MANCHESTER
1824

The University of Manchester

Sun, Stars & Planets Group

And the stuff between them

Gary Fuller

ALMA

EUROPEAN ARC

ALMA Regional Centre || UK

Group Members

- Albert Zijlstra
- Andrew Markwick
- Eamonn Kerins
- Gary Fuller
- Malcolm Gray
- Myfanwy Lloyd
- Philippa Browning
- Tim O'Brien

- Adam Avison
- Alessio Traficante
- Anita Richards
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- Mykola Gordovskyy
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- *Tom Muxlow*
- *Clive Dickinson*

- Amy Tyndall
- Teo Mocnik
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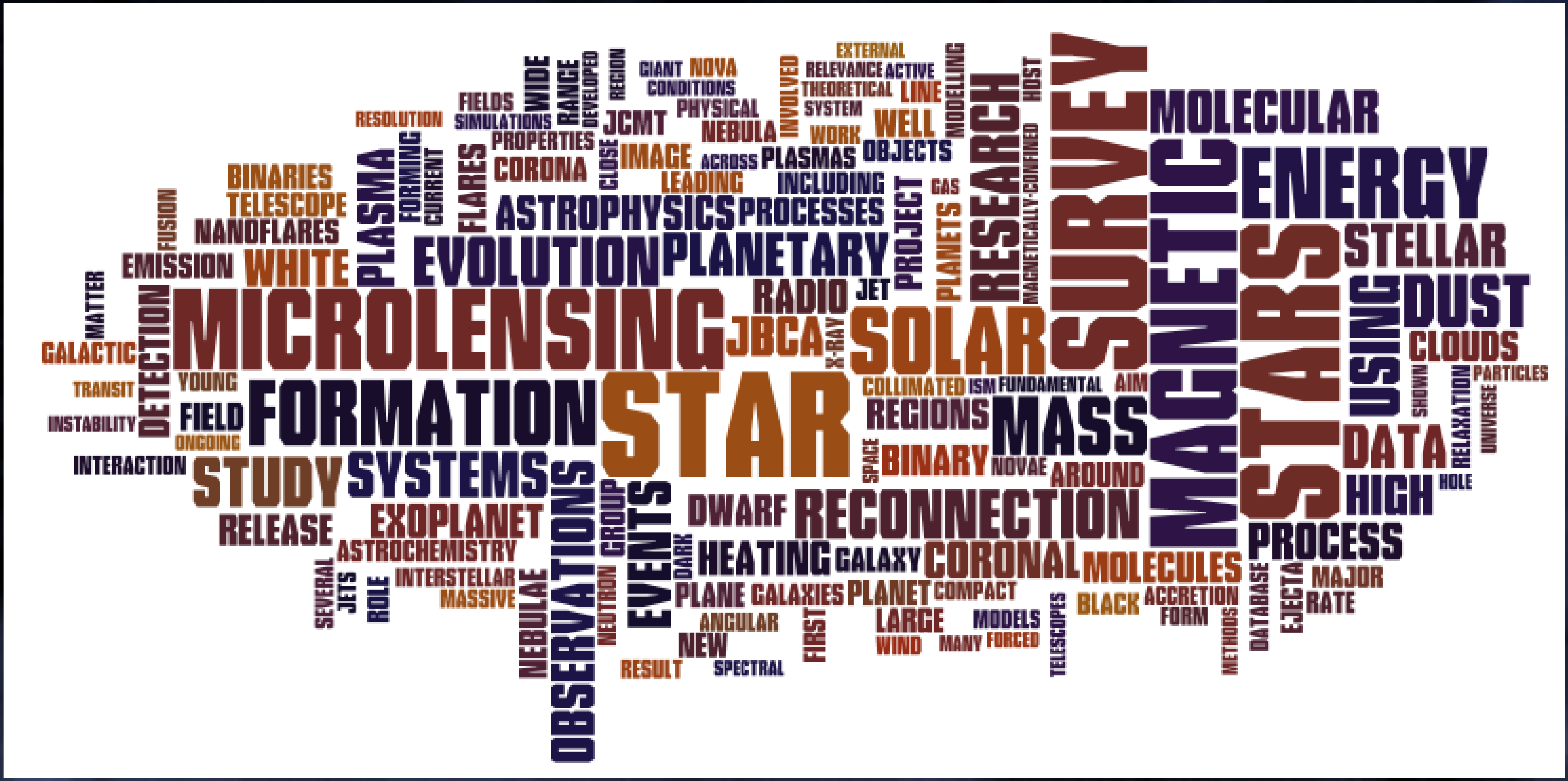
- Liz Guzman-Ramirez
- Christina Smith
- Clare Lykou
- Olivia Jones
- Andrew Jones
- Markus Harrop
- Adam Stanier
- Marion Mathelie-Guinlet

Research



SURVEY
MAGNETIC
STARS
STAR
MICROLENSING
FORMATION
SOLAR
RECONNECTION
MASS
ENERGY
MOLECULAR
EVOLUTION
PLANETARY
RESEARCH
OBSERVATIONS
STUDY
SYSTEMS
EXOPLANET
EVENTS
CORONAL
STELLAR
DUST
USING
DATA
HIGH
PROCESS
CLOUDS
MOLECULES
HEATING
ASTROPHYSICS
PROCESSES
PLASMA
WHITE
JBCA
RADIO
DWARF
RELEASE
BINARY
REGIONS
ASTROCHEMISTRY
EMISSION
NANOFLARES
TELESCOPE
BINARIES
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RESULT
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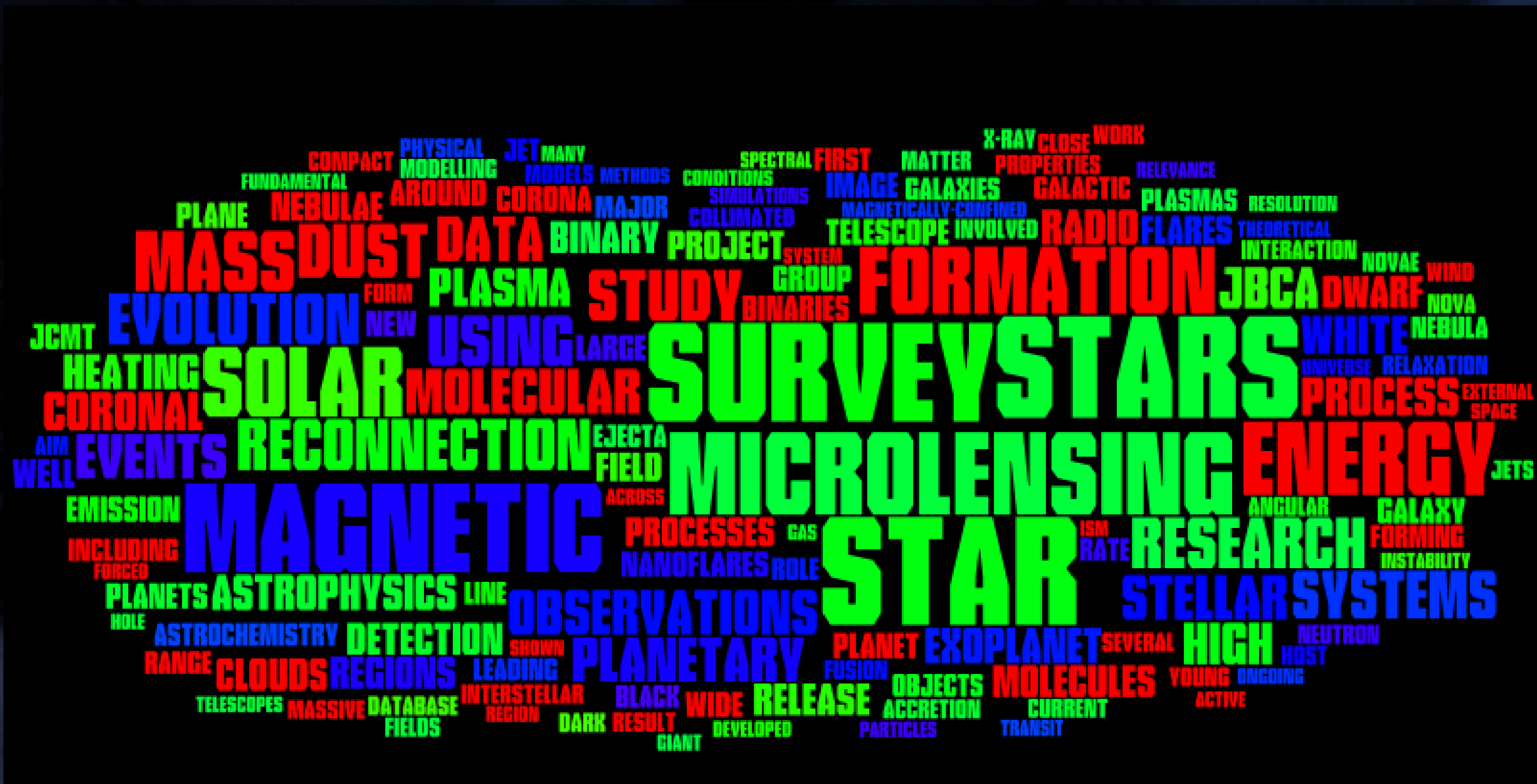
Research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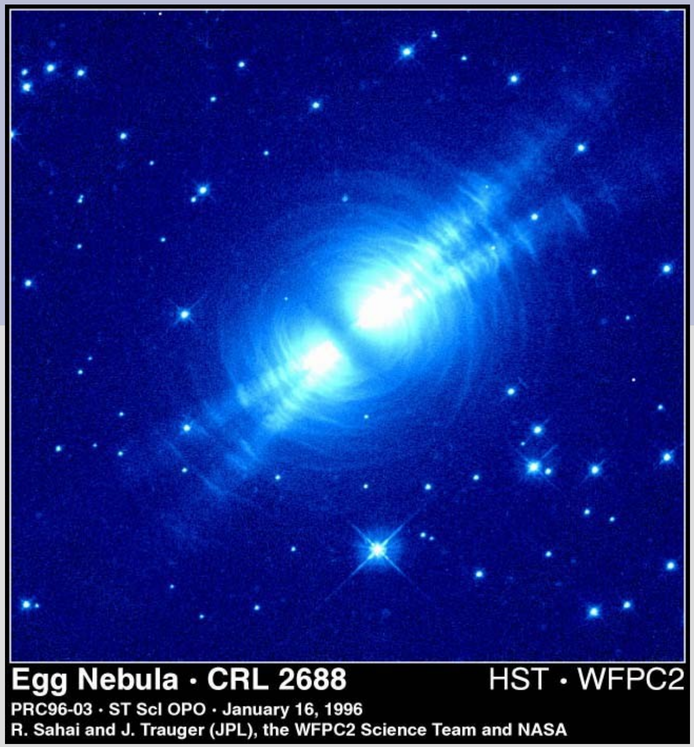
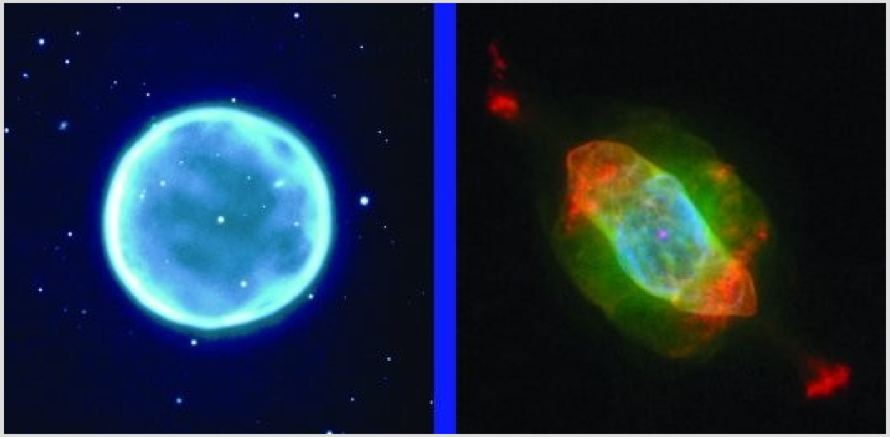
Stars:
The End

