Detecting Transport Processes in Protostellar Disks

Neal Turner

Jet Propulsion Laboratory, California Institute of Technology

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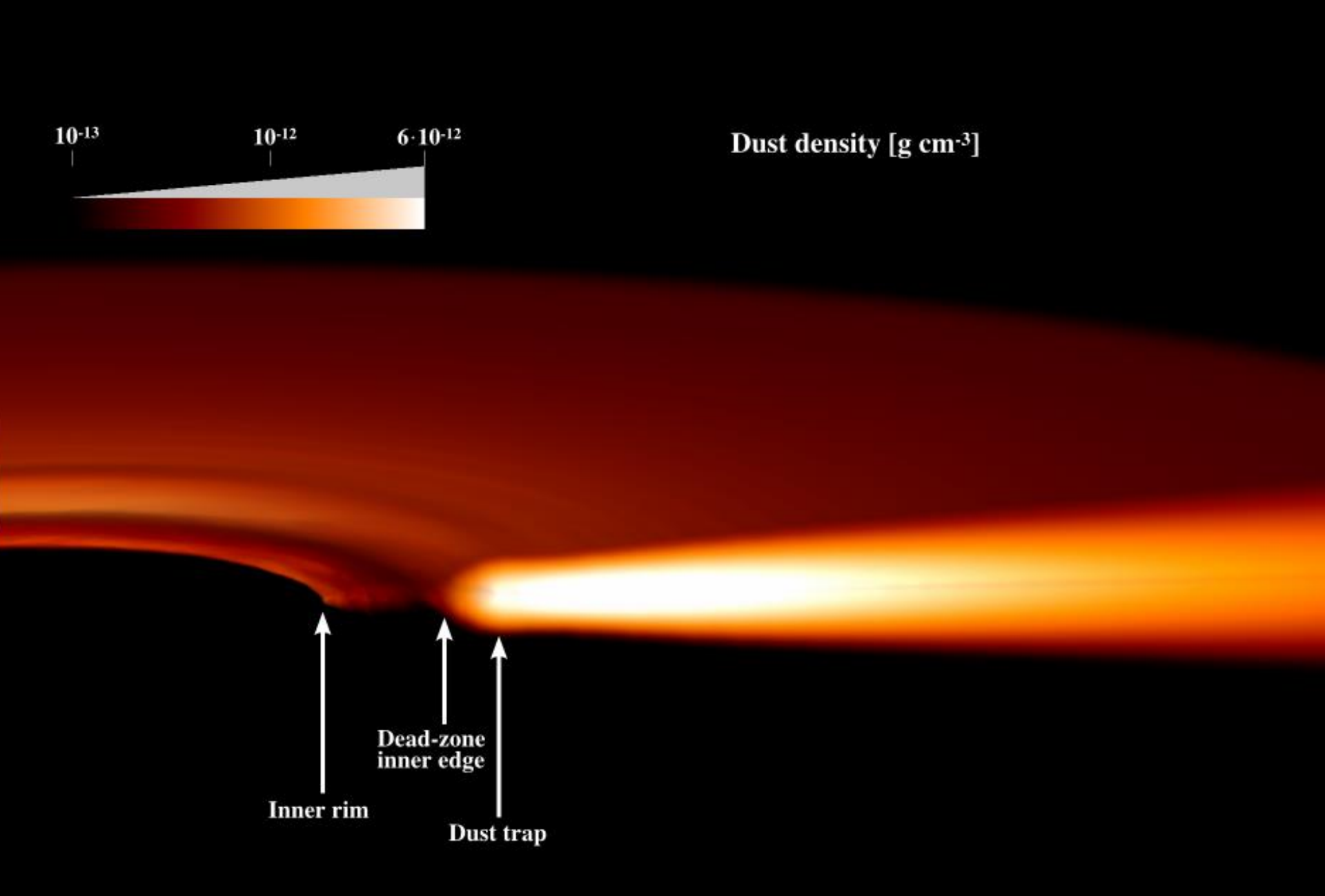
10^{-13}
10^{-12}
$6 \cdot 10^{-12}$
Dust density [g cm^{-3}]
Dead-zone
inner edge
Inner rim
Dust trap

M. Flock+ 2017

Digitized Sky Survey 2 / Davide De Martin

We can detect gas flows by

1. **trace species' kinematics**
2. **effects on trace species' abundances**
3. **effects on solid particles**

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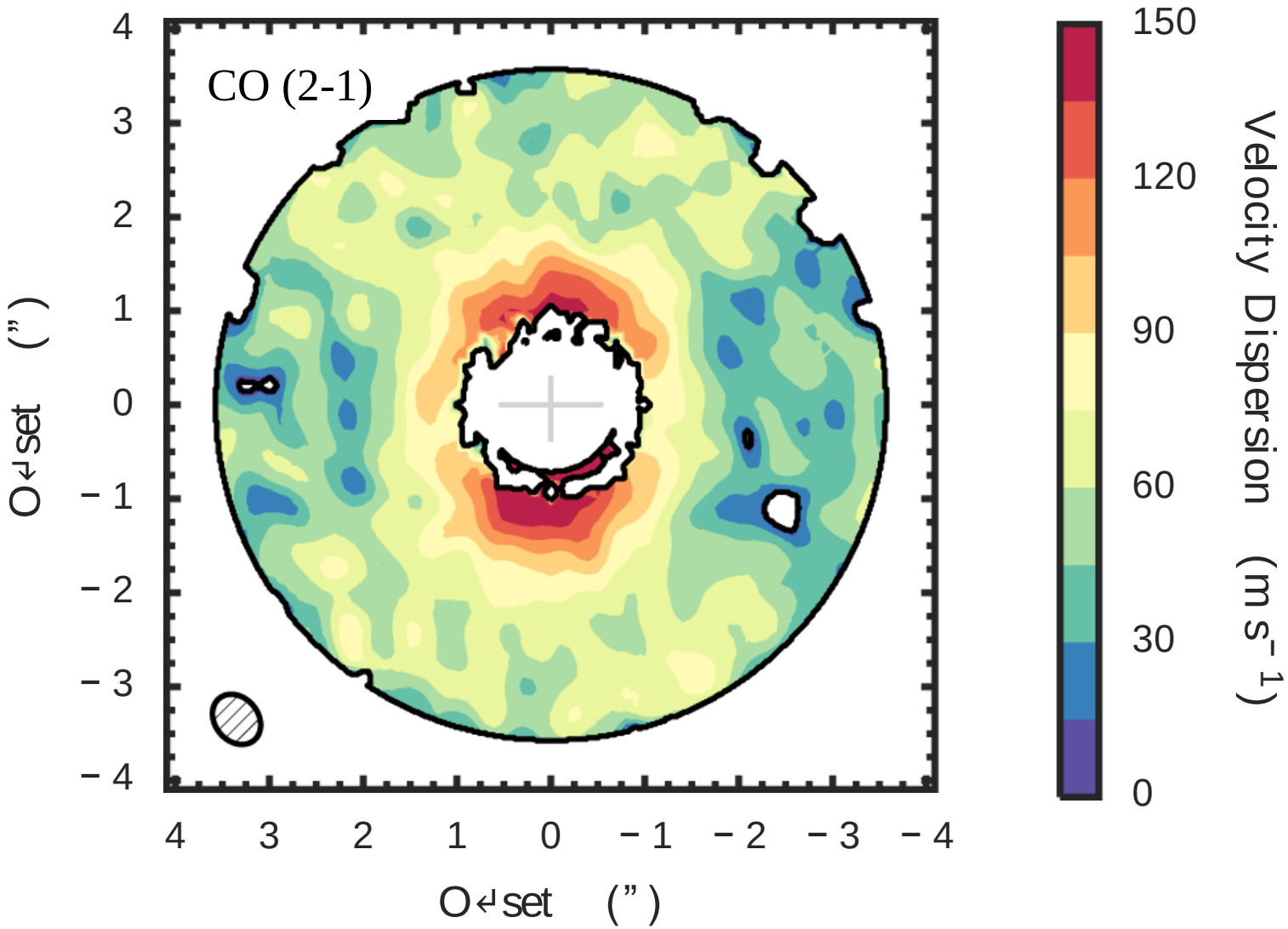
1. trace species' kinematics – from millimeter lines



