Millimeter emission from "Water Fountain" evolved stars

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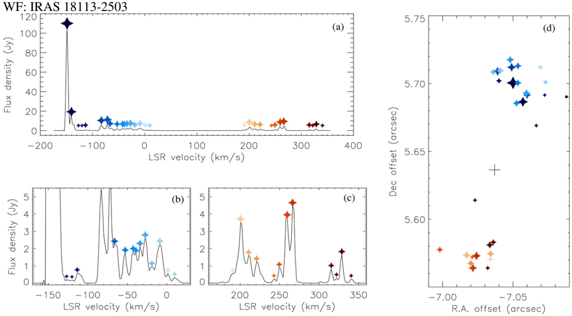
Water Fountains

- They are in a stage between AGB to PN, the exceptions are:
  a late AGB (W43A; *Imai et al. 2002*),
  a Young - PN (IRAS 15103-5754; *Suárez et al. 2009; 2013*)
- came from low to intermediate-mass stars ($0.8 - 8\,M_{\odot}$)
- show large (100-500 AU) and bipolar collimated jets.
- H_2O maser emision shows large velocities ($\gtrsim 100 \mathrm{km\ s^{-1}}$; *Gómez et al. 2011*)

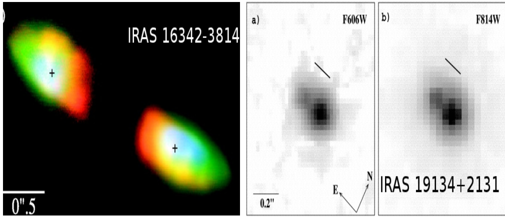
WF: IRAS 18113-2503



· So far 14 WF candidates are known to date.

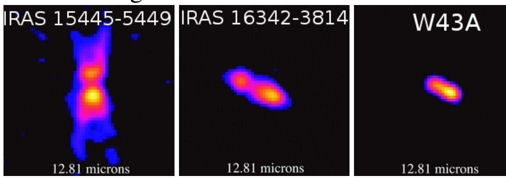
· Difficult to image, in the Optical and IR wavelenghts, due to their thick envelopes, but

· Optical images



(*Sahai et al. 1999*)

· Mid-IR images



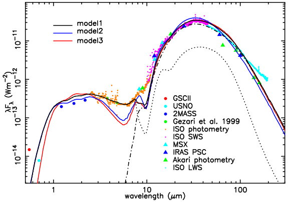
(*Lagadec et al. 2011*)

Motivation

- ♢ Gas & dust emission mapping @ mm/sub-mm would provide a direct determination of the circumstellar material.
- ♢ Modeling of the Spectral Energy Distribution (SED) from IR to mm allows us to determine (or constrain) important physical parameters such as: central star luminosity, circumstellar masses, and distances.
- ♢ Scarce continuum data @ mm/sub-mm for WF (except for IRAS 16342-3814 *Ladjal et al. 2010; Guertler et al. 1996*). Observed but not detected: IRAS 18043-2116 (*Imai et a.ł2012*); IRAS 18286-0959 (*Imai et al. 2009*); IRAS 18460-0151 & IRAS 19134+2131 (*Sanchez Contreras & Sahai 2012*)
- ♢ We modified models of the envelope and disk around young stellar objects (*Kenyon, Calvet & Hartmann 1993*; *D′Alessio et al. 2003*) in order to use them to fit the SED of WFs.

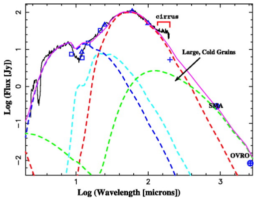
Previous Modeling

+ WF: IRAS 16342-3814 (*Murakawa & Izumiura, 2012*) → multiple components: $R_{inner\ disk} = 200$ AU, $R_{torus} = 1000$ AU, $R_{bipolar\ lobes} = 5000$ AU and $R_{env} = 12000$ AU.



