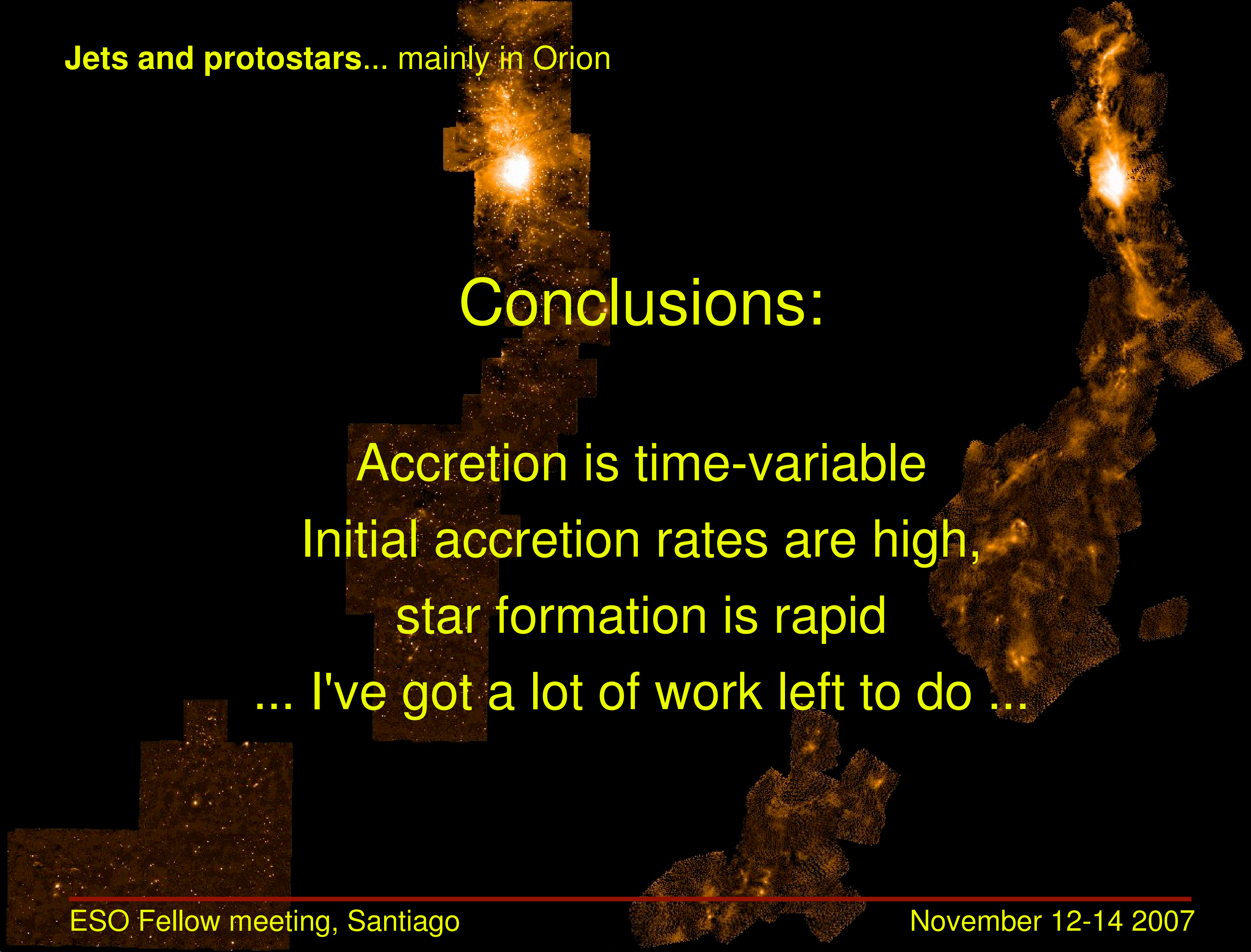



SEST SIMBA:

1.3mm dust continuum

ESO 2.2m:

HH objects



# Conclusions:

Accretion is time-variable

Initial accretion rates are high,

star formation is rapid

... I've got a lot of work left to do ...