Stellar mass loss

- Evolved stars eject 40%-80% of their mass
- Mass loss is driven by strong pulsations and radiation pressure
- Leaves white dwarf surrounded by expanding planetary nebula





Importance

- Mass loss end stellar evolution:
  - Sets white dwarf mass distribution
  - Sets SNe Ia rate
  - Sets Lower mass limit core collapse SNe
- Mass loss drives galactic evolution
  - Origin of half of all recycled ISM
  - Major source of carbon and dust
  - Origin of half of all elements heavier than iron

Science

- We study
  - Evolved stellar populations in ours and nearby galaxies
    - Quantify mass loss and dust production as funtion of stellar mass and metallicity
  - What drives the mass loss
    - Dust or pulsations?
  - What shapes the mass loss
    - Binaries: Angular momentum in cold storage
  - Evolution of dust
    - Of silicates, PAHs and the missing iron

Understanding Planetary Nebulae

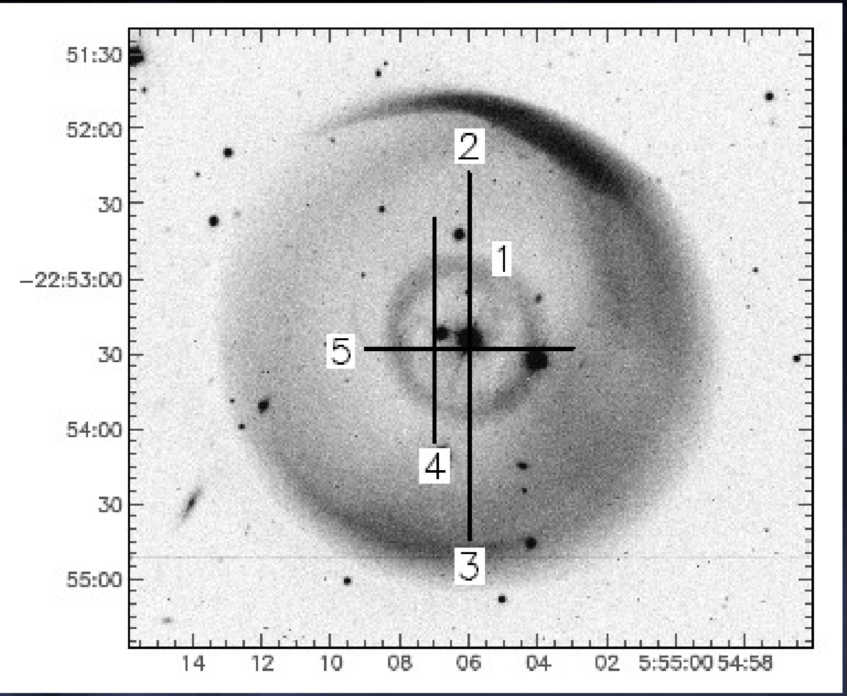
We are looking for observational evidence to link the shapes of planetary nebulae to their central stellar systems.

Binarity thought to be the most important shaping factor but still not much hard evidence.

Learning more about binary interactions, eg chemical pollution and spin-up from angular momentum transfer.

LoTr1 (Amy)

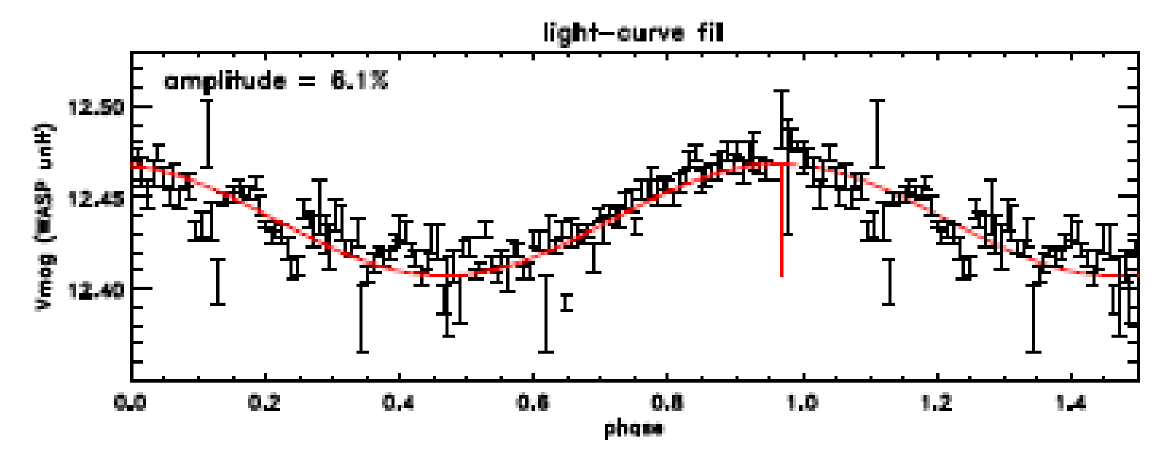
A Barium star (ie mass transfer ➡ binary) in a ‘circular’ nebula.



VLT spectra – K1III giant with mild BaII pollution.

(IUE spectra – hot WD,Teff>100kK)

EMMI and AAT nebular spectroscopy – nebula may be end-on hourglass.



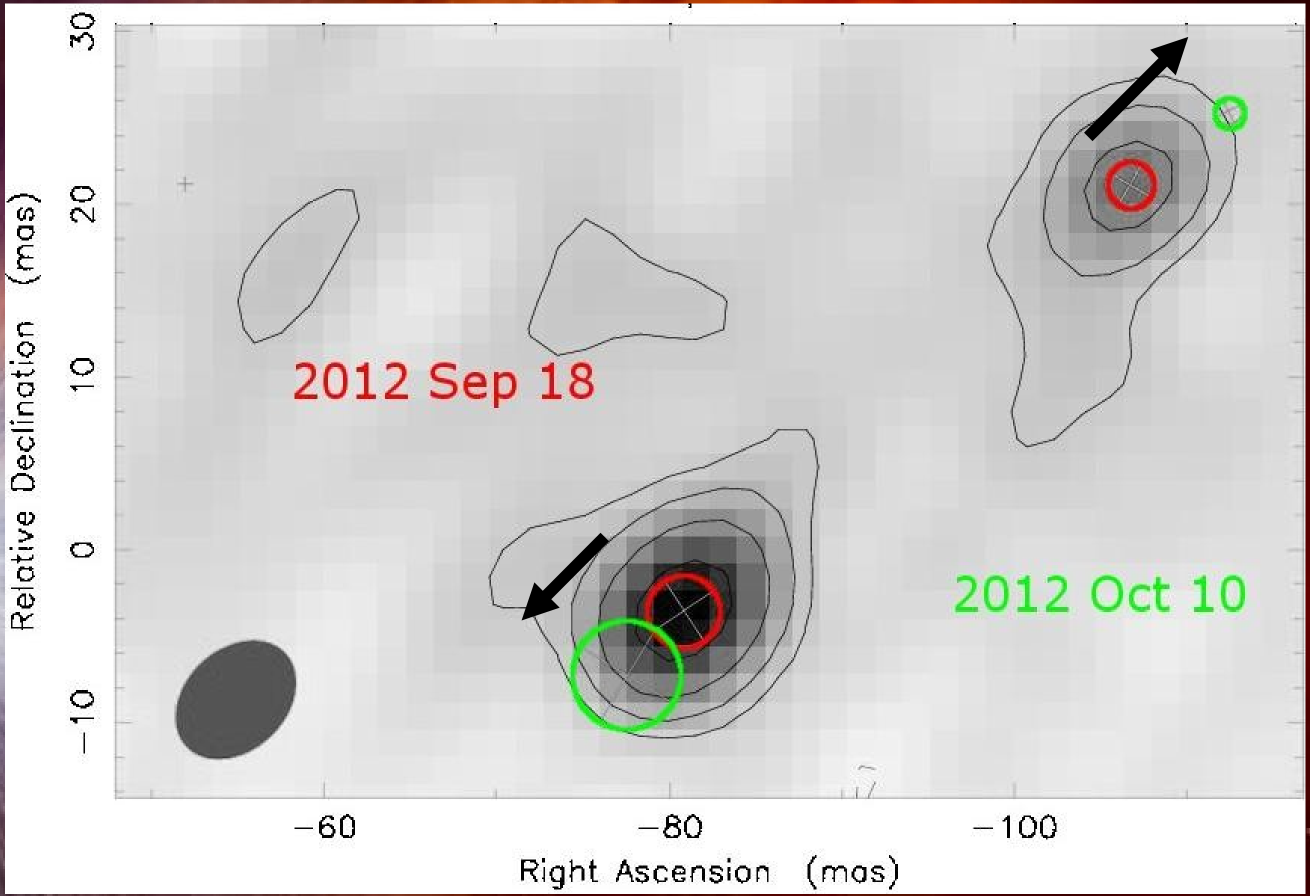
SuperWASP photometry - Period 6.4 days

Photometric variation likely due to spots on cool star

Nova Explosions

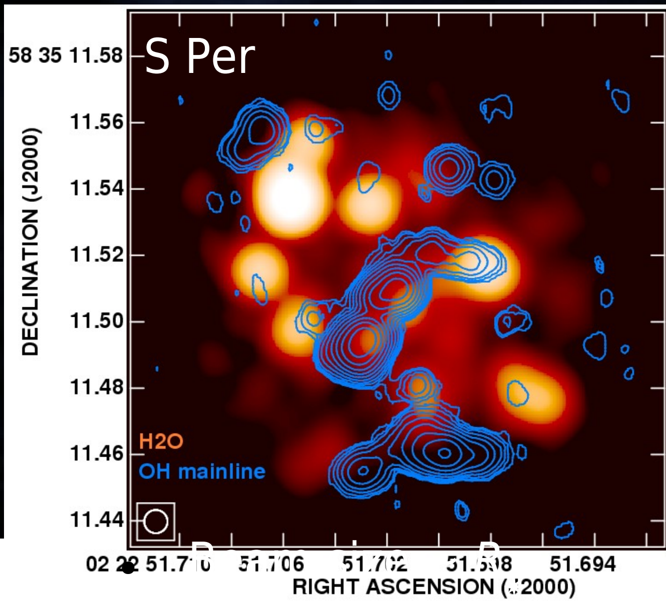
Thermonuclear explosion on white dwarf in close binary system
Matter ejected, intra-ejecta and ejecta-csm shocks
Observations from radio to gamma-ray

