

Young extrasolar planetary systems: formation, evolution and star-planet interaction



AUDIZIONI SCHEDE INAF – 19-20 MAGGIO 2021

S. BENATTI (OAPA), A. F. LANZA (OACT) & TEAM EXO-YOUNG + EXO-SPI

EXO-Young and EXO-SPI

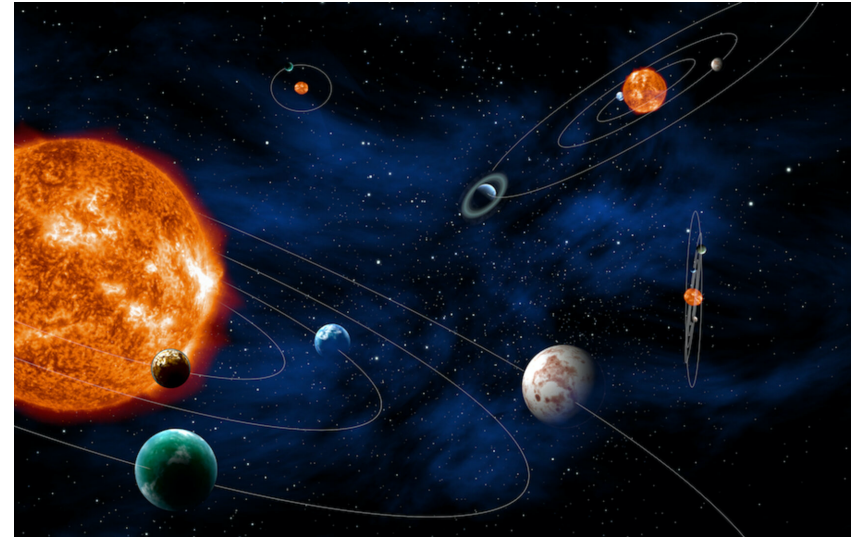
Why do we study **young extrasolar planets**?

- ▶ To understand the initial conditions of the planetary systems: planet formation and migration mechanisms

- ▶ To validate theoretical models

Where can we find them and how?

- ▶ Large separation (imaging)
- ▶ Short separation (transits, radial velocity)



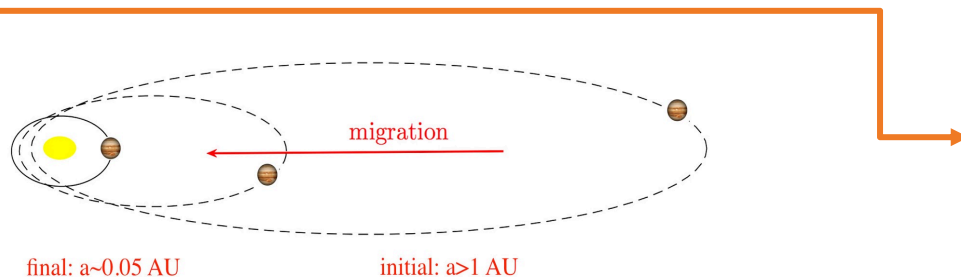
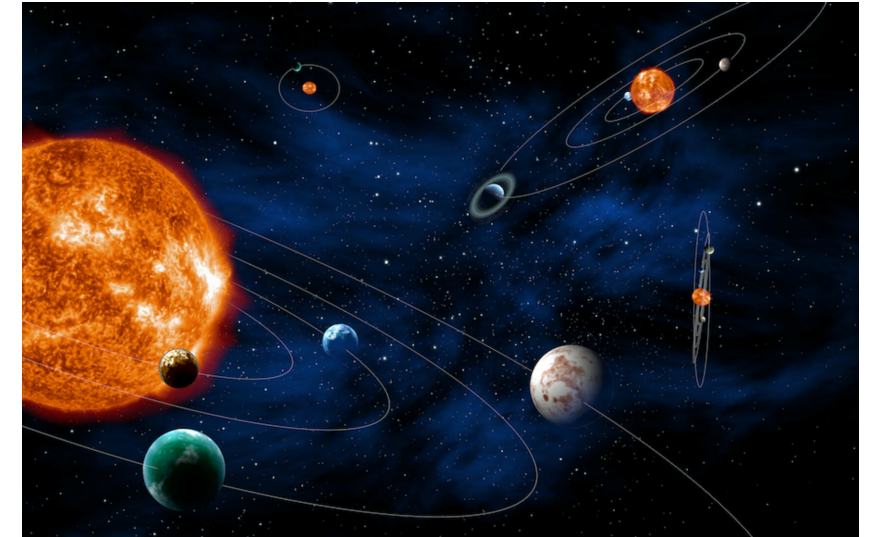
EXO-Young and EXO-SPI