R. Teague+ 2016

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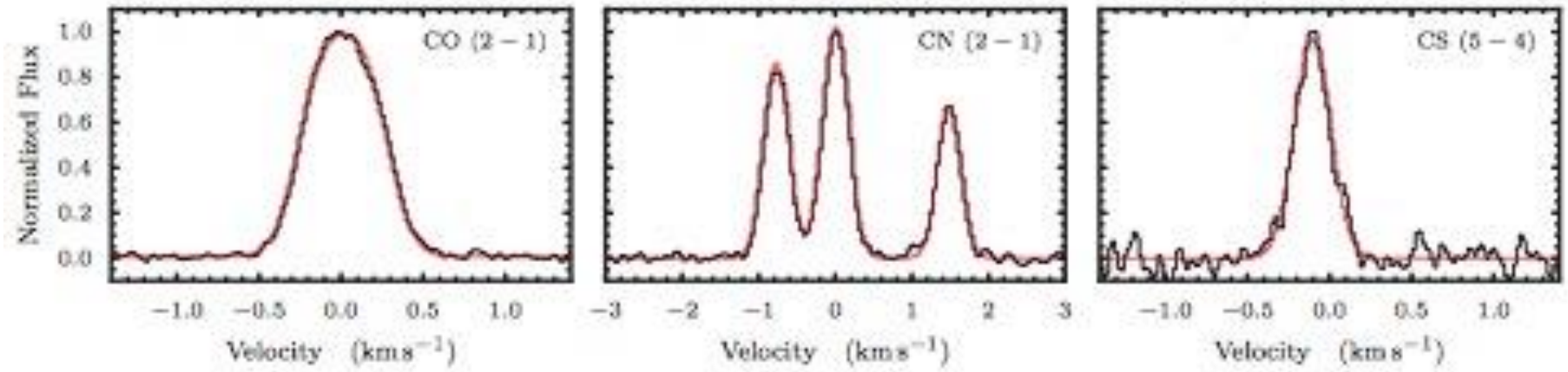

R. Teague+ 2016

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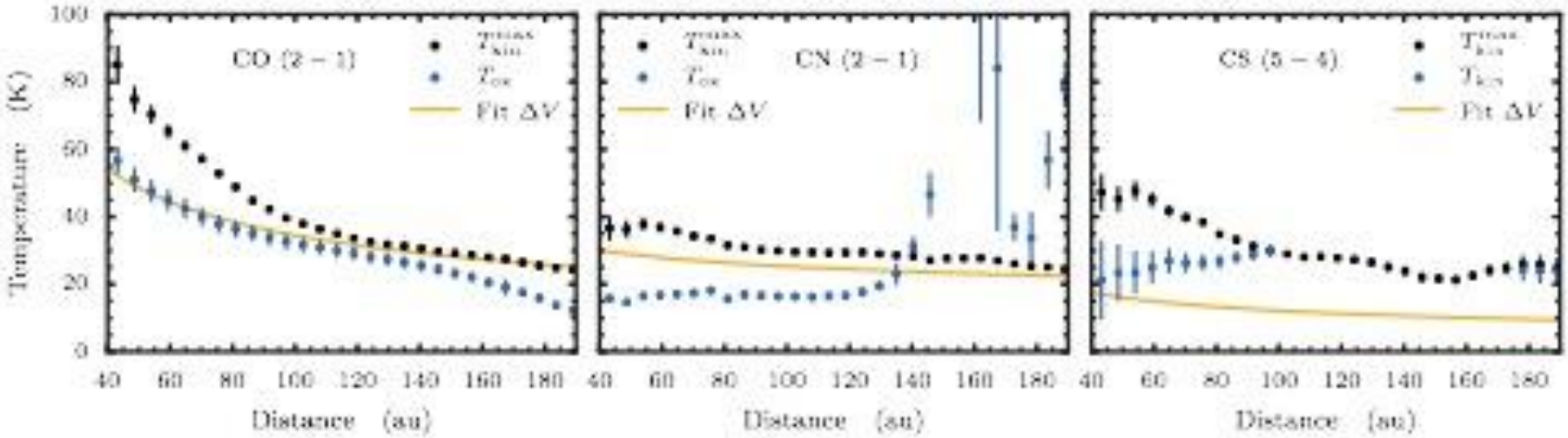

R. Teague+ 2016

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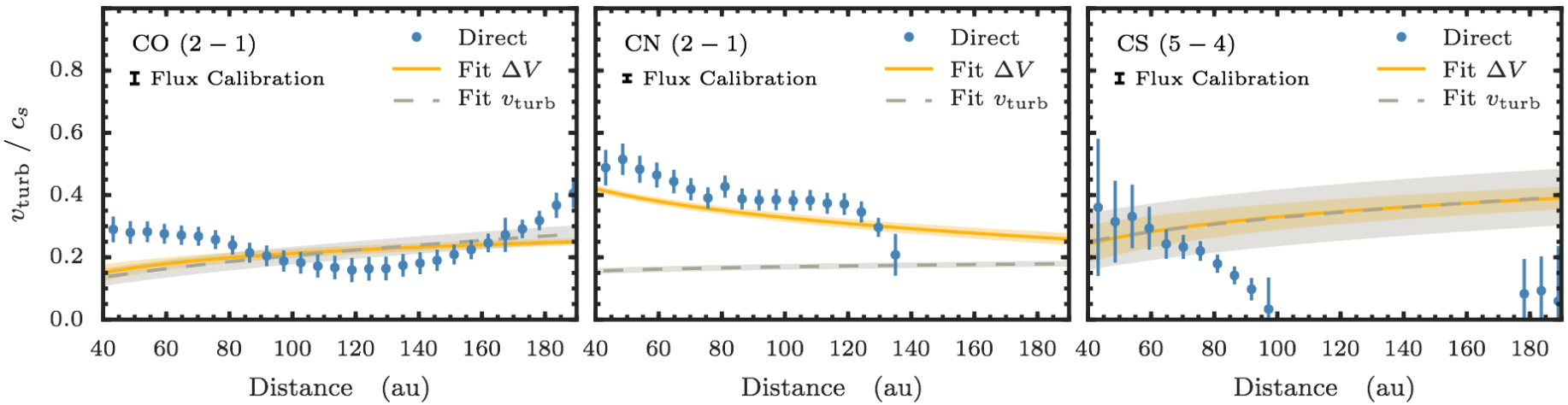
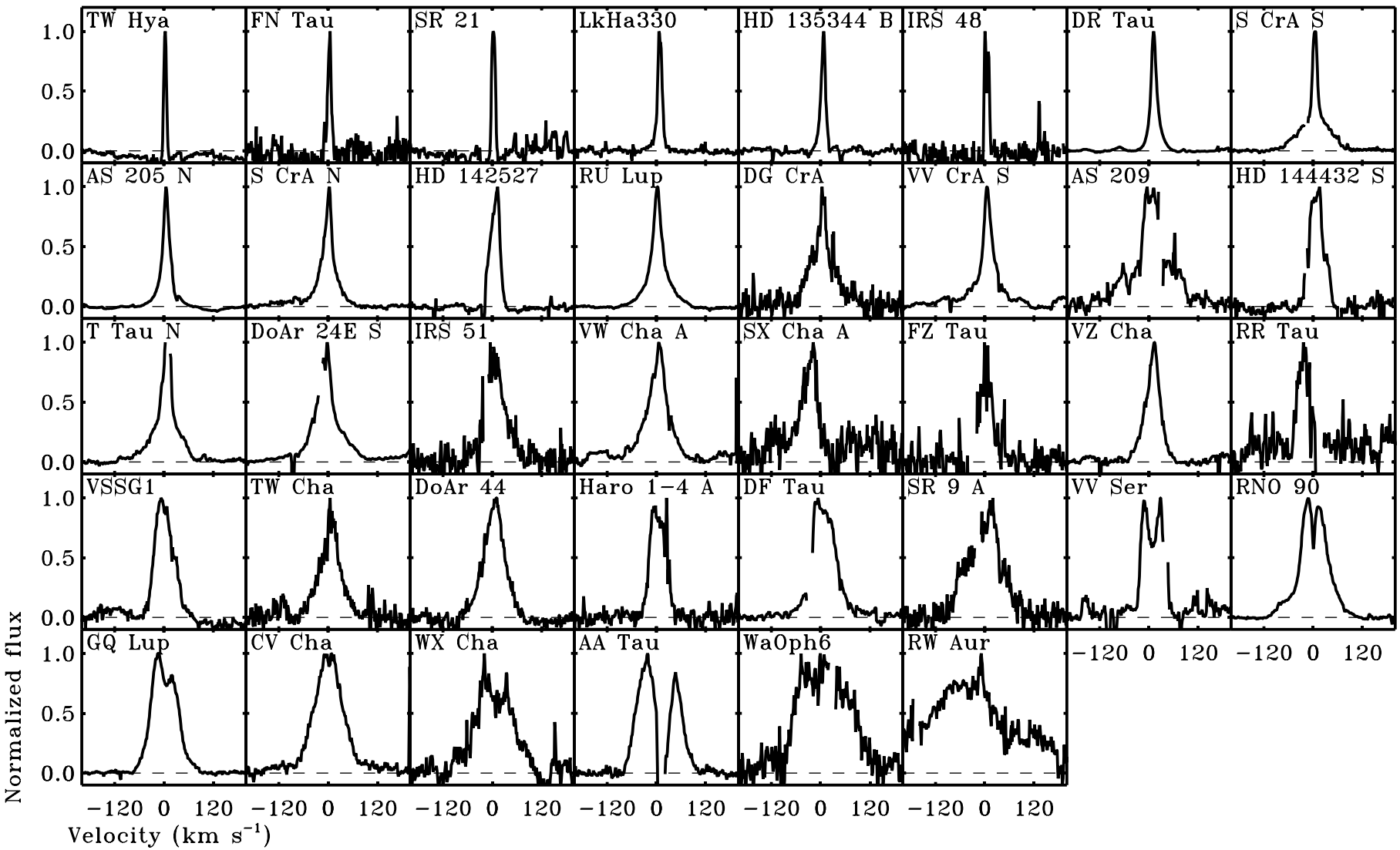