Recent EVN imaging of Nova Mon 2012 (a gamma-ray nova) showing expanding bipolar jets

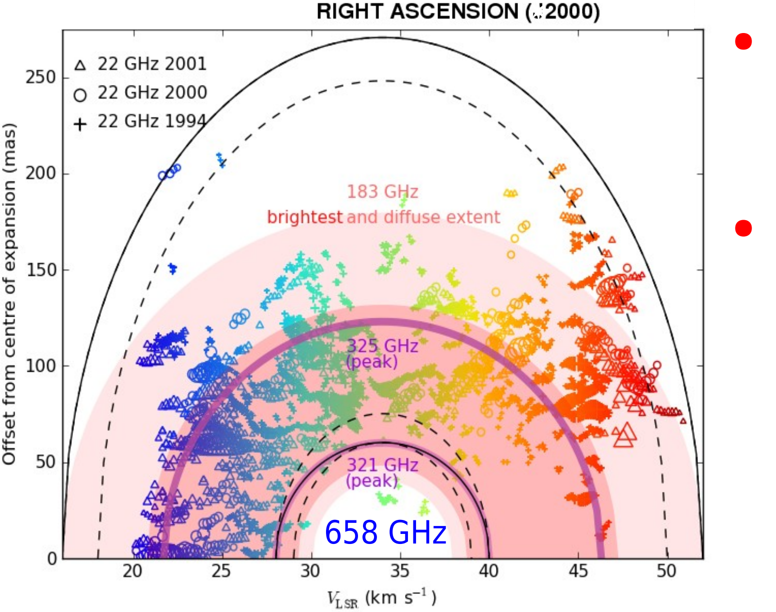


- Are some novae the progenitors of Type Ia SNe
- Do some novae eject jets and, if so, how?
- What causes gamma-ray emission?

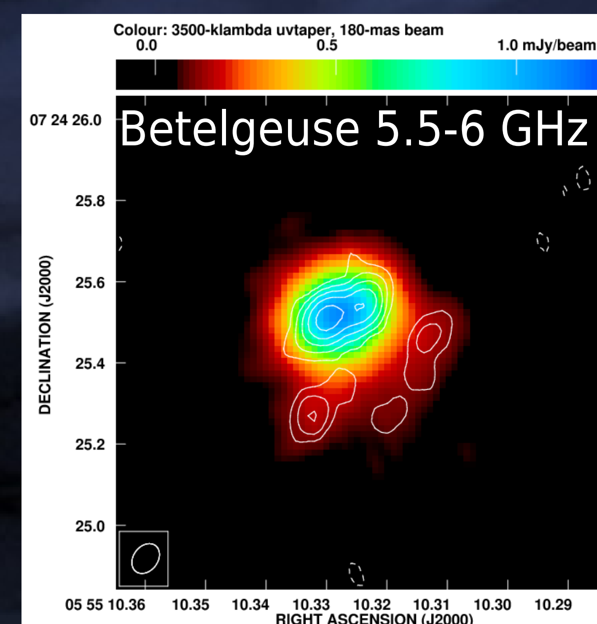
How do evolved stars return material to ISM?



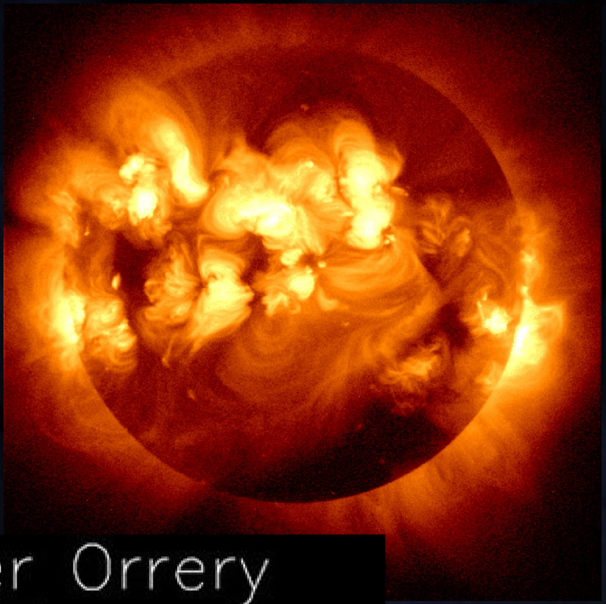
- MERLIN/EVN sub-AU imaging shows ~90% mass loss in clumps <1% volume
- Thick H_2O maser shell varies at once
  - Radiative cause, not shocks
- Size of clumps ∝ R_* – convection cells?
  - *Richards et al. 2010, 2012*

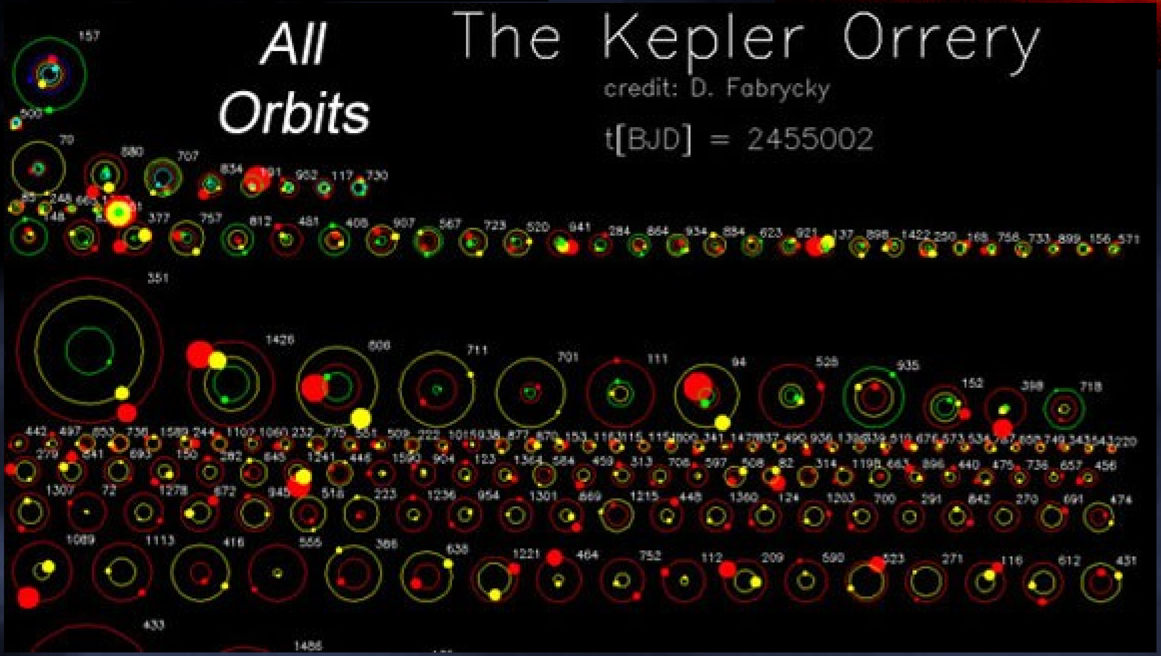


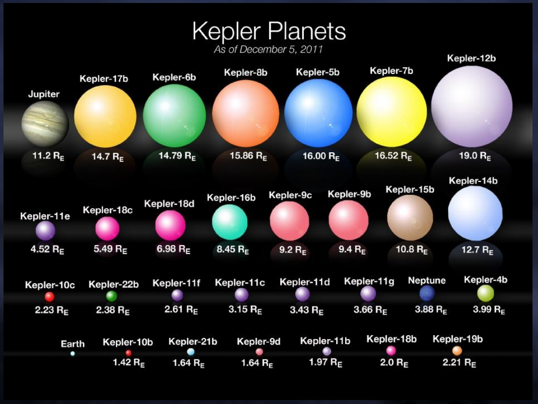
- ALMA sub-mm masers+dust imaging will give much better constraints
- e-MERLIN resolves Betelgeuse
  - ~monthly ALMA, JVLA, e-MERLIN obs. at increasing λ
  - Trace material from photosphere to ~6R_*



Stars: Middle Age





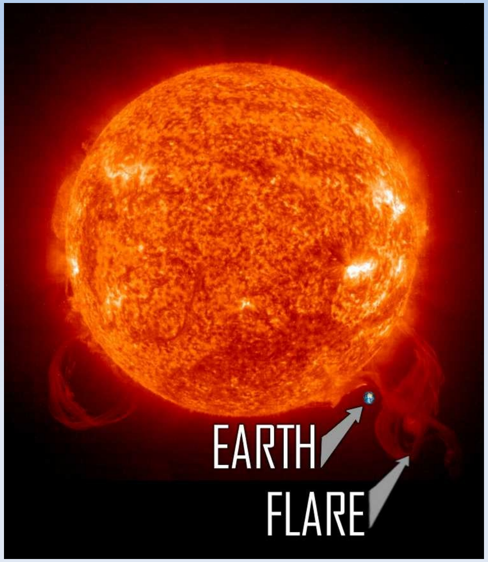


Solar Plasmas

Understanding interactions between plasma and magnetic field, especially in the solar atmosphere

Fundamental processes - magnetic reconnection, relaxation and particle acceleration