870 μm & 1130 μm (*Ladjal et al. 2010; Guertler et al. 1996*)

+ Another example of evolved star is the proto-PN IRAS 22036+5306 (*Sahai, et al. 2006*) → Modeled as separated Black Bodies: Total spectra: $T_{cool\ env} \sim 67$K, $T_{warm\ env} \sim 145$K, $T_{hot\ inner\ disk} \sim 1000$K, $T_{large\&cold\ grains} \sim 50$K



Millimeter Observations

We observed 11 of the 14 WF candidates to date

Source	S_{249GHz} (mJy)	S_{93GHz} (mJy)	S_{99GHz} (mJy)
IRAS 15445-5449	⋯	5.9±2.3	6.9±2.4
IRAS 15544-5332	⋯	< 0.14	< 0.08
IRAS 16342-3814	⋯	7.5±2.3	8.1±2.5
IRAS 16552-3050	19±3	0.53±0.24	0.6±0.4
IRAS 18043-2116	21±10	⋯	⋯
OH 12.8 - 0.90	12±6	⋯	⋯
IRAS 18286-0959*	62±9	⋯	⋯
W43A	350±50	9±3	13.0±0.4
IRAS 18460-0151*	24±5	⋯	⋯
IRAS 18596+0315	16±4	⋯	⋯
IRAS 19134+2131*	6.9±2.1	⋯	⋯

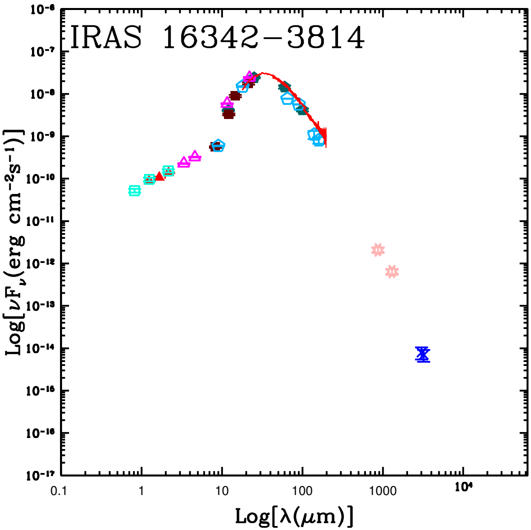
+ IRAM 30-meter telescope: 1.2mm (249 GHz)

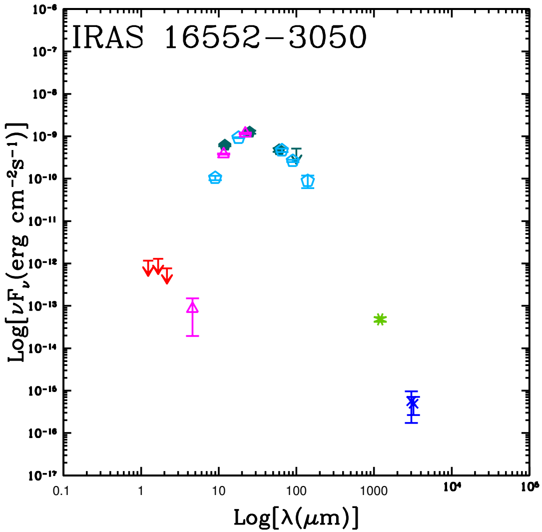
+ ATCA - Australia Telescope Compact Array: 3.3mm (93 GHz), 3.0mm (99 GHz)

* Annual parallax distance. Kinematic distance.

Spectral Energy Distribution

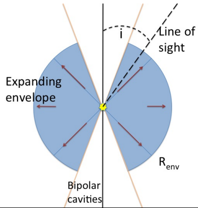
- 2MASS, Denis, MSX, Spitzer, WISE, IRAS, Akari, APEX, IRAM, ATCA, and ISO spectroscopy.
- Our main aim is to model the spectra from 3 μm to mm wavelenght range
- We do not pretend to model the SED below 3 μm due to scattering.