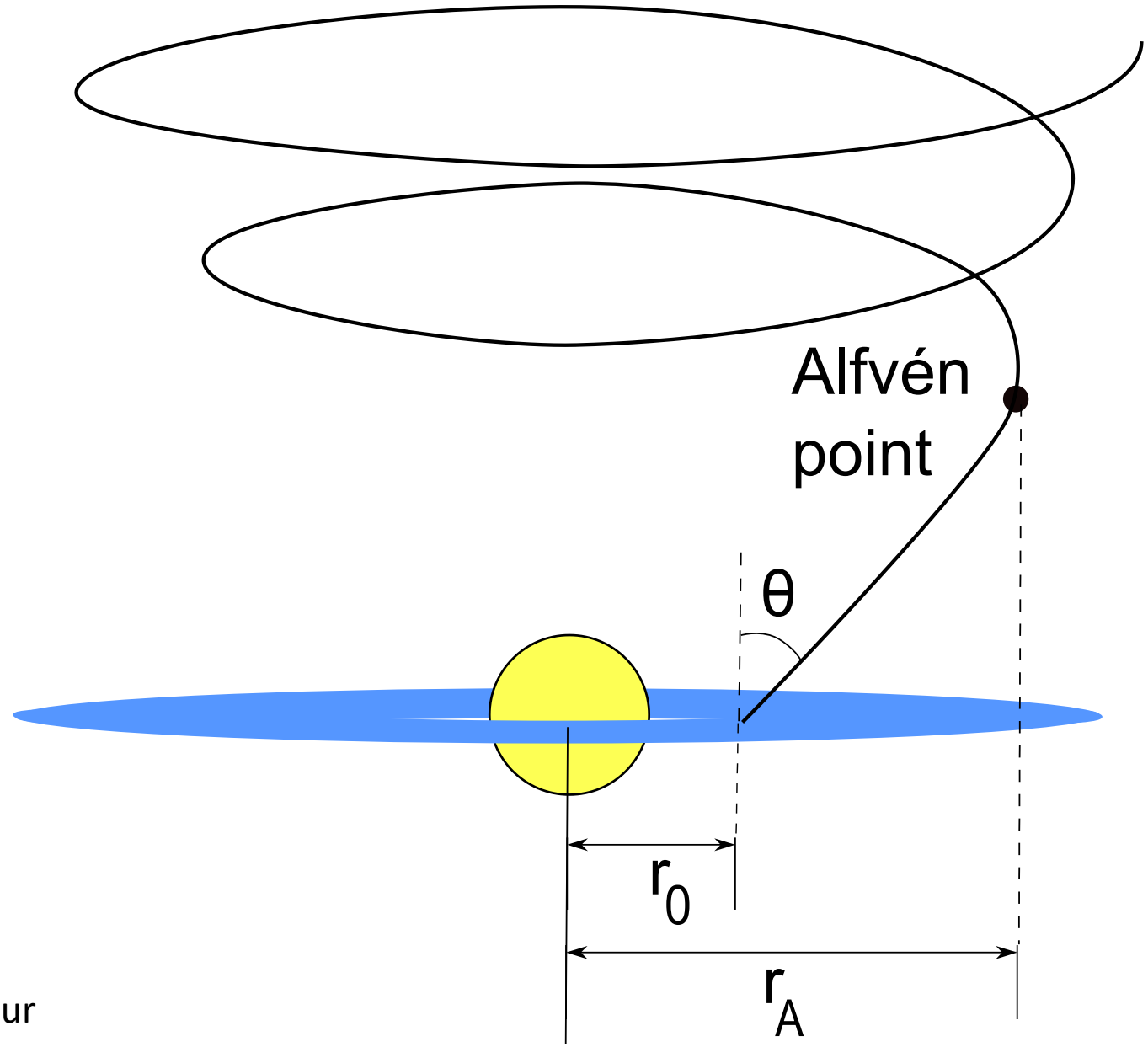
R. Teague+ 2016

1. trace species' kinematics – from infrared lines



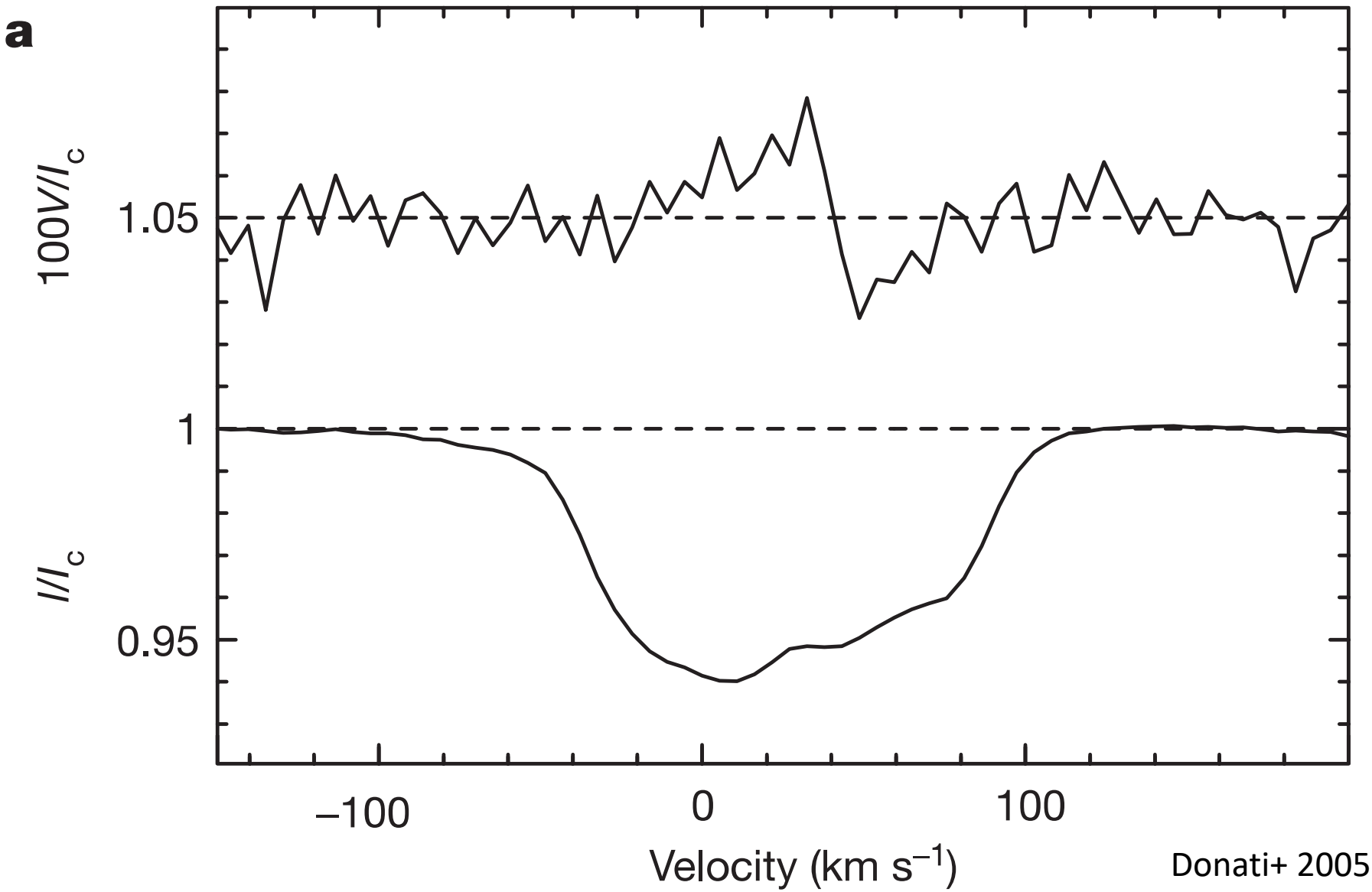
J. Brown+ 2013

1. trace species' kinematics – from infrared lines



By G. Lesur

1. trace species' kinematics – and magnetic fields!



Donati+ 2005

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2. effects on trace species' abundances – water

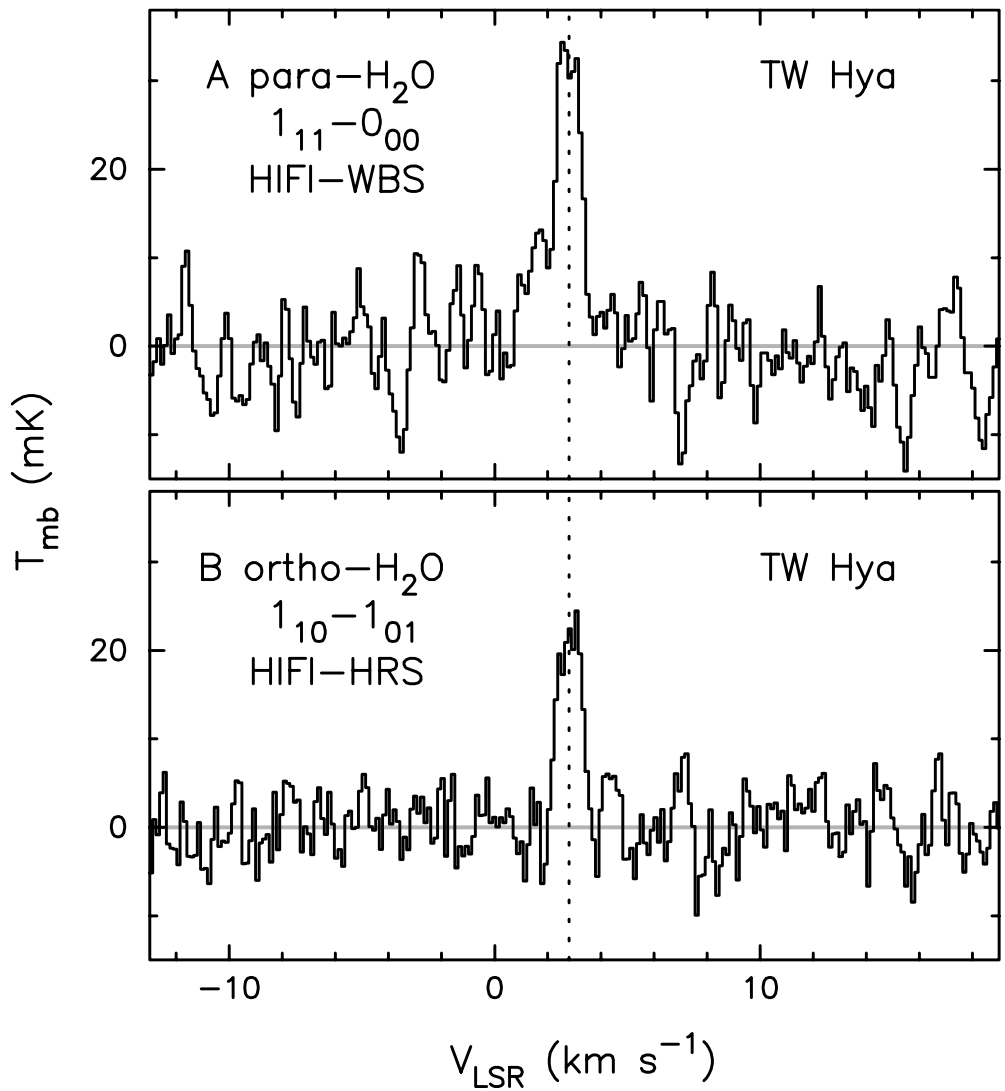