- **Solar flares**
  - What is the origin of energetic non-thermal particles in flares
- **Solar coronal heating**
  - How is solar coronal plasma heated to over 1 million K?
- **Reconnection in fusion plasmas**
  - Merging-compression in MAST Spherical Tokamak



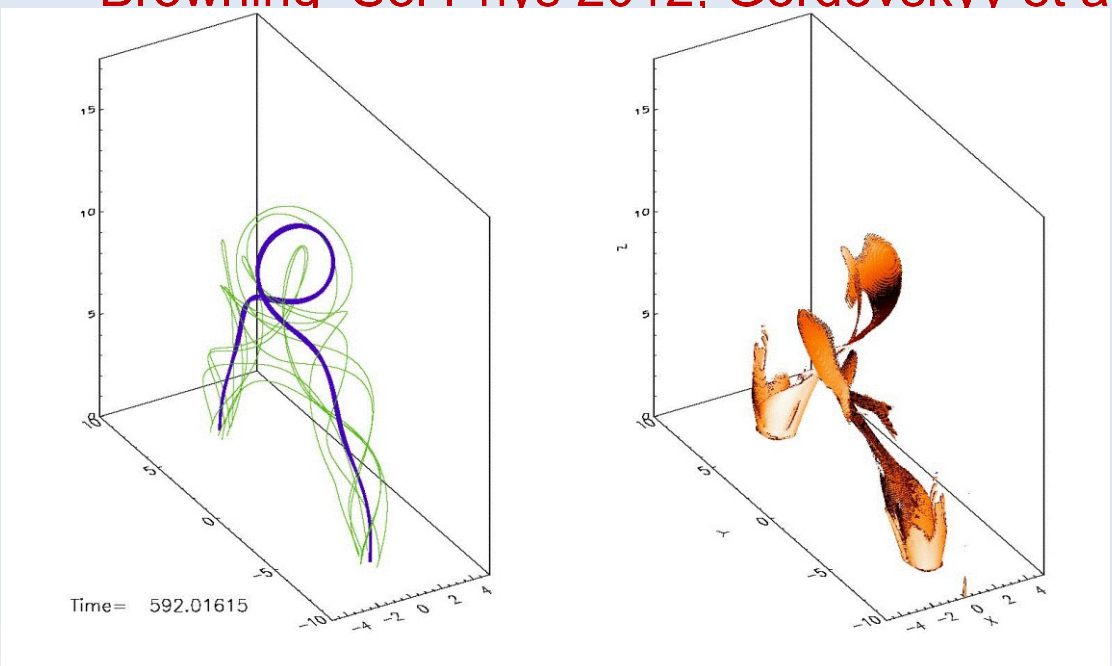
Current/recent research

How are charged particles accelerated in flares? Analytical or numerical model of electric and magnetic fields with test particle model – full trajectory or guiding-centre

Particle acceleration at 3D magnetic null points (e.g. Stanier et al A&A 2012)

Coupled time-dependent test particle and MHD simulations

- 2D fragmented current sheets (e.g. Gordovskyy et al Ap J 2010)
- High energy particles in unstable twisted loops (e.g. Gordovskyy and Browning Sol Phys 2012, Gordovskyy et al 2012)



Kink instability of unstable twisted loop leads to formation of fragmented current sheet
Strong electric fields accelerate charged particles
Recently - include loop curvature and collisions of test particles

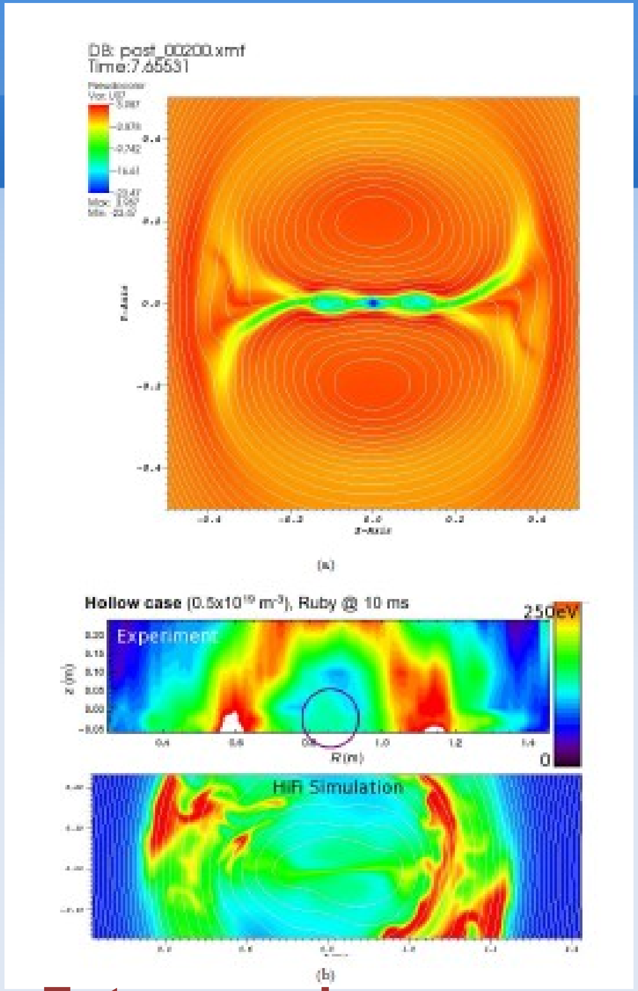
The solar corona may be heated by combined effect of many small "nanoflares"

- Simulations of unstable twisted loops and new "partial relaxation" model (e.g Hood et al 2009, Bareford et al 2012, Tam et al 2012)
- Distributions of nanoflares and relaxation-based models
- (e.g. Bareford et al 2011, 2012)

MHD, Hall MHD and PIC simulations of reconnection in merging plasmas relevant to MAST spherical tokamak –

High temperature laboratory plasma – may study processes relevant to solar corona (Stanier, Gordovskyy

in collaboration with Culham Laboratory



Hall simulations (2D) with HiFi code

Temperature – code + experiment

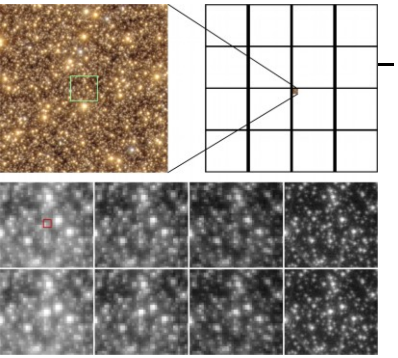
Future work

- Self consistent models of particle acceleration
- More realistic models of 3D nulls
- Comparison with data e.g. RHESSI, ALMA
- Coronal heating – role of field topology
- Partially ionised plasmas

Exoplanets and time-domain surveys

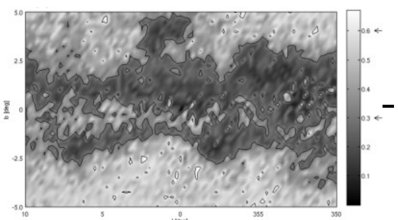
- Research areas:
  - Exoplanet detection with microlensing and transit techniques. Mostly theory.
  - VVV: near infrared variability survey with VISTA of the inner Galaxy. Difference imaging data reduction pipeline

Exoplanets



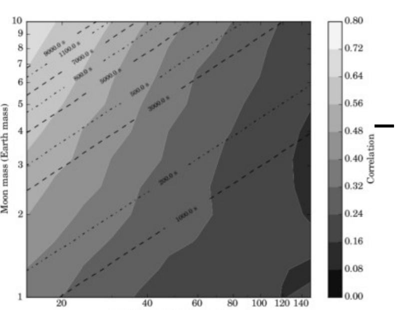
Plot by Matthew Penny

- Development of exoplanet detection as an additional science program with ESA Euclid dark energy mission. Co-leadership of Euclid Science Working Group



Plot by Makiko Ban

- Synthetic microlensing maps used to optimize exoplanet surveys and to understand Galactic structure

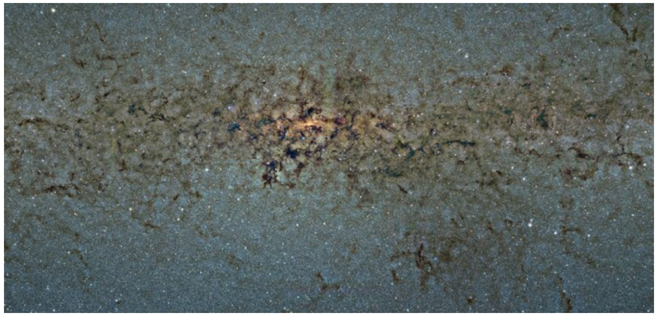


Plot by Supachai Awiphan

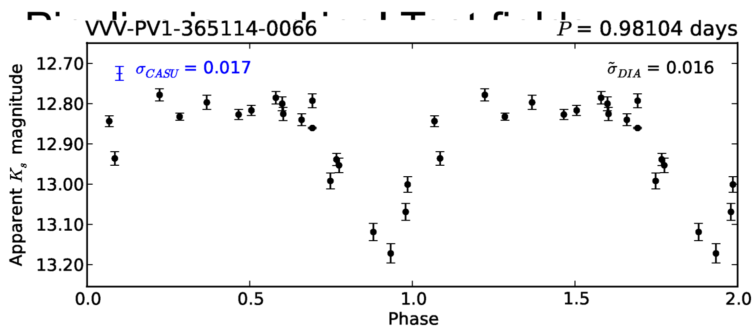
- Modeling Kepler sensitivity to transit timing variations due to an exomoon around a planet

VVV survey

- Largest ever survey of near-infrared time variability in inner Galaxy



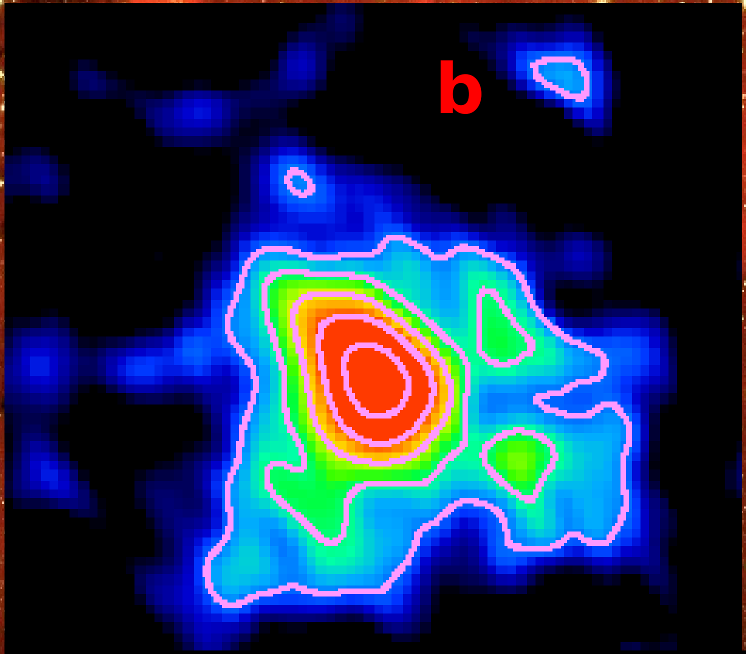
- Using VISTA: 5 year monitoring of 520 sq deg in K band + JYHZ colours.
- We are building the difference image photometry pipeline to reduce around 2.5 million images and find up to 10 million variable objects.