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Star-planet interaction

- ▶ Mostly operating at close distances ($\lesssim 0.2$ au) and within 1 Gyr
- ▶ Crucial in the orbital circularization in case of high-eccentricity migration (not only for young planets)

An Overview on the EXO-Young & EXO-SPI: Schede madri – schede figlie

EXO-Young

Formazione ed
evoluzione iniziale
di sistemi planetari

Coord.: S. Benatti

Ongoing projects
Submitted projects
Instruments/Space missions

AMS
EXO-DEMO
ERIS
EXO-FAMILIES
SHARK-NIR
SHARK-VIS
SPHERE-GTO
SPHERE+
EXO-SELENE
TASSEL

GAPS2
PLATEA
THE-StellaR-Path
ARIEL
PLATO

EXO-SPI

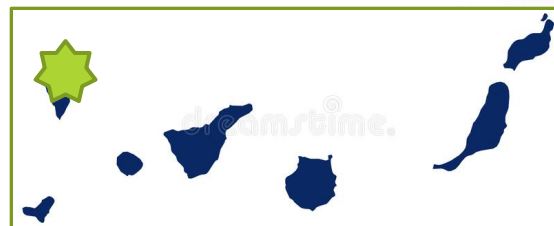
Interazione stella-
planeta in sistemi
planetari extrasolari

Coord.:
A. F. Lanza

CHEOPS
HARPS-N/GTO
HOT-ATMOS
Ecube
ACMEonJAM
CLIMAX
DaZzLING
Athena

EXO-Young & EXO-SPI: our Team

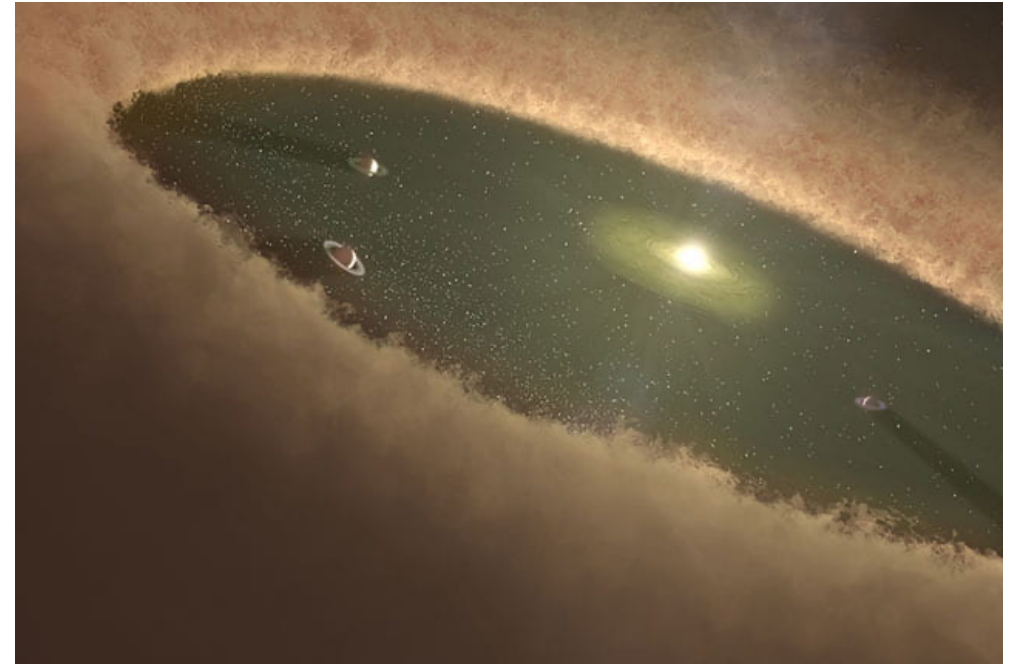
- ▶ 11 INAF Institutes
- ▶ TNG – FGG
- ▶ Collaborators in 15 national and international institutions including 7 Italian Universities
- ▶ About 100 researchers
- ▶ FTE INAF TI (2021-23)= 26.5
- ▶ FTE INAF TD (2021-23)= 17



Science: key questions

What is the **origin** of the planetary system **diversity**?

- ▶ What are the properties of the young exoplanet population at **large separation**?
- ▶ What are the properties of the young **close-in** exoplanet population?
- ▶ Young close-in planets: what is the role of the atmospheric **evaporation** induced by the high-energy irradiation and the S-P **tidal** heating?
- ▶ How do the planets **form** and **evolve**?