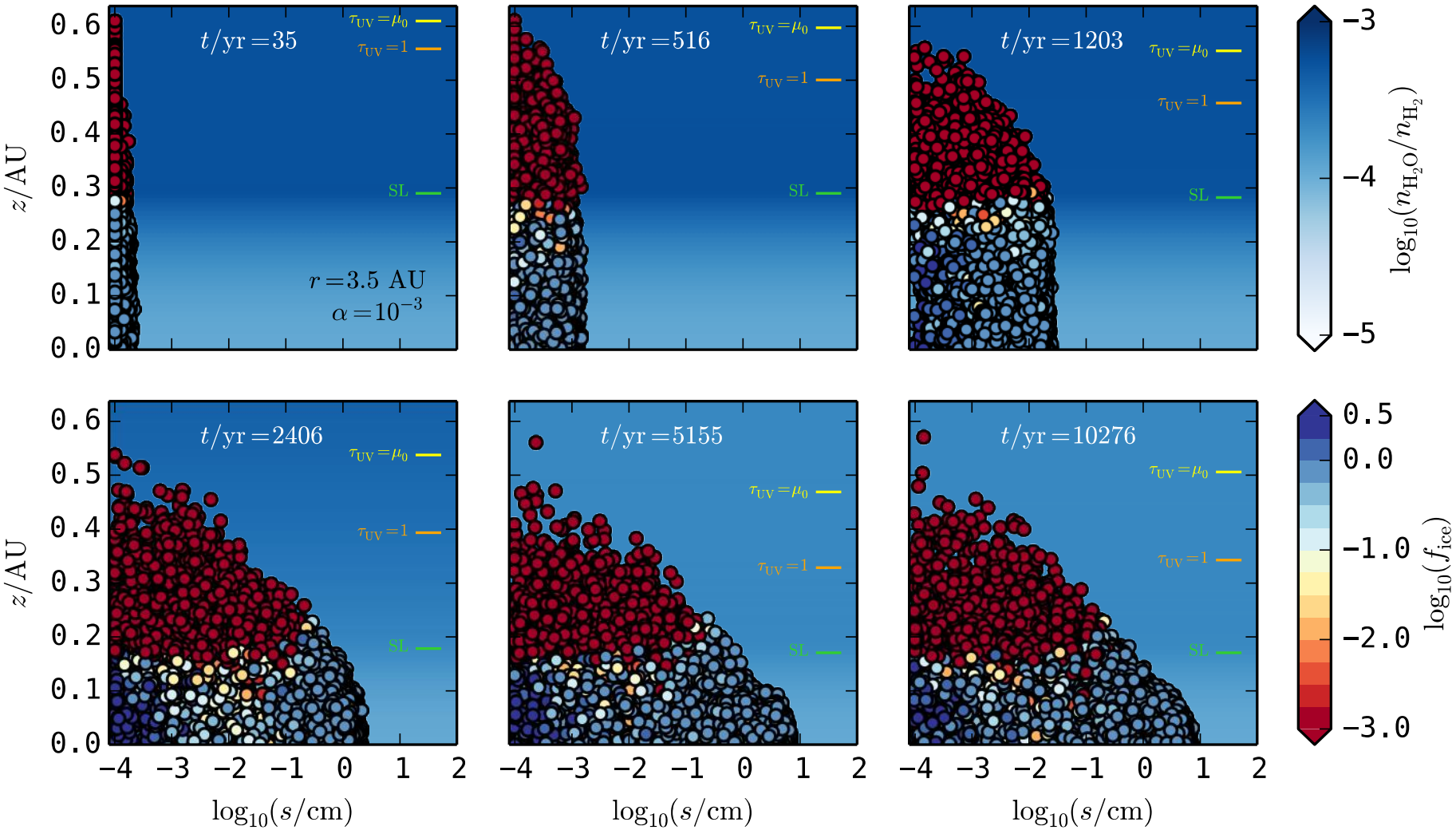


Fig. 1. Spectra of para-H_2O 1_{11}-0_{00} (**A**) and ortho-H_2O 1_{10}-1_{01} (**B**) obtained with HIFI on the Herschel Space Observatory toward the protoplanetary disk around TW Hya after subtraction of the continuum emission. The vertical dotted lines show the system's velocity of +2.8 km s^{-1} relative to the Sun's local environment (local standard of rest).