Plot by Leo Huckvale

Planets

- Formation of planets
  - cm-wave interferometry resolves clusters of cm-sized pebbles in protoplanetary discs
  - Planet Earth Building BLocks e-MERLIN legacy project
    - PI Greaves, also incl. Muxlow
- and their atmospheres
  - ALMA observations of CO around Pluto and other minor Kuiper Belt planets.



Greaves, Rice, Richards, Muxlow VLA+PT, 22 GHz

Stars: The Beginning

UMIST RATE12 / astrochemistry.net

- 5th public release (1991, 1995, 1999, 2006, 2012)
- most comprehensive resource for astrochemistry online
- integration brings models, commenting & analysis
- new chemistry (anions), many updates
- benchmark models released – dark cloud, C-rich AGB CSE
- deuterium network released for the first time
- ortho/para network
- comparison of models between networks
- sensitivity analysis published for the first time
- paper in submission, nice referee report received

spectrafactory

- >60000 spectra served
- major update in preparation

splatalogue

- most comprehensive database of astrophysically relevant spectral line data ever compiled
- fully integrated in ALMA OT and CASA

Theoretical Astrochemistry: current and future

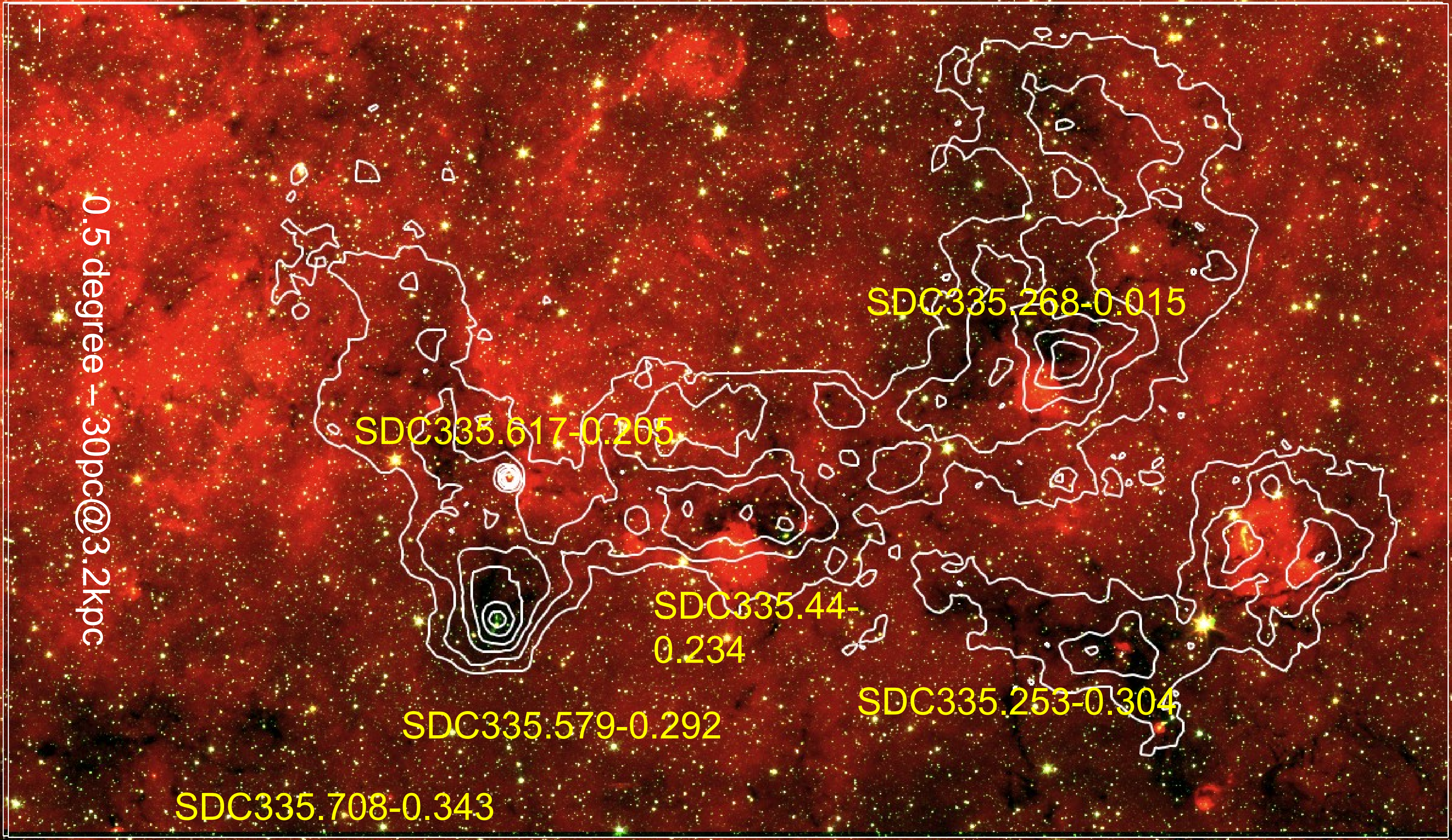
- isotope fractionation simultaneously in 2H, 13C, 18O (first ever model - Marion)
- clumpy ‘3D’ model of AGB envelope
- condensation sequence at low metallicity
- investigate newly observed and related species (e.g. CH3O, HNCNH, NH2CN)
- proper study of isomers, tautomers, linear and cyclic species
- resurrection of ISM – protoplanetary disk – comet work for Big Bright Comet 2013

Tools

- General RT:
- - 3 isotopologue SiO
- - analytical core/shell model (PN etc.)
- - finite element code
- Maser Studies:
- - book, ISBN978-0-521-87980
- - computer models (traditional)
- - population tracing (computer algebra)
- - fundamental properties (radiation stats.)

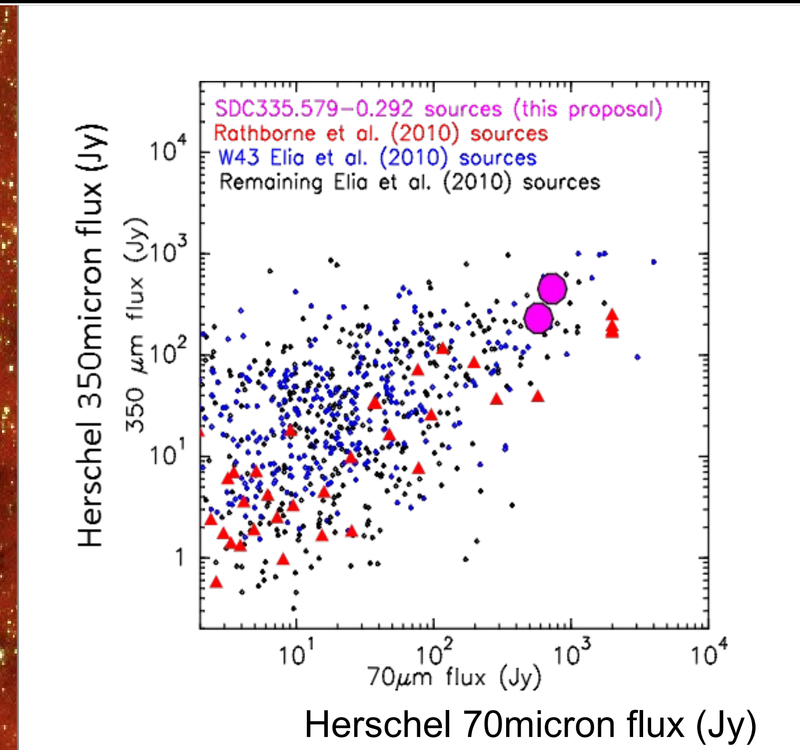
IRDC: Initial Conditions

Spitzer & Herschel surveys



A Massive Filamentary IRDC

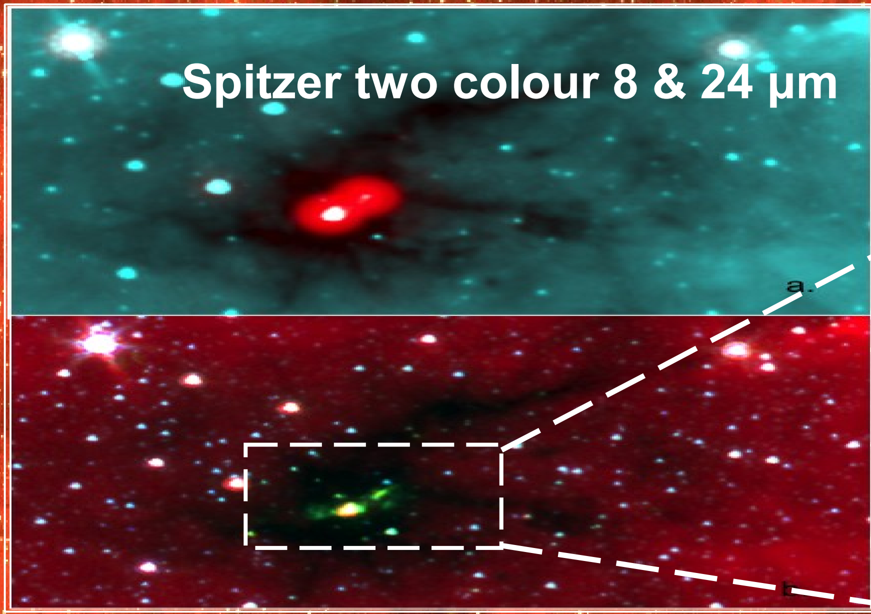
SDC335.579-0.292: 5000 Mo in a diameter of 2pc (@3.2kpc); Presence of an EGO (Cyganowski et al. 2008); No free-free emission (Garay et al. 2002)



Filamentary structures seen in silhouette converging toward central two very bright YSOs in far-IR with Herschel/Hi-GAL

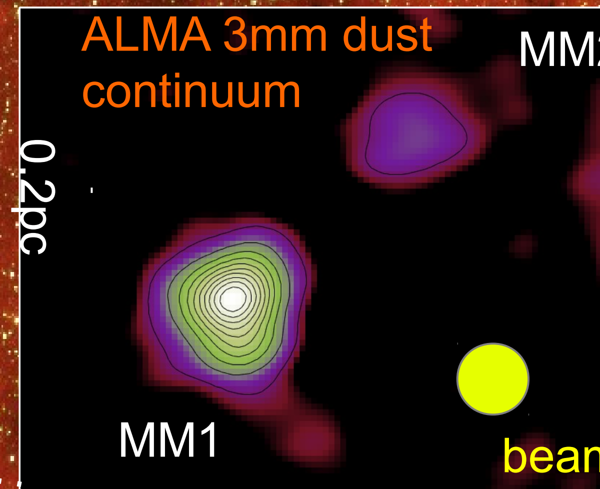
ALMA cycle 0 mosaic of 11 fields at 3mm in compact configuration (4" resolution):
Kinematics of the IRDC & the mass of central sources

The most massive protostar known?