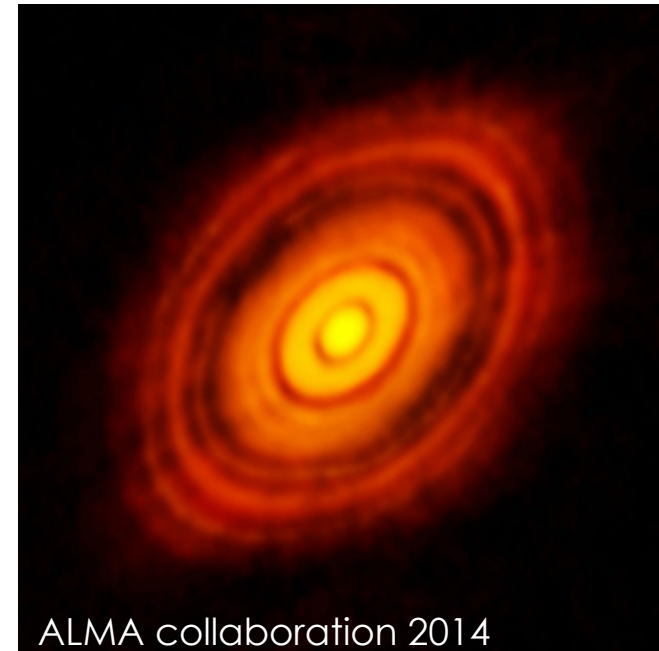


Science: results & perspectives

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Planets form at large separation from the central star (tens to hundreds of au)



ALMA collaboration 2014

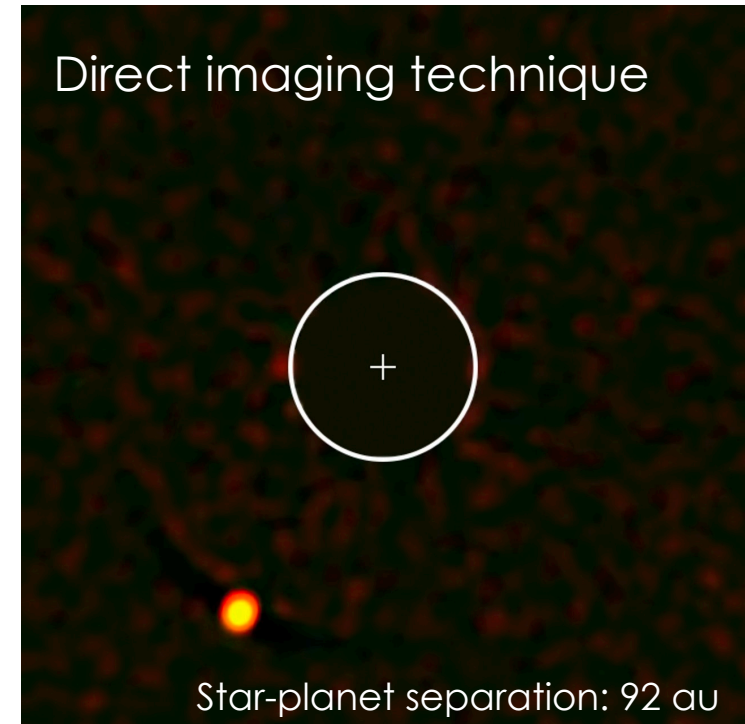
At this stage, planets experience contraction, they are hot and bright: they can be observed!

Science: results & perspectives

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Direct imaging technique

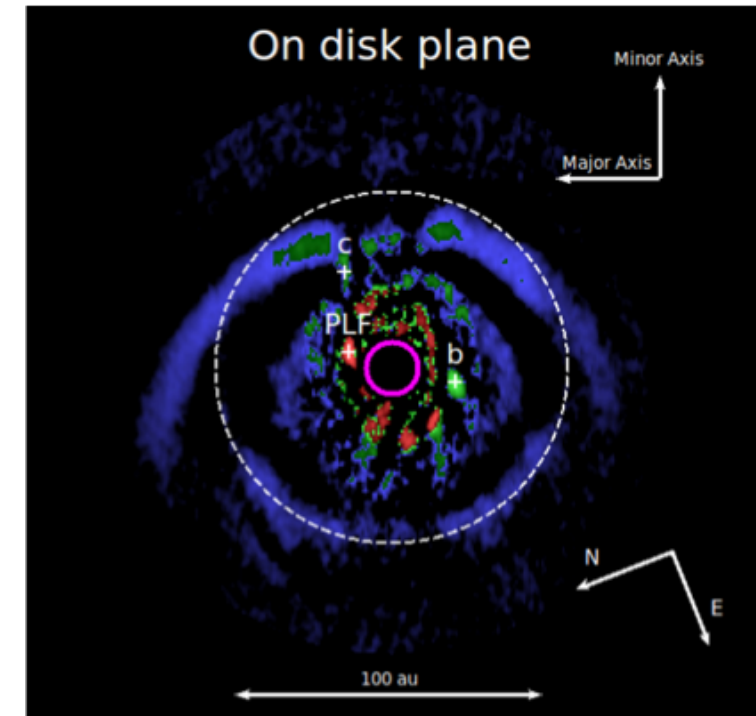


Chauvin, Desidera et al. 2017: HIP 65426 b, the first planet from the SHINE survey with SPHERE@VLT