M. Hogerheijde+ 2011

2. effects on trace species' abundances – water



S. Krijt+ 2016

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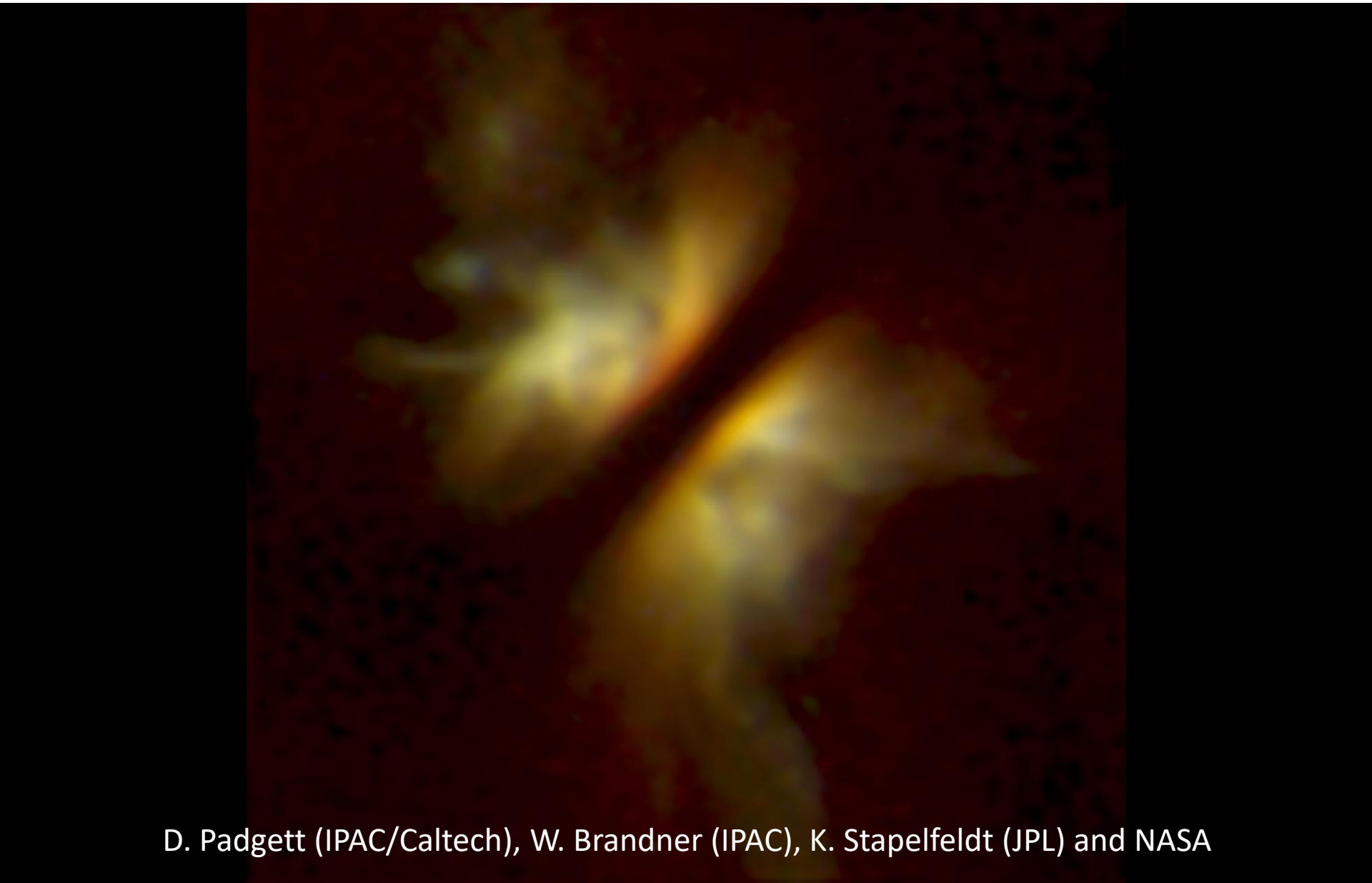
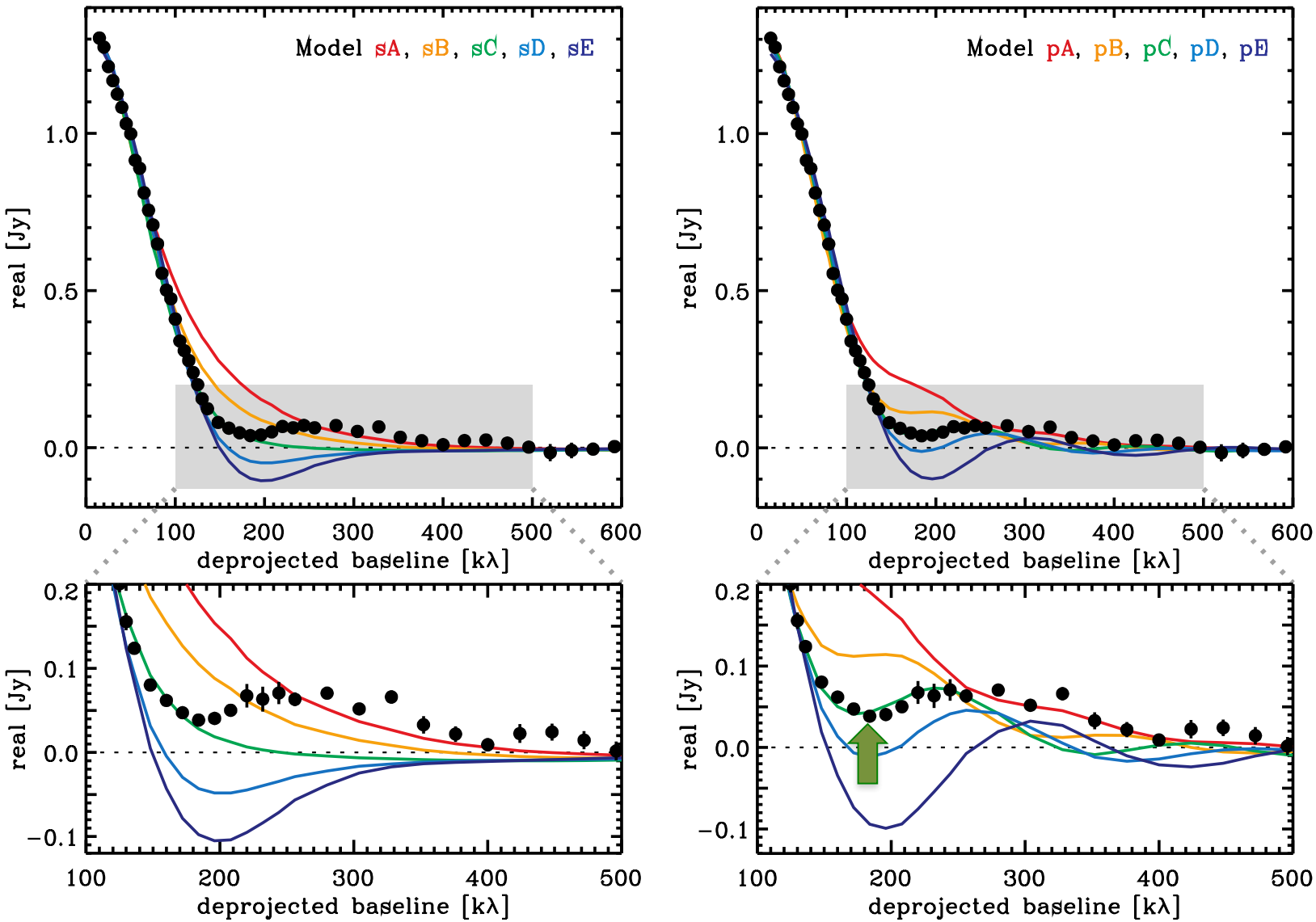
3. effects on solid particles – NIR scattered starlight