3 arcmin - 3 pc

ALMA Cycle 0 observations

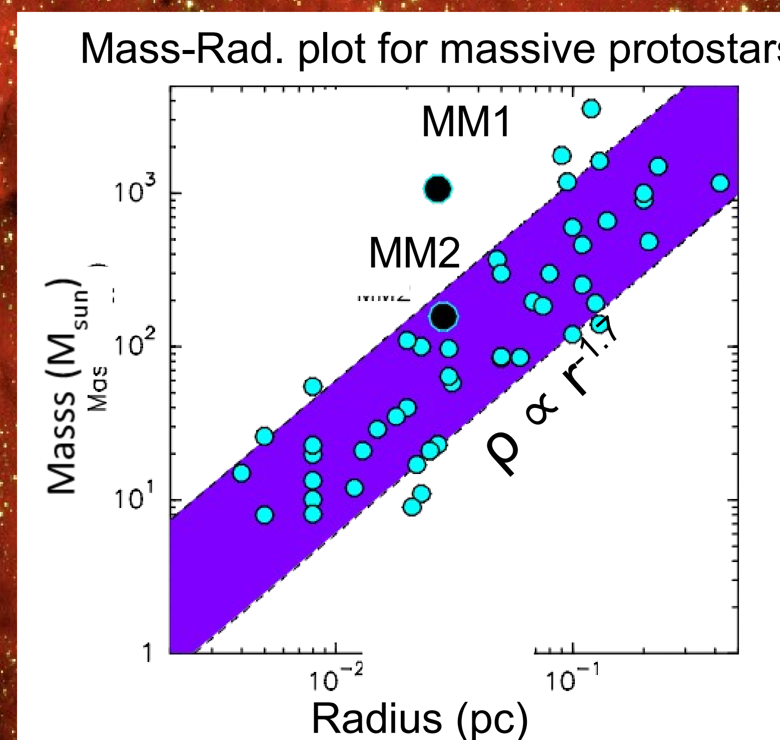


M_{H2}(MM1)=1000 M_{sun} in D_{dec}=0.05 pc (T_d=30K)

M_{H2}(MM2)=130 M_{sun} in D_{dec}=0.05 pc

MM1 is (one of) the most massive protostars ever observed

Sufficient mass within region to form very massive star & cluster



Peretto, Fuller, Duarte Cabral, et al., 2012 (in prep.)

ALMA: Dense Gas Velocity Field

Integrated $N_2H^+(1\text{-}0)$ (contours) on Spitzer 8micron image

Dense gas velocity field

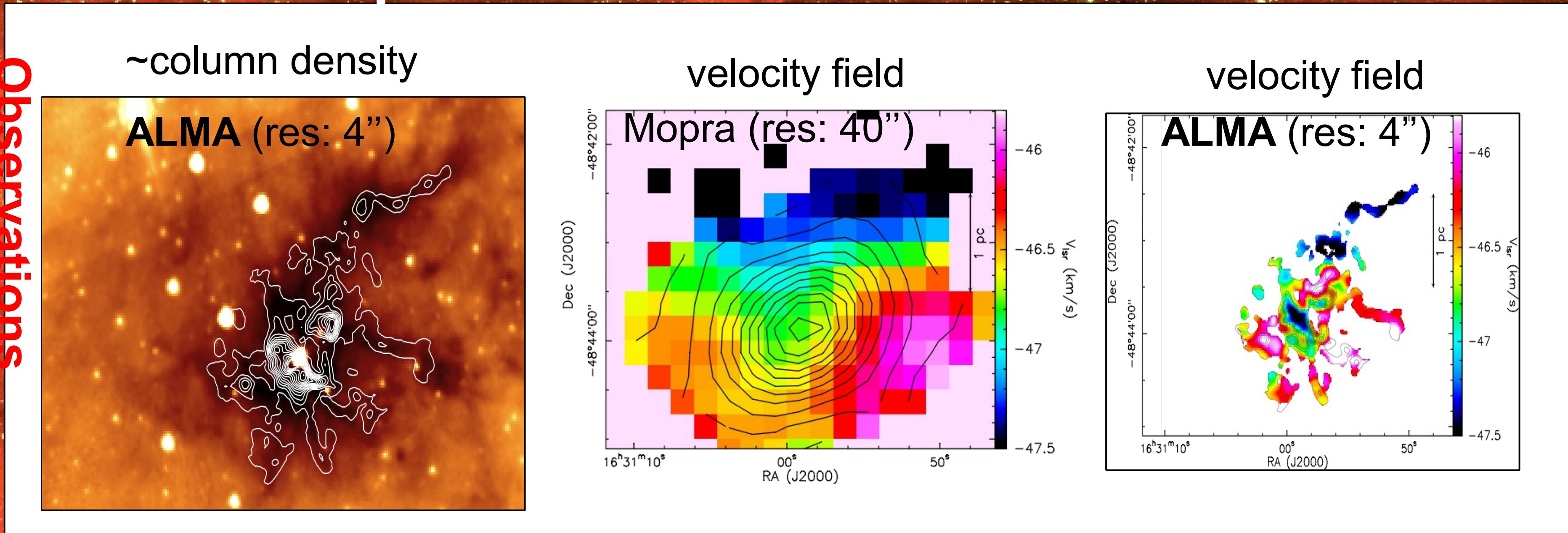
ALMA resolves velocity field – SDC335 is NOT a rotating pc-scale clump
Each filament shows uniform but different velocities (max 2 km/s difference)
Filaments are converging and overlap at the centre
The infall rate through filaments is ~ 10^{-3} M_{sun}/yr

This is consistent with a picture of pc-scale filamentary collapse set by large scale Jeans instability, feeding the two central massive protostars

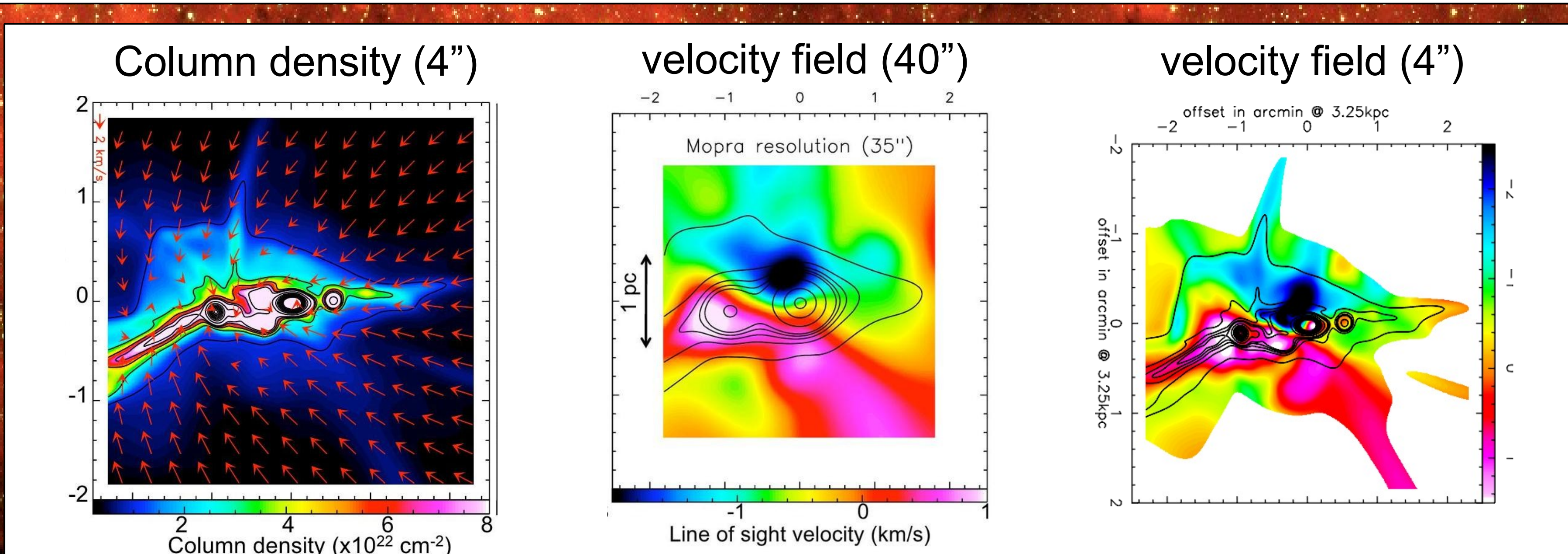
Peretto, Fuller, Duarte Cabral, et al., 2012 (in prep.)