Science: results & perspectives

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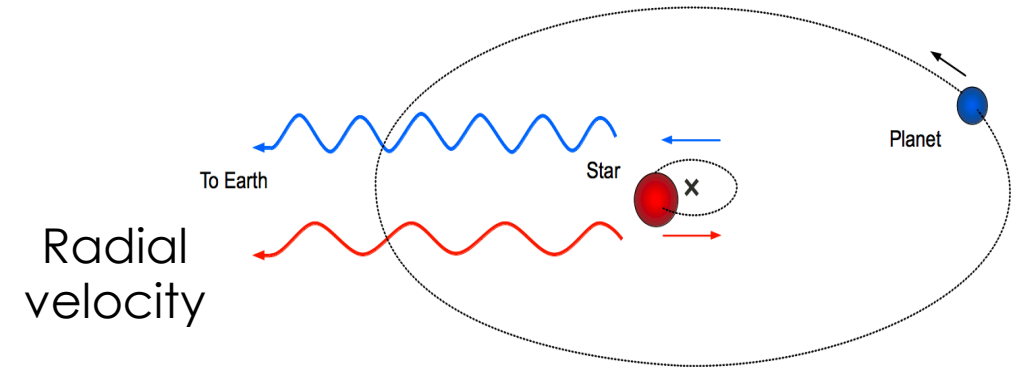
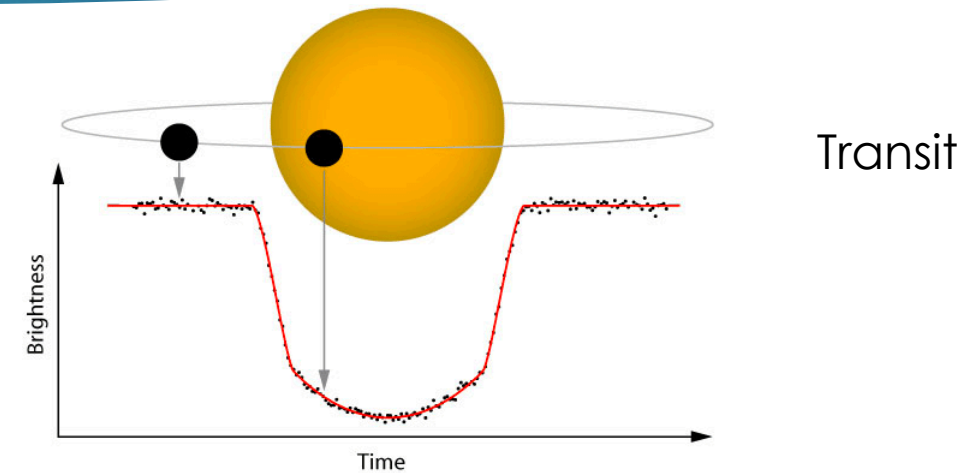


Mesa et al. 2019: the system of PDS70 revealed through the dust of the disk shows one additional structure, still not constrained

Science: results & perspectives

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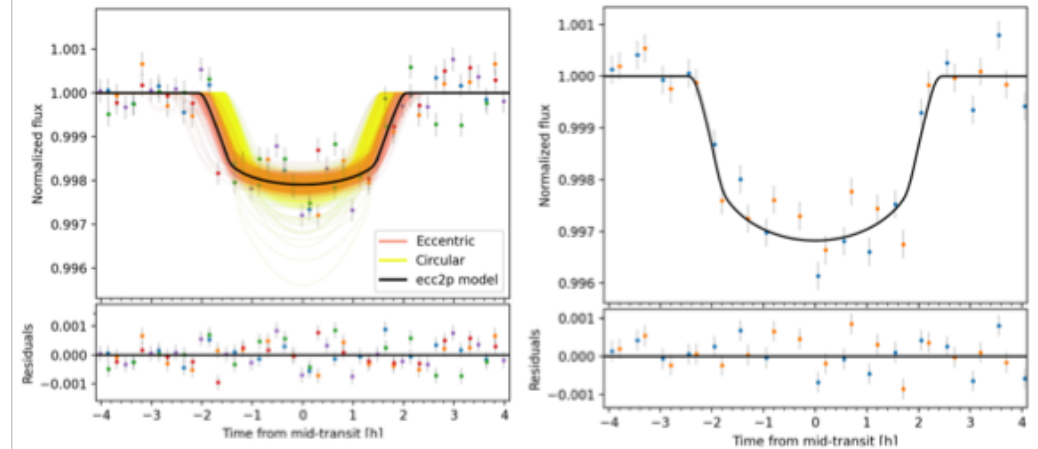