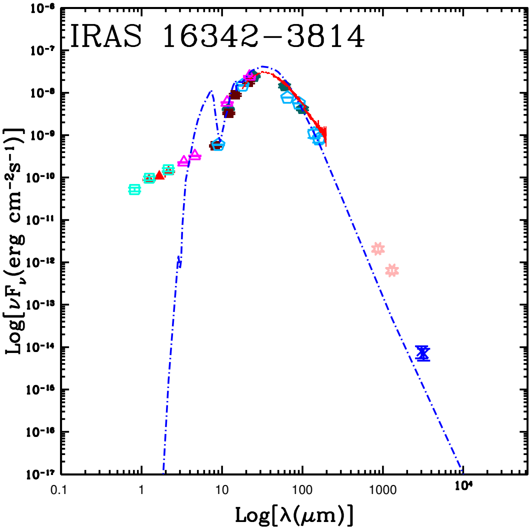


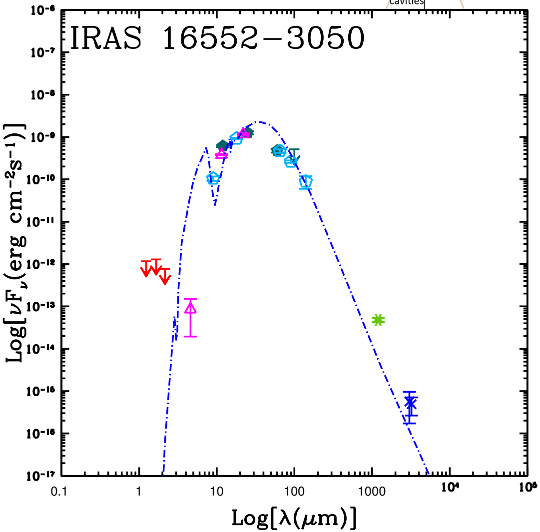


Model: Envelope

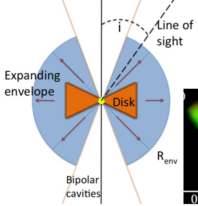
- Expanding envelope ($\rho \propto r^{-2}$) heated from the star.
  Temp. calculated from radiative equilibrium (*Kenyon, Calvet & Hartmann 1993*).
  openning angles of cavities: 20°, R_{env} = 10000AU
- Dust grain mixture includes silicates & graphites of millimeter size.