Comparison with Simulations

Observations

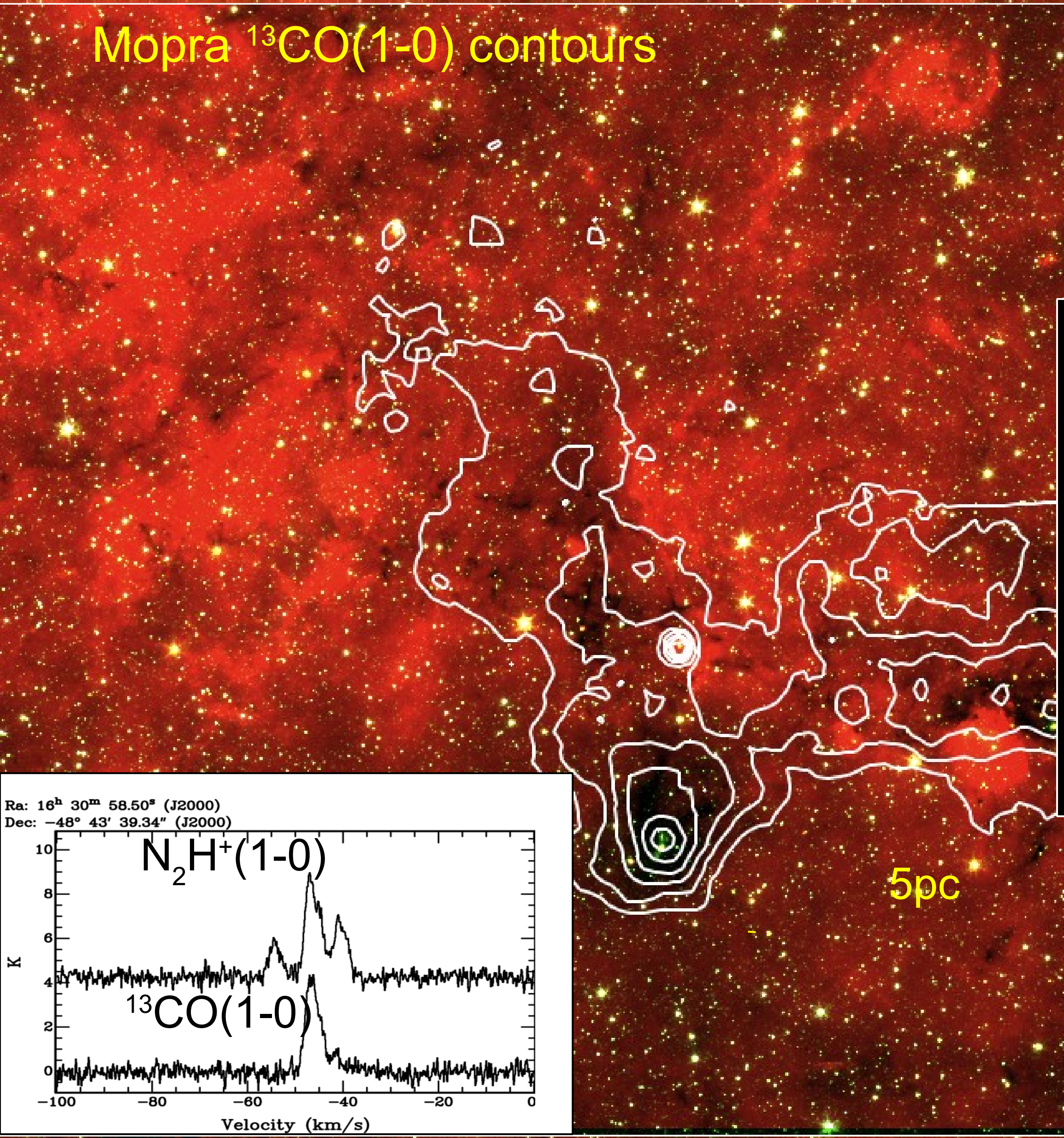


MHD Simulations



Simu. from Schneider et al. (2010), performed by P. Hennebelle

Large scale Jeans fragmentation of a molecular cloud



Jeans analysis:

$$M_J = 10.7 M_\odot \times \left(\frac{\sigma_{H_2}}{0.2\ km/s}\right)^3 \left(\frac{n}{10^3 cm^{-3}}\right)^{-0.5}$$

$$L_J = 0.73\ pc \times \left(\frac{\sigma_{H_2}}{0.2\ km/s}\right)\left(\frac{n}{10^3 cm^{-3}}\right)^{-0.5}$$

Large scale: σ_{13CO}= 1.4 km/s, n=10^3 cm^{-3}

M_J= 3600 M_{sun}; L_J = 5.1pc

M_{IRDC}=5000 M_{sun}; L_{IRDC}=3pc

Clump scale: σ_{N2H+}= 0.9 km/s, n=10^4 cm^{-3}

M_J= 1000 M_{sun} ; L_J = 1pc

M_{MM1}=1000M_{sun}; L_{MM1}< 0.1pc

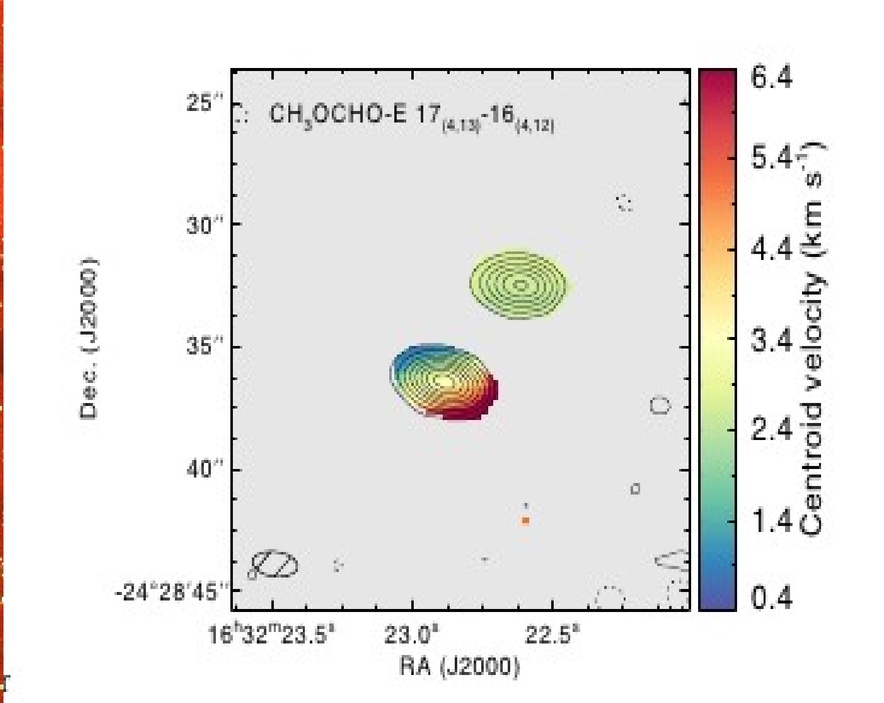
$$t_{ff} = 1.07\ Myr \times \left(\frac{n}{10^3 cm^{-3}}\right)^{-0.5}$$

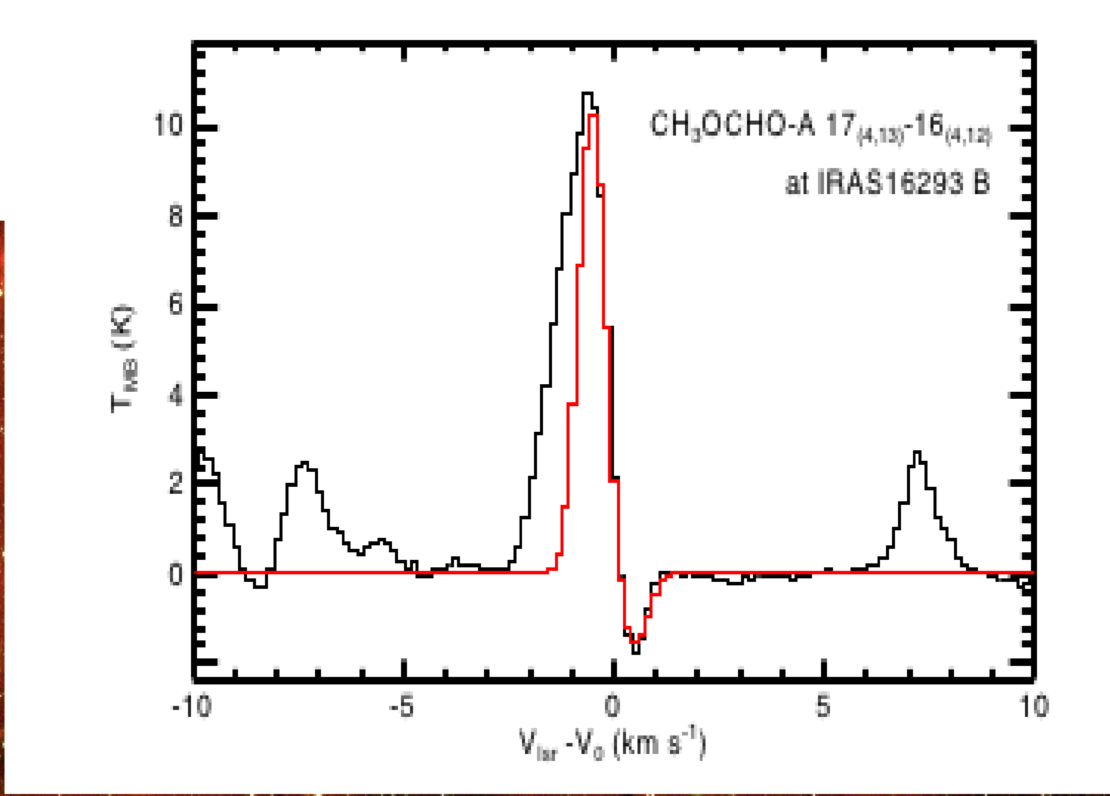
$$< V_{ff} >= \frac{1}{2} L_J / t_{ff} = 0.33\ km/s \times \left(\frac{\sigma_{H_2}}{0.2\ km/s}\right)$$

$<V_{ff}>$ = 1.3-1.7 km/s

Peretto, Fuller, Duarte Cabral, et al., 2012 (in prep.)