D. Padgett (IPAC/Caltech), W. Brandner (IPAC), K. Stapelfeldt (JPL) and NASA

3. effects on solid particles – millimeter continuum



S. Andrews+ 2012

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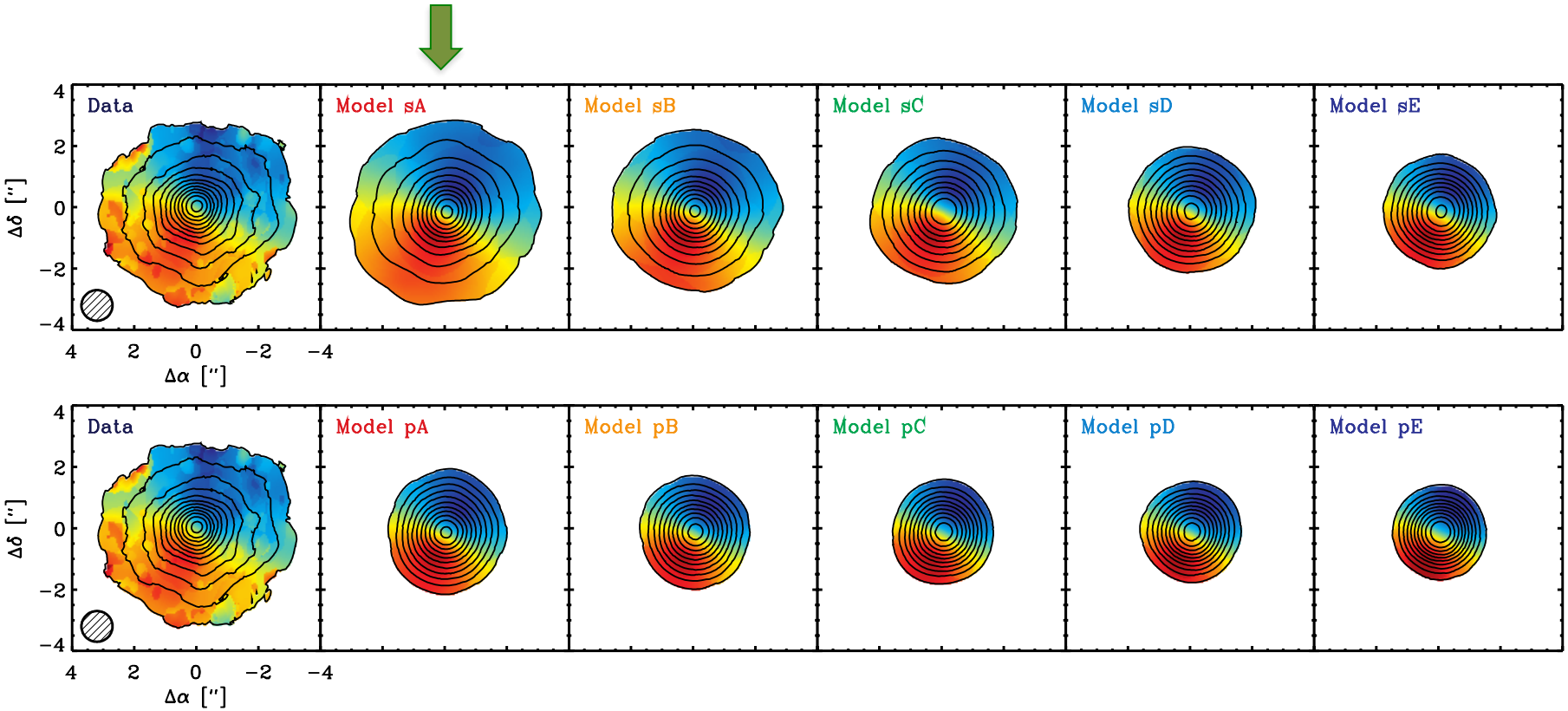

S. Andrews+ 2012

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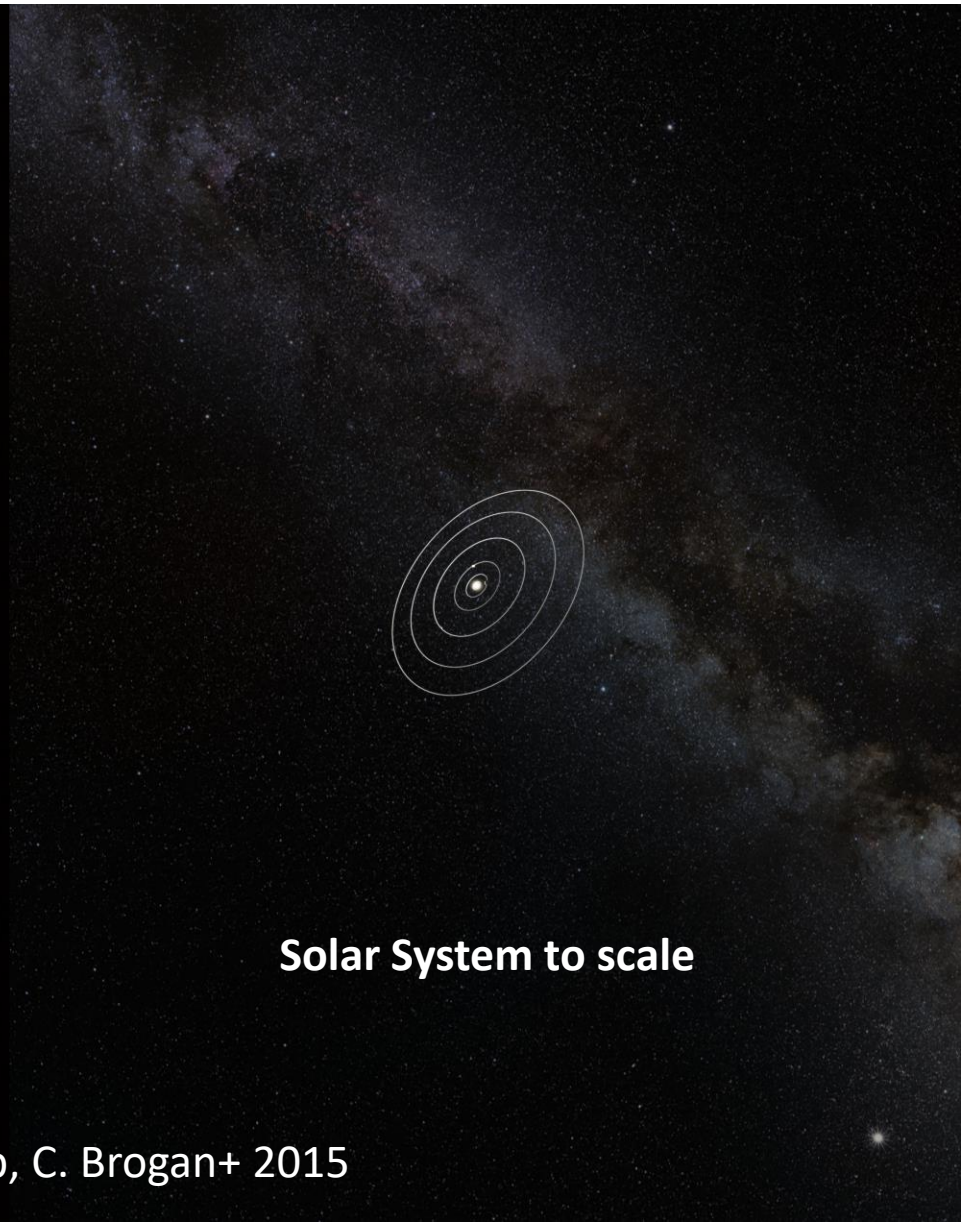
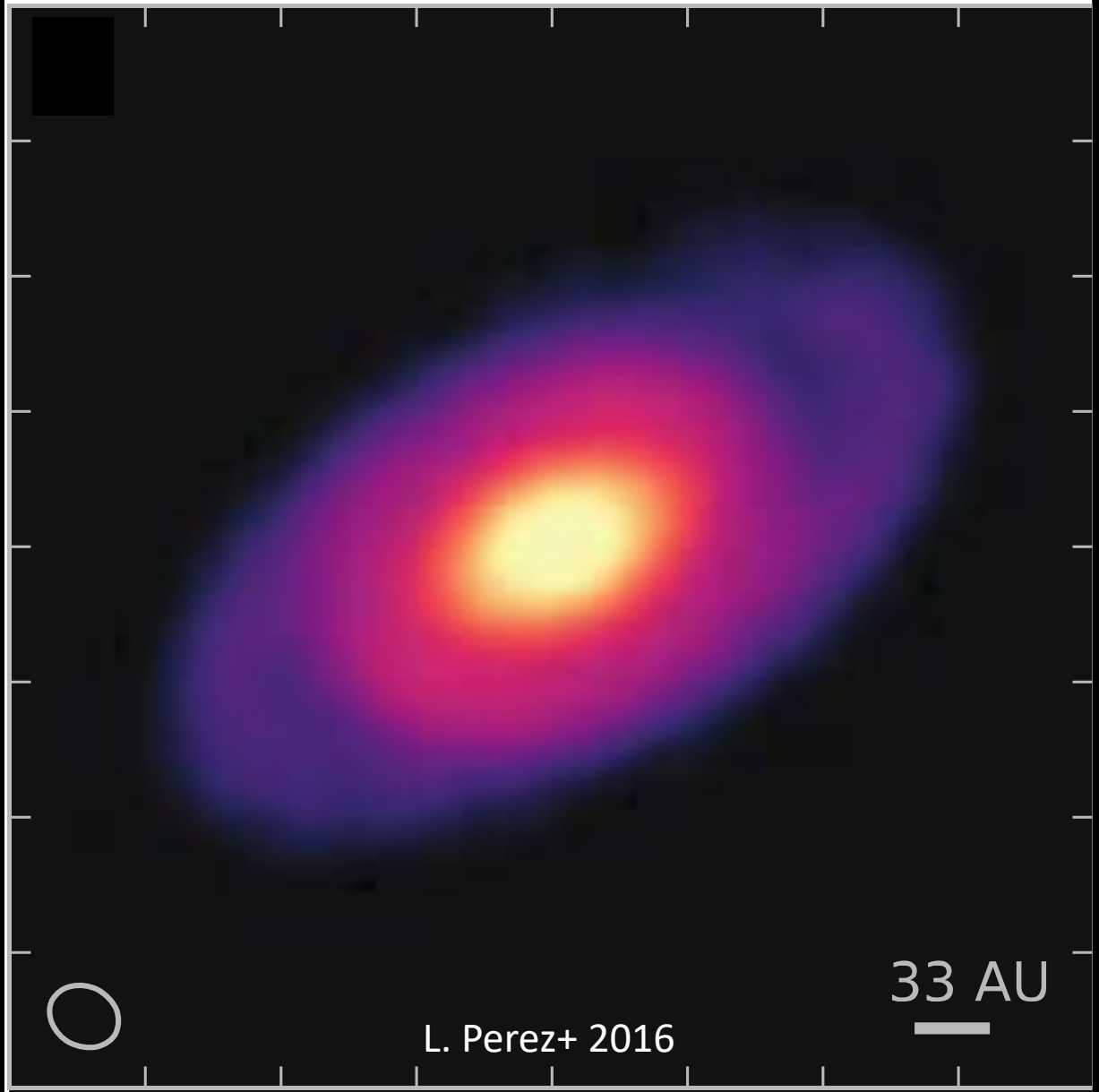