Science: results & perspectives

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Planets at young ages seem to have relatively small radii, in contrast with the previous claims

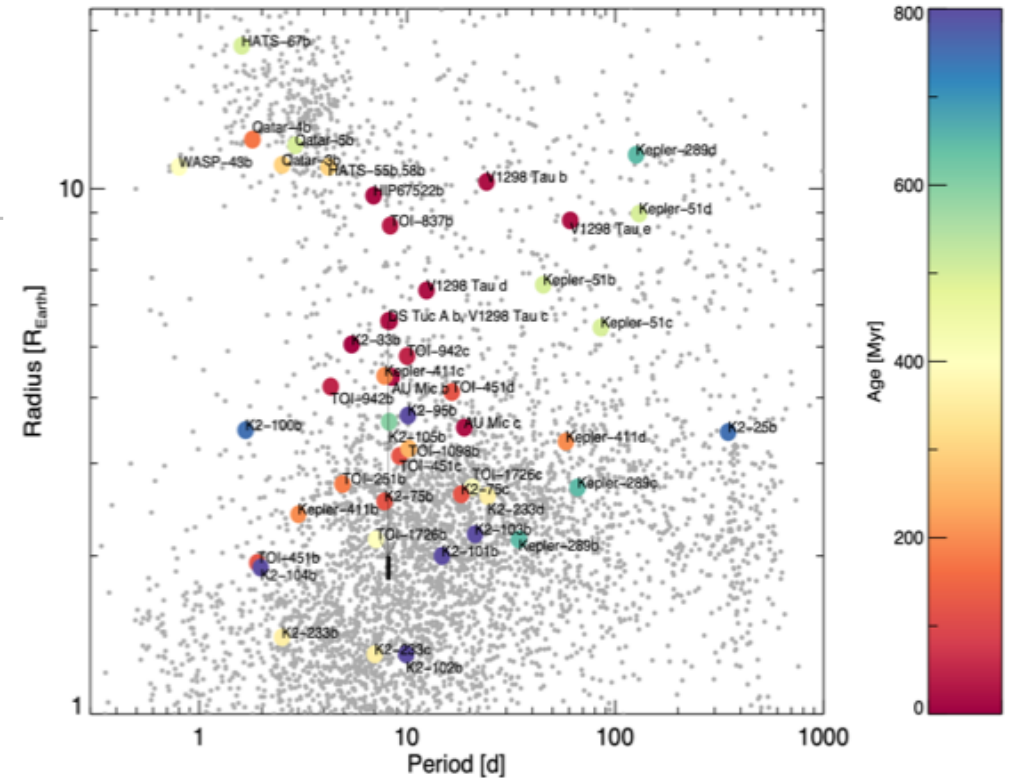


Carleo et al. 2021: two Neptune size planets around the 50 Myr old K2 star TOI-942