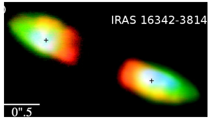




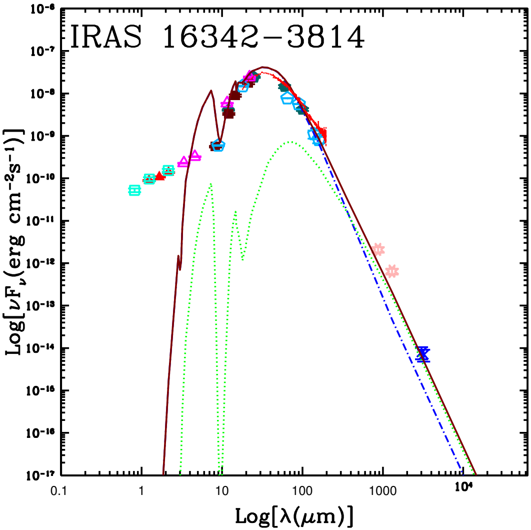


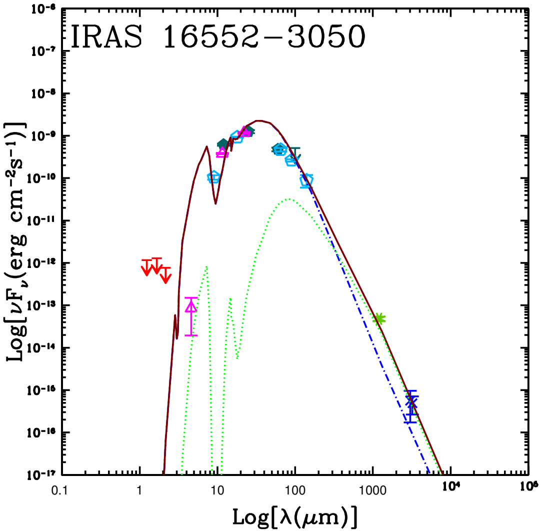
Model: Envelope + Disk

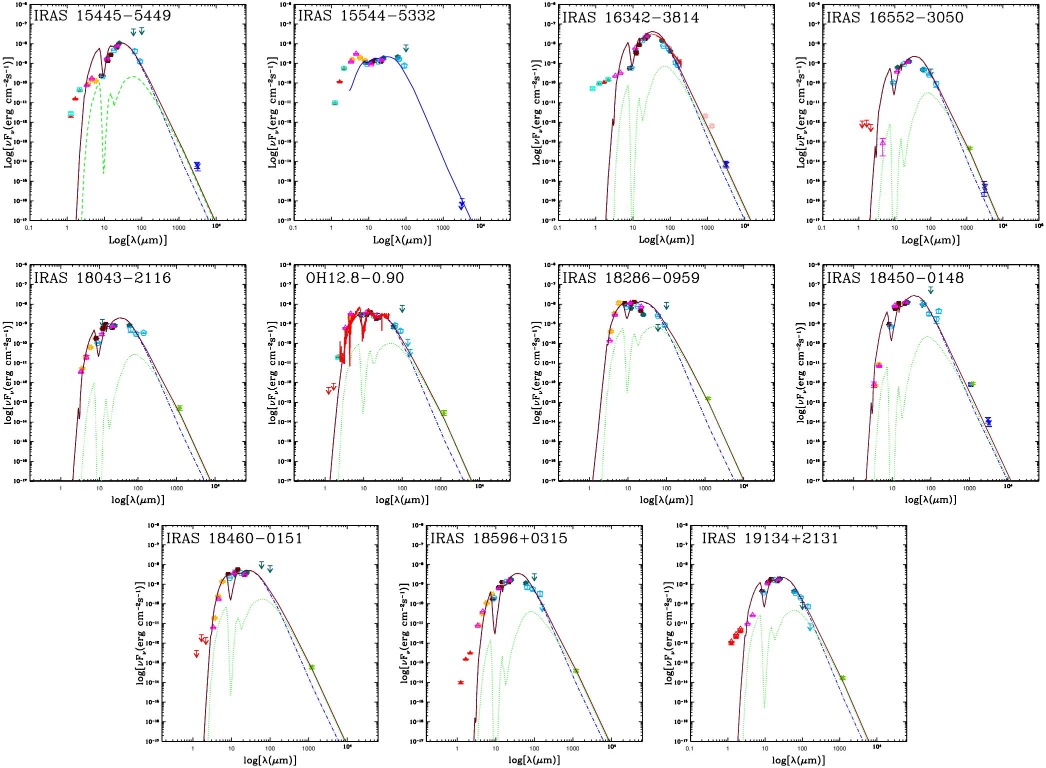




- We adapted flared passive disk (*D'Alessio et al. 2001; 2006*) with R_{disk} = 750 AU
- Dust grain mixture includes silicates & graphites of millimeter size







Durán-Rojas et al. in prep.

Obtained parameters of the modeled Water Fountains

Identifier	L_* ($L_\odot$)	i (degree)	$M_{\rm env}$ ($M_\odot$)	$M_{\rm disk}$ ($M_\odot$)	$M_{\rm tot}$ ($M_\odot$)	D
IRAS 15445-5449	6000	50	0.8	2.1	2.9	3.5
IRAS 15544-5332	1000	30	1.1	...	1.1	4.0
IRAS 16342-3814	6000	30	1.8	1.9	3.7	2.0
IRAS 16552-3050	3000	30	1.5	2.4	3.9	6.0*
IRAS 18043-2116	3000	30	1.5	2.4	3.9	6.4
OH 12.8 - 0 .90	10000	30	0.5	1.6	2.1	8.0
IIRAS 18286-0959*	7500	30	0.5	1.9	2.4	3.6
W43A	6000	30	2.8	1.9	4.7	2.6
IRAS 18460-0151*	1000	40	0.3	0.2	0.5	2.1
IRAS 18596+0315	3000	50	1.5	1.8	3.3	4.6*
IRAS 19134+2131*	6000	40	0.8	1.9	2.7	8.0

$M_{\rm tot} = M_{\rm env} + M_{\rm disk}$
$R_{\rm env}$=10000 AU
$R_{\rm disk}$=750 AU

Parameters strongly depend on distance

* Annual parallax distance
* The shortest kinematic distance

Durán-Rojas et al. in prep.

Conclusions

- We were able to fit the Spectral Energy Distribution (SED) of the WFs from NIR to mm wavelengths using an expanding envelope and a circumstellar disk.
- We obtained that the central star luminosity of the WFs are in the range of $10^3 - 10^4 L_\odot$.
- The mass of the envelope (R_{env} = 10000 AU):
  $0.3\ M_\odot \leq M_{env} \leq 2.8\ M_\odot$.
- In order to fit the mm data a massive disk is requiered (R_{disk} = 750 AU):
  $0.5\ M_\odot \leq M_{disk} \leq 2.5\ M_\odot$.

  It suggests that $\Longrightarrow$ relatively massive progenitors.
- The modeling and the obtained parameters strongly depend on distance and in some cases the fit enable us to derive the distance.