Infall Of Gas to Make the Stars



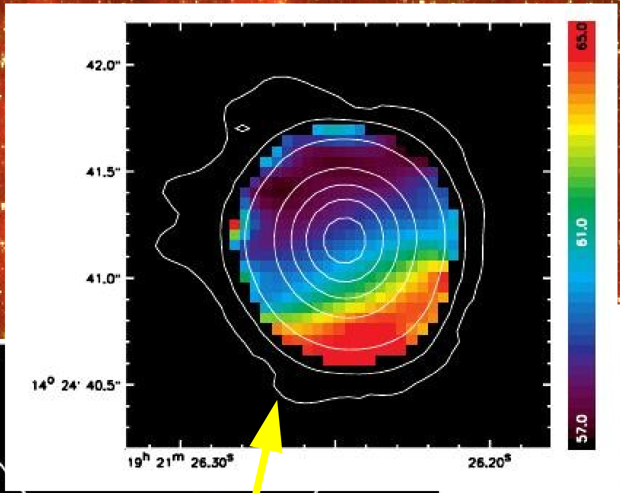


ALMA Science Verification data
Pineda et al. 2012

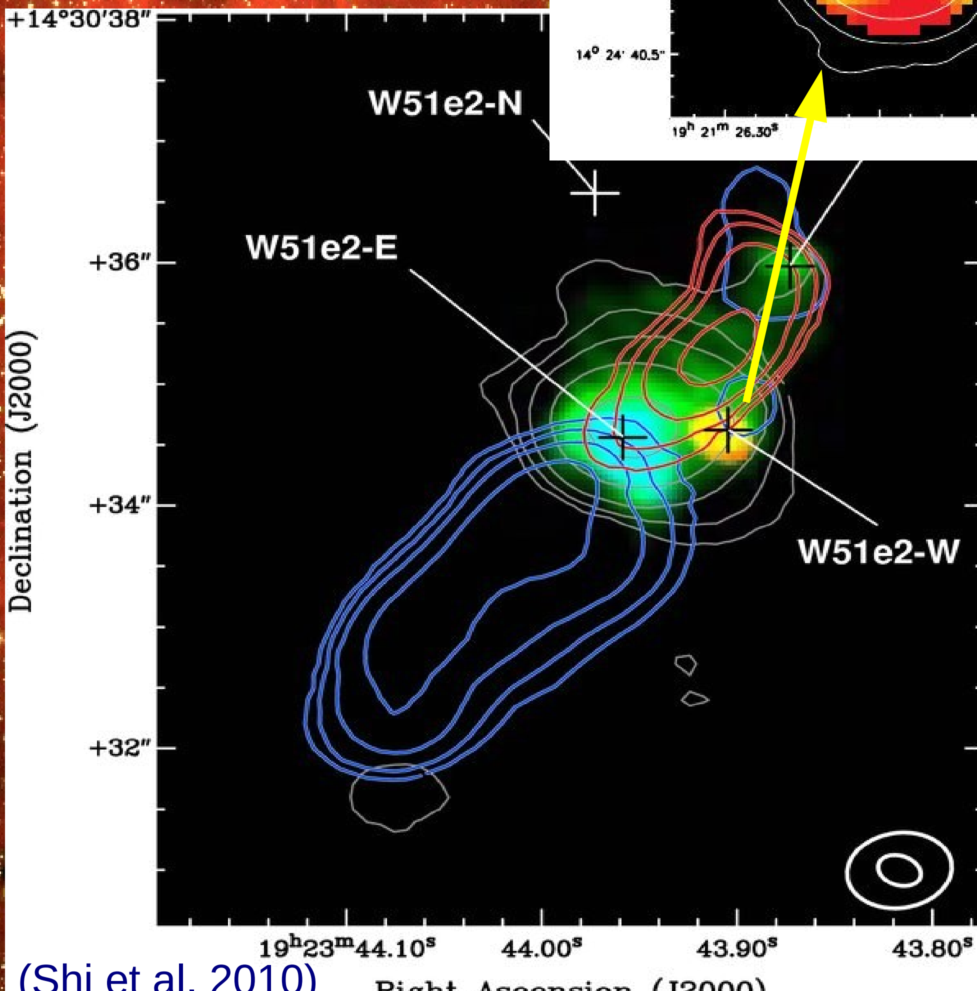
The inner most regions

W51e2
Outflow
dv~200 km/s

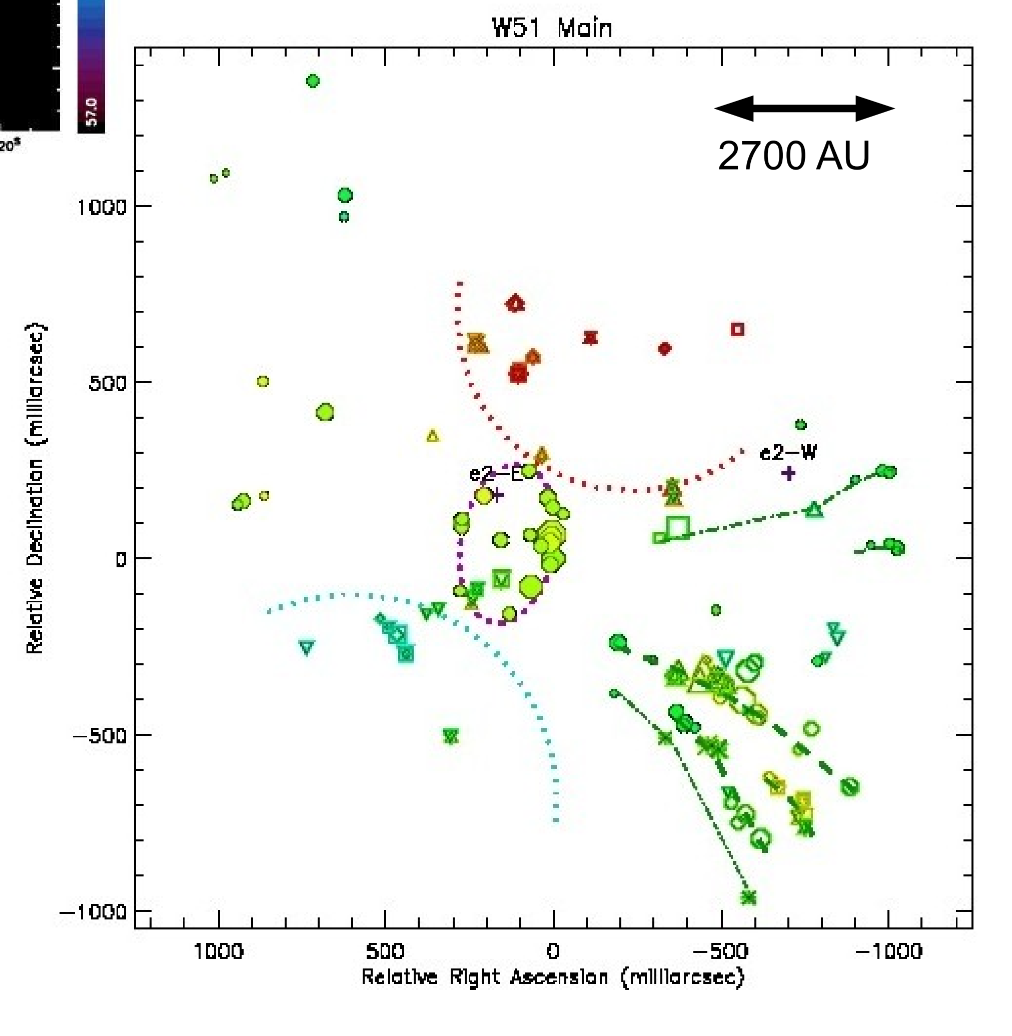
HII recomb. Line velocity gradient
(Keto & Klaassen 2008)

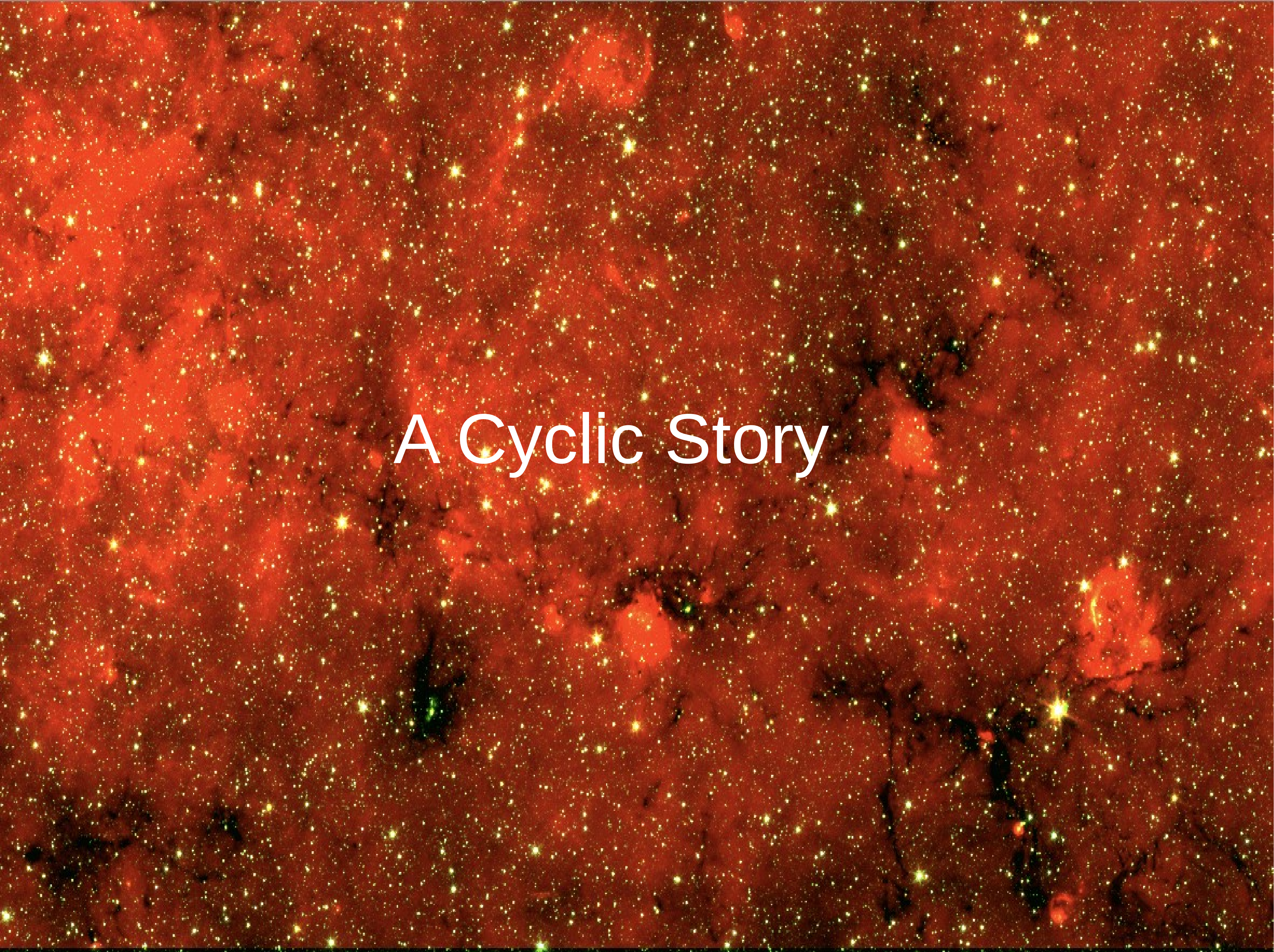


Methanol & OH masers
(Etoka, Gray & Fuller 2011)



(Shi et al. 2010)




A Cyclic Story