1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023, 2024, 2025, 2026, 2027, 2028, 2029, 2030, 2031, 2032, 2033, 2034, 2035, 2036, 2037, 2038, 2039, 2040, 2041, 2042, 2043, 2044, 2045, 2046, 2047, 2048, 2049, 2050, 2051, 2052, 2053, 2054, 2055, 2056, 2057, 2058, 2059, 2060, 2061, 2062, 2063, 2064, 2065, 2066, 2067, 2068, 2069, 2070, 2071, 2072, 2073, 2074, 2075, 2076, 2077, 2078, 2079, 2080, 2081, 2082, 2083, 2084, 2085, 2086, 2087, 2088, 2089, 2090, 2091, 2092, 2093, 2094, 2095, 2096, 2097, 2098, 2099, 2100, 2101, 2102, 2103, 2104, 2105, 2106, 2107, 2108, 2109, 2110, 2111, 2112, 2113, 2114, 2115, 2116, 2117, 2118, 2119, 2120, 2121, 2122, 2123, 2124, 2125, 2126, 2127, 2128, 2129, 2130, 2131, 2132, 2133, 2134, 2135, 2136, 2137, 2138, 2139, 2140, 2141, 2142, 2143, 2144, 2145, 2146, 2147, 2148, 2149, 2150, 2151, 2152, 2153, 2154, 2155, 2156, 2157, 2158, 2159, 2160, 2161, 2162, 2163, 2164, 2165, 2166, 2167, 2168, 2169, 2170, 2171, 2172, 2173, 2174, 2175, 2176, 2177, 2178, 2179, 2180, 2181, 2182, 2183, 2184, 2185, 2186, 2187, 2188, 2189, 2190, 2191, 2192, 2193, 2194, 2195, 2196, 2197, 2198, 2199, 2200, 2201, 2202, 2203, 2204, 2205, 2206, 2207, 2208, 2209, 2210, 2211, 2212, 2213, 2214, 2215, 2216, 2217, 2218, 2219, 2220, 2221, 2222, 2223, 2224, 2225, 2226, 2227, 2228, 2229, 2230, 2231, 2232, 2233, 2234, 2235, 2236, 2237, 2238, 2239, 2240, 2241, 2242, 2243, 2244, 2245, 2246, 2247, 2248, 2249, 2250, 2251, 2252, 2253, 2254, 2255, 2256, 2257, 2258, 2259, 2260, 2261, 2262, 2263, 2264, 2265, 2266, 2267, 2268, 2269, 2270, 2271, 2272, 2273, 2274, 2275, 2276, 2277, 2278, 2279, 2280, 2281, 2282, 2283, 2284, 2285, 2286, 2287, 2288, 2289, 2290, 2291, 2292, 2293, 2294, 2295, 2296, 2297, 2298, 2299, 2300, 2301, 2302, 2303, 2304, 2305, 2306, 2307, 2308, 2309, 2310, 2311, 2312, 2313, 2314, 2315, 2316, 2317, 2318, 2319, 2320, 2321, 2322, 2323, 2324, 2325, 2326, 2327, 2328, 2329, 2330, 2331, 2332, 2333, 2334, 2335, 2336, 2337, 2338, 2339, 2340, 2341, 2342, 2343, 2344, 2345, 2346, 2347, 2348, 2349, 2350, 2351, 2352, 2353, 2354, 2355, 2356, 2357, 2358, 2359, 2360, 2361, 2362, 2363, 2364, 2365, 2366, 2367, 2368, 2369, 2370, 2371, 2372, 2373, 2374, 2375, 2376, 2377, 2378, 2379, 2380, 2381, 2382, 2383, 2384, 2385, 2386, 2387, 2388, 2389, 2390, 2391, 2392, 2393, 2394, 2395, 2396, 2397, 2398, 2399, 2400, 2401, 2402, 2403, 2404, 2405, 2406, 2407, 2408, 2409, 2410, 2411, 2412, 2413, 2414, 2415, 2416, 2417, 2418, 2419, 2420, 2421, 2422, 2423, 2424, 2425, 2426, 2427, 2428, 2429, 2430, 2431, 2432, 2433, 2434, 2435, 2436, 2437, 2438, 2439, 2440, 2441, 2442, 2443, 2444, 2445, 2446, 2447, 2448, 2449, 2450, 2451, 2452, 2453, 2454, 2455, 2456, 2457, 2458, 2459, 2460, 2461, 2462, 2463, 2464, 2465, 2466, 2467, 2468, 2469, 2470, 2471, 2472, 2473, 2474, 2475, 2476, 2477, 2478, 2479, 2480, 2481, 2482, 2483, 2484, 2485, 2486, 2487, 2488, 2489, 2490, 2491, 2492, 2493, 2494, 2495, 2496, 2497, 2498, 2499, 2500, 2501, 2502, 2503, 2504, 2505, 2506, 2507, 2508, 2509, 2510, 2511, 2512, 2513, 2514, 2515, 2516, 2517, 2518, 2519, 2520, 2521, 2522, 2523, 2524, 2525, 2526, 2527, 2528, 2529, 2530, 2531, 2532, 2533, 2534, 2535, 2536, 2537, 2538, 2539, 2540, 2541, 2542, 2543, 2544, 2545, 2546, 2547, 2548, 2549, 2550, 2551, 2552, 2553, 2554, 2555, 2556, 2557, 2558, 2559, 2560, 2561, 2562, 2563, 2564, 2565, 2566, 2567, 2568, 2569, 2570, 2571, 2572, 2573, 2574, 2575, 2576, 2577, 2578, 2579, 2580, 2581, 2582, 2583, 2584, 2585, 2586, 2587, 2588, 2589, 2590, 2591, 2592, 2593, 2594, 2595, 2596, 2597, 2598, 2599, 2600, 2601, 2602, 2603, 2604, 2605, 2606, 2607, 2608, 2609, 2610, 2611, 2612, 2613, 2614, 2615, 2616, 2617, 2618, 2619, 2620, 2621, 2622, 2623, 2624, 2625, 2626, 2627, 2628, 2629, 2630, 2631, 2632, 2633, 2634, 2635, 2636, 2637, 2638, 2639, 2640, 2641, 2642, 2643, 2644, 2645, 2646, 2647, 2648, 2649, 2650, 2651, 2652, 2653, 2654, 2655, 2656, 2657, 2658, 2659, 2660, 2661, 2662, 2663, 2664, 2665, 2666, 2667, 2668, 2669, 2670, 2671, 2672, 2673, 2674, 2675, 2676, 2677, 2678, 2679, 26