ALMA Partnership, C. Brogan+ 2015

3. effects on solid particles – millimeter continuum



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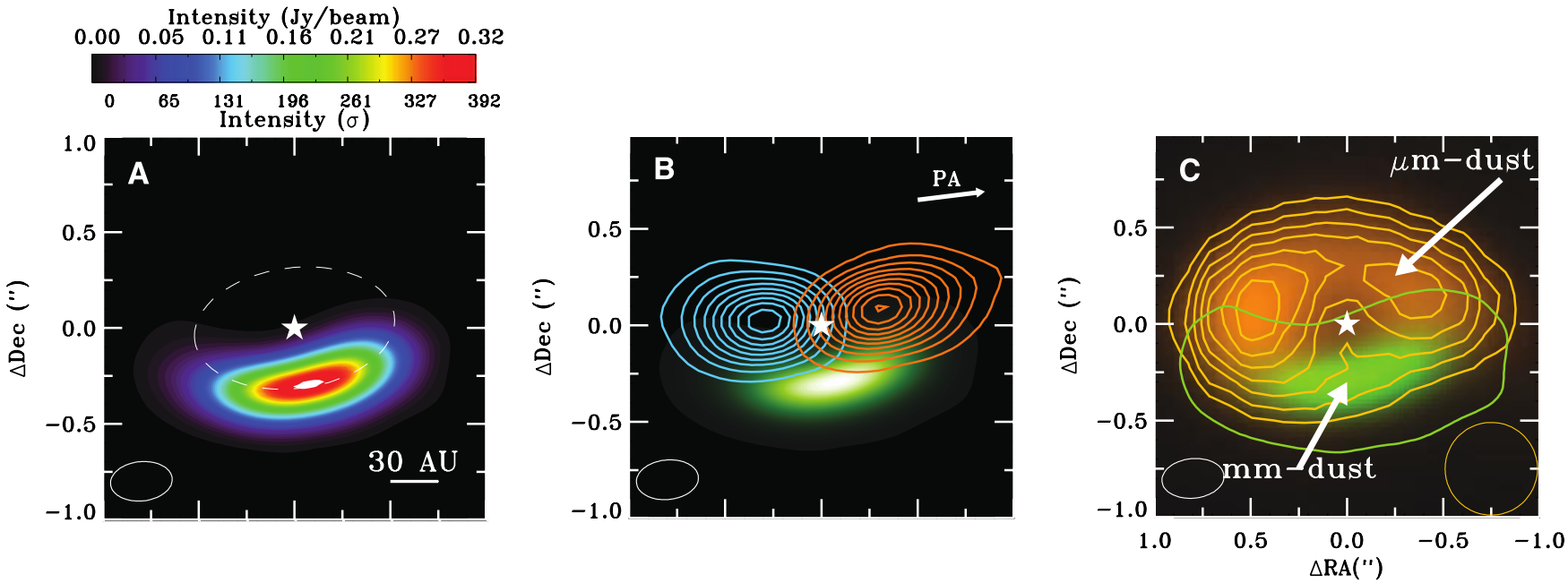

440 μm continuum

CO 6-5 blue & red wings, 440 μm continuum

18.7 μm, 440 μm continua

N. van der Marel+ 2013

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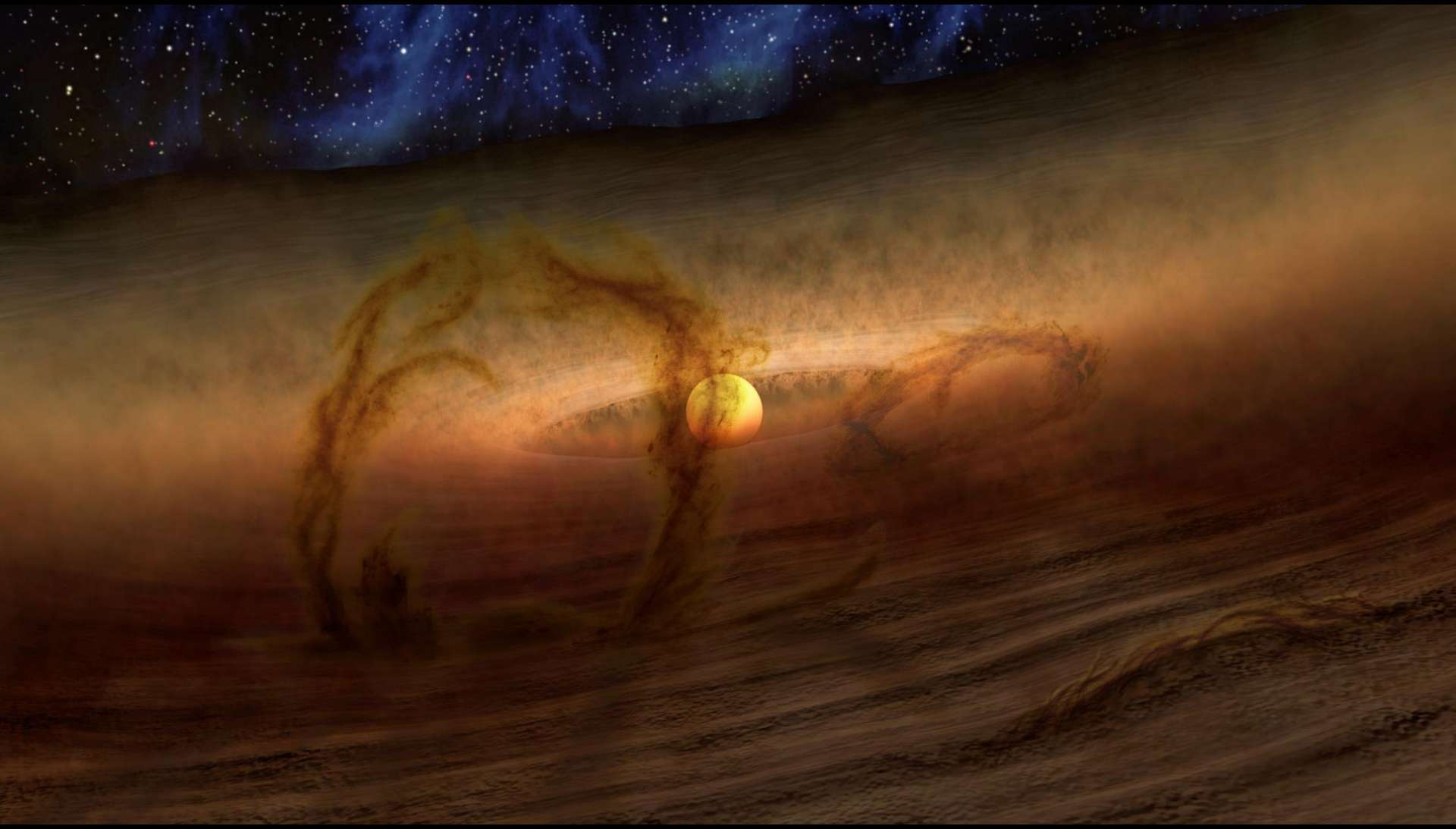
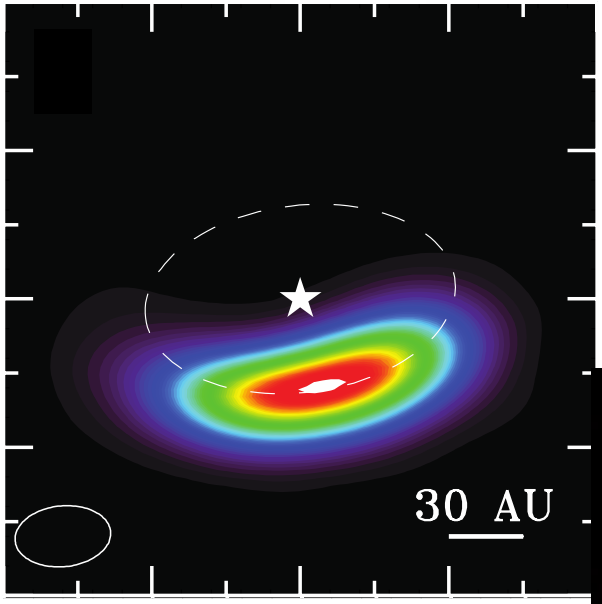
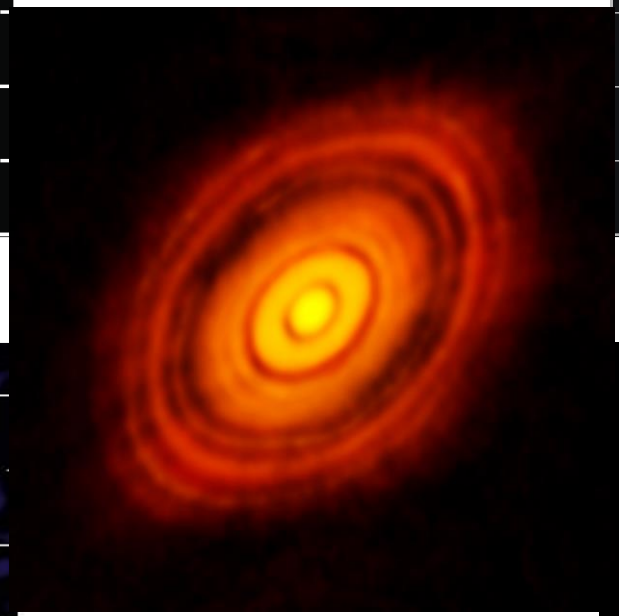
How to recognize each transport process?



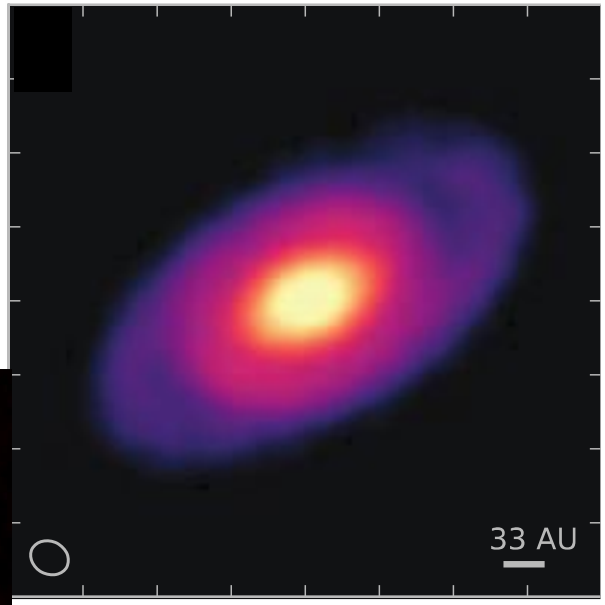
Artwork by Robert Hurt (IPAC/Caltech)



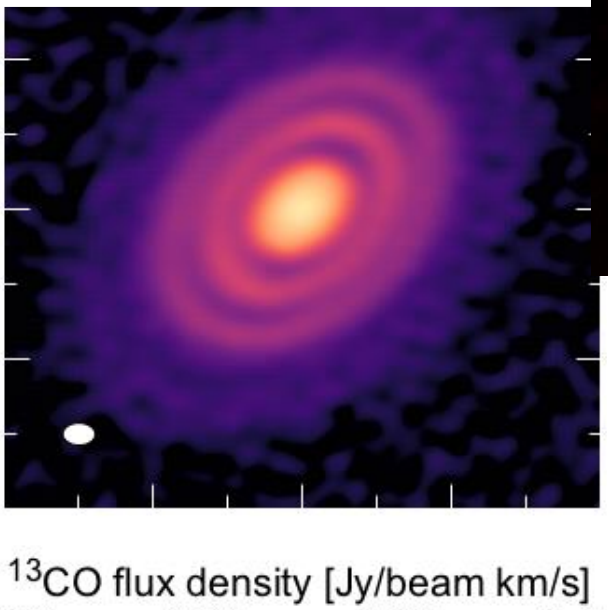
van der Marel+ 2013



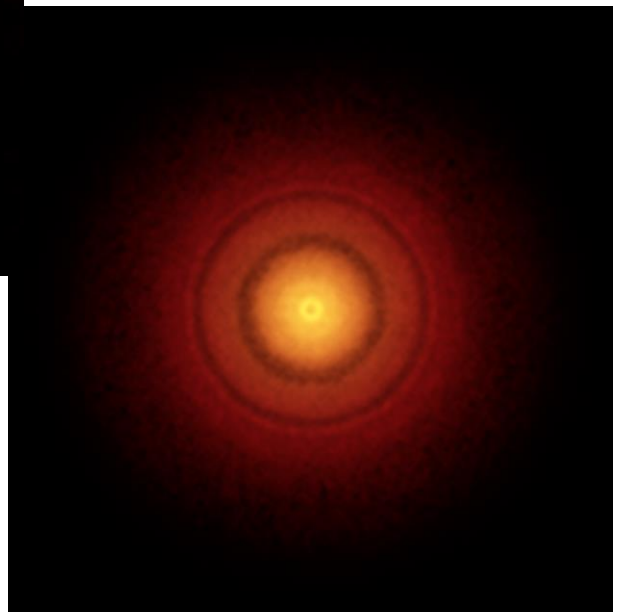
ALMA Partnership, Brogan+ 2015



Perez+ 2016



Isella+ 2016



Andrews+ 2016

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