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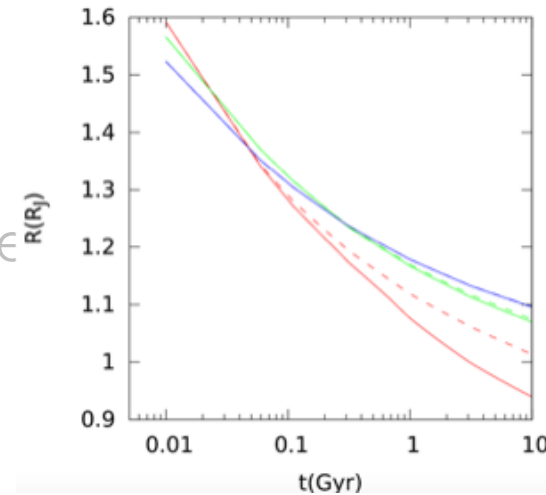


Benatti et al. 2021: DS Tuc A b (40 Myr) and the first ensemble view of young close-in planets

Science: results & perspectives

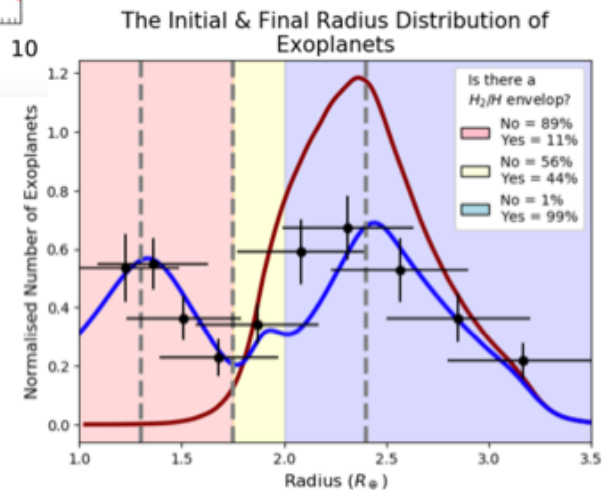
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Locci et al 2019:
Radius evolution with time as induced by the irradiation of the young stellar host

Modirrousta-Galian et al. 2020:
Photoevaporation is consistent with the bimodal radius distribution of exoplanets

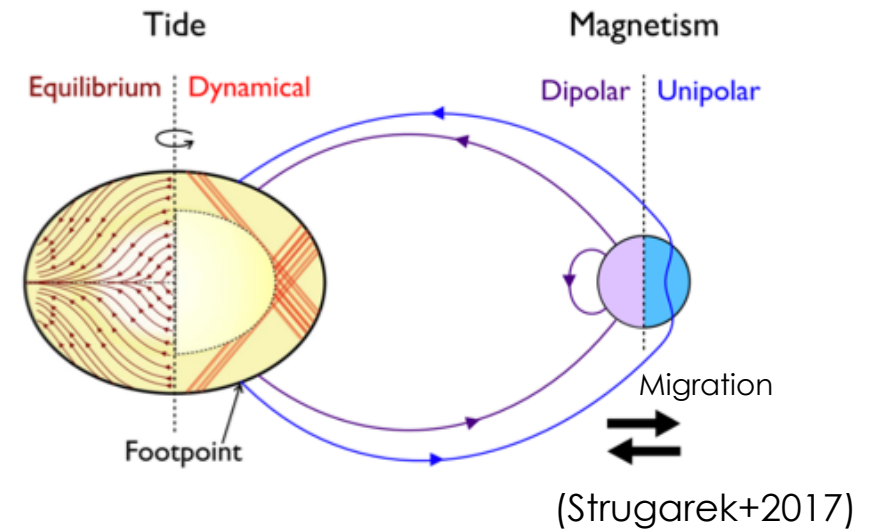


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Tidal and magnetic interaction



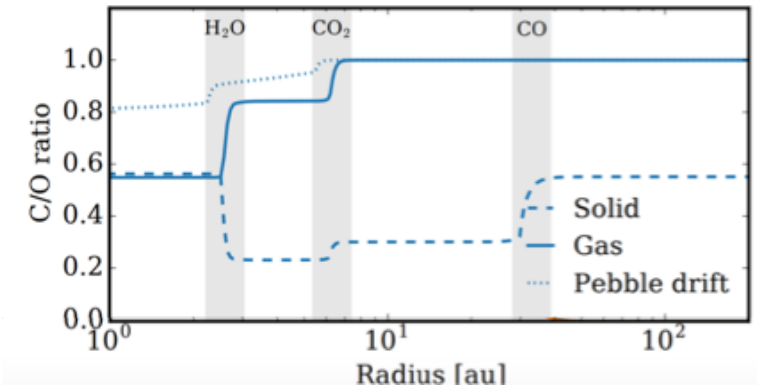
Lanza 2009: energy budget estimation of the SPI
Bonomo et al. 2017: statistical study on the hot Jupiter migration and tidal interaction

Science: results & perspectives

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The C/O ratio in the chemical abundances of planetary atmospheres tells the formation and migration history of a planet



(Madhusudhan 2019)

Giacobbe et al. 2021: measurement of the C/O ratio for the mature planet HD209458b
Turrini et al. 2021: better constraints by using other elemental ratios (C/N, N/O, S/N)

INAF Leadership

- EXO-SPI: 2005 to date
- EXO-Young: 2014 to date

Acknowledged experience of INAF researchers:

- ▶ **SPI MODELLING and OBSERVATIONS:** physics of magnetic fields, stellar activity, X-ray and EUV emission, tidal effects (Lanza 2009, Sanz-Forcada+2011, Maggio+2015, Pillitteri+2015, Bonomo+2017, Locci+2019, Lodato+2019, Modirrousta-Galian+2020)
- ▶ **TECHNOLOGY:** in particular with adaptive optics systems, like SPHERE, SHARK-NIR, SHARK-VIS, ERIS (Claudi+2008, Farinato+2014, Mattioli+2018, Davies, Esposito+2018, Marafatto+2020) and the GIANO/GIARPS project (Claudi+2017)
- ▶ **Young Planets OBSERVATIONS:** GTO/large programs dedicated to young planets at large and close separation, advance in GP modeling (Fedele+2018, Mesa+2019, Desidera+2021, Nardiello 2020, Damasso+2020, Carleo+2021, Benatti+2021)

Future planning

- ▶ **Currently**, several projects are ongoing or have just started (→ 2023/2024):
 - Observations (e.g. GAPS2, HARPS-N GTO, SPHERE GTO, TASSEL, HOT-ATMOS)
Modelling/Computation (e.g. AMS, CLIMAX) or both (e.g. THE-StellaR-Path, PLATEA)
- ▶ **Future** projects are proposed, more in the forthcoming years:
 - EXO-DEMO, EXO-FAMILIES, EXO-SELENE, Ecube
- ▶ Several **instruments** are producing data or are close to their integration phase. **Space missions** are flying or adopted by ESA (>2026). **Multiband** approach:
 - Ground-based: SPHERE, HARPS-N, GIANO-B, GIARPS, SHARK-VIS&NIR, ERIS,...
 - Space-based: CHEOPS, XMM-Newton, PLATO, ARIEL, ATHENA,...

Funds

- ▶ PRIN INAF PLATEA: almost completely dedicated to EXO-Young & EXO-SPI
- ▶ PRIN INAF Genesis-SKA (SPHERE)
- ▶ ASI-INAF 2018.16.HH.0 (THE StellaR Path and TASSEL): partially dedicated to EXO-Young & EXO-SPI
- ▶ ASI-INAF 2018.22.HH.0 (ARIEL): limited to the science team activities on EXO-Young
- ▶ PLATO: limited to the science team activities on EXO-Young
- ▶ AMS (Mainstream): partially dedicated to EXO-Young
- ▶ Premiale WOW: implementation of the GIARPS observing mode at TNG
- ▶ Premiale FRONTIERA, T-Rex: limited on this topic (e.g. SPHERE)
- ▶ Marie-Curie (SPHERE)
- ▶ SHARK-NIR + VIS: limited to the science team activities on EXO-Young

Critical points

Scientific issues

- ▶ Stellar activity treatment preventing a robust estimate of the planetary mass: implication on the planet atmospheric characterization and evolution → effort in data analysis is ongoing
- ▶ Planet candidate validation with imaging + planets embedded in their protoplanetary disc → this should be mitigated with the availability of SHARKs + LMIRcam @LBT
- ▶ Limited expertise in Italy on planetary structure and planet evolutionary tracks → need of new professional figures
- ▶ Promote the joining of modeling and observations communities

Program issues: this is a new, attractive, rapidly growing and demanding field

- ▶ High competition with teams having institutionally granted access to different observing facilities enabling quick planet candidate validation
- ▶ Difficult planning because of the long and discontinuous procedure of national calls, projects evaluation and funding distribution
- ▶ We are/must be present in the main international projects: it is crucial to strengthen the resources to capitalize our effort performed up to now

Thank you for your attention